SWIG Users Manual

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Preface

Introduction

SWIG is a tool for solving problems.

More specifically, SWIG is a simple tool for building interactive C/C++ programs with common scripting languages such as Tcl, Perl, and Python. Of course, more importantly, SWIG is a tool for making C programming more enjoyable and promoting laziness (an essential feature). SWIG is not part of an overgrown software engineering project, an attempt to build some sort of monolithic programming environment, or an attempt to force everyone to rewrite all of their code (ie. code reuse). In fact, none of these things have ever been a priority.

SWIG was originally developed in the Theoretical Division at Los Alamos National Laboratory for building interfaces to large materials science research simulations being run on the Connection Machine 5 and Cray T3D supercomputers. In this environment, we were faced with the problems of working with huge amounts of data, complicated machines, and constantly changing code. As scientists, we needed a mechanism for building interactive programs that was extremely easy to use, could keep pace with code that was constantly changing, and didn't get in the way of the real problems that were being solved. Mainly, we just wanted to "cut the crap" and work on the real problem at hand.

While SWIG was originally developed for scientific applications, it is a general purpose tool that is being used in an increasing variety of other computing applications--in fact almost anything where C/C++ programming is involved. Development has been pragmatic in nature--features have been added to address problems as they arise. Most of the really cool stuff has been contributed or suggested by SWIG's users.

SWIG resources

The official location of SWIG related material is

```
http://www.cs.utah.edu/~beazley/SWIG
```

This site contains the latest version of the software, users guide, and information regarding bugs, installation problems, and implementation tricks. The latest version of the software and related files are also available via anonymous ftp at

```
ftp://ftp.cs.utah.edu/pub/beazley/SWIG
```

You can also subscribe to the SWIG mailing list by sending a message with the text "subscribe swig" to

```
majordomo@cs.utah.edu
```

The mailing list often discusses some of the more technical aspects of SWIG along with information about beta releases and future work.

About this manual

This manual has been written in parallel with the development of SWIG because I hate black boxes and I hate using software that is poorly documented. This manual attempts to describe all aspects of SWIG and how it can be used to solve interesting problems. Don't let the size scare you, SWIG is really quite easy to use. However, it can also do quite a few interesting things that might not be so obvious at first glance (and I hope to clarify many of these aspects).

Prerequisites

This manual assumes that you are interested in writing interactive C/C++ programs and that you have at least heard of scripting languages such as Tcl, Python, and Perl. A detailed knowledge of these scripting languages is not required although some familiarity certainly won't hurt. No prior experience with building C extensions to these languages is required---after all, this is what SWIG allows you to do automatically.

Organization of this manual

The first few chapters of this manual describe SWIG in general and provide an overview of its capabilities. The remaining chapters are devoted to specific SWIG language modules and are self contained. Thus, if you are using SWIG to build Python interfaces, you can skip right to that chapter and find just about everything you need to know. So, in a sense, you are really getting 3 or 4 manuals in one.

How to avoid reading the manual

If you hate reading manuals, glance at the "Introduction" which contains a few simple examples and the overall philosophy. These examples will tell you about 95% of everything you need to know to use SWIG. After that, simply use the language-specific chapters for reference. The SWIG distribution also comes with a large directory of examples that illustrate how to do most kinds of things.

Credits

This work would certainly not be possible without the support of many people. I would like to acknowledge Peter Lomdahl, Brad Holian, Shujia Zhou, Niels Jensen, and Tim Germann at Los Alamos National Laboratory for allowing me to pursue this project and for being the first users. Patrick Tullmann at the University of Utah suggested the idea of automatic documentation generation. John Schmidt and Kurtis Bleeker at the University of Utah tested out the early versions. I'd also like to acknowledge Chris Johnson and the Scientific Computing and Imaging Group at the University of Utah for their continued support. John Buckman, Larry Virden, and Tom Schwaller provided valuable input on the first releases and improving the portability of SWIG. David Fletcher and Gary Holt have provided a great deal of input on improving SWIG's Perl5 implementation. I'd also like to thank Kevin Butler for his valuable input and contribution of a Windows NT port. Finally, I'd like to acknowledge all of the users who have braved the first few releases and have been instrumental in suggesting way to make SWIG more fun to use than I ever imagine.

What's new?

The following significant features are new in version 1.1

- Support for typemaps.
- Multiple inheritance now supported.
- Default/optional arguments.
- Perl5 shadow classes.
- Tcl8.0 module (uses the native Tcl8 object interface).
- An entirely new documentation system.
- Limited support for nested structures.
- New object oriented Tcl interface.,
- %inline directive for simplified interface generation.
- %extern directive for working with multiple files.
- Lots of minor bug fixes to almost everything.

This release should be backwards compatible with interface files generated for SWIG 1.0. However, many things have changed in the C API so special purpose SWIG C++ extensions will need to be modified.

Bug reports

While every attempt has been made to make SWIG bug-free, occasionally bugs will arrise. To report a bug, send mail to the SWIG mailing list at `swig@cs.utah.edu`. In your message, be as specific as possible, including (if applicable), error messages, tracebacks (if a core dump occurred), corresponding portions of the SWIG interface file used, and any important pieces of the SWIG generated wrapper code. I attempt to respond to all bug reports, but I can only fix bugs if I know about them.

Introduction 1

What is SWIG?

SWIG is a code development tool that makes it possible to quickly build powerful scripting language interfaces to C/C++ programs. In a nutshell, SWIG is a compiler that takes C declarations and turns them into the "glue" needed to access them from common scripting languages including Perl, Python, and Tcl. SWIG requires no modifications to existing C code and can often be used to build a working interface in a matter of minutes. Of course, this simplicity makes it possible to do a number of interesting things including :

- Building powerful interfaces to existing C programs.
- Rapid prototyping and application development.
- Interactive debugging.
- Making a graphical user interface (using Tk for example).
- Powerful testing of C libraries and programs (using scripts).
- Building high performance C/C++ modules for scripting languages.
- Making C/C++ programming more enjoyable (or tolerable depending on your point of view)
- Impressing your friends.

There are some computer scientists who seem to believe that the only way to solve complicated problems is to create software of epic proportions and to have some sort of "grand" software design. Unfortunately this seems to lead to solutions that are even more complicated than the original problem. This, in turn enables the user to forget about the original problem and spend their time cursing at their machine (hence, the term "enabling technology"). SWIG, on the other hand, was developed because I was fed up with how much time I was wasting trying to develop flexible scientific applications. I wanted a tool that would let me use scripting languages to glue different things together, but didn't get in the way of the real problems I was working on. I wanted a simple tool that scientists and engineers could use to put together applications involving number crunching, data analysis, and visualization without having to worry about tedious systems programming, making substantial modifications to existing code, trying to figure out a big monolithic computing "environment," or having to get a second degree in computer science.

Life before SWIG

SWIG was developed to make my life easier as a C programmer. While C is great for high performance and systems programming, trying to make an interactive and highly flexible C program is a nightmare (in fact, it's much worse than that, but I digress). The real problem is that for every C program I wrote, I needed to have some sort of interface, but being more interested in the real problem at hand, I would always end up writing a really bad interface that was hard to extend, hard to modify, and hard to use. I suppose I could have tried to do something fancy using X11, but who has time to waste weeks or months trying to come up with an interface that is probably going to end up being larger than the original C code. There are more interesting problems to work on.

The real problem, perhaps, is that most C programs end up being structured as follows :

- A collection of functions and variables.
- A `main()` program that does something.
- And a bunch of hacks added to make it usuable.

The `main()` program may be written to handle command line arguments or to read data from `stdin`, but either way, modifying or extending the program to do something new requires changing the C code, recompiling, and testing. If you make a mistake, you need to repeat this cycle until things work. Of course, as more and more features are added, your C program turns into a hideous unintelligible mess that is even more difficult to modify than it was before.

Life after SWIG

With SWIG, I was hoping to avoid many of the headaches of working with C programs, by structuring things as follows :

- A collection of functions and variables.
- A nice interpreted interface language that can be used to access everything.

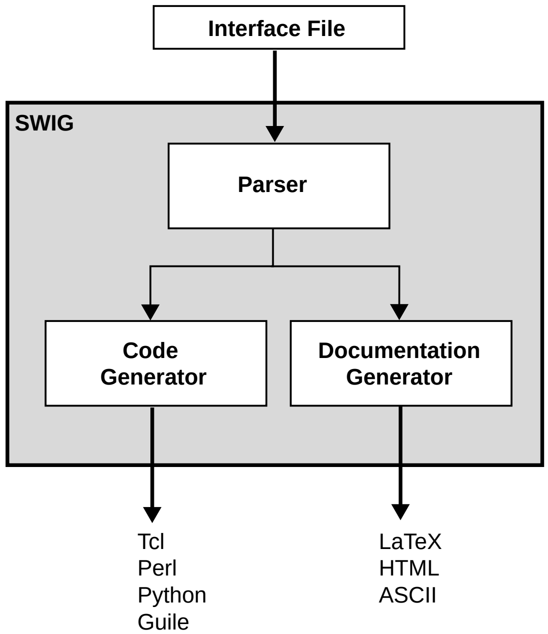
With this model, you keep all of the functionality of your C program, but access it through a scripting language interface instead of writing more C code. This is nice because you are given full freedom to call functions in any order, access variables, and write scripts to do all sorts of interesting things. If you want to change something, just modify a script, and rerun it. If you're trying to debug a collection of functions, you can call them individually and see what they do. If you're trying to build a package out of various components, you can just glue everything together with a scripting language and have a common interface to all of the various pieces.

SWIG tries to make the integration between scripting languages and C/C++ as painless as possible. This allows you to focus on the underlying C program and using the high-level scripting language interface, but not the tedious and complex chore of making the two languages talk to each other.

I like this model of programming. Once you've tried it, chances are you won't ever want to go back to a traditional style of C/C++ programming either.

The SWIG package

SWIG is a compiler that takes ANSI C/C++ declarations and turns them into a file containing the C code for binding C functions, variables, and constants to a scripting language. Input is specified in the form of an "interface file" containing declarations (input can also be given from C source files provided they are sufficiently clean). The SWIG parser takes this input file and passes it on to a code generation and documentation module. These modules produce an interface for a particular scripting language along with a document describing the interface that was created. Different scripting languages are supported by writing new back-end modules to the system.



A SWIG example

The best way to illustrate SWIG is with a simple example. Consider the following C code:

```
/* File : example.c */
double  My_variable  = 3.0;

/* Compute factorial of n */
int  fact(int n) {
       if (n <= 1) return 1;
       else return n*fact(n-1);
}

/* Compute n mod m */
int my_mod(int n, int m) {
       return(n % m);
}
```

Suppose that you wanted to add these functions and the global variable `My_variable` to the `tclsh` program (the Tcl interpreter). We start by making a SWIG interface file as shown below (by convention, these files carry a .i suffix) :

SWIG interface file

```
/* File : example.i */
%module example
%{
/* Put headers and other declarations here */
%}
```

```
%include tclsh.i      // Include init code

extern double My_variable;
extern int    fact(int);
extern int    my_mod(int n, int m);
```

The interface file contains ANSI C function prototypes and variable declarations. In addition, the file may include directives such as "`%include tclsh.i`". This inserts additional code that needs to be included in order to initialize user defined functions and build a stand-alone `tclsh` application.

The swig command

SWIG is invoked using the `swig` command. We can use this to build our new `tclsh` program and run it as follows :

```
unix > swig -tcl example.i
Generating wrappers for Tcl.
unix > gcc example.c example_wrap.c -I/usr/local/include \
       -L/usr/local/lib -ltcl -lm -o my_tclsh
unix > my_tclsh
% fact 4
24
% my_mod 23 7
2
% expr $My_variable + 4.5
7.5
%
```

The `swig` command produced a new file called `example_wrap.c` that should be compiled and linked with the `example.c` file and the Tcl library. `my_tclsh` is functionally identical to the original `tclsh` program except that it now has our variables and functions added to it.

Building a Perl5 module

Now, let's turn these functions into a Perl5 module. Without making any changes type the following :

```
unix > swig -perl5 example.i
Generating wrappers for Perl5
tclsh.i not found (ignored)
unix > gcc -c example.c example_wrap.c \
       -I/usr/local/lib/perl5/sun4-solaris/5.003/CORE
unix> ld -G example.o example_wrap.o -o example.so       # This is for Solaris
unix > perl5.003
use example;
print example::fact(4), "\n";
print example::my_mod(23,7), "\n";
print $example::My_variable + 4.5, "\n";
<ctrl-d>
24
2
7.5
unix >
```

Building a Python module

Finally, let's build a module for Python1.3.

```
unix > swig -python example.i
Generating wrappers for Python
tclsh.i not found (ignored)
unix > gcc -c example.c example_wrap.c \
       -I/usr/local/include/Py
unix > ld -G example.o example_wrap.o -o example.so
unix > Python
Python 1.3 (Mar 26 1996)  [GCC 2.7.0]
Copyright 1991-1995 Stichting Mathematisch Centrum,
Amsterdam
>>> import example
>>> example.fact(4)
24
>>> example.my_mod(23,7)
2
>>> example.cvar.My_variable + 4.5
7.5
```

Shortcuts

To the truly lazy programmer, one may wonder why we needed the extra interface file at all. As it turns out, we can often do without it. For example, we could also build a Perl5 module by just running SWIG on the C source as follows

```
% swig -perl5 -module example example.c
unix > gcc -c example.c example_wrap.c \
       -I/usr/local/lib/perl5/sun4-solaris/5.003/CORE
unix> ld -G example.o example_wrap.o -o example.so
unix > perl5.003
use example;
print example::fact(4), "\n";
print example::my_mod(23,7), "\n";
print $example::My_variable + 4.5, "\n";
<ctrl-d>
24
2
7.5
```

Of course, there are some restrictions as SWIG is not a full C/C++ parser. If you make heavy use of the C preprocessor, complicated declarations, or C++, giving SWIG a raw source file probably isn’t going to work very well (in this case, you would probably want to use a separate interface file).

SWIG also supports a limited form of conditional compilation. If we wanted to make a combination SWIG/C header file, we might do the following :

```
/* File : example.h */
#ifdef SWIG
%module example
%include tclsh.i
#endif
extern double My_variable;
```

```
extern int    fact(int);
extern int    my_mod(int n, int m);
```

Documentation generation

In addition to producing an interface, SWIG also produces documentation. For our simple example, the documentation file may look like this :

```
example_wrap.c

[ Module : example, Package : example ]

$My_variable
        [ Global : double My_variable ]

fact(n);
        [ returns int  ]

my_mod(n,m);
        [ returns int  ]

get_time();
        [ returns char * ]
```

C comments can be used to provide additional descriptions. SWIG can even grab these out of C source files in a variety of ways. For example, if we process `example.c` as follows :

```
swig -perl5 -Sbefore -module example example.c
```

We will get a documentation file that looks like this (with our C comments added) :

```
example_wrap.c

[ Module : example, Package : example ]


$My_variable
        [ Global : double My_variable ]

fact(n);
        [ returns int  ]
        Compute factorial of n

my_mod(n,m);
        [ returns int  ]
        Compute n mod m
```

Building libraries and modules

In addition to generating wrapper code, SWIG provides extensive support for handling multiple files and building interface libraries. For example, our `example.i` file, could be used in another interface as follows :

```
%module foo
```

```
%include example.i              // Get definitions from example.i

... Now more declarations ...
```

In a large system, an interface might be built from a variety of pieces. For example :

```
%module package

%include network.i
%include file.i
%include graphics.i
%include objects.i
%include simulation.i
```

SWIG comes with a library of existing functions known as the SWIG library. The library contains a mix of language independent and language dependent functionality. For example, the file ‘`array.i`’ provides access to C arrays while the file ‘`wish.i`’ includes specialized code for rebuilding the Tcl wish interpreter. Using the library, you can use existing modules and build up your own personalized environment for building interfaces.

C syntax, but not a C compiler

SWIG uses ANSI C/C++ syntax, but is not a full ANSI C compiler. By using C syntax, I hope to make SWIG easy to use with most C programs, easy to learn, and easy to remember. Other tools tend to use a precise interface definition language, but I personally find this approach to be painful. When I want to build an interface to a collection of several hundred C functions, I don’t necessarily want to write a special interface definition for each one. Nor do I want to have to go dig up the manual because I can’t remember the syntax.

On the other hand, using C syntax can be ambiguous. For example, if you have the following declaration

```
int foo(double *a);
```

We don’t really know if `a` is an array of some fixed size, a dynamically allocated block of memory, or an output value of the function. For the most part, SWIG tries to do what is reasonable (or typical), but you may need to help it out. Thus, the input to SWIG is often a mix of C declarations, special directives and hints.

SWIG does not currently parse every conceivable type of C declaration that it might encounter in a C/C++ file. Many things may be difficult or impossible to integrate with a scripting language (C++ templates for example). Thus, SWIG may not recognize advanced C/C++ constructions---as I said, SWIG was never intended to be a full C/C++ parser.

Non-intrusive interface building

When used as I intended, SWIG requires no modification to existing C/C++ code. This makes SWIG extremely easy to use with existing packages, but also promotes software reuse and modularity. By making the C code independent of the high level interface, you can change the interface and reuse the code in other applications. In a similar spirit, I don’t believe that there is any one “best” scripting language--use whichever one you like (they’re all pretty good). There’s no real reason why a particular application couldn't support multiple scripting language interfaces to serve different needs.

Hands off code generation

SWIG is designed to produce working code that needs no hand-modification (in fact, if you look at the output, you probably won't want to modify it). Ideally, SWIG should be invoked automatically inside a Makefile just as one would call the C compiler. You should think of your scripting language interface being defined entirely by the input to SWIG, not the resulting output file. While this approach may limit flexibility for hard-core hackers, it allows others to forget about the low-level implementation details. This is my goal.

Event driven C/C++ programming

By adding a scripting language interface to a program, SWIG encourages an event-driven style of programming (although it may not be immediately obvious). An event driven program basically consists of a large-collection of functions (called callback functions), and an infinite loop that just sits and waits for the user to do something. When the user does something like type a command, hit a key, or move the mouse the program will call a function to perform an operation--this is an event. Of course, unless you've been living in cave for the last 20 years, you've used this kind of approach when running any sort of graphical user interface.

While you may not be using SWIG to develop a GUI, the underlying concept is the same. The scripting language acts as an event-loop waiting for you to issue commands. Unlike a traditional C/C++ application (that may use command line options), there is no longer a fixed sequence of operations. Commands may be issued in any order and at any time. Of course, this flexibility is exactly what we want!

However, there are a number of things to keep in mind when developing an application with SWIG :

- Functions may be called at any time and in any order. It is always a good idea for functions to check their arguments and internal state to see if it's legal to proceed.
- Code should be structured as a collection of independent modules, not a huge mess of interrelated functions and variables (ie. spaghetti code).
- Global variables should be used with care.
- Careful attention to the naming of variables and functions may be required to avoid namespace conflicts when combining packages.

While it may be hard to address all these problems in a legacy code, I believe that using SWIG encourages all of the above qualities when developing new applications. This, in turn, results in code that is more reliable, more modular, and easier to integrate into larger packages. For this reason, By providing a non-intrusive, easy to use tool, it is possible to develop highly reliable even-driven code from the start--not as a hack to be added later. As a final sales pitch, in the initial application for which SWIG was developed, code reliability and flexibility has increased substantially while code size has decreased by more than 25%. I believe this is a good thing.

Automatic documentation generation

SWIG makes it very easy to build large interactive C/C++ programs, but it can sometimes be hard to remember what C functions are available and how they are called in the scripting language interface. To address this problem, SWIG automatically generates a documentation file in a number of different formats. C comments can be used to provide additional descriptions of each function, and documentation can be grouped into a hierarchy of sections and subsections. The documentation file is intended to provide a reasonable description of the scripting language interface. While it's probably no competition for a full-blown C code documentation generator, the documentation system can do a reasonable job of documenting an interface.

Summary

At this point, you know about 95% of everything you need to know to start using SWIG. First, functions and variables are specified using ANSI C/C++ syntax. These may appear in a separate interface file or you can use a C source file (if it is sufficiently clean). SWIG requires no modifications to existing C code so it's easy to get started. To build a module, you use the `swig` command with an appropriate target language option. This generates a C file that you need to compile with the rest of your code and you're ready to go.

I don't consider there to be a "right" or "wrong" way to use SWIG, although I personally use separate interface files for a variety of reasons :

- It helps keep me organized.
- It's usually not necessary to wrap every single C function in a program.
- SWIG provides a number of directives that I tend to use alot.
- Having a special interface file makes it clear where the scripting language interface is defined. If you decide to change something in the interface, it's easy to track down if you have special file.

Again your mileage may vary.

SWIG for Windows and Macintosh

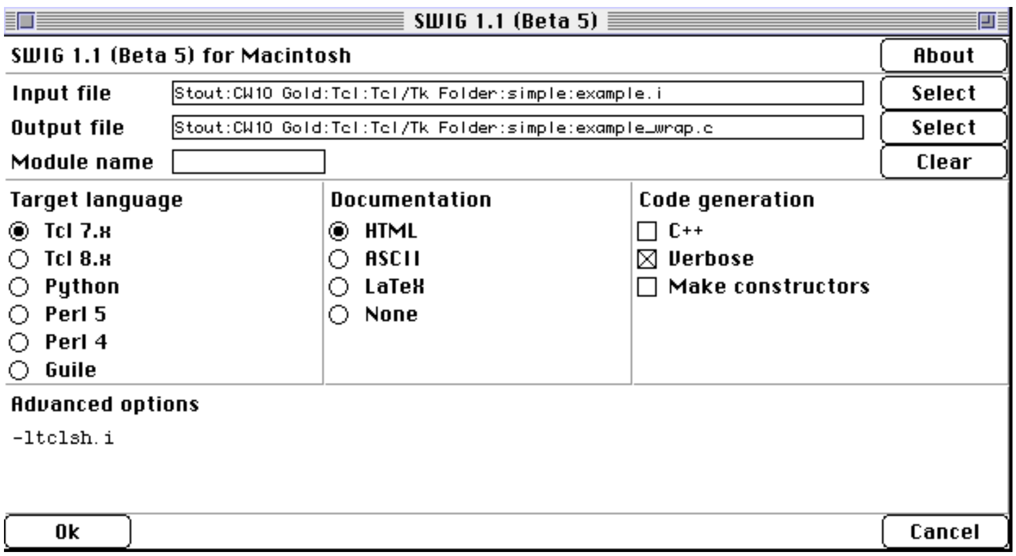
SWIG was originally developed and designed to work with Unix-based applications. However, most of the scripting languages supported by SWIG are available on a variety of other platforms including Windows 95/NT and Macintosh. SWIG generated code is mostly compatible with these versions (and SWIG itself can now be run on these platforms).

SWIG on Windows 95/NT

The Windows 95/NT port of SWIG (provided by Kevin Butler), is a straightforward translation of the Unix version. At this time it is only known to work with Microsoft Visual C++ 4.x, but there is nothing to prevent its use with other compilers (at least not that I'm aware of). SWIG should be invoked from the MS-DOS prompt in exactly the same manner as in Unix. SWIG can also be used in NMAKE build files and added to Visual C++ projects under the custom build setting. As of this writing, SWIG is known to work with Windows versions of Tcl/Tk, Python, and Perl (including the ActiveWare Perl for Win32 port). SWIG makes extensive use of long filenames, so it is unlikely that the SWIG compiler will operate correctly under Windows 3.1 or DOS (the wrapper code generated by SWIG may compile however).

SWIG on the Power Macintosh

A Macintosh port of SWIG is also available, but is highly experimental at this time. It only works on PowerPC based Macintosh systems running System 7 or later. Modules can be compiled with the Metrowerks Code Warrior compiler, but support for other compilers is unknown. Due to the lack of command line options on the Mac, SWIG has been packaged in a Tcl/Tk interface that allows various settings and command line options to be specified with a graphical user interface. Underneath the hood, SWIG is identical to the Unix/Windows version. It recognizes the same set of options and generates identical code. Any SWIG command line option listed in this manual can be given to the Mac version under “Advanced Options” shown in the figure. At this writing, SWIG is only known to support Mac versions of Tcl/Tk. Work on Macintosh versions of Python and Perl is underway.



Cross platform woes

While SWIG and various freely available scripting languages are supported on different platforms, developing cross platform applications with these tools is still immature and filled with pitfalls. In fact, it’s probably only recommended for masochists and other crazy individuals. Despite this, it’s an interesting to think about using freely available tools to provide common interfaces to C/C++ code. I believe that SWIG may help, but it is by no means a solution by itself.

How to survive this manual

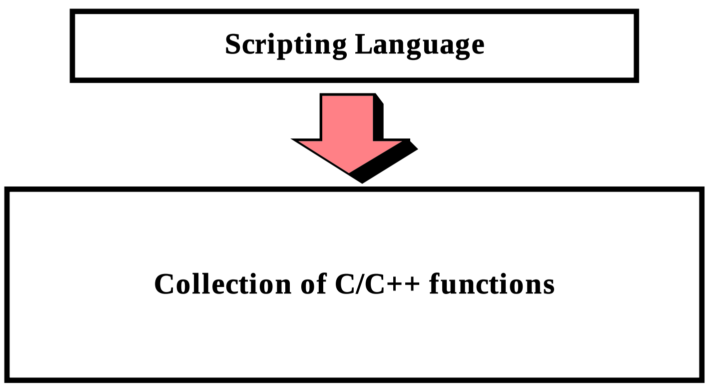
This manual was written to support the Unix version of SWIG. However, all of the concepts and usage of SWIG itself also apply to the Windows and Macintosh versions. You should be forewarned that most of the examples are Unix-centric and may not compile correctly on other machines. When applicable, I will try to point out incompatibilities, but make no promises...

Scripting Languages 2

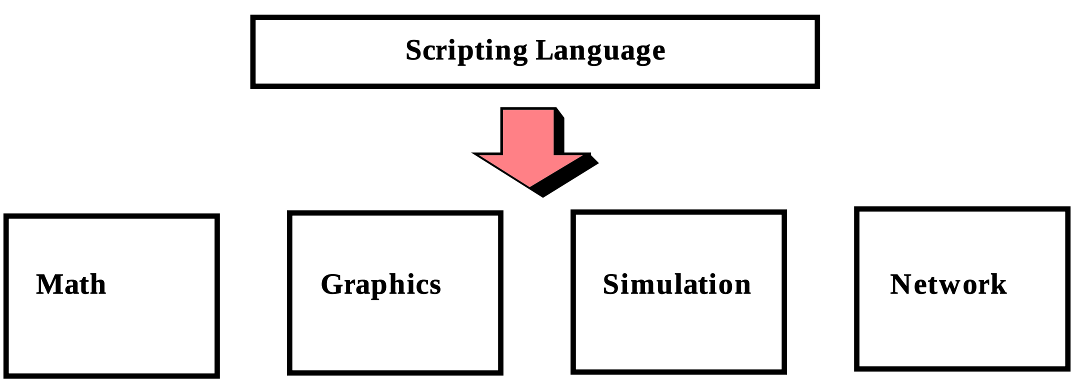
SWIG is all about using scripting languages with C/C++ to make flexible applications. This chapter provides a brief overview of several concepts and important aspects of this interface. Many of SWIG's potential users may not have considered using a scripting language before, so I hope that this chapter can provide a little motivation.

The two language view of the world

With SWIG, we are trying to build systems that are loosely structured as follows :



Of course, in reality, an application might look more like this :



In either case, we are interested in controlling a C/C++ program with a scripting language interface. Our interface may be for a small group of functions, or a large collection of C libraries for performing a variety of tasks. In this model C functions are turned into a collection of commands. To control the program, the user now types these commands or writes scripts to perform a particular operation. If you have used commercial packages such as MATLAB or IDL, it is a very similar model--you execute commands and write scripts, yet most of the underlying functionality is still written in C or Fortran for performance.

The two-language model of computing is extremely powerful because it exploits the strengths of each language. C/C++ can be used for maximal performance and complicated systems programming tasks. Scripting languages can be used for rapid prototyping, interactive debugging, scripting, and access to high-level data structures such as lists, arrays, and hash tables.

Will scripting languages make my C program inefficient?

One of the criticisms of scripting languages is that they are interpreted and slow. No doubt about it, a scripting language will always run much slower than C. However, if you are using a scripting language to control a big C program, most of your functionality is still written in C and still fast. Thus, there is really no difference between writing the following in C

```
for (i = 0; i < 1000; i++) {
       call a bunch of C functions to do something
}
```

or writing the same thing in Python :

```
for i in range(0,1000):
       call a bunch of C functions to do something
```

Most of the time is still spent in the underlying C functions. Now of course, you wouldn't want to write the inner loop of a matrix multiply in a scripting language, but you already knew this.

Will adding a scripting language to my C program make it unmanagable?

A fear among some users is that by adding a second language, you will end up with a package that is hard to maintain and use. I believe that there are two answers to this question. If you find yourself modifying the C code to fit it into a specific scripting language, then it will be difficult to maintain. By doing this, you will lock yourself into a particular language. If that language changes or disappears off the face of the earth, then you will be left with serious maintenance problems. On the flip side of the coin, a non-invasive tool like SWIG can build interfaces without requiring language-specific modifications to the underlying C code. If the scripting language changes, it is easy to update the resulting interface. If you decide that you want to scrap the whole interface scheme and try something else, you have a clean set of C libraries that are easy to use.

My personal experience has been that adding a scripting language to a C program makes the C program more managable! You are forced to think about how your C program is structured and how you want things to work. In every program in which I have added a scripting interface, the C code has actually decreased in size, improved in reliability, become easier to maintain, while becoming more functional and flexible than before.

How does a scripting language talk to C?

Scripting languages are built around a small parser that reads and executes statements on the fly as your program runs. Within the parser, there is a mechanism for executing commands or accessing variables. However, in order to access C functions and variables, it is necessary to give tell the parser additional information such as the name of the function, what kind of arguments does it takes, and what to do when it is called. Unfortunately, this process can be extremely tedious and technical. Of course, SWIG automates the process and allows you to forget about it. In any case, it's probably a good idea to know what's going on under the hood.

Wrapper functions

Suppose you have an ordinary C function like this :

```
int fact(int n) {
        if (n <= 1) return 1;
        else return n*fact(n-1);
}
```

In order to access this function from a scripting language, it is necessary to write a special "wrapper" function that serves as the glue between the scripting language and the underlying C function. A wrapper function must do three things :

- Gather function arguments and make sure they are valid.
- Call the C function.
- Convert the return value into a form recognized by the scripting language.

As an example, the Tcl wrapper function for the `fact()` function above example might look like the following :

```
int wrap_fact(ClientData clientData, Tcl_Interp *interp,
                int argc, char *argv[]) {
        int _result;
        int _arg0;
        if (argc != 2) {
                interp->result = "wrong # args";
                return TCL_ERROR;
        }
        _arg0 = atoi(argv[1]);
        _result = fact(_arg0);
        sprintf(interp->result,"%d", _result);
        return TCL_OK;
}
```

Once we have created a wrapper function, the final step is to tell the scripting language about our new function. This is usually done in an initialization function called by the language when our module is loaded. For example, adding the above function to the Tcl interpreter would require code like the following :

```
int Wrap_Init(Tcl_Interp *interp) {
       Tcl_CreateCommand(interp, "fact", wrap_fact, (ClientData) NULL,
                              (Tcl_CmdDeleteProc *) NULL);
       return TCL_OK;
}
```

When executed, Tcl will now have a new command called “`fact`” that you can use like any other Tcl command.

While the process of adding a new function to Tcl has been illustrated, the procedure is almost identical for Perl and Python. Both require special wrappers to be written and both need additional initialization code.

Variable linking

Variable linking is a slightly more difficult problem. The idea here is to map a C/C++ global variable into a variable in the scripting language (we are “linking” a variable in the scripting language to a C variable). For example, if you have the following variable:

```
double My_variable = 3.5;
```

It would be nice to be able to access it from a script as follows (shown for Perl):

```
$a = $My_variable * 2.3;
```

Unfortunately, the process of linking variables is somewhat problematic and not supported equally in all scripting languages. There seem to be two primary methods for approaching this problem:

- **Direct access**. Tcl provides a mechanism for directly accessing C `int`, `double`, and `char` * datatypes as Tcl variables. Whenever these variables are used in a Tcl script, the interpreter will directly access the corresponding C variable. While this approach is easy to support it is also somewhat problematic. Not all C datatypes are supported, and having Tcl directly manipulate your variables in its native representation could be potentially dangerous.
- **Access through function calls**. Languages such as Perl and Python can access global variables using a function call mechanism. Rather than allowing direct access, the idea here is to provide a pair of set/get functions that set or get the value of a particular variable. In many cases, this mechanism may be completely hidden. For example, it is possible to create a magical Perl variable that looks and feels just like a normal Perl variable, but is really mapped into a C variable via a pair of set/get functions underneath. The advantage of this approach is that it is possible to support almost all C datatypes. The disadvantage is that it introduces alot of complexity to the wrapper code as it is now necessary to write a pair of C functions for every single global variable.

SWIG supports both styles of variable linking although the latter is more common. In some cases, a hybrid approach is taken (for example, the Tcl module will create a pair of set/get functions if it encounters a datatype that Tcl can’t support). Fortunately, global variables are relatively rare when working with modular code.

Constants

Constants can easily be created by simply creating a new variable in the target language with the appropriate value. Unfortunately, this can have the undesirable side-effect of making the constant non-constant. As a result, a somewhat better (although perhaps inefficient) method of creating constants is to install them as read-only variables. SWIG tends to prefer this approach.

Shadow classes

When one starts to work with more complex data structures, things get complicated. Most scripting languages do not provide any direct mechanism for manipulating C structs and C++ classes. Therefore most solutions to this problem fall into the category of clever hacks---not that this is a bad thing of course.

In a nutshell, a “shadow class” is a funny kind of object that gets created in a scripting language to access a C/C++ class (or struct) in a way that looks like the original structure (that is, it “shadows” the real C++ class). For example, if you have the following C definition :

```
class Vector {
public:
        Vector();
        ~Vector();
        double x,y,z;
};
```

A shadow classing mechanism would allow you to access the structure in a natural manner. For example, in Python, you might do the following,

```
>>> v = Vector()
>>> v.x = 3
>>> v.y = 4
>>> v.z = -13
>>> ...
>>> del v
```

while in Perl5, it might look like this :

```
$v = new Vector;
$v->{x} = 3;
$v->{y} = 4;
$v->{z} = -13;
```

and in Tcl :

```
Vector v
v configure -x 3 -y 4 -z 13
```

SWIG currently supports shadow classing for Perl5, Python and Tcl. For other languages, SWIG provides a low-level interface to complex objects--in fact, shadow classes are usually built on top of this low-level interface, but this is described in detail later.

Building scripting language extensions

The final step in using a scripting language with your C/C++ application is adding your extensions to the scripting language itself. There are two fundamental approaches for doing this. First, you can build an entirely new version of the scripting language interpreter with your extensions built into it. Alternatively, you could build a shared library and dynamically load it into the scripting language as needed. Both approachs are described below :

Static linking

With static linking you rebuild the scripting language interpreter with extensions. The process usually involves compiling a short main program that adds your customized command to the language and starts the interpreter. You then link your program with a library to produce a new executable. When using static linking, SWIG will provide a `main()` program for you so you usually just have to compile as follows (shown for Tcl) :

```
unix > swig -tcl example.i
Generating wrappers for Tcl.
unix > gcc example.c example_wrap.c -I/usr/local/include \
       -L/usr/local/lib -ltcl -lm -o my_tclsh
```

The `my_tclsh` is a new executable containing the Tcl intepreter. `my_tclsh` will be exactly the same as tclsh except with your new commands added to it.

Virtually all machines support static linking and in some cases, it may be the only way to build an extension. The downside to static linking is that you can end up with a large executable. In a very large system, the size of the executable may be prohibitively large.

Shared libraries and dynamic loading

An alternative to static linking is to build a shared library. With this approach, you build a shared object file containing only the code related to your module. Unfortunately the process of building these modules varies on every single machine, but the procedure for a few common machines is show below :

```
# Build a shared library for Solaris
gcc -c example.c example_wrap.c -I/usr/local/include
ld -G example.o example_wrap.o -o example.so

# Build a shared library for Irix
gcc -c example.c example_wrap.c -I/usr/local/include
ld -shared example.o example_wrap.o -o example.so

# Build a shared library for Linux
gcc -fpic -c example.c example_wrap.c -I/usr/local/include
gcc -shared example.o example_wrap.o -o example.so
```

To use your shared library, you simply use the corresponding command in the scripting language (load, import, use, etc...). This will import your module and start using it.

The advantages to dynamic loading is that you can use modules as they are needed and they can be loaded on the fly. The disadvantage is that dynamic loading is not supported on all machines.

SWIG Basics 3

Running SWIG

SWIG is invoked by the `swig` command. This command has a number of options including:

```
swig <options> filename

-tcl                Generate Tcl wrappers
-tcl8               Generate Tcl 8.0 wrappers
-perl5              Generate Perl5 wrappers
-python             Generate Python wrappers
-perl4              Generate Perl4 wrappers
-guile              Generate Guile wrappers
-debug              Debugging language module (used only for testing)
-dascii             ASCII documentation
-dlatex             LaTeX documentation
-dhtml              HTML documentation
-dnone              No documentation
-c++                Enable C++ handling
-Idir               Set SWIG include directory
-lfile              Include a SWIG library file.
-c                  Generate raw wrapper code (omit supporting code)
-v                  Verbose mode (perhaps overly verbose)
-o outfile          Name of output file
-d docfile          Set name of documentation file (without suffix)
-module name        Set name of SWIG module
-Dsymbol            Define a symbol
-version            Show SWIG's version number
-help               Display all options
```

This is only a partial list of options. A full listing of options can be obtained by invoking "`swig -help`". Each target language may have additional options which can be displayed using "`swig -lang -help`" where `-lang` is one of the target languages above.

Input format

As input, SWIG takes a file containing ANSI C/C++ declarations[1]. This file may be a special "interface file" (usually given a .i suffix), a C header file or a C source file. The most common method of using SWIG is with a special interface file. These files contain ANSI C/C++ declarations like a header file, but also contain SWIG directives and documentation. These files usually have the following format :

1. Older style C declarations are not supported

```
%module mymodule
%{
#include "myheader.h"
%}
// Now list ANSI C variable and function declarations
```

The name of the module (if supplied) must always appear before the first C declaration or be supplied on the SWIG command line using the `-module` option (When the module name is specified on the command line, it will override any module name present in a file). Everything inside the `%{,%}` block is copied into the resulting output file. The `%{,%}` block is optional, but most interface files use one to include the proper header files.[1]

SWIG Output

By default an interface file with the name `myfile.i` will be transformed into a file called `myfile_wrap.c`. The name of the output file can be changed using the `-o` option. The output file usually contains everything that is needed to build a working module for the target scripting language. Compile it along with your C program, link it, and you should be ready to run.

Comments

C and C++ style comments may be placed in interface files, but these are used to support the automatic documentation system. Please see the documentation section for more details on this. Otherwise, SWIG throws out all comments so you can use a C++ style comment even if the resulting wrapper file is compiled with the C compiler.

C Preprocessor directives

SWIG does not run the C preprocessor. If your input file makes extensive use of the C preprocessor, SWIG will probably hate it. However, SWIG does recognize a few C preprocessor constructs that are quite common in C code :

- `#define`. Used to create constants
- `#ifdef,#ifndef,#else,#endif`, `#if, #elif`. Used for conditional compilation

All other C preprocessor directives are ignored by SWIG (including macros created using `#define`).

SWIG Directives

SWIG directives are always preceded by a "%" to distinguish them from normal C directives and declarations.

Limitations in the Parser (and various things to keep in mind)

It was never my intent to write a full C/C++ parser. Therefore SWIG has a number of limitations to keep in mind.

- Functions with variable length arguments (ie. "...") are not supported.
- Complex declarations such as function pointers and arrays are problematic. You may

1. Previous versions of SWIG required a `%{,%}` block. This restriction has been lifted in SWIG 1.1.

need to remove these from the SWIG interface file.
- C++ source code (what would appear in a .C file) is especially problematic. Running SWIG on C++ source code is highly discouraged.
- More sophisticated features of C++ such as templates and operator overloading are not supported. Please see the section on using SWIG with C++ for more details. When encountered, SWIG may issue a warning message or a syntax error if it can't figure out you are trying to do.

Many of these limitations may be eliminated in future releases. It is worth noting that many of the problems associated with complex declarations can sometimes be fixed by clever use of `typedef`.

If you are not sure whether SWIG can handle a particular declaration, the best thing to do is try it and see. SWIG will complain loudly if it can't figure out what's going on.

Simple C functions, variables, and constants

SWIG supports just about any C function, variable, or constant involving built-in C datatypes. For example :

```
%module example

extern double sin(double x);
extern int strcmp(const char *, const char *);
extern int My_variable;
#define STATUS 50
const char *VERSION="1.1";
```

will create two commands called "`sin`" and "`strcmp`", a global variable "`My_variable`", and two constants "`STATUS`" and "`VERSION`". Things work about like you would expect. For example, in Tcl :

```
% sin 3
5.2335956
% strcmp Dave Mike
-1
% puts $My_variable
42
% puts $STATUS
50
% puts $VERSION
1.1
```

The main concern when working with simple functions is SWIG's treatment of basic datatypes which is described next.

Integers

SWIG maps the following C integer datatypes into a integers in the target scripting language.

```
int
short
long
```

```
unsigned
signed
unsigned short
unsigned long
unsigned char
signed char
bool
```

Scripting languages usually only support a single integer type that corresponds to either the `int` or `long` datatype in C. When converting from C, all of the above datatypes are cast into the representation used by the target scripting language. Thus, a 16 bit short in C may be converted to a 32 bit integer. When integers are converted from the scripting language back into C, the value will be cast into the appropriate type. The original value will simply be truncated if it is too large to fit into the corresponding C datatype.

The `unsigned char` and `signed char` datatypes are special cases that are treated as integers by SWIG. Normally, the `char` datatype is mapped as an ASCII string.

The `bool` datatype is cast to and from an integer value or 0 and 1.

Some care is in order for large integer values. If a scripting language uses 32 bit integers, mapping a 64 bit long integer may lead to errors. Similar problems may arise with 32 bit unsigned integers. As a rule of thumb, the `int` datatype and all variations of `char` and `short` datatypes are safe to use. For `unsigned int` and `long` datatypes, you should verify the correct operation of your program after wrapping it with SWIG.

Floating Point

SWIG recognizes the following floating point types :

```
float
double
```

Floating point numbers are mapped to and from the natural representation of floats in the target language. This is almost always a `double` except in Tcl 7.x which uses character strings. The rarely used datatype of “long double” is not supported by SWIG.

Character Strings

The `char` datatype is mapped into a NULL terminated ASCII string with a single character. When used in a scripting language it will show up as a tiny string containing the character value. When converting the value back into C, SWIG will take a character string from the scripting language and strip off the first character as the char value. Thus if you try to assigned the value “foo” to a `char` datatype, it will get the value ‘f’.

The `char *` datatype is assumed to be a NULL-terminated ASCII string. SWIG maps this into a character string in the target language. SWIG converts character strings in the target language to NULL terminated strings before passing them into C/C++. It is illegal for these strings to have embedded NULL bytes. However, there are ways to remap SWIG’s treatment of any datatype.

The `signed char` and `unsigned char` datatypes are mapped into integer values. The following example illustrates the mapping of `char` datatypes.

```
%{
#include <stdio.h>
#include <ctype.h>
#include <string.h>
char sum(char a, char b) { return a+b;}
%}

int  strcmp(char *, char *);
char toupper(char);
signed char sum(signed char a, signed char b);
```

A Tcl script using these functions (and the resulting output) might be as follows.

```
tclsh > strcmp Mike John
1
tclsh > toupper g
G
tclsh > sum 17 -8
9
```

Constants

Constants can be created using `#define`, `const`, or enumerations. Constant expressions are also allowed. The following interface file shows a few valid constant declarations :

```
#define I_CONST       5                     // An integer constant
#define F_CONST       3.14159               // A Floating point constant
#define S_CONST       "hello world"         // A string constant
#define NEWLINE       '\n'                  // Character constant
#define MODE          DEBUG                 // Sets MODE to DEBUG.
                                            // DEBUG is assumed to be an
                                            // int unless declared earlier
enum boolean {NO=0, YES=1};
enum months {JAN, FEB, MAR, APR, MAY, JUN, JUL, AUG,
              SEP, OCT, NOV, DEC};
const double PI 3.141592654;
#define F_CONST2      (double) 5            // A floating pointer constant with cast
#define PI_4 PI/4
#define FLAGS 0x04 | 0x08 | 0x40
```

In `#define` declarations, the type of a constant is inferred by syntax or can be explicitly set using a case. For example, a number with a decimal point is assumed to be floating point. When no explicit value is available for a constant, SWIG will use the value assigned by the C compiler. For example, no values are given to the `months` enumeration, but this is no problem---SWIG will use whatever the C compiler picks.

The use of constant expressions is allowed, but SWIG does not evaluate them. Rather, it passes them through to the output file and lets the C compiler perform the final evaluation.

For enumerations, it is critical that the original enum definition be included somewhere in the interface file (either in a header file or in the `%{,%}` block). SWIG only translates the enumeration into code needed to add the constants to a scripting language. It needs the original enumeration declaration to retrieve the correct values.

Pointers and complex objects

Of course, as we all know, most C programs have much more than just integers, floating pointer numbers, and character strings. There may be pointers, arrays, structures, and other objects floating around. Fortunately, this is usually not a problem for SWIG.

Simple pointers

Pointers to basic C datatypes such as

```
int *
double ***
char **
```

can be used freely in an interface file. SWIG encodes pointers into a representation containing the actual value of the pointer and a string representing the datatype. Thus, the SWIG representation of the above pointers (in Tcl), might look like the following :

```
_10081012_int_p
_1008e124_double_ppp
_f8ac_char_pp
```

A NULL pointer is represented by the string “NULL” or the value 0 with no type information.

All pointers are treated as opaque objects by SWIG. A pointer may be returned by a function and passed around to other C functions in the scripting language interface as needed. For all practical purposes, the scripting language interface works in exactly the same way as you would write a C program (well, with a few limitations and benefits of course).

The scripting language representation of a pointer should never be manipulated directly (although nothing prevents this). SWIG does not normally map pointers into high-level objects such as associative arrays or lists (for example, it might be desirable to convert an `int *` into an list of integers). There are several reasons for this :

- Adding special cases would make SWIG more complicated and difficult to maintain.
- There is not enough information in a C file to properly map pointers into higher level constructs. For example, an `int *` may indeed be an array of integers, but if it contains one million elements, converting it into a Tcl, Perl, or Python list would probably be an extremely stupid idea.
- By treating all pointers equally, it is easy to know what you’re going to get when you create an interface (you may not like the mapping, but at least you’ll know what it is--back to the consistency issue).

As it turns out, you can remap any C datatype to behave in new ways so these points may be of little concern. Keep reading...

Run time pointer type checking

By allowing pointers to be manipulated interactively in a scripting language, we have effectively bypassed the type-checker in the C/C++ compiler. By encoding pointer values with a datatype, SWIG is able to perform run-time type-checking in order to prevent mysterious system crashes and other anomalies. By default, SWIG uses a strict-type checking model that checks the datatype of all pointers before allowing them to be given to C/C++. However, safety is not always a good thing so you can change the handling of pointers using the `-strict` option:

```
-strict 0            No type-checking (living on the edge)
-strict 1            Generate warning messages (somewhat annoying)
-strict 2            Strict type checking (the default)
```

Strict type checking is the recommended default since is the most reliable and most closely follows the type checking rules of C.

By default, SWIG will allow a "NULL" pointer to be passed to C/C++. This has the potential to crash code and cause other problems if you are not careful. Checks can be placed on certain values but this requires the use of typemaps (described in later chapters).

Like C, it should also be noted that functions involving void pointers can accept any kind of pointer object.

Derived types, structs, and classes

For everything else (structs, classes, arrays, etc...) SWIG applies a very simple rule :

All complex datatypes are pointers

In other words, SWIG manipulates everything else by reference. This model makes sense because most C/C++ programs make heavy use of pointers and we can use the type-checked pointer mechanism already present in SWIG for handling pointers to basic datatypes.

While all of this probably sounds complicated, it's really quite simple. Suppose you have an interface file like this :

```
%module fileio
FILE *fopen(char *, char *);
int fclose(FILE *);
unsigned read(void *ptr, unsigned size, unsigned nobj, FILE *);
unsigned write(void *ptr, unsigned size, unsigned nobj, FILE *);
void *malloc(int nbytes);
void free(void *);
```

In this file, SWIG doesn't know what a `FILE` is, but it's used as a pointer, so it doesn't really matter what it is. If you wrapped this module into Python, you could use it just like you would expect :

```
# Copy a file
def filecopy(source,target):
       f1 = fopen(source,"r")
       f2 = fopen(target,"w")
       buffer = malloc(8192)
       nbytes = fread(buffer,8192,1,f1)
       while (nbytes > 0):
              fwrite(buffer,8192,1,f2)
              nbytes = fread(buffer,8192,1,f1)
       free(buffer)
```

In this case f1,f2, and buffer are all opaque objects containing C pointers. It doesn't really matter what value they contain.

