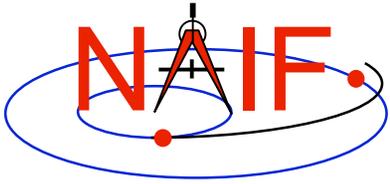


Navigation and Ancillary Information Facility

Welcome
to the
SPICE Tutorials

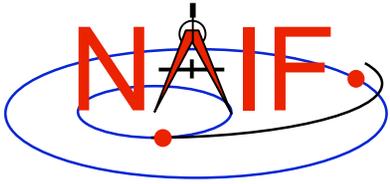
January 2009



Class Objectives

Navigation and Ancillary Information Facility

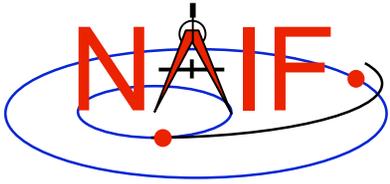
- **For you**
 - Provide an overview of the entire SPICE system
 - Provide a sense of the purpose and uses of SPICE
 - Provide an introduction to the use of primary SPICE components
 - Provide examples of how to use SPICE software and data files
 - Provide some insight into conventions and common problems
 - Provide a variety of “hands-on” programming exercises
 - Provide a peek at new capabilities being worked on or considered
 - Familiarize you with available SPICE resources
- **For NAIF**
 - Get student’s feedback on today’s SPICE system
 - » Especially what’s hard to understand, hard to use, missing
 - Get student’s suggestions for further development of SPICE
 - Get student’s suggestions for improvements to NAIF support of the space science community



Class Scope

Navigation and Ancillary Information Facility

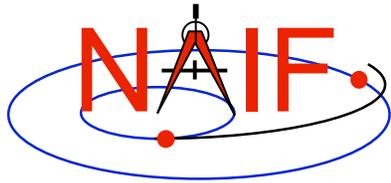
- **Broad coverage**
 - Begins at a high level, but quickly drills down to details
 - Touches on many SPICE-related topics that could be of interest to science and engineering teams
 - » Depth of discussion varies somewhat amongst topics
- **Provides information for FORTRAN, C, IDL and MATLAB programmers**
- **Some topics are addressed very little or not at all**
 - Archiving SPICE data



Repeated Material

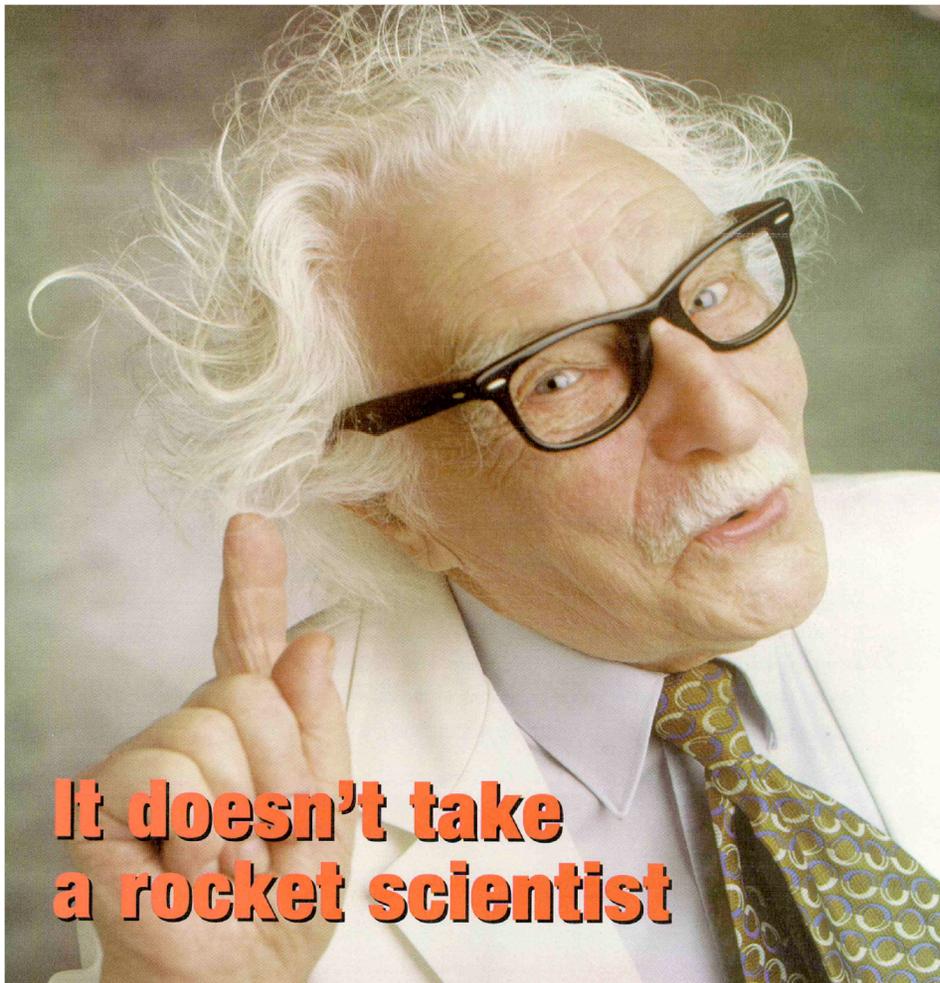
Navigation and Ancillary Information Facility

- **Some topics will be repeated in two or more tutorials**
 - **We're not trying to bore you, but...**
 - » **we don't wish to assume people will read all of the tutorials at the same time**
 - » **we think some items are sufficiently important to mention them more than once**



Your SPICE Odyssey Begins Here

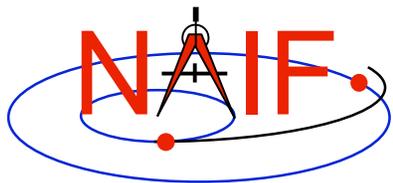
Navigation and Ancillary Information Facility



**It doesn't take
a rocket scientist**

... but it does take a modest amount of effort to learn enough about SPICE to begin to use its features with good success.

It helps to have some math skills, some innate sense of spatial orientation, and some familiarity with your computer and its operating system, a code editor, and compiler or Integrated Development Environment (IDE).



SPICE is a Large Product

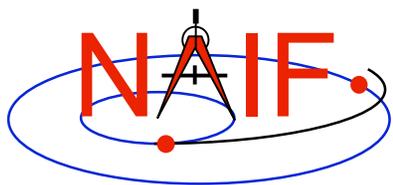
Navigation and Ancillary Information Facility

The generic SPICE Toolkit contains:

- around 1000 individual public modules
 - » most customers use only a handful of these
- about 13 utility and application executables (with User Guides)
- about 23 subsystem reference documents
- 4 “cookbook” tutorial programs (with User Guides)
and assorted other documents, scripts and libraries.

Don't let that bother you...

... just work your way into it bit by bit.

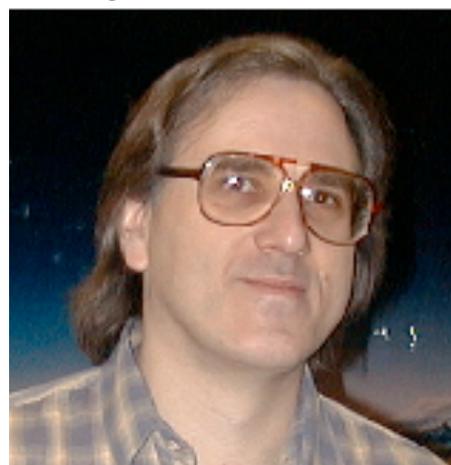


The NAIF Team at JPL

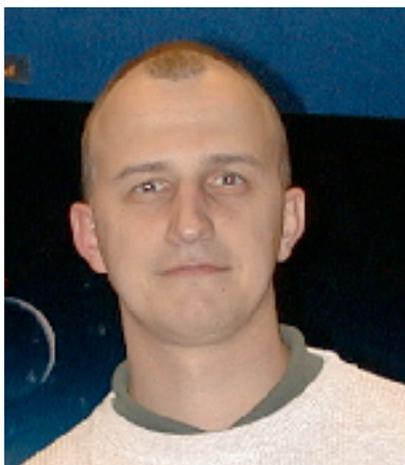
Navigation and Ancillary Information Facility



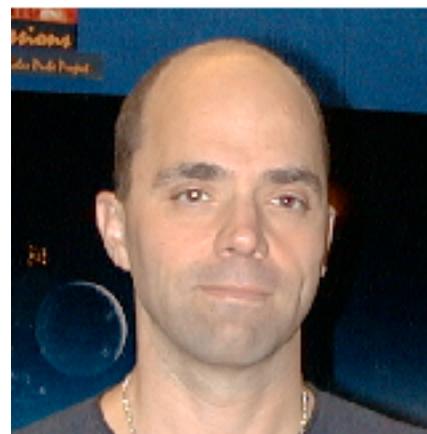
Chuck Acton



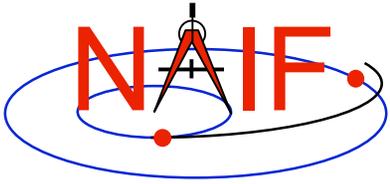
Nat Bachman



Boris Semenov



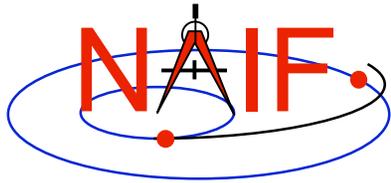
Ed Wright



Navigation and Ancillary Information Facility

SPICE Introduction

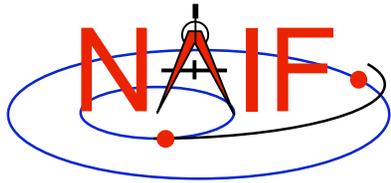
January 2009



History

Navigation and Ancillary Information Facility

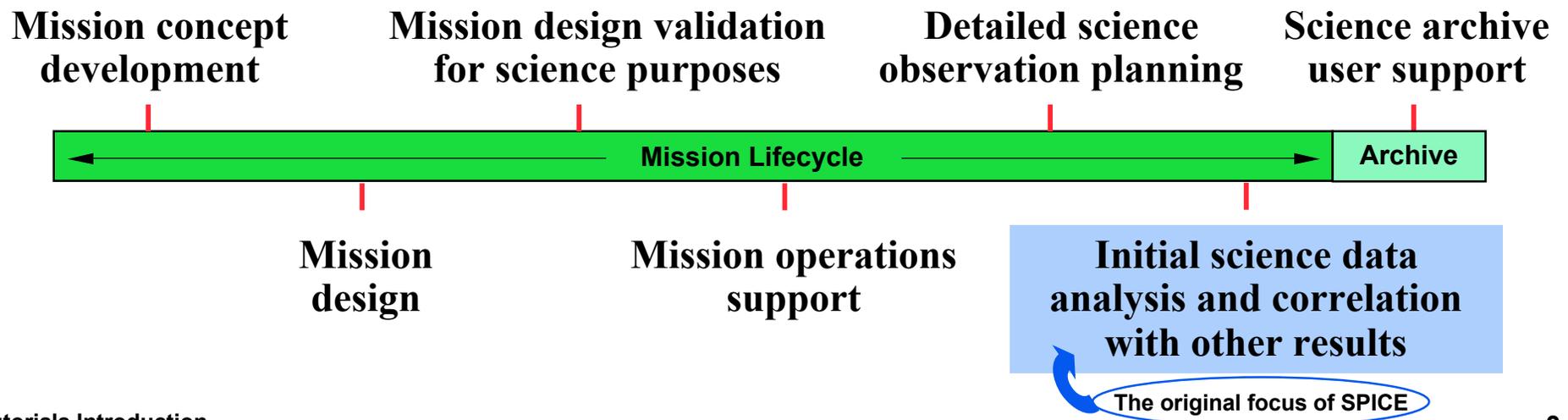
- **Implementation of a precursor to SPICE was initiated by scientists in 1984 as part of a major initiative to improve archiving and distribution of space science data in all NASA disciplines**
- **Responsibility for leading SPICE development was assigned to the newly-created Navigation and Ancillary Information Facility (NAIF), located at the Jet Propulsion Laboratory**
- **Today's SPICE system dates from about 1991**

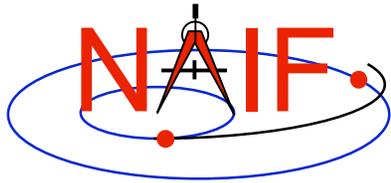


Breadth of Use

Navigation and Ancillary Information Facility

- The original focus of SPICE was on “ancillary” data and associated software needed by scientists for:
 - science data analysis for one instrument, and
 - correlation with results from other instruments/missions.
- The scope of SPICE usage has now grown to cover the full lifecycle of a mission as well as post-mission archive uses.



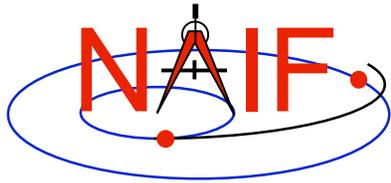


Major SPICE Users*

Navigation and Ancillary Information Facility

- **SPICE is used on essentially all NASA solar system exploration projects**
 - Examples: All Mars missions, Cassini, Deep Impact, Messenger, Juno
- **Limited SPICE data have been (or are being) created for some past missions**
 - Examples: Voyager, Viking Orbiter
- **SPICE is used to some degree in support of some space physics and astrophysics missions**
 - Examples: Hubble Space Telescope, SIRTf, Genesis, Kepler
- **SPICE was or is used on some non-NASA missions**
 - **Russia's** Mars 96; **ESA's** Huygens Probe, Smart-1, Mars Express, Rosetta and Venus Express; **Japan's** Hayabusa and SELENE; **India's** Chandrayaan-1
- **SPICE ephemerides are used at some terrestrial observatories**
- **SPICE is used by NASA's Deep Space Network for both scheduling and operating the DSN antennas.**

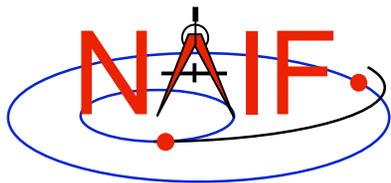
* Not all are supported by NAIF; some are using SPICE on their own.



Ancillary Data Archives

Navigation and Ancillary Information Facility

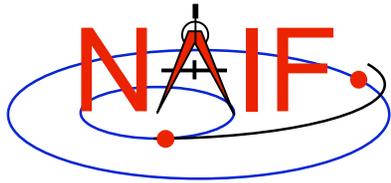
- **SPICE is the U.S. Planetary Data System's normal means for archiving ancillary data**
 - (But it's not a formal requirement)
- **SPICE data for European planetary missions are archived in ESA's Planetary Science Archive**
 - Some of these data will be mirrored on the NAIF server
- **SPICE data for some Japanese and Indian missions will be available in the future from their local archives**
 - Already the case for Hayabusa
- **SPICE, or some SPICE ideas, might play a role in the future International Planetary Data Alliance (IPDA)**



Distribution

Navigation and Ancillary Information Facility

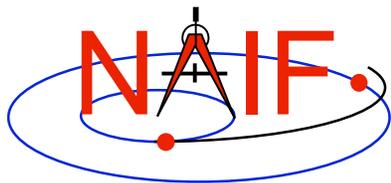
- **SPICE system components are freely distributed**
 - Projects pay for local deployment and operation, done either by their own personnel, or by NAIF, or a combination
 - No ITAR restrictions on distribution
- **Users get complete source code and much documentation**



Quality of Training Materials

Navigation and Ancillary Information Facility

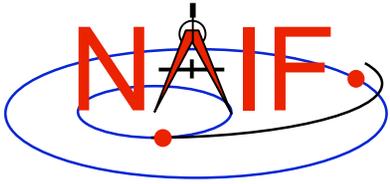
- **This set of tutorials has been presented and revised numerous times**
 - **No matter how hard we try, it seems impossible to:**
 - » **Get all the facts absolutely right and up-to-date**
 - » **Get the level of detail “right” for every student**
 - » **Get all of the language clear, complete and concise**
 - » **Present everything in the “correct” order**
- **These training materials are meant to supplement—not replace—the subroutine headers and the “required reading” reference documents that are the primary sources for user information about SPICE**



Navigation and Ancillary Information Facility

Motivation for Developing SPICE

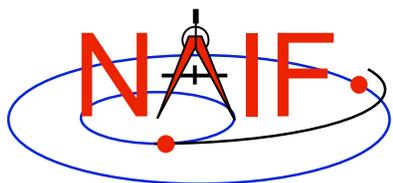
January 2009



Why Did NAIF Build SPICE?

Navigation and Ancillary Information Facility

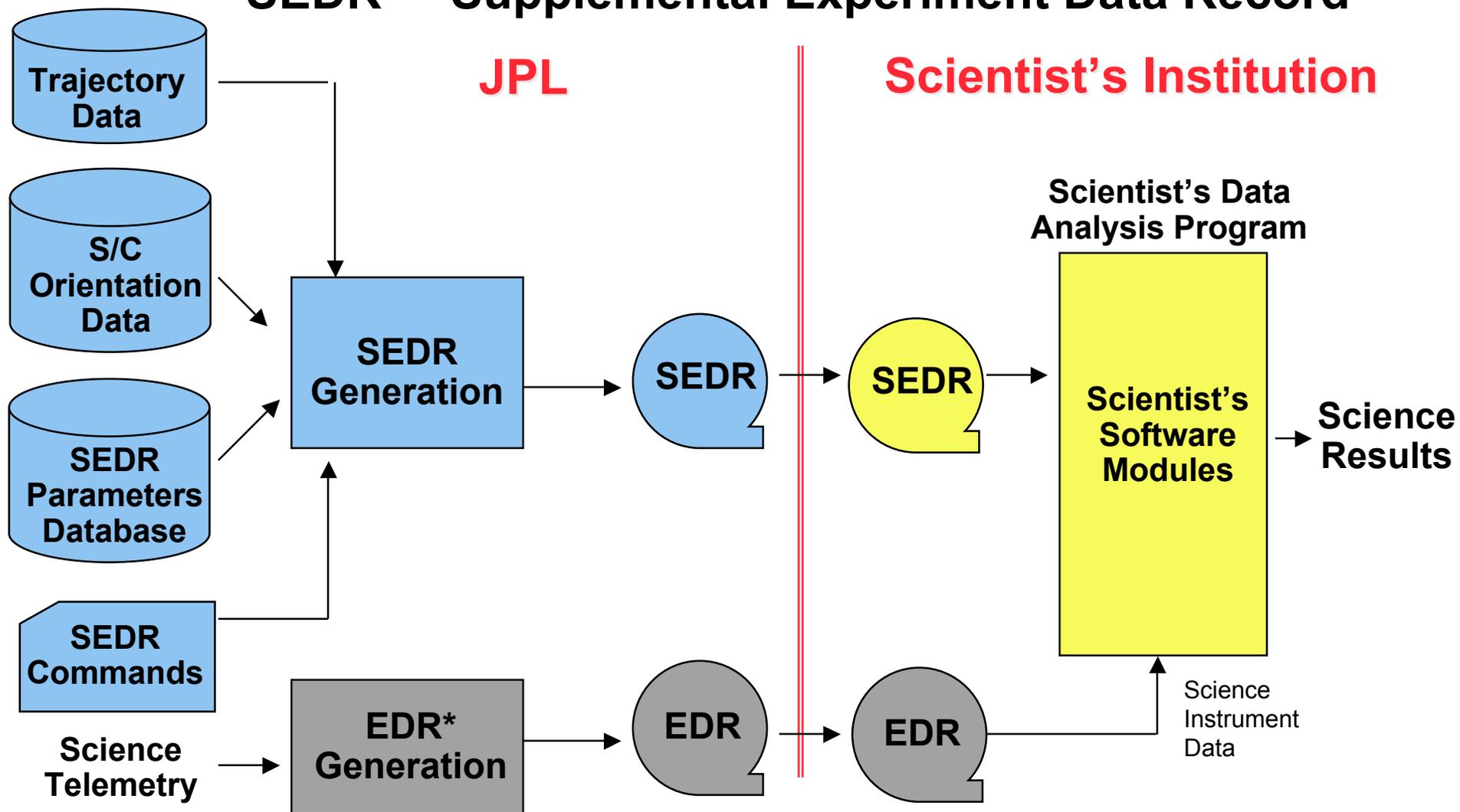
- **Scientists said they would like to:**
 - **use common tools and methods throughout a project's lifecycle, and for all projects (national and international)**
 - **understand the calculations and transformations used to produce observation geometry data**
 - **be able to produce custom geometry calculations themselves, whenever and however they want**
 - **have the ability to revise the fundamental data and software tools used to produce their own observation geometry data**



What Existed Prior to SPICE ?

Navigation and Ancillary Information Facility

“SEDR” - Supplemental Experiment Data Record



Motivation for SPICE

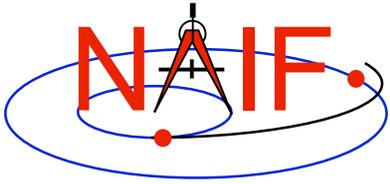
* EDR = Experiment Data Record = "raw" science instrument data



SEDR System Characteristics

Navigation and Ancillary Information Facility

- **The SEDR Generation program was built and operated at JPL**
 - **Scientist's requirements on SEDR had to be provided long before launch**
 - » **Late or post-launch updates were hard/expensive to accommodate**
 - **Difficult to change WHAT gets computed**
 - **Difficult to change HOW items are computed (algorithms, parameters)**
 - **Difficult to change TIMEs at which items get computed**
 - **Generally only one SEDR file produced for each period of time**
 - » **Result: the scientist can't get better ancillary data if/when better inputs (e.g. spacecraft trajectory or orientation) are determined**
 - **SEDR generation was done "in the blind"**
 - » **Operators were not familiar with processes used to make the inputs**
 - » **Operators were not familiar with scientist's processing schemes**
 - » **Result: SEDR may not optimally meet science team's expectations**
 - **SEDR system was not exportable to other institutions**

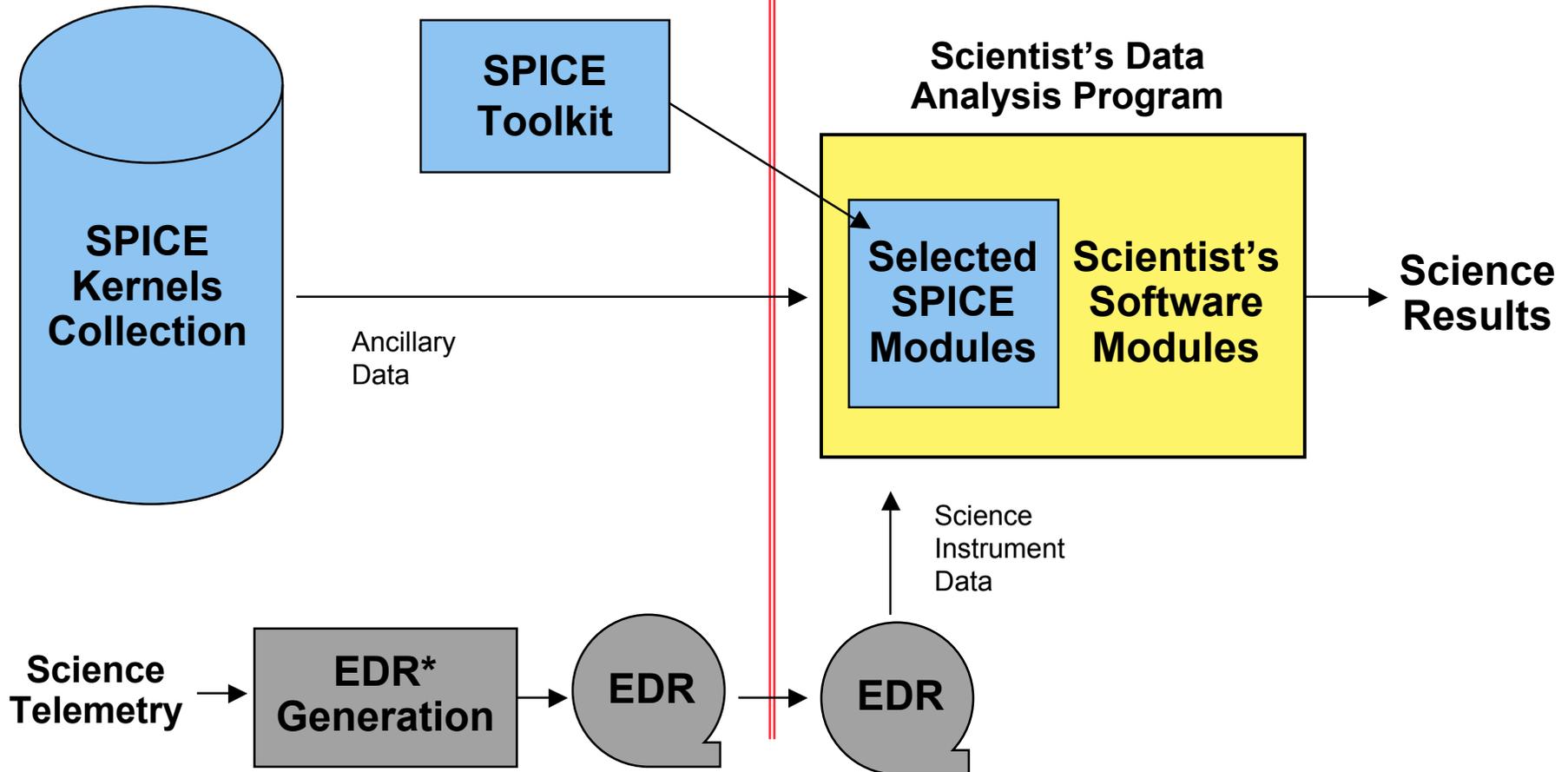


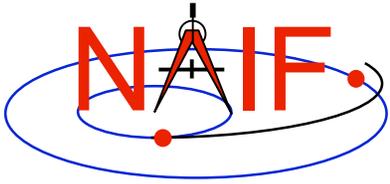
The SPICE Idea

Navigation and Ancillary Information Facility

**Any Mission
Operations Center**

Scientist's Institution

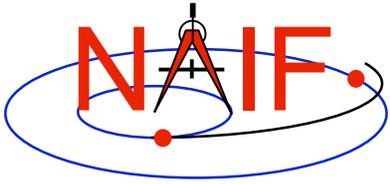




SPICE Benefits vs. SEDR

Navigation and Ancillary Information Facility

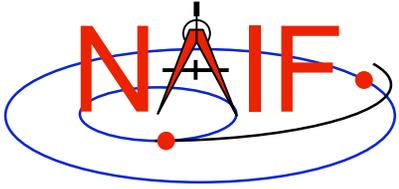
- **The customer has great flexibility in deciding:**
 - what observation geometry parameters are computed
 - at what times or at what frequency these parameters are computed
 - for what time span these parameters are computed
 - electing if/when to re-do parameter computations using new (better) or otherwise different kernels or other data as inputs
- **The customer also has:**
 - common tools and methods that can be reused on many tasks
 - good visibility into algorithms and data used in geometry calculations
- **The flight project operations center can:**
 - concentrate on producing better kernel data, rather than on producing lots of SEDRs and frequently updating the SEDR software
- **The SPICE process may be replicated anywhere**



SPICE Detriments vs. SEDR

Navigation and Ancillary Information Facility

- **End users ("consumers") must do some non-trivial programming to read SPICE kernels and compute whatever is needed**
- **If the mission operations center is other than JPL, the appropriate project folks need to learn how to produce SPICE kernels**
- **In some areas of SPICE the offering of choices to allow correct handling of different situations may present complexity that is unwarranted for "simple" problems**



Navigation and Ancillary Information Facility

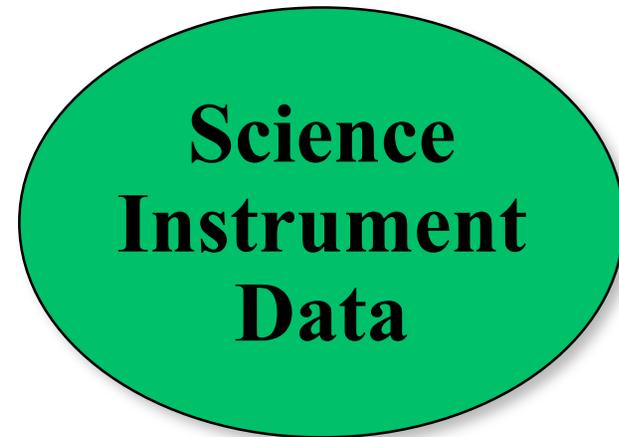
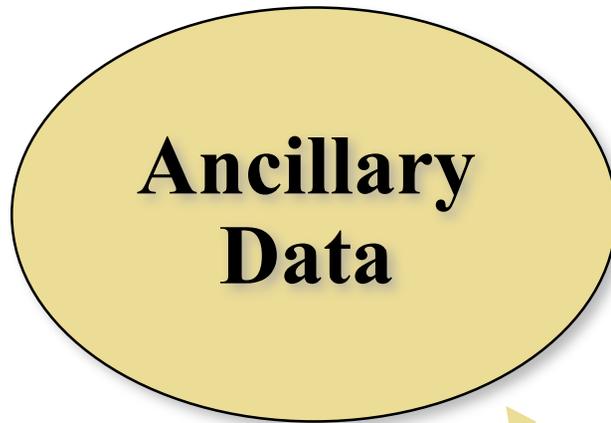
An Overview of SPICE

January 2009



Space Science Data: Two Kinds

Navigation and Ancillary Information Facility

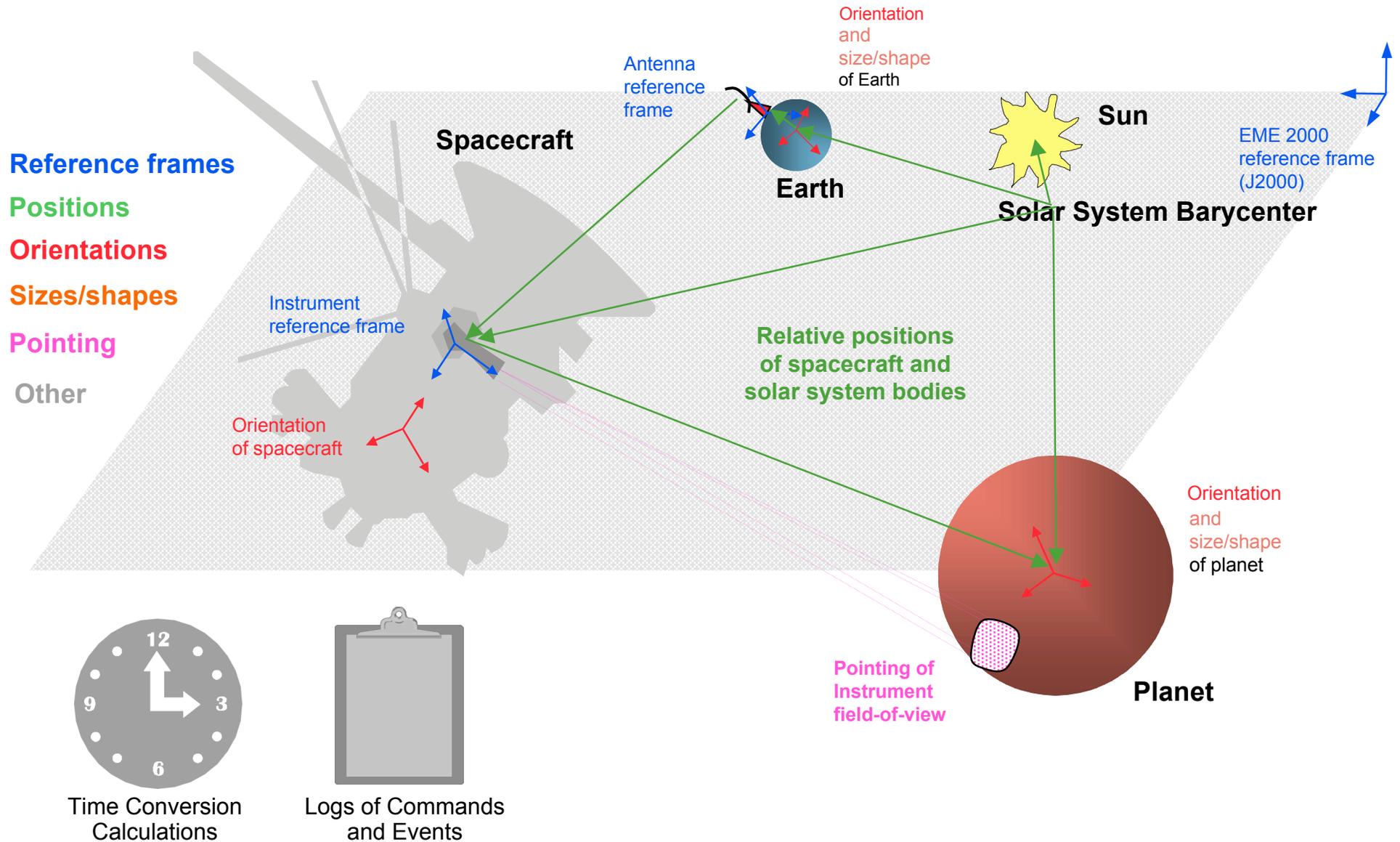


SPICE deals with **these** data to support the
planning for and analysis of **these** data

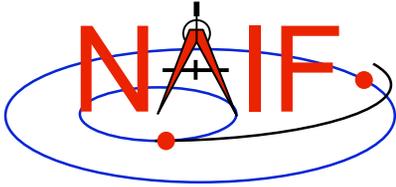


What are “Ancillary Data?”

Navigation and Ancillary Information Facility



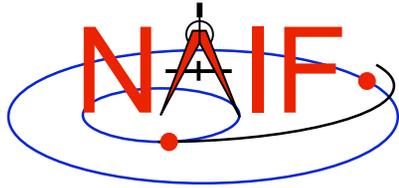
Overview of SPICE



What are “Ancillary Data”?

Navigation and Ancillary Information Facility

- **“Ancillary data” are those that help scientists and engineers determine:**
 - where the spacecraft was located
 - how the spacecraft and its instruments were oriented (pointed)
 - what was the location, size, shape and orientation of the target being observed
 - what events were occurring on the spacecraft or ground that might affect interpretation of science observations
- **In the above we’ve used past tense, but doing the same functions for future times is equally applicable**

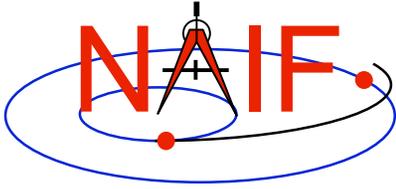


From Where do Ancillary Data Come?

Navigation and Ancillary Information Facility

- **Some come from the spacecraft**
- **Some come from the mission control center**
- **Some come from the spacecraft and instrument builders**
- **Some come from scientists**

- **SPICE is used to organize and package these data in a collection of useful, stable file types—called "kernels."**
- **The kernels are made available, along with SPICE Toolkit software:**
 - **to help scientists in the planning for and analysis of science observations, and**
 - **to help engineers in planning for and analysis of spacecraft and ground system operations.**



Why SPICE?

Navigation and Ancillary Information Facility

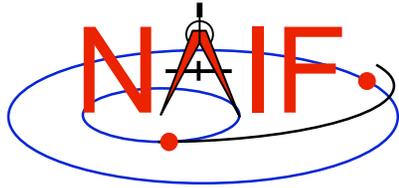
- **Knowing observation geometry and events is an important element:**
 - in the design of space missions,
 - in the selection of observations,
 - and in analysis of the science data returned from the instruments.
- **Having proven, extensive and reusable means for producing and using ancillary data reduces cost and risk, and can help scientists and engineers achieve more substantive, accurate and timely results.**



SPICE System Components

Navigation and Ancillary Information Facility

- **The principal SPICE system components are:**
 - **Data files**, often called “kernels” or “kernel files”
 - **Software**, known as the SPICE Toolkit, consisting of:
 - » a subroutine/function library
 - » a number of programs (executables)
 - Some are “meaty” applications
 - Some are “simple” utilities focused on kernel management
 - » a few “cookbook” programs
 - Simple examples of using SPICE toolkit subroutines
 - **Documentation**
 - User Guides for programs
 - Substantial source code documentation for all subroutines
 - Provided explicitly for those who will use Toolkit subroutines to make their own application programs
 - Technical reference documents for major families of subroutines
 - A permuted index
 - **Tutorials**
 - **Programming lessons**, which focus on using SPICE subroutines
 - » Include tips, data, and NAIF’s solution code and numeric results



Genesis of the SPICE Acronym*

Navigation and Ancillary Information Facility

S

Spacecraft

P

Planet

I

Instrument

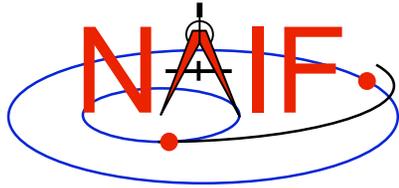
C

C-matrix

E

Events

* Coined by Dr. Hugh Kieffer, USGS Astrogeology Branch, Flagstaff AZ



Logical versus Physical View

Navigation and Ancillary Information Facility

Logical View

S
Spacecraft

P
Planet

I
Instrument

C
Camera-matrix

E
Events

S
Software

Physical View

SPK

PcK

IK

CK

EK
ESP ESQ

Others

FK
LSK
SCLK

SPICE Toolkit

Content

Space vehicle or target body trajectory (ephemeris)

Target body size, shape and orientation

Instrument field-of-view size, shape and orientation

Orientation of space vehicle or any articulating structure on it

Events information:
- Science Plan (ESP)
- Sequence of events (ESQ)
- Experimenter's Notebook (ENB)

Reference frame specifications
Leapseconds tabulation
Spacecraft clock coefficients

API libraries, some application and utility programs, software documentation



SPICE System Contents - 1

Navigation and Ancillary Information Facility

SPK

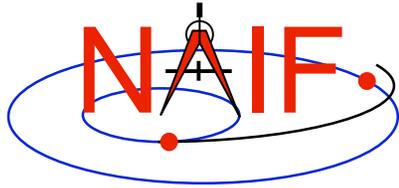
- **Space vehicle ephemeris (trajectory)**
- **Planet, satellite, comet and asteroid ephemerides**
- **More generally, position of something relative to something else**

PcK

- **Planet, satellite, comet and asteroid orientations, sizes, shapes**
- **Possibly other similar “constants” such as parameters for gravitational model, atmospheric model or rings model**

IK

- **Instrument information such as:**
 - **Field-of-view size, shape, orientation**
 - **Internal timing**



SPICE System Contents - 2

Navigation and Ancillary Information Facility

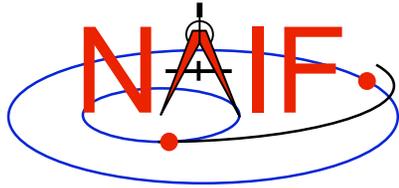


- Instrument platform (e.g. spacecraft) attitude
- More generally, orientation of something relative to a specified reference frame



- ~~“Events,” broken into three components:~~
 - ~~ESP: Science observation plans~~
 - ~~ESQ: Spacecraft & instrument commands~~
 - ~~ENB: Experiment “notebooks” and ground data system logs~~

*The Events kernel idea has not taken hold.
After Cassini it may disappear.*



SPICE System Contents - 3

Navigation and Ancillary Information Facility

FK

- **Frames**
 - Definitions of and specification of relationships between reference frames (coordinate systems)
 - Both “fixed” and “dynamic” frames are available

LSK

- **Leapseconds Tabulation**
 - Used for UTC <--> ET time conversions

SCLK

- **Spacecraft Clock Coefficients**
 - Used for SCLK <--> ET time conversions

**Other
Kernels**

- Shape models (DEM and tessellated plates) (DSK) ¹
- Star (sky) catalog ²

¹ under development

² development is stalled



SPICE System Contents - 4

Navigation and Ancillary Information Facility

SPICE Toolkit

FORTRAN

C

IDL

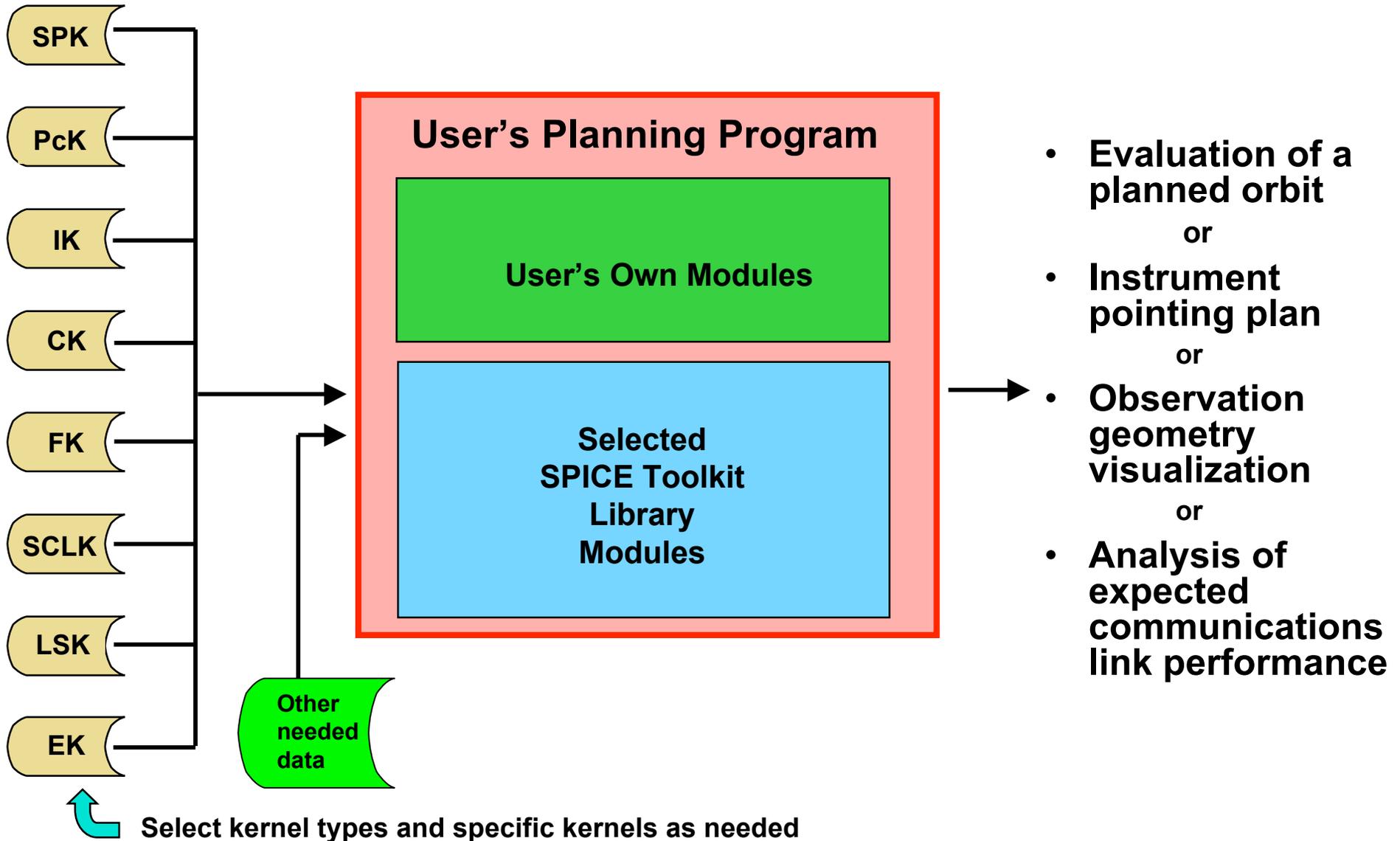
MATLAB

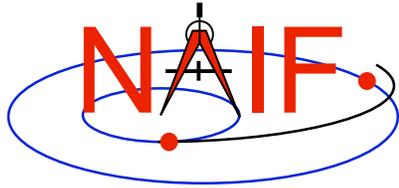
- **Library of modules used to:**
 - write binary SPICE kernel files
 - read all (binary and text) SPICE kernel files
 - compute quantities derived from SPICE kernel data
- **Example (“cookbook”) programs**
- **Utility programs**
 - Kernel summarization or characterization
 - Kernel porting
- **Application programs (a few)**
 - e.g. “chronos” time conversion application
- **Kernel production programs (a few)**
 - e.g. “mkspk” SPK production program



Using SPICE in Science Planning

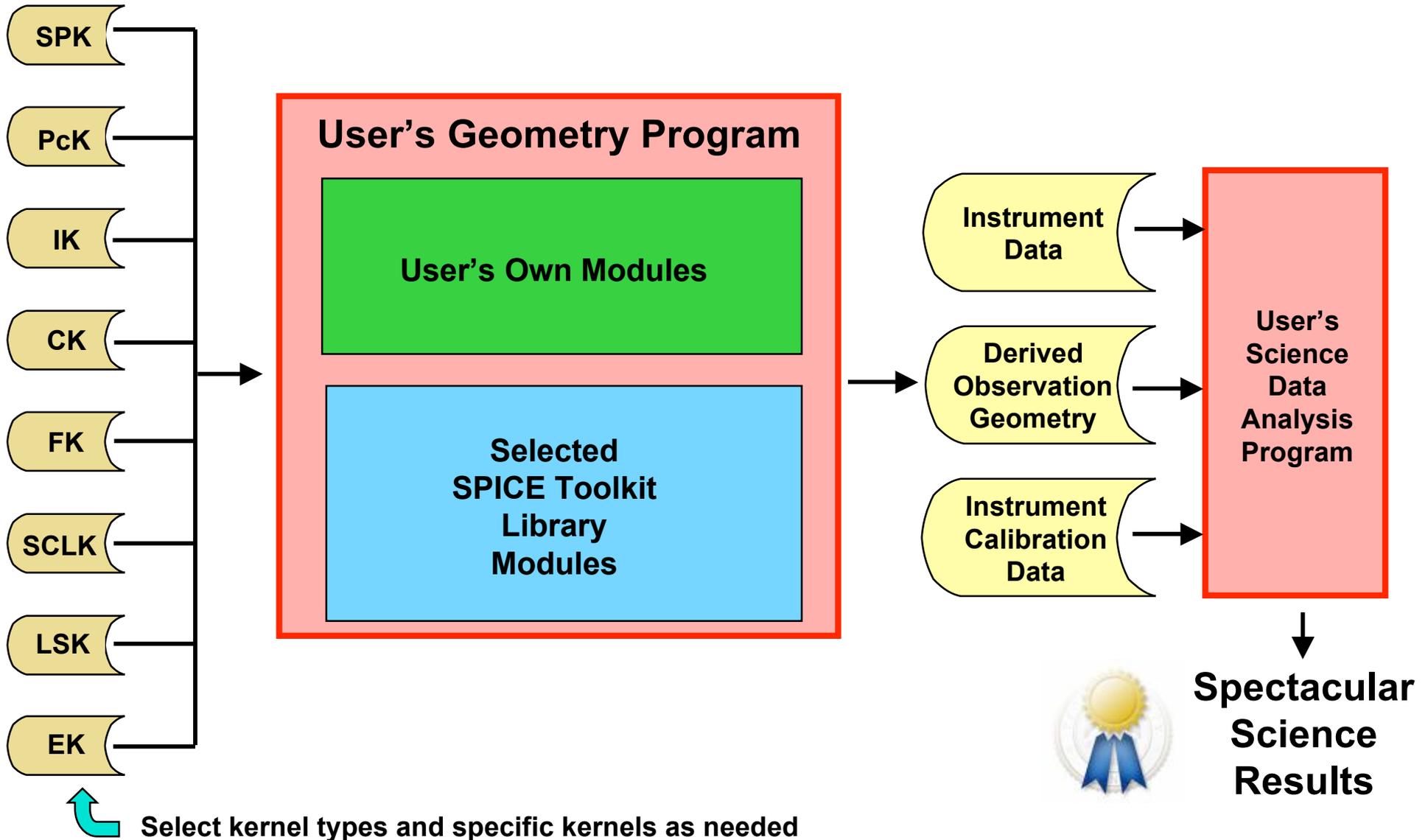
Navigation and Ancillary Information Facility

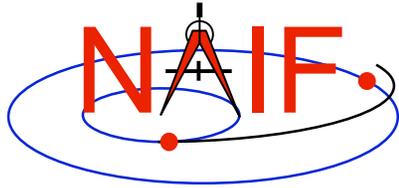




Using SPICE in Science Data Analysis

Navigation and Ancillary Information Facility

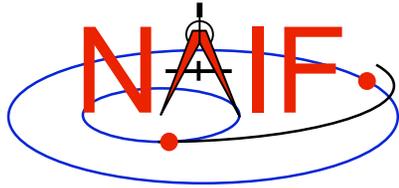




SPICE System Characteristics - 1

Navigation and Ancillary Information Facility

- **Portable SPICE kernel files**
- **Portable NAIF Toolkit software**
- **Code is well tested before being released to users**
- **New Toolkits are always backwards compatible**
- **Extensive user-oriented documentation is provided**
- **A set of SPICE tutorials is available**
- **“Open book” programming lessons are offered as a part of each NAIF-provided training class**



SPICE System Characteristics - 2

Navigation and Ancillary Information Facility

- **All numeric computations use double precision**
- **System includes built-in exception handling**
 - Catches most invalid inputs
 - Offers a traceback and configurable action upon detection of a problem
- **Gives you access to most of JPL's integrated ephemerides for spacecraft and natural bodies (planets, satellites, comets, asteroids)**
- **Kernel files are separable**
 - Use only those you need for a particular application
- **Kernel files are extensible**
 - New data “types” can be added within a family
 - New kinds of kernels can be developed as needed
- **Broad applicability, means good value**
 - **Multimission and multidiscipline**
 - » Use it over and over again, no matter which mission you're working on



SPICE System Characteristics - 3

Navigation and Ancillary Information Facility

- **Funding**
 - SPICE system development is funded by NASA's Planetary Science Division
 - NASA flight projects fund NAIF or others to deploy and operate SPICE in support of NASA's planetary missions
 - Foreign institutions fund their own people for deployment and operation of SPICE in support of their own projects
 - SPICE Toolkit software is free to individual end users
 - Access to SPICE kernels produced by NAIF is free and open to all
 - » Includes mission operations kernels as well as those archived in the PDS
 - Access to SPICE kernels produced by others so far appears free
 - » But access restrictions often exist prior to data archiving
- **Distribution of SPICE software is not restricted under U.S. Government regulations**
 - » SPICE is classified TSPA (“Technology and Software Publicly Available”)
 - » No ITAR restrictions on data, training or consulting
- **Commercial use of SPICE software is allowed**
 - No license fees or other restrictions



Supported Platforms

Navigation and Ancillary Information Facility

- **The SPICE Toolkit has been ported to a wide variety of popular “environments”**
 - Each environment is characterized by...
 - » Hardware type (platform)
 - » Operating System
 - » Compiler
 - » Sometimes even selected compilation options
- **NAIF provides separate, ready-built SPICE Toolkit packages for each supported environment**
 - If you need to port the Toolkit to a new environment yourself, consult with NAIF staff



For What Jobs is SPICE Used ?

Navigation and Ancillary Information Facility

Increasing
mission
maturity
(time)



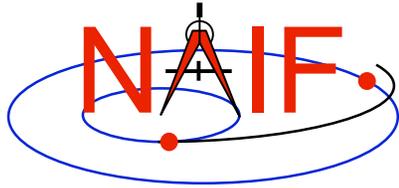
- Mission planning, modeling and visualization
- Pre-flight mission evaluation from a science perspective
- Detailed science observation planning
- Mission operations engineering functions

• Science data analysis, including correlation of results between instruments, and with data obtained from other missions

• Data archiving, for future use by others

← The original focus of SPICE

- Education and Public outreach

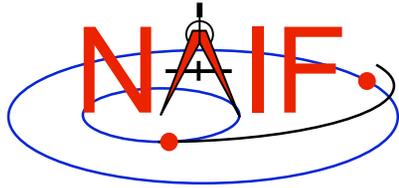


Examples - 1

What Can You Do With SPICE ?

Navigation and Ancillary Information Facility

- **Mission Design**
 - Compute interesting orbit properties; compare these with those of another design, or of another mission
 - Evaluate possibilities for relay link times and duration
- **Mission Operations (mission engineering)**
 - Predict or evaluate telecommunications link performance
 - Analyze spacecraft orientation history
 - Determine elevation and rise/set times of sun and tracking stations
 - Compute location and lighting conditions for a rover

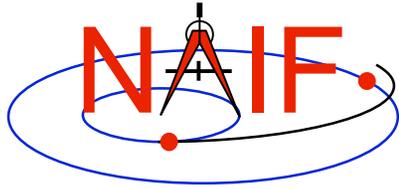


Examples - 2

What Can You Do With SPICE ?

Navigation and Ancillary Information Facility

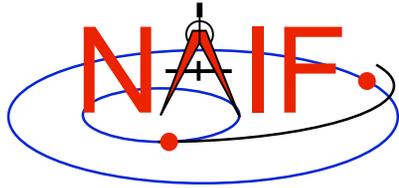
- **Science: Planning, Product Generation and Data Analysis**
 - Design specific observations to be acquired
 - Compute observation geometry needed for science data product labels, to later be used in searching a catalog for science data of interest
 - Compute observation geometry needed to analyze science data, or to correlate multiple science data sets
 - » Examples of “observation geometry”:
 - Lighting angles (phase, incidence, emission)
 - Location (LAT/LON) of instrument footprint
 - Range and local time
 - Local season
- **Visualization, Education and Public Outreach**
 - Provide geometry used to drive web pages giving interesting parameters such as ranges, velocities, time of day on Mars
 - Provide geometry for animations showing spacecraft location and orientation, instrument footprint projected on the surface, and locations of surface assets or natural features of interest



What “Vehicle” Types Can Be Supported ?

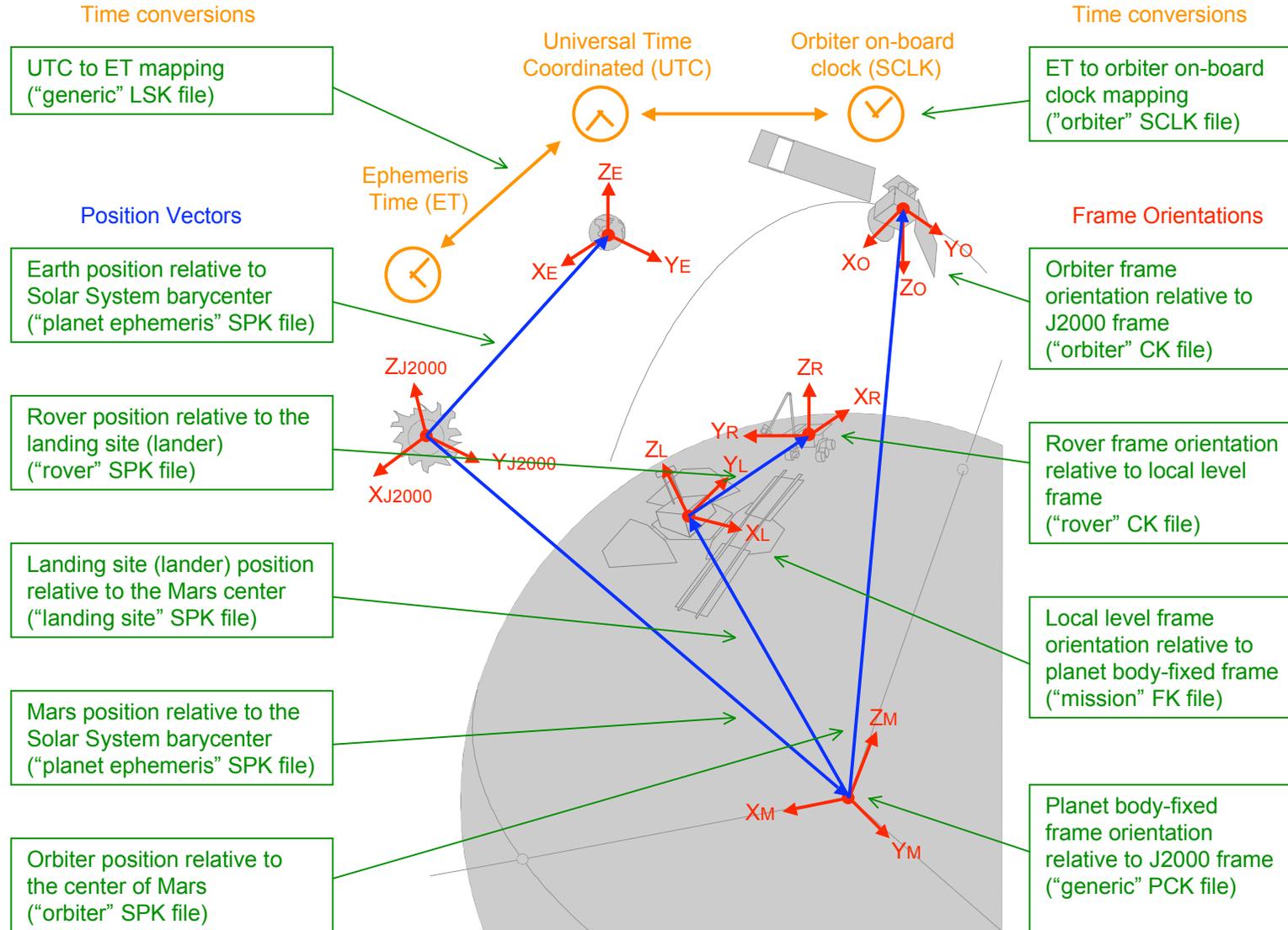
Navigation and Ancillary Information Facility

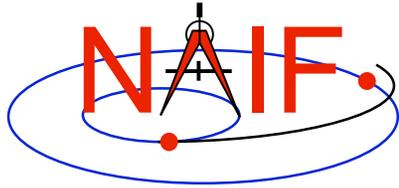
- **Cruise/Flyby**
 - Remote sensing
 - In-situ measurement
 - Instrument calibration
- **Orbiters**
 - Remote sensing
 - In-situ measurement
 - Communications relay
- **Balloons***
 - Remote sensing
 - In-situ measurements
- **Landers**
 - Remote sensing
 - In-situ measurements
 - Rover or balloon relay
- **Rovers**
 - Remote sensing
 - In-situ sensing
 - Local terrain characterization
- **Terrestrial applications**
 - Ephemerides for observers
 - Tracking station needs



Global SPICE Geometry

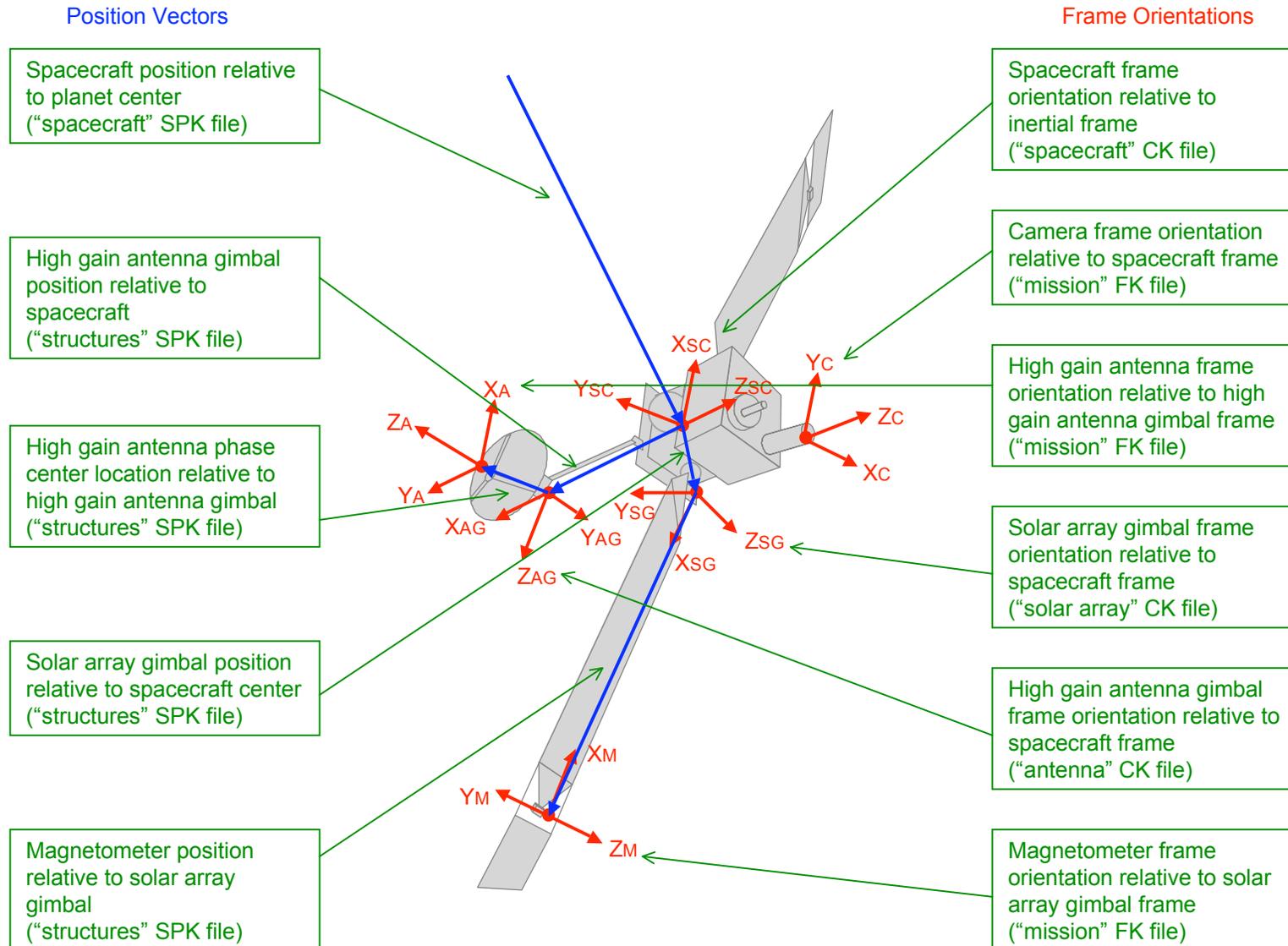
Navigation and Ancillary Information Facility

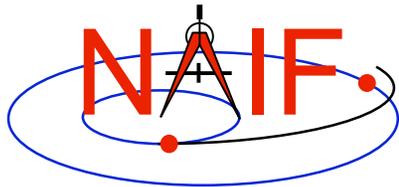




Orbiter Geometry

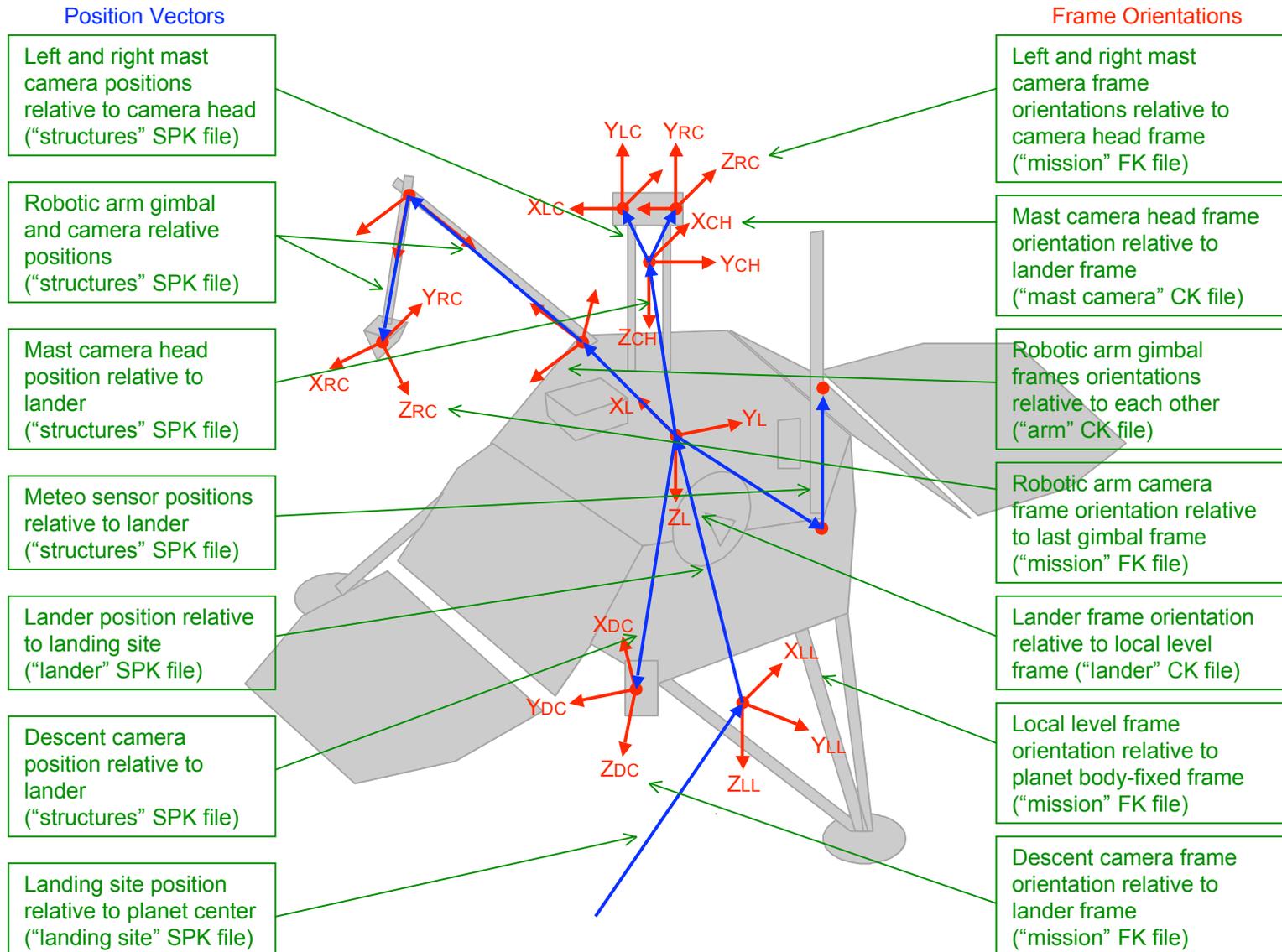
Navigation and Ancillary Information Facility

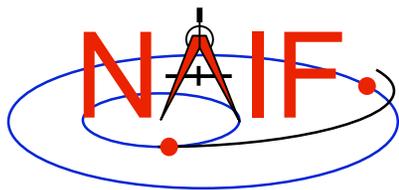




Lander Geometry

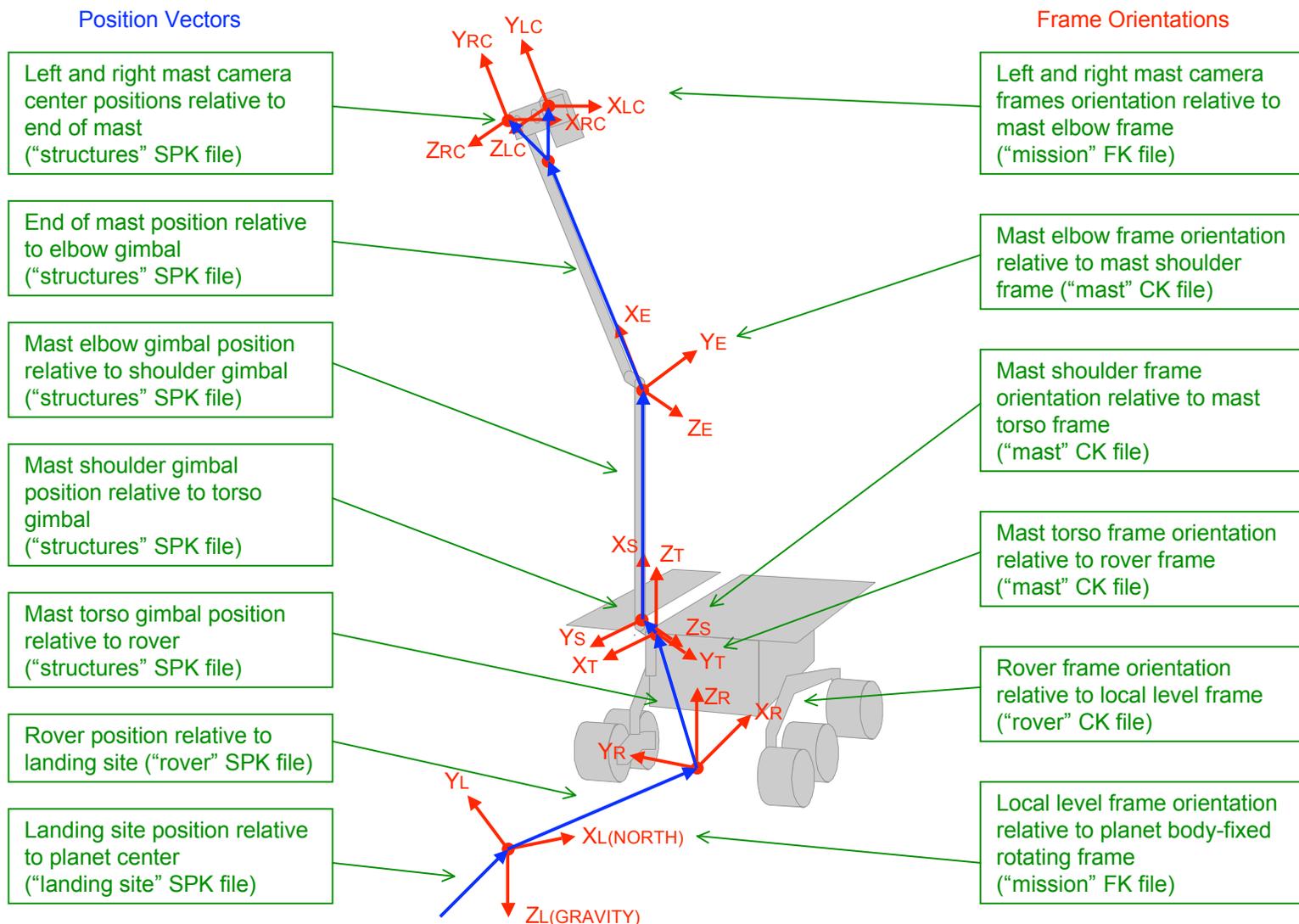
Navigation and Ancillary Information Facility

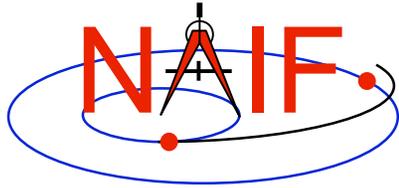




Rover Geometry

Navigation and Ancillary Information Facility



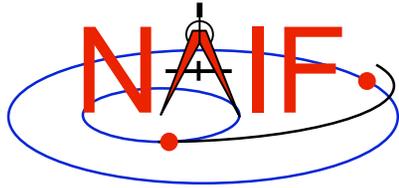


Major SPICE Users

Navigation and Ancillary Information Facility

<i>Restorations</i>	<i>Past Users</i>	<i>Current Users</i>	<i>Anticipated</i>
Apollo 15, 16 [L]	Magellan [L]	Cassini Orbiter	NASA Mars Program
Mariner 9 [L]	Clementine (NRL)	Mars Odyssey	NASA Discovery Program
Mariner 10 [L]	Mars Observer	Mars Exploration Rover	NASA Scout Program
Viking Orbiters [L]	Mars 96 [F] (RSA)	Mars Express (ESA)	NASA New Frontiers Program
Viking Landers [L]	Hubble Space Telescope [S]	Mars Reconnaissance Orbiter	Next outer planet mission
Pioneer 10/11 [L]	ISO [S] (ESA)	DAWN	Grunt (RSA)
Haley armada [L]	MSTI-3 (NRL/ACT Corp.)	New Horizons	Future ISRO planetary missions
Phobos 2 [L] (RSA)	Optical Transient Detector	Messenger	
Ulysses [L]	Mars Pathfinder	Mars Science Lab	
Voyagers [L]	Mars Climate Orbiter [F]	Rosetta (ESA)	
Lunar Orbiter [L]	Mars Polar Lander [F]	Venus Express (ESA)	<i>Future ?</i>
	NEAR	Hayabusa (JAXA)	Constellation
	Deep Space 1	Kaygua (JAXA)	ExoMars (ESA)
	CONTOUR [F]	NExT, EPOXI	
	Space VLBI [L] (multinational)	LCROSS	<i>Examples of Numerous Unaffiliated Users</i>
[L] = limited use	Galileo	Lunar Reconnaissance Orbiter	
[S] = special services	Genesis	Juno	Kepler [L]
[F] = mission failed	Deep Impact	Chandrayaan (ISRO)	Planck [L] (ESA)
	Huygens Probe (ESA)	Planet-C (JAXA)	WISE [L]
	Stardust	Beppi Colombo (ESA)	
	Mars Global Surveyor		NASA Deep Space Network
	Smart-1 (ESA)	Planetary Data System	
	Spitzer Space Telescope [L]	Planetary Science Archive (ESA)	
	Phoenix		

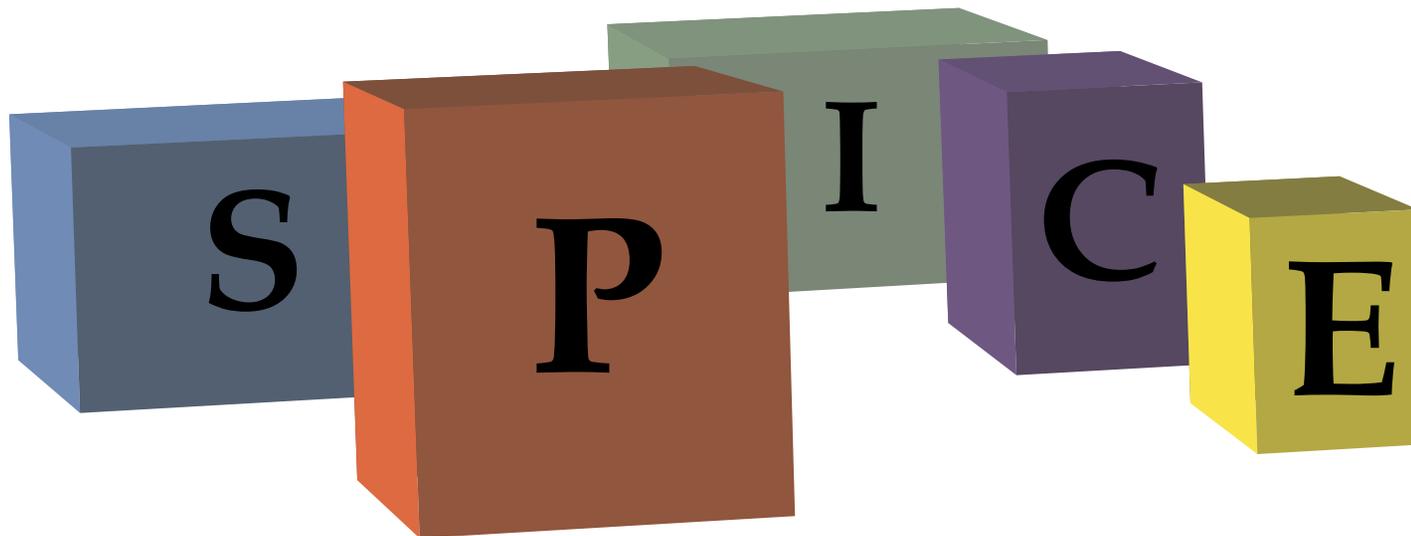
- NAIF has/had project-supplied funding to support mission operations, consultation for flight team members, and data archive preparation.
- NAIF has token funding to consult with kernel producers at APL.
- NAIF has modest PDS-supplied funding to consult only on assembly of a SPICE archive.
- NAIF has NASA funding to support ESA in SPICE operations and review of SPICE archive, and to consult with flight team users.
- NAIF has PDS funding to help any professional scientist with using SPICE data that have been archived at the NAIF Node of the PDS: http://naif.jpl.nasa.gov/naif/data_pds_archived.html



Building Blocks for Your Applications

Navigation and Ancillary Information Facility

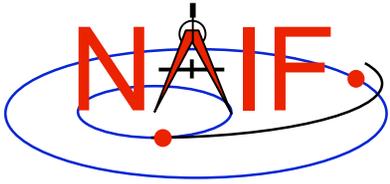
NAIF offers the “SPICE” ancillary information system as a set of blocks for building tools that can help execute a multimission, international space exploration program



SPICE: the ancillary information system that NAIF builds and often operates.

NAIF: the JPL entity responsible for development and deployment of SPICE.

NAIF Node of the PDS: one responsibility of the NAIF Group--archiving and providing long-term access to SPICE data for the worldwide science community.

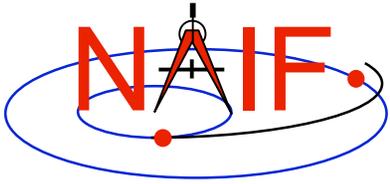


Navigation and Ancillary Information Facility

SPICE Conventions

**A summary of many “standards,” lingo
and common usage within SPICE**

January 2009



SPICE Lexicon - 1

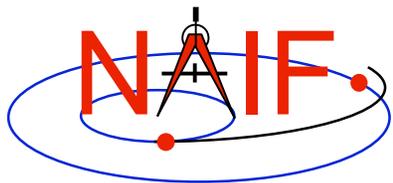
Navigation and Ancillary Information Facility

SPICE

- The name of this ancillary information system

NAIF

- The name of the team of people at JPL who lead development of the SPICE system.
- Also the name of the ancillary data node of NASA's Planetary Data System (PDS).



SPICE Lexicon - 2

Navigation and Ancillary Information Facility

SPICE Toolkit

NAIF Toolkit

The Toolkit

- Names that refer to the principal collection of software produced by JPL's NAIF Team as part of the SPICE information system. May include mission- or domain-specific augmentations.

Generic Toolkit

- A Toolkit that contains no mission-specific or enterprise-specific augmentations. This is what is available from NAIF's website.

SPICELIB

- The principal user library found within Fortran versions of the Toolkit.

CSPICE

- The principal user library found within C versions of the Toolkit. Also used to refer to the entire C Toolkit.

Icy

- An IDL interface to CSPICE

Mice

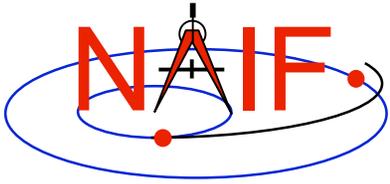
- A MATLAB interface to CSPICE



SPICE Lexicon - 3

Navigation and Ancillary Information Facility

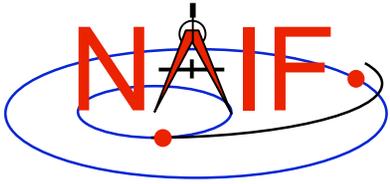
- **Text kernel**
 - Any kernel type consisting entirely of ASCII information, with each line terminated using the local operating system convention (CR, LF, CR+LF)
 - Text kernel types are FK, IK, text Pck, LSK, SCLK, MK (“Furnsh”)
 - Any and all text kernels could be combined in a single file.
 - » But this is certainly not recommended!
- **Binary kernel**
 - Any kernel type using a binary file format
 - Binary types are SPK, binary Pck, CK, DBK and DSK
 - Different binary kernel types cannot be combined together
- **Transfer format kernel**
 - A hexadecimal (ASCII) version of a binary kernel, used ONLY for porting a binary kernel between incompatible computers.
 - Not as important as it was prior to the addition of the so-called “binary kernel run-time translation” capability added in Toolkit N0052 (1/2002).
 - » But still has a role in making native binary kernels required for some operations.



SPICE Lexicon - 4

Navigation and Ancillary Information Facility

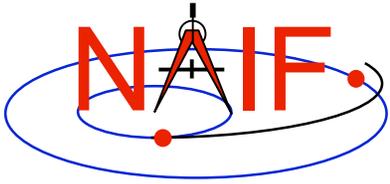
- **Database Kernel (DBK)**
 - A SPICE kernel that, in conjunction with Toolkit DBK software, provides a self-contained SQL-like database capability.
- **“Command file”**
 - Many SPICE application and utility programs either require, or optionally accept, an input file containing program directives and sometimes input data.
 - Unfortunately NAIF has not used a consistent approach for referring to such files. The following names have been used:
 - » Setup file, preferences file, command file, specifications file, definitions file



SPICE Lexicon - 5

Navigation and Ancillary Information Facility

- **Deprecated software**
 - Code that, while still useable, has been superseded with a newer and presumably better version
 - We encourage you to not use deprecated SPICE software
 - » (But, for your convenience, we won't remove it from the Toolkit packages) 😊
- **Toolkit version naming**
 - "Nxxxx" e.g. N0062 is Version 62
 - » Often shortened to just Nxx (e.g. N62)
- **“Satellite” is used to refer only to a natural satellite, never to a spacecraft.**



SPICE Lexicon - 6

Navigation and Ancillary Information Facility

Names used synonymously

- Kernel, SPICE file, SPICE kernel, SPICE kernel file
- Metadata, comments
- Time, Epoch
- Encoded SCLK, ticks*
- Frame, Reference Frame**
- Ephemeris, trajectory
- Rectangular coordinates, Cartesian coordinates**
- Geodetic, Planetodetic (coordinate system)
- Ephemeris time (ET), Barycentric Dynamical Time (TDB)
- Attitude and orientation
- International Celestial Reference Frame (ICRF) and Earth Mean Equator and Equinox of 2000 reference frame (J2000)
- Meta-kernel and Furnsh kernel
- Module, routine, subroutine, procedure, and function
- “Body”, “solar system object” and “ephemeris object”

* Encoded SCLK always refers to absolute time; “ticks” is used to refer to both durations and absolute times.

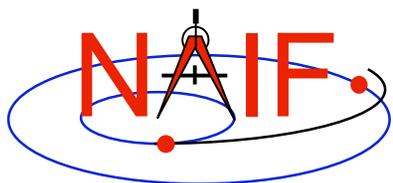
** Outside of SPICE the term “coordinate system” is often used synonymously with “frame” or “reference frame.” We prefer to use “coordinate system” in the sense of describing how coordinates are measured (e.g. cylindrical coordinate system, rectangular coordinate system, polar coordinate system, etc), and to use “frame” in the sense of a set of three orthogonal vectors.



Kernel File Names

Navigation and Ancillary Information Facility

- **SPICE imposes some restrictions on kernel file names**
 - No white space allowed within a name
 - Maximum length of a name (including any path specifications) is 255 characters
 - » See the tutorial “Intro_to_kernels” for limitations on file name specifications contained within meta kernels (“furnsh kernels”)
- **NAIF suggests names conform to the PDS standard: “36.3”**
 - <1 to 36 alphanumeric characters>.<1 to 3 chars>
 - (Note: This is a recent change from the old 27.3 standard.)
- **Common usage within NAIF for SPICE kernel file name extensions is listed on the next page, with the following general style used:**
 - t* text format (e.g. pck00008.tpc)
 - b* binary format (e.g. de421.bsp)
 - x* transfer format (e.g. de421.xsp)



Common SPICE Kernel File Name Extensions

Navigation and Ancillary Information Facility

SPK:

- .bsp** binary SPK file
- .xsp** transfer format SPK file

PcK:

- .tpc** text PcK file
(This is the most common type PcK)
- .bpc** binary PcK file
(few instances of this)
- .xpc** transfer format PcK file
(few instances of this)

IK:

- .ti** text IK file

FK:

- .tf** text FK file

LSK:

- .tls** text LSK file

CK:

- .bc** binary CK file
- .xc** transfer format CK file

SCLK:

- .tsc** text SCLK file

MK:

- .tm** text meta-kernel file (“FURNISH kernel”)

DSK:

- .bds** binary DSK file

EK Family (ESP, ESQ, ENB)

ESP:

- .tep** text Science Plan EK file

ESQ:

- .bes** binary Sequence Component EK file
- .xes** transfer format Sequence Component EK file

ENB:

- n/a** (www interface)

These are suggestions, not requirements



Common Document Name Extensions

Navigation and Ancillary Information Facility

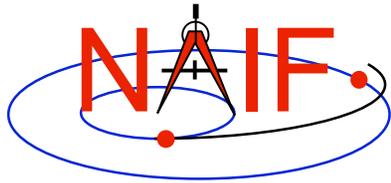
- **These extensions are used for plain ASCII documents included with each Toolkit delivery**
 - .ug** **User's Guide**
 - .req** **"Required Reading" reference document**
 - .txt** **Used for a few miscellaneous documents**
 - .idx** **Used only for the permuted index document**
- **All HTML documents included in the Toolkit have extension .html**
- **Alternate formats of some of the Toolkit documents are available from the NAIF anonymous ftp server**
 - .pdf** **PDF documents**



Public and Private Modules

Navigation and Ancillary Information Facility

- **All Toolkits include public and private modules**
- **Public modules are available for your use**
 - Names of public APIs are different in the four SPICE library implementations. For example, the top level SPK reader SPKEZR has the following names
 - » in SPICELIB (FORTRAN) **SPKEZR**
 - » In CSPICE (C) **spkezt_c**
 - » ICY (IDL) **cspice_spkezt**
 - » Mice (MATLAB) **cspice_spkezt** and **mice_spkezt**
 - The API Reference Guide included in the Toolkit HTML documentation provides the complete list of all public SPICE APIs available in a specific implementation of the Toolkit
- **Private modules are for NAIF staff use only**
 - Names of private modules start with “ZZ”
 - They are present in the Toolkit only to support operations of “public” modules
 - Private APIs are not listed in the API Reference Guide but can be seen in the source code directories for SPICELIB, CSPICE, and Mice
 - Do not use “private” modules in your code – they may change



Reference Frame and Coordinate System Conventions

Navigation and Ancillary Information Facility

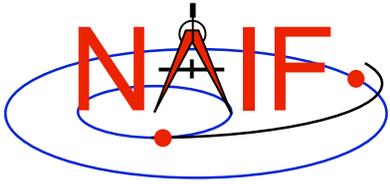
- **All reference frames used within SPICE are right handed systems: $X \text{ cross } Y = Z$**
- **In planetocentric reference frames the +Z axis (+90 LAT) always points to the north side of the invariable plane (the plane whose normal vector is the angular momentum vector of the solar system)**
 - Planetocentric longitude increases positively eastward
 - Planetocentric latitude increases positively northward
- **In planetographic reference frames:**
 - Planetographic longitude is usually defined such that the sub-observer longitude increases with time as seen by a distant, fixed observer in an inertial reference frame
 - » The earth, moon and sun are exceptions; planetographic longitude is positive east by default
 - Planetographic latitude increases positively northward



Quaternions

Navigation and Ancillary Information Facility

- The SPICE system uses quaternions in C-kernels
- There are different “styles” of quaternions used in science and engineering applications. Styles are characterized by
 - The order of the quaternion elements
 - The quaternion multiplication formula
 - The convention for associating quaternions with rotation matrices
- Two of the commonly used styles are
 - “SPICE”
 - » Used by Sir William Rowan Hamilton (discoverer of quaternions)
 - » Used in math and physics textbooks
 - “Engineering” or “MSOP”
 - » Widely used in JPL ACS/AACS and other aerospace applications
- The relationship between SPICE and MSOP quaternions:
 - Let M be a rotation matrix such that for any vector v , $M*v$ is the result of rotating v by Θ radians in the counterclockwise direction about unit vector A . Then the quaternions representing M are:
 - » SPICE: $(+/-) (\cos(\Theta/2), \sin(\Theta/2)A(1), \sin(\Theta/2)A(2), \sin(\Theta/2)A(3))$
 - » MSOP: $(+/-) (-\sin(\Theta/2)A(1), -\sin(\Theta/2)A(2), -\sin(\Theta/2)A(3), \cos(\Theta/2))$
- Details about SPICE quaternions are found in:
 - Rotations Required Reading document
 - NAIF white paper on quaternions: ftp://naif.jpl.nasa.gov/pub/naif/misc/Quaternion_White_Paper/
 - SPICE quaternion conversion routines: M2Q, Q2M



Names and IDs

Navigation and Ancillary Information Facility

- **Many items within SPICE have assigned names (text strings) and IDs (integer numbers)**
- **The NAIF/SPICE rules, standards, practices and exceptions regarding these names and IDs are discussed in a separate tutorial (“Names and IDs”)**

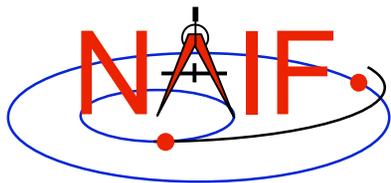


Navigation and Ancillary Information Facility

NAIF IDs and Names

for Physical Objects and Reference Frames

January 2009

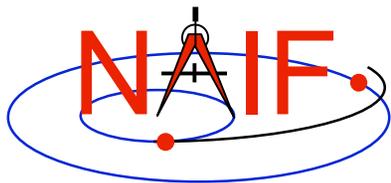


Overview

Navigation and Ancillary Information Facility

- **Summary of naming/numbering schemes used in SPICE**
- **Naming/numbering of [physical objects](#)**
- **Naming/numbering of [reference frames](#)**
- **Connection between the schemes**

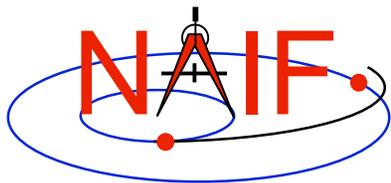
Caution: users sometimes confuse the ID assigned to an object and the ID(s) assigned to a reference frame or frames associated with that object. Read on for details.



Overview

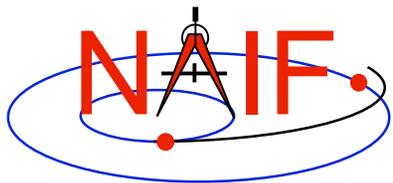
Navigation and Ancillary Information Facility

- **SPICE uses IDs and names to identify:**
 - physical objects
 - reference frames
- **A name is a text string; an ID is an integer number**
- **The naming/numbering schemes for physical objects and for frames are **independent****
 - This means that in general **SPICE does not make any assumptions about frame names/IDs based on the physical objects' names/IDs and vice versa**
 - » There are some exceptions though; they will be mentioned later



Navigation and Ancillary Information Facility

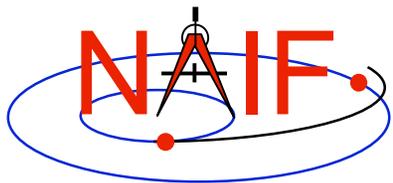
Names and IDs associated with Objects



Object IDs/Names

Navigation and Ancillary Information Facility

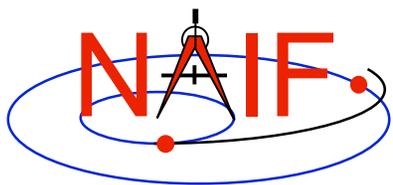
- **Names and IDs are assigned to the following types of **physical objects**:**
 - Natural bodies -- planets, satellites, comets, asteroids
 - Artificial bodies -- spacecraft, spacecraft structures, science instruments, individual detectors within science instruments, DSN stations
 - Any other point, the location of which can be known within the SPICE context
 - » Barycenters of solar system and planetary systems, landing sites, corners of solar arrays, focal points of antennas, etc.
- **A single ID is assigned to each physical object, but multiple names can be associated with (map to) that ID**
 - On input, the names are treated as synonyms
 - On output, the name that was last associated with the ID is used



Object IDs -- How Used

Navigation and Ancillary Information Facility

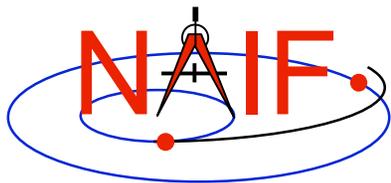
- **Physical object IDs** are used:
 - in **kernels** as data identifiers:
 - » **SPKs** -- to identify a body and its center of motion
 - » **text PCKs** -- in keywords associated with a body
 - » **IKs** -- in keywords associated with instrument/detector
 - » **FKs** -- to specify the center for computing LT correction, and to identify the body in PCK-based frames
 - » **FKs** -- to identify target and observer in dynamic frames specifications
 - » **SCLKs** -- normally the SCLK ID used in keywords is the negative of the spacecraft's ID (thus a positive integer)
 - » ... and more...



Object IDs -- How Used

Navigation and Ancillary Information Facility

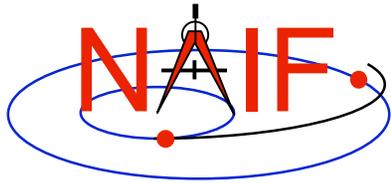
- **Physical object IDs** are used:
 - in some APIs as input and/or output arguments:
 - » Older SPK routines -- SPKEZ, SPKEZP, SPKGEO, ...
 - » Older derived geometry routines -- ET2LST, ...
 - » Older PCK routines -- BODVAR, BODMAT, ...
 - » IK routines -- GETFOV, indirectly in G*POOL, ...
 - » SCLK routines -- SCE2C, SCT2E, ...
 - » Coverage routines -- SPKOBJ, SPKCOV, CKOBJ, CKCOV
 - » ... and more...



Object Names -- How Used

Navigation and Ancillary Information Facility

- **Physical object names** are used in the following APIs as input and/or output arguments:
 - » Newer SPK routines -- SPKEZR, SPKPOS
 - » Newer derived geometry routines -- SINCPPT, ILUMIN, SUBPNT, SUBSLR, ...
 - » Newer PCK routines -- BODVRD, ...
- **Physical object names** are **not** used as data identifiers within kernels.



Object IDs/Names -- How Defined

Navigation and Ancillary Information Facility

- **Name/ID mappings used by SPICE may be defined in two places**
 - Inside the Toolkit: hard-coded in the source code
 - » See NAIF_IDS.REQ for a complete listing of built-in (default) assignments
 - In text kernels
 - » You may define additional mappings using **KEYWORD = VALUE** assignments. For example, for a spacecraft:
 - NAIF_BODY_NAME += ('spacecraft_name')*
 - NAIF_BODY_CODE += (spacecraft_ID_number)*
 - » These assignments exist most often in FKs (e.g. DI, GNS, M01, MER, SIRTF), sometimes in IKs (e.g. CASSINI, MGS), but can be placed in any text kernel
 - » Normally text kernels are used to define name/ID mappings for instruments, their subsystems/detectors and other spacecraft structures
 - See comments and the actual data sections in a text kernel for the complete listing of the names/IDs defined in that kernel
 - » Mappings defined in text kernels take **precedence** over those defined in Toolkit source code.

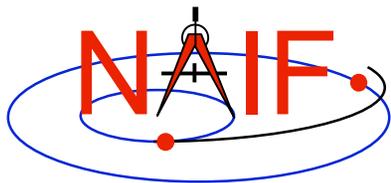
* See Kernels Required Reading for information about the “+=” operator



Object IDs/Names Spacecraft and Ground Stations

Navigation and Ancillary Information Facility

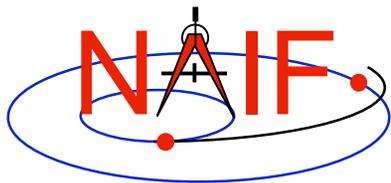
- **Spacecraft (negative numbers)**
 - Within NASA, this number is generally the negative of the numeric ID assigned by the NASA control authority at GSFC
 - -6 ‘PIONEER-6’, ‘P6’
 - -7 ‘PIONEER-7’, ‘P7’,
 - -82 ‘CASSINI’, ‘CAS’
 - -94 ‘MARS GLOBAL SURVYOR’, ‘MGS’
 - ...
 - Unfortunately sometimes NASA re-uses a number
 - » This will happen with increasing frequency in the future
 - » Probably a new scheme is needed
- **DSN ground stations (399000 + station number)**
 - 399005 ‘DSS-05’
 - ...
 - 399066 ‘DSS-66’
- **Non-DSN stations (398000 + some integer 0 to 999)**
 - 398990 ‘NEW_NORCIA’
 - ...



Object IDs/Names -- Planets

Navigation and Ancillary Information Facility

- **Sun and Solar System Barycenter (10 and 0)**
 - 0 'SOLAR SYSTEM BARYCENTER', 'SSB'
 - 10 'SUN'
- **Planetary barycenters (numbers from 1 to 9)**
 - 1 'MERCURY BARYCENTER'
 - 2 'VENUS BARYCENTER'
 - 3 'EARTH MOON BARYCENTER', 'EMB', ...
 - 4 'MARS BARYCENTER'
 - ...
 - 9 'PLUTO BARYCENTER'
- **Planet centers (planet barycenter ID * 100 + 99)**
 - 199 'MERCURY'
 - 299 'VENUS'
 - 399 'EARTH'
 - 499 'MARS'
 - ...
 - 999 'PLUTO'

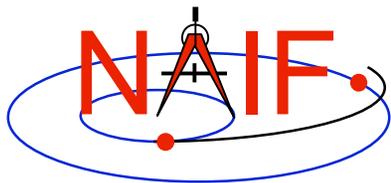


Object IDs/Names -- Satellites

Navigation and Ancillary Information Facility

- **Satellites (planet barycenter ID*100 + number <1... 98>)**
 - 301 'MOON'
 - 401 'PHOBOS'
 - 402 'DEIMOS'
 - 501 'IO'
 - ...
 - 901 'CHARON', '1978P1'

See the **BACKUP** section for details about
how to handle more than 98 satellites.



Object IDs/Names Comets & Asteroids

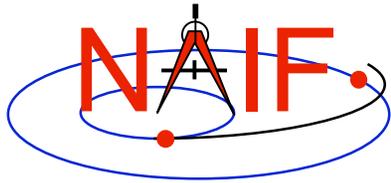
Navigation and Ancillary Information Facility

- **Periodic Comets (1000000 + number)**

- 1000001 'ARENDA'
- 1000002 'ARENDA-REGAUX'
- ...
- 1000032 'HALE-BOPP'

- **Numbered Asteroids (2000000 + asteroid number)**

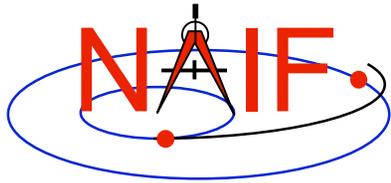
- 2000001 'CERES'
- 2000004 'VESTA'
- ...
- 2009969 'BRAILLE', '1992KD'
- There are a few exceptions; see NAIF_IDS.REQ



Object IDs/Names -- Instruments

Navigation and Ancillary Information Facility

- **Science Instruments (s/c ID*1000 - inst. number)**
 - A number should be picked for EVERY instrument, instrument subsystem or detector, or spacecraft structure, the parameters for which are to be stored in IKs, or the location of which is to be stored in SPKs
 - Instrument numbers are picked from the range 0...999. The only requirement is that they must be unique
 - ...
 - -82760 'CASSINI_MIMI_CHEMS'
 - -82761 'CASSINI_MIMI_INCA'
 - -82762 'CASSINI_MIMI_LEMMS1'
 - -82763 'CASSINI_MIMI_LEMMS2'
 - ...
 - -82001 'CASSINI_SRU-A'
 - -82002 'CASSINI_SRU-B'
 - -82008 'CASSINI_SRU-A_RAD'
 - -82009 'CASSINI_SRU-B_RAD'
 - ...



Object IDs/Names -- Mapping APIs

Navigation and Ancillary Information Facility

- **SPICE provides two routines to map physical object IDs to names, and vice versa**

- To get the ID for a given physical object name:

CALL BODN2C (NAME, ID, FOUND)

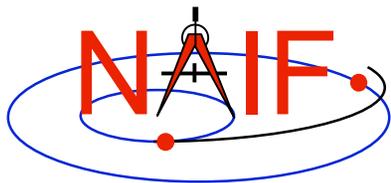
CALL BODS2C (NAME, ID, FOUND)

(This is a more general version as compared to BODN2C. Use this one.)

- To get the name for a given physical object ID:

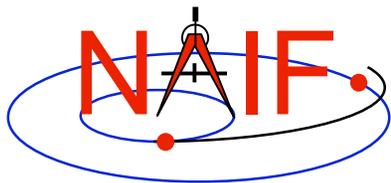
CALL BODC2N(ID, NAME, FOUND)

- If the “FOUND” flag returned by either of these routines comes back **FALSE**, then the input ID or name cannot be mapped



Navigation and Ancillary Information Facility

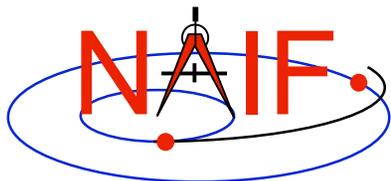
Names and IDs associated with Reference Frames



Frame IDs/Names

Navigation and Ancillary Information Facility

- **Names and IDs are assigned to the following kinds of reference frames**
 - Inertial frames
 - Body-fixed frames
 - Spacecraft and instrument frames
 - Topocentric frames
 - Any other reference frame for which the orientation may be needed to compute observation geometry
- **Unlike for objects, only a single ID and a single name are assigned to each reference frame**
 - “Aliases” for a frame name can only be set up by defining new zero-offset frames with their own unique names and IDs



Frame IDs/Names -- How Used

Navigation and Ancillary Information Facility

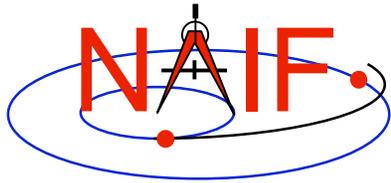
- **Reference frame **IDs** are used**
 - in the following kernels as data identifiers:
 - » **FKs** -- to “glue” frame definition keywords together
 - » **SPKs** -- to identify base reference frames
 - » **PCKs** -- to identify base reference frames
 - » **CKs** -- to identify base reference frames
 - in the following APIs as input and/or output arguments:
 - » **Almost nowhere** -- users rarely or never need to deal with or be aware of reference frame IDs
- **Reference frame **names** are used**
 - as arguments in all high level APIs that require a reference frame to be specified on the input
 - » **Derived geometry routines** -- SINCPT, ILUMIN, SUBPNT, ...
 - » **Frame transformation routines** -- PXFORM, SXFORM
 - » **SPK routines** -- SPKEZR, SPKPOS, ...
 - **Frame names are NOT used as data identifiers within kernels**



Frame IDs/Names -- How Defined

Navigation and Ancillary Information Facility

- **The reference frame name/ID mappings used by the SPICE system are defined in two places**
 - **Built into the Toolkit: hard-coded in source code**
 - » For inertial frames
 - » For body-fixed frames defining the orientation for planets and most satellites
 - » See **FRAMES REQUIRED READING** for a complete listing
 - **In text kernels: provided by KEYWORD=VALUE sets**
 - » **Almost always in FKs (DI, GNS, M01, MER, SIRTf, ...), very rarely in other kernels, but can be in any text kernel**
 - (For example during operations MGS frames were defined in IKs and SCLK)
 - » **Text kernels define spacecraft frames, instrument frames, spacecraft subsystem frames, DSN station frames, etc.**
 - See comments/data sections in a text kernel for the complete listing of the frames defined in that kernel

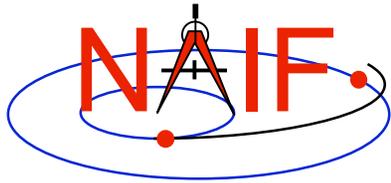


Frame IDs/Names -- Inertial and Body-fixed

Navigation and Ancillary Information Facility

The samples of frame **IDs** shown below are shown for completeness. Users would rarely if ever need to know or use them.

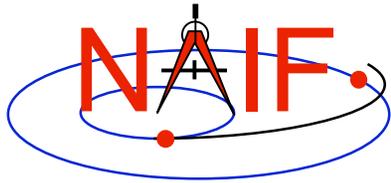
- Inertial frames (positive integers starting at 1)
 - 1 'J2000'
 - ...
 - 16 'MARSIAU'
 - 17 'ECLIPJ2000'
 - ...
 - 21 'DE-143'
- Body-fixed frames (positive integers starting at 10001)
 - 10001 'IAU_MERCURY_BARYCENTER'
 - ...
 - 10011 'IAU_MERCURY'
 - ...
 - 10020 'IAU_MOON'
 - ...
 - 10081 'EARTH_FIXED'
 - ...



Frame IDs/Names -- Spacecraft and Instrument

Navigation and Ancillary Information Facility

- **IDs for frames associated with spacecraft, spacecraft structures, and instruments are usually:**
 - s/c ID times 1000 minus an arbitrary number
- **As example, for Cassini:**
 - **Spacecraft frame (ID and name)**
 - 82000 'CASSINI_SC_COORD'
 - **Spacecraft structure frame (ID and name)**
 - 82001 'CASSINI_SRU-A'
 - **Instrument frames (ID and name)**
 - 82760 'CASSINI_MIMI_CHEMS'
 - 82761 'CASSINI_MIMI_LEMMS_INCA'
 - 82762 'CASSINI_MIMI_LEMMS1'
 - 82763 'CASSINI_MIMI_LEMMS2'
 - 82764 'CASSINI_MIMI_LEMMS_BASE'
 - 83765 'CASSINI_MIMI_LEMMS_ART'
 - ...
- **SPICE users would rarely if ever need to know or use frame IDs; you'll use the associated frames name instead.**



Frame IDs/Names -- Mapping APIs

Navigation and Ancillary Information Facility

- **SPICE provides two routines to convert (map) reference frame IDs to names, and vice versa**

- To get the ID for a given reference frame name:

CALL NAMFRM(NAME, ID)

- To get the name for a given reference frame ID:

CALL FRMNAM(ID, NAME)

- If the ID or name cannot be mapped, these routines return zero and an empty/blank string respectively.

- **Users will rarely if ever need to call these routines.**



Name/ID Schemes Connections

Navigation and Ancillary Information Facility

- Although physical object and reference frame naming/numbering schemes are independent, in practice there is a lot of overlap in the way **objects** and **frames** are named and numbered
- This overlap is due to the following reasons
 - Conventions adopted over the course of SPICE implementation
 - » Example: PCK-based body-fixed frames for planets and satellites are named 'IAU_<body name>'
 - However, the IDs of these **frames** have nothing in common with the IDs of the **objects** (bodies) for which these frames are defined
 - The need for the object and frame IDs to be unique
 - » For this reason both the instrument (**object**) IDs and the instrument **frame** IDs are derived from the ID of the spacecraft on which the instrument is flown
 - The need for the object and frame names to be meaningful
 - » For this reason the instrument **frame** names normally contain both the name of the spacecraft and the name of the instrument



“Odd Ball” Cases

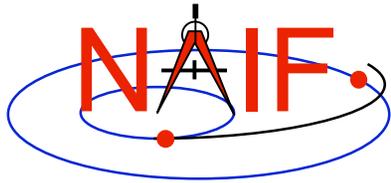
Navigation and Ancillary Information Facility

- **CK IDs**

- Historically IDs used in CKs are called structure IDs but in reality they are much more closely related to frames than to physical objects
- To find which frame is associated with a particular CK ID, look through FK for a frame whose `_CLASS_ID` keyword is set to the CK ID
 - » In practice, for CK-based frames both the frame ID and frame `_CLASS_ID` are set to the CK ID

- **SCLK IDs**

- Because most spacecraft have only one on-board clock, the SCLK ID of that clock is the same as the spacecraft ID
- Should a spacecraft carry more than one independent clock, unique SCLK IDs for these other clocks would be needed
 - » Normally the ID of an additional clock will be set to the ID of the instrument, of which that clock is a part
- SCLK IDs are used in SCLK APIs (must be provided by the user) and by the frames subsystem when it reads CKs to determine orientation of CK-based frames (gets SCLK ID from `CK_*_SCLK` keyword provided in the frame definition or computes it by dividing CK ID by 1000)



Name/IDs Example -- CASSINI (1)

Navigation and Ancillary Information Facility

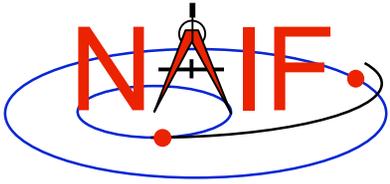
	<u>Objects IDs/Names</u>		<u>Frames IDs/Names</u>	
Ephemeris objects	10	'SUN'	1	'J2000'
	399	'EARTH'	10013	'IAU_EARTH'
	699	'SATURN'	10016	'IAU_SATURN'
	601	'MIMAS'	10039	'IAU_MIMAS'
	602	'ENCELADUS'	10040	'IAU_ENCELADUS'
Spacecraft and its structures	-82	'CASSINI'	-82000	'CASSINI_SC_COORD'
	-82001	'CASSINI_SRU-A'	-82001	'CASSINI_SRU-A'
CDA instrument	-82790	'CASSINI_CDA'	-82790	'CASSINI_CDA'
			-82791	'CASSINI_CDA_ART'
			-82792	'CASSINI_CDA_BASE'
CAPS instrument	-82820	'CASSINI_CAPS_IMS'	-82820	'CASSINI_CAPS'
	-82821	'CASSINI_CAPS_ELS'	-82821	'CASSINI_CAPS_ART'
	-82822	'CASSINI_CAPS_IBS_DT1'	-82822	'CASSINI_CAPS_BASE'
	-82823	'CASSINI_CAPS_IBS_DT2'		
	-82824	'CASSINI_CAPS_IBS_DT3'		



Name/IDs Example -- CASSINI (2)

Navigation and Ancillary Information Facility

- **The lists provided on the previous page are by no means complete**
 - There are many more Saturnian satellites and other natural bodies of interest to the Cassini mission, each having an associated frame
 - There are many more instruments on the Cassini spacecraft, with multiple frames associated with each of them
- **To find names and IDs associated with these objects and frames users should refer as follows**
 - For names/IDs of natural objects: **NAIF_IDS.REQ**
 - For names/IDs of Cassini instruments and their subsystems: **IK files**
 - » For other missions this information is in the mission's **FK file**
 - For names of inertial frames and body-fixed frames associated with natural bodies: **FRAMES.REQ**
 - For names of the reference frames associated with the Cassini spacecraft, its subsystems and instruments: **FK file**



Navigation and Ancillary Information Facility

Backup

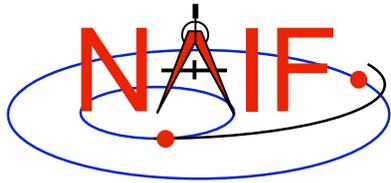
**How to handle more than 98
satellites for one planet**



Object IDs/Names -- Satellites (2)

Navigation and Ancillary Information Facility

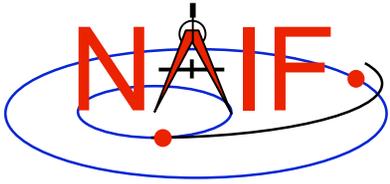
- **The scheme described for satellites can accommodate only 98 natural satellites. How do we handle more than 98?**
 - For IAU provisional assignments, use “psbbb” also, where:
 - » p = planet barycenter ID
 - » s = separator, set equal to “5”
 - » bbb = satellite number
 - Start with the next available unused IAU two-digit number with a “0” pre-pended, when we elect to put this scheme into effect
 - Increment by one thereafter
 - For IAU permanent assignments, use “psbbb” where:
 - » p = planet barycenter ID
 - » s = separator, set equal to “0”
 - » bbb = satellite number
 - Use “099” for the first new permanent assignment after “p98” from the current range is used



Object IDs/Names -- Satellites (3)

Navigation and Ancillary Information Facility

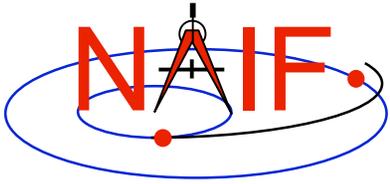
- The satellite extended numbering scheme described on the previous page attempts to, but may not be able to, maintain consistency in the last three digits as the boundary between 98 and 99 is crossed.
 - This is because the IAU sometimes changes the numbering order of new satellites when migrating from provisional to permanent status.
- It has been suggested that some JPL entity maintain a public web page showing the history of all assignments.
 - (Not done so far...)
- It is recommended that any SPK file made using provisional IDs be trashed (or hidden away) when a new file using permanent IDs is obtained.
 - If no new file is expected, the *bspidmod* program can be used to replace provisional ID(s) with official ID(s) in the old file



Navigation and Ancillary Information Facility

Fundamental Concepts

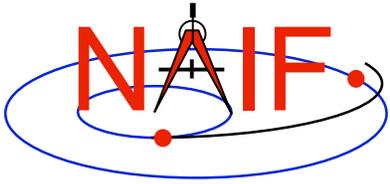
January 2009



Topics

Navigation and Ancillary Information Facility

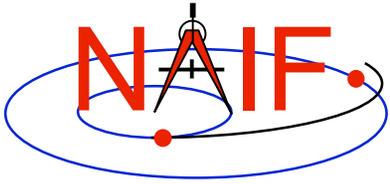
- **Preface**
- **Time**
- **Reference Frames**
- **Coordinate Systems**
- **Positions and States**
- **Aberration Corrections**



Preface

Navigation and Ancillary Information Facility

- **This tutorial introduces terminology and concepts used in the later SPICE tutorials.**
- **Some of this material is more difficult than what follows in later presentations.**
 - A complete understanding of this material is *not* essential in order to use SPICE.
- **Still, we think this information may be helpful, so... on we go!**

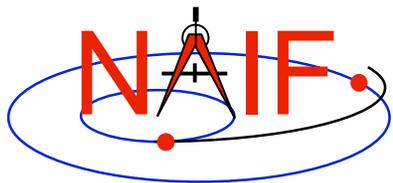


Time

Navigation and Ancillary Information Facility

- **An epoch is an instant in time specified by some singular event**
 - Passage of a star across your zenith meridian
 - Eclipse of a spacecraft signal as it passes behind a solid body
- **Clocks** 
 - More mundane specifications are given as a count: “regular” oscillations of a pendulum, quartz crystal, or electromagnetic radiation from a specified source, measured from an agreed upon reference epoch.
 - Careful specification of epochs using clocks requires reference to the particular clock and the location of that clock.
- **Time Systems**
 - Agreed upon standards for “naming” epochs, measuring time, and synchronizing clocks

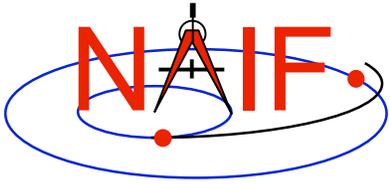




Atomic Time and UTC

Navigation and Ancillary Information Facility

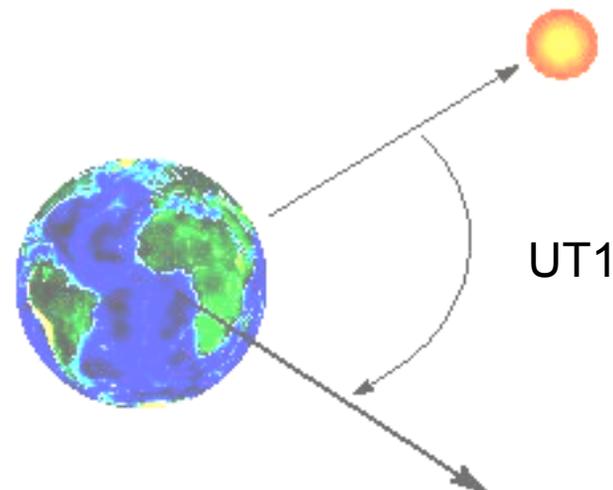
- **International Atomic Time (TAI)**
 - **Statistical time scale**
 - » **Based on data from ~200 atomic clocks in over 50 national laboratories**
 - **Maintained by Bureau International des Poids et Mesures (BIPM)**
 - **Unit is the SI (System International) second**
 - » **duration of 9192631770 periods of the radiation corresponding to the transition between two hyperfine levels of the ground state of the cesium 133 atom**
 - **Count of atomic seconds past the astronomically determined instant of midnight 1 Jan 1958 00:00:00**
- **Coordinated Universal Time (UTC)**
 - **Civil Time at Greenwich England (~GMT)**
 - **Usual Calendar Formats plus Hour:Minute:Second.fraction**
 - **UTC + 10 seconds + number of leap seconds = TAI**
 - » **Valid only after Jan 01, 1972**

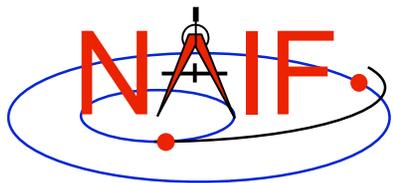


Astronomical Time

Navigation and Ancillary Information Facility

- **Astronomical Time (UT1) is an hour representation of the angle between the Greenwich zenith meridian and the location of the “computed mean sun.”**
- **Used prior to atomic time for civil time keeping**

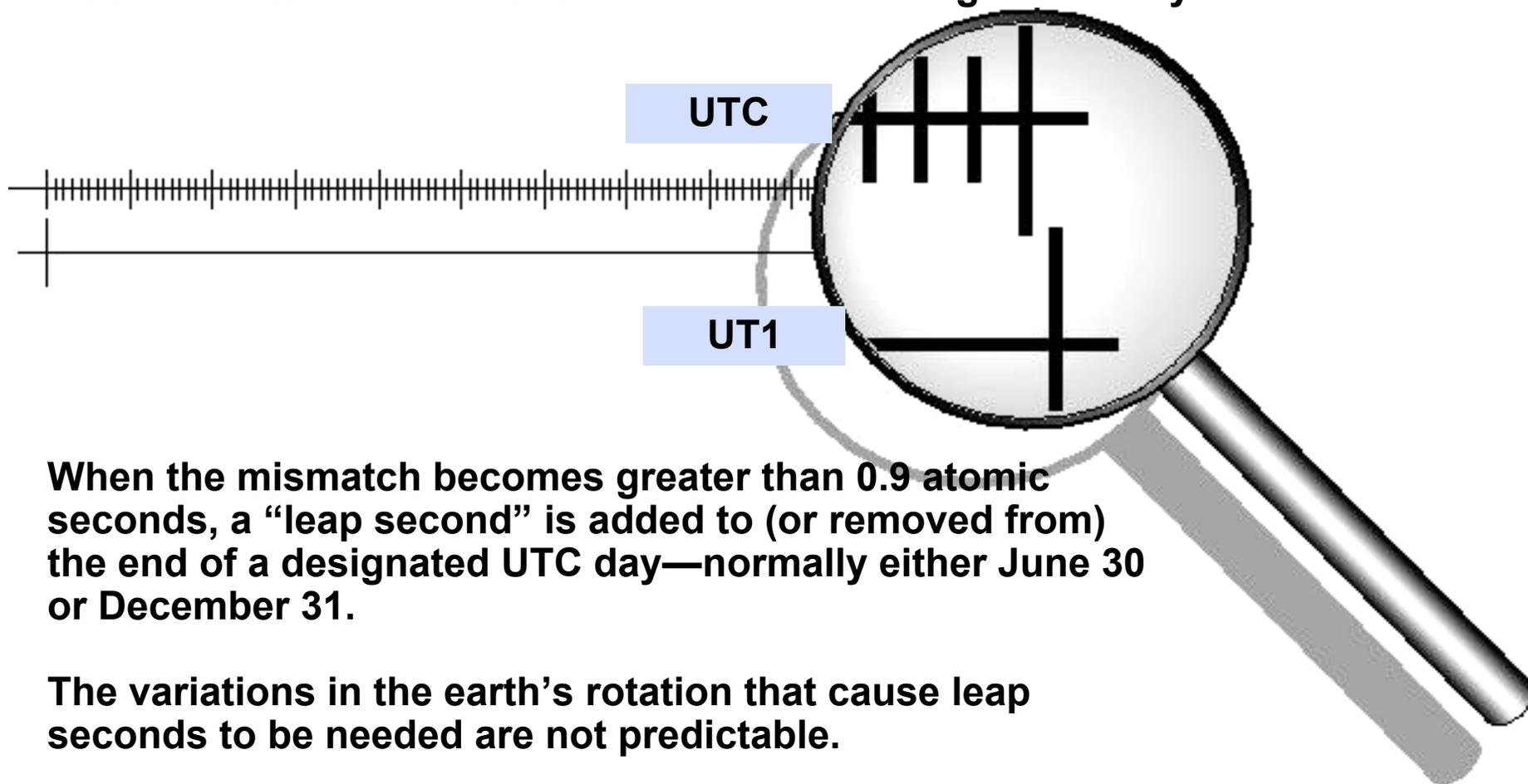




Tying UTC to Earth's Rotation

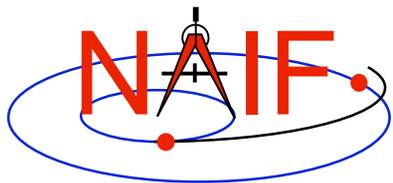
Navigation and Ancillary Information Facility

Ideally, UTC noon and astronomical noon at Greenwich (UT1) should occur simultaneously. However, the earth's rotation is not uniform. Eventually, UTC noon and astronomical noon at Greenwich get out of sync.



When the mismatch becomes greater than 0.9 atomic seconds, a “leap second” is added to (or removed from) the end of a designated UTC day—normally either June 30 or December 31.

The variations in the earth's rotation that cause leap seconds to be needed are not predictable.



Leapseconds (+ and -)

Navigation and Ancillary Information Facility

- **“Normal” sequence of UTC time tags**

- 1998 Dec 31 23:59:58.0
- 1998 Dec 31 23:59:59.0
- 1999 Jan 01 00:00:00.0
- 1999 Jan 01 00:00:01.0

Leap seconds complicate the task of finding the duration between two UTC epochs:

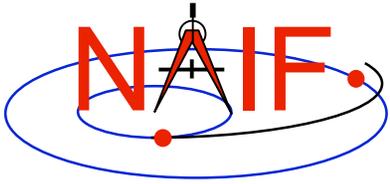
- You need to know when past leap seconds occurred to compute durations defined by pairs of past UTC epochs.
- Durations defined by pairs of future UTC epochs are indeterminate if leap seconds could occur in the interim.

- **Sequence with a Positive Leapsecond**

- 1998 Dec 31 23:59:58.0
- 1998 Dec 31 23:59:59.0
- **1998 Dec 31 23:59:60.0**
- 1999 Jan 01 00:00:00.0
- 1999 Jan 01 00:00:01.0

- **Sequence with a Negative Leapsecond**

- 1998 Dec 31 23:59:57.0
- **1998 Dec 31 23:59:58.0**
- **1999 Jan 01 00:00:00.0**
- 1999 Jan 01 00:00:01.0



Barycentric Dynamical Time

Navigation and Ancillary Information Facility

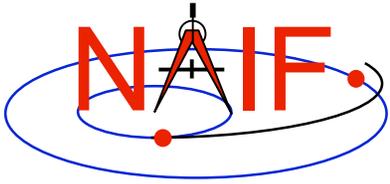
- **Barycentric Dynamical Time (TDB) and Ephemeris Time (ET) are synonyms in SPICE documentation.**
- **TDB is**
 - **Mathematical Ideal used in the equations of motion.**
 - **Used as the independent time variable for many SPICE subroutine interfaces.**
 - **Related to ideal Time at the Solar System Barycenter (TCB) by a scale factor, so that TDB advances on average at the same rate as TAI.**



Terrestrial Dynamical Time

Navigation and Ancillary Information Facility

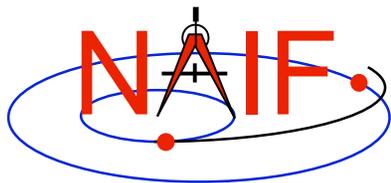
- **Terrestrial Dynamical Time (TDT)**
 - IAU has adopted the name “Terrestrial Time” (TT)
 - » But called TDT throughout SPICE documentation
 - Ideal Time (proper time) on Earth at sea level
 - $TDT = TAI + 32.184$ seconds
- **TDB and TDT have same reference epoch (approximately 1 Jan 2000, 12:00:00 at Greenwich England)**
- **TDB and TDT advance at different rates.**
 - Variations are small ~ 1.6 milliseconds
 - Variations are periodic with a period of 1 sidereal year (to first order)
 - Variations are due to relativistic effects
 - » $TDB = TDT + 0.001657 \sin(E + 0.01671 \sin(E))$
- **Use of TDT in the SPICE system is quite limited.**
 - SCLK kernels
 - Duration computations involving UTC



Spacecraft Clocks

Navigation and Ancillary Information Facility

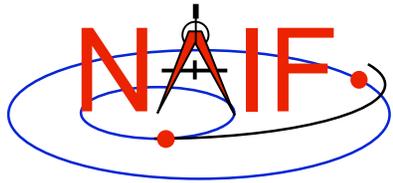
- **Spacecraft have onboard clocks to control scheduling of observations, maneuvers, attitude adjustments, etc.**
- **Used to time stamp data**
- **Fundamental unit of time is the “tick”**
 - Smallest increment possible for spacecraft clock
- **Spacecraft clock time is a count of ticks since some reference tick.**
- **The duration of the tick drifts with respect to other time systems.**



More about Spacecraft Clocks

Navigation and Ancillary Information Facility

- **SCLK string formats vary from one spacecraft clock to the next.**
 - **Cassini: Maximum reading for partition 1 = 1/4294967295.255**
 - » **Partition number:** 1
 - » **Seconds:** 4294967295
 - » **Ticks (for Cassini, unit = 1/256 second):** 255
 - **Galileo: Maximum reading for partition 1 = 1/16777215:90:09:07**
 - » **Partition number:** 1
 - » **"RIM" count (unit = 60 2/3 seconds):** 16777215
 - » **"Mod 91" count (unit = 2/3 second):** 90
 - » **"RTI" count (unit = 1/15 second):** 9
 - » **"Mod 8" count (unit = 1/120 second):** 7
- **Format of spacecraft clock and relationship between tick count and other time systems (usually UTC) is captured in a SPICE SCLK kernel**
 - **Pronounced “ess-clock”**
 - » **sometimes the more vulgar “sclock” pronunciation is used**



Reference Frames: Definition

Navigation and Ancillary Information Facility

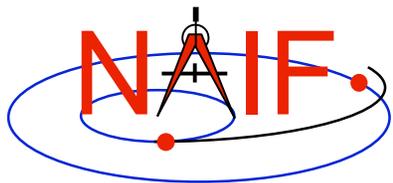
- **A reference frame is an ordered set of three mutually orthogonal (possibly time dependent) unit-length direction vectors, coupled with a location called the frame’s “center” or “origin.”**
 - **SPICE documentation frequently uses the shorthand “frame.”**
 - **A reference frame is also called a “basis,” but SPICE documentation very rarely uses this term.**



Reference Frame Center

Navigation and Ancillary Information Facility

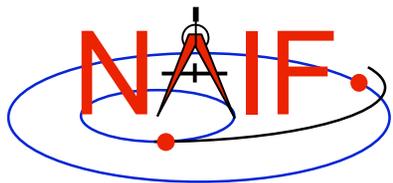
- **A frame's center is an ephemeris object whose location is coincident with the origin (0, 0, 0) of a reference frame.**
 - The center of the IAU_<body> frame is <body>.
 - The center of any inertial frame is (in SPICE) the solar system barycenter.
 - » Even for frames naturally associated with accelerated bodies, such as MARSIAU.
- **A frame's center plays little role in specification of states**
 - Origin cancels out when doing vector arithmetic
 - » Whether positions of objects A and B are specified relative to centers C1 or C2 makes no difference:
$$(A - C1) - (B - C1) = (A - C2) - (B - C2) = A - B$$
 - But the center *is* used in computing light time to centers of non-inertial frames
 - » When the aberration-corrected state of Titan as seen from the Cassini orbiter is computed in the body-fixed IAU_Titan frame, light time is computed from Titan's center to the Cassini orbiter, and this light time is used to correct both the state and orientation of Titan.



