ISCE Documentation

Release 0.3

JPL

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INSTALLATION

Obtain the ISCE source code from the download-site. Unpack the tarball in a temporary folder, referred to below as *ISCE_SRC*. You can delete that folder after the complete installation of ISCE.

Before installing ISCE, several software packages - called dependencies - need to be installed. The dependencines can be installed using standard repository management tools or with the custom installation script included in the ISCE distribution or manually.

Note: To install ISCE and its dependencies, you will need approximately 3.1 GB of free space on the hard drive, or 400 MB after removing the source and build directories.

2.1 Dependencies with repository management tools

The dependencies for ISCE can be installed using standard repository management tools like *yum* or *apt* on Linux and *Macports* on OS X platforms. We list simple commands for installing various dependencies for OS X and Ubuntu platforms. Repository management tools typically install the software in standard locations, e.g, /usr, /usr/local or /opt/local. If this is not desired, we suggest that the users install dependencies using the install script provided with the ISCE distribution.

Package	OS X	Ubuntu 12.04
Compilers	• `sudo port install mp-gcc46` • `sudo port select gcc mp-gcc46`	`sudo yum install build-essential gfortran`
Python	• `sudo port install python27` • `sudo port select python python27`	`sudo yum install python2.7-dev`
FFTW3	• `sudo port install fftw-3 +gcc46` • `sudo port install fftw-3-single + gcc46`	`sudo yum install libfftw3-3 libfftw3-dev`
X11 files	`sudo port install openmotif`	`sudo yum install lesstif2 lesstif2-dev libxt-dev`
HDF5	`sudo port install py27-h5py`	`sudo yum install python-h5py libhdf5-serial-dev`
scons	`sudo port install scons`	`sudo yum install scons`
numpy	`sudo port install py27-numpy +gcc46`	`sudo yum install python-numpy`

Once you have installed these dependencies, ISCE can be installed using the provided installation script (*Installing ISCE Only*) or manually (*Building ISCE*).

Note: On Linux distributions other than Ubuntu 12.04, users must identify equivalent packages to the ones listed above and use the correct package names in the *yum* or *apt* commands.

2.2 With Installation Script

This distribution includes a script that is designed to download, build and install all relevant packages needed for ISCE. The installation script is a bash script called *install.sh*, located in the setup directory of *ISCE_SRC*. Before running it, you should first `cd` to the setup directory. To get a quick help, issue the following command:

```
./install.sh -h
```

Note: To build all the dependencies, you need the following packages to be preinstalled on your computer: gcc, g++, make, m4. Use your favorite package manager to install them (see *Tested Platforms*).

2.2.1 Quick Installation

It is recommended to install ISCE and all its dependencies at the same time by means of the installation script. For quick installation, use *install.sh* with the -p option (-p as in prefix):

```
./install.sh -p INSTALL_FOLDER
```

where *INSTALL_FOLDER* is the ISCE root folder where everything will be installed. *INSTALL_FOLDER* should be a local directory away from the system areas to avoid conflicts and so that administration privileges are not needed.

Warning: Do not use ISCE_SRC or any directory within the source tree as the installation folder.

2.2.2 Understanding the Script

The *install.sh* bash script checks some system parameters before installing the dependencies and then ISCE.

1. The script checks for *gcc*, *g++*, *make* and *m4*, needed to build other packages. Your system should already come with both compilers *gcc* and *g++*. Any version will do. The required version of *gcc* (and *g++*) will be installed later by the script. *m4* is needed to create makefiles and *make* to run them. If you do not have any of those packages, you need to install it manually before using the installation script (see *Tested Platforms*).
2. The script checks that you have Python installed and that its version is later than the required one. The script will also look for the *Python.h* file to make sure that you have the development package of Python. If not, Python will be installed by the script.
3. The script downloads, unpacks, builds and installs all the relevant packages needed for ISCE (see *ISCE Prerequisites*). The file *setup_config.py* contains a list of places where the packages currently exist (i.e. where they should be downloaded from). By commenting out a particular package with a # at the beginning of the line, you can prevent that package from being installed, for example because an appropriate version is already installed on your system elsewhere. If the specified server for a particular package in this file is not available, then you can simply browse the web for a different server for this package and replace it in the *setup_config.py* file.
4. After checking some system parameters, the script generates a config file for *scons* to install ISCE, called *SConfigISCE*, located in the directory *$HOME/.isce*.
5. The script calls *scons* to install ISCE, using parameters from the *SConfigISCE* file.
6. Once ISCE is installed, a *.isceenv* file is placed in the directory *$HOME/.isce*. You have to source that file to export the environment variables each time you want to run ISCE: `source ~/.isce/.isceenv`

Note: If an error occurs during the installation, the script exits and displays an error message. Try to fix it or send a copy of the message to the ISCE team. Once the error is fixed, you can run the script again (see *Adding Options*).

2.2.3 Adding Options

You can pass some options to the script so that the installation does not start from the beginning. You might want to download or install some packages only, especially after an abnormal script termination. Or you might want to install ISCE only, if all the dependencies are already installed. Again, it is recommended to use the **quick installation** step ; add options to the script only if you want to save time or reinstall a few packages.

Choosing Your Dependencies

By default, the script will download, unpack and install all the dependencies given in the *setup_config.py* file. If at some point, any of the dependencies has already been downloaded, unpacked or installed in the *INSTALL_FOLDER*, you can control the behaviour of the script with three extra options: -d -u -i, along with the -p option.

- `-d DEP_LIST`: download the list of dependencies
- `-u DEP_LIST`: unpack the list of dependencies
- `-i DEP_LIST`: install the list of dependencies

where *DEP_LIST* can be **ALL | NONE | dep1,dep2...** (a comma-separated string, with no space). The dependencies can be: **GMP,MPFR,MPC,GCC,SCONS,FFTW,SZIP,HDF5,NUMPY,H5PY**

You can thus customize the installation with the following command: `./install.sh -p INSTALL_FOLDER -d DEP_LIST -u DEP_LIST -i DEP_LIST`

Note that if an option is omitted, it defaults to NONE. But at least one of the three options (-d -u -i) has to be given, otherwise it equals to a quick installation.

-d) If a package has already been dowloaded to the *INSTALL_FOLDER*, you do not need to download it again. Specify only the packages you want to download with the **-d option** (those packages will then be untarred and installed).

-u) It might take time to untar some packages. You might want to skip that step if it has already been done inside the *INSTALL_FOLDER*. Specify only the dependencies that you want to unpack with the **-u option** (those dependencies will then be installed too). You do not need to pass those already given with the -d option.

-i) To install specific packages, pass them to the **-i option**. You do not need to pass those already given with the -d and -u options.

Note: At each step (download, unpack, install), the script processes all the specified packages before moving to the next step. If the script fails somewhere, you can just start from that step after fixing the bug.

Note: After installing the dependencies, the script will go on with the installation of ISCE, based on the generated *SConfigISCE* file.

Possible Combinations

The following table shows how you can combine the three options -d, -u and -i to customize the installation of the dependencies. In any case, ISCE will be built after the specified dependencies are installed.

-d	-u	-i	download	unpack	install
NONE	NONE	NONE	nothing	nothing	nothing
NONE	NONE	list I	nothing	nothing	list I
NONE	NONE	ALL	nothing	nothing	everything
NONE	list U	NONE	nothing	list U	list U
NONE	list U	list I	nothing	list U	lists U & I
NONE	list U	ALL	nothing	list U	everything
NONE	ALL	*	nothing	everything	everything
list D	NONE	NONE	list D	list D	list D
list D	NONE	list I	list D	list D	lists D & I
list D	NONE	ALL	list D	list D	everything
list D	list U	NONE	list D	lists D & U	lists D & U
list D	list U	list I	list D	lists D & U	lists D & U & I
list D	list U	ALL	list D	lists D & U	everything
list D	ALL	*	list D	everything	everything
ALL	*	*	everything	everything	everything

Note: Where NONE is present, you can just omit that option... except when all three are NONE: give at least one option with NONE to restrict the installation to the ISCE package. For example, the following combinations are equivalent: `-d NONE -u NONE -i NONE` and `-d NONE -i NONE` and `-i NONE`

Note: The symbol * means that the argument for that particular option does not matter.

Installing ISCE Only

If you have all the dependencies already installed, you might want to install the ISCE package only. Two possibilities are offered:

1. Pass NONE to the three options -d, -u and -i (see note in previous section): `./install.sh -p INSTALL_FOLDER -i NONE`

Here the script generates a SConfigISCE based on your system configuration and sets up the environment for the installation.

2. Pass the *SConfigISCE* file as an argument to the -c option: `./install.sh [-p INSTALL_FOLDER] -c SConfigISCE_FILE`

Here the environment variables are supposed to have been set up for the installation so that the script can find all it needs. You might need to pass the *INSTALL_FOLDER* with the -p option so the script knows where the dependencies have been installed.

Use the **-c option** if you have edited the *SConfigISCE* file generated by the script, e.g. to add path to X11 or Open Motif libraries. Or if you have created the *SConfigISCE* file manually, e.g. after a manual installation.

2.2.4 Tested Platforms

Warning: The following packages need to be preinstalled on your computer: gcc, g++, make, m4. If not, use a package manager to do so (check examples in the third column of the table below).

Warning: On a 64-bit platform, you need to have the C standard library so that gcc can generate code for 32-bit platform. To get it: `sudo apt-get install libc6-dev-i386` or `sudo yum install glibc-devel.i686` or `sudo zypper install glibc-devel-32bit`

Operating system	Platform	Installing prerequisites	Results
Ubuntu 10.04 lucid	32-bit	`sudo apt-get install gcc g++ make m4`	OK
Ubuntu 12.04 precise	64-bit	`sudo apt-get install gcc g++ make m4`	OK
Linux Mint 13 Maya	64-bit	`sudo apt-get install gcc g++ make m4`	OK
openSUSE 12.1	32-bit	`sudo zypper install gcc gcc-c++ make m4`	OK
Fedora 17 Desktop Edition	64-bit	`sudo yum install gcc gcc-c++ make m4`	OK
Mac OS X Lion 10.7.2	64-bit	*install Xcode*	OK
CentOS 6.3	64-bit	`sudo yum install gcc gcc-c++ make m4`	OK

2.3 Manual Installation

If you would prefer to install all the required packages by hand, read carefully the following sections and the installation guides accompanying the packages.

2.3.1 ISCE Prerequisites

To compile ISCE, you will first need the following prerequisites:

- gcc >= 4.3.5 (C, C++, and Fortran compiler collection)
- fftw 3.2.2 (Fourier transform routines)
- Python >= 2.6 (Interpreted programming language)
- scons >= 2.0.1 (Software build system)
- For COSMO-SkyMed support
  - hdf5 >= 1.8.5 (Library for the HDF5 scientific data file format)
  - h5py >= 1.3.1 (Python interface to the HDF5 library)

Many of these prerequisites are available through package managers such as *MacPorts*, *Homebrew* and *Fink* on the Mac OS X operating system, *yum* on Fedora Linux, and *apt-get/aptitude* on Ubuntu. The only prerequisites that require special build procedures is fftw 3.2.2, the remaining prerequisites can be installed using the package managers listed above. At the very minimum, you should attempt to build all of the prerequisites, as well as ISCE itself with a set of compilers from the same build/version. This will reduce the possibility of build-time and run-time issues.

Building gcc

Building gcc from source code can be a difficult undertaking. Refer to the detailed directions at http://gcc.gnu.org/install/ for further help.

On a Mac OS operating system, you can install Xcode to get gcc and some other tools. See https://developer.apple.com/xcode/

Building fftw-3.2.2

- Get fftw-3.2.2 from http://www.fftw.org/fftw-3.2.2.tar.gz
- Untar the file *fftw-3.2.2.tar.gz* using `tar -zxvf fftw-3.2.2.tar.gz`
- Go into the directory that was just created with `cd fftw-3.2.2`
- Configure the build process by running `./configure --enable-single --enable-shared --prefix=<directory>` where <directory> is the full path to an installation location where you have write access.
- Build the code using `make`
- Finally, install fftw using `make install`

Building python

- Get the Python source code from http://www.python.org/ftp/python/2.7.2/Python-2.7.2.tgz
- Untar the file *Python-2.7.2.tgz* using `tar -zxvf Python-2.7.2.tgz`
- Go into the directory that was just created with `cd Python-2.7.2`
- Configure the build process by running `./configure --prefix=<directory>` where <directory> is the full path to an installation location where you have write access.
- Build Python by typing `make`
- Install Python by typing `make install`

Building scons

Warning: Ensure that you build scons using the python executable built in the previous step!

- Get scons from http://prdownloads.sourceforge.net/scons/scons-2.0.1.tar.gz
- Untar the file *scons-2.0.1.tar.gz* using `tar -zxvf scons-2.0.1.tar.gz`
- Go into the directory that was just created with `cd scons-2.0.1.tar.gz`
- Build scons by typing `python setup.py build`
- Install scons by typing `python setup.py install`

Building hdf5

Note: Only necessary for COSMO-SkyMed support

- Get the source code from http://www.hdfgroup.org/ftp/HDF5/releases/hdf5-1.8.8/src/hdf5-1.8.8.tar.gz
- Untar the file *hdf5-1.8.8.tar.gz* using `tar -zxvf hdf5.1.8.8.tar.gz`
- Go into the directory that was just created with `cd hdf5-1.8.8`
- Configure the build process by running `./configure --prefix=<directory>` where <directory> is the full path to an installation location where you have write access.
- Build hdf5 by typing `make`
- Install hdf5 by typing `make install`

Building h5py

Note: Only necessary for COSMO-SkyMed support

Warning: Ensure that you have Numpy and HDF5 already installed

Warning: Ensure that you build h5py using the python executable built in a few steps back!

- Get the h5py source code from http://h5py.googlecode.com/files/h5py-1.3.1.tar.gz
- Untar the file *h5py-1.3.1.tar.gz* using `tar -zxvf h5py-1.3.1.tar.gz`
- Go into the directory that was just created with `cd h5py-1.3.1`
- Configure the build process by running `python setup.py configure -hdf5=<HDF5_DIR>`
- Build h5py by typing `python setup.py build`
- Install h5py by typing `python setup.py install`

Note: Once all these packages are built, you must setup your PATH and LD_LIBRARY_PATH variables in the unix shell to ensure that these packages are used for compiling and linking rather than the default system packages.

Note: If you use a pre-installed version of python to build numpy or h5py, you might need to have write access to the folder *dist-packages* or *site-packages* of python. If you are not root, you can install a python package in another folder and setup PYTHONPATH variable to point to the *site-packages* of that folder.

2.3.2 Building ISCE

Creating *SConfigISCE* File

Scons requires that configuration information be present in a directory specified by the environment variable SCONS_CONFIG_DIR. First, create a build configuration file, called *SConfigISCE* and place it in your chosen SCONS_CONFIG_DIR. The *SConfigISCE* file should contain the following information, note that the #-symbol denotes a comment and does not need to be present in the *SConfigISCE* file.:

```
# The directory in which ISCE will be built
PRJ_SCONS_BUILD = $HOME/build/isce-build
# The directory into which ISCE will be installed
PRJ_SCONS_INSTALL = $HOME/isce
# The location of libraries, such as libstdc++, libfftw3
LIBPATH = $HOME/lib64 $HOME/lib
# The location of Python.h
CPPPATH = $HOME/include/python2.7
# The location of your Fortran compiler
FORTRAN = $HOME/bin/gfortran
# The location of your C compiler
CC = $HOME/bin/gcc
# The location of your C++ compiler
CXX = $HOME/bin/g++

#libraries needed for mdx display utility
MOTIFLIBPATH = /opt/local/lib     # path to libXm.dylib
X11LIBPATH = /opt/local/lib       # path to libXt.dylib
MOTIFINCPATH = /opt/local/include # path to location of the Xm directory with .h files
X11INCPATH = /opt/local/include   # path to location of the X11 directory with .h files
```

Warning: The C, C++, and Fortran compilers should all be the same version to avoid build and run-time issues.

Installing ISCE

Untar the file *isce.tar.gz* to the folder *ISCE_SRC*

Now, ensure that your PYTHONPATH environment variable includes the ISCE configuration directory located in the ISCE source tree e.g.

```
export PYTHONPATH=<ISCE_SRC>/configuration
```

Create the environment variable SCONS_CONFIG_DIR that contains the path where *SConfigISCE* is stored:

```
export SCONS_CONFIG_DIR=<PATH_TO_SConfigISCE_FOLDER>
```

Warning: The path for SCONS_CONFIG_DIR should not end with '/'

Note: The configuration folder and SCONS_CONFIG_DIR are only required during the ISCE build phase, and is not needed once ISCE is installed.

Once everything is setup appropriately, issue the command

```
scons install
```

from the root of the isce source tree. This will build the necessary components into the directory specified in the configuration file as PRJ_SCONS_BUILD and install them into the location specified by PRJ_SCONS_INSTALL.

Setting Up Environment Variables

After the installation, each time you want to run ISCE, you need to setup PYTHONPATH and add a new environment variable ISCE_HOME:

`export ISCE_HOME=<isce_directory>` where <isce_directory> is the directory specified in the configuration file as PRJ_SCONS_INSTALL `export PYTHONPATH=$ISCE_HOME/components; <parent_of_isce_directory>` where <parent_of_isce_directory> is the parent directory of ISCE_HOME.

2.4 Special Notes on Creating Documentation

2.4.1 Generating Documentation

ISCE documentation is generated from rst files that are based on the markup syntax called reStructuredText.

To generate the documentation, navigate to the *docs/manual* folder inside the ISCE source tree. There, use the Makefile: `make html` or `make latexpdf` according to the type of output you want. Issue the command `make` to have a list of available output types.

2.4.2 Prerequisites

To convert rst files, you need to have Sphinx installed (get it with your package manager or from Sphinx website).

If you want to build Sphinx from source, you might need to have Python compiled with zlib and the Python module setuptools. To generate LaTex files, install first the LaTex software.

CHAPTER

THREE

RUNNING ISCE

Once everything is installed, you will need to set up a few environment variables to run the scripts included in ISCE (see *Setting Up Environment Variables*):

```
export ISCE_HOME=<isce_directory>
export PYTHONPATH=$ISCE_HOME/applications:$ISCE_HOME/components
```

where <isce_directory> is the directory specified in the *SConfigISCE* file as PRJ_SCONS_INSTALL, usually $HOME/isce

If you have installed ISCE using the installation script, you can simply source the *.isceenv* file located in the $HOME/.isce folder.

3.1 Interferometry with insarApp

The standard interferometric processing script is *insarApp.py*, which is invoked with the command:

```
$ISCE_HOME/applications/insarApp.py insar.xml
```

where *insar.xml* (or whatever you would like to call it) contains input parameters (known as "properties") and names of supporting input xml files (known as "catalogs") needed to run the script.

Warning: Before issuing the above command, navigate first to the output folder where all the generated files will be written to.

3.1.1 Input Xml File

The input xml file that is passed to *insarApp.py* describes the data needed to generate an interferogram, which basically are:

- a pair of images taken from the same scene, one is called *master* and the other *slave*,
- a digital elevation model (DEM) of the same area.

The input data are restricted to image products as provided by the vendor (mostly Level 0 products), accompanied by their metadata i.e., header files. ISCE supports the following sensors: ALOS, COSMO_SKYMED, ERS, ENVISAT, JERS, RADARSAT1, RADARSAT2, TERRASARX, GENERIC. The DEM is not mandatory since the application can download a suitable one from the SRTM database.

In the ISCE distribution, there is a subdirectory called *"examples/"* that contains sample xml input files specific to *insarApp.py* for several of the supported satellites.

Describing the Input Data

Even though the overall structure of the xml file is fixed, the information needed to describe the input data depends on the sensor that is used.

For example, for the ALOS satellite, *insar.xml* would look as follows:

```
<?xml version="1.0" encoding="UTF-8"?>
<insarApp>
<component name="insar">
    <property name="Sensor Name">
        <value>ALOS</value>
    </property>
    <component name="Master">
        <property name="IMAGEFILE">
            <value>../ALOS2/IMG-HH-ALPSRP028910640-H1.0__A</value>
        </property>
        <property name="LEADERFILE">
            <value>../ALOS2/LED-ALPSRP028910640-H1.0__A</value>
        </property>
        <property name="OUTPUT">
            <value>master.raw</value>
        </property>
    </component>
    <component name="Slave">
        <property name="IMAGEFILE">
            <value>../ALOS2/IMG-HH-ALPSRP042330640-H1.0__A</value>
        </property>
        <property name="LEADERFILE">
            <value>../ALOS2/LED-ALPSRP042330640-H1.0__A</value>
        </property>
        <property name="OUTPUT">
            <value>slave.raw</value>
        </property>
    </component>
    <component name="Dem">
        <catalog>dem.xml</catalog>
    </component>
</component>
</insarApp>
```

insarApp accepts the following properties in the *insar.xml* file:

Property	Note	Description
Sensor Name	M	Name of the sensor (ALOS, ENVISAT, ERS...)
Doppler Method	D	Doppler calculation method. Can be: useDOPIQ (*default*), useCalcDop, useDoppler
Azimuth Patch Size	C	Size of overlap/save patch size for formslc
Number of Patches	C	Number of patches to process of all available patches
Patch Valid Pulses	C	Number of good lines per patch
Posting	D	Pixel size of the resampled image (*default*: 15)
Unwrap	D	If True (*default*), performs the unwrapping
useHighResolutionDe-mOnly	D	If True, only download dem if SRTM high res dem is available. (*default*: False)

Notes:
M: This property is mandatory.

C: This property is optional and its value is calculated by *insarApp*, if not specified.

D: This property is optional and uses the default value, if not specified.

The following components are also accepted by the application:

Property	Note	Description
Master	S	Description of the first image
Slave	S	Description of the second image
Dem	O	Description of the DEM

Notes:

S: The Master and Slave components are mandatory. Their properties (e.g. IMAGEFILE, LEADERFILE, etc.) depend on the sensor type.

O: The DEM component is optional. If not specified, the application will try to download one from the SRTM database.

Describing the DEM

The file *dem.xml* is a catalog that specifies the parameters describing a DEM which is to be used to remove the topographic phase in the interferogram. Presently ISCE supports only one format for DEM (short integer equiangular projection). The xml file should contain the following information:

```
<component>
    <name>Dem</name>
    <property>
        <name>DATA_TYPE</name>
        <value>SHORT</value>
    </property>
    <property>
        <name>TILE_HEIGHT</name>
        <value>1</value>
    </property>
    <property>
        <name>WIDTH</name>
        <value>3601</value>
    </property>
    <property>
        <name>FILE_NAME</name>
        <value>SaltonSea.dem</value>
    </property>
    <property>
        <name>ACCESS_MODE</name>
        <value>read</value>
    </property>
    <property>
        <name>DELTA_LONGITUDE</name>
        <value>0.000833333</value>
    </property>
    <property>
        <name>DELTA_LATITUDE</name>
        <value>-0.000833333</value>
    </property>
    <property>
        <name>FIRST_LONGITUDE</name>
        <value>-117.0</value>
    </property>
    <property>
        <name>FIRST_LATITUDE</name>
        <value>34.0</value>
    </property>
</component>
```

If a DEM component is given and the DEM is referenced to the EGM96 datum (which is the case for SRTM DEMs), the DEM component will be converted into WGS84 datum. A new DEM file with suffix *wgs84* is created. If the given DEM is already referenced to the WGS84 datum no conversion occurs.

If a DEM compoenent is not given in the input file, *insarApp.py* attempts to download a suitable DEM from the publicly available SRTM database. After downloading and datum-converting the DEM, there will be two files, a EGM96 SRTM DEM with no suffix and a WGS84 SRTM DEM with the *wgs84* suffix. If no DEM component is specified and no SRTM data exists, *insarApp.py* cannot produce any geocoded or topo-corrected products.

There are a number of optional input parameters that are specifiably in the input file. They control how the processing is done. *insarApp.py* picks reasonable defaults for these, and for the most part they do not need to be set by the user. See the examples directory for specification and usage.

In order to run the interferometric application, the user is assumed to have gathered all needed data (master and slave images, with their metadata, and optionnally a DEM) and generated the xml files (*insar.xml* and, if a DEM is given, *dem.xml*). In the near future (as of July 2012), the distribution will include a script to guide the user in the generation of xml input files.

3.1.2 Input Arguments

Alternatively, the user can choose to pass arguments and options directly in the command line when calling *insarApp.py*:

```
python $ISCE_HOME/applications/insarApp.py LIST_OF_ARGS
```

where LIST_OF_ARGS is a list of arguments that will be parsed by the application.

The arguments have to be passed as a pair of key and value in this form: `key=value` where *key* represents the name of the attribute whose value is to be specified, e.g. `insarApp.sensorName=ALOS`. The above xml file parameters would look like this in the command line:

```
python $ISCE_HOME/applications/insarApp.py insarApp.sensorName=ALOS
   insarApp.Master.imagefile=../ALOS2/IMG-HH-ALPSRP028910640-H1.0__A
   insarApp.Master.leaderfile=../ALOS2/LED-ALPSRP028910640-H1.0__A
   insarApp.Master.output=master.raw
   insarApp.Slave.imagefile=../ALOS2/IMG-HH-ALPSRP042330640-H1.0__A
   insarApp.Slave.leaderfile=../ALOS2/LED-ALPSRP042330640-H1.0__A
   insarApp.Slave.output=slave.raw
   insarApp.Dem.dataType=SHORT
   insarApp.Dem.tileHeight=1
   insarApp.Dem.width=3601
   insarApp.Dem.filename=SaltonSea.dem
   insarApp.Dem.accessMode=read
   insarApp.Dem.deltaLongitude=0.000833333
   insarApp.Dem.deltaLatitude=-0.000833333
   insarApp.Dem.firstLongitude=-117.0
   insarApp.Dem.firstLatitude=34.0
```

As it can be seen, passing all the arguments might be painstaking and requires the user to know the private name of each attribute. That is why it is recommended to use an xml file instead.

3.2 Comparison Between ROI_PAC and ISCE Parameters

The following table, valid as of July 1, 2012, shows the parameters used within ROI_PAC and their equivalents in ISCE.

