

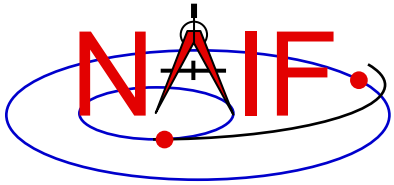
Navigation and Ancillary Information Facility

“Camera-matrix” Kernel CK

(Orientation or Attitude Kernel)

Focused on reading CK files

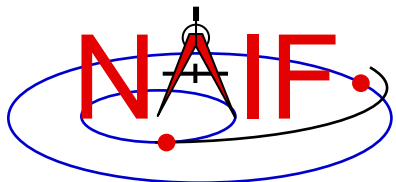
January 2020



CK File Contents - 1

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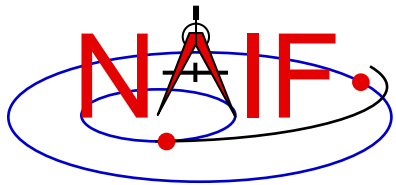
- **A CK file holds orientation data for a spacecraft or a moving structure on the spacecraft**
 - “Orientation data” \Rightarrow quaternions, from which orientation matrices are formed by SPICE software. These matrices are used to rotate position vectors from a base reference frame (the “from” frame) into a second reference frame (the “to” frame)
 - » In SPICE this is often called the “C-matrix or “Camera matrix”
 - Optionally may include angular velocity 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

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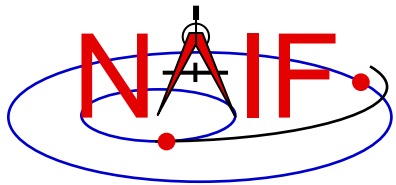
- **A single CK file can hold orientation data for one, or for any combination of spacecraft or spacecraft moving structures**
 - **Some examples**
 1. Huygens Probe
 2. Cassini Orbiter and its CDA instrument mirror
 3. Mars Express Orbiter, PFS scanner, Beagle Lander
 4. MRO orbiter, MRO high gain antenna,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



C-Kernel Varieties - 1

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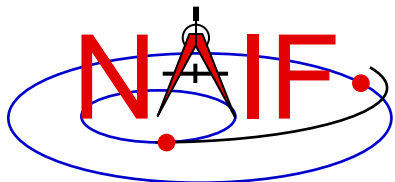
- **“Reconstruction” CK (also called “definitive” CK)**
 - A CK file can be made from downlinked orientation telemetry returned from a spacecraft or other structure
 - A CK might also be made from some process that improves upon the pointing determined from downlinked telemetry (“C-smithing”)
 - Most often 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
 - Most often used for science observation planning, quick-look science data analysis, engineering assessments and software testing
 - » If of known high quality, it might be used to substitute for any data gaps in reconstruction CKs
 - » In some cases (ESA in particular) the predict meets the reconstruction accuracy requirements; thus a true reconstruction CK is not generally produced



