
radontea Documentation

Release 0.3.1

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May 18, 2018

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Radontea is a Python 3 library for computerized tomographic image reconstruction. Radontea implements several iterative and non-iterative reconstruction algorithms. This is the documentaion of radontea version 0.3.1.

There are several methods to compute the inverse **Radon** transform. The module `radontea` implements some of them. I focused on code readability and thorough comments. The result is a collection of algorithms that are suitable for **teaching** the basics of computerized tomography.

1.1 Recommended literature

- Aninash C. Kak and Malcom Slaney. *Principles of Computerized Tomographic Imaging*. Ed. by Robert E. O'Malley. SIAM, 2001, p. 327. ISBN: 089871494X.
- Johann Radon. *Über die Bestimmung von Funktionen durch ihre Integralwerte längs gewisser Mannigfaltigkeiten*. Tech. rep. Leipzig: Berichte über die Verhandlungen der Königlich-Sächsischen Gesellschaft der Wissenschaften zu Leipzig, 1917, pp. 262–277.
- R A Crowther, D J DeRosier, and A Klug. *The Reconstruction of a Three-Dimensional Structure from Projections and its Application to Electron Microscopy*. In: Proceedings of the Royal Society of London. A. Mathematical and Physical Sciences 317.1530 (1970), pp. 319–340. doi: [10.1098/rspa.1970.0119](https://doi.org/10.1098/rspa.1970.0119).

1.2 Obtaining radontea

If you have Python and `numpy` installed, simply run

```
pip install radontea
```

The source code of `radontea` is available at <https://github.com/RI-imaging/radontea>.

1.3 Citing radontea

Please cite this package if you are using it in a scientific publication.

This package should be cited like this (replace “x.x.x” with the actual version of `radontea` that you used):

cite

Paul Müller (2013) *radontea: Python algorithms for the inversion of the Radon transform* (Version x.x.x) [Software]. Available at <https://pypi.python.org/pypi/radontea/>

You can find out what version you are using by typing (in a Python console):

```
>>> import radontea
>>> radontea.__version__
'0.1.4'
```


2.1 Parallel beam geometry

<code>radon_parallel(arr, angles[, count, max_count])</code>	Compute the Radon transform (sinogram) of a circular image.
<code>backproject(sinogram, angles[, filtering, ...])</code>	2D backprojection algorithm
<code>fourier_map(sinogram, angles[, intp_method, ...])</code>	2D Fourier mapping with the Fourier slice theorem
<code>integrate(sinogram, angles[, count, max_count])</code>	2D sum-reconstruction with the Fourier slice theorem
<code>art(sinogram, angles[, initial, iterations, ...])</code>	Algebraic Reconstruction Technique
<code>sart(sinogram, angles[, initial, ...])</code>	Simultaneous Algebraic Reconstruction Technique

2.1.1 Radon transform

`radon`.`radon_parallel` (*arr*, *angles*, *count=None*, *max_count=None*)

Compute the Radon transform (sinogram) of a circular image.

The `scipy` Radon transform performs this operation on the entire image, whereas this implementation requires an input image that has gray-scale values of 0 outside of a circle with diameter equal to the image size.

Parameters

- **arr** (*ndarray*, *shape* (N, N)) – the input image.
- **angles** (*ndarray*, *length* A) – angles or projections in radians
- **max_count** (*count*,) – Can be used to monitor the progress of the algorithm. Initially, the value of `max_count.value` is incremented by the total number of steps. At each step, the value of `count.value` is incremented.

Returns **outarr** – Sinogram of the input image. The i 'th row contains the projection data of the i 'th angle.

Return type `ndarray` of floats, shape (A, N)

See also:

`scipy.ndimage.interpolation.rotate()` The interpolator used to rotate the image.

2.1.2 Non-iterative reconstruction

Computes the inverse Radon transform with non-iterative techniques. The linear system of equations that describes the forward process can be inverted with several algorithms, most notably the backprojection algorithm `radontea.backproject()`. The reconstruction is based on the Fourier slice theorem. A Fourier-based interpolation algorithm is implemented in `radontea.fourier_map()`.

