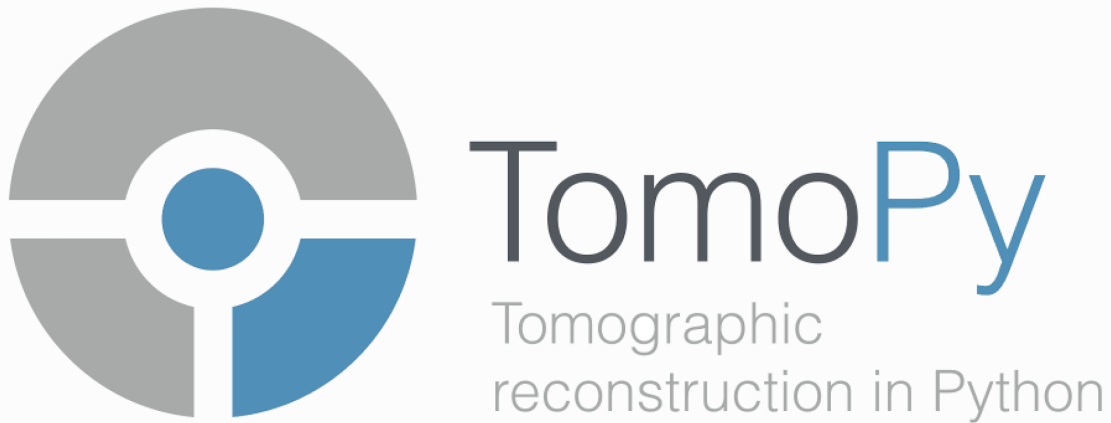

TomoPy Documentation

Release 1.0.0

Argonne National Laboratory

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Tomopy is an open-source Python package for tomographic data processing and image reconstruction.

- Image reconstruction algorithms for tomography.
- Various filters, ring removal algorithms, phase retrieval algorithms.
- Forward projection operator for absorption and wave propagation.

Contribute

- Issue Tracker: <https://github.com/tomopy/tomopy/issues>
- Documentation: <https://github.com/tomopy/tomopy/tree/master/doc>
- Source Code: <https://github.com/tomopy/tomopy/tree/master/tomopy>
- Tests: <https://github.com/tomopy/tomopy/tree/master/test>

Table of Contents

2.1 About

Tomographic reconstruction creates three-dimensional views of an object by combining two-dimensional images taken from multiple directions, for example, this is how a CAT (computer-aided tomography) scanner generates 3D views of the heart or brain.

Data collection can be rapid, but the required computations are massive and often the beamline staff can be overwhelmed by data that are collected far faster than corrections and reconstruction can be performed [C12]. Further, many common experimental perturbations can degrade the quality of tomographs, unless corrections are applied.

To address the needs for image correction and tomographic reconstruction in an instrument independent manner, the TomoPy code was developed [A1], which is a parallelizable high performance reconstruction code.

2.2 Install directions

This section covers the basics of how to download and install TomoPy.

Contents:

- *Installing from Conda*
- *Updating the installation*

2.2.1 Installing from Conda

First you must have [Conda](#) installed, then open a terminal or a command prompt window and run:

```
conda install -c dgursoy tomopy
```

2.2.2 Updating the installation

TomoPy is an active project, so we suggest you update your installation frequently. To update the installation run in your terminal:

```
conda update -c dgursoy tomopy
```

For some more information about using Conda, please refer to the [docs](#).

2.3 Tomographic data files

For reading tomography files formatted in different ways, please go check the [DXchange](#) package. There are various examples and demonstration scripts about how to use the package for loading your datasets.

The package can be installed by simply running the following in a terminal:

```
conda install -c dgursoy dxchange
```

2.4 Development

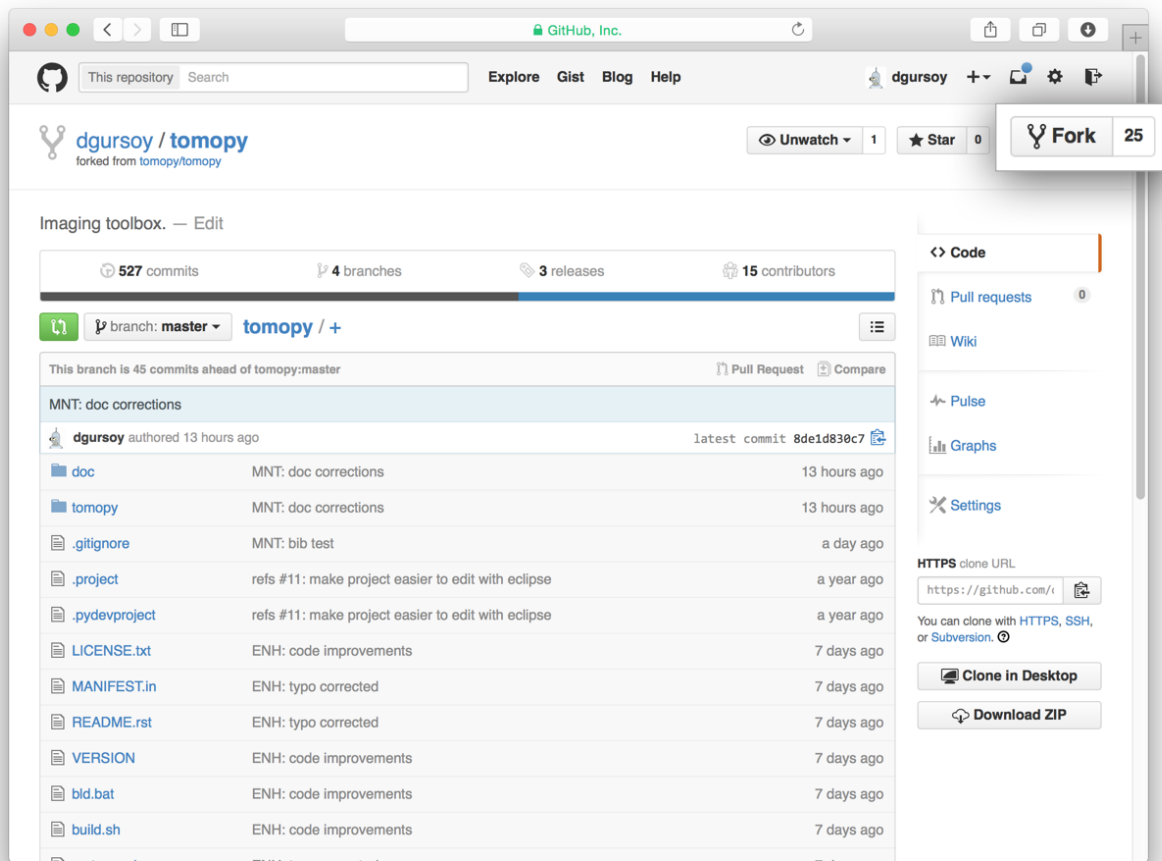
This section explains the basics for developers who wish to contribute to the TomoPy project.

Contents:

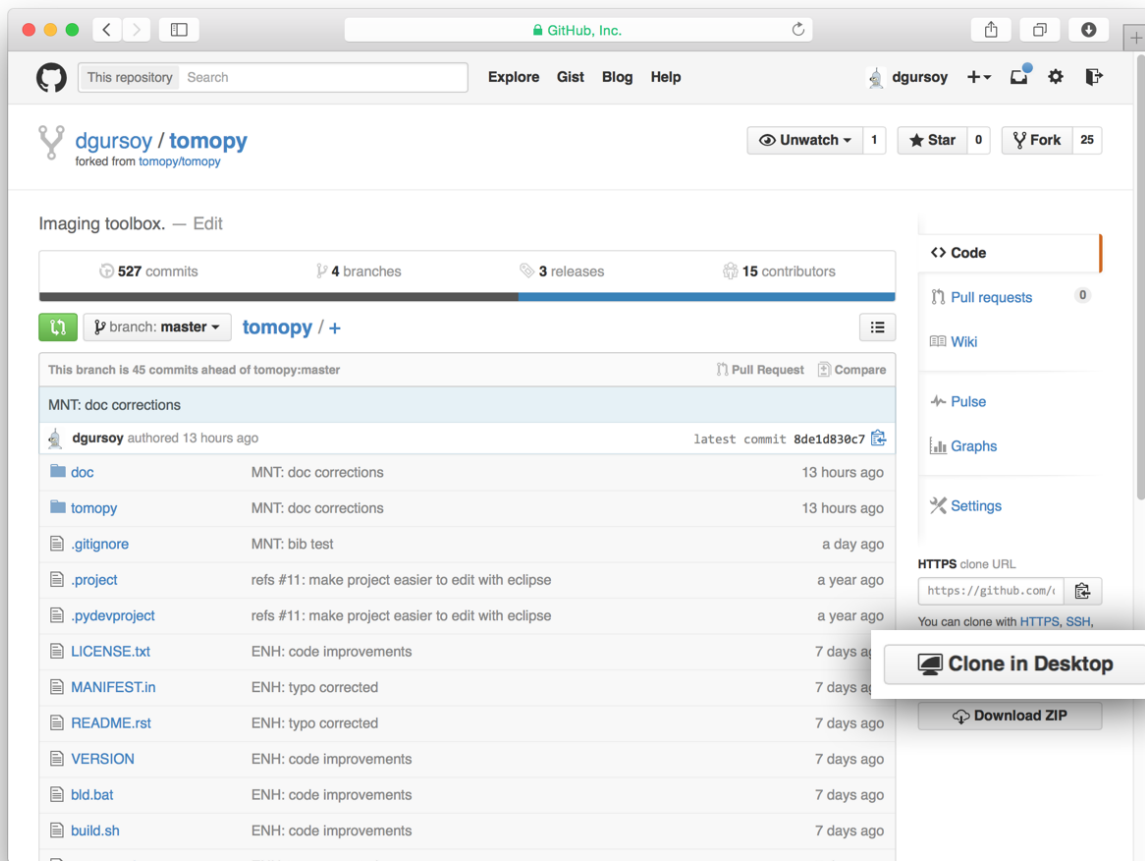
- *Cloning the repository*
- *Coding conventions*
- *Package versioning*
- *Committing changes*
- *Contributing back*

