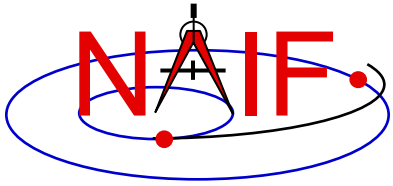


Navigation and Ancillary Information Facility

Writing an Icy (IDL) Based Program

April 2023



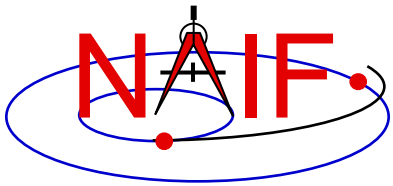
Viewing This Tutorial

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Undefined variables are displayed in **red**

Results are displayed in **blue**

Please read the tutorial “Preparing for Programming” prior to attempting the exercise contained in this tutorial.



Introduction

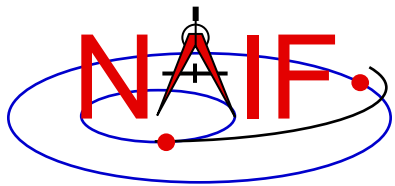
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First, let's go over the important steps in the process of writing an Icy-based program and putting it to work:

- **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)

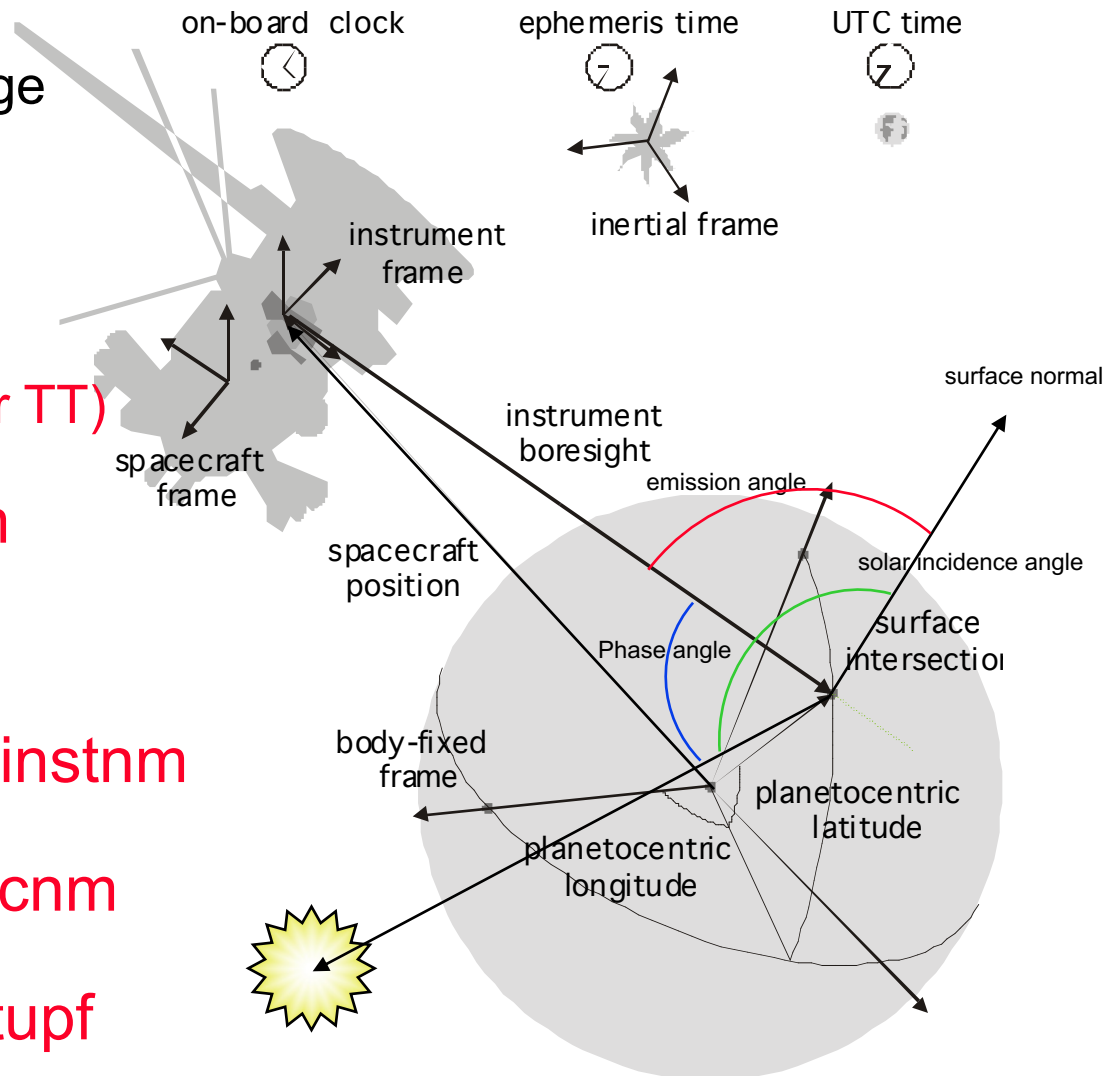
On what object? **satnm**

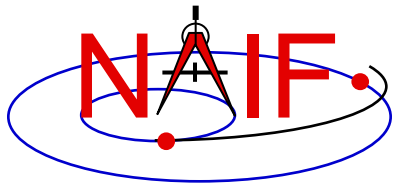
In what frame? **fixref**

For which instrument? **instnm**

For what spacecraft? **scnm**

Using what model? **setupf**





Needed Data

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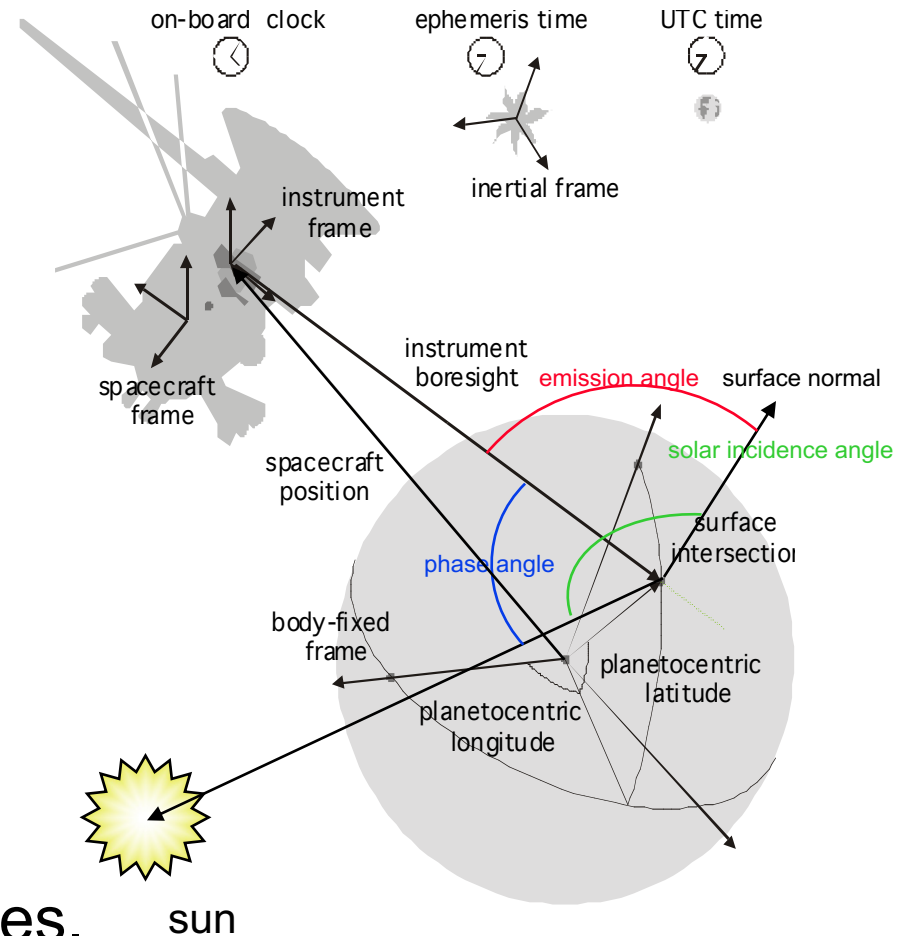
Time transformation kernels

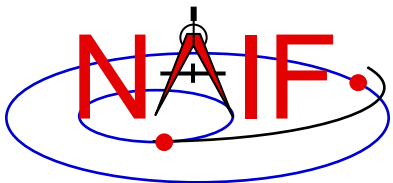
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





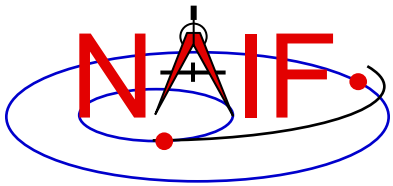
Which Kernels are Needed?

