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 Perl5.003 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 finish building 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). There are several methods for doing this.

Getting the right header files

In order to compile, 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 used in the SWIG interface file. If you used '`%module example`', then the target should be named '`example.so`', '`example.sl`', or the appropriate name on your system (check the man pages for the linker).

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 dynamic module with MakeMaker

It is also possible to use Perl to build dynamically loadable modules for you using the MakeMaker utility. To do this, write a simple Perl script such as the following :

```
# File : Makefile.PL
use ExtUtils::MakeMaker;
WriteMakefile(
       'NAME'    => 'example',                  # Name of package
       'LIBS'    => ['-lm'],                    # Name of custom libraries
       'OBJECT'  => 'example.o example_wrap.o'  # Object files
);
```

Now, to build a module, simply follow these steps :

```
% perl Makefile.PL
% make
% make install
```

This is the preferred approach if you building general purpose Perl5 modules for distribution. More information about MakeMaker can be found in "Programming Perl, 2nd ed." by Larry Wall, Tom Christiansen, and Randal Schwartz.

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 same thing can be accomplished by running SWIG as follows :

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

To build your new Perl executable, follow the exact same procedure as for a dynamic module, but change the link line 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 with 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 also a tricky business. When compiling C++ modules, you may need to link using the C++ compiler such as :

```
unix > c++ -shared example_wrap.o example.o -o example.so
```

It may also be necessary to 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`" and the invalid use of the "explicit" keyword. To work around this problem, put the option `-Dexplicit=` in your compiler flags.

If all else fails, put on your wizard cap and start looking around in the header files. 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 assumes you are using SWIG with Microsoft Visual C++ 4.x although the procedure may be similar with other compilers. SWIG currently supports the ActiveWare Perl for Win32 port and Perl 5.004. If using the ActiveWare version, all Perl extensions must be compiled using C++!

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 requires 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.cxx $(InputPath)`" in the "Build command(s) field"
- Enter "`$(ProjDir)\$(InputName)_wrap.c`xx" 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 all extensions to the ActiveWare port must be compiled with the C++ compiler since Perl has been encapsulated in a C++ class.
- 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";
```

It appears that DLL's will work if they are placed in the current working directory. To make a generally DLL available, it should be place (along with its support files) in the `Lib\Auto\[module]` sub-directory of the Perl directory where [module] is the name of your module.

Using NMAKE

Alternatively, SWIG extensions can be built by 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 /c /W3 /nologo

# Perl 5.004
PERL_INCLUDE = -Id:\perl5\lib\CORE
PERLLIB      = d:\perl5\lib\CORE\perl.lib
PERLFLAGS    = /DWIN32 /DMSWIN32 /DWIN32IO_IS_STDIO

# ActiveWare
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 (note that you may be to run `vcvars32` before doing this to set the correct environment variables). This is a simplistic Makefile, but hopefully its enough to get you started.

Modules, packages, and classes

When you create a SWIG extension, everything gets thrown together into a single Perl5 module. The name of the module is determined by the `%module` directive. To use the module, do 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 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 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
```

Perl supports object oriented programming using packages. A package can be thought of as a namespace for a class containing methods and data. The reader is well advised to consult “Programming Perl, 2nd Ed.” by Wall, Christiansen, and Schwartz for most of the gory details.

Basic Perl interface

Functions

C functions are converted into new Perl commands (or subroutines). 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 methods 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. A blessed reference is the same as a Perl reference except that it has additional information attached to it indicating what kind of reference it is. 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. 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 gets 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);
```

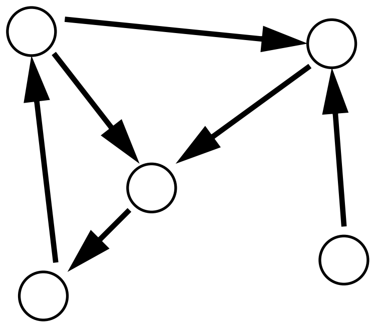
To use the class, simply use these functions. As it turns out, SWIG has a mechanism for creating shadow classes that hides these functions and uses an object oriented interface instead--keep reading.

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             // Get structure definition
%include graph.c             // Get support functions
```

We'll call our module "graph" and simply read in both the files `graph.h` and `graph.c` to build an interface.