Types of Reference Frames

Navigation and Ancillary Information Facility

- **Inertial**
 - Non-rotating
 - » With respect to fixed stars
 - Non-accelerating origin
 - » Velocity is typically non-zero; acceleration is negligible
 - Examples:
 - » J2000 (also called ICRF), B1950
- **Non-Inertial**
 - Examples
 - » Body-fixed
 - Centered at body center
 - Topocentric
 - » Instrument
 - » Dynamic frames
 - For example, frames defined by time-dependent vectors



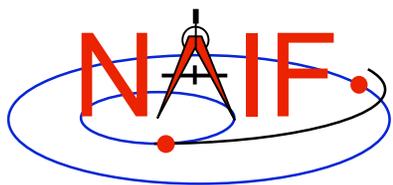
Frames Defined by Dynamics

Navigation and Ancillary Information Facility

- **Mean Equator**
 - Model gives mean direction of north pole of earth accounting for precession
 - Defines z-axis of frame
 - Defines a mean plane of equator
- **Mean Ecliptic**
 - Model gives mean direction of the “pole” of the earth's orbit
 - Defines a mean plane of the ecliptic
- **Intersection of planes at a particular epoch determines x-axis**

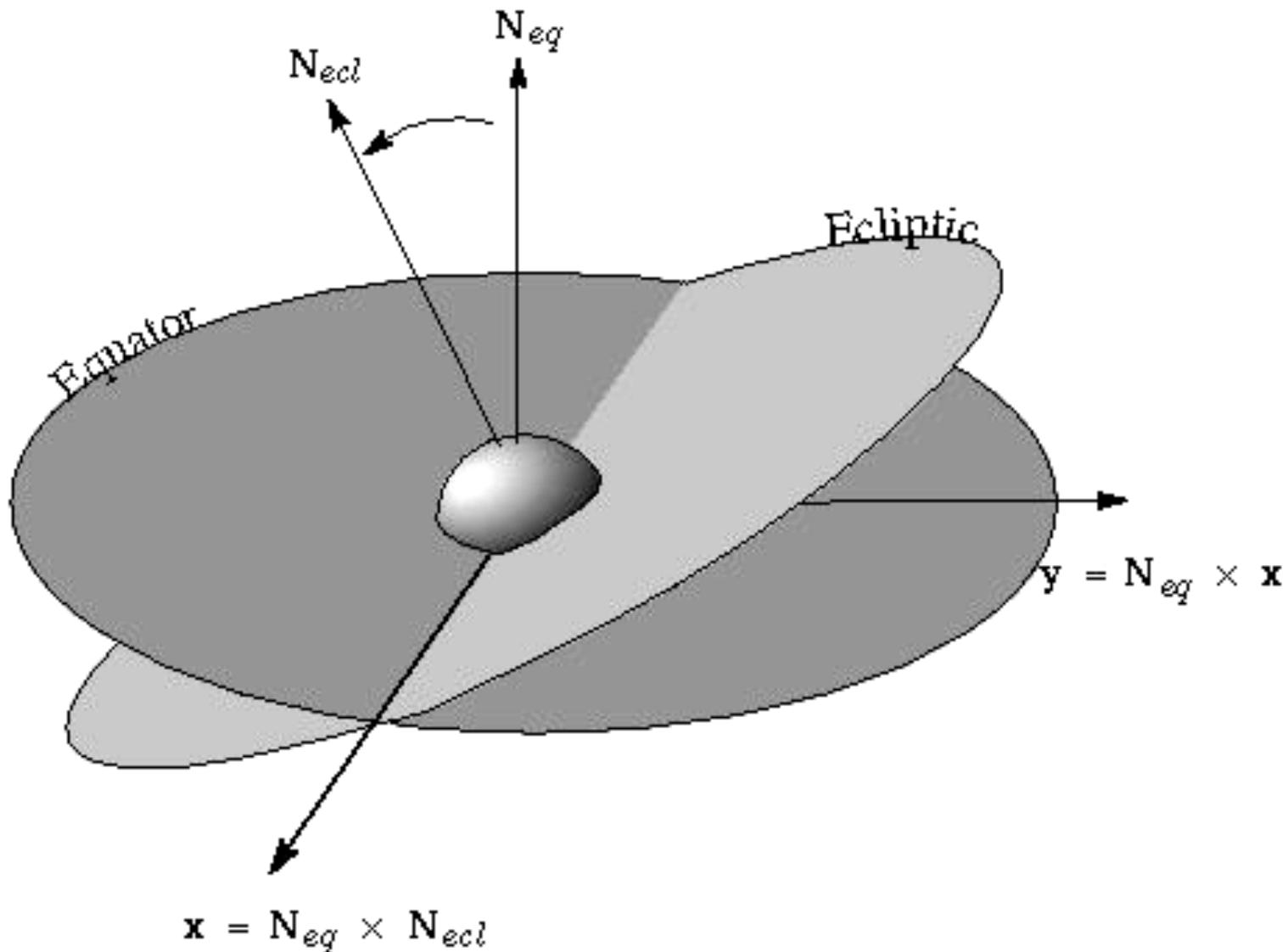


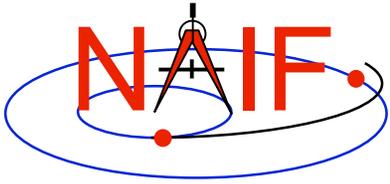
Ecliptic Plane



J2000 (ICRF) Frame

Navigation and Ancillary Information Facility

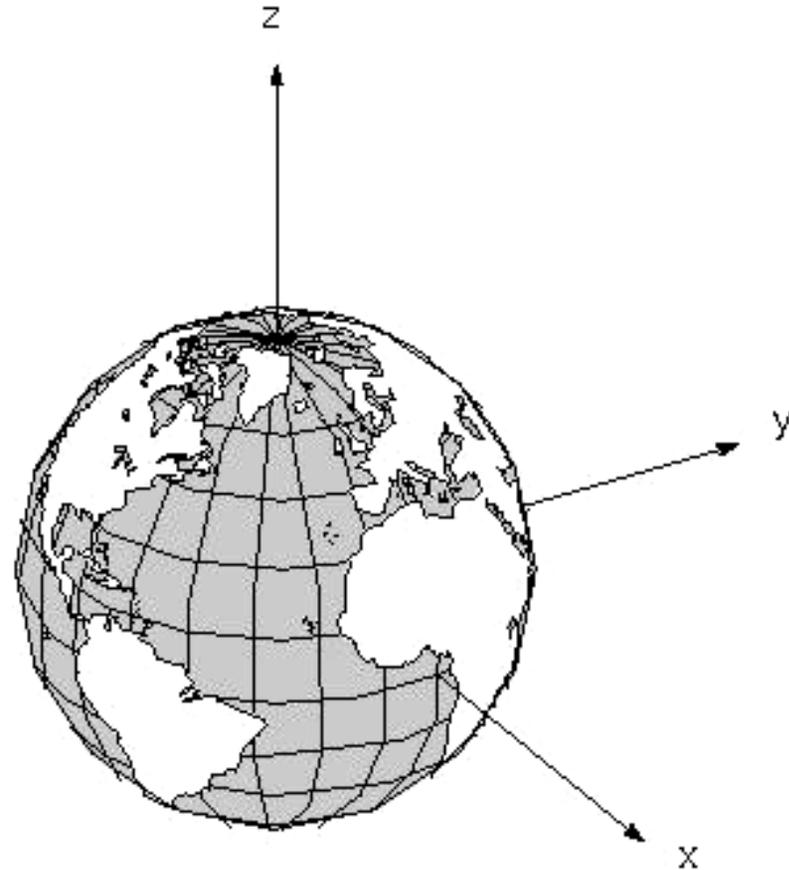


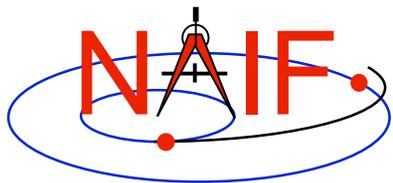


Rotating Frames

Navigation and Ancillary Information Facility

- **Rotating frames rotate with respect to Inertial Frames. Directions of axes are not constant w.r.t. inertial frames**
- **Centers may accelerate**
- **Examples:**
 - **Body-fixed frames are tied to the surface of a body and rotate with it.**
 - **Spacecraft-fixed frames are defined by the time-varying orientation of a spacecraft**

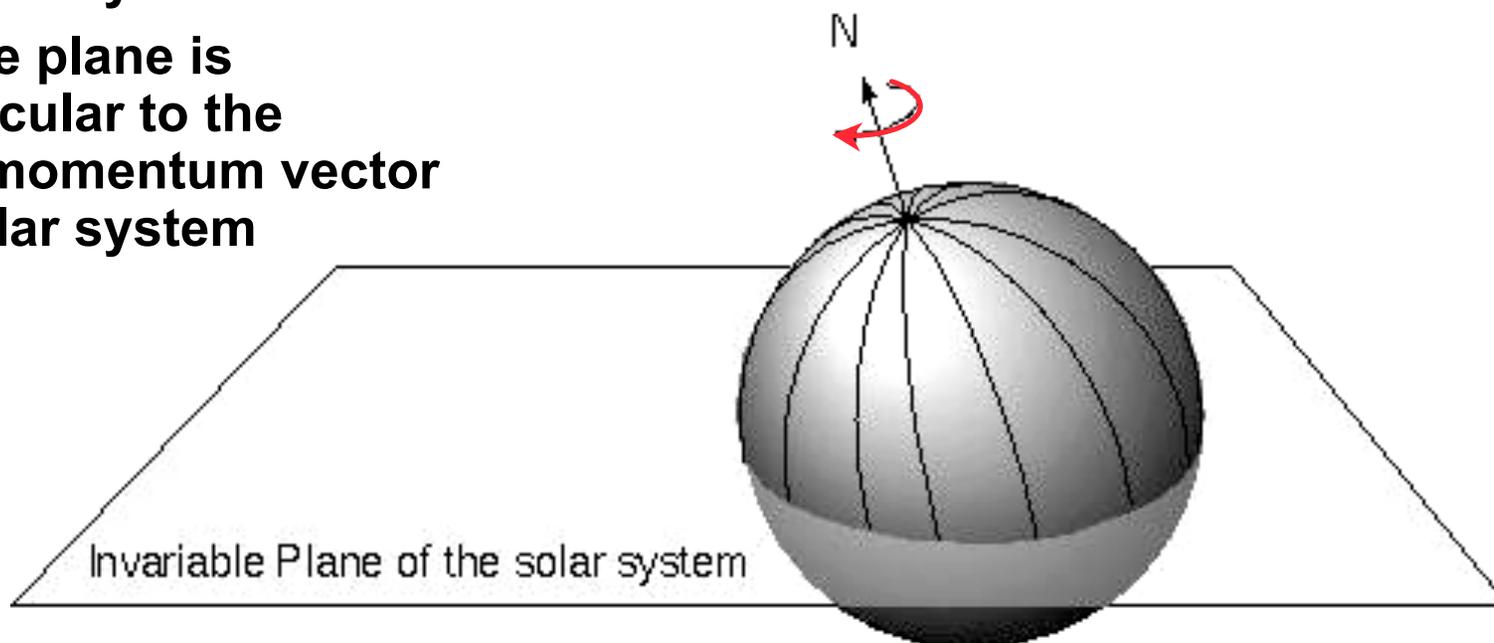


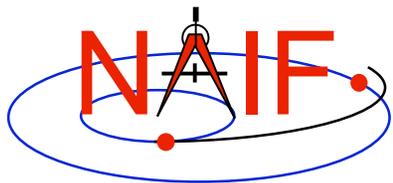


IAU Bodyfixed Frames

Navigation and Ancillary Information Facility

- **Defined with simple models for position of spin axis and motion of prime meridian**
- **Z-axis points to the “north” side of the invariable plane of the solar system**
- **Invariable plane is perpendicular to the angular momentum vector of the solar system**

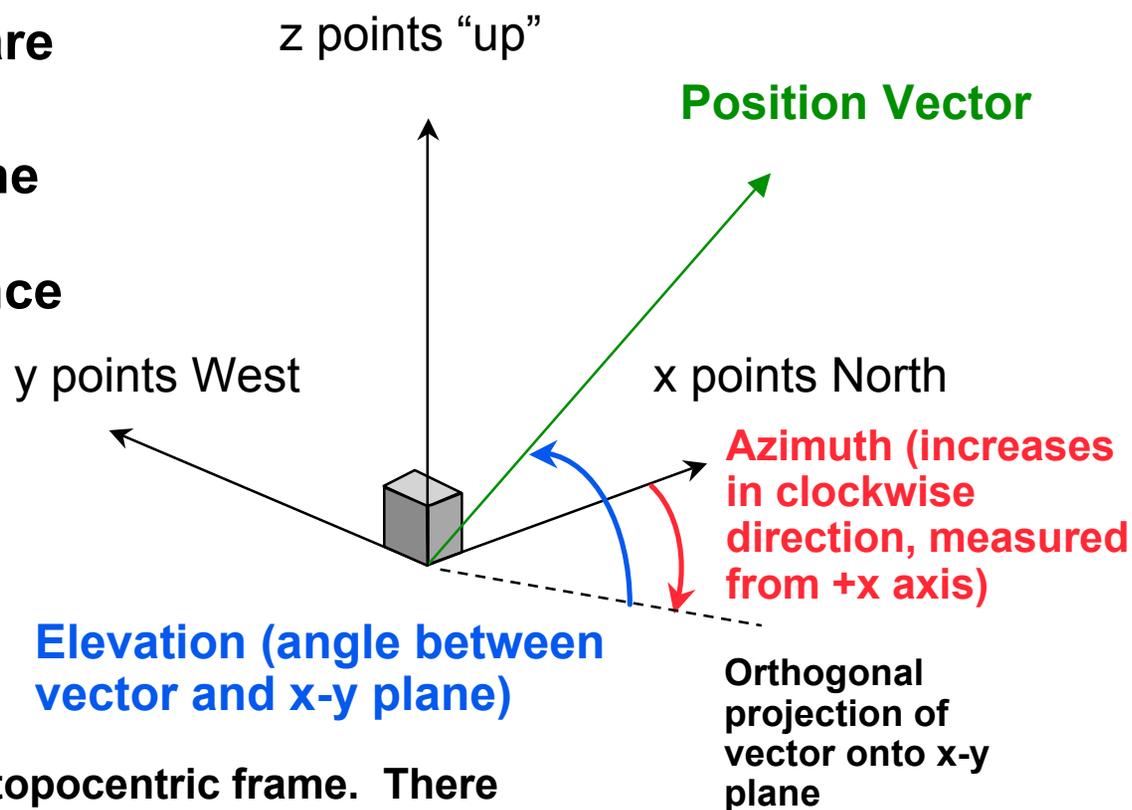




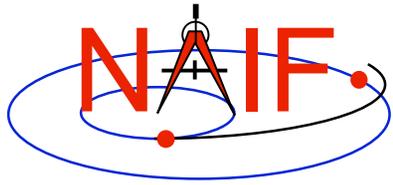
Topocentric Frames

Navigation and Ancillary Information Facility

- Topocentric frames are attached to a surface
- Z-axis is parallel to the gravity gradient or orthogonal to reference spheroid



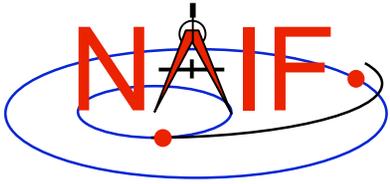
One example of a topocentric frame. There are other types of topocentric frames: for example, the z-axis could point down, the x-axis North, and the y-axis East.



Spacecraft and Instrument Frames

Navigation and Ancillary Information Facility

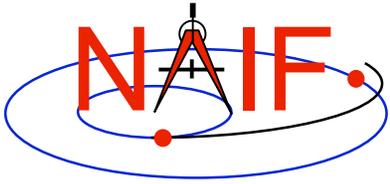
- **Defined relative to structures**
 - **Spacecraft**
 - **Scan platform**
 - **Instrument**
 - » **For example you might have:**
 - **z-axis lies along instrument boresight**
 - **x and y axes defined by instrument characteristics**



State Vectors

Navigation and Ancillary Information Facility

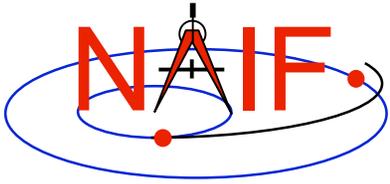
- **The state of an object is its position and velocity relative to a second object**
 - In SPICE, these objects are often referred to as “target” and “observer” or “center”
 - E.g. Saturn relative to Saturn barycenter; Titan relative to Huygens probe
- **In the SPK subsystem a state is a six dimensional vector**
 - First three components are Cartesian position: x, y, z
 - Second three components are Cartesian velocity: $dx/dt, dy/dt, dz/dt$
 - Units are km, km/sec
- **A state is specified relative to a reference frame**



Transforming States

Navigation and Ancillary Information Facility

- To perform algebraic operations on states they must be in the same frame.
- Position-only frame transformations require only a rotation* matrix given as a function of time.
 - » $P_B(t) = R_{A \text{ to } B}(t) P_A(t)$
- Position and velocity frame transformations require that we differentiate the above equation
 - » $dP_B(t)/dt = dR_{A \text{ to } B}(t)/dt P_A(t) + R_{A \text{ to } B}(t) dP_A(t)/dt$
- We can use a 6x6 matrix to combine these two transformations into a single equation



Transforming States

Navigation and Ancillary Information Facility

$$\mathbf{S}_B(t) = \mathbf{T}_{A \text{ to } B}(t) \mathbf{S}_A(t)$$

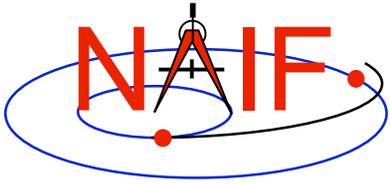
where

$$\mathbf{S}_i(t) = \begin{pmatrix} \mathbf{P}_i(t) \\ d\mathbf{P}_i(t)/dt \end{pmatrix} \quad i = A \text{ or } B$$

and

$$\mathbf{T}_{A \text{ to } B}(t) = \left(\begin{array}{c|c} \mathbf{R}_{A \text{ to } B}(t) & \mathbf{0} \\ \hline d\mathbf{R}_{A \text{ to } B}(t)/dt & \mathbf{R}_{A \text{ to } B}(t) \end{array} \right)$$

The SPICELIB routines SXFORM and PXFORM return state transformation and position transformation matrices respectively.



Coordinate Systems

Navigation and Ancillary Information Facility

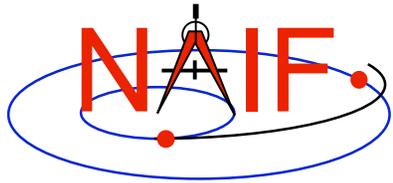
- **Planetocentric**
 - **Latitude:** measured from X-Y plane
 - **Longitude:** increases counterclockwise w.r.t. the +Z axis
 - » +Z points to the north side of the invariable plane
 - **Radius:** measured from center of object
- **Planetographic, Geodetic, Planetodetic**
 - Tied to a reference surface
 - **Latitude:** for a point on a reference ellipsoid, angle measured from X-Y plane to the surface normal at the point of interest. For other points, equals latitude at the nearest point on the reference ellipsoid.
 - **Longitude**
 - » -odetic: same as for planetocentric
 - » -ographic: longitude of sub-observer point, for a distant, fixed observer in the J2000 frame, increases with time
 - **Height above reference surface**



Aberration Corrections: Introduction

Navigation and Ancillary Information Facility

- **Within the SPICE system, “aberration corrections” are adjustments made to state vectors and time-dependent reference frames to accurately reflect the apparent—as opposed to the actual—state and attitude of a target object as seen from a specified observer at a specified time.**
 - Actual, uncorrected states from an ephemeris are called “geometric” states.
 - When computing state vectors, SPICE users may request geometric or aberration-corrected states.
- **Aberration corrections are needed to accurately answer questions such as:**
 - In which direction must a remote sensing instrument be pointed to observe a target of interest?
 - For a given pointing direction and observation time, what target body surface location would be observed by a remote sensing instrument?
 - In which direction must an antenna be pointed to transmit a signal to a specified target?

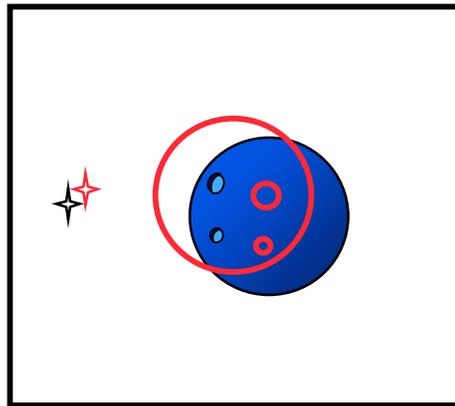


Example: Predicted vs Actual Photo

Navigation and Ancillary Information Facility

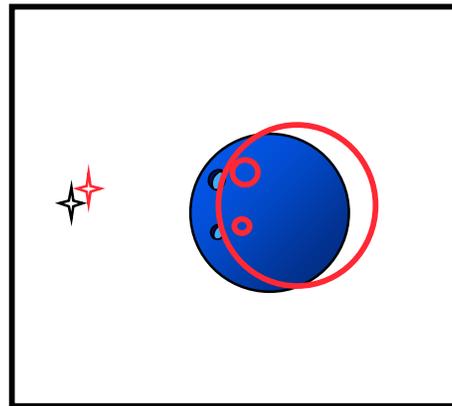
We compare the predicted appearance of a photograph from an optical camera against the actual photograph. We show three predictions derived using different aberration corrections: NONE, LT ("light time only"), and LT+S ("light time plus stellar aberration").

For each prediction, we use red overlays to indicate the expected location in the photo of the images of an extended target body (for example, a natural satellite), of features on the surface of the target body, and of a star.



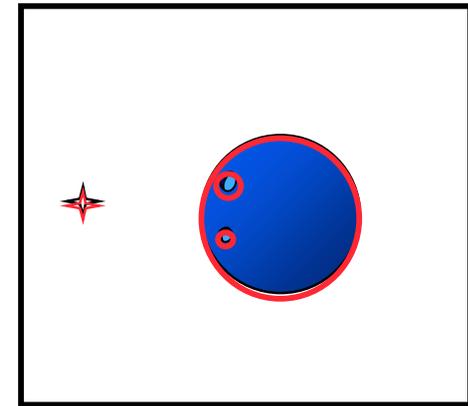
NONE

Predicted images using uncorrected target position and orientation and uncorrected star direction vector



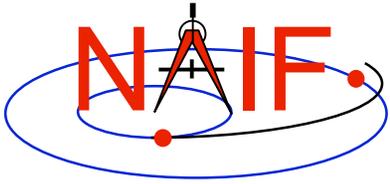
LT

Predicted images using light time-corrected target position and orientation and uncorrected star direction vector



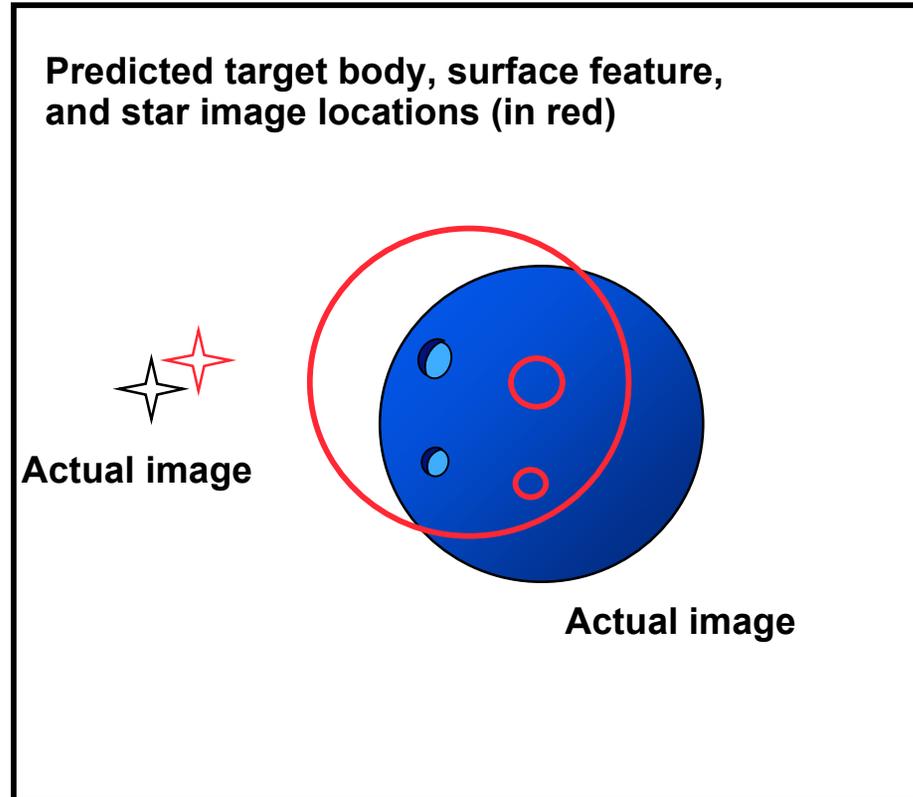
LT+S

Predicted images using light time and stellar aberration-corrected target position, light time-corrected target orientation, and stellar aberration-corrected star direction vector



Prediction Without Corrections

Navigation and Ancillary Information Facility

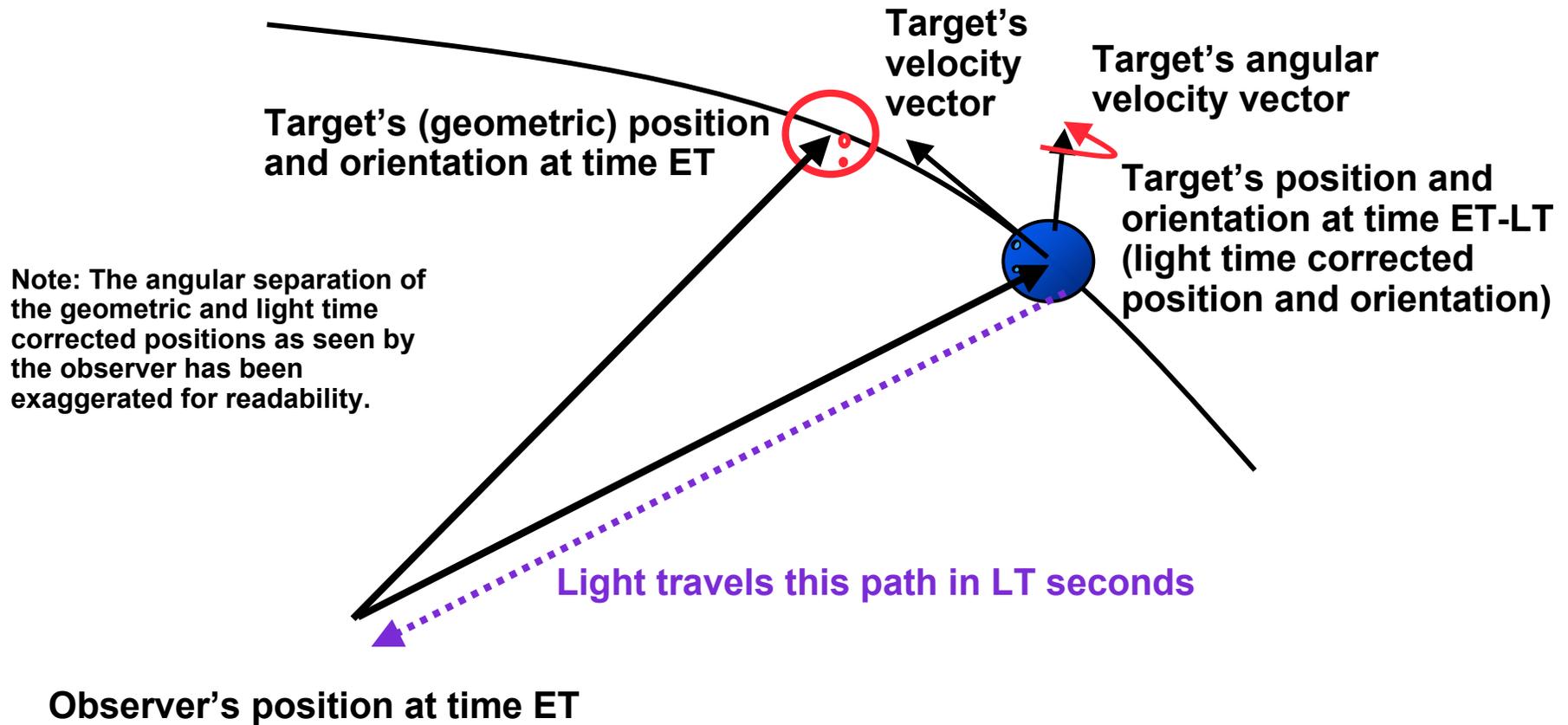


Using geometric target positions, target images in photos or other remote-sensing observations don't appear at their predicted locations.

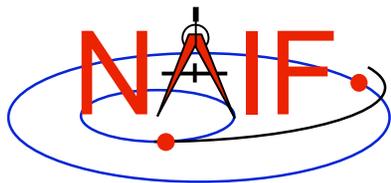


Light Time Corrections

Navigation and Ancillary Information Facility

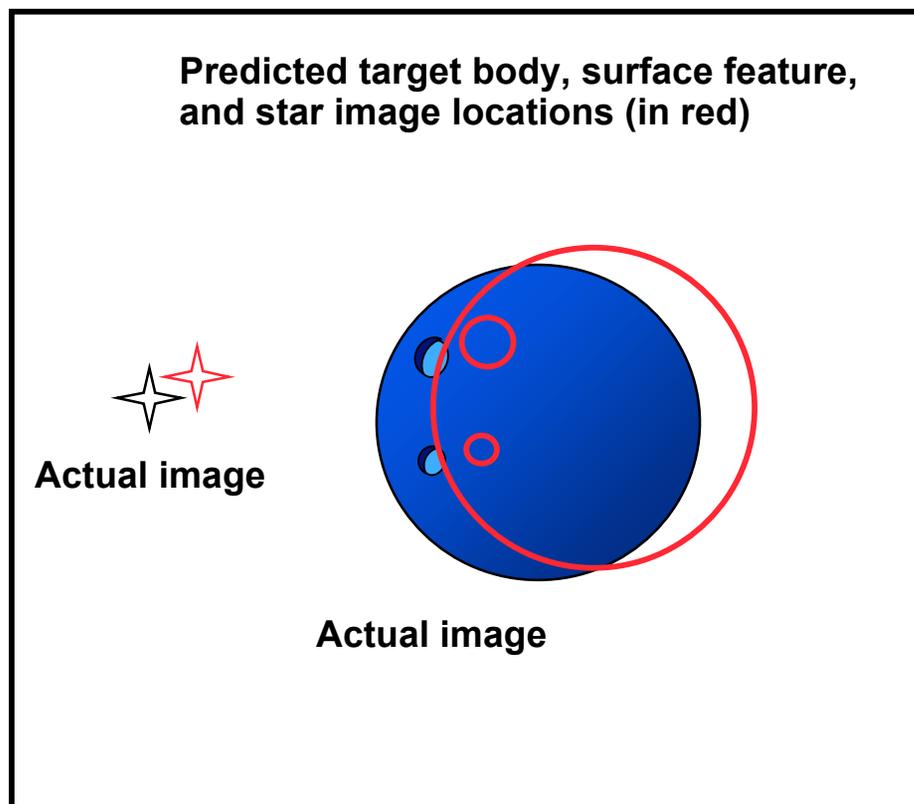


At time ET, the observer's camera records photons emitted from the target at time ET-LT, where LT is the one-way light time. The camera "sees" the target's position and orientation at ET-LT.



Prediction Using Light Time Corrections

Navigation and Ancillary Information Facility

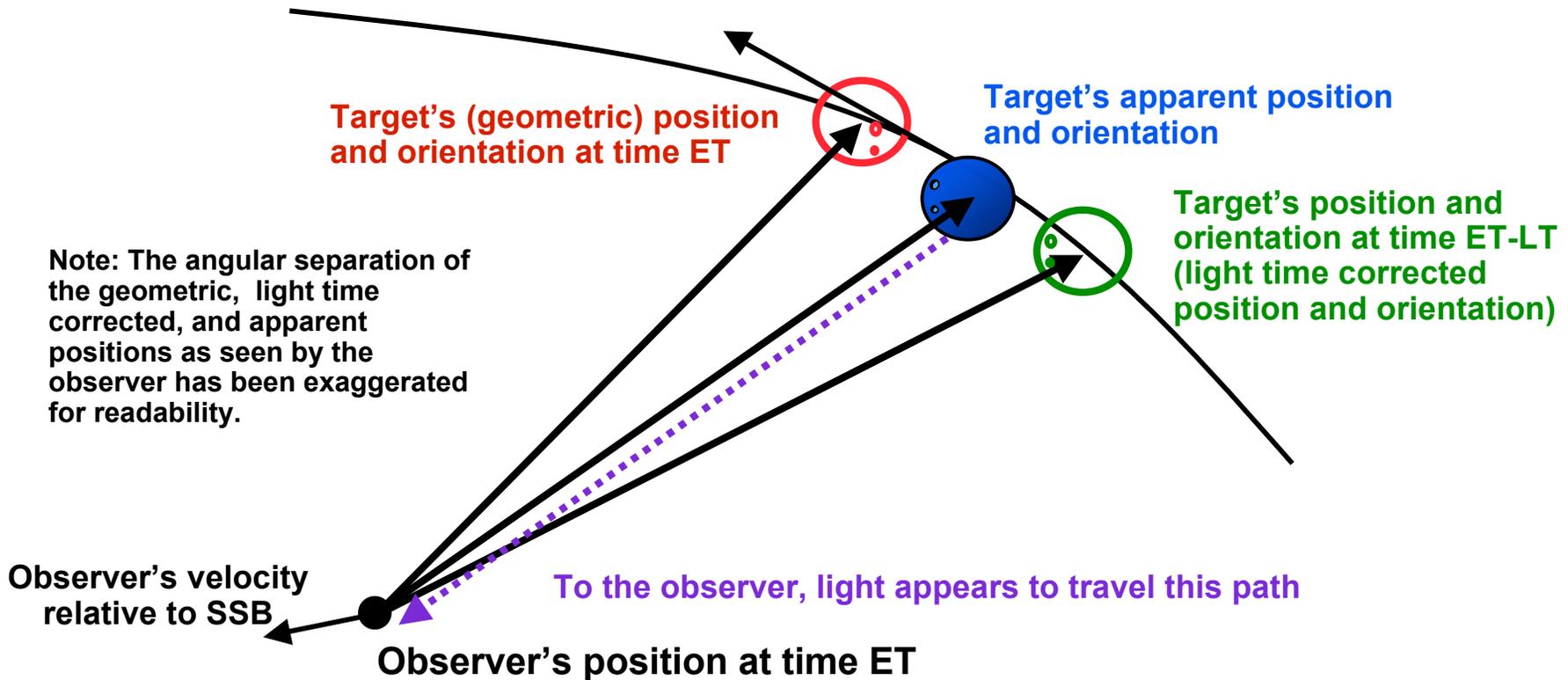


Using the light time corrected target position and orientation, the predicted locations in the photo of the target image and surface features have changed, but the accuracy of the prediction may still be poor.



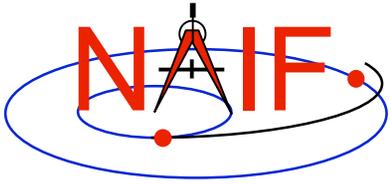
Stellar Aberration Correction

Navigation and Ancillary Information Facility



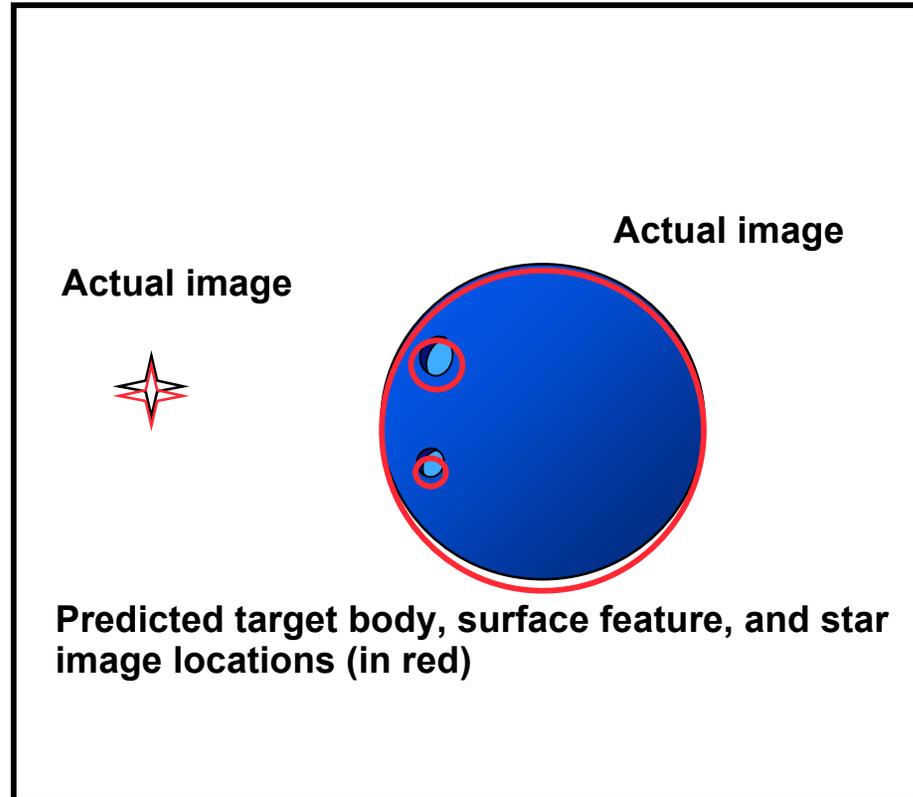
At time ET, the observer's camera records photons emitted from the target at time ET-LT, where LT is the one-way light time.

The vector from the observer at ET to the location of the target at ET-LT is displaced by a physical phenomenon called stellar aberration. The displaced vector yields the apparent position of the target.



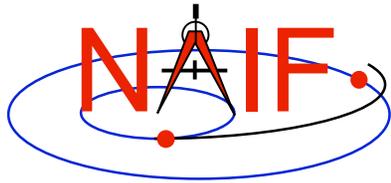
Prediction Using "LT+S" Corrections

Navigation and Ancillary Information Facility



Using the light time and stellar aberration-corrected target position, light time-corrected target orientation, and stellar aberration-corrected star direction, we obtain a significantly improved image location predictions.

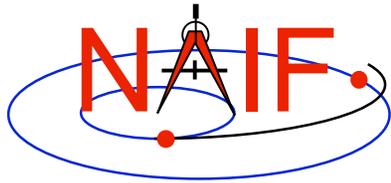
Remaining prediction errors may be due to, among other causes, pointing error, spacecraft and target ephemeris errors, and timing errors.



Effect of Aberration Corrections - 1

Navigation and Ancillary Information Facility

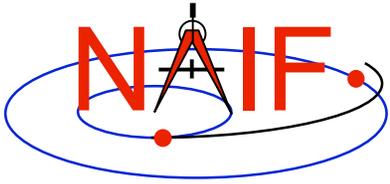
- **Angular offsets between corrected and uncorrected position vectors over the time span 2004 Jan 1--2005 Jan1**
 - **Mars as seen from MEX:**
 - » **LT+S vs NONE: .0002 to .0008 degrees**
 - » **LT vs NONE: .0006 to .0047 degrees**
 - **Earth as seen from MEX:**
 - » **LT+S vs NONE: .0035 to .0106 degrees**
 - » **LT vs NONE: .0000 to .0057 degrees**
 - **MEX as seen from Earth:**
 - » **LT+S vs NONE: .0035 to .0104 degrees**
 - » **LT vs NONE: .0033 to .0048 degrees**
 - **Sun as seen from Mars:**
 - » **LT+S vs NONE: .0042 to .0047 degrees**
 - » **LT vs NONE: .0000 to .0000 degrees**



Effect of Aberration Corrections - 2

Navigation and Ancillary Information Facility

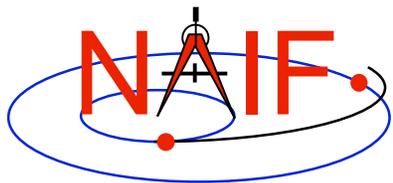
- **Angular offsets between corrected and uncorrected position vectors over the time span 2004 Jan 1--2008 Jan1**
 - **Saturn as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0058 degrees**
 - » **LT vs NONE: .0001 to .0019 degrees**
 - **Titan as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0057 degrees**
 - » **LT vs NONE: .0000 to .0030 degrees**
 - **Earth as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0107 degrees**
 - » **LT vs NONE: .0000 to .0058 degrees**
 - **CASSINI as seen from Earth:**
 - » **LT+S vs NONE: .0000 to .0107 degrees**
 - » **LT vs NONE: .0000 to .0059 degrees**
 - **Sun as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0059 degrees**
 - » **LT vs NONE: .0000 to .0000 degrees**



Navigation and Ancillary Information Facility

Introduction to Kernels

January 2009



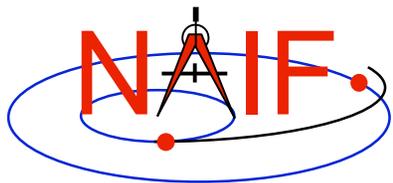
What is a SPICE “Kernel”

Navigation and Ancillary Information Facility

Kernel = File

Kernel = File containing ancillary data

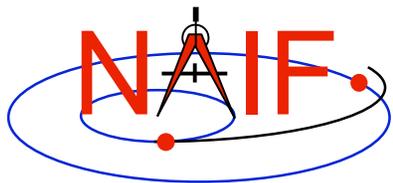
Kernel = a file containing "low level" ancillary data that may be used, along with other data and SPICE software, to determine higher level observation geometry parameters of use to scientists and engineers in planning and carrying out space missions, and analyzing data returned from missions.



SPICE Kernels Family

Navigation and Ancillary Information Facility

- **SPK**
 - Spacecraft and Planet Ephemeris
- **PcK**
 - Planetary Constants, for natural bodies
 - » Orientation
 - » Size and shape
- **IK**
 - Instrument
- **CK**
 - Pointing (“C-matrix”)
- **EK**
 - Events, up to three distinct components
 - » ESP: science plan
 - » ESQ: sequence
 - » ENB: experimenter’s notebook
- **FK**
 - Reference frame specifications
- **SCLK**
 - Spacecraft clock correlation data
- **LSK**
 - Leapseconds
- **Meta-Kernel** (a.k.a. “FURNSH kernel”)
 - Mechanism for aggregating and easily loading a collection of kernel files
- **DSK (under development)**
 - Digital shape kernel
 - » Tessellated plate model
 - » Digital elevation model



Text and Binary Kernels

Navigation and Ancillary Information Facility

SPICE **text** kernels are:

- text PCK (the most common type of PCK)
- IK
- FK
- LSK
- SCLK

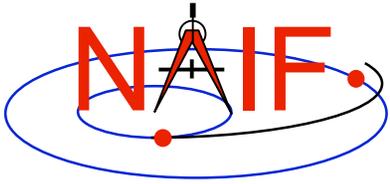
- MK (“Furnsh” meta-kernel)

SPICE **binary** kernels are:

- SPK
- binary PCK (exists only for Earth and moon)
- CK
- ESQ (part of the E-kernel)
- DBK (database kernel)

- DSK (digital shape kernel)*

* New kind of kernel under development



SPICE Kernel Forms

Navigation and Ancillary Information Facility

- **Binary form: SPK, binary PCK, CK, EK/ESQ¹, DSK**
 - Binary kernels are not human-readable and require the use of Toolkit software to examine the data contents.
- **Text form: text PCK, IK, FK, LSK, SCLK, FURNISH (MK)**
 - Text kernels contain only printing characters (ASCII values 32-126), i.e. human-readable text.
- **“Transfer” form of a binary kernel**
 - This is an ASCII representation of a binary kernel
 - Was used for porting the file between computers with incompatible binary representations (e.g. PC and UNIX)
 - Use of the transfer kernel is no longer needed for porting
 - » But is one way to convert a non-native binary kernel into native format, needed for modifying the kernel or improving read efficiency

[1] The ESP and ENB components of the EK might be binary, text, or html, depending on specific implementation.



Example Text Kernel

Navigation and Ancillary Information Facility

This is a sample SPICE text kernel. The `\begindata` and `\begintext` markers on lines by themselves set off the start of data and text blocks respectively.

```
KPL/<kernel type>
\begindata
  NAME           = 'Sample text value'
  NaMe           = 'Keywords are case sensitive'

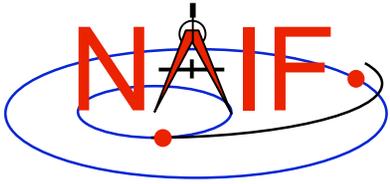
  NUMBERS        = ( 10.123, +151.241, -1D14 )
  NUMBERS        += ( 1.0,    1,      -10    )
  NUMBERS        += ( 1.542E-12, 1.123125412 )

  NAIF_BODY_NAME += ( 'SPEEDO', 'NEETO' )
  NAIF_BODY_CODE += ( -678,    -679    )

  TIME           = @1972-JAN-1

\begintext
  < some comments about the data >
\begindata
  < more data, given again in keyword = value syntax >
\begintext
  < etc., etc. >
```

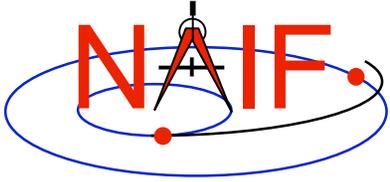
The above assignments demonstrate that text kernels can contain characters, times, and numeric values. For more detailed information see Kernel Required Reading.



Text Kernel Operators

Navigation and Ancillary Information Facility

- The “+=” operator adds additional values to an existing variable. It creates a new variable if the referenced variable doesn’t already exist.
- The “@” symbol preceding a calendar date identifies a date string. The string must not contain embedded blanks. The string will be parsed and converted to an internal double precision representation of that epoch. The date is interpreted as ephemeris time (ET).
 - This conversion does not need a leapseconds kernel.

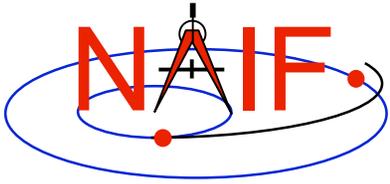


Example Binary Kernel

Navigation and Ancillary Information Facility

A binary kernel contains lots of non-printing (unintelligible) data, usually interspersed with occasional occurrences of ASCII characters.

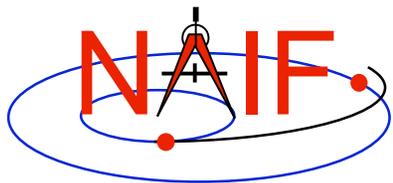
Other than moving binary kernels around on your computer, or between computers, the only way to use a binary kernel is to read it or add to it using a SPICE subroutine or program.



Metadata In SPICE Kernels

Navigation and Ancillary Information Facility

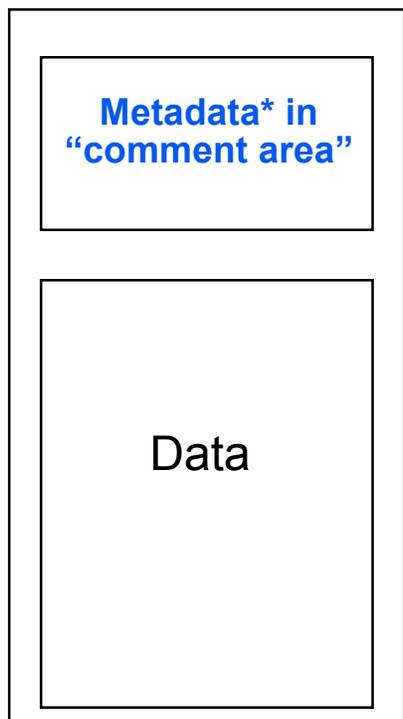
- **All SPICE kernels can and should contain metadata—descriptive information about the basic kernel data.**
- **Metadata might convey:**
 - when, where, how and by whom the file was made
 - for what purpose the file was made
 - what source data were used to make the file
 - key characteristics of the file, such as:
 - » start and stop times
 - » information about data gaps
 - » notes on expected data accuracy
 - cautions on use of the file
 - whatever else the file creator thinks could be useful to consumers of the data product



Examples of Metadata

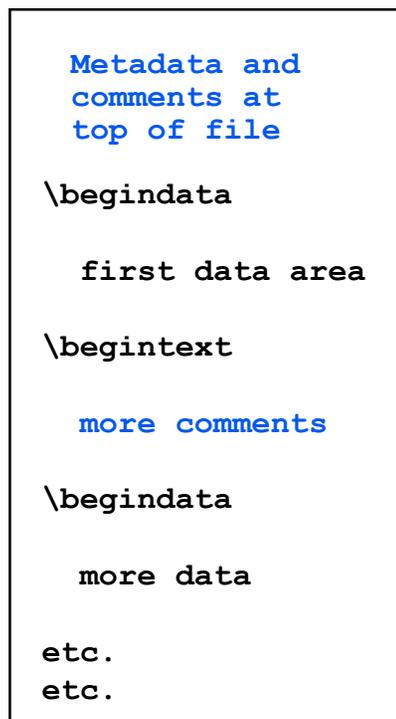
Navigation and Ancillary Information Facility

SPICE Binary Kernel



*Metadata in the comment area of a binary kernel can be accessed only using SPICE software.

SPICE Text Kernel



Example of metadata as a PDS label

```
MISSION_NAME           = "MARS GLOBAL SURVEYOR"
SPACECRAFT_NAME        = "MARS GLOBAL SURVEYOR"
DATA_SET_ID            = "MGS-M-SPICE-6-V1.0"
KERNEL_TYPE_ID         = SPK
PRODUCT_ID              = "MGS_MAP1.BSP"
PRODUCT_CREATION_TIME  = 2000-01-14T08:26:18
PRODUCER_ID            = "MSOPNAV/JPL"
MISSION_PHASE_NAME     = MAPPING
PRODUCT_VERSION_TYPE   = ACTUAL
PLATFORM_OR_MOUNTING_NAME = "N/A"
START_TIME              = 1999-03-09T00:58:56
STOP_TIME               = 1999-06-02T00:58:56
etc.
```

Example of metadata as free-form text

```
Mars Global Surveyor Mapping SPK file, MGSNAV Solution
=====
Created by Boris Semenov, NAIF/JPL, June 14, 1999

Objects in the Ephemeris
-----
This file contains ephemeris data for the Mars
Global Surveyor (MGS)
spacecraft. NAIF ID code for MGS is -94.

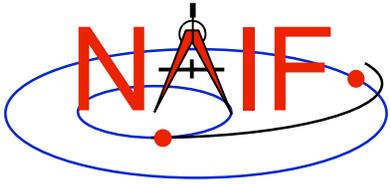
Approximate Time Coverage
-----
This file covers first three 28-day mapping cycles
of the Mapping phase of the mission (mapping orbits 1
through 1040):
COVERAGE BEGIN TIME (TDB): 1999 MAR 09 01:00:00.000
COVERAGE END TIME (TDB): 1999 JUN 02 01:00:00.000
etc.
```



Loading Kernels - 1

Navigation and Ancillary Information Facility

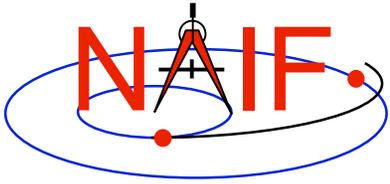
- To make kernels available to SPICE programs you “load” them.
- When you load a text kernel:
 - the file is opened
 - the kernel contents are read into memory
 - » variable names and associated values are stored in a data structure called the “kernel pool”
 - the file is closed
- When you load a binary kernel:
 - the file is opened
 - for SPK, CK, and binary PCK files, no data are read until a read request is made by Toolkit software
 - for ESQ files, the schema description is read, checked, and stored in memory at load time, but no data are read until a query/fetch is made
 - for all practical purposes the binary file remains open unless specifically unloaded by you



Loading Kernels - 2

Navigation and Ancillary Information Facility

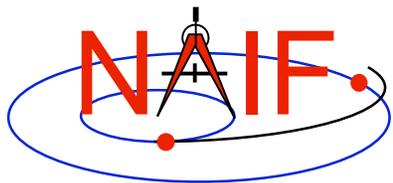
- Use the FURNISH routine to load all kernels—text and binary.
 - Sample FORTRAN, C, IDL and MATLAB calls:
 - » `CALL FURNISH ('name.ext')`
 - » `furnsh_c ("name.ext");`
 - » `cspice_furnsh, 'name.ext'`
 - » `cspice_furnsh ('name.ext')`
- **Best practices: don't hard code filenames—list these in a “meta-kernel” and load the meta-kernel using FURNISH. (See next page.)**
 - `CALL FURNISH ('meta-kernel_name')`
- **Caution: "Transfer format" versions of binary kernels can not be loaded; they must first be converted to binary with the Toolkit utility program *tobin* or *spacit*.**



What is a “Meta-Kernel”

Navigation and Ancillary Information Facility

- **The terms “meta-kernel” and “FURNISH kernel” are used synonymously**
- **Using a meta-kernel makes it easy to manage which SPICE files are loaded into your program**
- **A meta-kernel is a file that lists names (and locations) of a collection of SPICE kernels that are to be used together in some SPICE-based application**
 - **You can then simply load the meta-kernel, causing all of the kernels listed in it to be loaded**
- **A meta-kernel is implemented using the SPICE text kernel standards**



Sample Meta-Kernel Contents (1)

Navigation and Ancillary Information Facility

This is a sample meta-kernel that the Toolkit routine FURNISH could use to load a collection of kernels.

```
KPL/MK
```

```
\begindata
```

```
  KERNELS_TO_LOAD = (  
    '/home/mydir/kernels/lowest_priority.bsp',  
    '/home/mydir/kernels/next_priority.bsp',  
    '/home/mydir/kernels/highest_priority.bsp',  
    '/home/mydir/kernels/leapseconds.tls',  
    '/home/mydir/kernels/sclk.tsc',  
    '/home/mydir/kernels/c-kernel.bc',  
    '/home/mydir/kernels+',  
    '/custom/kernel_data/p_constants.tpc',  
  )
```

The commas
are optional

The last file listed in this example (p_constants.tpc) demonstrates how to use the continuation character '+' to work around the 80 character limitation imposed on string sizes by the text kernel standards.



Sample Meta-Kernel Contents (2)

Navigation and Ancillary Information Facility

This sample meta-kernel uses `PATH_VALUES`/`PATH_SYMBOLS` keywords to specify directory where the kernels are located.

```
KPL/MK
```

```
\begindata
```

```
  PATH_VALUES      = ( '/home/mydir/kernels' )
  PATH_SYMBOLS     = ( 'KERNELS'           )
  KERNELS_TO_LOAD = (
    '$KERNELS/lowest_priority.bsp',
    '$KERNELS/next_priority.bsp',
    '$KERNELS/highest_priority.bsp',
    '$KERNELS/leapseconds.tls',
    '$KERNELS/sclk.tsc',
    '$KERNELS/c-kernel.bc',
    '$KERNELS/custom/kernel_data/p_constants.tpc'
  )
```

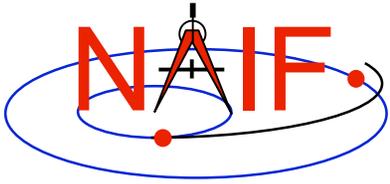
Although the OS environment variable notation `$NAME` is used to refer to the symbols set by the `PATH_VALUES`/`PATH_SYMBOLS` keywords, these symbols are NOT OS environment variables and are set and used for substitution by `SPICE` only in the context of this particular meta-kernel.



Limits on Loaded Kernels

Navigation and Ancillary Information Facility

- **The number of binary kernels that may be loaded at any time is large, but limited.**
 - For SPK, CK, and binary PCK files:
 - » Loaded SPKs + Loaded CKs + Loaded binary PCKs ≤ 1000
 - For ESQ files:
 - » Loaded ESQs ≤ 20
 - For all kernels:
 - » Loaded kernels ≤ 1300
 - Assumes each has been loaded only once, and not unloaded.
- **There are also limits on the number of keywords and values for all loaded text kernels:**
 - Maximum number of keywords is 5003.
 - Maximum number of numeric data items is 40,000.
 - Maximum number of character data items is 4000.



Kernel Precedence Rule

Navigation and Ancillary Information Facility

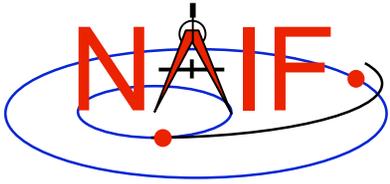
- **The order in which SPICE kernels are loaded at run-time determines their priority when requests for data are made**
 - For binary kernels, data from a higher priority file will be used in the case when two or more files contain data overlapping in time for a given object.
 - » For SPKs, CKs and binary PCKs the file loaded **last** takes precedence (has higher priority).
 - » Priority doesn't apply to ESQ files – all data from all loaded files are available.
 - If two (or more) text kernels assign value(s) to a single keyword using the “=” operator, the data value(s) associated with the last loaded occurrence of the keyword are used—all earlier values have been replaced with the last loaded value(s).
 - Orientation data from a binary PCK always supersedes orientation data (for the same object) obtained from a text PCK, no matter the order in which the kernels are loaded.



Unloading Kernels

Navigation and Ancillary Information Facility

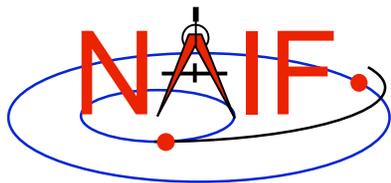
- **The unloading of a kernel is infrequently needed for FORTRAN or CSPICE applications but is essential for Icy and Mice scripts**
 - **Because of the way IDL and MATLAB interact with external shared object libraries any kernels loaded during an IDL or MATLAB session will stay loaded until the end of the session unless they are specifically unloaded**
- **The routines KCLEAR and UNLOAD may be used to unload kernels containing data you wish to be no longer available to your program.**
 - **KCLEAR unloads all kernels and clears the kernel pool**
 - **UNLOAD unloads specified kernels**
 - **KCLEAR and UNLOAD are only capable of unloading kernels that have been loaded with the routine FURNISH. They will not unload any files that have been loaded with older load routines such as SPKLEF (those used prior to availability of FURNISH).**
- **Caution: unloading text kernels with UNLOAD will also remove any kernel pool data provided through the kernel pool API (P*POOL)**



Backup

Navigation and Ancillary Information Facility

- **How kernels are made and used**
- **Why and how kernels are modified**
- **SPICE data structures hierarchy**

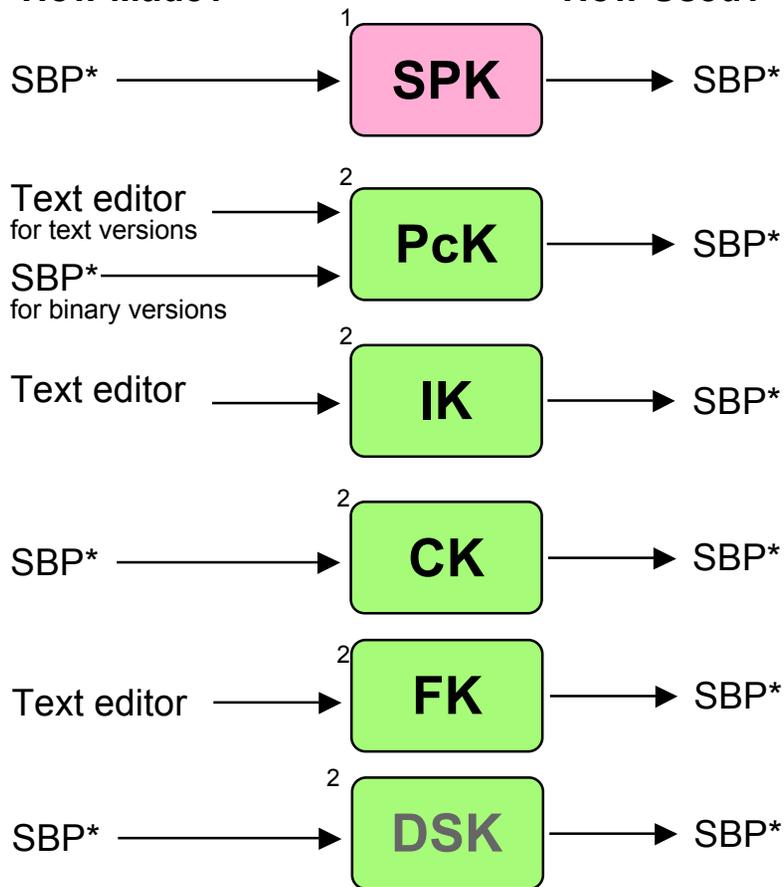


How Kernels are Made and Used at JPL

Navigation and Ancillary Information Facility

How Made?

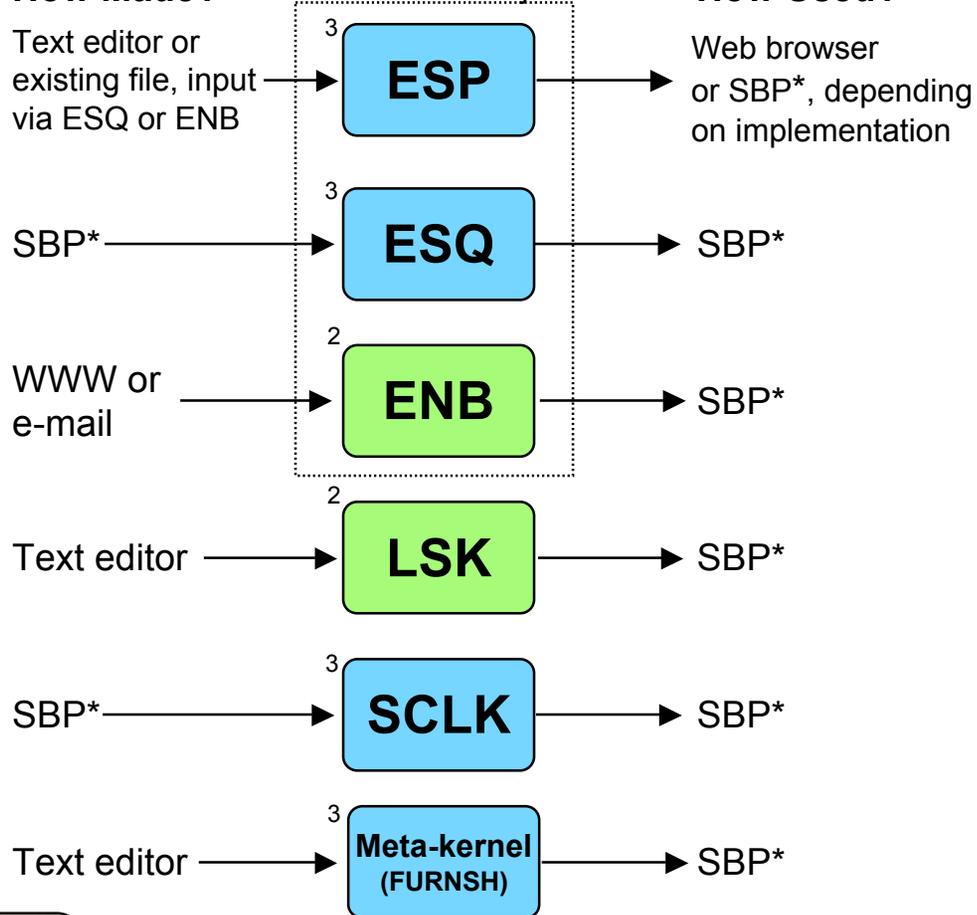
How Used?



How Made?

The EK family

How Used?

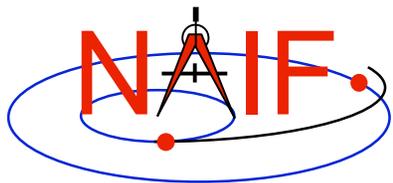


Who usually makes the kernels at JPL?

- 1 ● NAV and NAIF
- 2 ● NAIF
- 3 ● NAIF or other

This represents current practice for most JPL missions, but is by no means a requirement. **Anyone can make SPICE files.**

***SBP** = SPICE-based program that uses modules from the SPICE Toolkit. In some cases the Toolkit contains such a program already built. In some cases NAIF may have such a ready-built program that is not in the SPICE Toolkit.



Why & How Kernels are “Modified” - 1

Navigation and Ancillary Information Facility

File Type

Why Modified

How Modified

SPK

- To add metadata (comments)
- To merge files or subset a file
- To correct/revise an object ID

- COMMNT, SPACIT or SPICELIB module
- SPKMERGE
- BSPIDMOD

PcK
Text version

- To revise data values
- To add additional data items and values

- Text editor
- Text editor

IK

- To revise data values
- To add additional data items and values

- Text editor
- Text editor

CK

- To add metadata (comments)
- To merge files
- To revise the interpolation interval
- To subset a file

- COMMNT, SPACIT, or SPICELIB module
- DAFCAT, CKSMRG
- CKSPANIT, CKSMRG
- CKSLICER

FK

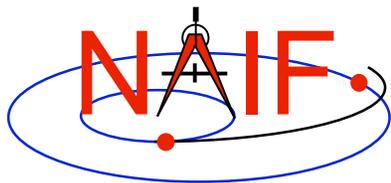
- To revise data values
- To add additional data items and values

- Text editor
- Text editor

DSK

- To add metadata (comments)
- To merge files or subset a file

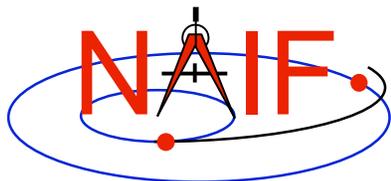
- COMMNT, SPACIT or SPICELIB module
- DSKMERGE



Why & How Kernels are “Modified” - 2

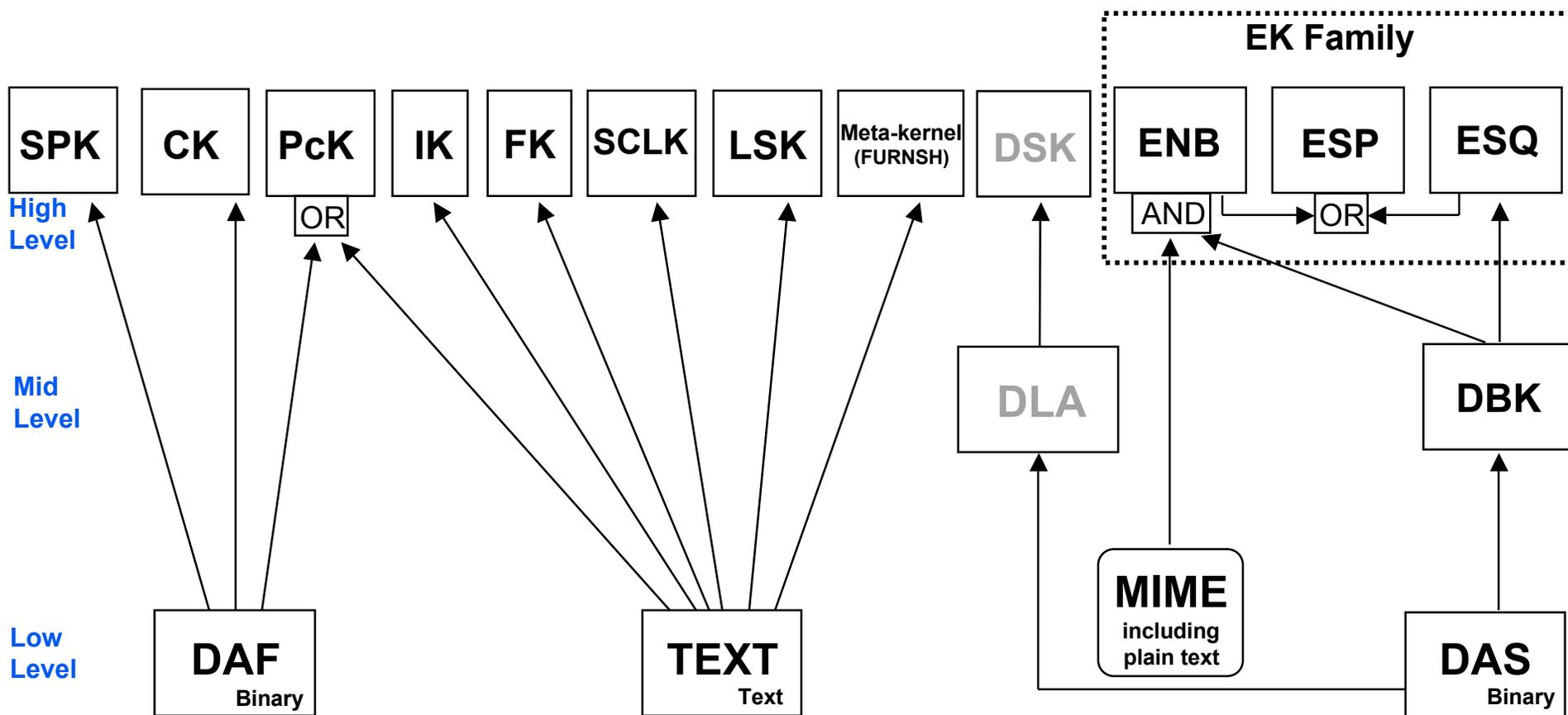
Navigation and Ancillary Information Facility

<u>File Type</u>	<u>Why Modified</u>	<u>How Modified</u>
<p>The EK family</p> <div style="border: 1px dashed black; padding: 5px;"> <p>ESP</p> <p>ESQ</p> <p>ENB</p> </div>	<ul style="list-style-type: none"> -To add, revise or delete “data” -To add metadata (comments) 	<ul style="list-style-type: none"> - (Depends on implementation) - (Depends on implementation)
	<ul style="list-style-type: none"> -To add additional data -To revise data -To delete data -To add metadata (comments) -To merge files 	<ul style="list-style-type: none"> - Toolkit modules - Toolkit modules - Toolkit modules - COMMNT, SPACIT or SPICELIB module - (under development)
	<ul style="list-style-type: none"> -To change entry status (public <--> private) -To delete an entry 	<ul style="list-style-type: none"> - WWW - WWW
LSK	<ul style="list-style-type: none"> - To add a new leapsecond 	<ul style="list-style-type: none"> - Text editor
SCLK	<ul style="list-style-type: none"> - To add metadata 	<ul style="list-style-type: none"> - Text editor
Meta-kernel (FURNISH)	<ul style="list-style-type: none"> - To revise contents in any way 	<ul style="list-style-type: none"> - Text editor



SPICE Data Structures Hierarchy

Navigation and Ancillary Information Facility



DAF = Double Precision Array File

DSK = Digital Shape Kernel (under development)

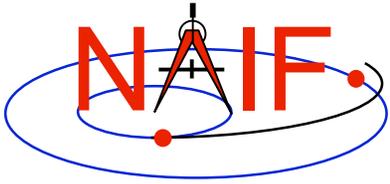
DBK = Data Base Kernel

DLA = DAS Linked Array (under development)

DAS = Direct Access, Segregated

Excepting MIME, each of these data structures is built entirely of SPICE components.

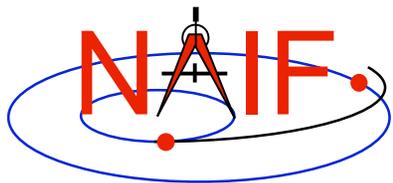
PcK files are usually text-based, but binary versions exist for the earth and moon. The ESP has been implemented using both the ENB and ESQ mechanisms. The DBK is a SQL-like, homebrew database.



Navigation and Ancillary Information Facility

Porting Kernels

January 2009



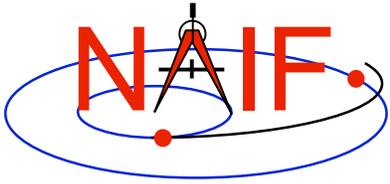
Introduction

Navigation and Ancillary Information Facility

- **The situation with regard to porting SPICE kernels between computers has evolved substantially over the years.**
- **Trying to explain all requirements—past and current—is a complex undertaking and can be rather confusing to customers.**
- **Here we will address only “current” requirements:**
 - those pertaining to the use of Toolkit version N60* or later
 - those pertaining to the use of only computing environments currently supported by NAIF**

* Toolkit version N60 was released January 2006

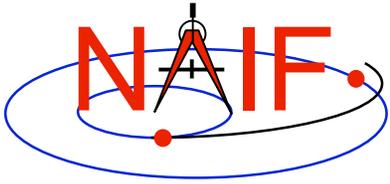
** Currently supported environments are enumerated in the “whats.new” text file bundled with each Toolkit, and in the “Intro to Toolkit” tutorial



Porting Issues - 1

Navigation and Ancillary Information Facility

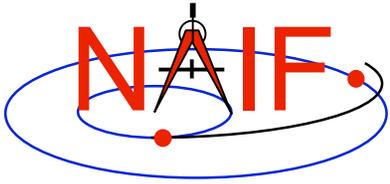
- **Data formats vary across platforms, so data files created on platform “X” may not be usable on platform “Y.”**
 - **Binary data formats: different platforms use different bit patterns to represent numbers (and possibly characters).**
 - **Text formats: different platforms use different mechanisms to represent “lines” in text files.**
 - › **Usually a “line terminator character sequence” indicates end-of-line.**
- **We say two platforms have “compatible” binary or text formats if they use the same binary or text data representations.**
- **We say that a file is “native” if its format is that used on the computer being used by you.**



Porting Issues - 2

Navigation and Ancillary Information Facility

- Toolkit software **can** often read kernels obtained from an incompatible platform
 - Binary SPK, CK, or PCK kernels from one system can be read on an incompatible system (e.g. any pair of PC, Mac, Sun).
 - Text kernels from one system can be read on an incompatible system (e.g. any pair of PC, Mac, Sun) when using a C, IDL or MATLAB toolkit.
- The Toolkit **cannot** read certain kernels from incompatible platforms
 - DAS-based files, such as E-kernels (ESQ) or shape model kernels (DSK)
 - Text kernels, if using a FORTAN toolkit



Porting Issues - 3

Navigation and Ancillary Information Facility

- **When the Toolkit cannot read an incompatible kernel, conversion is required to make the kernel usable. Several options are available.**
 - Use *bingo* for both binary and text kernels
 - › Available only from the NAIF website; not provided in Toolkit packages
 - For text kernels, file transfer using ftp in ASCII mode will perform the required format conversion on the fly.
 - Web browsers often do text format conversion.
 - › However ASCII mode may not be available – sftp clients usually don't provide it. In such cases other tools such as dos2unix and unix2dos must be used.
 - For binary kernels, the SPICE *toxfr* and *tobin* tools may be used to convert files to and from SPICE transfer format
 - › This is an ASCII format that may be transferred in the same way as other ASCII files.

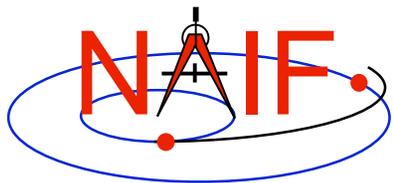


Compatible Environments for Text Kernels

Navigation and Ancillary Information Facility

Since text kernels are only text files...

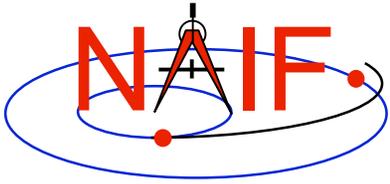
	<u>Groupings of Text Compatible Environments</u>	<u>End of line indicator</u>
1	PC using Windows or N T	<CR><LF>
2	Unix PC with LINUX Macintosh OSX (Motorola or Intel chip)	<LF>



Compatible Environments for Binary Kernels

Navigation and Ancillary Information Facility

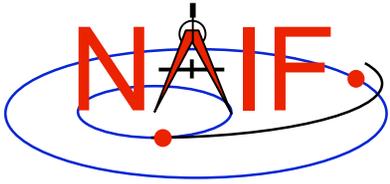
	<u>Groupings of Binary Compatible Environments</u>	<u>Binary Representation</u>
1	PC/ Windows PC/Linux Mac Pro (Intel chip) (the new ones)	IEEE - Little endian
2	Sun Mac Power PC (Motorola chip)	IEEE - Big endian



Caution Using Email

Navigation and Ancillary Information Facility

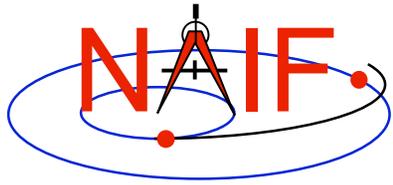
- **NAIF recommends against the use of email to transfer kernels...**
...unless tests prove successful using the same conditions/computers intended for current use. Possible causes of problems are:
 - incompatible binary or text representations (as already discussed).
 - an attachment size limit somewhere in the e-mail chain.
 - the sender's or recipient's mail client modifies the kernel based on file name or presumed content.
- **When you must email kernels, compress either with zip, or gzip (or stuffit), then send the compressed file as an email attachment.**



Binary Kernels - Caveats

Navigation and Ancillary Information Facility

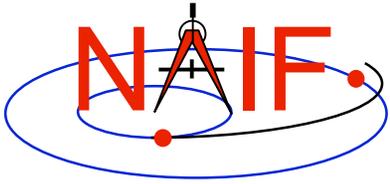
- **If the kernel you are using is a non-native binary kernel you can read this file but you may not write data to this file.**
 - The reading is accomplished using run-time conversion
 - You can not use the SPICE Toolkit's "commnt" or "spacit" programs, or any other means, to write information into the comment area, or to delete information from the comment area.
 - You cannot append additional data to the kernel.
- **Run-time conversion does not work for E-kernel (ESQ) or shape model (DSK) kernels.**
 - More generally, it does not yet work for any file built upon the SPICE "DAS" architecture.



Binary Kernels Allowed Operations

Navigation and Ancillary Information Facility

- You may “load” and read both non-native and native binary kernels in the same runtime instance
- You may merge any combination of native and non-native SPK files
 - The resultant, merged SPK file will be in native format



Navigation and Ancillary Information Facility

“Metadata” In SPICE Kernels

Also known as “comments”

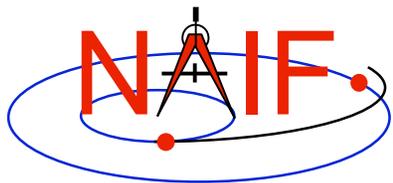
January 2009



What are Metadata?

Navigation and Ancillary Information Facility

- **Metadata are information that describe the context of kernel data, i.e. “data about data”**
- **Metadata are provided as plain text (prose)**
- **Examples of metadata:**
 - **Data descriptions**
 - » **“This file contains representations of the trajectories for bodies X, Y and Z over the interval from launch to landing”**
 - **Data accuracy**
 - **Data pedigree**
 - » **How and by whom was the kernel created**
 - **The program(s) and/or steps used in creation**
 - **Contact information for user’s questions**
 - **email address**
 - **phone numbers**
 - » **Data sources used as inputs when creating the kernel**
 - **Intended kernel usage**
 - **Companion files**
- **In SPICE, we often refer to metadata as “comments”**

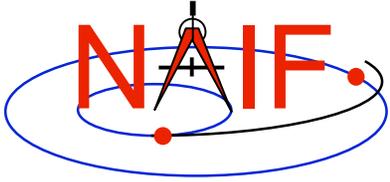


Where are Comments Stored?

Navigation and Ancillary Information Facility

- **Binary kernels contain a reserved “comment” area to hold comments**
- **Text kernels have comments interleaved with the data**
 - Comments may be placed at the beginning of the text kernel, before any data
 - Comments may be inserted between data using `\begintext` and `\begindata` as start and end markers:

```
\begintext
  Some comments
\begindata
  Some data
```



Adding Comments to Kernels

Navigation and Ancillary Information Facility

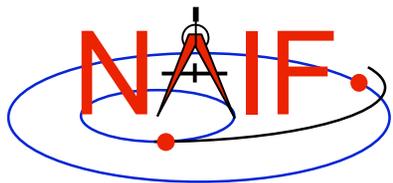
- **Binary Kernels**
 - Use the *commnt* utility program, available in the Toolkit
 - Include comment information at the time of kernel creation using SPICE APIs (subroutines)
 - » This capability is not yet available in Mice
- **Text Kernels**
 - Use a text editor
 - » Begin comment sections with the “\begintext” marker alone on a line
 - (The marker is not needed for comments placed at the beginning of a text kernel)
 - » End comment sections with a “\begindata” marker alone on a line
 - (The marker is not needed if there are no data following the comments)
- **Restrictions**
 - For both binary and text kernels
 - » Comment line length limit is 255 characters. However, NAIF recommends using no more than 80 characters per line as this makes your comments far more readable!
 - » Use only printing characters (ASCII 32 - 126)
 - » Manipulating binary kernel comments requires the kernel be in the native binary format for the machine being used
 - For text kernels
 - » Refer to “Kernel Required Reading” (*kernel.req*) for details



Viewing Comments in Kernels

Navigation and Ancillary Information Facility

- **Binary kernels:**
 - Use either the *commnt* or *spacit* utility program
 - » Both are available in all Toolkits
- **Text kernels:**
 - Use any available text file utility, such as:
 - » more, cat, vi, emacs
 - » Notepad, TextEdit, BBEdit, Word, etc.



Viewing Comments in Binary Kernels

Navigation and Ancillary Information Facility

This example shows reading the comments

```
Terminal Window
prompt> commnt

Welcome to COMMNT Version: 6.0.1
(SPICE Toolkit N0062)

COMMNT Options

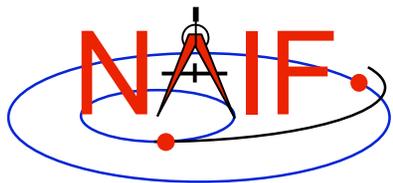
( Q ) Quit.
( A ) Add comments to a binary file.
( R ) Read the comments in a binary file.
( E ) Extract the comments from a binary file.
( D ) Delete the comments in a binary file.

Option: R

Enter the name of the binary file.

Filename? /home/mydirectory/myproject/kernels/spk/de403s.bsp
```

Filename must include any required path and contain no more than 255 characters



Viewing Comments in Text Kernels

Navigation and Ancillary Information Facility

```
Terminal Window
prompt> more naif0008.tls

KPL/LSK

LEAPSECONDS KERNEL FILE
=====

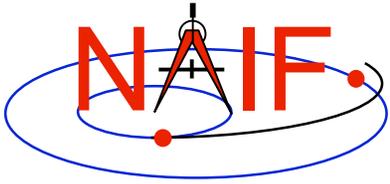
Modifications:
-----
2005, Aug. 3   NJB   Modified file to account for the leapsecond
                 that will occur on December 31, 2005.

1998, Jun 17  WLT   Modified file to account for the leapsecond
                 that will occur on December 31, 1998.

1997, Feb 22  WLT   Modified file to account for the leapsecond
                 that will occur on June 30, 1997.

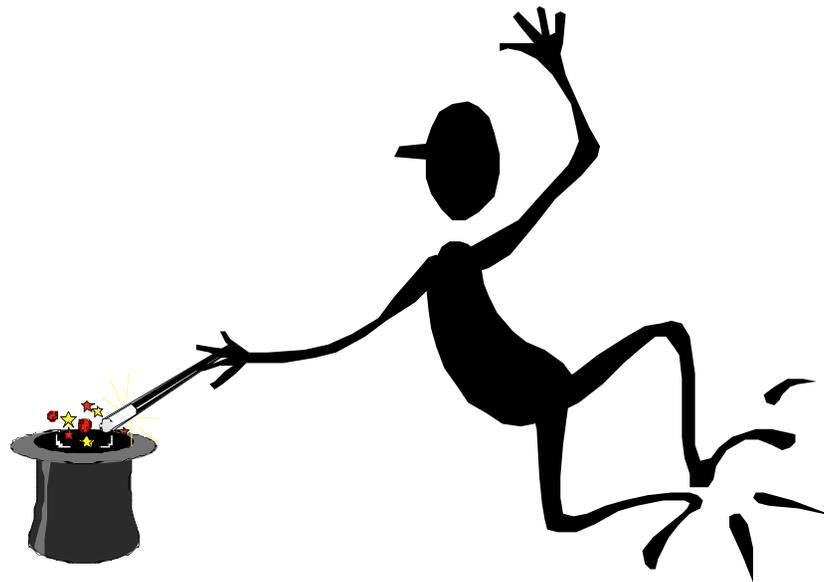
...etc.

-More-- (19%)
```

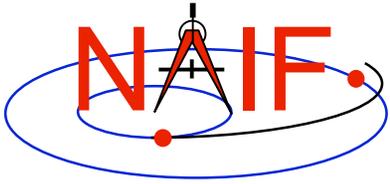


Navigation and Ancillary Information Facility

Getting and Installing the SPICE Toolkit



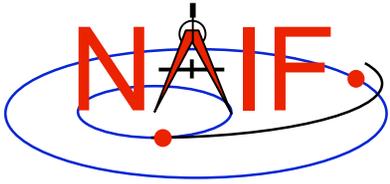
January 2009



Summary

Navigation and Ancillary Information Facility

- **All instances of the SPICE Toolkit are available 24x7 from the NAIF anonymous ftp server**
 - FORTRAN, C, IDL, MATLAB
 - All supported platform/OS/compiler combinations
- **No password or identification is needed**
- **Select either a complete “package,” or individual application/utility executables**
 - **No need to select both!**
- **If you select a package:**
 - first get and read the README instructions
 - use the installation script provided by NAIF (if there is one)
 - get and read the Toolkit description document (dscriptn.txt)



Don't Port It Yourself

Navigation and Ancillary Information Facility

- **Get the package for one of the environments supported by NAIF that has been built and tested for you.**
 - We highly recommend you **NOT** try to port any instance of the Toolkit to some other environment, especially without consulting with NAIF first.
 - » There are both portability issues and compiler optimization issues that must be carefully dealt with.



ftp - 1

Navigation and Ancillary Information Facility

```
Terminal Window

prompt> ftp naif.jpl.nasa.gov

Connected to naif.jpl.nasa.gov
220 Welcome to the NAIF FTP service.

Name (your.sight:your_name): anonymous
331 Please specify the password
Password: your@e.mail.address
230-
230- =====
230- |                               Jet Propulsion Laboratory                               |
230- |                               * * *   W A R N I N G   * * *                               |
230- |                               Property of the                                         |
230- |                               UNITED STATES GOVERNMENT                               |
230- |=====
230-
230 Login successful. Have fun.
Remote system type is UNIX.
Using binary mode to transfer files.

ftp> cd pub/naif/toolkit/<FORTRAN or C or IDL or MATLAB>
250 CWD command successful.
ftp> dir
```



ftp - 2

Navigation and Ancillary Information Facility

Terminal Window

FORTRAN	C	IDL	MATLAB
<pre>ftp> dir Mac_OSX_Abssoft Mac_OSX_IFORT Mac_OSX_g77 PC_Cygwin PC_Linux PC_Windows_Digital PC_Windows_IFORT PC_Windows_Lahey Sun_Solaris</pre>	<pre>ftp> dir Mac_OSX_Apple_C Mac_OSX_Intel_C PC_Cygwin_C PC_Linux_C PC_Linux_C_64bit PC_Windows_Visual_C Sun_Solaris_C Sun_Solaris_GCC Sun_Solaris_GCC_64bit</pre>	<pre>ftp> dir Mac_OSX_Apple_C Mac_OSX_Intel_C PC_Linux_C PC_Windows_Visual_C Sun_Solaris_C Sun_Solaris_GCC</pre>	<pre>ftp> dir Mac_OSX_Apple_C Mac_OSX_Intel_C PC_Linux_C PC_Windows_Visual_C</pre>

The environments available at the time you download the Toolkit may differ from those shown here.



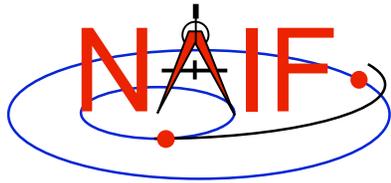
Copying the Toolkit and Installation

Navigation and Ancillary Information Facility

```
Terminal Window

ftp> cd <environment>/packages
ftp> binary
200 Type set to I
ftp> get toolkit.tar.Z
      ( or toolkit.exe
        or cspice.tar.Z
        or cspice.exe
        or icy.tar.Z
        or icy.exe
        or mice.tar.Z
        or mice.exe )

. . . .
ftp> ascii
200 Type set to A
ftp> get importSpice.csh
      ( not available for Windows environment )
ftp> get README
ftp> get dscrip tn.txt
ftp> get whats.new
ftp> quit
```



Copying the Toolkit and Installation

Navigation and Ancillary Information Facility

Terminal Window

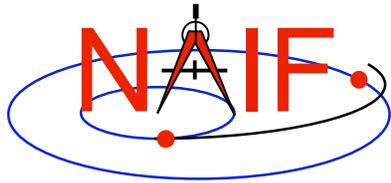
- Follow the directions given in the README. Normally this consists of the following (not applicable for PC Windows):

```
prompt> chmod u+x importSpice.csh
prompt> ./importSpice.csh
prompt> rm toolkit.tar
```

- For PC Windows, execute the toolkit.exe application (or cspice or icy or mice) to expand the archive.

```
> toolkit
```

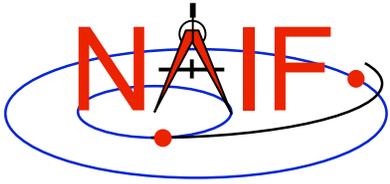
- You now have the expanded toolkit (or cspice or icy or mice) package.



Configuring Your Computer

Navigation and Ancillary Information Facility

- For some programming environments there are **required** additional steps to prepare for programming using SPICE.
- For some programming environments there are **recommended** additional steps to make program development easier.
- **Read the “Preparing for Programming” tutorial and the “README” file found in the Toolkit download directory for more information!**



Check It Out

Navigation and Ancillary Information Facility

- **Try the executables**
 - Use *tobin* to convert the SPICE transfer format SPK and CK files supplied with the Toolkit to local binary.
 - » *cook_01.tsp*, *cook_02.tsp*, *cook_01.tc*, and *cook_02.tc* are found in the *../data* directory
 - Use *brief*, *ckbrief* or *spacit* to summarize the converted kernels.
- **Problems may occur if operating systems or compiler versions are out of sync**
 - Rebuild the Toolkit using the script “*makeall.csh*” (or “*makeall.bat*”) located in the “top level” directory (*toolkit* or *cspice* or *icy* or *mice*).
- **In the rare circumstance that things still don’t work, contact your System Administrator or NAIF.**



Navigation and Ancillary Information Facility

Preparing for Programming Using the SPICE Toolkit

January 2009



Setting Path to Toolkit Executables

Navigation and Ancillary Information Facility

Recommended for all languages

- **Unix**

- **csh, tcsh:** Use the set command to add the location of toolkit executables to your path.

- » set path = (\$path /*my_directory*/toolkit/exe)
 - » set path = (\$path /*my_directory*/cspice/exe)
 - » set path = (\$path /*my_directory*/icy/exe)
 - » set path = (\$path /*my_directory*/mice/exe)

- **bash**

- » PATH=\$PATH:/*my_directory*/toolkit/exe
 - » PATH=\$PATH:/*my_directory*/cspice/exe
 - » PATH=\$PATH:/*my_directory*/icy/exe
 - » PATH=\$PATH:/*my_directory*/mice/exe

- **Windows**

- Add location of toolkit executables to the environment variable PATH from the *Advanced* pane on the System Control Panel (*Control Panel->System->Advanced*).

- » *drive*:\my_directory\toolkit\exe
 - » *drive*:\my_directory\cspice\exe
 - » *drive*:\my_directory\icy\exe
 - » *drive*:\my_directory\mice\exe

Replace the *italics* with the path in which you installed the toolkit on your computer.



Unix/Linux: Build

Navigation and Ancillary Information Facility

- **Compile and link an application, say *program*, against the SPICELIB/CSPICE libraries**
 - **Assume SPICE is installed at `/naif/toolkit/` or CSPICE is installed at `/naif/cspice/`**
 - » **C**

```
$ gcc program.c -I/naif/cspice/include /naif/cspice/lib/csupport.a \  
/naif/cspice/lib/cspice.a -lm
```
 - » **FORTRAN**

```
$ g77 program.f /naif/toolkit/support.a /naif/toolkit/spicelib.a
```
 - » **Some FORTRAN compilers (e.g. Absoft) require an additional flag "`-lU77`" when linking against SPICELIB to pull in the standard Unix symbols**
- **The default SPICE library names do not conform to the UNIX convention `libname.a`. So you cannot use the library path/name options `-L/path_to_libs/` and `-lname` unless you rename the SPICE library.**



Windows: Compiler settings

Navigation and Ancillary Information Facility

- **The standard installation of Microsoft Visual Studio or Visual Toolkit may not update environment variables needed to use the C compiler (cl) from the standard DOS shell.**
 - **Example, environment variables for "cl" - Visual Studio 7:**
 - » **INCLUDE**
 - C:\Program Files\Microsoft Visual Studio .NET\Vc7\include\
 - C:\Program Files\Microsoft Visual Studio .NET\FrameworkSDK\include\
 - » **LIB**
 - C:\Program Files\Microsoft Visual Studio .NET\Vc7\lib\
 - C:\Program Files\Microsoft Visual Studio .NET\FrameworkSDK\Lib\
 - » **PATH**
 - C:\Program Files\Microsoft Visual Studio .NET\Vc7\bin\
 - **You can set the environment variables either by appending the directory paths shown above to the corresponding environment variable in the *Advanced* pane of the *System Control Panel* or by executing one of the "vars32" batch scripts supplied with the Microsoft compiler:**
 - » **vars32.bat**
 - » **vcvars32.bat**
 - » **vsvars32.bat**



Windows: Builds

Navigation and Ancillary Information Facility

- **Assume SPICE is installed at `C:\naif\toolkit\` with CSPICE installed at `C:\naif\cspice\`**

- **Compile and link an application, say *program*, against the SPICELIB/CSPICE libraries**

- » **C**

- > `cl program.c -IC:\naif\cspice\include C:\naif\cspice\lib\csupport.lib \`
`C:\naif\cspice\lib\cspice.lib`

- » **FORTRAN**

- > `df program.f C:\naif\toolkit\lib\SUPPORT.LIB \`
`C:\naif\toolkit\lib\SPICELIB.LIB`



Icy: Register the Icy DLM to IDL (1)

Navigation and Ancillary Information Facility

Required for “Icy”

- **Unix and Windows**

- Use the IDL register command:

```
IDL> dlm_register, <path to icy.dlm>
```

- copy icy.dlm and icy.so (icy.dll) to IDL's binary directory {The IDL install directory}/bin/bin.<your_arch>, e.g.:

- » /usr/local/itt/idl64/bin/bin.linux.x86/

- » C:\ITT\IDL64\bin\bin.x86\

- **Unix specific:**

- » Start the IDL application from a shell in the directory containing both icy.dlm and icy.so.

- » Append the path to your icy.dlm to the IDL_DLM_PATH environment variable to include the directory containing icy.dlm and icy.so, e.g.:

- `setenv IDL_DLM_PATH "<IDL_DEFAULT>:<path to icy.dlm directory>"`

- **Windows specific:**

- » Set environment variable IDL_DLM_PATH as described above from the *Advanced* pane of the *System Control Panel*.



Icy: Register the Icy DLM to IDL (2)

Navigation and Ancillary Information Facility

- **Confirm IDL recognizes and can access Icy**

- **Using the help command:**

```
IDL> help, 'icy', /DLM
```

```
**ICY - IDL/CSPICE interface from JPL/NAIF (not loaded)
```

(Appearance of the words “not loaded” might suggest something is wrong, but this is expected state until you execute an Icy command.)

- **Execute a trivial Icy command:**

```
IDL> print, cspice_icy('version')
```

```
% Loaded DLM: ICY.
```

```
Icy 1.4.20 25-DEC-2008 (EDW)
```



Icy: Using the IDL IDE

Navigation and Ancillary Information Facility

Recommended for “Icy”

- **Use the IDL IDE’s preferences panel to set the current working directory to the location where you will be developing your lessons’ code.**
- **Optional: Place your `dln_register` command in a start up script. Specify the script using the IDL IDE’s preferences panel.**

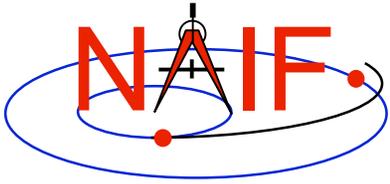


Mice

Navigation and Ancillary Information Facility

Required for “Mice”

- **Assume Mice is installed at `C:\naif\mice\` on Windows, or `/naif/mice/` on Unix/Linux. Use of Mice from MATLAB requires the Mice source and library directories exist in the MATLAB search path.**
 - **On Windows:**
 - » `addpath('C:\naif\mice\lib')`
 - » `addpath('C:\naif\mice\src\mice')`
 - **On Unix/Linux:**
 - » `addpath('/naif/mice/lib')`
 - » `addpath('/naif/mice/src/mice')`



Navigation and Ancillary Information Facility

Introduction to the Family of SPICE Toolkits

January 2009



Topics

Navigation and Ancillary Information Facility

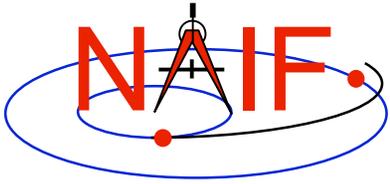
- **SPICE Toolkits**
 - SPICELIB (FORTRAN)
 - CSPICE (C)
 - Icy (IDL)
 - Mice (MATLAB)
- **Installed Directory Structure**
- **Toolkit Documentation**
- **Toolkit Utility Programs**
- **Toolkit Application Programs**
- **Supported Platforms**



SPICE Toolkit

Navigation and Ancillary Information Facility

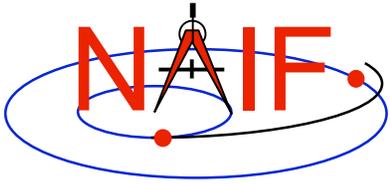
- **The SPICE Toolkit is available in Fortran, C, IDL (Interactive Data Language), and MATLAB**
- **Toolkits contain:**
 - **Software**
 - » **Subroutine libraries, with source code**
 - SPICELIB (Fortran)
 - CSPICE (C)
 - Icy (C)
 - Mice (C and MATLAB script)
 - » **Executable programs**
 - application and utility programs
 - cookbook examples
 - » **Installation/build scripts**
 - **Documentation**
 - » Available in ASCII and HTML
 - **Data**
 - » **Sample kernel files**
 - Supplied **ONLY** for use with cookbook programs, not valid for general use



SPICE Toolkit

Navigation and Ancillary Information Facility

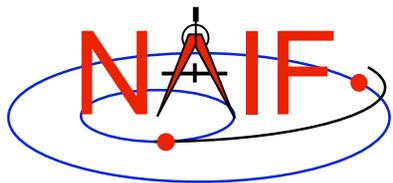
- **The components listed on the previous page comprise the generic Toolkit**
 - Toolkits delivered to missions or other special customers may be augmented with mission- or customer-specific products
- **The Fortran, C, IDL, and MATLAB Toolkits are delivered as standalone products**
 - The IDL and MATLAB products include the CSPICE Toolkit
- **For a given computer and operating system, the Fortran, CSPICE, IDL, and MATLAB Toolkits use identical kernel files.**
 - » (See the “Porting Kernels” tutorial for information about using kernels received from a machine different from what you are using.)



Toolkit Versions

Navigation and Ancillary Information Facility

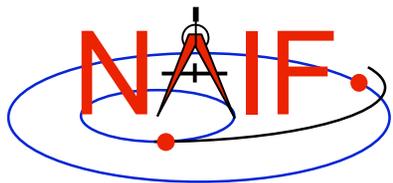
- **Toolkit Version**
 - **Generic SPICE Toolkits have an associated Version number**
 - » **Example: “N0062” (also written as “N62”)**
 - **The version number applies to the Fortran, C, IDL and MATLAB implementations for all supported platforms.**
 - **When does NAIF release new SPICE Toolkit versions?**
 - » **Not according to a fixed schedule**
 - » **Primarily driven by addition of significant new capabilities**
 - **For example, Icy or Mice or the geometry finder subsystem**
 - » **On rare occasion a Toolkit update is released to fix bugs, improve documentation, or satisfy an urgent request from a flight project**



Toolkit Characteristics

Navigation and Ancillary Information Facility

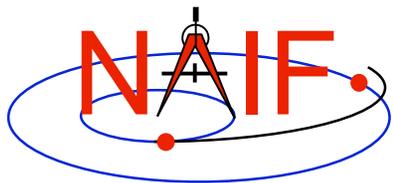
- **Portable SPICE kernel files**
- **Portable NAIF Toolkit software**
- **Code is well tested before being released to users**
- **New Toolkits are always backwards compatible**
 - An application that worked when linked against an older Toolkit will link and work, without need for changes, using a new Toolkit
 - Past functionality is never changed or removed
 - » Enhancements of existing routines are allowed
 - NAIF reserves the right to fix bugs
- **Extensive user-oriented documentation is provided**
 - Includes highly documented source code



Toolkit Library Functionality

Navigation and Ancillary Information Facility

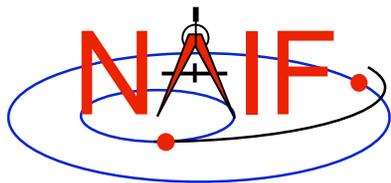
- **Toolkit libraries contain a broad set of capabilities related to the computations needed for “observation geometry” and time conversions.**
 - Broad categories are enumerated on the next several pages
- **Caution:** not all functionality is present in all four language versions of the Toolkit library.
 - The Fortran (SPICE) and C (CSPICE) Toolkits provide virtually identical functionality.
 - The Icy (IDL) toolkit duplicates most functionality from the C Toolkit wrapper routines.
 - The Mice (MATLAB) Toolkit provides interfaces to those routines NAIF considers the most often needed by users.
 - » Where not needed, a module is not implemented.



Toolkit Library Functionality

Navigation and Ancillary Information Facility

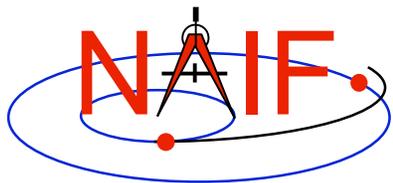
- **Kernel read access**
 - “Load” kernels
 - Get state or position vectors (SPK)
 - Get orientation of planets, natural satellites, etc. (PCK)
 - Get body shape parameters or physical constants (PCK)
 - Get orientation of spacecraft or spacecraft instruments or structures (CK, FK)
 - Get instrument parameters (e.g., FOV) (IK)
 - Query binary EK files (EK-ESQ)
- **Kernel write access**
 - SPK writers
 - CK writers
 - EK writers (sequence component, ESQ)
 - PCK writers (only for binary PCK files)



Toolkit Library Functionality

Navigation and Ancillary Information Facility

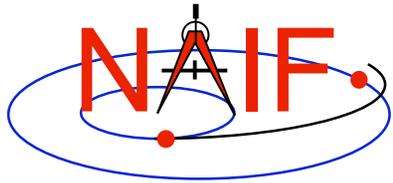
- **Additional ephemeris functions**
 - Classical osculating elements
 - Two-body Keplerian propagation
 - NORAD two line elements sets (TLE) propagation
 - Light time and Stellar aberration computation
- **Frame transformation**
 - Obtain 3x3 matrices for frame transformations of positions
 - Obtain 6x6 matrices for frame transformations of states
- **Time conversion**
 - Conversion between standard systems: TDB, TT (TDT), UTC
 - Conversion between SCLK and other systems
 - Parsing and formatting



Toolkit Library Functionality

Navigation and Ancillary Information Facility

- **Math**
 - Vector/Matrix operations
 - Rotations, Euler angles, quaternions
 - Coordinate conversion (systems: latitudinal, cylindrical, rectangular, RA and DEC, spherical, geodetic, planetographic)
 - Geometry: ellipsoids, ellipses, planes
 - High-level functions: illumination angles, sub-observer point, sub-solar point, surface intercept point.
- **Constants**
 - Julian date of epoch J2000, SPD(seconds per day), PI, etc.
- **Strings**
 - Parsing: find tokens, words
 - Numeric conversion
 - Pattern matching
 - Replace marker, substring
 - Suffix, prefix
 - Case conversion
 - Find first/last non-blank character, first/last printing character



Toolkit Library Functionality

Navigation and Ancillary Information Facility

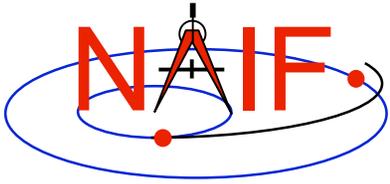
- **Arrays**
 - Sorting, finding order vector, reordering
 - Searching: linear, binary
 - Insertion and deletion
- **Name/code conversion**
 - Bodies
 - Frames
- **I/O support**
 - Logical unit management (Fortran toolkits)
 - Open, read, write text files
 - Kernel pool API
- **Exception handling**
 - Control exception handling behavior: mode, message set, output device
 - Construct error messages



Toolkit Library Functionality

Navigation and Ancillary Information Facility

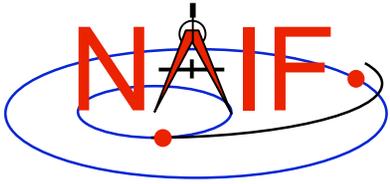
- **Advanced data types**
 - Cells, Sets
 - Windows (sometimes called schedules)
 - Symbol Tables
 - Planes, Ellipses



Fortran SPICE Toolkit

Navigation and Ancillary Information Facility

- **SPICELIB, the Fortran SPICE Toolkit**
 - **Developed first: in use since February 1990**
 - **Contains code written in ANSI Standard Fortran 77**
 - » **A few widely supported non-ANSI extensions are used, for example DO WHILE, DO...END DO**
 - **Compiles under a wide variety of Fortran compilers**
 - » **While NAIF cannot guarantee proper functioning of SPICE under F90/F95 compilers except on officially supported environments, those compilers might properly compile SPICELIB with the resulting libraries being callable from F90/F95 code if that compiler supports the F77 standard.**

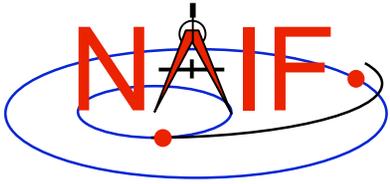


CSPICE Toolkit

Navigation and Ancillary Information Facility

- **CSPICE, the C-language Toolkit**
 - Designed to duplicate the functionality of the Fortran Toolkit
 - All CSPICE source code is in ANSI C
 - » The Fortran SPICE Toolkit code is converted to ANSI C using the automatic translation program `f2c`
 - » High-level functions have been hand-coded in C and documented in C style in order to provide a natural C-style API. These functions are called “wrappers”
 - » Most wrappers encapsulate calls to C functions generated by `f2c`
 - The simpler wrappers do their work in-line to boost performance
 - » `f2c`'d functions may be called directly, but this is strongly discouraged since `f2c`'d functions emulate Fortran functionality:
 - Call by reference
 - Fortran-style array indexing
 - Fortran-style strings

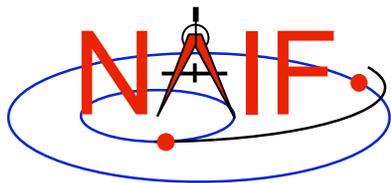
continued on next page



CSPICE Toolkit

Navigation and Ancillary Information Facility

- **CSPICE runs under a wide variety of ANSI C compilers**
- **CSPICE functions may be called from within C++ source code**
 - » **CSPICE prototypes are protected from name mangling**
- **Current CSPICE Limitations**
 - » **Not all “Required Reading” reference documents have been converted to C style, with C examples**
 - Eventually all will be converted
 - » **CSPICE wrappers do not exist for every functionality provided in the Fortran toolkits**
 - Includes all the most commonly used modules
 - More will be added as time permits
 - » **In some very limited cases, code generated by f2c fails to emulate Fortran accurately. Should not be a problem.**
 - List-directed I/O has some problems (not consequential for CSPICE)
 - Treatment of white space in text output is slightly different in CSPICE
 - Logical unit-to-file name translation does not handle file name "synonyms" properly under Linux: once opened with a specified name, a file must be referred to using the same name throughout a program run.



Icy Toolkit

Navigation and Ancillary Information Facility

- **Icy, the Interactive Data Language Toolkit**
 - Provides an IDL-callable “wrapper” interface for many CSPICE wrapper routines
 - » **Example:**
 - CSPICE: `spkeqr_c (targ, et, ref, abcorr, obs, state, &itime);`
 - Icy: `cspice_spkeqr, targ, et, ref, abcorr, obs, state, itime`
 - » **NAIF will add additional interfaces to Icy as time permits**
 - **By necessity the Icy Toolkit includes the complete CSPICE Toolkit.**
 - » **Additional Icy software components are:**
 - IDL interface wrappers (implemented in ANSI C)
 - Icy cookbook programs (implemented in IDL)
 - **Icy Documentation**
 - » **Icy Reference Guide**
 - Principal documentation showing how to call Icy wrappers
 - Each Icy wrapper has an HTML page containing usage examples serving as the Icy “module header”
 - » **Icy Required Reading**
 - Provides background information essential for programming with Icy



Mice Toolkit

Navigation and Ancillary Information Facility

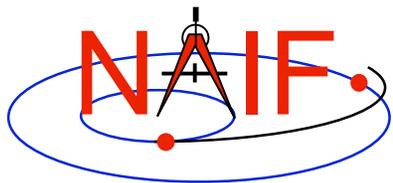
- **Mice, the MATLAB Toolkit**
 - Mice provides a MATLAB-callable “wrapper” interface for many CSPICE wrapper routines
 - » **Example:**
 - CSPICE: `spkezc (targ, et, ref, abcorr, obs, state, <ime);`
 - Mice: `[state, ltime] = cspice_spkezc(targ, et, ref, abcorr, obs)`
 - » **More MATLAB-callable wrappers will be added as time permits**
 - **By necessity all Mice Toolkit packages include the complete CSPICE Toolkit.**
 - » **Additional Mice software components are:**
 - MATLAB interface wrappers (implemented in MATLAB wrapper scripts calling the ANSI C based interface library)
 - Mice cookbook programs (implemented in MATLAB script)
 - **Mice Documentation**
 - » **Mice Reference Guide**
 - Principal documentation showing how to call Mice wrappers
 - Each Mice wrapper script has a documentation header containing usage examples, serving as SPICE “module header”, available from the `help` command. This documentation also exists as a HTML page.
 - » **Mice Required Reading**
 - Provides background information essential for programming with Mice



Installed Directory Structure

Navigation and Ancillary Information Facility

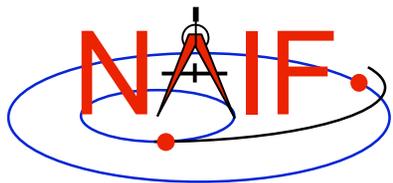
- **The top level directory name for each Toolkit is:**
 - “**toolkit**” for Fortran Toolkits
 - “**cspice**” for C Toolkits
 - “**icy**” for IDL Toolkits
 - “**mice**” for MATLAB Toolkits
- **Directory structures for the Toolkits are almost identical. However...**
 - The **CSPICE**, **Icy** and **Mice** Toolkits also have a directory for include files
 - The names for application source code directories in **CSPICE**, **Icy** and **Mice** differ slightly from those in the Fortran toolkit
 - **Icy** and **Mice** include additional directories for
 - » **Icy/Mice** source code
 - » **Icy/Mice** cookbook programs



Installed Directory Structure

Navigation and Ancillary Information Facility

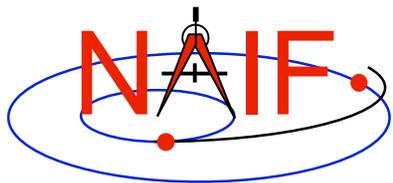
- **The next level is comprised of:**
 - **data**
 - » Cookbook example kernels (use ONLY for training with cookbook programs)
 - **doc**
 - » Text documents — *.req, *.ug, spicelib.idx/cspice.idx, whats.new, dscripnt.txt, version.txt.
 - » Subdirectory containing HTML documentation, called “html”.
 - The “html” subdirectory contains a single file — the top level HTML documentation index called “index.html” — and a number of subdirectories, one for each of the various groups of documents in HTML format (API Reference Guide pages, User’s Guide pages, etc.)
 - **etc**
 - » In generic Toolkits this directory is empty.
 - **exe**
 - » Executables for brief, chronos, ckbrief, commnt, inspekt, mkspk, msopck, spacit, spkdiff, spkmerge, tobin, toxfr, version.
 - » Executables for the several cookbook example programs.



Installed Directory Structure

Navigation and Ancillary Information Facility

- **include** (applies to CSPICE, Icy, and Mice)
 - » **API header files.**
 - File to include in callers of CSPICE is SpiceUsr.h
- **lib**
 - » **Toolkit libraries:**
 - **For Fortran SPICE Toolkits**
 - spicelib.a or spicelib.lib (public modules; use these)
 - support.a or support.lib (private modules; don't use these)
 - **For CSPICE Toolkits**
 - cspice.a or cspice.lib (public modules; use these)
 - csupport.a or csupport.lib (private modules; don't use these)
 - **For Icy Toolkits:**
 - icy.so (shared object library)
 - icy.dlm (dynamically loadable module)
 - cspice.a or cspice.lib
 - csupport.a or csupport.lib
 - **For Mice Toolkits:**
 - mice.mex* (shared object library)
 - cspice.a or cspice.lib
 - csupport.a or csupport.lib
- **src**
 - » **Source code directories for executables and libraries**
 - Files have type *.f, *.for, *.inc, *.pgm, *.c, *.h, *.x, *.pro, *.m
 - *.h files appearing here are not part of the user API



Toolkit Documentation

Navigation and Ancillary Information Facility

- **All Toolkits include documentation in plain text and HTML formats**
 - Plain text documents are located under the “doc” directory
 - HTML documents are located under the “<toolkit_name>/doc/html” (Unix) or “<toolkit name>\doc\html” (Windows) directory
 - » “<toolkit_name>/doc/html/index.html” or “<toolkit_name>\doc\html\index.html” is the top level index
- **All Toolkits include the following kinds of documents**
 - **Module headers**
 - » **Act as primary functional specification: I/O, exceptions, particulars defining behavior of module**
 - » **Contain code examples**
 - » **A standard format is used for each routine or entry point**
 - » **Plain text Module Headers:**
 - **Fortran:** the top comment block in the source code files under “src/spicelib”
 - **C:** the top comment block in the source code files under “src/cspice”
 - **IDL:** Idl Module Headers are not available in plain text format
 - **MATLAB** accessible via “help *function_name*” command
 - » **HTML Module Headers are accessible using the “API Reference Guide” link from the top level index.**

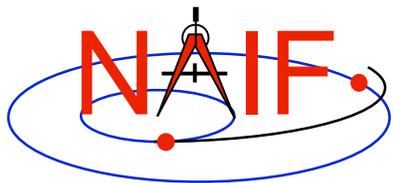
continues on next page



Toolkit Documentation

Navigation and Ancillary Information Facility

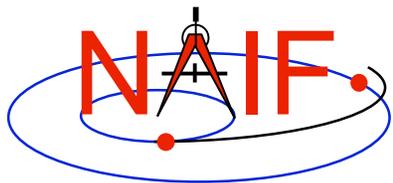
- **Required Reading**
 - » **References for principal subsystems**
 - » **Provide many low-level details**
 - » **Provide code examples**
 - » **Plain text versions are located under “doc” and have extension “.req”**
 - » **HTML versions are accessible using the “Required Reading Documents” link from the top level index.**
 - » **Not all of Required Readings were adapted for all languages**
 - **Some of the Required Reading documents provided with CSPICE still cover Fortran SPICE**
 - **No Required Readings are yet adapted for Icy or Mice (Icy and Mice toolkits contain CSPICE Required Readings)**
- **User’s Guides**
 - » **Interface specifications for the Toolkit utility programs and applications**
 - » **Plain text versions are located under “doc” and have extension “.ug”**
 - » **HTML versions are accessible using the “User’s Guide Documents” link from the top level index.**



Toolkit Documentation

Navigation and Ancillary Information Facility

- **Other documents**
 - **Permuted Index**
 - » **Maps phrases describing functionality to corresponding module names and file names**
 - » **Shows names of all entry points in Fortran toolkit APIs**
 - » **Plain text version is located under “doc” and has extension “.idx”:**
 - **Fortran: spicelib.idx**
 - **C: cspice.idx**
 - **IDL: icy.idx and cspice .idx**
 - **MATLAB: mice.idx and cspice.idx**
 - » **HTML version is accessible using the “Permuted Index” link from the top level index.**
 - **Toolkit Description**
 - » **Describes the directory structure and contents of an installed Toolkit**
 - » **Customized based on set of delivered products and platform**
 - » **Plain text version is “doc/dscriptn.txt”**
 - » **HTML version is accessible using the “Toolkit Contents” link from the top level index.**



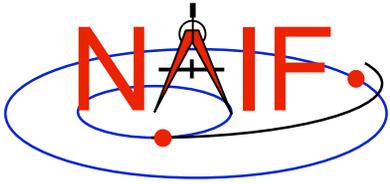
Toolkit Documentation

Navigation and Ancillary Information Facility

- **Other documents (continued)**
 - **Introduction to SPICE**
 - » **Brief introduction to the Toolkit and SPICE system**
 - » **Not available in plain text**
 - » **HTML version is accessible using the “Introduction to the SPICE System” link from the top level index.**

 - **What’s New in SPICE**
 - » **Describes new features and bug fixes**
 - » **Plain text version is “doc/whats.new”**
 - » **HTML version is accessible using the “What’s New in SPICE” link from the top level index.**

 - **Toolkit Version Description**
 - » **Indicates Toolkit version**
 - » **Plain text version is “doc/version.txt”**
 - » **Not available in HTML**

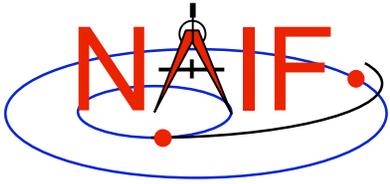


Toolkit Utility Programs

Navigation and Ancillary Information Facility

- **SPICE Toolkit utility programs are available to:**
 - **port binary SPICE kernels between incompatible systems***
 - » tobin, toxfr, spacit
 - » bingo (available only from the NAIF webpage)
 - **port text SPICE kernels between incompatible systems**
 - » bingo (available only from the NAIF webpage)
 - **add comments to binary kernels**
 - » commnt
 - **read comments from binary kernels**
 - » commnt, spacit
 - » inspekt (only for EK/ESQ files)
 - **summarize coverage of binary kernels**
 - » brief, ckbrief, spacit
 - **merge or subset SPK files**
 - » spkmerge
 - **indicate current Toolkit version**
 - » version

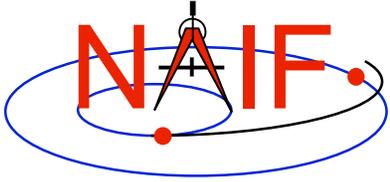
* Usually not needed



Toolkit Application Programs

Navigation and Ancillary Information Facility

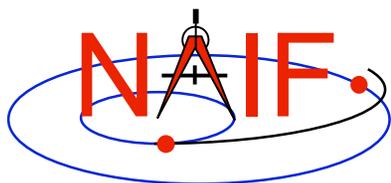
- **SPICE Toolkit application programs perform various tasks:**
 - create a new SPK file from a text file of state vectors or elements
 - » `mkspk`
 - compare (diff) two SPKs
 - » `spkdiff`
 - create a new CK from a text file of attitude data
 - » `msopck`
 - carry out a wide assortment of time conversions
 - » `chronos`
 - query Event Kernels (EKs)
 - » `inspekt`



Supported Environments

Navigation and Ancillary Information Facility

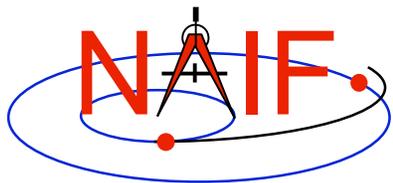
- **NAIF ports the SPICE Toolkit to several popular environments**
 - Each environment is characterized by
 - » Language
 - » Hardware type (platform)
 - » Operating System
 - » Compiler
 - » Selected compilation options
- **NAIF provides SPICE Toolkit packages for each supported environment**
 - If you cannot find a package built for the environment of interest to you, contact NAIF
 - » **Don't try to use or port a Toolkit built for another environment**



Supported Environments - Fortran

Navigation and Ancillary Information Facility

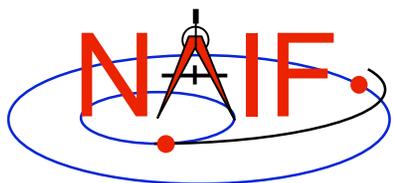
| Product Name | Operating System | Compiler |
|--|----------------------|--|
| Mac/PowerPC, OS-X, Absoft FORTRAN | OS X 10.3.x | Absoft Pro Fortran 9.0 |
| Mac/Intel, OS-X, Intel FORTRAN | OS X 10.4.x | Intel Fortran 10.1 |
| Mac/PowerPC, OS-X, g77 | OS X 10.3.x | g77, GNU Fortran 3.4.4 |
| PC, CYGWIN, g77 | Windows/Cygwin | g77, GNU Fortran 3.2 |
| PC, Linux, g77 | Red Hat Linux (RHE4) | g77, GNU Fortran 3.4.6 |
| PC, Linux, Intel FORTRAN (IFORT) | Red Hat Linux (RHE4) | Intel Fortran 10.0 |
| PC, Windows, Compaq Visual (Digital) FORTRAN | Windows NT/2K/XP | Compaq Digital Fortran 6.0 |
| PC, Windows, Intel FORTRAN (IFORT) | Windows XP | Intel Fortran 10.0 |
| PC, Windows, Lahey FORTRAN95 | Windows NT/2K/XP | Lahey FORTRAN 95 5.6 |
| Sun, Solaris, SUN FORTRAN | Solaris 9 | Sun WorkShop 6 update 2 FORTRAN 77 5.3 |



Supported Environments - C

Navigation and Ancillary Information Facility

| Product Name | Operating System | Compiler |
|---------------------------------|----------------------|------------------------------------|
| Mac/PowerPC, OS-X, Apple C | OS X 10.3.x | gcc, GNU C 4.0.1 |
| Mac/Intel, OS-X, Apple C | OS X 10.4.x | gcc, GNU C 4.0.1 |
| PC, CYGWIN, gCC | Windows/Cygwin | gcc, GNU C 3.2 |
| PC, Linux, gCC | Red Hat Linux (RHE4) | gcc, GNU C 3.4.6 |
| PC, Linux, gCC/64bit | Red Hat Linux (RHE4) | gcc, GNU C 3.4.6 |
| PC, Windows, Microsoft Visual C | Windows NT/2K/XP | Microsoft Visual Studio .NET 7.0 C |
| Sun, Solaris, SUN C | Solaris 9 | Sun WorkShop 6 update 2 C 5.3 |
| Sun, Solaris, gCC | Solaris 9 | gcc, GNU C 3.3.2 |
| Sun, Solaris, gCC/64bit | Solaris 9 | gcc, GNU C 3.3.2 |

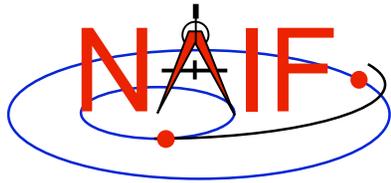


Supported Environments - IDL*

Navigation and Ancillary Information Facility

| Product Name | Operating System | Compiler |
|-------------------------------------|----------------------|------------------------------------|
| Mac/PowerPC, OS-X, Apple C/IDL | OS X 10.3.x | gcc, GNU C 4.0.1 |
| Mac/Intel, OS-X, Apple C/IDL | OS X 10.4.x | gcc, GNU C 4.0.1 |
| PC, Linux, gcc/IDL | Red Hat Linux (RHE4) | gcc, GNU C 3.4.6 |
| PC, Windows, Microsoft Visual C/IDL | Windows XP | Microsoft Visual Studio .NET 7.0 C |
| Sun, Solaris, SUN C/IDL | Solaris 9 | Sun WorkShop 6 update 2 C 5.3 |
| Sun, Solaris, gcc/IDL | Solaris 9 | gcc, GNU C 3.3.2 |

***NAIF built and tested Icy using IDL version 6.4, but these Toolkits work with IDL 7 as well.**

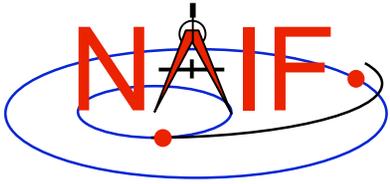


Supported Environments - MATLAB*

Navigation and Ancillary Information Facility

| Product Name | Operating System | Compiler |
|---------------------------------|----------------------|------------------------------------|
| Mac/PowerPC, OS-X, Apple C | OS X 10.3.x | gcc, GNU C 4.0.1 |
| Mac/Intel, OS-X, Apple C | OS X 10.4.x | gcc, GNU C 4.0.1 |
| PC, Linux, gCC | Red Hat Linux (RHE4) | gcc, GNU C 3.4.6 |
| PC, Windows, Microsoft Visual C | Windows XP | Microsoft Visual Studio .NET 7.0 C |

***NAIF built and tested Mice using MATLAB version 7.4 (2007a)**



Navigation and Ancillary Information Facility

Matlab Interface to CSPICE “Mice”

How to Access the CSPICE library Using Matlab[©]

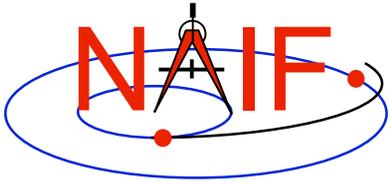
January 2009



Topics

Navigation and Ancillary Information Facility

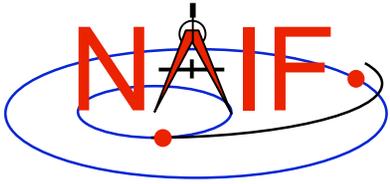
- **Mice Benefits**
- **How does it work?**
- **Distribution**
- **Mice Operation**
- **Vectorization**
- **Simple Mice Example**



Mice Benefits

Navigation and Ancillary Information Facility

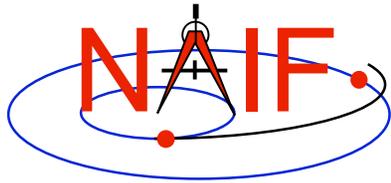
- **Mice operates as an extension to the Matlab environment.**
- **All Mice calls are functions regardless of the call format of the underlying CSPICE routine, returning Matlab native data types.**
- **Mice has some capability not available in CSPICE such as vectorization.**
- **CSPICE error messages return to Matlab in the form usable by the *try...catch* construct.**



How Does It Work? (1)

Navigation and Ancillary Information Facility

- **The Matlab environment includes an intrinsic capability to use external routines.**
 - **Mice functions as a Matlab Executable, MEX, consisting of the Mice MEX shared object library and a set of .m wrapper files.**
 - » **The Mice library contains the Matlab callable C interface routines that wrap a subset of CSPICE wrapper calls.**
 - » **The wrapper files, named `cspice_*.m` and `mice_*.m`, provide the Matlab calls to the interface functions.**
 - » **A function prefixed with ‘`cspice_`’ retains essentially the same argument list as the CSPICE counterpart.**
 - » **An interface prefixed with ‘`mice_`’ returns a structure, with the fields of the structure corresponding to the output arguments of the CSPICE counterpart.**
 - » **The wrappers include a header section describing the function call, displayable by the Matlab *help* command.**



How Does It Work? (2)

Navigation and Ancillary Information Facility

When a user invokes a call to a Mice function:

- 1. Matlab calls...**
- 2. the function's wrapper, which calls...**
- 3. the Mice MEX shared object library, which performs its function then returns the result...**
- 4. to the wrapper, which...**
- 5. returns the result to the user**

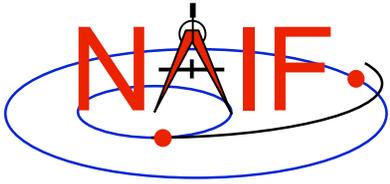
... transparent from the user's perspective.



Mice Distribution

Navigation and Ancillary Information Facility

- **NAIF distributes Mice as a complete, standalone package.**
- **The package includes:**
 - the CSPICE source files
 - the Mice interface source code
 - platform specific build scripts for Mice and CSPICE
 - Matlab versions of the SPICE cookbook programs, *states*, *tictoc*, *subpt*, and *simple*
 - an HTML based help system for both Mice and CSPICE, with the Mice help cross-linked to CSPICE
 - the Mice MEX shared library and the M wrapper files. The system is ready for use after installation of the the library and wrapper files.
- **Note: You do not need a C compiler to use Mice.**



Mice Operation (1)

Navigation and Ancillary Information Facility

- **A possible irritant exists in loading kernels using the `cspice_furnsh` function.**
 - **Kernels load into your Matlab session, not into your Matlab scripts. This means:**
 - » loaded binary kernels remain accessible (“active”) throughout your Matlab session
 - » data from loaded text kernels remain in the kernel pool (in the memory space used by CSPICE) throughout your Matlab session
 - **Consequence: some kernel data may be available to one of your scripts even though not intended to be so.**
 - » You could get **incorrect results!**
 - » If you run only one script during your Matlab session, there’s no problem.



Mice Operation (2)

Navigation and Ancillary Information Facility

- **Mitigation: two approaches**
 - **Load all needed SPICE kernels for your Matlab session at the beginning of the session, paying careful attention to the files loaded and the loading order (loading order affects precedence)**
 - » **Convince yourself that this approach will provide ALL of the scripts you will run during this Matlab session with the appropriate SPICE data**
 - **At or near the end of every Matlab script:**
 - » **include a call to `cspice_unload` for each kernel loaded using `cspice_furnsh`**
 - » **or include a call to `cspice_kclear` to remove ALL kernel data from the kernel pool loaded using `cspice_furnsh`**



Mice Vectorization (1)

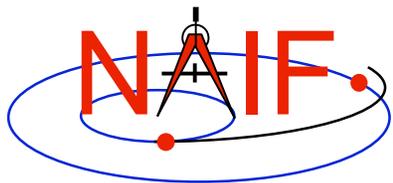
Navigation and Ancillary Information Facility

- **Most Mice functions include use of vectorized arguments, a capability not available in C or Fortran toolkits.**
- **Example: use Mice to retrieve state vectors and light-time values for 1000 ephemeris times.**
 - **Create the array of 1000 ephemeris times in steps of 10 hours, keyed on July 1, 2005:**

```
start = cspice_str2et('July 1 2005');  
et     = (0:999)*36000 + start;
```

- **Retrieve the state vectors and corresponding light times from Mars to earth at each `et` in the J2000 frame with LT+S aberration correction:**

```
[state, ltime] = cspice_spke zr( 'Earth', et, 'J2000', 'LT+S', 'MARS');  
or  
starg = mice_spke zr( 'Earth', et, 'J2000', 'LT+S', 'MARS');
```



Mice Vectorization (2)

Navigation and Ancillary Information Facility

- Access the *ith* state 6-vector (6x1 array) corresponding to the *ith* ephemeris time with the expression

```
state_i = state(:,i)
```

or

```
state_i = starg(i).state
```

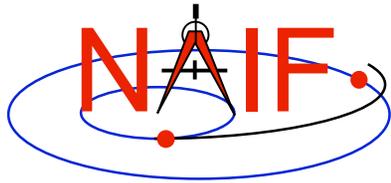
- Convert the ephemeris time vector et from the previous example to UTC calendar strings with three decimal places of precision in the seconds field.

```
format = 'C';
```

```
prec = 3;
```

```
utcstr = cspice_et2utc( et, format, prec );
```

- The call returns `utcstr`, an array of 1000 strings (dimensioned 1000x24), where each *ith* string is the calendar date corresponding to $et(i)$.



Mice Vectorization (3)

Navigation and Ancillary Information Facility

- Access the *ith* string of `utcstr` corresponding to the *ith* ephemeris time with the expression

```
utcstr_i = utcstr(i,:)
```

- Convert the position components (the first three components in a state vector) of the *N* state vectors returned in `state` by the `cspice_spkezr` function to latitudinal coordinates.

```
[radius, latitude, longitude] = cspice_reclat( state(1:3,:) );
```

- The call returns three double precision `1x1000` arrays (vectorized scalars): `radius`, `latitude`, `longitude`.



