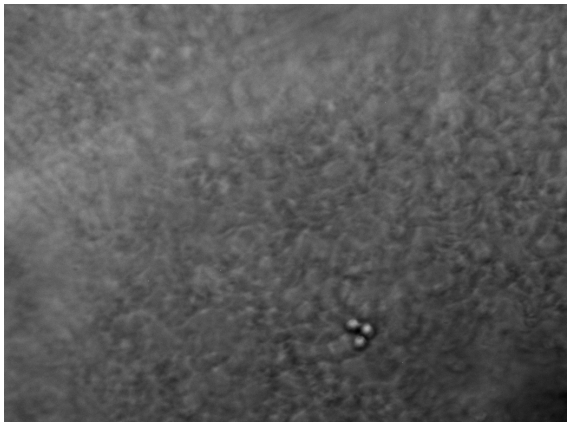
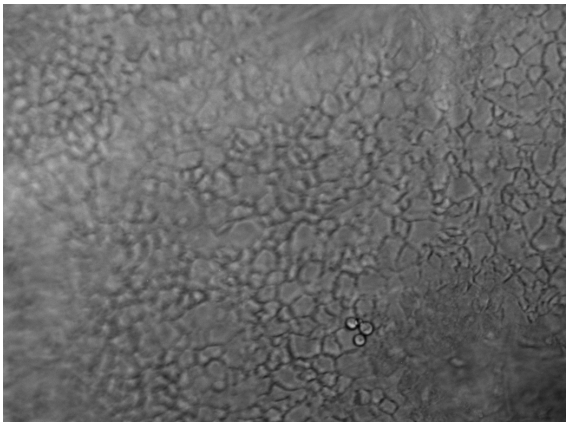
Tutorial: Shape From Focus

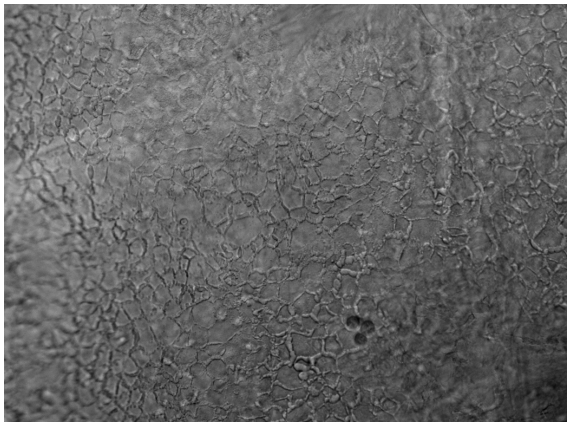
This tutorial introduces the basic shape from focus concepts. The objective is to reconstruct a focused image from a serie (generally a stack) of images with inhomogene focus (see Fig. 1).



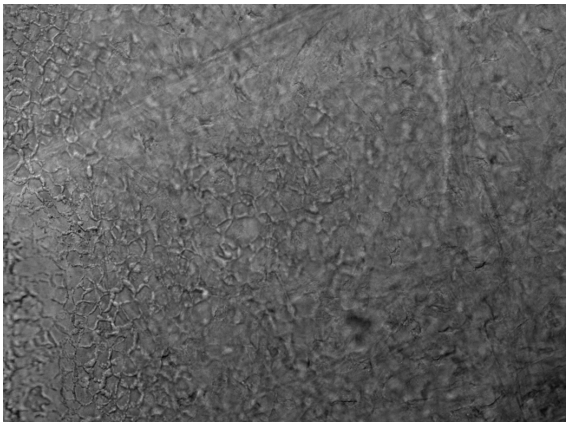
(a) Layer 1



(b) Layer 9



(c) Layer 18



(d) Layer 24

Figure 1: Different images of the stack, from a corneal endothelium in optical microscopy (with 3D microscope).

1 Introduction to classical methods

An optic system has a limited depth of field. When observing non plane surfaces with a microscope, some parts of the observation may be blurred as well as some others may be correctly focused.

To overcome this problem and reconstruct an all-focused image as well as a surface (see Fig. 2), an algorithm will look at every pixel of the images in the stack and select the most focused one, by the way of a focus measure. This tutorial proposes to test some classical focus measures. You can have a look at [1] and [2] to see real applications.

