Grouping and Segmentation

Computer Vision
CS 543 / ECE 549
University of Illinois

Derek Hoiem

Last week

- EM
- Mixture of Gaussians
- Segmentation using EM and graph cuts

Today’s class

- Segmentation and grouping
  - Gestalt cues
  - By clustering (mean-shift)
  - By boundaries (watershed)

Gestalt grouping

Gestalt psychology or **gestaltism**

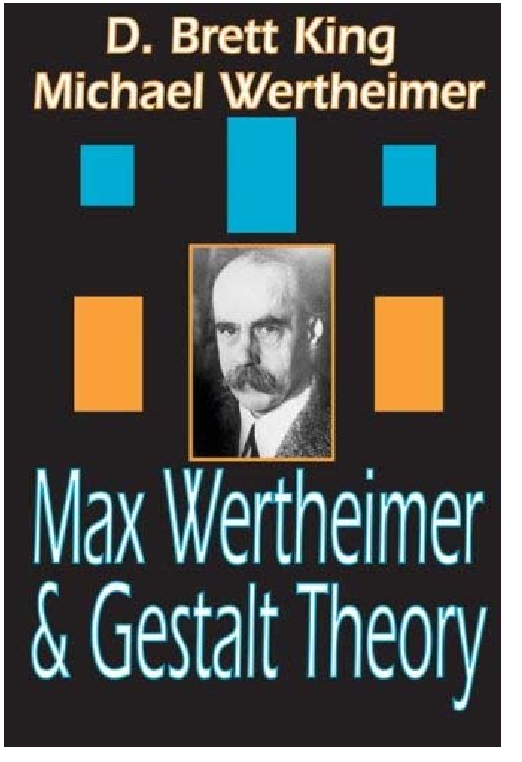
German: *Gestalt* - "form" or "whole”

Berlin School, early 20th century

Kurt Koffka, Max Wertheimer, and Wolfgang Köhler

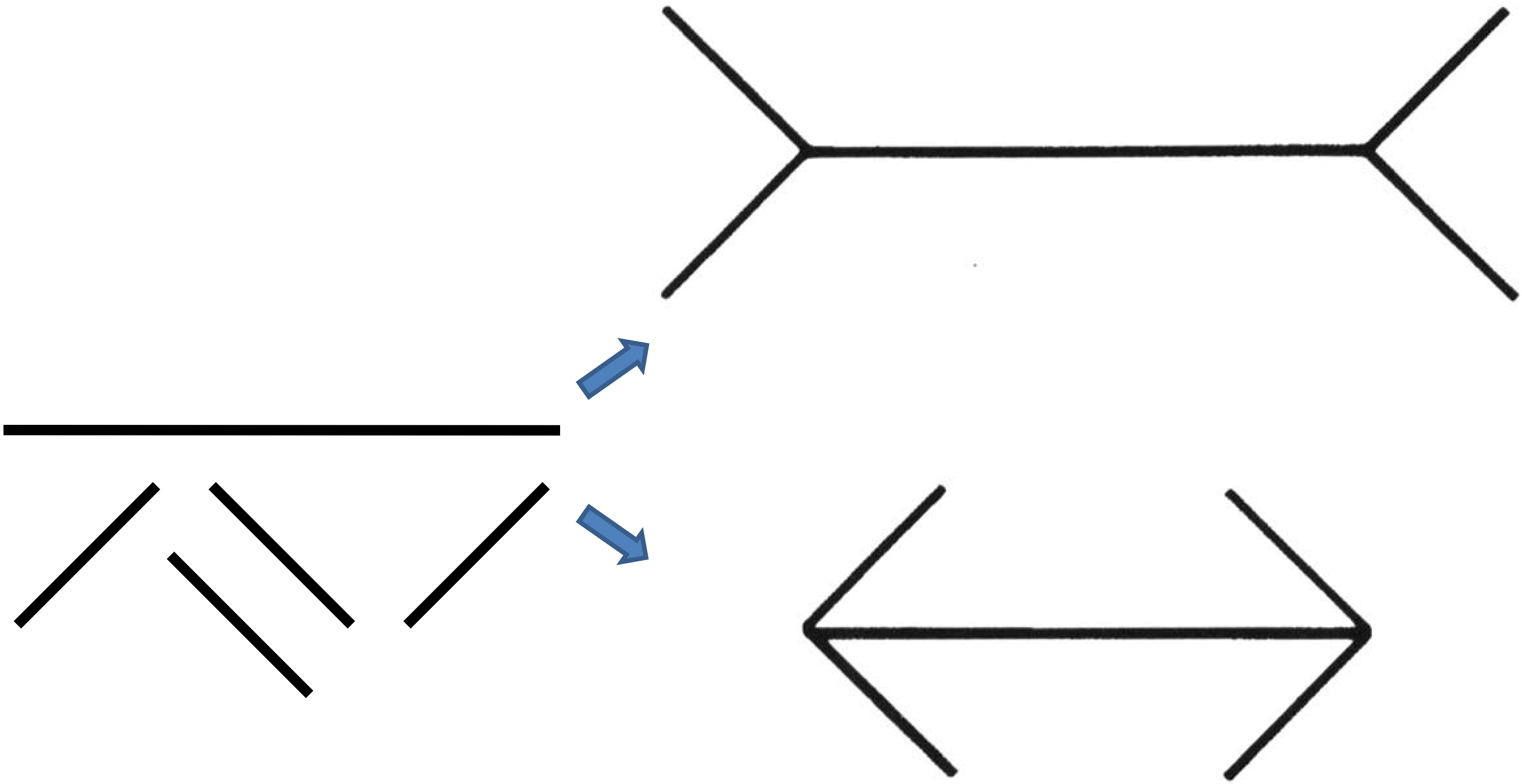
View of brain:

- whole is more than the sum of its parts
- holistic
- parallel
- analog
- self-organizing tendencies