2.1.2.1 Backprojection

`radontea.backproject` (*sinogram*, *angles*, *filtering*='ramp', *weight_angles*=True, *padding*=True, *padval*=0, *count*=None, *max_count*=None, *verbose*=0)
2D backprojection algorithm

Computes the inverse of the Radon transform using filtered backprojection.

Parameters

- **sinogram** (*ndarray*, *shape* (A,N)) – Two-dimensional sinogram of line recordings.
- **angles** ((A,) *ndarray*) – Angular positions of the *sinogram* in radians from zero to PI.
- **filtering** (({'ramp', 'shepp-logan', 'cosine', 'hamming', 'hann'}, *optional*)) – Specifies the Fourier filter. Either of
 - "ramp": mathematically correct reconstruction
 - "shepp-logan"
 - "cosine"
 - "hamming"
 - "hann"
- **weight_angles** (*bool*) – If True, weights each backpropagated projection with a factor proportional to the angular distance between the neighboring projections.

$$\Delta\phi_0 \mapsto \Delta\phi_j = \frac{\phi_{j+1} - \phi_{j-1}}{2}$$

New in version 0.1.9.

- **padding** (*bool*, *optional*) – Pad the input data to the second next power of 2 before Fourier transforming. This reduces artifacts and speeds up the process for input image sizes that are not powers of 2.
- **padval** (*float*) – The value used for padding. If *padval* is None, then the edge values are used for padding (see documentation of `numpy.pad`).
- **max_count** (*count*,) – Can be used to monitor the progress of the algorithm. Initially, the value of *max_count.value* is incremented by the total number of steps. At each step, the value of *count.value* is incremented.
- **verbose** (*int*) – Increment to increase verbosity.

Returns *out* – The reconstructed image.

Return type *ndarray*

Examples

```
>>> import numpy as np
>>> from radontea import backproject
>>> N = 5
>>> A = 7
>>> x = np.linspace(-N/2, N/2, N)
>>> projection = np.exp(-x**2)
>>> sinogram = np.tile(projection, A).reshape(A,N)
>>> angles = np.linspace(0, np.pi, A, endpoint=False)
>>> backproject(sinogram, angles)
array([[ 0.03813283, -0.01972347, -0.02221885,  0.03822303,  0.01903376],
       [ 0.04033526, -0.01591647,  0.02262173,  0.04203002,  0.02123619],
       [ 0.02658797,  0.11375576,  0.41525594,  0.17170226,  0.0074889 ],
       [ 0.04008672,  0.11139209,  0.27650193,  0.16933859,  0.02098764],
       [ 0.02140445,  0.0334597 ,  0.07691547,  0.0914062 ,  0.00230537]])
```

2.1.2.2 Fourier mapping

`radontea.fourier_map` (*sinogram*, *angles*, *intp_method*='cubic', *count*=None, *max_count*=None)
2D Fourier mapping with the Fourier slice theorem

Computes the inverse of the Radon transform using Fourier interpolation. Warning: This is the naive reconstruction that assumes that the image is rotated through the upper left pixel nearest to the actual center of the image. We do not have this problem for odd images, only for even images.

Parameters

- **sinogram** ((A, N) *ndarray*) – Two-dimensional sinogram of line recordings.
- **angles** ($(A,)$ *ndarray*) – Angular positions of the *sinogram* in radians equally distributed from zero to π .
- **intp_method** ($\{ 'cubic', 'nearest', 'linear' \}$, *optional*) – Method of interpolation. For more information see *scipy.interpolate.griddata*. One of
 - "nearest": instead of interpolating, use the points closest to the input data
 - "linear": bilinear interpolation between data points
 - "cubic": interpolate using a two-dimensional polynomial surface
- **max_count** (*count*,) – Can be used to monitor the progress of the algorithm. Initially, the value of *max_count.value* is incremented by the total number of steps. At each step, the value of *count.value* is incremented.

Returns out – The reconstructed image.

