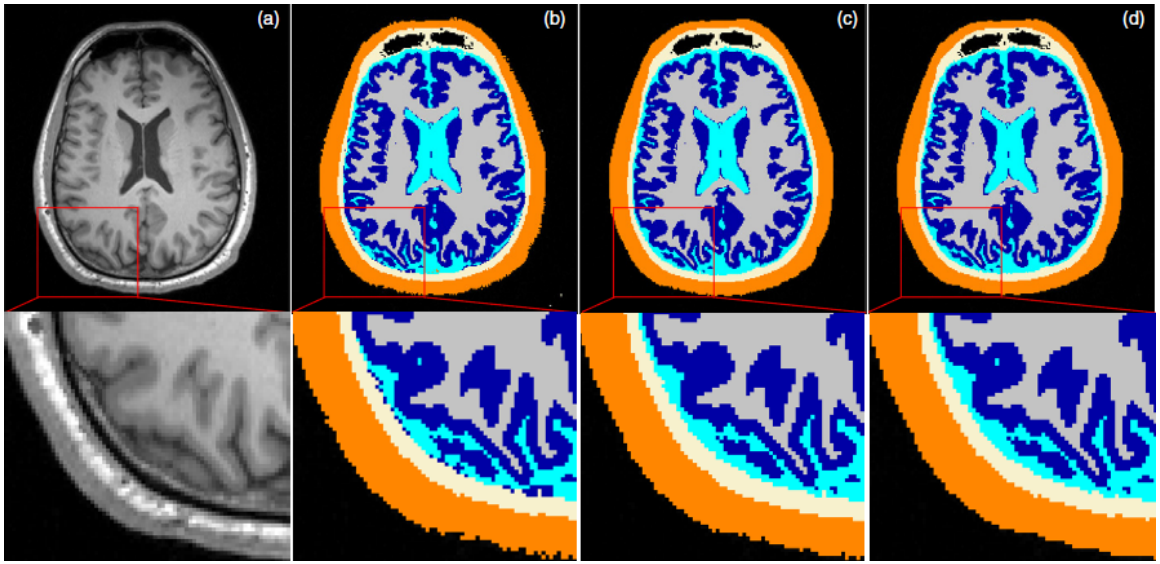
(Medical) Image Segmentation



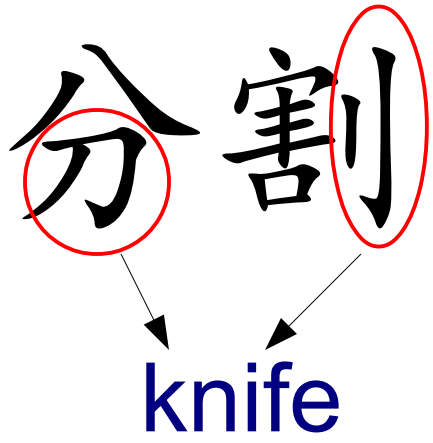
Huang et al 2013

Yu (Andy) Huang
Nov. 26, 2013

some slides from Chris Alvino

What is segmentation?

- to partition
- to separate
- homogeneous regions
- similar intensity, texture, etc.
- locate objects, areas of interest



Why segmentation?

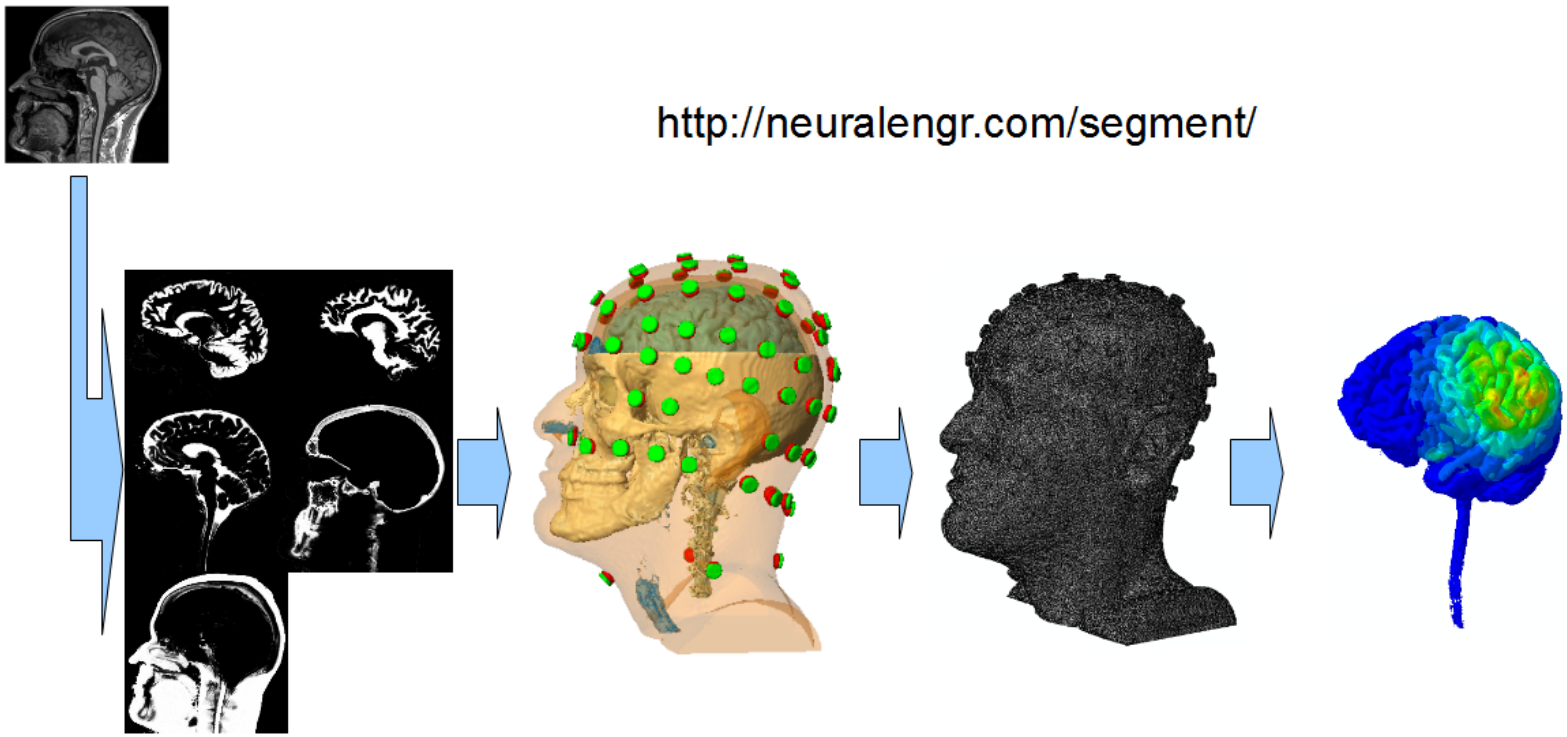
- Study region of interest

  statistics, structure shape, measure size
- Improve visualization
- Assisting other imaging problems

  e.g., registration
- Facilitating computer modeling

  e.g., tDCS

Example



How?

- Discontinuity detection
- Thresholding and Morphology
- Region growing
- Active contour method
- Deformable surface approach
- Clustering-based method
- Classification-based method
- Shape/appearance model
- Graph-based method

How?

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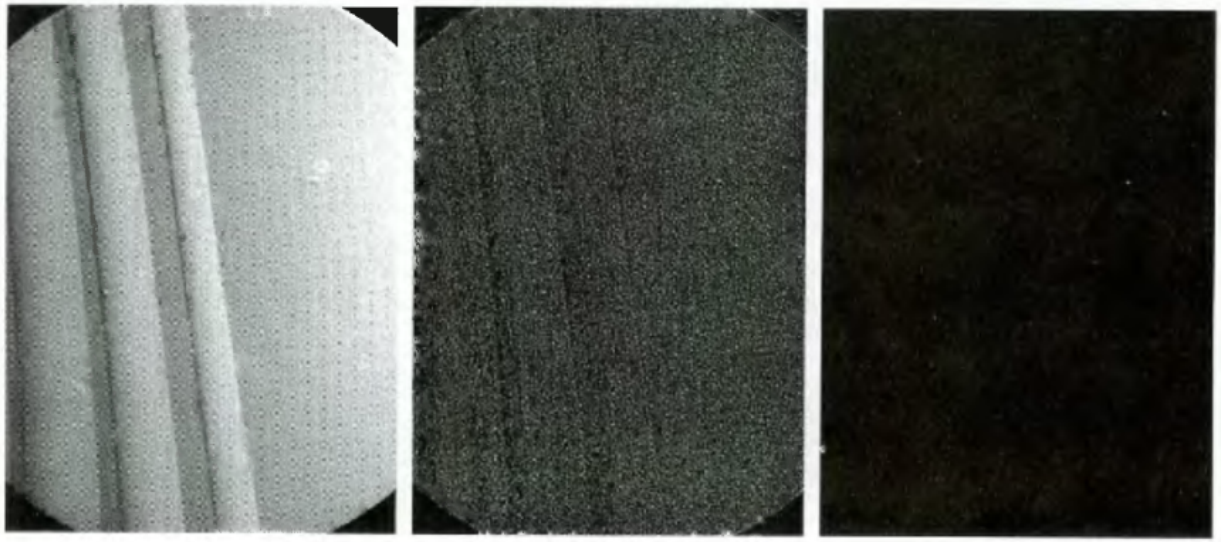
- Graph-based method

