On the role of curvature singularities in the perception of outline drawings of objects

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Aim

To provide a brief overview of a large-scale research program on this topic

- general ideas and findings
- several recent papers (send email to johan.wagemans@psy.kuleuven.be)
- benchmark data sets to test specific ideas (also from computer vision)

overview paper:

De Winter, J., & Wagemans, J. (2004). Contour-based object identification and segmentation: Stimuli, norms and data, and software tools. *Behavior Research Methods, Instruments, & Computers, 36 (4),* 604-624.

Overview

1. Introduction
2. Identification study with silhouette and outline versions
3. Saliency study
4. Identification study with straight-line versions
5. Identification study with fragmented versions
6. Segmentation study
7. Current directions

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Introduction

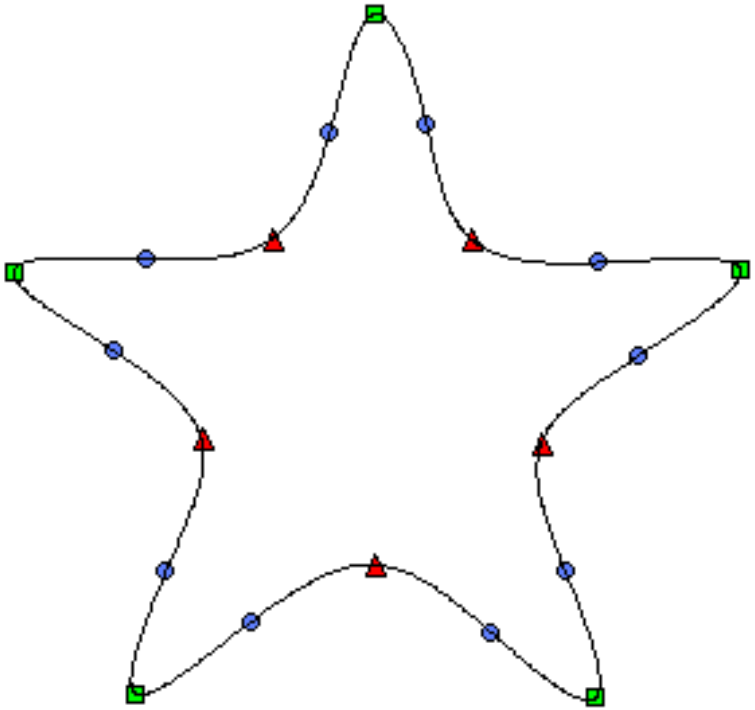
- shape-based object identification
- information about shape in line drawings
- old problem but limited understanding

Introduction (ctd)

- Attneave (1954). Some informational aspects of visual perception. *Psychological Review, 61,* 183-193.
- two demonstrations of importance of curvature extrema
- first: some basic definitions

Introduction (ctd)

- 3 types of curvature singularities:

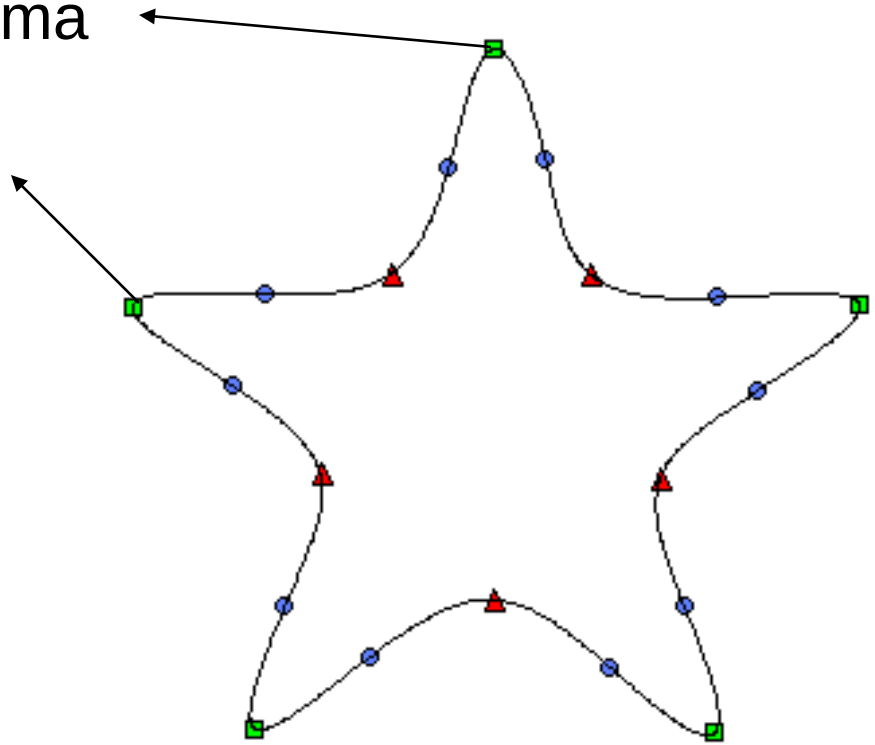


Introduction (ctd)

- 3 types of curvature singularities:

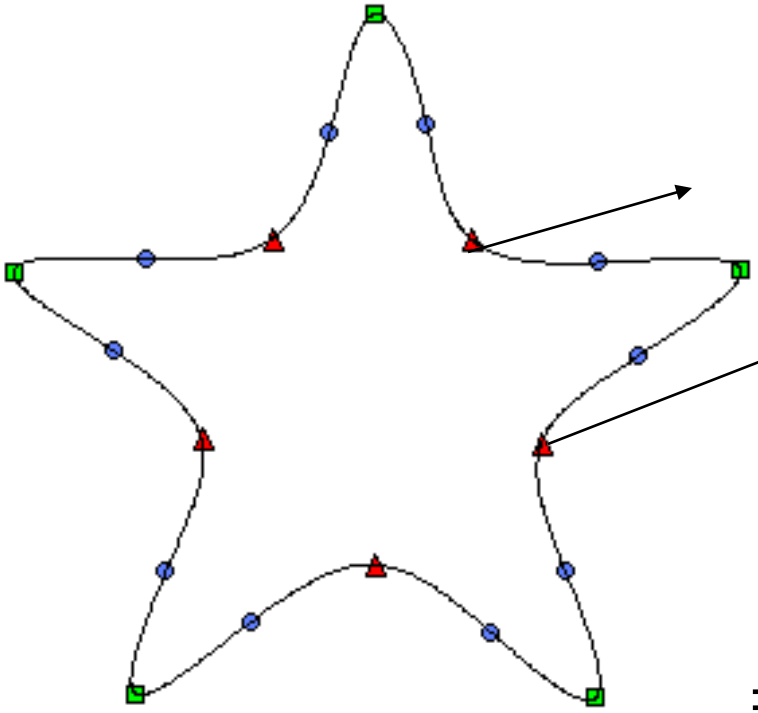
positive maxima

M+



Introduction (ctd)

- 3 types of curvature singularities:



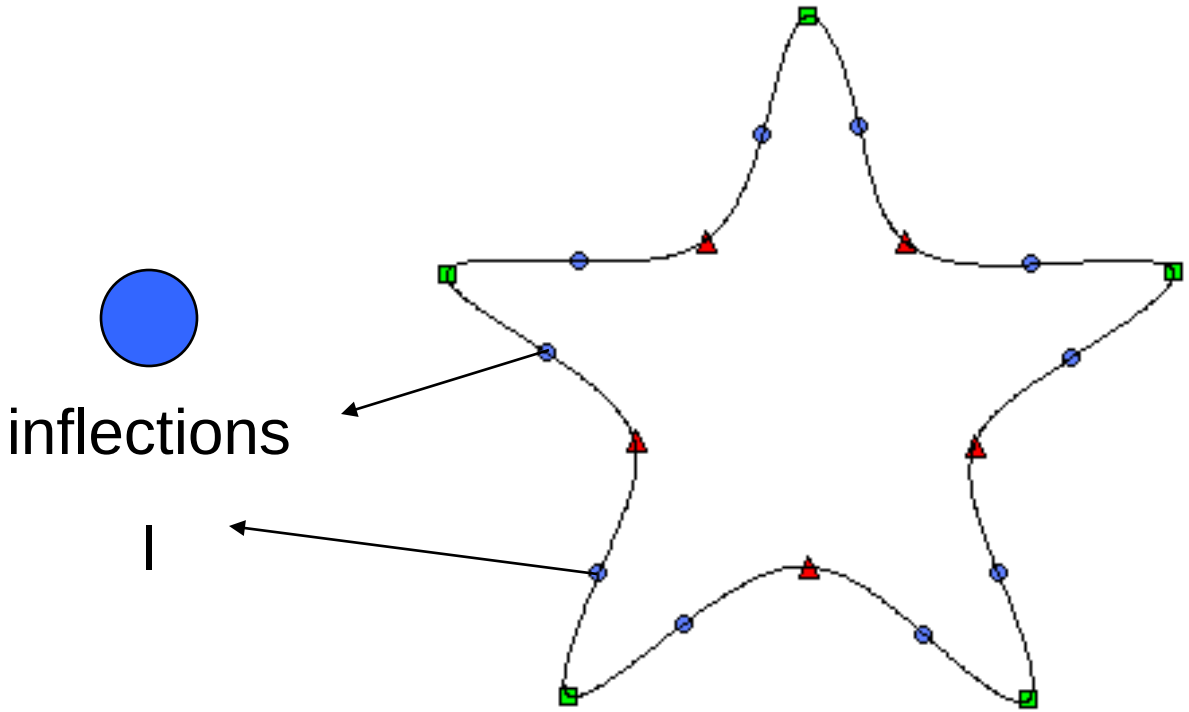
negative minima

m-

M+ and m-
= Extrema (E)

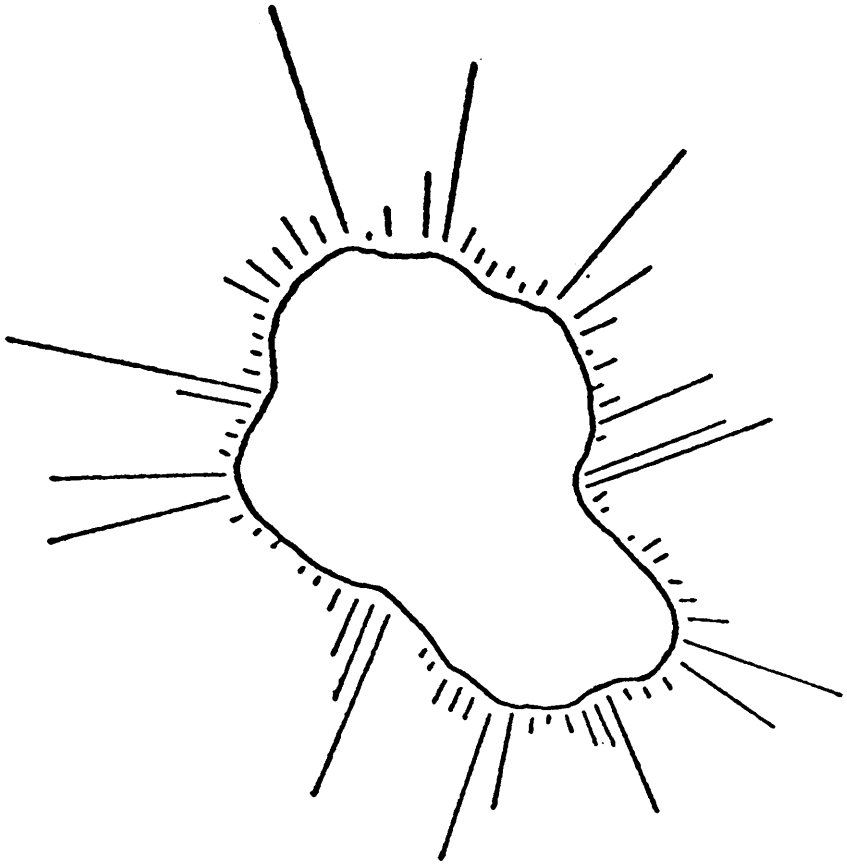
Introduction (ctd)

- 3 types of curvature singularities:



Introduction (ctd)

- Attneave (1954): demonstration 1

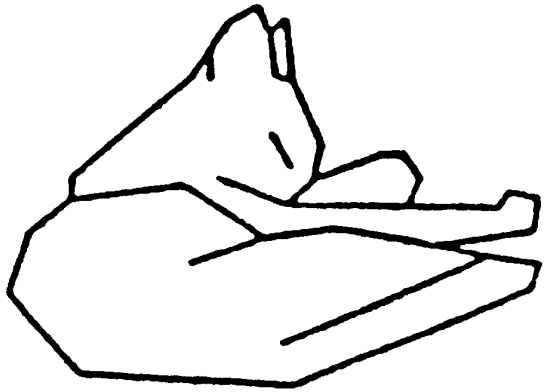


Introduction (ctd)

- Attneave (1954): demonstration 2

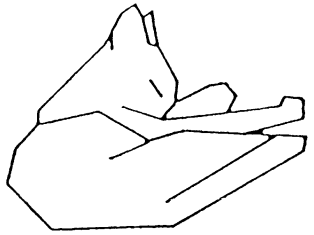
- some nice demonstrations but also good reasons to study this in more detail
  - just demonstrations
  - some empirical doubts

a)



b)

Lowe (1986)



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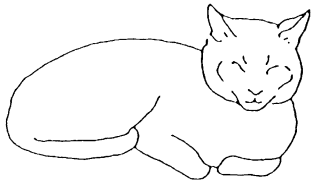

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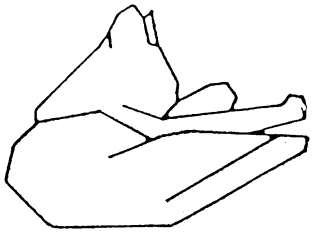

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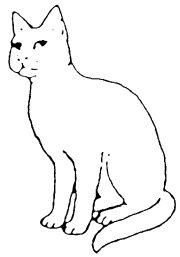

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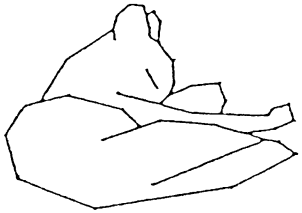

