Planning and Processing Space Science Observations Using NASA's SPICE System[1]

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Abstract–The Navigation and Ancillary Information Facility (NAIF) team, acting under the directions of NASA's Office of Space Science, has built a data system–named SPICE–to assist scientists in planning and interpreting scientific observations from space-borne instruments. The principal objective of this data system is that it will provide geometric and other ancillary data used to plan space science missions and subsequently recover the full value of science instrument data returned from these missions, including correlation of individual instrument data sets with data from other instruments on the same or other spacecraft. SPICE is also used to support a host of mission engineering functions, such as telecommunications system analysis and operation of NASA's Deep Space Network antennas. This paper describes the SPICE system, including where and how it is used. It also touches on possibilities for further development and invites participation it this endeavor.

1. Introduction

Solar system exploration is increasingly a joint venture, demanding close cooperation amongst those scientists and agencies participating in the planning, operations and data analysis phases. Cooperating agencies must employ an array of common practices, standards and tools to achieve technical success within available financial and schedule resources. Common business practices, use of the English language for human-to-human communications and use of ASCII computer codes for exchange of electronic information are well established standards. There also exist a number of commonly accepted standards for scientific measurements.

There is room for more use of standards to advance common goals. To facilitate widespread–even international–cooperation on the design and execution of space science missions, and on the timely and correct interpretation of scientific data obtained from these missions, it seems advisable to establish data standards and develop tools for the exchange and use of ancillary or engineering data. One approach to providing such standards is described in this paper. Possible extensions are also described.

2. Ancillary Data System Standards

What are "Ancillary Data?"

In the context of this paper, ancillary data are loosely defined as mission engineering and spacecraft housekeeping data needed throughout a project's lifecycle to ensure that quality observations by science instruments are acquired and fully interpreted.

Why Establish Ancillary Data Standards ?

Ancillary data standards help promote the exchange of good ideas for mission design and the validation of a selected design. They help distributed team members participate in constructing detailed observation sequence designs, or in simply understanding what the planned observations are. They help maximize the complete and precise interpretation of scientific data returned from those observations, including when cross correlation between datasets is attempted. They facilitate the access to such data by future scientists who might have improved data or methods for analyzing old data. And they can reduce local data system development costs, particularly as re-use comes into play.

What Vehicles Should Be Supported ?

The challenges of planning observations and providing ancillary data to help analyze the data returned from those observations are associated with every kind of robotic vehicle in use today and planned for the future exploration of the solar system–interplanetary spacecraft, orbiters, landers, rovers, balloons and airplanes. Vehicles examining the earth and the solar environment are equally good candidates for use of such standards.

Prime Components of an Ancillary Data System

Data are the fundamental component of an ancillary data system. Ancillary data provide supporting information about

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the mission, for example: vehicle position and velocity; target body size, shape and orientation; vehicle or instrument pointing; instrument aperture size, shape and orientation; and logs of observation plans, spacecraft and instrument commands, and notes detailing how things worked. Reference systems are another key component: coordinate systems and time systems are prime examples. Documents providing precise and complete definitions of the data and reference systems are a third component. Archives that provide easy and timely access to the data and other system components are important and must exist for pre-flight, mission operations, and post-flight long-term data analysis phases.

Software that helps a scientist find, acquire and utilize ancillary data should also be considered a prime data system component. Adding software to this "mix" makes the job of building an ancillary data system much larger, but if done properly the payoff is well worth the extra investment. This software suite could include general application programs, utility programs and scripts, and subroutine libraries used by scientists in building their own applications.

Requirements on Ancillary Data System Components

A number of requirements are mandatory to ensure meeting expectations of the large and diverse customer community. Portable: data files and software must be useable on and easily moved between all popular computing platforms. Extensible: it must be easy to add or extend functionality. Correct: all components must be thoroughly tested and validated, including peer review where appropriate. Precise: generally all calculations must be done to meet the needs of the most demanding customer; the use of approximations must be carefully controlled. Documented: data and software must be clearly, fully documented. Convenient: all components must be freely available and easily obtained by all interested parties. Supported: professional help for customers must be available. Open: providing a fully open system–including providing source code for software–invites extra confidence and participation of the user community.