Simple Mice Example (1)

Navigation and Ancillary Information Facility

- **As an example of Mice use, calculate and plot the trajectory in the J2000 inertial frame of the Cassini spacecraft from June 20, 2004 to December 1, 2005. This example uses the `cspice_spkpos` function to retrieve position data.**

```
% Define the number of divisions of the time interval and the time interval.
STEP = 1000;

% Load the needed kernels. Use a meta kernel "standard.ker" to load the kernels
% "naif0009.tls," "de405_2000-2050.bsp," "pck00008.tpc."

cspice_furnsh( { 'standard.tm', '/kernels/cassini/spk/T18-5TDJ5.bsp' } )

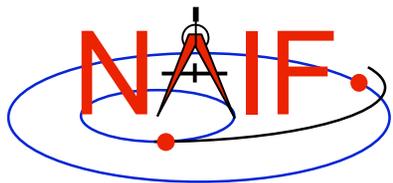
et          = cspice_str2et( {'Jun 20, 2004', 'Dec 1, 2005'} );
times      = (0:STEP-1) * ( et(2) - et(1) )/STEP + et(1);

[pos,ltime]= cspice_spkpos( 'Cassini', times, 'J2000', 'NONE', 'SATURN BARYCENTER' );

% Plot the resulting trajectory.
x = pos(1,:);
y = pos(2,:);
z = pos(3,:);

plot3(x,y,z)

cspice_kclear
```



Simple Mice Example (2)

Navigation and Ancillary Information Facility

- **The example script using the `mice_spkezt` function.**

```
% Define the number of divisions of the time interval and the time interval.
STEP = 1000;

% Load the needed kernels. Use a meta kernel "standard.ker" to load the kernels
% "naif0000.tls," "de405_2000-2050.bsp," "pck00008.tpc."

cspice_furnsh( { 'standard.tm', '/kernels/cassini/spk/T18-5TDJ5.bsp' } )

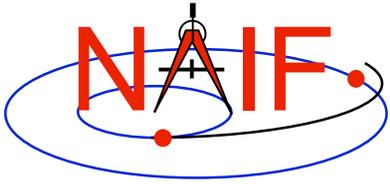
et    = cspice_str2et( {'Jun 20, 2004', 'Dec 1, 2005'} );
times = (0:STEP-1) * ( et(2) - et(1) )/STEP + et(1);

ptarg = mice_spkpos( 'Cassini', times, 'J2000', 'NONE', 'SATURN BARYCENTER' );
pos    = [ptarg.pos];

% Plot the resulting trajectory.
x = pos(1,:);
y = pos(2,:);
z = pos(3,:);

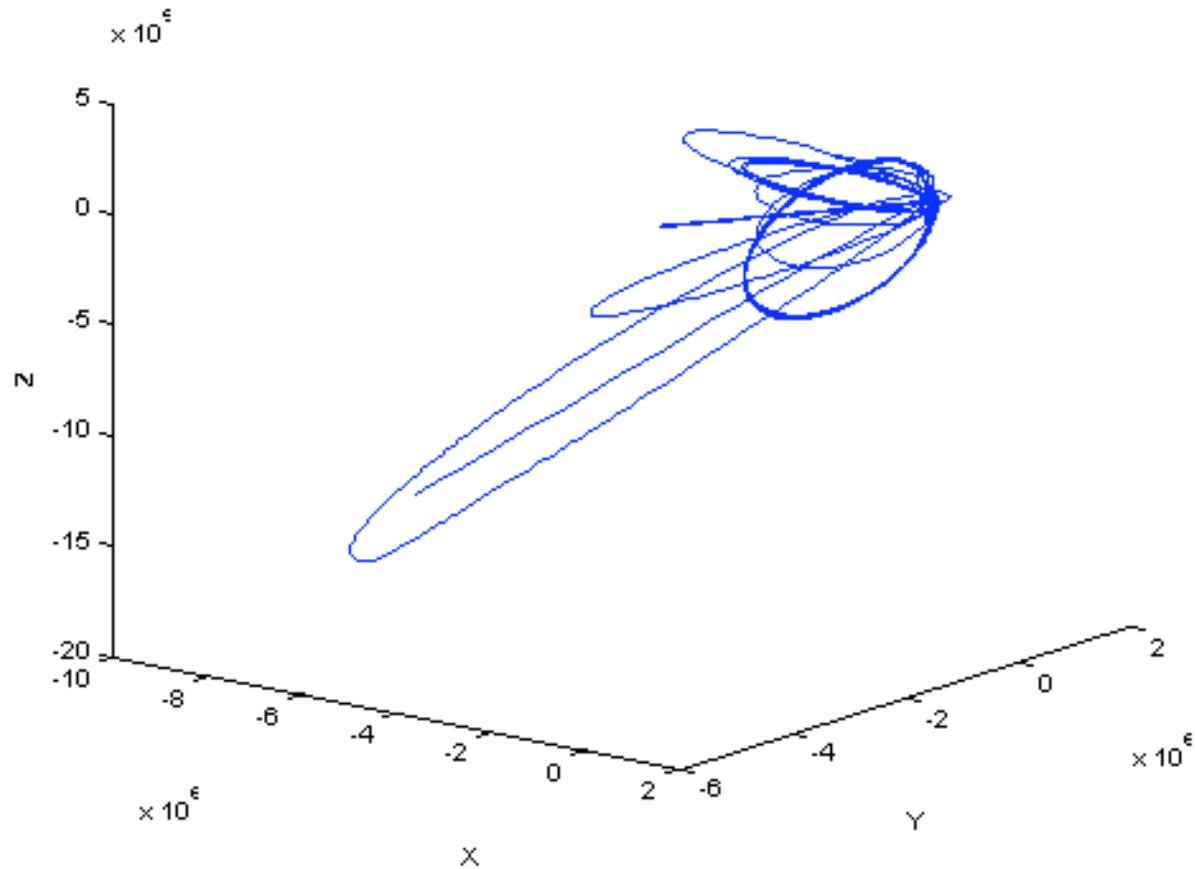
plot3(x,y,z)

cspice_kclear
```



Mice Example Graphic Output

Navigation and Ancillary Information Facility



Trajectory of the Cassini vehicle in the J2000 frame, for June 20, 2004 to Dec 1, 2005



Navigation and Ancillary Information Facility

IDL Interface to CSPICE “Icy”

How to Access the CSPICE library Using Interactive Data Language (IDL)®

January 2009



Topics

Navigation and Ancillary Information Facility

- **Icy Benefits**
- **How does it work?**
- **Distribution**
- **Icy Operation**
- **Vectorization**
- **Simple Use of Icy Functionality**



Icy Benefits

Navigation and Ancillary Information Facility

- **Ease of use: Icy operates as an extension to the IDL language regime.**
- **Icy supports more than three-hundred CSPICE routines.**
- **Icy calls usually correspond to the call format of the underlying CSPICE routine, returning IDL native data types.**
- **Icy has some capability not available in CSPICE such as vectorization.**
- **CSPICE error messages return to IDL in a form usable by the *catch* error handler construct.**



How Does It Work? (1)

Navigation and Ancillary Information Facility

- **The IDL environment includes an intrinsic capability to use external routines.**
 - **Icy functions as an IDL Dynamically Loadable Module (DLM). A DLM consists of a shared object library (icy.so/.dll) and a DLM text definition file (icy.dlm).**
 - » **The shared library contains a set of IDL callable C interface routines that wrap a subset of CSPICE wrapper calls.**
 - » **The text definition file lists the routines within the shared library and the format for the routine's call parameters.**
- **Using Icy from IDL requires you register the Icy DLM with IDL to access the interface routines. Several means exist to do so:**
 - **on Unix/Linux, start IDL from the directory containing icy.dlm and icy.so**

continued on next page



How Does It Work? (2)

Navigation and Ancillary Information Facility

- from the IDL interpreter (or from a command script), execute the `dml_register` command

```
IDL> dml_register, <path to icy.dml>
```

» **Such as:**

- IDL> `dml_register, '/naif/icy/lib/icy.dml'`
- IDL> `dml_register, 'c:\naif\icy\lib\icy.dml'`

- copy `icy.dml` and `icy.so` (`icy.dll`) to IDL's binary directory

```
{The IDL install directory}/bin/bin.<your_arch>
```

» **Such as:**

- `/usr/local/itt/idl64/bin/bin.linux.x86/`
- `C:\ITT\IDL64\bin\bin.x86\`

- append to the `IDL_DLM_PATH` environment variable the directory name containing `icy.dml` and `icy.so` (`icy.dll`) e.g.:

```
setenv IDL_DLM_PATH "<IDL_DEFAULT>:<path to icy.dml directory>"
```



How Does It Work? (3)

Navigation and Ancillary Information Facility

When a user invokes a call to a DLM routine:

- 1. IDL calls...**
- 2. the interface routine in the shared object library, linked against...**
- 3. CSPICE, which performs its function and returns the result...**
- 4. to IDL...**

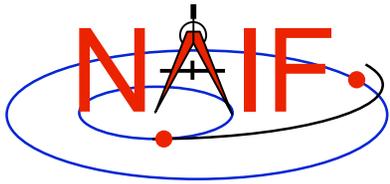
... transparent from the user's perspective.



Icy Distribution

Navigation and Ancillary Information Facility

- **NAIF distributes the Icy package as an independent product analogous to SPICELIB and CSPICE.**
- **The package includes:**
 - the CSPICE source files
 - the Icy interface source code
 - platform specific build scripts for Icy and CSPICE
 - IDL versions of the SPICE cookbook programs, *states*, *tictoc*, *subpt*, and *simple*
 - an HTML based help system for both Icy and CSPICE, with the Icy help cross-linked to CSPICE
 - the Icy shared library and DLM file. The system is ready for use after installation of the these files
- **Note: You do not need a C compiler to use Icy.**



Icy Operation (1)

Navigation and Ancillary Information Facility

- **A user may occasionally encounter an IDL math exception:**

```
% Program caused arithmetic error: Floating underflow
```

- **This warning occurs most often as a consequence of CSPICE math operations.**
- **In all known cases, the SIGFPE exceptions caused by CSPICE can be ignored. CSPICE assumes numeric underflow as zero.**
 - **A user can adjust IDL's response to math exceptions by setting the !EXCEPT variable:**
 - » **!EXCEPT = 0 suppresses the SIGFPE messages, and even more (e.g. a fatal error).**
 - » **!EXCEPT = 1, the default, reports math exceptions on return to the interactive prompt.**
 - **NAIF recommends this be used.**
 - » **!EXCEPT = 2 reports exceptions immediately after executing the command.**



Icy Operation (2)

Navigation and Ancillary Information Facility

- **A possible irritant exists in loading kernels using the `cspice_furnsh` function.**
 - **Kernels are loaded into your IDL session, not into your IDL scripts. This means:**
 - » loaded binary kernels remain accessible (“active”) throughout your IDL session
 - » data from loaded text kernels remain in the kernel pool (in the IDL memory space) throughout your IDL session
 - **Consequence: some kernel data may be available to one of your scripts even though not intended to be so.**
 - » You could get **incorrect results!**
 - » (If you run only one script during your IDL session, there’s no problem.)



Icy Operation (3)

Navigation and Ancillary Information Facility

– Mitigation: two approaches

- » **Load all needed SPICE kernels for your IDL session at the beginning of the session, paying careful attention to the files loaded and the loading order (loading order affects precedence)**
 - **Convince yourself that this approach will provide ALL of the scripts you will run during this IDL session with the appropriate SPICE data**
- » **At or near the end of every IDL script you write:**
 - **provide a call to `cspice_unload` for each kernel loaded using `cspice_furnsh`**
 - **provide a call to `cspice_kclear` to remove ALL kernel data from the kernel pool**



Icy Vectorization (1)

Navigation and Ancillary Information Facility

- **Several common icy functions include use of vectorized arguments, a capability not available in C or FORTRAN toolkits.**
 - **Note: IDL indexes arrays using a base value of zero as opposed to FORTRAN, which uses a base value of one.**
 - » **Example: access the first element of an IDL 1xN array using array[0], the second element using array[1], etc.**
- **Example: use icy to retrieve state vectors and light-time values for 1000 ephemeris times.**
 - **Create an array of 1000 ephemeris times with step size of 10 hours, starting from July 1, 2005.**

```
cspice_str2et, 'July 1, 2005', start  
et = dindgen( 1000 )*36000.d + start
```

continued on next page



Icy Vectorization (2)

Navigation and Ancillary Information Facility

- Retrieve the state vectors and corresponding light times from Mars to earth at each et , in the J2000 frame, using LT+S aberration correction:

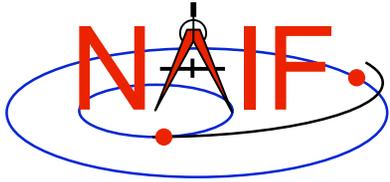
```
cspice_spkezr, 'Earth', et, 'J2000', 'LT+S', 'MARS', state, ltime
```

- Access the i th state 6-vector corresponding to the i th ephemeris time with the expression

```
state_i = state[*,i]
```

- Convert the ephemeris time vector et from the previous example to UTC calendar strings with three decimal places accuracy.

```
format = 'C'  
prec   = 3  
cspice_et2utc, et, format, prec, utcstr
```



Icy Vectorization (3)

Navigation and Ancillary Information Facility

- The call returns `utcstr`, an array of 1000 strings each *ith* string the calendar date corresponding to `et[i]`. Access the *ith* string of `utcstr` corresponding to the *ith* ephemeris time with the expression

```
utcstr_i = utcstr[i]
```

- Convert the position components of the N state vectors to latitudinal coordinates (the first three components of a state vector - IDL uses a zero based vector index).

```
cspice_reclat, state[0:2,*], radius, latitude, longitude
```

- The call returns three double precision variables of type **Array[1000] (vectorized scalars)**: `radius`, `latitude`, `longitude`.



Simple Use of Icy Functionality

Navigation and Ancillary Information Facility

- **As an example of Icy use with vectorization, calculate and plot the trajectory in the J2000 inertial frame of the Cassini spacecraft from June 20, 2004 to December 1, 2005.**

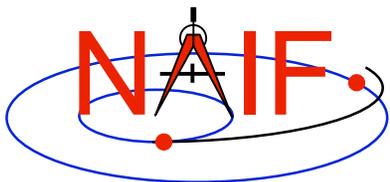
```
;; Define the number of divisions of the time interval and the time interval.
STEP = 10000
utc = [ 'Jun 20, 2004', 'Dec 1, 2005' ]

;; Load the needed kernels
cspice_furnsh, 'standard.tm'
cspice_furnsh, '/kernels/cassini/spk/T18-5TDJ5.bsp'

cspice_str2et, utc, et
times = dindgen(STEP)*(et[1]-et[0])/STEP + et[0]
cspice_spkpos, 'Cassini', times, 'J2000', 'NONE', 'SATURN BARYCENTER', pos, ltime

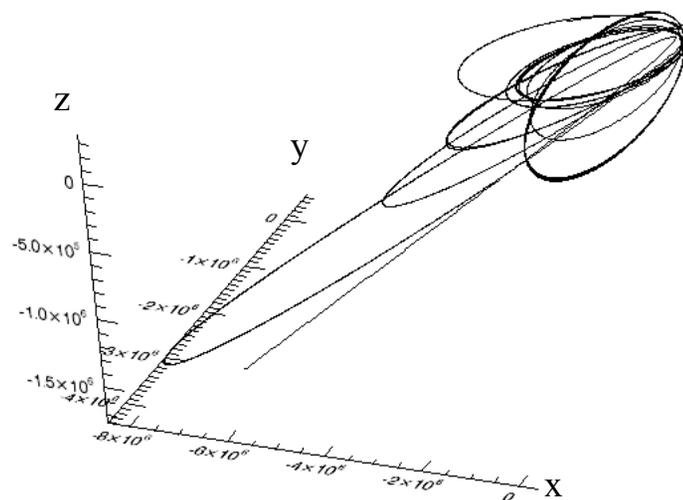
;; Plot the resulting trajectory.
x = pos[0,*]
y = pos[1,*]
z = pos[2,*]
iplot, x, y, z

cspice_kclear
```

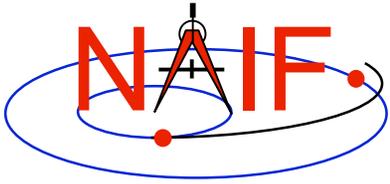


Graphic Output using IDL iTool

Navigation and Ancillary Information Facility



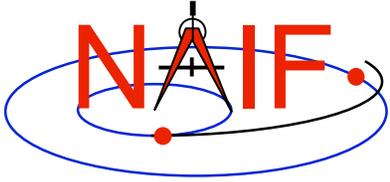
Trajectory of the Cassini vehicle in the J2000 frame, for June 20, 2004 to Dec 1, 2005



Navigation and Ancillary Information Facility

Using Module Headers

January 2009



Topics

Navigation and Ancillary Information Facility

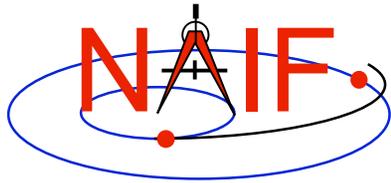
- **Module Header Purpose**
- **FORTRAN Module Header Locations**
- **C Module Header Locations**
- **Icy Module Header Locations**
- **Mice Module Header Locations**
- **Examine a Typical Header**



Module Header Purpose

Navigation and Ancillary Information Facility

- **NAIF uses source code module headers to provide SPICE users with detailed information describing a module's function and design.**
- **These headers are provided for all Toolkit modules, whether FORTRAN, C, IDL, or MATLAB Toolkits.**
 - All FORTRAN, C, and MATLAB source code files include a module header; Icy does not.
 - All Toolkit distributions include HTML versions of the module headers.
- **The next four charts provide the header locations.**
 - Using the HTML formats is usually the best approach.



Fortran Module Header Locations

Navigation and Ancillary Information Facility

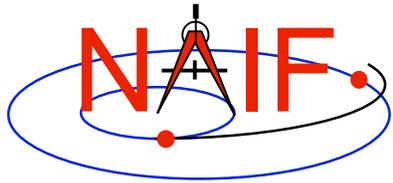
- In FORTRAN Toolkits, the headers are provided within the source code modules.
 - **<path to SPICELIB>/toolkit/src/spicelib/<name.f or <name>.for**
 - In most cases there is a single “header” at the top of the source code. For cases where a FORTRAN module has multiple entry points, there are additional “headers” at each entry point. For example:
 - » “keeper.f” has entries for:
 - FURNISH, KTOTAL, KINFO, KDATA, KCLEAR, and UNLOAD
- HTML versions of the headers are also available:
 - **<path to SPICELIB>/toolkit/doc/html/spicelib/index.html**



C Module Header Locations

Navigation and Ancillary Information Facility

- In C Toolkits, the headers are provided within the source code modules.
 - [<path to CSPICE>/cspice/src/cspice/<name>_c.c](#)
- HTML versions of the headers are also available
 - [<path to CSPICE>/cspice/doc/html/cspice/index.html](#)



Icy Module Header Locations

Navigation and Ancillary Information Facility

- **In IDL (“Icy”) toolkits, two sets of headers are provided.**
 - Icy headers in HTML format:
 - » `<path to icy>/icy/doc/html/icy/index.html`
 - CSPICE headers, in text and HTML formats:
 - » `<path to icy>/icy/src/cspice/<name>_c.c`
 - » `<path to icy>/icy/doc/html/cspice/index.html`
- **The information provided in an “Icy” wrapper is minimal in some cases; the corresponding CSPICE wrapper provides more detail.**
 - A link to the corresponding CSPICE wrapper is provided in the Icy wrapper.

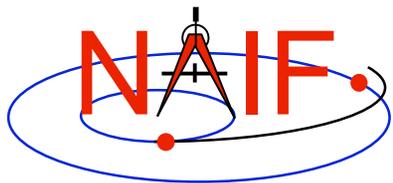


Mice Module Header Locations

Navigation and Ancillary Information Facility

- In Matlab (“Mice”) toolkits, two sets of headers are provided.
 - Mice headers in HTML format:
 - » `<path to Mice>/mice/doc/html/mice/index.html`
 - » The user can also access the information presented in the HTML document via the Matlab `help` command, e.g.

```
>> help cspice_str2et
```
 - CSPICE headers, in text and HTML formats:
 - » `<path to Mice>/mice/src/cspice/<name>_c.c`
 - » `<path to Mice>/mice/doc/html/cspice/index.html`
- The information provided in a “Mice” wrapper is minimal in some cases; the corresponding CSPICE wrapper provides more detail.
 - A link to the corresponding CSPICE wrapper is provided in the Mice wrapper.

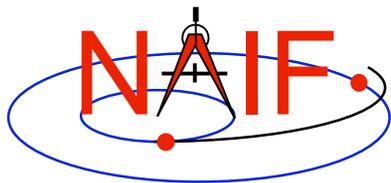


Examine a Typical Header

Navigation and Ancillary Information Facility

- As example, look for and examine one of these headers:

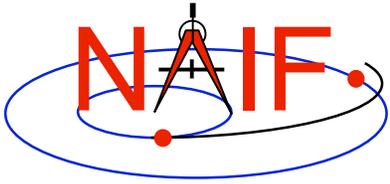
| <u>FORTRAN</u> | <u>C</u> | <u>IDL (lcy)</u> | <u>MATLAB (Mice)</u> |
|----------------|----------|------------------|----------------------|
| SPKEZR | spkezt_c | cspice_spkezt | cspice_spkezt |
| STR2ET | str2et_c | cspice_str2et | cspice_str2et |



Navigation and Ancillary Information Facility

Time Conversion and Time Formats

January 2009



Topics

Navigation and Ancillary Information Facility

- **Time Systems and Kernels**
- **Converting Time Strings**
 - **Calendar, Day-of-Year (DOY) and Julian Date strings to Ephemeris Time**
 - **Spacecraft Clock string to Ephemeris Time**
 - **Spacecraft Clock string to Encoded Spacecraft Clock (aka “Ticks”)**
- **Converting Numeric Times - 1**
 - **Ephemeris Time to Calendar, DOY and Julian Date strings**
- **Use of Format Picture**
- **Converting Numeric Times - 2**
 - **Ephemeris Time to Spacecraft Clock String**
 - **Encoded Spacecraft Clock to Spacecraft Clock String**
 - **Ephemeris Time to Local Solar Time String**
- **Conversions Between Uniform Time Systems**
- **Customizing the Time System**
- **Pictorial Layout of the Time System**



Time Systems and Kernels

Navigation and Ancillary Information Facility

- **Three time systems are commonly used in SPICE for inputs and outputs in SPICE application programs:**
 - Coordinated Universal Time (UTC)
 - Spacecraft Clock (SCLK)
 - Ephemeris Time (ET, also referred to as Barycentric Dynamical Time, TDB)
- **Two time systems are commonly used in SPICE for kernel data look-ups or for computations**
 - Ephemeris Time (ET, TDB)
 - » Used in SPK, frames, PCK
 - » Used in high-level geometry interfaces
 - Encoded Spacecraft Clock (Ticks)
 - » Used in the intermediate level CK interfaces
- **The SPICE Leapseconds Kernel and Spacecraft Clock Kernel capture the relationships between**
 - UTC and ET (Leapseconds Kernel)
 - UTC or ET and SCLK (SCLK Kernel)
 - **Caution: the long-term future relationships between these systems cannot be accurately predicted**



Converting Time Strings

Navigation and Ancillary Information Facility

Examples for FORTRAN, C, IDL and MATLAB are shown on this page only.
Examples on subsequent pages are shown only in FORTRAN.

- **UTC, TDB, or TDT (TT) String to Ephemeris Time**

- STR2ET (*string*, ET)
- str2et_c (*string*, &et)
- cspice_str2et, *string*, et
- et = cspice_str2et (*string*)

Converts any string in a format recognized by SPICE, excepting SCLK

Requires Leapseconds Kernel (LSK)

- **Spacecraft Clock String to Ephemeris Time**

- SCS2E (*scid*, *string*, ET)
- scs2e_c (*scid*, *string*, &et)
- cspice_scs2e, *scid*, *string*, et
- et = cspice_scs2e (*scid*, *string*)

Requires Spacecraft Clock Kernel (SCLK)

Normally requires Leapseconds Kernel (LSK) as well, to handle a very small (~2 msec.) difference between TDB and TT

- **Spacecraft Clock String to Encoded Spacecraft Clock (used in the mid-level interfaces of the C-kernel system)**

- SCENCD (*scid*, *string*, SCLKDP)
- scncd_c (*scid*, *string*, &sclkdp)
- cspice_scncd, *scid*, *string*, sclkdp
- sclkdp = cspice_scncd (*scid*, *string*)

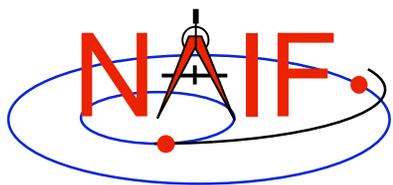
Requires Spacecraft Clock Kernel (SCLK)



Converting Numeric Times - 1

Navigation and Ancillary Information Facility

- **Ephemeris Time to Calendar, DOY or Julian Date String**
 - **TIMOUT** (*et*, *fmtpic*, **STRING**)
 - » The input *fmtpic* is a specification giving the user great flexibility in setting the appearance of the output time string, and the time system used (UTC, TDB, TDT).
 - YYYY Mon DD, HR:MN:SC.### ::UTC
 - 1999 Jan 12, 23:28:28.289
 - YYYY Mon DD, AP:MN:SC.### ampm ::UTC-8 (PST)
 - 1999 Jan 12, 03:28:28.289 p.m. (PST)
 - See the header for the TIMOUT module
 - The module TPICTR may be useful in constructing a format picture specification from a sample string
 - » **Requires Leapseconds Kernel**
 - **ET2UTC** (*et*, *format*, *prec*, **UTCSTR**)
 - » The *format* input specifies calendar, DOY, or Julian Date format for **UTCSTR**
 - » **Requires Leapseconds Kernel**
 - » **Note: TIMOUT is a more capable routine**
 - **ETCAL** (*et*, **STRING**)
 - » **STRING**, fixed format ephemeris calendar time string
 - » **No Leapseconds Kernel is required.**

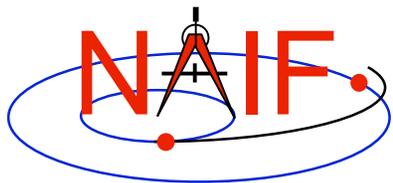


Use of Format Picture

Navigation and Ancillary Information Facility

Example Time Strings and the Corresponding Format Pictures

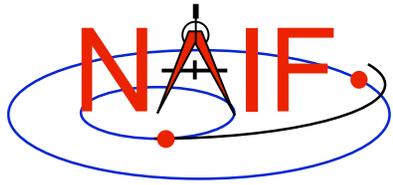
| Time String | Format Picture Used (<i>fmtpic</i>) |
|--------------------------------|---------------------------------------|
| 1999-283T12:28:29 (UTC) | YYYY-DOYTHR:MN:SC (UTC) |
| 1999-283T12:29:33 (TDB) | YYYY-DOYTHR:MN:SC (TDB) ::TDB |
| Wed Nov 03, 19:29:05 1999 | Wkd Mon DD, HR:MN:SC YYYY |
| 465 B.C. Jan 12 03:15:23 p.m. | YYYY ERA Mon DD AP:MN:SC ampm |
| 1987-11-03T04:29:58 | YYYY-MM-DDTHR:MN:SC |
| 04:28:55 A.M. June 12, 1982 | AP:MN:SC AMPM Month DD, YYYY |
| Thursday November 04, 1999 | Weekday Month DD, YYYY |
| DEC 31, 15:59:60.12 1998 (PST) | MON DD, HR:MN:SC YYYY (PST)::UTC-8 |
| 2450297.1994 JDUTC | JULIAND.#### JDUTC |



Converting Numeric Times - 2

Navigation and Ancillary Information Facility

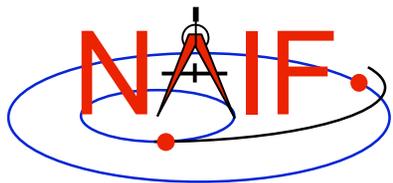
- **Ephemeris Time to Spacecraft Clock String**
 - SCE2S (*scid*, *et*, SCLKCH)
 - » Requires both LSK and SCLK
- **Encoded Spacecraft Clock to Spacecraft Clock String**
 - SCDECD (*scid*, *sclkdp*, SCLKCH)
 - » Requires SCLK
 - » SCLK string examples:
 - 1/1487147147.203 (Cassini, MGS)
 - 1/05812:00:001 (Voyager 1 and 2)
 - When literal clock strings are used as arguments in modules they must be contained in quotes:
 - Single quotes for Fortran, IDL, Matlab
 - Double quotes for C
- **Ephemeris Time to Local Solar Time String**
 - ET2LST(*et*, *body*, *long*, *type*, HR, MN, SC, TIME, AMPM)
 - » Requires SPK, PCK



Conversion Between Uniform Time Systems

Navigation and Ancillary Information Facility

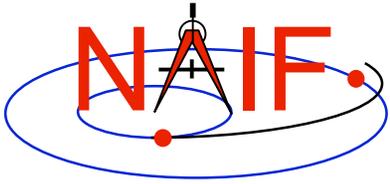
- **Conversion between numeric representations of TAI, TDB(ET), TDT, JDTDB(JED), JDTDT**
 - **Return value** = UNITIM (*epoch*, *insys*, *outsys*)



Customizing the Time System

Navigation and Ancillary Information Facility

- **Defaults**
 - Two digit year (a bad idea but supported):1969-2068
 - Time System: UTC
 - Calendar: Gregorian
- **Adjustments**
 - The one hundred year interval to which two digit years belong may be set. For example 1980-2079
 - Time Systems: UTC, TDB, TT (Terrestrial Time)
 - Calendar: Gregorian, Julian, or Mixed.
- **See the TIMDEF module header and *Time Required Reading* (time.req) for details**



Navigation and Ancillary Information Facility

Leapseconds and Spacecraft Clock Kernels

LSK and SCLK

January 2009

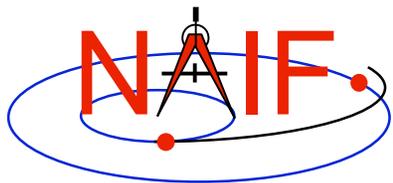


SPICE Time Conversion Kernels

Navigation and Ancillary Information Facility

In most cases one or two kernel files are needed to perform conversions between supported time systems.

- **LSK - The leapseconds kernel is used in conversions between ephemeris time (ET/TDB) and Coordinated Universal Time (UTC).**
- **SCLK - The spacecraft clock kernel is used in conversions between spacecraft clock time (SCLK) and ephemeris time (ET/TDB).**
 - (It's possible there could be two or more clocks associated with a given spacecraft.)

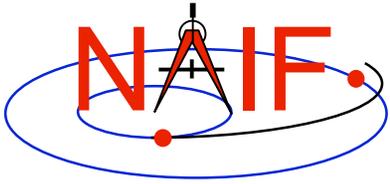


The Leapseconds Kernel (LSK)

Navigation and Ancillary Information Facility

The leapseconds kernel contains a tabulation of all the leapseconds that have occurred, plus additional terms.

- **Used in $ET \leftrightarrow UTC$ and in $ET \leftrightarrow SCLK$ conversions.**
 - Utility programs using LSK: *spkmerge*, *chronos*, *spacit*, etc.
 - Subroutines using LSK: `STR2ET`, `TIMOUT`, `ET2UTC`, etc.
- **As with all SPICE kernels, load it using FURNSH.**
- **NAIF updates the LSK when a new leapsecond is announced by the International Earth Rotation Service (IERS).**
 - The latest LSK file is always available from the NAIF server.
 - » The latest is always the best one to use.
 - Announcement of each new LSK is made using the “spice_announce” system.
 - » http://naif.jpl.nasa.gov/mailman/listinfo/spice_announce



Out of Date LSKs

Navigation and Ancillary Information Facility

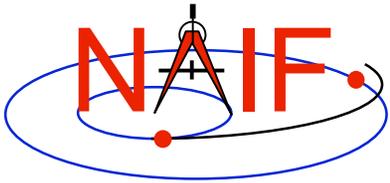
- **An out-of-date leapseconds kernel can be used successfully for conversions that occur at epochs **prior** to the epoch of the first missing leapsecond.**
 - But any conversions of epochs occurring after the epoch of a missing leapsecond will introduce inaccuracies in multiples of one second per missed leapsecond.
- **Using the latest leapseconds kernel to perform conversions at epochs more than six months ahead of the last leapsecond listed may result in an error if, later on, a new leapsecond is declared for a time prior to the epochs you processed.**



The Spacecraft Clock Kernel (SCLK)

Navigation and Ancillary Information Facility

- **The spacecraft clock kernel contains data to perform conversions from SCLK to other time systems.**
- **It is required by Toolkit utilities and routines that utilize SCLK time.**
 - For example, the SPICE CK subsystem makes heavy use of spacecraft clock time.
- **As with all SPICE kernels, use FURNSH to load it.**
- **Ensure you have the correct version of the SCLK file for your spacecraft since this kernel may be updated rather frequently.**
 - SCLK files are usually maintained on a flight project's database.
 - » For JPL operated missions they can always be found on the NAIF server as well.
 - When using a CK, “correct SCLK” means compatible with that CK.
 - » For reconstructed CKs, this is most likely the latest version of the SCLK.
 - » For “predict” CKs, this is probably the SCLK kernel used when the CK was produced.



SCLK File Example

Navigation and Ancillary Information Facility

`\begindata`

```

SCLK_KERNEL_ID          = ( @1999-08-02/10:53:19.72 )
SCLK_DATA_TYPE_82      = ( 1 ) ← Clock Type
SCLK01_TIME_SYSTEM_82  = ( 2 ) ← Time system ID:
                           1 --> TDB, Barycentric Dynamical Time
                           2 --> TDT, Terrestrial Dynamic Time
SCLK01_N_FIELDS_82     = ( 2 )
SCLK01_MODULI_82       = ( 4294967296 256 )
SCLK01_OFFSETS_82     = ( 0 0 )
SCLK01_OUTPUT_DELIM_82 = ( 1 )
SCLK_PARTITION_START_82 = ( 1.7772134886400E+11 ) ← Encoded clock readings at
SCLK_PARTITION_END_82  = ( 1.0995116277750E+12 ) ← partition start and stop.
SCLK01_COEFFICIENTS_82 = (

```

```

0.000000000000000E+00  -6.3119514881600E+08  1.0001400000000E+00
1.2098765056000E+10   -5.8393434781600E+08  1.0000900000000E+00
2.0171981312000E+10   -5.5239834681600E+08  1.0001200000000E+00
2.8245197568000E+10   -5.2086234581600E+08  1.0001100000000E+00
4.4413748224000E+10   -4.5770394481600E+08  1.0000800000000E+00

```

```

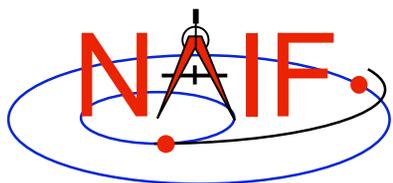
)
SCLK value
TDT or TDB value
corresponding to
SCLK value
Clock Rate
(seconds per most
significant component)
\begintext
```



Forms of SCLK Time Within SPICE

Navigation and Ancillary Information Facility

- **SCLK time in SPICE is represented in two different ways:**
 - a character string
 - a double precision (DP) number called “ticks”
- **A SCLK character string is composed of one or more cascading integer numbers – similar to a digital clock.**
 - This form is what is generally found in downlinked telemetry, whether for science or engineering/housekeeping data.
- **A SCLK value encoded as a double precision (DP) number (called “ticks”) is used within SPICE because it’s easy to convert this to other time systems, such as ephemeris time (ET).**



Sample SCLK String - 1

Navigation and Ancillary Information Facility

The Cassini orbiter SCLK time **string** consists of three fields separated by delimiters.

Partition
Delimiter

1 / 4132564 . 034

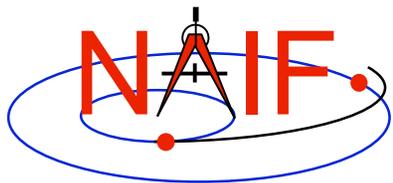
Clock Field Delimiter*
(**not** a decimal point)

Partition: Accounts for
clock resets or counter
roll-over.

Least Significant Clock Field:
Ranges from 0 to 255. Nominally
1/256th of a second increment.

Most Significant Clock Field:
Ranges from 0 to 4294967295 ($2^{32}-1$). Nominally
1 second increment.

* Several SCLK delimiter characters are available in SPICE. See "SCLK Required Reading" for details.



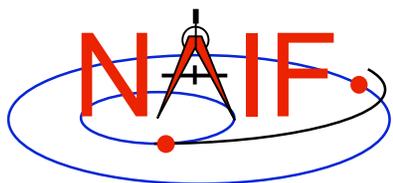
What is a Partition?

Navigation and Ancillary Information Facility

1/4132564 . 034

The portion of the SCLK string circled above indicates the partition to which the remaining portion of the string is related.

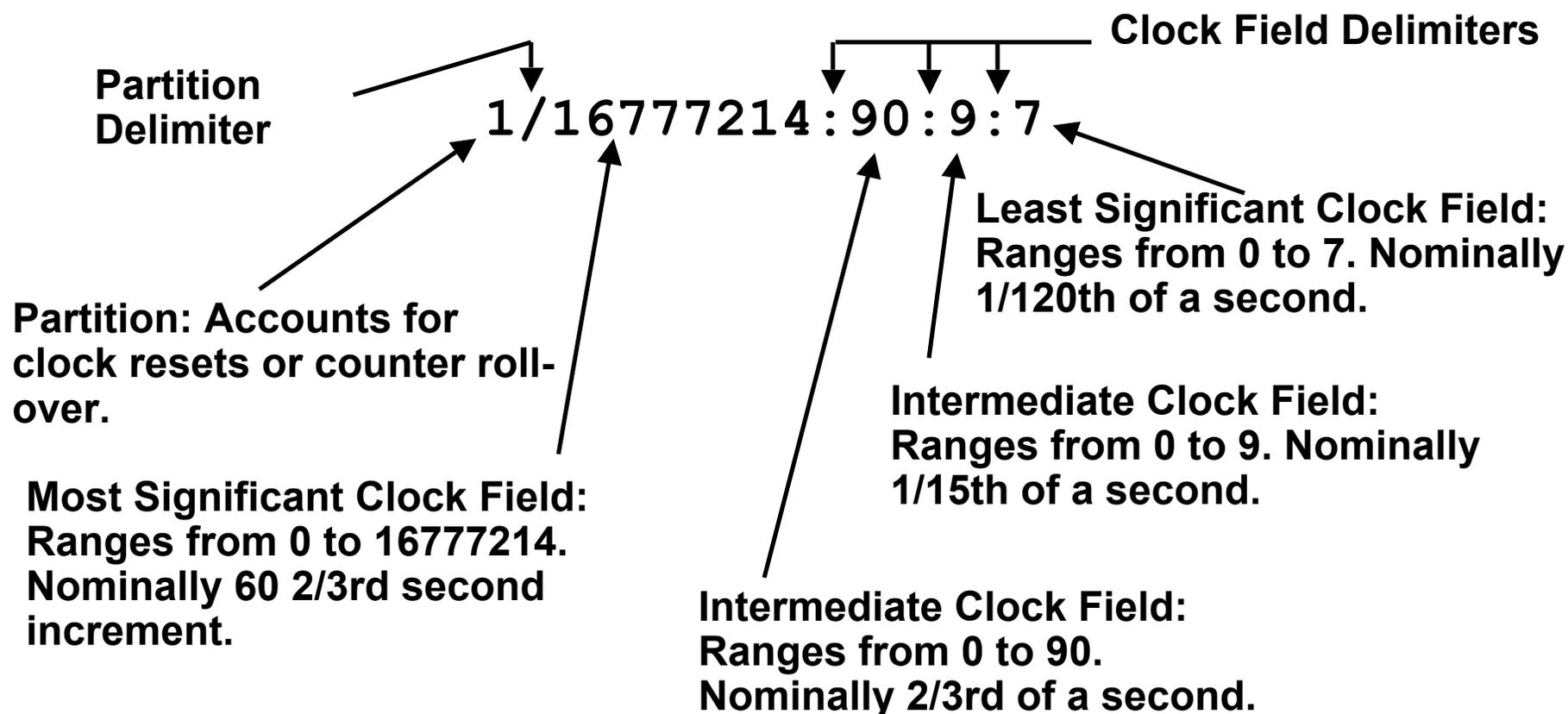
- **A partition is a NAIF-created construct to handle spacecraft clock rollovers or resets.**
- **When referring to epochs in the first partition, the leading '1/' may be omitted.**
- **Modern spacecraft rarely use a partition other than 1/.**

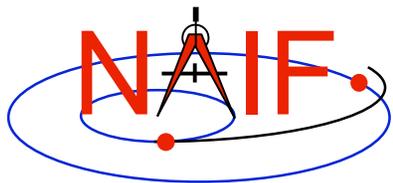


Sample SCLK String - 2

Navigation and Ancillary Information Facility

The Galileo spacecraft SCLK time **string** consists of five fields separated by delimiters.





Sample SCLK Strings - 3

Navigation and Ancillary Information Facility

The following are examples of SCLK strings* from missions using SPICE.

- **Cassini**
1/1334314108.134
- **DS1**
1/67532406.010
- **Galileo**
1/16777214:90:9:7
- **Genesis**
1/666230496.204
- **MGS**
1/655931592.103
- **MPF**
1/559627908.058
- **Mariner 9**
1/11542909
- **Mars Odyssey**
1/687231994.091
- **NEAR**
1/40409721942
- **Stardust**
1/697451990.042
- **Viking 1&2**
1/32233616
- **Voyager 1&2**
1/05812:00:001
- **Mars Express**
1/0090979196.29713
- **Venus Express**
1/0033264000.50826
- **Rosetta**
1/0101519975.65186

- * When clock strings are used as arguments in modules they must be contained in quotes:
- Single quotes for Fortran
 - Double quotes for C
 - Single quotes for IDL and MATLAB



Encoded SCLK (Ticks)

Navigation and Ancillary Information Facility

The representation of SCLK time in the SPICE system is a double precision encoding of a SCLK string.

- **Encoded spacecraft clock values represent “ticks since spacecraft clock start.”**
 - The time corresponding to tick “0” is mission dependent and does not necessarily relate to launch time. In fact it is often an arbitrary epoch occurring before launch.
- **A tick is the smallest increment of time that a spacecraft clock measures. For example, in the case of the Cassini orbiter this is nominally 1/256th of a second.**
- **Encoded SCLK increases continuously independent of leapseconds, clock resets, and counter rollovers.**



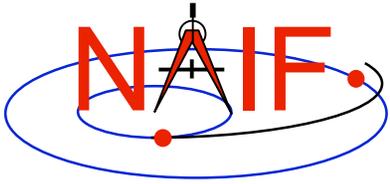
SCLK Interface Routines

Navigation and Ancillary Information Facility

Convert SCLK times using the following routines

| | |
|--|-------------------------------------|
| SCS2E (SC, SCLKCH, ET) | (SCLK String⇒ET) |
| SCE2S (SC, ET, SCLKCH) | (ET⇒SCLK String) |
| SCT2E (SC, SCLKDP, ET) | (Encoded SCLK⇒ET) |
| SCE2C ¹ (SC, ET, SCLKDP) | (ET⇒Continuous Encoded SCLK) |
| SCE2T (SC, ET, SCLKDP) | (ET⇒Discrete Encoded SCLK) |
| SCENC D (SC, SCLKCH, SCLKDP) | (Encode SCLK) |
| SCDEC D (SC, SCLKDP, SCLKCH) | (Decode SCLK) |

¹ Use SCE2C (not SCE2T) for C-kernel data access.

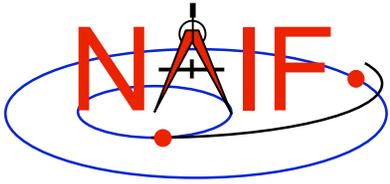


Navigation and Ancillary Information Facility

Introduction to the SPICE Ephemeris Subsystem SPK

**Focused on
reading SPK files**

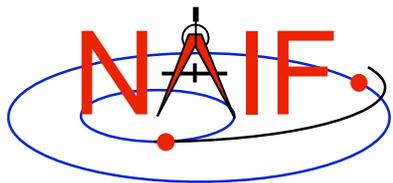
January 2009



SPICE Ephemeris Data

Navigation and Ancillary Information Facility

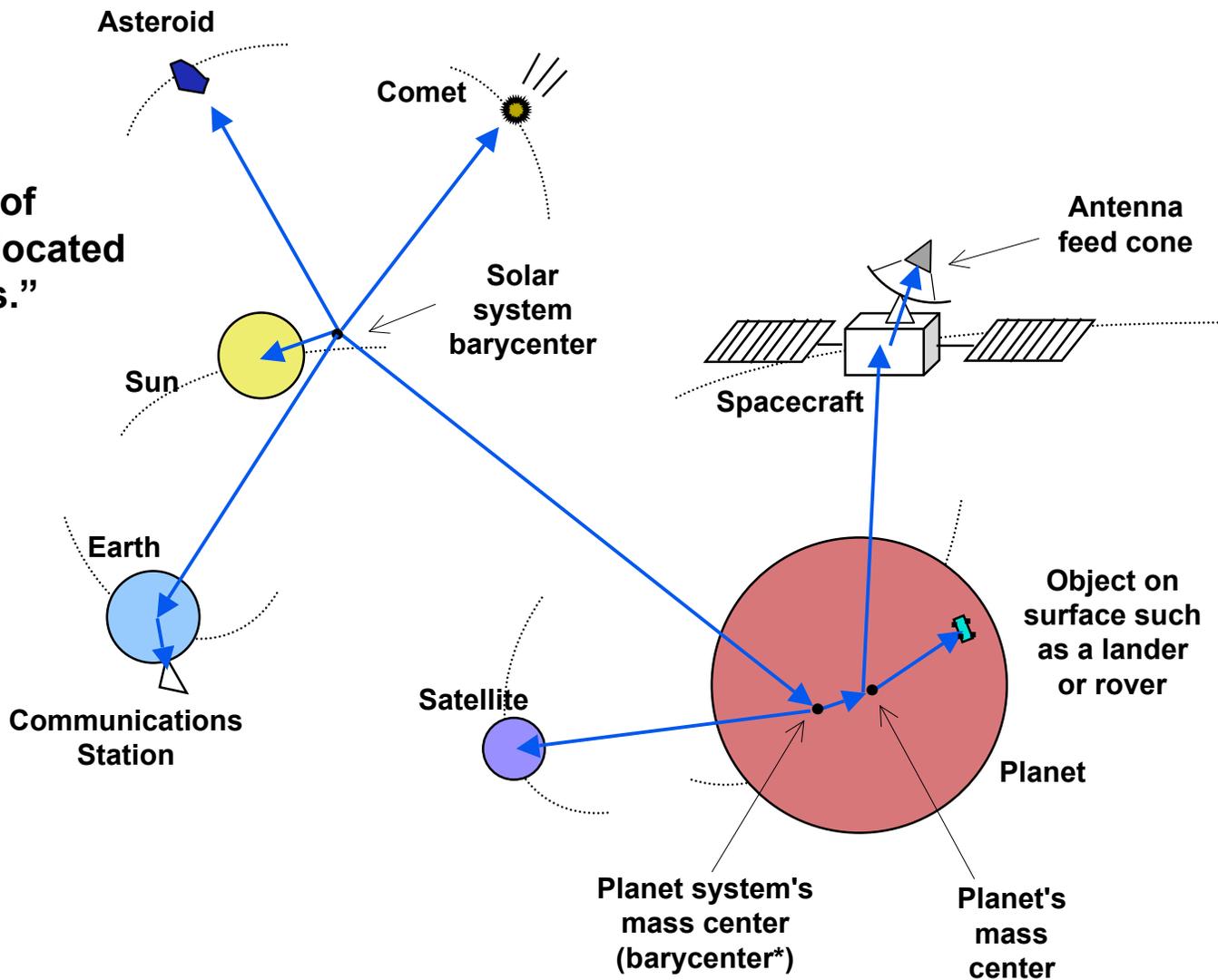
- **An SPK file contains ephemeris (trajectory) data for "ephemeris objects."**
- **Spacecraft, planets, satellites, comets and asteroids are the obvious kinds of "ephemeris objects," but many other possibilities exist, such as:**
 - a rover on the surface of a body
 - a camera on top of a mast on a lander
 - a transmitter cone on a spacecraft
 - a deep space communications antenna on the earth
 - the center of mass of a planet/satellite system (planet barycenter)
 - the center of mass of our solar system (solar system barycenter)
- **See the next page for a pictorial representation of some of these objects.**



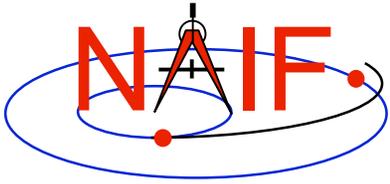
Examples of Ephemeris Objects

Navigation and Ancillary Information Facility

The head and the tail of every blue arrow are located at "ephemeris objects."



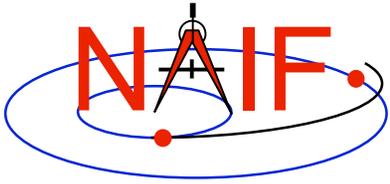
*A barycenter is the center of mass of a set of bodies, such as Saturn plus all of Saturn's satellites.



Inside an SPK: Bodies and Centers of Motion

Navigation and Ancillary Information Facility

- **Inside an SPK file ephemeris objects come in pairs: a “body” and a “center of motion.”**
 - The ephemeris is given for the body moving relative to the center of motion.
 - » For the position component, the vector points **TO** the body **FROM** the center of motion.
 - There can be, and often are, multiple such pairs within an SPK file.



Reading an SPK: Observers and Targets

Navigation and Ancillary Information Facility

- When you read an SPK file you specify which ephemeris object is the “target” and which is the “observer.”
- The SPK system returns the state of the target relative to the observer.
 - The **position** data point from the “observer” to the “target.”
 - The **velocity** is of the “target” relative to the “observer.”



Caution: state (observer, target) \neq - state (target, observer)
unless the state is geometric (no aberration corrections).



SPK File Coverage

Navigation and Ancillary Information Facility

- **We call the time period over which an SPK file provides data for an ephemeris object the “coverage” or “time coverage” for that object.**
 - An SPK file’s coverage for an object consists of one or more time intervals.
 - Often the coverage for all objects in an SPK file is a single, common time interval.
 - » Example: a planetary SPK file such as de421.bsp
 - » Counterexample: Cassini tour SPK with merged Huygens probe ephemeris
- **For any request time within any time interval comprising the coverage for an object, the SPK system can return a vector representing the state of that body relative to its center of motion.**
 - The SPK system will automatically interpolate ephemeris data to produce a state vector at the request time.
 - To a user application, the ephemeris data appear to be **continuous** over each time interval, even if the data stored inside the SPK file are discrete.



Reference Frames as Used in Both Writing and Reading SPKs

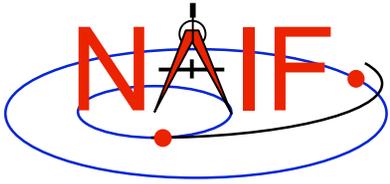
Navigation and Ancillary Information Facility

On Writing

- **All ephemeris data in an SPK file have an associated reference frame**
 - There could be multiple such frames, each for a different chunk of data called a segment
 - To be useful, this/these frames must be “known” to the program that wants to use the ephemeris data

On Reading

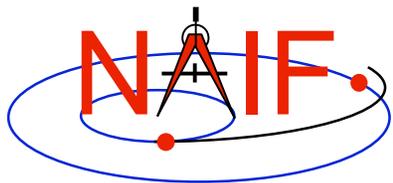
- **The application “reading” an SPK file(s) must specify relative to what reference frame the output state or position vectors are to be given**
 - This frame must be “known” to the SPICE-based program
- **“Known” means either a built-in frame (“hard coded”) or one fully specified at run-time**
 - The user’s program may need to have access to additional SPICE data in order to construct any of these frames



Navigation and Ancillary Information Facility

Using SPK Files

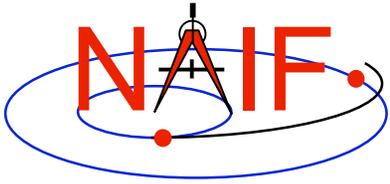
A Brief Introduction



Retrieving Position or State Vectors

Navigation and Ancillary Information Facility

- **To retrieve position or state vectors of ephemeris objects from an SPK file one normally needs two kinds of SPICE kernels**
 - Ephemeris kernel(s) (SPK)
 - » Sometimes just one is needed
 - » Sometimes two or more are needed to chain together the "target" and "observer" you have selected
 - Leapseconds kernel (LSK)
 - » Used to convert between Coordinated Universal Time (UTC) and Ephemeris Time (ET)
 - » Usually needed since most people work with UTC time
- **Retrieving ephemeris data from an SPK file is usually called “reading” the file**
 - This term is not very accurate since the SPK “reader” software also performs interpolation, and may chain together data from multiple sources and/or perform aberration corrections
- **State and position vectors retrieved from an SPK file by the SPK “reader” routines are of the form:**
 - X, Y, Z, dX, dY, dZ for a state vector
 - X, Y, Z for a position vector



Retrieving a State Vector

Navigation and Ancillary Information Facility

Initialization...typically done **once** per program execution

Tell your program which SPICE files to use (“loading” files)

```
CALL FURNISH ('spk_file_name')  
CALL FURNISH ('leapseconds_file_name')
```

} Better yet, replace these two calls with a single call to a “furnsh kernel” containing the names of all kernel files to load.

Loop... do as many times as you need to

Convert UTC time to ephemeris time (TDB), if needed

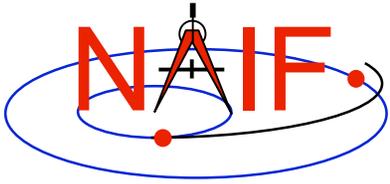
```
CALL STR2ET ('utc_string', tdb)
```

Retrieve state vector from the SPK file at your requested time

```
CALL SPKEZR (target, tdb, 'frame', 'correction', observer, state, light time)
```



Now use the returned state vector in other SPICE routines to compute observation geometry of interest.



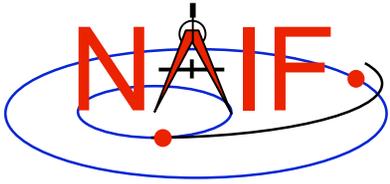
Arguments of SPKEZR - 1

Navigation and Ancillary Information Facility

INPUTS

- **TARGET*** and **OBSERVER***: Character names or NAIF IDs for the end point and origin of the state vector (Cartesian position and velocity vectors) to be returned.
 - The position component of the requested state vector points from observer to target.
- **TDB**: The time at the observer at which the state vector is to be computed. The time system used is Ephemeris Time (ET), now generally called Barycentric Dynamical Time (TDB).
- **FRAME**: The SPICE name for the reference frame in which your output state vector is to be given. SPK software will automatically convert data to the frame you specify (if needed). SPICE must know the named frame. If it is not a built-in frame SPICE must have sufficient data at run time to construct it.

* Character names work for the target and observer inputs only if built into SPICE or if registered using the SPICE ID-body name mapping facility. Otherwise use the SPICE numeric ID in quotes, as a character string.



Arguments of SPKEZR - 2

Navigation and Ancillary Information Facility

- **CORRECTION:** Specification of what kind of aberration correction(s), if any, to apply in computing the output state vector.
 - Use 'LT+S' to obtain the apparent state of the target as seen by the observer. 'LT+S' invokes light time and stellar aberration corrections.
 - Use 'NONE' to obtain the uncorrected (aka “geometric”) state, as given by the source SPK file or files.

See the header for subroutine SPKEZR, the document SPK Required Reading, or the “Fundamental Concepts” tutorial for details. See the backup charts for examples of aberration correction magnitudes.

OUTPUTS

- **STATE:** This is the Cartesian state vector you requested. Contains 6 components: three for position (x,y,z) and three for velocity (dx, dy, dz) of the target with respect to the observer. The position component of the state vector points from the *observer* to the *target*.
- **LIGHT TIME:** The one-way light time between the (optionally aberration-corrected) position of target and the geometric position of the observer at the specified epoch.



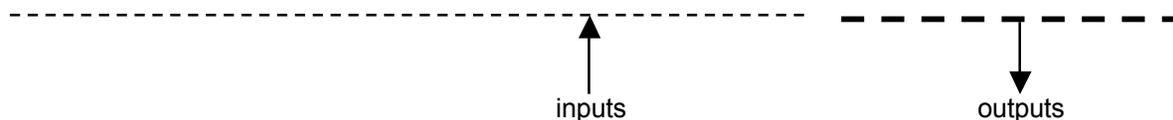
Retrieving a Position Vector

Navigation and Ancillary Information Facility

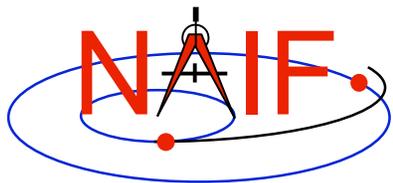
- **The SPICE routine SPKPOS is the position-only analog of SPKEZR**
 - The arguments of SPKPOS are identical to those of SPKEZR, except that SPKPOS returns a 3-component position vector instead of a 6-component state vector
- **When velocity data are not needed, using SPKPOS offers several advantages over using SPKEZR**
 - SPKPOS executes more quickly than SPKEZR when stellar aberration corrections are used
 - SPKPOS can be used when reference frame transformations of velocity are not possible due to absence of C-kernel angular velocity data

Retrieve a position vector from the SPK file at your requested time

CALL SPKPOS (target, tdb, 'frame', 'correction', observer, *positn*, *light time*)



Use the returned position vector in other SPICE routines



A Simple Example of Retrieving State Vectors

Navigation and Ancillary Information Facility

Initialization - typically do this just **once** per program execution

```
CALL FURNISH ( 'NAIF0009.TLS' )  
CALL FURNISH ( 'HUYGENS_3_MERGE.BSP' )
```

} Better to use a “furnsh kernel” instead of these individual FURNISH statements

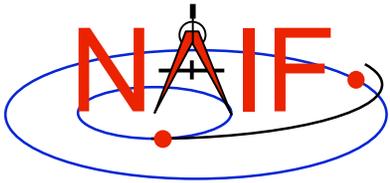
Repeat in a loop if/as needed to solve your particular problem

```
CALL STR2ET ( '2004 NOV 21 02:40:21.3' , TDB )  
CALL SPKEZR ( 'TITAN' , TDB , 'J2000' , 'LT+S' , 'HUYGENS PROBE' ,  
             STATE , LT )
```

(Insert additional code here to make derived computations such as spacecraft sub-latitude and longitude, lighting angles, etc. Use more SPICE subroutines to help.)

In this example we get the state (STATE) of Titan as seen from the Huygens probe at the UTC epoch 2004 NOV 21 02:40:21.3. The state vector is returned in the J2000 inertial reference frame and has been corrected for both light time and stellar aberration (LT+S). The one-way light time (LT) is also returned.

A SPICE leapseconds file (NAIF0009.TLS) is used, as is a SPICE ephemeris file (HUYGENS_3_MERGE.BSP) containing ephemeris data for the Huygens probe (-150), Saturn barycenter (6), Saturn mass center (699), Saturn's satellites (6xx) and the sun (10), relative to the solar system barycenter.



A Slightly More Complex Example - 1 Kernel Data Needed

Navigation and Ancillary Information Facility

- To get state vectors referenced to a non-inertial reference frame, or when the data within the SPK file are provided in a non-inertial frame, typically more kernels will be needed.
 - To get the state of an object relative to a planet in the planet's **IAU body-fixed reference frame** you'll need:
 - » Pck file containing orientation data for the planet
 - » SPK(s) for the object, planet, and (typically) planet barycenter
 - » LSK
 - To get the state of an object in a **spacecraft-fixed reference frame** you'll need:
 - » FK, CK and SCLK for the spacecraft
 - » SPK(s) for the spacecraft and object
 - » LSK



A Slightly More Complex Example - 2 Retrieving State Vectors

Navigation and Ancillary Information Facility

Obtaining a state vector in a body-fixed reference frame

Initialization...typically **once** per program execution

Tell your program which SPICE files to use (“loading” files)

```
CALL FURNISH ('spk_file_name')  
CALL FURNISH ('leapseconds_file_name')  
CALL FURNISH ('pck_file_name')
```

} Better to use a “furnsh kernel”
instead of these three
individual FURNISH
statements

Loop... do as many times as you need

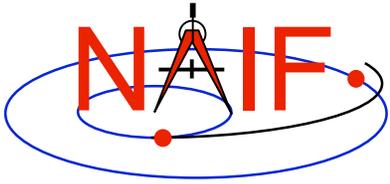
Convert UTC time to ephemeris time (TDB), if needed

```
CALL STR2ET ('utc_string', tdb)
```

Get state vector from SPK file at requested time, in planet’s IAU body-fixed frame

```
CALL SPKEZR (target, tdb, 'IAU_<body_name>', 'correction',  
observer, state, lighttime)
```

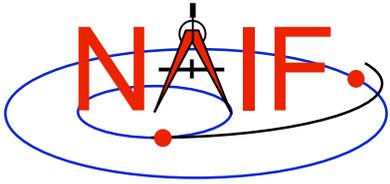
(Insert additional code here to make derived computations such as spacecraft sub-latitude and longitude, lighting angles, etc. Use more SPICE subroutines to help.)



Chaining Data

Navigation and Ancillary Information Facility

- **If needed, the SPK software will automatically chain together two or more state vectors needed to connect your "target" to your "observer." (See next chart.)**
- **SPK software can chain together state vectors provided by a single SPK file, or by multiple SPK files.**
- **In doing the chaining, if needed the SPK software will also transform the various state vectors into a common reference frame for addition or subtraction, then transform the result to the reference frame you have selected for output.**
 - **Your selected output reference frame must be one known to the SPICE system, and your application program must have available all needed SPICE data to construct this reference frame.**
- **See the chaining example on the next page.**



Example of Chaining

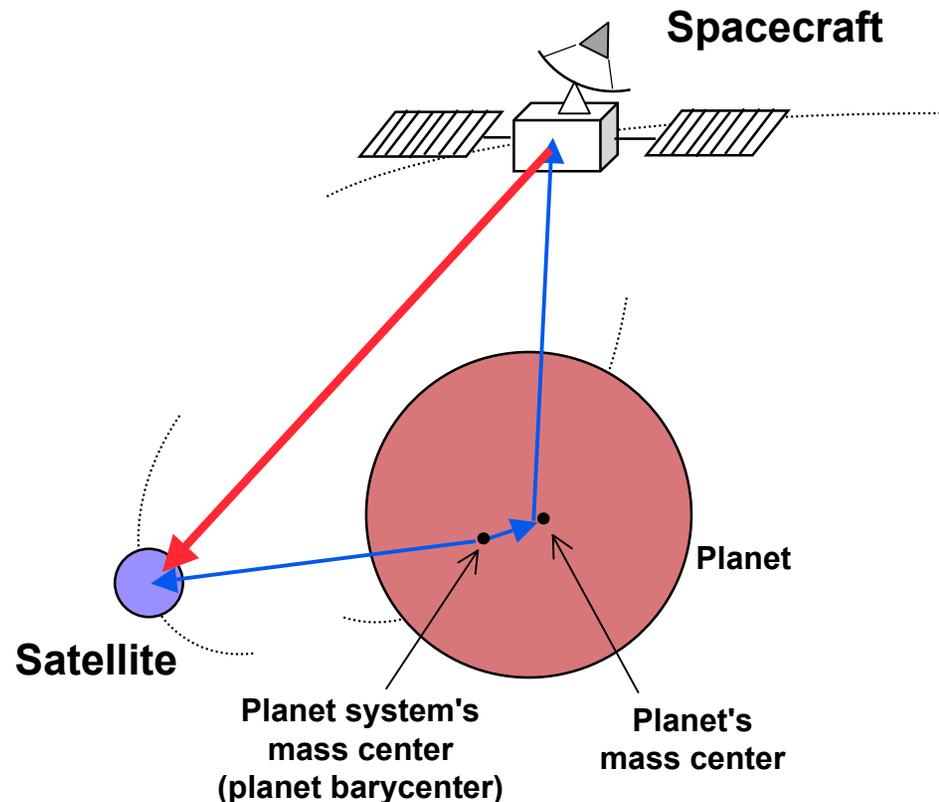
Navigation and Ancillary Information Facility

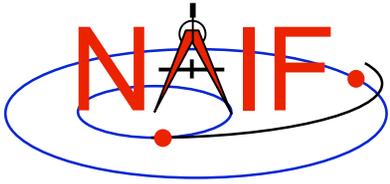
Suppose you ask for the position of the satellite relative to the spacecraft.

Your SPK may not contain exactly the ephemeris you want.

But, if all the needed data are available in your SPK file the SPK subsystem will chain together the position vectors indicated by the **three blue arrows**, the data explicitly contained in an SPK file, to give you the position vector indicated by the **red arrow**—the one you asked for.

This might require the loading of two SPK files, one containing data for the spacecraft relative to the planet mass center, and another containing data for the planet mass center and the satellite relative to the planet barycenter.



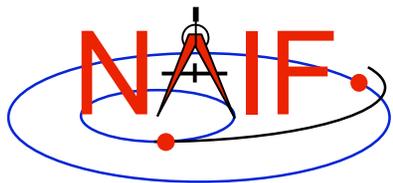


Navigation and Ancillary Information Facility

More About SPK Files

Here we provide some more details on the design and structure of SPK files.

However, still more information is provided in the “Making an SPK” tutorial.



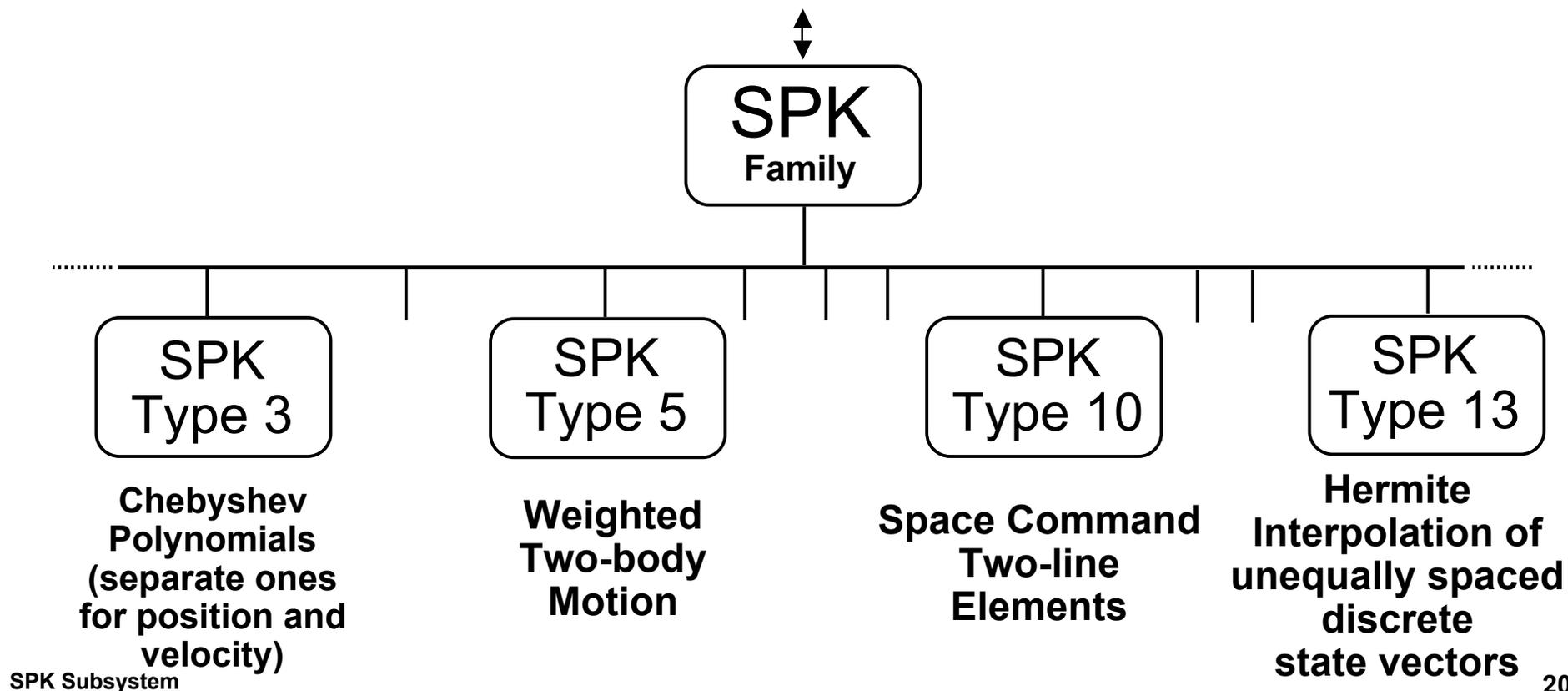
SPK Data Type Concept

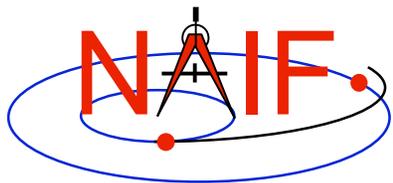
Navigation and Ancillary Information Facility

SPK files contain various mathematical representations of ephemeris data ("data types"), but the high-level user interfaces (SPK "readers") are type-independent:

```
CALL SPKEZR ('target', time, 'frame', 'correction', 'observer', state, light_time)
```

```
CALL SPKPOS ('target', time, 'frame', 'correction', 'observer', positn, light_time)
```

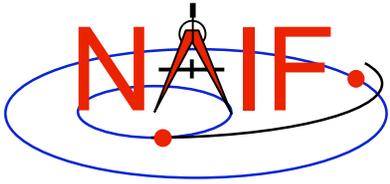




Why Have Multiple Data Types?

Navigation and Ancillary Information Facility

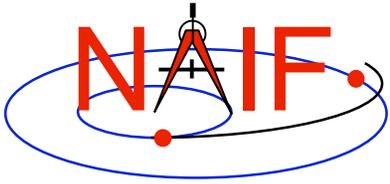
- **To allow SPK producers to choose an ephemeris representation well-suited for their applications. For example:**
 - **Weighted two-body extrapolation (type 5) yields compact files; may be used with sparse data. Only accurate for motion that is well approximated by the two-body model.**
 - **SPK files based on sliding-window Lagrange and Hermite interpolation (types 9 and 13) are easy to create. Position can be made arbitrarily accurate with sufficiently small time separation of states.**
 - **Chebyshev polynomials (types 2, 3, 14) yield the best combination of evaluation speed and accuracy. The file creator must do more work to use these data types.**
- **To replicate data originally provided in other formats.**
 - **Types 1, 2, 3, 8, 10, 14, 15, 17 and 18 were developed to enable accurate duplication of data obtained from ephemeris developers.**



Widely Used SPK Data Types

Navigation and Ancillary Information Facility

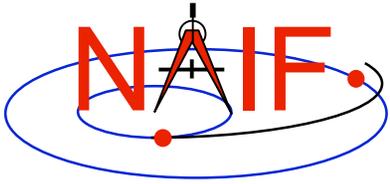
- **Type 1 (Modified divided difference arrays)** is the representation used by JPL orbit determination software for spacecraft ephemerides.
- **Type 2 (Chebyshev polynomials for position, velocity given by differentiation)** is used for JPL planetary ephemerides.
- **Type 3 (Separate Chebyshev polynomials for position and velocity)** is used for JPL satellite ephemerides.
- **Type 5 (Weighted two-body extrapolation)** is often used for comets and asteroids, as well as for sparse data sets where a piecewise two-body approximation is acceptable.
- **Type 10 (Space command two-line elements)** is often used for earth orbiters.
- **Types 9 and 13 (Sliding-window Lagrange and Hermite interpolation of unequally-spaced states)** are often used by non-JPL ephemeris producers and by MKSPK users.
- **Type 18 (ESOC DDID Hermite/Lagrange interpolation)** is used in SPKs made by ESA's MEX, VEX, Rosetta and SMART-1 missions.



SPK Segments - 1

Navigation and Ancillary Information Facility

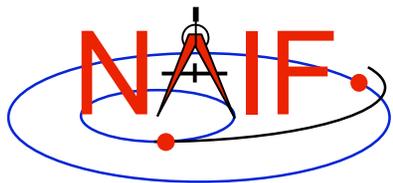
- **An SPK file is mostly made up of one or more blocks of ephemeris data called “segments.”**
 - Each segment contains position and velocity data for one body, relative to one center of motion, given in one reference frame, using one mathematical representation (called the SPK “data type”), for a specified time interval.
 - Data for one body, relative to one center of motion, in one reference frame, using one SPK data type may be placed in many segments. This is often the case for spacecraft.
 - You can observe the segment-by-segment contents of an SPK file using the SPACIT utility program.



SPK Segments - 2

Navigation and Ancillary Information Facility

- An SPK segment, by definition, contains a **continuous** representation of ephemeris data over an interval of time.
 - You can request a position or state vector at **any time** within the covered interval.
 - » Achieved through interpolation of discrete data, or by evaluating an analytical function, depending on the SPK type.
- However, interpolation across segments and extrapolation beyond the time bounds of a segment are not permitted by the SPK “readers.”



SPK File Structure: The User's View

Navigation and Ancillary Information Facility

Logical Organization of an SPK File



■
■
■



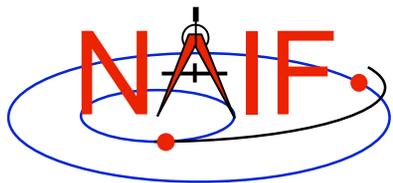
■
■
■

Always present

Possibly present

- sometimes by choice
- sometimes required

See the tutorial named Making an SPK for details about segment architecture and contents.

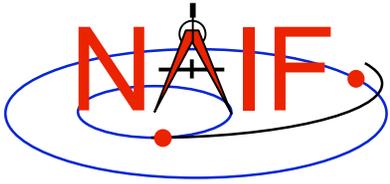


SPK Segment Order and Priority

Navigation and Ancillary Information Facility

- **Within a single SPK file...**
 - The segments in an SPK file **need not** be ordered according to time or body.
 - Segment order **does** imply priority. When two segments from the same SPK file both contain data for a given target and time that satisfy a request, the SPK system selects the segment located **later** in the file.
 - » The centers of motion, frames and SPK types are irrelevant to this selection.
- **If using two or more SPK files...**
 - Segments from SPK files loaded **later** have higher priority: when two segments from two different SPK files both contain data for a given target and time, the SPK system selects the segment from the SPK file that was loaded later.

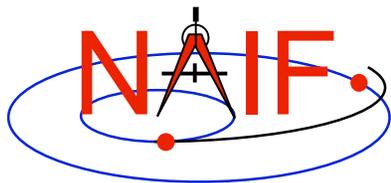
**Important
stuff!** 



SPK File Ephemeris Contents

Navigation and Ancillary Information Facility

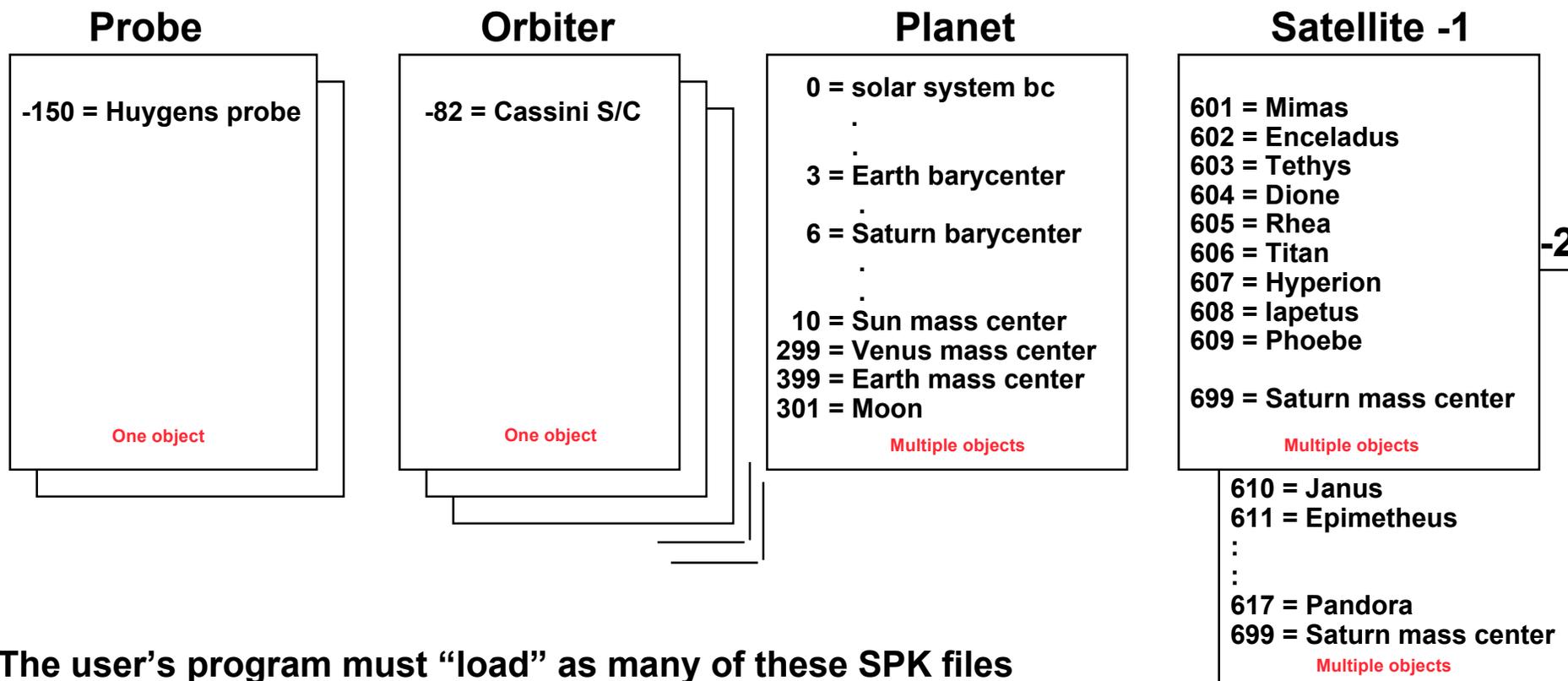
- **A single SPK file can hold data for one ephemeris object, or for many ephemeris objects.**
 - This is illustrated in the next four charts



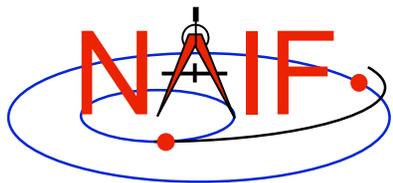
Example of Flight Project SPK Files

Navigation and Ancillary Information Facility

This made up example shows four collections of SPK files for the Cassini-Huygens mission.



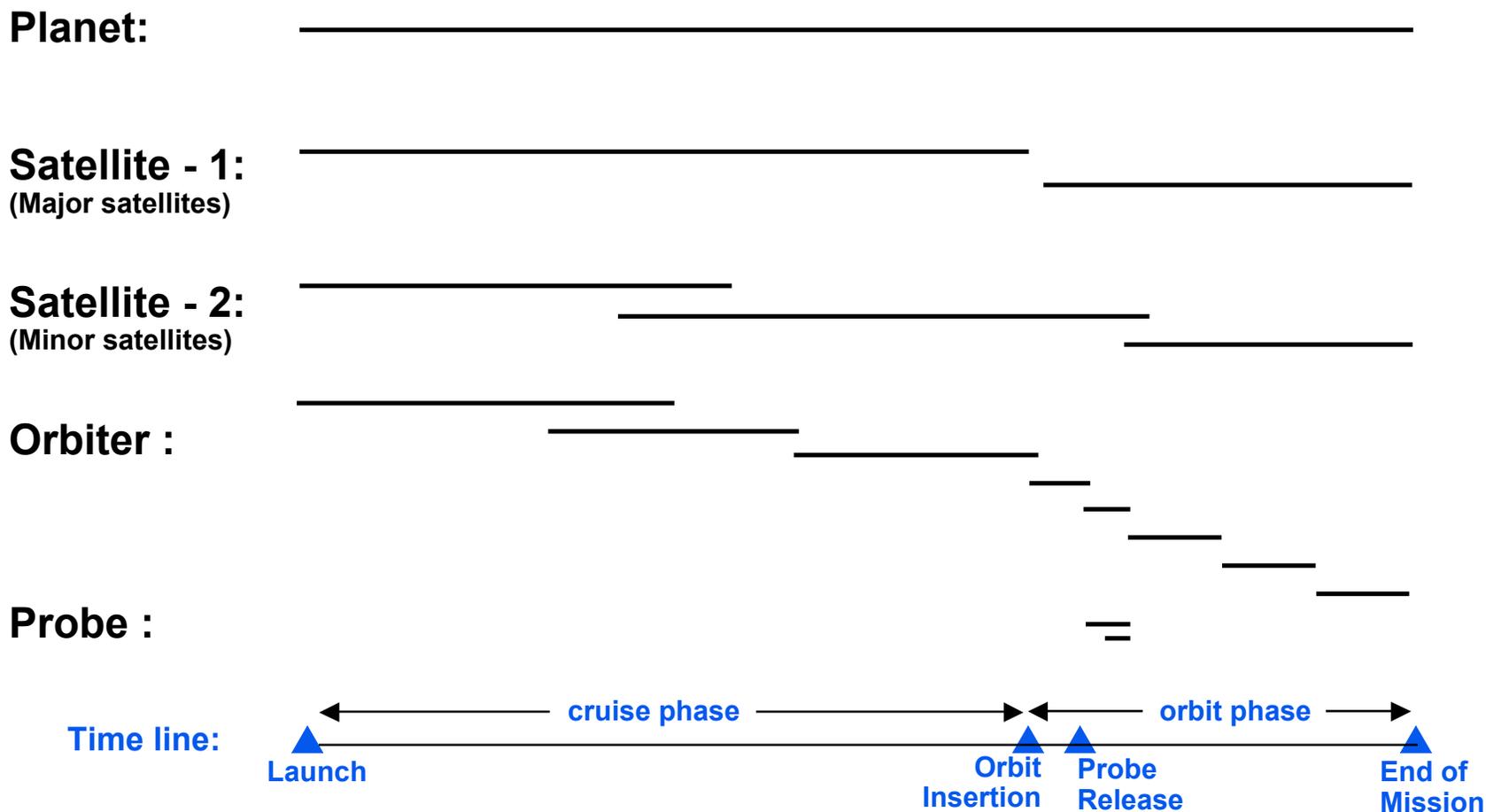
The user's program must "load" as many of these SPK files as needed to satisfy her/his requirements. NAIF strongly recommends that such programs have the flexibility to load a list of SPK files provided to the program at run time; this is easily accomplished by listing the SPK files in a "furnsh kernel" using the Toolkit's FURNISH routine.



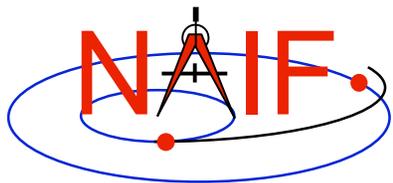
Possible* SPK File Time Coverages for the Previous Example

Navigation and Ancillary Information Facility

Each bar represents a separate file



* Note: This is likely not a real Cassini scenario; it is simply an illustration of some of the possibilities for ephemeris delivery on a planetary mission.

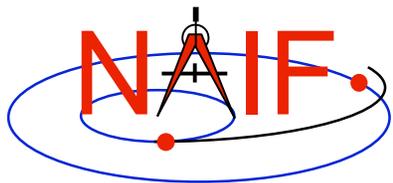


Planets and Planet Barycenters

Navigation and Ancillary Information Facility

- **A planet and its satellites orbit the planet system's barycenter**
 - For example, the Jupiter mass center (599) and each of Jupiter's satellites (501 - 5xx) orbit the Jupiter system barycenter (5)
- **Planet system barycenters (i.e. 1 through 9) and the sun (10) orbit the solar system barycenter (0)**
- **Because Mercury and Venus have no satellites, their barycenters (1 and 2) occupy the same locations as their mass centers (199 and 299)***
- **Because the masses of Phobos and Deimos are so small compared to the mass of Mars, the mass center for Mars (499)* is treated as equivalent to the Mars barycenter (4)**

* These equivalences hold true **ONLY** in the SPK subsystem, not in the PCK subsystem



Examples of Generic SPK File Contents

Navigation and Ancillary Information Facility

de421.bsp
Planet Ephemeris

| | |
|-----|------------|
| 0 | S.S. BC |
| 1 | Merc. BC |
| 199 | Mercury |
| 2 | Venus BC |
| 299 | Venus |
| 3 | Earth BC |
| 301 | Moon |
| 399 | Earth |
| 4 | Mars BC |
| 499 | Mars |
| 5 | Jupiter BC |
| 6 | Saturn BC |
| 7 | Uranus BC |
| 8 | Neptune BC |
| 9 | Pluto BC |
| 10 | Sun |

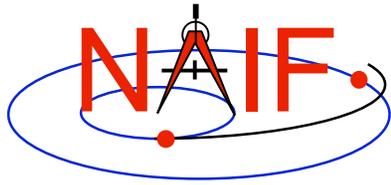
my_asteroids.bsp
Asteroid Ephemeris

| | |
|---------|----------|
| 2000253 | Mathilde |
| 2000433 | Eros |

jup230.bsp
Merged Planet and
Satellite Ephemeris

| | |
|-----|------------|
| 3 | Earth BC |
| 399 | Earth |
| 5 | Jupiter BC |
| 501 | Io |
| 502 | Europa |
| 503 | Ganymede |
| 504 | Callisto |
| 505 | Amalthea |
| 514 | Thebe |
| 599 | Jupiter |
| 10 | Sun |

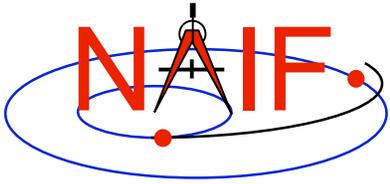
Generic SPK files can be obtained from the NAIF server.



SPKs for Objects Located on the Surface of a Natural Body

Navigation and Ancillary Information Facility

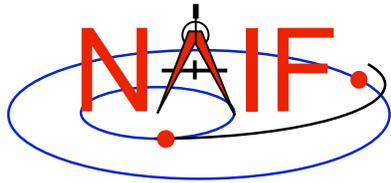
- **An SPK file may contain positions of tracking stations, observatories, roving vehicles, etc.**
 - The object could be stationary or moving
- **One reads this file the same as for any other SPK file**
 - Use the name or NAIF ID of the antenna, observatory or rover as the “target” or “observer” in an SPK reader argument list
 - Also requires use of a SPICE Pck file if you request vectors to be returned in an inertial frame such as J2000



Understanding an SPK File

Navigation and Ancillary Information Facility

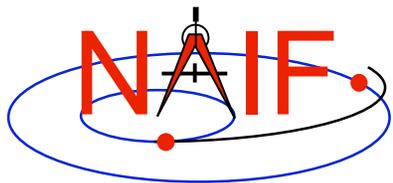
- **The SPK producer should have provided descriptive meta-data inside an SPK file, in the “comment area”**
 - The comments should say when/why/how and for what purpose the file was made
 - Additional useful information could also be provided by the producer
- **These comments may be extracted or viewed using an API (subroutine) or a SPICE utility program.**



Manipulating and Using SPK Files

Navigation and Ancillary Information Facility

- **You can subset an SPK file, or merge two or more files**
 - The merge may key off of objects, or time, or both
- **You can read data from just one, or many* SPK files in your application program**
- **Don't forget the precedence rule: data in a later loaded file take precedence over data from an earlier loaded file**
(* The allowed number of simultaneously loaded DAF-based files is currently set to 1000.)



Summarizing an SPK File - 1

Navigation and Ancillary Information Facility

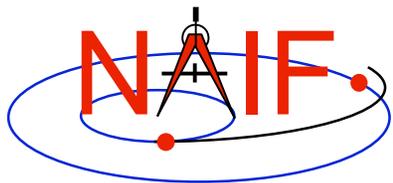
- A brief summary can be made using the SPICE Toolkit utility “brief”
 - Summary is for objects present and their start and stop epochs
- At your command line prompt, type the program name (with path), followed by the name of the binary SPK file that is to be summarized
- See the brief User’s Guide or on-line help (%brief -h) for more details

```
% brief 070413BP_SCPSE_07097_07121.bsp  
Brief. Version: 2.3.1 (SPICE Toolkit N0061)
```

```
Summary for: 070413BP_SCPSE_07097_07121.bsp
```

```
Bodies: CASSINI (-82)          PLUTO BARYCENTER (9)      TETHYS (603)  
MERCURY BARYCENTER (1)     SUN (10)                  DIONE (604)  
VENUS BARYCENTER (2)      MERCURY (199)             RHEA (605)  
EARTH BARYCENTER (3)     VENUS (299)               TITAN (606)  
MARS BARYCENTER (4)      MOON (301)                HYPERION (607)  
JUPITER BARYCENTER (5)   EARTH (399)               IAPETUS (608)  
SATURN BARYCENTER (6)    MARS (499)                PHOEBE (609)  
URANUS BARYCENTER (7)    MIMAS (601)               SATURN (699)  
NEPTUNE BARYCENTER (8)   ENCELADUS (602)  
Start of Interval (ET)          End of Interval (ET)  
-----  
2007 APR 07 16:22:23.000      2007 MAY 01 09:34:03.000
```

Note, the default is ET, not UTC!



Summarizing an SPK File - 2

Navigation and Ancillary Information Facility

- A detailed summary can be made using the Toolkit utility “SPACIT”
- See the SPACIT User’s Guide for details

```
Summary for SPK file: sat240.bsp
Leapseconds File      : /kernels/gen/lsk/leapseconds.ker
Summary Type         : Entire File
```

```
Segment ID           : SAT240
Target Body          : Body 601, MIMAS
Center Body          : Body 6, SATURN BARYCENTER
Reference frame:     : Frame 1, J2000
SPK Data Type        : Type 3
  Description        : Fixed Width, Fixed Order Chebyshev Polynomials: Pos, Vel
UTC Start Time       : 1969 DEC 31 00:00:00.000
UTC Stop Time        : 2019 DEC 02 00:00:00.000
ET Start Time        : 1969 DEC 31 00:00:41.183
ET Stop time         : 2019 DEC 02 00:01:05.183
```

```
Segment ID           : SAT240
Target Body          : Body 602, ENCELADUS
Center Body          : Body 6, SATURN BARYCENTER
Reference frame:     : Frame 1, J2000
SPK Data Type        : Type 3
  Description        : Fixed Width, Fixed Order Chebyshev Polynomials: Pos, Vel
UTC Start Time       : 1969 DEC 31 00:00:00.000
UTC Stop Time        : 2019 DEC 02 00:00:00.000
ET Start Time        : 1969 DEC 31 00:00:41.183
ET Stop time         : 2019 DEC 02 00:01:05.183
```

⋮

(This is a partial output; not all data could be displayed on this chart)



Summarizing an SPK File - 3

Navigation and Ancillary Information Facility

Summarizing an SPK at the API Level

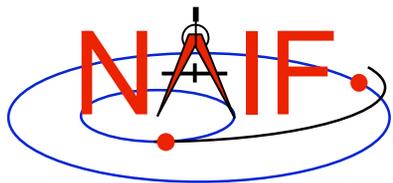
- **Call SPKOBJ to find the set of objects for which a specified SPK provides data.**
 - **INPUT:** an SPK file name and initialized SPICE integer “Set” data structure. The set may optionally contain ID codes obtained from previous calls.
 - **OUTPUT:** the input set, to which have been added (via set union) the ID codes of objects for which the specified SPK provides coverage.

```
CALL SPKOBJ ( SPK, IDSET )
```

- **Call SPKCOV to find the window of times for which a specified SPK file provides coverage for a specified body:**
 - **INPUT:** an SPK file name, body ID code and initialized SPICE double precision “Window” data structure. The window may optionally contain coverage data from previous calls.
 - **OUTPUT:** the input window, to which have been added (via window union) the sequence of start and stop times of segment coverage intervals of the specified SPK, expressed as seconds past J2000 TDB.

```
CALL SPKCOV ( SPK, IDCODE, COVER )
```

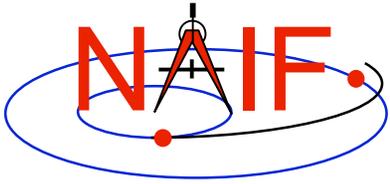
- **See the headers of these routines for example programs.**
- **Also see the CELLS, SETS and WINDOWS Required Reading for background information on these SPICE data types.**



Additional Information on SPK

Navigation and Ancillary Information Facility

- **For more information about SPK, look at the following:**
 - Backup slides in this tutorial
 - The STATES cookbook program (source code) and its User's Guide
 - The *Most Useful SPICELIB Subroutines* document
 - The *SPK Required Reading* document
 - Headers of the subroutines mentioned
 - The Using Frames tutorial
 - The *BRIEF User's Guide* and the *SPACIT User's Guide*
- **Related documents:**
 - NAIF_IDS Required Reading
 - Frames Required Reading
 - Time Required Reading
 - Kernel Required Reading
- **All code and documents noted above are included in every SPICE Toolkit delivery**



Backup

Navigation and Ancillary Information Facility

- **Problems Using SPK Files**
- **Don't Mix Planet Ephemerides**
- **Barycenters and Mass Centers**
- **Effect of Aberration Corrections**
- **Retrieving State Vectors: "Under the Hood"**
- **SPK File Structure**

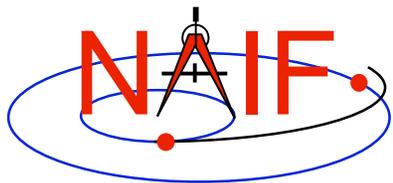


Problems Using SPK Files - 1

Navigation and Ancillary Information Facility

- **The file, or files, you loaded do not contain data for both your target and observer bodies**
 - You may have loaded the wrong file, or assumed the file contains data that it doesn't
 - You may not have loaded all the files needed
- **The file, or files, you loaded do not cover the time at which you requested a state vector**
 - This could occur if you've been given a file coverage summary in calendar ET form and you mistook this for UTC
($ET = UTC + DELTAET$, where DELTAET is about 65 secs as of 10/1/08)
 - This could occur if you are requesting a light-time corrected state and the SPK files being used do not have data at the time that is one-way light-time away* from your ET epoch of interest
 - » * Earlier, for the receive case; later, for the transmission case
- **In the above situations you'll get an error message like the following:**

```
SPICE (SPKINSUFFDATA) - -  
Insufficient ephemeris data has been loaded to  
compute the state of xxx relative to yyy.
```



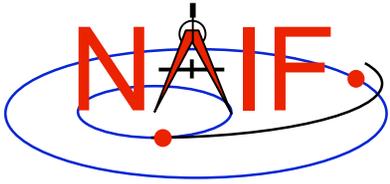
Problems Using SPK Files - 2

Navigation and Ancillary Information Facility

- **You have requested aberration-corrected states but the file, or files, you loaded do not contain sufficient data to relate both your target and observer bodies back to the solar system barycenter.**
 - You may not have loaded all the files needed
 - You may have assumed the file contains data that it doesn't

In the above situations you'll get an error message like the following:

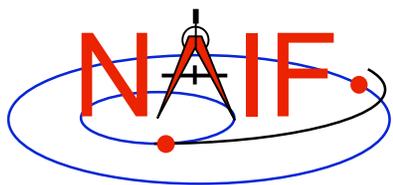
```
SPICE (SPKINSUFFDATA) - -  
Insufficient ephemeris data has been loaded to  
compute the state of xxx relative to yyy.
```



Problems Using SPK Files – 3a

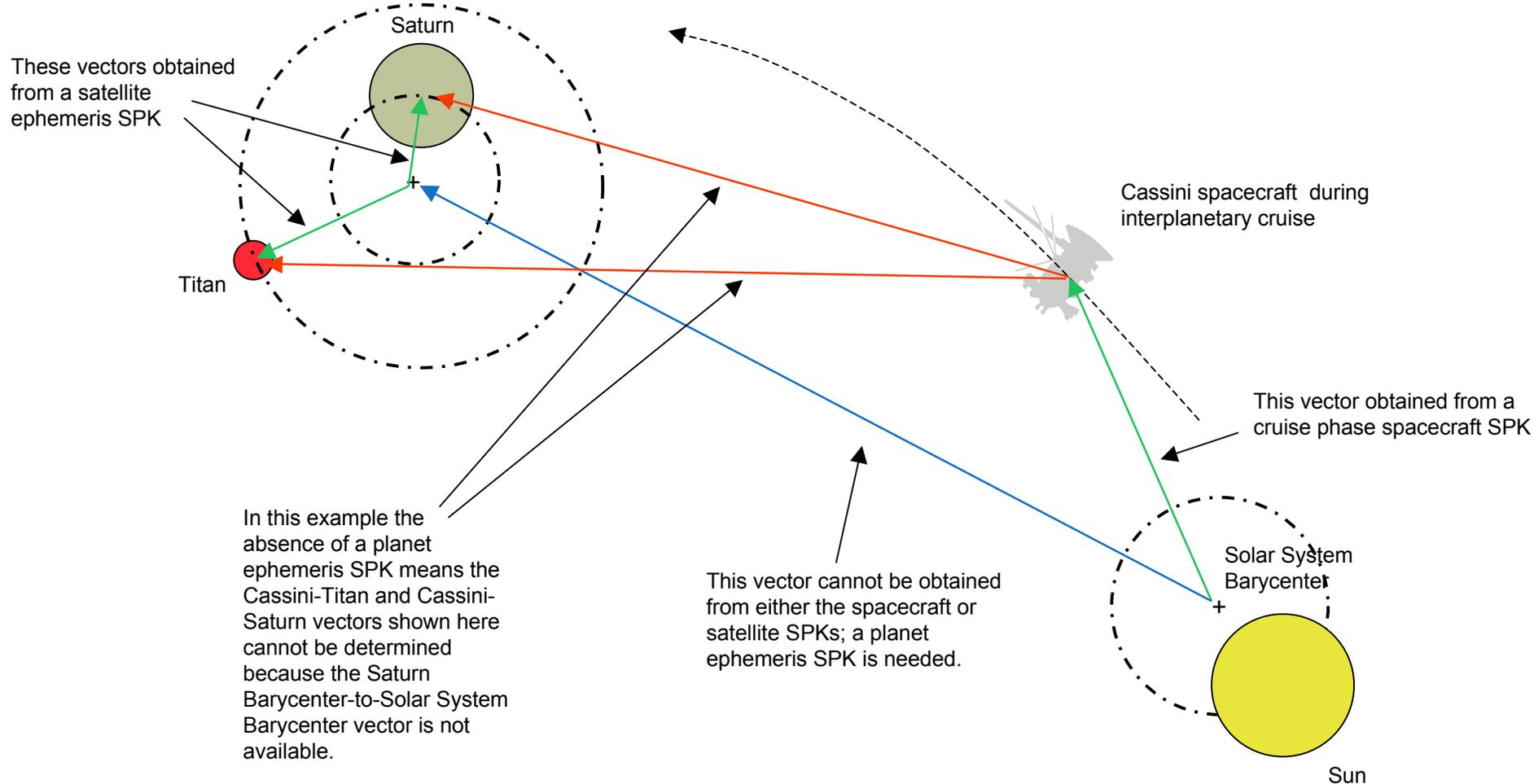
Navigation and Ancillary Information Facility

- **An infrequent problem occurs when your SPK file(s) contain data for both target and observer, and cover the period of interest, but ephemeris data for an intermediate body needed to link the target and observer together is missing.**
 - **Example: You load a spacecraft SPK containing ephemeris for Cassini (-82) relative to the solar system barycenter (0), and you load a satellite SPK containing the ephemeris for Titan (606) and Saturn (699) relative to the Saturn barycenter (6). But you forgot to load a planet SPK file that contains data for the Saturn barycenter relative to the solar system barycenter. The SPK software cannot “connect” Cassini to Titan or to Saturn. (See the drawing on the next page.)**
 - **In this case, knowing what is the “Center Body” of movement for each target body is important; this is shown in SPACIT, and in BRIEF summaries if the -c command line option is used.**



Problems Using SPK Files - 3b (drawing)

Navigation and Ancillary Information Facility



- Given...
- available in SPK files
 - not available in SPK files
- Therefore...
- can't be computed



Problems Using SPK Files - 4

Navigation and Ancillary Information Facility

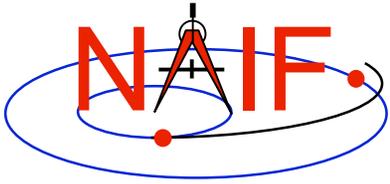
- **You see an error message to the effect that pole RA (right ascension) data cannot be found**
 - **You are requesting results in a body-fixed frame, but you have not loaded a SPICE Pck file that defines this frame.**



Problems Using SPK Files - 5

Navigation and Ancillary Information Facility

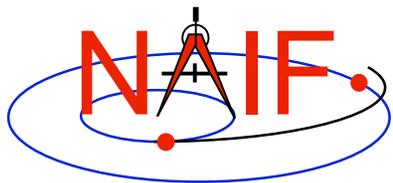
- **Segment Masking: You've loaded sufficient data to "connect" target and observer, but the SPK subsystem can't make the connection.**
 - This can happen when a high-priority segment that can't be connected to both target and observer "masks" a lower-priority segment that can be connected.
 - **Example: you want the state of earth as seen from the Galileo orbiter at a specified ephemeris time ET1.**
 - » **You have loaded SPK files providing:**
 - the state of the Galileo orbiter relative to the asteroid Gaspra
 - the state of the orbiter relative to the sun
 - the state of the earth relative to the earth-moon barycenter
 - the states of the sun and earth-moon barycenter relative to the solar system barycenter
 - » **If an SPK segment for the orbiter relative to Gaspra covering ET1 has higher priority than the segment for the orbiter relative to the sun covering ET1, no connection between the orbiter and the earth will be made.**
 - » **Solution:**
 - Load an SPK file providing the ephemeris of Gaspra relative to the sun or the solar system barycenter (for a time interval containing ET1)



Problems Using SPK Files - 6

Navigation and Ancillary Information Facility

- **Other missing data... not obvious.**
 - You may need CK (and SCLK), FK or PCK data to construct a state (or position) vector in your requested output frame.
- **Mistaking ET for UTC, or vice-versa.**
- **You must have loaded sufficient SPKs to be able to chain states to the solar system barycenter if doing aberration corrections.**
- **Using light time corrections requires target ephemeris data at the light time-corrected epoch.**
 - If you're working near the beginning of an SPK, the light time-corrected epoch may occur earlier than available data.



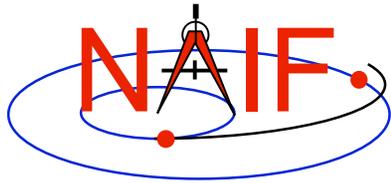
Problems Using SPK Files - 7

Navigation and Ancillary Information Facility

- You've assumed that:

state (observer, target) = - state (target, observer)

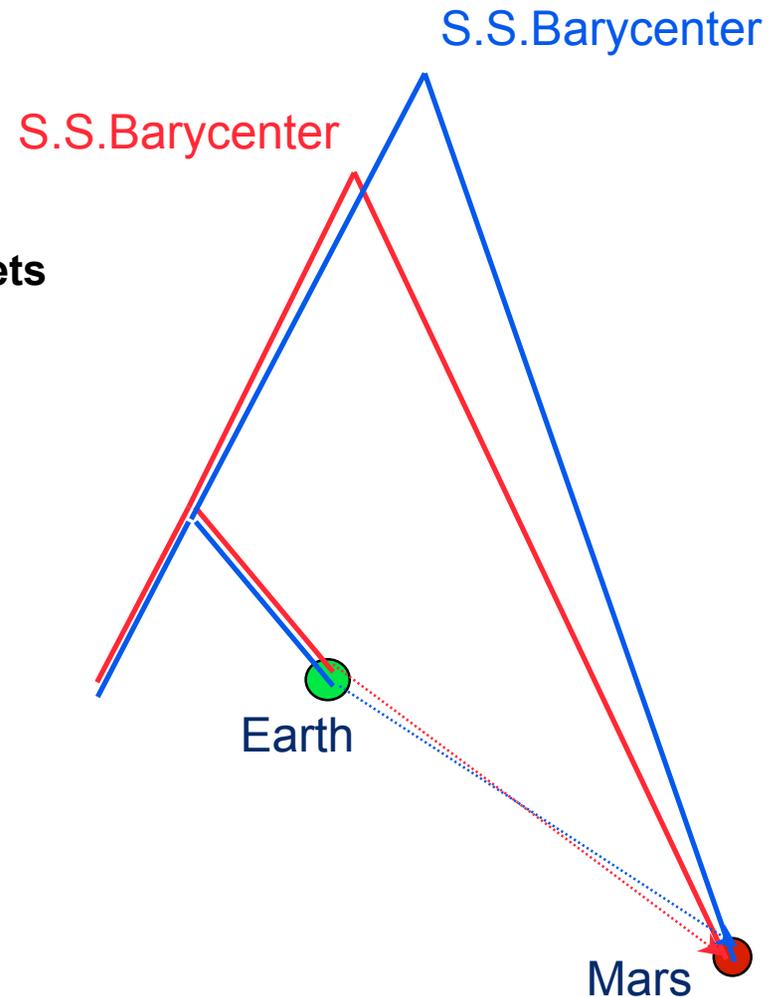
- This is **NOT** true unless you have requested geometric states in both cases (i.e. no light time or stellar aberration corrections are applied)

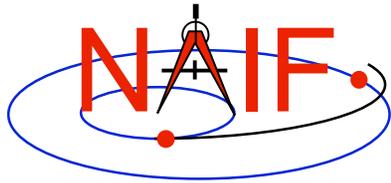


Comparing Apples and Oranges-1

Navigation and Ancillary Information Facility

- With each new integration of the solar system, the solar system barycenter moves w.r.t. the planets
- Planet to planet offset variations are much smaller than the barycenter to planet variations

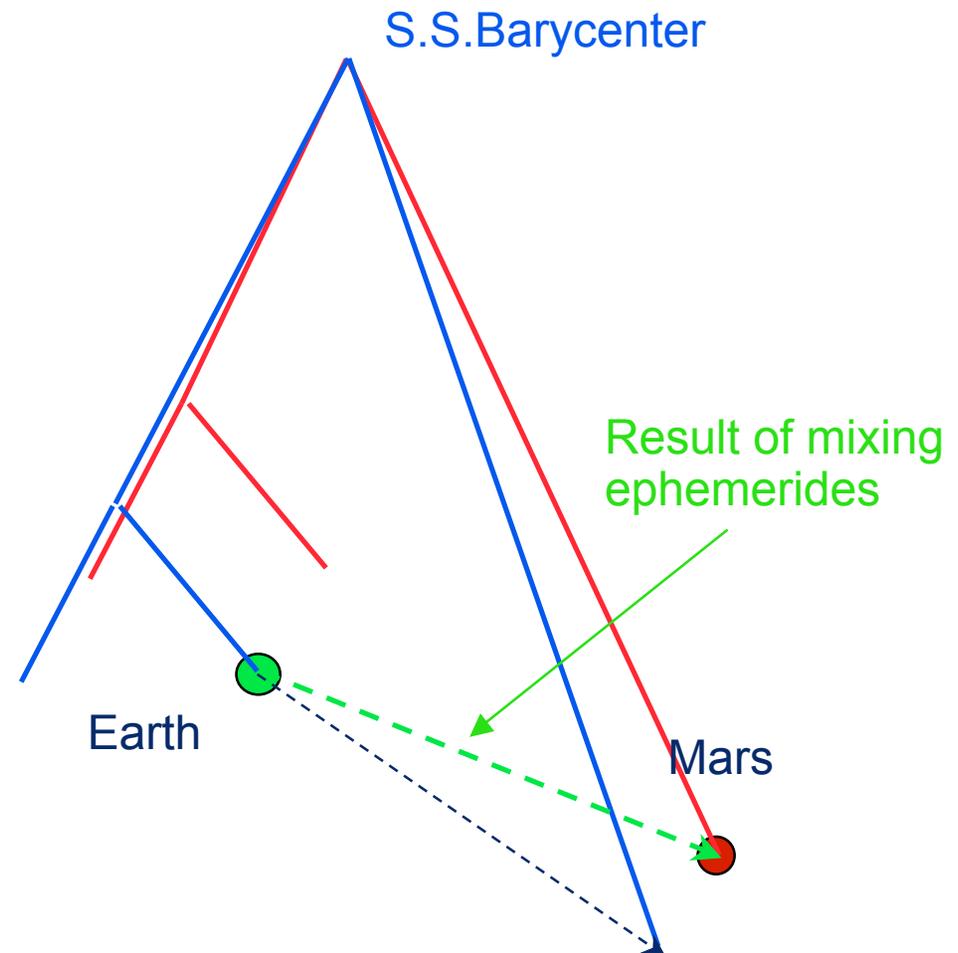


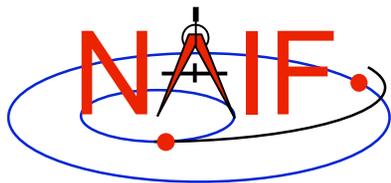


Comparing Apples and Oranges-2

Navigation and Ancillary Information Facility

- **SPICE allows you to “load” different planetary ephemerides (or portions of them)**
 - » Potentially can subtract the solar system barycenter-relative positions from different ephemerides to get relative states
- **Don't mix planetary ephemerides**
- **For missions, a consistent set of ephemerides is provided**



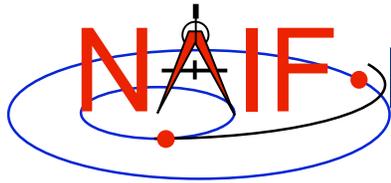


Barycenters and Mass Centers

Navigation and Ancillary Information Facility

| <u>Body Mass Center</u> | <u>System Barycenter</u> | <u>Body center offset from Barycenter (km)*</u> | <u>Offset as % of body radius*</u> |
|-------------------------|--------------------------|---|------------------------------------|
| Sun (10) | SSB (0) | 1,378,196 | 198% |
| Mercury (199) | M. BC (1) | 0 | 0 |
| Venus (299) | V. BC (2) | 0 | 0 |
| Earth (399) | E. BC (3) | 4942 | 77% |
| Mars (499) | M. BC (4) | ~0 | ~0 |
| Jupiter (599) | J. BC (5) | 220 | 0.3% |
| Saturn (699) | S. BC (6) | 312 | 0.5% |
| Uranus (799) | U. BC (7) | 43 | 0.17% |
| Neptune (899) | N. BC (8) | 74 | 0.3% |
| Pluto (999) | P. BC (9) | 2080 | 174% |

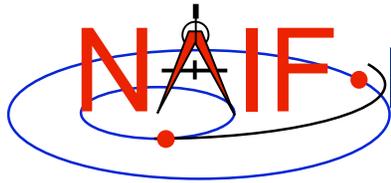
* Estimated maximum values over the time range 2000-2050



Effect of Aberration Corrections - 1

Navigation and Ancillary Information Facility

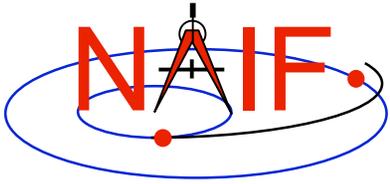
- **Angular offsets between corrected and uncorrected position vectors over the time span 2004 Jan 1--2005 Jan1**
 - **Mars as seen from MEX:**
 - » **LT+S vs NONE: .0002 to .0008 degrees**
 - » **LT vs NONE: .0006 to .0047 degrees**
 - **Earth as seen from MEX:**
 - » **LT+S vs NONE: .0035 to .0106 degrees**
 - » **LT vs NONE: .0000 to .0057 degrees**
 - **MEX as seen from Earth:**
 - » **LT+S vs NONE: .0035 to .0104 degrees**
 - » **LT vs NONE: .0033 to .0048 degrees**
 - **Sun as seen from Mars:**
 - » **LT+S vs NONE: .0042 to .0047 degrees**
 - » **LT vs NONE: .0000 to .0000 degrees**



Effect of Aberration Corrections - 2

Navigation and Ancillary Information Facility

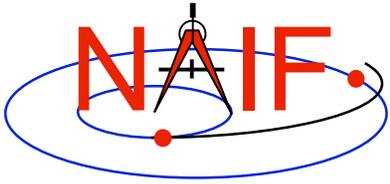
- **Angular offsets between corrected and uncorrected position vectors over the time span 2004 Jan 1--2008 Jan1**
 - **Saturn as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0058 degrees**
 - » **LT vs NONE: .0001 to .0019 degrees**
 - **Titan as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0057 degrees**
 - » **LT vs NONE: .0000 to .0030 degrees**
 - **Earth as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0107 degrees**
 - » **LT vs NONE: .0000 to .0058 degrees**
 - **CASSINI as seen from Earth:**
 - » **LT+S vs NONE: .0000 to .0107 degrees**
 - » **LT vs NONE: .0000 to .0059 degrees**
 - **Sun as seen from CASSINI:**
 - » **LT+S vs NONE: .0000 to .0059 degrees**
 - » **LT vs NONE: .0000 to .0000 degrees**



Retrieving State Vectors: "Under the Hood" - 1

Navigation and Ancillary Information Facility

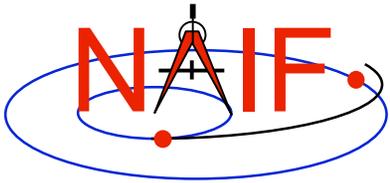
- **Example: find the geometric state of the MGS orbiter relative to Mars the at observation epoch ET, expressed in the J2000 reference frame.**
 - CALL SPKEZR ('MGS', ET, 'J2000', 'NONE', 'MARS', STATE, LT)
 - The SPK subsystem locates an SPK segment containing the ephemeris of the orbiter relative to Mars covering epoch ET, interpolates the ephemeris data at ET, and returns the interpolated state vector.
- **Example: find the geometric state of Titan relative to the earth at ET, expressed in the J2000 reference frame.**
 - CALL SPKEZR ('TITAN', ET, 'J2000', 'NONE', 'EARTH', STATE, LT)
 - The SPK subsystem looks up and interpolates ephemeris data to yield:
 - » The state of the earth relative to the earth-moon barycenter (A)
 - » The state of the earth-moon barycenter relative to the solar system barycenter (B)
 - » The state of Titan relative to the Saturn system barycenter at ET (C)
 - » The state of the Saturn system barycenter relative to the solar system barycenter at ET (D)
 - SPKEZR then returns the state vector
 - » $C + D - (A + B)$



Retrieving State Vectors: "Under the Hood" - 2

Navigation and Ancillary Information Facility

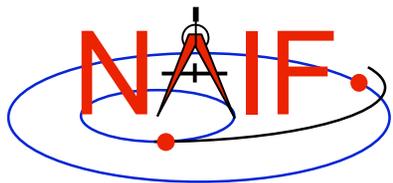
- **Example: find the apparent state of the Cassini orbiter relative to the DSN station DSS-14, expressed in the topocentric reference frame centered at DSS-14, at a specified observation epoch ET.**
 - **CALL SPKEZR ('CASSINI', ET, 'DSS-14_TOPO', 'LT+S', 'DSS-14', STATE, LT)**
 - **The SPK subsystem looks up and interpolates ephemeris data to yield:**
 - » **The state of DSS-14 relative to the earth in the ITRF93 terrestrial reference frame (A)**
 - » **The state at ET of the earth relative to the earth-moon barycenter in the J2000 reference frame (B)**
 - » **The state at ET of the earth-moon barycenter relative to the solar system barycenter in the J2000 frame (C)**
 - » **The state at the light time-corrected epoch ET-LT of the Cassini orbiter relative to the Saturn system barycenter (other centers are possible) in the J2000 frame (D)**



Retrieving State Vectors: "Under the Hood" - 3

Navigation and Ancillary Information Facility

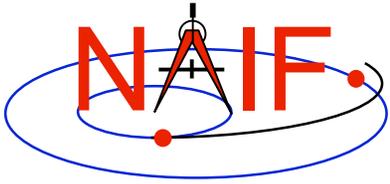
- » The state at ET-LT of the Saturn system barycenter relative to the solar system barycenter in the J2000 frame (E)
- The SPK subsystem also looks up transformation matrices to map states:
 - » From the J2000 frame to the ITRF93 terrestrial (earth body-fixed) frame at the observation epoch ET (T1)
 - » From the ITRF93 terrestrial frame to the DSS-14-centered topocentric frame (T2)
- SPKEZR then computes the J2000-relative, light-time corrected observer-target state vector
 - » $E + D - ((T1)^{-1} * A + B + C)$
- SPKEZR corrects this vector for stellar aberration
 - » Call the result "V_J2000_apparent"
- and finally returns the requested state vector in the DSS-14 topocentric reference frame
 - » $STATE = T2 * T1 * V_J2000_apparent$



SPK File Structure

Navigation and Ancillary Information Facility

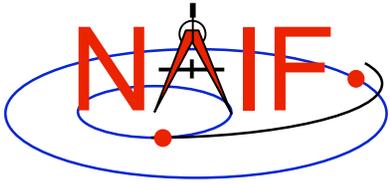
- **A description of SPK file structure is shown near the beginning of the “Making and SPK” tutorial.**



Navigation and Ancillary Information Facility

Planetary Constants Kernel PCK

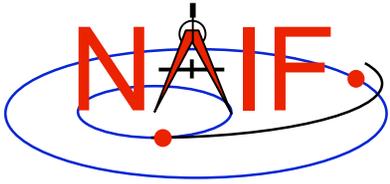
January 2009



Topics

Navigation and Ancillary Information Facility

- **Overview**
- **Using PCKs**
- **Text PCKs**
- **IAU Models**
- **Binary PCKs**
- **Interface Routines**
- **PCK Reference Frames**



Overview

Navigation and Ancillary Information Facility

- **The P_{constants} kernel (PCK or Pck) is logically a part of the “planet kernel.”**
- **SPICE PCK data consist of:**
 - **Orientation (also known as “rotation”) models for extended, natural solar system bodies: sun, planets, natural satellites, a few asteroids**
 - » Location of the pole and prime meridian
 - » Axis directions of a body-fixed, body-centered reference frame
 - » Spin rate
 - **Physical and cartographic constants**
 - » Sets of radii for triaxial shape models.
 - » Additional items could be included, such as
 - prime meridian offset from the principal axis
 - magnetic dipole location
 - gravity parameters: GM, J2, higher order gravity field terms
 - ring model parameters
- **PCK data files are called “PCK kernels,” “PCKs” or “PCK files.”**
- **The PCK subsystem supports text and binary PCK file formats.**
 - **Text PCKs may contain orientation, shape, and other cartographic or physical data.**
 - **Binary PCKs are used for high-accuracy orientation data.**
 - » Binary PCKs are available only for the earth and the moon.



Using PCKs

Navigation and Ancillary Information Facility

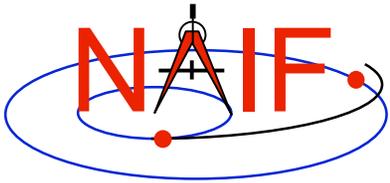
- **Load PCKs using FURNISH**
 - Orientation data from a binary PCK always supersede orientation data (for the same object) obtained from a text PCK, no matter the order in which the kernels are loaded
- **PCK orientation data are usually accessed via Frame system or SPK calls**
 - **Example: Get the IAU_SATURN body-fixed reference frame to J2000 position or state transformation matrix at ET:**
 - » CALL PIFORM ('IAU_SATURN', 'J2000', ET, RMAT)
 - » CALL SXFORM ('IAU_SATURN', 'J2000', ET, XFORM)
 - **Example: Get state of Saturn relative to Cassini in the IAU_SATURN body-fixed reference frame:**
 - » CALL SPKEZR ('SATURN', ET, 'IAU_SATURN', 'LT+S', 'CASSINI', STATE, LT)
 - **Example: Get state of Cassini relative to the DSN station DSS-13 in the J2000 inertial reference frame:**
 - » CALL SPKEZR ('CASSINI', ET, 'J2000', 'LT+S', 'DSS-13', STATE, LT)
 - An Earth PCK **must** be loaded in order for this call to work.
 - Even though the specified reference frame is inertial
 - This call, in the course of its work, converts the position of the DSN station relative to the Earth's center from an Earth-fixed, earth-centered frame to the J2000 frame.
- **Access to PCK shape and other data is discussed in the section titled “Interface Routines”**



Text PCKs - 1

Navigation and Ancillary Information Facility

- **Text PCK files may contain orientation, shape and other data associated with natural solar system bodies.**
- **NAIF creates and distributes “generic” text PCK files based on IAU/IAG reports, published in *ICARUS*.**
 - These PCKs contain orientation and shape data provided by the reports.
 - SPICE PCK software is designed to use these data to compute orientation of body-fixed frames.
- **NAIF provides a “masses” PCK containing GM values for the Sun and planetary systems.**
 - Values from this file may be used with SPICE osculating element routines
- **Text PCKs are sometimes produced by flight projects and others—not only by NAIF.**



Text PCKs - 2

Navigation and Ancillary Information Facility

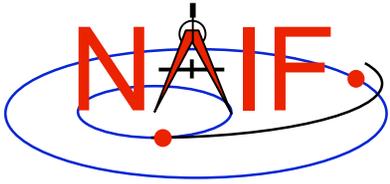
- **The SPICE **text** kernel mechanism is used to implement generic PCK files.**
 - Users may easily visually inspect data.
 - Users may (carefully!) modify text PCKs with a text editor.
 - » Data or comments may be added, deleted, or changed.
 - » Comments should be added to explain changes.
 - Kernel variables contain the mathematical terms appearing in rotation or shape models.
 - » `BODY699_RADII = (60268 60268 54364)`
 - » `BODY699_POLE_RA = (40.58 -0.036 0.)`
 - The user may include additional kernel variables to change the base frame or reference epoch.
 - Kernel variable names are **case-sensitive**.
 - » NAIF uses only upper case for variable names; we suggest you do the same.



IAU Rotation Models - 1

Navigation and Ancillary Information Facility

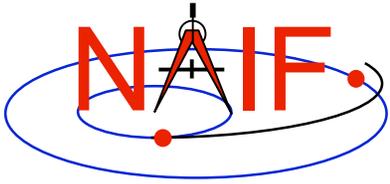
- **SPICE PCK shape models use data from the IAU/IAG (formerly IAU/IAG/COSPAR) Working Group Report, as published in *ICARUS*.**
 - The latest IAU report used by NAIF was issued in 2000.
- **IAU rotation models are provided:**
 - for the sun and planets:
 - » IAU models use low-degree (typically linear) polynomials to represent RA and DEC of the pole (body-fixed +Z-axis) as a function of time.
 - » The prime meridian is also represented by a low-degree polynomial.
 - » Trigonometric polynomial terms are supported by SPICE
 - but are rarely used in IAU models for planet orientation
 - for natural satellites:
 - » Additional trigonometric polynomial terms are used to more accurately represent precession and nutation.
 - » A few satellites exhibit chaotic rotation and so are not modeled.
 - for some major asteroids (e.g. Ida, Eros, Gaspra, Vesta)



IAU Rotation Models - 2

Navigation and Ancillary Information Facility

- **IAU body-fixed frames are planetocentric.**
 - **Z-axis is aligned with +/- spin axis. The positive Z-axis points toward the north side of the invariable plane of the solar system.**
 - **The invariable plane is normal to the solar system's angular momentum vector. It is**
 - » **approximately the same as Jupiter's orbital plane.**
 - » **roughly parallel to the ecliptic plane.**
 - **X-axis defines the prime meridian.**
 - **Y-axis completes the right-handed frame.**
- **The IAU base frame is the IERS-defined International Celestial Reference Frame (ICRF).**
 - **SPICE treats the ICRF as equivalent to J2000 (EME2000).**
- **The IAU reference epoch is J2000 (2000 Jan 1 12:00:00 TDB).**



IAU Shape Models

Navigation and Ancillary Information Facility

- **IAU shape models are nominally triaxial ellipsoids**

- Triaxial ellipsoid shape models have the form:

$$\frac{x^2}{a^2} + \frac{y^2}{b^2} + \frac{z^2}{c^2} = 1$$

- For many bodies, two of the axes (equatorial axes) have the same value (spheroidal)

- For some bodies, one or more radii have not been determined.

- **Although many bodies are in fact modeled by spheroids or oblate spheroids, SPICE deals with the general, triaxial case.**

- **Exception: SPICE supports geodetic coordinate transformations only for bodies modeled as spheroids or oblate spheroids.**

- » RECGEO and GEOREC are the modules performing these transformations.

- **Exception: SPICE supports planetographic coordinate transformations only for bodies modeled as spheroids or oblate spheroids.**

- » PGRREC, RECPGR, DPGRDR and DRDPGR are the modules supporting these transformations.



Binary PCKs

Navigation and Ancillary Information Facility

- **The SPICE system stores high-accuracy orientation models in binary PCKs.**
 - **Binary PCKs are implemented using the DAF file architecture (as are SPK files)**
 - » Binary PCKs are not human-readable.
 - » SPICE API routines enable applications to create binary PCKs.
 - » SPICE Toolkit utilities enable reading and writing comments, summarizing, and porting binary PCKs.
 - **Like SPK files, binary PCKs support multiple data representations (“data types”).**
 - » **Type 2: Chebyshev polynomials for Euler angles, angular velocity obtained by differentiation, constant interval length.**
 - » **Type 3: Separate Chebyshev polynomials for Euler angles and their derivatives, variable interval length.**
- **Binary PCKs are limited to storing orientation data.**
 - Applications that require shape data must also load a text PCK.
- **Binary PCKs are available for the Earth and Moon.**
 - The orientation data provided by these kernels are much more accurate than those provided by generic text PCKs based on the IAU/IAG reports.
 - These kernels are the topic of the tutorial on high-accuracy orientation data and associated frames for the Earth and Moon.



Interface Routines - 1

Navigation and Ancillary Information Facility

- **Call FURNISH to load PCKs.**
 - CALL UNLOAD or KCLEAR to unload them.
- **Call SXFORM to return a state transformation.**
 - Returns 6x6 matrix (attitude and angular velocity)

```
CALL SXFORM ( FROM, TO, ET, XFORM )  
sxform_c ( from, to, et, xform );  
cspice_sxform, from, to, et, xform  
xform = cspice_sxform ( from, to, et )
```

- **Call PXFORM to return a position transformation.**
 - Returns 3x3 matrix (attitude only)

```
CALL PXFORM ( FROM, TO, ET, RMAT )  
pxform_c ( from, to, et, rmat );  
cspice_pxform, from, to, et, rmat  
rmat = cspice_pxform ( from, to, et )
```

- **The older routines TISBOD, TIPBOD, and BODMAT are still supported, but NAIF recommends users not call them directly.**



Interface Routines - 2

Navigation and Ancillary Information Facility

- Call **BODVRD** or **BODVCD** to retrieve constants associated with a body. For example):

```
FORTRAN  CALL BODVRD ( 'SATURN' , 'RADII' , 3 ,      N , RADII )
          CALL BODVCD ( 699 ,    'RADII' , 3 ,      N , RADII )
```

```
C        bodvrd_c    ( "SATURN" , "RADII" , 3 ,      &n , radii ) ;
          bodvcd_c    ( 699 ,      "RADII" , 3 ,      &n , radii ) ;
```

```
IDL      cspice_bodvrd, 'SATURN' , 'RADII' , 3 , radii
          cspice_bodvcd, 699 ,      'RADII' , 3 , radii
```

```
MATLAB   radii = cspice_bodvrd ( 'SATURN' , 'RADII' , 3 )
          radii = cspice_bodvcd ( 699 ,      'RADII' , 3 )
```

- These calls retrieve values associated with the variable **BODY699_RADII**.
- The variable name is **case-sensitive**, so the string “RADII” above must be in upper case.

- You can use general kernel pool fetch routines to fetch data assigned to any non-standard names
 - GCPOOL, GDPOOL, GIPOOL



PCK Reference Frames - 1

Navigation and Ancillary Information Facility

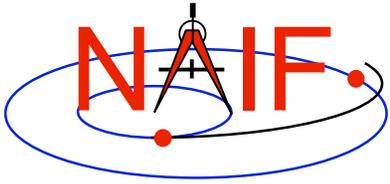
- **Many PCK reference frame specifications are built-in to SPICE.**
 - Just add orientation data (load PCK files) to use these frames. Examples:
 - » IAU frames: IAU_SATURN, IAU_TITAN, IAU_EARTH, IAU_MOON, etc.
 - » IERS frames: ITRF93
- **Other PCK frames are not built in and must be specified at run time by loading frame kernels, for example:**
 - **Body fixed frames for asteroids or “newer” natural satellites**
 - » See the Frames Required Reading for information on creating frame kernels that specify PCK reference frames.
 - **Lunar body-fixed frames: MOON_ME, MOON_PA**
 - » See the tutorial on “high-accuracy” orientation data and associated frames for the Earth and Moon” for details.
- **SPICE makes default associations between bodies and built-in PCK frames**
 - For example, the default PCK frames for the planets are IAU_MERCURY, IAU_VENUS, IAU_EARTH, etc.
 - You can look up the default PCK frame associated with a body by calling CNMFRM or CIDFRM.
 - » Neither is yet available in Mice.



PCK Reference Frames - 2

Navigation and Ancillary Information Facility

- **Some (mostly deprecated) SPICE routines implicitly use the default PCK frames (IAU_<body name>).**
- **You can change the default PCK frame associated with a body by loading a frame kernel that assigns a new default frame to that body.**
 - For the Earth or Moon, you can load a “frame association kernel” provided by NAIF.
 - For any body, you can load a frame kernel containing the assignment
`OBJECT_<body name>_FRAME = '<new default frame name>'`
» **Example:** `OBJECT_MOON_FRAME = 'MOON_ME'`
- **For high-accuracy work involving the Earth or Moon and any SPICE routines that use the default PCK frames, you normally would override the SPICE default frames by loading frame association kernels.**
 - Reference the tutorial on “high-accuracy” orientation data and associated frames for the Earth and Moon for details.



