RASCIL Documentation

Release 1.2.0

Tim Cornwell, Peter Wortmann, Bojan Nikolic, Feng Wang, Vlad St

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CONTENTS

The Radio Astronomy Simulation, Calibration and Imaging Library expresses radio interferometry calibration and imaging algorithms in python and numpy. The interfaces all operate with familiar data structures such as image, visibility table, gain table, etc.

Source code: https://gitlab.com/ska-telescope/external/rascil-main

As of version 1.0.0, the library mostly contains high-level workflows and pipelines, while the data models and a large number of processing components (functions) have been migrated to ska-sdp-datamodels and ska-sdp-func-python, which are directly used within RASCIL.

As of version 0.2.0, the data classes are built on the Xarray library, offering a rich API for applications. For more details including how to update existing scripts, see *Use of xarray*.

To achieve sufficient performance we take a dual pronged approach - using threaded libraries for shared memory processing, and the Dask library for distributed processing.

CHAPTER

ONE

THE ROLE OF THE RASCIL IN SKA SCIENCE DATA PROCESSING (SDP)

RASCIL was developed in SDP under the name ARL (Algorithm Reference Library) with the emphasis of creating reference versions of standard algorithms. The ARL was therefore designed to present primarily imaging algorithms in a simple Python-based form so that the implemented functions could be seen and understood easily. This also fulfilled the requirement of providing a simple test version where algorithms could be tested and compared as necessary.

For an overview of the SDP see the SDP CDR documentation

More details can be found at: SKA1 SDP Algorithm Reference Library (ARL) Report

Subsequent to the conclusion of the SDP project, it became clear that ARL could play a larger role than being limited to a reference library. Hence, it was renamed to the Radio Astronomy Simulation, Calibration and Imaging Library (RASCIL) and is undergoing continued development. The Algorithm Reference Library (ARL) is now frozen. The background motivation and requirements of the ARL/RASCIL are detailed further in *Background*.

1.1 Installation

RASCIL can be run on a Linux or macOS machine or cluster of machines. At least 16GB physical memory is necessary to run the full test suite. In general more memory is better. RASCIL uses Dask for multi-processing and can make good use of multi-core and multi-node machines.

1.1.1 Installation via pip

If you just wish to run the package and do not intend to run simulations or tests, RASCIL can be installed using pip:

```
pip3 install --index-url=https://artefact.skao.int/repository/pypi-all/simple rascil
```

This will download the latest stable version. At the moment, the wheel requires python 3.9 or 3.10. We regularly update the package to comply with the latest python versions. Compatibility with more recent versions will also be updated.

For simulations, you must add the data in a separate step:

```
mkdir rascil_data
cd rascil_data
curl https://ska-telescope.gitlab.io/external/rascil-main/rascil_data.tgz -o rascil_data.
↪tgz
tar zxf rascil_data.tgz
cd data
export RASCIL_DATA=`pwd`
```

If you wish to run the RASCIL examples or tests, use one of the steps below.

1.1.2 Installation via docker

If you are familiar with docker, an easy approach is to use that:

Dockerfiles for RASCIL

RASCIL supports the publishing of various docker images. The related Dockerfiles can be found in the `docker` directory and its subdirectories. The images are based on a python wheel created from RASCIL.

Makefiles are also included, which support building, pushing, and tagging images. The images are named as specified in the `release` file of the docker image directory, and tagged by the RASCIL version stored in `rascil/version.py`.

There are various directories for docker files:

- rascil-base: A minimal RASCIL, without data
- rascil-full: Base with data
- rascil-notebook: Supports running jupyter notebook
- rascil-imaging-qa: Runs the Continuum Imaging Quality Assessment tool
- rascil-rcal: Supports running RCAL as consumer of SDP visibility receive data. Note that this is not published as of rascil==1.1.0

Automatic publishing

The docker images are automatically built by the CI pipeline.

When the repository is tagged, and a new version of it is released, a versioned docker images of each type is published to the Central Artifact Repository (CAR). To find out what versions you can download, look for the relevant RASCIL docker image in the CAR. Example:

```
artefact.skao.int/rascil-base:1.0.0
```

Upon every commit an image with the commit tag is published to the GitLab Registry. Note that these are development images and should only be used with caution.

```
registry.gitlab.com/ska-telescope/external/rascil/rascil-imaging-qa:<commit-
↪tag>
```

The list of available development images can be found here, where you can find the `commit-tag` as well:

```
https://gitlab.com/ska-telescope/external/rascil-main/container_registry/
```

Build, push, and tag a set of Dockerfiles

If you want to build an image yourself, follow these steps:

- `cd` into one of the subdirectories
- Build the image with `make build`

Other useful make commands :

- `push` pushes the images to the docker registry

- `push_latest` pushes the `:latest` tag
- `push_version` pushes a version tag without the git SHA

Note, the above make commands use environment variables to determine the image name and repository. For a full list and defaults, please consult the Makefile in `docker/make/`.

Useful make commands that can be run from the `docker` directory:

- `build_all_latest` builds, and tags as latest, all the images
- `rm_all` removes all the images
- `ls_all` lists all the images

Test the images

The `docker/Makefile` contains commands for testing all the images. These write results into the host /tmp area. For docker:

- make test_base
- make test_full
- make test_notebook
- make test_imaging_qa
- make test_rcal

And for singularity:

- make test_base_singularity
- make test_full_singularity
- make test_notebook_singularity
- make test_imaging_qa_singularity
- make test_rcal_singularity

Generic RASCIL images

rascil-base and rascil-full

The base and full images are available at:

```
artefact.skao.int/rascil-base
artefact.skao.int/rascil-full
```

`rascil-base` does not have the RASCIL test data but is smaller in size. However, for many of the tests and demonstrations the test data is needed, which are included in `rascil-full`.

To run RASCIL with your home directory available inside the image:

```
docker run -it --volume $HOME:$HOME artefact.skao.int/rascil-full:<version>
```

Now let's run an example. First it simplifies using the container if we do not try to write inside the container, and that's why we mapped in our $HOME directory. So to run the /rascil/examples/scripts/imaging.py script, we first change directory to the name of the HOME directory, which is the same inside and outside

the container, and then give the full address of the script inside the container. This time we will show the prompts from inside the container:

```
% docker run -p 8888:8888 -v $HOME:$HOME -it artefact.skao.int/rascil-full:1.0.
↪0
rascil@d0c5fc9fc19d:/rascil$ cd /<your home directory>
rascil@d0c5fc9fc19d:/<your home directory>$ python3 /rascil/examples/scripts/
↪imaging.py
...
rascil@d0c5fc9fc19d:/<your home directory>$ ls -l imaging*.fits
-rw-r--r-- 1 rascil rascil 2102400 Feb 11 14:04 imaging_dirty.fits
-rw-r--r-- 1 rascil rascil 2102400 Feb 11 14:04 imaging_psf.fits
-rw-r--r-- 1 rascil rascil 2102400 Feb 11 14:04 imaging_restored.fits
```

In this example, we change directory to an external location (my home directory in this case, use yours instead), and then we run the script using the absolute path name inside the container.

RASCIL Notebooks

The docker image to use with RASCIL Jupyter Notebooks is:

```
artefact.skao.int/rascil-notebook
```

Run Jupyter Notebooks inside the container:

```
docker run -it -p 8888:8888 --volume $HOME:$HOME artefact.skao.int/rascil-
↪notebook:1.0.0
cd /<your home directory>
jupyter notebook --no-browser --ip 0.0.0.0  /rascil/examples/notebooks/
```

The Juptyer server will start and output possible URLs to use:

```
[I 14:08:39.041 NotebookApp] Serving notebooks from local directory: /rascil/
↪examples/notebooks
[I 14:08:39.041 NotebookApp] The Jupyter Notebook is running at:
[I 14:08:39.042 NotebookApp] http://d0c5fc9fc19d:8888/?
↪token=f050f82ed0f8224e559c2bdd29d4ed0d65a116346bcb5653
[I 14:08:39.042 NotebookApp]  or http://127.0.0.1:8888/?
↪token=f050f82ed0f8224e559c2bdd29d4ed0d65a116346bcb5653
[I 14:08:39.042 NotebookApp] Use Control-C to stop this server and shut down␣
↪all kernels (twice to skip confirmation).
[W 14:08:39.045 NotebookApp] No web browser found: could not locate runnable␣
↪browser.
```

The 127.0.0.1 is the one we want. Enter this address in your local browser. You should see the standard Jupyter directory page.

Images of RASCIL applications

Continuum imaging Quality Assessment tool (a.k.a imaging_qa)

imaging_qa finds compact sources in a continuum image and compares them to the sources used in the simulation, thus revealing the quality of the imaging.

DOCKER

Pull the image:

```
docker pull artefact.skao.int/rascil-imaging-qa:<version>
```

Run the image:

```
docker run -v ${PWD}:/myData -e DOCKER_PATH=${PWD} \
    -e CLI_ARGS='--ingest_fitsname_restored /myData/my_restored.fits \
    --ingest_fitsname_residual /myData/my_residual.fits' \
    --rm artefact.skao.int/rascil-imaging-qa:1.0.0
```

Run it from the directory where your images you want to check are. The output files will appear in the same directory. Update the `CLI_ARGS` string with the command line arguments of the imaging_qa code as needed. `DOCKER_PATH` is used to extract the path of the output files the app produced in your local machine, not in the docker container. This is used for generating the output file index files.

SINGULARITY

Pull the image:

```
singularity pull rascil-imaging-qa.img docker://artefact.skao.int/
rascil-imaging-qa:1.0.0
```

Run the image:

```
singularity run \
    --env CLI_ARGS='--ingest_fitsname_restored test-imaging-pipeline-dask_
↪continuum_imaging_restored.fits \
        --ingest_fitsname_residual test-imaging-pipeline-dask_continuum_
↪imaging_residual.fits' \
    rascil-imaging-qa.img
```

Run it from the directory where your images you want to check are. The output files will appear in the same directory. If the singularity image you downloaded is in a different path, point to that path in the above command. Update the `CLI_ARGS` string with the command line arguments of the imaging qa code as needed.

Providing input arguments from a file

You may create a file that contains the input arguments for the app. Here is an example of it, called *args.txt*:

```
::

    –ingest_fitsname_restored=/myData/test-imaging-pipeline-dask_continuum_imaging_restored.fits
    –ingest_fitsname_residual=/myData/test-imaging-pipeline-dask_continuum_imaging_residual.fits
    –check_source=True –plot_source=True
```

Make sure each line contains one argument, there is an equal sign between arg and its value, and that there aren't any trailing white spaces in the lines (and no empty lines). The paths to images and other input files has to be the absolute path within the container. Here, we use the `DOCKER` example of mounting our data into the `/myData` directory.

Then, calling `docker run` simplifies as:

```
docker run -v ${PWD}:/myData  -e DOCKER_PATH=${PWD} -e CLI_ARGS='@/myData/args.
↪txt' \
--rm artefact.skao.int/rascil-imaging-qa:1.0.0
```

Here, we assume that your custom args.txt file is also mounted together with the data into `/myData`. Provide the absolute path to that file when your run the above command.

You can use an args file to run the singularity version with same principles, baring in mind that singularity will automatically mount your filesystem into the container with paths matching those on your system.

RCAL visibility receive consumer

The rascil_rcal directory contains the necessary extra code and Dockerfile to build a docker image that can be used as a consumer for the visibility receive script. This processing script can be deployed in the SDP system. It receives data packets from the Correlator and Beam Former (CBF) or its emulator.

A prototype rcal-consumer has been added to the docker image. It formats the received data packets into objects that can be passed into a VisibilityBucket. A VisibilityBucket is filled up until full, i.e. when it received all frequency channel data for a single time sample. The resulting Visibility object is then passed to RCAL, which processes the data and produces the resulting gain solutions (and optional png images).

The docker image is available from the Central Artifact Repository (tagged with the release version number):

```
artefact.skao.int/rascil-rcal:<version>
```

and from the GitLab container registry (tagged with latest and updated upon merge to master):

```
registry.gitlab.com/ska-telescope/external/rascil/rascil-rcal:latest
```

Note: as of rascil==1.1.0, the rcal image is no longer released by default.

Running RASCIL as a cluster

The following methods of running RASCIL as a cluster, will provide a set of docker-based environments, which host a Dask scheduler, various Dask workers (numbers can be customized), and a Jupyter lab notebook, which directly connects to the scheduler.

Kubernetes

RASCIL can be run as a cluster in Kubernetes using helm and kubectl (you need to have these two installed). If you want to run it in a local developer environment (e.g. a laptop), we recommend using Minikube.

A custom `values.yaml` files is provided in /rascil/docker/kubernetes. It is meant to be used with a custom Dask Helm chart maintained by SKA developers, hosted in a GitLab repository. The documentation and details of the SKA Dask Helm chart can be found at https://developer.skao.int/projects/ska-sdp-helmdeploy-charts/en/latest/charts/dask.html.

You can modify the `values.yaml` file, if needed, e.g. you can change the number of worker replicas, or the docker image used (e.g. the version that should be run). If you don't use a PersistentVolumeClaim, remove `mounts` and `volume` sections from the jupyter and worker entries. (See also /rascil/docker/kubernetes/README.md)

Start Minikube and add the helm repository:

```
helm repo add ska-helm https://gitlab.com/ska-telescope/sdp/ska-sdp-helmdeploy-
↪charts/-/raw/master/chart-repo
helm repo update
```

`cd` into the `/rascil/docker/kubernetes` directory and install the RASCIL cluster:

```
helm install test ska-helm/dask -f values.yaml
```

Instructions on how to connect to the Dask dashboard and the Jupyter lab notebook are printed in the screen, please follow those. You can follow the deployment process and access logs using `kubectl` or via ``*k9s*`` <https://k9scli.io/>`_.

To uninstall the chart and clean out all pods, run:

```
helm uninstall test
```

Note: this will remove changes you might have made in the Jupyter notebooks.

Singularity

Singularity can be used to load and run the docker images:

```
singularity pull RASCIL-full.img docker://artefact.skao.int/rascil-full:1.0.0
singularity exec RASCIL-full.img python3 /rascil/examples/scripts/imaging.py
```

As in docker, don't run from the /rascil/ directory.

Inside a SLURM file singularity can be used by prefacing dask and python commands with "singularity exec". For example:

```
ssh $host singularity exec /home/<your-name>/workspace/RASCIL-full.img dask-
↪scheduler --port=8786 &
ssh $host singularity exec /home/<your-name>/workspace/RASCIL-full.img dask-
↪worker --host ${host} --nprocs 4 --nthreads 1  \
--memory-limit 100GB $scheduler:8786 &
CMD="singularity exec /home/<your-name>/workspace/RASCIL-full.img python3 ./
↪cluster_test_ritoy.py ${scheduler}:8786 | tee ritoy.log"
eval $CMD
```

Customisability

The docker images described here are ones we have found useful. However, if you have the RASCIL code tree installed then you can also make your own versions working from these Dockerfiles.

Important updates

Starting with version 0.3.0, RASCIL is installed as a package into the docker images and the repository is not cloned anymore. Hence, every python script (except the ones in the `examples` directory) within the image has to be called with the `-m` switch in the following format, when running within the docker container, e.g.:

```
python -m rascil.apps.rascil_advise <args>
```

1.1.3 Installation via git clone

Use of git clone is necessary if you wish to develop and possibly contribute to the RASCIL codebase. Installation should be straightforward. We strongly recommend the use of a python virtual environment.

RASCIL requires python 3.9+.

The installation steps are:

- Use git to make a local clone of the Github repository:

  ```
  git clone https://gitlab.com/ska-telescope/external/rascil-main.git --recurse-
  ↪submodules
  ```

  Note that RASCIL uses the ska-cicd-makefile submodule, hence why you need to clone using the `--recurse-submodules` option.

- Change into that directory:

  ```
  cd rascil
  ```

- Install the required python packages and RASCIL package (in an activated virtual environment). The following command uses pip to install all of the requirements, including test and docs:

  ```
  make install_requirements
  ```

- RASCIL makes use of a number of data files. These can be downloaded using Git LFS:

```
pip install git-lfs
git lfs install
git-lfs pull
```

The data will be pulled into the `data` directory within the `rascil-main` git source directory. If git-lfs is not already available, then lfs will not be recognised as a valid option for git in the second step. In this case, git-lfs can be installed via `sudo apt install git-lfs` or from a tar file

- Put the following definitions in your .bashrc:

```
export RASCIL=/path/to/rascil
export PYTHONPATH=$RASCIL:$PYTHONPATH
```

  Note: if you use a virtual environment, you will not need to update your PYTHONPATH.

1.1.4 Trouble-shooting

Testing

Check your installation by running a subset of the tests:

```
pip install pytest pytest-xdist
py.test -n 4 tests/processing_components
```

Or the full set:

```
py.test -n 4 tests
```

- Ensure that pip is up-to-date. If not, some strange install errors may occur.
- Check that the contents of the data directories have plausible contents. If gif-lfs has not been run successfully then the data files will just contain meta data, leading to strange run-time errors.
- There may be some dependencies that require either conda (or brew install on a mac).
- Ensure that you have made the directory test_results to store the test results.

Casacore installation

RASCIL requires python-casacore to be installed. This is included in the requirements for the RASCIL install and so should be installed automatically via pip. In some cases there may not be a compatible binary install (wheel) available via pip. If not, pip will download the source code of casacore and attempt a build from source. The most common failure mode during the source build is that it cannot find the boost-python libraries. These can be installed via pip. If errors like this occur, once rectified, re-installing python-casacore separately via pip may be required, prior to re-commencing the RASCIL install.

Trouble-shooting problems with a source install can be difficult. If available, this can be avoided by using anaconda (or miniconda) as the base for an environment. It supports python-casacore which can be installed with:

```
conda install -c conda-forge python-casacore
```

It may also be possible to avoid some of the more difficult issues with building python-casacore by downloading CASA prior to the RASCIL install.

On MacOS, we recommend using conda, and installing python-casacore with that prior to installing the other RASCIL requirements. This proved to be the simplest way of getting casacore working without having to install separate boost and casacore packages.

RASCIL data in notebooks

In some case the notebooks may not automatically find the RASCIL data directory, in which case explicitly setting the RASCIL_DATA environment variable may be required: `%env RASCIL_DATA=~/rascil_data/data`.

1.2 Examples

1.2.1 Running notebooks

The best way to get familiar with RASCIL is via jupyter notebooks. For example:

```
jupyter notebook examples/notebooks/imaging.ipynb
```

See the jupyter notebooks below:

- Imaging and deconvolution demonstration
- Simple demonstration of the use of Dask/rsexecute
- Bandpass calibration demonstration
- Demonstrate visibility xarray format

Some functions initially developed for the LOFAR telescope pipeline are made available in RASCIL. The following notebooks show how the functions are integrated.

- Deconvolution with Rascil and Radler
- Multi frequency deconvolution with Rascil and Radler

In addition, there are other notebooks in examples/notebooks that are not built as part of this documentation. In some cases it may be necessary to add the following to the notebook to locate the RASCIL data `%env RASCIL_DATA=~/rascil_data/data`

1.2.2 Running scripts

Some example scripts are found in the directory examples/scripts.

- examples/scripts/imaging.py
- examples/scripts/primary_beam_zernikes.py

1.2.3 SKA simulations

- genindex
- modindex

1.3 Structure

Those familiar with other calibration and imaging packages will find the following information useful in navigating the RASCIL. Not all functions are listed here but are contained in the API.

The long form of the name is given for all entries but all function names are unique so a given function can be accessed using the very top level import:

```
import rascil.processing_components
import rascil.workflows
import rascil.apps
```

1.3.1 Data containers used by RASCIL

RASCIL holds data in python Classes. The bulk data and attributes are usually kept in a xarray.Dataset. For each xarray based class there is an accessor which holds class specific methods and properties.

Note that the data models have been migrated into the SKA SDP Python-based Data Models directory. Please refer to the documentation there for more information.

1.3.2 Functions

NOTE: Some processing functions have been migrated to the ska-sdp-func-python repository, please refer to the documentation there for information. Functions on this page is an incomplete list.

Read existing Measurement Set

Casacore must be installed for MS reading and writing:

- List contents of a MeasurementSet: `rascil.processing_components.visibility.base.list_ms()`
- Creates a list of Visibilities, one per FIELD_ID and DATA_DESC_ID: `rascil.processing_components.visibility.base.create_visibility_from_ms()`

Image

- Image operations: *rascil.processing_components.image.operations()*
- Import from FITS: *rascil.processing_components.image.operations.import_image_from_fits()*
- Re-project coordinate system: *rascil.processing_components.image.operations.reproject_image()*
- Smooth image: *rascil.processing_components.image.operations.smooth_image()*
- FFT: *rascil.processing_components.image.operations.fft_image_to_griddata_with_wcs()*

- Remove continuum: *rascil.processing_components.image.operations.remove_continuum_image()*

1.3.3 Workflows

Workflows coordinate processing using the data models, processing components, and processing library. These are high level functions, and are available in an rsexecute (i.e. dask) version and sometimes a scalar version.

Calibration workflows

- Calibrate workflow: *rascil.workflows.rsexecute.calibration.calibrate_list_rsexecute_workflow()*

Imaging workflows

- Invert: *rascil.workflows.rsexecute.imaging.invert_list_rsexecute_workflow()*
- Predict: *rascil.workflows.rsexecute.imaging.predict_list_rsexecute_workflow()*
- Deconvolve: *rascil.workflows.rsexecute.imaging.deconvolve_list_rsexecute_workflow()*

Pipeline workflows

- ICAL: *rascil.workflows.rsexecute.pipelines.ical_skymodel_list_rsexecute_workflow()*
- Continuum imaging: *rascil.workflows.rsexecute.pipelines.continuum_imaging_skymodel_list_rsexecute_wor*
- Spectral line imaging: *rascil.workflows.rsexecute.pipelines.spectral_line_imaging_skymodel_list_rsexecut*
- MPCCAL: `rascil.workflows.rsexecute.pipelines.mpccal_skymodel_list_rsexecute_workflow()`

Simulation workflows

- Testing and simulation support: *rascil.workflows.rsexecute.simulation.simulate_list_rsexecute_workflow()*

Execution

- Execution framework (an interface to Dask): *rascil.workflows.rsexecute.execution_support()*

1.3.4 Apps

Apps are command line applications written using the data models, processing components, and processing library.

Imaging

rascil_imager

rascil_imager is a command line app written using RASCIL. It supports three ways of making an image:

- invert: Inverse Fourier Transform of the visibilities to make a dirty image (or point spread function)
- cip: The SKA Continuum Imaging Pipeline.
- ical: The SKA Iterative Calibration Pipeline (ICAL)

Notable features:

- Reads a CASA MeasurementSet and writes FITS files
- Image size can be a composite of 2, 3, 5
- Distribute processing across processors using Dask
- Multi Frequency Synthesis Multiscale CLEAN available, also with distribution of CLEAN over facets
- Distribution of restoration over facets
- Wide field imaging using the fast and accurate nifty gridder
- Modelling of bright sources by fitting with sub-pixel locations
- Selfcalibration available for atmosphere (T), complex gains (G), and bandpass (B)
- Selection of data by uv range and r range (where r is the distance of station/dish from array centre

CLI arguments are grouped:

- `--mode` prefixed parameters controls which algorithm is run.
- `--imaging` prefixed parameters control the details of the imaging such as number of pixels, cellsize
- `--clean` prefixed parameters control the clean deconvolutions (active only for modes cip and ical)
- `--calibration` prefixed parameters control the calibration in the ICAL pipeline. (active only for mode ical)
- `--dask` prefixed parameters control the use of Dask/rsexecute for distributing the processing

MeasurementSet ingest

Although a CASA MeasurementSet can hold heterogeneous observations, identified by data descriptors. rascil-imager can only process identical data descriptors from a MS. The number of channels and polarisation must be the same.

Each selected data descriptor is optionally split into a number of channels optionally averaged and placed into one Visibility.

For example, using the arguments:

```
--ingest_msname SNR_G55_10s.calib.ms --ingest_dd 0 1 2 3 --ingest_vis_nchan 64 \
--ingest_chan_per_vis 8 --ingest_average_vis True
```

will read data descriptors 0, 1, 2, 3, each of which has 64 channels. Each set of 64 channels are split into blocks of 8 and averaged. We thus end up with 32 separate datasets in RASCIL, each of which is a Visibility and has 1 channel, for a total of 32 channels. If the argument `--ingest_average_vis` is set to False, each Visibility has eight channels, for a total of 256 channels.

Selection

rascil_imager supports selection of data by uv range `--imaging_uvmin` `--imaging_uvmax`, and by dish/station based on distance from the array centre `--imaging_rmin` `--imaging_rmax`

Imaging

To make an image from visibilities or to predict visibilities from a model, it is necessary to use a gridder. Nifty gridder (https://gitlab.mpcdf.mpg.de/ift/nifty_gridder) is currently the best gridder to use in RASCIL. It is written in c and uses OpenMP to distribute the processing across multiple threads. The Nifty Gridder uses an improved wstacking algorithm uses many fewer w-planes than w stacking or w projection. It is not necessary to explicitly set the number of w-planes.

The gridder is set by the `--imaging_context` argument. The default, `--imaging_context ng` is the Nifty Gridder.

CLEAN

rascil-imager supports Hogbom CLEAN, MultiScale CLEAN, and Multi-Frequency Synthesis MultiScale Clean (also known as MMCLEAN). The first two work independently on different frequency channels, while MMClean works jointly cross all channels using a Taylor Series expansion in frequency for the emission.

The clean methods support a number of processing speed enhancements:

- The multi-frequency-synthesis CLEAN works by fitting a Taylor series in frequency. The `--ingest_chan_per_vis` argument controls the aggregation of channels in the MeasurementSet to form image planes for the CLEAN. Within a Visibility the different channels are gridded together to form one image. Each image is then used in the mmclean algorithm. For example, a data set may have 256 channels spread over 4 data descriptors. We can split these into 32 BlockVisibilities and then run the mmclean over these 32 channels.
- Only a limited central region of the PSF will be subtracted during the minor cycles.
- The cleaning may be partitioned into overlapping facets, each of which is cleaned independently, and then merged with neighbours using a taper function. This works well for fields of compact sources but is likely to not perform well for extended emission.
- The restoration may be distributed via subimages. This requires that the subimages have significant overlap such that the clean beam can fit within the overlap area.

Bright compact sources can optionally be represented by discrete components instead of pixels.