3. SPICE System Components

About fifteen years ago the U.S. space science community made a strong recommendation to NASA for the establishment of new data systems and their attendant standards to help make ready access to, and use of, archived scientific data more of an expectation and less of a dream. While most of the discussion focused on data obtained directly from instruments, included in this report was a recommendation for the establishment of standards and processes for obtaining and using the relevant ancillary/engineering data needed to help fully understand science instrument measurements, and to correlate results across instruments and missions. Out of this recommendation was born NASA's "SPICE" ancillary data system, implemented by the Navigation and Ancillary Information Facility (NAIF) Team at Caltech's Jet Propulsion Laboratory. The SPICE implementation strives to address the suggested requirements outlined earlier.

A logical depiction of the primary SPICE components, based on the acronym, is shown in Table 1. The acronym doesn't quite fit reality, however. Figure 1 is a "map" translating the acronym into real SPICE data products, often called kernels. ("Kernel" implies a fundamental dataset used in producing derived products.) This figure shows "planet" information is split into two SPICE kernels: spacecraft ephemeris data are combined with planet ephemeris data in the SP-Kernel (SPK), while planet cartographic constants are placed in a Pc-Kernel (PcK).

Figure 1 also indicates that SPICE encompasses some additional kernels not covered by the acronym, including reference frame definitions (FDK), leapseconds (LSK) and spacecraft clock coefficients (SCLK) kernels used for time conversion functions, and a database kernel (DBK) providing a generic, tightly coupled quasi-relational database capability.

Perhaps the "SPICE" acronym should have been "SPICES," with the final "S" standing for Software. The SPICE system includes the SPICE Toolkit, a large collection of allied software available in both ANSI FORTRAN 77 and ANSI C. The principal element of this Toolkit is a library of routines used to write kernels, to read kernels, and to calculate many commonly used observation geometry parameters derived from data provided in the kernels. Customers integrate these SPICE Toolkit routines into their own application programs to compute observation geometry parameters and similar ancillary information.

Also part of the SPICE Toolkit are:

- Utility programs
  - Used to summarize and manage SPICE data files
- Cookbook programs
  - Provide basic examples of using SPICE Toolkit software and with SPICE data
- Documentation
  - Extensive tutorials, user guides and reference documents

Table 1 Primary SPICE System Components

Component	Contents
S	Spacecraft ephemeris, or more generally, location of an observer, given as a function of time.
P	Planet, satellite, comet, or asteroid ephemerides, or more generally, location of a target body, given as a function of time. The P kernel also logically includes certain physical, dynamical and cartographic constants for target bodies, such as size and shape specifications, and orientation of the spin axis and prime meridian.
I	Instrument description kernel, containing descriptive and operational data peculiar to a particular scientific instrument, such as field-of-view model parameters and internal timing relative to the spacecraft clock.
C	Pointing kernel, containing a transformation traditionally called the **C**-matrix that provides time-tagged pointing (orientation) angles for a spacecraft structure upon which science instruments are mounted.
E	Events kernel, summarizing mission activities–both planned and unanticipated. Three distinct classes of events data are defined: Science Plans, Sequences, and Experiment Notes.