Return type *ndarray*

See also:

`scipy.interpolate.griddata()` interpolation method used

2.1.2.3 Slow integration

`radontea.integrate` (*sinogram*, *angles*, *count*=None, *max_count*=None)
2D sum-reconstruction with the Fourier slice theorem

Computes the inverse of the Radon transform by computing the integral in real space.

Parameters

- **sinogram** ((A, N) *ndarray*) – Two-dimensional sinogram of line recordings.
- **angles** ($(A,)$ *ndarray*) – Angular positions of the *sinogram* in radians equally distributed from zero to PI .
- **max_count** (*count,*) – Can be used to monitor the progress of the algorithm. Initially, the value of *max_count.value* is incremented by the total number of steps. At each step, the value of *count.value* is incremented.

Returns **out** – The reconstructed image.

Return type *ndarray*

2.1.3 Iterative reconstruction

Inversion of Radon-based tomography methods using iterative algorithms. The convergence of these algorithms might be slow. The implementation is not optimized.

2.1.3.1 ART

`radontea.art` (*sinogram, angles, initial=None, iterations=1, count=None, max_count=None*)

Algebraic Reconstruction Technique

The Algebraic Reconstruction Technique (ART) iteratively computes the inverse of the Radon transform in two dimensions. The reconstruction technique uses *rays* of the diameter of one pixel to iteratively solve the system of linear equations that describe the projection process. The binary weighting factors are

- 1, if the center of the a pixel is within the *ray*
- 0, else

Parameters

- **sinogram** (*ndarray, shape (A, N)*) – Two-dimensional sinogram of line recordings.
- **angles** (*ndarray, length A*) – Angular positions of the *sinogram* in radians. The angles at which the sinogram slices were recorded do not have to be distributed equidistantly as in *backproject()*. The angles are internally converted to modulo PI .
- **initial** (*ndarray, shape (N, N), optional*) – The initial guess for the solution.
- **iterations** (*int*) – Number of iterations to perform.
- **max_count** (*count,*) – Can be used to monitor the progress of the algorithm. Initially, the value of *max_count.value* is incremented by the total number of steps. At each step, the value of *count.value* is incremented.

Notes

For theoretical background, see Kak, A. C., & Slaney, M.. *Principles of Computerized Tomographic Imaging*, SIAM, (2001)

Sec. 7.2: “ART reconstructions usually suffer from salt and pepper noise, which is caused by the inconsistencies introduced in the set of equations by the approximations commonly used for w_{ik} ‘s.”

2.1.3.2 SART

`radontea.sart` (*sinogram, angles, initial=None, iterations=1, count=None, max_count=None*)

Simultaneous Algebraic Reconstruction Technique

SART computes an inverse of the Radon transform in two dimensions. The reconstruction technique uses “rays” of the diameter of one pixel to iteratively solve the system of linear equations that describe the image. The weighting factors are bilinear elements. At the beginning and end of each ray, only partial weights are used. The pixel values of the image are updated only after each iteration is complete.

Parameters

- **sinogram** (*ndarray, shape (A,N)*) – Two-dimensional sinogram of line recordings.
- **angles** (*ndarray, length A*) – Angular positions of the *sinogram* in radians. The angles at which the sinogram slices were recorded do not have to be distributed equidistantly as in backprojection techniques. The angles are internally converted to modulo PI.
- **initial** (*ndarray, shape (N,N), optional*) – the initial guess for the solution.
- **iterations** (*integer*) – Number of iterations to perform.
- **max_count** (*count,*) – Can be used to monitor the progress of the algorithm. Initially, the value of *max_count.value* is incremented by the total number of steps. At each step, the value of *count.value* is incremented.

Notes

Algebraic reconstruction technique (ART) (see *art*): Iterations are performed over each ray of each projection. Weighting factors are binary (1 if center of pixel is within ray, 0 else). This leads to salt and pepper noise.

Simultaneous iterative reconstruction technique (SIRT): Same idea as ART, but for each iteration, the change of the image f is computed for all rays and projections separately and the weights are applied simultaneously after each iteration. The result is a slower convergence but the final image is also less noisy.