- `--clean_component_threshold 0.5` All sources > 0.5 Jy to be fitted
- `--clean_component_method fit` non-linear last squares algorithm to find source parameters

The skymodel written at the end of processing will include both the image model and the skycomponents.

Polarisation

The polarisation processing behaviour is controlled by `--image_pol`.

- `--image_pol stokesI` will image only the I Stokes parameter
- `--image_pol stokesIQUV` will image all Stokes parameters I, Q, U, V

Note that the combination of MM CLEAN and stokesIQUV imaging is not likely to be meaningful.

Self-calibration

rascil-imager supports self-calibration as part of the imaging. At the end of each major cycle a calibration solution and application may optionally be performed.

Calibration uses the Hamaker Bregman Sault formalism with the following Jones matrices supported: T (Atmospheric phase), G (Electronics gain), B - (Bandpass).

An example consider the arguments:

```
calibration_T_first_selfcal = 2
calibration_T_phase_only = True
calibration_T_timeslice = None
calibration_G_first_selfcal = 5
calibration_G_phase_only = False
calibration_G_timeslice = 1200.0
calibration_B_first_selfcal = 8
calibration_B_phase_only = False
calibration_B_timeslice = 1.0e5
calibration_global_solution = True
calibration_calibration_context = "TGB"
```

These will perform a phase only solution of the T term after the second major cycle for every integration, solution of G after 5 major cycles with timescale of 1200s, and solution of B after 8 major cycles, integrating across all frequencies where appropriate. Note, that T and G terms are averages across frequency.

SkyModel in ICAL

When running rascil_imager in mode ical, optionally, an initial SkyModel can be used. To do this, set `--use_initial_skymodel` to True. The SkyModel is made up of model images (created based on input BlockVisibilities), and SkyComponents. The kind of SkyComponent(s) to use in the initial SkyModel is controlled by the `--input_skycomponent_file` and `--num_bright_sources` arguments:

1. If no input file is provided, a point source at the phase centre, with brightness of 1 Jy is used as the component.
2. **If either an HDF file or a TXT file is provided, the components are read from the file.**
    a. if `--num_bright_sources` is left as `None`, all of the components are used for the SkyModel
    b. if `--num_bright_sources` is an integer *n* (*n>0*), then *n* number of the brightest components are used for the SkyModel

This SkyModel is then overwritten during the remaining cycles of the run.

By default, `--use_initial_skymodel` is set to False, and hence no initial SkyModel is used.

In addition, you can decide whether to reset the initial skymodel after first calibration, or not, by setting the `--calibration_reset_skymodel` either to True or False.

Dask

Dask is used to distribute processing across multiple cores or nodes. The setup and execution of a set of workers is controlled by a scheduler. By default, rascil uses the process scheduler which sets up a number of processes each with a number of threads. If the host has 16 cores, the set up will be 4 processes each with 4 threads for a total of 16 Dask workers.

For distribution across a cluster, the Dask distributed processor is required. See *RASCIL and DASK* for more details.

Example script

The following runs the cip on a data set from the CASA examples:

```
#!/bin/bash
# Run this in the directory containing SNR_G55_10s.calib.ms
# (The dataset can be downloaded at
# http://casa.nrao.edu/Data/EVLA/SNRG55/SNR_G55_10s.calib.tar.gz)
python $RASCIL/rascil/apps/rascil_imager.py --mode cip \
--ingest_msname SNR_G55_10s.calib.ms --ingest_dd 0 1 2 3 --ingest_vis_nchan 64 \
--ingest_chan_per_vis 8 --ingest_average_vis True \
--imaging_npixel 1280 --imaging_cellsize 3.878509448876288e-05 \
--imaging_weighting robust --imaging_robustness -0.5 \
--clean_nmajor 5 --clean_algorithm mmclean --clean_scales 0 6 10 30 60 \
--clean_fractional_threshold 0.3 --clean_threshold 0.12e-3 --clean_nmoment 5 \
--clean_psf_support 640 --clean_restored_output integrated
```

Command line arguments

RASCIL continuum imager

```
usage: rascil_imager.py [-h] [--mode MODE] [--logfile LOGFILE]
                        [--performance_file PERFORMANCE_FILE]
                        [--ingest_msname INGEST_MSNAME]
                        [--ingest_dd [INGEST_DD ...]]
                        [--ingest_vis_nchan INGEST_VIS_NCHAN]
                        [--ingest_chan_per_vis INGEST_CHAN_PER_VIS]
                        [--ingest_average_vis INGEST_AVERAGE_VIS]
                        [--imaging_phasecentre IMAGING_PHASECENTRE]
                        [--imaging_pol IMAGING_POL]
                        [--imaging_nchan IMAGING_NCHAN]
                        [--imaging_context IMAGING_CONTEXT]
                        [--imaging_ng_threads IMAGING_NG_THREADS]
                        [--imaging_w_stacking IMAGING_W_STACKING]
                        [--imaging_flat_sky IMAGING_FLAT_SKY]
                        [--imaging_npixel IMAGING_NPIXEL]
                        [--imaging_cellsize IMAGING_CELLSIZE]
                        [--imaging_weighting IMAGING_WEIGHTING]
                        [--imaging_robustness IMAGING_ROBUSTNESS]
                        [--imaging_gaussian_taper IMAGING_GAUSSIAN_TAPER]
                        [--imaging_dopsf IMAGING_DOPSF]
```

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```
                        [--imaging_dft_kernel IMAGING_DFT_KERNEL]
                        [--imaging_uvmax IMAGING_UVMAX]
                        [--imaging_uvmin IMAGING_UVMIN]
                        [--imaging_rmax IMAGING_RMAX]
                        [--imaging_rmin IMAGING_RMIN]
                        [--perform_flagging PERFORM_FLAGGING]
                        [--flagging_strategy_name FLAGGING_STRATEGY_NAME]
                        [--calibration_reset_skymodel CALIBRATION_RESET_SKYMODEL]
                        [--calibration_T_first_selfcal CALIBRATION_T_FIRST_SELFCAL]
                        [--calibration_T_phase_only CALIBRATION_T_PHASE_ONLY]
                        [--calibration_T_timeslice CALIBRATION_T_TIMESLICE]
                        [--calibration_G_first_selfcal CALIBRATION_G_FIRST_SELFCAL]
                        [--calibration_G_phase_only CALIBRATION_G_PHASE_ONLY]
                        [--calibration_G_timeslice CALIBRATION_G_TIMESLICE]
                        [--calibration_B_first_selfcal CALIBRATION_B_FIRST_SELFCAL]
                        [--calibration_B_phase_only CALIBRATION_B_PHASE_ONLY]
                        [--calibration_B_timeslice CALIBRATION_B_TIMESLICE]
                        [--calibration_global_solution CALIBRATION_GLOBAL_SOLUTION]
                        [--calibration_context CALIBRATION_CONTEXT]
                        [--use_initial_skymodel USE_INITIAL_SKYMODEL]
                        [--input_skycomponent_file INPUT_SKYCOMPONENT_FILE]
                        [--num_bright_sources NUM_BRIGHT_SOURCES]
                        [--calibrate_with_dp3 CALIBRATE_WITH_DP3]
                        [--input_dp3_skymodel INPUT_DP3_SKYMODEL]
                        [--clean_algorithm CLEAN_ALGORITHM]
                        [--clean_use_radler CLEAN_USE_RADLER]
                        [--clean_beam CLEAN_BEAM CLEAN_BEAM CLEAN_BEAM]
                        [--clean_scales [CLEAN_SCALES ...]]
                        [--clean_nmoment CLEAN_NMOMENT]
                        [--clean_nmajor CLEAN_NMAJOR]
                        [--clean_niter CLEAN_NITER]
                        [--clean_psf_support CLEAN_PSF_SUPPORT]
                        [--clean_gain CLEAN_GAIN]
                        [--clean_threshold CLEAN_THRESHOLD]
                        [--clean_component_threshold CLEAN_COMPONENT_THRESHOLD]
                        [--clean_component_method CLEAN_COMPONENT_METHOD]
                        [--clean_fractional_threshold CLEAN_FRACTIONAL_THRESHOLD]
                        [--clean_facets CLEAN_FACETS]
                        [--clean_overlap CLEAN_OVERLAP]
                        [--clean_taper CLEAN_TAPER]
                        [--clean_restore_facets CLEAN_RESTORE_FACETS]
                        [--clean_restore_overlap CLEAN_RESTORE_OVERLAP]
                        [--clean_restore_taper CLEAN_RESTORE_TAPER]
                        [--clean_restored_output CLEAN_RESTORED_OUTPUT]
                        [--use_dask USE_DASK] [--dask_nthreads DASK_NTHREADS]
                        [--dask_memory DASK_MEMORY]
                        [--dask_memory_usage_file DASK_MEMORY_USAGE_FILE]
                        [--dask-nodes [DASK_NODES ...]]
                        [--dask_nworkers DASK_NWORKERS]
                        [--dask_scheduler DASK_SCHEDULER]
                        [--dask_scheduler_file DASK_SCHEDULER_FILE]
                        [--dask_tcp_timeout DASK_TCP_TIMEOUT]
```

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```
                        [--dask_connect_timeout DASK_CONNECT_TIMEOUT]
                        [--dask_malloc_trim_threshold DASK_MALLOC_TRIM_THRESHOLD]
```

Named Arguments

--mode Processing cip | ical | invert | load

Default: "cip"

--logfile Name of logfile (default is to construct one from msname)

--performance_file Name of json file to contain performance information

--ingest_msname MeasurementSet to be read

--ingest_dd Data descriptors in MS to read (all must have the same number of channels)

Default: [0]

--ingest_vis_nchan Number of channels in a single data descriptor in the MS

--ingest_chan_per_vis Number of channels per vis (before any average)

Default: 1

--ingest_average_vis Average all channels in vis?

Default: "False"

--imaging_phasecentre Phase centre (in SkyCoord string format)

--imaging_pol RASCIL polarisation frame for image

Default: "stokesI"

--imaging_nchan Number of channels per image

Default: 1

--imaging_context Imaging context i.e. the gridder used 2d | ng

Default: "ng"

--imaging_ng_threads Number of Nifty Gridder threads to use (4 is a good choice)

Default: 4

--imaging_w_stacking Use the improved w stacking method in Nifty Gridder?

Default: True

--imaging_flat_sky If using a primary beam, normalise to flat sky?

Default: False

--imaging_npixel Number of pixels in ra, dec: Should be a composite of 2, 3, 5

--imaging_cellsize Cellsize (radians). Default is to calculate.

--imaging_weighting Type of weighting uniform or robust or natural)

Default: "uniform"

--imaging_robustness Robustness for robust weighting

Default: 0.0

--imaging_gaussian_taper Size of Gaussian smoothing, implemented as taper in weights (rad)

--imaging_dopsf Make the PSF instead of the dirty image?

Default: "False"

--imaging_dft_kernel DFT kernel: cpu_looped | gpu_raw

--imaging_uvmax Maximum uv (wavelengths)

--imaging_uvmin Minimum uv (wavelengths)

--imaging_rmax Maximum distance of dish/station from array center (wavelengths)

--imaging_rmin Minimum distance of dish/station from array center (wavelengths)

--perform_flagging If enabled, runs AOFlagger flagging strategy

Default: "False"

--flagging_strategy_name Contains the name of the flagging strategy to use when perform_flagging is True. There are strategies available for different telescopes: AARTFAAC, ARECIBO, ARECIBO 305M, BIGHORNS, EVLA, JVLA, LOFAR, MWA, PARKES, PKS, ATPKSMB, WSRT. If the desired telescope is not listed here, you can use one of the strategies defined in the AOFlagger repository (https://gitlab.com/aroffringa/aoflagger/-/tree/master/data/strategies) or define a new strategy interactively using the AOFlagger rfigui (https://aoflagger.readthedocs.io/en/latest/using_rfigui.html)

Default: "generic"

--calibration_reset_skymodel Reset the initial skymodel after initial calibration?

Default: "True"

--calibration_T_first_selfcal First selfcal for T (complex gain). T is common to both receptors

Default: 1

--calibration_T_phase_only Phase only solution

Default: "True"

--calibration_T_timeslice Solution length (s) 0 means minimum

--calibration_G_first_selfcal First selfcal for G (complex gain). G is different for the two receptors

Default: 3

--calibration_G_phase_only Phase only solution?

Default: "False"

--calibration_G_timeslice Solution length (s) 0 means minimum

--calibration_B_first_selfcal First selfcal for B (bandpass complex gain). B is complex gain per frequency.

Default: 4

--calibration_B_phase_only Phase only solution

Default: "False"

--calibration_B_timeslice Solution length (s)

--calibration_global_solution Solve across frequency

Default: "True"

--calibration_context Terms to solve (in order e.g. TGB)

Default: "T"

--use_initial_skymodel Whether to use an initial SkyModel in ICAL or not

Default: False

--input_skycomponent_file Input name of skycomponents file (in hdf or txt format) for initial SkyModel in ICAL

--num_bright_sources Number of brightest sources to select for initial SkyModel (if None, use all sources from input file)

--calibrate_with_dp3 Enables calibration using DP3 Gaincal step (https://dp3.readthedocs.io/en/latest/steps/GainCal.html)

Default: False

--input_dp3_skymodel Path to a .skymodel file as expected by DP3

--clean_algorithm Type of deconvolution algorithm (hogbom or msclean or mmclean)

Default: "mmclean"

--clean_use_radler If enabled, RADLER is used for deconvolution

Default: "False"

--clean_beam Clean beam: major axis, minor axis, position angle (deg)

--clean_scales Scales for multiscale clean (pixels) e.g. [0, 6, 10]

Default: [0]

--clean_nmoment Number of frequency moments in mmclean (1 is a constant, 2 is linear, etc.)

Default: 4

--clean_nmajor Number of major cycles in cip or ical

Default: 5

--clean_niter Number of minor cycles in CLEAN (i.e. clean iterations)

Default: 1000

--clean_psf_support Half-width of psf used in cleaning (pixels)

Default: 256

--clean_gain Clean loop gain

Default: 0.1

--clean_threshold Clean stopping threshold (Jy/beam)

Default: 0.0001

--clean_component_threshold Sources with absolute flux > this level (Jy) are fit or extracted using skycomponents

--clean_component_method Method to convert sources in image to skycomponents: 'fit' in frequency or 'extract' actual values

Default: "fit"

--clean_fractional_threshold Fractional stopping threshold for major cycle

Default: 0.3

--clean_facets Number of overlapping facets in faceted clean (along each axis)

Default: 1

--clean_overlap Overlap of facets in clean (pixels)

Default: 32

--clean_taper Type of interpolation between facets in deconvolution (none or linear or tukey)

Default: "tukey"

--clean_restore_facets Number of overlapping facets in restore step (along each axis)

Default: 1

--clean_restore_overlap Overlap of facets in restore step (pixels)

Default: 32

--clean_restore_taper Type of interpolation between facets in restore step (none or linear or tukey)

Default: "tukey"

--clean_restored_output Type of restored image output: taylor, list, or integrated

Default: "list"

--use_dask Use Dask processing? False means that graphs are executed as they are constructed.

Default: "True"

--dask_nthreads Number of threads in each Dask worker (None means Dask will choose)

--dask_memory Memory per Dask worker (GB), e.g. 5GB (None means Dask will choose)

--dask_memory_usage_file File in which to track Dask memory use (using dask-memusage)

--dask-nodes Node names for SSHCluster

--dask_nworkers Number of workers (None means Dask will choose)

--dask_scheduler Externally defined Dask scheduler e.g. 127.0.0.1:8786 or ssh for SSHCluster or existing for current scheduler

--dask_scheduler_file Externally defined Dask scheduler file to setup dask cluster

--dask_tcp_timeout Dask TCP timeout

--dask_connect_timeout Dask connect timeout

--dask_malloc_trim_threshold Threshold for trimming memory on release (0 is aggressive)

Default: 0

rascil_sensitivity

rascil_sensitivity is a command line app written using RASCIL. It allows calculation of point source sensitivity (pss) and surface brightness sensitivity (sbs). The analysis is based on Dan Briggs's PhD thesis https://casa.nrao.edu/Documents/Briggs-PhD.pdf

rascil_sensitivity works by constructing a Visibility set and running invert to obtain the point spread function. The visibility weights in the Visibility are constructed to be equal to the time-bandwidth product each visibility sample. For natural weighting, these weights are used as the imaging weights. The sum of gridded weights therefore gives the total time-bandwidth of the observation. Given Tsys and efficiency it can then calculate the point source sensitivity. To

obtain the surface brightness sensitivity, we calculate the solid angle of the clean beam fitted to the PSF, and divide the point source sensitivity by the solid angle.

Weighting schemes such as robust weighting and visibility tapering modify the imaging weights. The point source sensitivity always worsens compared to natural weighting but the surface brightness sensitivity may improve.

The robustness parameter and the visibility taper can be specified as single values or as a list of values to test.

The array configuration is specified by 2 parameters: *configuration* identifies a table with details of the available dishes, *subarray* names a json file listing the ids (i.e. row numbers in the configuration table) of the dishes to be used. If no subarray is specified then all dishes will be selected. The json format is:

```
{"ids": [64, 65, 66, 67, 68, 69, 70, ....etc.]}
```

The principal output is a CSV file, written by pandas in which all values of robustness and taper are tested, along with natural weighting.

The processing is distributed using Dask over all frequency channels specified.

Example script

The following:

```
python $RASCIL/rascil/apps/rascil_sensitivity.py --results range_0.5_int_20 --time_range␣
↪-0.25 0.25 \
    --integration_time 20 --msfile range_0.5_int_20.ms
```

produces the output:

```
Final results:
   weighting  robustness  taper  cleanbeam_bmaj  cleanbeam_bmin  cleanbeam_bpa  ...      ␣
↪pss_casa reltonat_casa            sa           sbs            tb     sbs_casa
0    uniform         0.0    0.0        0.000124        0.000106       0.348636  ...  5.
↪055773e-08      4.214877  5.290084e-12  4.844478e+06  7.435200e+13  9557.074591
1     robust        -2.0    0.0        0.000125        0.000107       0.346705  ...  4.
↪907281e-08      4.091084  5.423607e-12  4.528158e+06  8.096404e+13  9048.003290
2     robust        -1.5    0.0        0.000138        0.000119       0.366295  ...  4.
↪237805e-08      3.532957  6.570541e-12  2.905383e+06  1.339994e+14  6449.703859
3     robust        -1.0    0.0        0.000220        0.000209      19.006936  ...  3.
↪168845e-08      2.641790  1.669975e-11  6.384441e+05  4.295821e+14  1897.540277
4     robust        -0.5    0.0        0.000328        0.000316      40.826795  ...  2.
↪208990e-08      1.841582  3.703912e-11  1.701715e+05  1.229183e+15   596.393758
5     robust         0.0    0.0        0.000454        0.000437      33.235117  ...  1.
↪618849e-08      1.349596  7.111900e-11  5.956637e+04  2.721061e+15   227.625391
6     robust         0.5    0.0        0.000600        0.000577      30.284717  ...  1.
↪360183e-08      1.133952  1.242658e-10  2.643972e+04  4.523710e+15   109.457521
7     robust         1.0    0.0        0.000729        0.000702    -149.373492  ...  1.
↪228866e-08      1.024476  1.836020e-10  1.549264e+04  6.035397e+15    66.930950
8     robust         1.5    0.0        0.000791        0.000761      30.715780  ...  1.
↪200501e-08      1.000829  2.160325e-10  1.241103e+04  6.792939e+15    55.570408
9     robust         2.0    0.0        0.000802        0.000772    -149.271796  ...  1.
↪199519e-08      1.000010  2.221125e-10  1.194877e+04  6.932970e+15    54.005008
10   natural         0.0    0.0        0.000804        0.000773    -149.270574  ...  1.
↪199506e-08      1.000000  2.228600e-10  1.189396e+04  6.950160e+15    53.823312
```

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```
[11 rows x 24 columns]
```

Command line arguments

Calculate relative sensitivity for MID observations

```
usage: rascil_sensitivity.py [-h] [--use_dask USE_DASK]
                             [--imaging_npixel IMAGING_NPIXEL]
                             [--msfile MSFILE]
                             [--imaging_cellsize IMAGING_CELLSIZE]
                             [--imaging_oversampling IMAGING_OVERSAMPLING]
                             [--imaging_weighting IMAGING_WEIGHTING]
                             [--imaging_robustness [IMAGING_ROBUSTNESS ...]]
                             [--imaging_taper [IMAGING_TAPER ...]] [--ra RA]
                             [--tsys TSYS] [--efficiency EFFICIENCY]
                             [--diameter DIAMETER] [--declination DECLINATION]
                             [--configuration CONFIGURATION]
                             [--subarray SUBARRAY] [--rmax RMAX]
                             [--frequency FREQUENCY]
                             [--integration_time INTEGRATION_TIME]
                             [--time_range TIME_RANGE TIME_RANGE]
                             [--nchan NCHAN] [--channel_width CHANNEL_WIDTH]
                             [--verbose VERBOSE] [--results RESULTS]
```

Named Arguments

--use_dask Use dask processing?

Default: “True”

--imaging_npixel Number of pixels in ra, dec: Should be a composite of 2, 3, 5

Default: 1024

--msfile Export Measurement file.

Default: “”

--imaging_cellsize Cellsize (radians). Default is to calculate.

--imaging_oversampling Oversampling of synthesised_beam (Default 3.0)

Default: 3.0

--imaging_weighting Type of weighting: uniform or robust or natural

--imaging_robustness Robustness for robust weighting,

Default: [-2.0, -1.5, -1.0, -0.5, 0.0, 0.5, 1.0, 1.5, 2.0]

--imaging_taper If set, use value for Gaussian taper, specified as radians in image plane

--ra Right ascension (degrees)

Default: 15.0

--tsys	System temperature (K) Default: 20.0
--efficiency	Correlator efficiency Default: 1.0
--diameter	MID antenna diameter (m) Default: 15.0
--declination	Declination (degrees) Default: -45.0
--configuration	Name of configuration or path: MID(=MIDR5), MIDR5, MEERKAT+ Default: "MIDR5"
--subarray	Name of json file describing subarray to be used, default is all antennas Default: ""
--rmax	Maximum distance of station from centre (m) Default: 200000.0
--frequency	Centre frequency (Hz) Default: 1360000000.0
--integration_time	Integration time (s) Default: 600
--time_range	Hour angle range in hours Default: [-4.0, 4.0]
--nchan	Number of channels Default: 1
--channel_width	Channel bandwidth (Hz) Default: 100000000.0
--verbose	Verbose output? Default: "False"
--results	Root name for output files Default: "rascil_sensitivity"

rascil_rcal

rascil_rcal is a command line app written using RASCIL. It simulates the real-time calibration pipeline RCAL. In the SKA, an initial calibration is performed in real-time as the visibility data are accumulated. An accurate sky model is assumed to be available or a point source model is used.

In rascil_rcal a MeasurementSet is read in and then iterated through in time-order solving for the gains. The gaintables are accumulated into a single gain table that is written as an HDF file.

There is also an additional plotting function that plots the gaintable values (gain amplitude, phase and residual) over time. If plotting is required, please make sure you have the correct path *–plot_dir* set up. The output file name will contain the datetime of the first time sample in the data.

RFI Flagger

rascil_rcal also implements reading RFI (Radio Frequency Interference) flags and using them as part of the pipeline. Flagging is optional and can be controlled with the *flag_rfi* argument.

RASCIL's Visibility object contains a "flags" data array with the same dimensions as the visibilities. This array is updated with the results of the SKA Processing Function Library RFI Flagger, which uses the sum-threshold method for flagging. The RFI flagger requires *initial threshold* and *rho* values (both needed to provide a list of thresholds used for finding RFI signal in the data), which can be set via CLI arguments, though we recommend using the defaults at this stage.

Example script

The following runs the real time calibration pipeline on an MS generated by the MID continuum imaging simulations (with an optional input components file):

```
#!/bin/bash
python3 $RASCIL/rascil/apps/rascil_rcal.py \
--ingest_msname SKA_MID_SIM_custom_B2_dec_-45.0_nominal_nchan100_actual.ms \
--ingest_components_file SKA_MID_SIM_custom_B2_dec_-45.0_nominal_nchan100_components.hdf
```

There are also additional options if you want the sky model to have primary beams applied. Currently we support internal beam from MID and LOW, or additional beam file (in FITS format). An example:

```
#!/bin/bash
python3 $RASCIL/rascil/apps/rascil_rcal.py \
--ingest_msname myms.ms \
--ingest_components_file my_components.hdf \
--apply_beam True --ingest_beam_file my_beam.fits \
```

Command line arguments

RASCIL RCAL simulator

```
usage: rascil_rcal.py [-h] [--ingest_msname INGEST_MSNAME]
                      [--ingest_dd [INGEST_DD ...]] [--logfile LOGFILE]
                      [--ingest_components_file INGEST_COMPONENTS_FILE]
                      [--apply_beam APPLY_BEAM]
                      [--ingest_beam_file INGEST_BEAM_FILE] [--cal_type {T,G}]
                      [--do_plotting DO_PLOTTING] [--plot_dir PLOT_DIR]
                      [--use_previous_gaintable USE_PREVIOUS_GAINTABLE]
                      [--phase_only_solution PHASE_ONLY_SOLUTION]
                      [--solution_tolerance SOLUTION_TOLERANCE]
                      [--flag_rfi FLAG_RFI]
                      [--initial_threshold INITIAL_THRESHOLD] [--rho RHO]
```

Named Arguments

--ingest_msname MeasurementSet to be read

--ingest_dd Data descriptors in MS to read (all must have the same number of channels)

Default: [0]

--logfile Name of logfile (default is to construct one from msname)

--ingest_components_file Name of components file (HDF5/txt) format

--apply_beam If yes, apply primary beam correction to the ingested components

Default: False

--ingest_beam_file Name of external beam file in FITS format

--cal_type Possible choices: T, G

Type of calibration to perform. T=Atmospheric Phase, G=Electronics Gain

Default: "T"

--do_plotting If yes, plot the gain table values over time

Default: False

--plot_dir Full path of the directory to save the gain plots into (default is the same directory the MS file is located)

--use_previous_gaintable Use previous gaintable as starting point for solution

Default: "False"

--phase_only_solution Solution should be for phases only

Default: "True"

--solution_tolerance Tolerance for solution: stops iteration when changes below this level

Default: 1e-12

--flag_rfi Whether to run the RFI flagger (before obtaining calibration solutions), or not.

Default: "False"

--initial_threshold The initial threshold to be used by the flagger. Used for calculating a list of thresholds.Note: use default value since flagger is still under development

Default: 8.0

--rho The initial rho used by flagger. Used for calculating a list of thresholds. Note: use default value since flagger is still under development

Default: 1.5

rascil_vis_ms

rascil_vis_ms is a command line app written using RASCIL for simple visualisation of an MS. It's primary use is for the RFI simulations.

Example script

The following runs the visualisation on an MS generated by the RFI simulations:

```
#!/bin/bash
# Run this in the directory containing ./simulate_rfi.ms
python3 $RASCIL/rascil/apps/rascil_vis_ms.py --ingest_msname ./simulate_rfi.ms
```

Command line arguments

RASCIL ms visualisation

```
usage: rascil_vis_ms.py [-h] [--ingest_msname INGEST_MSNAME]
                        [--logfile LOGFILE]
```

Named Arguments

--ingest_msname	MeasurementSet to be read
--logfile	Name of logfile (default is to construct one from msname)

rascil_advise

rascil_advise is a command line app written using RASCIL. It provides advice on imaging parameters for a CASA MeasurementSet.

Example script

The following provides advice on an MS generated by the MID continuum imaging simulations:

```
#!/bin/bash
# Run this in the directory containing SKA_MID_SIM_custom_B2_dec_-45.0_nominal_nchan100_
↪nominal.ms
python3 $RASCIL/rascil/apps/rascil_advise.py --ingest_msname SKA_MID_SIM_custom_B2_dec_-
↪45.0_nominal_nchan100_nominal.ms
```

Command line arguments

RASCIL imaging advise

```
usage: rascil_advise.py [-h] [--ingest_msname INGEST_MSNAME]
                        [--ingest_dd [INGEST_DD ...]] [--logfile LOGFILE]
                        [--guard_band_image GUARD_BAND_IMAGE]
                        [--oversampling_synthesised_beam OVERSAMPLING_SYNTHESISED_BEAM]
                        [--dela DELA]
```

Named Arguments

--ingest_msname MeasurementSet to be read

--ingest_dd Data descriptors in MS to read (all must have the same number of channels)

Default: [0]

--logfile Name of logfile (default is to construct one from msname)

--guard_band_image Size of field of view in primary beams

Default: 3.0

--oversampling_synthesised_beam Pixels per syntheised beam

Default: 3

--dela Maximum allowed decorrelation

Default: 0.02

rascil_image_check

rascil_image_check is a command line app written using RASCIL. It allows simple check on an image statistics.

The allowed fields are the statistics checked by qa_image function within the Image class

Example script

The following provides a check on the maximum of an image suitable for use in a shell script. The value returned is 0 if the constraint is obeyed and 1 if not:

```
python3 $RASCIL/rascil/apps/rascil_image_check.py --image $RASCIL/data/models/M31_
↪canonical.model.fits --stat max --min 0.0 --max 1.2
```

Command line arguments

RASCIL image check

```
usage: rascil_image_check.py [-h] [--image IMAGE] [--stat STAT] [--min MIN]
                             [--max MAX]
```

Named Arguments

--image	Image to be read
--stat	Image QualityAssessment field to check
	Default: "max"
--min	Minimum value
--max	Maximum value

imaging_qa

imaging_qa is a command line app written using RASCIL. It uses the python package PyBDSF to find sources in an image and check with the original inputs. Currently it features the following:

- Reads FITS images.
- Finds sources above a certain threshold and outputs the catalogue (in CSV, FITS and skycomponents format). For multi-frequency images, the source detection can be performed on the central channel or average over all channels.
- Produces image statistics and diagnostic plots including: running mean plots of the residual, restored, background and sources and a histogram with fitted Gaussian and power spectrum of the residual are also plotted.
- Optional: Read in the sensitivity image and apply a primary beam correction to the fluxes.
- Optional: Estimate the spectral index by reading in frequency moment images (in FITS format) containing higher order Taylor terms.
- Optional: compares with input source catalogue : takes hdf5 and txt format. The source input should has columns of "RA(deg), Dec(deg), FluxI(Jy), FluxQ(Jy), FluxU(Jy), FluxV(Jy), Ref. Freq.(Hz), Spectral Index".
- Optional: plot the comparison and error of positions and fluxes for input and output source catalogue.

Example:

The following runs the a data set from the RASCIL test:

```
#!/bin/bash
# Run this in the directory containing both the
# restored and residual fits files:
python $RASCIL/rascil/apps/imaging_qa_main.py \
--ingest_fitsname_restored test-imaging-pipeline-dask_continuum_imaging_restored.fits \
--ingest_fitsname_residual test-imaging-pipeline-dask_continuum_imaging_residual.fits
```

If a source check is required:

```
#!/bin/bash
# This example deals with the multi-frequency image
python $RASCIL/rascil/apps/imaging_qa_main.py \
--ingest_fitsname_restored test-imaging-pipeline-dask_continuum_imaging_restored_cube.
↪fits \
--check_source True --plot_source True \
 --input_source_filename test-imaging-pipeline-dask_continuum_imaging_components.hdf
```

If primary beam correction is required:

```
#!/bin/bash
# This example deals with the multi-frequency image
python $RASCIL/rascil/apps/imaging_qa_main.py \
--ingest_fitsname_restored test-imaging-pipeline-dask_continuum_imaging_restored_cube.
↪fits \
--check_source True --plot_source True --apply_primary True\
--ingest_fitsname_residual test-imaging-pipeline-dask_continuum_imaging_sensitivity.fits␣
↪\
--input_source_filename test-imaging-pipeline-dask_continuum_imaging_components.hdf
```

Supplying arguments from a file:

You can also load arguments into the app from a file.

Example arguments file, called *args.txt*:

```
--ingest_fitsname_restored=test-imaging-pipeline-dask_continuum_imaging_restored.fits
--ingest_fitsname_residual=test-imaging-pipeline-dask_continuum_imaging_residual.fits
--check_source=True
--plot_source=True
```

Make sure each line contains one argument, there is an equal sign between arg and its value, and that there aren't any trailing white spaces in the lines.

Then run the imaging_qa code as follows:

```
python imaging_qa_main.py @args.txt
```

Specifying the `@` sign in front of the file name will let the code know that you want to ready the arguments from a file instead of directly from the command line.

What happens when the image files, the argument file, and the imaging_qa code are not all in the same directory? Let's take the following directory structure as an example:

```
- rascil # this is the root directory of the RASCIL git repository
    - rascil
        - apps
            imaging_qa_main.py
        - my_data
            my_restored_file.fits
            my_residual_file.fits
        args.txt
```

With such a setup, the best way to run the imaging_qa code is from the top-level `rascil` directory (the git root directory). Your `args.txt` file will need to contain either the relative or absolute path to your FITS files. E.g.:

```
--ingest_fitsname_restored=rascil/my_data/test-imaging-pipeline-dask_continuum_imaging_
↪restored.fits
--ingest_fitsname_residual=rascil/my_data/test-imaging-pipeline-dask_continuum_imaging_
↪residual.fits
--check_source=True
--plot_source=True
```

And you need to provide similarily the relative or absolute path both to the args file and the code you are running:

```
python rascil/apps/imaging_qa_main.py @rascil/args.txt
```

Docker image

A Docker image is available at `artefact.skao.int/rascil-imaging-qa` which can be run with either Docker or Singularity. Instructions can be found at

under **Running the imaging_qa** section.

Output plots

A list of plots are generated to analyze the image as well as comparing the input and output source catelogues.

Plots for restored image:

```
..._restored_plot.png  # Running mean of restored image
..._sources_plot.png  # Running mean of the sources
..._background_plot.png  # Running mean of background
..._restored_power_spectrum.png # Power spectrum of restored image
```

Plots for residual image:

```
..._residual_hist.png  # Histogram and Gaussian fit of residual image
..._residual_power_spectrum.png  # Power spectrum of residual image
```

Plots for position matching:

```
..._position_value.png  # RA, Dec values of input and output sources
..._position_error.png  # RA, Dec error (output-input)
..._position_distance.png # RA, Dec error with respect to distance from the centre
```

Plots for wide field accuracy:

```
..._position_quiver.png  # Quiver plot of the movement of source positions
..._gaussian_beam_position.png  # Gaussian fitted beam sizes for output sources
```

Plots for flux matching:

```
..._flux_value.png  # Values of output flux vs. input flux of sources
..._flux_ratio.png  # Ratio of flux out/flux in
..._flux_histogram.png  # Histogram of flux comparison
..._flux_position.png # Flux vs. RA and Dec of the sources
```

Plots for spectral index:

```
..._spec_index.png # Spectral index of input vs output fluxes over frequency.
..._spec_index_diagnostics_dist.png # Spectral index out/in vs. distance to centre
..._spec_index_diagnostics_flux.png # Spectral index out/in vs. input sources flux
```

Command line arguments

RASCIL continuum imaging checker

```
usage: imaging_qa_main.py [-h]
                          [--ingest_fitsname_restored INGEST_FITSNAME_RESTORED]
                          [--ingest_fitsname_residual INGEST_FITSNAME_RESIDUAL]
                          [--ingest_fitsname_sensitivity INGEST_FITSNAME_SENSITIVITY]
                          [--ingest_fitsname_moment INGEST_FITSNAME_MOMENT]
                          [--finder_beam_maj FINDER_BEAM_MAJ]
                          [--finder_beam_min FINDER_BEAM_MIN]
                          [--finder_beam_pos_angle FINDER_BEAM_POS_ANGLE]
                          [--finder_thresh_isl FINDER_THRESH_ISL]
                          [--finder_thresh_pix FINDER_THRESH_PIX]
                          [--finder_multichan_option FINDER_MULTICHAN_OPTION]
                          [--perform_diagnostics PERFORM_DIAGNOSTICS]
                          [--apply_primary APPLY_PRIMARY]
                          [--use_frequency_moment USE_FREQUENCY_MOMENT]
                          [--telescope_model TELESCOPE_MODEL]
                          [--check_source CHECK_SOURCE]
                          [--plot_source PLOT_SOURCE]
                          [--input_source_filename INPUT_SOURCE_FILENAME]
                          [--match_sep MATCH_SEP] [--flux_limit FLUX_LIMIT]
                          [--trim_image TRIM_IMAGE] [--trim_box TRIM_BOX]
                          [--quiet_bdsf QUIET_BDSF]
                          [--source_file SOURCE_FILE]
                          [--rascil_source_file RASCIL_SOURCE_FILE]
                          [--logfile LOGFILE]
                          [--savefits_rmsim SAVEFITS_RMSIM]
                          [--restart RESTART] [--use_dask USE_DASK]
                          [--dask_scheduler DASK_SCHEDULER]
                          [--dask_memory DASK_MEMORY]
                          [--dask_nworkers DASK_NWORKERS]
                          [--dask_nthreads DASK_NTHREADS]
```

Named Arguments

--ingest_fitsname_restored FITS file of the restored image to be read

--ingest_fitsname_residual FITS file of the residual image to be read

--ingest_fitsname_sensitivity FITS file of the sensitivity image to be read

--ingest_fitsname_moment FITS file of the frequency moment images to be read (Note: Use the prefix of the fits files, e.g. if the restored image is test_image_restored.fits here should input test_image)

--finder_beam_maj Major axis of the restoring beam (degrees) (usually not needed, passed in restored image)

Default: 1.0

--finder_beam_min Minor axis of the restoring beam (degrees) (usually not needed, passed in restored image)

Default: 1.0

--finder_beam_pos_angle Positioning angle of the restoring beam (degrees) (usually not needed, passed in restored image)

Default: 0.0

--finder_thresh_isl Threshold to determine the size of the islands used in BDSF (Blob Detector and Source Finder)

Default: 5.0

--finder_thresh_pix Threshold to detect source (peak value) used in BDSF

Default: 10.0

--finder_multichan_option For multi-channel images, what mode to perform source detection on (single or average)

Default: "single"

--perform_diagnostics Whether to perform diagnostics of the images (restored and residual)

Default: "False"

--apply_primary Whether to divide by primary beam after BDSF to correct source flux

Default: "False"

--use_frequency_moment Whether to use frequency moment images after BDSF to correct spectral index

Default: "False"

--telescope_model The telescope to generate primary beam correction

Default: "MID"

--check_source Option to check with original input source catalogue

Default: "False"

--plot_source Option to plot position and flux errors for source catalogue

Default: "False"

--input_source_filename If use external source file, the file name of source file

--match_sep	Maximum separation in radians for the source matching Default: 1e-05
--flux_limit	Minimum flux where comparison plots are generated Default: 0.001
--trim_image	For spectral index calculation, do we trim the image to avoid the edge effects? Default: "False"
--trim_box	If trim_image is true, proportion of the box that is trimmed (default is 3%) Default: 0.03
--quiet_bdsf	If True, suppress bdsf.process_image() text output to screen. Output is still sent to the log file. Default: "False"
--source_file	Name of output source file
--rascil_source_file	Name of output RASCIL components hdf file
--logfile	Name of output log file
--savefits_rmsim	This parameter is a Boolean (default is False). If True, save background rms image as a FITS file. Default: "False"
--restart	If true, surpass BDSF when the output already exists. The checker will start from reading the BDSF csv file Default: "False"
--use_dask	Default: "True"
--dask_scheduler	Externally defined Dask scheduler e.g. 127.0.0.1:8786 or ssh for SSHCluster or existing for current scheduler
--dask_memory	Memory per Dask worker (GB), e.g. 5GB (None means Dask will choose)
--dask_nworkers	Number of workers (None means Dask will choose)
--dask_nthreads	Number of threads in each Dask worker (None means Dask will choose)

performance_analysis

performance_analysis is a command line app written using RASCIL. It helps in analysis of performance files written by rascil_imager.

The performance files can be obtained using a script to iterate over some parameter. For example:

```
#!/usr/bin/env bash
#
results_dir=${HOME}/results/5km_resource_modelling
for int_time in 2880 1440 720 360
  do
    mshome=${HOME}/data/int_time${int_time}
    for npixel in 512 1024 2048 4096 8192
    do
```

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```
    results_dir=${HOME}/data/int_time${int_time}_npixel${npixel}
    mkdir -p ${results_dir}
    python3 ${RASCIL}/rascil/apps/rascil_imager.py --mode cip \
      --clean_nmoment 3 --clean_facets 4 --clean_nmajor 10 \
      --clean_threshold 3e-5 --clean_restore_facets 4 --clean_restore_overlap 32 \
      --use_dask True --imaging_context ng --imaging_npixel ${npixel} --imaging_pol␣
↪stokesI --clean_restored_output list \
      --imaging_cellsize 5e-6 --imaging_weighting uniform --imaging_nchan 1 \
      --ingest_vis_nchan 100 --ingest_chan_per_vis 16 \
      --ingest_msname ${mshome}/SKA_MID_SIM.ms \
      --performance_file ${results_dir}/performance_rascil_imager_${int_time}_${npixel}
↪.json
   done
 done
```

In addition, the memory usage can be tracked using a dask plugin. Currently this requires setting up the dask scheduler with the plugin:

```
ssh $scheduler dask-scheduler --port=8786 --preload dask_memusage --memusage-csv \
./performance_rascil_imager_${1}_${2}.csv  &
```

Command line arguments

RASCIL performance analysis

```
usage: performance_analysis.py [-h] [--mode MODE]
                               [--performance_files [PERFORMANCE_FILES ...]]
                               [--memory_file MEMORY_FILE] [--tag TAG]
                               [--parameters [PARAMETERS ...]]
                               [--functions [FUNCTIONS ...]]
                               [--vis_nvis VIS_NVIS] [--verbose VERBOSE]
                               [--results RESULTS]
```

Named Arguments

--mode Processing mode: line | bar | contour | summary | fit

Default: “summary”

--performance_files Names of json performance files to analyse: default is all json files in working directory

--memory_file Name of memusage csv file

--tag Informational tag used in plot titles and file names

Default: “”

--parameters Name of parameters from cli_args e.g. imaging_npixel_sq, used for line (1 parameter) and contour plots (2 parameters)

Default: [‘imaging_npixel_sq’, ‘vis_nvis’]

--functions	Names of values from dask_profile to plot e.g. skymodel_predict_calibrate Default: ['skymodel_predict_calibrate', 'skymodel_calibrate_invert', 'invert_ng', 'restore_cube', 'image_scatter_facets', 'image_gather_facets']
--vis_nvis	Number of visibilities for use if vis_nvis not in json files
--verbose	Verbose output? Default: "False"
--results	Directory for results, default is current directory Default: "./"

Other

1.3.5 RASCIL and DASK

RASCIL uses Dask for distributed processing:

http://dask.pydata.org/en/latest/

https://github.com/dask/dask-tutorial

Running RASCIL and Dask on a single machine is straightforward. First define a graph and then compute it either by calling the compute method of the graph or by passing the graph to a dask client.

A typical graph will flow from a set of input visibility sets to an image or set of images. In the course of constructing a graph, we will need to know the data elements and the functions transforming brtween them. These are well-modeled in RASCIL.

In order that Dask.delayed processing can be switched on and off, and that the same code is used for Dask and non-Dask processing, we have wrapped Dask.delayed in *rascil.workflows.rsexecute.execution_support()*. An example is:

```
rsexecute.set_client(use_dask=True)
continuum_imaging_list = \
    continuum_imaging_list_rsexecute_workflow(vis_list, model_imagelist=self.model_
↪imagelist, context='2d',
                                algorithm='mmclean', facets=1,
                                scales=[0, 3, 10],
                                niter=1000, fractional_threshold=0.1,
                                nmoments=2, nchan=self.freqwin,
                                threshold=2.0, nmajor=5, gain=0.1,
                                deconvolve_facets=8, deconvolve_overlap=16,
                                deconvolve_taper='tukey')
clean, residual, restored = rsexecute.compute(continuum_imaging_list, sync=True)
```

By default, rsexecute is initialised to use the Dask process scheduler with one worker per core. This can be changed by a call to rsexecute.set_client:

```
rsexecute.set_client(use_dask=True, nworkers=4)
```

If use_dask is True then a Dask graph is constructed via calls to rsexecute.execute() for subsequent execution.

If use_dask is False then the named function is called immediately, and the execution is therefore single threaded:

```
rsexecute.set_client(use_dask=False)
```

Note that debugging is easiest if Dask is switched off (use_dask=False)

The pipeline workflow `rascil.workflows.rsexecute.pipelines.continuum_imaging_list_rsexecute_workflow()` is itself assembled using the execution framework (an interface to Dask): *rascil.workflows.rsexecute.execution_support()*.

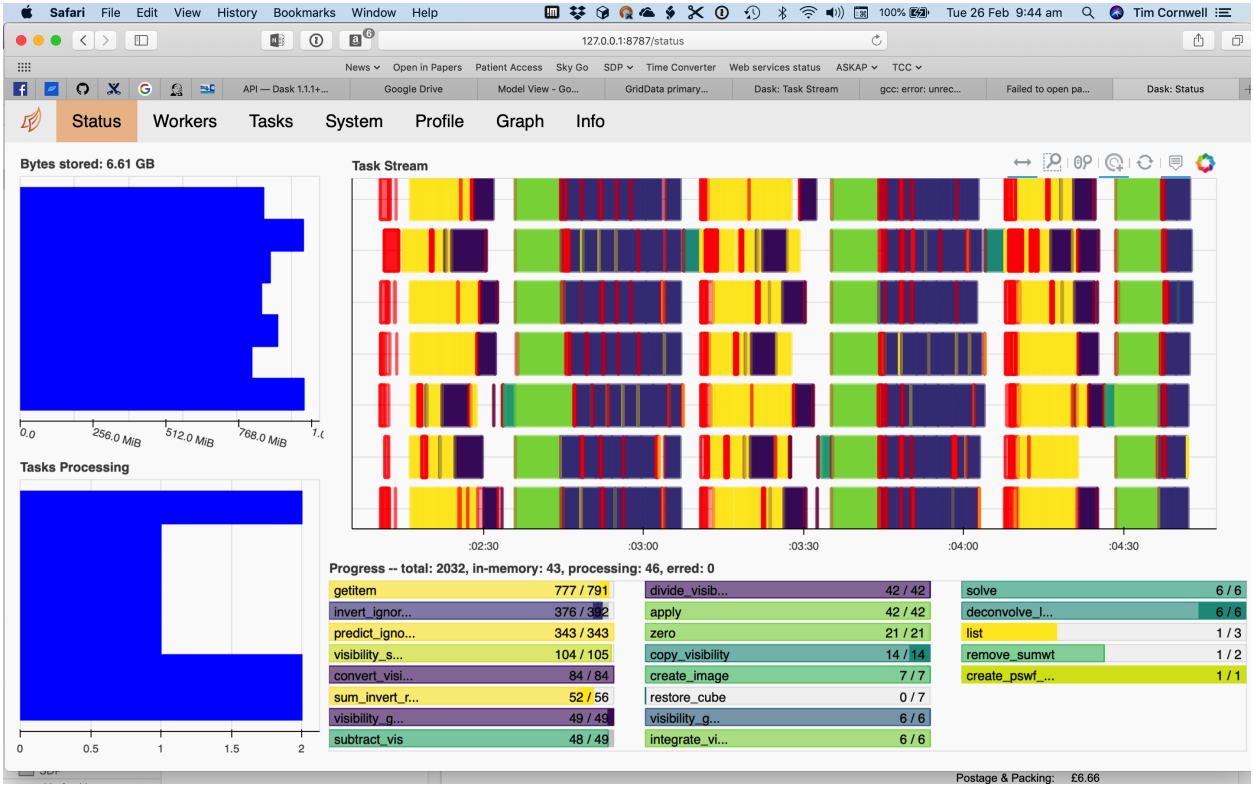
The functions for creating graphs are:

- Calibrate workflow: *rascil.workflows.rsexecute.calibration.calibrate_list_rsexecute_workflow()*
- Invert: *rascil.workflows.rsexecute.imaging.invert_list_rsexecute_workflow()*
- Predict: *rascil.workflows.rsexecute.imaging.predict_list_rsexecute_workflow()*
- Deconvolve: *rascil.workflows.rsexecute.imaging.deconvolve_list_rsexecute_workflow()*
- ICAL: `rascil.workflows.rsexecute.pipelines.ical_list_rsexecute_workflow()`
- Continuum imaging: `rascil.workflows.rsexecute.pipelines.continuum_imaging_list_rsexecute_workflow()`
- Spectral line imaging: `rascil.workflows.rsexecute.pipelines.spectral_line_imaging_list_rsexecute_workflow`
- MPCCAL: `rascil.workflows.rsexecute.pipelines.mpccal_skymodel_list_rsexecute_workflow()`
- Testing and simulation support: *rascil.workflows.rsexecute.simulation.simulate_list_rsexecute_workflow()*

In addition there are notebooks that use components in workflows/notebooks:

- Simple demonstration of the use of Dask/rsexecute

These notebooks are scaled to run on a 2017-era laptop (4 cores, 16GB) but can be changed to larger scales. Both explicitly create a client and output the URL (usually http://127.0.0.1:8787) for the Dask diagnostics. Of these the status page is most useful, but the other pages are each worth investigating.



Using RASCIL and Dask on a cluster

Running on a cluster is a bit more complicated. On a single node, Dask/rsexecute use a process-oriented scheduler. On a cluster, it is necessary to use the distributed scheduler.

You can start the distributed scheduler and workers by hand, using the dask-ssh command (more below). To communicate the IP address of the scheduler, set the environment variable RASCIL_DASK_SCHEDULER appropriately:

```
export RASCIL_DASK_SCHEDULER=192.168.2.10:8786
```

If you do this, remember to start the workers as well. dask-ssh is useful for this:

```
c=get_dask_client(timeout=30)
rsexecute.set_client(c)
```

get_dask_client will look for a scheduler via the environment variable RASCIL_DASK_SCHEDULER. It that does not exist, it will start a Client using the default Dask approach but that will be a single node scheduler.

Darwin and P3 uses SLURM for scheduling. There is python binding of DRMAA that could in principle be used to queue the processing. However a simple edited job submission script is also sufficient.