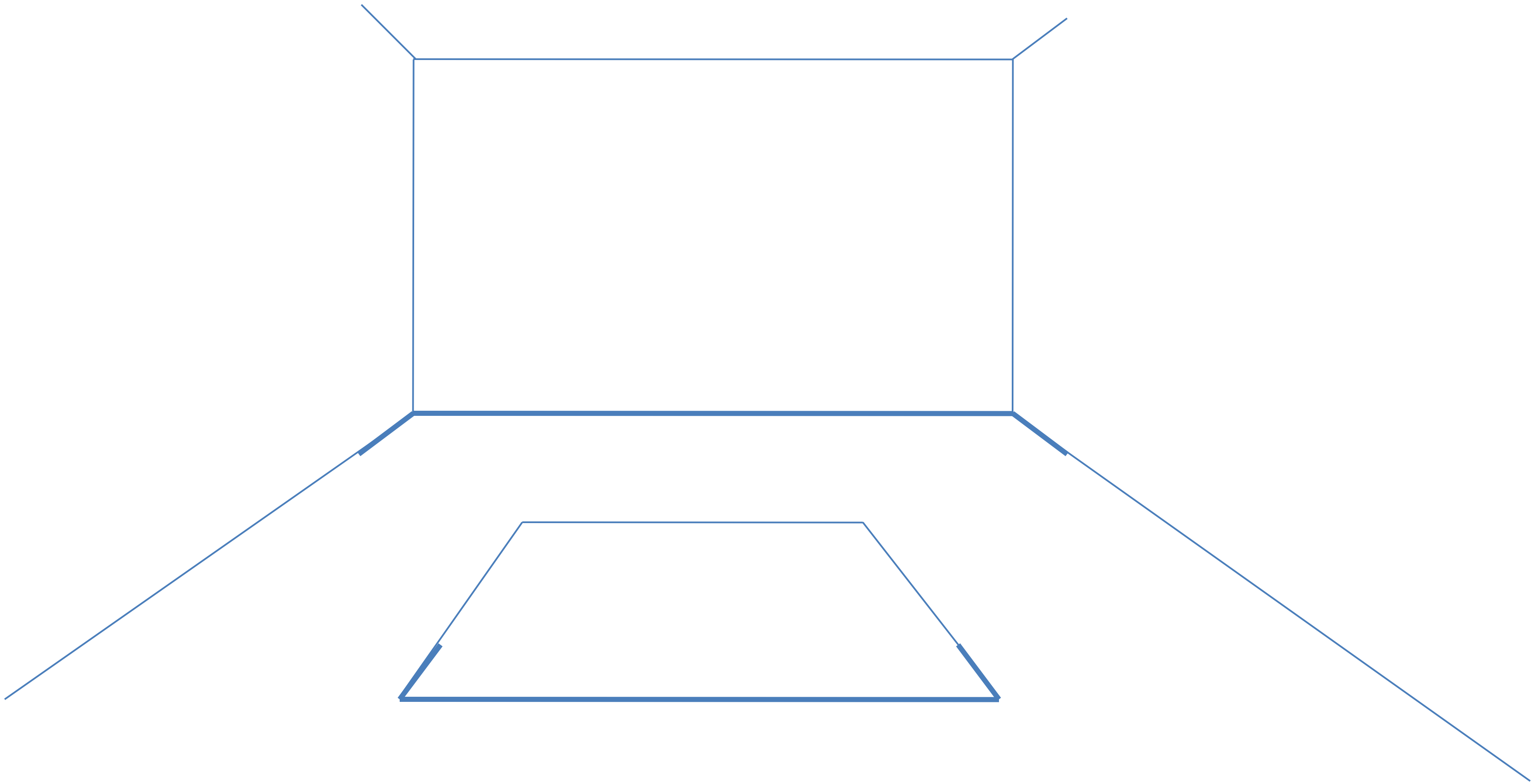
Slide from S. Saverese

Gestaltism

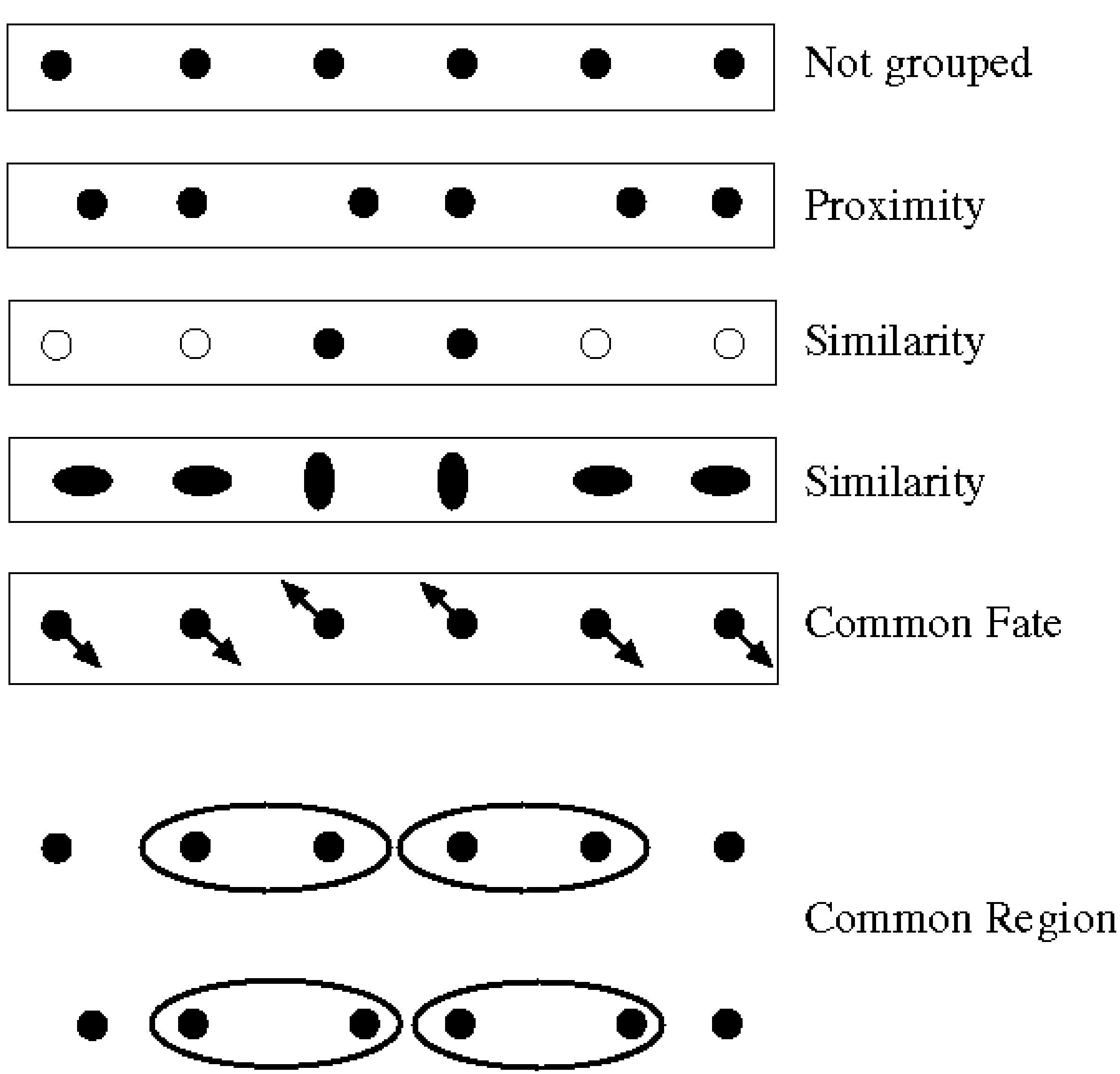


The Muller-Lyer illusion

We perceive the interpretation, not the senses

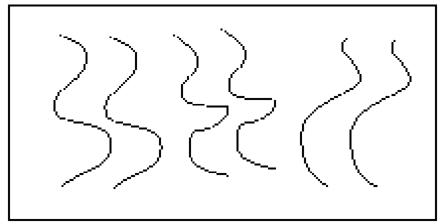


Principles of perceptual organization

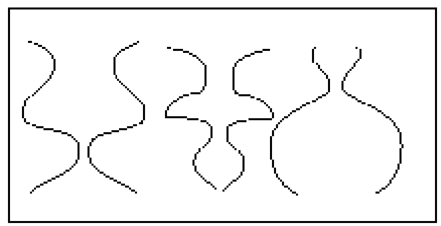


From Steve Lehar: The Constructive Aspect of Visual Perception

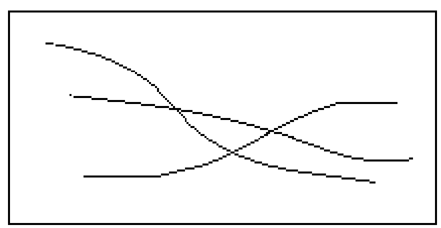
Principles of perceptual organization



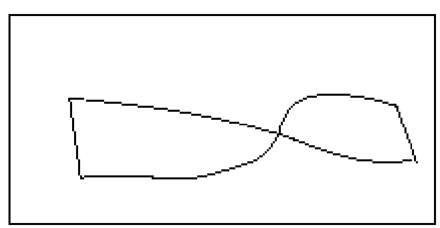
Parallelism



Symmetry

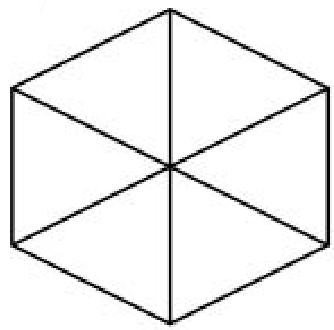


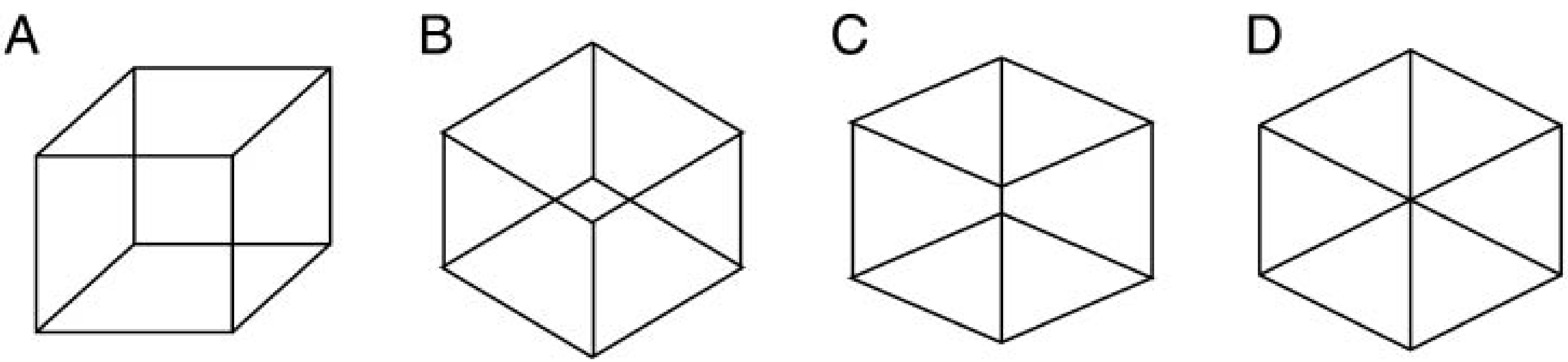
Continuity



Closure

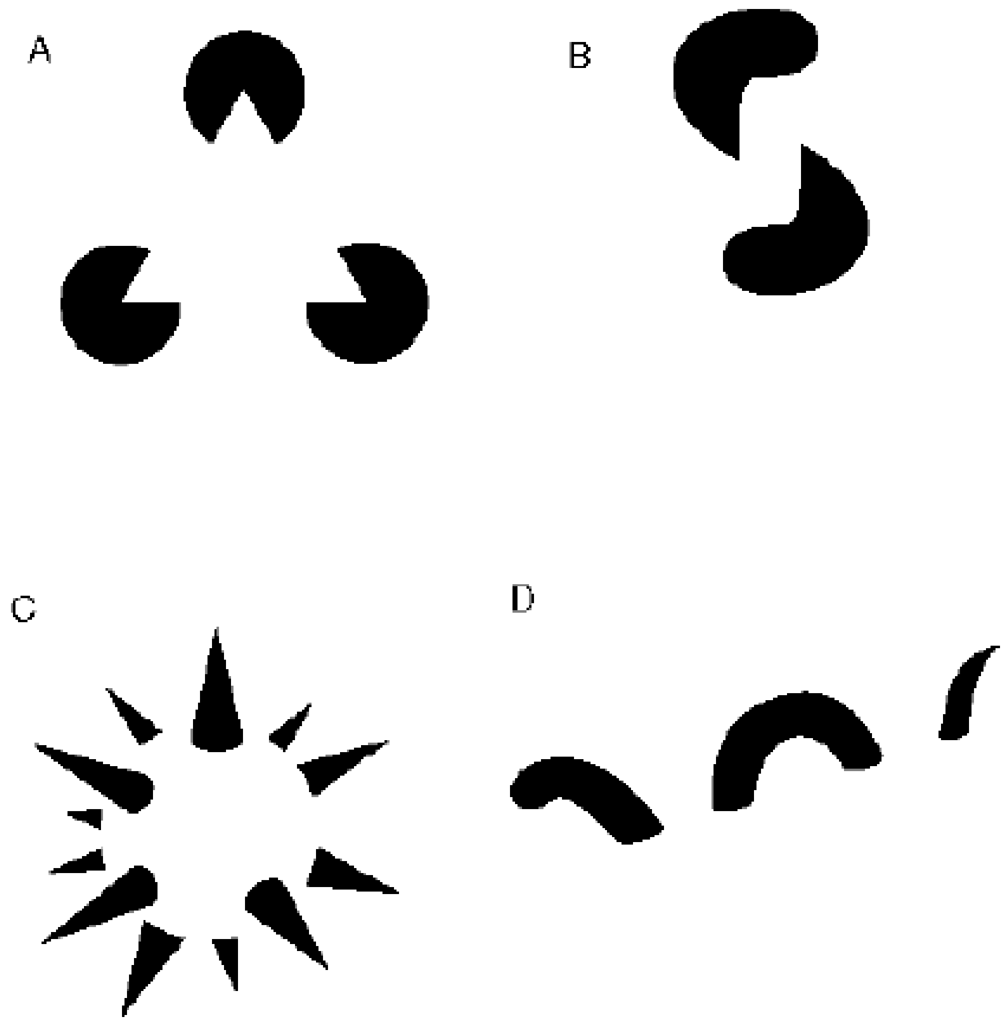
Gestaltists do not believe in coincidence





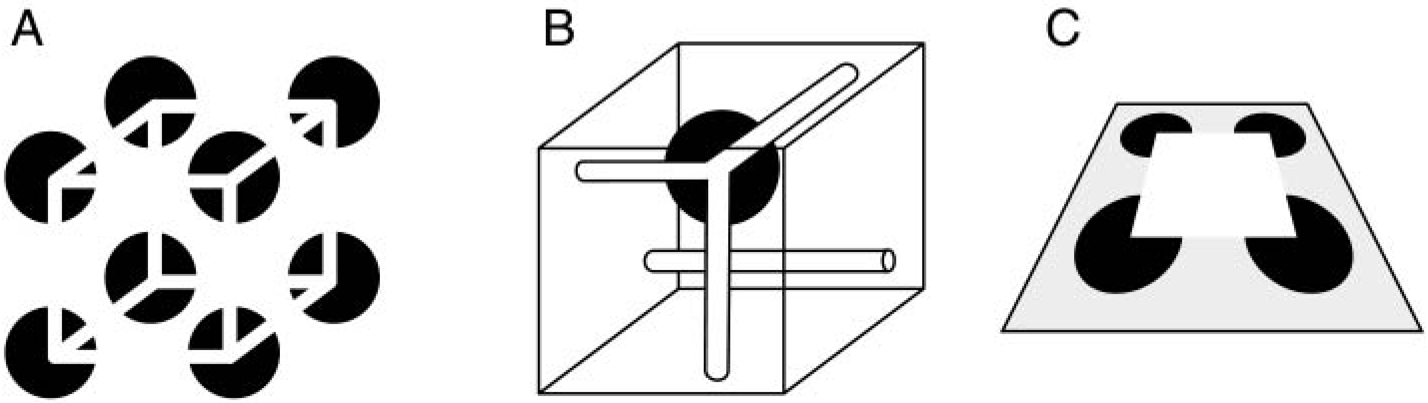
Emergence

Grouping by invisible completion



From Steve Lehar: The Constructive Aspect of Visual Perception

Grouping involves global interpretation



From Steve Lehar: The Constructive Aspect of Visual Perception

Grouping involves global interpretation

A

B

From Steve Lehar: The Constructive Aspect of Visual Perception

Gestalt cues

- Good intuition and basic principles for grouping
- Basis for many ideas in segmentation and occlusion reasoning
- Some (e.g., symmetry) are difficult to implement in practice

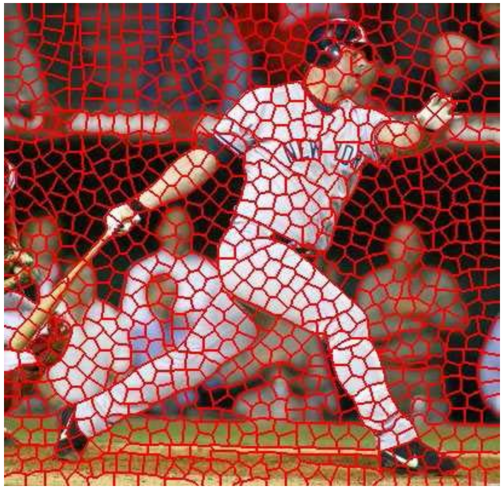
Moving on to image segmentation …

Goal: Break up the image into meaningful or perceptually similar regions

Segmentation for feature support

Segmentation for efficiency

[Felzenszwalb and Huttenlocher 2004]



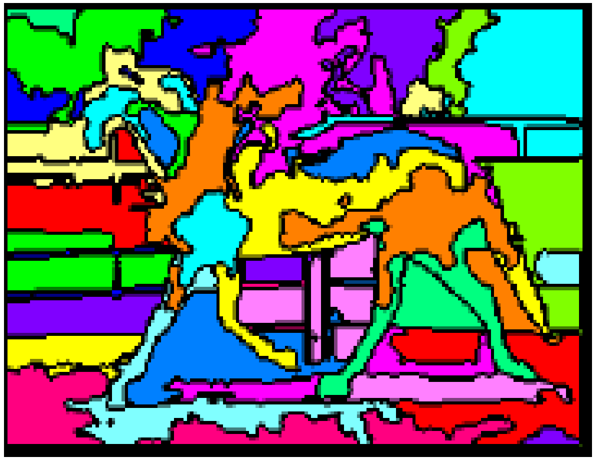
[Shi and Malik 2001]

[Hoiem et al. 2005, Mori 2005]

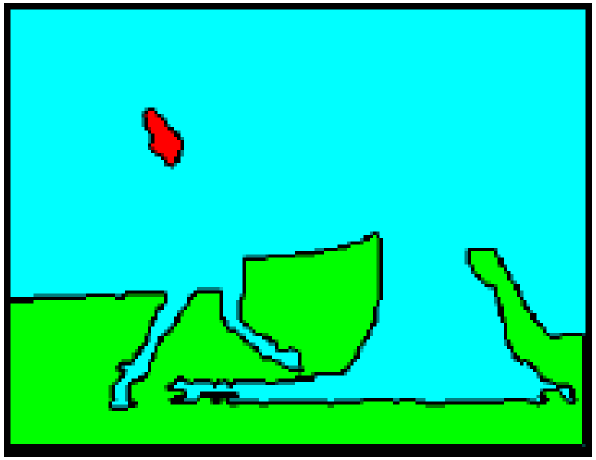
Segmentation as a result

Rother et al. 2004

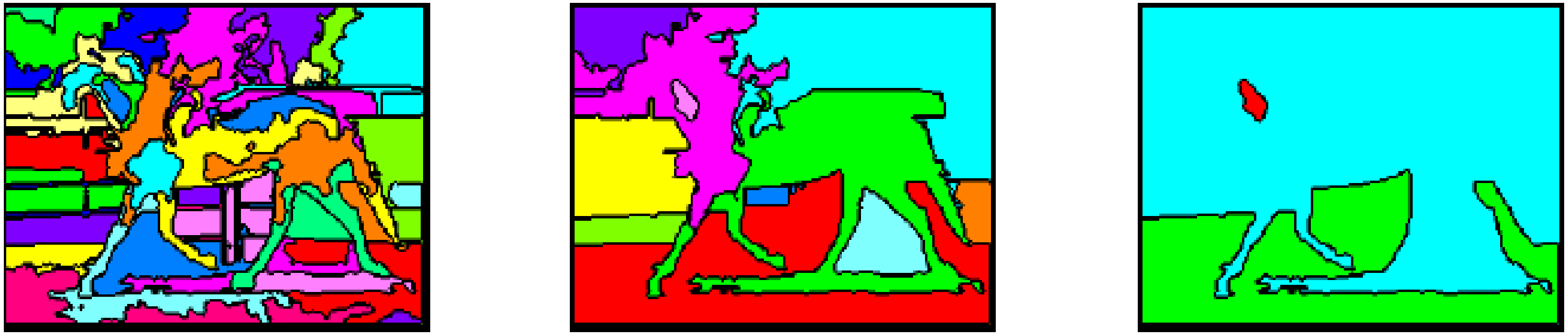
Types of segmentations



Oversegmentation



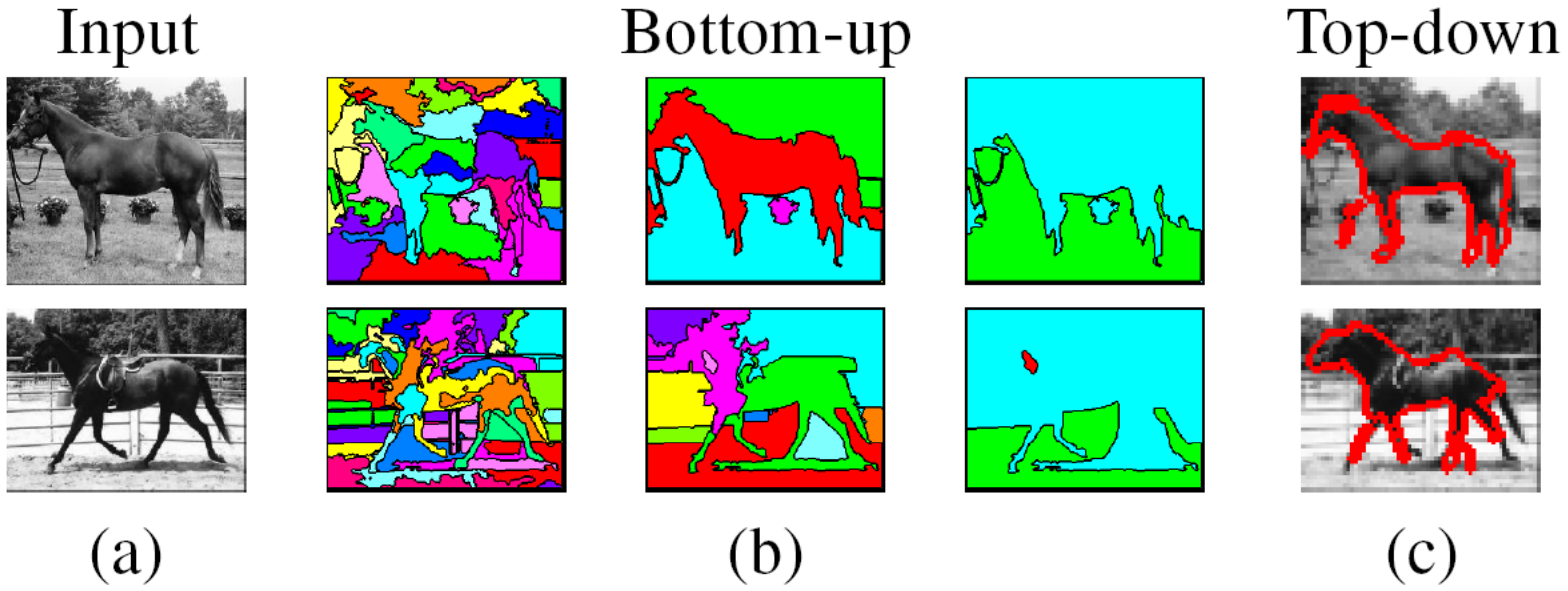
Undersegmentation



Multiple Segmentations

Major processes for segmentation

- Bottom-up: group tokens with similar features
- Top-down: group tokens that likely belong to the same object



