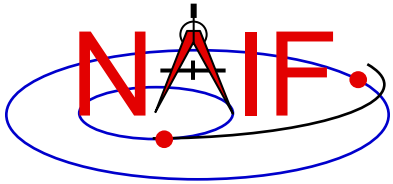


Navigation and Ancillary Information Facility

Writing a CSPICE (C) Based Program

April 2023

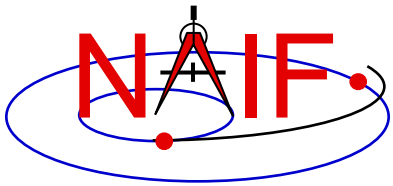


Viewing This Tutorial

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Undefined variables are displayed in **red**

Results are displayed in **blue**



Introduction

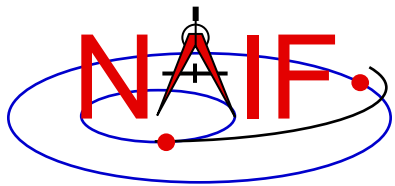
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First, let's go over the important steps in the process of writing a CSPICE-based program and putting it to work:

- **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.**
- **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)

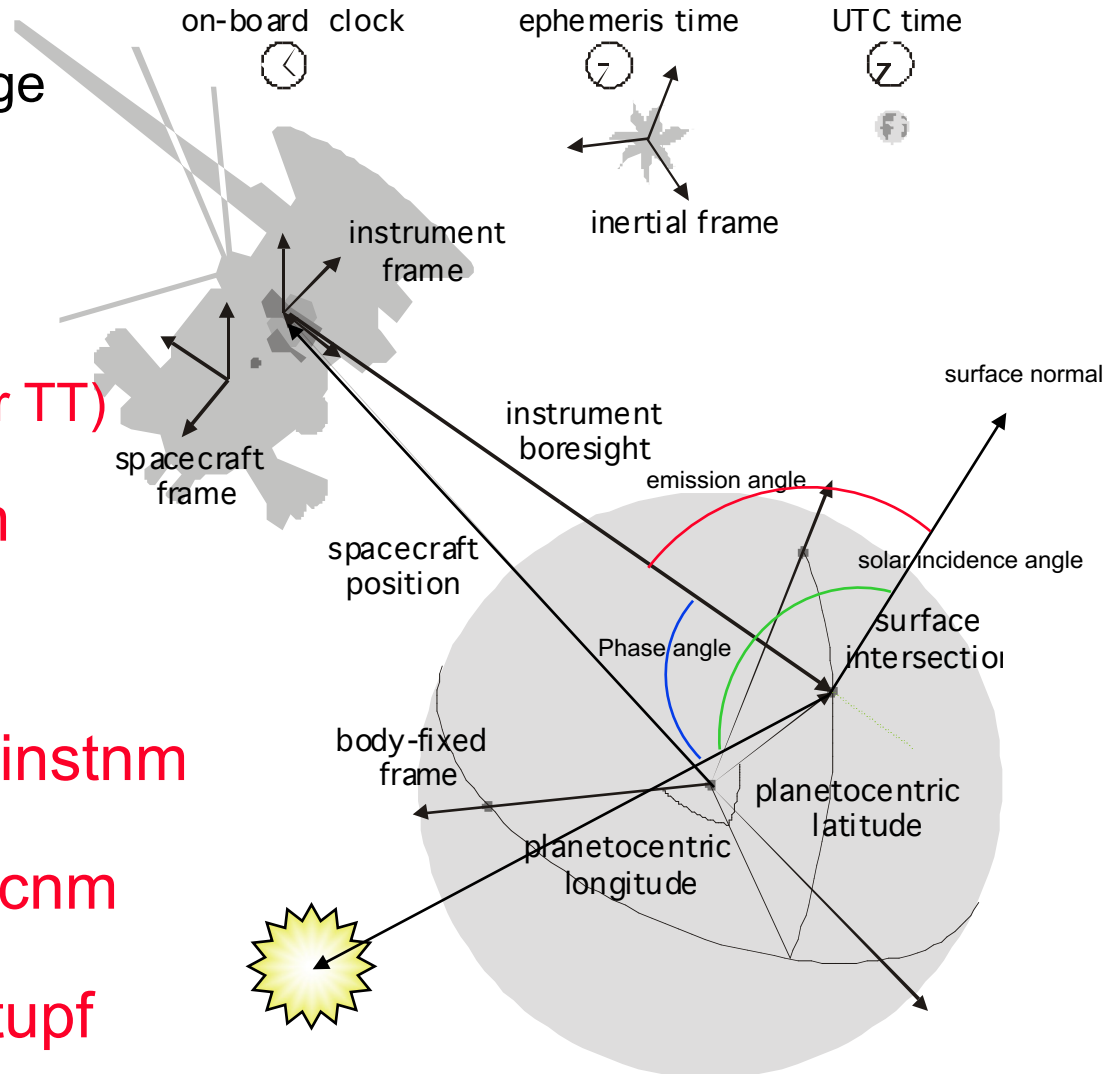
On what object? **satnm**

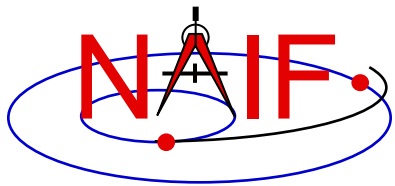
In what frame? **fixref**

For which instrument? **instnm**

For what spacecraft? **scnm**

Using what model? **setupf**





Needed Data

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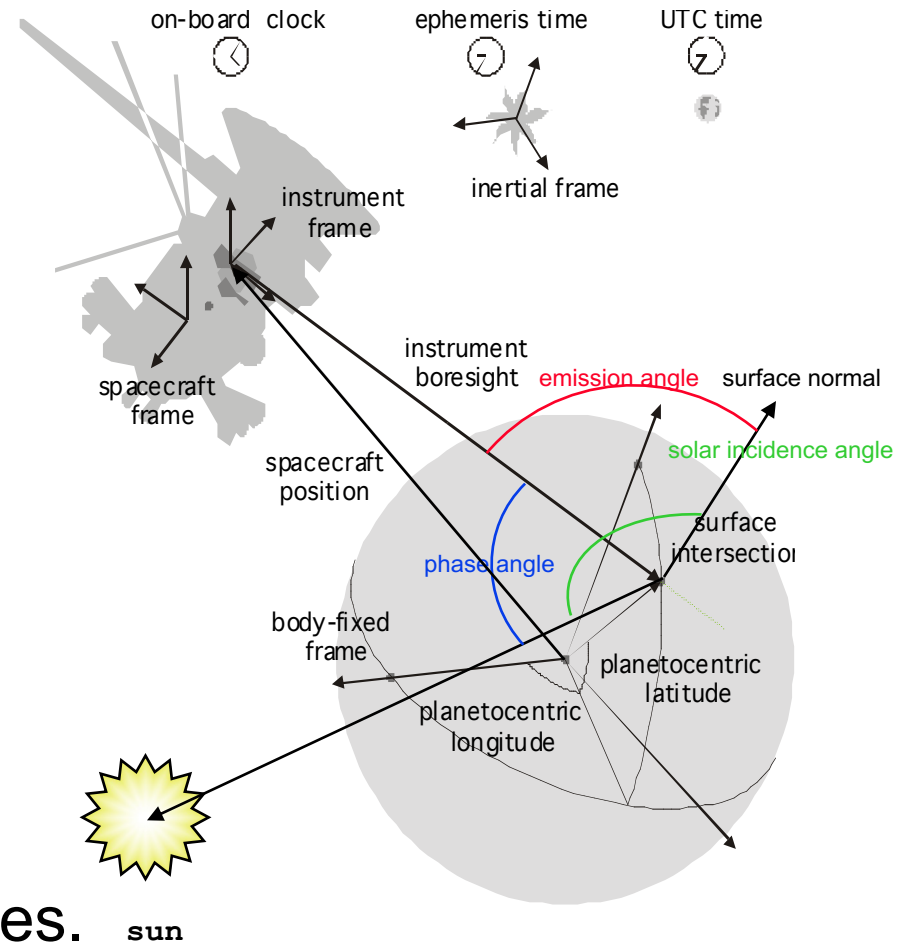
Time transformation kernels

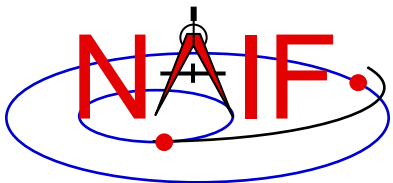
Orientation models

Instrument descriptions

Shapes of satellites, planets

Ephemerides for spacecraft,
Saturn barycenter and satellites.





