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pyGFC – A Python Extension to the C++ Geodesy Foundation Classes

by Binh Q. Nguyen

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14. ABSTRACT
This report describes the results of the development of the pyGFC module, including the multi-step procedure and the implemented computer code. The pyGFC module is a Python extension to the C++ Geodesy Foundation Class, which has been used in the range model of the Mobile Ad-hoc Network (MANET) Emulation (MANE) software system that enables the dynamic connectivity of a MANET system in the Wireless Emulation Laboratory of the U.S. Army Research Laboratory (ARL). The pyGFC module was created to support the visualization of network topologies using the ARL Topodef tool, a graphical design and animation tool for custom-designing and editing a mobility scenario to create specific network topologies.

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1. Introduction

1.1 Background

The Wireless Emulation Laboratory (WEL) of the U.S. Army Research Laboratory (ARL) exists to support research in wireless mobile networks and mobile ad-hoc network (MANET) security (*1*) and to demonstrate ARL-developed solutions. A key component of the WEL is an emulation test bed, which is based on the Mobile Ad-hoc Network (MANET) Emulator (MANE) architecture that was originally developed by the U.S. Naval Research Laboratory (NRL) (*2*). The MANE system consists of hardware and software. The hardware system is a scalable high-performance network of physical computers. The software system enables the emulation of a dynamic MANET by managing and executing the effects of mobility on network connectivity. Effectively it creates virtual network topologies that evolve with time, a dependent variable of mobility.

Mobility is about changes of the geodetic positions of the participating mobile nodes over a fixed time interval, i.e., a mobility scenario. The geodetic positions of each node are predetermined, arranged in ascending order by time, and stored in a *log* file, which is basically a text file containing the mobility traces of a mobile node. The *log* files are usually created off-line using the ARL Topodef™ tool (*3*), a graphical system and method for visually creating and editing specific network topologies of an emulated MANET. A network topology is a snapshot in time showing the number of participating nodes, their relative geographical positions on the screen, and their interconnections or communication links. A custom-designed network topology consists of a predetermined number of nodes being placed at exact locations and a desirable set of communication links.

A communication link between a pair of any two nodes depends on the range of their equipped radios. A link is established whenever one of the radios can intelligibly receive the signal transmitted by the other radio and deconstructed if it cannot. When both can intelligibly receive signals from one another's radio, a bidirectional link is established. The range is now computed using the values of their radio parameters over the horizontal distance (line-of-sight) between two nodes. The radio parameters include, but are not limited to, radio frequency, transmitting power, and receiving sensitivity. Computing the range is performed by the range model (RM) component of the MANE software system. The RM component relies on the Geodesy Foundation Classes (GFC) (*4*) to calculate the geodetic distances that are needed in the determination of the network connectivity between a pair of two nodes.

The ARL Topodef™ tool also calculates the range between a pair of every two nodes to determine a possible communication link, which is necessary for the creation of a network topology. The tool then extracts the time-dependent geodetic positions of each node from the

generated network topologies and records them in the *log* files. Providing the MANE software system with these *log* files should recreate the same network topology in the test bed as they have been designed and verified. Therefore, having consistent results of geodesic distances calculated in the tool and in the MANE software system is imperative for a successful emulation of a dynamic MANET as intended.

To achieve this objective, the same algorithm and its implementation for calculating the distance between two geodetic locations should be used in the ARL Topodef™ tool and in the MANE system. The implementation of this solution has two options: (1) selecting, implementing, and integrating an appropriate algorithm into the tool and in the MANE system, or (2) using an implementation that has already been integrated in the MANE system. Between the two options, the latter requires lesser effort by leaving the MANE software system intact and by creating a Python (*5*) extension to the GFC library, which consists of C++ classes.

1.2 Scope

This report describes the successful development of the pyGFC module, a Python extension that enables the integration and use of C++ classes and methods in a Python application, the ARL Topodef™ tool. The intended purposes of this report are to:

- Describe and discuss the method used in the development of the pyGFC module
- Identify other development tools and methods for creating Python extensions to C++
- Document the application programming interfaces of the pyGFC module

The rest of this report is organized in the order of its intended purposes. The next section, section 2, presents and discusses the method that was used to create the pyGFC module and briefly describes other development tools and methods for creating Python extensions to C++ libraries. Section 3 summarizes the findings and concludes the report.

