A Brief Introduction to Image Processing

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2. Tools
   - Software packages
   - Example - counting and measuring cells
3. Some image processing tasks
   - Enhancement
   - Restoration
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4. Mathematical Morphology
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Software and tools

Popular image processing tools and libraries (APIs) - might be able to solve 90% of your image processing needs:

Netpbm
Web: http://netpbm.sourceforge.net, free open source.
Description: Netpbm® is a toolkit for manipulation of graphic images in 2D and 3D, including conversion of images between a variety of different formats. There are over 300 separate tools in the package including converters for about 100 graphics formats. *Netpbm does not contain interactive tools and doesn't have a graphical interface*.
Native formats: Images have a very simple format in either plain text or binary (no compression) thus making it easy to interpret and work with.
PBM - Portable Bit Map (black & white), PGM - Portable Gray Map (grayscale), PPM - Portable Pixel Map (color)

P2 → magic number to indicate file type (P2 indicates PGM plain text)
257 257 → image dimensions, height and width
255 → maximum itensity value per pixel, quantization

22 26 26 24 26 29 29 24 18 25 27 20 16 21 27 23 19 3 12 35 43 30 23 29 20 11 7 13 24 32
31 27 17 18 11 11 17 15 18 31 33 23 15 16 26 33 22 5 0 3 11 20...

Software and tools

ImageMagick
Web: http://www.imagemagick.org, open source.
Description: ImageMagick® is a software suite to create, edit, and compose digital images. It can read, convert and write images in a variety of formats (over 100). Use ImageMagick to translate, flip, mirror, rotate, scale, shear and transform images, adjust image colors, apply various special effects, or draw text, lines, polygons, ellipses and Bézier curves. APIs for C, C++, Python, Ruby, PHP, Perl, and many others.

Software and tools

Matlab Image Processing Toolbox
Web: http://mathworks.com/products/image, commercial
Description: It provides a comprehensive set of reference-standard algorithms and graphical tools for image processing, analysis, visualization, and algorithm development. You can restore noisy or degraded images, enhance images for improved intelligibility, extract features, analyze shapes and textures, and register two images. Most toolbox functions are written in the open MATLAB® language, giving you the ability to inspect the algorithms, modify the source code, and create your own custom functions. **Free for Caltech community**.

Software and tools

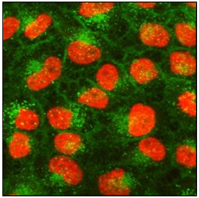
Gimp
Web: http://www.gimp.org, open source
Description: GIMP is an acronym for GNU Image Manipulation Program. It is a program for such tasks as photo retouching, image composition and image authoring. **This is your free Photoshop**. It can be used as a simple paint program, an expert quality photo retouching program, an online batch processing system, a mass production image renderer, an image format converter, etc. The advanced scripting interface allows everything from the simplest task to the most complex image manipulation procedures to be easily scripted. GIMP is GUI front end for many programs available in Netpbm.

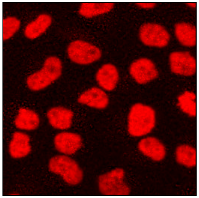
Software and tools

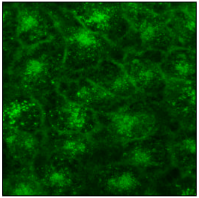
ImageJ (and Fiji)
Web: http://rsb.info.nih.gov/ij, open source.
Description: ImageJ is a public domain Java image processing program inspired by NIH Image for the Macintosh. It runs either as an online applet or as a downloadable application, on any computer with a Java 1.4 or later virtual machine. Downloadable distributions are available for Windows, Mac OS, Mac OS X and Linux. Very popular among biologists. Fiji is a recent image processing package based on ImageJ (actually, a rewrite).

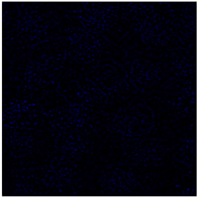
Counting cells

A biological example of an image processing task: counting concentration in the nuclei of HeLa cells.









pamchannel -infile hela.ppm -tupletype GRAYSCALE 0 ⟶ extract red channel
pamchannel -infile hela.ppm -tupletype GRAYSCALE 1 ⟶ extract green channel
pamchannel -infile hela.ppm -tupletype GRAYSCALE 2 ⟶ extract blue channel

Counting cells

A biological example of an image processing task: counting concentration in the nuclei of HeLa cells.