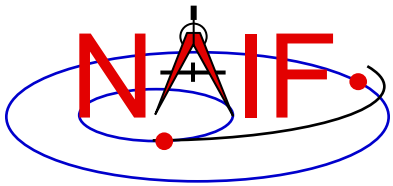
Which Kernels are Needed?

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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 `furnsh_c`. 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.

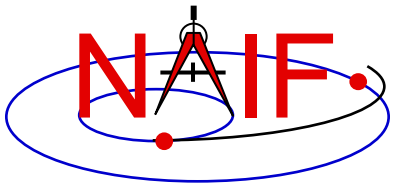
```
\begindata
```

```
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:

```
prompt_c ( "Enter setup file name > ", FILESZ, setupf );  
furnsh_c ( setupf );
```



Programming Solution

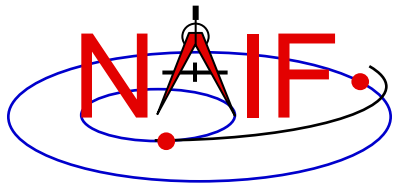
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- Prompt for setup file (“metakernel”) name; load kernels specified via setup file. (Done on previous chart.)
- Prompt for user inputs required to completely specify problem. Obtain further inputs required by geometry routines via CSPICE calls.
- Compute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

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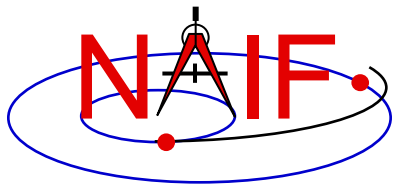
Compute the intercept point (**point**) of the boresight vector (**insite**) specified in the instrument frame (**iframe**) of the instrument mounted on the spacecraft (**scnm**) with the surface of the satellite (**satnm**) at the TDB time of interest (**et**) in the satellite's body-fixed frame (**fixref**).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

```
sincpt_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, iframe, insite,  
          point, &trgepc, srfvec, &found );
```

The range we want is obtained from the outputs of `sincpt_c`. 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 CSPICE function `vnorm_c` to obtain the norm:

```
vnorm_c ( 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.

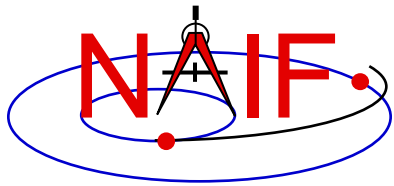
```
if ( found )
{
    reclat_c ( point,  &r,  &pclon, &pclat );

    /* 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;

    recgeo_c ( point, re, f, &pdlon, &pdlat, &alt);
}
```

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

```
ilumin_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, point,
           &trgepc, srfvec, &phase, &solar, &emissn );
```



Geometry Calculations: Summary

Navigation and Ancillary Information Facility

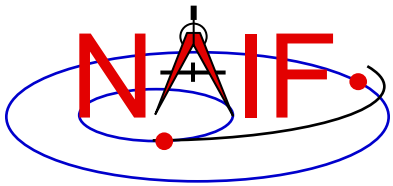
```
/* Compute the boresight ray intersection with the surface of the
   target body. */

sincpt_c ( "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 )
{
    reclat_c ( 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;
    recgeo_c ( point, re, f, &pdlon, &pdlat, &alt );

    /* Compute illumination angles at the surface point. */
    ilumin_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, point,
              &trgepc, srfvec, &phase, &solar, &emissn );
    ...
}
else
{ ... }
```