This implementation does NOT use a hamming window to filter the data and to emphasize points at the center of the reconstruction region.

For theoretical background, see Kak, A. C., & Slaney, M.. *Principles of Computerized Tomographic Imaging*, SIAM, (2001)

Sec 7.4: “[SART] seems to combine the best of ART and SIRT. [...] Here are the main features of SART: First, [...] the traditional pixel basis is abandoned in favor of bilinear elements [e.g. interpolation]. Also, for a circular reconstruction region, only partial weights are assigned to the first and last picture elements on the individual rays. To further reduce the noise [...], the correction terms are simultaneously applied for all the rays in one projection [...].”

2.2 Fan beam geometry

<code>fan.radon_fan(arr, det_size[, det_spacing, ...])</code>	Compute the Radon transform for a fan beam geometry
<code>fan.get_det_coords(size, spacing)</code>	Compute pixel-center positions for 2D detector
<code>fan.get_fan_coords(size, spacing, distance, ...)</code>	Compute equispaced angular coordinates for 2d detector
<code>fan.lino2sino(linogram, lds[, stepsize, ...])</code>	Convert linogram to sinogram for an equispaced detector.
<code>fan.fan_rec(linogram, lds, method[, ...])</code>	2D synthetic aperture reconstruction

2.2.1 Coordinate transforms

`radontea.fan.get_det_coords(size, spacing)`

Compute pixel-center positions for 2D detector

The centers of the pixels of a detector are usually not aligned to a pixel grid. If we center the detector at the origin, odd images will have a pixel at zero, whereas even images will have two pixels next to the actual center.

Parameters

- **size** (*int*) – Size of the detector (number of detection points).
- **spacing** (*float*) – Distance between two detection points in pixels.

Returns `arr` – Pixel coordinates.

Return type 1D ndarray

`radontea.fan.get_fan_coords(size, spacing, distance, numang)`

Compute equispaced angular coordinates for 2d detector

The centers of the pixels of a detector are usually not aligned to a pixel grid. If we center the detector at the origin, odd images will have a pixel at zero, whereas even images will have two pixels next to the actual center. We want to compute an equispaced array of *numang* angles that go between the centers of the outmost far pixels of the detector.

Parameters

- **size** (*int*) – Size of the detector (number of detection points).
- **spacing** (*float*) – Distance between two detection points in pixels.
- **distance** (*float*) – Axial distance from the detector to the angular measurement position in pixels.
- **numang** (*int*) – Number of angles.

Returns `angles, latpos` – Angles and pixel coordinates at the detector.

Return type two 1D ndarrays

Notes

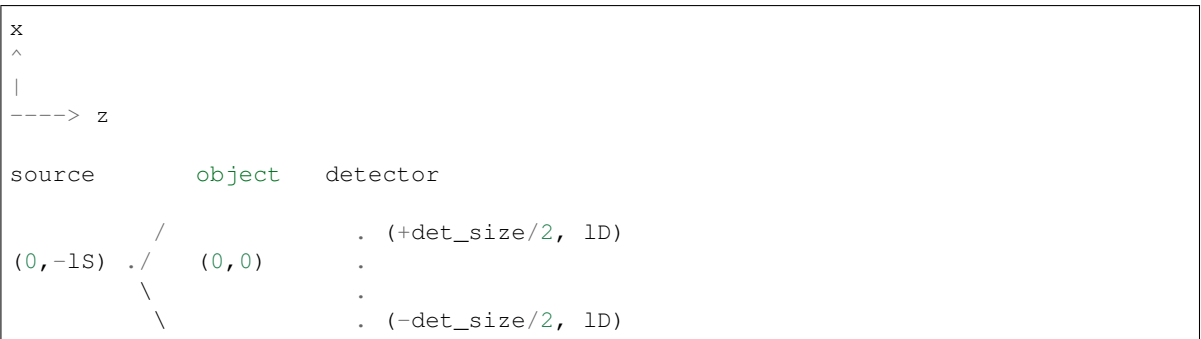
Actually one would not need to define spacing and distance, but for convenience, these parameters are separated and an arbitrary unit ‘pixel’ is defined.