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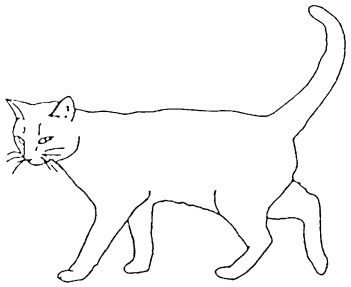
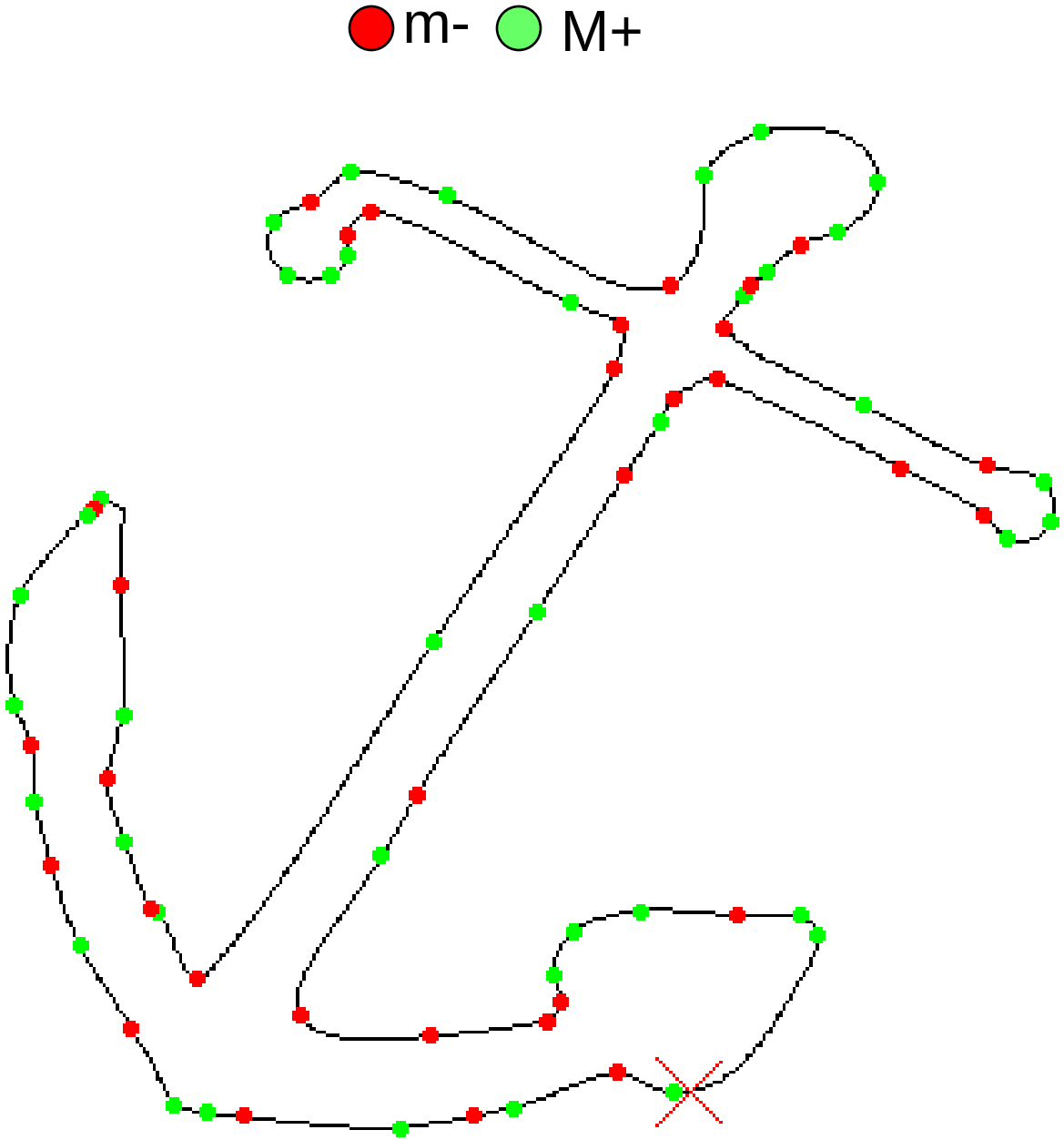


714 (0)

Biederman (1988)

- some nice demonstrations but also good reasons to study this in more detail
  - just demonstrations
  - some empirical doubts
  - some computational concerns


m-
M+

- some nice demonstrations but also good reasons to study this in more detail
  - just demonstrations
  - some empirical doubts
  - some computational concerns
  - some additional theoretical work, e.g.
    - Koenderink (1984) and Koenderink & van Doorn (1982): inflections on contours mark boundary between positively and negatively curved surface patches on 3-D objects
    - Feldman & Singh (2005): information-theoretical analysis (m- more salient than M+)

Introduction (ctd)

- Snodgrass and Vanderwart stimuli (1980)
  - 260 line drawings of everyday objects
  - norms of name agreement, complexity, familiarity, etc.
  - widely used in research on object identification, picture naming, priming, etc.

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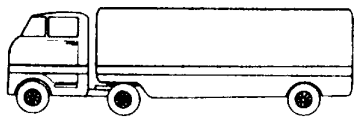
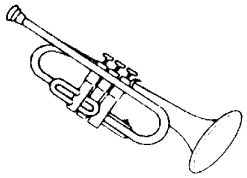
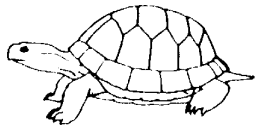
242 

243 

244 

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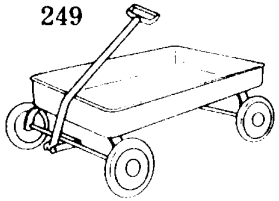
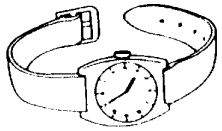
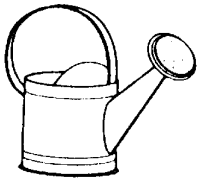
249 

250 

251 

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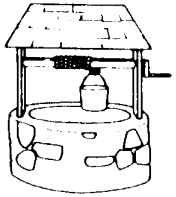
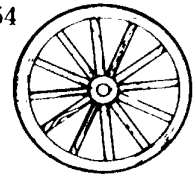
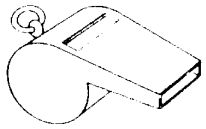
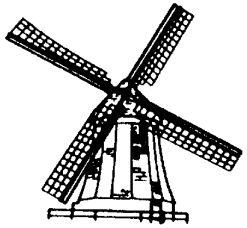
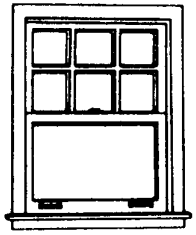
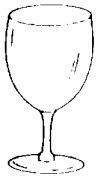
253 

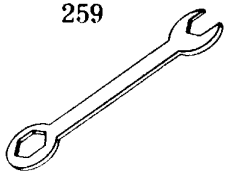
254 

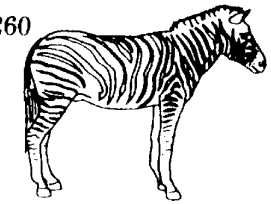
255 

256 

257 

258 

259 

260 

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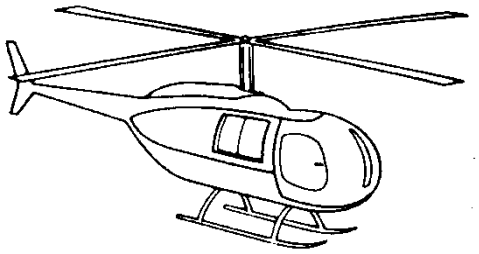
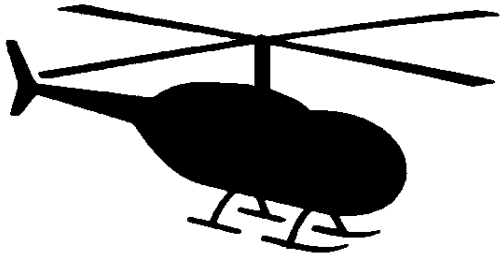
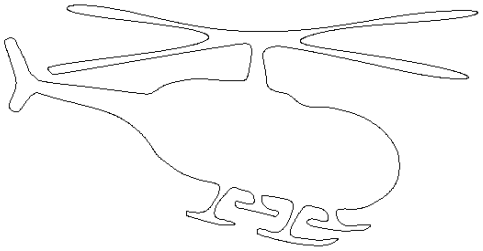
- Wagemans, J., De Winter, J., Op de Beeck, H. P., Ploeger, A., Beckers, T., & Vanroose, P. (2008). Identification of everyday objects on the basis of silhouette and outline versions. *Perception, 37*, 207-244.

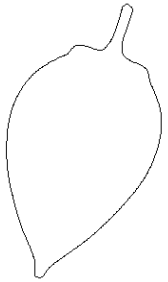
Introduction (ctd)

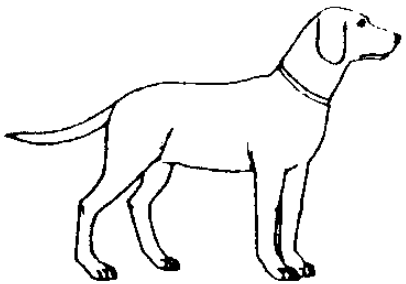
- our variants of the Snodgrass and Vanderwart stimuli:
  - silhouettes (completely black inside)
  - outlines (edge extraction and spline fitting)
  - identification norms

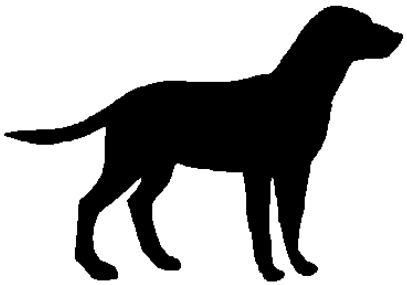


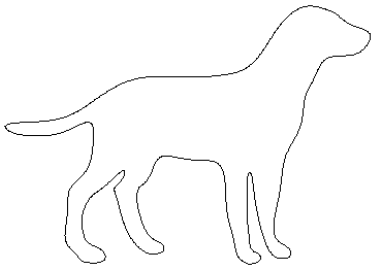


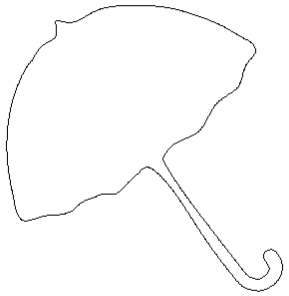


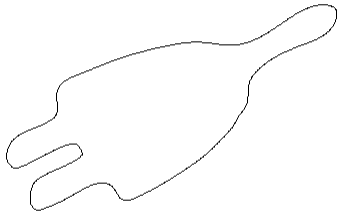


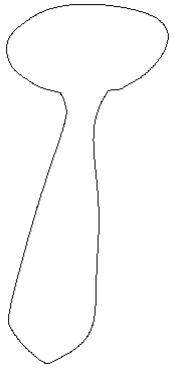


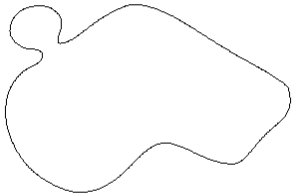


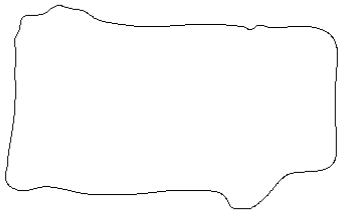












- our variants of the Snodgrass and Vanderwart stimuli:
  - complete, closed, smooth contours
  - discrete pixels with curvature values
  - curvature graph with singularities