Discontinuity detection

- Point

−1	−1	−1
−1	8	−1
−1	−1	−1



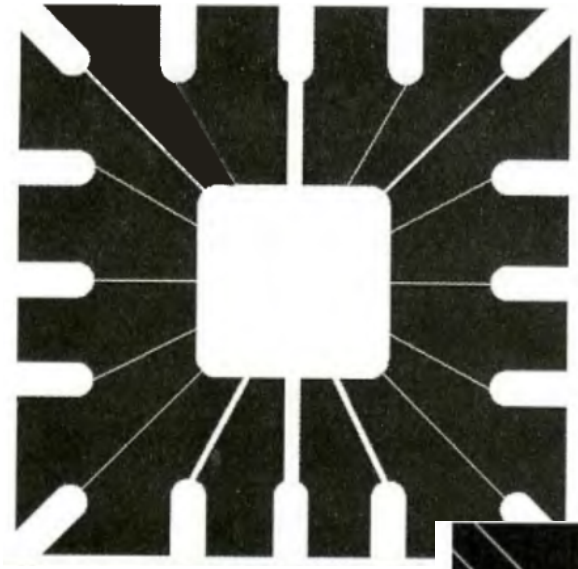
a
b c d

FIGURE 10.2
(a) Point detection mask. (b) X-ray image of a turbine blade with a porosity. (c) Result of point detection. (d) Result of using Eq. (10.1-2). (Original image courtesy of X-TEK Systems Ltd.)

Gonzalez & Woods 2002

Discontinuity detection

- Line



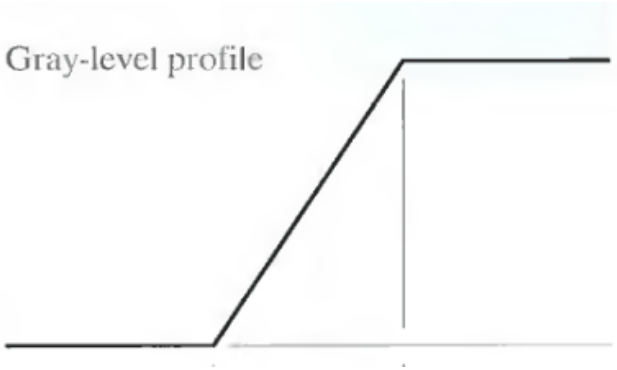
2	−1	−1
−1	2	−1
−1	−1	2

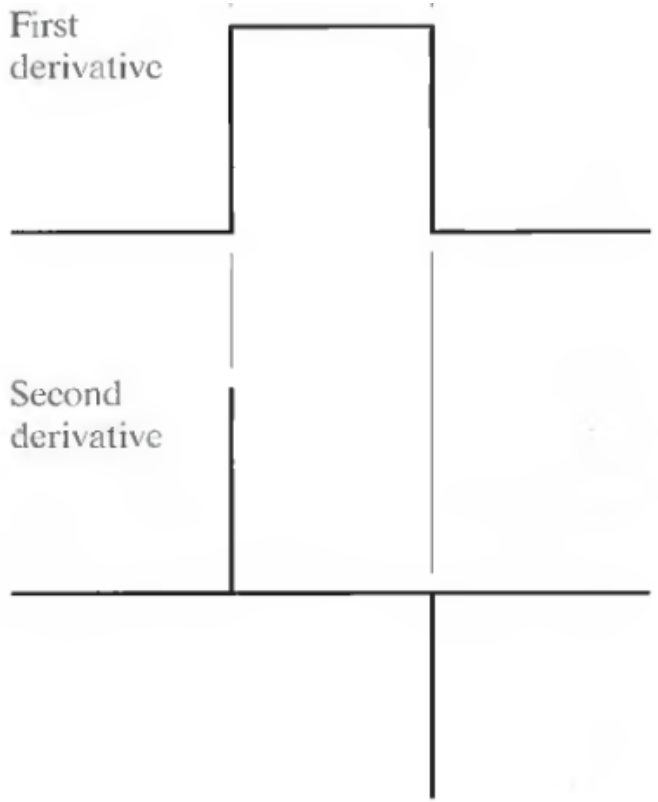
−45°

Gonzalez & Woods 2002

Discontinuity detection

- Edge





Gonzalez & Woods 2002

Edge detection

- Gradient operators

−1	0
0	1

0	−1
1	0

Roberts

−1	−2	−1
0	0	0
1	2	1

−1	0	1
−2	0	2
−1	0	1

Sobel

−1	−1	−1
0	0	0
1	1	1

−1	0	1
−1	0	1
−1	0	1

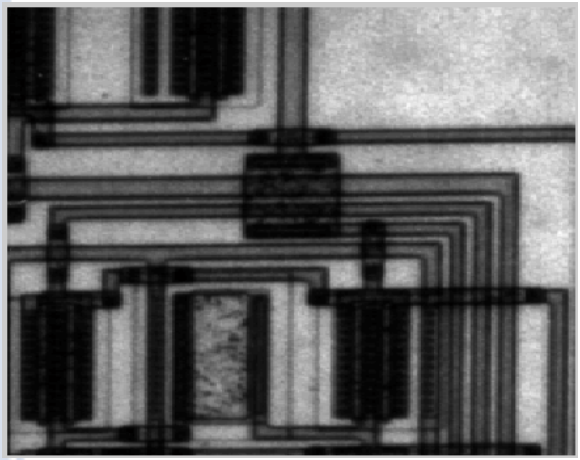
Prewitt

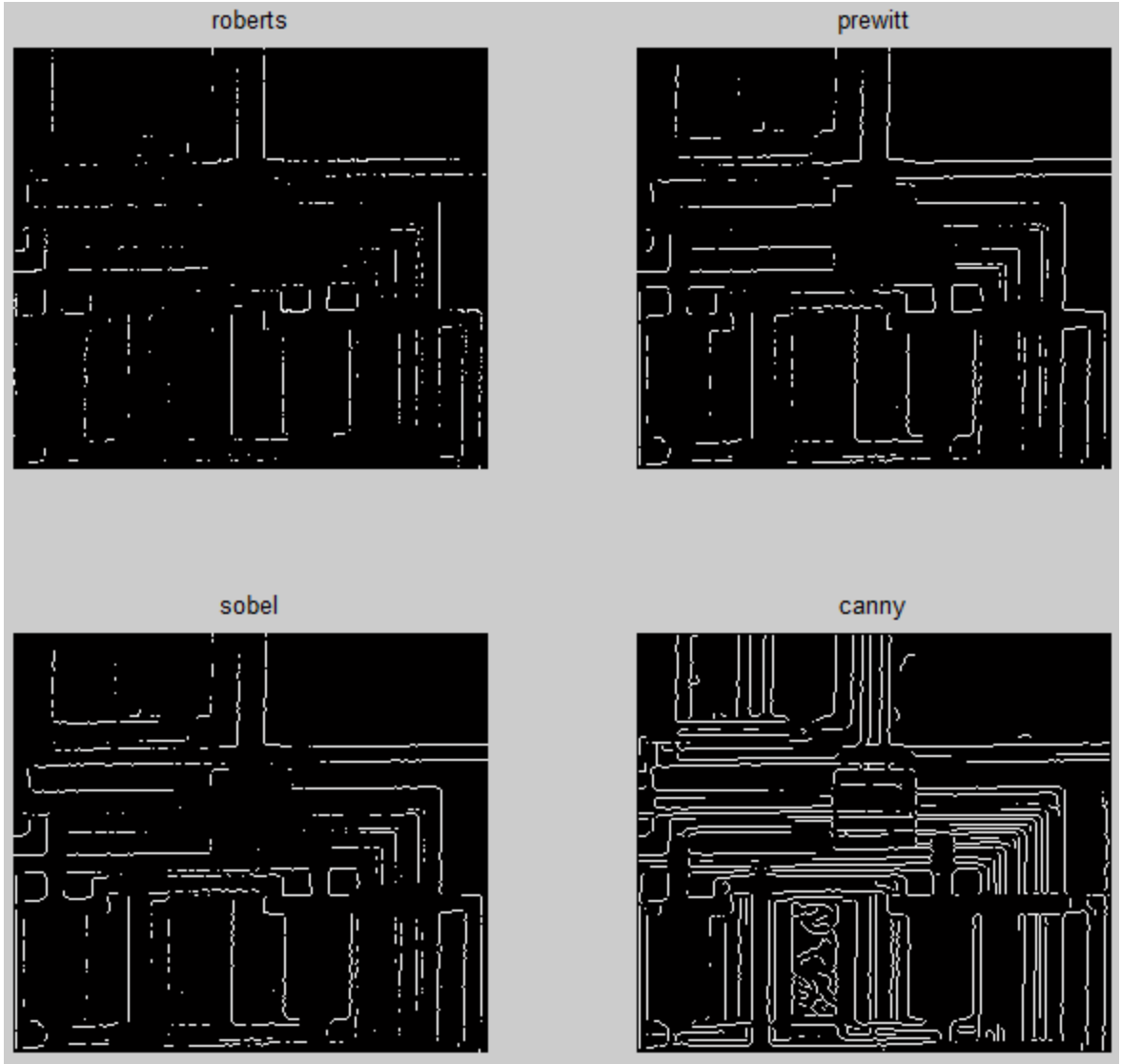
Canny: the best!