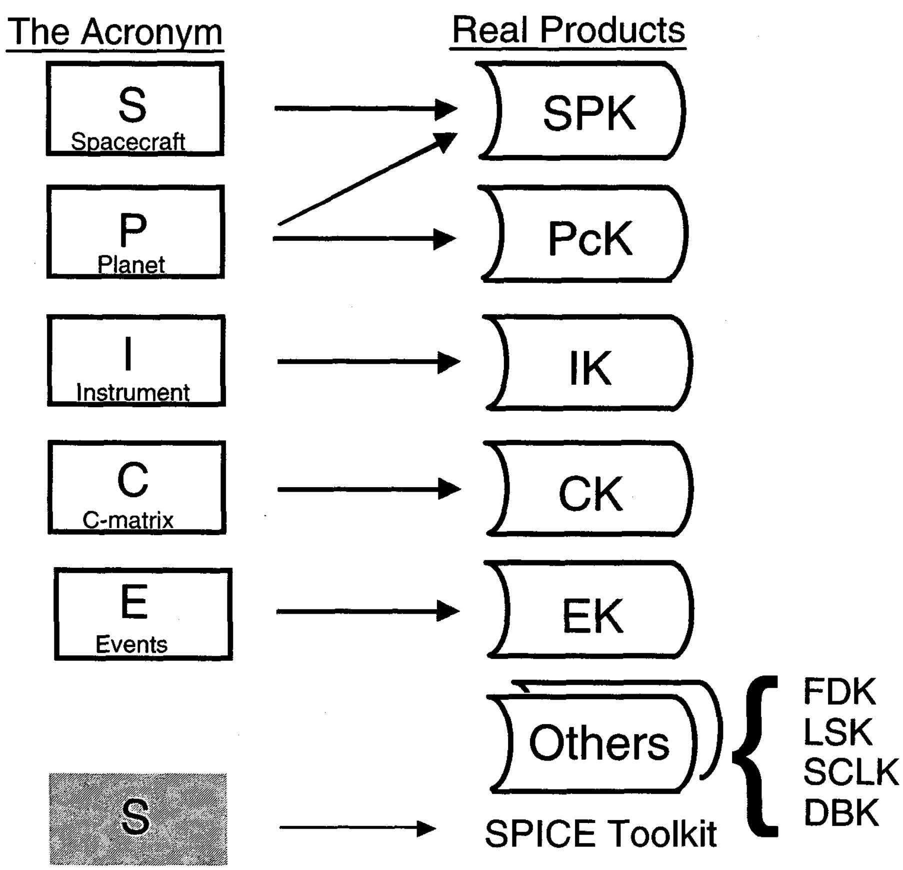

Figure 1 Translating the SPICE Acronym Into Real Products

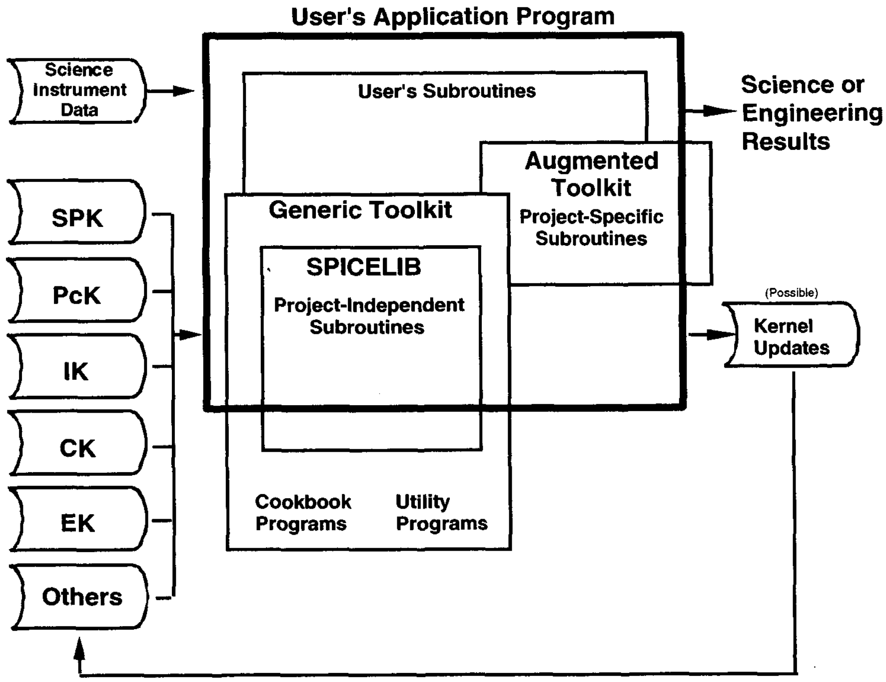

Figure 2 Integrating SPICE Software into an Application Program

4. Using SPICE

A SPICE customer integrates needed SPICE Toolkit routines into an application program. These routines include readers for needed SPICE files as well as routines that compute derived quantities. Combined with the user's own routines, a complete, focused application is constructed, Figure 2. The user's application program produces science or engineering results. An update to a SPICE kernel could be one result.

