X-ray Image Analysis Documentation

Release 0.0.1

Argonne National Laboratory

Jan 10, 2018

Contents

1 Few examples 3

2 How to Contribute 5

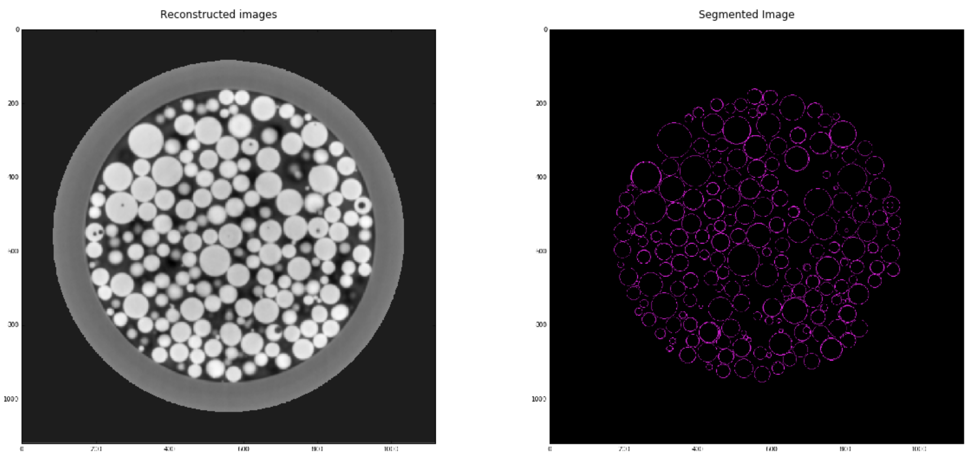
Bibliography 27

The X-image is a collection of tools and tutorials for segmenting X-ray and RGB images using image processing and compute vision techniques.

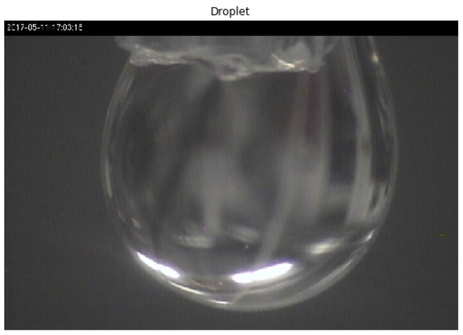
CHAPTER 1

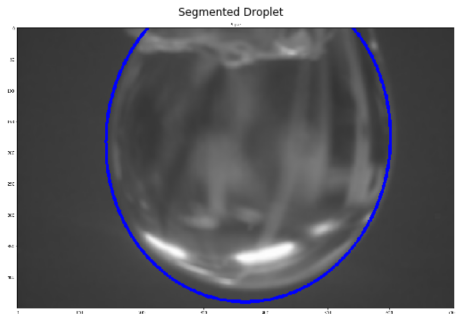
Few examples

Detecting location and size of cells in X-ray images:



Detecting droplets using RGB camera images:


Droplet
2017-05-11 17:03:15


Segmented Droplet

CHAPTER 2

How to Contribute

If you are working on a segmentation tool and would like to contribute

- Documentation: https://github.com/tomography/ximage/tree/master/doc
- Issue Tracker: https://github.com/tomography/ximage/docs/issues
- Source Code: https://github.com/tomography/ximage/ximage

2.1 About

The X-Image is a collebrative space for gathering tools and tutorials for segmenting data for X-Ray sciences.

2.2 Install

This section covers the basics of how to download and install X-Image. We recommend you to install the Anaconda Python distribution.

Contents:

- *Installing from source*

2.2.1 Installing from source

Clone ximage from GitHub repository:

```
git clone https://github.com/tomography/ximage.git ximage
```

then:

```
cd ximage
python setup.py install
```

2.3 Development

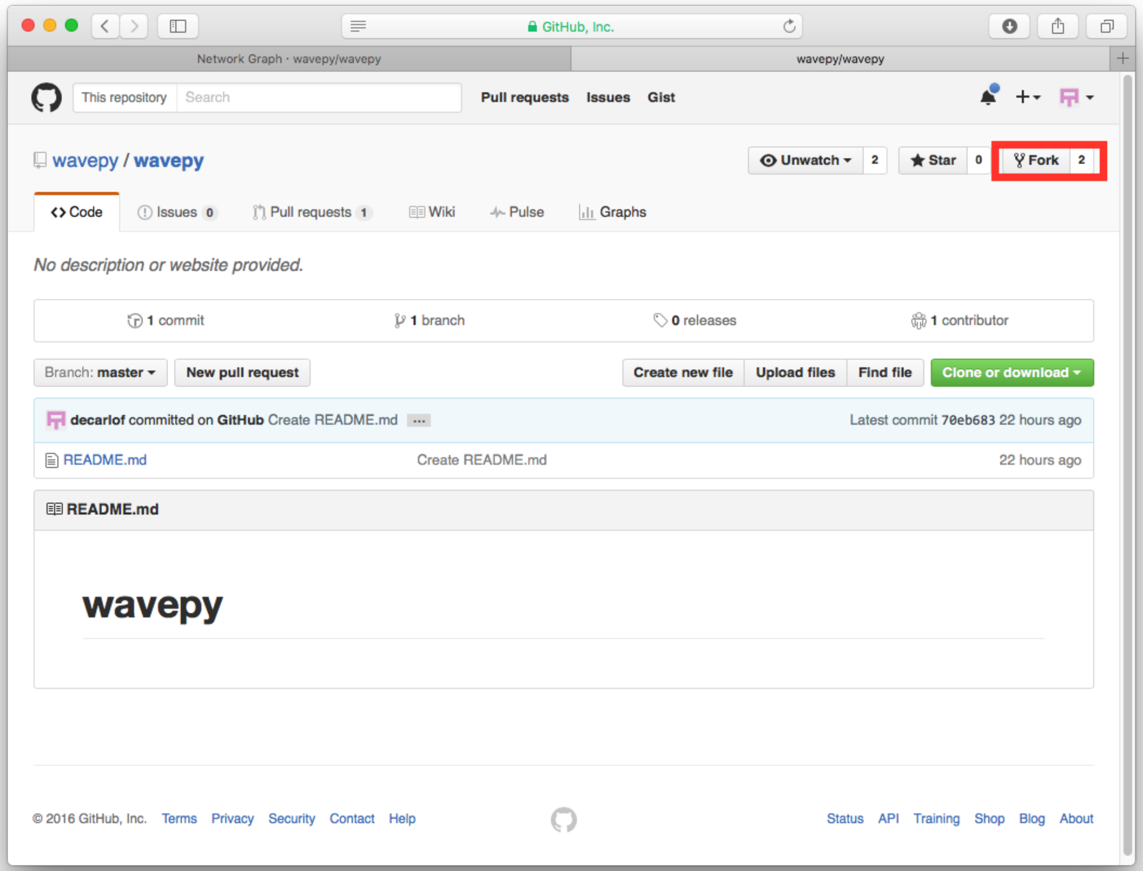
This section explains the basics for developers who wish to contribute to a project mantained on GitHub and using the fork / pull request mechanism for accepting developer contributions.

Contents:

- *Fork the repository*
- *Clone the repository*
- *Coding conventions*
- *Package versioning*
- *Commiting changes*
- *Contributing back*

2.3.1 Fork 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 Project repository by clicking the **Fork** button in the header of the Project repository:



No description or website provided.

decarlof committed on GitHub Create README.md ... Latest commit 70eb683 22 hours ago

