Today

- What is image segmentation?
- A smörgåsbord of methods for image segmentation:
  - Thresholding
  - Edge-based segmentation
  - Hough transform
  - Region-based segmentation
  - Watershed
  - Match-based segmentation

Chapter 10.1-10.2.5, and 10.3-10.5 in Gonzalez & Woods: Digital Image Processing, 3rd ed., 2008
What is segmentation?

Dividing the image into different regions. Separating objects from background and giving them individual ID numbers (labels).
Why segmentation?

Accurate segmentation of objects of interest in an image greatly facilitates further analysis of these objects. For example, it allows us to:

- Count the number of objects of a certain type.
- Measure geometric properties (e.g., area, perimeter) of objects in the image.
- Study properties of an individual object (intensity, texture, etc.)
- ...
Segmentation

Segmentation is often the most difficult problem to solve in image analysis.

There is no universal solution!
Wikipedia on segmentation

-“In computer vision, Segmentation is the process of partitioning a digital image into multiple segments”

-“More precisely, image segmentation is the process of assigning a label to every pixel in an image such that pixels with the same label share certain visual characteristics.”

-“Each of the pixels in a region are similar with respect to some characteristic or computed property, such as color, intensity, or texture. Adjacent regions are significantly different with respect to the same characteristic(s).”

-“Since there is no general solution to the image segmentation problem, these [general purpose] techniques often have to be combined with domain knowledge in order to effectively solve an image segmentation problem for a problem domain.”
Targeted Segmentation

Segmentation is an ill-posed problem...

What is a correct segmentation of this image?
Targeted Segmentation

...unless we specify a segmentation target.

“Segment the orange car from the background”

“Segment all road signs from the background”
Targeted Segmentation

A segmentation can also be defined as a mapping from the set of pixels to some application dependent target set, e.g.

- \{Object, Background\}
- \{Humans, Other objects\}
- \{1,2,3,4,...\}
- \{Healthy tissue, Tumors\}

To perform accurate segmentation, we (or our algorithms) need to somehow know how to differentiate between different elements of the target set.
Segmentation

Segmentation algorithms are often based on one of the following two basic properties of intensity values:

**Similarity**
Partitioning an image into regions that are similar according to a set of predefined criteria.

**Discontinuity**
Detecting boundaries of regions based on local discontinuity in intensity.
Four types of segmentation algorithms

Thresholding - *Similarity*
Based on pixel intensities (shape of histogram is often used for automation).

Edge-based - *Discontinuity*
Detecting edges that separate regions from each other.

Region-based - *Similarity*
Grouping similar pixels (with e.g. region growing or merge & split).

**Watershed segmentation** - *Discontinuity*
Find regions corresponding to local minima in intensity.

Match-based - *Similarity*
Comparison to a given template.
Thresholding
Thresholding

A threshold $T$, a gray level intensity, classifies every pixel as belonging to objects (foreground) or background. (Or rather, {dark objects, bright objects}).
Thresholding

Global threshold
The same value is used for the whole image.

Optimal global threshold
Based on the shape of the current image histogram. Searching for valleys, Gaussian distribution etc.

Local (or dynamic) threshold
The image is divided into non-overlapping sections, which are thresholded one by one.
Global thresholding

We chose a **threshold** $T$ midway between the two gray value distributions.

*Here:* In the thresholded binary image, pixel values below $T$ belong to the object (black), pixels above $T$ are background (white).
How to find a global threshold

Example method

1. Choose initial threshold $T_o$
2. Define $f(x,y) > T_o$ as background and $f(x,y) < T_o$ as foreground
3. Calculate mean for background $\mu_{bg}$ and foreground $\mu_{fg}$
4. Set next threshold $T_i = (\mu_{bg} + \mu_{fg})/2$
5. Repeat 2.-4. until stopping criteria, $T_i = T_{i-1}$, is fulfilled
When does intensity based thresholding work?

[Images of histograms and images with intensity values]
Local thresholding

Example method
Subdivide image into non-overlapping rectangles. These rectangles are chosen small enough so that the illumination of each is approximately uniform. Then determine a global threshold for each subimage.
Edge-based segmentation
Edge-based segmentation

Detection of sharp, local changes in intensity.

Step | Ramp | Line | Point
--- | --- | --- | ---
light | | | |
dark | | | |
Edge-based segmentation

General workflow

1. Detect edges, i.e., mark each pixel as "edge" or "not edge".

2. Divide the image into regions, based on the detected edges. (Edge linking, Hough transform)
Edge-based segmentation

General workflow

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This part is non-trivial!
Edge detection

Edge detection typically consists of two steps:

1. **Enhance edges**
   Apply an edge/point detector (e.g. Sobel, Laplace)

2. **Extract edges**
   Segment edges of interest (e.g. thresholding)
**Task:** Find lines in this image, that are 1 pixel thick and have an orientation of -45°.

**Example**

*Original image*  
(Wire-bond mask of an electric circuit)

*Filtered*

*Thresholded*
Hough transform

A method for detecting lines (or other parametric objects) in images.

