pixcorrect development

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1 Initial state

1.1 imsupport

The imsupport product contains C code for loading, saving, and otherwise working with DES images. Particularly significant contents of this product are:

mask bit definitions are defined in C pre-processor directives, duplicated in include/imutils.h and include/imsupport.h. There are separates sets of bits for use in the initial BPM and the mask HDUs of DES images.

desimage struct include/imreadsubs.h contains the desimage C struct, which includes elements for metadata corresponding to some FITS keywords, and pointers to arrays containing science data, weight, and mask pixel data.

1.2 imcorrect

The imcorrect C code does the actual pixel-level correction on DES images. For each operation, there appears to be a central bit of code that actually does the calculation on each pixels. Sometimes these are combined in the same loop over pixels, sometimes a calculation is contained in its own loop.

1.3 fitsio

fitsio is a python wrapper around the CFITSIO library, and can be used to manipulate headers, and load and save pixel data as numpy arrays.

1.4 ctypes

ctypes is a base python method of calling C libraries. C manitulates memory at a lower level than is typical for python program, and ctypes includes tools for generating and interpreting arbitrary C structures, mapping them to python objects.

Using ctypes with numpy can be slightly tricky. Internally, numpy can store data in a variety of ways (row-major or column major ordering of array elemets, big-endian or little-endian, and the assorted combinations thereof). When numpy is used intirely within python, the way in which the data is stored is invisible to the user: the numpy code keeps track and does whatever is appropriate.

When one needs to pass a pointer to arrays of pixels to C code, however, one needs to be sure that numpy is storing the pixels in the order, type, and endian-ness expected by the C library. numpy includes tools for supporting this.

2 Progress

2.1 despyfits

despyfits contains code for manipulating DES images from python libraries, roughly analogous to imsupport.

despyfits includes a header file, with lines cut-and-pasted from imsupport's include/imsupport.h, that define bits in pixel masks. There is also a trivial C library that imports these and assigns the values to C extern variables, and a python module that

uses ctypes to provide access to these values from python. So, for example, the BAD–PIX_SATURATE bit can be printed from python thus:

```
Python 2.7.6 (default, Nov 10 2014, 12:26:08)
[GCC 4.4.7 20120313 (Red Hat 4.4.7-3)] on linux2
Type "help", "copyright", "credits" or "license" for more information.
>>> from despyfits import maskbits
>>>
>>> print maskbits.BADPIX_SATURATE
2
>>>
```

To make sure there is only one cannonical definition of mask bits, imsupport's imutils.h and imsupport.h now need to be modified to include the file from despyfits rather than their own definitions. Who owns imsupport?

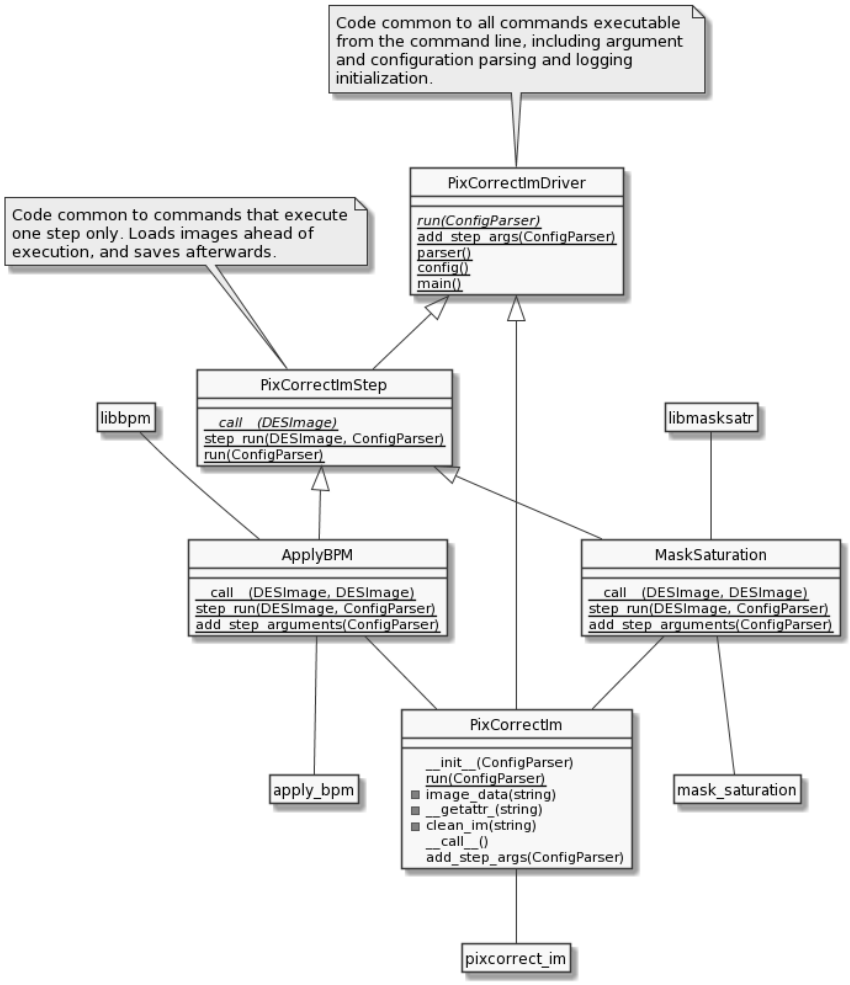
despyfits includes a DESImage class for holding data associated with a DES image, roughly analogous to the desimage C struct.