2.4.1 Cloning the repository

The project is maintained on GitHub, which is a version control and a collaboration platform for software developers. To start first register on [GitHub](#) and fork the TomoPy repository by clicking the **Fork** button in the header of the [TomoPy repository](#):



This successfully creates a copy of the project in your personal GitHub space. The next thing you want to do is to clone it to your local machine. You can do this by clicking the **Clone in Desktop** button in the bottom of the right hand side bar:



This will launch the GitHub desktop application (available for both [Mac](#) and [Win](#)) and ask you where you want to save it. Select a location in your computer and feel comfortable with making modifications in the code.

2.4.2 Coding conventions

We try to keep a consistent and readable code. So, please keep in mind the following style and syntax guidance before you start coding.

First of all the code should be well documented, easy to understand, and integrate well into the rest of the project. For example, when you are writing a new function always describe the purpose and the parameters:

```
def my_awesome_func(a, b):
    """
    Adds two numbers.

    Parameters
    -----
    a : scalar (float)
        First number to add

    b : scalar (float)
        Second number to add

    Returns
```

```

-----
output : scalar (float)
    Added value
"""
return a+b

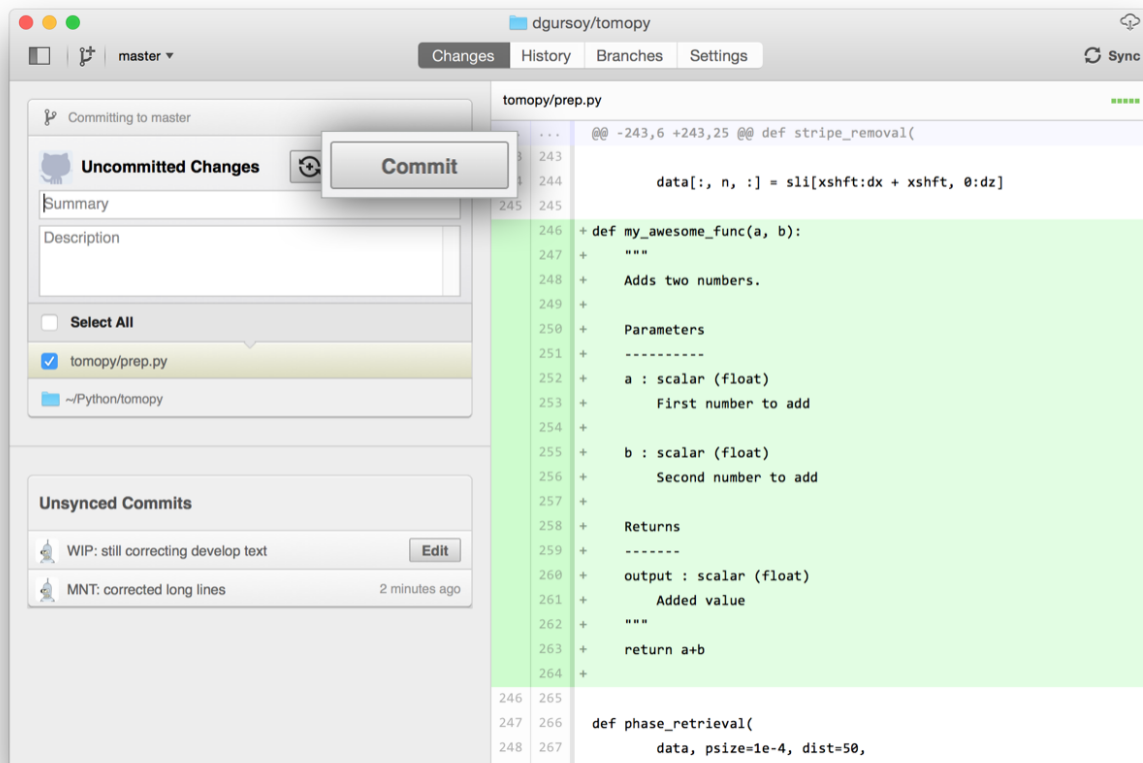
```

2.4.3 Package versioning

We follow the X.Y.Z (Major.Minor.Patch) semantic for package versioning. The version should be updated before each pull request accordingly. The patch number is incremented for minor changes and bug fixes which do not change the software's API. The minor version is incremented for releases which add new, but backward-compatible, API features, and the major version is incremented for API changes which are not backward-compatible. For example, software which relies on version 2.1.5 of an API is compatible with version 2.2.3, but not necessarily with 3.2.4.

2.4.4 Committing changes

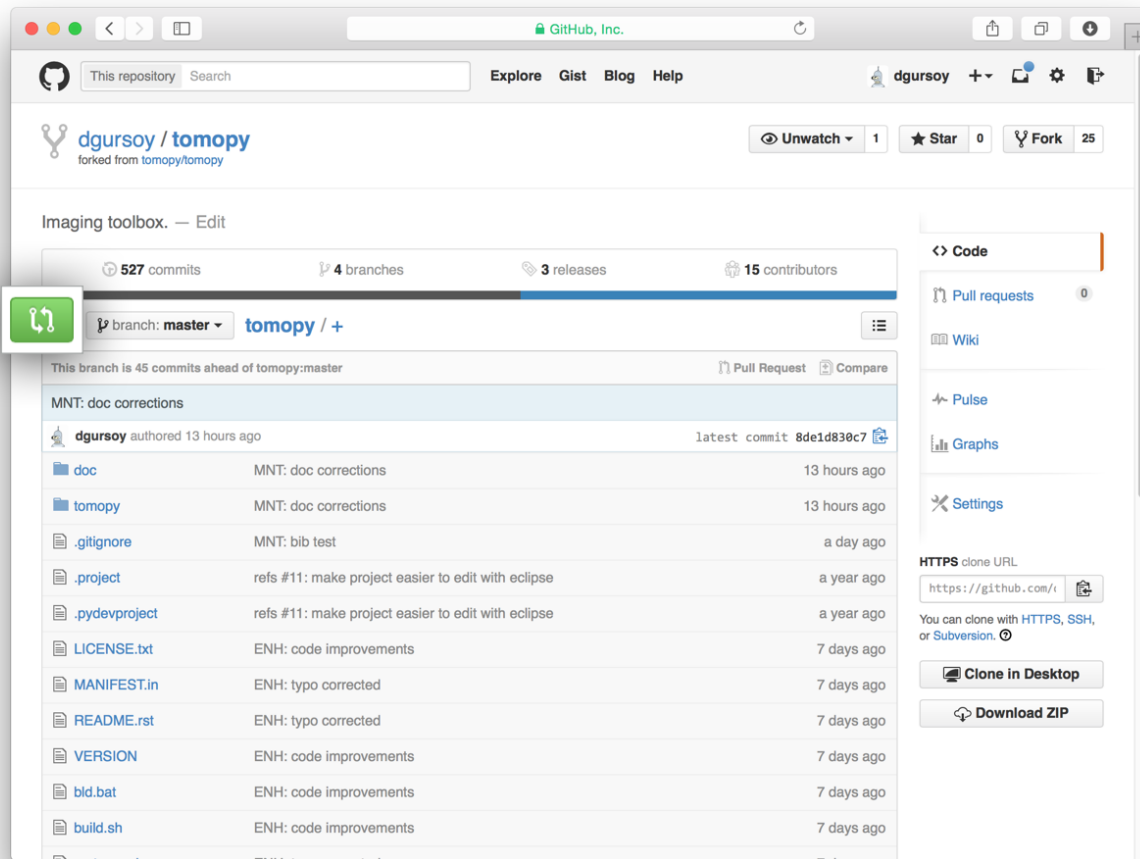
After making some changes in the code, you may want to take a *snapshot* of the edits you made. That's when you make a *commit*. To do this, launch the GitHub desktop application and it should provide you all the changes in your code since your last commit. Write a brief *Summary* and *Description* about the changes you made and click the **Commit** button:



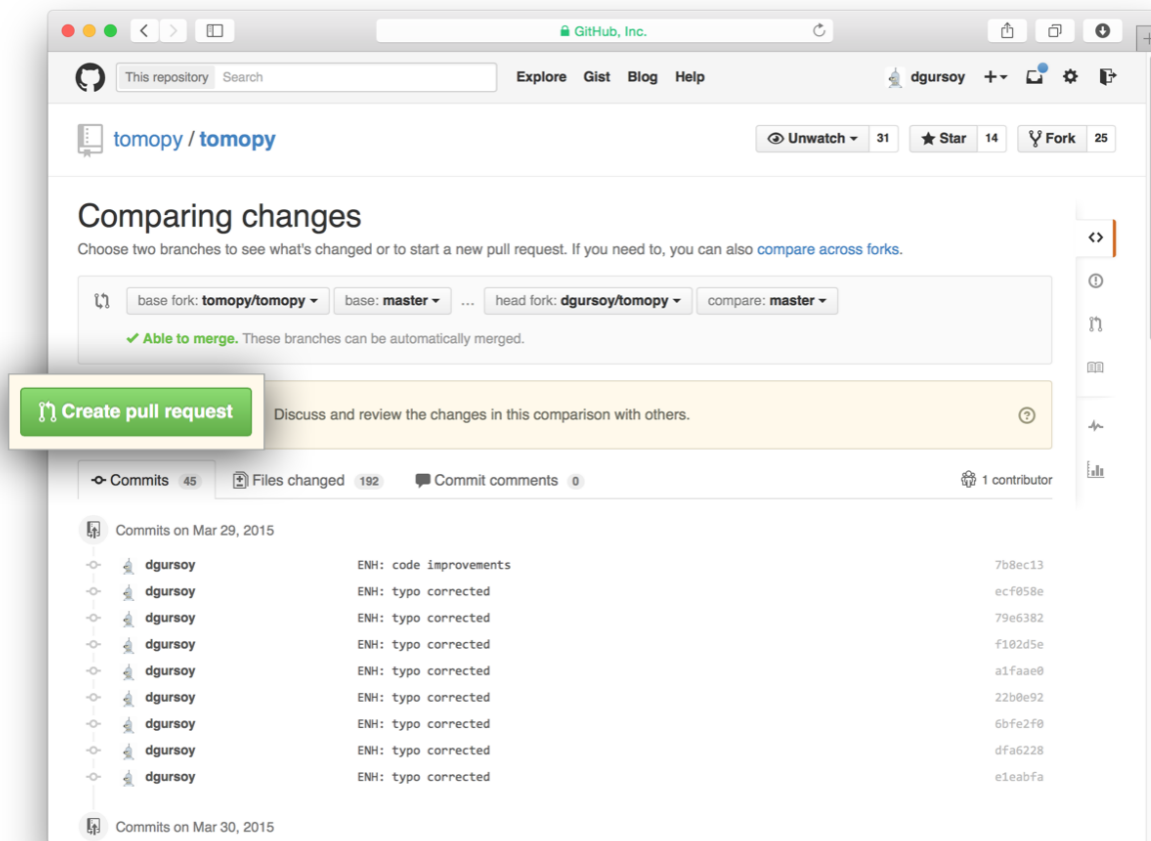
You can continue to make changes, add modules, write your own functions, and take more *Commit snapshots* of your code writing process.

2.4.5 Contributing back

Once you feel that the functionality you added would benefit the community, then you should consider contributing back to the TomoPy project. For this, go to your online GitHub repository of the project and click on the *green* button to compare, review and create a pull request.



After clicking on this button, you are presented with a review page where you can get a high-level overview of what exactly has changed between your forked branch and the original TomoPy repository. When you're ready to submit your pull request, click **Create pull request**:



Clicking on **Create pull request** sends you to a discussion page, where you can enter a title and optional description. It's important to provide as much useful information and a rationale for why you're making this Pull Request in the first place.

When you're ready typing out your heartfelt argument, click on **Send pull request**. You're done!

2.5 Release Notes

2.5.1 TomoPy 1.0.0 Release Notes

- *New features*
- *New functions*
- *New packages in Conda channel*
- *Deprecated features*
- *Backward incompatible changes*
- *Contributors*

New features

- FFTW implementation is now adopted. All functions that rely on FFTs such as `gridrec`, `phase retrieval`, `stripe removal`, etc. are now using the FFTW implementation through [PyFFTW](#).
- `sinogram_order` is added to `recon` as an additional argument. It determines whether data is a stack of sinograms (True, y-axis first axis) or a stack of radiographs (False). Default is False, but we plan to make it True in the upcoming release.
- Reconstruction algorithms only copies data if necessary.
- Updated library to support new `mproc` and `recon` functions. The data is now passed in sinogram order to `recon` functions. Also updated tests.
- `ncores` and `nchunks` are now independent.
- Setting `nchunks` to zero removes the dimension. That allows for the functions work on 2D data rather than 3D data.
- Sliced data are used so that each process only receives the data it needs. No more `istart` and `iend` variables for setting up indices in parallel processes.
- Functions will reuse `sharedmem` arrays if they can.

New functions

- `minus_log`
- `trim_sinogram`

New packages in Conda channel

- [dxchange 0.1.1](#)
- [fftw 3.3.4](#)
- [pyfftw 0.9.2](#)
- [pywavelets 0.4.0](#)
- [xraylib 3.1.0](#)

Deprecated features

- All data I/O related functions are deprecated. They are available through [DXchange](#) package.
- Removed `fft.h` and `fft.c`, they are now completely replaced with FFTW.

Backward incompatible changes

- `emission` argument is removed from `recon`. After this change the tomographic image reconstruction algorithms always assume data to be normalized.

Contributors

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2.6 API reference

This section contains the API reference and usage information for TomoPy.

TomoPy Modules:

2.6.1 `tomopy.misc.corr`

Module for data correction and masking functions.

Functions:

<code>adjust_range(arr[, dmin, dmax])</code>	Change dynamic range of values in an array.
<code>circ_mask(arr, axis[, ratio, val])</code>	Apply circular mask to a 3D array.
<code>gaussian_filter(arr[, sigma, order, axis, ncore])</code>	Apply Gaussian filter to 3D array along specified axis.
<code>median_filter(arr[, size, axis, ncore])</code>	Apply median filter to 3D array along specified axis.
<code>sobel_filter(arr[, axis, ncore])</code>	Apply Sobel filter to 3D array along specified axis.
<code>remove_nan(arr[, val])</code>	Replace NaN values in array with a given value.
<code>remove_neg(arr[, val])</code>	Replace negative values in array with a given value.
<code>remove_outlier(arr, dif[, size, axis, ncore])</code>	Remove high intensity bright spots from a 3D array along specified dimension.
<code>remove_ring(rec[, center_x, center_y, ...])</code>	Remove ring artifacts from images in the reconstructed domain.

`tomopy.misc.corr.adjust_range(arr, dmin=None, dmax=None)`

Change dynamic range of values in an array.

Parameters

- **arr** (*ndarray*) – Input array.
- **dmin, dmax** (*float, optional*) – Minimum and maximum values to rescale data.

Returns *ndarray* – Output array.

`tomopy.misc.corr.circ_mask(arr, axis, ratio=1, val=0.0)`

Apply circular mask to a 3D array.

Parameters

- **arr** (*ndarray*) – Arbitrary 3D array.
- **axis** (*int*) – Axis along which mask will be performed.
- **ratio** (*int, optional*) – Ratio of the mask's diameter in pixels to the smallest edge size along given axis.
- **val** (*int, optional*) – Value for the masked region.

Returns *ndarray* – Masked array.

`tomopy.misc.corr.gaussian_filter(arr, sigma=3, order=0, axis=0, ncore=None)`

Apply Gaussian filter to 3D array along specified axis.

Parameters

- **arr** (*ndarray*) – Input array.
- **sigma** (*scalar or sequence of scalars*) – Standard deviation for Gaussian kernel. The standard deviations of the Gaussian filter are given for each axis as a sequence, or as a single number, in which case it is equal for all axes.
- **order** (*{0, 1, 2, 3} or sequence from same set, optional*) – Order of the filter along each axis is given as a sequence of integers, or as a single number. An order of 0 corresponds to convolution with a Gaussian kernel. An order of 1, 2, or 3 corresponds to convolution with the first, second or third derivatives of a Gaussian. Higher order derivatives are not implemented
- **axis** (*int, optional*) – Axis along which median filtering is performed.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.

Returns *ndarray* – 3D array of same shape as input.

`tomopy.misc.corr.median_filter(arr, size=3, axis=0, ncore=None)`

Apply median filter to 3D array along specified axis.