Sample Perl Script

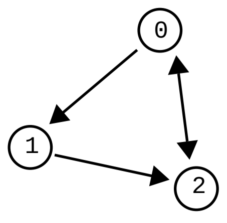
Once compiled, we can now start using our new module. All of the C functions found in `graph.h` and `graph.c` can be called normally . Even though we are using pointers, this is not a problem. Here is a very simple script :

```
# 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)) {                   # This checks for a NULL pointer
              my $anode = Edge_node_get($adj);
              my $v = Node_v_get($anode);
              print "$v ";
              $adj = Edge_next_get($adj);        # Move to next node
       }
       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 to build a simple graph in Perl along with a debugging function for printing out node information. In fact, without making any modifications to the 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, 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. Perl, on the other hand, is very good at managing these tasks.

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 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 `.c` file and put their prototypes 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];
}
%}
```

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.

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
```

Implementing methods 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 is reasonably easy to manipulate complex structures in Perl and to mix them with C code (well, with a little practice perhaps).

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 significantly more supporting Perl code. While there are some rather subtle aspects of this transformation, for now we’ll omit the details and illustrate the changes in an example first (the use of shadow classes has been underlined)

```
# 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 objects:

```
    /* 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 object.

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 for clarity) :.

```
/* 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 (bunch ‘o math) */
...
  /* 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 (one might also consider using the already existing gd module for Perl as well).

```
%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 :

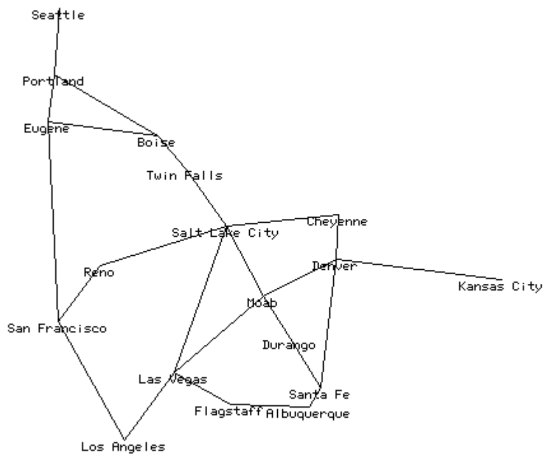
```
read_cities("cities");
read_locations("locations");
```

```
# 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 now get the following :



Not too bad for just 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 (this can often be found by just running SWIG).
- 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, and library of functions for creating and manipulating matrices, and a collection of utility function. A full description can be found in the "External Interface Guide" provided with MATLAB. Even if you don't have MATLAB, this section can provide some ideas on how to handle other libraries.

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, each function requires an object "Engine". 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;
}
%}

/* 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); “);
```

Creates a simple 3D surface plot.

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;
              }
       }
%}
```

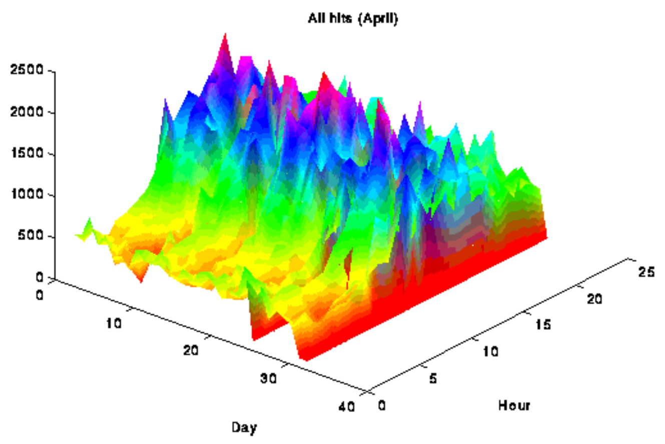
While we could write this function in Perl, it will be much faster in C. If we're processing a huge file, then the extra bit of performance will help us out. Once compiled, we can now write a Perl5 script like the following :

```
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) :



Handling output values (the easy way)

Some C libraries rely on functions that return values in their arguments. For example :

```
void fadd(double a, double b, double *result) {
       *result = a+b;
}
```

By default, SWIG does not handle this case (leaving it up to you to figure out what to do about the `result` parameter). However, this problem is easily fixed using the `typemaps.i` library file (see the Typemaps chapter for more information). For example :

```
// SWIG interface file with output arguments
%module example

%include typemaps.i                         // Load the typemaps librayr
%apply double *OUTPUT {double *result};     // Make "result" an output parameter

void fadd(double a, double b, double *result);
```

When used in a Perl script, the fadd function now takes 2 parameters and returns the result.