Because the code that does the calculations in imcorrect makes heavy use of imsupport's desimage struct, and we would like to cut-and-paste this code into C libraries to be called by python through ctypes, DESImage includes a method that returns a ctypes.Structure object that supplies a subset of the elements defined in imsupport's desimage struct, and a C header file that declares a C structure that corresponds to the structure generated by DESImage. When the DESImage class is used to create this ctypes.Structure, it automatically ensures that the numpy arrays are stored in the right endianness and memory layout for use in C code. If data in numpy arrays are passed to C code by some other mechanism, this needs to be done in the new code, because numpy does not guarantee the memory layout or endianness by default.

2.2 pixcorrect

The development of the python utility that replicates imcorrect is in progress.

It will include C libraries that replicate operations performed by imcorrect, with C code copied directly from imcorrect. There will be python modules that correspond to each operation, each of which can be loaded independenly in python or executed independently from a shell. In addition, there is a high-level driver that loads each, and executes each in the proper order, loading and saving files to disk only as necessary.



3 Instructions for adding steps from `imcorrect` to `pixcorrect`

3.1 Find the code in `imcorrect` that does the pixel level calculation

3.2 Verify and update `desimage` if neede

3.2.1 Check `desimage`

Check that all elements of `imsupport`'s `desimage` structure used in this code are present in `despyfits`'s `desimage` (in `include/desimage.h`). Hopefully, all elements needed by the `imcorrect` code to be moved will already by present, in which case you can skip to the next step.

3.2.2 Supplement `include/desimage.h` in `despyfits`.

If there are needed elements missing from `include/desimage.h` in `despyfits`, copy them from the declaration of the `desimage` struct in `include/imreadsubs.h` in `imsupport`.

3.2.3 Supplement `DESImageCStruct` class in `python/despyfits/DESImage.py`

Add the missing elements to the `DESImageCStruct` class in `python/despyfits/DESImage.py`. Be sure to both add the new helement to the `_fields_` property and the code to set the values in the class's `__init__` method.

The `_fields_` property must list the same elements in the same order with types corresponding to the declarations in the C header. The mapping between `ctypes` types and basic C types can be found here.

If pointers are needed, use `ctypes.POINTER`. If an array of values is needed, the clearest way to handle it is probably by declaring a new python class. For example, the `ampsecan` field in the `desimage` structure is an array of four integers, so the the `DESImage` python module declares the class `FourInts` thus:

```
FourInts = ctypes.c_int * 4
```

and the `ampsecan` element of the `_fields_` property of the `DESImageCStruct` class is declared to be of that type.

3.2.4 recompile `despyfits` using the `setup.py`

The C libraries used in `despyfits` depend on the `desimage.h` header, and so must be recompiled to incorporate any changes. Because this is a python package, use python's `setuptools` to do this:

```
cd $DESPYFITS_DIR
python setup.py build
```

3.2.5 check the updated `depyfits` into `svn`, and `svn update` `pixcorrect`

The `desimage.h` header file appears in the `pixcorrect` product by way on an `svn external` directory; to be seen by the `pixcorrect` C code, it must be checked into `svn` from `despyfits`, and the `svn update=d into your checked out =pixcorrect` product.

3.3 Wrap C code from `imcorrect.c`

Copy the code in `imcorrect.c` to a C file in `pixcorrect`'s `src` directory, calling it `lib${STEPNAME}.c`. Make sure the loop over pixels is included in the library; see `src/libbpm.c` or `src/libmasksatr.c` for examples.

