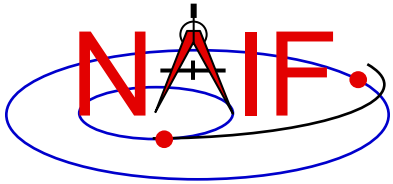


Navigation and Ancillary Information Facility

Writing a SPICE (FORTRAN) Based Program

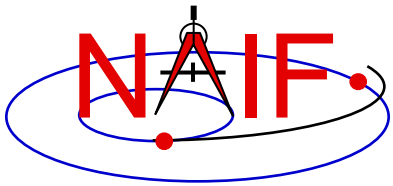
April 2023



Viewing This Tutorial

Navigation and Ancillary Information Facility

Undefined variables are displayed in **red**
Results are displayed in **blue**



Introduction

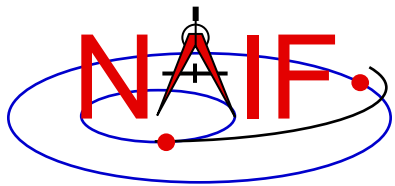
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First, let's go over the important steps in the process of writing a SPICE-based Fortran program and putting it to work:

- Understand the geometry problem.
- Identify the set of SPICE kernels that contain the data needed to perform the computation.
- Select the SPICE APIs needed to compute the quantities of interest.
- Write and compile the program.
- Get actual kernel files and verify that they contain the data needed to support the computation for the time(s) of interest.
- Run the program.

To illustrate these steps, let's write a program that computes the apparent intersection of the boresight ray of a given CASSINI science instrument with the surface of a given Saturnian satellite. The program will compute

- Planetocentric and planetodetic (geodetic) latitudes and longitudes of the intercept point.
- Range from spacecraft to intercept point.
- Illumination angles (phase, solar incidence, and emission) at the intercept point.



Observation geometry

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We want the boresight intercept on the surface, range from s/c to intercept, and illumination angles at the intercept point.

When? **TIME** (UTC, TDB or TT)