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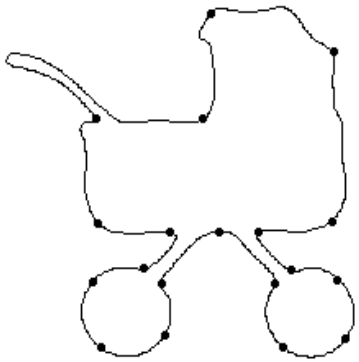
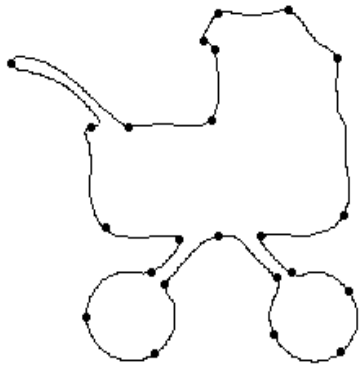
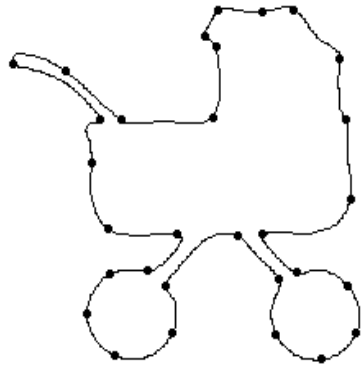
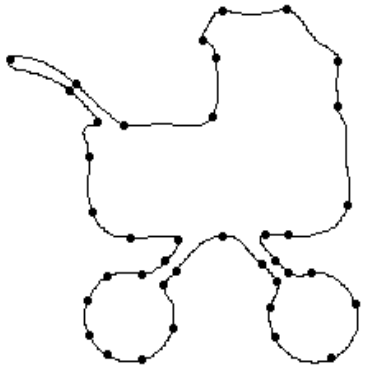
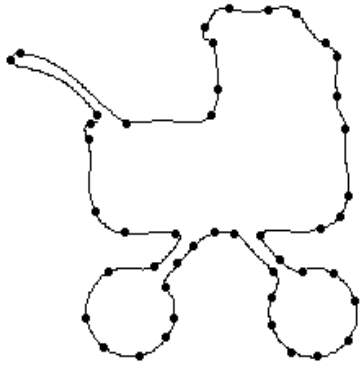
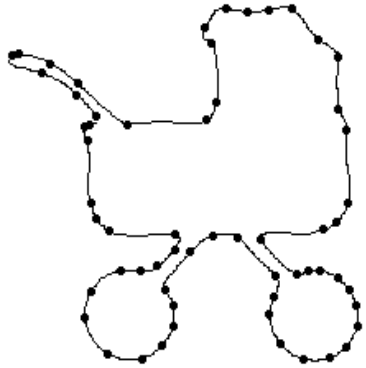
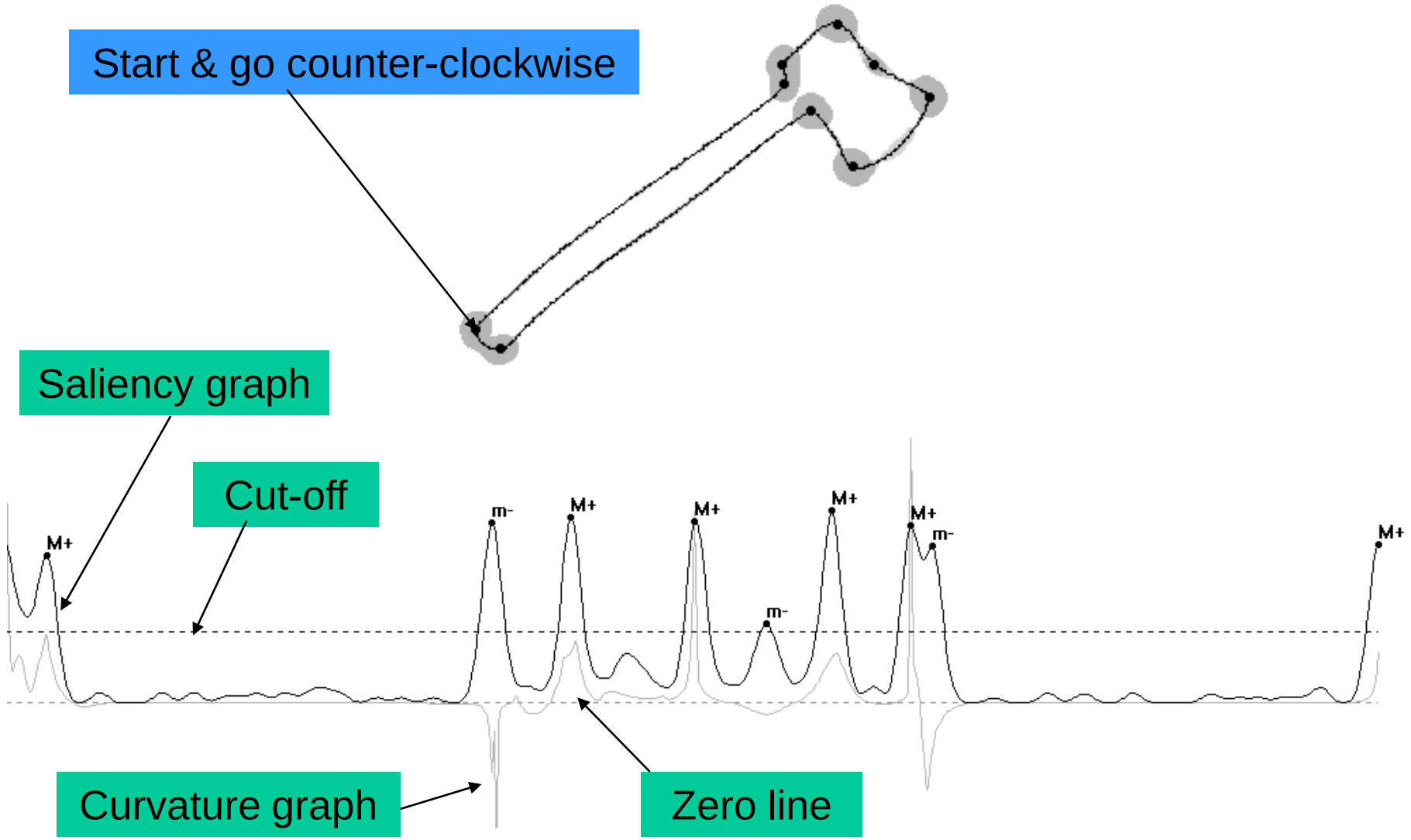
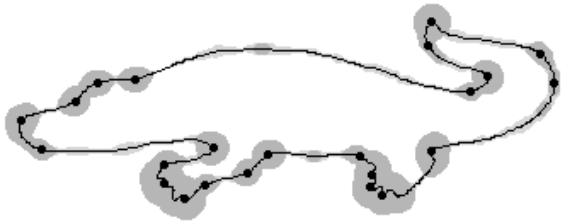
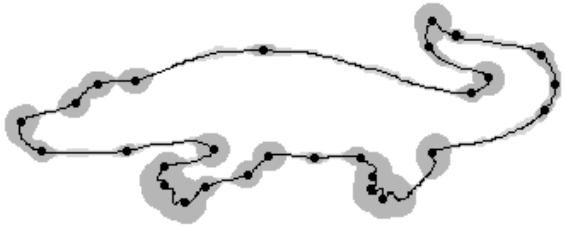
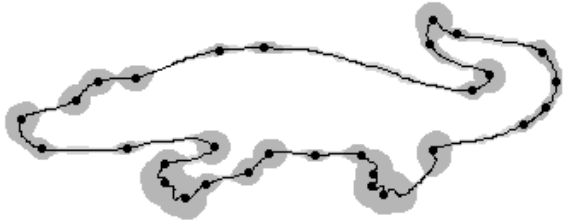
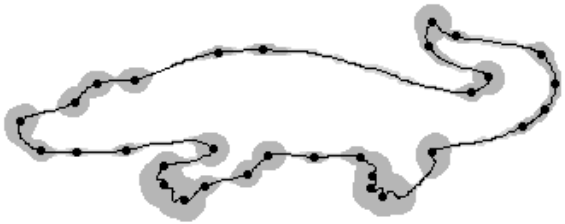
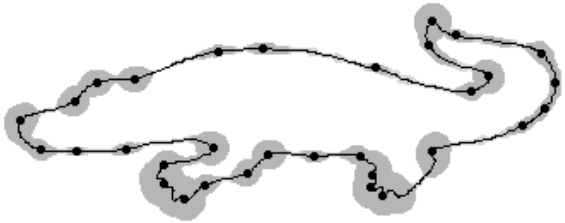
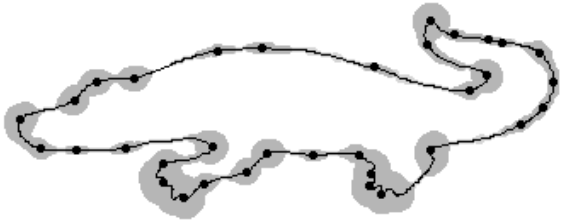
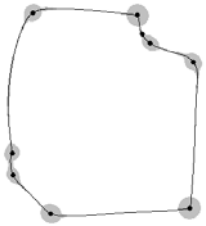
- De Winter, J., & Wagemans, J. (2008). Perceptual saliency of points along the contour of everyday objects: A large-scale study. *Perception & Psychophysics, 70 (1),* 50-64.

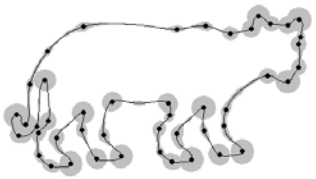
- 161 subjects: first-year psychology students at the University of Leuven
- subjects look at shape as a whole (1 sec)
- mark visually salient points [1-∞] using a computer mouse [5-∞ sec] e.g.
    - points that attract your attention
    - points that can allow shape reconstruction
- each subject: 65 outlines (4 balanced sets)
- each outline: N = 40 (2.2)

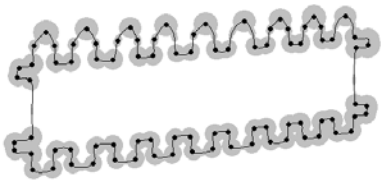







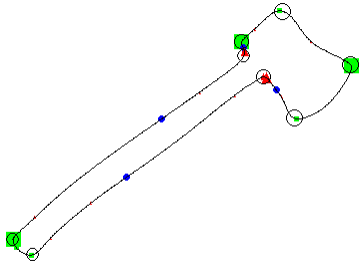
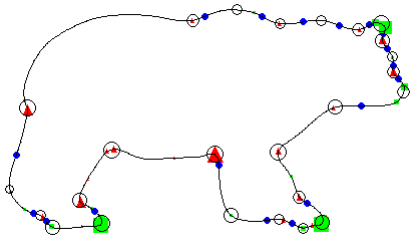
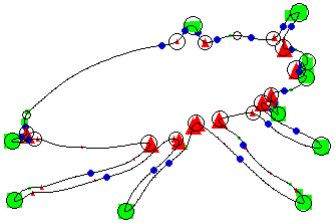
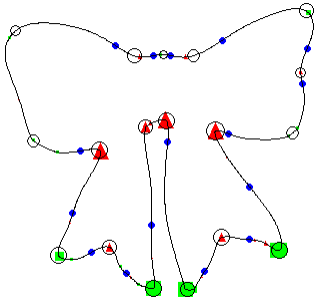
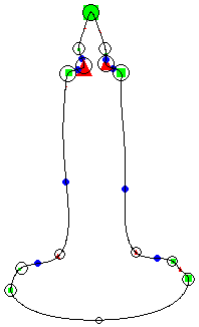
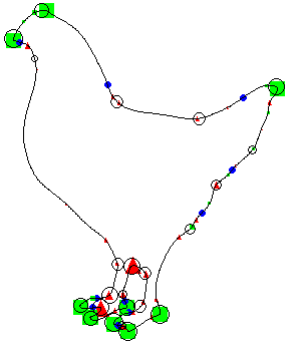
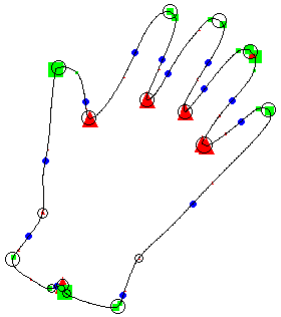
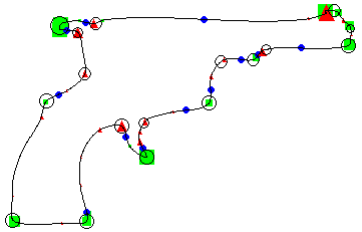
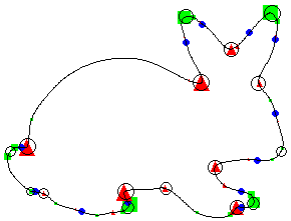
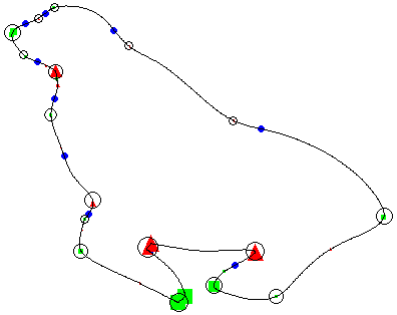
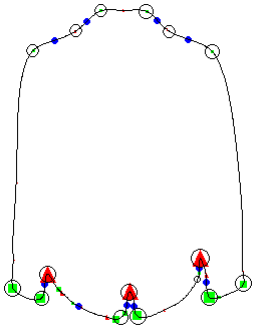
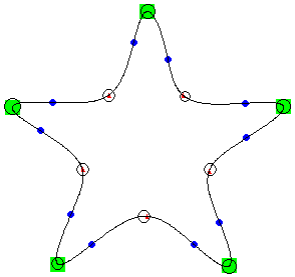

Start & go counter-clockwise
Saliency graph
Cut-off
M+
m-
M+
M+
m-
M+
M+
m-
M+
Curvature graph
Zero line







Overview

1. Introduction
2. Identification study with silhouette and outline versions
3. Saliency study
4. Identification study with straight-line versions
5. Identification study with fragmented versions
6. Segmentation study
7. Current directions

- De Winter, J., & Wagemans, J. (2008). The awakening of Attneave's sleeping cat: Identification of everyday objects on the basis of straight-line versions of outlines. *Perception, 37,* 245-270.

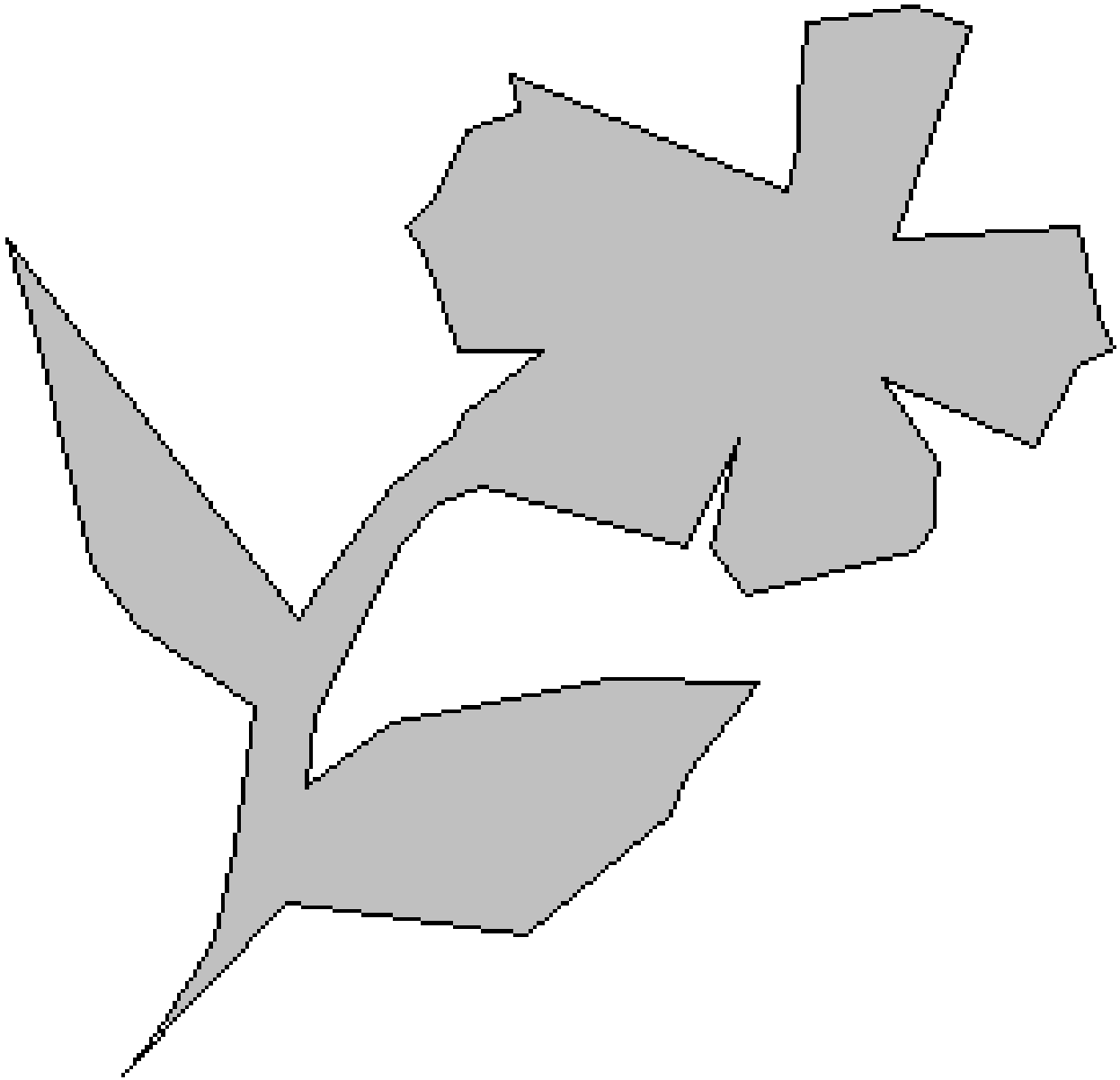
- very simple idea
- select particular types of points along the contour and connect these by straight lines
- compare identification rates for versions with different selected points
- two basic types of points:
  - mathematically defined curvature singularities
  - subject-defined salient points