Parameters

- **arr** (*ndarray*) – Input array.
- **size** (*int, optional*) – The size of the filter.
- **axis** (*int, optional*) – Axis along which median filtering is performed.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.

Returns *ndarray* – Median filtered 3D array.

`tomopy.misc.corr.sobel_filter(arr, axis=0, ncore=None)`

Apply Sobel filter to 3D array along specified axis.

Parameters

- **arr** (*ndarray*) – Input array.
- **axis** (*int, optional*) – Axis along which sobel filtering is performed.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.

Returns *ndarray* – 3D array of same shape as input.

```
tomopy.misc.corr.remove_nan(arr, val=0.0)
```

Replace NaN values in array with a given value.

Parameters

- **arr** (*ndarray*) – Input array.
- **val** (*float, optional*) – Values to be replaced with NaN values in array.

Returns *ndarray* – Corrected array.

```
tomopy.misc.corr.remove_neg(arr, val=0.0)
```

Replace negative values in array with a given value.

Parameters

- **arr** (*ndarray*) – Input array.
- **val** (*float, optional*) – Values to be replaced with negative values in array.

Returns *ndarray* – Corrected array.

```
tomopy.misc.corr.remove_outlier(arr, dif, size=3, axis=0, ncore=None)
```

Remove high intensity bright spots from a 3D array along specified dimension.

Parameters

- **arr** (*ndarray*) – Input array.
- **dif** (*float*) – Expected difference value between outlier value and the median value of the array.
- **size** (*int*) – Size of the median filter.
- **axis** (*int, optional*) – Axis along which median filtering is performed.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.

Returns *ndarray* – Corrected array.

```
tomopy.misc.corr.remove_ring(rec, center_x=None, center_y=None, thresh=300.0,
                             thresh_max=300.0, thresh_min=-100.0, theta_min=30, rwidth=30,
                             ncore=None, nchunk=None)
```

Remove ring artifacts from images in the reconstructed domain. Descriptions of parameters need to be more clear for sure.

Parameters

- **arr** (*ndarray*) – Array of reconstruction data
- **center_x** (*float, optional*) – abscissa location of center of rotation
- **center_y** (*float, optional*) – ordinate location of center of rotation
- **thresh** (*float, optional*) – maximum value of an offset due to a ring artifact
- **thresh_max** (*float, optional*) – max value for portion of image to filter
- **thresh_min** (*float, optional*) – min value for portion of image to filter
- **theta_min** (*int, optional*) – minimum angle in degrees (int) to be considered ring artifact
- **rwidth** (*int, optional*) – Maximum width of the rings to be filtered in pixels
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Corrected reconstruction data

2.6.2 tomopy.misc.morph

Module for data size morphing functions.

Functions:

<code>downsample(arr[, level, axis])</code>	Downsample along specified axis of a 3D array.
<code>upsample(arr[, level, axis])</code>	Upsample along specified axis of a 3D array.
<code>pad(arr, axis[, npad, mode])</code>	Pad an array along specified axis.
<code>sino_360_t0_180(data[, overlap, rotation])</code>	Converts 0-360 degrees sinogram to a 0-180 sinogram.
<code>trim_sinogram(data, center, x, y, diameter)</code>	Provide sinogram corresponding to a circular region of interest by trimming the corners.

`tomopy.misc.morph.downsample(arr, level=1, axis=2)`

Downsample along specified axis of a 3D array.

Parameters

- **arr** (*ndarray*) – 3D input array.
- **level** (*int, optional*) – Downsampling level in powers of two.
- **axis** (*int, optional*) – Axis along which downsampling will be performed.

Returns *ndarray* – Downsampled 3D array in float32.

`tomopy.misc.morph.upsample(arr, level=1, axis=2)`

Upsample along specified axis of a 3D array.

Parameters

- **arr** (*ndarray*) – 3D input array.
- **level** (*int, optional*) – Downsampling level in powers of two.
- **axis** (*int, optional*) – Axis along which upsampling will be performed.

Returns *ndarray* – Upsampled 3D array in float32.

`tomopy.misc.morph.pad(arr, axis, npad=None, mode=u'constant', **kwargs)`

Pad an array along specified axis.

Parameters

- **arr** (*ndarray*) – Input array.
- **npad** (*int, optional*) – New dimension after padding.
- **axis** (*int, optional*) – Axis along which padding will be performed.
- **mode** (*str or function*) – One of the following string values or a user supplied function.
 - **'constant'** Pads with a constant value.
 - **'edge'** Pads with the edge values of array.
- **constant_values** (*float, optional*) – Used in 'constant'. Pad value

Returns *ndarray* – Padded 3D array.

`tomopy.misc.morph.sino_360_t0_180(data, overlap=0, rotation=u'left')`

Converts 0-360 degrees sinogram to a 0-180 sinogram.

Parameters

- **data** (*ndarray*) – Input 3D data.
- **overlap** (*scalar, optional*) – Overlapping number of pixels.
- **rotation** (*string, optional*) – Left if rotation center is close to the left of the field-of-view, right otherwise.

Returns *ndarray* – Output 3D data.

`tomopy.misc.morph.trim_sinogram(data, center, x, y, diameter)`

Provide sinogram corresponding to a circular region of interest by trimming the complete sinogram of a compact object.

Parameters

- **data** (*ndarray*) – Input 3D data.
- **center** (*float*) – Rotation center location.
- **x, y** (*int, int*) – x and y coordinates in pixels (image center is (0, 0))
- **diameter** (*float*) – Diameter of the circle of the region of interest.

Returns *ndarray* – Output 3D data.

2.6.3 tomopy.misc.phantom

Module for generating synthetic phantoms.

Functions:

<code>baboon([size, dtype])</code>	Load test baboon image array.
<code>barbara([size, dtype])</code>	Load test Barbara image array.
<code>cameraman([size, dtype])</code>	Load test cameraman image array.
<code>checkerboard([size, dtype])</code>	Load test checkerboard image array.
<code>lena([size, dtype])</code>	Load test Lena image array.
<code>peppers([size, dtype])</code>	Load test peppers image array.
<code>phantom(size, params[, dtype])</code>	Generate a cube of given size using a list of ellipsoid parameters.
<code>shepp2d([size, dtype])</code>	Load test Shepp-Logan image array.
<code>shepp3d([size, dtype])</code>	Load 3D Shepp-Logan image array.

`tomopy.misc.phantom.baboon(size=512, dtype=u'float32')`

Load test baboon image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.barbara(size=512, dtype=u'float32')`

Load test Barbara image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.cameraman (size=512, dtype=u'float32')`
Load test cameraman image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.checkerboard (size=512, dtype=u'float32')`
Load test checkerboard image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.lena (size=512, dtype=u'float32')`
Load test Lena image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.peppers (size=512, dtype=u'float32')`
Load test peppers image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.shepp2d (size=512, dtype=u'float32')`
Load test Shepp-Logan image array.

Parameters

- **size** (*int or tuple of int, optional*) – Size of the output image.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.shepp3d (size=128, dtype=u'float32')`
Load 3D Shepp-Logan image array.

Parameters

- **size** (*int or tuple, optional*) – Size of the 3D data.
- **dtype** (*str, optional*) – The desired data-type for the array.

Returns *ndarray* – Output 3D test image.

`tomopy.misc.phantom.phantom` (*size, params, dtype=u'float32'*)

Generate a cube of given size using a list of ellipsoid parameters.

Parameters

- **size** (*tuple of int*) – Size of the output cube.
- **params** (*list of dict*) – List of dictionaries with the parameters defining the ellipsoids to include in the cube.
- **dtype** (*str, optional*) – Data type of the output ndarray.

Returns *ndarray* – 3D object filled with the specified ellipsoids.

2.6.4 tomopy.prep.normalize

Module for data normalization.

Functions:

<code>normalize</code> (<i>arr, flat, dark[, cutoff, ncore, out]</i>)	Normalize raw projection data using the flat and dark field projections.
<code>normalize_bg</code> (<i>tomo[, air, ncore, nchunk]</i>)	Normalize 3D tomography data based on background intensity.
<code>normalize_nf</code> (<i>tomo, flats, dark, flat_loc[, ...]</i>)	Normalize raw 3D projection data with flats taken more than once during tomogra

`tomopy.prep.normalize.minus_log` (*arr, out=None*)

In-place computation of the minus log of a given array.

Parameters

- **arr** (*ndarray*) – 3D stack of projections.
- **out** (*ndarray, optional*) – Output array for result. If same as arr, process will be done in-place.

Returns *ndarray* – Minus-log of the input data.

`tomopy.prep.normalize.normalize` (*arr, flat, dark, cutoff=None, ncore=None, out=None*)

Normalize raw projection data using the flat and dark field projections.

Parameters

- **arr** (*ndarray*) – 3D stack of projections.
- **flat** (*ndarray*) – 3D flat field data.
- **dark** (*ndarray*) – 3D dark field data.
- **cutoff** (*float, optional*) – Permitted maximum vaue for the normalized data.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **out** (*ndarray, optional*) – Output array for result. If same as arr, process will be done in-place.