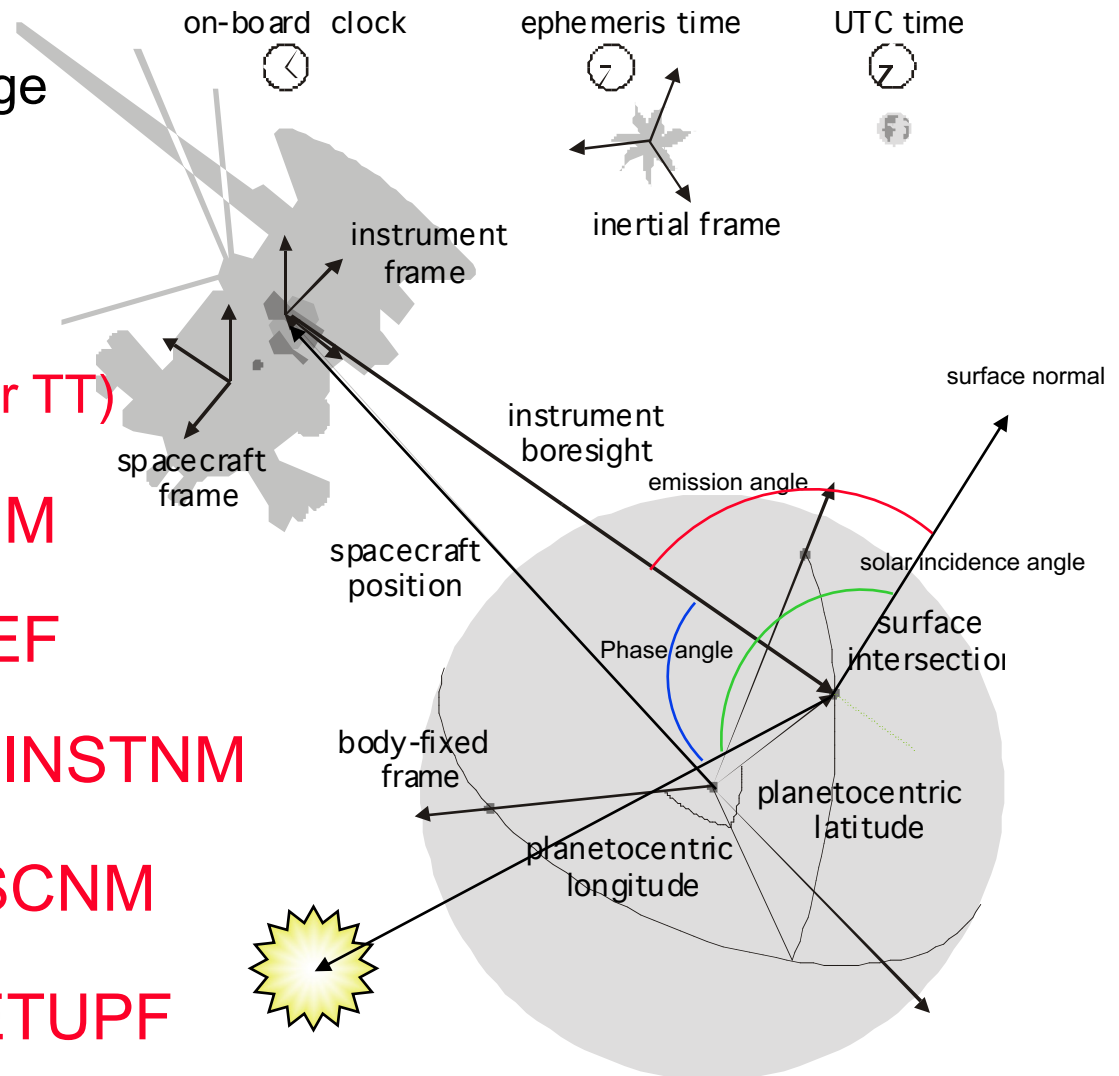
On what object? **SATNM**

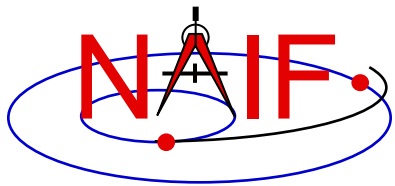
In what frame? **FIXREF**

For which instrument? **INSTNM**

For what spacecraft? **SCNM**

Using what model? **SETUPF**





Needed Data

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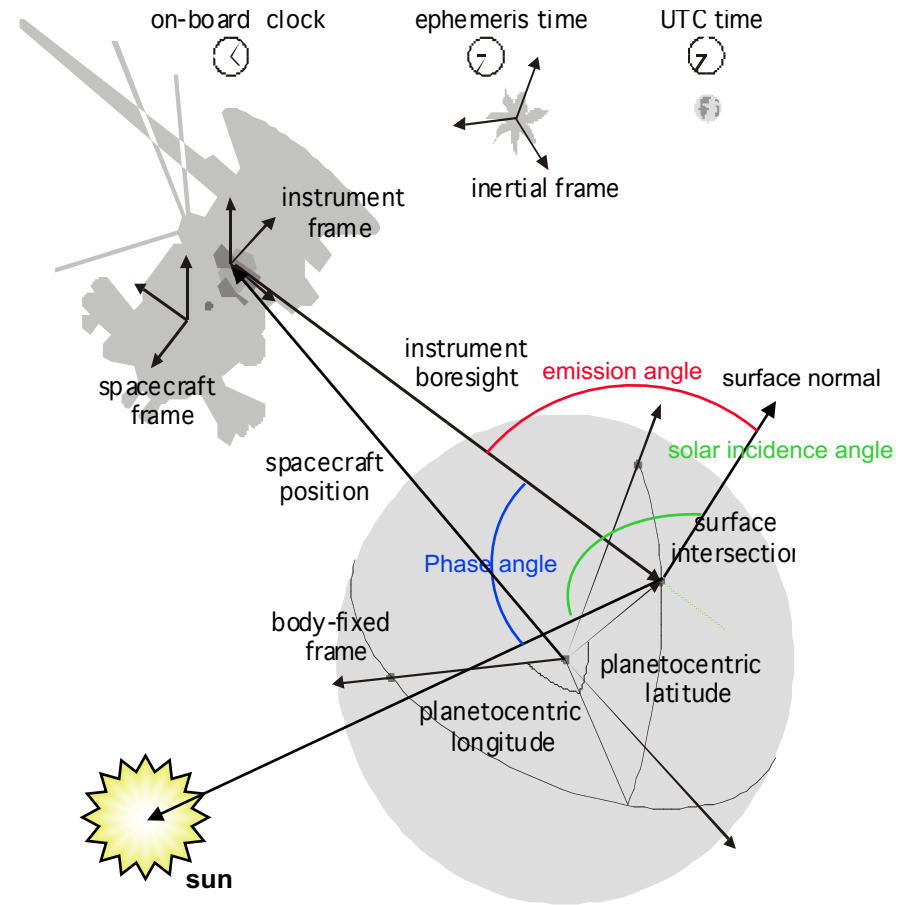
Time transformation kernels