`radontea.fan.radon_fan(arr, det_size, det_spacing=1, shift_size=1, lS=1, lD=None, return_ang=False, count=None, max_count=None)`

Compute the Radon transform for a fan beam geometry

In contrast to `radon_parallel()`, this function uses (1) a fan-beam geometry (the integral is taken along rays that meet at one point), and (2) translates the object laterally instead of rotating it. The result is sometimes referred to as ‘linogram’.

Problem sketch:



The algorithm computes all angular projections for discrete movements of the object. The position of the object is changed such that its lower boundary starts at $(\text{det_size}/2, 0)$ and its upper boundary ends at $(-\text{det_size}/2, 0)$ at increments of `shift_size`.

Parameters

- **arr** (*ndarray, shape (N,N)*) – the input image.
- **det_size** (*int*) – The total detector size in pixels. The detector centered to the source. The axial position of the detector is the center of the pixels on the far right of the object.
- **det_spacing** (*float*) – Distance between detection points in pixels.
- **shift_size** (*int*) – The amount of pixels that the object is shifted between projections.
- **1S** (*multiples of 0.5*) – Source position relative to the center of *arr*. $1S \geq 1$.
- **1D** (*int*) – Detector position relative to the center *arr*. Default is $N/2$.
- **return_ang** (*bool*) – Also return the angles corresponding to the detector pixels.
- **max_count** (*count,*) – Can be used to monitor the progress of the algorithm. Initially, the value of `max_count.value` is incremented by the total number of steps. At each step, the value of `count.value` is incremented.

Returns `outarr` – Linogram of the input image. Where $N+\text{det_size}$ determines the lateral position of the sample.

Return type `ndarray of floats, shape (N+det_size,det_size)`

See also:

`scipy.ndimage.interpolation.rotate()` The interpolator used to rotate the image.

`radontea.fan.lino2sino(linogram, lds, stepsize=1, det_spacing=1, numang=None, retang=False, count=None, max_count=None)`

Convert linogram to sinogram for an equispaced detector.

Parameters

- **linogram** (*real 2d ndarray of shape (D, A*)*) – Linogram from synthetic aperture measurements.
- **lds** (*float*) – Distance from point source to detector in au.
- **stepsize** (*float*) – Translational increment of object in au (stepsize in D).

- **det_spacing** (*float*) – Distance between detector positions in au.
- **numang** (*int*) – Number of equispaced angles, defaults to `linogram.shape[1]`
- **retang** (*bool*) – Return the corresponding angles for the sinogram.
- **max_count** (*count,*) – Can be used to monitor the progress of the algorithm. Initially, the value of `max_count.value` is incremented by the total number of steps. At each step, the value of `count.value` is incremented.

Returns **sinogram** – The distortion-corrected sinogram. If `retang` is `True`, then the equispaced angles are returned as well.

Return type 2d ndarray of shape (D, A)

Notes

This function can be used to convert a linogram obtained with fan-beam tomography to a sinogram, which then can be reconstructed with the backprojection or fourier mapping algorithms.

2.2.2 Reconstruction

`radontea.fan.fan_rec` (*linogram, lds, method, stepsize=1, det_spacing=1, numang=None, count=None, max_count=None, **kwargs*)
2D synthetic aperture reconstruction

Computes the inverse of the fan-beam Radon transform using interpolation of the linogram and one of the inverse algorithms for tomography with the Fourier slice theorem.

Parameters

- **linogram** (*2d ndarray of shape (D, A)*) – Input linogram from the synthetic aperture measurement.
- **lds** (*float*) – Distance in pixels between source and detector.
- **method** (*callable*) – Reconstruction method, e.g. `radontea.backproject`.
- **numang** (*int*) – Number of angles to be used for the sinogram. A higher number increases quality, but interpolation takes longer. By default `numang = linogram.shape[1]`.
- **max_count** (*count,*) – Can be used to monitor the progress of the algorithm. Initially, the value of `max_count.value` is incremented by the total number of steps. At each step, the value of `count.value` is incremented.
- ****kwargs** (*dict*) – Keyword arguments for `method`.