On P3, each node has 16 cores, and each core has 8GB. Usually this is sometimes insufficient for RASCIL and so some cores must be not used so the memory can be used by other cores. To run 8 workers and one scheduler on 8 nodes, the SLURM batch file should look something like:

```
#!/bin/bash
#!
#! Dask job script for P3
#! Tim Cornwell
#!
#! Name of the job:
#SBATCH -J IMAGING
#! Which project should be charged:
#SBATCH -A SKA-SDP
#! How many whole nodes should be allocated?
#SBATCH --nodes=8
#! How many (MPI) tasks will there be in total? (<= nodes*16)
#SBATCH --ntasks=8
#! Memory limit: P3 has roughly 107GB per node
#SBATCH --mem 107000
#! How much wallclock time will be required?
#SBATCH --time=23:59:59
#! What types of email messages do you wish to receive?
#SBATCH --mail-type=FAIL,END
#! Where to send email messages
#SBATCH --mail-user=realtimcornwell@gmail.com
#! Uncomment this to prevent the job from being requeued (e.g. if
#! interrupted by node failure or system downtime):
##SBATCH --no-requeue
#! Do not change:
#SBATCH -p compute

#SBATCH --exclusive

#! Modify the settings below to specify the application's environment, location
```

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```
#! and launch method:

#! Optionally modify the environment seen by the application
#! (note that SLURM reproduces the environment at submission irrespective of ~/.bashrc):
module purge                                # Removes all modules still loaded

#! Set up python
# . $HOME/alaska-venv/bin/activate
export PYTHONPATH=$PYTHONPATH:$ARL
echo "PYTHONPATH is ${PYTHONPATH}"

echo -e "Running python: `which python`"
echo -e "Running dask-scheduler: `which dask-scheduler`"

cd $SLURM_SUBMIT_DIR
echo -e "Changed directory to `pwd`.\n"

JOBID=${SLURM_JOB_ID}
echo ${SLURM_JOB_NODELIST}

#! Create a hostfile:
scontrol show hostnames $SLURM_JOB_NODELIST | uniq > hostfile.$JOBID

scheduler=$(head -1 hostfile.$JOBID)
hostIndex=0
for host in `cat hostfile.$JOBID`; do
    echo "Working on $host ...."
    if [ "$hostIndex" = "0" ]; then
        echo "run dask-scheduler"
        ssh $host dask-scheduler --port=8786 &
        sleep 5
    fi
    echo "run dask-worker"
    ssh $host dask-worker --nprocs 1 --nthreads 8 --interface ib0 \
    --memory-limit 256GB --local-directory /mnt/storage-ssd/tim/dask-workspace/${host}
↪$scheduler:8786  &
        sleep 1
    hostIndex="1"
done
echo "Scheduler and workers now running"

#! We need to tell dask Client (inside python) where the scheduler is running
export ARL_DASK_SCHEDULER=${scheduler}:8786
echo "Scheduler is running at ${scheduler}"

CMD="python ../clean_ms_noniso.py --ngroup 1 --nworkers 0 --weighting uniform --context␣
↪wprojectwstack --nwslabs 9 \
--mode pipeline --niter 1000 --nmajor 3 --fractional_threshold 0.2 --threshold 0.01 \
--amplitude_loss 0.02 --deconvolve_facets 8 --deconvolve_overlap 16 --restore_facets 4 \
--msname /mnt/storage-ssd/tim/Code/sim-low-imaging/data/noniso/GLEAM_A-team_EoR1_160_MHz_
↪no_errors.ms \
--time_coal 0.0 --frequency_coal 0.0 --channels 0 1 \
```

(continues on next page)

(continued from previous page)

```
--plot False --fov 2.5 --single False | tee clean_ms.log"

eval $CMD
```

In the command CMD remember to shutdown the Client so the batch script will close the background dask-ssh and then exit.

Thw diagnostic pages can be tunneled. RASCIL emits the URL of the diagnostic page. For example:

```
http://10.143.1.25:8787
```

Then to tunnel the pages:

```
ssh hpccorn1@login.hpc.cam.ac.uk -L8080:10.143.1.25:8787
```

The diagnostic page is available from your local browser at:

```
127.0.0.1:8080
```

Logging

Logging is difficult when using distributed processing. Here's a solution that works. At the beginning of your script or notebook, define a function to initialize the logger:

```
def init_logging():
    log.info("Logging to %s/clean_ms_dask.log" % cwd)
    logging.basicConfig(filename='%s/clean_ms_dask.log' % cwd,
                        filemode='a',
                        format='%(thread)s %(asctime)s.%(msecs)d %(name)s %(levelname)s
↪%(message)s',
                        datefmt='%H:%M:%S',
                        level=logging.DEBUG)


log = logging.getLogger()
log.setLevel(logging.INFO)
log.addHandler(logging.StreamHandler(sys.stdout))
log.addHandler(logging.StreamHandler(sys.stderr))
init_logging()
...
rsexecute.run(init_logging)
```

To ensure that the Dask workers get the same setup, you will need to run init_logging() on each worker using the rsexecute.run() function:

```
rsexecute.run(init_logging)
```

or:

```
rsexecute.set_client(use_dask=True)
rsexecute.run(init_logging)
```

This will log to the same file. It is also possible to set up separate log file per worker by suitably changing init_logger.

1.3.6 Use of xarray

From release 0.2+, RASCIL has moved to use the Xarray library instead of numpy in the data classes. RASCIL data classes are now all derived from xarray.Dataset. This change is motivated by the large range of capababilities available from xarray. These include:

- Named dimensions and coordinates, allowing access via quantities such as time. frequency, polarisation, receptor
- Indexing, selection, iteration, and conditions
- Support of split-apply-recombine operations
- Interpolation in coordinates, including missing values
- Automatic invocation of Dask for array operations
- Arbitrary meta data as attributes

We have chosen to make the RASCIL data classes derive from xarray.Dataset. Instead of adding class methods to the RASCIL data class, which would introduce some interface fragility as xarray changes over time, we have used data accessors to control access to methods specfic to the class. This design is suggested in the xarray documentation on extending xarray. Examples:

```
# Flagged visibility
vis.visibility_acc.flagged_vis

# UVW in wavelengths
vis.visibility_acc.uvw_lambda

# DataArray sizes
vis.visibility_acc.datasizes

# Phasecentre as an astropy.SkyCoord
im.image_acc.phasecentre

# Image RA, Dec grid
im.image_acc.ra_dec_mesh

# Gaintable number of receptors
gt.gaintable_acc.nrec
```

For examples of the capabilities afforded by xarray see the jupyter notebooks below:

- Demonstrate visibility xarray format

Here is a simple example of how the capabilities of xarray can be used:

```
vis = create_visibility_from_ms(ms)[0]

# Don't squeeze out the unit dimensions because we will want
# them for the concat
chan_vis = [v[1] for v in vis.groupby_bins(dim, bins=2)]

# Predict visibility from a model.
chan_vis = [predict_ng(vis, model) in chan_vis]

# Now concatenate
newvis = xarray.concat(chan_vis, dim=dim, data_vars="minimal")
```

1.3.7 Conversion from previous data classes

The steps required are:

- For Image, GridData, and ConvolutionFunction, the name of the data variable is pixels so for example:

```
# The previous numpy format
im.data
# as an Xarray becomes
im["pixels"]
# as an numpy array or Dask array becomes
im["pixels"].data
# as an numpy array becomes
im["pixels"].values
# The properties now require using the accessor class. For example:
im.nchan
# becomes
im.image_acc.nchan
# or directly to the attributes of the xarray.Dataset
im.attrs["nchan"]
```

- For Visibility, the various columns become data variables:

```
# The numpy format
bvis.data["vis"]
# becomes
bvis["vis"]
# as an numpy array or Dask array becomes
bvis["vis"].data
# as an numpy array becomes
bvis["vis"].values
# The properties now require using the accessor class. For example:
bvis.nchan
# becomes
bvis.visibility_acc.nchan
# or directly to the attributes of the xarray.Dataset
bvis.attrs["nchan"]
# The convenience methods for handling flags also require the accessor:
bvis.flagged_vis
# becomes
bvis.visibility_acc.flagged_vis
```

1.3.8 RASCIL and WAGG

RASCIL can use GPU-based version of nifty-gridder called WAGG for the gridding-degridding operations:

https://gitlab.com/ska-telescope/sdp/ska-gridder-nifty-cuda/-/tree/sim-874-python-wrapper

There are two function counterparts to predict_ng and invert_ng called predict_wg and invert_wg,

WAGG needs to be installed from its repository after the RASCIL installation. WAGG uses numpy to build the installation wheel, and it will download the recent one if numpy is absent in a system. The numpy version mismatch can cause the WAGG crash. By installing WAGG after RASCIL, we make sure it uses the numpy version that RASCIL requires for the build.

Installing WAGG module

To install WAGG it is required to clone the repository, switch to the python wrapper branch, change to *python* folder and run *pip install .* , i.e.:

```
git clone https://gitlab.com/ska-telescope/sdp/ska-gridder-nifty-cuda.git
cd ska-gridder-nifty-cuda
git checkout --track origin/sim-874-python-wrapper
cd python
pip install .
```

Alternatively, WAGG can be installed directly with *pip*:

```
pip install git+http://gitlab.com/ska-telescope/sdp/ska-gridder-nifty-cuda.git@sim-874-
↪python-wrapper#subdirectory=python
```

Using WAGG GPU-based predict and invert functions

WAGG module makes a use of Nvidia runtime system, called *NVRTC*. It is a runtime compilation library for CUDA C++. It accepts CUDA C++ source code in the form of a string, and outputs GPU-specific PTX (Parallel Thread Execution) instructions. The PTX code generated by NVRTC can be loaded and linked with other modules of the CUDA Driver API. More information on *NVRTC* can be found on CUDA website, https://docs.nvidia.com/cuda/nvrtc/index.html .

When the runtime support is installed, the functions predict_wg and invert_wg can be used as the CPU-based predict_ng and invert_ng since the parameters are the same. One can find an example on how to use the functions predict_ng and invert_ng in the Imaging and deconvolution demonstration Jupyter notebook in *Examples* section.

1.4 API

Here is a quick guide to the layout of the package:

- rascil.processing_components: Processing functions used in algorithms
- rascil.workflows: Distributed processing workflows
- rascil.apps: CLI apps
- examples: Example scripts and notebooks
- tests: Unit and regression tests
- docs: Complete documentation. Includes non-interactive output of examples.
- rascil.data: Data used for simulations

The API is specified in the rascil directory.

1.4.1 Processing Components

Calibration

Calibration is performed by fitting observed visibilities to a model visibility.

The scalar equation to be minimised is:

$$S = \sum_{t,f} \sum_{i,j} w_{t,f,i,j} \left| V^{\text{obs}}_{t,f,i,j} - J_i J_j^* V^{\text{mod}}_{t,f,i,j} \right|^2$$

The least squares fit algorithm uses an iterative substitution (or relaxation) algorithm from Larry D'Addario in the late seventies.

rascil.processing_components.calibration.iterators Module

GainTable iterators for iterating through a GainTable

Functions

gaintable_timeslice_iter(gt, **kwargs)	GainTable iterator

gaintable_timeslice_iter

gaintable_timeslice_iter(*gt: GainTable*, ***kwargs*) → ndarray

GainTable iterator

Parameters

- **gt** – GainTable
- **timeslice** – 'auto' or time in seconds
- **gaintable_slices** – Number of slices (second in precedence to timeslice)

Returns

Boolean array with selected rows=True

rascil.processing_components.calibration.operations Module

Functions for calibration, including creation of gaintables, application of gaintables, and merging gaintables.

Functions

append_gaintable(gt, othergt)	Append othergt to gt
create_gaintable_from_rows(gt, rows[, makecopy])	Create a GainTable from selected rows
gaintable_plot(gt[, cc, title, ants, ...])	Standard plot of gain table

append_gaintable

append_gaintable(*gt: GainTable*, *othergt: GainTable*) → GainTable

Append othergt to gt

Parameters

- **gt** –
- **othergt** –

Returns

GainTable gt + othergt

create_gaintable_from_rows

create_gaintable_from_rows(*gt: GainTable*, *rows: ndarray*, *makecopy=True*) → GainTable | None

Create a GainTable from selected rows

Parameters

- **gt** – GainTable
- **rows** – Boolean array of row selection
- **makecopy** – Make a deep copy (True)

Returns

GainTable

gaintable_plot

gaintable_plot(*gt: GainTable*, *cc='T'*, *title=''*, *ants=None*, *channels=None*, *label_max=0*, *min_amp=1e-05*, *cmap='rainbow'*, ***kwargs*)

Standard plot of gain table

Parameters

- **gt** – Gaintable
- **cc** – Type of gain table e.g. 'T', 'G, 'B'
- **value** – 'amp' or 'phase' or 'residual'
- **ants** – Antennas to plot
- **channels** – Channels to plot
- **kwargs** –

Returns

Flagging

rascil.processing_components.flagging.operations Module

Functions that Flagging Visibility and Visibility.

The flags of Visibility has axes [chan, pol, z, y, x] where z, y, x are spatial axes in either sky or Fourier plane. The order in the WCS is reversed so the grid_WCS describes UU, VV, WW, STOKES, FREQ axes.

Functions

flagging_visibility(bvis[, baselines, ...])	Flagging Visibility
flagging_aoflagger(vis, strategy_name)	Flagging Visibility using the AOFlagger package The flagging strategy can be telescope name (AARTFAAC, ARECIBO, ARECIBO 305M, BIGHORNS, EVLA, JVLA, LOFAR, MWA, PARKES, PKS, ATPKSMB, or WSRT) or a LUA file like the ones in https://gitlab.com/aroffringa/aoflagger/-/tree/master/data/strategies

flagging_visibility

flagging_visibility(*bvis*, *baselines=None*, *antennas=None*, *channels=None*, *polarisations=None*)

Flagging Visibility

Parameters

- **bvis** – Visibility
- **baselines** – The list of baseline numbers to flag
- **antennas** – The list of antenna number to flag
- **channels** – The list of Channel number to flag
- **polarisations** – The list of polarisations to flag

Returns

Visibility

flagging_aoflagger

flagging_aoflagger(*vis*, *strategy_name*)

Flagging Visibility using the AOFlagger package The flagging strategy can be telescope name (AARTFAAC, ARECIBO, ARECIBO 305M, BIGHORNS, EVLA, JVLA, LOFAR, MWA, PARKES, PKS, ATPKSMB, or WSRT) or a LUA file like the ones in https://gitlab.com/aroffringa/aoflagger/-/tree/master/data/strategies

You can define a new strategy interactively using the AOFlagger rfigui (https://aoflagger.readthedocs.io/en/latest/using_rfigui.html)

Parameters

- **vis** – Visibility object
- **strategy_name** – Strategy to use: can be a LUA file or a telescope name. If the strategy for the selected telescope is not available, a generic strategy is used.

Returns
Visibility where the flags field has been updated

Gridding Data

rascil.processing_components.griddata.convolution_functions Module

Functions that define and manipulate ConvolutionFunctions.

The griddata has axes [chan, pol, z, dy, dx, y, x] where z, y, x are spatial axes in either sky or Fourier plane. The order in the WCS is reversed so the grid_WCS describes UU, VV, DUU, DVV, WW, STOKES, FREQ axes.

GridData can be used to hold the Fourier transform of an Image or gridded visibilities. In addition, the convolution function can be stored in a GridData, most probably with finer spatial sampling.

Functions

calculate_bounding_box_convolutionfunction(c	Calculate bounding boxes
apply_bounding_box_convolutionfunction(cf[, ...])	Apply a bounding box to a convolution function
export_convolutionfunction_to_fits(cf[, ...])	Write a convolution function to fits

calculate_bounding_box_convolutionfunction

calculate_bounding_box_convolutionfunction(*cf*, *fractional_level=0.0001*)

Calculate bounding boxes

Returns a list of bounding boxes where each element is (z, (y0, y1), (x0, x1))

These can be used in griddata/degridding.

Parameters

- **cf** –
- **fractional_level** –

Returns
list of bounding boxes

apply_bounding_box_convolutionfunction

apply_bounding_box_convolutionfunction(*cf*, *fractional_level=0.0001*)

Apply a bounding box to a convolution function

Parameters

- **cf** –
- **fractional_level** –

Returns

bounded convolution function

export_convolutionfunction_to_fits

export_convolutionfunction_to_fits(*cf: ConvolutionFunction*, *fitsfile: str = 'cf.fits'*)

Write a convolution function to fits

Parameters

- **cf** – Convolu
- **fitsfile** – Name of output fits file in storage

Returns

None

See also

`rascil.processing_components.image.operations.import_image_from_array()`

rascil.processing_components.griddata.kernels Module

Functions that define and manipulate kernels

Functions

create_pswf_convolutionfunction(im[, ...])	Fill an Anti-Aliasing filter into a ConvolutionFunction
create_box_convolutionfunction(im[, ...])	Fill a box car function into a ConvolutionFunction
create_awterm_convolutionfunction(im[, ...])	Fill AW projection kernel into a GridData.
create_vpterm_convolutionfunction(im[, ...])	Fill voltage pattern kernel projection kernel into a GridData.

create_pswf_convolutionfunction

create_pswf_convolutionfunction(*im*, *oversampling=127*, *support=8*, *polarisation_frame=None*)

Fill an Anti-Aliasing filter into a ConvolutionFunction

Fill the Prolate Spheroidal Wave Function into a GriData with the specified oversampling. Only the inner non-zero part is retained

Also returns the griddata correction function as an image

Parameters

- **im** – Image template
- **oversampling** – Oversampling of the convolution function in uv space

Returns
griddata correction Image, griddata kernel as ConvolutionFunction

create_box_convolutionfunction

create_box_convolutionfunction(*im*, *oversampling=1*, *support=1*, *polarisation_frame=None*)

Fill a box car function into a ConvolutionFunction

Also returns the griddata correction function as an image

Parameters

- **im** – Image template
- **oversampling** – Oversampling of the convolution function in uv space

Returns
griddata correction Image, griddata kernel as ConvolutionFunction

create_awterm_convolutionfunction

create_awterm_convolutionfunction(*im*, *make_pb=None*, *nw=1*, *wstep=1000000000000000.0*, *oversampling=9*, *support=8*, *use_aaf=True*, *maxsupport=512*, *pa=None*, *normalise=True*, *polarisation_frame=None*)

Fill AW projection kernel into a GridData.

Parameters

- **im** – Image template
- **make_pb** – Function to make the primary beam model image (hint: use a partial)
- **nw** – Number of w planes
- **wstep** – Step in w (wavelengths)
- **oversampling** – Oversampling of the convolution function in uv space

Returns
griddata correction Image, griddata kernel as GridData

create_vpterm_convolutionfunction

create_vpterm_convolutionfunction(*im*, *make_vp=None*, *oversampling=8*, *support=6*, *use_aaf=False*, *maxsupport=512*, *pa=None*, *normalise=True*, *polarisation_frame=None*)

Fill voltage pattern kernel projection kernel into a GridData.

The makes the convolution function for gridding polarised data with a voltage pattern.

Parameters

- **im** – Image template
- **make_vp** – Function to make the voltage pattern model image (hint: use a partial)
- **oversampling** – Oversampling of the convolution function in uv space

Returns
griddata correction Image, griddata kernel as GridData

Images

rascil.processing_components.image.gradients Module

Image operations visible to the Execution Framework as Components

Functions

image_gradients(im)	Calculate image first order gradients numerically

image_gradients

image_gradients(*im: Image*)

Calculate image first order gradients numerically

Two images are returned: one with respect to x and one with respect to y

Gradient units are (incoming unit)/pixel e.g. Jy/beam/pixel

Parameters
im – Image

Returns
Gradient images

rascil.processing_components.image.operations Module

Image operations visible to the Execution Framework as Components

Functions

add_image(im1, im2)	Add two images
average_image_over_frequency(im)	Integrate image across frequency
create_w_term_like(im, w[, phasecentre, ...])	Create an image with a w term phase term in it:
create_window(template, window_type, **kwargs)	Create a window image using one of a number of methods
fft_image_to_griddata_with_wcs(im)	WCS-aware FFT of a canonical image
import_image_from_fits(fitsfile[, fixpol])	Read an Image from fits
pad_image(im, shape)	Pad an image to desired shape, adding equally to all edges
sub_image(im, shape)	Subsection an image to desired shape, cutting equally from all edges
polarisation_frame_from_wcs(wcs, shape)	Convert wcs to polarisation_frame
remove_continuum_image(im[, degree, mask])	Fit and remove continuum visibility in place
reproject_image(im, newwcs[, shape])	Re-project an image to a new coordinate system
show_components(im, comps[, npixels, fig, ...])	Show components against an image
show_image(im[, fig, title, pol, chan, cm, ...])	Show an Image with coordinates using matplotlib, optionally with components
smooth_image(model[, width, normalise])	Smooth an image with a 2D Gaussian kernel
scale_and_rotate_image(im[, angle, scale, order])	Scale and then rotate and image in x, y axes
apply_voltage_pattern_to_image(im, vp[, ...])	Apply a voltage pattern to an image

add_image

add_image(*im1: Image*, *im2: Image*) → Image

Add two images

Parameters

- **im1** – Image
- **im2** – Image

Returns

Image

average_image_over_frequency

average_image_over_frequency(*im: Image*) → Image

Integrate image across frequency

Returns

Integrated image

create_w_term_like

create_w_term_like(*im: Image*, *w*, *phasecentre=None*, *remove_shift=False*, *dopol=False*) → Image

Create an image with a w term phase term in it:

$$I(l,m) = e^{-2\pi j(w(\sqrt{1-l^2-m^2}-1)}$$

The phasecentre is used as the delay centre for the w term (i.e. where n==0)

Parameters

- **im** – template image
- **phasecentre** – SkyCoord definition of phasecentre
- **w** – w value to evaluate
- **remove_shift** –
- **dopol** – Do screen in polarisation?

Returns
Image

create_window

create_window(*template*, *window_type*, ***kwargs*)

Create a window image using one of a number of methods

The window is 1.0 or 0.0

window types:
'quarter': Inner quarter of the image

'no_edge': 'window_edge' pixels around edge set to zero

'threshold': template image pixels < 'window_threshold' absolute
value set to zero

Parameters

- **template** – Template image
- **window_type** – 'quarter' | 'no_edge' | 'threshold'

Returns
New image containing window

See also
`rascil.processing_components.image.deconvolution.deconvolve_cube()`

fft_image_to_griddata_with_wcs

fft_image_to_griddata_with_wcs(*im*)

WCS-aware FFT of a canonical image

The only transforms supported are:

RA–SIN, DEC–SIN <-> UU, VV XX, YY <-> KX, KY

For example:

```
from rascil.processing_components import
    create_test_image, fft_image_to_griddata_with_wcs
im = create_test_image()
print(im)
    Image:
        Shape: (1, 1, 256, 256)
        WCS: WCS Keywords
    Number of WCS axes: 4
    CTYPE : 'RA---SIN'  'DEC--SIN'  'STOKES'  'FREQ'
    CRVAL : 0.0  35.0  1.0  100000000.0
    CRPIX : 129.0  129.0  1.0  1.0
    PC1_1 PC1_2 PC1_3 PC1_4  : 1.0  0.0  0.0  0.0
    PC2_1 PC2_2 PC2_3 PC2_4  : 0.0  1.0  0.0  0.0
    PC3_1 PC3_2 PC3_3 PC3_4  : 0.0  0.0  1.0  0.0
    PC4_1 PC4_2 PC4_3 PC4_4  : 0.0  0.0  0.0  1.0
    CDELT : -0.000277777791  0.000277777791  1.0  100000.0
    NAXIS : 0  0
        Polarisation frame: stokesI
print(fft_image_to_griddata_with_wcs(im))
    Image:
        Shape: (1, 1, 256, 256)
        WCS: WCS Keywords
    Number of WCS axes: 4
    CTYPE : 'UU'  'VV'  'STOKES'  'FREQ'
    CRVAL : 0.0  0.0  1.0  100000000.0
    CRPIX : 129.0  129.0  1.0  1.0
    PC1_1 PC1_2 PC1_3 PC1_4  : 1.0  0.0  0.0  0.0
    PC2_1 PC2_2 PC2_3 PC2_4  : 0.0  1.0  0.0  0.0
    PC3_1 PC3_2 PC3_3 PC3_4  : 0.0  0.0  1.0  0.0
    PC4_1 PC4_2 PC4_3 PC4_4  : 0.0  0.0  0.0  1.0
    CDELT : -805.7218610503596  805.7218610503596  1.0  100000.0
    NAXIS : 0  0
        Polarisation frame: stokesI
```

Parameters

im –

Returns

See also

ska_sdp_func_python.fourier_transforms.fft_support.fft() ska_sdp_func_python.fourier_transforms.fft_support.ifft()

import_image_from_fits

import_image_from_fits(*fitsfile: str*, *fixpol=True*) → Image

Read an Image from fits

Parameters
fitsfile – FITS file in storage

Returns
Image

pad_image

pad_image(*im: Image*, *shape*)

Pad an image to desired shape, adding equally to all edges

Appropriate for standard 4D image with axes (freq, pol, y, x). Only pads in y, x

The wcs crpix is adjusted appropriately.

Parameters

- **im** – Image to be padded
- **shape** – Shape in 4 dimensions

Returns
Padded image

sub_image

sub_image(*im: Image*, *shape*)

Subsection an image to desired shape, cutting equally from all edges

Appropriate for standard 4D image with axes (freq, pol, y, x). Only works in y, x

The wcs crpix is adjusted appropriately.

Parameters

- **im** – Image to be padded
- **shape** – Shape in 4 dimensions

Returns
Padded image

polarisation_frame_from_wcs

polarisation_frame_from_wcs(*wcs*, *shape*) → PolarisationFrame

Convert wcs to polarisation_frame

See FITS definition in Table 29 of https://fits.gsfc.nasa.gov/standard40/fits_standard40draft1.pdf or subsequent revision

1 I Standard Stokes unpolarized 2 Q Standard Stokes linear 3 U Standard Stokes linear 4 V Standard Stokes circular 1 RR Right-right circular 2 LL Left-left circular 3 RL Right-left cross-circular 4 LR Left-right cross-circular 5 XX X parallel linear 6 YY Y parallel linear 7 XY XY cross linear 8 YX YX cross linear

stokesI [1] stokesIQUV [1,2,3,4] circular [-1,-2,-3,-4] linear [-5,-6,-7,-8]

For example::

pol_frame =
polarisation_frame_from_wcs(im.image_acc.wcs, im["pixels"].data.shape)

Parameters

- **wcs** – World Coordinate System
- **shape** – Shape corresponding to wcs

Returns
Polarisation_Frame object

remove_continuum_image

remove_continuum_image(*im: Image*, *degree=1*, *mask=None*)

Fit and remove continuum visibility in place

Fit a polynomial in frequency of the specified degree where mask is True and remove it from the image

Parameters

- **im** –
- **degree** – 1 is a constant, 2 is a slope, etc.
- **mask** – Frequency mask

Returns

reproject_image

reproject_image(*im: ~ska_sdp_datamodels.image.image_model.Image*, *newwcs: ~astropy.wcs.wcs.WCS*, *shape=None*) -> (<class 'ska_sdp_datamodels.image.image_model.Image'>, <class 'ska_sdp_datamodels.image.image_model.Image'>)

Re-project an image to a new coordinate system

Currently uses the reproject python package. This seems to have some features do be careful using this method. For timeslice imaging griddata is used.

Parameters

- **im** – Image to be reprojected
- **newwcs** – New WCS
- **shape** – Desired shape

Returns
Reprojected Image, Footprint Image

show_components

show_components(*im*, *comps*, *npixels=128*, *fig=None*, *vmax=None*, *vmin=None*, *title=''*)

Show components against an image

Parameters

- **im** –
- **comps** –
- **npixels** –
- **fig** –

Returns

show_image

show_image(*im: Image*, *fig=None*, *title: str = ''*, *pol=0*, *chan=0*, *cm='Greys'*, *components=None*, *vmin=None*, *vmax=None*, *vscale=1.0*)

Show an Image with coordinates using matplotlib, optionally with components

Parameters

- **im** – Image
- **fig** – Matplotlib figure
- **title** – String for title of plot
- **pol** – Polarisation to show (index)
- **chan** – Channel to show (index)
- **components** – Optional components to be overlaid
- **vmin** – Clip to this minimum
- **vmax** – Clip to this maximum
- **vscale** – scale max, min by this amount

Returns

smooth_image

smooth_image(*model: Image*, *width=1.0*, *normalise=True*)

Smooth an image with a 2D Gaussian kernel

Parameters

- **model** – Image
- **width** – Kernel width in pixels
- **normalise** – Normalise kernel peak to unity

scale_and_rotate_image

scale_and_rotate_image(*im*, *angle=0.0*, *scale=None*, *order=5*)

Scale and then rotate and image in x, y axes

Applies scale then rotates

Parameters

- **im** – Image
- **angle** – Angle in radians
- **scale** – Scale [scale_x, scale_y]
- **order** – Order of interpolation (0-5)

Returns

apply_voltage_pattern_to_image

apply_voltage_pattern_to_image(*im: Image*, *vp: Image*, *inverse=False*, *min_det=0.1*, ***kwargs*) → Image

Apply a voltage pattern to an image

For each pixel, the application is as follows:

I_{corrected}(l,m) = vp(l,m) I(l,m) jones(j,m).H

Parameters

- **im** – Image to have jones applied
- **vp** – Jones image to be applied
- **inverse** – Apply the inverse (default=False)
- **min_det** – Minimum determinant to correct

Returns
new Image with Jones applied

Imaging

rascil.processing_components.imaging.imaging_params Module

Functions

get_rowmap(col[, ucol])	Map to unique cols
get_polarisation_map(vis[, im])	Get the mapping of visibility polarisations to image polarisations
get_frequency_map(vis[, im])	Map channels from visibilities to image

get_rowmap

get_rowmap(*col*, *ucol=None*)

Map to unique cols

Parameters

- **col** – Data column
- **ucol** – Unique values in col

get_polarisation_map

get_polarisation_map(*vis: Visibility*, *im: Image | None = None*)

Get the mapping of visibility polarisations to image polarisations

get_frequency_map

get_frequency_map(*vis*, *im: Image | None = None*)

Map channels from visibilities to image

rascil.processing_components.imaging.primary_beams Module

Functions to create primary beam and voltage pattern models

Functions

set_pb_header(pb[, use_local])	Fill in PB header correctly for local coordinates.
create_pb(model[, telescope, ...])	Create an image containing the primary beam for a number of cases
create_pb_generic(model[, pointingcentre, ...])	Create a generic analytical model of the primary beam
create_vp([model, telescope, ...])	Create an image containing the dish voltage pattern for a number of cases
create_vp_generic(model[, pointingcentre, ...])	Create a generic analytical model of the voltage pattern
create_vp_generic_numeric(model[, ...])	Make an image like model and fill it with an analytical model of the primary beam
create_low_test_beam(model[, use_local, azel])	Create a test power beam for LOW
create_low_test_vp(model[, use_local, azel])	Create a test voltage beam for LOW
create_mid_allsky([frequency, npixel, cellsize])	Approximate all sky MID beam
convert_azelvp_to_radec(vp, im, pa)	Convert AZELGEO image to image coords at specific parallactic angle
normalise_vp(vp)	Normalise the vp in place so that the peak gain on axis for parallel pols is equal

set_pb_header

set_pb_header(*pb*, *use_local=True*)

Fill in PB header correctly for local coordinates.

There is no convention on how to represent primary beams. We use axes 'AZELGEO long' and 'AZELGEO lati'

Parameters

pb –

Returns

create_pb

create_pb(*model*, *telescope='MID'*, *pointingcentre=None*, *use_local=True*)

Create an image containing the primary beam for a number of cases

Parameters

- **model** – Template image
- **telescope** – 'VLA' or 'ASKAP'

Returns

Primary beam image

create_pb_generic

create_pb_generic(*model*, *pointingcentre=None*, *diameter=25.0*, *blockage=1.8*, *use_local=True*)

Create a generic analytical model of the primary beam

Feeed legs are ignored

Parameters

- **model** –
- **diameter** – Diameter of dish (m)
- **blockage** – Diameter of blockage

Returns

create_vp

create_vp(*model=None*, *telescope='MID'*, *pointingcentre=None*, *padding=4*, *use_local=True*, *fixpol=True*)

Create an image containing the dish voltage pattern for a number of cases

Parameters

- **model** – Template image (Can be None for some cases)
- **telescope** –

Returns

Primary beam image

create_vp_generic

`create_vp_generic`(*model*, *pointingcentre=None*, *diameter=25.0*, *blockage=1.8*, *use_local=True*)

Create a generic analytical model of the voltage pattern

Feeed legs are ignored

Parameters

- **model** –
- **diameter** – Diameter of dish (m)
- **blockage** – Diameter of blockage

Returns

create_vp_generic_numeric

`create_vp_generic_numeric`(*model*, *pointingcentre=None*, *diameter=15.0*, *blockage=0.0*, *taper='gaussian'*, *edge=0.03162278*, *zernikes=None*, *padding=4*, *use_local=True*)

Make an image like model and fill it with an analytical model of the primary beam

The elements of the analytical model are: - dish, optionally blocked - Gaussian taper, default is -12dB at the edge - Offset to pointing centre (optional) - zernikes in a list of dictionaries. Each list element is of the form

{“coeff”:0.1, “noll”:5}. See aotools for more details

- **Output image can be in RA, DEC coordinates or AZELGEO coordinates (the default).**
  use_local=True means to use AZELGEO coordinates centered on 0deg 0deg.

The dish is zero padded according to padding and FFT’ed to get the voltage pattern.

Parameters

- **model** –
- **pointingcentre** – SkyCoord of desired pointing centre
- **diameter** – Diameter of dish in metres
- **blockage** – Blockage of dish in metres
- **taper** – “Gaussian” or None
- **edge** – Value of taper at the end of the dish (default corresponds to -12dB)
- **zernikes** – Zernikes to be applied as phase across the dish (see above)
- **padding** – Pad the image by this amount
- **use_local** – Use local frame (AZELGEO)?

Returns

create_low_test_beam

create_low_test_beam(*model: Image*, *use_local=True*, *azel=None*) → Image

Create a test power beam for LOW

This uses an approximation that ignores the antennas

Parameters

- **model** – Template image
- **use_local** – Use az el coordinates instead of ra dec
- **azel** – Tuple (Azimuth, Elevation) radians

create_low_test_vp

create_low_test_vp(*model: Image*, *use_local=True*, *azel=None*) → Image

Create a test voltage beam for LOW

This uses an approximation that ignores the antennas

Parameters

- **model** – Template image
- **use_local** – Use az el coordinates instead of ra dec
- **azel** – Tuple (Azimuth, Elevation) radians

Returns
Image

create_mid_allsky

create_mid_allsky(*frequency=array([1.e+09])*, *npixel=512*, *cellsize=None*)

Approximate all sky MID beam

Unlocked 15m dish with no taper. Actual sidelobes are likely to be lower than this model implies.

Parameters

- **frequency** – Frequencies to use array(float) (Hz) default is [1e9]
- **npixel** – Number of pixels per axis (int) Default is 512
- **cellsize** – Cellsize in radians. Default is pi/npixel

Returns
Image

convert_azelvp_to_radec

convert_azelvp_to_radec(*vp*, *im*, *pa*)

Convert AZELGEO image to image coords at specific parallactic angle

Parameters

- **pb** – Primary beam or voltage pattern
- **im** – Template image
- **pa** – Parallactic angle (radians)

Returns

normalise_vp

normalise_vp(*vp*)

Normalise the vp in place so that the peak gain on axis for parallel pols is equal

Parameters
vp –

Returns

Simulation

rascil.processing_components.simulation.atmospheric_screen Module

Functions for tropospheric and ionospheric modeling : see `SDP Memo 97 <http://ska-sdp.org/sites/default/files/attachments/

direction_dependent_self_calibration_in_arl_-_signed.pdf>`_

Functions

find_pierce_points(station_locations, ha, ...)	Find the pierce points for a flat screen at specified height
create_gaintable_from_screen(vis, sc, screen)	Create gaintables from a screen calculated using ARatmospy
grid_gaintable_to_screen(vis, gaintables, screen)	Grid a gaintable to a screen image
calculate_sf_from_screen(screen)	Calculate structure function image from screen
plot_gaintable_on_screen(vis, gaintables[, ...])	Plot a gaintable on an ionospheric screen

find_pierce_points

find_pierce_points(*station_locations*, *ha*, *dec*, *phasecentre*, *height*)

Find the pierce points for a flat screen at specified height

A pierce point is where the line of site from a station or dish to a source passes through a thin screen

Parameters

- **station_locations** – station locations [:3]
- **ha** – Hour angle
- **dec** – Declination
- **phasecentre** – Phase centre
- **height** – Height of screen

Returns

create_gaintable_from_screen

create_gaintable_from_screen(*vis*, *sc*, *screen*, *height=None*, *vis_slices=None*, *r0=5000.0*, *type_atmosphere='ionosphere'*, *reference_component=None*, *jones_type='B'*, ***kwargs*)

Create gaintables from a screen calculated using ARatmospy

Screen axes are ['XX', 'YY', 'TIME', 'FREQ']

Parameters

- **vis** –
- **sc** – Sky components for which pierce points are needed
- **screen** – Image or string (for fits file which will be memory mapped in
- **height** – Height (in m) of screen above telescope e.g. 3e5
- **r0** – r0 in meters
- **type_atmosphere** – 'ionosphere' or 'troposphere'
- **reference** – Use the first component as a reference
- **jones_type** – Type of calibration matrix T or G or B

Returns

grid_gaintable_to_screen

grid_gaintable_to_screen(*vis*, *gaintables*, *screen*, *height=300000.0*, *gaintable_slices=None*, *scale=1.0*, *r0=5000.0*, *type_atmosphere='ionosphere'*, *vis_slices=None*, ***kwargs*)

Grid a gaintable to a screen image

Screen axes are ['XX', 'YY', 'TIME', 'FREQ']

The phases are just averaged per grid cell, no phase unwrapping is performed.

Parameters

- **vis** –
- **gaintables** – input gaintables
- **screen** –
- **height** – Height (in m) of screen above telescope e.g. 3e5
- **r0** – r0 in meters
- **type_atmosphere** – 'ionosphere' or 'troposphere'
- **scale** – Multiply the screen by this factor

Returns
gridded screen image, weights image

calculate_sf_from_screen

calculate_sf_from_screen(*screen*)

Calculate structure function image from screen

Screen axes are ['XX', 'YY', 'TIME', 'FREQ']

Parameters
screen –

Returns

plot_gaintable_on_screen

plot_gaintable_on_screen(*vis*, *gaintables*, *height=300000.0*, *gaintable_slices=None*, *plotfile=None*)

Plot a gaintable on an ionospheric screen

Screen axes are ['XX', 'YY', 'TIME', 'FREQ']

Parameters

- **vis** –
- **gaintables** –
- **height** – Height (in m) of screen above telescope e.g. 3e5
- **scale** – Multiply the screen by this factor

Returns
gridded screen image, weights image

rascil.processing_components.simulation.noise Module

Functions that add noise.

Functions

calculate_noise_visibility(bandwidth, ...)	Calculate noise rms per visibility [nchan, npol]
addnoise_visibility(vis[, t_sys, eta, seed])	Add noise to a visibility

calculate_noise_visibility

calculate_noise_visibility(*bandwidth*, *int_time*, *diameter*, *t_sys*, *eta*)

Calculate noise rms per visibility [nchan, npol]

Parameters

- **bandwidth** – (Hz)
- **int_time** – Integration time (s)
- **diameter** – Diameter (m)
- **t_sys** –

(K)

- **eta** – Efficiency

Returns

Sigma [nrows, nchan]

addnoise_visibility

addnoise_visibility(*vis*, *t_sys=None*, *eta=None*, *seed=None*)

Add noise to a visibility

TODO: Obtain sensitivity values from vis as a function of frequency

Parameters

- **vis** –
- **t_sys** – System temperature
- **eta** – Efficiency

Returns

vis with noise added

rascil.processing_components.simulation.pointing Module

Functions for simulating pointing errors

Functions

simulate_gaintable_from_pointingtable(vis, ...)	Create gaintables from a pointing table
simulate_pointingtable_from_timeseries(pt[, ...])	Create a pointing table with time series created from PSD.
simulate_pointingtable(pt, pointing_error[, ...])	Simulate a gain table

simulate_gaintable_from_pointingtable

simulate_gaintable_from_pointingtable(*vis*, *sc*, *pt*, *vp*, *vis_slices=None*, *scale=1.0*, *order=3*, *elevation_limit=0.2617993877991494*, *jones_type='G'*, ***kwargs*)

Create gaintables from a pointing table

Note that the column "nominal" is not used

Parameters

- **vis** –
- **sc** – Sky components for which pierce points are needed
- **pt** – Pointing table
- **vp** – Voltage pattern in AZELGEO frame
- **scale** – Multiply the screen by this factor
- **order** – order of spline (default is 3)
- **jones_type** – Type of calibration matrix T or G or B

Returns

simulate_pointingtable_from_timeseries

simulate_pointingtable_from_timeseries(*pt*, *type='wind'*, *time_series_type='precision'*, *pointing_directory=None*, *reference_pointing=False*, *seed=None*)

Create a pointing table with time series created from PSD.

Parameters

- **pt** – Pointing table to be filled
- **type** – Type of pointing: 'tracking' or 'wind'
- **time_series_type** – Type of wind condition precision|standard|degraded
- **pointing_directory** – Name of pointing file directory
- **reference_pointing** – Use reference pointing?

Returns

simulate_pointingtable

simulate_pointingtable(*pt: PointingTable*, *pointing_error*, *static_pointing_error=None*, *global_pointing_error=None*, *seed=None*, ***kwargs*) → PointingTable

Simulate a gain table

Parameters

- **pointing_error** – std of normal distribution (radians)
- **static_pointing_error** – std of normal distribution (radians)
- **global_pointing_error** – 2-vector of global pointing error (rad)
- **kwargs** –

Returns

PointingTable

rascil.processing_components.simulation.rfi Module

Functions used to simulate RFI. Developed as part of SP-122/SIM.

The scenario is: * There is a TV station at a remote location (e.g. Perth), emitting a broadband signal (7MHz) of known power (50kW). * The emission from the TV station arrives at LOW stations with phase delay and attenuation. Neither of these are well known but they are probably static. * The RFI enters LOW stations in a side-lobe of the main beam. Calculations by Fred Dulwich indicate that this provides attenuation of about 55 - 60dB for a source close to the horizon. * The RFI enters each LOW station with fixed delay and zero fringe rate (assuming no e.g. ionospheric ducting) * In tracking a source on the sky, the signal from one station is delayed and fringe-rotated to stop the fringes for one direction on the sky. * The fringe rotation stops the fringe from a source at the phase tracking centre but phase rotates the RFI, which now becomes time-variable. * The correlation data are time- and frequency-averaged over a timescale appropriate for the station field of view. This averaging de-correlates the RFI signal. * We want to study the effects of this RFI on statistics of the images: on source and at the pole.

Functions

calculate_averaged_correlation(correlation, ...)	Average the correlation in time and frequency :param correlation: Correlation(ntimes, nant, nants, nchan] :param channel_width: Number of channels to average :param time_width: Number of integrations to average :return:
simulate_rfi_block_prop(bvis, ...[, ...])	Simulate RFI in a BlockVisility
calculate_station_correlation_rfi(...)	Form the correlation from the rfi at the station

calculate_averaged_correlation

calculate_averaged_correlation(*correlation*, *time_width*, *channel_width*)

Average the correlation in time and frequency :param correlation: Correlation(ntimes, nant, nants, nchan] :param channel_width: Number of channels to average :param time_width: Number of integrations to average :return:

simulate_rfi_block_prop

simulate_rfi_block_prop(*bvis*, *apparent_emitter_power*, *apparent_emitter_coordinates*, *rfi_sources*, *rfi_frequencies*, *low_beam_gain=None*, *apply_primary_beam=True*)

Simulate RFI in a BlockVisility

Parameters

- **bvis** – input Visibility, to be updated with RFI
- **apparent_emitter_power** – RFI emitter power as received by an isotropic SKA antenna [nrfi_sources x ntimes x nantennas x nchannels]
- **apparent_emitter_coordinates** – azimuth, elevation, distance information of RFI emitters [nrfi_sources x ntimes x nantennas x 3]
- **rfi_sources** – RFI source names or IDs
- **rfi_frequencies** – frequency channels where there is RFI information length = nchannels
- **low_beam_gain** – beam gain data / information for Low. If provided, it is either a single value, or a numpy array with dimensions [nrfi_sources x nstations x nchannels]; for Mid, use None
- **apply_primary_beam** – Apply the primary beam, not used for Low

Returns

Visibility

calculate_station_correlation_rfi

calculate_station_correlation_rfi(*rfi_at_station*, *baselines*)

Form the correlation from the rfi at the station

Parameters

- **rfi_at_station** – [btimes, nchan, nants, nants]
- **baselines** – Visibility baselines object

Returns

correlation(ntimes, nbaselines, nchan] in Jy

rascil.processing_components.simulation.simulation_helpers Module

Functions that help with SKA simulations

Functions

plot_visibility(vis_list[, colors, title, ...])	Standard plot of visibility
plot_visibility_pol(vis_list[, title, y, x, ...])	Standard plot of visibility
find_times_above_elevation_limit(...)	Find all times for which a phasecentre is above the elevation limit
plot_uvcoverage(vis_list[, ax, plot_file, title])	Standard plot of uv coverage
plot_uwcoverage(vis_list[, ax, plot_file, title])	Standard plot of uw coverage
plot_vwcoverage(vis_list[, ax, plot_file, title])	Standard plot of vw coverage
plot_configuration(config[, ax, plot_file, ...])	Standard plot of uv coverage
plot_azel(bvis_list[, plot_file])	Standard plot of az el coverage
plot_gaintable(gt_list[, title, value, ...])	Standard plot of gain table
plot_pointingtable(pt_list, plot_file, ...)	Standard plot of pointing table
find_pb_width_null(pbtype, frequency, **kwargs)	Rough estimates of HWHM and null locations
create_mid_simulation_components(...[, ...])	Construct components for simulation
plot_pa(bvis_list[, plot_file])	Standard plot of parallactic angle coverage

plot_visibility

plot_visibility(*vis_list*, *colors=None*, *title='Visibility'*, *y='amp'*, *x='uvdist'*, *plot_file=None*, *chan=0*, *markersize=0.2*, ***kwargs*)

Standard plot of visibility

Parameters

- **vis_list** –
- **plot_file** –
- **kwargs** –

Returns

plot_visibility_pol

plot_visibility_pol(*vis_list*, *title='Visibility_pol'*, *y='amp'*, *x='uvdist'*, *plot_file=None*, *chan=0*, ***kwargs*)

Standard plot of visibility

Parameters

- **vis_list** –
- **plot_file** –
- **kwargs** –

Returns

find_times_above_elevation_limit

`find_times_above_elevation_limit`(*start_times*, *end_times*, *location*, *phasecentre*, *elevation_limit*)

Find all times for which a phasecentre is above the elevation limit

Parameters

- **start_times** –
- **end_times** –
- **location** –
- **phasecentre** –
- **elevation_limit** –

Returns

plot_uvcoverage

`plot_uvcoverage`(*vis_list*, *ax=None*, *plot_file=None*, *title='UV coverage'*, ***kwargs*)

Standard plot of uv coverage

Parameters

- **vis_list** –
- **plot_file** –
- **kwargs** –

Returns

plot_uwcoverage

`plot_uwcoverage`(*vis_list*, *ax=None*, *plot_file=None*, *title='UW coverage'*, ***kwargs*)

Standard plot of uw coverage

Parameters

- **vis_list** –
- **plot_file** –
- **kwargs** –

Returns

plot_vwcoverage

plot_vwcoverage(*vis_list*, *ax=None*, *plot_file=None*, *title='VW coverage'*, ***kwargs*)

Standard plot of vw coverage

Parameters

- **vis_list** –
- **plot_file** –
- **kwargs** –

Returns

plot_configuration

plot_configuration(*config*, *ax=None*, *plot_file=None*, *title='Configuration'*, *label=False*, ***kwargs*)

Standard plot of uv coverage

Parameters

- **vis_list** –
- **plot_file** –
- **kwargs** –

Returns

plot_azel

plot_azel(*bvis_list*, *plot_file=None*, ***kwargs*)

Standard plot of az el coverage

Parameters

- **bvis_list** –
- **plot_file** –
- **kwargs** –

Returns

plot_gaintable

plot_gaintable(*gt_list*, *title=''*, *value='amp'*, *plot_file=None*, ***kwargs*)

Standard plot of gain table

Parameters

- **gt_list** –
- **title** –
- **plot_file** –
- **kwargs** –

Returns

plot_pointingtable

plot_pointingtable(*pt_list*, *plot_file*, *title*, ***kwargs*)

Standard plot of pointing table

Parameters

- **pt_list** –
- **plot_file** –
- **title** –
- **kwargs** –

Returns

find_pb_width_null

find_pb_width_null(*pbtype*, *frequency*, ***kwargs*)

Rough estimates of HWHM and null locations

Parameters

- **pbtype** –
- **frequency** –
- **kwargs** –

Returns

create_mid_simulation_components

create_mid_simulation_components(*phasecentre*, *frequency*, *flux_limit*, *pbradius*, *pb_npixel*, *pb_cellsize*, *show=False*, *fov=10*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.PolarisationFr object>*, *flux_max=10.0*, *pb_type='MID'*, *apply_pb=True*)

Construct components for simulation

Parameters

- **context** – singlesource or null or s3sky
- **phasecentre** – Centre of components
- **frequency** – Frequency
- **pbtype** – Type of primary beam
- **offset_dir** – Offset in ra, dec degrees
- **flux_limit** – Lower limit flux
- **pbradius** – Radius of components in radians
- **pb_npixel** – Number of pixels in the primary beam model
- **pb_cellsize** – Cellsize in primary beam model

- **fov** – FOV in degrees (used to select catalog)
- **flux_max** – Maximum flux in model before application of primary beam
- **polarisation_frame** –
- **apply_pb** – Apply the primary beam to the output components
- **show** –

Returns

plot_pa

plot_pa(*bvis_list*, *plot_file=None*, ***kwargs*)

Standard plot of parallactic angle coverage

Parameters

- **bvis_list** –
- **plot_file** –
- **kwargs** –

Returns

rascil.processing_components.simulation.surface Module

Functions for dish surface modeling

Functions

simulate_gaintable_from_zernikes(vis, sc, ...)	Create gaintables for a set of zernikes
simulate_gaintable_from_voltage_pattern(vis, ...)	Create gaintables from a list of components and voltage patterns

simulate_gaintable_from_zernikes

simulate_gaintable_from_zernikes(*vis*, *sc*, *vp_list*, *vp_coeffs*, *vis_slices=None*, *order=3*, *elevation_limit=0.2617993877991494*, *jones_type='B'*, ***kwargs*)

Create gaintables for a set of zernikes

Parameters

- **vis** –
- **sc** – Sky components for which pierce points are needed
- **vp** – List of Voltage patterns in AZELGEO frame
- **vp_coeffs** – Fractional contribution [nants, nvp]
- **order** – order of spline (default is 3)
- **jones_type** – Type of calibration matrix T or G or B

Returns

simulate_gaintable_from_voltage_pattern

simulate_gaintable_from_voltage_pattern(*vis*, *sc*, *vp*, *vis_slices=None*, *order=3*, *elevation_limit=0.2617993877991494*, *jones_type='B'*, ***kwargs*)

Create gaintables from a list of components and voltage patterns

Parameters

- **elevation_limit** –
- **vis_slices** –
- **vis** –
- **sc** – Sky components for which pierce points are needed
- **vp** – Voltage pattern in AZELGEO frame, can also be a list of voltage patterns, indexed alphabetically
- **order** – order of spline (default is 3)
- **jones_type** – Type of calibration matrix T or G or B

Returns

rascil.processing_components.simulation.testing_support Module

Functions that aid testing in various ways. A typical use would be:

```
lowcore = create_named_configuration('LOWBD2-CORE')
times = numpy.linspace(-3, +3, 13) * (numpy.pi / 12.0)

frequency = numpy.array([1e8])
channel_bandwidth = numpy.array([1e7])

# Define the component and give it some polarisation and spectral behaviour
f = numpy.array([100.0])
flux = numpy.array([f])

phasecentre =
    SkyCoord(ra=+15.0 * u.deg, dec=-35.0 * u.deg, frame='icrs', equinox='J2000')
compabsdirection =
    SkyCoord(ra=17.0 * u.deg, dec=-36.5 * u.deg, frame='icrs', equinox='J2000')

comp = SkyComponent(flux=flux, frequency=frequency, direction=compabsdirection,
                                polarisation_frame=PolarisationFrame('stokesI'))
image = create_test_image(frequency=frequency,
                          phasecentre=phasecentre,
                          cellsize=0.001,
                          polarisation_frame=PolarisationFrame('stokesI'))
vis = create_visibility(lowcore, times=times, frequency=frequency,
                            channel_bandwidth=channel_bandwidth,
                            phasecentre=phasecentre, weight=1,
```

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```
                                polarisation_frame=PolarisationFrame('stokesI'),
                                integration_time=1.0)
```

Functions

create_low_test_image_from_gleam([npixel, ...])	Create LOW test image from the GLEAM survey
create_low_test_skycomponents_from_gleam([...]	Create sky components from the GLEAM survey
create_low_test_skymodel_from_gleam([...])	Create LOW test skymodel from the GLEAM survey
create_test_image([cellsize, frequency, ...])	Create a useful test image
create_test_image_from_s3([npixel, ...])	Create MID test image from S3
create_test_skycomponents_from_s3([...])	Create test image from S3
create_unittest_components(model, flux[, ...])	
create_unittest_model(vis, model_pol[, ...])	
ingest_unittest_visibility(config, ...[, ...])	Make a standard visibility simulation
insert_unittest_errors(vt[, seed, ...])	Simulate gain errors and apply
replicate_image(im[, polarisation_frame, ...])	Make a new canonical shape Image, extended along third and fourth axes by replication.
simulate_gaintable(gt[, phase_error, ...])	Simulate a gain table

create_low_test_image_from_gleam

create_low_test_image_from_gleam(*npixel=512*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.PolarisationFr object>*, *cellsize=1.5e-05*, *frequency=array([1.e+08])*, *channel_bandwidth=None*, *phasecentre=None*, *kind='cubic'*, *applybeam=False*, *flux_limit=0.1*, *flux_max=inf*, *flux_min=-inf*, *radius=None*, *insert_method='Nearest'*) → Image

Create LOW test image from the GLEAM survey

Stokes I is estimated from a cubic spline fit to the measured fluxes. The polarised flux is always zero.

See http://www.mwatelescope.org/science/gleam-survey The catalog is available from Vizier.