Mathematically defined curvature singularities

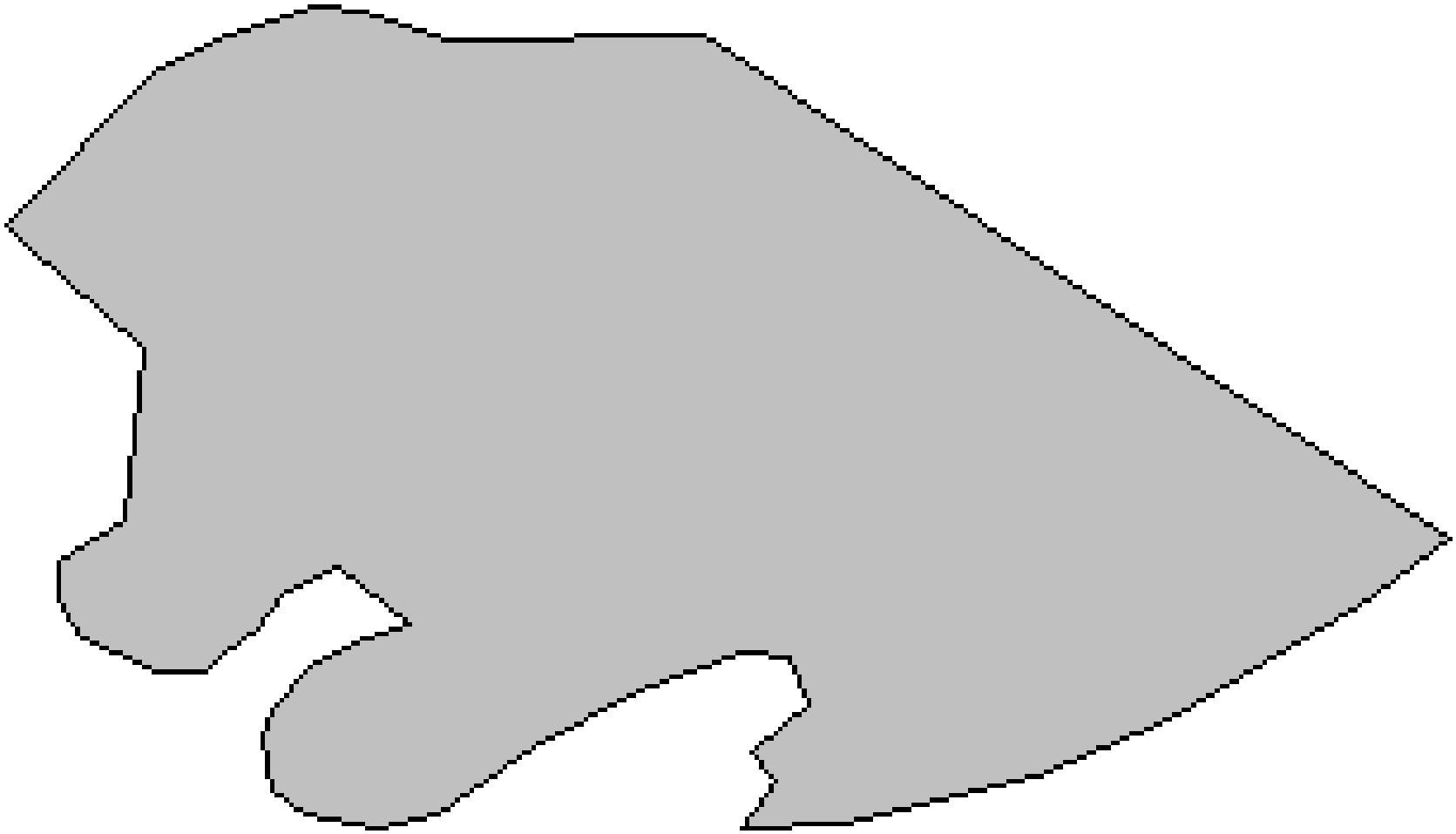
- 184 stimuli: those that are reasonably well identified on the basis of the whole contour
- 108 subjects: first-year psychology students at the University of Leuven

- different selection of mathematical singularities in 2 conditions: E versus I
- different number of singularities in 2 versions of the experiment:
  - one extremum per segment (*N* = 58)
  - number of singularities depending on number of salient points in the second study (*N* = 50)

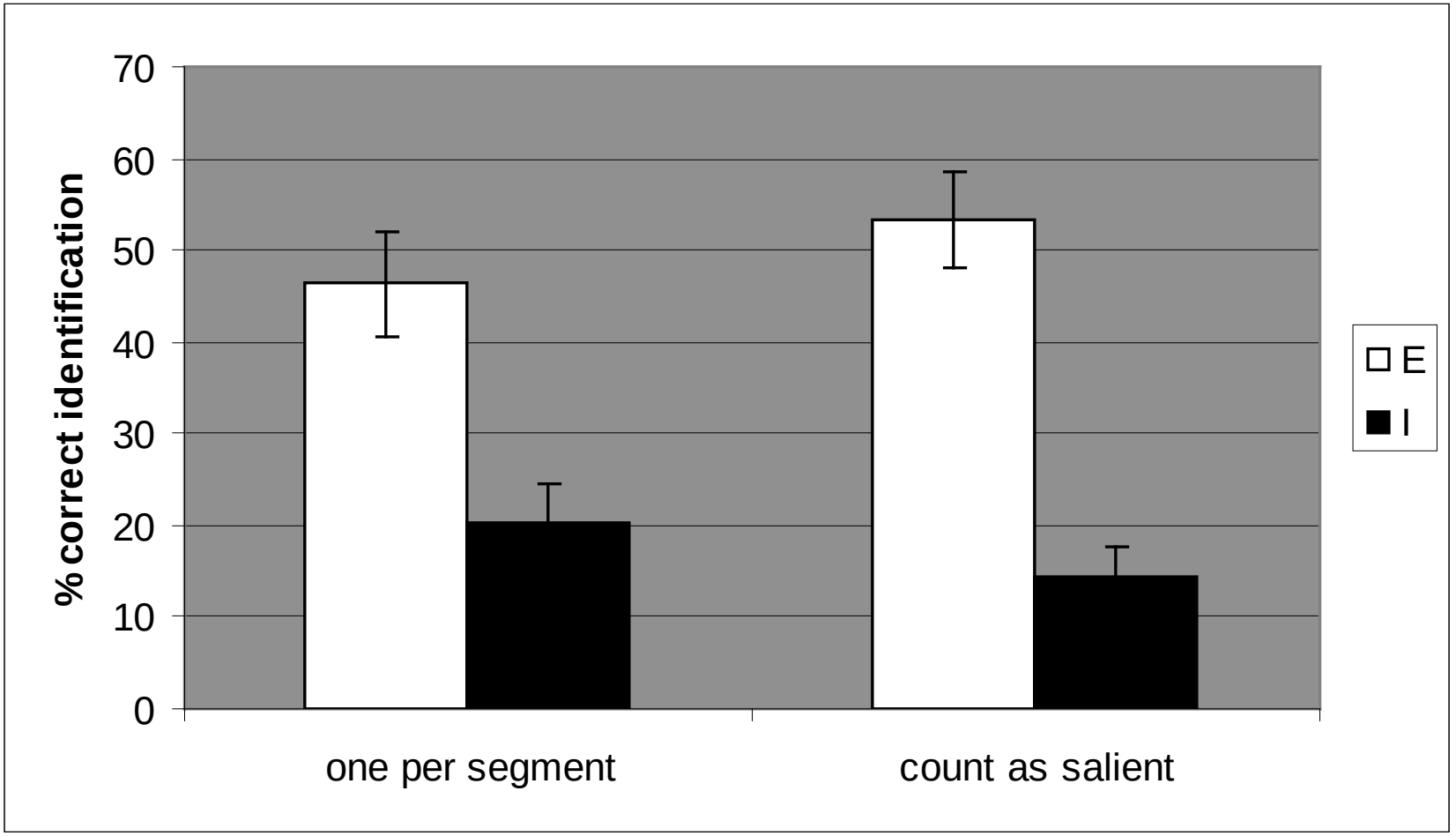
- each subject received both conditions (E and I) with different stimuli per condition (stimulus assignment counterbalanced across subjects)
- each stimulus presented only once per subject (for max. 5 sec each)



1a (E)



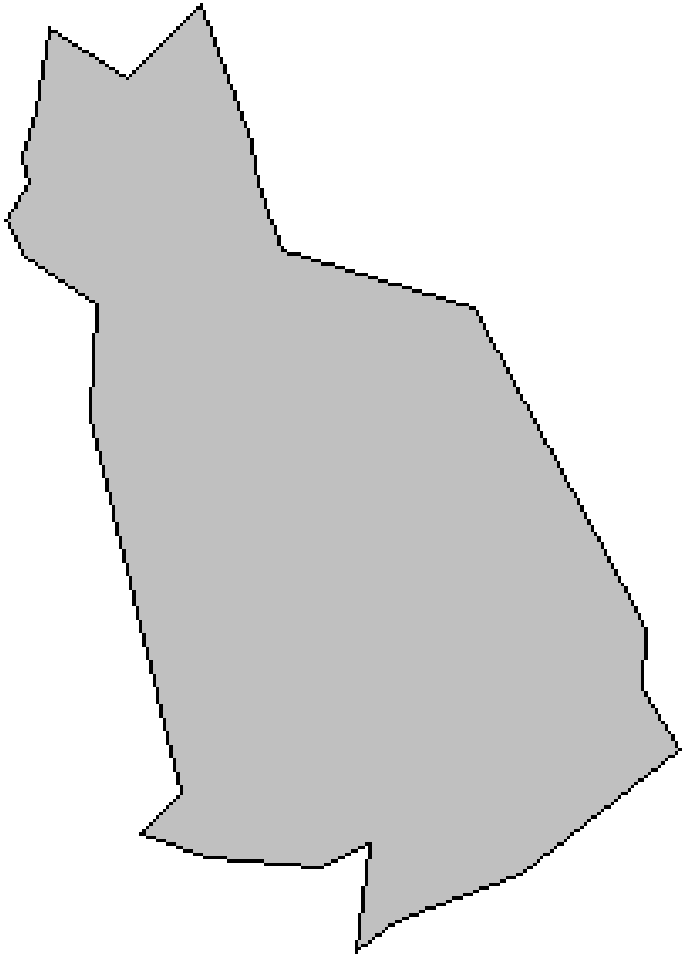
1a (I)

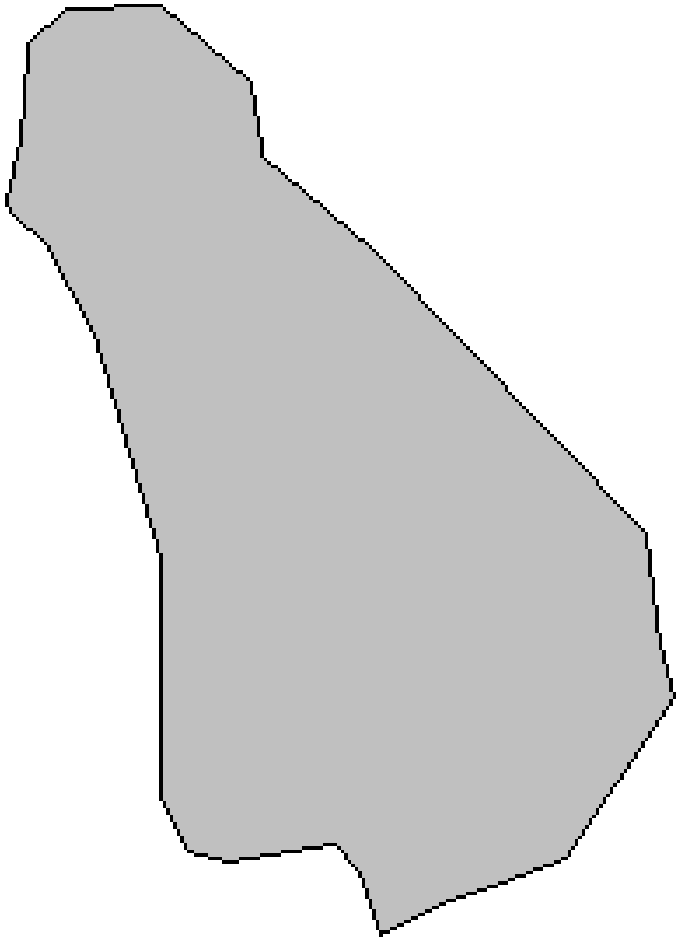

% correct identification
70
60
50
40
30
20
10
0
one per segment
count as salient
E
I

- intuition of Attneave (1954) clearly confirmed: E are most informative
  - robust finding: no strong effects of selection criterion
  - but in addition: some interesting stimulus differences

E (93%)

I (4%)

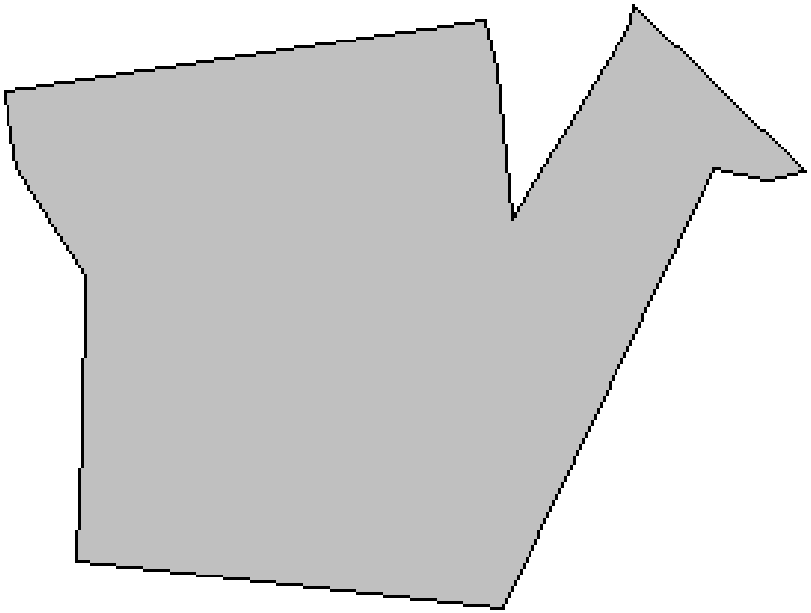


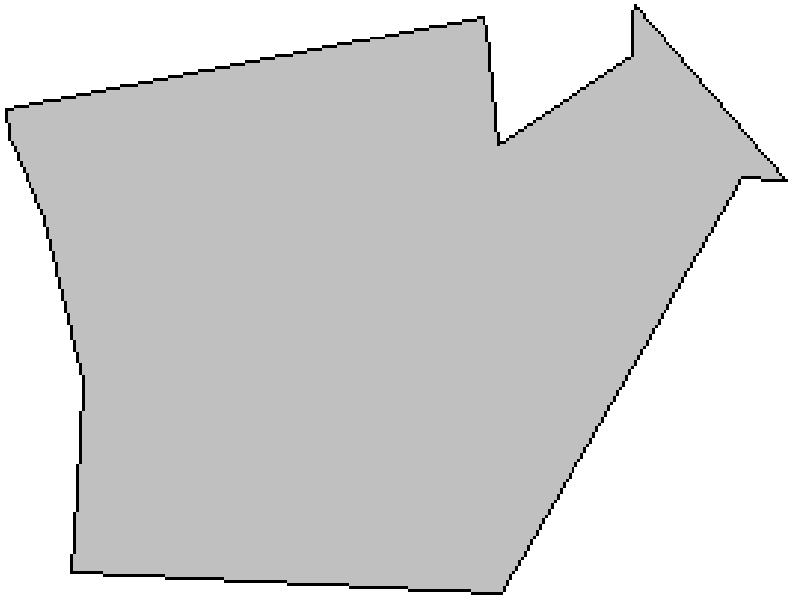


N = 127

E (86%)

I (96%)