Returns *ndarray* – Normalized 3D tomographic data.

`tomopy.prep.normalize.normalize_bg` (*tomo, air=1, ncore=None, nchunk=None*)

Normalize 3D tomography data based on background intensity.

Weight sinogram such that the left and right image boundaries (i.e., typically the air region around the object) are set to one and all intermediate values are scaled linearly.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **air** (*int, optional*) – Number of pixels at each boundary to calculate the scaling factor.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Corrected 3D tomographic data.

`tomopy.prep.normalize.normalize_roi(arr; roi=[0, 0, 10, 10], ncore=None)`

Normalize raw projection data using an average of a selected window on projection images.

Parameters

- **arr** (*ndarray*) – 3D tomographic data.
- **roi** (*list of int, optional*) – [top-left, top-right, bottom-left, bottom-right] pixel coordinates.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.

Returns *ndarray* – Normalized 3D tomographic data.

`tomopy.prep.normalize.normalize_nf(tomo, flats, dark, flat_loc, cutoff=None, ncore=None)`

Normalize raw 3D projection data with flats taken more than once during tomography. Normalization for each projection is done with the mean of the nearest set of flat fields (nearest flat fields).

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **flats** (*ndarray*) – 3D flat field data.
- **dark** (*ndarray*) – 3D dark field data.
- **flat_loc** (*list of int*) – Indices of flat field data within tomography
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.

Returns *ndarray* – Normalized 3D tomographic data.

2.6.5 tomopy.prep.phase

Module for phase retrieval.

Functions:

`retrieve_phase(tomo[, pixel_size, dist, ...])` Perform single-step phase retrieval from phase-contrast measurements [C6].

`tomopy.prep.phase.retrieve_phase(tomo, pixel_size=0.0001, dist=50, energy=20, alpha=0.001, pad=True, ncore=None, nchunk=None)`

Perform single-step phase retrieval from phase-contrast measurements [C6].

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **pixel_size** (*float, optional*) – Detector pixel size in cm.
- **dist** (*float, optional*) – Propagation distance of the wavefront in cm.

- **energy** (*float, optional*) – Energy of incident wave in keV.
- **alpha** (*float, optional*) – Regularization parameter.
- **pad** (*bool, optional*) – If True, extend the size of the projections by padding with zeros.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Approximated 3D tomographic phase data.

2.6.6 tomo.py.prep.stripe

Module for pre-processing tasks.

Functions:

<code>remove_stripe_fw(tomo[, level, wname, ...])</code>	Remove horizontal stripes from sinogram using the Fourier-Wavelet (FW) based method [C4].
<code>remove_stripe_ti(tomo[, nblock, alpha, ...])</code>	Remove horizontal stripes from sinogram using Titarenko's approach [C8].
<code>remove_stripe_sf(tomo[, size, ncore, nchunk])</code>	Normalize raw projection data using a smoothing filter approach.

`tomo.py.prep.stripe.remove_stripe_fw(tomo, level=None, wname=u'db5', sigma=2, pad=True, ncore=None, nchunk=None)`
Remove horizontal stripes from sinogram using the Fourier-Wavelet (FW) based method [C4].

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **level** (*int, optional*) – Number of discrete wavelet transform levels.
- **wname** (*str, optional*) – Type of the wavelet filter. 'haar', 'db5', 'sym5', etc.
- **sigma** (*float, optional*) – Damping parameter in Fourier space.
- **pad** (*bool, optional*) – If True, extend the size of the sinogram by padding with zeros.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Corrected 3D tomographic data.

`tomo.py.prep.stripe.remove_stripe_ti(tomo, nblock=0, alpha=1.5, ncore=None, nchunk=None)`
Remove horizontal stripes from sinogram using Titarenko's approach [C8].

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **nblock** (*int, optional*) – Number of blocks.
- **alpha** (*int, optional*) – Damping factor.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Corrected 3D tomographic data.

```
tomopy.prep.stripe.remove_stripe_sf(tomo, size=5, ncore=None, nchunk=None)
```

Normalize raw projection data using a smoothing filter approach.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **size** (*int, optional*) – Size of the smoothing filter.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Corrected 3D tomographic data.

2.6.7 tomopy.recon.algorithm

Module for reconstruction algorithms.

Functions:

recon(tomo, theta[, center, sinogram_order, ...]) Reconstruct object from projection data.

```
tomopy.recon.algorithm.recon(tomo, theta, center=None, sinogram_order=False, algo-
                             rithm=None, init_recon=None, ncore=None, nchunk=None,
                             **kwargs)
```

Reconstruct object from projection data.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **theta** (*array*) – Projection angles in radian.
- **center** (*array, optional*) – Location of rotation axis.
- **sinogram_order** (*bool, optional*) – Determines whether data is a stack of sinograms (True, y-axis first axis) or a stack of radiographs (False, theta first axis).
- **algorithm** (*{str, function}*) – One of the following string values.
 - ‘**art**’ Algebraic reconstruction technique [C2].
 - ‘**bart**’ Block algebraic reconstruction technique.
 - ‘**fbp**’ Filtered back-projection algorithm.
 - ‘**gridrec**’ Fourier grid reconstruction algorithm [C5], [C17].
 - ‘**mlem**’ Maximum-likelihood expectation maximization algorithm [C3].
 - ‘**osem**’ Ordered-subset expectation maximization algorithm [C13].
 - ‘**ospml_hybrid**’ Ordered-subset penalized maximum likelihood algorithm with weighted linear and quadratic penalties.
 - ‘**ospml_quad**’ Ordered-subset penalized maximum likelihood algorithm with quadratic penalties.
 - ‘**pml_hybrid**’ Penalized maximum likelihood algorithm with weighted linear and quadratic penalties [C14].

- **'pml_quad'** Penalized maximum likelihood algorithm with quadratic penalty.
- **'sirt'** Simultaneous algebraic reconstruction technique.
- **num_gridx, num_gridy** (*int, optional*) – Number of pixels along x- and y-axes in the reconstruction grid.
- **filter_name** (*str, optional*) – Name of the filter for analytic reconstruction.
 - **'none'** No filter.
 - **'shepp'** Shepp-Logan filter (default).
 - **'cosine'** Cosine filter.
 - **'hann'** Cosine filter.
 - **'hamming'** Hamming filter.
 - **'ramlak'** Ram-Lak filter.
 - **'parzen'** Parzen filter.
 - **'butterworth'** Butterworth filter.
- **filter_par** (*list, optional*) – Filter parameters as a list.
- **num_iter** (*int, optional*) – Number of algorithm iterations performed.
- **num_block** (*int, optional*) – Number of data blocks for intermediate updating the object.
- **ind_block** (*array of int, optional*) – Order of projections to be used for updating.
- **reg_par** (*float, optional*) – Regularization parameter for smoothing.
- **init_recon** (*ndarray, optional*) – Initial guess of the reconstruction.
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – Reconstructed 3D object.

Warning: Filtering is not implemented for fbp.

Example

```
>>> import tomopy
>>> obj = tomopy.shepp3d() # Generate an object.
>>> ang = tomopy.angles(180) # Generate uniformly spaced tilt angles.
>>> sim = tomopy.project(obj, ang) # Calculate projections.
>>> rec = tomopy.recon(sim, ang, algorithm='art') # Reconstruct object.
>>>
>>> # Show 64th slice of the reconstructed object.
>>> import pylab
>>> pylab.imshow(rec[64], cmap='gray')
>>> pylab.show()
```

Example using the ASTRA toolbox for reconstruction

For more information, see <http://sourceforge.net/p/astra-toolbox/wiki/Home/> and <https://github.com/astra-toolbox/astra-toolbox>. To install the ASTRA toolbox with conda, use:

```
conda install -c https://conda.binstar.org/astra-toolbox astra-toolbox
```

```
>>> import tomopy
>>> obj = tomopy.shepp3d() # Generate an object.
>>> ang = tomopy.angles(180) # Generate uniformly spaced tilt angles.
>>> sim = tomopy.project(obj, ang) # Calculate projections.
>>>
>>> # Reconstruct object:
>>> rec = tomopy.recon(sim, ang, algorithm=tomopy.astra,
>>>     options={'method':'SART', 'num_iter':10*180,
>>>     'proj_type':'linear',
>>>     'extra_options':{'MinConstraint':0}})
>>>
>>> # Show 64th slice of the reconstructed object.
>>> import pylab
>>> pylab.imshow(rec[64], cmap='gray')
>>> pylab.show()
```

`tomopy.recon.algorithm.init_tomo(tomo, sinogram_order, sharedmem=True)`

2.6.8 tomopy.recon.rotation

Module for functions related to finding axis of rotation.

Functions:

<code>find_center(tomo, theta[, ind, init, tol, ...])</code>	Find rotation axis location.
<code>find_center_vo(tomo[, ind, smin, smax, ...])</code>	Find rotation axis location using Nghia Vo's method.
<code>find_center_pc(proj1, proj2[, tol])</code>	Find rotation axis location by finding the offset between the first projection and a
<code>write_center(tomo, theta[, dpath, ...])</code>	Save images reconstructed with a range of rotation centers.

