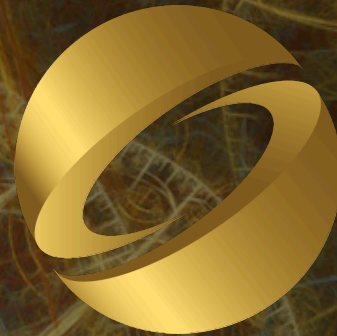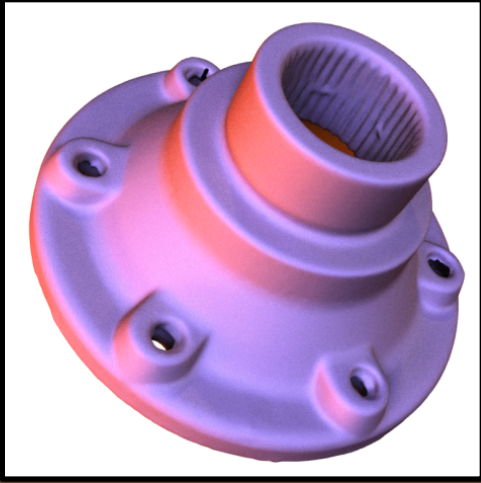SIGGRAPH2008

Where Do People Draw Lines?

SIGGRAPH2008

Forrester Cole, Aleksey Golovinskiy, Alex Limpaecher, Heather Stoddart Barros, Adam Finkelstein, Thomas Funkhouser, and Szymon Rusinkiewicz
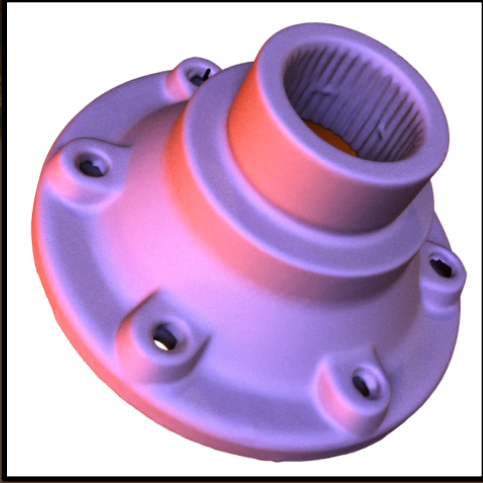
Princeton University

Project Goals

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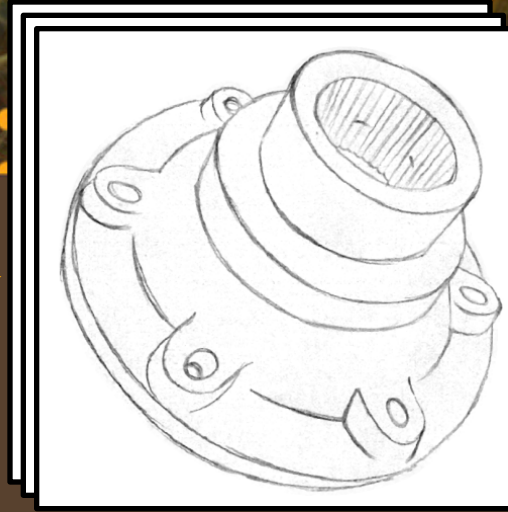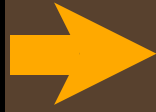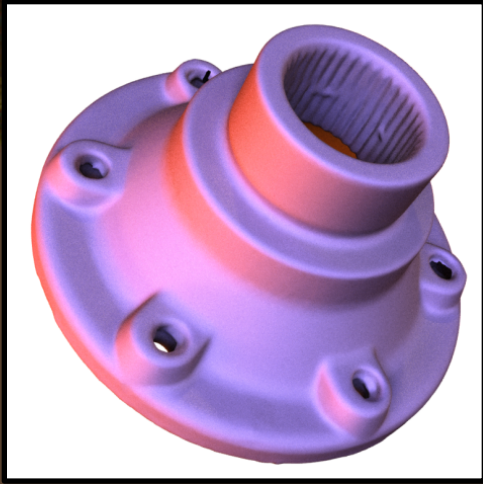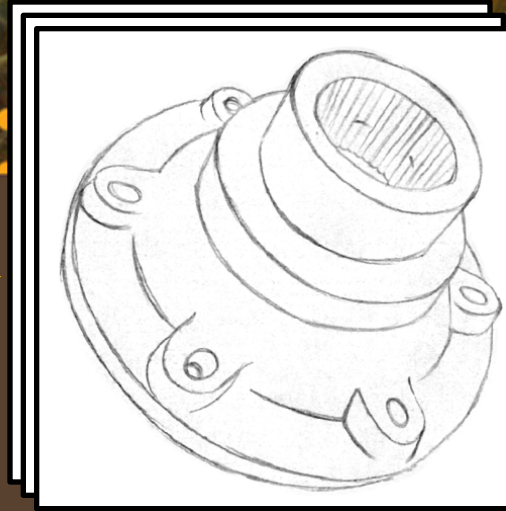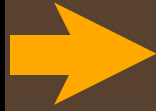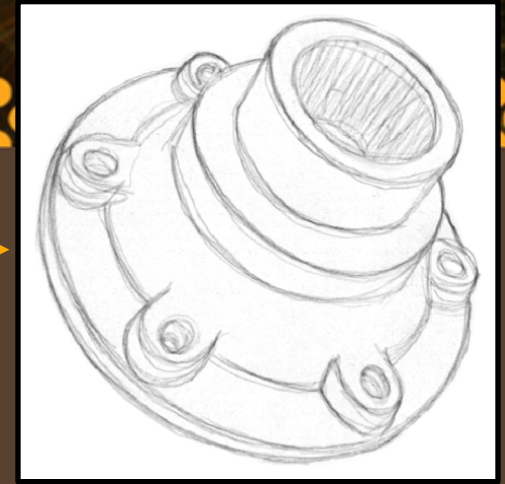- Describe these lines mathematically

Prompt

Prompt

Drawings

Prompt → Drawings → Average Drawing

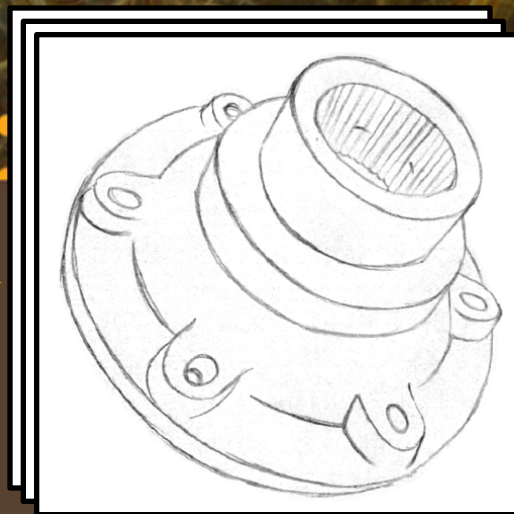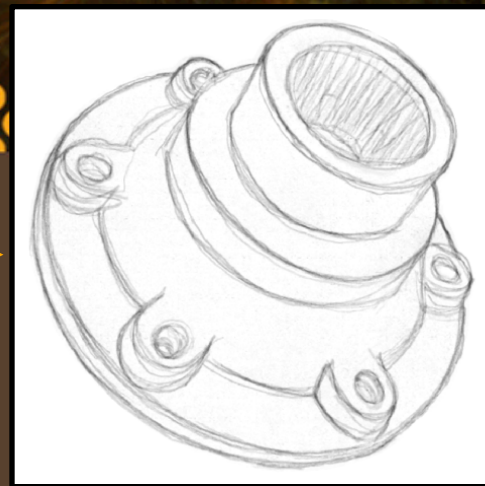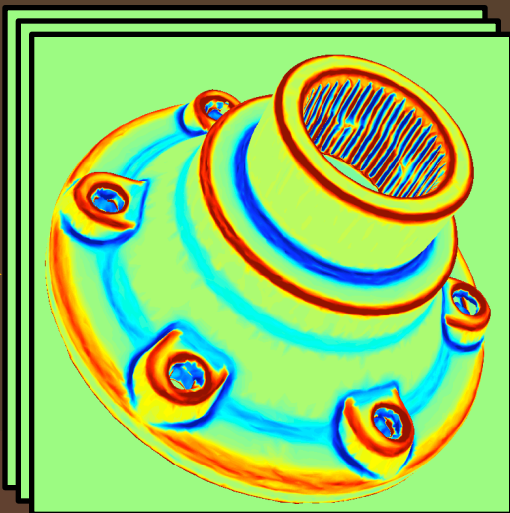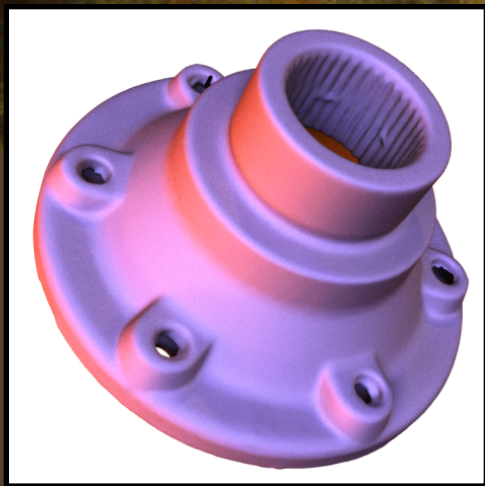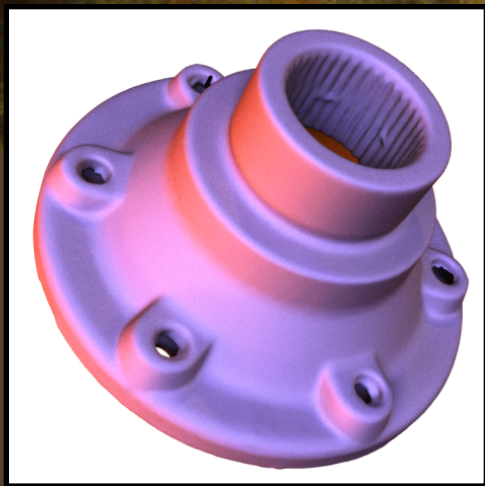Prompt