What happens when SWIG encounters an unknown datatype?

When SWIG encounters an unknown datatype, it automatically assumes that it is some sort of complex datatype. For example, suppose the following function appeared in a SWIG input file:

```
void matrix_multiply(Matrix *a, Matrix *b, Matrix *c);
```

SWIG has no idea what a "Matrix" is so it will assume that you know what you are doing and map it into a pointer. Of course, this makes perfect sense because the underlying C function is using pointers in the first place. Unlike C or C++, SWIG does not actually care whether Matrix has been previously defined in the interface file or not. While this may sound strange, it makes it possible for SWIG to generate interfaces from only partial information. Many times, you may not care what a Matrix really is as long as you can pass references to one around in the scripting language interface. The downside to this relaxed approach is that typos may go completely undetected by SWIG[1]. You can also end up shooting yourself in the foot, but presumably you've passed your programming safety course.

Typedef

Finally, it is important to note that typedef can be used to remap datatypes within SWIG. For example :

```
typedef unsigned int size_t;
```

This makes SWIG treat size_t like an unsigned int. Use of typedef is fairly critical in most applications. Without it, SWIG would consider size_t to be some sort of complex object which is entirely incorrect. SWIG is fairly good at tracking typedef definitions within an interface file and you should use them to your benefit.

Getting down to business

So far, you know just about everything you need to know to use SWIG to build interfaces. In fact, using nothing but basic datatypes and opaque pointers it is possible to build scripting language interfaces to most kinds of C/C++ packages. However, as the novelty wears off, you will want to do more. This section describes SWIG's treatment of more sophsticated problems.

Passing complex datatypes by value

Unfortunately, not all C programs manipulate complex objects by reference. When encountered, SWIG will transform the corresponding C/C++ declaration to use references instead. For example, suppose you had the following function :

```
double dot_product(Vector a, Vector b);
```

In this case, the function is taking two structure datatypes as arguments, but these are being

1. Fortunately, if you make a typo, the C compiler will usually catch it when it tries to compile the SWIG generated wrapper file.

passed by value. SWIG will transform this function call into the equivalent of the following :

```
double wrap_dot_product(Vector *a, Vector *b) {
       return dot_product(*a,*b);
}
```

In the scripting language, `dot_product` will now take references to Vectors instead of Vectors. However, in most cases, you may not notice this change.

Return by value

C functions that return complex datatypes by value are more difficult to handle. Consider the following function:

```
Vector cross(Vector v1, Vector v2);
```

This function is returning a complex object, yet SWIG only likes to work with references. Clearly, something must be done with the return result, or it will be lost forever. As a result, SWIG transforms this function into the following code :

```
Vector *wrap_cross(Vector *v1, Vector *v2) {
       Vector *result;
       result = (Vector *) malloc(sizeof(Vector));
       *(result) = cross(*v1,*v2);
       return result;
}
```

or if using C++ :

```
Vector *wrap_cross(Vector *v1, Vector *v2) {
       Vector *result;
       result = new Vector;
       *(result) = cross(*v1,*v2);
       return result;
}
```

Thus, SWIG is forced to create a new object and return a reference to it. It is up to the user to delete the returned object when it is no longer in use. When used improperly, this can lead to memory leaks and other problems. Of couse, I'd rather live with a potential memory leak than forbid the use of such a function. In any case, some care is probably in order (you should probably be aware of this behavior in any case).

Linking to complex variables

When global variables or class members involving complex datatypes are encountered, SWIG converts them into a reference. For example, a global variable like this :

```
Vector unit_i;
```

Will get mapped to a pair of set/get functions that look like this :

```
Vector *unit_i_get() {
       return &unit_i;
}
Vector *unit_i_set(Vector *value) {
```

```
        return (unit_i = *value);
}
```

Returning a reference to the variable makes it accessible like any other object of this type. When setting the value, we simply make a copy of some other Vector reference. Again some caution is in order. A global variable created in this manner will show up as a reference in the target scripting language. It would be an extremely bad idea to free or destroy such a reference. Similarly, one can run into problems when copying C++ objects in this manner. Fortunately, in well-written modular code, excessive use (or abuse) of global variables is rare.

Arrays

The use of arrays in the current version of SWIG is somewhat discouraged. If simple arrays appear, they will be mapped into a pointer representation. Thus, the following declarations :

```
int foobar(int a[40]);
void grok(char *argv[]);
void transpose(double a[20][20]);
```

will be processed as if they were declared like this:

```
int foobar(int *a);
void grok(char **argv);
void transpose(double *a);
```

Multi-dimensional arrays are transformed into a single pointer since `a[][]` and `**a` are not the same thing (even though they can be used in similar ways). Rather, `a[][]` is mapped to *a, where `*a` is the equivalent of `&a[0][0]`. Support for arrays is currently being improved and may be more flexible in a future release.

Be aware that use of arrays may cause compiler warnings or errors when compiling SWIG generated modules. While every attempt has been made to eliminate these problems, handling of arrays remains problematic due to the subtle differences between an array and a C pointer.

Creating read-only variables

A read-only variable can be created by using the `%readonly` directive as shown :

```
// File : interface.i

int    a;                  // Can read/write
%readonly
int    b,c,d               // Read only variables
%readwrite
double x,y                 // read/write
```

The `%readonly` directive enables read-only mode until it is explicitly disable using the `%readwrite` directive.

Renaming things

Normally, the name of a C function is used as the name of the command added to the target scripting language. Unfortunately, this name may conflict with a keyword or already existing function in the scripting language. Naming conflicts can be resolved using the `%name` directive as shown :

```
// interface.i

%name(my_print) extern void print(char *);
%name(foo) extern int a_really_long_and_annoying_name;
```

SWIG still calls the correct C functions, but in this case the function `print()` will really be called "`my_print()`" in the scripting language.

SWIG does not perform any checks to see if the functions it adds are already defined in the target scripting language. However, if you are careful about namespaces and your use of modules, this is rarely a problem.

Overriding call by reference

SWIG is quite literal in its interpretation of datatypes. If you give it a pointer, it will use pointers. Unfortunately, this can sometimes be annoying. For example, if you're trying to call a function in a Fortran library (through its C interface) all function parameters will have to be passed by reference. Similarly, some C functions may use pointers in unusual ways. The `%val` directive can be used to change the calling mechanism for a C function. For example :

```
// interface.i
%{
#include <time.h>
%}

typedef long time_t;
time_t time(time_t *t);
struct tm *localtime(%val time_t *t);
char *asctime(struct tm *);
```

The `localtime()` function takes a pointer to a `time_t` value, but we have forced it to take a value instead in order to match up nicely with the return value of the `time()` function. When used in Perl, this allows us to do something like this :

```
$t = time(0);
$tm = localtime($t); # Note passing $t by value here
print $asctime($tm);
```

Internally, the `%val` directive creates a temporary variable. The argument value is stored in this variable and a function call is made using a pointer to the temporary variable. Of course, if the function returns a value in this temporary variable, it will be lost forever. Functions may return values in their arguments if they are pointers, but given SWIG's literal interpretation of pointers, this can be a little awkward when used in a scripting language.

Default/optional arguments

SWIG allows default arguments to be used in both C/C++ code as follows :

```
int plot(double min, double max, int color=WHITE);
```

To specify a default argument, simply specify it the function prototype as shown. When used, SWIG will generate wrapper code in which the default arguments are optional. For example, this function could be used in Tcl as follows :

```
% plot -3.4 7.5              # Use default value
% plot -3.4 7.5 10           # set color to 10 instead
```

While ANSI C does not specify default arguments, default arguments used in a SWIG generated interface work with both C and C++ code.

Pointers to functions

At the moment, the SWIG parser has difficulty handling pointers to functions (a deficiency that is being corrected). However, having function pointers is useful for managing C callback functions and other things. To properly handle function pointers, it is currently necessary to use `typedef.` For example, the function

```
void do_operation(double (*op)(double,double), double a, double b);
```

should be handled as follows :

```
typedef double (*OP_FUNC)(double,double);
void do_operation(OP_FUNC op, double a, double b);
```

SWIG understands both the typedef declaration and the later function call. It will treat `OP_FUNC` just like any other complex datatype. In order for this approach to work, it is necessary that the typedef declaration be present in the original C code--otherwise, the C compiler will complain. If you are building a separate interface file to an existing C program and do not want to make changes to the C source, you can also do the following :

```
// File : interface.i
%typedef double (*OP_FUNC)(double,double);
double do_operation(OP_FUNC op, double a, double b);
```

`%typedef` forces SWIG to generate a `typedef` in the C output code for you. This would allow the interface file shown to work with the original unmodified C function declaration.

Constants containing the addresses of C functions can also be created. For example, suppose you have the following callback functions :

```
extern double op_add(double a, double b);
extern double op_sub(double a, double b);
extern double op_mul(double a, double b);
```

The addresses of these functions could be installed as constants as follows :

```
// interface.i
typedef double (*OP_FUNC)(double,double);
...
const OP_FUNC ADD = op_add;
const OP_FUNC SUB = op_sub;
const OP_FUNC MUL = op_mul;
...
```

When wrapped, this would create the constants `ADD`,`SUB`, and `MUL` containing the addresses of C callback functions. We could then pass these to other C functions expecting such function pointers as arguments as shown (for Tcl) :

```
%do_operation $ADD 3 4
7
%
```

Structures, unions, and object oriented C programming

If SWIG encounters the definition of a structure or union, it will create a set of accessor functions for you. While SWIG does not need structure definitions to build an interface, providing definitions make it possible to access structure members from the scripting language interface. The accessor functions generated by SWIG simply take a pointer to an object and allow access to an individual member. For example, the declaration :

```
struct Vector {
       double x,y,z;
}
```

gets mapped into the following set of functions :

```
double Vector_x_get(Vector *obj) {
       return obj->x;
}
double Vector_y_get(Vector *obj) {
       return obj->y;
}
double Vector_z_get(Vector *obj) {
       return obj->z;
}

double Vector_x_set(Vector *obj, double value) {
       return (obj->x = value);
}
double Vector_y_set(Vector *obj, double value) {
       return {obj->y = value);
}
double Vector_z_set(Vector *obj, double value) {
       return (obj->z = value);
}
```

Typedef and structures

SWIG supports the following construct which is quite common in C programs :

```
typedef struct {
       double x,y,z;
} Vector;
```

When encountered, SWIG will assume that the name of the object is ‘Vector’ and create accessor functions like before. If two different names are used like this :

```
typedef struct vector_struct {
       double x,y,z;
} Vector;
```

the name 'Vector' will still be used.

Character strings and structures

Structures involving character strings require some care. SWIG assumes that all members of type `char *` have been dynamically allocated using `malloc()` and that they are NULL-terminated ASCII strings. When such a member is modified, the previously contents will be freed, and the new contents allocated. For example :

```
%module mymodule
...
struct Foo {
       char *name;
       ...
}
```

This results in the following accessor functions :

```
char *Foo_name_get(Foo *obj) {
       return Foo->name;
}

char *Foo_name_set(Foo *obj, char *c) {
       if (obj->name) free(obj->name);
       obj->name = (char *) malloc(strlen(c)+1);
       strcpy(obj->name,c);
       return obj->name;
}
```

This seems to work most of the time, but occasionally it's not always what you want. Fortunately, there are several ways to change this.

Array members

Arrays used as the members of structures are allowed by SWIG, but will be read-only. SWIG will write an accessor function that returns the pointer to the first element of the array, but will not write a function to change the array itself. This restriction is due to the fact that C won't let us change the "value" of an array. SWIG typemaps can be used to work around this problem.

C constructors and destructors

While not part of the C language, it is usually useful to have some mechanism for creating and destroying an object. You can, of course, do this by making an appropriate call to `malloc()`, but SWIG can make such functions for you automatically if you write your interface file like this :

```
%module mymodule
...
struct Vector {
       Vector();              // Tell SWIG to create a C constructor
       ~Vector();             // Tell SWIG to create a C destructor
       double x,y,z;
}
```

When used with C code, SWIG will create two additional functions like this :

```
Vector *new_Vector() {
        return (Vector *) malloc(sizeof(Vector));
}

void delete_Vector(Vector *v) {
        free(v);
}
```

Thus, while C knows nothing about constructors and destructors, SWIG does---and it can automatically create some for you if you want. Of course, this only applies to C code, handling of C++ is different.

As an alternative to explicitly defining constructors and destructors, SWIG can also automatically generate them using either a command line option or a pragma. For example :

```
swig -make_default example.i
```

or

```
%module foo
...
%pragma make_default                // Make default constructors
... declarations ...
%pragma no_default                  // Disable default constructors
```

This works with both C and C++.

Adding member functions

Many scripting languages provide a mechanism for creating classes and supporting object oriented programming. While there is a natural mapping of C++ to such a scheme, there is no direct mechanism for utilizing it with C code. However, SWIG provides a special `%addmethods` directive that makes it possible to attach member functions to C structures for purposes of building an object oriented scripting language interface. Suppose you have a C header file with the following declaration :

```
/* file : vector.h */
...
typedef struct {
        double x,y,z;
} Vector;
```

You can make an object oriented SWIG interface to it like this :

```
// file : vector.i
%module mymodule
%{
#include "vector.h"
%}

%include vector.h             // Just grab original C header file
%addmethods Vector {          // Attach these functions to struct Vector
        Vector(double x, double y, double z) {
                Vector *v;
```

```
                v = (Vector *v) malloc(sizeof(Vector));
                v->x = x;
                v->y = y;
                v->z = z;
                return v;
        }
        ~Vector() {
                free(self);
        }
        double magnitude() {
                return sqrt(self->x*self->x+self->y*self->y+self->z*self->z);
        }
        void print() {
                printf("Vector [%g, %g, %g]\n", self->x,self->y,self->z);
        }
};
```

Now, when used with shadow classes in Python, you can do things like this :

```
>>> v = Vector(3,4,0)                   # Create a new vector
>>> print v.magnitude()                 # Print magnitude
5.0
>>> v.print()                           # Print it out
[ 3, 4, 0 ]
>>> del v                               # Destroy it
```

The `%addmethods` directive can also be used in the definition of the Vector structure. For example:

```
// file : vector.i
%module mymodule
%{
#include "vector.h"
%}

typedef struct {
        double x,y,z;
        %addmethods {
                Vector(double x, double y, double z) { ... }
                ~Vector() { ... }
                ...
        }
} Vector;
```

Finally, `%addmethods` can work with externally written functions provided they follow the naming convention used in this example :

```
/* File : vector.c */
/* Vector methods */
#include "vector.h"
Vector *new_Vector(double x, double y, double z) {
        Vector *v;
        v = (Vector *) malloc(sizeof(Vector));
        v->x = x;
        v->y = y;
        v->z = z;
        return v;
}
```

```
void delete_Vector(Vector *v) {
	free(v);
}

double Vector_magnitude(Vector *v) {
	return sqrt(v->x*v->x+v->y*v->y+v->z*v->z);
}

// File : vector.i
// Interface file
%module mymodule
%{
#include “vector.h”
%}

typedef struct {
	double x,y,z;
	%addmethods {
		double magnitude();   // This will map onto Vector_magnitude
		...
	}
} Vector;
```

So why bother with all of this `%addmethods` business? In short, you can use it to make some pretty cool object oriented scripting language interfaces to C programs without having to deal with all of the problems involved with using a C++ implementation.

Nested structures

Occasionally, a C program will involve structures like this :

```
typedef struct Object {
	int objtype;
	union {
		int    ivalue;
		double dvalue;
		char   *strvalue;
		void   *ptrvalue;
	} intRep;
} Object;
```

When SWIG encounters this, it performs a structure splitting operation that transforms the declaration into the equivalent of the following:

```
typedef union {
	int           ivalue;
	double        dvalue;
	char          *strvalue;
	void          *ptrvalue;
} Object_intRep;

typedef struct Object {
	int objType;
	Object_intRep intRep;
} Object;
```

SWIG will create an `Object_intRep` structure for use inside the interface file. Accessor functions will be created for both structures. In this case, functions like this would be created :

```
Object_intRep *Object_intRep_get(Object *o) {
        return (Object_intRep *) &o->intRep;
}
int Object_intRep_ivalue_get(Object_intRep *o) {
        return o->ivalue;
}
int Object_intRep_ivalue_set(Object_intRep *o, int value) {
        return (o->ivalue = value);
}
double Object_intRep_dvalue_get(Object_intRep *o) {
        return o->dvalue;
}
... etc ...
```

Is it hairy? You bet. Does it work? Well, surprisingly yes. When used with Python and Perl5 shadow classes, it's possible to access the nested members just like you expect :

```
# Perl5 script for accessing nested member
$o = CreateObject();         # Create an object somehow
$o->{intRep}->{ivalue} = 7   # Change value of o.intRep.ivalue
```

If you've got a bunch of nested structure declarations, it is certainly advisable to check them out after running SWIG. However, there is a good chance that they will work. If not, you can always remove the nested structure declaration and write your own set of accessor functions.

Other things to note about structures

SWIG doesn't actually care if the definition of a structure exactly matches that used in the underlying C code (except in the case of nested structures). For this reason, there are no problems omitting problematic members or simply omitting the structure definition altogether. If you are happy simply passing pointers around, this can be done without ever giving SWIG a structure definition.

It is also important to note that most language modules may choose to build a more advanced interface. You may never use the low-level interface described here, however most of SWIG's language modules use it in some way or another.

C++ support

SWIG's support for C++ relies heavily on the concepts described for C functions and variables. However, SWIG only supports a subset of the C++ language. It has never been my goal to write a full C++ compiler or to turn to turn scripting languages into some sort of weird pseudo C++ interpreter (considering how hard it is to write a C++ compiler, I'm not sure this would even be feasible anyways). SWIG's C++ implementation relies heavily on SWIG's treatment of pointers and datatypes previously described.

This section describes SWIG's low-level access to C++ declarations. In many instances, this low-level interface may be hidden by shadow classes or an alternative calling mechanism (this is usually language dependent and is described in detail in later chapters).

Supported C++ features

SWIG supports the following C++ features :

- Simple class definitions
- Constructors and destructors
- Virtual functions
- Public inheritance (including multiple inheritance)
- Static functions
- References

The following C++ features are not currently supported :

- Operator overloading
- Function overloading (without renaming)
- Templates
- Friends
- Nested classes
- Namespaces

Since SWIG's C++ support is a "work in progress", many of these limitations may be lifted in future releases. In particular, function overloading and nested classes, may be supported in the future. Operator overloading and templates are unlikely to be supported anytime in the near future, but I'm not going to rule out the possibility in later releases.

C++ example

The following code shows a SWIG interface file for a simple C++ class.

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

// Very simple C++ example for linked list

class List {
public:
  List();
  ~List();
  int  search(char *value);
  void insert(char *);
  void remove(char *);
  char *get(int n);
  int  length;
static void print(List *l);
};
```

When compiling C++ code, it is critical that SWIG be called with the '`-c++`' option. This changes the way a number of critical features are handled with respect to differences between C and C++. Without the `-c++` flag, SWIG will issue a warning if it find any C++ code in an interface file.

Constructors and destructors

C++ constructors and destructors are translated into C functions like the following :

```
List * new_List(void) {
       return new List;
}
void delete_List(List *l) {
       delete l;
}
```

If the original C++ class does not have any constructors or destructors, putting constructors and destructors in the SWIG interface file will cause SWIG to generate wrappers for the default constructor and destructor of an object.

Member functions

Member functions are translated into a C accessor function like this :

```
int List_search(List *obj, char *value) {
       return obj->search(value);
}
```

Virtual member functions are treated in an identical manner since the C++ compiler will figure everything out when the resulting wrapper code is compiled.

Static members

Static member functions are called directly without making any additional C wrappers. For example, the static member function `print(List *l)` will simply be called as `List::print(List *l)` in the resulting wrapper code.

Member data

Member data is handled in exactly the same manner as used for C structures. A pair of accessor functions will be created. For example :

```
int List_length_get(List *obj) {
       return obj->length;
}
int List_length_set(List *obj, int value) {
       return obj->length = value;
}
```

A read-only member can be created using the `%readonly` and `%readwrite` directives. For example :

```
struct FooBar {
       %readonly
       double x;
       char *name;
       %readwrite
};
```

Protection

SWIG can only wrap class members that are declared public. Anything specified in a private or protected section will simply be ignored. To simplify your interface file, you may want to consider eliminating all private and protected declarations (if you've copied a C++ header file for example).

By default, members of a class definition are assumed to be private until you explicitly give a '`public:`' declaration.

Enums and constants

Enumerations and constants placed in a class definition are mapped into constants with the classname as a prefix. For example :

```
class Swig {
public:
	enum {ALE, LAGER, PORTER, STOUT};
};
```

Generates the following set of constants in the target scripting language :

```
Swig_ALE = Swig::ALE
Swig_LAGER = Swig::LAGER
Swig_PORTER = Swig::PORTER
Swig_STOUT = Swig::STOUT
```

Members declared as `const` are wrapped in a similar manner.

References

C++ references are supported, but SWIG will treat them as pointers. For example, a declaration like this :

```
class Foo {
public:
	double bar(double &a);
}
```

will be accessed using a function like this :

```
double Foo_bar(Foo *obj, double *a) {
	obj->bar(*a);
}
```

Functions returning a reference will be mapped into functions returning pointers as well.

Inheritance

SWIG supports basic C++ public inheritance of classes and allows both single and multiple inheritance. The SWIG type-checker knows about the relationship between base and derived classes and will allow pointers to any object of a derived class to be used in functions of a base class. The type-checker properly casts pointer values and is safe to use with multiple inheritance. SWIG does not support private or protected inheritance (it will be parsed, but ignored).

The following example shows how SWIG handles inheritance. For clarity, the full C++ code has been omitted.

```
// shapes.i
%module shapes
%{
#include "shapes.h"
%}

class Shape {
public:
        virtual double area() = 0;
        virtual double perimeter() = 0;
        void    set_location(double x, double y);
};
class Circle : public Shape {
public:
        Circle(double radius);
        ~Circle();
        double area();
        double perimeter();
};
class Square : public Shape {
public:
        Square(double size);
        ~Square();
        double area();
        double perimeter();
}
```

When wrapped into Perl5, we can now perform the following operations :

```
beazley@slack% perl5.003
use shapes;
$circle = shapes::new_Circle(7);
$square = shapes::new_Square(10);
print shapes::Circle_area($circle),"\n";
# Notice use of base class below
print shapes::Shape_area($circle),"\n";
print shapes::Shape_area($square),"\n";
shapes::Shape_set_location($square,2,-3);
print shapes::Shape_perimeter($square),"\n";
<ctrl-d>
153.93804004599999757
153.93804004599999757
100.00000000000000000
40.00000000000000000
```

In our example, we have created Circle and Square objects. We can call member functions on each object by making calls to `Circle_area`, `Square_area`, and so on. However, we can can accomplish the same thing by simply using the `Shape_area` function on either object.

Renaming

C++ member functions and data can be renamed with the `%name` directive. The `%name` directive only replaces the member function name. For example :

```
class List {
public:
  List();
%name(ListSize) List(int maxsize);
  ~List();
  int  search(char *value);
%name(find)    void insert(char *);
%name(delete)  void remove(char *);
  char *get(int n);
  int  length;
static void print(List *l);
};
```

This will create the functions `List_find`, `List_delete`, and a function named `new_ListSize` for the overloaded constructor.

The `%name` directive can be applied to all members including constructors, destructors, static functions, data members, and enumeration values.

The class name prefix can be changed by specifying

```
%name(newname) class List {
...
}
```

If newname is empty, then the class name will be stripped off all members (including constructors and destructors). However, the renaming of classes is generally discouraged since it seems to make things more confusing (and it may even be broken).

Adding new methods

New methods can be added to a class using the `%addmethods` directive. This directive is primarily used in conjunction with shadow classes to provide additional functionality. For example :

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

class Vector {
public:
       double x,y,z;
       Vector();
       ~Vector();
       ... bunch of C++ methods ...
       %addmethods {
              char *__str__() {
                     static char temp[256];
                     sprintf(temp,"[ %g, %g, %g ]", v->x,v->y,v->z);
                     return &temp[0];
              }
       }
};
```

This code adds a `__str__` method to our class for producing a string representation of the object. In Python, such a method would allow us to print the value of an object using the print command.

```
>>>
>>> v = Vector();
>>> v.x = 3
>>> v.y = 4
>>> v.z = 0
>>> print(v)
[ 3.0, 4.0, 0.0 ]
>>>
```

The `%addmethods` directive follows all of the same conventions as its use with C structures.

Partial class definitions

Since SWIG is still somewhat limited in its support of C++, it may be necessary to only use partial class information in an interface file. This should not present a problem as SWIG does not care if the class your specify exactly matches the real C++ specification. As a general rule, you should strip all classes of operator overloading, friends, and other declarations before giving them to SWIG (although SWIG will generate only warnings for most of these things).

As a rule of thumb, running SWIG on raw C++ header or source files is currently discouraged. Given the complexity of C++ parsing and limitations in SWIG's parser it will still take some time for SWIG's parser to evolve to a point of being able to safely handle most C++ files.

The future of C++ and SWIG

SWIG's support of C++ is best described as an ongoing project. It will probably remain evolutionary in nature for the foreseeable future. In the short term, work is already underway for supporting nested classes and function overloading. As always, these developments will take time. Feedback and contributions are always welcome.

Conditional compilation

SWIG does not run the C preprocessor, but it does support conditional compilation of interface files in a manner similar to the C preprocessor. This can be done by placed `#ifdef`, `#ifndef`, `#if`, `#else`, `#elif`, and `#endif` directives in your interface file. These directives can be safely nested. In addition, SWIG skips all text found in the 'false' part of a conditional. This allows one to conditionally compile out troublesome C/C++ code if necessary. For example, the following file can serve as both a C header file and a SWIG interface file :

```
#ifdef SWIG
%module mymodule
%{
#include "header.h"
%}

%include wish.i
#endif

... normal C declarations here ...
```

Similarly, conditional compilation can be used to customize an interface. The following interface file can be used to build a Perl5 module that works with either static or dynamic linking :

```
%module mymodule
%{
#include "header.h"
%}

... Declarations ...

#ifdef STATIC
%include perlmain.i          // Include code for static linking
#endif
```

Defining symbols

To define symbols, you can use the `-D` option as in :

```
swig -perl5 -static -DSTATIC interface.i
```

Symbols can also be defined using `#define` with no arguments. For example :

```
%module mymodule
#define STATIC

... etc ...
```

The #if directive

The `#if` directive can only be used in the following context :

```
#if defined(SYMBOL)
...
#elif !defined(OTHERSYMBOL)
...
#endif
```

The C processor version supports any constant integral expression as an argument to `#if`, but SWIG does not contain an expression evaluator so this is not currently supported.

Predefined Symbols

One or more of the following symbols will be defined by SWIG when it is processing an interface file :

```
SWIG                        Always defined when SWIG is processing a file
SWIGTCL                     Defined when using Tcl
SWIGTCL8                    Defined when using Tcl8.0
SWIGPERL                    Defined when using Perl
SWIGPERL4                   Defined when using Perl4
SWIGPERL5                   Defined when using Perl5
SWIGPYTHON                  Defined when using Python
SWIGGUILE                   Defined when using Guile
```

Interface files can look at these symbols as necessary to change the way in which an interface is generated or to mix SWIG directives with C code.

Code Insertion

Sometimes it is necessary to insert special code into the resulting wrapper file generated by SWIG. For example, you may want to include additional C code to perform initialization or other operations. There are four ways to insert code.

Code blocks

A code block is enclosed by a `%{, %}` and is used to insert code into the header portion of the resulting wrapper file. Everything in the block is copied verbatim into the output file and will appear before any generated wrapper functions. Most SWIG input files have at least one code block that is normally used to include header files and supporting C code. Additional code blocks may be placed anywhere in a SWIG file as needed.

```
%module mymodule
%{
#include “my_header.h”
%}

... Declare functions here
%{

... Include Tcl_AppInit() function here ...

%}
```

Code blocks are also typically used to write “helper” functions. These are functions that are used specifically for the purpose of building an interface and are generally not visible to the normal C program. For example :

```
%{

/* Create a new vector */
Vector *new_Vector() {
       return (Vector *) malloc(sizeof(Vector));
}

%}

// Now wrap it
Vector *new_Vector();
```

Inlined code blocks

Because the process of writing helper functions is fairly common, there is a special inlined form of code block that is used as follows :

```
%inline %{
/* Create a new vector */
Vector *new_Vector() {
```

```
        return (Vector *) malloc(sizeof(Vector));
}
%}
```

The `%inline` directive inserts all of the code that follows verbatim into the header portion of an interface file. The code is then fed into the SWIG parser and turned into an interface. Thus, the above example creates a new command `new_Vector` using only one declaration. Since the code inside an `%inline %{ ... %}` block is given to both the C compiler and SWIG, it is illegal to include any SWIG directives inside the `%{ ... %}` block.

Initialization blocks

Code may also be inserted using an initialization block, as shown below :

```
%init %{

        init_variables();
%}
```

This code is inserted directly into SWIG's initialization function. You can use it to perform additional initialization and operations. Since this code is inserted directly into another function, it should not declare functions or include header files. Primarily this can be used to add callouts to widgets and other packages that might also need to be initialized.

Wrapper code blocks

Code may be inserted in the wrapper code section of an output file using the `%wrapper` directive as shown :

```
%wrapper %{
        ... a bunch of code ...
%}
```

This directive, for almost all practical purposes, is identical to just using a `%{,%}` block, but may be required for more sophisticated applications. It is mainly only used for advanced features in the SWIG library. As a general rule, you should avoid using this directive unless you absolutely know what you are doing.

A general interface building strategy

This section describes the general approach for building interface with SWIG. The specifics related to a particular scripting language are found in later chapters.

Preparing a C program for SWIG

SWIG doesn't require modifications to your C code, but if you feed it a collection of raw C header files or source code, the results might not be what you expect---in fact, they might be awful. Here's a series of steps you can follow to make an interface for a C program :

- Identify the functions that you want to wrap. It's probably not necessary to access every single function in a C program--thus, a little forethought can dramatically simplify the resulting scripting language interface. C header files are particularly good source for finding things to wrap.

- Create a new interface file to describe the scripting language interface to your program.
- Copy the appropriate declarations into the interface file or use SWIG's `%include` directive to process an entire C source / header file. Either way, this step is fairly easy.
- Make sure everything in the interface file uses ANSI C / C++syntax.
- Check to make sure there aren't any functions involving multidimensional arrays, function pointers, or variable length arguments since SWIG doesn't like these very much.
- Eliminate unnecessary C preprocessor directives. SWIG will probably remove most of them, but better safe than sorry. Remember, SWIG does not run the C preprocessor.
- Make sure all necessary '`typedef`' declarations and type-information is available in the interface file.
- If your program has a main() function, you may need to rename it (read on).
- Run SWIG and compile.

While this may sound complicated, the process turns out to be relatively easy in practice--for example, making an interface to the entire OpenGL library only takes about 5-10 minutes.

In the process of building an interface, you are encouraged to use SWIG to find problematic declarations and specifications. SWIG will report syntax errors and other problems along with the associated file and line number. As a result, tracking down errors is usually straightforward.

The SWIG interface file

The preferred method of using SWIG is to generate separate interface file for building an interface. Suppose you have the following C header file :

```
/* File : header.h */

#include <stdio.h>
#include <math.h>

extern int foo(double);
extern double bar(int, int);
extern void dump(FILE *f);
```

A typical SWIG interface file for this header file would look like the following :

```
/* File : interface.i */
%module mymodule
%{
#include “header.h”
%}
extern int foo(double);
extern double bar(int, int);
extern void dump(FILE *f);
```

Of course, in this case, our header file is pretty simple so we could have made an interface file like this as well:

```
/* File : interface.i */
%module mymodule
%include header.h
```

Naturally, your mileage may vary.

Getting the right header files

Sometimes, it is necessary to use certain header files in order for the code generated by SWIG to compile properly. You can have SWIG include certain header files by using a `%{,%}` block as follows :

```
%module graphics
%{
#include <GL/gl.h>
#include <GL/glu.h>
%}

// Put rest of declarations here
...
```

What to do with main()

If your program defines a `main()` function, you may need to get rid of it or rename it in order to use a scripting language. Most scripting languages define their own `main()` procedure that must be called instead. There are a few approaches to solving the `main()` conflict :

- Get rid of `main()` entirely. This is the brute force approach.
- Rename `main()` to something else. You can do this by compiling your C program with an option like `-Dmain=oldmain`.
- Use conditional compilation to only include `main()` when not using a scripting language.

Getting rid of `main()` may cause potential initialization problems of a program. To handle this problem, you may consider writing a special function called `program_init()` that initializes your program upon startup. This function could then be called either from the scripting language as the first operation, or when the SWIG generated module is loaded.

As a general note, many C programs only use the `main()` function to parse command line options and to set parameters. However, by using a scripting language, you are probably trying to create a program that is more interactive. In many cases, the old `main()` program can be completely replaced by a Perl, Python, or Tcl script.

How to cope with C++

Given the complexity of C++, it will almost always be necessary to build a special interface file containing suitably edited C++ declarations. If you are working with a system involving 400 header files, this process will not be trivial. Perhaps the best word of advice is to think hard about what you want this interface to be. Also, is it absolutely critical to wrap every single function in a C++ program? SWIG's support of C++ will improve with time, but I'll be the first to admit that SWIG works much better with pure ANSI C code.

How to avoid creating the interface from hell

SWIG makes it pretty easy to build a big interface really fast. In fact, if you apply it to a large enough package, you'll find yourself with a rather large chunk of code being produced in the resulting wrapper file. To give you an idea, wrapping a 1000 line C header file with a large number of structure declarations may result in a wrapper file containing 20,000-30,000 lines of code. I can only imagine what wrapping a huge C++ class hierarchy would generate. Here's a few rules of thumb for making smaller interfaces :

- Ask yourself if you really need to access particular functions. It is usually not necessary to wrap every single function in a package. In fact, you probably only need a relatively small subset.
- SWIG does not require structure definitions to operate. If you are never going to access the members of a structure, don't wrap the structure definition.
- Eliminate unneeded members of C++ classes.
- Think about the problem at hand. If you are only using a subset of some library, there is no need to wrap the whole thing.
- Write support or helper functions to simplify common operations. Some C functions may not be easy to use in a scripting language environment. You might consider writing an alternative version and wrapping that instead.

Writing a nice interface to a package requires work. Just because you use SWIG it doesn't mean that you're going to end up with a good interface. SWIG is primarily designed to eliminate the tedious task of writing wrapper functions. It does not eliminate the need for proper planning and design when it comes to building useful applications. In short, a little forethought can go a long way.

Of course,if you're primarily interested in just slapping something together for the purpose of debugging, rapid application development, and prototyping, SWIG will gladly do it for you.

Multiple files and the SWIG library 4

For increased modularity and convenience, it is usually useful to break an interface specification up into multiple files or modules. SWIG provides a number of features for doing just this.

The %include directive

The `%include` directive inserts code from another file into the current interface file. It is primarily used to build a package from a collection of smaller modules. For example :

```
// File : interface.i
%module package
%include equations.i
%include graphics.i
%include fileio.i
%include data.i
%include network.c
%include "../Include/user.h"
```

When used in this manner, SWIG will create a single wrapper file containing all of the included functions. [1]

The `%include` directive can process SWIG interface files, C header files, and C source files (provided they are sufficiently clean). When processing a C source file, SWIG will automatically declare all functions it finds as "extern". Thus, use of a header file may not be required in this case.

Static initialization of multiple modules

When using static linking, some language modules allow multiple modules to be initialized as follows :

```
%module package, equations, graphics, fileio, data, network, user

... More declarations ...
```

1. If you are using dynamic loading, this is unncessary as each module can be wrapped individually and loaded into the scripting language. Unfortunately, dynamic loading almost always seems to create more problems than it solves...

The module list can contain SWIG generated modules or third-party applications. Refer to the appropriate language chapter for a detailed description of this feature.

Generating raw wrapper code

By default, SWIG includes all of the code needed to build a module in the output file. This includes the SWIG pointer type checker, and other support code. If multiple SWIG modules are being used in the same system, this code can be shared if you use the `-c` option

```
swig -c example.i
```

The `-c` option omits code related to the type checker and assumes that it will be supplied by a library file or different wrapper file. The exact use of the option is somewhat language specific. See the documentation on each target language for more details.

The %extern directive

The `%extern` directive is like `%include` except that it only scans a file for type and class information. It does not actually wrap anything found in the input file. This directive is primarily used for handling class hierarchies and multiple modules. For example :

```
%module derived
%extern baseclass.h          // Grab definition of a base class

// Now wrap a derived class
class Derived : public BaseClass {
public:
        ...
};
```

This interface file would grab the member functions and data from a baseclass, but only use them in the specification of a derived class. `%extern` processing of files is also useful for picking up common typedefs and definitions in a large package.

The %import directive

The `%extern` directive is used to gather declarations from files that you don't want to wrap into an interface. Unfornunately, the exact role of these files is not always clear. They could just contain definitions, or they might correspond to an entrirely different SWIG module. The `%import` directive is a stronger version of `%extern` that tells SWIG that all of the declarations in the file are indeed, in an entirely different SWIG module. This information may affect the code generated by various language modules since they will have a better idea of where things are defined and how they are used.

Including files on the command line

Much like the C or C++ compiler, SWIG can also include library files on the command line using the `-l` option as shown

```
# Include a library file at compile time
% swig -tcl -lwish.i interface.i
```

This approach turns out to be particularly useful for debugging and building extensions to different kinds of languages. When libraries are specified in this manner, they are included after all of the declarations in `interface.i` have been wrapped. Thus, this does not work if you are trying to include common declarations, typemaps, and other files.

The SWIG library

SWIG comes with a library of functions that can be used to build up more complex interfaces. As you build up a collection of modules, you may also find yourself with a large number of interface files. While the `%include` directive can be used to insert files, it also searches the files installed in the SWIG library (think of this as the SWIG equivalent of the C library). When you use `%include`, SWIG will search for the file in the following order :

- The current directory
- Directories specified with the -I option
- `./swig_lib`
- `/usr/local/lib/swig_lib` (or wherever you installed SWIG)

Within each directory, you can also create subdirectories for each target language. If found, SWIG will search these directories first, allowing the creation of language-specific implementations of a particular library file.

You can override the location of the SWIG library by setting the `SWIG_LIB` environment variable.

Library example

To illustrate the use of the libraries, we consider two different library files--one to build a new `tclsh` program, and one to add a few memory management functions.

tclsh.i

To build a new `tclsh` application, you need to supply a `Tcl_AppInit()` function. This can be done using the following SWIG interface file (simplified somewhat for clarity) :

```
// File : tclsh.i
%{
#if TCL_MAJOR_VERSION == 7 && TCL_MINOR_VERSION >= 4
int main(int argc, char **argv) {
  Tcl_Main(argc, argv, Tcl_AppInit);
  return(0);
}
#else
extern int main();
#endif
int Tcl_AppInit(Tcl_Interp *interp){
  int SWIG_init(Tcl_Interp *);

  if (Tcl_Init(interp) == TCL_ERROR)
```

```
    return TCL_ERROR;

  /* Now initialize our functions */

  if (SWIG_init(interp) == TCL_ERROR)
    return TCL_ERROR;

  return TCL_OK;
}
%}
```

In this case, the entire file consists of a single code block. This code will be inserted directly into the resulting wrapper file, providing us with the needed `Tcl_AppInit()` function.

malloc.i

Now suppose we wanted to write a file malloc.i that added a few memory management functions. We could do the following :

```
// File : malloc.i
%{
#include <malloc.h>
%}

%typedef unsigned int size_t
void *malloc(size_t nbytes);
void *realloc(void *ptr, size_t nbytes);
void free(void *);
```

In this case, we have a general purpose library that could be used whenever we needed access to the `malloc()` functions.

Creating library files

While both of our examples are SWIG interface files, they are quite different in functionality since `tclsh.i` would only work with Tcl while `malloc.i` would work with any of the target languages. Thus, we should put these files into the library as follows :

```
./swig_lib/malloc.i
./swig_lib/tcl/tclsh.i
```

When used in other interface files, this will allow us to use `malloc.i` with any target language while `tclsh.i` will only be accessible if creating for wrappers for Tcl (ie. when creating a Perl5 module, SWIG will not look in the `tcl` subdirectory.

It should be noted that language specific libraries can mask general libraries. For example, if you wanted to make a Perl specific modification to `malloc.i`, you could make a special version and call it `./swig_lib/perl5/malloc.i`. When using Perl, you'd get this version, while all other target languages would use the general purpose version.

More about the SWIG library

Full documentation about the SWIG library is included in the SWIG source distribution. In fact, the documentation is automatically generated by SWIG, which leads us to the next section...

Documentation System 5

Introduction

While SWIG makes it easy to build interfaces, it is often difficult to keep track of all of the different functions, variables, constants, and other objects that have been wrapped. This especially becomes a problem when your interface starts to grow in size from a handful to several hundred functions. To address these concerns, SWIG can automatically generate documentation in a number of formats including ASCII, HTML, and LaTeX. The goal is that you could look at the documentation file to see what functions were wrapped and how they are used in the target scripting language.

Usage documentation is generated for each declaration found in an interface file. This documentation is generated by the target language module so the Tcl module will follow Tcl syntax, the Perl module will use Perl syntax, and so on. In addition, C/C++ comments can be used to add descriptive text to each function. Comments can be processed in a number of different styles to suit personal preferences or to match the style used in a particular input file.

Automatic documentation generation for C/C++ programs is a fairly formidable problem and SWIG was never intended to be a substitute for a full-blown documentation generator. However, I feel that is does a reasonable job of painlessly documenting scripting language interfaces. It seems to do just fine for many of SWIG's primary applications--rapid prototyping, debugging, and development.

How it works

For each declaration in an interface file, SWIG creates a "Documentation Entry." This entry contains three components; (1) a usage string, (2) a C information string, and (3) descriptive text. For example, suppose you have this declaration in an interface file :

```
int fact(int n);
/* This function computes a factorial */
```

The documentation entry produced by the SWIG ASCII module will look like this for Tcl:

```
fact n
        [ returns int ]
        This function computes a factorial
```

The first line shows how to call the function, the second line shows some additional information about the function, while the third line contains the comment text. The first two lines are automatically generated by SWIG and may be different for each language module. For example, the Perl5 module would generate the following output :

```
fact($n)
       [ returns int ]
       This function computes a factorial
```

Of course, this is only a simple example, more sophisticated things are possible.

Choosing a documentation format

The type of documentation is selected using the following command line options :

```
-dascii                 Produce ASCII documentation
-dhtml                  Produce HTML documentation
-dlatex                 Produce LaTeX documentation
-dnone                  Produce no documentation
```

The various documentation modules are implemented in a manner similar to language modules so the exact choice may change in the future. With a little C++ hacking, it is also possible for you to add your own modules to SWIG. For example, with a bit of work you could turn all of the documentation into an online help command in your scripting language.

Function usage and argument names

The function usage string is produced to match the declaration given in the SWIG interface file. The names of arguments can be specified by using argument names in your SWIG interface file. For example, the declarations

```
void insert_item(List *, char *);
char *lookup_item(char *name);
```

will produce the following documentation (for Python) :

```
insert_item(List *, char *)
       [ returns void ]

lookup_item(name)
       [ returns char * ]
```

When argument names are omitted, SWIG will use the C datatypes of the arguments in the documentation. While this may suffice when working with special datatypes, it is not always very descriptive. If an argument name is specified, SWIG will use that in the documentation instead. Of course, it is up to each language module to create an appropriate usage string so your results may vary depending on how things have been implemented in each module.

Titles, sections, and more

The SWIG documentation system is hierarchical in nature and is organized into a collection of sections, subsections, subsubsections, and so on. The following SWIG directives can be used to organize an interface file :

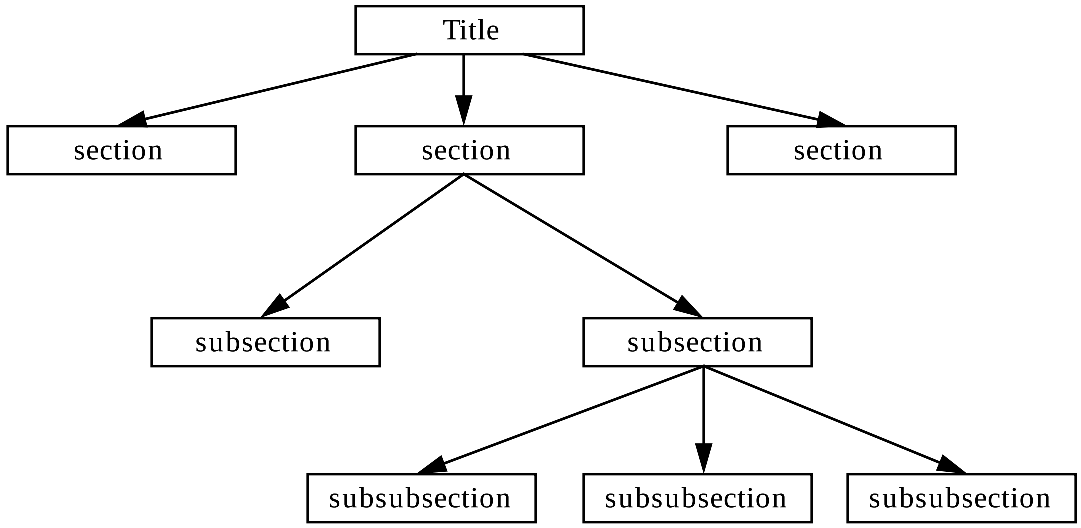
- `%title “Title Text”`. Set the documentation title (may only be used once)
- `%section “Section title”`. Start a new section.
- `%subsection “Subsection title”`. Create a new subsection.
- `%subsubsection “Subsubsection title”`. Create a new subsubsection.

The `%title` directive should be placed prior to the first declaration in an interface file and may only be used once (subsequent occurrences will simply be ignored). The section directives may be placed anywhere. However, `%subsection` can only be used after a `%section` directive and `%subsubsection` can only be used after a `%subsection` directive.

With the organization directives, a SWIG interface file looks something like this :

```
%title “Example Interface File”
%module example
%{
#include “my_header.h”
%}

%section “Mathematical Functions”

... declarations ...

%section “Graphics”
%subsection “2D Plotting”
... Declarations ...
%subsection “3D Plotting”
%subsubsection “Viewing transformations”
... Declarations ...
%subsubsection “Lighting”
... Declarations ...
%subsubsection “Primitives”
... Declarations ...

%section “File I/O”

... Declarations ...
```

Internally, SWIG represents the documentation for this file in a tree like this :



Each node of the documentation tree may have C/C++ declarations attached. Interface files with no sections will have all documentation entries attached to the Title node. As it turns out, every node of the tree is a documentation entry. Thus, descriptive text can be attached to titles, sections, and subsections, in addition to the normal C/C++ declarations you would see in an interface file. The tree structure is also used to manage formatting information as described shortly.

Formatting

Documentation text can be sorted, chopped, sliced, and diced in a variety of ways. Formatting information is specified using a comma separated list of parameters after the `%title`, `%section`, `%subsection`, or `%subsubsection` directives. For example :

```
%title "My Documentation", sort, before, pre
```

This tells SWIG to sort all of the documentation, use comments that are before each declaration, and to allow 1 blank line between comments and the declaration. These formatting directives are applied to all children in the documentation tree--in this case, everything in an interface file.

If formatting information is specified for a section like this

```
%subsection "3D Graphics", nosort, after
```

then the effect will only apply to that particular section (and all of its children). In this case, the formatting of the subsection would override any previous formatting, but these changes would only apply to this subsection. The next subsection could use its own formatting or use its parents formatting.

Style parameters can also be specified using the `%style` and `%localstyle` parameters. The `%style` directive applies a new format to the current section and all of its parents. The `%localstyle` directive applies a new format to the current section. For example :

```
%style sort,before, skip=1          # Apply these formats everywhere
%localstyle sort                    # Apply this format to the current section
```

Use of these directives usually isn't required since it's easy enough to simply specify the information after each section.

Default Formatting

By default, SWIG will reformat comment text, produce documentation in the order encountered in an interface file (nosort), and annotate descriptions with a C information string. This behavior most closely matches that used in SWIG 1.0, although it is not an exact match due to differences in the old documentation system.