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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 these kernels available to the program is via `cspice_furnsh`. 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.

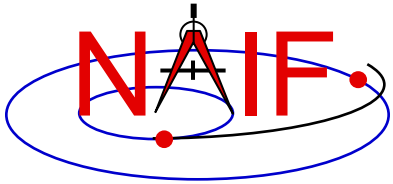
```
\begindata
```

```
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:

```
read, setupf, PROMPT='Enter setup file name > '  
cspice_furnsh, setupf
```



Programming Solution

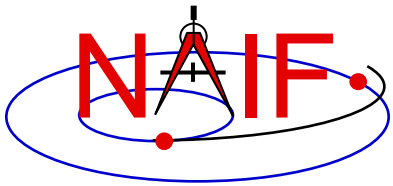
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- Prompt for setup file (“metakernel”) name; load kernels specified via setup file. (Done on previous chart.)
- Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via lcy calls.
- Compute 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 intersection 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 first.



Compute surface intercept

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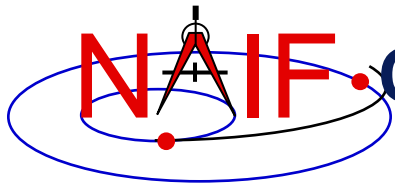
Compute the intercept point (**point**) of the boresight vector (**insite**) specified in the instrument frame (**iframe**) of the instrument mounted on the spacecraft (**scnm**) with the surface of the satellite (**satnm**) at the TDB time of interest (**et**) in the satellite's body-fixed frame (**fixref**). 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.

```
cspice_sincpt, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, iframe, $  
             insite, point, trgepc, srfvec, found
```

The range we want is obtained from the outputs of `cspice_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 lcy function `cspice_vnorm` to obtain the norm:

```
cspice_vnorm( srfvec )
```

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



Compute Lat/Lon and Illumination Angles

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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 begin
    cspice_reclat, point, r, pclon, pclat

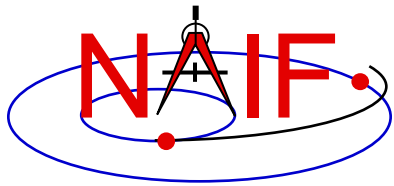
    ;; Let re, rp, and f be the satellite's longer equatorial
    ;; radius, polar radius, and flattening factor.

    re = radii[0]
    rp = radii[2]
    f = ( re - rp ) / re;

    cspice_recgeo, point, re, f, pdlon, pdlat, alt
```

The illumination angles we want are the outputs of `cspice_ilumin`. Units are radians.

```
cspice_ilumin, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
               point, trgepc, srfvec, phase, solar, emissn
```



Geometry Calculations: Summary

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```
;; Compute the boresight ray intersection with the surface of the  
;; target body.
```

```
cspice_sincpt, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $  
            iframe, insite, point, trgepc, srfvec, found
```

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

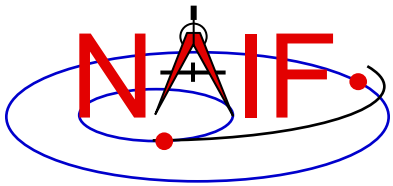
```
if ( found ) then begin  
    cspice_reclat, point, r, pclon, pclat  
    ;; Let re, rp, and f be the satellite's longer equatorial  
    ;; radius, polar radius, and flattening factor.  
    re = radii[0]  
    rp = radii[2]  
    f = ( re - rp ) / re;  
    cspice_recgeo, point, re, f, pdlon, pdlat, alt
```

```
;; Compute illumination angles at the surface point.
```

```
cspice_ilumin, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $  
            point, trgepc, srfvec, phase, solar, emissn
```

```
...  
endif else begin
```

```
...
```



Get inputs - 1

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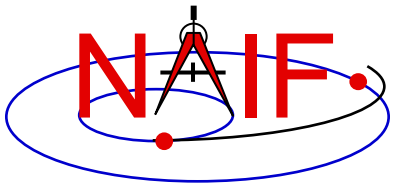
The code above used quite a few inputs that we don't have yet:

- 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 lcy 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**):

```
read, satnm , PROMPT='Enter satellite name > '  
read, fixref, PROMPT='Enter satellite frame > '  
read, scnm , PROMPT='Enter spacecraft name > '  
read, instnm, PROMPT='Enter instrument name > '  
read, time , PROMPT='Enter time > '
```



Get Inputs - 2

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

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

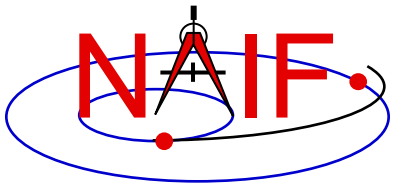
```
cspice_str2et, time, et
```

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