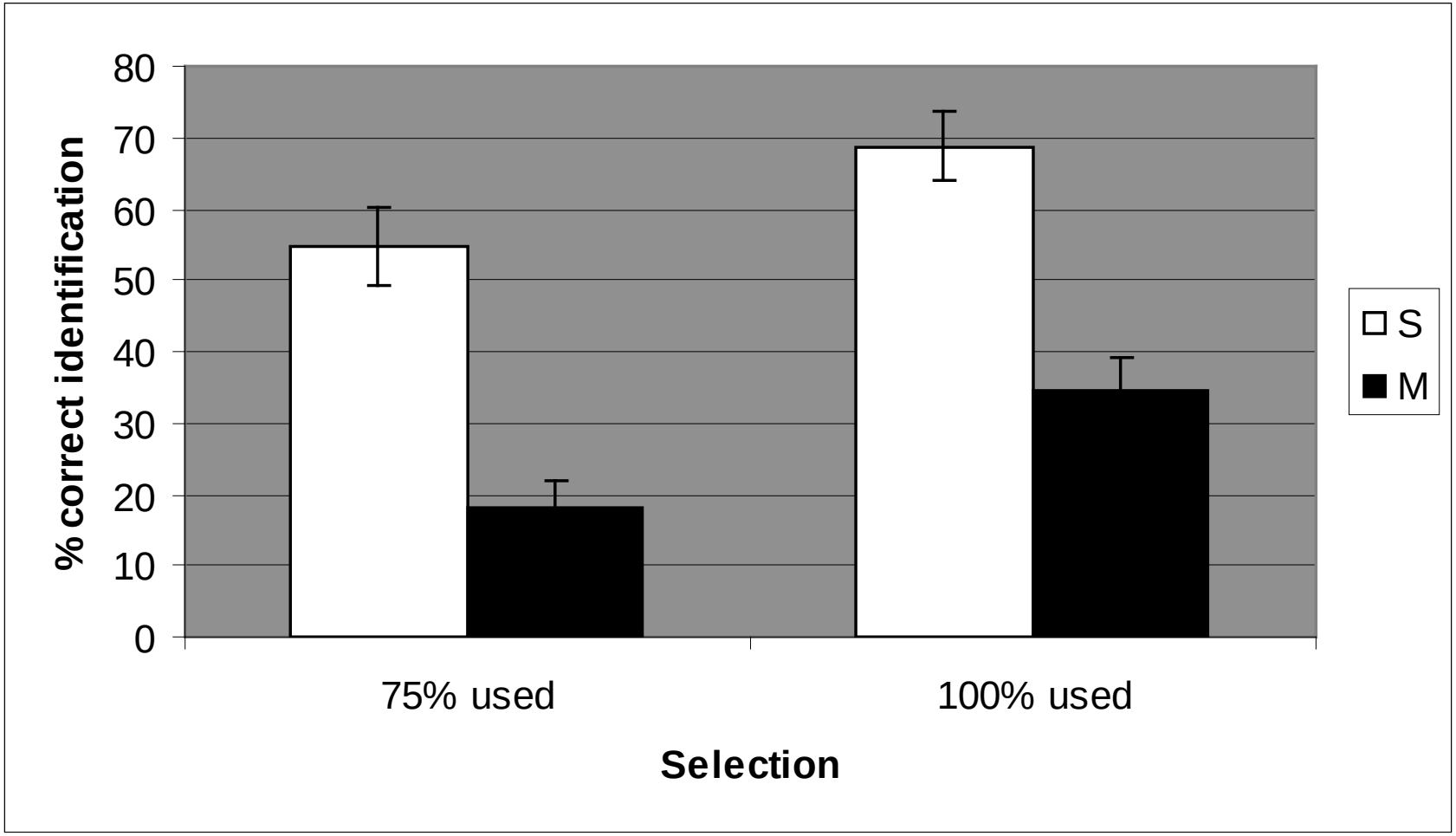


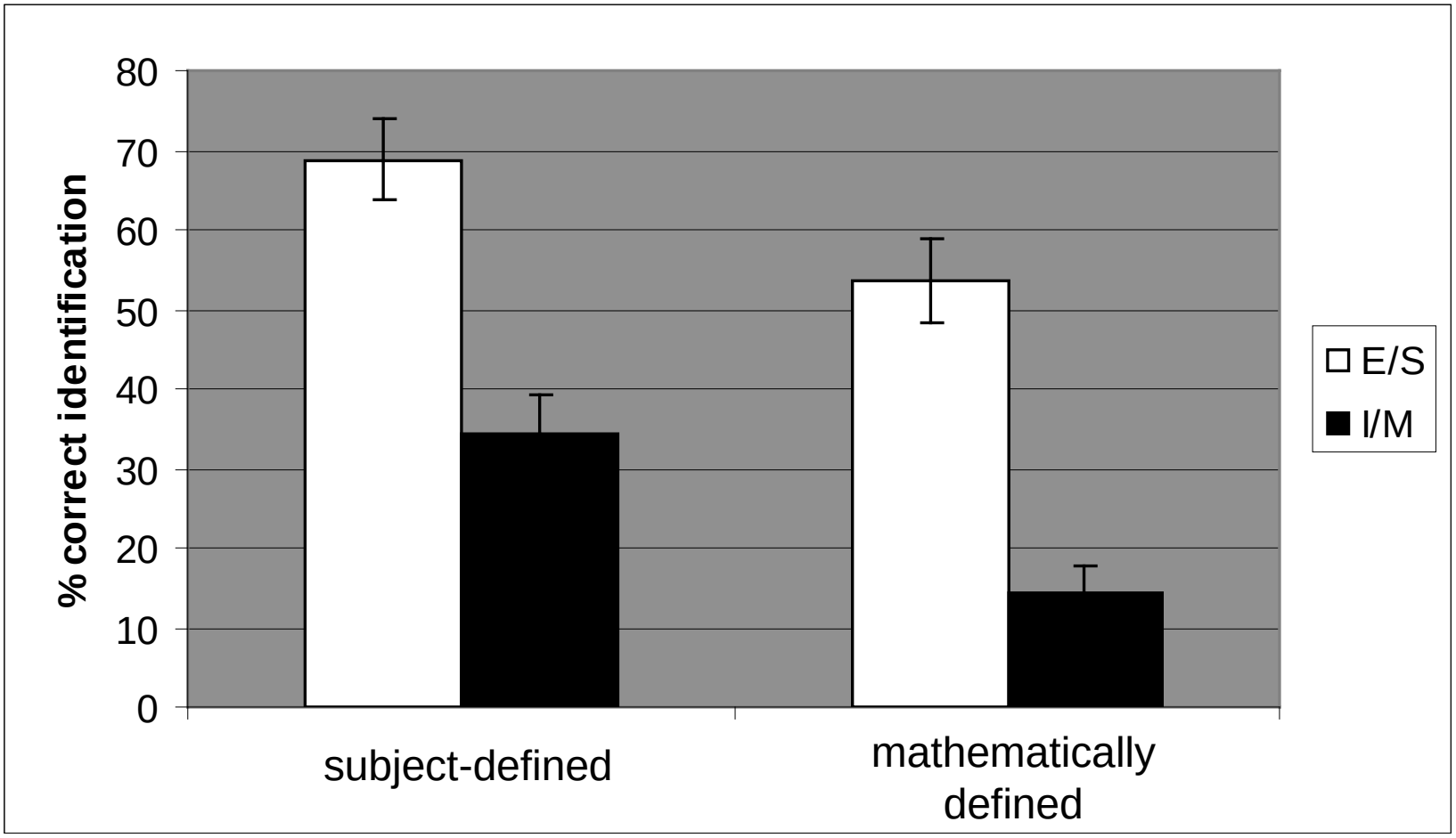
N = 12

Subject-defined salient points

- 108 new subjects
- selection of subject-defined salient points (with fixed parameter values for smoothing and threshold) and points halfway in-between (S versus M)
- 2 versions
  - 100%
  - 75%

- each subject received all four conditions (S 100%, M 100%, S 75%, and M 75%) with different stimuli per condition (stimulus assignment counterbalanced across subjects)
- each stimulus presented only once per subject (for max. 5 sec each)


80
70
60
50
40
30
20
10
0
% correct identification
75% used
100% used
Selection
S
M


% correct identification
80
70
60
50
40
30
20
10
0
subject-defined
mathematically defined
E/S
I/M

Overview

1. Introduction
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- Panis, S., De Winter, J., Vandekerckhove, J., & Wagemans, J. (2008). Identification of everyday objects on the basis of fragmented versions of outlines. *Perception, 37,* 271-289.

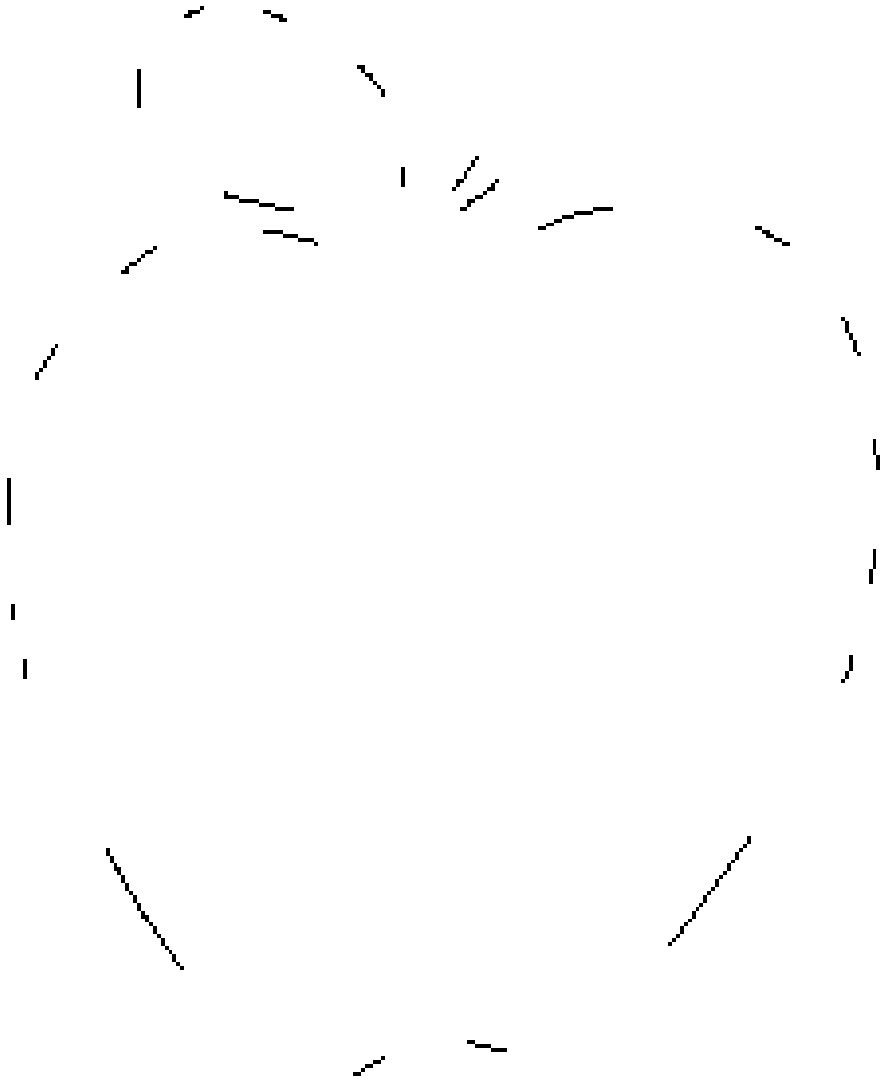
very simple idea

- present only fragments of the contour, centered on particular points
- compare identification rates for versions with different selected points

- 188 stimuli: those that are reasonably well identified on the basis of the whole contour
- 200 subjects: first-year psychology students at the University of Leuven

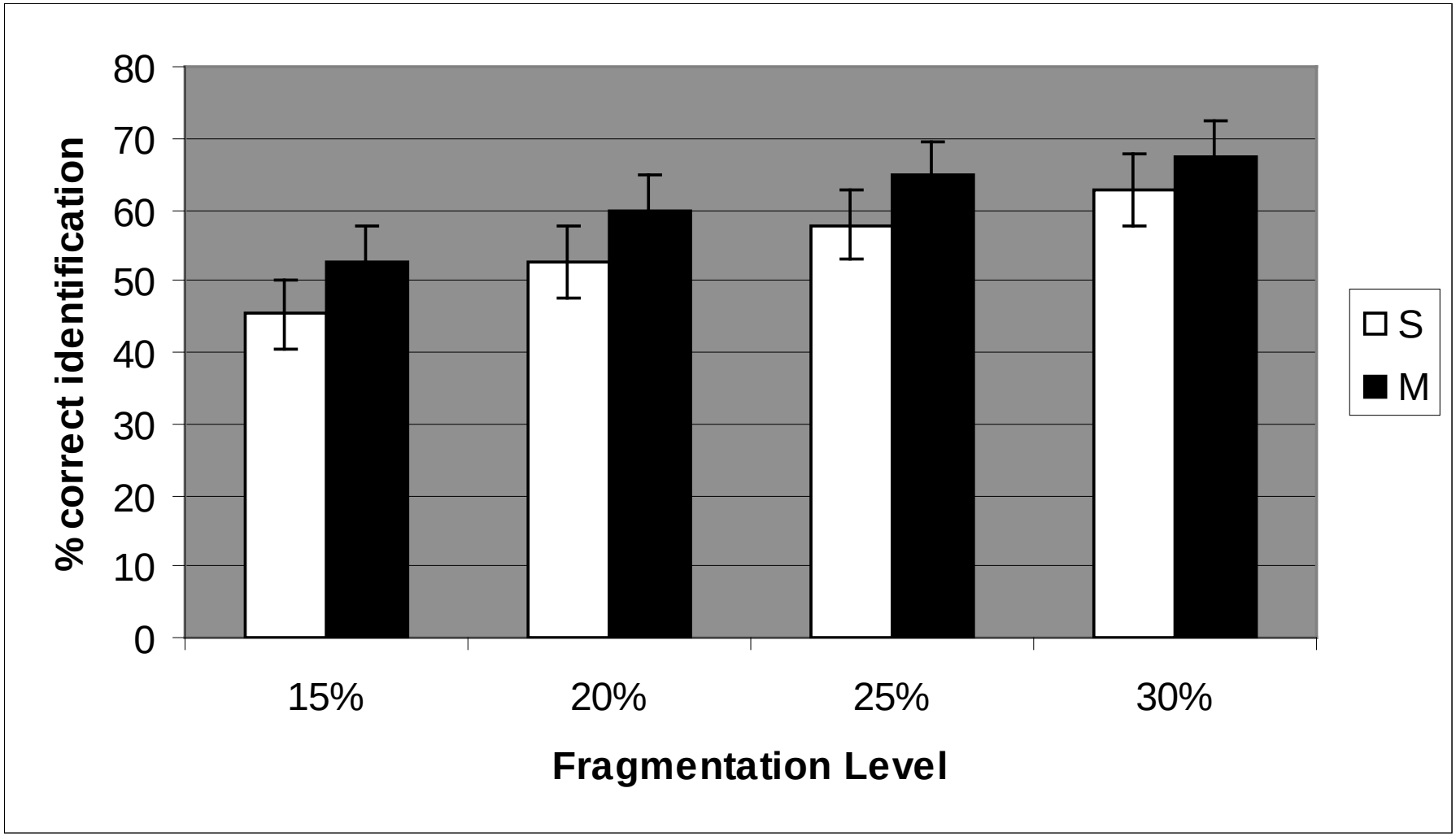
- two types of fragments:
  - centered on salient points (S)
  - centered on midpoints (M)
- four levels of fragmentation: 15, 20, 25, 30% of the contour presented