Get Inputs - 1

Navigation and Ancillary Information Facility

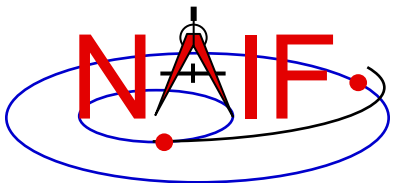
The code above used quite a few inputs that we don't have yet:

- 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 CSPICE 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**):

```
prompt_c ( "Enter satellite name > ", WORDSZ, satnm );  
prompt_c ( "Enter satellite frame > ", WORDSZ, fixref );  
prompt_c ( "Enter spacecraft name > ", WORDSZ, scnm );  
prompt_c ( "Enter instrument name > ", WORDSZ, instnm );  
prompt_c ( "Enter time > ", WORDSZ, time );
```



Get Inputs - 2

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

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

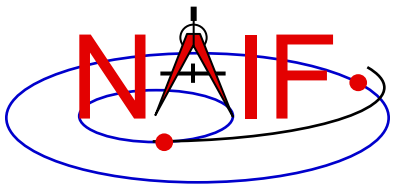
```
str2et_c ( time, &et );
```

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

```
bodvrd_c ( 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:

```
getfvn_c ( instnm, ROOM, WORDSZ, WORDSZ,  
           shape, iframe, insite, &n, bundry );
```



Getting Inputs: Summary

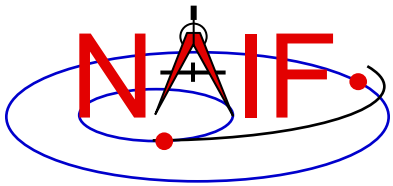
Navigation and Ancillary Information Facility

```
/* Prompt for the user-supplied inputs for our program */
prompt_c ( "Enter setup file name > ", FILESZ, setupf );
furnsh_c ( setupf );
prompt_c ( "Enter satellite name > ", WORDSZ, satnm );
prompt_c ( "Enter satellite frame > ", WORDSZ, fixref );
prompt_c ( "Enter spacecraft name > ", WORDSZ, scnm );
prompt_c ( "Enter instrument name > ", WORDSZ, instnm );
prompt_c ( "Enter time > ", WORDSZ, time );

/* Get the epoch corresponding to the input time: */
str2et_c ( time, &et );

/* Get the radii of the satellite. */
bodvrd_c ( satnm, "RADII", 3, &i, radii );

/* Get the instrument boresight and frame name. */
getfvn_c ( instnm, ROOM, WORDSZ, WORDSZ,
          shape, iframe, insite, &n, bundry );
```

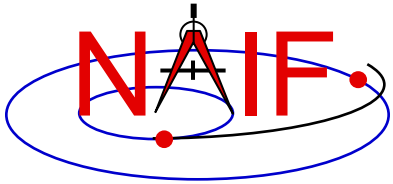


Display Results

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```
/* Display results.  Convert angles from radians to degrees for output. */
printf ( "\n"
        "Intercept planetocentric longitude      (deg):  %11.6f\n"
        "Intercept planetocentric latitude      (deg):  %11.6f\n"
        "Intercept planetodetic longitude        (deg):  %11.6f\n"
        "Intercept planetodetic latitude        (deg):  %11.6f\n"
        "Range from spacecraft to intercept point  (km):  %11.6f\n"
        "Intercept phase angle                    (deg):  %11.6f\n"
        "Intercept solar incidence angle          (deg):  %11.6f\n"
        "Intercept emission angle                 (deg):  %11.6f\n",
        dpr_c() * pclon,
        dpr_c() * pclat,
        dpr_c() * pdlon,
        dpr_c() * pdlat,
        vnorm_c( srfvec ),
        dpr_c() * phase,
        dpr_c() * solar,
        dpr_c() * emissn
        );

}
else
{
    printf ( "No intercept point found at %s\n", time );
}
```

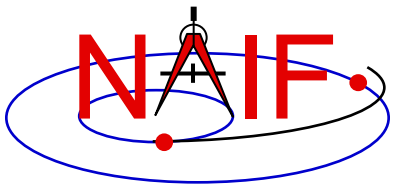


Complete the Program

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 C code required to make a syntactically valid program