Gaussian smoothing → gradient magnitude & direction matching → nonmax suppression (make edge thinner) → hysteresis thresholding (2 thresholds)

Gonzalez & Woods 2002

Edge detection (example)



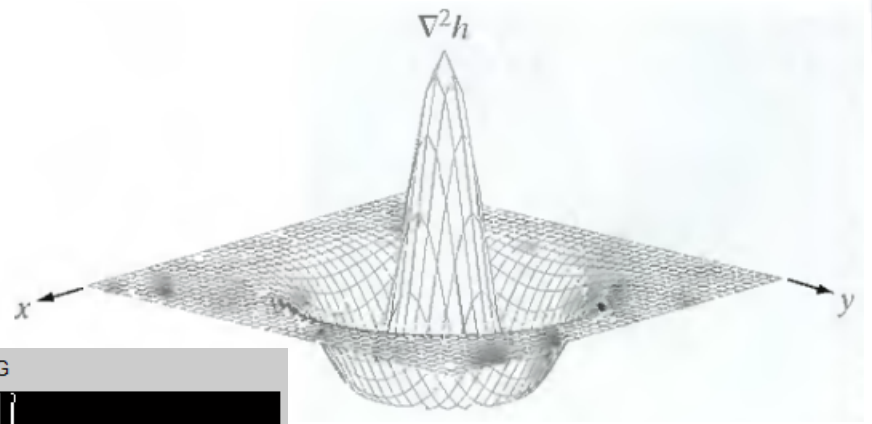


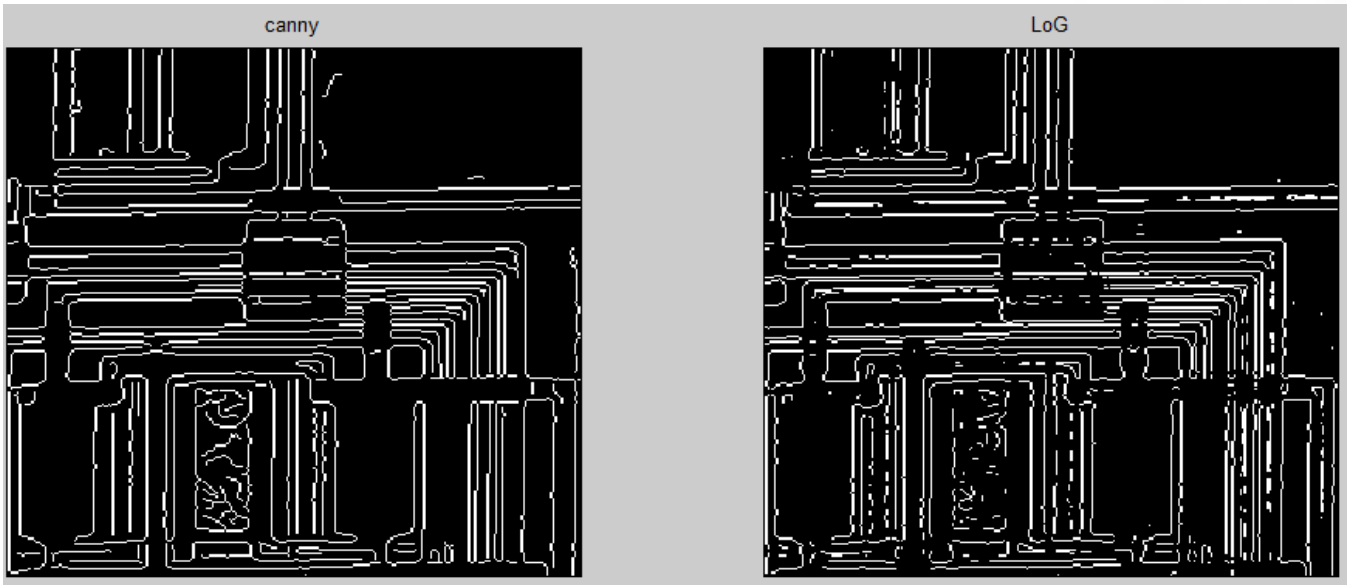
Edge detection

- Laplacian

0	−1	0	−1	−1	−1
−1	4	−1	−1	8	−1
0	−1	0	−1	−1	−1

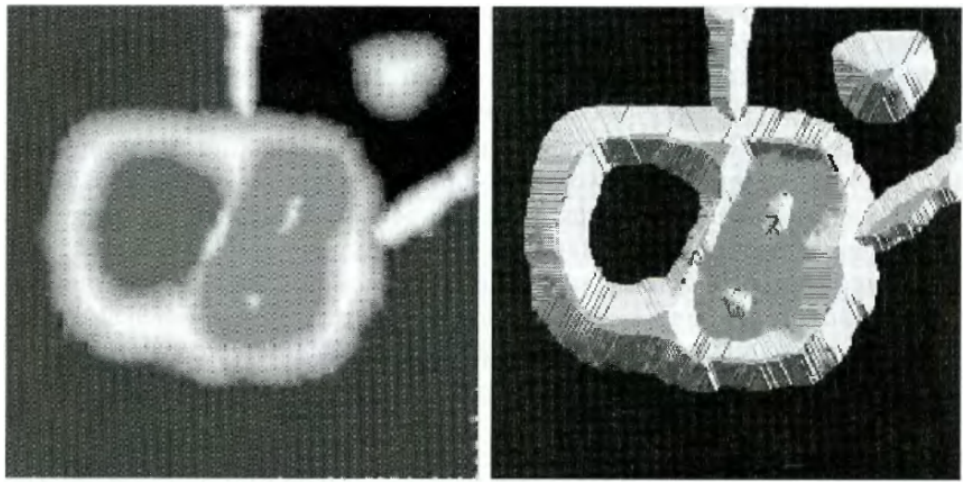
- Laplacian of Gaussian

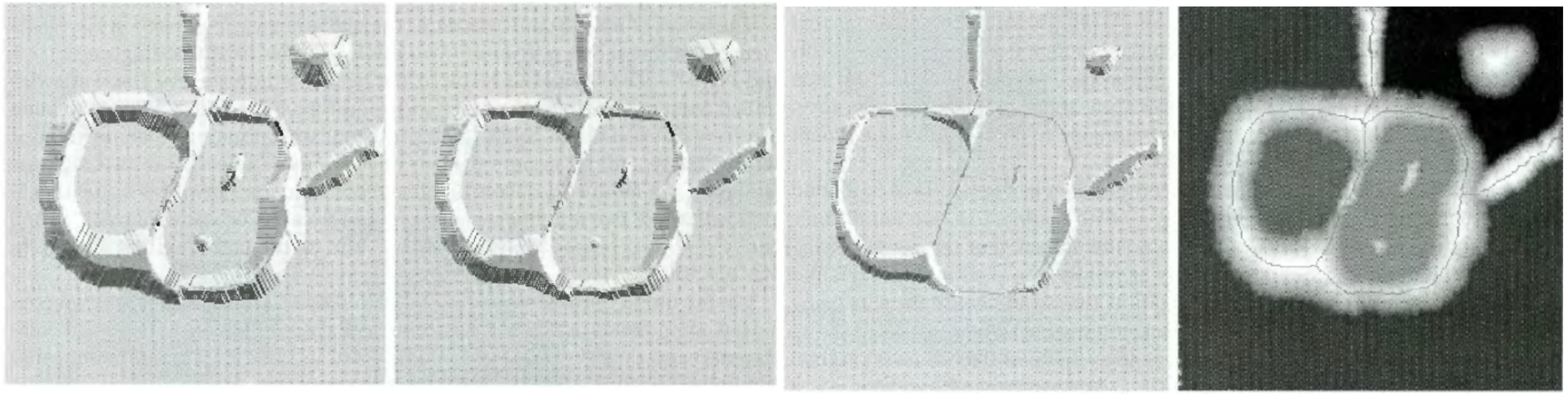




Edge detection – Watershed Algorithm

- Topographic view
- Water flooding
- Dam construction





Gonzalez & Woods 2002

Edge detection – Watershed Algorithm

- Pros:

  fast, can get continuous edges
- Cons:

  sensitive to noises, over-segmentation

Edge detection

- Pros:

  Don’t rely on specific intensity models

  Very fast
- Cons:

  Often very sensitive to noise

  Don’t produce masks directly

How?