```
cspice_bodvrd, satnm, "RADII", 3, radii
```

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

```
cspice_getfvn, instnm, ROOM, shape, iframe, insite, bundry
```



Getting inputs: summary

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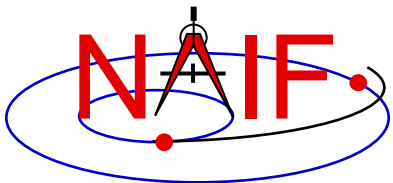
```
;; Prompt for the user-supplied inputs for our program
read, setupf, PROMPT='Enter setup file name > '
cspice_furnsh, setupf

read, satnm , PROMPT='Enter satellite name > '
read, fixref, PROMPT='Enter satellite frame > '
read, scnm  , PROMPT='Enter spacecraft name > '
read, instnm, PROMPT='Enter instrument name > '
read, time  , PROMPT='Enter time > '

;; Get the epoch corresponding to the input time:
cspice_str2et, time, et

;; Get the radii of the satellite.
cspice_bodvrd, satnm, "RADII", 3, radii

;; Get the instrument boresight and frame name.
cspice_getfvn, instnm, ROOM, shape, iframe, insite, bundry
```



Display results

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```
;; Display results. Convert angles from radians to degrees for output.
```

```
print
```

```
print, 'Intercept planetocentric longitude      (deg): ', $  
                                         cspice_dpr()*pclon
```

```
print, 'Intercept planetocentric latitude      (deg): ', $  
                                         cspice_dpr()*pclat
```

```
print, 'Intercept planetodetic longitude       (deg): ', $  
                                         cspice_dpr()*pdlon
```

```
print, 'Intercept planetodetic latitude        (deg): ', $  
                                         cspice_dpr()*pdlat
```

```
print, 'Range from spacecraft to intercept point (km): ', $  
                                         cspice_vnorm(srfvec)
```

```
print, 'Intercept phase angle                  (deg): ', $  
                                         cspice_dpr()*phase
```

```
print, 'Intercept solar incidence angle        (deg): ', $  
                                         cspice_dpr()*solar
```

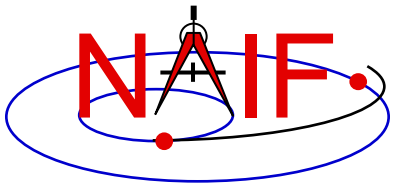
```
print, 'Intercept emission angle              (deg): ', $  
                                         cspice_dpr()*emissn
```

```
endif else begin
```

```
    print, 'No intercept point found at ' + time
```

```
endelse
```

```
END
```



Complete the program

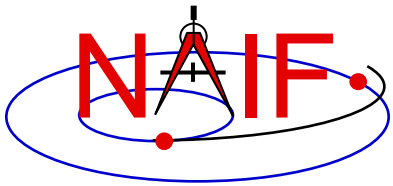
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To finish up the program we need to declare the variables we've used.

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

```
PRO PROG_GEOMETRY

ROOM    = 10L
setupf  = ''
satnm    = ''
fixref   = ''
scnm     = ''
instnm   = ''
time     = ''
R2D      = cspice_dpr()
```

Complete source code - 1

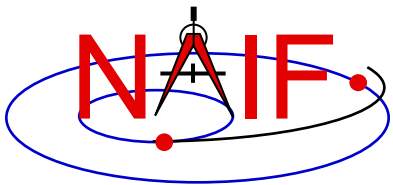
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```
;; Prompt for the user-supplied inputs for our program.
read, setupf, PROMPT='Enter setup file name > '
cspice_furnsh, setupf
read, satnm , PROMPT='Enter satellite name > '
read, fixref, PROMPT='Enter satellite frame > '
read, scnm , PROMPT='Enter spacecraft name > '
read, instnm, PROMPT='Enter instrument name > '
read, time , PROMPT='Enter time > '