ROI_PAC Name	ISCE Name	Type	Description	Defaults
<no equivalent>	Sensor Name	property	Name of satellite from which data was taken	None (could be “ERS1”, “ERS2”, “Envisat”, “ALOS”, “Terrasar-X”, “Cosmo-Skymed”, “Radarsat-1”, “Radarsat-2”)
<no equivalent>	Debug	property	Switch to enable debugging logging	None
<no equivalent>	Posting	property	Output posting of the Geocoded file	None (use DEM natural posting)
im1	Image Raw Data File	property	File name of the master raw data file	None
im2	Image Raw Data File	property	File name of the slave raw data file	None
SarDir1	<no equivalent>	N/A	Directory containing master raw data file and derived products	N/A
SarDir2	<no equivalent>	N/A	Directory containing slsave raw data file and derived products	N/A
IntDir	<no equivalent>	N/A	Directory containing interferometric data produces	N/A
SimDir	<no equivalent>	N/A	Directory containing simulations to be used; create if necessary	N/A
DEM	Dem	Component	Component that allows different DEM file types to be imported	None
	needs xml description file	Catalog	Separate file that describes the DEM and its properties	None
			alternatively specify all DEM properties, including file name,	
			datum, coordinate system etc, bounding box, etc. in top-level catalog	
GeoDir	<no equivalent>	N/A	Directory containing geocoded output create if necessary	N/A

Continued on next page

Table 3.1 – continued from previous page

ROI_PAC Name	ISCE Name	Type	Description	Defaults
FilterStrength	Adaptive Filter Weight	property	Goldstein-Werner adaptive filter alpha weight	0.5 (must be > 0)
UnwrappedThreshold	Unwrapping Correlation Threshold	property	Correlation value below which to not unwrap	0.1 (0-1)
OrbitType	Orbit Type	property of Frame	Format of orbit file used to process data	None
BaselineType	Baseline Type	N/A	Format of baseline	$OrbitType
Rlooks_sim*	Range Looks for Simulation	property	Number of range looks to take relative to SLC spacing in simulation	4
Rlooks_int*	Range Looks for Interferogram	property	Number of range looks to take relative to SLC spacing in interferogram	$Rlooks_sim
Rlooks_unw*	Range Looks for Unwrapping	property	Number of range looks to take relative to SLC spacing in unwrapped	$Rlooks_sim
Rlooks_sml**	Range Looks for Thumbnails	property	Number of range looks to take for thumbnail images	16
Alooks_sml**	Azimuth Looks for Thumbnails	property	Number of range looks to take for thumbnail images	$Rlooks_sml*$pixel_ratio
pixel_ratio*	Pixel Aspect Ratio	property	Intrinsic aspect ratio for all interferometric data	5 (should be sensor/mode dependent)
	(Azimuth looks / Range looks)			
usergivendop1	<no equivalent>	property	Actually not used, but a method to set a fixed Doppler for processing	0
usergivendop2	<no equivalent>	property	Actually not used, but a method to set a fixed Doppler for processing	0
unw_seedx*	Unwrapping Seed Coordinates	property	Range,Azimuth pixel coordinate to place unwrapping seed	None
unw_seedy*	Would be a coordinate pair in ISCE			
x_start*	Coarse Offset between SLC Images	property	Range, Azimuth pixel offset to coarsely align two SLC images	None
y_start*	Would be a coordinate pair in ISCE			

Continued on next page

Table 3.1 – continued from previous page

ROI_PAC Name	ISCE Name	Type	Description	Defaults
Threshold_mag**	Magnitude Threshold for Unwrapping	property	Magnitude threshold to use in creating a mask for unwrapping	5.0e-5
Threshold_ph_grd**	Phase Gradient Threshold for Unwrapping	property	Magnitude threshold to use in creating a mask for unwrapping	5.0e-5
sigma_thresh**	Phase Sigma Threshold for Unwrapping	property	Magnitude threshold to use in creating a mask for unwrapping	5.0e-5
slope_width**	Slope Resolution for Thresholding	property	Magnitude threshold to use in creating a mask for unwrapping	5.0e-5
smooth_width**	Smoothing Resolutino for Thresholding	property	Magnitude threshold to use in creating a mask for unwrapping	5.0e-5
concurrent_roi	<no equivalent>	N/A	If yes, kick off two roi jobs simultaneously	no
mapping	<no equivalent>	N/A	Uses a DEM to computer mapping from DEM to radar coordinates	dem_based (other option: “inverse”)
cleanup	<no equivalent>	N/A	Remove large intermediate files if set to yes	no
CO_MODEL**	Coseismic Model	component	Component that allows various Co-Seismic model files to be imported	None
	needs xml description file	catalog	Separate file that describes the model and its properties	None
			alternatively specify all model properties, including file name,	
			datum, coordinate system etc, bounding box, etc. in top-level catalog	
INTER_MODEL**	Interseismic Model	component	Component that allows various interseismic model files to be imported	None
	needs xml description file	catalog	Separate file that describes the model and its properties	None
			alternatively specify all model properties, including file name,	

Continued on next page

Table 3.1 – continued from previous page

ROI_PAC Name	ISCE Name	Type	Description	Defaults
			datum, coordinate system etc, bounding box, etc. in top-level catalog	
Filt_method*	Adaptive Filter Method	property	Version smoothing of interferogram to employ	psfilt (other options: "adapt_filt", "Nons")
unw_method	Unwrapping Method	property	Unwrapping method to use	old (other options are "icu", "snaphu")
flattening	<no equivalent>	N/A	In ROIPAC, selects either to use TOPO or reference surface to flatten	topo (other option: "orbit")
do_sim	Topo Simulation File Name	property	If file name is specified, use it as source for simulation output	None
do_mod	Coseismic Simulation File Name	property	If file name is specified, use it as source for simulation output	None
<no equivalent>	Interseismic Simulation File Name	property	If file name is specified, use it as source for simulation output	None
unw_mod	Not sure what this is	yes (other option: "no")		
MAN_CUT	Unwrapping Cuts File Name	property	Filename of man_cut (for SIM)	None
BaselineOrder	Polynomial Order for Baseline Fit	property	Self explanatory	QUAD (other option: "LIN")
MPI_PARA	<no equivalent>	N/A	Unsupported parallelization flag	N/A
NUM_PROC	<no equivalent>	N/A	Unsupported number of parallel cores to use	N/A
ROMIO	<no equivalent>	N/A	Unsupported parallel IO specification variable	N/A
ref_height**	Reference Height	property	Reference height to use for initial flattening and mocomp	0.
before_z_ext*	Azimuth Processing Advancement	property	Percent of synthetic aperture length to extend earlier in time	None (0-100%)
after_z_ext*	Azimuth Processing Extension	property	Percent of synthetic aperture length to extend later in time	None (0-100%)
near_rng_ext*	Range Processing Advancement	property	Percent of chirp length to extend earlier in time	None (0-100%)
far_rng_ext*	Range Processing Extension	property	Percent of chirp length to extend later in time	None (0-100%)

Continued on next page

Table 3.1 – continued from previous page

ROI_PAC Name	ISCE Name	Type	Description	Defaults
valid_samples	Valid Pulses in Patch	property	Number of pulses of azimuth circular convolution to save	None (up to Patch Size)
patch_size	Patch Size	property	Power of 2 size of patch for azimuth circular convolution processing	None (2k, 4k, 8k, etc.)
number_of_patches*	Number of Patches	property	Total number of patches to compute even if there are more available	None (1-N)
<no equivalent>	Doppler	component		
geo_files	<no equivalent>	property	Flag to decide if all files should be geocoded or only some	twopass (other option: “all”)
geo_intfiles	<no equivalent>	property	Flag to decide if interferograms should be geocoded	no (other option: “yes”)

Legend:
** Not yet implemented in ISCE.
* Implemented in ISCE, but hardcoded at a lower level; not yet exposed to user.
N/A not applicable in ISCE

Types:
“property” is the ISCE name for an input parameter
“component” is the ISCE name for a collection of input parameters and other components that configure a function to be performed
“catalog” is the ISCE name for a parameter file

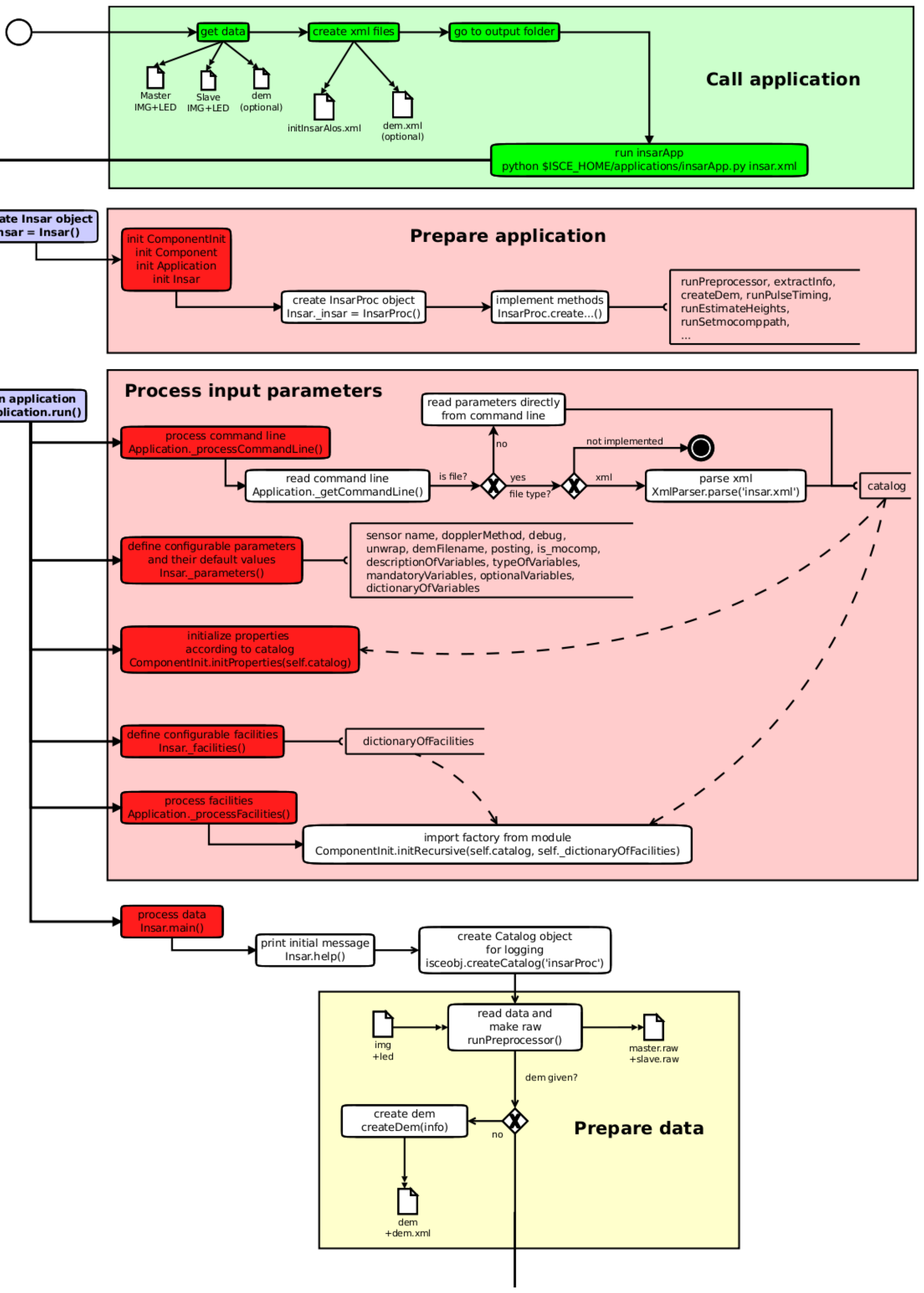
3.3 Process Workflow

Once the input data are ready (see previous sections), the user can run the *insarApp* application, which will generate an interferogram according to parameters given in the xml file.

The process invoked by *insarApp.py* can be broken down into several simple steps:

- *Preparing the application to run*
- *Processing the input parameters*
- *Preparing the data to be processed*
- *Running the interferometric application*

The following diagram gives an overview of the steps taken by the *insarApp* script to generate an interferogram, including the initial part under the user’s control (in green).


Call application
get data
create xml files
go to output folder
Master IMG+LED
Slave IMG+LED
dem (optional)
initInsarAlos.xml
dem.xml (optional)
run insarApp
python $ISCE_HOME/applications/insarApp.py insar.xml
create Insar object
insar = Insar()
Prepare application
init ComponentInit
init Component
init Application
init Insar
create InsarProc object
Insar._insar = InsarProc()
implement methods
InsarProc.create...()
runPreprocessor, extractInfo,
createDem, runPulseTiming,
runEstimateHeights,
runSetmocomppath,
...
run application
Application.run()
Process input parameters
process command line
Application._processCommandLine()
read command line
Application._getCommandLine()
is file?
no
yes
read parameters directly
from command line
file type?
not implemented
xml
parse xml
XmlParser.parse('insar.xml')
catalog
define configurable parameters
and their default values
Insar._parameters()
sensor name, dopplerMethod, debug,
unwrap, demFilename, posting, is_mocomp,
descriptionOfVariables, typeOfVariables,
mandatoryVariables, optionalVariables,
dictionaryOfVariables
initialize properties
according to catalog
ComponentInit.initProperties(self.catalog)
define configurable facilities
Insar._facilities()
dictionaryOfFacilities
process facilities
Application._processFacilities()
import factory from module
ComponentInit.initRecursive(self.catalog, self._dictionaryOfFacilities)
process data
Insar.main()
print initial message
Insar.help()
create Catalog object
for logging
isceobj.createCatalog('insarProc')
read data and
make raw
runPreprocessor()
img
+led
master.raw
+slave.raw
dem given?
no
create dem
createDem(info)
dem
+dem.xml
Prepare data

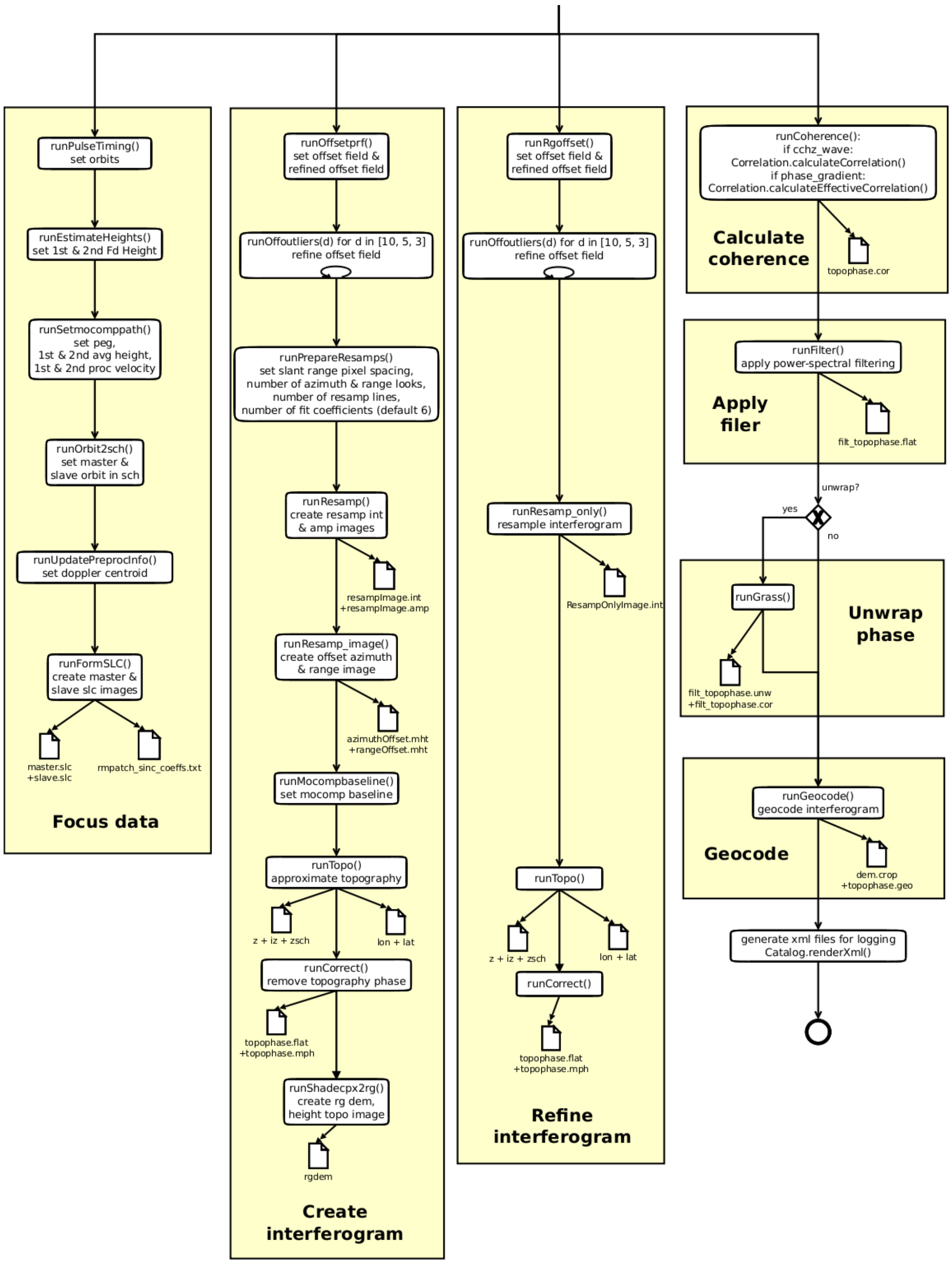


Fig. 3.1: insarApp workflow diagram

Convention: In the next sections where we describe the process more in detail, we use the following emphasis convention:

- *path/to/folder/*: path to a folder or a file (relative to $ISCE_HOME)
- *file.ext*: file name (the file path should be easily deduced from context)
- *variableName*: name of a variable used in the Python code
- `function()`: name of a function or a method
- **Class**: class name (if not given, the name of the file that implements it should be *class.py*)

3.3.1 Preparing the Application to Run

Once the required data have been gathered, the user can call *insarApp.py* with *insar.xml* as argument, where the xml file is an ASCII-file describing the input parameters. The python code starts by preparing the application to run while implementing all the methods needed to generate an interferogram.

When the user issues the command:

```
python $ISCE_HOME/applications/insarApp.py insar.xml
```

python starts by executing the `__main__` block inside *insarApp.py*. The first line of that block creates an **Insar** object called *insar*:

```
insar = Insar()
```

Note: The above command creates an instance of the **Insar** class (also known as an **Insar** object) and calls its `__init__()` method.

The **Insar** class, defined in *insarApp.py*, is a child class of **Application** that inherits from **Component**, which in turn derives from **ComponentInit**. Hence, when instantiated through its method `__init__()`, *insar* has all the properties and methods of its ancestors.

An object *_insar* of type **InsarProc** is then added to *insar*:

```
self._insar = InsarProc.InsarProc()
```

That object holds the properties, along with the methods (setters and getters) to modify and return their values, which will be useful for the interferometric process.

Using the **RunWrapper** class and the functions defined in *Factories.py*, the application will then wrap all the methods needed to run *insar*, e.g.:

```
self.runPreprocessor = InsarProc.createPreprocessor(self)
```

Note: The above command calls the function `createPreprocessor()`, found in *Factories.py* (imported by *__init__.py* inside *components/isceobj/InsarProc/*). It takes the function `runPreprocessor()` defined in *components/isceobj/InsarProc/runPreprocessor.py* and attaches it to the object *insar* by means of a **RunWrapper** object. Now, *insar* has an attribute called *runPreprocessor* which is linked to a function also called `runPreprocessor()`.

The methods thus defined become methods of *insar* and will be called later, directly from *insar*, to process the data.

Once the initialization is done, the code calls the method `run()` defined in **Application**, *insar*'s parent class:

```
insar.run()
```

3.3.2 Processing the Input Parameters

After the initialization of the application, the command line is processed to extract the argument(s) passed to *insarApp.py*. The application needs parameters to be given in order to run. Those input parameters can be passed directly in the command line or via an xml file (called e.g. *insar.xml*) and are used to initialize the properties and the facilities of the application.

Note: Only xml files are supported in the current distribution.

The command line is processed by **Application**'s method `_processCommandLine()`, which gets the command line and parses it through the method `commandLineParser()` of a **Parser** object *PA*. Since the passed argument refers to an xml file, *PA* calls the method `parse()` of an **XmlParser** instance.

The parsing is facilitated by the ElementTree XML API (module xml.etree.ElementTree) which reads the xml file and stores its content in an **ElementTree** object called *root*. *root* is then parsed recursively by a **Parser** object to extract the components and the properties inside the file (`parseComponent()`, `parseProperty()`). When done, we get a dictionary called *catalog*, containing a cascading set of dictionaries with all the properties included in the xml file(s). In our example, *catalog*'s content would look like this:

```
{ 'sensor name': 'ALOS',
  'Master': { 'imagefile': '../ALOS2/IMG-HH-ALPSRP028910640-H1.0__A',
              'leaderfile': '../ALOS2/LED-ALPSRP028910640-H1.0__A',
              'output': 'master.raw' },
  'Slave': { 'imagefile': '../ALOS2/IMG-HH-ALPSRP042330640-H1.0__A',
             'leaderfile': '../ALOS2/LED-ALPSRP042330640-H1.0__A',
             'output': 'slave.raw' },
  'Dem': { 'data_type': 'SHORT',
           'tile_height': 1,
           'width': 3601,
           'file_name': 'SaltonSea.dem',
           'access_mode': 'read'
           'delta_longitude': 0.000833333,
           'delta_latitude': -0.000833333,
           'first_longitude': -117.0,
           'first_latitude': 34.0 } }
```

Then, the application parameters are defined through *insar*'s method `_parameters()`: those are the parameters that can be configured in the input xml file. For each parameter, the following information is needed: private name (known to the application only), public name (disclosed to the user), type (int, string, etc.), units, default value (if parameter is omitted), mandatoriness (the parameter must be present in the xml file or not), description. Each and everyone of those parameters are represented by an attribute of the *insar* object, whose name is the parameter's private name and whose value is given by the parameter's default value. Also, we end up with several dictionaries (*descriptionOfVariables*, *typeOfVariables* and *dictionaryOfVariables*) and lists (*mandatoryVariables* and *optionalVariables*) that help organize the parameters according to their characteristics.

With the configurable parameters thus defined, the code calls `initProperties()` which checks *catalog*'s content and assigns the user's values to the given parameters.

Then, the application facilities are defined through *insar*'s method `_facilities()`. Facilities are objects whose class can only be determined when the code reads the user's parameters. Their nature cannot be hardcoded in advance, so that they will be created by the code at runtime using modules called factories. For *insarApp.py*, those facilities are *master* (master sensor), *slave* (slave sensor), *masterdop* (master doppler), *slavedop* (slave doppler) and *dem*. For each facility, the following information is needed: private name (known to the application only), public name (disclosed to the user), module (package where the factory is present), factory (name of the method capable of creating the facility), args and kwargs (additional arguments that the factory might need in order to create the facility), mandatoriness, description. Each and everyone of those facilities are represented by an attribute of the *insar* object, whose name is the facility's private name and whose value is an object of class **EmpytFacility**. The *dictionaryOfFacilities* is updated to reflect the list of facilities that can be configured in the input xml file.

Finally, the facilities are given their actual type and properties according to the user's parameters, with the method `_processFacilities()`.

3.3.3 Preparing the Data to Be Processed

The application needs to read and ingest the pair of image products with their header files and the given doppler method to produce raw data which will be processed later. If a dem has not been given, the application proceeds to download one from the SRTM database (make sure that you have an internet connection).

At this step, `run()` executes *insar*'s `main()` method which calls `help()` to output an initial message about the application and creates a **Catalog** object for logging purposes:

```
self.insarProcDoc = isceobj.createCatalog('insarProc')
```

The current time is also recorded in order to assess the duration of the following steps, the first of which is `runPreprocessor()`.

`runPreprocessor()` takes the four input facilities (*master*, *slave*, *masterdop* and *slavedop*) and generates one raw image for each pair of **Sensor** and **Doppler** objects: *master.raw* and *slave.raw* (the output names can be configured in the xml file). First, `runPreprocessor()` passes the pair *master/masterdop* to a `make_raw()` method - to avoid confusion, let's call it `insar.make_raw()`, which returns a **make_raw** object. To do that, `insar.make_raw()` creates a **make_raw** object (whose class is defined in *applications/make_raw.py*), wires the pair of facilities as input ports to that object and executes its `make_raw()` method - called `make_raw.make_raw()` to avoid confusion.

`make_raw.make_raw()` starts by activating the **make_raw** object's ports, i.e., adding *master* as its sensor attribute and *masterdop* as its doppler attribute. Then, it extracts the raw data from *master*. Here it is assumed that each supported sensor has implemented a method called `extractImage()`. For example, the **ALOS** class, defined in *components/isceobj/Sensor/ALOS.py*, expects four parameters, of which three are mandatory, to be given in the input xml file: IMAGEFILE, LEADERFILE, OUTPUT and RESAMPLE_FLAG (optional). `extractImage()` parses the *leaderfile* and the *imagefile*, extracts raw data to *output* (with resampling or not), creates the appropriate metadata objects with `populateMetadata()` (**Platform**, **Instrument**, **Frame**, **Orbit**, **Attitude** and **Distortion**) and generates a *.aux* file (*master.raw.aux*) with `readOrbitPulse()`. Once the raw data has been extracted, `make_raw.make_raw()` calculates the doppler values and fits a polynomial to those values by calling *masterdop*'s method `calculateDoppler()` and `fitDoppler()`. The Doppler polynomial coefficients and the pulse repetition frequency are then transferred to a **Doppler** object called *dopplerValues*. The spacecraft height and height_dt (`calculateHeighDt()`), velocity (`calculateVelocity()`) and squint angle (`calculateSquint()`) are also computed whereas the sensing start is adjusted according to values in the pulse timing *.aux* file (`adjustSensingStart()`).

Most of the attributes in the **make_raw** object are copied to a **RawImage** object, called *masterRaw*: filename, Xmin, Xmax, number of good bytes (Xmax - Xmin), width (Xmax). The same steps are done with the pair *slave/slavedop* as well. Finally, the following values are assigned to *_insar*'s attributes: *_masterRawImage*, *_slaveRawImage*, *_masterFrame*, *_slaveFrame*, *_masterDoppler*, *_slaveDoppler*, *_masterSquint*, *_slaveSquint*.

Once `runPreprocessor()` has been executed, *insar*'s `main()` method checks if a dem has been given. If not, it assesses the common geographic area between the master and slave frames, taking into account the master and slave squint angles, with the method `extractInfo()`. Then, `createDem()` downloads a DEM from the STRM database, generates an xml file and creates a **DemImage** object assigned to *_insar* as *_demImage*.

3.3.4 Running the Interferometric Application

Now that all the data and metadata are ready to get processed, we can proceed to the core of the interferometric application with the following steps:

1. data focussing
2. interferogram building
3. interferogram refining
4. coherence computing
5. filter application
6. phase unwrapping
7. geocoding

1. Data Focussing

   (a) *runPulseTiming*

   This wrapper is linked to the method `runPulseTiming()` which generates an interpolated orbit for each image (master and slave).

   From the master frame, the method `pulseTiming()` generates an **Orbit** object containing a list of **StateVector** objects - one for each range line in the frame. The state vectors are interpolated from the original orbit, using the Hermite interpolation scheme (a C code). The satellite's position and velocity are evaluated at the time of each pulse.

   Idem for the slave frame.

   The pair of pulse **Orbit** objects generated are assigned to *_insar* as *_masterOrbit* and *_slaveOrbit*.

   (b) *runEstimateHeights*

   This wrapper is linked to the method `runEstimateHeights()` which calculates the height and the velocity of the platform for each image (master and slave).

   For the master image (and then for the slave image), the code starts by instantiating a **CalcSchHeightVel** object using the function `createCalculateFdHeights()` defined in *components/stdproc/orbit/__init__.py*. The **CalcSchHeightVel** class is defined in *components/stdproc/orbit/orbitLib/CalcSchHeightVel.py*. Three input ports are wired to the **CalcSchHeightVel** object: *_masterFrame* (*_slaveFrame* for the slave image), *_masterOrbit* (*_slaveOrbit*) and *planet*. *planet* is extracted from *_masterFrame*. The **CalcSchHeightVel** object's method `calculate()` is then called, computing the height and the velocity of the platform.