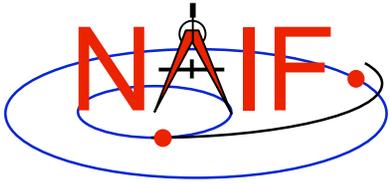
Navigation and Ancillary Information Facility

“Camera-matrix” Kernel CK

(Orientation or Attitude Kernel)

Emphasis on reading CK files

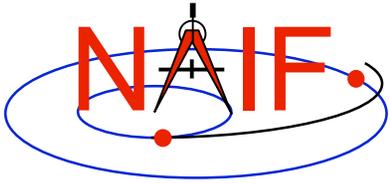
January 2009



CK File Contents - 1

Navigation and Ancillary Information Facility

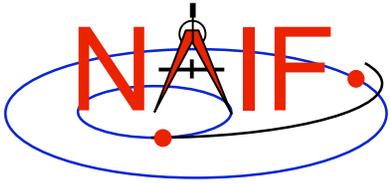
- **A CK file holds orientation data for a spacecraft or a moving structure on the spacecraft**
 - “Orientation data” \Rightarrow quaternions, from which orientation matrices are formed by SPICE software. These matrices are used to rotate position vectors from a base reference frame (the “from” frame) into a second reference frame (the “to” frame)
 - » In SPICE this is often called the “C-matrix, short for “Camera matrix”
 - Optionally may include angular velocity of rotation of the “to” frame with respect to the “from” frame
 - » Angular velocity vectors are expressed relative to the “from” frame.
- **A CK file should also contain comments—sometimes called metadata—that provide some details about the CK such as:**
 - the purpose for this particular CK
 - when and how it was made
 - what time span(s) the data cover



CK File Contents - 2

Navigation and Ancillary Information Facility

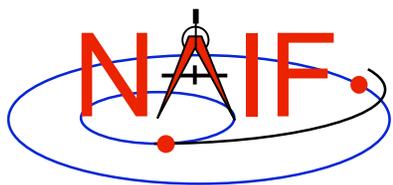
- **A single CK file can hold orientation data for one, or for any combination of spacecraft or their structures**
 - **Some examples**
 1. Huygens Probe
 2. Cassini Orbiter and its CDA instrument mirror
 3. Mars Express Orbiter, PFS scanner, Beagle Lander
 4. MRO orbiter, MRO high gain antenna, MRO solar arrays
- **In practice CKs usually contain data for just one structure**



CK File Varieties

Navigation and Ancillary Information Facility

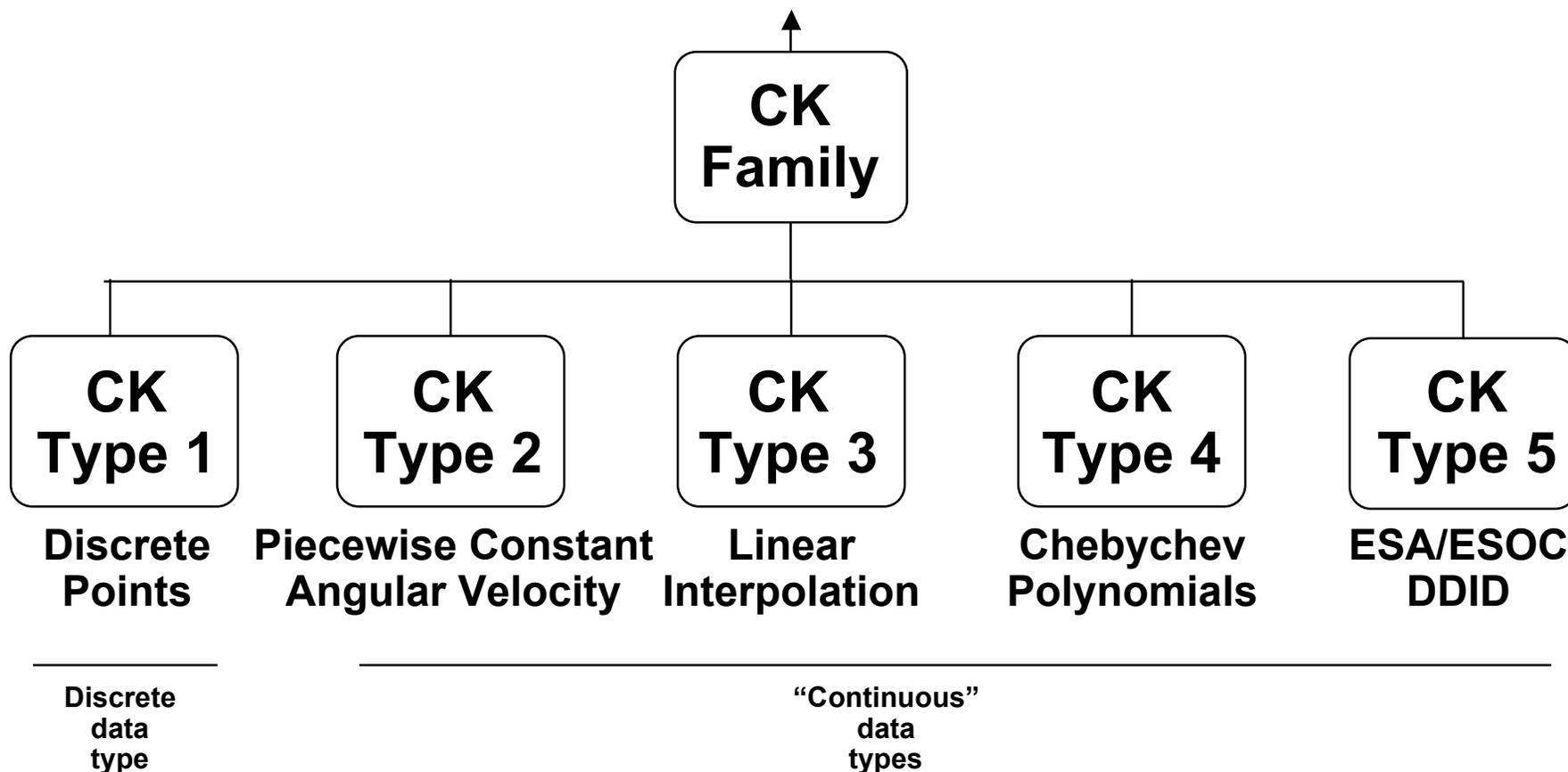
- **“Reconstruction” CK (also called “definitive” CK)**
 - A CK file can be made from orientation telemetry returned from a spacecraft or other structure
 - A CK might also be made from some process that improves upon the pointing determined from downlinked telemetry (“C-smithing”)
 - These kinds of files are generally used for science data analysis or spacecraft performance analysis
- **“Predict” CK**
 - A CK file can be made using information that predicts what the orientation will be some time in the future
 - » Input data usually come from a modeling program, or a set of orientation rules
 - This kind of file is generally used for engineering assessment, science observation planning, software testing and quick-look science data analysis
 - » If it has good fidelity, such a file might be used to “fill in the data gaps” of a reconstruction CK file
 - » In some cases (ESA in particular) the predict meets the reconstruction accuracy requirements; a true reconstruction CK is not produced

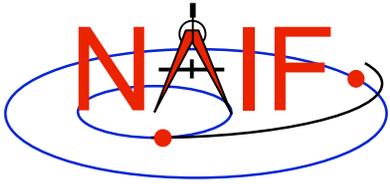


CK Data Types Concept

Navigation and Ancillary Information Facility

The underlying orientation data are of varying types, but the user interface to each of these CK types is the same.





Kernel Data needed

Navigation and Ancillary Information Facility

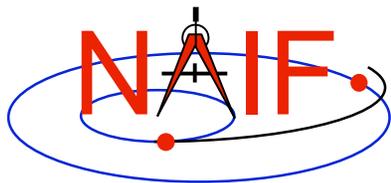
- **To get orientation (rotation matrix) and angular velocity of a spacecraft or one of its moving structures, one needs at least three SPICE kernel types: CK, SCLK and LSK. One may also need an FK, if he or she plans to access CK data via high level SPICE interfaces.**
 - **CK contains spacecraft or other structure orientation**
 - **SCLK and LSK contain time correlation coefficients used to convert between ephemeris time (ET) and spacecraft clock time (SCLK)**
 - » **Sometimes an LSK is not needed in this conversion, but best to have it available as it is usually needed for other purposes**
 - **FK associates reference frames with CK IDs**
 - » **Needed if high level SPICE interfaces are used to access CK data (see next page)**



What SPICE Routines Access CKs?

Navigation and Ancillary Information Facility

- **High-level SPICELIB routines are used more often than the “original” CK readers to access CK data. These high-level routines are:**
 - **Position or state transformation matrix determination**
 - » **PXFORM**: return a rotation matrix (3x3) from one frame to another, either of which can be a CK-based frame or have CK-based frames as “links” in its chain
 - » **SXFORM**: return a state transformation matrix (6x6) from one frame to another, either of which can be a CK-based frame or have CK-based frames as “links” in its chain
 - **Position or state vector determination**
 - » **SPKPOS**: return a position vector (3x1) in a specified frame, which can be a CK-based frame or have CK-based frames as “links” in its chain
 - » **SPKEZR**: return a state vector (6x1) in a specified frame, which can be a CK-based frame or have CK-based frames as “links” in its chain
- **Use of the above mentioned routines is discussed in the frames (FK and Using_frames) and SPK tutorials**
- **The “original” CK access routines are CKGP and CKGPAV**
 - **Use of these routines is described in this tutorial, along with topics applicable to all of the routines mentioned above**



One Example of How To Read a CK File

Navigation and Ancillary Information Facility

Initialization ... typically once per program run

Tell your program which SPICE files to use (“loading” files)

```
CALL FURNISH( 'lsk_file_name' )  
CALL FURNISH( 'sclk_file_name' )  
CALL FURNISH( 'ck_file_name' )
```

} Better yet, use a “furnsh kernel”
to load all the needed files.

Loop ... do as often as you need

Convert UTC to SCLK ticks *

```
CALL STR2ET( 'utc_string', tdb )  
CALL SCE2C ( spacecraft_id, tdb, sclkdp )
```

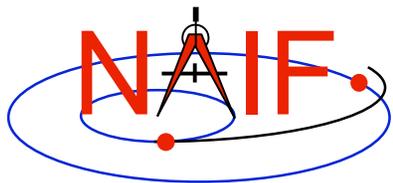
Get rotation matrix, or rotation matrix and angular velocity at requested time

```
or CALL CKGP (instid,sclkdp,tol,'ref_frame',cmat, clkout,found)  
CALL CKGPAV (instid,sclkdp,tol,'ref_frame',cmat,av,clkout,found)
```

inputs

outputs

* Although most spacecraft have a single on-board clock and this clock has the same ID as the spacecraft, the user should know which SCLK was used to tag data in a CK file to specify the correct ID in a call to SCE2C.



Arguments of CKGPAV

Navigation and Ancillary Information Facility

Inputs

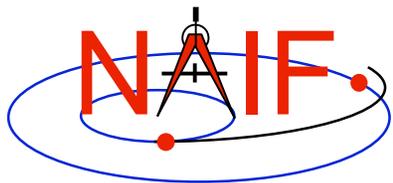
- instid** NAIF ID for the spacecraft, instrument or other structure for which the orientation is to be returned
- sclmdp** the time at which the orientation matrix and angular velocity are to be computed. The time system used is encoded spacecraft clock time (SCLK). The units are ticks since the zero epoch of the clock
- tol*** the tolerance, expressed as number of SCLK ticks, to be used in searching for and computing the orientation data
- ref_frame** the name of the reference frame with respect to which the orientation is to be computed. This is also called the “base” or “from” frame.

Outputs

- cmat** the 3x3 rotation matrix that you requested
- av** the angular velocity that you requested
- clkout** the exact time for which the orientation and angular velocity was computed
- found** the logical flag indicating whether the orientation and angular velocity data were found. Note that if the loaded CK file(s) do not contain angular velocity data, CKGPAV will return a FALSE found flag even if orientation could have been computed. If “found” is .FALSE., then the values of the output arguments “cmat” and “av” are undefined and **should not be used!**

Always check the FOUND flag returned by CKGPAV and CKGP!

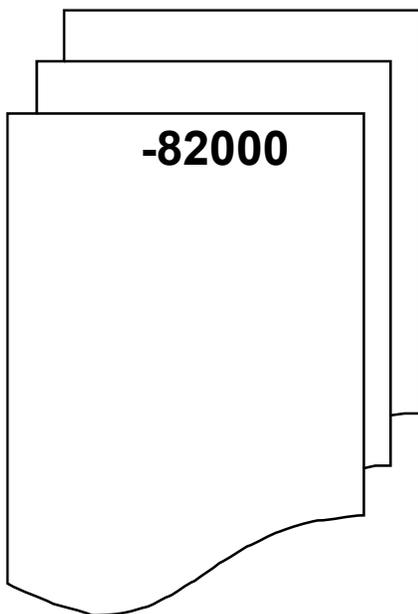
* tol is explained in detail later on



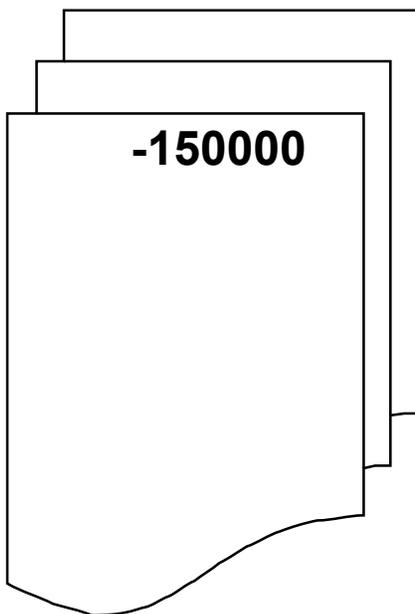
An Example of Project CK Files

Navigation and Ancillary Information Facility

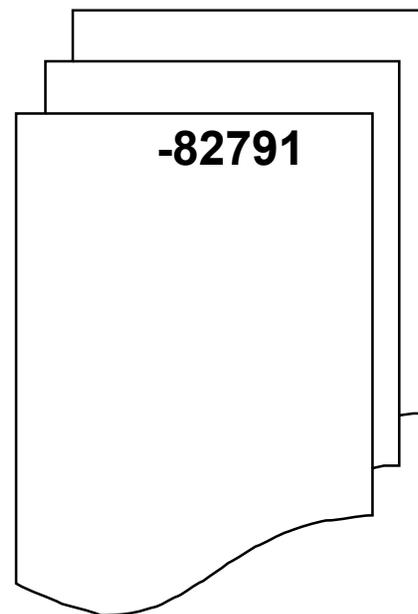
**CASSINI
SPACECRAFT**



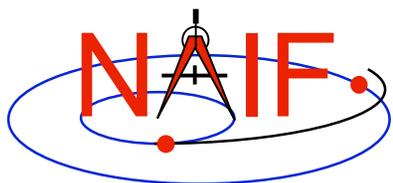
**HUYGENS
PROBE**



**CASSINI
CDA MIRROR**



A user's program must be able to load as many of these files as needed to satisfy his/her requirements. It is strongly recommended that such programs have the flexibility to load a list of CK files provided to the program at run time; this is easily accomplished using the Toolkit's FURNISH routine.

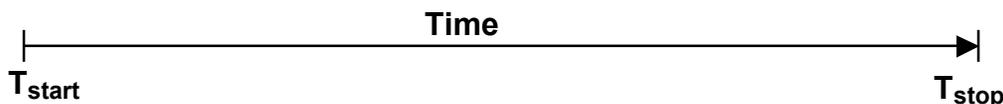


Sample CK Data Coverage - 2

Navigation and Ancillary Information Facility

Even though a project's CK production process may suggest that CK files provide continuous coverage for the interval of time for which they were generated, in reality this is rarely the case. CK files almost always contain gaps in coverage. Below is an example of this.

Coverage of ...



a CK file:
as appears in file name/comments



CK file segments:
as appears in ckbrief/spacit summary



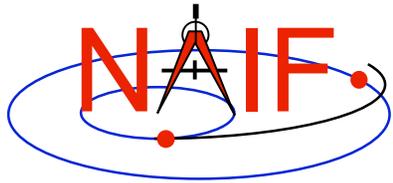
Segments with "continuous" data:
(Types 2 - 5)



Summary of pointing available to the CK reader for this CK file:



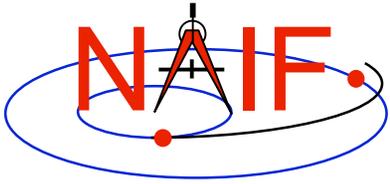
Blue line segments represent interpolation intervals—times when pointing will be returned and the FOUND flag set to "TRUE."



What is an Interpolation interval?

Navigation and Ancillary Information Facility

- **An interpolation interval is a time period for which the CK reader routines can compute and return pointing.**
 - For CK Types 3 and 5 the pointing is computed by interpolating between the attitude data points that fall within the interval.
 - For CK Type 2 the pointing within each interval is computed by extrapolating from a single attitude and associated angular velocity.
 - For CK Type 4 the pointing is computed by evaluating polynomials covering the interval.
 - For CK Type 1 (discrete pointing instances) the notion of an interpolation interval is not relevant.
- **The time periods between interpolation intervals are gaps during which the CK readers are not able to compute pointing.**
- **The interpolation intervals in Type 3 CK segments can be modified without changing the actual pointing data.**
 - The CKSPANIT and CKSMRG programs are used to make these changes.

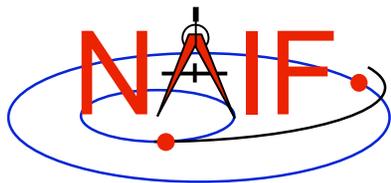


The Meaning of Tolerance - 1

Navigation and Ancillary Information Facility

- **The CKGP and CKGPAV routines use a time tolerance, “tol,” measured in ticks, in executing pointing lookups.**
 - No matter whether your CK is a discrete type (Type 1) or a continuous type (Types 2 - 5), if pointing information is not found within +/- tol of your pointing request time, no pointing will be returned and the “found flag” will be set to “FALSE.”
 - For Type 1 (discrete) CKs, the pointing instance **nearest*** to your request time will be returned, as long as it is within tol of your request time.
 - » If the nearest pointing instances on each side of your request time are equidistant from your request time, the later instance will be selected.
 - For Types 2 - 5 (continuous pointing), pointing for **exactly** your request time will be returned if this time falls anywhere within an interpolation interval.
 - For all Types, the time tag associated with the pointing data will also be returned.

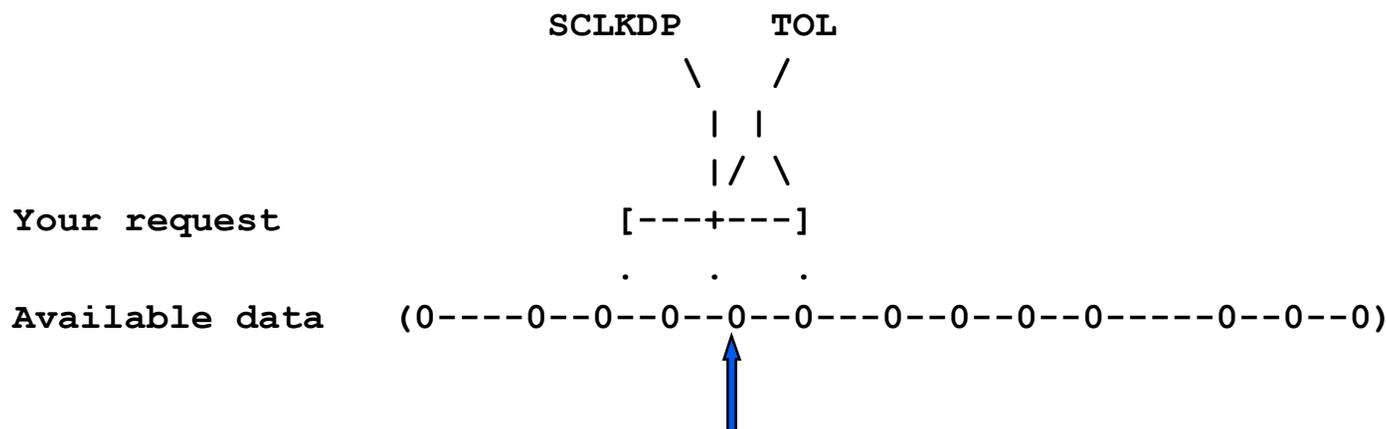
*Ignoring segment priority



The Meaning of Tolerance - 2

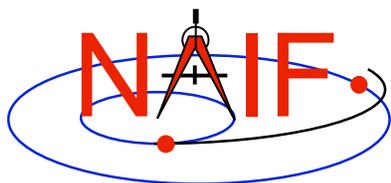
Navigation and Ancillary Information Facility

When reading a Type 1 CK containing **discrete** pointing instances



A SPICELIB CK reader returns this pointing instance

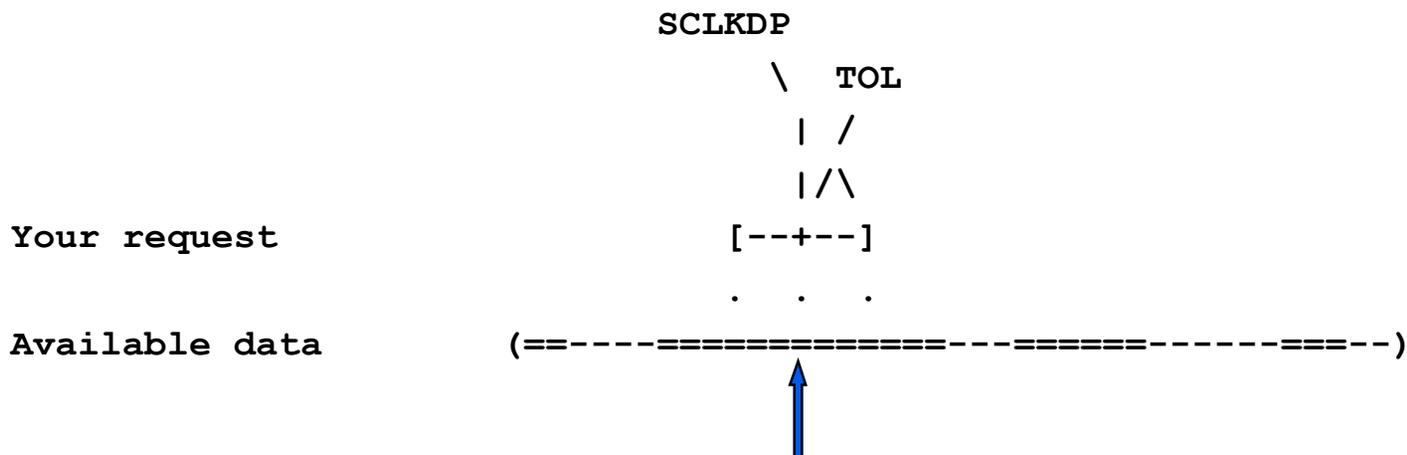
- “0” is used to represent discrete pointing instances (quaternions)
- “ () ” are used to represent the end points of a segment within a CK file
- SCLKDP is the time at which you have requested pointing
- TOL is the time tolerance you have specified in your pointing request
- The quaternions occurring in the segment need not be evenly spaced in time



The Meaning of Tolerance - 3

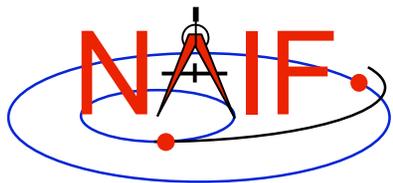
Navigation and Ancillary Information Facility

When reading a Type 2, 3, 4 or 5 CK (**continuous pointing**), with a “pointing request” that falls within a span of continuous pointing (an “interpolation interval”)



A SPICELIB CK reader returns pointing at precisely the requested epoch

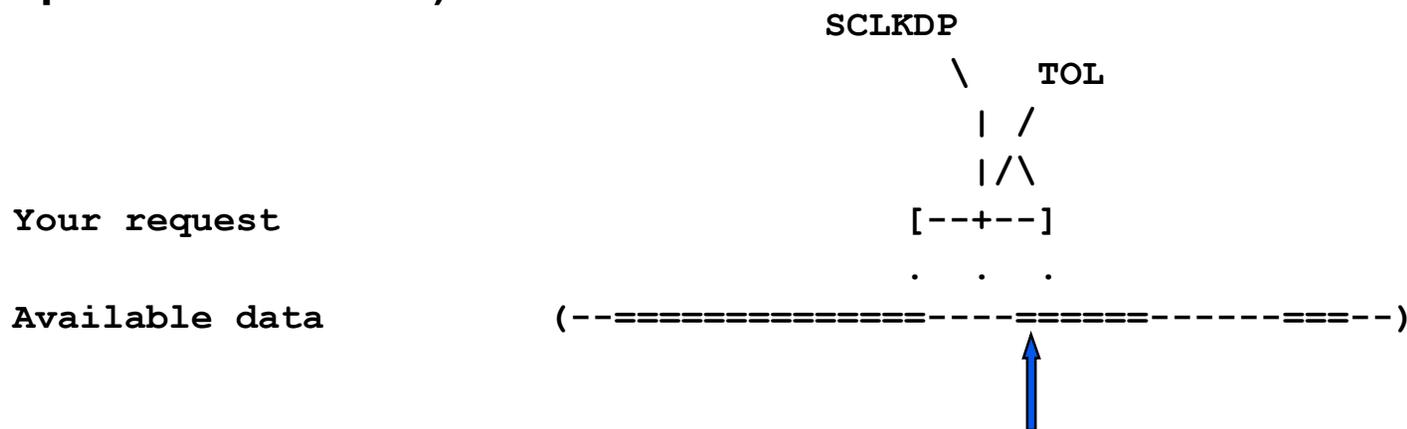
- “==” is used to indicate interpolation intervals of continuous pointing
- “ () ” are used to represent the end points of a segment within a CK file
- SCLKDP is the time at which you have requested pointing
- TOL is the time tolerance you have specified in your pointing request; for this particular case it does not come into play
- The quaternions occurring in the periods of continuous pointing need not be evenly spaced in time



The Meaning of Tolerance - 4

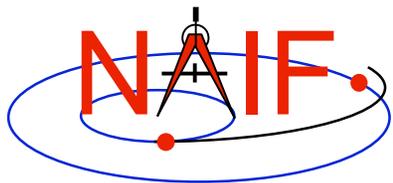
Navigation and Ancillary Information Facility

When reading a Type 2, 3, 4 or 5 CK (continuous pointing), with a “pointing request” that is NOT within a span of continuous pointing (an “interpolation interval”)



A SPICELIB CK reader returns pointing at the epoch closest to the request time, if this is within TOL of that request time.

- “==” is used to indicate interpolation intervals of continuous pointing
- “ () ” are used to represent the end points of a segment within a CK file
- SCLKDP is the time at which you have requested pointing
- TOL is the time tolerance you have specified in your pointing request
- The quaternions occurring in the periods of continuous pointing need not be evenly spaced in time



Summarizing a CK file - 1

Navigation and Ancillary Information Facility

- A brief summary of a CK can be made using the Toolkit utility **CKBRIEF**

- At your command prompt, type the program name followed by the names of CK, LSK and SCLK files (given in any order)

```
% ckbrief 07102_07107ra.bc naif0008.tls cas00106.tsc
```

```
CKBRIEF Version: 3.2.0, 2006-11-02. SPICE Toolkit  
Version: N0061.
```

```
Summary for: 07102_07107ra.bc
```

```
Object: -82000
```

| Interval Begin ET | Interval End ET | AV |
|--------------------------|--------------------------|----|
| 2007-APR-12 00:01:06.462 | 2007-APR-17 00:01:03.726 | Y |



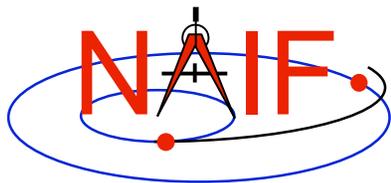
Summarizing a CK file - 2

Navigation and Ancillary Information Facility

- A detailed summary of a CK can be made using the Toolkit utility SPACIT. See the SPACIT User's Guide for details.

```
-----  
Segment ID      : CASSINI ATT: -Y TO TITAN, +Z - VELCTY  
Instrument Code: -82000  
Spacecraft     : Body -82, CAS  
Reference Frame: Frame 1, J2000  
CK Data Type   : Type 3  
  Description  : Continuous Pointing: Linear Interpolation  
Available Data : Pointing and Angular Velocity  
UTC Start Time : 2005 FEB 15 07:59:59.999  
UTC Stop Time  : 2005 FEB 15 08:59:59.998  
SCLK Start Time: 1/1487147147.203  
SCLK Stop Time : 1/1487150747.209  
-----
```

```
      .           .  
      .           .  
      etc.       etc.
```



Obtaining Coverage of CK File

Navigation and Ancillary Information Facility

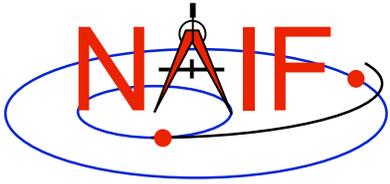
- **High-level subroutine interfaces for obtaining CK coverage information were introduced in the N0058 version of the SPICE Toolkit.**
 - **Call CKOBJ to find the set of structures for which a specified CK provides data.**
 - » **INPUT:** an CK file name and initialized SPICE integer “Set” data structure. The set may optionally contain ID codes obtained from previous calls.
 - » **OUTPUT:** the input set, to which have been added (via set union) the ID codes of structures for which the specified CK provides coverage.

```
CALL CKOBJ ( CK, IDS )
```

- **Call CKCOV to find the window of times for which a specified CK file provides coverage for a specified structure:**
 - » **INPUT:** a CK file name, structure ID code, flag indicating whether angular rates are needed, flag indicating whether coverage on segment or interval level is to be returned, tolerance, output time system, and initialized SPICE double precision “Window” data structure. The window may optionally contain coverage data from previous calls.
 - » **OUTPUT:** the input window, to which have been added (via window union) the sequence of start and stop times of coverage intervals of the specified CK, expressed as encoded SCLK or ET seconds past J2000.

```
CALL CKCOV ( CK, ID, NEEDAV, LEVEL, TOL, TIMSYS, COVER)
```

- **See the headers of these routines for example programs.**
- **Also see the CELLS, SETS and WINDOWS Required Reading for background information on these SPICE data types.**

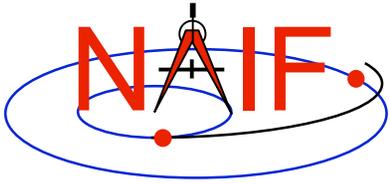


Make Use of CKCOV

Navigation and Ancillary Information Facility

- **When using high-level routines* that need orientation data from a C-kernel, it's often a good idea to first determine what are the valid interpolation intervals in your CK using CKCOV.**
 - If using multiple CKs, all of which are needed to construct a frame chain, call CKCOV for each one and then intersect the coverage windows.
- **Then check each time of interest for your geometry calculations against the window of valid intervals before proceeding onwards.**

* E.g. SPKEZR, SPKPOS, SXFORM, PXFORM, SINCPT

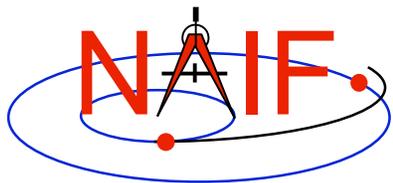


CK Utility Programs

Navigation and Ancillary Information Facility

- **The following CK utility programs are included in the Toolkit:**
 - CKBRIEF** summarizes coverage for one or more CK files
 - SPACIT** generates segment-by-segment summary of a CK file
 - MSOPCK** converts attitude data provided in a text file into a CK file.
- **These additional CK utility programs are provided on the NAIF Web site (<http://naif.jpl.nasa.gov/naif/utilities.html>)**
 - CKSLICER** subsets a CK file
 - CKSMRG** merges segments in a type 3 CK file (*)
 - CKSPANIT** modifies interpolation interval information stored in the segments of a Type 3 CK file
 - DAFCAT** concatenates together CK files (*)
 - prediCkt** creates a CK file containing data representing an orientation profile described by a set of orientation specification rules and a schedule defining when these rules are to be followed

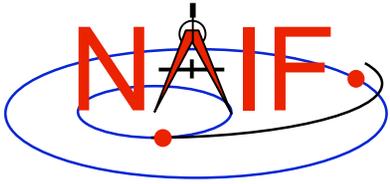
(*) DAFCAT and SKSMRG are frequently used together to first merge many CK files into a single file using DAFCAT and then merge segments inside the merged file using CKSMRG.



Additional Information on CK

Navigation and Ancillary Information Facility

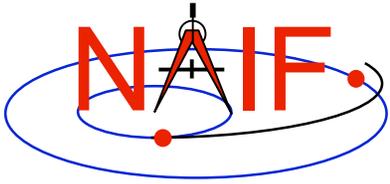
- **For more information about CK, look at the following documents**
 - CK Required Reading
 - headers for the CKGP and CKGPAV routines
 - Most Useful SPICELIB Routines
 - CKBRIEF and SPACIT User's Guides
 - Frames tutorials: FK and Using Frames ← *don't miss these*
 - Porting_kernels tutorial
- **Related documents**
 - SCLK Required Reading
 - Time Required Reading
 - Frames Required Reading
 - NAIF_IDS Required Reading
 - Rotations Required Reading



Navigation and Ancillary Information Facility

Backup

Examples of Problems Encountered When Using the CK Subsystem



Problems using CK - 1

Navigation and Ancillary Information Facility

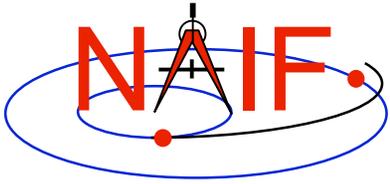
- **The file or files you loaded do not contain orientation data for the object of interest.**
 - Make sure the ID that you use in a call to CKGP or CKGPAV matches one in the CK file(s) you have loaded.
 - Make sure the frame that you specify in a call to SXFORM, PXFORM, SPKEZR, or SPKPOS is transformable to one available in the loaded CK files.
- **CKGP or CKGPAV returns a transformation matrix and/or angular velocity that does not appear correct.**
 - Probably the FOUND flag is “FALSE” and you are using data left over from a previous query. Remember to **always check the FOUND flag!** (If the FOUND flag is “TRUE” but the data seem bad, contact the data producer.)



Problems using CK - 2

Navigation and Ancillary Information Facility

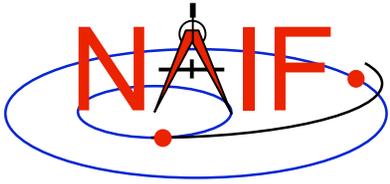
- **The file, or files, you loaded do not cover the time at which you requested orientation**
 - Check file coverage on the segment level by summarizing the file(s) using CKBRIEF or SPACIT
 - Check interpolation interval coverage using CKBRIEF with option “-dump,” or by examining comments provided in the comment area of the file - you may be asking for data within a coverage gap (outside of interpolation intervals)
- **One of the frames routines (SPKEZR, SPKPOS, SXFORM, PXFORM, SINCP) signals an error**
 - All frames routines read CK files using tolerance = 0
 - » For discrete CKs (Type 1) the orientation of a CK-based frame will be computed only if the time provided to a Frames routine exactly matches one of the times stored in the CK file; otherwise an error will be signaled.
 - » For continuous CKs (all but Type 1) the orientation of a CK-based frame will be computed only if the time provided to a frame routine falls within one of the interpolation intervals defined by the CK file; otherwise an error will be signaled.



Problems using CK - 3

Navigation and Ancillary Information Facility

- **You've confirmed not having any of the previously described problems, but the FOUND flag comes back "FALSE" when using CKGPAV, or SXFORM or SPKEZR signals a frame related error.**
 - **You are using a SPICE routine that expects angular velocity as well as orientation, but the CK segments available at your requested epoch don't contain angular velocity.**
 - » **Routines expecting AV are: CKGPAV, SXFORM, SPKEZR**
 - » **Routines not expecting AV are: CKGP, PXFORM, SPKPOS**



Problems using CK - 4

Navigation and Ancillary Information Facility

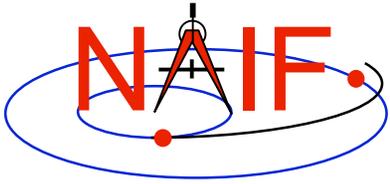
- **The FOUND flag comes back “TRUE” when using CKGPAV but returned angular velocity does not appear correct.**
 - While many other sources of the angular rate data, for example spacecraft telemetry, specify it relative to the spacecraft frame, SPICE CK files store it, and CKGPAV returns it, with respect to the base frame. So the CK style of returned angular velocity may be unexpected.
- **The FOUND flag comes back “TRUE” when using CKGP/CKPGAV but the quaternion computed from the returned transformation matrix via a call to M2Q does not appear correct.**
 - The quaternion returned by M2Q follows the SPICE style, which is different from the quaternion styles used by some other sources of orientation data, for example most spacecraft telemetry.
 - » See the headers of the M2Q and Q2M routines, and the Rotations Required reading document for more details.
 - » NAIF also prepared and can provide a “white paper” explaining differences between various quaternion styles commonly used in space applications.



Problems using CK - 5

Navigation and Ancillary Information Facility

- **You're trying to use a CK file that is not properly formatted for your computer**
 - You can read only a binary CK file with the CK subroutines; you can't read a "transfer format" file
 - » Although not required, binary CK files often have a name like "xxxxxx.bc"
 - » Although not required, transfer format CK files often have a name like "xxxxxx.xc"
 - If using Toolkit Version N0051 or earlier you must have the proper kind of CK binary file for your computer (a native binary file)
 - » Sun, HP, SGI and MAC (Motorola cpu) use the unix binary standard
 - » PC (Windows or Linux) uses its own binary standard
 - » The pair of utility programs named TOBIN and TOXFR, or the utility program SPACIT, can be used to port CK files between computers having incompatible binary standards



Navigation and Ancillary Information Facility

Frames Kernel FK

January 2009



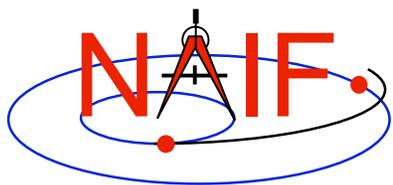
Introduction

Navigation and Ancillary Information Facility

What does the FRAMES subsystem do?

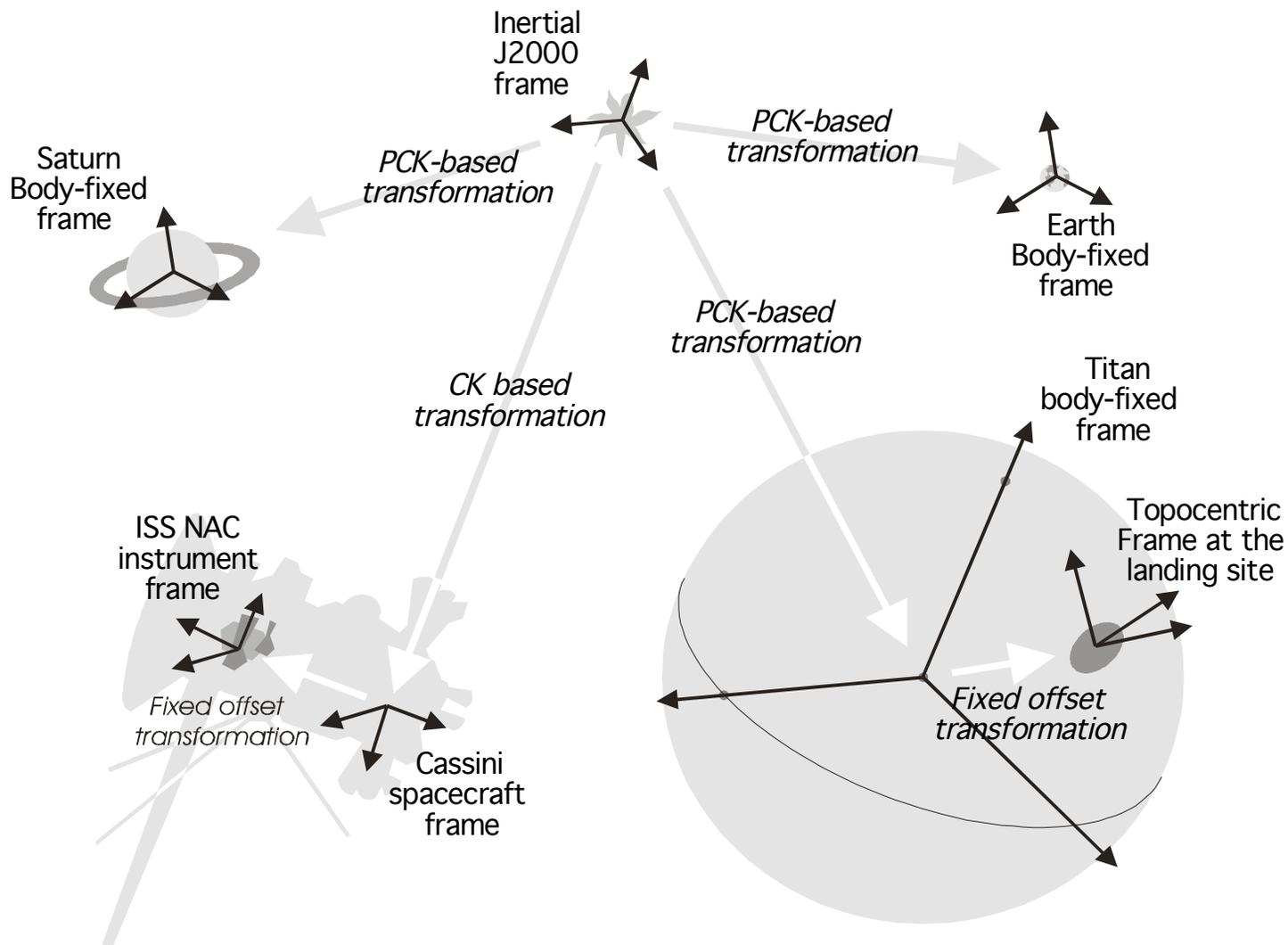
- It establishes relationships between reference frames used in geometry computations -- it "chains frames together."
- It connects frames with sources of their orientation specifications.
- Based on these relationships and orientation source information, it allows SPICE software to compute transformations between neighboring frames in the "chain," and to combine these transformations in the right order, thus providing an ability to compute orientation of any frame in the chain with respect to any other frame in the chain at any time. (*)

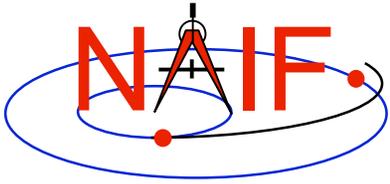
(*) If the complete set of underlying SPICE data needed to compute the transformation is available.



Sample Frame Tree and Chains

Navigation and Ancillary Information Facility





Frame Classes

Navigation and Ancillary Information Facility

Frame class

Examples

Inertial

- Earth Equator/Equinox of Epoch (J2000, ...)
- Planet Equator/Equinox of Epoch (MARSIAU, ...)
- Ecliptic of Epoch (ECLIPJ2000, ...)

Body-fixed

- Solar system body IAU frames (IAU_SATURN, ...)
- High accuracy Earth frames (ITRF93, ...)
- High accuracy Moon frames (MOON_PA, MOON_ME)

CK-based

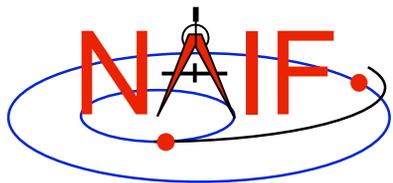
- Spacecraft (CASSINI_SC_BUS, ...)
- Moving parts of an instrument (MPL_RA_JOINT1, ...)

Fixed Offset

- Instrument mounting alignment (CASSINI_ISS_NAC, ...)
- Topocentric (DSS-14_TOPO, ...)

Dynamic

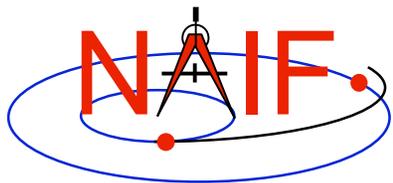
- See the Dynamic Frames tutorial



Frames Class Specifications

Navigation and Ancillary Information Facility

| <u>Frame class</u> | <u>Frame Defined in</u> | <u>Orientation provided in</u> |
|---------------------------|--------------------------------|---|
| Inertial | Toolkit | Toolkit |
| Bodyfixed | Toolkit or FK | PCK |
| CK based | FK | CK |
| Fixed offset | FK | FK |
| Dynamic | FK | Toolkit, or computed using FK, SPK, CK, and/or PCK |



FRAMES Subsystem Interfaces

Navigation and Ancillary Information Facility

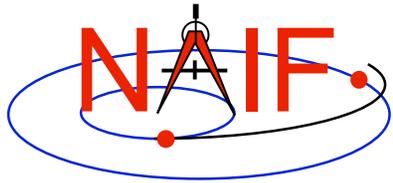
SXFORM/PXFORM returns state or position transformation matrix

```
CALL SXFORM ( 'FROM_FRAME_NAME', 'TO_FRAME_NAME', ET, MAT6x6 )  
CALL PXFORM ( 'FROM_FRAME_NAME', 'TO_FRAME_NAME', ET, MAT3X3 )
```

SPKEZR/SPKPOS returns state or position vector in specified frame

```
CALL SPKEZR ( BOD, ET, 'FRAME_NAME', CORR, OBS, STATE, LT )  
CALL SPKPOS ( BOD, ET, 'FRAME_NAME', CORR, OBS, POSITN, LT )
```

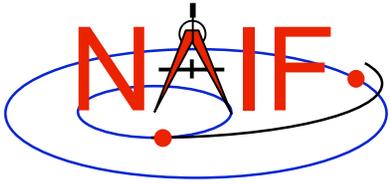
The above are FORTRAN examples, using SPICELIB modules.
The same interfaces exist for C, using CSPICE modules, and for Icy and Mice.



What are the Names of Frames?

Navigation and Ancillary Information Facility

- Refer to “NAIF IDs” Tutorial for an introduction to reference frame names and IDs
- Refer to FRAMES.REQ for the list of NAIF “built in” (hard coded) inertial and body-fixed frames
- Refer to a project’s Frames Kernel (FK) file for a list of frames defined for the spacecraft, its subsystems and instruments
- Refer to an earth stations FK for a list of frames defined for the DSN and other stations
- Refer to the moon FKs for descriptions of the body-fixed frames defined for the moon

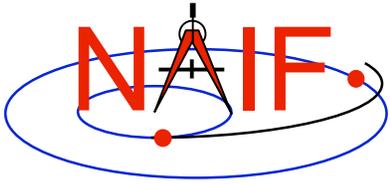


Frames Kernel File

Navigation and Ancillary Information Facility

- Uses the SPICE text kernel file standards
- Loaded using the FURNISH routine
- Usually contains comprehensive information about the defined frames in the text section(s) of the file
- Contains frame definition information consisting of a set of keywords in the data sections of the file. For example, the frame for the scanner assembly of the ASPERA instrument on the Mars Express spacecraft is defined as:

```
\begindata
  FRAME_MEX_ASPERA_SAF          = -41111
  FRAME_-41111_NAME             = 'MEX_ASPERA_SAF'
  FRAME_-41111_CLASS            = 3
  FRAME_-41111_CLASS_ID         = -41111
  FRAME_-41111_CENTER           = -41
  CK_-41111_SCLK                = -41
  CK_-41111_SPK                 = -41
\beginertext
```



Frame Definition Details - 1

Navigation and Ancillary Information Facility

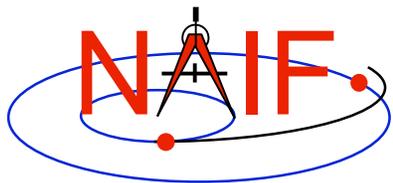
- **Frame ID** is an integer number used by the SPICE system as a “handle” in buffering and retrieving various parameters associated with a frame. In an FK it “glues” together the keywords defining the frame.
- **FRAME...NAME** assigns a name to the Frame ID code.
- **FRAME...CLASS** specifies the method by which the frame is related to some other frame — inertial, PCK, CK, TK, dynamic.



Frame Definition Details - 2

Navigation and Ancillary Information Facility

- **FRAME...CLASS_ID** is the number that connects a frame with the orientation data for it.
 - For body-fixed frames CLASS_ID is the ID of the natural body. It is used as input to PCK routines called by the Frame subsystem to compute orientation of the frame.
 - » Frame ID and CLASS_ID are not the same for the body-fixed frames defined in the Toolkit but they can be the same for frames defined in FK files.
 - For CK-based frames CLASS_ID is the CK structure ID. It is used as input to CK routines called by the Frame subsystem to compute orientation of the frame.
 - » Normally CLASS_ID of a CK-based frame is the same as the frame ID.
 - For fixed offset and dynamic frames CLASS_ID is the ID that is used to retrieve the frame definition keywords.
 - » CLASS_ID of a fixed offset or dynamic frame is the same as the frame ID
- **FRAME...CENTER** specifies the ephemeris object at which the frame origin is located.
- **CK...SCLK** identifies the spacecraft clock associated with the CK structure ID. Used by the frames subsystem to convert ET to SCLK used to look up CK data.
- **CK...SPK** identifies the ephemeris object associated with the CK structure ID (not currently used; included for future use).

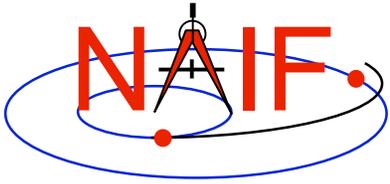


CK-Based Frames “Must Know”

Navigation and Ancillary Information Facility

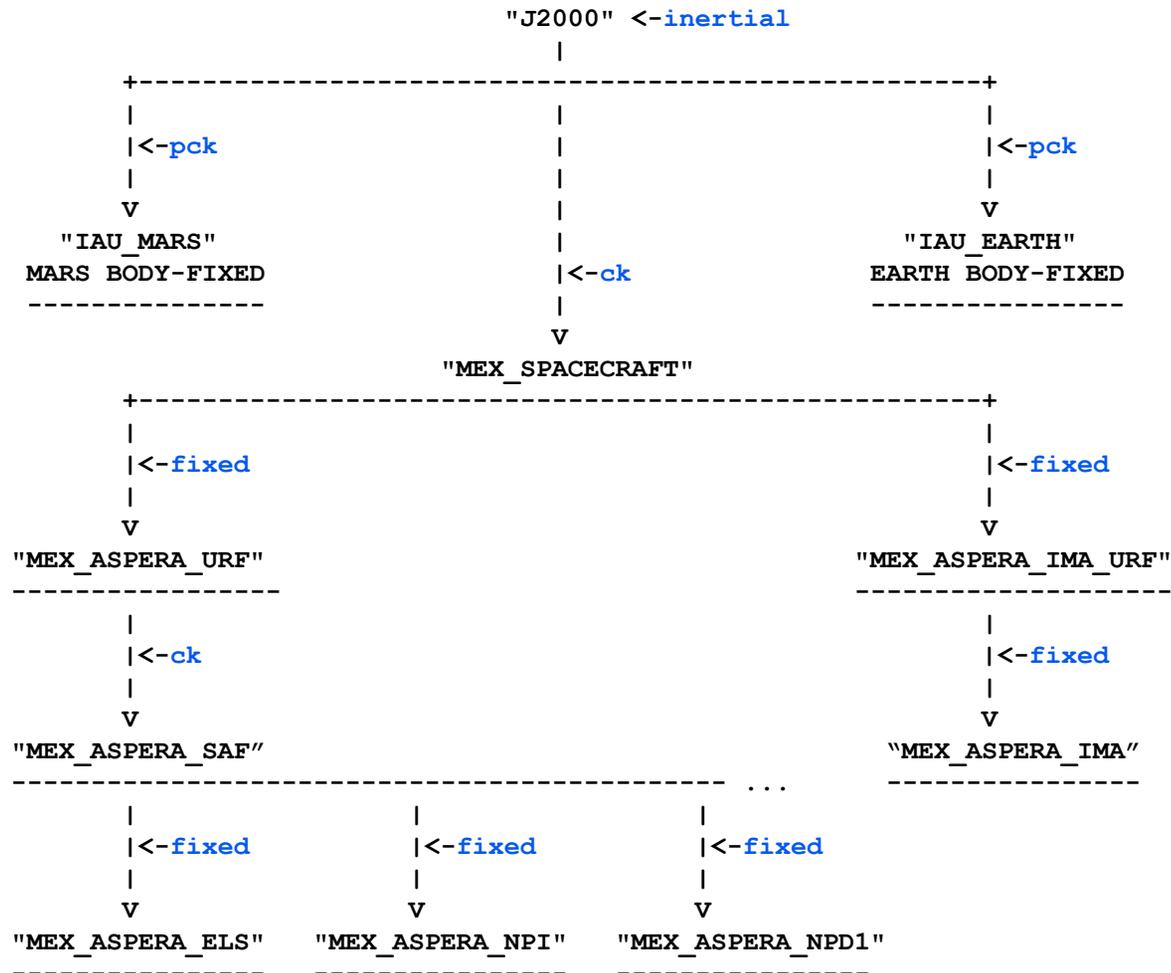
These are VERY IMPORTANT points you must understand!

- **The frames routines (SPKEZR, SPKPOS, SXFORM, PXFORM) all read CK files using tolerance = 0**
 - For **discrete** CKs the orientation of a CK-based frame will be computed only if the time provided to a Frames routine exactly matches one of the times stored in the CK file; otherwise an error will be signaled.
 - For **continuous** CKs the orientation of a CK-based frame will be computed only if the time provided to a Frames routine falls within one of the interpolation intervals defined by the CK file; otherwise an error will be signaled.
- **Using SPKEZR or SXFORM requires CKs with angular rates**
 - Since these routines return a state vector (6x1) or state transformation matrix (6x6), angular rates must be present in the CK in order to compute vectors and matrices; if rates are not present, an error will be signaled.
 - SPKPOS and PXFORM, which return a position vector (3x1) and a position transformation matrix (3x3) respectively, can be used instead because they require only orientation data to be present in the CK.
- **Ephemeris time input to Frames routines is converted to SCLK to access CKs**
 - SCLK and LSK kernels must be loaded to support this conversion.
 - SCLK ID is specified in one of the CK frame definition keywords; if not, it's assumed to be the Frame ID divided by a 1000.

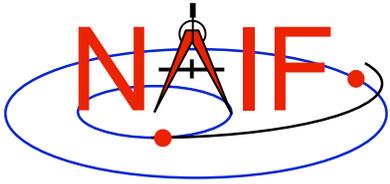


Frame Tree Example: ASPERA Instrument on Mars Express

Navigation and Ancillary Information Facility



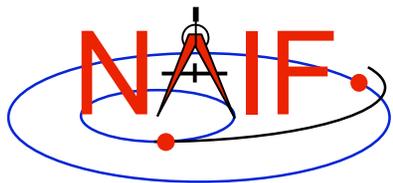
Blue text indicates frame class



Navigation and Ancillary Information Facility

Using the Frames Subsystem

January 2009



What is the Power of Frames?

Navigation and Ancillary Information Facility

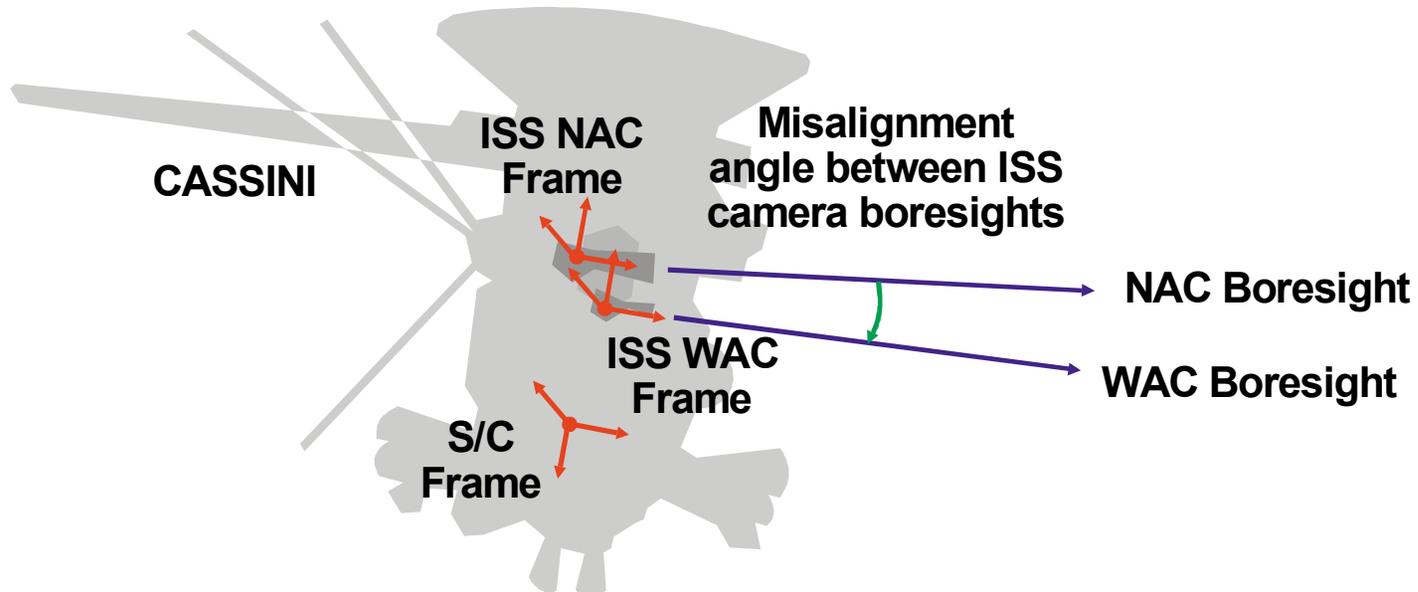
- The “power” of the Frames capability stems from the SPICE system’s ability to construct complex reference frame transformations with no programming effort required of you - the end user
 - But your selecting and loading the needed kernels is crucial
- The principal benefit from the Frames capability is obtained through the main SPK subsystem interfaces (SPKEZR and SPKPOS) and the Frames subsystem interfaces (SXFORM and PXFORM)
- The remaining pages illustrate typical use of frames
- Several **VERY IMPORTANT** usage issues are mentioned in the core Frames tutorial (fk.*); be sure to also read that.

In SPICE terminology: “reference frame” \neq “coordinate system”



Offset Between Instruments

Navigation and Ancillary Information Facility



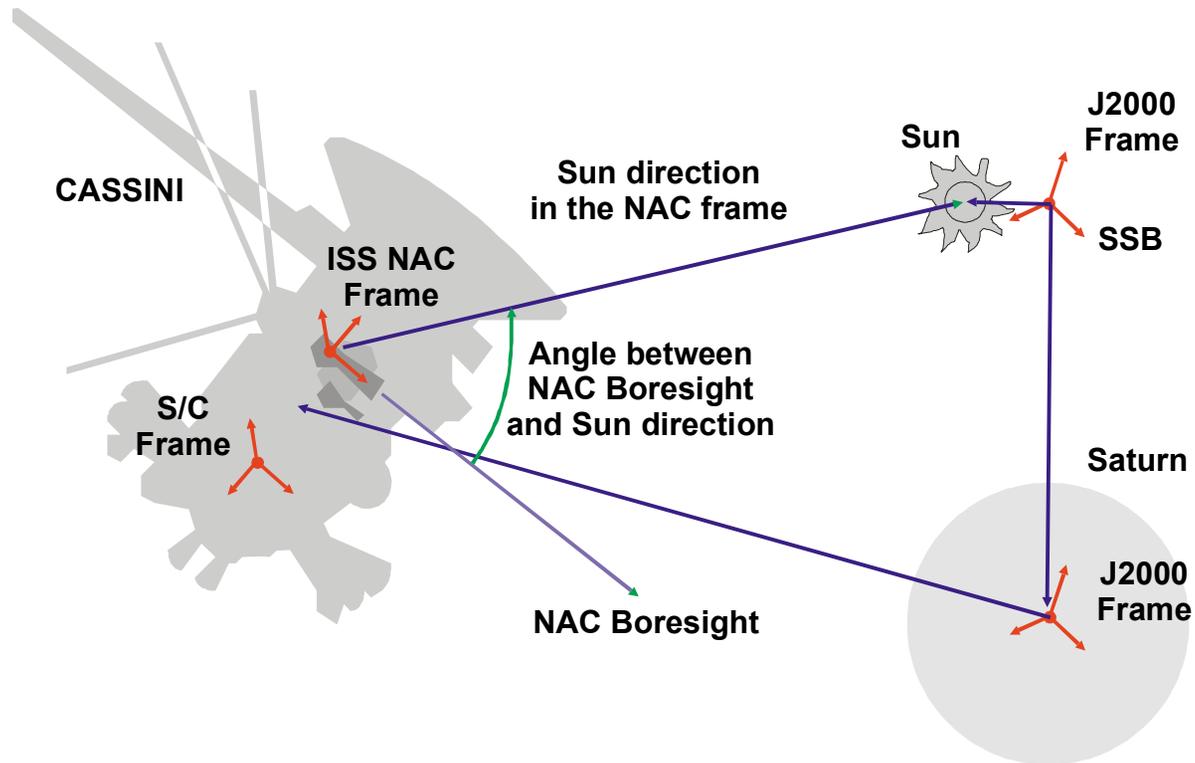
Compute the angular separation between the ISS Narrow Angle Camera and Wide Angle Camera boresights:

```
C Retrieve the matrix that transforms vectors from NAC to WAC frame
CALL PXFORM( 'CASSINI_ISS_NAC', 'CASSINI_ISS_WAC', ET, MAT )
C Transform NAC boresight to WAC frame and find separation angle
CALL MXV ( MAT, NAC_BORESIGHT_nac, NAC_BORESIGHT_wac )
ANGLE = VSEP( NAC_BORESIGHT_wac , WAC_BORESIGHT_wac )
```



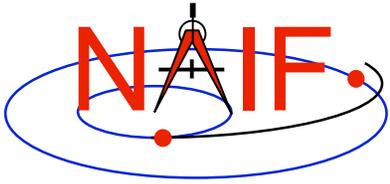
Angular Constraints

Navigation and Ancillary Information Facility



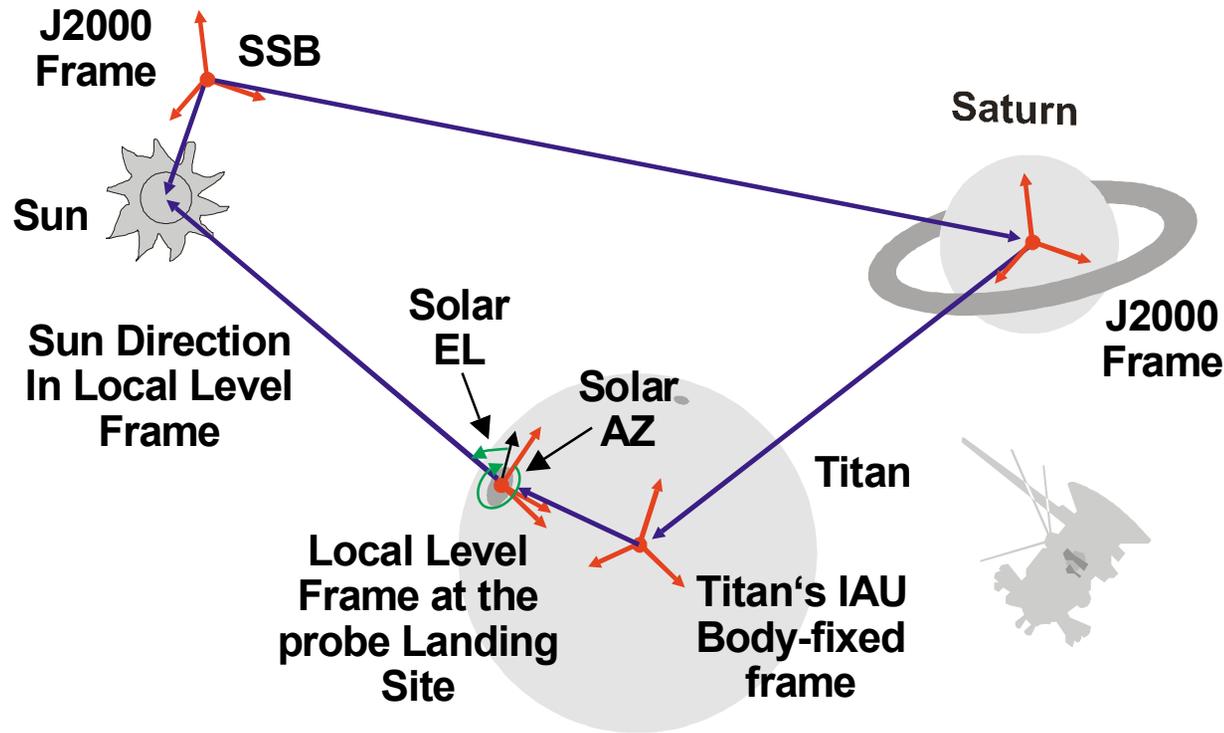
Check whether the angle between camera boresight and direction to Sun is within allowed range:

```
CALL SPKPOS( 'SUN', ET, 'CASSINI_ISS_NAC', 'LT+S', 'CASSINI', SUNVEC, LT )
ANGLE = VSEP( NAC_BORESIGHT_nac, SUNVEC )
IF ( ANGLE .LE. CONSTRAINT ) WRITE(*,*) 'WE ARE IN TROUBLE!'
```



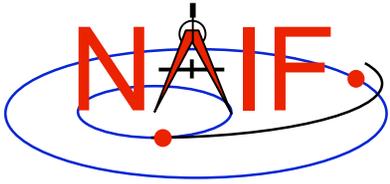
Angles at the Surface

Navigation and Ancillary Information Facility



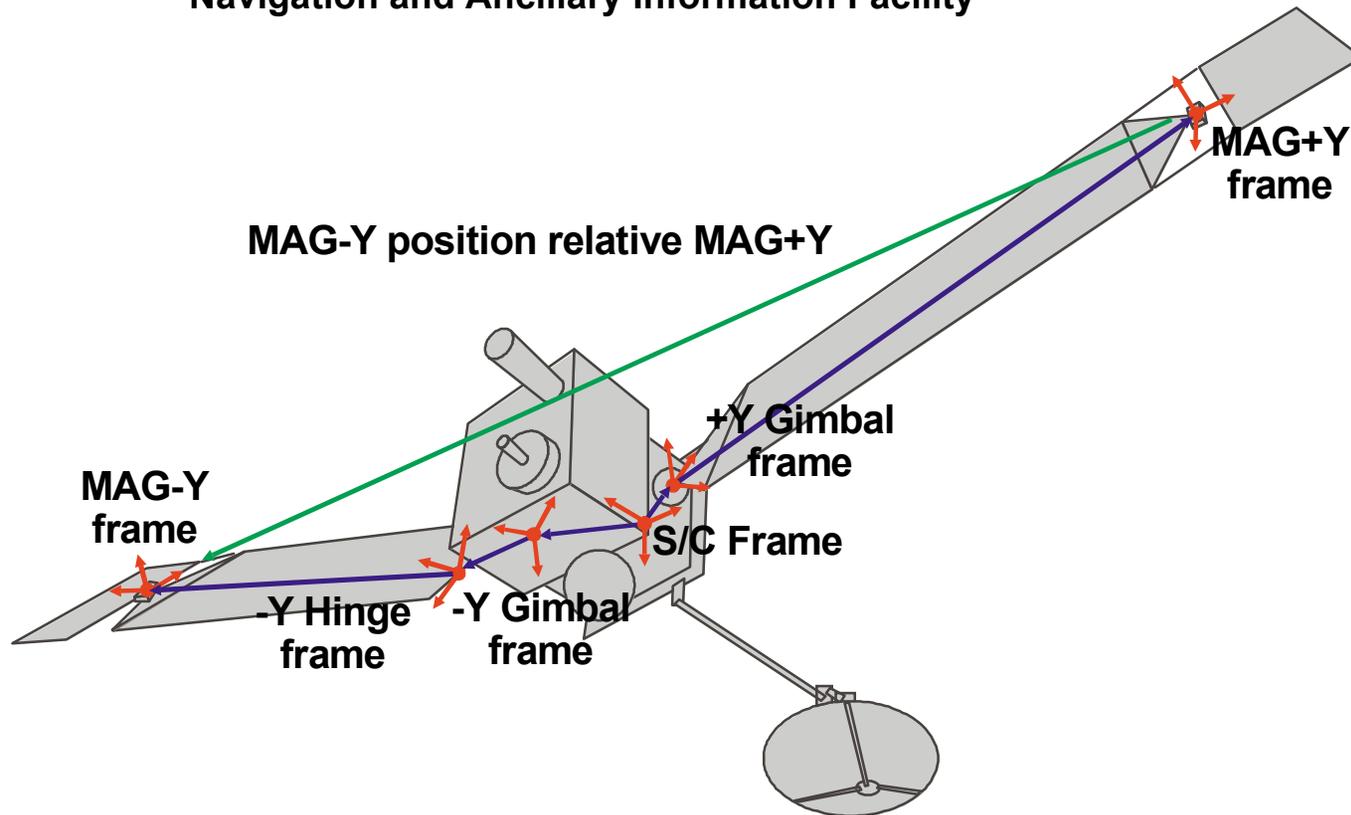
Compute solar azimuth and elevation at the Huygens probe landing site

```
CALL SPKPOS ('SUN', ET, 'HUYGENS_LOCAL_LEVEL', 'LT+S', 'HUYGENS_PROBE', SUNVEC, LT)
CALL RECLAT(SUNVEC, R, AZIMUTH, ELEVATION)
ELEVATION = -ELEVATION
IF (AZIMUTH .LT. 0.D0) THEN
    AZIMUTH = AZIMUTH + TWOPI()
ENDIF
```



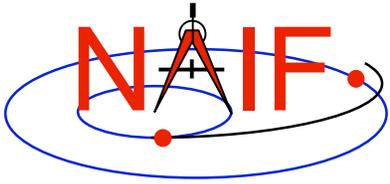
Relative Position of Sensors

Navigation and Ancillary Information Facility



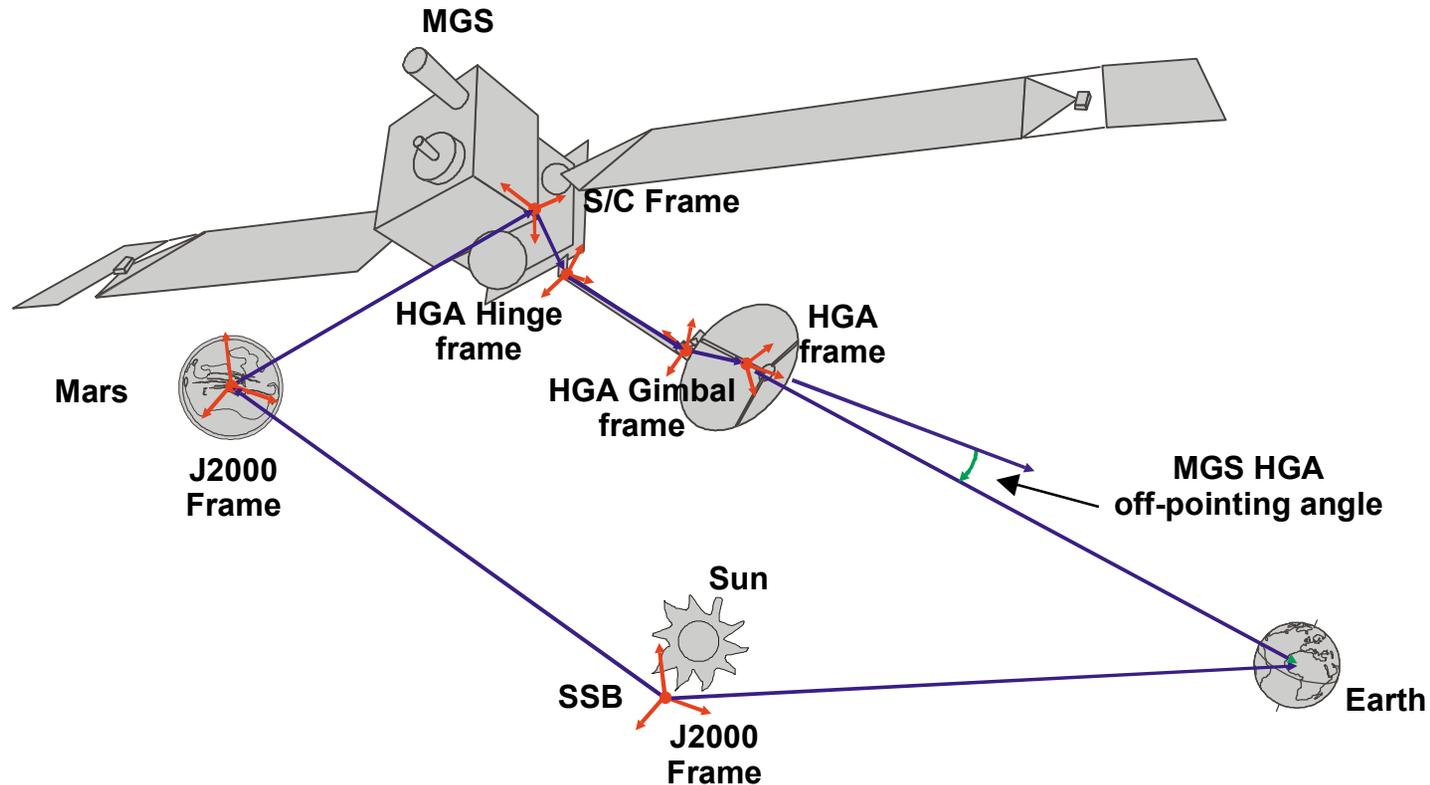
Find the position of one MGS MAG sensor with respect to the other in the MGS s/c frame. Also find the relative orientation of sensors:

```
CALL SPKEZR('MGS_MAG-Y', ET, 'MGS_SPACECRAFT', 'NONE', 'MGS_MAG+Y', STATE, LT)  
CALL PXFORM('MGS_MAG_+Y_SENSOR', 'MGS_MAG_-Y_SENSOR', ET, MAT)
```



Manipulators - 1

Navigation and Ancillary Information Facility



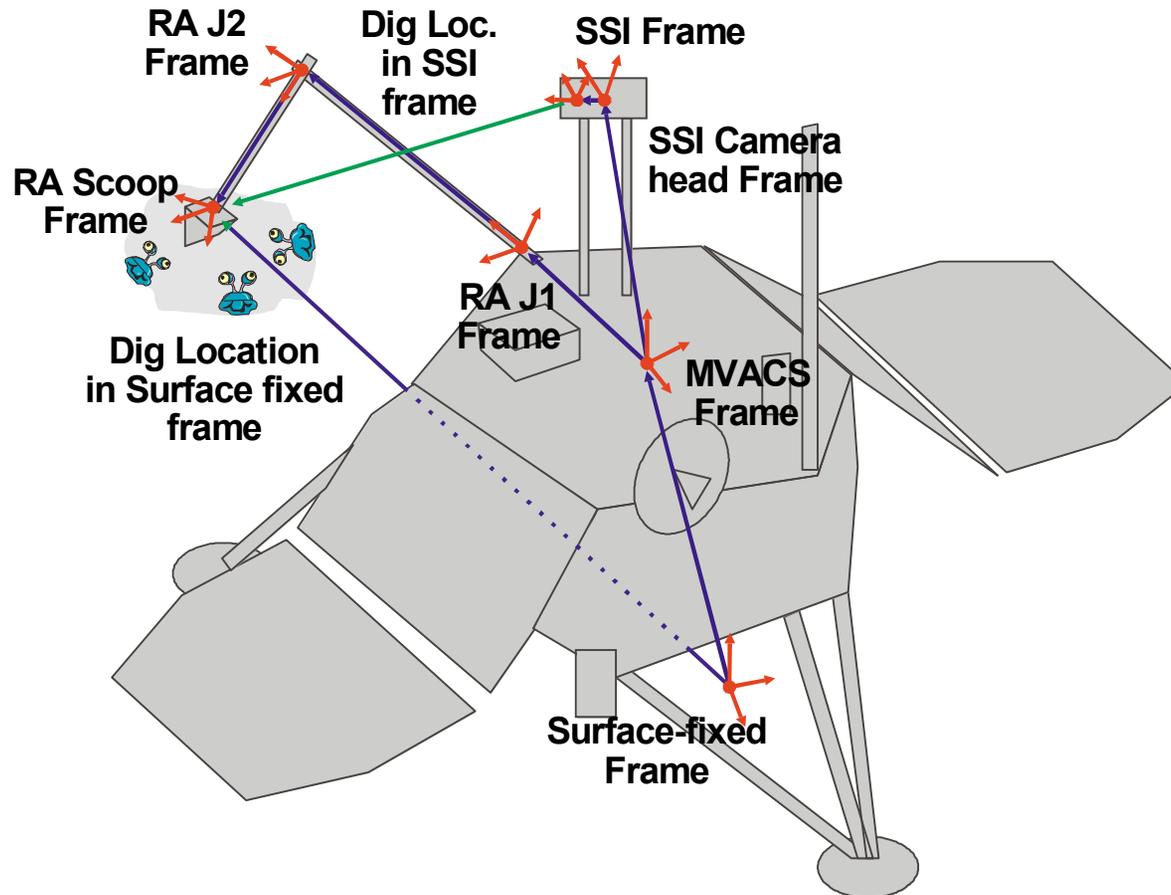
Compute the angle between the direction to Earth and the MGS HGA boresight:

```
CALL SPKEZR( 'EARTH', ET, 'MGS_HGA', 'LT+S', 'MGS', EARTH_STATE, LT )
ANGLE = VSEP( HGA_BORESIGHT, EARTH_STATE )
```



Manipulators - 2

Navigation and Ancillary Information Facility

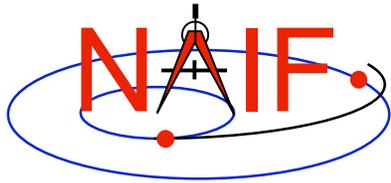


Compute the dig location in MPL surface-fixed and camera left eye frames:

```
CALL SPKEZR( 'MPL_RA_SCOOP', ET, 'MPL_SURFACE_FIXED', 'NONE', 'MPL_SURF', ST1, LT )
```

```
CALL SPKEZR( 'MPL_RA_SCOOP', ET, 'MPL_SSI_LEFT', 'NONE', 'MPL_SSI', ST2, LT )
```

Using Frames



Navigation and Ancillary Information Facility

Dynamic Reference Frames

January 2009



Topics

Navigation and Ancillary Information Facility

- **Introduction to Dynamic Reference Frames**
- **Terminology**
- **Parameterized Dynamic Reference Frames**
- **Defining Dynamic Reference Frames**
 - Two-Vector Frame Concepts
 - Two-Vector Frame Examples
 - "Of-Date" Frames
 - Euler Frames
 - Frozen Dynamic Frames
 - Inertial Dynamic Frames
- **Generic Dynamic Reference Frame Kernel**
- **Backup**

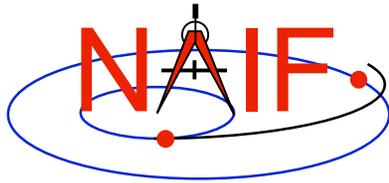


Introduction to Dynamic Frames - 1

Navigation and Ancillary Information Facility

- **The Dynamic Reference Frames subsystem is an extension to the original SPICE Frames system.**
- **What are "dynamic reference frames"?**
 - **Dynamic reference frames ("dynamic frames" for short) have time-dependent orientation.**
 - **Dynamic frames are specified via a frame kernel (FK).**
 - **CK and PCK frames are not considered to be dynamic frames (although they are time-varying).**
- **The Dynamic Frames capability enables the SPICE system to conveniently use a wide variety of frames that are not "built in" to SPICE. Examples include:**
 - **Nadir-oriented frame for planetary orbiter**
 - **Geocentric Solar Ecliptic (GSE)**
 - **Solar Magnetic (SM)**

(continued on next page)



Introduction to Dynamic Frames - 2

Navigation and Ancillary Information Facility

- **Spacecraft-centered roll-celestial frame**
- **Geocentric Solar Magnetospheric (GSM)**
- **Geomagnetic (MAG)**
 - » **Using constant north centered geomagnetic dipole**
 - » **Using dipole direction defined by time-dependent Euler angles**
- **Geocentric Solar Equatorial (GSEQ)**
- **Solar Equatorial frame for any ephemeris object**
- **Orbital frame for any ephemeris object**
- **Earth mean equator and equinox of date**
- **Earth true equator and equinox of date**
- **Earth mean ecliptic and equinox of date**
- **RTN ("radial, tangential, normal") frames**
- **And many more...**



Introduction to Dynamic Frames - 3

Navigation and Ancillary Information Facility

- **Using already defined dynamic frames in a SPICE-based program is straightforward.**
 - **At program initialization:**
 - » **Load one or more dynamic frame kernels to make the frame definitions known to SPICE.**
 - » **Load any kernels on which the dynamic frames depend.**
 - **Some dynamic frames are defined using data from SPK, FK, PCK, CK or other SPICE kernels.**
 - **Then, refer to the dynamic frame or frames by name in calls to SPICE routines**
 - » **Just as you would do with built-in frames such as "J2000."**



Introduction to Dynamic Frames - 4

Navigation and Ancillary Information Facility

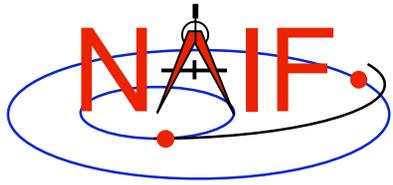
- » For example, find the 6x6 matrix to transform states from the J2000 frame to the Geocentric Solar Ecliptic (GSE) frame at the TDB epoch given by ET1.

```
CALL SXFORM( 'J2000', 'GSE', ET1, XFORM )
```

- » Or look up the state of Jupiter relative to the earth in the GSE frame:

```
CALL SPKEZR( 'JUPITER', ET1, 'GSE',  
            'NONE', 'EARTH', STATE, LT )
```

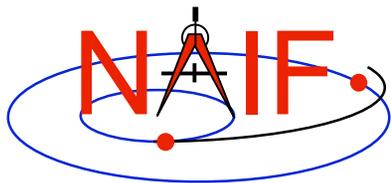
- You can refer to dynamic frames in SPK or CK files, for example:
 - When you create an SPK file, you can have an SPK segment reference its ephemeris data to the true earth equator and equinox of date reference frame.
 - » However, some restrictions apply to use of dynamic frames in SPICE kernels (see Backup slides).



Introduction to Dynamic Frames - 5

Navigation and Ancillary Information Facility

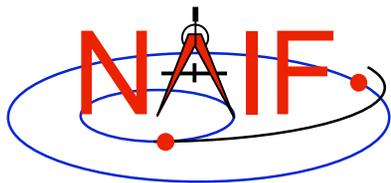
- **To define dynamic frames via a frame kernel, a fairly detailed understanding of the SPICE dynamic frame capability is required.**
- **A good understanding of the basic SPICE system (in particular, the SPK and Frame systems) is also a prerequisite for defining dynamic frames.**
- **See the Frames Required Reading for the most detailed documentation available.**
- **The rest of this tutorial is concerned with:**
 - explaining the SPICE dynamic frames capability.
 - showing how to create dynamic frame kernels.
 - » **We present many frame definition examples.**



Terminology - 1

Navigation and Ancillary Information Facility

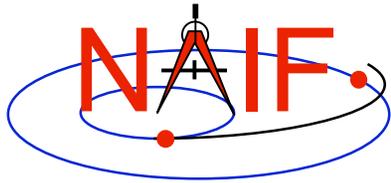
- **Terms involving reference frames and vectors:**
 - "Frame" is an abbreviation for "reference frame."
 - A frame can be thought of as a set of three mutually orthogonal, unit-length vectors.
 - » These vectors are called "basis vectors." The lines containing the basis vectors are the "axes" of the frame.
 - » The basis vectors indicate the "positive" axis directions; we label these vectors +X, +Y, and +Z. The negatives of these vectors are labeled -X, -Y, and -Z.
 - » We number the axes as follows:
X = axis 1; Y = axis 2; Z = axis 3
 - All of the frames we'll deal with are "right-handed": this means +Z is the cross product +X x +Y.
 - A reference frame's orientation is always defined relative to another specified frame: the "base frame."



Terminology - 2

Navigation and Ancillary Information Facility

- **When we say that a frame is "time-dependent" or "time-varying," we mean:**
 - » **The orientation of the frame is time-dependent.**
 - » **Equivalently, the rotation between the frame and its base frame is time-dependent.**
- **By "evaluating" a frame or "evaluating the orientation of a frame," we mean computing the rotation between the frame and its base frame.**
 - » **An epoch is required in order to evaluate a dynamic frame.**
- **In the SPICE system, frames are considered to have "centers."**
 - » **The center of a frame is always an ephemeris object, something whose location can be specified with an SPK file.**
 - » **Frame centers come into play when light time corrections are used: the apparent orientation of a time-dependent frame as seen by an observer is affected by the one-way light time between the frame's center and the observer.**



Terminology - 3

Navigation and Ancillary Information Facility

- When we say that a vector is "aligned" with another vector, we mean that the angular separation between the two vectors is zero.
- We use the terms "defining a frame" and "specifying a frame" interchangeably. Both refer to creating a frame definition in a frame kernel.
- Other definitions:
 - The term "API" stands for "Application Programming Interface." This term refers to the set of SPICE routines that are intended to be called directly by SPICE-based programs.
 - The notation

$[\text{theta}]_n$

indicates a frame rotation of theta radians about axis n, where n is one of {1, 2, 3}. This transformation rotates vectors by $-\text{theta}$ radians about axis n.



Parameterized Dynamic Frames - 1

Navigation and Ancillary Information Facility

- **Parameterized dynamic frames**
 - This is the only frame definition style currently supported by the dynamic frames subsystem.
 - » Future versions of SPICE might support additional styles.
 - Frames are defined via parameterized formulas
 - » The code implementing the formulas is built into SPICE.
 - » The parameters are specified in a frame kernel.
 - Parameterized dynamic frames are grouped into frame "families". Each family corresponds to a distinct, parameterized geometric formula providing a frame definition. The families are:
 - » **Two-Vector Frames**
 - » **Mean Equator and Equinox of Date Frames**
 - » **True Equator and Equinox of Date Frames**
 - » **Mean Ecliptic and Equinox of Date Frames**
 - » **Euler Frames**



Parameterized Dynamic Frames - 2

Navigation and Ancillary Information Facility

- **Defining Parameterized Dynamic Frames**

- Parameterized Dynamic frames are defined using "keyword=value" assignments in a frame kernel.
- The following items must be specified in the frame definition:
 - » **Frame name**
 - » **Frame ID code**
 - The range 1400000-2000000 is reserved for people outside of the NAIF group
 - » **Class (=5 for dynamic frames)**
 - » **Class ID code (=frame ID code for dynamic frames)**
 - » **Frame center (=name or NAIF ID code for central body)**
 - » **Frame definition style (= 'PARAMETERIZED')**
 - » **Base frame**
 - Frame definition specifies mapping from dynamic frame to the base frame.
 - » **Frame family**
 - » **Family-specific assignments**



Parameterized Dynamic Frames - 3

Navigation and Ancillary Information Facility

» Rotation state

- Possible states are 'ROTATING' and 'INERTIAL'.
 - A frame is treated as rotating or inertial for the purpose of velocity transformations.
- The default dynamic frame rotation state is 'ROTATING'.
- For rotating two-vector and Euler frames, the rotation state assignment can be omitted from the frame definition.
- For "of-date" frames, the frame definition must either specify the rotation state or designate the frame as "frozen" at a specified epoch.

» Freeze epoch

- Presence of this optional assignment in a frame kernel indicates that the frame orientation, relative to the base frame, is held constant ("frozen") at the specified epoch.
- Most dynamic frames are not frozen.



Two-Vector Frame Concepts - 1

Navigation and Ancillary Information Facility

- **Two-vector frames are defined using two time-dependent vectors: the "primary" and "secondary" vectors.**
 - Each may be defined by a variety of geometric means:
 - » Position vector
 - » Target near point vector
 - » Velocity vector
 - » Constant vector
- **The user associates specified positive or negative axes of the two-vector frame with the primary and secondary vectors.**
 - Two-vector frames are always right-handed and have orthogonal axes, so two non-parallel vectors and associations of axes with these vectors suffice to define the orientation of a frame.

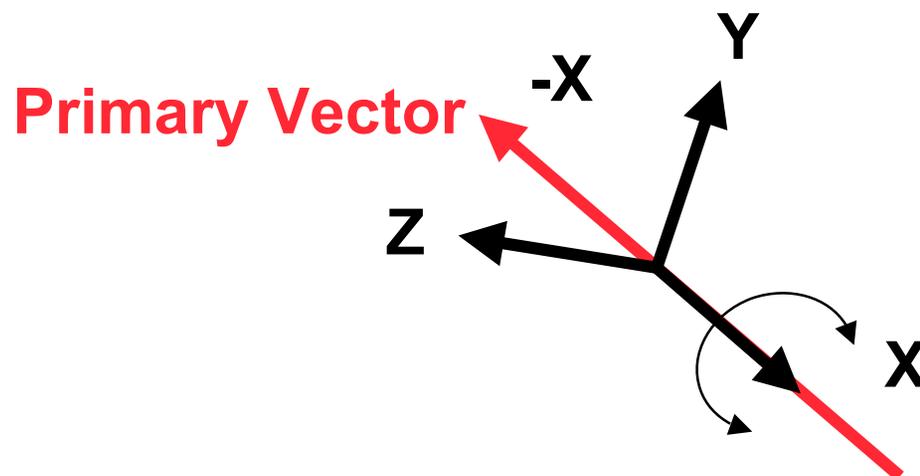


Two-Vector Frame Concepts - 2

Navigation and Ancillary Information Facility

- **Primary Vector**

- A specified positive or negative axis of the two-vector frame is aligned with this vector.
 - » The frame kernel creator assigns to this vector one of the axis designations $\{ +X, -X, +Y, -Y, +Z, -Z \}$.
- Two degrees of freedom of the frame orientation are removed by association of an axis with the primary vector. The third degree of freedom is the frame's rotation about the primary vector.
- Example: a frame's $-X$ axis is aligned with the primary vector:



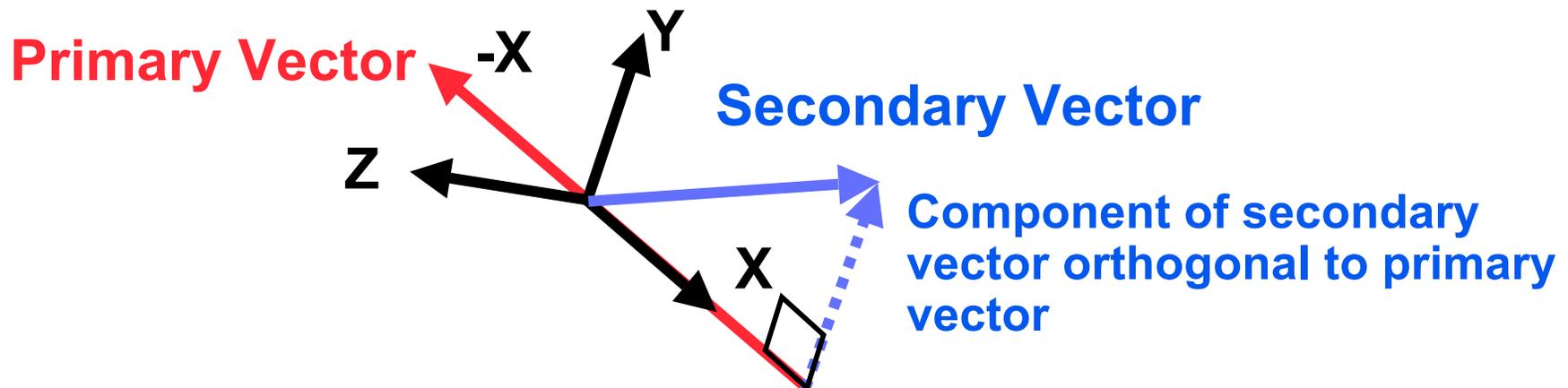


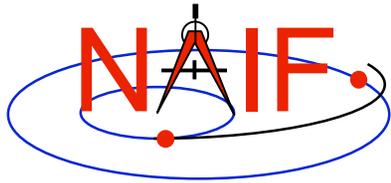
Two-Vector Frame Concepts - 3

Navigation and Ancillary Information Facility

- **Secondary Vector**

- A specified positive or negative axis of the two-vector frame is aligned with the component of the secondary vector orthogonal to the primary vector.
 - » The frame kernel creator associates with this vector one of the axis designations { +X, -X, +Y, -Y, +Z, -Z }, where the axis is orthogonal to that associated with the primary vector.
- Example, continued: the frame's +Y axis is associated with the secondary vector. The component of the secondary vector orthogonal to the primary vector is aligned with the frame's +Y axis. The secondary vector thus lies in the frame's X-Y plane.





Two-Vector Frame Concepts - 4

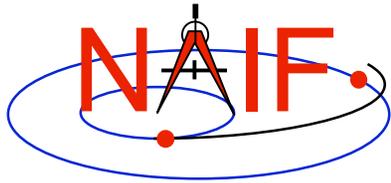
Navigation and Ancillary Information Facility

- **Secondary Vector, continued**

- Typically the secondary vector itself is not orthogonal to the primary vector.
- The secondary vector must be linearly independent of the primary vector.
 - » Near-degenerate geometry can lead to extreme loss of precision.
 - This problem can be difficult to diagnose.
 - » SPICE enforces independence using a default angular separation tolerance of 1 milliradian. The angular separation of the primary and secondary vectors may not differ from 0 or Pi radians by less than this tolerance.
 - » A frame kernel creator can specify a different tolerance value. The frame kernel assignment for this is:

```
FRAME_<frame_ID>_ANGLE_SEP_TOL = <tolerance>
```

where the tolerance is given in radians.
- Designers of two-vector frames should ensure that the primary and secondary vectors can't become nearly parallel for any realistic evaluation epoch.



Two-Vector Frame Concepts - 5

Navigation and Ancillary Information Facility

- **Position Vector**

- Is defined by the position of one ephemeris object relative to another. The frame kernel creator specifies:
 - » the target
 - » the observer
 - » the aberration correction
 - The vector may optionally be corrected for light time and stellar aberration.
- The epoch at which the position vector is computed is supplied via a call to a SPICE API routine:
 - » as an input to an SPK routine, e.g. SPKEZR, SPKPOS.
 - » as an input to a frame system routine, e.g. SXFORM, PXFORM.
- The reference frame relative to which the vector is expressed is not specified by the frame kernel creator.
 - » SPICE automatically selects this frame.



Two-Vector Frame Concepts - 6

Navigation and Ancillary Information Facility

- **Target Near Point Vector**

- Is defined as the vector from an observer to the nearest point on a specified extended target body to that observer. The frame kernel creator specifies:
 - » the target
 - » the observer
 - » the aberration correction
 - The vector may optionally be corrected for one-way light time and stellar aberration.
 - When one-way light time correction is used, both the position and orientation of the target body are corrected for light time.
- The extended target body is modeled as a triaxial ellipsoid.
 - » Size and shape data are given by a PCK.
- The epoch is supplied via a SPICE API call, as for position vectors.
- The reference frame relative to which the vector is expressed is not specified by the frame kernel creator.
 - » SPICE automatically selects this frame.



Two-Vector Frame Concepts - 7

Navigation and Ancillary Information Facility

- **Velocity Vector**

- Is defined by the velocity of a target ephemeris object relative to an observing ephemeris object. The frame kernel creator specifies:
 - » the target
 - » the observer
 - » the velocity reference frame
 - This frame may be distinct from the base frame.
 - Different velocity frame choices can lead to radically different two-vector frame definitions.
 - » the aberration correction
 - The velocity vector may optionally be corrected for one-way light time and stellar aberration.
 - Use of light time correction also implies evaluation of the velocity vector's frame at a light time corrected epoch: the epoch is corrected for light time between the velocity frame's center and the observer, if the velocity frame is non-inertial.
- The epoch is supplied via a SPICE API call, as for position vectors.

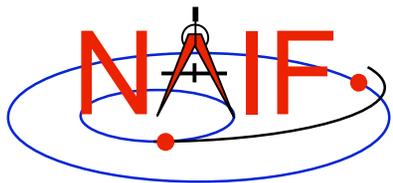


Two-Vector Frame Concepts - 8

Navigation and Ancillary Information Facility

- **Constant Vector**

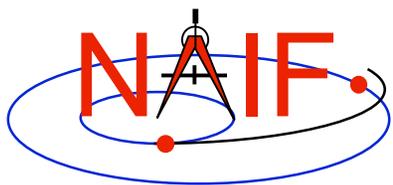
- The vector is constant in a frame specified by the kernel creator.
 - » The constant vector's frame may be time-dependent.
 - » This frame may be distinct from the base frame.
- The vector may be specified in a variety of coordinate systems.
 - » Cartesian
 - » Latitudinal
 - » Right ascension/declination (RA/DEC)
- An observer may optionally be associated with a constant vector for the purpose of defining aberration corrections.
 - » The orientation of the constant vector's frame may optionally be corrected for one-way light time between the frame's center and the observer: if the frame is non-inertial, it is evaluated at a light time corrected epoch.



Two-Vector Frame Concepts - 9

Navigation and Ancillary Information Facility

- » **A constant vector may optionally be corrected for stellar aberration due to motion of observer relative to solar system barycenter.**
 - **Stellar aberration can be specified without light time correction; the string indicating stellar aberration correction alone is**
'S'
 - **This correction specification is not supported elsewhere in the SPICE Toolkit API.**
- **The epoch is supplied via a SPICE API call, as for position vectors.**
 - » **If the constant vector's frame is time-dependent, that frame is evaluated at this epoch, optionally adjusted for light time.**

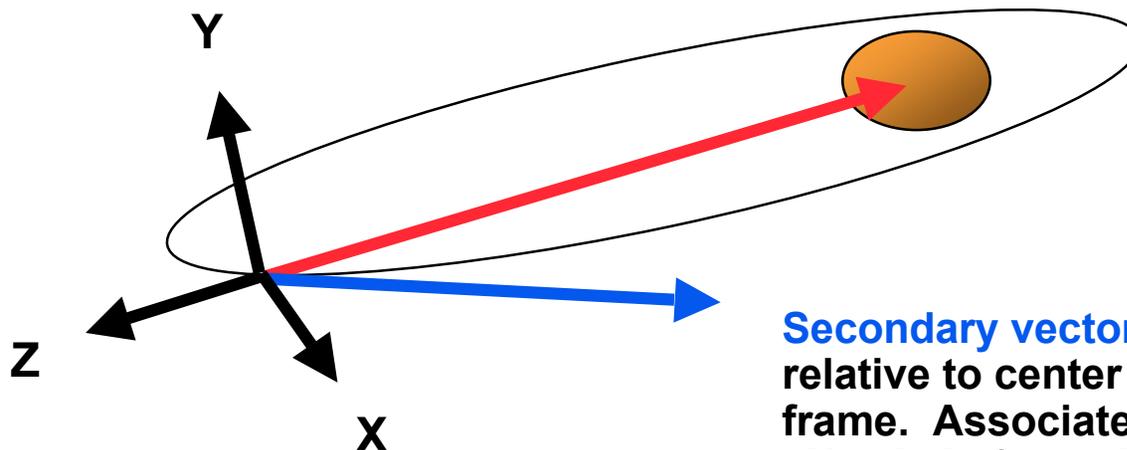


Two-Vector Frame Examples - 1

Navigation and Ancillary Information Facility

Nadir-Oriented Spacecraft-Centered Frame

$Y = Z \times X$, completing the right-handed frame.



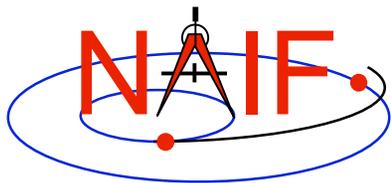
Primary vector: spacecraft nadir direction vector. Associated with nadir frame's -Z axis in frame kernel.

Nadir vector can be defined to point to either:

- closest point to spacecraft on ellipsoid
- center of mass of orbited body

Secondary vector: spacecraft velocity relative to center of motion in J2000 frame. Associated with nadir frame's +X axis in frame kernel.

Normalized component of secondary vector orthogonal to primary vector. This vector is aligned with the nadir frame's +X axis.



Two-Vector Frame Examples - 2

Navigation and Ancillary Information Facility

Nadir-Oriented Spacecraft-Centered Frame: Frame kernel specification.

The -Z axis points from the spacecraft toward the closest point on Mars.

The component of inertially referenced spacecraft velocity vector orthogonal to Z is aligned with the +X axis.

The +Y axis is the cross product of the +Z axis and the +X axis.

\begindata

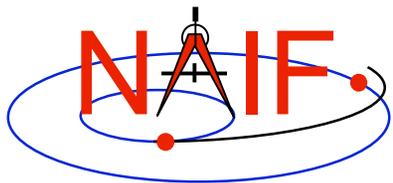
```

FRAME <frame_name>           = <frame_ID>
FRAME <frame_ID>_NAME        = <frame_name>
FRAME <frame_ID>_CLASS       = 5
FRAME <frame_ID>_CLASS_ID    = <frame_ID>
FRAME <frame_ID>_CENTER      = <orbiter_ID>
FRAME <frame_ID>_RELATIVE    = 'J2000'
FRAME <frame_ID>_DEF_STYLE   = 'PARAMETERIZED'
FRAME <frame_ID>_FAMILY      = 'TWO-VECTOR'
FRAME <frame_ID>_PRI_AXIS    = '-Z'
FRAME <frame_ID>_PRI_VECTOR_DEF = 'TARGET_NEAR_POINT'
FRAME <frame_ID>_PRI_OBSERVER = <orbiter_ID/name>
FRAME <frame_ID>_PRI_TARGET  = 'MARS'
FRAME <frame_ID>_PRI_ABCORR  = 'NONE'
FRAME <frame_ID>_SEC_AXIS    = 'X'
FRAME <frame_ID>_SEC_VECTOR_DEF = 'OBSERVER_TARGET_VELOCITY'
FRAME <frame_ID>_SEC_OBSERVER = 'MARS'
FRAME <frame_ID>_SEC_TARGET  = <orbiter_ID/name>
FRAME <frame_ID>_SEC_ABCORR  = 'NONE'
FRAME <frame_ID>_SEC_FRAME   = 'J2000'

```

Definitions

| | |
|-------------------|--------------------------------------|
| <frame_ID> | = integer frame ID code |
| <frame_name> | = user-specified frame name |
| <orbiter_ID> | = NAIF ID code of spacecraft |
| <orbiter_ID/name> | = NAIF ID code or name of spacecraft |

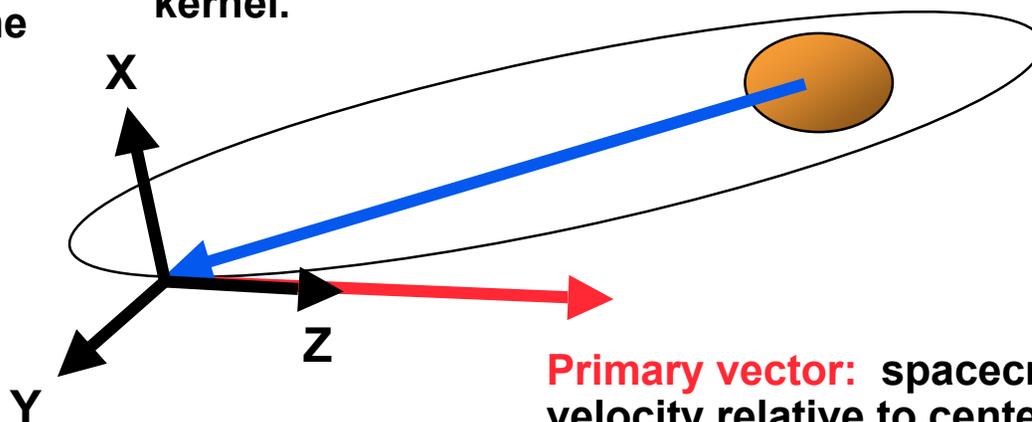


Two-Vector Frame Examples - 3

Navigation and Ancillary Information Facility

Spacecraft "View Frame"

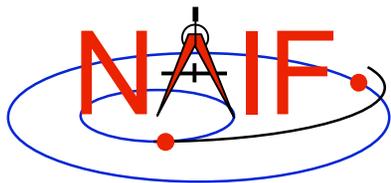
$X = Y \times Z$, completing the right-handed frame. ("Out of plane" direction)



Secondary vector: spacecraft position relative to center of motion. Associated with view frame's +Y axis in frame kernel.

Normalized component of secondary vector orthogonal to primary vector. This vector is aligned with the view frame's +Y axis. ("In plane" direction)

Primary vector: spacecraft velocity relative to center of motion in J2000 frame. Associated with view frame's +Z axis in frame kernel. ("Down track" direction)



Two-Vector Frame Examples - 4

Navigation and Ancillary Information Facility

Spacecraft "View Frame": Frame kernel specification.

The +Z axis is aligned with the J2000-referenced velocity of the spacecraft relative to Mars.

The component of the spacecraft position orthogonal to +Z is aligned with the +Y axis.

The +X axis is the cross product of the +Y axis and the +Z axis.

\begindata

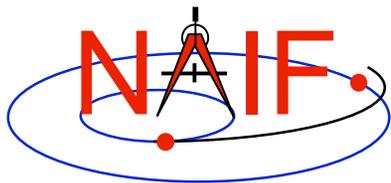
```

FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER       = <orbiter_ID>
FRAME_<frame_ID>_RELATIVE     = 'J2000'
FRAME_<frame_ID>_DEF_STYLE    = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY       = 'TWO-VECTOR'
FRAME_<frame_ID>_PRI_AXIS     = 'Z'
FRAME_<frame_ID>_PRI_VECTOR_DEF = 'OBSERVER_TARGET_VELOCITY'
FRAME_<frame_ID>_PRI_OBSERVER  = 'MARS'
FRAME_<frame_ID>_PRI_TARGET    = <orbiter_ID/name>
FRAME_<frame_ID>_PRI_ABCORR   = 'NONE'
FRAME_<frame_ID>_PRI_FRAME    = 'J2000'
FRAME_<frame_ID>_SEC_AXIS     = 'Y'
FRAME_<frame_ID>_SEC_VECTOR_DEF = 'OBSERVER_TARGET_POSITION'
FRAME_<frame_ID>_SEC_OBSERVER  = 'MARS'
FRAME_<frame_ID>_SEC_TARGET    = <orbiter_ID/name>
FRAME_<frame_ID>_SEC_ABCORR   = 'NONE'

```

Definitions

| | |
|-------------------|--------------------------------------|
| <frame_ID> | = integer frame ID code |
| <frame_name> | = user-specified frame name |
| <orbiter_ID> | = NAIF ID code of spacecraft |
| <orbiter_ID/name> | = NAIF ID code or name of spacecraft |

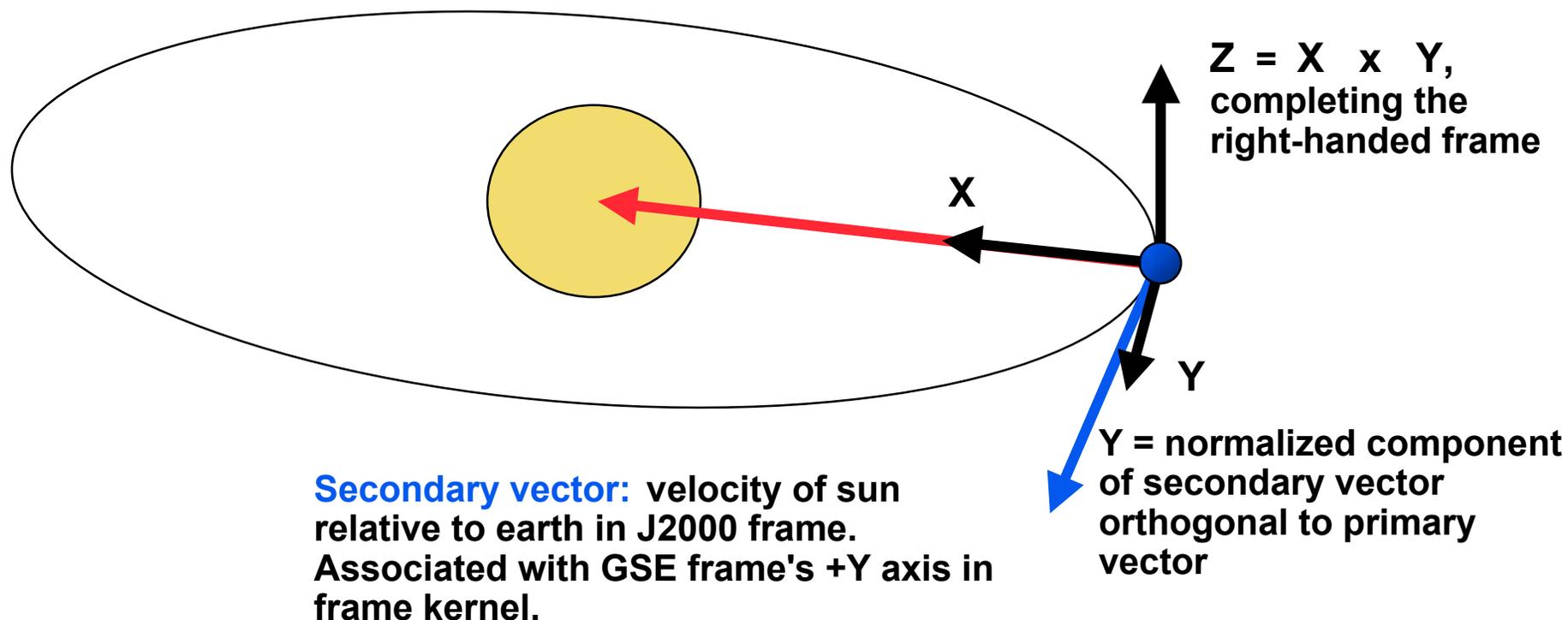


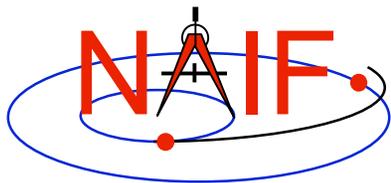
Two-Vector Frame Examples - 5

Navigation and Ancillary Information Facility

Geocentric Solar Ecliptic Frame (GSE)

Primary vector: position of sun relative to earth
Associated with GSE frame's +X axis in frame kernel.





Two-Vector Frame Examples - 6

Navigation and Ancillary Information Facility

Geocentric Solar Ecliptic (GSE) frame:

+X is parallel to the geometric earth-sun position vector.

+Y axis is the normalized component of the geometric earth-sun velocity vector orthogonal to the GSE +X axis.

+Z axis is parallel to the cross product of the GSE +X axis and the GSE +Y axis.

\begindata

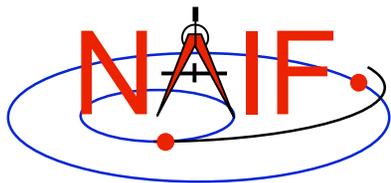
```

FRAME_GSE = <frame_ID>
FRAME_<frame_ID>_NAME = 'GSE'
FRAME_<frame_ID>_CLASS = 5
FRAME_<frame_ID>_CLASS_ID = <frame_ID>
FRAME_<frame_ID>_CENTER = 399
FRAME_<frame_ID>_RELATIVE = 'J2000'
FRAME_<frame_ID>_DEF_STYLE = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY = 'TWO-VECTOR'
FRAME_<frame_ID>_PRI_AXIS = 'X'
FRAME_<frame_ID>_PRI_VECTOR_DEF = 'OBSERVER_TARGET_POSITION'
FRAME_<frame_ID>_PRI_OBSERVER = 'EARTH'
FRAME_<frame_ID>_PRI_TARGET = 'SUN'
FRAME_<frame_ID>_PRI_ABCORR = 'NONE'
FRAME_<frame_ID>_SEC_AXIS = 'Y'
FRAME_<frame_ID>_SEC_VECTOR_DEF = 'OBSERVER_TARGET_VELOCITY'
FRAME_<frame_ID>_SEC_OBSERVER = 'EARTH'
FRAME_<frame_ID>_SEC_TARGET = 'SUN'
FRAME_<frame_ID>_SEC_ABCORR = 'NONE'
FRAME_<frame_ID>_SEC_FRAME = 'J2000'

```

Definition

<frame_ID> = integer frame ID code

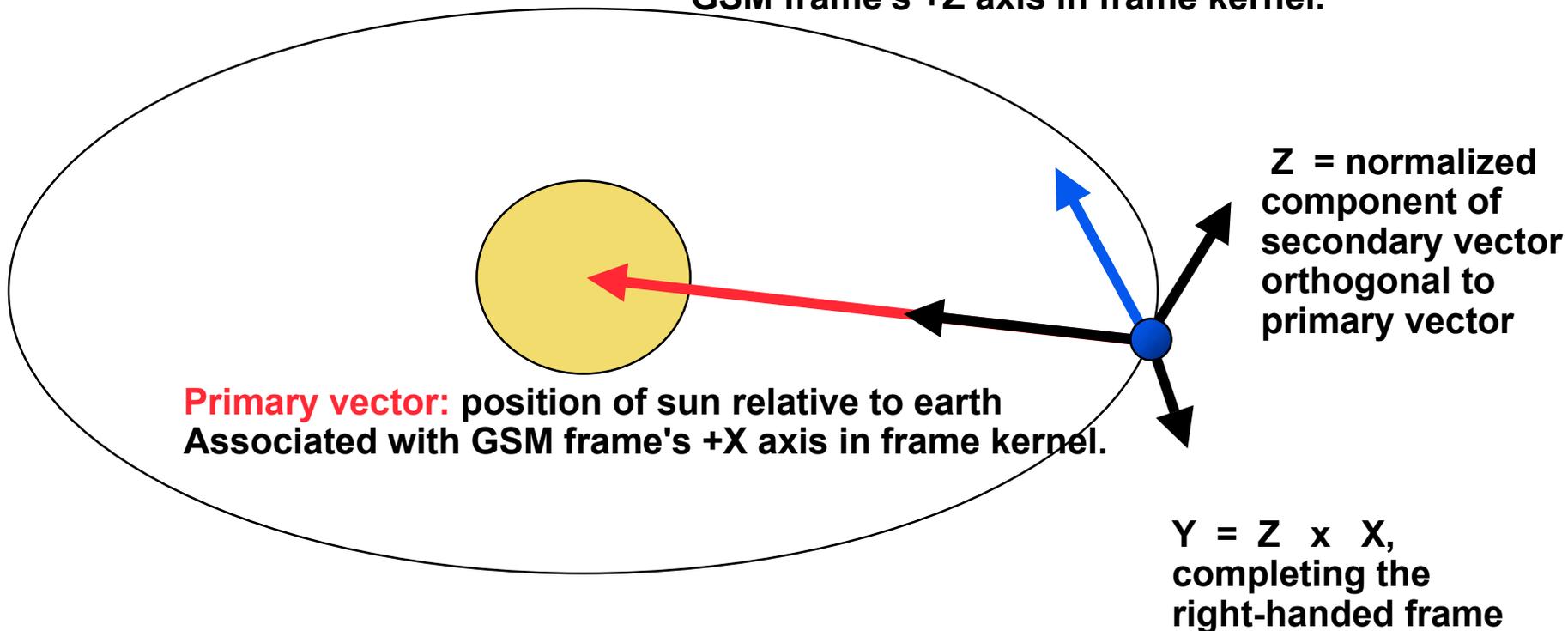


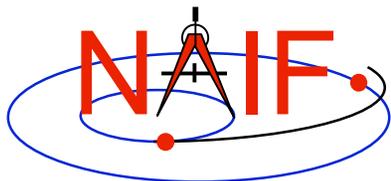
Two-Vector Frame Examples - 7

Navigation and Ancillary Information Facility

Geocentric Solar Magnetospheric Frame (GSM)

Secondary vector: North geomagnetic centered dipole in IAU_EARTH frame. Associated with GSM frame's +Z axis in frame kernel.





Two-Vector Frame Examples - 8

Navigation and Ancillary Information Facility

Geocentric Solar Magnetospheric (GSM) frame:

+X is parallel to the geometric earth-sun position vector.

+Z axis is normalized component of north centered geomagnetic dipole vector orthogonal to GSM +X axis.

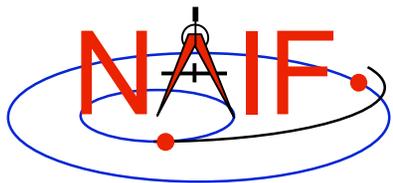
+Y completes the right-handed frame.

\begindata

```
FRAME_GSM = <frame_ID>
FRAME_<frame_ID>_NAME = 'GSM'
FRAME_<frame_ID>_CLASS = 5
FRAME_<frame_ID>_CLASS_ID = <frame_ID>
FRAME_<frame_ID>_CENTER = 399
FRAME_<frame_ID>_RELATIVE = 'J2000'
FRAME_<frame_ID>_DEF_STYLE = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY = 'TWO-VECTOR'
FRAME_<frame_ID>_PRI_AXIS = 'X'
FRAME_<frame_ID>_PRI_VECTOR_DEF = 'OBSERVER_TARGET_POSITION'
FRAME_<frame_ID>_PRI_OBSERVER = 'EARTH'
FRAME_<frame_ID>_PRI_TARGET = 'SUN'
FRAME_<frame_ID>_PRI_ABCORR = 'NONE'
FRAME_<frame_ID>_SEC_AXIS = 'Z'
FRAME_<frame_ID>_SEC_VECTOR_DEF = 'CONSTANT'
FRAME_<frame_ID>_SEC_FRAME = 'IAU_EARTH'
FRAME_<frame_ID>_SEC_SPEC = 'LATITUDINAL'
FRAME_<frame_ID>_SEC_UNITS = 'DEGREES'
FRAME_<frame_ID>_SEC_LONGITUDE = 288.43
FRAME_<frame_ID>_SEC_LATITUDE = 79.54
```

Definition

<frame_ID> = integer frame ID code

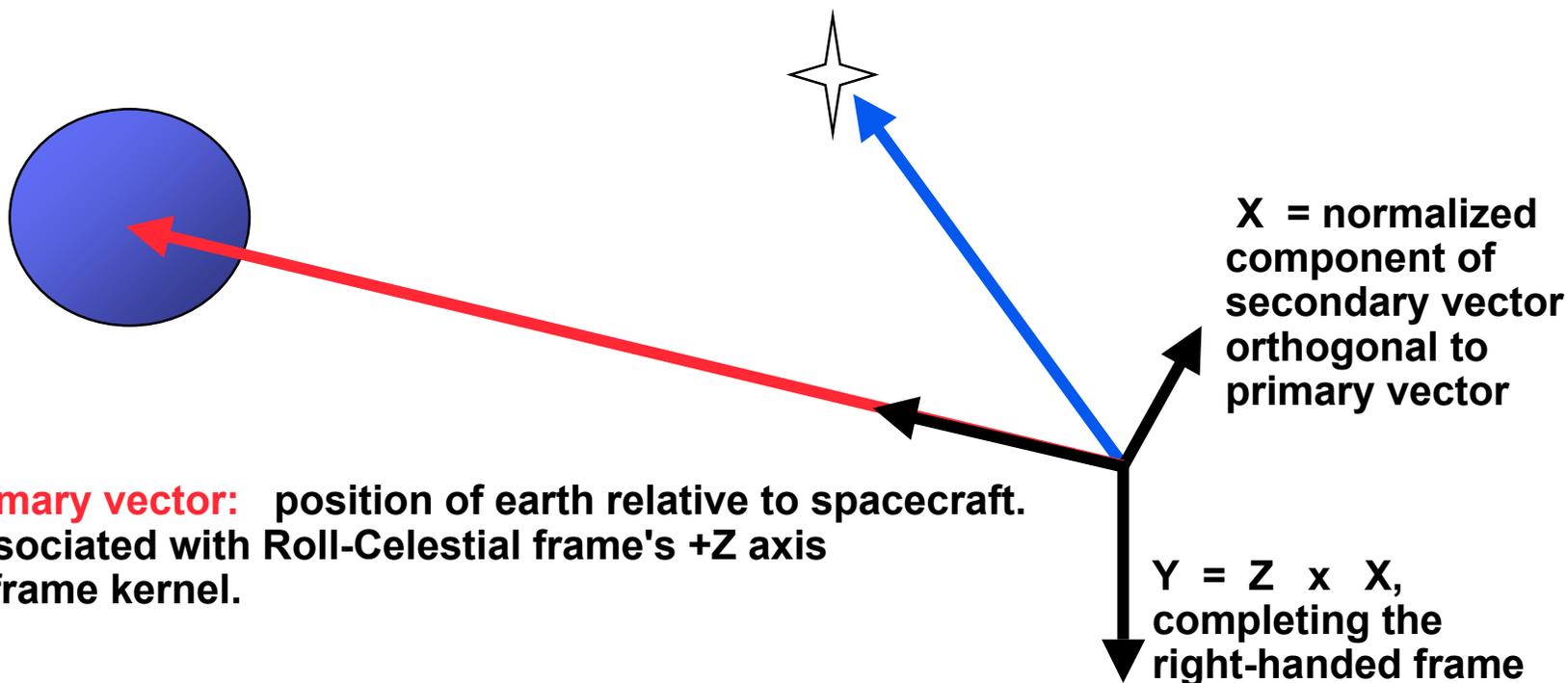


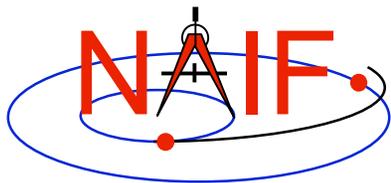
Two-Vector Frame Examples - 9

Navigation and Ancillary Information Facility

Spacecraft-Centered Roll-Celestial Frame

Secondary vector: Lock star direction in J2000 frame, corrected for stellar aberration due to spacecraft motion. Associated with Roll-Celestial frame's +X axis in frame kernel.





Two-Vector Frame Examples - 10

Navigation and Ancillary Information Facility

Spacecraft-centered roll-celestial frame:

+Z is parallel to the geometric earth-sun position vector.

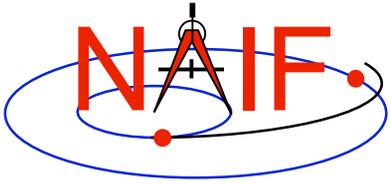
+X axis is normalized component of star direction orthogonal to Z axis. The star direction is corrected for stellar aberration due to motion of the spacecraft.

+Y completes the right-handed frame.

```
\begindata
FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER       = <spacecraft_ID>
FRAME_<frame_ID>_RELATIVE     = 'J2000'
FRAME_<frame_ID>_DEF_STYLE    = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY       = 'TWO-VECTOR'
FRAME_<frame_ID>_PRI_AXIS     = 'Z'
FRAME_<frame_ID>_PRI_VECTOR_DEF = 'OBSERVER_TARGET_POSITION'
FRAME_<frame_ID>_PRI_OBSERVER  = <spacecraft_ID/name>
FRAME_<frame_ID>_PRI_TARGET   = 'EARTH'
FRAME_<frame_ID>_PRI_ABCORR   = 'NONE'
FRAME_<frame_ID>_SEC_AXIS     = 'X'
FRAME_<frame_ID>_SEC_VECTOR_DEF = 'CONSTANT'
FRAME_<frame_ID>_SEC_FRAME    = 'J2000'
FRAME_<frame_ID>_SEC_SPEC     = 'RA/DEC'
FRAME_<frame_ID>_SEC_UNITS    = 'DEGREES'
FRAME_<frame_ID>_SEC_RA       = <star right ascension in degrees>
FRAME_<frame_ID>_SEC_DEC     = <star declination in degrees>
FRAME_<frame_ID>_SEC_OBSERVER = <spacecraft_ID/name>
FRAME_<frame_ID>_SEC_ABCORR  = 'S'
```

Definitions

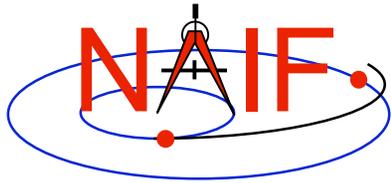
| | |
|----------------------|--------------------------------------|
| <frame_ID> | = integer frame ID code |
| <frame_name> | = user-specified frame name |
| <spacecraft_ID> | = NAIF ID code of spacecraft |
| <spacecraft_ID/name> | = NAIF ID code or name of spacecraft |



"Of-Date" Frames - 1

Navigation and Ancillary Information Facility

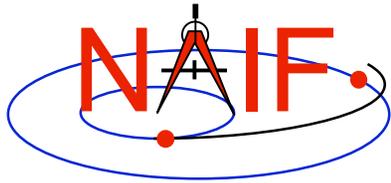
- **Of-date frames are associated with user-specified bodies and are based on user-selected dynamical models.**
 - Implementations of these models are built into SPICE.
- **The currently supported "of-date" frame families are**
 - Mean Equator and Equinox of Date
 - True Equator and Equinox of Date
 - Mean Ecliptic and Equinox of Date
- **The earth is the only currently supported body.**



"Of-Date" Frames - 2

Navigation and Ancillary Information Facility

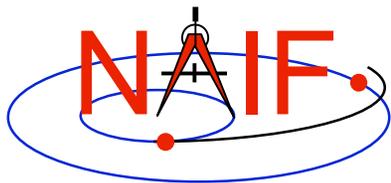
- **The currently supported types of models are**
 - Precession
 - Nutation
 - Mean obliquity
- **The of-date frame implementation is intended to be flexible...**
 - The set of supported bodies can grow over time.
 - The set of supported models can grow over time.
 - » **SPICE is not forever locked into using a single hard-coded implementation, such as the 1976 IAU precession model**
 - The set of supported frame families can grow, if necessary.



"Of-Date" Frames - 3

Navigation and Ancillary Information Facility

- **Mean Equator and Equinox of Date Family**
 - **For all reference frames in this family...**
 - » **The frame's relationship to the J2000 frame is given by a precession model.**
 - » **The frame kernel creator selects a precession model from those built into the SPICE software.**
 - **Currently supported only for the earth**
 - **1976 IAU precession model (Lieske model)**
 - » **The frame kernel creator must either specify the frame's rotation state or must designate the frame "frozen" at a specified "freeze epoch."**



"Of-Date" Frames - 4

Navigation and Ancillary Information Facility

Earth mean equator and equinox of date frame:

+Z axis is perpendicular to mean equator of date and points north.

+X axis is parallel to the cross product of the +Z axis and the north-pointing vector normal to the mean ecliptic of date.

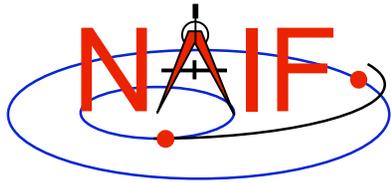
+Y axis completes the right-handed frame.

`\begindata`

```
FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER        = 399
FRAME_<frame_ID>_RELATIVE      = 'J2000'
FRAME_<frame_ID>_DEF_STYLE     = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY        = 'MEAN_EQUATOR_AND_EQUINOX_OF_DATE'
FRAME_<frame_ID>_PREC_MODEL    = 'EARTH_IAU_1976'
FRAME_<frame_ID>_ROTATION_STATE = 'ROTATING'
```

Definitions

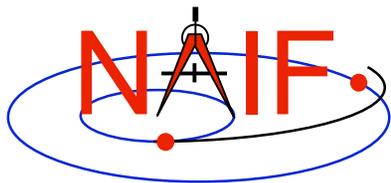
| | |
|---------------------------------|-----------------------------|
| <code><frame_ID></code> | = integer frame ID code |
| <code><frame_name></code> | = user-specified frame name |



"Of-Date" Frames - 5

Navigation and Ancillary Information Facility

- **True Equator and Equinox of Date Family**
 - For all reference frames in this family...
 - » The frame's relationship to the J2000 frame is given by a precession model and a nutation model.
 - » The frame kernel creator selects models from those built into the SPICE software.
 - Currently supported only for the earth
 - 1976 IAU precession model (aka Lieske model)
 - 1980 IAU nutation model
 - » The frame kernel creator must either specify the frame's rotation state or must designate the frame "frozen" at a specified "freeze epoch."



"Of-Date" Frames - 6

Navigation and Ancillary Information Facility

Earth true equator and equinox of date frame:

+Z axis is perpendicular to true equator of date and points north.

+X axis is parallel to the cross product of the +Z axis and the north-pointing vector normal to mean ecliptic of date.

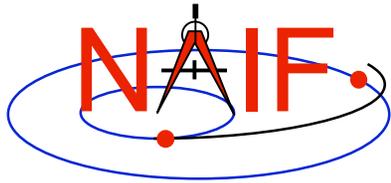
+Y axis completes the right-handed frame.

`\begindata`

```
FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER       = 399
FRAME_<frame_ID>_RELATIVE     = 'J2000'
FRAME_<frame_ID>_DEF_STYLE     = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY       = 'TRUE_EQUATOR_AND_EQUINOX_OF_DATE'
FRAME_<frame_ID>_PREC_MODEL    = 'EARTH_IAU_1976'
FRAME_<frame_ID>_NUT_MODEL     = 'EARTH_IAU_1980'
FRAME_<frame_ID>_ROTATION_STATE = 'ROTATING'
```

Definitions

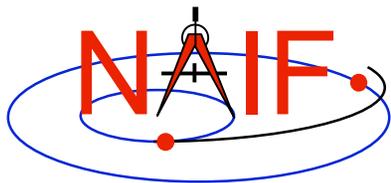
| | |
|---------------------------------|-----------------------------|
| <code><frame_ID></code> | = integer frame ID code |
| <code><frame_name></code> | = user-specified frame name |



"Of-Date" Frames - 7

Navigation and Ancillary Information Facility

- **Mean Ecliptic and Equinox of Date Family**
 - For all reference frames in this family:
 - » The frame's relationship to the J2000 frame is given by a precession model and an obliquity model.
 - » The frame kernel creator selects models from those built into the SPICE software.
 - » Currently supported only for the earth
 - 1976 IAU precession model (aka Lieske model)
 - 1980 IAU mean obliquity model
 - » The frame kernel creator must either specify the frame's rotation state or must designate the frame "frozen" at a specified "freeze epoch."



"Of-Date" Frames - 8

Navigation and Ancillary Information Facility

Earth mean ecliptic and equinox of date frame:

+Z axis is perpendicular to mean ecliptic of date and points toward ecliptic north.

+X axis is parallel to the cross product of the north-pointing vector normal to mean equator of date and the +Z axis.

+Y axis completes the right-handed frame.

\begindata

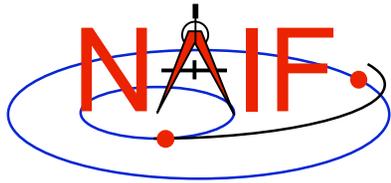
```

FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER       = 399
FRAME_<frame_ID>_RELATIVE     = 'J2000'
FRAME_<frame_ID>_DEF_STYLE     = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY       = 'MEAN_ECLIPTIC_AND_EQUINOX_OF_DATE'
FRAME_<frame_ID>_PREC_MODEL    = 'EARTH_IAU_1976'
FRAME_<frame_ID>_OBLIQ_MODEL   = 'EARTH_IAU_1980'
FRAME_<frame_ID>_ROTATION_STATE = 'ROTATING'

```

Definitions

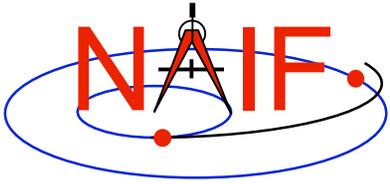
| | |
|--------------|-----------------------------|
| <frame_ID> | = integer frame ID code |
| <frame_name> | = user-specified frame name |



Euler Frames - 1

Navigation and Ancillary Information Facility

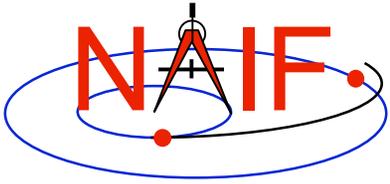
- **Euler frames are defined by a time-dependent rotation relative to a base frame.**
 - The rotation from an Euler frame to its base frame is given by three Euler angles.
 - Each angle is given by a separate polynomial.
 - » The polynomials may have different degrees.
 - » The independent variable is a time offset, in TDB seconds, from an epoch specified by the frame kernel creator.
 - » The units associated with the angles are specified by the frame kernel creator. Angles are converted to radians internally by SPICE.
 - » The sequence of rotation axes is specified by the frame kernel creator.
 - The central axis must differ from the other two.
 - The rotation from the Euler frame to the base frame is $[\text{angle_1}]_{\text{axis_1}} [\text{angle_2}]_{\text{axis_2}} [\text{angle_3}]_{\text{axis_3}}$ (units are radians)



Euler Frames - 2

Navigation and Ancillary Information Facility

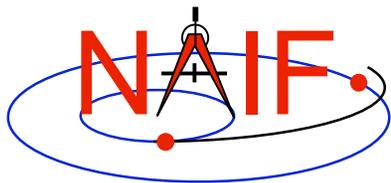
- **Examples of applications:**
 - **Dynamic version of earth magnetospheric frame (MAG)**
 - » **Latitude and longitude of the north centered geomagnetic dipole are given by polynomials.**
 - **Spinning spacecraft frame**
 - » **The base frame could be a:**
 - **Built-in inertial frame**
 - **C-kernel frame**
 - **Roll-celestial frame (using lock star)**
 - **Nadir frame**
 - **Topocentric frames for tracking stations for which plate motion is modeled**
 - » **The frame rotation keeps the frame orientation consistent with the changing station location.**



Euler Frames - 3

Navigation and Ancillary Information Facility

- Mean or true body equator and earth equinox of date frame, where the body is a planet or satellite other than the earth
 - » The base frame is an IAU_<body> frame.
 - » The Euler frame "removes" the body's rotation about the spin axis.
- Variation on supported "of date" frame
 - » An existing supported "of date" frame is used as the base frame.
 - » Perturbations to the "of date" frame are expressed using Euler angles.