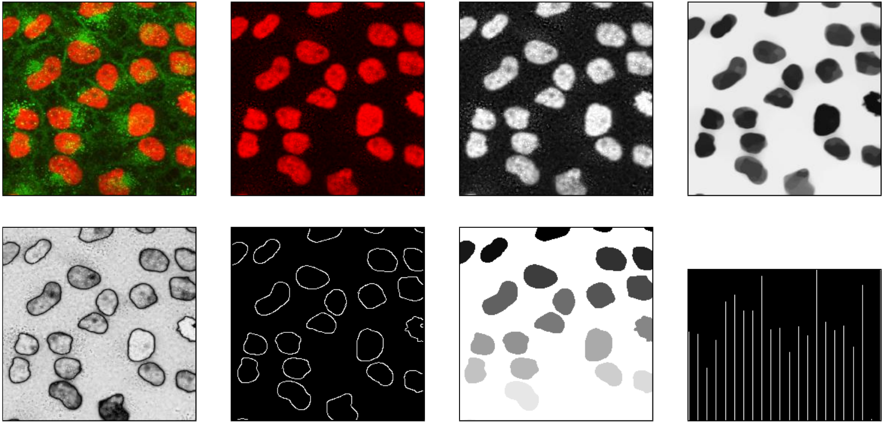


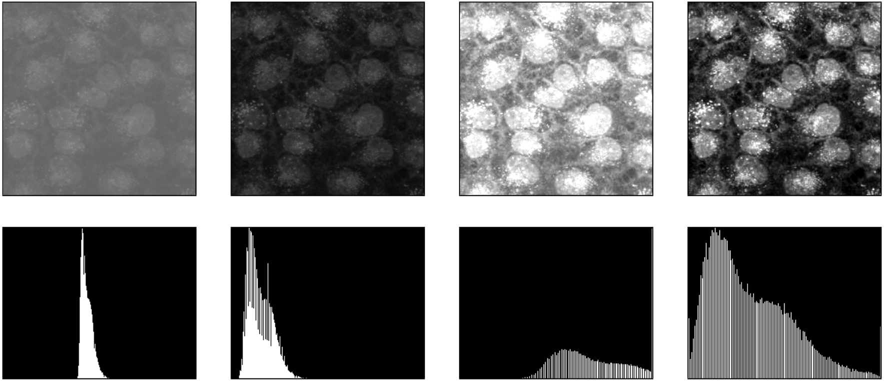
Image processing tasks

The majority of image processing tasks belongs in one of the following categories:

- **Enhancement** (contrast improvement, smoothing, sharpening)
- **Restoration** (noise reduction, deblurring)
- **Segmentation** (counting, identification, separation)
- **Registration** (comparison)
- **Compression** (transmission, storage, fast processing)
- **Pattern recognition** (classification, matching)
- **Others** (tomography, morphing, inpainting, color correction,...)

Image enhancement

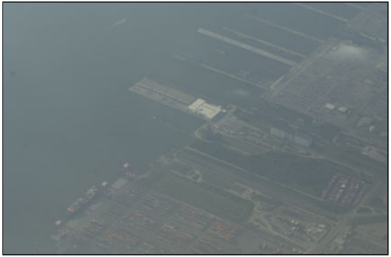
Enhance image contrast by manipulating its intensity and/or histogram.

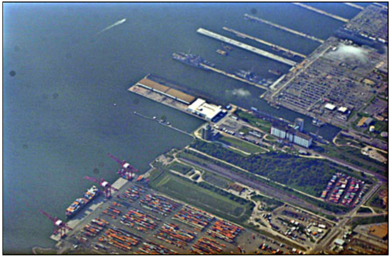


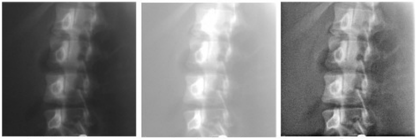
- Contrast stretching: expand intensities to cover full range [0,255] while discarding the 1% to 2% tails.