When used in the default mode, comment text may contain documentation specific formatting markup. For example, you could embed LaTeX or HTML markup in comments to have precise control over the look of the final document.

Comment Formatting variables

The default formatting can be changed by changing one or more of the following formatting variables :

```
after                Use comments after a declaration
before               Use comments before a declaration
chop_top=nlines      Comment chopping (preformatted)
chop_bottom=nlines   Comment chopping (preformatted)
chop_left=nchar      Comment chopping (preformatted)
chop_right=nchar     Comment chopping (preformatted)
format               Allow SWIG to reformat text (the default)
ignore               Ignore comments
info                 Print C information text
keep                 Keep comments (opposite of ignore)
noinfo               Don’t print C information text
nosort               Don’t sort documentation
pre                  Assume text is preformatted
skip=nlines          Number of blank lines between comment and declaration
sort                 Sort documentation
tabify               Leave tabs intact
untabify             Convert tabs to spaces
```

More variables may be available depending on particular documentation modules. The use of these variables is described in the next few sections.

Sorting

Documentation can be sorted using the '`sort`' parameter. For example :

```
%title “My interface”,sort
```

When used, all documentation entries, including sections will be alphabetically sorted. Sorting can be disabled in particular sections and subsection by specifying the '`nosort`' parameter in a section declaration. By default, SWIG does not sort documentation. As a general rule, it really only comes in handy if you have a really messy interface file.

For backwards compatibility with earlier versions of SWIG, the following directives can be used to specify sorting.

```
%alpha        Sort documentation alphabetically
%raw          Keep documentation in order
```

These directives only apply globally and should near the beginning of file. Future support of these directives is not guaranteed and generally discouraged.

Comment placement and formatting

Comments may be placed before or after a declaration. This is specified using the '`before`' and '`after`' parameters. The space between a comment and a declaration can be set by changing the '`skip`' parameter. By default, `skip=1`, indicating that a comment and declaration must be on adjacent lines. Use of the `skip` parameter makes it possible for the documentation generator to ignore comments that are too far away and possibly unrelated to the a declaration.

By default, SWIG reformats the text found in a comment. However, in many cases, your file may have preformatted comments or comment blocks. To handle such comments correctly, you can use preformatted mode. This is specified using the 'pre' parameter as follows :

```
%section "Preformmated Section",pre
%section "Reformatted Section", format
```

All declarations in this section will now be assumed to have preformatted comments. When using the preformat mode, a variety of other parameters are available as shown in the following diagram :

.

```
             chop_left                                                chop_right

   chop_top    /*****************************************************************
                * void Plot2D_line(int x1, int y1, int x2, int y2, Pixel color
                *
                * Draws a line between the points (x1,y1) and (x2,y2) using the
                * the given color.   The line is cropped to fit in the current
                * bounding box.
                *
                * Uses the Bresenham line drawing algorithm.
 chop_bottom    *****************************************************************/
        skip
               extern void Plot2D_line(int x1, int y1, int x2, int y2, Pixel color);
```

The chopping parameters can be used to strip out the text of block comments. For example, using `chop_left=3`, `chop_top=1`, `chop_bottom=1` on the above comment produces the following output :

```
Plot2D_line x1 y1 x2 y2 color
       [ returns void ]
       void Plot2D_line(int x1, int y1, int x2, int y2, Pixel color

       Draws a line between the points (x1,y1) and (x2,y2) using the
       the given color.   The line is cropped to fit in the current
       bounding box.
```

```
Uses the Bresenham line drawing algorithm.
```

The chopping parameters only apply if a comment is sufficiently large (i.e.. if the number of lines exceed `chop_top`+`chop_bottom`). Thus, in our example, a one line comment will be unaltered even though chopping has been set. By default, SWIG sets chop_left=3 and all others to zero. This setting allows the sequence '`/* `' or '`// `' to be removed from a comment.

By default, SWIG will convert all tabs found in a comment to white space. This is done assuming that tabs are placed every 8 columns. To disable the tab conversion, use the '`tabify`' parameter.

Tabs and other annoyances

When using the preformatted mode, SWIG will automatically convert tabs to white space. This is done assuming that tabs are placed every 8 characters. The tabification mode can be selected using the 'tabify' and 'untabify' parameters :

```
%section "Untabified Section",untabify
%section "Leave those tabs alone", tabify
```

Tabs are simply ignored when comments are reformatted (well, actually, they're just copied into the output, but the target documentation method will ignore them).

Ignoring comments

To ignore the comments in a particular section, you can use the 'ignore' parameter. For example :

```
%section "No Comments", ignore
%section "Keep Comments", keep
```

The '`keep`' parameter is used to disable the effect of an ignore parameter (if set by a section's parent).

C Information

Normally, each declaration in a file will have a C information tag attached to it. This is usually enclosed in [ ] and contains the return type of a function along with other information. This text can disabled using the 'noinfo' parameters and reenabled using the 'info' parameter.

```
%section "No C Information", noinfo
%section "Print C Information", info
```

Adding Additional Text

Additional documentation text can be added using the `%text` directive as shown :

```
%text %{

This is some additional documentation text.

%}
```

The `%text` directive is primarily used to add text that is not associated with any particular declarations. For example, you may want to provide a general description of a module before defining all of the functions. Any text can be placed inside the `%{,%}` block except for a '`%}`' when ends the block.

Disabling all documentation

All documentation can be suppressed for a portion of an interface file by using the `%disabledoc` and `%enabledoc` directives. These would be used as follows:

```
%disabledoc
... A a bunch of declarations with no documentation ...
%enabledoc
... Now declarations are documented again ...
```

These directives can be safely nested. Thus, the occurrence of these directives inside a `%disabledoc` section has no effect (only the outer-most occurrence is important).

The primary use of these directives is for disabling the documentation on commonly used modules that you might use repeatedly. For example :

```
%disabledoc
%include wish.i
%include array.i
%include timer.i
%enabledoc
```

An Example

To illustrate the documentation system in action, here is the code from the SWIG library file 'array.i'.

```
//
// array.i
// This SWIG library file provides access to C arrays.

%module carray

%section "SWIG C Array Module",info,after,pre,nosort,skip=1,chop_left=3,
chop_right=0,chop_top=0,chop_bottom=0

%text %{
%include array.i

This module provides scripting language access to various kinds of C/C++
arrays. For each datatype, a collection of four functions are created :

   <type>_array(size)              : Create a new array of given size
   <type>_get(array, index)        : Get an element from the array
   <type>_set(array, index, value) : Set an element in the array
   <type>_destroy(array)           : Destroy an array
```

```
The functions in this library are only low-level accessor functions
designed to directly access C arrays.  Like C, no bounds checking is
performed so use at your own peril.
%}

// -----------------------------------------------------------------------
// Integer array support
// -----------------------------------------------------------------------

%subsection "Integer Arrays"
/* The following functions provide access to integer arrays (mapped
   onto the C 'int' datatype. */

%{
       ... Supporting C code ...
%}
int *int_array(int nitems);
/* Creates a new array of integers. nitems specifies the number of elements.
   The array is created using malloc() in C and new() in C++. */

void int_destroy(int *array);
/* Destroys the given array. */

int int_get(int *array, int index);
/* Returns the value of array[index]. */

int int_set(int *array, int index, int value);
/* Sets array[index] = value.  Returns value. */

// -----------------------------------------------------------------------
// Floating point
// -----------------------------------------------------------------------

%subsection "Floating Point Arrays"
/* The following functions provide access to arrays of floats and doubles. */

%{
       .. Supporting C code ...
%}
double *double_array(int nitems);
/* Creates a new array of doubles. nitems specifies the number of elements.
   The array is created using malloc() in C and new() in C++. */

void double_destroy(double *array);
/* Destroys the given array. */

double double_get(double *array, int index);
/* Returns the value of array[index]. */

double double_set(double *array, int index, double value);
/* Sets array[index] = value.  Returns value. */

float *float_array(int nitems);
/* Creates a new array of floats. nitems specifies the number of elements.
   The array is created using malloc() in C and new() in C++. */

void float_destroy(float *array);
/* Destroys the given array. */
```

```
float float_get(float *array, int index);
/* Returns the value of array[index]. */

float float_set(float *array, int index, float value);
/* Sets array[index] = value.  Returns value. */

// --------------------------------------------------------------------
// Character strings
// --------------------------------------------------------------------

%subsection "String Arrays"

%text %{
The following functions provide support for the 'char **' datatype.   This
is primarily used to handle argument lists and other similar structures that
need to be passed to a C/C++ function.
%}

#if defined(SWIGTCL)
%text %{
To convert from a Tcl list into a 'char **', the following code can be used :

     # $list is a list
     set args [string_array expr {[llength $list] + 1}]
     set i 0
     foreach a $list {
        string_set $args $i $a
        incr i 1
     }
     string_set $i ""
     # $args is now a char ** type
%}
#elif defined(SWIGPERL)

%text %{
To convert from a Perl list into a 'char **', code similar to the following
can be used :

    # @list is a list
    my $l = scalar(@list);
    my $args = string_array($l+1);
    my $i = 0;
    foreach $arg (@list) {
        string_set($args,$i,$arg);
        $i++;
    }
    string_set($args,$i,"");

(of course, there is always more than one way to do it)
%}
#elif defined(SWIGPYTHON)

%text %{
To convert from a Python list to a 'char **', code similar to the following
can be used :

    # 'list' is a list
    args = string_array(len(list)+1)
    for i in range(0,len(list)):
```

```
        string_set(args,i,list[i])
    string_set(args,len(list),"")
%}

#endif

%{
        ... Supporting C code ...
%}
char **string_array(int nitems);
/* Creates a new array of strings. nitems specifies the number of elements.
   The array is created using malloc() in C and new() in C++. Each element
   of the array is set to NULL upon initialization. */

void string_destroy(char *array);
/* Destroys the given array. Each element of the array is assumed to be
   a NULL-terminated string allocated with malloc() or new().  All of
   these strings will be destroyed as well. (It is probably only safe to
   use this function on an array created by string_array) */

char *string_get(char **array, int index);
/* Returns the value of array[index]. Returns a string of zero length
   if the corresponding element is NULL. */

char *string_set(char **array, int index, char *value);
/* Sets array[index] = value.  value is assumed to be a NULL-terminated
   string.  A string of zero length is mapped into a NULL value.  When
   setting the value, the value will be copied into a new string allocated
   with malloc() or new().  Any previous value in the array will be
   destroyed. */
```

In this file, all of the declarations are placed into a new section. We specify formatting information for our section. Since this is a general purpose library file, we have no idea what formatting our parent might be using so an explicit declaration makes sure we get it right. Each comment contains preformatted text describing each function. Finally, in the case of the string functions, we are even using a combination of conditional compilation and documentation system directives to produce language-specific documentation. In this case, the documentation contains a usage example in the target scripting language.

When processed through the ASCII module, this file will produce documentation similar to the following :

```
7.  SWIG C Array Module
=======================

%include array.i

This module provides scripting language access to various kinds of C/C++
arrays. For each datatype, a collection of four functions are created :

   <type>_array(size)              : Create a new array of given size
   <type>_get(array, index)        : Get an element from the array
   <type>_set(array, index, value) : Set an element in the array
   <type>_destroy(array)           : Destroy an array

The functions in this library are only low-level accessor functions
```

```
designed to directly access C arrays.  Like C, no bounds checking is
performed so use at your own peril.

7.1.  Integer Arrays
--------------------
The following functions provide access to integer arrays (mapped
onto the C 'int' datatype.


int_array(nitems)
        [ returns int * ]
        Creates a new array of integers. nitems specifies the number of elements.
        The array is created using malloc() in C and new() in C++.

int_destroy(array)
        [ returns void  ]
        Destroys the given array.

int_get(array,index)
        [ returns int  ]
        Returns the value of array[index].

int_set(array,index,value)
        [ returns int  ]
        Sets array[index] = value.  Returns value.

7.2.  Floating Point Arrays
---------------------------
The following functions provide access to arrays of floats and doubles.


double_array(nitems)
        [ returns double * ]
        Creates a new array of doubles. nitems specifies the number of elements.
        The array is created using malloc() in C and new() in C++.

double_destroy(array)
        [ returns void  ]
        Destroys the given array.

double_get(array,index)
        [ returns double  ]
        Returns the value of array[index].

double_set(array,index,value)
        [ returns double  ]
        Sets array[index] = value.  Returns value.

float_array(nitems)
        [ returns float * ]
        Creates a new array of floats. nitems specifies the number of elements.
        The array is created using malloc() in C and new() in C++.

float_destroy(array)
        [ returns void  ]
        Destroys the given array.

float_get(array,index)
        [ returns float  ]
```

```
        Returns the value of array[index].

float_set(array,index,value)
        [ returns float  ]
        Sets array[index] = value.  Returns value.

7.3.  String Arrays
-------------------

The following functions provide support for the 'char **' datatype.   This
is primarily used to handle argument lists and other similar structures that
need to be passed to a C/C++ function.

To convert from a Python list to a 'char **', code similar to the following
can be used :

    # 'list' is a list
    args = string_array(len(list)+1)
    for i in range(0,len(list)):
       string_set(args,i,list[i])
    string_set(args,len(list),"")

string_array(nitems)
        [ returns char ** ]
        Creates a new array of strings. nitems specifies the number of elements.
        The array is created using malloc() in C and new() in C++. Each element
        of the array is set to NULL upon initialization.

string_destroy(array)
        [ returns void  ]
        Destroys the given array. Each element of the array is assumed to be
        a NULL-terminated string allocated with malloc() or new().  All of
        these strings will be destroyed as well. (It is probably only safe to
        use this function on an array created by string_array)

string_get(array,index)
        [ returns char * ]
        Returns the value of array[index]. Returns a string of zero length
        if the corresponding element is NULL.

string_set(array,index,value)
        [ returns char * ]
        Sets array[index] = value.  value is assumed to be a NULL-terminated
        string.  A string of zero length is mapped into a NULL value.  When
        setting the value, the value will be copied into a new string allocated
        with malloc() or new().  Any previous value in the array will be
        destroyed.
```

ASCII Documentation

The ASCII module produces documentation in plaintext as shown in the previous example. Two formatting options are available (default values shown) :

```
ascii_indent = 8
ascii_columns = 70
```

'ascii_indent' specifies the number of characters to indent each function description. 'ascii_columns' specifies the width of the output when reformatting text.

When reformatting text, all extraneous white-space is stripped and text is filled to fit in the specified number of columns. The output text will be left-justified. A single newline is ignored, but multiple newlines can be used to start a new paragraph. The character sequence '\\' can be used to force a newline.

Preformatted text is printed into the resulting output unmodified although it may be indented when used as part of a function description.

HTML Documentation

The HTML module produces documentation in HTML format (who would have guessed?). However, a number of style parameters are available (shown with default values)

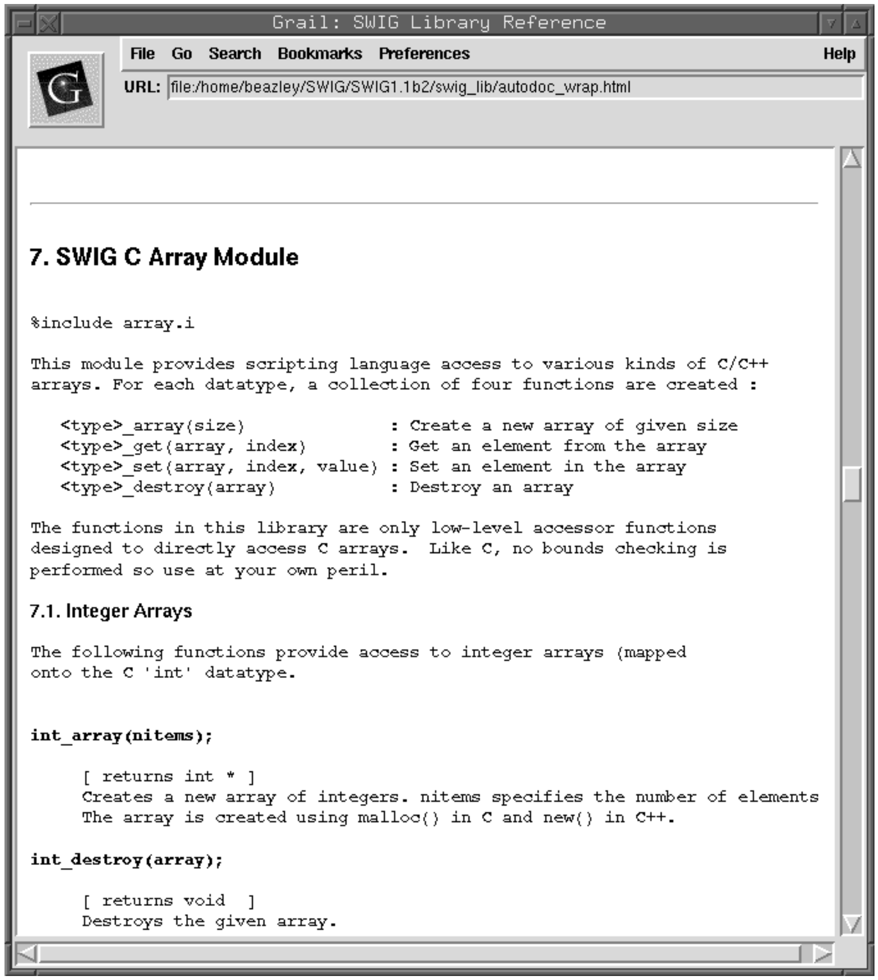
```
html_title = "<H1>:</H1>"
html_contents = "<H1>:</H1>"
html_section = "<HR><H2>:</H2>"
html_subsection = "<H3>:</H3>"
html_subsubsection = "<H4>:</H4>"
html_usage = "<B><TT>:</TT></B>"
html_descrip = "<BLOCKQUOTE>:</BLOCKQUOTE>"
html_text = "<P>"
html_cinfo = ""
html_preformat = "<PRE>:</PRE>"
html_body = "<BODY bg_color=\"#ffffff\">:</BODY>"
```

Any of these parameters can be changed, by simply specifying them after a %title or %section directive. However, the effects are applied globally so it probably makes sense to use the %style directive instead. For example :

```
%style html_contents="<HR><H1>:</H1>"
... Rest of declarations ...
```

Each tag uses a ":" to separate the start and end tags. Any text will be inserted in place of the ":". Since strings are specified in SWIG using quotes, any quotes that need to be inserted into a tag should be escaped using the "\" character.

Sample HTML output is shown below :



7. SWIG C Array Module

```
%include array.i

This module provides scripting language access to various kinds of C/C++
arrays. For each datatype, a collection of four functions are created :

   <type>_array(size)              : Create a new array of given size
   <type>_get(array, index)        : Get an element from the array
   <type>_set(array, index, value) : Set an element in the array
   <type>_destroy(array)           : Destroy an array

The functions in this library are only low-level accessor functions
designed to directly access C arrays.  Like C, no bounds checking is
performed so use at your own peril.
```

7.1. Integer Arrays

```
The following functions provide access to integer arrays (mapped
onto the C 'int' datatype.
```

int_array(nitems);

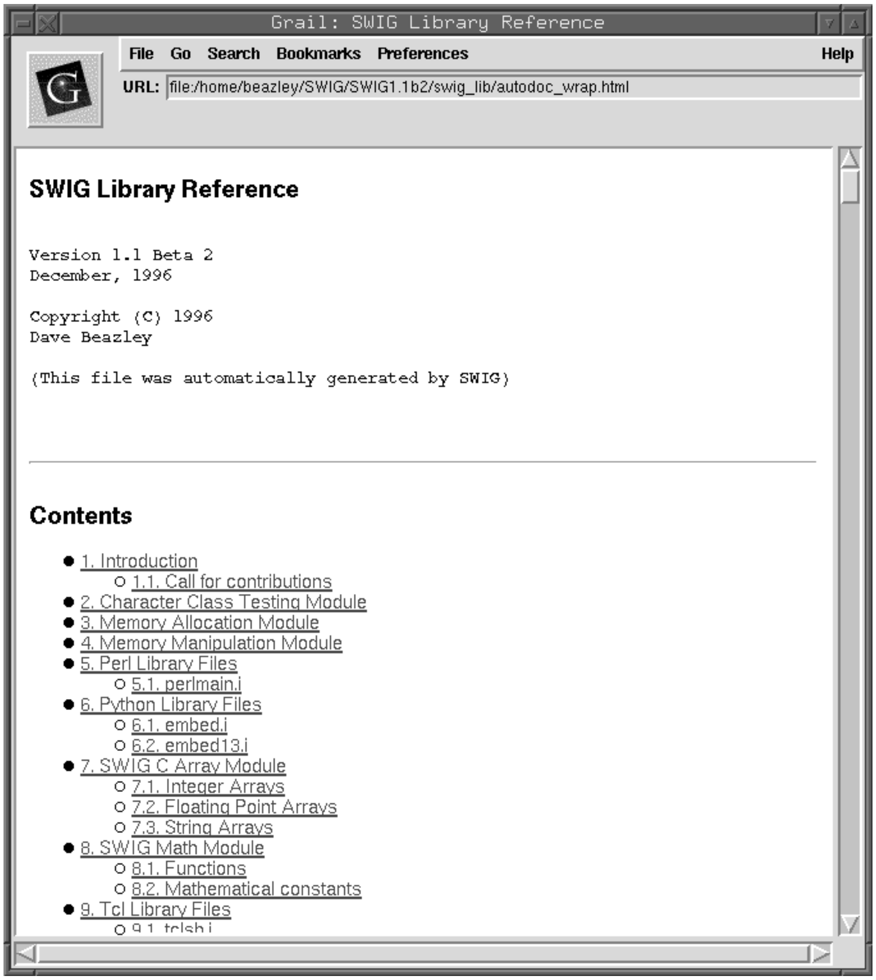
```
     [ returns int * ]
     Creates a new array of integers. nitems specifies the number of elements
     The array is created using malloc() in C and new() in C++.
```

int_destroy(array);

```
     [ returns void  ]
     Destroys the given array.
```

Since our example used preformatted text, the output is very similar to the ASCII module. However, if you use the default mode, it is possible to insert HTML markup directly into your C comments for a more personalized document.

For navigation within the document, SWIG also produces a table of contents with links to each section within the document. With a large interface, the contents may look something like this :



LaTeX Documentation

The LaTeX module operates in a manner similar to the HTML module. The following style parameters are available (some knowledge of LaTeX is assumed).

```
latex_parindent = “0.0in”
latex_textwidth = “6.5in”
latex_documentstyle = “[11pt]{article}”
latex_oddsidemargin = “0.0in”
latex_pagestyle = “\\pagestyle{headings}”
latex_title = “{\\Large \\bf :} \\\\\n”
latex_preformat = “{\\small \\begin{verbatim}:\\end{verbatim}}”
latex_usage = “{\\tt \\bf : }”
latex_descrip = “{\\\\\n \\makebox[0.5in]{} \begin{minipage}[t]{6in} : \n
\\end{minipage} \\\\”;
latex_text = “:\\\\”
```

```
latex_cinfo = "{\\tt : }"
latex_section = "\\section{:}"
latex_subsection = "\\subsection{:}"
latex_subsubsection = "\\subsubsection{:}"
```

The style parameters, well, look downright ugly as shown. Keep in mind that the strings used by SWIG have escape codes in them so it's necessary to represent the '\' character as '\\'. Thus, within SWIG your code will look something like this :

```
%style latex_section="\\newpage \n \\section{:}"
```

The default values should be sufficient for creating a readable LaTeX document in any case you don't want to worry changing the default style parameters.

C++ Support

C++ classes are encapsulated in a new subsection of the current section. This subsection contains descriptions of all of the member functions and variables. Since language modules are responsible for creating the documentation, the use of shadow classes will result in documentation describing the resulting shadow classes, not the lower level interface to the code.

While it's not entirely clear that this is the best way to document C++ code, it is a start (and it's better than no documentation).

The Final Word?

Early versions of SWIG used a fairly primitive documentation system, that could best be described as "barely usable." The system described here represents an almost total rewrite of documentation support of SWIG. While it is, by no means, a perfect solution, I think it is a step in the right direction. As proof, the SWIG library is now entirely self-documenting and is a good source of documentation examples. As always suggestions and improvements are welcome.

SWIG Typemaps

6

Introduction

For most applications, SWIG's treatment of basic datatypes and pointers is enough to build a good interface. However, in certain cases, it is desirable to change SWIG's treatment of a particular datatype. For example, we may want a `char **` to act like a list of strings instead of a pointer. Similarly, we might want to map a datatype of `float[4]` into a 4 element tuple. Typemaps provide a mechanism for customizing the output of SWIG to support special datatypes. Typemaps are new to SWIG 1.1, but it should be emphasized that they are <u>not</u> required to build an interface.

Okay, before diving in, first ask yourself do I really need to change SWIG's default behavior? The basic pointer model works pretty well most of the time and I encourage you to use it--after all, I wanted SWIG to be easy enough to use so that you didn't need to worry about low level details. If, after contemplating this for awhile, you've decided that you really want to change something, a word of caution is in order. Writing a typemap usually requires a detailed knowledge of the internal workings of a particular scripting language. It is also quite easy to break all of the output code generated by SWIG if you don't know what you're doing. On the plus side, once a typemap has been written it can be reused over and over again by putting it in the SWIG library. There are already several useful typemap files available in the SWIG library. This section describes the basics of typemaps. Language specific information (which can be quite technical) is contained in the later chapters.

Motivation for using typemaps

Suppose you have a C function such as the following :

```
void glLightfv(GLenum light, Glenum pname, GLfloat parms[4]);
```

In this case, the third argument takes a 4 element array. If you do nothing, SWIG will convert the last argument into a pointer. When used in the scripting language, you will need to pass a "`GLfloat *`" object to the function to make it work.

Managing special data-types with helper functions

Helper functions provide one mechanism for dealing with odd datatypes. With a helper function, you provide additional functionality for creating and destroying objects or converting values into a useful form. These functions are usually just placed into your interface file with the rest of the functions. For example, a few helper functions to work with 4 element arrays for the above function, might look like this :

```
%inline %{
/* Create a new GLfloat [4] object */
GLfloat *newfv4(double x, double y, double z, double w) {
       GLfloat *f = (GLfloat *) malloc(4*sizeof(GLfloat));
       f[0] = x;
       f[1] = y;
       f[2] = z;
       f[3] = w;
       return f;
}

/* Destroy a GLfloat [4] object */
void delete_fv4(GLfloat *d) {
       free(d);
}
%}
```

When wrapped, our helper functions will show up the interface and can be used as follows :

```
% set light [newfv4 0.0 0.0 0.0 1.0]              # Creates a GLfloat *
% glLightfv GL_LIGHT0 GL_AMBIENT $light           # Pass it to the function
...
% delete_fv4 $light                               # Destroy it (When done)
```

While not the most elegant approach, helper functions provide a simple mechanism for working with more complex datatypes. In most cases, they can be written without diving into SWIG's internals. Before typemap support was added to SWIG, helper functions were the only method for handling these kinds of problems. As a rule of thumb, I recommend that you try to use this approach before jumping into typemaps.

A Typemap Implementation

With a typemap, you can often eliminate the need for helper functions. Without diving into the details just yet, a typemap implementation of the previous example can permit you to pass an array or list of values directly into the C function like this :

```
% glLightfv GL_LIGHT0 GL_AMBIENT {0.0 0.0 0.0 1.0}
```

This is a more natural implementation that replaces the low-level pointer method. Now we will look into how one actually specifies a typemap.

What is a typemap?

Simply stated, a typemap is a mechanism for changing SWIG's treatment of a particular datatype. A typemap is specified using the `%typemap` directive in your interface file. A simple typemap might look liks this :

```
%module example
%typemap(tcl,in) int {
       $target = atoi($source);
       printf("Received an integer : %d\n", $target);
}
```

```
int add(int a, int b);
```

In this case, we changed the processing of integers as input arguments to functions. When used in a a Tcl script, we would get the following debugging information:

```
% set a [add 7 13]
Received an integer : 7
Received an integer : 13
```

In the typemap specification, the symbols `$source` and `$target` are holding places for C variable names that SWIG is going to use when generating wrapper code. In this example, `$source` would contain a Tcl string and `$target` would be the C integer value that is going to be passed into the “add” function.

Creating a new typemap

A new typemap can be created as follows :

```
%typemap(lang,method) Datatype {
        ... Conversion code ...
}
```

`lang` specifies the target language, `method` defines a particular conversion, and `Datatype` gives the corresponding C datatype. The code corresponding to the typemap is enclosed in braces after the declaration. There are about a dozen different kinds of typemaps that are used within SWIG, but we will get to that in a minute.

A single conversion can be applied to multiple datatypes by giving a comma separated list of datatypes. For example :

```
%typemap(tcl,in) int, short, long, signed char {
        $target = ($type) atol($source);
}
```

Datatypes may also carry names as in

```
%typemap(perl5,in) char **argv {
        ... Turn a perl array into a char ** ...
}
```

A “named”typemap will only apply to an object that matches both the C datatype and the name. Thus the `char **argv` typemap will only be applied to function arguments that exactly match “`char **argv`”.

Finally, there is a shortened form of the typemap directive :

```
%typemap(method) Datatype {
        ...
}
```

When the language name is ommitted, the typemap will be applied to the current target language. This form is only recommended for typemap methods that are language independent (there are a few). It is not recommended if you are building interfaces for multiple languages.

Deleting a typemap

A typemap can be deleted by providing no conversion code. For example :

```
%typemap(lang,method) Datatype;            // Deletes this typemap
```

Copying a typemap

A typemap can be copied using the following declaration :

```
%typemap(python,out) unsigned int = int;   // Copies a typemap
```

This specifies that the typemap for "`unsigned int`" should be the same as the "`int`" typemap. This is most commonly used when working with library files.

Typemap matching rules

When you specify a typemap, SWIG is going to try and match it with all future occurrences of the datatype you specify. The matching process is based upon the target language, typemap method, datatype, and optional name. Because of this, it is perfectly legal for multiple typemaps to exist for a single datatype at any given time. For example :

```
%typemap(tcl,in) int * {
       ... Convert an int * ...
}
%typemap(tcl,in) int [4] {
       ... Convert an int[4] ...
}
%typemap(tcl,in) int out[4] {
       ... Convert an out[4] ...
}
%typemap(tcl,in) int *status {
       ... Convert an int *status ...
}
```

These typemaps all involve the "`int *`" datatype in one way or another, but are all considered to be distinct. There is an extra twist to typemaps regarding the similarity between C pointers and arrays. A typemap applied to a pointer will also work for any array of the same type. On the other hand, a typemap applied to an array will only work for arrays, not pointers. Assuming that you're not completely confused at this point, the following rules are applied in order to match pointers and arrays :

- Named arrays
- Unnamed arrays
- Named datatypes
- Unnamed datatypes

The following interface file shows how these rules are applied.

```
void foo1(int *);           // Apply int * typemap
void foo2(int a[4]);        // Apply int[4] typemap
void foo3(int out[4]);      // Apply int out[4] typemap
void foo4(int *status);     // Apply int *status typemap
```

```
void foo5(int a[20]);       // Apply int * typemap (because int [20] is an int *)
```

Because SWIG uses a name-based approach, it is possible to attach special properties to named parameters. For example, we can make an argument of "`int *OUTPUT`" always be treated as an output value of a function or make a "`char **argv`" always accept a list of string values.

Common typemap methods

The following methods are supported by most SWIG language modules. Individual language may provide any number of other methods not listed here.

Common Typemap Methods

`%typemap(lang,in)`	Convert function arguments from the scripting language to a C representation.
`%typemap(lang,out)`	Converts the return value from a function to a scripting language representation.
`%typemap(lang,ret)`	Cleans up the return value of a function. For example, this could be used to free up memory that might have been allocated by the underlying C function. This code is executable before a function returns control back to the scripting language.

`%typemap(lang,freearg)`
 	
`%typemap(lang,argout)`
	Cleans up arguments. This method can be used to clean up function arguments that might have required memory allocation or other special processing.
	
	Outputs. This typemap can be used to make a function return a value from one of its arguments.

`%typemap(lang,check)`	Checks validity of function inputs. Can be used to apply constraints, raise exceptions, or simply for debugging.
`%typemap(lang,varin)`	Used by some languages to set the value of a C global variable. Converts a datatype from the scripting language to C. This method is only used if the "in" method won't work for some reason.

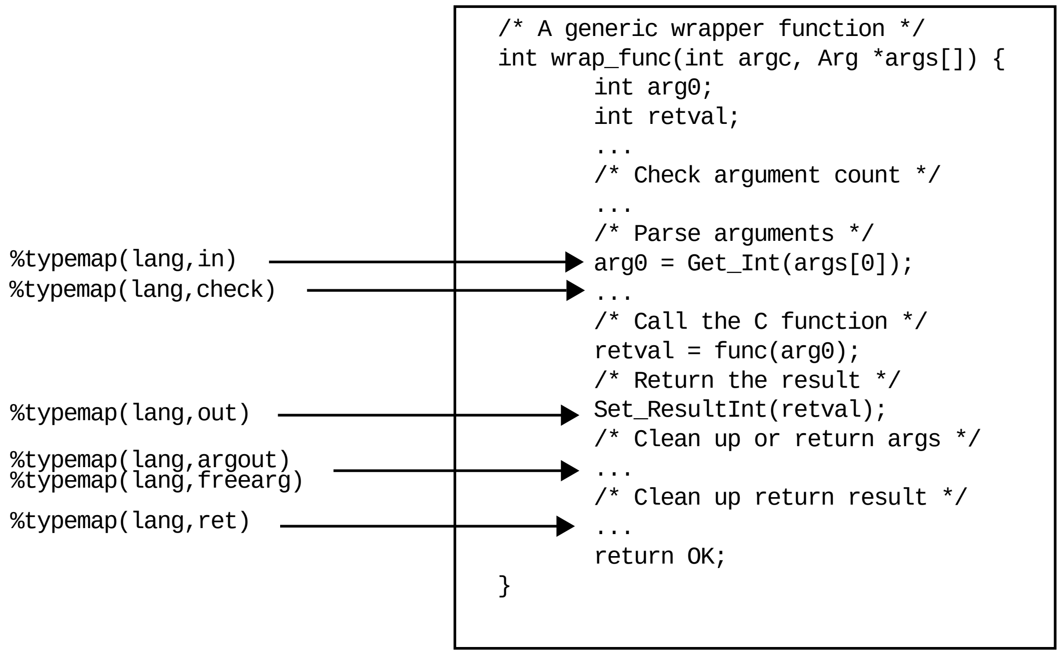
`%typemap(lang,varout)`
 	
`%typemap(lang,const)`
	Variable. Convert the value of a C global variable to a scripting language representation.
	
	Specifies the code used to create a constant in the module initialization function. Not supported by all languages.

`%typemap(lang,memberin)`	Set structure member. Specifies special processing of structure and class members when setting a value.
`%typemap(lang,memberout)`	Get structure member. Special processing applied when retrieving a structure member.
`%typemap(lang,default)`	Can be used to set a default argument value.

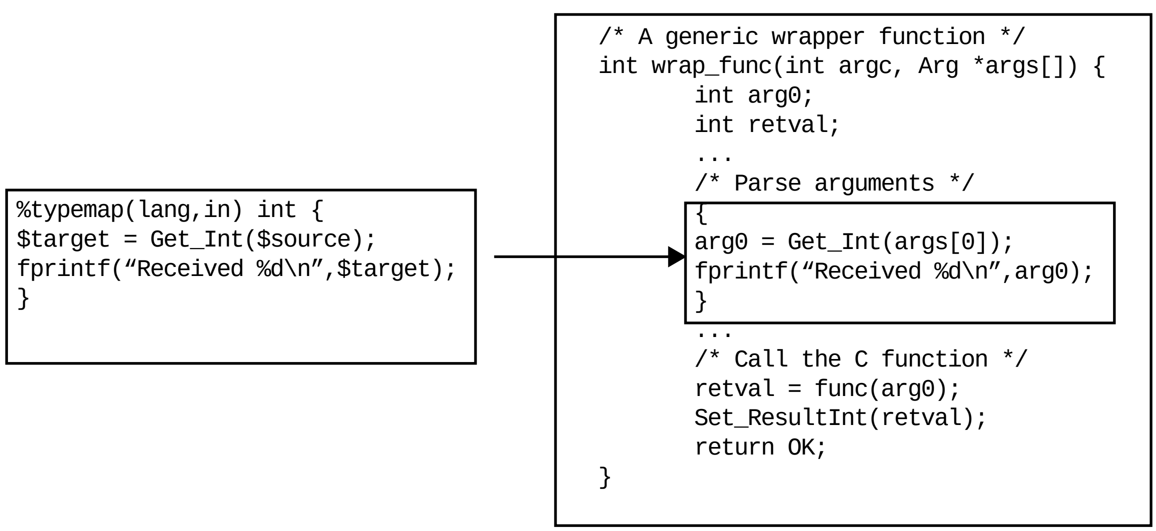
Common Typemap Methods

`%typemap(lang,ignore)`	Set an argument to a default value and ignore it for the purposes of generating wrapper code. (An ignored argument becomes a hidden argument in the scripting interface).

Understanding how some of these methods are applied takes a little practice and better understanding of what SWIG does when it creates a wrapper function. The next few diagrams show the anatomy of a wrapper function and how the typemaps get applied. More detailed examples of typemaps can be found on the chapters for each target language.



Wrapper function typemaps and where they are applied



How a typemap gets applied to a wrapper function

Writing typemap code

The conversion code supplied to a typemap needs to follow a few conventions described here.

Scope

Typemap code is enclosed in braces when it is inserted into the resulting wrapper code (using C's block-scoping capability). It is perfectly legal to declare local and static variables in a typemap. However, local variables will only exist in the tiny portion of code you supply. In other words, any local variables that you create in a typemap will disappear when the typemap has completed its work.

Special variables

The following special variables may be used within a typemap conversion code :

Special variables

`$source`	C Variable containing source value
`$target`	C Variable where result is to be placed
`$type`	A string containing the datatype (will be a pointer if working with arrays).

`$mangle`
 	
`$value`
	Mangled string representing the datatype (used for creating pointer values)
	
	Value of contants (const typemap only)

`$<op>`	Insert the code for any previously defined typemap. <op> must match the name of the the typemap being defined (ie. "in", "out", "argout", etc...). This is used for typemap chaining and is not recommended unless you absolutely know what you're doing.

When found in the conversion code, these variables will be replaced with the correct values.

Typemaps for handling arrays

One of the most common uses of typemaps is providing some support for arrays. Due to the subtle differences between pointers and arrays in C, array support is somewhat limited unless you provide additional support. For example, consider the following structure appears in an interface file :

```
struct Person {
       char name[32];
       char address[64];
       int id;
};
```

When SWIG is run, you will get the following warnings :

```
swig -python  example.i
```

```
Generating wrappers for Python
example.i : Line 2. Warning. Array member will be read-only.
example.i : Line 3. Warning. Array member will be read-only.
```

These warning messages indicate that SWIG does not know how you want to set the name and address fields. As a result, you will only be able to query their value, not change it.

To fix this, we could supply two typemaps in the file such as the following :

```
%typemap(memberin) char [32] {
        strncpy($target,$source,32);
}
%typemap(memberin) char [64] {
        strncpy($target,$source,64);
}
```

The "memberin" typemap is used to set members of structures and classes. When you run the new version through SWIG, the warnings will go away and you can now set each member. It is important to note that `char[32]` and `char[64]` are different datatypes as far as SWIG typemaps are concerned. However, both typemaps can be combined as follows :

```
// A better typemap for char arrays
%typemap(memberin) char [ANY] {
        strncpy($target,$source,$dim0);
}
```

The `ANY` keyword can be used in a typemap to match any array dimension. When used, the special variable `$dim0` will contain the real dimension of the array and can be used as shown above.

Multidimensional arrays can also be handled by typemaps. For example :

```
// A typemap for handling any int [][] array
%typemap(memberin) int [ANY][ANY] {
        int i,j;
        for (i = 0; i < $dim0; i++)
                for (j = 0; j < $dim1; j++) {
                        $target[i][j] = *($source+$dim1*i+j);
                }
}
```

When multi-dimensional arrays are used, the symbols `$dim0`, `$dim1`, `$dim2`, etc... get replaced by the actual array dimensions being used.

The ANY keyword can be combined with any specific dimension. For example :

```
%typemap(python,in) int [ANY][4] {
        ...
}
```

A typemap using a specific dimension always has precedence over a more general version. For example, `[ANY][4]` will be used before `[ANY][ANY]` if possible.

Typemaps and the SWIG Library

Writing typemaps is a tricky business. For this reason, many common typemaps can be placed into a SWIG library file and reused in other modules without having to worry about nasty underlying details. To do this, you first write a file containing typemaps such as this :

```
// file : stdmap.i
// A file containing a variety of useful typemaps

%typemap(tcl,in) int INTEGER {
       ...
}
%typemap(tcl,in) double DOUBLE {
       ...
}
%typemap(tcl,out) int INT {
       ...
}
%typemap(tcl,out) double DOUBLE {
       ...
}
%typemap(tcl,argout) double DOUBLE {
       ...
}
// and so on...
```

This file may contain dozens or even hundreds of possible mappings. Now, to use this file with other modules, simply do this :

```
// interface.i
// My interface file

%include stdmap.i                          // Load the typemap library

// Now grab the typemaps we want to use

%typemap(out) double = double DOUBLE;      // Copy output typemap from stdmap.i
%typemap(in) double = double DOUBLE;       // Copy input typemap from stdmap.i

// Rest of your declarations
```

In this case, `stdmap.i` contains a variety of standard mappings. We may not want to use all of them so we pick and choose by copying. On the other hand, if you know exactly what you want to do for your application, you can make a file with specific typemaps and include it in all your interface files as well.

Implementing constraints with typemaps

One particularly interesting application of typemaps is the implementation of constraints which can be done with the “check” typemap. When used, this allows you to provide code for checking the values of function arguments. For example :

```
%module math

%typemap(perl5,check) double *posdouble {
	if ($target < 0) {
		croak("Expecting a positive number");
	}
}

...
double sqrt(double posdouble);
```

This provides a sanity check to your wrapper function. If a negative number is passed to this function, a Perl exception will be raised and your program terminated with an error message.

This kind of checking can be particularly useful when working with pointers. For example :

```
%typemap(python,check) Vector * {
	if ($target == 0) {
		PyErr_SetString(PyExc_TypeError,"NULL Pointer not allowed");
		return NULL;
	}
}
```

will prevent any function involving a Vector * from accepting a NULL pointer. As a result, SWIG can often prevent a potential segmentation faults or other run-time problems by raising an exception rather than blindly passing values to the underlying C/C++ program.

Typemap examples

Typemaps are inherently language dependent so more examples appear in later chapters. The SWIG `Examples` directory also includes a variety of typemap examples.

Exception Handling 7

In some cases, it is desirable to catch errors that occur in C functions and propagate them up to the scripting language interface (ie. raise an exception). By default, SWIG provides no support for this, but you can create a user-definable exception handler using the `%except` directive.

The %except directive

The `%except` directive allows you to define a user-definable exception handler. It works something like this :

```
%except(python) {
        try {
        $function
        }
        catch (RangeError) {
                PyErr_SetString(PyExc_IndexError,"index out-of-bounds");
                 return NULL;
        }
}
```

As an argument, you need to specify the target language. The exception handling C/C++ code is then enclosed in braces. The symbol `$function` is replaced with the real C/C++ function call that would be ordinarily made in the wrapper code. The C code you specify inside the `%except` directive can be anything you like including custom C code and C++ exceptions.

To delete an exception handler, simply use the `%except` directive with no code. For example :

```
%except(python);            // Deletes any previously defined handler
```

Exceptions can be redefined as necessary. The scope of an exception handler is from the point of definition to the end of the file, the definition of a new exception handler, or until the handler is deleted.

Handling exceptions in C code

Okay, now we're in dangerous territory. C has no formal mechanism for handling exceptions so there are many possibilities here. The first approach is to simply provide some functions for setting and checking an error code. For example :

```
/* File : except.c */

static char error_message[256];
static int error_status = 0;

void throw_exception(char *msg) {
       strcpy(error_message,msg);
       error_status = 1;
}

void clear_exception() {
       error_status = 0;
}
char *check_exception() {
       if (error_status) return error_message;
       else return NULL;
}
```

To use these, functions will need to explicitly call `throw_exception()` to indicate an error occurred. For example :

```
double inv(double x) {
       if (x != 0) return 1.0/x;
       else {
              throw_exception("Division by zero");
              return 0;
       }
}
```

To catch exceptions within SWIG, you can write a simple exception handler such as the following (shown for Perl5) :

```
%except(perl5) {
       char *err;
       clear_exception();
       $function
       if ((err = check_exception())) {
              croak(err);
       }
}
```

Now, when an error occurs, it will translate into a Perl error. The downside to this approach is that it isn't particularly clean and it assumes that your C code is a willing participant in generating error messages. (This isn't going to magically add exceptions to a code that doesn't have them).

Exception handling with longjmp()

Exception handling can also be added to C code using the `<setjmp.h>` library. This usually isn't documented very well (at least not in any of my C books). In any case, here's one way you can do it with clever use of the C preprocessor.

```
/* File : except.c
   Just the declaration of a few global variables we're going to use */

#include <setjmp.h>
jmp_buf exception_buffer;
int exception_status;

/* File : except.h */
#include <setjmp.h>
extern jmp_buf exception_buffer;
extern int exception_status;

#define try if ((exception_status = setjmp(exception_buffer)) == 0)
#define catch(val) else if (exception_status == val)
#define throw(val) longjmp(exception_buffer,val)
#define finally else

/* Exception codes */

#define RangeError     1
#define DivisionByZero 2
#define OutOfMemory    3
```

Now, within a C program, you would use these as follows :

```
double inv(double x) {
       if (x) return 1.0/x;
       else throw(DivisionByZero);
}
```

Finally, to create a SWIG exception handler compatible with this, you can do the following :

```
%{
#include "except.h"
%}

%except(perl5) {
       try {
              $function
       } catch(RangeError) {
              croak("Range Error");
       } catch(DivisionByZero) {
              croak("Division by zero");
       } catch(OutOfMemory) {
              croak("Out of memory");
       } finally {
              croak("Unknown exception");
       }
}
```

At this point, you're saying this sure looks alot like C++ and you'd be right (C++ exceptions are often implemented using `longjmp`). As always, the usual disclaimers apply--your mileage may vary.

Handling C++ exceptions

Handling C++ exceptions is almost completely trivial (well, all except for the actual C++ part). A typical SWIG exception handler will look like this :

```
%except(perl5) {
        try {
                $function
        } catch(RangeError) {
                croak("Range Error");
        } catch(DivisionByZero) {
                croak("Division by zero");
        } catch(OutOfMemory) {
                croak("Out of memory");
        } catch(...) {
                croak("Unknown exception");
        }
}
```

The exception types need to be declared as classes elsewhere, possibly in a header file :

```
class RangeError {};
class DivisionByZero {};
class OutOfMemory {};
```

Newer versions of the SWIG parser should ignore exceptions specified in function declarations. For example, a declaration like this

```
double inv(double) throw(DivisionByZero);
```

will pass through the SWIG parser without errors (although SWIG merely ignores the exception specification).

Defining different exception handlers

By default, the `%except` declaration creates an exception handler that will be used for all wrapper functions that follow it. Creating one universal exception handler for all functions may be unwieldy and promote excessive code bloat since the handler will be inlined into each wrapper function. For this reason, the exception handler can be redefined at any point in an interface file. Thus, a more efficient use of exception handling may work like this :

```
%except(python) {
        ... your exception handler ...
}
/* Define critical operations that can throw exceptions here */

%except(python);         // Clear the exception handler

/* Define non-critical operations that don't throw exceptions */
```

Applying exception handlers to specific datatypes.

An alternative approach to using the `%except` directive is to use the “except” typemap. This allows you to attach an error handler to specific datatypes and function (if you give a name). The typemap is applied to the return value of a function. For example :

```
%typemap(python,except) void * {
        $function
        if (!$source) {
                PyExc_SetString(PyExc_MemoryError,"Out of memory in $name");
                return NULL;
        }
}

void *malloc(int size);
```

When applied, this will automatically check the return value of `malloc()` and raise an exception if it’s invalid. For example :

```
Python 1.4 (Jan 16 1997)  [GCC 2.7.2]
Copyright 1991-1995 Stichting Mathematisch Centrum, Amsterdam
>>> from example import *
>>> a = malloc(2048)
>>> b = malloc(1500000000)
Traceback (innermost last):
  File "<stdin>", line 1, in ?
MemoryError: Out of memory in malloc
>>>
```

Since typemaps can be named, you can define an exception handler for a specific function as follows :

```
%typemap(python,except) void *malloc {
        ...
}
```

This will only be applied to the `malloc()` function returning `void *`. While one probably wouldn’t want to write a different exception handler for every function, it is possible to have a high degree of control if you need it. When typemaps are used, they override any exception handler defined with `%except`.