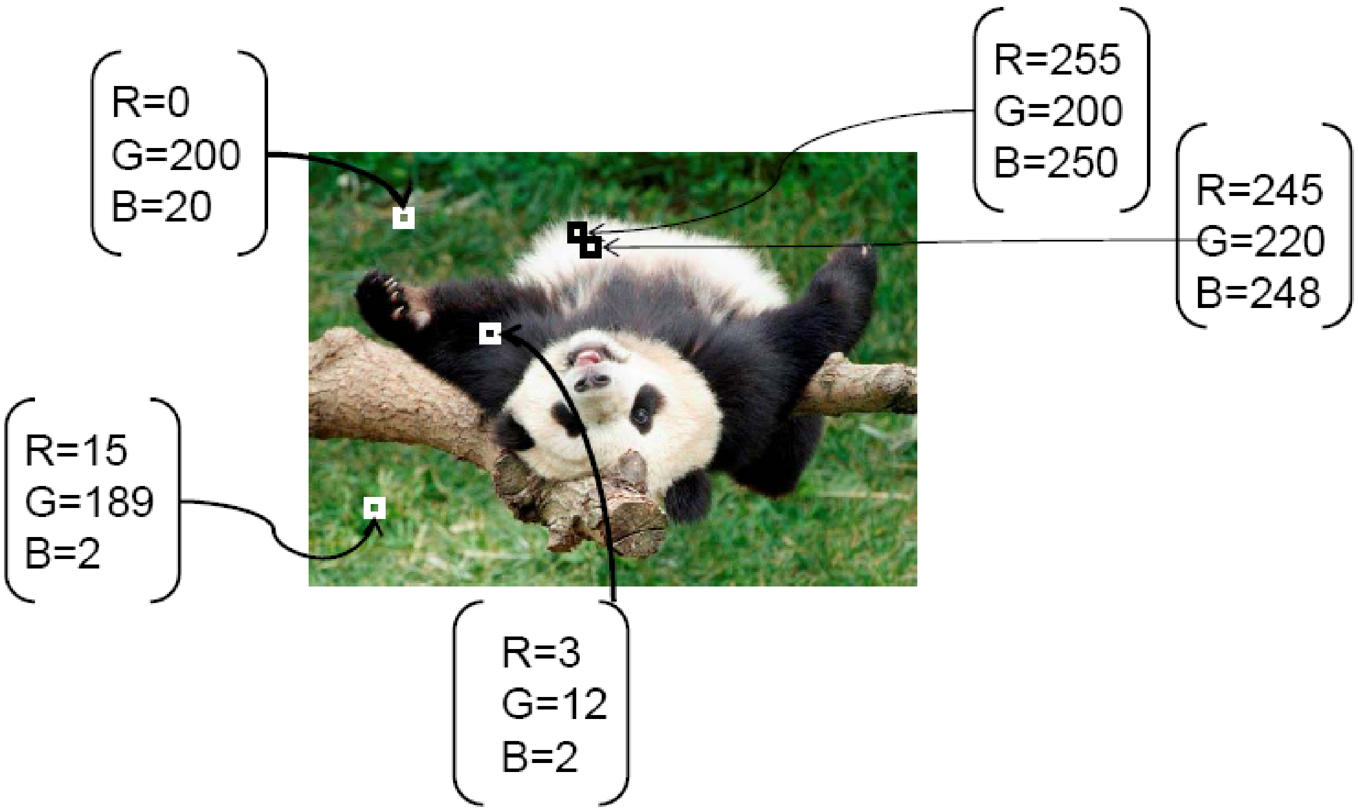
[Levin and Weiss 2006]

Segmentation using clustering

- Kmeans

- Mean-shift

Feature Space

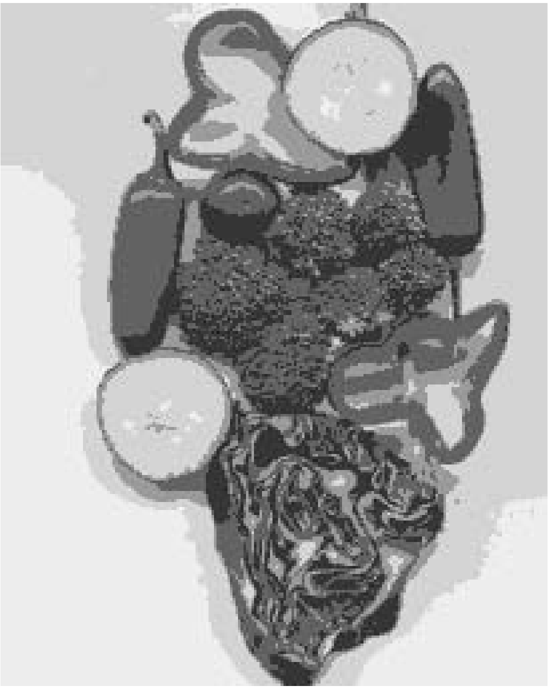


Source: K. Grauman

K-means clustering using intensity alone and color alone

Image

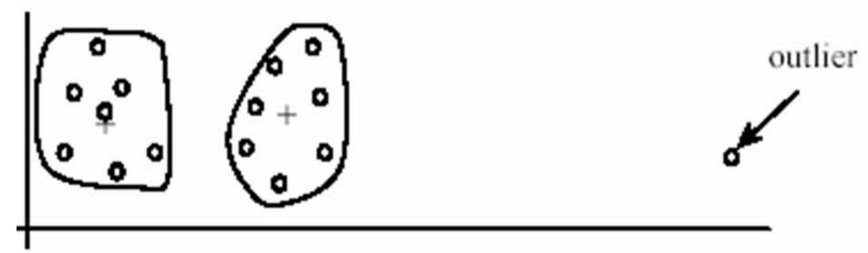
Clusters on intensity



Clusters on color

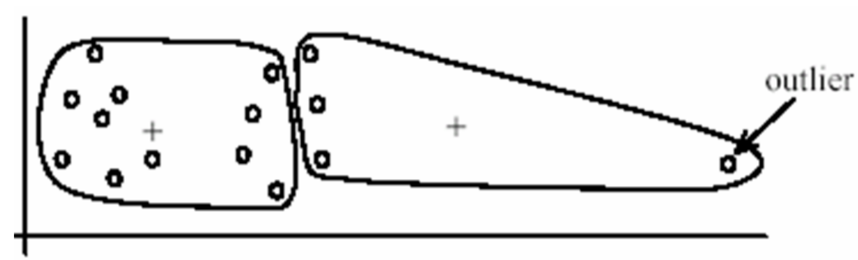
K-Means pros and cons

- Pros
  - Simple and fast
  - Easy to implement
- Cons
  - Need to choose K
  - Sensitive to outliers



(B): Ideal clusters

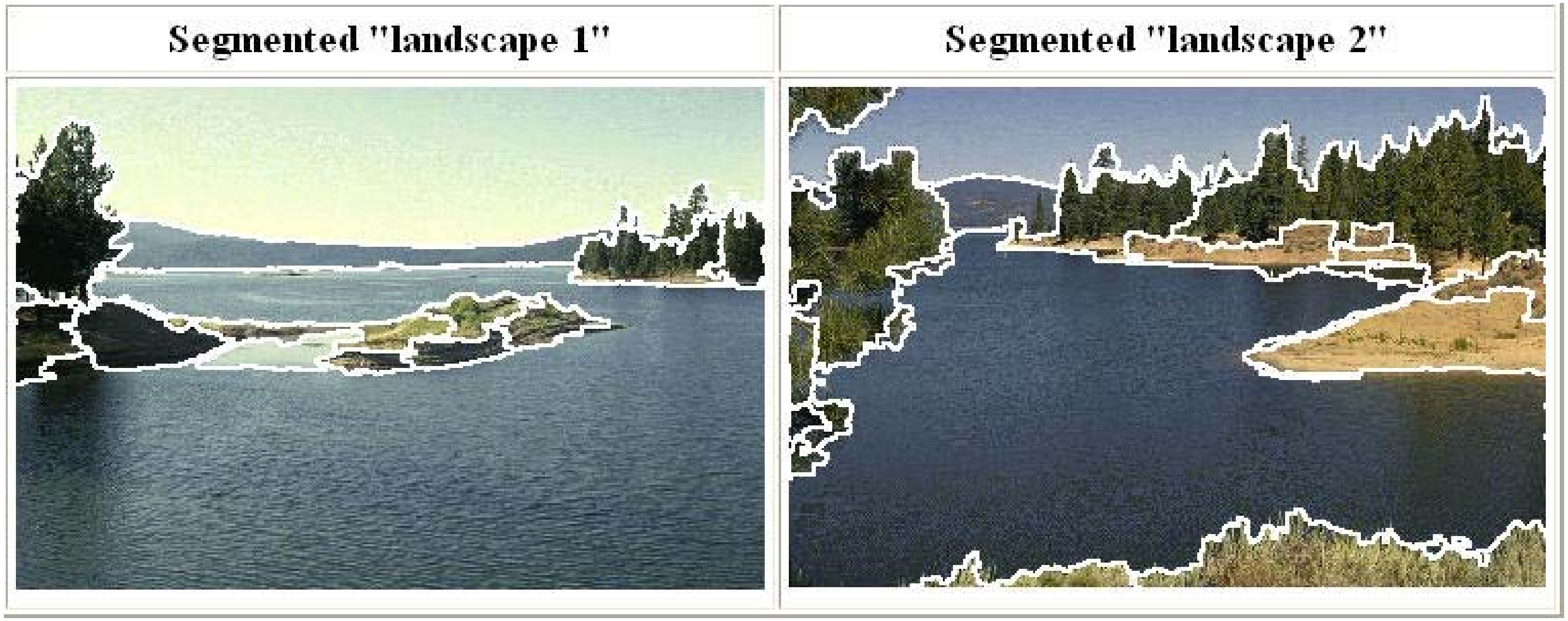
- Usage
  - Rarely used for pixel segmentation



Mean shift segmentation

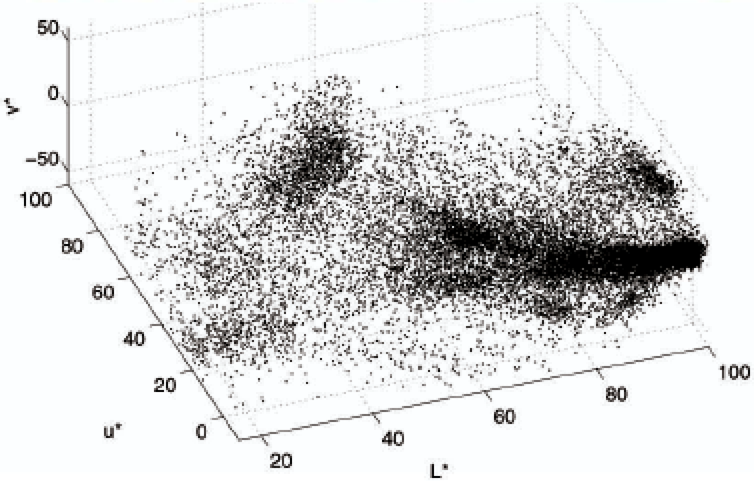
D. Comaniciu and P. Meer, Mean Shift: A Robust Approach toward Feature Space Analysis, PAMI 2002.