2.3 Volumetric reconstruction

For a slice-wise 3D reconstruction, `radontea` can use multiprocessing to parallelize the reconstruction process.

2.3.1 Convenience functions

`radontea.backproject_3d` (*sinogram, angles, filtering='ramp', weight_angles=True, padding=True, padval=0, count=None, max_count=None, ncpus=None*)
Convenience wrapper for 3D backprojection reconstruction

See `backproject()` for parameter definitions. The additional parameter `ncpus` sets the number of CPUs used.

`radontea.fourier_map_3d(sinogram, angles, intp_method='cubic', count=None, max_count=None, ncpus=None)`
 Convenience wrapper for 3D Fourier mapping reconstruction

See `fourier_map()` for parameter definitions. The additional parameter `ncpus` sets the number of CPUs used.

2.3.2 General 3D reconstruction

`radontea.volume_recon(func2d, sinogram=None, angles=None, count=None, max_count=None, ncpus=None, **kwargs)`
 Slice-wise 3D inversion of the Radon transform

Computes the slice-wise 3D inverse of the Radon transform using multiprocessing.

Parameters

- **func2d** (*callable*) – A method for the slice-wise reconstruction (e.g. `backproject()`).
- **sinogram** (*ndarray, shape (A,M,N)*) – Three-dimensional sinogram of line recordings. The axis *l* iterates through the *M* slices. The rotation takes place through axis *l*.
- **angles** (*(A,) ndarray*) – Angular positions of the *sinogram* in radians in the interval $[0, \text{PI}]$.
- **max_count** (*count,*) – Can be used to monitor the progress of this function. The value of `max_count.value` is set initially and the value of `count.value` is incremented until it reaches the end of the algorithm (`max_count.value`).
- ****kwargs** (*dict*) – Additional keyword arguments to `func2d`.

Returns **out** – The reconstructed image.

Return type ndarray

3.1 Comparison of parallel-beam reconstruction methods

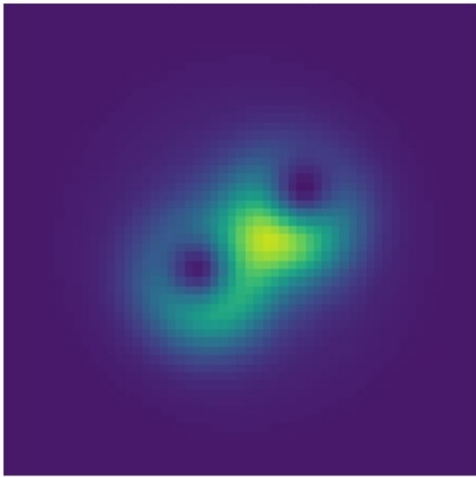
This example illustrates the performance of the different reconstruction techniques for a parallel-beam geometry. The left column shows the reconstruction of the original image and the right column shows the reconstruction of the corresponding binary images. Note that the SART process could be sped-up by computing an initial guess with a non-iterative method and setting it with the `initial` keyword argument.

