Extending and Embedding Python

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Guido van Rossum
and the Python development team

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Python Software Foundation
Email: docs@python.org

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This document describes how to write modules in C or C++ to extend the Python interpreter with new modules. Those modules can not only define new functions but also new object types and their methods. The document also describes how to embed the Python interpreter in another application, for use as an extension language. Finally, it shows how to compile and link extension modules so that they can be loaded dynamically (at run time) into the interpreter, if the underlying operating system supports this feature.

This document assumes basic knowledge about Python. For an informal introduction to the language, see tutorial-index. reference-index gives a more formal definition of the language. library-index documents the existing object types, functions and modules (both built-in and written in Python) that give the language its wide application range.

For a detailed description of the whole Python/C API, see the separate c-api-index.

CHAPTER

ONE

RECOMMENDED THIRD PARTY TOOLS

This guide only covers the basic tools for creating extensions provided as part of this version of CPython. Third party tools like Cython, cffi, SWIG and Numba offer both simpler and more sophisticated approaches to creating C and C++ extensions for Python.

See also:

Python Packaging User Guide: Binary Extensions The Python Packaging User Guide not only covers several available tools that simplify the creation of binary extensions, but also discusses the various reasons why creating an extension module may be desirable in the first place.

CHAPTER

TWO

CREATING EXTENSIONS WITHOUT THIRD PARTY TOOLS

This section of the guide covers creating C and C++ extensions without assistance from third party tools. It is intended primarily for creators of those tools, rather than being a recommended way to create your own C extensions.

2.1 Extending Python with C or C++

It is quite easy to add new built-in modules to Python, if you know how to program in C. Such *extension modules* can do two things that can't be done directly in Python: they can implement new built-in object types, and they can call C library functions and system calls.

To support extensions, the Python API (Application Programmers Interface) defines a set of functions, macros and variables that provide access to most aspects of the Python run-time system. The Python API is incorporated in a C source file by including the header `"Python.h"`.

The compilation of an extension module depends on its intended use as well as on your system setup; details are given in later chapters.

Note: The C extension interface is specific to CPython, and extension modules do not work on other Python implementations. In many cases, it is possible to avoid writing C extensions and preserve portability to other implementations. For example, if your use case is calling C library functions or system calls, you should consider using the `ctypes` module or the cffi library rather than writing custom C code. These modules let you write Python code to interface with C code and are more portable between implementations of Python than writing and compiling a C extension module.

2.1.1 A Simple Example

Let's create an extension module called `spam` (the favorite food of Monty Python fans...) and let's say we want to create a Python interface to the C library function `system()`[1]. This function takes a null-terminated character string as argument and returns an integer. We want this function to be callable from Python as follows:

```
>>> import spam
>>> status = spam.system("ls -l")
```

Begin by creating a file `spammodule.c`. (Historically, if a module is called `spam`, the C file containing its implementation is called `spammodule.c`; if the module name is very long, like `spammify`, the module name can be just `spammify.c`.)

The first two lines of our file can be:

[1] An interface for this function already exists in the standard module `os` — it was chosen as a simple and straightforward example.

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>
```

which pulls in the Python API (you can add a comment describing the purpose of the module and a copyright notice if you like).

Note: Since Python may define some pre-processor definitions which affect the standard headers on some systems, you *must* include `Python.h` before any standard headers are included.

It is recommended to always define `PY_SSIZE_T_CLEAN` before including `Python.h`. See *Extracting Parameters in Extension Functions* for a description of this macro.

All user-visible symbols defined by `Python.h` have a prefix of `Py` or `PY`, except those defined in standard header files. For convenience, and since they are used extensively by the Python interpreter, `"Python.h"` includes a few standard header files: `<stdio.h>`, `<string.h>`, `<errno.h>`, and `<stdlib.h>`. If the latter header file does not exist on your system, it declares the functions `malloc()`, `free()` and `realloc()` directly.

The next thing we add to our module file is the C function that will be called when the Python expression `spam.system(string)` is evaluated (we'll see shortly how it ends up being called):

```
static PyObject *
spam_system(PyObject *self, PyObject *args)
{
    const char *command;
    int sts;

    if (!PyArg_ParseTuple(args, "s", &command))
        return NULL;
    sts = system(command);
    return PyLong_FromLong(sts);
}
```

There is a straightforward translation from the argument list in Python (for example, the single expression `"ls -l"`) to the arguments passed to the C function. The C function always has two arguments, conventionally named *self* and *args*.

The *self* argument points to the module object for module-level functions; for a method it would point to the object instance.

The *args* argument will be a pointer to a Python tuple object containing the arguments. Each item of the tuple corresponds to an argument in the call's argument list. The arguments are Python objects — in order to do anything with them in our C function we have to convert them to C values. The function `PyArg_ParseTuple()` in the Python API checks the argument types and converts them to C values. It uses a template string to determine the required types of the arguments as well as the types of the C variables into which to store the converted values. More about this later.

`PyArg_ParseTuple()` returns true (nonzero) if all arguments have the right type and its components have been stored in the variables whose addresses are passed. It returns false (zero) if an invalid argument list was passed. In the latter case it also raises an appropriate exception so the calling function can return `NULL` immediately (as we saw in the example).

2.1.2 Intermezzo: Errors and Exceptions

An important convention throughout the Python interpreter is the following: when a function fails, it should set an exception condition and return an error value (usually a `NULL` pointer). Exceptions are stored in a static global variable inside the interpreter; if this variable is `NULL` no exception has occurred. A second global variable stores the "associated value" of the exception (the second argument to `raise`). A third variable contains the stack traceback in case the error originated in Python code. These three variables are the C equivalents of the result in Python of `sys.exc_info()` (see the section on module `sys` in the Python Library Reference). It is important to know about them to understand how errors are passed around.

The Python API defines a number of functions to set various types of exceptions.

The most common one is `PyErr_SetString()`. Its arguments are an exception object and a C string. The exception object is usually a predefined object like `PyExc_ZeroDivisionError`. The C string indicates the cause of the error and is converted to a Python string object and stored as the "associated value" of the exception.

Another useful function is `PyErr_SetFromErrno()`, which only takes an exception argument and constructs the associated value by inspection of the global variable `errno`. The most general function is `PyErr_SetObject()`, which takes two object arguments, the exception and its associated value. You don't need to `Py_INCREF()` the objects passed to any of these functions.

You can test non-destructively whether an exception has been set with `PyErr_Occurred()`. This returns the current exception object, or `NULL` if no exception has occurred. You normally don't need to call `PyErr_Occurred()` to see whether an error occurred in a function call, since you should be able to tell from the return value.

When a function *f* that calls another function *g* detects that the latter fails, *f* should itself return an error value (usually `NULL` or `-1`). It should *not* call one of the `PyErr_*()` functions — one has already been called by *g*. *f*'s caller is then supposed to also return an error indication to *its* caller, again *without* calling `PyErr_*()`, and so on — the most detailed cause of the error was already reported by the function that first detected it. Once the error reaches the Python interpreter's main loop, this aborts the currently executing Python code and tries to find an exception handler specified by the Python programmer.

(There are situations where a module can actually give a more detailed error message by calling another `PyErr_*()` function, and in such cases it is fine to do so. As a general rule, however, this is not necessary, and can cause information about the cause of the error to be lost: most operations can fail for a variety of reasons.)

To ignore an exception set by a function call that failed, the exception condition must be cleared explicitly by calling `PyErr_Clear()`. The only time C code should call `PyErr_Clear()` is if it doesn't want to pass the error on to the interpreter but wants to handle it completely by itself (possibly by trying something else, or pretending nothing went wrong).

Every failing `malloc()` call must be turned into an exception — the direct caller of `malloc()` (or `realloc()`) must call `PyErr_NoMemory()` and return a failure indicator itself. All the object-creating functions (for example, `PyLong_FromLong()`) already do this, so this note is only relevant to those who call `malloc()` directly.

Also note that, with the important exception of `PyArg_ParseTuple()` and friends, functions that return an integer status usually return a positive value or zero for success and `-1` for failure, like Unix system calls.

Finally, be careful to clean up garbage (by making `Py_XDECREF()` or `Py_DECREF()` calls for objects you have already created) when you return an error indicator!

The choice of which exception to raise is entirely yours. There are predeclared C objects corresponding to all built-in Python exceptions, such as `PyExc_ZeroDivisionError`, which you can use directly. Of course, you should choose exceptions wisely — don't use `PyExc_TypeError` to mean that a file couldn't be opened (that should probably be `PyExc_IOError`). If something's wrong with the argument list, the `PyArg_ParseTuple()` function usually raises `PyExc_TypeError`. If you have an argument whose value must be in a particular range or must satisfy other conditions, `PyExc_ValueError` is appropriate.

You can also define a new exception that is unique to your module. For this, you usually declare a static object variable at the beginning of your file:

```
static PyObject *SpamError;
```

and initialize it in your module's initialization function (`PyInit_spam()`) with an exception object:

```
PyMODINIT_FUNC
PyInit_spam(void)
{
    PyObject *m;

    m = PyModule_Create(&spammodule);
    if (m == NULL)
        return NULL;

    SpamError = PyErr_NewException("spam.error", NULL, NULL);
    Py_XINCREF(SpamError);
    if (PyModule_AddObject(m, "error", SpamError) < 0) {
        Py_XDECREF(SpamError);
        Py_CLEAR(SpamError);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

Note that the Python name for the exception object is `spam.error`. The `PyErr_NewException()` function may create a class with the base class being `Exception` (unless another class is passed in instead of `NULL`), described in bltin-exceptions.

Note also that the `SpamError` variable retains a reference to the newly created exception class; this is intentional! Since the exception could be removed from the module by external code, an owned reference to the class is needed to ensure that it will not be discarded, causing `SpamError` to become a dangling pointer. Should it become a dangling pointer, C code which raises the exception could cause a core dump or other unintended side effects.

We discuss the use of `PyMODINIT_FUNC` as a function return type later in this sample.

The `spam.error` exception can be raised in your extension module using a call to `PyErr_SetString()` as shown below:

```
static PyObject *
spam_system(PyObject *self, PyObject *args)
{
    const char *command;
    int sts;

    if (!PyArg_ParseTuple(args, "s", &command))
        return NULL;
    sts = system(command);
    if (sts < 0) {
        PyErr_SetString(SpamError, "System command failed");
        return NULL;
    }
    return PyLong_FromLong(sts);
}
```

2.1.3 Back to the Example

Going back to our example function, you should now be able to understand this statement:

```
if (!PyArg_ParseTuple(args, "s", &command))
    return NULL;
```

It returns `NULL` (the error indicator for functions returning object pointers) if an error is detected in the argument list, relying on the exception set by `PyArg_ParseTuple()`. Otherwise the string value of the argument has been copied to the local variable `command`. This is a pointer assignment and you are not supposed to modify the string to which it points (so in Standard C, the variable `command` should properly be declared as `const char *command`).

The next statement is a call to the Unix function `system()`, passing it the string we just got from `PyArg_ParseTuple()`:

```
sts = system(command);
```

Our `spam.system()` function must return the value of `sts` as a Python object. This is done using the function `PyLong_FromLong()`.

```
return PyLong_FromLong(sts);
```

In this case, it will return an integer object. (Yes, even integers are objects on the heap in Python!)

If you have a C function that returns no useful argument (a function returning `void`), the corresponding Python function must return `None`. You need this idiom to do so (which is implemented by the `Py_RETURN_NONE` macro):

```
Py_INCREF(Py_None);
return Py_None;
```

`Py_None` is the C name for the special Python object `None`. It is a genuine Python object rather than a `NULL` pointer, which means "error" in most contexts, as we have seen.

2.1.4 The Module's Method Table and Initialization Function

I promised to show how `spam_system()` is called from Python programs. First, we need to list its name and address in a "method table":

```
static PyMethodDef SpamMethods[] = {
    ...
    {"system",  spam_system, METH_VARARGS,
     "Execute a shell command."},
    ...
    {NULL, NULL, 0, NULL}        /* Sentinel */
};
```

Note the third entry (`METH_VARARGS`). This is a flag telling the interpreter the calling convention to be used for the C function. It should normally always be `METH_VARARGS` or `METH_VARARGS | METH_KEYWORDS`; a value of `0` means that an obsolete variant of `PyArg_ParseTuple()` is used.

When using only `METH_VARARGS`, the function should expect the Python-level parameters to be passed in as a tuple acceptable for parsing via `PyArg_ParseTuple()`; more information on this function is provided below.

The `METH_KEYWORDS` bit may be set in the third field if keyword arguments should be passed to the function. In this case, the C function should accept a third `PyObject *` parameter which will be a dictionary of keywords. Use `PyArg_ParseTupleAndKeywords()` to parse the arguments to such a function.

The method table must be referenced in the module definition structure:

```
static struct PyModuleDef spammodule = {
    PyModuleDef_HEAD_INIT,
    "spam",   /* name of module */
    spam_doc, /* module documentation, may be NULL */
    -1,       /* size of per-interpreter state of the module,
                 or -1 if the module keeps state in global variables. */
    SpamMethods
};
```

This structure, in turn, must be passed to the interpreter in the module's initialization function. The initialization function must be named `PyInit_name()`, where *name* is the name of the module, and should be the only non-`static` item defined in the module file:

```
PyMODINIT_FUNC
PyInit_spam(void)
{
    return PyModule_Create(&spammodule);
}
```

Note that PyMODINIT_FUNC declares the function as `PyObject *` return type, declares any special linkage declarations required by the platform, and for C++ declares the function as `extern "C"`.

When the Python program imports module `spam` for the first time, `PyInit_spam()` is called. (See below for comments about embedding Python.) It calls `PyModule_Create()`, which returns a module object, and inserts built-in function objects into the newly created module based upon the table (an array of `PyMethodDef` structures) found in the module definition. `PyModule_Create()` returns a pointer to the module object that it creates. It may abort with a fatal error for certain errors, or return `NULL` if the module could not be initialized satisfactorily. The init function must return the module object to its caller, so that it then gets inserted into `sys.modules`.

When embedding Python, the `PyInit_spam()` function is not called automatically unless there's an entry in the `PyImport_Inittab` table. To add the module to the initialization table, use `PyImport_AppendInittab()`, optionally followed by an import of the module:

```
int
main(int argc, char *argv[])
{
    wchar_t *program = Py_DecodeLocale(argv[0], NULL);
    if (program == NULL) {
        fprintf(stderr, "Fatal error: cannot decode argv[0]\n");
        exit(1);
    }

    /* Add a built-in module, before Py_Initialize */
    if (PyImport_AppendInittab("spam", PyInit_spam) == -1) {
        fprintf(stderr, "Error: could not extend in-built modules table\n");
        exit(1);
    }

    /* Pass argv[0] to the Python interpreter */
    Py_SetProgramName(program);

    /* Initialize the Python interpreter.  Required.
       If this step fails, it will be a fatal error. */
    Py_Initialize();

    /* Optionally import the module; alternatively,
       import can be deferred until the embedded script
```

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```
       imports it. */
    PyObject *pmodule = PyImport_ImportModule("spam");
    if (!pmodule) {
        PyErr_Print();
        fprintf(stderr, "Error: could not import module 'spam'\n");
    }

    ...

    PyMem_RawFree(program);
    return 0;
}
```

Note: Removing entries from `sys.modules` or importing compiled modules into multiple interpreters within a process (or following a `fork()` without an intervening `exec()`) can create problems for some extension modules. Extension module authors should exercise caution when initializing internal data structures.

A more substantial example module is included in the Python source distribution as `Modules/xxmodule.c`. This file may be used as a template or simply read as an example.

Note: Unlike our `spam` example, `xxmodule` uses *multi-phase initialization* (new in Python 3.5), where a PyModuleDef structure is returned from `PyInit_spam`, and creation of the module is left to the import machinery. For details on multi-phase initialization, see **PEP 489**.

2.1.5 Compilation and Linkage

There are two more things to do before you can use your new extension: compiling and linking it with the Python system. If you use dynamic loading, the details may depend on the style of dynamic loading your system uses; see the chapters about building extension modules (chapter *Building C and C++ Extensions*) and additional information that pertains only to building on Windows (chapter *Building C and C++ Extensions on Windows*) for more information about this.

If you can't use dynamic loading, or if you want to make your module a permanent part of the Python interpreter, you will have to change the configuration setup and rebuild the interpreter. Luckily, this is very simple on Unix: just place your file (`spammodule.c` for example) in the `Modules/` directory of an unpacked source distribution, add a line to the file `Modules/Setup.local` describing your file:

```
spam spammodule.o
```

and rebuild the interpreter by running **`make`** in the toplevel directory. You can also run **`make`** in the `Modules/` subdirectory, but then you must first rebuild `Makefile` there by running '**`make`** Makefile'. (This is necessary each time you change the `Setup` file.)

If your module requires additional libraries to link with, these can be listed on the line in the configuration file as well, for instance:

```
spam spammodule.o -lX11
```

2.1.6 Calling Python Functions from C

So far we have concentrated on making C functions callable from Python. The reverse is also useful: calling Python functions from C. This is especially the case for libraries that support so-called "callback" functions. If a C interface makes use of callbacks, the equivalent Python often needs to provide a callback mechanism to the Python programmer; the implementation will require calling the Python callback functions from a C callback. Other uses are also imaginable.

Fortunately, the Python interpreter is easily called recursively, and there is a standard interface to call a Python function. (I won't dwell on how to call the Python parser with a particular string as input — if you're interested, have a look at the implementation of the `-c` command line option in `Modules/main.c` from the Python source code.)

Calling a Python function is easy. First, the Python program must somehow pass you the Python function object. You should provide a function (or some other interface) to do this. When this function is called, save a pointer to the Python function object (be careful to `Py_INCREF()` it!) in a global variable — or wherever you see fit. For example, the following function might be part of a module definition:

```
static PyObject *my_callback = NULL;

static PyObject *
my_set_callback(PyObject *dummy, PyObject *args)
{
    PyObject *result = NULL;
    PyObject *temp;

    if (PyArg_ParseTuple(args, "O:set_callback", &temp)) {
        if (!PyCallable_Check(temp)) {
            PyErr_SetString(PyExc_TypeError, "parameter must be callable");
            return NULL;
        }
        Py_XINCREF(temp);         /* Add a reference to new callback */
        Py_XDECREF(my_callback);  /* Dispose of previous callback */
        my_callback = temp;       /* Remember new callback */
        /* Boilerplate to return "None" */
        Py_INCREF(Py_None);
        result = Py_None;
    }
    return result;
}
```

This function must be registered with the interpreter using the `METH_VARARGS` flag; this is described in section *The Module's Method Table and Initialization Function*. The `PyArg_ParseTuple()` function and its arguments are documented in section *Extracting Parameters in Extension Functions*.

The macros `Py_XINCREF()` and `Py_XDECREF()` increment/decrement the reference count of an object and are safe in the presence of `NULL` pointers (but note that *temp* will not be `NULL` in this context). More info on them in section *Reference Counts*.

Later, when it is time to call the function, you call the C function `PyObject_CallObject()`. This function has two arguments, both pointers to arbitrary Python objects: the Python function, and the argument list. The argument list must always be a tuple object, whose length is the number of arguments. To call the Python function with no arguments, pass in `NULL`, or an empty tuple; to call it with one argument, pass a singleton tuple. `Py_BuildValue()` returns a tuple when its format string consists of zero or more format codes between parentheses. For example:

```
int arg;
PyObject *arglist;
PyObject *result;
...
arg = 123;
```

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```
...
/* Time to call the callback */
arglist = Py_BuildValue("(i)", arg);
result = PyObject_CallObject(my_callback, arglist);
Py_DECREF(arglist);
```

`PyObject_CallObject()` returns a Python object pointer: this is the return value of the Python function. `PyObject_CallObject()` is "reference-count-neutral" with respect to its arguments. In the example a new tuple was created to serve as the argument list, which is `Py_DECREF()`-ed immediately after the `PyObject_CallObject()` call.

The return value of `PyObject_CallObject()` is "new": either it is a brand new object, or it is an existing object whose reference count has been incremented. So, unless you want to save it in a global variable, you should somehow `Py_DECREF()` the result, even (especially!) if you are not interested in its value.

Before you do this, however, it is important to check that the return value isn't `NULL`. If it is, the Python function terminated by raising an exception. If the C code that called `PyObject_CallObject()` is called from Python, it should now return an error indication to its Python caller, so the interpreter can print a stack trace, or the calling Python code can handle the exception. If this is not possible or desirable, the exception should be cleared by calling `PyErr_Clear()`. For example:

```
if (result == NULL)
    return NULL; /* Pass error back */
...use result...
Py_DECREF(result);
```

Depending on the desired interface to the Python callback function, you may also have to provide an argument list to `PyObject_CallObject()`. In some cases the argument list is also provided by the Python program, through the same interface that specified the callback function. It can then be saved and used in the same manner as the function object. In other cases, you may have to construct a new tuple to pass as the argument list. The simplest way to do this is to call `Py_BuildValue()`. For example, if you want to pass an integral event code, you might use the following code:

```
PyObject *arglist;
...
arglist = Py_BuildValue("(l)", eventcode);
result = PyObject_CallObject(my_callback, arglist);
Py_DECREF(arglist);
if (result == NULL)
    return NULL; /* Pass error back */
/* Here maybe use the result */
Py_DECREF(result);
```

Note the placement of `Py_DECREF(arglist)` immediately after the call, before the error check! Also note that strictly speaking this code is not complete: `Py_BuildValue()` may run out of memory, and this should be checked.