Image enhancement

Enhancement using the Retinex algorithm by Edwin Land (look for it in GIMP):







Original X-ray image

Conventional processing

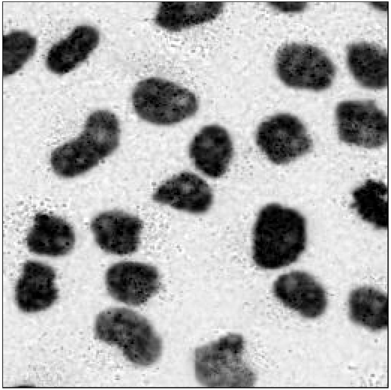
Retinex

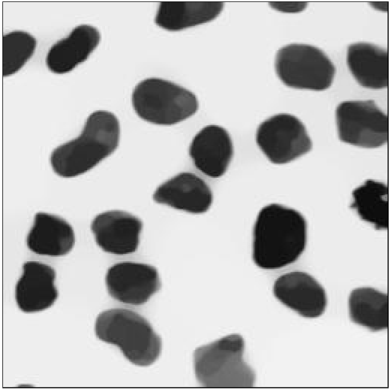
Application of retinex image processing to medical x-ray image

- Retinex tries to ensure that the perceived color of objects remains relatively constant under varying illumination conditions. Images from NASA Langley Research Center.

Image restoration

Most images are contaminated with some type of noise which is due either to the acquisition process or noisy transmission lines.





The goal of noise reduction is to remove as much noise as possible from the image while maitaining the signal intact.

Image restoration

A simple denoising model is to assign to each pixel the average intensity of neighboring pixels. This blurs the image and destroys sharpness.

The system

$$\frac{\partial u(x,t)}{\partial t} = -\nabla \cdot \nabla u(x,t) = \Delta u(x,t), \quad u(x,0) = f(x)$$

smoothes pixel values everywhere *including at edges*. This is exactly Gaussian convolution with variance t:

$$u(x,t) = G_{\sqrt{t}} * f(x)$$

as $t \rightarrow \infty$ image gets blurred. when to stop?

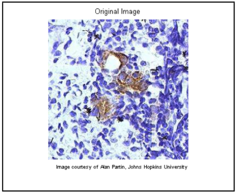

Original Image

Image courtesy of Alan Partin, Johns Hopkins University

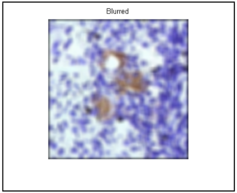
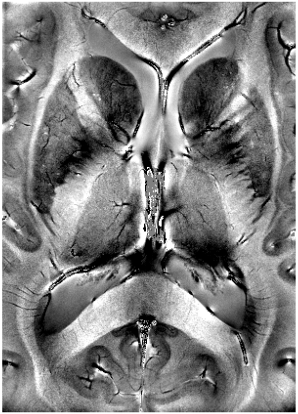
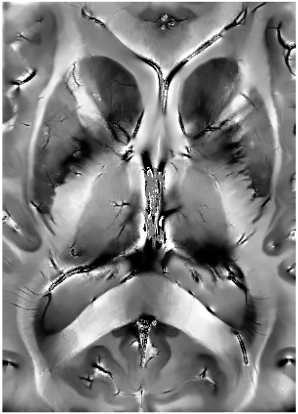

Blurred

Image restoration

We can do much better. Example of filtering a high resolution MRI where edges are preserved and noise judiciously removed with the *nonlocal means* method.



noisy image

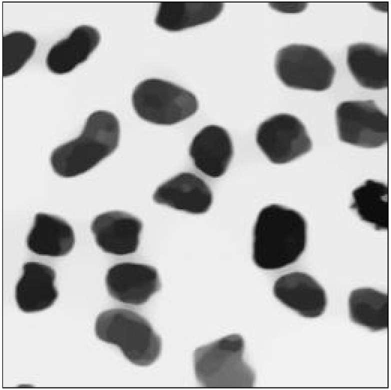


denoised

Note that the thin filaments were not blurred nor destroyed after denoising.

Image segmentation

Segmentation is the process of separating distinct, homogeneous regions from other regions and the background.