Drawings

Average Drawing

Shape Features

Prompt
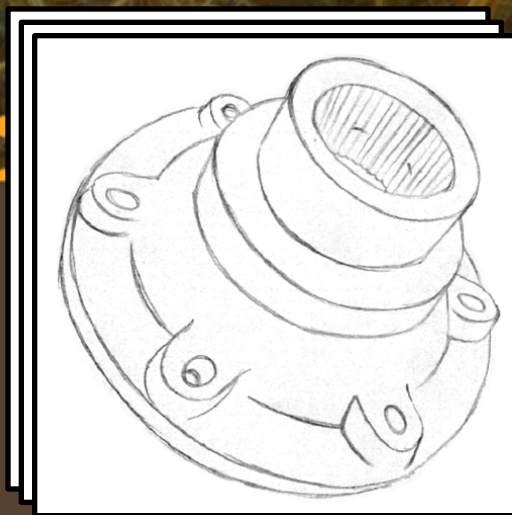
Drawings
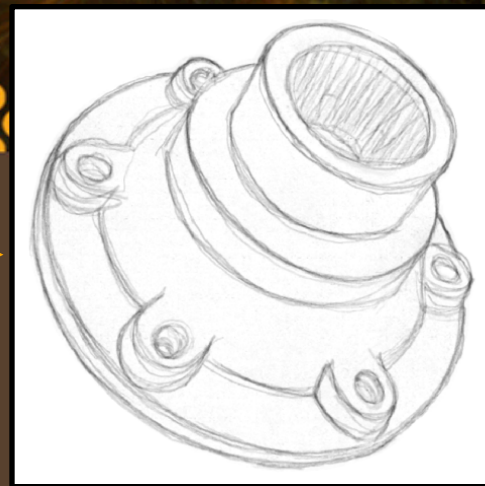
Average Drawing
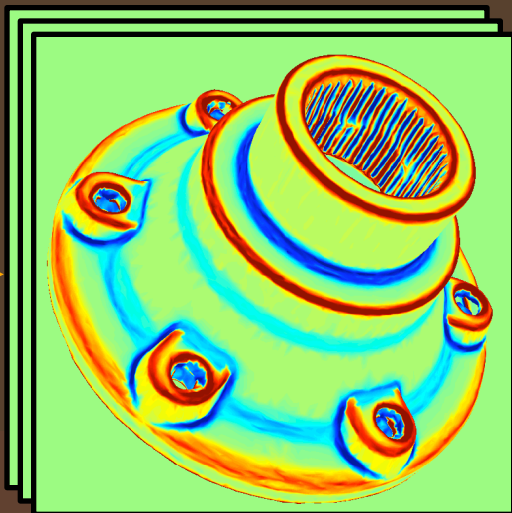
Shape Features
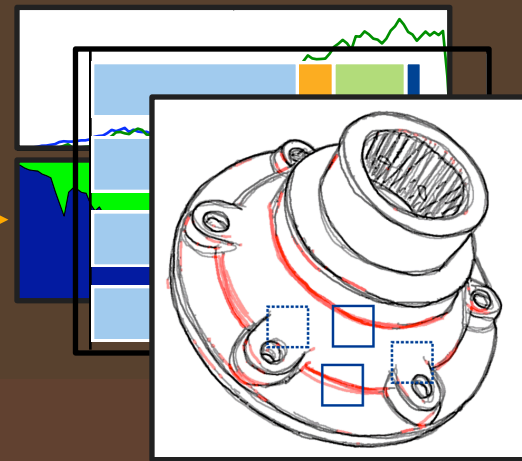
Mathematical Descriptions

Overview

- Background
  - Books on drawing
  - Algorithmic line drawing
  - Evaluation studies
- Study Design
- Analysis and Results
- Conclusion
- Dataset Demo

SIGGRAPH2008

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
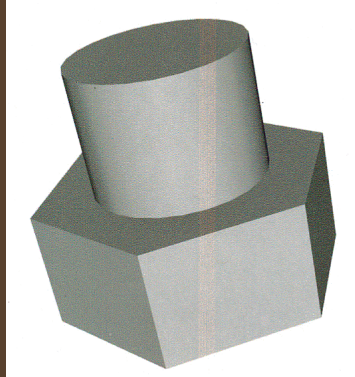 - Deliberately used ambiguous shapes

Overview

- Background

- Study Design
  - Artistic Style
  - Drawing Prompts
  - Study Protocol

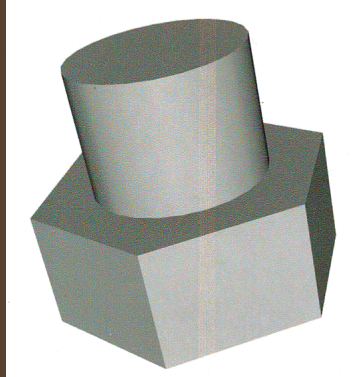- Analysis and Results

- Conclusion

- Dataset Demo

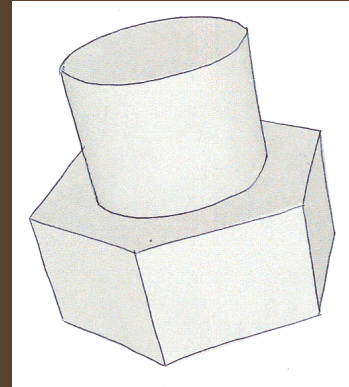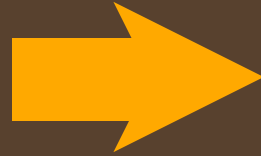SIGGRAPH2008

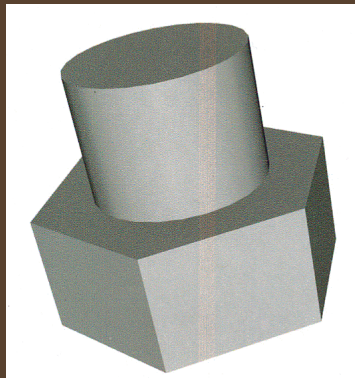# Artistic Style

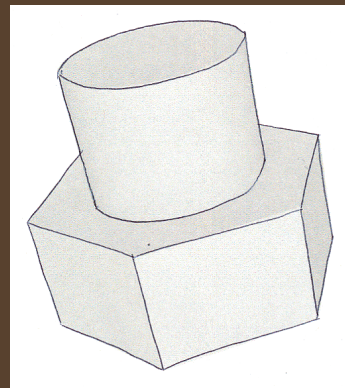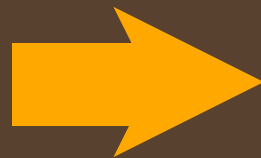Prompt Image

Artistic Style

Prompt Image

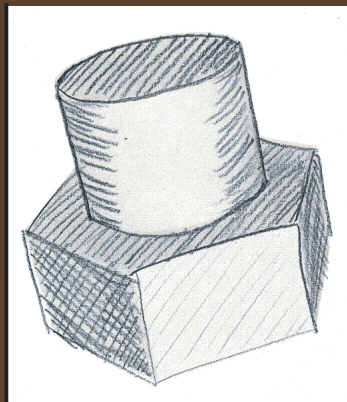Solid, Smooth Feature Lines

Artistic Style
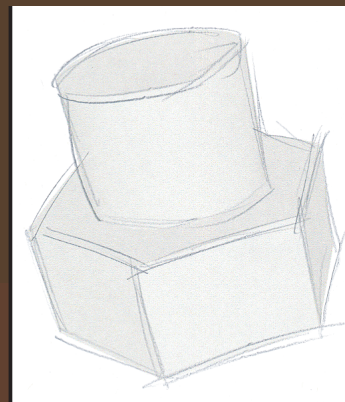

Prompt Image

Solid, Smooth Feature Lines
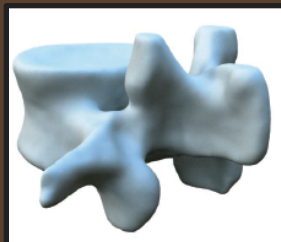
Disallow:

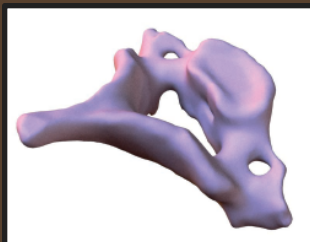Hatching and Shading

Sketchy Lines

Prompt Models

vertebra   cervical   tooth   femur
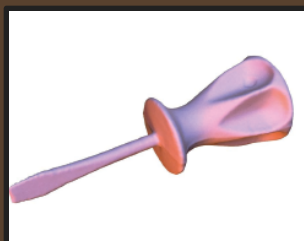
— Bones —

twoboxcloth   lumpcloth
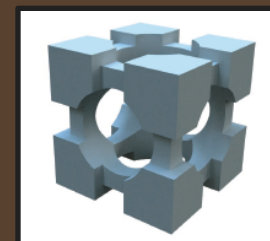
— Tablecloths —

screwdriver   flange   rockerarm   pulley

— Mechanical Parts —
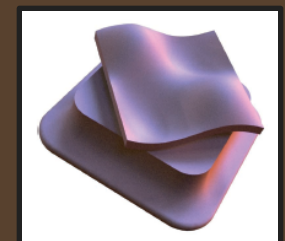
cubehole   bumps

— Abstract Shapes —

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Study Protocol
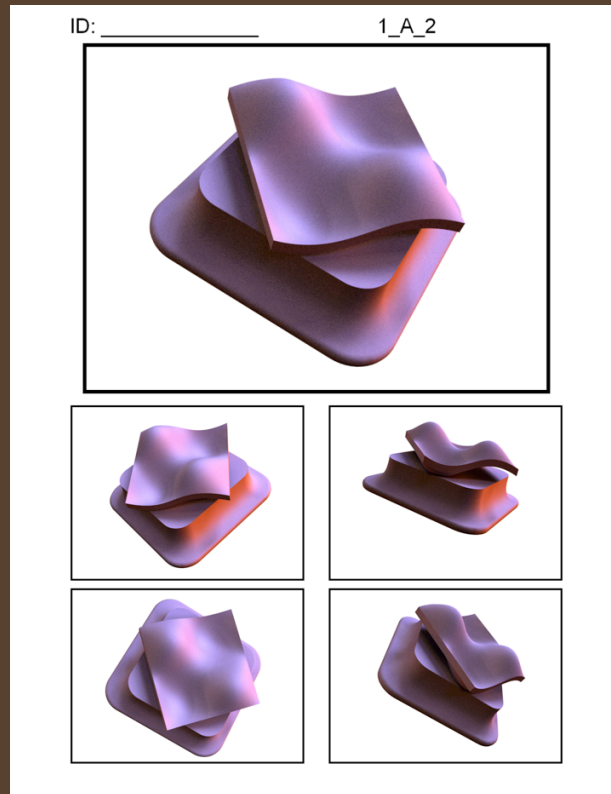
Prompt Page
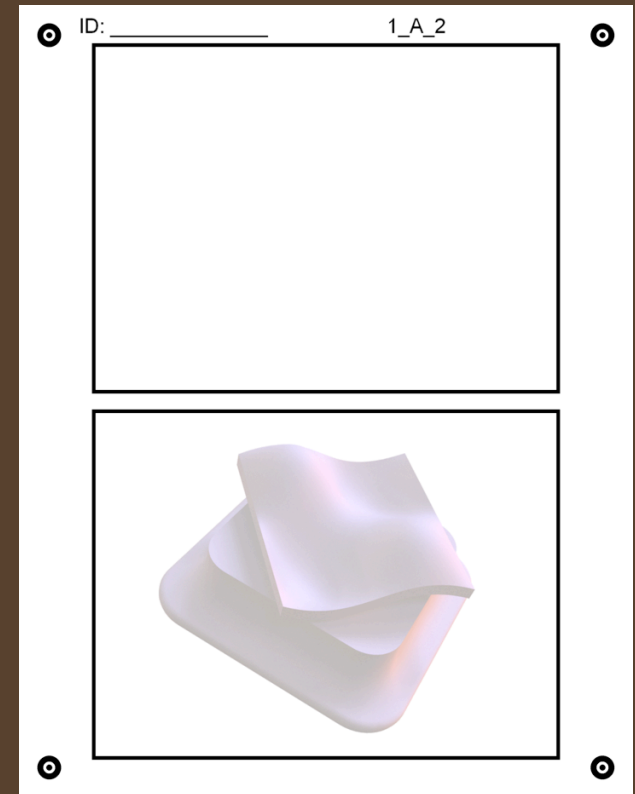
Drawing Page

Study Protocol
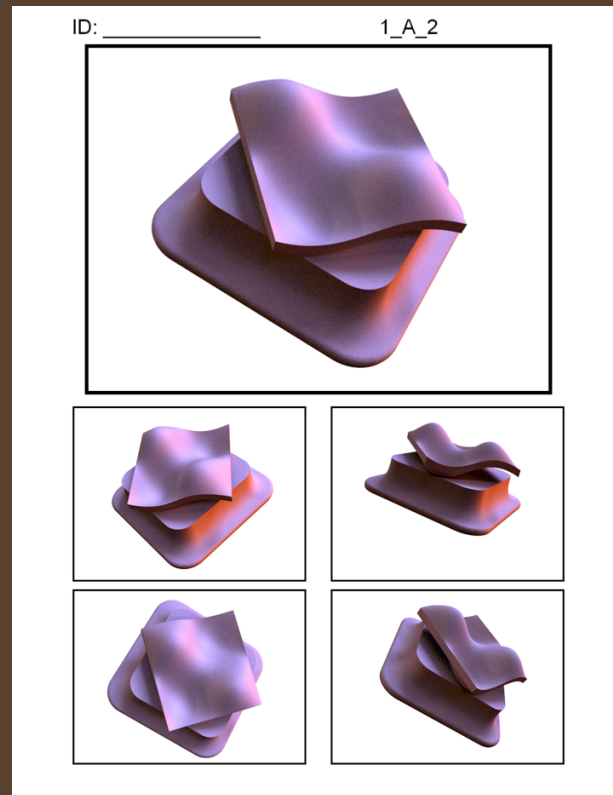
Steps:

Prompt Page
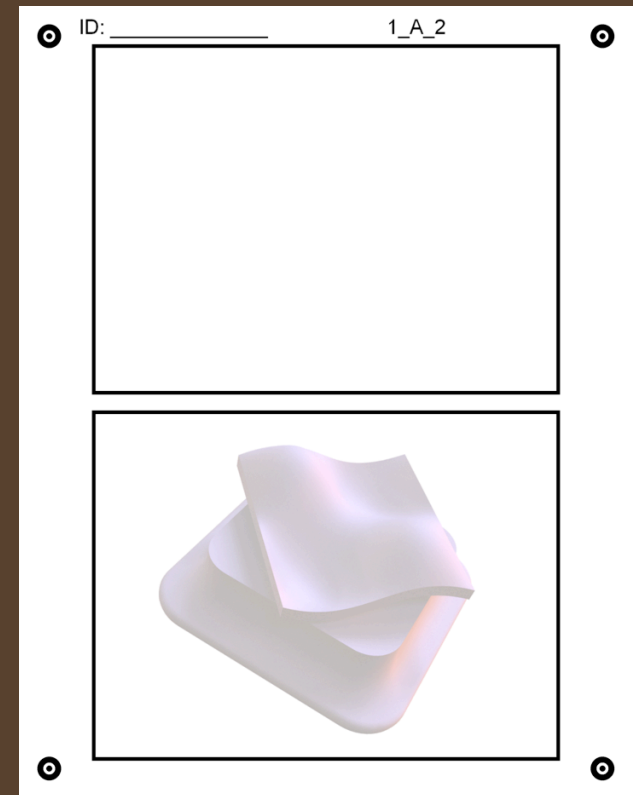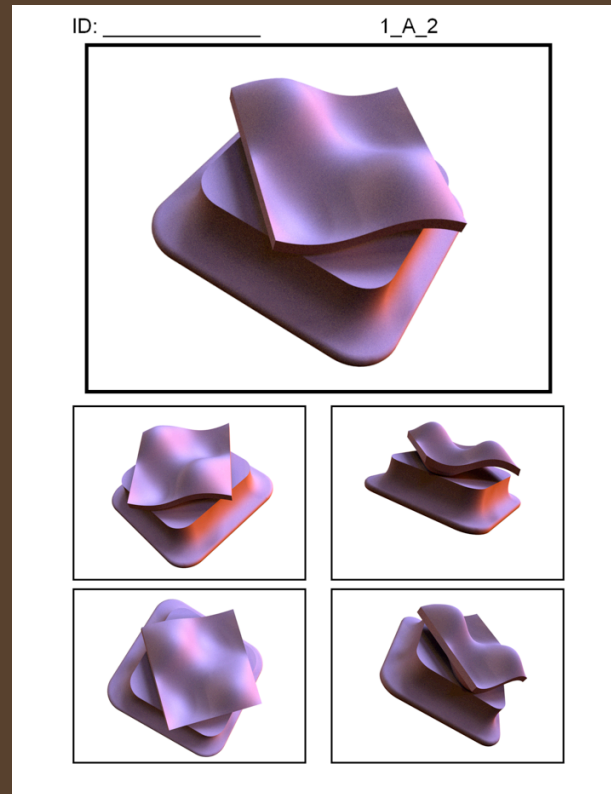
Drawing Page

