

Perceptual Organization & Scene Understanding



CS280: Computer Vision
A. Efros, UC Berkeley, Spring 2023

On to Research Frontiers!

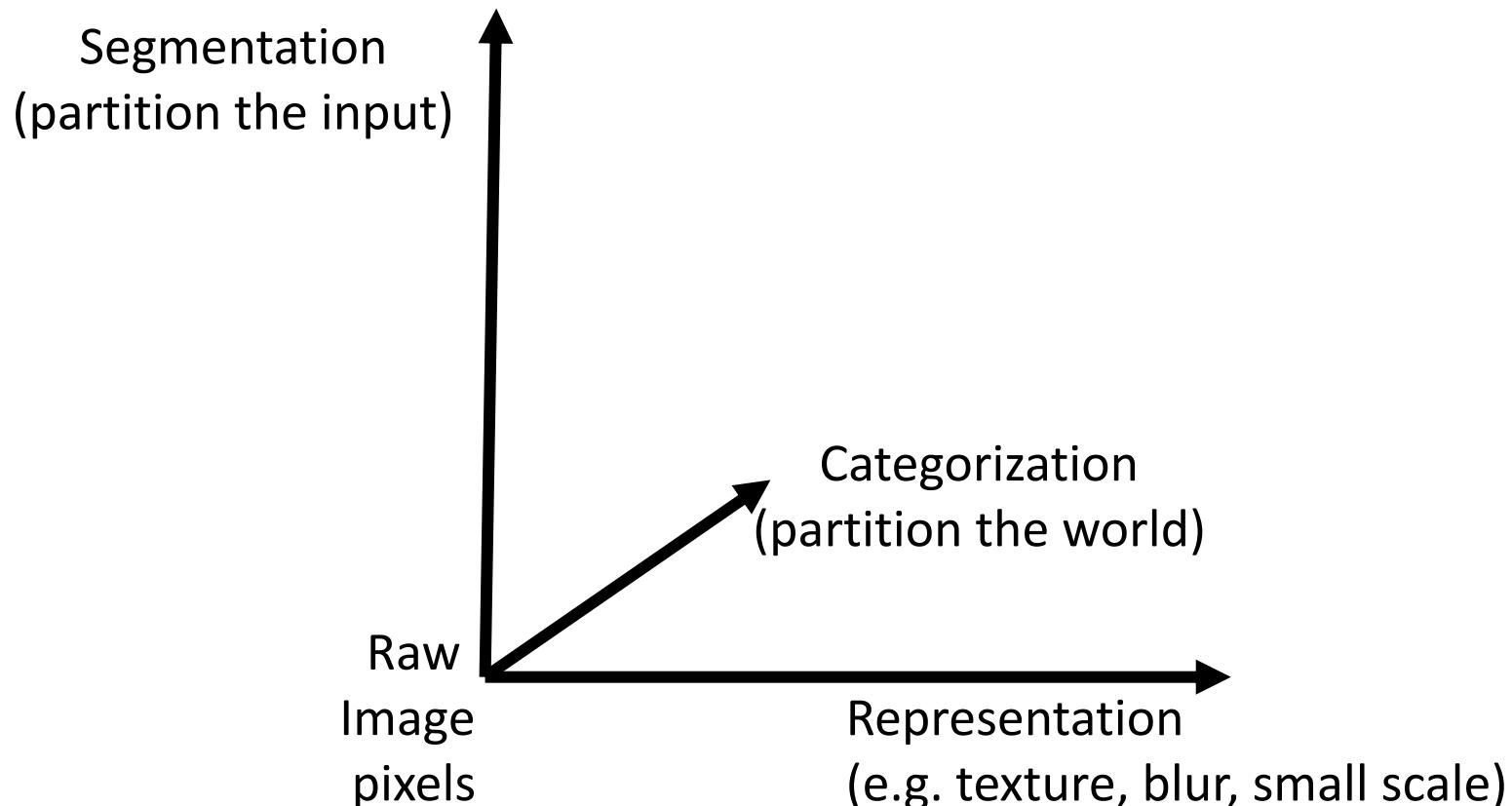


Terra Incognita

Need to handle complexity!

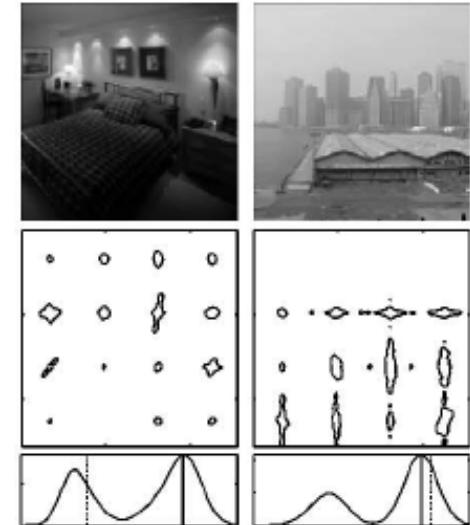


Ways of Reducing Complexity

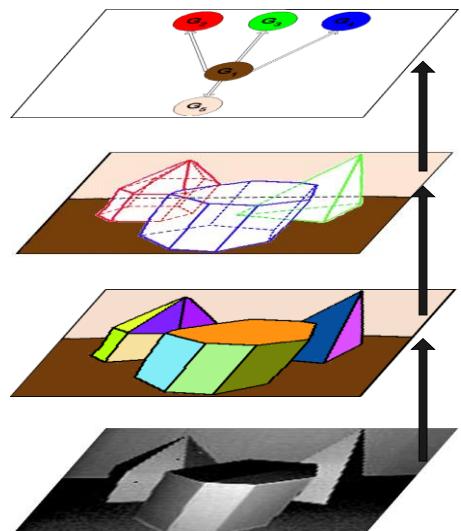


The Whole vs. Sum of Parts

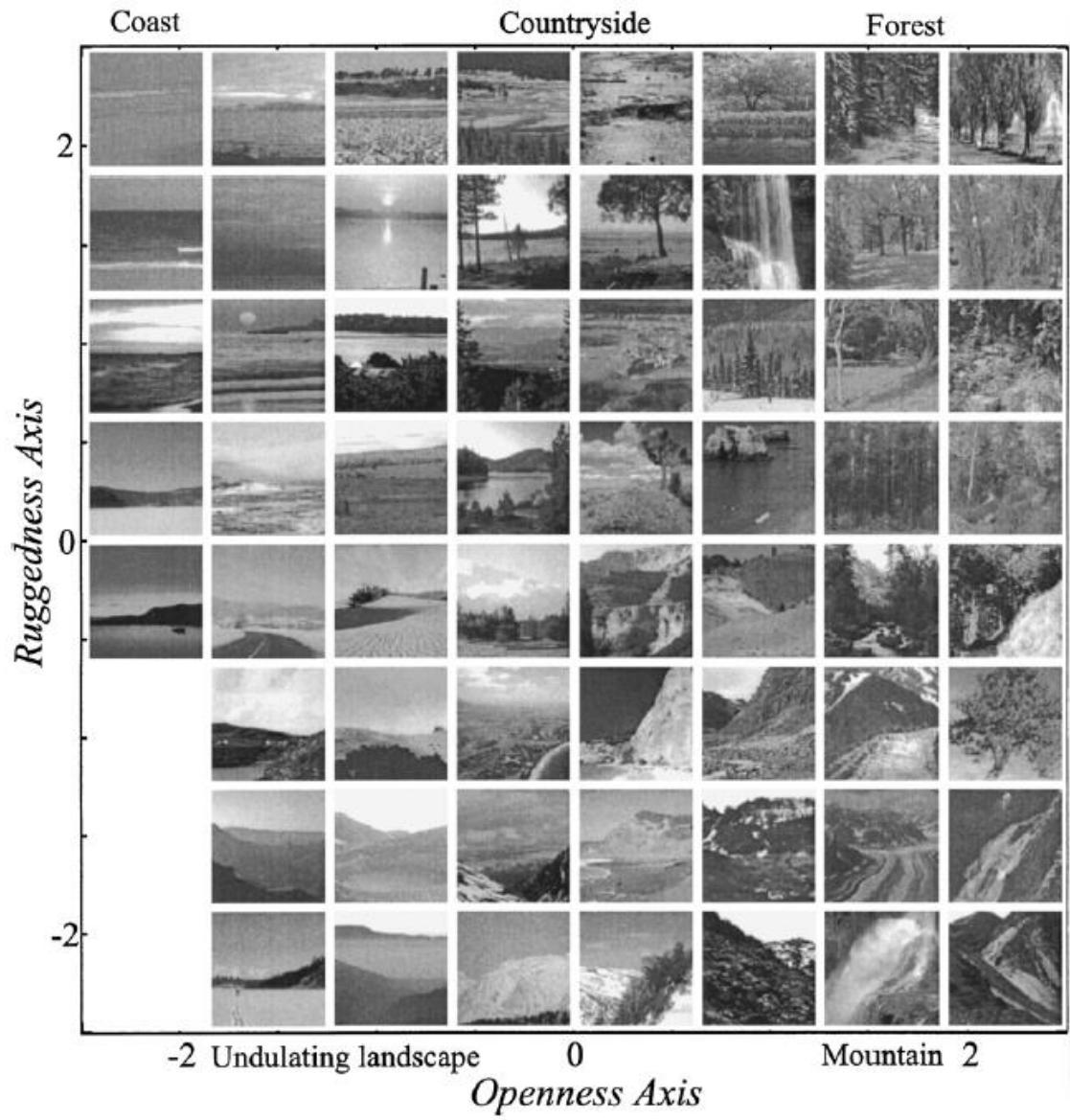
- Recognize full scenes
 - aka the “Julesz / Torralba way”
 - Needs lots of data!



- Parse scenes into parts
 - The compositionality way
 - Needs segmentation
 - Also needs data...



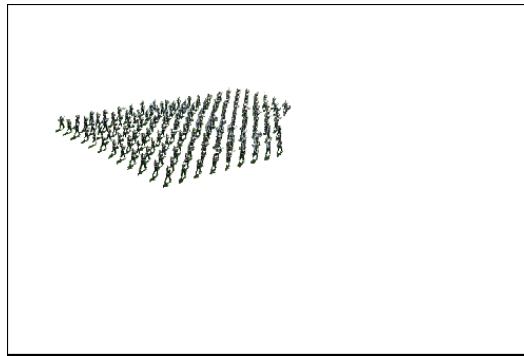
Learning a global Scene Space



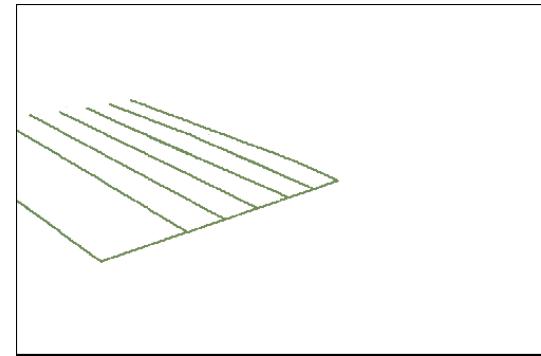
Scene Parsing (hopeful figure)



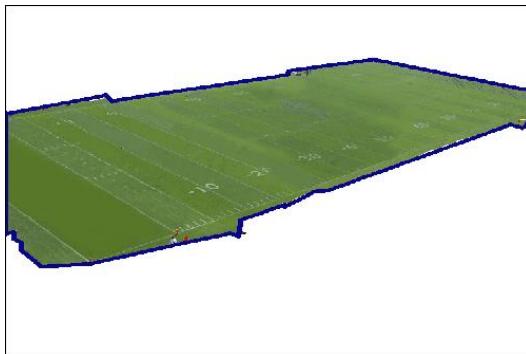
input image



point process



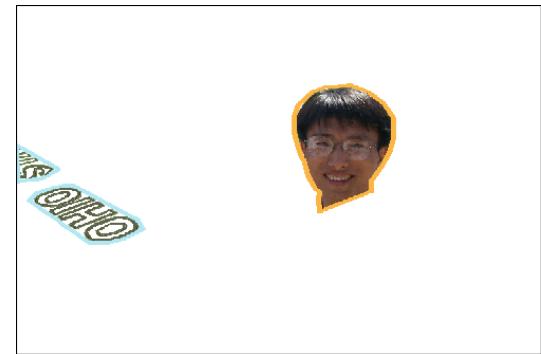
curve process



a color region



texture regions



objects

- **1960s: Toy worlds**
 - E.g. Blocks World
- **1970s: Disentanglement**
 - Intrinsic Images
 - Shape from X
- **1980s: Multiview Geometry**
- **1990s: Holistic Scene Modeling**
 - Scene gist
 - Scene Recognition
 - Texture Recognition
- **2000s: Scene Parsing**
 - Segmentation
 - Figure/ground, Occasion Reasoning
 - Qualitative 3D
 - Image Parsing
- **2010s: Object Detection**
 - Sliding windows
 - Multiple segmentations / selective search
 - “Semantic segmentation” (texture recognition)
- **2020s: Toy worlds ?**

History is cyclical

- **1960s: Toy worlds**
 - E.g. Blocks World
- **1970s: Disentanglement**
 - Intrinsic Images
 - Shape from X
- **1980s: Multiview Geometry**
- **1990s: Holistic Scene Modeling**
 - Scene gist
 - Scene Recognition
 - Texture Recognition
- **2000s: Scene Parsing**
 - Segmentation
 - Figure/ground, Occasion Reasoning
 - Qualitative 3D
 - Image Parsing
- **2010s: Object Detection**
 - Sliding windows
 - Multiple segmentations / selective search
 - “Semantic segmentation” (texture recognition)
- **2020s: Toy worlds ?**

1. Buildup

2. Golden Age

1. Decline

Roberts, Blocks world, Copy Demo (1960s)

If you don't like the world – get your own!

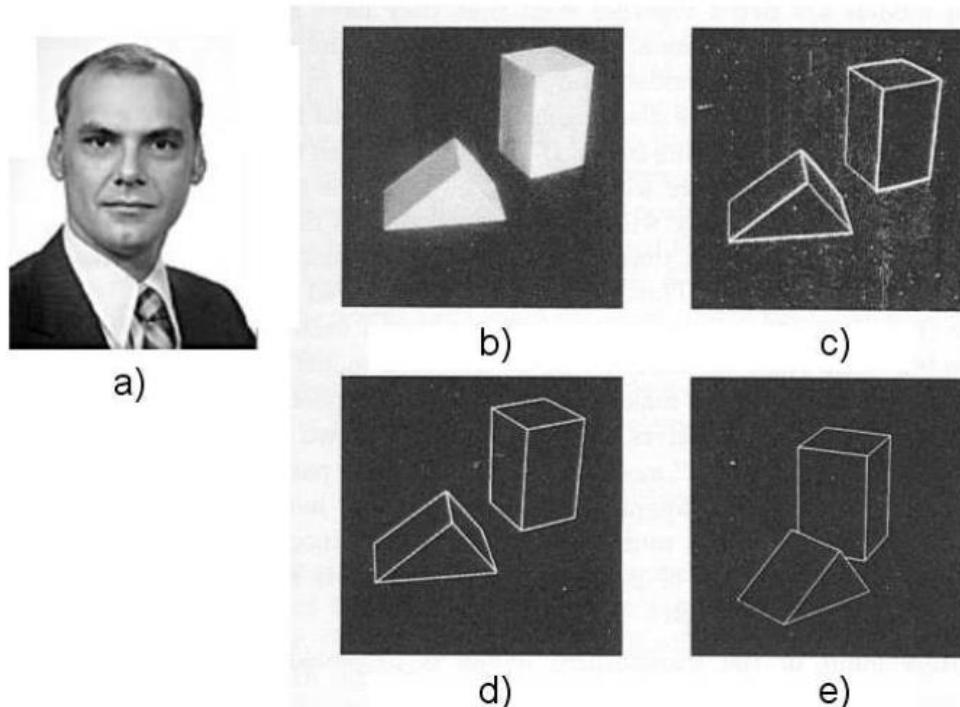
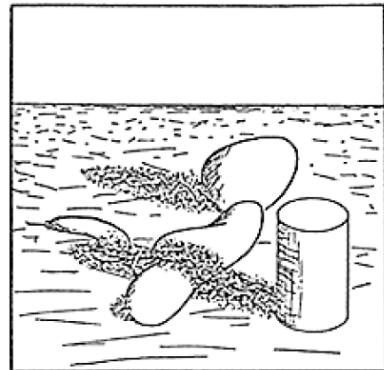
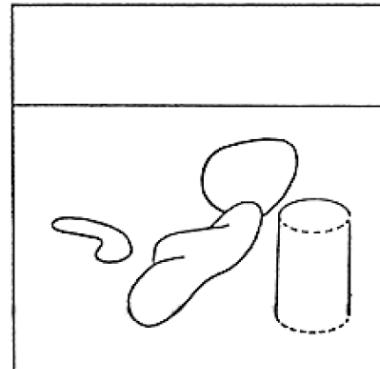


Fig. 1. A system for recognizing 3-d polyhedral scenes. a) L.G. Roberts. b) A blocks world scene. c) Detected edges using a 2×2 gradient operator. d) A 3-d polyhedral description of the scene, formed automatically from the single image. e) The 3-d scene displayed with a viewpoint different from the original image to demonstrate its accuracy and completeness. (b) - e) are taken from [64] with permission MIT Press.)

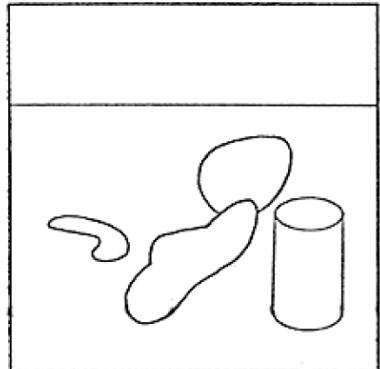
Disentanglement: Intrinsic Images '78 [Barrow & Tenenbaum]



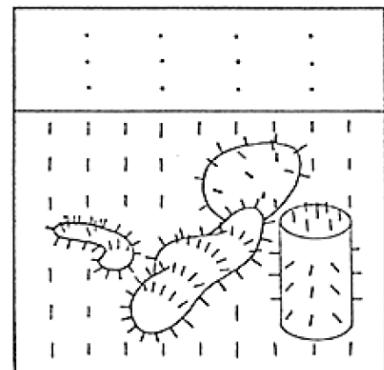
(a) ORIGINAL SCENE



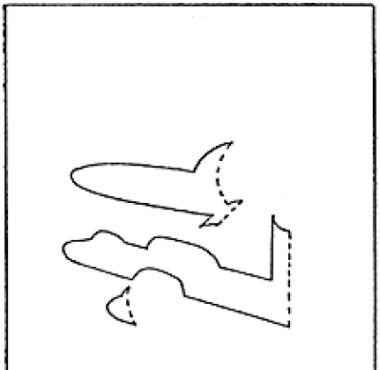
(b) DISTANCE



(c) REFLECTANCE



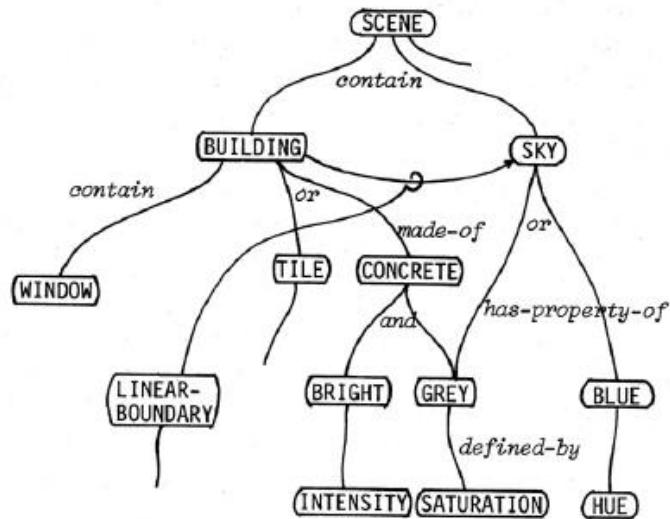
(d) ORIENTATION (VECTOR)



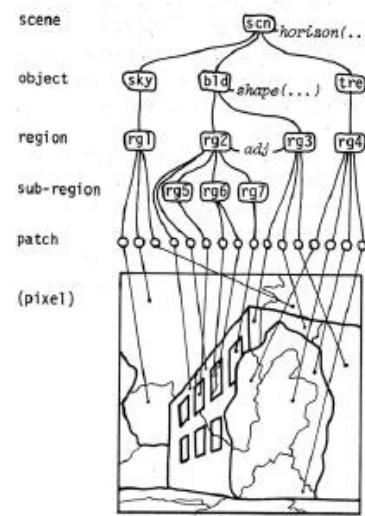
(e) ILLUMINATION

Figure 3 A set of intrinsic images derived from a single monochrome intensity image. The images are depicted as line drawings, but, in fact, would contain values at every point. The solid lines in the intrinsic images represent discontinuities in the scene characteristic; the dashed lines represent discontinuities in its derivative.