;; Get the epoch corresponding to the input time:
cspice_str2et, time, et

;; Get the radii of the satellite.
cspice_bodvrd, satnm, 'RADII', 3, radii

;; Get the instrument boresight and frame name.
cspice_getfvn, instnm, ROOM, shape, iframe, insite, bundry
```



Complete source code - 2

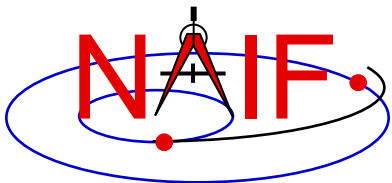
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```
;; Compute the boresight ray intersection with the surface of the
;; target body.
cspice_sincpt, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
    iframe, insite, point, trgepc, srfvec, found

;; If an intercept is found, compute planetocentric and planetodetic
;; latitude and longitude of the point.
if ( found ) then begin
    cspice_reclat, point, r, pclon, pclat
    ;; Let re, rp, and f be the satellite's longer equatorial
    ;; radius, polar radius, and flattening factor.
    re = radii[0]
    rp = radii[2]
    f = ( re - rp ) / re
    cspice_recgeo, point, re, f, pdlon, pdlat, alt

    ;; Compute illumination angles at the surface point.
    cspice_ilumin, 'Ellipsoid', satnm, et, fixref, 'CN+S', scnm, $
        point, trgepc, srfvec, phase, solar, emissn

    ;; Display results. Convert angles from radians to degrees
    ;; for output.
    print
    print, 'Intercept planetocentric longitude      (deg): ', $
        R2D*pclon
```



Complete source code - 3

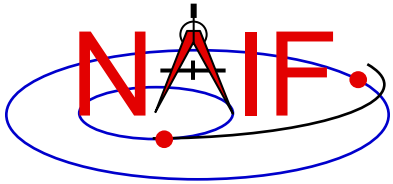
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```
print, 'Intercept planetocentric latitude      (deg): ', $
      R2D*pclat
print, 'Intercept planetodetic longitude      (deg): ', $
      R2D*pdlon
print, 'Intercept planetodetic latitude      (deg): ', $
      R2D*pdlat
print, 'Range from spacecraft to intercept point (km): ', $
      cspice_vnorm(srfvec)
print, 'Intercept phase angle                (deg): ', $
      R2D*phase
print, 'Intercept solar incidence angle      (deg): ', $
      R2D*solar
print, 'Intercept emission angle            (deg): ', $
      R2D*emissn

endif else begin
  print, 'No intercept point found at ' + time
endelse

;; Unload the kernels and clear the kernel pool
cspice_kclear

END
```



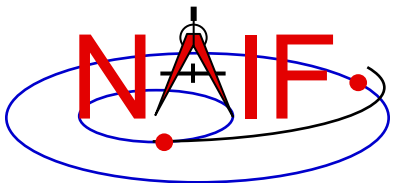
Compile the program - 1

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Though IDL functions in a manner similar to interpreted languages, it does compile source files to a binary form.

Ensure that both the Icy Toolkit, and an IDL installation are properly installed. IDL must load the Icy DLM, `icy.dlm/icy.so(dll)` to compile those scripts containing Icy calls. IDL loads DLMs from default locations and from the current directory when the user ran IDL. The user may also explicitly load a DLM with the `dml_register` command.

Now compile the code.

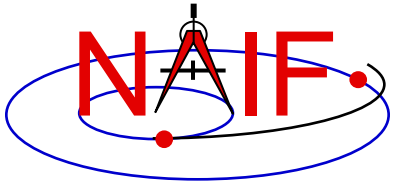


Compile the program - 2

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A screenshot of a terminal window titled "Terminal Window". The window has a standard Mac OS-style title bar with a close button in the top right corner. On the left side, there is a vertical scrollbar and two arrow buttons (up and down). The terminal text shows the IDL command to compile a program and the resulting message.

```
IDL> .compile prog_geometry.pro  
% Compiled module: PROG_GEOMETRY.
```



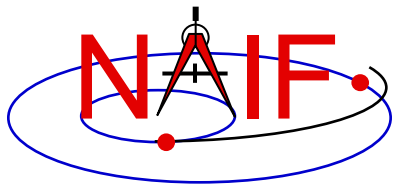
Running the program

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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 the program**

Let's run it.



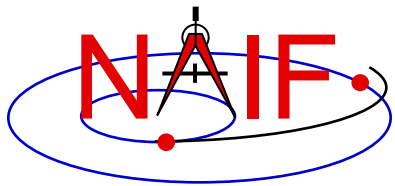
Running the program

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```
Terminal Window

IDL>  prog_geometry
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):      4.1958778
Intercept planetodetic longitude        (deg):      39.843719
Intercept planetodetic latitude         (deg):      5.0480106
Range from spacecraft to intercept point (km):      2089.1697
Intercept phase angle                   (deg):      28.139479
Intercept solar incidence angle          (deg):      18.247220
Intercept emission angle                 (deg):      17.858309
```



Backup

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- **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).