C-Kernel Varieties - 2

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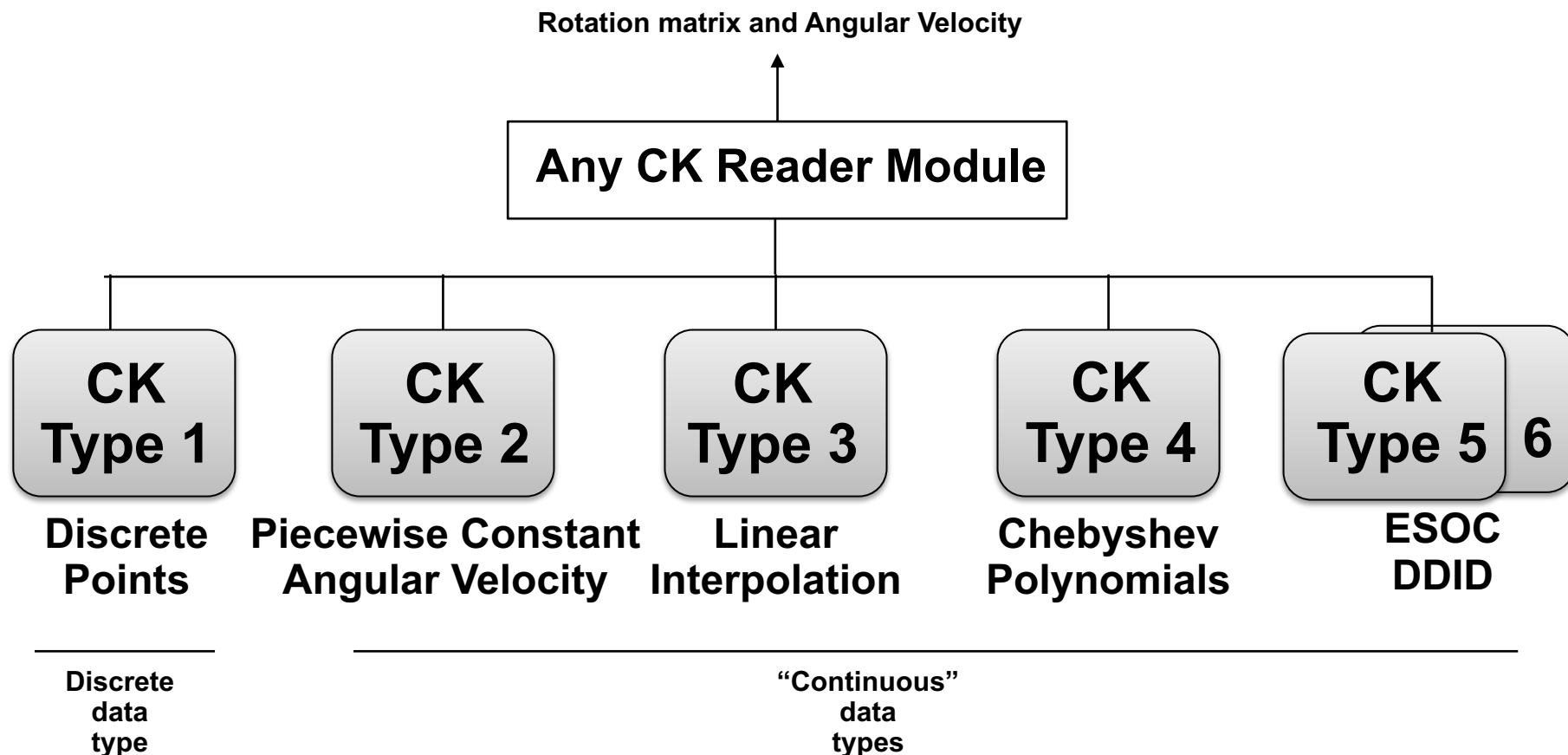
- **Knowledge of CK variety—“reconstruction” or “predict”—might be implicit in the file naming schema, and/or might be provided in the comment section, but is not available using a SPICE API**
- **It is inadvisable that both “reconstruction” and “predict” data be combined in a single file**

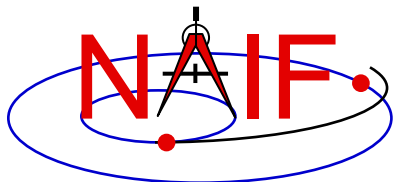


CK Data Types

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

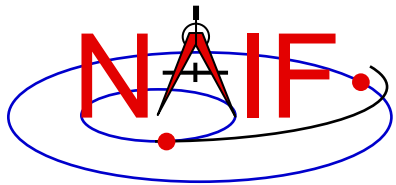




Kernel Data needed

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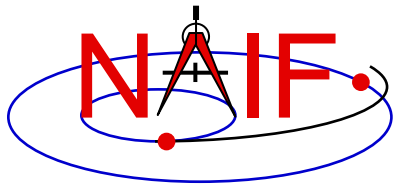
- To obtain orientation one needs at least three SPICE kernel types: **CK**, **SCLK**, and **LSK**.
 - CK contains spacecraft or other structure orientation.
 - SCLK and LSK contain time correlation coefficients used to convert between encoded spacecraft clock time (SCLK) and ephemeris time (ET).
 - » Sometimes an LSK is not needed in this conversion, but it's best to have it available as it is usually needed for other purposes.
- One may also need an **FK** if planning to access CK data via high level SPICE interfaces.
 - FK associates reference frames with CK data via CK IDs.



What SPICE Routines Access CKs?