1.3 Method

The development of the pyGFC module used software development tools that came with the Red Hat Enterprise operating system and on the information, tutorials, and usage instructions that were available on the Web. An objective of the development was to minimize the development effort, the modification to the host environment, and the costs of administrative overhead associated with the acquisition, installation, and configuration of additional software systems.

2. The pyGFC Module Development

- The pyGFC module was created on a computer running the Red Hat Enterprise Linux® operating system. All the tools needed for the creation of the module were already available in the host: (i) the GFC source code, (ii) the SWIG command, and (iii) the ar archive program, and (iv) the C++ compiler.
- The GFC files came with the MANE software system, and the last two were already included in the Linux OS packages. The SWIG command whose name was derived from its longer name reflecting its functionality: the Simplified Wrapper and Interface Generator (SWIG) development tool. SWIG facilitates the use of C/C++ functionality from other languages among them is the Python programming language. It is usually included in Linux and Cygwin (*6*) distributions and also available separately for downloading and installation in other operating environments, e.g., Microsoft Windows® operating systems and Minimalist GNU for Windows (MinGW) (*7*).
- The ar archive program was used to organize and combine multiple files into a single file, a library. The C++ compiler was used to translate the C++ source files into object code and to create the shared library needed by the pyGFC module.

2.1 Platform Identification and Tool Versions

The information about the platform and the version of the tool was retrieved using the following commands and options that were typed into a console window.

/bin/uname -r -o	2.6.18-8.el5 GNU/Linux
/usr/bin/c++ --version	c++ (GCC) 4.1.1 20070105 (Red Hat 4.1.1-52)
/usr/bin/ar --version	GNU ar 2.17.50.0.6-2.el5 20061020
/usr/bin/swig -version	SWIG Version 1.3.29

The version of the GFC files was embedded in the source files, and they were the same although they had different modification time:

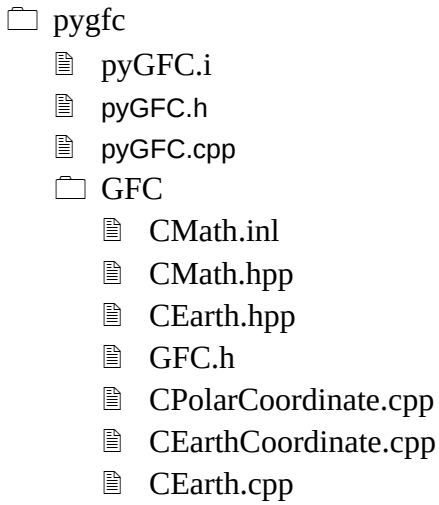
CEarth.cpp	Revision: 1.1.1.1 Modtime: 9/01/98 9:56p
CEarthCoordinate.cpp	Revision: 1.1.1.1 Modtime: 2/07/98 10:34a
CPolarCoordinate.cpp	Revision: 1.1.1.1 Modtime: 2/07/98 10:35a

2.2 Files and Directories

The development of the pyGFC module using the SWIG command required the creation of the following files:

- *The pyGFC.cpp file and its corresponding header file, pyGFC.h*. The files define the GFCCoord class interfacing directly with the GFC library to calculate geodetic distances and providing Python applications a way to use geodetic computing services. Although these two files were not required by SWIG, they were custom-created to support the use of the GFC library in the ARL Topodef™ tool and other Python applications that dealt with geodetic coordinates.
- *The pyGFC.i interface file*. The contents of the pyGFC.i file specify the required header files for the creation of the wrapper file and expose all the functions of the GFC library, the GFCCoord class, and the error functions that were available in the standard C math library, but excluded from the Python math module. The SWIG command then followed the specifications in the pyGFC.i file to create two files: a Python file and a C++ file. The C++ file wraps the GFC library, and the Python file provides transparent functionality of the GFC library in Python applications.