Patented by Paul Hough in 1962. The version of the method as it is used today was invented by Richard Duda and Peter Hart in 1972.

Richard Duda

Peter Hart
Hough transform

- Consider a point \((x_i, y_i)\) in the plane. Infinitely many lines pass through \((x_i, y_i)\), all satisfying the equation \(y_i = ax_i + b\) for varying \(a\) and \(b\).
- We can rewrite this equation as \(b = -x_i a + y_i\). The set of lines passing through the fixed point \((x_i, y_i)\) in the \(xy\)-plane form a single line in the \(ab\)-plane (parameter space).
- A second point \((x_j, y_j)\) is also associated with a line in parameter space. This line intersects the line associated with \((x_i, y_i)\) at a point \((a', b')\) corresponding to the line containing both \((x_i, y_i)\) and \((x_j, y_j)\). In fact, all points on this line have lines in parameter space that intersect at \((a', b')\).
Hough transform

- Assume that we are given n points in an image (detected edge points).
- Each of these points can be considered as “evidence” for the family of lines passing through that point (a line in parameter space).
- In principle, the parameter space line corresponding to each point could be plotted, and principal lines in the image could be found by identifying points in parameter space where a large number of lines intersect.
- A practical problem is that the slope of the line approaches infinity as the line approaches the vertical direction. This can be solved by using the following representation of a line: $x \cos \Theta + y \sin \Theta = \rho$. 
Hough transform

Original image

Hough transform
(Matlab: hough(image);)
The Hough transform groups edge points into object candidates. This is performed by an explicit voting procedure over a set of parameterized image objects.

What is it good for?
“Holes“ (missing pixels) in the desired curves. Noisy edge points (detected by the edge detector)

The Hough transform can also be extended to find other parametric objects (curves, ellipses, etc.)
Region-based segmentation
Region-based segmentation

Region splitting and merging  (*Top-down approach*)
1. Set up criteria for what is a uniform area (e.g. mean, variance, bi-modality of histogram, texture, etc.).
2. Start with the full image and *split* it into four sub-images.
3. Check each sub-image. If it is not uniform, *split* it again into four sub-images.
4. Repeat 3. until no more splitting is performed.
5. Compare sub-images with the neighboring regions and *merge*, if they are uniform.
6. Repeat 5. until no more merging is performed.

The method is also called *quad-tree* division.
Region-based segmentation

**Region growing** (*Bottom-up approach*)

1. Find starting points.
2. Include neighboring pixels with similar feature (gray level, texture, color, etc.).
3. Continue until all pixels have been associated with one of the starting points.

**Problems**

Non trivial to find good starting points, difficult to automate and needs good criteria for similarity.
Watershed segmentation
Watershed

The watershed algorithm was introduced in 1978 and extended by Serge Beucher in 1982.
Watershed -flooding analogy

Think of the gray level image as a landscape. Let water rise from the bottom of each valley (the water from the valley it given its own label). As soon as the water from two valleys meet, build a dam, or a watershed. These watersheds will define the borders between different regions in the image.

The watershed algorithm can be used directly on the image, on an edge enhanced image or on a distance transformed image.
Watershed - drop of water analogy

Think of the gray level image as a **landscape**. A drop of water landing at any point in the landscape will flow down to a local minimum in the landscape.

For any local minimum in the landscape, there is a set of points, called the *catchment basin*, from which a drop of water will flow to that given minimum.

The boundaries between adjacent catchment basins form the watershed.
Watershed

Example of watershed directly applied on gray level image:

Original image

Inverted image
(starting points are in valleys)

Segmentation result
Watershed

Example of watershed directly applied on gray level image:

Original image

Segmentation result

```matlab
>> image = imread('coins.png');
>> ws = watershed(image);
>> imagesc(ws);
>>
```
Watershed

Example of watershed directly applied on gray level image:

Blurred image  Segmentation result
Distance transform

Original image

Distance measure

Distance transform
Watershed

Example of watershed on distance transformed image:

- Original image
- Distance transform
- DT as intensity
- DT inverse
- "Intensity landscape"
- Segmentation result
Seeded watershed

Example for seeded watershed:
Every cell has a cell nucleus, which can be detected by thresholding and watershed segmentation. Using these nuclei as seeds, the cytoplasms are easy to find.
Computing watersheds

Algorithm by F. Meyer (early 90's)

1. A set of markers, pixels where the flooding shall start, are chosen. Each is given a unique label.
2. The neighboring pixels of each marked area are inserted into a priority queue with a priority level corresponding to the gray level of the pixel.
3. The pixel with the highest priority level is extracted from the priority queue. If the neighbors of the extracted pixel that have already been labeled all have the same label, then the pixel is labeled with their label. All non-marked neighbors that are not yet in the priority queue are put into the priority queue.
4. Redo step 3 until the priority queue is empty.

The non-labeled pixels are the watershed lines.
Match-based segmentation
Match-based segmentation

Compare a template to the underlying image to find objects with a certain intensity distribution or shape.
Match-based segmentation

Computational problem: Testing all possible transformation (translation, rotation, scaling) of the template.