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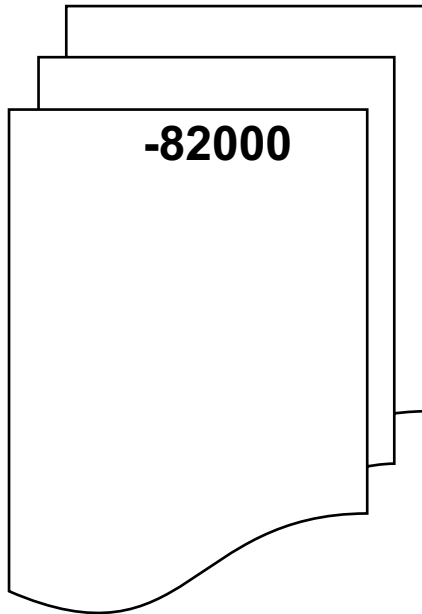
- **High-level SPICELIB routines are used more often than the “original” CK readers to access CK data. These high-level routines are:**
 - **Position or state transformation matrix determination**
 - » **PXFORM, PXFRM2**: return a rotation matrix (3x3) from one frame to another, either of which can be 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 FK, Using Frames, and SPK tutorials**
- **The “original” CK access routines are CKGP and CKGPAV**
 - Use of these routines is described in the BACKUP section of this tutorial



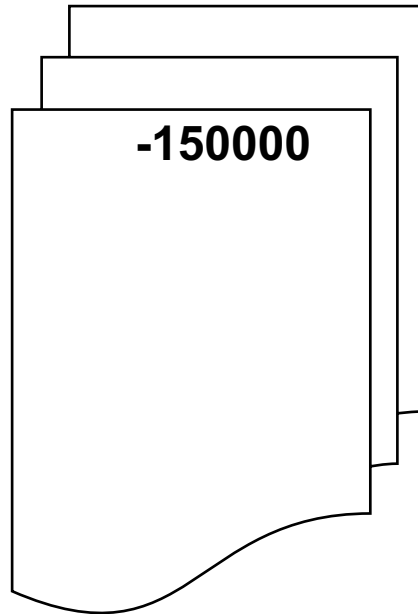
An Example of Project CK Files

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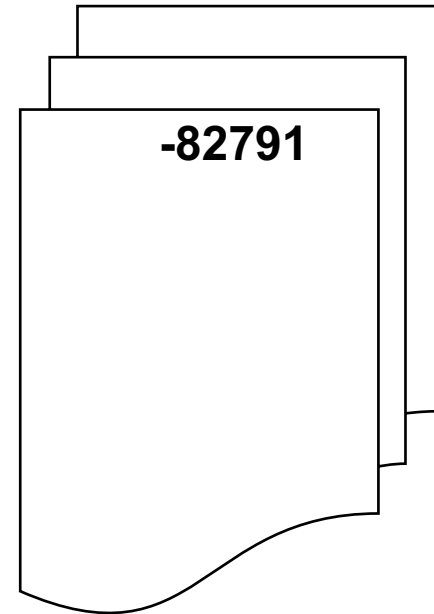
**CASSINI
SPACECRAFT**



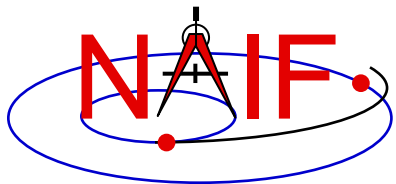
**HUYGENS
PROBE**



**CASSINI
CDA MIRROR**



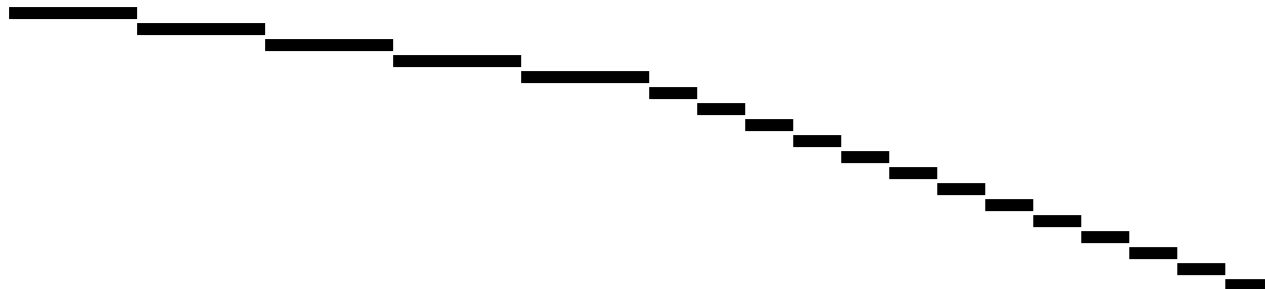
A user's program must be able to load as many of these files as needed to satisfy his/her requirements. It is strongly recommended that users' programs have the flexibility to load a list of CK files provided to the program at run time; this is easily accomplished using the Toolkit's FURNISH routine.