The three files were placed in the pygfc directory, which also had the GFC subdirectory containing the original GFC source code as shown below:



2.3 Procedure

The procedure for creating the pyGFC module consisted of five steps. Each step produced one or more files, which were then needed for subsequent steps. Figure 1 illustrates the procedure by showing connected block diagrams of processes and their required input and output files. At the end, only two files are needed by a Python application: the shared library file _pyGFC.so and the Python wrapper file pyGFC.py.

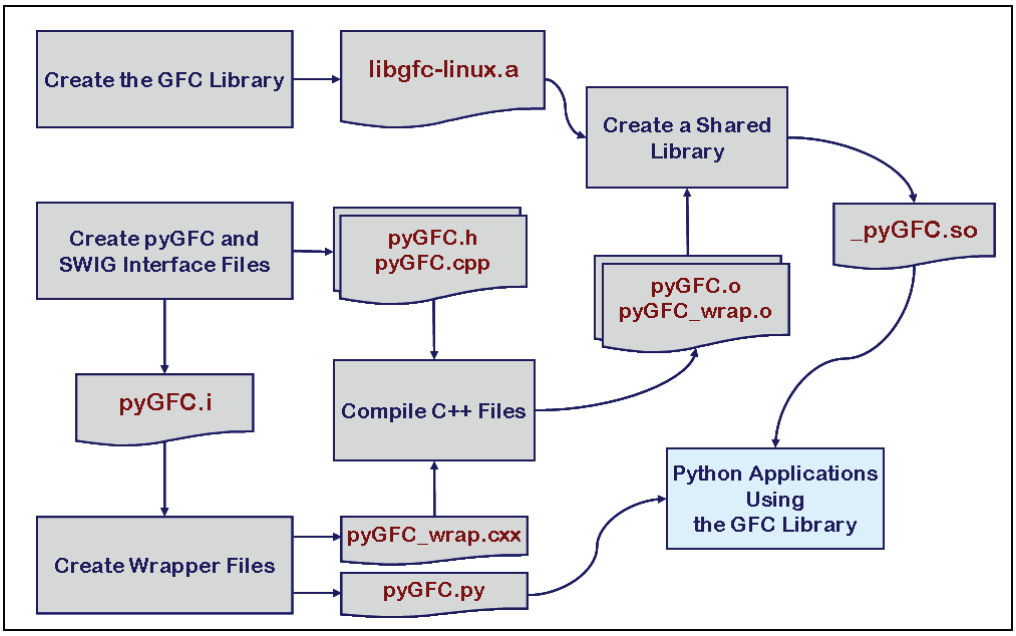


Figure 1. Procedure for creating the pyGFC module.

- Step 1: Creating the GFC library using the C++ compiler and the ar commands:

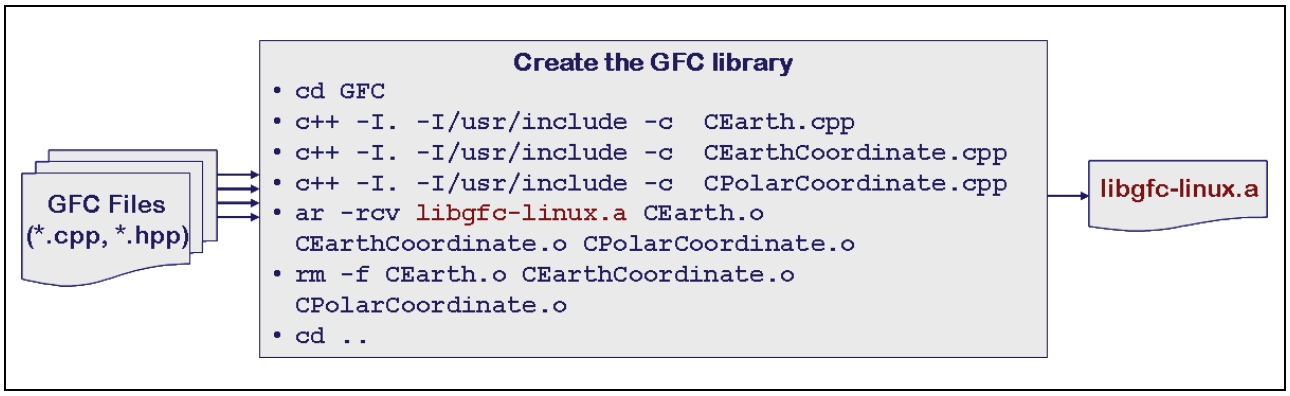


Figure 2. Creating the GFC library.