README.md Create README.md 22 hours ago

README.md

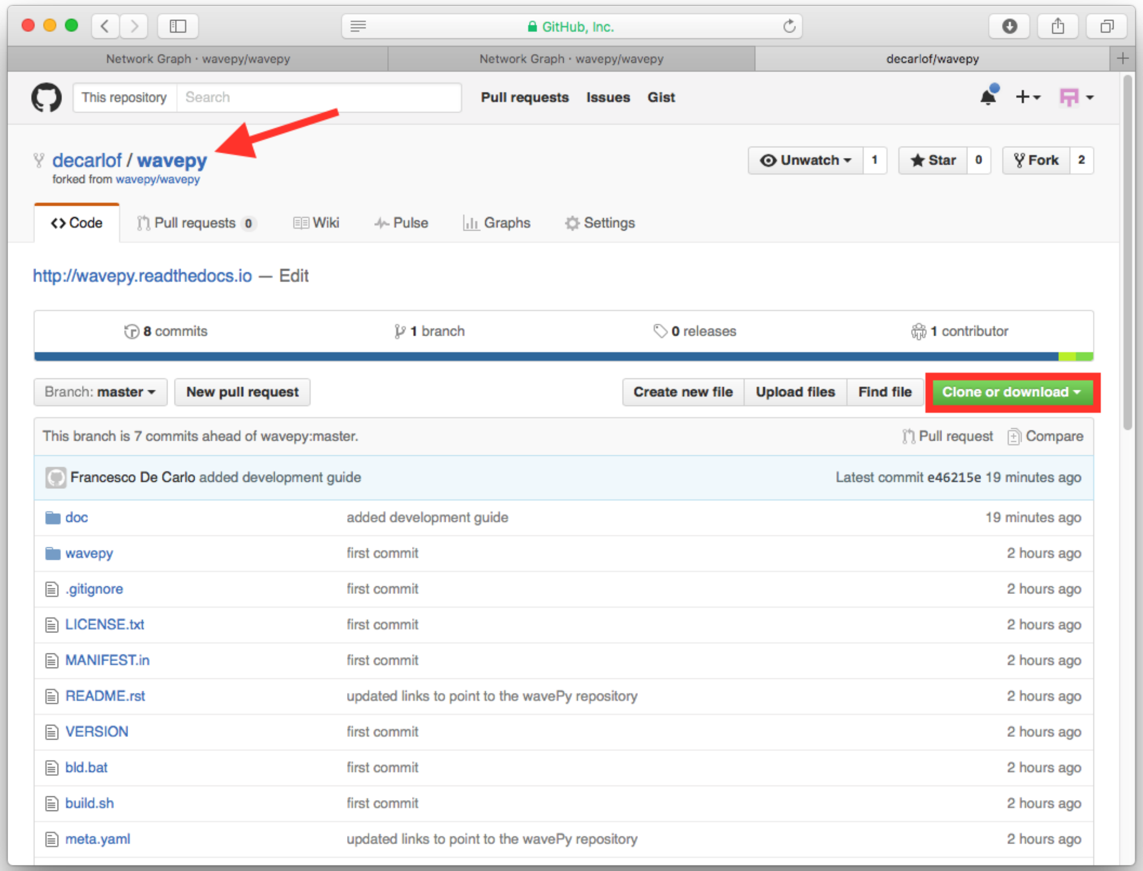
wavepy

This successfully creates a copy of hspeed in your personal GitHub space.

2.3.2 Clone the repository

The next thing you want to do is to clone the repository you just created in your personal GitHub space to your local machine.

You can do this by clicking the **Clone in Desktop** button in the bottom of the right hand side bar:



decarlof / wavepy
forked from wavepy/wavepy

http://wavepy.readthedocs.io — Edit

8 commits | 1 branch | 0 releases | 1 contributor

This branch is 7 commits ahead of wavepy:master.

Francesco De Carlo added development guide — Latest commit e46215e 19 minutes ago

doc	added development guide	19 minutes ago
wavepy	first commit	2 hours ago
.gitignore	first commit	2 hours ago
LICENSE.txt	first commit	2 hours ago
MANIFEST.in	first commit	2 hours ago
README.rst	updated links to point to the wavePy repository	2 hours ago
VERSION	first commit	2 hours ago
bld.bat	first commit	2 hours ago
build.sh	first commit	2 hours ago
meta.yaml	updated links to point to the wavePy repository	2 hours ago

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.

2.3.3 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 hspeed. For example, when you are writing a new function always describe the purpose and the parameters:

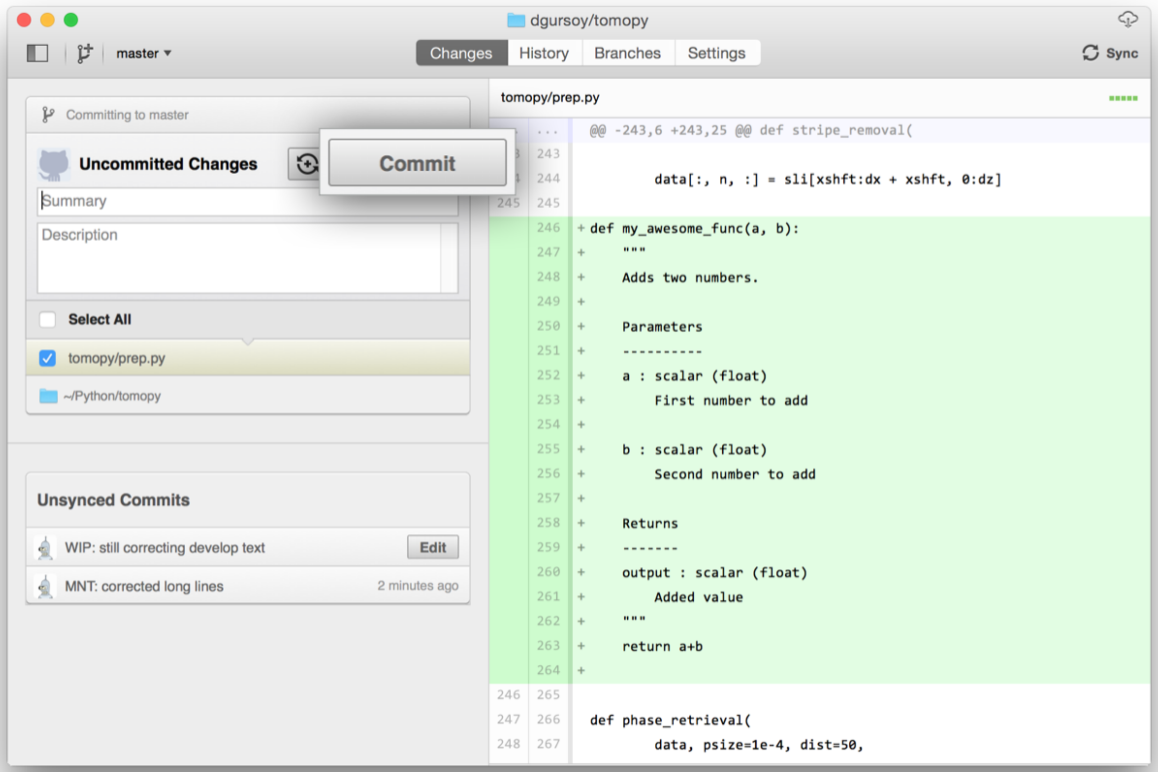
```python
def my_awesome_func(a, b):
    """
    Adds two numbers.

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

    b : scalar (float)
        Second number to add
    Returns
    -------
    output : scalar (float)
        Added value
    """
    return a+b
```

2.3.4 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.

2.3.5 Commiting 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:



WIP: still correcting develop text

MNT: corrected long lines

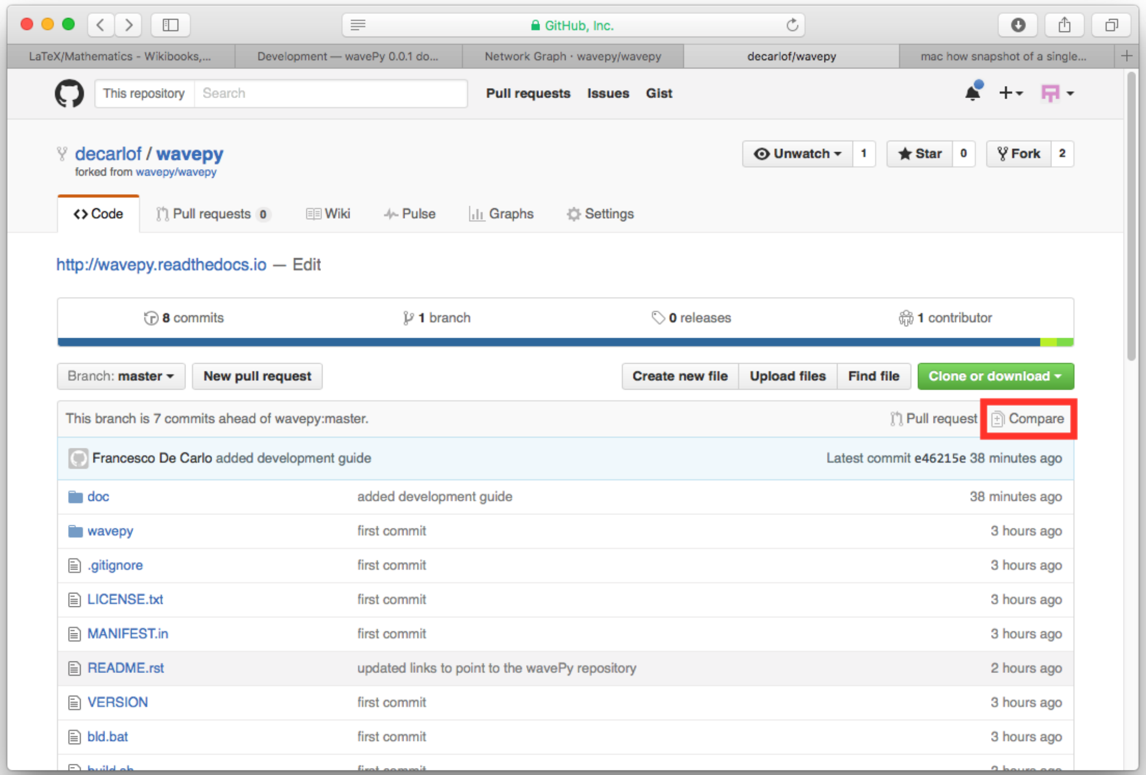
tomopy/prep.py

```
@@ -243,6 +243,25 @@ def stripe_removal(

         data[:, n, :] = sli[xshft:dx + xshft, 0:dz]

+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
+

 def phase_retrieval(
         data, psize=1e-4, dist=50,
```