Sample* CK File Coverage - 1

Navigation and Ancillary Information Facility

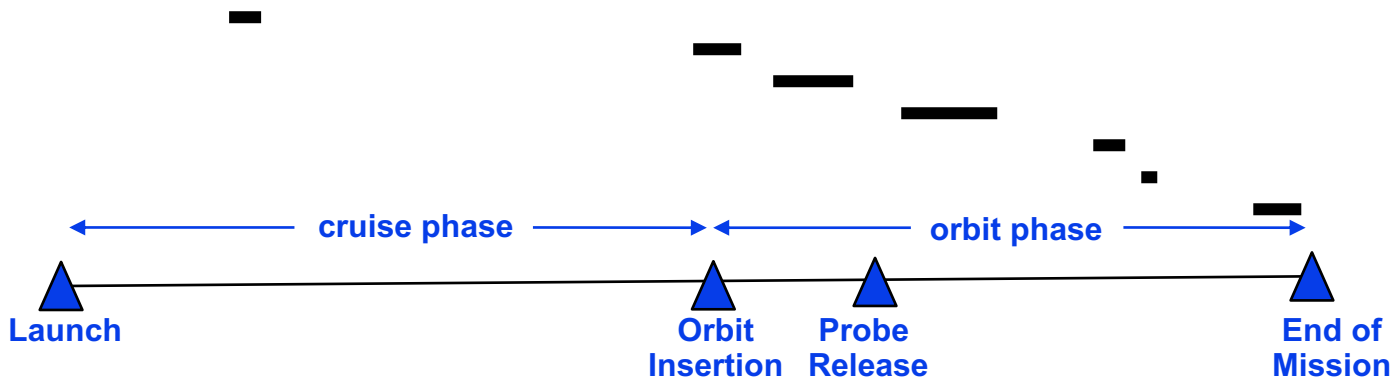
Cassini
orbiter CK:



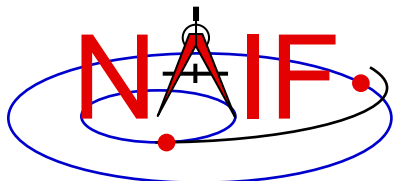
Huygens
probe CK:



Cassini
instrument
mirror CK:



* Note: This is not an actual Cassini/Huygens scenario; it is a highly simplified illustration of some of the possibilities for orientation delivery on a planetary mission.

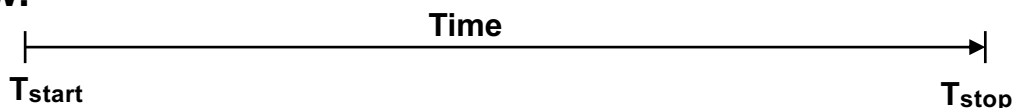


Sample CK Data Coverage - 2

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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 very often contain gaps in coverage!** An example of this is depicted below.

Coverage of ...



a CK file:
as appears in file name/comments



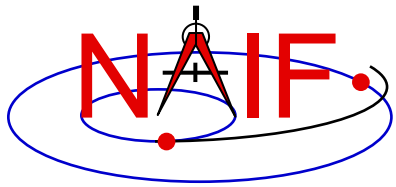
CK file segments:
as appears in ckbrief/spacit summary



CK segments having data gaps:
(CK Types 2 - 6)



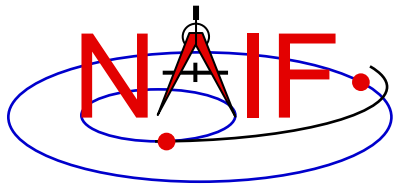
The **blue line segments** represent interpolation intervals – times when pointing will be returned and the FOUND flag returns as “TRUE.”



What is an Interpolation interval?

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- **An interpolation interval is a time period for which routines that access CKs can compute and return pointing.**
 - For CK Types 3, 5 and 6 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 CK access routines 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.

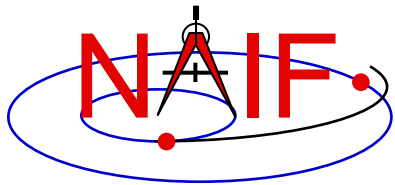


How are Requests Falling in Gaps Handled?

