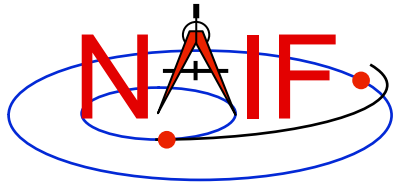


Navigation and Ancillary Information Facility

Making a CK file

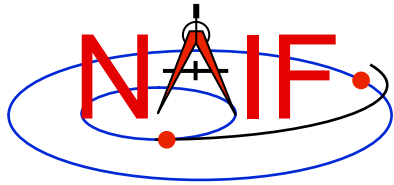
March 2010



Summary

Navigation and Ancillary Information Facility

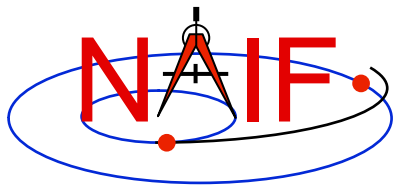
- **SPICE provides means to create CK files either by packaging orientation computed elsewhere or by first computing orientation and then packaging it in a CK file**
- **Packaging of already existing orientation data can be done in two ways:**
 - Use SPICE CK writer routines by calling them from within 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

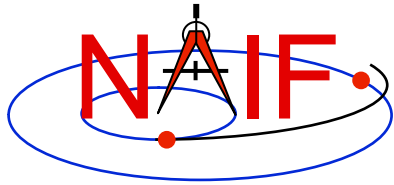


Type 3 Writer Example - 1

Navigation and Ancillary Information Facility

- **The following C-language code fragment illustrates the creation of a Type 3 C-kernel having a single segment.**

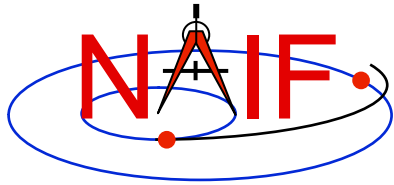
```
ckopn_c ( filename, "my-ckernel", 0, &handle );  
/*  
    Insert code that properly constructs the  
    sclkdp, quats, avvs, and starts arrays.  
*/  
ckw03_c ( handle, begtim, endtim, inst,  
          "reference_frame", avflag, "segment_id",  
          nrec, sclkdp, quats, avvs, nints, starts );  
  
ckcls_c ( handle );
```



Type 3 Writer Example - 2

Navigation and Ancillary Information Facility

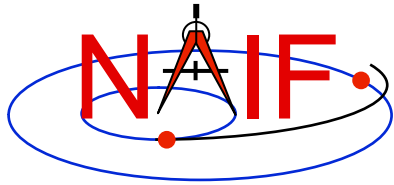
- **handle** - file handle for the newly created C-kernel.
- **begtim, endtim** - start and stop times in SCLK ticks for the segment.
- **inst** - ID code for the instrument for which the C-kernel is being made.
- **ref** - name of the base reference frame. Must be one known to SPICE during your program 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**.



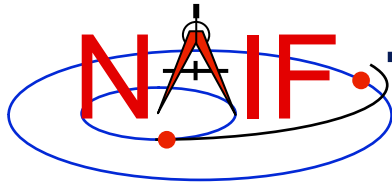
Type 3 writer - Making Up Rates

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] );  
}
```

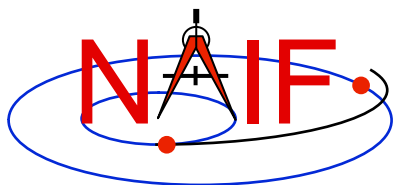
- **Then copy the (nrec-1) value of avvs into the last element of avvs.**



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.**

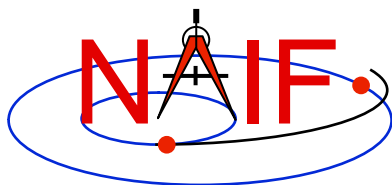


MSOPCK

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

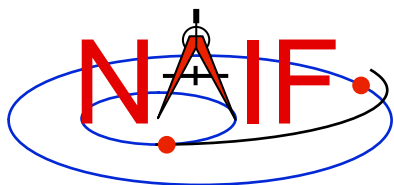
Output CK
Specifications

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'

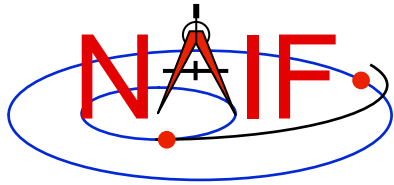
Input file:

```
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

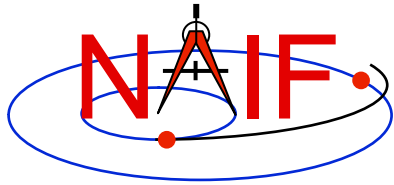
```
EULER_ROTATIONS_ORDER = ( 'axis3', 'axis2', 'axis1' )
```

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

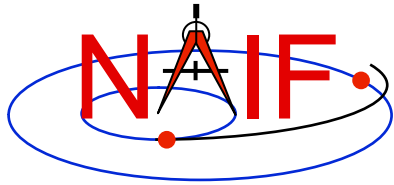
(*) NAIF prepared and provides on request a “white paper” explaining differences between various quaternion styles.



MSOPCK - Input Details (3)

Navigation and Ancillary Information Facility

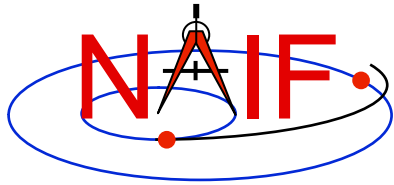
- **Angular rates are an optional input. Their presence or absence must be indicated using the ANGULAR_RATE_PRESENT keyword**
 - If angular rates are provided (ANGULAR_RATE_PRESENT = 'YES'), they must be in the form of a 3d vector expressed either in the base frame (less common) or instrument frame (more 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

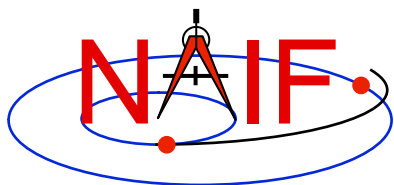
- ***msopck* can generate Type 1, 2, or 3 CKs**
 - Type 1 is rarely used - only in cases when the input contains very few data points that are far apart so that interpolation between them makes no sense
 - Type 2 is also rarely used, primarily to package orientation for spinners
 - » Normally the input 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

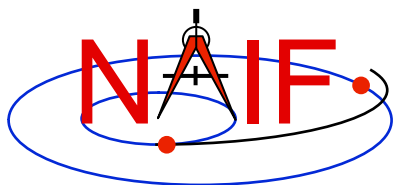
- **The time tags may be adjusted by a constant value specified in seconds using the `TIME_CORRECTION` keyword**
- **The output CK file contains one or more CK segments**
 - Multiple segments are generated if the input data volume is large and does not fit into the program's internal buffer (100,000 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
-----

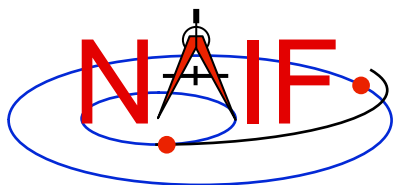
This file contains sample orientation for the Mars Surveyor '01
Orbiter (M01) spacecraft frame, 'M01_SPACECRAFT', relative
to the Mars Mean Equator and IAU vector of J2000, 'MARSIAU', inertial
frame. The NAIF ID code for the 'M01_SPACECRAFT' frame is -53000.

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.

...