Debugging and other interesting uses for %except

Since the `%except` directive allows you to encapsulate the actual C function call, it can also be used for debugging and tracing operations. For example :

```
%except(tcl) {
        printf("Entering function : $name\n");
        $function
        printf("Leaving function : $name\n");
}
```

allows you to follow the functionin order to see where an application might be crashing.

Exception handlers can also be chained. For example :

```
%except(tcl) {
        printf("Entering function : $name\n");
        $except
        printf("Leaving function : $name\n");
}
```

Any previously defined exception handler will be inserted in place of the "`$except`" symbol. As a result, you can attach debugging code to existing handlers if necessary. However, it should be noted that this must be done before any C/C++ declarations are made (as except handlers are applied immediately to all functions that follow them).

More Examples

By now, you know most of the exception basics. See the SWIG Examples directory for more examples and ideas. Further chapters show how to generate exceptions in specific scripting languages.

SWIG and Perl5

8

In this chapter, we discuss SWIG's support of Perl5. While the Perl5 module is one of the earliest SWIG modules, it has continued to evolve and has been improved greatly with the help of SWIG users. For the best results, it is recommended that SWIG be used with Perl5.002 or later. Earlier versions are problematic and SWIG generated extensions may not compile or run correctly.

Preliminaries

In order for this section to make much sense, you will need to have Perl5.002 (or later) installed on your system. You should also determine if your version of Perl has been configured to use dynamic loading or not. SWIG will work with or without it, but the compilation process will be different.

Running SWIG

To build a Perl5 module, run swig using the `-perl5` option as follows :

```
swig -perl5 example.i
```

This will produce 3 files. The first file, `example_wrap.c` contains all of the C code needed to build a Perl5 module. The second file, `example.pm` contains supporting Perl code needed to properly load the module into Perl. The third file will be a documentation file (the exact filename depends on the documentation style). To build a module, you will need to compile the file `example_wrap.c` and link it with the rest of your program (and possibly Perl itself).

Getting the right header files

In order to compiler, you will need to use the following Perl5 header files :

```
#include "Extern.h"
#include "perl.h"
#include "XSUB.h"
```

These are usually located in a directory like this

```
/usr/local/lib/perl5/arch-osname/5.003/CORE
```

The SWIG configuration script will try to find this directory, but it's not entirely foolproof. You may have to dig around yourself.

Compiling a dynamic module

To compile a dynamically loadable module, you will need to do something like the following,

```
% gcc example.c
% gcc example_wrap.c -I/usr/local/lib/perl5/arch-osname/5.003/CORE
      -Dbool=char -c
% ld -shared example.o example_wrap.o -o example.so    # Irix
```

The name of the shared object file must match the module name you used in the SWIG interface file. If you used '`%module example`', then the target should be named '`example.so`', '`example.sl`', or whatever the appropriate name is on your system.

Unfortunately, the process of building dynamic modules varies on every single machine. Both the C compiler and linker may need special command line options. SWIG tries to guess how to build dynamic modules on your machine in order to run its example programs. Again, the configure script isn't foolproof .

Building a static version of Perl

If you machine does not support dynamic loading, or if you've tried to use it without success, you can build a new version of the Perl interpreter with your SWIG extensions added to it. To build a static extension, you first need to invoke SWIG as follows :

```
% swig -perl5 -static example.i
```

By default SWIG includes code for dynamic loading, but the `-static` option takes it out.

Next, you will need to supply a `main()` function that initializes your extension and starts the Perl interpreter. While, this may sound daunting, SWIG can do this for you automatically as follows :

```
%module example

extern double My_variable;
extern int fact(int);

// Include code for rebuilding Perl
%include perlmain.i
```

The `permain.i` file inserts Perl's `main()` function into the wrapper code and automatically initializes the SWIG generated module. If you just want to make a quick a dirty module, this may be the easiest way. By default, the `perlmain.i` code does not initialize any other Perl extensions. If you need to use other packages, you will need to modify it appropriately. You can do this by just copying `perlmain.i` out of the SWIG library, placing it in your own directory, and modifying it to suit your purposes.

Finally, to build your new Perl executable, follow the exact same procedure as for a dynamic module, but make the link line appear as follows :

```
% ld example.o example_wrap.o -L/usr/local/lib/perl5/arch/5.003/CORE \
      -lperl -lsocket -lnsl -lm -o myperl
```

This will produce a new version of Perl called `myperl`. It should be functionality identical to Perl with your C/C++ extension added to it. Depending on your machine, you may need to link in additional libraries such as `-lsocket, -lnsl, -ldl`, etc...

Compilation problems and compiling with C++

In some cases, you may get alot of error messages about the '`bool`' datatype when compiling a SWIG module. If you experience this problem, you can try the following :

- Use `-DHAS_BOOL` when compiling the SWIG wrapper code
- Or use `-Dbool=char` when compiling.

Compiling dynamic modules for C++ is a tricky business. If you code has static constructors in it, it will probably not work properly at all. When compiling C++, you may also need link against the `libgcc.a`, `libg++.a`, and `libstdc++.a` libraries (assuming g++). C++ may also complain about one line in the Perl header file "`perl.h`". To work around this problem, put the option `-Dexplicit=` in your compiler flags.

If all else fails, put on your wizards cap and start looking around in the header files. Fortunately, once you've figured out how to get one module to compile, you can compile just about all other modules.

Building Perl Extensions under Windows 95/NT

Building a SWIG extension to Perl under Windows 95 / NT is roughly similar to the process used with Unix. Normally, you will want to produce a DLL that can be loaded into the Perl interpreter. This section covers the process of using SWIG with Microsoft Visual C++ 4.x although the procedure may be similar with other compilers as well. SWIG currently supports the ActiveWare Perl for Win32 port, but is rumored to work with Perl 5.004 for Windows as well.

Running SWIG from Developer Studio

If you are developing your application within Microsoft developer studio, SWIG can be invoked as a custom build option. The process roughly follows these steps :

- Open up a new workspace and use the AppWizard to select a DLL project.
- Add both the SWIG interface file (the .i file), any supporting C files, and the name of the wrapper file that will be created by SWIG (ie. `example_wrap.c`). Note : If using C++, choose a different suffix for the wrapper file such as `example_wrap.cxx`. Don't worry if the wrapper file doesn't exist yet--Developer studio will keep a reference to it around.
- Select the SWIG interface file and go to the settings menu. Under settings, select the "Custom Build" option.
- Enter "SWIG" in the description field.
- Enter "`swig -perl5 -o $(ProjDir)\$(InputName)_wrap.c $(InputPath)`" in the "Build command(s) field"
- Enter "`$(ProjDir)\$(InputName)_wrap.c`" in the "Output files(s) field".
- Next, select the settings for the entire project and go to "C++:Preprocessor". Add the include directories for your Perl 5 installation under "Additional include directories".
- Define the symbols WIN32 and MSWIN32 under preprocessor options. If using the ActiveWare port, also define the symbol PERL_OBJECT. Note that extensions to the ActiveWare port must be compiled with the C++ compiler.
- Finally, select the settings for the entire project and go to "Link Options". Add the Perl library file to your link libraries. For example "perl.lib". Also, set the name of the output file to match the name of your Perl module (ie. example.dll).

- Build your project.

Now, assuming all went well, SWIG will be automatically invoked when you build your project. Any changes made to the interface file will result in SWIG being automatically invoked to produce a new version of the wrapper file. To run your new Perl extension, simply run Perl and use the use command as normal. For example :

```
DOS > perl
use example;
$a = example::fact(4);
print "$a\n";
```

Using NMAKE

Alternatively, SWIG extensions can be built by simply writing a Makefile for NMAKE. To do this, make sure the environment variables for MSVC++ are available and the MSVC++ tools are in your path. Now, just write a short Makefile like this :

```
# Makefile for building an ActiveWare Perl for Win32 extension
# Note : Extensions must be compiled with the C++ compiler!

SRCS          = example.cxx
IFILE         = example
INTERFACE     = $(IFILE).i
WRAPFILE      = $(IFILE)_wrap.cxx

# Location of the Visual C++ tools (32 bit assumed)

TOOLS         = c:\msdev
TARGET        = example.dll
CC            = $(TOOLS)\bin\cl.exe
LINK          = $(TOOLS)\bin\link.exe
INCLUDE32     = -I$(TOOLS)\include
MACHINE       = IX86

# C Library needed to build a DLL

DLLIBC        = msvcrt.lib oldnames.lib

# Windows libraries that are apparently needed
WINLIB        = kernel32.lib advapi32.lib user32.lib gdi32.lib comdlg32.lib
winspool.lib

# Libraries common to all DLLs
LIBS          = $(DLLIBC) $(WINLIB)

# Linker options
LOPT      = -debug:full -debugtype:cv /NODEFAULTLIB /RELEASE /NOLOGO /
MACHINE:$(MACHINE) -entry:_DllMainCRTStartup@12 -dll

# C compiler flags

CFLAGS        = /Z7 /Od /WX /c /W3 /nologo
PERL_INCLUDE  = -Id:\perl -Id:\perl\inc
PERL_LIB        = d:\perl\Release\perl300.lib
```

```
PERLFLAGS = /DWIN32 /DMSWIN32 /DPERL_OBJECT

perl::
	..\..\swig -perl5 -o $(WRAPFILE) $(INTERFACE)
	$(CC) $(CFLAGS) $(PERLFLAGS) $(PERL_INCLUDE) $(SRCS) $(WRAPFILE)
	set LIB=$(TOOLS)\lib
	$(LINK) $(LOPT) -out:example.dll $(LIBS) $(PERLLIB) example.obj
example_wrap.obj
```

To build the extension, run NMAKE. This is a pretty simplistic Makefile, but hopefully its enough to get you started.

Modules, packages, and classes

When you create SWIG extension, everything gets thrown together into a single Perl5 module. The name of the module is determined by the SWIG `%module` directive. To use the module, you simply need to do something like the following :

```
% perl5
use example;                    # load the example module
print example::fact(4),"\n"     # Call a function in it
24
```

Usually, a module consists of a common collection of code that is contained within a single file. A package, on the other hand, is the Perl equivalent of a namespace. A package is alot like a module, except that it is independent of files. Any number of files may be part of the same package--or a package may be broken up into a collection of modules if you prefer to think about it in this way.

By default, SWIG installs its functions into a package with the same name as the module. This can be changed by giving SWIG the -package option :

```
% swig -perl5 -package FooBar example.i
```

In this case, we may still create a module called '`example`', but all of the functions in that module will be installed into the package '`FooBar`.' For example :

```
use example;                    # Load the module like before
print FooBar::fact(4),"\n";     # Call a function in package FooBar
```

Finally, Perl supports object oriented programming using packages. A package can be thought of as a namespace for a class containing methods and data. While one could write much about Perl's module/package/class system, the reader is well advised to consult "Programming Perl, 2nd Ed." by Wall, Christiansen, and Schwartz for all of the gory details.

Basic Perl interface

Functions

C functions are converted into new Perl commands with the same usage as the C function. Default/optional arguments are also allowed. An interface file like this :

```
%module example
int foo(int a);
double bar (double, double b = 3.0);
...
```

Will be used in Perl like this :

```
use example;
$a = &example::foo(2);
$b = &example::bar(3.5,-1.5);
$c = &example::bar(3.5);           # Use default argument for 2nd parameter
```

Okay, this is pretty straightforward...enough said.

Global variables

Global variables are handled using pure magic--well, Perl's magic variable mechanism that is. In a nutshell, it is possible to make certain Perl variables "magical" by attaching various methods to them for getting and setting values among other things. SWIG generates a pair of functions for accessing C global variables and attaches them to a Perl variable of the same name. Thus, an interface like this

```
%module example;
...
double Spam;
...
```

is accessed as follows :

```
use example;
print $example::Spam,"\n";
$example::Spam = $example::Spam + 4
# ... etc ...
```

SWIG supports global variables of all C datatypes including pointers and complex objects.

Constants

Constants are created as read-only magical variables and operate in exactly the same manner.

Pointers

SWIG represents pointers as blessed references. That is, if you have a C declaration like this :

```
Matrix *new_Matrix(int n, int m);
```

SWIG will return a value as if you had done this :

```
$ptr = new_Matrix(int n, int m);     # Save pointer return result
bless $ptr, "MatrixPtr";             # Bless it as a MatrixPtr
```

SWIG uses the "blessing" to check the datatype of various pointers. In the event of a mismatch, an error or warning message will be generated.

To check to see if a value is the NULL pointer, use the `defined()` command :

```
if (defined($ptr)) {
       print "Not a NULL pointer.";
} else {
       print "Is a NULL pointer.";
}
```

To create a NULL pointer, you should pass the `undef` value to a function.

The "value" of a Perl reference is not the same as the underlying C pointer that SWIG wrapper functions return. Suppose that `$a` and `$b` are two references that point to the same C object. Then, in general, `$a` and `$b` will be different--since they are different references. Thus, it is a mistake to check the equality of `$a` and `$b` to check the equality of two C pointers. The correct method to check equality of C pointers is to dereference them as follows :

```
if ($$a == $$b) {
       print "a and b point to the same thing in C";
} else {
       print "a and b point to different objects.";
}
```

It is easy to get burned by references in more subtle ways. For example, if you are storing a hash table of objects, it may be best to use the actual C pointer value rather than the Perl reference as a key. Since each Perl reference to the same C object may be different, it would be impossible to find anything in the hash without this. As a general rule, the best way to avoid problems with references is to make sure hash tables, comparisons, and other pointer operations use the value of the reference (ie. `$$a`), not the reference itself.

Structures and C++ classes

For structures and classes, SWIG produces a set of accessor functions for member functions and member data. For example :

```
%module vector

class Vector {
public:
       double x,y,z;
       Vector();
       ~Vector();
       double magnitude();
};
```

This will get turned into the following collection of Perl functions :

```
vector::Vector_x_get($obj);
vector::Vector_x_set($obj,$x);
vector::Vector_y_get($obj);
```

```
vector::Vector_y_set($obj,$y);
vector::Vector_z_get($obj);
vector::Vector_z_set($obj,$z);
vector::new_Vector();
vector::delete_Vector($obj);
vector::Vector_magnitude($obj);
```

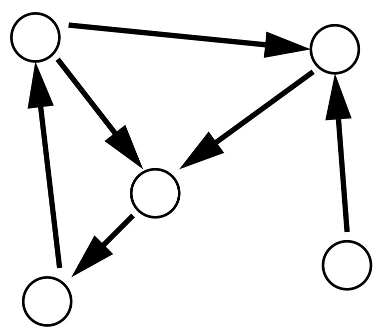
To use the class, simply use these functions. As it turns out, SWIG has a mechanism for creating shadow classes that can hide all of these functions and use an object oriented interface instead--keep reading.

A simple Perl example

In the next few sections, use of the Perl5 module will be illustrated through a series of increasingly complex examples. In the example, we will write some simple graph algorithms to illustrate how C and Perl can interact with each other.

Graphs

A directed graph is simply a collection of nodes (or vertices) that are connected to each other by a collection of edges :



A graph

To represent simple graphs, we can use the following C data structures :

```
/* File : graph.h */
/* Simple data structures for directed graph of Nodes and Edges */

struct Edge;
typedef struct Node {
  int          v;           /* Vertex number              */
  struct Edge  *adj;        /* Adjacency List             */
} Node;

typedef struct Edge {
  Node         *node;       /* Connecting Node            */
  double           w;       /* Weight (optional)          */
  struct Edge   *next;      /* Next edge                  */
} Edge;
```

Each node contains a unique number v for identifying it, and a linked list of other nodes that are nearby. This linked list is managed by the `Edge` structure. Associated with each edge is an optional weighting factor. This could be something like miles between cities, bandwidth, or some other numerical property about a particular link. Okay, enough talk about data structures for now.

To construct nodes and add edges, we can use the following C code :

```
/* File : graph.c           */
/* Directed graph functions */

#include "graph.h"
static int node_count = 0;          /* Number of nodes created */

/* Create a new Node */
Node *new_Node() {
  Node *node;
  node = (Node *) malloc(sizeof(Node));
  node->v = node_count++;       /* Bump up the count */
  node->adj = (Edge *) 0;
  return node;
}

/* Add an "edge" to another node. */

Edge *Node_addedge(Node *mynode, Node *othernode, double w) {
  Edge *edge;
  edge = (Edge *) malloc(sizeof(Edge));
  edge->node = othernode;
  edge->w = w;
  edge->next = mynode->adj;    /* add to my adjacency list */
  mynode->adj = edge;
  return edge;
}
```

A simple SWIG interface file

So far, the code doesn't do much, but it's enough to wrap into Perl5 module. Since the C code is fairly simple right now, we can do this by creating the following interface file :

```
%module graph
%{
#include “graph.h”
%}
%include graph.h
%include graph.c

#ifdef STATIC
%include perlmain.i
#endif
```

We'll call our module "graph" and simply read in both the files `graph.h` and `graph.c` to build an interface. The conditional compilation allows us to build both a static and dynamic Perl5 module from the same file. To select the static version, simply give SWIG the `-DSTATIC` option.

Sample Perl Script

Once compiled, we can now start using our new module. All of the C functions found in `graph.h` and `graph.c` can be called normally . Even though we are using pointers, this is not a problem. Here is a very simple script :

```
# Perl code to use our graph code

use graph;
package graph;

# Create some nodes
$n0 = new_Node();
$n1 = new_Node();
$n2 = new_Node();

# Make some edges
Node_addedge($n0,$n1,0);        #  0 -> 1
Node_addedge($n0,$n2,0);        #  0 -> 2
Node_addedge($n1,$n2,0);        #  1 -> 2
Node_addedge($n2,$n0,0);        #  2 -> 0

# A procedure to print out a node and its adjacency list
sub print_node {
       my $node = shift;
       print "Node : ", Node_v_get($node), ", Adj : ";
       my $adj = Node_adj_get($node);
       while (defined($adj)) {
              my $anode = Edge_node_get($adj);
              my $v = Node_v_get($anode);
              print "$v ";
              $adj = Edge_next_get($adj);
       }
       print "\n";
}

# Print out node information
print_node($n0);
print_node($n1);
print_node($n2);
```

When executed, this script produces the following output :

```
Node : 0, Adj : 2 1
Node : 1, Adj : 2
Node : 2, Adj : 0
```

While our two C functions are used in the script, SWIG also created a collection of accessor functions for managing the two C data structures. The functions `Node_v_get()`, `Node_adj_get()`, `Edge_node_get()`, and `Edge_next_get()` are used to access the corresponding members of our `Node` and `Edge` structures. As arguments, these functions simply take a pointer to the corresponding structure.

There are a few other things to notice about the code.

- Pointers to complex objects are manipulated like ordinary scalar values, but in reality they are blessed references. For all practical purposes, you should think of them as funny opaque objects (in other words, don't worry about it).
- To check for a NULL pointer, use the expression `defined($ptr)`. This will return true if a pointer is non-NULL, false if it isn't. In our example, we use this to walk down a linked list of pointers until we reach a NULL value.

Even though the original C code was rather useless by itself, we have used it build a simple graph in Perl along with a debugging function for printing out node information. In fact, without making an modifications to C code, we can use this to build up something more complex such as a database of cities and mileages.

```
Denver, Cheyenne,           100
Denver, Santa Fe,           362
Denver, Kansas City,        600
Santa Fe, Albuquerque,      55
Santa Fe, Durango,          214
...
Durango, Moab,              160
Moab, Salt Lake City,       237
Moab, Denver,               310
Cheyenne, Salt Lake City,   436
```

Some cities and mileages

Here's a slightly more complicated Perl script to read in the above mileage table and turn it into a graph:

```
# Read a file with cities into a graph

use graph;
package graph;

%Cities = ();              # Hash table mapping cities to nodes
%Nodes = ();               # Mapping of Node indicies to cities
sub read_cities {
    my $filename = shift;
    open(CITIES,$filename);
    while (<CITIES>) {
              chop;
              my @a = split(/, +/);
              my $node1;
              my $node2;
              # Check to see if a given city is already a node
              if (!exists $Cities{$a[0]}) {
                     $node1 = new_Node();
                     $Cities{$a[0]} = $node1;
                     my $node_num = Node_v_get($node1);
                     $Nodes{$node_num} = $a[0];
              } else {
                     $node1 = $Cities{$a[0]};
              }
              if (!exists $Cities{$a[1]}) {
                     $node2 = new_Node();
                     $Cities{$a[1]} = $node2;
```

```
                my $node_num = Node_v_get($node2);
                $Nodes{$node_num} = $a[1];
            } else {
                $node2 = $Cities{$a[1]};
            }
            # Add edges
            Node_addedge($node1,$node2,$a[2]);
            Node_addedge($node2,$node1,$a[2]);
        }
}



sub print_near {
    my $city = shift;
    if (exists $Cities{$city}) {
            my $node = $Cities{$city};
            print "Cities near $city : ";
            my $adj = Node_adj_get($node);
            while (defined($adj)) {
                    my $anode = Edge_node_get($adj);
                    my $v = Node_v_get($anode);
                    print $Nodes{$v},", ";
                    $adj = Edge_next_get($adj);
            }
    }
    print "\n";
}
read_cities("cities");
print_near("Denver");
print_near("Las Vegas");
```

This produces the following output :

```
Cities near Denver : Moab, Kansas City, Santa Fe, Cheyenne, Albuquerque,
Cities near Las Vegas : Flagstaff, Los Angeles, Moab, Salt Lake City,
```

In this example, we are using the same functions as before, but we are now introducing two Perl hash tables. The `%Cities` hash is used to associate city names with a corresponding node in the graph. The `%Nodes` hash does exactly the opposite---mapping node numbers back to the names of cities. Both of these will come in quite handy for mapping things between the Perl world and the C world later.

Before proceeding, let's stop and summarize what we have done. Given a couple of very simple C data structures for a graph, we have written a program that can read in a mileage table, construct a weighted graph of the data and print out a list of the cities that are nearby other cities. Yet, the C code knows nothing about the Perl interface or this whole mileage program we've built up around it. While we could have written the entire program in C, it would already be complicated at this point. We would have had to write a main program, some code to read the input file, and a hash table structure to keep track of the mapping between nodes and cities. Modifying the C code to work exclusively with this problem may be unacceptable. After all, it would be nice if the C code could be reused for other purposes--not just this one problem.

Accessing arrays and other strange objects

Now let's add some new functionality to our graph program from the previous example. In this case, we'll add a depth-first search algorithm to see if two nodes are connected to each other (possibly through many other nodes in-between).

We'll first add the following constants to the file `graph.h`

```
/* File : graph.h */
...
#define MAX_NODES   1000
#define UNSEEN      -1
```

Now, a modified version of `graph.c` :

```
/* File : graph.c */
/* Directed graph functions */

#include <stdio.h>
#include "graph.h"

int node_count = 0;          /* Number of nodes created     */
int seen[MAX_NODES];         /* Used by the search function */

...

/* Function to search for node with given vertex number */
static int visit(Node *n,int v) {
  Edge *e;

  if (seen[n->v] != UNSEEN) return UNSEEN;  /* Cycle detected */
  if (n->v == v) return 1;                  /* Match found    */
  e = n->adj;
  while (e) {
    seen[n->v] = e->node->v;
    if (visit(e->node,v) > 0) return 1;
    e = e->next;
  }
  return 0;
}


/* Depth-first search for a given node */
int Node_search(Node *start, int v) {
  int i;

  for (i = 0; i < node_count; i++)
    seen[i] = UNSEEN;
  return visit(start,v);
}
```

The idea here is simple, the function `Node_search()` takes a starting node and starts looking for a node with given vertex. Upon startup, the search function clears an array of values indicating whether a node has been seen or not. While this array is primarily used to detect cycles, it can also be used to store the path between two nodes as we proceed through the algorithm. Upon exit, we can then use the array to figure out how we got between the starting and ending node. Of course, this leads us to the question of how we access this array in Perl.

As a general rule, handling arrays is somewhat problematic since the mapping between arrays and pointers may not be exactly what you expect (even in C) and there is not necessarily a natural mapping between arrays in C and arrays in Perl (for example, if we've got a C array with 1 million elements in it, we almost certainly wouldn't want to convert it to a Perl array!).

To access our array, we will write a C helper function that allows us to access invidual elements. However, rather than adding this function to the C code, we can insert it directly into our SWIG interface file. We will also strip the function names out of the `.h` file and declare them in the header file :

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

%inline %{
/* Get seen value for a particular node  */
int get_seen(int index) {
  extern int node_count;
  extern int seen[];
  if ((index < 0) || (index >= node_count)) return -1;
  else return seen[index];
}
%}
#ifdef STATIC
%include perlmain.i
#endif
```

This interface file illustrates one of the key points about SWIG--even though SWIG uses C syntax, wrapping arbitrary C code doesn't always result in a good interface. Almost any significant package will require the use of a few "helper" functions to get at certain data structures or to change the way in which a function is called. This is only one of the reasons why SWIG prefers the use of a special interface file over raw C source, but I digress...

With our new C search function, we can now write a Perl function to find a route between two cities. This function simply takes the names of two cities, uses the `Cities` hash to look up their nodes and calls the C `Node_search()` function. Afterwards, we walk through the `seen[]` array using our helper function and print the route.

```
sub find_route {
    my $start = shift;
    my $dest = shift;
    # Lookup nodes from names
    if ((!exists $Cities{$start}) || (!exists $Cities{$dest})) {
       return;
    }
    my $node1 = $Cities{$start};
    my $node2 = $Cities{$dest};
    print "$start --> $dest :\n";

    # Depth first search for a route between cities
```

```
    my $found = Node_search($node1,Node_v_get($node2));
    if ($found) {
       $v = Node_v_get($node1);
       while ($v != $UNSEEN) {
           print "    $Nodes{$v}\n";
           $v = get_seen($v);
       }
    } else {
       print "    You can't get there from here\n";
    }
}

read_cities("cities");
find_route("Salt Lake City","Denver");
```

Of course, depth first search isn't very good at finding an optimal route---obviously this output must be the very scenic route!

```
Salt Lake City --> Denver :
    Salt Lake City
    Twin Falls
    Boise
    Portland
    Eugene
    San Francisco
    Los Angeles
    Las Vegas
    Flagstaff
    Albuquerque
    Santa Fe
    Durango
    Moab
    Denver
```

Rapid prototyping in Perl

Obviously, our depth search algorithm isn't so useful in this specific application. Perhaps we would like to try a breadth-first search algorithm instead. We could choose to write it in C, but the breadth first search algorithm depends on the use of a queue to hold the list of nodes to visit. Thus, we'd have to write a queue data structure first. However, a Perl array smells alot like a queue if we manipulate it in the right way. So we can use Perl to come up with a quick and dirty breadth first search without dropping down into C :

```
%visit;
sub breadth_search {
    my $node1 = shift;
    my $node2 = shift;
    my @queue;
    %visit = ();
    # Put starting node into queue
    push @queue, $node1;
    $visit{Node_v_get($node1)} = Node_v_get($node1);
    while (@queue) {            # Loop until queue is empty
       my $n = shift @queue;     # Pop off an node
       my $nv = Node_v_get($n);
       return 1 if ($$n == $$node2);   # Exit if we found the destination
```

```
        # Put children onto the queue
        my $e = Node_adj_get($n);
        while (defined($e)) {
            my $m = Edge_node_get($e);
            my $v = Node_v_get($m);
            if (!exists $visit{$v}) {
               push @queue, $m;
               $visit{$v} = $nv;
            }
            $e = Edge_next_get($e);
        }
    }
    return 0;
}

sub find_route {
    my $start = shift;
    my $dest = shift;
    # Lookup nodes from names
    return if ((!exists $Cities{$start}) || (!exists $Cities{$dest}));
    print "$start --> $dest :\n";
    my $node1 = $Cities{$start};
    my $node2 = $Cities{$dest};
    my $found = breadth_search($node1,$node2);
    my @path;
    if ($found) {
       my $v = Node_v_get($node2);
       delete $visit{Node_v_get($node1)};
       while (exists($visit{$v})) {
           unshift @path,$Nodes{$v};
           $v = $visit{$v};
       }
       unshift @path,$start;
       foreach $c (@path) { print "    $c\n";}
    } else {
       print "    You can't get there from here\n";
    }
}
```

Our Perl implementation creates a queue using an array and manipulating it with shift and push operations. The global hash `%visit` is used to detect cycles and to determine how we got to each node. When we find a route, we can march backwards through the route to determine the entire path. When we run our new code, we get the following :

```
find_route(“Salt Lake City”, “Denver”);
Salt Lake City --> Denver :
    Salt Lake City
    Cheyenne
    Denver
```

Clearly this is a more efficient route--although admittedly not very scenic. If we wanted to get even more serious, we could add a priority search based on mileages. Later on we might implement these features in C for better performance. Either way, it can be reasonably easy to manipulate complex structures in Perl and to mix them with C code.

Shadow classes

By now, you've probably noticed that examples have been using alot of accessor functions to get at the members of our `Node` and `Edge` structures. This tends to make the Perl code look rather cluttered (well, more than normal Perl code in any case) and it isn't very object oriented.

With a little magic, SWIG can turn C structs and C++ classes into fully functional Perl classes that work in a more-or-less normal fashion. This transformation is done by writing an additional Perl layer that builds Perl classes on top of the low-level SWIG interface. These Perl classes are said to "shadow" an underlying C/C++ class.

To have SWIG create shadow classes, use the `-shadow` option :

```
% swig -perl5 -shadow graph.i
```

This will produce the same files as before except that the `.pm` file will now contain supporting Perl code. While there are some rather subtle aspects of this transformation, for now we'll omit the details and show how you can use shadow classes with our mileage example.

```
# Read a file with cities into a graph
# Uses shadow classes

use graph;
package graph;

%Cities;              # Hash table mapping cities to nodes
%Nodes;               # Mapping of Node indicies to cities

sub read_cities {
    my $filename = shift;
    open(CITIES,$filename);
    while (<CITIES>) {
       chop;
       my @a = split(/, +/);
       my $node1;
       my $node2;
       # Check to see if a given city is already a node
       if (!exists $Cities{$a[0]}) {
           $node1 = new_Node();
           $Cities{$a[0]} = $node1;
           $Nodes{$node1->{v}} = $a[0];      # Note access of 'v'
       } else {
           $node1 = $Cities{$a[0]};
       }
       if (!exists $Cities{$a[1]}) {
           $node2 = new Node;
           $Cities{$a[1]} = $node2;
           $Nodes{$node2->{v}} = $a[1];
       } else {
           $node2 = $Cities{$a[1]};
       }
       # Add edges
       Node_addedge($node1,$node2,$a[2]);
       Node_addedge($node2,$node1,$a[2]);
    }
```

```
}

%visit;
sub breadth_search {
    my $node1 = shift;
    my $node2 = shift;
    my @queue;
    %visit = ();
    my $dest = $node2->{v};
    # Put starting node into queue
    push @queue, $node1;
    $visit{$node1->{v}} = $node1->{v};
    while (@queue) {
       my $n = shift @queue;
       return 1 if ($n->{v} == $node2->{v});
       # Put children onto the queue
       my $e = $n->{adj};
       while (defined($e)) {
           if (!exists $visit{$e->{node}->{v}}) {
              push @queue, $e->{node};
              $visit{$e->{node}->{v}} = $n->{v};
           }
           $e = $e->{next};
       }
    }
    return 0;
}

sub find_route {
    my $start = shift;
    my $dest = shift;
    # Lookup nodes from names
    return if ((!exists $Cities{$start}) || (!exists $Cities{$dest}));
    print "$start --> $dest :\n";
    my $node1 = $Cities{$start};
    my $node2 = $Cities{$dest};
    my $found = breadth_search($node1,$node2);
    my @path;
    if ($found) {
       my $v = $node2->{v};
       delete $visit{$node1->{v}};
       while (exists($visit{$v})) {
           unshift @path,$Nodes{$v};
           $v = $visit{$v};
       }
       unshift @path,$start;
       foreach $c (@path) {
           print "    $c\n";
       }
    } else {
       print "    You can't get there from here\n";
    }
}
read_cities("cities");

find_route("Salt Lake City","Denver");
```

For the most part, the code is the same except that we can now access members of complex data structures using `->` instead of the low level accessor functions. like before. However, this example is only scratching the surface of what can be done with shadow classes...keep reading.

Getting serious

Now that we've got a very simple example working, it's time to get really serious. Suppose that in addition to working with the mileage data of various cities, we want to make a graphical representation from geographical data (lattitude/longitude). To do this, we'll use SWIG to glue together a bunch of stuff. First, for the purposes of illustration, let's create a new C data structure for holding a geographical location with the assumption that we might want to use it in some C functions later :

```
/* File : location.h */
/* Data structure for holding longitude and lattitude information */

typedef struct Location {
  char    *name;
  double  lat_degrees;
  double  lat_minutes;
  double  lat_seconds;
  char    lat_direction;
  double  long_degrees;
  double  long_minutes;
  double  long_seconds;
  char    long_direction;
} Location;

extern Location *new_Location(char *name);
```

We also probably want a C function for creating one of these things :

```
/* File : location.c */
#include <string.h>

/* Make a new location */
Location *new_Location(char *name) {
  Location *l;
  l = (Location *) malloc(sizeof(Location));
  l->name = (char *) malloc(strlen(name)+1);
  strcpy(l->name,name);
  return l;
}
```

Now let's make an interface file for this module :

```
// File : location.i
%module location
%{
#include "location.h"
%}

%include location.h
```

We could use this interface file to make an entirely new Perl5 module or we can combine it with the graph module. In this latter case, we simply need to put "`%include location.i`" in the file `graph.i`.

Now, finally, we could write a Perl function to read data in the following format :

```
Santa Fe,       35 41 13 N 105 56 14 W
Denver,         39 44 21 N 104 59 03 W
Albuquerque,    35 05 00 N 106 39 00 W
Cheyenne,       41 08 00 N 104 49 00 W
Kansas City,    39 05 51 N 94 37 38 W
Durango,        37 16 31 N 107 52 46 W
Moab,           38 34 24 N 109 32 57 W
Salt Lake City, 40 45 39 N 111 53 25 W
Reno,           39 31 47 N 119 48 46 W
San Francisco,  37 46 30 N 122 25 06 W
Las Vegas,      36 10 30 N 115 08 11 W
Flagstaff,      35 11 53 N 111 39 02 W
Los Angeles,    34 03 08 N 118 14 34 W
Eugene,         44 03 08 N 123 05 08 W
Portland,       45 31 24 N 122 40 30 W
Seattle,        47 36 23 N 122 19 51 W
Boise,          43 36 49 N 116 12 09 W
Twin Falls,     42 33 47 N 114 27 36 W
```

Geographic data

```
sub read_locations {
    my $filename = shift;
    open(LOCATIONS,$filename);
    while (<LOCATIONS>) {
       chop;
       my @a = split(/, +/);
       my $loc;
       # Check to see if this is a city I know about
       if (exists $Cities{$a[0]}) {
           # Create a new location
           $loc = new_Location($a[0]);
           my @coords = split(' ',$a[1]);
           # A nice way to assign attributes to an object
           %$loc = (lat_degrees => $coords[0],
                    lat_minutes => $coords[1],
                    lat_seconds => $coords[2],
                    lat_direction => $coords[3],
                    long_degrees => $coords[4],
                    long_minutes => $coords[5],
                    long_seconds => $coords[6],
                    long_direction => $coords[7]);
           my $v = $Cities{$a[0]}->{v};
           $Locations{$v} = $loc;
       }
    }
    close LOCATIONS;
}
```

Again, we are using shadow classes which are allowing us to assign all of the attributes of a C structure in the same way as one would create a Perl hash table. We have also created the `%Locations` hash to associate node numbers with a given location.

Of course, having locations isn't too useful without a way to look at them so we'll grab the public domain `gd` library by Thomas Boutell. First, we'll write a simple C function to draw two locations and draw a line between them (some code has been omitted) :.

```
/* File : plot.c */
#include <gd.h>
#include <gdfonts.h>
#include "location.h"
double xmin,ymin,xmax,ymax;   /* Plotting range */

/* Make a plot of two locations with a line between them */
void plot_cities(gdImagePtr im, Location *city1, Location *city2,
                   int color) {
...
  /* Convert the two locations into screen coordinates */
...
  /* Draw the cities */
  gdImageString(im,gdFontSmall,...)
  gdImageString(im,gdFontSmall,...)
  gdImageLine(im,ix1,height-iy1,ix2,height-iy2,color);
}
```

Next, we'll wrap a few critical gd functions into Perl. We don't need the entire library so there's not much sense in wrapping the whole thing (it's easy enough to do if you really want to of course). We'll just wrap a couple of functions to illustrate how it can be used.

```
%module gd
%{
#include "gd.h"
%}
typedef struct gdImageStruct gdImage;
typedef gdImage * gdImagePtr;

/* Functions to manipulate images. */
gdImagePtr gdImageCreate(int sx, int sy);
int  gdImageColorAllocate(gdImagePtr im, int r, int g, int b);
%inline %{
  /* Shortcut for dumping a file */
  void dump_gif(gdImagePtr im, char *filename) {
    FILE *f;
    f = fopen(filename, "w");
    gdImageGif(im,f);
    fclose(f);
  }
%}
```

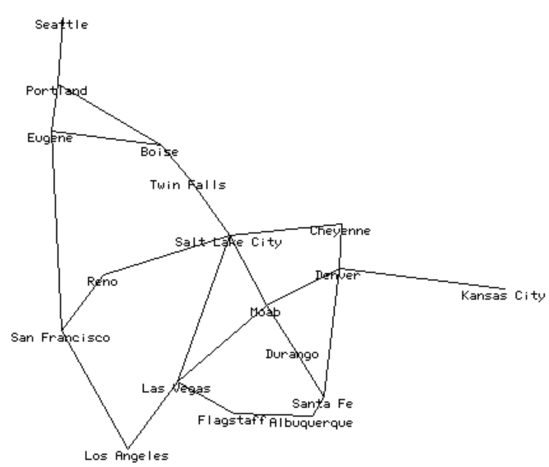
We can now slap everything together using a new interface file like this. we'll keep the old graph module name so our existing scripts still work :

```
// File : package.i
%module graph
%include graph.i          // The original graph program
%include location.i       // The location data structure and functions
%include gd.i             // gd module
%include plot.c           // Function to plot cities
```

Whew! After all of that work, we can do the following :

```
read_cities("cities");
read_locations("locations");

# Create a new image with gd
$im = gdImageCreate(500,500);
$white = gdImageColorAllocate($im,255,255,255);
$black = gdImageColorAllocate($im,0,0,0);

# Set plotting range (variables in the C code)
$xmin = -130;
$xmax = -90;
$ymin = 30;
$ymax = 50;

# Make a plot of the entire graph
@loc = each %Cities;
while (@loc) {
    my $city = $loc[0];
    my $node = $Cities{$city};
    if (exists $Locations{$node->{v}}) {
       my $loc1 = $Locations{$node->{v}};
       my $e = $node->{adj};
       while (defined($e)) {
             if (exists $Locations{$e->{node}->{v}}) {
                my $loc2 = $Locations{$e->{node}->{v}};
                plot_cities($im,$loc1,$loc2,$black);
             }
             $e = $e->{next};
         }
    }
    @loc = each %Cities;
}
# Dump out a GIF file
dump_gif($im,"test.gif");
```

When run, we get the following :



Not too bad for a little work....

Wrapping C libraries and other packages

SWIG can be used to build Perl interfaces to existing C libraries and packages. The general strategy for doing this is as follows :

- Locate important header files for the package.
- Copy them into a SWIG interface file.
- Edit the interface file by removing problematic declarations, unneeded functions, and other clutter.
- Add support functions to improve the interface.

While SWIG can sometimes be used to simply process a raw header file, the results aren't always what you would expect. By working with a separate interface file, you get an opportunity to clean things up. If you're using a stable package, chances are that it's not going to change suddenly so there is really little problem in doing this. To illustrate the process, we will build a Perl5 interface to MATLAB in the next example.

Building a Perl5 interface to MATLAB

To illustrate the process, we can build a Perl5 interface to MATLAB by wrapping its C API. The MATLAB system consists of the MATLAB engine (a separate process), and library of functions for creating and manipulating matrices along with a variety of utility function. A full description can be found in the "External Interface Guide" provided with MATLAB.

The MATLAB engine interface

The first step in building an interface will be to provide access to the MATLAB engine. This is a separate process that runs in the background, but we need to have some mechanism for starting it and issuing commands. The following functions are defined in the MATLAB interface.,

```
int engClose(Engine *ep);
int engEvalString(Engine *ep, char *string);
Matrix *engGetMatrix(Engine *ep, char *name);
int engPutMatrix(Engine *ep, Matrix *mp);
Engine *engOpen(char *startcommand);
void engOutputBuffer(Engine *ep, char *p, int size);
```

While we could wrap these directly. They could be a little annoying to use in Perl since we would have to pass a pointer to the engine with every command. This probably isn't necessary or desired. Thus, we could write some wrappers around these to produce a better interface as follows :

```
// engine.i : SWIG file for MATLAB engine
%{
#define BUFFER_SIZE   32768
static Engine  *eng = 0;
static char   ml_output[BUFFER_SIZE];   /* Result Buffer */
%}

%inline %{
```

```
/* Initialize the MATLAB engine */
int init(void) {
       if (eng) return -1;   /* Already open */
       if (!(eng = engOpen(“matlab42”))) {
         fprintf(stderr,"Unable to open matlab.\n");
         return -1;
       }
       engOutputBuffer(eng,ml_output,BUFFER_SIZE);
       return 0;
}
/* Execute a MATLAB command */
char *matlab(char *c) {
       if (!eng) return “not initialized!”;
       engEvalString(eng, c);
       return &ml_output[0];
}

/* Get a matrix from MATLAB */
Matrix *GetMatrix(char *name) {
       if (!eng) return (Matrix *) 0;
       return(engGetMatrix(eng,name));
}

/* Send a matrix to MATLAB */
int PutMatrix(Matrix *m) {
       if (!eng) return -1;
       return(engPutMatrix(eng,m));
}
%}
```

Wrapping the MATLAB matrix functions

Next, we need to build an interface to the MATLAB matrix manipulation library. This library contains about 30 functions to manipulate both real and complex valued matrices. Here we will only consider real-valued matrices. To provide access to the matrices, we’ll write a different interface file with a list of the functions along with a few helper functions.

```
//
// mx.i : SWIG file for MATLAB matrix manipulation
%inline %{
/* Get an element from a matrix */
double getr(Matrix *mat, int i, int j) {
  double *pr;
  int m;
  pr = mxGetPr(mat);
  m = mxGetM(mat);
  return pr[m*j + i];
}
/* Set an element of a matrix */
void setr(Matrix *mat, int i, int j, double val) {
  double *pr;
  int m;
  pr = mxGetPr(mat);
  m = mxGetM(mat);
    pr[m*j + i] = val;
}
```

```
/* Convert a C row-major array to a MATLAB column major array */
void c2matlab(Matrix *mat, double *array, int m, int n) {
   int i,j;
   for (i = 0; i < m; i++)
        for (j = 0; j < n; j++)
             setr(mat, i, j, array[i][j]);
}
%}

/* Now some MATLAB command */
Matrix *mxCreateFull(int m, int n, int ComplexFlag);
int mxGetM(Matrix *mat);
int mxGetN(Matrix *mat);
char *mxGetName(Matrix *mat);
void mxSetName(Matrix *mat, char *name);
double *mxGetPr(Matrix *mat);
void mxSetPr(Matrix *mat, double *pr);
double mxGetScalar(Matrix *mat);
void mxFreeMatrix(Matrix *pm);
```

Putting it all together

Finally we are ready to put our interface together. There is no need to build a big monolithic interface file--we can simply build it up in pieces :

```
// matlab.i
// Simple SWIG interface to MATLAB
%module matlab
%{
#include “engine.h”
%}
%include engine.i
%include mx.i
```

Our module can be compiled as follows :

```
unix > swig -perl5 matlab.i
unix > gcc -c matlab_wrap.c -I/usr/local/lib/perl5/arch-osname/5.003/CORE -Dbool=char
       -I$(MATLAB)/extern/include
unix > ld -shared matlab_wrap.o -L$(MATLAB)/extern/lib -lmat -o matlab.so
```

Where `$(MATLAB)` is the location of the MATLAB installation (you may have to dig for this).

With our new MATLAB module, we can now write Perl scripts that issue MATLAB commands. For example :

```
use matlab;
matlab::init();
matlab::matlab(“x = -8:.25:8; \
                y = x; \
                [X,Y] = meshgrid(x,y); \
                R = sqrt(X.^2 + Y.^2)+eps; \
                Z = sin(R)./R; \
                mesh(Z); ”);
```

This will create a simple 3D surface plot from Perl.

Graphical Web-Statistics in Perl5

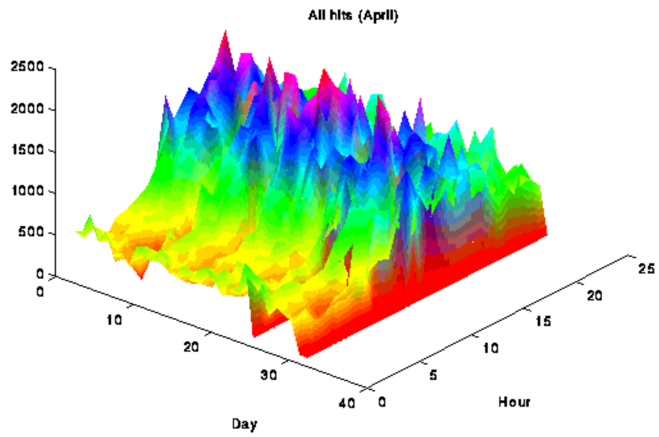
Now, lets use our MATLAB module to generate plots of web-server hits for a given month. To do this, we'll use our MATLAB module, and create a special purpose function for processing days and hours.

```
// Simple C function for recording a hit
%module webgraph
%inline %
        void hit(double *m, int day, int hour) {
                if ((day >= 0) && (day <= 31)) {
                        *(m+24*(day-1)+hour) += 1.0;
                }
        }
%}
```

While we could write this function in Perl, it will be much faster in C. If we're processing a huge file, then the extra bit of performance will help us out. Once compiled, we can now write a Perl5 script like the following :

```
use matlab;
use webgraph;

# Initialize matlab engine
matlab::init();
# Make a matrix for all hits
$m_all = matlab::mxCreateFull(24,31,0);
matlab::mxSetName($m_all,"all");
$all = matlab::mxGetPr($m_all);         # Get double * of Matrix

foreach $file (@ARGV) {
  open(FILE,$file);
  print "Processing ",$file,"\n";
  while (<FILE>) {
    @fields = split(/\s+/, $_);
    next if ($fields[8] != 200);
    @datetime = split(/\[|\/|:/, $fields[3]);
    if ($datetime[2] =~ /Apr/) {
      webgraph::hit($all, $datetime[1],$datetime[4]);
    }
  }
  # Dump temporary results
}  #foreach
matlab::PutMatrix($m_all);
matlab::matlab("figure(1); \
                surf(all); \
                view(40,40); \
                shading interp; \
                title('All hits'); \
                set(gca,'xlabel',text(0,0,'Day')); \
                set(gca,'ylabel',text(0,0,'Hour')); \
                print -dgif8 stats_all.gif");
```

When run on the web-server logs for the University of Utah, this script produces the following GIF file (showing hits per hour) :



Although SWIG was primarily designed for rapid prototyping and building interfaces to your own programs, it can also be used to build powerful tools and add capabilities to Perl scripts.

Exception handling

The SWIG `%except` directive can be used to create a user-definable exception handler in charge of converting exceptions in your C/C++ program into Perl exceptions. The chapter on exception handling contains more details, but suppose you have a C++ class like the following :

```
class RangeError {};   // Used for an exception

class DoubleArray {
  private:
    int n;
    double *ptr;
  public:
    // Create a new array of fixed size
    DoubleArray(int size) {
      ptr = new double[size];
      n = size;
    }
    // Destroy an array
    ~DoubleArray() {
       delete ptr;
    }
    // Return the length of the array
    int   length() {
      return n;
    }

    // Get an item from the array and perform bounds checking.
    double getitem(int i) {
      if ((i >= 0) && (i < n))
        return ptr[i];
```

```
        else
          throw RangeError();
      }

      // Set an item in the array and perform bounds checking.
      void setitem(int i, double val) {
        if ((i >= 0) && (i < n))
          ptr[i] = val;
        else {
          throw RangeError();
        }
      }
    };
```

The functions associated with this class can throw a range exception for an out-of-bounds array access. We can catch this in our Perl extension by specifying the following in an interface file :

```
%except(perl5) {
  try {
    $function                // Gets substituted by actual function call
  }
  catch (RangeError) {
    croak("Array index out-of-bounds");
  }
}
```

Now, when the C++ class throws a RangeError exception, our wrapper functions will catch it, turn it into a Perl exception, and allow a graceful death as opposed to just having some sort of mysterious program crash. Since SWIG's exception handling is user-definable, we are not limited to C++ exception handling. Please see the chapter on exception handling for more details.

Remapping datatypes with typemaps

While SWIG does a reasonable job with most C/C++ datatypes, it doesn't always do what you want. However, you can remap SWIG's treatment of just about any datatype using a typemap. A typemap simply specifies a conversion between Perl and C datatypes and can be used to process function arguments, function return values, and more. A similiar mechanism is used by the xsubpp compiler provided with Perl although the SWIG version provides many more options.

A simple typemap example

The following example shows how a simple typemap can be written :

```
%module example

%typemap(perl5,in) int {
       $target = (int) SvIV($source);
       printf("Received an integer : %d\n", $target);
}
...
extern int fact(int n);
```

Typemaps require a language name, method name, datatype, and conversion code. For Perl5, "perl5" should be used as the language name. The "in" method refers to the input arguments of a function. The 'int' datatype tells SWIG that we are remapping integer. The conversion code is used to convert from a Perl scalar value to the corresponding datatype. Within the support code, the variable `$source` contains the source data (the Perl object) and `$target` contains the destination of the conversion (a C local variable).

When this example is used in Perl5, it will operate as follows :

```
use example;
$n = example::fact(6);
print "$n\n";
...

