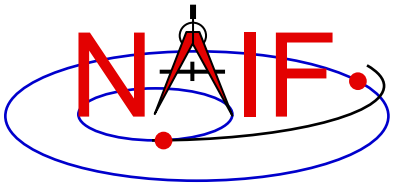


Making a CK file

January 2020

Summary

- SPICE provides means to create CK files, either by packaging orientation computed by others, or by first computing orientation within SPICE 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 your own SPICE-based application
    - » Convert a text file containing orientation data to a CK using the Toolkit's *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 your own SPICE-based application
      - Constructing orientation using SPICE routines is not discussed here
    - » Convert orientation rules and schedules to a CK using the *prediCkt* program available from the NAIF website

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)
  - For Type 6 CK
    - » CKW06 (no CSPICE, Icy or Mice wrappers)
- Only the Type 3 writer is discussed in this tutorial
  - Writers for Types 1 and 2 have very similar interfaces
  - Types 4, 5 and 6 are are not commonly used

Type 3 Writer Example - 1

- **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,
          "ref", avflag, "segid", nrec,
          sclkdp, quats, avvs, nints, starts );

ckcls_c ( handle );
```

Type 3 Writer Example - 2

- `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

- `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 or calculated.
- `quats` - a list of SPICE quaternions that rotate vectors from the base frame specified by the `ref` argument to the `inst` frame.
- `avvs` - angular rate vectors given in the base frame specified by the `ref` argument.
- `nints` - number of entries in starts.
- `starts` - a list of SCLK ticks indicating the start of interpolation intervals. They must correspond to entries in `sclkdp`.

Type 3 writer - Making Up Rates

- **One of the easiest ways to make up angular rates 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`.**

continued on next page

Type 3 Writer - Making Up Rates (2)

- Constructing angular rates in this fashion assumes that no more than one 180-degree rotation has occurred between adjacent quaternions.
  - `raxisa_c` chooses the smallest angle that performs the rotation encapsulated in the input matrix.

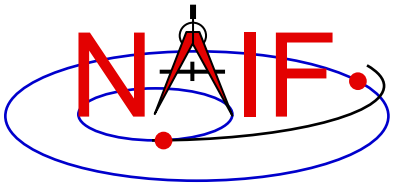
- Other techniques exist, including differentiating quaternions. Care must be exercised when taking that approach.

MSOPCK

- ***msopck*** **makes CK files from orientation data provided in a time- tagged, space-delimited table in text format**
- ***msopck*** **can process quaternions (SPICE and non-SPICE styles), Euler angles, or rotation matrices, tagged with UTC, SCLK, or ET time tags**
- ***msopck*** **requires all program directives 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

Navigation and Ancillary Information Facility

Supporting Kernels/Files

```
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'
```

Output CK Specifications

```
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 data Specifications

```
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')
CHECK_TIME_ORDER        = 'YES' or 'NO' (default 'NO')
```

Optional and conditional keywords are shown in green

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 = 'ROTATION 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)

- **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 to 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 a "white paper" explaining differences between various quaternion styles:

https://naif.jpl.nasa.gov/pub/naif/misc/Quaternion_White_Paper/Quaternions_White_Paper.pdf

MSOPCK - Input Details (3)

- **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 a uniform rotation algorithm implemented in Type 3 CKs, 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 string, SCLK ticks or ET, as specified using the INPUT_TIME_TYPE keyword**
  - **Time tags must not have embedded spaces**

MSOPCK - Output Details (1)

- ***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 spinning spacecraft**
    - » **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 specified in units of 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**

```
Vinst = [ROTinput] * [ROToffset] * Vref
```

MSOPCK - Output Details (2)

- The time tags may be adjusted by a constant value, specified in seconds, using the TIME_CORRECTION keyword
- The order of input time tags can be checked using the CHECK_TIME_ORDER 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 a 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* makes 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 specifications 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* and its User Guide are available only from the Utilities link of the NAIF webpages

PREDICKT - Usage

- ***prediCkt* has the following command line arguments**

```
-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

- A “FURNSH” kernel lists SPICE kernels that are to be used by prediCkt to determine geometry needed to compute orientations
- A prediCkt attitude specification (spec) file, using 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 FURNSH kernel and the spec file are included in the comment area of the output CK file

PREDICKT - Directions

- **Dynamic directions can be of the following types**
  - **Based on ephemeris (position vectors, velocity vectors)**
  - **Fixed with respect to a reference frame (expressed as a 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 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

- **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 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)

- 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)

- 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 kernel 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
  - the “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)
$
```