- each subject received all eight conditions with different stimuli per condition (stimulus assignment counterbalanced across subjects)
- each stimulus presented only once per subject (for max. 5 sec each)



30% M

20% S

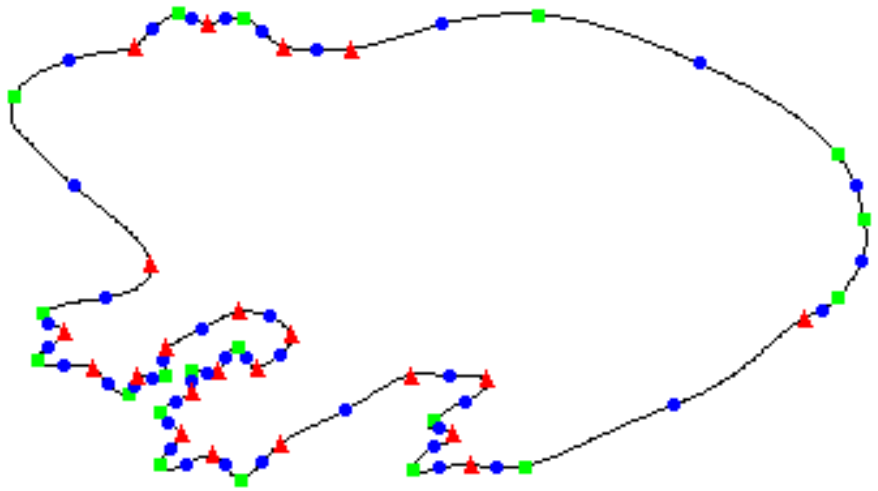

80
70
60
50
40
30
20
10
0
% correct identification
15%
20%
25%
30%
Fragmentation Level
S
M

S 25%

38%

M 25%

73%



S 30%

44%

M 30%

84%

- in sharp contrast to straight-line versions, fragments centered on midpoints more informative than fragments centered on salient points
- possible reasons
  - larger number of longer fragments
  - better direction information
  - easier grouping
  - …

See also

- Panis, S., & Wagemans, J. (2008). Time-course contingencies in perceptual organization and identification of fragmented object outlines. *Journal of Experimental Psychology: Human Perception and Performance,* in press.
  - brief exposures
  - more focus on differences between shapes/objects
  - more focus on differences with Biederman & Blickle (1985)

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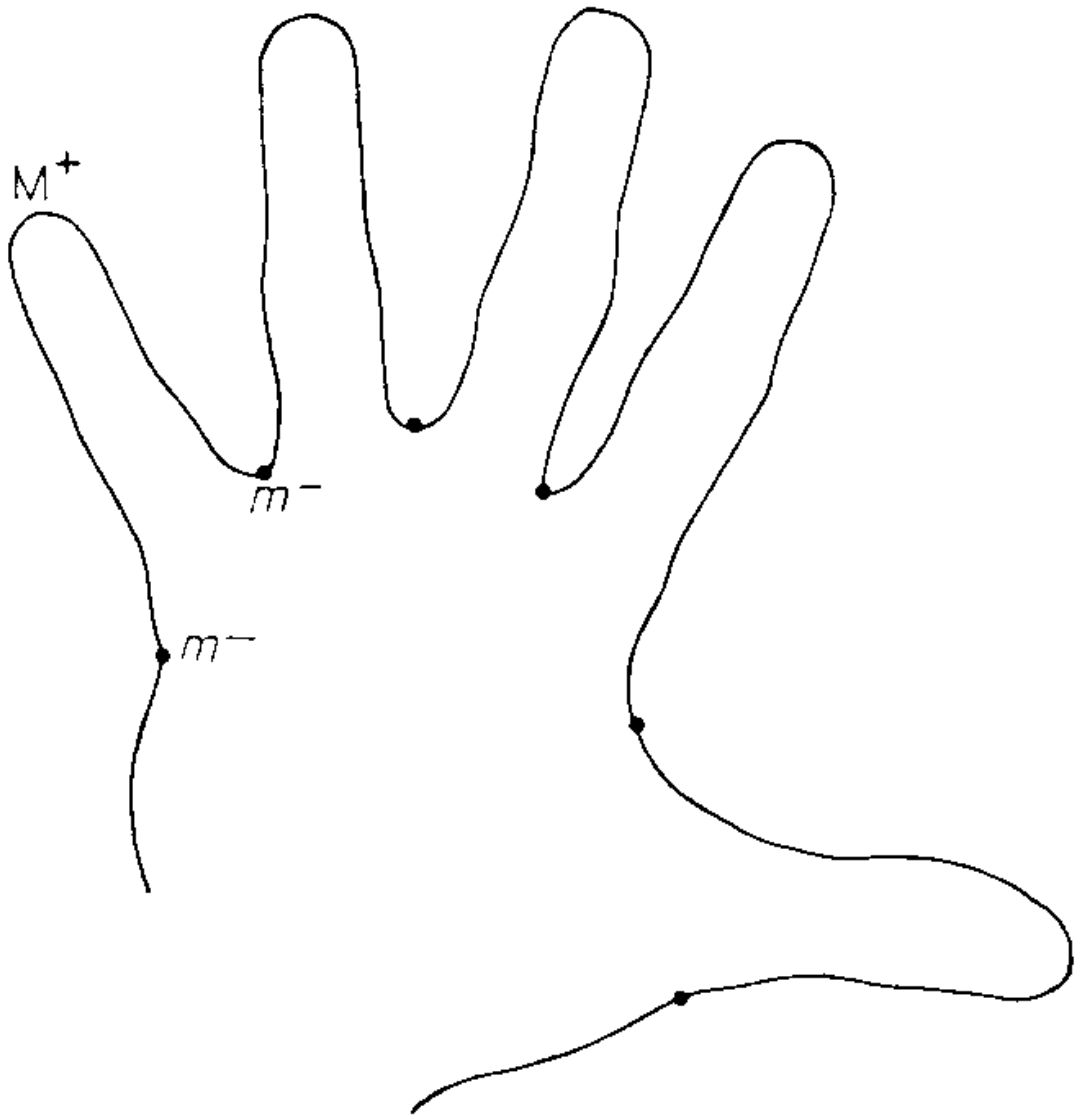
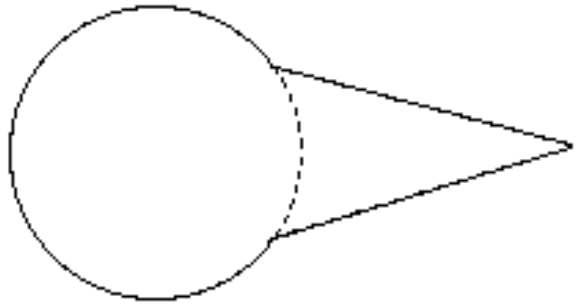
7. Current directions

- De Winter, J., & Wagemans, J. (2006). Segmentation of object outlines into parts: A large-scale, integrative study. *Cognition*, *99*, 275-325.

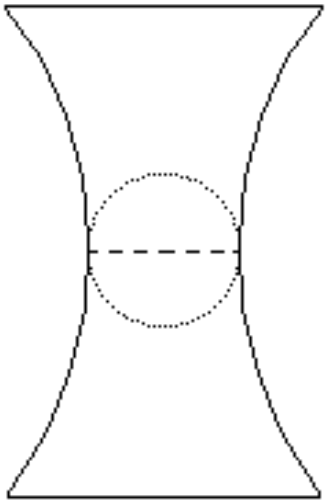
- 88 stimuli: 44 that are reasonably well identified on the basis of the whole contour and 44 difficult to identify
- 201 subjects: first-year psychology students at the University of Leuven
- 22 stimuli per subject
- paper-and-pencil test



Minima rule by Hoffman & Richards (1984)

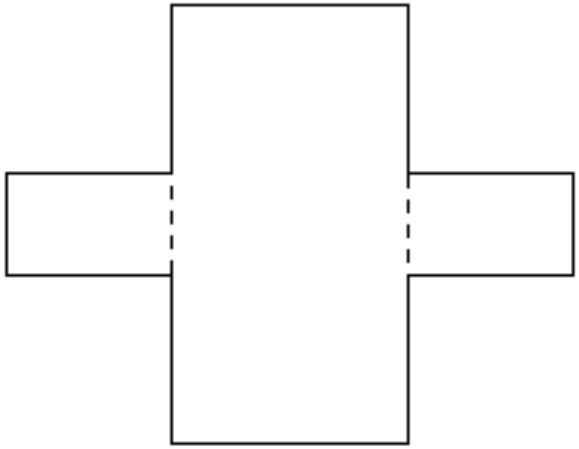


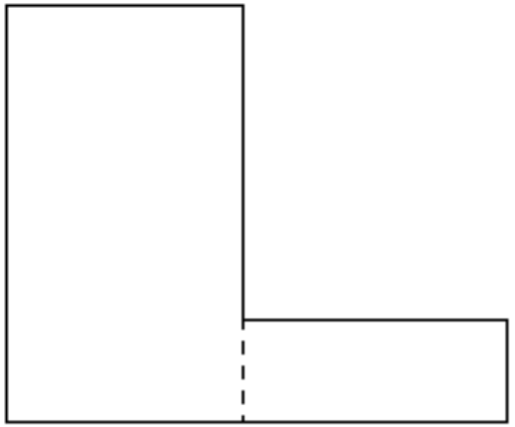
Limb



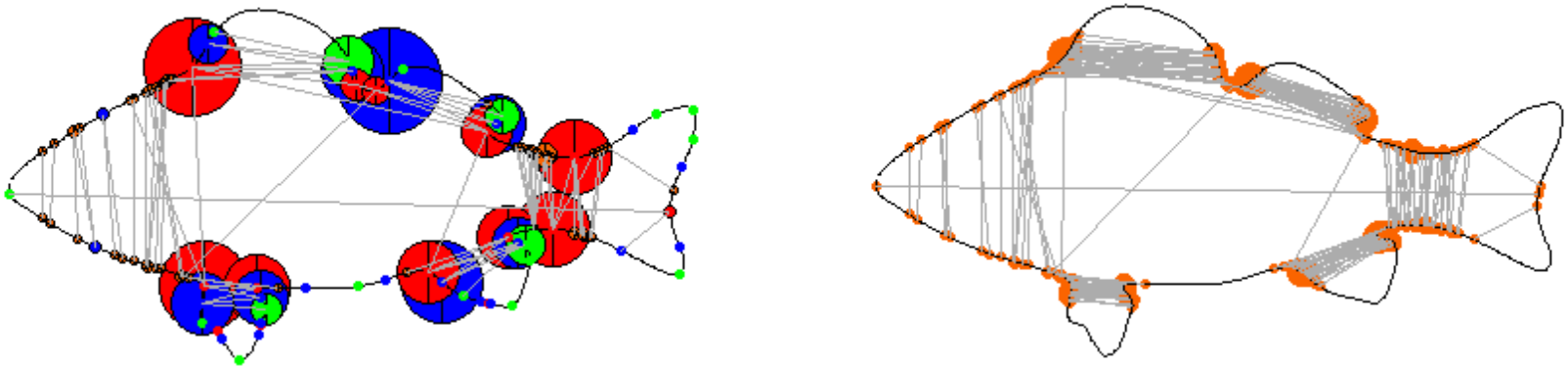
Neck

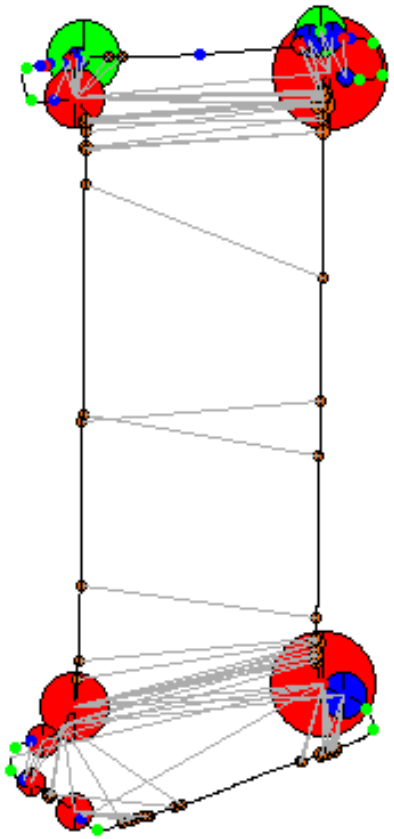
Limbs and necks by Siddiqi et al. (1996)