Complete Source Code - 1

Navigation and Ancillary Information Facility

```
#include <stdio.h>
#include "SpiceUtr.h"

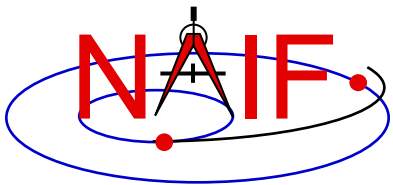
int main ()
{
    #define    FILESZ        256
    #define    WORDSZ        41
    #define    ROOM          10

    SpiceBoolean    found;

    SpiceChar        iframe[WORDSZ];
    SpiceChar        instnm[WORDSZ];
    SpiceChar        satnm [WORDSZ];
    SpiceChar        fixref[WORDSZ];
    SpiceChar        scnm  [WORDSZ];
    SpiceChar        setupf[FILESZ];
    SpiceChar        shape [WORDSZ];
    SpiceChar        time  [WORDSZ];

    SpiceDouble      alt;
    SpiceDouble      bundry[ROOM][3];
    SpiceDouble      emissn;
    SpiceDouble      et;
    SpiceDouble      f;
    SpiceDouble      insite[3];
    SpiceDouble      srfvec[3];
    SpiceDouble      pclat;
    SpiceDouble      pclon;
    SpiceDouble      pdlat;
    SpiceDouble      pdlon;
    SpiceDouble      phase;
    SpiceDouble      point [3];
    SpiceDouble      r;
    SpiceDouble      radii [3];
    SpiceDouble      re;
    SpiceDouble      rp;
    SpiceDouble      solar;
    SpiceDouble      trgepc;

    SpiceInt         i;
    SpiceInt         n;
```



Complete Source Code - 2

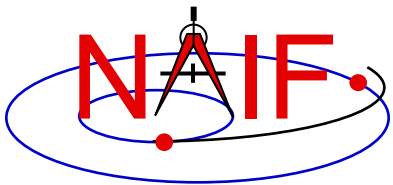
Navigation and Ancillary Information Facility

```
/* Prompt for the user-supplied inputs for our program */
prompt_c ( "Enter setup file name > ", FILESZ, setupf );
furnsh_c ( setupf );
prompt_c ( "Enter satellite name > ", WORDSZ, satnm );
prompt_c ( "Enter satellite frame > ", WORDSZ, fixref );
prompt_c ( "Enter spacecraft name > ", WORDSZ, scnm );
prompt_c ( "Enter instrument name > ", WORDSZ, instnm );
prompt_c ( "Enter time > ", WORDSZ, time );

/* Get the epoch corresponding to the input time: */
str2et_c ( time, &et );

/* Get the radii of the satellite. */
bodvrd_c ( satnm, "RADII", 3, &i, radii );

/* Get the instrument boresight and frame name. */
getfvn_c ( instnm, ROOM, WORDSZ, WORDSZ,
          shape, iframe, insite, &n, bundry );
```



Complete Source Code - 3

Navigation and Ancillary Information Facility

```

/* Compute the boresight ray intersection with the surface of the
   target body. */

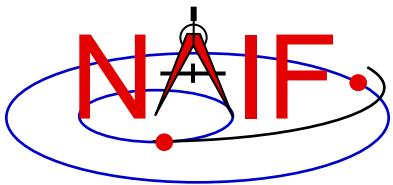
sincpt_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm,
           iframe, insite, point, &trgepc, srfvec, &found );

/* If an intercept is found, compute planetocentric and planetodetic
   latitude and longitude of the point. */
if ( found )
{
    reclat_c ( 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;
    recgeo_c ( point, re, f, &pdlon, &pdlat, &alt );

    /* Compute illumination angles at the surface point. */
    ilumin_c ( "Ellipsoid", satnm, et, fixref, "CN+S", scnm, point,
              &trgepc, srfvec, &phase, &solar, &emissn );

    /* Display results. Convert angles to degrees for output. */
    printf ( "\n"
             "Intercept planetocentric longitude      (deg):    %11.6f\n"
             "Intercept planetocentric latitude        (deg):    %11.6f\n"

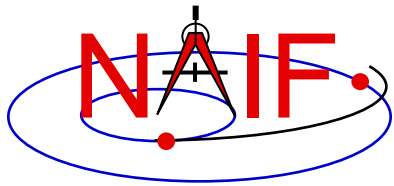
```