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

2.3.6 Contributing back

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



decarlof / wavepy
forked from wavepy/wavepy

http://wavepy.readthedocs.io — Edit

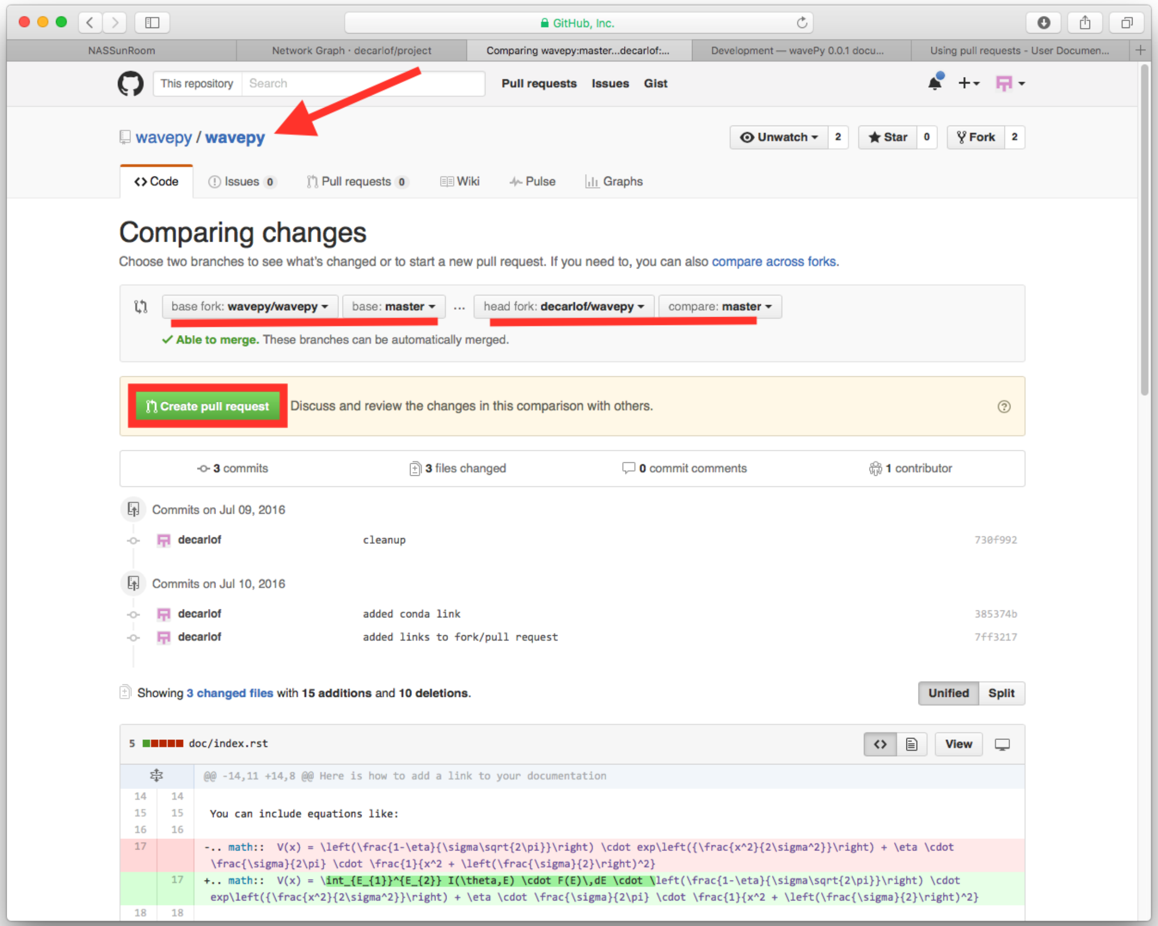
8 commits | 1 branch | 0 releases | 1 contributor

This branch is 7 commits ahead of wavepy:master.

Francesco De Carlo added development guide — Latest commit e46215e 38 minutes ago

doc	added development guide	38 minutes ago
wavepy	first commit	3 hours ago
.gitignore	first commit	3 hours ago
LICENSE.txt	first commit	3 hours ago
MANIFEST.in	first commit	3 hours ago
README.rst	updated links to point to the wavePy repository	2 hours ago
VERSION	first commit	3 hours ago
bld.bat	first commit	3 hours ago

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 project repository. When you're ready to submit your pull request, click **Create pull request**:



Comparing changes

Choose two branches to see what's changed or to start a new pull request. If you need to, you can also compare across forks.

✓ Able to merge. These branches can be automatically merged.

Discuss and review the changes in this comparison with others.

Commits on Jul 09, 2016

decarlof	cleanup	730f992

Commits on Jul 10, 2016

decarlof	added conda link	385374b
decarlof	added links to fork/pull request	7ff3217

Showing 3 changed files with 15 additions and 10 deletions.

```
5 doc/index.rst
@@ -14,11 +14,8 @@ Here is how to add a link to your documentation

 You can include equations like:

-.. math::  V(x) = \left(\frac{1-\eta}{\sigma\sqrt{2\pi}}\right) \cdot exp\left({\frac{x^2}{2\sigma^2}}\right) + \eta \cdot
 \frac{\sigma}{2\pi} \cdot \frac{1}{x^2 + \left(\frac{\sigma}{2}\right)^2}
+.. math::  V(x) = \int_{E_{1}}^{E_{2}} I(\theta,E) \cdot F(E)\,dE \cdot \left(\frac{1-\eta}{\sigma\sqrt{2\pi}}\right) \cdot
 exp\left({\frac{x^2}{2\sigma^2}}\right) + \eta \cdot \frac{\sigma}{2\pi} \cdot \frac{1}{x^2 + \left(\frac{\sigma}{2}\right)^2}
```

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!

2.4 API reference

ximage Modules:

2.4.1 `ximage.util`

2.4.2 `ximage.widget`

2.5 Examples

This section contains Jupyter Notebooks and Python scripts examples for various ximage functions.

