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;
    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;
    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.

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);
    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_CallNoArgs(self->my_callback);
        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.

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);
}
```

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.

3.3.1. 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 descriptors 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.

3.3.2. 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;
}
```

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;
 }
```

3.5. Abstract Protocol Support

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

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);
    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.

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 ... */
    .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);
}
```

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