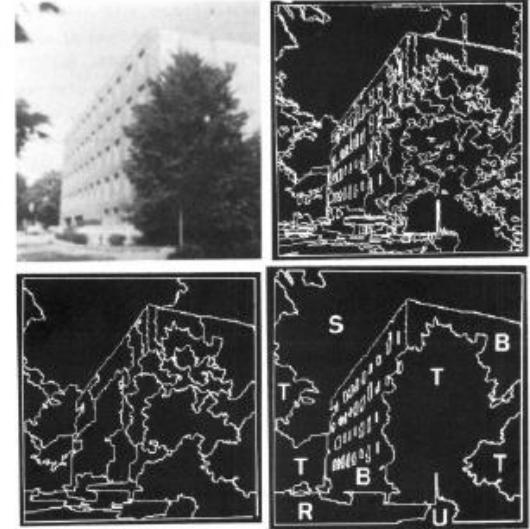
Computational Scene Understanding (*The Age of Titans*)



(a) Bottom-up process



(b) Top-down process



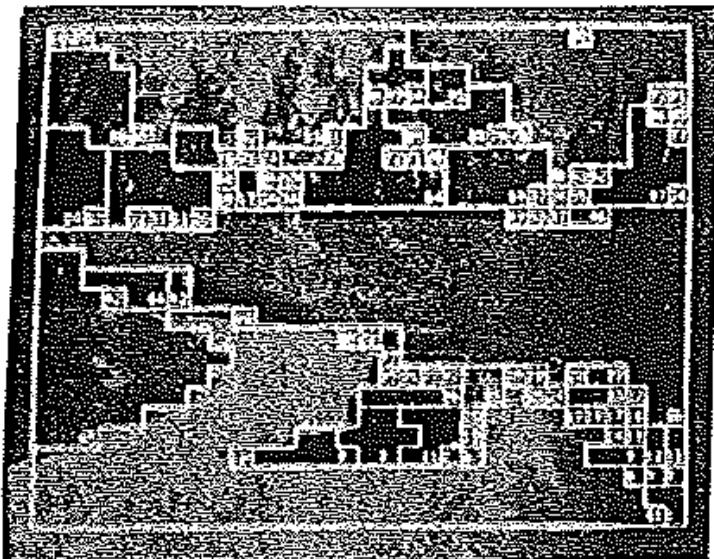
(c) Result

[Ohta & Kanade 1978]

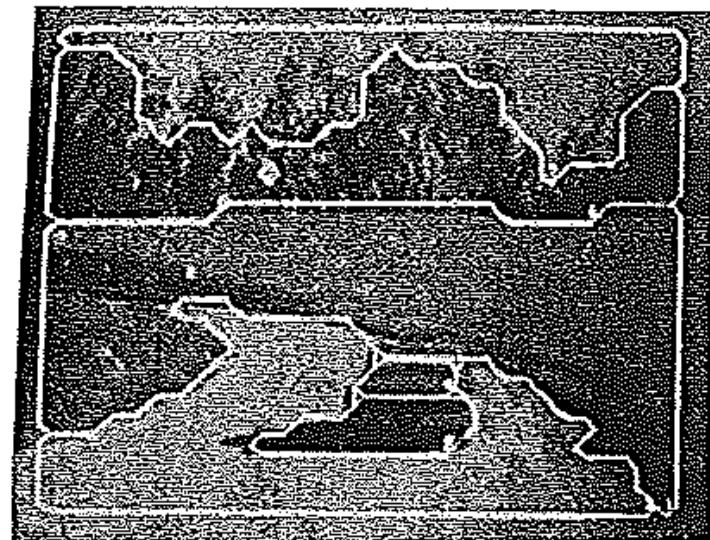
- Guzman (*SEE*), 1968
- Yakimovsky & Feldman, 1973
- Hansen & Riseman (*VISIONS*), 1978
- Barrow & Tenenbaum 1978
- Brooks (*ACRONYM*), 1979
- Marr, 1982
- Ohta & Kanade, 1978

Yakimovsky & Feldman '73

- Did everything: super-pixels, bottom-up segmentation, top-down parsing, inter- and intra-region reasoning, Bayesian formulation!



(B-2) Output of the non-semantic weakest boundary melted first region grower.



(B-5) Grouping regions by their assigned meaning, all regions considered mergable.

Geons (Biederman '87)

Partial Tentative Geon Set Based on Nonaccidentalness Relations

Geon	CROSS SECTION			
	Edges Straight S Curved C	Symmetry Rot & Ref ++ Ref + Asymm -	Size Constant ++ Expanded - Exp & Cont --	Axis Straight + Curved -
	S	++	++	+
	C	++	++	+
	S	+	-	+
	S	++	+	-
	C	++	-	+
	S	+	+	+

What went wrong?

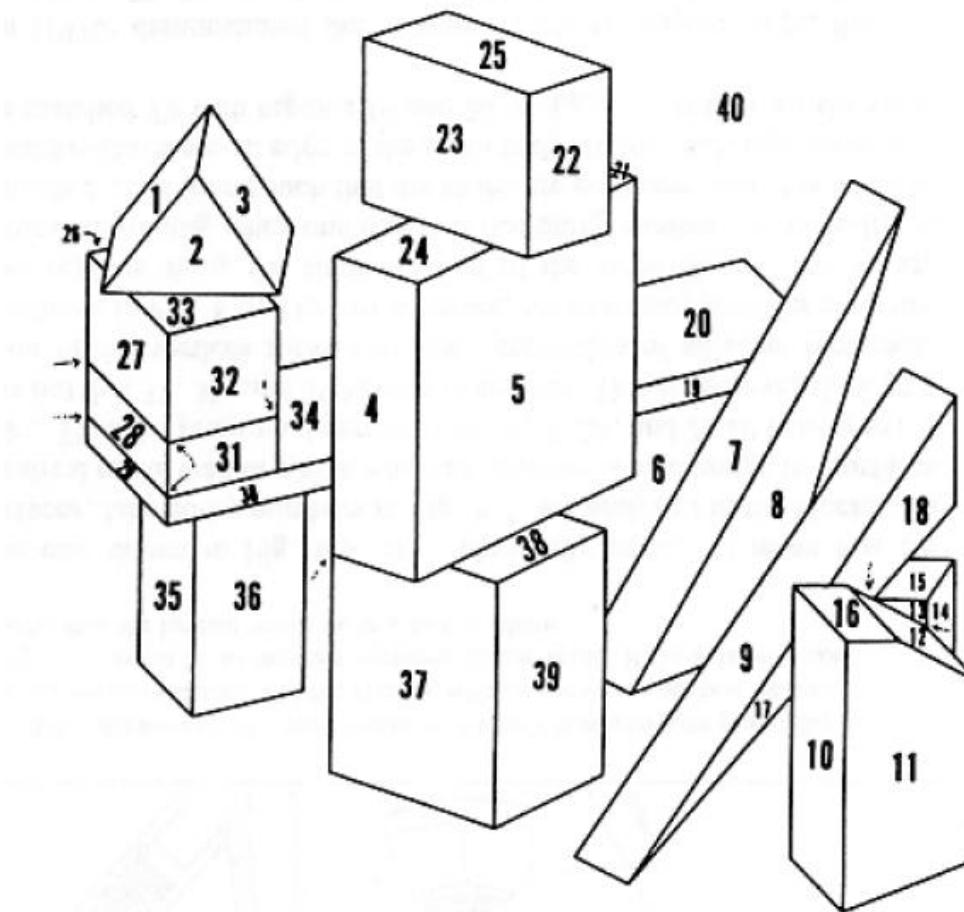
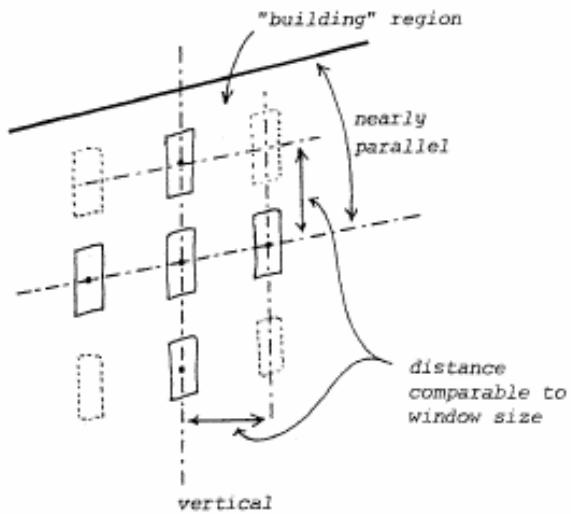


FIG. 8.5. "MOMO," an aggregate of blocks that Guzman's SEE program can correctly parse. (From Guzman, 1968a, p. 177).

What went wrong?



(a) "Windows" and "building"

```
[(ACT (IF (AND (IS-PLAN *PCH *MRGN)
                  .... (1)
                  (*VERTICALLY-LONG *PCH))
                (THEN (GET-SET *PLSET (PLAN *MRGN) PATCHES) .... (2)
                      (AND (ALL-FETCH *WLIKE *PLSET .... (3)
                            (AND (IS (LABEL *WLIKE) NIL)
                                 (*VERTICALLY-LONG *WLIKE)))
                            (ALL-FETCH *WIND *WLIKE .... (4)
                                (THERE-IS *WK *WLIKE
                                  (*W-RELATION *WIND *WK))))))
                  (THEN (CONCLUDE P-LABEL B-WINDOW)
                        (FOR-EACH *WIND (AND (MUST-BE *WIND P-LABEL B-WINDOW)
                                              (DONE-FOR *WIND)))
                          (SCORE-IS (ADD 2.1 (DIV (NUMBER-OF *WIND) 100.0)))))))
                    (*PCH *MRGN)]
```

(b) Listing of the to-do rule for "windows" detection

What went wrong?