The various elements of SPICE are used at JPL and numerous other institutions in mission design, observation planning, mission operations (including visualization), and science data analysis. The SPICE Toolkit is available in both ANSI FORTRAN 77 and ANSI C, and is supported on most popular platforms, including PC, Macintosh, Sun, SGI, HP, DEC Alpha and VAX.

The ephemeris component of SPICE is now the standard for customers of NASA's Deep Space Network. It is used for long and short term scheduling of DSN antennas and for pointing these antennas and tuning transmitters and receivers during tracking passes.

SPICE has many applications in space science. Depicted in Figure 3 is the use of SPICE to coordinate time, orientations and locations of a disparate suite of natural and man-made "objects." Providing such measures, and the transformations between those systems in which the measurements are made, is routine work using SPICE.

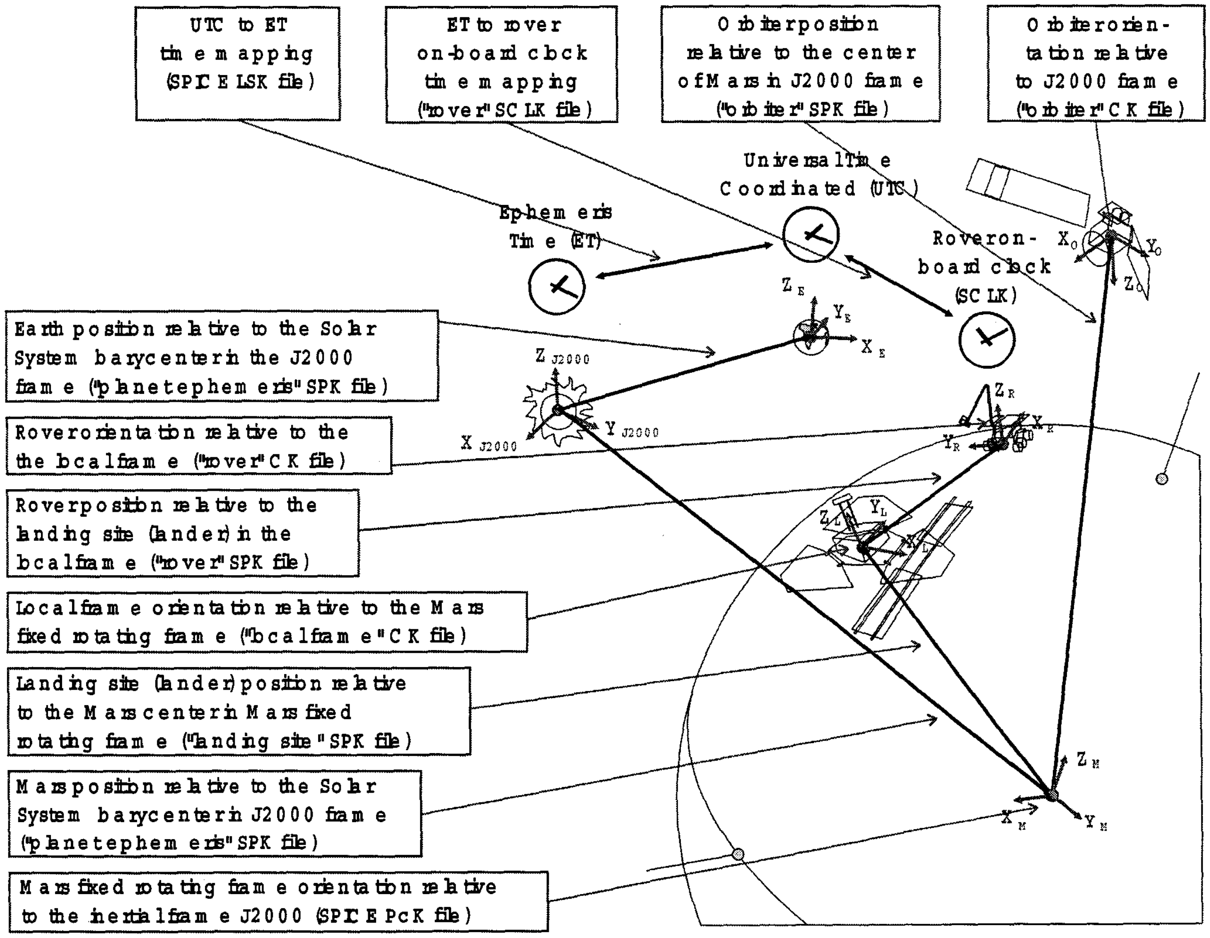

Figure 3 Connecting Geometry and Time Using SPICE

The NAIF Team believes there is a lot of room for new applications of these standards in support of space science endeavors and solicits suggestions from the community for such as well as interest in teaming in implementation.

The SPICE system has been, is being, or is planned for use on a large assortment of space science missions as indicated in Table 2. While the principle use of SPICE has been in the planetary science discipline, astrophysics, space physics and Earth science projects are also using this technology.

5. Further Development of SPICE

The SPICE system has been undergoing continuing development for over eight years. The current version of SPICE (version N0050) is quite mature and has a great deal of capability, but more work remains to be done.

Recent major new features include a plate model applicable to small, irregularly shaped bodies and a high precision earth orientation capability. Currently under development are a generic sky catalog, new tools for creating SPICE ephemeris (SPK) files, a method for providing high performance access to high precision comet and asteroid ephemerides, and new software to improve the portability of binary-format SPICE files.

Examples of possible extensions to SPICE include:

- integration of digital shape models for small, irregular target bodies such as asteroids
- design and implementation of a tightly coupled surface features database
- design and implementation of a more robust instrument model