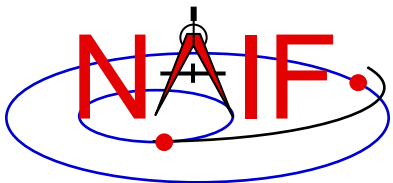
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





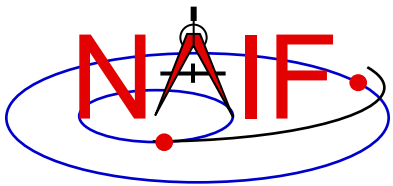
Which Kernels are Needed?

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Data required to compute vectors, rotations and other parameters shown in the picture are stored in the SPICE kernels listed below.

Note: these kernels have been selected to support this presentation; they should not be assumed to be appropriate for user applications.

Parameter	Kernel Type	File name
-----	-----	-----
time conversions	generic LSK	naif0009.tls
	CASSINI SCLK	cas00084.tsc
satellite orientation	CASSINI PCK	cpck05Mar2004.tpc
satellite shape	CASSINI PCK	cpck05Mar2004.tpc
satellite position	planet/sat	
	ephemeris SPK	020514_SE_SAT105.bsp
planet barycenter position	planet SPK	981005_PLTEPH-DE405S.bsp
spacecraft position	spacecraft SPK	030201AP_SK_SM546_T45.bsp
spacecraft orientation	spacecraft CK	04135_04171pc_psiv2.bc
instrument alignment	CASSINI FK	cas_v37.tf
instrument boresight	Instrument IK	cas_iss_v09.ti



Load Kernels

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The easiest and most flexible way to make required kernels available to the program is via FURNISH. For this example we make a setup file (also called a “metakernel” or “furnsh kernel”) containing a list of kernels to be loaded:

Note: these kernels have been selected to support this presentation they should not be assumed to be appropriate for user applications.

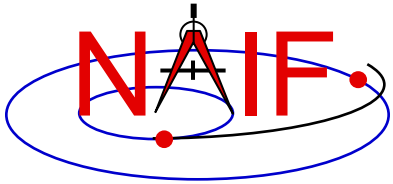
```
\begindata
```

```
KERNELS_TO_LOAD = ('naif0009.tls', 'cas00084.tsc', 'cpck05Mar2004.tpc',  
                    '020514_SE_SAT105.bsp', '981005_PLTEPH-DE405S.bsp',  
                    '030201AP_SK_SM546_T45.bsp', '04135_04171pc_psiv2.bc',  
                    'cas_v37.tf', 'cas_iss_v09.ti')
```

```
\begintext
```

and we make the program prompt for the name of this setup file:

```
CALL PROMPT ( 'Enter setup file name > ', SETUPF )  
CALL FURNISH ( SETUPF )
```



Programming Solution

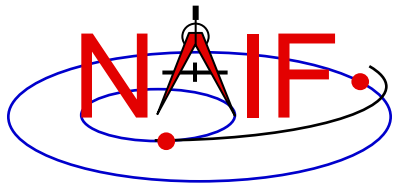
Navigation and Ancillary Information Facility

- Prompt for setup file (“metakernel”) name load kernels specified via setup file. (Done on previous chart.)
- Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via SPICELIB calls.
- Compute the intersection of the boresight direction ray with the surface of the satellite, presented as a triaxial ellipsoid.

If there is an intersection,

- Convert Cartesian coordinates of the intercept point to planetocentric latitudinal and planetodetic coordinates
 - Compute spacecraft-to-intercept point range
 - Find the illumination angles (phase, solar incidence, and emission) at the intercept point
- Display the results.

We discuss the geometric portion of the problem next.