   The computed master and slave heights are assigned to *_insar* as *_fdH1* (with `setFirstFdHeight()`) and *_fdH2* (with `setSecondFdHeight()`) respectively.

   (c) *runSetmocomppath*

   This wrapper is linked to the method `runSetmocomppath()` which selects a common motion compensation path for both images.

   The method begins with the instantiation of a **Setmocomppath** object using the function `createSetmocomppath()` found in *components/stdproc/orbit/__init__.py*. The **Setmocomppath** class is defined in *Setmocomppath.py*, located in the same folder. Three input ports are wired to the **Setmocomppath** object: *planet*, *_masterOrbit* and *_slaveOrbit*. Then, the method `setmocomppath()` of that object is executed: using a Fortran code, it takes the pair of orbits and picks a motion compensation trajectory. It returns a **Peg** object (representing a peg point with the following information: longitude, latitude, heading and radius of curvature), which is the average of the two peg points computed from the master orbit and the slave orbit. It gives also the average height and velocity of each platform.

   The computed peg, average heights and velocities are assigned to *_insar* as *_peg*, *_pegH1* (with `setFirstAverageHeight()`), *_pegH2* (with `setSecondAverageHeight()`), *_pegV1* (with `setFirstProcVelocity()`) and *_pegV2* (with `setSecondProcVelocity()`).

(d) *runOrbit2sch*

This wrapper is linked to the method `runOrbit2sch()` which converts the orbital state vectors of the master and slave orbits from xyz to sch coordinates.

For the master orbit (and then for the slave orbit), the method starts by instantiating an **Orbit2sch** object using the function `createOrbit2sch()` found in *components/stdproc/orbit/__init__.py*. The **Orbit2sch** class is defined in *Orbit2sch.py*, located in the same folder. The mean value of *_pegH1* and *_pegH2* (first and second average heights) is assigned to the **Orbit2sch** object while three input ports are wired to it: *planet*, *_masterOrbit* (*_slaveOrbit* for the slave image) and *_peg*. Then, the `orbit2sch()` method converts the coordinates of the orbit into the sch coordinate system, using a Fortran code. It returns an **Orbit** object with a list of **StateVector** objects whose coordinates are now in sch.

The two newly-computed orbits replace *_masterOrbit* and *_slaveOrbit* in *_insar*.

(e) *updatePreprocInfo*

This wrapper is linked to the method `runUpdatePreprocInfo()` that calls `runFdMocomp()` to calculate the motion compensation correction for Doppler centroid: here, it returns *fd*, the average correction for *masterOrbit* and *slaveOrbit*. *fd* is used as the fractional centroid of *averageDoppler*, which is the average of *_masterDoppler* and *_slaveDoppler* (the doppler centroids previously calculated in `runPreprocessor()`).

averageDoppler is then assigned to *_insar* as *_dopplerCentroid*.

(f) *runFormSLC*

This wrapper is linked to the method `runFormSLC()` which focuses the two raw images using a range-doppler algorithm with motion compensation.

For the master raw image (and then for the slave raw image), the method starts by instantiating a **Formslc** object using the function `createFormSLC()` found in *components/stdproc/stdproc/formslc/__init__.py*. The **Formslc** class is defined in *Formslc.py*, located in the same folder. Seven input ports are wired to the **Formslc** object: *_masterRawImage* (*_slaveRawImage*), *masterSlcImage* (*slaveSlcImage*), *_masterOrbit* (*_slaveOrbit*), *_masterFrame* (*_slaveFrame*), *planet*, *_masterDoppler* (*_slaveDoppler*) and *_peg*. The spacecraft height is set to the mean value of *_fdH1* (first Fd Height) and *_fdH2* (second Fd Height), and its velocity to the mean value of *_pegV1* (first Proc Velocity) and *_pegV2* (second Proc Velocity). The method `formslc()` of the **Formslc** object is then called, which generates a *.slc* file (*master.slc* and *slave.slc*).

The two generated **SlcImage** objects are assigned to *_insar* as *_masterSlcImage* and *_slaveSlcImage*, along with *_patchSize*, *_numberValidPulses* and *_numberPatches*. The two **Formslc** objects used to generate the slcs are also assigned to *_insar* as *_formSLC1* and *_formSLC2*.

2. Interferogram Building

(a) *runOffsetprf*

This wrapper is linked to the method `runOffsetprf()` which calculates the offset between the two slc images.

It starts by instantiating an **Offsetprf** object using the function `createOffsetprf()` found in *components/isceobj/Util/__init__.py*. The **Offsetprf** class is defined in *Offsetprf.py*, located in the same folder. The method `offsetprf()` of the **Offsetprf** object is then called, with *_masterSlcImage* and *_slaveSlcImage* passed as arguments. It returns, via a Fortran code, an **OffsetField** object which compiles a list of **Offset** objects, each describing the coordinates of an offset, its value in both directions (across and down) and the signal-to-noise ratio (SNR).

The computed **OffsetField** object is assigned to *_insar* twice: as *_offsetField* and *_refinedOffsetField*.

(b) *runOffoutliers*

This wrapper is linked to the method `runOffoutliers()` which culls outliers from the previously computed offset field. The offset field is approximated by a best fitting plane, and offsets are deemed to be outliers if they are greater than a user selected distance.

It is executed three times with a *distance* value set to 10, 5 then 3 meters. For each iteration, it makes use of an **Offoutliers** object, created by the function `createOffoutliers()` found in *components/isceobj/Util/__init__.py*. The **Offoutliers** class is defined in *Offoutliers.py*, located in the same folder. One input port is wired to the **Offouliers** object: *_refinedOffsetField*. The SNR is fixed to 2.0 while the distance is the value set at each iteration. The method `offoutliers()` of the **Offoutliers** object is then called and returns a new **OffsetField** object, replacing *_refinedOffsetField* in *_insar*.

(c) *prepareResamps*

This wrapper is linked to the method `runPrepareResamps()` which calculates some parametric values for resampling (slant range pixel spacing, number of azimuth looks, number of range looks, number of resamp lines) and fixes the number of fit coefficients to 6.

(d) *runResamp*

This wrapper is linked to the method `runResamp()` which resamples the interferogram based on the provided offset field.

It begins with the instantiation of a **Resamp** object, using the function `createResamp()` found in *components/stdproc/stdproc/resamp/__init__.py*. The **Resamp** class is defined in *Resamp.py*, located in the same folder. Two input ports are wired to the **Resamp** object: *_refinedOffsetField* and *instrument*, along with some more parameters. The method `resamp()` is then called with four input arguments: the two slcs as well as **AmpImage** and **IntImage** objects. Through a Fortran code, the two slcs are coregistered and processed to form an interferogram that is then multilooked according to the values calculated in the previous step. Two files are generated: *resampImage.amp* and *resampImage.int*.

The **AmpImage** and **IntImage** objects are assigned to *_insar* as *_resampAmpImage* and *_resampIntImage*.

(a) *runResamp_image*

This wrapper is linked to the method `runResamp_image()` which plots the offsets as an image.

It begins with the instantiation of a **Resamp_image** object using the function `createResamp_image()` found in *components/stdproc/stdproc/resamp_image/__init__.py*. The **Resamp_image** class is defined in *Resamp_image.py*, located in the same folder. Two input ports are wired to the **Resamp_image** object: *_refinedOffsetField* and *instrument*, along with some more parameters. Then, the method `resamp_image()` of that object is called with two **OffsetImage** objects as arguments (one accross and one down): using a Fortran code, that method takes the offsets and plots them as an image, generating two files: *azimuthOffset.mht* and *rangeOffset.mht*.

The accross **OffsetImage** and down **OffsetImage** objects are assigned to *_insar* as *_offsetRangeImage* and *_offsetAzimuthImage* respectively.

(a) *runMocompbaseline*

This wrapper is linked to the method `runMocompbaseline()` which calculates the mocomp baseline. It iterates over the S-component of the master image and interpolates linearly the SCH coordinates at the corresponding S-component in the slave image. The difference between the master SCH coordinates and the slave SCH coordinates provides a 3-D baseline.

It begins with the instantiation of a **Mocompbaseline** object using the function `createMocompbaseline()` found in *components/stdproc/orbit/__init__.py*. The **Mocompbaseline** class is defined in *Mocompbaseline.py*, located in the same folder. Four input ports are wired to the **Mocompbaseline** object: *_masterOrbit*, *_slaveOrbit*, *ellipsoid* and *_peg*, along with some more parameters. Then, the method `mocompbaseline()` of that object is called: using a Fortran code, that method gets the insar baseline from mocomp and position files, updating the properties of the **Mocompbaseline** object.

The **Mocompbaseline** object is assigned to *_insar* as *_mocompBaseline*.

(a) *runTopo*

This wrapper is linked to the method `runTopo()` which approximates the topography for each pixel of the interferogram.

At this step, *_resampIntImage* is duplicated as *_topoIntImage* inside *_insar*. Then the code starts by instantiating a **Topo** object using the function `createTopo()` found in *components/stdproc/stdproc/topo/__init__.py*. The **Topo** class is defined in *Topo.py*, located in the same folder. Five input ports are wired to the **Topo** object: *_peg*, *_masterFrame*, *planet*, *_demImage* and *_topoIntImage*, along with some more parameters. Then, the method `topo()` of that object is called: using a Fortran code, it approximates the topography and generates temporary files giving, for each pixel, the following values: latitude (*lat*), longitude (*lon*), height in SCH coordinates (*zsch*), real height in XYZ coordinates (*z*) and the height in XYZ coordinates rounded to the nearest integer (*iz*).

The **Topo** object is assigned to *_insar* as *_topo*.

(b) *runCorrect*

This wrapper is linked to the method `runCorrect()` which carries out a flat earth correction of the interferogram.

It starts by instantiating a **Correct** object using the function `createCorrect()` found in *components/stdproc/stdproc/correct/__init__.py*. The **Correct** class is defined in *Correct.py*, located in the same folder. Four input ports are wired to the **Correct** object: *_peg*, *_masterFrame*, *planet*, and *_topoIntImage*, along with some more parameters. Then, the method `correct()` of that object is called: using a Fortran code, it reads the interferogram and the SCH height file, and removes the topography phase from the interferogram. It generates two files: *topophase.flat* (the flattened interferogram) and *topophase.mph* (the topography phase).

(c) *runShadecpx2rg*

This wrapper is linked to the method `runShadecpx2rg()` which combines a shaded relief from the DEM in radar coordinates and the SAR complex magnitude image into a single two-band image.

It begins with the instantiation of a **Shadecpx2rg** object using the function `createShadecpx2rg()` found in *components/isceobj/Util/__init__.py*. The **Shadecpx2rg** class is defined in *Shadecpx2rg.py*, located in the same folder. After initializing some parameters, the method `shadecpx2rg()` of that object is called with four arguments: a **DemImage** object referencing the height file (*iz*), an **IntImage** object referencing the resampled amplitude image (*resampImage.amp*), an **IntImage** object referencing the Rg Dem image to be written (*rgdem*) and a shade factor equal to 3. Using a Fortran code, that method computes, for each pixel, a shade value and multiplies that factor to the magnitude value. It generates a file called *rgdem*.

The **RgImage** object referencing the file *rgdem* and the **DemImage** referencing the file *iz* are assigned to *_insar* as *_rgDemImage* and *_heightTopoImage* respectively.

13. Interferogram Refining

(a) *runRgoffset*

This wrapper is linked to the method `runRgoffset()` which estimates the subpixel offset between two images stored as one rg file.

It starts by instantiating an **Rgoffset** object using the function `createRgoffset()` found in *components/isceobj/Util/__init__.py*. The **Rgoffset** class is defined in *Rgoffset.py*, located in the same folder. After initializing some parameters, the method `rgoffset()` of that object is called with an **RgImage** object as argument, referencing the file *rgdem*.

It generates an **OffsetField** object that is assigned to *_insar*, replacing *_offsetField* and *_refinedOffsetField*.

(b) *runOffoutliers*

See step 8. This method culls outliers from the offset field. It is executed three times with a *distance* value set to 10, 5 then 3 meters.

(c) *runResamp_only*

This wrapper is linked to the method `runResamp_only()` which resamples the interferogram.

It begins with the instantiation of a **Resamp_only** object using the function `createResamp_only()` found in *components/stdproc/stdproc/resamp_only/__init__.py*. The **Resamp_only** class is defined in *Resamp_only.py*, located in the same folder. Two input ports are wired to the **Resamp_only** object: *_refinedOffsetField* and *instrument*, along with some more parameters. Then, the method `resamp_only()` of that object is called with two **IntImage** objects as arguments (one referencing the resampled interferogram *resampImage.int* to be read, and the other referencing a file called *resampOnlyImage.int* to be written): using a Fortran code, that method takes the interferogram and resamples it to coordinates set by offsets (*_refinedOffsetField*), generating a file called *resampOnlyImage.int*.

The **IntImage** object referencing the file *resampOnlyImage.int* is assigned to *_insar* as *_resampOnlyImage*.

(d) *runTopo*

At this step, *_resampOnlyImage* is duplicated as *_topoIntImage* inside *_insar*. Then the code approximates the topography as in step 13.

(e) *runCorrect*

See step 14.

16. Coherence Computation

(a) *runCoherence*

This wrapper is linked to the method `runCoherence()` which calculates the interferometric correlation.

It starts by instantiating a **Correlation** object, whose class is defined in *components/mroipac/correlation/correlation.py*. Two input ports are wired to that object: an **IntImage** referencing the file *topophase.flat* and an **AmpImage** object referencing the amplitude image *resampImage.amp*. One output port is also wired to that object: an **OffsetImage** object referencing a file called *topophase.cor* to be written. Then, one of the **Correlation** object's methods is executed: `calculateEffectiveCorrelation()` if method is 'phase_gradient', or `calculateCorrelation()` if method is 'cchz_wave'. Both rely on C codes to calculate the interferometric correlation.

Here the default method is 'phase_gradient': the script executes `calculateEffectiveCorrelation()`. That method uses the phase gradient to calculate the effective correlation:

- First, `phase_slope()` is called to calculate the phase gradient. It takes nine arguments: the interferogram filename (*topophase.flat*), the phase gradient filename (a temporary file to be written), the number of samples per row (interferogram width), the size of the window for the gradient calculation (default: 5), the gradient threshold for phase gradient masking (default: 0), the starting range pixel offset (0), the last range pixel offset (-1), the starting azimuth pixel offset (0) and the last azimuth pixel offset (-1).
- Then, `phase_mask()` is called to create the phase gradient mask. It takes eleven arguments: the interferogram filename, the phase gradient filename (the temporary file previously created), the phase standard deviation filename (a temporary file to be written), the standard deviation threshold for phase

gradient masking (default: 1), the number of samples per row, the range and azimuth smoothing window for the phase gradient (default: 5x5), the starting/last range/azimuth pixel offsets.

- Finally, `magnitude_threshold()` is called to threshold the phase file using the magnitude values in the coregistered interferogram. It takes five arguments: the interferogram filename, the phase standard deviation filename (the temporary file previously created), the output filename (*topophase.cor*), the magnitude threshold for phase gradient masking (default: 5e-5) and the number of samples per row.

The other method `calculateCorrelation()` uses the maximum likelihood estimator to calculate the correlation. It calls `cchz_wave()` which takes nine arguments: the interferogram filename, the amplitude filename (*resampImage.amp*), the output correlation filename (*topophase.cor*), the width of the interferogram file, the width of the triangular smoothing function (default: 5 pixels), the starting/last range/azimuth pixel offsets.

21. Filter Application

    (a) *runFilter*

    This wrapper is linked to the method `runFilter()` which applies the Goldstein-Werner power-spectral filter to the flattened interferogram.

    It starts by instantiating a **Filter** object, whose class is defined in *components/mroipac/filter/Filter.py*. One input port and one output port are wired to that object: an **IntImage** referencing the flattened interferogram (*topophase.flat*), and another **IntImage** object referencing the filtered interferogram to be created (*filt_topophase.flat*), respectively. Then, the method `goldsteinWerner()` is called with an argument *alpha*, representing the strength of the Goldstein-Werner filter (default: 0.5). That method applies a power-spectral smoother to the phase of the interferogram:

    - First, separate the magnitude and phase of the interferogram and save both bands.
    - Second, apply the power-spectral smoother to the original interferogram.
    - Third, take the phase regions that were zero in the original image and apply them to the smoothed phase.
    - Fourth, combine the smoothed phase with the original magnitude, since the power-spectral filter distorts the magnitude.

    The first steps are done with the method `psfilt()` while the last one is done with the method `rescale_magnitude()`. Both methods are based on C code.

    Now *_topophaseFlatFilename* in *_insar* is set to *filt_topophase.flat*.

22. Phase Unwrapping

    (a) *runGrass*

    This wrapper is linked to the method `runGrass()` which unwraps the filtered interferogram using the grass algorithm.

    This step is executed only if required by the user in the xml file. It starts by instantiating a **Grass** object, whose class is defined in *components/mroipac/grass/grass.py*. Two input ports are wired to that object: an **IntImage** referencing the filtered interferogram (*filt_topophase.flat*) and an **OffsetImage** object referencing the coherence image to be created (*filt_topophase.cor*). One output port is also wired to the **Grass** object: an **IntImage** object referencing the unwrapped interferogram to be created (*filt_topophase.unw*). Then, the method `unwrap()` is called:

    - First, it creates a flag file for masking out the areas of low correlation (default threshold: 0.1) calling the following C functions: `residues()`, `trees()` and `corr_flag()`.
    - Then, it unwraps the interferogram using the grass algorithm with the C function `grass()`.

23. Geocoding

    (a) *runGeocode*

    This wrapper is linked to the method `runGeocode()` which generates a geocoded interferogram.

    It begins with the instantiation of a **Geocode** object using the function `createGeocode()` found in *components/stdproc/rectify/__init__.py*. The **Geocode** class is defined in *Geocode.py*, located in the subfolder *components/stdproc/rectify/geocode/*. Five input ports are wired to the **Geocode** object: *_peg*, *_masterFrame*, *planet*, *_demImage* and an *IntImage* object referencing the filtered interferogram (*filt_topophase.flat*), along with some more parameters. Then, the method `geocode()` of that object is called: using a Fortran code, that method takes the interferogram and orthorectifies it (i.e., correcting its geometry so that it can fit a map with no distortions).

    Two files are generated at this step: a geocoded interferogram (*topophase.geo*) and a cropped dem (*dem.crop*).

After the interferometric process is done, the application stops the timer and returns the total time required to finish all the operations. Finally, it dumps all the metadata about the process into an *insarProc.xml* file:

```
self.insarProcDoc.renderXml()
```

CHAPTER

FOUR

IONOSPHERIC FARADAY ROTATION

4.1 Background

4.1.1 Motivation

Inhomogeneities in ionospheric structure such as plasma irregularities lead to distortions in low frequency (L-band and lower) Synthetic Aperture Radar (SAR) images *[FreSa04]*. These inhomogeneities hamper the interpretation of ground deformation when these SAR images are combined to form interferograms. To mitigate the effects of these distortions, *[Pi12]* outlined a methodology for the estimation and removal of ionospheric artifacts from individual, fully-polarimetric SAR images. The estimation methodology also provides a way to create temporal snapshots of ionospheric behavior with large (40km) spatial extent. To demonstrate these capabilities for fully polarimetric space-borne SAR to provide images of the ionosphere, we have developed computer software to implement the methodology outlined in *[Pi12]*.

4.1.2 Methodology behind ISSI

The measured scattering matrix from an L-band polarimetric SAR can be written as:

$$M = A(r,\theta)e^{i\phi}R^T R_F S R_F T + N, \tag{4.1}$$

with

$$\begin{aligned}
M &= \begin{pmatrix} M_{hh} & M_{hv} \\ M_{vh} & M_{vv} \end{pmatrix} \\
R^T &= \begin{pmatrix} 1 & \delta_1 \\ \delta_2 & f_1 \end{pmatrix} \\
R_F &= \begin{pmatrix} \cos\Omega & \sin\Omega \\ -\sin\Omega & \cos\Omega \end{pmatrix} \\
S &= \begin{pmatrix} S_{hh} & S_{hv} \\ S_{vh} & S_{vv} \end{pmatrix} \\
T &= \begin{pmatrix} 1 & \delta_3 \\ \delta_4 & f_2 \end{pmatrix}
\end{aligned}$$

where S_{ij} is the scattering matrix, $A(r,\theta)$ is the gain of the radar as a function of range and elevation angle, δ_i are the cross-talk parameters, f_i are the channel imbalances, and Ω is the Faraday rotation *[Fre04]*. By rearranging equation (4.1), we can apply the cross-talk and channel imbalance corrections while preserving the effects of Faraday rotation, yielding.

$$M' = R_F S R_F = \frac{1}{f_1 - \delta_1\delta_2}\frac{1}{f_1 - \delta_3\delta_4}\begin{pmatrix} f_1 & -\delta_2 \\ -\delta_1 & 1 \end{pmatrix} M \begin{pmatrix} f_2 & -\delta_3 \\ -\delta_4 & 1 \end{pmatrix}.$$

We can now use M', the partially-polarimetrically calibrated data matrix, to estimate the Faraday rotation using the method outlined in *[Bick65]*. We begin by transforming M' into a circular basis, yielding,

$$\begin{pmatrix} Z_{11} & Z_{12} \\ Z_{21} & Z_{22} \end{pmatrix} = \begin{pmatrix} 1 & i \\ i & 1 \end{pmatrix} M' \begin{pmatrix} 1 & i \\ i & 1 \end{pmatrix}. \tag{4.2}$$

The Faraday rotation can then be calculated as,

$$\Omega = \arg(Z_{12}Z_{21}^{*}) \tag{4.3}$$

Given a measurement of Faraday rotation and an estimate of the strength of the Earth's magnetic B-field, one can then estimate the Total Electron Count (TEC) using the relationship,

$$\int n_e B \cos\theta ds = \frac{\Omega f^2}{k}, \tag{4.4}$$

where $k = \frac{|e|^3}{8\pi^2 c\epsilon_0 m_e^2}$ with e being the elementary charge, c is the speed of light ϵ_0 is the permittivity of free space, m_e is the electron mass, n_e is the electron density, θ is the angle between the SAR signal propagation direction and the B-field and f is the carrier frequency of the radar. Since the the angle $theta$, does not change much along the path through the ionosphere, we can move the $B\cos\theta$ term out of the integral in equation (4.4). This allows us to rewrite equation (4.4) as,

$$TEC = \frac{\Omega f^2}{kB\cos\theta} \tag{4.5}$$

where $TEC = \int n_e ds$.

Ideally, we would calculate the strength of the Earth's B-field along the path from the radar to the ground at each pixel in the SAR image. Since, at the scale of a typical SAR image, the B-field is smoothly varying, we will make the assumption that we can approximate the effect of the magnetic field by using the *average* B-field value over the area of the SAR image. Additionally, we will make the assumption that B-field is homogeneous enough to allow us to replace the line-of-sight path integration with a vertical integration through the ionosphere. This is an assumption that can easily be changed in the future. We begin by calculating the geographic coordinates of the corners of our SAR image. Then, we estimate the total strength of the magnetic B-field in the direction of the radar line-of-sight in a vertical column above each geographic location. The average total strength of the magnetic B-field in radar line-of-sight is then used to calculate the TEC at each pixel in the SAR image using equation (4.5).

Finally, the phase change contribution to the SAR image from the Faraday rotation can be calculated using the estimate of TEC found from equation (4.5) as,

$$\begin{aligned} \phi_I &= -\frac{\omega}{2c}\int X ds \\ &= -\frac{2\pi}{c}\frac{e^2}{8\pi^2\epsilon_0 m_e f}\int n_e ds \\ &= \frac{8.45\times 10^{-7}}{f} TEC \end{aligned}$$

, where $X = \frac{\omega_p}{\omega}$, and $\omega_p = \left(\frac{n_e e^2}{\epsilon_0 m_e}\right)^{\frac{1}{2}}$ is the angular plasma frequency. This value can be calculated at each pixel in the SAR image.

4.2 Running ISSI

SAR data can be acquired from ground processing facilities as raster images of focused or unfocused radar echos. ISSI can accept either data format and produce images of Faraday rotation, TEC and phase delay. The most straightforward application of the ISSI methodology begins with focused and aligned SAR data, which typically comes in the form of single-look complex (SLC) images. These images are first rotated into a circular basis using equation (4.2), and an estimate of Faraday rotation is formed using equation (4.3). TEC and phase delay are then calculated using subsequent results.

When beginning with unfocused radar echos, we must first prepare SLC images, taking care to focus the radar echos using the same Doppler parameters for each transmit and receive polarity combination. Once SLC's have been produced, we must align each SLC by resampling the SAR data transmitted with vertical polarization such that it lies on the same pixel locations as the SAR data transmitted with horizontal polarization. Once these steps have been completed, we may proceed as before in converting the images to a circular basis and forming Faraday rotation, TEC and phase delay images.

As input to the ISSI scripts, we require a set of XML files. Begin by creating a file called *FR.xml* and put the following information in it:

```
<component>
  <property>
          <name>HH</name>
          <factoryname>createALOS</factoryname>
          <factorymodule>isceobj.Sensor</factorymodule>
          <value>HH.xml</value>
  </property>
  <property>
          <name>HV</name>
          <factoryname>createALOS</factoryname>
          <factorymodule>isceobj.Sensor</factorymodule>
          <value>HV.xml</value>
  </property>
  <property>
          <name>VH</name>
          <factoryname>createALOS</factoryname>
          <factorymodule>isceobj.Sensor</factorymodule>
          <value>VH.xml</value>
  </property>
  <property>
          <name>VV</name>
          <factoryname>createALOS</factoryname>
          <factorymodule>isceobj.Sensor</factorymodule>
          <value>VV.xml</value>
  </property>
</component>
```

Next, we will specify our output file names and options. Create a file called *output.xml* and put the following information in it:

```
<component>
 <property>
         <name>FILTER</name>
         <value>None</value>
 </property>
 <property>
         <name>FILTER_SIZE_X</name>
         <value>21</value>
 </property>
 <property>
         <name>FILTER_SIZE_Y</name>
         <value>11</value>
 </property>
 <property>
```

```
        <name>TEC</name>
        <value>tec.slc</value>
 </property>
 <property>
        <name>FARADAY_ROTATION</name>
        <value>fr.slc</value>
 </property>
 <property>
        <name>PHASE</name>
        <value>phase.slc</value>
 </property>
</component>
```

Finally, create four XML files, one for each polarity combination, *HH.xml*, *HV.xml*, *VH.xml* and *VV.xml*, and place the following information in them:

```
<component>
 <property>
        <name>LEADERFILE</name>
        <value>LED-ALPSRP016410640-P1.0__A</value>
 </property>
 <property>
        <name>IMAGEFILE</name>
        <value>IMG-HH-ALPSRP016410640-P1.0__A</value>
 </property>
</component>
```

We can now produce estimates of Faraday rotation, TEC and phase delay by running

```
$ISCE_HOME/applications/ISSI.py FR.xml output.xml
```

The code will create the Faraday rotation output in a file named fr.slc, TEC output in a file named tec.slc, and phase delay in a file named phase.slc.