Study Protocol

Steps:
1. Fold

Prompt Page

Drawing Page

SIGGRAPH2008
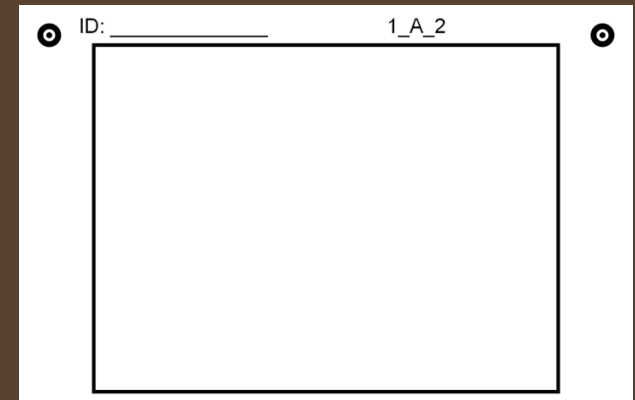
Study Protocol
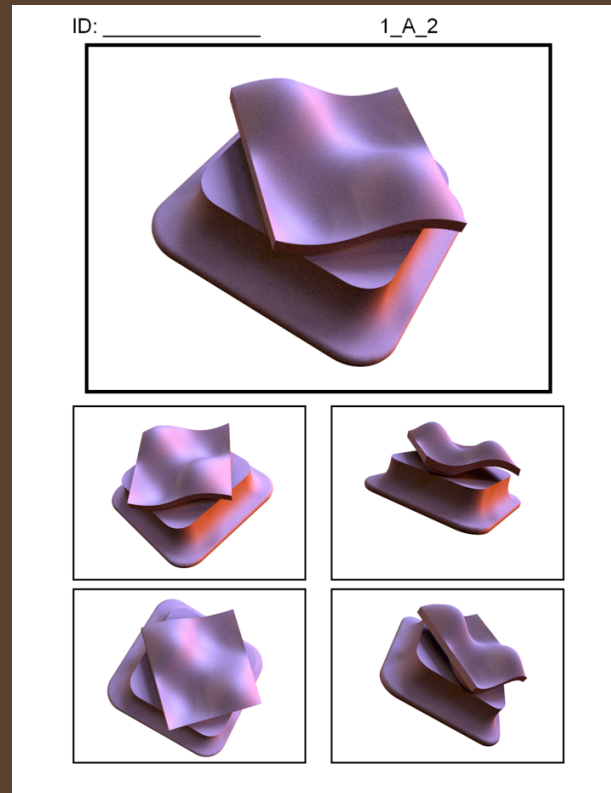
Steps:

1. Fold
2. Draw

Prompt Page
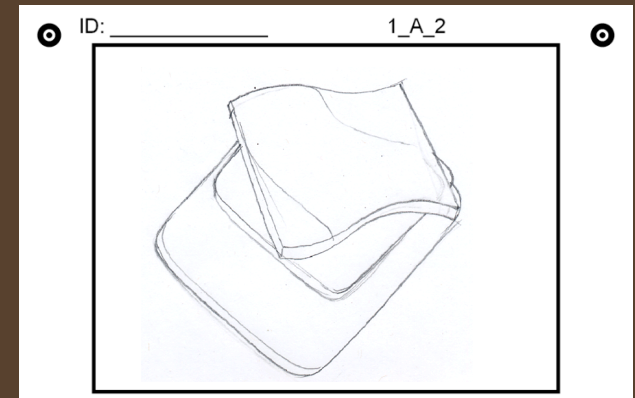
Drawing Page

Study Protocol

Steps:

1. Fold
2. Draw
3. Unfold

Prompt Page

Drawing Page

SIGGRAPH2008
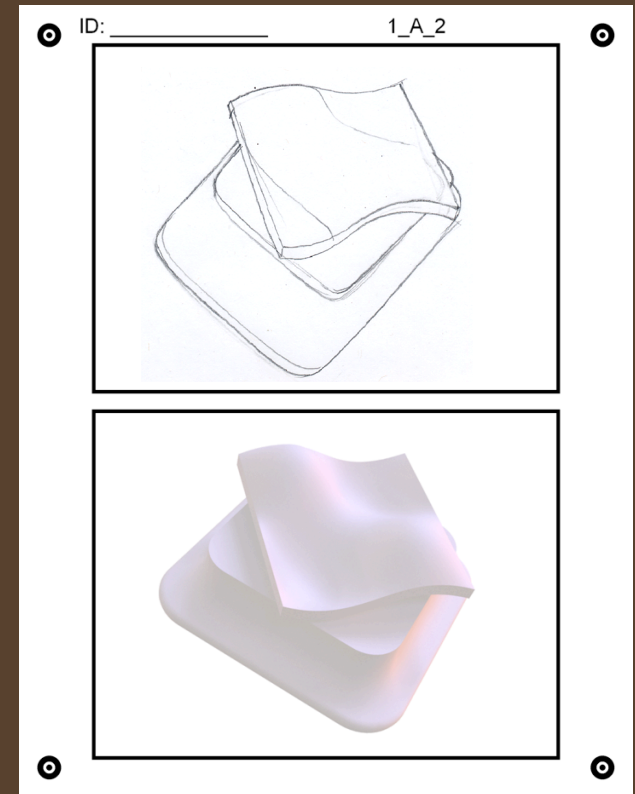
Study Protocol

Steps:

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

Prompt Page

Drawing Page

SIGGRAPH2008
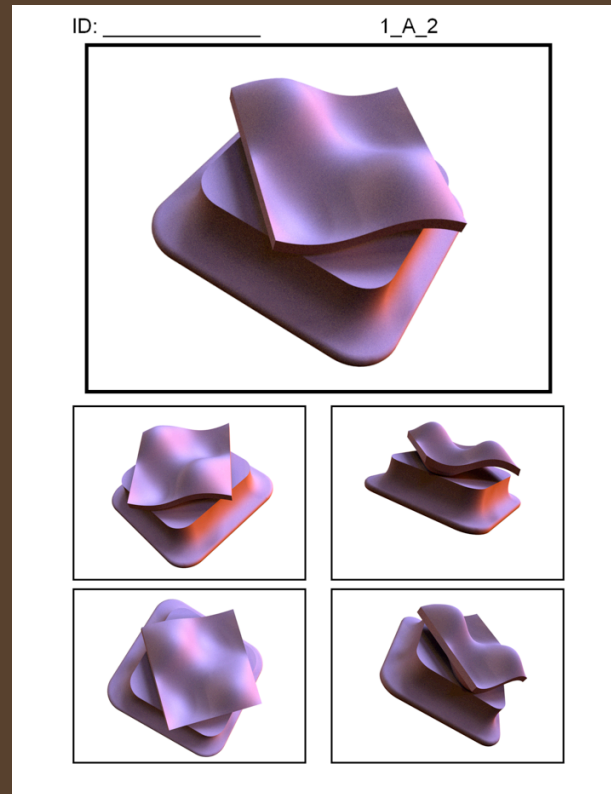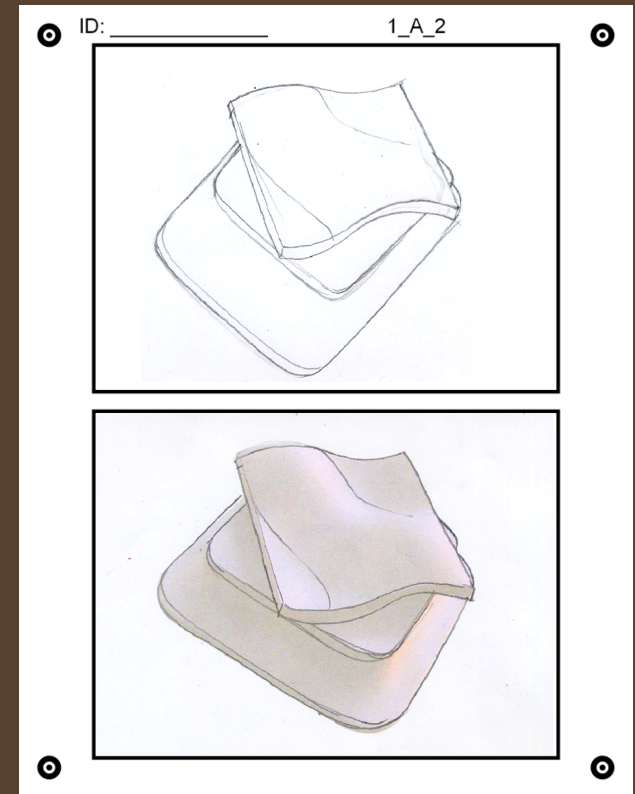
Study Protocol

Steps:

1. Fold
2. Draw
3. Unfold
4. Trace
5. Scan

Prompt Page

Drawing Page

SIGGRAPH2008
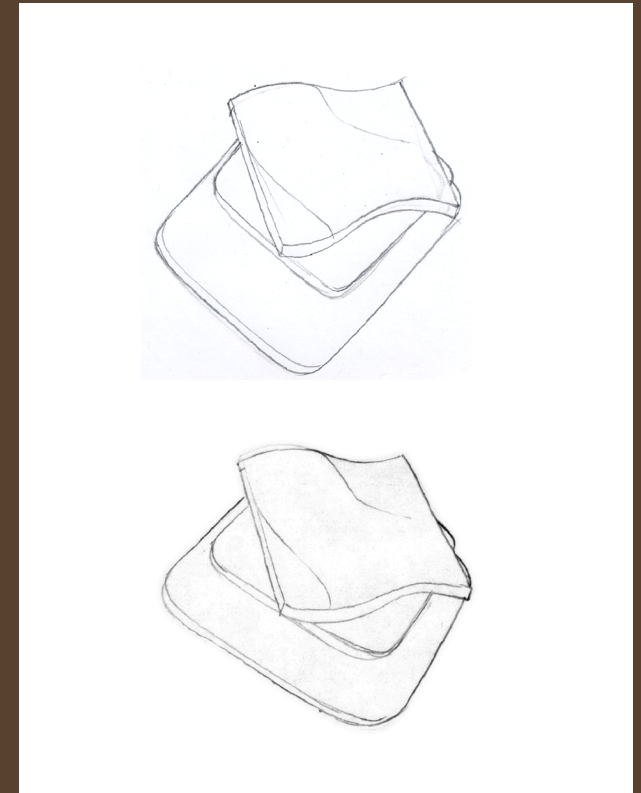
Protocol Trade-offs

- Benefits
  - Artists draw freely
  - Results are registered
- Limitations
  - Takes extra effort
  - Possible to change drawing
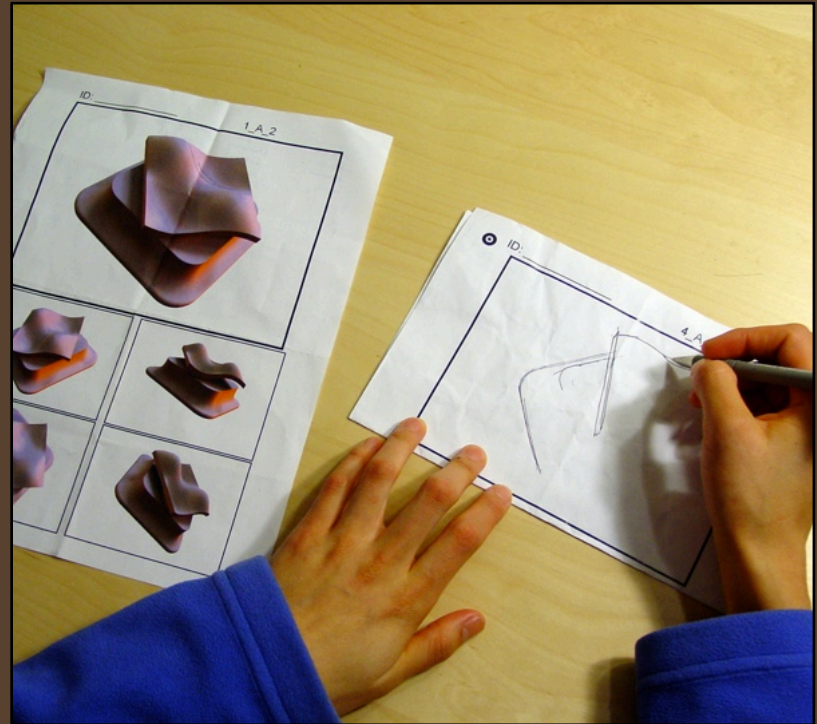
Collection Results

- 29 artists, art students and some professionals

- 208 drawings collected

- 170 "precise" drawings

  – Traced 90% of exterior silhouette within 1mm
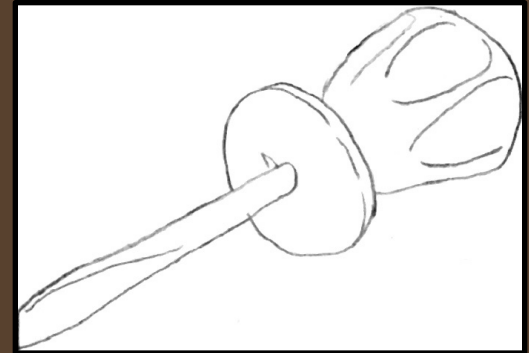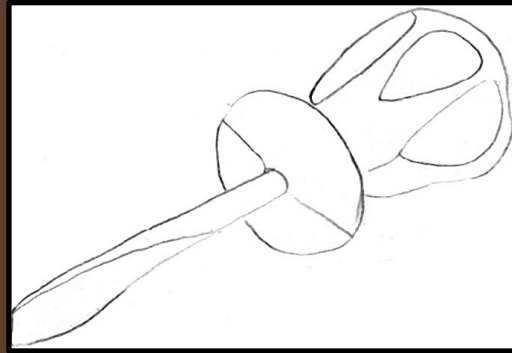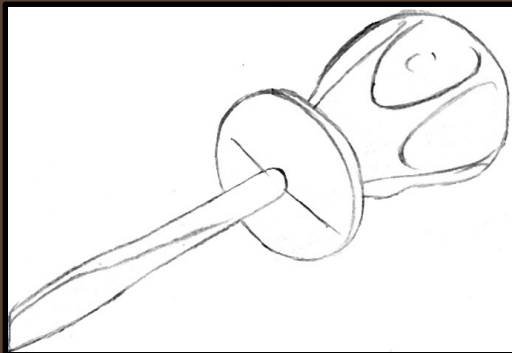
Overview

- 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

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Averaged Drawings
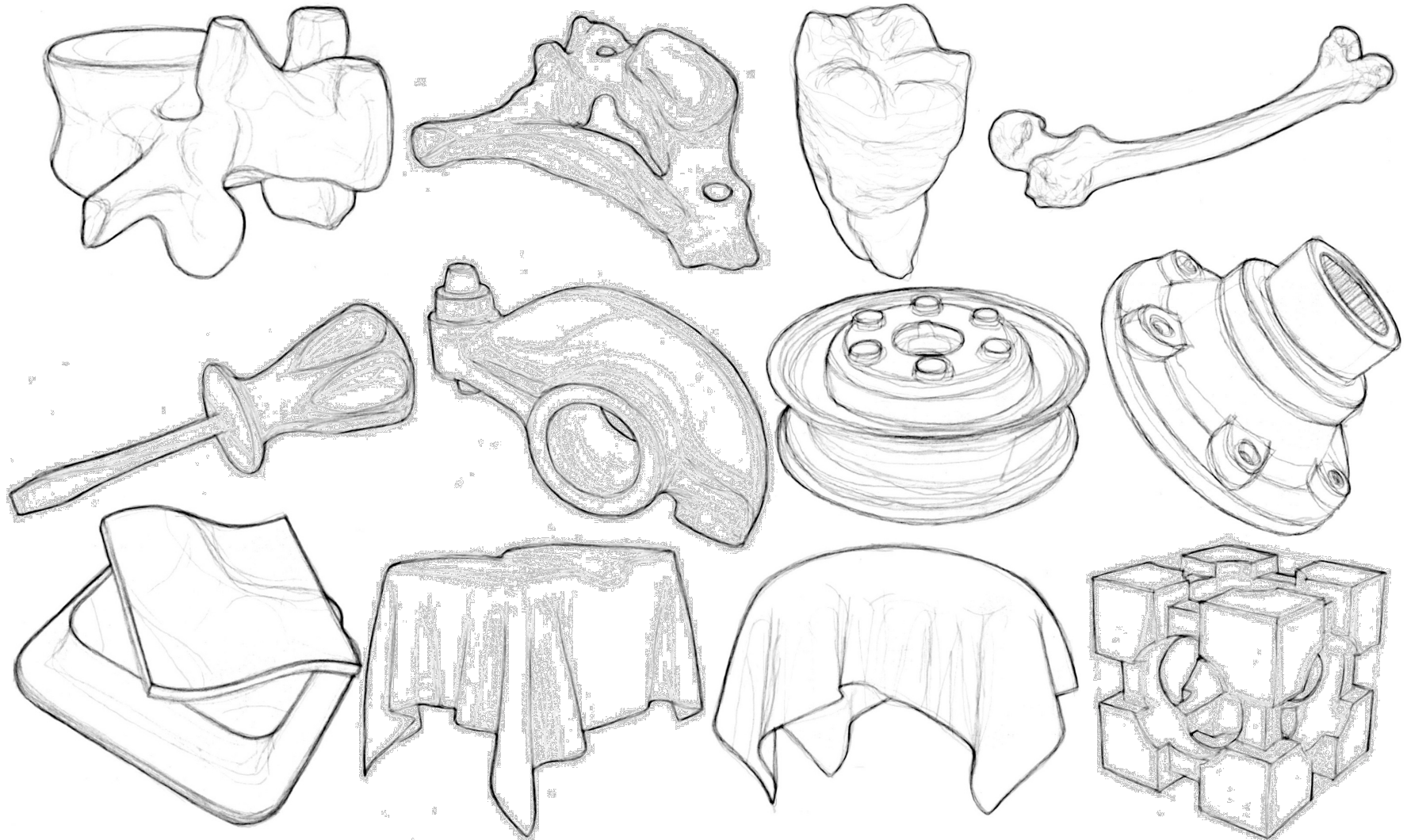
Quantifying Similarity