Appendix-B Complete Listing of the Model

```

<SCENE> knowledge-block-of-scene
  OBJECTS (<SKY> <TREE> <BUILDING> <ROAD> <UNKNOWN>
            <SUB-OBJECTS> <WINDOW> <C-SHADOW>
            KEY-PATCH-1S {(>GREATERP (AREA <PCH>) 300) (<PCH>)}
            PLAN-IMAGE-GENERATION [(DIV (BOUNDARY-LENGTH <PCH>)
                (MULT (R-2-DIFFERENCE <PCH> <PCH>)
                      (BOUNDARY-CONTRAST <PCH> <PCH>))
                (<PCH> <PCH>))

            IF-PLAN-IS-MODIFIED (IF-DONE {
              rule-for-horizon-detection
                (FACT (IF (IS (OF (PLAN-REGIONS) NIL)
                  (ALL-FETCH <PCH> <PLAN-REGIONS>
                    (IF (AND (NOT (PROBABLY ROAD <PCH>))
                      (NOT (PROBABLY HORIZON <PCH>)))
                      (ALL-FETCH <PCH> <PLAN-REGIONS>
                        (IF (AND (MAY-BE ROAD <PCH>)
                          (ABOVE <PCH> <PCH>)
                          (NOT (<SAME-COLOR> <PCH> <PCH>))
                          (FACING HORIZONTALLY <PCH> <PCH>))
                          (MULT (SUB (FACING HORIZONTALLY <PCH> <PCH>) 0.5)
                            (SUB (MIN (ASK-VALUE ROAD <PCH> 8.6)
                              (ASK-VALUE ROAD <PCH> 8.6))
                                (VALUE <PCH> <PCH>)))))))
                    (THEN (MEMO (SCENE) ROAD-ZONE
                      (WITH-MBR-LOW-SIDE <PCH> 256 1 256))
                      (MEMO (SCENE) HORIZON (MBR-LOW-SIDE <PCH>))
                      (EXECUTE PLAN-EVALUATION)) ) ) )
                P-SELECT (TO-DO {
                  rule-for-initial-start
                    (FACT (AND (PROBABLY BUILDING <PCH>) (NOTFOUND BUILDING)))
                  rule-for-tree-occlusion
                    (FACT (AND (DAIRK <PCH> (<UPPER> <PCH>
                      (OR (TOUCHING <PCH> UP-SIDE) (TOUCHING <PCH> SIDE)))
                      (THERE-IS <TR> <REGIONS>
                        (AND (IS (LABEL <TR>) TREE)
                          (ABOVE <PCH> <TR>)
                          (TOUCHING <PCH> <TR>)
                          (<WITH-IN> <PCH> (V-ZONE <TR>)))))))
                    (THEN (CONCLUDE P-LABEL TREE)
                      (CONCLUDE O-MERGE (WITH OCCLUDE <TR> FRAME))
                      (SCORE-1S 1.0)) (<PCH>)

                  rule-for-tree-occlusion
                    (FACT (PROBABLY TREE <PCH>)
                      (THEN (INCLUDE P-LABEL TREE)
                        (SCORE-1S (ASK-VALUE TREE <PCH>))) (<PCH>))

                  P-LABEL (IF-DONE {
                    if-done-rule-to-be-activated-when-keypatch-is-labeled
                      (FACT (NOT (IS (OF PLAN <PCH>) NIL))
                        (THEN (EXECUTE PLAN-EVALUATION)) ) ) )
                  <SKY> knowledge-block-of-sky
                    PROPERTY-RULES {
                      (GEN (NOT (ALDIER <PCH>)) (1.8 . 8.6)) (<PCH>)
                      (GEN (ASHINING <PCH>)) (1.8 . 8.2)) (<PCH>)
                      (GEN (OR (eBLUE <PCH>) (eGRAY <PCH>)) (1.8 . 8.2)) (<PCH>)
                      (GEN (NOT (eTEXTURAL <PCH>)) (1.8 . 8.7)) (<PCH>)
                      (ISTR (TOUCHING <PCH> UP-SIDE) (0.7 . 0.2)) (<PCH>)

                    RELATION-RULES {
                      (ISTR (AND (<L>NEAR-BOUNDARY <PCH> <PCH>2))
                        (IF (<L>NEAR-BOUNDARY (POSITION DOUN <PCH> <PCH>2))
                          (0 . 0.5) FOR SKY (<PCH> <PCH>2))
                          (ISTR (IF (NOT (IS (OF BUILDING-ZONE) NIL))
                            (FUZZY1 (O-RATIO <PCH> (OF BUILDING-ZONE (SCENE))) 0.5 0.9)
                            (0.8 . 0.5) FOR SCENE) (<PCH> <PCH>2))
                          (IF-DONE {
                            (FACT <P> (<P> (THEN (INCLUDE P-LABEL TREE)
                              (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                            P-SELECT (TO-DO {
                              T0-DO {
                                (ACT (MAY-BE SKY <PCH>)
                                  (THEN (SCORE-1S (ADD 2.0 (ASK-VALUE SKY <PCH>))) (<PCH>))
                                  (ACT (AND (IS-PLAN <PCH> <PCH>)
                                    (BRIGHT <PCH>))
                                    (THEN (SCORE-1S 3.0)) (<PCH> <PCH>))
                                    (ACT (<BRIGHT> <PCH> (THEN (SCORE-1S 0.95))) (<PCH>))

                                IF-DONE {
                                  (FACT <P> (<P> (THEN (INCLUDE P-LABEL SKY)
                                    (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                                  P-SELECT (APRIORI-VALUE-1S 8.1)

                                <TREE> knowledge-block-of-tree
                                  MADE-OF (<LEAVES>)
                                  PROPERTY-RULES {
                                    (GEN (eMIDDLE <PCH>)) (0.6 . 0.3)) (<PCH>)
                                    (ISTR (eHEAVY-TEXTURE <PCH>)) (0.8 . 0.2)) (<PCH>)

                                  P-SELECT (TO-DO {
                                    (ACT (MAY-BE TREE <PCH>)
                                      (THEN (SCORE-1S (ADD 2.0 (ASK-VALUE TREE <PCH>))) (<PCH>))
                                      (ACT (AND (IS-PLAN <PCH> <PCH>)
                                        (NOT (eSHINING <PCH>)))
                                          (THEN (SCORE-1S 3.0))) (<PCH> <PCH>))

                                    IF-DONE {
                                      (FACT <P> (<P> (THEN (INCLUDE P-LABEL TREE)
                                        (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                                      P-SELECT (APRIORI-VALUE-1S 8.2)

                                    <ROAD> knowledge-block-of-road
                                      MADE-OF (<ASPHALT> <CONCRETE>)
                                      SUB-OBJECTS (<CAR> <C-SHADOW>)
                                      PROPERTY-RULES {
                                        (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.4)) (<PCH>)
                                        (IGER (<L>HORIZONTAL-LONG <PCH>)) (0.7 . 0.2)) (<PCH>)
                                        (ISTR (TOUCHING <PCH> <PCH>2)) (0.9 . 0.2)) (<PCH> <PCH>2)

                                      RELATION-RULES {
                                        (ISTR (AND (<S>AME-COLOR <PCH> <PCH>2) (TOUCHING <PCH> <PCH>2)))
                                          (0.5 . 0.2) FOR ROAD (<PCH> <PCH>2))
                                          (GEN (IF (NOT (IS (OF HORIZON (SCENE)) NIL)
                                            (O-RATIO <PCH> (OF ROAD-ZONE (SCENE))) 1.0 . 0.3)
                                            (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))
                                          (IF-DONE {
                                            (FACT <P> (<P> (THEN (INCLUDE P-LABEL ROAD)
                                              (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                                            P-SELECT (APRIORI-VALUE-1S 8.2)

                                          <BUILDING> knowledge-block-of-building
                                            MADE-OF (<CONCRETE> <ATILE> <BRICK>)
                                            SUB-OBJECTS (<B-WINDOW>)

                                            PROPERTY-RULES {
                                              (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.3)) (<PCH>)
                                              (ISTR (eMANHOLE <PCH>)) (0.6 . 0.2)) (<PCH>)
                                              (IGEN (<L>HOLELINE <PCH>)) (0.9 . 0.5)) (<PCH>)

                                            RELATION-RULES {
                                              (GEN (AND (<L>NEAR-BOUNDARY <PCH> <PCH>2))
                                                (IF (<L>NEAR-BOUNDARY <P> NOT (POSITION UP <PCH> <PCH>2)))
                                                  (0.8 . 0.4) FOR SKY) (<PCH> <PCH>2))
                                              (ISTR (IF (NOT (IS (OF BUILDING-ZONE) (SCENE)) NIL)
                                                (AND (O-RATIO <PCH> (OF BUILDING-ZONE (SCENE))) 0.5 . 0.3)
                                                (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))

                                              P-SELECT (TO-DO {
                                                T0-DO {
                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                    (THERE-IS <BL> <REGIONS>
                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                        (NOT (IS (OF SHAPE VIEW (OBJECT <BL>)) 1))
                                                        (IS (OF ADJACENT OBJECT <BL>)) NIL)
                                                        (ODIFFERENT-ZONE <PCH> <BL>)))
                                                       (THEN (CONCLUDE P-LABEL BUILDING)
                                                         (CONCLUDE O-MERGE (WITH ADJACENT <BL>))
                                                         (SCORE-1S (ADD 0.6 (ASK-VALUE BUILDING <PCH>)))) (<PCH>)

                                                rule-for-build-ing-occlusion
                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                    (THERE-IS <BL> <REGIONS>
                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                        (SAME-ZONE <PCH> <BL>)
                                                        (<SAME-COLOR> <PCH> <BL>)
                                                        (THERE-IS <BL> <REGIONS>
                                                          (AND (IS (LABEL <BL>) BUILDING)
                                                            (NOT (IS (OF SHAPE VIEW (OBJECT <BL>)) 1))
                                                            (IS (OF ADJACENT <BL>))
                                                            (AND (BETWEEN <PCH> <BL>)
                                                              (OR (IS (LABEL <BL>) TREE)
                                                                (AND (IS (LABEL <BL>) BUILDING)
                                                                  (NOT (IS (OBJECT <BL>)
                                                                    (OBJECT <PCH>)))))))
                                                       (THEN (CONCLUDE P-LABEL BUILDING)
                                                         (CONCLUDE O-MERGE (WITH OCCLUDE <BL> (REGION <BL>)))
                                                         (SCORE-1S (ADD 1.0 (ASK-VALUE BUILDING <PCH>)))) (<PCH>)

                                                rule-for-build-ing-occlusion
                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                    (THERE-IS <BL> <REGIONS>
                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                        (SAME-ZONE <PCH> <BL>)
                                                        (<SAME-COLOR> <PCH> <BL>)
                                                        (THERE-IS <BL> <REGIONS>
                                                          (AND (IS (LABEL <BL>) BUILDING)
                                                            (NOT (IS (OBJECT <BL>)
                                                              (OBJECT <PCH>)))))))
                                                       (THEN (GET-SET <APLET> (<PCH> <PCH> PATCHES)
                                                         (AND (ALL-FETCH <BL> <APLET>)
                                                           (IS (SAME-ZONE <BL> <PCH>))
                                                           (VERTICALLY-LONG <BL> <PCH>)
                                                           (CONTACT <BL> <PCH>)))
                                                       (APLET <PCH> <PCH>)

                                                rule-for-window-detection
                                                  (FACT (IF (AND (P-MAY-BE-BUILDING <PCH>)
                                                    (THERE-IS <BL> <REGIONS>
                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                        (VERTICALLY-LONG <BL> <PCH>))
                                                        (CONTACT <BL> <PCH>)))
                                                       (THEN (GET-SET <APLET> (<PCH> <PCH> PATCHES)
                                                         (AND (ALL-FETCH <BL> <APLET>)
                                                           (IS (SAME-ZONE <BL> <PCH>))
                                                           (VERTICALLY-LONG <BL> <PCH>)
                                                           (CONTACT <BL> <PCH>)))
                                                       (APLET <PCH> <PCH>)

                                                P-SELECT (TO-DO {
                                                  T0-DO {
                                                    (FACT (AND (IS-PLAN <PCH> <PCH>)
                                                      (GANE-ZONE <PCH> <PCH>))
                                                       (FOR-EACH <WIND> (AND (MUST-BE <WIND> P-LABEL B-WINDOW)
                                                         (ONE-FOR <WIND>)))
                                                       (SCORE-1S (ADD 2.1 (DIV (NUMBER OF <WIND>) 100.0)))) (<PCH> <PCH>)

                                                    (FACT (AND (IS-PLAN <PCH> <PCH>)
                                                      (GANE-ZONE <PCH> <PCH>))
                                                       (CONCLUDE P-LABEL BUILDING)
                                                       (CONCLUDE R-MERGE <PCH>)
                                                       (SCORE-1S 2.0)) (<PCH> <PCH>)

                                                    O-MERGE (IF-DONE {
                                                      (FACT <P> (<P> (DESCRIBE-BUILDING (REGION <PCH>))) (<PCH>)) )

                                                    O-CREATE (IF-DONE {
                                                      (FACT <P> (<P> (THEN (EXTRACT-BUILDING-SHAPE (REGION <PCH>))
                                                        (DESCRIBE-BUILDING (REGION <PCH>))
                                                        (EXECUTE PLAN-EVALUATION)) ) (<PCH>)) )

                                                    APRIORI-VALUE-1S 8.2

                                                <ROAD> knowledge-block-of-road
                                                  MADE-OF (<ASPHALT> <CONCRETE>)
                                                  SUB-OBJECTS (<CAR> <C-SHADOW>)
                                                  PROPERTY-RULES {
                                                    (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.4)) (<PCH>)
                                                    (IGER (<L>HORIZONTAL-LONG <PCH>)) (0.7 . 0.2)) (<PCH>)
                                                    (ISTR (TOUCHING <PCH> <PCH>2)) (0.9 . 0.2)) (<PCH> <PCH>2)

                                                  RELATION-RULES {
                                                    (ISTR (AND (<S>AME-COLOR <PCH> <PCH>2) (TOUCHING <PCH> <PCH>2)))
                                                      (0.5 . 0.2) FOR ROAD (<PCH> <PCH>2))
                                                      (GEN (IF (NOT (IS (OF HORIZON (SCENE)) NIL)
                                                        (O-RATIO <PCH> (OF ROAD-ZONE (SCENE))) 1.0 . 0.3)
                                                        (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))
                                                      (IF-DONE {
                                                        (FACT <P> (<P> (THEN (INCLUDE P-LABEL ROAD)
                                                          (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                                                          P-SELECT (APRIORI-VALUE-1S 8.2)

                                                        <BUILDING> knowledge-block-of-building
                                                          MADE-OF (<CONCRETE> <ATILE> <BRICK>)
                                                          SUB-OBJECTS (<B-WINDOW>)

                                                          PROPERTY-RULES {
                                                            (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.3)) (<PCH>)
                                                            (ISTR (eMANHOLE <PCH>)) (0.6 . 0.2)) (<PCH>)
                                                            (IGEN (<L>HOLELINE <PCH>)) (0.9 . 0.5)) (<PCH>)

                                                          RELATION-RULES {
                                                            (GEN (AND (<L>NEAR-BOUNDARY <PCH> <PCH>2))
                                                              (IF (<L>NEAR-BOUNDARY <P> NOT (POSITION UP <PCH> <PCH>2)))
                                                                (0.8 . 0.4) FOR SKY) (<PCH> <PCH>2))
                                                              (ISTR (IF (NOT (IS (OF BUILDING-ZONE) (SCENE)) NIL)
                                                                (AND (O-RATIO <PCH> (OF BUILDING-ZONE (SCENE))) 0.5 . 0.3)
                                                                (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))

                                                              P-SELECT (TO-DO {
                                                                T0-DO {
                                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                                    (THERE-IS <BL> <REGIONS>
                                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                                        (NOT (IS (OF SHAPE VIEW (OBJECT <BL>)) 1))
                                                                        (IS (OF ADJACENT OBJECT <BL>)) NIL)
                                                                        (ODIFFERENT-ZONE <PCH> <BL>)))
                                                                     (THEN (CONCLUDE P-LABEL BUILDING)
                                                                       (CONCLUDE O-MERGE (WITH ADJACENT <BL>))
                                                                       (SCORE-1S (ADD 0.6 (ASK-VALUE BUILDING <PCH>)))) (<PCH>)

                                                                rule-for-build-ing-occlusion
                                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                                    (THERE-IS <BL> <REGIONS>
                                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                                        (SAME-ZONE <PCH> <BL>)
                                                                        (<SAME-COLOR> <PCH> <BL>)
                                                                        (THERE-IS <BL> <REGIONS>
                                                                          (AND (IS (LABEL <BL>) BUILDING)
                                                                            (NOT (IS (OBJECT <BL>)
                                                                              (OBJECT <PCH>)))))))
                                                                     (THEN (CONCLUDE P-LABEL BUILDING)
                                                                       (CONCLUDE O-MERGE (WITH OCCLUDE <BL> (REGION <BL>)))
                                                                       (SCORE-1S (ADD 1.0 (ASK-VALUE BUILDING <PCH>)))) (<PCH>)

                                                                rule-for-build-ing-occlusion
                                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                                    (THERE-IS <BL> <REGIONS>
                                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                                        (SAME-ZONE <PCH> <BL>)
                                                                        (<SAME-COLOR> <PCH> <BL>)
                                                                        (THERE-IS <BL> <REGIONS>
                                                                          (AND (IS (LABEL <BL>) BUILDING)
                                                                            (NOT (IS (OBJECT <BL>)
                                                                              (OBJECT <PCH>)))))))
                                                                     (THEN (GET-SET <APLET> (<PCH> <PCH> PATCHES)
                                                                       (AND (ALL-FETCH <BL> <APLET>)
                                                                         (IS (SAME-ZONE <BL> <PCH>))
                                                                         (VERTICALLY-LONG <BL> <PCH>)
                                                                         (CONTACT <BL> <PCH>)))
                                                                     (APLET <PCH> <PCH>)

                                                                rule-for-window-detection
                                                                  (FACT (IF (AND (P-MAY-BE-BUILDING <PCH>)
                                                                    (THERE-IS <BL> <REGIONS>
                                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                                        (VERTICALLY-LONG <BL> <PCH>))
                                                                        (CONTACT <BL> <PCH>)))
                                                                     (THEN (GET-SET <APLET> (<PCH> <PCH> PATCHES)
                                                                       (AND (ALL-FETCH <BL> <APLET>)
                                                                         (IS (SAME-ZONE <BL> <PCH>))
                                                                         (VERTICALLY-LONG <BL> <PCH>)
                                                                         (CONTACT <BL> <PCH>)))
                                                                       (APLET <PCH> <PCH>)

                                                                P-SELECT (TO-DO {
                                                                  T0-DO {
                                                                    (FACT (AND (IS-PLAN <PCH> <PCH>)
                                                                      (GANE-ZONE <PCH> <PCH>))
                                                                       (FOR-EACH <WIND> (AND (MUST-BE <WIND> P-LABEL B-WINDOW)
                                                                         (ONE-FOR <WIND>)))
                                                                       (SCORE-1S (ADD 2.1 (DIV (NUMBER OF <WIND>) 100.0)))) (<PCH> <PCH>)

                                                                    (FACT (AND (IS-PLAN <PCH> <PCH>)
                                                                      (GANE-ZONE <PCH> <PCH>))
                                                                       (CONCLUDE P-LABEL BUILDING)
                                                                       (CONCLUDE R-MERGE <PCH>)
                                                                       (SCORE-1S 2.0)) (<PCH> <PCH>)

                                                                    O-MERGE (IF-DONE {
                                                                      (FACT <P> (<P> (DESCRIBE-BUILDING (REGION <PCH>))) (<PCH>)) )

                                                                    O-CREATE (IF-DONE {
                                                                      (FACT <P> (<P> (THEN (EXTRACT-BUILDING-SHAPE (REGION <PCH>))
                                                                        (DESCRIBE-BUILDING (REGION <PCH>))
                                                                        (EXECUTE PLAN-EVALUATION)) ) (<PCH>)) )

                                                                    APRIORI-VALUE-1S 8.2

                                                                <ROAD> knowledge-block-of-road
                                                                  MADE-OF (<ASPHALT> <CONCRETE>)
                                                                  SUB-OBJECTS (<CAR> <C-SHADOW>)
                                                                  PROPERTY-RULES {
                                                                    (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.4)) (<PCH>)
                                                                    (IGER (<L>HORIZONTAL-LONG <PCH>)) (0.7 . 0.2)) (<PCH>)
                                                                    (ISTR (TOUCHING <PCH> <PCH>2)) (0.9 . 0.2)) (<PCH> <PCH>2)

                                                                  RELATION-RULES {
                                                                    (ISTR (AND (<S>AME-COLOR <PCH> <PCH>2) (TOUCHING <PCH> <PCH>2)))
                                                                      (0.5 . 0.2) FOR ROAD (<PCH> <PCH>2))
                                                                      (GEN (IF (NOT (IS (OF HORIZON (SCENE)) NIL)
                                                                        (O-RATIO <PCH> (OF ROAD-ZONE (SCENE))) 1.0 . 0.3)
                                                                        (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))
                                                                      (IF-DONE {
                                                                        (FACT <P> (<P> (THEN (INCLUDE P-LABEL ROAD)
                                                                          (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                                                                          P-SELECT (APRIORI-VALUE-1S 8.2)

                                                                        <BUILDING> knowledge-block-of-building
                                                                          MADE-OF (<CONCRETE> <ATILE> <BRICK>)
                                                                          SUB-OBJECTS (<B-WINDOW>)

                                                                          PROPERTY-RULES {
                                                                            (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.3)) (<PCH>)
                                                                            (ISTR (eMANHOLE <PCH>)) (0.6 . 0.2)) (<PCH>)
                                                                            (IGEN (<L>HOLELINE <PCH>)) (0.9 . 0.5)) (<PCH>)

                                                                          RELATION-RULES {
                                                                            (GEN (AND (<L>NEAR-BOUNDARY <PCH> <PCH>2))
                                                                              (IF (<L>NEAR-BOUNDARY <P> NOT (POSITION UP <PCH> <PCH>2)))
                                                                                (0.8 . 0.4) FOR SKY) (<PCH> <PCH>2))
                                                                              (ISTR (IF (NOT (IS (OF BUILDING-ZONE) (SCENE)) NIL)
                                                                                (AND (O-RATIO <PCH> (OF BUILDING-ZONE (SCENE))) 0.5 . 0.3)
                                                                                (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))

                                                                              P-SELECT (TO-DO {
                                                                                T0-DO {
                                                                                  (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                                                    (THERE-IS <BL> <REGIONS>
                                                                                      (AND (IS (LABEL <BL>) BUILDING)
                                                                                        (NOT (IS (OF SHAPE VIEW (OBJECT <BL>)) 1))
                                                                                        (IS (OF ADJACENT OBJECT <BL>)) NIL)
                                                                                        (ODIFFERENT-ZONE <PCH> <BL>)))
                                                                                     (THEN (CONCLUDE P-LABEL BUILDING)
                                                                                       (CONCLUDE O-MERGE (WITH ADJACENT <BL>))
                                                                                       (SCORE-1S (ADD 0.6 (ASK-VALUE BUILDING <PCH>)))) (<PCH>)

                                                                              rule-for-build-ing-occlusion
                                                                                (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                                                  (THERE-IS <BL> <REGIONS>
                                                                                    (AND (IS (LABEL <BL>) BUILDING)
                                                                                      (SAME-ZONE <PCH> <BL>)
                                                                                      (<SAME-COLOR> <PCH> <BL>)
                                                                                      (THERE-IS <BL> <REGIONS>
                                                                                        (AND (IS (LABEL <BL>) BUILDING)
                                                                                            (NOT (IS (OBJECT <BL>)
                                                                                              (OBJECT <PCH>)))))))
                                                                                   (THEN (CONCLUDE P-LABEL BUILDING)
                                                                                     (CONCLUDE O-MERGE (WITH OCCLUDE <BL> (REGION <BL>)))
                                                                                     (SCORE-1S (ADD 1.0 (ASK-VALUE BUILDING <PCH>)))) (<PCH>)

                                                                              rule-for-build-ing-occlusion
                                                                                (FACT (AND (P-MAY-BE-BUILDING <PCH>)
                                                                                  (THERE-IS <BL> <REGIONS>
                                                                                    (AND (IS (LABEL <BL>) BUILDING)
                                                                                      (SAME-ZONE <PCH> <BL>)
                                                                                      (<SAME-COLOR> <PCH> <BL>)
                                                                                      (THERE-IS <BL> <REGIONS>
                                                                                        (AND (IS (LABEL <BL>) BUILDING)
                                                                                            (NOT (IS (OBJECT <BL>)
                                                                                              (OBJECT <PCH>)))))))
                                                                                   (THEN (GET-SET <APLET> (<PCH> <PCH> PATCHES)
                                                                                     (AND (ALL-FETCH <BL> <APLET>)
                                                                                       (IS (SAME-ZONE <BL> <PCH>))
                                                                                       (VERTICALLY-LONG <BL> <PCH>)
                                                                                       (CONTACT <BL> <PCH>)))
                                                                                   (APLET <PCH> <PCH>)

                                                                              rule-for-window-detection
                                                                                (FACT (IF (AND (P-MAY-BE-BUILDING <PCH>)
                                                                                  (THERE-IS <BL> <REGIONS>
                                                                                    (AND (IS (LABEL <BL>) BUILDING)
                                                                                      (VERTICALLY-LONG <BL> <PCH>))
                                                                                      (CONTACT <BL> <PCH>)))
                                                                                 (THEN (GET-SET <APLET> (<PCH> <PCH> PATCHES)
                                                                                   (AND (ALL-FETCH <BL> <APLET>)
                                                                                     (IS (SAME-ZONE <BL> <PCH>))
                                                                                     (VERTICALLY-LONG <BL> <PCH>)
                                                                                     (CONTACT <BL> <PCH>)))
                                                                                   (APLET <PCH> <PCH>)

                                                                              P-SELECT (TO-DO {
                                                                                T0-DO {
                                                                                  (FACT (AND (IS-PLAN <PCH> <PCH>)
                                                                                    (GANE-ZONE <PCH> <PCH>))
                                                                                     (FOR-EACH <WIND> (AND (MUST-BE <WIND> P-LABEL B-WINDOW)
                                                                                       (ONE-FOR <WIND>)))
                                                                                     (SCORE-1S (ADD 2.1 (DIV (NUMBER OF <WIND>) 100.0)))) (<PCH> <PCH>)

                                                                                  (FACT (AND (IS-PLAN <PCH> <PCH>)
                                                                                    (GANE-ZONE <PCH> <PCH>))
                                                                                     (CONCLUDE P-LABEL BUILDING)
                                                                                     (CONCLUDE R-MERGE <PCH>)
                                                                                     (SCORE-1S 2.0)) (<PCH> <PCH>)

                                                                                  O-MERGE (IF-DONE {
                                                                                    (FACT <P> (<P> (DESCRIBE-BUILDING (REGION <PCH>))) (<PCH>)) )

                                                                                  O-CREATE (IF-DONE {
                                                                                    (FACT <P> (<P> (THEN (EXTRACT-BUILDING-SHAPE (REGION <PCH>))
                                                                                      (DESCRIBE-BUILDING (REGION <PCH>))
                                                                                      (EXECUTE PLAN-EVALUATION)) ) (<PCH>)) )

                                                                                  APRIORI-VALUE-1S 8.2

                                                                              <ROAD> knowledge-block-of-road
                                                                                MADE-OF (<ASPHALT> <CONCRETE>)
                                                                                SUB-OBJECTS (<CAR> <C-SHADOW>)
                                                                                PROPERTY-RULES {
                                                                                  (IGER (<L>NEAR-BOUNDARY <PCH>)) (0.5 . 0.4)) (<PCH>)
                                                                                  (IGER (<L>HORIZONTAL-LONG <PCH>)) (0.7 . 0.2)) (<PCH>)
                                                                                  (ISTR (TOUCHING <PCH> <PCH>2)) (0.9 . 0.2)) (<PCH> <PCH>2)

                                                                                RELATION-RULES {
                                                                                  (ISTR (AND (<S>AME-COLOR <PCH> <PCH>2) (TOUCHING <PCH> <PCH>2)))
                                                                                    (0.5 . 0.2) FOR ROAD (<PCH> <PCH>2))
                                                                                    (GEN (IF (NOT (IS (OF HORIZON (SCENE)) NIL)
                                                                                      (O-RATIO <PCH> (OF ROAD-ZONE (SCENE))) 1.0 . 0.3)
                                                                                      (0.8 . 0.3) FOR SCENE) (<PCH> <PCH>2))
                                                                                    (IF-DONE {
                                                                                      (FACT <P> (<P> (THEN (INCLUDE P-LABEL ROAD)
                                                                                        (CONCLUDE R-MERGE (MASTER <PCH>)) (<PCH>)) )
                                                                                      P-SELECT (APRIORI-VALUE-1S 8.2)

                                                                                      <BUILDING> knowledge-block-of-building
                        
```

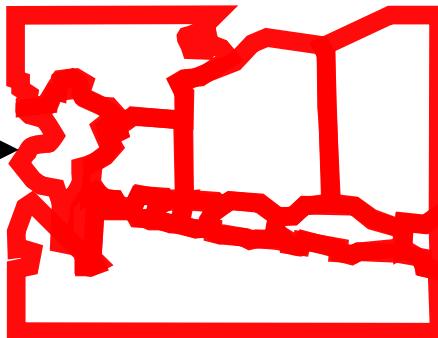
The Age of Segmentation

in Theory

Input Image



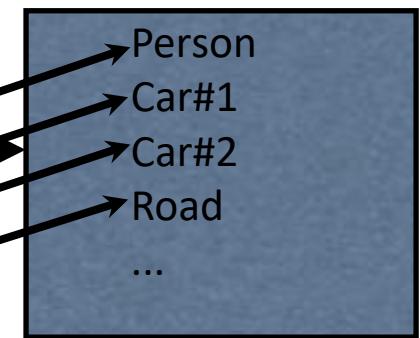
Boundaries



Segmentation



Recognition



in Practice

Input Image



Edges



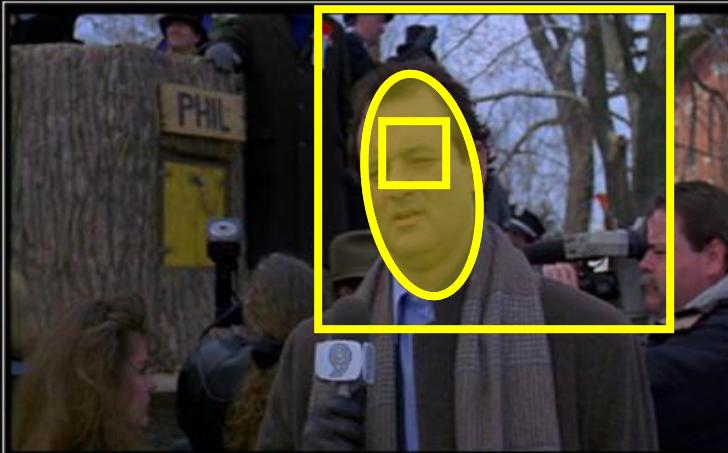
Segmentation



Recognition



Spatial Support

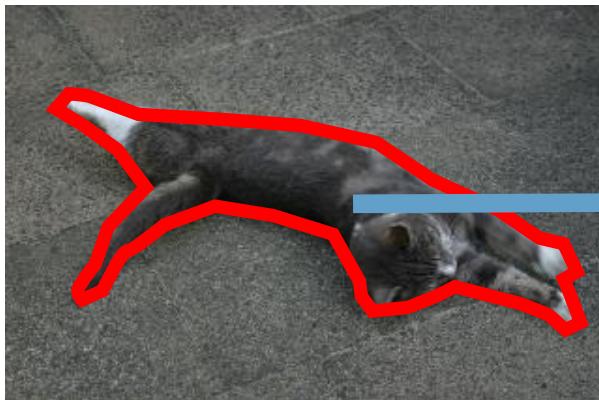


model

- Spatial Support
 - Which pixels to include?
- Similarity Metric
 - Which statistics to compute?