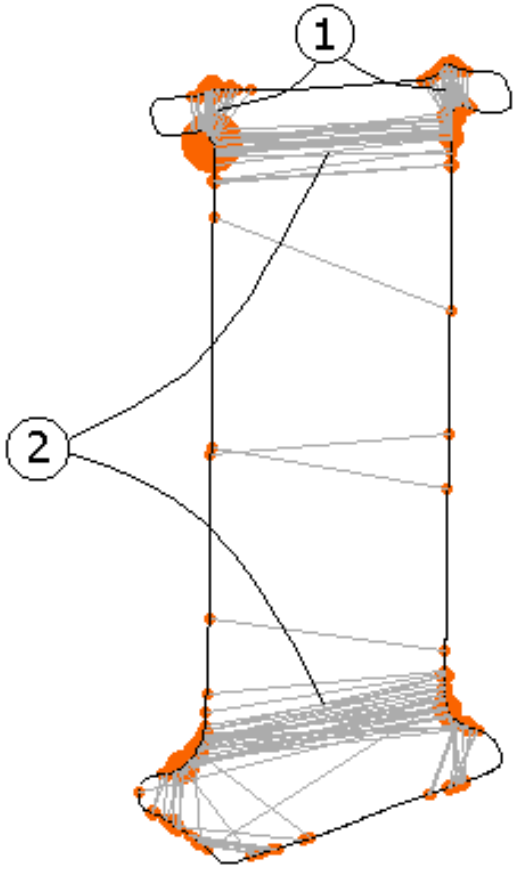


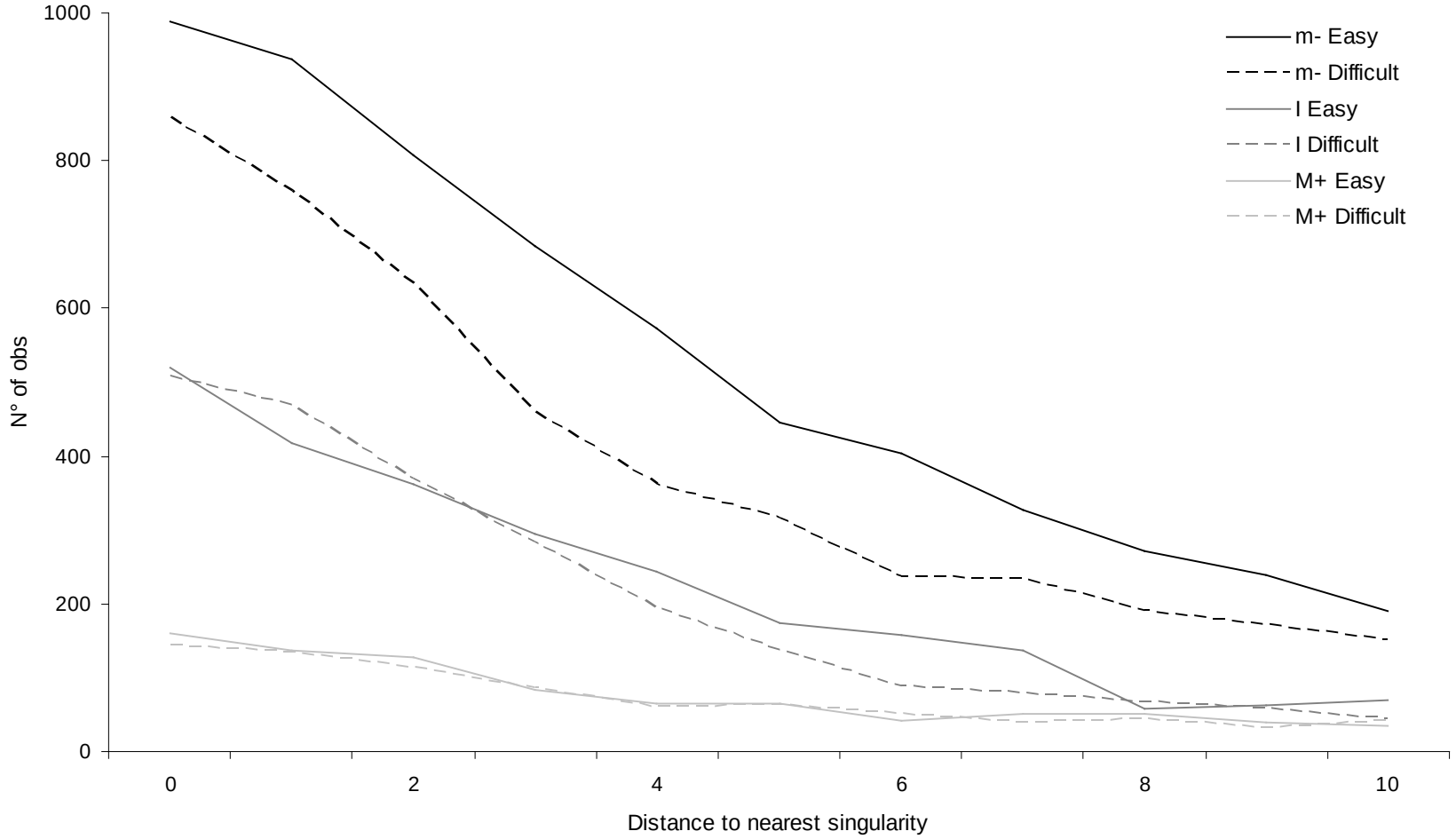


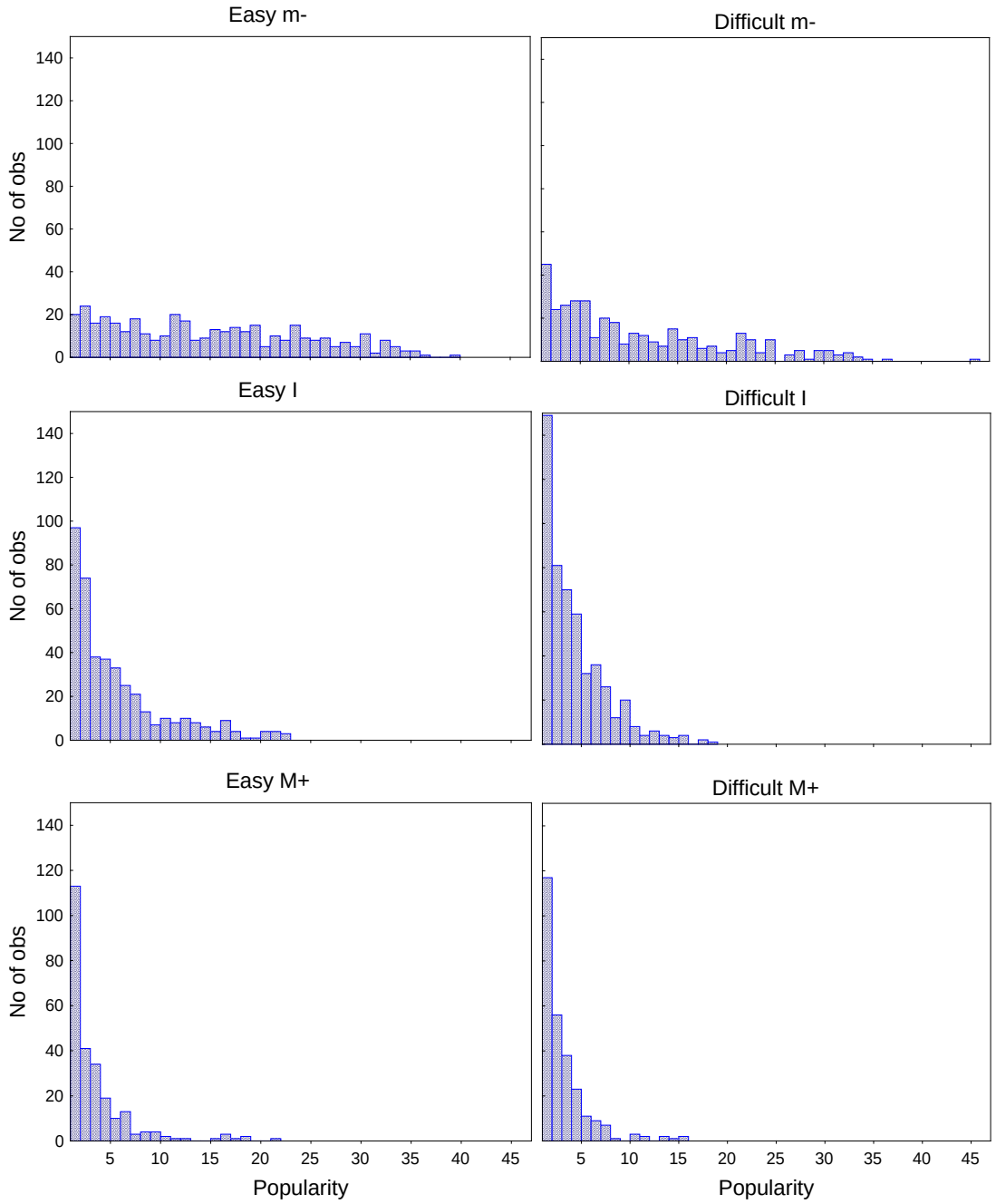
Short-cut rule by Singh et al. (1999)

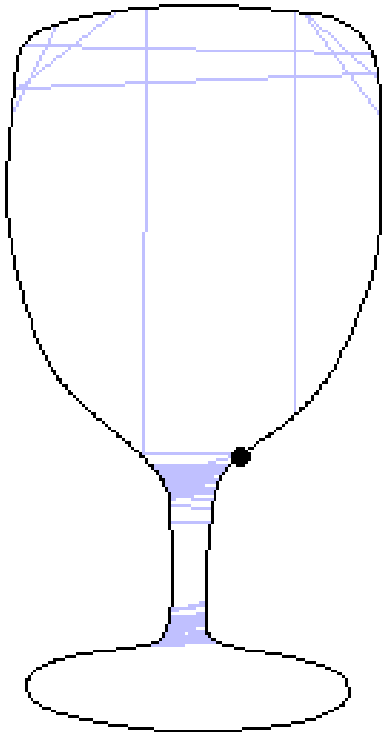


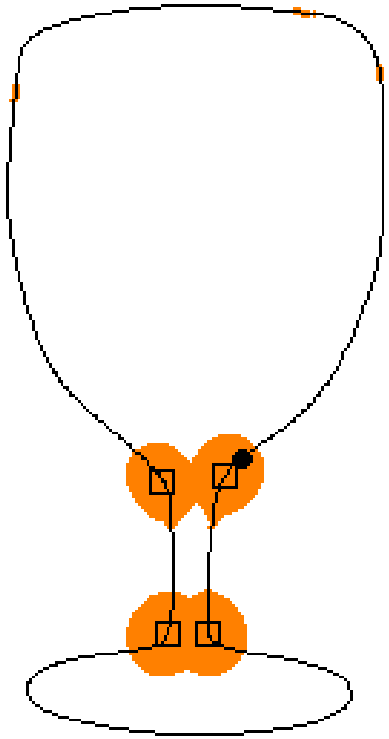


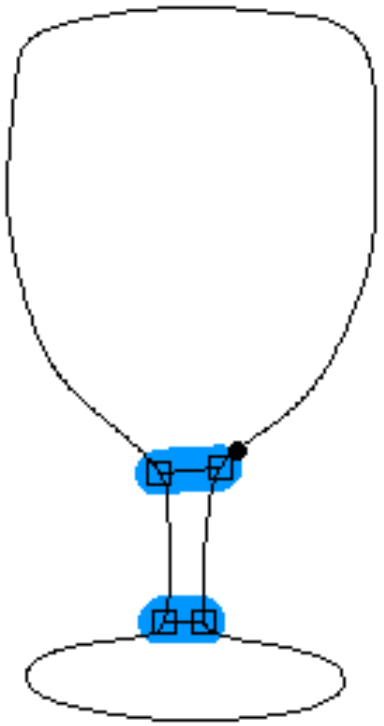

1
2

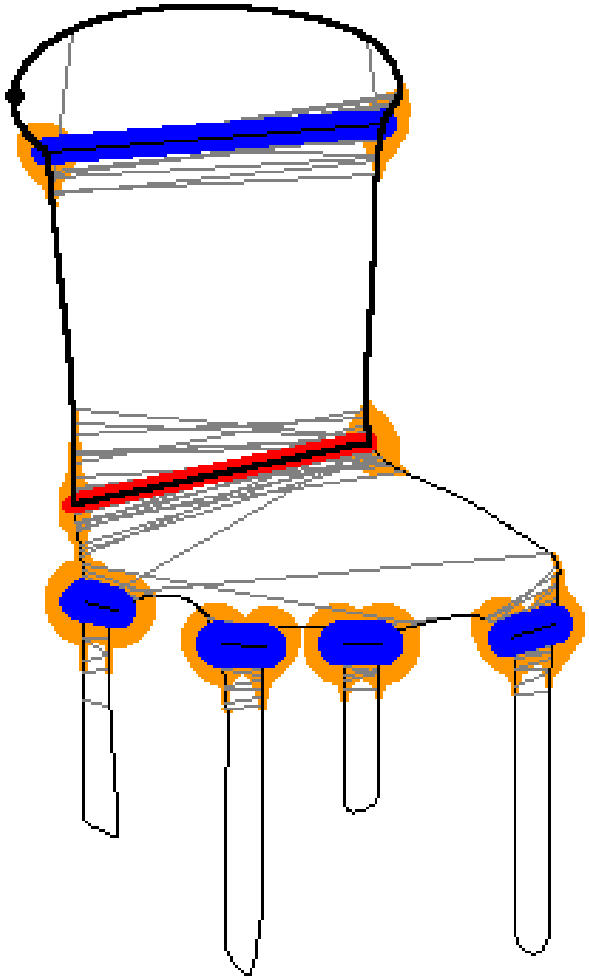

1000
800
600
400
200
0
N° of obs
0
2
4
6
8
10
Distance to nearest singularity
m- Easy
m- Difficult
I Easy
I Difficult
M+ Easy
M+ Difficult

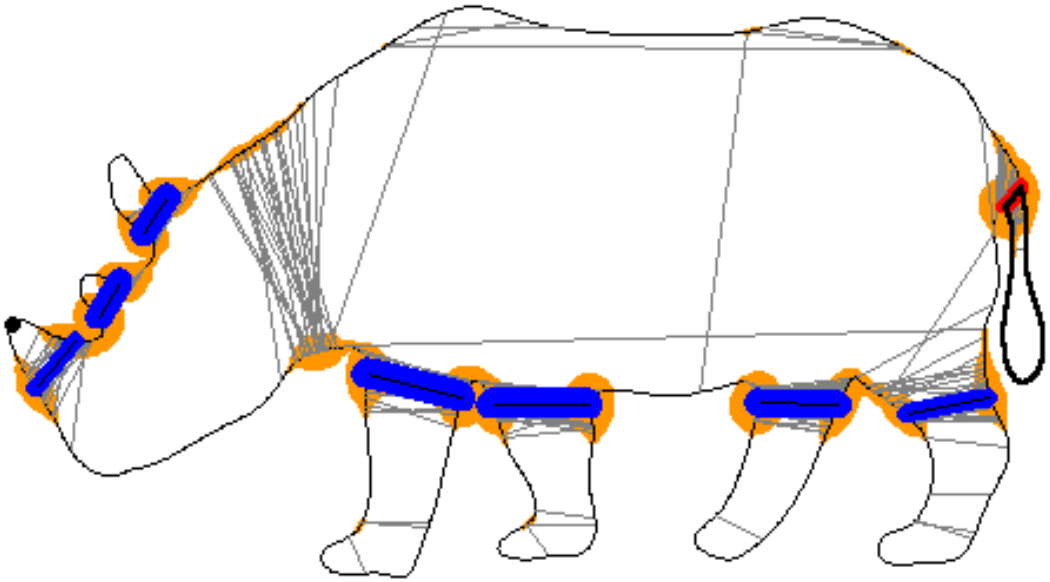

Easy m-
Difficult m-
Easy I
Difficult I
Easy M+
Difficult M+
No of obs
0
20
40
60
80
100
120
140
5
10
15
20
25
30
35
40
45
Popularity