You may also call a function with keyword arguments by using `PyObject_Call()`, which supports arguments and keyword arguments. As in the above example, we use `Py_BuildValue()` to construct the dictionary.

```
PyObject *dict;
...
dict = Py_BuildValue("{s:i}", "name", val);
result = PyObject_Call(my_callback, NULL, dict);
Py_DECREF(dict);
if (result == NULL)
    return NULL; /* Pass error back */
/* Here maybe use the result */
Py_DECREF(result);
```

2.1.7 Extracting Parameters in Extension Functions

The `PyArg_ParseTuple()` function is declared as follows:

```
int PyArg_ParseTuple(PyObject *arg, const char *format, ...);
```

The *arg* argument must be a tuple object containing an argument list passed from Python to a C function. The *format* argument must be a format string, whose syntax is explained in arg-parsing in the Python/C API Reference Manual. The remaining arguments must be addresses of variables whose type is determined by the format string.

Note that while `PyArg_ParseTuple()` checks that the Python arguments have the required types, it cannot check the validity of the addresses of C variables passed to the call: if you make mistakes there, your code will probably crash or at least overwrite random bits in memory. So be careful!

Note that any Python object references which are provided to the caller are *borrowed* references; do not decrement their reference count!

Some example calls:

```
#define PY_SSIZE_T_CLEAN  /* Make "s#" use Py_ssize_t rather than int. */
#include <Python.h>
```

```
int ok;
int i, j;
long k, l;
const char *s;
Py_ssize_t size;

ok = PyArg_ParseTuple(args, ""); /* No arguments */
    /* Python call: f() */
```

```
ok = PyArg_ParseTuple(args, "s", &s); /* A string */
    /* Possible Python call: f('whoops!') */
```

```
ok = PyArg_ParseTuple(args, "lls", &k, &l, &s); /* Two longs and a string */
    /* Possible Python call: f(1, 2, 'three') */
```

```
ok = PyArg_ParseTuple(args, "(ii)s#", &i, &j, &s, &size);
    /* A pair of ints and a string, whose size is also returned */
    /* Possible Python call: f((1, 2), 'three') */
```

```
{
    const char *file;
    const char *mode = "r";
    int bufsize = 0;
    ok = PyArg_ParseTuple(args, "s|si", &file, &mode, &bufsize);
    /* A string, and optionally another string and an integer */
    /* Possible Python calls:
       f('spam')
       f('spam', 'w')
       f('spam', 'wb', 100000) */
}
```

```
{
    int left, top, right, bottom, h, v;
    ok = PyArg_ParseTuple(args, "((ii)(ii))(ii)",
```

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```
                &left, &top, &right, &bottom, &h, &v);
    /* A rectangle and a point */
    /* Possible Python call:
       f(((0, 0), (400, 300)), (10, 10)) */
}
```

```
{
    Py_complex c;
    ok = PyArg_ParseTuple(args, "D:myfunction", &c);
    /* a complex, also providing a function name for errors */
    /* Possible Python call: myfunction(1+2j) */
}
```

2.1.8 Keyword Parameters for Extension Functions

The `PyArg_ParseTupleAndKeywords()` function is declared as follows:

```
int PyArg_ParseTupleAndKeywords(PyObject *arg, PyObject *kwdict,
                                const char *format, char *kwlist[], ...);
```

The *arg* and *format* parameters are identical to those of the `PyArg_ParseTuple()` function. The *kwdict* parameter is the dictionary of keywords received as the third parameter from the Python runtime. The *kwlist* parameter is a `NULL`-terminated list of strings which identify the parameters; the names are matched with the type information from *format* from left to right. On success, `PyArg_ParseTupleAndKeywords()` returns true, otherwise it returns false and raises an appropriate exception.

Note: Nested tuples cannot be parsed when using keyword arguments! Keyword parameters passed in which are not present in the *kwlist* will cause `TypeError` to be raised.

Here is an example module which uses keywords, based on an example by Geoff Philbrick (philbrick@hks.com):

```
#define PY_SSIZE_T_CLEAN  /* Make "s#" use Py_ssize_t rather than int. */
#include <Python.h>

static PyObject *
keywdarg_parrot(PyObject *self, PyObject *args, PyObject *keywds)
{
    int voltage;
    const char *state = "a stiff";
    const char *action = "voom";
    const char *type = "Norwegian Blue";

    static char *kwlist[] = {"voltage", "state", "action", "type", NULL};

    if (!PyArg_ParseTupleAndKeywords(args, keywds, "i|sss", kwlist,
                                     &voltage, &state, &action, &type))
        return NULL;

    printf("-- This parrot wouldn't %s if you put %i Volts through it.\n",
           action, voltage);
    printf("-- Lovely plumage, the %s -- It's %s!\n", type, state);
```

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```
    Py_RETURN_NONE;
}

static PyMethodDef keywdarg_methods[] = {
    /* The cast of the function is necessary since PyCFunction values
     * only take two PyObject* parameters, and keywdarg_parrot() takes
     * three.
     */
    {"parrot", (PyCFunction)(void(*)(void))keywdarg_parrot, METH_VARARGS | METH_
↪KEYWORDS,
     "Print a lovely skit to standard output."},
    {NULL, NULL, 0, NULL}   /* sentinel */
};

static struct PyModuleDef keywdargmodule = {
    PyModuleDef_HEAD_INIT,
    "keywdarg",
    NULL,
    -1,
    keywdarg_methods
};

PyMODINIT_FUNC
PyInit_keywdarg(void)
{
    return PyModule_Create(&keywdargmodule);
}
```

2.1.9 Building Arbitrary Values

This function is the counterpart to `PyArg_ParseTuple()`. It is declared as follows:

```
PyObject *Py_BuildValue(const char *format, ...);
```

It recognizes a set of format units similar to the ones recognized by `PyArg_ParseTuple()`, but the arguments (which are input to the function, not output) must not be pointers, just values. It returns a new Python object, suitable for returning from a C function called from Python.

One difference with `PyArg_ParseTuple()`: while the latter requires its first argument to be a tuple (since Python argument lists are always represented as tuples internally), `Py_BuildValue()` does not always build a tuple. It builds a tuple only if its format string contains two or more format units. If the format string is empty, it returns `None`; if it contains exactly one format unit, it returns whatever object is described by that format unit. To force it to return a tuple of size 0 or one, parenthesize the format string.

Examples (to the left the call, to the right the resulting Python value):

```
Py_BuildValue("")                       None
Py_BuildValue("i", 123)                 123
Py_BuildValue("iii", 123, 456, 789)     (123, 456, 789)
Py_BuildValue("s", "hello")             'hello'
Py_BuildValue("y", "hello")             b'hello'
Py_BuildValue("ss", "hello", "world")   ('hello', 'world')
Py_BuildValue("s#", "hello", 4)         'hell'
Py_BuildValue("y#", "hello", 4)         b'hell'
Py_BuildValue("()")                     ()
```

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```
Py_BuildValue("(i)", 123)                  (123,)
Py_BuildValue("(ii)", 123, 456)            (123, 456)
Py_BuildValue("(i,i)", 123, 456)           (123, 456)
Py_BuildValue("[i,i]", 123, 456)           [123, 456]
Py_BuildValue("{s:i,s:i}",
              "abc", 123, "def", 456)      {'abc': 123, 'def': 456}
Py_BuildValue("((ii)(ii)) (ii)",
              1, 2, 3, 4, 5, 6)            (((1, 2), (3, 4)), (5, 6))
```

2.1.10 Reference Counts

In languages like C or C++, the programmer is responsible for dynamic allocation and deallocation of memory on the heap. In C, this is done using the functions `malloc()` and `free()`. In C++, the operators `new` and `delete` are used with essentially the same meaning and we'll restrict the following discussion to the C case.

Every block of memory allocated with `malloc()` should eventually be returned to the pool of available memory by exactly one call to `free()`. It is important to call `free()` at the right time. If a block's address is forgotten but `free()` is not called for it, the memory it occupies cannot be reused until the program terminates. This is called a *memory leak*. On the other hand, if a program calls `free()` for a block and then continues to use the block, it creates a conflict with re-use of the block through another `malloc()` call. This is called *using freed memory*. It has the same bad consequences as referencing uninitialized data — core dumps, wrong results, mysterious crashes.

Common causes of memory leaks are unusual paths through the code. For instance, a function may allocate a block of memory, do some calculation, and then free the block again. Now a change in the requirements for the function may add a test to the calculation that detects an error condition and can return prematurely from the function. It's easy to forget to free the allocated memory block when taking this premature exit, especially when it is added later to the code. Such leaks, once introduced, often go undetected for a long time: the error exit is taken only in a small fraction of all calls, and most modern machines have plenty of virtual memory, so the leak only becomes apparent in a long-running process that uses the leaking function frequently. Therefore, it's important to prevent leaks from happening by having a coding convention or strategy that minimizes this kind of errors.

Since Python makes heavy use of `malloc()` and `free()`, it needs a strategy to avoid memory leaks as well as the use of freed memory. The chosen method is called *reference counting*. The principle is simple: every object contains a counter, which is incremented when a reference to the object is stored somewhere, and which is decremented when a reference to it is deleted. When the counter reaches zero, the last reference to the object has been deleted and the object is freed.

An alternative strategy is called *automatic garbage collection*. (Sometimes, reference counting is also referred to as a garbage collection strategy, hence my use of "automatic" to distinguish the two.) The big advantage of automatic garbage collection is that the user doesn't need to call `free()` explicitly. (Another claimed advantage is an improvement in speed or memory usage — this is no hard fact however.) The disadvantage is that for C, there is no truly portable automatic garbage collector, while reference counting can be implemented portably (as long as the functions `malloc()` and `free()` are available — which the C Standard guarantees). Maybe some day a sufficiently portable automatic garbage collector will be available for C. Until then, we'll have to live with reference counts.

While Python uses the traditional reference counting implementation, it also offers a cycle detector that works to detect reference cycles. This allows applications to not worry about creating direct or indirect circular references; these are the weakness of garbage collection implemented using only reference counting. Reference cycles consist of objects which contain (possibly indirect) references to themselves, so that each object in the cycle has a reference count which is non-zero. Typical reference counting implementations are not able to reclaim the memory belonging to any objects in a reference cycle, or referenced from the objects in the cycle, even though there are no further references to the cycle itself.

The cycle detector is able to detect garbage cycles and can reclaim them. The `gc` module exposes a way to run the detector (the `collect()` function), as well as configuration interfaces and the ability to disable the detector at runtime. The cycle detector is considered an optional component; though it is included by default, it can be disabled at build time using

the `--without-cycle-gc` option to the **`configure`** script on Unix platforms (including Mac OS X). If the cycle detector is disabled in this way, the `gc` module will not be available.

Reference Counting in Python

There are two macros, `Py_INCREF(x)` and `Py_DECREF(x)`, which handle the incrementing and decrementing of the reference count. `Py_DECREF()` also frees the object when the count reaches zero. For flexibility, it doesn't call `free()` directly — rather, it makes a call through a function pointer in the object's *type object*. For this purpose (and others), every object also contains a pointer to its type object.

The big question now remains: when to use `Py_INCREF(x)` and `Py_DECREF(x)`? Let's first introduce some terms. Nobody "owns" an object; however, you can *own a reference* to an object. An object's reference count is now defined as the number of owned references to it. The owner of a reference is responsible for calling `Py_DECREF()` when the reference is no longer needed. Ownership of a reference can be transferred. There are three ways to dispose of an owned reference: pass it on, store it, or call `Py_DECREF()`. Forgetting to dispose of an owned reference creates a memory leak.

It is also possible to *borrow*[2] a reference to an object. The borrower of a reference should not call `Py_DECREF()`. The borrower must not hold on to the object longer than the owner from which it was borrowed. Using a borrowed reference after the owner has disposed of it risks using freed memory and should be avoided completely[3].

The advantage of borrowing over owning a reference is that you don't need to take care of disposing of the reference on all possible paths through the code — in other words, with a borrowed reference you don't run the risk of leaking when a premature exit is taken. The disadvantage of borrowing over owning is that there are some subtle situations where in seemingly correct code a borrowed reference can be used after the owner from which it was borrowed has in fact disposed of it.

A borrowed reference can be changed into an owned reference by calling `Py_INCREF()`. This does not affect the status of the owner from which the reference was borrowed — it creates a new owned reference, and gives full owner responsibilities (the new owner must dispose of the reference properly, as well as the previous owner).

Ownership Rules

Whenever an object reference is passed into or out of a function, it is part of the function's interface specification whether ownership is transferred with the reference or not.

Most functions that return a reference to an object pass on ownership with the reference. In particular, all functions whose function it is to create a new object, such as `PyLong_FromLong()` and `Py_BuildValue()`, pass ownership to the receiver. Even if the object is not actually new, you still receive ownership of a new reference to that object. For instance, `PyLong_FromLong()` maintains a cache of popular values and can return a reference to a cached item.

Many functions that extract objects from other objects also transfer ownership with the reference, for instance `PyObject_GetAttrString()`. The picture is less clear, here, however, since a few common routines are exceptions: `PyTuple_GetItem()`, `PyList_GetItem()`, `PyDict_GetItem()`, and `PyDict_GetItemString()` all return references that you borrow from the tuple, list or dictionary.

The function `PyImport_AddModule()` also returns a borrowed reference, even though it may actually create the object it returns: this is possible because an owned reference to the object is stored in `sys.modules`.

When you pass an object reference into another function, in general, the function borrows the reference from you — if it needs to store it, it will use `Py_INCREF()` to become an independent owner. There are exactly two important exceptions to this rule: `PyTuple_SetItem()` and `PyList_SetItem()`. These functions take over ownership of

[2] The metaphor of "borrowing" a reference is not completely correct: the owner still has a copy of the reference.

[3] Checking that the reference count is at least 1 **does not work** — the reference count itself could be in freed memory and may thus be reused for another object!

the item passed to them — even if they fail! (Note that `PyDict_SetItem()` and friends don't take over ownership — they are "normal.")

When a C function is called from Python, it borrows references to its arguments from the caller. The caller owns a reference to the object, so the borrowed reference's lifetime is guaranteed until the function returns. Only when such a borrowed reference must be stored or passed on, it must be turned into an owned reference by calling `Py_INCREF()`.

The object reference returned from a C function that is called from Python must be an owned reference — ownership is transferred from the function to its caller.

Thin Ice

There are a few situations where seemingly harmless use of a borrowed reference can lead to problems. These all have to do with implicit invocations of the interpreter, which can cause the owner of a reference to dispose of it.

The first and most important case to know about is using `Py_DECREF()` on an unrelated object while borrowing a reference to a list item. For instance:

```
void
bug(PyObject *list)
{
    PyObject *item = PyList_GetItem(list, 0);

    PyList_SetItem(list, 1, PyLong_FromLong(0L));
    PyObject_Print(item, stdout, 0); /* BUG! */
}
```

This function first borrows a reference to `list[0]`, then replaces `list[1]` with the value `0`, and finally prints the borrowed reference. Looks harmless, right? But it's not!

Let's follow the control flow into `PyList_SetItem()`. The list owns references to all its items, so when item 1 is replaced, it has to dispose of the original item 1. Now let's suppose the original item 1 was an instance of a user-defined class, and let's further suppose that the class defined a `__del__()` method. If this class instance has a reference count of 1, disposing of it will call its `__del__()` method.

Since it is written in Python, the `__del__()` method can execute arbitrary Python code. Could it perhaps do something to invalidate the reference to `item` in `bug()`? You bet! Assuming that the list passed into `bug()` is accessible to the `__del__()` method, it could execute a statement to the effect of `del list[0]`, and assuming this was the last reference to that object, it would free the memory associated with it, thereby invalidating `item`.

The solution, once you know the source of the problem, is easy: temporarily increment the reference count. The correct version of the function reads:

```
void
no_bug(PyObject *list)
{
    PyObject *item = PyList_GetItem(list, 0);

    Py_INCREF(item);
    PyList_SetItem(list, 1, PyLong_FromLong(0L));
    PyObject_Print(item, stdout, 0);
    Py_DECREF(item);
}
```

This is a true story. An older version of Python contained variants of this bug and someone spent a considerable amount of time in a C debugger to figure out why his `__del__()` methods would fail…

The second case of problems with a borrowed reference is a variant involving threads. Normally, multiple threads in the Python interpreter can't get in each other's way, because there is a global lock protecting Python's entire object space.

However, it is possible to temporarily release this lock using the macro `Py_BEGIN_ALLOW_THREADS`, and to re-acquire it using `Py_END_ALLOW_THREADS`. This is common around blocking I/O calls, to let other threads use the processor while waiting for the I/O to complete. Obviously, the following function has the same problem as the previous one:

```
void
bug(PyObject *list)
{
    PyObject *item = PyList_GetItem(list, 0);
    Py_BEGIN_ALLOW_THREADS
    ...some blocking I/O call...
    Py_END_ALLOW_THREADS
    PyObject_Print(item, stdout, 0); /* BUG! */
}
```

NULL Pointers

In general, functions that take object references as arguments do not expect you to pass them `NULL` pointers, and will dump core (or cause later core dumps) if you do so. Functions that return object references generally return `NULL` only to indicate that an exception occurred. The reason for not testing for `NULL` arguments is that functions often pass the objects they receive on to other function — if each function were to test for `NULL`, there would be a lot of redundant tests and the code would run more slowly.

It is better to test for `NULL` only at the "source:" when a pointer that may be `NULL` is received, for example, from `malloc()` or from a function that may raise an exception.

The macros `Py_INCREF()` and `Py_DECREF()` do not check for `NULL` pointers — however, their variants `Py_XINCREF()` and `Py_XDECREF()` do.

The macros for checking for a particular object type (`Pytype_Check()`) don't check for `NULL` pointers — again, there is much code that calls several of these in a row to test an object against various different expected types, and this would generate redundant tests. There are no variants with `NULL` checking.

The C function calling mechanism guarantees that the argument list passed to C functions (`args` in the examples) is never `NULL` — in fact it guarantees that it is always a tuple[4].

It is a severe error to ever let a `NULL` pointer "escape" to the Python user.

2.1.11 Writing Extensions in C++

It is possible to write extension modules in C++. Some restrictions apply. If the main program (the Python interpreter) is compiled and linked by the C compiler, global or static objects with constructors cannot be used. This is not a problem if the main program is linked by the C++ compiler. Functions that will be called by the Python interpreter (in particular, module initialization functions) have to be declared using `extern "C"`. It is unnecessary to enclose the Python header files in `extern "C" {...}` — they use this form already if the symbol `__cplusplus` is defined (all recent C++ compilers define this symbol).

[4] These guarantees don't hold when you use the "old" style calling convention — this is still found in much existing code.

2.1.12 Providing a C API for an Extension Module

Many extension modules just provide new functions and types to be used from Python, but sometimes the code in an extension module can be useful for other extension modules. For example, an extension module could implement a type "collection" which works like lists without order. Just like the standard Python list type has a C API which permits extension modules to create and manipulate lists, this new collection type should have a set of C functions for direct manipulation from other extension modules.

At first sight this seems easy: just write the functions (without declaring them `static`, of course), provide an appropriate header file, and document the C API. And in fact this would work if all extension modules were always linked statically with the Python interpreter. When modules are used as shared libraries, however, the symbols defined in one module may not be visible to another module. The details of visibility depend on the operating system; some systems use one global namespace for the Python interpreter and all extension modules (Windows, for example), whereas others require an explicit list of imported symbols at module link time (AIX is one example), or offer a choice of different strategies (most Unices). And even if symbols are globally visible, the module whose functions one wishes to call might not have been loaded yet!

Portability therefore requires not to make any assumptions about symbol visibility. This means that all symbols in extension modules should be declared `static`, except for the module's initialization function, in order to avoid name clashes with other extension modules (as discussed in section *The Module's Method Table and Initialization Function*). And it means that symbols that *should* be accessible from other extension modules must be exported in a different way.

Python provides a special mechanism to pass C-level information (pointers) from one extension module to another one: Capsules. A Capsule is a Python data type which stores a pointer (`void *`). Capsules can only be created and accessed via their C API, but they can be passed around like any other Python object. In particular, they can be assigned to a name in an extension module's namespace. Other extension modules can then import this module, retrieve the value of this name, and then retrieve the pointer from the Capsule.

There are many ways in which Capsules can be used to export the C API of an extension module. Each function could get its own Capsule, or all C API pointers could be stored in an array whose address is published in a Capsule. And the various tasks of storing and retrieving the pointers can be distributed in different ways between the module providing the code and the client modules.

Whichever method you choose, it's important to name your Capsules properly. The function `PyCapsule_New()` takes a name parameter (`const char *`); you're permitted to pass in a `NULL` name, but we strongly encourage you to specify a name. Properly named Capsules provide a degree of runtime type-safety; there is no feasible way to tell one unnamed Capsule from another.

In particular, Capsules used to expose C APIs should be given a name following this convention:

```
modulename.attributename
```

The convenience function `PyCapsule_Import()` makes it easy to load a C API provided via a Capsule, but only if the Capsule's name matches this convention. This behavior gives C API users a high degree of certainty that the Capsule they load contains the correct C API.

The following example demonstrates an approach that puts most of the burden on the writer of the exporting module, which is appropriate for commonly used library modules. It stores all C API pointers (just one in the example!) in an array of `void` pointers which becomes the value of a Capsule. The header file corresponding to the module provides a macro that takes care of importing the module and retrieving its C API pointers; client modules only have to call this macro before accessing the C API.

The exporting module is a modification of the `spam` module from section *A Simple Example*. The function `spam.system()` does not call the C library function `system()` directly, but a function `PySpam_System()`, which would of course do something more complicated in reality (such as adding "spam" to every command). This function `PySpam_System()` is also exported to other extension modules.

The function `PySpam_System()` is a plain C function, declared `static` like everything else:

```
static int
PySpam_System(const char *command)
{
    return system(command);
}
```

The function `spam_system()` is modified in a trivial way:

```
static PyObject *
spam_system(PyObject *self, PyObject *args)
{
    const char *command;
    int sts;

    if (!PyArg_ParseTuple(args, "s", &command))
        return NULL;
    sts = PySpam_System(command);
    return PyLong_FromLong(sts);
}
```

In the beginning of the module, right after the line

```
#include <Python.h>
```

two more lines must be added:

```
#define SPAM_MODULE
#include "spammodule.h"
```

The `#define` is used to tell the header file that it is being included in the exporting module, not a client module. Finally, the module's initialization function must take care of initializing the C API pointer array:

```
PyMODINIT_FUNC
PyInit_spam(void)
{
    PyObject *m;
    static void *PySpam_API[PySpam_API_pointers];
    PyObject *c_api_object;

    m = PyModule_Create(&spammodule);
    if (m == NULL)
        return NULL;

    /* Initialize the C API pointer array */
    PySpam_API[PySpam_System_NUM] = (void *)PySpam_System;

    /* Create a Capsule containing the API pointer array's address */
    c_api_object = PyCapsule_New((void *)PySpam_API, "spam._C_API", NULL);

    if (PyModule_AddObject(m, "_C_API", c_api_object) < 0) {
        Py_XDECREF(c_api_object);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

Note that `PySpam_API` is declared `static`; otherwise the pointer array would disappear when `PyInit_spam()` terminates!