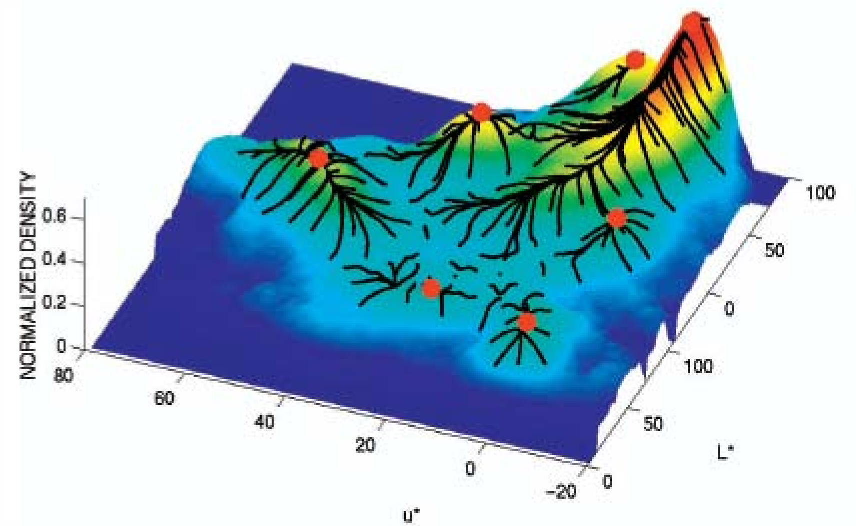
- Versatile technique for clustering-based segmentation

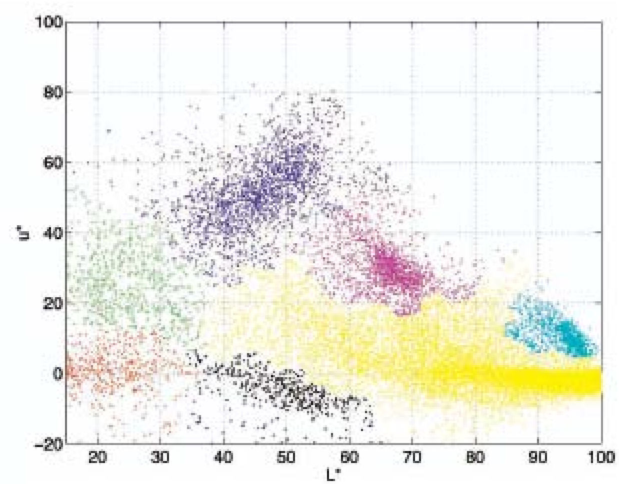


Mean shift algorithm

- Try to find *modes* of this non-parametric density







Kernel density estimation

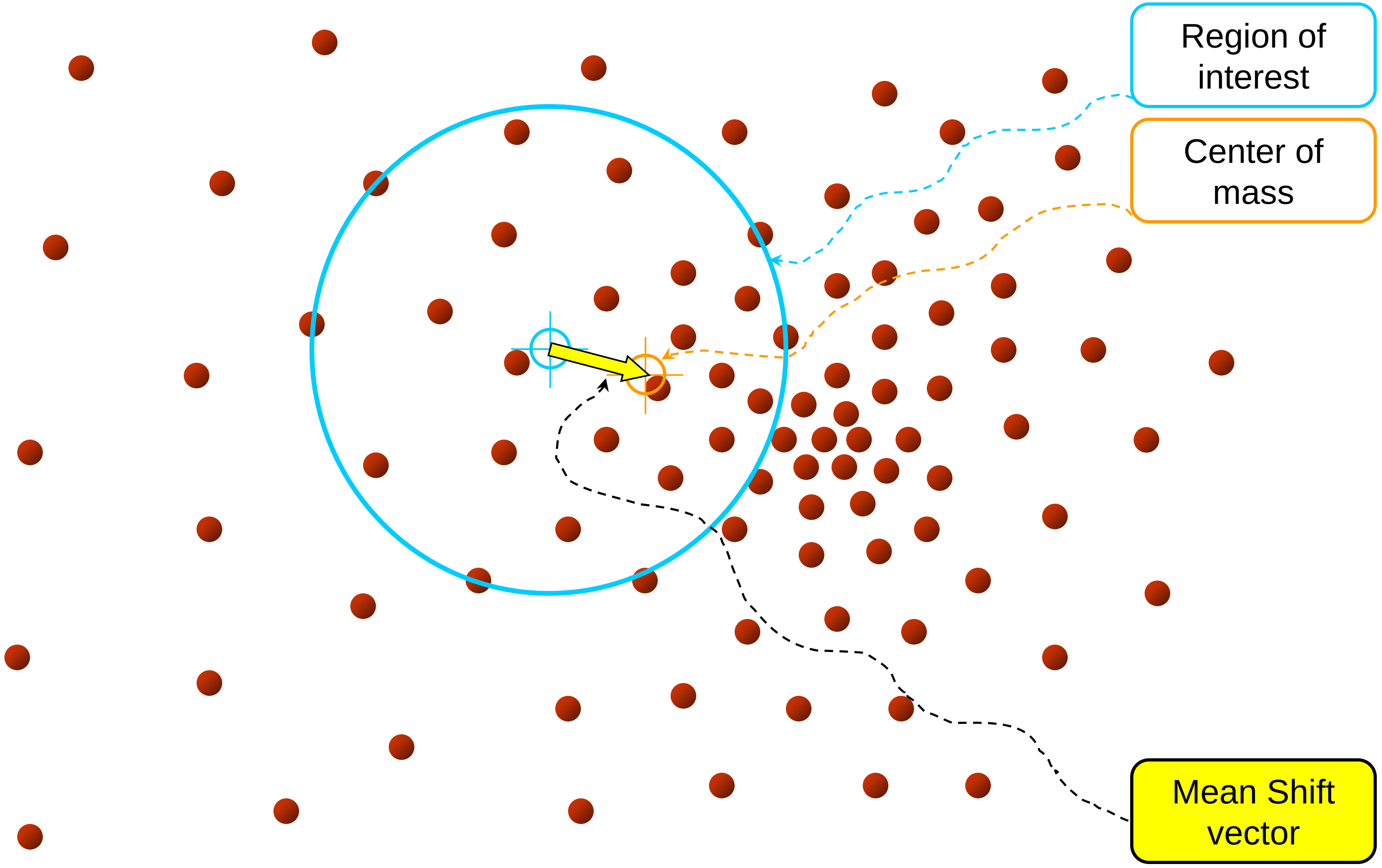
Kernel density estimation function

$$\widehat{f}_h(x) = \frac{1}{nh}\sum_{i=1}^{n} K\left(\frac{x - x_i}{h}\right)$$

Gaussian kernel

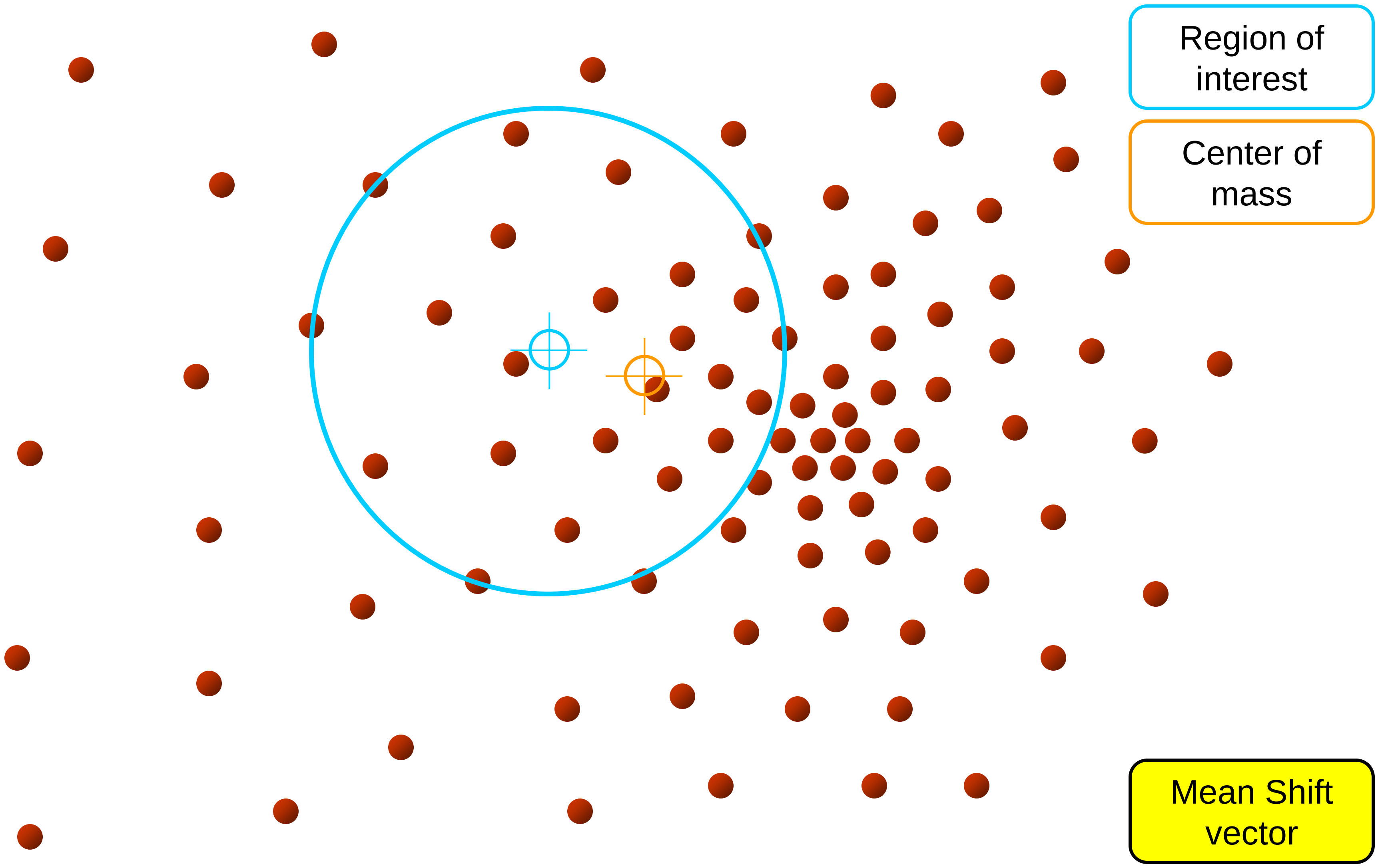
$$K\left(\frac{x - x_i}{h}\right) = \frac{1}{\sqrt{2\pi}} e^{-\frac{(x-x_i)^2}{2h^2}}.$$

Mean shift



Slide by Y. Ukrainitz & B. Sarel

Mean shift



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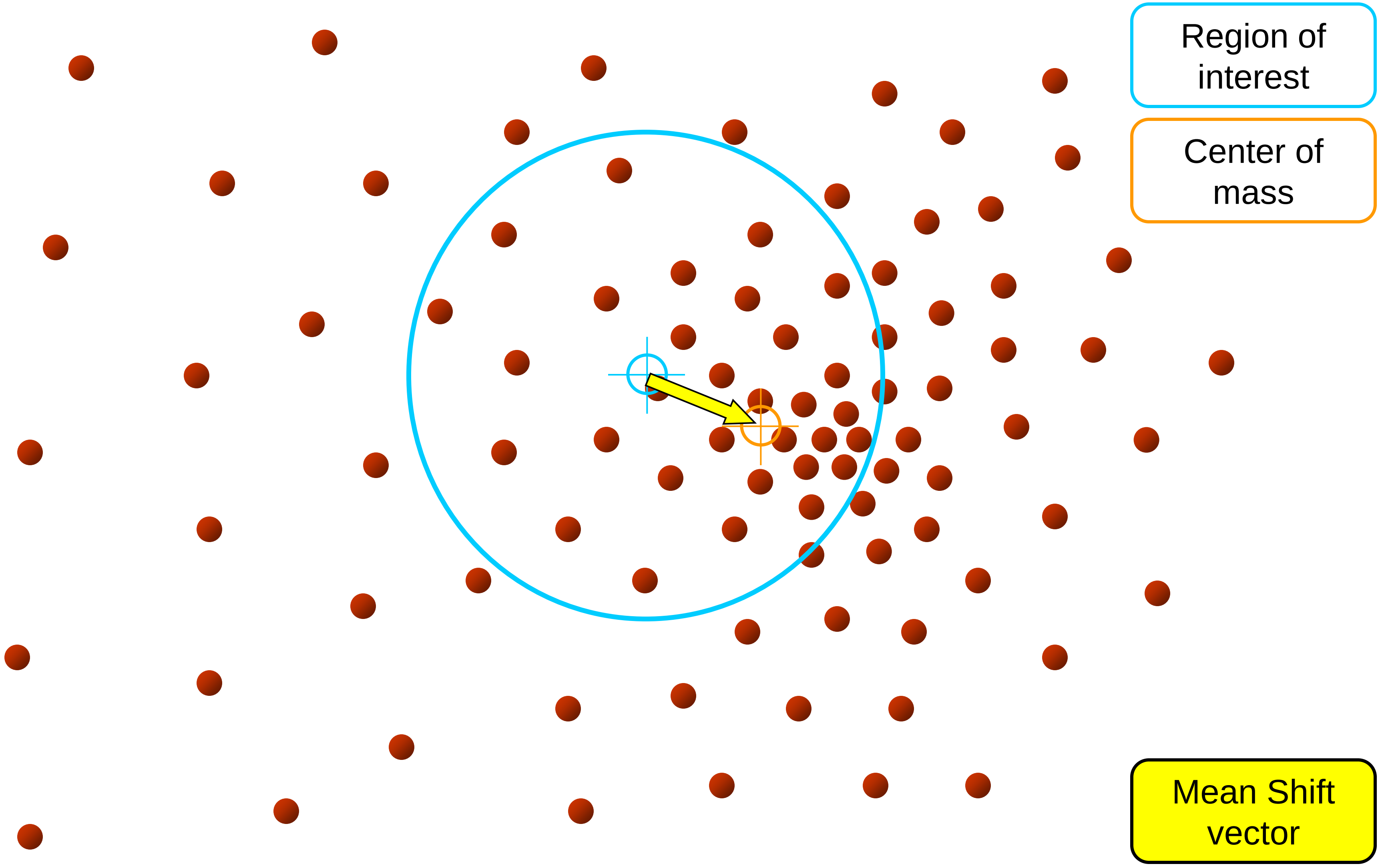
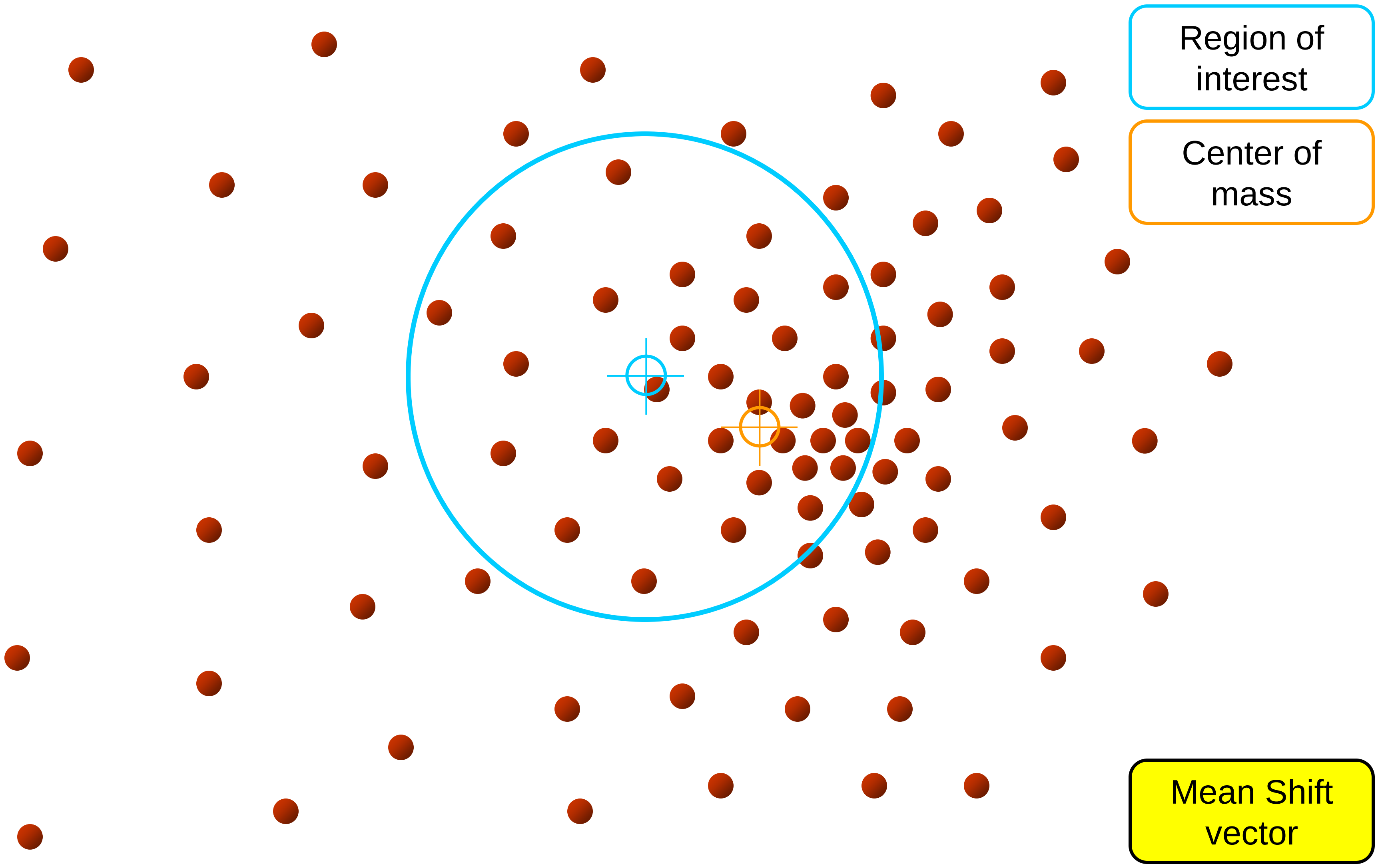
Mean shift