Compute Surface Intercept and Ranges

Navigation and Ancillary Information Facility

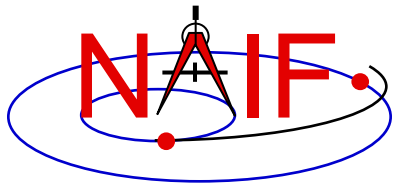
Compute the intercept point (**POINT**) of the boresight vector (**INSITE**) specified in the instrument frame (**IFRAME**) of the instrument mounted on the spacecraft (**SCNM**) with the surface of the satellite (**SATNM**) at the TDB time of interest (**ET**) in the satellite's body-fixed frame (**FIXREF**). This call also returns the light-time corrected epoch at the intercept point (**TRGEPC**), the spacecraft-to-intercept point vector (**SRFVEC**), and a flag indicating whether the intercept was found (**FOUND**). We use "converged Newtonian" light time plus stellar aberration corrections to produce the most accurate surface intercept solution possible. We model the surface of the satellite as an ellipsoid.

```
CALL SINCPT ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM, IFRAME,  
             INSITE, POINT, TRGEPC, SRFVEC, FOUND )
```

The range we want is obtained from the outputs of `SINCPT`. These outputs are defined only if a surface intercept is found. If **FOUND** is true, the spacecraft-to-surface intercept range is the norm of the output argument **SRFVEC**. Units are km. We use the SPICELIB function `VNORM` to obtain the norm:

```
VNORM ( SRFVEC )
```

We'll write out the range data along with the other program results.



Compute Lat/Lon and Illumination Angles

Navigation and Ancillary Information Facility

Compute the planetocentric latitude (**PCLAT**) and longitude (**PCLON**), as well as the planetodetic latitude (**PDLAT**) and longitude (**PDLON**) of the intersection point.

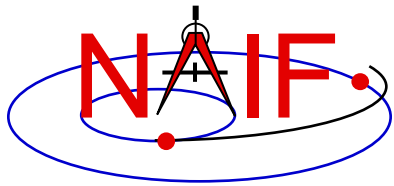
```
IF ( FOUND ) THEN
    CALL RECLAT ( POINT, R, PCLON, PCLAT )

C      Let RE, RP, and F be the satellite's longer equatorial
C      radius, polar radius, and flattening factor.
RE   = RADII(1)
RP   = RADII(3)
F    = ( RE - RP ) / RE

    CALL RECGeo ( POINT, RE, F, PDLON, PDLAT, ALT )
```

The illumination angles we want are the outputs of **ILUMIN**. Units are radians.

```
CALL ILUMIN ( 'Ellipsoid', SATNM, ET, FIXREF,
.           'CN+S', SCNM, POINT, TRGEPC, SRFVEC,
.           PHASE, SOLAR, EMISSN )
```



Geometry Calculations: Summary

Navigation and Ancillary Information Facility

C Compute the boresight ray intersection with the surface of the
C target body.

```
CALL SINCPT ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM, IFRAME,  
              INSITE, POINT, TRGEPC, SRFVEC, FOUND )
```

C If an intercept is found, compute planetocentric and planetodetic
C latitude and longitude of the point.

```
IF( FOUND ) THEN
```

```
    CALL RECLAT ( POINT, R, PCLON, PCLAT )
```

C Let RE, RP, and F be the satellite's longer equatorial
C radius, polar radius, and flattening factor.

```
    RE = RADII(1)
```

```
    RP = RADII(3)
```

```
    F  = ( RE - RP ) / RE
```

```
    CALL RECGEO ( POINT, RE, F, PDLON, PDLAT, ALT )
```

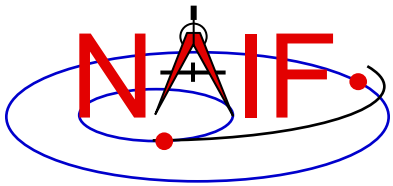
C Compute illumination angles at the surface point.

```
    CALL ILUMIN ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM,  
                  POINT, TRGEPC, SRFVEC, PHASE, SOLAR, EMISSN )
```

```
    ...
```

```
ELSE
```

```
    ...
```



Get Inputs - 1

Navigation and Ancillary Information Facility

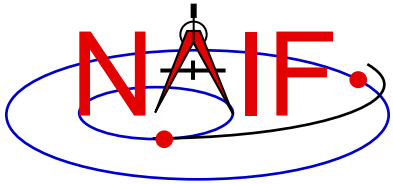
The code above used quite a few inputs that we don't have yet:

- TDB epoch of interest (**ET**)
- satellite and s/c names (**SATNM**, **SCNM**)
- satellite body-fixed frame name (**FIXREF**)
- satellite ellipsoid radii (**RADII**)
- instrument fixed frame name (**IFRAME**)
- instrument boresight vector in the instrument frame (**INSITE**)

Some of these values are user inputs others can be obtained via SPICELIB calls once the required kernels have been loaded.