To run these examples in a notebooks install Jupyter or run the python scripts from here

2.5.1 Particle Tracking

This is an example of particle tracking in additive manufacturing high speed x-ray imaging. You can download this eaxample as `jupyter notebook` or as `python script`

```
import matplotlib.pyplot as plt
%matplotlib inline
```

```
import ximage
import fnmatch
import tomopy
import numpy as np
```

```
top = '/local/dataraid/am/104_Ti_04_p90_S1/'
```

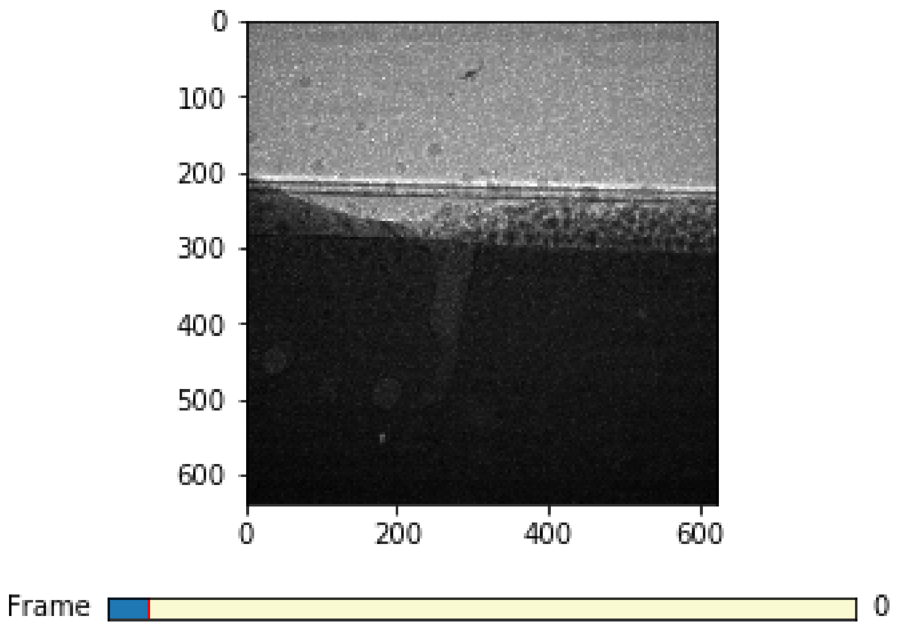
```
index_start = 1
```

```
# Total number of images to read
nfile = len(fnmatch.filter(os.listdir(top), '*.tif'))
print(nfile)
```

```
361
```

```
rdata = ximage.load_raw(top, index_start)
```

```
ximage.slider(rdata[150:160:,:])
```



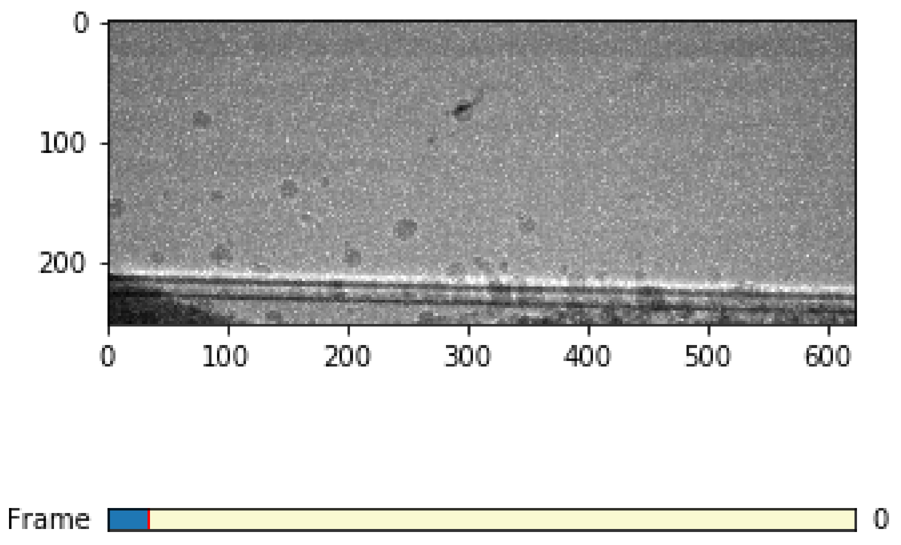
```
particle_bed_reference = ximage.particle_bed_location(rdata[0])
```

```
print("Particle bed location: ", particle_bed_reference)
```

```
('Particle bed location: ', 253)
```

```
# Cut the images to remove the particle bed
cdata = rdata[:, 0:particle_bed_reference, :]
```

```
ximage.slider(cdata[150:160:,:])
```



```
# Find the image when the shutter starts to close
dark_index = ximage.shutter_off(rdata)
print("Shutter CLOSED on image: ", dark_index)
```

```
('Shutter CLOSED on image: ', 344)
```

```
# Find the images when the laser is on
laser_on_index = ximage.laser_on(rdata, particle_bed_reference, alpha=1.0)
print("Laser ON on image: ", laser_on_index)
```

```
('Laser ON on image: ', 46)
```

```
# Set the [start, end] index of the blocked images, flat and dark.
flat_range = [0, 1]
data_range = [laser_on_index, dark_index]
dark_range = [dark_index, nfile]

flat = cdata[flat_range[0]:flat_range[1], :, :]
proj = cdata[data_range[0]:data_range[1], :, :]
dark = np.zeros((dark_range[1]-dark_range[0], proj.shape[1], proj.shape[2]))
```

```
# Normalize the images
ndata = tomopy.normalize(proj, flat, dark)
ndata = tomopy.normalize_bg(ndata, air=ndata.shape[2]/2.5)
ndata = tomopy.minus_log(ndata)
```

```
blur_radius = 3.0
threshold = .04
nddata = ximage.label(ndata, blur_radius, threshold)
```

```
Image 0 contains 8 particles
Image 1 contains 13 particles
Image 2 contains 10 particles
Image 3 contains 13 particles
Image 4 contains 12 particles
Image 5 contains 19 particles
Image 6 contains 21 particles
Image 7 contains 26 particles
Image 8 contains 23 particles
Image 9 contains 22 particles
Image 10 contains 24 particles
Image 11 contains 25 particles
Image 12 contains 29 particles
Image 13 contains 28 particles
Image 14 contains 29 particles
Image 15 contains 26 particles
Image 16 contains 28 particles
Image 17 contains 24 particles
Image 18 contains 24 particles
Image 19 contains 21 particles
Image 20 contains 23 particles
Image 21 contains 24 particles
Image 22 contains 23 particles
....
Image 295 contains 61 particles
Image 296 contains 57 particles
Image 297 contains 55 particles
```

2.5.2 Circle Detection

Here is an example of a tomographic data set of a sample consisting of spheres. The goal is to detect the circles contained in a tomographic reconstructed slice. First step is the tomographic reconstruction followed by sharpening, defect detection and finally circle detection.

You can download this eaxample as `jupyter notebook`

```
import matplotlib.pyplot as plt
%matplotlib inline
```

Image reconstruction

```
import tomopy
import dxchange

# Set path to the micro-CT data to reconstruct.
fname = '/local/decarlo/sector1/g120f5/g120f5_'

# Select the sinogram range to reconstruct.
start = 100
end = 116
```

```
# Read the APS 1-ID raw data.
proj, flat, dark = dxchange.read_aps_1id(fname, sino=(start, end))

# Set data collection angles as equally spaced between 0-180 degrees.
theta = tomopy.angles(proj.shape[0], ang1=0.0, ang2=360.0)

# Flat-field correction of raw data.
proj = tomopy.normalize(proj, flat, dark)

# Ring removal.
proj = tomopy.remove_stripe_sf(proj)

# phase retrieval
proj = tomopy.retrieve_phase(proj, alpha=1e-3, pad=True)

# -log.
proj = tomopy.minus_log(proj)

# Reconstruct object using Gridrec algorithm.
rec = tomopy.recon(proj, theta, center=576, algorithm='gridrec')

# Mask each reconstructed slice with a circle.
rec = tomopy.circ_mask(rec, axis=0, ratio=0.85)
```

```
plt.figure(figsize=(12, 12))
plt.imshow(rec[8], cmap='gray', interpolation='none')
```

```
<matplotlib.image.AxesImage at 0x7fecb2578ef0>
```