```
$a = fadd(3,4);              # $a gets the value of double *result
```

When multiple output arguments are involved, a Perl array of values will be returned instead. It is also possible to use Perl references as function values. This is done as shown :

```
// SWIG interface file with output arguments
%module
%include typemaps.i
```

```
%apply double *REFERENCE {double *result};        // Make “result” a Perl reference

void fadd(double a, double b, double *result);
```

Now in a Perl script, the function works like this :

```
$c = 0.0;                     # Variable for holding the result
fadd(3,4,\$c);                # fadd() places the result in $c
```

In addition to handling pointers as output values or references, two other methods are available. The `INPUT` method indicates that a pointer is an input value and the `BOTH` method indicates that a pointer is both an input and output value. These would be specified as follows :

```
%apply double *INPUT {double *in};         // double *in is an input value
%apply double *BOTH {double *r};           // double *r is both an input/output value
```

This processing of datatypes is built using SWIG’s typemap mechanism. The details of typemaps is described shortly although the `typemaps.i` library already includes a variety of useful typemaps ready for use.

Exception handling

The SWIG `%except` directive can be used to create a user-definable exception handler for 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. It is also possible to write a language-independent exception handler that works with other scripting languages. 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);
```

Typemap specifications 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 integers. The conversion code is used to convert from a Perl scalar value to the corresponding datatype. Within the support code, the variable `$source` contains the source data (a Perl object) and `$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
```

General discussion of typemaps can be found in the main SWIG users reference.

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(perl5,check)`	Check value of input parameter.

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.

Due to the name matching scheme, typemaps do not follow typedef declarations. For example :

```
%typemap(perl5,in) double {
       ... get a double ...
}

double foo(double);                 // Uses the double typemap above
typedef double Real;
Real bar(Real);                     // Does not use the typemap above (double != Real)
```

Is is odd behavior to be sure, but you can work around the problem using the `%apply` directive as follows :

```
%typemap(perl5,in) double {
       ... get a double ...
}
double foo(double);                 // Uses the double typemap above

typedef double Real;
%apply double { Real };             // Apply the double typemap to Reals.
Real bar(Real);                     // Uses the double typemap already defined.
```

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 a Perl5 array to a char **

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);
       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 this case. 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,ignore) double *OutDouble(double junk) {
       $target = &junk;       /* junk is a local variable that has been declared */
}

// 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\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. However, we can write a typemap that will work for any array dimension as follows :

```
        %typemap(memberin) char [ANY] {
                strncpy($target,$source,$dim0);
        }
```

When code is generated, `$dim0` gets filled in with the real array dimension.

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;
        }
```

A common misinterpretation of this function is the following Perl script :

```
        # 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 a Perl reference--well, at least note of the type used in the above script).

However, you can use a typemap to get the desired effect. For example :

```
        %typemap(perl5,in) double * (double dvalue) {
          SV* tempsv;
          if (!SvROK($source)) {
            croak("expected a reference\n");
          }
          tempsv = SvRV($source);
          if ((!SvNOK(tempsv)) && (!SvIOK(tempsv))) {
            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 easily shoot yourself in the foot with typemaps--of course SWIG is has never been too concerned about legislating morality....

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. It should be stressed that SWIG can be usef quite effectively without knowing any of these details--especially now that there are typemap libraries that can already been written.

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)`	Create a new Perl scalar value from a char * and length.
`int SvPOK(SV *)`	Checks to see if a Perl scalar is a string.
`void sv_catpv(SV *, char *)`	Appends a string to a scalar value.
`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 given a name.

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);` `}`

Function argument typemaps

`char *`	`%typemap(perl5,in) char * {`
	`    $target = SvPV($source,na);`
	`}`

Function 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++;`
	`}`

`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.

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 total number of return values should not exceed the number of input values unless you explicitly extend the argument stack. This can be done using the `EXTEND()` macro as in :

```
%typemap(perl5,argout) int *OUTPUT {
        if (argvi >= items) {
                EXTEND(sp,1);              /* Extend the stack by 1 object */
        }
        $target = sv_newmortal();
        sv_setiv($target,(IV) *($source));
        argvi++;
}
```

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 enabled, 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 creates 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 (the original package is hidden, but working behind the scenes).

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 creates 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 and are always named “new” and “DESTROY”. 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 `%BLESSEDMEMBERS` 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 mechanism 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). In Perl, both vectors will be indistinguishable---clearly a 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 contains 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 (under the assumption that someone else must have created it).

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 done 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 does not provide reference counting, garbage collection, or advanced features one might find in sophisticated languages.

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);
```

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 in the form of tied hash tables. This is done by creating a Perl function like this :

```
sub dot_product {
    my @args = @_;
    $args[0] = tied(%{$args[0]});         # Get the real pointer values
    $args[1] = tied(%{$args[1]});
    my $result = vectorc::dot_product(@args);
    return $result;
}
```

This function replaces the original function, but operates in an identical manner.

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. However, be forewarned that this is not a trivial problem. In particular, inheritance of data members is extremely tricky (and I'm not even sure if it really works).

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
```

However, this is not a deep copy so they probably works better with C than with C++.

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.