- Discontinuity detection
- Thresholding and Morphology
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- Graph-based method

Thresholding

- Global thresholding
- Local thresholding
- Detrending → thresholding
- Adaptive thresholding: Otsu's method

- Pros: simple, fast
- Cons: no spatial info is used

Morphological operations

- Erosion $A \ominus B = \{z \in E | B_z \subseteq A\}$,

  $(f \ominus b)(x) = \inf_{y \in E}[f(y) - b(y - x)]$,

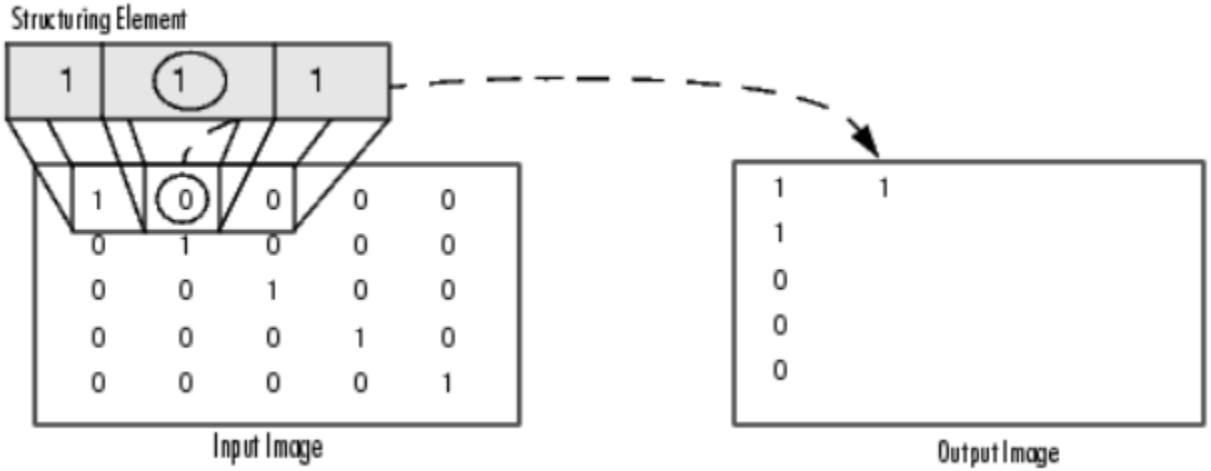
- Dilation $A \oplus B = \{z \in E | (B^s)_z \cap A \neq \varnothing\}$

  $(f \oplus b)(x) = \sup_{y \in E}[f(y) + b(x - y)]$,

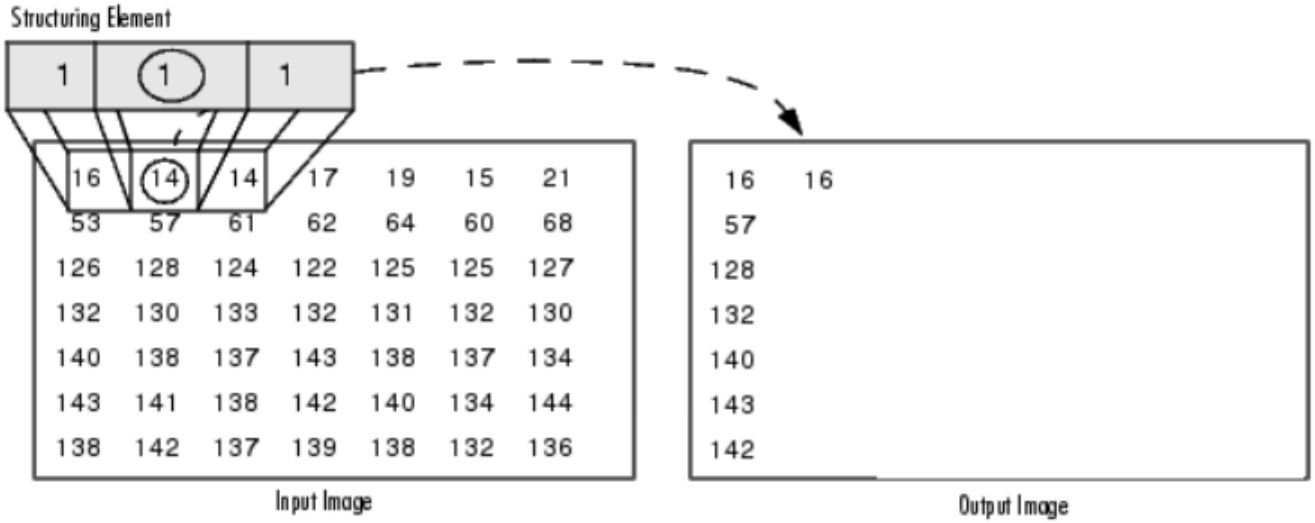
- Opening $A \circ B = (A \ominus B) \oplus B$.

- Closing $A \bullet B = (A \oplus B) \ominus B$.

Morphological operations (how?)



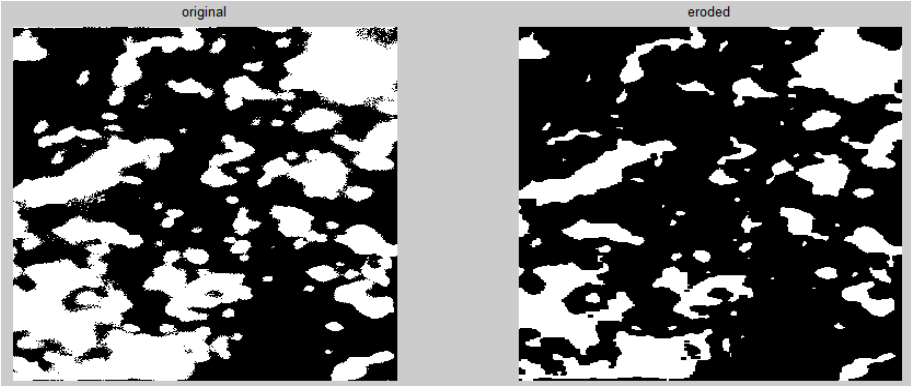
Binary image

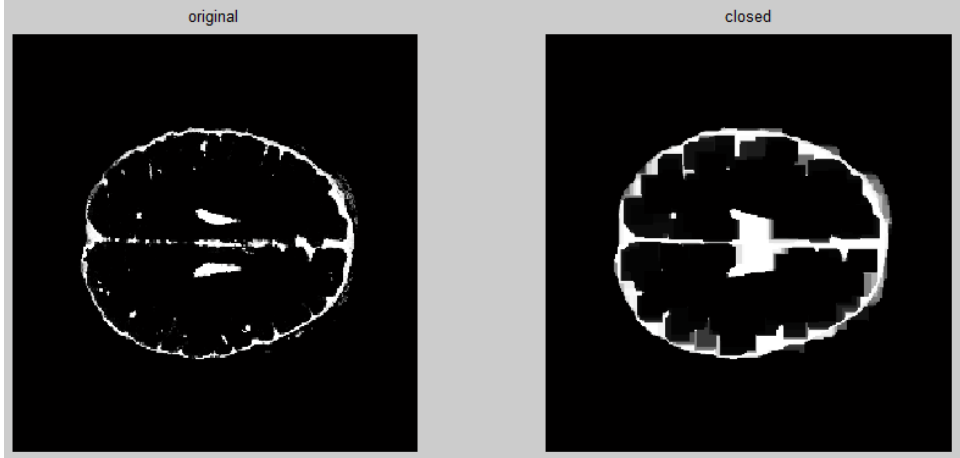


Gray-scale image

http://www-rohan.sdsu.edu/doc/matlab/toolbox/images/morph4.html

Morphological operations (examples)





Morphological operations

- Pros:

  Can be appended to any other seg. technique

  Can fill in holes, remove “floating” pixels (false positives)

- Cons:

  Hard to know right structuring element

  Gain something, lose something

How?