Surprising Result: second will get easier, if we make progress on the first

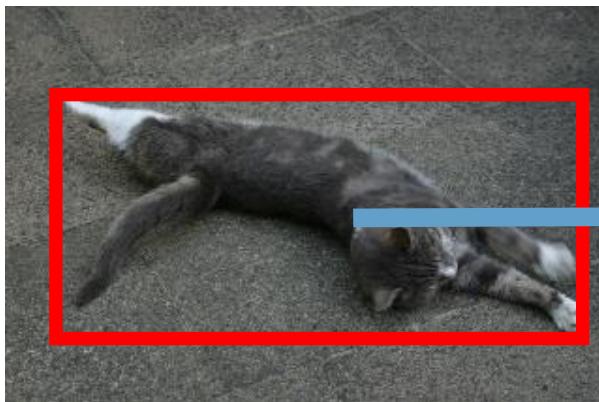
Does Spatial Support Matter?



Ground-Truth Segment

Classify

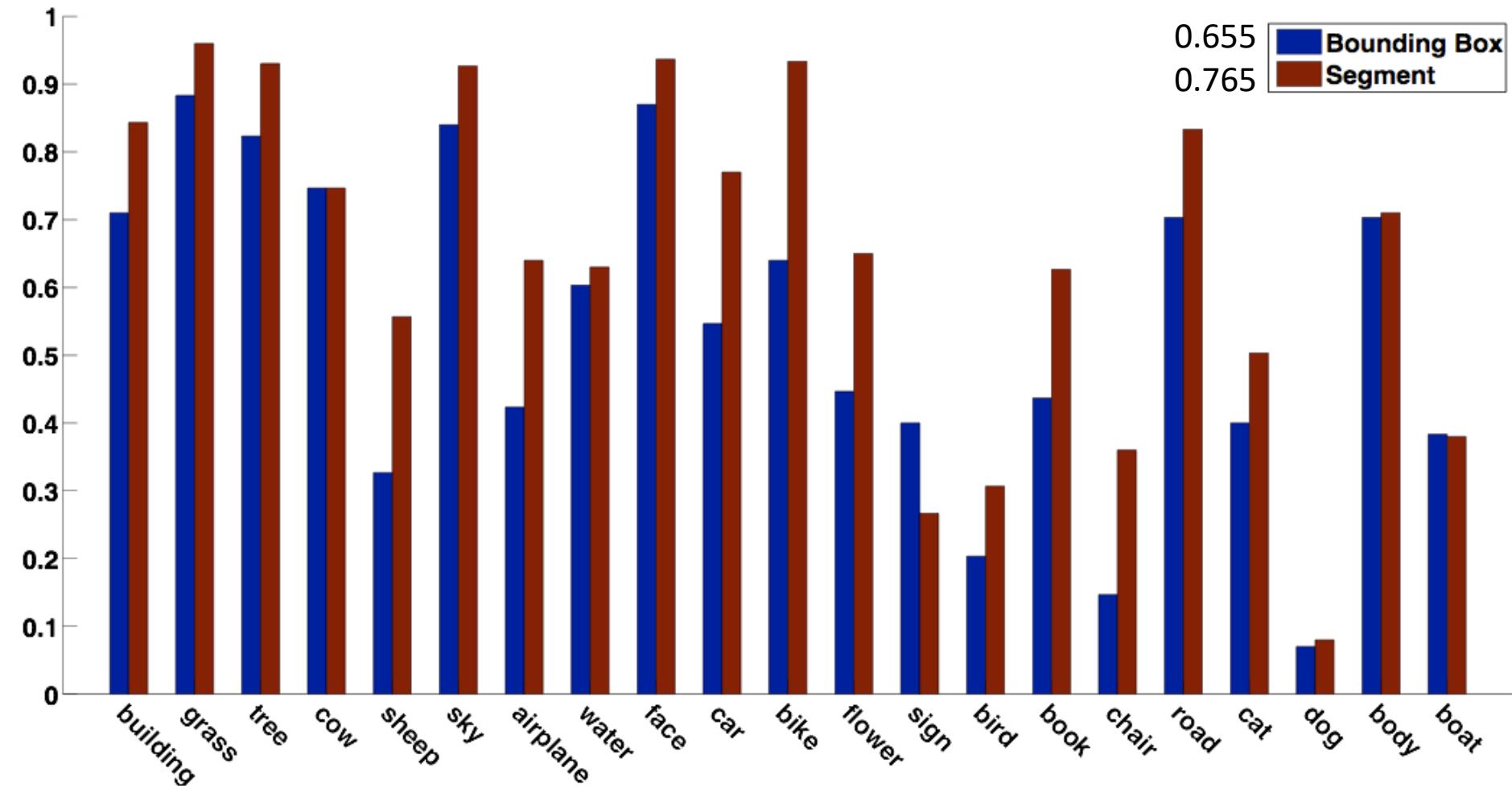
VS.



Bounding Box

Classify

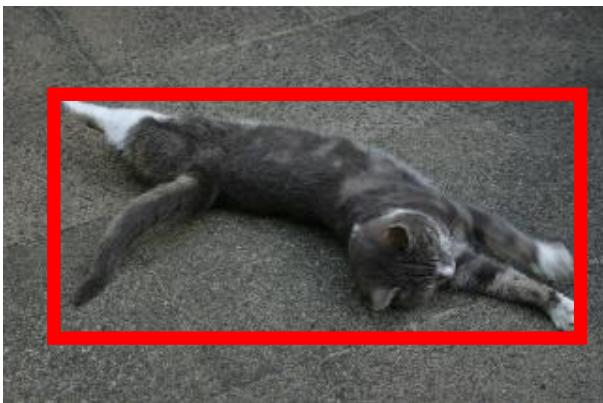
Spatial Support Matters!





Ground-Truth Segment

VS.



Bounding Box

Gestalt psychology or gestaltism

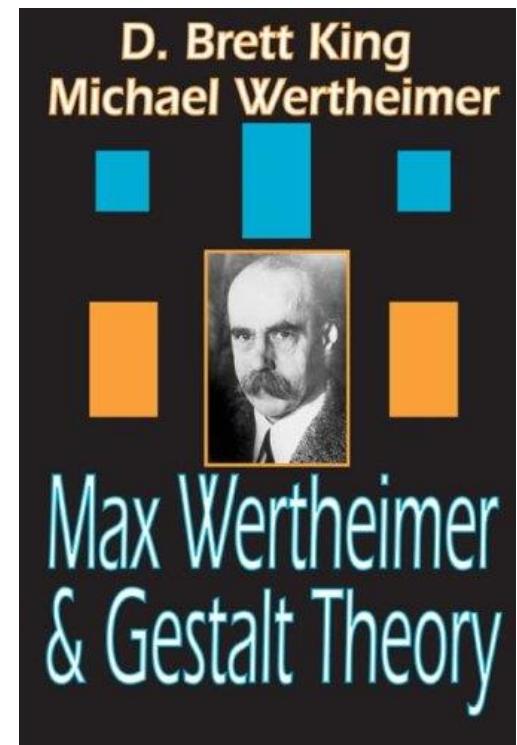
German: *Gestalt* - "form" or "whole"

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



JOAN STEINER

LOOK-ALIKES JR.



Compositionality

"The whole is different from its parts"

-- Kurt Koffka

Principles of perceptual organization



Not grouped



Proximity



Similarity



Similarity



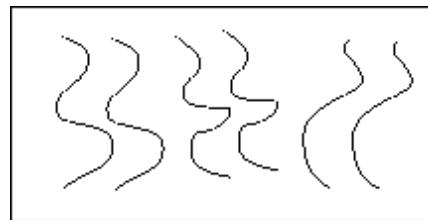
Common Fate



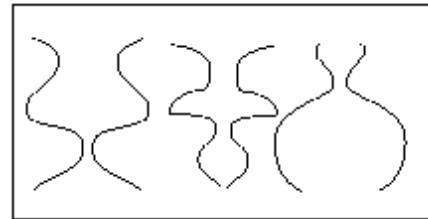
Common Region



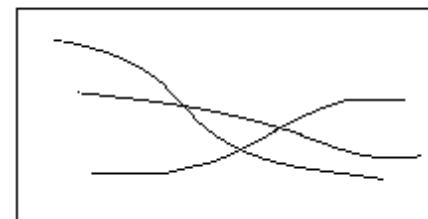
Principles of perceptual organization



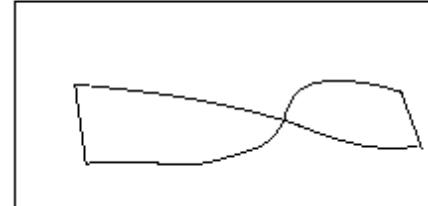
Parallelism



Symmetry



Continuity



Closure

Similarity



Slide credit: Kristen Grauman

http://chicagoist.com/attachments/chicagoist_alicia/GEESE.jpg, http://www.delivery.superstock.com/WI/223/1532/PreviewComp/SuperStock_1532R-0831.jpg

Symmetry



Common fate

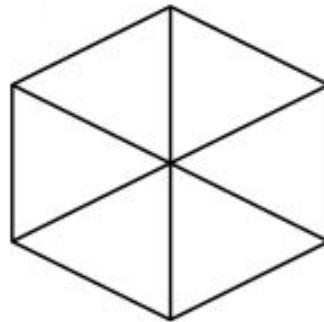


Image credit: Arthus-Bertrand (via F. Durand)

Proximity

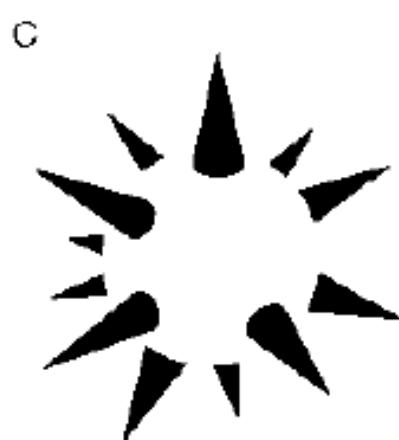
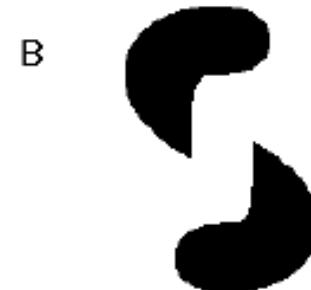
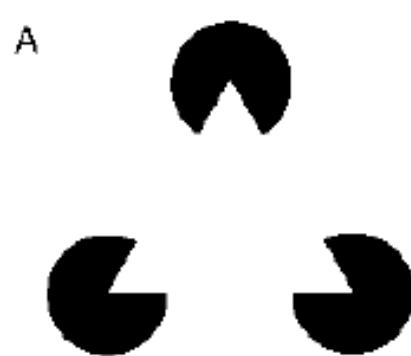


Gestaltists do not believe in coincidence

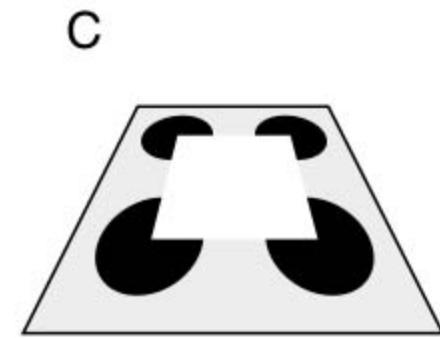
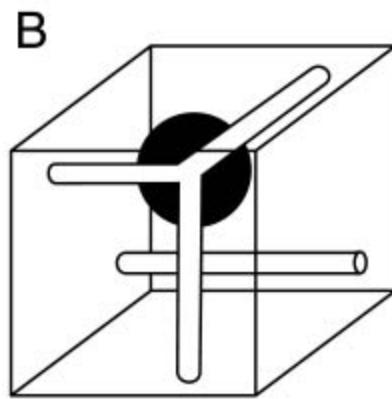
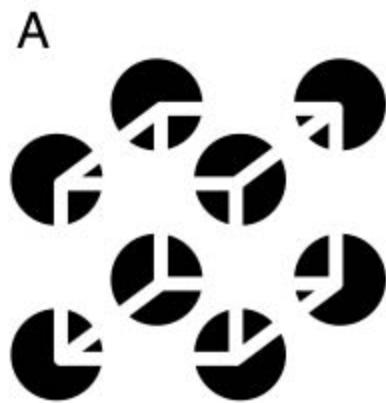


- A A cube with lines connecting the midpoints of opposite edges, forming a smaller cube inside.
- B A cube with lines connecting the midpoints of adjacent edges, forming a central cross shape.
- C A cube with lines connecting the midpoints of opposite edges, forming a smaller cube inside.
- D A cube with lines connecting opposite vertices, forming a star-like pattern.

Grouping by invisible completion



Grouping involves global interpretation



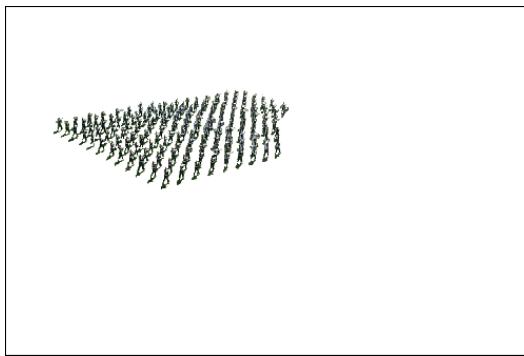
Emergence



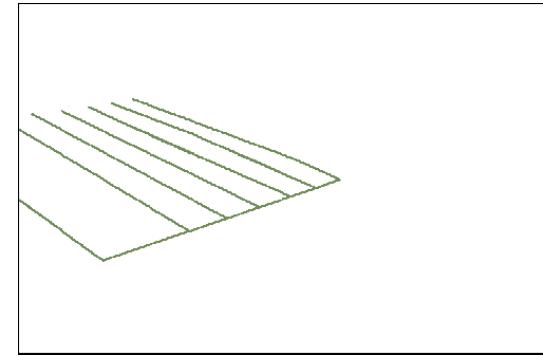
Segmentation is not an aim in itself – it's a result of image understanding!



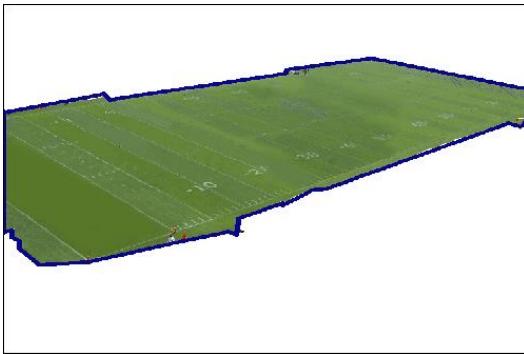
input image



point process



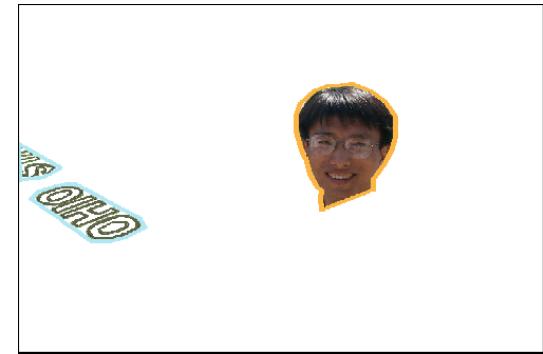
curve process



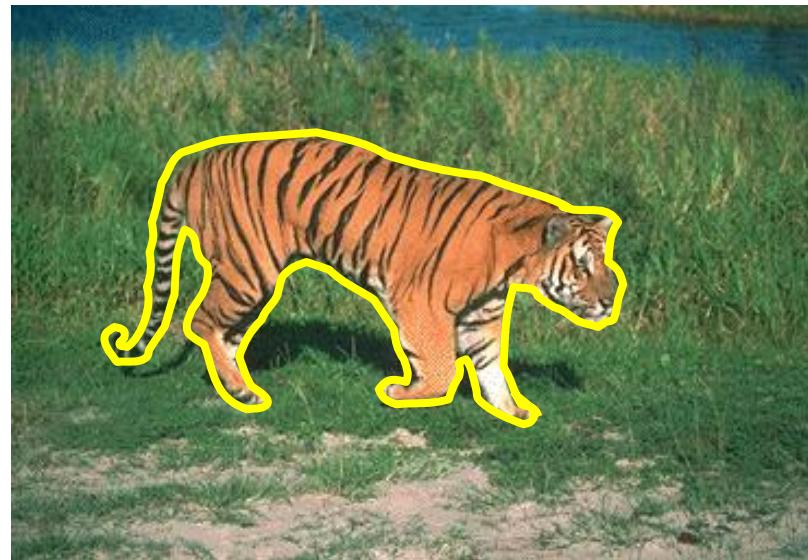
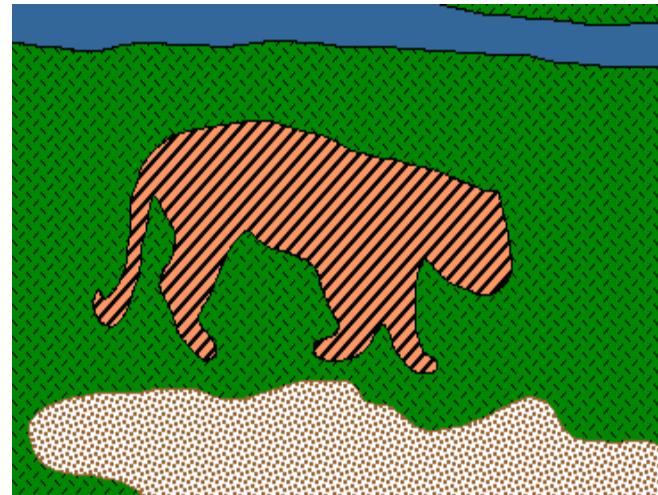
a color region



texture regions



objects



What's wrong with K-means or EM?