Complete Source Code - 4

Navigation and Ancillary Information Facility

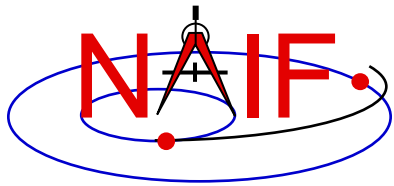
```
"Intercept planetodetic longitude           (deg):    %11.6f\n"
"Intercept planetodetic latitude            (deg):    %11.6f\n"
"Range from spacecraft to intercept point   (km):    %11.6f\n"
"Intercept phase angle                      (deg):    %11.6f\n"
"Intercept solar incidence angle            (deg):    %11.6f\n"
"Intercept emission angle                  (deg):    %11.6f\n",
dpr_c() * pclon,
dpr_c() * pclat,
dpr_c() * pdlon,
dpr_c() * pdlat,
vnorm_c( srfvec ),
dpr_c() * phase,
dpr_c() * solar,
dpr_c() * emissn
);
}
else {
    printf ( "No intercept point found at %s\n", time );
}
return(0);
}
```



Compile and Link the Program - 1

Navigation and Ancillary Information Facility

- **First be sure that both the CSPICE Toolkit and a C compiler are properly installed.**
 - A "hello world" C program must be able to compile, link, and run successfully in your environment.
 - Any of the mkprodct.* scripts in the cspice/src/* paths of the CSPICE 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 cspice/src/cook_c path of your CSPICE 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.
 - » If your compiler supports it, add a -I option to reference the cspice/include path to make CSPICE *.h files available. Otherwise, copy those files from the include path to your 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 CSPICE object library `cspice.a` (`cspice.lib` under MS Visual C++/C) and the C math library. On a PC running Linux and gcc, if

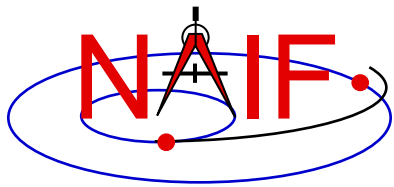
- » The gcc compiler is in your path
 - As indicated by the response to the command "which gcc"
- » the Toolkit is installed in the path (for the purpose of this example) `/myhome/cspice`
- » You've named the program `demo.c`

then you can compile and link your program using the command

```
» gcc -I/myhome/cspice/include \  
    -o demo \  
    demo.c /myhome/cspice/lib/cspice.a -lm
```

- Note: the preprocessor flag
 `-DNON_UNIX_STDIO`

used in the `mkprodct.csh` script is needed for code generated by `f2c`, but is usually unnecessary for compiling user code.



Compile and Link the Program - 3

Navigation and Ancillary Information Facility

```
Terminal Window

Prompt> mkprodct.csh

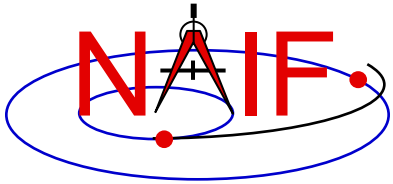
        Setting default compiler:
gcc

        Setting default compile options:
-c -ansi -O2 -DNON_UNIX_STDIO

        Setting default link options:
-lm

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

Prompt>
```



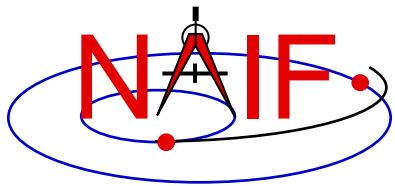
Running the Program - 1

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.



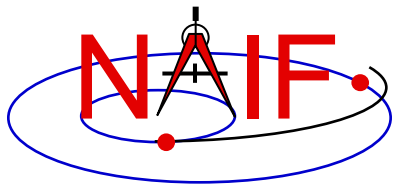
Running the Program - 2

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).