- For each pixel, find closest pixel in the other drawings of the same prompt

- ~75% of distances fall within 1mm (6 pixels)

Pairwise Counts (y-axis)

Distance (mm): 0, 1, 2, 3, >=4 (x-axis)
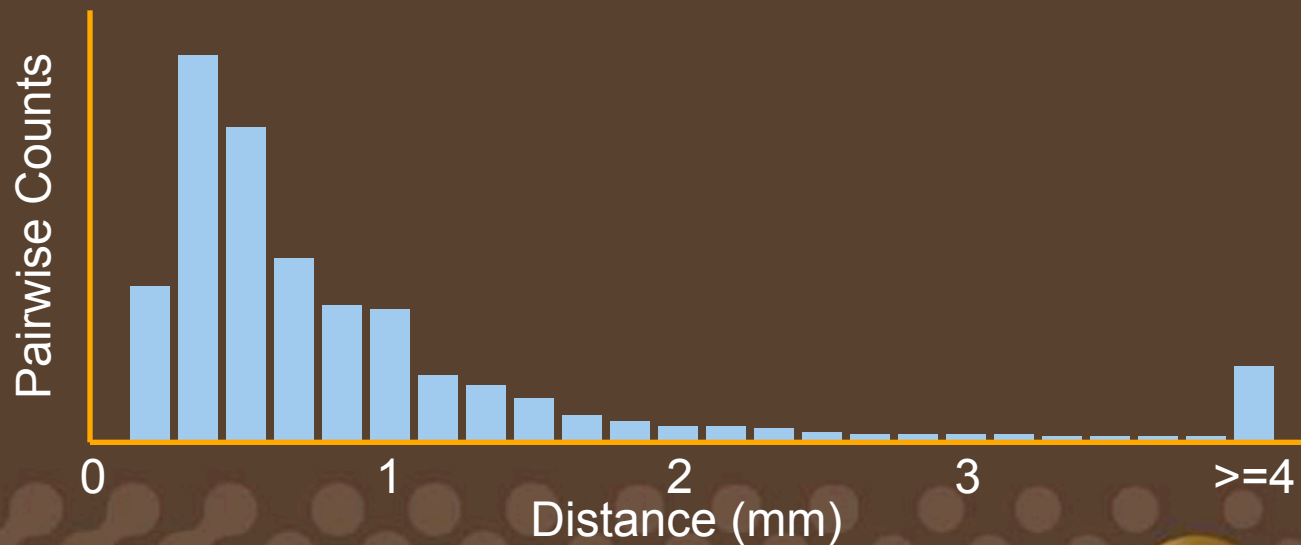
Describing with CG Lines

- 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
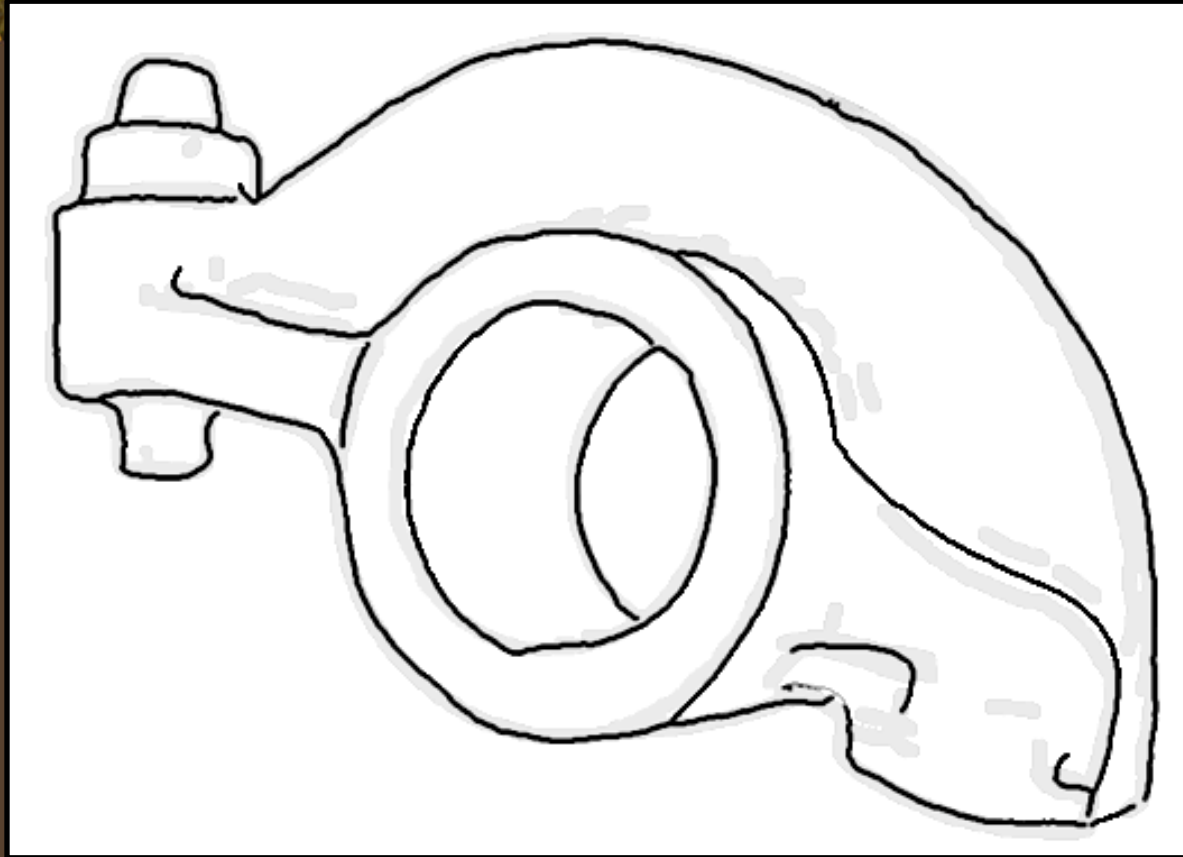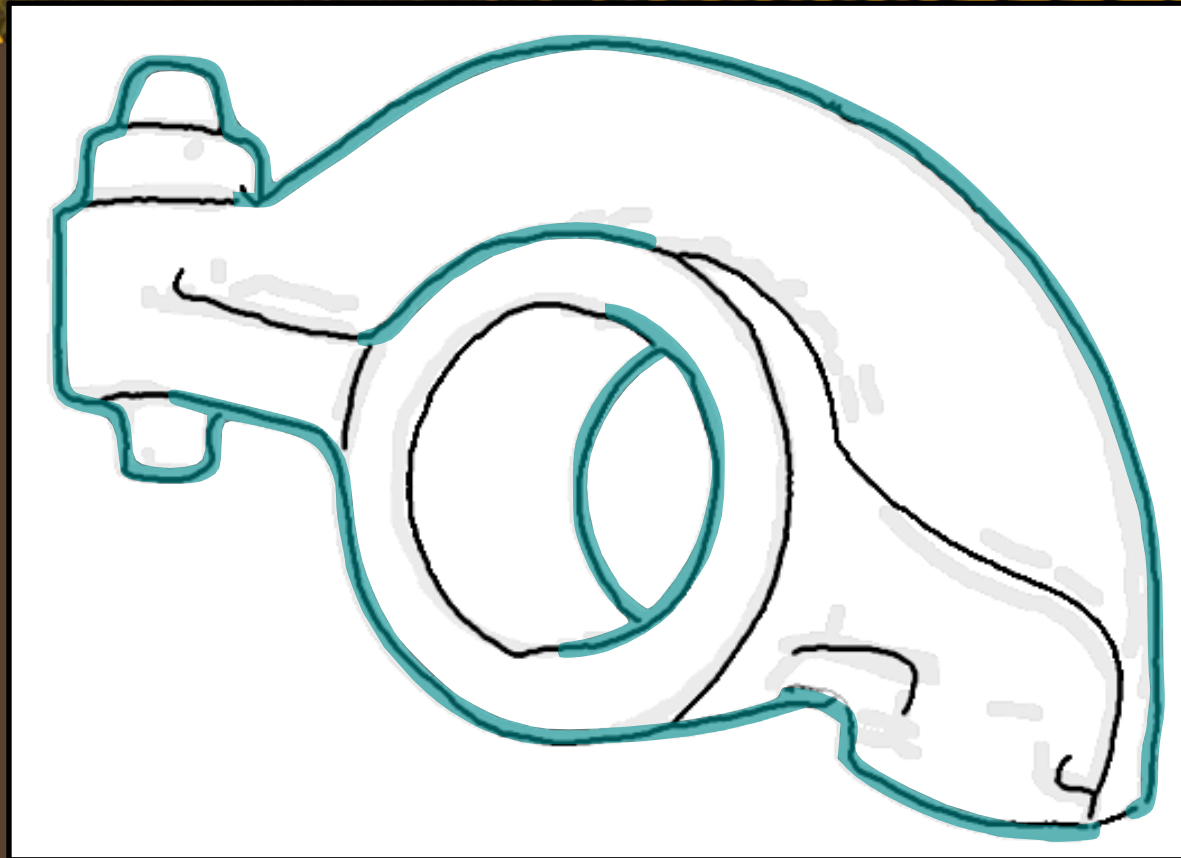
CG Line Matching Example