Navigation and Ancillary Information Facility

- **When using high-level SPICE routines* in a fashion that requires CK data, if the time of your requested computation falls within a CK gap (thus, outside of a CK interpolation interval), the routine will signal an error.**
 - Usually this is a frame-related error
- **If using a low-level CK reader, CKGP or CKGPAV, valid pointing data will not be returned and the reader's "found flag" will be set to false.**
 - **Be sure to check the "found flag!"**

* For example: SPKEZR, SPKPOS, SXFORM, PXFORM, SINCPT



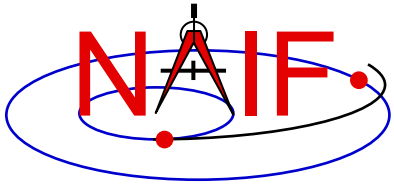
Obtaining Coverage of a CK File

Navigation and Ancillary Information Facility

- **High-level subroutine interfaces allow for obtaining CK coverage information.**
 - **Call CKOBJ to find the set of structures for which a specified CK provides data.**
 - » **INPUT:** a 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.**

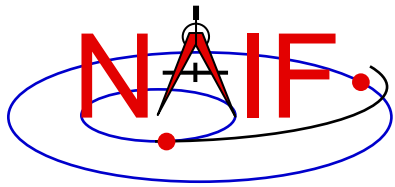


Using CKCOV

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. (wnintd is the SPICE intersection API.)
- **Then check each time of interest for your geometry calculations against the window of valid intervals before proceeding onwards.**

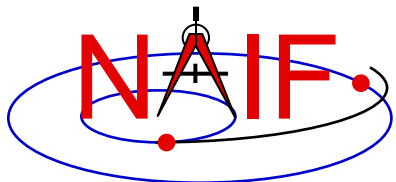
* For example: SPKEZR, SPKPOS, SXFORM, PXFORM, SINCP



Determine Coverage Using Utilities

Navigation and Ancillary Information Facility

- **Three Toolkit utility programs can provide various kinds of CK summaries, including listings of gaps or of interpolation intervals**
 - CKBRIEF
 - FRMDIFF
 - SPACIT



Summarizing a CK File - 1

Navigation and Ancillary Information Facility

- A summary of a CK can be made using CKBRIEF
 - At your command prompt, type the program name followed by the names of CK, LSK and SCLK files (given in any order)

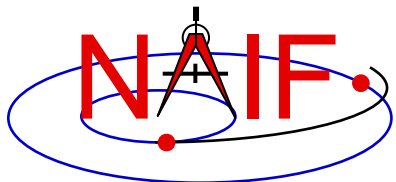
```
% ckbrief 07102_07107ra.bc naif0008.tls cas00106.tsc
```

```
CKBRIEF Ver 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 summary of interpolation intervals within a CK can be made with CKBRIEF, using its '-dump' option

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

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

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

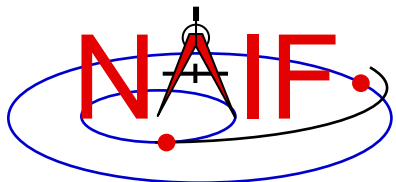
```
Segment No.: 1
```

```
Object: -82000
```

Interval Begin ET	Interval End ET	AV
-----	-----	---
2007-APR-12 00:01:06.462	2007-APR-12 05:58:02.576	Y
2007-APR-12 05:58:22.576	2007-APR-12 21:34:26.221	Y

```
. . .
```

continued on next page



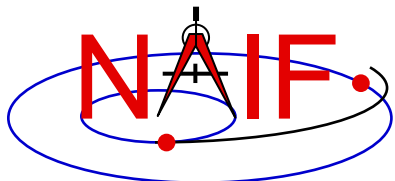
Summarizing a CK File - 3

Navigation and Ancillary Information Facility

continued from previous page

- A summary of interpolation intervals within a CK can also be made using FRMDIFF, using its '-t dumpc' option
- A summary of gaps between interpolation intervals in a CK can be made using FRMDIFF, using its '-t dumpg' option

```
% frmdiff -t dumpg \  
          -k cas_v40.tf naif0008.tls cas00106.tsc \  
          -f 'YYYY-DOYTHR:MN:SC ::RND' \  
          07102_07107ra.bc  
  