Similarity and dissimilarity

- Which colors are *similar*?



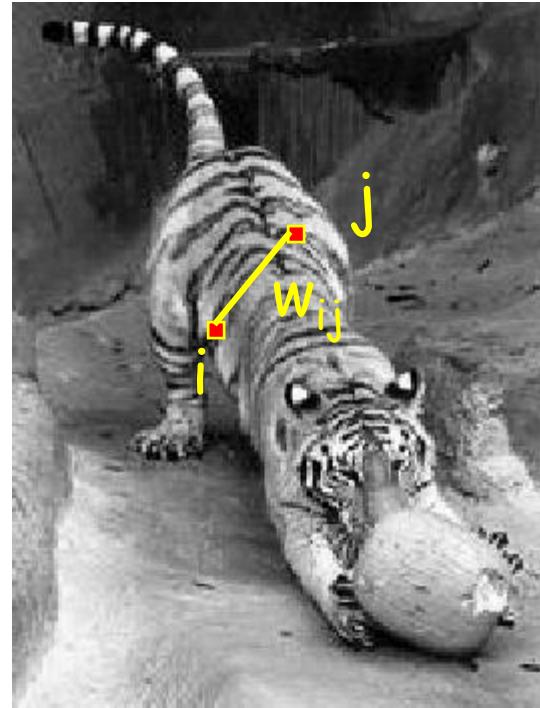
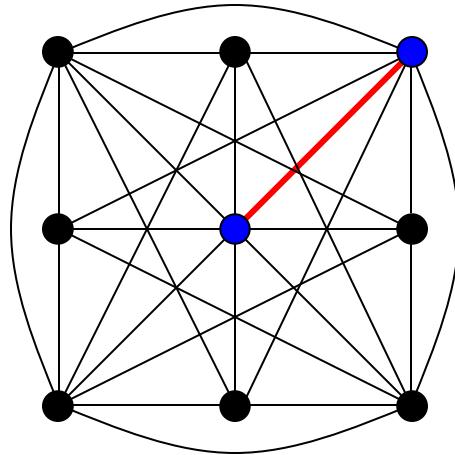
3/6/2003 Which ones are *dissimilar*?
Image Segmentation

Similarity and dissimilarity

- Similarity:
- comparable properties:
 - brightness, color, texture, motion
- Dissimilarity:
- changes in properties
 - edges, motion discontinuities



Graph-based segmentation

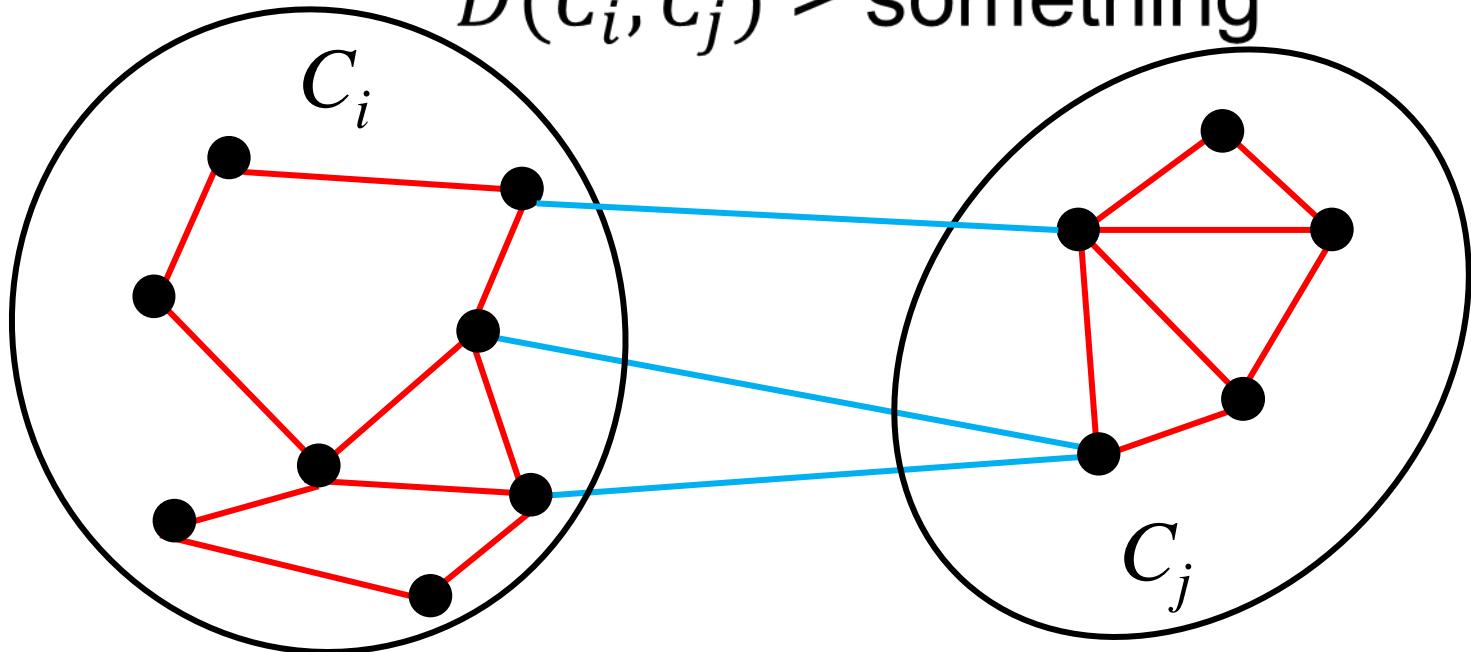


- **Node** = pixel
- **Edge** = pair of neighboring pixels
- **Edge weight** = similarity or dissimilarity of the respective nodes

$$D(C_i, C_j) = \min_{\{a \in C_i, b \in C_j\}} w(a, b)$$

Don't merge if:

$D(C_i, C_j) > \text{something}$



- Idea:
 - Iteratively merge subgraphs (starting with initially nodes) if the edge(s) between them are “weak” enough.
 - Question: How to evaluate the strength of edges between subgraphs



$$w(v_i, v_j) = |f_i - f_j|$$

$$f = [r \ g \ b \ x \ y]$$

$$\sigma = 0.8, k = 300$$

Superpixels

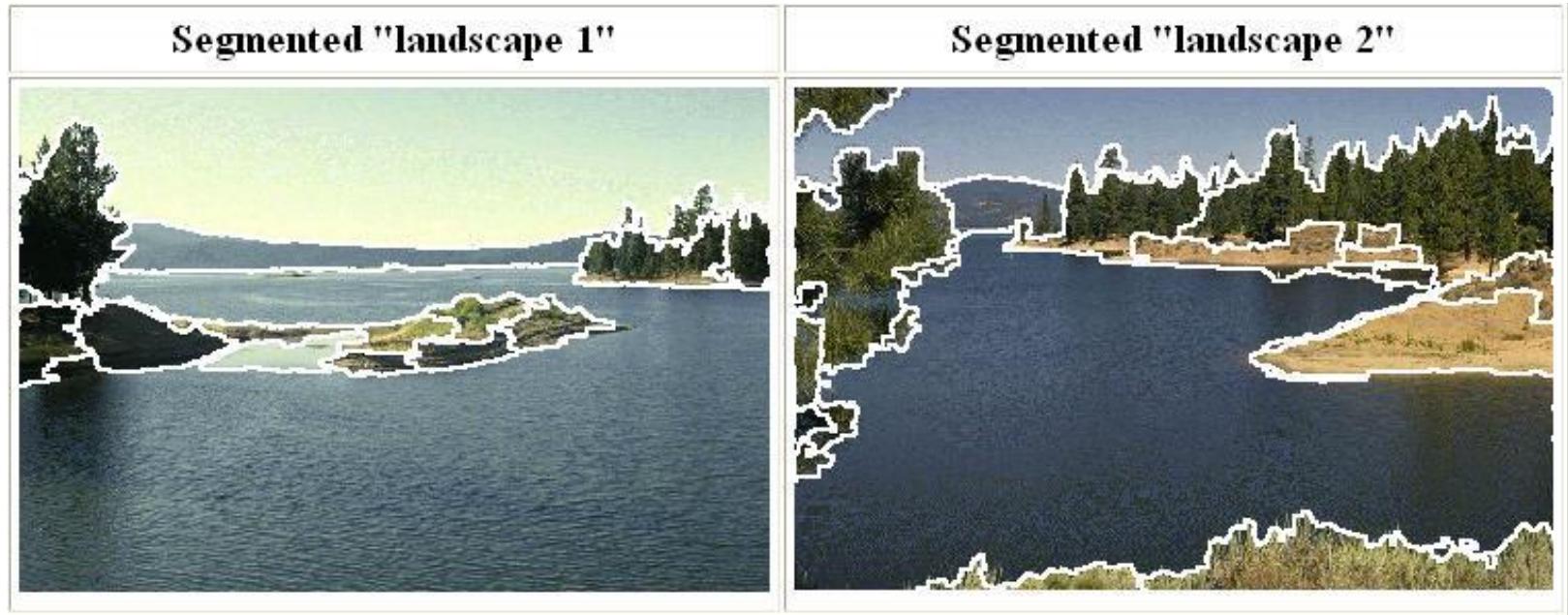


[GS04] Graph-based segmentation

[NC05] Normalized cuts

Mean shift clustering and segmentation

- An advanced and versatile technique for clustering-based segmentation



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

D. Comaniciu and P. Meer, [Mean Shift: A Robust Approach toward Feature Space Analysis](#), PAMI 2002.

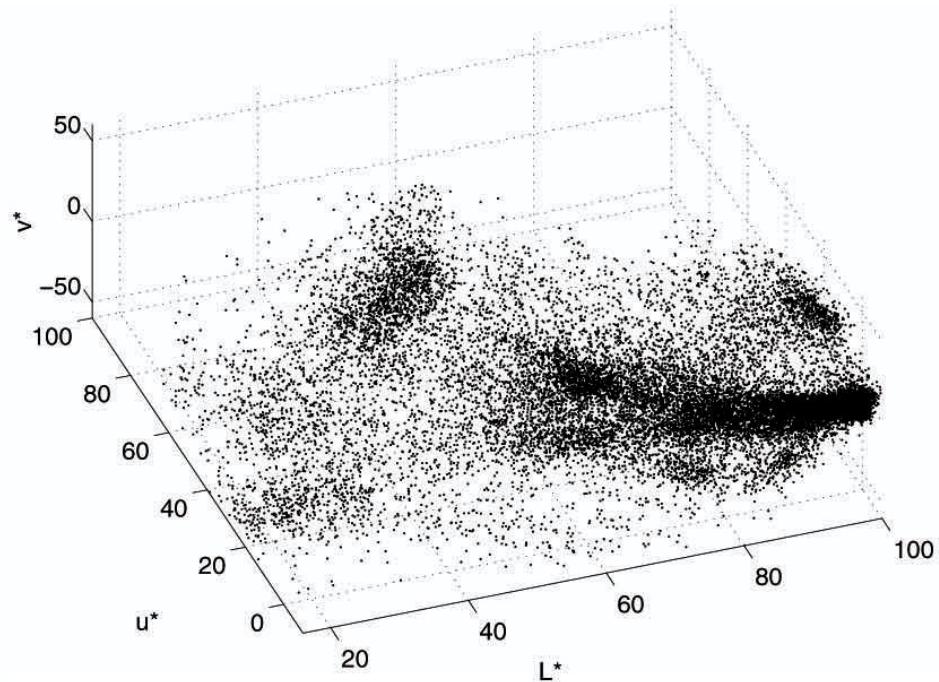
Mean shift algorithm

- The mean shift algorithm seeks *modes* or local maxima of density in the feature space

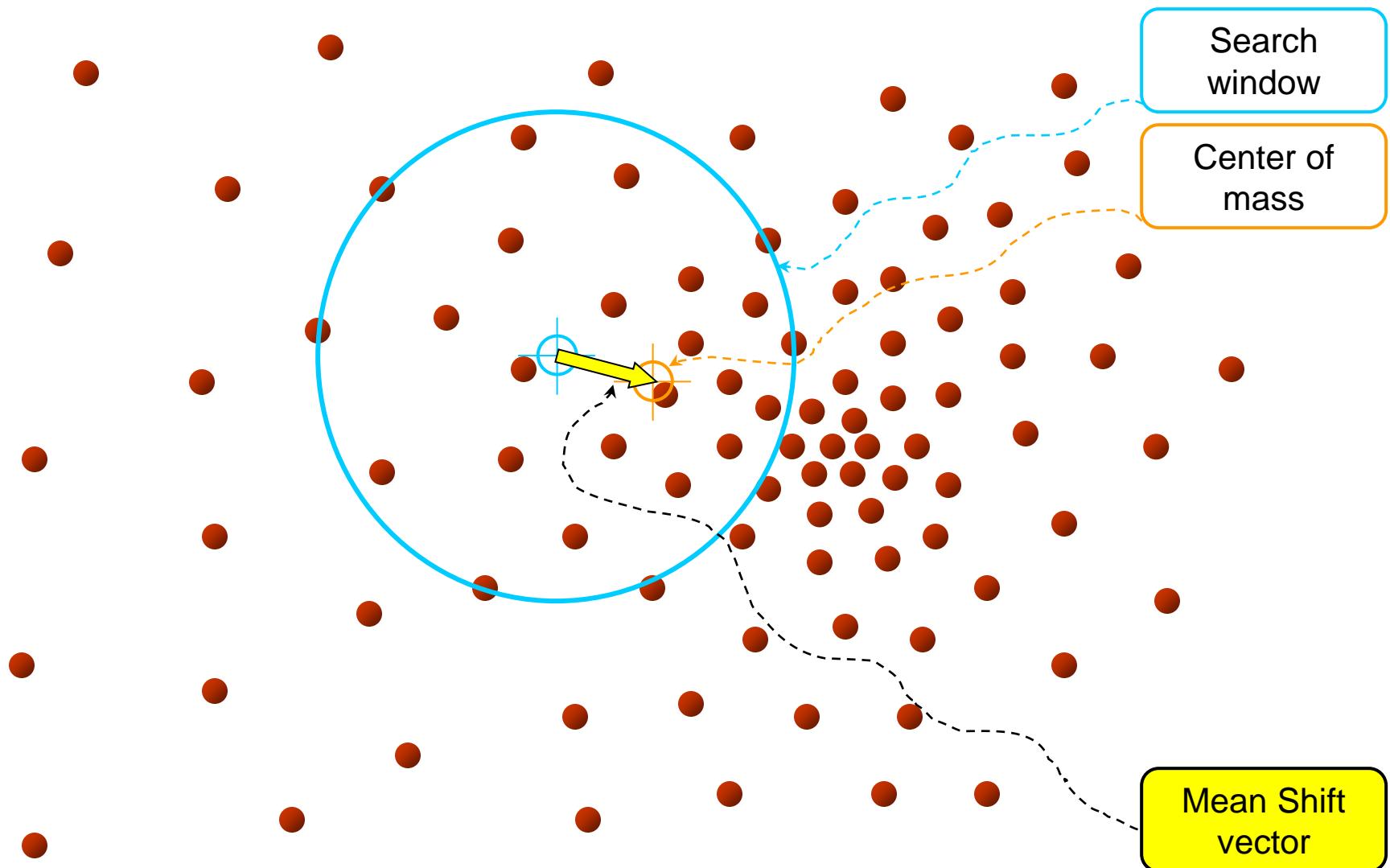
image



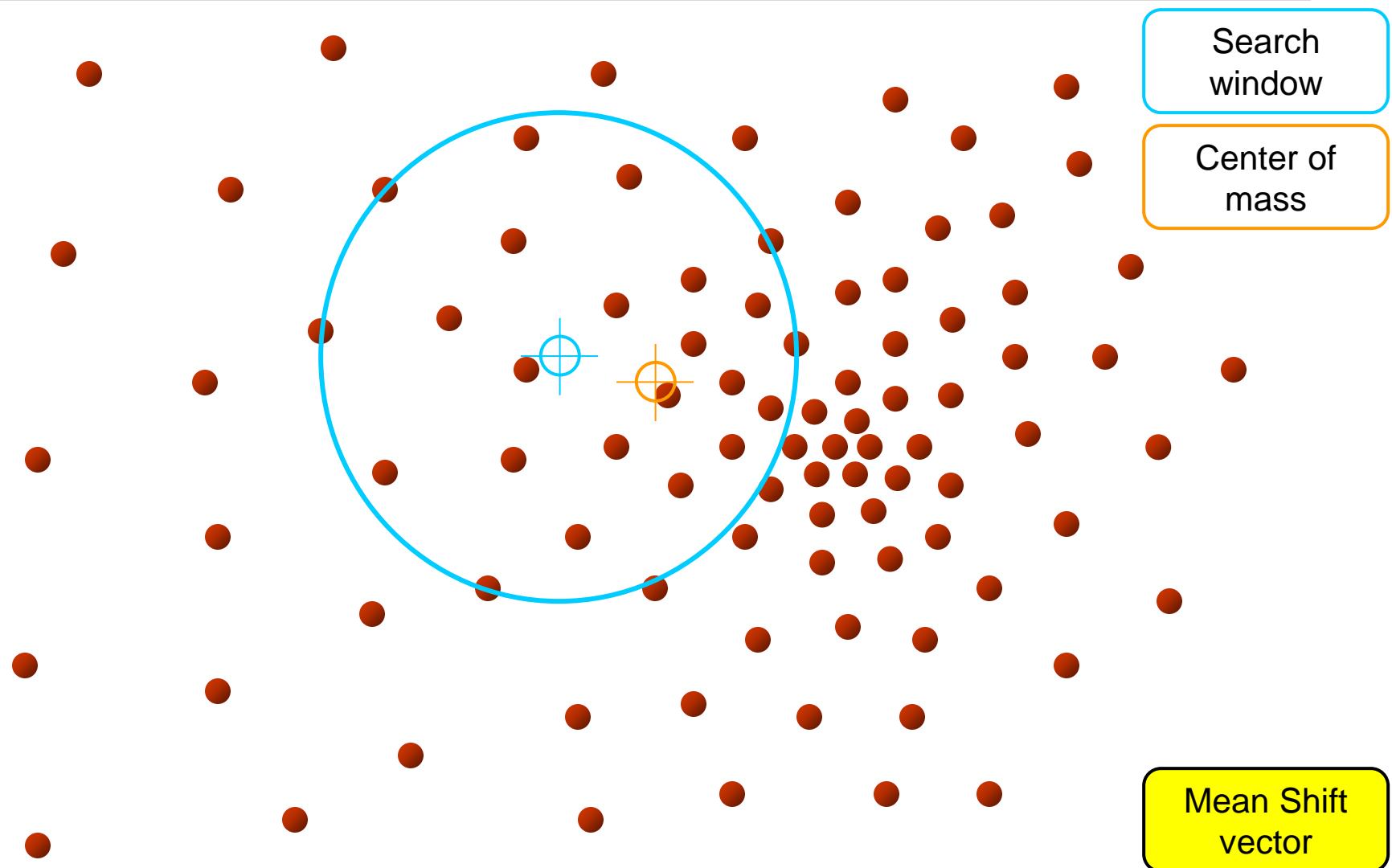
Feature space
($L^*u^*v^*$ color values)