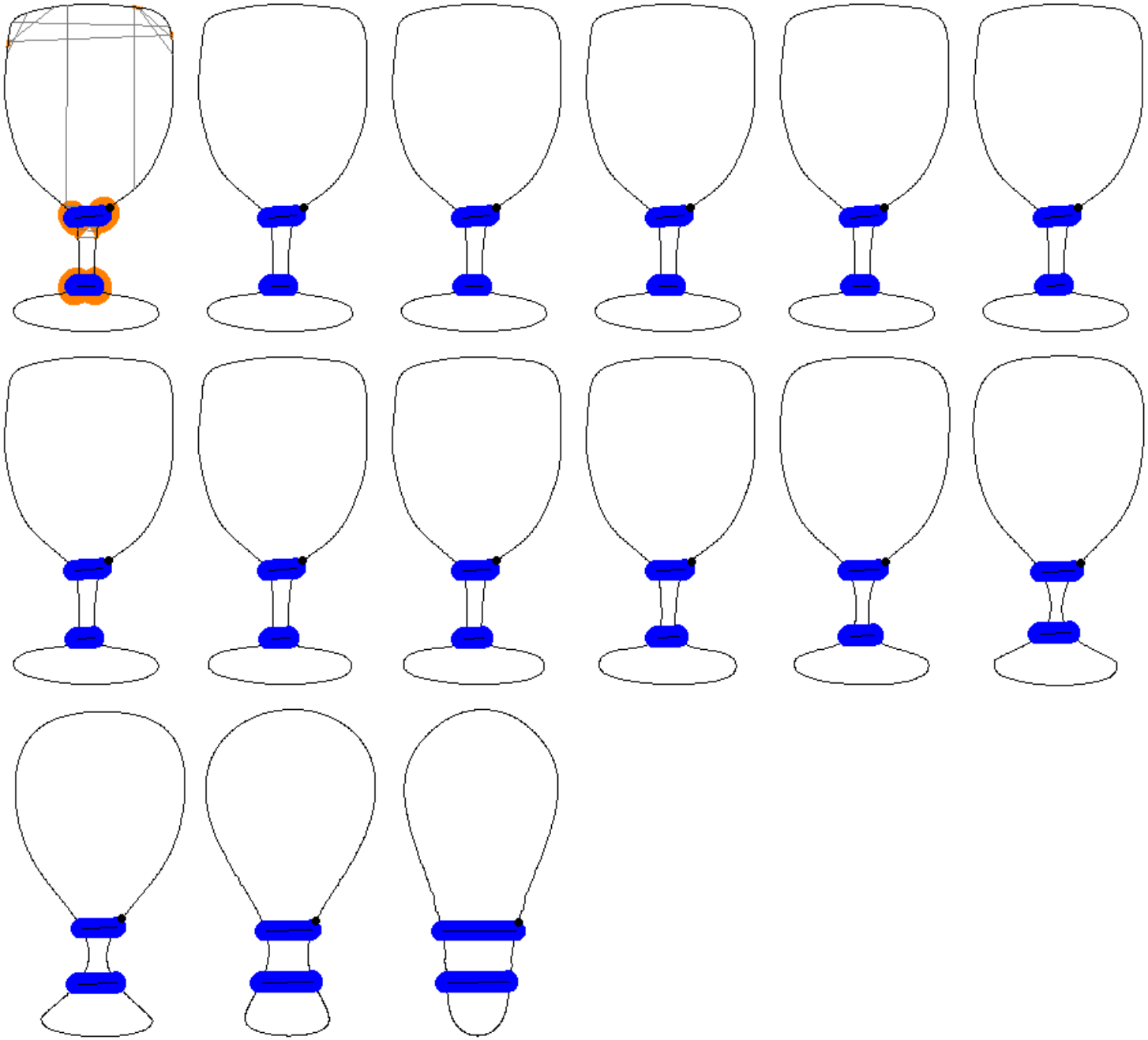


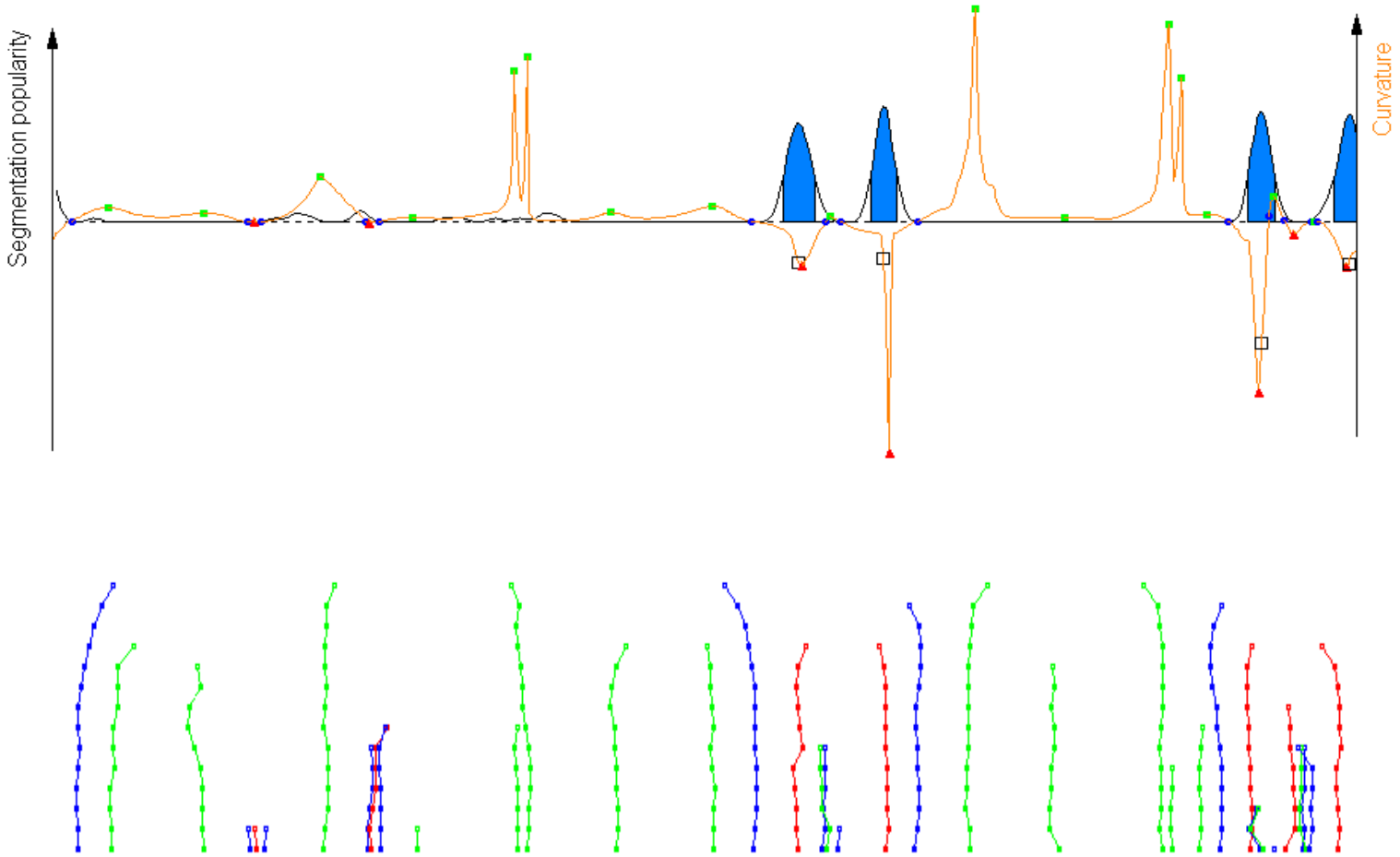


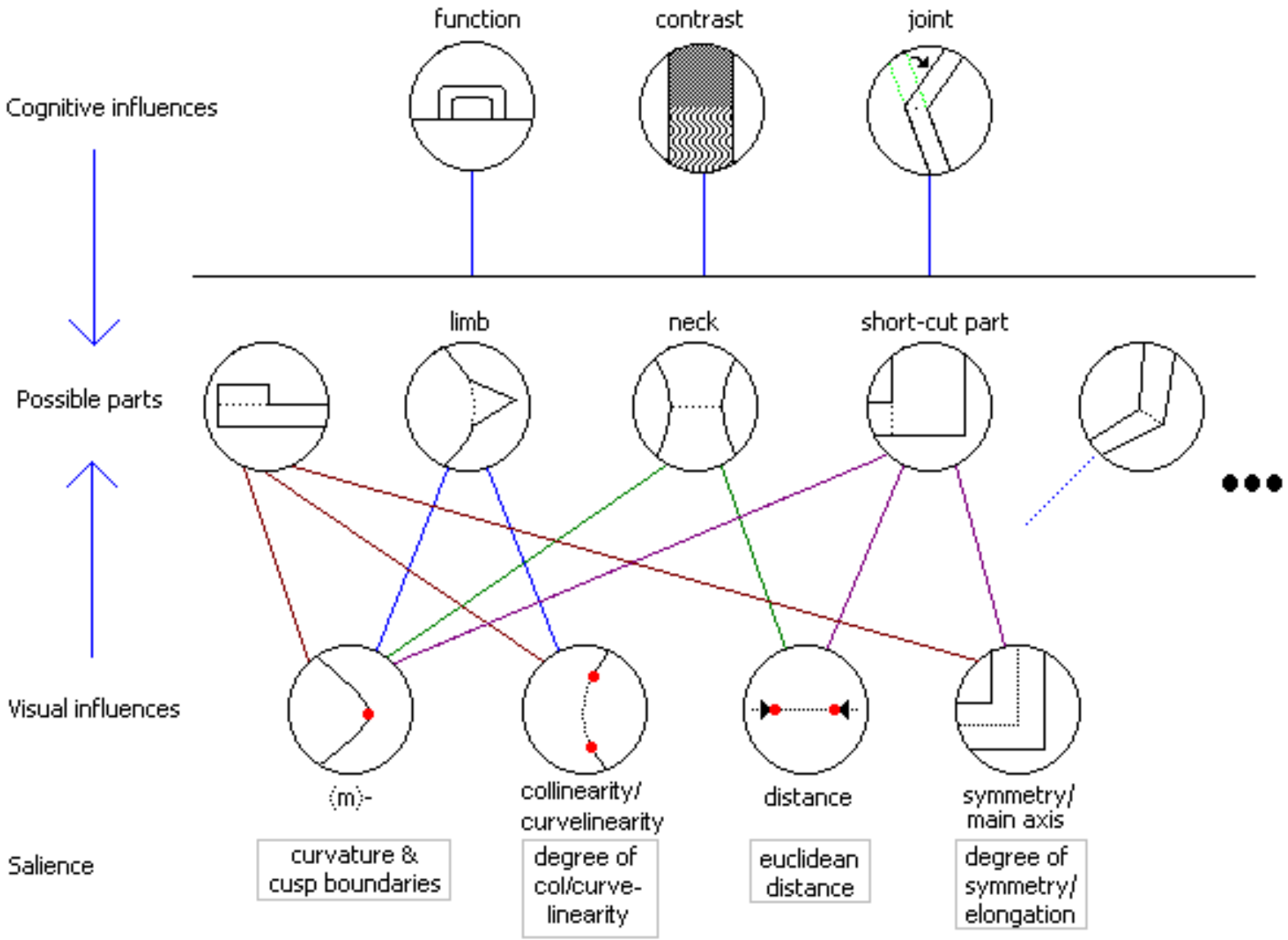









Segmentation popularity
Curvature


function
contrast
joint
Cognitive influences
limb
neck
short-cut part
Possible parts
Visual influences
(m)-
collinearity/
curvelinearity
distance
symmetry/
main axis
Salience
curvature &
cusp boundaries
degree of
col/curve-
linearity
euclidean
distance
degree of
symmetry/
elongation

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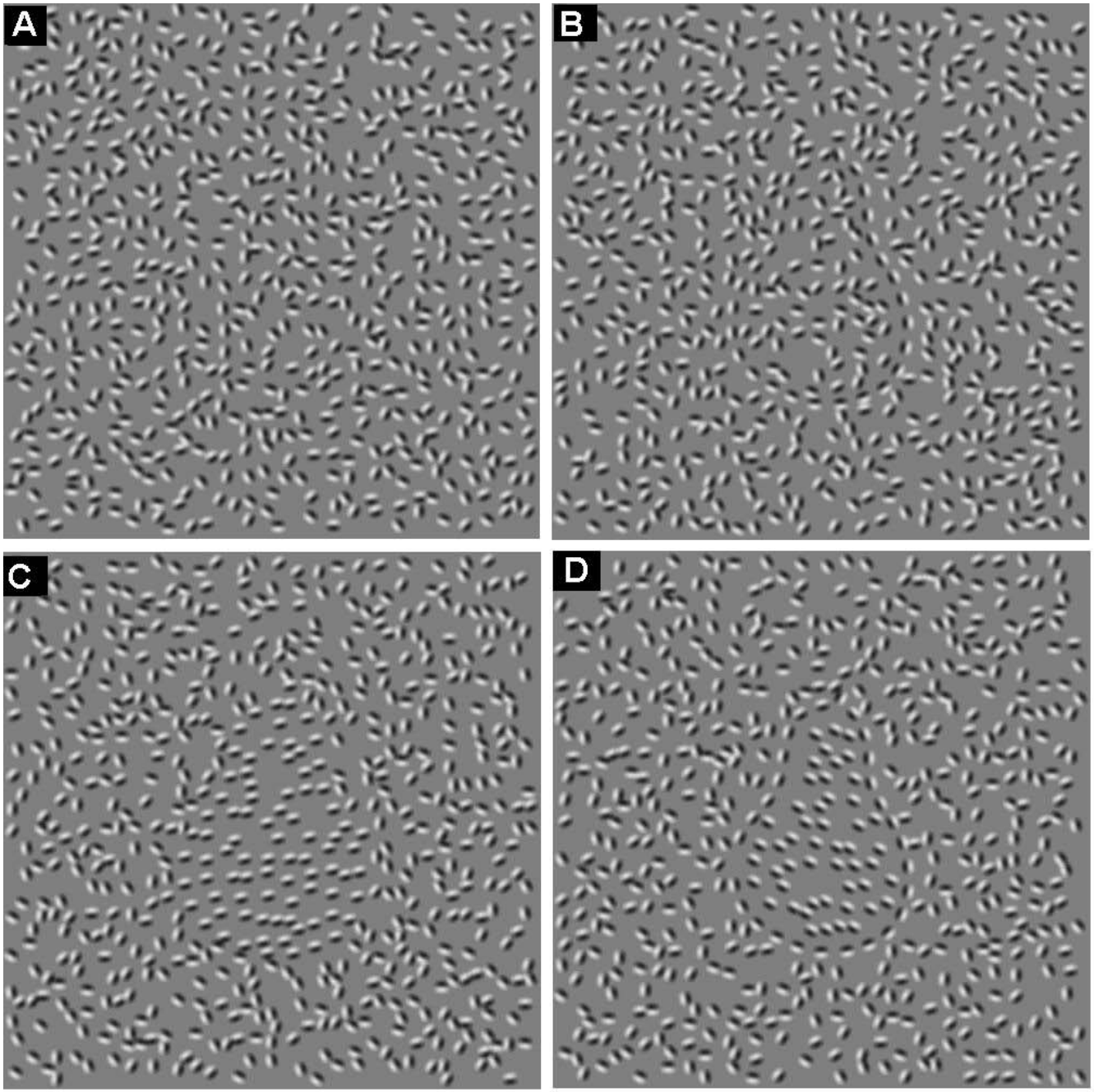
Current directions

- More fine-grained analysis of differences between shapes/objects

- Interactions between contour grouping, figure-ground segmentation and object identification


A
B
C
D

Take home message

- Contours, curvature, and curvature singularities are clearly important
- More global information also plays an important role (e.g. collinearity, good continuation, parallelism, symmetry, …)

Thank you

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- http://www.psy.kuleuven.be/~johanw/