Output :
Received an integer : 6
720
```

More discussion of typemaps can be found in the main SWIG users reference. We will primarily be concerned with Perl5 typemaps here.

Perl5 typemaps

The following typemap methods are available to Perl5 modules

`%typemap(perl5,in)`	Converts Perl5 object to input function arguments.
`%typemap(perl5,out)`	Converts function return value to a Perl5 value.
`%typemap(perl5,varin)`	Converts a Perl5 object to a global variable.
`%typemap(perl5,varout)`	Converts a global variable to a Perl5 object.
`%typemap(perl5,freearg)`	Cleans up a function argument after a function call
`%typemap(perl5,argout)`	Output argument handling
`%typemap(perl5,ret)`	Clean up return value from a function.
`%typemap(memberin)`	Setting of C++ member data (all languages).
`%typemap(memberout)`	Return of C++ member data (all languages).

Typemap variables

The following variables may be used within the C code used in a typemap :

$source	Source value of a conversion
$target	Target of conversion (where result should be stored)
$type	C datatype being remapped
$mangle	Mangled version of datatype (for blessing objects)
$arg	Function argument (when applicable).

Name based type conversion

Typemaps are based both on the datatype and an optional name attached to a datatype. For example :

```
%module foo

// This typemap will be applied to all char ** function arguments
%typemap(perl5,in) char ** { ... }
```

```
// This typemap is applied only to char ** arguments named 'argv'
%typemap(perl5,in) char **argv { ... }
```

In this example, two typemaps are applied to the char ** datatype. However, the second typemap will only be applied to arguments named 'argv'. A named typemap will always override an unnamed typemap.

Named typemaps are extremely useful for managing special cases. It is also possible to use named typemaps to process output arguments (ie. function arguments that have values returned in them).

*Converting char ** to a Perl5 array*

A common problem in many C programs is the processing of command line arguments, which are usually passed in an array of NULL terminated strings. The following SWIG interface file allows a Perl5 array reference to be used as a char ** datatype.

```
%module argv

// This tells SWIG to treat char ** as a special case
%typemap(perl5,in) char ** {
        AV *tempav;
        I32 len;
        int i;
        SV  **tv;
        if (!SvROK($source))
            croak("$source is not a reference.");
         if (SvTYPE(SvRV($source)) != SVt_PVAV)
            croak("$source is not an array.");
        tempav = (AV*)SvRV($source);
        len = av_len(tempav);
        $target = (char **) malloc((len+2)*sizeof(char *));
        for (i = 0; i <= len; i++) {
            tv = av_fetch(tempav, i, 0);
            $target[i] = (char *) SvPV(*tv,na);
         }
        $target[i] = 0;
};

// This cleans up our char ** array after the function call
%typemap(perl5,freearg) char ** {
        free($source);
}

// Creates a new Perl array and places a char ** into it
%typemap(perl5,out) char ** {
        AV *myav;
        SV **svs;
        int i = 0,len = 0;
        /* Figure out how many elements we have */
        while ($source[len])
           len++;
        svs = (SV **) malloc(len*sizeof(SV *));
        for (i = 0; i < len ; i++) {
            svs[i] = sv_newmortal();
            sv_setpv((SV*)svs[i],$source[i]);
        };
```

```
        myav = av_make(len,svs);
        for (i = 0; i < len; i++) {
          /*     SvREFCNT_dec(svs[i]); */
        }
        free(svs);
        $target = newRV((SV*)myav);
        sv_2mortal($target);
}

// Now a few test functions
%inline %{
int print_args(char **argv) {
    int i = 0;
    while (argv[i]) {
         printf("argv[%d] = %s\n", i,argv[i]);
         i++;
    }
    return i;
}

// Returns a char ** list
char **get_args() {
    static char *values[] = { "Dave", "Mike", "Susan", "John", "Michelle", 0};
    return &values[0];
}
%}
```

When this module is compiled, our wrapped C functions can be used in a Perl script as follows :

```
use argv;
@a = ("Dave", "Mike", "John", "Mary");           # Create an array of strings
argv::print_args(\@a);                           # Pass it to our C function
$b = argv::get_args();                           # Get array of strings from C
print @$b,"\n";                                  # Print it out
```

Of course, there are many other possibilities. As an alternative to array references, we could pass in strings separated by some delimeter and perform a splitting operation in C.

Using typemaps to return values

Sometimes it is desirable for a function to return a value in one of its arguments. A named typemap can be used to handle these cases. For example :

```
%module return

// This tells SWIG to treat an double * argument with name 'OutDouble' as
// an output value.

%typemap(perl5,argout) double *OutDouble {
       $target = sv_newmortal();
       sv_setnv($target, *$source);
       argvi++;                     /* Increment return count -- important! */
}

// If we don't care what the input value is, we can make the typemap ignore it.

%typemap(perl5,in) double *OutDouble {
```

```
        static double junk;  // Static needed so temporary variable doesn't disappear
        $target = &junk;
}

// Now a function to test it
%{

/* Returns the first two input arguments */
int multout(double a, double b, double *out1, double *out2) {
        *out1 = a;
        *out2 = b;
        return 0;
};
%}

// If we name both parameters OutDouble both will be output

int multout(double a, double b, double *OutDouble, double *OutDouble);
...
```

When output arguments are encountered, they are simply appended to the stack used to return results. This will show up as an array when used in Perl. For example :

```
@r = multout(7,13,"","");
print "multout(7,13) = $r[0],$r[1],$r[2]\n";
```

Accessing array structure members

Consider the following data structure :

```
#define NAMELEN   32
typedef struct {
        char   name[NAMELEN];
        ...
} Person;
```

By default, SWIG doesn't know how to the handle the name structure since it's an array, not a pointer. In this case, SWIG will make the array member readonly. However, member typemaps can be used to make this member writable from Perl as follows :

```
%typemap(memberin) char[NAMELEN] {
        /* Copy at most NAMELEN characters into $target */
        strncpy($target,$source,NAMELEN);
}
```

Whenever a `char[NAMELEN]` type is encountered in a structure or class, this typemap provides a safe mechanism for setting its value. An alternative implementation might choose to print an error message if the name was too long to fit into the field.

It should be noted that the `[NAMELEN]` array size is attached to the typemap. A datatype involving some other kind of array would be affected.

Turning Perl references into C pointers

A frequent confusion on the SWIG mailing list is errors caused by the mixing of Perl references and C pointers. For example, suppose you have a C function that modifies its arguments like this :

```
void add(double a, double b, double *c) {
       *c = a + b;
}
```

One interpretation of this function may be the following Perl code :

```
# Perl script
$a = 3.5;
$b = 7.5;
$c = 0.0;          # Output value
add($a,$b,\$c);    # Place result in c (Except that it doesn't work)
```

Unfortunately, this does NOT work. There are many reasons for this, but the main one is that SWIG has no idea what a `double *` really is. It could be an input value, an output value, or an array of 2 million elements. As a result, SWIG leaves it alone and looks exclusively for a C pointer value (which is not the same as the Perl reference above).

However, you can use a typemap to get the desired effect. For example :

```
%typemap(perl5,in) double * {
  SV* tempsv;
  static double dvalue;
  if (!SvROK($source)) {
    croak("expected a reference\n");
  }
  tempsv = SvRV($source);
  if (SvTYPE(tempsv) != SVt_NV) {
    croak("expected a double reference\n");
  }
  dvalue = SvNV(tempsv);
  $target = &dvalue;
}

%typemap(perl5,argout) double * {
  SV *tempsv;
  tempsv = SvRV($arg);
  sv_setnv(tempsv, *$source);
}
```

Now, if you place this before our add function, we can do this :

```
$a = 3.5;
$b = 7.5;
$c = 0.0;
add($a,$b,\$c);            # Now it works!
print "$c\n";
```

You'll get the output value of "11.0" which is exactly what we wanted. While this is pretty cool, it should be stressed that you can still shoot yourself in the foot.

Useful functions

When writing typemaps, it is necessary to work directly with Perl5 objects. This, unfortunately, can be a daunting task. Consult the "perlguts" man-page for all of the really ugly details. A short summary of commonly used functions is provided here for reference.

Perl Integer Conversion Functions

`int SvIV(SV *)`	Convert a Perl scalar value to an integer.
`void sv_setiv(SV *sv, (IV) value)`	Set a Perl scalar to the value of a C integer (in value).
`SV *newSViv((IV) value)`	Create a new Perl scalar from a C value.
`int SvIOK(SV *)`	Checks to see if a Perl scalar is an integer.

Perl Floating Point Conversion Functions

`double SvNV(SV *)`	Convert a Perl scalar value to a double precision float.
`void sv_setnv(SV *, (NV) value)`	Set a Perl5 scalar to the value of a C double.
`SV *newSVnv((NV) value)`	Create a new Perl scalar from a C double.
`int SvNOK(SV *)`	Check to see if a Perl scalar is a floating point value.

Perl String Conversion Functions

`char *SvPV(SV *, int len)`	Convert a scalar value to a char *. Returns the length in len unless you set it to the special value 'na'.
`void sv_setpv(SV *, char *val)`	Copy a NULL terminated ASCII string into a Perl scalar.
`void sv_setpvn(SV *, char *val, int len)`	Copy a string of len bytes into a Perl scalar.
`SV *newSVpv(char *value, int len)` `int SvPOK(SV *)`	Create a new Perl scalar value from a char * and length. Checks to see if a Perl scalar is a string.
`void sv_catpv(SV *, char *)`	Appends a string to a scalar value.

Perl String Conversion Functions

`void sv_catpvn(SV *, char *, int)`	Appends a string of specified length to a scalar value.

Perl References

`void sv_setref_pv(SV *, char *, void *ptr)`	Create a blessed reference.
`int sv_isobject(SV *)`	Checks to see if a scalar corresponds to an object (is a reference).
`SV *SvRV(SV *)`	Returns a scalar value from a reference.
`int sv_isa(SV *, char *)`	Checks the type of a reference

Standard typemaps

The following typemaps show how to convert a few common types of objects between Perl and C (and to give a better idea of how everything works).

Function argument typemaps

`int,`
`short,`
`long,`
	`%typemap(perl5,in) int,short,long {`
	`    $target = ($type) SvIV($source);`
	`}`

`float,`
`double`
	`%typemap(perl5,in) float, double {`
	`    $target = ($type) SvNV($source);`
	`}`

`char *`	`%typemap(perl5,in) char * {`
	`    $target = SvPV($source,na);`
	`}`

Function/argument return typemaps

`int,`
`short,`
`long`
	`%typemap(perl5,out) int,short,long {`
	`    $target = sv_newmortal();`
	`    sv_setiv($target,(IV) $source);`
	`    argvi++;`
	`}`

`float,`
`double`
	`%typemap(perl5,out) float, double {`
	`    $target = sv_newmortal();`
	`    sv_setiv($target,(double) $source);`
	`    argvi++;`
	`}`

Function/argument return typemaps

`char *`	`%typemap(perl5,out) char * {`
	`    $target = sv_newmortal();`
	`    sv_setpv($target,$source);`
	`    argvi++;`
	`}`

Pointer handling

SWIG pointers are represented as blessed references. The following functions can be used to create and read pointer values.

SWIG Pointer Conversion Functions

`void sv_setref_pv(SV *sv, char *type, void *ptr)`	Turn the scalar value sv into a pointer. type is the type string and ptr is the actual pointer value.
`char *SWIG_GetPtr(SV *sv, void **ptr, char *type)`	Extract a pointer value from scalar value sv. Performs type-checking and pointer casting if necessary. If type is NULL, any pointer value will be accepted. The result will be stored in ptr and NULL returned. On failure, a pointer to the invalid portion of the type string will be returned.

These functions can also be used in typemaps although there usually little need to do so.

Return values

Return values are placed on the argument stack of each wrapper function. The current value of the argument stack pointer is contained in a variable `argvi`. Whenever a new output value is added, it is critical that this value be incremented. For multiple output values, the final value of `argvi` should be the total number of output values.

The gory details on shadow classes

Perl5 shadow classes are constructed on top of the low-level C interface provided by SWIG. By implementing the classes in Perl instead of C, we get a number of advantages :

- The classes are easier to implement (after all Perl makes lots of things easier).
- By writing in Perl, the classes tend to interact better with other Perl objects and programs.
- You can modify the resulting Perl code without recompiling the C module.

Shadow classes are new in SWIG 1.1 and still somewhat experimental. The current implementation is a combination of contributions provided by Gary Holt and David Fletcher--many thanks!

Module and package names

When shadow classing is enable, SWIG generates a low-level package named 'modulec' where 'module' is the name of the module you provided with the `%module` directive (SWIG appends a 'c' to the name to indicate that it is the low-level C bindings). This low-level package is exactly the same module that SWIG would have created without the '`-shadow`' option, only renamed.

Using the low-level interface, SWIG will then create Perl wrappers around classes, structs, and functions. This collection of wrappers becomes the Perl module that you will use in your Perl code, not the low-level package.

What gets created?

Suppose you have the following SWIG interface file :

```
%module vector
struct Vector {
       Vector(double x, double y, double z);
       ~Vector();
       double x,y,z;
};
```

When wrapped, SWIG will create the following set of low-level accessor functions.

```
Vector *new_Vector(double x, double y, double z);
void    delete_Vector(Vector *v);
double  Vector_x_get(Vector *v);
double  Vector_x_set(Vector *v, double value);
double  Vector_y_get(Vector *v);
double  Vector_y_set(Vector *v, double value);
double  Vector_z_get(Vector *v);
double  Vector_z_set(Vector *v, double value);
```

These functions can now be used to create a Perl shadow class that looks like this :

```
package Vector;
@ISA = qw( vector );
%OWNER = ();
%BLESSEDMEMBERS = ();

sub new () {
    my $self = shift;
    my @args = @_;
    $self = vectorc::new_Vector(@args);
    return undef if (!defined($self));
    bless $self, "Vector";
    $OWNER{$self} = 1;
    my %retval;
    tie %retval, "Vector", $self;
    return bless \%retval,"Vector";
}

sub DESTROY {
    my $self = shift;
    if (exists $OWNER{$self}) {
        delete_Vector($self));
        delete $OWNER{$self};
```

```
}

sub FETCH {
    my ($self,$field) = @_;
    my $member_func = "vectorc::Vector_${field}_get";
    my $val = &$member_func($self);
    if (exists $BLESSEDMEMBERS{$field}) {
        return undef if (!defined($val));
        my %retval;
        tie %retval,$BLESSEDMEMBERS{$field},$val;
        return bless \%retval, $BLESSEDMEMBERS{$field};
    }
    return $val;
}

sub STORE {
    my ($self,$field,$newval) = @_;
    my $member_func = "vectorc::Vector_${field}_set";
    if (exists $BLESSEDMEMBERS{$field}) {
        &$member_func($self,tied(%{$newval}));
    } else {
        &$member_func($self,$newval);
    }
}
```

Each structure or class is mapped into a Perl package of the same name. The C++ constructors and destructors are mapped into constructors and destructors for the package. The constructor always returns a tied hash table. This hash table is used to access the member variables of a structure in addition to being able to invoke member functions. The `%OWNER` and `%BLESSED-MEMBERS` hash tables are used internally and described shortly.

To use our new shadow class we can simply do the following:

```
# Perl code using Vector class
$v = new Vector(2,3,4);
$w = Vector->new(-1,-2,-3);

# Assignment of a single member
$v->{x} = 7.5;

# Assignment of all members
%$v = ( x=>3,
        y=>9,
        z=>-2);

# Reading members
$x = $v->{x};

# Destruction
$v->DESTROY();
```

Object Ownership

In order for shadow classes to work properly, it is necessary for Perl to manage some system of object ownership. Here's the crux of the problem---suppose you had a function like this :

```
Vector *Vector_get(Vector *v, int index) {
       return &v[i];
}
```

This function takes a Vector pointer and returns a pointer to another Vector. Such a function might be used to manage arrays or lists of vectors (in C). Now contrast this function with the constructor for a Vector object :

```
Vector *new_Vector(double x, double y, double z) {
       Vector *v;
       v = new Vector(x,y,z);        // Call C++ constructor
       return v;
}
```

Both functions return a Vector, but the constructor is returning a brand-new Vector while the other function is returning a Vector that was already created (hopefully). However, in Perl, both vectors will be indistinguishable---a clear problem considering that we would probably like the newly created Vector to be destroyed when we are done with it.

To manage these problems, each class two methods that access an internal hash table called `%OWNER`. This hash keeps a list of all of the objects that Perl knows that it has created. This happens in two cases: (1) when the constructor has been called, and (2) when a function implicitly creates a new object (as is done when SWIG needs to return a complex datatype by value). When the destructor is invoked, the Perl shadow class module checks the `%OWNER` hash to see if Perl created the object. If so, the C/C++ destructor is invoked. If not, we simply destroy the Perl object and leave the underlying C object alone.

This scheme works remarkably well in practice but it isn't foolproof. In fact, it will fail if you create a new C object in Perl, pass it on to a C function that remembers the object, and then destroy the corresponding Perl object (this situation turns out to come up frequently when constructing objects like linked lists and trees). When C takes possession of an object, you can change Perl's owership by simply deleting the object from the `%OWNER` hash. This is down using the `DISOWN` method.

```
# Perl code to change ownership of an object
$v = new Vector(x,y,z);
$v->DISOWN();
```

To acquire ownership of an object, the ACQUIRE method can be used.

```
# Given Perl ownership of a file
$u = Vector_get($v);
$u->ACQUIRE();
```

As always, a little care is in order. SWIG certainly isn't foolproof when it comes to determining the ownership of objects.

Nested Objects

Suppose that we have a new object that looks like this :

```
struct Particle {
       Vector r;
```

```
        Vector v;
        Vector f;
        int    type;
}
```

In this case, the members of the structure are complex objects that have already been encapsulated in a Perl shadow class. To handle these correctly, we use the `%BLESSEDMEMBERS` hash which would look like this (along with some supporting code) :

```
package Particle;
...
%BLESSEDMEMBERS = (
       r => 'Vector',
       v => 'Vector',
       f => 'Vector',
);
```

When fetching members from the structure, %BLESSEDMEMBERS is checked. If the requested field is present, we create a tied-hash table and return it. If not, we just return the corresponding member unmodified.

This implementation allows us to operate on nested structures as follows :

```
# Perl access of nested structure
$p = new Particle();
$p->{f}->{x} = 0.0;
%${$p->{v}} = ( x=>0, y=>0, z=>0);         ### CHECK THIS!
```

Shadow Functions

When functions take arguments involving a complex object, it is sometimes necessary to write a shadow function. For example :

```
double dot_product(Vector *v1, Vector *v2);
```

Since Vector is an object already wrapped into a shadow class, we need to modify this function to accept arguments that are given as tied hash tables. This is done by creating a Perl function like this :

```
sub dot_product {
    my @args = @_;
    $args[0] = tied(%{$args[0]});
    $args[1] = tied(%{$args[1]});
    my $result = vectorc::dot_product(@args);
    return $result;
}
```

This function replaces the original function, but operates in an identical manner. Of course, internally, this new function is calling the original version.

Inheritance

Simple C++ inheritance is handled using the Perl `@ISA` array in each class package. For example, if you have the following interface file :

```
// shapes.i
// SWIG interface file for shapes class
%module shapes
%{
#include “shapes.h”
%}

class Shape {
public:
       virtual double area() = 0;
       virtual double perimeter() = 0;
       void    set_location(double x, double y);
};
class Circle : public Shape {
public:
       Circle(double radius);
       ~Circle();
       double area();
       double perimeter();
};
class Square : public Shape {
public:
       Square(double size);
       ~Square();
       double area();
       double perimeter();
}
```

The resulting, Perl wrapper class will create the following code :

```
Package Shape;
@ISA = (shapes);
...
Package Circle;
@ISA = (shapes Shape);
...
Package Square;
@ISA = (shapes Shape);
```

The `@ISA` array determines where to look for methods of a particular class. In this case, both the `Circle` and `Square` classes inherit functions from `Shape` so we’ll want to look in the `Shape` base class for them. All classes also inherit from the top-level module `shapes`. This is because certain common operations needed to implement shadow classes are implemented only once and reused in the wrapper code for various classes and structures.

Since SWIG shadow classes are implemented in Perl, it is easy to subclass from any SWIG generated class. To do this, simply put the name of a SWIG class in the `@ISA` array for your new class.

Iterators

With each class or structure, SWIG also generates a pair of functions to support Perl iterators. This makes it possible to use the `keys` and `each` functions on a C/C++ object. Iterators are implemented using code like this :

```
sub FIRSTKEY {
    my $self = shift;
```

```
        @ITERATORS{$self} = ['x','y','z', ];
        my $first = shift @{$ITERATORS{$self}};
        return $first;
    }

    sub NEXTKEY {
        my $self = shift;
        $nelem = scalar @{$ITERATORS{$self}};
        if ($nelem > 0) {
            my $member = shift @{$ITERATORS{$self}};
            return $member;
        } else {
            @ITERATORS{$self} = ['x','y','z', ];
            return ();
        }
    }
```

The `%ITERATORS` hash table maintains the state of each object for which the `keys` or `each` function has been applied to. The state is maintained by keeping a list of the member names.

While iterators may be of limited use when working with C/C++ code, it turns out they can be used to perform an element by element copy of an object.

```
$v = new Vector(1,2,3);
$w = new Vector(0,0,0);
%$w = %$v;                # Copy contents of v into w
```

Where to go from here?

The SWIG Perl5 module is constantly improving to provide better integration with Perl and to be easier to use. The introduction of shadow classes and typemaps in this release are one more step in that direction. The SWIG `Examples` directory contains more simple examples of building Perl5 modules. As always, suggestions for improving the Perl5 implementation are welcome.

SWIG and Python 9

This chapter describes SWIG's support of Python. Many of the example presented here will have a scientific bias given Python's increasing use in scientific applications, but the techniques are widely applicable to other areas.

Preliminaries

SWIG 1.1 works with both Python 1.3 and Python 1.4. Given the choice, you should use the latest version of Python. You should also determine if your system supports shared libraries and dynamic loading. SWIG will work with or without dynamic loading, but the compilation process will vary.

Running SWIG

To build a Python module, run SWIG using the `-python` option :

```
%swig -python example.i
```

This will produce 2 files. The file `example_wrap.c` contains all of the C code needed to build a Python module and a documentation file describes the resulting interface. To build a Python module, you will need to compile the file `example_wrap.c` and link it with the rest of your program (and possibly Python itself). When working with shadow classes, SWIG will also produce a `.py` file, but this is described later.

Getting the right header files

In order to compile, you will need to locate the following directories that are part of the Python distribution :

For Python 1.3 :

```
/usr/local/include/Py
/usr/local/lib/python/lib
```

For Python 1.4 :

```
/usr/local/include/python1.4
/usr/local/lib/python1.4/config
```

The exact location may vary on your machine, but the above locations are typical.

Compiling a dynamic module

To build a shared object file, you need to compile your module in a manner similar to the following (shown for Irix 5.3):

```
% swig -python example.i
% gcc -c example.c
% gcc -c example_wrap.c -DHAVE_CONFIG_H -I/usr/local/include/python1.4 \
       -I/usr/local/lib/python1.4/config
% ld -shared example.o example_wrap.o -o examplemodule.so
```

Unfortunately, the process of building a shared object file varies on every single machine so you may need to read up on the man pages for your C compiler and linker.

When building a dynamic module, the name of the output file is important. If the name of your SWIG module is "`example`", the name of the corresponding object file should be "`examplemodule.so`" (or equivalent depending on your machine). The name of the module is specified using the `%module` directive or `-module` command line option.

While dynamic loading is the preferred method for making SWIG modules, it is not foolproof and not supported on all machines. It also doesn't work well with C++. In these cases, you can rebuild the Python interpreter with your extensions added.

Rebuilding the Python interpreter (aka. static linking)

The normal procedure for adding a new module to Python involves finding the Python source, adding an entry to the `Modules/Setup` file, and rebuilding the interpreter using the Python Makefile. While it's possible to simplify the process by using the VPATH feature of 'make', I've always found the process to be a little complicated for rapid prototyping.

SWIG provides an extremely easy, although somewhat unconventional, mechanism for rebuilding Python using SWIG's library feature. When you want to build a static version of Python, simply make an interface file like this :

```
%module example

extern int fact(int);
extern int mod(int, int);
extern double My_variable;

%include embed.i            // Include code for a static version of Python
```

The `embed.i` library file includes supporting code that contains everything needed to rebuild Python. To build your module, simply do the following :

```
% swig -python example.i
% gcc example.c example_wrap.c -DHAVE_CONFIG_H -I/usr/local/include/python1.4 \
       -I/usr/local/lib/python1.4/config \
       -L/usr/local/lib/python1.4/config -lModules -lPython -lObjects -lParser -lm \
       -o mypython
```

On some machines, you may need need to supply additional libraries on the link line. In particular, you may need to supply `-lsocket`, `-lnsl`, and `-ldl`.

The `embed.i` file will use all of the modules that are currently being used in your installed version of Python. Thus, your new version of Python will be identical to the old one except with your new module added. If you have configured Python to use modules such as `tkinter`, you may also need to supply linkage to the Tcl/Tk libraries and X11 libraries.

Python's `main()` program is rather unfriendly towards C++ code, but SWIG's `embed.i` module provides a replacement that can be compiled with the C++ compiler--making it easy to build C++ Python extensions.

The `embed.i` library should only be used with Python 1.4. If you are using Python 1.3, you should use the file `embed13.i` instead (this can be done by making a symbolic link in the SWIG library).

Building dynamic/static modules

A SWIG interface file can be used for both dynamic loading and static linking if you structure it as follows :

```
%module mymodule

#ifdef STATIC
%include embed.i
#endif

... declarations ...
```

Running SWIG with the `-DSTATIC` option will enable you to rebuild the Python interpreter in case dynamic loading is not supported. Most of SWIG's examples are structured in this manner.

Using your module

To use your module in Python, simply use Python's import command. The process is identical regardless of whether or not you used dynamic loading or rebuilt the Python interpreter :

```
% python
>>> import example
>>> example.fact(4)
24
>>>
```

Compilation problems and compiling with C++

For the most part, compiling Python modules is straightforward, but there are a number of potential problems :

- Dynamic loading is not supported on all machines. If you can't get a module to build, you might try building a new version of Python using static linking instead.
- Dynamic loading and C++ do not mix well. If your C++ code contains any static constructors, you will need to rebuild the Python interpreter instead of building a dynamic module.
- If building a dynamic C++ module using g++, you may need to link against `libgcc.a`, `libg++.a`, and `libstc++.a` libraries.

- Make sure you are using the correct header files and libraries. A module compiled with Python 1.3 probably won't work with Python 1.4.

Building Python Extensions under Windows 95/NT

Building a SWIG extension to Python under Windows 95/NT is roughly similar to the process used with Unix. Normally, you will want to produce a DLL that can be loaded into the Python interpreter. This section covers the process of using SWIG with Microsoft Visual C++ 4.x although the procedure may be similar with other compilers as well. SWIG currently supports both the basic Python release and Pythonwin. In order to build extensions, you will probably need to download the source to these packages as you will need the Python header files.

Running SWIG from Developer Studio

If you are developing your application within Microsoft developer studio, SWIG can be invoked as a custom build option. The process roughly follows these steps :

- Open up a new workspace and use the AppWizard to select a DLL project.
- Add both the SWIG interface file (the .i file), any supporting C files, and the name of the wrapper file that will be created by SWIG (ie. `example_wrap.c`). Note : If using C++, choose a different suffix for the wrapper file such as `example_wrap.cxx`. Don't worry if the wrapper file doesn't exist yet--Developer studio will keep a reference to it around.
- Select the SWIG interface file and go to the settings menu. Under settings, select the "Custom Build" option.
- Enter "SWIG" in the description field.
- Enter "`swig -python -o $(ProjDir)\$(InputName)_wrap.c $(InputPath)`" in the "Build command(s) field"
- Enter "`$(ProjDir)\$(InputName)_wrap.c`" in the "Output files(s) field".
- Next, select the settings for the entire project and go to "C++:Preprocessor". Add the include directories for your Python installation under "Additional include directories".
- Define the symbols __WIN32__ under preprocessor options.
- Finally, select the settings for the entire project and go to "Link Options". Add the Python library file to your link libraries. For example "python14.lib". Also, set the name of the output file to match the name of your Python module (ie. example.dll).
- Build your project.

Now, assuming all went well, SWIG will be automatically invoked when you build your project. Any changes made to the interface file will result in SWIG being automatically invoked to produce a new version of the wrapper file. To run your new Python extension, simply run Python and use the use command as normal. For example :

```
MSDOS > python
>>> import example
>>>print example.fact(4)
24
>>>
```

Using NMAKE

Alternatively, SWIG extensions can be built by simply writing a Makefile for NMAKE. To do this, make sure the environment variables for MSVC++ are available and the MSVC++ tools are in your path. Now, just write a short Makefile like this :

```
# Makefile for building a Python extension

SRCS          = example.c
IFILE         = example
INTERFACE     = $(IFILE).i
WRAPFILE      = $(IFILE)_wrap.c

# Location of the Visual C++ tools (32 bit assumed)

TOOLS         = c:\msdev
TARGET        = example.dll
CC            = $(TOOLS)\bin\cl.exe
LINK          = $(TOOLS)\bin\link.exe
INCLUDE32     = -I$(TOOLS)\include
MACHINE       = IX86

# C Library needed to build a DLL

DLLIBC        = msvcrt.lib oldnames.lib

# Windows libraries that are apparently needed
WINLIB        = kernel32.lib advapi32.lib user32.lib gdi32.lib comdlg32.lib
winspool.lib

# Libraries common to all DLLs
LIBS          = $(DLLIBC) $(WINLIB)

# Linker options
LOPT      = -debug:full -debugtype:cv /NODEFAULTLIB /RELEASE /NOLOGO \
             /MACHINE:$(MACHINE) -entry:_DllMainCRTStartup@12 -dll

# C compiler flags

CFLAGS        = /Z7 /Od /WX /c /W3 /nologo
PY_INCLUDE    = -Id:\python-1.4\Include -Id:\python-1.4 -Id:\python-1.4\Pc
PY_LIB        = d:\python-1.4\vc40\python14.lib
PY_FLAGS = /D__WIN32__

python::
       swig -python -o $(WRAPFILE) $(INTERFACE)
       $(CC) $(CFLAGS) $(PY_FLAGS) $(PY_INCLUDE) $(SRCS) $(WRAPFILE)
       set LIB=$(TOOLS)\lib
       $(LINK) $(LOPT) -out:example.dll $(LIBS) $(PY_LIB) example.obj example_wrap.obj
```

To build the extension, run NMAKE. This is a pretty simplistic Makefile, but hopefully its enough to get you started.

The low-level Python/C interface

The SWIG Python module is based upon a basic low-level interface that provides access to C functions, variables, constants, and C++ classes. This low-level interface is often used to create more sophisticated interfaces (such as shadow classes) so it may be hidden in practice.

Modules

The SWIG `%module` directive specifies the name of the Python module. If you specified '`%module example`', then everything found in a SWIG interface file will be contained within the Python '`example`' module. Make sure you don't use the same name as a built-in Python command or standard module or your results may be unpredictable.

Functions

C/C++ functions are mapped directly into a matching Python function. For example :

```
%module example
extern int fact(int n);
```

gets turned into the Python function `example.fact(n)` :

```
>>> import example
>>> print example.fact(4)
24
>>>
```

Variable Linking

SWIG provides access to C/C++ global variables, but the mechanism is slightly different than one might expect due to object model used in Python. When you type the following in Python :

```
a = 3.4
```

"a" becomes a name for an object containing the value 3.4. If you later type

```
b = a
```

Then "a" and "b" are both names for the object containing the value 3.4. In other words, there is only one object containing 3.4 and "a" and "b" are both names that refer to it. This is a very different model than that used in C. For this reason, there is no mechanism for mapping "assignment" in Python onto C global variables (because assignment is Python is really a naming operation).

Thus, to provide access to C global variables, SWIG creates a special Python object called '`cvar`' that is added to each SWIG generated module. This object is then used to access global variables as follows :

```
// SWIG interface file with global variables
%module example
...
extern int My_variable;
extern double density;
...
```

Now in Python :

```
>>> import example
```

```
>>> # Print out value of a C global variable
>>> print example.cvar.My_variable
4
>>> # Set the value of a C global variable
>>> example.cvar.density = 0.8442
>>> # Use in a math operation
>>> example.cvar.density = example.cvar.density*1.10
```

Just remember, all C globals need to be prefixed with a "`cvar.`" and you will be set. If you would like to use a name other than "`cvar`", it can be changed using the `-globals` option :

```
% swig -python -globals myvar example.i
```

Some care is in order when importing multiple SWIG modules. If you use the "`from <file> import *`" style of importing, you will get a name clash on the variable '`cvar`' and will only be able to access global variables from the last module loaded. SWIG does not create `cvar` if there are no global variables in a module.

Constants

C/C++ constants are installed as new Python objects containing the appropriate value. These constants are given the same name as the corresponding C constant. "Constants" are not guaranteed to be constants in Python---in other words, you are free to change them and suffer the consequences!

Pointers

Pointers to C/C++ objects are represented as character strings such as the following :

```
_100f8e2_Vector_p
```

A NULL pointer is represented by the string "NULL". By default, SWIG wrapper functions will not accept a "NULL" pointer value. If you want to pass a NULL value, you can compile the SWIG wrapper file with the option `-DALLOW_NULL`, or you can explicitly create a NULL pointer consisting of the value 0 and a type such as :

```
_0_Vector_p
```

To some Python users, the idea of representing pointers as strings may seem strange, but keep in mind that pointers are meant to be opaque objects. In practice, you may never notice that pointers are character strings. There is also a certain efficiency in using this representation as it is easy to pass pointers around between modules and it is unnecessary to rely on a new Python datatype. Eventually, pointers may be represented as special Python objects, but the string representation works remarkably well so there has been little need to replace it.

Structures

The low-level SWIG interface only provides a simple interface to C structures. For example :

```
struct Vector {
        double x,y,z;
};
```

gets mapped into the following collection of C functions :

```
double Vector_x_get(Vector *obj)
double Vector_x_set(Vector *obj, double x)
double Vector_y_get(Vector *obj)
double Vector_y_set(Vector *obj, double y)
double Vector_z_get(Vector *obj)
double Vector_z_set(Vector *obj, double z)
```

These functions are then used in the resulting Python interface. For example :

```
# v is a Vector that got created somehow
>>> Vector_x_get(v)
3.5
>>> Vector_x_set(v,7.8)             # Change x component
>>> print Vector_x_get(v), Vector_y_get(v), Vector_z_get(v)
7.8 -4.5 0.0
>>>
```

Similar access is provided for unions and the data members of C++ classes.

C++ Classes

C++ classes are handled by building a set of low level accessor functions. Consider the following class :

```
class List {
public:
  List();
  ~List();
  int  search(char *item);
  void insert(char *item);
  void remove(char *item);
  char *get(int n);
  int  length;
static void print(List *l);
};
```

When wrapped by SWIG, the following functions will be created :

```
List *new_List();
void delete_List(List *l);
int List_search(List *l, char *item);
void List_insert(List *l, char *item);
void List_remove(List *l, char *item);
char *List_get(List *l, int n);
int List_length_get(List *l);
int List_length_set(List *l, int n);
void List_print(List *l);
```

Within Python, these are the functions used to access the C++ class :

```
>>> l = new_List()
>>> List_insert(l,"Ale")
>>> List_insert(l,"Stout")
>>> List_insert(l,"Lager")
>>> List_print(l)
Lager
```

```
Stout
Ale
>>> print List_length_get(l)
3
>>> print l
_1008560_List_p
>>>
```

C++ objects are really just pointers (which are represented as strings). Member functions and data are accessed by simply passing a pointer into a collection of accessor functions that take the pointer as the first argument.

While somewhat primitive, the low-level SWIG interface provides direct and flexible access to C++ objects. As it turns out, a more elegant method of accessing structures and classes is available using shadow classes.

Python shadow classes

The low-level interface generated by SWIG provides access to C structs and C++ classes, but it doesn't look much like a class that might be created in Python (in fact, it looks nothing like one!). However, it is possible to use the low-level C interface to write a Python class that looks like the original C++ class. In this case, the Python class is said to "shadow" the C++ class.

A simple example

For our earlier List class, a Python shadow class could be written like this :

```
class List:
       def __init__(self):
              self.this = new_List()
       def __del__(self):
              delete_List(self.this)
       def search(self,item):
              return List_search(self.this,item)
       def insert(self,item):
              List_insert(self.this,item)
       def remove(self,item):
              List_remove(self.this,item)
       def get(self,n):
              return List_get(self.this,n)
       def __getattr__(self,name):
              if name == "length":  return List_length_get(self.this))
              else :                return self.__dict__[name]
       def __setattr__(self,name,value):
              if name == "length":  List_length_set(self.this,value)
              else :                self.__dict__[name] = value
```

When used in a Python script, we could now do things like this :

```
>>> l = List()
>>> l.insert("Ale")
>>> l.insert("Stout")
>>> l.insert("Lager")
>>> List_print(l.this)
```

```
Lager
Stout
Ale
>>> l.length
3
```

Obviously, this is a much nicer interface than before--and it only required a small amount of Python coding.

Why write shadow classes in Python?

While one could wrap C/C++ objects directly into Python as new Python types, this approach has a number of problems. First, as the C/C++ code gets complicated, the resulting wrapper code starts to become extremely ugly. It also becomes hard to handle inheritance and more advanced language features. A second, and more serious problem, is that Python "types" created in C can not be subclassed or used in the same way as one might use a real Python class. As a result, it is not possible to do interesting things like create Python classes that inherit from C++ classes.

By writing shadow classes in Python instead of C, the classes become real Python classes that can be used as base-classes in an inheritance hierarchy or for other applications. Writing the shadow classes in Python also greatly simplies coding complexity as writing in Python is much easier than trying to accomplish the same thing in C. Finally, by writing shadow classes in Python, they are easy to modify and can be changed without ever recompiling any of the C code.

The problems of combining C++ and Python have been of great interest to the Python community. SWIG is primarily concerned with accessing C++ from Python. Readers who are interested in more than this (and the idea of accessing Python classes from C++) are encouraged to look into the MESS extension which aims to provide a tighter integration between C++ and Python. The recently announced GRAD package also shows much promise and provides very comprehensive C++/Python interface.

Automated shadow class generation

SWIG can automatically generated shadow classes if you use the `-shadow` option :

```
swig -python -shadow interface.i
```

This will create the following two files :

```
interface_wrap.c
module.py
```

The file `interface_wrap.c` contains the normal SWIG C/C++ wrappers. The file `module.py` contains the Python code corresponding to shadow classes. The name of this file will be the same as specified by the `%module` directive in the SWIG interface file.

Associated with the two files are TWO Python modules. The C module '`modulec`' contains the low-level C interface that would have been created without the `-shadow` option. The Python module '`module`' contains the Python shadow classes that have been built around the low-level interface. To use the module, simply use '`import module`'. For all practical purposes, the '`modulec`' module is completely hidden although you can certainly use it if you want to.

Compiling modules with shadow classes

To compile a module involving shadow classes, you can use the same procedure as before except that the module name now has an extra ‘c’ added to the end of the name. Thus, an interface file like this

```
%module example
... a bunch of declarations ...
```

might be compiled as follows :

```
% swig -python -shadow example.i
% gcc -c example.c example_wrap.c -I/usr/local/include/python1.4 \
       -I/usr/local/lib/python1.4/config -DHAVE_CONFIG_H
% ld -shared example.o example_wrap.o -o examplecmodule.so
```

Notice the naming of ‘examplecmodule.so’ as opposed to ‘examplemodule.so’ that would be used without shadow classes.

When using static linking, no changes need to be made to the compilation process.

Where to go for more information

Shadow classes turn out to be so useful that they are used almost all of the time with SWIG. All of the examples presented here will assume that shadow classes have been enabled. The precise implementation of shadow classes is described at the end of this chapter and is not necessary information in order to effectively use SWIG.

About the Examples

The next few sections will go through a series of Python examples in varying complexity. These examples are designed to illustrate how SWIG can be used to integrate C/C++ and Python in a variety of ways. Some of the things that will be covered include :

- Controlling a simple C++ program with Python
- Wrapping a C library.
- Adding Python methods to existing C++ classes
- Accessing arrays and other common data structures.
- Building reusable components.
- Writing C/C++ callback functions in Python.
- And a bunch of other really cool stuff.

Solving a simple heat-equation

In this example, we will show how Python can be used to control a simple physics application--in this case, some C++ code for solving a 2D heat equation. This example is probably overly simplistic, but hopefully it’s enough to give you some ideas.

The C++ code

Our simple application consists of the following two files :

```
// File : pde.h
// Header file for Heat equation solved

#include <math.h>
#include <stdio.h>

// A simple 2D Grid structure

// A simple structure for holding a 2D grid of values
struct Grid2d {
  Grid2d(int ni, int nj);
  ~Grid2d();
  double **data;
  int      xpoints;
  int      ypoints;
};

// Simple class for solving a heat equationequation */
class Heat2d {
private:
  Grid2d    *work;                        // Temporary grid, needed for solver
  double    h,k;                          // Grid spacing
public:
  Heat2d(int ni, int nj);
  ~Heat2d();
  Grid2d    *grid;                        // Data
  double     dt;                          // Timestep
  double     time;                        // Elapsed time
  void       solve(int nsteps);           // Run for nsteps
  void       set_temp(double temp);       // Set temperature
};
```

The supporting C++ code implements a simple partial differential equation solver and some operations on the grid data structure. The precise implementation isn't important here, but all of the code can be found in the "`Examples/python/manual`" directory of the SWIG distribution.

Making a quick and dirty Python module

Given our simple application, making a Python module is easy. Simply use the following SWIG interface file :

```
// File : pde.i
%module pde
%{
#include "pde.h"
%}

%include pde.h

// This allows us to statically link Python (optional)
#ifdef STATIC
%include embed.i
```

```
#endif
```

Since `pde.h` is fairly simple, we can simply include it directly into our interface file using `%include`. However, we also need to make sure we also include it in the `%{,%}` block--otherwise we'll get a huge number of compiler errors when we compile the resulting wrapper file.

To build the module simply run SWIG with the following options

```
swig -python -shadow pde.i
```

and compile using the techniques described in the beginning of this chapter.

Using our new module

We are now ready to use our new module. To do this, we can simply write a Python script like this :

```
# A fairly uninteresting example

from pde import *

h = Heat2d(50,50)

h.set_temp(1.0)
print "Dt = ", h.dt

# Solve something

for i in range(0,25):
       h.solve(100)
       print "time = ", h.time
```

When run, we get rather exciting output such as the following :

```
Dt =  2.5e-05
time =  0.0025
time =  0.005
time =  0.0075
...
time =  0.06
time =  0.0625
```

(okay, well it's not that exciting--well, at least not yet).

While this has only been a simple example it is important to note that we could have just as easily written the same thing in C++. For example :

```
// Python example written in C++

#include "pde.h"
#include <stdio.h>

int main(int argc, char **argv) {
```

```
    Heat2d *h;

    h = new Heat2d(50,50);
    printf("Dt = %g\n", h->dt);

    h->set_temp(1.0);

    for (int i = 0; i < 25; i++) {
      h->solve(100);
      printf("time = %g\n", h->time);
    }
  }
```

For the most part, the code looks identical (although the Python version is simpler). As for performance, the Python version runs less than 1% slower than the C++ version on my machine. Given that most of the computational work is written in C++, there is very little performance penalty for writing the outer loop of our calculation in Python in this case.

Unfortunately, our Python version suffers a number of drawbacks. Most notably, there is no way for us to access any of the grid data (which is easily accomplished in C++). However, there are ways to fix this :

Accessing array data

Now, let's modify our heat equation problem so that we can access grid data directly from Python. This can be done by modifying our interface file as follows :

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

%include pde.h

// Add a few "helper" functions to extract grid data
%inline %{
double  Grid2d_get(Grid2d *g, int i, int j) {
      return g->data[i][j];
}
void    Grid2d_set(Grid2d *g, int i, int j, double val) {
      g->data[i][j] = val;
}
%}
```

Rather than modifying our C++ code, it is easy enough to supply a few accessor functions directly in our interface file. These function may only be used from Python so this approach makes sense and it helps us keep our C++ code free from unnecessary clutter. The %inline directive is a convenient method for adding helper functions since it both includes and wraps the enclosed code.

We can now use our accessor functions to write a more sophisticated Python script :

```
# An example using our set/get functions

from pde import *
```

```
# Set up an initial condition
def initcond(h):
       h.set_temp(0.0)
       nx = h.grid.xpoints
       for i in range(0,nx):
              Grid2d_set(h.grid,i,0,1.0)                        # Set grid values

# Dump out to a file
def dump(h,filename):
       f = open(filename,"w")
       nx = h.grid.xpoints
       ny = h.grid.ypoints
       for i in range(0,nx):
              for j in range(0,ny):
                     f.write(str(Grid2d_get(h.grid,i,j))+"\n")  # Get grid value
       f.close()

# Set up a problem and run it

h = Heat2d(50,50)
initcond(h)
fileno = 1
for i in range(0,25):
       h.solve(100)
       dump(h,"Dat"+str(fileno))
       print "time = ", h.time
       fileno = fileno+1
```

We now have a Python script that can create a grid, set up an initial condition, run a simulation, and dump a collection of datafiles. So, with just a little supporting code in our interface file, we can start to do useful work from Python.

Use Python for prototyping, C for performance

Now that it is possible to access grid data from Python, it is possible to quickly write code for all sorts of operations. However, Python may not provide enough performance for certain operations. For example, the `dump()` function in the previous example may become quite slow as problem sizes increase. Thus, we might consider writing it in C++ such as the follows:

```
void dump(Heat2d *h, char *filename) {
      FILE *f;
      int   i,j;

      f = fopen(filename,"w");
      for (i = 0; i < h->grid->xpoints; i++)
       for (j = 0; j < h->grid->ypoints; j++)
         fprintf(f,"%0.17f\n",h->grid->data[i][j]);
      fclose(f);
}
```

To use this new function, simple put its declaration in the SWIG interface file and get rid of the old Python version. The Python script won't know that you changed the implementation.