#  
# . . . <FRMDIFF report header> . . .  
#  
# gap_start, gap_stop, gap_duration_sec, gap_duration_string  
2007-102T05:56:57 2007-102T05:57:17 19.999 0:00:00:19.999  
2007-102T21:33:21 2007-102T21:33:41 19.999 0:00:00:19.999  
2007-102T21:34:57 2007-102T21:35:25 27.999 0:00:00:27.999  
.  
.  
.
```



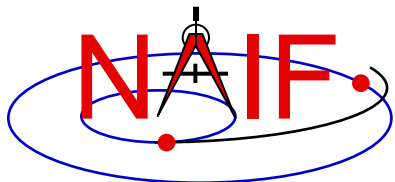
Summarizing a CK file - 4

Navigation and Ancillary Information Facility

- A detailed summary of a CK can be made using 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.
```



CK Utility Programs

Navigation and Ancillary Information Facility

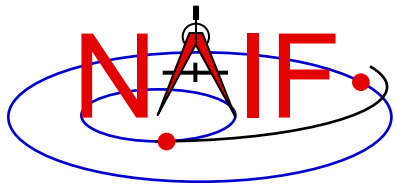
- **The following CK utility programs are included in the Toolkit:**

CKBRIEF	summarizes coverage for one or more CK files
SPACIT	generates segment-by-segment summary of a CK file
COMMNT	reads, appends, or deletes comments in an CK file
MSOPCK	converts attitude data provided in a text file into a CK file
FRMDIFF	samples or compares orientation of CK-based frames

- **These additional CK utility programs are provided on the NAIF Web site**

CKSLICER	subsets a CK file
CKSMRG	merges segments in a type 3 CK file (*)
DAFCAT	concatenates together CK files (*)
CKSPANIT	modifies interpolation interval information in a Type 3 CK file
DAFMOD	alters structure or frame IDs in a CK file
PREDICKT	creates a CK file representing an orientation profile described by a set of orientation rules and a schedule
BFF	displays binary file format of a CK file
BINGO	converts CK files between IEEE and PC binary formats

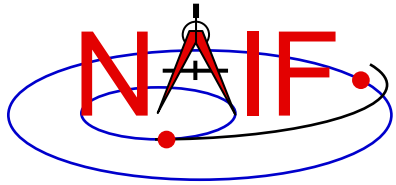
(*) DAFCAT and SKSMRG are frequently used together to first merge many CK files into a single file using DAFCAT and then merge segments inside the merged file using CKSMRG.



Additional Information on CK

Navigation and Ancillary Information Facility

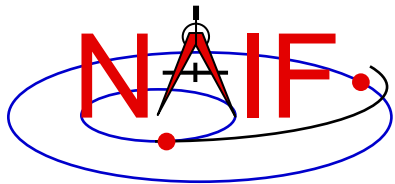
- **For more information about CK, look at the following documents**
 - CK Required Reading
 - headers for the CKGP and CKGPAV routines
 - Most Useful SPICELIB Routines
 - CKBRIEF and FRMDIFF User's Guides
 - Frames tutorials: FK and Using Frames ← *don't miss these*
 - Porting_kernels tutorial
- **Related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



Backup

Navigation and Ancillary Information Facility

- **The meaning of Tolerance**
- **Examples of Problems Encountered When Using the CK Subsystem**
- **Using the CK “reader” APIs**

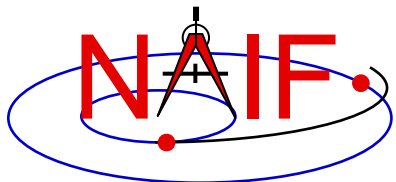


The Meaning of Tolerance - 1

Navigation and Ancillary Information Facility

- **The low level 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 - 6), if pointing information is not found within +/- tol of your pointing request time, no pointing will be returned and the “found flag” will return as “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 instance with the later time tag will be selected.
 - For Types 2 - 6 (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.
- **See the next three charts for graphic depictions.**