Be careful allocating and freeing memory within the C library. Python's memory managemen and garbage collection knows nothing about memory allocated or freed within the library, so if you allocate code and do not free it, it will be a memory leak, and if you free memory allocated by python (and seen by the C library through a passed pointer), it will cause python to segfault.

3.4 Add the new C library to `setup.py` in `pixcorrect`

The `setup.py` builds the libraries in the `pixcorrect` product. Two changes are need for this. First, an object of class `SharedLibrary` needs to be created with instructions for building the new library. For example, the creation of the `SharedLibrary` object for `libbpm` looks like this:

```
libbpm = SharedLibrary(
    'bpm',
    sources = ['src/libbpm.c'],
    include_dirs = ['include'],
    extra_compile_args = ['-O3','-g','-Wall','-shared','-fPIC'])
```

Other libraries are likely to look very similar.

Then, this new object needs to be added to the list of shared libraries that need to be built to build the product, specified in the `shlibs` parameter in the `setup` call.

3.5 Compile `pixcorrect`

Run `setup.py` in the root of `pixcorrect`:

```
cd ${PIXCORRECT_DIR}
python setup.py build
```

3.6 Create a python module for the new step

The module should supply an API for calling the step programatically, and also code for running it stand-alone. mask_saturation.py is an example of an operation that uses only the data desimage structure itself for paramaters and returns, and apply_bpm is a slightly more complex example, where a second desimage is used.

3.6.1 Example 1: mask_saturation

Following the mask_saturation example, it begins by declaring a module constant that defines the section of a configuration file from which the stand-alone executable might read its input:

```
config_section = 'mask_saturation'
```

(This same string will also be used as the switch to determine whether this step is performed in the driver that drives multiple steps.)

Next comes the code that loads the C library:

```
masksatr_lib = load_shlib('libmasksatr')
mask_saturation_c = masksatr_lib.mask_saturation
mask_saturation_c.restype = ctypes.c_int
mask_saturation_c.argtypes = [DESImageCStruct, ctypes.POINTER(ctypes.c_int)]
```

The first line loads the library. The second maps the mask_saturation function in that library to the python callable object referenced by mask_saturation_c (in other words, mask_saturation_c acts like a python function).

The assignments to mask_saturation_c.restype and and mask_saturation_c.argtypes set the return type and argument types for the C function, respectively.

The value of DESImageCStruct corresponds to a desimage argument in the C function, and the ctypes.POINTER(ctypes.c_int) to a pointer to an int.

Following this management of the C library, the MaskSaturation class is declared. It is a subclass of PixCorrectImStep, from which it gets most of its functionality; only code specific to this step is here.

At the start of the class definition are the properties description and step_name, which determine the help string to be provided on the command line in response to an --help argument and the switch to be used to turn on and off execution of this function (mapped here to the module's config_section constant).

Then, a __call__ method is defined. __call__ is a special python method which is called when an instance if an object is called as if it were a function, an in this case it defines the main functionality of the step.

The definition begins with defining the num_saturated variable to a ctypes.c_int(), which gets python to allocate the appropraite memory so it can pass a pointer to it in the next line.

The next line actually calls the function in the C library. The first argument triggers the creation of a DESImageCStruct object from the DESImage object, and the second the pointer to the variable in which the number of flagged pixels will be returned.

After definition of the MaskSaturation class, this line:

```
mask_saturation = MaskSaturation()
```

creates an instance of the class and assigns it to mask_saturation, meaning that mask_saturation can now be treated like a function (in which case MaskSaturation.__call__ will be called).

3.6.2 Example 2: apply_bpm

The apply_bpm step is similar, but has the additional complication that a second image, the bad pixel mask, needs to be loaded and passed to the call.

The first thing that needs to happend is that a new command line argument needs to be made to let the user supply the file name for the BPM. This is done by the add_step_args method. For additional information on adding arguments to a python argument parser, see the python argparse documentation.

We also need to add the code to load the BPM image, which is done in the `step_run` method. Note that the second argument of the `config.get` call needs to match the second argument of the `parse.add_argument` call in `add_step_args`, which is also the option that would be used if the file name were to be loaded from a configuration file.

Note that `MaskSaturation` class also has `step_run` and `add_step_args` method, but these are inhereted from the `PixCorrectImStep` parent class, and do not do anything special.