Slide by Y. Ukrainitz & B. Sarel

Mean shift



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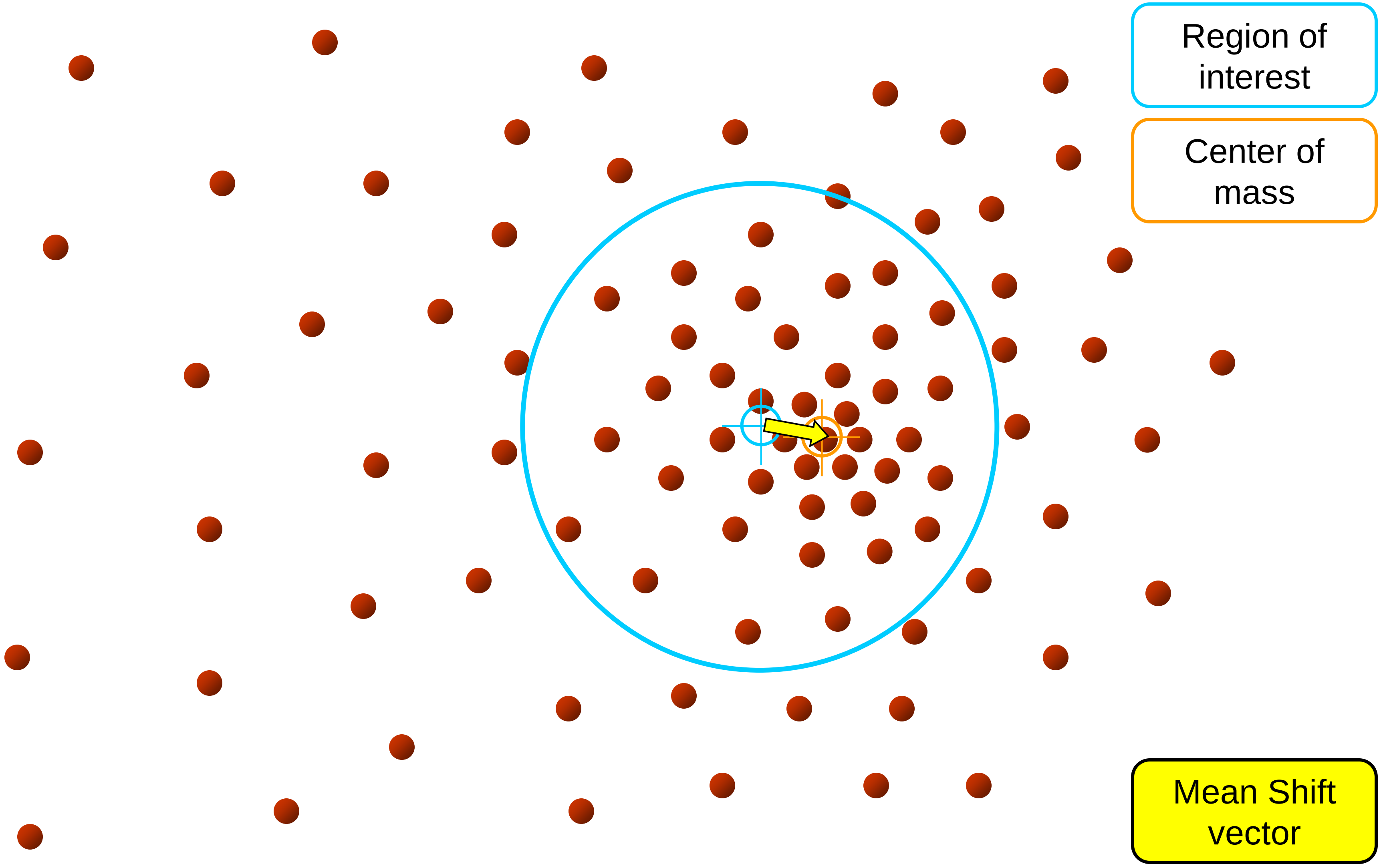
Mean shift



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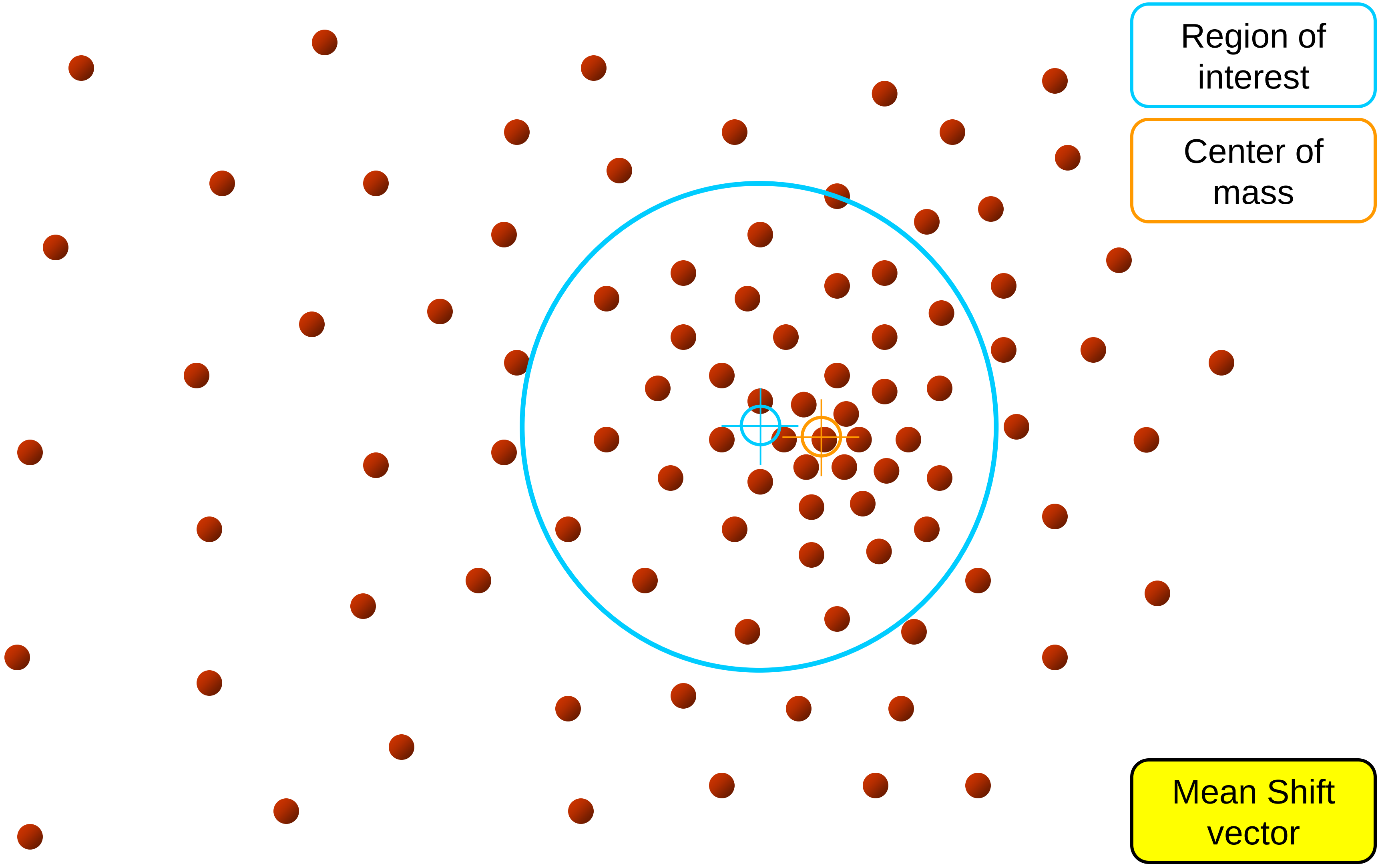
Mean shift



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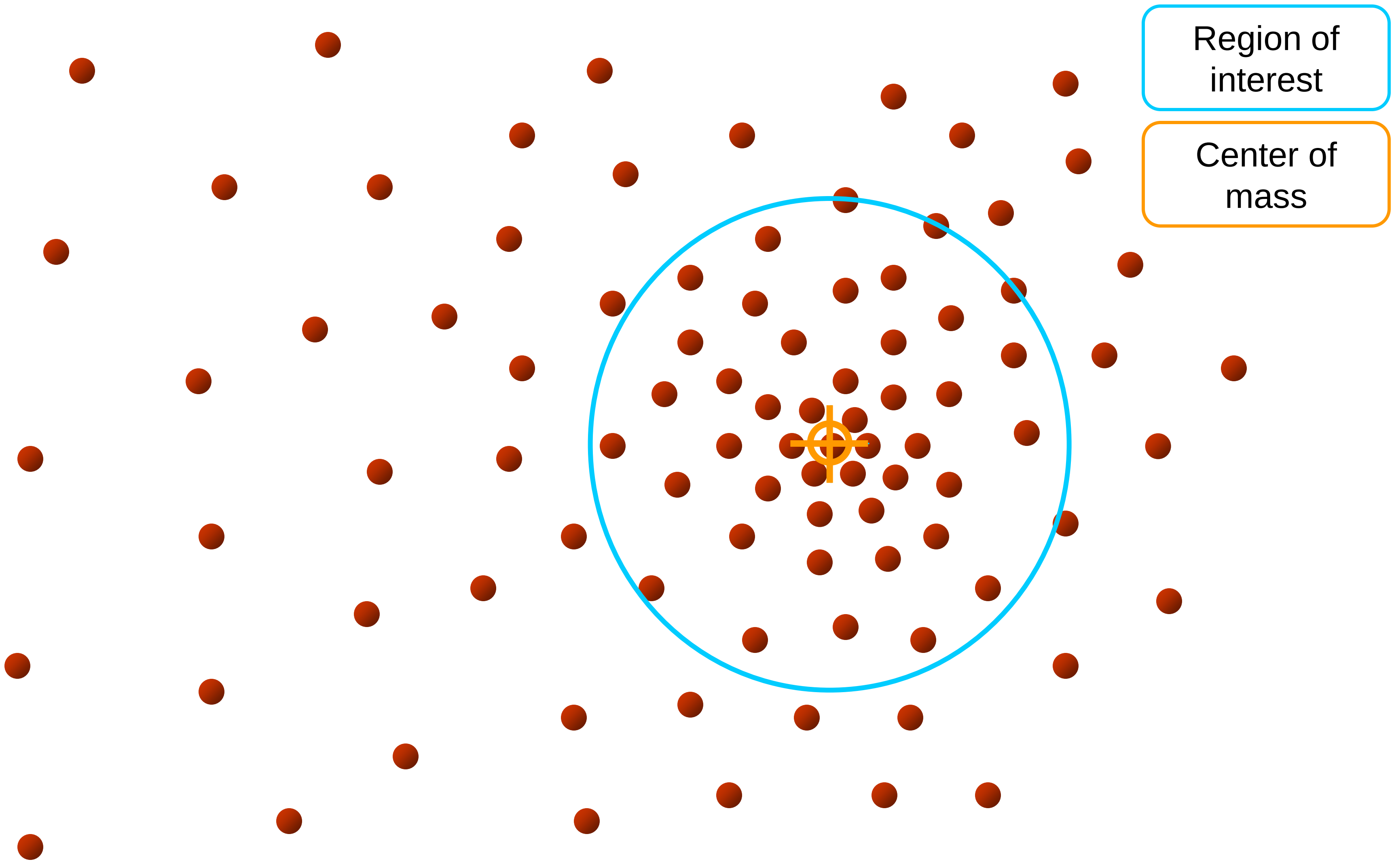
Mean shift



