Where Do People Draw Lines?

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Project Goals

- Study what lines artists are likely to draw
- Describe these lines mathematically
Prompt

Drawings

Average Drawing
Average Drawing
Drawings
Prompt
Shape Features
Average Drawing
Overview

• Background
  – Books on drawing
  – Algorithmic line drawing
  – Evaluation studies

• Study Design
• Analysis and Results
• Conclusion
• Dataset Demo
Books on Drawing

- Many, many books on principles of drawing
- Tend to focus on high level issues
- Some describe and suggest good lines
  - Particular lines on the nose [Peck 1982]
  - Contours and ridges [Smith 1997]
- Not particularly formal
Algorithmic Line Drawing

- Well-known lines
  - Occluding contours [Hertzmann 2000]
  - Geometric ridges and valleys [Ohtake 2004]
- New ideas for lines
  - Suggestive contours, highlights [DeCarlo 2003, 2007]
  - Apparent ridges [Judd 2007]
  - Lines via abstracted shading [Lee 2007]
- Informally compared with artists’ drawings
Studies of Artists’ Drawings

• Qualitative comparison with CG [Isenberg 2006]
• Analysis of texture statistics [Maciejewski 2008]
• Line depiction of 3D shapes [Phillips 2005]
  – Correlated lines with shading and curvature
  – Measured how accurately artists draw contours
  – Deliberately used ambiguous shapes
Overview

- Background
- Study Design
  - Artistic Style
  - Drawing Prompts
  - Study Protocol
- Analysis and Results
- Conclusion
- Dataset Demo
Artistic Style

Prompt Image
Artistic Style

Prompt Image

Solid, Smooth Feature Lines
Artistic Style

Prompt Image

Solid, Smooth Feature Lines

Disallow:

Hatching and Shading

Sketchy Lines
Prompt Models

Vertebral column, cervical vertebrae, tooth, femur, tablecloth, lump cloth, screwdriver, flange, rocker arm, pulley, cube hole, bumps.
Study Protocol

Prompt Page

Drawing Page
Study Protocol

Steps:

Prompt Page

Drawing Page
Study Protocol

Steps:
1. Fold
Study Protocol

Steps:
1. Fold
2. Draw
Study Protocol

Steps:
1. Fold
2. Draw
3. Unfold
Study Protocol

Steps:
1. Fold
2. Draw
3. Unfold
4. Trace

Prompt Page

Drawing Page
Study Protocol

Steps:
1. Fold
2. Draw
3. Unfold
4. Trace
5. Scan
Protocol Trade-offs

• Benefits
  – Artists draw freely
  – Results are registered

• Limitations
  – Takes extra effort
  – Possible to change drawing
Collection Results

• 29 artists, art students and some professionals
• 208 drawings collected
• 170 “precise” drawings
  – Traced 90% of exterior silhouette within 1mm
Overview

- Background
- Study Design
- Analysis and Results
  - How similar are the artists’ drawings?
  - Can known CG lines explain artists’ lines?
  - What about other possible definitions?
- Conclusion
- Dataset Demo
Averaged Drawings
Quantifying Similarity

- For each pixel, find closest pixel in the other drawings of the same prompt
- ~75% of distances fall within 1mm (6 pixels)
Describing with CG Lines

- Find fraction of artists’ lines matched by CG lines
- Object-space lines
  - Occluding contours [Hertzmann 2000]
  - Suggestive contours [DeCarlo 2003]
  - Ridges and valleys [Ohtake 2004]
  - Apparent ridges [Judd 2007]
- Image-space lines
  - Image edges [Canny 1986]
CG Line Matching Example
CG Line Matching Example
CG Line Matching Example

Occluding Contours
CG Line Matching Example
CG Line Matching Example

Occluding Contours

Apparent Ridges
Categorization of Lines

- Contours explain 50-65% of all lines
- Other object-space lines explain 15-30%
- Image features alone explain ~5%
Other Object-Space Lines

- Ridge and valley lines very important
- Suggestive contours important for smooth models
- No definition dominates

Bar chart showing:

- Bone
- Mechanical
- Cloth
- Abstract

Legend:
- Other overlap
- RV
- RV & AR
- AR
- SC & AR
- SC

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Artistic Variation

Artist A

Artist B
Artistic Variation

Artist A

Artist B

Legend:
- Other Overlap
- RV
- RV & AR
- AR
- SC & AR
- SC

Tablecloth variations depicted for Artist A and Artist B with color codes for different overlap categories.
Artistic Variation

Artist A

Artist B

Legend:
- Other Overlap
- RV
- RV & AR
- AR
- SC & AR
- SC

0 0.1 0.2 0.3
Artistic Variation

Artist A

Artist B

Legend:
- Other Overlap
- RV
- RV & AR
- AR
- SC & AR
- SC

Values:
- 0
- 0.1
- 0.2
- 0.3
Artistic Variation

Artist A

Artist B

Legend:
- Other Overlap
- RV
- RV & AR
- AR
- SC & AR
- SC
Results for Known Lines

- Can confidently explain 80-90% of lines with known definitions
  - Exact coverage values vary with thresholds
  - Qualitative results remain the same
- What about other possible definitions?
Examining Local Features

- All CG line definitions based on 1-2 local features
- Could we combine more?
- Which are most important?

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<th>Image-Space</th>
<th>Object-Space</th>
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<tbody>
<tr>
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<td>View-Dependent</td>
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<td>( \mathbf{N} \cdot \mathbf{V} )</td>
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<td>ViewDepCurv</td>
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<td>RadialTorsion</td>
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Individual Local Features

- Compare pixels near artists’ lines to remainder

![Graph showing probability of Near Line and Not near line](image-url)
Features in Combination

Regression Tree Model:

\[
\text{ImgGradMag} > 2433.08 \\
\mid \text{ImgGradMag} > 4706.19 \\
\mid \mid 0.181 \\
\mid \mid 0.0341 \\
\mid \text{RadialCurvDeriv} > 0.02 \\
\mid \mid \text{ViewDepCurvDeriv} > 0.044 \\
\mid \mid \mid 0.0455 \\
\mid \mid \mid 0.0175 \\
\mid \mid \text{SurfGaussianCurv} > -0.004 \\
\mid \mid \mid \text{ViewDepCurv} > 0.076 \\
\mid \mid \mid \mid 0.0113 \\
\mid \mid \mid \mid 0.0252 \\
\mid \mid \mid \mid \text{SurfMaxCurvDeriv} > 0.014 \\
\mid \mid \mid \mid \mid \text{SurfMinCurv} > 0.022 \\
\mid \mid \mid \mid \mid 0.0044 \\
\mid \mid \mid \mid \mid 0.0125 \\
\mid \mid \mid \mid 0.0023 \\
\ldots
\]
Feature Importance

• Estimated via Random Forests [Breimann 2001]
• Overall, *image gradient* is most important
• Importance by category:
  – Image space
  – View-dependent object space
  – View-independent object space
Image Edges vs. Others

- Most lines match both image edge and other
- Image edges best single predictor of placement

Bar chart showing:
- Bone: 0.75 image edge, 0.25 other
- Mechanical: 0.50 image edge, 0.50 other
- Cloth: 0.25 image edge, 0.75 other
- Abstract: 0.0 image edge, 1.00 other

Legend:
- Red: Only image edge
- Green: Both
- Blue: Only other
Overview

- Background
- Study Design
- Analysis and Results
- Conclusion
  - Summary of Results
  - Future Work
- Dataset Demo
Summary of Results

- Artists’ lines overlap heavily with other artists’
- Best predictors
  - Image edges: best coverage
  - Occluding contours: most commonly drawn
- All CG lines together explain 80-90% of all lines
Unexplained Lines

• How to explain remaining lines?
  – Artistic license
  – Need better local feature definitions
  – Choices based on global features
How to explain remaining lines?
- Artistic license
- Need better local feature definitions
- Choices based on global features
Future Work

• New studies
  – Shading and stylization effects
  – Perception of shape in artists’ drawings
• Data-driven line drawing synthesis
Synthesis Future Work

Artists’ Composite

Individual Drawing

Probability Image

Synthesized Lines
Dataset Plug

• You can download the full dataset at:

  www.cs.princeton.edu/gfx/proj

• Viewer demo
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