`tomopy.recon.rotation.find_center(tomo, theta, ind=None, init=None, tol=0.5, mask=True, ratio=1.0, sinogram_order=False)`

Find rotation axis location.

The function exploits systematic artifacts in reconstructed images due to shifts in the rotation center. It uses image entropy as the error metric and “Nelder-Mead” routine (of the `scipy` optimization module) as the optimizer [C7].

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **theta** (*array*) – Projection angles in radian.
- **ind** (*int, optional*) – Index of the slice to be used for reconstruction.
- **init** (*float*) – Initial guess for the center.
- **tol** (*scalar*) – Desired sub-pixel accuracy.
- **mask** (*bool, optional*) – If `True`, apply a circular mask to the reconstructed image to limit the analysis into a circular region.
- **ratio** (*float, optional*) – The ratio of the radius of the circular mask to the edge of the reconstructed image.
- **sinogram_order** (*bool, optional*) – Determines whether data is a stack of sinograms (`True`, y-axis first axis) or a stack of radiographs (`False`, theta first axis).

Returns *float* – Rotation axis location.

`tomopy.recon.rotation.find_center_vo(tomo, ind=None, smin=-40, smax=40, srad=10, step=1, ratio=2.0, drop=20)`
Find rotation axis location using Nghia Vo's method. [C18].

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **ind** (*int, optional*) – Index of the slice to be used for reconstruction.
- **smin, smax** (*int, optional*) – Reference to the horizontal center of the sinogram.
- **srad** (*float, optional*) – Fine search radius.
- **step** (*float, optional*) – Step of fine searching.
- **ratio** (*float, optional*) – The ratio between the FOV of the camera and the size of object. It's used to generate the mask.
- **drop** (*int, optional*) – Drop lines around vertical center of the mask.

Returns *float* – Rotation axis location.

`tomopy.recon.rotation.find_center_pc(proj1, proj2, tol=0.5)`

Find rotation axis location by finding the offset between the first projection and a mirrored projection 180 degrees apart using phase correlation in Fourier space. The `register_translation` function uses cross-correlation in Fourier space, optionally employing an upsampled matrix-multiplication DFT to achieve arbitrary subpixel precision. [C11].

Parameters

- **proj1** (*ndarray*) – 2D projection data.
- **proj2** (*ndarray*) – 2D projection data.
- **tol** (*scalar, optional*) – Subpixel accuracy

Returns *float* – Rotation axis location.

`tomopy.recon.rotation.write_center(tomo, theta, dpath=u'tmp/center', cen_range=None, ind=None, mask=False, ratio=1.0, sinogram_order=False)`

Save images reconstructed with a range of rotation centers.

Helps finding the rotation center manually by visual inspection of images reconstructed with a set of different centers. The output images are put into a specified folder and are named by the center position corresponding to the image.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **theta** (*array*) – Projection angles in radian.
- **dpath** (*str, optional*) – Folder name to save output images.
- **cen_range** (*list, optional*) – [start, end, step] Range of center values.
- **ind** (*int, optional*) – Index of the slice to be used for reconstruction.
- **mask** (*bool, optional*) – If `True`, apply a circular mask to the reconstructed image to limit the analysis into a circular region.
- **ratio** (*float, optional*) – The ratio of the radius of the circular mask to the edge of the reconstructed image.

- **sinogram_order** (*bool, optional*) – Determines whether data is a stack of sinograms (True, y-axis first axis) or a stack of radiographs (False, theta first axis).

2.6.9 tomopy.sim.project

Module for simulation of x-rays.

Functions:

<code>angles(nang[, angl, ang2])</code>	Return uniformly distributed projection angles in radian.
<code>project(obj, theta[, center, emission, ...])</code>	Project x-rays through a given 3D object.
<code>fan_to_para(tomo, dist, geom)</code>	Convert fan-beam data to parallel-beam data.
<code>para_to_fan(tomo, dist, geom)</code>	Convert parallel-beam data to fan-beam data.
<code>add_gaussian(tomo[, mean, std])</code>	Add Gaussian noise.
<code>add_poisson(tomo)</code>	Add Poisson noise.
<code>add_salt_pepper(tomo[, prob, val])</code>	Add salt and pepper noise.
<code>add_focal_spot_blur(tomo, spotsize)</code>	Add focal spot blur.

`tomopy.sim.project.angles` (*nang, angl=0.0, ang2=180.0*)
Return uniformly distributed projection angles in radian.

Parameters

- **nang** (*int, optional*) – Number of projections.
- **ang1** (*float, optional*) – First projection angle in degrees.
- **ang2** (*float, optional*) – Last projection angle in degrees.

Returns *array* – Projection angles

`tomopy.sim.project.project` (*obj, theta, center=None, emission=True, sinogram_order=False, ncore=None, nchunk=None*)
Project x-rays through a given 3D object.

Parameters

- **obj** (*ndarray*) – Voxelized 3D object.
- **theta** (*array*) – Projection angles in radian.
- **center** (*array, optional*) – Location of rotation axis.
- **emission** (*bool, optional*) – Determines whether output data is emission or transmission type.
- **sinogram_order** (*bool, optional*) – Determines whether output data is a stack of sinograms (True, y-axis first axis) or a stack of radiographs (False, theta first axis).
- **ncore** (*int, optional*) – Number of cores that will be assigned to jobs.
- **nchunk** (*int, optional*) – Chunk size for each core.

Returns *ndarray* – 3D tomographic data.

`tomopy.sim.project.fan_to_para` (*tomo, dist, geom*)
Convert fan-beam data to parallel-beam data.

Warning: Not implemented yet.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **dist** (*float*) – Distance from fan-beam vertex to rotation center.
- **geom** (*str*) – Fan beam geometry. ‘arc’ or ‘line’.

Returns *ndarray* – Transformed 3D tomographic data.

`tomopy.sim.project.para_to_fan(tomo, dist, geom)`
Convert parallel-beam data to fan-beam data.

Warning: Not implemented yet.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **dist** (*float*) – Distance from fan-beam vertex to rotation center.
- **geom** (*str*) – Fan beam geometry. ‘arc’ or ‘line’.

Returns *ndarray* – Transformed 3D tomographic data.

`tomopy.sim.project.add_gaussian(tomo, mean=0, std=None)`
Add Gaussian noise.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **mean** (*float, optional*) – Mean of the Gaussian distribution.
- **std** (*float, optional*) – Standard deviation of the Gaussian distribution.

Returns *ndarray* – 3D tomographic data after Gaussian noise added.

`tomopy.sim.project.add_poisson(tomo)`
Add Poisson noise.

Parameters **tomo** (*ndarray*) – 3D tomographic data.

Returns *ndarray* – 3D tomographic data after Poisson noise added.

`tomopy.sim.project.add_salt_pepper(tomo, prob=0.01, val=None)`
Add salt and pepper noise.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **prob** (*float, optional*) – Independent probability that each element of a pixel might be corrupted by the salt and pepper type noise.
- **val** (*float, optional*) – Value to be assigned to the corrupted pixels.

Returns *ndarray* – 3D tomographic data after salt and pepper noise added.

`tomopy.sim.project.add_focal_spot_blur(tomo, spotsize)`
Add focal spot blur.

Warning: Not implemented yet.

Parameters

- **tomo** (*ndarray*) – 3D tomographic data.
- **spotsize** (*float*) – Focal spot size of circular x-ray source.

2.6.10 tomopy.sim.propagate

Module for simulation of x-rays.

Functions:

propagate_tie(*mu*, *delta*, *pixel_size*, *dist*) Propagate emitting x-ray wave based on Transport of Intensity.

`tomopy.sim.propagate.calc_intensity` (*probe*, *proj*, *shift_x=None*, *shift_y=None*,
mode=u'near')

Calculate far field intensity.

Parameters

- **probe** (*ndarray*) – Rectangular x-ray source kernel.
- **proj** (*ndarray*) – Object plane intensity image.
- **shift_x, shift_y** (*int, optional*) – Shift amount of probe along x and y axes.
- **mode** (*str, optional*) – Specify the regime. ‘near’ or ‘far’

Returns *ndarray* – Individual raster scanned far field images as 3D array.

`tomopy.sim.propagate.propagate_tie` (*mu*, *delta*, *pixel_size*, *dist*)

Propagate emitting x-ray wave based on Transport of Intensity.

Parameters

- **mu** (*ndarray, optional*) – 3D tomographic data for attenuation.
- **delta** (*ndarray*) – 3D tomographic data for refractive index.
- **pixel_size** (*float*) – Detector pixel size in cm.
- **dist** (*float*) – Propagation distance of the wavefront in cm.

Returns *ndarray* – 3D propagated tomographic intensity.