- Step 2: Creating the pyGFC.cpp file, its corresponding pyGFC.h file, and the pyGFC.i interface file using a text editor, e.g., vi. The pyGFC.i file contains the directives for the SWIG command: the header files that are needed by the wrapper file and the interfaces that are made available to a Python application. In this development, the interfaces are specified in the pyGFC.h, which is then included in the pyGFC.i. Appendix B lists the source code of these files.
- Step 3: Creating wrapper files using the SWIG command. SWIG took in the pyGFC.i file and produced two files: the pyGFC.py and the pyGFC_wrap.cxx files.

Figure 3. Generating wrapper files.

- Step 4: Compiling the pyGFC_wrap.cxx and the pyGFC.cpp files using :

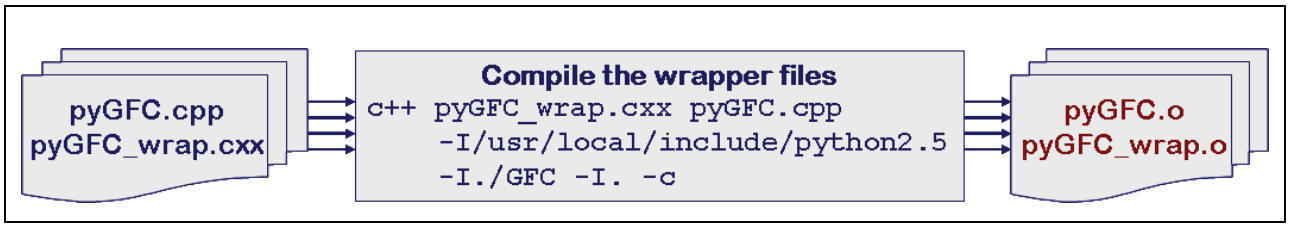


Figure 4. Compiling the wrapper files.

- Step 5: Creating the pyGFC library using the C++ compiler:

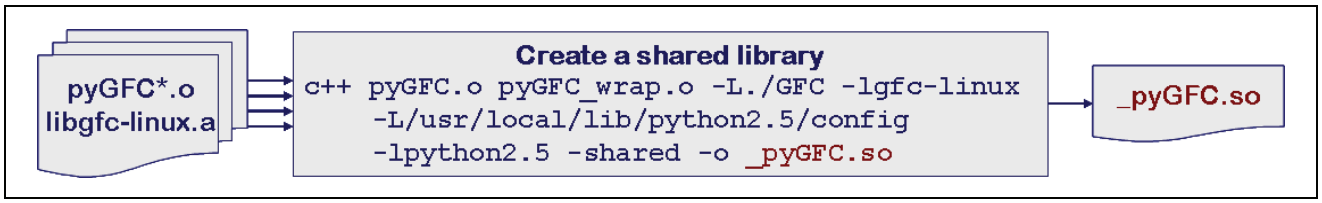


Figure 5. Creating the shared library.