- Discontinuity detection
- Thresholding and Morphology
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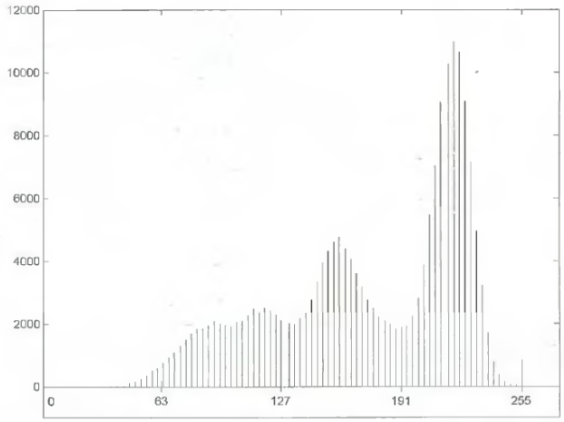
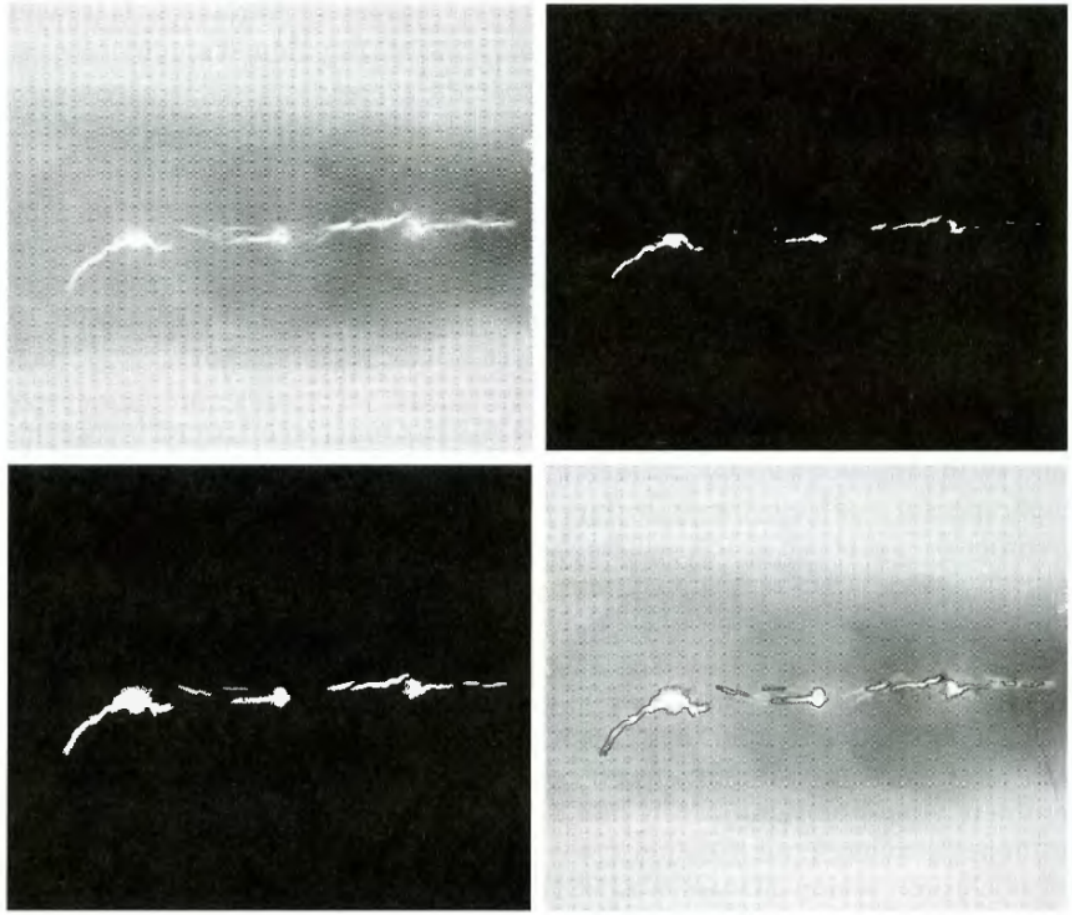
- Graph-based method

Region growing



a b
c d

FIGURE 10.40
(a) Image showing defective welds. (b) Seed points. (c) Result of region growing. (d) Boundaries of segmented defective welds (in black). (Original image courtesy of X-TEK Systems, Ltd.).



Gonzalez & Woods 2002

Region growing

- Pros

  Intensity + spatial info

  Simple to implement

- Cons

  seed points, not fully automated

How?

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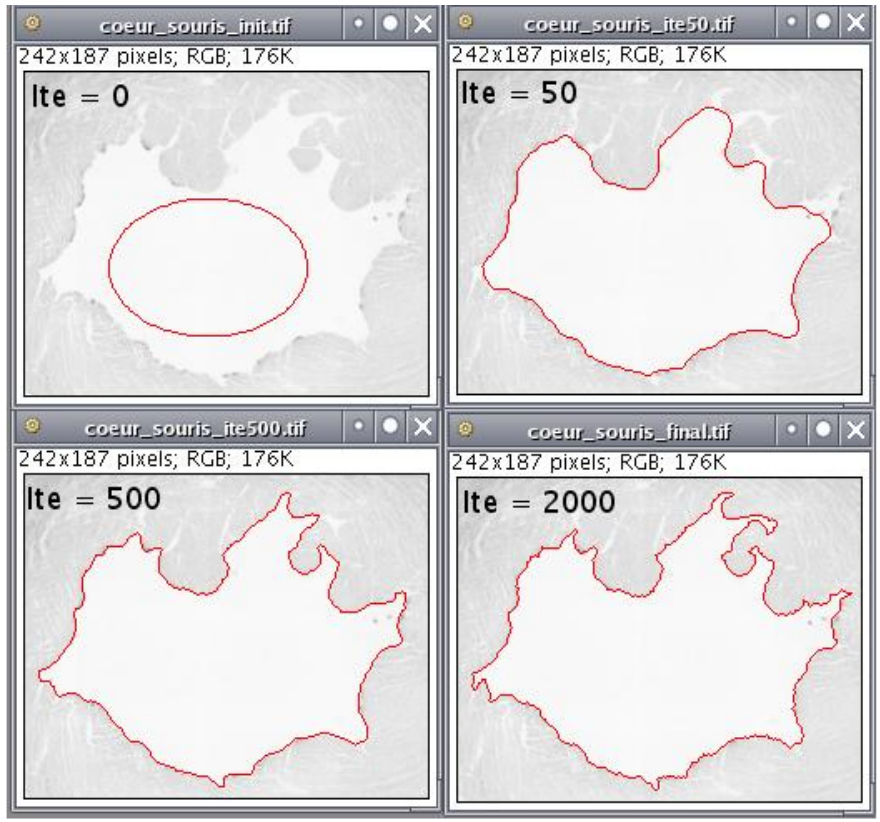
Active contour method

- Active contour: a smart “snake”
- Evolve to give your segmentation
- Described by a PDE

$$\frac{\partial C(t,s)}{\partial t} = F\,\vec{N}$$

- Steady-state solution

$$\frac{\partial C(t,s)}{\partial t} = 0 \longrightarrow \text{Seg. result}$$



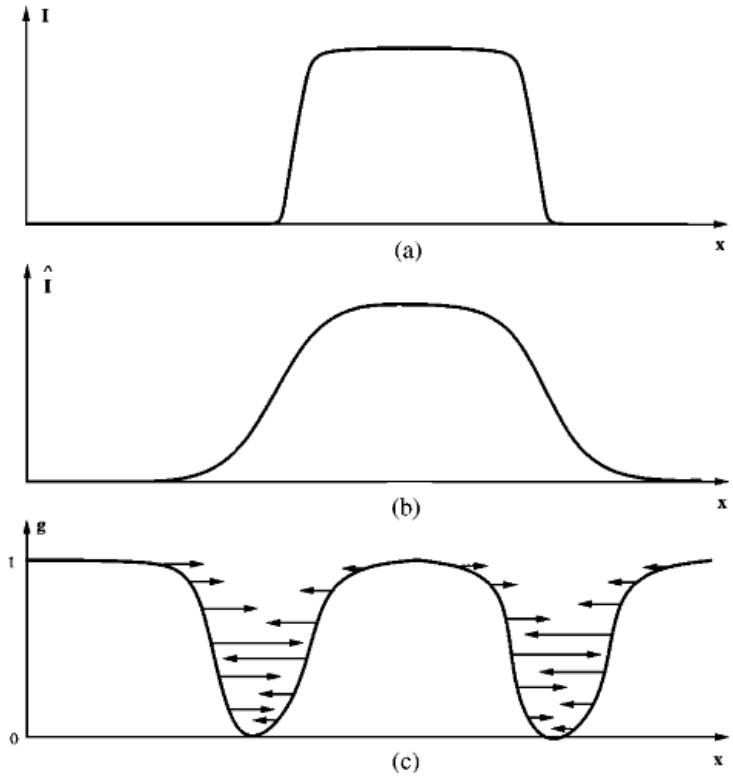
http://imagejdocu.tudor.lu/doku.php?id=plugin:segmentation:active_contour:start

Active contour method (what force?)