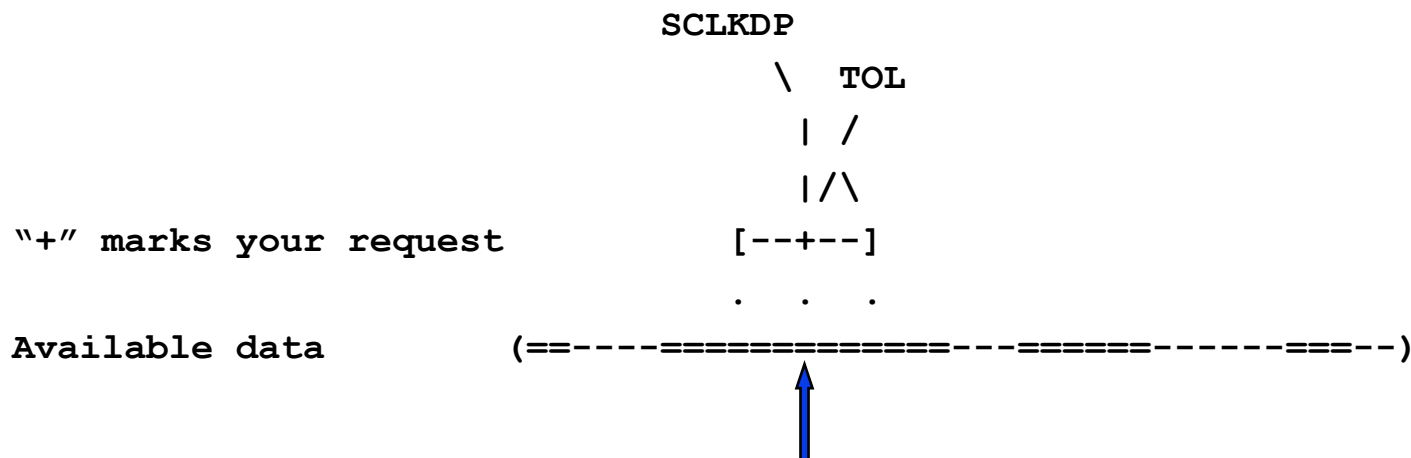
*Ignoring segment priority



The Meaning of Tolerance - 3

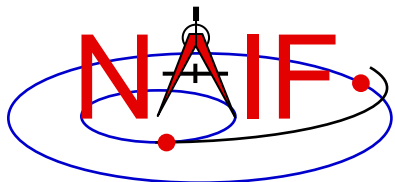
Navigation and Ancillary Information Facility

When reading a Type 2, 3, 4, 5 or 6 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

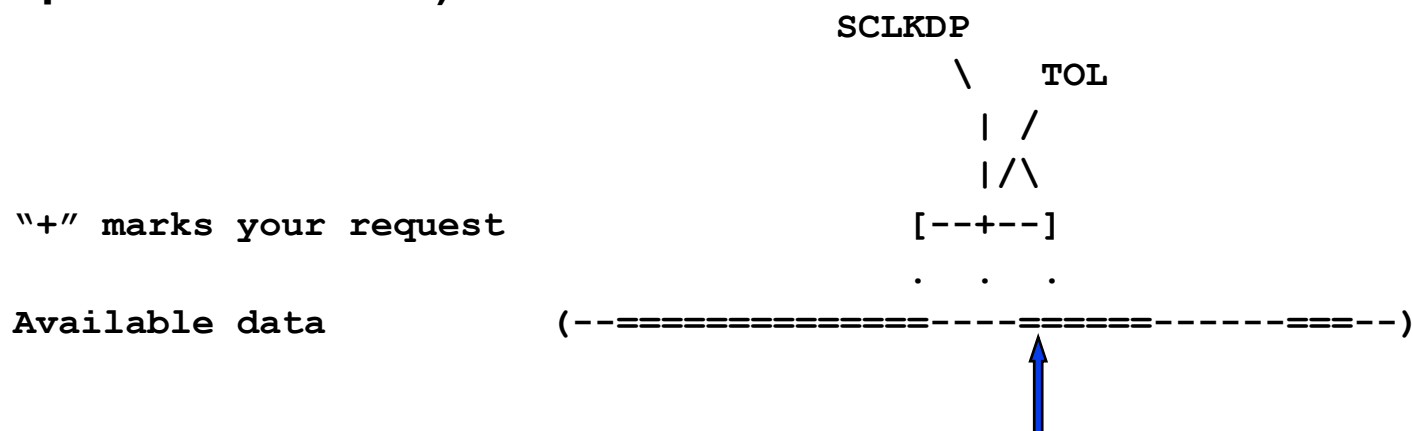
- “==” is used to indicate interpolation intervals of continuous pointing
- “ () ” are used to represent the end points of a segment within a CK file
- SCLKDP is the time at which you have requested pointing
- TOL is the time tolerance you have specified in your pointing request; for this particular 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

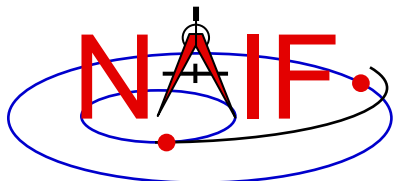
Navigation and Ancillary Information Facility

When reading a Type 2, 3, 4, 5 or 6 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.