The bulk of the work is in the header file `spammodule.h`, which looks like this:

```
#ifndef Py_SPAMMODULE_H
#define Py_SPAMMODULE_H
#ifdef __cplusplus
extern "C" {
#endif

/* Header file for spammodule */

/* C API functions */
#define PySpam_System_NUM 0
#define PySpam_System_RETURN int
#define PySpam_System_PROTO (const char *command)

/* Total number of C API pointers */
#define PySpam_API_pointers 1


#ifdef SPAM_MODULE
/* This section is used when compiling spammodule.c */

static PySpam_System_RETURN PySpam_System PySpam_System_PROTO;

#else
/* This section is used in modules that use spammodule's API */

static void **PySpam_API;

#define PySpam_System \
 (*(PySpam_System_RETURN (*)PySpam_System_PROTO) PySpam_API[PySpam_System_NUM])

/* Return -1 on error, 0 on success.
 * PyCapsule_Import will set an exception if there's an error.
 */
static int
import_spam(void)
{
    PySpam_API = (void **)PyCapsule_Import("spam._C_API", 0);
    return (PySpam_API != NULL) ? 0 : -1;
}

#endif

#ifdef __cplusplus
}
#endif

#endif /* !defined(Py_SPAMMODULE_H) */
```

All that a client module must do in order to have access to the function `PySpam_System()` is to call the function (or rather macro) `import_spam()` in its initialization function:

```
PyMODINIT_FUNC
PyInit_client(void)
```

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```
{
    PyObject *m;

    m = PyModule_Create(&clientmodule);
    if (m == NULL)
        return NULL;
    if (import_spam() < 0)
        return NULL;
    /* additional initialization can happen here */
    return m;
}
```

The main disadvantage of this approach is that the file `spammodule.h` is rather complicated. However, the basic structure is the same for each function that is exported, so it has to be learned only once.

Finally it should be mentioned that Capsules offer additional functionality, which is especially useful for memory allocation and deallocation of the pointer stored in a Capsule. The details are described in the Python/C API Reference Manual in the section capsules and in the implementation of Capsules (files `Include/pycapsule.h` and `Objects/pycapsule.c` in the Python source code distribution).

2.2 Defining Extension Types: Tutorial

Python allows the writer of a C extension module to define new types that can be manipulated from Python code, much like the built-in `str` and `list` types. The code for all extension types follows a pattern, but there are some details that you need to understand before you can get started. This document is a gentle introduction to the topic.

2.2.1 The Basics

The *CPython* runtime sees all Python objects as variables of type `PyObject*`, which serves as a "base type" for all Python objects. The `PyObject` structure itself only contains the object's *reference count* and a pointer to the object's "type object". This is where the action is; the type object determines which (C) functions get called by the interpreter when, for instance, an attribute gets looked up on an object, a method called, or it is multiplied by another object. These C functions are called "type methods".

So, if you want to define a new extension type, you need to create a new type object.

This sort of thing can only be explained by example, so here's a minimal, but complete, module that defines a new type named `Custom` inside a C extension module `custom`:

Note: What we're showing here is the traditional way of defining *static* extension types. It should be adequate for most uses. The C API also allows defining heap-allocated extension types using the `PyType_FromSpec()` function, which isn't covered in this tutorial.

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>

typedef struct {
    PyObject_HEAD
    /* Type-specific fields go here. */
} CustomObject;
```

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```
static PyTypeObject CustomType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    .tp_name = "custom.Custom",
    .tp_doc = "Custom objects",
    .tp_basicsize = sizeof(CustomObject),
    .tp_itemsize = 0,
    .tp_flags = Py_TPFLAGS_DEFAULT,
    .tp_new = PyType_GenericNew,
};

static PyModuleDef custommodule = {
    PyModuleDef_HEAD_INIT,
    .m_name = "custom",
    .m_doc = "Example module that creates an extension type.",
    .m_size = -1,
};

PyMODINIT_FUNC
PyInit_custom(void)
{
    PyObject *m;
    if (PyType_Ready(&CustomType) < 0)
        return NULL;

    m = PyModule_Create(&custommodule);
    if (m == NULL)
        return NULL;

    Py_INCREF(&CustomType);
    if (PyModule_AddObject(m, "Custom", (PyObject *) &CustomType) < 0) {
        Py_DECREF(&CustomType);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

Now that's quite a bit to take in at once, but hopefully bits will seem familiar from the previous chapter. This file defines three things:

1. What a `Custom` **object** contains: this is the `CustomObject` struct, which is allocated once for each `Custom` instance.
2. How the `Custom` **type** behaves: this is the `CustomType` struct, which defines a set of flags and function pointers that the interpreter inspects when specific operations are requested.
3. How to initialize the `custom` module: this is the `PyInit_custom` function and the associated `custommodule` struct.

The first bit is:

```
typedef struct {
    PyObject_HEAD
} CustomObject;
```

This is what a Custom object will contain. `PyObject_HEAD` is mandatory at the start of each object struct and defines a field called `ob_base` of type `PyObject`, containing a pointer to a type object and a reference count (these can be

accessed using the macros `Py_REFCNT` and `Py_TYPE` respectively). The reason for the macro is to abstract away the layout and to enable additional fields in debug builds.

Note: There is no semicolon above after the `PyObject_HEAD` macro. Be wary of adding one by accident: some compilers will complain.

Of course, objects generally store additional data besides the standard `PyObject_HEAD` boilerplate; for example, here is the definition for standard Python floats:

```
typedef struct {
    PyObject_HEAD
    double ob_fval;
} PyFloatObject;
```

The second bit is the definition of the type object.

```
static PyTypeObject CustomType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    .tp_name = "custom.Custom",
    .tp_doc = "Custom objects",
    .tp_basicsize = sizeof(CustomObject),
    .tp_itemsize = 0,
    .tp_flags = Py_TPFLAGS_DEFAULT,
    .tp_new = PyType_GenericNew,
};
```

Note: We recommend using C99-style designated initializers as above, to avoid listing all the `PyTypeObject` fields that you don't care about and also to avoid caring about the fields' declaration order.

The actual definition of `PyTypeObject` in `object.h` has many more fields than the definition above. The remaining fields will be filled with zeros by the C compiler, and it's common practice to not specify them explicitly unless you need them.

We're going to pick it apart, one field at a time:

```
PyVarObject_HEAD_INIT(NULL, 0)
```

This line is mandatory boilerplate to initialize the `ob_base` field mentioned above.

```
.tp_name = "custom.Custom",
```

The name of our type. This will appear in the default textual representation of our objects and in some error messages, for example:

```
>>> "" + custom.Custom()
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: can only concatenate str (not "custom.Custom") to str
```

Note that the name is a dotted name that includes both the module name and the name of the type within the module. The module in this case is `custom` and the type is `Custom`, so we set the type name to `custom.Custom`. Using the real dotted import path is important to make your type compatible with the `pydoc` and `pickle` modules.

```
.tp_basicsize = sizeof(CustomObject),
.tp_itemsize = 0,
```

This is so that Python knows how much memory to allocate when creating new `Custom` instances. `tp_itemsize` is only used for variable-sized objects and should otherwise be zero.

Note: If you want your type to be subclassable from Python, and your type has the same `tp_basicsize` as its base type, you may have problems with multiple inheritance. A Python subclass of your type will have to list your type first in its `__bases__`, or else it will not be able to call your type's `__new__()` method without getting an error. You can avoid this problem by ensuring that your type has a larger value for `tp_basicsize` than its base type does. Most of the time, this will be true anyway, because either your base type will be `object`, or else you will be adding data members to your base type, and therefore increasing its size.

We set the class flags to `Py_TPFLAGS_DEFAULT`.

```
.tp_flags = Py_TPFLAGS_DEFAULT,
```

All types should include this constant in their flags. It enables all of the members defined until at least Python 3.3. If you need further members, you will need to OR the corresponding flags.

We provide a doc string for the type in `tp_doc`.

```
.tp_doc = "Custom objects",
```

To enable object creation, we have to provide a `tp_new` handler. This is the equivalent of the Python method `__new__()`, but has to be specified explicitly. In this case, we can just use the default implementation provided by the API function `PyType_GenericNew()`.

```
.tp_new = PyType_GenericNew,
```

Everything else in the file should be familiar, except for some code in `PyInit_custom()`:

```
if (PyType_Ready(&CustomType) < 0)
    return;
```

This initializes the `Custom` type, filling in a number of members to the appropriate default values, including `ob_type` that we initially set to `NULL`.

```
Py_INCREF(&CustomType);
if (PyModule_AddObject(m, "Custom", (PyObject *) &CustomType) < 0) {
    Py_DECREF(&CustomType);
    Py_DECREF(m);
    return NULL;
}
```

This adds the type to the module dictionary. This allows us to create `Custom` instances by calling the `Custom` class:

```
>>> import custom
>>> mycustom = custom.Custom()
```

That's it! All that remains is to build it; put the above code in a file called `custom.c` and:

```
from distutils.core import setup, Extension
setup(name="custom", version="1.0",
      ext_modules=[Extension("custom", ["custom.c"])])
```

in a file called `setup.py`; then typing

```
$ python setup.py build
```

at a shell should produce a file `custom.so` in a subdirectory; move to that directory and fire up Python — you should be able to `import custom` and play around with Custom objects.

That wasn't so hard, was it?

Of course, the current Custom type is pretty uninteresting. It has no data and doesn't do anything. It can't even be subclassed.

Note: While this documentation showcases the standard `distutils` module for building C extensions, it is recommended in real-world use cases to use the newer and better-maintained `setuptools` library. Documentation on how to do this is out of scope for this document and can be found in the Python Packaging User's Guide.

2.2.2 Adding data and methods to the Basic example

Let's extend the basic example to add some data and methods. Let's also make the type usable as a base class. We'll create a new module, `custom2` that adds these capabilities:

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>
#include "structmember.h"

typedef struct {
    PyObject_HEAD
    PyObject *first; /* first name */
    PyObject *last;  /* last name */
    int number;
} CustomObject;

static void
Custom_dealloc(CustomObject *self)
{
    Py_XDECREF(self->first);
    Py_XDECREF(self->last);
    Py_TYPE(self)->tp_free((PyObject *) self);
}

static PyObject *
Custom_new(PyTypeObject *type, PyObject *args, PyObject *kwds)
{
    CustomObject *self;
    self = (CustomObject *) type->tp_alloc(type, 0);
    if (self != NULL) {
        self->first = PyUnicode_FromString("");
        if (self->first == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->last = PyUnicode_FromString("");
        if (self->last == NULL) {
            Py_DECREF(self);
            return NULL;
        }
```

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```
        self->number = 0;
    }
    return (PyObject *) self;
}

static int
Custom_init(CustomObject *self, PyObject *args, PyObject *kwds)
{
    static char *kwlist[] = {"first", "last", "number", NULL};
    PyObject *first = NULL, *last = NULL, *tmp;

    if (!PyArg_ParseTupleAndKeywords(args, kwds, "|OOi", kwlist,
                                     &first, &last,
                                     &self->number))
        return -1;

    if (first) {
        tmp = self->first;
        Py_INCREF(first);
        self->first = first;
        Py_XDECREF(tmp);
    }
    if (last) {
        tmp = self->last;
        Py_INCREF(last);
        self->last = last;
        Py_XDECREF(tmp);
    }
    return 0;
}

static PyMemberDef Custom_members[] = {
    {"first", T_OBJECT_EX, offsetof(CustomObject, first), 0,
     "first name"},
    {"last", T_OBJECT_EX, offsetof(CustomObject, last), 0,
     "last name"},
    {"number", T_INT, offsetof(CustomObject, number), 0,
     "custom number"},
    {NULL}  /* Sentinel */
};

static PyObject *
Custom_name(CustomObject *self, PyObject *Py_UNUSED(ignored))
{
    if (self->first == NULL) {
        PyErr_SetString(PyExc_AttributeError, "first");
        return NULL;
    }
    if (self->last == NULL) {
        PyErr_SetString(PyExc_AttributeError, "last");
        return NULL;
    }
    return PyUnicode_FromFormat("%S %S", self->first, self->last);
}

static PyMethodDef Custom_methods[] = {
    {"name", (PyCFunction) Custom_name, METH_NOARGS,
```

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```
     "Return the name, combining the first and last name"
    },
    {NULL}  /* Sentinel */
};

static PyTypeObject CustomType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    .tp_name = "custom2.Custom",
    .tp_doc = "Custom objects",
    .tp_basicsize = sizeof(CustomObject),
    .tp_itemsize = 0,
    .tp_flags = Py_TPFLAGS_DEFAULT | Py_TPFLAGS_BASETYPE,
    .tp_new = Custom_new,
    .tp_init = (initproc) Custom_init,
    .tp_dealloc = (destructor) Custom_dealloc,
    .tp_members = Custom_members,
    .tp_methods = Custom_methods,
};

static PyModuleDef custommodule = {
    PyModuleDef_HEAD_INIT,
    .m_name = "custom2",
    .m_doc = "Example module that creates an extension type.",
    .m_size = -1,
};

PyMODINIT_FUNC
PyInit_custom2(void)
{
    PyObject *m;
    if (PyType_Ready(&CustomType) < 0)
        return NULL;

    m = PyModule_Create(&custommodule);
    if (m == NULL)
        return NULL;

    Py_INCREF(&CustomType);
    if (PyModule_AddObject(m, "Custom", (PyObject *) &CustomType) < 0) {
        Py_DECREF(&CustomType);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

This version of the module has a number of changes.

We've added an extra include:

```
#include <structmember.h>
```

This include provides declarations that we use to handle attributes, as described a bit later.

The `Custom` type now has three data attributes in its C struct, *first*, *last*, and *number*. The *first* and *last* variables are Python strings containing first and last names. The *number* attribute is a C integer.

The object structure is updated accordingly:

```
typedef struct {
    PyObject_HEAD
    PyObject *first; /* first name */
    PyObject *last;  /* last name */
    int number;
} CustomObject;
```

Because we now have data to manage, we have to be more careful about object allocation and deallocation. At a minimum, we need a deallocation method:

```
static void
Custom_dealloc(CustomObject *self)
{
    Py_XDECREF(self->first);
    Py_XDECREF(self->last);
    Py_TYPE(self)->tp_free((PyObject *) self);
}
```

which is assigned to the `tp_dealloc` member:

```
.tp_dealloc = (destructor) Custom_dealloc,
```

This method first clears the reference counts of the two Python attributes. `Py_XDECREF()` correctly handles the case where its argument is `NULL` (which might happen here if `tp_new` failed midway). It then calls the `tp_free` member of the object's type (computed by `Py_TYPE(self)`) to free the object's memory. Note that the object's type might not be `CustomType`, because the object may be an instance of a subclass.

Note: The explicit cast to `destructor` above is needed because we defined `Custom_dealloc` to take a `CustomObject *` argument, but the `tp_dealloc` function pointer expects to receive a `PyObject *` argument. Otherwise, the compiler will emit a warning. This is object-oriented polymorphism, in C!

We want to make sure that the first and last names are initialized to empty strings, so we provide a `tp_new` implementation:

```
static PyObject *
Custom_new(PyTypeObject *type, PyObject *args, PyObject *kwds)
{
    CustomObject *self;
    self = (CustomObject *) type->tp_alloc(type, 0);
    if (self != NULL) {
        self->first = PyUnicode_FromString("");
        if (self->first == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->last = PyUnicode_FromString("");
        if (self->last == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->number = 0;
    }
    return (PyObject *) self;
}
```

and install it in the tp_new member:

```
.tp_new = Custom_new,
```

The tp_new handler is responsible for creating (as opposed to initializing) objects of the type. It is exposed in Python as the __new__() method. It is not required to define a tp_new member, and indeed many extension types will simply reuse PyType_GenericNew() as done in the first version of the Custom type above. In this case, we use the tp_new handler to initialize the first and last attributes to non-NULL default values.

tp_new is passed the type being instantiated (not necessarily CustomType, if a subclass is instantiated) and any arguments passed when the type was called, and is expected to return the instance created. tp_new handlers always accept positional and keyword arguments, but they often ignore the arguments, leaving the argument handling to initializer (a.k.a. tp_init in C or __init__ in Python) methods.

Note: tp_new shouldn't call tp_init explicitly, as the interpreter will do it itself.

The tp_new implementation calls the tp_alloc slot to allocate memory:

```
self = (CustomObject *) type->tp_alloc(type, 0);
```

Since memory allocation may fail, we must check the tp_alloc result against NULL before proceeding.

Note: We didn't fill the tp_alloc slot ourselves. Rather PyType_Ready() fills it for us by inheriting it from our base class, which is object by default. Most types use the default allocation strategy.

Note: If you are creating a co-operative tp_new (one that calls a base type's tp_new or __new__()), you must *not* try to determine what method to call using method resolution order at runtime. Always statically determine what type you are going to call, and call its tp_new directly, or via type->tp_base->tp_new. If you do not do this, Python subclasses of your type that also inherit from other Python-defined classes may not work correctly. (Specifically, you may not be able to create instances of such subclasses without getting a TypeError.)

We also define an initialization function which accepts arguments to provide initial values for our instance:

```
static int
Custom_init(CustomObject *self, PyObject *args, PyObject *kwds)
{
    static char *kwlist[] = {"first", "last", "number", NULL};
    PyObject *first = NULL, *last = NULL, *tmp;

    if (!PyArg_ParseTupleAndKeywords(args, kwds, "|OOi", kwlist,
                                     &first, &last,
                                     &self->number))
        return -1;

    if (first) {
        tmp = self->first;
        Py_INCREF(first);
        self->first = first;
        Py_XDECREF(tmp);
    }
    if (last) {
        tmp = self->last;
        Py_INCREF(last);
```

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```
        self->last = last;
        Py_XDECREF(tmp);
    }
    return 0;
}
```

by filling the `tp_init` slot.