CG Line Matching Example
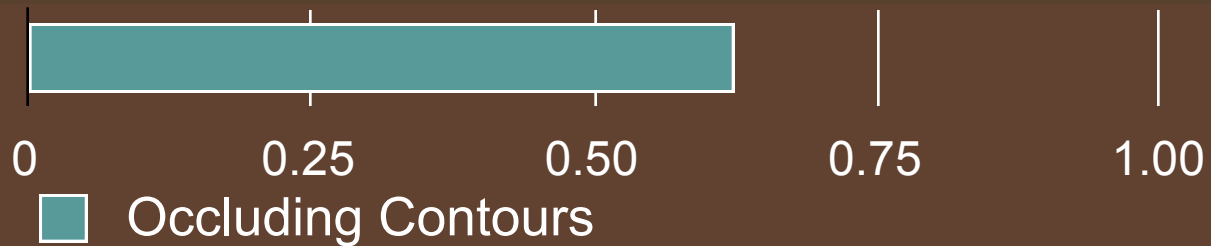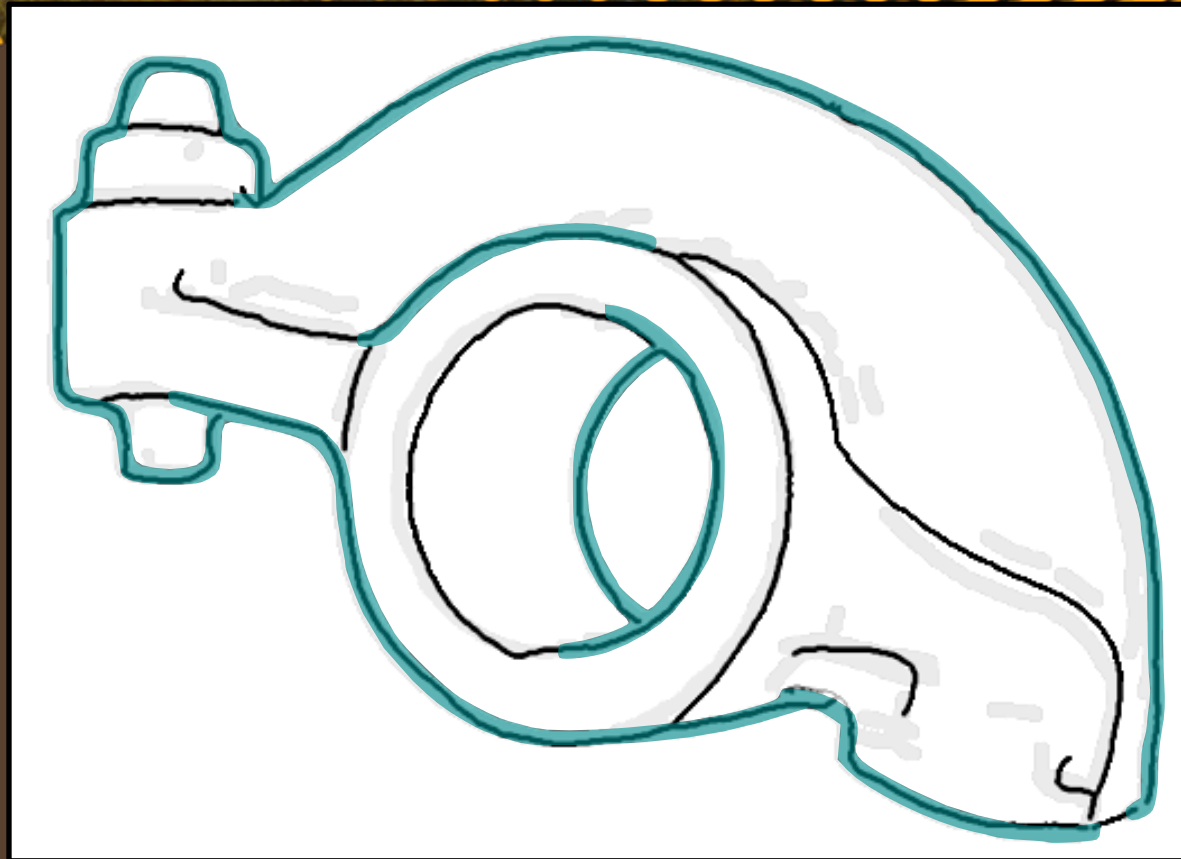
Occluding Contours

CG Line Matching Example

Occluding Contours
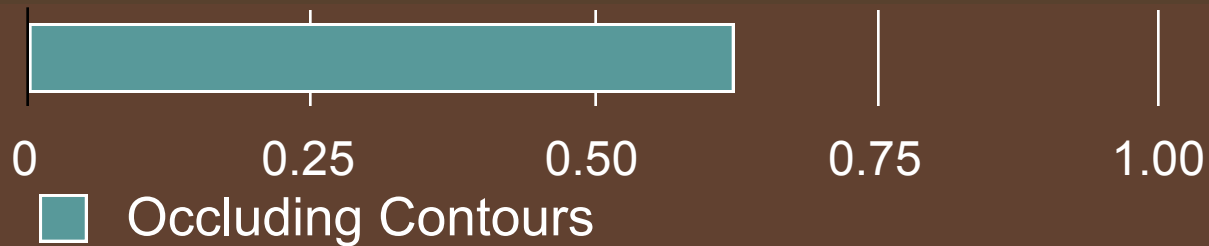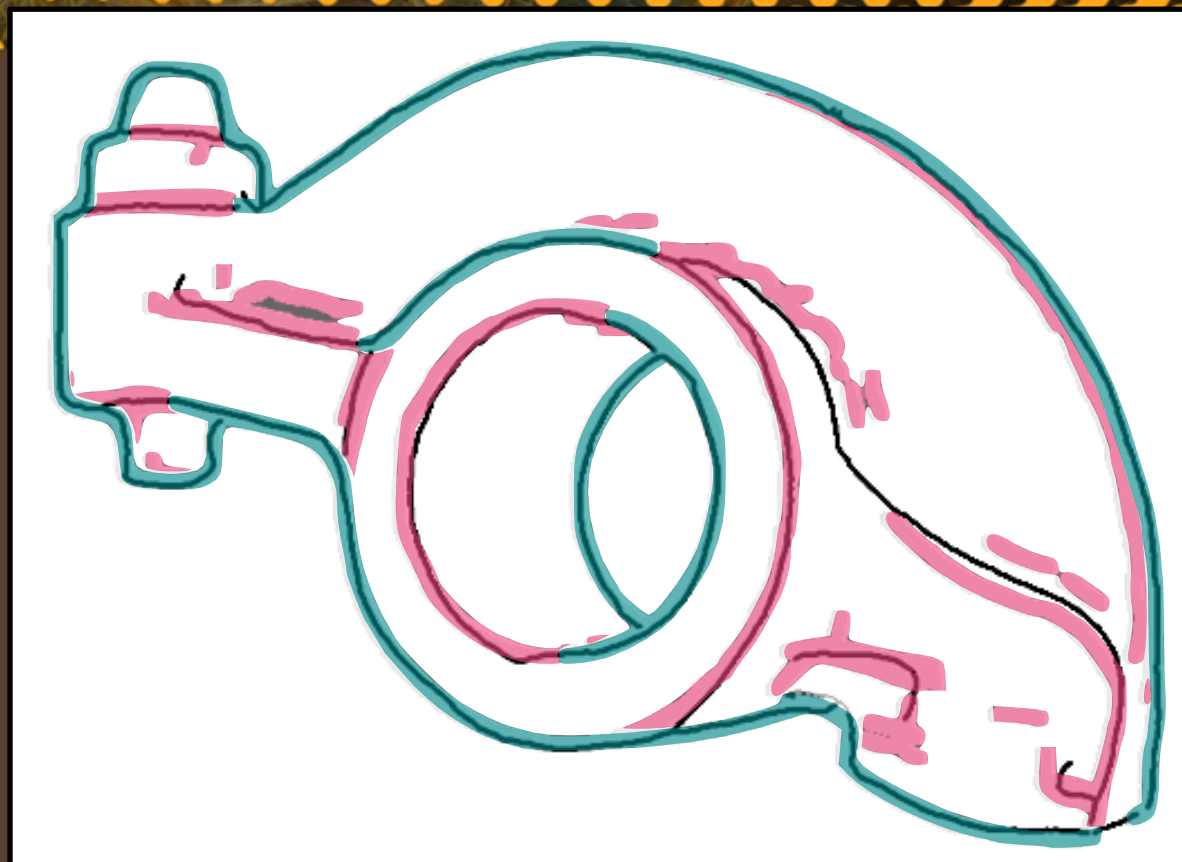
CG Line Matching Example
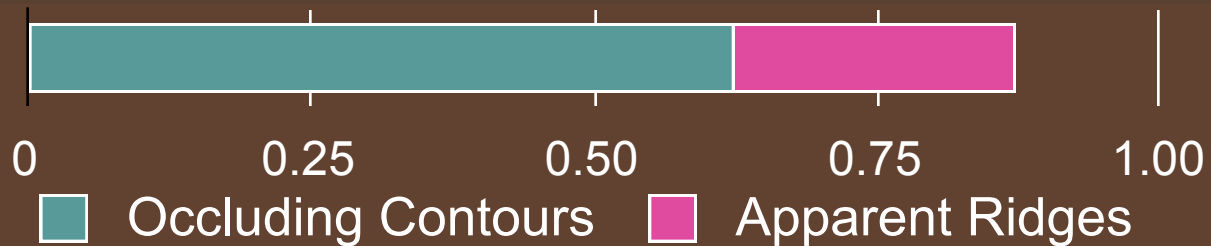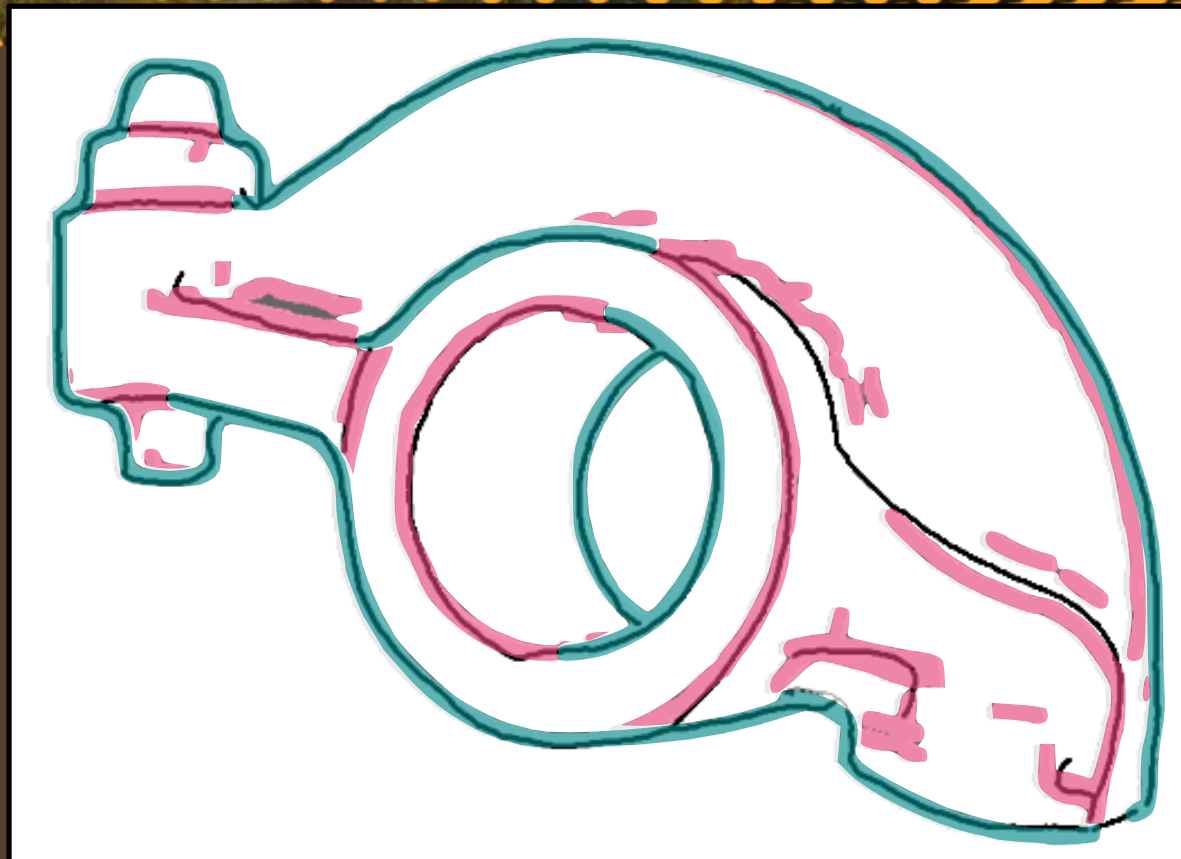
Categorization of Lines