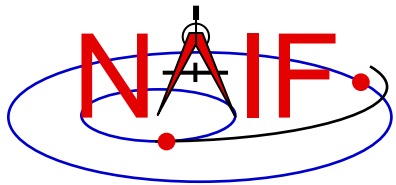
- “==” is used to indicate interpolation intervals of continuous pointing
- “ () ” are used to represent the end points of a segment within a CK file
- SCLKDP is the time at which you have requested pointing
- TOL is the time tolerance you have specified in your pointing request
- The quaternions occurring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



Problems using CK - 1

Navigation and Ancillary Information Facility

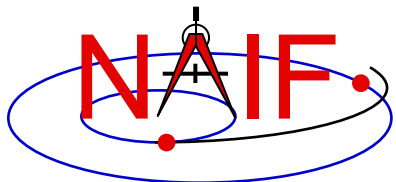
- **The file or files you loaded do not contain orientation data for the object of interest.**
 - Make sure the ID that you use in a call to CKGP or CKGPAV matches one in the CK file(s) you have loaded.
 - Make sure the frame that you specify in a call to SXFORM, PXFORM, SPKEZR, or SPKPOS is transformable to one available in the loaded CK files.
- **One of the low-level routines, 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

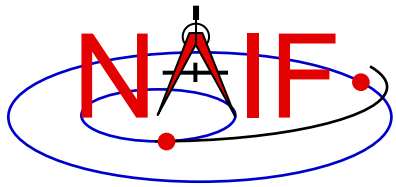
- **The file, or files, you loaded do not cover the time at which you requested orientation**
 - Check file coverage on the segment level by summarizing the file(s) using CKBRIEF or SPACIT
 - Check interpolation interval coverage using CKBRIEF with option “-dump,” or by examining comments provided in the comment area of the file - you may be asking for data within a coverage gap (your request time is outside of interpolation intervals)
- **One of the high-level routines (SPKEZR, SPKPOS, SXFORM, PXFORM, SINCP) signals an error**
 - These 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

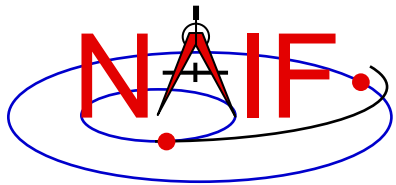
- **You've confirmed not having any of the previously described problems, but the FOUND flag returns as "FALSE" when using CKGPAV, or SXFORM or SPKEZR signals a frame related error.**
 - **You are using a SPICE routine that requires angular velocity as well as orientation, but the CK segments available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



Problems using CK - 4

Navigation and Ancillary Information Facility

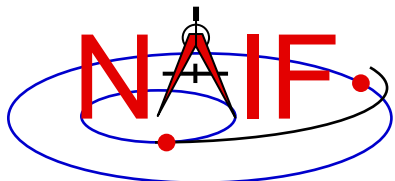
- **The FOUND flag returns as “TRUE” when using CKGPAV but returned angular velocity does not appear correct.**
 - While many sources of angular rate data, for example spacecraft telemetry, specify it relative to the spacecraft frame, SPICE CK files store it, and CKGPAV returns it, with respect to the base frame. So the sense of returned angular velocity in a CK may be unexpected.
- **The FOUND flag returns as “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 technical reference document for more details.
 - » NAIF prepared a “white paper” explaining differences between various quaternion styles commonly used in space applications:
 - https://naif.jpl.nasa.gov/pub/naif/misc/Quaternion_White_Paper/Quaternions_White_Paper.pdf



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)
 - » PC (Windows or Linux) and Mac OSX use the IEEE Little-endian binary standard
 - » Sun and very old Mac (Motorola cpu) use the IEEE Big-endian 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



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 )
```

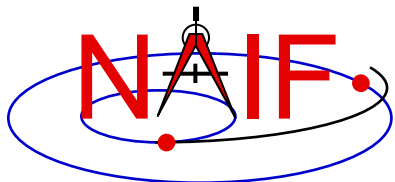
Get rotation matrix, or rotation matrix and angular velocity at requested time

```
CALL CKGP (instid,sclkdp,tol,'ref_frame',cmat,  clkout,found)  
or  
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 in order 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 earlier in these backup slides