Euler Frames - 4

Navigation and Ancillary Information Facility

As an example, we construct an Euler frame called IAU_MARS_EULER. Frame IAU_MARS_EULER is mathematically identical to the PCK frame named IAU_MARS. The PCK data defining the underlying IAU_MARS frame are:

```
BODY499_POLE_RA = ( 317.68143 -0.1061 0. )
BODY499_POLE_DEC = ( 52.88650 -0.0609 0. )
BODY499_PM      = ( 176.630 350.89198226 0. )
```

Relative to the angles used to define the IAU_MARS frame, the angles for our Euler frame definition are reversed and the signs negated. Angular units are degrees. Rate units are degrees/second, unlike the PCK units of degrees/day.

| | | | | | |
|------|------------|----------|--------------|------------|-----------|
| | angle_3 is | 90 + RA | | angle_1 is | -90 - RA |
| PCK: | angle_2 is | 90 - Dec | Euler Frame: | angle_2 is | -90 + Dec |
| | angle_1 is | PM | | angle_3 is | - PM |

```
\begindata
FRAME_IAU_MARS_EULER           = <frame_ID>
FRAME_<frame_ID>_NAME          = 'IAU_MARS_EULER'
FRAME_<frame_ID>_CLASS         = 5
FRAME_<frame_ID>_CLASS_ID      = <frame_ID>
FRAME_<frame_ID>_CENTER        = 499
FRAME_<frame_ID>_RELATIVE      = 'J2000'
FRAME_<frame_ID>_DEF_STYLE     = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY        = 'EULER'
FRAME_<frame_ID>_EPOCH         = @2000-JAN-1/12:00:00
FRAME_<frame_ID>_AXES          = ( 3 1 3 )
FRAME_<frame_ID>_UNITS         = 'DEGREES'
FRAME_<frame_ID>_ANGLE_1_COEFFS = ( -47.68143 0.33621061170684714E-10 )
FRAME_<frame_ID>_ANGLE_2_COEFFS = ( -37.1135 -0.19298045478743630E-10 )
FRAME_<frame_ID>_ANGLE_3_COEFFS = ( -176.630 -0.40612497946759260E-02 )
```

Definition

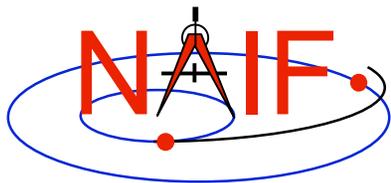
| | |
|------------|-------------------------|
| <frame_ID> | = integer frame ID code |
|------------|-------------------------|



Frozen Dynamic Frames - 1

Navigation and Ancillary Information Facility

- **A frozen dynamic frame is a "Snapshot" of a dynamic frame at a specified epoch.**
 - The frame is frozen relative to the base frame specified by the frame kernel creator in the frame kernel definition.
 - The rotation from the frozen frame to the base frame is constant.
 - The rotation is not frozen with respect to inertial frames unless the base frame is inertial.
 - A frame is designated frozen by the presence of a "freeze epoch" specification in the frame definition, for example:
`FRAME_<FRAME_ID>_FREEZE_EPOCH = @1949-DEC-31/22:09:46.861901`
 - The freeze epoch is given in SPICE text kernel format, as is used in a leapseconds kernel.



Frozen Dynamic Frames - 2

Navigation and Ancillary Information Facility

Frozen version of Earth mean equator and equinox of date frame:

+Z axis is perpendicular to mean equator of date.

+X axis is parallel to cross product of +Z axis and vector normal to mean ecliptic of date.

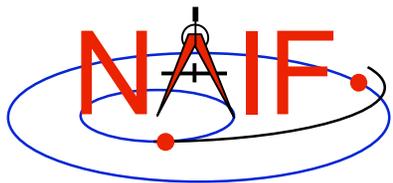
+Y axis completes the right-handed frame.

\begindata

```
FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER       = 399
FRAME_<frame_ID>_RELATIVE     = 'J2000'
FRAME_<frame_ID>_DEF_STYLE     = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY       = 'MEAN_EQUATOR_AND_EQUINOX_OF_DATE'
FRAME_<frame_ID>_PREC_MODEL    = 'EARTH_IAU_1976'
FRAME_<frame_ID>_FREEZE_EPOCH = @1949-DEC-31/22:09:46.861901
```

Definitions

| | |
|--------------|-----------------------------|
| <frame_ID> | = integer frame ID code |
| <frame_name> | = user-specified frame name |



Inertial Dynamic Frames - 1

Navigation and Ancillary Information Facility

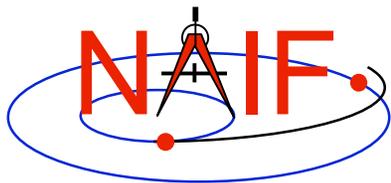
- **Inertial dynamic frames are specified by setting the rotation state to 'INERTIAL' in the rotation state assignment:**

FRAME_<FRAME_ID>_ROTATION_STATE = 'INERTIAL'

- The 'INERTIAL' state implies the frame is treated as inertial for the purpose of velocity transformations.
- The state transformation between any inertial frame and "inertial dynamic frame" has zero derivative block: the state transformation matrix has the form

$$\begin{array}{c|c} R(t) & 0 \\ \hline 0 & R(t) \end{array}$$

where $R(t)$ is a time-dependent rotation.



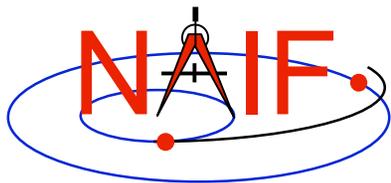
Inertial Dynamic Frames - 2

Navigation and Ancillary Information Facility

- In contrast, for any rotating frame $R(t)$, the state transformation between any inertial frame and $R(t)$ has a corresponding matrix of the form

$$\begin{array}{c|c} R(t) & 0 \\ \hline \frac{dR(t)}{dt} & R(t) \end{array}$$

- The inertial rotation state
 - » Simplifies velocity transformations: velocities are transformed by a rotation.
 - » May be useful for maintaining consistency with other dynamic frame implementations.
 - » Only makes sense if the "inertial" dynamic frame actually rotates very slowly!



Inertial Dynamic Frames - 3

Navigation and Ancillary Information Facility

Inertial version of Earth true equator and equinox of date frame:

+Z axis is perpendicular to true equator of date.

+X axis is parallel to cross product of +Z axis and vector normal to mean ecliptic of date.

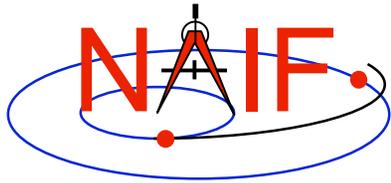
+Y axis completes the right-handed frame.

`\begindata`

```
FRAME_<frame_name>           = <frame_ID>
FRAME_<frame_ID>_NAME         = <frame_name>
FRAME_<frame_ID>_CLASS        = 5
FRAME_<frame_ID>_CLASS_ID     = <frame_ID>
FRAME_<frame_ID>_CENTER       = 399
FRAME_<frame_ID>_RELATIVE     = 'J2000'
FRAME_<frame_ID>_DEF_STYLE    = 'PARAMETERIZED'
FRAME_<frame_ID>_FAMILY       = 'TRUE EQUATOR AND EQUINOX OF DATE'
FRAME_<frame_ID>_PREC_MODEL   = 'EARTH_IAU_1976'
FRAME_<frame_ID>_NUT_MODEL    = 'EARTH_IAU_1980'
FRAME_<frame_ID>_ROTATION_STATE = 'INERTIAL'
```

Definitions

| | |
|---------------------------------|-----------------------------|
| <code><frame_ID></code> | = integer frame ID code |
| <code><frame_name></code> | = user-specified frame name |



Generic Dynamic Frames Kernel

Navigation and Ancillary Information Facility

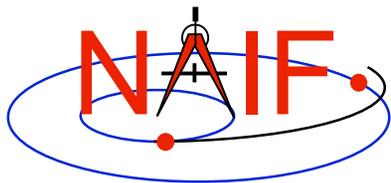
- **NAIF may develop a "generic" dynamic frames kernel.**
 - **Would contain widely applicable dynamic frame definitions.**
 - **Analogous to generic PCK file.**
 - **Examples of included frames:**
 - » **GSE, GSM, MAG**
 - » **Earth mean equator and equinox of date, 1976 version**
 - » **Earth true equator and equinox of date, 1980 version**



Backup

Navigation and Ancillary Information Facility

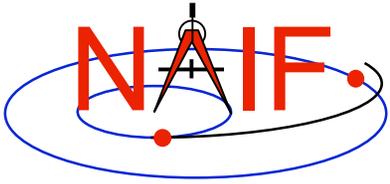
- **Rationale**
- **Numerical Issues**
- **Limitations**



Rationale

Navigation and Ancillary Information Facility

- **Why provide dynamic frames?**
 - User could build a C-kernel for *any* frame.
 - SPICE could provide a limited number of "built-in" dynamic frames which wouldn't require a frame kernel.
 - Users can (and do) create their own routines to implement dynamic frames.
- **Benefits**
 - **Convenience:** using a formula rather than a C-kernel avoids C-kernel creation, dissemination, storage, and consistency issues
 - **Flexibility:** the dynamic frame mechanism enables creation of a vast variety of reference frames
 - **Integration:** once defined, and once supporting kernels are loaded, dynamic frames may be referenced in SPICE API calls.



Numerical Issues - 1

Navigation and Ancillary Information Facility

- **Two-vector frame derivatives may be inaccurate. Let $R(t)$ represent a time-dependent rotation:**
 - If $R(t)$ depends on CK data, $dR(t)/dt$ may be inaccurate because CK rates frequently have low accuracy.
 - If $R(t)$ depends on velocity vectors, then $dR(t)/dt$ depends on acceleration determined via numerical differentiation. Typically such derivatives suffer loss of accuracy.
 - » However, if velocities are "well-behaved," numerically derived acceleration can be quite good. Example: GSE frame.
 - If $R(t)$ depends on position vectors, the velocities associated with those vectors by the SPK system may not be mathematically consistent with the positions. This can happen for SPK types with separate polynomials for position and velocity, such as types 3, 8, 9, and 14.
 - If $R(t)$ depends on aberration-corrected vectors, the associated velocities may be inaccurate due to accuracy limitations of the aberration corrections applied to velocities by the SPK system.



Numerical Issues - 2

Navigation and Ancillary Information Facility

- **Recommendations**

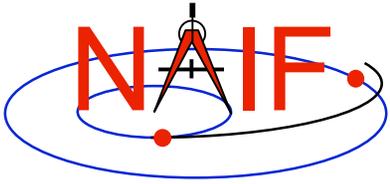
- **Avoid using aberration corrections in two-vector frame definitions if accurate velocity transformations are required.**
- **Be aware of the accuracy of the data on which two-vector frames are based.**



Limitations - 1

Navigation and Ancillary Information Facility

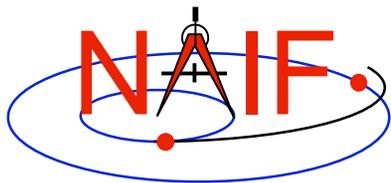
- **Simulated recursion:**
 - **ANSI Fortran 77 doesn't support recursion, so the SPICE dynamic frame system implements limited, simulated recursion.**
 - » **Basically, two levels of recursion are supported for selected SPK and Frame System routines.**
 - **Users must avoid requesting "deeper" recursion than the SPICE dynamic frame system can support.**
 - » **When defining dynamic frames:**
 - **Choose J2000 as the base frame for two-vector frames.**
 - **Except for Euler frames, avoid using dynamic frames as base frames.**
 - **Try to avoid choosing a dynamic frame as the frame associated with a velocity or constant vector.**
 - » **In SPK, CK, or PCK kernels, don't use two-vector frames as the base frame relative to which ephemeris or attitude data are specified.**
 - **"Of-date" or Euler frames are OK for this purpose.**



Limitations - 2

Navigation and Ancillary Information Facility

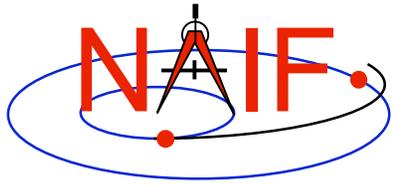
- **Run-time efficiency:**
 - **Dynamic frame evaluation typically requires more computation than is needed for CK or PCK frames.**
 - » **For example, evaluation of a two-vector frame may involve several SPK calls.**
 - » **Euler frames are an exception: these are fairly efficient as long as they don't have a base frame that requires a lot of computation to evaluate.**
 - **To minimize the performance penalty:**
 - » **Use J2000 as the base frame for two-vector frames.**
 - » **Use the simplest frames possible for association with velocity or constant vectors in two-vector frame definitions.**
 - **Prefer non-dynamic frames to dynamic frames and inertial frames to non-inertial frames where there is a choice.**



Navigation and Ancillary Information Facility

“High Accuracy” Orientation and Body-fixed Frames for the Moon and Earth

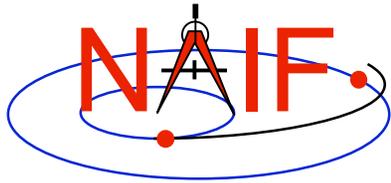
January 2009



Topics

Navigation and Ancillary Information Facility

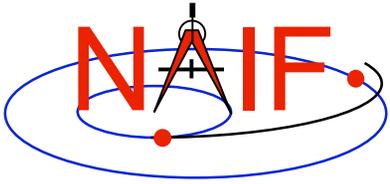
- **Introduction**
- **Earth binary PCKs**
- **Lunar binary PCKs**
- **Lunar Frames Kernel**
 - Frame specifications
 - Frame alias names
- **Binary PCK file format**
- **Using Binary PCKs**
- **Backup**
 - Earth and Moon frame association kernels



Introduction-1

Navigation and Ancillary Information Facility

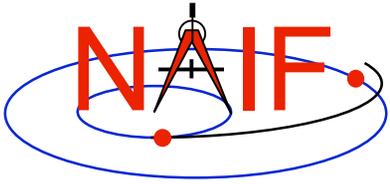
- Now that you are an expert in “standard” PCKs and FKs you may want to learn about several “special” PCKs and FKs dealing with the Earth and the Moon.
- While it is ultimately up to you, **in most cases you should use the PCK and FK kernels described here when working with the Moon or the Earth.**



Introduction-2

Navigation and Ancillary Information Facility

- **NAIF provides “High accuracy” orientation data for the Earth and Moon in binary PCKs.**
 - For the Earth
 - » High accuracy, frequently updated file
 - Contains high accuracy historical data and fairly accurate, short-term predict data
 - » High accuracy, infrequently updated historical file
 - » Lower accuracy long term predict file
 - For the Moon, there’s a long-term file for each JPL “Developmental Ephemeris” (DE) version. The current version is DE-421.
 - » Contains accurate historical and predict data
- **To use these kernels:**
 - Select PCKs with required time coverage
 - » unlike text PCKs, the time span covered by binary PCKs is limited
 - Load the PCK(s) via FURNISH
 - For the Moon, also load the Lunar FK
 - Reference the Earth body-fixed frame using the name ‘ITRF93’
 - Reference the high-accuracy Lunar body-fixed frames using one of these names:
 - » MOON_ME (Moon Mean Earth/Rotation axis frame)
 - » MOON_PA (Moon Principal Axes frame)
 - » IAU_MOON (**can not** be used to reference high-accuracy lunar orientation data)



Navigation and Ancillary Information Facility

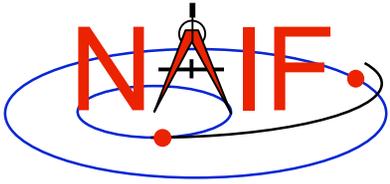
Earth Binary PCKs



“High Accuracy” Earth Rotation Model

Navigation and Ancillary Information Facility

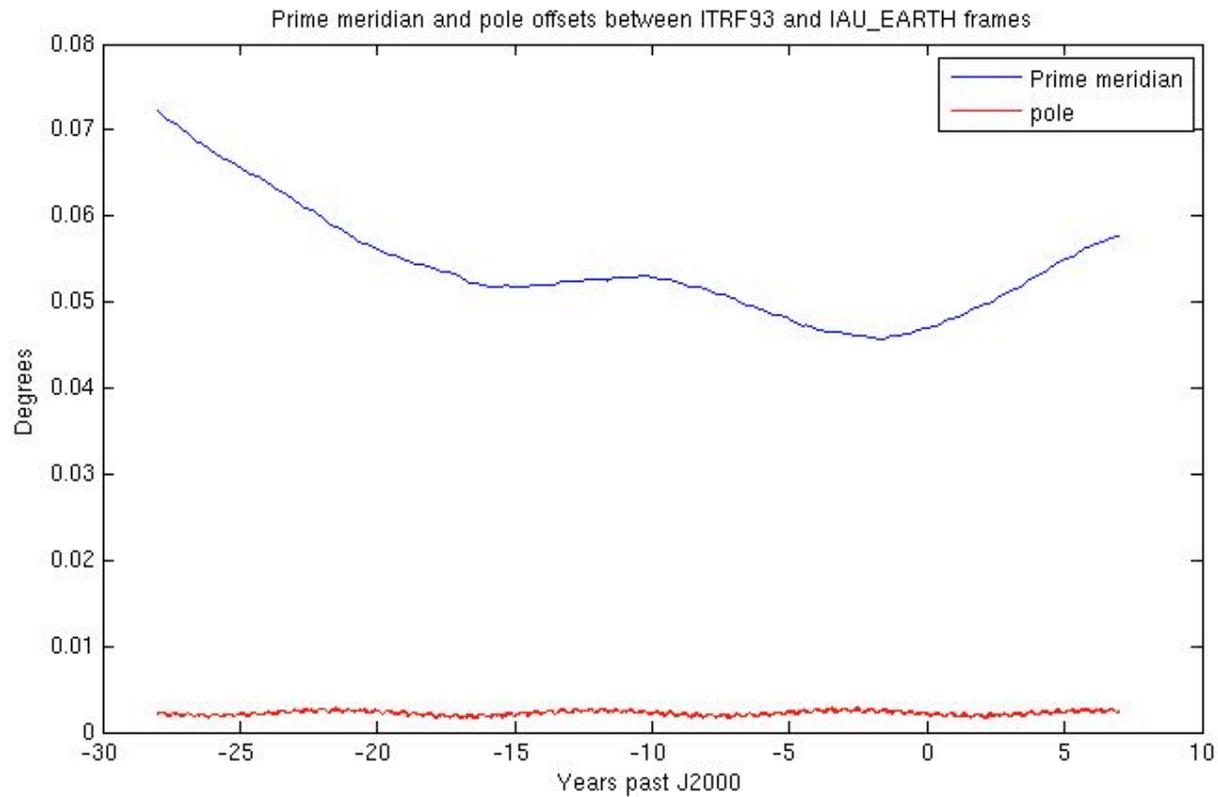
- **The ITRF93 high accuracy Earth rotation model takes into account:**
 - Precession: 1976 IAU model due to Lieske.
 - Nutation: 1980 IAU model, with IERS corrections due to Herring et al.
 - True sidereal time using accurate values of TAI-UT1
 - Polar motion
- **It is more accurate than the IAU rotation models found in text PCKs.**
 - See the plot on the next slide comparing orientation of the ITRF93 frame to that of the IAU_EARTH frame.
 - » IAU_EARTH frame orientation error is ~1 milliradian, or ~6km on a great circle!
- **The highest accuracy is obtainable only for past epochs.**
 - Unpredictable variations of UT1-TAI and polar motion limits the accuracy of predicted Earth orientation. See plot on page 8.

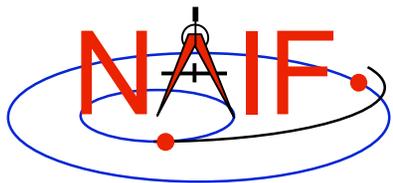


IAU_EARTH vs ITRF93 Comparison Plot

Navigation and Ancillary Information Facility

Difference between the IAU_Earth frame and the ITRF93 frame

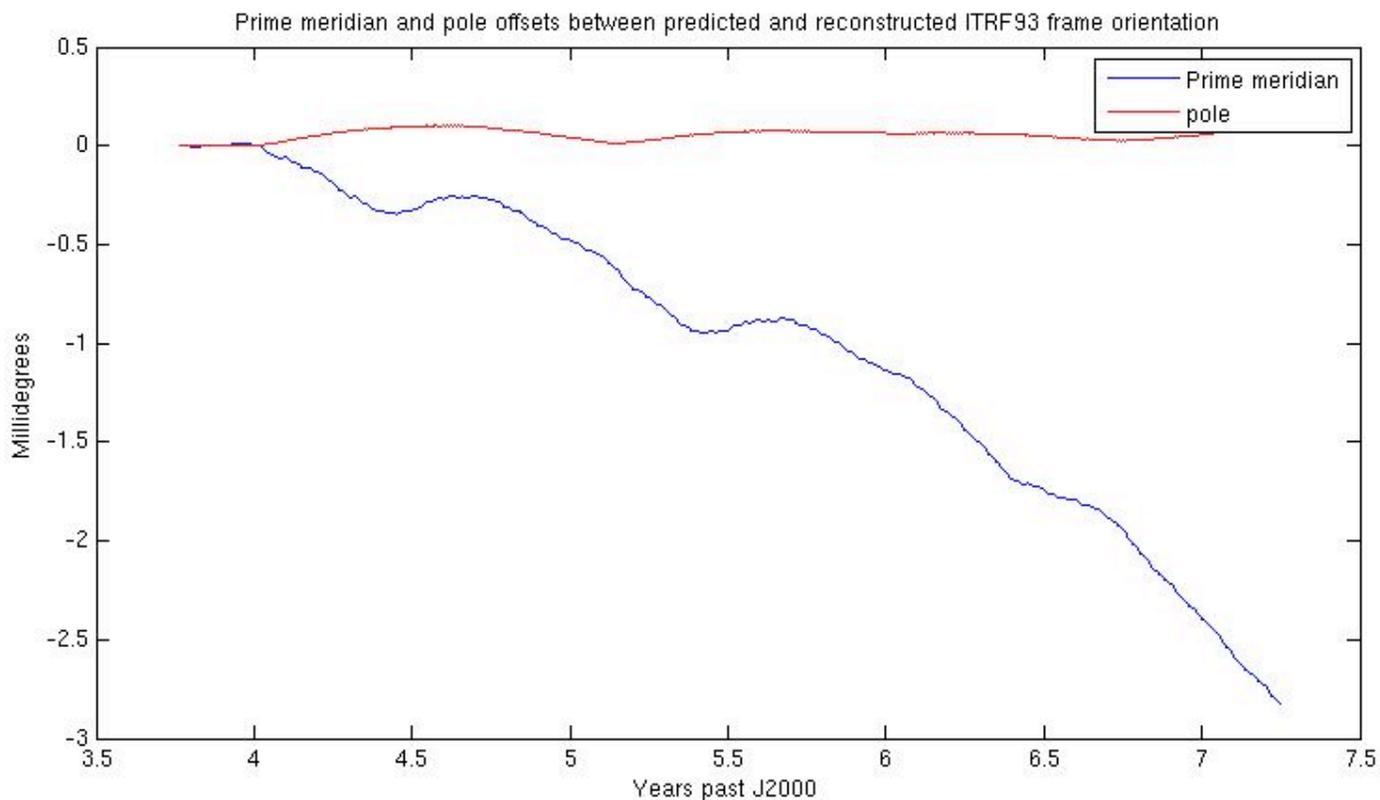


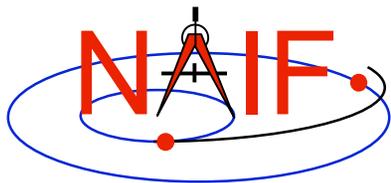


Earth Predicted vs Reconstructed ITRF93 Plot

Navigation and Ancillary Information Facility

Difference between predicted and reconstructed orientation of ITRF93 frame





Data Source for Earth “High Accuracy” Model

Navigation and Ancillary Information Facility

- **Data for the Earth come from a JPL Earth Orientation Parameters file (EOP).**
 - **Binary Earth PCKs represent the orientation of an Earth ITRFxx body-fixed reference frame relative to the ICRF*.**
 - » **ITRF* frames are defined by the International Earth Rotation Service (IERS).**
 - » **Currently only the ITRF93 frame is supported within SPICE.**

ICRF = International Celestial Reference Frame, often referred to in SPICE as the “J2000” frame, and also often referred to as the EME 2000 frame. This is an inertial frame.

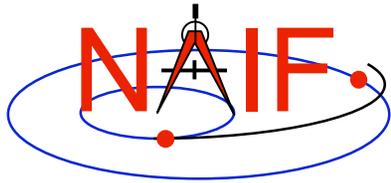
ITRF = International Terrestrial Reference Frame



Earth PCK Production Scheme

Navigation and Ancillary Information Facility

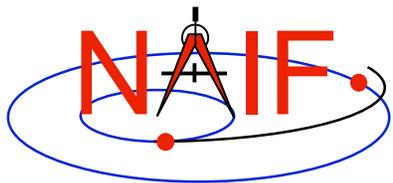
- **Three versions of the “high accuracy” binary Earth PCK are produced**
 - **“The latest,”** using each new release of a reconstructed EOP file by JPL
 - » Covers well into the past and approximately two months into the future beyond the production date
 - » Accuracy of the future data degrades rapidly past the production date
 - » Produced several times per week using an automatic script
 - **Long term predict,** for future uses not requiring high accuracy
 - » Produced infrequently
 - » Covers several years into the past and approximately 30 years into the future
 - » Accuracy at epochs in the future is low compared to that for past epochs, but any of it is far better than what is obtained from the IAU rotation model for the Earth provided in any text PCK
 - **History file,** containing only high accuracy historical data
- **All are in the pck directory under generic_kernels on the NAIF server:** `ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/pck/`
 - Read the “aareadme” file to see the file naming schema and more details



Accurate Earth Surface Locations

Navigation and Ancillary Information Facility

- **High accuracy determination of surface locations relative to an inertial frame involves motions in addition to Earth rotation, including:**
 - tectonic plate motion
 - tidal effects
 - ocean and atmospheric loading
 - relativistic effects
- **Tectonic plate motion is accounted for in NAIF's DSN and some non-DSN station SPK files.**
- **The other non-rotational effects affecting surface locations are NOT accounted for by a PCK or any other SPICE component.**



Kernel Usage Summary: Earth

Navigation and Ancillary Information Facility

- **To use high accuracy Earth orientation data**
 - Load one or more binary Earth PCKs
 - » If a long-term predict is used, load this kernel ***before*** loading any kernel containing reconstructed data so that the reconstructed data have precedence during the overlap period.
 - If your application uses any of the old, pre-N0062 APIs that make use of the default Earth body-fixed frame (see Backup slides), load an Earth frame association kernel making ITRFxx the default earth body-fixed frame.
 - » **But best to switch to use the “new” APIs that require you to specify which frame to use.**
 - **New APIs: ILUMIN, SINCPT, SUBPNT, SUBSLR**
 - **If you’re using SPICE to access Earth size and shape information, you’ll also need to load a text PCK file containing these data.**
 - Typically use the latest generic text PCK: pck000xx.tpc



Navigation and Ancillary Information Facility

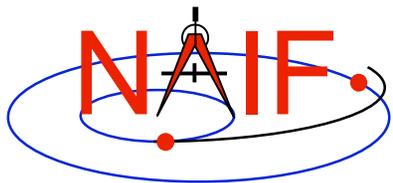
Lunar Binary PCKs



“High Accuracy” Lunar Rotation Model

Navigation and Ancillary Information Facility

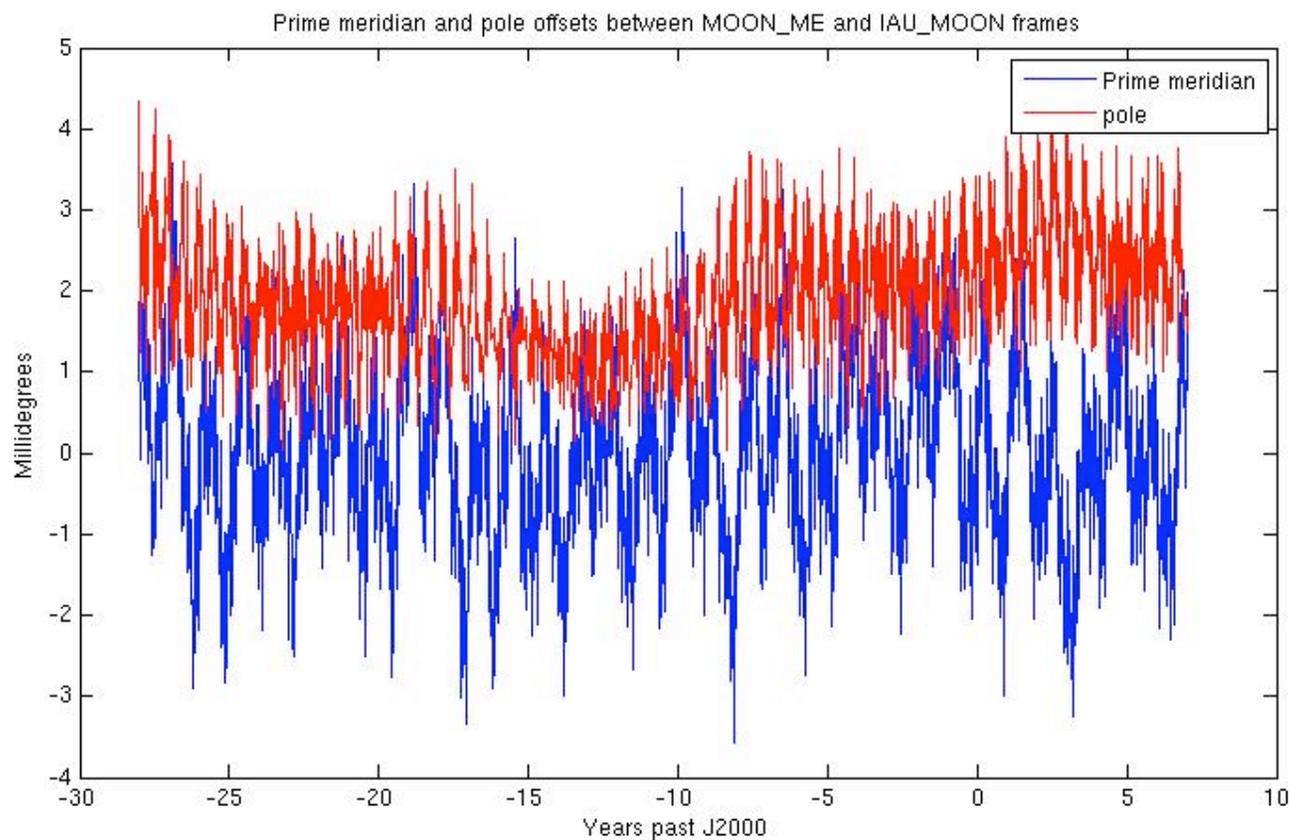
- **More accurate than the IAU rotation models found in text PCKs.**
 - Rotation error between IAU_MOON and corresponding “high accuracy” MOON_ME (mean Earth/rotation axis) frame is, for the DE-421 and 2000 IAU data sets and the time period 2000-2020, approximately
 - » **Worst case: ~0.0051 degrees, or ~155m on a great circle**
 - » **Average: ~0.0025 degrees, or ~76m on a great circle**
 - Error is due to truncation of the libration series in the IAU model
 - Error is not nearly as large as that for IAU_EARTH vs ITRF93
 - See the plot in the following chart comparing the IAU lunar rotation model to the integrated DE-421 model.
 - » Note that the IAU_MOON model was developed in 2000, published in 2002 (see documentation in pck00008.tpc).



IAU_Moon vs MOON_ME Comparison Plot

Navigation and Ancillary Information Facility

Difference between the IAU_Moon frame and the Moon_ME frame (equivalent to the Moon_ME_DE421 frame)



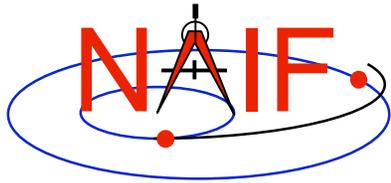


Lunar Rotation Model Effects

Navigation and Ancillary Information Facility

- **The DE421 high accuracy lunar orientation model represents the result of a simultaneous numerical integration of lunar rotation and orbit, and of orbits of the planets.**
 - **The DE421 integration model includes*:**
 - » **A “solid Moon”**
 - » **Torques on Moon from the static gravity field of degree 2-4. Torque is due to Earth, Sun, Venus, and Jupiter.**
 - » **Torques on Moon and moments of inertia due to (degree 2) tides raised by Earth**
 - » **Dissipation effects on torques and moments due to tides on the Moon.**
 - » **Torques due to Earth J2 interacting with Moon degree 2 (J2 and C22).**
 - **Lunar quantities fit for DE421 include**
 - » **Initial conditions for lunar orbit and rotation of body**
 - » **Moment of inertia difference $(C-A)/B$ and $(B-A)/C$**
 - » **Third-degree gravity field coefficients**
 - » **Tidal Love numbers and dissipation**
 - » **Locations of four laser retroreflector arrays**
- **It is anticipated that further improvements in the orientation of the moon will become available in new Dexxx-based kernels in the future.**

*Description provided by James G. Williams (JPL)



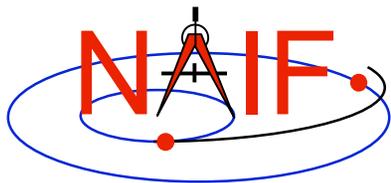
Data Sources for “High Accuracy” Models

Navigation and Ancillary Information Facility

- **Data for the Moon come from JPL’s DExxx planet/lunar ephemeris (e.g. DE421).**
 - **Binary lunar PCKs represent the orientation of the Moon’s “principal axis” reference frame, MOON_PA_DExxx, relative to the ICRF*.**

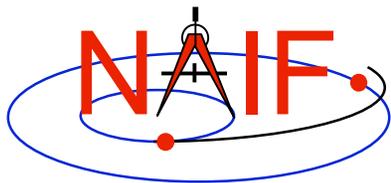
ICRF = International Celestial Reference Frame, often referred to in SPICE as the “J2000” frame, and also often referred to as the EME 2000 frame. This is an inertial frame.

ITRF = International Terrestrial Reference Frame



Navigation and Ancillary Information Facility

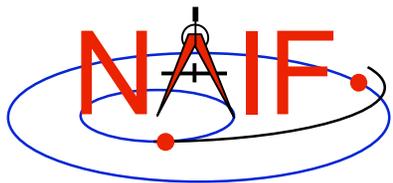
Lunar Frames Kernel



Lunar Frames Kernel

Navigation and Ancillary Information Facility

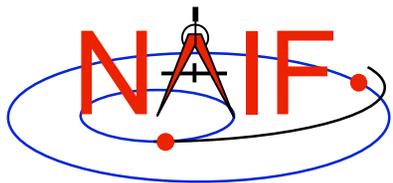
- **A lunar frames kernel is maintained and available from NAIF. It has four functions.**
 1. **Make two lunar frames—Principal Axes (PA) and Mean Earth/Polar Axis (ME)—known to the SPICE system.**
 - » Within SPICE their names are MOON_PA_DExxx and MOON_ME_DExxx
 - » These frames are unique to a particular JPL-produced lunar and planetary ephemeris (DE/Lexxx, which is often referred to as simply DExxx).
 2. **Connect the MOON_PA_DExxx frame name to the high accuracy lunar orientation PCK data that implement the PA orientation (relative to the ICRF).**
 3. **Provide specifications, in the SPICE context, for implementing the rotation between the PA frame and the ME frame.**
 - » Makes the MOON_ME_DExxx frame available to SPICE.
 4. **Provide generic frame names, aliased to the MOON_PA_DExxx and MOON_ME_DExxx frame names.**
 - » The generic frame names are simply MOON_PA and MOON_ME.
 - » The generic names need not be changed in your programs when the MOON_PA_DExxx and MOON_ME_DExxx names change due to use of new defining data.
 - » The DE-specific frames to which these aliases “point” will be updated by NAIF whenever a new binary lunar orientation PCK is produced. NAIF will release a new lunar FK at that time.
- **To access the PA or ME frame you must load the lunar FK into your program in addition to the lunar binary PCK that implements the lunar PA frame orientation.**



Kernel Usage Summary: Moon

Navigation and Ancillary Information Facility

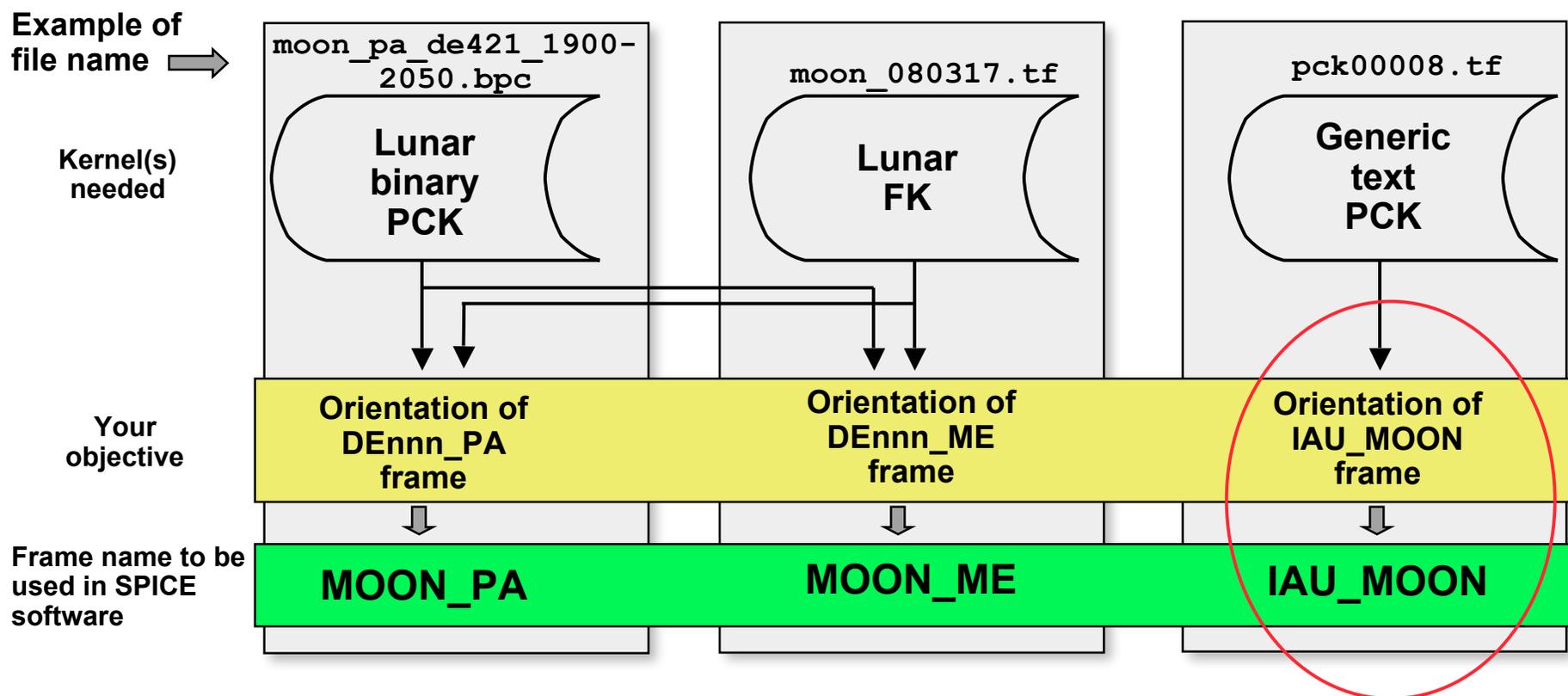
- **To use high accuracy Moon orientation data**
 - Load the current binary lunar PCK
 - Load the current lunar FK
 - If your application uses any of the old, pre-N0062 APIs that make use of the default lunar body-fixed frame (see Backup), load a moon frame association kernel making either MOON_ME or MOON_PA the default lunar body-fixed frame.
 - » **But best to switch to use the “new” APIs that require you to specify which frame to use.**
 - **New APIs: ILUMIN, SINCPT, SUBPNT, SUBSLR**
- **If you’re using SPICE to access Moon size and shape information, you’ll also need to load a text PCK file containing these data.**
 - Typically use the latest generic text PCK, such as pck00008.tpc



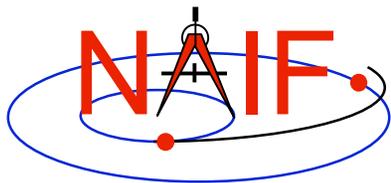
Lunar PCK/FK Summary

Navigation and Ancillary Information Facility

Which kernels are needed to access each of the three lunar body-fixed reference frames providing lunar orientation?

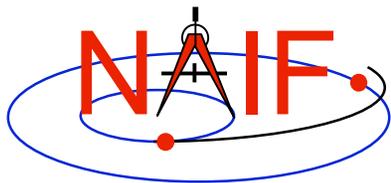


Usually a bad choice for the moon!



Navigation and Ancillary Information Facility

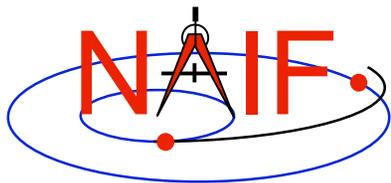
Binary PCK File Format



Binary PCK File Format

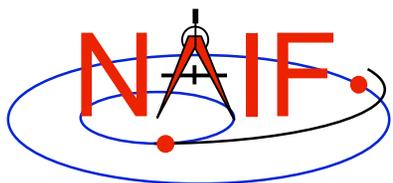
Navigation and Ancillary Information Facility

- **SPICE binary PCK files are used to accommodate “high accuracy” rotation models.**
 - Just as for SPKs and CKs, the data are held in SPICE Double Precision Array files (DAF)
 - Multiple types are supported
 - » Type 2: Chebyshev polynomials are used to represent Euler angles giving orientation as a function of time. Rates are obtained by differentiating polynomials. Coverage intervals have fixed length.
 - Used for the Earth and the Moon
 - » Type 3: Separate sets of Chebyshev polynomials are used to represent Euler angles and their rates. Coverage intervals have variable length.
 - Not currently used for Earth or Moon
 - Binary PCKs include a “comment area” for storing descriptive metadata
 - » Access the comment area using the Toolkit’s *commnt* utility program
 - Binary PCKs support high-speed direct access
 - » Cheby polynomials are fit to source Euler angles; these evaluate very quickly



Navigation and Ancillary Information Facility

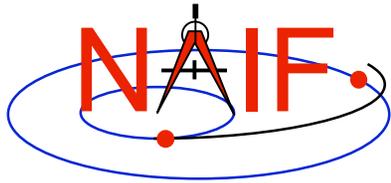
Using Binary PCKs



Precedence Rules for Text and Binary PCKs

Navigation and Ancillary Information Facility

- If two (or more) binary PCKs with functionally equivalent data are loaded, a later loaded file takes precedence.
- Loading one text PCK that supersedes another can lead to errors if data from the “old” PCK remain in the kernel pool.
 - It’s essential to unload the old text PCK before loading the new one.
 - » Use UNLOAD or KCLEAR to unload the old text PCK.
 - This problem doesn’t apply to binary PCKs.
- If both a binary and a text PCK provide orientation for the same frame, data available from the binary PCK **always** take precedence over data available from the text PCK.
 - This is independent of file loading order
 - The binary PCKs discussed in this tutorial define earth-fixed and moon-fixed frames different from those defined by a NAIF text PCK (e.g. pck00008.tpc), so there is no conflict.



Tools for use with Binary PCKs

Navigation and Ancillary Information Facility

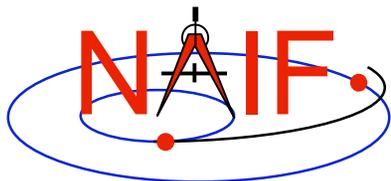
- Use the *commnt* utility to access a binary PCK comment area
 - Read, extract or insert metadata
- Use the *brief* or *spacit* utility to summarize a binary PCK
 - *brief* is easier to use; *spacit* provides more information
- Non-native binary PCKs can be read **without** first being converted to the native binary form
 - If you need to write to a non-native binary PCK you must first convert it to native binary form using *bingo* or the pair of *toxfr* and *tobin*
 - » *toxfr* and *tobin* are available in each Toolkit; *bingo* is available only from the NAIF website
 - Converting a non-native binary PCK to native form will also speed up data access somewhat



Navigation and Ancillary Information Facility

Backup

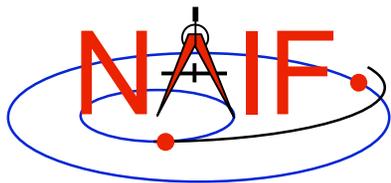
**Association Frames Kernels
for the Earth and the Moon**



Association FKs: Introduction

Navigation and Ancillary Information Facility

- In most SPICE modules that deal with one or more reference frames the name(s) of that/those frame(s) must be provided as input argument(s), for example:
 - CALL SPKEZR (target,time, **frame**, observer, correction, state, lighttime)
- NAIF's SPICE developers assumed there would be only one body-fixed reference frame associated with each natural body during a program run.
 - Thus a specific body-fixed frame name would rarely be needed as an input to modules dealing with body-fixed frames
 - Instead, SPICE could use the body-fixed frame associated with a given body simply by knowing the body name or ID
 - » For most bodies SPICE associates the body with a body-fixed frame named IAU_<body name> (example: IAU_MOON)
 - » This is known as the default body-fixed frame
- This was a bad assumption... at least for the Earth and the Moon!
 - Multiple body-fixed frames exist for the Moon and Earth
 - The default body-fixed frames for the Moon and the Earth, for which the defining data are provided in a generic text PCK (taken from an IAU report) are very inaccurate representations of the actual orientations of these bodies

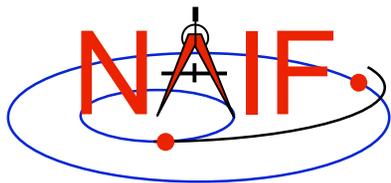


Better Choice for the Default

Navigation and Ancillary Information Facility

- For the Earth and the Moon there are other choices for body-fixed frame that are almost certainly better than the default body-fixed frame conjured up by SPICE

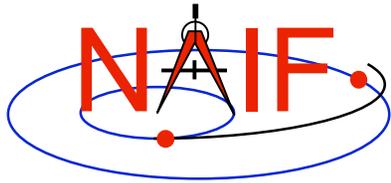
| <u>Body</u> | <u>SPICE Default Body-fixed Frame</u> | <u>Better choice</u> |
|-------------|---------------------------------------|----------------------------------|
| Earth | IAU_Earth | ITRF93
ITRFxx (in the future) |
| Moon | IAU_Moon | Moon_PA or
Moon_ME |



The Problem

Navigation and Ancillary Information Facility

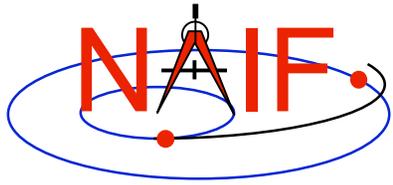
- **The SPICE modules that make use of the default body-fixed reference frame are these**
 - LSPCN, ET2LST, **ILLUM, SRFXPT, SUBPT, SUBSOL** (and their C, Icy and Mice equivalents) *Still available, but better to use those noted below*
 - Your code might overtly call one of these, or it could call one indirectly through use of a parameterized dynamic frame
- **NAIF rules regarding stability of our software offerings prevent us from changing the designs of those modules**
 - So we must provide you means to change the default body-fixed frame associated with any solar system body of interest to you. See the next several pages.
- **However, starting with the version N62 Toolkits, a new set of modules is available for those calculations where precision body orientation is important.**
 - These modules require the user to name the desired body-fixed frame, rather than using a default body-fixed frame
 - The new N62 modules are these *New: safer to use, and offer improved accuracy in some cases*
 - » **ILUMIN, SINCPT, SUBPNT, SUBSLR**



Changing the Default Body-Fixed Frame Name

Navigation and Ancillary Information Facility

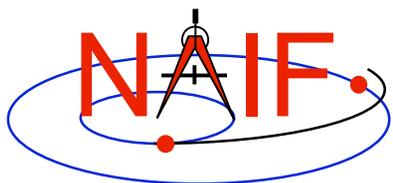
- **All bodies for which a body-fixed frame is defined by the IAU, and where the defining data are found in a SPICE text PCK file, have an associated default body-fixed frame name within SPICE:**
 - **The name pattern is:** `IAU_<body name>`
 - **Examples:** `IAU_MARS`, `IAU_MOON`, `IAU_EARTH`
- **A different default body-fixed frame name can be assigned within a program by placing the following assignment in any text kernel that is loaded into the program:**
 - `OBJECT_<body name>_FRAME = '<new default frame name>'`
 - **Example:** `OBJECT_MOON_FRAME = 'MOON_ME'`
- **NAIF offers three “association FKs” to accomplish this.**
 - See next page.



Using Association FKs to Change the Default

Navigation and Ancillary Information Facility

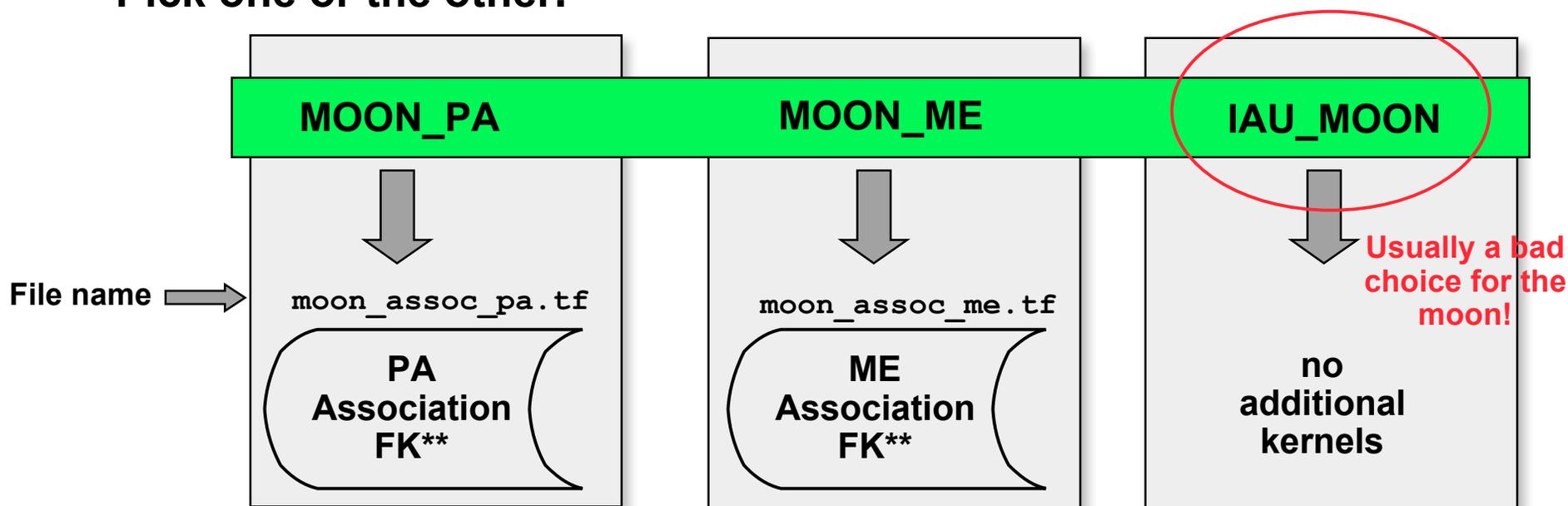
- **For the Earth and the Moon, changing the default body-fixed frame name as described on the previous page can be accomplished by loading the appropriate “association” frame kernel provided by NAIF. The association kernels available are shown below**
 - **For the Earth:**
 - » `earth_assoc_itrf93.tf`
 - **For the Moon: (pick one or the other—not both)**
 - » `moon_assoc_me.tf`
 - » `moon_assoc_pa.tf`
- **These kernels are available on the NAIF server**
 - **For the Earth:**
 - » `ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/fk/planets/`
 - **For the Moon:**
 - » `ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/fk/satellites/`



Lunar FK/PCK/Association FK Usage

Navigation and Ancillary Information Facility

Which **additional** kernel is needed to use the indicated frame in those (older) SPICE APIs* that use a default (assumed) frame? Pick one or the other.

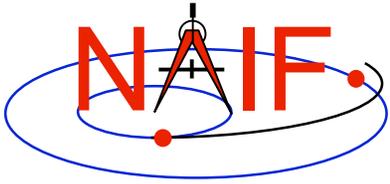


* ET2LST, ILLUM, SRFXPT, SUBPT, SUBSOL (and their C, Icy and Mice equivalents)

**Any version of one or the other of these kernels is good indefinitely; you do not need to use the latest instance offered on the NAIF server.

But best to use the N62 replacements for these four, which don't use a default body-fixed frame:

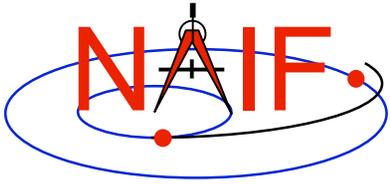
- ILUMIN
- SINCPT
- SUBPNT
- SUBSLR



Navigation and Ancillary Information Facility

Instrument Kernel IK

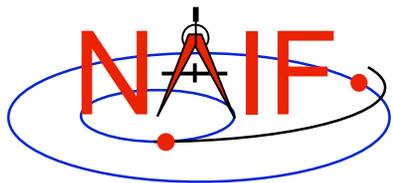
January 2009



Purpose

Navigation and Ancillary Information Facility

- **The Instrument kernel serves as a repository for instrument specific information that may be useful within the SPICE context.**
 - Always included:
 - » Specifications for an instrument's field-of-view (FOV) size, shape, and orientation
 - Other possibilities:
 - » Internal instrument timing parameters and other data relating to SPICE computations might also be placed in an I-kernel
 - » Instrument geometric calibration data
- **Instrument mounting alignment data are specified in a mission's frames kernel (FK)**
 - (Wasn't true for some of the earliest missions)



I-Kernel Structure

Navigation and Ancillary Information Facility

- An I-Kernel is a SPICE text kernel. The format and structure of a typical I-Kernel is shown below.

```
KPL/IK
```

```
Comments describing the keywords and values  
to follow, as well as any other pertinent  
information.
```

```
\begindata  
  Keyword = Value(s) Assignment  
  Keyword = Value(s) Assignment
```

```
\begintext
```

```
More descriptive comments.
```

```
\begindata  
  Keyword = Value(s) Assignment  
\begintext
```

```
More descriptive comments.
```

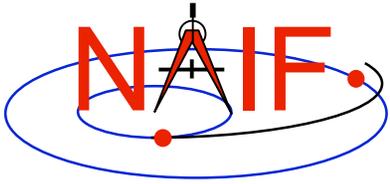
```
etc ...
```



I-Kernel Contents (1)

Navigation and Ancillary Information Facility

- **The requirements on keywords in an IK are the following:**
 - Keywords must begin with **INS[#]**, where [#] is replaced with the NAIF instrument ID code (which is a negative number)
 - The total length of the keyword must be less than or equal to 32 characters
 - Keywords are case-sensitive (Keyword != KEYWORD)
- **Examples of IK keywords, with descriptions:**
 - **INS-94031_FOCAL_LENGTH** MGS MOC NA focal length
 - **INS-41220_IFOV** MEX HRSC SRC pixel angular size
 - **INS-41130_NUMBER_OF_SECTORS** MEX ASPERA NPI number of sectors
- **In general SPICE does not require any specific keywords to be present in an IK**
 - One exception is a set of keywords defining an instrument's FOV, if the SPICE Toolkit's GETFOV routine is planned to be used to retrieve the FOV attributes
 - » Keywords required by GETFOV will be covered later in this tutorial



I-Kernel Contents (2)

Navigation and Ancillary Information Facility

- **IKs should contain extensive comments regarding:**
 - Instrument overview
 - Reference source(s) for the data included in the IK
 - Names/IDs assigned to the instrument and its parts
 - Explanation of each keyword included in the file
 - Description of the FOV and detector layout
 - Sometimes descriptions of the algorithms in which parameters provided in the IK are used, and even fragments of source code implementing these algorithms
 - » For example optical distortion models or timing algorithms
- **This documentation exists primarily to assist users in integrating I-Kernel data into their applications**
 - One needs to know the keyword name to get its value(s) from the IK data
 - One needs to know what each value means in order to use it properly



I-Kernel Interface Routines

Navigation and Ancillary Information Facility

- As with any SPICE kernel, an IK is loaded using FURNISH

```
CALL FURNISH ( 'ik_file_name.ti' )    { Better yet, use a FURNISH kernel }
```

- By knowing the name and type (DP, integer, or character) of a keyword of interest, the value(s) associated with that keyword can be retrieved using G*POOL routines

```
CALL GDPOOL ( NAME, START, ROOM, N, VALUES, FOUND )
```

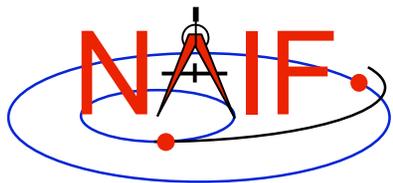
```
CALL GIPOOL ( NAME, START, ROOM, N, VALUES, FOUND )
```

```
CALL GCPOOL ( NAME, START, ROOM, N, VALUES, FOUND )
```

- When an instrument's FOV is defined in the IK using a special set of keywords discussed later in this tutorial, the FOV shape, reference frame, boresight vector, and boundary vectors can be retrieved by calling the GETFOV routine

```
CALL GETFOV ( INSTID, ROOM, SHAPE, FRAME, BSIGHT, N, BOUNDS )
```

FORTRAN examples are shown



FOV Definition Keywords (1)

Navigation and Ancillary Information Facility

- The following keywords defining FOV attributes for the instrument with NAIF ID (#) must be present in the IK if the SPICE Toolkit's GETFOV module will be used
 - Keyword defining shape of the FOV

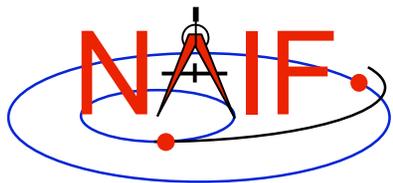
`INS#_FOV_SHAPE` = 'CIRCLE' or 'ELLIPSE' or
'RECTANGLE' or 'POLYGON'

- Keyword defining reference frame in which the boresight vector and FOV boundary vectors are specified

`INS#_FOV_FRAME` = 'frame name'

- Keyword defining the boresight vector

`INS#_BORESIGHT` = (X, Y, Z)



FOV Definition Keywords (2)

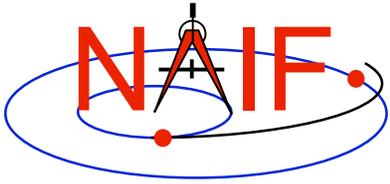
Navigation and Ancillary Information Facility

- Keyword(s) defining FOV boundary vectors, in either of two ways
 - » By specifying boundary vectors explicitly

```
INS#_FOV_CLASS_SPEC           = 'CORNERS'           (optional)
INS#_FOV_BOUNDARY_CORNERS     = ( X(1), Y(1), Z(1),
                                   ...                ...                ...
                                   X(n), Y(n), Z(n) )
```

where the `FOV_BOUNDARY_CORNERS` keyword provides an array of vectors that point to the "corners" of the instrument field of view.

Note that use of the `INS#_FOV_CLASS_SPEC` keyword is optional when explicit boundary vectors are provided.



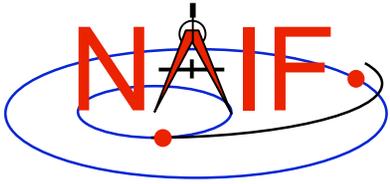
FOV Definition Keywords (3)

Navigation and Ancillary Information Facility

- » By providing half angular extents of the FOV (possible only for circular, elliptical or rectangular FOVs)

| | |
|-----------------------------------|------------------------------------|
| <code>INS#_FOV_CLASS_SPEC</code> | = 'ANGLES' |
| <code>INS#_FOV_REF_VECTOR</code> | = (X, Y, Z) |
| <code>INS#_FOV_REF_ANGLE</code> | = halfangle1 |
| <code>INS#_FOV_CROSS_ANGLE</code> | = halfangle2 |
| <code>INS#_FOV_ANGLE_UNITS</code> | = 'DEGREES' or
'RADIANS' or ... |

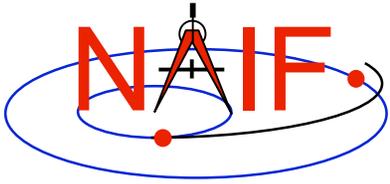
where the `FOV_REF_VECTOR` keyword specifies a reference vector that, together with the boresight vector, define the plane in which the half angle given in the `FOV_REF_ANGLE` keyword is measured. The other half angle given in the `FOV_CROSS_ANGLE` keyword is measured in the plane normal to this plane and containing the boresight vector.



FOV Definition Keywords (4)

Navigation and Ancillary Information Facility

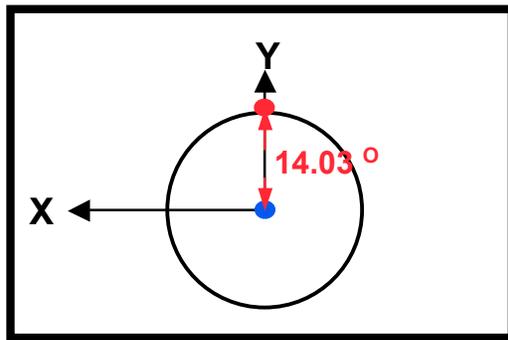
- **Neither the boresight nor reference vector has to be co-aligned with one of the FOV frame's axes**
 - But for convenience, each is frequently defined to be along one of the FOV axes
- **Neither the boresight nor corner nor reference vector has to be a unit vector**
 - But these frequently are defined as unit vectors
- **When a FOV is specified using the half angular extents method, the boresight and reference vectors have to be linearly independent but they don't have to be perpendicular**
 - But for convenience the reference vector is usually picked to be normal to the boresight vector
- **Half angular extents for a rectangular FOV specify the angles between the boresight and the FOV sides, i.e. they are for the middle of the FOV**



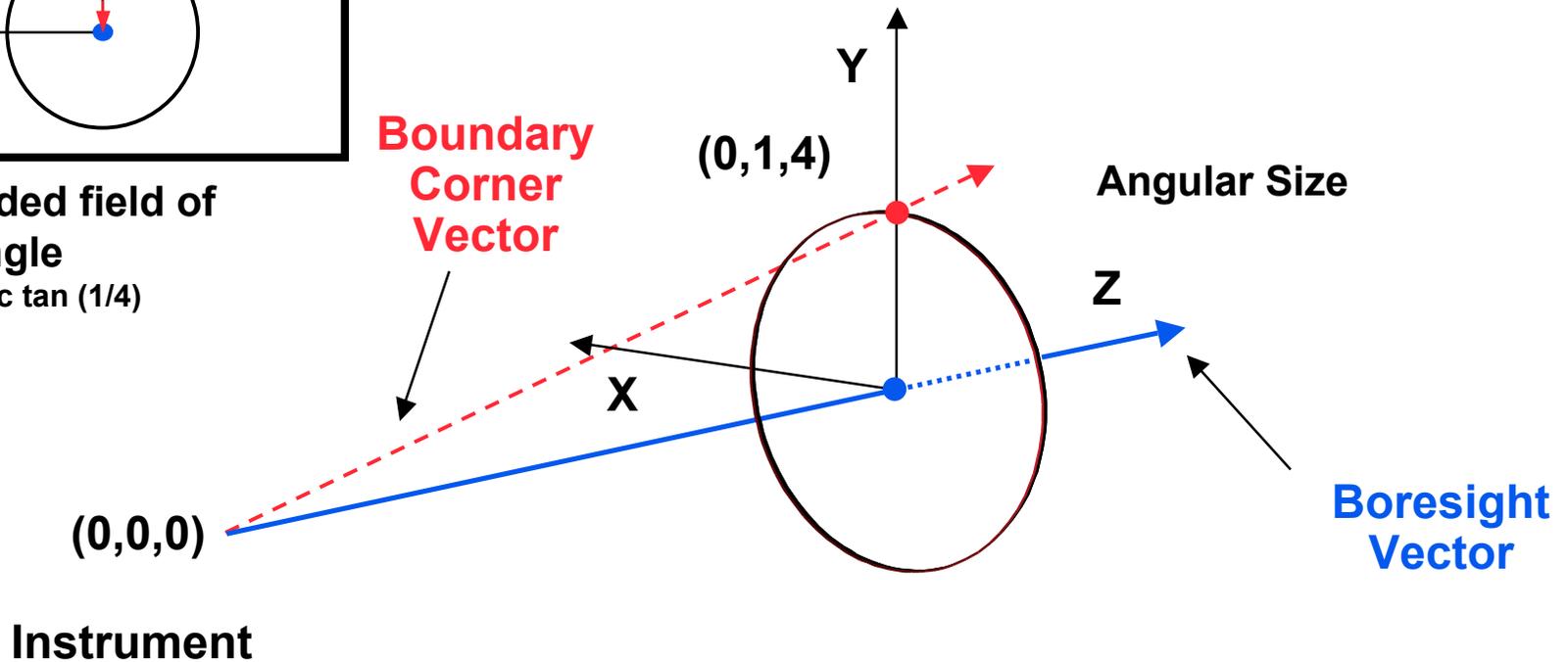
Circular Field of View

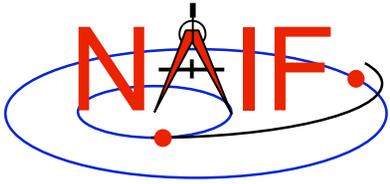
Navigation and Ancillary Information Facility

Consider an instrument with a circular field of view.



Subtended field of view angle
 $14.03 = \arctan(1/4)$





Circular FOV Definition

Navigation and Ancillary Information Facility

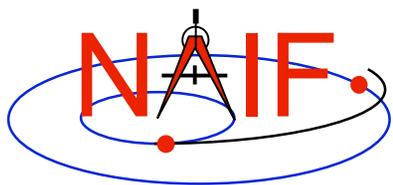
The following sets of keywords and values describe this circular field of view:

Specifying boundary vectors explicitly:

```
INS-11111_FOV_SHAPE           = 'CIRCLE'  
INS-11111_FOV_FRAME          = 'FRAME_FOR_INS-11111'  
INS-11111_BORESIGHT          = ( 0.0  0.0  1.0 )  
INS-11111_FOV_BOUNDARY_CORNERS = ( 0.0  1.0  4.0 )
```

Specifying half angular extents of the FOV:

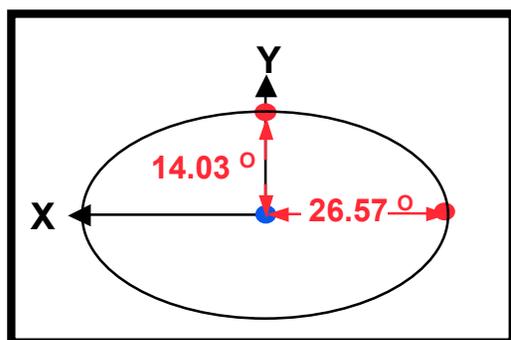
```
INS-11111_FOV_SHAPE           = 'CIRCLE'  
INS-11111_FOV_FRAME          = 'FRAME_FOR_INS-11111'  
INS-11111_BORESIGHT          = ( 0.0  0.0  1.0 )  
INS-11111_FOV_CLASS_SPEC     = 'ANGLES'  
INS-11111_FOV_REF_VECTOR     = ( 0.0  1.0  0.0 )  
INS-11111_FOV_REF_ANGLE      = 14.03624347  
INS-11111_FOV_ANGLE_UNITS    = 'DEGREES'
```



Elliptical Field of View

Navigation and Ancillary Information Facility

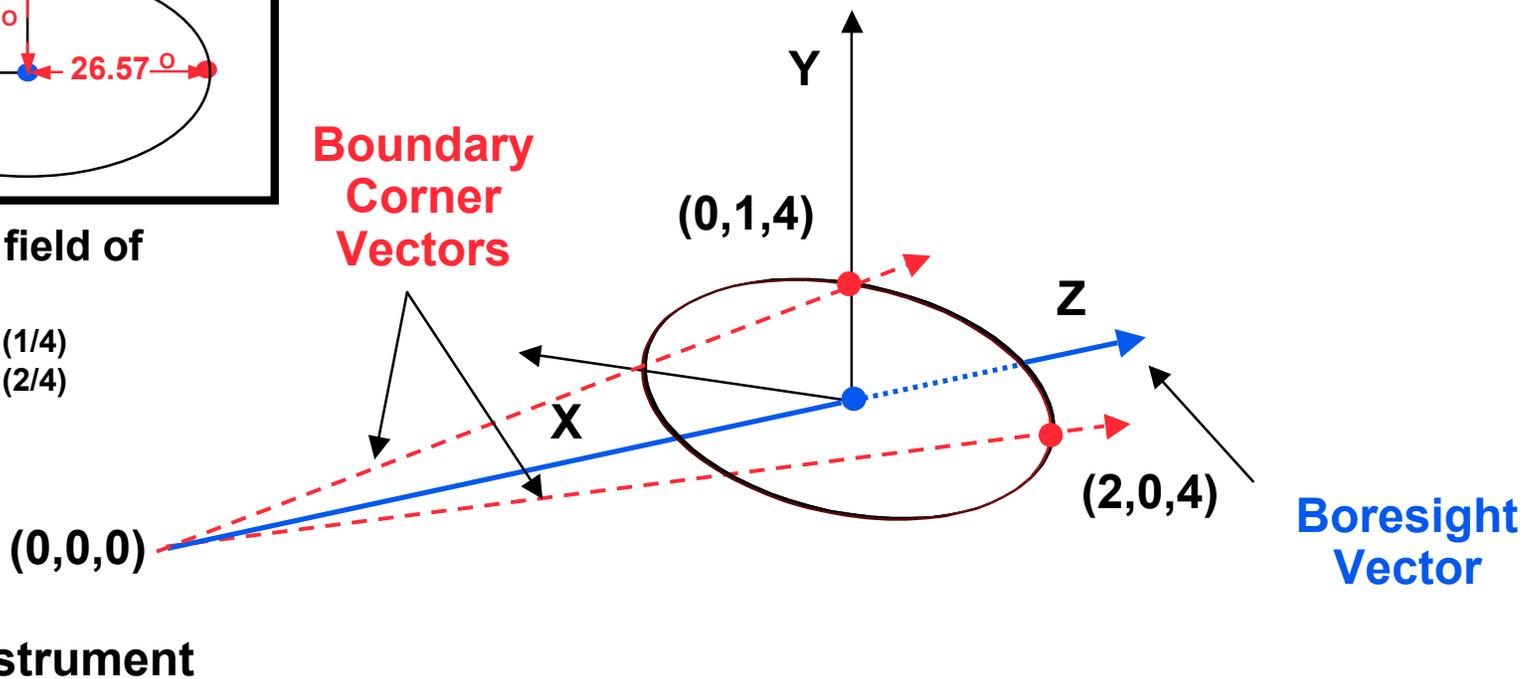
Consider an instrument with an elliptical field of view.

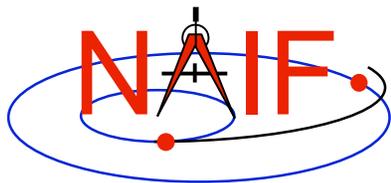


Subtended field of view angle

$$14.03 = \arctan(1/4)$$

$$26.57 = \arctan(2/4)$$





Elliptical FOV Definition

Navigation and Ancillary Information Facility

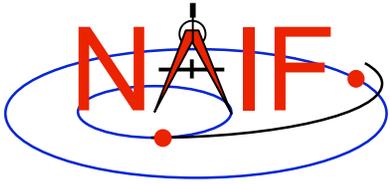
The following sets of keywords and values describe this elliptical field of view:

Specifying boundary vectors explicitly:

```
INS-22222_FOV_SHAPE           = ' ELLIPSE '  
INS-22222_FOV_FRAME          = ' FRAME_FOR_INS-22222 '  
INS-22222_BORESIGHT          = ( 0.0  0.0  1.0 )  
INS-22222_FOV_BOUNDARY_CORNERS = ( 0.0  1.0  4.0  
                                   2.0  0.0  4.0 )
```

Specifying half angular extents of the FOV:

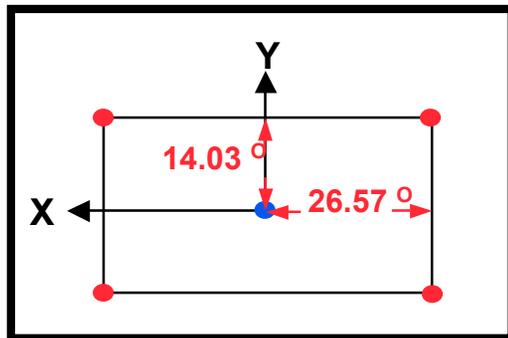
```
INS-22222_FOV_SHAPE           = ' ELLIPSE '  
INS-22222_FOV_FRAME          = ' FRAME_FOR_INS-22222 '  
INS-22222_BORESIGHT          = ( 0.0  0.0  1.0 )  
INS-22222_FOV_CLASS_SPEC     = ' ANGLES '  
INS-22222_FOV_REF_VECTOR     = ( 0.0  1.0  0.0 )  
INS-22222_FOV_REF_ANGLE      = 14.03624347  
INS-22222_FOV_CROSS_ANGLE    = 26.56505118  
INS-22222_FOV_ANGLE_UNITS    = ' DEGREES '
```



Rectangular Field of View

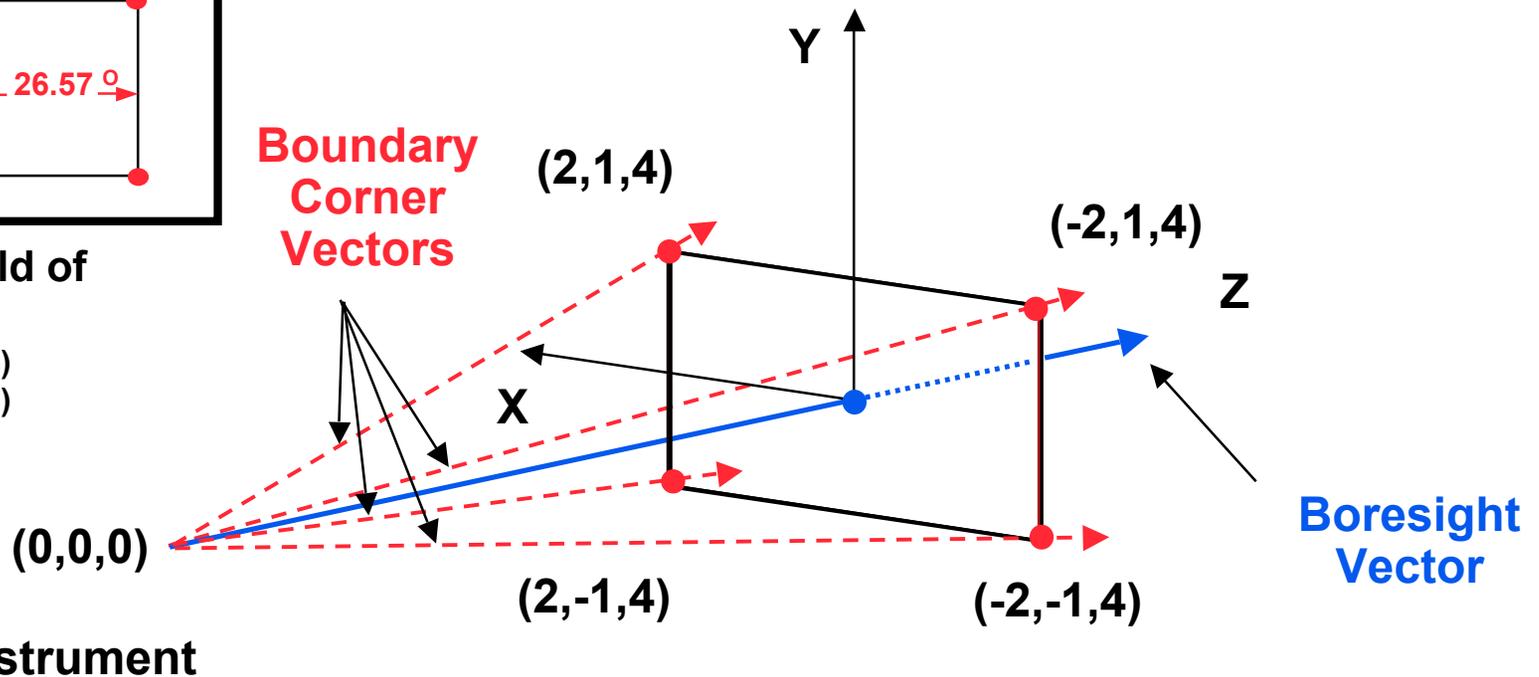
Navigation and Ancillary Information Facility

Consider an instrument with a rectangular field of view.

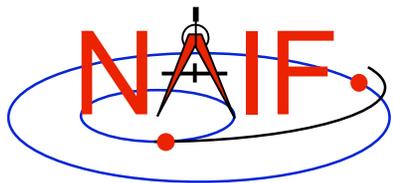


Subtended field of view angle

$14.03 = \arctan(1/2)$
 $26.57 = \arctan(2/4)$



Note: there is not currently (Toolkit Vers. N62) a required order for listing the boundary corner vectors, but there will be such a requirement in the future.



Rectangular FOV Definition

Navigation and Ancillary Information Facility

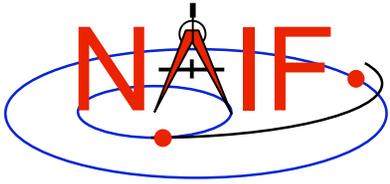
The following sets of keywords and values describe this rectangular field of view:

Specifying boundary vectors explicitly:

```
INS-33333_FOV_SHAPE           = 'RECTANGLE'  
INS-33333_FOV_FRAME           = 'FRAME_FOR_INS-33333'  
INS-33333_BORESIGHT           = ( 0.0  0.0  1.0 )  
INS-33333_FOV_BOUNDARY_CORNERS = ( 2.0  1.0  4.0  
                                   -2.0  1.0  4.0  
                                   -2.0 -1.0  4.0  
                                   2.0 -1.0  4.0 )
```

Specifying half angular extents of the FOV:

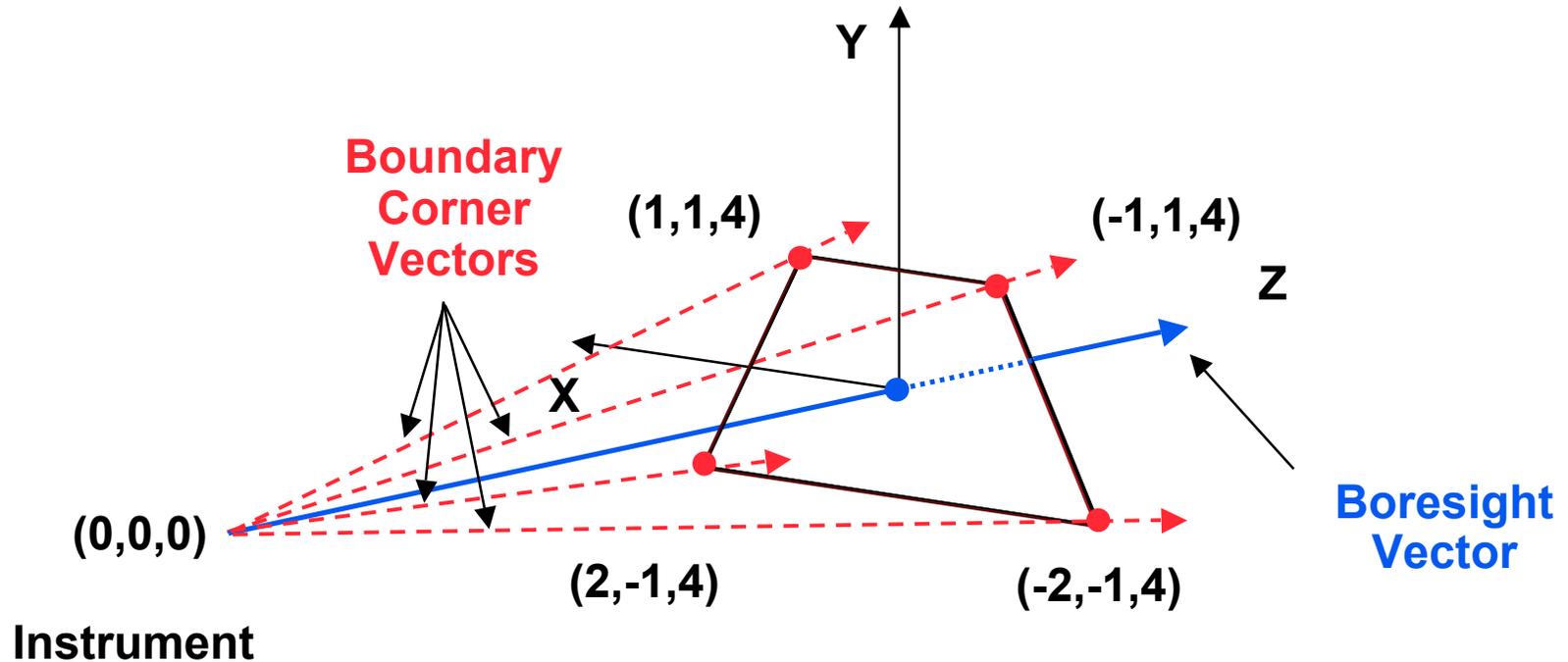
```
INS-33333_FOV_SHAPE           = 'RECTANGLE'  
INS-33333_FOV_FRAME           = 'FRAME_FOR_INS-33333'  
INS-33333_BORESIGHT           = ( 0.0  0.0  1.0 )  
INS-33333_FOV_CLASS_SPEC      = 'ANGLES'  
INS-33333_FOV_REF_VECTOR      = ( 0.0  1.0  0.0 )  
INS-33333_FOV_REF_ANGLE       = 14.03624347  
INS-33333_FOV_CROSS_ANGLE     = 26.56505118  
INS-33333_FOV_ANGLE_UNITS     = 'DEGREES'
```

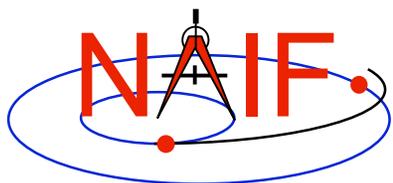


Polygonal Fields of View

Navigation and Ancillary Information Facility

Consider an instrument with a trapezoidal field of view.





Polygonal FOV Definition

Navigation and Ancillary Information Facility

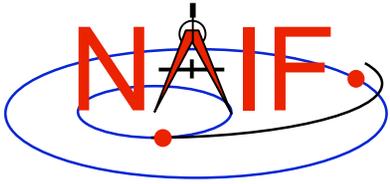
The following sets of keywords and values describe this polygonal field of view:

Specifying boundary vectors explicitly:

```
INS-44444_FOV_SHAPE           = 'POLYGON'  
INS-44444_FOV_FRAME           = 'FRAME_FOR_INS-44444'  
INS-44444_BORESIGHT           = ( 0.0  0.0  1.0 )  
INS-44444_FOV_BOUNDARY_CORNERS = ( 1.0  1.0  4.0  
                                   -1.0  1.0  4.0  
                                   -2.0 -1.0  4.0  
                                   2.0 -1.0  4.0 )
```

Notes:

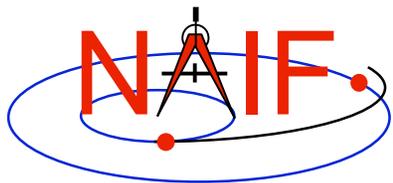
- A polygonal FOV cannot be specified using half angular extents.
- There is not currently (N62) a required order for listing the boundary corner vectors, but there will be such a requirement in the future.



Backup

Navigation and Ancillary Information Facility

- **IK file example**
- **Computing angular extents from corner vectors returned by GETFOV**



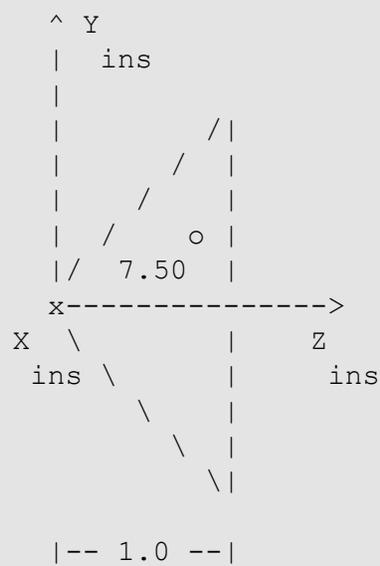
Sample IK Data

Navigation and Ancillary Information Facility

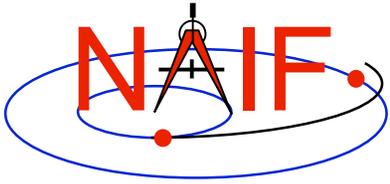
The following LEMMS1 FOV definition was taken from the Cassini MIMI IK (cas_mimi_v11.ti):

```
Low Energy Magnetospheric Measurements System 1 (LEMMS1)
```

```
Since the MIMI_LEMMS1 detector's FOV is circular and it's diameter is 15.0 degrees, looking down the X-axis in the CASSINI_MIMI_LEMMS1 frame, we have: (Note we are arbitrarily choosing a vector that terminates in the Z=1 plane.)
```



continues



Sample IK Data

Navigation and Ancillary Information Facility

FOV definition from the Cassini MIMI IK (continued):

The Y component of one 'boundary corner' vector is:

$$\begin{aligned} \text{Y Component} &= 1.0 * \tan (7.50 \text{ degrees}) \\ &= 0.131652498 \end{aligned}$$

The boundary corner vector as displayed below is normalized to unit length:

\begindata

INS-82762_FOV_FRAME = 'CASSINI_MIMI_LEMMS1'

INS-82762_FOV_SHAPE = 'CIRCLE'

INS-82762_BORESIGHT = (

0.0000000000000000 0.0000000000000000 +1.0000000000000000

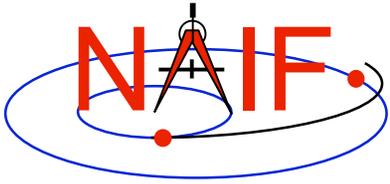
)

INS-82762_FOV_BOUNDARY_CORNERS = (

0.0000000000000000 +0.1305261922200500 +0.9914448613738100

)

\begintext



Circular FOV Angular Size

Navigation and Ancillary Information Facility

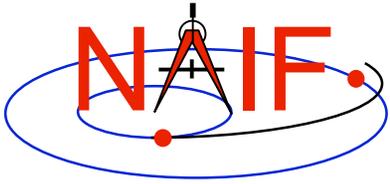
The angular separation between the boundary corner vector and the boresight is the angular size.

FORTRAN EXAMPLE

```
C Retrieve FOV parameters.  
CALL GETFOV(-11111, 1, SHAPE, FRAME, BSGHT, N, BNDS)  
  
C Compute the angular size.  
ANGSIZ = VSEP( BSGHT, BNDS(1,1) )
```

C EXAMPLE

```
/* Define the string length parameter. */  
#define STRSIZ 80  
  
/* Retrieve the field of view parameters. */  
getfov_c(-11111, 1, STRSIZ, STRSIZ, shape, frame,  
        bsght, &n, bnds);  
  
/* Compute the angular separation. */  
angsiz = vsep_c( bsght, &(bnds[0][0]));
```



Elliptical FOV Angular Size - 1

Navigation and Ancillary Information Facility

The angular sizes are the angular separations between the boresight and the boundary vectors.

FORTRAN EXAMPLE

```
C Retrieve the FOV parameters from the kernel pool.  
CALL GETFOV(-22222, 2, SHAPE, FRAME, BSGHT, N, BNDS)  
  
C Compute the angular separations.  
ANG1 = VSEP( BSGHT, BNDS(1,1) )  
ANG2 = VSEP( BSGHT, BNDS(1,2) )  
  
C The angle along the semi-major axis is the larger  
C of the two separations computed.  
LRGANG = MAX( ANG1, ANG2 )  
SMLANG = MIN( ANG1, ANG2 )
```



Elliptical FOV Angular Size - 2

Navigation and Ancillary Information Facility

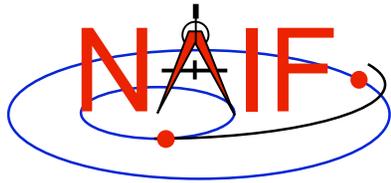
C EXAMPLE

```
/* Define the string length parameter. */
#define STRSIZ      80

/* Retrieve the FOV parameters from the kernel pool. */
getfov_c(-22222, 2, STRSIZ, STRSIZ, shape, frame,
         bsght, &n, bnds);

/* Compute the angular separations. */
ang1 = vsep_c( bsght, &(bnds[0][0]));
ang2 = vsep_c( bsght, &(bnds[1][0]));

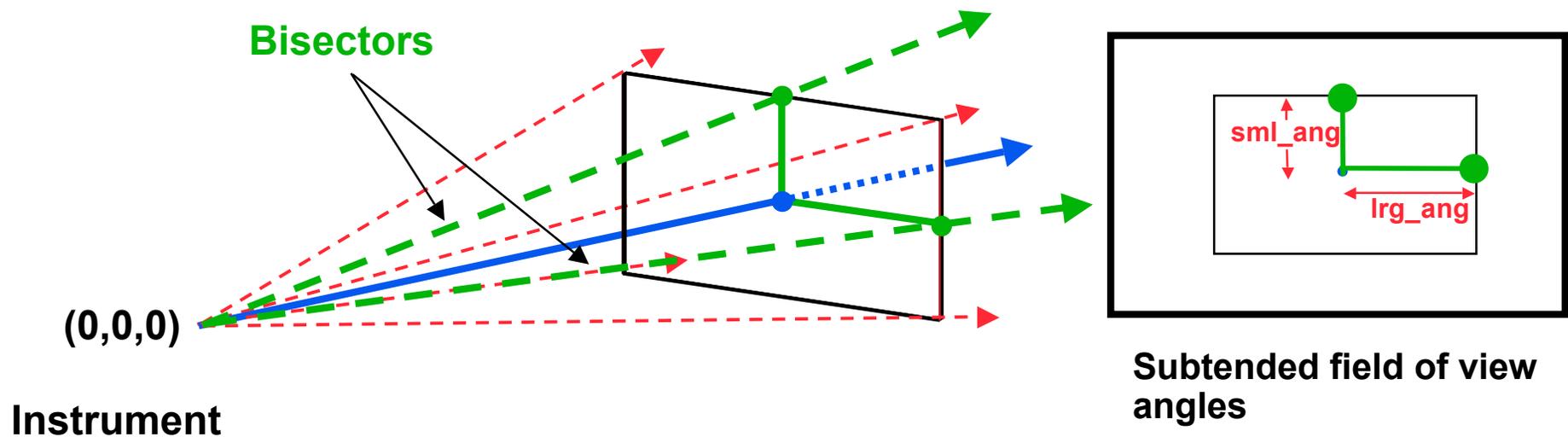
/* The angle along the semi-major axis is the larger of the
two separations computed. */
if ( ang1 > ang2 ) {
    lrgang = ang1; smlang = ang2; }
else {
    lrgang = ang2; smlang = ang1; }
```

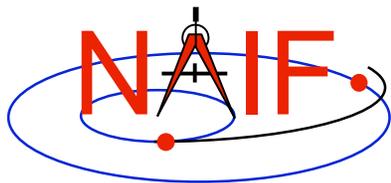


Rectangular FOV Angular Size - 1

Navigation and Ancillary Information Facility

The angular extents of the FOV are computed by calculating the angle between the bisector of adjacent unit boundary vectors and the boresight.





Rectangular FOV Angular Size - 2

Navigation and Ancillary Information Facility

FORTRAN EXAMPLE

```
C Retrieve FOV parameters from the kernel pool.
CALL GETFOV(-33333, 4, SHAPE, FRAME, BSGHT, N, BNDS)

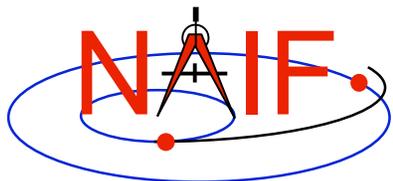
C Normalize the 3 boundary vectors
CALL UNORM(BNDS(1,1), UNTBND(1,1), MAG)
CALL UNORM(BNDS(1,2), UNTBND(1,2), MAG)
CALL UNORM(BNDS(1,3), UNTBND(1,3), MAG)

C Compute the averages.
CALL VADD(UNTBND(1,1), UNTBND(1,2), VEC1)
CALL VSCL(0.5, VEC1, VEC1)

CALL VADD(UNTBND(1,2), UNTBND(1,3), VEC2)
CALL VSCL(0.5, VEC2, VEC2)

C Compute the angular separations
ANG1 = VSEP( BSGHT, VEC1 )
ANG2 = VSEP( BSGHT, VEC2 )

C Separate the larger and smaller angles.
LRGANG = MAX( ANG1, ANG2)
SMLANG = MIN( ANG1, ANG2)
```



Rectangular FOV Angular Size - 3

Navigation and Ancillary Information Facility

C EXAMPLE

```
/* Define the string length parameter. */
#define STRSIZ      80

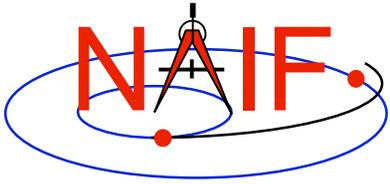
/* Retrieve the FOV parameters from the kernel pool. */
getfov_c(-33333, 4, STRSIZ, STRSIZ, shape, frame,
         bsght, &n, bnds);

/* Normalize the 3 boundary vectors. */
unorm_c(&(bnds[0][0]), &(untbnd[0][0]), &mag);
unorm_c(&(bnds[1][0]), &(untbnd[1][0]), &mag);
unorm_c(&(bnds[2][0]), &(untbnd[2][0]), &mag);

/* Compute the averages */
vadd_c(&(untbnd[0][0]), &(untbnd[1][0]), vec1);
vscl_c(0.5, vec1, vec1);
vadd_c(&(untbnd[1][0]), &(untbnd[2][0]), vec2);
vscl_c(0.5, vec2, vec2);

/* Compute the angular separations. */
ang1 = vsep_c( bsght, vec1);
ang2 = vsep_c( bsght, vec2);

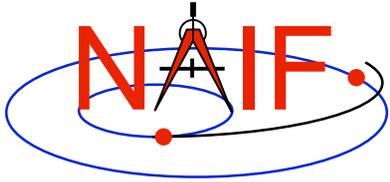
/* Separate the larger and smaller angles. */
if ( ang1 > ang2 ) {
    lrgang = ang1; smlang = ang2; }
else {
    lrgang = ang2; smlang = ang1; }
```



More Information

Navigation and Ancillary Information Facility

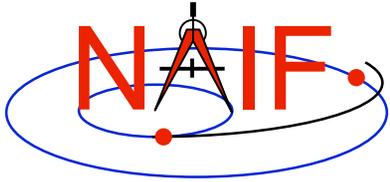
- **The best way to learn more about IKs is to examine some found in the NAIF Node archives.**
 - Start looking here:
http://naif.jpl.nasa.gov/naif/data_archived.html
- **(Don't yet have an “I-Kernel Required Reading” document.)**



Navigation and Ancillary Information Facility

Reading FKs and IKs

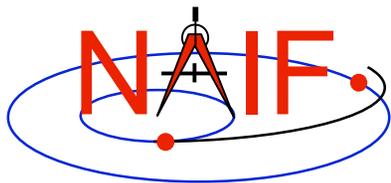
January 2009



See The Real Stuff

Navigation and Ancillary Information Facility

- It may be useful for the student to examine a few existing Frames Kernels and Instrument Kernels to get a better understanding of the FK and IK tutorial information.
- NAIF suggests you use your browser to examine some of the following “real life” kernels.
- **DEEP IMPACT:**
 - ftp://naif.jpl.nasa.gov/pub/naif/pds/data/di-c-spice-6-v1.0/disp_1000/data/fk/*.tf
 - ftp://naif.jpl.nasa.gov/pub/naif/pds/data/di-c-spice-6-v1.0/disp_1000/data/ik/*.ti
- **CASSINI:**
 - ftp://naif.jpl.nasa.gov/pub/naif/pds/data/co-s_j_e_v-spice-6-v1.0/cosp_1000/data/fk/*.tf
 - ftp://naif.jpl.nasa.gov/pub/naif/pds/data/co-s_j_e_v-spice-6-v1.0/cosp_1000/data/ik/*.ti
- **MESSENGER:**
 - ftp://naif.jpl.nasa.gov/pub/naif/pds/data/mess-e_v_h-spice-6-v1.0/messsp_1000/data/fk/*.tf
 - ftp://naif.jpl.nasa.gov/pub/naif/pds/data/mess-e_v_h-spice-6-v1.0/messsp_1000/data/ik/*.ti
- **MARS EXPRESS:**
 - ftp://naif.jpl.nasa.gov/pub/naif/MEX/kernels/fk/*.TF
 - ftp://naif.jpl.nasa.gov/pub/naif/MEX/kernels/ik/*.TI



Navigation and Ancillary Information Facility

Derived Quantities

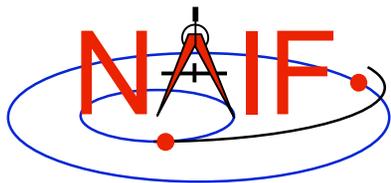
January 2009



Overview

Navigation and Ancillary Information Facility

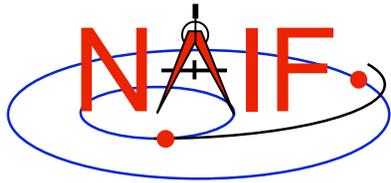
- **What are “derived quantities?”**
- **A quick tour of some of the routines provided for the computation of derived quantities**
 - **Vector/Matrix Routines**
 - **Geometry Routines**
 - **Coordinate System Routines**
- **Computing Illumination Angles**
- **Computing Ring Plane Intercepts**
- **Computing Occultation Events**



What are Derived Quantities?

Navigation and Ancillary Information Facility

- **Derived quantities are data produced from states, C-matrices, frame transformations, physical constants, time conversions, etc.**
 - **These are the primary reason that SPICE exists!** 
- **Examples are:**
 - Angles, Angular Rates
 - Distances, Speeds
 - Directions
 - Lighting conditions
 - Cartographic parameters
 - Schedules of events
- **The SPICE Toolkit contains many routines that assist with the computations of derived quantities.**
 - Some are fairly low level, some are quite high level.
 - More are being added as time permits.

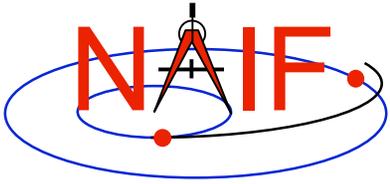


A Quick Tour

Navigation and Ancillary Information Facility

- **Vector/Matrix Routines**
 - Vector and vector derivative arithmetic
 - Matrix arithmetic
- **Geometric “Objects”**
 - Planes
 - Ellipses
 - Ellipsoids
 - Rays
- **Coordinate Systems**
 - Spherical: latitude/longitude, co-latitude/longitude, right ascension/declination; Geodetic, Cylindrical, Rectangular, Planetographic
- **Others**

The lists on the following pages are just a subset of what’s available in the Toolkit.



Vectors

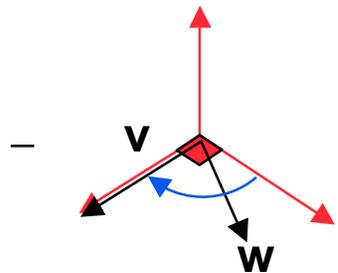
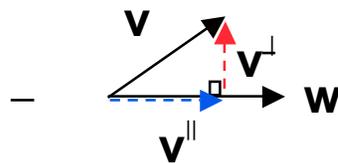
Navigation and Ancillary Information Facility

- **Function**

- $\langle \mathbf{v}, \mathbf{w} \rangle$
- $\mathbf{v} \times \mathbf{w}$
- $\mathbf{v} / |\mathbf{v}|$
- $\mathbf{v} \times \mathbf{w} / |\mathbf{v} \times \mathbf{w}|$
- $\mathbf{v} + \mathbf{w}$
- $\mathbf{v} - \mathbf{w}$
- $a\mathbf{v} [+ b\mathbf{w} [+ c\mathbf{u}]]$
- angle between \mathbf{v} and \mathbf{w}
- $|\mathbf{v}|$

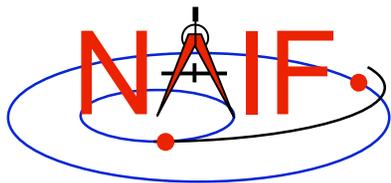
- **Routine**

- $\mathbf{VDOT}, \quad \mathbf{DVDOT}$
- $\mathbf{VCROSS}, \quad \mathbf{DVCROSS}$
- $\mathbf{VHAT}, \quad \mathbf{DVHAT}$
- $\mathbf{UCROSS}, \quad \mathbf{DUCROSS}$
- $\mathbf{VADD}, \quad \mathbf{VADDG}$
- $\mathbf{VSUB}, \quad \mathbf{VSUBG}$
- $\mathbf{VSCL}, \quad [\mathbf{VLCOM}, \quad [\mathbf{VLCOM3}]]$
- \mathbf{VSEP}
- \mathbf{VNORM}



- $\mathbf{VPROJ}, \quad \mathbf{VPERP}$

- $\mathbf{TWOVEC}, \quad \mathbf{FRAME}$



Matrices

Navigation and Ancillary Information Facility

Selected Matrix-Vector Linear Algebra Routines

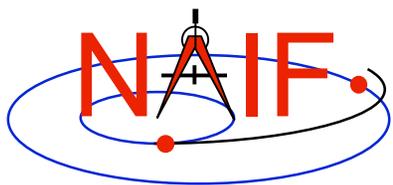
- Function

- $M \times v$
- $M \times M$
- $M^t \times v$
- $M^t \times M$
- $M \times M^t$
- $v^t \times M \times v$
- M^t
- M^{-1}

- Routine

- MXV
- MXM
- $MTXV$
- $MTXM$
- $MXMT$
- $VTMV$
- $XPOSE$
- $INVERSE, INVSTM$

M = Matrix
 v = Vector
 x = Multiplication
 T = Transpose

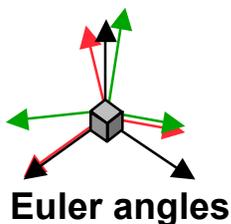


Matrix Conversions

Navigation and Ancillary Information Facility

Function

Routines

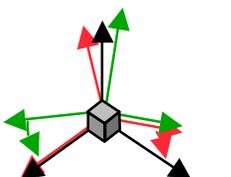


← Transform between →

$$\begin{matrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \end{matrix}$$

3x3 rotation matrix

– EUL2M, M2EUL

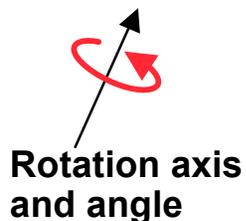


← Transform between →

$$\begin{matrix} a_x & a_y & a_z & & & \\ b_x & b_y & b_z & & & 0 \\ c_x & c_y & c_z & & & \\ \alpha_x & \alpha_y & \alpha_z & a_x & a_y & a_z \\ \beta_x & \beta_y & \beta_z & b_x & b_y & b_z \\ \gamma_x & \gamma_y & \gamma_z & c_x & c_y & c_z \end{matrix}$$

6x6 state transformation
matrix

– EUL2XF, XF2EUL
RAV2XF, XF2RAV



← Transform between →

$$\begin{matrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \end{matrix}$$

3x3 rotation matrix

– RAXISA, AXISAR
ROTATE, ROTMAT

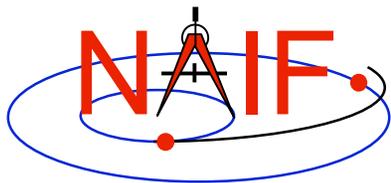
(Q_0, Q_1, Q_2, Q_3)
SPICE Style
Quaternion

← Transform between →

$$\begin{matrix} a_x & a_y & a_z \\ b_x & b_y & b_z \\ c_x & c_y & c_z \end{matrix}$$

3x3 rotation matrix

– Q2M, M2Q



Geometry

Navigation and Ancillary Information Facility

Function

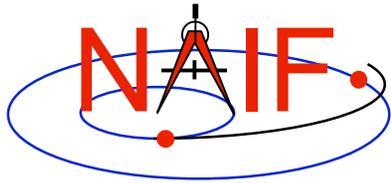
- **Ellipsoids**
 - nearest point [derivative]
 - surface ray intercept
 - surface normal
 - limb
 - slice with a plane
 - altitude of ray w.r.t. to ellipsoid
- **Planes**
 - intersect ray and plane
- **Ellipses**
 - project onto a plane
 - find semi-axes of an ellipse

Routine

- NEARPT , SUBPNT , DNEARP
- SURFPT , SINCPT
- SURFNM
- EDLIMB
- INELPL
- NPEDLN

- INRYPL

- PJELPL
- SAELGV



Position Coordinate Transformations

Navigation and Ancillary Information Facility

Coordinate Transformation

- Latitudinal to/from Rectangular
- Planetographic to/from Rectangular
- R.A. Dec to/from Rectangular
- Geodetic to/from Rectangular
- Cylindrical to/from Rectangular
- Spherical to/from Rectangular

Routine

- LATREC
RECLAT
- PGRREC
RECPGR
- RADREC
RECRAD
- GEOREC
REC GEO
- CYLREC
RECCYL
- SPHREC
RECSPH



Velocity Coordinate Transformations - 1

Navigation and Ancillary Information Facility

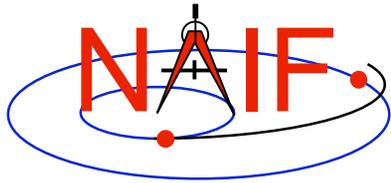
- **Coordinate Transformation**

- Latitudinal to/from Rectangular
- Planetographic to/from Rectangular
- R.A. Dec to/from Rectangular
- Geodetic to/from Rectangular
- Cylindrical to/from Rectangular
- Spherical to/from Rectangular

- **Jacobian (Derivative) Matrix Routine**

- DRDLAT
DLATDR
- DRDPGR
DPGRDR
- DRDLAT*
DLATDR*
- DRDGEO
DGEODR
- DRDCYL
DCYLDR
- DRDSPH
DSPHDR

* Jacobian matrices for the R.A and Dec to/from rectangular mappings are identical to those for the latitudinal to/from rectangular mappings



Velocity Coordinate Transformations - 2

Navigation and Ancillary Information Facility

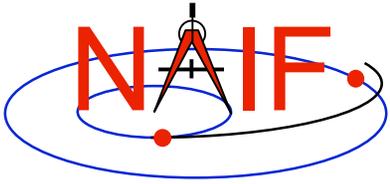
- **Transform velocities from one coordinate system to another using the SPICE Jacobian matrix routines. Example:**
 - Let (x, y, z) be a time-dependent vector expressed in rectangular coordinates:
$$(x, y, z) = \Gamma(t)$$
 - Let (α, β, γ) be the same vector expressed in spherical coordinates:
$$(\alpha, \beta, \gamma) = \Phi(\Gamma(t))$$
 - Then the chain rule gives us the time derivative of the position in spherical coordinates:
$$d(\Phi(\Gamma(t))) / dt = J(\Gamma(t)) * d\Gamma(t) / dt$$
 - The left hand side above is the velocity in spherical coordinates. The first factor on the right is the “Jacobian matrix” of the mapping from rectangular to spherical coordinates; the second factor on the right is the velocity in rectangular coordinates.



Velocity Coordinate Transformations - 3

Navigation and Ancillary Information Facility

- **The SPICE calls that implement this computation are:**
 - `CALL SPKEZR (TARG, ET, REF, CORR, OBS, STATE, LT)`
 - `CALL DSPHDR (STATE(1), STATE(2), STATE(3), JACOBI)`
 - `CALL MXV (JACOBI, STATE(4), SPHVEL)`
- **After these calls, the vector SPHVEL contains the velocity in spherical coordinates: specifically, the derivatives**
($d(r) / dt$, $d(\text{colatitude}) / dt$, $d(\text{longitude}) / dt$)
- **Caution: coordinate transformations often have singularities, so derivatives may not exist everywhere.**
 - Exceptions are described in the headers of the SPICE Jacobian matrix routines.
 - SPICE Jacobian matrix routines signal errors if asked to perform an invalid computation.

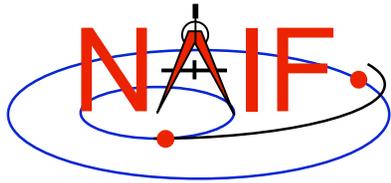


Other Derived Quantities

Navigation and Ancillary Information Facility

- **Illumination angles (phase, incidence, emission)**
 - ILUMIN*
- **Subsolar point**
 - SUBSLR*
- **Subobserver point**
 - SUBPNT*
- **Surface intercept point**
 - SINCPT*
- **Longitude of the sun (L_s), an indicator of season**
 - LSPCN

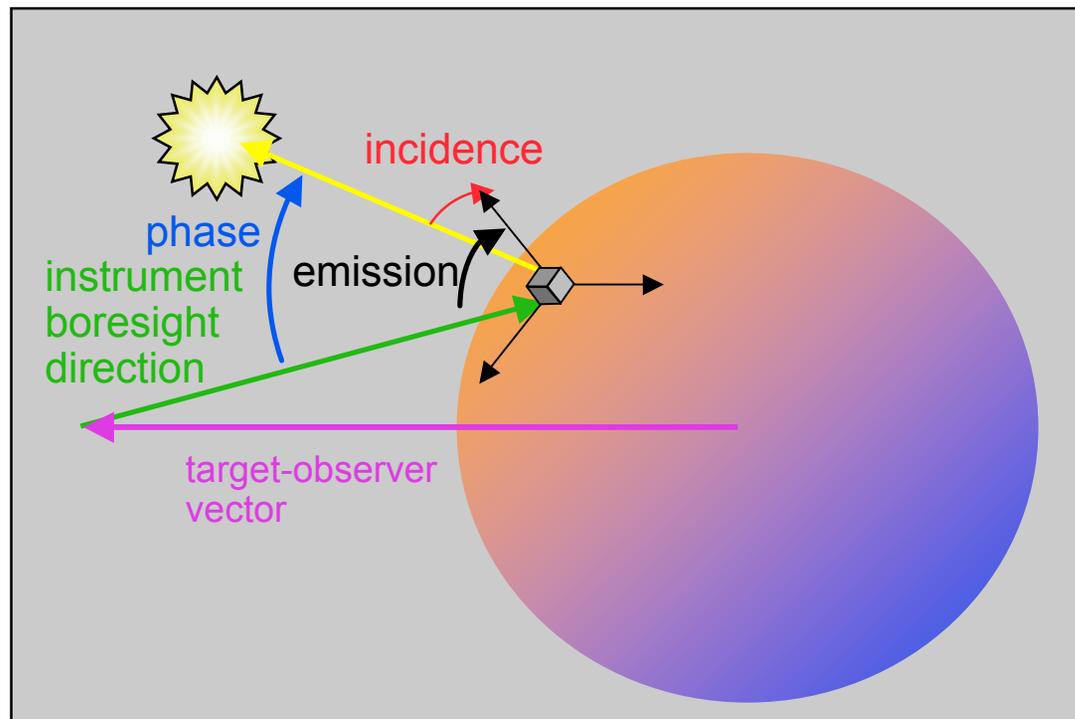
* These routines supercede the now deprecated routines ILLUM, SUBSOL, SUBPT and SRFXPT



Computing Illumination Angles

Navigation and Ancillary Information Facility

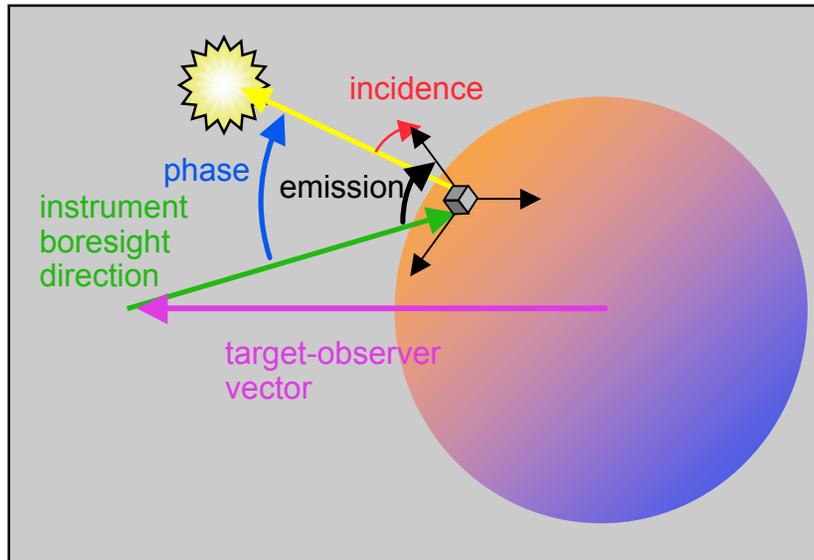
- **Given the direction of an instrument boresight in a bodyfixed frame, return the illumination angles (incidence, phase, emission) at the surface intercept on a tri-axial ellipsoid**



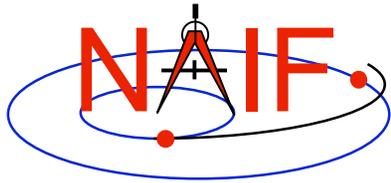


Computing Illumination Angles

Navigation and Ancillary Information Facility



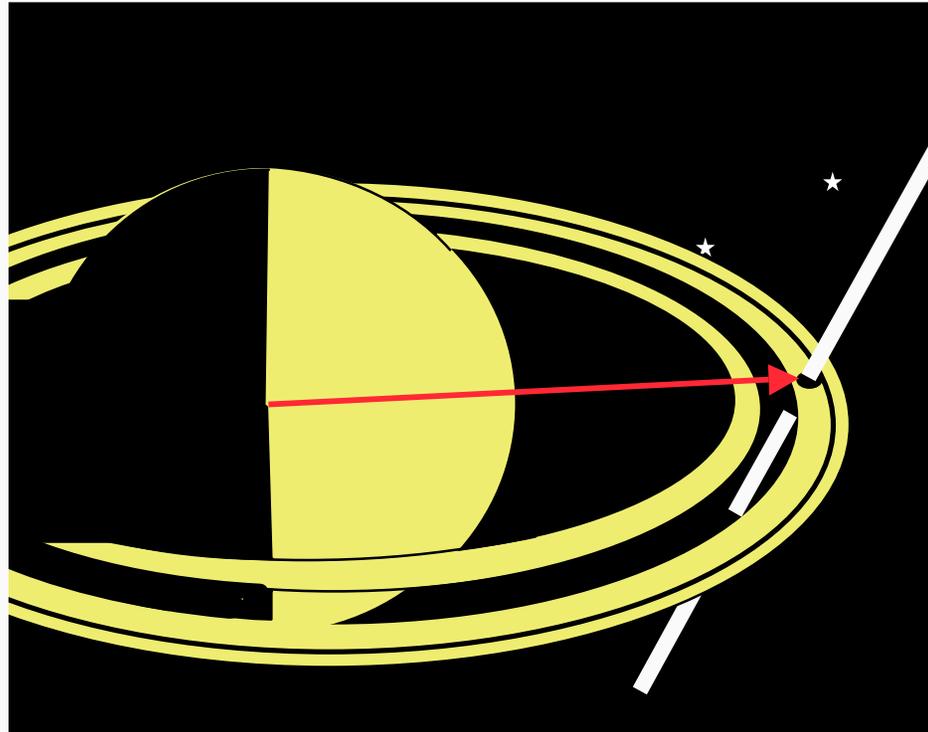
- CALL **GETFOV** to obtain boresight direction vector.
- CALL **SINCPT** to find intersection of direction vector with surface.
- CALL **ILUMIN** to determine illumination angles.

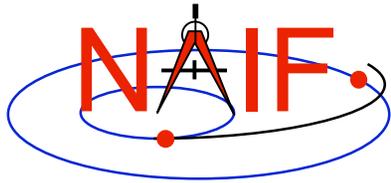


Computing Ring Plane Intercepts

Navigation and Ancillary Information Facility

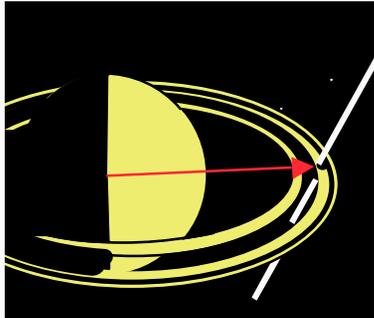
- **Determine the intersection of the apparent line of sight vector between Earth and Cassini with Saturn's ring plane and determine the distance of this point from the center of Saturn.**





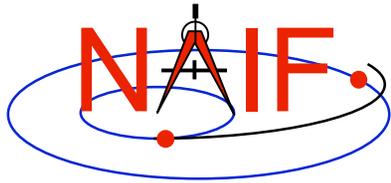
Computing Ring Plane Intercepts

Navigation and Ancillary Information Facility



This simplified computation ignores the difference between the light time from Saturn to the observer and the light time from the intercept point to the observer. It also ignores the difference in stellar aberration between the observer-Saturn vector and the observer-intercept vector.

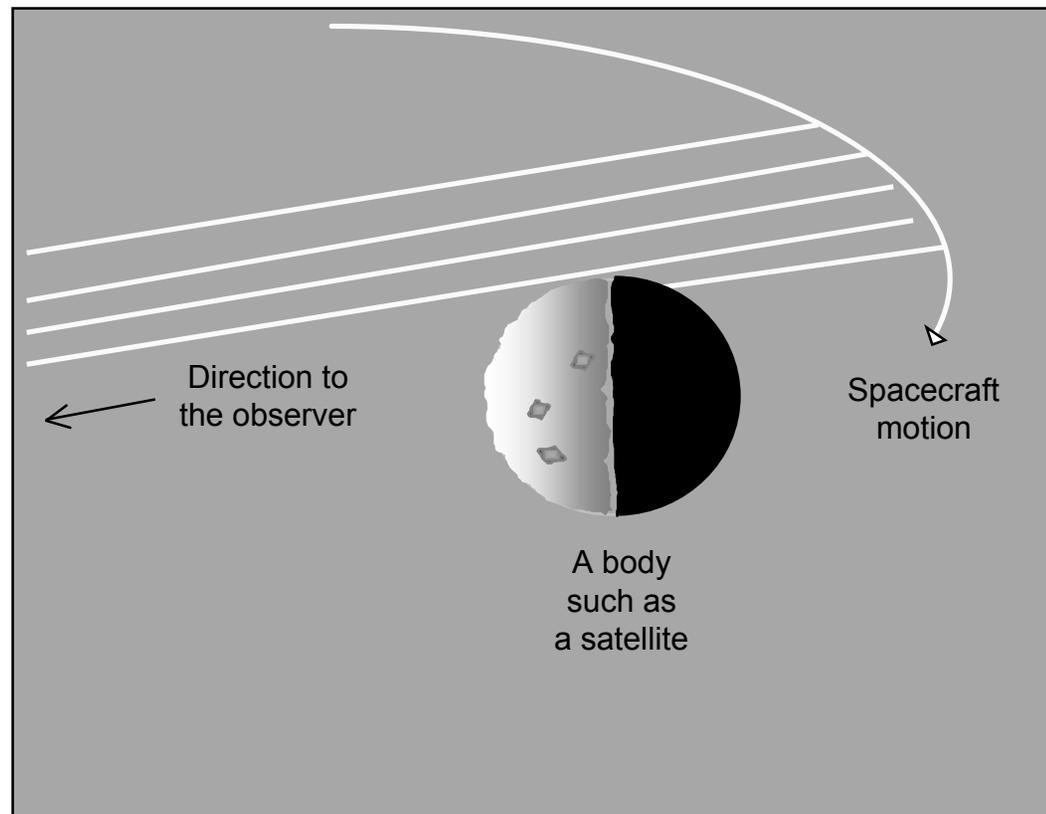
- CALL **SPKEZR** to get apparent position of spacecraft as seen from earth at time ET in J2000 reference frame SCVEC.
- CALL **SPKEZR** to get apparent position of center of Saturn at time ET as seen from earth in J2000 frame SATCTR.
- CALL **PXFORM** to get rotation from Saturn body-fixed coordinates to J2000 at light-time corrected epoch. The third column of this matrix gives the pole direction of Saturn in the J2000 frame SATPOL.
- CALL **NVP2PL** and use SATCTR and SATPOL to construct the ring plane RPLANE.
- CALL **INRYPL** to intersect Earth-spacecraft vector SCVEC with the Saturn ring plane RPLANE to produce the intercept point X.
- CALL **VSUB** to get position of intercept point with respect to Saturn XSAT (subtract SATCTR from X) and use **VNORM** to get the distance of XSAT from the center of Saturn.



Computing Occultation Events

Navigation and Ancillary Information Facility

- **Determine when the spacecraft will be occulted by an object (such as a natural satellite) as seen from an observer (such as earth).**

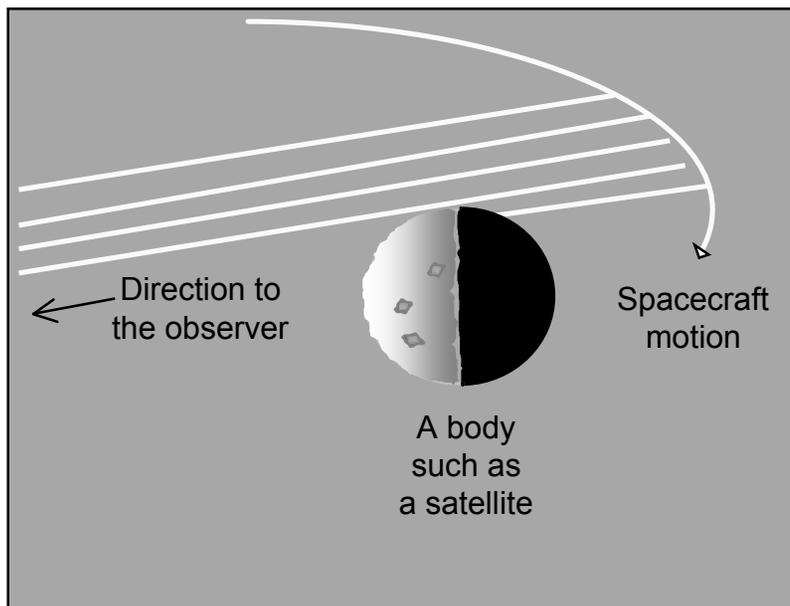


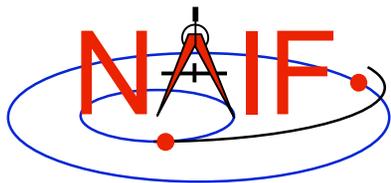


Find Epoch of Occultation Ingress

Navigation and Ancillary Information Facility

- **Select a start epoch, stop epoch and step size.**
 - Start and stop epochs should bracket a single occultation ingress epoch.
 - Step size should be smaller than occultation duration, but large enough to solve problem with reasonable speed.
- **WHILE ($ET < \text{"stop epoch"}$)**
 - CALL **SINCPT** to see if the apparent direction of the spacecraft as seen by the observer intersects the surface of the body; do this by examining the "FOUND" flag. Take note of any such transition.
 - If an intersection is found, check that the spacecraft is further from the observer than the intersection point.
 - » Can now refine time of occultation ingress via binary search.
 - » Exit loop.
 - Otherwise, increment ET.

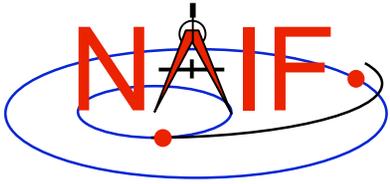




Event Finding Software

Navigation and Ancillary Information Facility

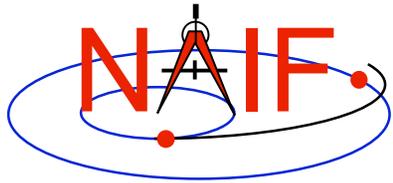
- **NAIF is busy building new software—the “geometry finder” subsystem—that will find a large number of geometric events, such as occultations, transits, periapsis passage, etc.**
- **A preview of these new capabilities will be provided in a later presentation.**
- **A portion of this subsystem will be provided in the N63 Toolkit... the next release.**
 - **Should be available by March 1, 2009**



Navigation and Ancillary Information Facility

Other Useful Functions (Using FORTRAN Examples)

January 2009

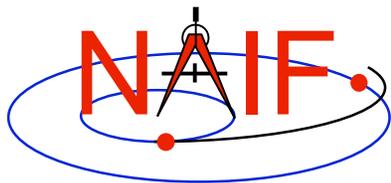


Topics

Navigation and Ancillary Information Facility

- **Overview**
- **Language-specific status**
- **Text I/O***
- **File Operations***
- **String Manipulation***
- **Searching, Sorting and Other Array Manipulations**
- **Windows (also referred to as schedules)**
- **Symbol Tables**
- **Sets and Cells**
- **Constants and Unit Conversion**
- **Numerical Functions**

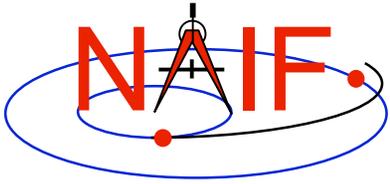
* These routines provide capabilities similar to some of Perl's text manipulation functions



Overview

Navigation and Ancillary Information Facility

- **Many (not all) of the routines described in this tutorial have a CSPICE API equivalent (a CSPICE “wrapper”)**
- **Not all routines have an Icy or Mice equivalent at present**
 - NAIF adds more “wrappers” to the CSPICE library and interface routines to Icy and Mice as needed.
 - Not all functionality is needed in all four language versions of the Toolkit library. Where not needed, a routine is not implemented.
- **Routines listed in this tutorial include a language “identifier” or set of identifiers to indicate which Toolkit language(s) include that routine.**
 - [F] available from FORTRAN (SPICELIB)
 - [C] available from C (CSPICE)
 - [M] available from MATLAB (Mice)
 - [I] available from IDL (Icy)

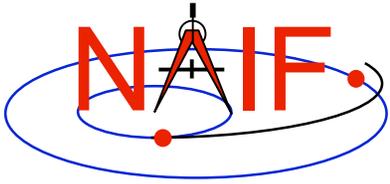


Text I/O

Navigation and Ancillary Information Facility

- **Text files provide a simple, human readable mechanism for sharing data.**
- **The Toolkit contains several utility routines to assist with the creation and parsing of text, and with the reading and writing of text files.**
 - **[F,C] RDTEXT: read a line of text from a text file**
 - **[F] TOSTDO: write a line of text to standard output**
 - **[F,C] PROMPT: display a prompt, wait for and return user's response**
 - **[F] TXTOPN: open a new text file returning a logical unit**
 - **[F] WRITLN: write a line of text to the file attached to a logical unit.**





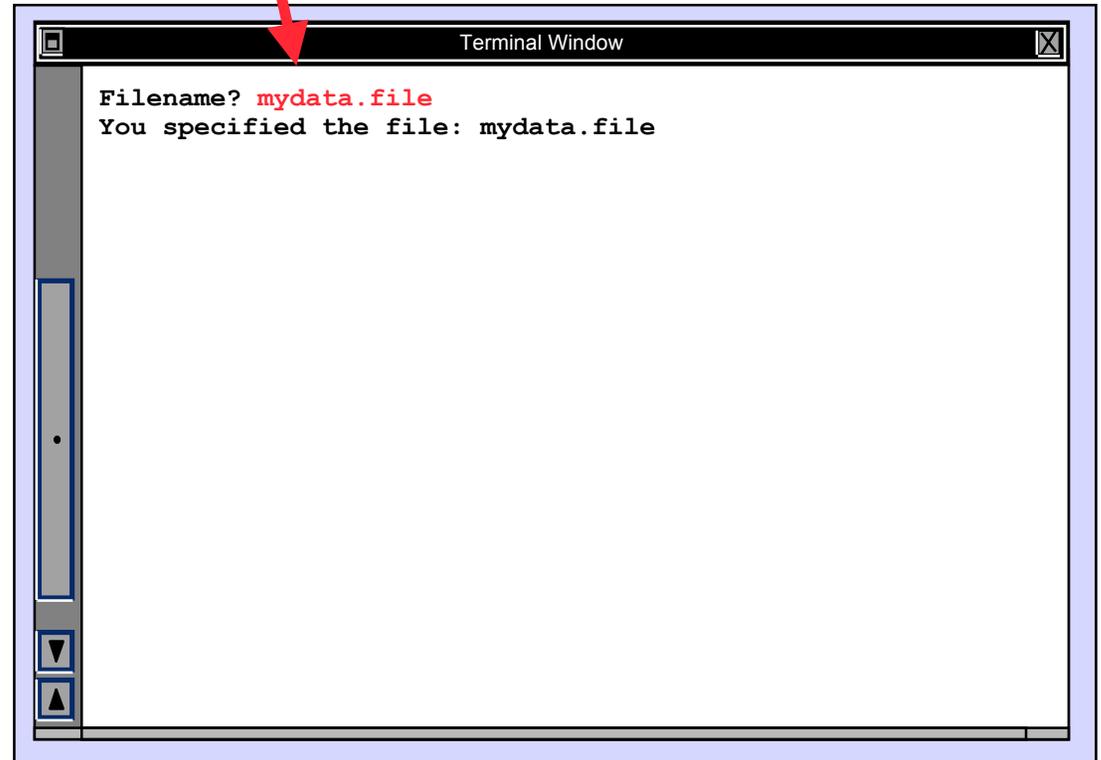
Text I/O - 2

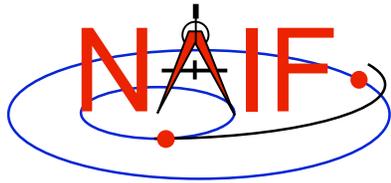
Navigation and Ancillary Information Facility

```
CALL PROMPT ( 'Filename? ', NAME )  
CALL TOSTDO ( 'You specified the file: '// NAME )
```

Now that we have the filename, read
and process its contents

```
CALL RDTEXT ( NAME, LINE, EOF )  
  
DO WHILE ( .NOT. EOF )  
    process the line just read  
    CALL RDTEXT ( NAME, LINE, EOF )  
END DO
```

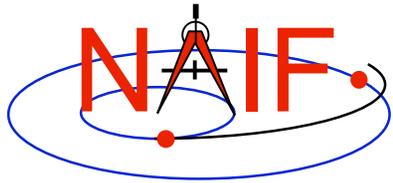




File Operations

Navigation and Ancillary Information Facility

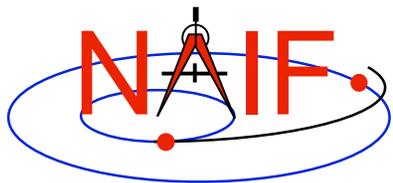
- **Logical unit management - specific to FORTRAN**
 - **RESLUN:** (reserve logical unit) prohibits SPICE systems from using specified units
 - **FRELUN:** (free logical unit) places “reserved” units back into service for SPICE
 - **GETLUN:** (get logical unit) locates an unused, unreserved logical unit.
- **Determining whether or not a file exists**
 - **[F,C,I] EXISTS**
- **Deleting an existing file**
 - **[F] DELFIL**



String Manipulation - Parsing 1

Navigation and Ancillary Information Facility

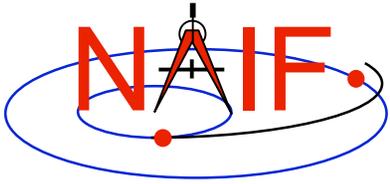
- **Breaking apart a list**
 - [F,C,I] LPARSE: parses a list of items delimited by a single character
 - [F,C] LPARSM: parses a list of items separated by multiple delimiters
 - [F] NEXTWD: returns the next word in a given character string
 - [F] NTHWD: returns the nth word in a string and the location of the word in the string
 - [F,C] KXTRCT: extracts a substring starting with a keyword
- **Removing unwanted parts of a string**
 - [F,C,I] CMPRSS: compresses a character string by removing instances of more than N consecutive occurrences of a specified character
 - [F] ASTRIP: removes a set ASCII characters from a string
 - [F] REMSUB: removes a substring from a string



String Manipulation - Parsing 2

Navigation and Ancillary Information Facility

- **Locating substrings**
 - Return the location of the leftmost or rightmost non-blank character
 - » [F] LTRIM, RTRIM
 - Locate substring or member of specified character set searching forward or backward
 - » [F,C] POS, CPOS, POSR, CPOSR, NCPOS, NCPOSR
- **Pattern matching**
 - [F,C,I] MATCHI: matches a string against a wildcard template, case insensitive
 - [F,C,I] MATCHW: matches a string against a wildcard template, case sensitive
- **Extracting numeric and time data**
 - [F] NPARSD, NPARSI, DXTRCT, TPARTV
 - [F,C,I] PRSDP, PRSINT, TPARSE
- **Heavy duty parsing**
 - [F] SCANIT



String Manipulation - Parsing

Navigation and Ancillary Information Facility

`'a dog, a cat, and a cow'`

`lparsm`

Split on a comma

`'a dog'`

`'a cat'`

`'and a cow'`

`'Remove extra spaces'`

`cmprss`

`'Remove extra spaces'`

`'Green eggs and ham'`

`'the cat in the hat'`

`'how the grinch stole Christmas'`

`matchi(*g*)`

`'green eggs and ham'`

`'how the grinch stole Christmas'`

Match any string containing a 'g'



String Manipulation - Creating (1)

Navigation and Ancillary Information Facility

- **Fill in the “Blank”**
 - **[F,C] REPMC: Replace a marker with a character string.**
CALL REPMC ('The file was: #', '#', 'foo.bar', OUT)
OUT becomes 'The file was: foo.bar'
 - **[F,C] REPMI: Replace a marker with an integer.**
CALL REPMI ('The value is: #', '#', 7, OUT)
OUT becomes 'The value is: 7'
 - **[F,C] REPMD: Replace a marker with a double precision number.**
CALL REPMD ('The value is: #', '#', 3.141592654D0, 10, OUT)
OUT becomes 'The value is: 3.141592654E+00'
 - **[F,C] REPMOT: Replace a marker with the text representation of an ordinal number.**
CALL REPMOT ('It was the # term.', '#', 'L', 2, OUT)
OUT becomes 'It was the second term.'