- Caselles 1997:

$$F = g(I)(c + \kappa) - \nabla g(I) \cdot \vec{N}$$

$$g(I) = \frac{1}{1 + |\nabla (G_\sigma * I)|^\lambda}$$



- Zhu *et al* 1996:

$$F = \kappa + \log \frac{P(I)_{obj}}{P(I)_{bg}}$$

Region competition

Active contour method (how to solve?)

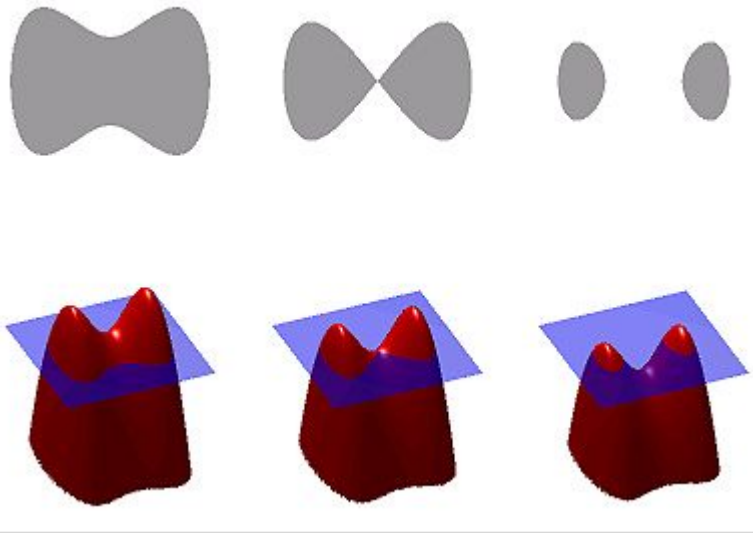
- Solve $\frac{\partial C(t,s)}{\partial t}=0$
- $\frac{\partial C(t,s)}{\partial t}=F\vec{N} \qquad F=f(C(t,s))$
- Hard, needs additional algo to detect topology change
- Level-set technique

Active contour method (level-set)

- Osher & Sethian 1988
- $$\frac{\partial C(t,s)}{\partial t} = F\vec{N}$$

$$\Updownarrow$$

$$\frac{\partial u(t)}{\partial t} = F|\nabla u|$$



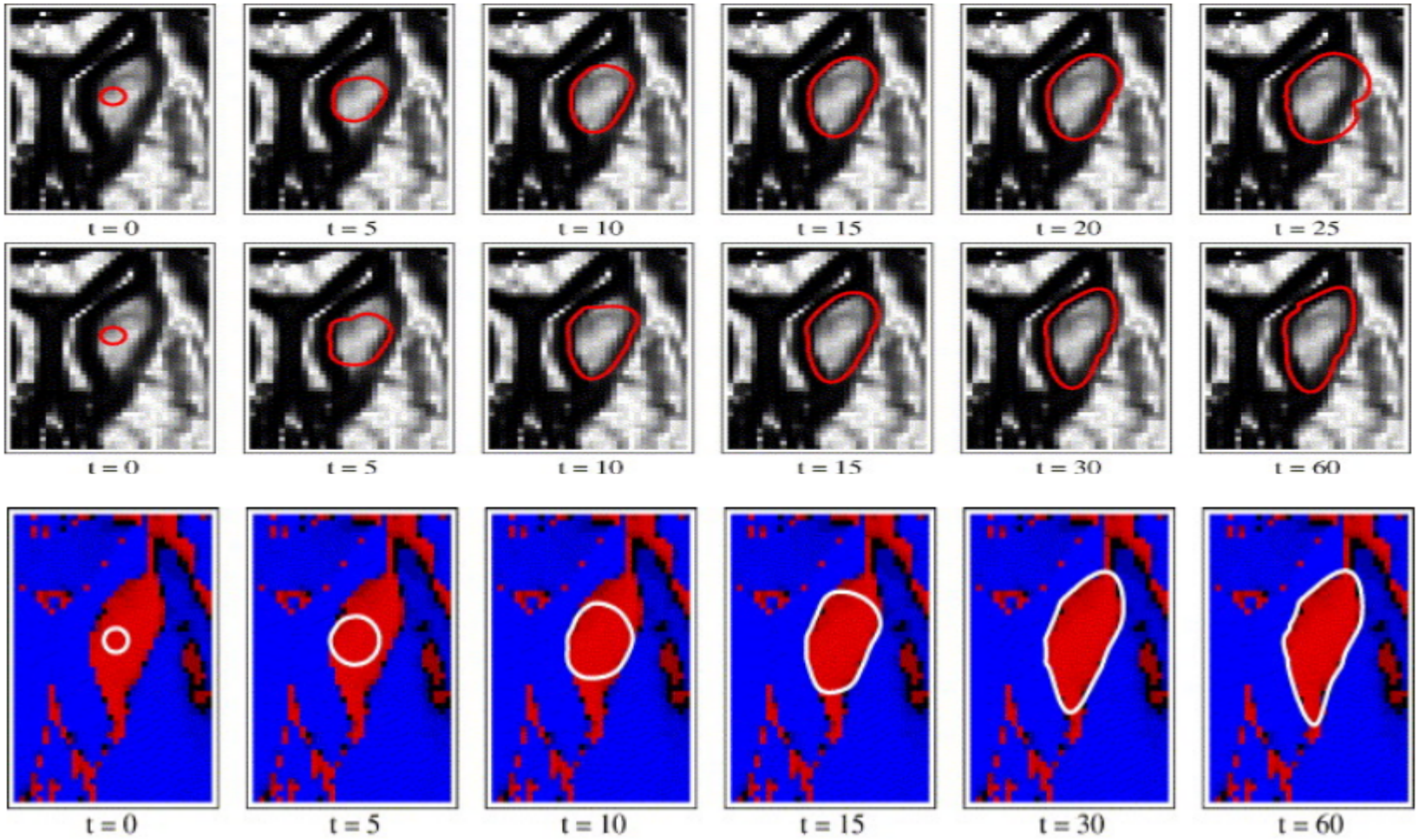
http://en.wikipedia.org/wiki/Level_set_method

u can be a signed distance function

$$u(t) = 0 \rightarrow C(t,s)$$

- An implementation: ITK-SNAP http://www.itksnap.org/pmwiki/pmwiki.php

Active contour method (examples)



Yushkevich *et al* 2006

Active contour method

- Pros:

  Can control shape well and get detailed structure

  Can detect topology change by level-set implementation

- Cons:

  Implementation difficult

  Heavily dependent on initialization → stuck in local minima

  Needs “seed” contour, not fully automated

How?

- Discontinuity detection
- Thresholding and Morphology
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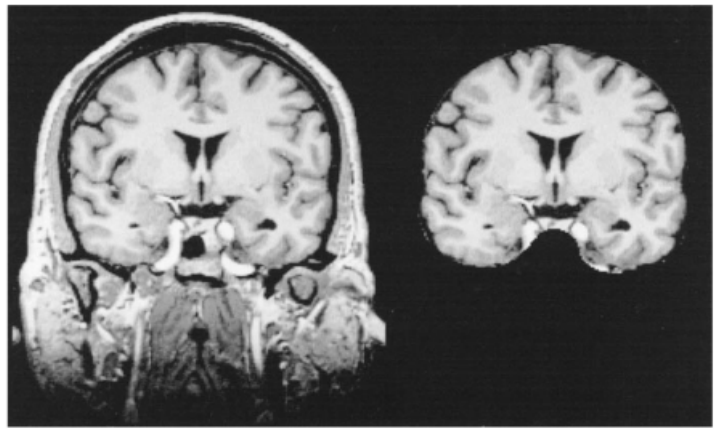
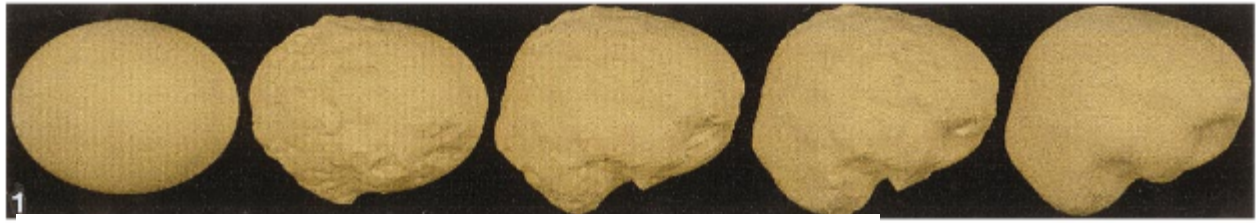
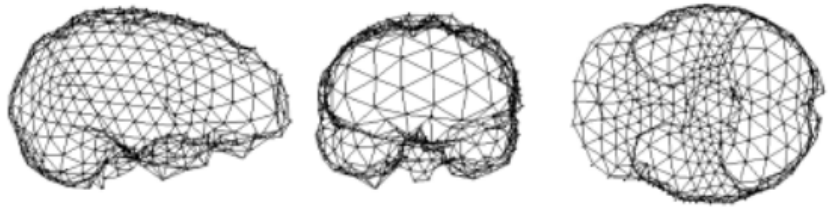
- Shape/appearance model
- Graph-based method