Getting even more serious about array access

We have provided access to grid data using a pair of get/set functions. However, using these functions is a little clumsy because they always have to be called as a separate function like this :

```
Grid2d_set(grid,i,j,1.0)
```

It might make more sense to make the get/set functions appear like member functions of the `Grid2D` class. That way we could use them like this :

```
grid.set(i,j,1.0)
grid.get(i,j)
```

Of course, SWIG provides a simple technique for doing just this as illustrated in the following interface file :

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

// Add a few "helper" functions to extract grid data
%{
    double  Grid2d_get(Grid2d *g, int i, int j) {
      return g->data[i][j];
    }
    void    Grid2d_set(Grid2d *g, int i, int j, double val) {
      g->data[i][j] = val;
    }
%}

// Now add these helper functions as methods of Grid2d

%addmethods Grid2d {
    double get(int i, int j);
    void   set(int i, int j, double val);
}
// %include embed.i           // Uncomment if rebuilding Python
```

The `%addmethods` directive tells SWIG that you want to add new functions to an existing C++ class or C structure for the purposes of building an interface. In reality, SWIG leaves the original C++ class unchanged, but the resulting Python interface will have some new functions that appear to be class members.

SWIG uses a naming convention for adding methods to a class. If you have a class `Foo` and you add a member function `bar(args),` SWIG will look for a function called `Foo_bar(this,args)` that implements the desired functionality. You can write this function yourself, as in the previous interface file, but you can also just supply the code immediately after a declaration like this :

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

```
%include pde.h

// Add some new accessor methods to the Grid2D class
%addmethods Grid2d {
  double get(int i, int j) {
    return self->data[i][j];
  };
  void set(int i, int j, double val) {
    self->data[i][j] = val;
  };
};
```

In this case, SWIG will take the supplied code, and automatically generate a function for the method. The special variable "`self`" is used to hold a pointer to the corresponding object. The `self` pointer is exactly like the C++ "`this`" pointer, except that the name has been changed in order to remind you that you aren't really writing a real class member function. (Actually, we can't use "this" because the C++ compiler won't let us!)

Finally, it is worth noting that the `%addmethods` directive may also be used inside a class definition like this :

```
struct Grid2d {
  Grid2d(int ni, int nj);
  ~Grid2d();
  double **data;
  int      xpoints;
  int      ypoints;
  %addmethods {
       double get(int i, int j);
       void   set(int i, int j, double value);
  }
};
```

This latter case is really only useful if the C++ class definition is included in the SWIG interface file itself. If you are pulling the class definition out of a separate file or a C++ header file, using a separate `%addmethods` directive is preferable.

Okay, enough talk. By adding the set/get functions as methods, we can now change our Python script to look like this :

```
# An example using our new set/get functions

from pde import *

# Set up an initial condition

def initcond(h):
       h.set_temp(0.0)
       nx = h.grid.xpoints
       for i in range(0,nx):
              h.grid.set(i,0,1.0)         # Note changed interface

# Dump out to a file
def dump(h,filename):
       f = open(filename,"w")
```

```
        nx = h.grid.xpoints
        ny = h.grid.ypoints
        for i in range(0,nx):
               for j in range(0,ny):
                      f.write(str(h.grid.get(i,j))+"\n")
        f.close()

# Set up a problem and run it

h = Heat2d(50,50)
initcond(h)
fileno = 1

for i in range(0,25):
       h.solve(100)
       h.dump("Dat"+str(fileno))
       print "time = ", h.time
       fileno = fileno+1
```

Now it's starting to look a little better, but we can do even better...

Getting really serious about arrays

Now that you're getting into the spirit of things, let's make it so that we can access our Grid2D data like a Python array. As it turns out, we can do this with a little trickery in the SWIG interface file. Don't forget to put on your Python's wizards cap...

```
// SWIG interface file with Python array methods added
%module pde
%{
#include "pde.h"
%}

%include pde.h

%inline %{
  // Define a new Grid2d row class
  struct Grid2dRow {
    Grid2d *g;       // Grid
    int    row;      // Row number
    // These function names should look familar
    double __getitem__(int i) {
      return g->data[row][i];
    };
    void __setitem__(int i, double val) {
      g->data[row][i] = val;
    };
  };
%}



// Now add a __getitem__ method to Grid2D to return a row
%addmethods Grid2d {
  Grid2dRow __getitem__(int i) {
    Grid2dRow r;
    r.g = self;
```

```
    r.row = i;
    return r;
  };
};
```

We have now replaced our get/set functions with `__getitem__` and `__setitem__` functions--the functions Python needs to access arrays. We have also added a special `Grid2dRow` class. This is needed to allow us to make a funny kind of “multidimensional” array in Python. Using this new interface file, we can now write a Python script like this :

```
# An example script using our array access functions

from pde import *

# Set up an initial condition

def initcond(h):
       h.set_temp(0.0)
       nx = h.grid.xpoints
       for i in range(0,nx):
              h.grid[i][0] = 1.0            # Note nice array access

# Set up a problem and run it

h = Heat2d(50,50)
initcond(h)
fileno = 1

for i in range(0,25):
       h.solve(100)
       h.dump("Dat"+str(fileno))
       print "time = ", h.time
       fileno = fileno+1

# Calculate average temperature over the region

sum = 0.0
for i in range(0,h.grid.xpoints):
       for j in range(0,h.grid.ypoints):
              sum = sum + h.grid[i][j]        # Note nice array access

avg = sum/(h.grid.xpoints*h.grid.ypoints)

print "Avg temperature = ",avg
```

Summary (so far)

In our first example, we have taken a very simple C++ problem and wrapped it into a Python module. With a little extra work, we have been able to provide array type access to our C++ data from Python and to write some computationally intensive operations in C++. At this point, it would easy to write all sorts of Python scripts to set up problems, run simulations, look at the data, and to debug new operations implemented in C++.

Wrapping a C library

In this next example, we focus on wrapping the gd-1.2 library. gd is public domain library for fast GIF image creation written by Thomas Boutell and available on the internet. gd-1.2 is copyright 1994,1995, Quest Protein Database Center, Cold Spring Harbor Labs. This example assumes that you have gd-1.2 available, but you can use the ideas here to wrap other kinds of C libraries.

Preparing a module

Wrapping a C library into a Python module usually involves working with the C header files associated with a particular library. In some cases, a header file can be used directly (without modification) with SWIG. Other times, it may be necessary to copy the header file into a SWIG interface file and make a few touch-ups and modifications. In either case, it's usually not too difficult.

To make a module, you can use the following checklist :

- Locate the header files associated with a package
- Look at the contents of the header files to see if SWIG can handle them. In particular, SWIG can not handle excessive use of C preprocessor macros, or non-ANSI C syntax.
- Make a SWIG interface file for your module specifying the name of the module, the appropriate header files, and any supporting documentation that you would like to provide.
- If the header file is clean, simply use SWIG's `%include` directive. If not, paste the header file into your interface file and edit it until SWIG can handle it.
- Clean up the interface by possibly adding supporting code, deleting unnecessary functions, and eliminating clutter.
- Run SWIG and compile.

In the case of the gd library, we can simply use the following SWIG interface file :

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

%section "gd-1.2",ignore
%include "/usr/local/include/gd.h"

// These will come in handy later
FILE *fopen(char *, char *);
void fclose(FILE *f);
```

In this file, we first tell SWIG to put all of the gd functions in a separate documentation section and to ignore all comments. This usually helps clean up the documentation when working with raw header files. Next, we simply include the contents of "gd.h" directly. Finally, we provide wrappers to `fopen()` and `fclose()` since these will come in handy in our Python interface.

If we give this interface file to SWIG, we will get the following output :

```
% swig -python -shadow  gd.i
Generating wrappers for Python
/usr/local/include/gd.h : Line 32.  Arrays not currently supported (ignored).
/usr/local/include/gd.h : Line 33.  Arrays not currently supported (ignored).
/usr/local/include/gd.h : Line 34.  Arrays not currently supported (ignored).
/usr/local/include/gd.h : Line 35.  Arrays not currently supported (ignored).
/usr/local/include/gd.h : Line 41.  Arrays not currently supported (ignored).
/usr/local/include/gd.h : Line 42.  Arrays not currently supported (ignored).
%
```

While SWIG was able to handle most of the header file, it also ran into a few unsupported declarations---in this case, a few data structures with array members. However, the warning messages also tell us that these declarations have simply been ignored. Thus, we can choose to continue and build our interface anyways. As it turns out in this case, the ignored declarations are of little or no consequence so we can ignore the warnings.

If SWIG is unable to process a raw header file or if you would like to eliminate the warning messages, you can structure your interface file as follows :

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

%section "gd-1.2",ignore

... paste the contents of gd.h here and remove problems ...

// A few extra support functions

FILE *fopen(char *, char *);
void fclose(FILE *f);

// %include embed.i         // Uncomment if rebuilding Python
```

This latter option requires a little more work (since you need to paste the contents of gd.h into the file and edit it), but is otherwise not much more difficult to do. For highly complex C libraries or header files that go overboard with the C preprocessor, you may need to do this more often. Your mileage may vary.

Using the gd module

Now, that we have created a module from the gd library, we can use it it Python scripts. The following script makes a simple image of a black background with a white line drawn on it. Notice how we have used our wrapped versions of `fopen()` and `fclose()` to create a FILE handle for use in the gd library (there are also ways to use Python file objects, but this is described later).

```
# Simple gd program

from gd import *

im = gdImageCreate(64,64)
black = gdImageColorAllocate(im,0,0,0)
white = gdImageColorAllocate(im,255,255,255)
gdImageLine(im,0,0,63,63,white)
```

```
out = fopen("test.gif","w")
gdImageGif(im,out)
fclose(out)
gdImageDestroy(im)
```

That was simple enough--and it only required about 5 minutes of work. Unfortunately, our gd module has a few problems...

Extending and fixing the gd module

While our first attempt at wrapping gd works for simple functions, there are a number of problems. For example, the gd-1.2 library contains the following function for drawing polygons :

```
void gdImagePolygon(gdImagePtr im, gdPointPtr points, int pointsTotal, int color);
```

The `gdImagePtr` is created by another function in our module and the parameters `pointsTotal` and `color` are simple integers. However, the 2nd argument is a pointer to an array of points as defined by the following data structure in the gd-1.2 header file :

```
typedef struct {
       int x, y;
} gdPoint, *gdPointPtr;
```

Unfortunately, there is no way to create a gdPoint in Python and consequently no way to call the gdImagePolygon function. A temporary setback, but one that is not difficult to solve using the `%addmethods` directive as follows :

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

%include "/usr/local/include/gd.h"

// Fix up the gdPoint structure a little bit
%addmethods gdPoint {
  // Constructor to make an array of "Points"
  gdPoint(int npoints) {
    return (gdPoint *) malloc(npoints*sizeof(gdPoint));
  };
  // Destructor to destroy this array
  ~gdPoint() {
    free(self);
  };
  // Python method for array access
  gdPoint *__getitem__(int i) {
    return self+i;
  };
};

FILE *fopen(char *, char *);
void fclose(FILE *f);
```

With these simple additions, we can now create arrays of points and use the polygon function as follows :

```
# Simple gd program

from gd import *

im = gdImageCreate(64,64)
black = gdImageColorAllocate(im,0,0,0)
white = gdImageColorAllocate(im,255,255,255)

pts = gdPoint(3);                    # Create an array of Points
pts[0].x,pts[0].y = (5,5)            # Assign a set of points
pts[1].x,pts[1].y = (60,25)
pts[2].x,pts[2].y = (16,60)

gdImagePolygon(im,pts,3,white)       # Draw a polygon from our array of points
out = fopen("test.gif","w")
gdImageGif(im,out)
fclose(out)
gdImageDestroy(im)
```

Building a simple 2D imaging class

Now it's time to get down to business. Using our gd-1.2 module, we can write a simple 2D imaging class that hides alot of the underlying details and provides scaling, translations, and a host of other operations. (It's a fair amount code, but still an interesting example).

```
# image.py
# Generic 2D Image Class
#
# Built using the 'gd-1.2' library by Thomas Boutell
#

import gd

class Image:
       def __init__(self,width,height,xmin=0.0,ymin=0.0,xmax=1.0,ymax=1.0):
              self.im = gd.gdImageCreate(width,height)
              self.xmin   = xmin
              self.ymin   = ymin
              self.xmax   = xmax
              self.ymax   = ymax
              self.width  = width
              self.height = height
              self.dx     = 1.0*(xmax-xmin)
              self.dy     = 1.0*(ymax-ymin)
              self.xtick  = self.dx/10.0
              self.ytick  = self.dy/10.0
              self.ticklen= 3
              self.name   = "image.gif"
              gd.gdImageColorAllocate(self.im,0,0,0)        # Black
              gd.gdImageColorAllocate(self.im,255,255,255)  # White
              gd.gdImageColorAllocate(self.im,255,0,0)      # Red
              gd.gdImageColorAllocate(self.im,0,255,0)      # Green
              gd.gdImageColorAllocate(self.im,0,0,255)      # Blue

       def __del__(self):
              print "Deleting"
```

```
        gd.gdImageDestroy(self.im)

    # Dump out this image to a file
    def write(self,name="NONE"):
        if name == "NONE":
            name = self.name
        f = gd.fopen(name,"w")
        gd.gdImageGif(self.im,f)
        gd.fclose(f)
        self.name = name

    # Virtual method that derived classes define
    def draw(self):
        print "No drawing method specified."

    # A combination of write and draw
    def show(self,filename="NONE"):
        self.draw()
        self.write(filename)

    # Load up a colormap from a Python array of (R,G,B) tuples
    def colormap(self, cmap):
        for i in range(0,255):
            gd.gdImageColorDeallocate(self.im,i)
        for c in cmap:
            gd.gdImageColorAllocate(self.im,c[0],c[1],c[2])

    # Change viewing region
    def region(self,xmin,ymin,xmax,ymax):
        self.xmin = xmin
        self.ymin = ymin
        self.xmax = xmax
        self.ymax = ymax
        self.dx     = 1.0*(xmax-xmin)
        self.dy     = 1.0*(ymax-ymin)

    # Transforms a 2D point into screen coordinates
    def transform(self,x,y):
        npt = []
        ix = (x-self.xmin)/self.dx*self.width + 0.5
        iy = (self.ymax-y)/self.dy*self.height + 0.5
        return (ix,iy)

    # A few graphics primitives
    def clear(self,color):
        gd.gdImageFilledRectangle(self.im,0,0,self.width,self.height,color)

    def plot(self,x,y,color):
        ix,iy = self.transform(x,y)
        gd.gdImageSetPixel(self.im,ix,iy,color)

    def line(self,x1,y1,x2,y2,color):
        ix1,iy1 = self.transform(x1,y1)
        ix2,iy2 = self.transform(x2,y2)
        gd.gdImageLine(self.im,ix1,iy1,ix2,iy2,color)

    def box(self,x1,y1,x2,y2,color):
        ix1,iy1 = self.transform(x1,y1)
        ix2,iy2 = self.transform(x2,y2)
```

```
        gd.gdImageRectangle(self.im,ix1,iy1,ix2,iy2,color)

def solidbox(self,x1,y1,x2,y2,color):
        ix1,iy1 = self.transform(x1,y1)
        ix2,iy2 = self.transform(x2,y2)
        gd.gdImageFilledRectangle(self.im,ix1,iy1,ix2,iy2,color)

def arc(self,cx,cy,w,h,s,e,color):
        ix,iy = self.transform(cx,cy)
        iw = (x - self.xmin)/self.dx * self.width
        ih = (y - self.ymin)/self.dy * self.height
        gd.gdImageArc(self.im,ix,iy,iw,ih,s,e,color)

def fill(self,x,y,color):
        ix,iy = self.transform(x,y)
        gd.gdImageFill(self,ix,iy,color)

def axis(self,color):
        self.line(self.xmin,0,self.xmax,0,color)
        self.line(0,self.ymin,0,self.ymax,color)
        x = -self.xtick*(int(-self.xmin/self.xtick)+1)
        while x <= self.xmax:
            ix,iy = self.transform(x,0)
            gd.gdImageLine(self.im,ix,iy-self.ticklen,ix,iy+self.ticklen,color)
            x = x + self.xtick
        y = -self.ytick*(int(-self.ymin/self.ytick)+1)
        while y <= self.ymax:
            ix,iy = self.transform(0,y)
            gd.gdImageLine(self.im,ix-self.ticklen,iy,ix+self.ticklen,iy,color)
            y = y + self.ytick

# scalex(s).  Scales the x-axis.  s is given as a scaling factor
def scalex(self,s):
        xc = self.xmin + self.dx/2.0
        dx = self.dx*s
        xmin = xc - dx/2.0
        xmax = xc + dx/2.0
        self.region(xmin,self.ymin,xmax,self.ymax)

# scaley(s).  Scales the y-axis.
def scaley(self,s):
        yc = self.ymin + self.dy/2.0
        dy = self.dy*s
        ymin = yc - dy/2.0
        ymax = yc + dy/2.0
        self.region(self.xmin,ymin,self.xmax,ymax)

# Zooms a current image.  s is given as a percent
def zoom(self,s):
        s = 100.0/s
        self.scalex(s)
        self.scaley(s)

# Move image left.  s is given in range 0,100. 100 moves a full screen left
def left(self,s):
        dx = self.dx*s/100.0
        xmin = self.xmin + dx
        xmax = self.xmax + dx
        self.region(xmin,self.ymin,xmax,self.ymax)
```

```
        # Move image right.  s is given in range 0,100. 100 moves a full screen right
        def right(self,s):
                self.left(-s)

        # Move image down.  s is given in range 0,100. 100 moves a full screen down
        def down(self,s):
                dy = self.dy*s/100.0
                ymin = self.ymin + dy
                ymax = self.ymax + dy
                self.region(self.xmin,ymin,self.xmax,ymax)

        # Move image up.  s is given in range 0,100. 100 moves a full screen up
        def up(self,s):
                self.down(-s)

        # Center image
        def center(self,x,y):
                self.right(50-x)
                self.up(50-y)
```

Our image class provides a number of methods for creating images, plotting points, making lines, and other graphical objects. We have also provided some methods for moving and scaling the image. Now, let's use this image class to do some interesting things :

A mathematical function plotter

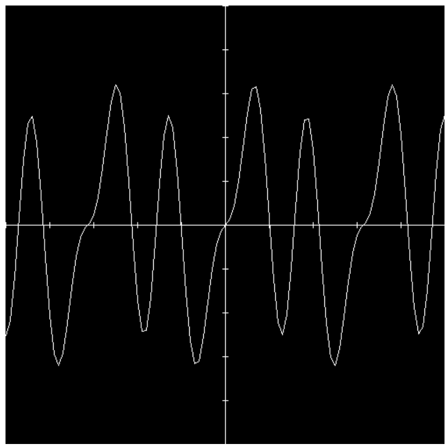
Here's a simple class that can be used to plot mathematical functions :

```
# funcplot.py

from image import *

class PlotFunc(Image):
        def __init__(self,func,xmin,ymin,xmax,ymax,width=500,height=500):
                Image.__init__(self,width,height,xmin,ymin,xmax,ymax)
                self.func = func
                self.npoints = 100
                self.color = 1
        def draw(self):
                self.clear(0)
                lastx = self.xmin
                lasty = self.func(lastx)
                dx = 1.0*(self.xmax-self.xmin)/self.npoints
                x = lastx+dx
                for i in range(0,self.npoints):
                        y = self.func(x)
                        self.line(lastx,lasty,x,y,self.color)
                        lastx = x
                        lasty = y
                        x = x + dx

                self.axis(1)
```

Most of the functionality is implemented in our image class so this is pretty simple. However, if we wanted to make a GIF image of a mathematical function, we could just do this :

```
>>> from funcplot import *
>>> import math
>>> p = PlotFunc(lambda x: 0.5*math.sin(x)+0.75*math.sin(2*x)-0.6*math.sin(3*x),
                 -10,-2,10,2)
>>> p.show("plot.gif")
```

Which would produce the following GIF image :



Plotting an unstructured mesh

Of course, perhaps we want to plot something a little more complicated like a mesh. Recently, a colleague came to me with some unstructured mesh data contained in a pair of ASCII formatted files. These files contained a collection of points, and a list of connectivities defining a mesh on these points. Reading and plotting this data in Python turned out to be relatively easy using the following script and our image base class :

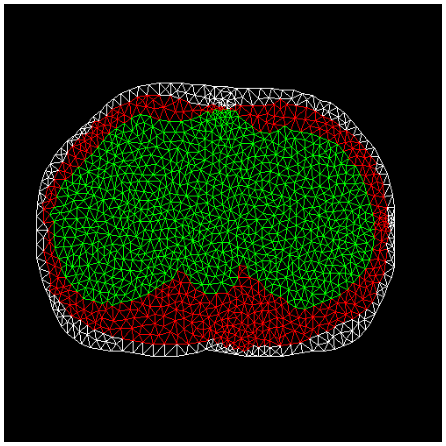
```
# plotmesh.py
# Plots an unstructured mesh stored as an ASCII file
from image import *
import string

class PlotMesh(Image):
        def __init__(self,filename,xmin,ymin,xmax,ymax,width=500,height=500):
                Image.__init__(self,width,height,xmin,ymin,xmax,ymax)
                # read in a mesh file in pieces
                pts = []
                # Read in data points
                atoi = string.atoi
                atof = string.atof
                f = open(filename+".pts","r")
                npoints = atoi(f.readline())
                for i in range(0,npoints):
                        l = string.split(f.readline())
                        pts.append((atof(l[0]),atof(l[1])))
                f.close()

                # Read in mesh data
```

```
                f = open(filename+".tris","r")
                ntris = string.atoi(f.readline())
                tris = [ ]
                for i in range(0,ntris):
                        l = string.split(f.readline())
                        tris.append((atoi(l[0])-1,atoi(l[1])-1,atoi(l[2])-1,atoi(l[3])))
                f.close()

        # Set up local attributes
                self.pts = pts
                self.npoints = npoints
                self.tris = tris
                self.ntris = ntris

        # Draw mesh
        def draw(self):
                self.clear(0);
                i = 0
                while i < self.ntris:
                        tri = self.tris[i]
                        pt1 = self.pts[tri[0]]
                        pt2 = self.pts[tri[1]]
                        pt3 = self.pts[tri[2]]
                        # Now draw the mesh
                        self.triangle(pt1[0],pt1[1],pt2[0],pt2[1],pt3[0],pt3[1],tri[3]);
                        i = i + 1

        # Draw a triangle
        def triangle(self,x1,y1,x2,y2,x3,y3,color):
                self.line(x1,y1,x2,y2,color)
                self.line(x2,y2,x3,y3,color)
                self.line(x3,y3,x1,y1,color)
```

This class simply reads the data into a few Python lists, has a drawing function for making a plot, and adds a special method for making triangles. Making a plot is now easy, just do this :

```
>>> from plotmesh.py import *
>>> mesh = PlotMesh("mesh",5,0,35,25)
>>> mesh.show(“mesh.gif”)
```

This produces the following GIF image :



When run interactively, we can also use simple commands to zoom in and move the image around. For example :

```
>>> mesh = PlotMesh("mesh",5,0,35,25)
>>> mesh.zoom(200)                   # Enlarge by 200%
>>> mesh.left(50)                    # Move image half a screen to left
>>> mesh.show()
>>>
```

From C to SWIG to Python

This example illustrates a number of things that are possible with SWIG and Python. First, it is usually relatively easy to build a Python interface to an existing C library. With a little extra work, it is possible to improve the interface by adding a few support functions such as our Point extensions. Finally, once in Python, it is possible to encapsulate C libraries in new kinds of Python objects and classes. We built a simple Image base class and used it to plot mathematical functions and unstructured 2D mesh data---two entirely different tasks, yet easily accomplished with a small amount of Python code. If we later decided to use a different C library such as OpenGL, we could wrap it in SWIG, change the Image base class appropriately , and use the function and mesh plotting examples without modification. I think this is pretty cool.

Putting it all together

Finally, let's combine our heat equation solver and graphics module into a single application. To do this, we first need to know how to combine two different SWIG generated modules. When different SWIG modules need to be combined, there are a number of things you can do.

Merging modules

Two SWIG modules can be combined into a single module if you make an interface file like this :

```
%module package
%include pde.i
%include gd.i
```

This will combine everything in both interface files into a single super-module called "package". The advantage to this approach is that it is extremely quick and easy. The disadvantage is that the module names of "pde" and "gd" will be lost. If you had a bunch of scripts that relied on those names, they would no longer work. Thus, combining modules in this way is probably only a good idea if the modules are closely related.

Using dynamic loading

If your system supports dynamic loading, you can build each SWIG module into a separate dynamically loadable module and load each one individually into Python. This is the preferred approach if it is supported on your system. SWIG wrapper files declare virtually everything as "static" so using dynamic loading with multiple SWIG generated modules will not usually cause any namespace clashes.

Use static linking

As an alternative to dynamic loading, you can use a special form of the `%module` directive as follows :

```
%module package, pdec, gdc
%include embed.i
```

This will build a static version of Python with 3 extension modules added (`package`, `pdec`, and `gdc`). When using this technique, the names of the modules refer to the low-level SWIG generated C/C++ modules. Thus, when shadow classes are used these modules must have an extra 'c' appended to the name (thus, "pdec" and "gdc" instead of "pde" and "gd"). The extra modules specified with the `%modules` directive do not necessarily have to be SWIG-generated modules. In practice, almost any kind of Python module can be listed here. It should also be noted that extra modules names are completely ignored if the `embed.i` library file is not used.

Building large multi-module systems

By default, SWIG includes the C code for the SWIG type-checker and variable linking into every module. However, when, building systems involving large numbers of SWIG modules, common code such as the SWIG pointer type-checker and variable linking extensions can be shared if you run SWIG with the `-c` option. For example :

```
% swig -c -python graphics.i
% swig -c -python network.i
% swig -c -python analysis.i
% swig -c -python math.i
% gcc -c graphics_wrap.c network_wrap.c analysis_wrap.c math_wrap.c
% ld -shared graphics_wrap.o -lswigpy -o graphicsmodule.so
% ld -shared network_wrap.o -lswigpy -o networkmodule.so
% ld -shared analysis_wrap.o -lswigpy -o analysismodule.so
% ld -shared math_wrap.o -o -lswigpy mymathmodule.so
```

`swigpy` is a special purpose library that contains the SWIG pointer type checker and other support code (see the `Misc` subdirectory of the SWIG distribution). When used in this manner, the same support code will be used for all of the modules. The `swigpy` library can also be applied when static linking is being used.

A complete application

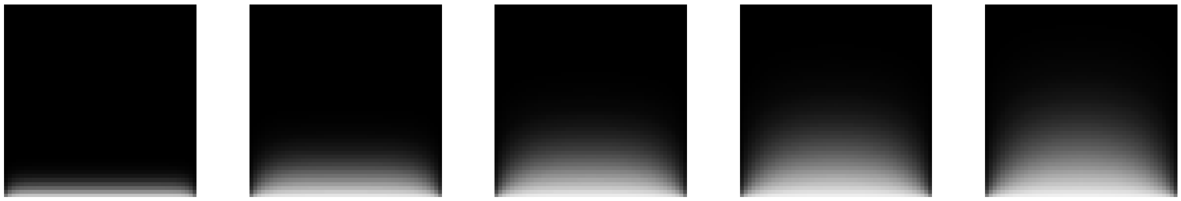
The following Python script shows an application that combines our C++ heat equation solver, our gd library, and our Image base class that we developed.

```
# Solve the heat equation.
# Make a series of data files
# Make a movie of GIF images

from pde import *
from image import *
import string

# Image class
class HeatImg(Image):
       def __init__(self,h,width=300,height=300):
              Image.__init__(self,width,height,0.0,0.0,1.0,1.0)
```

```
                self.h = h
                # Create a greyscale colormap
                cmap = []
                for i in range(0,255):
                        cmap.append((i,i,i))
                self.colormap(cmap)
                self.cmin = 0.0
                self.cmax = 1.0
                self.imgno = 1
        def draw(self):
                self.clear(0)
                dx = 1.0/(self.h.grid.xpoints-2)
                dy = 1.0/(self.h.grid.ypoints-2)
                i = 1
                x = 0.0
                while i < self.h.grid.xpoints:
                        j = 1;
                        y = 0.0
                        while j < self.h.grid.ypoints:
                                c = int((self.h.grid[i][j]-self.cmin)/(self.cmax-
                                         self.cmin)*255)
                                self.solidbox(x,y+dy,x+dx,y,c)
                                j = j + 1
                                y = y + dy
                        i = i + 1
                        x = x + dx
                self.name = "image"+string.zfill(self.imgno,4)+".gif"
                self.imgno = self.imgno+1

# Set up an initial condition
def initcond(h):
        h.set_temp(0.0)
        nx = h.grid.xpoints
        for i in range(0,nx):
                h.grid[i][0] = 1.0

# Set up a problem and run it
h = Heat2d(50,50)

# Make an image object
img = HeatImg(h)

initcond(h)
fileno = 1

# Run it
for i in range(0,25):
        h.solve(100)
        h.dump("Dat"+str(fileno))
        img.show()
        print "time = ", h.time
        fileno = fileno+1

# Calculate average temperature and exit
sum = 0.0
for i in range(0,h.grid.xpoints):
        for j in range(0,h.grid.ypoints):
                sum = sum + h.grid[i][j]
avg = sum/(h.grid.xpoints*h.grid.ypoints)
```

```
print "Avg temperature = ",avg
```

When run, we now get a collection of datafiles and series of images like this :



Thus, we have a simple physics application that only takes about 1 page of Python code, runs a simulation, creates data files, and a movie of images. We can easily change any aspect of the simulation, interactively query variables and examine data. New procedures can be written and tested in Python and later implemented in C++ if needed. More importantly, we have an application that is actually fun to use and modify (well, at least I think so).

Exception handling

The SWIG `%except` directive can be used to create a user-definable exception handler in charge of converting exceptions in your C/C++ program into Python exceptions. The chapter on exception handling contains more details, but suppose you have a C++ class like the following :

```
class RangeError {};   // Used for an exception

class DoubleArray {
  private:
    int n;
    double *ptr;
  public:
    // Create a new array of fixed size
    DoubleArray(int size) {
      ptr = new double[size];
      n = size;
    }
    // Destroy an array
    ~DoubleArray() {
       delete ptr;
    }
    // Return the length of the array
    int   length() {
      return n;
    }

    // Get an item from the array and perform bounds checking.
    double getitem(int i) {
      if ((i >= 0) && (i < n))
        return ptr[i];
      else
        throw RangeError();
    }

    // Set an item in the array and perform bounds checking.
```

```
        void setitem(int i, double val) {
          if ((i >= 0) && (i < n))
            ptr[i] = val;
          else {
            throw RangeError();
          }
        }
      };
```

The functions associated with this class can throw a range exception for an out-of-bounds array access. We can catch this in our Python extension by specifying the following in an interface file :

```
    %except(python) {
      try {
        $function
      }
      catch (RangeError) {
        PyErr_SetString(PyExc_IndexError,"index out-of-bounds");
        return NULL;
      }
    }
```

Now, when the C++ class throws a RangeError exception, our wrapper functions will catch it, turn it into a Python exception, and allow a graceful death as opposed to just having some sort of mysterious program crash. Since SWIG's exception handling is user-definable, we are not limited to C++ exception handling. Please see the chapter on exception handling for more details.

Python exceptions can be raised using the `PyErr_SetString()` function as shown above. The following table provides a listing of the different Python exceptions available.

Built-in Python Exceptions

`PyExc_AttributeError`	Raised when an attribute reference or assignment fails
`PyExc_EOFError`	Indicates the end-of-file condition for I/O operations.
`PyExc_IOError`	Raised when an I/O occurs, e.g, 'file not found', 'permission denied', etc...
`PyExc_ImportError`	Raised when an 'import' statement fails.
`PyExc_IndexError`	Indicates a subscript out of range--usually for array and list indexing.
`PyExc_KeyError`	Raised when a dictionary key is not found in the set of existing keys. Could be used for hash tables and similar objects.
`PyExc_KeyboardInterrupt`	Raised when the user hits the interrupt key.
`PyExc_MemoryError`	Indicates a recoverable out of memory error.
`PyExc_NameError`	Raised to indicate a name not found.

Built-in Python Exceptions

`PyExc_OverflowError`	Raised when results of arithmetic computation is too large to be represented.
`PyExc_RuntimeError`	A generic exception for “everything else”. Errors that don’t fit into other categories.
`PyExc_SyntaxError`	Normally raised when the Python parser encounters a syntax error.
`PyExc_SystemError`	Used to indicate various system errors.
`PyExc_SystemExit`	A serious error, abandon all hope now.
`PyExc_TypeError`	Raised when an object is of invalid type.
`PyExc_ValueError`	Raised when an object has the right type, but an inappropriate value.
`PyExc_ZeroDivisionError`	Division by zero error.

Remapping C datatypes with typemaps

This section describes how SWIG’s treatment of various C/C++ datatypes can be remapped using the SWIG `%typemap` directive. While not required, this section assumes some familiarity with Python’s C API. The reader is advised to consult the Python reference manual or one of the books on Python. A glance at the chapter on SWIG typemaps will also be useful.

What is a typemap?

A typemap is mechanism by which SWIG’s processing of a particular C datatype can be overridden. A simple typemap might look like this :

```
%module example

%typemap(python,in) int {
       $target = (int) PyLong_AsLong($source);
       printf("Received an integer : %d\n",$target);
}
...
extern int fact(int n);
```

Typemaps require a language name, method name, datatype, and conversion code. For Python, “python” should be used as the language name. The “in” method in this example refers to an input argument of a function. The datatype ‘int’ tells SWIG that we are remapping integers. The supplied code is used to convert from a `PyObject *` to the corresponding C datatype. Within the supporting C code, the variable `$source` contains the source data (the `PyObject` in this case) and `$target` contains the destination of a conversion.

When this example is compiled into a Python module, it will operate as follows :

```
>>> from example import *
>>> fact(6)
Received an integer : 6
```

```
720
```

A full discussion of typemaps can be found in the main SWIG users reference. We will primarily be concerned with Python typemaps here.

Python typemaps

The following typemap methods are available to Python modules :

`%typemap(python,in)`	Converts Python objects to input function arguments
`%typemap(python,out)`	Converts return value of a C function to a Python object
`%typemap(python,varin)`	Assigns a global variable from a Python object
`%typemap(python,varout)`	Returns a global variable as a Python object
`%typemap(python,freearg)`	Cleans up a function argument (if necessary)
`%typemap(python,argout)`	Output argument processing
`%typemap(python,ret)`	Cleanup of function return values
`%typemap(python,const)`	Creation of Python constants
`%typemap(memberin)`	Setting of C++ member data
`%typemap(memberout)`	Return of C++ member data

Typemap variables

The following variables may be used within the C code used in a typemap:

`$source`	Source value of a conversion
`$target`	Target of conversion (where the result should be stored)
`$type`	C datatype being remapped
`$mangle`	Mangled version of data (used for pointer type-checking)
`$value`	Value of a constant (const typemap only)

Name based type conversion

Typemaps are based both on the datatype and an optional name attached to a datatype. For example :

```
%module foo

// This typemap will be applied to all char ** function arguments
%typemap(python,in) char ** { ... }

// This typemap is applied only to char ** arguments named ‘argv’
%typemap(python,in) char **argv { ... }
```

In this example, two typemaps are applied to the char ** datatype. However, the second typemap will only be applied to arguments named ‘argv’. A named typemap will always override an unnamed typemap.

Named typemaps are extremely useful for managing special cases. It is also possible to use named typemaps to process output arguments (ie. function arguments that have values returned in them).

*Converting char ** to a Python list*

A common problem in many C programs is the processing of command line arguments, which are usually passed in an array of NULL terminated strings. The following SWIG interface file allows a Python list object to be used as a `char **` object.

```
%module argv

// This tells SWIG to treat char ** as a special case
%typemap(python,in) char ** {
  /* Check if is a list */
  if (PyList_Check($source)) {
    int size = PyList_Size($source);
    int i = 0;
    $target = (char **) malloc((size+1)*sizeof(char *));
    for (i = 0; i < size; i++) {
      PyObject *o = PyList_GetItem($source,i);
      if (PyString_Check(o))
       $target[i] = PyString_AsString(PyList_GetItem($source,i));
      else {
       PyErr_SetString(PyExc_TypeError,"list must contain strings");
       free($target);
       return NULL;
      }
    }
    $target[i] = 0;
  } else {
    PyErr_SetString(PyExc_TypeError,"not a list");
    return NULL;
  }
}

// This cleans up the char ** array we malloc'd before the function call
%typemap(python,freearg) char ** {
  free((char *) $source);
}

// This allows a C function to return a char ** as a Python list
%typemap(python,out) char ** {
  int len,i;
  len = 0;
  while ($source[len]) len++;
  $target = PyList_New(len);
  for (i = 0; i < len; i++) {
    PyList_SetItem($target,i,PyString_FromString($source[i]));
  }
}

// Now a few test functions
%inline %{
int print_args(char **argv) {
    int i = 0;
    while (argv[i]) {
         printf("argv[%d] = %s\n", i,argv[i]);
         i++;
    }
    return i;
}
```

```
// Returns a char ** list

char **get_args() {
    static char *values[] = { "Dave", "Mike", "Susan", "John", "Michelle", 0};
    return &values[0];
}
%}
```

When this module is compiled, our wrapped C functions now operate as follows :

```
>>> from argv import *
>>> print_args([“Dave”,”Mike”,”Mary”,”Jane”,”John”])
argv[0] = Dave
argv[1] = Mike
argv[2] = Mary
argv[3] = Jane
argv[4] = John
5
>>> get_args()
[‘Dave’, ‘Mike’, ‘Susan’, ‘John’, ‘Michelle’]
>>>
```

Thus, our type-mapping makes the Python interface to these functions more natural and easy to use.

Converting a Python file object to a FILE *

In our previous example involving gd-1.2, we had to write wrappers around `fopen()` and `fclose()` so that we could provide gd with a `FILE *` pointer. However, we could have used a typemap like this :

```
// Type mapping for grabbing a FILE * from Python

%typemap(python,in) FILE * {
  if (!PyFile_Check($source)) {
      PyErr_SetString(PyExc_TypeError, "Need a file!");
      return NULL;
  }
  $target = PyFile_AsFile($source);
}
```

Now, we can rewrite one of our earlier examples like this :

```
# Simple gd program

from gd import *

im = gdImageCreate(64,64)
black = gdImageColorAllocate(im,0,0,0)
white = gdImageColorAllocate(im,255,255,255)
gdImageLine(im,0,0,63,63,white)
f = open(“test.gif”,”w”)              # Create a Python file object
gdImageGif(im,f)                      # Pass to a C function as FILE *
f.close()
gdImageDestroy(im)
```

Using typemaps to return arguments

A common problem in some C programs is that values may be returned in arguments rather than in the return value of a function. For example :

```
/* Returns a status value and two values in out1 and out2 */
int spam(double a, double b, double *out1, double *out2) {
       ... Do a bunch of stuff ...
       *out1 = result1;
       *out2 = result2;
       return status;
};
```

A named typemap can be used to handle this case as follows :

```
%module outarg

// This tells SWIG to treat an double * argument with name 'OutValue' as
// an output value.  We'll append the value to the current result which
// is guaranteed to be a List object by SWIG.

%typemap(python,argout) double *OutValue {
       PyObject *o;
       o = PyFloat_FromDouble(*$source);
       PyList_Append($target,o);
       Py_DECREF(o);              /* This is very important! */
}

int spam(double a, double b, double *OutValue, double *OutValue);
```

When an “argout” typemap is detected, SWIG automatically converts the result of the function into a Python List object. The first element of the list will contain the normal return value of the function. Output arguments should be handled by appending new `PyObject` values to the list as shown. However, as presented, our function needs to take 4 arguments, the last two being pointers to doubles. We may not want to pass anything into these arguments so this could be changed as follows :

```
%typemap(python,in) double *OutValue {
       static double temp;  // Static needed variable doesn't disappear
       $target = &temp;
}
```

Now, in a Python script, we could do this :

```
>>> a = spam(4,5,None,None)
>>> print a
[0, 2.45, 5.0]
>>>
```

While not a perfect solution, it is sometimes possible to do better using default arguments and other techniques.

Mapping Python tuples into small arrays

In some applications, it is sometimes desirable to pass small arrays of numbers as arguments. For example :

```
extern void set_direction(double a[4]);       // Set direction vector
```

This too, can be handled used typemaps as follows :

```
// Grab a 4 element array as a Python 4-tuple
%typemap(python,in) double[4] {
  static double temp[4];
  int i;
  if (PyTuple_Check($source)) {
    if (!PyArg_ParseTuple($source,"dddd",temp,temp+1,temp+2,temp+3)) {
      PyErr_SetString(PyExc_TypeError,"tuple must have 4 elements");
      return NULL;
    }
    $target = &temp[0];
  } else {
    PyErr_SetString(PyExc_TypeError,"expected a tuple.");
    return NULL;
  }
}
```

This allows our `set_direction` function to be called from Python as follows :

```
>>> set_direction((0.5,0.0,1.0,-0.25))
```

Since our mapping copies the contents of a Python tuple into a C array, such an approach would not be recommended for huge arrays, but for small structures, this kind of scheme works fine.

Accessing array structure members

Consider the following data structure :

```
#define NAMELEN   32
typedef struct {
       char   name[NAMELEN];
       ...
} Person;
```

By default, SWIG doesn't know how to the handle the name structure since it's an array, not a pointer. In this case, SWIG will make the array member readonly. However, member typemaps can be used to make this member writable from Python as follows :

```
%typemap(memberin) char[NAMELEN] {
       /* Copy at most NAMELEN characters into $target */
       strncpy($target,$source,NAMELEN);
}
```

Whenever a `char[NAMELEN]` type is encountered in a structure or class, this typemap provides a safe mechanism for setting its value. An alternative implementation might choose to print an error message if the name was too long to fit into the field.

It should be noted that the `[NAMELEN]` array size is attached to the typemap. A datatype involving some other kind of array would not be affected.

Useful Functions

When writing typemaps, it is often necessary to work directly with Python objects instead of using the conventional `PyArg_ParseTuple()` function that is usually used when writing Python extensions. However, there are a number of useful Python functions available for you to use.

Python Integer Conversion Functions

`PyObject *PyInt_FromLong(long l)`	Convert long to Python integer
`long PyInt_AsLong(PyObject *)`	Convert Python integer to long
`int PyInt_Check(PyObject *)`	Check if Python object is an integer

Python Floating Point Conversion Functions

`PyObject *PyFloat_FromDouble(double)`	Convert a double to a Python float
`double PyFloat_AsDouble(PyObject *)`	Convert Python float to a double
`int PyFloat_Check(PyObject *)`	Check if Python object is a float

Python String Conversion Functions

`PyObject *PyString_FromString(char *)`	Convert NULL terminated ASCII string to a Python string
`PyObject *PyString_FromStringAndSize(char *, int len)`	Convert a string and length into a Python string. May contain NULL bytes.
`int PyString_Size(PyObject *)`	Return length of a Python string

`char *PyString_AsString(PyObject *)`
 	
`int PyString_Check(PyObject *)`
	Return Python string as a NULL terminated ASCII string.
	
	Check if Python object is a string

Python List Conversion Functions

`PyObject *PyList_New(int size)`	Create a new list object
`int PyList_Size(PyObject *list)`	Get size of a list
`PyObject *PyList_GetItem(PyObject *list, int i)`	Get item i from list

`int PyList_SetItem(PyObject *list, int i, PyObject *item)`
 	
`int PyList_Insert(PyObject *list, int i, PyObject *item)`
	Set list[i] to item.
	
	Inserts item at list[i].

`int PyList_Append(PyObject *list, PyObject *item)`	Appends item to list

Python List Conversion Functions

`PyObject *PyList_GetSlice(PyObject *list, int i, int j)`	Returns list[i:j]
`int PyList_SetSlice(PyObject *list, int i, int j, PyObject *list2)`	Sets list[i:j] = list2
`int PyList_Sort(PyObject *list)`	Sorts a list
`int PyList_Reverse(PyObject *list)`	Reverses a list
`PyObject *PyList_AsTuple(PyObject *list)`	Converts a list to a tuple
`int PyList_Check(PyObject *)`	Checks if an object is a list

Python Tuple Functions

`PyObject *PyTuple_New(int size)`	Create a new tuple
`int PyTuple_Size(PyObject *t)`	Get size of a tuple
`PyObject *PyTuple_GetItem(PyObject *t,int i)`	Get object t[i]
`int PyTuple_SetItem(PyObject *t, int i, PyObject *item)`	Set t[i] = item
`PyObject *PyTuple_GetSlice(PyObject *t,int i int j)`	Get slice t[i:j]
`int PyTuple_Check(PyObject *)`	Check if an object is a tuple

Python File Conversions

`PyObject *PyFile_FromFile(FILE *f)`	Convert a FILE * to a Python file object
`FILE *PyFile_AsFile(PyObject *)`	Return FILE * from a Python object
`int PyFile_Check(PyObject *)`	Check if an object is a file

Standard typemaps

The following typemaps show how to convert a few common kinds of objects between Python and C (and to give a better idea of how typemaps work)

Function argument typemaps

int,
short,
long
	<pre>%typemap(python,in) int,short,long {
	  if (!PyInt_Check($source)) {
	    PyErr_SetString(PyExc_TypeError,"not an integer”);
	    return NULL;
	  }
	  $target = ($type) PyInt_AsLong($source);
	}</pre>

Function argument typemaps

`float,`
`double`
	`%typemap(python,in) float,double {`
	`  if (!PyFloat_Check($source)) {`
	`    PyErr_SetString(PyExc_TypeError,”not a float”);`
	`    return NULL;`
	`  }`
	`  $target = ($type) PyFloat_AsDouble($source);`
	`}`

`char *`	`%typemap(python,in) char * {`
	`  if (!PyString_Check($source)) {`
	`    PyErr_SetString(PyExc_TypeError,”not a string”);`
	`    return NULL;`
	`  }`
	`  $target = PyString_AsString($source);`
	`}`

`FILE *`	`%typemap(python,in) FILE * {`
	`  if (!PyFile_Check($source)) {`
	`    PyErr_SetString(PyExc_TypeError,”not a file”);`
	`    return NULL;`
	`  }`
	`  $target = PyFile_AsFile($source);`
	`}`

Function return typemaps

`int,`
`short`
	`%typemap(python,out) int,short {`
	`    $target = PyBuild_Value(“i”, ($type) $source);`
	`}`

`long`	`%typemap(python,out) long {`
	`    $target = PyBuild_Value(“l”,$source);`
	`}`

`float,`
`double`
	`%typemap(python,out) float,double {`
	`    $target = PyBuild_Value(“d”,($type) $source);`
	`}`

`char *`	`%typemap(python,out) char * {`
	`    $target = PyBuild_Value(“s”,$source);`
	`}`

`FILE *`	`%typemap(python,out) FILE * {`
	`    $target = PyFile_FromFile($source);`
	`}`

Pointer handling

SWIG pointers are mapped into Python strings containing the hexadecimal value and type. The following functions can be used to create and read pointer values .

SWIG Pointer Conversion Functions

`void SWIG_MakePtr(char *str, void *ptr, char *type)`	Makes a pointer string and saves it in `str`, which must be large enough to hold the result. `ptr` contains the pointer value and `type` is the string representation of the type.
`char *SWIG_GetPtr(char *str, void **ptr, char *type)`	Attempts to read a pointer from the string `str`. `ptr` is the address of the pointer to be created and `type` is the expected type. If `type` is NULL, then any pointer value will be accepted. On success, this function returns NULL. On failure, it returns the pointer to the invalid portion of the pointer string.

These functions can be used in typemaps as well although there is usually little need to do so. For example, the following typemap makes an argument of “`char *buffer`” accept a pointer instead of a NULL-terminated ASCII string.

```
%typemap(python,in) char *buffer {
        PyObject *o;
        char     *str;
        if (!PyString_Check(o)) {
                PyErr_SetString(PyExc_TypeError,”not a string”);
                return NULL;
        }
        str = PyString_AsString(o);
        if (SWIG_GetPtr(str, (void **) &$target, “$mangle”)) {
                PyErr_SetString(PyExc_TypeError,”not a pointer”);
                return NULL;
        }
}
```

Note that the `$mangle` variable generates the type string associated with the datatype used in the typemap.

By now you hopefully have the idea that typemaps are a powerful mechanism for building more specialized applications. While writing typemaps can be technical, many have already been written for you. See the SWIG library reference for more information.

Implementing C callback functions in Python

Now that you’re an expert, you’ve graduated to the bigtime--in this example, we will implement simple C callback functions in Python and use them in a C++ code.