2.4 Result & Discussion

The development of the pyGFC module was straightforward and relatively smooth because the interfaces to the GFC library were simple, and throughout the process, only a minor syntactical error in the SWIG-generated pyGFC_wrap.cxx file was encountered and easily fixed. The following lines show the errors and how they were fixed:

```
$ c++ pyGFC_wrap.cxx pyGFC.cpp -I/usr/local/include/python2.5 -I./GFC -I. -c
    pyGFC_wrap.cxx: In function 'int SWIG_Python_ConvertFunctionPtr(PyObject*, void**, swig_type_info*)':
    pyGFC_wrap.cxx:2051: error: invalid conversion from 'const char*' to 'char*'
    pyGFC_wrap.cxx: In function 'void SWIG_Python_FixMethods(PyMethodDef*, swig_const_info*,
    swig_type_info**, swig_type_info**)':
    pyGFC_wrap.cxx:7961: error: invalid conversion from 'const char*' to 'char*'
```

These two errors that occurred in line numbers 2051 and 7961 were of the same category. Fixing them required the use of a text editor to insert the expression **`(char *)`** to the lines that caused the error as shown in the following two lines:

```
2051  char *doc = (char *)(((PyCFunctionObject *)obj) -> m_ml -> ml_doc);
7961  char *c = (char *) methods[i].ml_doc;
```

Once the problem had been fixed, the process continued without a hitch. The final phase was to test the newly created pyGFC module in a Python development environment, the Python's Integrated Development Environment (IDLE). Figure 6 is the screen dump of a Python interactive session that imported the pyGFC module, showing four different actions performed to ensure the operability of the module:

- Displaying the contents of the pyGFC module. All the C++ classes defining the GFC library are available as they are listed on the screen, e.g., CEarth, CEarthCoordinate, CPolarCoordinate.
- Ensuring that the erf and the erfc functions would work correctly. The sum of erf(x) and erfc(x) equals 1.0 because erfc(x) = 1 – erf(x) by definition.
- Displaying the attributes and methods of the GFCCoord class; e.g., alt, lat, lon, get_distance.
- Setting two geodetic locations and calculating the distance between them.