4.3 ISSI in Detail

This section details the structure and usage of ISSI.py, an application within ISCE that performs polarimetric processing. It assumes that the user has already installed Python and ISCE successfully. ISSI.py was written over a year ago by a computer scientist, no longer contributing to the project at NASA JPL. As a result it is structured differently from most other scripts written by the current software developers. Unfortunately, this means that understanding the processing flow of ISSI.py is difficult, and other applications within ISCE do not serve as templates to help with the task. Also, the structure of this program is extremely object oriented, where executing a function in ISSI.py may call methods from up to five different Python scripts located elsewhere within ISCE's file structure. Thus, this task ultimately devolves to tracing out the processing flow as it takes you from script to script. Throughout this journey into ISSI.py we limit the depth of understanding to processing tasks directly relevant to polarimetric processing. Other components such as the wrapping process, the wrapped C and Fortran code itself, and computer resource management are worthy of mention, but we do not dig into the specifics of their operation. We treat these portions of the code as black boxes whose functionality is well understood.

The following diagram gives an overview of the steps taken by the ISSI scripts to calculate Faraday rotation, TEC and phase delay.

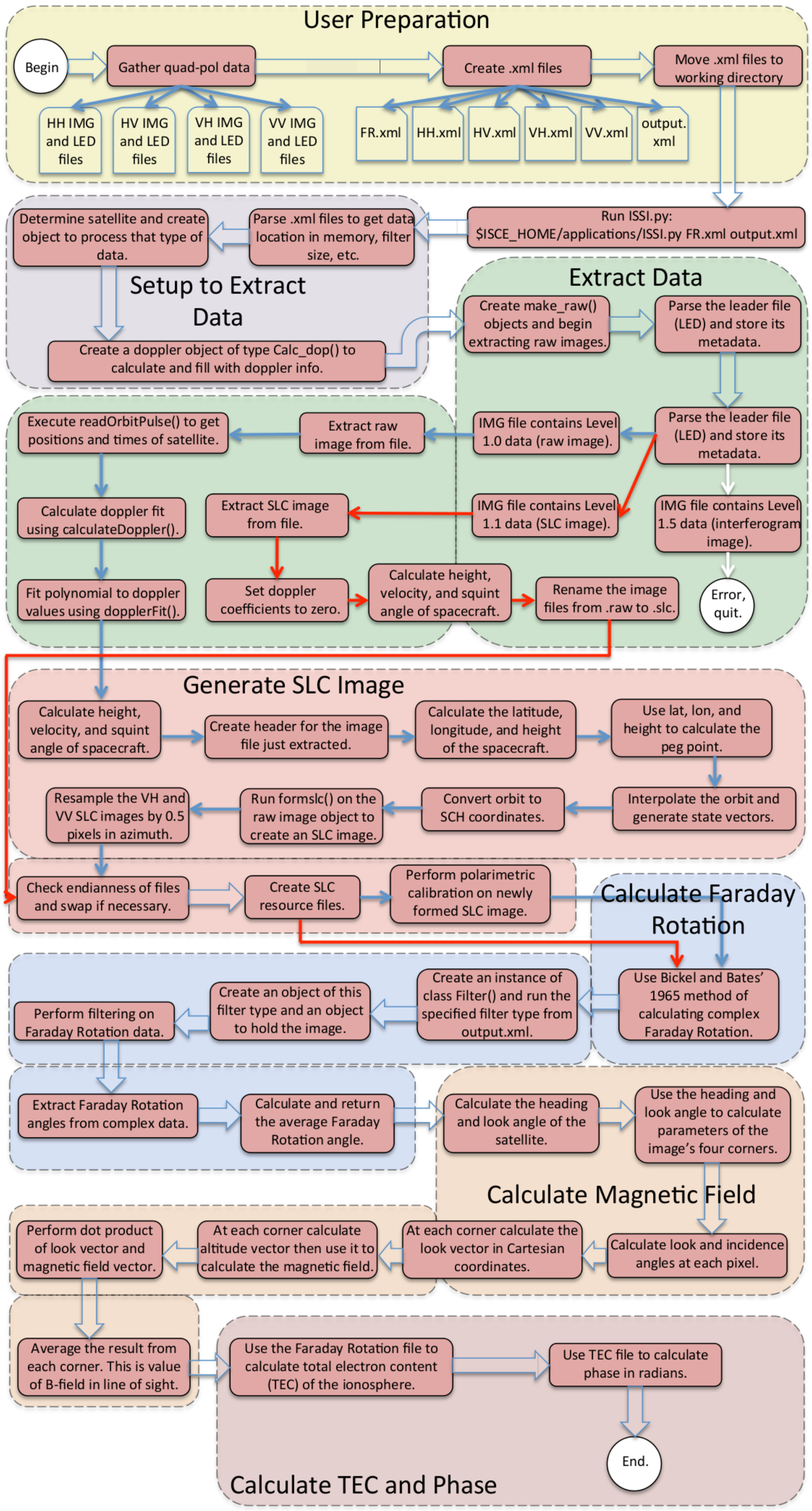

User Preparation
Begin
Gather quad-pol data
Create .xml files
Move .xml files to working directory
HH IMG and LED files
HV IMG and LED files
VH IMG and LED files
VV IMG and LED files
FR.xml
HH.xml
HV.xml
VH.xml
VV.xml
output.xml
Run ISSI.py: $ISCE_HOME/applications/ISSI.py FR.xml output.xml
Parse .xml files to get data location in memory, filter size, etc.
Determine satellite and create object to process that type of data.
Setup to Extract Data
Create a doppler object of type Calc_dop() to calculate and fill with doppler info.
Extract Data
Create make_raw() objects and begin extracting raw images.
Parse the leader file (LED) and store its metadata.
Parse the leader file (LED) and store its metadata.
IMG file contains Level 1.0 data (raw image).
Extract raw image from file.
Execute readOrbitPulse() to get positions and times of satellite.
IMG file contains Level 1.1 data (SLC image).
IMG file contains Level 1.5 data (interferogram image).
Extract SLC image from file.
Calculate doppler fit using calculateDoppler().
Fit polynomial to doppler values using dopplerFit().
Set doppler coefficients to zero.
Calculate height, velocity, and squint angle of spacecraft.
Rename the image files from .raw to .slc.
Error, quit.
Generate SLC Image
Calculate height, velocity, and squint angle of spacecraft.
Create header for the image file just extracted.
Calculate the latitude, longitude, and height of the spacecraft.
Use lat, lon, and height to calculate the peg point.
Interpolate the orbit and generate state vectors.
Convert orbit to SCH coordinates.
Run formslc() on the raw image object to create an SLC image.
Resample the VH and VV SLC images by 0.5 pixels in azimuth.
Check endianness of files and swap if necessary.
Create SLC resource files.
Perform polarimetric calibration on newly formed SLC image.
Calculate Faraday Rotation
Use Bickel and Bates' 1965 method of calculating complex Faraday Rotation.
Create an instance of class Filter() and run the specified filter type from output.xml.
Create an object of this filter type and an object to hold the image.
Perform filtering on Faraday Rotation data.
Extract Faraday Rotation angles from complex data.
Calculate and return the average Faraday Rotation angle.
Calculate the heading and look angle of the satellite.
Use the heading and look angle to calculate parameters of the image's four corners.
Calculate Magnetic Field
Calculate look and incidence angles at each pixel.
At each corner calculate the look vector in Cartesian coordinates.
At each corner calculate altitude vector then use it to calculate the magnetic field.
Perform dot product of look vector and magnetic field vector.
Average the result from each corner. This is value of B-field in line of sight.
Use the Faraday Rotation file to calculate total electron content (TEC) of the ionosphere.
Use TEC file to calculate phase in radians.
End.
Calculate TEC and Phase

Fig. 4.1: ISSI workflow diagram

4.3.1 Extracting Information from Xml Files

ISSI.py begins by running its `main()` method. It first creates an object called *fi* which is an instance of the class FactoryInit. FactoryInit is a class in FactoryInit.py whose methods and attributes allow the program to extract information found in the six xml files required for processing (FR.xml, output.xml, HH.xml, HV.xml, VH.xml, VV.xml; see *Running ISSI*). Whenever the program creates an instance of a Python class, it always runs the `__init__()` method found within that class' script. The FactoryInit class' `__init__()` method simply defines the attributes of the object and then returns to ISSI.py. In the remainder of the document, we gloss over this initialization process for other objects because they all follow identical procedures.

ISSI.py then extracts information from the first input argument, FR.xml. To do this it sets two attributes of *fi*, *fileInit* and *defaultInitModule*, to 'FR.xml' and 'InitFromXmlFile', respectively, and then runs the method `initComponentFromFile()`. FactoryInit.py contains the definition of `initComponentFromFile()` because it is a method of the FactoryInit class; it returns a dictionary with all information found within FR.xml. The function `getComponent()`, again inside FactoryInit.py, searches that dictionary and returns an instance of the Sensor (i.e., the satellite) class responsible for creating that particular data file defined as the input argument of `getComponent()`. ISSI.py supports different Sensor classes, and this guide follows the processing path assuming all four raw images are products of the ALOS/PALSAR mission. We therefore indicate by *hh*, *hv*, *vh* and *vv* the four instances of the class ALOS, found in ALOS.py.

At this point, ISSI.py moves to the second input argument, output.xml. Frustratingly, extracting information from this xml file requires a completely new object of class InitFromXmlFile, found in InitFromXmlFile.py. One of its methods called `init()` (**NOT** to be confused with `__init__()`) extracts information from output.xml and returns it to an attribute local to ISSI.py called *variables*. ISSI.py then distributes the information found in *variables* to other different local attributes, including filter size and file names to be used later, that serve as input variables to an instance of the class Focuser called *focuser*. `main()` in ISSI.py concludes by setting the *filter* and *filterSize* attributes of *focuser* and then running `focuser()`, a method in the Focuser class that begins processing the raw images.

`focuser()` begins by calling the function `useCalcDop()`, found in __init__.py, that instantiates and returns an instance, called *doppler*, of the class Calc_dop, found within Calc_dop.py. We see that `useCalcDop()` simply redirects the program to the class Calc_dop. The object *doppler* later provides the attributes and methods necessary to calculate Doppler information about the processed radar images.

4.3.2 Extracting Data from Input Files

Extraction of raw data from the input files begins with the creation of objects, called *hh.raw*, *hv.raw*, *vh.raw* and *vv.raw*, which hold the output raw data from the extraction process. Following this the program runs the method `make_raw()`, in ISSI.py, with both the raw data and Doppler objects passed as input arguments. The method `make_raw()` immediately creates an instance of the class make_raw, called *mr*. The class make_raw resides in another ISCE application named make_raw.py.

During the initialization of this class the program creates two input port objects. Port objects essentially serve as conduits between Python objects, allowing one to access the attributes of another. After generating *mr*, the method `make_raw()`, back in ISSI.py, finalizes the input ports by running the method `wireInputPort()`. The relevance of this method lies only with Python object communication rather than polarimetric radar processing, so we will not examine it in detail here. Finally, the object *mr* runs its own method called `make_raw()`.

Note: We pause here to show the importance of constant vigilance when working with ISCE components. Follow closely: we just ran ISSI.py's method called `make_raw()`, which then created an instance of the class make_raw, found in make_raw.py, which then ran `make_raw()`, a method of the class make_raw located in make_raw.py.

Then, in the `make_raw()` method of make_raw.py, the method `extractImage()` runs. The sensor class of the image file, in our case ALOS for all four polarized images, contains the method `extractImage()`. Note that the script ALOS.py contains definitions for not one but four different classes. The user must therefore look closely to see which methods in ALOS.py fall under which classes; this will become relevant soon.

`extracImage()` begins with if statements designed to ensure that the user passed correct xml and image files to ISSI.py. The first if statement ensures that the attributes *_imageFileList* and *_leaderFileList* are lists rather than strings. The second quits the program if the number of leader and image files is not the same. The final if statements protect against the case that an image file contains more than one image; if the user operates ISSI.py as instructed, these if statements should be inconsequential. The program then creates instances of three new classes: an instance of Frame, in Frame.py, called *frame*, and instances of the classes LeaderFile and ImageFile, called *leaderFile* and *imageFile*, respectively, both in ALOS.py. The input argument to initialization of the LeaderFile class is the leader file in memory.

The program then attempts to parse the leader file by running `parse()` on *leaderFile*. After opening the leader file in read mode, `parse()` then creates an instance of the class CEOSDB, in CEOS.py, called *leaderFDR*. An xml file containing the ALOS leader file record (also known as CEOS data file), provided already by ISCE, and the leader file itself serve as input arguments for the initialization of CEOSDB. During initialization a local variable called *rootChildren* stores an element tree of the information stored in the ALOS leader file record xml file. If the image file being processed comes from a spacecraft with no leader file record, *rootChildren* simply becomes an empty list.

With *leaderFDR* completely initialized, it runs its method `parse()`. `parse()` opens the ALOS leader file record and extracts any information it contains via an element tree; this user manual does not look any more closely at how ISSI.py parses xml files. Find documentation on element trees for more information. If values found within *leaderFDR*'s recently parsed metadata indicate to, the final lines of `parse()`, the method acting upon *leaderFile*, perform the same element tree parsing process on scene header, platform position, spacecraft attitude, and spacecraft calibration xml files, also all provided within ISCE. After closing the leader file, we return to `extractImage()` where *imageFile* submits itself to a similar parsing process, also called `parse()` but found under the class ImageFile.

Then, we open the image file and, just like before, create an instance of the class CEOSDB called *imageFDR*, run `parse()` on this object, set the number SAR channels as found in *imageFDR*'s metadata, and run `_calculateRawDimensions()` if the input argument *calculateRawDimensions* is true. For the ALOS case, *calculateRawDimensions* is false so the program skips over `_calculateRawDimensions()`. Finally, we close the image file and return to `extractImage()`.

The next portion of code decides whether the image ought to be resampled; it currently does not resample the image. Instead it moves on to run `extractImage()`, a method of the class ImageFile, on the image file itself. `extractImage()` checks the data type of the image file. If the data is Level 1.5, it raises an exception and exits the program. If the data is Level 1.1, a single-look-complex (SLC) image, it runs the method `extractSLC()`. Finally, if the data is Level 1.0, the original raw image, the program runs `extractRaw()`. Level 1.0 data is the most basic form of radar image, so we will explore this branch in order to ensure complete coverage of ISSI.py. If the processing facility for the image file is ERSDAC, the program runs the method `alose_Py()` to extract the raw image. If not, it runs `alos_Py()`.

Note: Whether the SLCs are resampled or not, a config.txt file is created giving image metadata in PolSARpro format.

Note: Whenever you encounter a method whose name ends with _Py, you have found the beginning of the wrapping process described elsewhere in ISCE.pdf. In the current case, alos_Py ultimately refers to a function found in ALOS_pre_process.c, one of the many pieces of original scientific software that inspired the ISCE project. Other sections of ISCE.pdf describe in detail the Python wrapping process, and understanding the source code is left to radar scientists. Therefore here we go no further into any method ending in _Py.

The methods `alos_Py()` and `alose_Py()` both perform the actual image extraction; look closely at ALOS_pre_process.c to understand how. After they run, the program sets some local variables and then runs a method `createRawImage()`. `createRawImage()` returns an instance of the class RawImage, in RawImageBase.py, called *rawImage*. The RawImage class serves as ISSI.py's means of storing and manipulating a raw image. The program creates a new instance of this class every time it needs to process a raw image in any way. After setting some attributes of *rawImage* with information from the raw image's metadata, it sets the raw image to be the image in the frame of the original ALOS sensor object. Frames can hold more than one image, however the design of ISSI.py ensures that each frame holds only one.

4.3.3 Pre-Focusing Calculations

Minor bookkeeping as well as orbit and Doppler calculations follow the data extraction procedure. `populateMetadata()`, a method of the ALOS class, first creates and fills metadata objects from the CEOS format metadata generated earlier. It is worth noting here that one of the methods in `populateMetadata()`, called `_populateDistortions()`, creates the transmit and receive polarimetric calibration distortion matrices. The polarimetric calibration process later implements these matrices during the formation of the SLC image.

The method `readOrbitPulse()`, with the leader file, image file, and image width as input parameters, prepares to calculate the ALOS positions and times of the raw image. The method creates instances of three image classes, RawImage, StreamImage, and Image, called *rawImage*, *leaImage* and *auxImage*, respectively. The class StreamImage holds and manipulates the leader file in memory while the Image class creates a generic image object. Each image object has an associated image accessor, which it passes to other objects, allowing them to access the image in memory. Finally, `readOrbitPulse()` runs three separate methods called `setNumberBitesPerLine_Py()`, `setNumberLines_Py()` and `readOrbitPulse_Py()`. These methods wrap Fortran source code that fills *auxImage* with an auxiliary file of file extension .raw.aux, containing the ALOS positions and times of the raw image. After this process, the method finalizes the three image objects and returns to `extractImage()`. The program appends the frame created earlier to the list of frames in memory and then returns to `make_raw()` to begin Doppler calculations.

If the image extracted earlier is Level 1.0 data, `make_raw()` wires three input ports to *doppler* so that it may access attributes of the instrument, raw image, and frame objects. *doppler* then calculates the Doppler fit for the raw image using `calculateDoppler()`, a method of the Calc_dop class. This method creates yet another RawImage object to access the image, and then passes that object's accessor to `calc_dop_Py()`, a method that wraps the source code calc_dop.f90. As with all methods that include wrapped source code, `calculateDoppler()` contains a significant amount of pre-processing steps, including setting the state of Fortran compatible parameters necessary for the wrapped source code as well as allocating memory for its processes. After calc_dop.f90 calculates the Doppler fit for the image, `calculateDoppler()` deallocates memory and runs `getState()`, a method that grabs the information calc_dop.f90 calculated and loads it into attributes of the Python object *doppler*.

Next, *doppler* runs its method `fitDoppler()`, whose original purpose is to fit a polynomial to the Doppler values. Inside the `fitDoppler()` method itself, however, we find that rather than perform a polynomial fit, it simply sets the first Doppler coefficient to the zero order term found earlier, leaving all others at zero. To conclude Doppler processing, `make_raw()` establishes both pulse repetition frequency and the Doppler coefficients as local variables and then loads them directly into an object called *dopplerValues*, an instance of the class Doppler found in Doppler.py. If the original input data is Level 1.1, an SLC image, the program does not calculate Doppler values and instead loads all zeros into *dopplerValues*. Doppler coefficients allow the generation of an SLC image from a raw image; if the data comes in as an SLC image, the Doppler coefficients are unnecessary.

Following Doppler processing, `make_raw()` comes to a close by calculating the velocity, squint angle, and change in height of the spacecraft. Each calculation requires a different method, and each method gets certain parameters of the image and uses them to calculate the desired result in Python. The only method worth investigating here is `calculateHeightDt()` because it implements the method `interpolateOrbit()`. Found in Orbit.py, `interpolateOrbit()` offers three ways of interpolating the state vector of an orbit; it performs linear interpolation, interpolation with an eighth order Legendre polynomial, or Hermite interpolation. The math of these different interpolation techniques lies beyond the scope of this user guide. After interpolating the orbit at both the start and mid-times of the image capture, `calculateHeightDt()` calculates the height of the spacecraft using a method in Orbit.py called `calculateHeight()`. `calculateHeight()` itself runs a method called `xyz_to_llh()` that converts the spacecraft ellipsoid from Cartesian coordinates to latitude, longitude, and height, and returns height. The method `calculateHeightDt()` concludes using the height and time parameters just calculated to determine the change in height over time.

Finally, `make_raw()` concludes with `renderHdr()`, a method in Image.py that creates an xml file containing important parameters of the raw image.

4.3.4 Focusing the Raw Image

The process of creating an SLC image begins with estimating an average Doppler coefficient *fd* for all of the polarized images. It adds all four coefficients together and divides by four. ISSI.py then runs `focus()`, with the raw image object and average Doppler coefficient as input arguments.

The first step in `focus()`, after getting parameters necessary for processing, calculates a value called peg point. Also found in ISSI.py, `calculatePegPoint()` passes the frame, planet, and orbit and returns peg, height, and velocity values. It also makes heavy use of both the `interpolateOrbit()` and `xyz_to_llh()` methods to calculate points in both location and time. It also implements `geo_hdg()`, another method in Ellipsoid.py, that calculates the spacecraft's heading given its start and middle locations. An instance of the class Peg, in Peg.py, called *peg*, stores the peg point information; `calculatePegPoint()` returns the Peg object as well as height and speed.

Interpolating and returning the spacecraft's orbit comes next, beginning with the method `createPulsetiming()`. This method returns an instance of the class Pulsetiming, in Pulsetiming.py, called *pt*, which runs the method `pulsetiming()`. `pulsetiming()` interpolates the spacecraft orbit and calculates a state vector for each line of the image. It appends each successive state vector together in order to return the complete orbit of the spacecraft. The program then converts this complete orbit to SCH coordinates with an instance of the class Orbit2sch, found in Orbit2sch.py, called *o2s*. It wires a few input ports, sets the average height of the spacecraft, and then performs the conversion with its method `orbit2sch()`. After setting parameters and allocating memory, `orbit2sch()` runs orbit2sch.F, source code wrapped by the method `orbit2sch_Py()`.

Back now in ISSI.py, `focus()` creates instances of the RawImage and SlcImage classes called *rawImage* and *slcImage*, respectively. While *rawImage* provides access to the raw image in memory, *slcImage* facilitates the creation of the SLC image in memory. The program also creates an instance of the class Formslc, found in Formslc.py, called *focus*, which contains the attributes and methods necessary to process raw data into an SLC image. With these objects prepared, `focus()` wires input ports and sets variables necessary for generating the SLC image. Notice that, while `focus()` has many lines, the vast majority of its commands simply get and set data calculated elsewhere; most of `focus()` simply prepares for the actual SLC generation, executed in method called `formslc()`.

`formslc()` finishes wiring the ported objects, allocates memory, sets parameters, and runs `formslc_Py()`, the method that wraps formslc.f90. This Fortran code completely generates the SLC image, and after it finishes, another wrapping function called `getMocompPositionSize_Py()` returns information about motion compensation performed in formslc.f90. `formslc()` concludes by setting a few more local variables, running `getState()`, which returns more motion compensation parameters from the Fortran processing, deallocating memory, and creating an xml header file for the new SLC image.

Once more in `focus()`, both *rawImage* and *slcImage* run their `finalizeImage()` methods. Now only one last step remains for `focus()`, to convert the SLC image from writeable to readable. It accomplishes this by creating another SlcImage object identical to that created earlier, but setting it as readable rather than writeable. Finalizing this image object and defining local variables of image length and width conclude the conversion process from raw data to SLC image.

4.3.5 Resampling the SLC Image

`focuser()` next runs the method `resample()`, in ISSI.py, on the VH and VV polarized SLC images. As usual, `resample()` begins by getting and setting parameters and objects relevant to the resampling process. It creates two SlcImage objects called *slcImage*, which refers to the SLC image currently in memory, and *resampledSlcImage*, which facilitates the creation of a resampled SLC image file. Following this, it creates an instance of the class OffsetField, in

Offset.py, called *offsetField*, that represents a collection of offsets defining an offset field. The program then proceeds to create an instance of the class Offset, also in Offset.py, called *offset*, with a constant 0.5 pixel shift in azimuth. This offset adds to the offset field, ready for use later in the resampling process.

An instance of the class Resamp_only, found in Resamp_only.py, called *resamp*, enables the resampling process. After setting local parameters and establishing ports, resamp runs the method `resamp_only()` on the two SlcImage objects. As usual, the method imports objects from ports, establishes parameters, allocates memory, and runs the wrapping method, in this case `resamp_only_Py()`, which points to resamp_only.f90. Resamp_only.f90 concludes, `getState()` runs, and `resamp_only()` deallocates memory before returning to `resample()`. It finalizes both image objects, renames the resampled image files to be the new SLC images, and returns to the `focuser()` processing flow.

Once more in `focuser()`, if the original input data is Level 1.1, the program changes the extracted files' extensions from .raw to .slc. This step is necessary because the extraction process detailed earlier gives the files .raw extensions by default. And finally, just before beginning polarimetric processing, `focuser()` checks the endianness of the image files and swaps it if necessary.

4.3.6 Polarimetric Processing

The final line of `focuser()` executes the method `combine()`, which combines all four polarized images to form Faraday rotation (FR), total electron content (TEC) and phase images. The method `combine()` begins with an instance of the class FR, found in FR.py, called `issiObj`. All of the SLC images as well as size parameters and objects to hold the ouput of polarimetric processing pass as input arguments to the initialization of FR. If the input data to ISSI.py is Level 1.0, as we assume, issiObj runs the method `polarimetricCorrection()`, with the distortion matrices as its input arguments.

Before this point in ISSI.py, nearly all the wrapped source code is Fortran. For polarimetric processing, however, nearly all the source code is compiled C code. Fortunately for us, Python interacts well with C and requires a much simpler wrapping process. This process consists of converting Python parameters, such as strings, characters, floats, etc., into C compatible parameters via built in Python functions such as `c_char_p()` or `c_float()`, and then executing the wrapped code itself. Such a straightforward wrapping procedure greatly simplifies understanding ISSI.py, and therefore this user guide.

`polarimetricCorrection()` creates the appropriate ctype parameters, including file names and distortion matrices, and runs `polcal()`, found in polcal.c. Interestingly, polcal.c performs only part of the calibration process, calling upon yet another wrapped file polarimetricCalibration.f to perform the calibration computation. The interconnection of C and Fortran code is beyond the scope of this section. After the source code completes its tasks, `polarimetricCorrection()` shifts the results to the output files and returns to `combine()` in ISSI.py.

The program next calculates Faraday rotation (FR) via the method `calculateFaradayRotation()`, also in FR.py. This method begins with `_combinePolarizations()`, which itself creates necessary ctype parameters and then runs the wrapping method `cfr()`, which points to cfr.c. Using the Bickel and Bates 1965 method, cfr.c calculates complex FR from the four polarized images. Following this, `calculateFaradayRotation()` calls `_filterFaradayRotation()`, a method that utilizes the filter parameters found in output.xml to filter the FR. After generating an instance of the class Filter, found in Filter.py, the method runs one of three possible filter types, medianFilter, gaussianFilter, and meanFilter. Each of these filter methods establishes important parameters and then runs a Python wrapping method, `medianFilter_Py()`, `gaussianFilter_Py()`, or `meanFilter_Py()`, that actually performs the filtering process. These filtering methods actually call upon more than one piece of source code. See the appendix workflow for more detail.

Calculation of the average real valued FR follows next. The program generates the appropriate ctype parameters and then runs `cfrToFr()`, a Python method that wraps cfrToFr.c. After `cfrToFr()` calculates and returns the average real valued FR at each pixel (in radians), `calculateFaradayRotation()` generates a resource for the new FR file and then returns to `combine()`.

The final portion of polarimetric processing requires calculation of the geodetic corners of the images. To this end the program sets the date and radar frequency as local parameters and then executes `calculateLookDirections()`, in ISSI.py, which calculates the satellite's look direction at each corner of the image. To do this it first calculates the satellite heading at mid-orbit with the function `calculateHeading()`. Calculate heading gets the orbit and ellipse parameters of the images and, as before, interpolates the orbit and converts the state vector outputs to latitude, longitude and height. The function `geo_hdg()` uses that information to calculate the satellite's heading, and `calculateHeading()` returns this information in degrees. `calculateLookDirections()` takes the heading value, adds to it the yaw value plus 90 degrees, and returns it as the look direction.