Let’s say that we wanted to write a simple C++ 2D plotting widget layered on top of the gd-1.2 library. A class definition might look like this :

```
// -------------------------------------------------------------------
// Create a C++ plotting "widget" using the gd-1.2 library by Thomas Boutell
//
// This example primarily illustrates how callback functions can be
// implemented in Python.
// -------------------------------------------------------------------

#include <stdio.h>
extern "C" {
#include "gd.h"
}

typedef double (*PLOTFUNC)(double, void *);

class PlotWidget {
private:
  double      xmin,ymin,xmax,ymax;         // Plotting range
  PLOTFUNC    callback;                    // Callback function
  void       *clientdata;                  // Client data for callback
  int         npoints;                     // Number of points to plot
  int         width;                       // Image width
  int         height;                      // Image height
  int         black,white;                 // Some colors
  gdImagePtr  im;                          // Image pointer
  void        transform(double,double,int&,int&);
public:
  PlotWidget(int w, int h,double,double,double,double);
  ~PlotWidget();
  void set_method(PLOTFUNC func, void *clientdata);    // Set callback method
  void set_range(double,double,double,double);         // Set plot range
  void set_points(int np) {npoints = np;}              // Set number of points
  void plot();                                         // Make a plot
  void save(FILE *f);                                  // Save a plot to disk
};
```

The widget class hides all of the underlying implementation details so this could have just as easily been implemented on top of OpenGL, X11 or some other kind of library. When used in C++, the widget works like this :

```
// Simple main program to test out our widget
#include <stdio.h>
#include "widget.h"
#include <math.h>

// Callback function
double my_func(double a, void *clientdata) {
  return sin(a);
}

int main(int argc, char **argv) {
  PlotWidget *w;
  FILE *f;

  w = new PlotWidget(500,500,-6.3,-1.5,6.3,1.5);
  w->set_method(my_func,0);              // Set callback function
  w->plot();                             // Make plot
  f = fopen("plot.gif","w");
  w->save(f);
```

```
  fclose(f);
  printf("wrote plot.gif\n");
}
```

Okay, that was simple enough. Now suppose that we wanted to use our widget interactively from Python. While possible, it is going to be difficult because we would really like to implement the callback function in Python, not C++. We also don't want to go in and hack or C++ code to support this. Fortunately, you can do it with SWIG using the following interface file :

```
// SWIG interface to our PlotWidget
%module plotwidget
%{
#include "widget.h"
%}

// Grab a Python function object as a Python object.
%typemap(python,in) PyObject *pyfunc {
  if (!PyCallable_Check($source)) {
      PyErr_SetString(PyExc_TypeError, "Need a callable object!");
      return NULL;
  }
  $target = $source;
}

// Type mapping for grabbing a FILE * from Python
%typemap(python,in) FILE * {
  if (!PyFile_Check($source)) {
      PyErr_SetString(PyExc_TypeError, "Need a file!");
      return NULL;
  }
  $target = PyFile_AsFile($source);
}

// Grab the class definition
%include widget.h

%{
/* This function matches the prototype of the normal C callback
   function for our widget. However, we use the clientdata pointer
   for holding a reference to a Python callable object. */

static double PythonCallBack(double a, void *clientdata)
{
   PyObject *func, *arglist;
   PyObject *result;
   double    dres = 0;

   func = (PyObject *) clientdata;               // Get Python function
   arglist = Py_BuildValue("(d)",a);             // Build argument list
   result = PyEval_CallObject(func,arglist);     // Call Python
   Py_DECREF(arglist);                           // Trash arglist
   if (result) {                                 // If no errors, return double
     dres = PyFloat_AsDouble(result);
   }
   Py_XDECREF(result);
   return dres;
}
%}
```

```
// Attach a new method to our plot widget for adding Python functions
%addmethods PlotWidget {
   // Set a Python function object as a callback function
   // Note : PyObject *pyfunc is remapped with a typempap
   void set_pymethod(PyObject *pyfunc) {
     self->set_method(PythonCallBack, (void *) pyfunc);
     Py_INCREF(pyfunc);
   }
}
```

While this is certainly not a trivial SWIG interface file, the results are quite cool. Let's try out our new Python module :

```
# Now use our plotting widget in variety of ways

from plotwidget import *
from math import *

# Make a plot using a normal Python function as a callback
def func1(x):
       return 0.5*sin(x)+0.25*sin(2*x)+0.125*cos(4*x)

print "Making plot1.gif..."
# Make a widget and set callback
w = PlotWidget(500,500,-10,-2,10,2)
w.set_pymethod(func1)                     # Register our Python function
w.plot()
f = open("plot1.gif","w")
w.save(f)
f.close()

# Make a plot using an anonymous function

print "Making plot2.gif..."
w1 = PlotWidget(500,500,-4,-1,4,16)
w1.set_pymethod(lambda x: x*x)            # Register x^2 as a callback
w1.plot()
f = open("plot2.gif","w")
w1.save(f)
f.close()

# Make another plot using a built-in function

print "Making plot3.gif..."
w2 = PlotWidget(500,500,-7,-1.5,7,1.5)
w2.set_pymethod(sin)                      # Register sin(x) as a callback
w2.plot()
f = open("plot3.gif","w")
w2.save(f)
f.close()
```

The "plot" method for each widget is written entirely in C++ and assumes that it is calling a callback function written in C/C++. Little does it know that we have actually implemented this function in Python. With a little more work, we can even write a simple function plotting tool :

```
# Plot a function and spawn xv

import posix
import sys
import string
from plotwidget import *
from math import *

line = raw_input("Enter a function of x : ")
ranges = string.split(raw_input("Enter xmin,ymin,xmax,ymax :"),",")

print "Making a plot..."
w = PlotWidget(500,500,string.atof(ranges[0]),string.atof(ranges[1]),
               string.atof(ranges[2]),string.atof(ranges[3]))

# Turn user input into a Python function
code = "def func(x): return " + line
exec(code)

w.set_pymethod(func)
w.plot()
f = open("plot.gif","w")
w.save(f)
f.close()
posix.system("xv plot.gif &")
```

Other odds and ends

Adding native Python functions to a SWIG module

Sometimes it is desirable to add a native Python method to a SWIG wrapper file. Suppose you have the following Python / C function :

```
PyObject *spam_system(PyObject *self, PyObject *args) {
       char *command;
       int sts;
       if (!PyArg_ParseTuple(args,"s",&command))
              return NULL;
       sts = system(command);
       return Py_BuildValue("i",sts);
}
```

This function can be added to a SWIG module using the following declaration :

```
%native(system) spam_system;        // Create a command called 'system'
```

Alternatively, you can use the full function declaration like this

```
%native(system) PyObject *spam_system(PyObject *self, PyObject *args);
```

or

```
%native(system) extern PyObject *spam_system(PyObject *self, PyObject *args);
```

The gory details of shadow classes

This section describes the process by which SWIG creates shadow classes and some of the more subtle aspects.

A simple shadow class

Consider the following declaration from our previous example :

```
%module pde
struct Grid2d {
  Grid2d(int ni, int nj);
  ~Grid2d();
  double **data;
  int      xpoints;
  int      ypoints;
};
```

The SWIG generated class for this structure looks like the following :

```
# This file was created automatically by SWIG.
import pdec
class Grid2dPtr :
    def __init__(self,this):
        self.this = this
        self.thisown = 0
    def __del__(self):
        if self.thisown == 1 :
            pdec.delete_Grid2d(self.this)
    def __setattr__(self,name,value):
        if name == "data" :
            pdec.Grid2d_data_set(self.this,value)
            return
        if name == "xpoints" :
            pdec.Grid2d_xpoints_set(self.this,value)
            return
        if name == "ypoints" :
            pdec.Grid2d_ypoints_set(self.this,value)
            return
        self.__dict__[name] = value
    def __getattr__(self,name):
        if name == "data" :
            return pdec.Grid2d_data_get(self.this)
        if name == "xpoints" :
            return pdec.Grid2d_xpoints_get(self.this)
        if name == "ypoints" :
            return pdec.Grid2d_ypoints_get(self.this)
        return self.__dict__[name]
    def __repr__(self):
        return "<C Grid2d instance>"
class Grid2d(Grid2dPtr):
    def __init__(self,arg0,arg1) :
        self.this = pdec.new_Grid2d(arg0,arg1)
        self.thisown = 1
```

Module names

Shadow classes are built using the low-level SWIG generated C interface. This interface is named "modulec" where "module" is the name of the module specified in a SWIG interface file. The Python code for the shadow classes is created in a file "module.py". This is the file that should be loaded when a user wants to use the module.

Two classes

For each structure or class found in an interface file, SWIG creates two Python classes. If a class is named "`Grid2d`", one of these classes will be named "`Grid2dPtr`" and the other named "`Grid2d`". The `Grid2dPtr` class is used to turn wrap a Python class around an already preexisting `Grid2d` pointer. For example :

```
>>> gptr = create_grid2d()         # Returns a Grid2d from somewhere
>>> g = Grid2dPtr(gptr)            # Turn it into a Python class
>>> g.xpoints
50
>>>
```

The `Grid2d` class, on the other hand, is used when you want to create a new `Grid2d` object from Python. In reality, it inherits all of the attributes of a `Grid2dPtr`, except that its constructor calls the corresponding C++ constructor to create a new object. Thus, in Python, this would look something like the following :

```
>>> g = Grid2d(50,50)           # Create a new Grid2d
>>> g.xpoints
50
>>>
```

This two class model is a tradeoff. In order to support C/C++ properly, it is necessary to be able to create Python objects from both pre-existing C++ objects and to create entirely new C++ objects in Python. While this might be accomplished using a single class, it would complicate the handling of constructors considerably. The two class model, on the other hand, works, is consistent, and is relatively easy to use. In practice, you probably won't even be aware that there are two classes working behind the scenes.

The this pointer

Within each shadow class, the member "`this`" contains the actual C/C++ pointer to the object. You can check this out yourself by typing something like this :

```
>>> g = Grid2d(50,50)
>>> print g.this
_1008fe8_Grid2d_p
>>>
```

Direct manipulation of the "`this`" pointer is generally discouraged. In fact forget that you read this.

Object ownership

Ownership is a critical issue when mixing C++ and Python. For example, suppose I create a new object in C++, but later use it to create a Python object. If that object is being used elsewhere in the C++ code, we clearly don't want Python to delete the C++ object when the Python object is deleted. Similarly, what if I create a new object in Python, but C++ saves a pointer to it and starts using it repeatedly. Clearly, we need some notion of who owns what. Since sorting out all of the possibilities is probably impossible, SWIG shadow classes always have an attribute "`thisown`" that indicates whether or not Python owns an object. Whenever an object is created in Python, Python will be given ownership by setting `thisown` to `1`. When a Python class is created from a pre-existing C/C++ pointer, ownership is assumed to belong to the C/C++ code and `thisown` will be set to 0.

Ownership of an object can be changed as necessary by changing the value of thisown. When set, Python will call the C/C++ destructor when the object is deleted. If it is zero, Python will never call the C/C++ destructor.

Constructors and Destructors

C++ constructors and destructors will be mapped into Python's `__init__` and `__del__` methods respectively. Shadow classes always contain these methods even if no constructors or destructors were available in the SWIG interface file. The Python destructor will only call a C/C++ destructor if `self.thisown` is set.

Member data

Member data of an object is accessed through Python's `__getattr__` and `__setattr__` methods.

Printing

SWIG automatically creates a Python `__repr__` method for each class. This forces the class to be relatively well-behaved when printing or being used interactively in the Python interpreter.

Shadow Functions

Suppose you have the following declarations in an interface file :

```
%module vector
struct Vector {
       Vector();
       ~Vector();
       double x,y,z;
};

Vector addv(Vector a, Vector b);
```

By default, the function `addv` will operate on `Vector` pointers, not Python classes. However, the SWIG Python module is smart enough to know that `Vector` has been wrapped into a Python class so it will create the following replacement for the `addv()` function.

```
def addv(a,b):
       result = VectorPtr(vectorc.addv(a.this,b.this))
       result.thisown = 1
       return result
```

Function arguments are modified to use the "this" pointer of a Python Vector object. The result is a pointer to the result which has been allocated by malloc or new (this behavior is described in the chapter on SWIG basics), so we simply create a new VectorPtr with the return value. Since the result involved an implicit malloc, we set the ownership to 1 indicating that the result is to be owned by Python and that it should be deleted when the Python object is deleted. As a result, operations like this are perfectly legal and result in no memory leaks :

```
>>> v = add(add(add(add(a,b),c),d),e)
```

Substitution of complex datatypes occurs for all functions and member functions involving structure or class definitions. It is rarely necessary to use the low-level C interface when working with shadow classes.

Nested objects

SWIG shadow classes support nesting of complex objects. For example, suppose you had the following interface file :

```
%module particle

typedef struct {
  Vector();
  double x,y,z;
} Vector;

typedef struct {
  Particle();
 ~Particle();
  Vector r;
  Vector v;
  Vector f;
  int    type;
} Particle;
```

In this case you will be able to access members as follows :

```
>>> p = Particle()
>>> p.r.x = 0.0
>>> p.r.y = -1.5
>>> p.r.z = 2.0
>>> p.v = addv(v1,v2)
>>> ...
```

Nesting of objects is implemented using Python's `__setattr__` and `__getattr__` functions. In this case, they would look like this :

```
class ParticlePtr:
       ...
       def __getattr__(self,name):
              if name == "r":
                     return particlec.VectorPtr(Particle_r_get(self.this))
              elif name == "v":
                     return particlec.VectorPtr(Particle_v_get(self.this))
              ...

       def __setattr__(self,name,value):
              if name == "r":
```

```
                particlec.Particle_r_set(self.this,value.this)
        elif name == “v”:
                particlec.Particle_v_set(self.this,value.this)
        ...
```

The attributes of any given object are only converted into a Python object when referenced. This approach is more memory efficient, faster if you have a large collection of objects that aren’t examined very often, and works with recursive structure definitions such as :

```
struct Node {
        char *name;
        struct Node *next;
};
```

Nested structures such as the following are also supported by SWIG. These types of structures tend to arise frequently in database and information processing applications.

```
typedef struct {
        unsigned int dataType;
        union {
                int       intval;
                double    doubleval;
                char     *charval;
                void     *ptrvalue;
                long      longval;
                struct {
                        int    i;
                        double f;
                        void   *v;
                        char name[32];
                } v;
        } u;
} ValueStruct;
```

Access is provided in an entirely natural manner,

```
>>> v = new_ValueStruct()       # Create a ValueStruct somehow
>>> v.dataType
1
>>> v.u.intval
45
>>> v.u.longval
45
>>> v.u.v.v = _0_void_p
>>>
```

To support the embedded structure definitions, SWIG has to extract the internal structure definitions and use them to create new Python classes. In this example, the following shadow classes are created :

```
# Class corresponding to union u member
class ValueStruct_u :
        ...
# Class corresponding to struct v member of union u
class ValueStruct_u_v :
        ...
```

The names of the new classes are formed by appending the member names of each embedded structure.

Inheritance and shadow classes

Since shadow classes are implemented in Python, you can use any of the automatically generated classes as a base class for more Python classes. However, you need to be extremely careful when using multiple inheritance. When multiple inheritance is used, at most ONE SWIG generated shadow class can be involved. If multiple SWIG generated classes are used in a multiple inheritance hierarchy, you will get name clashes on the this pointer, the `__getattr__` and `__setattr__` functions won't work properly and the whole thing will probably crash and burn. Perhaps it's best to think of multiple inheritance as a big hammer that can be used to solve alot of problems, but it hurts quite alot if you accidently drop it on your foot....

Performance concerns and hints

Shadow classing is primarily intended to be a convenient way of accessing C/C++ objects from Python. However, if you're directly manipulating huge arrays of complex objects from Python, performance may suffer greatly. In these cases, you should consider implementing the functions in C or thinking of ways to optimize the problem.

There are a number of ways to optimize programs that use shadow classes. Consider the following two code fragments involving the `Particle` data structure in a previous example :

```
def force1(p1,p2):
	dx = p2.r.x - p1.r.x
	dy = p2.r.y - p1.r.y
	dz = p2.r.z - p1.r.z
	r2 = dx*dx + dy*dy + dz*dz
	f = 1.0/(r2*math.sqrt(r2))
	p1.f.x = p1.f.x + f*dx
	p2.f.x = p2.f.x - f*dx
	p1.f.y = p1.f.y + f*dy
	p2.f.y = p2.f.y - f*dy
	p1.f.z = p1.f.z + f*dz
	p2.f.z = p2.f.z - f*dz

def force2(p1,p2):
	r1 = p1.r
	r2 = p2.r
	dx = r2.x - r1.x
	dy = r2.y - r1.y
	dz = r2.z - r1.z
	r2 = dx*dx + dy*dy + dz*dz
	f = 1.0/(r2*math.sqrt(r2))
	f1 = p1.f
	f2 = p2.f
	f1.x = f1.x + f*dx
	f2.x = f2.x - f*dx
	f1.y = f1.y + f*dy
	f2.y = f2.y - f*dy
	f1.z = f1.z + f*dz
	f2.z = f2.z - f*dz
```

The first calculation simply works with each Particle structure directly. Unfortunately, it performs alot of dereferencing of objects. If the calculation is restructured to use temporary variables as shown in force2, it will run significantly faster--in fact, on my machine, the second code fragment runs more than twice as fast as the first one.

If performance is even more critical you can use the low-level C interface which eliminates all of the overhead of going through Python's class mechanism (at the expense of coding simplicity). When Python shadow classes are used, the low level C interface can still be used by importing the 'modulec' module where 'module' is the name of the module you used in the SWIG interface file.

SWIG and Tcl 10

This chapter discusses SWIG's support of Tcl. SWIG supports Tcl versions 7.3 and newer, including Tcl 8.0. Tk 3.6 and newer can also be used. However, for the best results you should consider using Tcl 7.5/Tk4.1 or later.

Preliminaries

You will need to install Tcl/Tk on your system if you haven't done so already. If you are using Tcl 7.5 or newer, you should also determine if your system supports dynamic loading and shared libraries. SWIG will work with or without it, but the compilation process varies.

Running SWIG

To build a Tcl module, run swig using the `-tcl` option as follows :

```
swig -tcl example.i
```

This will produce 2 files. The first file `example_wrap.c` contains all of the C code needed to build a Tcl module. The second file will containing supporting documentation and may be named `example_wrap.doc`, `example_wrap.html`, `example_wrap.tex`, etc... To build a Tcl extension you will need to compile the `example_wrap.c` file and link it with the rest of your program (and possibly Tcl itself).

Additional SWIG options

The following options are also available with the Tcl module :

```
-tcl8         Produce Tcl8.0 native wrappers (use in place of -tcl).
-module       Set the module name.
-namespace    Use [incr Tcl] namespaces.
-prefix pkg   Set a package prefix of 'pkg'. This prefix will be
              attached to each function.
-htcl tcl.h   Set name of Tcl header file.
-htk tk.h     Set name of Tk header file.
-plugin       Generate additional code for the netscape plugin.
-noobject     Omit object oriented extensions (compatibility with SWIG 1.0)
```

Many of these options will be described later.

Getting the right header files and libraries

In order to compile Tcl/Tk extensions, you will need to locate the "`tcl.h`" and "`tk.h`" header files. These are usually located in `/usr/local/include`. You will also need to locate the Tcl/

Tk libraries `libtcl.a` and `libtk.a`. These are usually located in `/usr/local/lib`.
When locating the right header and libraries files, check to make sure the files you use are the correct version and form a matching pair. SWIG works with the following Tcl/Tk releases.

```
Tcl 7.3, Tk 3.6
Tcl 7.4, Tk 4.0
Tcl 7.5, Tk 4.1
Tcl 7.6, Tk 4.2
Tcl 8.0a2, Tk 8.0a2
```

Do not mix versions. Although the code might compile if you do, it will usually core dump mysteriously. By default, SWIG looks for the header files "`tcl.h`" and "`tk.h`", but your installed version of Tcl/Tk may use slightly different names such as "`tcl7.5.h`" and "`tk4.1.h`". If you need to use different header files, you can use the `-htcl` and `-htk` options as in :

```
swig -tcl -htcl tcl7.5.h -htk tk4.1.h example.i
```

If you are installing Tcl/Tk yourself, it is often easier to set up a symbolic links between `tcl.h` and the header files for the latest installed version.

Compiling a dynamic module (Unix)

To compile a dynamically loadable module, you will need to compile your SWIG extension into a shared library. This usually looks something like the following (shown for Linux).

```
unix > swig -tcl example.i
unix > gcc -fpic example_wrap.c example.c -I/usr/local/include
unix > gcc -shared example.o example_wrap.o -o example.so       # Linux
```

Unfortunately, the process of building of building shared libraries varies on every single machine. SWIG will try to guess when you run configure, but it isn't always successful. It's always a good idea to read the man pages on the compiler/linker to find out more information.

Using a dynamic module

To use a dynamic module, you will need to load it using the Tcl load command as follows :

```
load ./example.so example
```

The first argument is the name of the shared library while the second argument is the name of the module (the same as what you specified with the `%module` directive).

Static linking

If you machine does not support dynamic loading or you've tried to use it without success, you can build a new versions of `tclsh` (the Tcl shell) or `wish` (Tcl/Tk shell) with your extensions added. To do this, you can useSWIG's `%include` directive to use some supporting code as follows :

```
%module mymodule
... declarations ...

%include tclsh.i     // Support code for rebuilding tclsh
```

To rebuild tclsh, you will need to compile as follows :

```
unix > swig -tcl example.i
unix > gcc example_wrap.c example.c -I/usr/local/include -L/usr/local/lib -ltcl -ldl \
       -lm -o my_tclsh
```

Alternatively, you can use SWIG's -l option to added the tclsh.i library file without modifying the interface file. For example :

```
unix > swig -tcl -ltclsh.i example.i
unix > gcc example_wrap.c example.c -I/usr/local/include -L/usr/local/lib -ltcl -ldl \
       -lm -o my_tclsh
```

The `-ldl` option will be required if your Tcl/Tk supports dynamic loading. On some machines (most notably Solaris),it will also be necessary to add `-lsocket -lnsl` to the compile line. This will produce a new version of `tclsh` that is identical to the old one, but with your extensions added.

If you are using Tk, you will want to rebuild the wish executable instead. This can be done as follows :

```
%module mymodule
... declarations ...

%include wish.i       // Support code for rebuilding wish
```

The compilation process is similar as before, but now looks like this :

```
unix > swig -tcl example.i
unix > gcc example_wrap.c example.c -I/usr/local/include -L/usr/local/lib -ltk -ltcl \
       -lX11 -ldl -lm -o my_wish
```

In this case you will end up with a new version of the `wish` executable with your extensions added.

Compilation problems

Tcl is one of the easiest languages to compile extensions for. The Tcl header files should work without problems under C and C++. Perhaps the only tricky task is that of compiling dynamically loadable modules for C++. If your C++ code has static constructors in it, it is unlikely to work at all. In this case, you will need to build new versions of the `tclsh` or `wish` executables instead. Otherwise, you may need to link against the `libgcc.a`, `libg++.a`, and `libstdc++.a` libraries (assuming g++).

Setting a package prefix

To avoid namespace problems, you can instruct SWIG to append a package prefix to all of your functions and variables. This is done using the -prefix option as follows :

```
swig -tcl -prefix Foo example.i
```

If you have a function "`bar`" in the SWIG file, the prefix option will append the prefix to the name when creating a command and called it "`Foo_bar`".

Using [incr Tcl] namespaces

Alternatively, you can have SWIG install your module into an [incr Tcl] namespace by specifying the -namespace option :

```
swig -tcl -namespace example.i
```

By default, the name of the namespace will be the same as the module name, but you can override it using the `-prefix` option.

When the -namespace option is used, the resulting wrapper code can be compiled under both Tcl and [incr Tcl]. When compiling under Tcl, the namespace will turn into a package prefix such as in `Foo_bar`. When running under [incr Tcl], it will be something like `Foo::bar.`

Building Tcl/Tk Extensions under Windows 95/NT

Building a SWIG extension to Tcl/Tk under Windows 95/NT is roughly similar to the process used with Unix. Normally, you will want to produce a DLL that can be loaded into tclsh or wish. This section covers the process of using SWIG with Microsoft Visual C++ 4.x although the procedure may be similar with other compilers as well.

Running SWIG from Developer Studio

If you are developing your application within Microsoft developer studio, SWIG can be invoked as a custom build option. The process roughly follows these steps :

- Open up a new workspace and use the AppWizard to select a DLL project.
- Add both the SWIG interface file (the .i file), any supporting C files, and the name of the wrapper file that will be created by SWIG (ie. `example_wrap.c`). Note : If using C++, choose a different suffix for the wrapper file such as `example_wrap.cxx`. Don't worry if the wrapper file doesn't exist yet--Developer studio will keep a reference to it around.
- Select the SWIG interface file and go to the settings menu. Under settings, select the "Custom Build" option.
- Enter "SWIG" in the description field.
- Enter "`swig -tcl -o $(ProjDir)\$(InputName)_wrap.c $(InputPath)`" in the "Build command(s) field"
- Enter "`$(ProjDir)\$(InputName)_wrap.c`" in the "Output files(s) field".
- Next, select the settings for the entire project and go to "C++:Preprocessor". Add the include directories for your Tcl installation under "Additional include directories".
- Finally, select the settings for the entire project and go to "Link Options". Add the Tcl library file to your link libraries. For example "tcl80.lib". Also, set the name of the output file to match the name of your Tcl module (ie. example.dll).
- Build your project.

Now, assuming all went well, SWIG will be automatically invoked when you build your project. Any changes made to the interface file will result in SWIG being automatically invoked to produce a new version of the wrapper file. To run your new Tcl extension, simply run Tcl and use the load command. For example :

```
DOS > tclsh80
% load ./example.dll
% fact 4
24
%
```

Using NMAKE

Alternatively, SWIG extensions can be built by simply writing a Makefile for NMAKE. To do this, make sure the environment variables for MSVC++ are available and the MSVC++ tools are in your path. Now, just write a short Makefile like this :

```
# Makefile for building various SWIG generated extensions

SRCS          = example.c
IFILE         = example
INTERFACE     = $(IFILE).i
WRAPFILE      = $(IFILE)_wrap.c

# Location of the Visual C++ tools (32 bit assumed)

TOOLS         = c:\msdev
TARGET        = example.dll
CC            = $(TOOLS)\bin\cl.exe
LINK          = $(TOOLS)\bin\link.exe
INCLUDE32     = -I$(TOOLS)\include
MACHINE       = IX86

# C Library needed to build a DLL

DLLIBC        = msvcrt.lib oldnames.lib

# Windows libraries that are apparently needed
WINLIB        = kernel32.lib advapi32.lib user32.lib gdi32.lib comdlg32.lib
winspool.lib

# Libraries common to all DLLs
LIBS          = $(DLLIBC) $(WINLIB)

# Linker options
LOPT      = -debug:full -debugtype:cv /NODEFAULTLIB /RELEASE /NOLOGO /
MACHINE:$(MACHINE) -entry:_DllMainCRTStartup@12 -dll

# C compiler flags

CFLAGS    = /Z7 /Od /WX /c /W3 /nologo
TCL_INCLUDES  = -Id:\tcl8.0a2\generic -Id:\tcl8.0a2\win
TCLLIB        = d:\tcl8.0a2\win\tcl80.lib

tcl::
       ..\..\swig -tcl -o $(WRAPFILE) $(INTERFACE)
       $(CC) $(CFLAGS) $(TCL_INCLUDES) $(SRCS) $(WRAPFILE)
       set LIB=$(TOOLS)\lib
       $(LINK) $(LOPT) -out:example.dll $(LIBS) $(TCLLIB) example.obj example_wrap.obj
```

To build the extension, run NMAKE. This is a pretty minimal Makefile, but hopefully its enough to get you started. With a little practice, you'll be making lots of Tcl extensions.

Basic Tcl Interface

Functions

C functions are turned into new Tcl commands with the same usage as the C function. Default/optional arguments are also allows. An interface file like this :

```
%module example
int foo(int a);
double bar (double, double b = 3.0);
...
```

Will be used in Tcl like this :

```
set a [foo 2]
set b [bar 3.5 -1.5]
set b [bar 3.5]             # Note : default argument is used
```

There isn't much more to say...this is pretty straightforward.

Global variables

For global variables, things are a little more complicated. For the following C datatypes, SWIG will use Tcl's variable linking mechanism to provide direct access :

```
int, unsigned int,
double,
char *,
```

When used in an interface file and script, it will operate as follows :

```
// example.i
%module example
...
double My_variable;
...

# Tcl script
puts $My_variable           # Output value of C global variable
set My_variable 5.5         # Change the value
```

For all other C datatypes, SWIG will generate a pair of set/get functions. For example :

```
// example.i
short My_short;
```

will be accessed in Tcl as follows :

```
puts [My_short_get]                 # Get value of global variable
My_short_set 5.5                    # Set value of global variable
```

While not the most elegant solution, this is the only solution for now. Tcl's normal variable linking mechanism operates directly on a variables and would not work correctly on datatypes other than the 3 basic datatypes supported by Tcl.

Constants

Constants are created as read-only variables. For odd datatypes (not supported by the variable linking mechanism), SWIG will generate a string representation of the constant and use that instead (you shouldn't notice this however since everything is already a string in Tcl). It is never necessary to use a special "get" function with constants like it is with certain types of variables.

Pointers

Pointers to C/C++ objects are represented as character strings such as the following :

```
_100f8e2_Vector_p
```

A NULL pointer is represented by the string "NULL". NULL pointers can also be explicitly created as follows :

```
_0_Vector_p
```

In Tcl 8.0, pointers are represented using a new type of Tcl object, but the string representation is the same (and is interchangable). As a general, direct manipulation of pointer values is discouraged.

Structures

SWIG generates a basic low-level interface to C structures. For example :

```
struct Vector {
       double x,y,z;
};
```

gets mapped into the following collection of C functions :

```
double Vector_x_get(Vector *obj)
double Vector_x_set(Vector *obj, double x)
double Vector_y_get(Vector *obj)
double Vector_y_set(Vector *obj, double y)
double Vector_z_get(Vector *obj)
double Vector_z_set(Vector *obj, double z)
```

These functions are then used in the resulting Tcl interface. For example :

```
# v is a Vector that got created somehow
% Vector_x_get $v
3.5
% Vector_x_set $v 7.8               # Change x component
```

Similar access is provided for unions and the data members of C++ classes.

C++ Classes

C++ classes are handled by building a set of low level accessor functions. Consider the following class :

```
class List {
public:
  List();
  ~List();
  int  search(char *item);
  void insert(char *item);
  void remove(char *item);
  char *get(int n);
  int  length;
static void print(List *l);
};
```

When wrapped by SWIG, the following functions will be created :

```
List *new_List();
void delete_List(List *l);
int List_search(List *l, char *item);
void List_insert(List *l, char *item);
void List_remove(List *l, char *item);
char *List_get(List *l, int n);
int List_length_get(List *l);
int List_length_set(List *l, int n);
void List_print(List *l);
```

Within Tcl, these are the functions used to access the C++ class :

```
% set l [new_List]
% List_insert $l Ale
% List_insert $l Stout
% List_insert $l Lager
% List_print $l
Lager
Stout
Ale
% puts [List_length_get $l]
3
% puts $l
_1008560_List_p
%
```

C++ objects are really just pointers (which are represented as strings). Member functions and data are accessed by simply passing a pointer into a collection of accessor functions that take the pointer as the first argument.

While somewhat primitive, the low-level SWIG interface provides direct and flexible access to C++ objects. As it turns out, it is possible to do some rather amazing things with this interface as will be shown in some of the examples. SWIG 1.1 also generates an object oriented interface that can be used in addition to the basic interface just described.

The object oriented interface

With SWIG 1.1, a new object oriented to C structures and C++ classes is supported. This interface supplements the low-level SWIG interface already defined--in fact, both can be used simultaneously. To illustrate this interface, consider our previous `List` class :

```
class List {
public:
  List();
  ~List();
  int  search(char *item);
  void insert(char *item);
  void remove(char *item);
  char *get(int n);
  int  length;
static void print(List *l);
};
```

Using the object oriented interface requires no additional modifications or recompilation of the SWIG module (the functions are just used differently).

Creating new objects

The name of the class becomes a new command for creating an object. There are 5 methods for creating an object (`MyObject` is the name of the corresponding C++ class)

```
MyObject o                  # Creates a new object 'o'

MyObject o -this $objptr    # Turn a pointer to an existing C++ object into a
                            # Tcl object 'o'

MyObject -this $objptr      # Turn the pointer $objptr into a Tcl "object"

MyObject -args args         # Create a new object and pick a name for it. The
                            # will be returned and is the same as the pointer value.

MyObject                    # The same as MyObject -args, but for constructors that
                            # take no arguments.
```

Thus, for our List class, we can create new List objects as follows :

```
List l                      # Create a new list l

set listptr [new_List]      # Create a new List using low level interface
List l2 -this $listptr      # Turn it into a List object named 'l2'

set l3 [List]               # Create a new list. The name of the list is in $l3

List -this $listptr         # Turn $listptr into a Tcl object of the same name
```

Invoking member functions

Member functions are invoked using the name of the object followed by the method name and any arguments. For example :

```
% List l
% l insert "Bob"
% l insert "Mary"
% l search "Dave"
0
% ...
```

Or if you let SWIG generate the name of the object...

```
% set l [List]
% $l insert "Bob"                 # Note $l contains the name of the object
% $l insert "Mary"
% $l search "Dave"
0
%
```

Deleting objects

Since objects are created by adding new Tcl commands, they can be deleted by simply renaming them. For example :

```
% rename l ""                # Destroy list object 'l'
```

SWIG will automatically call the corresponding C/C++ destructor and cleanup, with one caveat--SWIG will not destroy an object if you created it from an already existing pointer (using the -this option). Since the pointer already existed when you created the Tcl object, Tcl doesn't own the object so it would probably be a bad idea to destroy it.

Accessing member data

Member data of an object can be access using the `cget` method. The approach is quite similar to that used in [incr Tcl] and other Tcl extensions. For example :

```
% l cget -length             # Get the length of the list
13
```

The `cget` method currently only allows retrieval of one member at a time to extracting multiple members will require repeated calls.

The member `-this` contains the pointer to the object that is compatible with other SWIG functions. Thus, the following call would be legal

```
% List l                          # Create a new list object
% l insert Mike
% List_print [l cget -this]       # Print it out using low-level function
```

Changing member data

To change the value of member data, the `configure` method can be used. For example :

```
% l configure -length 10     # Change length to 10 (probably not a good idea, but
                             # possible).
```

In a structure such as the following :

```
struct Vector {
       double x, y, z;
};
```

you can change the value of all or some of the members as follows :

```
% v configure -x 3.5 -y 2 -z -1.0
```

Relationship with pointers

The object oriented interface is mostly compatible with all of the functions that accept pointer values as arguments. Here are a couple of things to keep in mind :

- If you explicitly gave a name to an object, the pointer value can be retrieved using the '`cget -this`' method. This pointer value is what you should give to other SWIG generated functions if necessary.
- If you let SWIG generate the name of an object for you, then the name of the object is the same as the pointer value. This is the preferred approach.
- If you have a pointer value but it's not a Tcl object, you can turn it into one by calling the constructor with the '`-this`' option.

Here is a script that illustrates how these things work :

```
# Example 1 : Using a named object

List l                      # Create a new list
l insert Dave               # Call some methods
l insert Jane
l insert Pat
List_print [l cget -this]   # Call a static method (which requires the pointer value)

# Example 2: Let SWIG pick a name

set l [List]                # Create a new list
$l insert Dave              # Call some methods
$l insert Jane
$l insert Pat
List_print $l               # Call static method (name of object is same as pointer)

# Example 3: Already existing object
set l [new_List]            # Create a raw object using low-level interface
List_insert $l Dave         # Call some methods (using low-level functions)
List -this $l               # Turn it into a Tcl object instead
$l insert Jane
$l insert Part
List_print $l               # Call static method (uses pointer value as before).
```

Performance concerns and disabling the object oriented interface

The object oriented interface is mainly provided for ease of programming at the expense of introducing more overhead and increased code size (C code that is). If you are concerned about these things use the basic SWIG interface instead. It provides direct access and is much faster. As it turns out, it is possible to build an object oriented interface directly in Tcl as well--an example we'll return to a little later.

To disable the object oriented interface, run SWIG with the `-noobject` option. This will strip out all of the extra code and produce an interface comparable to the output of SWIG 1.0.

About the examples

The next few sections will cover a variety of Tcl examples of varying complexity. These are primarily designed to illustrate how SWIG can be used to integrate C/C++ and Tcl in a variety of ways. Some of the things that will be covered are :

- Controlling C programs with Tcl
- Building C data structures in Tcl.
- Use of C objects with Tk
- Wrapping a C library (OpenGL in this case)
- Accessing arrays and other common data structures
- Using Tcl to build new Tcl interfaces to C programs.
- Modifying SWIG's handling of datatypes.
- And a bunch of other cool stuff.

Binary trees in Tcl

In this example, we will show Tcl can be used to manipulate binary trees implemented in C. This will involve accessing C data structures and functions.

C files

We will build trees using the following C header file :

```
/* tree.h */
typedef struct Node Node;
struct Node {
       char          *key;
       char          *value;
       Node          *left;
       Node          *right;
};

typedef struct Tree {
       Node          *head;         /*  Starting node */
       Node          *z;            /* Ending node (at leaves) */
} Tree;

extern Node *new_Node(char *key, char *value);
extern Tree *new_Tree();
```

The C functions to create new nodes and trees are as follows :

```
/* File : tree.c */
#include <string.h>
#include "tree.h"
Node *new_Node(char *key, char *value) {
       Node *n;
       n = (Node *) malloc(sizeof(Node));
       n->key = (char *) malloc(strlen(key)+1);
       n->value = (char *) malloc(strlen(value)+1);
       strcpy(n->key,key);
       strcpy(n->value,value);
       n->left = 0;
```

```
        n->right = 0;
        return n;
};
Tree *new_Tree() {
        Tree *t;
        t = (Tree *) malloc(sizeof(Tree));
        t->head = new_Node("","__head__");
        t->z = new_Node("__end__","__end__");
        t->head->right = t->z;
        t->z->left = t->z;
        t->z->right = t->z;
        return t;
}
```

Making a quick a dirty Tcl module

To make a quick Tcl module with these functions, we can do the following :

```
// file : tree.i
%module tree
%{
#include "tree.h"
%}
%include tree.h              // Just grab header file since it's fairly simple
%module tclsh.i              // Build a new version of tclsh
```

To build the module, run SWIG as follows and compile the resulting output :

```
% swig -tcl tree.i
% gcc tree.c tree_wrap.c -I/usr/local/include -L/usr/local/lib -ltcl -lm -o my_tclsh
```

We can now tree out the module interactively by just running the new '`my_tclsh`' executable.

```
unix > my_tclsh
% set t [new_Tree]                # Create a new tree
_8053198_Tree_p
% set n [Tree_head_get $t]        # Get first node
_80531a8_Node_p
% puts [Node_value_get $n]        # Get its value
__head__
% Node -this $n
% $n cget -value                  # Altenative method for getting value
__head__
```

Building a C data structure in Tcl

Given our simple Tcl interface, it is easy to write Tcl functions for building up a C binary tree. For example :

```
# Insert an item into a tree
proc insert_tree {tree key value} {
    set tree_head [Tree_head_get $tree]
    set tree_z [Tree_z_get $tree]
    set p $tree_head
    set x [Node_right_get $tree_head]
    while {[Node_key_get $x] != "__end__"} {
        set p $x
```

```
            if {$key < [Node_key_get $x]} {
                  set x [Node_left_get $x]
            } {
                  set x [Node_right_get $x]
            }
        }
        set x [new_Node $key $value]
        if {$key < [Node_key_get $p]} {
            Node_left_set $p $x
        } {
            Node_right_set $p $x
        }
        Node_left_set $x $tree_z
        Node_right_set $x $tree_z
    }

    # Search tree and return all matches
    proc search_tree {tree key} {
        set tree_head [Tree_head_get $tree]
        set tree_z [Tree_z_get $tree]
        set found {}
        set x [Node_right_get $tree_head]
        while {[Node_key_get $x] != "__end__"} {
            if {[Node_key_get $x] == $key} {
                lappend found [Node_value_get $x]
            }
            if {$key < [Node_key_get $x]} {
                set x [Node_left_get $x]
            } {
                set x [Node_right_get $x]
            }
        }
        return $found
    }
```

While written in Tcl, these functions are building up a real C binary tree data structure that could be passed into other C function (but more on that in abit). To use our new functions, we could write a function that globs an entire directory and builds a tree structure as follows :

```
    # Insert all of the files in pathname into a binary tree

    proc build_dir_tree {tree pathname} {
        set error [catch {set filelist [glob -nocomplain $pathname/*]}]
        if {$error == 0} {
            foreach f $filelist {
                if {[file isdirectory $f] == 1} {
                    insert_tree $tree [file tail $f] $f
                    if {[file type $f] != "link"} {build_dir_tree $tree $f}
                } {
                    insert_tree $tree [file tail $f] $f
                }
            }
        }
    }
```

We can test out our function interactively as follows :

```
    % source tree.tcl
```

```
% set t [new_Tree]           # Create a new tree
_80533c8_Tree_p
% build_dir_tree $t /home/beazley/SWIG/SWIG1.1
% search_tree $t tcl
/home/beazley/SWIG/SWIG1.1/Examples/tcl /home/beazley/SWIG/SWIG1.1/swig_lib/tcl
%
```

Implementing methods in C

While our Tcl methods may be fine for small problems, it may be faster reimplement the insert and search methods in C such as the following :

```
void insert_tree(Tree *t, char *key, char *value) {
       Node *p;
       Node *x;

       p = t->head;
       x = t->head->right;
       while (x != t->z) {
              p = x;
              if (strcmp(key,x->key) < 0)
                     x = x->left;
              else
                     x = x->right;
       }
       x = new_Node(key,value);
       if (strcmp(key,p->key) < 0)
              p->left = x;
       else
              p->right = x;
       x->left = t->z;
       x->right = t->z;
}
```

To use this function, simply put a declaration into the file `tree.h` or `tree.i`.

When this function is reimplemented in C, the underlying Tcl script may not notice the difference. For example, our directory subroutine would not care if `insert_tree` had been written in Tcl or C. Of course, by writing this function C, we will get significantly better performance.

Building an object oriented C interface

So far our tree example has been using the basic SWIG interface. With a little work in the interface file, we can improve the interface a little bit.

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

%include tree.h
%include tclsh.i

%{

  /* Function to count up Nodes */
  static  int count_nodes(Node *n, Node *end) {
    if (n == end) return 0;
```

```
    return 1+count_nodes(n->left,end)+count_nodes(n->right,end);
  }

%}

// Attach some new methods to the Tree structure

%addmethods Tree {
   void insert(char *key, char *value) {
        insert_tree(self,key,value);
   }
   char *search(char *key) {
        return search_tree(self,key);
   }
   char *findnext(char *key) {
     return find_next(self,key);
   }
   int count() {
     return count_nodes(self->head->right,self->z);
   }
   Tree();        // This is just another name for new_Tree
}
```

The `%addmethods` directive can be used to attach methods to existing structures and classes. In this case, we are attaching some methods to the `Tree` structure. Each of the methods are simply various C functions we have written for accessing trees. This type of interface file comes in particularly handy when using the Tcl object oriented interface. For example, we can rewrite our directory globber as follows :

```
proc build_dir_tree {tree pathname} {
    set error [catch {set filelist [glob -nocomplain $pathname/*]}]
    if {$error == 0} {
        foreach f $filelist {
            if {[file isdirectory $f] == 1} {
                $tree insert [file tail $f] $f      # Note new calling method
                if {[file type $f] != "link"} {build_dir_tree $tree $f}
            } {
                $tree insert [file tail $f] $f
            }
        }
    }
}
```

Now using it :

```
% source tree.tcl
% Tree t                    # Create a new Tree object
_8054610_Tree_p
% build_dir_tree t /home/beazley/SWIG/SWIG1.1
% t count
1770
% t search glaux.i
/home/beazley/SWIG/SWIG1.1/Examples/OpenGL/glaux.i
% t search typemaps
/home/beazley/SWIG/SWIG1.1/Examples/perl5/typemaps
% t findnext typemaps
/home/beazley/SWIG/SWIG1.1/Examples/python/typemaps
% t findnext typemaps
```

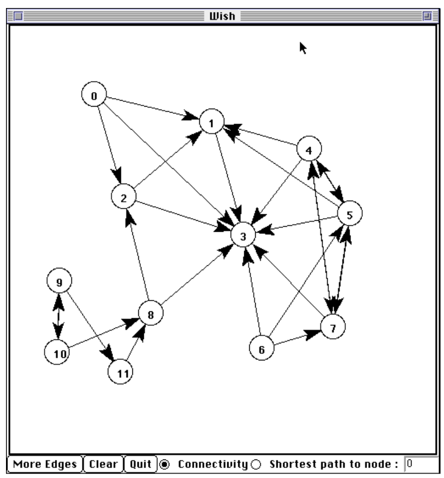
```
/home/beazley/SWIG/SWIG1.1/Examples/tcl/typemaps
% t findnext typemaps
None
%
```

With a little extra work, we've managed to turn an ordinary C structure into a class-like object in Tcl.

Building C/C++ data structures with Tk

Given the direct access to C/C++ objects provided by SWIG, it can be possible to use Tk to interactively build a variety of interesting data structures. To do this, it is usually useful to maintain a mapping between canvas items and an underlying C data structure. This can be easily done using associative arrays to map C pointers to canvas items and canvas items back to pointers.

Suppose that we have a C program for manipulating directed graphs and that we wanted to provide a Tk interface for building graphs using a ball-and-stick model such as the following :



The SWIG interface file for this might look something like this :

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

/* Get a node's number */
int GetNum(Node *n);                              /* Get a node's number         */
AdjList *GetAdj(Node *n);;                        /* Get a node's adjacency list */
AdjList *GetNext(AdjList *l);                     /* Get next node in adj. list  */
Node *GetNode(AdjList *l);                        /* Get node from adj. list     */
Node *new_node();                                 /* Make a new node             */
void AddLink(Node *v1, Node *v2);                 /* Add an edge                 */
... etc ...
```

The interface file manipulates `Node` and `AdjList` structures. The precise implementation of these doesn't matter here--in fact SWIG doesn't even need it. Within a Tcl/Tk script however, we can keep track of these objects as follows :

```
# Make a new node and put it on the canvas
proc mkNode {x y} {
    global nodeX nodeY nodeP nodeMap nodeList edgeFirst edgeSecond
    set new [.c create oval [expr $x-15] [expr $y-15] \
                [expr $x+15] [expr $y+15] -outline black \
                -fill white -tags node]
    set newnode [new_node]                                ;# Make a new C Node
    set nnum [GetNum $newnode]                            ;# Get our node's number
    set id [.c create text [expr $x-4] [expr $y+10] \
            -text $nnum -anchor sw -tags nodeid]
    set nodeX($new) $x                                    ;# Save coords of canvas item
    set nodeY($new) $y
    set nodeP($new) $newnode                              ;# Save C pointer
    set nodeMap($newnode) $new                            ;# Map pointer to Tk widget
    set edgeFirst($new) {}
    set edgeSecond($new) {}
    lappend nodeList $new                                 ;# Keep a list of all C
                                                          ;# Pointers we've made
}

# Make a new edge between two nodes and put an arrow on the canvas
proc mkEdge {first second new} {
    global nodeP edgeFirst edgeSecond
    set edge [mkArrow $first $second]                     ;# Make an arrow
    lappend edgeFirst($first) $edge                       ;# Save information
    lappend edgeSecond($second) $edge
    if {$new == 1} {
# Now add an edge within our C data structure
        AddLink $nodeP($first) $nodeP($second)            ;# Add link to C structure
    }
}
```

In these functions, the array `nodeP()` allows us to associate a particular canvas item with a C object. When manipulating the graph, this makes it easy to move from the Tcl world to C. A second array, `nodeMap()` allows us to go the other way--mapping C pointers to canvas items. A list `nodeList` keeps track of all of the nodes we've created just in case we want to examine all of the nodes. For example, suppose a C function added more edges to the graph. To reflect the new state of the graph, we would want to add more edges to the Tk canvas. This might be accomplished as follows :

```
# Look at the C data structure and update the canvas
proc mkEdges {} {
    global nodeX nodeY nodeP nodeMap nodeList edgeFirst edgeSecond
    unset edgeFirst
    unset edgeSecond
    .c delete arc              # Edges have been tagged with arc (not shown)

    foreach node $nodeList {   ;# clear old lists
       set edgeFirst($node) {}
       set edgeSecond($node) {}
    }
    foreach node $nodeList {                     ;# Go through all of the nodes
       set v $nodeP($node)                       ;# Get the node pointer
       set v1 [GetAdj $v]                        ;# Get its adjacency list
       while {$v1 != "NULL"} {
           set v2 [GetNode $v1]                  ;# Get node pointer
```

```
            set w $nodeMap($v2)               ;# Get canvase item
            mkEdge $node $w 0                 ;# Make an edge between them
            set v1 [GetNext $v1]              ;# Get next node
        }
    }
}
```

This function merely scans through all of the nodes and walks down the adjacency list of each one. The `nodeMap()` array maps C pointers onto the corresponding canvas items. We use this to construct edges on the canvas using the `mkEdge` function.