comparison_parallel.py

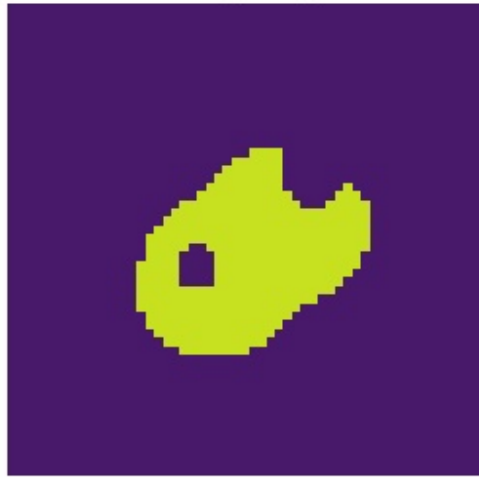
```
1 from matplotlib import pylab as plt
2 import numpy as np
3
4 import radontea
5 from radontea.logo import get_original
6
7 N = 55 # image size
8 A = 13 # number of sinogram angles
9 ITA = 10 # number of iterations a
10 ITB = 100 # number of iterations b
11
12 angles = np.linspace(0, np.pi, A)
13
14 im = get_original(N)
15 sino = radontea.radon_parallel(im, angles)
16 fbp = radontea.backproject(sino, angles)
17 fintp = radontea.fourier_map(sino, angles).real
18 sarta = radontea.sart(sino, angles, iterations=ITA)
19 sartb = radontea.sart(sino, angles, iterations=ITB)
20
21 im2 = (im >= (im.max() / 5)) * 255
22 sino2 = radontea.radon_parallel(im2, angles)
23 fbp2 = radontea.backproject(sino2, angles)
24 fintp2 = radontea.fourier_map(sino2, angles).real
```

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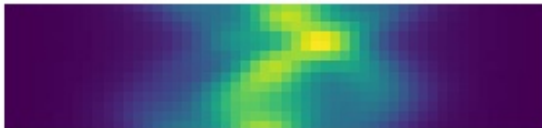
original image



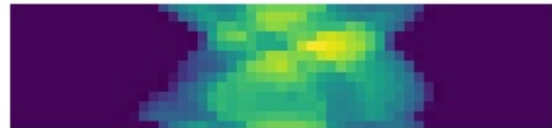
binary image



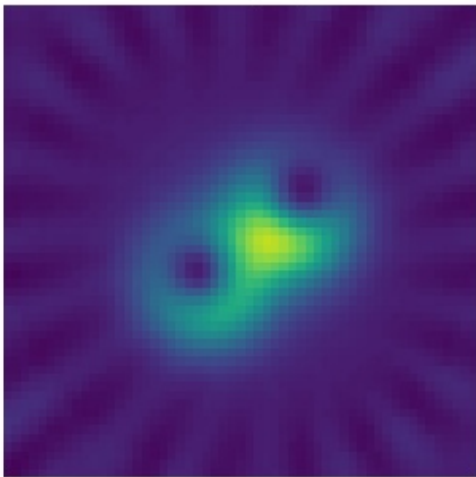
sinogram (from original)



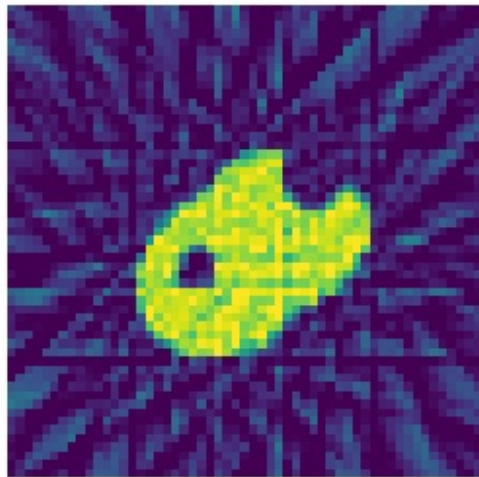
sinogram (from binary)