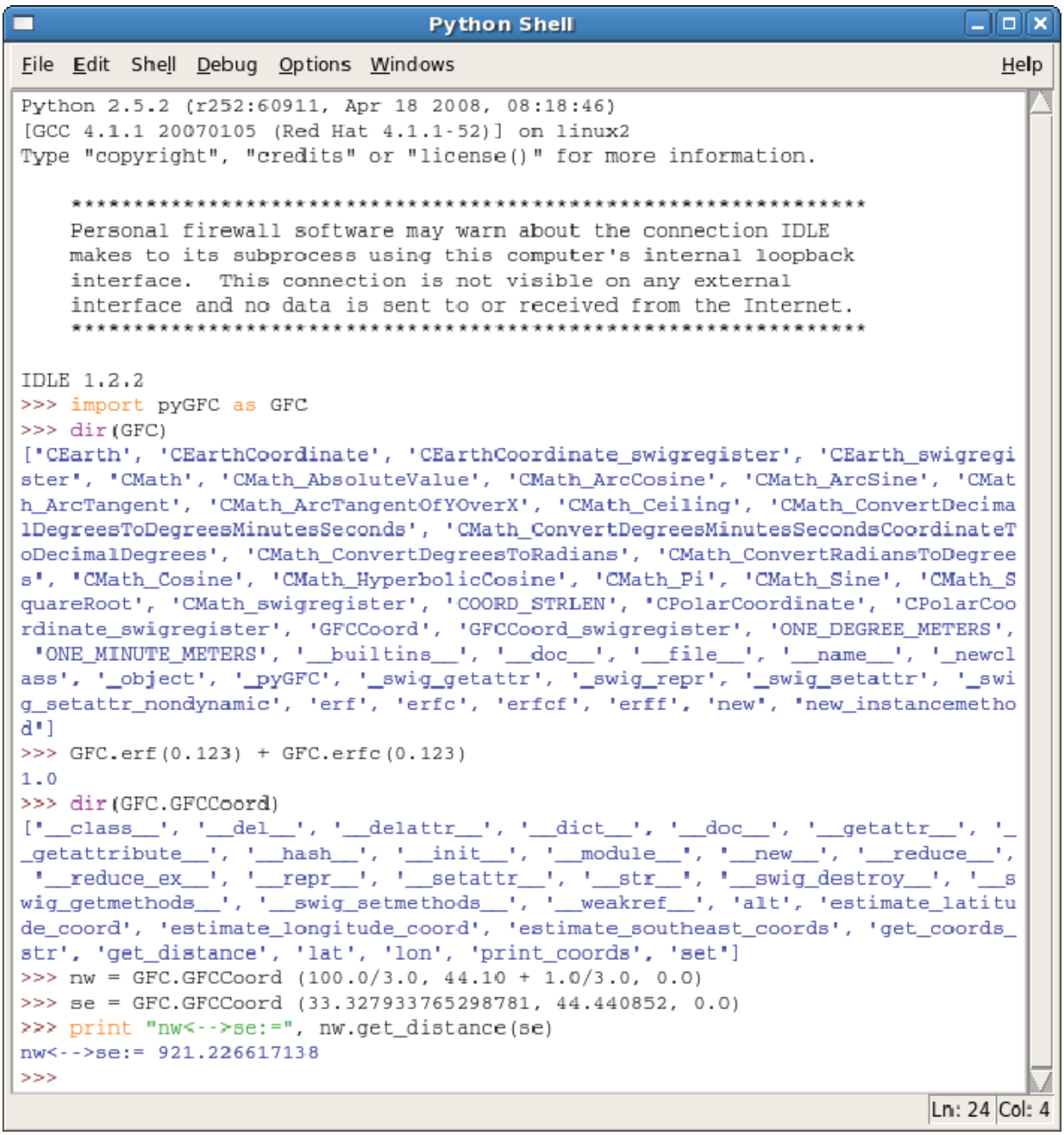


Figure 6. Results – an interactive session with the pyGFC module.

2.5 Other Development Tools for Creating Python Extensions to C++

In addition to the SWIG development tool, several other open-source tools for creating Python extensions are available on the Web. They include but are not limited to *Boost.Python*, *PyRex*, *PyCXX*, and *Weave*. A brief description of what they are is included in this section. More detailed description and usage instructions can be obtained from their respective Web sites (appendix A).

- *Boost.Python* emerges as a competent development tool for the development of Python extensions to C/C++. Using *Boost.Python* requires extensive knowledge of the C++ programming language, especially the C++ templates.
- *PyCXX* appears to be a capable development tool whose principal goal is to ease the writing of Python extensions.
- *PyRex* enables the mixing of Python and C/C++ in a Python program using its own language which is very similar to Python and C; therefore, *PyRex* itself is a computer language.
- *Weave* also enables the mixing C/C++ code in a Python program to improve its performance and to generate Python extensions.

3. Summary

The creation of the pyGFC module using SWIG was relative easy on a Linux® environment because the interfaces to the GFC library were simple. The described multi-step procedure is expected to reproduce the same results in a Linux-like environment; for example, Cygwin and MSYS/MinGW environments.

4. References

1. Ivanic, Natalie; et al. A Scalable Test Bed for Emulating Wireless Mobile Ad-hoc Networks. submitted to MILCOM'2008 for inclusion in the conference proceeding.
2. Networks and Communications Systems Branch, "Mobile Ad-hoc Network Emulator (MANE)," The U.S. Naval Research Laboratory, Code 5520, 4555 Overlook Ave., SW, Washington, DC 20375-5337. URL: http://cs.itd.nrl.navy.mil/work/mane (accessed date 21 July 2008)
3. Nguyen, Binh. The ARL Topodef™ Tool for Designing Mobile Ad-Hoc Network Topologies to Support Emulation. *Military Communications Conference, 2007. MILCOM 2007. IEEE* 29-31 Oct. 2007.
4. Blackburn, Sam. The Geodesy Foundation Classes, URL: http://www.samblackburn.com/gfc/, E-Mail: sam_blackburn@pobox.com (accessed 21 July 2008)
5. The Python programming language, URL: http://www.python.org (accessed 22 July 2008).
6. Cygwin, a Linux-like environment for Windows, URL: http://cygwin.com (accessed date 29 July 2008)
7. Minimalist GNU for Windows (MinGW), URL: http://www.mingw.org (accessed date 29 July 2008)