Next, the program calculates the corner locations via `calculateCorners()`. This method sets the image planet as a local parameter, ports an instance of the class Geolocate, found in Geolocate.py, and sets many more local parameters before running `geolocate()` on each corner. `geolocate()` creates the necessary ctypes and calls `geolocate_wrapper()`, a Python method that wraps geolocate_wrapper.c. The C code calls `geolocate()`, which itself derives from source code called geolocate.f; this Fortran calculates the corners and look angle at each corner. Back in `geolocate()` in Geolocate.py, the Python script creates an instance of the class Coordinate, which stores the latitude, longitude, and height of the corner just calculated. It returns the coordinate object, as well as the look and incidence angles, to `calculateCorners()` in ISSI.py, which itself returns the parameters for all four corners to `combine()`.

The program next calls `makeLookIncidenceFiles()` to create files containing look and incidence angles in order to test antenna pattern calibration. This method also ports an instance of the Geolocate class, sets planet, orbit, range, etc. as local parameters, and opens the two files meant to store the new angle information. It then gets the time of the acquisition and uses `interpolateOrbit()` to return a state vector which is itself used as each pixel in the range direction (width of the image) to calculate the coordinate, look angle, and incidence angle via `geolocate()`, the method used earlier to calculate corners. The program then stores the look and incidence angle values, calculated for each pixel in the range direction, in every pixel of the column located at that width. `makeLookIncidenceFiles()` closes the two files and returns to `combine()`.

The second to last polarimetric processing method is `frToTEC()`. Given a coordinate, look angle, and look direction, `frToTEC()` calculates the average magnetic field value in the radar line-of-sight. It starts by, for each corner, setting a local parameter k to be the look vector, calculated from look angle and look direction, via the method `_calculateLookVector()`. Then it appends the result of performing the dot product of k, the look vector, and magnetic field, via the method `_integrateBVector()`, to a list of such dot products at each corner. `_integrateBVector()` creates a vector of altitude information and at each height in that vector calculates the magnetic field vector with `_calculateBVector()`. `_calculateBVector()` establishes necessary ctypes and runs `calculateBVector()`, a Python method that wraps calculateBVector.c, which itself calls upon igrf2005_sub.f. This Fortran code calculates and returns the magnetic field value at each input coordinate, and `_calculateBVector()` returns the North, East, and down components of the magnetic field at each point. `_integrateBVector()` then performs the dot product between the magnetic field and look vector and calculates and returns the average dot product value for all points in the height vector. Given the mean value of the dot product and the radar frequency, `_scaleFRToTEC()` applies a scaling factor to FR in order to arrive at TEC. With the correct ctypes, `_scaleFRToTEC()` calls upon frToTEC.c to perform the actual scaling conversion. After arriving at TEC, `ftToTEC()` creates a resource file for the TEC file, and returns to `combine()` in ISSI.py.

Finally, `combine()` executes the final method of ISSI.py and runs `tecToPhase()`, also found in FR.py, which applies a scalar value to TEC in order to return phase. With the correct ctypes, `tecToPhase()` calls `convertToPhase()`, a method that wraps tecToPhase.c, which applies the scaling factor. The program concludes by creating a resource file for the phase file. Here lies the end of ISSI.py. *[Zeb10]* *[LavSim10]*

CHAPTER

FIVE

MODULE DOCUMENTATION

5.1 ISCE Structure

5.1.1 Python Terminology

In Python terminology, a module is the basic block of code that can be imported by some other code. There are three main types of modules: packages, pure Python modules and external modules.

A **package** is a module that contains other modules. It is basically a directory in the filesystem, distinguished from other directories by the presence of a file *__init__.py*. That file might be empty but it can also execute initialization code for the package.

Note: Even empty, the file *__init.py__* is required for a directory to be treated as a containing package. Otherwise, it is considered as a normal directory in the filesystem. For example, the folder *bin* in the ISCE tree is not a Python package.

A **pure Python module** (or a pure module) is written in Python and contained in a single *.py* file. For example, the package *applications* in the ISCE tree contains only pure modules. Since ISCE is object-oriented, many of its pure modules implement classes of objects with their attributes and methods. Whenever possible, classes are also shown in the following diagrams.

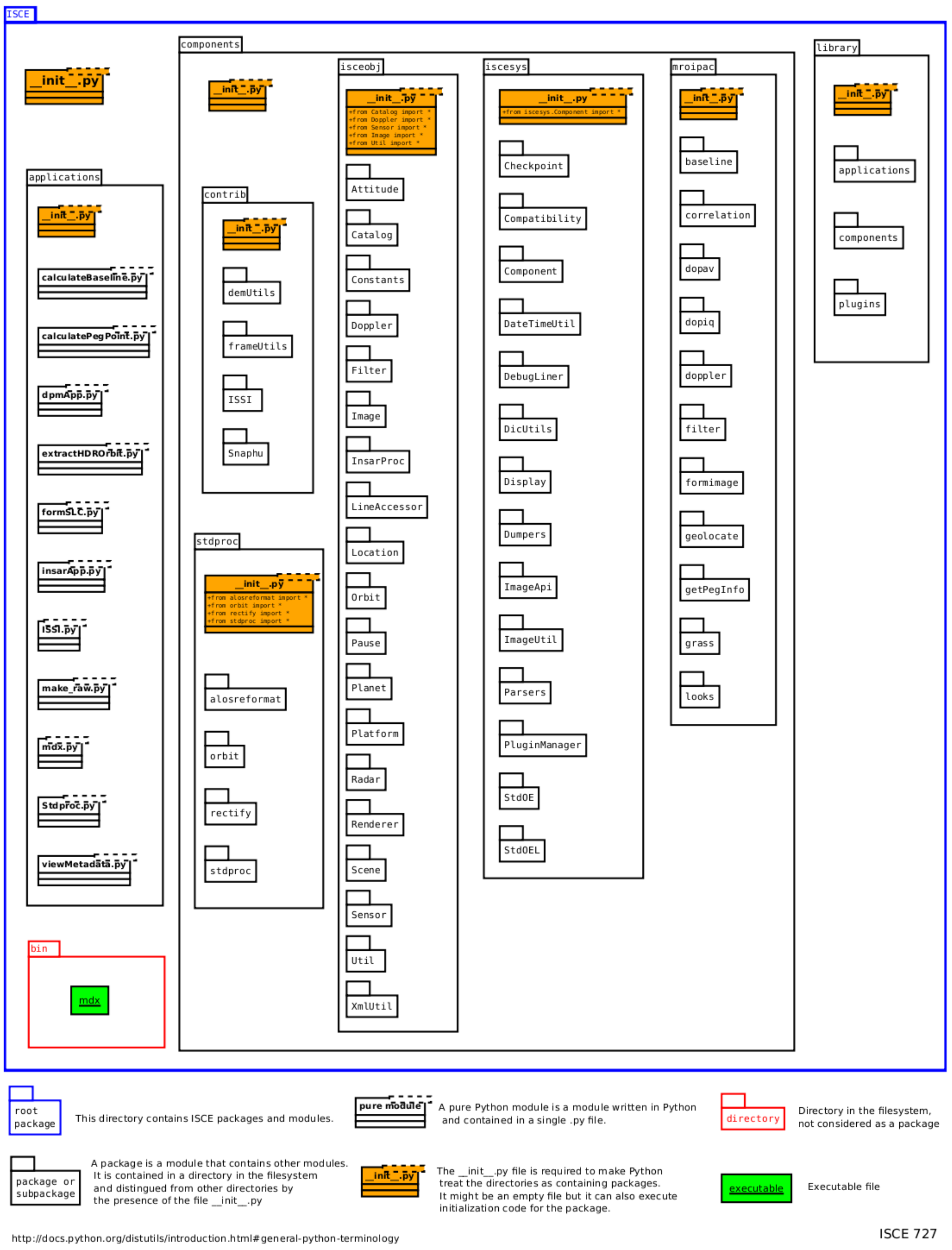
Finally, an **external module** contains code written in languages other than Python (e.g. C/C++, Fortran, Java...) and is typically packed in a single dynamically loadable file (e.g. a shared object *.so* or a dynamic-link library *.dll*).

5.1.2 Module Diagrams

The diagrams shown in this section reflect the structure of ISCE, as of July 1, 2012.

The first figure (*Overall structure of ISCE*) gives an overview of ISCE packages and modules. The root package of ISCE contains 3 packages: *applications*, *components* and *library*. The package *components* holds 5 subpackages that are detailed in the other figures:

- *ISCEOBJ package*
- *ISCESYS package*
- *STDPROC package*
- *CONTRIB package*
- *MROIPAC package*



This directory contains ISCE packages and modules.

A pure Python module is a module written in Python and contained in a single .py file.

Directory in the filesystem, not considered as a package

A package is a module that contains other modules. It is contained in a directory in the filesystem and distingued from other directories by the presence of the file __init__.py

The __init__.py file is required to make Python treat the directories as containing packages. It might be an empty file but it can also execute initialization code for the package.

Executable file

http://docs.python.org/distutils/introduction.html#general-python-terminology

Fig. 5.1: Overall structure of ISCE

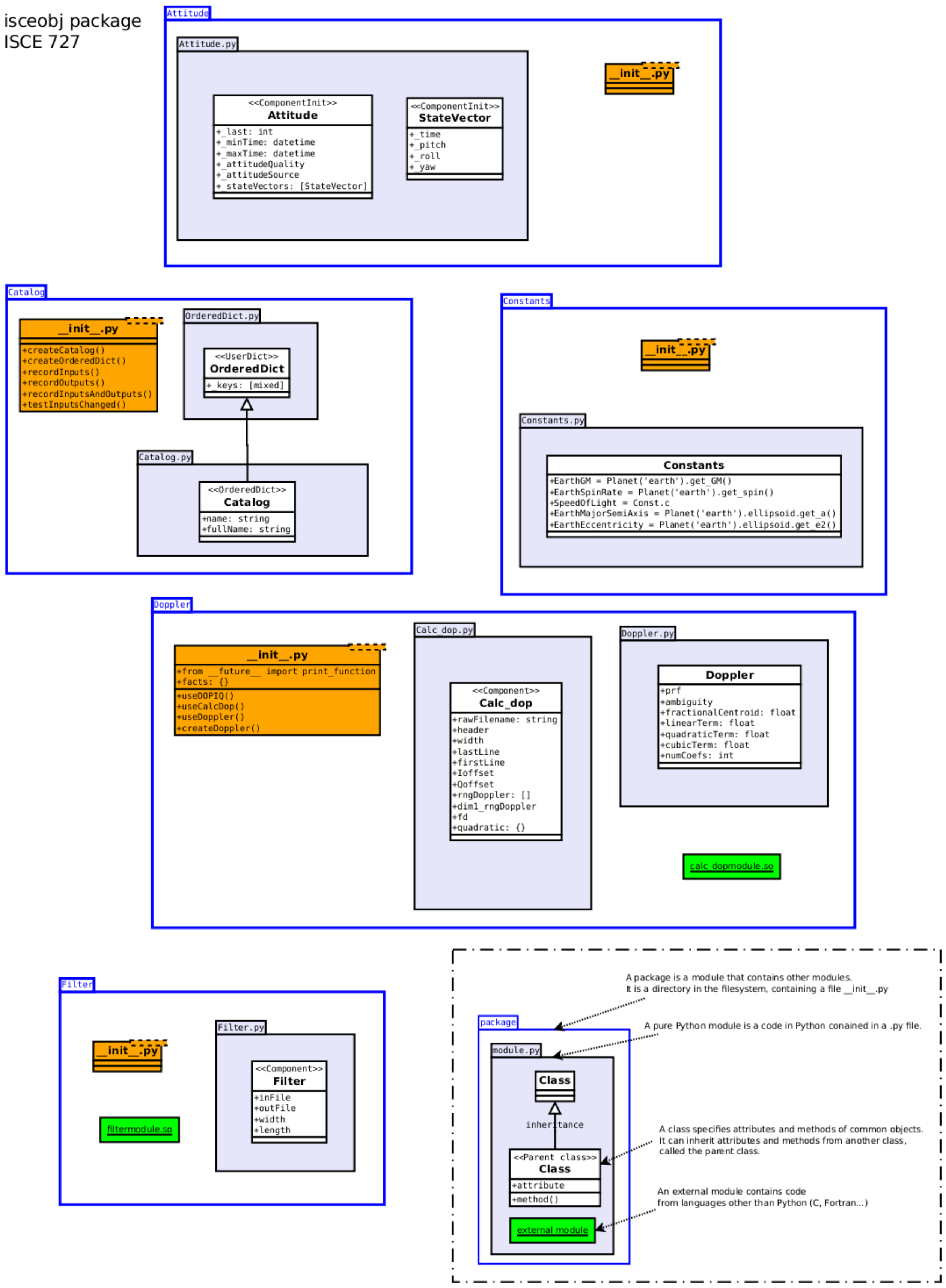


Fig. 5.2: ISCEOBJ package

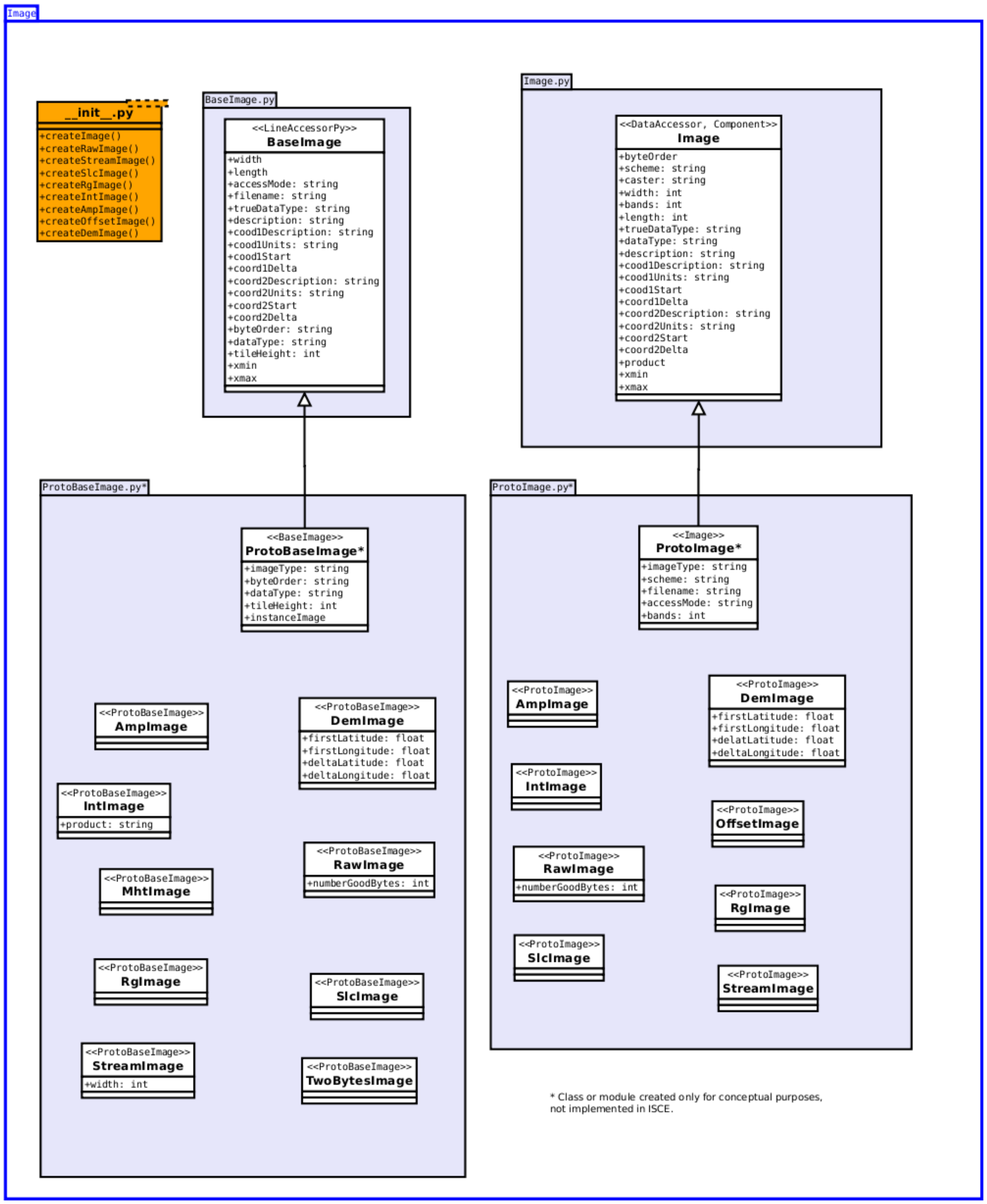


Fig. 5.3: ISCEOBJ package (2/7)

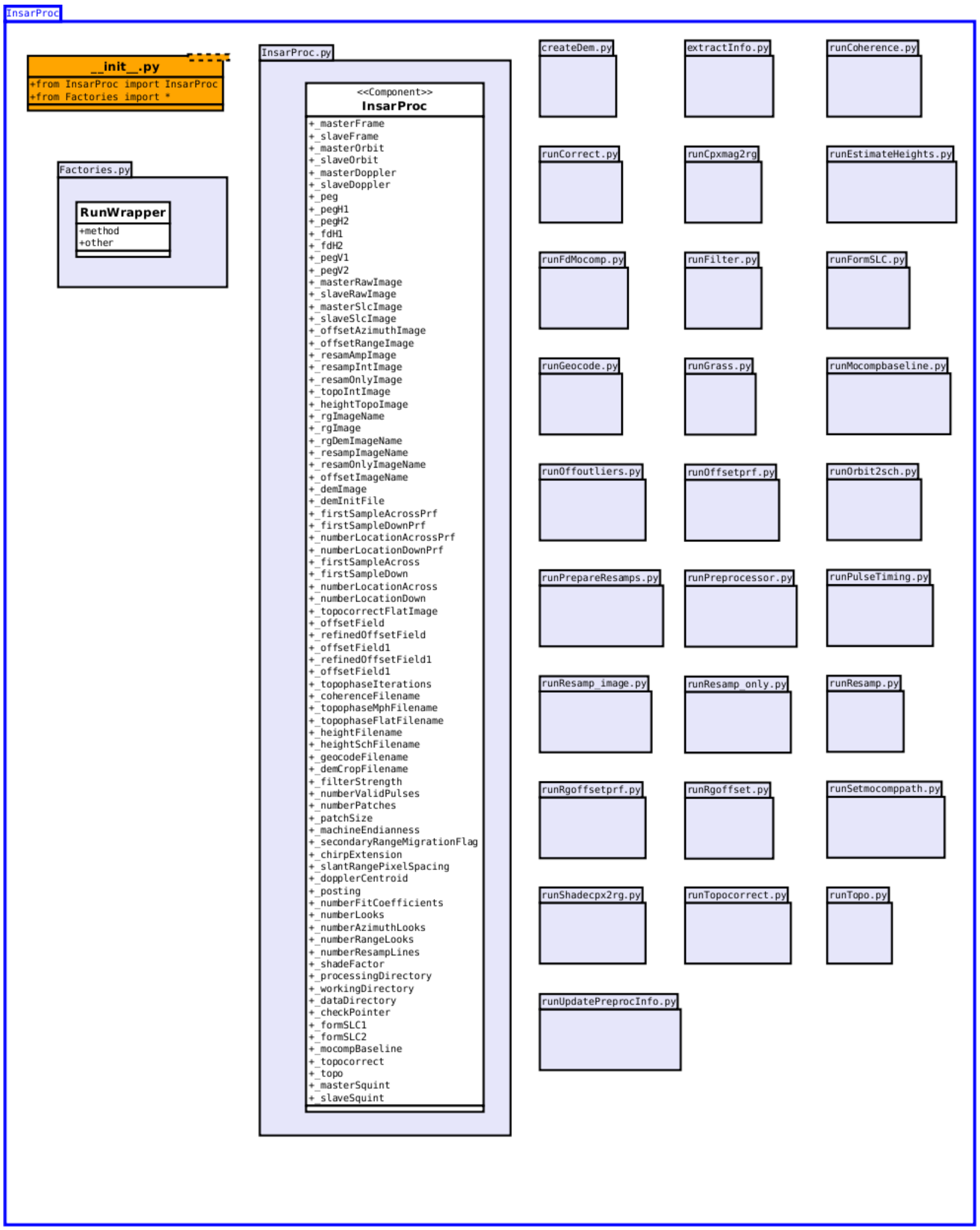


Fig. 5.4: ISCEOBJ package (3/7)

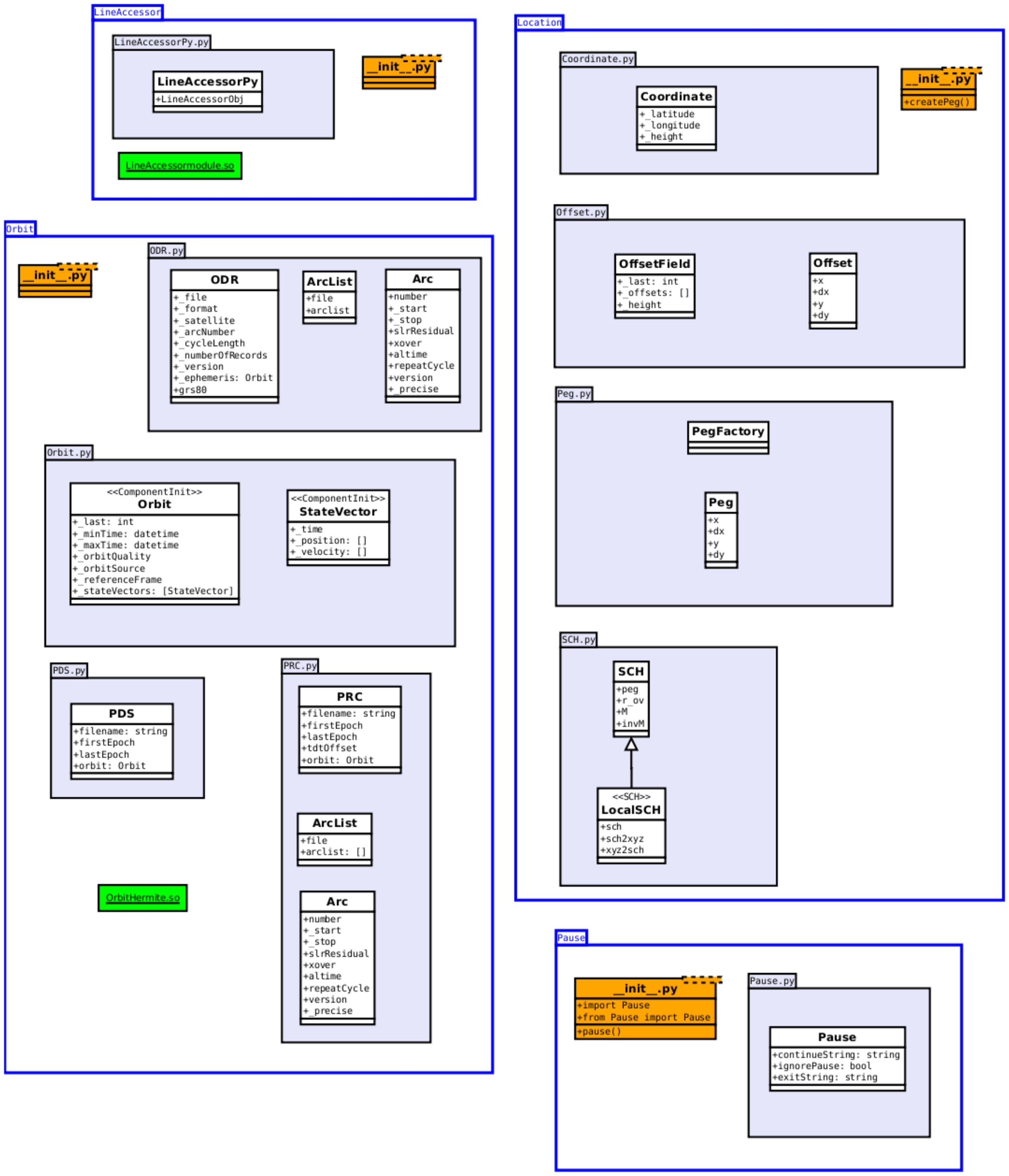


Fig. 5.5: ISCEOBJ package (4/7)

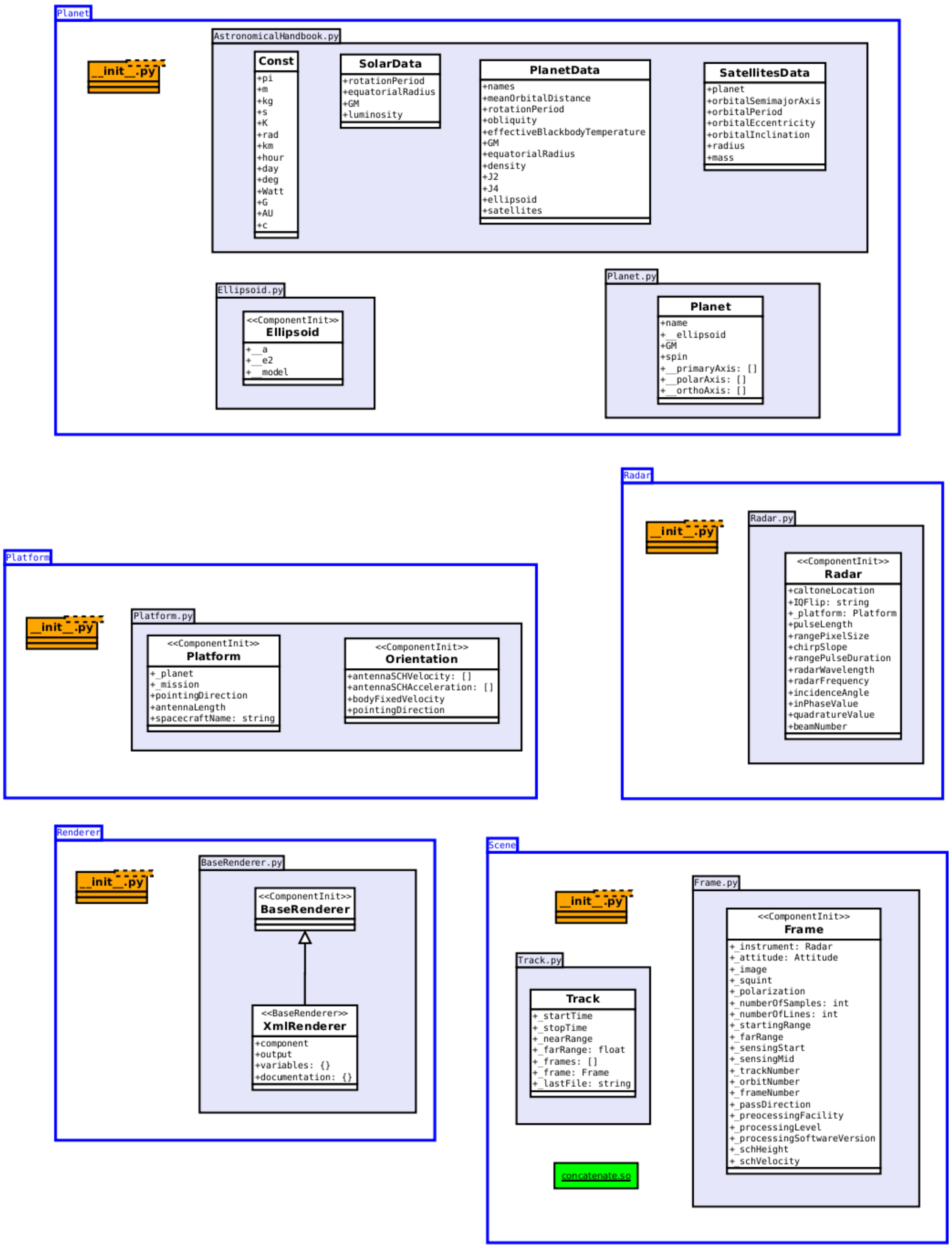


Fig. 5.6: ISCEOBJ package (5/7)