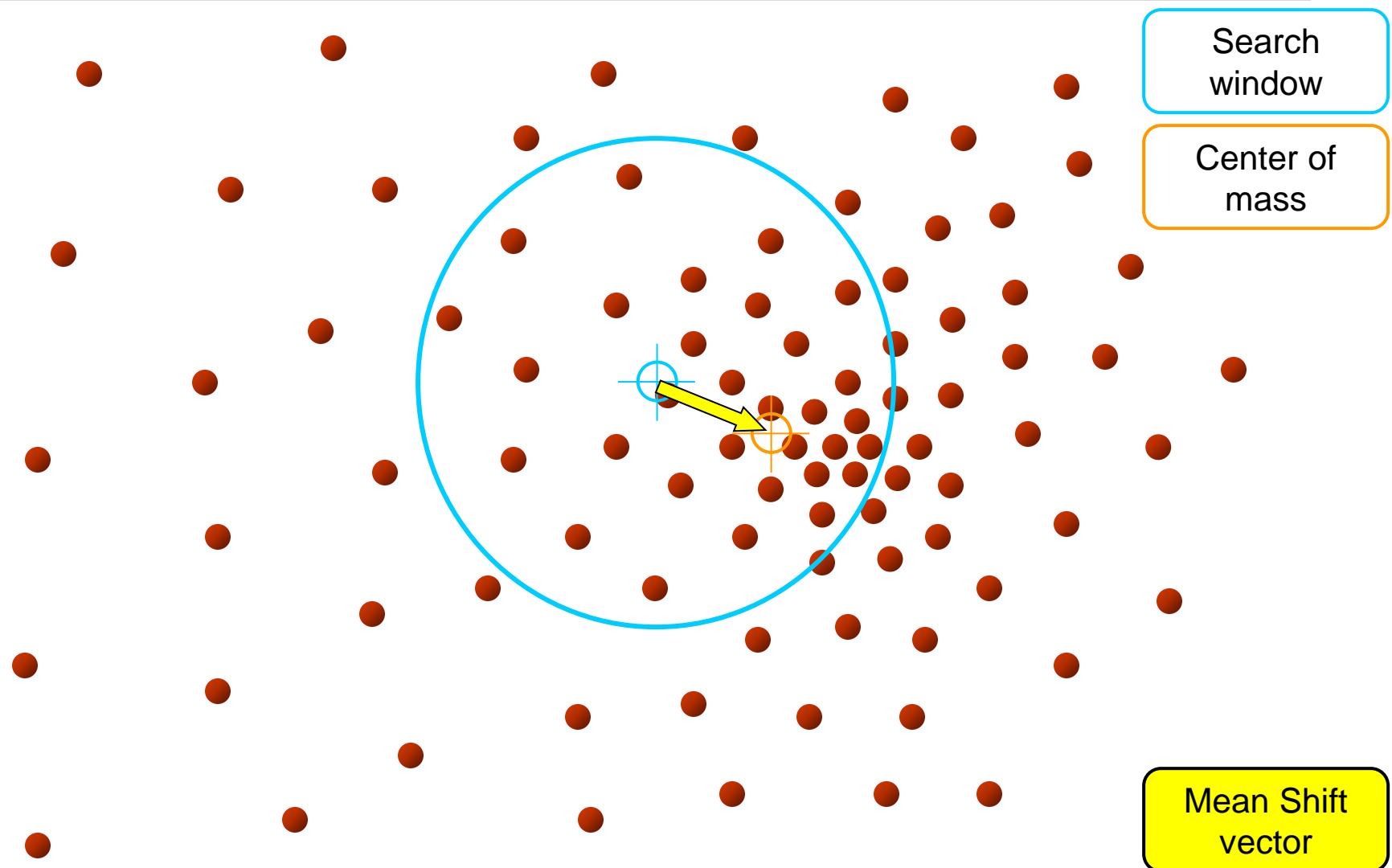
Mean shift



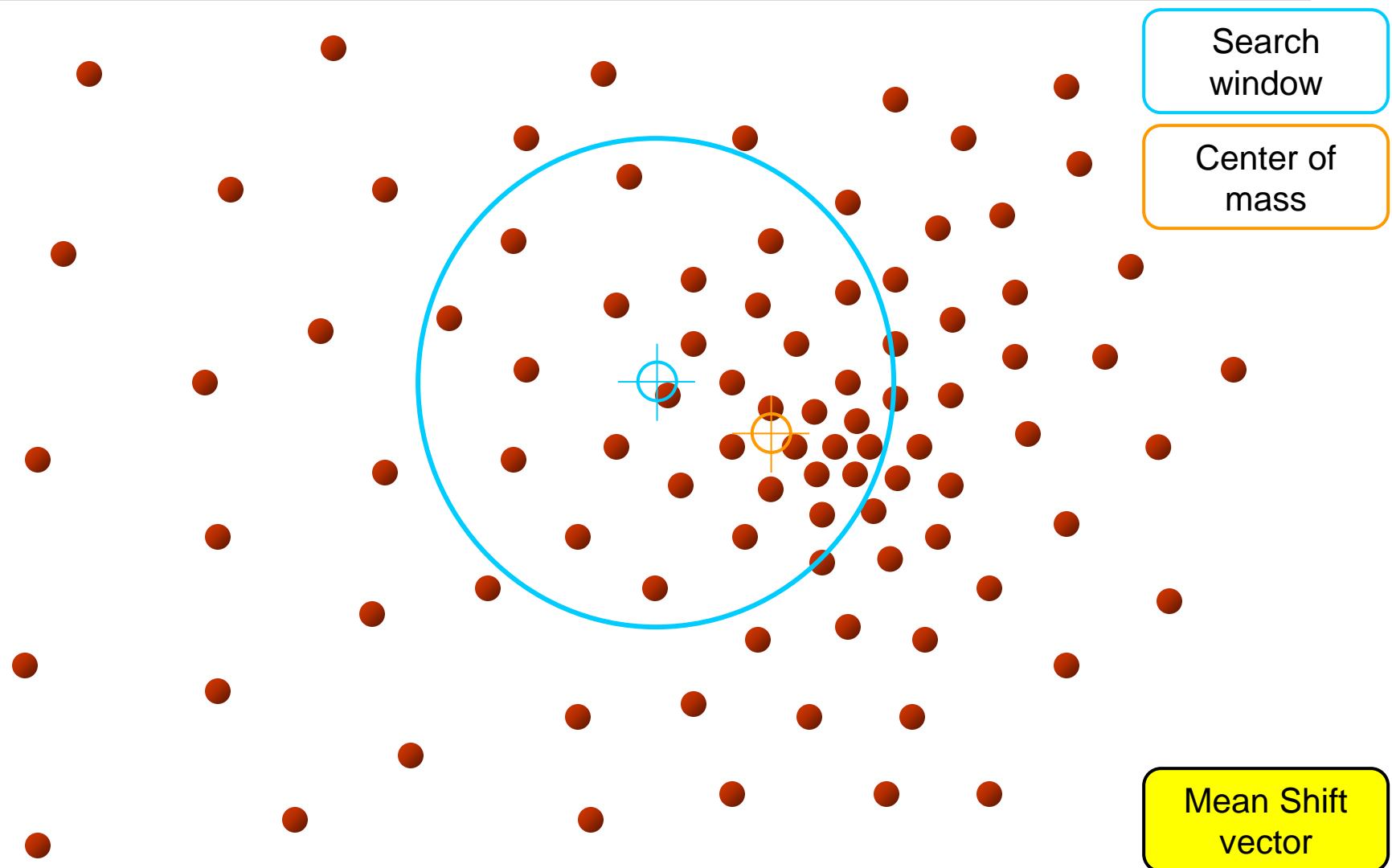
Mean shift



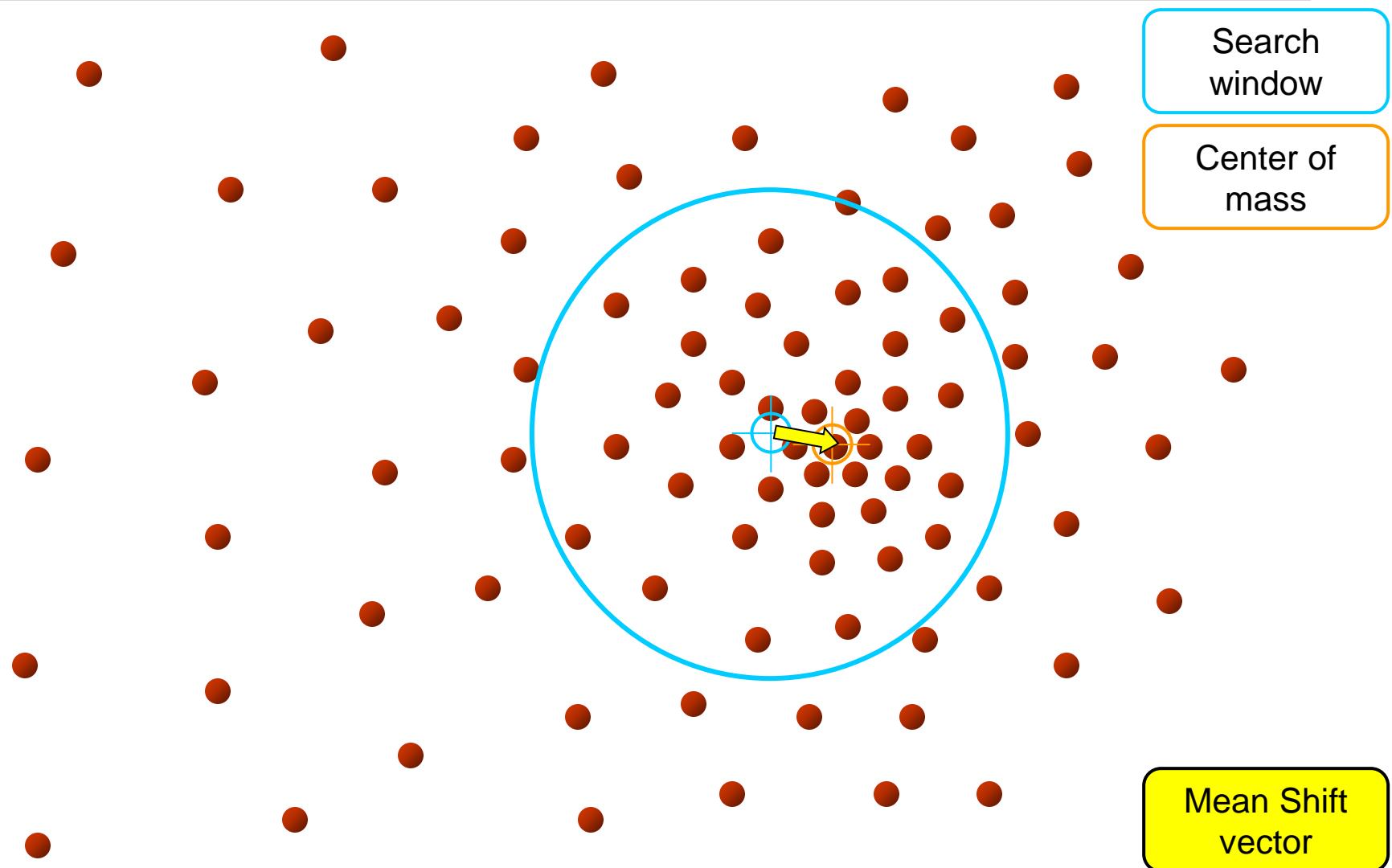
Mean shift



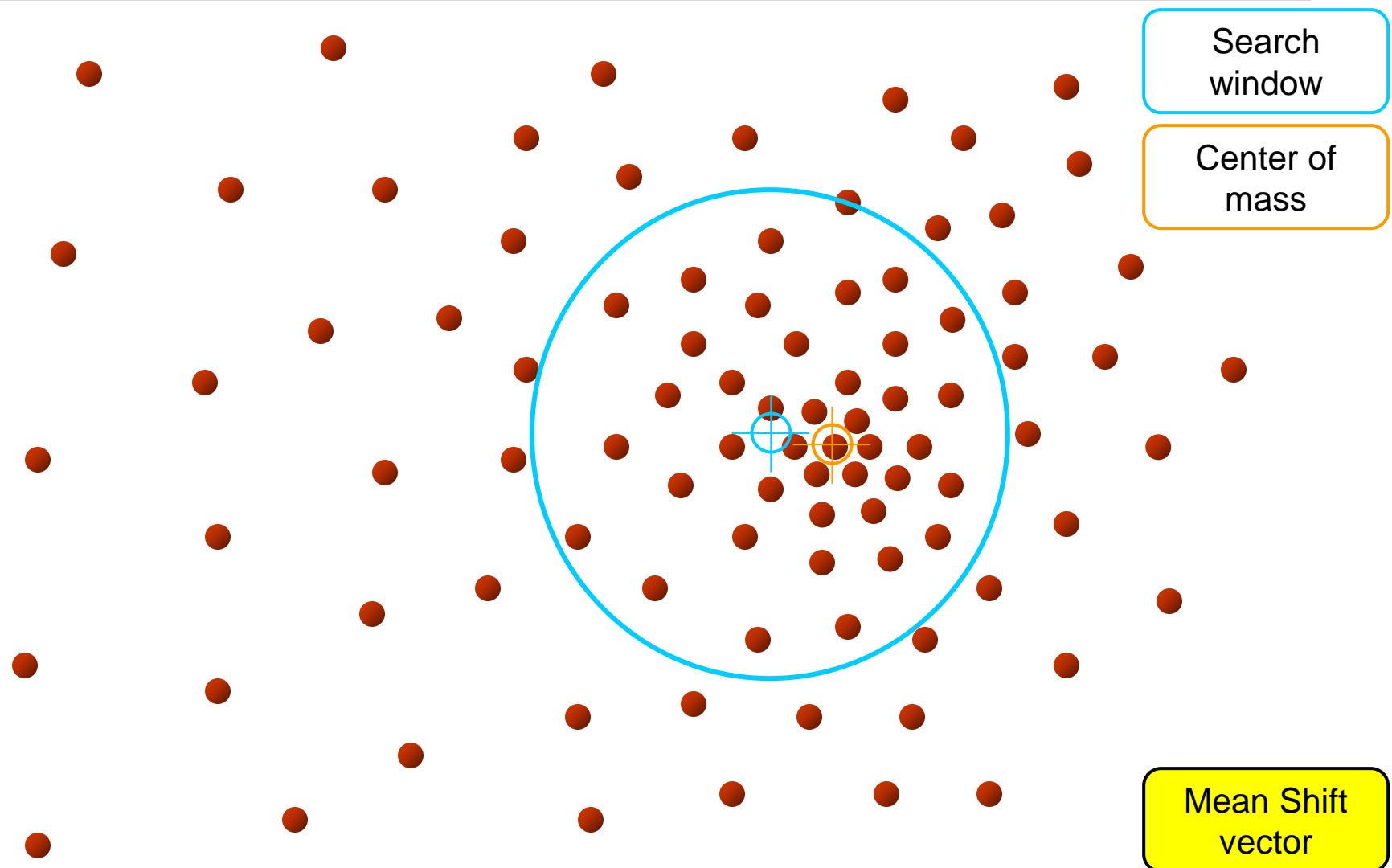
Mean shift



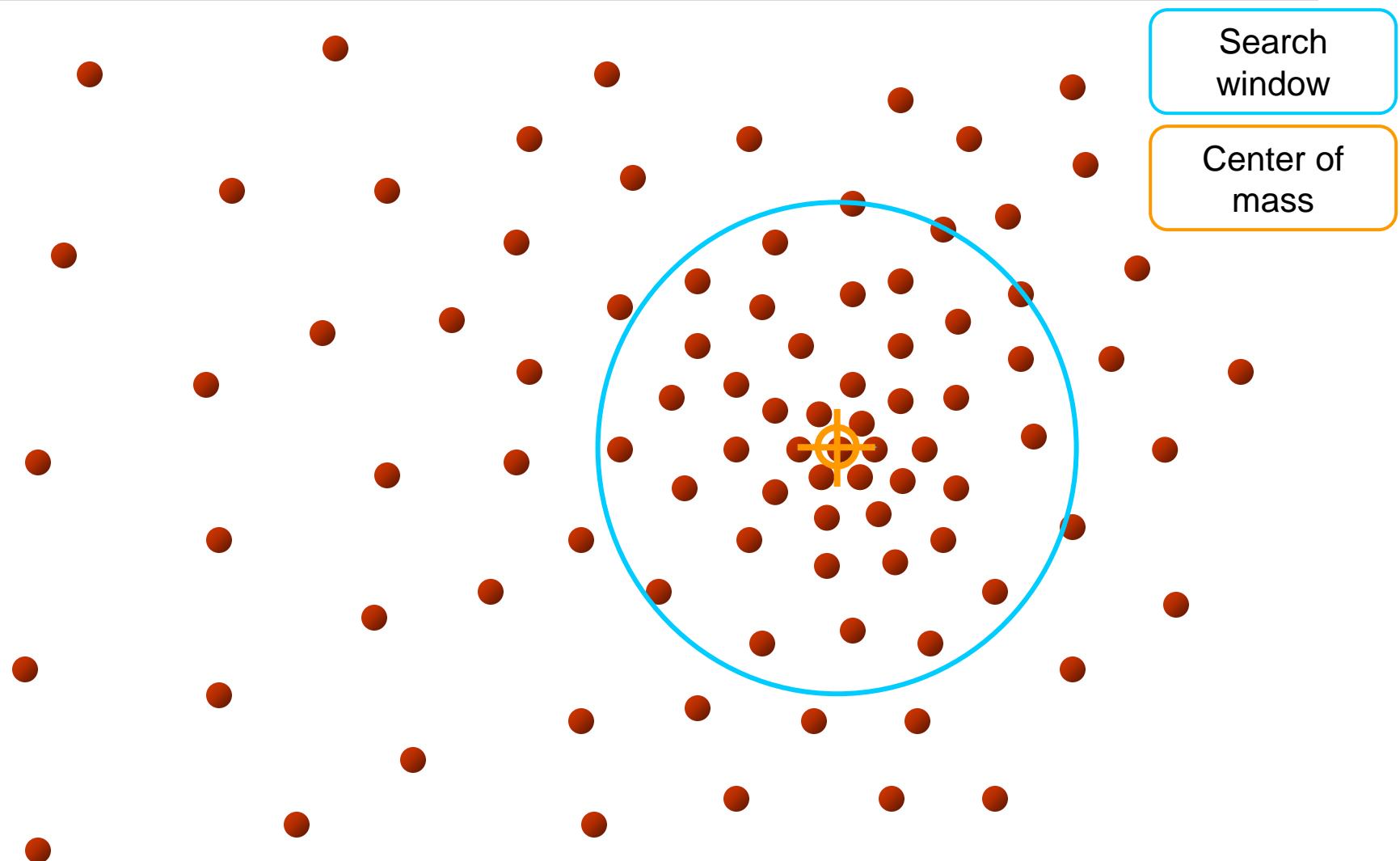
Mean shift



Mean shift

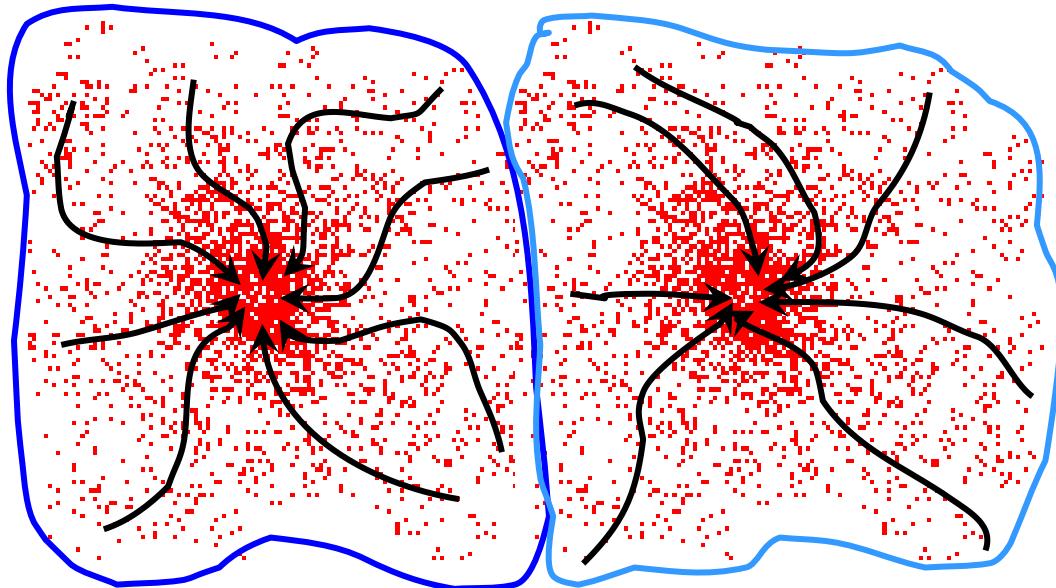


Mean shift



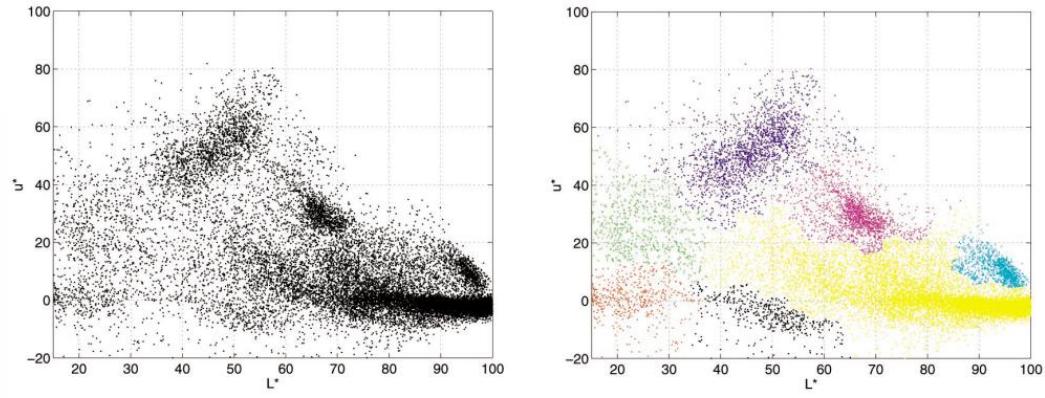
Mean shift clustering

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



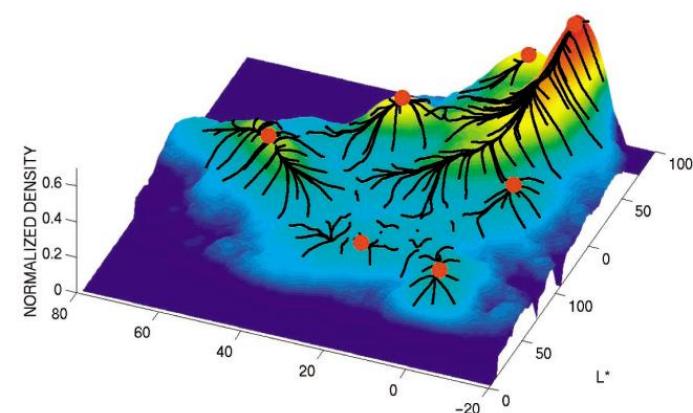
Mean shift clustering/segmentation

- Find features (color, gradients, texture, etc)
- Initialize windows at individual feature points
- Perform mean shift for each window until convergence
- Merge windows that end up near the same “peak” or mode



