

# numpy.i: a SWIG Interface File for NumPy

**Author:** Bill Spotz  
**Institution:** Sandia National Laboratories  
**Date:** 10 March, 2007

## Introduction

The Simple Wrapper and Interface Generator (or [SWIG](#)) is a powerful tool for generating wrapper code for interfacing to a wide variety of scripting languages. [SWIG](#) can parse header files, and using only the code prototypes, create an interface to the target language. But [SWIG](#) is not omnipotent. For example, it cannot know from the prototype:

```
double rms(double* seq, int n);
```

what exactly `seq` is. Is it a single value to be altered in-place? Is it an array, and if so what is its length? Is it input-only? Output-only? Input-output? [SWIG](#) cannot determine these details, and does not attempt to do so.

Making an educated guess, humans can conclude that this is probably a routine that takes an input-only array of length `n` of `double` values called `seq` and returns the root mean square. The default behavior of [SWIG](#), however, will be to create a wrapper function that compiles, but is nearly impossible to use from the scripting language in the way the C routine was intended.

For [python](#), the preferred way of handling contiguous (or technically, *strided*) blocks of homogeneous data is with the module [NumPy](#), which provides full object-oriented access to arrays of data. Therefore, the most logical python interface for the `rms` function would be:

```
def rms(seq):
```

where `seq` would be a [NumPy](#) array of `double` values, and its length `n` would be extracted from `seq` internally before being passed to the C routine. Even better, since [NumPy](#) supports construction of arrays from arbitrary [python](#) sequences, `seq` itself could be a nearly arbitrary sequence (so long as each element can be converted to a `double`) and the wrapper code would internally convert it to a [NumPy](#) array before extracting its data and length.

[SWIG](#) allows these types of conversions to be defined via a mechanism called typemaps. This document provides information on how to use `numpy.i`, a [SWIG](#) interface file that defines a series of typemaps intended to make the type of array-related conversions described above relatively simple to implement. For example, suppose that the `rms` function prototype defined above was in a header file named `rms.h`. To obtain the python interface discussed above, your [SWIG](#) interface file would need the following:

```
%{  
#define SWIG_FILE_WITH_INIT  
#include "rms.h"  
%}  
  
%include "numpy.i"
```

```
%init %{
import_array();
%}

%apply (double* IN_ARRAY1, int DIM1) {(double* seq, int n)};
#include "rms.h"
```

Typemaps are keyed off a list of one or more function arguments, either by type or by type and name. We will refer to such lists as *signatures*. One of the many typemaps defined by `numpy.i` is used above and has the signature `(double* IN_ARRAY1, int DIM1)`. The argument names are intended to suggest that the `double*` argument is an input array of one dimension and that the `int` represents that dimension. This is precisely the pattern in the `rms` prototype.

Most likely, no actual prototypes to be wrapped will have the names `IN_ARRAY1` and `DIM1`. We use the `%apply` directive to apply the typemap for one-dimensional input arrays of type `double` to the actual prototype used by `rms`. Using `numpy.i` effectively, therefore, requires knowing what typemaps are available and what they do.

Note that if the C function signature was in a different order:

```
double rms(int n, double* seq);
```

that `SWIG` would not match the typemap signature given above with the argument list for `rms`. Fortunately, `numpy.i` has a set of typemaps with the data pointer given last:

```
%apply (int DIM1, double* IN_ARRAY1) {(int n, double* seq)};
```

## Using numpy.i

The `numpy.i` file is currently located in the `numpy/docs/swig` sub-directory under the `numpy` installation directory. Typically, you will want to copy it to the directory where you are developing your wrappers. If it is ever adopted by `SWIG` developers, then it will be installed in a standard place where `SWIG` can find it.