3.7 Create an executable file for the step

Once the step's class has been defined as above, this is trivial. In the case of `apply_bpm`, for example, a python script, `${PIXCORRECT_DIR}/bin/apply_bpm`, that looks like this:

```
#!/usr/bin/env python

from pixcorrect.apply_bpm import apply_bpm

if __name__ == '__main__':
    apply_bpm.main()
```

does the trick.

Note that we could accomplish the same thing by just running `apply_bpm.py` directly, and so we could have gotten away with just putting a symlink to `apply_bpm.py` in `${PIXCORRECT_DIR}/bin`, but I personally prefer to keep them as real, distinct files, for reasons too obscure to go in to here.

3.8 Add the step to `pixcorrect_im.py`

The code that runs all steps in sequence can be found in `${PIXCORRECT_DIR}/python/pixcorrect/pixcorrect_im.py`.

Start adding your new step by adding an import of the callable instance of your object defined above, for example in the case of `fix_cols` this is:

```
from pixcorrect.fix_cols import fix_cols
```

Next, if your new step requires arguments not already supplied by other steps, add them to the `PixCorrectIm.add_step_args` method. In the case of `fix_cols`, the `bpm` argument was already present, but the `--fix_cols` switch to set whether to perform that step was not. So, these lines were needed to support `fix_cols`:

```
parser.add_argument('--bpm', nargs=1,
                    default=None,
                    help='bad pixel mask filename')
parser.add_argument('--fix_cols', action='store_true',
                    help='fix bad columns')
```

Then, figure out where your new step should be called in the `PixCorrectIm.__call__` method, and add it. For example, in the case of `fixcol`, the new code added was:

```
if do_step('fix_cols'):
    fix_cols(self.sci, self.bpm)
```

Note that the argument to `do_step` is the same as the option name in the `add_argument` statement above.

Other methods of the `PixCorrectIm` class (which do not need to be modified for new steps) make sure the images passed to `fix_cols`, `self.sci` and `self.bpm`, get loaded as needed. When you reference a method of `PixCorrectIm` that is not already defined, the class looks for a command line argument (or parameter in the config file) with the same name, and if one is present, it interprets it as a file name for a `DESImage` and loads it. Once it is loaded, future references to the same member just return the same loaded object, avoiding the need to load the image multiple times from disk.

The `clean_im` method releases the memory for images loaded in this way. For example, this line:

```
self.clean_im('bpm')
```

tell python it can free them memory into which the BPM was loaded. If `self.bpm` is referenced after this, it will need to be reread from disk. (Note that python does not guarantee that it will free the memory as soon as it is allowed to.)

3.9 Add a `doctest` or `unittest`

3.9.1 Test infrastructure in `pixcorrect`

Python has two built-in mechanisms for automated testing, `doctest` and `unittest`. Which is more useful depends on what tests you are performing. Personally, if the test code itself does not require a lot of debugging, I find doctests easier, but if the testing code itself is complicated and likely to have bugs, I find the unittest approach easier.

The `pixcorrect` product has a driver for running tests of both types.

Each doctest is in a text file in `${PIXCORRECT_DIR}/test/doctests` and each unittest in is a python file in `${PIXCORRECT_DIR}/test/unittests`.

The configuration file `${PIXCORRECT_DIR}/test/test.config` has options corresponding to each unittest in its `unittest` section, and each doctest in its `docs` section. Set the values of these options to true or false depending on whether you want to run those tests, and run the desired tests thus:

```
setup pixcorrectTestData
cd $PIXCORRECT_DIR/test
python test.py
```

Note that you can use a different configuration file if you wish, and run it thus:

```
setup pixcorrectTestData
cd $PIXCORRECT_DIR/test
python test.py my_favourite_tests.config
```

3.9.2 `doctests`

At present, the doctests in `pixcorrect` mostly just test that the various modules run without crashing.

doctests are particularly easy to write in python. When a doctest test document is run, the test driver looks through the text document for anything that looks like example code, and tries to run it and check that it gets the same results as in the example.

So, when I first start testing a piece of python code interactively, once I get an example that works, I just cut and paste the output on the terminal into a text document, put a little explanatory text around it, and make that the initial doctest.

Note that doctest can be used to test examples embedded in python code itself, but I won't describe that here.

3.9.3 `unittest`

`unittest` more closely resembles the unit testing approach. So far, I have put code that tests whether the steps accurately reproduce the results from `imcorrect` in this framework.