Appendix A. URL of Development Tools

SWIG	http://www.swig.org
PyRex	http://www.cosc.canterbury.ac.nz/greg.ewing/python/Pyrex
Boost.Python	http://www.boost.org
PyCXX	http://sourceforge.net/projects/cxx/
Weave	http://www.scipy.org/Weave

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Appendix B. Source Files

Table B-1. The pyGFC.h file.

```
#ifndef   PYGFC
#define   PYGFC

#include <iostream>
#include "GFC.h"

using namespace std;

#define ONE MINUTE METERS   (1852.0)
#define ONE DEGREE METERS   (60.0 * ONE MINUTE METERS)
#define COORD STRLEN        (64)

class GFCCoord
{
public:
        GFCCoord( const GFCCoord * );
        GFCCoord(double lat=0.0, double lon=0.0, double alt=0.0);
        virtual ~GFCCoord();

        void    set(const GFCCoord *);
        void    set(double , double , double);

        void    print coords();
        char    *get coords str();
        double  get distance(const GFCCoord * );
        double  get distance(const GFCCoord *, const GFCCoord *);

        double  estimate latitude coord( GFCCoord *, double);
        double  estimate longitude coord( GFCCoord *, double);
        GFCCoord *estimate southeast coords(double, double);

        double  lat;
        double  lon;
        double  alt;

private:
        CEarth  *earth;
        char    *cstr;
};

#endif
```