```
.tp_init = (initproc) Custom_init,
```

The `tp_init` slot is exposed in Python as the `__init__()` method. It is used to initialize an object after it's created. Initializers always accept positional and keyword arguments, and they should return either `0` on success or `-1` on error.

Unlike the `tp_new` handler, there is no guarantee that `tp_init` is called at all (for example, the `pickle` module by default doesn't call `__init__()` on unpickled instances). It can also be called multiple times. Anyone can call the `__init__()` method on our objects. For this reason, we have to be extra careful when assigning the new attribute values. We might be tempted, for example to assign the `first` member like this:

```
if (first) {
    Py_XDECREF(self->first);
    Py_INCREF(first);
    self->first = first;
}
```

But this would be risky. Our type doesn't restrict the type of the `first` member, so it could be any kind of object. It could have a destructor that causes code to be executed that tries to access the `first` member; or that destructor could release the *Global interpreter Lock* and let arbitrary code run in other threads that accesses and modifies our object.

To be paranoid and protect ourselves against this possibility, we almost always reassign members before decrementing their reference counts. When don't we have to do this?

- when we absolutely know that the reference count is greater than 1;
- when we know that deallocation of the object[1] will neither release the *GIL* nor cause any calls back into our type's code;
- when decrementing a reference count in a `tp_dealloc` handler on a type which doesn't support cyclic garbage collection[2].

We want to expose our instance variables as attributes. There are a number of ways to do that. The simplest way is to define member definitions:

```
static PyMemberDef Custom_members[] = {
    {"first", T_OBJECT_EX, offsetof(CustomObject, first), 0,
     "first name"},
    {"last", T_OBJECT_EX, offsetof(CustomObject, last), 0,
     "last name"},
    {"number", T_INT, offsetof(CustomObject, number), 0,
     "custom number"},
    {NULL}  /* Sentinel */
};
```

and put the definitions in the `tp_members` slot:

```
.tp_members = Custom_members,
```

[1] This is true when we know that the object is a basic type, like a string or a float.

[2] We relied on this in the `tp_dealloc` handler in this example, because our type doesn't support garbage collection.

Each member definition has a member name, type, offset, access flags and documentation string. See the *Generic Attribute Management* section below for details.

A disadvantage of this approach is that it doesn't provide a way to restrict the types of objects that can be assigned to the Python attributes. We expect the first and last names to be strings, but any Python objects can be assigned. Further, the attributes can be deleted, setting the C pointers to `NULL`. Even though we can make sure the members are initialized to non-`NULL` values, the members can be set to `NULL` if the attributes are deleted.

We define a single method, `Custom.name()`, that outputs the objects name as the concatenation of the first and last names.

```
static PyObject *
Custom_name(CustomObject *self, PyObject *Py_UNUSED(ignored))
{
    if (self->first == NULL) {
        PyErr_SetString(PyExc_AttributeError, "first");
        return NULL;
    }
    if (self->last == NULL) {
        PyErr_SetString(PyExc_AttributeError, "last");
        return NULL;
    }
    return PyUnicode_FromFormat("%S %S", self->first, self->last);
}
```

The method is implemented as a C function that takes a `Custom` (or `Custom` subclass) instance as the first argument. Methods always take an instance as the first argument. Methods often take positional and keyword arguments as well, but in this case we don't take any and don't need to accept a positional argument tuple or keyword argument dictionary. This method is equivalent to the Python method:

```
def name(self):
    return "%s %s" % (self.first, self.last)
```

Note that we have to check for the possibility that our `first` and `last` members are `NULL`. This is because they can be deleted, in which case they are set to `NULL`. It would be better to prevent deletion of these attributes and to restrict the attribute values to be strings. We'll see how to do that in the next section.

Now that we've defined the method, we need to create an array of method definitions:

```
static PyMethodDef Custom_methods[] = {
    {"name", (PyCFunction) Custom_name, METH_NOARGS,
     "Return the name, combining the first and last name"
    },
    {NULL}  /* Sentinel */
};
```

(note that we used the `METH_NOARGS` flag to indicate that the method is expecting no arguments other than *self*)

and assign it to the `tp_methods` slot:

```
.tp_methods = Custom_methods,
```

Finally, we'll make our type usable as a base class for subclassing. We've written our methods carefully so far so that they don't make any assumptions about the type of the object being created or used, so all we need to do is to add the `Py_TPFLAGS_BASETYPE` to our class flag definition:

```
.tp_flags = Py_TPFLAGS_DEFAULT | Py_TPFLAGS_BASETYPE,
```

We rename `PyInit_custom()` to `PyInit_custom2()`, update the module name in the `PyModuleDef` struct, and update the full class name in the `PyTypeObject` struct.

Finally, we update our `setup.py` file to build the new module:

```
from distutils.core import setup, Extension
setup(name="custom", version="1.0",
      ext_modules=[
         Extension("custom", ["custom.c"]),
         Extension("custom2", ["custom2.c"]),
         ])
```

2.2.3 Providing finer control over data attributes

In this section, we'll provide finer control over how the `first` and `last` attributes are set in the `Custom` example. In the previous version of our module, the instance variables `first` and `last` could be set to non-string values or even deleted. We want to make sure that these attributes always contain strings.

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>
#include "structmember.h"

typedef struct {
    PyObject_HEAD
    PyObject *first; /* first name */
    PyObject *last;  /* last name */
    int number;
} CustomObject;

static void
Custom_dealloc(CustomObject *self)
{
    Py_XDECREF(self->first);
    Py_XDECREF(self->last);
    Py_TYPE(self)->tp_free((PyObject *) self);
}

static PyObject *
Custom_new(PyTypeObject *type, PyObject *args, PyObject *kwds)
{
    CustomObject *self;
    self = (CustomObject *) type->tp_alloc(type, 0);
    if (self != NULL) {
        self->first = PyUnicode_FromString("");
        if (self->first == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->last = PyUnicode_FromString("");
        if (self->last == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->number = 0;
    }
    return (PyObject *) self;
```

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```
}

static int
Custom_init(CustomObject *self, PyObject *args, PyObject *kwds)
{
    static char *kwlist[] = {"first", "last", "number", NULL};
    PyObject *first = NULL, *last = NULL, *tmp;

    if (!PyArg_ParseTupleAndKeywords(args, kwds, "|UUi", kwlist,
                                     &first, &last,
                                     &self->number))
        return -1;

    if (first) {
        tmp = self->first;
        Py_INCREF(first);
        self->first = first;
        Py_DECREF(tmp);
    }
    if (last) {
        tmp = self->last;
        Py_INCREF(last);
        self->last = last;
        Py_DECREF(tmp);
    }
    return 0;
}

static PyMemberDef Custom_members[] = {
    {"number", T_INT, offsetof(CustomObject, number), 0,
     "custom number"},
    {NULL}  /* Sentinel */
};

static PyObject *
Custom_getfirst(CustomObject *self, void *closure)
{
    Py_INCREF(self->first);
    return self->first;
}

static int
Custom_setfirst(CustomObject *self, PyObject *value, void *closure)
{
    PyObject *tmp;
    if (value == NULL) {
        PyErr_SetString(PyExc_TypeError, "Cannot delete the first attribute");
        return -1;
    }
    if (!PyUnicode_Check(value)) {
        PyErr_SetString(PyExc_TypeError,
                        "The first attribute value must be a string");
        return -1;
    }
    tmp = self->first;
    Py_INCREF(value);
    self->first = value;
```

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```
    Py_DECREF(tmp);
    return 0;
}

static PyObject *
Custom_getlast(CustomObject *self, void *closure)
{
    Py_INCREF(self->last);
    return self->last;
}

static int
Custom_setlast(CustomObject *self, PyObject *value, void *closure)
{
    PyObject *tmp;
    if (value == NULL) {
        PyErr_SetString(PyExc_TypeError, "Cannot delete the last attribute");
        return -1;
    }
    if (!PyUnicode_Check(value)) {
        PyErr_SetString(PyExc_TypeError,
                        "The last attribute value must be a string");
        return -1;
    }
    tmp = self->last;
    Py_INCREF(value);
    self->last = value;
    Py_DECREF(tmp);
    return 0;
}

static PyGetSetDef Custom_getsetters[] = {
    {"first", (getter) Custom_getfirst, (setter) Custom_setfirst,
     "first name", NULL},
    {"last", (getter) Custom_getlast, (setter) Custom_setlast,
     "last name", NULL},
    {NULL}  /* Sentinel */
};

static PyObject *
Custom_name(CustomObject *self, PyObject *Py_UNUSED(ignored))
{
    return PyUnicode_FromFormat("%S %S", self->first, self->last);
}

static PyMethodDef Custom_methods[] = {
    {"name", (PyCFunction) Custom_name, METH_NOARGS,
     "Return the name, combining the first and last name"
    },
    {NULL}  /* Sentinel */
};

static PyTypeObject CustomType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    .tp_name = "custom3.Custom",
    .tp_doc = "Custom objects",
    .tp_basicsize = sizeof(CustomObject),
```

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```
    .tp_itemsize = 0,
    .tp_flags = Py_TPFLAGS_DEFAULT | Py_TPFLAGS_BASETYPE,
    .tp_new = Custom_new,
    .tp_init = (initproc) Custom_init,
    .tp_dealloc = (destructor) Custom_dealloc,
    .tp_members = Custom_members,
    .tp_methods = Custom_methods,
    .tp_getset = Custom_getsetters,
};

static PyModuleDef custommodule = {
    PyModuleDef_HEAD_INIT,
    .m_name = "custom3",
    .m_doc = "Example module that creates an extension type.",
    .m_size = -1,
};

PyMODINIT_FUNC
PyInit_custom3(void)
{
    PyObject *m;
    if (PyType_Ready(&CustomType) < 0)
        return NULL;

    m = PyModule_Create(&custommodule);
    if (m == NULL)
        return NULL;

    Py_INCREF(&CustomType);
    if (PyModule_AddObject(m, "Custom", (PyObject *) &CustomType) < 0) {
        Py_DECREF(&CustomType);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

To provide greater control, over the `first` and `last` attributes, we'll use custom getter and setter functions. Here are the functions for getting and setting the `first` attribute:

```
static PyObject *
Custom_getfirst(CustomObject *self, void *closure)
{
    Py_INCREF(self->first);
    return self->first;
}

static int
Custom_setfirst(CustomObject *self, PyObject *value, void *closure)
{
    PyObject *tmp;
    if (value == NULL) {
        PyErr_SetString(PyExc_TypeError, "Cannot delete the first attribute");
        return -1;
    }
```

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```
    if (!PyUnicode_Check(value)) {
        PyErr_SetString(PyExc_TypeError,
                        "The first attribute value must be a string");
        return -1;
    }
    tmp = self->first;
    Py_INCREF(value);
    self->first = value;
    Py_DECREF(tmp);
    return 0;
}
```

The getter function is passed a `Custom` object and a "closure", which is a void pointer. In this case, the closure is ignored. (The closure supports an advanced usage in which definition data is passed to the getter and setter. This could, for example, be used to allow a single set of getter and setter functions that decide the attribute to get or set based on data in the closure.)

The setter function is passed the `Custom` object, the new value, and the closure. The new value may be `NULL`, in which case the attribute is being deleted. In our setter, we raise an error if the attribute is deleted or if its new value is not a string.

We create an array of `PyGetSetDef` structures:

```
static PyGetSetDef Custom_getsetters[] = {
    {"first", (getter) Custom_getfirst, (setter) Custom_setfirst,
     "first name", NULL},
    {"last", (getter) Custom_getlast, (setter) Custom_setlast,
     "last name", NULL},
    {NULL}  /* Sentinel */
};
```

and register it in the `tp_getset` slot:

```
.tp_getset = Custom_getsetters,
```

The last item in a `PyGetSetDef` structure is the "closure" mentioned above. In this case, we aren't using a closure, so we just pass `NULL`.

We also remove the member definitions for these attributes:

```
static PyMemberDef Custom_members[] = {
    {"number", T_INT, offsetof(CustomObject, number), 0,
     "custom number"},
    {NULL}  /* Sentinel */
};
```

We also need to update the `tp_init` handler to only allow strings[3] to be passed:

```
static int
Custom_init(CustomObject *self, PyObject *args, PyObject *kwds)
{
    static char *kwlist[] = {"first", "last", "number", NULL};
    PyObject *first = NULL, *last = NULL, *tmp;
```

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[3] We now know that the first and last members are strings, so perhaps we could be less careful about decrementing their reference counts, however, we accept instances of string subclasses. Even though deallocating normal strings won't call back into our objects, we can't guarantee that deallocating an instance of a string subclass won't call back into our objects.

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```
    if (!PyArg_ParseTupleAndKeywords(args, kwds, "|UUi", kwlist,
                                     &first, &last,
                                     &self->number))
        return -1;

    if (first) {
        tmp = self->first;
        Py_INCREF(first);
        self->first = first;
        Py_DECREF(tmp);
    }
    if (last) {
        tmp = self->last;
        Py_INCREF(last);
        self->last = last;
        Py_DECREF(tmp);
    }
    return 0;
}
```

With these changes, we can assure that the `first` and `last` members are never `NULL` so we can remove checks for `NULL` values in almost all cases. This means that most of the `Py_XDECREF()` calls can be converted to `Py_DECREF()` calls. The only place we can't change these calls is in the `tp_dealloc` implementation, where there is the possibility that the initialization of these members failed in `tp_new`.

We also rename the module initialization function and module name in the initialization function, as we did before, and we add an extra definition to the `setup.py` file.

2.2.4 Supporting cyclic garbage collection

Python has a *cyclic garbage collector (GC)* that can identify unneeded objects even when their reference counts are not zero. This can happen when objects are involved in cycles. For example, consider:

```
>>> l = []
>>> l.append(l)
>>> del l
```

In this example, we create a list that contains itself. When we delete it, it still has a reference from itself. Its reference count doesn't drop to zero. Fortunately, Python's cyclic garbage collector will eventually figure out that the list is garbage and free it.

In the second version of the `Custom` example, we allowed any kind of object to be stored in the `first` or `last` attributes[4]. Besides, in the second and third versions, we allowed subclassing `Custom`, and subclasses may add arbitrary attributes. For any of those two reasons, `Custom` objects can participate in cycles:

```
>>> import custom3
>>> class Derived(custom3.Custom): pass
...
>>> n = Derived()
>>> n.some_attribute = n
```

To allow a `Custom` instance participating in a reference cycle to be properly detected and collected by the cyclic GC, our `Custom` type needs to fill two additional slots and to enable a flag that enables these slots:

[4] Also, even with our attributes restricted to strings instances, the user could pass arbitrary `str` subclasses and therefore still create reference cycles.

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>
#include "structmember.h"

typedef struct {
    PyObject_HEAD
    PyObject *first; /* first name */
    PyObject *last;  /* last name */
    int number;
} CustomObject;

static int
Custom_traverse(CustomObject *self, visitproc visit, void *arg)
{
    Py_VISIT(self->first);
    Py_VISIT(self->last);
    return 0;
}

static int
Custom_clear(CustomObject *self)
{
    Py_CLEAR(self->first);
    Py_CLEAR(self->last);
    return 0;
}

static void
Custom_dealloc(CustomObject *self)
{
    PyObject_GC_UnTrack(self);
    Custom_clear(self);
    Py_TYPE(self)->tp_free((PyObject *) self);
}

static PyObject *
Custom_new(PyTypeObject *type, PyObject *args, PyObject *kwds)
{
    CustomObject *self;
    self = (CustomObject *) type->tp_alloc(type, 0);
    if (self != NULL) {
        self->first = PyUnicode_FromString("");
        if (self->first == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->last = PyUnicode_FromString("");
        if (self->last == NULL) {
            Py_DECREF(self);
            return NULL;
        }
        self->number = 0;
    }
    return (PyObject *) self;
}

static int
```

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```
Custom_init(CustomObject *self, PyObject *args, PyObject *kwds)
{
    static char *kwlist[] = {"first", "last", "number", NULL};
    PyObject *first = NULL, *last = NULL, *tmp;

    if (!PyArg_ParseTupleAndKeywords(args, kwds, "|UUi", kwlist,
                                     &first, &last,
                                     &self->number))
        return -1;

    if (first) {
        tmp = self->first;
        Py_INCREF(first);
        self->first = first;
        Py_DECREF(tmp);
    }
    if (last) {
        tmp = self->last;
        Py_INCREF(last);
        self->last = last;
        Py_DECREF(tmp);
    }
    return 0;
}

static PyMemberDef Custom_members[] = {
    {"number", T_INT, offsetof(CustomObject, number), 0,
     "custom number"},
    {NULL}  /* Sentinel */
};

static PyObject *
Custom_getfirst(CustomObject *self, void *closure)
{
    Py_INCREF(self->first);
    return self->first;
}

static int
Custom_setfirst(CustomObject *self, PyObject *value, void *closure)
{
    if (value == NULL) {
        PyErr_SetString(PyExc_TypeError, "Cannot delete the first attribute");
        return -1;
    }
    if (!PyUnicode_Check(value)) {
        PyErr_SetString(PyExc_TypeError,
                        "The first attribute value must be a string");
        return -1;
    }
    Py_INCREF(value);
    Py_CLEAR(self->first);
    self->first = value;
    return 0;
}

static PyObject *
```

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```
Custom_getlast(CustomObject *self, void *closure)
{
    Py_INCREF(self->last);
    return self->last;
}

static int
Custom_setlast(CustomObject *self, PyObject *value, void *closure)
{
    if (value == NULL) {
        PyErr_SetString(PyExc_TypeError, "Cannot delete the last attribute");
        return -1;
    }
    if (!PyUnicode_Check(value)) {
        PyErr_SetString(PyExc_TypeError,
                        "The last attribute value must be a string");
        return -1;
    }
    Py_INCREF(value);
    Py_CLEAR(self->last);
    self->last = value;
    return 0;
}

static PyGetSetDef Custom_getsetters[] = {
    {"first", (getter) Custom_getfirst, (setter) Custom_setfirst,
     "first name", NULL},
    {"last", (getter) Custom_getlast, (setter) Custom_setlast,
     "last name", NULL},
    {NULL}  /* Sentinel */
};

static PyObject *
Custom_name(CustomObject *self, PyObject *Py_UNUSED(ignored))
{
    return PyUnicode_FromFormat("%S %S", self->first, self->last);
}

static PyMethodDef Custom_methods[] = {
    {"name", (PyCFunction) Custom_name, METH_NOARGS,
     "Return the name, combining the first and last name"
    },
    {NULL}  /* Sentinel */
};

static PyTypeObject CustomType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    .tp_name = "custom4.Custom",
    .tp_doc = "Custom objects",
    .tp_basicsize = sizeof(CustomObject),
    .tp_itemsize = 0,
    .tp_flags = Py_TPFLAGS_DEFAULT | Py_TPFLAGS_BASETYPE | Py_TPFLAGS_HAVE_GC,
    .tp_new = Custom_new,
    .tp_init = (initproc) Custom_init,
    .tp_dealloc = (destructor) Custom_dealloc,
    .tp_traverse = (traverseproc) Custom_traverse,
    .tp_clear = (inquiry) Custom_clear,
```

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```
    .tp_members = Custom_members,
    .tp_methods = Custom_methods,
    .tp_getset = Custom_getsetters,
};

static PyModuleDef custommodule = {
    PyModuleDef_HEAD_INIT,
    .m_name = "custom4",
    .m_doc = "Example module that creates an extension type.",
    .m_size = -1,
};

PyMODINIT_FUNC
PyInit_custom4(void)
{
    PyObject *m;
    if (PyType_Ready(&CustomType) < 0)
        return NULL;

    m = PyModule_Create(&custommodule);
    if (m == NULL)
        return NULL;

    Py_INCREF(&CustomType);
    if (PyModule_AddObject(m, "Custom", (PyObject *) &CustomType) < 0) {
        Py_DECREF(&CustomType);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

First, the traversal method lets the cyclic GC know about subobjects that could participate in cycles:

```
static int
Custom_traverse(CustomObject *self, visitproc visit, void *arg)
{
    int vret;
    if (self->first) {
        vret = visit(self->first, arg);
        if (vret != 0)
            return vret;
    }
    if (self->last) {
        vret = visit(self->last, arg);
        if (vret != 0)
            return vret;
    }
    return 0;
}
```

For each subobject that can participate in cycles, we need to call the `visit()` function, which is passed to the traversal method. The `visit()` function takes as arguments the subobject and the extra argument *arg* passed to the traversal method. It returns an integer value that must be returned if it is non-zero.

Python provides a `Py_VISIT()` macro that automates calling visit functions. With `Py_VISIT()`, we can minimize

the amount of boilerplate in `Custom_traverse`:

```
static int
Custom_traverse(CustomObject *self, visitproc visit, void *arg)
{
    Py_VISIT(self->first);
    Py_VISIT(self->last);
    return 0;
}
```

Note: The `tp_traverse` implementation must name its arguments exactly *visit* and *arg* in order to use `Py_VISIT()`.

Second, we need to provide a method for clearing any subobjects that can participate in cycles:

```
static int
Custom_clear(CustomObject *self)
{
    Py_CLEAR(self->first);
    Py_CLEAR(self->last);
    return 0;
}
```

Notice the use of the `Py_CLEAR()` macro. It is the recommended and safe way to clear data attributes of arbitrary types while decrementing their reference counts. If you were to call `Py_XDECREF()` instead on the attribute before setting it to `NULL`, there is a possibility that the attribute's destructor would call back into code that reads the attribute again (*especially* if there is a reference cycle).

Note: You could emulate `Py_CLEAR()` by writing:

```
PyObject *tmp;
tmp = self->first;
self->first = NULL;
Py_XDECREF(tmp);
```

Nevertheless, it is much easier and less error-prone to always use `Py_CLEAR()` when deleting an attribute. Don't try to micro-optimize at the expense of robustness!

The deallocator `Custom_dealloc` may call arbitrary code when clearing attributes. It means the circular GC can be triggered inside the function. Since the GC assumes reference count is not zero, we need to untrack the object from the GC by calling `PyObject_GC_UnTrack()` before clearing members. Here is our reimplemented deallocator using `PyObject_GC_UnTrack()` and `Custom_clear`:

```
static void
Custom_dealloc(CustomObject *self)
{
    PyObject_GC_UnTrack(self);
    Custom_clear(self);
    Py_TYPE(self)->tp_free((PyObject *) self);
}
```

Finally, we add the `Py_TPFLAGS_HAVE_GC` flag to the class flags:

```
.tp_flags = Py_TPFLAGS_DEFAULT | Py_TPFLAGS_BASETYPE | Py_TPFLAGS_HAVE_GC,
```

That's pretty much it. If we had written custom `tp_alloc` or `tp_free` handlers, we'd need to modify them for cyclic garbage collection. Most extensions will use the versions automatically provided.

2.2.5 Subclassing other types

It is possible to create new extension types that are derived from existing types. It is easiest to inherit from the built in types, since an extension can easily use the `PyTypeObject` it needs. It can be difficult to share these `PyTypeObject` structures between extension modules.

In this example we will create a `SubList` type that inherits from the built-in `list` type. The new type will be completely compatible with regular lists, but will have an additional `increment()` method that increases an internal counter:

```
>>> import sublist
>>> s = sublist.SubList(range(3))
>>> s.extend(s)
>>> print(len(s))
6
>>> print(s.increment())
1
>>> print(s.increment())
2
```

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>

typedef struct {
    PyListObject list;
    int state;
} SubListObject;

static PyObject *
SubList_increment(SubListObject *self, PyObject *unused)
{
    self->state++;
    return PyLong_FromLong(self->state);
}

static PyMethodDef SubList_methods[] = {
    {"increment", (PyCFunction) SubList_increment, METH_NOARGS,
     PyDoc_STR("increment state counter")},
    {NULL},
};

static int
SubList_init(SubListObject *self, PyObject *args, PyObject *kwds)
{
    if (PyList_Type.tp_init((PyObject *) self, args, kwds) < 0)
        return -1;
    self->state = 0;
    return 0;
}

static PyTypeObject SubListType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    .tp_name = "sublist.SubList",
    .tp_doc = "SubList objects",
```

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```
    .tp_basicsize = sizeof(SubListObject),
    .tp_itemsize = 0,
    .tp_flags = Py_TPFLAGS_DEFAULT | Py_TPFLAGS_BASETYPE,
    .tp_init = (initproc) SubList_init,
    .tp_methods = SubList_methods,
};

static PyModuleDef sublistmodule = {
    PyModuleDef_HEAD_INIT,
    .m_name = "sublist",
    .m_doc = "Example module that creates an extension type.",
    .m_size = -1,
};

PyMODINIT_FUNC
PyInit_sublist(void)
{
    PyObject *m;
    SubListType.tp_base = &PyList_Type;
    if (PyType_Ready(&SubListType) < 0)
        return NULL;

    m = PyModule_Create(&sublistmodule);
    if (m == NULL)
        return NULL;

    Py_INCREF(&SubListType);
    if (PyModule_AddObject(m, "SubList", (PyObject *) &SubListType) < 0) {
        Py_DECREF(&SubListType);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

As you can see, the source code closely resembles the `Custom` examples in previous sections. We will break down the main differences between them.

```
typedef struct {
    PyListObject list;
    int state;
} SubListObject;
```

The primary difference for derived type objects is that the base type's object structure must be the first value. The base type will already include the `PyObject_HEAD()` at the beginning of its structure.