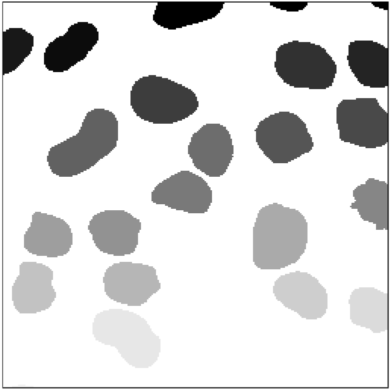


Image segmentation

Robust and efficient segmentation methods are sought everywhere (in Astronomy, Medicine, Neuroscience, Forensics, Biology, Materials Science, Robotics,...):

DIADEM CHALLENGE

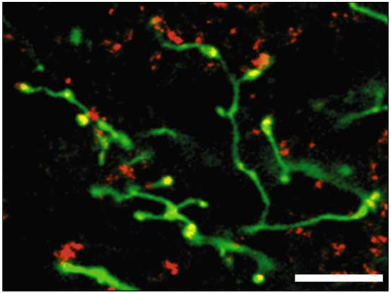
http://www.diademchallenge.org

From DIADEM web page: **The lack of powerful - and effective - computational tools to automatically reconstruct neuronal arbors in 3D has emerged as a major technical bottleneck in neuroscience research**. Despite the advent of computer technology that enables mapping in three dimensions, neuronal reconstructions are still largely performed by hand and reconstructing a single cell may take months.

Organizers of a new competition hope to provide incentives for the development of new computer algorithms to advance the field - including a cash prize of up to $75,000 for the qualifying winner.

Image segmentation

Neuronal arbor segmentation:



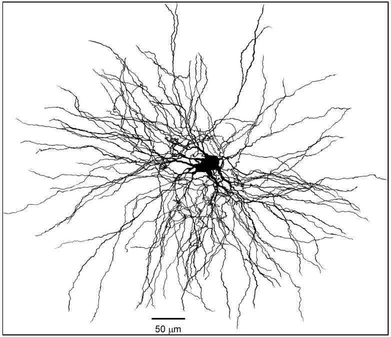


Image registration

When we register two images we aim to align them so that their *features* match as close as possible. A displacement map is usually produced which gives us an idea of how much warping is needed to achieve a good matching.

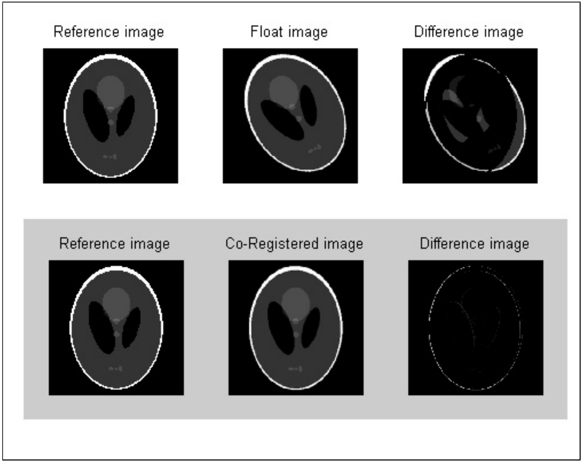


Image registration

A warped image grid gives an idea of the displacements necessary to match the purple contour to the red contour representing the boundaries of human brain ventricles.

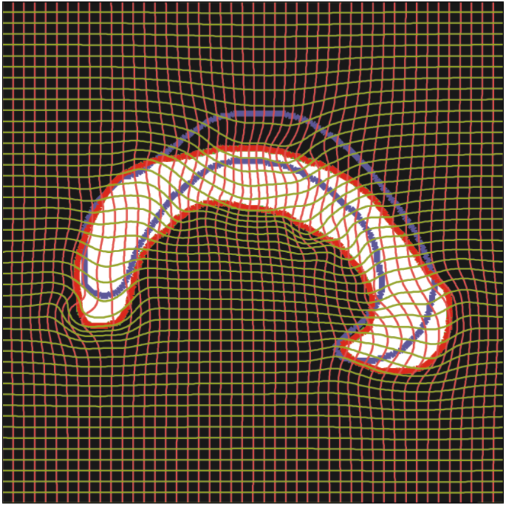
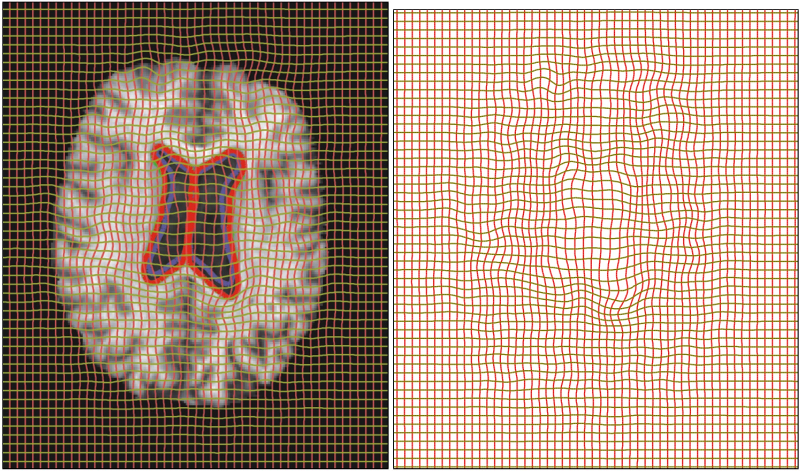