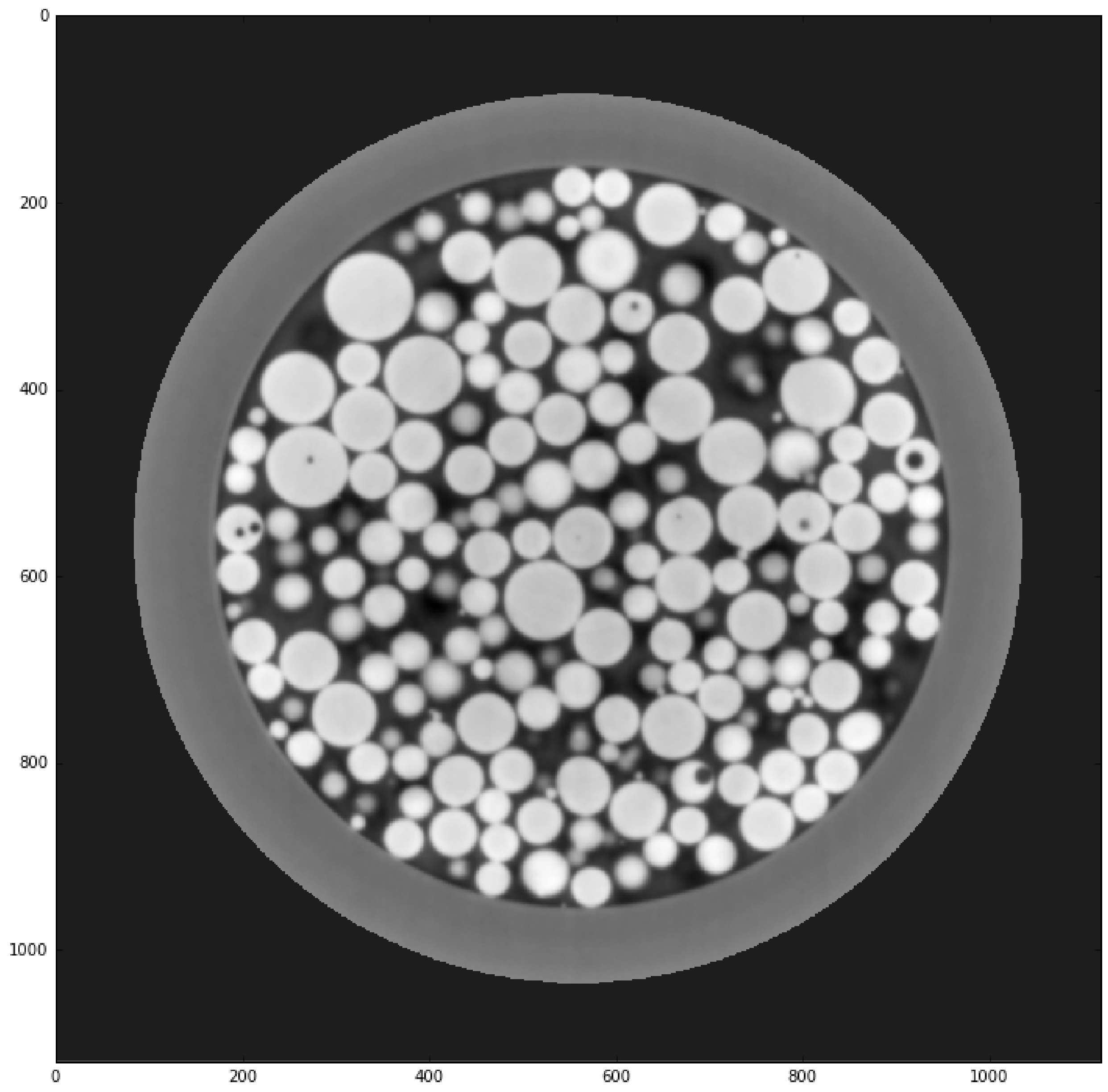
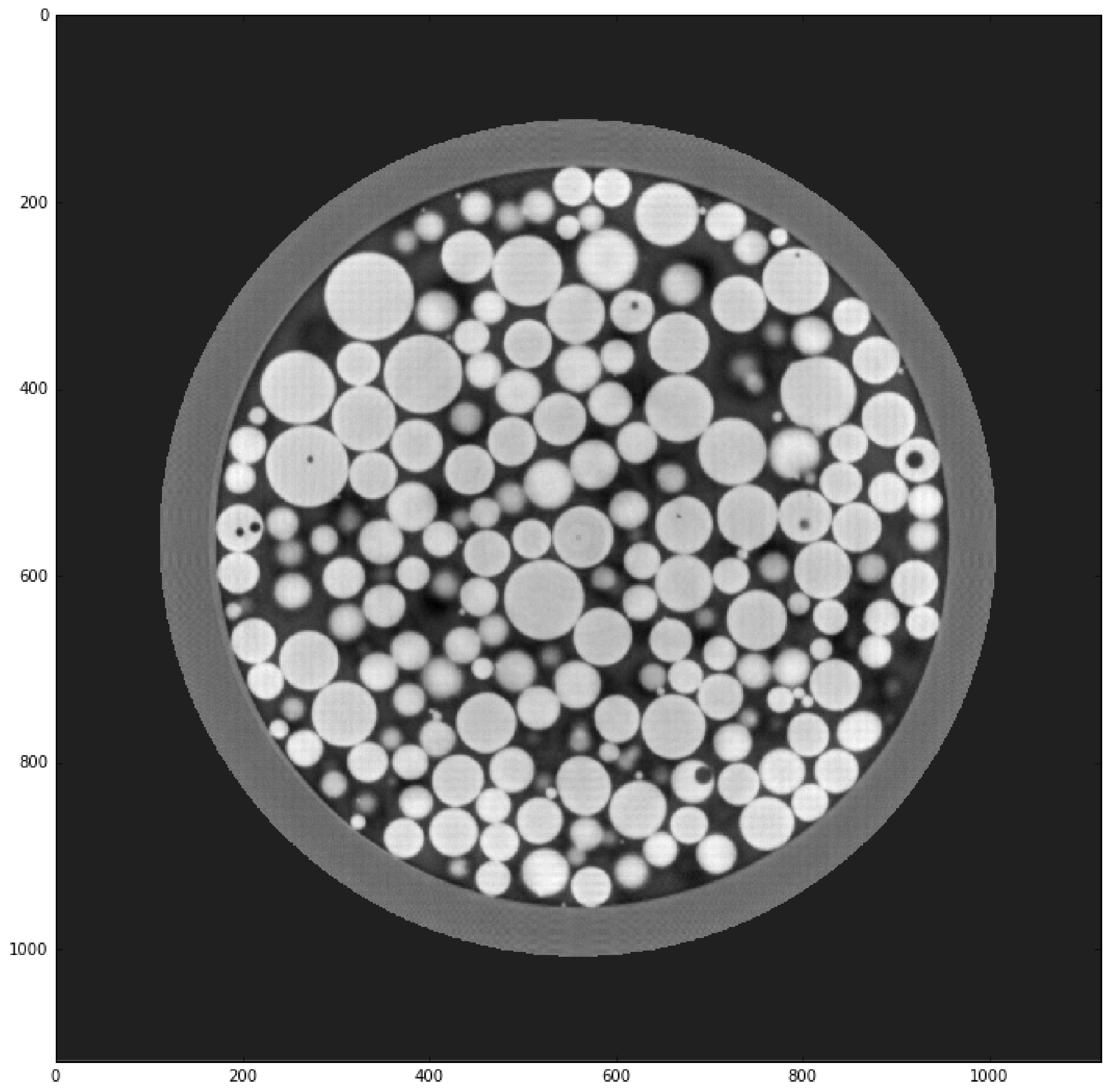


Image sharpening

```
import cv2
import numpy as np

# Pick one slice for further processing.
img = rec[8].copy()

kernel = np.array([[-1,-1,-1], [-1,9,-1], [-1,-1,-1]])
img = cv2.filter2D(img, -1, kernel)
img = tomopy.circ_mask(np.expand_dims(img, 0), axis=0, ratio=0.8)[0]

plt.figure(figsize=(12, 12))
plt.imshow(img, cmap='gray', interpolation='none')
```

```
<matplotlib.image.AxesImage at 0x7fec14e48048>
```