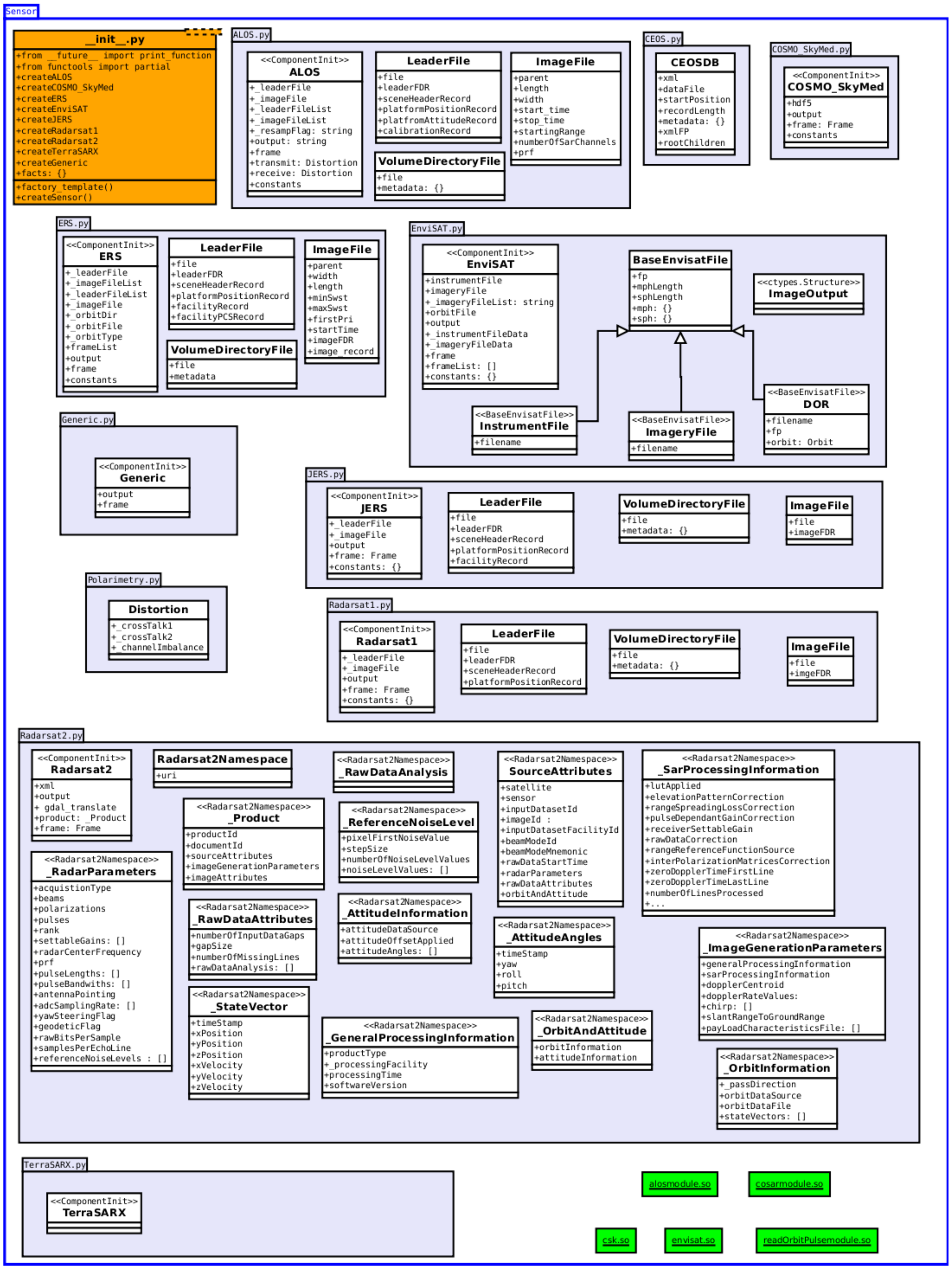


Fig. 5.7: ISCEOBJ package (6/7)

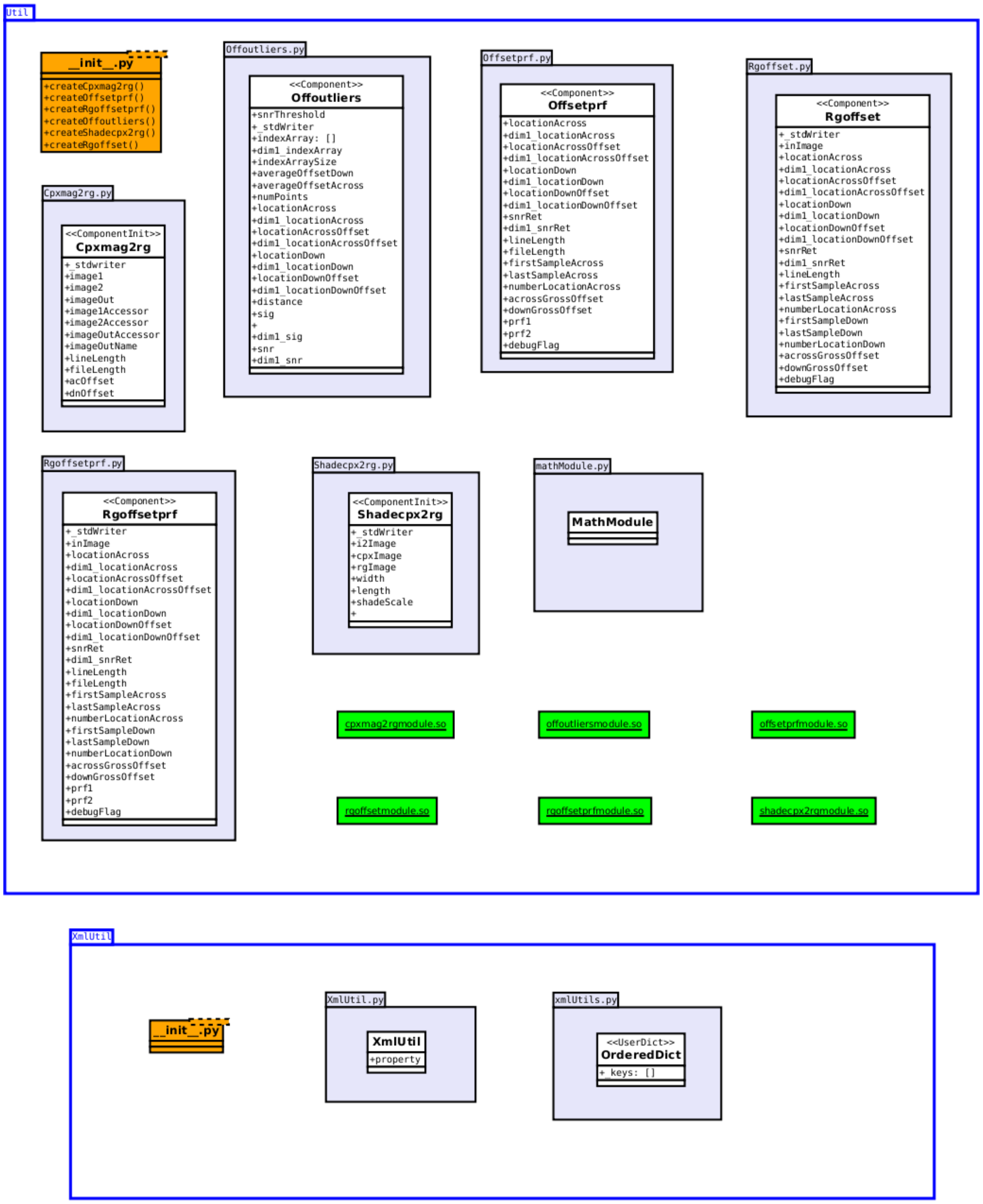


Fig. 5.8: ISCEOBJ package (7/7)

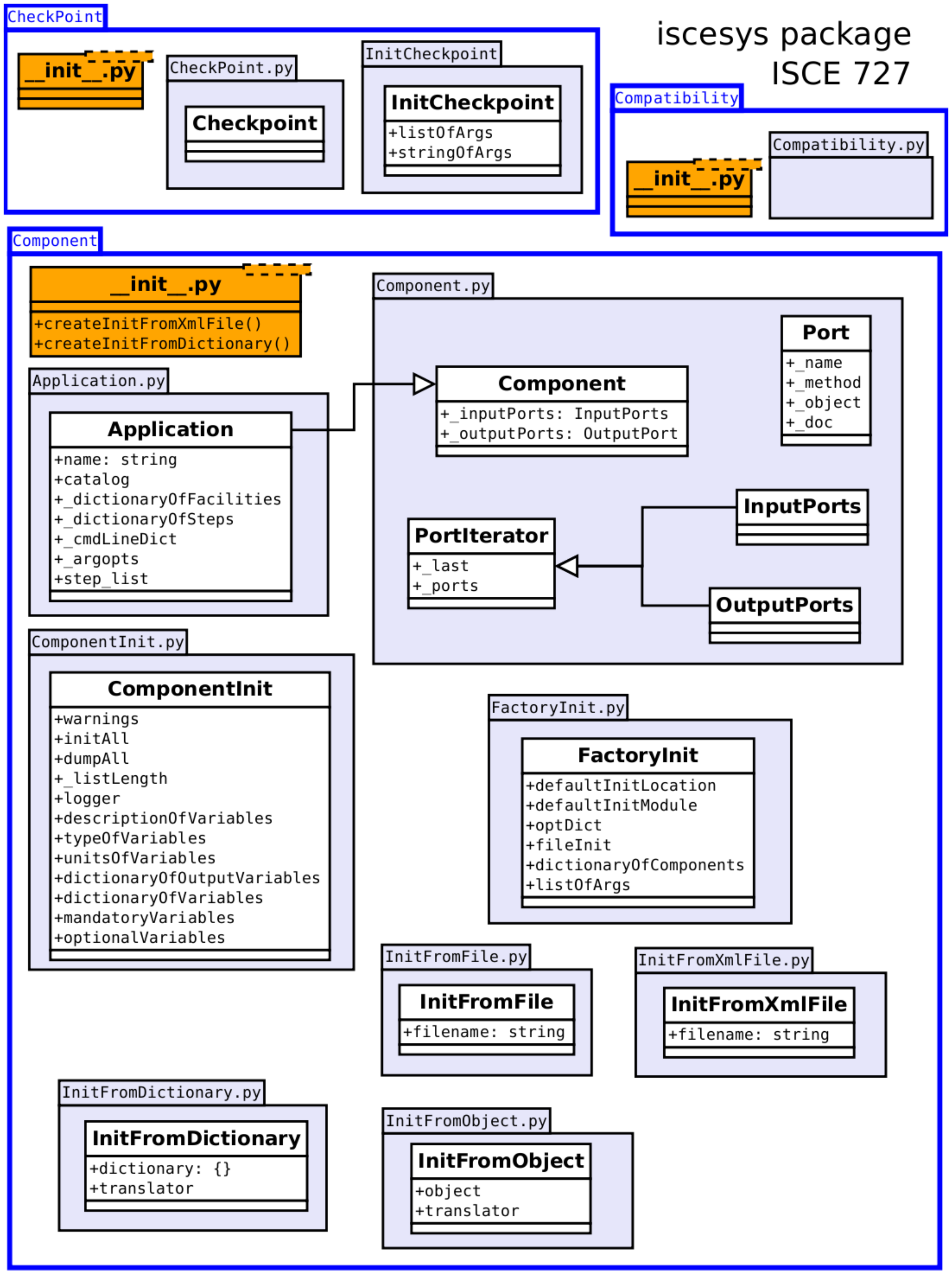


Fig. 5.9: ISCESYS package

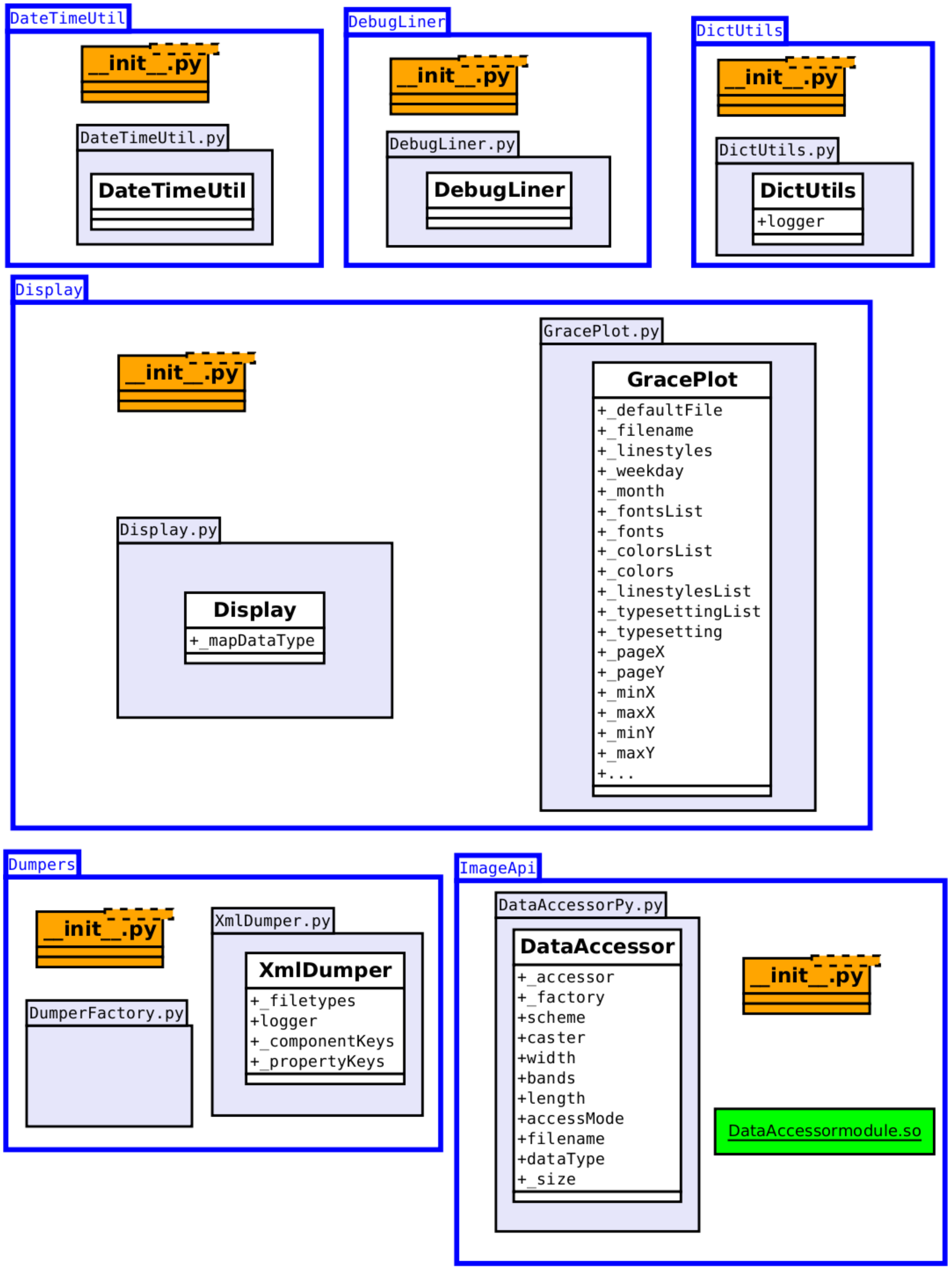


Fig. 5.10: ISCESYS package (2/3)

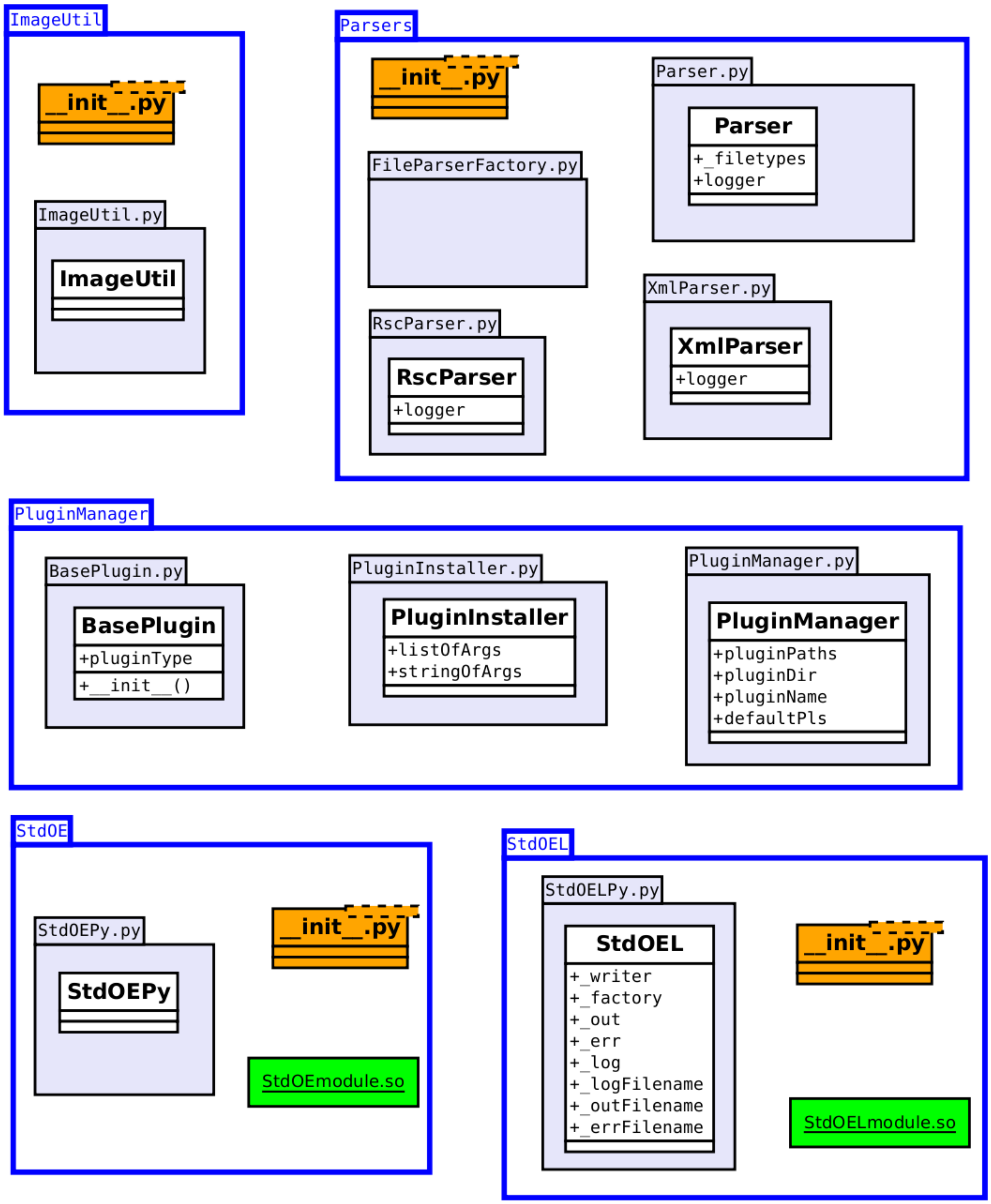


Fig. 5.11: ISCESYS package (3/3)

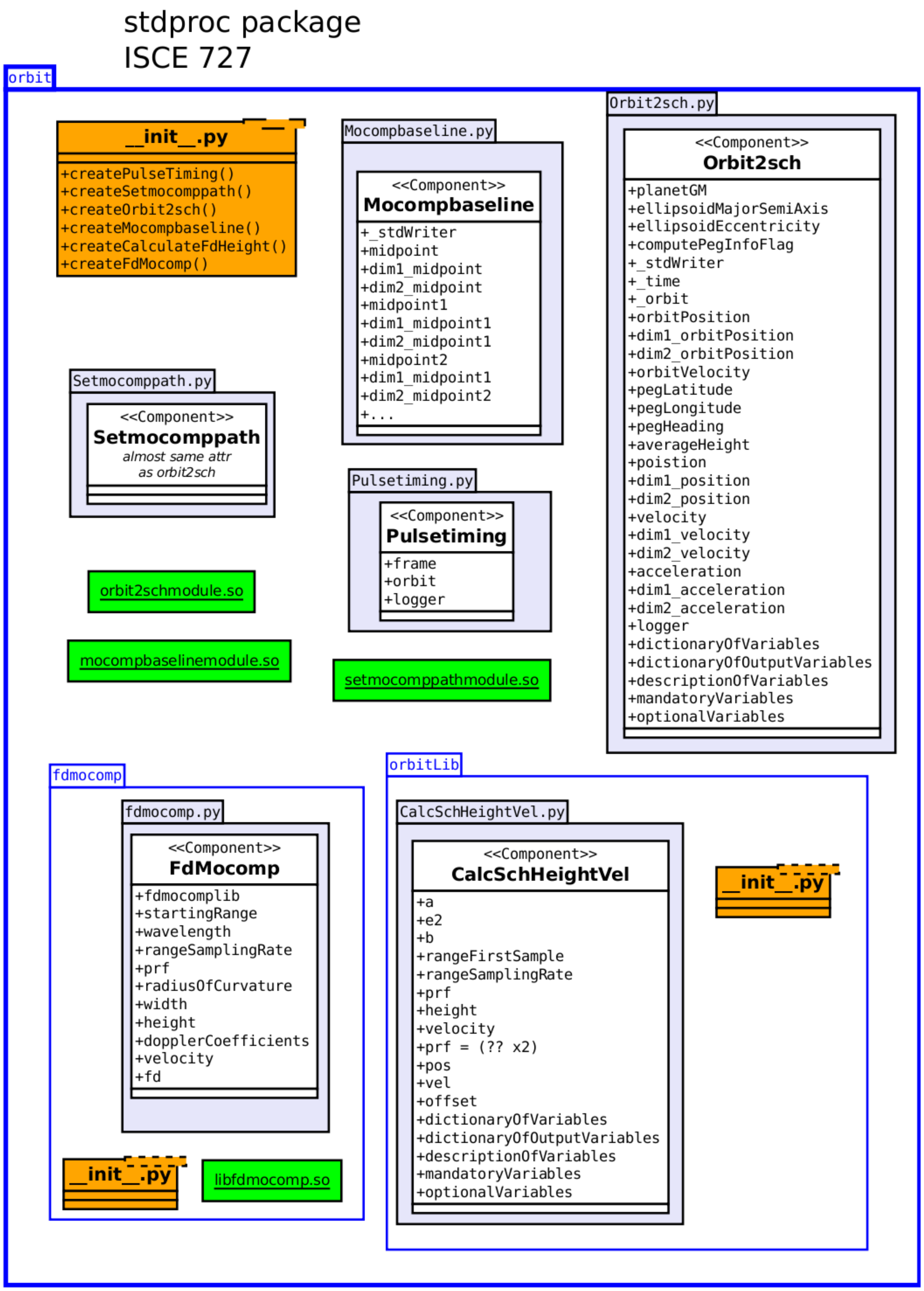


Fig. 5.12: STDPROC package

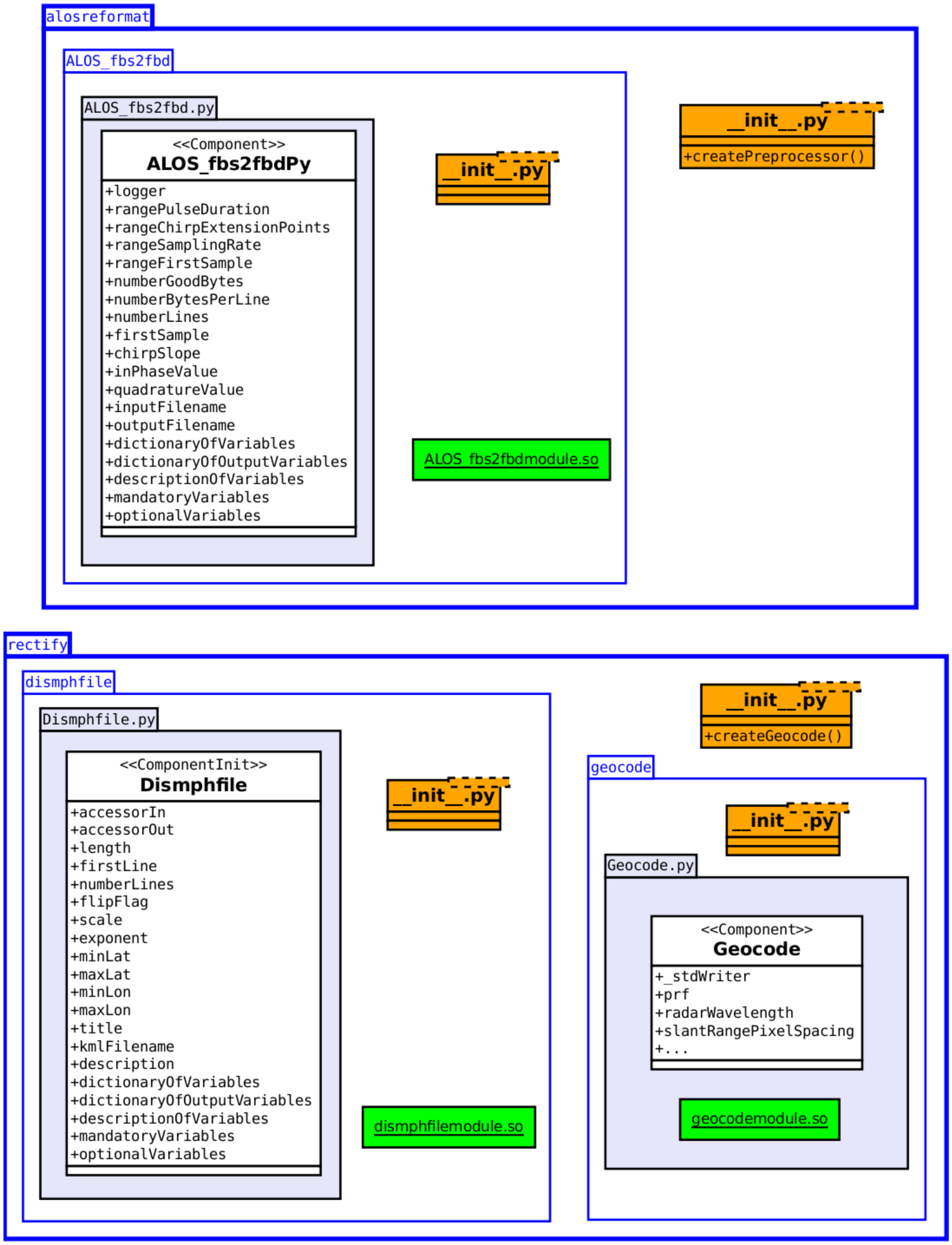


Fig. 5.13: STDPROC package (2/6)