A simple module that only uses a single `SWIG` interface file should include the following:

```
%{
#define SWIG_FILE_WITH_INIT
%}
#include "numpy.i"
%init %{
import_array();
%}
```

Within a compiled python module, `import_array()` should only get called once. This could be in a C/C++ file that you have written and is linked to the module. If this is the case, then none of your interface files should `#define SWIG_FILE_WITH_INIT` or call `import_array()`. Or, this initialization call could be in a wrapper file generated by `SWIG` from an interface file that has the `%init` block as above. If this is the case, and you have more than one `SWIG` interface file, then only one interface file should `#define SWIG_FILE_WITH_INIT` and call `import_array()`.

## Available Typemaps

The typemap directives provided by `numpy.i` for arrays of different data types, say `double` and `int`, are identical to one another except for the C and `NumPy` type specifications. The typemaps are therefore implemented (typically behind the scenes) via a macro:

```
%numpy_typedmaps(TYPE, TYPECODE)
```

that can be invoked for appropriate (TYPE, TYPECODE) pairs. For example:

```
%numpy_typedmaps(double, NPY_DOUBLE)
%numpy_typedmaps(int,    NPY_INT    )
```

The `numpy.i` interface file uses the `%numpy_typedmaps` macro to implement typedmaps for the following C-types:

- signed char
- unsigned char
- short
- unsigned short
- int
- unsigned int
- long
- unsigned long
- long long
- unsigned long long
- float
- double
- PyObject
- char

Note that C++ type `bool` is not supported in the list above. NumPy bools are a single byte, while the C++ `bool` is four bytes (at least on my system). Therefore:

```
%numpy_typedmaps(bool, NPY_BOOL)
```

will result in typedmaps that will produce code that reference improper data lengths. You can implement the following macro expansion:

```
%numpy_typedmaps(bool, NPY_UINT)
```

to fix the data length problem, and [Input Arrays](#) will work fine, but [In-place Arrays](#) might fail type-checking.

In the following descriptions, we reference a generic TYPE, which could be any of the C-types listed above.

## Input Arrays

Input arrays are defined as arrays of data that are passed into a routine but are not altered in-place or returned to the user. The python input array is therefore allowed to be almost any python sequence (such as a list) that can be converted to the requested type of array. The input array signatures are

- (TYPE\* IN\_ARRAY1, int DIM1)
- (TYPE\* IN\_ARRAY2, int DIM1, int DIM2)
- (int DIM1, TYPE\* IN\_ARRAY1)
- (int DIM1, int DIM2, TYPE\* IN\_ARRAY2)

## In-place Arrays

In-place arrays are defined as arrays that are modified in-place. The input values may or may not be used, but the values at the time the function returns are significant. The provided python argument must therefore be a [NumPy](#) array of the required type. The in-place signatures are

- (TYPE\* INPLACE\_ARRAY1, int DIM1)
- (TYPE\* INPLACE\_ARRAY2, int DIM1, int DIM2)
- (int DIM1, TYPE\* INPLACE\_ARRAY1)
- (int DIM1, int DIM2, TYPE\* INPLACE\_ARRAY2)

## Argout Arrays

Argout arrays are arrays that appear in the input arguments in C, but are in fact output arrays. This pattern occurs often when there is more than one output variable and the single return argument is therefore not sufficient. In python, the conventional way to return multiple arguments is to pack them into a tuple and return the tuple. This is what the argout typemaps do. If a wrapped function that uses these argout typemaps has more than one return argument, they are so packed. The python user does not pass these arrays in, they simply get returned. The argout signatures are

- (TYPE ARGOUT\_ARRAY1[ANY])
- (TYPE ARGOUT\_ARRAY2[ANY][ANY])

## Helper Functions

The `numpy.i` file contains several macros and routines that it uses internally to build its typemaps. However, these functions may be useful elsewhere in your interface file.

### Macros

- is\_array(a)** Evaluates as true if **a** is non-NULL and can be cast to a `PyArrayObject*`.
- array\_type(a)** Evaluates to the integer data type code of **a**, assuming **a** can be cast to a `PyArrayObject*`.
- array\_dimensions(a)** Evaluates to the integer number of dimensions of **a**, assuming **a** can be cast to a `PyArrayObject*`.
- array\_size(a,i)** Evaluates to the *i*-th dimension size of **a**, assuming **a** can be cast to a `PyArrayObject*`.
- array\_is\_contiguous(a)** Evaluates as true if **a** is a contiguous array. Equivalent to `(PyArray_ISCONTIGUOUS(a))`.