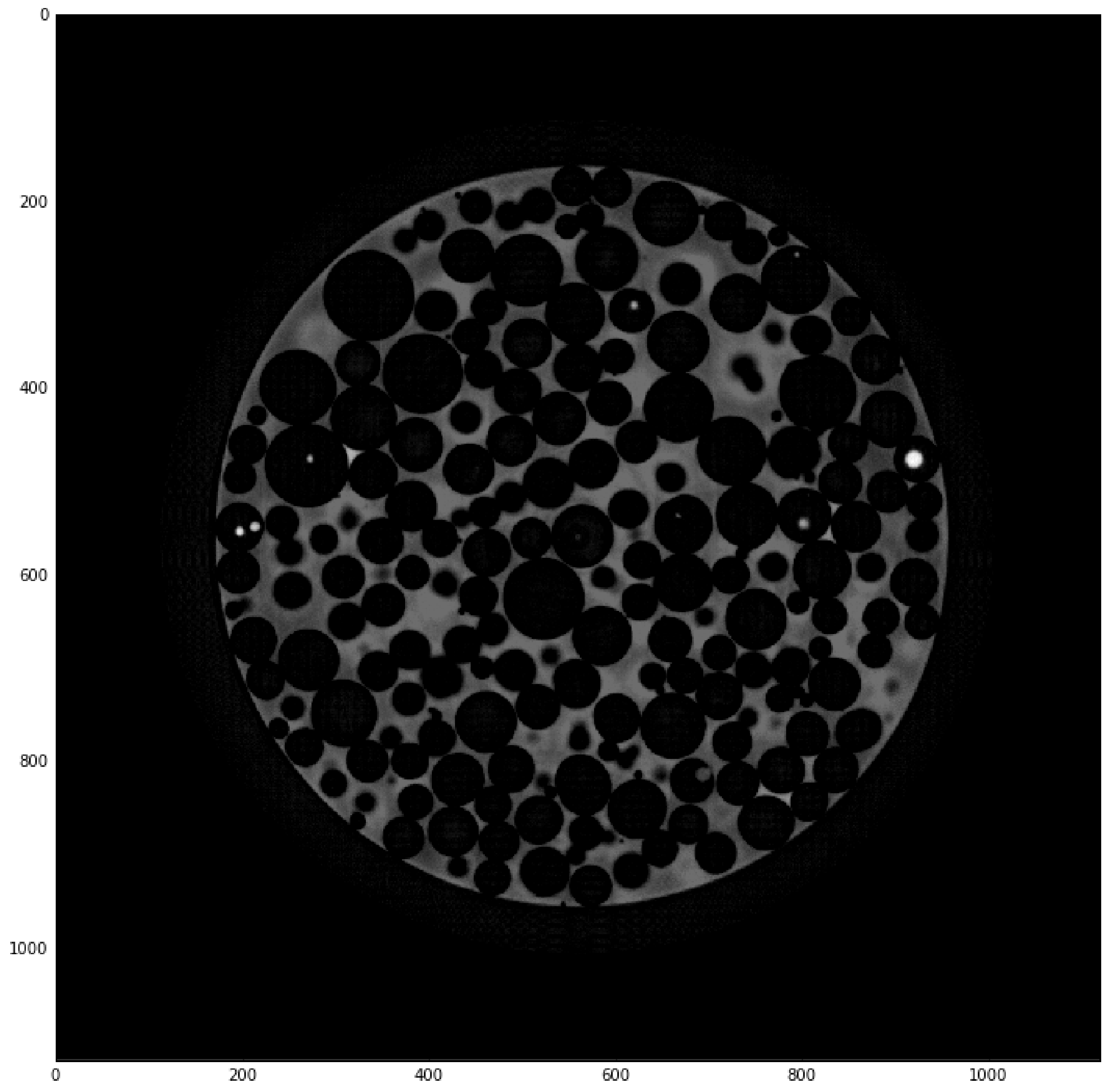


Artifact detection

```
from skimage.morphology import reconstruction

img0 = (255 * (img - img.min()) / (img - img.min()).max()).astype('uint8')
mask = img0
seed1 = np.copy(img0)
seed2 = np.copy(img0)
seed1[1:-1, 1:-1] = img0.max()
seed2[1:-1, 1:-1] = img0.min()
eris = reconstruction(seed1, mask, method='erosion')
```

```
dila = reconstruction(seed2, mask, method='dilation')
img0 = (eris+dila-img0)
# img0 = img0 > 120

plt.figure(figsize=(12, 12))
plt.imshow(img0, cmap='gray', interpolation='none')
```

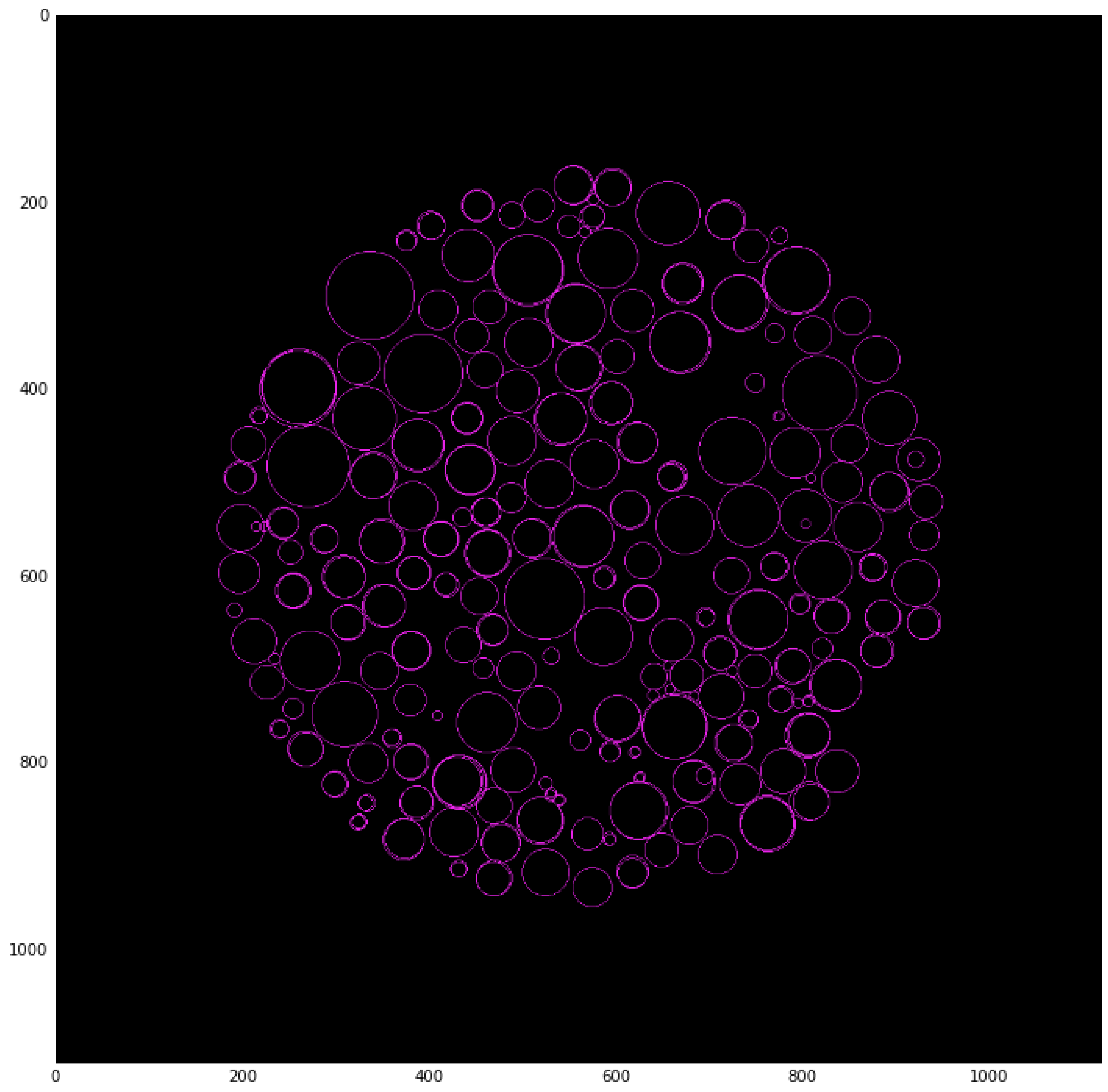
```
<matplotlib.image.AxesImage at 0x7fec141e9a20>
```



Circle detection

```
from skimage import color
from skimage.transform import hough_circle, hough_circle_peaks
from skimage.feature import canny
from skimage.draw import circle_perimeter

img0 = (255 * (img - img.min()) / (img - img.min()).max()).astype('uint8')
edges = canny(img0, sigma=2)
hough_radii = np.arange(5, 50, 1)
hough_res = hough_circle(edges, hough_radii)
accums, cx, cy, radii = hough_circle_peaks(hough_res, hough_radii, total_num_
↪peaks=300)

img1 = np.zeros(img0.shape)
img1 = color.gray2rgb(img1)
for center_y, center_x, radius in zip(cy, cx, radii):
    circy, circx = circle_perimeter(center_y, center_x, radius)
    img1[circy, circx] = (20, 220, 20)

plt.figure(figsize=(12, 12))
plt.imshow(img1)
```

```
<matplotlib.image.AxesImage at 0x7fec13d65908>
```



