Reading Instructions

Chapters for this lecture

- Chapter 10, but not 10.2.3, or 10.6 in Gonzales-Woods.
Previous Lectures

Image processing
- Point processing (Spatial domain, pixel-wise)
- Local neighborhoods (Spatial domain, filtering)
- Fourier transform (Frequency domain, filtering)

Image analysis
- Segmentation (Easier said, than done!)

Fundamental steps in problem solving
using digital image analysis

1. Problem
2. Image acquisition
3. Preprocessing
4. Segmentation
5. Representation and Description
   - Classification, recognition, interpretation
   - Solution
Segmentation
Divide the image contents into its constituent regions

- **Full segmentation**: Individual objects are separated from the background and given individual ID numbers (labels).
- **Partial segmentation**: The amount of data is reduced (usually by separating objects from the background) to speed up further processing.

**Segmentation ...**

... is often the most difficult problem to solve in image analysis; there is no universal solution!

- The problem can be made much easier if solved in cooperation with the constructor of the imaging system (choice of sensors, illumination, background, etc.).

**Four types of segmentation**

- **Thresholding**: Based on pixel intensities, often using the shape of the histogram for automation.
- **Region-based**: Group similar pixels: region growing, merge & split.
- **Edge-based**: Search for discontinuities in the image, and try to connect objects or borders (often by a region-based technique).
- **Match-based**: Comparison to a template (more in lecture 8 or 9, and next course).
Segmentation
based on two basic properties of intensity values

- **Similarity**: thresholding, region growing, split and merge.
- **Discontinuity**: Edges.

**Thresholding**

A threshold $T$, a gray level intensity, classifies every pixel as belonging to objects (foreground) or background.

- **Fixed thresholds**: The same value is used for all images.
- **Optimal thresholding**: Based on the shape of the current image histogram. Searching for valleys, Gaussian distributions, etc.
- **Local (or dynamic) thresholding**: The image is divided into overlapping sections which are thresholded one by one.

Lighting conditions are extremely important, and it will only work under very controlled circumstances.
Global thresholding

- (a) Original image.
- (b) Image histogram.
- (c) Result of global thresholding with $T$ midway between the maximum and minimum gray levels.

Thresholded binary image, all pixel values are 0 (object) or 1 (background).

Example method

1. Choose initial threshold $T_0$.
2. Then $f(x, y) < T_0$ is background, and $f(x, y) \geq T_0$.
3. Calculate mean for background $\mu_{bg}$, and foreground $\mu_{fg}$.
4. Set next threshold $T_i = 0.5 \times (\mu_{bg} + \mu_{fg})$.
5. Repeat 2 – 4 until stopping criteria is fulfilled.
Threshold examples

Local thresholding

Original image.

Image segmented by local thresholding.
Labeling
Identifying objects

- Once the objects are separated background and from each other, each separate object is given an ID number.
- Use a two-pass algorithm

How many objects are there in the image?

Edge-based segmentation

- First apply an edge/point detector
  - gradient operator (Sobel)
  - second derivative (Laplace)
- Second “Threshold” edges and link and segment by:
  - local processing or
  - Hough transform (global)
- or... use, e.g., region growing or watershed to transform the edge image into a full segmentation.
Edge-based segmentation

Find edges of a given thickness in a given direction using a designed filter. E.g., Sobel $-45^\circ$

\[
\begin{array}{ccc}
0 & -1 & -2 \\
1 & 0 & -1 \\
2 & 1 & 0
\end{array}
\]

Result after filtering with Sobel filter for $-45^\circ$ and thresholding on gradient magnitude (can be further processed by, e.g., removal of single points).

The Hough transform

Transform local information into global information in parameter space and search for common “patterns”.

- Represent all edge points $(x_i, y_i)$ as lines in a $(a, b)$ parameter space (where $a$, and $b$ comes from the equation for a straight line $y = ax + b$).
- Look for points $(a', b')$ were many lines meet = edge points from a line.
- Divide parameter space into accumulator cells.
The Hough transform

Problems with vertical lines \((a, b \text{ approaching infinity})\) are avoided by representing each point \((x, y)\) with an angle \(t\) and a radius \(r\). We will then have

\[ x \cos(t) + y \sin(t) = r, \]

and each pixel will be described by a curve in the \(r, t\)-plane, where \(t\) can vary in the interval \(\pm90^\circ\).