`tomopy.sim.propagate.probe_gauss` (*nx*, *ny*, *fwhm=None*, *center=None*, *max_int=1*)

Simulate incident x-ray beam (probe) as a square Gaussian kernel.

Parameters

- **nx, ny** (*int*) – Grid size along x and y axes.
- **fwhm** (*float, optional*) – Effective radius of the source.
- **center** (*array_like, optional*) – x and y coordinates of the center of the gaussian function.
- **max_int** (*int*) – Maximum x-ray intensity.

Returns *ndarray* – 2D source intensity distribution.

2.7 Examples

This section contains [Jupyter Notebooks](#) and Python scripts examples for various tomoPy functions.

To run these examples in a [notebooks](#) install [Jupyter](#) or run the python scripts from [here](#)

2.7.1 Gridrec

Here is an example on how to use the gridrec [\[C5\]](#) reconstruction algorithm with [TomoPy \[A1\]](#). You can download the python scrip [here](#) or the Jupyter notebook [here](#)

```
%pylab inline
```

Install TomoPy then:

```
import tomopy
```

Tomographic data input in TomoPy is supported by [DXchange](#).

```
import dxchange
```

matplotlib provide plotting of the result in this notebook. [Paraview](#) or other tools are available for more sophisticated 3D rendering.

```
import matplotlib.pyplot as plt
```

Set the path to the micro-CT data to reconstruct.

```
fname = '../..../tomopy/data/tooth.h5'
```

Select the sinogram range to reconstruct.

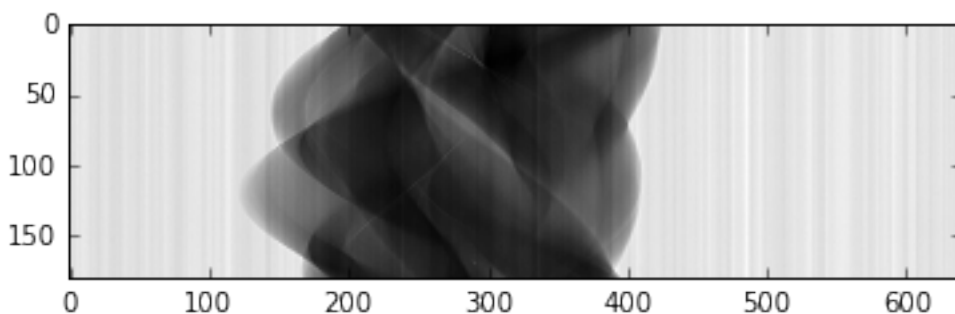
```
start = 0
end = 2
```

tooth.h5 data set file format follows the [APS beamline 2-BM and 32-ID data-exchange](#) file format definition. Major synchrotron file format [examples](#) are available at [DXchange](#).

```
proj, flat, dark = dxchange.read_aps_32id(fname, sino=(start, end))
```

Plot the sinogram:

```
plt.imshow(proj[:, 0, :], cmap='Greys_r')
plt.show()
```



If the angular information is not available from the raw data you need to set the data collection angles. In this case theta is set as equally spaced between 0-180 degrees.

```
theta = tomopy.angles(proj.shape[0])
```

Perform the flat-field correction of raw data:

$$\frac{proj - dark}{flat - dark}$$

```
proj = tomopy.normalize(proj, flat, dark)
```

Tomopy provides various methods ([C7], [C18], [C11]) to find the [rotation center](#).

```
rot_center = tomopy.find_center(proj, theta, init=290, ind=0, tol=0.5)
```

```
tomopy.rotation:Trying center: [ 290.]
tomopy.rotation:Trying center: [ 304.5]
tomopy.rotation:Trying center: [ 275.5]
tomopy.rotation:Trying center: [ 282.75]
tomopy.rotation:Trying center: [ 297.25]
tomopy.rotation:Trying center: [ 304.5]
tomopy.rotation:Trying center: [ 304.5]
tomopy.rotation:Trying center: [ 293.625]
tomopy.rotation:Trying center: [ 290.]
tomopy.rotation:Trying center: [ 295.4375]
tomopy.rotation:Trying center: [ 291.8125]
tomopy.rotation:Trying center: [ 294.53125]
tomopy.rotation:Trying center: [ 295.4375]
tomopy.rotation:Trying center: [ 294.078125]
```

Calculate

$$-log(proj)$$

```
proj = tomopy.minus_log(proj)
```

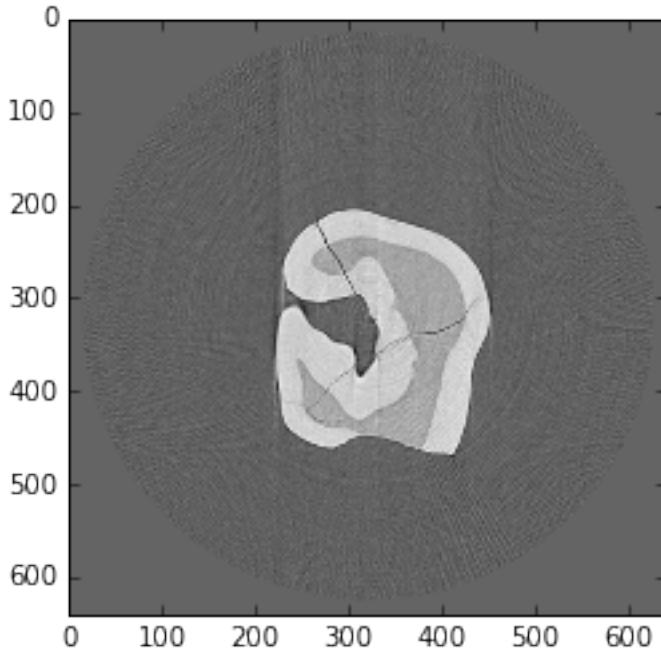
Reconstruction using Gridrec algorithm. Tomopy provides various [reconstruction](#) methods including the one part of the [ASTRA toolbox](#).

```
recon = tomopy.recon(proj, theta, center=rot_center, algorithm='gridrec')
```

Mask each reconstructed slice with a circle.

```
recon = tomopy.circ_mask(recon, axis=0, ratio=0.95)
```

```
plt.imshow(recon[0, :, :], cmap='Greys_r')
plt.show()
```



2.8 Frequently asked questions

Here's a list of questions.

Questions

- *How can I report bugs?*
- *Are there any video tutorials?*
- *Can I run this on a HPC cluster?*
- *Are there any segmentation routines?*
- *Are there any tools for aligning projections?*
- *What is ASTRA toolbox?*
- *Why TomoPy and ASTRA were integrated?*
- *Which platforms are supported?*
- *Does ASTRA support all GPUs?*

2.8.1 How can I report bugs?

The easiest way to report bugs or get help is to open an issue on GitHub. Simply go to the [project GitHub page](#), click on [Issues](#) in the right menu tab and submit your report or question.

2.8.2 Are there any video tutorials?

We currently do not have specific plans in this direction, but we agree that it would be very helpful.

2.8.3 Can I run this on a HPC cluster?

In their default installation packages, TomoPy and the ASTRA toolbox are limited to running on a multicore single machine. The ASTRA toolbox, and TomoPy through the presented ASTRA integration, are able to use multiple GPUs that are installed in a single machine. Both toolboxes can be run on a HPC cluster through parallelization using MPI, but since installation and running on a HPC cluster is often cluster specific, the default installation packages do not include these capabilities.

As such, the integrated packages that is presented in the manuscript currently does not support running on a HPC cluster. Note that the ASTRA toolbox provides a separate MPI enabled package for use on a HPC cluster. We refer to [C19] for more details about TomoPy's planned HPC implementation. It is a MapReduce type MPI implementation layer, which was successfully used on many clusters, i.e. Stampede, Cori, Mira. There are plans to allow user access to TomoPy on a HPC cluster (e.g. through a client or webportal), but these projects will take some time before they are being matured for user's use.

2.8.4 Are there any segmentation routines?

Some data processing operations can be applied after reconstruction. Examples of these type of operations are image based ring removal methods, and gaussian filtering or median filtering the reconstructed image. Typically, these methods are called "postprocessing algorithms, since they occur after the reconstruction.

The package does not include segmentation algorithms, since we are currently focused on tomography, while we feel that segmentation are more part of the application specific data analysis that occurs after tomographic processing. An important exception is when segmentation steps are used as part of the tomographic reconstruction algorithm, such as in the DART algorithm.

2.8.5 Are there any tools for aligning projections?

We wish we have! But currently neither TomoPy nor the ASTRA toolbox currently provides any tools for automatically aligning projection images. Note that they might be included in TomoPy in the future. There are multiple groups interested and working on developing robust methods for automatic alignment, and if they can justify their utility, the developed methods will be readily included in TomoPy. Also note that the building blocks provided by the ASTRA toolbox could be used to develop new alignment methods.