When a Python object is a `SubList` instance, its `PyObject *` pointer can be safely cast to both `PyListObject *` and `SubListObject *`:

```
static int
SubList_init(SubListObject *self, PyObject *args, PyObject *kwds)
{
    if (PyList_Type.tp_init((PyObject *) self, args, kwds) < 0)
        return -1;
    self->state = 0;
    return 0;
```

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```
}
```

We see above how to call through to the `__init__` method of the base type.

This pattern is important when writing a type with custom `tp_new` and `tp_dealloc` members. The `tp_new` handler should not actually create the memory for the object with its `tp_alloc`, but let the base class handle it by calling its own `tp_new`.

The `PyTypeObject` struct supports a `tp_base` specifying the type's concrete base class. Due to cross-platform compiler issues, you can't fill that field directly with a reference to `PyList_Type`; it should be done later in the module initialization function:

```
PyMODINIT_FUNC
PyInit_sublist(void)
{
    PyObject* m;
    SubListType.tp_base = &PyList_Type;
    if (PyType_Ready(&SubListType) < 0)
        return NULL;

    m = PyModule_Create(&sublistmodule);
    if (m == NULL)
        return NULL;

    Py_INCREF(&SubListType);
    if (PyModule_AddObject(m, "SubList", (PyObject *) &SubListType) < 0) {
        Py_DECREF(&SubListType);
        Py_DECREF(m);
        return NULL;
    }

    return m;
}
```

Before calling `PyType_Ready()`, the type structure must have the `tp_base` slot filled in. When we are deriving an existing type, it is not necessary to fill out the `tp_alloc` slot with `PyType_GenericNew()` – the allocation function from the base type will be inherited.

After that, calling `PyType_Ready()` and adding the type object to the module is the same as with the basic `Custom` examples.

2.3 Defining Extension Types: Assorted Topics

This section aims to give a quick fly-by on the various type methods you can implement and what they do.

Here is the definition of `PyTypeObject`, with some fields only used in debug builds omitted:

```
typedef struct _typeobject {
    PyObject_VAR_HEAD
    const char *tp_name; /* For printing, in format "<module>.<name>" */
    Py_ssize_t tp_basicsize, tp_itemsize; /* For allocation */

    /* Methods to implement standard operations */

    destructor tp_dealloc;
```

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```
    Py_ssize_t tp_vectorcall_offset;
    getattrfunc tp_getattr;
    setattrfunc tp_setattr;
    PyAsyncMethods *tp_as_async; /* formerly known as tp_compare (Python 2)
                                    or tp_reserved (Python 3) */
    reprfunc tp_repr;

    /* Method suites for standard classes */

    PyNumberMethods *tp_as_number;
    PySequenceMethods *tp_as_sequence;
    PyMappingMethods *tp_as_mapping;

    /* More standard operations (here for binary compatibility) */

    hashfunc tp_hash;
    ternaryfunc tp_call;
    reprfunc tp_str;
    getattrofunc tp_getattro;
    setattrofunc tp_setattro;

    /* Functions to access object as input/output buffer */
    PyBufferProcs *tp_as_buffer;

    /* Flags to define presence of optional/expanded features */
    unsigned long tp_flags;

    const char *tp_doc; /* Documentation string */

    /* call function for all accessible objects */
    traverseproc tp_traverse;

    /* delete references to contained objects */
    inquiry tp_clear;

    /* rich comparisons */
    richcmpfunc tp_richcompare;

    /* weak reference enabler */
    Py_ssize_t tp_weaklistoffset;

    /* Iterators */
    getiterfunc tp_iter;
    iternextfunc tp_iternext;

    /* Attribute descriptor and subclassing stuff */
    struct PyMethodDef *tp_methods;
    struct PyMemberDef *tp_members;
    struct PyGetSetDef *tp_getset;
    struct _typeobject *tp_base;
    PyObject *tp_dict;
    descrgetfunc tp_descr_get;
    descrsetfunc tp_descr_set;
    Py_ssize_t tp_dictoffset;
    initproc tp_init;
    allocfunc tp_alloc;
    newfunc tp_new;
```

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```
    freefunc tp_free; /* Low-level free-memory routine */
    inquiry tp_is_gc; /* For PyObject_IS_GC */
    PyObject *tp_bases;
    PyObject *tp_mro; /* method resolution order */
    PyObject *tp_cache;
    PyObject *tp_subclasses;
    PyObject *tp_weaklist;
    destructor tp_del;

    /* Type attribute cache version tag. Added in version 2.6 */
    unsigned int tp_version_tag;

    destructor tp_finalize;

} PyTypeObject;
```

Now that's a *lot* of methods. Don't worry too much though – if you have a type you want to define, the chances are very good that you will only implement a handful of these.

As you probably expect by now, we're going to go over this and give more information about the various handlers. We won't go in the order they are defined in the structure, because there is a lot of historical baggage that impacts the ordering of the fields. It's often easiest to find an example that includes the fields you need and then change the values to suit your new type.

```
const char *tp_name; /* For printing */
```

The name of the type – as mentioned in the previous chapter, this will appear in various places, almost entirely for diagnostic purposes. Try to choose something that will be helpful in such a situation!

```
Py_ssize_t tp_basicsize, tp_itemsize; /* For allocation */
```

These fields tell the runtime how much memory to allocate when new objects of this type are created. Python has some built-in support for variable length structures (think: strings, tuples) which is where the `tp_itemsize` field comes in. This will be dealt with later.

```
const char *tp_doc;
```

Here you can put a string (or its address) that you want returned when the Python script references `obj.__doc__` to retrieve the doc string.

Now we come to the basic type methods – the ones most extension types will implement.

2.3.1 Finalization and De-allocation

```
destructor tp_dealloc;
```

This function is called when the reference count of the instance of your type is reduced to zero and the Python interpreter wants to reclaim it. If your type has memory to free or other clean-up to perform, you can put it here. The object itself needs to be freed here as well. Here is an example of this function:

```
static void
newdatatype_dealloc(newdatatypeobject *obj)
{
    free(obj->obj_UnderlyingDatatypePtr);
```

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```
    Py_TYPE(obj)->tp_free(obj);
}
```

One important requirement of the deallocator function is that it leaves any pending exceptions alone. This is important since deallocators are frequently called as the interpreter unwinds the Python stack; when the stack is unwound due to an exception (rather than normal returns), nothing is done to protect the deallocators from seeing that an exception has already been set. Any actions which a deallocator performs which may cause additional Python code to be executed may detect that an exception has been set. This can lead to misleading errors from the interpreter. The proper way to protect against this is to save a pending exception before performing the unsafe action, and restoring it when done. This can be done using the `PyErr_Fetch()` and `PyErr_Restore()` functions:

```
static void
my_dealloc(PyObject *obj)
{
    MyObject *self = (MyObject *) obj;
    PyObject *cbresult;

    if (self->my_callback != NULL) {
        PyObject *err_type, *err_value, *err_traceback;

        /* This saves the current exception state */
        PyErr_Fetch(&err_type, &err_value, &err_traceback);

        cbresult = PyObject_CallObject(self->my_callback, NULL);
        if (cbresult == NULL)
            PyErr_WriteUnraisable(self->my_callback);
        else
            Py_DECREF(cbresult);

        /* This restores the saved exception state */
        PyErr_Restore(err_type, err_value, err_traceback);

        Py_DECREF(self->my_callback);
    }
    Py_TYPE(obj)->tp_free((PyObject*)self);
}
```

Note: There are limitations to what you can safely do in a deallocator function. First, if your type supports garbage collection (using `tp_traverse` and/or `tp_clear`), some of the object's members can have been cleared or finalized by the time `tp_dealloc` is called. Second, in `tp_dealloc`, your object is in an unstable state: its reference count is equal to zero. Any call to a non-trivial object or API (as in the example above) might end up calling `tp_dealloc` again, causing a double free and a crash.

Starting with Python 3.4, it is recommended not to put any complex finalization code in `tp_dealloc`, and instead use the new `tp_finalize` type method.

See also:

PEP 442 explains the new finalization scheme.

2.3.2 Object Presentation

In Python, there are two ways to generate a textual representation of an object: the `repr()` function, and the `str()` function. (The `print()` function just calls `str()`.) These handlers are both optional.

```
reprfunc tp_repr;
reprfunc tp_str;
```

The `tp_repr` handler should return a string object containing a representation of the instance for which it is called. Here is a simple example:

```
static PyObject *
newdatatype_repr(newdatatypeobject * obj)
{
    return PyUnicode_FromFormat("Repr-ified_newdatatype{{size:%d}}",
                                obj->obj_UnderlyingDatatypePtr->size);
}
```

If no `tp_repr` handler is specified, the interpreter will supply a representation that uses the type's `tp_name` and a uniquely-identifying value for the object.

The `tp_str` handler is to `str()` what the `tp_repr` handler described above is to `repr()`; that is, it is called when Python code calls `str()` on an instance of your object. Its implementation is very similar to the `tp_repr` function, but the resulting string is intended for human consumption. If `tp_str` is not specified, the `tp_repr` handler is used instead.

Here is a simple example:

```
static PyObject *
newdatatype_str(newdatatypeobject * obj)
{
    return PyUnicode_FromFormat("Stringified_newdatatype{{size:%d}}",
                                obj->obj_UnderlyingDatatypePtr->size);
}
```

2.3.3 Attribute Management

For every object which can support attributes, the corresponding type must provide the functions that control how the attributes are resolved. There needs to be a function which can retrieve attributes (if any are defined), and another to set attributes (if setting attributes is allowed). Removing an attribute is a special case, for which the new value passed to the handler is `NULL`.

Python supports two pairs of attribute handlers; a type that supports attributes only needs to implement the functions for one pair. The difference is that one pair takes the name of the attribute as a `char*`, while the other accepts a `PyObject*`. Each type can use whichever pair makes more sense for the implementation's convenience.

```
getattrfunc  tp_getattr;        /* char * version */
setattrfunc  tp_setattr;
/* ... */
getattrofunc tp_getattro;       /* PyObject * version */
setattrofunc tp_setattro;
```

If accessing attributes of an object is always a simple operation (this will be explained shortly), there are generic implementations which can be used to provide the `PyObject*` version of the attribute management functions. The actual need for type-specific attribute handlers almost completely disappeared starting with Python 2.2, though there are many examples which have not been updated to use some of the new generic mechanism that is available.

Generic Attribute Management

Most extension types only use *simple* attributes. So, what makes the attributes simple? There are only a couple of conditions that must be met:

1. The name of the attributes must be known when `PyType_Ready()` is called.
2. No special processing is needed to record that an attribute was looked up or set, nor do actions need to be taken based on the value.

Note that this list does not place any restrictions on the values of the attributes, when the values are computed, or how relevant data is stored.

When `PyType_Ready()` is called, it uses three tables referenced by the type object to create *descriptor*s which are placed in the dictionary of the type object. Each descriptor controls access to one attribute of the instance object. Each of the tables is optional; if all three are `NULL`, instances of the type will only have attributes that are inherited from their base type, and should leave the `tp_getattro` and `tp_setattro` fields `NULL` as well, allowing the base type to handle attributes.

The tables are declared as three fields of the type object:

```
struct PyMethodDef *tp_methods;
struct PyMemberDef *tp_members;
struct PyGetSetDef *tp_getset;
```

If `tp_methods` is not `NULL`, it must refer to an array of `PyMethodDef` structures. Each entry in the table is an instance of this structure:

```
typedef struct PyMethodDef {
    const char  *ml_name;       /* method name */
    PyCFunction  ml_meth;       /* implementation function */
    int          ml_flags;      /* flags */
    const char  *ml_doc;        /* docstring */
} PyMethodDef;
```

One entry should be defined for each method provided by the type; no entries are needed for methods inherited from a base type. One additional entry is needed at the end; it is a sentinel that marks the end of the array. The `ml_name` field of the sentinel must be `NULL`.

The second table is used to define attributes which map directly to data stored in the instance. A variety of primitive C types are supported, and access may be read-only or read-write. The structures in the table are defined as:

```
typedef struct PyMemberDef {
    const char *name;
    int         type;
    int         offset;
    int         flags;
    const char *doc;
} PyMemberDef;
```

For each entry in the table, a *descriptor* will be constructed and added to the type which will be able to extract a value from the instance structure. The `type` field should contain one of the type codes defined in the `structmember.h` header; the value will be used to determine how to convert Python values to and from C values. The `flags` field is used to store flags which control how the attribute can be accessed.

The following flag constants are defined in `structmember.h`; they may be combined using bitwise-OR.

Constant	Meaning
READONLY	Never writable.
READ_RESTRICTED	Not readable in restricted mode.
WRITE_RESTRICTED	Not writable in restricted mode.
RESTRICTED	Not readable or writable in restricted mode.

An interesting advantage of using the tp_members table to build descriptors that are used at runtime is that any attribute defined this way can have an associated doc string simply by providing the text in the table. An application can use the introspection API to retrieve the descriptor from the class object, and get the doc string using its __doc__ attribute.

As with the tp_methods table, a sentinel entry with a name value of NULL is required.

Type-specific Attribute Management

For simplicity, only the char* version will be demonstrated here; the type of the name parameter is the only difference between the char* and PyObject* flavors of the interface. This example effectively does the same thing as the generic example above, but does not use the generic support added in Python 2.2. It explains how the handler functions are called, so that if you do need to extend their functionality, you'll understand what needs to be done.

The tp_getattr handler is called when the object requires an attribute look-up. It is called in the same situations where the __getattr__() method of a class would be called.

Here is an example:

```
static PyObject *
newdatatype_getattr(newdatatypeobject *obj, char *name)
{
    if (strcmp(name, "data") == 0)
    {
        return PyLong_FromLong(obj->data);
    }

    PyErr_Format(PyExc_AttributeError,
                 "'%.50s' object has no attribute '%.400s'",
                 tp->tp_name, name);
    return NULL;
}
```

The tp_setattr handler is called when the __setattr__() or __delattr__() method of a class instance would be called. When an attribute should be deleted, the third parameter will be NULL. Here is an example that simply raises an exception; if this were really all you wanted, the tp_setattr handler should be set to NULL.

```
static int
newdatatype_setattr(newdatatypeobject *obj, char *name, PyObject *v)
{
    PyErr_Format(PyExc_RuntimeError, "Read-only attribute: %s", name);
    return -1;
}
```

2.3.4 Object Comparison

```
richcmpfunc tp_richcompare;
```

The `tp_richcompare` handler is called when comparisons are needed. It is analogous to the rich comparison methods, like `__lt__()`, and also called by `PyObject_RichCompare()` and `PyObject_RichCompareBool()`.

This function is called with two Python objects and the operator as arguments, where the operator is one of `Py_EQ`, `Py_NE`, `Py_LE`, `Py_GT`, `Py_LT` or `Py_GT`. It should compare the two objects with respect to the specified operator and return `Py_True` or `Py_False` if the comparison is successful, `Py_NotImplemented` to indicate that comparison is not implemented and the other object's comparison method should be tried, or `NULL` if an exception was set.

Here is a sample implementation, for a datatype that is considered equal if the size of an internal pointer is equal:

```
static PyObject *
newdatatype_richcmp(PyObject *obj1, PyObject *obj2, int op)
{
    PyObject *result;
    int c, size1, size2;

    /* code to make sure that both arguments are of type
       newdatatype omitted */

    size1 = obj1->obj_UnderlyingDatatypePtr->size;
    size2 = obj2->obj_UnderlyingDatatypePtr->size;

    switch (op) {
    case Py_LT: c = size1 <  size2; break;
    case Py_LE: c = size1 <= size2; break;
    case Py_EQ: c = size1 == size2; break;
    case Py_NE: c = size1 != size2; break;
    case Py_GT: c = size1 >  size2; break;
    case Py_GE: c = size1 >= size2; break;
    }
    result = c ? Py_True : Py_False;
    Py_INCREF(result);
    return result;
 }
```

2.3.5 Abstract Protocol Support

Python supports a variety of *abstract* 'protocols;' the specific interfaces provided to use these interfaces are documented in abstract.

A number of these abstract interfaces were defined early in the development of the Python implementation. In particular, the number, mapping, and sequence protocols have been part of Python since the beginning. Other protocols have been added over time. For protocols which depend on several handler routines from the type implementation, the older protocols have been defined as optional blocks of handlers referenced by the type object. For newer protocols there are additional slots in the main type object, with a flag bit being set to indicate that the slots are present and should be checked by the interpreter. (The flag bit does not indicate that the slot values are non-`NULL`. The flag may be set to indicate the presence of a slot, but a slot may still be unfilled.)

```
PyNumberMethods   *tp_as_number;
PySequenceMethods *tp_as_sequence;
PyMappingMethods  *tp_as_mapping;
```

If you wish your object to be able to act like a number, a sequence, or a mapping object, then you place the address of a structure that implements the C type `PyNumberMethods`, `PySequenceMethods`, or `PyMappingMethods`, respectively. It is up to you to fill in this structure with appropriate values. You can find examples of the use of each of these in the `Objects` directory of the Python source distribution.

```
hashfunc tp_hash;
```

This function, if you choose to provide it, should return a hash number for an instance of your data type. Here is a simple example:

```
static Py_hash_t
newdatatype_hash(newdatatypeobject *obj)
{
    Py_hash_t result;
    result = obj->some_size + 32767 * obj->some_number;
    if (result == -1)
       result = -2;
    return result;
}
```

`Py_hash_t` is a signed integer type with a platform-varying width. Returning `-1` from `tp_hash` indicates an error, which is why you should be careful to avoid returning it when hash computation is successful, as seen above.

```
ternaryfunc tp_call;
```

This function is called when an instance of your data type is "called", for example, if `obj1` is an instance of your data type and the Python script contains `obj1('hello')`, the `tp_call` handler is invoked.

This function takes three arguments:

1. *self* is the instance of the data type which is the subject of the call. If the call is `obj1('hello')`, then *self* is `obj1`.
2. *args* is a tuple containing the arguments to the call. You can use `PyArg_ParseTuple()` to extract the arguments.
3. *kwds* is a dictionary of keyword arguments that were passed. If this is non-`NULL` and you support keyword arguments, use `PyArg_ParseTupleAndKeywords()` to extract the arguments. If you do not want to support keyword arguments and this is non-`NULL`, raise a `TypeError` with a message saying that keyword arguments are not supported.

