Image segmentation: thresholding

• Suppose an image \( f(x,y) \) is composed of several light objects on a dark background.
• The histogram for such an image may look like the following: showing two dominate modes.
• An obvious way to extract object information is to select a threshold \( T \) that separates the two modes.
Thresholding (continued)

- Suppose several objects with differing gray levels (with a dark background) comprise the image.
- An object may be classified as belonging to one object class if \( T_1 < f(x,y) \leq T_2 \), to a second class if \( f(x,y) > T_2 \) or to the background if \( f(x,y) \leq T_1 \).
- This, however, is generally less reliable than single level thresholding.

\[
\begin{align*}
T_1 &< f(x,y) \leq T_2 \\
&\text{Object 1} \\
&\text{Object 2} \\
&\text{Background}
\end{align*}
\]

Thresholding (continued)

- Thresholding may be viewed as an operation that tests against a given function of the form

\[
T = T[x, y, p(x, y), f(x, y)]
\]

- where \( f(x,y) \) is the gray level of point \((x,y)\) and \( p(x,y) \) is some local property of the point -- the average gray level of a neighborhood around \((x,y)\).
- The thresholded image is given by

\[
g(x,y) = \begin{cases} 
1 & \text{if } f(x,y) > T \\
0 & \text{if } f(x,y) \leq T 
\end{cases}
\]

- Pixels labeled 1 (or any other convenient gray level value) correspond to objects.
Thresholding (continued)

- When \( T \) depends only on \( f(x,y) \) the threshold is called *global*.
- If \( T \) depends on \( f(x,y) \) and \( p(x,y) \) the threshold is *local*.
- If, in addition, \( T \) depends on the spatial coordinates \((x,y)\), the threshold is called *dynamic*.
- For example, a local threshold may be used if certain information about the nature of the objects in the image is known a priori.
- A dynamic threshold may be used in the case where object illumination is non-uniform.

Thresholding based on boundaries

- Important aspect of threshold selection: the ability to reliably identify mode peaks in a given histogram.
- The chances of selecting a “good” threshold are enhanced if mode peaks are
  - tall
  - narrow
  - symmetric
  - and separated by deep valleys.
- One approach for improving the histogram shape is to consider only those pixels that lie on or near a boundary between objects and the background.
Boundary characteristic thresholds (continued)

• An obvious advantage is that the histogram becomes less dependent on the size of objects in the image.

• By choosing pixels on or near object boundaries (assuming an equal probability of choosing a pixel on the object or boundary) the histogram peaks tend to be made more symmetric.

• Using pixels that satisfy some simple measures based on the gradient and Laplacian operators tends to deepen the valleys between histogram peaks.

Boundary characteristic thresholds (continued)

• Determining if a pixel lies on a boundary: compute the gradient.

• Determining what side, background (dark) or object (light), a pixel lies on: compute the Laplacian.

• Using the gradient and Laplacian, a three-level image may be formed according to

\[
s(x, y) = \begin{cases} 
0 & \text{if } \nabla f < T \\
+ & \text{if } \nabla f \geq T \text{ and } \nabla^2 f \geq 0 \\
- & \text{if } \nabla f \geq T \text{ and } \nabla^2 f < 0
\end{cases}
\]

• where 0, + and - are three distinct gray levels.
Boundary characteristic thresholds (continued)

• For a dark object on a light background, $s(x,y)$ is produced where
  – all pixels not on an edge are labeled 0
  – all pixels on the dark side of an edge are labeled +
  – all pixels on the light side of an edge are labeled -

• For a light object on a dark background, $s(x,y)$ is produced where
  – all pixels not on an edge are labeled 0
  – all pixels on the dark side of an edge are labeled -
  – all pixels on the light side of an edge are labeled +