Image registration

Registration is a standard tool in the construction and use of anatomical atlases where we map arbitrary subjects to a canonical space in order to make comparisons of shape and size.



Mathematical morphology

Morphological image processing consists of a set of operations that transform images according to rules of set theory. It was originally developed for binary images and later extended to grayscale images. It was primarily developed in the 60's by French mathematicians Jean Serra and Georges Matheron.

The basic idea in binary morphology is to probe an image with a simple, pre-defined shape, called the **structured element**, drawing conclusions on how this shape fits or misses the shapes in the image.

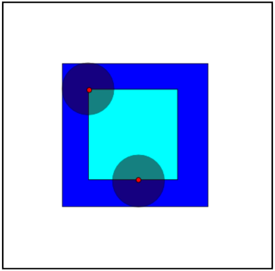
The four basic operations of mathematical morphology are:

- Erosion: shrink objects
- Dilation: grow objects
- Opening: erosion followed by dilation (disconnect parts)
- Closing: dilation followed by erosion (remove holes)

Matlab provides an almost complete set of math morphology routines.

Erosion

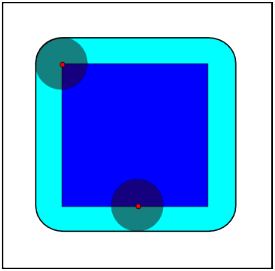
Given an image A and a structured element B we define the erosion operator $\ominus$ as
$A \ominus B = \bigcap_{b \in B} A_{-b}$
The dark blue image A is eroded by the circle B giving rise to a smaller region shown in light blue:



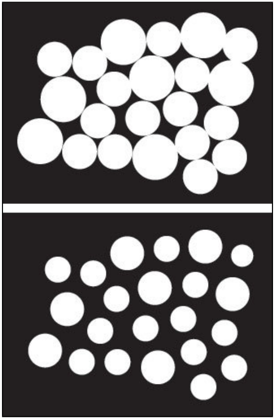
Dilation

Given an image A and a structured element B we define the dilation operator $\oplus$ as $A \oplus B = \bigcup_{b \in B} A_b$

The dark blue image A is dilated by the circle B producing a larger region which includes the additional light blue area:

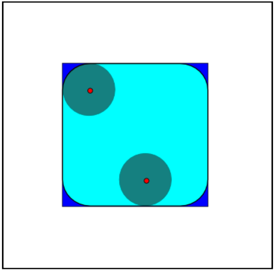


Erosion x Dilation, an example



Opening

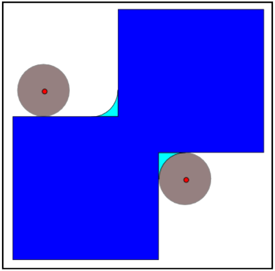
Given an image A and a structured element B we define the opening operator $\circ$ as an erosion followed by dilation, $A \circ B = (A \ominus B) \oplus B$
The dark blue square A is opened by the circle B producing a smaller rounded square which are the places ocupied by B when translated inside A.



Closing

Given an image A and a structured element B we define the closing operator $\bullet$ as an erosion followed by dilation, $A \circ B = (A \oplus B) \ominus B$

The dark blue region A is closed by the circle B producing a larger region with some rounded corners which are the places between the translation of B outside A and A itself.