Let's prompt for the satellite name (**SATNM**), satellite frame name (**FIXREF**), spacecraft name (**SCNM**), instrument name (**INSTNM**) and time of interest (**TIME**):

```
CALL PROMPT ( 'Enter satellite name > ', SATNM )  
CALL PROMPT ( 'Enter satellite frame > ', FIXREF )  
CALL PROMPT ( 'Enter spacecraft name > ', SCNM )  
CALL PROMPT ( 'Enter instrument name > ', INSTNM )  
CALL PROMPT ( 'Enter time > ', TIME )
```



Get Inputs - 2

Navigation and Ancillary Information Facility

Then we can get the rest of the inputs from SPICELIB calls:

To get the TDB epoch (**ET**) from the user-supplied time string (which may refer to the UTC, TDB or TT time systems):

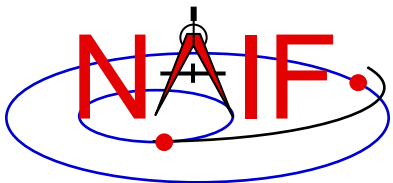
```
CALL STR2ET ( TIME, ET )
```

To get the satellite's ellipsoid radii (**RADII**):

```
CALL BODVRD ( SATNM, 'RADII', 3, I, RADII )
```

To get the instrument boresight direction (**INSITE**) and the name of the instrument frame (**IFRAME**) in which it is defined:

```
CALL GETFVN ( INSTNM, ROOM, SHAPE, IFRAME,  
              INSITE, N, BUNDRY )
```



Getting Inputs: Summary

Navigation and Ancillary Information Facility

C Prompt for the user-supplied inputs for our program.

```
CALL PROMPT ( 'Enter setup file name > ', SETUPF )
```

```
CALL FURNISH ( SETUPF )
```

```
CALL PROMPT( 'Enter satellite name > ', SATNM )
```

```
CALL PROMPT( 'Enter satellite frame > ', FIXREF )
```

```
CALL PROMPT( 'Enter spacecraft name > ', SCNM )
```

```
CALL PROMPT( 'Enter instrument name > ', INSTNM )
```

```
CALL PROMPT( 'Enter time > ', TIME )
```

C Get the epoch corresponding to the input time:

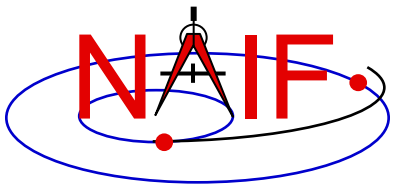
```
CALL STR2ET ( TIME, ET )
```

C Get the radii of the satellite.

```
CALL BODVRD ( SATNM, 'RADII', 3, I, RADII )
```

C Get the instrument boresight and frame name.

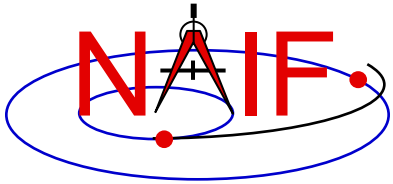
```
CALL GETFVN ( INSTNM, ROOM, SHAPE, IFRAME,  
             INSITE, N, BUNDRY )
```



Display Results

Navigation and Ancillary Information Facility

```
C      Display results.  Convert angles from radians to degrees
C      for output.
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept planetocentric longitude          (deg): ', DPR() * PCLON
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept planetocentric latitude           (deg): ', DPR() * PCLAT
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept planetodetic longitude            (deg): ', DPR() * PDLON
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept planetodetic latitude             (deg): ', DPR() * PDLAT
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Range from spacecraft to intercept point (km): ',
.      VNORM(SRFVEC)
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept phase angle                       (deg): ', DPR() * PHASE
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept solar incidence angle             (deg): ', DPR() * SOLAR
      WRITE ( *, ' (1X,A,F12.6)' )
.      'Intercept emission angle                   (deg): ',
.      DPR() * EMISSN
ELSE
      WRITE (*,*) 'No intercept point found at '// TIME
END IF
```



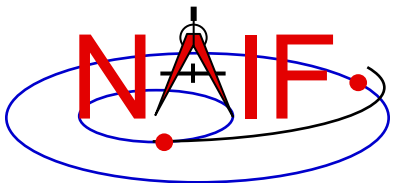
Complete the Program

Navigation and Ancillary Information Facility

To finish up the program we need to declare the variables we've used.