(a)

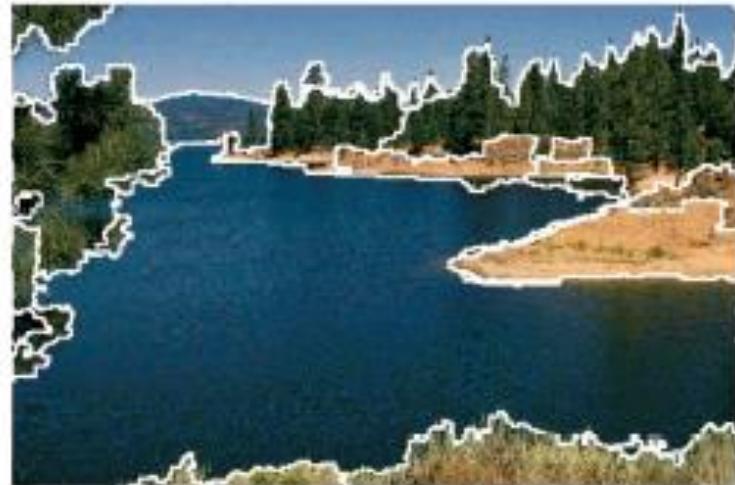
(b)



Mean shift segmentation results



Mean shift segmentation results



Segmentation: Spectral Graph Techniques

Exploiting global constraints: Image Segmentation as Graph Partitioning

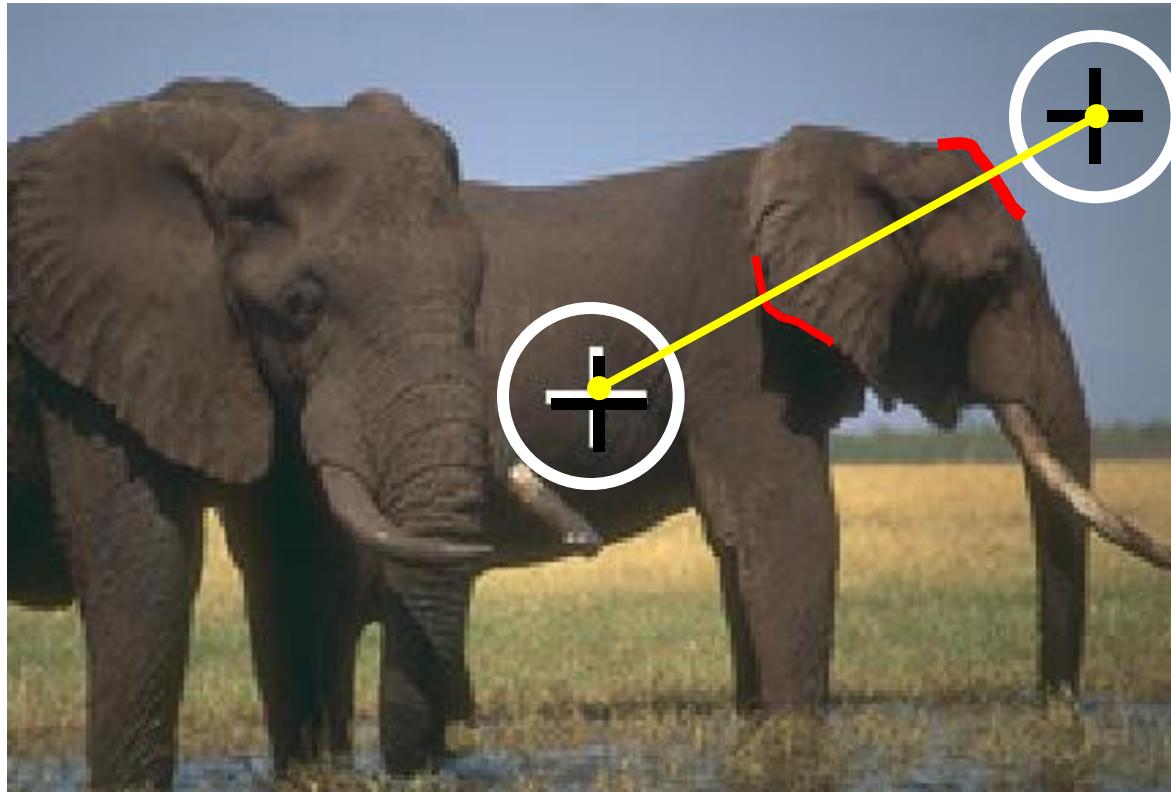


V: image pixels
E: connections between pairs of nearby pixels

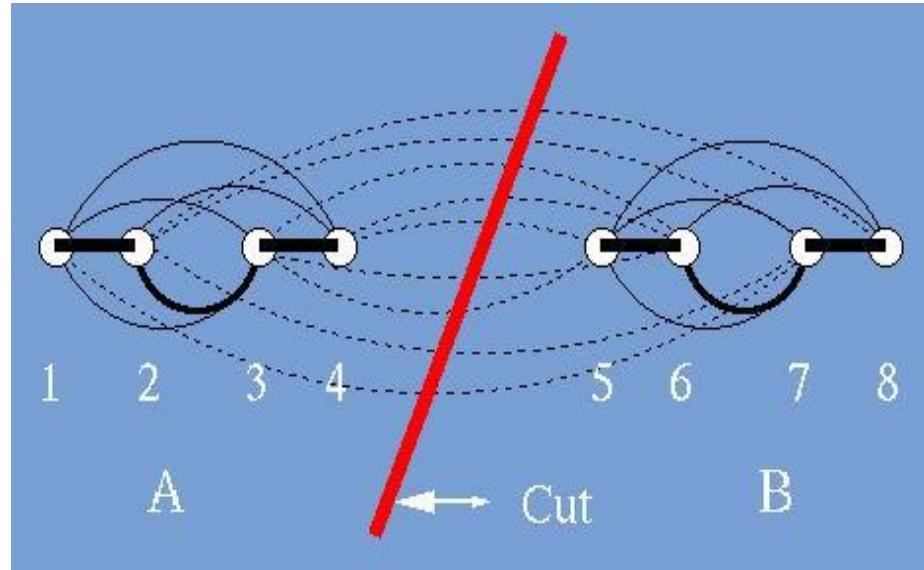
Partition graph so that similarity within group is large and similarity between groups is small -- ***Normalized Cuts*** [Shi & Malik 97]

Wij small when intervening contour strong, small when weak..

$C_{ij} = \max P_b(x,y) \text{ for } (x,y) \text{ on line segment } ij; \quad W_{ij} = \exp(-C_{ij}/\sigma)$ □



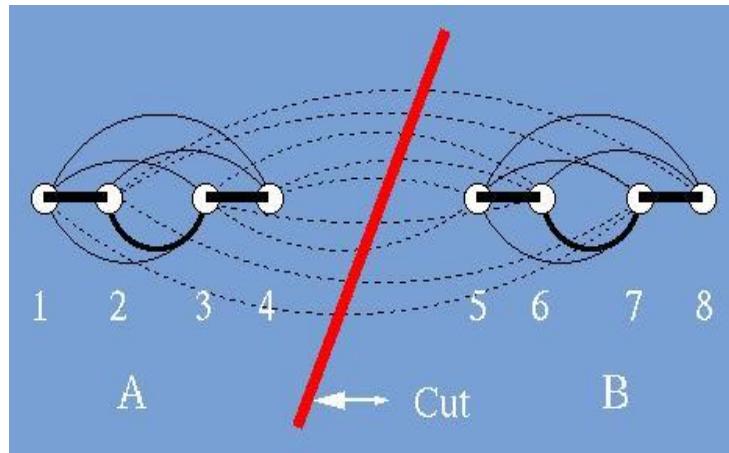
How to partition a graph



$$cut(A, B) = \sum_{u \in A, v \in B} w(u, v)$$

- We can find the minimum cut efficiently, but this tends to break the graph into isolated little pieces⁶¹

Normalized Cut is a better



- We normalize by the total volume of connections

$$Ncut(A, B) = \frac{cut(A, B)}{assoc(A, V)} + \frac{cut(A, B)}{assoc(B, V)}$$

$$Ncut(A, B) = \frac{cut(A, B)}{assoc(A, V)} + \frac{cut(A, B)}{assoc(B, V)}$$

where $assoc(A, V) = \sum_{u \in A, t \in V} w(u, t)$

Solving the Normalized Cut problem

- Exact discrete solution to Ncut is NP-hard even on regular grid [Papadimitriou'97]
- We first transform to

$$\min_{\mathbf{x}} Ncut(\mathbf{x}) = \min_{\mathbf{y}} \frac{\mathbf{y}^T (\mathbf{D} - \mathbf{W}) \mathbf{y}}{\mathbf{y}^T \mathbf{D} \mathbf{y}}$$

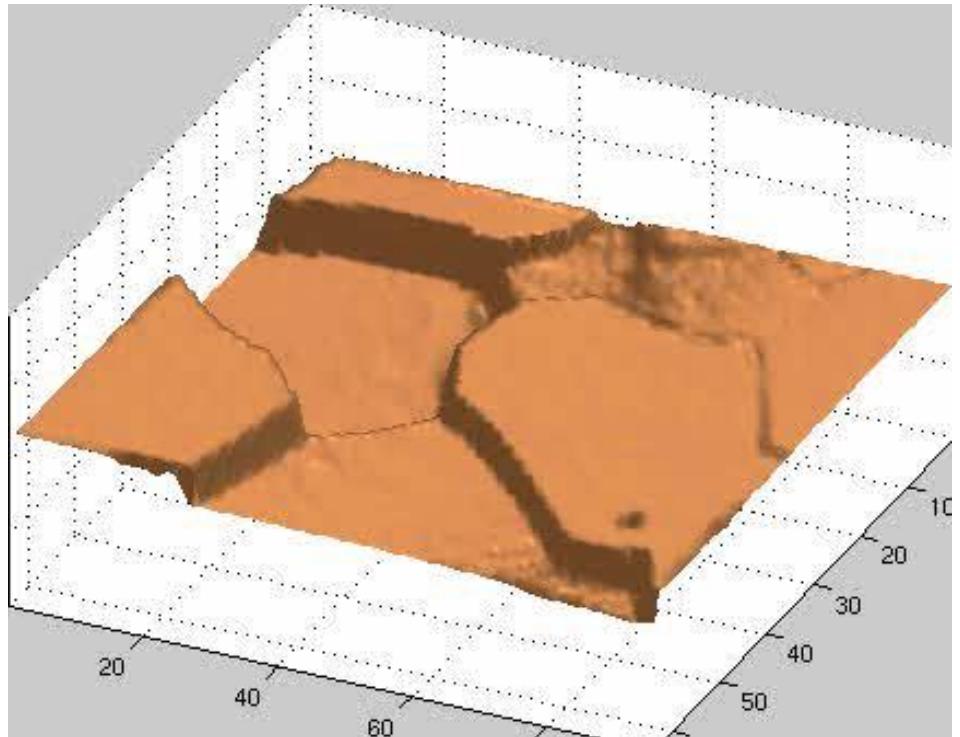
with the condition $y(i) \in \{1, -b\}$ and $\mathbf{y}^T \mathbf{D} \mathbf{1} = 0$

- Drawing on spectral graph theory, good approximation can be obtained by solving a generalized eigenvalue problem.

$$(\mathbf{D} - \mathbf{W}) \mathbf{y} = \lambda \mathbf{D} \mathbf{y}.$$

Normalized Cuts as a Spring-Mass system

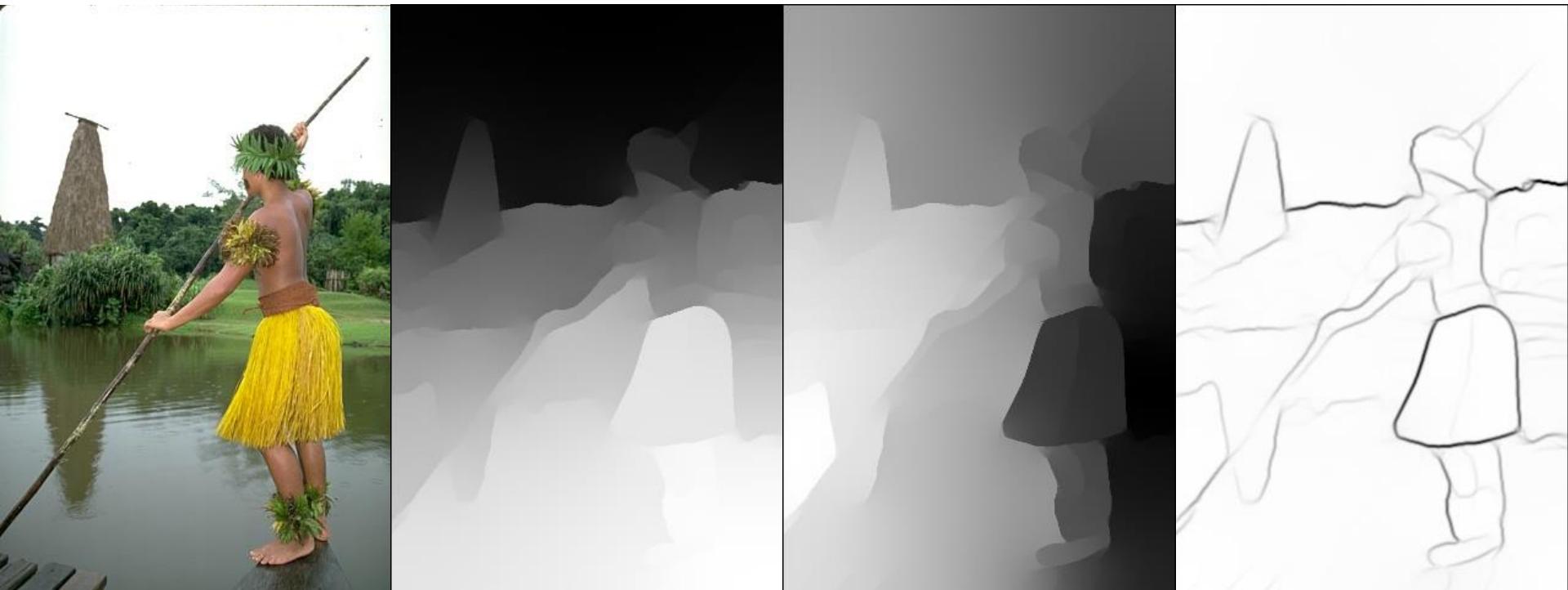
- Each pixel is a point mass; each connection is a spring:



$$(D - W)y = \lambda Dy$$

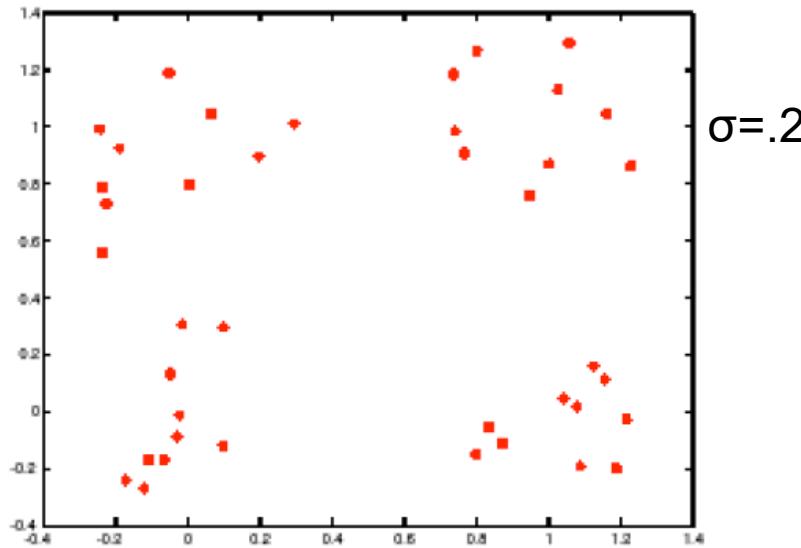
- Fundamental modes are generalized eigenvectors of
 $(D - W) y = \lambda Dy$