2.8.6 What is ASTRA toolbox?

The ASTRA toolbox provides highly efficient tomographic reconstruction methods by implementing them on graphic processing units (GPUs). It includes advanced iterative methods and allows for very flexible scanning geometries. The ASTRA toolbox also includes building blocks which can be used to develop new reconstruction methods, allowing for easy and efficient implementation and modification of advanced reconstruction methods. However, the toolbox is only focused on reconstruction, and does not include pre-processing or post-processing methods that are typically required for correctly processing synchrotron data. Furthermore, no routines to read data from disk are provided by the toolbox.

2.8.7 Why TomoPy and ASTRA were integrated?

The TomoPy toolbox is specifically designed to be easy to use and deploy at a synchrotron facility beamline. It supports reading many common synchrotron data formats from disk [C10], and includes several other processing algorithms commonly used for synchrotron data. TomoPy also includes several reconstruction algorithms, which can be run on multi-core workstations and large-scale computing facilities. The algorithms in TomoPy are all CPU-based, however,

which can make them prohibitively slow in the case of iterative methods, which are often required for advanced tomographic experiments.

By integrating the ASTRA toolbox in the TomoPy framework, the optimized GPU-based reconstruction methods become easily available for synchrotron beamline users, and users of the ASTRA toolbox can more easily read data and use TomoPy's other functionality for data filtering and cleaning.

2.8.8 Which platforms are supported?

TomoPy supports Linux and Mac OS X, and the ASTRA toolbox supports Linux and Windows. As such, the combined package currently supports only Linux, but we are working on supporting more operating systems.

2.8.9 Does ASTRA support all GPUs?

The GPU algorithms are all implemented using nVidia CUDA. As a result, only nVidia CUDA enabled video cards can be used to run them.

2.9 Credits

We kindly request that you cite the following article(s) [\[A1\]](#) if you use TomoPy (and also cite [\[A2\]](#) if you use ASTRA).

2.9.1 Applications

2.9.2 References

License

The project is licensed under the [BSD-3](#) license.

Indices and tables

- `genindex`
- `modindex`
- `search`

-
- [A1] Gürsoy D, De Carlo F, Xiao X, and Jacobsen C. Tomopy: a framework for the analysis of synchrotron tomographic data. *Journal of Synchrotron Radiation*, 21(5):1188–1193, 2014.
- [A2] Pelt D, Gürsoy D, Palenstijn WJ, Sijbers J, De Carlo F, and Batenburg KJ. Integration of tomopy and the astra toolbox for advanced processing and reconstruction of tomographic synchrotron data. *Journal of Synchrotron Radiation*, 23(3):842–849, 2016.
- [B1] Patterson BM, Cordes NL, Henderson K, Williams JJ, Stannard T, Singh SS, Ovejero AR, Xiao X, Robinson M, and Chawla N. In situ x-ray synchrotron tomographic imaging during the compression of hyper-elastic polymeric materials. *Journal of Materials Science*, 51(1):171–187, 2016.
- [B2] Phatak C and Gürsoy D. Iterative reconstruction of magnetic induction using lorentz transmission electron tomography. *Ultramicroscopy*, 150:54–64, 2015.
- [B3] Gürsoy D, Biçer T, Lanzirotti A, Newville MG, and De Carlo F. Hyperspectral image reconstruction for x-ray fluorescence tomography. *Optics Express*, 23(7):9014–9023, 2015.
- [B4] Gürsoy D, Biçer T, Almer JD, Kettimuthu R, Stock SR, and De Carlo F. Maximum a posteriori estimation of crystallographic phases in x-ray diffraction tomography. *Philosophical Transactions A*, 2015.
- [B5] Duke DJ, Swantek AB, Sovis N, Tilocco FZ, Powell CF, AL Kastengren, Gürsoy D, and Biçer T. Time-resolved x-ray tomography of gasoline direct injection sprays. *SAE International Journal of Engines*, 2015.
- [B6] Kamke FA, McKinley PE, Ching DJ, Zauner M, and Xiao X. Micro x-ray computed tomography of adhesive bonds in wood. *Wood and Fiber Science*, 2016.
- [B7] Birkbak ME, Leemreize H, Frohlich S, Stock SR, and Birkedal H. Diffraction scattering computed tomography: a window into the structures of complex nanomaterials. *Nanoscale*, 2015.
- [B8] Miller SM, Xiao X, and Faber KT. Freeze-cast alumina pore networks: effects of freezing conditions and dispersion medium. *Journal of the European Ceramic Society*, 35(13):3595–3605, 2015.
- [B9] Roncal WG, Dyer EL, Gürsoy D, Kording K, and Kasthuri N. From sample to knowledge: towards an integrated approach for neuroscience discovery. *arXiv*, 2016.
- [C1] Bergamaschi A, Medjoubi K, Messaoudi C, Marco S, and Somogyi A. Mmx-i: data-processing software for multimodal x-ray imaging and tomography. *Journal of Synchrotron Radiation*, 23:783–794, 2016.
- [C2] Kak AC and Slaney M. *Principles of computerized tomographic imaging*. volume 33. SIAM, 1988.
- [C3] Dempster AP, Laird NM, and Rubin DB. Maximum likelihood from incomplete data via the em algorithm. *Journal of the Royal Statistical Society, Series B*, 39(1):1–38, 1977.
-

- [C4] Münch B, Trtik P, Marone F, and Stampanoni M. Stripe and ring artifact removal with combined wavelet–fourier filtering. *Optics Express*, 17(10):8567–8591, 2009.
- [C5] Dowd BA, Campbell GH, Marr RB, Nagarkar VV, Tipnis SV, Axe L, and Siddons DP. Developments in synchrotron x-ray computed microtomography at the national synchrotron light source. In *Proc. SPIE*, volume 3772, 224–236. 1999.
- [C6] Paganin D, Mayo SC, Gureyev TE, Miller PR, and Wilkins SW. Simultaneous phase and amplitude extraction from a single defocused image of a homogeneous object. *Journal of Microscopy*, 206(1):33–40, 2002.
- [C7] Tilman D, Felix B, and Andreas S. Automated determination of the center of rotation in tomography data. *Journal of the Optical Society of America A*, 23(5):1048–1057, 2006.
- [C8] Miqueles EX, Rinkel J, O’Dowd F, and Bermúdez JSV. Generalized titarenko’s algorithm for ring artefacts reduction. *Journal of Synchrotron Radiation*, 21(6):1333–1346, 2014.
- [C9] Brun F, Pacile S, Accardo A, Kourousias G, Dreossi D, Mancini L, Tromba G, and Pugliese R. Enhanced and flexible software tools for x-ray computed tomography at the italian synchrotron radiation facility elettrá. *Fundamenta Informaticae*, 141(2-3):233–243, 2015.
- [C10] De Carlo F, Gürsoy D, Marone F, Rivers M, Parkinson YD, Khan F, Schwarz N, Vine DJ, Vogt S, Gleber SC, Narayanan S, Newville M, Lanzirotti T, Sun Y, Hong YP, and Jacobsen C. Scientific data exchange: a schema for hdf5-based storage of raw and analyzed data. *Journal of Synchrotron Radiation*, 21(6):1224–1230, 2014.
- [C11] Manuel GS, Thurman ST, and Fienup JR. Efficient subpixel image registration algorithms. *Optics Letters*, 33(2):156–158, 2008.
- [C12] Toby HB, Gürsoy D, De Carlo F, Schwarz N, Sharma H, and Jacobsen CJ. Practices and standards for data and processing at the APS. *Synchrotron Radiation News*, 28(2):15–21, 2015.
- [C13] Hudson HM and Larkin RS. Accelerated image reconstruction using ordered subsets of projection data. *Medical Imaging, IEEE Transactions on*, 13(4):601–609, 1994.
- [C14] Chang J-H, Anderson JMM, and Votaw JT. Regularized image reconstruction algorithms for positron emission tomography. *Medical Imaging, IEEE Transactions on*, 23(9):1165–1175, 2004.
- [C15] Mertens JCE and Chawla JJWN. A method for zinger artifact reduction in high-energy x-ray computed tomography. *Nuclear Instruments and Methods in Physics Research Section A*, 800:82–92, 2015.
- [C16] De Jonge MD, Ryan CG, and Jacobsen C. X-ray nanoprobe and diffraction-limited storage rings: opportunities and challenges of fluorescence tomography of biological specimens. *Journal of Synchrotron Radiation*, 21(5):1031–1047, 2014.
- [C17] Rivers ML. Tomorecon: high-speed tomography reconstruction on workstations using multi-threading. In *Proc. SPIE*, volume 8506, 85060U–85060U–13. 2012.
- [C18] Vo N, Drakopoulos M, Atwood RC, and Reinhard C. Reliable method for calculating the center of rotation in parallel-beam tomography. *Optics Express*, 22(16):19078–19086, 2014.
- [C19] Biçer T, Gürsoy D, Kettimuthu R, De Carlo F, Agrawal G, and Foster IT. Rapid tomographic image reconstruction via large-scale parallelization. In *Lecture Notes in Computer Science*, volume 9233, 289–302. 2015.

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