Deformable surface approach

- 3D active contour



- 



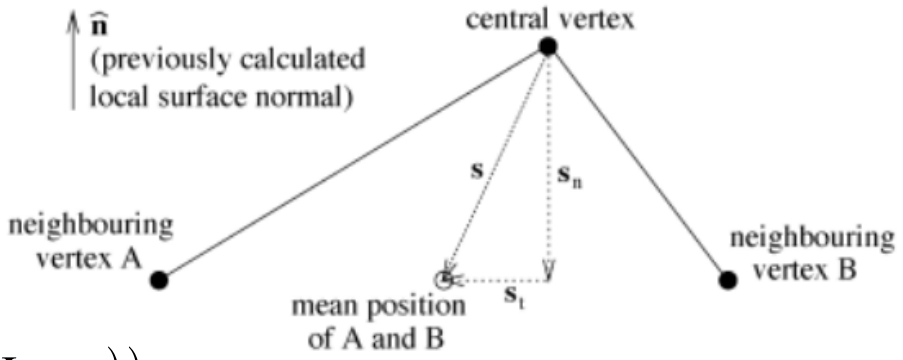
- $\Delta \vec{u} = \vec{F}$ $\quad \vec{F} = F_{\vec{internal}} + F_{\vec{external}}$

Dale *et al* 1999

Smith 2002

Deformable surface (what force)

$$\vec{F}_{internal} = \alpha \vec{s}_t + \beta \vec{s}_n$$



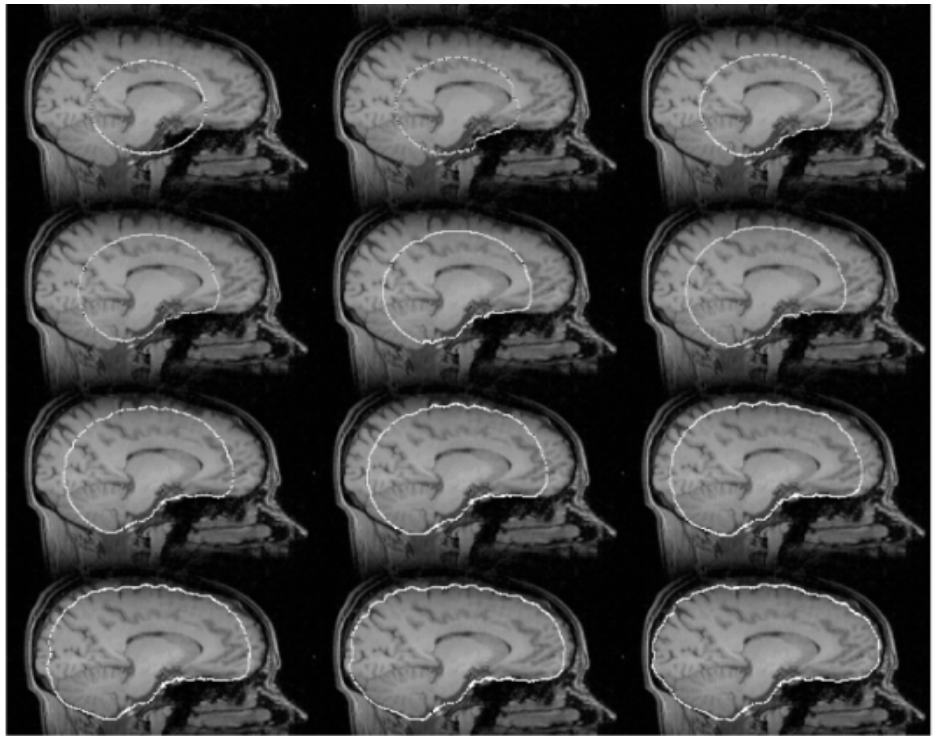
Dale et al 1999

$$\vec{F}_{external} = \gamma \hat{\vec{n}} \prod_{d=1}^{30} max\left(0, \tanh\left(I\left(x - d\,\vec{n}\right) - I_{thresh}\right)\right)$$

Smith 2002

$$\vec{F}_{external} = \gamma\left(I_{min} - t_{local}\right)$$

Deformable surface (example)



Implementations:

Freesurfer Dale *et al* 1999

http://surfer.nmr.mgh.harvard.edu/

FSL (BET) Smith 2002

http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/

Deformable surface approach

- Pros:

  Very application-specific method

- Cons:

  Only binary segmenation

  Maybe slow for dense mesh

How?

- Discontinuity detection
- Thresholding and Morphology
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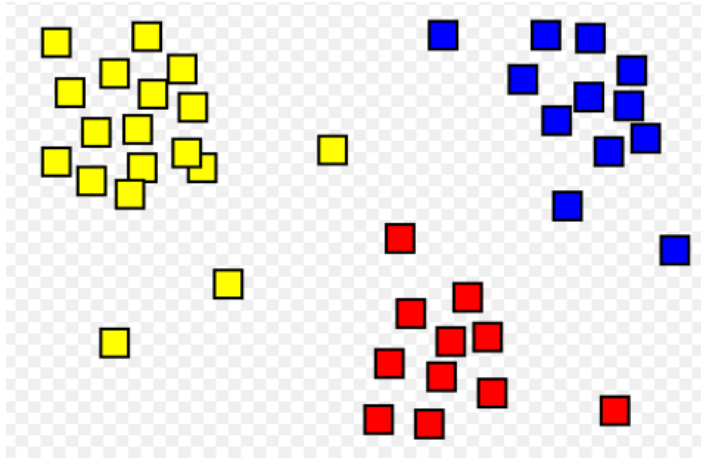
Clustering-based method

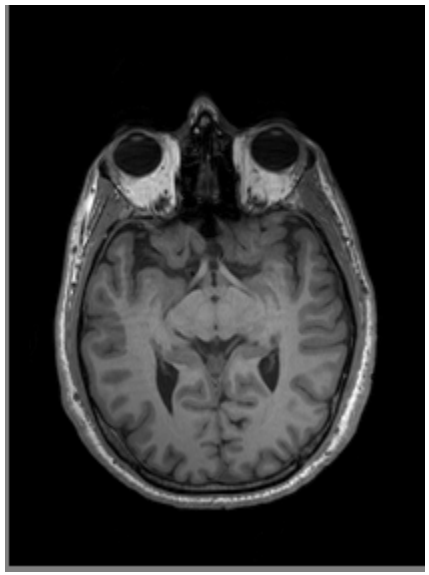
- Clustering: auto group together based on statistics