VIII/100 GaLactic and Extragalactic All-sky MWA survey (Hurley-Walker+, 2016)

GaLactic and Extragalactic All-sky Murchison Wide Field Array (GLEAM) survey. I: A low-frequency extragalactic catalogue. Hurley-Walker N., et al., Mon. Not. R. Astron. Soc., 464, 1146-1167 (2017), 2017MNRAS.464.1146H

Parameters

- **npixel** – Number of pixels
- **polarisation_frame** – Polarisation frame (default PolarisationFrame("stokesI"))
- **cellsize** – cellsize in radians
- **frequency** –
- **channel_bandwidth** – Channel width (Hz)
- **phasecentre** – phasecentre (SkyCoord)

- **kind** – Kind of interpolation (see scipy.interpolate.interp1d) Default: linear
- **radius** – radius of search area in radians (Default is half-width of the diagonal)

Returns
Image

create_low_test_skycomponents_from_gleam

create_low_test_skycomponents_from_gleam(*flux_limit=0.1*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.Pola object>*, *frequency=array([1.e+08])*, *kind='cubic'*, *phasecentre=None*, *radius=1.0*) → List[SkyComponent]

Create sky components from the GLEAM survey

Stokes I is estimated from a cubic spline fit to the measured fluxes. The polarised flux is always zero.

See http://www.mwatelescope.org/science/gleam-survey The catalog is available from Vizier.

VIII/100 GaLactic and Extragalactic All-sky MWA survey (Hurley-Walker+, 2016)

GaLactic and Extragalactic All-sky Murchison Wide Field Array (GLEAM) survey. I: A low-frequency extragalactic catalogue. Hurley-Walker N., et al., Mon. Not. R. Astron. Soc., 464, 1146-1167 (2017), 2017MNRAS.464.1146H

Parameters

- **flux_limit** – Only write components brighter than this (Jy)
- **polarisation_frame** – Polarisation frame (default PolarisationFrame("stokesI"))
- **frequency** – Frequencies at which the flux will be estimated
- **kind** – Kind of interpolation (see scipy.interpolate.interp1d) Default: linear
- **phasecentre** – Desired phase centre (SkyCoord) default None implies all sources
- **radius** – Radius of sources selected around phasecentre (default 1.0 rad)

Returns
List of SkyComponents

create_low_test_skymodel_from_gleam

create_low_test_skymodel_from_gleam(*npixel=512*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.Polarisatio object>*, *cellsize=1.5e-05*, *frequency=array([1.e+08])*, *channel_bandwidth=array([1000000.])*, *phasecentre=None*, *kind='cubic'*, *applybeam=True*, *flux_limit=0.1*, *flux_max=inf*, *flux_threshold=1.0*, *insert_method='Nearest'*, *telescope='LOW'*, *radius=None*) → SkyModel

Create LOW test skymodel from the GLEAM survey

Stokes I is estimated from a cubic spline fit to the measured fluxes. The polarised flux is always zero.

See http://www.mwatelescope.org/science/gleam-survey The catalog is available from Vizier.

VIII/100 GaLactic and Extragalactic All-sky MWA survey (Hurley-Walker+, 2016)

GaLactic and Extragalactic All-sky Murchison Wide Field Array (GLEAM) survey. I: A low-frequency extragalactic catalogue. Hurley-Walker N., et al., Mon. Not. R. Astron. Soc., 464, 1146-1167 (2017), 2017MNRAS.464.1146H

Parameters

- **telescope** –
- **npixel** – Number of pixels
- **polarisation_frame** – Polarisation frame (default PolarisationFrame("stokesI"))
- **cellsize** – cellsize in radians
- **frequency** –
- **channel_bandwidth** – Channel width (Hz)
- **phasecentre** – phasecentre (SkyCoord)
- **kind** – Kind of interpolation (see scipy.interpolate.interp1d) Default: cubic
- **applybeam** – Apply the primary beam?
- **flux_limit** – Weakest component
- **flux_max** – Maximum strength component to be included in components
- **flux_threshold** – Split between components (brighter) and image (weaker)
- **insert_method** – Nearest | PSWF | Lanczos
- **radius** – radius of search area in radians (Default is half-width of the axis)

Returns
SkyModel

create_test_image

create_test_image(*cellsize=None*, *frequency=None*, *channel_bandwidth=None*, *phasecentre=None*, *polarisation_frame=None*) → Image

Create a useful test image

This is the test image M31 widely used in ALMA and other simulations. It is actually part of an Halpha region in M31.

Parameters

- **cellsize** –
- **frequency** – Frequency (array) in Hz
- **channel_bandwidth** – Channel bandwidth (array) in Hz
- **phasecentre** – Phase centre of image (SkyCoord)
- **polarisation_frame** – Polarisation frame

Returns
Image

create_test_image_from_s3

create_test_image_from_s3(*npixel=16384*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.PolarisationFrame object>*, *cellsize=1.5e-05*, *frequency=array([1.e+08])*, *channel_bandwidth=array([1000000.])*, *phasecentre=None*, *fov=20*, *flux_limit=0.001*) → Image

Create MID test image from S3

The input catalog was generated using the following query::

Database: s3_sex SQL: select * from Galaxies where (pow(10,itot_151)*1000 > 1.0) and (right_ascension between -5 and 5) and (declination between -5 and 5);;

Number of rows returned: 29966

For frequencies < 610MHz, there are three tables to use:

```
data/models/S3_151MHz_10deg.csv, use fov=10
data/models/S3_151MHz_20deg.csv, use fov=20
data/models/S3_151MHz_40deg.csv, use fov=40
```

For frequencies > 610MHz, there are three tables:

data/models/S3_1400MHz_1mJy_10deg.csv, use flux_limit>= 1e-3 data/models/S3_1400MHz_100uJy_10deg.csv, use flux_limit < 1e-3 data/models/S3_1400MHz_10uJy_10deg.csv, use flux_limit < 1e-4 data/models/S3_1400MHz_1mJy_18deg.csv, use flux_limit>= 1e-3 data/models/S3_1400MHz_100uJy_18deg.csv, use flux_limit < 1e-3

The component spectral index is calculated from the 610MHz and 151MHz or 1400MHz and 610MHz, and then calculated for the specified frequencies.

If polarisation_frame is not stokesI then the image will a polarised axis but the values will be zero.

Parameters

- **npixel** – Number of pixels
- **polarisation_frame** – Polarisation frame (default PolarisationFrame("stokesI"))
- **cellsize** – cellsize in radians
- **frequency** –
- **channel_bandwidth** – Channel width (Hz)
- **phasecentre** – phasecentre (SkyCoord)
- **fov** – fov 10 | 20 | 40
- **flux_limit** – Minimum flux (Jy)

Returns

Image

create_test_skycomponents_from_s3

create_test_skycomponents_from_s3(*polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.Polar object>*, *frequency=array([1.e+08])*, *channel_bandwidth=array([1000000.])*, *phasecentre=None*, *fov=20*, *flux_limit=0.001*, *radius=None*)

Create test image from S3

The input catalog was generated using the following query::

Database: s3_sex SQL: select * from Galaxies where (pow(10,itot_151)*1000 > 1.0) and

(right_ascension between -5 and 5) and (declination between -5 and 5);;

Number of rows returned: 29966

For frequencies < 610MHz, there are three tables to use:

```
data/models/S3_151MHz_10deg.csv, use fov=10
data/models/S3_151MHz_20deg.csv, use fov=20
data/models/S3_151MHz_40deg.csv, use fov=40
```

For frequencies > 610MHz, there are three tables:

data/models/S3_1400MHz_1mJy_10deg.csv, use flux_limit>= 1e-3 data/models/S3_1400MHz_100uJy_10deg.csv, use flux_limit < 1e-3 data/models/S3_1400MHz_10uJy_10deg.csv, use flux_limit < 1e-4 data/models/S3_1400MHz_1mJy_18deg.csv, use flux_limit>= 1e-3 data/models/S3_1400MHz_100uJy_18deg.csv, use flux_limit < 1e-3

The component spectral index is calculated from the 610MHz and 151MHz or 1400MHz and 610MHz, and then calculated for the specified frequencies.

If polarisation_frame is not stokesI then the image will a polarised axis

but the values will be zero.

Parameters

- **polarisation_frame** – Polarisation frame (default PolarisationFrame("stokesI"))
- **frequency** –
- **channel_bandwidth** – Channel width (Hz)
- **phasecentre** – phasecentre (SkyCoord)
- **fov** – fov 10 | 20 | 40
- **flux_limit** – Minimum flux (Jy)
- **radius** – radius of search area in radians (Default is half-width of the axis)

Returns

SkyComponents

create_unittest_components

create_unittest_components(*model*, *flux*, *applypb=False*, *telescope='LOW'*, *npixel=None*, *scale=1.0*, *single=False*, *symmetric=False*, *angular_scale=1.0*, *offset=[0.0, 0.0]*)

create_unittest_model

create_unittest_model(*vis*, *model_pol*, *npixel=None*, *cellsize=None*, *nchan=1*)

ingest_unittest_visibility

ingest_unittest_visibility(*config*, *frequency*, *channel_bandwidth*, *times*, *vis_pol*, *phasecentre*, *zerow=False*, *times_are_ha=True*)

Make a standard visibility simulation

Parameters

- **config** – Configuration
- **frequency** – Frequency (array in Hz)
- **channel_bandwidth** – Channel bandwidth (array in Hz)
- **times** – Times (radians, utc or hour angle depending on times_are_ha
- **vis_pol** – Polarisation frame
- **phasecentre** – Phase centre (SkyCoord)
- **zerow** – Zero the w terms?
- **times_are_ha** – Are the times hourangles or utc (in radians)

Returns

insert_unittest_errors

insert_unittest_errors(*vt*, *seed=1805550721*, *calibration_context='TG'*, *amp_errors=None*, *phase_errors=None*)

Simulate gain errors and apply

Parameters

- **vt** –
- **seed** – Random number seed, set to big integer repeat values from run to run
- **phase_errors** – e.g. {'T': 1.0, 'G': 0.1, 'B': 0.01}
- **amp_errors** – e.g. {'T': 0.0, 'G': 0.01, 'B': 0.01}

Returns

replicate_image

replicate_image(*im: ~ska_sdp_datamodels.image.image_model.Image*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.PolarisationFrame object>*, *frequency=array([1.e+08])*) → Image

Make a new canonical shape Image, extended along third and fourth axes by replication.

The order of the data is [chan, pol, dec, ra]

Parameters

- **frequency** –
- **im** –
- **polarisation_frame** – Polarisation_frame

Returns
Image

simulate_gaintable

simulate_gaintable(*gt: GainTable*, *phase_error=0.1*, *amplitude_error=0.0*, *smooth_channels=1*, *leakage=0.0*, *seed=180550721*, ***kwargs*) → GainTable

Simulate a gain table

Parameters

- **phase_error** – std of normal distribution, zero mean
- **amplitude_error** – std of log normal distribution
- **leakage** – std of cross hand leakage
- **smooth_channels** – Use bspline over smooth_channels
- **kwargs** –

Returns
Gaintable

Sky components

rascil.processing_components.skycomponent.plot_skycomponent Module

Functions to manage plotting skycomponents in comparisons.

Functions

plot_skycomponents_positions(comps_test[, ...])	Generate position scatter plot for two lists of skycomponents
plot_skycomponents_position_distance(...[, ...])	Generate position error plot vs distance for two lists of skycomponents
plot_skycomponents_flux(comps_test, comps_ref)	Generate flux scatter plot for two lists of skycomponents
plot_skycomponents_flux_ratio(comps_test, ...)	Generate flux ratio plot vs distance for two lists of skycomponents
plot_skycomponents_flux_histogram(...[, ...])	Generate flux ratio plot vs distance for two lists of skycomponents
plot_skycomponents_position_quiver(...[, ...])	Generate position error quiver diagram for two lists of skycomponents
plot_gaussian_beam_position(comps_test, ...)	Plot the major and minor size of beams for two lists of skycomponents :param comps_test: List of components to be tested :param comps_ref: List of reference components :param phasecentre: Centre of image in SkyCoords :param image: Image to fit the skycomponents :param num: Number of the brightest sources to plot :param plot_file: Filename of the plot :param tol: Tolerance in rad
plot_multifreq_spectral_index(comps_test, ...)	Generate spectral index plot for two lists of multi-frequency skycomponents

plot_skycomponents_positions

plot_skycomponents_positions(*comps_test*, *comps_ref=None*, *img_size=1.0*, *plot_file=None*, *tol=1e-05*, *plot_error=True*, ***kwargs*)

Generate position scatter plot for two lists of skycomponents

Parameters

- **comps_test** – List of components to be tested
- **img_size** – Cell size per pixel in the image to compare
- **comps_ref** – List of reference components
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad
- **plot_error** – If True, plot error, else just plot absolute values

Returns

[ra_error, dec_error]: The error array for users to check

plot_skycomponents_position_distance

plot_skycomponents_position_distance(*comps_test*, *comps_ref*, *phasecentre*, *img_size*, *plot_file=None*, *tol=1e-05*, ***kwargs*)

Generate position error plot vs distance for two lists of skycomponents

Parameters

- **comps_test** – List of components to be tested
- **comps_ref** – List of reference components
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad
- **phasecentre** – Centre of image in SkyCoords
- **img_size** – Cell size per pixel in the image to compare

Returns

[ra_error, dec_error]: The error array for users to check

plot_skycomponents_flux

plot_skycomponents_flux(*comps_test*, *comps_ref*, *plot_file=None*, *tol=1e-05*, *refchan=None*, ***kwargs*)

Generate flux scatter plot for two lists of skycomponents

Parameters

- **comps_test** – List of components to be tested
- **comps_ref** – List of reference components
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad
- **refchan** – Reference channel for comparison, default is centre channel

Returns

[flux_in, flux_out]: The flux array for users to check

plot_skycomponents_flux_ratio

plot_skycomponents_flux_ratio(*comps_test*, *comps_ref*, *phasecentre*, *plot_file=None*, *tol=1e-05*, *refchan=None*, *max_ratio=2*, ***kwargs*)

Generate flux ratio plot vs distance for two lists of skycomponents

Parameters

- **comps_test** – List of components to be tested
- **comps_ref** – List of reference components
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad
- **phasecentre** – Centre of image in SkyCoords
- **refchan** – Reference channel for comparison, default is centre channel

- **max_ratio** – Maximum ratio to plot (default is 2.0)

Returns
[dist, flux_ratio]: The flux array for users to check

plot_skycomponents_flux_histogram

plot_skycomponents_flux_histogram(*comps_test*, *comps_ref*, *plot_file=None*, *nbins=10*, *tol=1e-05*, *refchan=None*, ***kwargs*)

Generate flux ratio plot vs distance for two lists of skycomponents

Parameters

- **comps_test** – List of components to be tested
- **comps_ref** – List of reference components
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad
- **nbins** – Number of bins for the histrogram
- **refchan** – Reference channel for comparison, default is centre channel

Returns
hist: The flux array for users to check

plot_skycomponents_position_quiver

plot_skycomponents_position_quiver(*comps_test*, *comps_ref*, *phasecentre*, *num=100*, *plot_file=None*, *tol=1e-05*, ***kwargs*)

Generate position error quiver diagram for two lists of skycomponents

Parameters

- **comps_test** – List of components to be tested
- **comps_ref** – List of reference components
- **phasecentre** – Centre of image in SkyCoords
- **num** – Number of the brightest sources to plot
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad

Returns
[ra_error, dec_error]: The error array for users to check

plot_gaussian_beam_position

plot_gaussian_beam_position(*comps_test*, *comps_ref*, *phasecentre*, *image*, *num=100*, *plot_file=None*, *tol=1e-05*, ***kwargs*)

Plot the major and minor size of beams for two lists of skycomponents :param comps_test: List of components to be tested :param comps_ref: List of reference components :param phasecentre: Centre of image in SkyCoords :param image: Image to fit the skycomponents :param num: Number of the brightest sources to plot :param plot_file: Filename of the plot :param tol: Tolerance in rad

Returns

[bmaj, bmin]: The beam parameters for users to check

plot_multifreq_spectral_index

plot_multifreq_spectral_index(*comps_test*, *comps_ref*, *phasecentre*, *plot_file=None*, *tol=1e-05*, *flux_limit=0.0*, *spec_indx_test=None*, *spec_indx_ref=None*, *plot_diagnostics=False*, ***kwargs*)

Generate spectral index plot for two lists of multi-frequency skycomponents

Parameters

- **comps_test** – List of components to be tested
- **comps_ref** – List of reference components
- **phasecentre** – Centre of image in SkyCoords
- **plot_file** – Filename of the plot
- **tol** – Tolerance in rad
- **flux_limit** – Cutoff for plot (only components with central flux larger than this are plotted)
- **spec_indx_test** – Spectral index of comps_test if provided (if None, fit from components)
- **spec_indx_ref** – Spectral index of comps_ref if provided (if None, fit from components)
- **plot_diagnostics** – Whether to plot diagnostics plot (flux in vs. spectral index out)

Returns

[spec_in, spec_out]: The spectral index array for users to check

Sky models

rascil.processing_components.skymodel.operations Module

Function to manage skymodels.

Functions

partition_skymodel_by_flux(sc, model[, ...])	Partition skymodel according to flux
show_skymodel(sms[, psf_width, cm, vmax, vmin])	Show a list of SkyModels
initialize_skymodel_voronoi(model, comps[, gt])	Create a skymodel by Voronoi partitioning of the components, fill with components
calculate_skymodel_equivalent_image(sm)	Calculate an equivalent image for a skymodel
update_skymodel_from_gaintables(sm, gt_list)	Update a skymodel from a list of gaintables
update_skymodel_from_image(sm, im[, damping])	Update a skymodel for an image, applying damping factor
expand_skymodel_by_skycomponents(sm, **kwargs)	Expand a sky model so that all components and the image are in separate skymodels
create_skymodel_from_skycomponents_gaintable	Create a list of sky model from lists of components and gaintables
extract_skycomponents_from_skymodel(sm[, im])	Extract the bright components from the image in a skymodel

partition_skymodel_by_flux

partition_skymodel_by_flux(*sc*, *model*, *flux_threshold=-inf*)

Partition skymodel according to flux

Bright skycomponents are put into a SkyModel as a list, and weak skycomponents are inserted into SkyModel as an image.

Parameters

- **sc** – List of skycomponents
- **model** – Model image
- **flux_threshold** –

Returns
SkyModel

For example:

```
fluxes = numpy.linspace(0, 1.0, 11)
sc = [create_skycomponent(direction=phasecentre, flux=numpy.array([[f]]),␣
↪frequency=frequency,
                          polarisation_frame=PolarisationFrame('stokesI')) for f in␣
↪fluxes]

sm = partition_skymodel_by_flux(sc, model, flux_threshold=0.31)
assert len(sm.components) == 7, len(sm.components)
```

show_skymodel

show_skymodel(*sms*, *psf_width=1.75*, *cm='Greys'*, *vmax=None*, *vmin=None*)

Show a list of SkyModels

Parameters

- **sms** – List of SkyModels
- **psf_width** – Width of PSF in pixels
- **cm** – matplotlib colormap
- **vmax** – Maximum in image display
- **vmin** – Minimum in image display

Returns

initialize_skymodel_voronoi

initialize_skymodel_voronoi(*model*, *comps*, *gt=None*)

Create a skymodel by Voronoi partitioning of the components, fill with components

Parameters

- **model** – Model image
- **comps** – SkyComponents
- **gt** – Gaintable

Returns

calculate_skymodel_equivalent_image

calculate_skymodel_equivalent_image(*sm*)

Calculate an equivalent image for a skymodel

Uses the image from the first skymodel as the template for the image

Parameters
sm – List of skymodels

Returns
Image

update_skymodel_from_gaintables

update_skymodel_from_gaintables(*sm*, *gt_list*, *calibration_context='T'*, *damping=0.5*)

Update a skymodel from a list of gaintables

Parameters

- **sm** – List of skymodels
- **gt_list** – List of gain tables
- **calibration_context** – Type of gaintable e.g. 'T', 'G'

Returns
List of skymodels

update_skymodel_from_image

`update_skymodel_from_image`(*sm*, *im*, *damping=0.5*)

Update a skymodel for an image, applying damping factor

Parameters

- **sm** – List of skymodels
- **im** – Image

Returns
List of SkyModels

expand_skymodel_by_skycomponents

`expand_skymodel_by_skycomponents`(*sm*, ***kwargs*)

Expand a sky model so that all components and the image are in separate skymodels

The mask and gaintable are taken to apply for all new skymodels.

Parameters
sm – SkyModel

Returns
List of SkyModels

create_skymodel_from_skycomponents_gaintables

`create_skymodel_from_skycomponents_gaintables`(*components*, *gaintables*, ***kwargs*)

Create a list of sky model from lists of components and gaintables

Parameters
sm – SkyModel

Returns
List of SkyModels

extract_skycomponents_from_skymodel

`extract_skycomponents_from_skymodel`(*sm*, *im=None*, ***kwargs*)

Extract the bright components from the image in a skymodel

This produces one component per frequency channel

Parameters

- **sm** – skymodel
- **im** – image to be searched
- **kwargs** – Parameters for functions
- **component_threshold** – (in kwargs) Threshold in Jy to be classified as a source

- **component_method** – (in kwargs) Method to extract skycomponents: fit

Returns
Updated skymodel

Utility

rascil.processing_components.util.compass_bearing Module

Functions

calculate_initial_compass_bearing(pointA, pointB)	Calculates the bearing between two points.

calculate_initial_compass_bearing

calculate_initial_compass_bearing(*pointA*, *pointB*)

Calculates the bearing between two points.

The formulae used is the following:

= atan2(sin(long).cos(lat2),
cos(lat1).sin(lat2) sin(lat1).cos(lat2).cos(long))

Parameters

- **pointA** – The tuple representing the latitude/longitude for the first point. Latitude and longitude must be in decimal degrees
- **pointB** – The tuple representing the latitude/longitude for the second point. Latitude and longitude must be in decimal degrees

Returns
The bearing in degrees

Returns Type
float

rascil.processing_components.util.installation_checks Module

Function to check the installation

Functions

check_data_directory([verbose, fatal])	Check the RASCIL data directory to see if it has been installed correctly

check_data_directory

check_data_directory(*verbose=False*, *fatal=True*)

Check the RASCIL data directory to see if it has been installed correctly

rascil.processing_components.util.performance Module

Functions for monitoring performance

These functions can be used to write various configuration and performance information to JSON files for subsequent analysis. These are intended to be used by apps such as rascil-imager:

```
parser = cli_parser()
args = parser.parse_args()
performance_environment(args.performance_file, mode="w")
performance_store_dict(args.performance_file, "cli_args", vars(args), mode="a")
performance_store_dict(args.performance_file, "dask_profile", dask_info, mode="a")
performance_dask_configuration(args.performance_file, mode='a')
```

Functions

git_hash()	Get the hash for this git repository.
performance_store_dict(performance_file, key, s)	Store dictionary in a file using json
performance_qa_image(performance_file, key, im)	Store image qa in a performance file
performance_dask_configuration(...[, ...])	Get selected Dask configuration info and write to performance file
performance_read(performance_file)	Read the performance file
performance_environment(performance_file[, ...])	Write the current processing environment to JSON file
performance_read_memory_data(memory_file)	Get the memusage data.
performance_merge_memory(performance, mem)	Merge memory data per function into performance data

git_hash

git_hash()

Get the hash for this git repository.

Requires that the code tree was created using git

Returns
string or "unknown"

performance_store_dict

performance_store_dict(*performance_file*, *key*, *s*, *indent=2*, *mode='a'*)

Store dictionary in a file using json

Parameters

- **performance_file** – The (JSON) file to which the environment is to be written
- **key** – Key to use for the configuration info e.g. "restored"
- **s** – dictionary to be written
- **indent** – Number of characters indent in performance file
- **mode** – Writing mode: 'w' or 'a' for write and append

performance_qa_image

performance_qa_image(*performance_file*, *key*, *im*, *indent=2*, *mode='a'*)

Store image qa in a performance file

Parameters

- **performance_file** – The (JSON) file to which the environment is to be written
- **key** – Key to use for the configuration info e.g. "restored"
- **im** – Image for which qa is to be calculated and written
- **indent** – Number of characters indent in performance file
- **mode** – Writing mode: 'w' or 'a' for write and append

performance_dask_configuration

performance_dask_configuration(*performance_file*, *rsexec*, *indent=2*, *mode='a'*)

Get selected Dask configuration info and write to performance file

Parameters

- **performance_file** – The (JSON) file to which the environment is to be written
- **rsexec** – rsexecute passed in to avoid dependency
- **indent** – Number of characters indent in performance file
- **mode** – Writing mode: 'w' or 'a' for write and append

performance_read

performance_read(*performance_file*)

Read the performance file

Parameters
performance_file –

Returns
Dictionary

performance_environment

performance_environment(*performance_file*, *indent=2*, *mode='a'*)

Write the current processing environment to JSON file

Parameters

- **performance_file** – The (JSON) file to which the environment is to be written
- **indent** – Number of characters indent in performance file
- **mode** – Writing mode: 'w' or 'a' for write and append

performance_read_memory_data

performance_read_memory_data(*memory_file*)

Get the memusage data.

An example of the csv file: task_key,min_memory_mb,max_memory_mb create_visibility_from_ms-6d4df60d-244b-4a45-8dca-a7d96b676455,219.80859375,7651.37109375 getitem-ab6cb10a048f6d5efce69194feafa125,0,0 performance_visibility-2dfe2b3a-e160-4724-a5e6-aed82bf0721c,0,0 create_visibility_from_ms-724c98e9-279b-44ef-92d6-06e689b037a2,223.72265625,7642.13671875

The task_key is split into task and key. The memory values are converted to GB.

Parameters

memory_file – Dictionary containing sequences of maximum and minimum memory for each function sampled

Returns

performance_merge_memory

performance_merge_memory(*performance*, *mem*)

Merge memory data per function into performance data

The memory usage information comes from the optional use of the dask-memusage scheduler plugin

Parameters

- **performance** – Performance data dictionary
- **mem** – Memory data dictionary

Returns

Visibility

rascil.processing_components.visibility.base Module

Base functions to create and export Visibility from UVFits files.

Functions

create_visibility_from_uvfits(fitsname[, ...])	Minimal UVFIT to Visibility converter
generate_baselines(nant)	Generate mapping from antennas to baselines Note that we need to include auto-correlations since some input measurement sets may contain auto-correlations

create_visibility_from_uvfits

create_visibility_from_uvfits(*fitsname*, *channum=None*, *antnum=None*)

Minimal UVFIT to Visibility converter

The UVFITS format is much more general than the RASCIL Visibility so we cut many corners.