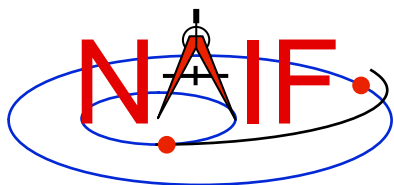
```



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
...
```

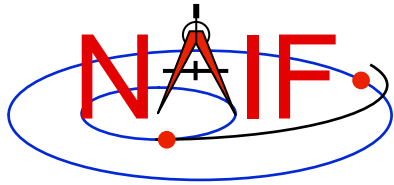


MSOPCK - Example (4)

Navigation and Ancillary Information Facility

```
Terminal Window
$ msopck msopck_setup.example msopck_input.example msopck_example_ck.bc

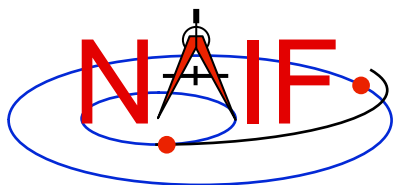
MSOPCK Utility Program, Version 3.0.0, 2003-05-05; SPICE Toolkit Ver. N0057
...
<comment file contents>
...
<setup file contents>
...
*****
RUN-TIME OBTAINED META INFORMATION:
*****
PRODUCT_CREATION_TIME = 2004-04-29T12:17:55
START_TIME             = 2004-04-27T00:00:05.516
STOP_TIME              = 2004-04-27T23:59:56.275
*****
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**



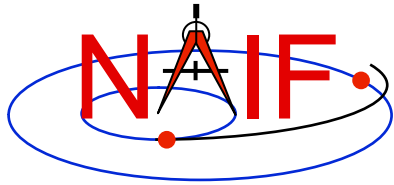
PREDICKT - Usage

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
```

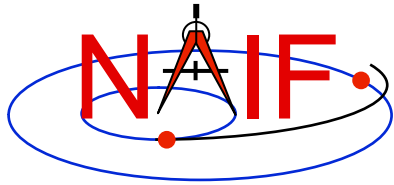
- **'-furnish', '-spec' and '-ck' are used to specify the input meta-kernel, input attitude specification file and output CK file**
- **'-tol' is used to specify the tolerance to which the orientation stored in the CK should match the specified attitude profile**
- **'-sclk' or '-newsclk' specify the 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

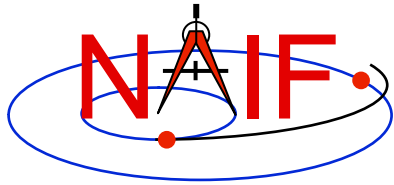


PREDICKT - Directions

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' )
```

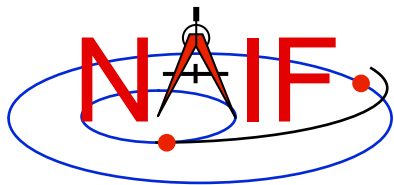


PREDICKT - Orientations

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'
```

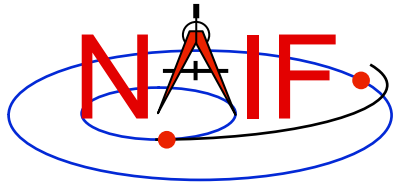



PREDICKT - Schedules (1)

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**

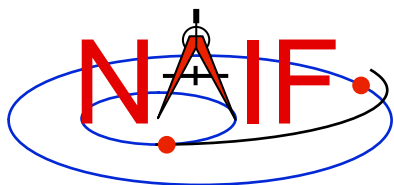
```
CK-SCLK           = 53
CK-SPK            = -53
CK-FRAMES         += -53000
CK-53000ORIENTATION += 'SOLUTION TO M01_THEMIS_IR = CameratoMars'
CK-53000START     += @2004-FEB-10-00:00
CK-53000STOP      += @2004-FEB-15-00:00
```



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)

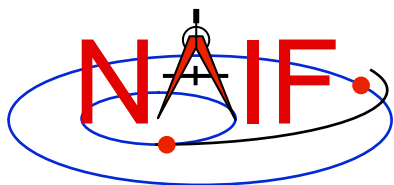
Navigation and Ancillary Information Facility

```
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)
$
```