Eigenvectors carry contour information

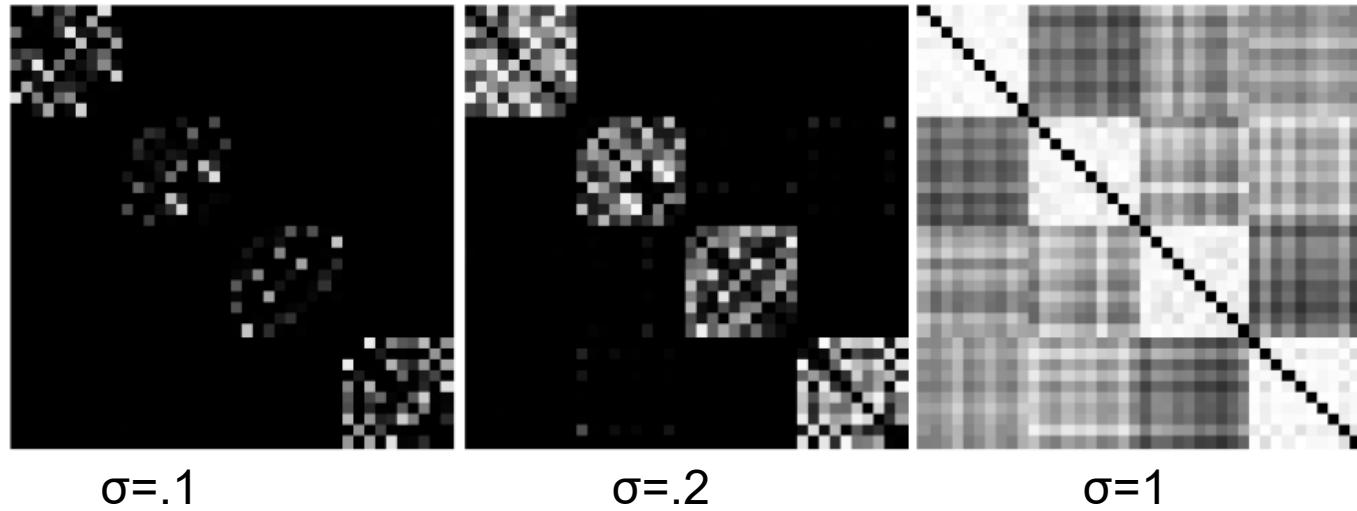


Measuring affinity

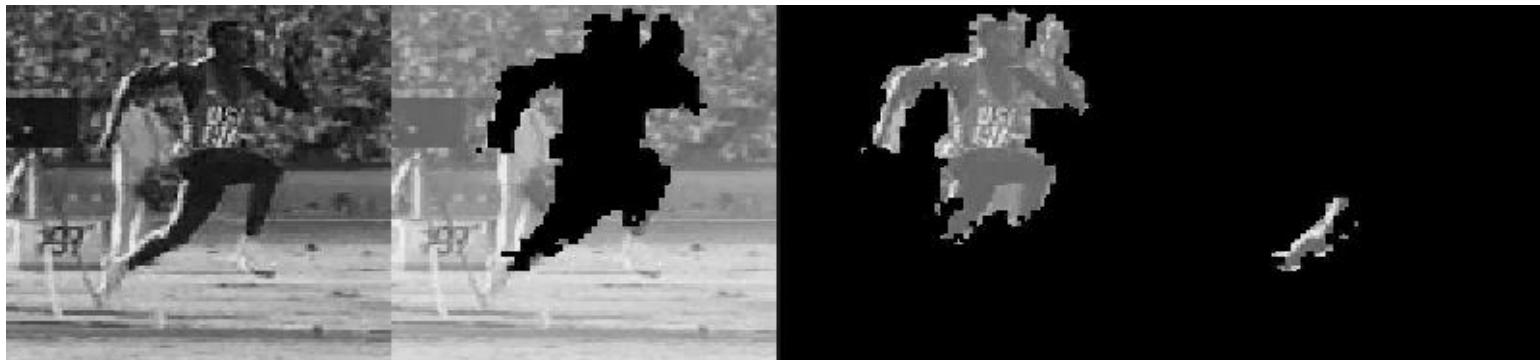
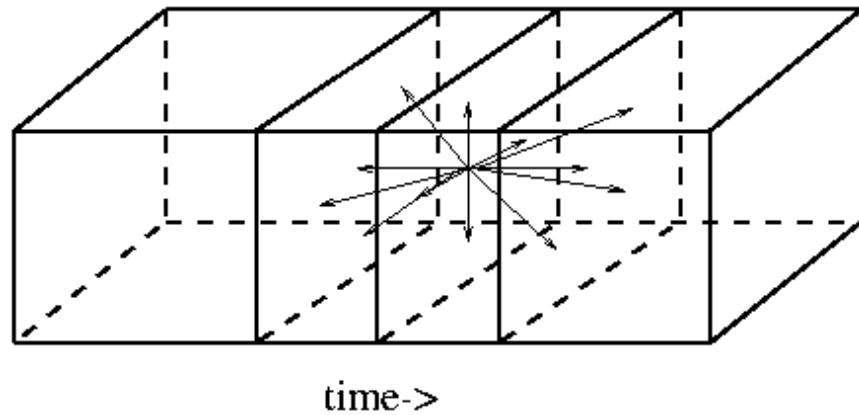
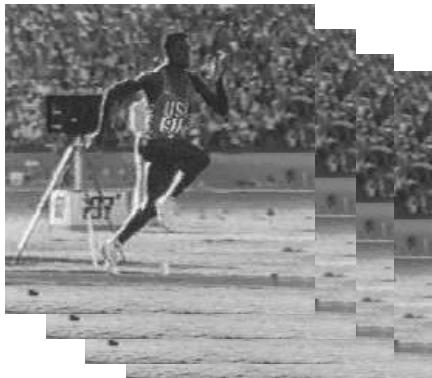
Data points



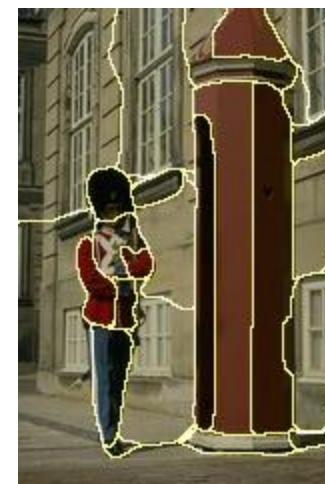
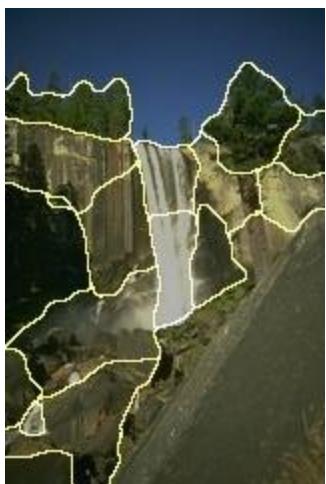
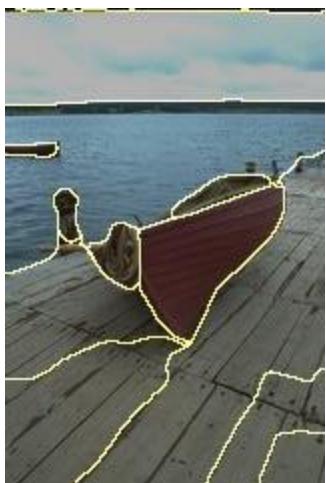
Affinity
matrices



Temporal NCuts [Shi & Malik, 98]



Results: Berkeley Segmentation Engine



<http://www.cs.berkeley.edu/~fowlkes/BSE/>

“What is a good segment?”

Ren and Malik (2003)



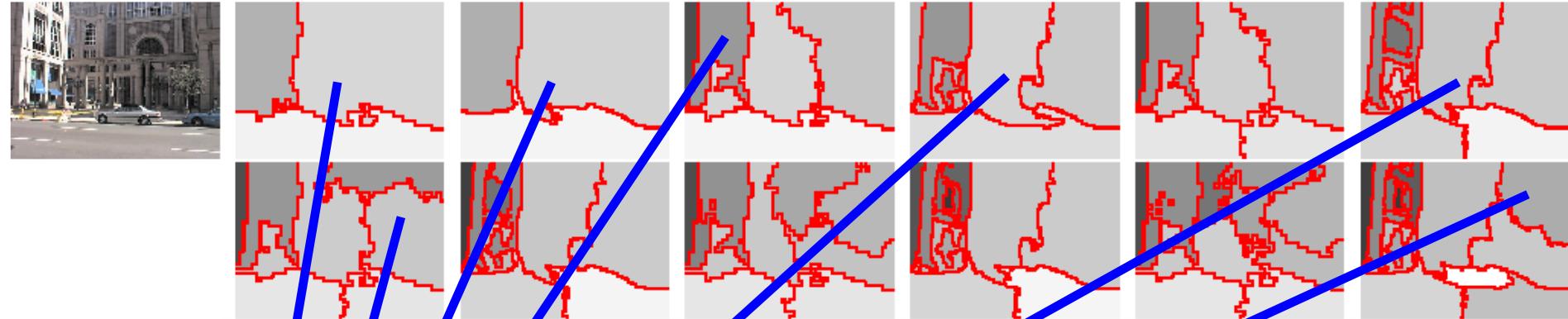


1. inter-region texture similarity $T_{ext}(S)$;
2. intra-region texture similarity $T_{int}(S)$;
3. inter-region brightness similarity $B_{ext}(S)$;
4. intra-region brightness similarity $B_{int}(S)$;
5. inter-region contour energy $E_{ext}(S)$;
6. intra-region contour energy $E_{int}(S)$;
7. curvilinear continuity $C(S)$.

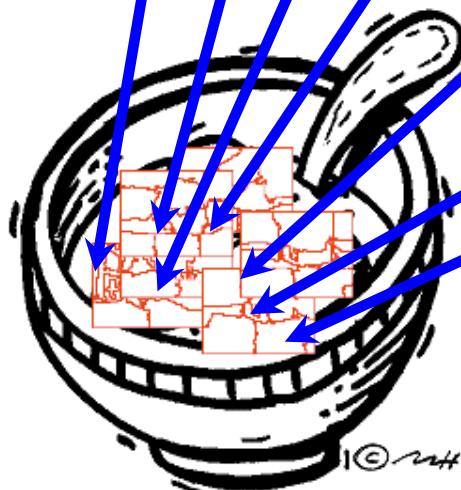
Discriminative Segmentation Model:

- Operates on super-pixels to reduce problem dimensionality
- Optimized by simple search
 - Make split / merge proposals

Multiple Segmentations



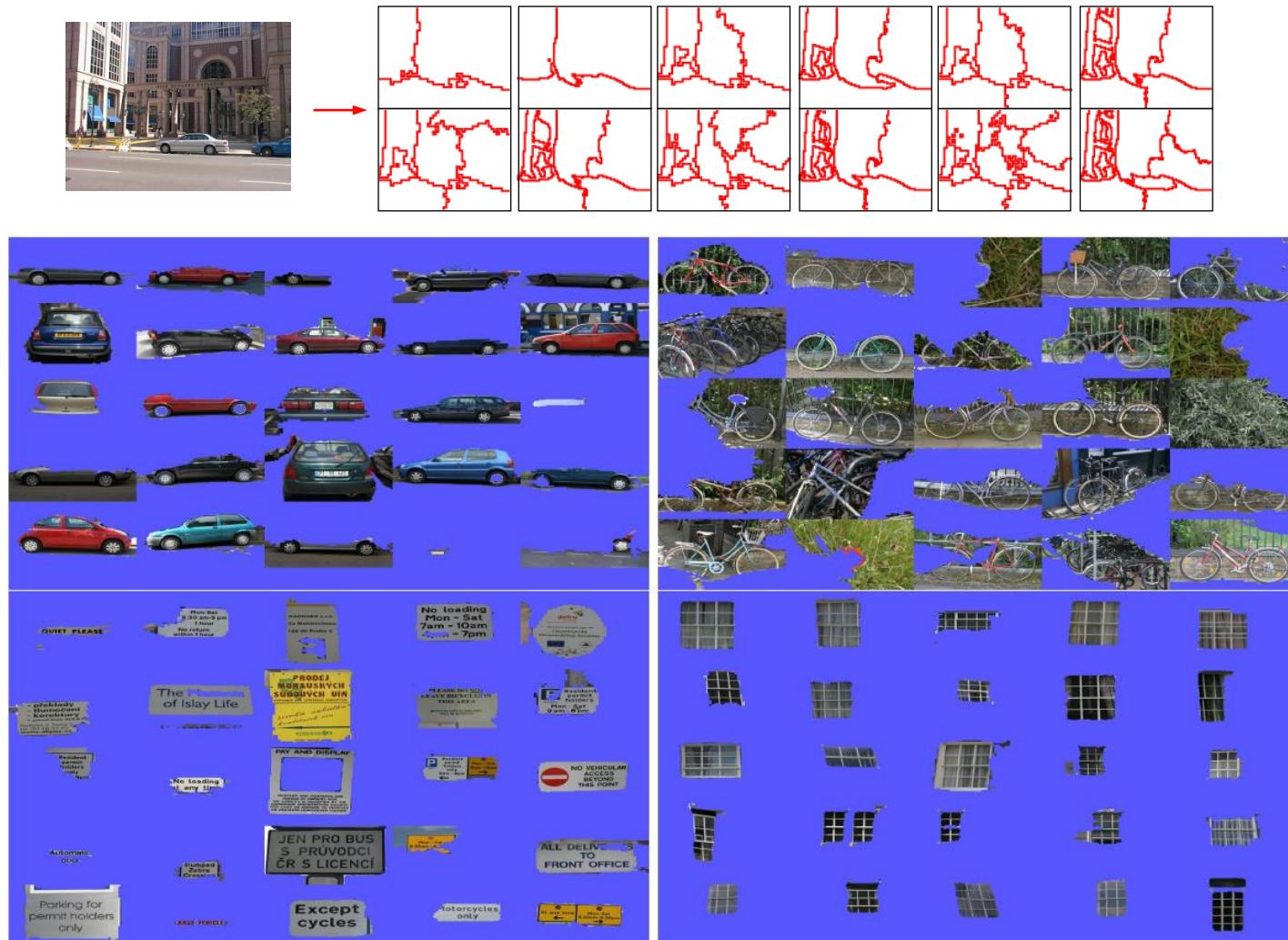
No Single Segmentation provides adequate spatial support



Use a Soup of Segments
(Hoiem *et al* 2005, Russell *et al* 2006)

Multiple segmentation for Object Discovery

Multiple segmentations



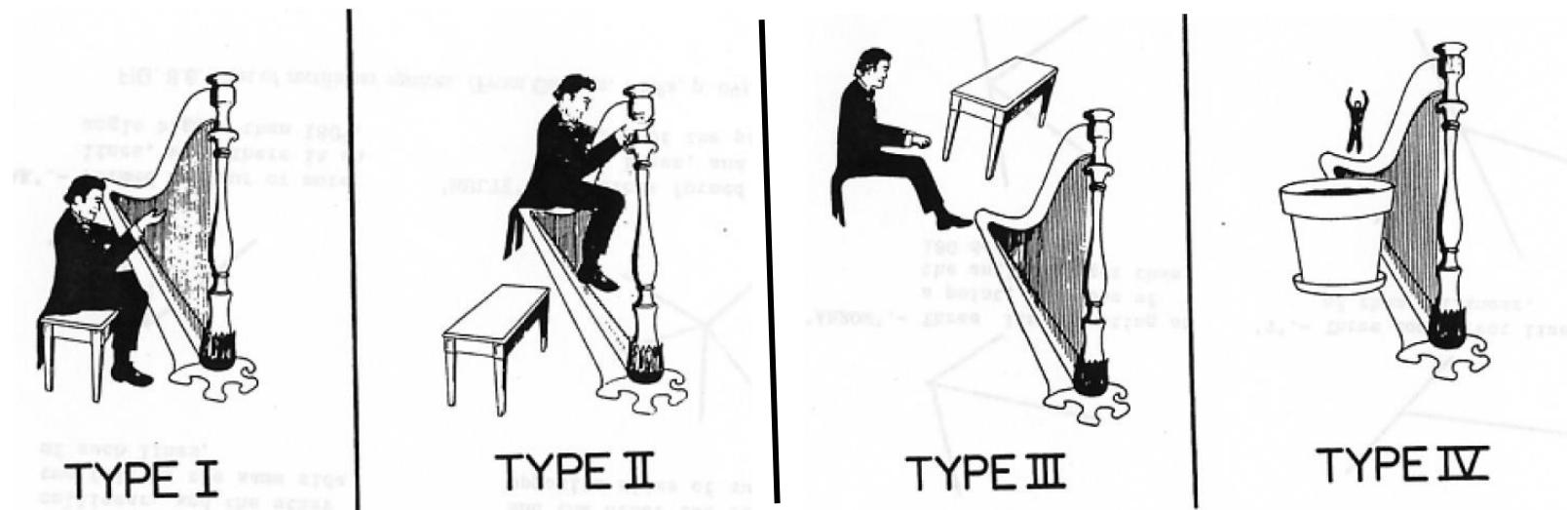
B. Russell et al., “[Using Multiple Segmentations to Discover Objects and their Extent in Image Collections](#),” CVPR 2006

Slide credit: Lana Lazebnik

Parsing in 2D is problematic

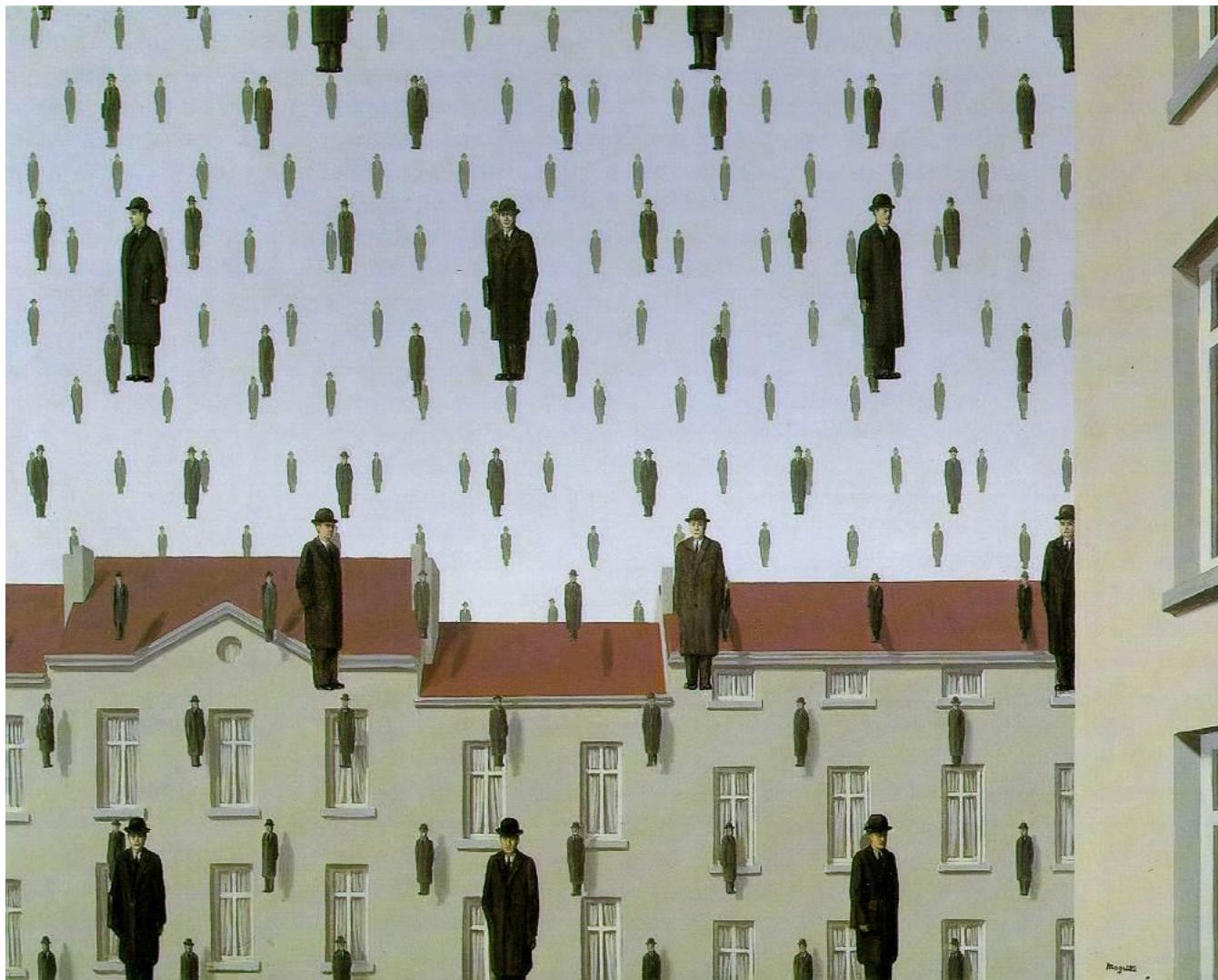


Qualitative 3D Scene Reasoning



- Biederman's Relations among Objects in a Well-Formed Scene (1981):
 - Support
 - Size
 - Position
 - Interposition
 - Likelihood of Appearance

Support



Rene Magritte, *Golconde*

Size



Rene Magritte, *The Listening Room*

Interposition



Rene Magritte, *Black Check*

Position, Probability, Size



Rene Magritte, *Personal Values*

Reasoning needs to happen in 3D