- We'll highlight techniques used by NAIF programmers
- Add remaining Fortran code required to make a syntactically valid program





Complete Source Code - 2

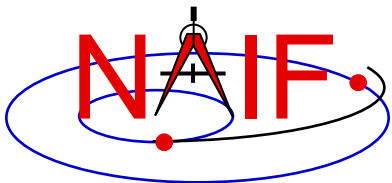
Navigation and Ancillary Information Facility

```
C      Prompt for the user-supplied inputs for our program.
      CALL PROMPT ( 'Enter setup file name > ', SETUPF )
      CALL FURNISH ( SETUPF )
      CALL PROMPT ( 'Enter satellite name > ', SATNM )
      CALL PROMPT ( 'Enter satellite frame > ', FIXREF )
      CALL PROMPT ( 'Enter spacecraft name > ', SCNM )
      CALL PROMPT ( 'Enter instrument name > ', INSTNM )
      CALL PROMPT ( 'Enter time                > ', TIME )

C      Get the epoch corresponding to the input time:
      CALL STR2ET ( TIME, ET )

C      Get the radii of the satellite.
      CALL BODVRD ( SATNM, 'RADII', 3, I, RADII )

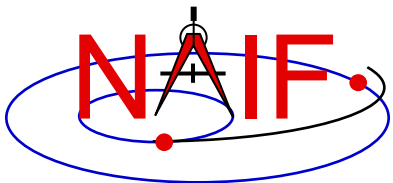
C      Get the instrument boresight and frame name.
      CALL GETFVN ( INSTNM, ROOM, SHAPE, IFRAME,
.                  INSITE, N,      BUNDRY )
```



Complete Source Code - 3

Navigation and Ancillary Information Facility

```
C      Compute the boresight ray intersection with the surface of the
C      target body.
      CALL SINCPT ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM, IFRAME,
.                INSITE, POINT, TRGEPC, SRFVEC, FOUND )
C      If an intercept is found, compute planetocentric and planetodetic
C      latitude and longitude of the point.
      IF( FOUND ) THEN
        CALL RECLAT ( POINT, R, PCLON, PCLAT )
C      Let RE, RP, and F be the satellite's longer equatorial
C      radius, polar radius, and flattening factor.
        RE = RADII(1)
        RP = RADII(3)
        F  = ( RE - RP ) / RE
        CALL REC GEO ( POINT, RE, F, PDLON, PDLAT, ALT )
C      Compute illumination angles at the surface point.
        CALL ILUMIN ( 'Ellipsoid', SATNM, ET, FIXREF, 'CN+S', SCNM,
.                POINT, TRGEPC, SRFVEC, PHASE, SOLAR, EMISSN )
C      Display results. Convert angles from radians to degrees
C      for output.
        WRITE ( *, * )
        WRITE ( *, '(1X,A,F12.6)' )
.      'Intercept planetocentric longitude      (deg): ', DPR()*PCLON
```

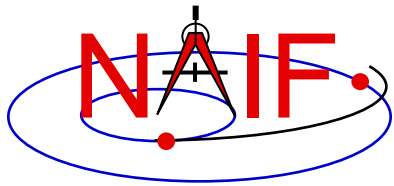


Complete Source Code - 4

Navigation and Ancillary Information Facility

```
WRITE ( *, ' (1X,A,F12.6)' )
. 'Intercept planetocentric latitude          (deg): ', DPR()*PCLAT
WRITE ( *, ' (1X,A,F12.6)' )
. 'Intercept planetodetic longitude          (deg): ', DPR()*PDLON
WRITE ( *, ' (1X,A,F12.6)' )
. 'Intercept planetodetic latitude          (deg): ', DPR()*PDLAT
WRITE ( *, ' (1X,A,F12.6)' )
. 'Range from spacecraft to intercept point (km): ',
. VNORM(SRFVEC)
WRITE ( *, ' (1X,A,F12.6)' )
. 'Intercept phase angle                    (deg): ', DPR()*PHASE
WRITE ( *, ' (1X,A,F12.6)' )
. 'Intercept solar incidence angle          (deg): ', DPR()*SOLAR
WRITE ( *, ' (1X,A,F12.6)' )
. 'Intercept emission angle                (deg): ',
. DPR()*EMISSN

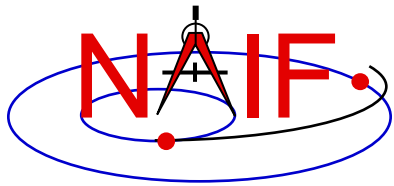
ELSE
  WRITE (*,*) 'No intercept point found at '// TIME
END IF
END
```