Here is a toy `tp_call` implementation:

```
static PyObject *
newdatatype_call(newdatatypeobject *self, PyObject *args, PyObject *kwds)
{
    PyObject *result;
    const char *arg1;
    const char *arg2;
    const char *arg3;

    if (!PyArg_ParseTuple(args, "sss:call", &arg1, &arg2, &arg3)) {
        return NULL;
    }
    result = PyUnicode_FromFormat(
        "Returning -- value: [%d] arg1: [%s] arg2: [%s] arg3: [%s]\n",
        obj->obj_UnderlyingDatatypePtr->size,
        arg1, arg2, arg3);
```

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```
    return result;
}
```

```
/* Iterators */
getiterfunc tp_iter;
iternextfunc tp_iternext;
```

These functions provide support for the iterator protocol. Both handlers take exactly one parameter, the instance for which they are being called, and return a new reference. In the case of an error, they should set an exception and return `NULL`. `tp_iter` corresponds to the Python `__iter__()` method, while `tp_iternext` corresponds to the Python `__next__()` method.

Any *iterable* object must implement the `tp_iter` handler, which must return an *iterator* object. Here the same guidelines apply as for Python classes:

- For collections (such as lists and tuples) which can support multiple independent iterators, a new iterator should be created and returned by each call to `tp_iter`.
- Objects which can only be iterated over once (usually due to side effects of iteration, such as file objects) can implement `tp_iter` by returning a new reference to themselves – and should also therefore implement the `tp_iternext` handler.

Any *iterator* object should implement both `tp_iter` and `tp_iternext`. An iterator's `tp_iter` handler should return a new reference to the iterator. Its `tp_iternext` handler should return a new reference to the next object in the iteration, if there is one. If the iteration has reached the end, `tp_iternext` may return `NULL` without setting an exception, or it may set `StopIteration` *in addition* to returning `NULL`; avoiding the exception can yield slightly better performance. If an actual error occurs, `tp_iternext` should always set an exception and return `NULL`.

2.3.6 Weak Reference Support

One of the goals of Python's weak reference implementation is to allow any type to participate in the weak reference mechanism without incurring the overhead on performance-critical objects (such as numbers).

See also:

Documentation for the `weakref` module.

For an object to be weakly referencable, the extension type must do two things:

1. Include a `PyObject*` field in the C object structure dedicated to the weak reference mechanism. The object's constructor should leave it `NULL` (which is automatic when using the default `tp_alloc`).
2. Set the `tp_weaklistoffset` type member to the offset of the aforementioned field in the C object structure, so that the interpreter knows how to access and modify that field.

Concretely, here is how a trivial object structure would be augmented with the required field:

```
typedef struct {
    PyObject_HEAD
    PyObject *weakreflist;  /* List of weak references */
} TrivialObject;
```

And the corresponding member in the statically-declared type object:

```
static PyTypeObject TrivialType = {
    PyVarObject_HEAD_INIT(NULL, 0)
    /* ... other members omitted for brevity ... */
```

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```
    .tp_weaklistoffset = offsetof(TrivialObject, weakreflist),
};
```

The only further addition is that `tp_dealloc` needs to clear any weak references (by calling `PyObject_ClearWeakRefs()`) if the field is non-`NULL`:

```
static void
Trivial_dealloc(TrivialObject *self)
{
    /* Clear weakrefs first before calling any destructors */
    if (self->weakreflist != NULL)
        PyObject_ClearWeakRefs((PyObject *) self);
    /* ... remainder of destruction code omitted for brevity ... */
    Py_TYPE(self)->tp_free((PyObject *) self);
}
```

2.3.7 More Suggestions

In order to learn how to implement any specific method for your new data type, get the *CPython* source code. Go to the `Objects` directory, then search the C source files for `tp_` plus the function you want (for example, `tp_richcompare`). You will find examples of the function you want to implement.

When you need to verify that an object is a concrete instance of the type you are implementing, use the `PyObject_TypeCheck()` function. A sample of its use might be something like the following:

```
if (!PyObject_TypeCheck(some_object, &MyType)) {
    PyErr_SetString(PyExc_TypeError, "arg #1 not a mything");
    return NULL;
}
```

See also:

Download CPython source releases. https://www.python.org/downloads/source/

The CPython project on GitHub, where the CPython source code is developed. https://github.com/python/cpython

2.4 Building C and C++ Extensions

A C extension for CPython is a shared library (e.g. a `.so` file on Linux, `.pyd` on Windows), which exports an *initialization function*.

To be importable, the shared library must be available on `PYTHONPATH`, and must be named after the module name, with an appropriate extension. When using distutils, the correct filename is generated automatically.

The initialization function has the signature:

PyObject* **`PyInit_modulename`**(void)

It returns either a fully-initialized module, or a `PyModuleDef` instance. See initializing-modules for details.

For modules with ASCII-only names, the function must be named `PyInit_<modulename>`, with `<modulename>` replaced by the name of the module. When using multi-phase-initialization, non-ASCII module names are allowed. In this case, the initialization function name is `PyInitU_<modulename>`, with `<modulename>` encoded using Python's *punycode* encoding with hyphens replaced by underscores. In Python:

```
def initfunc_name(name):
    try:
        suffix = b'_' + name.encode('ascii')
    except UnicodeEncodeError:
        suffix = b'U_' + name.encode('punycode').replace(b'-', b'_')
    return b'PyInit' + suffix
```

It is possible to export multiple modules from a single shared library by defining multiple initialization functions. However, importing them requires using symbolic links or a custom importer, because by default only the function corresponding to the filename is found. See the *"Multiple modules in one library"* section in **PEP 489** for details.

2.4.1 Building C and C++ Extensions with distutils

Extension modules can be built using distutils, which is included in Python. Since distutils also supports creation of binary packages, users don't necessarily need a compiler and distutils to install the extension.

A distutils package contains a driver script, `setup.py`. This is a plain Python file, which, in the most simple case, could look like this:

```
from distutils.core import setup, Extension

module1 = Extension('demo',
                    sources = ['demo.c'])

setup (name = 'PackageName',
       version = '1.0',
       description = 'This is a demo package',
       ext_modules = [module1])
```

With this `setup.py`, and a file `demo.c`, running

```
python setup.py build
```

will compile `demo.c`, and produce an extension module named `demo` in the `build` directory. Depending on the system, the module file will end up in a subdirectory `build/lib.system`, and may have a name like `demo.so` or `demo.pyd`.

In the `setup.py`, all execution is performed by calling the `setup` function. This takes a variable number of keyword arguments, of which the example above uses only a subset. Specifically, the example specifies meta-information to build packages, and it specifies the contents of the package. Normally, a package will contain additional modules, like Python source modules, documentation, subpackages, etc. Please refer to the distutils documentation in distutils-index to learn more about the features of distutils; this section explains building extension modules only.

It is common to pre-compute arguments to `setup()`, to better structure the driver script. In the example above, the `ext_modules` argument to `setup()` is a list of extension modules, each of which is an instance of the `Extension`. In the example, the instance defines an extension named `demo` which is build by compiling a single source file, `demo.c`.

In many cases, building an extension is more complex, since additional preprocessor defines and libraries may be needed. This is demonstrated in the example below.

```
from distutils.core import setup, Extension

module1 = Extension('demo',
                    define_macros = [('MAJOR_VERSION', '1'),
                                     ('MINOR_VERSION', '0')],
                    include_dirs = ['/usr/local/include'],
```

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```
                    libraries = ['tcl83'],
                    library_dirs = ['/usr/local/lib'],
                    sources = ['demo.c'])

setup (name = 'PackageName',
       version = '1.0',
       description = 'This is a demo package',
       author = 'Martin v. Loewis',
       author_email = 'martin@v.loewis.de',
       url = 'https://docs.python.org/extending/building',
       long_description = '''
This is really just a demo package.
''',
       ext_modules = [module1])
```

In this example, `setup()` is called with additional meta-information, which is recommended when distribution packages have to be built. For the extension itself, it specifies preprocessor defines, include directories, library directories, and libraries. Depending on the compiler, distutils passes this information in different ways to the compiler. For example, on Unix, this may result in the compilation commands

```
gcc -DNDEBUG -g -O3 -Wall -Wstrict-prototypes -fPIC -DMAJOR_VERSION=1 -DMINOR_
↪VERSION=0 -I/usr/local/include -I/usr/local/include/python2.2 -c demo.c -o build/
↪temp.linux-i686-2.2/demo.o

gcc -shared build/temp.linux-i686-2.2/demo.o -L/usr/local/lib -ltcl83 -o build/lib.
↪linux-i686-2.2/demo.so
```

These lines are for demonstration purposes only; distutils users should trust that distutils gets the invocations right.

2.4.2 Distributing your extension modules

When an extension has been successfully built, there are three ways to use it.

End-users will typically want to install the module, they do so by running

```
python setup.py install
```

Module maintainers should produce source packages; to do so, they run

```
python setup.py sdist
```

In some cases, additional files need to be included in a source distribution; this is done through a `MANIFEST.in` file; see manifest for details.

If the source distribution has been built successfully, maintainers can also create binary distributions. Depending on the platform, one of the following commands can be used to do so.

```
python setup.py bdist_wininst
python setup.py bdist_rpm
python setup.py bdist_dumb
```

2.5 Building C and C++ Extensions on Windows

This chapter briefly explains how to create a Windows extension module for Python using Microsoft Visual C++, and follows with more detailed background information on how it works. The explanatory material is useful for both the Windows programmer learning to build Python extensions and the Unix programmer interested in producing software which can be successfully built on both Unix and Windows.

Module authors are encouraged to use the distutils approach for building extension modules, instead of the one described in this section. You will still need the C compiler that was used to build Python; typically Microsoft Visual C++.

Note: This chapter mentions a number of filenames that include an encoded Python version number. These filenames are represented with the version number shown as `XY`; in practice, `'X'` will be the major version number and `'Y'` will be the minor version number of the Python release you're working with. For example, if you are using Python 2.2.1, `XY` will actually be `22`.

2.5.1 A Cookbook Approach

There are two approaches to building extension modules on Windows, just as there are on Unix: use the `distutils` package to control the build process, or do things manually. The distutils approach works well for most extensions; documentation on using `distutils` to build and package extension modules is available in distutils-index. If you find you really need to do things manually, it may be instructive to study the project file for the winsound standard library module.

2.5.2 Differences Between Unix and Windows

Unix and Windows use completely different paradigms for run-time loading of code. Before you try to build a module that can be dynamically loaded, be aware of how your system works.

In Unix, a shared object (`.so`) file contains code to be used by the program, and also the names of functions and data that it expects to find in the program. When the file is joined to the program, all references to those functions and data in the file's code are changed to point to the actual locations in the program where the functions and data are placed in memory. This is basically a link operation.

In Windows, a dynamic-link library (`.dll`) file has no dangling references. Instead, an access to functions or data goes through a lookup table. So the DLL code does not have to be fixed up at runtime to refer to the program's memory; instead, the code already uses the DLL's lookup table, and the lookup table is modified at runtime to point to the functions and data.

In Unix, there is only one type of library file (`.a`) which contains code from several object files (`.o`). During the link step to create a shared object file (`.so`), the linker may find that it doesn't know where an identifier is defined. The linker will look for it in the object files in the libraries; if it finds it, it will include all the code from that object file.

In Windows, there are two types of library, a static library and an import library (both called `.lib`). A static library is like a Unix `.a` file; it contains code to be included as necessary. An import library is basically used only to reassure the linker that a certain identifier is legal, and will be present in the program when the DLL is loaded. So the linker uses the information from the import library to build the lookup table for using identifiers that are not included in the DLL. When an application or a DLL is linked, an import library may be generated, which will need to be used for all future DLLs that depend on the symbols in the application or DLL.

Suppose you are building two dynamic-load modules, B and C, which should share another block of code A. On Unix, you would *not* pass `A.a` to the linker for `B.so` and `C.so`; that would cause it to be included twice, so that B and C would each have their own copy. In Windows, building `A.dll` will also build `A.lib`. You *do* pass `A.lib` to the linker for B and C. `A.lib` does not contain code; it just contains information which will be used at runtime to access A's code.

In Windows, using an import library is sort of like using `import spam`; it gives you access to spam's names, but does not create a separate copy. On Unix, linking with a library is more like `from spam import *`; it does create a separate copy.

2.5.3 Using DLLs in Practice

Windows Python is built in Microsoft Visual C++; using other compilers may or may not work (though Borland seems to). The rest of this section is MSVC++ specific.

When creating DLLs in Windows, you must pass `pythonXY.lib` to the linker. To build two DLLs, spam and ni (which uses C functions found in spam), you could use these commands:

```
cl /LD /I/python/include spam.c ../libs/pythonXY.lib
cl /LD /I/python/include ni.c spam.lib ../libs/pythonXY.lib
```

The first command created three files: `spam.obj`, `spam.dll` and `spam.lib`. `Spam.dll` does not contain any Python functions (such as `PyArg_ParseTuple()`), but it does know how to find the Python code thanks to `pythonXY.lib`.

The second command created `ni.dll` (and `.obj` and `.lib`), which knows how to find the necessary functions from spam, and also from the Python executable.

Not every identifier is exported to the lookup table. If you want any other modules (including Python) to be able to see your identifiers, you have to say `_declspec(dllexport)`, as in `void _declspec(dllexport) initspam(void)` or `PyObject _declspec(dllexport) *NiGetSpamData(void)`.

Developer Studio will throw in a lot of import libraries that you do not really need, adding about 100K to your executable. To get rid of them, use the Project Settings dialog, Link tab, to specify *ignore default libraries*. Add the correct `msvcrtxx.lib` to the list of libraries.

CHAPTER

THREE

EMBEDDING THE CPYTHON RUNTIME IN A LARGER APPLICATION

Sometimes, rather than creating an extension that runs inside the Python interpreter as the main application, it is desirable to instead embed the CPython runtime inside a larger application. This section covers some of the details involved in doing that successfully.

3.1 Embedding Python in Another Application

The previous chapters discussed how to extend Python, that is, how to extend the functionality of Python by attaching a library of C functions to it. It is also possible to do it the other way around: enrich your C/C++ application by embedding Python in it. Embedding provides your application with the ability to implement some of the functionality of your application in Python rather than C or C++. This can be used for many purposes; one example would be to allow users to tailor the application to their needs by writing some scripts in Python. You can also use it yourself if some of the functionality can be written in Python more easily.

Embedding Python is similar to extending it, but not quite. The difference is that when you extend Python, the main program of the application is still the Python interpreter, while if you embed Python, the main program may have nothing to do with Python — instead, some parts of the application occasionally call the Python interpreter to run some Python code.

So if you are embedding Python, you are providing your own main program. One of the things this main program has to do is initialize the Python interpreter. At the very least, you have to call the function `Py_Initialize()`. There are optional calls to pass command line arguments to Python. Then later you can call the interpreter from any part of the application.

There are several different ways to call the interpreter: you can pass a string containing Python statements to `PyRun_SimpleString()`, or you can pass a stdio file pointer and a file name (for identification in error messages only) to `PyRun_SimpleFile()`. You can also call the lower-level operations described in the previous chapters to construct and use Python objects.

See also:

c-api-index The details of Python's C interface are given in this manual. A great deal of necessary information can be found here.

3.1.1 Very High Level Embedding

The simplest form of embedding Python is the use of the very high level interface. This interface is intended to execute a Python script without needing to interact with the application directly. This can for example be used to perform some operation on a file.

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>

int
main(int argc, char *argv[])
{
    wchar_t *program = Py_DecodeLocale(argv[0], NULL);
    if (program == NULL) {
        fprintf(stderr, "Fatal error: cannot decode argv[0]\n");
        exit(1);
    }
    Py_SetProgramName(program);  /* optional but recommended */
    Py_Initialize();
    PyRun_SimpleString("from time import time,ctime\n"
                       "print('Today is', ctime(time()))\n");
    if (Py_FinalizeEx() < 0) {
        exit(120);
    }
    PyMem_RawFree(program);
    return 0;
}
```

The `Py_SetProgramName()` function should be called before `Py_Initialize()` to inform the interpreter about paths to Python run-time libraries. Next, the Python interpreter is initialized with `Py_Initialize()`, followed by the execution of a hard-coded Python script that prints the date and time. Afterwards, the `Py_FinalizeEx()` call shuts the interpreter down, followed by the end of the program. In a real program, you may want to get the Python script from another source, perhaps a text-editor routine, a file, or a database. Getting the Python code from a file can better be done by using the `PyRun_SimpleFile()` function, which saves you the trouble of allocating memory space and loading the file contents.

3.1.2 Beyond Very High Level Embedding: An overview

The high level interface gives you the ability to execute arbitrary pieces of Python code from your application, but exchanging data values is quite cumbersome to say the least. If you want that, you should use lower level calls. At the cost of having to write more C code, you can achieve almost anything.

It should be noted that extending Python and embedding Python is quite the same activity, despite the different intent. Most topics discussed in the previous chapters are still valid. To show this, consider what the extension code from Python to C really does:

1. Convert data values from Python to C,
2. Perform a function call to a C routine using the converted values, and
3. Convert the data values from the call from C to Python.

When embedding Python, the interface code does:

1. Convert data values from C to Python,
2. Perform a function call to a Python interface routine using the converted values, and
3. Convert the data values from the call from Python to C.

As you can see, the data conversion steps are simply swapped to accommodate the different direction of the cross-language transfer. The only difference is the routine that you call between both data conversions. When extending, you call a C routine, when embedding, you call a Python routine.

This chapter will not discuss how to convert data from Python to C and vice versa. Also, proper use of references and dealing with errors is assumed to be understood. Since these aspects do not differ from extending the interpreter, you can refer to earlier chapters for the required information.

3.1.3 Pure Embedding

The first program aims to execute a function in a Python script. Like in the section about the very high level interface, the Python interpreter does not directly interact with the application (but that will change in the next section).

The code to run a function defined in a Python script is:

```
#define PY_SSIZE_T_CLEAN
#include <Python.h>

int
main(int argc, char *argv[])
{
    PyObject *pName, *pModule, *pFunc;
    PyObject *pArgs, *pValue;
    int i;

    if (argc < 3) {
        fprintf(stderr,"Usage: call pythonfile funcname [args]\n");
        return 1;
    }

    Py_Initialize();
    pName = PyUnicode_DecodeFSDefault(argv[1]);
    /* Error checking of pName left out */

    pModule = PyImport_Import(pName);
    Py_DECREF(pName);

    if (pModule != NULL) {
        pFunc = PyObject_GetAttrString(pModule, argv[2]);
        /* pFunc is a new reference */

        if (pFunc && PyCallable_Check(pFunc)) {
            pArgs = PyTuple_New(argc - 3);
            for (i = 0; i < argc - 3; ++i) {
                pValue = PyLong_FromLong(atoi(argv[i + 3]));
                if (!pValue) {
                    Py_DECREF(pArgs);
                    Py_DECREF(pModule);
                    fprintf(stderr, "Cannot convert argument\n");
                    return 1;
                }
                /* pValue reference stolen here: */
                PyTuple_SetItem(pArgs, i, pValue);
            }
            pValue = PyObject_CallObject(pFunc, pArgs);
            Py_DECREF(pArgs);
            if (pValue != NULL) {
```

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```
                printf("Result of call: %ld\n", PyLong_AsLong(pValue));
                Py_DECREF(pValue);
            }
            else {
                Py_DECREF(pFunc);
                Py_DECREF(pModule);
                PyErr_Print();
                fprintf(stderr,"Call failed\n");
                return 1;
            }
        }
        else {
            if (PyErr_Occurred())
                PyErr_Print();
            fprintf(stderr, "Cannot find function \"%s\"\n", argv[2]);
        }
        Py_XDECREF(pFunc);
        Py_DECREF(pModule);
    }
    else {
        PyErr_Print();
        fprintf(stderr, "Failed to load \"%s\"\n", argv[1]);
        return 1;
    }
    if (Py_FinalizeEx() < 0) {
        return 120;
    }
    return 0;
}
```

This code loads a Python script using `argv[1]`, and calls the function named in `argv[2]`. Its integer arguments are the other values of the `argv` array. If you *compile and link* this program (let's call the finished executable **`call`**), and use it to execute a Python script, such as:

```
def multiply(a,b):
    print("Will compute", a, "times", b)
    c = 0
    for i in range(0, a):
        c = c + b
    return c
```

then the result should be:

```
$ call multiply multiply 3 2
Will compute 3 times 2
Result of call: 6
```

Although the program is quite large for its functionality, most of the code is for data conversion between Python and C, and for error reporting. The interesting part with respect to embedding Python starts with

```
Py_Initialize();
pName = PyUnicode_DecodeFSDefault(argv[1]);
/* Error checking of pName left out */
pModule = PyImport_Import(pName);
```

After initializing the interpreter, the script is loaded using `PyImport_Import()`. This routine needs a Python string as its argument, which is constructed using the `PyUnicode_FromString()` data conversion routine.