String Manipulation - Creating (2)

Navigation and Ancillary Information Facility

- **Fill in the “Blank” (cont.)**

- **[F,C] REPMCT: Replace a marker with the text representation of a cardinal number.**

CALL REPMCT ('Hit # errors.', '#', 6, 'L', OUT)

OUT becomes 'Hit six errors.'

- **Numeric Formatting**

- **[F] DPFMT: Using a format template, create a formatted string that represents a double precision number**

CALL DPFMT (PI(), 'xxx.yyyy', OUT)

OUT becomes ' 3.1416'

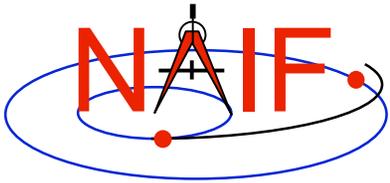
- **[F] DPSTR, INTSTR, INTTXT, INTORD**



String Manipulation - Creating (3)

Navigation and Ancillary Information Facility

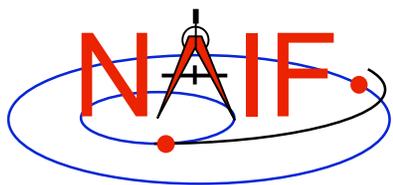
- **Time formatting**
 - [F,C,I,M] TPICTR: Given a sample time string, create a time format picture suitable for use by the routine TIMOUT.
 - [F,C,I,M] TIMOUT: Converts an input epoch to a character string formatted to the specifications of a user's format picture.
- **Changing case**
 - [F,C,I] UCASE: Convert all characters in string to uppercase.
 - [F,C,I] LCASE: Convert all characters in string to lowercase.
- **Building strings**
 - [F] SUFFIX: add a suffix to a string
 - [F] PREFIX: add a prefix to a string



Searching, Sorting and Other Array Manipulations

Navigation and Ancillary Information Facility

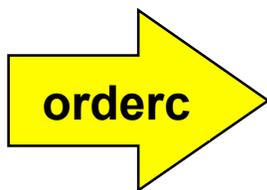
- **Sorting arrays**
 - [F,C] SHELLC, SHELLI, SHELLD, ORDERI, ORDERC, ORDERD, REORDC, REORDI, REORDD, REORDL
- **Searching ordered arrays**
 - [F,C] BSRCHC, BSRCHI, BSRCHD, LSTLEC, LSTLEI, LSTLED, LSTLTC, LSTLTI, LSTLTD, BSCHOI
- **Searching unordered arrays**
 - [F,C] ISRCHC, ISRCHI, ISRCHD, ESRCHC
- **Moving portions of arrays**
 - [F] CYCLAC, CYCLAD, CYCLAI
- **Inserting and removing array elements**
 - [F] INSLAC, INSLAD, INSLAI, REMLAC, REMLAD, REMLAI



Searching, Sorting and Other Array Manipulations

Navigation and Ancillary Information Facility

| Body | A.U. ¹ |
|---------|-------------------|
| sun | 00.0 |
| mercury | 00.455 |
| venus | 00.720 |
| earth | 00.983 |
| mars | 01.531 |
| jupiter | 05.440 |
| saturn | 09.107 |
| uranus | 20.74 |
| neptune | 30.091 |
| pluto | 31.052 |



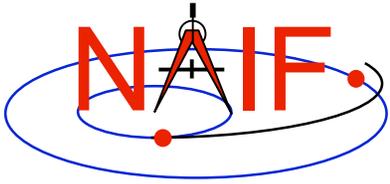
04
06
05
02
09
10
07
01
08
03



| Sorted Body | A.U. ¹ |
|-------------|-------------------|
| earth | 00.983 |
| jupiter | 05.440 |
| mars | 01.531 |
| mercury | 00.445 |
| neptune | 30.091 |
| pluto | 31.052 |
| saturn | 09.107 |
| sun | 00.000 |
| uranus | 20.74 |
| venus | 00.720 |

Vector of 'Body' indexes representing the list sorted in alphabetical order.

¹ Distance in A.U. at Jan 01, 2006.

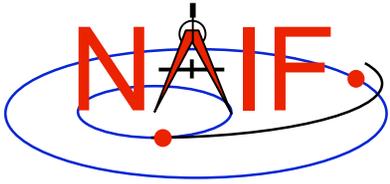


Windows*

Navigation and Ancillary Information Facility

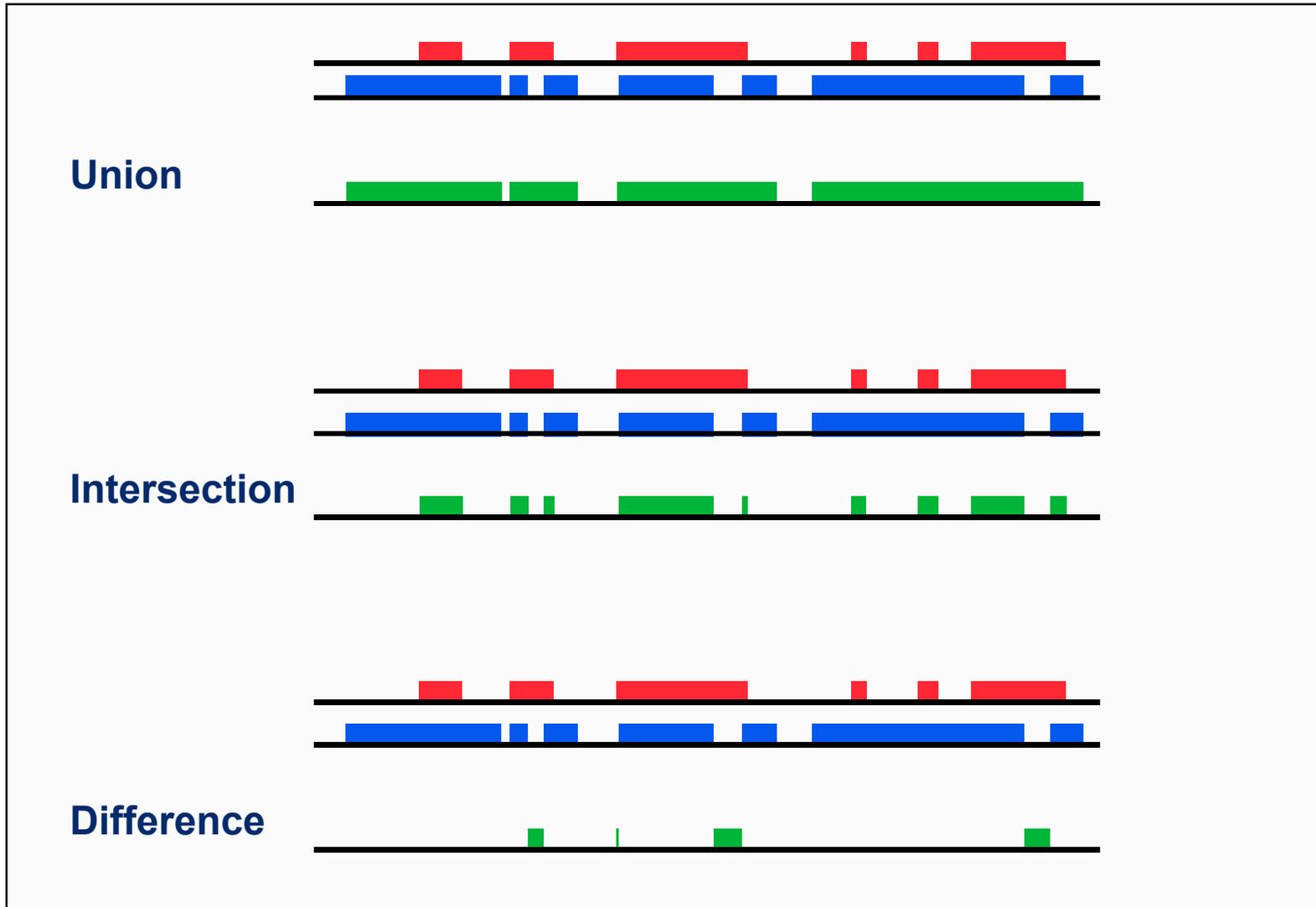
- **A SPICE window is a list of disjoint intervals arranged in ascending order.**
 - An interval is specified by a pair of double precision numbers, with the second greater than or equal to the first.
- **The Toolkit contains a family of routines for creating windows and performing “set arithmetic” on them.**
- **Frequently used to specify intervals of time when some set of user constraints are satisfied.**
 - Let window *NotBehind* contain intervals of time when Cassini is not behind Saturn as seen from earth.
 - Let window *Goldstone* contain intervals of time when Cassini is above the Goldstone horizon.
 - Cassini can be tracked from Goldstone during the intersection of these two windows ($Track = NotBehind * Goldstone$).
- **See *windows.req* for more information.**

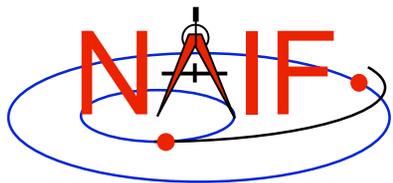
*Windows are sometimes referred to as **schedules**.



Windows Math

Navigation and Ancillary Information Facility

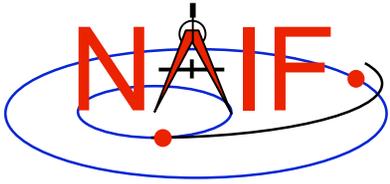




Symbol Tables

Navigation and Ancillary Information Facility

- **The Toolkit supports the use of associative arrays/hashtables through the use of an abstract data type called symbol tables.**
 - These are used to associate a set of names with collections of associated values.
 - Values associated with a name are exclusively character, exclusively integer or exclusively double precision
 - Routines to manipulate a symbol table have the form SY***<T> where <T> is the data type of the values (C, D, or I).
 - Implementation notes:
 - » Fully supported in SPICELIB (the FORTRAN Toolkits).
 - » In CSPICE, Symbol Table modules exist only in the f2c translated form—NAIF has not written the usual C language wrappers. The character handling instances are difficult to use correctly: we strongly recommend not using them.
 - » Symbol Tables do not exist in Icy and Mice.
- **Operations include:**
 - Insert a symbol
 - Remove a symbol
 - Push/Pop a value onto the list of values associated with a symbol
 - Fetch/Sort values associated with a symbol
- **See *symbols.req* for more information.**



Sets and Cells

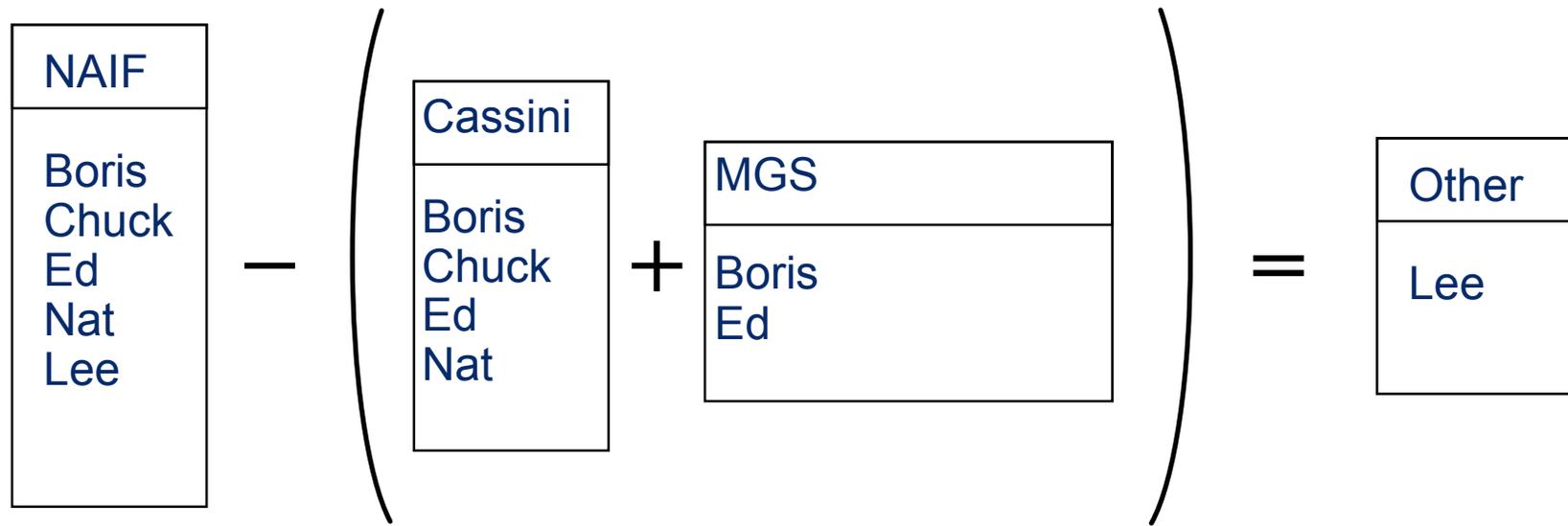
Navigation and Ancillary Information Facility

- **Cells are arrays that “know” how many addresses are available for use and how many are currently used.**
 - Routines that use cells typically have simpler interfaces than routines that use arrays.
 - see *cells.req* for more information
- **Sets are cells that contain no duplicate elements and whose elements are ordered in ascending order.**
 - Two Sets can be: intersected, unioned, differenced, differenced symmetrically (union - intersection)
 - See *sets.req* for more information
- **Language support for sets and cells**
 - Double Precision, Integer, and Character string cell types are supported in the Fortran and C Toolkits.
 - Double Precision and Integer cell types are supported in the IDL Toolkits.
 - Sets and cells aren't needed in the MATLAB Toolkits.
 - » MATLAB contains its own SETS functionality.

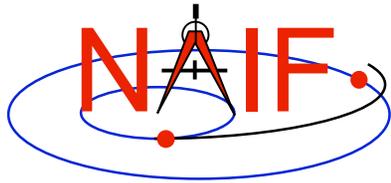


Sets and Cells - 2

Navigation and Ancillary Information Facility



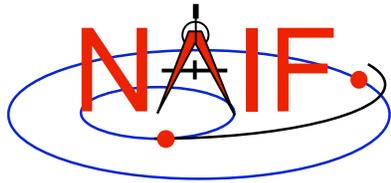
```
CALL UNIONC ( CASSINI, MGS, PROJECTS )
CALL DIFFC ( NAIF, PROJECTS, OTHER )
```



Constants and Unit Conversion

Navigation and Ancillary Information Facility

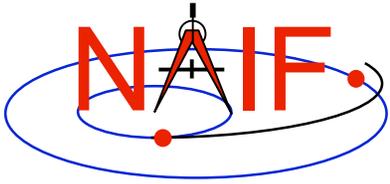
- **Constants are implemented in the Toolkit as functions.**
 - Thus the changing of a constant by NAIF requires only relinking by the Toolkit user—not recompiling.
 - » Users should NOT change constant functions in the Toolkit.
- **System Constants**
 - [F,C,I,M] DPMIN, DPMAX, INTMIN, INTMAX
- **Numeric Constants**
 - [F,C,I,M] PI, HALFPI, TWOPI, RPD (radians/degree), DPR(degrees/radian)
- **Physical Constants**
 - [F,C,I,M] CLIGHT, SPD, TYEAR, JYEAR
- **Epochs**
 - [F,C,I,M] J2000, J1950, J1900, J2100, B1900, B1950
- **Simple Conversion of Units**
 - [F,C,I,M] CONVRT



Numerical Functions (1)

Navigation and Ancillary Information Facility

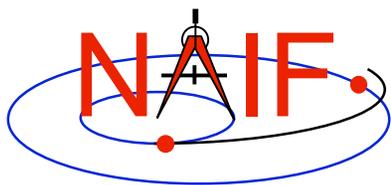
- **Several routines are provided to assist with numeric computations and comparisons.**
- **Functions**
 - [F] DCBRT: cube root
 - Hyperbolic Functions:
 - » [F] DACOSH, DATANH
 - Polynomial Interpolation and Evaluation:
 - » [F] LGRESP, LGRINT, LGRIND, POLYDS, HRMESP, HRMINT
 - Chebyshev Polynomial Evaluation:
 - » [F] CHBDER, CHBVAL, CHBINT



Numerical Functions (2)

Navigation and Ancillary Information Facility

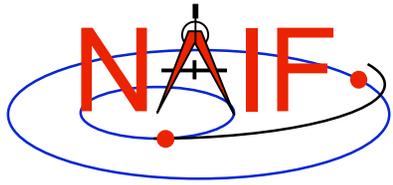
- **Numerical Decisions**
 - Same or opposite sign (Boolean):
 - » [F] SMSGND, SMSGNI, OPSGND, OPSGNI
 - Force a value into a range (bracket):
 - » [F,C] BRCKTD, BRCKTI
 - Determine parity of integers (Boolean):
 - » [F] ODD, EVEN
 - Truncate conditionally:
 - » [F] EXACT
- **Arithmetic**
 - Greatest common divisor:
 - » [F] GCD
 - Positive remainder:
 - » [F] RMAINI, RMAIND



Navigation and Ancillary Information Facility

Exception Handling

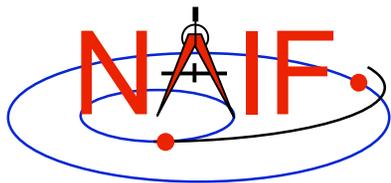
January 2009



Topics

Navigation and Ancillary Information Facility

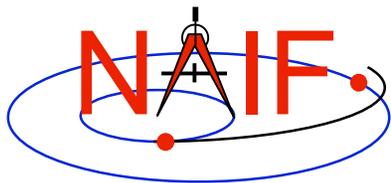
- **What Exceptions Are**
- **Language Dependencies**
- **C and Fortran Error Handling Features**
- **Error Messages**
- **Error Handling Actions**
- **Error Device**
- **Customize Error Handling**
- **Get Error Status**
- **Signal Errors**
- **Icy Error Handling**
- **Mice Error Handling**
- **Recommendations**



Exceptions Are... - 1

Navigation and Ancillary Information Facility

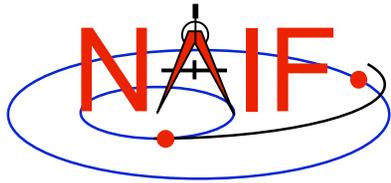
- **Run time error conditions**
 - **Files**
 - » **Required files not loaded.**
 - » **Gaps in data.**
 - » **Corrupted or malformed files (e.g. ftp'd in wrong mode).**
 - **Invalid subroutine/function arguments**
 - » **String values unrecognized.**
 - » **Numeric values out of range.**
 - » **Data type/dimension mismatch.**
 - **Arithmetic errors**
 - » **Divide by zero, square root of a negative number.**
 - **Environment problems**
 - » **Insufficient disk space for output files.**
 - » **Lack of required read/write permission/privileges.**



Exceptions Are... - 2

Navigation and Ancillary Information Facility

- **Valid but unusual conditions**
 - Examples are:
 - » Normalize the zero vector.
 - » Find the rotation axis of the identity matrix.
 - » Find the boresight intercept lat/lon for a non-intercept case.
 - » Find a substring where the end index precedes the start index.
 - Such cases are normally not SPICE “Error Conditions”
 - Typically must be handled by a logical branch
- **Errors found by analysis tools, such as parsers**
 - Examples are:
 - » Invalid SQL query.
 - » Invalid string representing number (borderline case).
 - Such cases are normally not SPICE “Error Conditions”
 - However, if a SPICE parsing routine failed because it couldn’t open a scratch file, THAT would be an “error condition.”



Language Dependencies

Navigation and Ancillary Information Facility

- **SPICELIB and CSPICE provide essentially identical error handling capabilities.**
- **Icy and Mice provide similar error handling functionality; this functionality is quite different from that of CSPICE.**
 - These systems do rely on CSPICE for most error detection.
 - Icy and Mice provide no API for customizing underlying CSPICE error handling behavior.
 - Short, long, and traceback error messages are merged into a single, parsable, message.
 - Use IDL or MATLAB features to customize error handling.
 - » Prevent your program from stopping
 - » Capture SPICE error messages
- **Most of this tutorial deals with SPICELIB and CSPICE error handling.**
 - There is a bit on Icy and Mice near the end.



Fortran and C Error Handling Features - 1

Navigation and Ancillary Information Facility

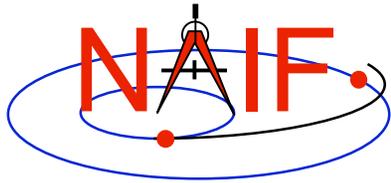
- **Error handling in SPICE: safety first**
 - Trap errors where they occur; don't let them propagate
 - » Don't let errors "fall through" to the operating system.
 - Supply meaningful diagnostic messages
 - » Incorporate relevant run-time data.
 - » Supply context in human-readable form.
 - Don't depend on callers to handle errors
 - » Normally, "error flags" are not returned to callers.
 - Stop unless told not to
 - » Don't try to continue by making "smart guesses."
- **Subroutine interface for error handling**
 - Interface routines called within SPICE may be called by users' application programs



Fortran and C Error Handling Features - 2

Navigation and Ancillary Information Facility

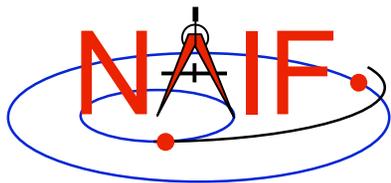
- **Signal errors**
 - Create descriptive messages when and where an error is detected
 - » Short message, long message, (explanation), traceback
 - “Signal” the error: set error status, output messages
 - » By default, CSPICE error output goes to stdout (not stderr)
- **Retrieve error information**
 - Get status and error messages via subroutine calls
- **Customize error response---actions taken when an error occurs.**
 - Set error handling mode (“action”)
 - Set error output device
 - Set message selection
- **Inhibit tracing**
 - To improve run-time performance (only for thoroughly debugged code)



Error Messages

Navigation and Ancillary Information Facility

- **Short message**
 - Up to 25 characters.
 - Can easily be compared with expected value.
 - » Example: `SPICE(FILEOPENFAILED)`.
- **Long message**
 - Up to 1840 characters.
 - Can contain values supplied at run time.
 - » Example: 'The file <sat077.bsp> was not found.'
- **Traceback**
 - Shows call tree above routine where error was signaled.
 - » Not dependent on system tracing capability.
 - » Don't need a "crash" to obtain a traceback.

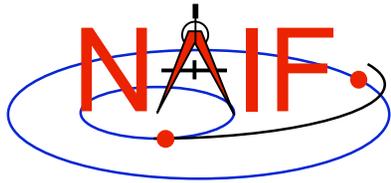


Error Handling Actions - 1

Navigation and Ancillary Information Facility

- **ABORT**
 - Designed for safety.
 - » Output messages and traceback to your screen or stdout.
 - » Stop program; return status code if possible.
- **RETURN**
 - For use in programs that must keep running.
 - Attempts to return control to the calling application.
 - Preserves error information so calling application can respond.
 - » Output messages to current error device.
 - » Set error status to “true”: `FAILED()` will return “true.”
 - » Set “return” status to “true”: `RETURN()` will return “true.”
 - » Most SPICE routines will return on entry. Very simple routines will generally execute anyway.

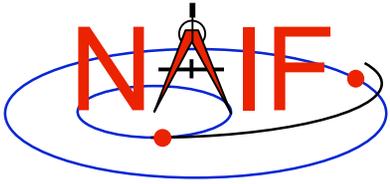
--continues--



Error Handling Actions - 2

Navigation and Ancillary Information Facility

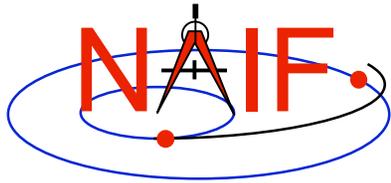
- » **Capture traceback at point where error was signaled.**
- » **Inhibit error message writing and error signaling.**
- » **Must call RESET to resume normal error handling.**



Error Device

Navigation and Ancillary Information Facility

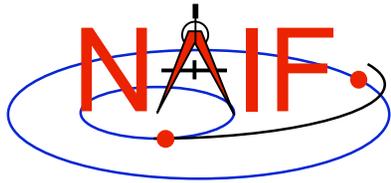
- **Destination of error messages**
 - Screen/stdout (default)
 - Designated file
 - » Error diagnostics are appended to the file as errors are encountered.
 - “NULL” --- suppress output
 - » When the NULL device is specified, error messages can still be retrieved using API calls.
- **Limitations**
 - In C, cannot send messages to stderr.
 - In C, writing to a file opened by means other than calling `errdev_c` is possible only if CSPICE routines were used to open the file.
 - » These limitations may be removed in a later version of CSPICE.



Customize Error Handling - 1

Navigation and Ancillary Information Facility

- **Set error action**
 - `CALL ERRACT ('SET', 'RETURN')`
 - `erract_c ("set", LEN, "return");`
 - » Length argument is ignored when action is "set"; when action is "get", LEN should be set to the available room in the output string, for example:
 - » `erract_c ("get", ACTLEN, action);`
- **Set error device**
 - `CALL ERRDEV ('SET', 'errlog.txt')`
 - `errdev_c ("set", LEN, "errlog.txt");`
- **Select error messages**
 - `CALL ERRPRT ('SET', 'NONE, SHORT, TRACEBACK')`
 - » If tracing is disabled, selecting TRACEBACK has no effect.
 - `errprt_c ("set", LEN, "none, short, traceback");`



Customize Error Handling - 2

Navigation and Ancillary Information Facility

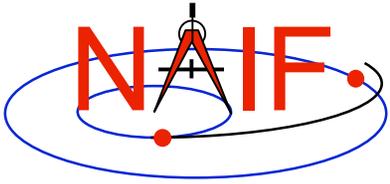
- **Disable tracing**
 - Normally done to speed up execution
 - Benefit is highly dependent on application
 - Speed-up has been a few percent to roughly 30%
 - » High end estimate based on older, slower tracing implementation.
 - Use TRCOFF:
 - » `CALL TRCOFF` or `trcoff_c()`;
 - When used, should be done at start of your program.
- **You cannot re-enable tracing during a program run.**



Get Error Status - 1

Navigation and Ancillary Information Facility

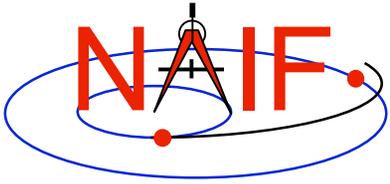
- **Use FAILED to determine whether an error has been signaled**
 - `IF (FAILED()) THEN ...`
 - `if (failed_c()) { ...`
- **Use FAILED after calling one or more SPICE routines in a sequence**
 - Normally, it's safe to call a series of SPICE routines without testing FAILED after each call
- **Use GETMSG to retrieve short or long error messages**
 - `CALL GETMSG ('SHORT' , SMSG)`
 - `getmsg_c ("short" , LEN , msg) ;`



Get Error Status - 2

Navigation and Ancillary Information Facility

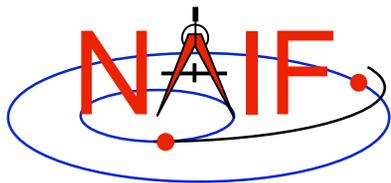
- **Use QCKTRC or TRCDEP and TRCNAM to retrieve traceback message**
 - In CSPICE, only f2c'd versions of these routines are available
- **Test value of RETURN() to determine whether routines should return on entry**
 - Only relevant if user code is designed to support RETURN mode
- **Handle error condition, then reset error status:**
 - `CALL RESET`
 - `reset_c()` ;
 - Only handle error condition in lcy-based applications; a reset is automatically performed by lcy



Signal Errors - 1

Navigation and Ancillary Information Facility

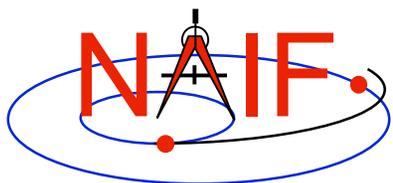
- **Create long error message**
 - Up to 1840 characters
 - Use SETMSG
 - » `CALL SETMSG ('File <#> was not found.')`
 - » `setmsg_c ("File <#> was not found.");`
- **Substitute string, integer, or d.p values at run time**
 - Use ERRCH
 - » `CALL ERRCH ('#', 'cassini.bsp')`
 - » `errch_c ("#", "cassini.bsp");`
 - Also can use ERRINT, ERRDP
 - In Fortran, can refer to files by logical unit numbers: **ERRFNM**



Signal Errors - 2

Navigation and Ancillary Information Facility

- **Signal error**
 - Use **SIGERR** to signal error. Supply short error message as input to **SIGERR**.
 - » `CALL SIGERR ('FILE OPEN FAILED')`
 - » `sigerr_c ("FILE OPEN FAILED");`
 - “Signaling” error causes **SPICE** error response to occur
 - » Output messages, if enabled
 - » Set error status
 - » Set return status, if error action is **RETURN**
 - » Inhibit further error signaling if in **RETURN** mode
 - » Stop program if in abort mode
- **Reset error status after handling error**
 - `CALL RESET()`
 - `reset_c()`

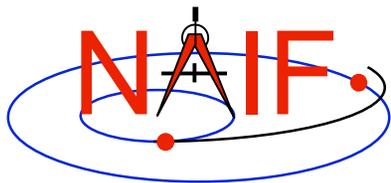


Icy Error Handling

Navigation and Ancillary Information Facility

- **Error action:**
 - By default, a SPICE error signal stops execution of IDL scripts; a SPICE error message is displayed; control returns to the execution level (normally the command prompt).
 - Icy sets the CSPICE shared object library's error handling system to RETURN mode. No other modes are used.
 - » The CSPICE error state is reset after detecting an error.
 - Use the IDL CATCH feature to respond to error condition.
- **Error status**
 - Value of !error_state.name
 - » ICY_M_BAD_IDL_ARGS - indicates invalid argument list.
 - » ICY_M_SPICE_ERROR - indicates occurrence of a SPICE error.
- **Error message**
 - CSPICE short, long, and traceback error messages are merged into a single, parsable, message.
 - » The merged error message is contained in the variable !error_state.msg.
 - » **Example:**

```
CSPICE_ET2UTC: SPICE (MISSINGTIMEINFO): [et2utc->ET2UTC->UNITIM]
The following, needed to convert between the
uniform time scales, could not be found in the
kernel pool: DELTET/DELTA_T_A, DELTET/K,
DELTET/EB, DELTET/M. Your program may have failed to load..
```

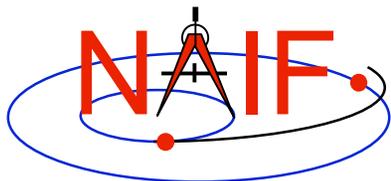


Mice Error Handling

Navigation and Ancillary Information Facility

- **Error action:**
 - By default, a SPICE error signal stops execution of MATLAB scripts; a SPICE error message is displayed; control returns to the execution level.
 - Mice sets the CSPICE shared object library's error handling system to RETURN mode. No other modes are used.
 - » The CSPICE error state is reset after detecting an error.
 - Use the MATLAB try/catch construct to respond to error condition.
- **Error message**
 - CSPICE short, long, and traceback error messages are merged into a single, parsable, message.
 - » **Example:**

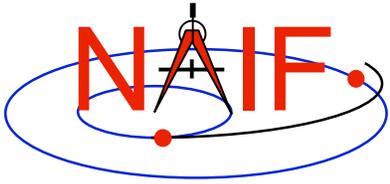
```
??? SPICE(MISSINGTIMEINFO): [et2utc->ET2UTC->UNITIM]
The following, needed to convert between the
uniform time scales, could not be found in the
kernel pool: DELTET/DELTA_T_A, DELTET/K,
DELTET/EB, DELTET/M. Your program may have failed to load..
```
- **Use the MATLAB function lasterror to retrieve SPICE error diagnostics. When a SPICE error occurs**
 - The “message” field of the structure returned by lasterror contains the SPICE error message.
 - The “stack” field of this structure refers to the location in the m-file from which the Mice wrapper was called (and so is generally not useful).
 - The “identifier” field of this structure currently is not set.



Recommendations

Navigation and Ancillary Information Facility

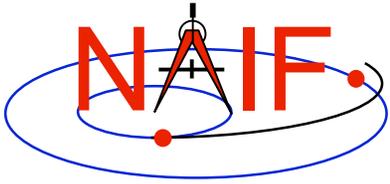
- **For easier problem solving**
 - Leave tracing enabled when debugging.
 - Always test FAILED after a sequence of one or more consecutive calls to SPICE routines.
 - Don't throw away error output. It may be the only reasonable clue as to what's going wrong.
 - » Programs that must suppress SPICE error output should trap it and provide a means for retrieving it.
 - Test FAILED to see whether an error occurred.
 - Use GETMSG to retrieve error messages
 - Use RESET to clear the error condition
 - Use SPICE error handling in your own code where appropriate.
 - When reporting errors to NAIF, have SPICE error message output available
 - » Note whether error output is actually from SPICE routines, from non-SPICE code, or was generated at the system level.



Navigation and Ancillary Information Facility

Toolkit Applications

January 2009



Toolkit Applications

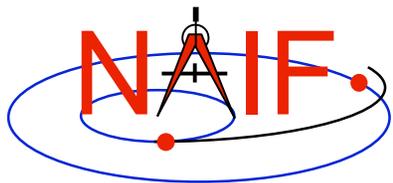
Navigation and Ancillary Information Facility

Toolkit applications create or manipulate kernels, or perform other functions such as time conversion.

Each of these applications is included in the generic Toolkits.

- Time conversion tool: *chronos*
- SPK generation tool: *mkspk*
- SPK merge and subset tool: *spkmerge*
- SPK comparison tool: *spkdiff*
- CK generation tool: *msopck*
- Kernel summary tools: *brief, ckbrief, spacit*
- Comments manipulation tools: *commnt, spacit*
- File format converters: *tobin, toxfr and bingo**

* bingo is not included in generic Toolkits; it is available only from NAIF's webpages



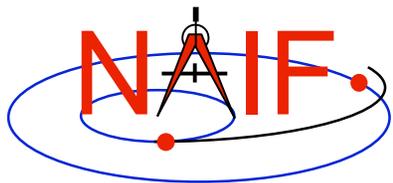
CHRONOS - Time Conversions

Navigation and Ancillary Information Facility

chronos is an application that provides a flexible interface to the SPICE Toolkit time conversion capabilities.

chronos supports time conversion between the following time systems/types:

| <i>Supported Time Systems</i> | <i>--></i> | <i>Supported Time Types</i> |
|--------------------------------|---------------|-----------------------------|
| ----- | | ----- |
| Universal Coord. Time (UTC) | --> | SCET, ERT, ETT, LT |
| Ephemeris Time (ET) | --> | SCET, ERT, ETT, SECONDS, LT |
| S/C On-board Clock Time (SCLK) | --> | SCLK, HEX, TICKS |
| Local Solar Time (LST) | --> | LST, LSUN |



CHRONOS - Input/Output Matrix

Navigation and Ancillary Information Facility

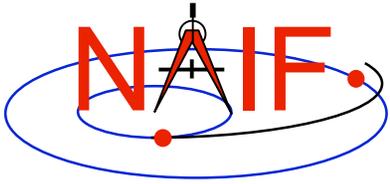
Input System/Type

UTC / SCET (*)
 UTC / ERT
 UTC / ETT
 ET / SCET (*)
 ET / ERT
 ET / ETT
 ET / SECONDS
 SCLK / SCLK (*)
 SCLK / HEX
 SCLK / TICKS
 LST / LST

Output System/Type

UTC / SCET (*)
 UTC / ERT
 UTC / ETT
 UTC / LT
 ET / SCET (*)
 ET / ERT
 ET / ETT
 ET / SECONDS
 ET / LT
 SCLK / SCLK (*)
 SCLK / HEX
 SCLK / TICKS
 LST / LST (*)
 LST / LSUN

(*) default input/output types



CHRONOS - Miscellaneous

Navigation and Ancillary Information Facility

- ***chronos* normally converts one input time but can run in batch mode to speed up conversion for multiple input times.**
- **OS shell alias capabilities can be used to define shortcuts for commonly used time conversions.**
- ***chronos* has an extensive User's Guide.**



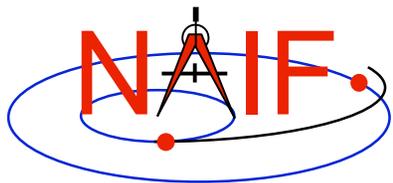
CHRONOS - Usage

Navigation and Ancillary Information Facility

```
Terminal Window
$ chronos
...
CHRONOS Usage
-----

To convert time from one supported system/type to another:

% CHRONOS -SETUP <setup file name OR kernel file name(s)>
  -FROM <"from" time system>
  [-FROMTYPE <"from" time type>]
  -TO <"to" time system>
  [-TOTYPE <"to" time type>]
  [-FORMAT <output time format picture>]
  -TIME <input time> | -BATCH
  [-SC <sc ID>]
  [-CENTER <cental body ID>]
  [-LANDINGTIME <UTC time of the landing>]
  [-SOL1INDEX <index of the first SOL>]
  [-NOLABEL]
  [-TRACE]
```



CHRONOS - Example

Navigation and Ancillary Information Facility

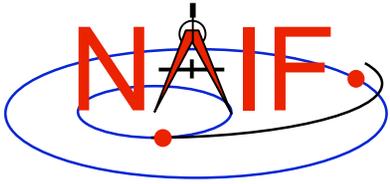
```
Terminal Window
$ cat chronos.cas
Sample CHRONOS setup file for Cassini
  \begindata
    KERNELS_TO_LOAD = ( 'naif0007.tls', 'cas00085.tsc' )
    SPACECRAFT_ID = -82
  \begintext

$ chronos -setup chronos.cas -from utc -to et -time 1999 JAN 12 12:00
1999-01-12, 12:01:04.184 (ET/SCET)

$ chronos -setup chronos.cas -from utc -to sclk -time 1999 JAN 12 12:00
1/1294833883.185 (SCLK/SCLK)

$ chronos -setup naif0007.tls cas00085.tsc -sc -82 -from sclk -to utc -time
1/1294833883.185
1999-01-12 11:59:59.998 (UTC/SCET)

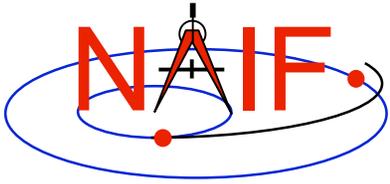
$ chronos -setup naif0007.tls cas00085.tsc -sc -82 -from sclk -to utc -time
1/1294833883.185 -format 'YYYY-DOYTHR:MN:SC ::RND' -nolabel
1999-012T12:00:00
```



MKSPK

Navigation and Ancillary Information Facility

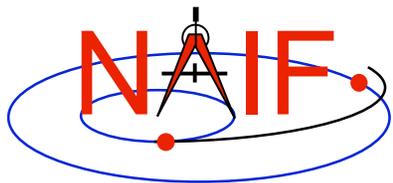
- ***mkspk* may be used to generate an SPK file from any of several types of data, such as discrete states, classic elements, and two-line elements**
- **Use of this program is discussed in a separate tutorial about making SPK files, and in the *mkspk* User's Guide.**



SPKMERGE

Navigation and Ancillary Information Facility

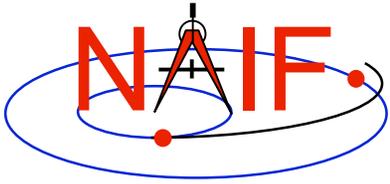
- **The contents of an SPK file or set of SPK files may be merged or subsetted using *spkmerge***
 - Extract an interval of time of interest from a single SPK file or a set of SPK files.
 - Extract data for one or more objects from a single SPK file or a set of SPK files.
 - You can combine both the time and object selection mechanisms for the greatest flexibility.



SPKMERGE - Precedence Rule

Navigation and Ancillary Information Facility

- **SPK files created with *spkmerge* have no overlapping ephemeris data. The order in which the source files are specified determines precedence when sources have overlapping coverage for a body of interest.**
 - **IMPORTANT NOTE:** Data from an **earlier** specified source file take precedence over data from a later specified source file when the new (merged) file is created.



SPKMERGE - Example

Navigation and Ancillary Information Facility

```
Terminal Window
$ cat spkmerge_cas_example.cmd
;This command file directs spkmerge to take data for
;Cassini, the Sun, the Earth, the Moon, and the Earth-
;Moon barycenter and place them into a single SPK.

leapseconds_kernel = naif0007.tls
spk_kernel          = output.bsp
bodies              = -82, 10, 301, 399, 3
source_spk_kernel  = de403s.bsp
source_spk_kernel  = 990825A_SCEPH_EM52_JP0.bsp

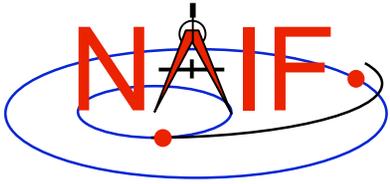
• $ spkmerge
SPKMERGE -- SPK Merge Tool, Version 3.2, SPICE Toolkit N0057

Enter the name of the command file

> spkmerge_cas_example.cmd

Creating output.bsp

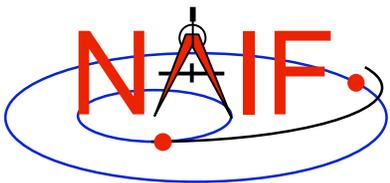
$
```



SPKDIFF

Navigation and Ancillary Information Facility

- ***spkdiff*** is a command line program for comparing trajectories provided by two SPK files
- ***spkdiff*** compares SPKs by computing a set of geometric states for a specified body, center and frame over an interval of time with a fixed time step using one SPK file, then computing another set of geometric states for the same or different body, center, and frame at the same times using the other SPK file, and then subtracting the corresponding states from each other
- Depending of the requested output type ***spkdiff*** prints to the screen:
 - only the maximum differences,
 - a complete table of differences, or
 - a statistical analysis of the differences.



SPKDIFF - Usage

Navigation and Ancillary Information Facility

```
Terminal Window

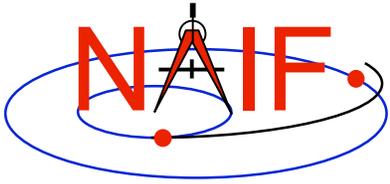
$ spkdiff

spkdiff computes differences between geometric states obtained from
two SPK files and either displays these differences or shows statistics
about them (see the User's Guide for more details.) The program usage is:

% spkdiff [options] <first SPK file> <second SPK file>

Options are shown below. Order and case of keys are not significant.
Values must be space-separated from keys, i.e. '-n 10', not '-n10'.

-b1 <first body name or ID>
-c1 <first center name or ID>
-r1 <first reference frame name>
-b2 <second body name or ID>
-c2 <second center name or ID>
-r2 <second reference frame name>
-k <other kernel file name(s)>
-b <interval start time>
-e <interval stop time>
-s <time step in seconds>
-n <number of states: 2 to 1000000 (default: 1000)>
-f <output time format (default: TDB seconds past J2000)>
-t <report type: basic|stats|dump|dumpvf (default: basic)>
```



SPKDIFF - Example 1

Navigation and Ancillary Information Facility

```
Terminal Window
$ spkdiff mro_psp.bsp mro_psp_rec.bsp
# Comparison of 1000 'J2000'-referenced geometric states
#
#   of 'MARS RECON ORBITER' (-74) relative to 'MARS BARYCENTER' (4)
#   from SPK 'mro_psp.bsp'
#
# with 1000 'J2000'-referenced geometric states
#
#   of 'MARS RECON ORBITER' (-74) relative to 'MARS BARYCENTER' (4)
#   from SPK 'mro_psp_rec.bsp'
#
# evenly-spaced with 2617.6524668123 second (0d 0h 43m 37.652467s) step size
# within the time interval
#
#   from '2007 APR 01 00:01:05.185 TDB' (228657665.18565 TDB seconds)
#   to   '2007 MAY 01 06:25:00.000 TDB' (231272700.00000 TDB seconds)
#
Relative differences in state vectors:
                                maximum          average
Position:                       8.4872836561757E-05  1.2312974450656E-05
Velocity:                       8.5232570159796E-05  1.2314285182022E-05

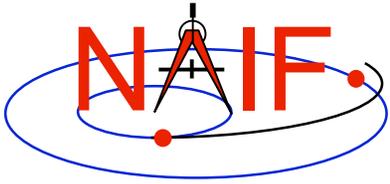
Absolute differences in state vectors:
                                maximum          average
Position (km):                  3.1341344106404E-01  4.5090516995222E-02
Velocity (km/s):                2.8848827480682E-04  4.2085874877127E-05
```



SPKDIFF - Example 2

Navigation and Ancillary Information Facility

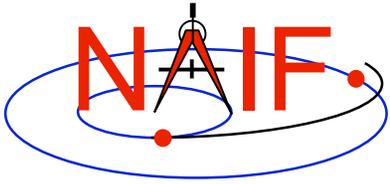
```
Terminal Window
$ spkdiff -t dumpvf mro_psp.bsp mro_psp_rec.bsp | more
# Comparison of 1000 'J2000'-referenced geometric states
#
#   of 'MARS RECON ORBITER' (-74) relative to 'MARS BARYCENTER' (4)
#   from SPK 'mro_psp.bsp'
#
# with 1000 'J2000'-referenced geometric states
#
#   of 'MARS RECON ORBITER' (-74) relative to 'MARS BARYCENTER' (4)
#   from SPK 'mro_psp_rec.bsp'
#
# evenly-spaced with 2617.6524668123 second (0d 0h 43m 37.652467s) step size
# within the time interval
#
#   from '2007 APR 01 00:01:05.185 TDB' (228657665.18565 TDB seconds)
#   to   '2007 MAY 01 06:25:00.000 TDB' (231272700.00000 TDB seconds)
#
# time, down_track_p_diff, normal_to_plane_p_diff, in_plane_p_diff, down_track_v
#_diff, normal_to_plane_v_diff, in_plane_v_diff
2.2865766518565E+08 +4.2593079332056E-02 -9.0540866105197E-05 -3.9705894066565E-04 -8.0803561182349E-08
-1.0394439243989E-07 -3.9614350816493E-05
2.2866028283812E+08 +4.2172435702119E-02 +2.3672255851626E-06 -1.1475679619731E-04 +1.3970238250217E-07
+1.4080506259574E-07 -3.9250157214024E-05
2.2866290049059E+08 +4.4830247467488E-02 +9.1590974014175E-05 -7.3802870365833E-04 +5.7800410436763E-07
-1.1724240528272E-07 -4.2099832045985E-05
2.2866551814305E+08 +4.5968515669515E-02 -1.3529652839857E-04 -7.5686845133612E-05 -4.7565892258325E-07
+3.4127364997784E-08 -4.2529268294482E-05
--More--
```



MSOPCK

Navigation and Ancillary Information Facility

- ***msopck* is a program for making CK files from orientation provided in a text file as a time tagged, space-delimited table**
 - has a simple command line interface
 - requires all setups to be provided in a setup file that follows the SPICE text kernel syntax
 - can process quaternions (SPICE and non-SPICE flavors), Euler angles, or matrixes, tagged with UTC, SCLK, or ET
 - for more details see the “Making a CK File” Tutorial

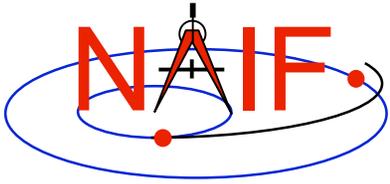


Kernel Summary

Navigation and Ancillary Information Facility

The contents of binary kernels can be summarized with the kernel summary tools.

- Use *brief* to find the bodies and associated time coverage contained in an SPK file or set of SPK files.
 - Also works on binary PCK files
- Use *ckbrief* to find the structure(s) and associated time coverage(s) stored in a C-Kernel or set of C-Kernel files.
- Use *spacit* for a segment by segment summary of the contents of a CK, SPK, binary PCK or EK/ESQ.
 - The program *spacit* also identifies the SPK or CK data type present in each segment.



Using *brief* - 1

Navigation and Ancillary Information Facility

- ***brief* is a simple command line program for summarizing the contents of SPK or binary PCK files.**
- **Use *brief* to quickly determine what bodies are present in an SPK file or set of SPKs.**

```
$ brief spk.bsp or $ brief *.bsp
```

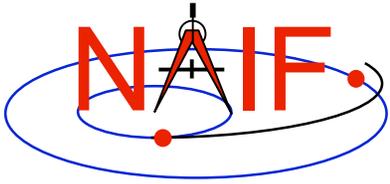
- **Find all the bodies in an SPK file for which there is coverage at an epoch or during an interval of time.**

```
$ brief -at '7/25/99' spk.bsp or
```

```
$ brief -from '7/25/99' -to '8/1/99' spk.bsp
```

- **Find out which SPK files contain coverage for a particular body.**

```
$ brief -CASSINI spk.bsp
```



Using *brief* - 2

Navigation and Ancillary Information Facility

- To show the central body around which each target moves, use the '-c' option.
- If you want to treat a group of SPK files as an ephemeris set, rather than individual files, use the '-a' option.
- To display results in a tabular format use the '-t' option.
- Options may be provided in any order on the command line.



Summarizing a Set of SPKs

Navigation and Ancillary Information Facility

```
Terminal Window
$ brief *.bsp
Brief. Version: 2.1          (SPICE Toolkit N0050)

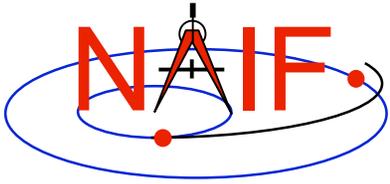
Summary for: 990825A_SCEPH_EM52_JP0.bsp

Body: CAS (-82)
Start of Interval (ET)          End of Interval (ET)
-----
1999 JUN 26 14:00:00.000      2000 DEC 30 11:00:00.000

Summary for: de405s.bsp

Bodies: MERCURY BARYCENTER (1)  SATURN BARYCENTER (6)  MERCURY (199)
VENUS BARYCENTER (2)           URANUS BARYCENTER (7)  VENUS (299)
EARTH BARYCENTER (3)          NEPTUNE BARYCENTER (8) MOON (301)
MARS BARYCENTER (4)           PLUTO BARYCENTER (9)   EARTH (399)
JUPITER BARYCENTER (5)        SUN (10)                MARS (499)
Start of Interval (ET)          End of Interval (ET)
-----
1997 JAN 01 00:01:02.183      2010 JAN 02 00:01:03.183

Note: The wild character "*" does not work as part of a command
line input in the PC/Windows environment.
```



Using *ckbrief* - 1

Navigation and Ancillary Information Facility

- ***ckbrief* is a simple command line program for summarizing the contents of CK files.**
- **Use *ckbrief* with just file names to quickly list the structures whose pointing is stored in one or more C-kernels.**

```
$ ckbrief ck.bc or $ ckbrief *.bc
```

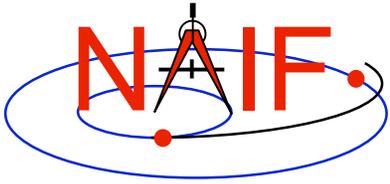
- **If you want to view coverage using SCLK times you need to also provide an SCLK kernel and specify the '-sclk' option.**

```
$ ckbrief sclk.ker ck.bc -sclk
```

- **If you want to view coverage using UTC times you need to provide both SCLK and LSK kernels and specify the '-utc' option.**

```
$ ckbrief sclk.ker naif0007.tls ck.bc -utc
```

- **The names of the kernel files and the options used may be provided in any order on the command line.**



Using *ckbrief* - 2

Navigation and Ancillary Information Facility

- Use the NAIF instrument ID to find out which files in a set of C-kernels contain pointing for the instrument of interest.

```
$ ckbrief -82000 *.bc
```

- Use the '-rel' option to find out to which frames the pointing is relative.

```
$ ckbrief -rel *.bc
```

- Frame kernel(s) may also be provided on the command line to make *ckbrief* display frame names rather than IDs in the 'relative to' column.

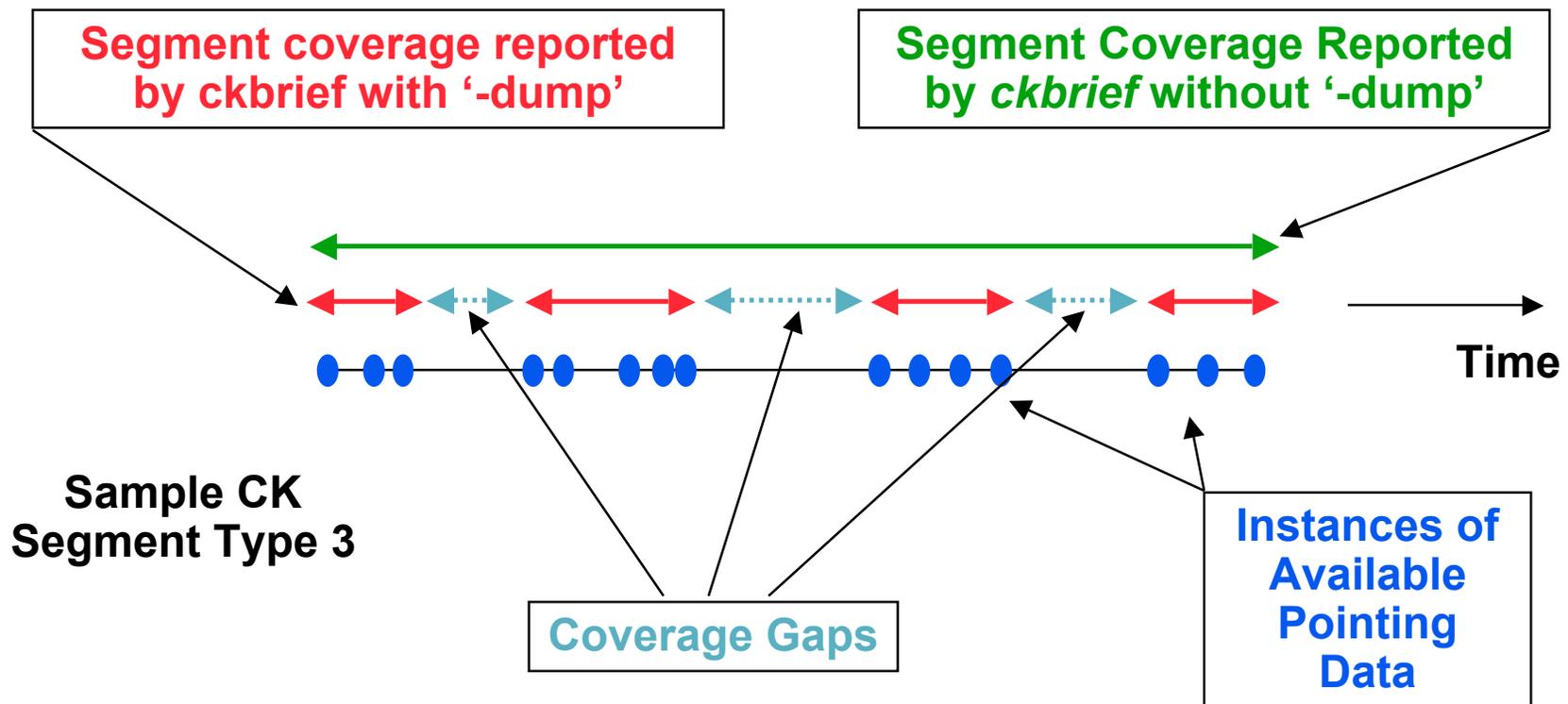
- A number of other options are also available
 - Type *ckbrief* with no arguments to see a help display.

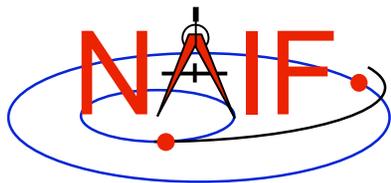


Using *ckbrief* - 3

Navigation and Ancillary Information Facility

- There often are coverage gaps within a CK segment
- To get a complete list of continuous coverage intervals for each segment, use the '-dump' option.





Summarizing CKs with UTC and SCLK

Navigation and Ancillary Information Facility

```
Terminal Window
$ ckbrief -sclk 981116_981228pa.bc sclk.ker

CKBRIEF Version: 1.0.0, 1999-09-09. SPICE Toolkit Version: N0050.

Summary for: 981116_981228pa.bc

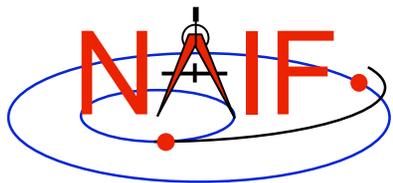
Object: -82000
Interval Begin SCLK          Interval End SCLK          AV
-----
1/1289865849.116            1/1293514473.118          N

$ ckbrief -utc sclk.ker naif0007.tls 990817_990818ra.bc

CKBRIEF Version: 1.0.0, 1999-09-09. SPICE Toolkit Version: N0050.

Summary for: 990817_990818ra.bc

Object: -82000
Interval Begin UTC          Interval End UTC          AV
-----
1999-AUG-17 17:30:01.418 1999-AUG-17 23:05:42.039 N
1999-AUG-17 23:05:45.289 1999-AUG-18 06:06:05.874 N
1999-AUG-18 06:06:09.124 1999-AUG-18 11:52:17.741 N
1999-AUG-18 11:52:20.991 1999-AUG-18 13:30:00.953 N
```



Summarizing CKs with '-dump'

Navigation and Ancillary Information Facility

```
Terminal Window
$ ckbrief mgs_spice_c_kernel_2004-099.bc MGS_SCLKSCET.00053.tsc naif0007.tls -dump
-rel -utc

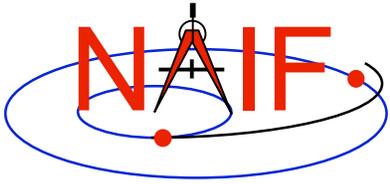
CKBRIEF Version: 2.0.0, 2001-05-16. SPICE Toolkit Version: N0057.

Summary for: mgs_spice_c_kernel_2004-099.bc

Segment No.: 1

Object: -94000

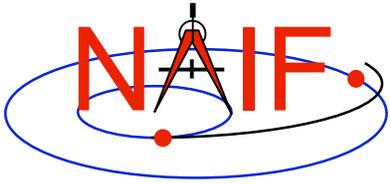
Interval Begin UTC          Interval End UTC          AV  Relative to FRAME
-----
2004-APR-08 00:00:59.809 2004-APR-08 06:53:47.805 Y   J2000
2004-APR-08 06:54:07.805 2004-APR-08 06:54:07.805 Y   J2000
2004-APR-08 06:54:19.805 2004-APR-08 06:54:35.805 Y   J2000
2004-APR-08 06:54:51.805 2004-APR-08 06:54:55.805 Y   J2000
2004-APR-08 06:55:07.805 2004-APR-08 06:55:07.805 Y   J2000
2004-APR-08 06:55:23.805 2004-APR-08 06:55:23.805 Y   J2000
2004-APR-08 06:55:35.805 2004-APR-08 11:59:55.802 Y   J2000
2004-APR-08 12:00:55.802 2004-APR-08 23:59:55.795 Y   J2000
```



Using *spacit*

Navigation and Ancillary Information Facility

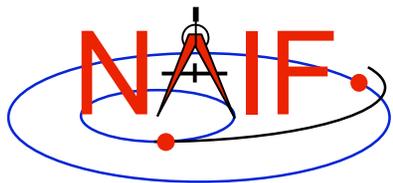
- ***spacit* may be used to obtain a more detailed summary of an SPK or CK file than that offered by *brief* or *ckbrief*, respectively**
 - ***spacit* may also be used to summarize a binary PCK or an EK/ESQ.**
 - ***spacit* is an interactive program**
 - » It will prompt you for all needed inputs
 - » It displays short menus where you choose the action desired
- ***spacit* may also be used to manage comments, and to convert between binary and transfer format**



Comment Manipulation Tools

Navigation and Ancillary Information Facility

- **Every kernel should contain metadata – called “comments” – describing the file contents, intended usage, etc.**
- **In binary kernels – SPKs, CKs, binary PCKs, and EKs – comments are stored in a special area of the file called the “comment area.”**
- **To read, extract, add or delete comments stored in the comment area, use the Toolkit utility *commnt*.**
 - **Caution:** you cannot add or delete comments if the kernel file is not in native format for the machine on which you’re working.
 - » You can convert a non-native binary format file to native binary format by converting the file to “transfer format” using *toxfr* and then converting it back to binary format using *tobin*.
 - » Or use the *bingo* utility (available only from the NAIF website).



Using *commnt* - 1

Navigation and Ancillary Information Facility

- ***commnt*** is both a command line utility and an interactive menu-driven program.
- To dump the comments from a binary kernel to the terminal using the command line use the ‘-r’ option:

```
$ commnt -r kernel_file
```

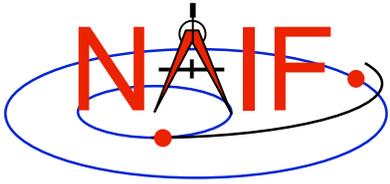
- To extract the comments from a binary kernel to a text file use the ‘-e’ option:

```
$ commnt -e kernel_file text_file
```

- To add or append new comments to a binary kernel, place them in a text file and use the ‘-a’ option:

```
$ commnt -a kernel_file comment_file
```

- These are appended to any previously added comments
- Note: the kernel must be in your computer’s native binary format



Using *commnt* - 2

Navigation and Ancillary Information Facility

- To delete comments from a binary kernel use the '-d' option:

```
$ commnt -d kernel_file
```

- Comments should only be deleted when they are to be replaced with updated information.
- All of the command line features of *commnt* are supported by the interactive invocation.
 - To run *commnt* interactively, type the utility with no command line arguments:

```
$ commnt
```



Using *commnt* Interactively

Navigation and Ancillary Information Facility

```
Terminal Window
$ commnt

Welcome to COMMNT Version: 6.0.0
(Spice Toolkit N0050)

COMMNT Options

( Q ) Quit.
( A ) Add comments to a binary file.
( R ) Read the comments in a binary file.
( E ) Extract comments from a binary file.
( D ) Delete the comments in a binary file.

Option: E

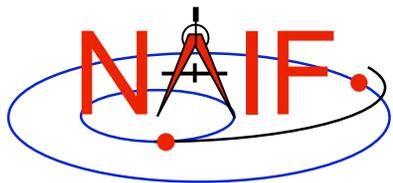
Enter the name of the binary file.

Filename? de405.bsp

Enter the name of the comment file to be created.

Filename? de405_comments.txt

The comments were successfully extracted.
```



Reading Comments with *commnt*

Navigation and Ancillary Information Facility

```
Terminal Window
$ commnt -r de405.bsp | more
; de405.bsp LOG FILE
;
; Created 1999-10-03/14:31:58.00.
;
; BEGIN NIOSPK COMMANDS

LEAPSECONDS_FILE      = /kernels/gen/lsk/naif0007.tls
SPK_FILE              = de405.bsp
SOURCE_NIO_FILE       = /usr2/nio/gen/de405.nio
  BODIES               = 1 2 3 4 5 6 7 8 9 10 301 399 199 299 499
  BEGIN_TIME          = CAL-ET 1950 JAN 01 00:00:41.183
  END_TIME            = CAL-ET 2050 JAN 01 00:01:04.183

; END NIOSPK COMMANDS

A memo describing the creation of the DE405 generic planet ephemeris is available from NAIF or from the author: Dr. Myles Standish of JPL's Solar System Dynamics Group. Because this memo was produced using the TeX processor and includes numerous equations

>>> Beginning of extract from Standish's DE405 memo <<<

-More-- (19%)
```

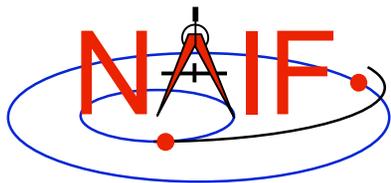


File Format Conversion

Navigation and Ancillary Information Facility

- **With modern Toolkits (N0052 and later) the porting of DAF-based binary kernels* between computers having dissimilar binary standards is usually not necessary.**
 - The advent of binary kernel readers that detect the binary style and do run-time translation if needed generally makes porting unnecessary for DAF-based types.
 - Refer to the “Porting Kernels” tutorial for more on this topic.
- **If true porting is needed (because you must modify or append to a kernel):**
 - use *toxfr* on the source computer and *tobin* on the destination computer
 - or use *bingo* on the destination computer
 - » **NOTE: bingo is NOT available in Toolkits; it must be downloaded from the NAIF website**

* DAF-based binary kernels are SPK, CK and binary PCK



Navigation and Ancillary Information Facility

Non-Toolkit Applications

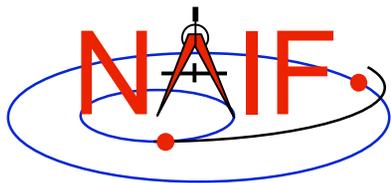
October 2008



Summary

Navigation and Ancillary Information Facility

- **NAIF developed and maintains a set of additional applications *not* included in the generic Toolkit. This set includes programs for:**
 - making and modifying SPK files
 - » *pinpoint, bspidmod*
 - validating, inspecting and analyzing an SPK file
 - » *spy*
 - making and modifying CK files
 - » *prediCkt, ckslicer, ckspanit, dafcat, cksmrg*
 - computing derived quantities
 - » *orbnum, optics*
 - determining SPICE kernel type
 - » *archtype*
- **Executables and User's Guides for selected computer environments are available from the NAIF server at:**
 - <http://naif.jpl.nasa.gov/naif/utilities.html>



PINPOINT

Navigation and Ancillary Information Facility

- ***pinpoint*** is a program for creating SPK files for objects whose position is a constant offset with respect to another object
 - Ground stations
 - Landing sites, sites along a rover path
 - Relative positions of manipulator joints, etc.
- ***pinpoint*** is a command line program with the following usage:

```
pinpoint -def deffile -spk spkfile [-pck tkfile]
```

- “deffile” is an input definitions file following text kernel file format and containing a set of keywords defining ID, center, reference frame, position (as XYZ or Gaussian Lat/Lon/R) and time coverage boundaries for one or more objects
 - » The contents of “deffile” are included in the comment area
- “spkfile” is an output SPK file containing a type 8 SPK segment for each of the objects specified in the “deffile”
- “tkfile” is optional PCK file (needed if positions in the “deffile” are given as Lat/Lon/Alt) or FK file (needed if one or more of the frames specified in “deffile” is not one of the frames built into the Toolkit)



PINPOINT Example

Navigation and Ancillary Information Facility

```
Terminal Window

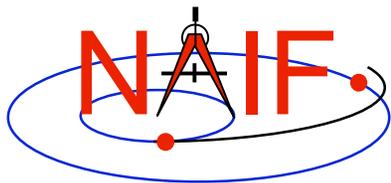
$ more mer1_meridiani.def

Sample PINPOINT input for MER-1 landing site coordinates.
\begindata
  SITES      = ( 'LS' )
  LS_CENTER  = 499
  LS_FRAME   = 'IAU_MARS'
  LS_IDCODE  = -253900
  LS_XYZ     = ( +3.3764222E+03  -3.2664876E+02  -1.1539218E+02 )
  LS_BOUNDS  = ( @2001-01-01-00:00:00.000, @2100-01-01-00:00:00.000 )
\begintext

$ pinpoint -def mer1_meridiani.def -spk mer1_meridiani.bsp

$ brief mer1_meridiani.bsp
Brief.  Version: 2.2.0          (SPICE Toolkit N0057)

Summary for: mer1_meridiani.bsp
Body: -253900* w.r.t. MARS (499)
      Start of Interval (ET)          End of Interval (ET)
      -----
      2001 JAN 01 00:00:00.000        2100 JAN 01 00:00:00.000
```



BSPIDMOD

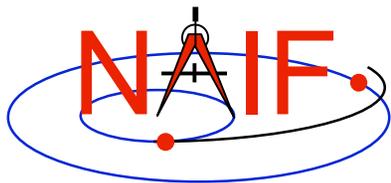
Navigation and Ancillary Information Facility

- ***bspidmod* is a program for altering the object IDs in a binary SPK file**
 - can be used to modify IDs in an SPK file(s) produced with a “bogus” spacecraft ID (or a simulation spacecraft ID)
 - can be used to replace “good” IDs with “bogus” IDs if two different trajectories for the same object need to be used in the same program at the same time (for example for comparison)

- ***bspidmod* is a command line program with the following usage:**

```
bspidmod -spki inpspk -idi inpid -ido outid -mod item -oflg
```

- “inpspk” is the input SPK file; “inpid” and “outid” are the current ID and new ID
- “item” indicates which IDs are to be replaced:
 - TARGET -- only target IDs are replaced,
 - CENTER -- only center IDs are replaced, or
 - OBJECT -- both target and center IDs are replaced
- » Replacements are made only when “inpid” matches an ID found in the input SPK
- “-oflg” flag indicating that change should be made directly in the input file; if not specified, the program produces output file with name that has “_out” appended to the name of the input file
- A note stating which IDs were modified is put in the comment area



BSPIDMOD Example

Navigation and Ancillary Information Facility

```
Terminal Window
$ brief mer2_crus_sim_id.bsp
Brief.  Version: 2.2.0          (SPICE Toolkit N0057)

Summary for: mer2_crus_sim_id.bsp

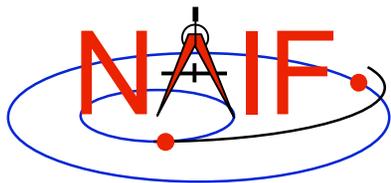
Body: -255
      Start of Interval (ET)          End of Interval (ET)
      -----
      2003 JUL 09 00:15:00.000       2004 JAN 04 04:25:42.557

$ bspidmod -spki mer2_crus_sim_id.bsp -idi -255 -ido -254 -mod target -oflg
The file mer2_crus_sim_id.bsp has been updated.

$ brief mer2_crus_sim_id.bsp
Brief.  Version: 2.2.0          (SPICE Toolkit N0057)

Summary for: mer2_crus_sim_id.bsp

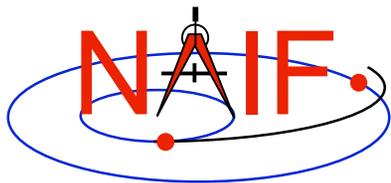
Body: MER-2 (-254)
      Start of Interval (ET)          End of Interval (ET)
      -----
      2003 JUL 09 00:15:00.000       2004 JAN 04 04:25:42.557
```



SPY

Navigation and Ancillary Information Facility

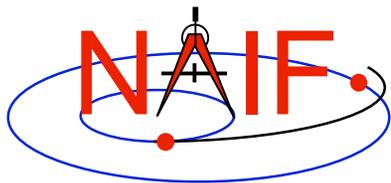
- ***Spy* is a command-driven utility for validating, inspecting, and analyzing SPK files**
- **Spy can:**
 - **Dump SPK file contents**
 - » **Data**
 - » **Summary information**
 - » **Comment area**
 - » **Bookkeeping information**
 - **Sample data from a set of loaded kernels**
 - » **Sample position, distance, velocity, derived velocity, speed, acceleration, acceleration magnitude, osculating elements**
 - **Check SPK files**
 - » **Validate SPK structure**
 - » **Check sampled data for bounds violations**
 - » **Locate invalid double precision numbers**
 - **Find some geometric events**
 - » **Distance: find times when specified constraints on observer-target distance are met**
 - » **Elevation: find times when specified constraints on elevation of target in specified frame are met**



SPY: Selected Features

Navigation and Ancillary Information Facility

- **Operating modes**
 - Interactive, batch, shell command line
- **Auxiliary files**
 - Start-up file, command files, log file, save file
- **Interactive command support**
 - Command history: recall, repetition, and command editing; editor selection; command error detection; (limited) automatic command error correction
- **User default support**
 - Set, show, reset default values
- **Input options**
 - Define user symbols in commands
 - Embed prompts in commands
- **Output options**
 - Dump subsets of SPK data
 - Show epoch and packet deltas in data dumps
 - Set sample count or density
 - Set time and number formats
 - Set angular units
 - Set coordinate system for sampled data
 - Control error diagnostic verbosity
- **Online help: command language summary**



SPY Example: Dump SPK Data

Navigation and Ancillary Information Facility

```
Terminal Window
Spy > dump data spk testspk.bsp segment index 13 stop packet 2;

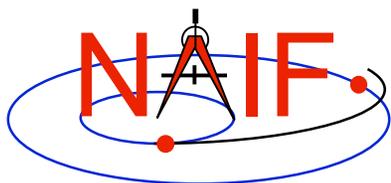
Dump of SPK File testspk.bsp
=====
Segment number 13
-----
Segment Summary:

Segment ID      : SPY test segment: type 18 subtype 0
Target Body    : Body 1800
Center Body    : Body 1899
Reference Frame : Frame 17, ECLIPJ2000
SPK Data Type  : Type 18
  Description   : Mex/Rosetta Hermite/Lagrange Interpolation
UTC Start Time : 2000 JAN 01 11:59:05.816
UTC Stop Time  : 2000 JAN 01 12:32:15.816
ET Start Time  : 2000-JAN-01 12:00:10.000000 (TDB)
ET Stop Time   : 2000-JAN-01 12:33:20.000000 (TDB)
DAF Begin Address: 35287
DAF End Address : 37890
-----
Segment Parameters:

Packet Count    : 200
Directory Count : 1
Window Size - 1 : 6
Polynomial Degree: 13
Subtype         : 0
  Description   : Hermite interpolation, 12-element packets
-----
Time Tags and Packets:

State Components: Position X, Y, Z (km)
                  Velocity X, Y, Z (km/s)
                  Velocity X, Y, Z (km/s)
                  Accel. X, Y, Z (km/s^2)

1      2000-JAN-01 12:00:10.000000 (TDB)  1.001033333E+03  1.002033333E+03  1.003033333E+03  1.004033333E+03  1.005033333E+03  1.006033333E+03
                                           1.007033333E+03  1.008033333E+03  1.009033333E+03  1.010033333E+03  1.011033333E+03  1.012033333E+03
2      2000-JAN-01 12:00:20.000000 (TDB)  2.001033333E+03  2.002033333E+03  2.003033333E+03  2.004033333E+03  2.005033333E+03  2.006033333E+03
                                           2.007033333E+03  2.008033333E+03  2.009033333E+03  2.010033333E+03  2.011033333E+03  2.012033333E+03
```



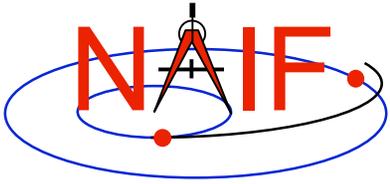
SPY Example: Sample State Vectors

Navigation and Ancillary Information Facility

```
Terminal Window

Spy > load naif0009.tls;
Spy > load de421.bsp;
Spy > sample states
  observer earth
  target moon
  start time 2008 oct 28 00:00:00.000000 TDB
  stop time 2008 oct 28 00:01:00.000000 TDB
  frame eclipJ2000
  aberration correction none
  coordinates latitudinal
  time format numeric E23.16
  number format F13.6
  step size 10.0;

Sample STATE Results
=====
Target           : moon
Observer         : earth
Frame            : eclipJ2000
Aberration Correction: none
Coordinate System : latitudinal
=====
0.2784240000000000E+09  395800.315095  -156.260092  -4.660937  0.035837  0.000145  -0.000005
0.2784240100000000E+09  395800.673459  -156.258644  -4.660983  0.035836  0.000145  -0.000005
0.2784240200000000E+09  395801.031820  -156.257196  -4.661028  0.035836  0.000145  -0.000005
0.2784240300000000E+09  395801.390177  -156.255748  -4.661074  0.035836  0.000145  -0.000005
0.2784240400000000E+09  395801.748532  -156.254300  -4.661120  0.035835  0.000145  -0.000005
0.2784240500000000E+09  395802.106883  -156.252851  -4.661165  0.035835  0.000145  -0.000005
0.2784240600000000E+09  395802.465231  -156.251403  -4.661211  0.035835  0.000145  -0.000005
=====
```



SPY Example: Check SPK Integrity

Navigation and Ancillary Information Facility

```
Terminal Window

Spy > check integrity spk testspk.bsp;

Structure Inspection of SPK File testspk.bsp
=====
Segment Number 11
-----
Segment Summary:

Segment ID       : SPY test segment: type 15
Target Body     : Body 1501
Center Body     : Body 1599
Reference Frame  : Frame 17, ECLIPJ2000
SPK Data Type   : Type 15
  Description    : Two-Body with J2 Precession
UTC Start Time  : 2000 JAN 01 11:59:05.816
UTC Stop Time   : 2000 JAN 01 12:32:15.816
ET Start Time   : 2000-JAN-01 12:00:10.000000 (TDB)
ET Stop Time    : 2000-JAN-01 12:33:20.000000 (TDB)
DAF Begin Address: 35259
DAF End Address  : 35274
-----
%% Error:  Invalid Unit Periapsis Pole Vector

      The periapsis pole vector should have unit length but in fact has length 4.58257569E+04.
-----
One error diagnostic and no warnings generated for SPK file testspk.bsp
=====
```



PREDICKT

Navigation and Ancillary Information Facility

- ***prediCkt* is a program for making CK files from a set of orientation specification rules and schedules defining when these rules are to be applied**
 - has a simple command line interface
 - requires orientation and schedule specification to be provided in a setup file that follows the SPICE text kernel syntax
 - requires all supporting kernels -- SPK, PCK, etc -- to be provided in a meta kernel
 - for more details see “Making CK Tutorial”



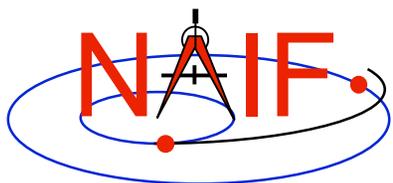
CKSLICER

Navigation and Ancillary Information Facility

- ***ckslicer* is a program for subsetting a CK file**
- ***ckslicer* is a command line program with the following usage**

```
ckslicer -lsk <lsk_file_name>  
        -sclk <sclk_file_name(s)>  
        -inputck <ck_file_name>  
        -outputck <ck_file_name>  
        -id <naif_id>  
        -timetype <utc|sclk|ticks>  
        -start <start_time>  
        -stop <stop_time>
```

- ***ckslicer* is useful in the situation when only a portion of a CK covering a short interval of time is needed (for example when the whole CK is not needed and it takes up a lot of space) or to cut parts from a few CKs with the intent to merge them together (if reconstructed CKs from different sources have too much overlap to simply “cat” them together)**
- **A note stating which subset was extracted is put into the comment area of the output CK file**



CKSLICER Example

Navigation and Ancillary Information Facility

```
Terminal Window
$ dir mgs_sc_ab1_v2.bc
-rw-rw-r--  1 naifuser  195535872 Jul 17  1999 mgs_sc_ab1_v2.bc

$ ckslicer -lsk naif0007.tls -sclk MGS_SCLKSCET.00054.tsc -inputck mgs_sc_ab1_v2.bc
-outputck mgs_sc_ab1_970915.bc -id -94000 -timetype utc -start 1997-SEP-15 18:00 -
stop 1997-SEP-15 21:00

CKSLICER: Version 1.0.1 July 17, 1999; Toolkit Version N0057

$ dir mgs_sc_ab1_970915.bc
• -rw-rw-rw-  1 naifuser   480256 Apr 25 10:23 mgs_sc_ab1_970915.bc

$ ckbrief mgs_sc_ab1_970915.bc naif0007.tls MGS_SCLKSCET.00054.tsc -utc

CKBRIEF Version: 2.0.0, 2001-05-16. SPICE Toolkit Version: N0057.

Summary for: mgs_sc_ab1_970915.bc

Object:  -94000
Interval Begin UTC      Interval End UTC      AV
-----
1997-SEP-15 18:00:00.001 1997-SEP-15 21:00:00.000 Y
```



CKSPANIT

Navigation and Ancillary Information Facility

- ***ckspanit*** is a program for modifying interpolation interval information in type 3 CK segments
 - it can also convert a type 1 CK to a type 2 or 3 CK
- ***ckspanit*** is used when one is dealing with a type 3 CK containing many small gaps within segments. It allows you to alter the CK in such a way that SPICE will interpolate over those gaps
- ***ckspanit*** is a command line program with the following usage

```
ckspanit -in inp_ck -out out_ck -tol threshold [-frm fk]
```

- “threshold” is the longest time interval over which interpolation is to be permitted in the output CK file

» must be specified in SCLK ticks

- For example if 1 tick is 1/256 of a second and interpolation over 30 second intervals is needed, “threshold” must be set to $256 \times 30 = 7680$

- “fk” is optional FK file name, needed only if the base frame in the input CK is not one of the frames built into the Toolkit

CAUTION: before running *ckspanit*, make sure that interpolation over larger gaps is appropriate for the vehicle or structure you are dealing with. You should add appropriate comments to the new CK file.



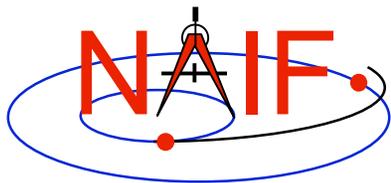
CKSPANIT Example

Navigation and Ancillary Information Facility

```
Terminal Window
$ ckbrief m01_sc_2004-04-22.bc naif0007.tls ORB1_SCLKSCET.00078.tsc -utc -dump
CKBRIEF Version: 2.0.0, 2001-05-16. SPICE Toolkit Version: N0057.
Summary for: m01_sc_2004-04-22.bc
Segment No.: 1
Object: -53000
Interval Begin UTC          Interval End UTC          AV
-----
2004-APR-22 00:00:05.455 2004-APR-22 18:53:29.054 Y
2004-APR-22 18:55:05.054 2004-APR-22 21:44:22.979 Y
2004-APR-22 21:51:34.974 2004-APR-22 23:59:58.919 Y

$ ckspanit -in m01_sc_2004-04-22.bc -out m01_sc_2004-04-22_sp.bc -tol 153600

$ ckbrief m01_sc_2004-04-22_sp.bc naif0007.tls ORB1_SCLKSCET.00078.tsc -utc -dump
CKBRIEF Version: 2.0.0, 2001-05-16. SPICE Toolkit Version: N0057.
Summary for: m01_sc_2004-04-22_sp.bc
Segment No.: 1
Object: -53000
Interval Begin UTC          Interval End UTC          AV
-----
2004-APR-22 00:00:05.455 2004-APR-22 23:59:58.919 Y
```



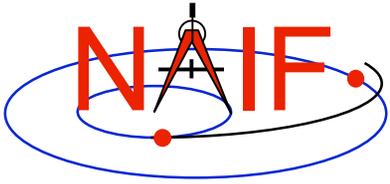
DAFCAT

Navigation and Ancillary Information Facility

- ***dafcat* is a program for concatenating binary DAF files by simply copying all data segments from all input files, in the order they are provided, into the output file**
 - Works on SPKs, CKs, and binary PCKs
 - » will not merge different types of kernels together, i.e. will not merge SPKs with CKs, CKs with PCKs, etc.
 - » should not be used for merging SPKs because *spkmerge* provides a much more powerful and sophisticated capability
- ***dafcat* is a command line program with the following usage**

```
dafcat output_file
```

 - “output_file” is the output file name and is the program’s only argument
 - Input file names should be provided from standard input
 - » this is very convenient for use with Unix shell pipes
- ***dafcat* does not put any information into the comment area of the output file, leaving this responsibility to the user (use *commnt* to do so)**



DAFCAT Examples

Navigation and Ancillary Information Facility

```
Terminal Window

$ dafcat m01.bc

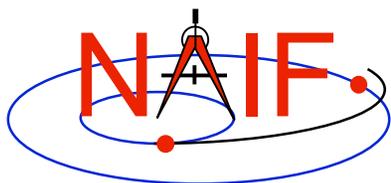
DAF binary files concatenation program version 1.00

m01_sc_2004-04-20.bc
m01_sc_2004-04-21.bc
^D
Concatenating files:
  m01_sc_2004-04-20.bc
  m01_sc_2004-04-21.bc
to:
  m01.bc

$ ls -1 m01_sc_2004-04-2*.bc | dafcat m01.bc

DAF binary files concatenation program version 1.00

Concatenating files:
  m01_sc_2004-04-20.bc
  m01_sc_2004-04-21.bc
to:
  m01.bc
```



CKSMRG

Navigation and Ancillary Information Facility

- ***cksmrg*** is a program for merging data from two or more uniform CK segments (same ID, base frame and type) provided in a single CK file
- ***cksmrg*** is used for eliminating gaps between segments (that cannot be removed by *ckspanit*) and removing duplicate data points contained in different segments
- ***cksmrg*** is a command line program with the following usage

```
cksmrg -k|-kernels <meta kernel name|kernel file names>  
-i|-input <input ck file name>  
-o|-output <output ck file name>  
-s|-segid <output ck segment id string>  
-f|-fileid <output ck file id string>  
-b|-body <body id|name>  
-r|-reference <reference id|name>  
-a|-av <drop|keep|make|makeavg>  
-t|-tolerance <tolerance (number units)>  
[-c|-correction <time delta|cor. table file>]
```

CAUTION: *cksmrg* should not be used to merge CKs from different sources, nor should it be used to merge overlapping predict CKs



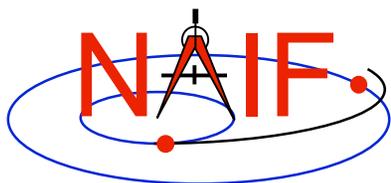
CKSMRG Example

Navigation and Ancillary Information Facility

```
Terminal Window
$ ckbrief m01.bc naif0007.tls ORB1_SCLKSCET.00078.tsc -utc -rel
. . .
Object: -53000
Interval Begin UTC          Interval End UTC          AV  Relative to FRAME
-----
2004-APR-20 00:00:03.622 2004-APR-20 23:59:56.288 Y  MARSIAU
2004-APR-21 00:00:02.288 2004-APR-21 23:59:59.455 Y  MARSIAU

$ cksmrg -k naif0007.tls ORB1_SCLKSCET.00078.tsc -i m01.bc -o m01s.bc -s 'CKSMRGed'
-f 'CKSMRGed' -b -53000 -r 'MARSIAU' -a keep -t 60 seconds
. . .
(cksmrg displays quite a lot of diagnostics and progress information)
. . .

$ ckbrief m01s.bc naif0007.tls ORB1_SCLKSCET.00078.tsc -utc -rel
. . .
Object: -53000
Interval Begin UTC          Interval End UTC          AV  Relative to FRAME
-----
2004-APR-20 00:00:03.622 2004-APR-21 23:59:59.455 Y  MARSIAU
```



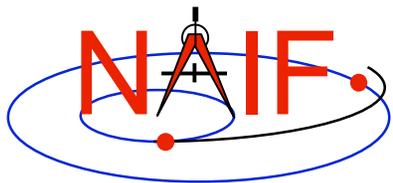
ORBNUM

Navigation and Ancillary Information Facility

- ***orbnum* is a program for generating a SPICE orbit number file containing orbit start/stop times and orbit numbers along with some additional derived quantities (orbital elements and coordinates of sub-spacecraft and sub-solar points)**
 - The orbit number increment can be specified as occurring at one of these events: periapsis, apoapsis, ascending equatorial node crossing, or descending equatorial node crossing
- ***orbnum* is a command line program with the following usage**

```
orbnum -pref pref_file -num init_orbit -file orbnum_file
```

 - “*pref_file*” is a preferences file using text kernel syntax, specifying setup parameters along with the kernels containing data to be used to search for orbit start and stop events -- spacecraft trajectory SPKs, center body PCK, spacecraft SCLK, etc.
 - “*init_orbit*” is the number to be assigned to the first orbit determined using the kernels provided; subsequent orbits are assigned by incrementing “*init_orbit*” by 1
- **If any of the command line arguments and some of the setup file parameters have not been provided, the program will prompt for them**
- **The program will also prompt for additional information such as the time span within which the search for orbit events is to be performed**



ORBNUM Example

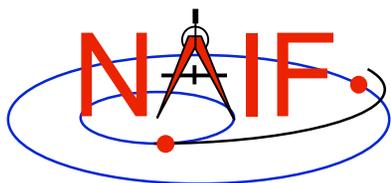
Navigation and Ancillary Information Facility

```
Terminal Window
$ more mex_orbnum.setup
\begindata
TARGET                = -41
OBSERVER              = 499
EVENT_DETECTION_FRAME = 'MARSIAU'
EVENT_DETECTION_KEY   = 'PERI'
ELEMENTS_INERTIAL_FRAME = 'MARSIAU'
ABERRATION_CORRECTION = 'NONE'
ORBIT_PARAMS          = ( 'Sub Sol Lon', 'Sub Sol Lat', .. )
TEXT_KERNELS         = ( 'de-245-masses.tpc', 'NAIF0007.TLS', 'mex_030722_step.tsc', .. )
BIN_KERNELS          = ( 'ORMF_PSTPIX_DB_00001.bsp', 'DE405S.BSP' )
SAFETY_MARGIN         = 0.5
\begintext

$ orbnum -pref mex_orbnum.setup -num 1 -file mex_orbnum.orb
....Loading Kernels

Start UTC (RET for default = 2004 JAN 13 15:54:19.8):<RETURN>
End   UTC (RET for default = 2004 AUG 05 02:10:24.8):<RETURN>

Working, please wait.
Program Finished!
```

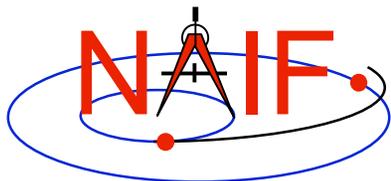


OPTIKS

Navigation and Ancillary Information Facility

- ***optiks* is a utility program that generates information about instrument fields of view (FOV) from parameters present in IK and FK files**
 - FOVs must be defined using the keywords required by the GETFOV routine
- ***optiks* is a command line program used in one of two ways**

```
optiks [options]... kernel ...  
optiks [options]... meta-kernel ...
```
- ***optiks* uses a set of SPICE kernels specified on the command line; one or more of these kernels may be a meta-kernel**
- **The output data are organized in two tables**
 - The first table lists the angular extents (size) of circular, elliptical, and rectangular FOVs. Using command line options “-units” and “-half” the user can select the unit of measure for the angular measurements, and whether half or full FOV angular extents are listed.
 - The second table contains FOV boresights in a user specified frame at a particular epoch, specified using the “-epoch” option



OPTIKS Example

Navigation and Ancillary Information Facility

```
Terminal Window
$ optiks -frame CASSINI_SC_COORD cas_iss_v09.ti cas_v37.tf naif0007.tls
cas00084.tsc
. . .
Kernels Loaded:
. . .
FOV full-angular extents computed in RADIANS

Field of View          Shape          Length          Width
-----
CASSINI_ISS_NAC        RECTANGULAR    +0.006108652382 +0.006108652382
CASSINI_ISS_NAC_RAD    CIRCULAR       +3.141592653590 +3.141592653590
CASSINI_ISS_WAC        RECTANGULAR    +0.060737457969 +0.060737457969
CASSINI_ISS_WAC_RAD    CIRCULAR       +3.141592653590 +3.141592653590

FOV boresights computed at epoch 2001-JAN-01 12:00
FOV boresights computed in frame CASSINI_SC_COORD
Field of View          Boresight Vector
-----
CASSINI_ISS_NAC        ( +0.000575958621, -0.999999819520, -0.000170972424 )
CASSINI_ISS_NAC_RAD    ( +1.000000000000, -0.000000000000, +0.000000000000 )
CASSINI_ISS_WAC        ( +0.001218344236, -0.999999225446, +0.000254451360 )
CASSINI_ISS_WAC_RAD    ( +1.000000000000, -0.000000000000, +0.000000000000 )
```



ARCHTYPE

Navigation and Ancillary Information Facility

- ***archtype* is a program that displays the file architecture and type of a SPICE kernel; it is useful for scripting applications**
 - To identify the architecture and type *archtype* uses the same mechanism as the FURNISH routine
- ***archtype* has a simple command line interface and requires only one argument -- the name of a kernel file:**

```
archtype kernel_name
```

- **Archtype prints architecture and type to standard output as two space delimited acronyms**
 - Architecture can be:
 - » 'DAF' or 'DAS' for binary kernels
 - » 'KPL' for text kernels
 - Type can be 'SPK', 'PCK', 'IK', 'CK', 'EK', 'LSK', 'FK'
- **If architecture and/or type cannot be determined, the program displays 'UNK'**
- **In order for text kernels to be recognized, the first few characters of the file must contain 'KPL/<type>' (i.e. 'KPL/IK', 'KPL/FK', etc.)**



ARCHTYPE Examples

Navigation and Ancillary Information Facility

```
Terminal Window
$ archtype 020514_SE_SAT105.bsp
DAF SPK

$ archtype 04135_04171pc_psiv2.bc
DAF CK

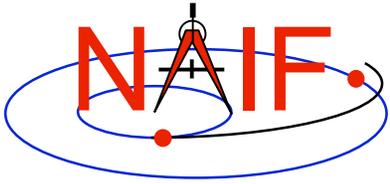
$ archtype cas00084.tsc
KPL SCLK

$ archtype cas_v37.tf
KPL FK

$ archtype cpck05Mar2004.tpc
KPL PCK

$ archtype naif0008.tls
KPL LSK

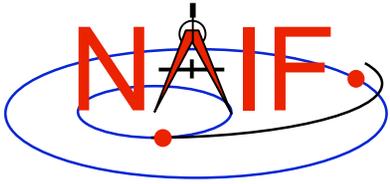
$ archtype .cshrc
UNK UNK
```



Navigation and Ancillary Information Facility

SPICE Toolkit Common Problems

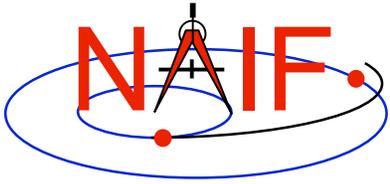
January 2009



Topics

Navigation and Ancillary Information Facility

- **Prevention**
- **The “Common Problems Required Reading” document**
- **Reporting a Problem to NAIF**

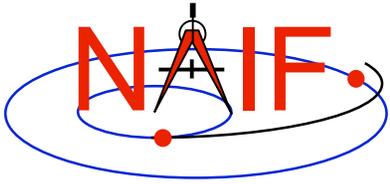


Prevention - 1

Navigation and Ancillary Information Facility

- **To minimize problems using SPICE:**
 - Use a Toolkit obtained directly from NAIF and intended for your specific environment (platform/OS/compiler/compiler options)
 - Use a current Toolkit
 - » **Newer Toolkits may have bug fixes and new features you need**
 - Toolkits are always backwards compatible, so you should have no problem re-linking your application to the latest Toolkit
 - Read the pertinent documentation
 - » Tutorials, module headers, Required Reading documents, comments inside kernels
 - Get the correct (usually latest) kernel files
 - » Verify that coverage and intended use are suitable
 - Verify use of the correct time system for your need
 - » e.g., TDB, UTC, or SCLK?
 - When using SCLK time tags, be sure to form your SCLK string to match the specification within the SCLK kernel
 - » Make sure the fractional part is in the form that is expected

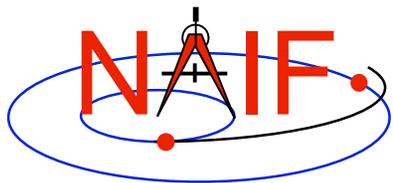
continued on next page



Prevention - 2

Navigation and Ancillary Information Facility

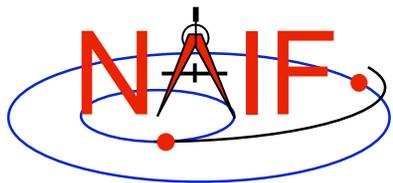
- **Verify that correct reference frames are used**
 - » e.g., MOON_PA versus MOON_ME?
 - » e.g. which version of the IAU_Mars body-fixed frame?
- **Check definitions of geometric quantities**
 - » Geodetic vs latitudinal coordinates
 - » Oblate vs spherical body shapes
- **Check aberration corrections**
 - » Converged Newtonian light time + stellar aberration, light time+stellar aberration, light time only, or none?
 - » Target orientation corrected for light time?
- **Don't confuse an instrument reference frame ID with the ID of the instrument itself (the object ID)**



PROBLEMS Required Reading

Navigation and Ancillary Information Facility

- **NAIF has compiled a list of common problems, probable causes, and solutions encountered by users of the various SPICE Toolkits:**
 - Refer to `.../doc/html/req/problems.html` or `...doc/req/PROBLEMS.REQ`, both of which are provided in each Toolkit package.
- **Some tutorials (e.g. SPK and CK) contain a section describing common problems.**
- **It may be useful to read these documents BEFORE embarking on extensive SPICE-based programming projects, since some problems are best solved early in the software development cycle.**



Reporting a Problem to NAIF

Navigation and Ancillary Information Facility

- **If you need help troubleshooting a programming or usage problem, you can send email to NAIF. At a minimum include these items in your email message.**
 - **The SPICE or operating system diagnostic messages written to the screen or to log files.**
 - **The name and version of the operating system you're using.**
 - **The name and version of the compiler or programming environment (IDL, Matlab).**
 - **The Toolkit version you are using, i.e. N0062.**
 - **Names of the kernel files being used.**
 - » **You may need to provide the kernels themselves if these are not available to NAIF.**
 - **Your inputs to SPICE modules that signaled the error.**
 - **If possible, a code fragment from where the error seems to occur.**
- **Send the email to anyone on the NAIF team.**



Navigation and Ancillary Information Facility

Finding SPICE Components

An Introduction to
the NAIF Server

January 2009



Overview

Navigation and Ancillary Information Facility

- **Many SPICE “products” are available from the NAIF server**
 - Access is via the http or ftp protocol
 - See next page for URLs
- **SPICE products made outside of JPL are controlled by the producing organizations. Some may be available from the NAIF server, some may be available at other public servers, or on restricted servers, or not at all.**
 - Some of these SPICE products may eventually become accessible from the NAIF server after they are formally archived within NASA’s Planetary Data System.



NAIF Server Basics

Navigation and Ancillary Information Facility

- **NAIF home page**

<http://naif.jpl.nasa.gov>

- Here you may access nearly all SPICE products available to NAIF*
 - kernels (generic, mission ops, PDS archived)
 - software (Toolkits and individual application programs)
 - documents
 - tutorials
 - programming lessons
 - problem solving tips
 - rules about using SPICE
 - links to useful resources

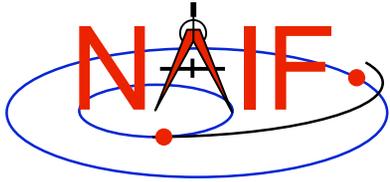
- **SPICE announcements (by NAIF)**

http://naif.jpl.nasa.gov/mailman/listinfo/spice_announce

- **SPICE discussion (by anyone)**

http://naif.jpl.nasa.gov/mailman/listinfo/spice_discussion

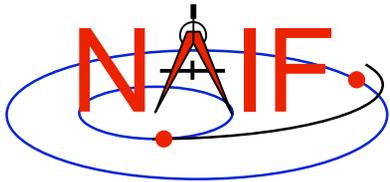
* Note: some SPICE products made outside of JPL may not be available to NAIF until formally archived with the Planetary Data System (PDS), or perhaps never.



Getting SPICE Kernels

Navigation and Ancillary Information Facility

- The remaining charts discuss where to find the various categories of SPICE kernel files:
 - **Mission operations** kernels, for (mostly JPL) active flight projects
 - **Archived** kernels, those formally delivered to and accepted by NASA's Planetary Data System
 - **Generic** kernels, not tied to a specific flight project or other task



Mission Ops Kernels - 1

Navigation and Ancillary Information Facility

Address: <ftp://naif.jpl.nasa.gov/pub/naif/CASSINI/kernels/>

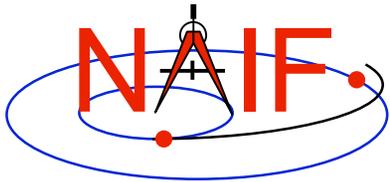
Jet Propulsion Laboratory
* * * W A R N I N G * * *
Property of the
UNITED STATES GOVERNMENT

This computer is funded by the United States Government and operated by the California Institute of Technology in support of ongoing U.S. Government programs and activities. If you are not authorized to access this system, disconnect now. Users of this system have no expectation of privacy. By continuing, you consent to your keystrokes and data content being monitored.

Login successful. Have fun.

Path: [\[naif.jpl.nasa.gov\]](#)[\[pub\]](#)[\[naif\]](#)[\[CASSINI\]](#)[\[kernels\]](#)

| Name | Size | Kind | Last Modified |
|------------------------------|-----------|------------|-----------------------------|
| aareadme.txt | 400 bytes | ASCII Text | Thu, Mar 11, 2004, 10:39 PM |
| ck | - | Folder | Tue, Apr 20, 2004, 5:10 PM |
| ek | - | Folder | Fri, Apr 16, 2004, 11:04 PM |
| fk | - | Folder | Thu, Mar 18, 2004, 11:45 PM |
| ik | - | Folder | Mon, Apr 12, 2004, 8:51 PM |
| lsk | - | Folder | Wed, Mar 20, 2002, 12:00 AM |
| pck | - | Folder | Thu, Mar 18, 2004, 11:47 PM |
| sck | - | Folder | Mon, Mar 29, 2004, 9:06 PM |
| spk | - | Folder | Fri, Apr 16, 2004, 4:58 PM |



Mission Ops Kernels - 2

Navigation and Ancillary Information Facility

Address: <ftp://naif.jpl.nasa.gov/pub/naif/CASSINI/kernels/spk/>

spk

.../CASSINI/kernels/spk

```
-----
      Jet Propulsion Laboratory
      * * *   W A R N I N G   * * *
      Property of the
      UNITED STATES GOVERNMENT

      This computer is funded by the United States Government and
      operated by the California Institute of Technology in support of
      ongoing U.S. Government programs and activities.  If you are not
      authorized to access this system, disconnect now.  Users of this
      system have no expectation of privacy.  By continuing, you consent
      to your keystrokes and data content being monitored.

      -----
Login successful. Have fun.

Path: \[naif.jpl.nasa.gov\]\[pub\]\[naif\]\[CASSINI\]\[kernels\]\[spk\]
```

| Name | Size | Kind | Last Modified |
|--|--------|----------|-----------------------------|
| 000202R_SK_LP0_V1P32.bsp | 238K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000202R_SK_LP0_V1P32.bsp.lbl | 2K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000202R_SK_V1P32_V2P12.bsp | 502K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000202R_SK_V1P32_V2P12.bsp.lbl | 2K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000202R_SK_V2P12_EP15.bsp | 198K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000202R_SK_V2P12_EP15.bsp.lbl | 2K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000203_SE_JUP156.bsp | 4,968K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000203_SE_JUP156.bsp.lbl | 3K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000331R_SK_LP0_V1P32.bsp | 307K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000331R_SK_LP0_V1P32.bsp.lbl | 3K | Document | Thu, Feb 21, 2002, 12:00 AM |
| 000331R_SK_V1P32_V2P12.bsp | 622K | Document | Thu, Feb 21, 2002, 12:00 AM |
| ⋮ | | | |
| aareadme.txt | | | |

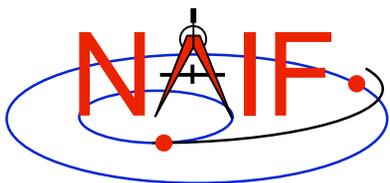
Kernel file
Kernel file detached label (text)
Kernel file naming conventions



Archived Kernels - 1

Navigation and Ancillary Information Facility

- **Two methods for obtaining PDS archived kernels are available.**
 - **Directly from the NAIF server, using your browser**
 - » **Recommended!**
 - » **Unless you have reason to do otherwise, download the entire archival data set using the ftp URL**
 - You'll get all the latest data, and you'll get the associated "furnsh files"
 - **Using the PDS central catalog interface, using your browser**
- **Pictorial examples are shown on the next several pages**



Archived Kernels - 2

Navigation and Ancillary Information Facility

| Mission Name | Archive Overview | Volume FTP Link | Data Size (gbytes) | Start Time | Stop Time |
|-----------------------------|------------------------------|-----------------------------|--------------------|------------|------------|
| Cassini Orbiter | aareadme.htm | cosp_1000 | 15.5 | 1996-11-06 | 2008-01-01 |
| Clementine | aareadme.htm | cisp_1000 | 0.8 | 1994-01-26 | 1994-05-07 |
| Deep Impact | aareadme.htm | disp_1000 | 0.5 | 2005-01-12 | 2009-01-15 |
| Deep Space 1 | aareadme.htm | ds1sp_1000 | 0.9 | 1998-10-24 | 2003-12-31 |
| MER 1 (Opportunity) | aareadme.htm | mer1sp_1000 | 1.6 | 2003-07-07 | 2008-02-12 |
| MER 2 (Spirit) | aareadme.htm | mer2sp_1000 | 1.4 | 2003-06-10 | 2008-01-21 |
| MESSENGER | aareadme.htm | messsp_1000 | 8.2 | 2004-08-03 | 2008-02-01 |
| Mars Global Surveyor | aareadme.htm | mgsp_1000 | 15.4 | 1996-11-06 | 2006-11-02 |
| Mars Odyssey | aareadme.htm | odsp_1000 | 7.7 | 2001-04-07 | 2007-12-31 |
| Mars Reconnaissance Orbiter | aareadme.htm | mrosp_1000 | 32.4 | 2005-08-12 | 2008-07-01 |
| Stardust | aareadme.htm | sdsp_1000 | 1.1 | 1999-02-07 | 2006-01-29 |

Index of ftp://naif.jpl.nasa.gov/pub/naif/pds/data/co-s_j_e_v-spice-6-v1.0/cosp_1000/

[Up to higher level directory](#)

Name

- [aareadme.htm](#)
- [aareadme.lbl](#)
- [aareadme.txt](#)
- [catalog](#)
- [data](#)
- [document](#)
- [errata.txt](#)
- [extras](#)
- [index](#)
- [software](#)
- [voldesc.cat](#)

[Up to higher level directory](#)

Name

- [ck](#)
- [ek](#)
- [fk](#)
- [ik](#)
- [lsk](#)
- [pck](#)
- [sclk](#)
- [spk](#)

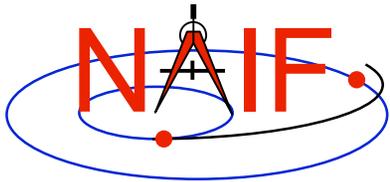
[Up to higher level directory](#)

Name

- [ckextra](#)
- [extrinfo.txt](#)
- [mk](#)
- [orbnum](#)

If you select “PDS Archive Area” on the NAIF web page you can follow a path like this one.

- You can use Unix “wget,” or the FileZilla tool, or some other equivalent with the ftp URL to download the entire data set (recommended!)
- Or you can select specific kernels from the kernel folders, and/or “furnsh” meta- kernels and other items from the extras folder



Archived Kernels - 3

Navigation and Ancillary Information Facility

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION

+ NASA Homepage
+ NASA en Español
+ Contact NASA

Planetary Data System

Home Data Services Tools Documents Related Sites About PDS Sitemap

Data Set Advanced Search

Select one or more parameters from below, then hit Go!
Click on to filter parameters. Click on parameter name for more information.

Missions: (pick one or many and Filter)
2001 Mars Odyssey
Cassini-Huygens
Deep Space 1
Mars Exploration Rover
Mars Global Surveyor
Near Earth Asteroid Rendezvous

Target Name: (pick one to Filter)
All

Instrument Type: (pick one to Filter)
All

Instruments: (pick one or many and Filter)
Spice Kernels

Start Date: YYYY-MM-DD

Stop Date: YYYY-MM-DD

Data Type: Spice Kernel

Data Set ID: All

Data Set Name: All

Instrument Host: (pick one or many)
2001 Mars Odyssey
Cassini Orbiter
Deep Space 1
Mars Exploration Rover 1
Mars Exploration Rover 2
Mars Global Surveyor

Instrument Host Type: Spacecraft

Quick Search | Power Search

Reset Go!

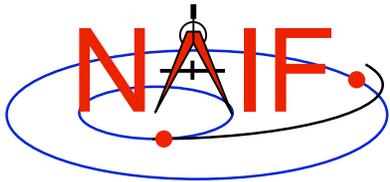
If you select “PDS Central Catalog” on the NAIF web page you will be offered a query capability as shown here. However, this provides access only to individual kernels, which is generally not a recommended/useful approach.

“Spice Kernels” has been pre-selected for you.

Select a “Mission,” or an “Instrument Host” (they are not always identical).

Select START and STOP dates, if desired.

Finally, press “GO” and see what turns up!



Generic Kernels Example - 1

Navigation and Ancillary Information Facility

generic_kernels

Address: ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/

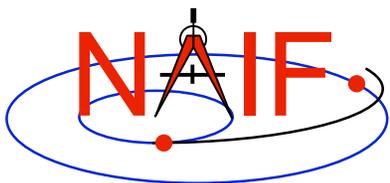
Jet Propulsion Laboratory
* * * W A R N I N G * * *
Property of the
UNITED STATES GOVERNMENT

This computer is funded by the United States Government and operated by the California Institute of Technology in support of ongoing U.S. Government programs and activities. If you are not authorized to access this system, disconnect now. Users of this system have no expectation of privacy. By continuing, you consent to your keystrokes and data content being monitored.

Login successful.

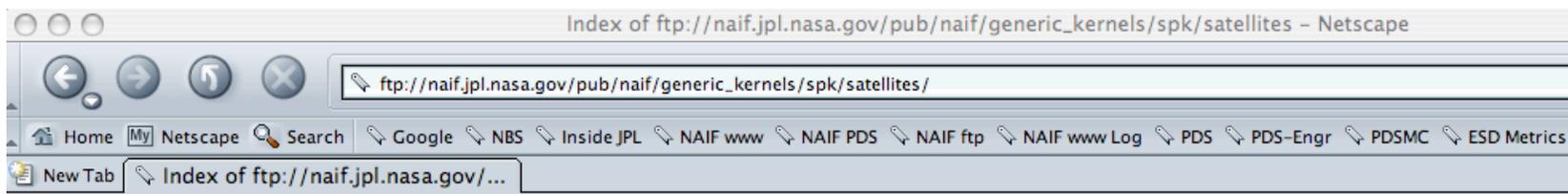
Path: [\[naif.jpl.nasa.gov\]](#)[\[pub\]](#)[\[naif\]](#)[\[generic_kernels\]](#)

| Name | Size | Kind | Last Modified |
|-----------------------------|------|--------|-----------------------------|
| fk | - | Folder | Wed, Sep 19, 2001, 12:00 AM |
| lsk | - | Folder | Fri, Jul 17, 1998, 12:00 AM |
| pck | - | Folder | Sat, Apr 2, 2005, 1:07 AM |
| plate_model | - | Folder | Thu, Jan 13, 2005, 6:23 PM |
| spk | - | Folder | Thu, Oct 18, 2001, 12:00 AM |
| stars | - | Folder | Fri, May 7, 2004, 12:00 AM |



Generic Kernels Example - 2

Navigation and Ancillary Information Facility



Index of ftp://naif.jpl.nasa.gov/pub/naif/generic_kernels/spk/satellites

[Up to higher level directory](#)

| | | | |
|--|----------|----------|-------------|
| a_old_versions | | 1/5/07 | 2:05:00 AM |
| aa_spk_production_dates_by-alpha.txt | 2 KB | 1/5/07 | 2:11:00 AM |
| aa_spk_production_dates_by-date.txt | 2 KB | 1/5/07 | 2:11:00 AM |
| aa_summaries.txt | 25 KB | 1/5/07 | 2:09:00 AM |
| iup230.bsp | 96440 KB | 8/12/04 | 12:00:00 AM |
| iup252.bsp | 3058 KB | 10/23/06 | 12:33:00 AM |
| iup252.cmt | 3 KB | 10/23/06 | 12:28:00 AM |
| iup252.inp | 1 KB | 10/23/06 | 12:33:00 AM |
| iup255.bsp | 2805 KB | 10/26/05 | 12:00:00 AM |
| iup255.cmt | 3 KB | 10/26/05 | 12:00:00 AM |
| iup255.inp | 1 KB | 10/26/05 | 12:00:00 AM |
| iup256.bsp | 24562 KB | 10/22/06 | 10:53:00 PM |
| iup256.cmt | 3 KB | 10/22/06 | 10:52:00 PM |
| iup256.inp | 1 KB | 10/22/06 | 10:48:00 PM |

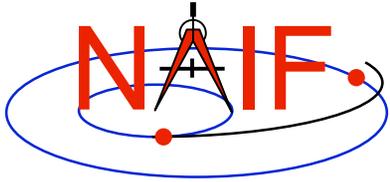
Folder containing older (no longer current) files

Summary of all SPK files in the directory, ordered by alpha and by date placed on the server

“brief -ct” summaries of all SPK files in the directory

Typical SPK file

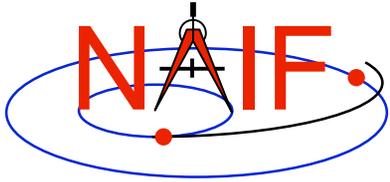
Comments about the file, also placed inside the SPK file



Navigation and Ancillary Information Facility

Summary of Key Points

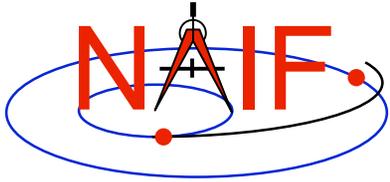
January 2009



Which Pieces of SPICE Must I Use?

Navigation and Ancillary Information Facility

- **There's not a simple answer**
 - Depends on what task you wish to accomplish
 - Depends on what mission you are working on
- **The next several charts highlight some key points**
 - We assume you have already looked at the major SPICE tutorials, or already have some familiarity with SPICE.
 - We assume you have successfully downloaded and installed the SPICE Toolkit.
- **Consider printing this tutorial and keeping it near your workstation**



Reminder of Key Subsystems

Navigation and Ancillary Information Facility

- **SPK: Position (and velocity) of things**
- **PCK: Size/shape/orientation of target bodies**
 - For binary PCKs, only orientation is provided; use a text PCK to obtain size/shape
- **IK: Instrument field-of-view geometry**
- **CK: Orientation of spacecraft or spacecraft structures that move**
- **FK: Definition/specification of non-core reference frames, including instrument mounting alignments**
- **LSK: UTC (SCET) \longleftrightarrow ET time conversions**
- **SCLK and LSK: SCLK \longleftrightarrow ET time conversions**



Primary Kernel Interfaces - 1

Navigation and Ancillary Information Facility

Which SPICE interface modules are most commonly called to use data obtained from a given kernel type?

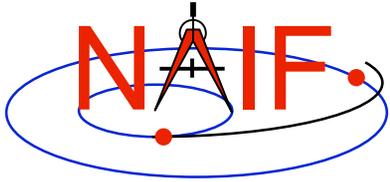
| | |
|------------|---|
| SPK | SPKEZR, SPKPOS,
SPKCOV, SPKOBJ |
| PCK | SXFORM, PXFORM,
SPKEZR, SPKPOS,
BODVRD |
| IK | G*POOL, GETFOV |
| CK | SXFORM, PXFORM
SPKEZR, SPKPOS,
CKCOV, CKOBJ
(CKGPAV, CKGP) |

| | |
|---------------|---|
| FK | SXFORM, PXFORM,
SPKEZR, SPKPOS |
| LSK | STR2ET, TIMOUT,
SCE2C, SCT2E,
SCE2S, SCS2E |
| SCLK | SCS2E, SCE2S
SXFORM, PXFORM,
SPKEZR, SPKPOS |
| EK/ESQ | EKFIND, EKG* |

Notes: FURNISH is used to load (provide access to) all SPICE kernels.

API names shown are for FORTRAN versions:

- use lower case and add an “_c” when using C
- use lower case and prepend “cspice_” when using Icy (IDL) and Mice (MATLAB)



Primary Kernel Interfaces - 2

Navigation and Ancillary Information Facility

For a given module, which kind(s) of kernel(s) will or may be needed?

Kernel Type(s) Needed

| Module Name | SPK | PCK | IK | CK | FK | LSK | SCLK |
|--------------------------------|-----|-----|----|----|----|-----|------|
| SPKEZR, SPKPOS | Y | M | | M | M | M | M |
| SXFORM, PXFORM | M | M | | M | M | M | M |
| CKGP, CKGPAV | | M | | Y | M | M | M |
| GETFOV | | | Y | | | | |
| G*POOL | | M | M | | | | |
| STR2ET, TIMOUT | | | | | | Y | |
| SCS2E, SCE2S | | | | | | Y | Y |
| CHRONOS (time conversion app.) | M | M | | M | M | Y | M |

Yes = the indicated kernel type is needed

Maybe = the indicated kernel type may be needed



Kernel “Coverage” Cautions

Navigation and Ancillary Information Facility

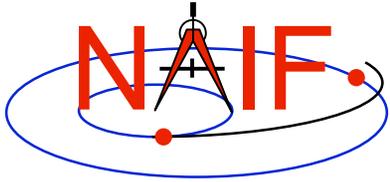
- **Your set of kernels must:**
 - contain data for all “objects” of interest
 - » Sometimes you must include intermediary objects that provide a connection
 - contain data covering the time span of interest to you
 - » Watch out for data gaps within that time span
 - » Watch out for the difference of ~66 seconds between ET and UTC
 - contain all the kernel types needed by SPICE to answer your question
 - » As the previous charts allude, you may need one or more kernels that are not obvious
 - be managed (loaded) properly if there are overlapping (competing) data within the set of files you are using



What Kernels are Available?

Navigation and Ancillary Information Facility

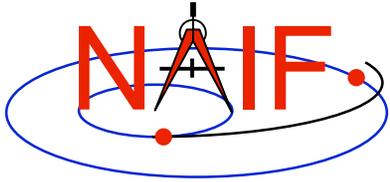
- It depends on the mission or task you are working on...
- If you're working with JPL mission data, there are three categories of kernel data available to you.
 - **Mission operations** kernels – those used by the flight teams to fly the mission and prepare the archival science products
 - **Archived** kernels – those that have been selected from (or made from) the mission ops kernels, and then are well organized and documented for the permanent PDS archive
 - **Generic** kernels – those that are used by many missions and are not tied to any one mission
 - » Note that appropriate generic kernels are usually included in the PDS SPICE archived kernels data sets mentioned above
- The situation may be very similar for non-JPL missions, but this is really up to whatever agency/institution is producing the kernels.



How Can I Find Possibly Useful Toolkit Modules?

Navigation and Ancillary Information Facility

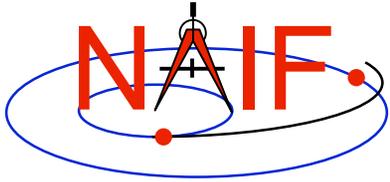
- **Review the previous charts**
- **Look at the appropriate SPICE tutorial(s)**
- **Look at the “Most Useful SPICELIB Subroutines” document**
`.../doc/html/info/mostused.html`
- **Search the permuted index:**
 - **spicelib_idx** for the FORTRAN toolkits `.../doc/html/info/spicelib_idx.html`
 - » This index also correlates entry point names with source code files.
 - **cspice_idx** for the C toolkits `.../doc/html/info/cspice_idx.html`
 - **icy_idx** for the IDL toolkits `.../doc/html/info/icy_idx.html`
 - **mice_idx** for the MATLAB toolkits `.../doc/html/info/mice_idx.html`
- **Read relevant portions of a SPICE “required reading” reference document (e.g. “spk.req”)**
 - `.../doc/html/req/spk.html` for the hyperlinked html version (best)
 - `.../doc/spk.req` for the plain text version



How Can I Understand How To Use Those Modules?

Navigation and Ancillary Information Facility

- **The primary user-oriented documentation about each module is found in the “header” located at the top of each source code file and in the module’s HTML page in the API reference guide.**
 - (More documentation is found at the additional entry points for those FORTRAN modules that have multiple entry points.)
- **Reference documentation for major subsystems is found in like-named “required reading” documents (e.g. spk.req, ck.req, etc.)**
- **The SPICE tutorials contain much helpful information**
- **See “SPICE Documentation Taxonomy” in the tutorials collection for additional reading suggestions**



Does NAIF Provide Any Examples?

Navigation and Ancillary Information Facility

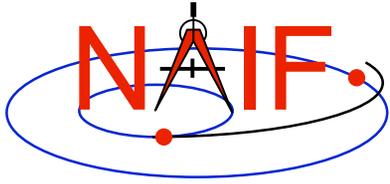
- **Nearly all module headers contain one or more working examples**
- **“Most Useful SPICELIB Subroutines” has code fragments**
`.../doc/html/info/mostused.html`
- **The “required reading” reference documents often contain examples** `.../doc/html/req/index.html`
- **Four tutorials offer programming examples**
- **Some simple “cookbook” programs are found in the Toolkit**
`.../src/cookbook/...`
- **Make use of the SPICE Programming Lessons available from the NAIF server**
 - `ftp://naif.jpl.nasa.gov/pub/naif/toolkit_docs/Lessons/`



Navigation and Ancillary Information Facility

Writing an Icy (IDL) Based Program

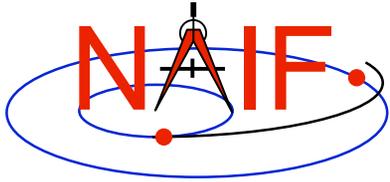
January 2009



Viewing This Tutorial

Navigation and Ancillary Information Facility

Undefined variables are displayed in red; results are displayed in blue.



Introduction

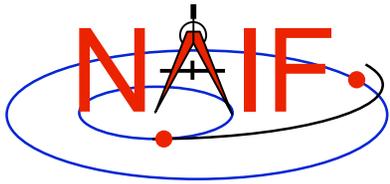
Navigation and Ancillary Information Facility

First, let's go over the important steps in the process of writing a Icy-based program and putting it to work:

- **Understand the geometry problem.**
- **Identify the set of SPICE kernels that contain the data needed to perform the computation.**
- **Formulate an algorithm to compute the quantities of interest using SPICE.**
- **Write and compile the program.**
- **Get actual kernel files and verify that they contain the data needed to support the computation for the time(s) of interest.**
- **Run the program.**

To illustrate these steps, let's write a program that computes the apparent intersection of the boresight ray of a given CASSINI science instrument with the surface of a given Saturnian satellite. The program will compute:

- **Planetocentric and planetodetic (geodetic) latitudes and longitudes of the intercept point.**
- **Range from spacecraft to intercept point.**
- **Illumination angles (phase, solar incidence, and emission) at the intercept point.**



Observation geometry

Navigation and Ancillary Information Facility

We want the boresight intercept on the surface, range from s/c to intercept, and illumination angles at the intercept point.

When? **TIME (UTC, TDB or TT)**

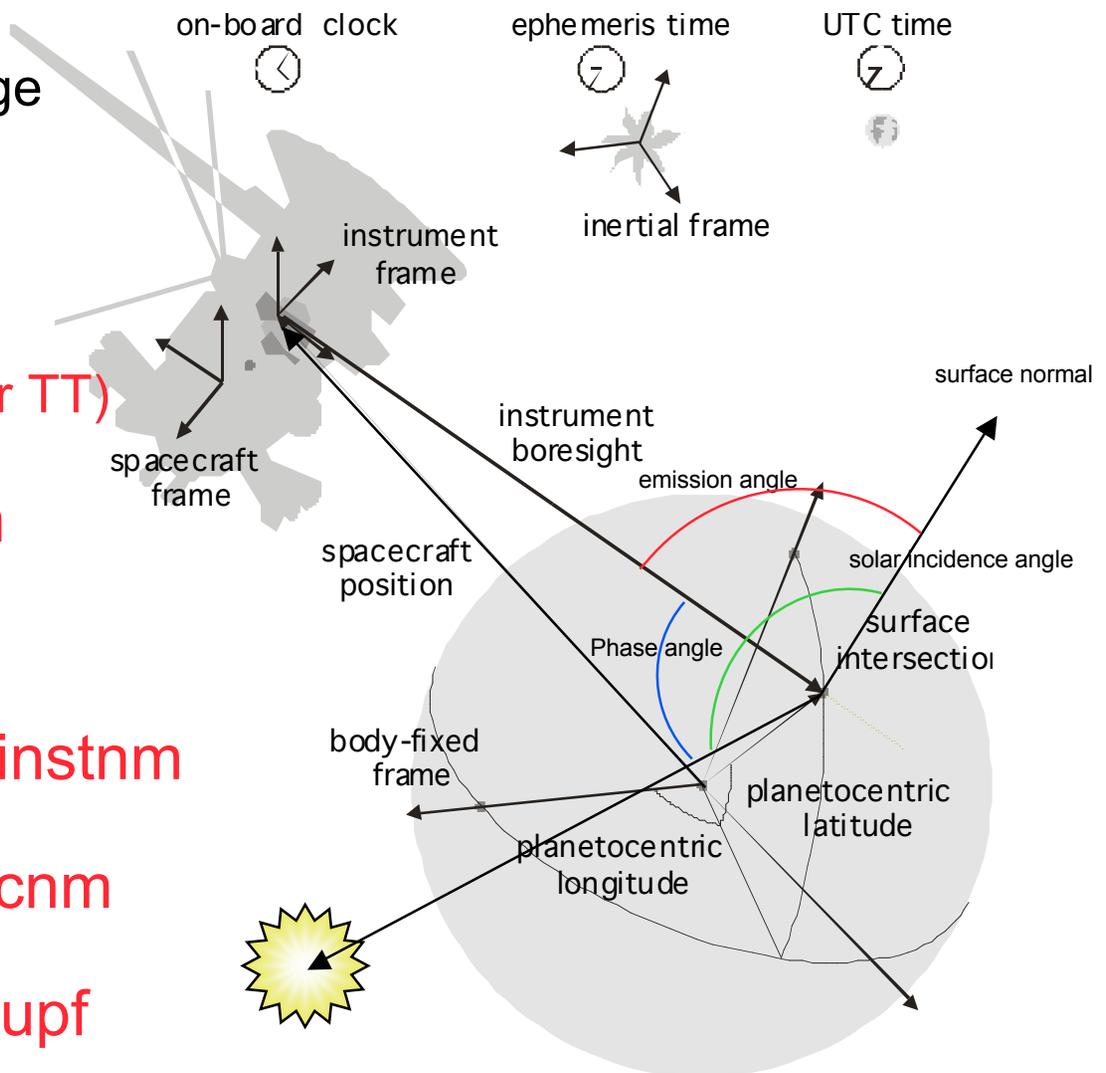
On what object? **satnm**

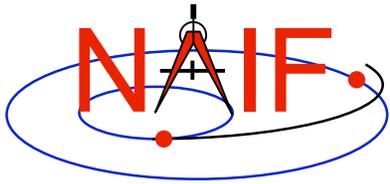
In what frame? **fixref**

For which instrument? **instnm**

For what spacecraft? **scnm**

Using what model? **setupf**





Needed Data

Navigation and Ancillary Information Facility

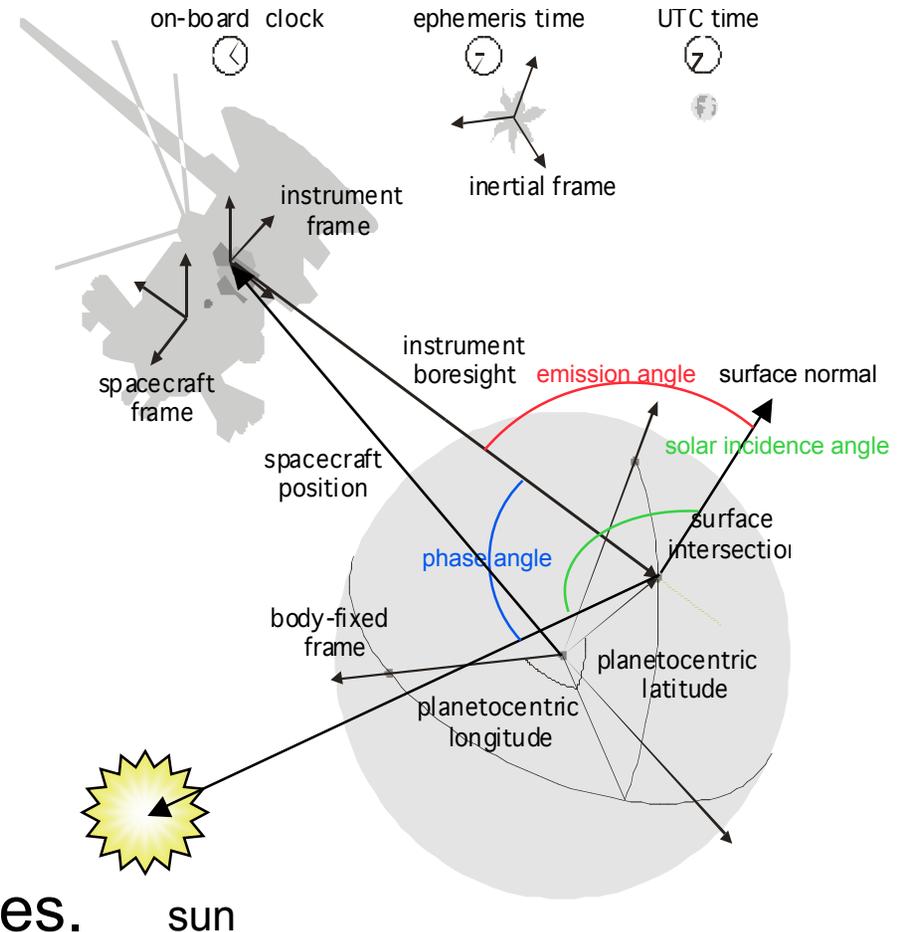
Time transformation kernels

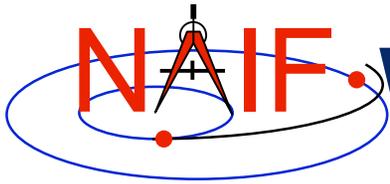
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





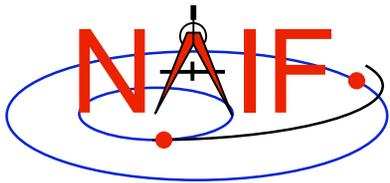
Which Kinds of Kernels are Needed?