Slide by Y. Ukrainitz & B. Sarel

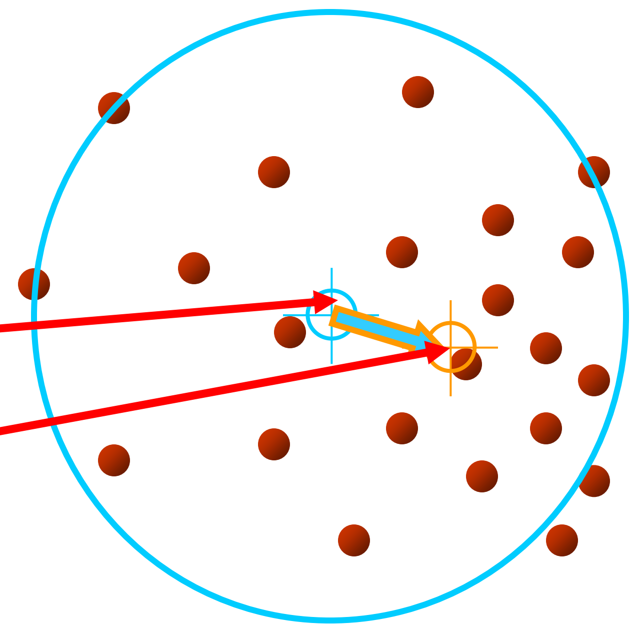
Computing the Mean Shift

Simple Mean Shift procedure:

- Compute mean shift vector

- Translate the Kernel window by **m(x)**

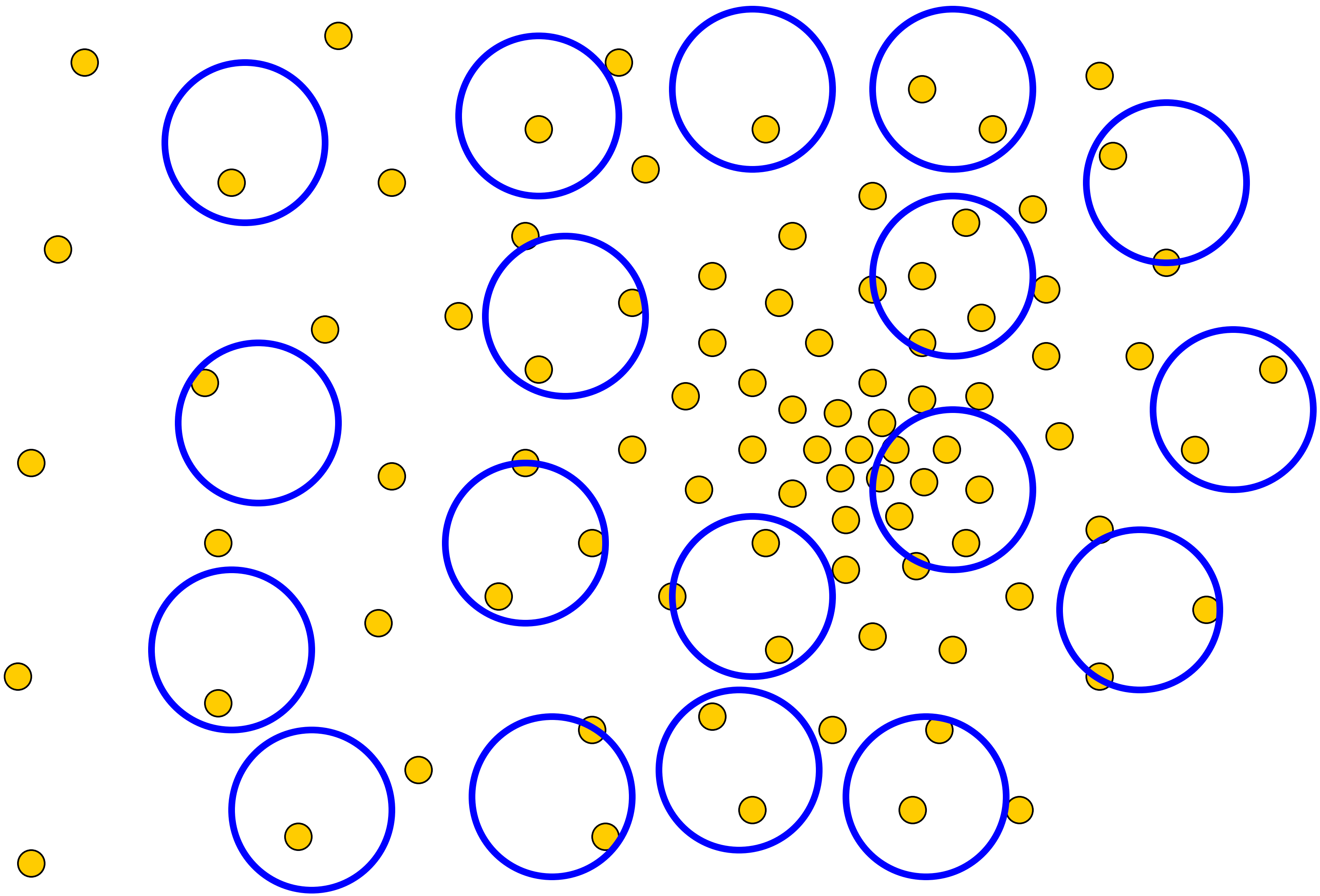
$$\mathbf{m}(\mathbf{x}) = \left[\boxed{\frac{\sum_{i=1}^{n} \mathbf{x}_i g\left(\frac{\left\| \mathbf{x} - \mathbf{x}_i \right\|^2}{h} \right)}{\sum_{i=1}^{n} g\left(\frac{\left\| \mathbf{x} - \mathbf{x}_i \right\|^2}{h} \right)}} - \boxed{\mathbf{x}} \right]$$



$$g(\mathbf{x}) = -k'(\mathbf{x})$$

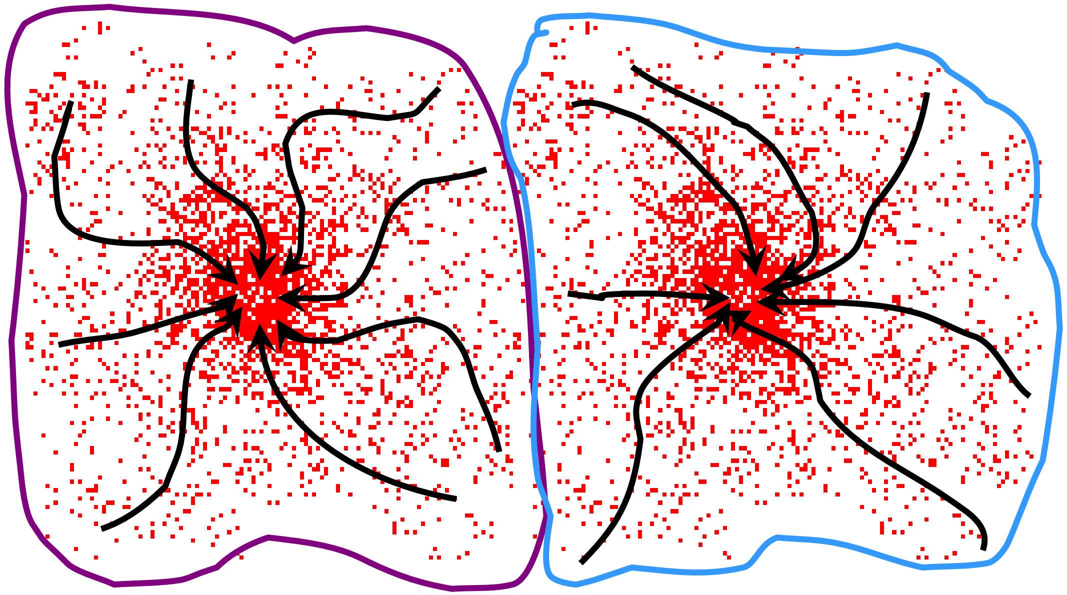
Slide by Y. Ukrainitz & B. Sarel

Real Modality Analysis



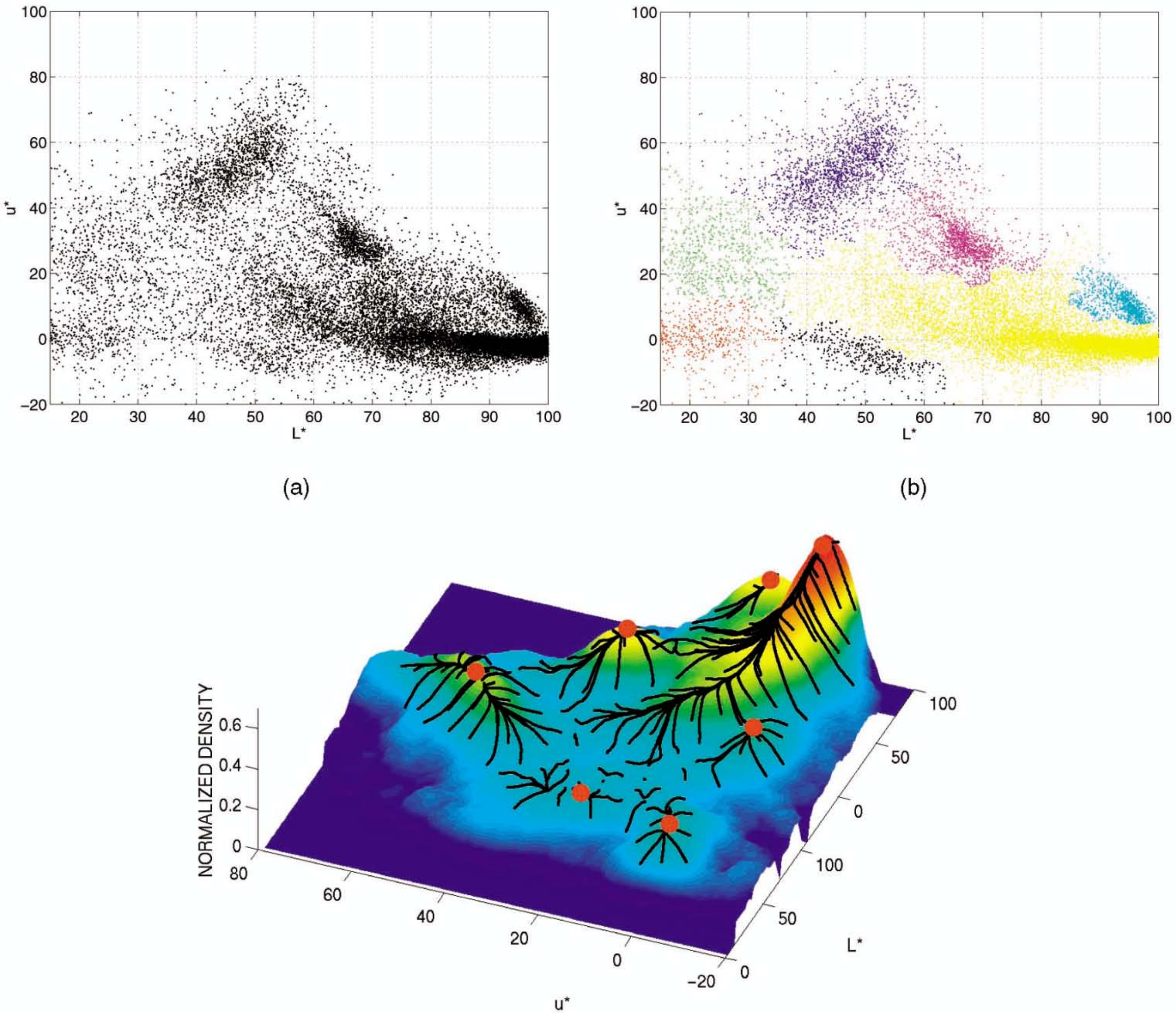
Attraction basin

- Attraction basin: the region for which all trajectories lead to the same mode
- Cluster: all data points in the attraction basin of a mode



Slide by Y. Ukrainitz & B. Sarel

Attraction basin

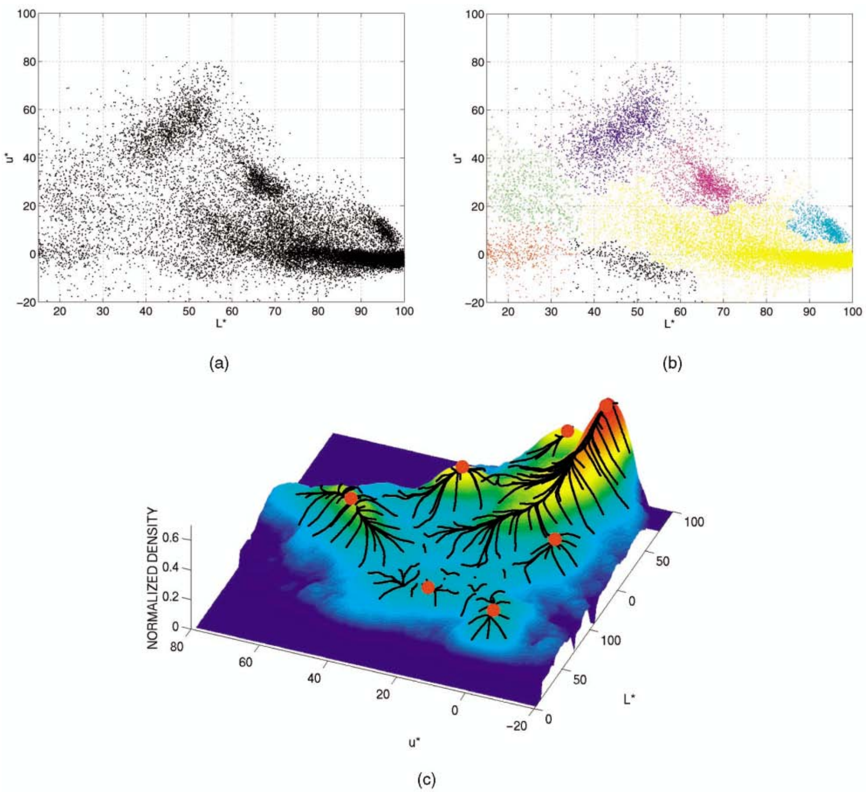


Mean shift clustering

- The mean shift algorithm seeks *modes* of the given set of points
  1. Choose kernel and bandwidth
  2. For each point:
     a) Center a window on that point
     b) Compute the mean of the data in the search window
     c) Center the search window at the new mean location
     d) Repeat (b,c) until convergence
  3. Assign points that lead to nearby modes to the same cluster