Other operators

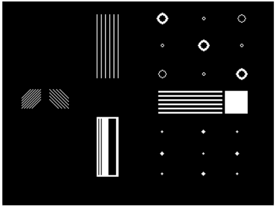
Other important math morphology operators are (mostly can be written as combinations of the basic operators):

- Thinning : reduce thick lines to thin, 1 pixel wide lines (repeated erosion)
- Thickening : opposite of thinning, produce wider lines (repeated dilation)
- Skeleton : generates a skeleton, a central line equidistant to the boundary of the shape
- Prunning : remove dangling lines, spurs
- Watershed : image segmentation

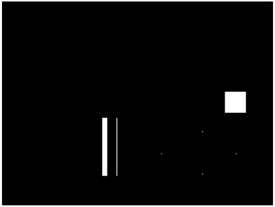
You can try all these in Matlab.

Example, random image

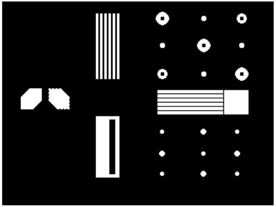
From left to right, top to bottom: sample image, erosion, dilation, opening, and closing.



sample image

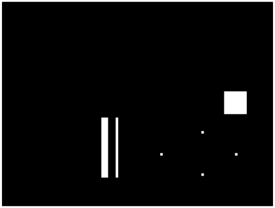


erosion

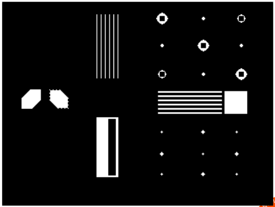


dilation

-

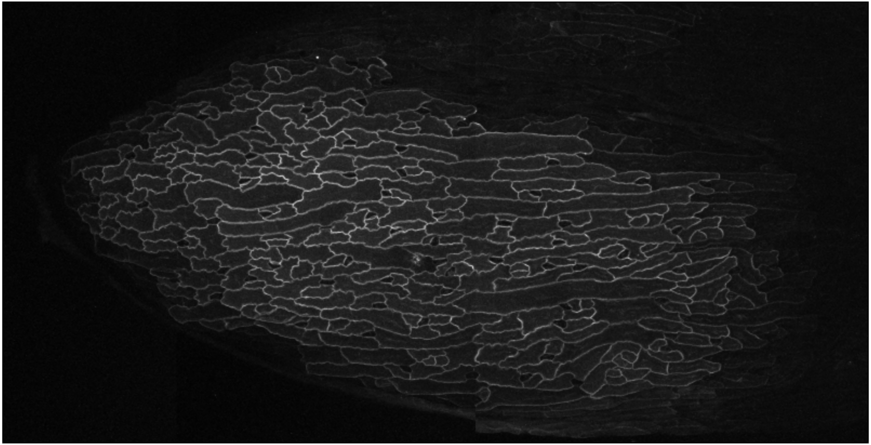


opening



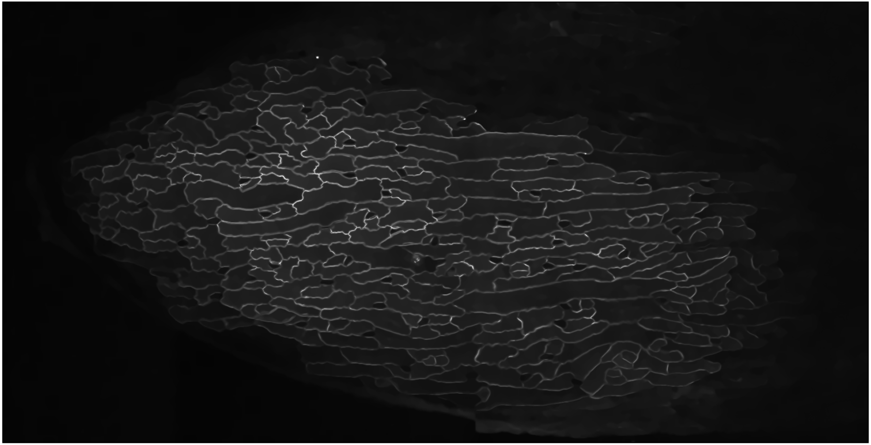
closing

Example, plant cells



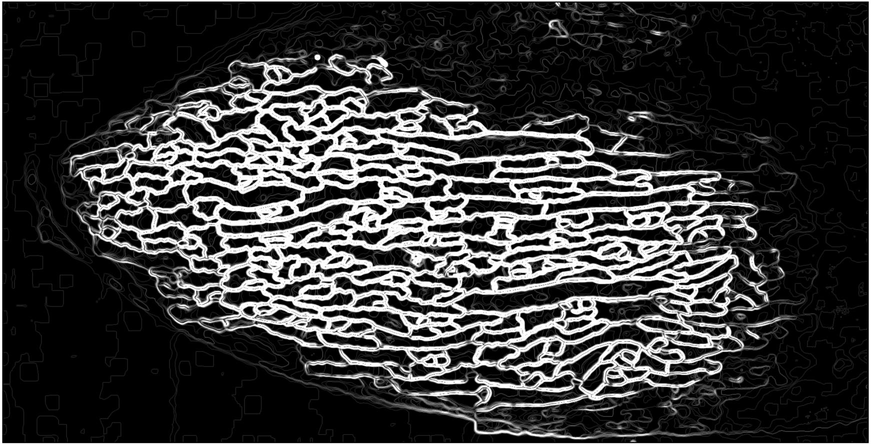
sepal cells in the Arabidopsis plant, acquired by confocal microscopy