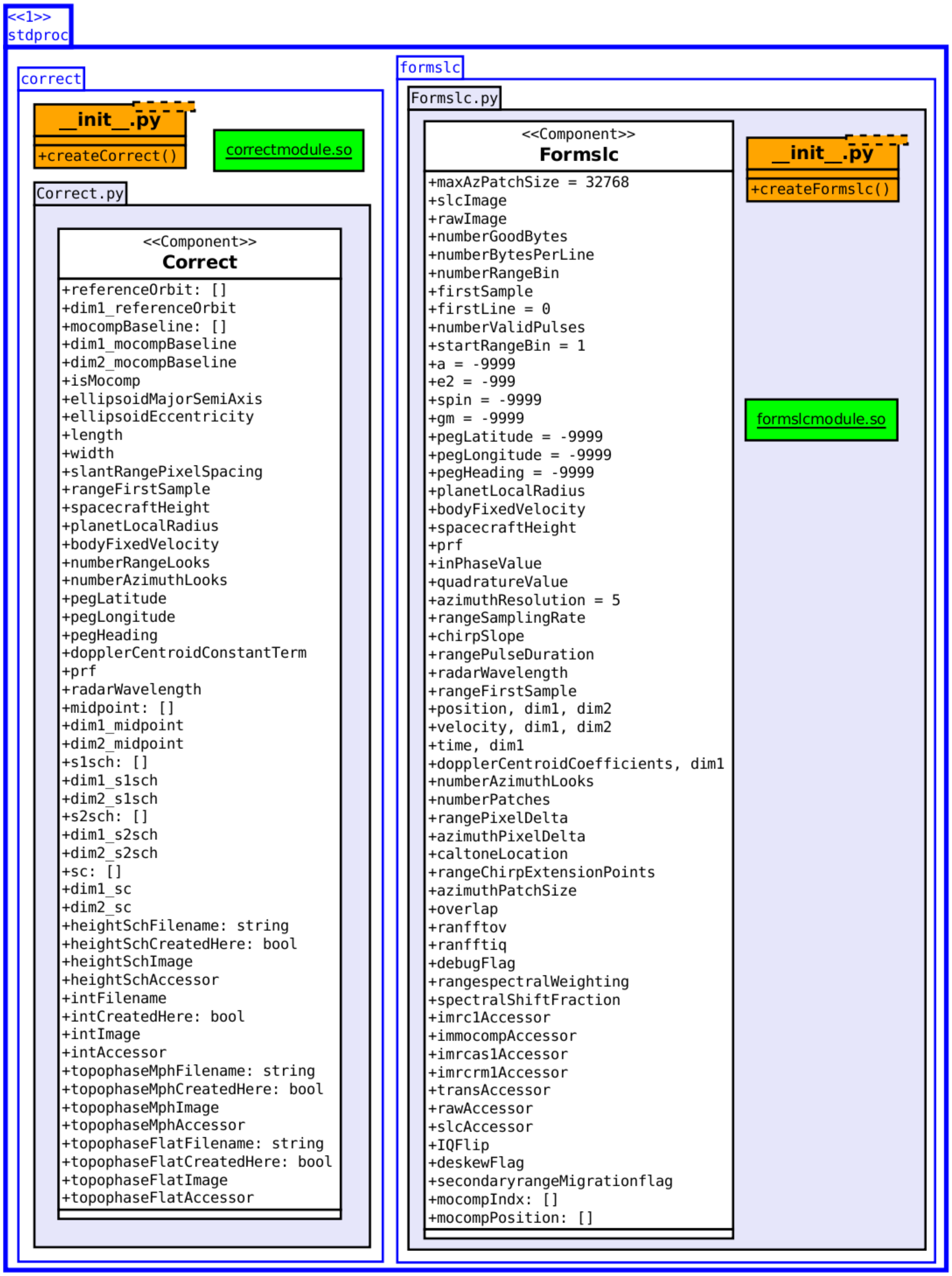


Fig. 5.14: STDPROC package (3/6)

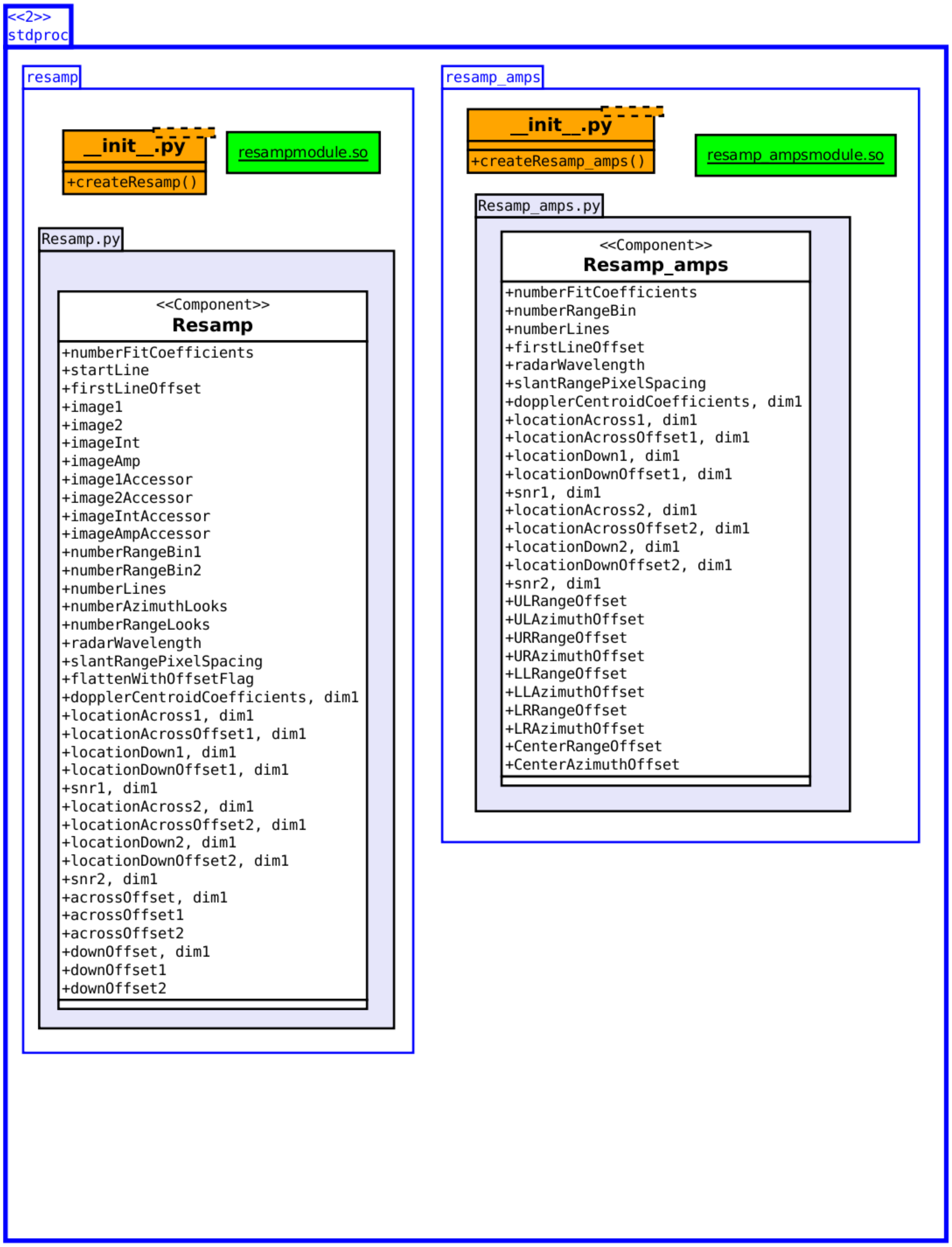


Fig. 5.15: STDPROC package (4/6)

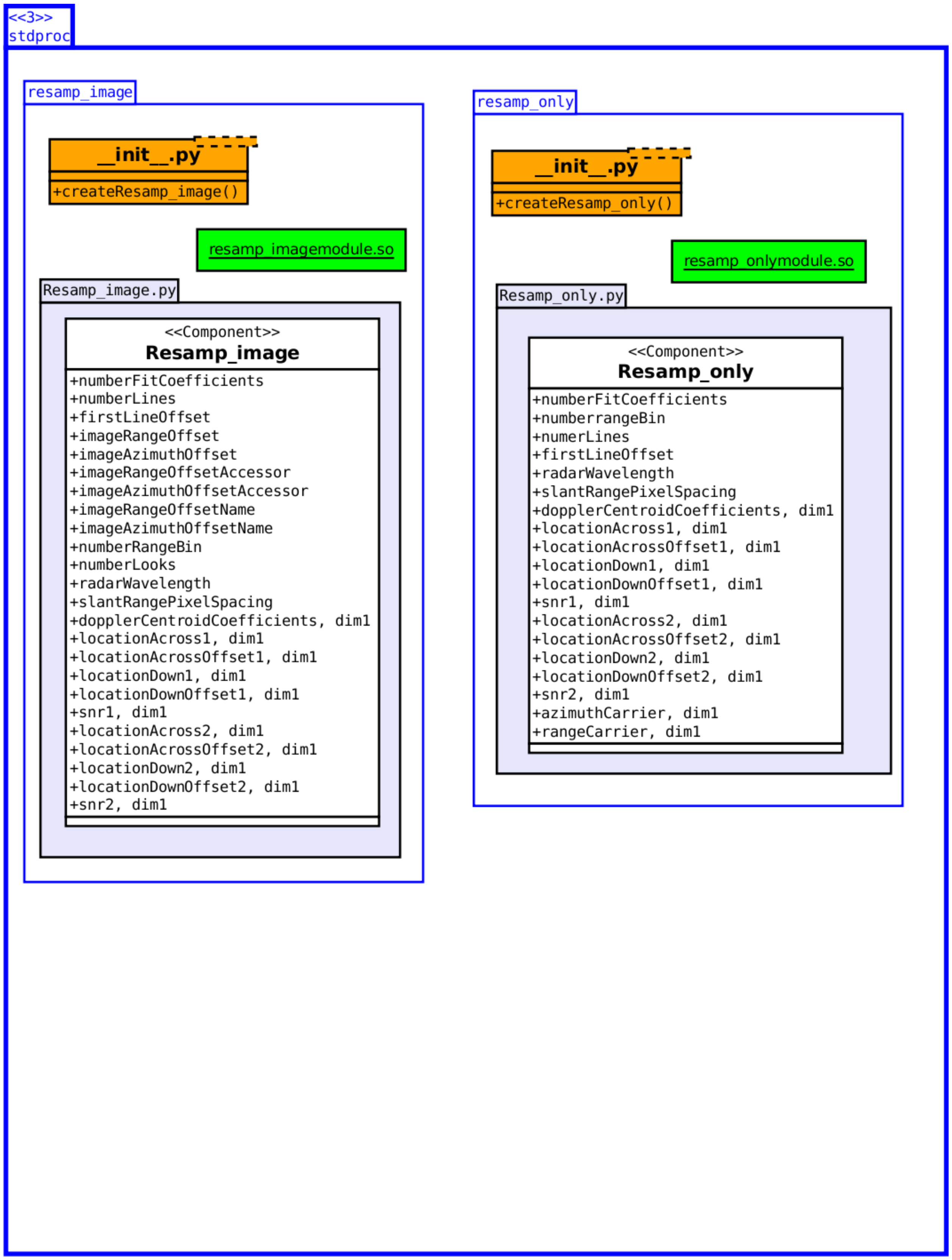


Fig. 5.16: STDPROC package (5/6)

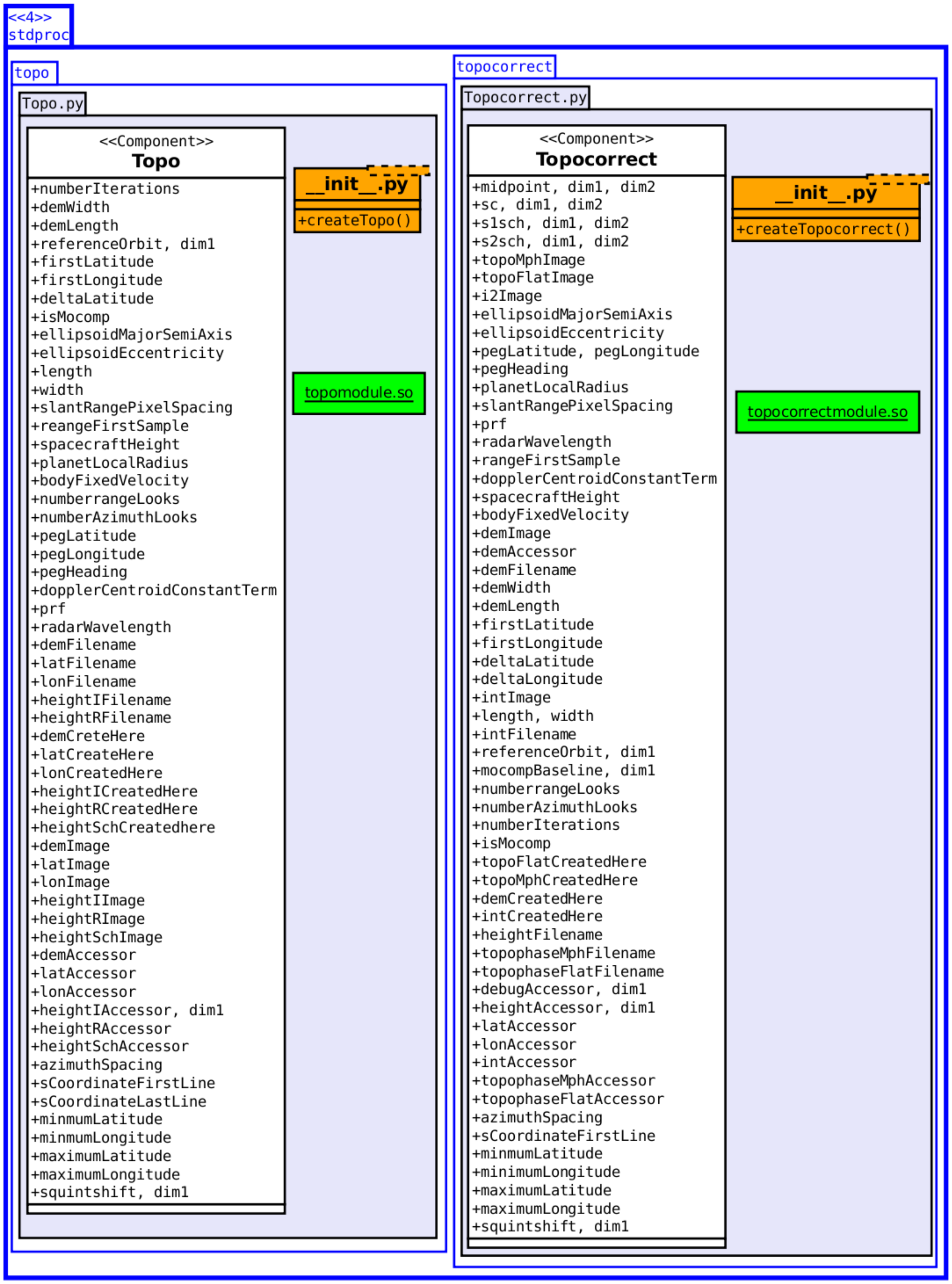


Fig. 5.17: STDPROC package (6/6)

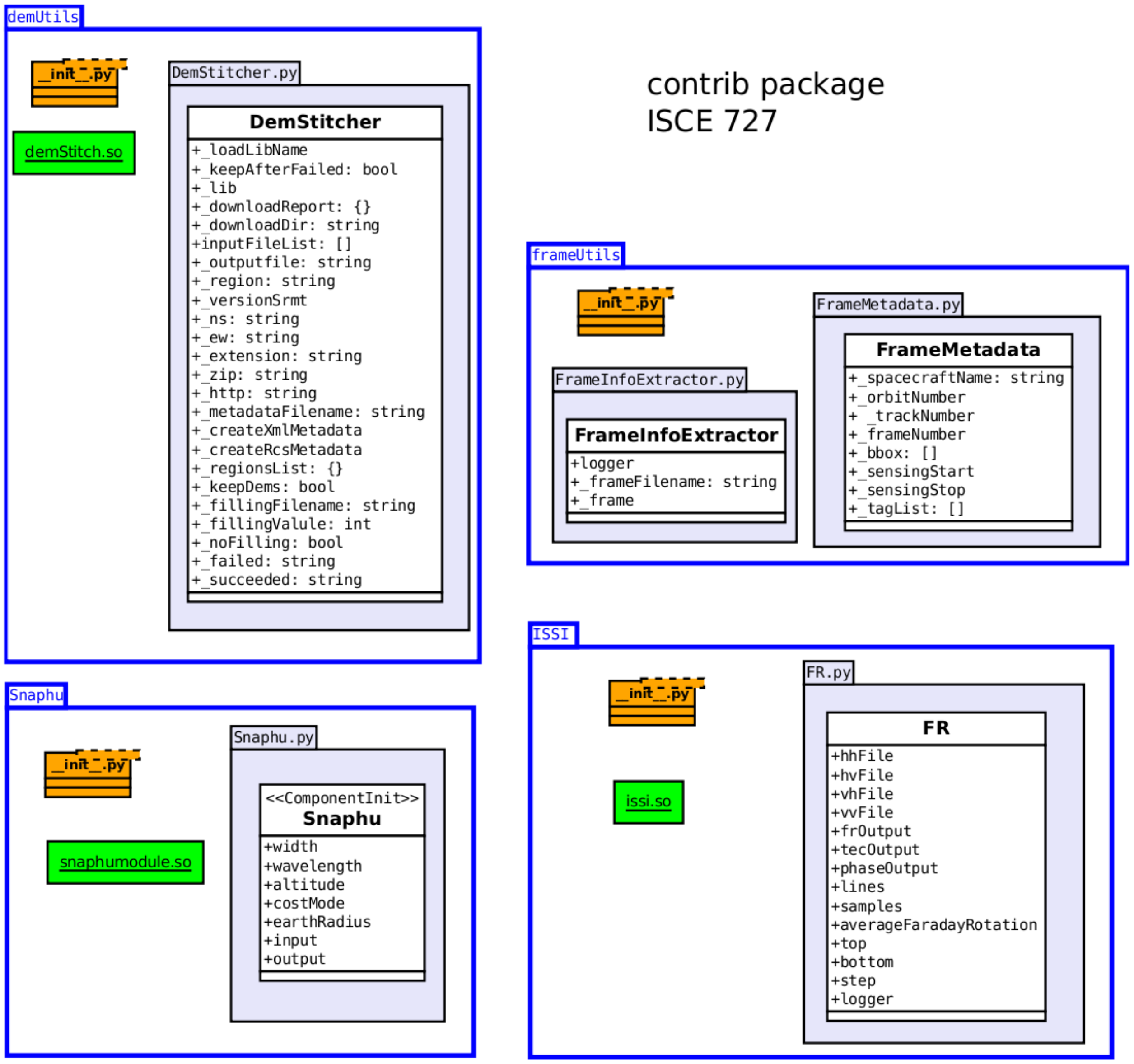


Fig. 5.18: CONTRIB package

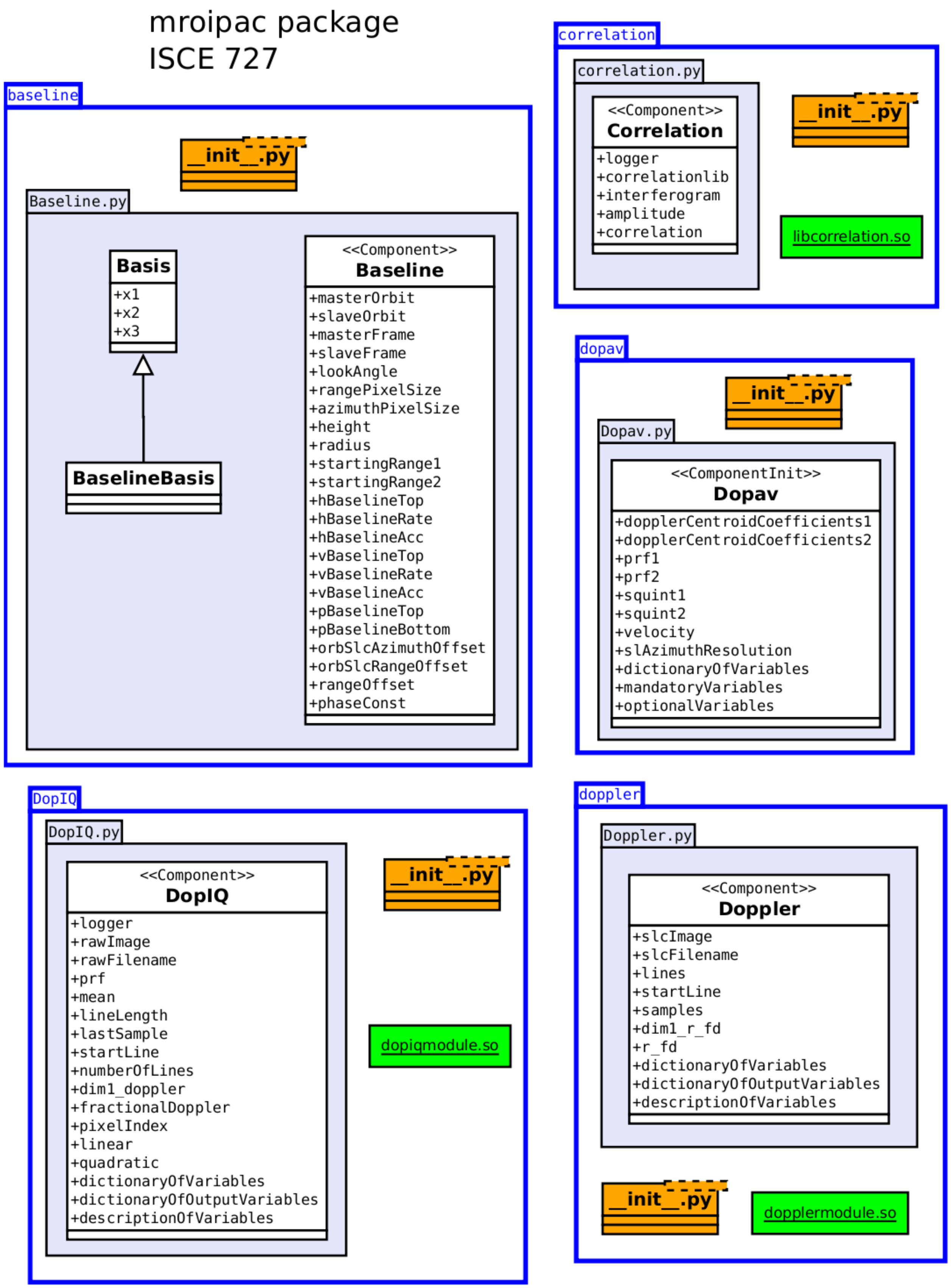


Fig. 5.19: MROIPAC package

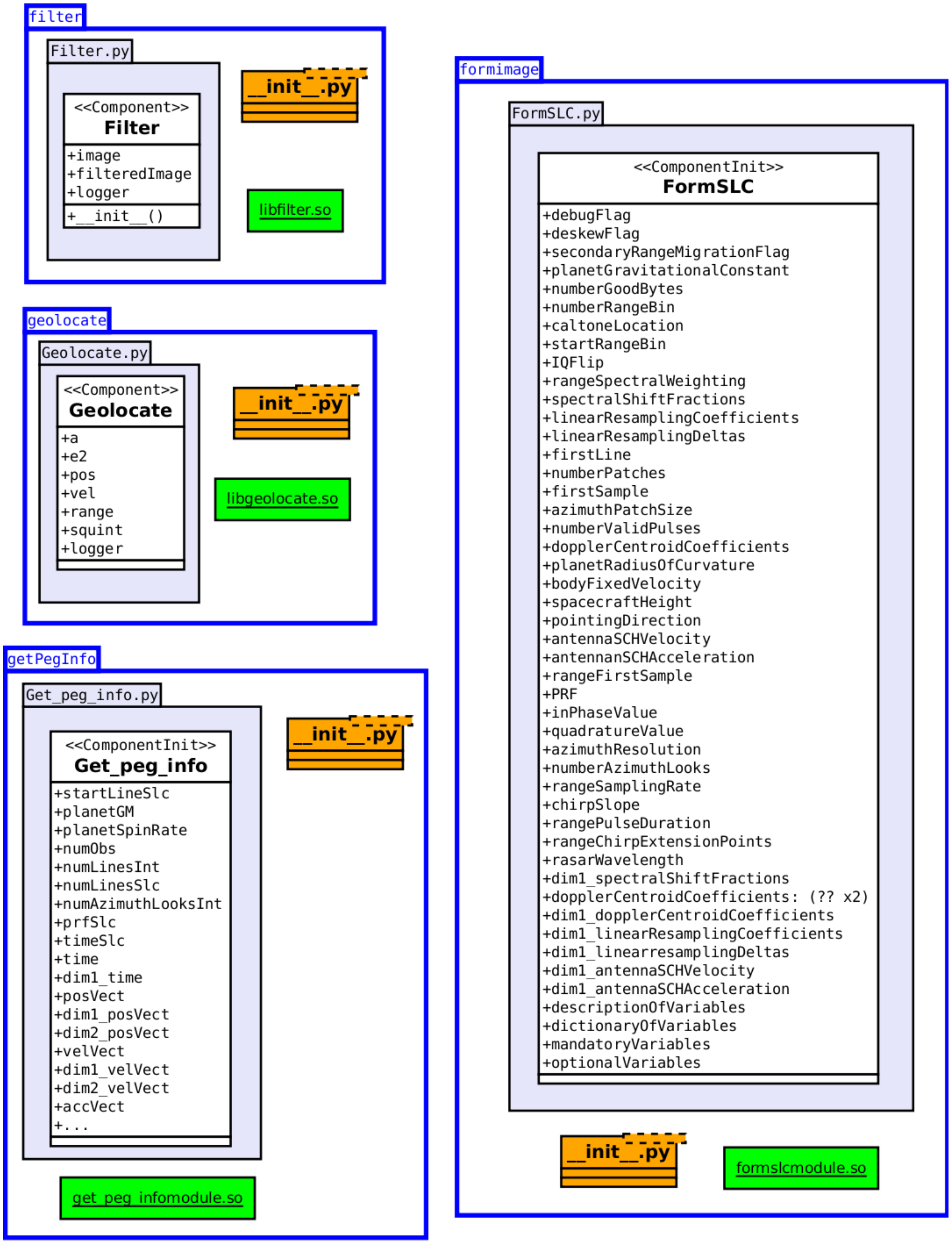


Fig. 5.20: MROIPAC package (2/3)

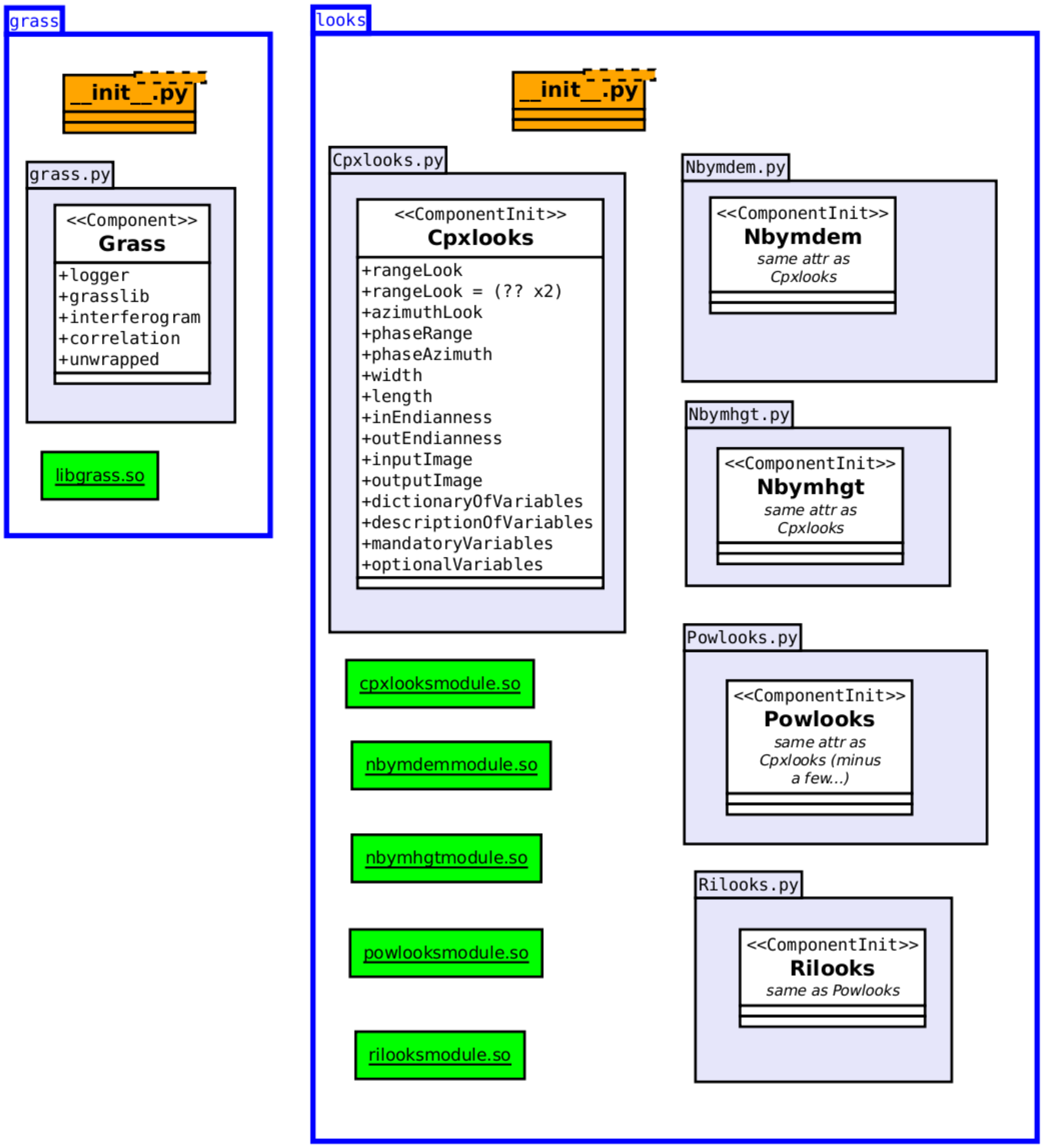


Fig. 5.21: MROIPAC package (3/3)

5.2 Modules

5.2.1 ISCE Objects

Module Descriptions

Orbit

class `isceobj.Orbit.`**`StateVector`**

This module provides a basic representation of an orbital element.