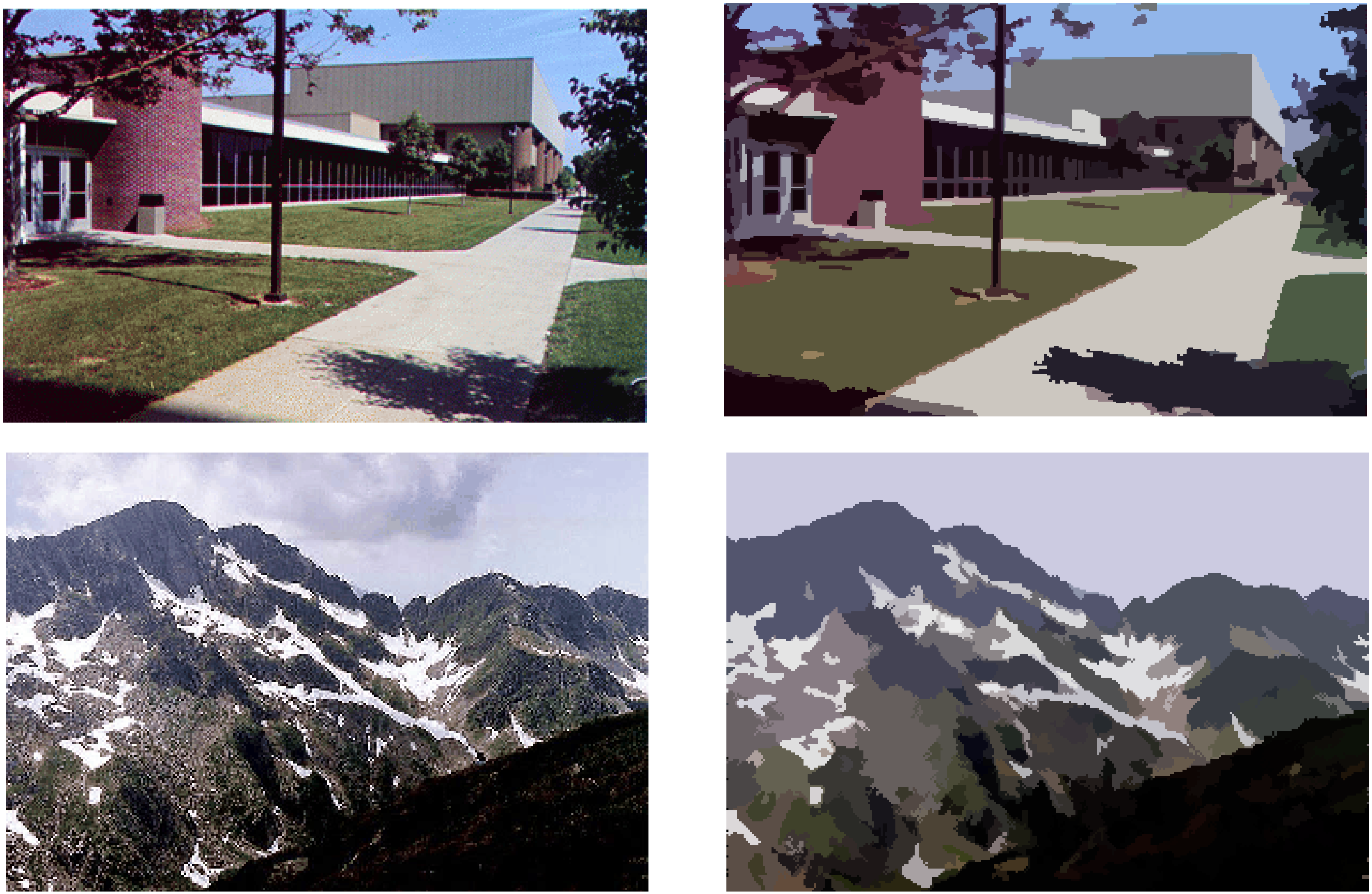
Segmentation by Mean Shift

- Compute features for each pixel (color, gradients, texture, etc)
- Set kernel size for features K_f and position K_s
- Initialize windows at individual pixel locations
- Perform mean shift for each window until convergence
- Merge windows that are within width of K_f and K_s

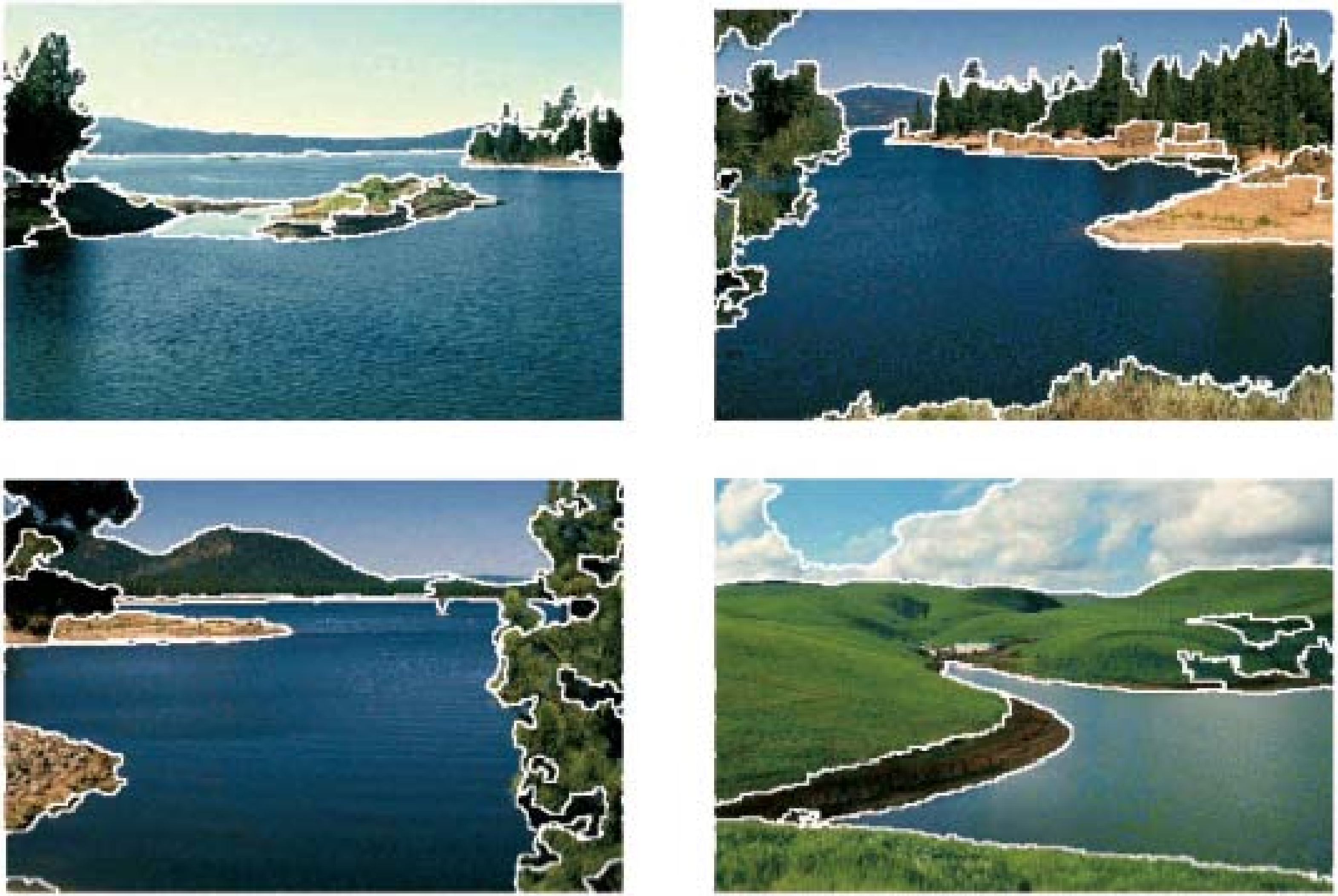


(a)
(b)
(c)

Mean shift segmentation results



http://www.caip.rutgers.edu/~comanici/MSPAMI/msPamiResults.html



http://www.caip.rutgers.edu/~comanici/MSPAMI/msPamiResults.html

Mean-shift: other issues

- Speedups
  - Binned estimation
  - Fast search of neighbors
  - Update each window in each iteration (faster convergence)

- Other tricks
  - Use kNN to determine window sizes adaptively

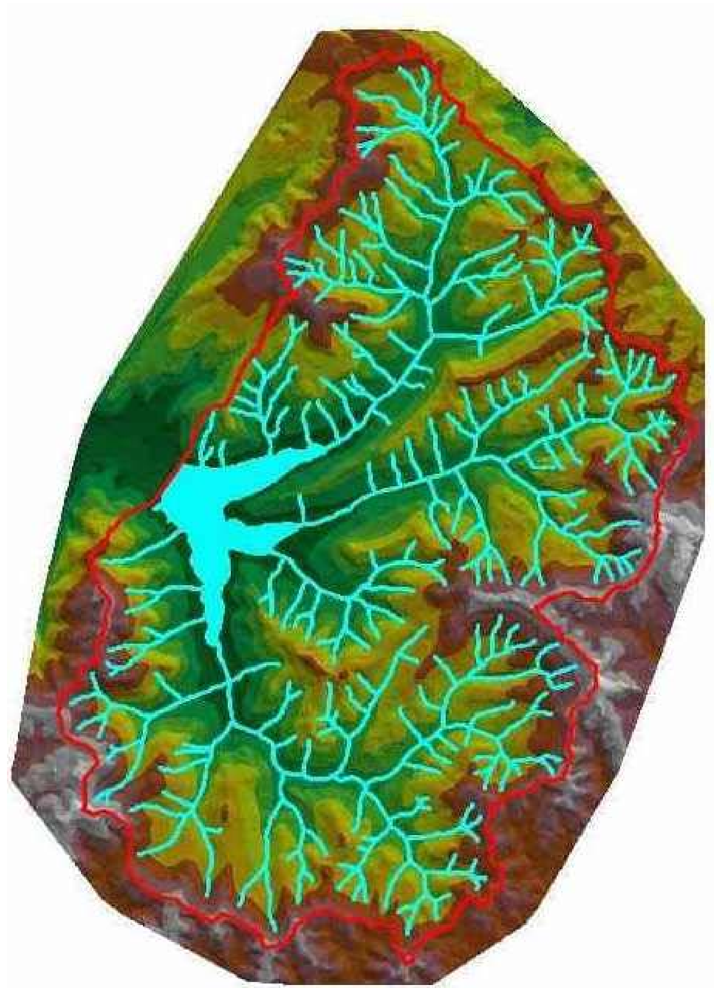
- Lots of theoretical support

  D. Comaniciu and P. Meer, Mean Shift: A Robust Approach toward Feature Space Analysis, PAMI 2002.

Mean shift pros and cons

- Pros
  - Good general-practice segmentation
  - Flexible in number and shape of regions
  - Robust to outliers
- Cons
  - Have to choose kernel size in advance
  - Not suitable for high-dimensional features
- When to use it
  - Oversegmentatoin
  - Multiple segmentations
  - Tracking, clustering, filtering applications

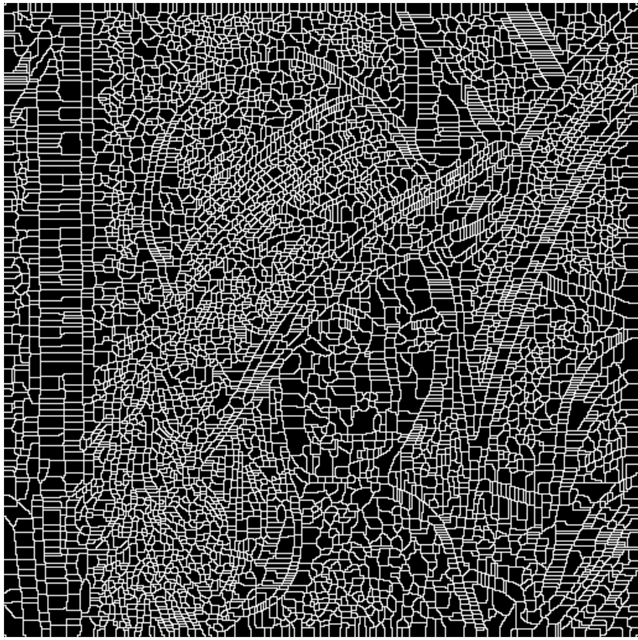
Watershed algorithm



Watershed segmentation

Image

Gradient



Watershed boundaries

Meyer's watershed segmentation

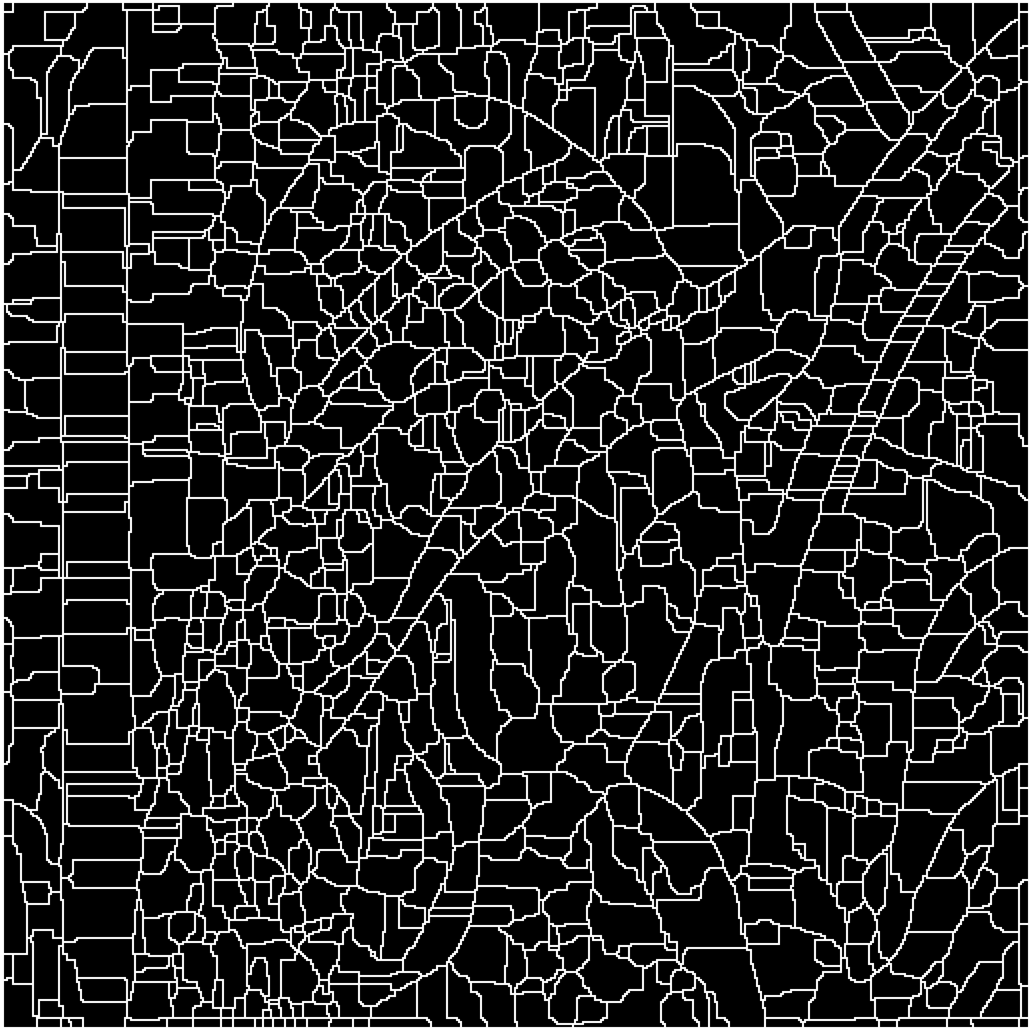
1. Choose local minima as region seeds
2. Add neighbors to priority queue, sorted by value
3. Take top priority pixel from queue
    1. If all labeled neighbors have same label, assign to pixel
    2. Add all non-marked neighbors
4. Repeat step 3 until finished

Matlab: seg = watershed(bnd_im)

Meyer 1991

Simple trick

- Use Gaussian or median filter to reduce number of regions



Watershed usage

- Use as a starting point for hierarchical segmentation
  - Ultrametric contour map (Arbelaez 2006)

- Works with any soft boundaries
  - Pb
  - Canny
  - Etc.