Creates a list of Visibility's, split by field and spectral window

Parameters

- **fitsname** – File name of UVFITS
- **channum** – range of channels e.g. range(17,32), default is None meaning all
- **antnum** – the number of antenna

Returns

rascil.processing_components.visibility.visibility_fitting Module

Visibility fitting

Functions

fit_visibility(vis, sc[, tol, niter, ...])	Fit a single component to a visibility

fit_visibility

fit_visibility(*vis*, *sc*, *tol=1e-06*, *niter=20*, *verbose=False*, *method='trust-exact'*, ***kwargs*)

Fit a single component to a visibility

Uses the scipy.optimize.minimize function.

Parameters

- **vis** – visibility
- **sc** – Initial component
- **tol** – Tolerance of fit
- **niter** – Number of iterations
- **verbose** –

- **method** – 'CG', 'BFGS', 'Powell', 'trust-ncg', 'trust-exact', 'trust-krylov': default 'trust-exact'
- **kwargs** –

Returns
SkyComponent, convergence info as a dictionary

Parameters

rascil.processing_components.parameters Module

We use the standard kwargs mechanism for arguments. For example:

```
kernelname = get_parameter(kwargs, "kernel", "2d")
oversampling = get_parameter(kwargs, "oversampling", 8)
padding = get_parameter(kwargs, "padding", 2)
```

The kwargs may need to be passed down to called functions.

All functions possess an API which is always of the form:

```
def processing_function(idatastruct1, idatastruct2, ..., *kwargs):
   return odatastruct1, odatastruct2,... other
```

Processing parameters are passed via the standard Python kwargs approach.

Inside a function, the values are retrieved can be accessed directly from the kwargs dictionary, or if a default is needed a function can be used:

```
log = get_parameter(kwargs, 'log', None)
vis = get_parameter(kwargs, 'visibility', None)
```

Function parameters should obey a consistent naming convention:

Name	Meaning
vis	Name of Visibility
sc	Name of SkyComponent
gt	Name of GainTable
conf	Name of Configuration
im	Name of input image
qa	Name of quality assessment
log	Name of processing log

If a function argument has a better, more descriptive name e.g. normalised_gt, newphasecentre, use it.

Keyword=value pairs should have descriptive names. The names should be lower case with underscores to separate words:

Name	Meaning	Example
loop_gain	Clean loop gain	0.1
niter	Number of iterations	10000
eps	Fractional tolerance	1e-6
threshold	Absolute threshold	0.001
fractional_threshold	Threshold as fraction of e.g. peak	0.1
G_solution_interval	Solution interval for G term	100
phaseonly	Do phase-only solutions	True
phasecentre	Phase centre (usually as SkyCoord)	**SkyCoord("-1.0d", "37.0d",** frame='icrs', equinox='J2000')
spectral_mode	Visibility processing mode	'mfs' or 'channel'

Functions

rascil_path(path)	Converts a path that might be relative to RASCIL root into an absolute path.
rascil_data_path(path[, check])	Converts a path that might be relative to the RASCIL data directory into an absolute path.
get_parameter(kwargs, key[, default])	Get a specified named value for this (calling) function

rascil_path

rascil_path(*path*)

Converts a path that might be relative to RASCIL root into an absolute path:

```
rascil_data_path('models/SKA1_LOW_beam.fits')
'/Users/timcornwell/Code/rascil/data/models/SKA1_LOW_beam.fits'
```

Parameters
path –

Returns
absolute path

rascil_data_path

rascil_data_path(*path*, *check=True*)

Converts a path that might be relative to the RASCIL data directory into an absolute path:

```
rascil_data_path('models/SKA1_LOW_beam.fits')
'/Users/timcornwell/Code/rascil/data/models/SKA1_LOW_beam.fits'
```

The data path default is rascil_path('data') but may be overriden with the environment variable RASCIL_DATA.

Parameters

- **check** – Check path exists
- **path** –

Returns
absolute path

get_parameter

get_parameter(*kwargs*, *key*, *default=None*)

Get a specified named value for this (calling) function

The parameter is searched for in kwargs

Parameters

- **kwargs** – Parameter dictionary
- **key** – Key e.g. 'loop_gain'
- **default** – Default value

Returns
result

1.4.2 Workflows

Workflows are higher level functions that make use of the processing components, and processing library, operating on data models.

rsexecute

rsexecute workflows can be used in two modes

- delayed using Dask.delayed
- serially executed immediately on definition,

Distribution is acheived by working on lists of data models, such as lists of BlockVisibilities.

For example:

```
from rascil.workflows import continuum_imaging_list_rsexecute_workflow, rsexecute
rsexecute.set_client(use_dask=True, threads_per_worker=1,
    memory_limit=32 * 1024 * 1024 * 1024, n_workers=8,
    local_dir=dask_dir, verbose=True)
continuum_imaging_list = continuum_imaging_list_rsexecute_workflow(vis_list,
    model_imagelist=model_list,
    context='wstack', vis_slices=51,
    scales=[0, 3, 10], algorithm='mmclean',
    nmoment=3, niter=1000,
    fractional_threshold=0.1, threshold=0.1,
    nmajor=5, gain=0.25,
    psf_support=64)

deconvolved_list, residual_list, restored_list = rsexecute.compute(continuum_imaging_
```

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```
↪list,
    sync=True)
```

The call to continuum_imaging_list_rsexecute_workflow does not execute immediately just generates a Dask.delayed object that can be computed subsequently. The higher level functions such as continuum_imaging_list_rsexecute_workflow are built from lower level functions such as invert_list_rsexecute_workflow.

In this example, changing use_dask to False will cause the definitions to be executed immediately.

The rsexecute framework relies upon a singleton object called rsexecute. This is documented below as the class _rsexecutebase.

rascil.workflows.rsexecute.calibration Package

Workflows for calibration

Functions

calibrate_list_rsexecute_workflow(vis_list, ...)	Create a set of components for (optionally global) calibration of a list of visibilities

calibrate_list_rsexecute_workflow

calibrate_list_rsexecute_workflow(*vis_list*, *model_vislist*, *gt_list=None*, *calibration_context='TG'*, *controls=None*, *global_solution=True*, ***kwargs*)

Create a set of components for (optionally global) calibration of a list of visibilities

If global solution is true then visibilities are gathered to a single visibility data set which is then self-calibrated. The resulting gaintable is then effectively scattered out for application to each visibility set. If global solution is false then the solutions are performed locally.

Parameters

- **vis_list** – list of visibilities (or graph)
- **model_vislist** – list of model visibilities (or graph)
- **calibration_context** – String giving terms to be calibrated e.g. 'TGB'
- **controls** – Calibration controls dictionary
- **global_solution** – Solve for global gains
- **kwargs** – Parameters for functions in components

Returns

list of calibrated vis, list of dictionaries of gaintables

rascil.workflows.rsexecute.image Package

Workflows for operating on images

Functions

image_gather_channels_rsexecute(image_list)	Gather a set of images in frequency, using a tree reduction or directly
image_rsexecute_map_workflow(im, imfunction)	Apply a function across an image: scattering to subimages, applying the function, and then gathering
sum_images_rsexecute(image_list[, split])	Sum a set of images, using a tree reduction

image_gather_channels_rsexecute

image_gather_channels_rsexecute(*image_list*, *split=0*)

Gather a set of images in frequency, using a tree reduction or directly

Parameters

- **image_list** – List of images
- **split** – Order of split i.e. 2 is binary, 0 is list

Returns

graph for summed image

image_rsexecute_map_workflow

image_rsexecute_map_workflow(*im*, *imfunction*, *facets=1*, *overlap=0*, *taper=None*, ***kwargs*)

Apply a function across an image: scattering to subimages, applying the function, and then gathering

Parameters

- **im** – Image to be processed
- **imfunction** – Function to be applied
- **facets** – See image_scatter_facets
- **overlap** – image_scatter_facets
- **taper** – image_scatter_facets
- **kwargs** – kwargs for imfunction

Returns

graph for output image

For example:

```
rsexecute.set_client(use_dask=True)
model = create_test_image(frequency=frequency, phasecentre=phasecentre, cellsize=0.
↪001,
                                  polarisation_frame=PolarisationFrame('stokesI'))
def imagerooter(im, **kwargs):
```

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```
    im["pixels"].data = numpy.sqrt(numpy.abs(im["pixels"].data))
    return im
root_graph = image_rsexecute_map_workflow(model, imagerooter, facets=16)
root_image = rsexecute.compute(root_graph, sync=True)
```

sum_images_rsexecute

sum_images_rsexecute(*image_list*, *split=2*)

Sum a set of images, using a tree reduction

Parameters
image_list – List of images

Returns
graph for summed image

rascil.workflows.rsexecute.imaging Package

Functions

deconvolve_list_channel_rsexecute_workflow(..	Create a graph for deconvolution by channels, adding to the model
deconvolve_list_rsexecute_workflow(...[, ...])	Create a graph for deconvolution, adding to the model
invert_list_rsexecute_workflow(vis_list, ...)	Sum results from invert, iterating over the scattered image and vis_list
predict_list_rsexecute_workflow(vis_list, ...)	Predict, iterating over both the scattered vis_list and image
residual_list_rsexecute_workflow(vis, ...[, ...])	Create a graph to calculate (list or graph) of residual images
restore_centre_rsexecute_workflow(...[, ...])	Create a graph to calculate the restored image
restore_list_rsexecute_workflow(...[, ...])	Create a graph to calculate the restored image
subtract_list_rsexecute_workflow(vis_list, ...)	Initialise vis to zero
sum_invert_results_rsexecute(image_list)	Sum a set of invert results with appropriate weighting
sum_predict_results_rsexecute(bvis_list[, split])	Sum a set of predict results
taper_list_rsexecute_workflow(vis_list, ...)	Taper to desired size
threshold_list_rsexecute(imagelist[, prefix])	Find actual threshold for list of results
weight_list_rsexecute_workflow(vis_list, ...)	Weight the visibility data
zero_list_rsexecute_workflow(vis_list[, copy])	Creates a new vis_list and initialises all to zero

deconvolve_list_channel_rsexecute_workflow

deconvolve_list_channel_rsexecute_workflow(*dirty_list*, *psf_list*, *model_imagelist*, *subimages*, ***kwargs*)

Create a graph for deconvolution by channels, adding to the model

Does deconvolution channel by channel.

Parameters

- **dirty_list** – list or graph of dirty images
- **psf_list** – list or graph of psf images. The psfs must be the size of a facet
- **model_imagelist** – list of graph of models
- **subimages** – Number of channels to split into
- **kwargs** – Parameters for functions in components

Returns
list of updated models (or graphs)

deconvolve_list_rsexecute_workflow

deconvolve_list_rsexecute_workflow(*dirty_list*, *psf_list*, *model_imagelist*, *sensitivity_list=None*, *prefix=''*, *mask=None*, ***kwargs*)

Create a graph for deconvolution, adding to the model

note dirty_list and psf_list must have sumwt trimmed before calling this function

Parameters

- **dirty_list** – list of dirty images (or graph)
- **psf_list** – list of psfs (or graph)
- **model_imagelist** – list of models (or graph)
- **prefix** – Informative prefix to log messages
- **mask** – Mask for deconvolution
- **kwargs** – Parameters for functions

Returns
graph for the deconvolution

For example:

```
dirty_imagelist = invert_list_rsexecute_workflow(vis_list, model_imagelist, context=
↪'2d',
                                                 dopsf=False, normalise=True)
psf_imagelist = invert_list_rsexecute_workflow(vis_list, model_imagelist, context=
↪'2d',
                                               dopsf=True, normalise=True)
dirty_imagelist = rsexecute.persist(dirty_imagelist)
psf_imagelist = rsexecute.persist(psf_imagelist)
dec_imagelist = deconvolve_list_rsexecute_workflow(dirty_imagelist, psf_imagelist,
        model_imagelist, niter=1000, fractional_threshold=0.01,
        scales=[0, 3, 10], algorithm='mmclean', nmoment=3, nchan=freqwin,
```

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```
        threshold=0.1, gain=0.7)
dec_imagelist = rsexecute.persist(dec_imagelist)
```

invert_list_rsexecute_workflow

invert_list_rsexecute_workflow(*vis_list*, *template_model_imagelist*, *context*, *dopsf=False*, *normalise=True*, ***kwargs*)

Sum results from invert, iterating over the scattered image and vis_list

Parameters

- **vis_list** – list of vis (or graph)
- **template_model_imagelist** – list of template models (or graph)
- **dopsf** – Make the PSF instead of the dirty image
- **normalise** – normalise by sumwt
- **context** – Imaging context
- **kwargs** – Parameters for functions in components

Returns

List of (image, sumwt) tuples, one per vis in vis_list

For example:

```
model_list = [rsexecute.execute(create_image_from_visibility)
    (v, npixel=npixel, cellsize=cellsize, polarisation_frame=pol_frame)
    for v in vis_list]

model_list = rsexecute.persist(model_list)
dirty_list = invert_list_rsexecute_workflow(vis_list, template_model_
↪imagelist=model_list, context='wstack',
                                            vis_slices=51)
dirty_sumwt_list = rsexecute.compute(dirty_list, sync=True)
dirty, sumwt = dirty_sumwt_list[centre]
```

predict_list_rsexecute_workflow

predict_list_rsexecute_workflow(*vis_list*, *model_imagelist*, *context*, ***kwargs*)

Predict, iterating over both the scattered vis_list and image

The visibility and image are scattered, the visibility is predicted on each part, and then the parts are assembled.

Parameters

- **vis_list** – list of vis (or graph)
- **model_imagelist** – list of models (or graph)
- **context** – Type of processing e.g. 2d, ng
- **kwargs** – Parameters for functions in components

Returns
List of vis_lists

For example:

```
dprepb_model = [rsexecute.execute(create_low_test_image_from_gleam)
    (npixel=npixel, frequency=[frequency[f]], channel_bandwidth=[channel_
↪bandwidth[f]],
    cellsize=cellsize, phasecentre=phasecentre, polarisation_
↪frame=PolarisationFrame("stokesI"),
    flux_limit=3.0, applybeam=True)
    for f, freq in enumerate(frequency)]

dprepb_model_list = rsexecute.persist(dprepb_model_list)
predicted_vis_list = predict_list_rsexecute_workflow(vis_list, model_
↪imagelist=dprepb_model_list,
    context='wstack', vis_slices=51)
predicted_vis_list = rsexecute.compute(predicted_vis_list , sync=True)
```

residual_list_rsexecute_workflow

residual_list_rsexecute_workflow(*vis*, *model_imagelist*, *context='2d'*, ***kwargs*)

Create a graph to calculate (list or graph) of residual images

Parameters

- **vis** – List of vis (or graph)
- **model_imagelist** – Model used to determine image parameters
- **context** – Imaging context e.g. '2d', 'ng'
- **kwargs** – Parameters for functions in components

Returns
list of (image, sumwt) tuples or graph

restore_centre_rsexecute_workflow

restore_centre_rsexecute_workflow(*model_imagelist*, *psf_imagelist*, *residual_imagelist=None*, ***kwargs*)

Create a graph to calculate the restored image

This does the following: - Takes the centre frequency slice of the model - Integrates the residual across the band - Fits to the band-integrated PSF - Restores the model, clean_beam, and residual

This will not give any information on the spectral behaviour, use residual_list_rsexecute_workflow for that purpose.

Parameters

- **model_imagelist** – Model list (or graph)
- **psf_imagelist** – PSF list (or graph)
- **residual_imagelist** – Residual list (or graph)
- **kwargs** – Parameters for functions in components

Returns
list of restored images (or graphs)

restore_list_rsexecute_workflow

restore_list_rsexecute_workflow(*model_imagelist*, *psf_imagelist*, *residual_imagelist=None*, *restore_facets=1*, *restore_overlap=8*, *restore_taper='tukey'*, *clean_beam=None*, ***kwargs*)

Create a graph to calculate the restored image

Parameters

- **model_imagelist** – Model list (or graph)
- **psf_imagelist** – PSF list (or graph)
- **residual_imagelist** – Residual list (or graph)
- **kwargs** – Parameters for functions in components
- **restore_facets** – Number of facets used per axis (used to distribute)
- **restore_overlap** – Overlap in pixels (0 is best)
- **restore_taper** – Type of taper between facets

Returns
list of restored images (or graph)

subtract_list_rsexecute_workflow

subtract_list_rsexecute_workflow(*vis_list*, *model_vislist*)

Initialise vis to zero

Parameters

- **vis_list** – List of vis (or graph)
- **model_vislist** – Model to be subtracted (or graph)

Returns
List of vis or graph

sum_invert_results_rsexecute

sum_invert_results_rsexecute(*image_list*)

Sum a set of invert results with appropriate weighting

Note that in the case of a single element of image_list a copy is made

Parameters
image_list – List of (image, sum weights) tuples

Returns
image, sum of weights

sum_predict_results_rsexecute

sum_predict_results_rsexecute(*bvis_list*, *split=2*)

Sum a set of predict results

Parameters

- **bvis_list** – List of (image, sum weights) tuples
- **split** – Split into

Returns

BlockVis

taper_list_rsexecute_workflow

taper_list_rsexecute_workflow(*vis_list*, *size_required*)

Taper to desired size

Parameters

- **vis_list** – List of vis (or graph)
- **size_required** – Size in radians

Returns

List of vis (or graph)

threshold_list_rsexecute

threshold_list_rsexecute(*imagelist*, *prefix=''*, ***kwargs*)

Find actual threshold for list of results

Parameters

- **prefix** – Prefix in log messages
- **imagelist** – List of images

Returns

weight_list_rsexecute_workflow

weight_list_rsexecute_workflow(*vis_list*, *model_imagelist*, *weighting='uniform'*, *robustness=0.0*, ***kwargs*)

Weight the visibility data

This is done collectively so the weights are summed over all vis_lists and then corrected

Parameters

- **vis_list** –
- **model_imagelist** – Model required to determine weighting parameters
- **weighting** – Type of weighting
- **kwargs** – Parameters for functions in graphs

Returns
List of vis_graphs

For example:

```
vis_list = weight_list_rsexecute_workflow(vis_list, model_list, weighting='uniform')
```

zero_list_rsexecute_workflow

zero_list_rsexecute_workflow(*vis_list*, *copy=True*)

Creates a new vis_list and initialises all to zero

Parameters

- **vis_list** – List of vis (or graph)
- **copy** – Make a new copy?

Returns
List of vis (or graph)

rascil.workflows.rsexecute.pipelines Package

Functions

continuum_imaging_skymodel_list_rsexecute_w	Create graph for the continuum imaging pipeline.
ical_skymodel_list_rsexecute_workflow(...[, ...])	Create graph for ICAL pipeline using SkyModel
spectral_line_imaging_skymodel_list_rsexecu	Create graph for spectral line imaging pipeline

continuum_imaging_skymodel_list_rsexecute_workflow

continuum_imaging_skymodel_list_rsexecute_workflow(*vis_list*, *model_imagelist*, *context*, *skymodel_list=None*, ***kwargs*)

Create graph for the continuum imaging pipeline.

Same as ICAL but with no selfcal.

Parameters

- **vis_list** – List of vis (or graph)
- **model_imagelist** – List of models (or graph)
- **skymodel_list** – list of SkyModels
- **context** – Imaging context
- **skymodel_list** – list of SkyModels
- **kwargs** – Parameters for functions in components

Returns

ical_skymodel_list_rsexecute_workflow

ical_skymodel_list_rsexecute_workflow(*vis_list*, *model_imagelist*, *context*, *skymodel_list=None*, *calibration_context='TG'*, *controls=None*, *do_selfcal=True*, *pipeline_name='ical'*, ***kwargs*)

Create graph for ICAL pipeline using SkyModel

Parameters

- **vis_list** – List of vis (or graph)
- **model_imagelist** – list of models (or graph)
- **skymodel_list** – list of SkyModels
- **context** – imaging context e.g. '2d'
- **calibration_context** – Sequence of calibration steps e.g. TGB
- **do_selfcal** – Do the selfcalibration?
- **perform_flagging** – Run flagging strategy
- **kwargs** – Parameters for functions in components

Returns

spectral_line_imaging_skymodel_list_rsexecute_workflow

spectral_line_imaging_skymodel_list_rsexecute_workflow(*vis_list*, *model_imagelist*, *context*, *continuum_model_imagelist=None*, ***kwargs*)

Create graph for spectral line imaging pipeline

Uses the continuum imaging rsexecute pipeline after subtraction of a continuum model

Parameters

- **vis_list** – List of vis (or graph)
- **model_imagelist** – List of Spectral line model (or graph)
- **continuum_model_imagelist** – Continuum model list (or graph)
- **context** – Imaging context e.g. ng or 2d
- **kwargs** – Parameters for functions in components

Returns

list of (deconvolved model, residual, restored) or graph

rascil.workflows.rsexecute.simulation Package

Functions

corrupt_list_rsexecute_workflow(vis_list[, ...])	Create a graph to apply gain errors to a vis_list
create_atmospheric_errors_gaintable_rsexecut	Create gaintable for atmospheric errors
create_heterogeneous_gaintable_rsexecute_wo	Create gaintable for polarisation effects
create_pointing_errors_gaintable_rsexecute_v	Create gaintable for pointing errors
create_polarisation_gaintable_rsexecute_work	Create gaintable for polarisation effects
create_standard_low_simulation_rsexecute_wo	Create the standard LOW simulation
create_standard_mid_simulation_rsexecute_wo	Create the standard MID simulation
create_surface_errors_gaintable_rsexecute_w	Create gaintable for surface errors :param band: B1, B2 or Ku :param sub_bvis_list: List of vis (or graph) :param sub_components: List of components (or graph) :param vp_directory: Location of voltage patterns :param elevation_sampling: Sampling in elevation (degrees) :return: (list of error-free gaintables, list of error gaintables) or graph
create_voltage_pattern_gaintable_rsexecute_v	Create gaintable for nominal voltage pattern
simulate_list_rsexecute_workflow([config, ...])	A component to simulate an observation

corrupt_list_rsexecute_workflow

corrupt_list_rsexecute_workflow(*vis_list*, *gt_list=None*, *jones_type='T'*, ***kwargs*)

Create a graph to apply gain errors to a vis_list

Parameters

- **vis_list** – List of vis (or graph)
- **gt_list** – Optional gain table graph
- **jones_type** – Type of calibration matrix T or G or B
- **kwargs** –

Returns

list of vis (or graph)

create_atmospheric_errors_gaintable_rsexecute_workflow

create_atmospheric_errors_gaintable_rsexecute_workflow(*sub_bvis_list*, *sub_components*, *r0=5000.0*, *screen=None*, *height=300000.0*, *type_atmosphere='iono'*, *reference_component=None*, *jones_type='B'*, ***kwargs*)

Create gaintable for atmospheric errors

Parameters

- **sub_bvis_list** – List of vis (or graph)
- **sub_components** – List of components (or graph)

- **r0** – r0 in m
- **screen** –
- **height** – Height (in m) of screen above telescope e.g. 3e5
- **type_atmosphere** – 'ionosphere' or 'troposhere'
- **jones_type** – Type of calibration matrix T or G or B

Returns
(list of error-free gaintables, list of error gaintables) or graph

create_heterogeneous_gaintable_rsexecute_workflow

create_heterogeneous_gaintable_rsexecute_workflow(*band*, *sub_bvis_list*, *sub_components*, *get_vp*, *default_vp='MID'*)

Create gaintable for polarisation effects

Compare with nominal and actual voltage patterns

Parameters

- **band** – B1, B2 or Ku
- **sub_bvis_list** – List of vis (or graph)
- **sub_components** – List of components (or graph)

Returns
(list of error-free gaintables, list of error gaintables) or graph

create_pointing_errors_gaintable_rsexecute_workflow

create_pointing_errors_gaintable_rsexecute_workflow(*sub_bvis_list*, *sub_components*, *sub_vp_list*, *pointing_error=0.0*, *static_pointing_error=None*, *global_pointing_error=None*, *time_series=''*, *time_series_type=''*, *seed=None*, *pointing_directory=None*)

Create gaintable for pointing errors

Parameters

- **sub_bvis_list** – List of vis (or graph)
- **sub_components** – List of components (or graph)
- **sub_vp_list** – List of model voltage patterns (or graph)
- **pointing_error** – rms pointing error
- **static_pointing_error** – static pointing error
- **global_pointing_error** – global pointing error
- **time_series** – Time series PSD file
- **time_series_type** – Type of time series 'wind'|"
- **seed** – Random number seed

- **pointing_directory** – Location of pointing files

Returns
(list of error-free gaintables, list of error gaintables) or graph

create_polarisation_gaintable_rsexecute_workflow

create_polarisation_gaintable_rsexecute_workflow(*band*, *sub_bvis_list*, *sub_components*, *get_vp*, *normalise=True*)

Create gaintable for polarisation effects

Compare with nominal and actual voltage patterns

Parameters

- **band** – B1, B2 or Ku
- **sub_bvis_list** – List of vis (or graph)
- **sub_components** – List of components (or graph)
- **normalise** – Normalise peak of each receptor

Returns
(list of error-free gaintables, list of error gaintables) or graph

create_standard_low_simulation_rsexecute_workflow

create_standard_low_simulation_rsexecute_workflow(*band*, *rmax*, *phasecentre*, *time_range*, *time_chunk*, *integration_time*, *polarisation_frame=None*, *zerow=False*)

Create the standard LOW simulation

Parameters

- **band** – B
- **rmax** – Maximum distance from array centre
- **phasecentre** – Phase centre (SkyCoord)
- **time_range** – Hour angle (in hours)
- **time_chunk** – Chunking of time in seconds
- **integration_time** –
- **polarisation_frame** – Desired polarisation frame
- **zerow** – Set w to zero (False)

Returns

create_standard_mid_simulation_rsexecute_workflow

create_standard_mid_simulation_rsexecute_workflow(*band*, *rmax*, *phasecentre*, *time_range*, *time_chunk*, *integration_time*, *polarisation_frame=None*, *zerow=False*, *configuration='MID'*)

Create the standard MID simulation

Parameters

- **band** – B1, B2, or Ku
- **rmax** – Maximum distance from array centre
- **phasecentre** – Phase centre (SkyCoord)
- **time_range** – Hour angle (in hours)
- **time_chunk** – Chunking of time in seconds
- **integration_time** –
- **polarisation_frame** – Desired polarisation frame
- **zerow** – Set w to zero (False)

Returns

create_surface_errors_gaintable_rsexecute_workflow

create_surface_errors_gaintable_rsexecute_workflow(*band*, *sub_bvis_list*, *sub_components*, *vp_directory*, *elevation_sampling=5.0*)

Create gaintable for surface errors :param band: B1, B2 or Ku :param sub_bvis_list: List of vis (or graph) :param sub_components: List of components (or graph) :param vp_directory: Location of voltage patterns :param elevation_sampling: Sampling in elevation (degrees) :return: (list of error-free gaintables, list of error gaintables) or graph

create_voltage_pattern_gaintable_rsexecute_workflow

create_voltage_pattern_gaintable_rsexecute_workflow(*band*, *sub_bvis_list*, *sub_components*, *get_vp*, *normalise=True*)

Create gaintable for nominal voltage pattern

Compare with nominal and actual voltage patterns

Parameters

- **band** – B1, B2 or Ku
- **sub_bvis_list** – List of vis (or graph)
- **sub_components** – List of components (or graph)
- **normalise** – Normalise peak of each receptor

Returns
(list of error-free gaintables, list of error gaintables) or graph

simulate_list_rsexecute_workflow

simulate_list_rsexecute_workflow(*config='LOWBD2'*, *phasecentre=<SkyCoord (ICRS): (ra, dec) in deg (15., -60.)>*, *frequency=None*, *channel_bandwidth=None*, *times=None*, *polarisation_frame=<ska_sdp_datamodels.science_data_model.polarisation_model.PolarisationFra object>*, *order='frequency'*, *format='vis'*, *rmax=1000.0*, *zerow=False*, *skip=1*)

A component to simulate an observation

The simulation step can generate a single Visibility or a list of Visibility's. The parameter keyword determines the way that the list is constructed. If order='frequency' then len(frequency) Visibility's with all times are created. If order='time' then len(times) Visibility's with all frequencies are created. If order = 'both' then len(times) * len(times) Visibility's are created each with a single time and frequency. If order = None then all data are created in one Visibility.

The output format can be either 'vis' (for calibration) or 'vis' (for imaging)

Parameters

- **config** – Name of configuration: def LOWBDS-CORE
- **phasecentre** – Phase centre def: SkyCoord(ra=+15.0 * u.deg, dec=-60.0 * u.deg, frame='icrs', equinox='J2000')
- **frequency** – def [1e8]
- **channel_bandwidth** – def [1e6]
- **times** – Observing times in radians: def [0.0]
- **polarisation_frame** – def PolarisationFrame("stokesI")
- **order** – 'time' or 'frequency' or 'both' or None: def 'frequency'
- **format** – 'vis' or 'vis': def 'vis'
- **zerow** – Set w to zero
- **skip** – Number of dishes/stations to skip

Returns

graph of vis_list with different frequencies in different elements

rascil.workflows.rsexecute.skymodel Package

Functions

deconvolve_skymodel_list_rsexecute_workflow(	Deconvolve using a skymodel
invert_skymodel_list_rsexecute_workflow(...)	Calibrate and invert from a skymodel, iterating over the skymodel
predict_skymodel_list_rsexecute_workflow(...)	Predict from a list of skymodels
restore_centre_skymodel_list_rsexecute_work	Create a graph to calculate the restored skymodel at the centre channel
restore_skymodel_list_rsexecute_workflow(...)	Create a graph to calculate the restored image

deconvolve_skymodel_list_rsexecute_workflow

deconvolve_skymodel_list_rsexecute_workflow(*dirty_image_list*, *psf_list*, *skymodel_list*, *prefix=''*, *fit_skymodel=False*, ***kwargs*)

Deconvolve using a skymodel

This will either fit for the brightest components and add those to the skymodel components or use (optionally faceted) CLEAN based deconvolution

Parameters

- **dirty_image_list** – List of dirty images (or graphs)
- **psf_list** – List of corresponding psf images (or graphs)
- **skymodel_list** – list of skymodels (or graph)
- **prefix** – Informational prefix for logging messages
- **fit_skymodel** – Fit the skymodel?
- **kwargs** –

Returns
list of skymodels (or graph)

invert_skymodel_list_rsexecute_workflow

invert_skymodel_list_rsexecute_workflow(*vis_list*, *skymodel_list*, ***kwargs*)

Calibrate and invert from a skymodel, iterating over the skymodel

The function get_pb should have the signature:

get_pb(Visibility, Image)

and should return the primary beam for the visibility.

The return is a graph for a set of tuples of (dirty, sensitivity image)

Parameters

- **vis_list** – List of Visibility data models
- **skymodel_list** – skymodel list
- **kwargs** – Parameters for functions in components

Returns
List of (image, weight) tuples)

predict_skymodel_list_rsexecute_workflow

predict_skymodel_list_rsexecute_workflow(*obsvis*, *skymodel_list*, ***kwargs*)

Predict from a list of skymodels

If obsvis is a list then we pair obsvis element and skymodel_list element and predict If obvis is Visibility then we calculate Visibility for each skymodel

Parameters

- **obsvis** – Observed Block Visibility or list or graph

- **skymodel_list** – skymodel list
- **kwargs** – Parameters for functions in components

Returns
List of vis_lists

restore_centre_skymodel_list_rsexecute_workflow

restore_centre_skymodel_list_rsexecute_workflow(*skymodel_list*, *psf_imagelist*, *residual_imagelist=None*, *clean_beam=None*, ***kwargs*)

Create a graph to calculate the restored skymodel at the centre channel

Parameters

- **skymodel_list** – Skymodel list (or graph)
- **psf_imagelist** – PSF list (or graph)
- **residual_imagelist** – Residual list (or graph)
- **kwargs** – Parameters for functions in components
- **clean_beam** – Clean beam e.g. {"bmaj":0.1, "bmin":0.05, "bpa":-60.0}. Units are deg, deg, deg

Returns
list of restored images (or graph)

restore_skymodel_list_rsexecute_workflow

restore_skymodel_list_rsexecute_workflow(*skymodel_list*, *psf_imagelist*, *residual_imagelist=None*, *restore_facets=1*, *restore_overlap=8*, *restore_taper='tukey'*, *clean_beam=None*, ***kwargs*)

Create a graph to calculate the restored image

Parameters

- **model_imagelist** – Model list (or graph)
- **psf_imagelist** – PSF list (or graph)
- **residual_imagelist** – Residual list (or graph)
- **clean_beam** – Clean beam e.g. {"bmaj":0.1, "bmin":0.05, "bpa":-60.0}. Units are deg, deg, deg
- **kwargs** – Parameters for functions in components
- **restore_facets** – Number of facets used per axis (used to distribute)
- **restore_overlap** – Overlap in pixels (0 is best)
- **restore_taper** – Type of taper between facets

Returns
list of restored images (or graph)

rascil.workflows.rsexecute.execution_support Package

Functions

get_dask_client([timeout, n_workers, ...])	Get a Dask.distributed Client to be used in rsexecute

get_dask_client

get_dask_client(*timeout=30*, *n_workers=None*, *threads_per_worker=None*, *processes=True*, *create_cluster=False*, *memory_limit=None*, *local_dir='.'*, *with_file=False*, *scheduler_file='./scheduler.json'*, *dashboard_address=':8787'*)

Get a Dask.distributed Client to be used in rsexecute

The default operation of rsexecute.set_client is to create a set of workes on one node. Hence if you want to use a cluster it is necessary to use get_dask_client.

The environment variable RASCIL_DASK_SCHEDULER is interpreted as pointing to the Dask distributed scheduler. and a client using that scheduler is returned. Otherwise a client for a LocalCluster is created.

The environment variable RASCIL_DASK_SCHEDULER_FILE is interpreted as pointing to the Dask scheduler file and a client using that scheduler is returned. If RASCIL_DASK_SCHEDULER_FILE is set, with_file option is set to true and scheduler_file name is overridden with the RASCIL_DASK_SCHEDULER_FILE

Parameters

- **timeout** – Time out for creation (30s)
- **n_workers** – Number of workers (cores available)
- **threads_per_worker** – 1
- **processes** – Use processes instead of threads (True)
- **create_cluster** – Create a LocalCluster (True)
- **memory_limit** – Memory limit per worker (bytes e.g. 8e9) (None)
- **scheduler_file** – Scheduler file for Dask (‘./scheduler.json’)
- **dashboard_address** – Port used for diagnostics (‘:8787’)

Returns

Dask client

Classes

The rsexecute framework relies upon a singleton object called rsexecute. This is documented below as the class _rsexecutebase. Note that by design it is not possible to create more than one _rsexecutebase object.

class _rsexecutebase(*use_dask=True*, *use_dlg=False*, *verbose=False*, *optimize=True*)

Initialise rsexecute framework

A singleton of this class is created and is available globally as rsexecute. Hence it is not necessary to declare an instance of _rsexecutebase.

For example:

```
from rascil.workflows import continuum_imaging_list_rsexecute_workflow, rsexecute
rsexecute.set_client(use_dask=True,
    memory_limit=32 * 1024 * 1024 * 1024, n_workers=8,
    local_dir=dask_dir, verbose=True)
continuum_imaging_list = continuum_imaging_list_rsexecute_workflow(vis_list,
    model_imagelist=model_list,
    context='wstack', vis_slices=51,
    scales=[0, 3, 10], algorithm='mmclean',
    nmoment=3, niter=1000,
    fractional_threshold=0.1, threshold=0.1,
    nmajor=5, gain=0.25,
    psf_support=64)

deconvolved_list, residual_list, restored_list = rsexecute.compute(continuum_
↪imaging_list,
    sync=True)
```

Parameters

- **use_dask** – Use dask (True)
- **use_dlg** – Use daluige (False)
- **verbose** – Be verbose in printing messages
- **optimize** – Optimize if using dask (True)

execute(*func*, **args*, ***kwargs*)

Wrap for immediate or deferred execution

Passes through if dask is not being used

Parameters

- **args** –
- **kwargs** –

Returns

delayed func or func

type()

Get the name of the execution system

Returns

set_client(*client=None*, *use_dask=True*, *use_dlg=False*, *verbose=False*, *optim=True*, ***kwargs*)

Set the Dask/DALiuGE client to be used

If you want to customise the Client or use an externally defined Scheduler use get_dask_client and pass it in.

Parameters

- **use_dask** – Use Dask?
- **client** – If None and use_dask is True, a client will be created otherwise the client is None
- **use_dlg** – Use Daliuge to execute graphs?
- **verbose** – Be verbose in output

- **optim** – Use dask.optimize via rsexecute.optimize function.

Returns

compute(*value*, *sync=False*)

Get the actual value

If not using dask then this returns the value directly since it already is computed If using dask and sync=True then this waits and resturns the actual wait. If using dask and sync=False then this returns a future, on which you will need to call .result()

Parameters

- **value** –
- **sync** – Return synchronously? (False)

Returns

persist(*graph*, ***kwargs*)

Persist graph data on workers

The graphs are placed on the workers but not computed

No-op if not using_dask

Parameters
graph –

Returns

scatter(*graph*, ***kwargs*)

Scatter graph data to workers

The data are placed on the workers

No-op if not using_dask :param graph: :return:

gather(*graph*)

Gather graph from workers

The data are gathered from the workers

No-op if not using_dask

Parameters
graph –

Returns

run(*func*, **args*, ***kwargs*)

Run a function on the client

Parameters
func –

Returns

optimize(**args*, ***kwargs*)

Run Dask optimisation of graphs

Only does something when using dask

Parameters

- **args** – for Dask.optimize

- **kwargs** – for Dask.optimize

Returns

`close()`

Close the client

`init_statistics()`

Initialise the profile and task stream info

rsexecute can save the Dask profile and Task Stream information for later saving

Returns

`save_statistics(name='dask')`

Save the statistics to html files

rsexecute can save the Dask profile and Task Stream information for later saving. This saves the current statistics to html files.

Parameters
name – prefix to name e.g. dask

`memusage(memusage_file='memusage.csv')`

Install the dask-memusage plugin

https://github.com/itamarst/dask-memusage/blob/master/dask_memusage.py

Note that there can only be one dask thread per process.

This only works for the process scheduler. For the distributed scheduler, preload the plugin. For example:

dask-scheduler –port=8786 –preload dask_memusage –memusage-csv ./memusage.csv

Parameters
memusage_file – Name of mem-usage file produced by dask-memusage plugin

Returns

`property client`

Client being used

Returns
client

`property using_dask`

Is dask being used?

Returns

`property using_dlg`

Is daluige being used?

Returns

`property optimizing`

Is Dask optimisation being performed?

Returns

1.4.3 Apps

The following command line apps are available.

- genindex
- modindex

1.5 RASCIL development

RASCIL is part of the SKA telescope organisation on GitLab https://gitlab.com/ska-telescope/external/rascil.git and development is ongoing. We welcome merge requests submitted via GitLab. Guidelines and instructions for contributing to code and documentation can be found here.

1.5.1 Developing in RASCIL

Use the SKA Python Coding Guidelines (http://developer.skatelescope.org/en/latest/development/python-codeguide.html).

We recommend using a tool to help ensure PEP 8 compliance. PyCharm does a good job at this and other code quality checks.

Process

- Use git to make a local clone of the Github respository:

```
git clone https://gitlab.com/ska-telescope/external/rascil-main.git
```

- Make a branch. Use a descriptive name e.g. abc-123-feature_improved_gridding, abc-1231-bugfix_issue_666 (Note that the branch name has to start with a Jira ticket ID)
- Make whatever changes are needed, including documentation.
- Always add appropriate test code in the tests directory.
- Consider adding to the examples area.
- Push the branch to gitlab. It will then be automatically built and tested on gitlab: https://gitlab.com/ska-telescope/external/rascil-main/-/pipelines
- Once it builds correctly, submit a merge request.

Design

The RASCIL has been designed in line with the following principles:

- Data are held in Classes.
- The Data Classes correspond to familiar concepts in radio astronomy packages e.g. visibility, gaintable, image.
- The data members of the Data Classes are directly accessible by name e.g. .data, .name, .phasecentre.
- Direct access to the data members is envisaged.
- There are no methods attached to the data classes apart from variant constructors as needed.
- Standalone, stateless functions are used for all processing.

Additions and changes should adhere to these principles.

Submitting code

RASCIL is part of the SKA telescope organisation on GitLab. https://gitlab.com/ska-telescope/external/rascil-main.git.

We welcome merge requests submitted via GitLab. Please note that we use Black to keep the python code style in good shape. The first step in the CI pipeline checks that the code complies with black formatting style, and will fail if that is not the case.

Automated testing in Dask

The CI pipeline automatically executes the test-dask job upon every commit to a branch. This job deploys a new Dask cluster on the Data Processing Cluster in the *dp-orca-p* namespace. A scheduled pipeline checks the namespace hourly and removes any deployments that are older than a given time (by default 1 hour).

1.5.2 Documenting RASCIL

- The primary documentation is written in reStructuredText (rst).
- We use Sphinx to extract code documentation.
- We use the package sphinx_automodapi to build the API informatiom.
- For this to work, all of the code must be loadable into python. To facilitate this, we make use of the dreaded `from somewhere import *`. This means that modules must use `__all__` to only export those names that are delivered by that module, as oopposed to the other names used in the module.

1.5.3 Build and Release process

Automatic builds

RASCIL is built automatically via a GitLab CI pipeline, which can be triggered by:

- on schedule
- commit to any branch
- merge/commit to master
- a tag is pushed to the repository

The following stages/jobs run, depending on the trigger mechanism:

- **on schedule: the `compile_requirements` job runs, whose sole purpose is to regularly update the** requirements files with the latest package versions. It also runs the `.post` stage.
- **commit to a branch: it runs the `linting` and `test` stages, as well as the `prepost` and `.post` ones.** The latter two creates and posts the `ci_metrics` data.
- **merge/commit to master:**
  - `linting`, and `test` stages run
  - `build` stage runs with the `data` and `build_package` jobs. The first builds and saves the RASCIL data to GitLab, while the second builds the RASCIL python package for later consumption

  - the `publish` stage's `docker_latest` job runs, which builds, tags and publishes the latest docker images to the Central Artefact Repository. This stage also runs the `pages` job, which publishes the documentation and rebuilds the data.
  - `prepost` and `.post` stages run

- **commit tag: tagging the repository is manual (see below), which triggers the following parts of the pipeline**
  - `linting` stage
  - `build` stage's `build_package` job, which builds the RASCIL python package
  - `publish` stage's `publish_to_car` and `docker_release` jobs. The first publishes the python package, while the second publishes the release-tagged (i.e. tagged with the package version) docker image to the Central Artefact Repository
  - `.post` stage

The above process makes sure that new code is automatically tested at every point of the development process, and that the correct version of the python package and the docker images are published with the appropriate tag and at the appropriate time.

Releasing a new version

The release process:

- Overall based on: https://developer.skao.int/ and in particular https://developer.skao.int/en/latest/tools/software-package-release-procedure.html
- Use semantic versioning: https://semver.org
- Follow the packaging process in: https://packaging.python.org/tutorials/packaging-projects/

The release of a new package happens in two stages:

- a release tag is pushed to the repository (manually by a maintainer)
- the CI pipeline's relevant stages publish the new package.

Note: while commits are allowed directly to master by maintainers of the repository, this should not be used as an option, but rather update the code via Merge Requests. This is only allowed for releasing a new version of the package.

Steps:

- Ensure that the current master builds on GitLab: https://gitlab.com/ska-telescope/external/rascil/-/pipelines
- Decide whether a release is warranted and what semantic version number it should be: https://semver.org
- Check if the documentation has been updated. If not, create a new branch, update the documentation, create a merge request and merge that to master (after approval).
- Check out master and pull the latest version of it.
- Update CHANGELOG.md for the relevant changes in this release, putting newer description at the top.
- Commit the changes (do not push!)
- Bump the version using the Makefile:

```
make release-[patch||minor||major]
```

  Note: `bumpver` needs to be installed. This step automatically commits the new version tag to the repository.

- Review the pipeline build for success
- Create a new virtualenv and try the install by using pip3 install rascil:

```
virtualenv test_env
. test_env/bin/activate
pip3 install --index-url=https://artefact.skao.int/repository/pypi-all/simple rascil
python3
>>> import rascil
```

1.5.4 Managing requirements

RASCIL requirements are stored in three files:

- `requirements.in` Python requirements for the main code base
- `requirements-test.in` Python requirements to run the tests
- `requirements-docs.in` Python requirements to build the documentation

`pip-compile` is used to generate the corresponding .txt files. `pip-compile` resolves all dependencies and saves them with their resolved versions in the .txt files.

This method is used to make sure we do not update requirements with every build, but rather install them from the .txt files, where they are pinned. We also have to make sure we regularly update these versions, by running `pip-compile` on the .in files, which ideally do not contain version pins.

Manually updating the requirements

The `Makefile` of RASCIL contains three options to work with requirements on your local machine:

- `make requirements` This will update the requirements in the .txt file, but will not install them
- `make install_requirements` This will install the existing requirements from the .txt files, but not update them
- `make update_requirements` This will first update all requirements, then install them (i.e it runs the first two commands)

The first and third commands change the .txt files, but do not commit the changes. Still, it is worth running them from a branch, and not directly from master.

Process automation

Regularly updating the requirements manually is prone to be forgotten, which can result in packages being out-of-date very quickly. Hence we set up a semi-automatic process using the GitLab CI pipeline with a job run on a schedule.

The scheduled pipeline only runs one job, with the following steps:

- run `make requirements`
- check if there are changes compared to the existing remote files
- if there, create and check out a new branch
- commit and push the changes to the new branch
- create a Merge Request (MR) of the new branch into the source branch
- assign the MR

- if there aren't any changes, do nothing

The tests are not run as part of this pipeline, because the MR created at the end of will have the tests run as part of its own pipeline.

The assignee now has the responsibility of keeping track how the pipeline of this new MR does. If it succeeds, then it should be merged to master. If it fails, then the failing tests should be checked and the reasons for failure should be fixed. Packages should not be pinned within the .in files, just because tests are failing, unless there is a very good reason for it. Packages pinned in the .in files should be regularly revisited and if possible, unpinned.

1.5.5 Background

This outlines the original motivation for the ARL. Some shift in emphasis has occurred as a result of the expansion of RASCIL beyond the original purpose of a reference library.

Core motivations

- In many software packages, the only function specification is the application code itself. Although the underlying algorithm may be published, the implementation tends to diverge over time, making this method of documentation less effective. The algorithm reference library is designed to present imaging algorithms in a simple Python-based form. This is so that the implemented functions can be seen and understood without resorting to interpreting source code shaped by real-world concerns such as optimisations.
- Maintenance of the reference library over time is a choice for operations and we do not discuss it further here.
- Desire for simple test version: for example, scientists may wish to understand how the algorithm works and see it tested in particular circumstances. Or a software developer wish to compare it to production code.

Purpose

- Documentation: The primary purpose of the library is to be easily understandable to people not familiar with radio interferometry imaging. This means that the library should be broken down into a number of small, well-documented functions. Aside from the code itself, these functions will be further explained by documentation as well as material demonstrating its usage. Where such efforts would impact the clarity of the code itself it should be kept separate (e.g. example notebooks).
- Testbed for experimentation: One purpose for the library is to facilitate experimentation with the algorithm without touching the production code. Production code may be specialised due to the need for optimization, however the reference implementation should avoid any assumptions not actually from the theory of interferometry imaging.
- Publication e.g. via github: All algorithms used in production code should be known and published. If the algorithms are available separately from the production code then others can make use of the published code for small projects or to start on an improved algorithm.
- Conduit for algorithms into SKA: The library can serve as a conduit for algorithms into the SKA production system. A scientist can provide Python Version of an algorithm which then can be translated into optimized production code by the SKA computer team.
- Algorithm unaffected by optimization: Production code is likely to be obscured by the need to optimize in various ways. The algorithms in the library will avoid this as much as possible in order to remain clear and transparent. Where algorithms need to be optimised in order to remain executable on typical hardware, we might opt for providing multiple equivalent algorithm variants.
- Deliver algorithms for construction phase: The algorithm reference library Will also serve as a resource for the delivery of algorithms to the construction phase. It is likely that much of the production code will be written

by people not intimately familiar with radio astronomy. Experience shows that such developers can often work from a simple example of the algorithm.

- Reference for results: The library will also serve to provide reference results for the production code. This is not entirely straightforward because the algorithms in both cases work in different contexts. Code that establishes interoperability with external code will have to kept separate to not clutter the core implementation. This means that we will not be able to guarantee comparability in all cases. In that case, it will be the responsibility other developers of the production code to establish it - for example by using suitably reduced data sets.

Stakeholders

- SDP design team: The principal stakeholders for the algorithm reference library are the SDP Design Team. They will benefit from having cleared descriptions of algorithms for all activities such as resource estimation, parameter setting, definition of pipelines, and so on.
- SKA Project Scientists: The SKA project scientists must be able to understand the algorithms used in the pipelines. This is essential if they are going to be assured that the processing is as desired, and relay that to the observers.
- External scientists: External scientists and observers using the telescope will benefit into ways. First, in understanding the processing taking place in the pipelines, and second, being able to bring new algorithms for deployment into the pipelines.
- SDP contractors: Depending upon the procurement model, SDP may be developed by a team without very much domain knowledge. While expect the documentation of the entire system to be in good shape after CDR, the algorithms are the very core of the system I must be communicated clearly and concisely. We can expect that any possible contractors considering a bid would be reassured by the presence of algorithm reference library.
- Outreach: Finally, outreach may be a consumer of the library. For example, the library could be made available to students at various levels to introduce them to astronomical data-processing concepts.

Prior art

LAPACK is an example of a library that mutated into a reference library. The original code was written in straightforward FORTRAN but now many variants have been spawned including for example Versions optimized for particular hardware, or using software scheduling techniques such as DAGs to arrange their internal processing. The optimized variants must always agree with the reference code.

Requirements

- Minimal implementation: The implementation should be minimal making use of as few external libraries as possible. Python is a good choice for the implementation because the associated libraries are powerful and well-defined.
- Use numpy whenever possible: Some form of numeric processing is inevitably necessary. There is also need for efficient bulk data transfer between functions. For consistency, we choose to adopt the numpy library for both algorithm and interface definition.
- Take algorithms with established provenance: While the purpose of the library is to define the algorithms clearly, the algorithms themselves should have well-defined provenance. Acceptable forms of provenance include publication in a peer-reviewed journal, publication in a well-defined memo series, and use in a well-defined production system. In time we might expect that the algorithm reference library will itself provide sufficient provenance. This depends upon the processes to maintain the library being stringently defined and applied.

- No optimization: No optimization should be performed on algorithms in the library if doing so obscures the fundamentals of the algorithm. Runtime of the testsuite should not be consideration except in so far as it prevents effective use.
- V&V begins here: Validation and verification of the pipeline processing begins in the algorithm reference library. That means that it should be held to high standards of submission, testing, curation, and documentation.
- Single threaded: All algorithms should be single threaded unless multi-threading is absolutely required to achieve acceptable performance. However, as distributed execution is going to be vital for the SDP, special take should be taken to document and demonstrate parallelism opportunities.
- Memory limit: The memory used should be compatible with execution on a personal computer or laptop.
- How we maintain the requirements: *Managing requirements*

Algorithms to be defined

The following list gives an initial set of algorithms to be defined. It is more important to have the overall framework in place expeditiously than to have each algorithm be state-of-the-art.

- Simulation
  - Station/Antenna locations
  - Illumination/Primary beam models
  - Generation of visibility data
  - Generation of gain tables
- Calibration
  - Calibration solvers
    - Stefcal
  - Calibration application
    - Gain interpolation
    - Gain application
  - Self-calibration
- Visibility plane
  - Convolution kernels
    - Standard
    - W Projection
    - AW Projection
    - AWI Projection
  - Degridding/Gridding
    - 2D
    - W projection
    - W slices
    - W snapshots
  - Preconditioning/Weighting

        * Uniform
        * Briggs
- Visibility plane to/from Image plane
  - DFT
  - Faceting
  - Phase rotation
  - Averaging/deaveraging
  - Major cycles
- Image plane
  - Source finding
  - Source fitting
  - Reprojection
  - Interpolation
  - MSClean minor cycle (for spectral line)
  - MSMFS minor cycle (for continuum)

To test and demonstrate completeness, the main pipelines will be implemented.

Testing

- Testing philosophy: The essence of an algorithm reference library is that it should be used as the standard for the structure and execution of a particular algorithm. This can only be done if the algorithm and the associated code are tested exhaustively.
- We will use three ways of performing testing of the code
  - Unit tests of all functions:
  - Regression tests of the complete algorithm over a complete set of inputs.
  - Code reviews (either single person or group read-throughs).
- Test suite via Jenkins: The algorithm reference library will therefore come with a complete set of unit tests and regression tests. These should be run automatically, by, for example, a framework such as Jenkins, on any change to ensure their errors are caught quickly and not compounded.
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PYTHON MODULE INDEX

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