Example, plant cells



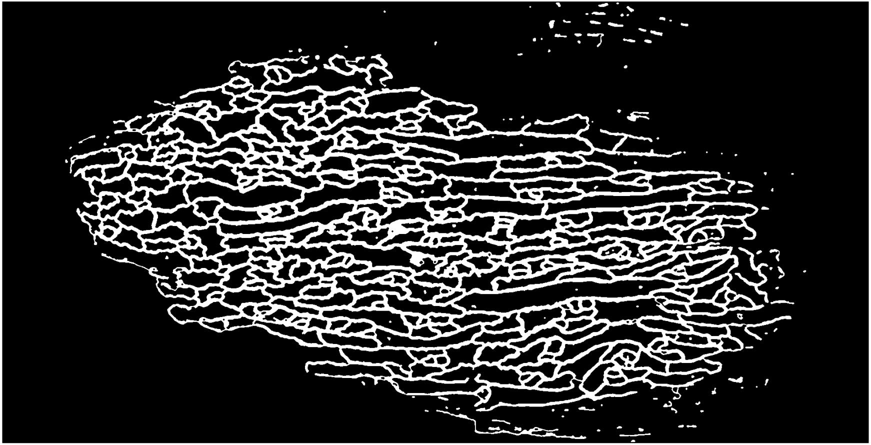
denoised cells

Example, plant cells



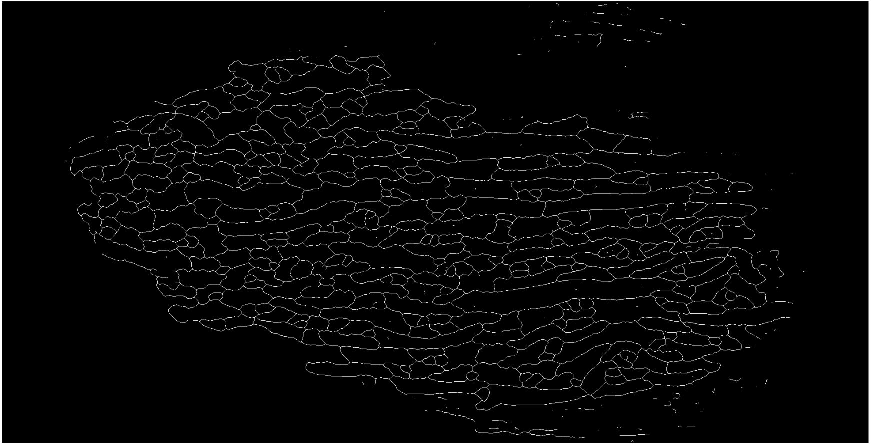
thick but discontinuous edges

Example, plant cells



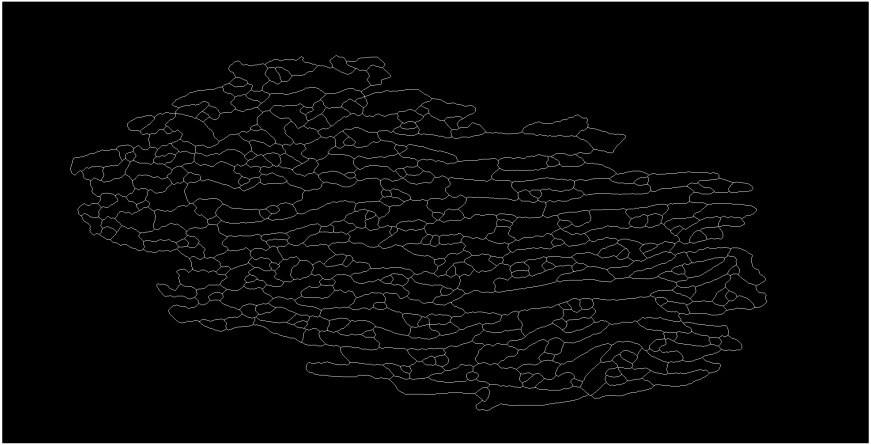
thick edges with filled holes

Example, plant cells



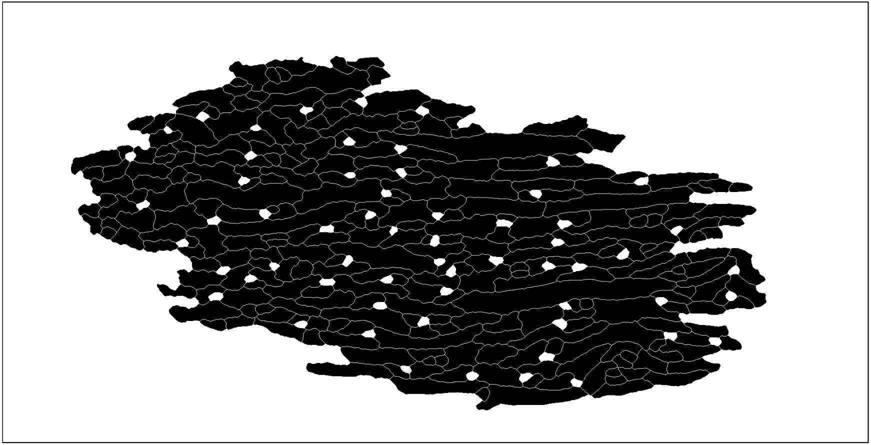
thin edges with spurs and dangling segments

Example, plant cells



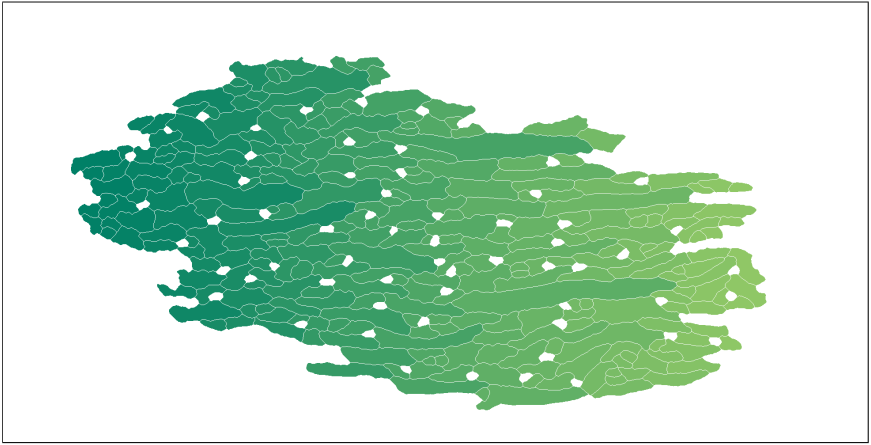
spurs and small islands removed

Example, plant cells



totally clean and nicely segmented image; guard cells manually removed

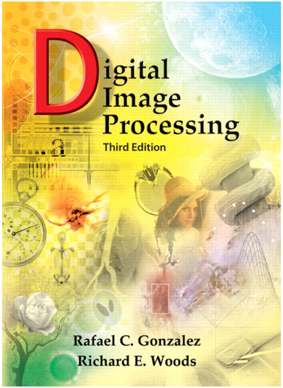
Example, plant cells



colored version

References

If you have to buy one book...



Digital Image Processing
Rafael C. Gonzalez and Richard E. Woods
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http://www.imageprocessingplace.com

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Other books of interest:

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