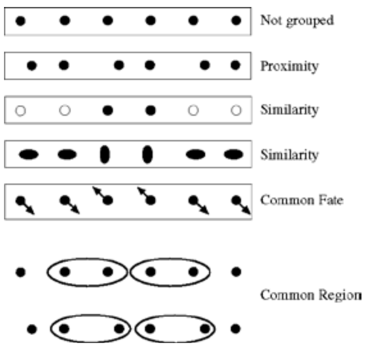
Watershed pros and cons

- Pros
  - Fast (< 1 sec for 512x512 image)
  - Among best methods for hierarchical segmentation
- Cons
  - Only as good as the soft boundaries
  - Not easy to get variety of regions for multiple segmentations
  - No top-down information

- Usage
  - Preferred algorithm for hierarchical segmentation

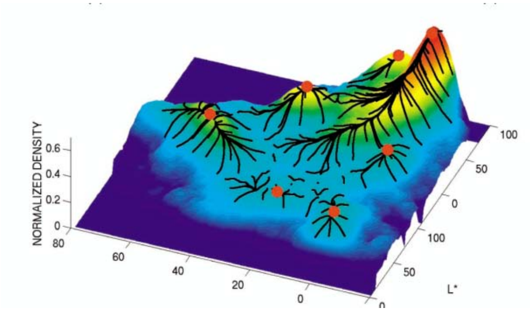
Things to remember

- Gestalt cues and principles of organization

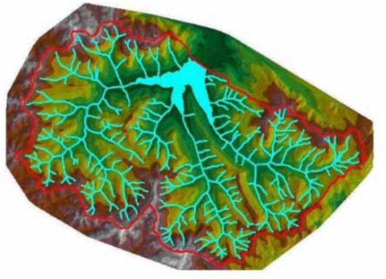


- Uses of segmentation
  - Efficiency
  - Better features
  - Want the segmented object

- Mean-shift segmentation
  - Good general-purpose segmentation method
  - Generally useful clustering, tracking technique



- Watershed segmentation
  - Good for hierarchical segmentation
  - Use in combination with boundary prediction



Further reading

- Nicely written mean-shift explanation (with math)

http://saravananthirumuruganathan.wordpress.com/2010/04/01/introduction-to-mean-shift-algorithm/

- Mean-shift paper by Comaniciu and Meer

http://www.caip.rutgers.edu/~comanici/Papers/MsRobustApproach.pdf

- Adaptive mean shift in higher dimensions

http://mis.hevra.haifa.ac.il/~ishimshoni/papers/chap9.pdf

- Contours to regions (watershed): Arbelaez et al. 2009

http://www.eecs.berkeley.edu/~arbelaez/publications/Arbelaez_Maire_Fowlkes_Malik_CVPR2009.pdf

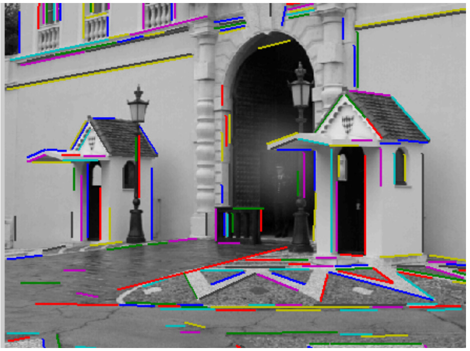
Recap of Grouping and Fitting

Edge and line detection

- Canny edge detector = smooth → derivative → thin → threshold → link

- Generalized Hough transform = points vote for shape parameters

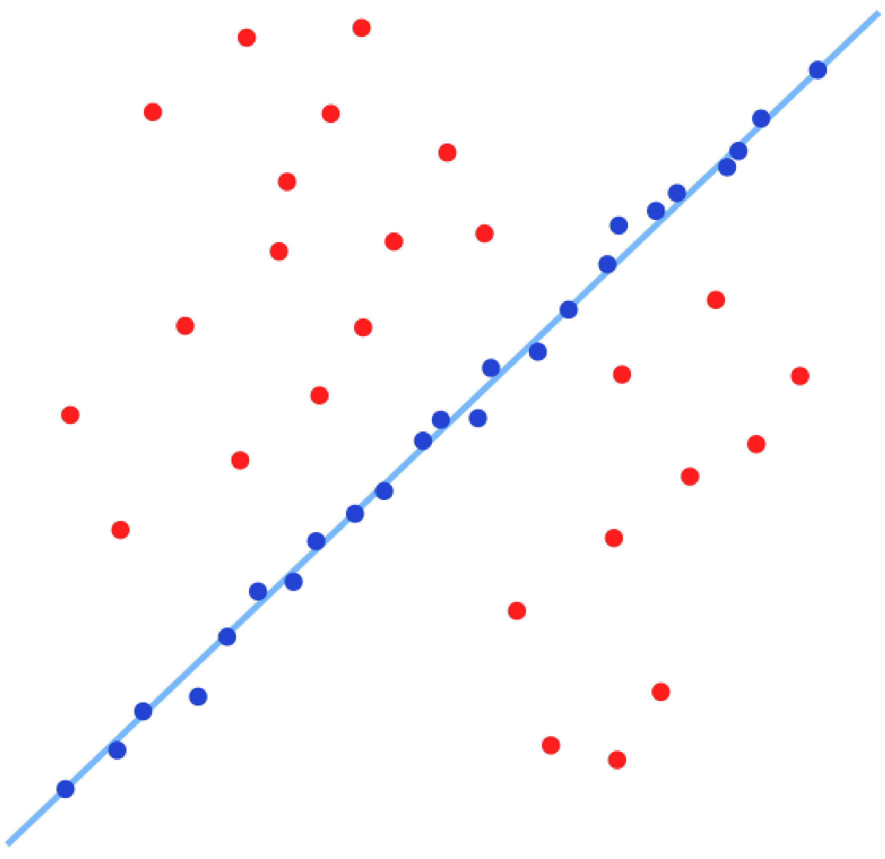
- Straight line detector = canny + gradient orientations → orientation binning → linking → check for straightness



Robust fitting and registration

Key algorithms

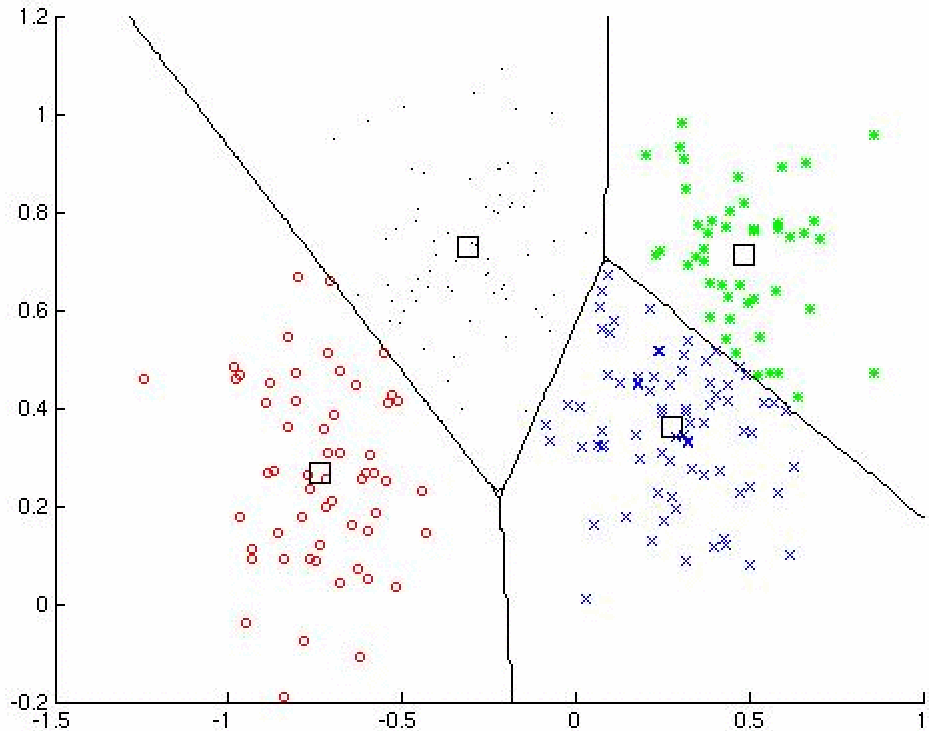
- RANSAC, Hough Transform



Clustering

Key algorithm

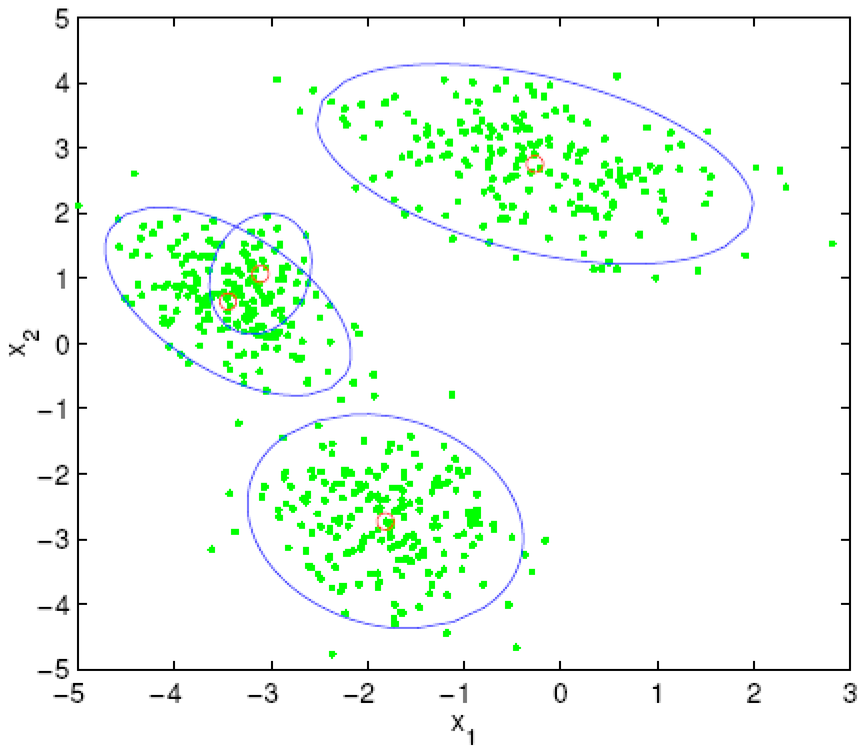
- K-means



EM and Mixture of Gaussians

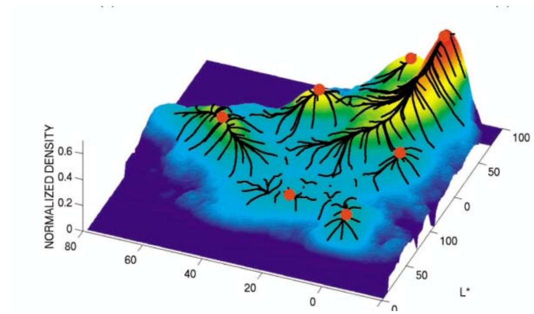
Tutorials:

- [http://www.cs.duke.edu/courses/spring04/cps196.1/.../**EM**/tomasiEM.pdf](http://www.cs.duke.edu/courses/spring04/cps196.1/.../EM/tomasiEM.pdf)
- http://www-clmc.usc.edu/~adsouza/notes/mix_gauss.pdf

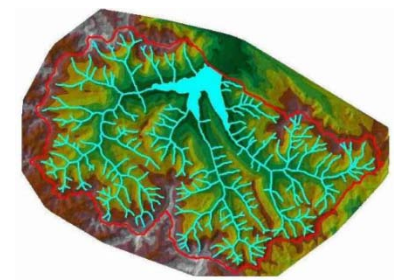


Segmentation

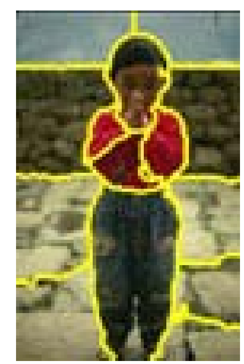
- Mean-shift segmentation
  - Flexible clustering method, good segmentation



- Watershed segmentation
  - Hierarchical segmentation from soft boundaries



- Normalized cuts
  - Produces regular regions
  - Slow but good for oversegmentation



- MRFs with Graph Cut
  - Incorporates foreground/background/object model and prefers to cut at image boundaries
  - Good for interactive segmentation or recognition

Next section: Recognition

- How to recognize
  - Specific object instances
  - Faces
  - Scenes
  - Object categories