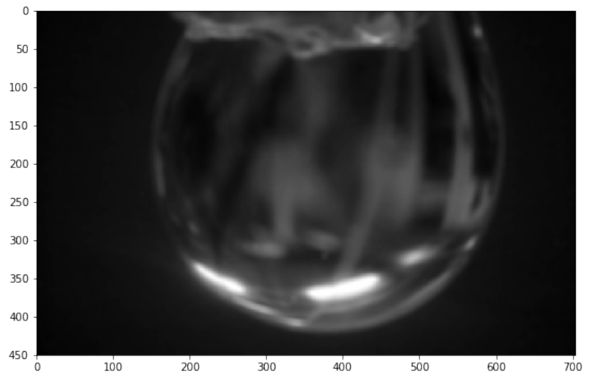
2.5.3 Droplet Detection

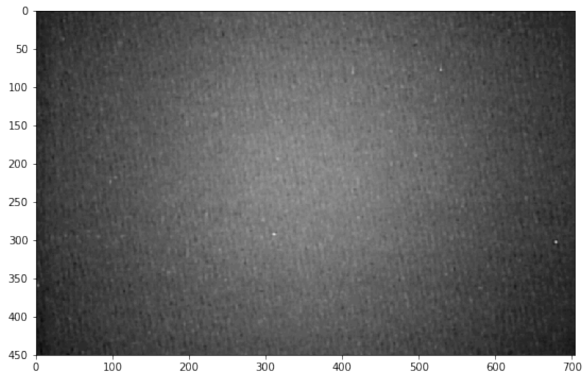
You can download this example as `jupyter notebook`

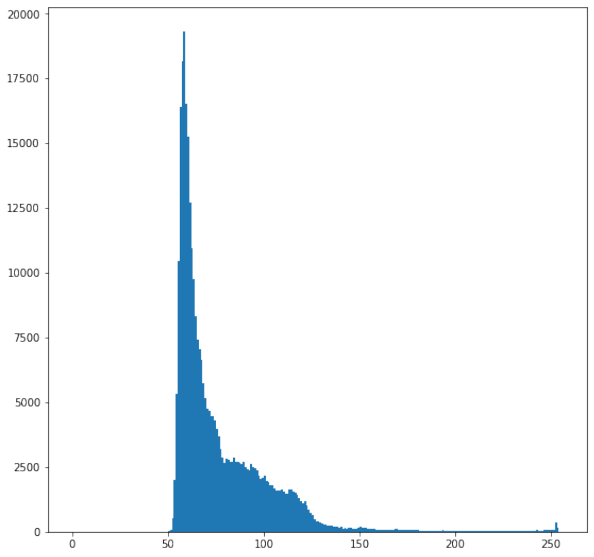
```
import numpy as np
import matplotlib.pyplot as plt
import matplotlib.image as mpimg
import cv2
import glob

from ipywidgets import interact

get_ipython().magic('matplotlib inline')
plt.rcParams['figure.figsize'] = (20.0, 15.0) # set default size of plots
plt.rcParams['image.interpolation'] = 'nearest'
plt.rcParams['image.cmap'] = 'gray'
plt.rcParams['axes.titlesize'] = 8

%matplotlib inline
```

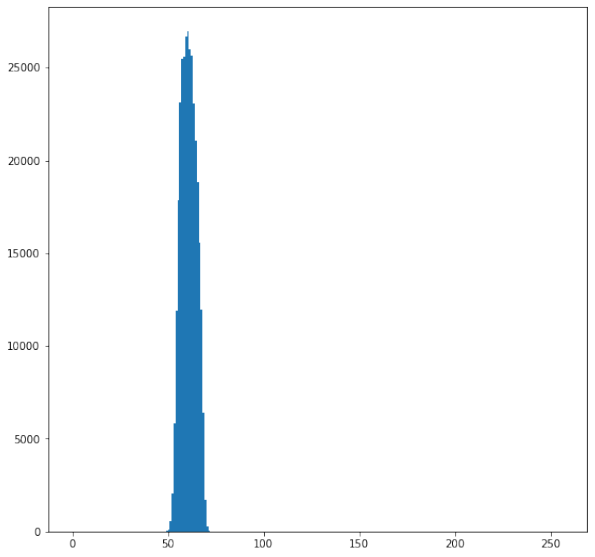
Detecting Background Pixels

```
bg = cv2.imread('./samples/bg_nolbl.jpg', 0)
droplet = cv2.imread('./samples/full_droplet_1.jpg', 0)

# crop the top
bg = bg[30:, :]
droplet = droplet[30:, :]

droplet = cv2.blur(droplet, ksize=(9,9))
bg = cv2.blur(bg, ksize=(3,3))

fig, ((ax1, ax2), (ax3, ax4)) = plt.subplots(2, 2, figsize=(20, 20))

ax1.imshow(droplet)
ax2.imshow(bg)
ax3.hist(droplet.ravel(), 256, [0, 256])
ax4.hist(bg.ravel(), 256, [0, 256])

plt.show()
```



