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:
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)


• 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+ and m-
= Extrema (E)
Introduction (ctd)

• 3 types of curvature singularities:

inflections
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
Lowe (1986)
• some nice demonstrations but also good reasons to study this in more detail
  – just demonstrations
  – some empirical doubts
  – some computational concerns
• 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+)
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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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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• 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

Curvature graph

Zero line
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• 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)
one per segment

count as salient
• 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)
Mathematically defined subject-defined
% correct identification

- E/S
- I/M

subject-defined
mathematically defined
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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)
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

  - brief exposures
  - more focus on differences between shapes/objects
  - more focus on differences with Biederman & Blickle (1985)
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• 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)
Limbs and necks by Siddiqi et al. (1996)
Short-cut rule by Singh et al. (1999)
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• More fine-grained analysis of differences between shapes/objects

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