• design and implementation of routines to search for specified geometric conditions

• design and implementation of means to incorporate and properly utilize trajectory/orbit accuracy information

Examples of possible application programs to be added to the SPICE family include:

• a highly evolved orbit characterization program

• tools to facilitate cooperative mission/observation planning in a distributed environment

• tools to facilitate planning for relay links

• visualization tools

Examples of possible new data management capabilities include:

• implementation of a means for aggregating a collection of files into an data "library"

• implementation of a web-based SPICE products selection and distribution mechanism

• establishment and operation of mirror sites

Development of tutorial materials–possibly in multiple languages–would also be of benefit to the growing user community, as would devising methods of applying these fundamental data to education and public outreach.

6. CONTACTING NAIF

Those interested in learning more about the SPICE system, in contributing to this system, or in organizing to address questions pertinent to ancillary data standards on a national or international basis are invited to contact the author and to view the NAIF web pages at http://pds.jpl.nasa.gov/naif/html.

Table 2 Missions and Activities Using SPICE

Restorations	Past	Current	Pending
Apollo 15 [P]	Voyagers [P]	Galileo	Muses-CN (ISAS)
Mariner 9 [P]	Magellan [P]	NEAR	Mars Express (ESA)
Mariner 10 [P]	Clementine (NRL)	Mar Global Surveyor	
Viking Orbiters [P]	Mars Observer	Space VLBI [P]	
Pioner 10/11 [P]	Mars 96 (Russia)	Stardust	Future Possibilities
Haley armada [P]	Hubble Telescope [S]	Cassini	
Phobos 2 [P] (Russia)	ISO [S]	Deep Space 1	Space Technology
Ulysses [P]	MSTI-3 (by ACT)	Mars Climate Orbiter	Planet - B (Japan)
	OTD (by MSFC)	Mars Polar Lander	Contour
	Mars Pathfinder	DSN Metric Predicts	EOS - MISR [P]
		Mars 01	EOS - TES
		SIRTF [S]	Messenger
		Genesis	Deep Impact
		Mars 03	Rosetta (ESA)
		Mars 05	Selene (Japan)
		SIM [P]	

[P] = partial use of SPICE [S] = special SPICE-based products

BIOGRAPHY

Charles Acton is Supervisor of the Mission and Science Analysis Software Group in JPL's Navigation and Mission Design Section, as well as manager of the NAIF Node of the Planetary Data System. He has lead his group's development of ancillary data system capabilities since 1983, starting with the Voyager 2 flyby of Uranus.

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