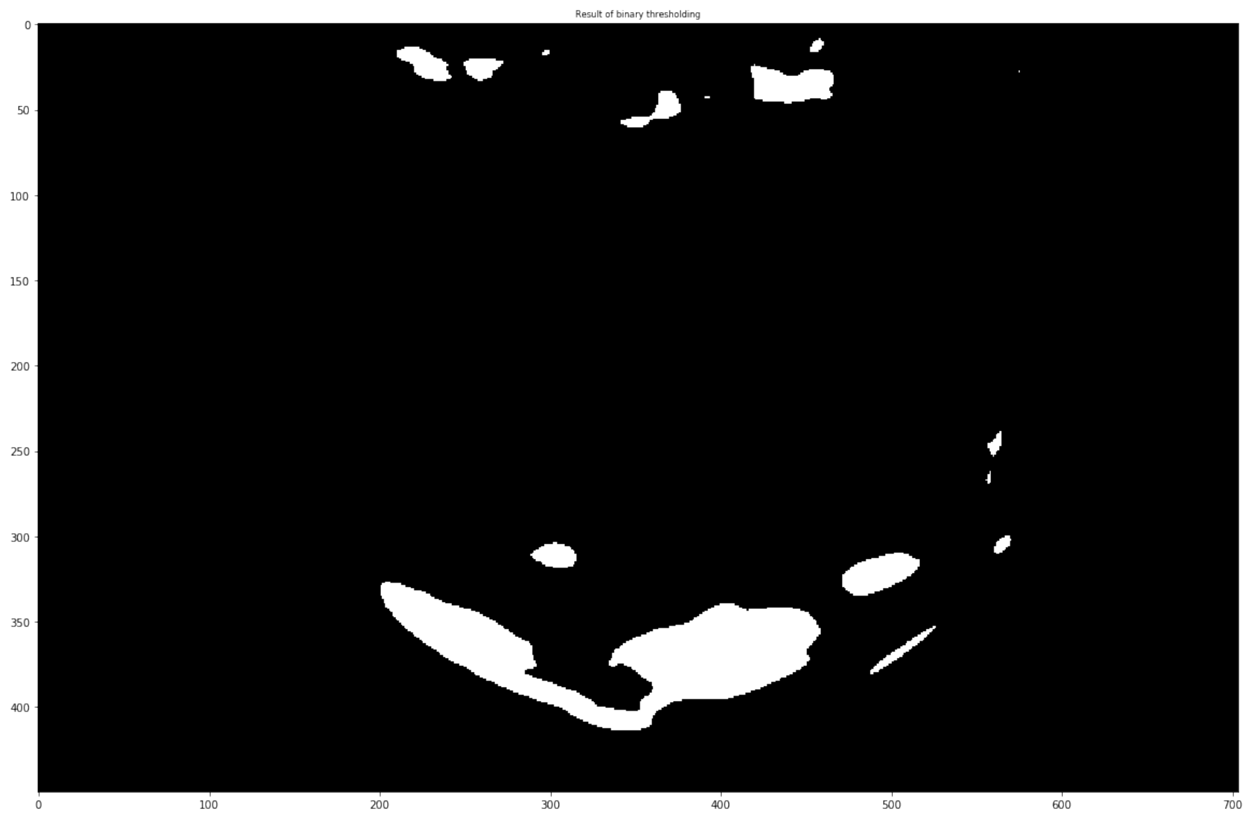






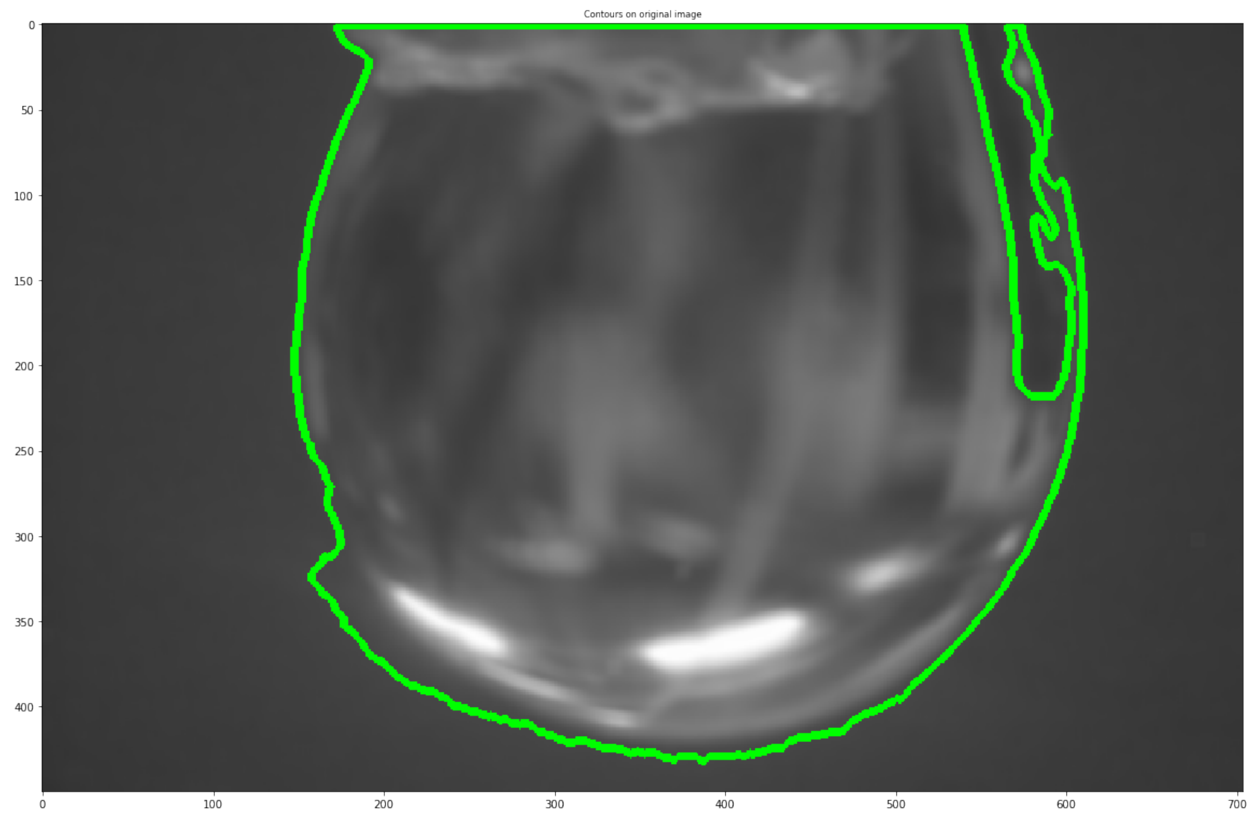
Apply thresholds

```
low_thresh = 100
high_thresh = 250

def apply_thresh(low, high):
    ret, binary = cv2.threshold(droplet, low, high, 0)
    plt.figure(figsize=(20, 20))
    plt.imshow(binary, cmap='gray')
    plt.title('Result of binary thresholding')
    plt.show()

interact(apply_thresh, low=(0,250), high=(0, 255));
```



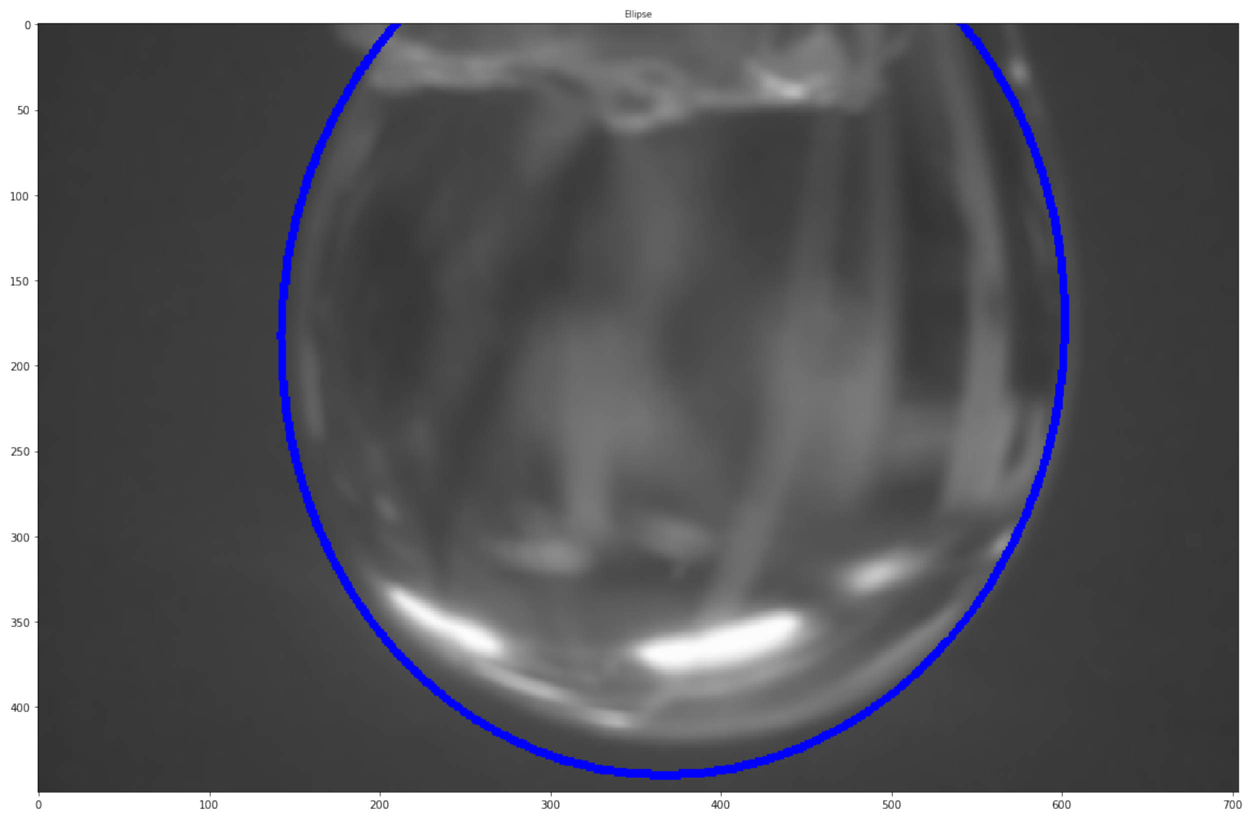
Finding Contours

```
low_thresh = 70
high_thresh = 255

ret, binary = cv2.threshold(droplet, low_thresh, high_thresh, 0)

im2, contours, hierarchy = cv2.findContours(binary, cv2.RETR_EXTERNAL, cv2.CHAIN_
↪APPROX_SIMPLE)
segmented_img = np.dstack((droplet, droplet, droplet))
cv2.drawContours(segmented_img, contours, -1, (0, 255, 0), 3)

plt.figure(figsize=(20, 20))
plt.title('Contours on original image')
plt.imshow(segmented_img)
plt.show()
```



Fitting an Ellipse

```
final = np.dstack((droplet, droplet, droplet))

for cnt in contours:
    if cnt.shape[0] > 5:
        an_ellipse = cv2.fitEllipse(cnt)
        cv2.ellipse(final, an_ellipse, (0, 0, 255), 3)

plt.figure(figsize=(20, 20))
plt.title('Ellipse')
plt.imshow(final)
plt.show()
```



2.6 Credits

2.6.1 Citations

We kindly request that you cite the following article *[A1]* if you use project.

2.6.2 References

Bibliography

[A1] Cang Zhao, Kamel Fezzaa, Ross W. Cunningham, Haidan Wen, Francesco De Carlo, Lianyi Chen, Anthony D. Rollett, and Tao Sun. Real-time monitoring of laser powder bed fusion process using high-speed x-ray imaging and diffraction. *Scientific Reports*, 7(1):3602, 2017. URL: http://dx.doi.org/10.1038/s41598-017-03761-2, doi:10.1038/s41598-017-03761-2.

[B1] Cang Zhao, Kamel Fezzaa, Ross W. Cunningham, Haidan Wen, Francesco De Carlo, Lianyi Chen, Anthony D. Rollett, and Tao Sun. Real-time monitoring of laser powder bed fusion process using high-speed x-ray imaging and diffraction. *Scientific Reports*, 7(1):3602, 2017. URL: http://dx.doi.org/10.1038/s41598-017-03761-2, doi:10.1038/s41598-017-03761-2.