Navigation and Ancillary Information Facility

Data required to compute vectors, rotations and other parameters shown in the picture are stored in the SPICE kernels listed below.

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

| Parameter | Kernel Type | File name |
|----------------------------|-----------------------------|------------------------------|
| time conversions | generic LSK
CASSINI SCLK | naif0008.tls
cas00084.tsc |
| satellite orientation | CASSINI PCK | cpck05Mar2004.tpc |
| satellite shape | CASSINI PCK | cpck05Mar2004.tpc |
| satellite position | planet/sat
ephemeris SPK | 020514_SE_SAT105.bsp |
| planet barycenter position | planet SPK | 981005_PLTEPH-DE405S.bsp |
| spacecraft position | spacecraft SPK | 030201AP_SK_SM546_T45.bsp |
| spacecraft orientation | spacecraft CK | 04135_04171pc_psiv2.bc |
| instrument alignment | CASSINI FK | cas_v37.tf |
| instrument boresight | Instrument IK | cas_iss_v09.ti |



Load kernels

Navigation and Ancillary Information Facility

The easiest and most flexible way to make these kernels available to the program is via `cspice_furnsh`. For this example we make a setup file (also called a “metakernel” or “furnsh kernel”) containing a list of kernels to be loaded:

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

```
\begindata
```

```
KERNELS_TO_LOAD = ('naif0008.tls', 'cas00084.tsc', 'cpck05Mar2004.tpc',  
                   '020514_SE_SAT105.bsp', '981005_PLTEPH-DE405S.bsp',  
                   '030201AP_SK_SM546_T45.bsp', '04135_04171pc_psisv2.bc',  
                   'cas_v37.tf', 'cas_iss_v09.ti')
```

```
\begintext
```

and we make the program prompt for the name of this setup file:

```
read, setupf, PROMPT='Enter setup file name > '  
cspice_furnsh, setupf
```



Programming Solution

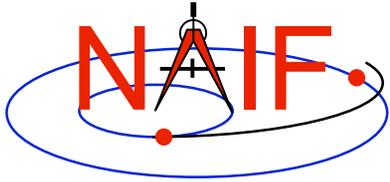
Navigation and Ancillary Information Facility

- **Prompt for setup file (“metakernel”) name; load kernels specified via setup file. (Done on previous chart.)**
- **Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via Icy calls.**
- **Compute the intersection of the boresight direction ray with the surface of the satellite, presented as a triaxial ellipsoid.**

If there is an intersection,

- **Convert Cartesian coordinates of the intersection point to planetocentric latitudinal and planetodetic coordinates**
 - **Compute spacecraft-to-intercept point range**
 - **Find the illumination angles (phase, solar incidence, and emission) at the intercept point**
- **Display the results.**

We discuss the geometric portion of the problem first.



Compute surface intercept

Navigation and Ancillary Information Facility

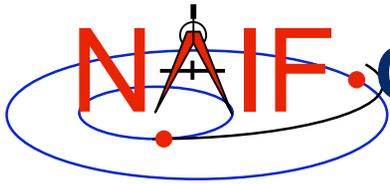
Compute the intercept point (`point`) of the boresight vector (`insite`) specified in the instrument frame (`iframe`) of the instrument mounted on the spacecraft (`scnm`) with the surface of the satellite (`satnm`) at the TDB time of interest (`et`) in the satellite's body-fixed frame (`fixref`). This call also returns the light-time corrected epoch at the intercept point (`trgepc`), the spacecraft-to-intercept point vector (`srfvec`), and a flag indicating whether the intercept was found (`found`). We use "converged Newtonian" light time plus stellar aberration corrections to produce the most accurate surface intercept solution possible. We model the surface of the satellite as an ellipsoid.

```
cspice_sincpt, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, iframe, $
               insite, point, trgepc, srfvec, found
```

The range we want is obtained from the outputs of `cspice_sincpt`. These outputs are defined only if a surface intercept is found. If `found` is true, the spacecraft-to-surface intercept range is the norm of the output argument `srfvec`. Units are km. We use the Icy function `cspice_vnorm` to obtain the norm:

```
cspice_vnorm( srfvec )
```

We'll write out the range data along with the other program results.



Compute Lat/Lon and Illumination Angles

Navigation and Ancillary Information Facility

Compute the planetocentric latitude (`pclat`) and longitude (`pclon`), as well as the planetodetic latitude (`pdlat`) and longitude (`pdlon`) of the intersection point.

```
if ( found ) then begin
    cspice_reclat, point, r, pclon, pclat

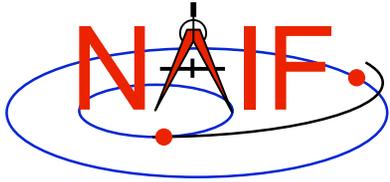
    ;; Let re, rp, and f be the satellite's longer equatorial
    ;; radius, polar radius, and flattening factor.

    re = radii[0]
    rp = radii[2]
    f = ( re - rp ) / re;

    cspice_recgeo, point, re, f, pdlon, pdlat, alt
```

The illumination angles we want are the outputs of `cspice_illum`. Units are radians.

```
cspice_ilumin, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
    point, trgepc, srfvec, phase, solar, emissn
```



Geometry Calculations: Summary

Navigation and Ancillary Information Facility

```
;; Compute the boresight ray intersection with the surface of the
;; target body.
```

```
cspice_sincpt, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
             iframe, insite, point, trgepc, srfvec, found
```

```
;; If an intercept is found, compute planetocentric and planetodetic
;; latitude and longitude of the point.
```

```
if ( found ) then begin
    cspice_reclat, point, r, pclon, pclat
    ;; Let re, rp, and f be the satellite's longer equatorial
    ;; radius, polar radius, and flattening factor.
    re = radii[0]
    rp = radii[2]
    f = ( re - rp ) / re;
    cspice_recgeo, point, re, f, pdlon, pdlat, alt
```

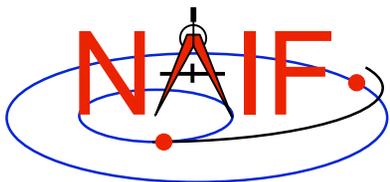
```
;; Compute illumination angles at the surface point.
```

```
cspice_ilumin, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
             point, trgepc, srfvec, phase, solar, emissn
```

```
...
```

```
endif else begin
```

```
...
```



Get inputs - 1

Navigation and Ancillary Information Facility

The code above used quite a few inputs that we don't have yet:

- TDB epoch of interest (`et`);
- satellite and s/c names (`satnm`, `scnm`);
- satellite body-fixed frame name (`fixref`);
- satellite ellipsoid radii (`radii`);
- instrument fixed frame name (`iframe`);
- instrument boresight vector in the instrument frame (`insite`);

Some of these values are user inputs; others can be obtained via CSPICE calls once the required kernels have been loaded.

Let's prompt for the satellite name (`satnm`), satellite frame name (`fixref`), spacecraft name (`scnm`), instrument name (`instnm`) and time of interest (`time`):

```
read, satnm , PROMPT='Enter satellite name > '  
read, fixref, PROMPT='Enter satellite frame > '  
read, scnm  , PROMPT='Enter spacecraft name > '  
read, instnm, PROMPT='Enter instrument name > '  
read, time  , PROMPT='Enter time > '
```



Get Inputs - 2

Navigation and Ancillary Information Facility

Then we can get the rest of the inputs from Icy calls:

To get the TDB epoch (**et**) from the user-supplied time string (which may refer to the UTC, TDB or TT time systems):

```
cspice_str2et, time, et
```

To get the satellite's ellipsoid radii (**radii**):

```
cspice_bodvrd, satnm, "RADII", 3, radii
```

To get the instrument boresight direction (**insite**) and the name of the instrument frame (**iframe**) in which it is defined:

```
cspice_bodn2c, instnm, instid, found
if ( NOT found ) then begin
    print, "Unable to determine ID for instrument: ", instnm
    return
endif
cspice_getfov, instid, ROOM, shape, iframe, insite, bundry
```



Getting inputs: summary

Navigation and Ancillary Information Facility

```
;; Prompt for the user-supplied inputs for our program
read, setupf, PROMPT='Enter setup file name > '
cspice_furnsh, setupf

read, satnm , PROMPT='Enter satellite name > '
read, fixref, PROMPT='Enter satellite frame > '
read, scnm  , PROMPT='Enter spacecraft name > '
read, instnm, PROMPT='Enter instrument name > '
read, time  , PROMPT='Enter time > '

;; Get the epoch corresponding to the input time:
cspice_str2et, time, et

;; Get the radii of the satellite.
cspice_bodvrd, satnm, "RADII", 3, radii

;; Get the instrument boresight and frame name.
cspice_bodn2c, instnm, instid, found
cspice_getfov, instid, ROOM, shape, iframe, insite, bundry
```

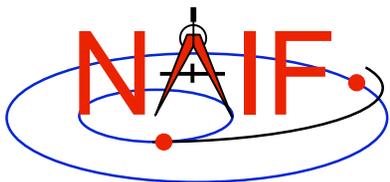


Display results

Navigation and Ancillary Information Facility

```
;; Display results. Convert angles from radians to degrees for output.
print
print, 'Intercept planetocentric longitude      (deg): ', $
                                         cspice_dpr()*pclon
print, 'Intercept planetocentric latitude      (deg): ', $
                                         cspice_dpr()*pclat
print, 'Intercept planetodetic longitude      (deg): ', $
                                         cspice_dpr()*pdlon
print, 'Intercept planetodetic latitude       (deg): ', $
                                         cspice_dpr()*pdlat
print, 'Range from spacecraft to intercept point (km): ', $
                                         cspice_vnorm(srfvec)
print, 'Intercept phase angle                 (deg): ', $
                                         cspice_dpr()*phase
print, 'Intercept solar incidence angle       (deg): ', $
                                         cspice_dpr()*solar
print, 'Intercept emission angle             (deg): ', $
                                         cspice_dpr()*emissn

endif else begin
  print, 'No intercept point found at ' + time
endif
END
```



Complete the program

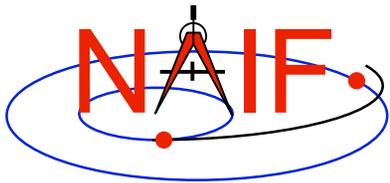
Navigation and Ancillary Information Facility

To finish up the program we need to declare the variables we've used.

- We'll highlight techniques used by NAIF programmers
- Add remaining IDL code required to make a syntactically valid program

```
PRO PROG_GEOMETRY

  ABCORR = 'CN+S'
  ROOM   = 10L
  setupf = ''
  satnm  = ''
  fixref = ''
  scnm   = ''
  instnm = ''
  time   = ''
  R2D    = cspice_dpr()
```



Complete source code -1

Navigation and Ancillary Information Facility

```
;; Prompt for the user-supplied inputs for our program.
read, setupf, PROMPT='Enter setup file name > '
cspice_furnsh, setupf
read, satnm, PROMPT='Enter satellite name > '
read, fixref, PROMPT='Enter satellite frame > '
read, scnm, PROMPT='Enter spacecraft name > '
read, instnm, PROMPT='Enter instrument name > '
read, time, PROMPT='Enter time > '

;; Get the epoch corresponding to the input time:
cspice_str2et, time, et

;; Get the radii of the satellite.
cspice_bodvrd, satnm, 'RADII', 3, radii

;; Get the instrument boresight and frame name.

cspice_bodn2c, instnm, instid, found
if ( NOT found ) then begin
    print, "Unable to determine ID for instrument: ", instnm
    return
endif
cspice_getfov, instid, ROOM, shape, iframe, insite, bundry
```



Complete source code -2

Navigation and Ancillary Information Facility

```
;; Compute the boresight ray intersection with the surface of the
;; target body.
cspice_sincpt, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
             iframe, insite, point, trgepc, srfvec, found

;; If an intercept is found, compute planetocentric and planetodetic
;; latitude and longitude of the point.
if ( found ) then begin
  cspice_reclat, point, r, pclon, pclat
  ;;Let re, rp, and f be the satellite's longer equatorial
  ;; radius, polar radius, and flattening factor.
  re = radii[0]
  rp = radii[2]
  f = ( re - rp ) / re
  cspice_recgeo, point, re, f, pdlon, pdlat, alt

  ;; Compute illumination angles at the surface point.
  cspice_ilumin, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
               point, trgepc, srfvec, phase, solar, emissn

  ;; Display results. Convert angles from radians to degrees
  ;; for output.
  print
  print, 'Intercept planetocentric longitude      (deg): ', $
        R2D*pclon
```



Complete source code -4

Navigation and Ancillary Information Facility

```
print, 'Intercept planetocentric latitude      (deg): ', $
      R2D*pclat
print, 'Intercept planetodetic longitude      (deg): ', $
      R2D*pdlon
print, 'Intercept planetodetic latitude       (deg): ', $
      R2D*pdlat
print, 'Range from spacecraft to intercept point (km): ', $
      cspice_vnorm(srfvec)
print, 'Intercept phase angle                 (deg): ', $
      R2D*phase
print, 'Intercept solar incidence angle       (deg): ', $
      R2D*solar
print, 'Intercept emission angle              (deg): ', $
      R2D*emissn

endif else begin
  print, 'No intercept point found at ' + time
endelse

;; Unload the kernels and clear the kernel pool
cspice_kclear
END
```



Compile the program

Navigation and Ancillary Information Facility

Though IDL functions in a manner similar to interpreted languages, it does compile source files to a binary form.

Ensure that both the Icy Toolkit, and an IDL installation are properly installed. IDL must load the Icy DLM, `icy.dlm/icy.so(dll)` to compile those scripts containing Icy calls. IDL loads DLMS from default locations and from the current directory when the user ran IDL. The user may also explicitly load a DLM with the `dml_register` command.

Now compile the code.



Compile and link the program - 2

Navigation and Ancillary Information Facility

A screenshot of a terminal window titled "Terminal Window". The window has a standard OS-style title bar with a close button in the top right corner. The terminal content shows the execution of an IDL command to compile a program.

```
IDL> .compile prog_geometry.pro  
% Compiled module: PROG_GEOMETRY.
```

The terminal window also features a vertical scrollbar on the left side and two arrow buttons (down and up) at the bottom left corner.



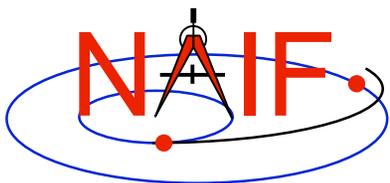
Running the program

Navigation and Ancillary Information Facility

It looks like we have everything taken care of:

- We have all necessary kernels
- We made a setup file (metakernel) pointing to them
- We wrote the program
- We compiled the program

Let's run it.



Running the program

Navigation and Ancillary Information Facility

```
Terminal Window

IDL>  prog_geometry
Enter setup file name > setup.ker
Enter satellite name > PHOEBE
Enter satellite frame > IAU_PHOEBE
Enter spacecraft name > CASSINI
Enter instrument name > CASSINI_ISS_NAC
Enter time             > 2004 jun 11 19:32:00

Intercept planetocentric longitude      (deg):      39.843719
Intercept planetocentric latitude       (deg):      4.1958778
Intercept planetodetic longitude        (deg):      39.843719
Intercept planetodetic latitude         (deg):      5.0480106
Range from spacecraft to intercept point (km):    2089.1697
Intercept phase angle                   (deg):      28.139479
Intercept solar incidence angle         (deg):      18.247220
Intercept emission angle                (deg):      17.858309
```

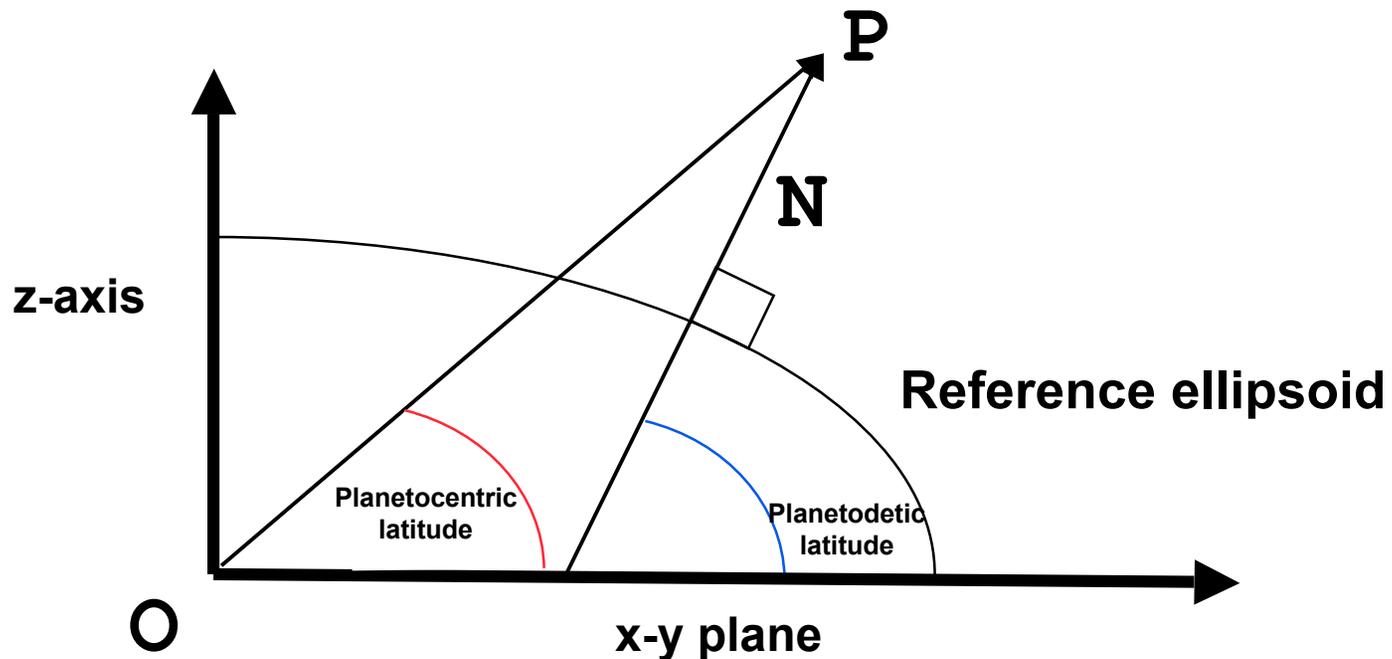


Backup

Navigation and Ancillary Information Facility

- **Latitude definitions:**

- Planetocentric latitude of a point P: angle between segment from origin to point and x-y plane (red arc in diagram).
- Planetodetic latitude of a point P: angle between x-y plane and extension of ellipsoid normal vector N that connects x-y plane and P (blue arc in diagram).

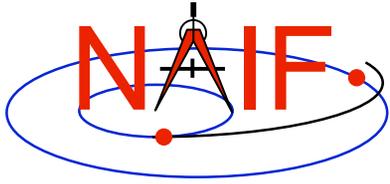




Navigation and Ancillary Information Facility

Writing an Mice (MATLAB) Based Program

January 2009



Viewing This Tutorial

Navigation and Ancillary Information Facility

Undefined variables are displayed in red; results are displayed in blue.



Introduction

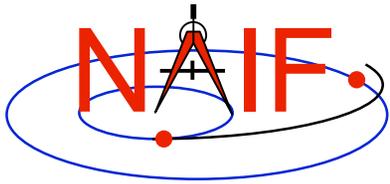
Navigation and Ancillary Information Facility

First, let's go over the important steps in the process of writing a Mice-based program and putting it to work:

- **Understand the geometry problem.**
- **Identify the set of SPICE kernels that contain the data needed to perform the computation.**
- **Formulate an algorithm to compute the quantities of interest using SPICE.**
- **Write and compile the program.**
- **Get actual kernel files and verify that they contain the data needed to support the computation for the time(s) of interest.**
- **Run the program.**

To illustrate these steps, let's write a program that computes the apparent intersection of the boresight ray of a given CASSINI science instrument with the surface of a given Saturnian satellite. The program will compute:

- **Planetocentric and planetodetic (geodetic) latitudes and longitudes of the intercept point.**
- **Range from spacecraft to intercept point.**
- **Illumination angles (phase, solar incidence, and emission) at the intercept point.**



Observation geometry

Navigation and Ancillary Information Facility

We want the boresight intercept on the surface, range from s/c to intercept, and illumination angles at the intercept point.

When? **TIME (UTC, TDB or TT)**

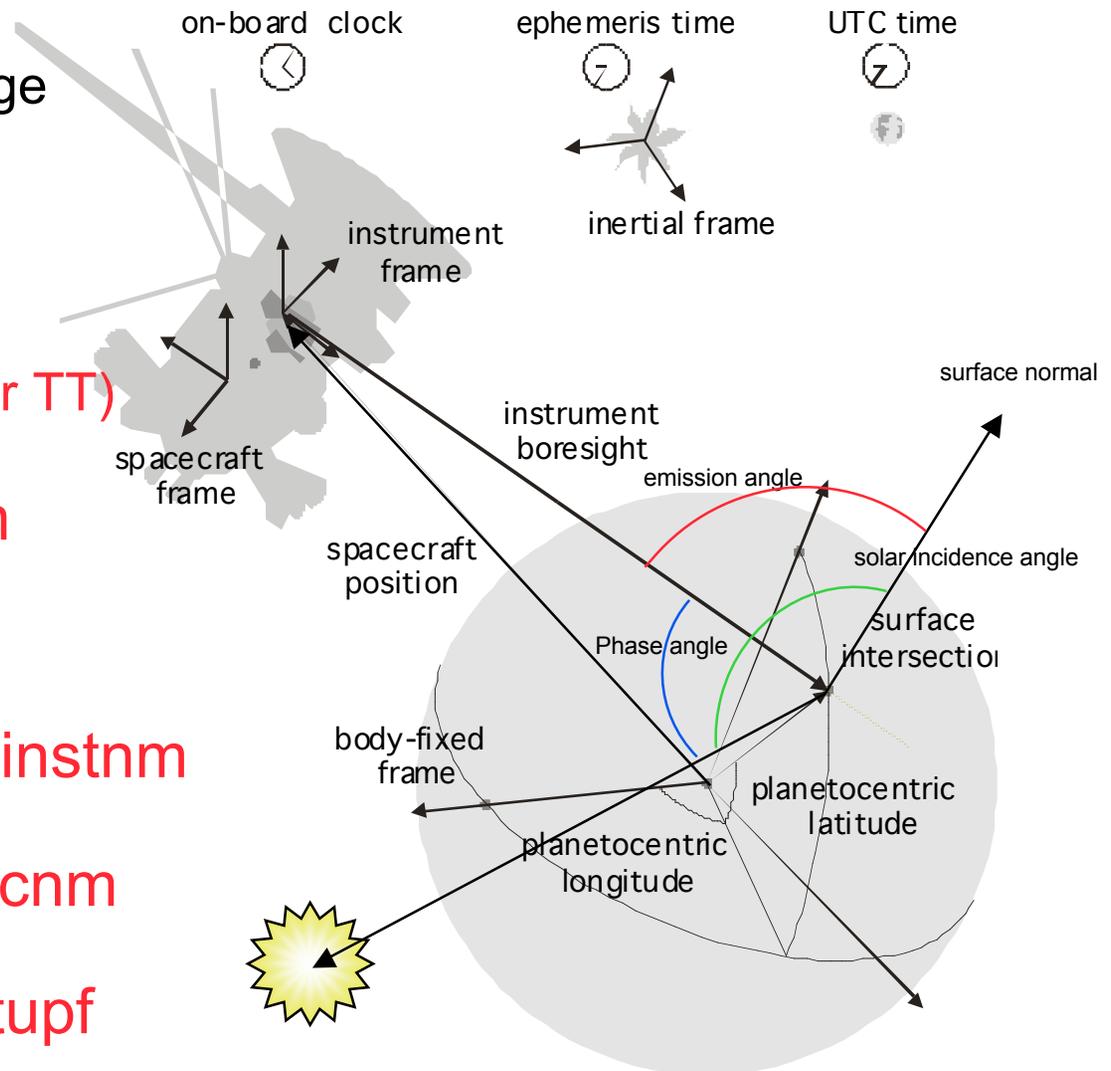
On what object? **satnm**

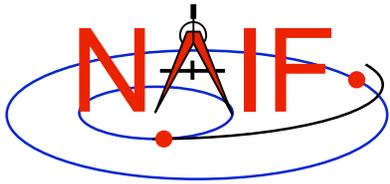
In what frame? **fixref**

For which instrument? **instnm**

For what spacecraft? **scnm**

Using what model? **setupf**





Needed Data

Navigation and Ancillary Information Facility

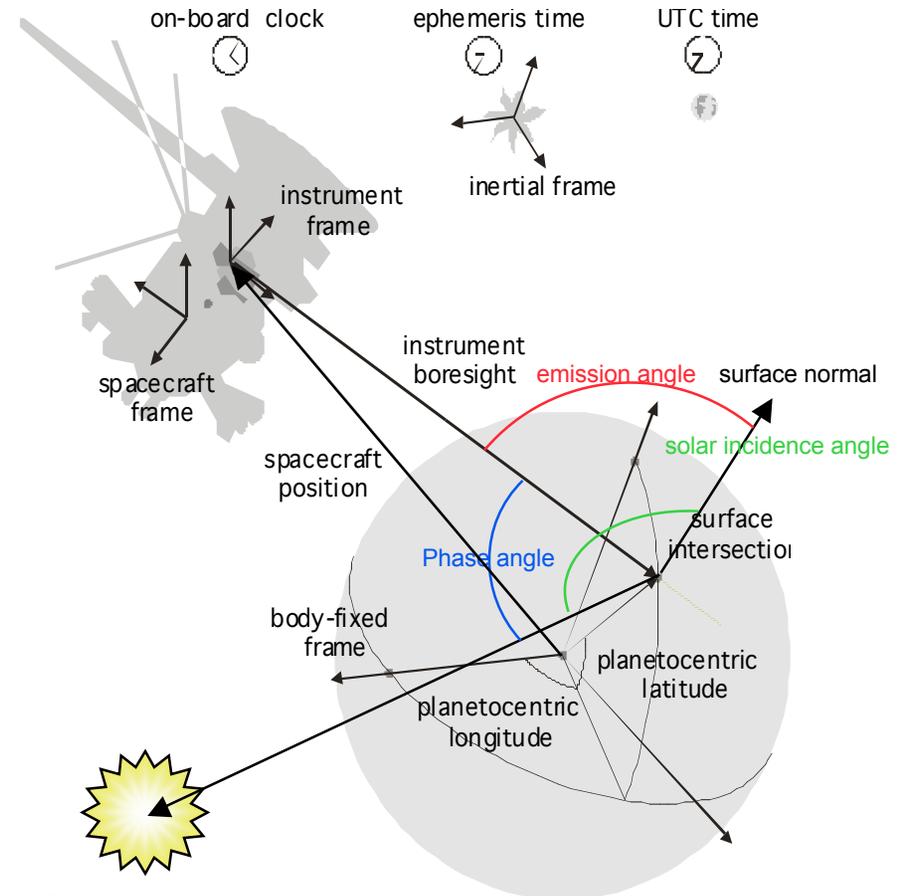
Time transformation kernels

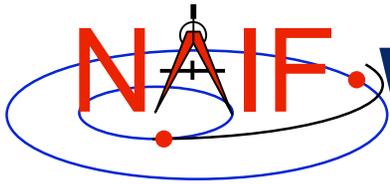
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





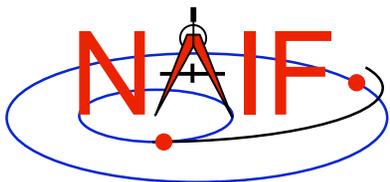
Which Kinds of Kernels are Needed?

Navigation and Ancillary Information Facility

Data required to compute vectors, rotations and other parameters shown in the picture are stored in the SPICE kernels listed below.

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

| Parameter | Kernel Type | File name |
|----------------------------|-----------------------------|------------------------------|
| time conversions | generic LSK
CASSINI SCLK | naif0008.tls
cas00084.tsc |
| satellite orientation | CASSINI PCK | cpck05Mar2004.tpc |
| satellite shape | CASSINI PCK | cpck05Mar2004.tpc |
| satellite position | planet/sat
ephemeris SPK | 020514_SE_SAT105.bsp |
| planet barycenter position | planet SPK | 981005_PLTEPH-DE405S.bsp |
| spacecraft position | spacecraft SPK | 030201AP_SK_SM546_T45.bsp |
| spacecraft orientation | spacecraft CK | 04135_04171pc_psiv2.bc |
| instrument alignment | CASSINI FK | cas_v37.tf |
| instrument boresight | Instrument IK | cas_iss_v09.ti |



Load kernels

Navigation and Ancillary Information Facility

The easiest and most flexible way to make these kernels available to the program is via `cspice_furnsh`. For this example we make a setup file (also called a “metakernel” or “furnsh kernel”) containing a list of kernels to be loaded:

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

```
\begindata
```

```
KERNELS_TO_LOAD = ('naif0008.tls', 'cas00084.tsc', 'cpck05Mar2004.tpc',  
                   '020514_SE_SAT105.bsp', '981005_PLTEPH-DE405S.bsp',  
                   '030201AP_SK_SM546_T45.bsp', '04135_04171pc_psiv2.bc',  
                   'cas_v37.tf', 'cas_iss_v09.ti')
```

```
\begintext
```

and we make the program prompt for the name of this setup file:

```
setupf = input('Enter setup file name > ', 's');  
cspice_furnsh( setupf )
```



Programming Solution

Navigation and Ancillary Information Facility

- **Prompt for setup file (“metakernel”) name; load kernels specified via setup file. (Done on previous chart.)**
- **Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via Mice calls.**
- **Compute the intersection of the boresight direction ray with the surface of the satellite, presented as a triaxial ellipsoid.**
- **If there is an intersection:**
 - **Convert Cartesian coordinates of the intersection point to planetocentric latitudinal and planetodetic coordinates**
 - **Compute spacecraft-to-intercept point range**
 - **Find the illumination angles (phase, solar incidence, and emission) at the intercept point**
- **Display the results.**

We discuss the geometric portion of the problem first.



Compute surface intercept

Navigation and Ancillary Information Facility

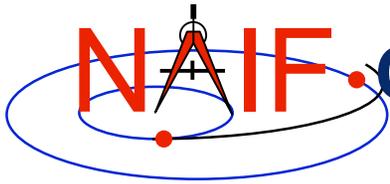
Compute the intercept point (`point`) of the boresight vector (`insite`) specified in the instrument frame (`iframe`) of the instrument mounted on the spacecraft (`scnm`) with the surface of the satellite (`satnm`) at the TDB time of interest (`et`) in the satellite's body-fixed frame (`fixref`). This call also returns the light-time corrected epoch at the intercept point (`trgepc`), the spacecraft-to-intercept point vector (`srfvec`), and a flag indicating whether the intercept was found (`found`). We use "converged Newtonian" light time plus stellar aberration corrections to produce the most accurate surface intercept solution possible. We model the surface of the satellite as an ellipsoid.

```
[point, trgepc, srfvec, found] = cspice_sincpt( ...  
    'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, iframe, insite );
```

The range we want is obtained from the outputs of `cspice_sincpt`. These outputs are defined only if a surface intercept is found. If `found` is true, the spacecraft-to-surface intercept range is the norm of the output argument `srfvec`. Units are km. We use the MATLAB function `norm` to obtain the norm:

```
norm( srfvec )
```

We'll write out the range data along with the other program results.



Compute Lat/Lon and Illumination Angles

Navigation and Ancillary Information Facility

Compute the planetocentric latitude (`pclat`) and longitude (`pclon`), as well as the planetodetic latitude (`pdlat`) and longitude (`pdlon`) of the intersection point.

```
if ( found )
    [r, pclon, pclat] = cspice_reclat( point );

    % Let re, rp, and f be the satellite's longer equatorial
    % radius, polar radius, and flattening factor.
    re = radii(1);
    rp = radii(3);
    f = ( re - rp ) / re;

    [pdlat, pdlon, alt] = cspice_recgeo( point, re, f );
```

The illumination angles we want are the outputs of `cspice_ilumin`. Units are radians.

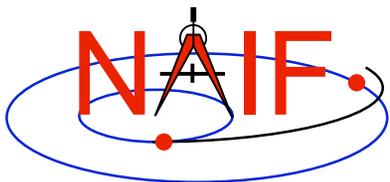
```
[trgepc, srfvec, phase, solar, emissn] = cspice_ilumin( ...
    'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, point );
```



Geometry Calculations: Summary

Navigation and Ancillary Information Facility

```
% Compute the boresight ray intersection with the surface of the
% target body.
[point, trgepc, srfvec, found] = cspice_sincpt( ...
    'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, iframe, insite );
% If an intercept is found, compute planetocentric and planetodetic
% latitude and longitude of the point.
if ( found )
    [r, pclon, pclat] = cspice_reclat( point );
    % Let re, rp, and f be the satellite's longer equatorial
    % radius, polar radius, and flattening factor.
    re = radii(1);
    rp = radii(3);
    f = ( re - rp ) / re;
    [pdlon, pdlat, alt] = cspice_recgeo( point, re, f );
    % Compute illumination angles at the surface point.
    [trgepc, srfvec, phase, solar, emissn] = cspice_ilumin( ...
        'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, point );
    ...
else
    ...
```



Get inputs - 1

Navigation and Ancillary Information Facility

The code above used quite a few inputs that we don't have yet:

- TDB epoch of interest (`et`);
- satellite and s/c names (`satnm`, `scnm`);
- satellite body-fixed frame name (`fixref`);
- satellite ellipsoid radii (`radii`);
- instrument fixed frame name (`iframe`);
- instrument boresight vector in the instrument frame (`insite`);

Some of these values are user inputs; others can be obtained via CSPICE calls once the required kernels have been loaded.

Let's prompt for the satellite name (`satnm`), satellite frame name (`fixref`), spacecraft name (`scnm`), instrument name (`instnm`) and time of interest (`time`):

```
satnm = input( 'Enter satellite name > ', 's');
fixref = input( 'Enter satellite frame > ', 's');
scnm   = input( 'Enter spacecraft name > ', 's');
instnm = input( 'Enter instrument name > ', 's');
time   = input( 'Enter time                > ', 's');
```



Get Inputs - 2

Navigation and Ancillary Information Facility

Then we can get the rest of the inputs from Mice calls:

To get the TDB epoch (`et`) from the user-supplied time string (which may refer to the UTC, TDB or TT time systems):

```
et = cspice_str2et( time );
```

To get the satellite's ellipsoid radii (`radii`):

```
radii = cspice_bodvrd( satnm, 'RADII', 3 );
```

To get the instrument boresight direction (`insite`) and the name of the instrument frame (`iframe`) in which it is defined:

```
[instid, found] = cspice_bodn2c( instnm );  
if ( ~found )  
    txt = sprintf( 'Unable to determine ID for instrument: %d', ...  
                  instnm );  
    error(txt)  
end  
  
[shape, iframe, insite, bundry] = cspice_getfov( instid, ROOM );
```



Getting inputs: summary

Navigation and Ancillary Information Facility

```
% Prompt for the user-supplied inputs for our program.
setupf = input( 'Enter setup file name > ', 's' );
cspice_furnsh( setupf )
satnm   = input( 'Enter satellite name   > ', 's' );
fixref  = input( 'Enter satellite frame > ', 's' );
scnm   = input( 'Enter spacecraft name > ', 's' );
instnm  = input( 'Enter instrument name > ', 's' );
time   = input( 'Enter time               > ', 's' );

% Get the epoch corresponding to the input time:
et = cspice_str2et( time );

% Get the radii of the satellite.
radii = cspice_bodvrd( satnm, 'RADII', 3 );

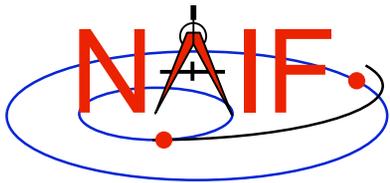
% Get the instrument boresight and frame name.
[instid, found] = cspice_bodn2c( instnm );
if ( ~found )
    txt = sprintf( 'Unable to determine ID for instrument: %d', ...
                  instnm );
    error(txt)
end
[shape, iframe, insite, bundry] = cspice_getfov( instid, ROOM );
```



Display results

Navigation and Ancillary Information Facility

```
...
% Display results. Convert angles from radians to degrees
% for output.
fprintf( 'Intercept planetocentric longitude      (deg): %11.6f\n', ...
        R2D*pclon )
fprintf( 'Intercept planetocentric latitude      (deg): %11.6f\n', ...
        R2D*pclat )
fprintf( 'Intercept planetodetic longitude       (deg): %11.6f\n', ...
        R2D*pdlon )
fprintf( 'Intercept planetodetic latitude        (deg): %11.6f\n', ...
        R2D*pdlat )
fprintf( 'Range from spacecraft to intercept point (km): %11.6f\n', ...
        norm(srfvec) )
fprintf( 'Intercept phase angle                  (deg): %11.6f\n', ...
        R2D*phase )
fprintf( 'Intercept solar incidence angle        (deg): %11.6f\n', ...
        R2D*solar )
fprintf( 'Intercept emission angle              (deg): %11.6f\n', ...
        R2D*emissn )
else
    disp( ['No intercept point found at ' time ] )
end
```



Complete the program

Navigation and Ancillary Information Facility

To finish up the program we need to declare the variables we've used.

- We'll highlight techniques used by NAIF programmers
- Add remaining MATLAB code required to make a syntactically valid program

```
ABCORR = 'CN+S';  
ROOM   = 10;  
R2D    = cspice_dpr;  
  
% Prompt for the user-supplied inputs for our program.  
setupf = input( 'Enter setup file name > ', 's' );  
cspice_furnsh( setupf )  
  
satnm  = input( 'Enter satellite name > ', 's' );  
fixref = input( 'Enter satellite frame > ', 's' );  
scnm   = input( 'Enter spacecraft name > ', 's' );  
instnm = input( 'Enter instrument name > ', 's' );  
time   = input( 'Enter time > ', 's' );
```



Complete source code - 1

Navigation and Ancillary Information Facility

```
% Get the epoch corresponding to the input time:
et = cspice_str2et( time );

% Get the radii of the satellite.
radii = cspice_bodvrd( satnm, 'RADII', 3 );

% Get the instrument boresight and frame name.
[instid, found] = cspice_bodn2c( instnm );

if ( ~found )
    txt = sprintf( 'Unable to determine ID for instrument: %d', ...
                  instnm );
    error(txt)
end

[shape, iframe, insite, bundry] = cspice_getfov( instid, ROOM );
```



Complete source code - 2

Navigation and Ancillary Information Facility

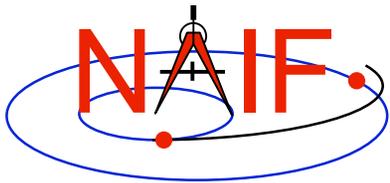
```
% Compute the boresight ray intersection with the surface of the
% target body.
[point, trgepc, srfvec, found] = cspice_sincpt( ...
    'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, iframe, insite );

% If an intercept is found, compute planetocentric and planetodetic
% latitude and longitude of the point.
if ( found )
    [r, pclon, pclat] = cspice_reclat( point );

    % Let re, rp, and f be the satellite's longer equatorial
    % radius, polar radius, and flattening factor.
    re = radii(1);
    rp = radii(3);
    f = ( re - rp ) / re;

    [pdlon, pdlat, alt] = cspice_recgeo( point, re, f );

    % Compute illumination angles at the surface point.
    [trgepc, srfvec, phase, solar, emissn] = cspice_ilumin( ...
        'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, point );
```



Complete source code - 3

Navigation and Ancillary Information Facility

```
% Display results.  Convert angles from radians to degrees
% for output.
fprintf( 'Intercept planetocentric longitude      (deg):  %11.6f\n', ...
        R2D*pclon )
fprintf( 'Intercept planetocentric latitude      (deg):  %11.6f\n', ...
        R2D*pclat )
fprintf( 'Intercept planetodetic longitude      (deg):  %11.6f\n', ...
        R2D*pdlon )
fprintf( 'Intercept planetodetic latitude      (deg):  %11.6f\n', ...
        R2D*pdlat )
fprintf( 'Range from spacecraft to intercept point (km): %11.6f\n', ...
        norm(srfvec) )
fprintf( 'Intercept phase angle                (deg):  %11.6f\n', ...
        R2D*phase )
fprintf( 'Intercept solar incidence angle      (deg):  %11.6f\n', ...
        R2D*solar )
fprintf( 'Intercept emission angle            (deg):  %11.6f\n', ...
        R2D*emissn )

else
    disp( ['No intercept point found at ' time ]
end

% Unload the kernels and clear the kernel pool
cspice_kclear
```



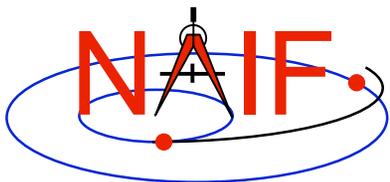
Running the program

Navigation and Ancillary Information Facility

It looks like we have everything taken care of:

- We have all necessary kernels
- We made a setup file (metakernel) pointing to them
- We wrote the program

Let's run it.



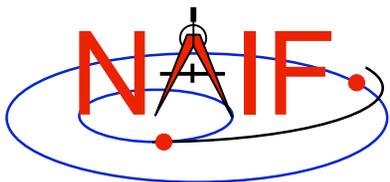
Running the program

Navigation and Ancillary Information Facility

```
Terminal Window

>> prog_geometry
Enter setup file name > setup.ker
Enter satellite name > PHOEBE
Enter satellite frame > IAU_PHOEBE
Enter spacecraft name > CASSINI
Enter instrument name > CASSINI_ISS_NAC
Enter time > 2004 jun 11 19:32:00

Intercept planetocentric longitude (deg): 39.843719
Intercept planetocentric latitude (deg): 4.195878
Intercept planetodetic longitude (deg): 39.843719
Intercept planetodetic latitude (deg): 5.048011
Range from spacecraft to intercept point (km): 2089.169724
Intercept phase angle (deg): 28.139479
Intercept solar incidence angle (deg): 18.247220
Intercept emission angle (deg): 17.858309
```

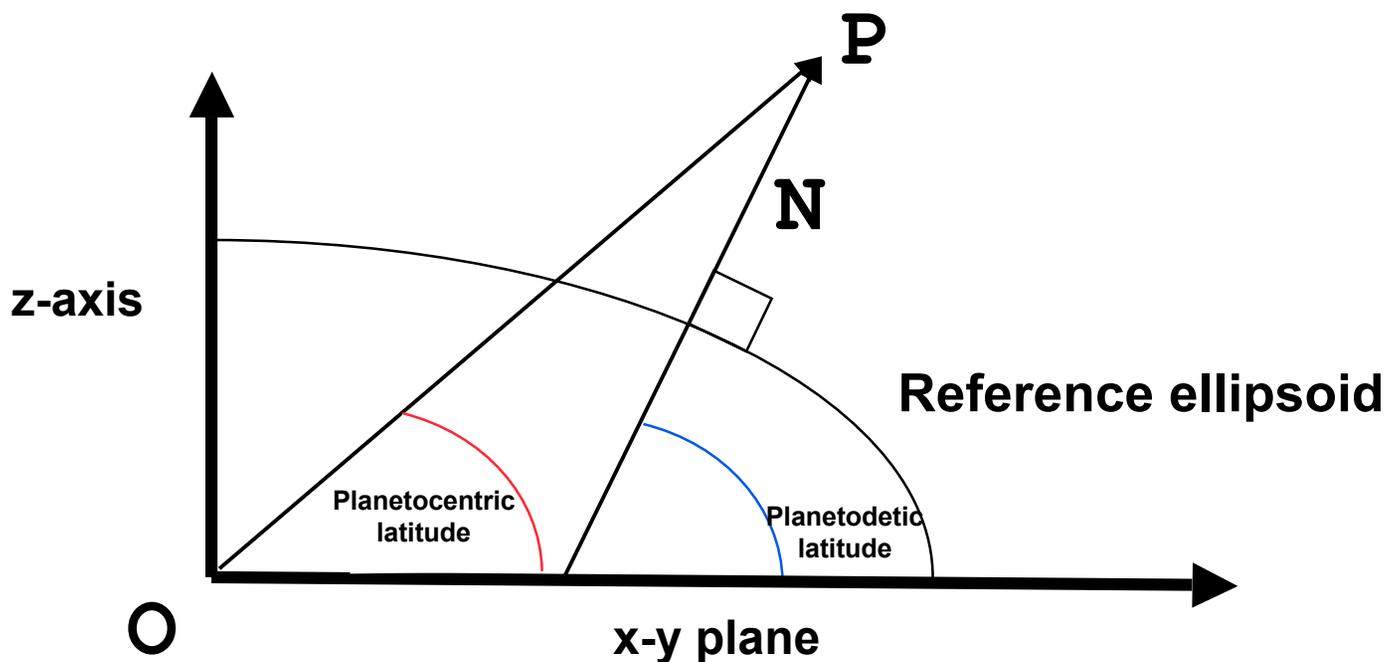


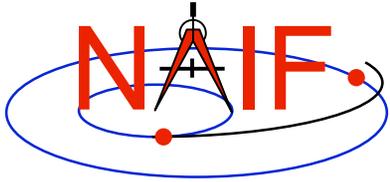
Backup

Navigation and Ancillary Information Facility

- **Latitude definitions:**

- Planetocentric latitude of a point P: angle between segment from origin to point and x-y plane (red arc in diagram).
- Planetodetic latitude of a point P: angle between x-y plane and extension of ellipsoid normal vector N that connects x-y plane and P (blue arc in diagram).





Navigation and Ancillary Information Facility

Writing a CSPICE (C) Based Program

January 2009



Viewing This Tutorial

Navigation and Ancillary Information Facility

Undefined variables are displayed in red; results are displayed in blue.



Introduction

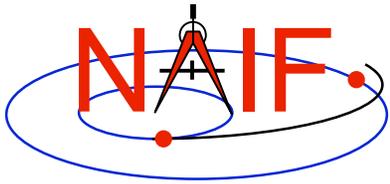
Navigation and Ancillary Information Facility

First, let's go over the important steps in the process of writing a CSPICE-based program and putting it to work:

- **Understand the geometry problem.**
- **Identify the set of SPICE kernels that contain the data needed to perform the computation.**
- **Formulate an algorithm to compute the quantities of interest using SPICE.**
- **Write and compile the program.**
- **Get actual kernel files and verify that they contain the data needed to support the computation for the time(s) of interest.**
- **Run the program.**

To illustrate these steps, let's write a program that computes the apparent intersection of the boresight ray of a given CASSINI science instrument with the surface of a given Saturnian satellite. The program will compute

- **Planetocentric and planetodetic (geodetic) latitudes and longitudes of the intercept point.**
- **Range from spacecraft to intercept point and from spacecraft to target center.**
- **Illumination angles (phase, solar incidence, and emission) at the intercept point.**



Observation geometry

Navigation and Ancillary Information Facility

We want the boresight intercept on the surface, range from s/c to intercept, and illumination angles at the intercept point.

When? **TIME (UTC, TDB or TT)**

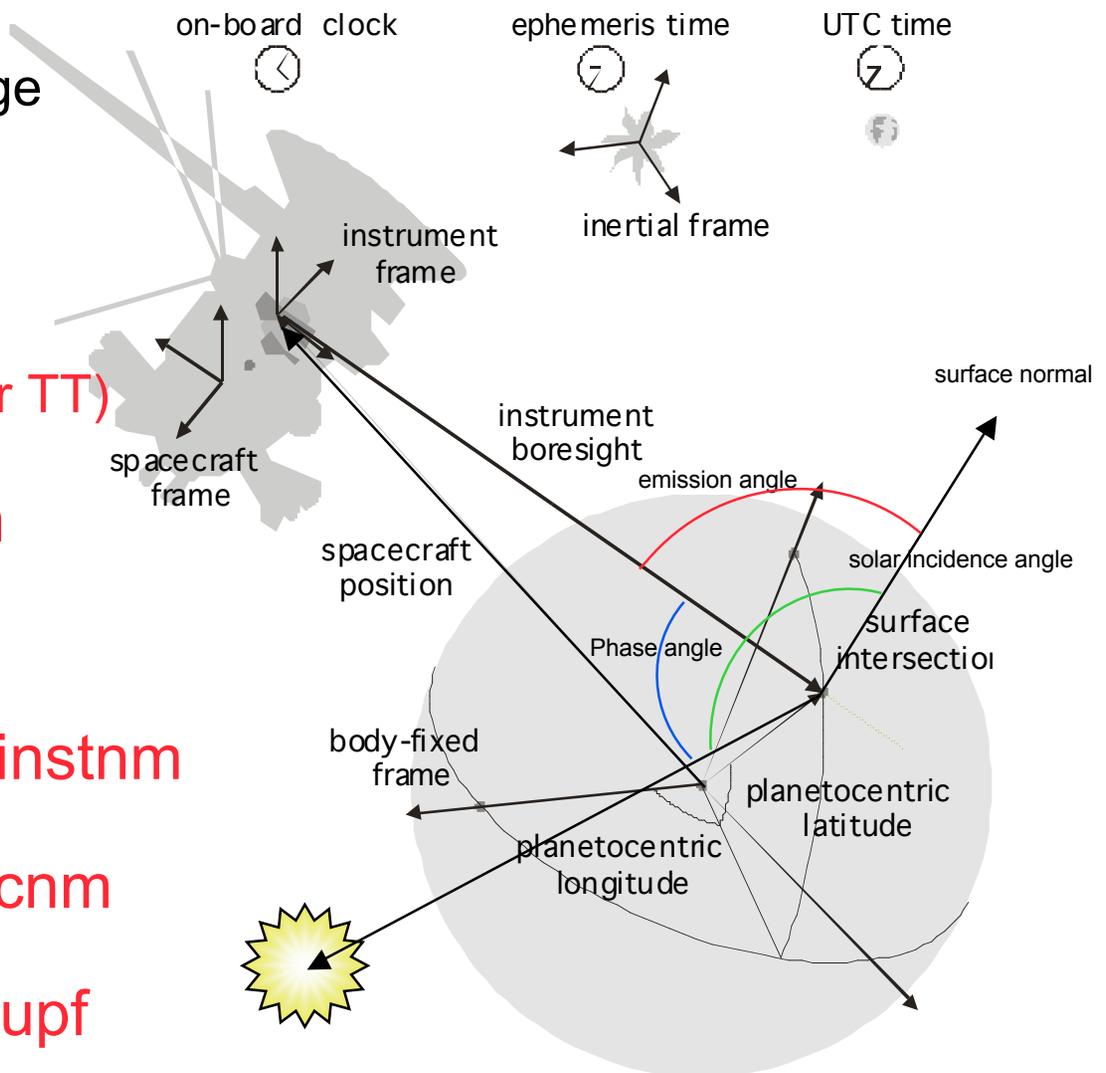
On what object? **satnm**

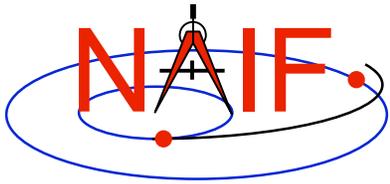
In what frame? **fixref**

For which instrument? **instnm**

For what spacecraft? **scnm**

Using what model? **setupf**





Needed Data

Navigation and Ancillary Information Facility

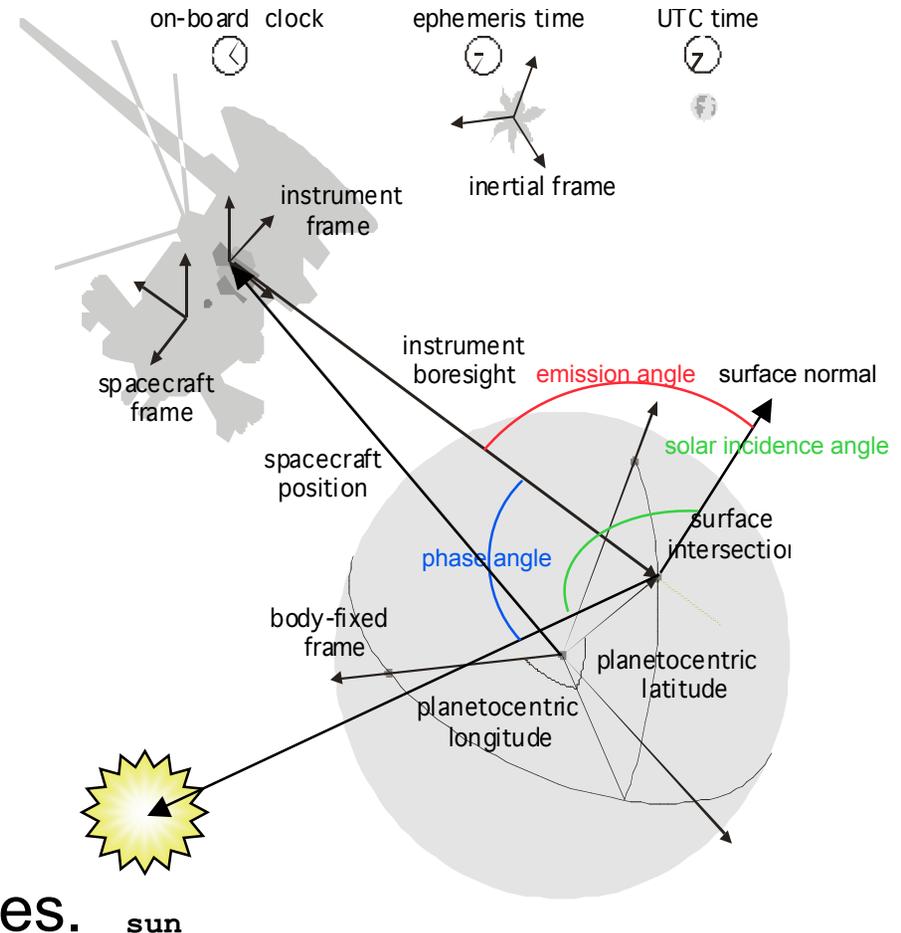
Time transformation kernels

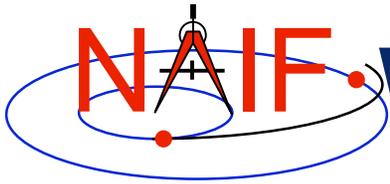
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





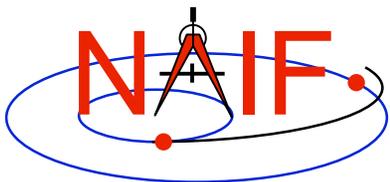
Which Kinds of Kernels are Needed?

Navigation and Ancillary Information Facility

Data required to compute vectors, rotations and other parameters shown in the picture are stored in the SPICE kernels listed below.

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

| Parameter | Kernel Type | File name |
|----------------------------|-----------------------------|------------------------------|
| time conversions | generic LSK
CASSINI SCLK | naif0008.tls
cas00084.tsc |
| satellite orientation | CASSINI PCK | cpck05Mar2004.tpc |
| satellite shape | CASSINI PCK | cpck05Mar2004.tpc |
| satellite position | planet/sat
ephemeris SPK | 020514_SE_SAT105.bsp |
| planet barycenter position | planet SPK | 981005_PLTEPH-DE405S.bsp |
| spacecraft position | spacecraft SPK | 030201AP_SK_SM546_T45.bsp |
| spacecraft orientation | spacecraft CK | 04135_04171pc_psiv2.bc |
| instrument alignment | CASSINI FK | cas_v37.tf |
| instrument boresight | Instrument IK | cas_iss_v09.ti |



Load Kernels

Navigation and Ancillary Information Facility

The easiest and most flexible way to make required kernels available to the program is via `furnsh_c`. For this example we make a setup file (also called a “metakernel” or “furnsh kernel”) containing a list of kernels to be loaded:

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

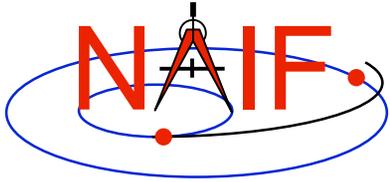
```
\begindata
```

```
KERNELS_TO_LOAD = ('naif0008.tls', 'cas00084.tsc', 'cpck05Mar2004.tpc',  
                    '020514_SE_SAT105.bsp', '981005_PLTEPH-DE405S.bsp',  
                    '030201AP_SK_SM546_T45.bsp', '04135_04171pc_psiv2.bc',  
                    'cas_v37.tf', 'cas_iss_v09.ti')
```

```
\begintext
```

and we make the program prompt for the name of this setup file:

```
prompt_c ( "Enter setup file name > ", FILESZ, setupf );  
furnsh_c ( setupf );
```



Programming Solution

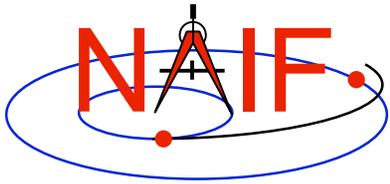
Navigation and Ancillary Information Facility

- Prompt for setup file (“metakernel”) name; load kernels specified via setup file. (Done on previous chart.)
- Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via CSPICE calls.
- Compute the intersection of the boresight direction ray with the surface of the satellite, presented as a triaxial ellipsoid.

If there is an intersection,

- Convert Cartesian coordinates of the intercept point to planetocentric latitudinal and planetodetic coordinates
 - Compute spacecraft-to-intercept point range
 - Find the illumination angles (phase, solar incidence, and emission) at the intercept point
- Display the results.

We discuss the geometric portion of the problem next.



Compute Surface Intercept and Ranges

Navigation and Ancillary Information Facility

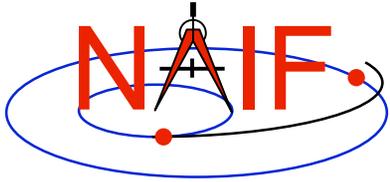
Compute the intercept point (`point`) of the boresight vector (`insite`) specified in the instrument frame (`iframe`) of the instrument mounted on the spacecraft (`scnm`) with the surface of the satellite (`satnm`) at the TDB time of interest (`et`) in the satellite's body-fixed frame (`fixref`). This call also returns the light-time corrected epoch at the intercept point (`trgepc`), the spacecraft-to-intercept point vector (`srfvec`), and a boolean flag indicating whether the intercept was found (`found`). We use "converged Newtonian" light time plus stellar aberration corrections to produce the most accurate surface intercept solution possible. We model the surface of the satellite as an ellipsoid.

```
sincpt_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, iframe, insite,  
          point, &trgepc, srfvec, &found );
```

The range we want is obtained from the outputs of `sincpt_c`. These outputs are defined only if a surface intercept is found. If `found` is true, the spacecraft-to-surface intercept range is the norm of the output argument `srfvec`. Units are km. We use the CSPICE function `vnorm_c` to obtain the norm:

```
vnorm_c ( srfvec )
```

We'll write out the range data along with the other program results.



Compute Lat/Lon and Illumination Angles

Navigation and Ancillary Information Facility

Compute the planetocentric latitude (`pclat`) and longitude (`pclon`), as well as the planetodetic latitude (`pdlat`) and longitude (`pdlon`) of the intersection point.

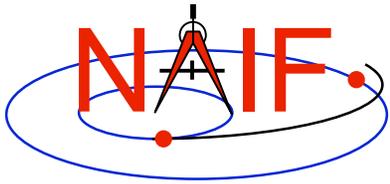
```
if ( found )
{
    reclat_c ( point, &r, &pclon, &pclat );

    /* Let re, rp, and f be the satellite's longer equatorial
       radius, polar radius, and flattening factor. */
    re = radii[0];
    rp = radii[2];
    f = ( re - rp ) / re;

    recgeo_c ( point, re, f, &pdlon, &pdlat, &alt);
}
```

The illumination angles we want are the outputs of `ilumin_c`. Units are radians.

```
ilumin_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, point,
          &trgepc, srfvec, &phase, &solar, &emissn );
```



Geometry Calculations: Summary

Navigation and Ancillary Information Facility

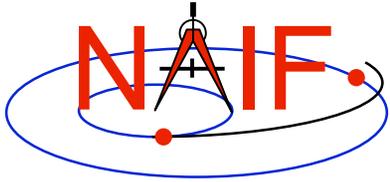
```
/* Compute the boresight ray intersection with the surface of the
   satellite. */

sincpt_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm,
           iframe, insite, point, &trgepc, srfvec, &found );

/* If an intercept is found, compute planetocentric and planetodetic
   latitude and longitude of the point. */

if ( found )
{
    reclat_c ( point, &r, &pclon, &pclat );
    /* Let re, rp, and f be the satellite's longer equatorial
       radius, polar radius, and flattening factor. */
    re = radii[0];
    rp = radii[2];
    f = ( re - rp ) / re;
    recgeo_c ( point, re, f, &pdlon, &pdlat, &alt );

    /* Compute illumination angles at the surface point. */
    ilumin_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, point,
              &trgepc, srfvec, &phase, &solar, &emissn );
    ...
}
else
{ ... }
```



Get Inputs - 1

Navigation and Ancillary Information Facility

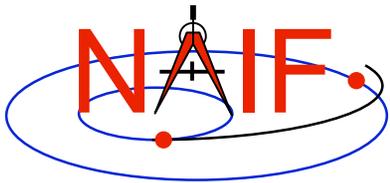
The code above used quite a few inputs that we don't have yet:

- TDB epoch of interest (`et`);
- satellite and s/c names (`satnm`, `scnm`);
- satellite body-fixed frame name (`fixref`);
- satellite ellipsoid radii (`radii`);
- instrument fixed frame name (`iframe`);
- instrument boresight vector in the instrument frame (`insite`);

Some of these values are user inputs; others can be obtained via CSPICE calls once the required kernels have been loaded.

Let's prompt for the satellite name (`satnm`), satellite frame name (`fixref`), spacecraft name (`scnm`), instrument name (`instnm`) and time of interest (`time`):

```
prompt_c ( "Enter satellite name > ", WORDSZ, satnm );
prompt_c ( "Enter satellite frame > ", WORDSZ, fixref );
prompt_c ( "Enter spacecraft name > ", WORDSZ, scnm );
prompt_c ( "Enter instrument name > ", WORDSZ, instnm );
prompt_c ( "Enter time > ", WORDSZ, time );
```



Get Inputs - 2

Navigation and Ancillary Information Facility

Then we can get the rest of the inputs from CSPICE calls:

To get the TDB epoch (**et**) from the user-supplied time string (which may refer to the UTC, TDB or TT time systems):

```
str2et_c ( time, &et );
```

To get the satellite's ellipsoid radii (**radii**):

```
bodvrd_c ( satnm, "RADII", 3, &i, radii );
```

To get the instrument boresight direction (**insite**) and the name of the instrument frame (**iframe**) in which it is defined:

```
bodn2c_c ( instnm, &instid, &found );

if ( !found )
{
    setmsg_c ( "Instrument name # could not be "
              "translated to an ID code."      );
    errch_c ( "#", instnm                       );
    sigerr_c ( "NAMENOTFOUND"                   );
}
getfov_c ( instid, ROOM, WORDSZ, WORDSZ,
           shape, iframe, insite, &n, bundry );
```



Getting Inputs: Summary

Navigation and Ancillary Information Facility

```
/* Prompt for the user-supplied inputs for our program      */
prompt_c ( "Enter setup file name > ", FILESZ, setupf );
furnsh_c ( setupf );
prompt_c ( "Enter satellite name > ", WORDSZ, satnm );
prompt_c ( "Enter satellite frame > ", WORDSZ, fixref );
prompt_c ( "Enter spacecraft name > ", WORDSZ, scnm );
prompt_c ( "Enter instrument name > ", WORDSZ, instnm );
prompt_c ( "Enter time                > ", WORDSZ, time );

/* Get the epoch corresponding to the input time: */
str2et_c ( time, &et );

/* Get the radii of the satellite. */
bodvrd_c ( satnm, "RADII", 3, &i, radii );

/* Get the instrument boresight and frame name. */
bodn2c_c ( instnm, &instid, &found );
if ( !found )
{
    setmsg_c ( "Instrument name # could not be "
              "translated to an ID code." );
    errch_c ( "#", instnm );
    sigerr_c ( "NAMENOTFOUND" );
}
getfov_c ( instid, ROOM, WORDSZ, WORDSZ,
           shape, iframe, insite, &n, bundry );
```



Display Results

Navigation and Ancillary Information Facility

```
/* Display results. Convert angles from radians to degrees for output. */
printf ( "\n"
        "Intercept planetocentric longitude      (deg):  %11.6f\n"
        "Intercept planetocentric latitude       (deg):  %11.6f\n"
        "Intercept planetodetic longitude         (deg):  %11.6f\n"
        "Intercept planetodetic latitude         (deg):  %11.6f\n"
        "Range from spacecraft to intercept point (km):  %11.6f\n"
        "Intercept phase angle                     (deg):  %11.6f\n"
        "Intercept solar incidence angle          (deg):  %11.6f\n"
        "Intercept emission angle                 (deg):  %11.6f\n",
        dpr_c() * pclon,
        dpr_c() * pclat,
        dpr_c() * pdlon,
        dpr_c() * pdlat,
        vnorm_c( srfvec ),
        dpr_c() * phase,
        dpr_c() * solar,
        dpr_c() * emissn
    );
}
else
{
    printf ( "No intercept point found at %s\n", time );
}
```



Complete the Program

Navigation and Ancillary Information Facility

To finish up the program we need to declare the variables we've used.

- We'll highlight techniques used by NAIF programmers
- Add remaining C code required to make a syntactically valid program



Complete Source Code - 1

Navigation and Ancillary Information Facility

```
#include <stdio.h>
#include "SpiceUsr.h"

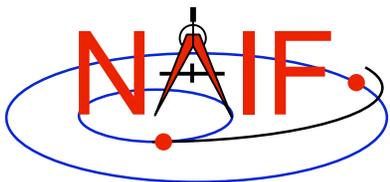
int main ()
{
    #define    FILESZ        256
    #define    WORDSZ        41
    #define    ROOM          10

    SpiceBoolean    found;

    SpiceChar        iframe [WORDSZ];
    SpiceChar        instnm [WORDSZ];
    SpiceChar        satnm  [WORDSZ];
    SpiceChar        fixref [WORDSZ];
    SpiceChar        scnm   [WORDSZ];
    SpiceChar        setupf [FILESZ];
    SpiceChar        shape  [WORDSZ];
    SpiceChar        time   [WORDSZ];

    SpiceDouble      alt;
    SpiceDouble      bundry [ROOM] [3];
    SpiceDouble      emissn;
    SpiceDouble      et;
    SpiceDouble      f;
    SpiceDouble      insite [3];
    SpiceDouble      srfvec [3];
    SpiceDouble      pclat;
    SpiceDouble      pclon;
    SpiceDouble      pdlat;
    SpiceDouble      pdlon;
    SpiceDouble      phase;
    SpiceDouble      point [3];
    SpiceDouble      r;
    SpiceDouble      radii [3];
    SpiceDouble      re;
    SpiceDouble      rp;
    SpiceDouble      solar;
    SpiceDouble      trgepc;

    SpiceInt         i;
    SpiceInt         instid;
    SpiceInt         n;
}
```



Complete Source Code - 2

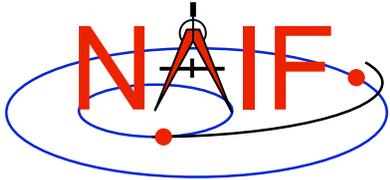
Navigation and Ancillary Information Facility

```
/* Prompt for the user-supplied inputs for our program      */
prompt_c ( "Enter setup file name > ", FILESZ, setupf );
furnsh_c ( setupf );
prompt_c ( "Enter satellite name > ", WORDSZ, satnm );
prompt_c ( "Enter satellite frame > ", WORDSZ, fixref );
prompt_c ( "Enter spacecraft name > ", WORDSZ, scnm );
prompt_c ( "Enter instrument name > ", WORDSZ, instnm );
prompt_c ( "Enter time                > ", WORDSZ, time );

/* Get the epoch corresponding to the input time: */
str2et_c ( time, &et );

/* Get the radii of the satellite. */
bodvrd_c ( satnm, "RADII", 3, &i, radii );

/* Get the instrument boresight and frame name. */
bodn2c_c ( instnm, &instid, &found );
if ( !found )
{
    setmsg_c ( "Instrument name # could not be "
              "translated to an ID code." );
    errch_c ( "#", instnm );
    sigerr_c ( "NAMENOTFOUND" );
}
getfov_c ( instid, ROOM, WORDSZ, WORDSZ,
          shape, iframe, insite, &n, bundry );
```



Complete Source Code - 3

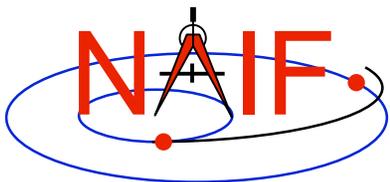
Navigation and Ancillary Information Facility

```
/* Compute the boresight ray intersection with the surface of the
   satellite. */
sincpt_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm,
           iframe, insite, point, &trgepc, srfvec, &found );
/* If an intercept is found, compute planetocentric and planetodetic
   latitude and longitude of the point. */
if ( found )
{
    reclat_c ( point, &r, &pclon, &pclat );
    /* Let re, rp, and f be the satellite's longer equatorial
       radius, polar radius, and flattening factor. */
    re = radii[0];
    rp = radii[2];
    f = ( re - rp ) / re;
    recgeo_c ( point, re, f, &pdlon, &pdlat, &alt );

    /* Compute illumination angles at the surface point. */
    ilumin_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, point,
              &trgepc, srfvec, &phase, &solar, &emissn );

    /* Display results. Convert angles to degrees for output. */
    printf ( "\n"
             "Intercept planetocentric longitude      (deg):  %11.6f\n"
             "Intercept planetocentric latitude        (deg):  %11.6f\n"

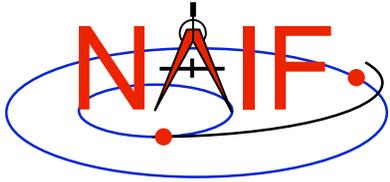
```



Complete Source Code - 4

Navigation and Ancillary Information Facility

```
"Intercept planetodetic longitude           (deg):  %11.6f\n"  
"Intercept planetodetic latitude           (deg):  %11.6f\n"  
"Range from spacecraft to intercept point  (km):  %11.6f\n"  
"Intercept phase angle                     (deg):  %11.6f\n"  
"Intercept solar incidence angle           (deg):  %11.6f\n"  
"Intercept emission angle                 (deg):  %11.6f\n",  
dpr_c() * pclon,  
dpr_c() * pclat,  
dpr_c() * pdlon,  
dpr_c() * pdlat,  
vnorm_c( srfvec ),  
dpr_c() * phase,  
dpr_c() * solar,  
dpr_c() * emissn  
    );  
}  
else {  
    printf ( "No intercept point found at %s\n", time );  
}  
return(0);  
}
```



Compile and Link the Program - 1

Navigation and Ancillary Information Facility

- **First be sure that both the CSPICE Toolkit and a C compiler are properly installed.**
 - A "hello world" C program must be able to compile, link, and run successfully in your environment.
 - Any of the mkprodct.* scripts in the cspice/src/* paths of the CSPICE installation should execute properly.
- **Ways to compile and link the program:**
 - If you're familiar with the "make" utility, create a makefile. Use compiler and linker options from the mkprodct.* script found in the cspice/src/cook_c path of your CSPICE installation.
 - Or, modify the cookbook mkprodct.* build script.
 - » Your program name must be *.pgm, for example demo.pgm, to be recognized by the script.
 - » Change the library references in the script to use absolute pathnames.
 - » Change the path for the executable to the current working directory.
 - » If your compiler supports it, add a -I option to reference the cspice/include path to make CSPICE *.h files available. Otherwise, copy those files from the include path to your current working directory.
 - » On some platforms, you must modify the script to refer to your program by name.



Compile and Link the Program - 2

Navigation and Ancillary Information Facility

- Or, compile the program on the command line. The program must be linked against the CSPICE object library `cspice.a` (`cspice.lib` under MS Visual C++/C) and the C math library. On a PC running Linux and `gcc`, if

- » The `gcc` compiler is in your path

- As indicated by the response to the command "which gcc"

- » the Toolkit is installed in the path (for the purpose of this example) `/myhome/cspice`

- » You've named the program `demo.c`

then you can compile and link your program using the command

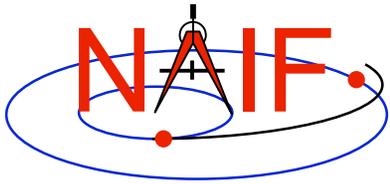
- »

```
gcc -I/myhome/cspice/include \  
-o demo \  
demo.c /myhome/cspice/lib/cspice.a -lm
```

- Note: the preprocessor flag

- `-DNON_UNIX_STDIO`

used in the `mkprodct.csh` script is needed for code generated by `f2c`, but is usually unnecessary for compiling user code.



Compile and Link the Program - 3

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> mkprodct.csh

        Setting default compiler:
gcc

        Setting default compile options:
-c -ansi -O2 -DNON_UNIX_STDIO

        Setting default link options:
-lm

        Compiling and linking:  demo.pgm
Compiling and linking:  demo.pgm

Prompt>
```



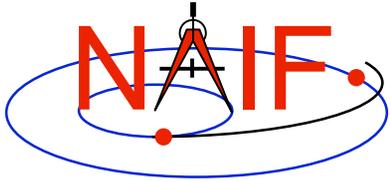
Running the Program - 1

Navigation and Ancillary Information Facility

It looks like we have everything taken care of:

- We have all necessary kernels
- We made a setup file (metakernel) pointing to them
- We wrote the program
- We compiled and linked it

Let's run it.



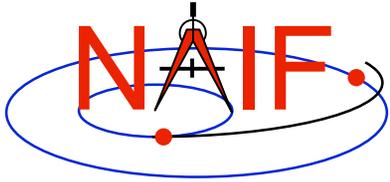
Running the Program - 2

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> demo
Enter setup file name > setup.ker
Enter satellite name > PHOEBE
Enter satellite frame > IAU_PHOEBE
Enter spacecraft name > CASSINI
Enter instrument name > CASSINI_ISS_NAC
Enter time > 2004 jun 11 19:32:00

Intercept planetocentric longitude (deg): 39.843719
Intercept planetocentric latitude (deg): 4.195878
Intercept planetodetic longitude (deg): 39.843719
Intercept planetodetic latitude (deg): 5.048011
Range from spacecraft to intercept point (km): 2089.169724
Intercept phase angle (deg): 28.139479
Intercept solar incidence angle (deg): 18.247220
Intercept emission angle (deg): 17.858309
Prompt>
```

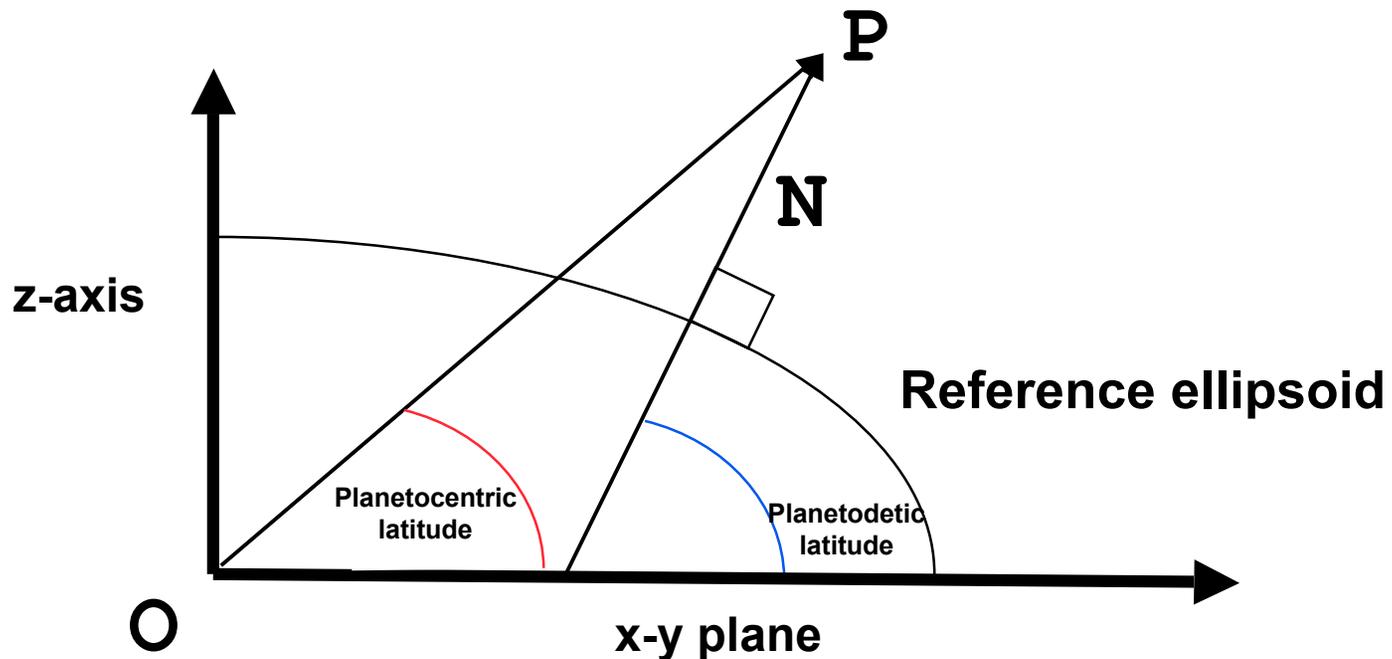


Backup

Navigation and Ancillary Information Facility

- **Latitude definitions:**

- Planetocentric latitude of a point P: angle between segment from origin to point and x-y plane (red arc in diagram).
- Planetodetic latitude of a point P: angle between x-y plane and extension of ellipsoid normal vector N that connects x-y plane and P (blue arc in diagram).





Navigation and Ancillary Information Facility

Writing a SPICE (FORTRAN) Based Program

January 2009



Viewing This Tutorial

Navigation and Ancillary Information Facility

Undefined variables are displayed in red; results are displayed in blue.



Introduction

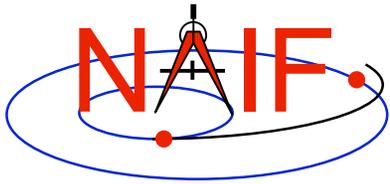
Navigation and Ancillary Information Facility

First, let's go over the important steps in the process of writing a SPICE-based Fortran program and putting it to work:

- Understand the geometry problem.
- Identify the set of SPICE kernels that contain the data needed to perform the computation.
- Formulate an algorithm to compute the quantities of interest using SPICE.
- Write and compile the program.
- Get actual kernel files and verify that they contain the data needed to support the computation for the time(s) of interest.
- Run the program.

To illustrate these steps, let's write a program that computes the apparent intersection of the boresight ray of a given CASSINI science instrument with the surface of a given Saturnian satellite. The program will compute

- Planetocentric and planetodetic (geodetic) latitudes and longitudes of the intercept point.
- Range from spacecraft to intercept point and from spacecraft to target center.
- Illumination angles (phase, solar incidence, and emission) at the intercept point.



Observation geometry

Navigation and Ancillary Information Facility

We want the boresight intercept on the surface, range from s/c to intercept, and illumination angles at the intercept point.

When? **TIME** (UTC, TDB or TT)

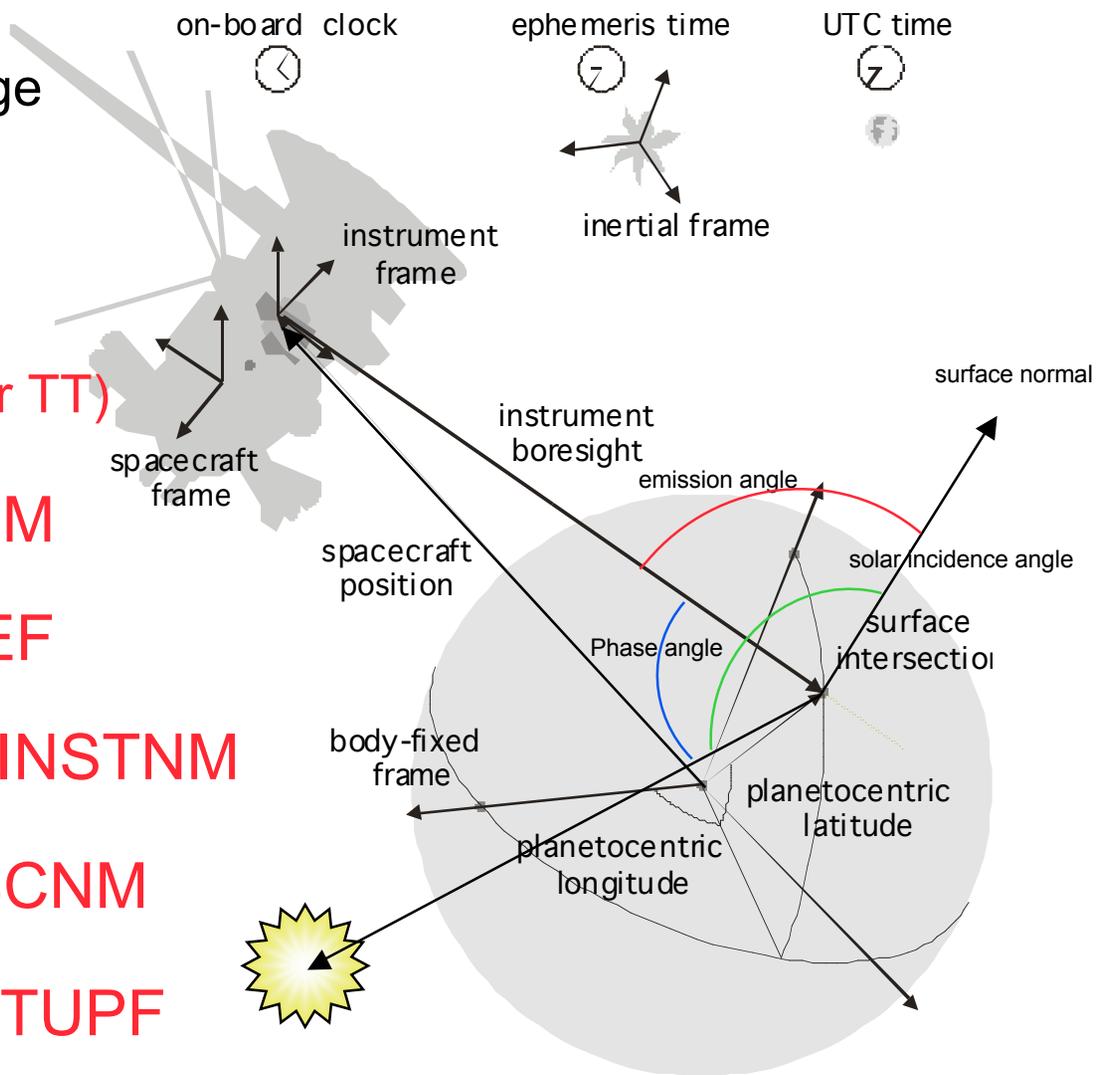
On what object? **SATNM**

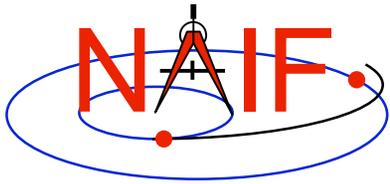
In what frame? **FIXREF**

For which instrument? **INSTNM**

For what spacecraft? **SCNM**

Using what model? **SETUPF**





Needed Data

Navigation and Ancillary Information Facility

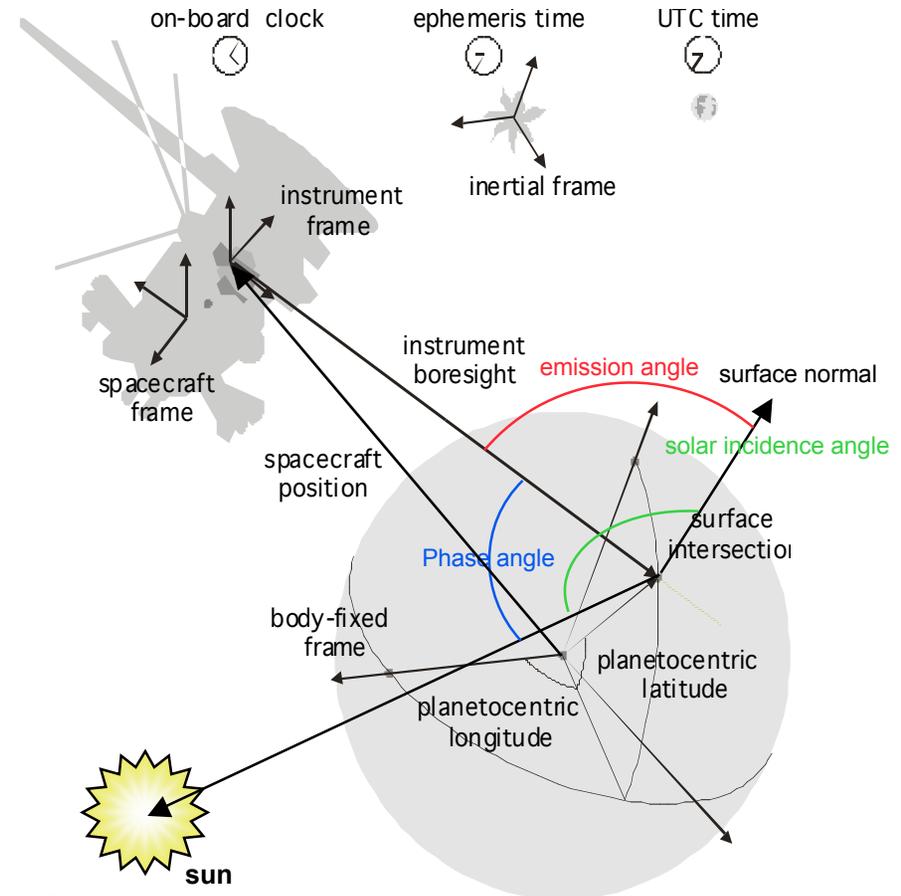
Time transformation kernels

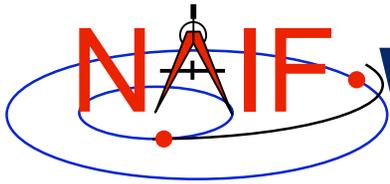
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





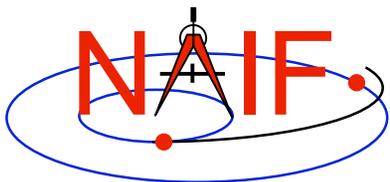
Which Kinds of Kernels are Needed?

Navigation and Ancillary Information Facility

Data required to compute vectors, rotations and other parameters shown in the picture are stored in the SPICE kernels listed below.

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

| Parameter | Kernel Type | File name |
|----------------------------|-----------------------------|------------------------------|
| time conversions | generic LSK
CASSINI SCLK | naif0008.tls
cas00084.tsc |
| satellite orientation | CASSINI PCK | cpck05Mar2004.tpc |
| satellite shape | CASSINI PCK | cpck05Mar2004.tpc |
| satellite position | planet/sat
ephemeris SPK | 020514_SE_SAT105.bsp |
| planet barycenter position | planet SPK | 981005_PLTEPH-DE405S.bsp |
| spacecraft position | spacecraft SPK | 030201AP_SK_SM546_T45.bsp |
| spacecraft orientation | spacecraft CK | 04135_04171pc_psiv2.bc |
| instrument alignment | CASSINI FK | cas_v37.tf |
| instrument boresight | Instrument IK | cas_iss_v09.ti |



Load Kernels

Navigation and Ancillary Information Facility

The easiest and most flexible way to make required kernels available to the program is via FURNISH. For this example we make a setup file (also called a “metakernel” or “furnsh kernel”) containing a list of kernels to be loaded:

Note: these kernels have been selected to support this presentation they should not be assumed to be appropriate for user applications.

```
\begindata
```

```
KERNELS_TO_LOAD = ('naif0008.tls', 'cas00084.tsc', 'cpck05Mar2004.tpc',  
                   '020514_SE_SAT105.bsp', '981005_PLTEPH-DE405S.bsp',  
                   '030201AP_SK_SM546_T45.bsp', '04135_04171pc_psiv2.bc',  
                   'cas_v37.tf', 'cas_iss_v09.ti')
```

```
\begintext
```

and we make the program prompt for the name of this setup file:

```
CALL PROMPT ( 'Enter setup file name > ', SETUPF )  
CALL FURNISH ( SETUPF )
```



Programming Solution

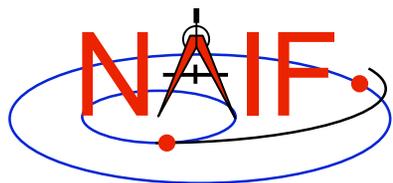
Navigation and Ancillary Information Facility

- Prompt for setup file (“metakernel”) name load kernels specified via setup file. (Done on previous chart.)
- Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via SPICELIB calls.
- Compute the intersection of the boresight direction ray with the surface of the satellite, presented as a triaxial ellipsoid.

If there is an intersection,

- Convert Cartesian coordinates of the intercept point to planetocentric latitudinal and planetodetic coordinates
 - Compute spacecraft-to-intercept point range
 - Find the illumination angles (phase, solar incidence, and emission) at the intercept point
- Display the results.

We discuss the geometric portion of the problem next.



Compute Surface Intercept and Ranges

Navigation and Ancillary Information Facility

Compute the intercept point (**POINT**) of the boresight vector (**INSITE**) specified in the instrument frame (**IFRAME**) of the instrument mounted on the spacecraft (**SCNM**) with the surface of the satellite (**SATNM**) at the TDB time of interest (**ET**) in the satellite's body-fixed frame (**FIXREF**). This call also returns the light-time corrected epoch at the intercept point (**TRGEPC**), the spacecraft-to-intercept point vector (**SRFVEC**), and a flag indicating whether the intercept was found (**FOUND**). We use "converged Newtonian" light time plus stellar aberration corrections to produce the most accurate surface intercept solution possible. We model the surface of the satellite as an ellipsoid.

```
CALL SINCPT ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM, IFRAME,  
             INSITE, POINT, TRGEPC, SRFVEC, FOUND )
```

The range we want is obtained from the outputs of `SINCPT`. These outputs are defined only if a surface intercept is found. If **FOUND** is true, the spacecraft-to-surface intercept range is the norm of the output argument **SRFVEC**. Units are km. We use the SPICELIB function `VNORM` to obtain the norm:

```
VNORM ( SRFVEC )
```

We'll write out the range data along with the other program results.



Compute Lat/Lon and Illumination Angles

Navigation and Ancillary Information Facility

Compute the planetocentric latitude (**PCLAT**) and longitude (**PCLON**), as well as the planetodetic latitude (**PDLAT**) and longitude (**PDLON**) of the intersection point.

```
IF ( FOUND ) THEN
    CALL RECLAT ( POINT, R, PCLON, PCLAT )

C      Let RE, RP, and F be the satellite's longer equatorial
C      radius, polar radius, and flattening factor.
RE   = RADII (1)
RP   = RADII (3)
F    = ( RE - RP ) / RE

    CALL RECGeo ( POINT, RE, F, PDLON, PDLAT, ALT )
```

The illumination angles we want are the outputs of **ILLUM**. Units are radians.

```
CALL ILUMIN ( 'Ellipsoid', SATNM, ET, FIXREF,
.            'CN+S', SCNM, POINT, TRGEPC, SRFVEC,
.            PHASE, SOLAR, EMISSN )
```



Geometry Calculations: Summary

Navigation and Ancillary Information Facility

C Compute the boresight ray intersection with the surface of the
C satellite.

```
CALL SINCPT ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM, IFRAME,  
              INSITE, POINT, TRGEPC, SRFVEC, FOUND )
```

C If an intercept is found, compute planetocentric and planetodetic
C latitude and longitude of the point.

```
IF( FOUND ) THEN
```

```
    CALL RECLAT ( POINT, R, PCLON, PCLAT )
```

C Let RE, RP, and F be the satellite's longer equatorial
C radius, polar radius, and flattening factor.

```
    RE = RADII(1)
```

```
    RP = RADII(3)
```

```
    F = ( RE - RP ) / RE
```

```
    CALL RECGeo ( POINT, RE, F, PDLON, PDLAT, ALT )
```

C Compute illumination angles at the surface point.

```
    CALL ILUMIN ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM,  
                  POINT, TRGEPC, SRFVEC, PHASE, SOLAR, EMISSN )
```

```
    ...
```

```
ELSE
```

```
    ...
```



Get Inputs - 1

Navigation and Ancillary Information Facility

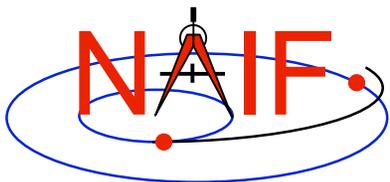
The code above used quite a few inputs that we don't have yet:

- TDB epoch of interest (**ET**)
- satellite and s/c names (**SATNM**, **SCNM**)
- satellite body-fixed frame name (**FIXREF**)
- satellite ellipsoid radii (**RADII**)
- instrument fixed frame name (**IFRAME**)
- instrument boresight vector in the instrument frame (**INSITE**)

Some of these values are user inputs others can be obtained via SPICELIB calls once the required kernels have been loaded.

Let's prompt for the satellite name (**SATNM**), satellite frame name (**FIXREF**), spacecraft name (**SCNM**), instrument name (**INSTNM**) and time of interest (**TIME**):

```
CALL PROMPT ( 'Enter satellite name > ', SATNM )
CALL PROMPT ( 'Enter satellite frame > ', FIXREF )
CALL PROMPT ( 'Enter spacecraft name > ', SCNM )
CALL PROMPT ( 'Enter instrument name > ', INSTNM )
CALL PROMPT ( 'Enter time > ', TIME )
```



Get Inputs - 2

Navigation and Ancillary Information Facility

Then we can get the rest of the inputs from SPICELIB calls:

To get the TDB epoch (**ET**) from the user-supplied time string (which may refer to the UTC, TDB or TT time systems):

```
CALL STR2ET ( TIME, ET )
```

To get the satellite's ellipsoid radii (**RADII**):

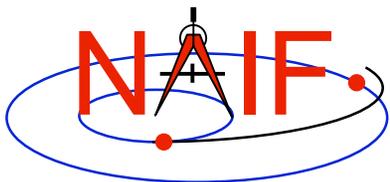
```
CALL BODVRD ( SATNM, 'RADII', 3, I, RADII )
```

To get the instrument boresight direction (**INSITE**) and the name of the instrument frame (**IFRAME**) in which it is defined:

```
CALL BODN2C ( INSTNM, INSTID, FOUND )
```

```
IF ( .NOT. FOUND ) THEN
  CALL SETMSG ( 'Instrument name # could not be ' //
                'translated to an ID code.'      )
  CALL ERRCH  ( '#', INSTNM                      )
  CALL SIGERR ( 'NAMENOTFOUND'                  )
END IF
```

```
CALL GETFOV ( INSTID, ROOM, SHAPE, IFRAME,
              INSITE, N, BUNDRY )
```



Getting Inputs: Summary

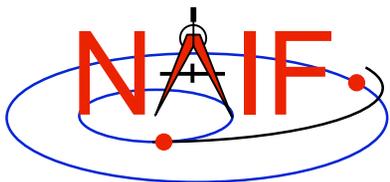
Navigation and Ancillary Information Facility

```
C      Prompt for the user-supplied inputs for our program.
      CALL PROMPT ( 'Enter setup file name > ', SETUPF )
      CALL FURNISH ( SETUPF )
      CALL PROMPT( 'Enter satellite name > ', SATNM )
      CALL PROMPT( 'Enter satellite frame > ', FIXREF )
      CALL PROMPT( 'Enter spacecraft name > ', SCNM )
      CALL PROMPT( 'Enter instrument name > ', INSTNM )
      CALL PROMPT( 'Enter time > ', TIME )

C      Get the epoch corresponding to the input time:
      CALL STR2ET ( TIME, ET )

C      Get the radii of the satellite.
      CALL BODVRD ( SATNM, 'RADII', 3, I, RADII )

C      Get the instrument boresight and frame name.
      CALL BODN2C ( INSTNM, INSTID, FOUND )
      IF ( .NOT. FOUND ) THEN
          CALL SETMSG ( 'Instrument name # could not be ' //
              'translated to an ID code.' )
          CALL ERRCH ( '#', INSTNM )
          CALL SIGERR ( 'NAMENOTFOUND' )
      END IF
      CALL GETFOV ( INSTID, ROOM, SHAPE, IFRAME,
          INSITE, N, BUNDRY )
```



Display Results

Navigation and Ancillary Information Facility

```
C      Display results.  Convert angles from radians to degrees
C      for output.
      WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept planetocentric longitude      (deg): ', DPR()*PCLON
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept planetocentric latitude      (deg): ', DPR()*PCLAT
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept planetodetic longitude      (deg): ', DPR()*PDLON
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept planetodetic latitude      (deg): ', DPR()*PDLAT
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Range from spacecraft to intercept point (km): ',
      .  VNORM(SRFVEC)
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept phase angle                  (deg): ', DPR()*PHASE
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept solar incidence angle      (deg): ', DPR()*SOLAR
        WRITE ( *, ' (1X,A,F12.6) ' )
      .  'Intercept emission angle              (deg): ',
      .  DPR()*EMISSN
      ELSE
        WRITE (*,*) 'No intercept point found at '// TIME
      END IF
```

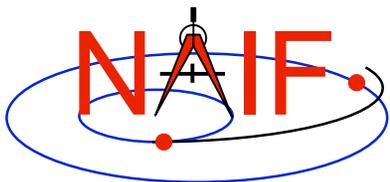


Complete the Program

Navigation and Ancillary Information Facility

To finish up the program we need to declare the variables we've used.

- We'll highlight techniques used by NAIF programmers
- Add remaining Fortran code required to make a syntactically valid program



Complete Source Code - 2

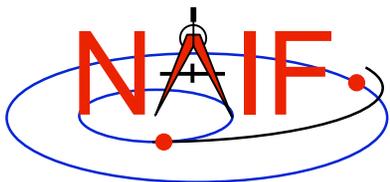
Navigation and Ancillary Information Facility

```
C      Prompt for the user-supplied inputs for our program.
      CALL PROMPT ( 'Enter setup file name > ', SETUPF )
      CALL FURNISH ( SETUPF )
      CALL PROMPT ( 'Enter satellite name > ', SATNM )
      CALL PROMPT ( 'Enter satellite frame > ', FIXREF )
      CALL PROMPT ( 'Enter spacecraft name > ', SCNM )
      CALL PROMPT ( 'Enter instrument name > ', INSTNM )
      CALL PROMPT ( 'Enter time > ', TIME )

C      Get the epoch corresponding to the input time:
      CALL STR2ET ( TIME, ET )

C      Get the radii of the satellite.
      CALL BODVRD ( SATNM, 'RADII', 3, I, RADII )

C      Get the instrument boresight and frame name.
      CALL BODN2C ( INSTNM, INSTID, FOUND )
      IF ( .NOT. FOUND ) THEN
          CALL SETMSG ( 'Instrument name # could not be ' //
.                   'translated to an ID code.' )
          CALL ERRCH ( '#', INSTNM )
          CALL SIGERR ( 'NAMENOTFOUND' )
      END IF
      CALL GETFOV ( INSTID, ROOM, SHAPE, IFRAME,
.                   INSITE, N, BUNDRY )
```



Complete Source Code - 3

Navigation and Ancillary Information Facility

```
C      Compute the boresight ray intersection with the surface of the
C      satellite.
      CALL SINCPT ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM, IFRAME,
      .             INSITE, POINT, TRGEPC, SRFVEC, FOUND )
C      If an intercept is found, compute planetocentric and planetodetic
C      latitude and longitude of the point.
      IF( FOUND ) THEN
          CALL RECLAT ( POINT, R, PCLON, PCLAT )
C      Let RE, RP, and F be the satellite's longer equatorial
C      radius, polar radius, and flattening factor.
          RE = RADII(1)
          RP = RADII(3)
          F  = ( RE - RP ) / RE
          CALL REC GEO ( POINT, RE, F, PDLON, PDLAT, ALT )
C      Compute illumination angles at the surface point.
          CALL ILUMIN ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM,
      .             POINT, TRGEPC, SRFVEC, PHASE, SOLAR, EMISSN )
C      Display results. Convert angles from radians to degrees
C      for output.
          WRITE ( *, * )
          WRITE ( *, '(1X,A,F12.6)' )
      .   'Intercept planetocentric longitude      (deg): ', DPR()*PCLON
```



Complete Source Code - 4

Navigation and Ancillary Information Facility

```
WRITE ( *, '(1X,A,F12.6)' )
. 'Intercept planetocentric latitude      (deg): ', DPR()*PCLAT
WRITE ( *, '(1X,A,F12.6)' )
. 'Intercept planetodetic longitude      (deg): ', DPR()*PDLON
WRITE ( *, '(1X,A,F12.6)' )
. 'Intercept planetodetic latitude      (deg): ', DPR()*PDLAT
WRITE ( *, '(1X,A,F12.6)' )
. 'Range from spacecraft to intercept point (km): ',
. VNORM(SRFVEC)
WRITE ( *, '(1X,A,F12.6)' )
. 'Intercept phase angle                  (deg): ', DPR()*PHASE
WRITE ( *, '(1X,A,F12.6)' )
. 'Intercept solar incidence angle       (deg): ', DPR()*SOLAR
WRITE ( *, '(1X,A,F12.6)' )
. 'Intercept emission angle              (deg): ',
. DPR()*EMISSN

ELSE
  WRITE (*,*) 'No intercept point found at '// TIME
END IF
END
```



Compile and Link the Program - 1

Navigation and Ancillary Information Facility

- **First be sure that both the SPICE Toolkit and a Fortran compiler are properly installed.**
 - A "hello world" Fortran program must be able to compile, link, and run successfully in your environment.
 - Any of the mkprodct.* scripts in the toolkit/src/* paths of the SPICE Toolkit installation should execute properly.
- **Ways to compile and link the program:**
 - If you're familiar with the "make" utility, create a makefile. Use compiler and linker options from the mkprodct.* script found in the toolkit/src/cookbook path of your SPICE Toolkit installation.
 - Or, modify the cookbook mkprodct.* build script.
 - » Your program name must be *.pgm, for example demo.pgm, to be recognized by the script.
 - » Change the library references in the script to use absolute pathnames.
 - » Change the path for the executable to the current working directory.
 - » On some platforms, you must modify the script to refer to your program by name.



Compile and Link the Program - 2

Navigation and Ancillary Information Facility

- Or, compile the program on the command line. The program must be linked against the SPICELIB object library spicelib.a (spicelib.lib under MS Windows systems). On a PC running Linux and g77, if

- » The g77 compiler is in your path
 - As indicated by the response to the command "which g77"
- » the Toolkit is installed in the path (for the purpose of this example) /myhome/toolkit
- » You've named the program demo.f

then you can compile and link your program using the command

```
» g77 -o demo demo.f \  
    /myhome/toolkit/lib/spicelib.a
```



Compile and Link the Program - 3

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> mkprodct.csh

    Using the g77 compiler.

    Setting default Fortran compile options:
    -c -C

    Setting default C compile options:
    -c

    Setting default link options:

    Compiling and linking:  demo.pgm
    Compiling and linking:  demo.pgm

Prompt>
```



Running the Program - 1

Navigation and Ancillary Information Facility

It looks like we have everything taken care of:

- We have all necessary kernels
- We made a setup file (metakernel) pointing to them
- We wrote the program
- We compiled and linked it

Let's run it.



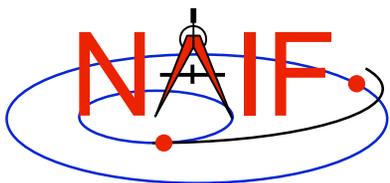
Running the Program - 2

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> demo
Enter setup file name > setup.ker
Enter satellite name > PHOEBE
Enter satellite frame > IAU_PHOEBE
Enter spacecraft name > CASSINI
Enter instrument name > CASSINI_ISS_NAC
Enter time > 2004 jun 11 19:32:00

Intercept planetocentric longitude (deg): 39.843719
Intercept planetocentric latitude (deg): 4.195878
Intercept planetodetic longitude (deg): 39.843719
Intercept planetodetic latitude (deg): 5.048011
Range from spacecraft to intercept point (km): 2089.169724
Intercept phase angle (deg): 28.139479
Intercept solar incidence angle (deg): 18.247220
Intercept emission angle (deg): 17.858309
Prompt>
```

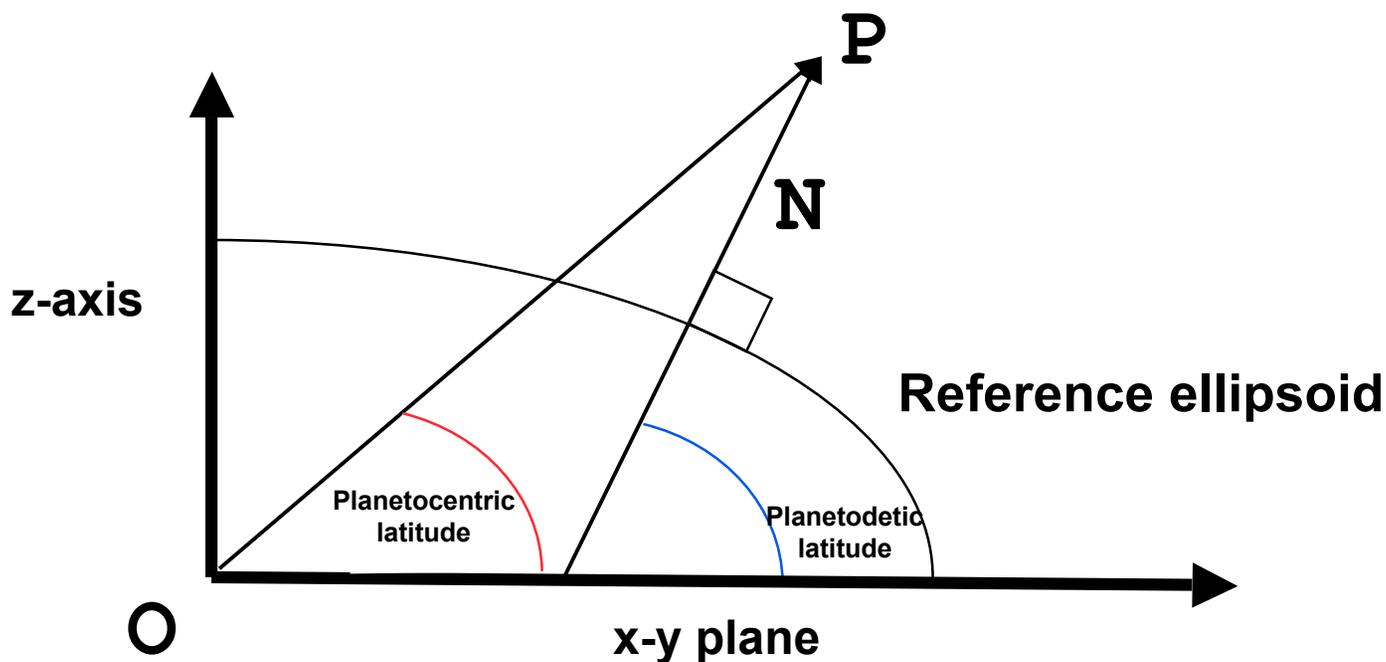


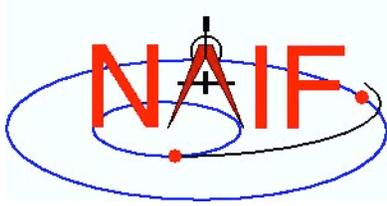
Backup

Navigation and Ancillary Information Facility

- **Latitude definitions:**

- Planetocentric latitude of a point P: angle between segment from origin to point and x-y plane (red arc in diagram).
- Planetodetic latitude of a point P: angle between x-y plane and extension of ellipsoid normal vector N that connects x-y plane and P (blue arc in diagram).





Navigation and Ancillary Information Facility

Making an SPK File

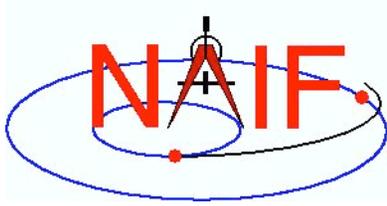
January 2009



Table of Contents

Navigation and Ancillary Information Facility

- **Purpose**
- **Scope**
- **Assumptions about user's knowledge**
- **SPK overview**
- **Summary of SPK architecture**
- **Discussion applicable to all production methods**
 - Recommended SPK types
- **Selecting the polynomial degree (for polynomial SPK types)**
- **SPK production methods**
 - Using the “Make SPK” (MKSPK) program
 - Using SPICELIB, CSPICE or IDL writer modules (subroutines)
- **Finishing up, applicable to all methods**
 - Adding comments
 - Validation
 - Merging
- **Special requirements for making SPKs to be used in DSN/SPS software for view period generation, scheduling, metric predicts generation, and related functions.**
 - Applies only to those entities not making JPL NAV-style “p-files”
- **Issues affecting performance (reading efficiency) and usability**



Purpose

Navigation and Ancillary Information Facility

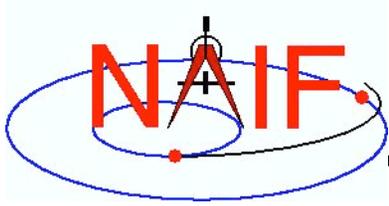
- **This tutorial provides guidance for producing (writing) an SPK file using software provided by NAIF:**
 - the MKSPK application program
 - or
 - SPK writer modules from the SPICELIB (FORTRAN) or CSPICE (C-language) library, or from the Icy (IDL) system
 - » Only partial implementation in Icy
 - » No SPK writers implemented in Mice



Scope

Navigation and Ancillary Information Facility

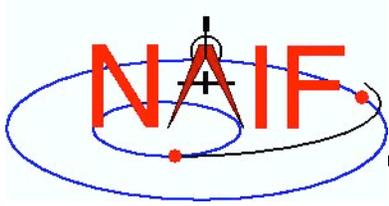
- **This tutorial addresses production of SPK files**
 - For general purposes
 - For use with NASA’s Deep Space Network (the “SPS”)
- **(Note: This tutorial does *not* address SPK production by JPL navigation teams using the NIOSPK application, which was specially built to process JPL’s NAVIO-format ephemeris/trajectory files.)**
 - Those NAV teams may simply learn how to use the NIOSPK program and any useful SPK-related utilities.



Background Assumptions

Navigation and Ancillary Information Facility

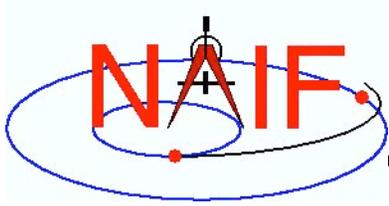
- **It is assumed the reader has some familiarity with the SPICE system, and with basic ideas of orbital mechanics.**
 - The SPICE Overview tutorial is available at:
ftp://naif.jpl.nasa.gov/pub/naif/toolkit_docs/Tutorials/
- **It is assumed the reader has read the “SPK Tutorial” that characterizes much of the SPK subsystem, but with emphasis on reading SPK files.**
 - The SPK “reading” tutorial is available at:
ftp://naif.jpl.nasa.gov/pub/naif/toolkit_docs/Tutorials/ (named 19_spk)
- **It is assumed the reader has available the SPK reference document entitled “SPK Required Reading,” supplied with each copy of the SPICE Toolkit (.../doc/spk.req)**
 - SPK Required Reading is also available at:
<http://naif.jpl.nasa.gov/naif/documentation.html>



SPK References

Navigation and Ancillary Information Facility

- **References for SPK production**
 - “Making an SPK” tutorial (this document)
 - “SPK (Ephemeris System)” tutorial (focused on reading an SPK)
 - “SPK Required Reading” ([spk.req](#))
 - “MKSPK Users Guide” ([mkspk.ug](#))
 - “SPKMERGE User’s Guide ([spkmerge.ug](#))
 - The source code “headers” provided as part of the SPK writer modules (subroutines)



Brief Overview - 1

Navigation and Ancillary Information Facility

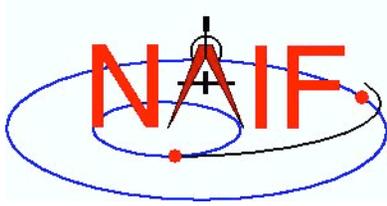
- **Understand the physics of your data and how that relates to SPK type.**
 - Type 5 implies an orbit well approximated by a sequence of one or more conic orbits.
 - Types 9 and 13 fit data regardless of the expected physics.
 - » **Caution: a good fit in the mathematical realm may not respect the physics of the trajectory. For example, fitting polynomials to an excessively sparse set of states for a planetary orbiter could result in an interpolated path that intersects the planet.**



Brief Overview - 2

Navigation and Ancillary Information Facility

- **Ordinarily, use the NAIF MKSPK application to create SPKs from Cartesian state data or conic elements.**
 - Depending on your source data, SPK types 5, 9, 10, and 13 will satisfy the requirements for most users.
 - » Type 5, yields compact SPK files when the trajectory is well approximated by piecewise two-body motion. May be the best choice for planetary or solar orbiters when available state data are sparse.
 - » Type 9, a good, general choice
 - » Type 13, when you have very accurate velocity data
 - » Type 10 applies ONLY to Two Line Element Sets (TLEs).
- **Alternatively, use the Toolkit's SPK writing subroutines in your own production program.**
- **Caution:** an SPK made for use by the NASA DSN has special requirements, discussed later on.



Navigation and Ancillary Information Facility

Summary of SPK Architecture



SPK File Structure: The User's View

Navigation and Ancillary Information Facility

Logical Organization of an SPK File



} Always present

} Possibly present
- sometimes by choice
- sometimes required



SPK File Structure - 1

Navigation and Ancillary Information Facility

A minimal SPK file, containing only one segment

Records are fixed-length: 1024 bytes

| | | | | | | | | | | |
|-------------------|----|----|--------|-----|-----|------|-----|-------|-----|-------|
| ID WORD | ND | NI | IFNAME | FWD | BWD | FREE | BFF | 0 PAD | FTP | 0 PAD |
| Comment area text | | | | | | | | | U* | |
| N/P/C | D1 | U | | | | | | | | |
| I1 | U | | | | | | | | | |
| Segment 1 | | | | | | | | | | |

- ▶ **File record:** One record.
- ▶ **Comment area:** Present only if used. If used, one or more records.
- ▶ **Descriptor record:** Contains 1 to 25 segment descriptors. One record.
- ▶ **Segment ID record:** Contains 1 to 25 segment IDs. One record.
- ▶ **Data segment:** One or more records.

ID WORD: Indicates file architecture and type
ND, NI: Number of d.p. and integer descriptor components
IFNAME: Internal file name
FWD, BWD: Forward and backward linked list pointers
FREE: First free DAF address
BFF: Binary file format ID
FTP: FTP corruption test string

N/P/C: Next, previous record pointers and descriptor count
Dn: Descriptor for segment n
In: Segment ID for segment n

U: Unused space
U*: Possibly unused space

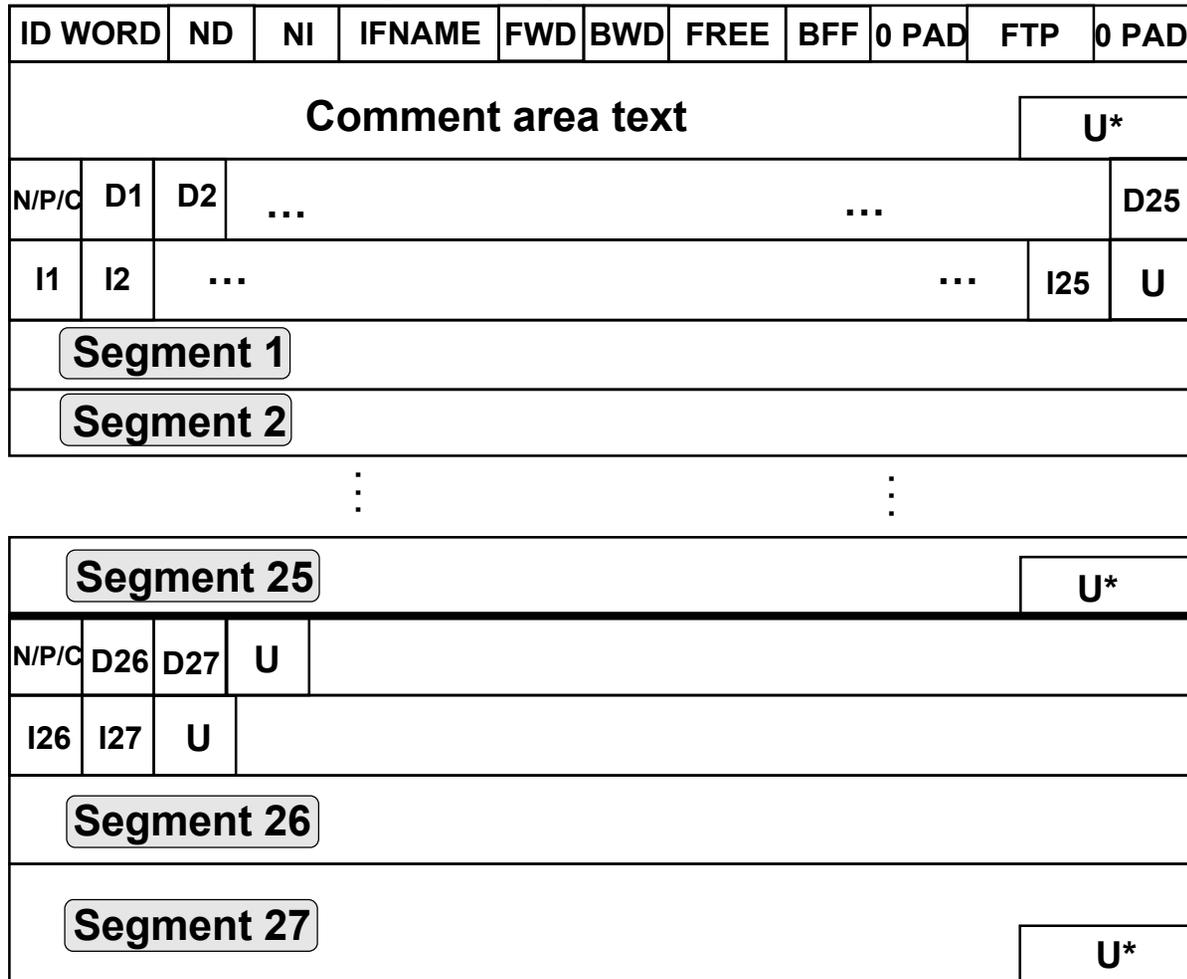


SPK File Structure - 2

Navigation and Ancillary Information Facility

An SPK file containing 27 segments

Records are fixed-length: 1024 bytes



File record: One record

Comment area: Always present but could be empty. One or more records.

Descriptor record: Contains 1 to 25 segment descriptors. One record.

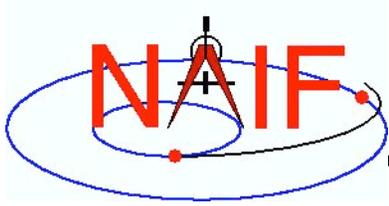
Segment ID record: Contains 1 to 25 segment IDs. One or more records.

Data segments: One or more records per segment. (Up to 25 segments.)

Descriptor record: Contains 1 to 25 segment descriptors. One record.

Segment ID record: Contains 1 to 25 segment IDs. One or more records.

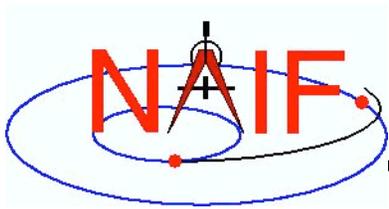
Data segments: One or more records per segment. (Up to 25 segments.)



SPK File Structure - Description

Navigation and Ancillary Information Facility

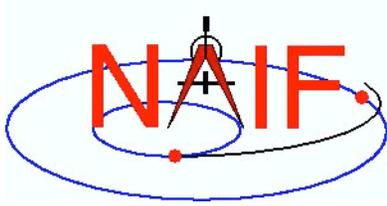
- **File record**
 - Contents
 - » Internal file name (set by file creator)
 - » Architecture and binary file format identifiers
 - » File structure parameters
 - » FTP transmission corruption detection string
 - Used by SPK reader and writer subroutines
- **Comment Area**
 - A place where “metadata” (data about data) may be placed to help a user of the SPK file understand the circumstances of its production and any recommendations about for what uses it was intended
- **Descriptor record and Segment ID record**
 - One of each of these is needed for every collection of 1-to-25 segments
- **Segment[s]**
 - Collection[s] of ephemeris data
 - » Minimum of one segment
 - » Maximum:
 - The practical maximum is a few thousand segments
 - Serious performance degradation occurs above 30000 segments for a single body
 - Absolute limits are imposed by the range of the INTEGER data type for your computer
 - Numerous SPK types may be used within an SPK file, but only one SPK type may appear within a given segment
 - Segments of different types may be intermixed within a given SPK file



What is an SPK Segment?

Navigation and Ancillary Information Facility

- **A segment is a collection of information:**
 - » **providing ephemeris (position and velocity) of a single object**
 - » **given relative to a single center of motion**
 - » **specified in a single reference frame known to SPICE**
 - **Either built-in (“hard coded”) or defined in a loaded frames kernel (FK)**
 - » **covering a specified, continuous period of time, and**
 - » **using a single SPK data type.**
- **Example: ephemeris for the Voyager 2 spacecraft, relative to the center of the Neptunian system (Neptune’s barycenter), given in the J2000 inertial reference frame, covering a specific period of time, and using the Hermite interpolation with variable length intervals SPK type (type 13)**
- **An SPK segment must contain enough data to yield an object’s state at any epoch within the time bounds associated with the segment**
 - **This has implications that depend on the SPK type being produced**



Navigation and Ancillary Information Facility

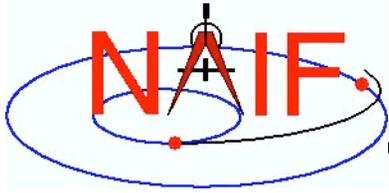
Discussion applicable to all SPK production methods



The SPK Family

Navigation and Ancillary Information Facility

| Type | Description | Notes |
|------|---|---|
| 1 | Modified divided difference arrays | Unique form produced at JPL; not likely to be useful to others. |
| 2 | Chebyshev polynomials for position; fixed length time intervals. | Velocity is obtained by differentiation. Used at JPL for planets. Evaluates quickly. |
| 3 | Chebyshev polynomials for position and velocity; fixed length time intervals | Separate polynomial sets for position and velocity. Used at JPL for natural satellites. |
| 4 | Special form used only by Hubble Space Telescope | Not available for general use. |
| 5 | Discreet states using weighted two-body propagation | Ok if motion very closely approximates two-body motion. |
| 6 | Special form of trigonometric expansion of elements for Phobos and Deimos | Not available for general use. |
| 7 | Precessing elements | Not available for general use. |
| 8 | Lagrange interpolation of position and velocity; fixed length intervals between states | Use Type 9 unless state spacing is truly uniform when measured in the TDB system. |
| 9 | Lagrange interpolation of position and velocity; variable length intervals between states | Versatile type; easy to use with MKSPK. |
| 10 | Weighted two-line element sets (Space Command) | Handles both "near-earth" and "deep space" versions. |
| 11 | Not used | |
| 12 | Hermite interpolation; fixed length intervals between states | Use Type 13 unless state spacing is truly uniform when measured in the TDB system. |
| 13 | Hermite interpolation; variable length intervals between states | Versatile type; easy to use with MKSPK. Use for DSN support. |
| 14 | Chebyshev polynomials for position and velocity, variable length time intervals | The most flexible of the Chebyshev types. |
| 15 | Precessing conic elements propagator | |
| 16 | Special form used by ESA's Infrared Space Observatory | Not available for general use. |
| 17 | Equinoctial elements | Used for some satellites. |
| 18 | Emulation of ESOC's "DDID" format | Used for SMART-1, MEX, VEX, and Rosetta |



Recommended SPK Data Types - 1

Navigation and Ancillary Information Facility

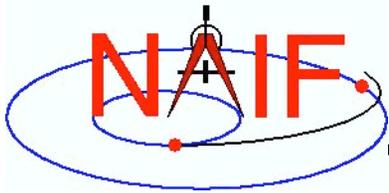
- **SPK type 2 (Chebyshev polynomials for position, velocity given by differentiation)** Used at JPL for planetary ephemerides.
- **SPK type 3 (Separate Chebyshev polynomials for position and velocity)** Used at JPL for satellite ephemerides.
- **SPK type 5 (Weighted two-body extrapolation)** Often used for comets and asteroids, as well as for sparse data sets where a two-body approximation is acceptable.
- **SPK types 9 and 13 (Sliding-window Lagrange and Hermite interpolation of unequally-spaced states)** Often used by non-JPL ephemeris producers and by users of NAIF's "Make SPK" (MKSPK) application.
- **SPK type 10 (weighted Space Command two-line element extrapolation)** Often used for earth orbiters.
- **SPK type 14 (Separate Chebyshev polynomials for position and velocity, with variable time steps)** This is the most flexible Chebyshev data type.
- **SPK type 15 (Precessing conic elements)** Provides a very compact ephemeris representation; limited to orbits where this type of approximation is valid.
- **SPK type 17 (Equinoctial elements)** Most suited for representation of ephemerides of natural satellites in equatorial or near-equatorial orbits.



Recommended SPK Data Types - 2

Navigation and Ancillary Information Facility

- **Each type has certain properties that may promote or limit its usefulness in a particular application. These properties include, but are not limited to the following.**
 - » Ability to model the actual ephemeris to be represented with the accuracy required for your application.
 - » Consistency between velocity and derivative of position.
 - » Evaluation speed (performance).
 - » Compactness (file size).
 - » Availability of SPICE software needed to write files of that type.
- **Users are encouraged to consult with NAIF about the suitability of an SPK type for a particular purpose.**



Creating Multiple SPK Segments

Navigation and Ancillary Information Facility

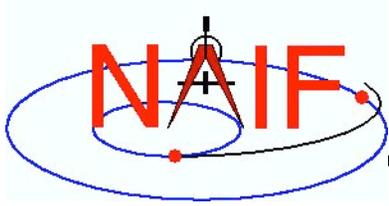
- **Each SPK segment must have a single object, center of motion, reference frame and SPK data type.**
- **Limiting segment size to 10,000 states or “packets of ephemeris data” can improve performance when searching within a segment.**
 - Absolute limits on segment size depend on the size of the INTEGER data type.
- **For good SPK reading performance, the total number of segments for any given body in a file should be kept under the dimension of the SPKBSR segment buffer, currently set to 30,000.**
 - More details about reading efficiency are provided at the end of this tutorial.
 - When reading data from multiple SPK files, a more stringent limit applies: the total number of loaded segments for any body, possibly contributed by multiple files, should be less than the SPKBSR segment buffer size.
 - For best efficiency, the total number of segments loaded should be less than this buffer size.
- **One may elect to initiate a new segment (or more) as the means for modeling a propulsive maneuver.**
 - This is because the SPK reader modules will NOT allow interpolation over a segment boundary.
- **When starting a new segment you may use a new segment identifier, for instance to indicate a new trajectory leg after a maneuver.**
 - Can only be done if using SPK write modules—not if using the MKSPK application.



Choosing Polynomial Degree

Navigation and Ancillary Information Facility

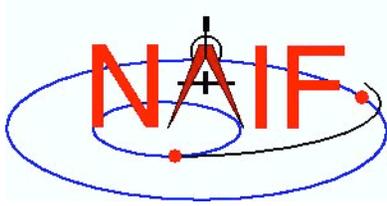
- **If you make a type 8 or 9 (Lagrange interpolation) or a type 12 or 13 (Hermite interpolation) SPK file you must specify the degree of the interpolating polynomial that the SPK reader subroutine will use.**
 - This choice needs some consideration about desired accuracy, file size and evaluation speed (performance).
 - This choice is also affected by the “smoothness” of the orbit data you wish to represent with an SPK file.
 - The allowed range of degree is 1-to-15. In addition, to ensure position and velocity continuity over the time span covered by the orbit data:
 - » for types 8 and 9, the polynomial degree **must** be odd.
 - » for types 12 and 13, the polynomial degree **must** be 3-mod-4, meaning degree 3, 7, 11 or 15.



Reference Frame

Navigation and Ancillary Information Facility

- **No matter the SPK Type, all ephemeris data must be provided in a well identified reference frame.**
- **Any reference frame known to the SPICE system, whether built-in (hard coded) or defined at run time through a Frames Kernel (FK), may be used for ephemeris data placed in an SPK file.**
- **Some examples of typical reference frames used:**
 - **Inertial (non-rotating):**
 - » **Earth Mean Equator and Equinox of J2000 (EME2000, a.k.a. J2000)**
 - » **Ecliptic of J2000**
 - **Body fixed (non-inertial)**
 - » **ITRF93 (for Earth)**
 - » **MOON_ME (MOON_MeanEarth)**



Navigation and Ancillary Information Facility

SPK Production Methods



Choices for Making an SPK File

Navigation and Ancillary Information Facility

- **There are two methods available for making an SPK file.**
 1. **Take a data file produced by your own trajectory propagator program and input this into the conversion utility (MKSPK) provided by NAIF that outputs an SPK file.**
 2. **Incorporate the appropriate SPK writer modules (subroutines) into your own code.**
 - » **Add these routines to your trajectory estimator/ propagator.**

or...