```
pFunc = PyObject_GetAttrString(pModule, argv[2]);
/* pFunc is a new reference */

if (pFunc && PyCallable_Check(pFunc)) {
    ...
}
Py_XDECREF(pFunc);
```

Once the script is loaded, the name we're looking for is retrieved using `PyObject_GetAttrString()`. If the name exists, and the object returned is callable, you can safely assume that it is a function. The program then proceeds by constructing a tuple of arguments as normal. The call to the Python function is then made with:

```
pValue = PyObject_CallObject(pFunc, pArgs);
```

Upon return of the function, `pValue` is either `NULL` or it contains a reference to the return value of the function. Be sure to release the reference after examining the value.

3.1.4 Extending Embedded Python

Until now, the embedded Python interpreter had no access to functionality from the application itself. The Python API allows this by extending the embedded interpreter. That is, the embedded interpreter gets extended with routines provided by the application. While it sounds complex, it is not so bad. Simply forget for a while that the application starts the Python interpreter. Instead, consider the application to be a set of subroutines, and write some glue code that gives Python access to those routines, just like you would write a normal Python extension. For example:

```
static int numargs=0;

/* Return the number of arguments of the application command line */
static PyObject*
emb_numargs(PyObject *self, PyObject *args)
{
    if(!PyArg_ParseTuple(args, ":numargs"))
        return NULL;
    return PyLong_FromLong(numargs);
}

static PyMethodDef EmbMethods[] = {
    {"numargs", emb_numargs, METH_VARARGS,
     "Return the number of arguments received by the process."},
    {NULL, NULL, 0, NULL}
};

static PyModuleDef EmbModule = {
    PyModuleDef_HEAD_INIT, "emb", NULL, -1, EmbMethods,
    NULL, NULL, NULL, NULL
};

static PyObject*
PyInit_emb(void)
{
    return PyModule_Create(&EmbModule);
}
```

Insert the above code just above the `main()` function. Also, insert the following two statements before the call to `Py_Initialize()`:

```
numargs = argc;
PyImport_AppendInittab("emb", &PyInit_emb);
```

These two lines initialize the `numargs` variable, and make the `emb.numargs()` function accessible to the embedded Python interpreter. With these extensions, the Python script can do things like

```
import emb
print("Number of arguments", emb.numargs())
```

In a real application, the methods will expose an API of the application to Python.

3.1.5 Embedding Python in C++

It is also possible to embed Python in a C++ program; precisely how this is done will depend on the details of the C++ system used; in general you will need to write the main program in C++, and use the C++ compiler to compile and link your program. There is no need to recompile Python itself using C++.

3.1.6 Compiling and Linking under Unix-like systems

It is not necessarily trivial to find the right flags to pass to your compiler (and linker) in order to embed the Python interpreter into your application, particularly because Python needs to load library modules implemented as C dynamic extensions (`.so` files) linked against it.

To find out the required compiler and linker flags, you can execute the `python`*`X.Y`*`-config` script which is generated as part of the installation process (a `python3-config` script may also be available). This script has several options, of which the following will be directly useful to you:

- `pythonX.Y-config --cflags` will give you the recommended flags when compiling:

```
$ /opt/bin/python3.4-config --cflags
-I/opt/include/python3.4m -I/opt/include/python3.4m -DNDEBUG -g -fwrapv -O3 -Wall␣
↪-Wstrict-prototypes
```

- `pythonX.Y-config --ldflags` will give you the recommended flags when linking:

```
$ /opt/bin/python3.4-config --ldflags
-L/opt/lib/python3.4/config-3.4m -lpthread -ldl -lutil -lm -lpython3.4m -Xlinker -
↪export-dynamic
```

Note: To avoid confusion between several Python installations (and especially between the system Python and your own compiled Python), it is recommended that you use the absolute path to `python`*`X.Y`*`-config`, as in the above example.

If this procedure doesn't work for you (it is not guaranteed to work for all Unix-like platforms; however, we welcome bug reports) you will have to read your system's documentation about dynamic linking and/or examine Python's `Makefile` (use `sysconfig.get_makefile_filename()` to find its location) and compilation options. In this case, the `sysconfig` module is a useful tool to programmatically extract the configuration values that you will want to combine together. For example:

```
>>> import sysconfig
>>> sysconfig.get_config_var('LIBS')
'-lpthread -ldl  -lutil'
>>> sysconfig.get_config_var('LINKFORSHARED')
'-Xlinker -export-dynamic'
```

APPENDIX

A

GLOSSARY

>>> The default Python prompt of the interactive shell. Often seen for code examples which can be executed interactively in the interpreter.

... Can refer to:

- The default Python prompt of the interactive shell when entering the code for an indented code block, when within a pair of matching left and right delimiters (parentheses, square brackets, curly braces or triple quotes), or after specifying a decorator.
- The `Ellipsis` built-in constant.

2to3 A tool that tries to convert Python 2.x code to Python 3.x code by handling most of the incompatibilities which can be detected by parsing the source and traversing the parse tree.

2to3 is available in the standard library as `lib2to3`; a standalone entry point is provided as `Tools/scripts/2to3`. See 2to3-reference.

abstract base class Abstract base classes complement *duck-typing* by providing a way to define interfaces when other techniques like `hasattr()` would be clumsy or subtly wrong (for example with magic methods). ABCs introduce virtual subclasses, which are classes that don't inherit from a class but are still recognized by `isinstance()` and `issubclass()`; see the `abc` module documentation. Python comes with many built-in ABCs for data structures (in the `collections.abc` module), numbers (in the `numbers` module), streams (in the `io` module), import finders and loaders (in the `importlib.abc` module). You can create your own ABCs with the `abc` module.

annotation A label associated with a variable, a class attribute or a function parameter or return value, used by convention as a *type hint*.

Annotations of local variables cannot be accessed at runtime, but annotations of global variables, class attributes, and functions are stored in the `__annotations__` special attribute of modules, classes, and functions, respectively.

See *variable annotation*, *function annotation*, **PEP 484** and **PEP 526**, which describe this functionality.

argument A value passed to a *function* (or *method*) when calling the function. There are two kinds of argument:

- *keyword argument*: an argument preceded by an identifier (e.g. `name=`) in a function call or passed as a value in a dictionary preceded by `**`. For example, `3` and `5` are both keyword arguments in the following calls to `complex()`:

```
complex(real=3, imag=5)
complex(**{'real': 3, 'imag': 5})
```

- *positional argument*: an argument that is not a keyword argument. Positional arguments can appear at the beginning of an argument list and/or be passed as elements of an *iterable* preceded by `*`. For example, `3` and `5` are both positional arguments in the following calls:

```
complex(3, 5)
complex(*(3, 5))
```

Arguments are assigned to the named local variables in a function body. See the calls section for the rules governing this assignment. Syntactically, any expression can be used to represent an argument; the evaluated value is assigned to the local variable.

See also the *parameter* glossary entry, the FAQ question on the difference between arguments and parameters, and **PEP 362**.

asynchronous context manager An object which controls the environment seen in an `async with` statement by defining `__aenter__()` and `__aexit__()` methods. Introduced by **PEP 492**.

asynchronous generator A function which returns an *asynchronous generator iterator*. It looks like a coroutine function defined with `async def` except that it contains `yield` expressions for producing a series of values usable in an `async for` loop.

Usually refers to an asynchronous generator function, but may refer to an *asynchronous generator iterator* in some contexts. In cases where the intended meaning isn't clear, using the full terms avoids ambiguity.

An asynchronous generator function may contain `await` expressions as well as `async for`, and `async with` statements.

asynchronous generator iterator An object created by a *asynchronous generator* function.

This is an *asynchronous iterator* which when called using the `__anext__()` method returns an awaitable object which will execute the body of the asynchronous generator function until the next `yield` expression.

Each `yield` temporarily suspends processing, remembering the location execution state (including local variables and pending try-statements). When the *asynchronous generator iterator* effectively resumes with another awaitable returned by `__anext__()`, it picks up where it left off. See **PEP 492** and **PEP 525**.

asynchronous iterable An object, that can be used in an `async for` statement. Must return an *asynchronous iterator* from its `__aiter__()` method. Introduced by **PEP 492**.

asynchronous iterator An object that implements the `__aiter__()` and `__anext__()` methods. `__anext__` must return an *awaitable* object. `async for` resolves the awaitables returned by an asynchronous iterator's `__anext__()` method until it raises a `StopAsyncIteration` exception. Introduced by **PEP 492**.

attribute A value associated with an object which is referenced by name using dotted expressions. For example, if an object *o* has an attribute *a* it would be referenced as *o.a*.

awaitable An object that can be used in an `await` expression. Can be a *coroutine* or an object with an `__await__()` method. See also **PEP 492**.

BDFL Benevolent Dictator For Life, a.k.a. Guido van Rossum, Python's creator.

binary file A *file object* able to read and write *bytes-like objects*. Examples of binary files are files opened in binary mode (`'rb'`, `'wb'` or `'rb+'`), `sys.stdin.buffer`, `sys.stdout.buffer`, and instances of `io.BytesIO` and `gzip.GzipFile`.

See also *text file* for a file object able to read and write `str` objects.

bytes-like object An object that supports the bufferobjects and can export a C-*contiguous* buffer. This includes all `bytes`, `bytearray`, and `array.array` objects, as well as many common `memoryview` objects. Bytes-like objects can be used for various operations that work with binary data; these include compression, saving to a binary file, and sending over a socket.

Some operations need the binary data to be mutable. The documentation often refers to these as "read-write bytes-like objects". Example mutable buffer objects include `bytearray` and a `memoryview` of a `bytearray`. Other operations require the binary data to be stored in immutable objects ("read-only bytes-like objects"); examples of these include `bytes` and a `memoryview` of a `bytes` object.

bytecode Python source code is compiled into bytecode, the internal representation of a Python program in the CPython interpreter. The bytecode is also cached in `.pyc` files so that executing the same file is faster the second time (recompilation from source to bytecode can be avoided). This "intermediate language" is said to run on a *virtual machine* that executes the machine code corresponding to each bytecode. Do note that bytecodes are not expected to work between different Python virtual machines, nor to be stable between Python releases.

A list of bytecode instructions can be found in the documentation for the dis module.

callback A subroutine function which is passed as an argument to be executed at some point in the future.

class A template for creating user-defined objects. Class definitions normally contain method definitions which operate on instances of the class.

class variable A variable defined in a class and intended to be modified only at class level (i.e., not in an instance of the class).

coercion The implicit conversion of an instance of one type to another during an operation which involves two arguments of the same type. For example, `int(3.15)` converts the floating point number to the integer `3`, but in `3+4.5`, each argument is of a different type (one int, one float), and both must be converted to the same type before they can be added or it will raise a `TypeError`. Without coercion, all arguments of even compatible types would have to be normalized to the same value by the programmer, e.g., `float(3)+4.5` rather than just `3+4.5`.

complex number An extension of the familiar real number system in which all numbers are expressed as a sum of a real part and an imaginary part. Imaginary numbers are real multiples of the imaginary unit (the square root of `-1`), often written `i` in mathematics or `j` in engineering. Python has built-in support for complex numbers, which are written with this latter notation; the imaginary part is written with a `j` suffix, e.g., `3+1j`. To get access to complex equivalents of the `math` module, use `cmath`. Use of complex numbers is a fairly advanced mathematical feature. If you're not aware of a need for them, it's almost certain you can safely ignore them.

context manager An object which controls the environment seen in a `with` statement by defining `__enter__()` and `__exit__()` methods. See **PEP 343**.

context variable A variable which can have different values depending on its context. This is similar to Thread-Local Storage in which each execution thread may have a different value for a variable. However, with context variables, there may be several contexts in one execution thread and the main usage for context variables is to keep track of variables in concurrent asynchronous tasks. See `contextvars`.

contiguous A buffer is considered contiguous exactly if it is either *C-contiguous* or *Fortran contiguous*. Zero-dimensional buffers are C and Fortran contiguous. In one-dimensional arrays, the items must be laid out in memory next to each other, in order of increasing indexes starting from zero. In multidimensional C-contiguous arrays, the last index varies the fastest when visiting items in order of memory address. However, in Fortran contiguous arrays, the first index varies the fastest.

coroutine Coroutines are a more generalized form of subroutines. Subroutines are entered at one point and exited at another point. Coroutines can be entered, exited, and resumed at many different points. They can be implemented with the `async def` statement. See also **PEP 492**.

coroutine function A function which returns a *coroutine* object. A coroutine function may be defined with the `async def` statement, and may contain `await`, `async for`, and `async with` keywords. These were introduced by **PEP 492**.

CPython The canonical implementation of the Python programming language, as distributed on python.org. The term "CPython" is used when necessary to distinguish this implementation from others such as Jython or IronPython.

decorator A function returning another function, usually applied as a function transformation using the `@wrapper` syntax. Common examples for decorators are `classmethod()` and `staticmethod()`.

The decorator syntax is merely syntactic sugar, the following two function definitions are semantically equivalent:

```
def f(...):
    ...
f = staticmethod(f)

@staticmethod
def f(...):
    ...
```

The same concept exists for classes, but is less commonly used there. See the documentation for function definitions and class definitions for more about decorators.

descriptor Any object which defines the methods `__get__()`, `__set__()`, or `__delete__()`. When a class attribute is a descriptor, its special binding behavior is triggered upon attribute lookup. Normally, using *a.b* to get, set or delete an attribute looks up the object named *b* in the class dictionary for *a*, but if *b* is a descriptor, the respective descriptor method gets called. Understanding descriptors is a key to a deep understanding of Python because they are the basis for many features including functions, methods, properties, class methods, static methods, and reference to super classes.

For more information about descriptors' methods, see descriptors.

dictionary An associative array, where arbitrary keys are mapped to values. The keys can be any object with `__hash__()` and `__eq__()` methods. Called a hash in Perl.

dictionary comprehension A compact way to process all or part of the elements in an iterable and return a dictionary with the results. `results = {n: n ** 2 for n in range(10)}` generates a dictionary containing key `n` mapped to value `n ** 2`. See comprehensions.

dictionary view The objects returned from `dict.keys()`, `dict.values()`, and `dict.items()` are called dictionary views. They provide a dynamic view on the dictionary's entries, which means that when the dictionary changes, the view reflects these changes. To force the dictionary view to become a full list use `list(dictview)`. See dict-views.

docstring A string literal which appears as the first expression in a class, function or module. While ignored when the suite is executed, it is recognized by the compiler and put into the `__doc__` attribute of the enclosing class, function or module. Since it is available via introspection, it is the canonical place for documentation of the object.

duck-typing A programming style which does not look at an object's type to determine if it has the right interface; instead, the method or attribute is simply called or used ("If it looks like a duck and quacks like a duck, it must be a duck.") By emphasizing interfaces rather than specific types, well-designed code improves its flexibility by allowing polymorphic substitution. Duck-typing avoids tests using `type()` or `isinstance()`. (Note, however, that duck-typing can be complemented with *abstract base classes*.) Instead, it typically employs `hasattr()` tests or *EAFP* programming.

EAFP Easier to ask for forgiveness than permission. This common Python coding style assumes the existence of valid keys or attributes and catches exceptions if the assumption proves false. This clean and fast style is characterized by the presence of many `try` and `except` statements. The technique contrasts with the *LBYL* style common to many other languages such as C.

expression A piece of syntax which can be evaluated to some value. In other words, an expression is an accumulation of expression elements like literals, names, attribute access, operators or function calls which all return a value. In contrast to many other languages, not all language constructs are expressions. There are also *statement*s which cannot be used as expressions, such as `while`. Assignments are also statements, not expressions.

extension module A module written in C or C++, using Python's C API to interact with the core and with user code.

f-string String literals prefixed with `'f'` or `'F'` are commonly called "f-strings" which is short for formatted string literals. See also **PEP 498**.

file object An object exposing a file-oriented API (with methods such as `read()` or `write()`) to an underlying resource. Depending on the way it was created, a file object can mediate access to a real on-disk file or to another

type of storage or communication device (for example standard input/output, in-memory buffers, sockets, pipes, etc.). File objects are also called *file-like objects* or *streams*.

There are actually three categories of file objects: raw *binary files*, buffered *binary files* and *text files*. Their interfaces are defined in the `io` module. The canonical way to create a file object is by using the `open()` function.

file-like object A synonym for *file object*.

finder An object that tries to find the *loader* for a module that is being imported.

Since Python 3.3, there are two types of finder: *meta path finders* for use with `sys.meta_path`, and *path entry finders* for use with `sys.path_hooks`.

See **PEP 302**, **PEP 420** and **PEP 451** for much more detail.

floor division Mathematical division that rounds down to nearest integer. The floor division operator is `//`. For example, the expression `11 // 4` evaluates to `2` in contrast to the `2.75` returned by float true division. Note that `(-11) // 4` is `-3` because that is `-2.75` rounded *downward*. See **PEP 238**.

function A series of statements which returns some value to a caller. It can also be passed zero or more *arguments* which may be used in the execution of the body. See also *parameter*, *method*, and the function section.

function annotation An *annotation* of a function parameter or return value.

Function annotations are usually used for *type hints*: for example, this function is expected to take two `int` arguments and is also expected to have an `int` return value:

```
def sum_two_numbers(a: int, b: int) -> int:
   return a + b
```

Function annotation syntax is explained in section function.

See *variable annotation* and **PEP 484**, which describe this functionality.

__future__ A pseudo-module which programmers can use to enable new language features which are not compatible with the current interpreter.

By importing the `__future__` module and evaluating its variables, you can see when a new feature was first added to the language and when it becomes the default:

```
>>> import __future__
>>> __future__.division
_Feature((2, 2, 0, 'alpha', 2), (3, 0, 0, 'alpha', 0), 8192)
```

garbage collection The process of freeing memory when it is not used anymore. Python performs garbage collection via reference counting and a cyclic garbage collector that is able to detect and break reference cycles. The garbage collector can be controlled using the `gc` module.

generator A function which returns a *generator iterator*. It looks like a normal function except that it contains `yield` expressions for producing a series of values usable in a for-loop or that can be retrieved one at a time with the `next()` function.

Usually refers to a generator function, but may refer to a *generator iterator* in some contexts. In cases where the intended meaning isn't clear, using the full terms avoids ambiguity.

generator iterator An object created by a *generator* function.

Each `yield` temporarily suspends processing, remembering the location execution state (including local variables and pending try-statements). When the *generator iterator* resumes, it picks up where it left off (in contrast to functions which start fresh on every invocation).

generator expression An expression that returns an iterator. It looks like a normal expression followed by a `for` clause defining a loop variable, range, and an optional `if` clause. The combined expression generates values for an enclosing function:

```
>>> sum(i*i for i in range(10))         # sum of squares 0, 1, 4, ... 81
285
```

generic function A function composed of multiple functions implementing the same operation for different types. Which implementation should be used during a call is determined by the dispatch algorithm.

See also the *single dispatch* glossary entry, the `functools.singledispatch()` decorator, and **PEP 443**.

GIL See *global interpreter lock*.

global interpreter lock The mechanism used by the *CPython* interpreter to assure that only one thread executes Python *bytecode* at a time. This simplifies the CPython implementation by making the object model (including critical built-in types such as `dict`) implicitly safe against concurrent access. Locking the entire interpreter makes it easier for the interpreter to be multi-threaded, at the expense of much of the parallelism afforded by multi-processor machines.

However, some extension modules, either standard or third-party, are designed so as to release the GIL when doing computationally-intensive tasks such as compression or hashing. Also, the GIL is always released when doing I/O.

Past efforts to create a "free-threaded" interpreter (one which locks shared data at a much finer granularity) have not been successful because performance suffered in the common single-processor case. It is believed that overcoming this performance issue would make the implementation much more complicated and therefore costlier to maintain.

hash-based pyc A bytecode cache file that uses the hash rather than the last-modified time of the corresponding source file to determine its validity. See pyc-invalidation.

hashable An object is *hashable* if it has a hash value which never changes during its lifetime (it needs a `__hash__()` method), and can be compared to other objects (it needs an `__eq__()` method). Hashable objects which compare equal must have the same hash value.

Hashability makes an object usable as a dictionary key and a set member, because these data structures use the hash value internally.

Most of Python's immutable built-in objects are hashable; mutable containers (such as lists or dictionaries) are not; immutable containers (such as tuples and frozensets) are only hashable if their elements are hashable. Objects which are instances of user-defined classes are hashable by default. They all compare unequal (except with themselves), and their hash value is derived from their `id()`.

IDLE An Integrated Development Environment for Python. IDLE is a basic editor and interpreter environment which ships with the standard distribution of Python.

immutable An object with a fixed value. Immutable objects include numbers, strings and tuples. Such an object cannot be altered. A new object has to be created if a different value has to be stored. They play an important role in places where a constant hash value is needed, for example as a key in a dictionary.

import path A list of locations (or *path entries*) that are searched by the *path based finder* for modules to import. During import, this list of locations usually comes from `sys.path`, but for subpackages it may also come from the parent package's `__path__` attribute.

importing The process by which Python code in one module is made available to Python code in another module.

importer An object that both finds and loads a module; both a *finder* and *loader* object.

interactive Python has an interactive interpreter which means you can enter statements and expressions at the interpreter prompt, immediately execute them and see their results. Just launch `python` with no arguments (possibly by selecting it from your computer's main menu). It is a very powerful way to test out new ideas or inspect modules and packages (remember `help(x)`).

interpreted Python is an interpreted language, as opposed to a compiled one, though the distinction can be blurry because of the presence of the bytecode compiler. This means that source files can be run directly without explicitly creating an executable which is then run. Interpreted languages typically have a shorter development/debug cycle than compiled ones, though their programs generally also run more slowly. See also *interactive*.

interpreter shutdown When asked to shut down, the Python interpreter enters a special phase where it gradually releases all allocated resources, such as modules and various critical internal structures. It also makes several calls to the *garbage collector*. This can trigger the execution of code in user-defined destructors or weakref callbacks. Code executed during the shutdown phase can encounter various exceptions as the resources it relies on may not function anymore (common examples are library modules or the warnings machinery).

The main reason for interpreter shutdown is that the `__main__` module or the script being run has finished executing.

iterable An object capable of returning its members one at a time. Examples of iterables include all sequence types (such as `list`, `str`, and `tuple`) and some non-sequence types like `dict`, *file objects*, and objects of any classes you define with an `__iter__()` method or with a `__getitem__()` method that implements *Sequence* semantics.

Iterables can be used in a `for` loop and in many other places where a sequence is needed (`zip()`, `map()`, ...). When an iterable object is passed as an argument to the built-in function `iter()`, it returns an iterator for the object. This iterator is good for one pass over the set of values. When using iterables, it is usually not necessary to call `iter()` or deal with iterator objects yourself. The `for` statement does that automatically for you, creating a temporary unnamed variable to hold the iterator for the duration of the loop. See also *iterator*, *sequence*, and *generator*.

iterator An object representing a stream of data. Repeated calls to the iterator's `__next__()` method (or passing it to the built-in function `next()`) return successive items in the stream. When no more data are available a `StopIteration` exception is raised instead. At this point, the iterator object is exhausted and any further calls to its `__next__()` method just raise `StopIteration` again. Iterators are required to have an `__iter__()` method that returns the iterator object itself so every iterator is also iterable and may be used in most places where other iterables are accepted. One notable exception is code which attempts multiple iteration passes. A container object (such as a `list`) produces a fresh new iterator each time you pass it to the `iter()` function or use it in a `for` loop. Attempting this with an iterator will just return the same exhausted iterator object used in the previous iteration pass, making it appear like an empty container.

More information can be found in typeiter.

key function A key function or collation function is a callable that returns a value used for sorting or ordering. For example, `locale.strxfrm()` is used to produce a sort key that is aware of locale specific sort conventions.

A number of tools in Python accept key functions to control how elements are ordered or grouped. They include `min()`, `max()`, `sorted()`, `list.sort()`, `heapq.merge()`, `heapq.nsmallest()`, `heapq.nlargest()`, and `itertools.groupby()`.

There are several ways to create a key function. For example. the `str.lower()` method can serve as a key function for case insensitive sorts. Alternatively, a key function can be built from a `lambda` expression such as `lambda r: (r[0], r[2])`. Also, the `operator` module provides three key function constructors: `attrgetter()`, `itemgetter()`, and `methodcaller()`. See the Sorting HOW TO for examples of how to create and use key functions.

keyword argument See *argument*.

lambda An anonymous inline function consisting of a single *expression* which is evaluated when the function is called. The syntax to create a lambda function is `lambda [parameters]: expression`

LBYL Look before you leap. This coding style explicitly tests for pre-conditions before making calls or lookups. This style contrasts with the *EAFP* approach and is characterized by the presence of many `if` statements.

In a multi-threaded environment, the LBYL approach can risk introducing a race condition between "the looking" and "the leaping". For example, the code, `if key in mapping: return mapping[key]` can fail if

another thread removes *key* from *mapping* after the test, but before the lookup. This issue can be solved with locks or by using the EAFP approach.

list A built-in Python *sequence*. Despite its name it is more akin to an array in other languages than to a linked list since access to elements is O(1).

list comprehension A compact way to process all or part of the elements in a sequence and return a list with the results. `result = ['{:#04x}'.format(x) for x in range(256) if x % 2 == 0]` generates a list of strings containing even hex numbers (0x..) in the range from 0 to 255. The `if` clause is optional. If omitted, all elements in `range(256)` are processed.

loader An object that loads a module. It must define a method named `load_module()`. A loader is typically returned by a *finder*. See **PEP 302** for details and `importlib.abc.Loader` for an *abstract base class*.

magic method An informal synonym for *special method*.

mapping A container object that supports arbitrary key lookups and implements the methods specified in the `Mapping` or `MutableMapping` abstract base classes. Examples include `dict`, `collections.defaultdict`, `collections.OrderedDict` and `collections.Counter`.

meta path finder A *finder* returned by a search of `sys.meta_path`. Meta path finders are related to, but different from *path entry finders*.

See `importlib.abc.MetaPathFinder` for the methods that meta path finders implement.

metaclass The class of a class. Class definitions create a class name, a class dictionary, and a list of base classes. The metaclass is responsible for taking those three arguments and creating the class. Most object oriented programming languages provide a default implementation. What makes Python special is that it is possible to create custom metaclasses. Most users never need this tool, but when the need arises, metaclasses can provide powerful, elegant solutions. They have been used for logging attribute access, adding thread-safety, tracking object creation, implementing singletons, and many other tasks.

More information can be found in metaclasses.

method A function which is defined inside a class body. If called as an attribute of an instance of that class, the method will get the instance object as its first *argument* (which is usually called `self`). See *function* and *nested scope*.

method resolution order Method Resolution Order is the order in which base classes are searched for a member during lookup. See The Python 2.3 Method Resolution Order for details of the algorithm used by the Python interpreter since the 2.3 release.

module An object that serves as an organizational unit of Python code. Modules have a namespace containing arbitrary Python objects. Modules are loaded into Python by the process of *importing*.

See also *package*.

module spec A namespace containing the import-related information used to load a module. An instance of `importlib.machinery.ModuleSpec`.

MRO See *method resolution order*.

mutable Mutable objects can change their value but keep their `id()`. See also *immutable*.

named tuple The term "named tuple" applies to any type or class that inherits from tuple and whose indexable elements are also accessible using named attributes. The type or class may have other features as well.

Several built-in types are named tuples, including the values returned by `time.localtime()` and `os.stat()`. Another example is `sys.float_info`:

```
>>> sys.float_info[1]                    # indexed access
1024
>>> sys.float_info.max_exp               # named field access
1024
```

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```
>>> isinstance(sys.float_info, tuple)    # kind of tuple
True
```

Some named tuples are built-in types (such as the above examples). Alternatively, a named tuple can be created from a regular class definition that inherits from `tuple` and that defines named fields. Such a class can be written by hand or it can be created with the factory function `collections.namedtuple()`. The latter technique also adds some extra methods that may not be found in hand-written or built-in named tuples.

namespace The place where a variable is stored. Namespaces are implemented as dictionaries. There are the local, global and built-in namespaces as well as nested namespaces in objects (in methods). Namespaces support modularity by preventing naming conflicts. For instance, the functions `builtins.open` and `os.open()` are distinguished by their namespaces. Namespaces also aid readability and maintainability by making it clear which module implements a function. For instance, writing `random.seed()` or `itertools.islice()` makes it clear that those functions are implemented by the `random` and `itertools` modules, respectively.

namespace package A **PEP 420** *package* which serves only as a container for subpackages. Namespace packages may have no physical representation, and specifically are not like a *regular package* because they have no `__init__.py` file.

See also *module*.

nested scope The ability to refer to a variable in an enclosing definition. For instance, a function defined inside another function can refer to variables in the outer function. Note that nested scopes by default work only for reference and not for assignment. Local variables both read and write in the innermost scope. Likewise, global variables read and write to the global namespace. The `nonlocal` allows writing to outer scopes.

new-style class Old name for the flavor of classes now used for all class objects. In earlier Python versions, only new-style classes could use Python's newer, versatile features like `__slots__`, descriptors, properties, `__getattribute__()`, class methods, and static methods.

object Any data with state (attributes or value) and defined behavior (methods). Also the ultimate base class of any *new-style class*.

package A Python *module* which can contain submodules or recursively, subpackages. Technically, a package is a Python module with an `__path__` attribute.

See also *regular package* and *namespace package*.

parameter A named entity in a *function* (or method) definition that specifies an *argument* (or in some cases, arguments) that the function can accept. There are five kinds of parameter:

- *positional-or-keyword*: specifies an argument that can be passed either *positionally* or as a *keyword argument*. This is the default kind of parameter, for example *foo* and *bar* in the following:

```
def func(foo, bar=None): ...
```

- *positional-only*: specifies an argument that can be supplied only by position. Positional-only parameters can be defined by including a `/` character in the parameter list of the function definition after them, for example *posonly1* and *posonly2* in the following:

```
def func(posonly1, posonly2, /, positional_or_keyword): ...
```

- *keyword-only*: specifies an argument that can be supplied only by keyword. Keyword-only parameters can be defined by including a single var-positional parameter or bare `*` in the parameter list of the function definition before them, for example *kw_only1* and *kw_only2* in the following:

```
def func(arg, *, kw_only1, kw_only2): ...
```

- *var-positional*: specifies that an arbitrary sequence of positional arguments can be provided (in addition to any positional arguments already accepted by other parameters). Such a parameter can be defined by prepending the parameter name with `*`, for example *args* in the following:

```
def func(*args, **kwargs): ...
```

- *var-keyword*: specifies that arbitrarily many keyword arguments can be provided (in addition to any keyword arguments already accepted by other parameters). Such a parameter can be defined by prepending the parameter name with `**`, for example *kwargs* in the example above.

Parameters can specify both optional and required arguments, as well as default values for some optional arguments.

See also the *argument* glossary entry, the FAQ question on the difference between arguments and parameters, the `inspect.Parameter` class, the function section, and **PEP 362**.

path entry A single location on the *import path* which the *path based finder* consults to find modules for importing.

path entry finder A *finder* returned by a callable on `sys.path_hooks` (i.e. a *path entry hook*) which knows how to locate modules given a *path entry*.

See `importlib.abc.PathEntryFinder` for the methods that path entry finders implement.

path entry hook A callable on the `sys.path_hook` list which returns a *path entry finder* if it knows how to find modules on a specific *path entry*.

path based finder One of the default *meta path finders* which searches an *import path* for modules.

path-like object An object representing a file system path. A path-like object is either a `str` or `bytes` object representing a path, or an object implementing the `os.PathLike` protocol. An object that supports the `os.PathLike` protocol can be converted to a `str` or `bytes` file system path by calling the `os.fspath()` function; `os.fsdecode()` and `os.fsencode()` can be used to guarantee a `str` or `bytes` result instead, respectively. Introduced by **PEP 519**.

PEP Python Enhancement Proposal. A PEP is a design document providing information to the Python community, or describing a new feature for Python or its processes or environment. PEPs should provide a concise technical specification and a rationale for proposed features.

PEPs are intended to be the primary mechanisms for proposing major new features, for collecting community input on an issue, and for documenting the design decisions that have gone into Python. The PEP author is responsible for building consensus within the community and documenting dissenting opinions.

See **PEP 1**.

portion A set of files in a single directory (possibly stored in a zip file) that contribute to a namespace package, as defined in **PEP 420**.

positional argument See *argument*.

provisional API A provisional API is one which has been deliberately excluded from the standard library's backwards compatibility guarantees. While major changes to such interfaces are not expected, as long as they are marked provisional, backwards incompatible changes (up to and including removal of the interface) may occur if deemed necessary by core developers. Such changes will not be made gratuitously – they will occur only if serious fundamental flaws are uncovered that were missed prior to the inclusion of the API.

Even for provisional APIs, backwards incompatible changes are seen as a "solution of last resort" - every attempt will still be made to find a backwards compatible resolution to any identified problems.

This process allows the standard library to continue to evolve over time, without locking in problematic design errors for extended periods of time. See **PEP 411** for more details.

provisional package See *provisional API*.

Python 3000 Nickname for the Python 3.x release line (coined long ago when the release of version 3 was something in the distant future.) This is also abbreviated "Py3k".

Pythonic An idea or piece of code which closely follows the most common idioms of the Python language, rather than implementing code using concepts common to other languages. For example, a common idiom in Python is to loop over all elements of an iterable using a `for` statement. Many other languages don't have this type of construct, so people unfamiliar with Python sometimes use a numerical counter instead:

```
for i in range(len(food)):
    print(food[i])
```

As opposed to the cleaner, Pythonic method:

```
for piece in food:
    print(piece)
```

qualified name A dotted name showing the "path" from a module's global scope to a class, function or method defined in that module, as defined in **PEP 3155**. For top-level functions and classes, the qualified name is the same as the object's name:

```
>>> class C:
...     class D:
...         def meth(self):
...             pass
...
>>> C.__qualname__
'C'
>>> C.D.__qualname__
'C.D'
>>> C.D.meth.__qualname__
'C.D.meth'
```

When used to refer to modules, the *fully qualified name* means the entire dotted path to the module, including any parent packages, e.g. `email.mime.text`:

```
>>> import email.mime.text
>>> email.mime.text.__name__
'email.mime.text'
```

reference count The number of references to an object. When the reference count of an object drops to zero, it is deallocated. Reference counting is generally not visible to Python code, but it is a key element of the *CPython* implementation. The `sys` module defines a `getrefcount()` function that programmers can call to return the reference count for a particular object.

regular package A traditional *package*, such as a directory containing an `__init__.py` file.

See also *namespace package*.

__slots__ A declaration inside a class that saves memory by pre-declaring space for instance attributes and eliminating instance dictionaries. Though popular, the technique is somewhat tricky to get right and is best reserved for rare cases where there are large numbers of instances in a memory-critical application.

sequence An *iterable* which supports efficient element access using integer indices via the `__getitem__()` special method and defines a `__len__()` method that returns the length of the sequence. Some built-in sequence types are `list`, `str`, `tuple`, and `bytes`. Note that `dict` also supports `__getitem__()` and `__len__()`, but is considered a mapping rather than a sequence because the lookups use arbitrary *immutable* keys rather than integers.

The `collections.abc.Sequence` abstract base class defines a much richer interface that goes beyond

just `__getitem__()` and `__len__()`, adding `count()`, `index()`, `__contains__()`, and `__reversed__()`. Types that implement this expanded interface can be registered explicitly using `register()`.

set comprehension A compact way to process all or part of the elements in an iterable and return a set with the results. `results = {c for c in 'abracadabra' if c not in 'abc'}` generates the set of strings `{'r', 'd'}`. See comprehensions.

single dispatch A form of *generic function* dispatch where the implementation is chosen based on the type of a single argument.

slice An object usually containing a portion of a *sequence*. A slice is created using the subscript notation, `[]` with colons between numbers when several are given, such as in `variable_name[1:3:5]`. The bracket (subscript) notation uses `slice` objects internally.

special method A method that is called implicitly by Python to execute a certain operation on a type, such as addition. Such methods have names starting and ending with double underscores. Special methods are documented in specialnames.

statement A statement is part of a suite (a "block" of code). A statement is either an *expression* or one of several constructs with a keyword, such as `if`, `while` or `for`.

text encoding A codec which encodes Unicode strings to bytes.

text file A *file object* able to read and write `str` objects. Often, a text file actually accesses a byte-oriented datastream and handles the *text encoding* automatically. Examples of text files are files opened in text mode (`'r'` or `'w'`), `sys.stdin`, `sys.stdout`, and instances of `io.StringIO`.

See also *binary file* for a file object able to read and write *bytes-like objects*.

triple-quoted string A string which is bound by three instances of either a quotation mark (") or an apostrophe ('). While they don't provide any functionality not available with single-quoted strings, they are useful for a number of reasons. They allow you to include unescaped single and double quotes within a string and they can span multiple lines without the use of the continuation character, making them especially useful when writing docstrings.

type The type of a Python object determines what kind of object it is; every object has a type. An object's type is accessible as its `__class__` attribute or can be retrieved with `type(obj)`.

type alias A synonym for a type, created by assigning the type to an identifier.

Type aliases are useful for simplifying *type hints*. For example:

```
from typing import List, Tuple

def remove_gray_shades(
        colors: List[Tuple[int, int, int]]) -> List[Tuple[int, int, int]]:
    pass
```

could be made more readable like this:

```
from typing import List, Tuple

Color = Tuple[int, int, int]

def remove_gray_shades(colors: List[Color]) -> List[Color]:
    pass
```

See `typing` and **PEP 484**, which describe this functionality.

type hint An *annotation* that specifies the expected type for a variable, a class attribute, or a function parameter or return value.

Type hints are optional and are not enforced by Python but they are useful to static type analysis tools, and aid IDEs with code completion and refactoring.

Type hints of global variables, class attributes, and functions, but not local variables, can be accessed using `typing.get_type_hints()`.

See `typing` and **PEP 484**, which describe this functionality.

universal newlines A manner of interpreting text streams in which all of the following are recognized as ending a line: the Unix end-of-line convention `'\n'`, the Windows convention `'\r\n'`, and the old Macintosh convention `'\r'`. See **PEP 278** and **PEP 3116**, as well as `bytes.splitlines()` for an additional use.

variable annotation An *annotation* of a variable or a class attribute.

When annotating a variable or a class attribute, assignment is optional:

```
class C:
    field: 'annotation'
```

Variable annotations are usually used for *type hints*: for example this variable is expected to take `int` values:

```
count: int = 0
```

Variable annotation syntax is explained in section annassign.

See *function annotation*, **PEP 484** and **PEP 526**, which describe this functionality.

virtual environment A cooperatively isolated runtime environment that allows Python users and applications to install and upgrade Python distribution packages without interfering with the behaviour of other Python applications running on the same system.

See also `venv`.

virtual machine A computer defined entirely in software. Python's virtual machine executes the *bytecode* emitted by the bytecode compiler.

Zen of Python Listing of Python design principles and philosophies that are helpful in understanding and using the language. The listing can be found by typing "`import this`" at the interactive prompt.

APPENDIX

B

ABOUT THESE DOCUMENTS

These documents are generated from reStructuredText sources by Sphinx, a document processor specifically written for the Python documentation.

Development of the documentation and its toolchain is an entirely volunteer effort, just like Python itself. If you want to contribute, please take a look at the reporting-bugs page for information on how to do so. New volunteers are always welcome!

Many thanks go to:

- Fred L. Drake, Jr., the creator of the original Python documentation toolset and writer of much of the content;
- the Docutils project for creating reStructuredText and the Docutils suite;
- Fredrik Lundh for his Alternative Python Reference project from which Sphinx got many good ideas.

B.1 Contributors to the Python Documentation

Many people have contributed to the Python language, the Python standard library, and the Python documentation. See Misc/ACKS in the Python source distribution for a partial list of contributors.

It is only with the input and contributions of the Python community that Python has such wonderful documentation – Thank You!

APPENDIX

C

HISTORY AND LICENSE

C.1 History of the software

Python was created in the early 1990s by Guido van Rossum at Stichting Mathematisch Centrum (CWI, see https://www.cwi.nl/) in the Netherlands as a successor of a language called ABC. Guido remains Python's principal author, although it includes many contributions from others.

In 1995, Guido continued his work on Python at the Corporation for National Research Initiatives (CNRI, see https://www.cnri.reston.va.us/) in Reston, Virginia where he released several versions of the software.

In May 2000, Guido and the Python core development team moved to BeOpen.com to form the BeOpen PythonLabs team. In October of the same year, the PythonLabs team moved to Digital Creations (now Zope Corporation; see https://www.zope.org/). In 2001, the Python Software Foundation (PSF, see https://www.python.org/psf/) was formed, a non-profit organization created specifically to own Python-related Intellectual Property. Zope Corporation is a sponsoring member of the PSF.

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2.0	1.6	2000	BeOpen.com	no
1.6.1	1.6	2001	CNRI	no
2.1	2.0+1.6.1	2001	PSF	no
2.0.1	2.0+1.6.1	2001	PSF	yes
2.1.1	2.1+2.0.1	2001	PSF	yes
2.1.2	2.1.1	2002	PSF	yes
2.1.3	2.1.2	2002	PSF	yes
2.2 and above	2.1.1	2001-now	PSF	yes

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Thanks to the many outside volunteers who have worked under Guido's direction to make these releases possible.

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```
A C-program for MT19937, with initialization improved 2002/1/26.
Coded by Takuji Nishimura and Makoto Matsumoto.

Before using, initialize the state by using init_genrand(seed)
or init_by_array(init_key, key_length).

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Any feedback is very welcome.
http://www.math.sci.hiroshima-u.ac.jp/~m-mat/MT/emt.html
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```

C.3.2 Sockets

The `socket` module uses the functions, `getaddrinfo()`, and `getnameinfo()`, which are coded in separate source files from the WIDE Project, http://www.wide.ad.jp/.

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- Use binascii module to do the actual line-by-line conversion
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- Arguments more compliant with Python standard
```

C.3.7 XML Remote Procedure Calls

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C.3.10 SipHash24

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Original location:
   https://github.com/majek/csiphash/

Solution inspired by code from:
   Samuel Neves (supercop/crypto_auth/siphash24/little)
   djb (supercop/crypto_auth/siphash24/little2)
   Jean-Philippe Aumasson (https://131002.net/siphash/siphash24.c)
```

C.3.11 strtod and dtoa

The file `Python/dtoa.c`, which supplies C functions dtoa and strtod for conversion of C doubles to and from strings, is derived from the file of the same name by David M. Gay, currently available from http://www.netlib.org/fp/. The original file, as retrieved on March 16, 2009, contains the following copyright and licensing notice:

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```
*
****************************************************************/
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C.3.12 OpenSSL

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C.3.18 W3C C14N test suite

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