Table B-2. The pyGFC.cpp file.

```
#include "pyGFC.h"

GFCCoord::GFCCoord(double lat, double lon, double alt)
{
    this->lat = lat;
    this->lon = lon;
    this->alt = alt;
    this->earth = new CEarth();
    this->cstr  = (char *)malloc(COORD STRLEN);
}
GFCCoord::GFCCoord( const GFCCoord * p )
{
    this->lat = p->lat;
    this->lon = p->lon;
    this->alt = p->alt;
    this->earth = new CEarth();
    this->cstr  = (char *)malloc(COORD STRLEN);
}
GFCCoord::~GFCCoord()
{
    delete this->earth;
    delete this->cstr;
}

void GFCCoord::set(const GFCCoord * p)
{
    this->lat = p->lat;
    this->lon = p->lon;
    this->alt = p->alt;
}

void GFCCoord::set(double lat, double lon, double alt)
{
    this->lat = lat;
    this->lon = lon;
    this->alt = alt;
}

void GFCCoord::print coords()
{
    cout << "("
        << this->lat   << ","
        << this->lon   << ","
        << this->alt
        << ")"
        << endl;
}

double GFCCoord::get distance(const GFCCoord *a, const GFCCoord *b)
{
    /*************************************************************
    This code is taken from the NRL-designed RangeDrop::getDistance()
    *************************************************************/
    CPolarCoordinate here, there;
    here.SetUpDownAngleInDegrees(a->lat);
    here.SetLeftRightAngleInDegrees(a->lon);
    here.SetDistanceFromSurfaceInMeters(a->alt);

    there.SetUpDownAngleInDegrees(b->lat);
    there.SetLeftRightAngleInDegrees(b->lon);
    there.SetDistanceFromSurfaceInMeters(b->alt);

    return this->earth->GetLineOfSightDistance(here,there);
}

char *GFCCoord::get coords str()
{
    sprintf(this->cstr, "(%.8f, %.8f, %8f)", this->lat, this->lon, this->alt);
    return this->cstr;
}

double GFCCoord::get distance(const GFCCoord * p)
{
    return this->get distance(this, p);
}

double GFCCoord::estimate_latitude_coord( GFCCoord *p, double target_distance )
```

```
{
    /*** estimate the latitude that is SOUTH of where p is */
    CPolarCoordinate here;
    here.SetUpDownAngleInDegrees(p->lat);
    here.SetLeftRightAngleInDegrees(p->lon);
    here.SetDistanceFromSurfaceInMeters(p->alt);

    GFCCoord *e = new GFCCoord( p );

    /* estimate the latitude then adjust it later. */
    e->lat  = p->lat - target distance/(double)ONE DEGREE METERS;
    CPolarCoordinate there;
    there.SetUpDownAngleInDegrees( e->lat );
    there.SetLeftRightAngleInDegrees( e->lon );
    there.SetDistanceFromSurfaceInMeters( e->alt );

    /* dlat = value used for incrementingly searching for the closest value */
    double dlat = -0.010/ONE DEGREE METERS;
    double est dist = this->earth->GetLineOfSightDistance(here,there);
    if ( est dist > target distance ) dlat = -1.0 * dlat;

    while ( est dist < target distance )
    {
        e->lat += dlat;
        there.SetUpDownAngleInDegrees(e->lat );
        est dist = earth->GetLineOfSightDistance(here,there);
    }
    return e->lat;
}

double GFCCoord::estimate longitude coord( GFCCoord *p, double target distance)
{
    /*** estimate the longitude that is EAST of where p is */

    CPolarCoordinate here;
    here.SetUpDownAngleInDegrees(p->lat);
    here.SetLeftRightAngleInDegrees(p->lon);
    here.SetDistanceFromSurfaceInMeters(p->alt);

    GFCCoord *e = new GFCCoord( p );

    /* estimate the longitude then adjust it later. */
    e->lon  = p->lon + target distance/(double)ONE DEGREE METERS;

    CPolarCoordinate there;
    there.SetUpDownAngleInDegrees(e->lat );
    there.SetLeftRightAngleInDegrees(e->lon );
    there.SetDistanceFromSurfaceInMeters(e->alt );

    double dlon = 0.010/ONE DEGREE METERS;
    double est dist = this->earth->GetLineOfSightDistance(here,there);
    if ( est dist > target distance ) dlon = -1.0 * dlon;

    while ( est dist < target distance )
    {
        e->lon += dlon;
        there.SetLeftRightAngleInDegrees(e->lon );
        est dist = earth->GetLineOfSightDistance(here,there);
    }
    return e->lon;
}

GFCCoord * GFCCoord::estimate southeast coords(double width, double height)
{
    /* estimate and return the SE corner given w, h in meters
        width & height should be less than 20 km.
       caveats: this implementation does not handle any location on earth.
    */
    CPolarCoordinate here;
    here.SetUpDownAngleInDegrees(this->lat);
    here.SetLeftRightAngleInDegrees(this->lon);
    here.SetDistanceFromSurfaceInMeters(this->alt);

    GFCCoord *e = new GFCCoord( this );

    /* estimate the latitude then adjust it later. */
    e->lat  = this->lat - height/ONE DEGREE METERS;
    CPolarCoordinate there;
    there.SetUpDownAngleInDegrees( e->lat );
    there.SetLeftRightAngleInDegrees( e->lon );
    there.SetDistanceFromSurfaceInMeters( e->alt );
```

```
    /* dlat = value used for incrementingly searching for the closest value */
    double dlat = -0.010/ONE DEGREE METERS;
    double est dist = this->earth->GetLineOfSightDistance(here,there);
    if ( est dist > height ) dlat = -1.0 * dlat;

    while ( est dist < height )
    {
        e->lat += dlat;
        there.SetUpDownAngleInDegrees(e->lat );
        est dist = earth->GetLineOfSightDistance(here,there);
    }

    double  saved lat = e->lat;
    e->lat  = this->lat;
    there.SetUpDownAngleInDegrees( e->lat );

    e->lon  = this->lon + width/ONE DEGREE METERS;
    double dlon = 0.010/ONE DEGREE METERS;

    est dist = this->earth->GetLineOfSightDistance(here,there);
    if ( est dist > width ) dlon = -1.0 * dlon;

    while ( est dist < width )
    {
        e->lon += dlon;
        there.SetLeftRightAngleInDegrees(e->lon );
        est dist = earth->GetLineOfSightDistance(here,there);
    }
    e->lat = saved lat;
    return e;
}
```

Table B-3. The pyGFC.i file.

```
%module pyGFC
%{
#include "pyGFC.h"
%}

%include "GFC.h"
%include "pyGFC.h"

// error functions from the math lib.
extern double erf(double x);
extern double erfc(double x);
extern float erff(float x);
extern float erfcf(float x);
```

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