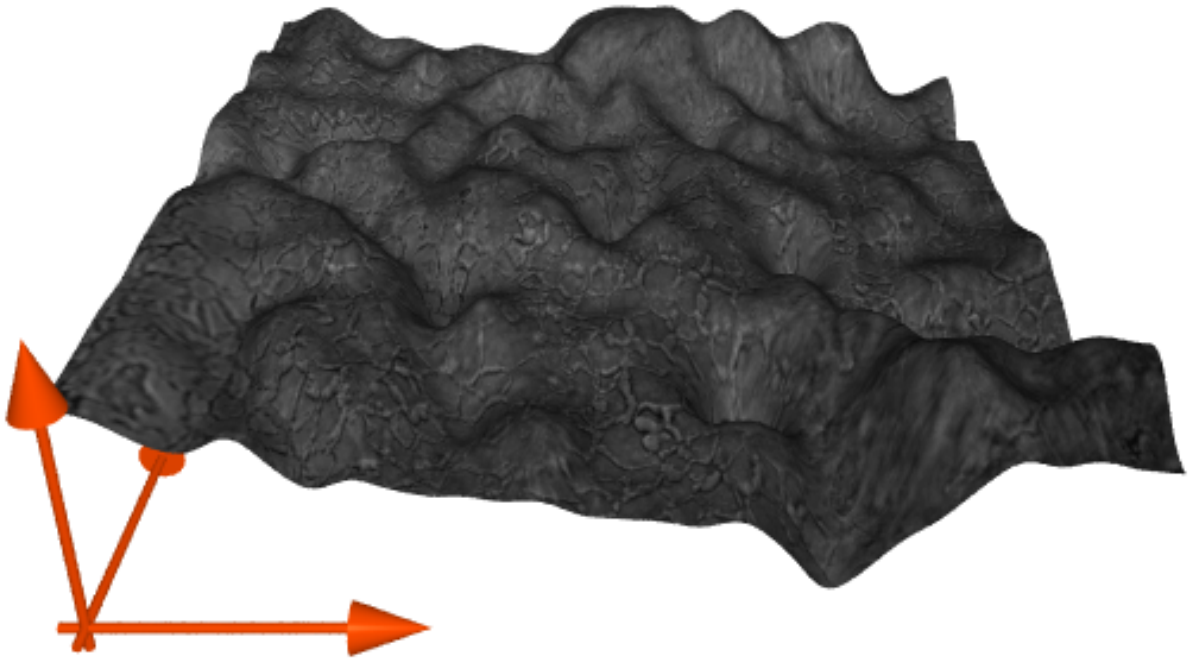


Figure 2: Reconstruction of the surface and the texture.

Practically, TIF files can handle stacks of images. Here is a way to open such a file:

```python
from skimage import io

I = io.imread('volume.tif');
I = I.astype('float');
```

```matlab
% load a stack of images in file
info = imfinfo(stackfile);
num_images = numel(info);

% store the images into stack
stack=zeros(info(1).Height, info(1).Width, num_images);

for k = 1:num_images
```

```
    stack(:,:,k)=imread(stackfile, k);
    % you can now do something with each image
end
```

In the following, each of the proposed methods will compute a focus measure layer by layer, and will maximize this measure over the stack to find the most focused layer.

1.1 Sum of Modified Laplacian

One of the first methods had been proposed by [5]. It is based on the second derivatives, specifically the Laplacian operator:

$$\triangle^2 I = \frac{\partial^2 I}{\partial x^2} + \frac{\partial^2 I}{\partial y^2}$$

The problem with this operator is that the second derivatives in the x and y dimensions can have opposite signs. One way to overcome this problem is to introduce the modified Laplacian as follows:

$$\triangle^2_M I = \left|\frac{\partial^2 I}{\partial x^2}\right| + \left|\frac{\partial^2 I}{\partial y^2}\right|$$

The discrete approximation of the modified Laplacian is computed as:

$$\begin{aligned} ML(x,y) = {} & |2I(x,y) - I(x-1,y) - I(x+1,y)| \\ & + |2I(x,y) - I(x,y-1) - I(x,y+1)| \end{aligned} \quad (1)$$

Then, the focus measure based on the modified Laplacian is:

$$F_{ML} = \sum_{(x,y)\in\omega} ML(x,y)$$

1.2 Variance

The measure of focus based on the variance is today the mainly used method [3, 6]. It is based on the computation of the variance in a window ω, with $N = \#\omega$ being the size of the window:

$$F_v = \sum_{\omega} \left(I - \underbrace{\frac{1}{\#\omega}\sum_{\omega} I}_{\text{Mean of I}} \right)^2$$

1.3 Tenengrad

In [4], we can find the definition of the tenengrad [7]. Let $S(x,y)$ be the norm of the Sobel gradient of image I.

$$F_t(I) = \sum_{\omega} S^2$$

Notice that the original definition requires a threshold value that requires heuristic choices, which is out of the topic of this tutorial.

1.4 Variance of Tenengrad

We define the variance of Tenengrad measure of focus by:

$$F_{vt}(I) = F_v(S)$$

.

2 Texture and surface reconstruction

A set of images (Vickers indentation test [1], and a human corneal endothelium [2]) are proposed. For all the detailed methods:

- reconstruct the surface and the texture of the image (an image focused on its all field of view).

2.1 Open question

Several methods have been implemented in order to perform the 3D surface/texture reconstruction. Propose a numerical measure that could compare the results and measure the effciciency of these methods? What is the best method?

References

[1] M. Fernandes, Y. Gavet, and J.-C. Pinoli. Improving focus measurements using logarithmic image processing. *Journal of Microscopy*, 242(3):228–241, 2010. 2, 4

[2] Mathieu Fernandes, Yann Gavet, and Jean-Charles Pinoli. Robust 3-d reconstruction of surfaces from image focus by local cross-sectional multivariate statistical analyses: Application to human *ex vivo* corneal endotheliums. *Medical Image Analysis*, 16(6):1293–1306, 2012. 2, 4

[3] Frans CA Groen, Ian T Young, and Guido Ligthart. A comparison of different focus functions for use in autofocus algorithms. *Cytometry*, 6(2):81–91, 1985. 3

[4] Eric Krotkov. Focusing. *International Journal of Computer Vision*, 1(3):223–237, 1988. 3

[5] Shree K Nayar and Yasuo Nakagawa. Shape from focus. *Pattern analysis and machine intelligence, IEEE Transactions on*, 16(8):824–831, 1994. 3

[6] Satoshi A Sugimoto and Yoshiki Ichioka. Digital composition of images with increased depth of focus considering depth information. *Applied optics*, 24(14):2076–2080, 1985. 3

[7] Jay Martin Tenenbaum. *Accommodation in computer vision.* PhD thesis, STANFORD UNIV CA DEPT OF COMPUTER SCIENCE, 1970. 3