Accessing arrays

In some cases, C functions may involve arrays and other objects. In these instances, you may have to write helper functions to provide access. For example, suppose you have a C function like this :

```
// Add vector a+b -> c
void vector_add(double *a, double *b, double *c, int size);
```

SWIG is quite literal in its interpretation of `double *`--it will expect a pointer to a `double`. To support this, a few helper functions can be written such as the following :

```
// SWIG helper functions for double arrays
%inline %{
double *new_double(int size) {
       return (double *) malloc(size*sizeof(double));
}
void delete_double(double *a) {
       free a;
}
double get_double(double *a, int index) {
       return a[index];
}
void set_double(double *a, int index, double val) {
       a[index] = val;
}
%}
```

Using our C function might involve something like the following :

```
# Tcl code to create some arrays and add them

set a [new_double 200]
set b [new_double 200]
set c [new_double 200]

# Fill a and b with some values
for {set i 0} {$i < 200} {incr i 1} {
       set_double $a $i 0.0
       set_double $b $i $i
}

# Add them and store result in c
```

```
vector_add $a $b $c 200
```

The functions `get_double` and `set_double` can be used to access individual elements of an array. To convert from Tcl lists to C arrays, one could write a few functions in Tcl such as the following :

```
# Tcl Procedure to turn a list into a C array
proc Tcl2Array {l} {
	set len [llength $l]
	set a [new_double $len]
	set i 0
	foreach item $l {
		set_double $a $i $item
		incr i 1
	}
	return $a
}

# Tcl Procedure to turn a C array into a Tcl List
proc Array2Tcl {a size} {
	set l {}
	for {set i 0} {$i < size} {incr i 1} {
		lappend $l [get_double $a $i]
	}
	return $l
}
```

While perhaps not optimal, one could use these to turn a Tcl list into a C representation. The C representation could be used repeatedly in a variety of C functions without having to repeatedly convert from strings (Of course, if the Tcl list changes one would want to update the C version). Likewise, it is relatively simple to go back from C into Tcl. This is not the only way to manage arrays--typemaps can be used as well. The SWIG library file '`array.i`' also contains a variety of pre-written helper functions for managing different kinds of arrays.

Building a simple OpenGL module

In this example, we consider building a SWIG module out of the OpenGL graphics library. The OpenGL library consists of several hundred functions for building complex 3D images. By wrapping this library, we will be able to play with it interactively from a Tcl interpreter.

Required files

To build an OpenGL module, you will need to have some variant of OpenGL installed on your machine. If unavailable, the Mesa graphics library is an OpenGL clone that runs on most machines that support X11. We will use the "GL/gl.h", "GL/glu.h", and the GL Auxilliary libraries.

Wrapping gl.h

The first step is to build an interface from the gl.h file. To do this, follow the following steps :

- Copy the file gl.h to a file gl.i which will become the interface.
- Edit the gl.i file by taking out unneeded C preprocessor directives and any other clutter that you find.

- Put the following code at the beginning of the gl.i file

```
// gl.i : SWIG file for OpenGL
%module gl
%{
#include <GL/gl.h>
%}

... Rest of edited gl.h file here ...
```

A critical part of this first step is to make sure you have the proper set of typedefs in the gl.i file. The first part of the file should include definitions such as the following :

```
typedef unsigned int GLenum;
typedef unsigned char GLboolean;
typedef unsigned int GLbitfield;
typedef signed char GLbyte;
typedef short GLshort;
typedef int GLint;
typedef int GLsizei;
typedef unsigned char GLubyte;
typedef unsigned short GLushort;
typedef unsigned int GLuint;
typedef float GLfloat;
typedef float GLclampf;
typedef double GLdouble;
typedef double GLclampd;
typedef void GLvoid;
```

Wrapping glu.h

Next we write a module for the glu library. The procedure is essential identical to gl.h--that is, we'll copy the header file and edit it slightly. In this case, the glu.h contains a few functions involving function pointers and arrays. These may generate errors or warnings. As a result, we can simply edit those declarations out. Fortunately, there aren't many declarations like this. The final glu.i file will look something like this :

```
%module glu
%{
#include <GL/glu.h>
%}

... rest of edited glu.h file here ...
```

Given these two files, we have a fairly complete OpenGL package. Unfortunately, we still don't have any mechanism for opening a GL window and creating images. To to this, we can wrap the OpenGL auxilliary library which contains functions to open windows and draw various kinds of objects.

Wrapping the aux library

Wrapping the aux library follows exactly the same procedure as before. You will create a file glaux.i such as the following :

```
// File :glaux.i
```

```
%module aux
%{
#include “aux.h”
%}

... Rest of edited aux.h file ...
```

A few helper functions

Finally, to make our library a little easier to use, we need to have a few functions to handle arrays since quite a few OpenGL calls use them as arguments. Small 4 element arrays are particularly useful so we create a few helper functions in a file called `help.i`.

```
// help.i : OpenGL helper functions

%inline %{
GLfloat *newfv4(GLfloat a,GLfloat b,GLfloat c,GLfloat d) {
  GLfloat *f;
    f = (GLfloat *) malloc(4*sizeof(GLfloat));
  f[0] = a; f[1] = b; f[2] = c; f[3] = d;
  return f;
}
void setfv4(GLfloat *fv, GLfloat a, GLfloat b, GLfloat c, GLfloat d) {
  fv[0] = a; fv[1] = b; fv[2] = c; fv[3] = d;
}
%}
%name(delfv4) void free(void *);
```

An OpenGL package

Whew, we’re almost done now. The last thing to do is to package up all of our interface files into a single file called `opengl.i`. This is easily done as follows :

```
//
// opengl.i.    SWIG Interface file for OpenGL
%module opengl

%include gl.i         // The main GL functions
%include glu.i        // The GLU library
%include glaux.i      // The aux library
%include help.i       // Our helper functions
```

To build the module, we can simply run SWIG as follows :

```
unix > swig -tcl opengl.i           #  Build a dynamicly loaded extension
```

or

```
unix > swig -tcl -lwish.i opengl.i  # Build a statically linked wish executable
```

Compile the file opengl_wrap.c with your C compiler and link with Tcl, Tk, and OpenGL to create the final module.

Using the OpenGL module

The module is now used by writing a Tcl script such as the following :

```
load ./opengl.so
auxInitDisplayMode [expr {$AUX_SINGLE | $AUX_RGBA | $AUX_DEPTH}]
auxInitPosition 0 0 500 500
auxInitWindow "Lit-Sphere"

# set up material properties
set mat_specular [newfv4 1.0 1.0 1.0 1.0]
set mat_shininess [newfv4 50.0 0 0 0]
set light_position [newfv4 1.0 1.0 1.0 0.0]

glMaterialfv $GL_FRONT $GL_SPECULAR $mat_specular
glMaterialfv $GL_FRONT $GL_SHININESS $mat_shininess
glLightfv $GL_LIGHT0 $GL_POSITION $light_position
glEnable $GL_LIGHTING
glEnable $GL_LIGHT0
glDepthFunc $GL_LEQUAL
glEnable $GL_DEPTH_TEST

# Set up view
glClearColor 0 0 0 0
glColor3f 1.0 1.0 1.0
glMatrixMode $GL_PROJECTION
glLoadIdentity
glOrtho -1 1 -1 1 -1 1
glMatrixMode $GL_MODELVIEW
glLoadIdentity

# Draw it
glClear $GL_COLOR_BUFFER_BIT
glClear $GL_DEPTH_BUFFER_BIT
auxSolidSphere 0.5

# Clean up
delfv4 $mat_specular
delfv4 $mat_shininess
delfv4 $light_position
```

In our interpreted interface, it is possible to interactively change parameters and see the effects of various OpenGL functions. This a great way to figure out what various functions do and to try different things without having to recompile and run after each change.

Problems with the OpenGL interface

While the OpenGL interface we have generated is fully usable, it is not without problems.

- OpenGL constants are installed as global variables. As a result, it is necessary to use the global keyword when writing Tcl subroutine. For example :

```
proc clear_screen { } {
       global GL_COLOR_BUFFER_BIT, GL_DEPTH_BUFFER_BIT
       glClear $GL_COLOR_BUFFER_BIT
       glClear $GL_DEPTH_BUFFER_BIT
}
```

- Arrays need to be accessed via helper functions such as our `newfv4()` function. This approach certainly works and its easy enough to implement, but it may be preferable to call certain OpenGL functions with a Tcl list instead. For example :

```
glMaterialfv $GL_FRONT $GL_SPECULAR {1.0 1.0 1.0 1.0}
```

While these are only minor annoyances, it turns out that you can address both problems using SWIG typemaps (which, coincidently, is our next topic).

Exception handling

The SWIG `%except` directive can be used to create a user-definable exception handler in charge of converting exceptions in your C/C++ program into Tcl exceptions. The chapter on exception handling contains more details, but suppose you extended the array example into a C++ class like the following :

```
class RangeError {};   // Used for an exception

class DoubleArray {
  private:
    int n;
    double *ptr;
  public:
    // Create a new array of fixed size
    DoubleArray(int size) {
      ptr = new double[size];
      n = size;
    }
    // Destroy an array
    ~DoubleArray() {
       delete ptr;
    }
    // Return the length of the array
    int   length() {
      return n;
    }

    // Get an item from the array and perform bounds checking.
    double getitem(int i) {
      if ((i >= 0) && (i < n))
        return ptr[i];
      else
        throw RangeError();
    }

    // Set an item in the array and perform bounds checking.
    void setitem(int i, double val) {
      if ((i >= 0) && (i < n))
        ptr[i] = val;
      else {
        throw RangeError();
      }
    }
  };
```

The functions associated with this class can throw a C++ range exception for an out-of-bounds array access. We can catch this in our Tcl extension by specifying the following in an interface file :

```
%except(tcl) {
  try {
    $function                // Gets substituted by actual function call
  }
  catch (RangeError) {
    interp->result = "Array index out-of-bounds";
    return TCL_ERROR;
  }
}
```

or in Tcl 8.0

```
%except(tcl8) {
  try {
    $function                // Gets substituted by actual function call
  }
  catch (RangeError) {
    Tcl_SetStringObj(tcl_result,"Array index out-of-bounds";
    return TCL_ERROR;
  }
}
```

Now, when the C++ class throws a `RangeError` exception, our wrapper functions will catch it, turn it into a Tcl exception, and allow a graceful death as opposed to just having some sort of mysterious program crash. Since SWIG's exception handling is user-definable, we are not limited to C++ exception handling. Please see the chapter on exception handling for more details on other possibilities.

Typemaps

This section describes how SWIG's treatment of various C/C++ datatypes can be remapped using the SWIG `%typemap` directive. While not required, this section assumes some familiarity with Tcl's C API. The reader is advised to consult a Tcl book. A glance at the chapter on SWIG typemaps will also be useful.

What is a typemap?

A typemap is mechanism by which SWIG's processing of a particular C datatype can be overridden. A simple typemap might look like this :

```
%module example

%typemap(tcl,in) int {
       $target = (int) atoi($source);
       printf("Received an integer : %d\n",$target);
}
...
extern int fact(int n);
```

Typemaps require a language name, method name, datatype, and conversion code. For Tcl,

"tcl" should be used as the language name. For Tcl 8.x, "tcl8" should be used if you are using the native object interface. The "in" method in this example refers to an input argument of a function. The datatype 'int' tells SWIG that we are remapping integers. The supplied code is used to convert from a Tcl string to the corresponding C datatype. Within the supporting C code, the variable `$source` contains the source data (a string in this case) and `$target` contains the destination of a conversion.

When this example is compiled into a Tcl module, it will operate as follows :

```
% fact 6
Received an integer : 6
720
%
```

A full discussion of typemaps can be found in the main SWIG users reference. We will primarily be concerned with Tcl typemaps here.

Tcl typemaps

The following typemap methods are available to Tcl modules :

`%typemap(tcl,in)`	Converts a string to input function arguments
`%typemap(tcl,out)`	Converts return value of a C function to a string
`%typemap(tcl,freearg)`	Cleans up a function argument (if necessary)
`%typemap(tcl,argout)`	Output argument processing
`%typemap(tcl,ret)`	Cleanup of function return values
`%typemap(tcl,const)`	Creation of Tcl constants
`%typemap(memberin)`	Setting of C++ member data
`%typemap(memberout)`	Return of C++ member data

Typemap variables

The following variables may be used within the C code used in a typemap:

`$source`	Source value of a conversion
`$target`	Target of conversion (where the result should be stored)
`$type`	C datatype being remapped
`$mangle`	Mangled version of data (used for pointer type-checking)
`$value`	Value of a constant (const typemap only)

Name based type conversion

Typemaps are based both on the datatype and an optional name attached to a datatype. For example :

```
%module foo

// This typemap will be applied to all char ** function arguments
%typemap(tcl,in) char ** { ... }

// This typemap is applied only to char ** arguments named 'argv'
%typemap(tcl,in) char **argv { ... }
```

In this example, two typemaps are applied to the `char **` datatype. However, the second typemap will only be applied to arguments named '`argv`'. A named typemap will always override an unnamed typemap.

Named typemaps are extremely useful for managing special cases. It is also possible to use named typemaps to process output arguments (ie. function arguments that have values returned in them).

*Converting char ** to a Tcl list*

A common problem in many C programs is the processing of command line arguments, which are usually passed in an array of NULL terminated strings. The following SWIG interface file allows a Tcl list to be used as a `char **` object.

```
%module argv

// This tells SWIG to treat char ** as a special case
%typemap(tcl,in) char ** {
        int tempc;
        if (Tcl_SplitList(interp,$source,&tempc,&$target) == TCL_ERROR)
              return TCL_ERROR;
}

// This gives SWIG some cleanup code that will get called after the function call
%typemap(tcl,freearg) char ** {
        free((char *) $source);
}

// Return a char ** as a Tcl list
%typemap(tcl,out) char ** {
        int i = 0;
        while ($source[i]) {
             Tcl_AppendElement(interp,$source[i]);
             i++;
        }
}

// Now a few test functions
%inline %{
int print_args(char **argv) {
    int i = 0;
    while (argv[i]) {
         printf("argv[%d] = %s\n", i,argv[i]);
         i++;
    }
    return i;
}


// Returns a char ** list
char **get_args() {
    static char *values[] = { "Dave", "Mike", "Susan", "John", "Michelle", 0};
    return &values[0];
}

// A global variable
char *args[] = { "123", "54", "-2", "0", "NULL", 0 };
```

```
%}
%include tclsh.i
```

When compiled, we can use our functions as follows :

```
% print_args {John Guido Larry}
argv[0] = John
argv[1] = Guido
argv[2] = Larry
3
% puts [get_args]
Dave Mike Susan John Michelle
% puts [args_get]
123 54 -2 0 NULL
%
```

Perhaps the only tricky part of this example is the implicit memory allocation that is performed by the `Tcl_SplitList` function. To prevent a memory leak, we can use the SWIG freearg typemap to clean up the argument value after the function call is made. In this case, we simply free up the memory that `Tcl_SplitList` allocated for us.

Remapping constants

By default, SWIG installs C constants as Tcl read-only variables. Unfortunately, this has the undesirable side effect that constants need to be declared as "global" when used in subroutines. For example :

```
proc clearscreen { } {
       global GL_COLOR_BUFFER_BIT
       glClear $GL_COLOR_BUFFER_BIT
}
```

If you have hundreds of functions however, this quickly gets annoying. Here's a fix using hash tables and SWIG typemaps :

```
// Declare some Tcl hash table variables
%{
static Tcl_HashTable  constTable;      /* Hash table          */
static int           *swigconst;       /* Temporary variable  */
static Tcl_HashEntry *entryPtr;        /* Hash entry          */
static int            dummy;           /* dummy value         */
%}

// Initialize the hash table (This goes in the initialization function)

%init %{
  Tcl_InitHashTable(&constTable,TCL_STRING_KEYS);
%}

// A Typemap for creating constant values
// $source = the value of the constant
// $target = the name of the constant

%typemap(tcl,const) int, unsigned int, long, unsigned long {
  entryPtr = Tcl_CreateHashEntry(&constTable,"$target",&dummy);
```

```
    swigconst = (int *) malloc(sizeof(int));
    *swigconst = $source;
    Tcl_SetHashValue(entryPtr, swigconst);
    /* Make it so constants can also be used as variables */
    Tcl_LinkVar(interp,"$target", (char *) swigconst, TCL_LINK_INT | TCL_LINK_READ_ONLY);
};

// Now change integer handling to look for names
%typemap(tcl,in) int, unsigned int, long, unsigned long {
  Tcl_HashEntry *entryPtr;
  entryPtr = Tcl_FindHashEntry(&constTable,$source);
  if (entryPtr) {
    $target = ($type) (*((int *) Tcl_GetHashValue(entryPtr)));
  } else {
    $target = ($type) atoi($source);
  }
}
```

Now, in our Tcl code, we can access constants by name without using the “global” keyword as follows :

```
proc clearscreen { } {
       glClear GL_COLOR_BUFFER_BIT
}
```

Returning values in arguments

The “argout” typemap can be used to return a value originating from a function argument. For example :

```
// A typemap defining how to return an argument
%typemap(tcl,argout) double *outvalue {
        char dtemp[TCL_DOUBLE_SPACE];
        Tcl_PrintDouble(interp,*($source),dtemp);
        Tcl_AppendElement(interp, dtemp);
}

// A typemap telling SWIG to ignore an argument for input
// However, we still need to pass a pointer to the C function
%typemap(tcl,ignore) double *outvalue {
       static double temp;         /* A temporary holding place */
       $target = &temp;
}

// Now a function returning two values
int mypow(double a, double b, double *outvalue) {
        if ((a < 0) || (b < 0)) return -1;
        *outvalue = pow(a,b);
        return 0;
};
```

When wrapped, SWIG matches the `argout` typemap to the “`double *outvalue`” argument. The “ignore” typemap tells SWIG to simply ignore this argument when generating wrapper code. As a result, a Tcl function using these typemaps will work like this :

```
% mypow 2 3     # Returns two values, a status value and the result
0 8
%
```

An alternative approach to this is to return values in a Tcl variable. For example :

```
%typemap(tcl,argout) double *outvalue {
       char temp[TCL_DOUBLE_SPACE];
       Tcl_PrintDouble(interp,*($source),dtemp);
       Tcl_SetVar(interp,$arg,temp,0);
}
%typemap(tcl,in) double *outvalue {
       static double temp;
       $target = &temp;
}
```

Our Tcl script can now do the following :

```
% set status [mypow 2 3 a]
% puts $status
0
% puts $a
8.0
%
```

Here, we have passed the name of a Tcl variable to our C wrapper function which then places the return value in that variable. This is now very close to way in which a C function calling this function would work.

Mapping C structures into Tcl Lists

Suppose you have a C structure like this :

```
typedef struct {
  char  login[16];           /* Login ID  */
  int   uid;                 /* User ID   */
  int   gid;                 /* Group ID  */
  char  name[32];            /* User name */
  char  home[256];           /* Home directory */
} User;
```

By default, SWIG will simply treat all occurrences of "`User`" as a pointer. Thus, functions like this :

```
extern void add_user(User u);
extern User *lookup_user(char *name);
```

Will work, but they will be weird. In fact, they may not work at all unless you write helper functions to create users and extract data. A typemap can be used to fix this problem however. For example :

```
// This works for both "User" and "User *"
%typemap(tcl,in) User * {
       int tempc;
       char **tempa;
```

```
        static User temp;
        if (Tcl_SplitList(interp,$source,&tempc,&tempa) == TCL_ERROR) return TCL_ERROR;
        if (tempc != 5) {
                free((char *) tempa);
                interp->result = "Not a valid User record";
                return TCL_ERROR;
        }
        /* Split out the different fields */
        strncpy(temp.login,tempa[0],16);
        temp.uid = atoi(tempa[1]);
        temp.gid = atoi(tempa[2]);
        strncpy(temp.name,tempa[3],32);
        strncpy(temp.home,tempa[4],256);
        $target = &temp;
        free((char *) tempa);
}

// Describe how we want to return a user record
%typemap(tcl,out) User * {
        char temp[20];
        if ($source) {
        Tcl_AppendElement(interp,$source->login);
        sprintf(temp,"%d",$source->uid);
        Tcl_AppendElement(interp,temp);
        sprintf(temp,"%d",$source->gid);
        Tcl_AppendElement(interp,temp);
        Tcl_AppendElement(interp,$source->name);
        Tcl_AppendElement(interp,$source->home);
        }
}
```

These function marshall Tcl lists to and from our `User` data structure. This allows a more natural implementation that we can use as follows :

```
% add_user {beazley 500 500 “Dave Beazley” “/home/beazley”}
% lookup_user beazley
beazley 500 500 {Dave Beazley} /home/beazley
```

This is a much cleaner interface (although at the cost of some performance). The only caution I offer is that the pointer view of the world is pervasive throughout SWIG. Remapping complex datatypes like this will usually work, but every now and then you might find that it breaks. For example, if we needed to manipulate arrays of Users (also mapped as a “`User *`”), the typemaps defined here would break down and something else would be needed.

Useful functions

The following tables provide some functions that may be useful in writing Tcl typemaps. Both Tcl 7.x and Tcl 8.x are covered. For Tcl 7.x, everything is a string so the interface is relatively simple. For Tcl 8, everything is now a Tcl object so a more precise set of functions is required. Given the alpha-release status of Tcl 8, the function described here may change in future releases.

Tcl 7.x Numerical Conversion Functions

`int Tcl_GetInt(Tcl_Interp *,char *, int *ip)`	Convert a string to an integer which is stored in ip. Returns TCL_OK on success, TCL_ERROR on failure.
`int Tcl_GetDouble(Tcl_Interp *, char *, double *dp)`	Convert a string to a double which is stored in *dp. Returns TCL_OK on success, TCL_ERROR on failure.
`Tcl_PrintDouble(Tcl_Interp *, double val, char *dest)`	Creates a string with a double precision value. The precision is determined by the value of the tcl_precision variable.

Tcl 7.x String and List Manipulation Functions

`void Tcl_SetResult(Tcl_Interp *, char *str, Tcl_FreeProc *freeProc)`	Set the Tcl result string. str is the string and freeProc is a procedure to free the result. This is usually TCL_STATIC, TCL_DYNAMIC, TCL_VOLATILE.
`void Tcl_AppendResult(Tcl_Interp *, char *str, char *str, ... (char *) NULL)`	Append string elements to the Tcl result string.
`void Tcl_AppendElement(Tcl_Interp *, char *string)`	Formats string as a Tcl list and appends it to the result string.
`int Tcl_SplitList(Tcl_Interp *, char *list, int *argcPtr, char ***argvPtr)`	Parses list as a Tcl list and creates an array of strings. The number of elements is stored in *argcPtr. A pointer to the string array is stored in ***argvPtr. Returns TCL_OK on success, TCL_ERROR if an error occurred. The pointer value stored in argvPtr must eventual be passed to free.
`char *Tcl_Merge(int argc, char **argv)`	The inverse of SplitList. Returns a pointer to a Tcl list that has been formed from the array argv. The result is dynamically allocated and must be passed to free by the caller.

Tcl 8.x Integer Conversion Functions

`Tcl_Obj *Tcl_NewIntObj(int Value)`	Create a new integer object.
`void Tcl_SetIntObj(Tcl_Obj *obj, int Value)`	Set the value of an integer object

Tcl 8.x Integer Conversion Functions

`int Tcl_GetIntFromObj(Tcl_Interp *, Tcl_Obj *obj, int *ip)`	Get the integer value of an object and return it in *ip. Returns TCL_ERROR if the object is not an integer.

Tcl 8.x Floating Point Conversion Functions

`Tcl_Obj *Tcl_NewDoubleObj(double value)`	Create a new Tcl object containing a double.
`Tcl_SetDoubleObj(Tcl_Obj *obj, double value)`	Set the value of a Tcl_Object.
`int Tcl_GetDoubleFromObj(Tcl_Interp, Tcl_Obj *o, double *dp)`	Get a double from a Tcl object. The value is stored in *dp. Returns TCL_OK on success, TCL_ERROR if the conversion can't be made.

Tcl 8.x String Conversion Functions

`Tcl_Obj *Tcl_NewStringObj(char *str, int len)`	Creates a new Tcl string object. str contains the ASCII string, len contains the number of bytes or -1 if the string is NULL terminated.
`Tcl_SetStringObj(Tcl_Obj *obj, char *str, int len)`	Sets a Tcl object to a given string. len is the string length or -1 if the string is NULL terminated.
`char *Tcl_GetStringFromObj(Tcl_Obj *obj, int *len)`	Retrieves the string associated with an object. The length is returned in *len;
`Tcl_StringObjAppend(Tcl_Obj *obj, char *str, int len)` `Tcl_StringObjAppendObj(Tcl_Obj *obj, Tcl_Obj *src)`	Appends the string str to the given Tcl Object. len contains the number of bytes of -1 if NULL terminated. Same as Tcl_StringObjAppend except that the string representation for src is appended.

Tcl 8.x List Conversion Functions

`Tcl_Obj *Tcl_NewListObj(int objc, Tcl_Obj *objv)`	Creates a new Tcl List object. objc contains the element count and objv is an array of Tcl objects.
`int Tcl_ListObjAppendList(Tcl_Interp *, Tcl_Obj *listPtr, Tcl_Obj *elemListPtr)`	Appends the objects in elemListPtr to the list object listPtr. Returns TCL_ERROR if an error occurred.

Tcl 8.x List Conversion Functions

int Tcl_ListObjAppendElement(Tcl_Interp *, Tcl_Obj *listPtr, Tcl_Obj *element)	Appends element to the end of the list object listPtr. Returns TCL_ERROR if an error occurred. Will convert the object pointed to by listPtr to a list if it isn't one already.
int Tcl_ListObjGetElements(Tcl_Interp *, Tcl_Obj *listPtr, int *objcPtr, Tcl_Obj ***objvPtr)	Converst a Tcl List object into an array of pointers to individual elements. objcPtr receives the list length and objvPtr receives a pointer to an array of Tcl_Obj pointers. Returns TCL_ERROR if the list can not be converted.
int Tcl_ListObjLength(Tcl_Interp *, Tcl_Obj *listPtr, int *intPtr)	Returns the length of a list in intPtr.If the object is not a list or an error occurs, the function returns TCL_ERROR.
int Tcl_ListObjIndex(Tcl_Interp *, Tcl_Obj *listPtr, int index, Tcl_Obj **objptr)	Returns the pointer to object with given index in the list. Returns TCL_ERROR if listPtr is not a list or the index is out of range. The pointer is returned in objptr.
int Tcl_ListObjReplace(Tcl_Interp *, Tcl_Obj *listPtr, int first, int count, int objc, Tcl_Obj *objv)	Replaces objects in a list. first is the first object to replace and count is the total number of objects. objc and objv define a set of new objects to insert into the list. If objv is NULL, no new objects will be added and the function acts as a deletion operation.

Tcl 8.x Object Manipulation

Tcl_Obj *Tcl_NewObj()	Create a new Tcl object
Tcl_Obj *Tcl_DuplicateObj(Tcl_Obj *obj)	Duplicate a Tcl object.
Tcl_IncrRefCount(Tcl_Obj *obj)	Increase the reference count on an object.
Tcl_DecrRefCount(Tcl_Obj *obj)	Decrement the reference count on an object.
int Tcl_IsShared(Tcl_Obj *obj)	Tests to see if an object is shared.

Standard typemaps

The following typemaps show how to convert a few common kinds of objects between Tcl and C (and to give a better idea of how typemaps work)

Function argument typemaps (Tcl 7.x)

`int,`
`short,`
`long`
	<pre>%typemap(tcl,in) int,short,long {
	   int temp;
	   if (Tcl_GetInt(interp,$source,&temp) == TCL_ERROR)
	       return TCL_ERROR;
	   $target = ($type) temp;
	}</pre>

`float,`
`double`
	<pre>%typemap(tcl,in) double,float {
	    double temp;
	    if (Tcl_GetDouble(interp,$source,&temp)
	        == TCL_ERROR)
	        return TCL_ERROR;
	    $target = ($type) temp;
	}</pre>

`char *`	<pre>%typemap(tcl,in) char * {
	  $target = $source;
	}</pre>

Function return typemaps (Tcl 7.x)

`int,`
`short,`
`long,`
	<pre>%typemap(tcl,out) int, short, long {
	   sprintf($target,"%ld", (long) $source);
	}</pre>

`float,`
`double`
	<pre>%typemap(tcl,out) float,double {
	    Tcl_PrintDouble(interp,$source,interp->result);
	}</pre>

`char *`	<pre>%typemap(tcl,out) char * {
	    Tcl_SetResult(interp,$source,TCL_VOLATILE);
	}</pre>

Function argument typemaps (Tcl 8.x)

`int,`
`short,`
`long`
	<pre>%typemap(tcl8,in) int,short,long {
	   int temp;
	   if (Tcl_GetIntFromObj(interp,$source,&temp) ==
	          TCL_ERROR)
	       return TCL_ERROR;
	   $target = ($type) temp;
	}</pre>

Function argument typemaps (Tcl 8.x)

`float,`
`double`
	`%typemap(tcl8,in) double,float {`
	`    double temp;`
	`    if (Tcl_GetDoubleFromObj(interp,$source,&temp)`
	`        == TCL_ERROR)`
	`        return TCL_ERROR;`
	`    $target = ($type) temp;`
	`}`

`char *`	`%typemap(tcl8,in) char * {`
	`  int len;`
	`  $target = Tcl_GetStringFromObj(interp,&len);`
	`}`

Function return typemaps (Tcl 8.x)

`int,`
`short,`
`long,`
	`%typemap(tcl8,out) int, short, long {`
	`   Tcl_SetIntObj($target,$source);`
	`}`

`float,`
`double`
	`%typemap(tcl8,out) float,double {`
	`    Tcl_SetDoubleObj($target,$source);`
	`}`

`char *`	`%typemap(tcl8,out) char * {`
	`    Tcl_SetStringObj($target,$source)`
	`}`

Pointer handling

SWIG pointers are mapped into Python strings containing the hexadecimal value and type. The following functions can be used to create and read pointer values .

SWIG Pointer Conversion Functions (Tcl 7.x/8.x)

`void SWIG_MakePtr(char *str, void *ptr,`
`                  char *type)`
 	
`void SWIG_SetPointerObj(Tcl_Obj *objPtr,`
`                   void *ptr, char *type)`
	Makes a pointer string and saves it in `str`, which must be large enough to hold the result. `ptr` contains the pointer value and `type` is the string representation of the type.

SWIG Pointer Conversion Functions (Tcl 7.x/8.x)

`char *SWIG_GetPtr(char *str, void **ptr, char *type)`
 	
`char *SWIG_GetPointerObj(Tcl_Interp *interp, Tcl_Obj *objPtr, void **ptr, char *_t)`
	Attempts to read a pointer from the string `str`. `ptr` is the address of the pointer to be created and `type` is the expected type. If `type` is NULL, then any pointer value will be accepted. On success, this function returns NULL. On failure, it returns the pointer to the invalid portion of the pointer string.

These functions can be used in typemaps as well although there is usually little need to do so. For example, the following typemap makes an argument of "`char *buffer`" accept a pointer instead of a NULL-terminated ASCII string.

```
%typemap(tcl,in) char *buffer {
        if (SWIG_GetPtr($source, (void **) &$target, "$mangle")) {
                Tcl_SetResult(interp,"Type error. Not a pointer", TCL_STATIC);
                return TCL_ERROR;
        }
}
```

Note that the `$mangle` variable generates the type string associated with the datatype used in the typemap.

By now you hopefully have the idea that typemaps are a powerful mechanism for building more specialized applications. While writing typemaps can be technical, many have already been written for you. See the SWIG library reference for more information.

Configuration management with SWIG

After you start to work with Tcl for awhile, you suddenly realize that there are an unimaginable number of extensions, tools, and other packages. To make matters worse, there are about 20 billion different versions of Tcl, not all of which are compatible with each extension (this is to make life interesting of course).

While SWIG is certainly not a magical solution to the configuration management problem, it can help out alot in a number of key areas :

- SWIG generated code can be used with all versions of Tcl/Tk newer than 7.3/3.6. This includes the Tcl Netscape Plugin and Tcl 8.0a2.
- The SWIG library mechanism can be used to manage various code fragments and initialization functions.
- SWIG generated code usually requires no modification so it is relatively easy to switch between different Tcl versions as necessary or upgrade to a newer version when the time comes (of course, the Sun Tcl/Tk team might have changed other things to keep you occupied)

Writing a main program and Tcl_AppInit()

The traditional method of creating a new Tcl extension required a programmer to write a special function called `Tcl_AppInit()` that would initialize your extension and start the Tcl interpreter. A typical `Tcl_AppInit()` function looks like the following :

```
/* main.c */
#include <tcl.h>

main(int argc, char *argv[]) {
        Tcl_Main(argc,argv);
        exit(0);
}

int Tcl_AppInit(Tcl_Interp *interp) {
        if (Tcl_Init(interp) == TCL_ERROR) {
                return TCL_ERROR;
        }

        /* Initialize your extension */
        if (Your_Init(interp) == TCL_ERROR) {
                return TCL_ERROR;
        }

        tcl_RcFileName = "~/.myapp.tcl";
        return TCL_OK;
}
```

While relatively simple to write, there are tons of problems with doing this. First, each extension that you use typically has their own `Tcl_AppInit()` function. This forces you to write a special one to initialize everything by hand. Secondly, the process of writing a main program and initializing the interpreter varies between different versions of Tcl and different platforms. For example, in Tcl 7.4, the variable "`tcl_RcFileName`" is a C variable while in Tcl7.5 and newer versions its a Tcl variable instead. Similarly, the `Tcl_AppInit` function written for a Unix machine might not compile correctly on a Mac or Windows machine.

In SWIG, it is almost never necessary to write a `Tcl_AppInit()` function because this is now done by SWIG library files such as `tclsh.i` or `wish.i`. To give a better idea of what these files do, here's the code from the SWIG `tclsh.i` file which is roughly comparable to the above code

```
// tclsh.i : SWIG library file for rebuilding tclsh
%{

/* A TCL_AppInit() function that lets you build a new copy
 * of tclsh.
 *
 * The macro SWIG_init contains the name of the initialization
 * function in the wrapper file.
 */

#ifndef SWIG_RcFileName
char *SWIG_RcFileName = "~/.myapprc";
#endif

int Tcl_AppInit(Tcl_Interp *interp){
```

```
  if (Tcl_Init(interp) == TCL_ERROR)
    return TCL_ERROR;

  /* Now initialize our functions */
  if (SWIG_init(interp) == TCL_ERROR)
    return TCL_ERROR;

#if TCL_MAJOR_VERSION > 7 || TCL_MAJOR_VERSION == 7 && TCL_MINOR_VERSION >= 5
   Tcl_SetVar(interp,"tcl_rcFileName",SWIG_RcFileName,TCL_GLOBAL_ONLY);
#else
   tcl_RcFileName = SWIG_RcFileName;
#endif
  return TCL_OK;
}

#if TCL_MAJOR_VERSION > 7 || TCL_MAJOR_VERSION == 7 && TCL_MINOR_VERSION >= 4
int main(int argc, char **argv) {
  Tcl_Main(argc, argv, Tcl_AppInit);
  return(0);

}
#else
extern int main();
#endif

%}
```

This file is essentially the same as a normal `Tcl_AppInit()` function except that it supports a variety of Tcl versions. When included into an interface file, the symbol `SWIG_init` contains the actual name of the initialization function (This symbol is defined by SWIG when it creates the wrapper code). Similarly, a startup file can be defined by simply defining the symbol `SWIG_RcFileName`. Thus, a typical interface file might look like this :

```
%module graph
%{
#include "graph.h"
#define SWIG_RcFileName "graph.tcl"
%}

%include tclsh.i

... declarations ...
```

By including the `tclsh.i`, you automatically get a `Tcl_AppInit()` function. A variety of library files are also available. `wish.i` can be used to build a new wish executable, `expect.i` contains the main program for Expect, and `ish.i`, `itclsh.i`, `iwish.i`, and `itkwish.i` contain initializations for various incarnations of [incr Tcl].

Creating a new package initialization library

If a particular Tcl particular requires special initialization, you can create a special SWIG library file to initialize it and load your extensions. For example, a library file to extend Expect looks like the following :

```
// expect.i : SWIG Library file for Expect
%{

/* main.c - main() and some logging routines for expect

Written by: Don Libes, NIST, 2/6/90

Design and implementation of this program was paid for by U.S. tax
dollars.  Therefore it is public domain.  However, the author and NIST
would appreciate credit if this program or parts of it are used.
*/

#include "expect_cf.h"
#include <stdio.h>
#include INCLUDE_TCL
#include "expect_tcl.h"

void
main(argc, argv)
int argc;
char *argv[];
{
        int rc = 0;
        Tcl_Interp *interp = Tcl_CreateInterp();
        int SWIG_init(Tcl_Interp *);

        if (Tcl_Init(interp) == TCL_ERROR) {
                fprintf(stderr,"Tcl_Init failed: %s\n",interp->result);
                exit(1);
        }
        if (Exp_Init(interp) == TCL_ERROR) {
                fprintf(stderr,"Exp_Init failed: %s\n",interp->result);
                exit(1);
        }

        /* SWIG initialization. --- 2/11/96  */
        if (SWIG_init(interp) == TCL_ERROR) {
                fprintf(stderr,"SWIG initialization failed: %s\n", interp->result);
                exit(1);
        }

        exp_parse_argv(interp,argc,argv);
        /* become interactive if requested or "nothing to do" */
        if (exp_interactive)
                (void) exp_interpreter(interp);
        else if (exp_cmdfile)
                rc = exp_interpret_cmdfile(interp,exp_cmdfile);
        else if (exp_cmdfilename)
                rc = exp_interpret_cmdfilename(interp,exp_cmdfilename);

        /* assert(exp_cmdlinecmds != 0) */
        exp_exit(interp,rc);
        /*NOTREACHED*/
}
%}
```

In the event that you need to write a new library file such as this, the process usually isn't too difficult. Start by grabbing the original `Tcl_AppInit()` function for the package. Enclose it in a `%{,%}` block. Now add a line that makes a call to `SWIG_init()`. This will automatically resolve to the real initialization function when compiled.

Combining Tcl/Tk Extensions

A slightly different problem concerns the mixing of various extensions. Most extensions don't require any special initialization other than calling their initialization function. To do this, we also use SWIG library mechanism. For example :

```
// blt.i : SWIG library file for initializing the BLT extension
%{
#ifdef __cplusplus
extern "C" {
#endif
extern int Blt_Init(Tcl_Interp *);
#ifdef __cplusplus
}
#endif
%}
%init %{
	if (Blt_Init(interp) == TCL_ERROR) {
		return TCL_ERROR;
	}
%}


// tix.i : SWIG library file for initializing the Tix extension
%{
#ifdef __cplusplus
extern "C" {
#endif
extern int Blt_Init(Tcl_Interp *);
#ifdef __cplusplus
}
#endif
%}
%init %{
	if (Tix_Init(interp) == TCL_ERROR) {
		return TCL_ERROR;
	}
%}
```

Both files declare the proper initialization function (to be C++ friendly, this should be done as shown). A call to the initialization function is then placed inside a `%init %{ ... %}` block.

To use our library files and build a new version of wish, we might now do the following :

```
// mywish.i : wish with a bunch of stuff added to it
%include wish.i
%include blt.i
%include tix.i

... additional declarations ...
```

Of course, the really cool part about all of this is that the file '`mywish.i`' can itself, serve as a library file. Thus, when building various versions of Tcl, we can place everything we want to use a special file and use it in all of our other interface files :

```
// interface.i
%module mymodule

%include mywish.i              // Build our version of Tcl with extensions

... C declarations ...
```

or we can grab it on the command line :

```
unix > swig -tcl -lmywish.i interface.i
```

Limitations to this approach

This interface generation approach is limited by the compatibility of each extension you use. If any one extension is incompatible with the version of Tcl you are using, you may be out of luck. It is also critical to pay careful attention to libraries and include files. An extension library compiled against an older version of Tcl may fail when linked with a newer version.

Dynamic loading (pancea or problem?)

Newer versions of Tcl support dynamic loading. With dynamic loading, you compile each extension into a separate module that can be loaded at run time. This simplifies a number of compilation and extension building problems at the expense of creating new ones. Most notably, the dynamic loading process varies widely between machines and is not even supported in some cases. It also does not work well with C++ programs that use static constructors. As a result, I usually find myself using both dynamic and static linking as appropriate.

Turning a SWIG module into a Tcl Package.

Tcl 7.4 introduced the idea of a extension package. By default, SWIG does not create "packages", but it is relatively easy to do. To make a C extension into a Tcl package, you need to provide a call to `Tcl_PkgProvide()` in the module initialization function. This can be done in an interface file as follows :

```
%init %{
        Tcl_PkgProvide(interp,"example","0.0");
%}
```

Where "example" is the name of the package and "0.0" is the version of the package.

Next, after building the SWIG generated module, you need to execute the "`pkg_mkIndex`" command inside tclsh. For example :

```
unix > tclsh
% pkg_mkIndex . exmaple.so
% exit
```

This creates a file "`pkgIndex.tcl`" with information about the package. To use your package, you now need to move it to its own subdirectory which has the same name as the package. For example :

```
./example/
          pkgIndex.tcl             # The file created by pkg_mkIndex
          example.so               # The SWIG generated module
```

Finally, assuming that you're not entirely confused at this point, make sure that the example subdirectory is visible from the directories contained in either the `tcl_library` or `auto_path` variables. At this point you're ready to use the package as follows :

```
unix > tclsh
% package require example
% fact 4
24
%
```

If you're working with an example in the current directory and this doesn't work, do this instead :

```
unix > tclsh
% lappend auto_path .
% package require example
% fact 4
24
```

As a final note, most SWIG examples do not yet use the `package` commands (hmm...).

Building new kinds of Tcl interfaces (in Tcl)

One of the most interesting aspects of Tcl and SWIG is that you can create entirely new kinds of Tcl interfaces in Tcl using the low-level SWIG accessor functions. For example, you had a low-level library of helper functions to access arrays :

```
/* File : array.i */
%module array

%inline %{
double *new_double(int size) {
        return (double *) malloc(size*sizeof(double));
}
void delete_double(double *a) {
        free(a);
}
double get_double(double *a, int index) {
        return a[index];
}
void set_double(double *a, int index, double val) {
        a[index] = val;
}
int *new_int(int size) {
        return (int *) malloc(size*sizeof(int));
}
void delete_int(int *a) {
        free(a);
```

```
}
int get_int(int *a, int index) {
        return a[index];
}
int set_int(int *a, int index, int val) {
        a[index] = val;
}
%}
```

While these could be called directly, we could also write a Tcl script like this :

```
proc Array {type size} {
    set ptr [new_$type $size]
    set code {
        set method [lindex $args 0]
        set parms [concat $ptr [lrange $args 1 end]]
        switch $method {
            get {return [eval "get_$type $parms"]}
            set {return [eval "set_$type $parms"]}
            delete {eval "delete_$type $ptr; rename $ptr {}"}
        }
    }
    # Create a procedure
    uplevel "proc $ptr args {set ptr $ptr; set type $type;$code}"
    return $ptr
}
```

Finally, our script allows easy array access as follows :

```
set a [Array double 100]                   ;# Create a double [100]
for {set i 0} {$i < 100} {incr i 1} {      ;# Clear the array
       $a set $i 0.0
}
$a set 3 3.1455                            ;# Set an individual element
set b [$a get 10]                          ;# Retrieve an element

set ia [Array int 50]                      ;# Create an int[50]
for {set i 0} {$i < 50} {incr i 1} {       ;# Clear it
       $ia set $i 0
}
$ia set 3 7                                ;# Set an individual element
set ib [$ia get 10]                        ;# Get an individual element

$a delete                                  ;# Destroy a
$ia delete                                 ;# Destroy ia
```

The cool thing about this approach is that it makes a common interface for two different types of arrays. In fact, if we were to add more C datatypes to our wrapper file, the Tcl code would work with those as well--without modification. If an unsupported datatype was requested, the Tcl code would simply return with an error so there is very little danger of blowing something up with this approach (although it is easily accomplished with an out of bounds array access).

Shadow classes

A similar approach can be applied to shadow classes. The following example is provided by Erik Bierwagen and Paul Saxe. To use it, run SWIG with the -noobject option (which disables the builtin object oriented interface). When running Tcl, simply source this file. Now, objects can be used in a more or less natural fashion.

```
# swig_c++.tcl
# Provides a simple object oriented interface using
# SWIG's low level interface.
#

proc new {objectType handle_r args} {
    # Creates a new SWIG object of the given type,
    # returning a handle in the variable "handle_r".
    #
    # Also creates a procedure for the object and a trace on
    # the handle variable that deletes the object when the
    # handle varibale is overwritten or unset
    upvar $handle_r handle
    #
    # Create the new object
    #
    eval set handle \[new_$objectType $args\]
    #
    # Set up the object procedure
    #
    proc $handle {cmd args} "eval ${objectType}_\$cmd $handle \$args"
    #
    # And the trace ...
    #
    uplevel trace variable $handle_r uw "{deleteObject $objectType $handle}"
    #
    # Return the handle so that 'new' can be used as an argument to a procedure
    #
    return $handle
}

proc deleteObject {objectType handle name element op} {
    #
    # Check that the object handle has a reasonable form
    #
    if {![regexp {_[0-9a-f]*_(.+)_p} $handle]} {
        error "deleteObject: not a valid object handle: $handle"
    }
    #
    # Remove the object procedure
    #
    catch {rename $handle {}}
    #
    # Delete the object
    #
    delete_$objectType $handle
}

proc delete {handle_r} {
    #
    # A synonym for unset that is more familiar to C++ programmers
    #
    uplevel unset $handle_r
}
```

To use this file, we simply source it and execute commands such as "new" and "delete" to manipulate objects. For example :

```
// list.i
%module List
%{
#include "list.h"
%}

// Very simple C++ example

class List {
public:
  List();  // Create a new list
  ~List(); // Destroy a list
  int  search(char *value);
  void insert(char *);  // Insert a new item into the list
  void remove(char *);  // Remove item from list
  char *get(int n);     // Get the nth item in the list
  int  length;          // The current length of the list
static void print(List *l);  // Print out the contents of the list
};
```

Now a Tcl script using the interface...

```
load ./list.so list        ; # Load the module
source swig_c++.tcl        ; # Source the object file

new List l
$l insert Dave
$l insert John
$l insert Guido
$l remove Dave
puts $l length_get

delete l
```

The cool thing about this example is that it works with any C++ object and requires no special compilation. Proof that a short, but clever Tcl script can be combined with SWIG to do many unexpected things.

Extending the Tcl Netscape Plugin

SWIG can also be used to extend the Tcl Netscape plugin with C functions. As of this writing SWIG has only been tested with version 1.0 of the plugin on Solaris and Irix 6.2. It may work on other machines as well. However, first a word of caution --- doing this might result in serious injury as you can add just about any C function you want. Furthermore, it's not portable (hey, we're talking C code here). It seems like the best application of this would be creating a browser interface to highly specialized application. Any scripts that you would write would not work on other machines unless they also installed the C extension code as well. Hmm... perhaps we should call this a plugin-plugin...

To use the plugin, use the -plugin option :

```
swig -tcl -plugin interface.i
```

This adds a "safe" initialization function compatible with the plugin (in reality, it just calls the function SWIG already creates). You also need to put the following symbol in your interface file for it to work :

```
%{
#define SAFE_SWIG
%}
```

The folks at Sun are quite concerned about the security implications of this sort extension and originally wanted the user to modify the wrapper code by hand to "remind" them that they were installing functions into a safe interpreter. However, having seen alot of SWIG generated wrapper code, I hated that idea (okay, so the output of SWIG is just a little messy). This is compromise--you need to put that `#define` into your C file someplace. You can also just make it a compiler option if you would like.

The step-by-step process for making a plugin extension.

Making a plugin extension is relatively straightforward but you need to follow these steps :

- Make sure you have Tcl7.6/Tk4.2 installed on your machine. We're going to need the header files into order to compile the extension.
- Make sure you have the Netscape plugin properly installed.
- Run SWIG using the '`-tcl -plugin`' options.
- Compile the extension using the Tcl 7.6/Tk4.2 header files, but linking against the plugin itself. For example :

```
unix > gcc -I/usr/local/include -c example.o interface_wrap.c
unix > ld -shared example.o interface_wrap.o \
       -L/home/beazley/.netscape/plugins/libtclplugin.so -o example.so
```

- Copy the shared object file to the `~/.tclplug/tcl7.7` directory.

Using the plugin

To use the plugin, place the following line in your Tcl scripts :

```
load $tcl_library/example.so example
```

With luck, you will now be ready to run (at least that's the theory).

Tcl8.0 features

SWIG 1.1 now supports Tcl 8.0. However, considering the alpha release nature of Tcl 8.0, anything presented here is subject to change. Currently only Tcl 8.0a2 is supported. Tcl 8.0a1 is not supported due to a change in the C API.

SWIG's Tcl 8.0 module uses the new Tcl 8.0 object interface whenever possible. Instead of using strings, the object interface provides more direct access to objects in their native representation. As a result, the performance is significantly better. The older Tcl SWIG module is also compatible with Tcl 8.0, but since it uses strings it will be much slower than the new version.

In addition to using native Tcl objects, the Tcl8.0 manipulates pointers directly in in a special Tcl object. On the surface it still looks like a string, but internally its represented a (value,type) pair. This too, should offer somewhat better performance.

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