### Routines

- char\* pytype\_string(PyObject\* py\_obj)** Given a `PyObject*`, return a string describing its type.
- char\* typecode\_string(int typecode)** Given a [NumPy](#) integer typecode, return a string describing the type.
- int type\_match(int actual\_type, int desired\_type)** Make sure input has correct [NumPy](#) type. Allow character and byte to match. Also allow int and long to match.

**PyArrayObject\* obj\_to\_array\_no\_conversion(PyObject\* input, int typecode)** Given a **PyObject\***, cast it to a **PyArrayObject\*** if legal. If not, set the python error string appropriately and return **NULL**.

**PyArrayObject\* obj\_to\_array\_allow\_conversion(PyObject\* input, int typecode, int\* is\_new\_object)** Convert the given **PyObject\*** to a **NumPy** array with the given typecode. On Success, return a valid **PyArrayObject\*** with the correct type. On failure, the python error string will be set and the routine returns **NULL**.

**PyArrayObject\* make\_contiguous(PyArrayObject\* ary, int\* is\_new\_object, int min\_dims, int max\_dims)** Given a **PyArrayObject\***, check to see if it is contiguous. If so, return the input pointer and flag it as not a new object. If it is not contiguous, create a new **PyArrayObject\*** using the original data, flag it as a new object and return the pointer.

**PyArrayObject\* obj\_to\_array\_contiguous\_allow\_conversion(PyObject\* input, int typecode, int\* is\_new\_object)** Convert a given **PyObject\*** to a contiguous **PyArrayObject\*** of the specified type. If the input object is not a contiguous **PyArrayObject\***, a new one will be created and the new object flag will be set.

**int require\_contiguous(PyArrayObject\* ary)** Test whether a **PyArrayObject\*** is contiguous. If array is contiguous, return 1. Otherwise, set the python error string and return 0.

**int require\_dimensions(PyArrayObject\* ary, int exact\_dimensions)** Require the given **PyArrayObject\*** to have a specified number of dimensions. If the array has the specified number of dimensions, return 1. Otherwise, set the python error string and return 0.

**int require\_dimensions\_n(PyArrayObject\* ary, int\* exact\_dimensions, int n)** Require the given **PyArrayObject\*** to have one of a list of specified number of dimensions. If the array has one of the specified number of dimensions, return 1. Otherwise, set the python error string and return 0.

**int require\_size(PyArrayObject\* ary, int\* size, int n)** Require the given **PyArrayObject\*** to have a specified shape. If the array has the specified shape, return 1. Otherwise, set the python error string and return 0.

**static PyArrayObject\* contiguous\_typed\_array(PyObject\* obj, int typecode, int expectnd, int\* expecteddims)** This function tries to create a contiguous **NumPy** array of type **typecode** from an arbitrary python object **obj**. This should work for any sequence object. The argument **expectnd** is the expected number of dimensions, ignored if  $\leq 0$ . The argument **expecteddims** is an array of expected dimensions, ignored if  $\leq 0$ . This routine raises a **ValueError** exception if the underlying **PyArray\_ContiguousFromObject** routine fails, if the array has a bad shape, if the extent of a given dimension doesn't match the specified extent. If **obj** is a contiguous **PyArrayObject\*** then a reference is returned; if **obj** is a python sequence, then a new **PyArrayObject\*** is created and returned.

## Acknowledgements

Many people have worked to glue **SWIG** and **NumPy** (and its predecessors **Numeric** and **numarray**) together. The effort to standardize this work into **numpy.i** began at the 2005 SciPy Conference with a conversation between Fernando Perez and myself. Fernando collected helper functions and typemaps from Michael Hunter, Anna Omelchenko and Michael Sanner. Their work has made this end result possible.

Generated on: 2007-03-14 20:28 UTC. Generated by **Docutils** from **reStructuredText** source.