filtered backprojection



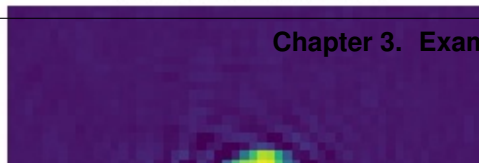
filtered backprojection



Fourier interpolation



Fourier interpolation



(continued from previous page)

```
25 sarta2 = radontea.sart(sino2, angles, iterations=ITA)
26 sartb2 = radontea.sart(sino2, angles, iterations=ITB)
27
28 plt.figure(figsize=(8, 22))
29 pltkw = {"vmin": -20,
30         "vmax": 280}
31
32 plt.subplot(6, 2, 1, title="original image")
33 plt.imshow(im, **pltkw)
34 plt.axis('off')
35
36 plt.subplot(6, 2, 2, title="binary image")
37 plt.imshow(im2, **pltkw)
38 plt.axis('off')
39
40 plt.subplot(6, 2, 3, title="sinogram (from original)")
41 plt.imshow(sino)
42 plt.axis('off')
43
44 plt.subplot(6, 2, 4, title="sinogram (from binary)")
45 plt.imshow(sino2)
46 plt.axis('off')
47
48 plt.subplot(6, 2, 5, title="filtered backprojection")
49 plt.imshow(fbp, **pltkw)
50 plt.axis('off')
51
52 plt.subplot(6, 2, 6, title="filtered backprojection")
53 plt.imshow(fbp2, **pltkw)
54 plt.axis('off')
55
56 plt.subplot(6, 2, 7, title="Fourier interpolation")
57 plt.imshow(fintp, **pltkw)
58 plt.axis('off')
59
60 plt.subplot(6, 2, 8, title="Fourier interpolation")
61 plt.imshow(fintp2, **pltkw)
62 plt.axis('off')
63
64 plt.subplot(6, 2, 9, title="SART ({} iterations)".format(ITA))
65 plt.imshow(sarta, **pltkw)
66 plt.axis('off')
67
68 plt.subplot(6, 2, 10, title="SART ({} iterations)".format(ITA))
69 plt.imshow(sarta2, **pltkw)
70 plt.axis('off')
71
72 plt.subplot(6, 2, 11, title="SART ({} iterations)".format(ITB))
73 plt.imshow(sartb, **pltkw)
74 plt.axis('off')
75
76 plt.subplot(6, 2, 12, title="SART ({} iterations)".format(ITB))
77 plt.imshow(sartb2, **pltkw)
78 plt.axis('off')
79
80
81 plt.tight_layout()
```

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```
82 plt.show()
```

3.2 Volumetric data reconstruction benchmark

This simple example can be used to quantify the speed-up due to multiprocessing on the hardware used. Note that `multiprocessing.cpu_count` does not return the number of physical cores.

benchmark_3d.py

```

1  from multiprocessing import cpu_count
2  import time
3
4  import numpy as np
5
6  import radontea as rt
7
8
9  A = 70      # number of angles
10 N = 128     # detector size x
11 M = 24     # detector size y (number of slices)
12
13 # generate random data
14 sino0 = np.random.random((A, N))      # for 2d example
15 sino = np.random.random((A, M, N))   # for 3d example
16 sino[:, 0, :] = sino0
17 angles = np.linspace(0, np.pi, A)    # for both
18
19 a = time.time()
20 data1 = rt.backproject_3d(sino, angles, ncpus=1)
21 print("time on 1 core: {:.2f} s".format(time.time() - a))
22
23 a = time.time()
24 data2 = rt.backproject_3d(sino, angles, ncpus=cpu_count())
25 print("time on {} cores: {:.2f} s".format(cpu_count(), time.time() - a))
26
27 assert np.all(data1 == data2), "2D and 3D results don't match"

```

3.3 Progress monitoring with progression

The progress of the reconstruction algorithms in radontea can be tracked with other packages such as [progression](#).

```

$python progression_3d.py
00:00:14 [65.2c/s] [=====] ] TTG 7.00s

```

progression_3d.py

```

1  from multiprocessing import cpu_count
2
3  import numpy as np
4  import progression as pr

```

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```
5
6 import radontea as rt
7
8
9 A = 55      # number of angles
10 N = 128    # detector size x
11 M = 24     # detector size y (number of slices)
12
13 # generate random data
14 sino0 = np.random.random((A, N))
15 sino = np.random.random((A, M, N))
16 sino[:, 0, :] = sino0
17 angles = np.linspace(0, np.pi, A)
18
19 count = pr.UnsignedIntValue()
20 max_count = pr.UnsignedIntValue()
21
22
23 with pr.ProgressBar(count=count,
24                    max_count=max_count,
25                    interval=0.3
26                    ) as pb:
27     pb.start()
28     rt.volume_recon(func2d=rt.sart, sinogram=sino, angles=angles,
29                    ncpus=cpu_count(), count=count, max_count=max_count)
```


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