Compile and Link the Program - 1

Navigation and Ancillary Information Facility

- **First be sure that both the SPICE Toolkit and a Fortran compiler are properly installed.**
 - A "hello world" Fortran program must be able to compile, link, and run successfully in your environment.
 - Any of the mkprodct.* scripts in the toolkit/src/* paths of the SPICE Toolkit installation should execute properly.
- **Ways to compile and link the program:**
 - If you're familiar with the "make" utility, create a makefile. Use compiler and linker options from the mkprodct.* script found in the toolkit/src/cookbook path of your SPICE Toolkit installation.
 - Or, modify the cookbook mkprodct.* build script.
 - » Your program name must be *.pgm, for example demo.pgm, to be recognized by the script.
 - » Change the library references in the script to use absolute pathnames.
 - » Change the path for the executable to the current working directory.
 - » On some platforms, you must modify the script to refer to your program by name.



Compile and Link the Program - 2

Navigation and Ancillary Information Facility

- Or, compile the program on the command line. The program must be linked against the SPICELIB object library spicelib.a (spicelib.lib under MS Windows systems). On a PC running Linux and g77, if

- » The g77 compiler is in your path

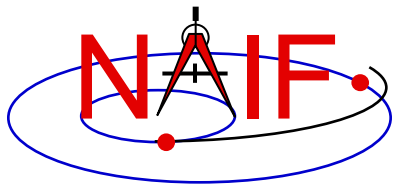
- As indicated by the response to the command "which g77"

- » the Toolkit is installed in the path (for the purpose of this example) /myhome/toolkit

- » You've named the program demo.f

then you can compile and link your program using the command

- » `g77 -o demo demo.f \`
`/myhome/toolkit/lib/spicelib.a`



Compile and Link the Program - 3

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> mkproduct.csh

        Using the g77 compiler.

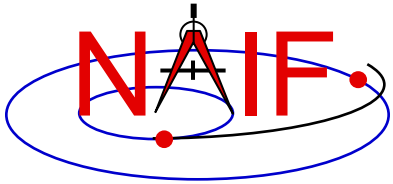
        Setting default Fortran compile options:
        -c -C

        Setting default C compile options:
        -C

        Setting default link options:

        Compiling and linking:  demo.pgm
        Compiling and linking:  demo.pgm

Prompt>
```



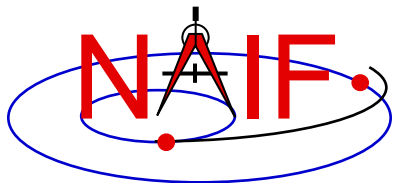
Running the Program - 1

Navigation and Ancillary Information Facility

It looks like we have everything taken care of:

- **We have all necessary kernels**
- **We made a setup file (metakernel) pointing to them**
- **We wrote the program**
- **We compiled and linked it**

Let's run it.



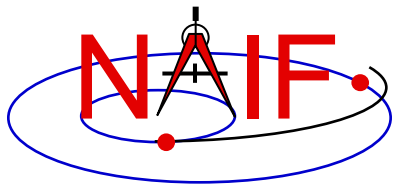
Running the Program - 2

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> demo
Enter setup file name > setup.ker
Enter satellite name > PHOEBE
Enter satellite frame > IAU_PHOEBE
Enter spacecraft name > CASSINI
Enter instrument name > CASSINI_ISS_NAC
Enter time > 2004 jun 11 19:32:00

Intercept planetocentric longitude (deg) : 39.843719
Intercept planetocentric latitude (deg) : 4.195878
Intercept planetodetic longitude (deg) : 39.843719
Intercept planetodetic latitude (deg) : 5.048011
Range from spacecraft to intercept point (km) : 2089.169724
Intercept phase angle (deg) : 28.139479
Intercept solar incidence angle (deg) : 18.247220
Intercept emission angle (deg) : 17.858309
Prompt>
```



Backup

Navigation and Ancillary Information Facility

- **Latitude definitions:**

- Planetocentric latitude of a point P: angle between segment from origin to point and x-y plane (red arc in diagram).
- Planetodetic latitude of a point P: angle between x-y plane and extension of ellipsoid normal vector N that connects x-y plane and P (blue arc in diagram).