`get/setTime()`

A Python `datetime.datetime` object indicating the time

`get/setPosition()`

A three element list indicating the position

`get/setVelocity()`

A three element list indicating the velocity

`getScalarVelocity``()`

Calculate the scalar velocity from the velocity vector

`calculateHeight``(`*ellipsoid*`)`

Calculate the height of the StateVector above the provided ellipsoid object.

- Notes Comparison of StateVector objects is done with reference to their time attribute.

class `isceobj.Orbit.`**`Orbit`**

This module provides the basic representation of an orbit.

`set/getOrbitQuality()`
A string representing the quality of the orbit (e.g. Preliminary, Final).

`set/getOrbitSource()`
A string representing the source of the orbital elements (e.g. Header, Delft)

`set/getReferenceFrame()`
A string representing the reference frame of the orbit (e.g. Earth-centered Earth-Fixed, Earth-centered inertial)

`addStateVector``(`*stateVector*`)`
Add an Orbit.StateVector object to the Orbit.

`interpolateOrbit``(`*time*, *method*`)`
Interpolate the orbit and return an Orbit.StateVector at the specified time using the specified method. The variable time must be a datetime.datetime object, and method must be a string. Currently, the interpolation methods include ‘linear’, ‘hermite’, and ‘legendre’.

`selectStateVectors``(`*time*, *before*, *after*`)`
Select a subset of orbital elements before and after the specified time. The variable time must be a datetime.datetime object, and before and after must be integers.

`trimOrbit``(`*startTime*, *stopTime*`)`
Select a subset of orbital elements using the time bounds, startTime and stopTime. Both startTime and stopTime must be datetime.datetime objects.

Attitude

class `isceobj.Attitude.`**`StateVector`**

This module provides the basic representation of a spacecraft attitude state vector.

`get/setTime()`
A Python datetime.datetime object indicating the time

`get/setPitch()`
The pitch

`get/setRoll()`
The roll

`get/setYaw()`
The yaw

class `isceobj.Attitude.`**`Attitude`**

This module provides the basic representation of the spacecraft attitude.

`get/setAttitudeQuality()`
A string representing the quality of the spacecraft attitude (e.g. Preliminary, Final)

`get/setAttitudeSource()`
A string representing the source of the spacecraft attitude (e.g. Header)

`addStateVector`(*stateVector*)
Add an Attitude.StateVector object to the Attitude.

`interpolate`(*time*)
Interpolate the attitude and return an Attitude.StateVector at the specified time. The variable time must be a datetime.datetime object. Currently, the interpolation method is 'linear'.

Doppler

class `isceobj.Doppler.`**`Doppler`**

This module provides a basic representation of the Doppler variation with range.

`get/setDopplerCoefficients(inHz=False)`
A list representing the cubic polynomial fit of Doppler with respect to range. The variable inHz is a boolean indicating whether the coefficients are expressed in Hz, or Hz/PRF.

`average`(*doppler*)
Average two sets of Doppler polynomial coefficients. The variable doppler should be another Doppler object.

Coordinate

class `isceobj.Location.Coordinate.`**`Coordinate`**(*latitude=None*, *longitude=None*, *height=None*)

This module provides a basic representation of a geodetic coordinate.

`get/setLatitude()`

`get/setLongitude()`

`get/setHeight()`

Peg

class `isceobj.Location.Peg.`**`PegFactory`**

static **`fromEllipsoid`**(*coordinate=None*, *heading=None*, *ellipsoid=None*)
Create an *`isceobj.Location.Peg`* object from an *`isceobj.Location.Coordinate`* object, a heading and an *`isceobj.Planet.Ellipsoid`* object.

class `isceobj.Location.Peg.`**`Peg`**(*latitude=None*, *longitude=None*, *heading=None*, *radiusOfCurvature=None*)
A class to hold Peg point data used in the definition of the SCH coordinate system.

`get/setHeading()`

`get/setRadiusOfCurvature()`

Offset

class `isceobj.Location.Offset.`**`Offset`**(*x=None*, *y=None*, *dx=None*, *dy=None*, *snr=0.0*)
A class to represent a two-dimensional offset

`setCoordinate`(*x*, *y*)

`setOffset`(*dx*, *dy*)

`setSignalToNoise`(*snr*)

`getCoordinate`()

`getOffset`()

`getSignalToNoise`()

class `isceobj.Location.Offset.`**`OffsetField`**
A class to represent a collection of offsets

`addOffset`(*offset*)
Add an *`isceobj.Location.Offset.Offset`* object to the offset field.

`cull`(*snr=0.0*)
Remove all offsets with a signal to noise lower the *snr*

`unpackOffsets`()
A convenience method for converting an offset field to a list of lists. This is useful for interfacing with Fortran and C code. The order of the elements in the list is: [[x,dx,y,dy,snr],[x,dx,y,dy,snr], ...]

SCH

class `isceobj.Location.SCH.`**`SCH`**(*peg=None*)
A class implementing SCH <-> XYZ coordinate conversions. The variable peg should be a *`isceobj.Location.Peg.Peg`* object.

`xyz_to_sch`(*xyz*)
Convert from XYZ to SCH coordinates. The variable xyz should be a three-element list of cartesian coordinates.

`sch_to_xyz`(*sch*)
Convert from SCH to XYZ coordinates. The variable sch should be a three-element list of SCH coordinates.

vxyz_to_vsch(*sch*, *vxyz*)
Convert from a Cartesian velocity vxyz, to an SCH velocity relative to the point sch.

vsch_to_vxyz(*sch*, *vsch*)
Convert from an SCH velocity vsch, to a Cartesian velocity relative to the point sch.

class `isceobj.Location.SCH.`**LocalSCH**(*peg=None*, *sch=None*)
A class for converting between SCH coordinate systems with different peg points.

xyz_to_localsch(*xyz*)

localsch_to_xyz(*sch*)

Planet

class `isceobj.Planet.AstronomicalHandbook.`**Const**
A class encapsulating numerous physical constants.

pi

G

AU

c

class `isceobj.Planet.Ellipsoid.`**Ellipsoid**(*a=1.0*, *e2=0.0*)
A class for defining a planets ellipsoid

get_a()
Return the semi-major axis

get_e()
Return the eccentricity

get_e2()
Return the eccentricity squared

get_f()
Return the flattening

get_b()
Return the semi-minor axis

get_c()
Return the distance from the center to the focus

set_a(*a*)

set_e(*e*)

set_e2(*e2*)

set_f(*f*)

set_b(*b*)

set_c(*c*)

xyz_to_llh(*xyz*)
Convert from Cartesian XYZ coordinates to latitude, longitude, height.

llh_to_xyz(*llh*)
Convert from latitude, longitude, height to Cartesian XYZ coordinates

geo_dis(*llh1*, *llh2*)
Calculate the distance along the surface of the ellipsoid from llh1 to llh2.

geo_hdg(*llh1*, *llh2*)
Calculate the heading from llh1 to llh2.

radiusOfCurvature(*llh*, *hdg=0.0*)
Calculate the radius of curvature at a given point in a particular direction.

localRadius(*llh*)
Compute the equivalent spherical radius at a given coordinate.

class isceobj.Planet.Planet.**Planet**(*name*)
A class to represent a planet

get_elp()
Return the *isceobj.Planet.Ellipsoid.Ellipsoid* object for the planet.

get_GM()

get_name()

get_spin()

Platform

class isceobj.Platform.Platform.**Platform**

planet

mission

pointingDirection

antennaLength

spacecraftName

Radar

class isceobj.Radar.**Radar**

platform
An *isceobj.Platform.Platform.Platform* object

pulseLength

rangePixelSize

PRF

rangeSamplingRate

radarWavelength

radarFrequency

incidenceAngle

inPhaseValue

quadratureValue

beamNumber

Scene

class `isceobj.Scene.Frame.`**`Frame`**

A class to represent the smallest SAR image unit.

instrument

An `isceobj.Radar.Radar.Radar` object.

orbit

An *`isceobj.Orbit.Orbit`* object.

attitude

An `isceobj.Attribute.Attribute` object.

image

An object that inherits from *`isceobj.Image.BaseImage`*.

squint

polarization

startingRange

farRange

sensingStart

sensingMid

sensingStop

trackNumber

orbitNumber

frameNumber

passDirection

processingFacility

processingSystem

processingLevel

processingSoftwareVersion

class `isceobj.Scene.Frame.`**`Track`**

A collection of Frames.

combineFrames (*output*, *frames*)

addFrame (*frame*)

Image

Image Format Descriptions

File name	Bands	Size	Interleaving
amp	2	real*4	BIP
int	1	complex*8	Single
mht	2	real*4	BIP
slc	1	complex*8	Single
raw	1	complex*2	Single
dem	1	int*2	Single

class `isceobj.Image.BaseImage.`**`BaseImage`**
The base class for image objects.

`width`

`length`

`accessMode`

`filename`

`byteOrder`

class `isceobj.Image.AmpImage.`**`AmpImage`**
A band-interleaved-by-pixel file, containing radar amplitude images in each band.

class `isceobj.Image.DemImage.`**`DemImage`**
A single-banded 2-byte integer file, representing a Digital Elevation Model (DEM).

class `isceobj.Image.IntImage.`**`IntImage`**
A single-banded, complex-valued interferogram.

class `isceobj.Image.MhtImage.`**`MhtImage`**
A band-interleaved-by-pixel Magnitude (M) and height (ht) image.

class `isceobj.Image.RawImage.`**`RawImage`**
A single-banded, 2-byte, complex-valued image. Typically used for unfocussed SAR data.

class `isceobj.Image.RgImage.`**`RgImage`**
A band-interleaved-by-pixel Red (r), Green (g) image.

class `isceobj.Image.SlcImage.`**`SlcImage`**
A single-banded, 8-byte, complex-valued image. Typically used for focussed SAR data.

5.2.2 Stdproc Modules

Module Descriptions

Pulsetiming

class `stdproc.orbit.pulsetiming.`**`pulsetiming`**
This pure-Python module resamples the orbital state vectors using a Hermite interpolation scheme. The satellite's position and velocity are evaluated at each range line.

- Input
  - frame: an *`isceobj.Scene.Frame`* object

- Output
  - orbit: The interpolated orbital elements

Setmocomppath

class `stdproc.orbit.setmocomppath.`**`setmocomppath`**
This module selects a peg point for the SCH coordinate system using the geometry of the orbits for each satellite.

- Input
  - foo
- Output
  - bar

Orbit2sch

class `stdproc.orbit.orbit2sch.`**`orbit2sch`**
This module converts orbital state vectors from cartesian to SCH. The SCH coordinate system is defined through the Peg object on input

- Input
  - orbit: an *`isceobj.Orbit.Orbit`* object in ECEF coordinates
  - planet: an :py:clas::*isceobj.Planet.Planet* object
  - peg: an *`isceobj.Location.Peg`* object
- Output
  - orbit: an isceobj.Orbit.Orbit object in SCH coordinates

Formslc

class `stdproc.stdproc.Formslc.`**`Formslc`**
This module focuses SAR data using a range-doppler algorithm with motion compensation.

- Input
  - foo
- Output
  - bar

Cpxmag2rg

class `stdproc.util.Cpxmag2rg.`**`cpxmag2rg`**
This is a data preparation step in which the amplitudes from two SAR images are combined into a single two-band image. The resulting image is band-interleaved by pixel.

- Input
  - foo
- Output

–bar

Rgoffsetprf

class `stdproc.util.Rgoffsetprf.`**`rgoffsetprf`**
This module calculates the offset between two images using a 2-D Fourier transform method. The initial guess for the bulk image offset is derived from orbital information.

Offoutliers

class `stdproc.util.Offoutlier.`**`offoutlier`**
This module removes outliers from and offset field. The offset field is approximated by a best fitting plane, and offsets are deemed to be outliers if they are greater than a user selected distance.

resamp

class `stdproc.stdproc.resamp.resamp.`**`resamp`**
This module resamples an interferogram based on the provided offset field.

Mocompbaseline

class `stdproc.orbit.mocompbaseline.`**`mocompbaseline`**
This module utilizes the S-component information from the focusing step to line up the master and slave images. This is done by iterating over the S-component of the master image and then linearly interpolating the SCH coordinate at the corresponding S-component in the slave image. The difference between the SCH coordinate of the master and slave is then calculated, providing a 3-D baseline.

Topocorrect

class `stdproc.stdproc.topocorrect.topocorrect.`**`topocorrect`**
This module implements the algorithm outlined in section 9 of [1] to remove the topographic signal in the interferogram.

shadecpxtorg

class `stdproc.util.shade2cpx.`**`shade2cpx`**
Create a single two-band image combining shaded relief from the DEM in radar coordinates and a SAR amplitude image.

Rgoffsetprf

class `stdproc.util.rgoffsetprf.`**`rgoffsetprf`**
Estimate the subpixel offset between two interferograms.

[1] Zebker, H. A., S. Hensley, P. Shanker, and C. Wortham (2010), Geodetically accurate insar data processor, IEEE T. Geosci. Remote.

Rgoffset

class `stdproc.util.rgoffset.`**`rgoffset`**

Estimate the subpixel offset between two images.

Geocode

class `stdproc.rectify.geocode.`**`geocode`**

- Input
  - foo
- Output
  - bar

Citations

5.2.3 MROIPAC Modules

Module Descriptions

filter

class `mroipac.filter.`**`filter`**

This module provides access to the Goldstein-Werner power spectral filter from ROI_PAC. The algorithm behind the Goldstein-Werner filtering is explained in [2].

- Input Ports
  - inteferogram: *`isceobj.Image.IntImage`*
- Output Ports
  - filtered inteferogram: *`isceobj.Image.IntImage`*

`goldsteinWerner`(*alpha=0.5*)

Apply the Goldstein-Werner filter with a smoothing value of alpha.

correlation

class `mroipac.correlation.correlation.`**`Correlation`**

This module encapsulates the correlation methods from ROI_PAC and phase gradient correlation methods.

- Input Ports
  - interferogram: *`isceobj.Image.IntImage`*
  - amplitude: *`isceobj.Image.AmpImage`*
- Output Ports
  - correlation: *`isceobj.Image.MhtImage`*

[2] Goldstein, R. M., and C. L. Werner (1998), Radar interferogram filtering for geophysical applications, Geophys. Res. Lett., 25(21), 4035–4038.

`calculateCorrelation``()`
Calculate the correlation using the standard correlation formula.

`calculateEffectiveCorrelation``()`
Calculate the effective correlation using the phase gradient

grass

class `mroipac.grass.grass.`**`Grass`**
This module encapsulates the grass unwrapping algorithm, an implementation of the branch-cut unwrapping outlined in [3].

- Input Ports
  - interferogram: an *`isceobj.Image.IntImage`* object
  - correlation: an *`isceobj.Image.MhtImage`* object
- Output Ports
  - unwrapped interferogram: an isceobj.Image.FOO

`unwrap``(`*x=-1*, *y=-1*, *threshold=0.1*`)`
Unwrap an interferogram with a seed location in pixels specified by x (range) and y (azimuth) and an unwrapping correlation threshold (default = 0.1).

Citations

5.2.4 ISCE System

Module Descriptions

MathModule

class `isceobj.Util.mathModule.`**`MathModule`**
A class for some common mathematical functions.

static **`multiplyMatrices`**`(`*mat1*, *mat2*`)`

static **`invertMatrix`**`(`*mat*`)`

static **`matrixTranspose`**`(`*mat*`)`

static **`matrixVectorProduct`**`(`*mat*, *vec*`)`

static **`crossProduct`**`(`*v1*, *v2*`)`

static **`normalizeVector`**`(`*v1*`)`

static **`norm`**`(`*v1*`)`

static **`dotProduct`**`(`*v1*, *v2*`)`

static **`median`**`(`*list*`)`

static **`mean`**`(`*list*`)`

static **`linearFit`**`(`*x*, *y*`)`

[3] Goldstein, R. M., H. A. Zebker, and C. L. Werner (1988), Satellite radar interferometry: two-dimensional phase unwrapping, Radio Science, 23(4), 713– 720.

static **quadraticFit** (*x*, *y*)

DateTimeUtil

class iscesys.DateTimeUtil.DateTimeUtil.**DateTimeUtil**

A class containing some useful, and common, date manipulations.

static **timeDeltaToSeconds** (*td*)

static **secondsSinceMidnight** (*dt*)

static **dateTimeToDecimalYear** (*dt*)

Component

class iscesys.Component.Component.**Port** (*name=None*, *method=None*, *doc=None*)

get/setName()

get/setMethod()

get/setObject()

class iscesys.Component.Component.**PortIterator**

add (*port*)

getPort (*name=None*)

hasPort (*name=None*)

class iscesys.Component.Component.**InputPorts**

class iscesys.Component.Component.**OutputPorts**

class iscesys.Component.Component.**Component**

wireInputPort (*name=None*, *object=None*)

listInputPorts ()

getInputPort (*name=None*)

activateInputPorts ()

wireOuputPort (*name=None*, *object=None*)

listOutputPorts ()

getOutputPort (*name=None*)

activateOutputPorts ()

CHAPTER

SIX

EXTENDING ISCE

It is possible to extend the functionality of ISCE with existing Fortran, C, or C++ code, or pure Python. For pure Python code, the process is straightforward. However, if you are choosing to extend ISCE's functionality with Fortran or C code, you have two options, C extensions or pure Python extensions.

6.1 C Extension

There are two primary ways of extending ISCE with existing C code, using the built-in ctypes module, or writing a Python extension. The topics covered here extend straightforwardly to Fortran extensions as well. To create a Fortran extension, one needs to provide a light C wrapper and then use one of the two methods explained below to provide the bridge between Python and Fortran via the light C wrapper. First, we'll cover *ctypes* extensions, since they are the most straightforward to create.

6.1.1 ctypes

First Steps

We'll begin by creating a HelloWorld program in C. First, create a file called helloWorld.c with the following contents:

```
#include <stdio.h>

void helloWorld() {
   printf("Hello World\n");
}
```

Compile this function into a shared object file called *hello.so*. Using the GNU C compiler, the invocation is:

```
gcc -fPIC -shared -o hello.so hello.c
```

Now, lets call this C-function from Python using the *ctypes* module. Create a Python file called *helloWorld.py* with the following contents:

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

import os
import ctypes

class Hello(object):

    def __init__(self):
        pass
    def callHelloC(self):
        helloC = ctypes.cdll.LoadLibrary(os.path.dirname(__file__)+'/hello.so')
        helloC.helloWorld();

if __name__ == "__main__":
    hello = Hello()
    hello.callHelloC()
```

The line:

```
helloC = ctypes.cdll.LoadLibrary(os.path.dirname(__file__)+'/hello.so')
```

loads the library file created from your C code, while the line:

```
helloC.helloWorld();
```

calls the *helloWorld()* function in the *hello.so* library. Now, running the script *helloWorld.py*, will result in the message "Hello World" appearing on your screen.

Passing and Retrieving Values

Let's add a function to our *hello.c* file to demonstrate passing data in to C from Python, and getting a result back. Add the calculateSQRT function to *hello.c* to calculate a square root. *hello.c* should now look like this:

```
#include <stdio.h>
#include <math.h>

void helloWorld() {
   printf("Hello World\n");
}

int calculateSQRT(double val, double *ans) {
    int retval;

    *ans = sqrt(val);

    if (isnan(*ans)) {
      retval = 1;
    } else {
      retval = 0;
    }
    return retval;
}
```

This overly pedantic example will demonstrate how to retrieve both the result of the call, and the return value of the function. We can now change our Python interface in *helloWorld.py* to:

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

import os
import ctypes

class Hello(object):

    def __init__(self):
        pass

    def callHelloC(self):
        helloC = ctypes.cdll.LoadLibrary(os.path.dirname(__file__)+'/hello.so')
        helloC.helloWorld();

    def callSqrtC(self,val):
        helloC = ctypes.cdll.LoadLibrary(os.path.dirname(__file__)+'/hello.so')

        val_C = ctypes.c_double(val)
        ans_C = ctypes.c_double()

        success = helloC.calculateSQRT(val_C,ctypes.byref(ans_C))
        if (success != 0):
            raise ValueError("math domain error")

        return ans_C.value

if __name__ == "__main__":
    hello = Hello()
    hello.callHelloC()

    print hello.callSqrtC(4.0)
    print hello.callSqrtC(-4.0)
```

Recompile *hello.so* and run *helloWorld.py*. You'll notice that the first call to *hello.callSqrtC()* returns a valid answer, however, the second call, raises a exception. One of the benefits of using *ctypes* is that we are essentially delegating the memory management of variables passed in to the C code to Python through the calls to *ctypes.c_double()*. Python will now track these resources and reclaim them using it's garbage collector when they fall out of scope. Using this approach reduces the chance of a memory leak.

6.1.2 Python Extension

Writing a C-based Python extension is the most powerful and most complicated way of extending ISCE. For starters, we'll begin with the basics of writing Python extensions. To begin, we need to create a directory tree like:

```
+-helloworld/
  +-Makefile
  +-helloWorld.py
  +-bindings/
  | +-helloworldmodule.cpp
  +-src/
  | +-hello.c
  +-include/
    +-helloworldmodule.h
```

For this example, we can resuse the *hello.c* file from the *ctypes* example. We'll begin with *helloworldmodule.cpp*:

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

extern "C" void inithelloworld() {
    Py_InitModule3("helloworld",hello_methods,moduleDoc);
}

PyObject *hello_C(PyObject *self,PyObject *args) {
    helloWorld();
    return Py_BuildValue("i",0);
}
```

```
PyObject *sqrt_C(PyObject *self,PyObject *args) {
    int retval;
    double val,*ans;
    PyObject *result;

    if(!PyArg_ParseTuple(args,"d",&val)) {
        return NULL;
    }

    ans = new double[1];
    retval = calculateSQRT(val,&ans);

    result = Py_BuildValue("d",*ans);
    delete[] ans;

    return result;
}
```

Now, we need to create the *helloworldmodule.h* header file:

```
#ifndef helloworldmodule_h
#define helloworldmodule_h

#include <Python.h>

extern "C" {
    PyObject *hello_C(PyObject *self,PyObject *args);
    PyObject *sqrt_C(PyObject *self,PyObject *args);
    int calculateSQRT(double val,double *ans);
    void helloWorld();
}

static char *moduleDoc = "module for exploring Python extensions";

static PyMethodDef hello_methods[]  =
    {
        {"callHelloC",hello_C,METH_VARARGS,"Say Hello"},
        {"callSqrtC",sqrt_C,METH_VARARGS,"Calculate a square root"},
        {NULL,NULL,0,NULL}
    };

#endif helloworldmodule_h
```

We now need to compile our C extension. The way in which this is done varies from platform to platform, but something along the lines of the following *Makefile* should work:

```
CC=gcc
CXX=g++
CFLAGS=-fPIC -shared
CPPFLAGS=-I/usr/include
LDFLAGS=-L/usr/lib
LIBS=-lpython
VPATH=src bindings

helloworldmodule.so: hello.o helloworldmodule.o
        $(CXX) $(CFLAGS) $^ -o $@ $(LIBS)

.c.o:
        $(CC) $(CPPFLAGS) -c $<
```

```
.cpp.o:
	$(CXX) $(CPPFLAGS) -c $<

clean:
	/bin/rm helloworldmodule.so \*.o
```

Finally, we can create *helloWorld.py*:

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

import helloworld

helloworld.callHelloC()
print helloworld.callSqrtC(4.0)
print helloworld.callSqrtC(-4.0)
```

Running *helloWorld.py* results in the same output as the *ctypes* program, but, compared the the *ctypes* approach, much of the memory management and low-level program control had to be written by us.

6.2 Application to ISCE

We can take the lessons learned from our simple *Hello World* modules and extend them straightforwardly to ISCE. To do so, we'll need to learn how to use scons, ISCE's build system.

As an example, lets add a quadratic interpolation method to our Orbit object.

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