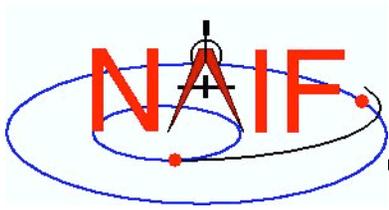
 - » **Write your own “post-processor” conversion utility, similar to MKSPK described above.**
- **Both methods are described in the next few pages.**



Making Your Choice - 1

Navigation and Ancillary Information Facility

- **Using the MKSPK program provided in the Toolkit could be easiest for “simple” situations.**
 - Provides considerable flexibility for accepting a wide assortment of input data formats.
 - Does allow one to make multi-segment SPK files when the target, center of motion, reference frame, or SPK type changes, but not as straight forward as it could/should be.
 - » Best done through multiple program executions (although one could be tricky and accomplish this in a single execution).
 - » A future version of MKSPK may better accommodate this.
 - » Note: production of multiple segments in type 5, 8, 9, 12 and 13 files when the amount of input data requires so, is automatically handled.



Making Your Choice - 2

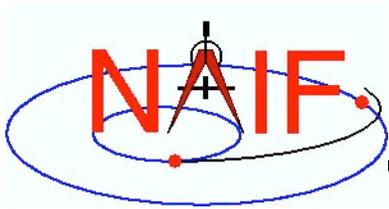
Navigation and Ancillary Information Facility

- **Using the SPK “writer” modules found in SPICELIB, CSPICE, and Icy offers the greatest flexibility and user control.**
 - Using these requires that you write your own program.
 - You’ll likely need to use some additional SPICE modules as well.



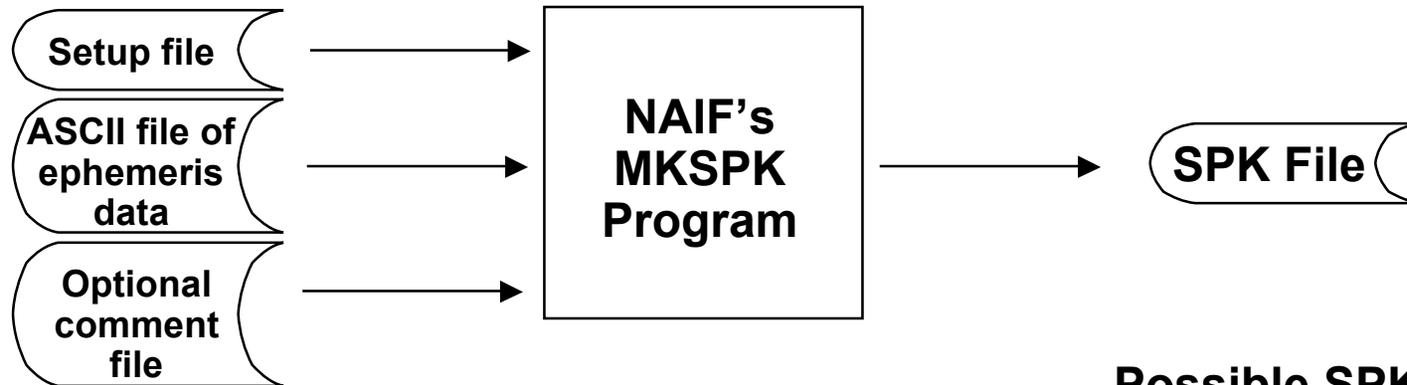
Navigation and Ancillary Information Facility

Using NAIF's MKSPK Application Program



Using the MKSPK Utility - 1

Navigation and Ancillary Information Facility



Suitable kinds of input ephemeris data are:

- Table of Cartesian state vectors
- Table of conic elements
- One or more sets of equinoctial elements
- One or more sets of Space Command two-line elements

Possible SPK data types produced are:

- Type 05
- Type 08
- Type 09
- Type 10
- Type 12
- Type 13
- Type 15
- Type 17



Using the MKSPK Utility - 2

Navigation and Ancillary Information Facility

This table indicates which SPK types can be made from the four kinds of input data accepted by MKSPK

| SPK Type Produced by MKSPK --> | 5 | 8 | 9 | 10 | 12 | 13 | 15 | 17 |
|---------------------------------|---|---|---|----|----|----|----|----|
| Input Data Type | | | | | | | | |
| Cartesian state vectors | Y | Y | Y | N | Y | Y | Y | Y |
| Conic elements | Y | Y | Y | N | Y | Y | Y | Y |
| Equinoctial elements | N | N | N | N | N | N | N | Y |
| Space Command Two-line elements | N | N | N | Y | N | N | N | N |

Y = Yes N = No



Using the MKSPK Utility - 3

Navigation and Ancillary Information Facility

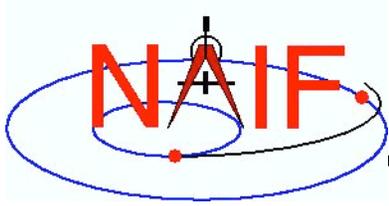
- **MKSPK will produce a file consisting of one or more segments as needed.**
 - It will write up to 10,000 data points in one segment.
 - For multi-segment files based on types 5, 8, 9, 12 and 13 the program will repeat sufficient data points at both sides of each interior segment boundary to ensure the SPK file will provide a continuous ephemeris through the segment boundary epoch.
- **You can use MKSPK to add a new segment to an existing SPK file.**
- **You can use SPKMERGE to merge two or more SPK files made from separate executions of MKSPK.**
 - It's important to fully understand how SPKMERGE works if you do this.



Using the MKSPK Utility - 4

Navigation and Ancillary Information Facility

- **MKSPK does not provide direct/specific means for including propulsive maneuvers within an SPK file.**
 - **Instead, use either of these two methods.**
 - » **Append a new SPK segment to an existing SPK file, using MKSPK.**
 - » **Merge a collection of SPK files, using SPKMERGE.**



Navigation and Ancillary Information Facility

Using SPK “Writer” Modules



Using SPK Writer Routines

Navigation and Ancillary Information Facility

- **The next several charts outline how to use the “SPK writer” modules available in the Toolkit libraries.**
 - **SPICELIB (FORTRAN)**
 - **CSPICE (C)**
 - » **All types supported except Type 1**
 - **Icy (IDL)**
 - » **All types supported except Type 1, 15, 17, 18**
 - **Mice (MATLAB)**
 - » **Currently no SPK writer modules are supported**
- **These routines could be embedded in your existing trajectory propagator program, or they could be used to build a separate conversion program analogous to MKSPK.**



What Routines To Use - 1

Navigation and Ancillary Information Facility

For all except SPK type 14

| | |
|-----------------|---|
| SPKOPN | Open a new SPK file. (Use SPKOPA to append to existing file.) |
| SPKWxx | Write a segment of SPK type xx |
| . | |
| . | |
| [SPKWxx] | [Write more segments] |
| . | [Repeat as needed] |
| . | |
| SPKCLS | Close the file |

[...] indicates possible multiple occurrences

These routine names are for the FORTRAN (SPICELIB) Toolkit. For CSPICE the names are the same but are in lower case and have an “_c” appended. For Icy, module names are case-insensitive and have "cspice_" prepended.



What Routines To Use - 2

Navigation and Ancillary Information Facility

For SPK type 14

SPKOPN, SPKOPA

Open file to add data

SPK14B

Begin a new segment

SPK14A

Add data to segment

[SPK14A]

Add more data

SPK14E

End the segment

SPK14B

Begin a new segment

SPK14A

Add data to segment

[SPK14A]

Add more data

SPK14E

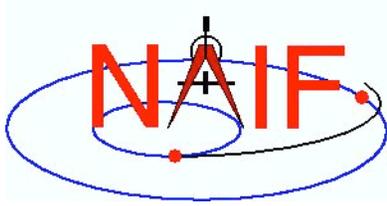
End the segment

etc.

SPKCLS

Close the file

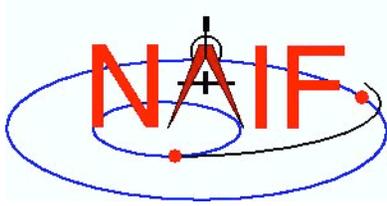
**Repeat
as needed**



Close the SPK File

Navigation and Ancillary Information Facility

- **Once you have completed the addition of all data to your SPK file, be sure to call the SPKCLS routine to close the file.**
 - Failure to properly close an SPK file will result in a problem file having been produced.
- **This point is emphasized here because it has been a frequent problem.**



Navigation and Ancillary Information Facility

Finishing Up



Not Quite Done Yet

Navigation and Ancillary Information Facility

- **You've now used either MKSPK or the appropriate SPK writer routines to produce an SPK file. To complete the job you should consider the following.**
 - **Add comments (metadata) to the comment area of the SPK file.**
 - » **This could have been done during execution of MKSPK.**
 - » **It can be done after the SPK has been created by using the Toolkit's "commnt" utility program.**
 - **Validate the file before sending it off to your customer.**
 - **Consider if there is a need to merge this newly made SPK file with others.**
- **See the next several charts for more information on these subjects.**



Add Comments (metadata)

Navigation and Ancillary Information Facility

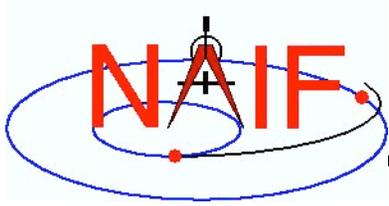
- **It is recommended (but not a technical requirement) that the producer of an SPK file add to the file, in the “comment area,” appropriate descriptive information.**
 - When, how and by whom the file was created.
 - Intended use for the file.
 - Cautions or restrictions on how the file is to be used.
- **The comments might also include some of these topics.**
 - Time coverage.
 - Ephemeris objects included.
 - Type(s) of data used (in the sense of reconstructed versus predicted).
 - Any available estimates of accuracy.
 - Sources of the data used to produce this SPK file.
 - Name(s) of previously generated SPK file(s) being replaced by this file.
 - Any knowledge of plans for future updates to (replacements for) this file.
 - Name and version number of your SPK production program.
 - Type of platform (hardware/OS/compiler) on which the SPK file was generated.



How to Add Comments to an SPK

Navigation and Ancillary Information Facility

- **Several means are available for adding comments (metadata) to an SPK file.**
 - An option in the MKSPK program allows comments supplied in a separate text file to be added to the comment area during MKSPK execution.
 - Use the “COMMNT” utility program from the SPICE Toolkit.
 - » This may be run as an interactive program or in command line mode within a script.
 - If using FORTRAN, C or IDL you can use APIs.
 - » Not currently supported in MATLAB.



Validate the SPK File

Navigation and Ancillary Information Facility

- **Validation of SPK files is recommended**
 - **Caution is needed more for one-of-a-kind files than for those generated in a previously tested, unchanging process.**
 - **Some SPICE utility programs might help with this validation.**
 - » **SPY: can do a variety of structure and semantic checks.**
 - SPY is available from the Utilities link of the NAIF website.
 - » **SPKDIFF: used to statistically compare two supposedly similar SPK files.**
 - SPKDIFF is available in each Toolkit package and also from the Utilities link of the NAIF website.
 - **Consider writing your own validation program.**
 - **Caution: successfully running an SPK summary program (e.g. BRIEF or SPACIT) or successfully running the format conversion program (TOXFR or SPACIT) is a positive sign, but is not a sufficient test.**



Validate the Overall Process

Navigation and Ancillary Information Facility

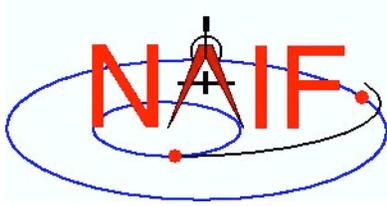
- **When you first start producing SPK files, or when changing the SPK “type” used or the kind of mission (trajectory) to be represented, validation (or revalidation) of the overall process is advised.**
 - Validation of not only SPKs, but of end products derived from SPKs, is advised.
- **Consider writing a program that compares states from your source data with states extracted from your new SPK file.**
 - Do this using **interpolated states** from your source data—not only the states placed in the SPK file.
 - Verify a uniformly good fit on the whole time interval covered by the file.



Make a Merged SPK File ?

Navigation and Ancillary Information Facility

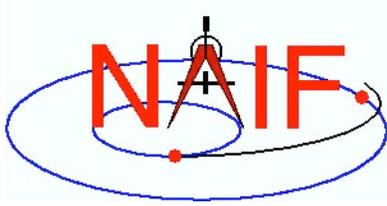
- **Sometimes it is helpful to customers if portions of two or more SPK files are merged into just one.**
 - (Sometimes the opposite is true, so be careful!)
- **If making a merged product is appropriate, use the SPICE utility SPKMERGE.**
 - Read the SPKMERGE User's Guide.
 - » Be especially aware of how SPKMERGE directives affect the **precedence order** of the data being merged. (This is different from the precedence order that applies when one reads an SPK file or files.)
 - Carefully examine your results (probably using either BRIEF or SPACIT) to help verify you got what you expected.
- **If you've made a merged SPK file, check to see that the included comments are appropriate.**



Get Help

Navigation and Ancillary Information Facility

- **If your project provides funding to NAIF for help with development:**
 - **Ask JPL's NAIF team for assistance with:**
 - » **picking the SPK type to be used**
 - » **picking the method for producing SPK files**
 - » **designing tests to validate the process**
 - **Ask NAIF for samples of SPK files from other missions that could help you check your process.**



Navigation and Ancillary Information Facility

Allowed SPK Types and Their Restrictions for Interfaces with the Service Preparation System (SPS) of NASA's Deep Space Network



DSN Interface Overview

Navigation and Ancillary Information Facility

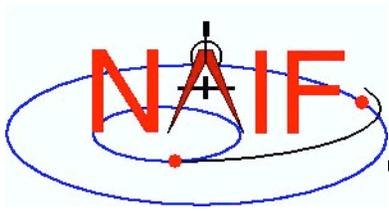
- **SPKs prepared for use in the DSN/SPS may be used in one or more of five software sets:**
 - **Metric Predicts Generator (MPG)**
 - » **Used for view period generation, DSN scheduling and DSN metric predicts (antenna pointing and tuning of the transmitters and receivers)**
 - **Telecomm Predictcs (UTP/TFP)**
 - » **Subsystem for prediction and analysis of telecommunications signal levels**
 - **Radiometric Modeling and Calibration Subsystem (RMC)**
 - » **Used to calibrate atmospheric effects on radio waves**
 - **Delta Differenced One-way Range (Delta-DOR) subsystem**
 - » **A special tracking data type providing additional precision to spacecraft navigation**
- **All SPKs delivered to the SPS must pass through a front-end validation program that has some restrictions.**
- **SPK files intended for use in any of these software sets may face some restrictions. See the next pages.**
 - **(Note: The restrictions that apply as of October 2008 are far less than before this date, due to full retirement of the SPS predecessor—the NSS.)**



SPS Validation Gate

Navigation and Ancillary Information Facility

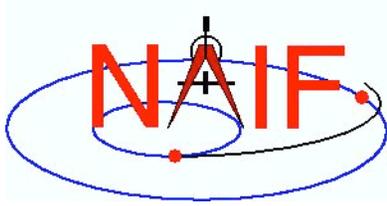
- **The SPS' front-end validation tool requires:**
 - **An SPK contain data for only one spacecraft**
 - » **The presence of non-spacecraft ephemeris data is ok**
 - **An SPK have no data gaps for the spacecraft**
 - **The spacecraft SPK must be of Type 1 or Type 13**



What SPK Type to Use for Interfaces with the DSN?

Navigation and Ancillary Information Facility

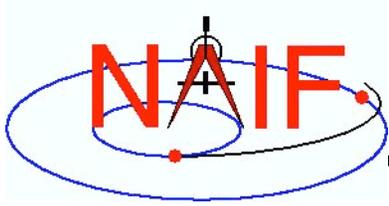
- **The Metric Predicts Generator does not inherently place any restrictions on the SPK files used.**
 - However, current rules of the SPS nevertheless restrict the SPK choice to only Type 1 or Type 13. (Other types not yet fully, formally tested.)
 - This restriction may be lifted in the near future: contact a DSN representative for the latest news.
 - Note: Only JPL NAV teams are able to produce Type 1 SPKs.
- **The telecommunications prediction software does not inherently place any restrictions on the SPK files used.**
- **The radiometric modeling and calibration software requires only Type 1 or Type 13 SPKs**
 - This restriction will be lifted approximately January 2009: contact a DSN representative for the latest news.
- **The delta-DOR software requires only Type 1 or Type 13 SPKs**
 - This restriction is likely to be lifted by approximately November 2009, maybe even sooner.



Navigation and Ancillary Information Facility

Issues Affecting SPK Reading Efficiency

The way you write an SPK file could substantially affect how quickly your customer's software will be able to read the file.



SPK Reading: Efficiency Issues - 1

Navigation and Ancillary Information Facility

- **SPK file creators should design files to support efficient read access.**
 - This requires knowledge of how SPK file attributes impact efficiency.
- **When you store "large" amounts ($>10^7$ states or data packets) of ephemeris data in one or more SPK files, SPK reading efficiency may be affected by:**
 - SPK segment size
 - Number of segments for a body in one SPK file
 - Number of segments for a body contributed by multiple SPK files
 - The number of loaded segments for all bodies
 - The number of loaded files



SPK Reading: Efficiency Issues - 2

Navigation and Ancillary Information Facility

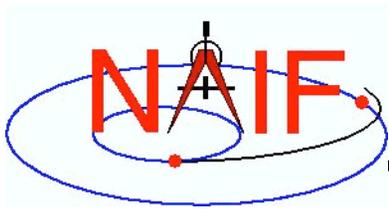
- **Segment size**
 - When a segment contains more than 10,000 states or data packets, the SPK readers will generally take longer to search the segment for requested data.
 - » When the segment is larger than this size, more records are read to look up segment directory information. If these records are not buffered, more physical records are read from the SPK file.
 - There is a trade-off between segment size and numbers of segments and files.
 - » It can be preferable to have large segments rather than have "too many" segments or files. (Read on)



SPK Reading: Efficiency Issues - 3

Navigation and Ancillary Information Facility

- **Number of segments for a body in one SPK file**
 - An SPK file **MUST** not contain more segments for one body than can be "buffered" at one time.
 - » The SPK reading system buffers coverage descriptions ("segment descriptors") for segments it has examined to satisfy previous requests for state data.
 - Don't confuse descriptor buffering with data buffering.
 - The SPK reading system also buffers segment DATA, as opposed to segment descriptors, but this is not relevant to this discussion.
 - » One fixed-size buffer is used for all SPK segments.
 - The size of this buffer is given by the parameter "STSIZE," declared in the SPKBSR suite of routines.
 - STSIZE is currently set by NAIF to 30,000.
 - NAIF recommends that users **NOT** change this parameter, since maintenance problems may result.
 - » Unsurprisingly, the system works best when all needed segment descriptors are buffered simultaneously.



SPK Reading: Efficiency Issues - 4

Navigation and Ancillary Information Facility

- **Number of segments for a body in one SPK file, continued:**
 - » The buffering scheme is "lazy": no descriptors are buffered for segments that haven't been examined.
 - But when an SPK file is searched for data for a specified body, descriptor data for ALL segments in the file for that body are buffered.
 - » The buffering algorithm can "make room" in the buffer by discarding unneeded, buffered descriptor data.
 - A "least cost" algorithm decides which buffered data to discard.
 - » When more buffer room is needed than can be found:
 - The SPK reading system reads data directly from SPK files without buffering descriptor information.
 - This is NOT an error case: the SPK system will continue to provide correct answers.
 - **BUT: the system will run VERY SLOWLY.**
 - This situation is analogous to "thrashing" in a virtual-memory operating system.
 - If buffer overflow occurs frequently, the SPK reading system may be too slow to be of practical use.



SPK Reading: Efficiency Issues - 5

Navigation and Ancillary Information Facility

- **Number of segments for a body contributed by multiple SPK files:**
 - **Buffer overflow can occur if too many segments for one body are contributed by multiple loaded SPK files.**
 - » **Overflow can take longer to occur than in the single-SPK case, due to lazy buffering: files that haven't been searched don't consume buffer space.**
 - Thus an impending overflow problem may not be detected early in a program run.
 - **User applications can avoid buffer overflow if data are appropriately spread across multiple SPK files.**
 - » **Applications can avoid buffer overflow by:**
 - loading only those files of immediate interest
 - unloading files once they're no longer needed



SPK Reading: Efficiency Issues - 6

Navigation and Ancillary Information Facility

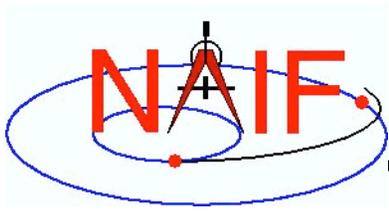
- **Number of segments for all bodies, contributed by all loaded SPK files:**
 - **Buffer overflow does not result from loading SPK files contributing more than STSIZE segments for different bodies.**
 - **However, if the total number of loaded segments for bodies of interest exceeds STSIZE, thrashing can occur as descriptor data are repeatedly discarded from the buffer and then re-read.**
 - » **Loaded segments for bodies for which data are not requested do not contribute to the problem.**
 - **For best efficiency, load only files contributing fewer than a total of STSIZE segments for all bodies of interest.**
 - » **When more than STSIZE segments are needed, applications should process data in batches: unload files containing unneeded data in order to make room for new files.**



SPK Reading: Efficiency Issues - 7

Navigation and Ancillary Information Facility

- **Number of loaded SPK files:**
 - **Up to 1000 SPK files may be loaded at one time by an application.**
 - » **The "1000" limit applies to DAF-based files, so loaded C-kernels and binary PCK kernels count against this limit.**
 - **But loading large numbers of SPK files hurts efficiency:**
 - » **Since operating systems usually allow a process to open much fewer than 1000 files, the SPK system must open and close files via the host system's file I/O API in order to provide a "virtual" view of 1000 open files.**
 - **The more such file I/O, the slower an application runs.**
 - » **Loading a large number of SPK files could result in a buffering problem if too many segments are loaded for bodies of interest.**

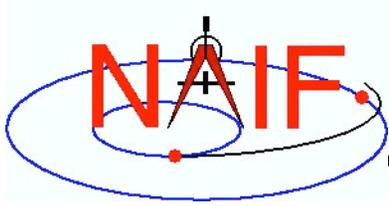


SPK Reading: Efficiency Issues - 8

Navigation and Ancillary Information Facility

- **Recommendations**

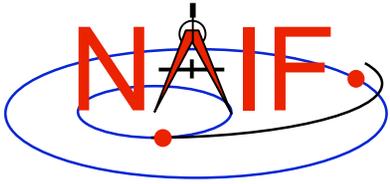
- **Limit segment counts to avoid buffer overflow and thrashing**
 - » **Never have more than STSIZE segments for one body in an SPK file and never have more than STSIZE segments for one body loaded simultaneously.**
 - » **Don't require users to have more than STSIZE segments loaded at one time.**
 - » **If necessary, use larger segments to enable smaller segment counts.**
- **Consider distributing SPK data across multiple files:**
 - » **so as to make selective SPK loading convenient**
 - **facilitate processing data in batches**
 - » **so that loading very large numbers of SPK files at once is unnecessary**



SPK Reading: Further Usability Issues

Navigation and Ancillary Information Facility

- **We've discussed reading efficiency in terms of application execution speed; other usability concerns include:**
 - ease with which files can be transferred between systems
 - simplicity of file management required of user applications
 - ease with which files of interest can be identified by users, both for current use and in an archival setting



Navigation and Ancillary Information Facility

Making a CK file

January 2009



Summary

Navigation and Ancillary Information Facility

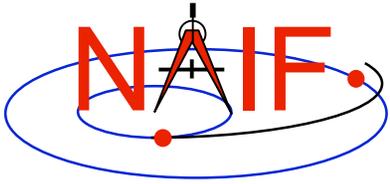
- **SPICE provides means to create CK files either by packaging orientation computed elsewhere or by first computing orientation and then packaging it in a CK file**
- **Packaging of already existing orientation data can be done in two ways:**
 - Use SPICE CK writer routines by calling them from within a SPICE-based application
 - Convert a text file containing attitude data to a CK using the *msopck* program
- **Computing as well as packaging orientation can be done in two ways:**
 - Use SPICE geometry routines and CK writer routines by calling them from within a SPICE-based application
 - » Constructing attitude using SPICE routines is not discussed here
 - Convert orientation rules and schedules to a CK using the *prediCkt* program



CK Writer Routines

Navigation and Ancillary Information Facility

- **The SPICE toolkit provides the following CK writer routines for the FORTRAN, C, IDL and MATLAB toolkits, respectively:**
 - For Type 1 CK
 - » CKW01 / ckw01_c / cspice_ckw01
 - For Type 2 CK
 - » CKW02 / ckw02_c / cspice_ckw02
 - For Type 3 CK
 - » CKW03 / ckw03_c / cspice_ckw03
 - For Type 4 CK
 - » CKW04B, CKW04A, CKW04E (no CSPICE, Icy, or Mice wrappers)
 - For Type 5 CK
 - » CKW05 / ckw05_c (no Icy or Mice wrapper)
- **Only the Type 3 writer is discussed in this tutorial**
 - Writers for Types 1 and 2 have very similar interfaces
 - Types 4 and 5 are are not commonly used

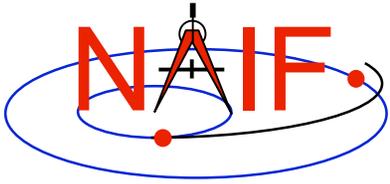


Type 3 Writer Example - 1

Navigation and Ancillary Information Facility

- **The following C-language code fragment illustrates the creation of a Type 3 C-kernel having a single segment.**

```
ckopn_c ( filename, "my-ckernel", 0, &handle );  
/*  
    Insert code that properly constructs the  
    sclkdp, quats, avvs, and starts arrays.  
*/  
ckw03_c ( handle, begtim, endtim, inst,  
         "reference_frame", avflag, "segment_id",  
         nrec, sclkdp, quats, avvs, nints, starts );  
  
ckcls_c ( handle );
```



Type 3 Writer Example - 2

Navigation and Ancillary Information Facility

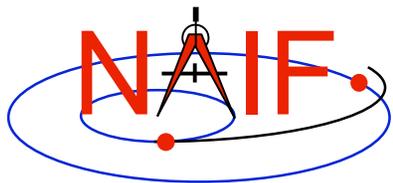
- **handle** - file handle for the newly created C-kernel.
- **begtim, endtim** - start and stop times in SCLK ticks for the segment.
- **inst** - ID code for the instrument for which the C-kernel is being made.
- **ref** - name of the base reference frame. Must be one known to SPICE during your program execution.
- **avflag** - a `SpiceBoolean` indicating whether or not to include angular velocity in the segment.
- **segid** - a string identifying the segment. It must be no more than 40 characters in length.



Type 3 Writer Example - 3

Navigation and Ancillary Information Facility

- **nrec** - number of records in **sclkdp**, **quats**, and **avvs**.
- **sclkdp** - monotonically increasing list of times, given in **SCLK** ticks, that identify when **quats** and **avvs** were sampled.
- **quats** - a list of **SPICE** quaternions that rotate vectors from the base frame specified by the **ref** argument to the **inst** frame.
 - `m2q_c (C_matrix, quaternion);`
- **avvs** - angular rate vectors given in the base frame specified by the **ref** argument.
- **starts** - a list of **SCLK** ticks indicating the start of interpolation intervals. They must correspond to entries in **sclkdp**.
- **nints** - number of entries in **starts**.



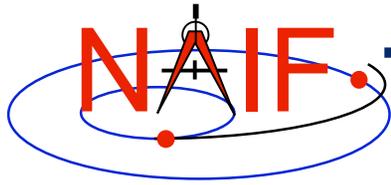
Type 3 writer - Making Up Rates

Navigation and Ancillary Information Facility

- **One of the easiest ways to accomplish this is to assume a constant rotation rate between subsequent quaternions:**

```
for(k=0; k<(nrec-1); k++ ) {  
    q2m_c ( quats[k][0], init_rot );  
    q2m_c ( quats[k+1][0], final_rot );  
    mtxm_c ( final_rot, init_rot, rotmat );  
    raxisa_c ( rotmat, axis, &angle );  
    sct2e_c ( scid, sclkdp[k], &init_et );  
    sct2e_c ( scid, sclkdp[k+1], &final_et );  
    vscl_c ( angle/(final_et-init_et), axis,  
            &avvs[k][0] );  
}
```

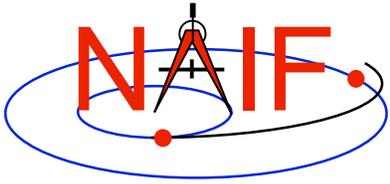
- **Then copy the (nrec-1) value of avvs into the last element of avvs.**



Type 3 Writer - Making Up Rates (2)

Navigation and Ancillary Information Facility

- **Constructing angular rates in this fashion assumes that no more than a 180-degree rotation has occurred between adjacent quaternions. In short, `raxisa_c` chooses the smallest angle that performs the rotation encapsulated in the input matrix.**
- **Other techniques exist, including differentiating quaternions. Care must be exercised when taking that particular approach, however.**

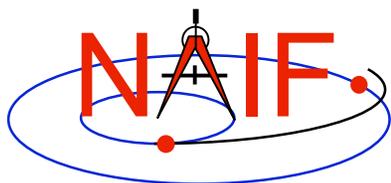


MSOPCK

Navigation and Ancillary Information Facility

- ***msopck* is a program for making CK files from orientation provided as a time tagged, space-delimited table in a text file**
- ***msopck* can process quaternions (SPICE and non-SPICE flavors), Euler angles, or matrixes, tagged with UTC, SCLK, or ET**
- ***msopck* requires all setups to be provided in a setup file that follows the SPICE text kernel syntax**
- ***msopck* has a simple command line interface with the following usage**

```
msopck setup_file input_data_file output_ck_file
```
- **If the specified output CK already exists, new segment(s) are appended to it**



MSOPCK

List of Setup File Keywords

Supporting
Kernels/Files

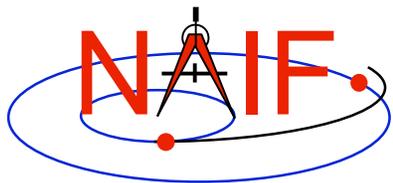
Output CK
Specifications

Input data
Specifications

Optional and
conditional
keywords are
shown in green

Navigation and Ancillary Information Facility

| | |
|------------------------|---|
| LSK_FILE_NAME | = 'LSK file' |
| SCLK_FILE_NAME | = 'SCLK file' (or MAKE_FAKE_SCLK='new SCLK file') |
| FRAMES_FILE_NAME | = 'FRAMES file' |
| COMMENTS_FILE_NAME | = 'file containing comments' |
| PRODUCER_ID | = 'producer group/person name' |
| INTERNAL_FILE_NAME | = 'internal file name string' |
| CK_SEGMENT_ID | = 'segment ID string' |
| CK_TYPE | = 1, 2, or 3 |
| INSTRUMENT_ID | = CK ID |
| REFERENCE_FRAME_NAME | = 'reference frame name' |
| MAXIMUM_VALID_INTERVAL | = interval length, seconds |
| INPUT_TIME_TYPE | = 'SCLK', 'UTC', 'TICKS', 'DPSCLK', or 'ET' |
| TIME_CORRECTION | = bias to be applied to input times, seconds |
| INPUT_DATA_TYPE | = 'MSOP QUATERNIONS', 'SPICE QUATERNIONS',
'EULER ANGLES', or 'MATRICES' |
| QUATERNION_NORM_ERROR | = maximum normalization error |
| EULER_ANGLE_UNITS | = 'DEGREES' or 'RADIANS' |
| EULER_ROTATIONS_ORDER | = ('axis3', 'axis2', 'axis1') |
| EULER_ROTATIONS_TYPE | = 'BODY' or 'SPACE' |
| ANGULAR_RATE_PRESENT | = 'YES', 'NO', 'MAKE UP', 'MAKE UP/NO AVERAGING' |
| ANGULAR_RATE_FRAME | = 'REFERENCE' or 'INSTRUMENT' |
| ANGULAR_RATE_THRESHOLD | = (max X rate, max Y rate, max Z rate) |
| OFFSET_ROTATION_ANGLES | = (angle3, angle2, angle1) |
| OFFSET_ROTATION_AXES | = ('axis3', 'axis2', 'axis1') |
| OFFSET_ROTATION_UNITS | = 'DEGREES' or 'RADIANS' |
| DOWN_SAMPLE_TOLERANCE | = down sampling tolerance, radians |
| INCLUDE_INTERVAL_TABLE | = 'YES' or 'NO' (default 'YES') |



MSOPCK - Input Details (1)

Navigation and Ancillary Information Facility

Four Examples

`INPUT_DATA_TYPE = 'SPICE QUATERNIONS'`

Input file:

```
TIME1 [TIME2] QCOS QSIN1 QSIN2 QSIN3 [ARX ARY ARZ ]  
.....  
TIME1 [TIME2] QCOS QSIN1 QSIN2 QSIN3 [ARX ARY ARZ ]
```

`INPUT_DATA_TYPE = 'MSOP QUATERNIONS'`

Input file:

```
TIME1 [TIME2] -QSIN1 -QSIN2 -QSIN3 QCOS [ARX ARY ARZ ]  
.....  
TIME1 [TIME2] -QSIN1 -QSIN2 -QSIN3 QCOS [ARX ARY ARZ ]
```

`INPUT_DATA_TYPE = 'EULER ANGLES'`

Input file:

```
TIME1 [TIME2] ANG3 ANG2 ANG1 [ARX ARY ARZ ]  
.....  
TIME1 [TIME2] ANG3 ANG2 ANG1 [ARX ARY ARZ ]
```

`INPUT_DATA_TYPE = 'MATRICES'`

Input file:

```
TIME1 [TIME2] M11 M12 M13 M21 ... M33 [ARX ARY ARZ ]  
.....  
TIME1 [TIME2] M11 M12 M13 M21 ... M33 [ARX ARY ARZ ]
```



MSOPCK - Input Details (2)

Navigation and Ancillary Information Facility

- **Quaternions**

- **INPUT_DATA_TYPE = 'SPICE QUATERNIONS'** indicates the quaternions being used follow the SPICE formation rules(*)
- **INPUT_DATA_TYPE = 'MSOP QUATERNIONS'** indicates the quaternions being used follow the traditional AACS formation rules(*)
 - » Normally quaternions that come in telemetry are of this type
- **QUATERNION_NORM_ERROR** keyword may be used to identify and filter out input records with quaternions that are not unit vectors
 - » It is set a tolerance for comparing the norm of the input quaternion with 1

- **Euler angles**

- All three angles must be provided
- For the angles provided on the input as

```
TIME1 [TIME2] ANG3 ANG2 ANG1 [ ARX ARY ARZ ]
```

and rotation axes specified in the setup as

```
EULER_ROTATIONS_ORDER = ( 'axis3', 'axis2', 'axis1' )
```

the matrix rotating vectors from base to the structure frame is computed as

```
Vinst = [ANG3]axis3 * [ANG2]axis2 * [ANG1]axis1 * Vref
```

- Angles can be provided in degrees or radians

(*) NAIF prepared and provides on request a “white paper” explaining differences between various quaternion styles.



MSOPCK - Input Details (3)

Navigation and Ancillary Information Facility

- **Angular rates are an optional input. Their presence or absence must be indicated using the `ANGULAR_RATE_PRESENT` keyword**
 - If angular rates are provided (`ANGULAR_RATE_PRESENT = 'YES'`), they must be in the form of a 3d vector expressed either in the base frame (less common) or instrument frame (more common)
 - » The `ANGULAR_RATE_FRAME` keyword must be set to indicate which of the two is used
 - If angular rates are not provided, the program can either make a CK without rates (`ANGULAR_RATE_PRESENT = 'NO'`), or try to compute rates from the orientation data by using uniform rotation algorithm implemented in Type 3 CK, either with averaging (`ANGULAR_RATE_PRESENT = 'MAKE UP'`) or without averaging (`ANGULAR_RATE_PRESENT = 'MAKE UP/NO AVERAGING'`) of the rates computed for adjacent orientation data points
 - `ANGULAR_RATE_THRESHOLD` may be used to identify and filter out input records with angular rate components that are too large to be real
- **Input data can be tagged with UTC, SCLK, SCLK ticks or ET, as specified using the `INPUT_TIME_TYPE` keyword**
 - Time tags must not have embedded spaces

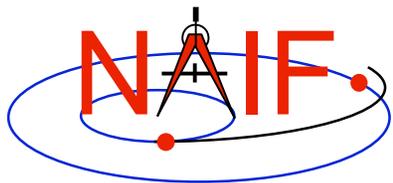


MSOPCK - Output Details (1)

Navigation and Ancillary Information Facility

- ***msopck* can generate Type 1, 2, or 3 CKs**
 - Type 1 is rarely used - only in cases when the input contains very few data points that are far apart so that interpolation between them makes no sense
 - Type 2 is also rarely used, primarily to package orientation for spinners
 - » Normally the input for making Type 2 CKs should contain two times and the angular rate in each record
 - Type 3 is the most commonly used type because it provides interpolation between the orientation data points stored in the CK
- **Interpolation intervals are determined based on the threshold value specified in the `MAXIMUM_VALID_INTERVAL` keyword**
 - The threshold interval is given in seconds
 - A Type 3 CK will allow interpolation between all input points for which the duration between points is less than or equal to the threshold
- **An additional transformation to be combined with the input attitude may be specified using `OFFSET_ROTATION_*` keywords**
 - The convention for specification of the offset rotation angles is the same as for the input Euler angles
 - A vector defined in the base frame is first multiplied by the offset rotation

$$V_{inst} = [ROT_{input}] * [ROT_{offset}] * V_{ref}$$



MSOPCK - Output Details (2)

Navigation and Ancillary Information Facility

- **The time tags may be adjusted by a constant value specified in seconds using the `TIME_CORRECTION` keyword**
- **The output CK file contains one or more CK segments**
 - Multiple segments are generated if the input data volume is large and does not fit into the program's internal buffer (100,000 pointing records)
 - When the output file has many segments, each segment's start time is equal to the stop time of the previous segment, i.e. there are no gaps at the segment boundaries
- **The Comment area of the output CK contains the following information:**
 - Contents of the comment file, if it was specified using the `COMMENT_FILE_NAME` keyword
 - Contents of the setup file
 - Summary of coverage for each segment written to the file, including a table listing interpolation intervals for segments of Type 2 or 3



MSOPCK - Example (1)

Navigation and Ancillary Information Facility

```
Terminal Window
$ more msopck_setup.example
MSOPCK setup for predict M'01 CK generation.
=====
\begindata
  PRODUCER_ID           = 'NAIF/JPL'
  LSK_FILE_NAME         = 'naif0007.tls'
  SCLK_FILE_NAME        = 'ORB1_SCLKSCET.00001.tsc'
  COMMENTS_FILE_NAME    = 'msopck_comments.example'
  INTERNAL_FILE_NAME     = 'sample M01 SC Orientation CK File'
  CK_SEGMENT_ID         = 'SAMPLE M01 SC BUS ATTITUDE'
  INSTRUMENT_ID         = -53000
  REFERENCE_FRAME_NAME  = 'MARSIAU'
  CK_TYPE                = 3
  MAXIMUM_VALID_INTERVAL = 60
  INPUT_TIME_TYPE        = 'SCLK'
  INPUT_DATA_TYPE        = 'MSOP QUATERNIONS'
  QUATERNION_NORM_ERROR  = 1.0E-3
  ANGULAR_RATE_PRESENT  = 'MAKE UP'
\begintext
$
```



MSOPCK - Example (2)

Navigation and Ancillary Information Facility

```
Terminal Window
$ more msopck_comments.example

Sample Mars Surveyor '01 Orbiter Spacecraft Orientation CK File
=====

Orientation Data in the File
-----

This file contains sample orientation for the Mars Surveyor '01
Orbiter (M01) spacecraft frame, 'M01_SPACECRAFT', relative
to the Mars Mean Equator and IAU vector of J2000, 'MARSIAU', inertial
frame. The NAIF ID code for the 'M01_SPACECRAFT' frame is -53000.

Status
-----

This file is a special sample C-Kernel file created by NAIF to illustrate
MSOPCK program. This file should not be used for any other purposes.

...

```



MSOPCK - Example (3)

Navigation and Ancillary Information Facility

```
Terminal Window
$ more msopck_input.example
0767491368.064    -0.24376335    0.68291384    0.28475901    0.62699316
0767491372.114    -0.24249471    0.68338563    0.28591829    0.62644323
0767491373.242    -0.24204185    0.68355329    0.28633291    0.62624605
0767491374.064    -0.24194814    0.68358228    0.28641744    0.62621196
0767491380.064    -0.24012676    0.68424169    0.28807922    0.62543010
0767491386.064    -0.23830473    0.68489895    0.28973563    0.62464193
0767491392.064    -0.23648008    0.68555126    0.29139303    0.62384833
0767491398.064    -0.23465389    0.68620253    0.29304524    0.62304745
0767491404.064    -0.23282999    0.68684150    0.29470173    0.62224580
0767491404.114    -0.23277293    0.68686688    0.29475362    0.62221455
0767491405.242    -0.23231585    0.68702790    0.29516507    0.62201253
0767491410.064    -0.23100059    0.68748174    0.29634561    0.62143935
0767491416.064    -0.22917353    0.68811325    0.29799308    0.62062853
0767491422.064    -0.22734161    0.68874177    0.29963482    0.61981412
0767491428.064    -0.22551078    0.68936246    0.30128030    0.61899473
0767491434.064    -0.22367453    0.68998299    0.30291779    0.61816987
0767491436.114    -0.22300583    0.69021050    0.30351804    0.61786298
0767491438.011    -0.22251770    0.69037871    0.30395477    0.61763631
...
```

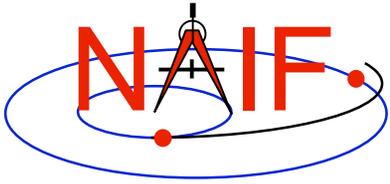


MSOPCK - Example (4)

Navigation and Ancillary Information Facility

```
Terminal Window
$ msopck msopck_setup.example msopck_input.example msopck_example_ck.bc

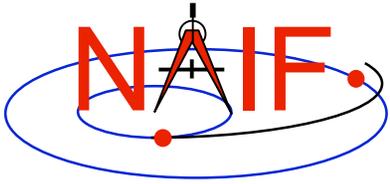
MSOPCK Utility Program, Version 3.0.0, 2003-05-05; SPICE Toolkit Ver. N0057
...
<comment file contents>
...
<setup file contents>
...
*****
RUN-TIME OBTAINED META INFORMATION:
*****
PRODUCT_CREATION_TIME = 2004-04-29T12:17:55
START_TIME             = 2004-04-27T00:00:05.516
STOP_TIME              = 2004-04-27T23:59:56.275
*****
INTERPOLATION INTERVALS IN THE FILE SEGMENTS:
*****
SEG.SUMMARY: ID -53000, COVERG: 2004-04-27T00:00:05.516 2004-04-27T23:59:56.275
-----
                2004-04-27T00:00:05.516      2004-04-27T20:05:26.282
                2004-04-27T20:11:20.278     2004-04-27T23:59:56.273
```



PREDICKT

Navigation and Ancillary Information Facility

- ***prediCkt* is a program for making CK files from a set of orientation specification rules, and schedules defining when these rules are to be followed**
- ***prediCkt* has a simple command line interface**
- ***prediCkt* requires orientation and schedule specification to be provided in a setup file that follows the SPICE text kernel syntax**
- ***prediCkt* requires the names of all supporting kernels -- SPK, PCK, etc -- be provided in a meta-kernel (a “furnsh kernel”)**
- ***prediCkt* is available only from the Utilities link of the NAIF webpages**



PREDICKT - Usage

Navigation and Ancillary Information Facility

- ***prediCkt* has the following command line arguments**

```
prediCkt -furnish support_data  
        -spec ck_specs  
        -ck outfile  
        -tol fit_tolerance [units]  
        -<sclk|newsclk> sclk_kernel
```

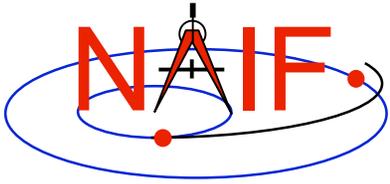
- **'-furnish', '-spec' and '-ck' are used to specify the input meta-kernel, input attitude specification file and output CK file**
- **'-tol' is used to specify the tolerance to which the orientation stored in the CK should match the specified attitude profile**
- **'-sclk' or '-newsclk' specify the name of an existing SCLK or the new "fake" SCLK to be created for use with the output CK**



PREDICKT - Furnsh and Spec Files

Navigation and Ancillary Information Facility

- **A “FURNISH” kernel lists SPICE kernels that are to be used by prediCkt to determine geometry needed to compute orientations**
- **A prediCkt attitude specification (spec) file following the text kernel syntax is used to provide three types of information:**
 - **Specification of dynamic directions**
 - **Specification of orientations based on these directions**
 - **Specification of the schedules defining when those orientations should be followed**
- **The contents of the FURNISH kernel and the spec file are included in the comment area of the output CK file**

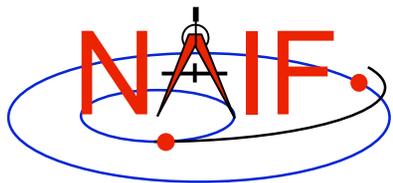


PREDICKT - Directions

Navigation and Ancillary Information Facility

- **Dynamic directions can be of the following types:**
 - Based on ephemeris (position vectors, velocity vectors)
 - Fixed with respect to a frame (expressed as Cartesian vector or specified by RA and DEC)
 - Towards sub-observer point
 - Based on the surface normal and lines of constant latitude or longitude
 - Based on other, already defined directions (rotated from them, computed as cross products using them, etc)
- **Example: these two sets of spec file keyword assignments specify nadir and spacecraft velocity directions for the M01 spacecraft**

```
DIRECTION_SPECS      += ( 'ToMars      = POSITION OF MARS -' )
DIRECTION_SPECS      += (                'FROM M01      -' )
DIRECTION_SPECS      += (                'CORRECTION NONE' )
DIRECTION_SPECS      += ( 'scVelocity = VELOCITY OF M01 -' )
DIRECTION_SPECS      += (                'FROM MARS      -' )
DIRECTION_SPECS      += (                'CORRECTION NONE' )
```

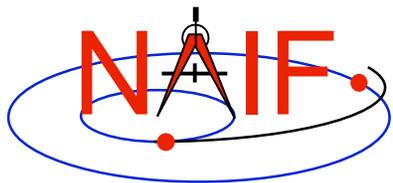


PREDICKT - Orientations

Navigation and Ancillary Information Facility

- **An orientation is specified by:**
 - defining that one of the frame's axes (+X,+Y,+Z,-X,-Y,-Z) points exactly along one of the defined directions
 - defining that another of the frame's axes points as closely as possible to another defined direction
 - » The third axis is the cross product of the first two
 - specifying the base frame with respect to which the orientation of this “constructed” frame is to be computed
- **Example: these spec file keyword assignments specify the nominal nadir orientation for the THEMIS instrument, flown on the M01 spacecraft**

```
ORIENTATION_NAME      += 'CameratoMars'  
PRIMARY                += '+Z = ToMars'  
SECONDARY              += '+Y = scVelocity'  
BASE_FRAME             += 'J2000'
```

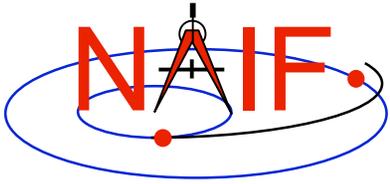


PREDICKT - Schedules (1)

Navigation and Ancillary Information Facility

- **A schedule is defined by specifying a series of time intervals during which a given orientation is to be followed**
 - For each interval for a given CK ID the spec file defines the orientation name, start time, and stop time (as Ephemeris Times)
- **Example: these spec file keyword assignments specify a schedule with a single window during which M01 (Mars Odyssey) will yield nadir-pointed orientation for the THEMIS instrument**

```
CK-SCLK           = 53
CK-SPK            = -53
CK-FRAMES         += -53000
CK-53000ORIENTATION += 'SOLUTION TO M01_THEMIS_IR = CameratoMars'
CK-53000START     += @2004-FEB-10-00:00
CK-53000STOP      += @2004-FEB-15-00:00
```



PREDICKT - Schedules (2)

Navigation and Ancillary Information Facility

- **In the example on the previous slide:**
 - the **CK-FRAMES** keyword specifies the CK ID to be used in the output CK
 - » This ID is incorporated into the keywords defining the schedule intervals
 - the **CK-SCLK** keyword specifies the ID of the SCLK to be used in creating the CK
 - the **CK-SPK** keyword specifies the ID of the object, the position of which is used in applying light time correction when orientation is computed
 - “**SOLUTION TO**” construct specifies that although the orientation is sought for the M01 spacecraft frame (ID -53000), it is computed for the camera frame (M01_THEMIS_IR) and then transformed to the spacecraft frame



PREDICKT - Example (1)

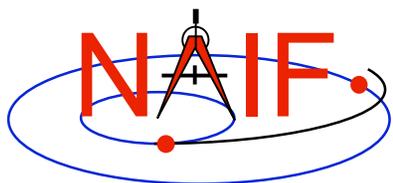
Navigation and Ancillary Information Facility

```
Terminal Window
$ cat m01_map_nadir.predicKt
\begindata
    DIRECTION_SPECS      += ( 'ToMars      = POSITION OF MARS -' )
    DIRECTION_SPECS      += (           'FROM M01      -' )
    DIRECTION_SPECS      += (           'CORRECTION NONE' )

    DIRECTION_SPECS      += ( 'scVelocity = VELOCITY OF M01 -' )
    DIRECTION_SPECS      += (           'FROM MARS      -' )
    DIRECTION_SPECS      += (           'CORRECTION NONE' )

    ORIENTATION_NAME     += 'CameratoMars'
    PRIMARY               += '+Z = ToMars'
    SECONDARY             += '+Y = scVelocity'
    BASE_FRAME            += 'J2000'

    CK-SCLK               = 53
    CK-SPK                = -53
    CK-FRAMES             += -53000
    CK-53000ORIENTATION  += 'SOLUTION TO M01_THEMIS_IR = CameratoMars'
    CK-53000START        += @2004-FEB-10-00:00
    CK-53000STOP         += @2004-FEB-15-00:00
\begintext
```



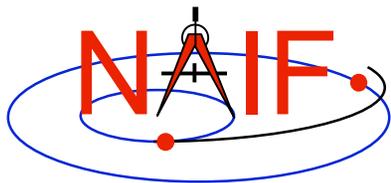
PREDICKT - Example (2)

Navigation and Ancillary Information Facility

```
Terminal Window
$ cat m01_map_nadir.furnsh
\begindata
  KERNELS_TO_LOAD = ( 'naif0007.tls'
                      'm01_v26.tf'
                      'mar033-5.bsp'
                      'm01_map_rec.bsp'
                      'm01.tsc' )
\begintext
$ prediCkt -furnish m01_map_nadir.furnsh -spec m01_map_nadir.predicKt -ck m01_map_nadir.bc -tol
0.01 degrees -sclk m01.tsc

Begin Segment: 1 --- SOLUTION TO M01_THEMIS_IR = CameratoMars

Constructing Segment
From: 2004 FEB 10 00:00:00.000
To   : 2004 FEB 15 00:00:00.000
Percentage finished: 0.0%
Percentage finished: 5.0 %   (50 quaternions)
...
Percentage finished: 95.0 %   (925 quaternions)
$
```



Navigation and Ancillary Information Facility

Introduction to the Events Kernel EK

January 2009

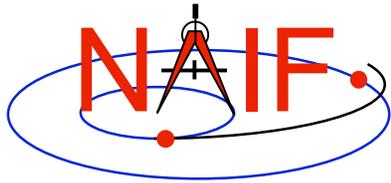
**Note: the EK is rarely used by flight projects.
Only a brief overview of the EK is provided.**



Scope

Navigation and Ancillary Information Facility

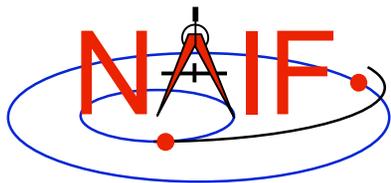
- **This tutorial provides an overview of the entire Events Kernel subsystem, comprised of three components:**
 - Science Plan ESP
 - Sequence ESQ
 - Notebook ENB
- **Depending on specific circumstances:**
 - the three components may exist as three distinct and different products
 - two components may be implemented with a single mechanism
 - one or more components may not be used at all



E-Kernel Subsystem Objectives

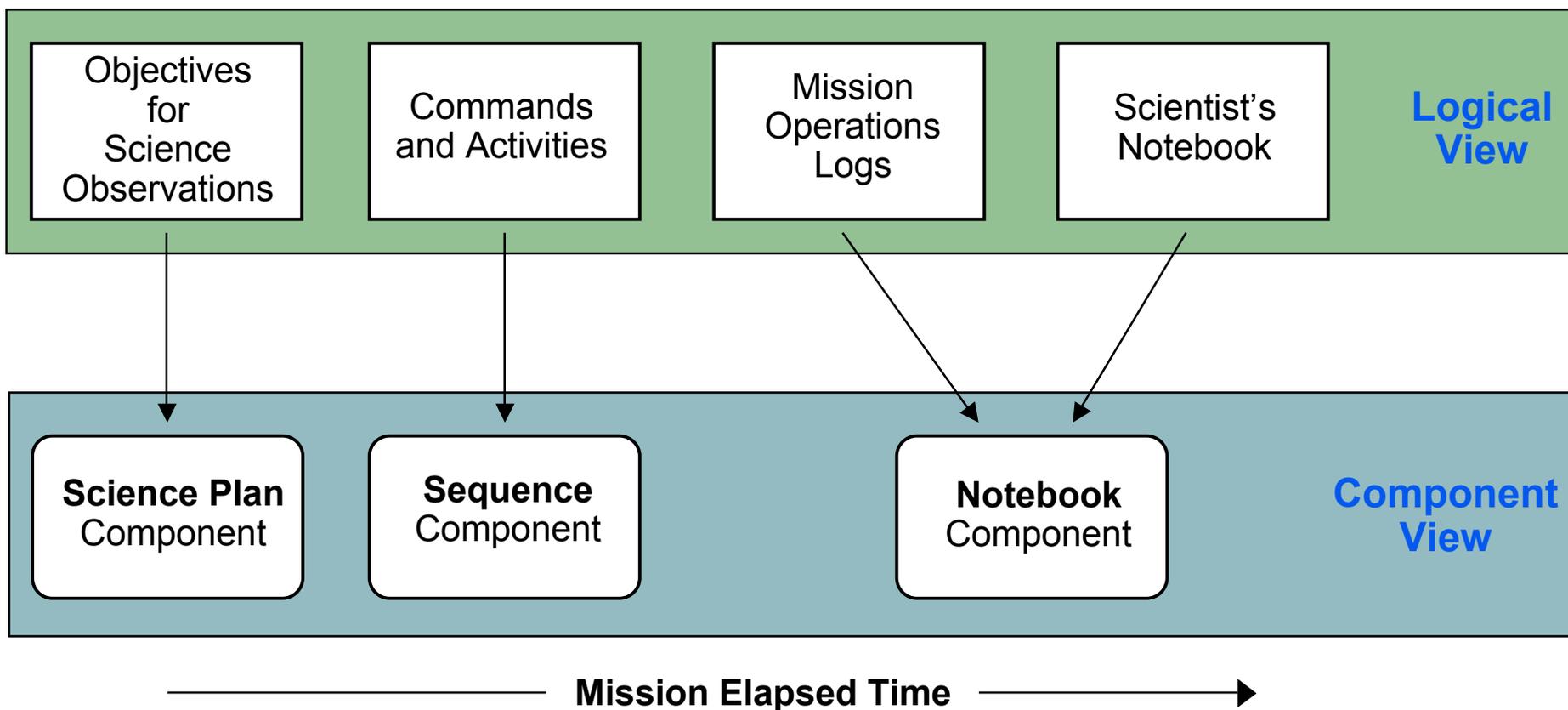
Navigation and Ancillary Information Facility

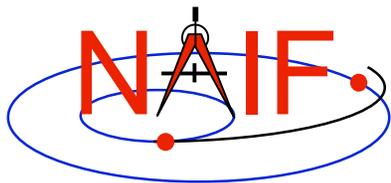
- **Assemble, archive and provide convenient and useful access to plans, commands and notes about the acquisition of space science observations:**
 - For use by on-going project science and engineering team members
 - For use by post-mission researchers
- **Accomplish the above with minimal impact on science and mission operations team members.**



Nominal E-kernel Composition

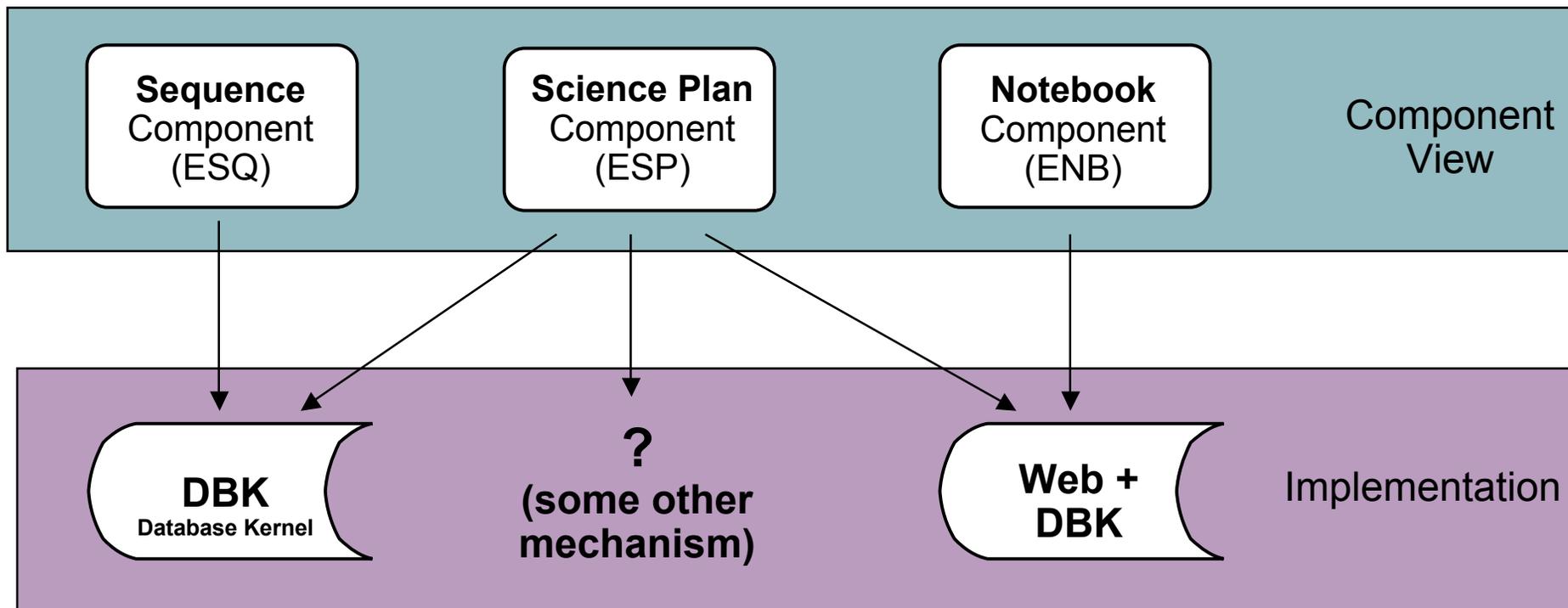
Navigation and Ancillary Information Facility

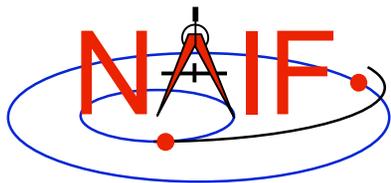




Nominal E-kernel Implementation

Navigation and Ancillary Information Facility

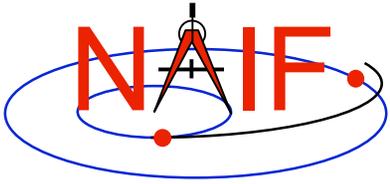




Science Plan - ESP

Navigation and Ancillary Information Facility

- **Each entry is a statement of science objectives for a series of coordinated observations to be made over a stated period of time**
 - **Might include some information about the planned mechanics (observation design) for obtaining the data**
- **This component could be implemented as a part of the SEQUENCE component (ESQ), or as a part of the NOTEBOOK component (ENB), or as a separate product using some other mechanism**



Sequence - ESQ

Navigation and Ancillary Information Facility

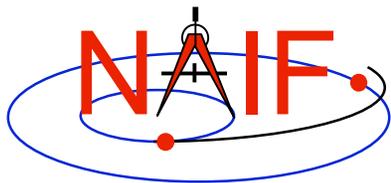
- **Principal entries are instrument and spacecraft “commands” or “macro calls” that carry out the objectives of the Science Plan. These contain the lowest level of detail that could be helpful while also being practical for inclusion in the E-kernel product.**
 - **Could include ground system events, such as tracking station status**
 - **Could include “announcements” of the occurrence of geometric conditions of wide interest, such as equator crossing, occultation entry, etc.**
 - **Could include “state records” that summarize the status of an instrument or subsystem or spacecraft at a given epoch. (If to be included, state records might be derived rather than actually stored as physical objects.)**



Notebook - ENB

Navigation and Ancillary Information Facility

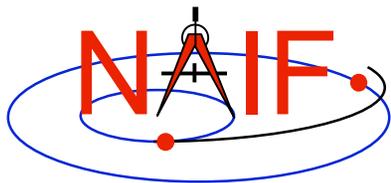
- **Entries are notes provided by scientists and flight team engineers about what happened as mission operations are conducted, including unplanned, unanticipated or unexplained occurrences**
- **Entries could also be general notes thought to be of interest to scientists**
- **Entries submitted using e-mail can include MIME attachments, such as GIF, JPEG, EXCEL, WORD, etc., in addition to plain ASCII text**
- **Entries submitted using WWW are limited to plain ASCII text**



E-Kernel Status

Navigation and Ancillary Information Facility

- **The E-kernel is the least well developed and least used component of the SPICE system**
 - Due in part to not being of as much interest to flight project instrument and engineering teams as the other components
 - » Their perception is that EK information could be useful to future users of a mission's data, but not so much to an active flight team
- **NAIF and other kernel producers seem unlikely to produce EK components in the future.**



Navigation and Ancillary Information Facility

SPICE Development Plans and Possibilities

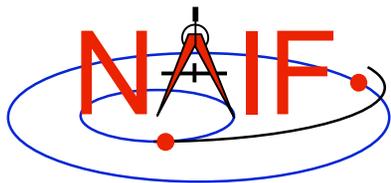
January 2009



Outline

Navigation and Ancillary Information Facility

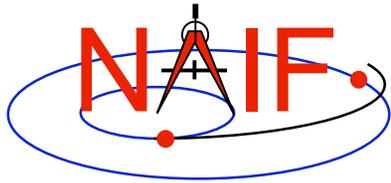
- **Work in progress**
 - Geometric Event Finder subsystem
 - Integrated shape model subsystem
- **Starting next Spring**
- **Future possibilities**
- **Your suggestions?**



Work In Progress

Navigation and Ancillary Information Facility

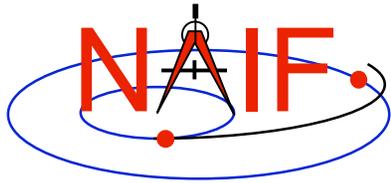
- **Geometric event finder subsystem**
 - Find time(s) when such-and-such a geometric condition exists
 - Alpha-test version being tested now
 - Official addition to Toolkit (N63), planned for release March 2009
 - » Partial subsystem—more capability will be added later
- **Shape model subsystem**
 - Synthesis of current shape model (triaxial ellipsoid), “plate model” for small, irregularly shaped bodies, and a digital elevation model
 - Official addition to Toolkit in approximately late CY2009



Starting Spring 2009

Navigation and Ancillary Information Facility

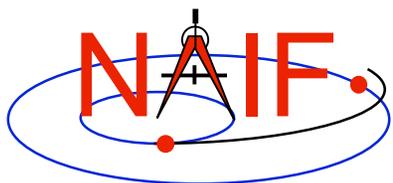
- **Additional interfaces to SPICE**
 - Java Native Interface (JNI) and Python
 - Schedule for release is TBD



Other Possibilities - 1

Navigation and Ancillary Information Facility

- **Provide a tool that will contrast a set of SPK files, thus aiding you in selecting the one(s) of interest**
- **Provide a tool for easier creation of a SPICE frame, and visualization thereof**
- **Provide a “predict spk” tool that makes it easy to construct an SPK file from simple rules**
- **Add more high-level computations, such as instrument footprint coverage**
- **Star catalog integrated with SPICE capabilities**
- **Run-time creation of SPK and CK**



Other Possibilities - 2

Navigation and Ancillary Information Facility

Java/Spice Interface test

Kernels Computations Drawings Log

Illumination Angles

"GEOCALC"

Target: Mars

Observer: MEX

Surface point longitude: 114.786907

Surface point latitude: -14.773171

Observation epoch: 2004 Jan 4 08:52:00.707724

Aberration Correction: NONE, LT, LT+S

Coordinate System: Planetocentric, Planetodetic

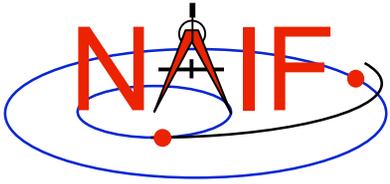
Compute

Illumination angles at surface point, as seen from observer

| | |
|--|----------------------------|
| Target | Mars |
| Observer | MEX |
| Aberration correction | NONE |
| Time | 2004 Jan 4 08:52:00.707724 |
| Surface planetocentric longitude (deg) | 114.786907 |
| Surface planetocentric latitude (deg) | -14.773171 |
| Phase angle (deg) | 37.317459 |
| Solar incidence angle (deg) | 37.317454 |
| Emission angle (deg) | 0.000007 |

Provide a GUI interface to a limited set of SPICE computations.

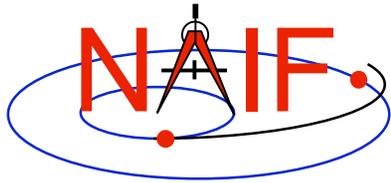
In this example, compute the illumination angles on Mars at LON 114.7 and LAT -14.7 as seen from Mars Express on 2004 JAN 4 08:52:00. The user can pick either a planetocentric or planetodetic reference frame.



Still Other Possibilities?

Navigation and Ancillary Information Facility

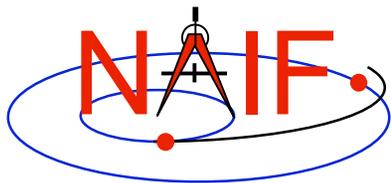
- **Additional target models: rings, gravity, atmosphere, magnetosphere, ...**
- **Develop a more flexible and extensible instrument modeling mechanism**



What do **You** Suggest?

Navigation and Ancillary Information Facility

- **NAIF solicits suggestions from the user community.**
 - We're a small team and have a large backlog, so we can't promise any particular action.
- **We're interested in programmatic ideas as well as technical ones.**
 - Should NAIF promote use of SPICE beyond NASA's planetary science program?
 - What amount of cooperation and interoperability with foreign partners is appropriate and achievable?
 - » Formal versus informal?
 - » With scientists and/or with engineers?

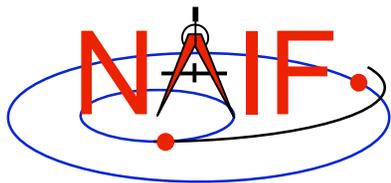


Navigation and Ancillary Information Facility

Shape Model Subsystem Preview

Capabilities, Current Status and Plans

January 2009



SPICE DSK Topics

Navigation and Ancillary Information Facility

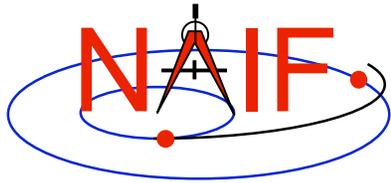
- **Overview**
- **Requirements**
- **DSK Data Representations**
- **DSK System Components**
- **DSK Software Components**
- **DSK API Examples**
- **Using Shape with Orientation Data**
- **DSK Development Status**



Overview

Navigation and Ancillary Information Facility

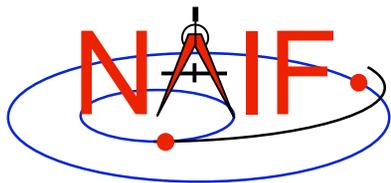
- **NAIF is developing a new SPICE kernel type: DSK (“digital shape kernel”)**
 - When completed, the DSK system will be incorporated into the SPICE Toolkit.
- **The SPICE DSK system deals with data sets describing topography of solar system objects, or more generally, shapes of 3-dimensional objects. Examples:**
 - Digital elevation models (DEM) for the surfaces of Mars or the Moon
 - Tessellated plate model for the surface of a natural satellite, asteroid or comet nucleus
 - Horizon masks for DSN stations
- **The DSK system facilitates high-accuracy, SPICE-based geometric computations using shape data**
 - Currently SPICE uses only triaxial ellipsoid shape models, which support low-accuracy computations
- **The DSK system comprises**
 - The DSK data file format
 - Software (subroutines and programs)
 - Documentation



Requirements -1

Navigation and Ancillary Information Facility

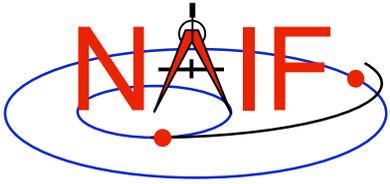
- **All “requirements” listed here are of an informal nature; they are derived from customer interaction and NAIF team members’ experience using SPICE.**
- **Overall requirement: facilitate high-accuracy geometry computations involving surfaces of extended bodies. Examples of computations that should be supported:**
 - » **Location of “sub-observer point” and height of observer above surface**
 - » **Ray-surface intercept point**
 - » **Occultation/transit state of a point target**
 - » **Limb and terminator location**
 - » **Illumination angles at a specified surface point**
 - » **Determine if a target is in an instrument’s field of view (FOV)**



Requirements -2

Navigation and Ancillary Information Facility

- **System should support popular shape representations**
 - For example: DEM, triangular plates
- **System should support efficient random access data search**
 - For example: for a given (LONGITUDE, LATITUDE) coordinate pair, return radius (distance from body center) of the corresponding surface point
- **System should support rapid, high volume data extraction (“bulk read”)**
 - Required for efficient use by graphics applications
- **System should be able to use data sets spread across multiple files**
 - Some current data sets exceed 2Gbytes in size
 - Larger data sets should be expected in the future
 - Impractical to store all needed data in one file
- **System should be able to work with models for different bodies simultaneously.**
 - For example: support simultaneous use of data sets for Mars and Phobos.



Requirements -3

Navigation and Ancillary Information Facility

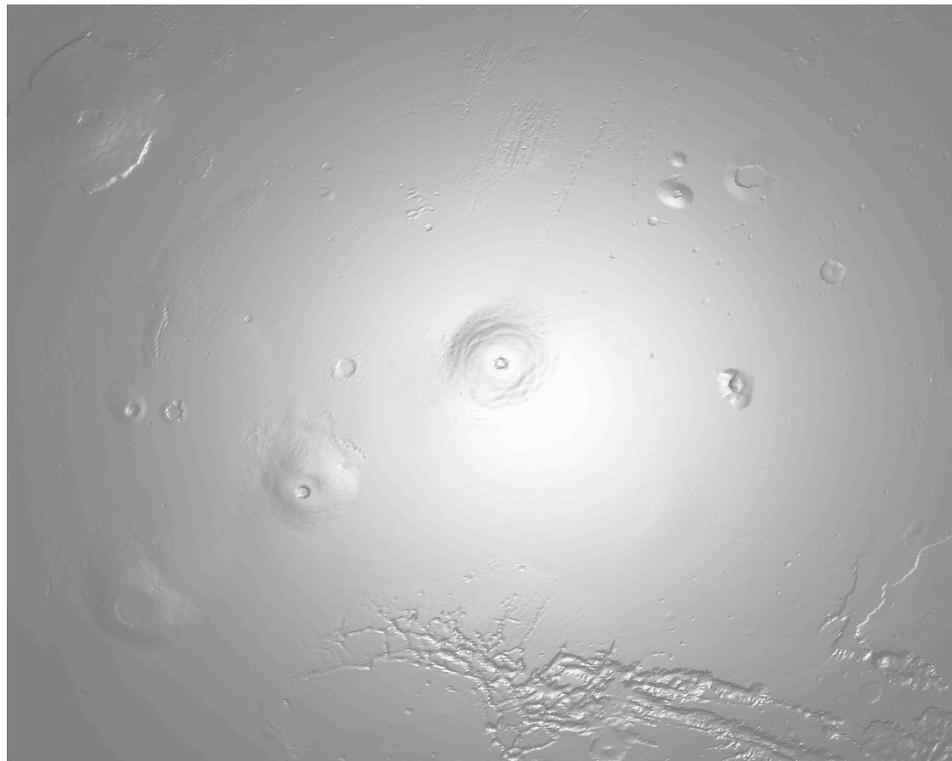
- **System should be able to work with multiple models for different parts of the surface of a specified body simultaneously.**
 - Support simultaneous use of multiple data sets having different resolutions, or even different mathematical representations, for different regions of the surface.
- **Data files should be portable**
- **Data files should support inclusion of metadata**
- **Tools should be provided for:**
 - summarizing contents of data files
 - accessing metadata in data files
 - merging or subsetting data files
 - ingesting data from other types of files
 - » For example: Bob Gaskell's and Peter Thomas' shape models

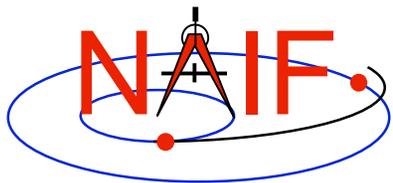


DSK Data Representations -1

Navigation and Ancillary Information Facility

- **Digital elevation model (DEM)**
 - Maps longitude/latitude to “elevation”
 - » Elevation of a surface point can be defined as distance from the origin of a body-fixed reference frame
 - » Elevation can be defined as height above a reference ellipsoid
 - Example: image created from MGS laser altimeter (MOLA) Mars DEM

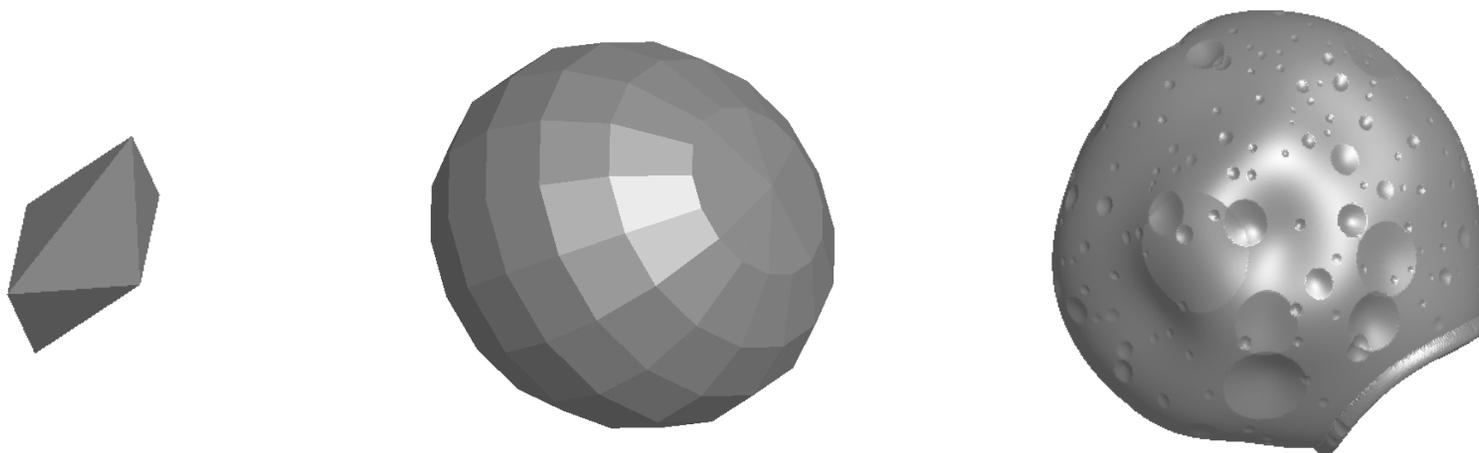




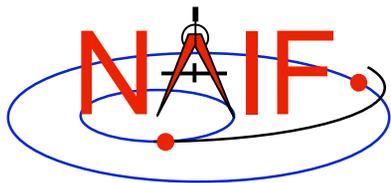
DSK Data Representations -2

Navigation and Ancillary Information Facility

- **Plate model**
 - Surface of object is represented as a collection of triangular plates
 - More flexible than digital elevation model: arbitrary 3-D surface can be modeled
 - » Surface could be a complicated shape with multiple surface points having the same latitude and longitude
 - Examples: “dumbbell”-shaped asteroid, caves, arches
 - Less efficient than digital elevation model of similar resolution in terms of storage and computational speed



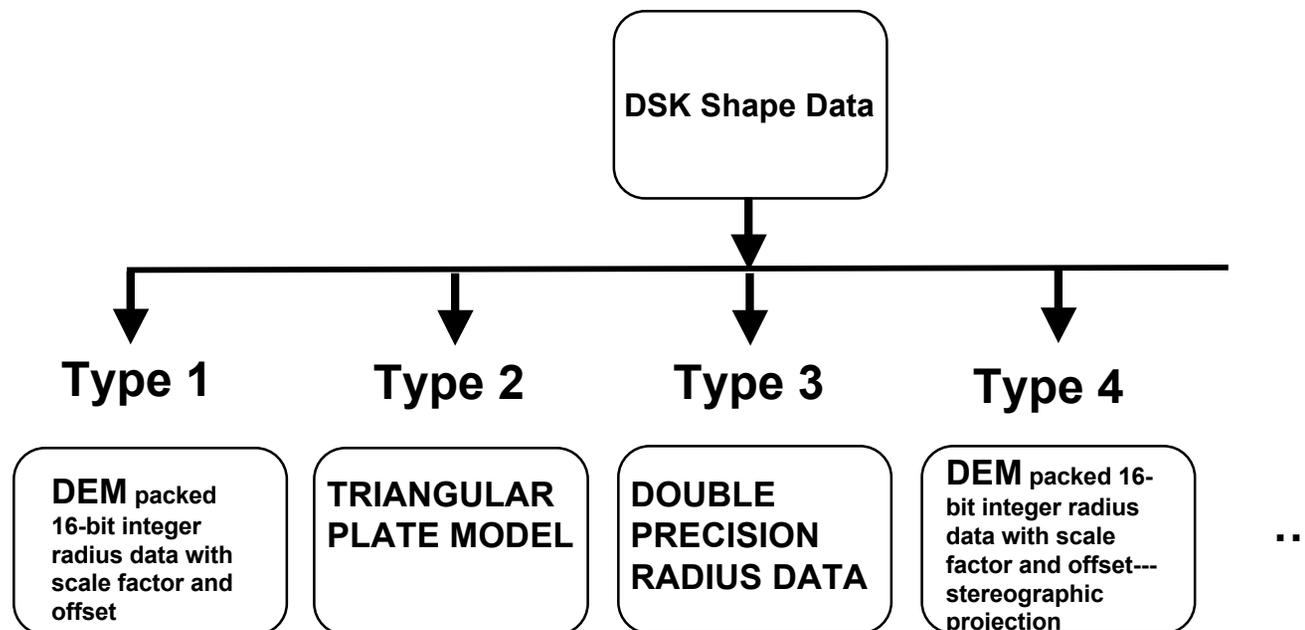
Example images created from DSK plate models (center and right images are based on Phobos data)



DSK Data Representations -3

Navigation and Ancillary Information Facility

- **DSK shape representations are polymorphic:**
 - DSK shape representations are called “Data Types.”
 - Each data type has its own mathematical representation of a surface
 - Each data type has associated software that implements common functionality, such as the ability to return a radius (distance of surface point from body center) value for a specified latitude and longitude.
 - Each data type may have additional, unique functionality.
 - » For example, type 2 has accessor routines that return plate and vertex data. These functions are not applicable to other data types.

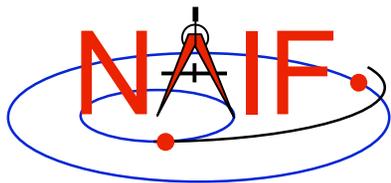




DSK System Components

Navigation and Ancillary Information Facility

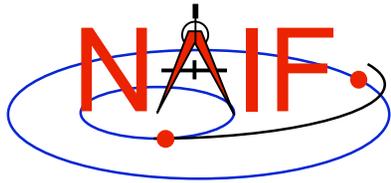
- **DSK Files**
 - Use the SPICE DAS file architecture
 - » Binary, direct access
 - » System-independent buffering built in
 - » Comment area built in
- **DSK Software**
 - SPICE software which enables users to create and use DSK kernels
 - » Writer routines
 - » Reader routines
 - » High-level API routines
 - For example: routines dealing with observer-target geometry
 - » Supporting utility programs
- **DSK Documentation**
 - Tutorial
 - Required Reading file
 - Module headers



DSK Software Components -1

Navigation and Ancillary Information Facility

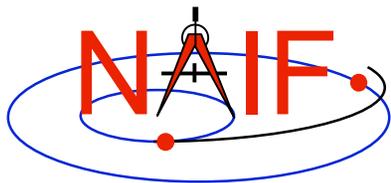
- **Writers**
 - Routines that enable a SPICE-based application to create a DSK kernel
 - » Open new DSK kernel for write access
 - » Open existing DSK kernel for write access
 - » Start new DSK segment (“segments” are partial DSK data sets containing data for a given region on a specified object)
 - » Add data to DSK segment
- **Readers**
 - Routines that extract data from a DSK file
 - » Return elevation of surface at given longitude/latitude
 - » Return specified attributes, for example the surface normal vector, for a specified longitude and latitude
 - » Rapidly obtain data for large portion of surface (“bulk read”)
 - » Return DSK attributes such as number of plates, pixel size, min/max elevation, etc.
- **High-level functions (including, but not limited to, the following):**
 - Compute sub-observer point on surface and height of observer above surface
 - Compute intercept of ray with surface
 - Determine whether a portion of a target body’s surface is within the FOV of specified instrument at specified time.
 - Determine occultation/transit state of a point target
 - Compute limb and terminator location
 - Compute illumination angles at a specified surface point



DSK Software Components -2

Navigation and Ancillary Information Facility

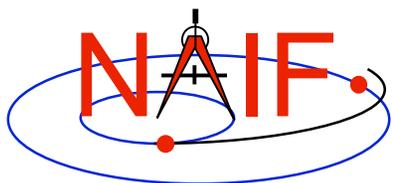
- **Utility programs that**
 - Create DSK files: import other surface shape data sets into SPICE DSK format
 - Port DSK files
 - Provide comment area access
 - Summarize DSK file contents
 - Subset or merge DSK files
 - Downsample DSK files
 - Convert one DSK data type to another
 - » Example: create type 2 DSK file from type 1



DSK API Examples

Navigation and Ancillary Information Facility

- **Get radius at surface point (inputs are in red, outputs in blue):**
 - CALL DSKRAD (**TARGET, LON, LAT, RADIUS**)
 - » Inputs: target body name, longitude and latitude of point of interest
 - » Output: radius (distance from target center) at surface point
- **Find sub-observer point on target:**
 - CALL SUBPT (**METHOD, TARGET, ET, ABCORR, OBSRVR, SPOINT, ALT**)
 - » SUBPT is a generic, high-level API. SUBPT doesn't assume the surface is modeled by a DSK.
 - » Input "METHOD" indicates surface model and sub-point definition
 - For ellipsoids, METHOD may be set to 'near point' or 'intercept'
 - For DSKs, set METHOD to 'DSK intercept', indicating that the sub-point is defined as the closest intersection to the observer of the observer-target center ray with the surface, and DSK model is to be used.
 - Note that SPICE should not assume DSK is to be used just because a DSK for the target body is loaded; may be too inefficient for some applications. Caller must say which model is to be used.
 - » Other inputs: target body name, epoch, aberration correction, observer name.
 - » Outputs: sub-observer point in Cartesian coordinates, expressed in the body-fixed frame associated with the target, and altitude of the observer above the sub-point.



Writing Shape and Orientation Kernels

Navigation and Ancillary Information Facility

LAT/LON and height
above ellipsoid or
distance from center
of frame

**MKDSK
Program**
(SPICE Toolkit)



Digital Terrain
Shape Model

Lists of plate
model vertices
and associated
plates, and
optionally,
albedo data for
each plate

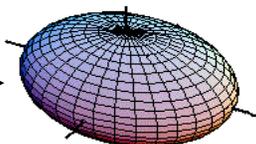
**MKDSK
Program**
(SPICE Toolkit)



Tessellated Plates
Shape Model

Axes dimensions
for tri-axial
ellipsoid

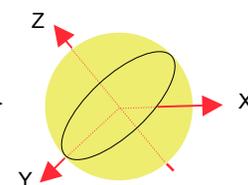
Text editor
(Usually done by
NAIF)



Triaxial Ellipsoid
Shape Model

Some source of
rotation state
information (pole
RA/DEC and
prime meridian
location)

Text editor
(Usually done by
NAIF)



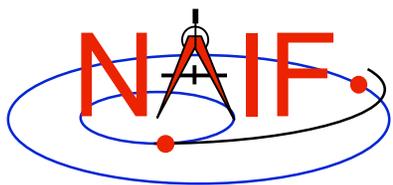
Orientation

DSK

Digital
shape kernel

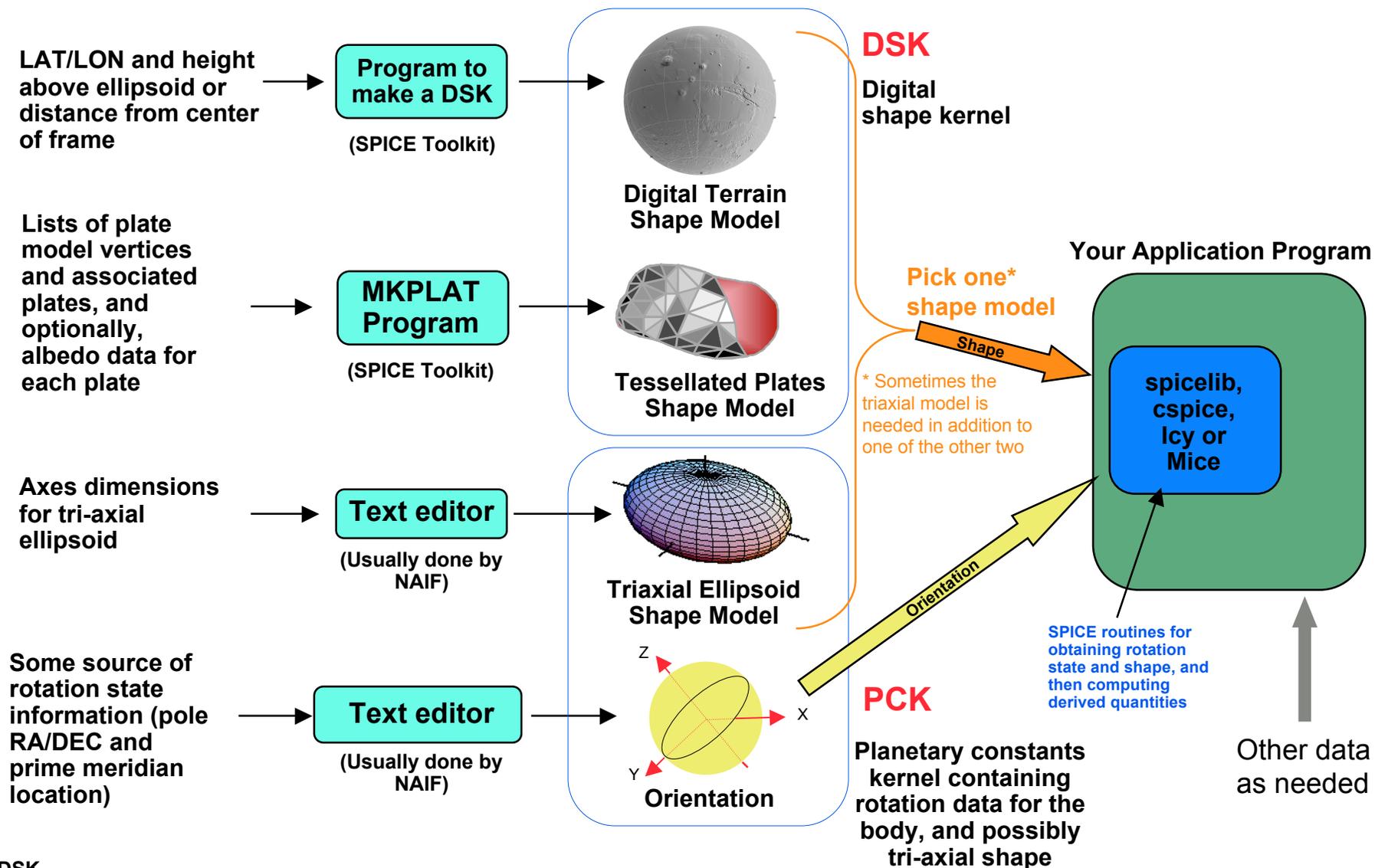
PCK

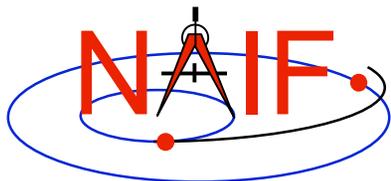
Planetary constants
kernel containing
rotation data for the
body, and possibly
tri-axial shape



Using Shape and Orientation Kernels

Navigation and Ancillary Information Facility





DSK Development Status

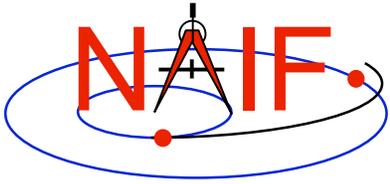
Navigation and Ancillary Information Facility

- **History**

- Precursor “Plate Model” system was delivered to NEAR and Hayabusa and used successfully on those missions
- A prototype version of the DSK system was delivered to the DAWN project in November 2006. This software has been integrated into the SOA (Science Opportunity Analyzer) program.
 - » SOA uses DSK files to import shape model data for Vesta and Ceres.
 - » SOA also uses DSK software, along with custom, higher-level DSK-based software provided by NAIF, to perform geometric computations involving target body shape data.

- **Plans**

- NAIF is currently developing the deliverable DSK system.
- NAIF plans to release an alpha-test version of the DSK system sometime in first half of CY2009 (TBC).
- Release date of a SPICE Toolkit that contains the DSK system is TBD.

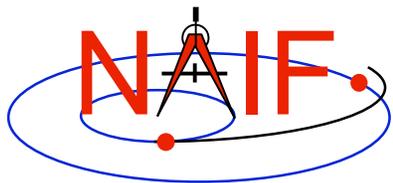


Navigation and Ancillary Information Facility

Event Finding Subsystem Preview

Capabilities, Current Status and Plans

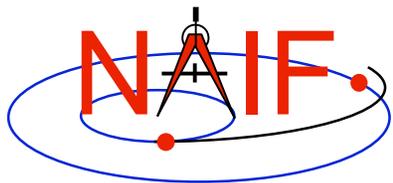
January 2009



Topics

Navigation and Ancillary Information Facility

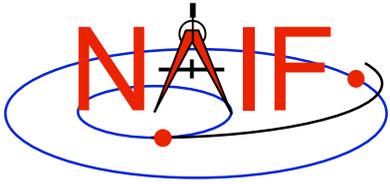
- **Overview**
- **Eclipse Events**
- **Occultation Events**
- **Field-of-View Events**
- **Numeric Events**
- **Windows Math**
- **Pictorial Examples**



Overview

Navigation and Ancillary Information Facility

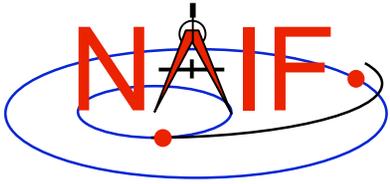
- **This subsystem is designed to identify the times, or time intervals, of particular geometric events.**
 - The Fortran and C Toolkits, SPICELIB and CSPICE, will contain all planned functionality.
 - The IDL and MATLAB Toolkits, Icy and Mice, will include a subset of the planned functionality.
- **The event subsystem algorithms detect four types of events:**
 - Eclipse
 - Occultation
 - Field-of-View
 - Numerical
- **The first three types describe a specific set of geometric conditions identified with the corresponding type name. The fourth type describes a geometric quantity satisfying a numeric relationship.**
- **Status**
 - An alpha-test version is available now.
 - Release of the official new subsystem will be in the next Toolkit (N63), planned for release by March 2009.
 - » **This will not contain all planned capabilities: more will be added in future Toolkit releases.**



Eclipse -1

Navigation and Ancillary Information Facility

- **The eclipse detection algorithm identifies twelve eclipse configurations (as observed from the eclipsed body).**
- **Eclipse models assume a spherical shape for eclipser and eclipsed bodies. A sphere or point object can represent the illumination source.**



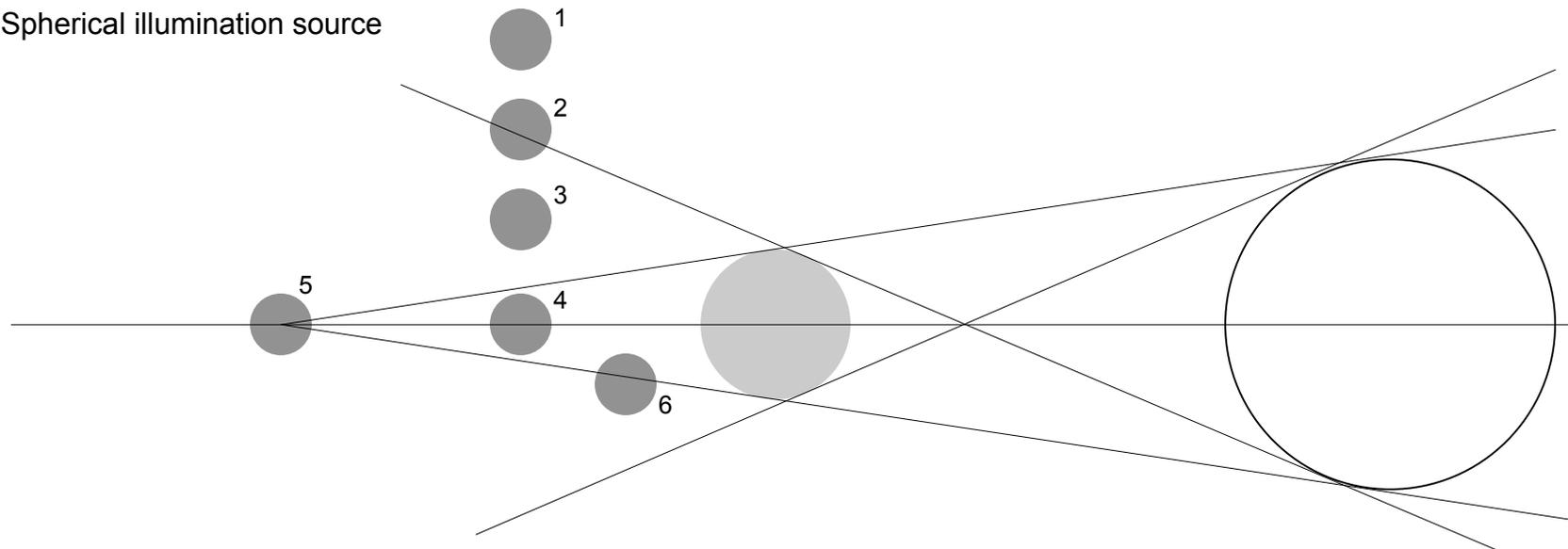
Eclipse - 2

Navigation and Ancillary Information Facility

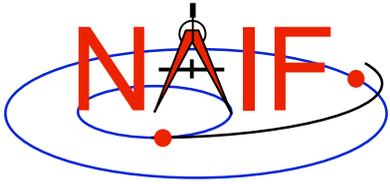
● Eclipsed body

● Eclipser body

○ Spherical illumination source



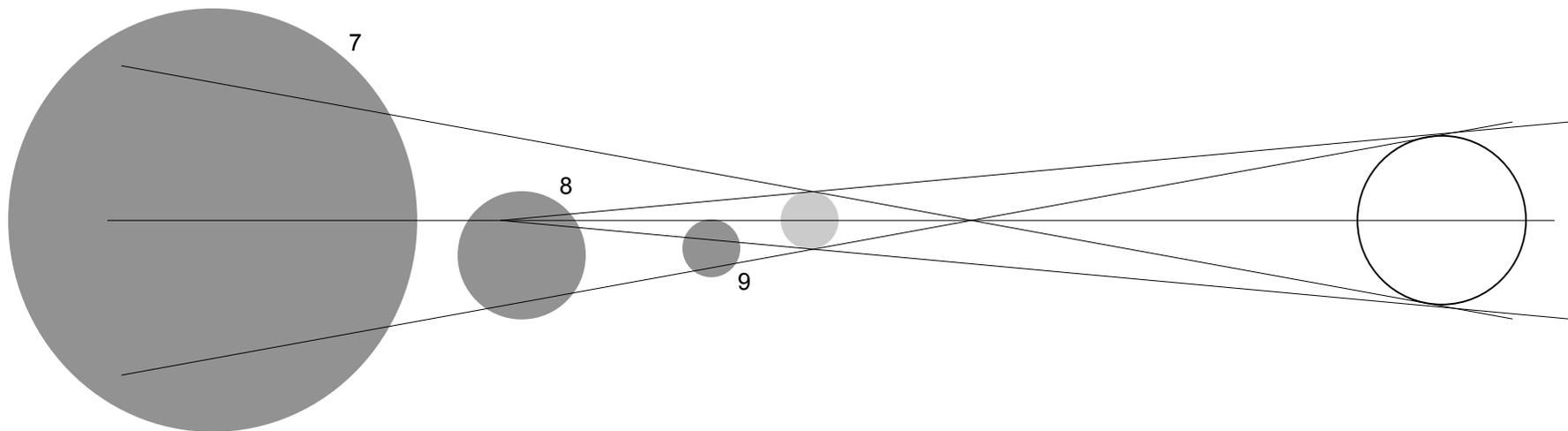
- 1: Eclipsed body in full illumination
- 2: Eclipsed body partially illuminated, partially in the penumbra
- 3: Eclipsed body exclusively in the penumbra
- 4: Eclipsed body completely in the umbra (NAIF defines this state as also in the penumbra.)
- 5: Eclipsed body fully in penumbra with complete umbral shadow on body
- 6: Eclipsed body partially in penumbral and partially in umbral regions



Eclipse - 3

Navigation and Ancillary Information Facility

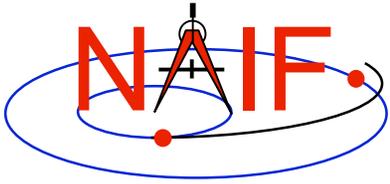
- Eclipsed body
- Eclipser body
- Spherical illumination source



7: Eclipsed body partially illuminated with the penumbral shadow completely on body, no umbral shadow

8: Eclipsed body in illuminated, penumbral, and umbral regions with full umbral shadow on body

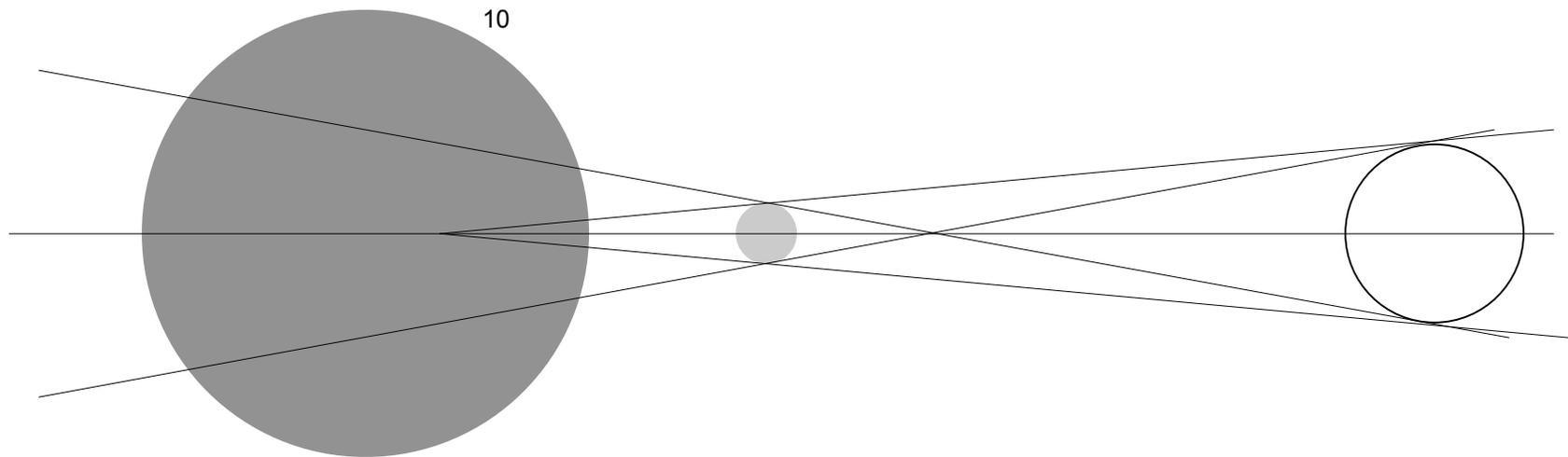
9: Eclipsed body in illuminated, penumbral, and umbral regions without full umbral shadow on body



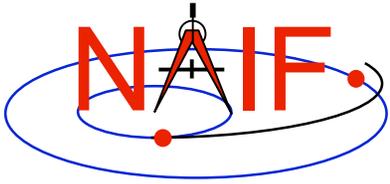
Eclipse - 4

Navigation and Ancillary Information Facility

-  Eclipsed body
-  Eclipser body
-  Spherical illumination source



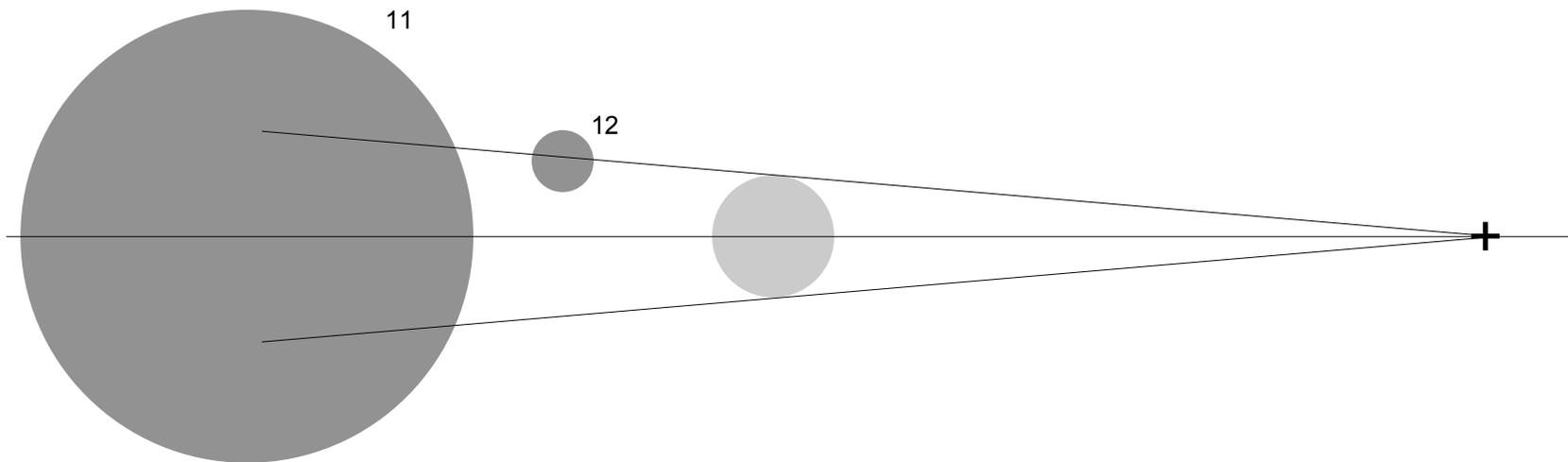
10: Eclipsed body partially illuminated with the penumbral and umbral shadows both fully on body



Eclipse - 5

Navigation and Ancillary Information Facility

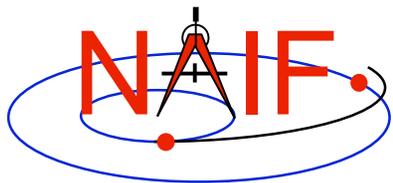
- Eclipsed body
- Eclipser body
- + Point illumination source



11: Eclipsed body partially illuminated with full umbral shadow on body, no penumbral shadow

12: Eclipsed body partially illuminated, partially in the umbra shadow, no penumbral shadow

Note, these configurations exist only for point illumination sources.

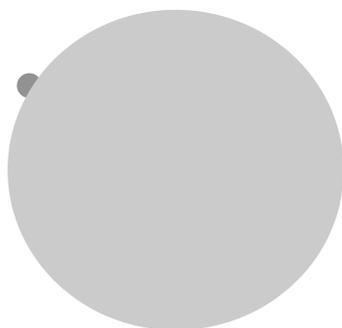


Occultation

Navigation and Ancillary Information Facility

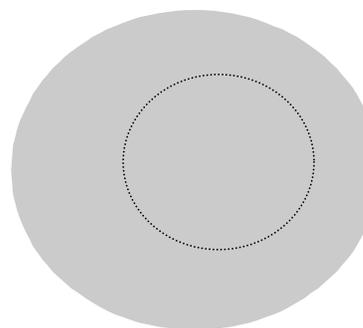
- **The occultation detection algorithm identifies configurations with a triaxial ellipsoid modeling the occulting body. A triaxial ellipsoid or point object models the occulted body.**

Point



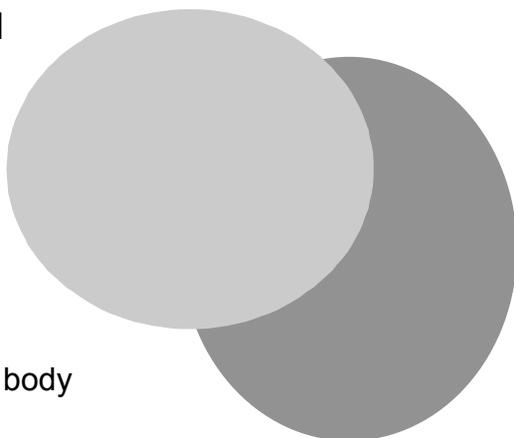
A point target occulted by a spheroid.

Full



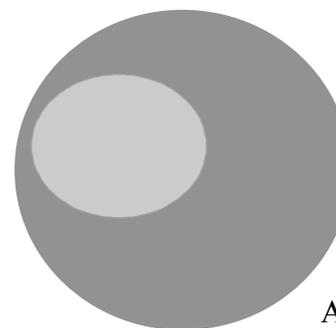
A spheroid fully occulting a second spheroid.

Partial

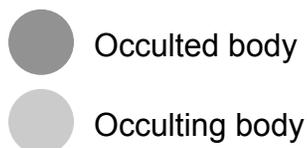


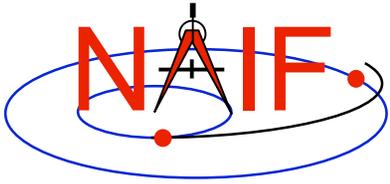
A spheroid partially occulting a second spheroid.

Annular



A smaller spheroid passing between a second, larger spheroid and the observer.

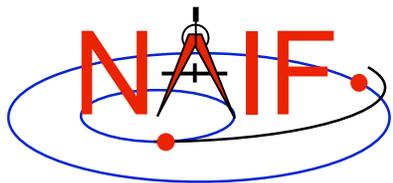




Field-of-View

Navigation and Ancillary Information Facility

- **The field-of-view detection algorithm identifies configurations where an instrument field-of-view intersects or contains a body of interest. The instrument's field-of-view properties are defined in a SPICE instrument kernel.**
 - **The field-of-view detection algorithms answer questions of the form:**
 - » ***“Given a time interval $[t1, t2]$ and a body, at what times within $[t1, t2]$ does the body intersect the instrument field-of-view?”*** (Can I see it, if so, when?)
 - **In order to answer questions of the form:**
 - » ***“Given a time interval $[t1, t2]$ and a set of bodies, which bodies will intersect the instrument field-of-view across $[t1, t2]$?”*** (What can I see?)
- The user performs a field-of-view search over $[t1, t2]$ for each body.**

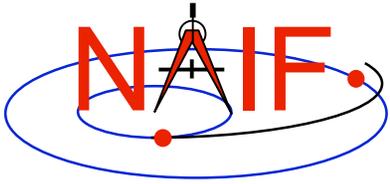


Numeric - 1

Navigation and Ancillary Information Facility

- **The numerical event detection algorithms identify configurations where a particular scalar geometric quantity satisfies some relationship, as defined by an operator and a reference value, or a unary operator.**
- **Geometric quantities:**
 - **Angular separation:** observed angular separation between limbs (where both targets are spherical bodies), separation between a limb and a target position (spherical body and point body), or separation between two target positions (both targets are point bodies)
 - **Angular speed:** magnitude of angular velocity of apparent target about an observer
 - **Angular rate:** the time derivative of the apparent angular separation
 - **Apparent angular diameter**
 - **Range:** $||r||$
 - **Range rate:** $d(||r||)/dt$
 - **Phase angle:** observer-target-Sun angle
 - **Coordinate:** an element of the position vector in a particular coordinate system and reference frame. The position vector is defined as either “observer to target” or “sub observer point on target.”
 - » **Coordinate systems and their corresponding coordinates:**

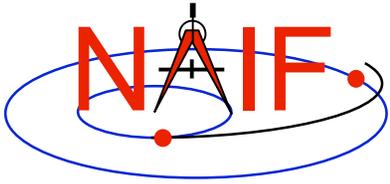
| | | | |
|-----------------------|------------|------------------|-------------|
| • <i>RECTANGULAR:</i> | X, | Y, | Z |
| • <i>CYLINDRICAL:</i> | RANGE, | LONGITUDE, | Z |
| • <i>GEODETIC:</i> | LONGITUDE, | LATITUDE, | ALTITUDE |
| • <i>LATITUDINAL:</i> | RANGE, | LONGITUDE, | LATITUDE |
| • <i>RA/DEC:</i> | RANGE, | RIGHT_ASCENSION, | DECLINATION |
| • <i>SPHERICAL:</i> | RANGE, | COLATITUDE, | LONGITUDE |



Numeric - 2

Navigation and Ancillary Information Facility

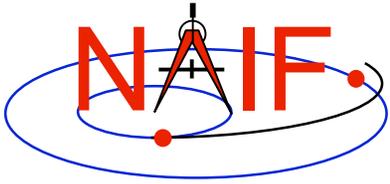
- **Applicable operators:**
 - > (quantity > reference_value)
 - = (quantity = reference_value)
 - < (quantity < reference_value)
 - ABSMAX** (quantity)
 - ABSMIN** (quantity)
 - LOCMAX** (quantity)
 - LOCMIN** (quantity)
- **Examples of detectable events using a numeric event search:**
 - **periapsis or closest approach**
 - » minimum distance between a body and center or between two bodies
 - **apoapsis**
 - » maximum distance between a body and center
 - **pointing constraints**
 - » angular separation between the look direction and Sun direction
 - **boundary confinement**
 - » a vehicle sub-point on a body lies within a latitude/longitude range
 - **node crossings**
 - » Z coordinate of a body position in equator based frame equals zero



Windows Math

Navigation and Ancillary Information Facility

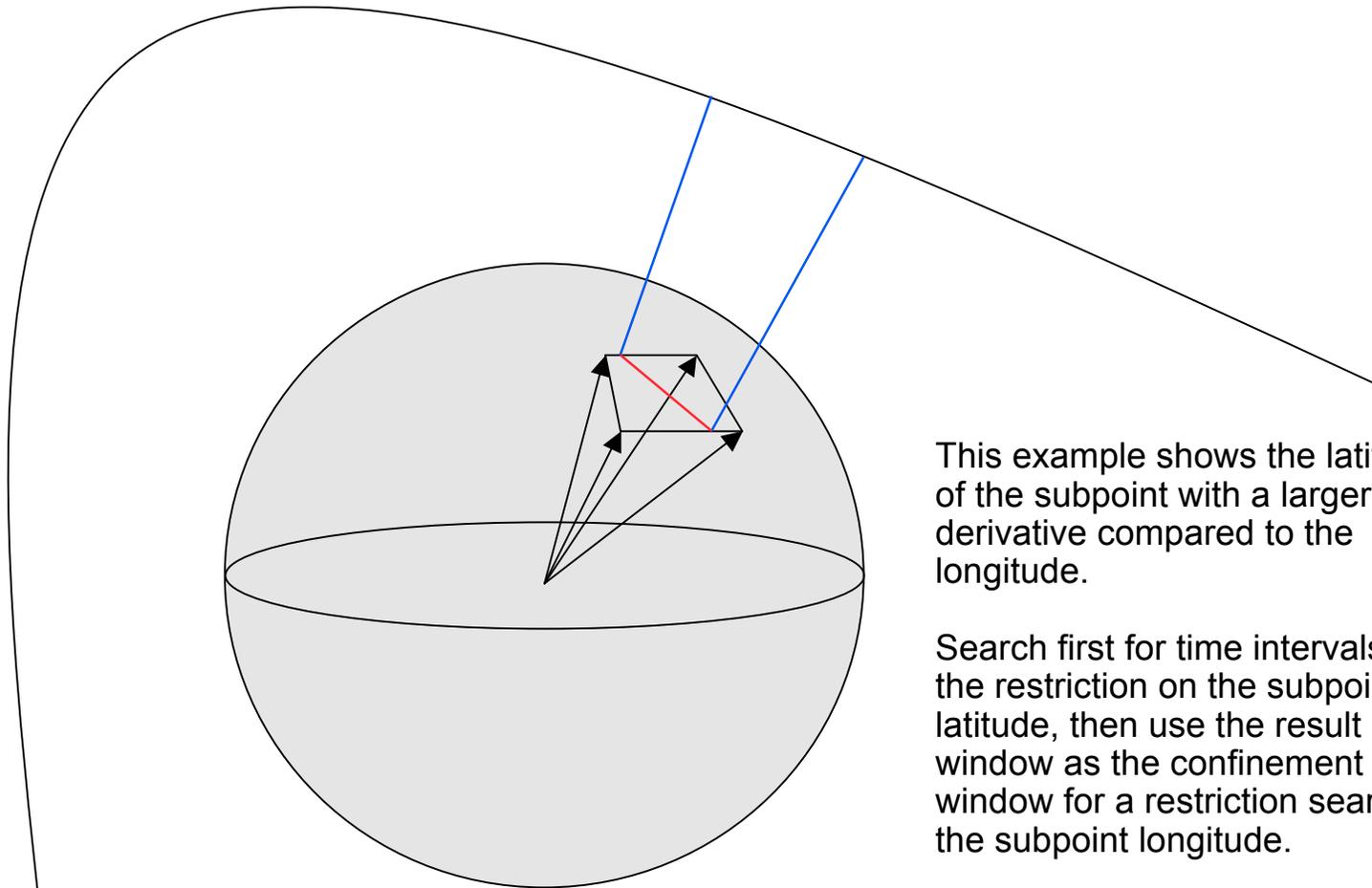
- **The events subsystem uses the SPICE windows data type as an input, named the confinement window, to define the time intervals to search. A window is also used as an output, named the result window, during which the event of interest occurs.**
 - **Windows are collections of zero or more ordered, disjoint intervals of double precision numbers. The event finder subsystem uses windows to define the initial search times and final result times.**
 - **The Toolkit contains a family of routines for creating windows and performing “set arithmetic” on them (union, intersection, difference, etc.).**
- **This windows based implementation allows a user to perform multiple searches where the window result of one search is used as the input (confinement) for the next, either to satisfy a restriction on multiple conditions or as a refinement process.**
 - **Note, the physics of a multi-event geometry may be such that the search for one event will proceed faster than another and markedly reduce the measure of the search space for the next search.**



Example - 1

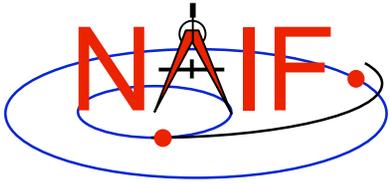
Navigation and Ancillary Information Facility

- Time interval for which the subpoint of a vehicle passes through a latitude/longitude “box.”



This example shows the latitude of the subpoint with a larger derivative compared to the longitude.

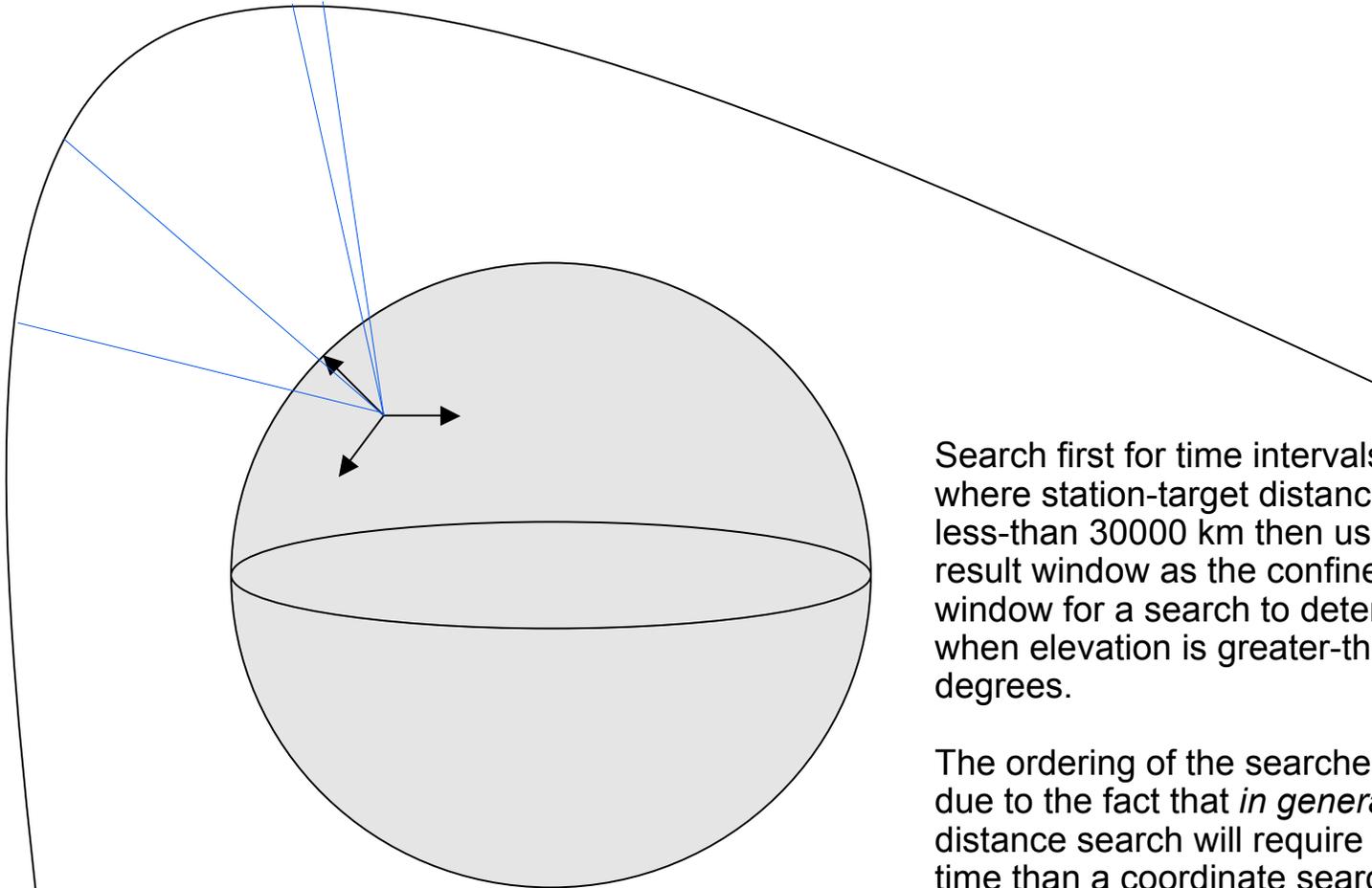
Search first for time intervals with the restriction on the subpoint latitude, then use the result window as the confinement window for a restriction search on the subpoint longitude.



Example - 2

Navigation and Ancillary Information Facility

- Time intervals for which an orbiter passes in line-of-sight of a station, with a local elevation above 30 degrees, with a maximum distance of 30000 km.



Search first for time intervals where station-target distance is less-than 30000 km then use that result window as the confinement window for a search to determine when elevation is greater-than 30 degrees.

The ordering of the searchers is due to the fact that *in general* a distance search will require less time than a coordinate search (particularly an angular coordinate).

SPICE Documentation Taxonomy

Arranged by Category

January 2009

General Reading, including installing the SPICE Toolkit

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|--|---------------------------|-----------------|---|
| Introduction to SPICE | intrdctn.req | T | An introduction to SPICE |
| Installing the SPICE Toolkit | Installing_toolkit | TUTOR | A collection of viewgraph-style packages providing tutorial information on nearly all components of the SPICE system. |
| Instructions for getting the Toolkit components from NAIF's FTP server | README | GETTK | Description of the files to be FTP'd in order to get, install and use the SPICE Toolkit. |
| Preparing your environment for programming with SPICE | Preparing_for_programming | TUTOR | |
| Toolkit Contents | dscriptn.txt | T | Describes the structure and contents of the Toolkit |
| New features and major changes | whats.new | T | Describes significant new features added to the Toolkit since the last version. |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit, in the /doc subdirectory

GETTK = Go to the desired language and then platform under <ftp://naif.jpl.nasa.gov/pub/naif/toolkit>

General SPICE Programming

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|--|---|-----------------|---|
| Must Useful SPICE Subroutines | Mostused.html | T | Practical but terse specifications, including examples, for many popular routines. |
| Permuted Index (SPICELIB or CSPICE) | Spicelib_idx.html or cspice_idx.html | T | Permuted index built from the "Brief Abstract" found in every routine. Helps focus your search for a routine that meets your needs. |
| CSPICE Required Reading
ICY Required Reading
MICE Required Reading | cspice.req or cspice.html
icy.req or icy.html
mice.req or mice.html | T | A discussion of how the product is produced and how to use it. |
| Summary of Key Points | Summary_key_points | TUTOR | Tips for getting started on programming with SPICE modules. |
| Module headers | *.f or *_c.c | T | Each module (subroutine) in SPICELIB and CSPICE contains an extensive "header" providing the detailed specifications for the routine needed by a programmer. Examples are included. |
| ICY and MICE "wrappers" around corresponding CSPICE modules | /doc/html/Index.html | T | IDL and MATLAB interface "wrappers" for the |
| NAIF IDs reference | naif_ids.req | T | A summary of numeric ID codes used throughout the SPICE system |
| Error Required Reading | error.req | T | Reference for configuring and using the exception handling system built-in to SPICELIB and CSPICE |
| Common Problems | problems.req | T | A discussion of the most commonly encountered problems using SPICE |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

Ephemerides for spacecraft and solar system bodies (SPK Subsystem)

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|---------------------------|------------------|-----------------|---|
| SPK Tutorial | spk | TUTOR | Tutorial on using SPK files |
| Making an SPK Tutorial | making_an_spk | TUTOR | Tutorial on making an SPK file |
| Using Frames Tutorial | using_frames | TUTOR | Tutorial on using frames, including in SPK routines |
| SPK Required Reading | spk.req | T | Reference for the SPK subsystem |
| Frames Required Reading | frames.req | T | Reference for working with reference frames |
| NAIF IDs Required Reading | naif_ids.req | T | Summarizes numeric ID codes used throughout the SPICE system |
| SPC Required Reading | spc.req | T | Reference for use of the "comment area" in binary kernels |
| BRIEF User's Guide | brief.ug | T | BRIEF produces a concise summary of the contents/coverage of an SPK file. |
| SPACIT User's Guide | spacit.ug | T | SPACIT provides file conversion, detailed summarization and read access to internal comments (metadata). |
| Convert User's Guide | convert.ug | T | Describes use of the command line utilities named TOBIN and TOXFR used to convert binary kernels to transfer format and vice-versa. |
| Comment User's Guide | commnt.ug | T | Comment is used to add, extract, read and delete comments (metadata) in binary kernels. |
| SPK Merge User's Guide | spkmerge.ug | T | SPKMERGE is a utility program used to merge two or more SPK files, or to subset a single SPK file. |
| SPKDIFF User's Guide | spkdifff.ug | T | SPKDIFF computes differences between geometric states obtained from two SPK files and either displays these or shows statistics about them. |
| SPY User's Guide | spy.txt | UTIL | SPY is a utility for validating, inspecting and analyzing SPK files. |
| MKSPK User's Guide | mkspk.ug | T | MKSPK is a utility for making an SPK file from a set of state vectors or conic elements or two-line elements. |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

UTIL = Utilities link on the NAIF website

Target body size, shape and orientation (PCK Subsystem)

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|--|--------------------|-----------------|---|
| PCK Tutorial | pck | TUTOR | Tutorial viewgraphs on using PC-kernels |
| High Accuracy Orientation and Body-fixed Frames for the Moon and Earth | lunar-earth_pck-fk | TUTOR | Tutorial viewgraphs on special orientation files (binary PCKs) and body-fixed frames for the moon and the earth |
| PCK Required Reading | pck.req | T | Reference for the PCK subsystem |
| Frames Required Reading | frames.req | T | Reference for working with reference frames |
| NAIF IDs Required Reading | naif_ids.req | T | Summarizes numeric ID codes used throughout the SPICE system |
| Kernel Required Reading | kernel.req | T | Reference for general specifications of text kernels |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

Instrument Information Pertinent to SPICE (IK Subsystem)

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|---------------------------|------------------|-----------------|--|
| IK Tutorial | ik | TUTOR | Tutorial viewgraphs on using I-kernels |
| IK Required Reading | ik.req | T | Reference for the IK subsystem (Toolkit version N0053 or later.) |
| n/a | *.ti | D | Look at an existing I-kernel; these are text files that contain substantial internal documentation |
| Frames Required Reading | frames.req | T | Reference for working with reference frames |
| NAIF IDs Required Reading | naif_ids.req | T | Summarizes numeric ID codes used throughout the SPICE system |
| Kernel Required Reading | kernel.req | T | Reference for general specifications of text kernels |

D = Project Data on NAIF web pages (<http://naif.jpl.nasa.gov/naif/data.html>)

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

Orientation of a Spacecraft or Structure (CK Subsystem)

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|----------------------------|------------------|-----------------|---|
| CK Tutorial | ck | TUTOR | Tutorial viewgraphs on using C-kernels |
| Using Frames Tutorial | using_frames | TUTOR | Tutorial on using frames, including in transformation modules |
| CK Required Reading | ck.req | T | Reference for the CK subsystem |
| Frames Required Reading | frames.req | T | Reference for working with reference frames |
| NAIF IDs Required Reading | naif_ids.req | T | Summarizes numeric ID codes used throughout the SPICE system |
| SPC Required Reading | spc.req | T | Reference for use of the "comment area" in binary kernels |
| Rotations Required Reading | rotation.req | T | Reference for construction and use of rotation matrices within the SPICE context |
| CKBRIEF User's Guide | ckbrief.ug | T | CKBRIEF produces a concise summary of the contents/coverage of an SPK file. |
| SPACIT User's Guide | spacit.ug | T | SPACIT provides file conversion, detailed summarization and read access to internal comments (metadata). |
| Convert User's Guide | convert.ug | T | Describes use of the command line utilities named TOBIN and TOXFR used to convert binary kernels to transfer format and vice-versa. |
| Comment User's Guide | commnt.ug | T | COMMENT is used to add, extract, read and delete comments (metadata) in binary kernels. |
| DAFCAT User's Guide | dafcat.ug | T | DAFCAT provides a very simple and simplistic file merge capability for CK files. |
| CKslicer User's Guide | ckslicer.txt | UTIL | CKSLICER subsets a CK into another CK file. |
| CKsmrg | chsmrg.txt | UTIL | CKSMRG merges segments in Type 3 CK files. |
| MSOPCK User's Guide | msopck.ug | T | MSOPCK is a utility for making a CK file from orientation data in the form of quaternions, Euler angles or rotation matrices. |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

UTIL = Utilities link on the NAIF website

Connectivity of Reference Frames (FK Subsystem)

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|----------------------------|------------------|-----------------|--|
| Frames Tutorial | fk | TUTOR | Tutorial viewgraphs on contents of a Frames kernel |
| Using Frames | using_frames | TUTOR | Tutorial viewgraphs on using Frames kernels |
| Dynamic Frames | dynamic_frames | TUTOR | Tutorial on defining/implementing custom so-called dynamic frames |
| n/a | *.tf | N | Look at an existing Frames kernel; these are text files and contain substantial internal documentation |
| Frames Required Reading | frames.req | T | Reference for the Frames subsystem |
| NAIF IDs Required Reading | naif_ids.req | T | Summarizes numeric ID codes used throughout the SPICE system |
| Rotations Required Reading | rotation.req | T | Reference for construction and use of rotation matrices within the SPICE context |
| Kernel Required Reading | kernel.req | T | Reference for general specifications of text kernels |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

"EVENTS", broken down into three sub-products (EK Subsystem)

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|------------------------------|------------------|-----------------|---|
| Introduction to EK subsystem | ek_intro | TUTOR | Tutorial Introduction to the Events subsystem |
| EK Required Reading | ek.req | T | Reference for the Events-kernel subsystem |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory

Time Conversion

| <u>Document Name</u> | <u>File Name</u> | <u>Location</u> | <u>Description/Comments</u> |
|-------------------------|------------------|-----------------|--|
| Time Tutorial | time | TUTOR | Tutorial viewgraphs on time conversions |
| Time Required Reading | time.req | T | Reference on time systems (excluding SCLK) |
| SCLK Required Reading | SCLK.req | T | Reference on spacecraft clock time |
| CHRONOS User's Guide | chronos.ug | T | CHRONOS is a full-featured, flexible time conversion utility program |
| Kernel Required Reading | kernel.req | T | Reference for general specifications of text kernels |

TUTOR = Tutorials on NAIF web pages (<http://naif.jpl.nasa.gov/tutorials.html>)

T = SPICE Toolkit:

Plain text, in the /doc subdirectory

HTML under the /doc/html/... subdirectory