- A probabilistic model based on intensity
- MRI segmentation of human head

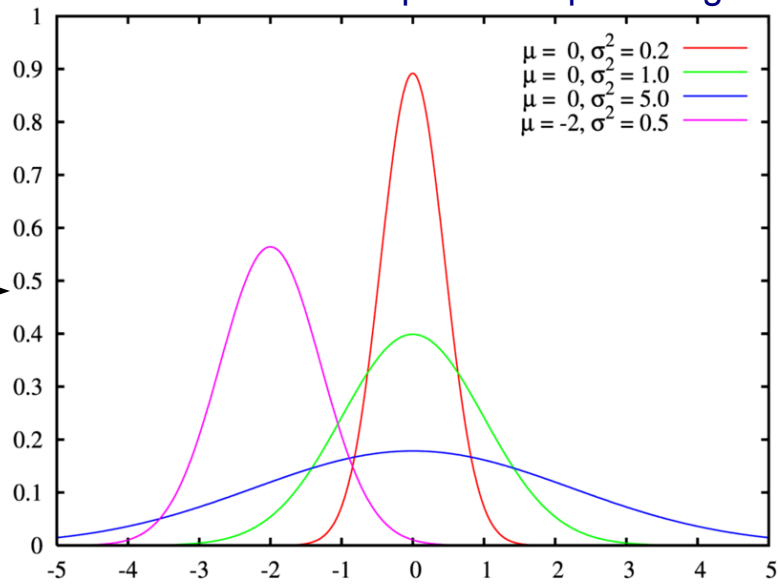


http://en.wikipedia.org/wiki/Cluster_analysis

Clustering-based method (ML formulation)



http://en.wikipedia.org/wiki/Mixture_model



y_i **θ?**

$max\ P(y_i|\theta)$

$\mu_k\ \sigma_k\ \gamma_k$ **θ**

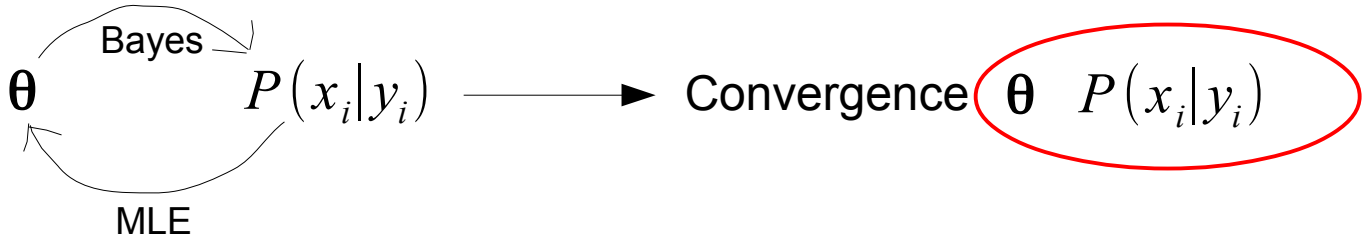
Clustering-based method (EM algo.)

- Solve $\frac{\partial P(y_i|\boldsymbol{\theta})}{\partial \boldsymbol{\theta}} = 0$?

- If only fitting 1 Gaussian, YES
- But fitting Gaussian mixture, NO

$$P(y_i|\boldsymbol{\theta}) = \sum_{k=1}^{K} P(y_i|x_i = k, \theta_k) P(x_i = k) \qquad x_i \quad \text{latent/hidden data}$$

- Solution: EM algorithm (Dempster *et al*. 1977)



Clustering-based method (EM algo.)

- E-step: $$P(x_i=k|y_i)=\frac{P(y_i|x_i=k,\theta_k)P(x_i=k)}{\sum_{m=1}^{K}P(y_i|x_i=m,\theta_m)P(x_i=m)}$$
- M-step: $$\mu_k=\frac{\sum_{i=1}^{N}P(x_i=k|y_i)\,y_i}{\sum_{i=1}^{N}P(x_i=k|y_i)} \qquad \sigma_k^2=\frac{\sum_{i=1}^{N}P(x_i=k|y_i)(\mu_k-y_i)^2}{\sum_{i=1}^{N}P(x_i=k|y_i)}$$
- More about prior term $P(x_i=k)$

Clustering-based method (prior info)

- Simplest model: $P(x_i = k)$ is a scalar for all pixels
- Spatial (anatomical) info is added:

  an atlas (Ashburner and Friston, 2005)
- Neighborhood constraint is added:

  an MRF – encode spatial consistency

  (Zhang et al., 2001)

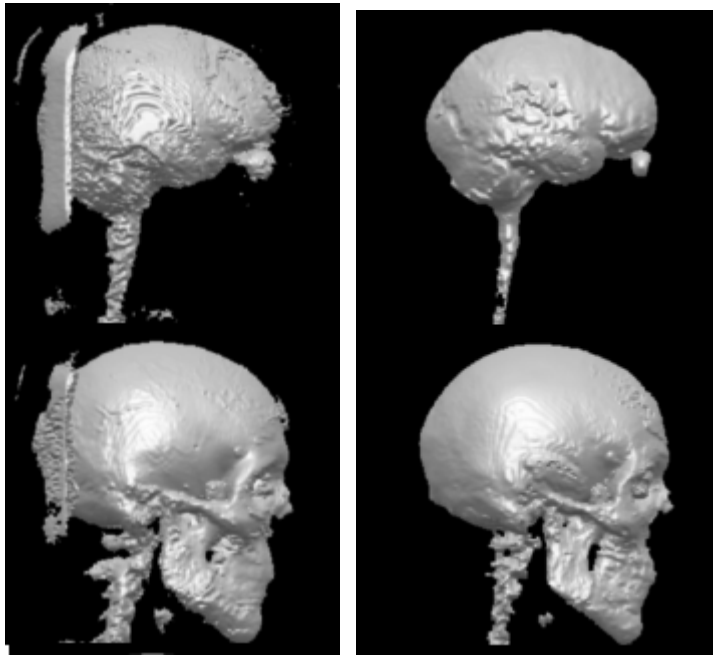
- Even powerful: atlas+MRF (Huang & Parra 2013, in preparation)

Clustering-based method (example)

- Implementations:

  SPM http://www.fil.ion.ucl.ac.uk/spm/

  FSL (FAST) http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/

- 

Huang & Parra 2013, in preparation

Clustering-based method

- Pros:

  fully automated

  easy to implement
- Cons:

  large amount of prior needed sometime (atlas or MRF)

  cannot obtain detailed structure unless some prior is used

How?

- Discontinuity detection
- Thresholding and Morphology
- Region growing
- Active contour method
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- Graph-based method

Classification-based method

- Popular in signal processing (e.g., EEG classification)
- General procedure:

Compute local features (Gabor filters, Wavelets, power spectrum, etc) →

Select features →

Train classifier to separate features (offline) (Linear regression, Logistic regression, SVM, Neural networks) →

Test classifier on unseen image

How?

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Shape/appearance model

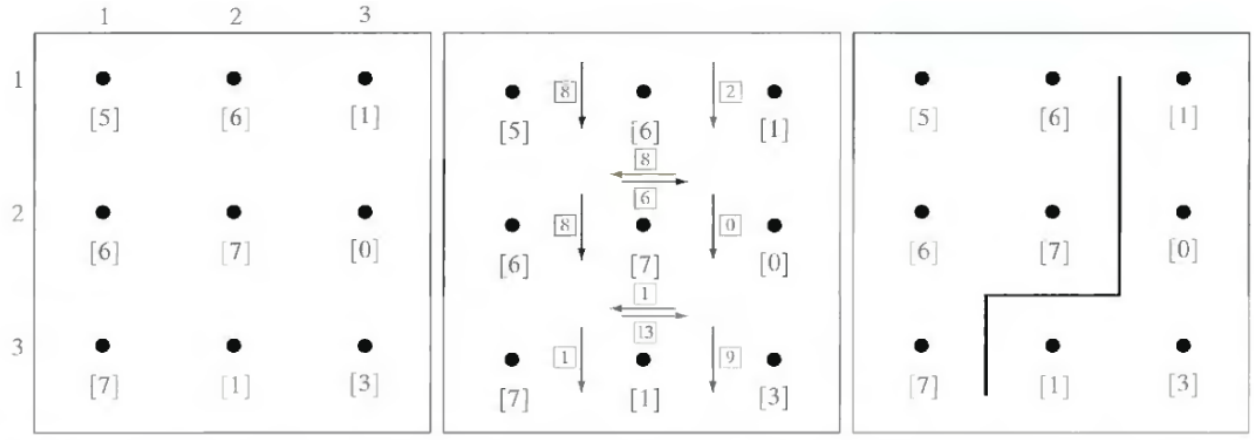
- Active Shape Model (ASM, Cootes *et al* 1995): model the distribution of the vertices of a specific shape (e.g., an anatomical structure)
- Active Appearance Model (AAM, Cootes *et al* 1998): ASM + intensity info (MOG)
- Can do automated subcortical segmentation

  but needs training data (Patenaude *et al* 2011)
- One implementation as in FSL (FIRST)

http://fsl.fmrib.ox.ac.uk/fsl/fslwiki/

Graph-based method

- Main idea: represent image lattice as a graph (collection of nodes and edges that connect them)
- Set up some criterion so that we are able to “cut” the graph into two or more pieces by breaking along edges
- Thereby yielding a spit of nodes (i.e., a segmentation)



a b c

FIGURE 10.23 (a) A 3 × 3 image region. (b) Edge segments and their costs. (c) Edge corresponding to the lowest-cost path in the graph shown in Fig. 10.24.

Gonzalez & Woods 2002

Thank you

Questions?