Other parameter spaces can be used to detect, e.g., the position of circles with a given radius. The Hough transform can also be applied locally to find curves that are only locally straight.

- (a) Infrared image.
- (b) Thresholded gradient image.
- (c) Hough transform.
- (d) Linked pixels.
The Hough transform

A detailed example

The Hough transform for finding straight lines uses the formula for the straight line $y = ax + b$, but expressed for the $a$ & $b$ parameter space,

$$b = -ax + y.$$

In the image to the right there are six non-zero pixels, such that
- (2, 0) give line $b = -2a$.
- (1, 1) give line $b = -a + 1$.
- (0, 2) give line $b = 2$.
- (2, 2) give line $b = -2a + 2$.
- (3, 3) give line $b = -3a + 3$.
- (4, 4) give line $b = -4a + 4$.

The six straight lines in the parameter space will cross each other if they are connected in a line. Discrete artifacts may create spurious responses. This time we select the two strongest responses in the $a$, $b$ parameter space at positions
- $(a, b) = (-1, 2)$.
- $(a, b) = (1, 0)$.

Which corresponds to two lines in the $x$, $y$ space,
- $y = -x + 2$.
- $y = x$. 
The Hough transform

Lines in image space

The equation for a circle in the \(x, y\) space is given by \((y - a)^2 + (x - b)^2 = r^2\) where \((a, b)\) is the center. The non-zero pixels give rise to the following equations,

- \((2, 0)\) give circle \((0 - a)^2 + (2 - b)^2 = 1\).
- \((1, 1)\) give circle \((1 - a)^2 + (1 - b)^2 = 1\).
- \((1, 3)\) give circle \((1 - a)^2 + (3 - b)^2 = 1\).
- \((2, 2)\) give circle \((2 - a)^2 + (2 - b)^2 = 1\).
- \((3, 5)\) give circle \((3 - a)^2 + (5 - b)^2 = 1\).
- \((4, 4)\) give circle \((4 - a)^2 + (4 - b)^2 = 1\).
- \((4, 6)\) give circle \((4 - a)^2 + (6 - b)^2 = 1\).
- \((5, 5)\) give circle \((5 - a)^2 + (5 - b)^2 = 1\).
The Hough transform

In the parameter space the eight non-zero pixels represent the center of eight circles with radius 1. Drawing the circles on top of each other will yield high response where the circles intersect. In this case we pick the two strongest signals,

- \((a, b) = (1, 2)\).
- \((a, b) = (4, 5)\).

Which corresponds to two center points for circles with the radius 1 in the \(x, y\) space.

The Hough transform

Circles in image space
Region based segmentation

Top-down approach

Region splitting and merging

1. Set up some 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 not uniform, divide into four new sub-images.
4. Compare regions with neighboring regions and merge if uniform.

Repeat 2 – 4 until nothing more happens. The method is also called “quad-tree” division.

Region based segmentation

Bottom-up approach

Region growing

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

Problems: Non trivial to find good starting points, difficult to automate, need good criteria for similarity. A method is watershed.
Watershed
A kind of region growing

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

Can be used directly on the image, on an edge enhanced image or on a distance transformed image.
Watershed
Example of watershed applied to a binary image with “round” objects

The model is that every object contains a “seed”, e.g., every cell has a cell nucleus which can be detected by thresholding and shape-based watershed segmentation. Using the nuclei as seeds, the cytoplasms are easy to find. Fully automatic analysis at the speed of 100 cells/second.
Watershed
Find individual nuclei in (2D & 3D) tissue samples

Model: A nucleus is a connected region that is ...

1. Brighter than the local background ...

2. Surrounded by a sharp edge ...

3. Convex

Watershed
Extension to 3D

Same approach as for 2D, but extending all $3 \times 3$ operators to $3 \times 3 \times 3$.

Maximum intensity projection (MIP) of a $256 \times 256 \times 100$ volume image.

Segmentation result: Each cell (in 3D) has its own label (ID number) and measurements can be made on the individual cells.
Match-based segmentation

Compare a “template” to the underlying image to find objects with a certain intensity distribution or shape (detailed in a later lecture).

Reading Instructions

Chapters for tomorrow's lecture

- Chapter 9 in Gonzales-Woods.