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

■ Exterior contours		■ Interior contours	
■ Other object-space		■ Image only	
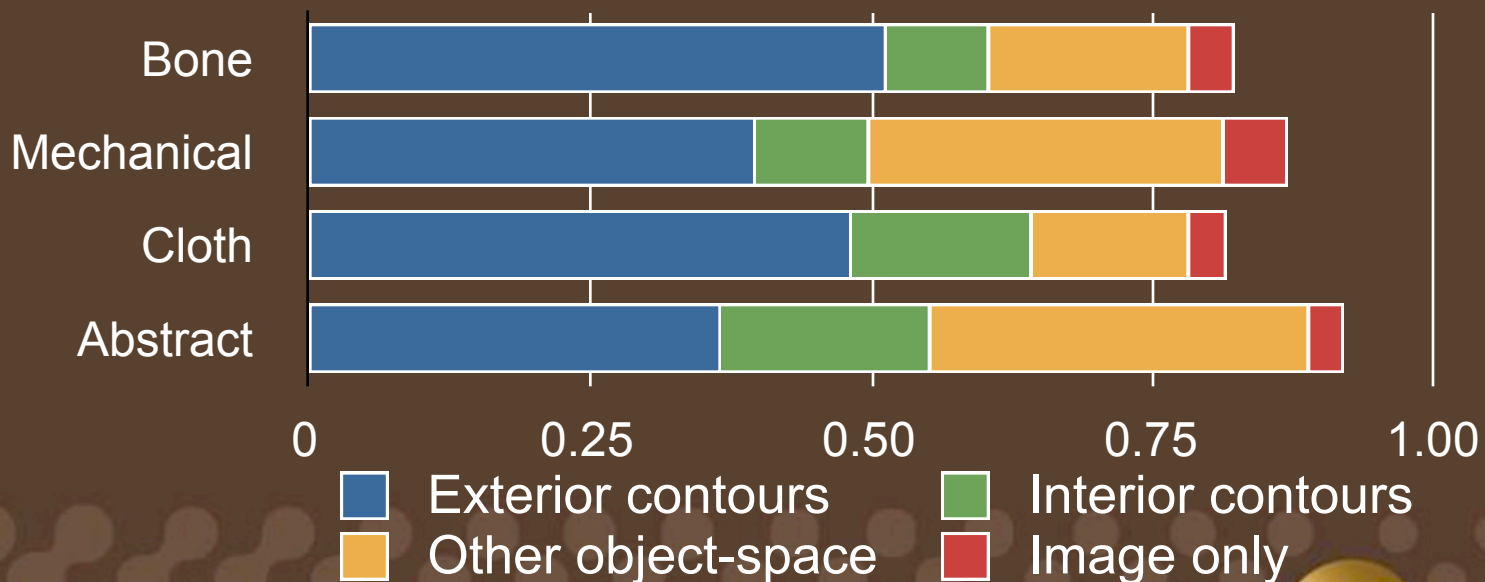
Other Object-Space Lines

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

Legend: Other overlap, RV, RV & AR, AR, SC & AR, SC
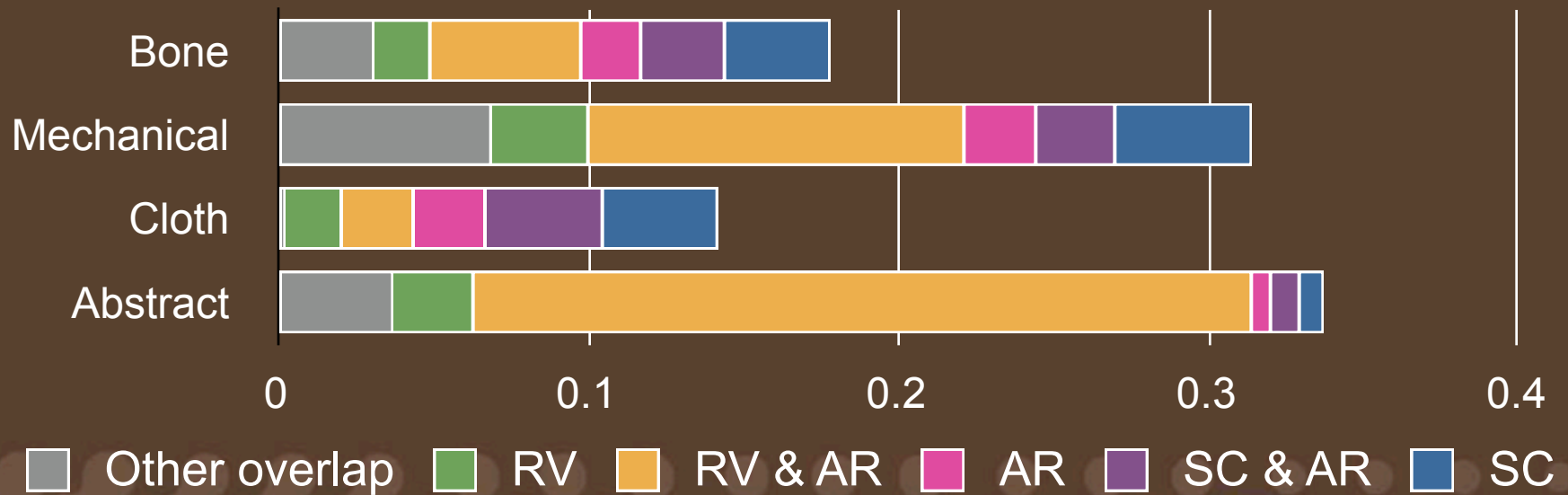
Artistic Variation
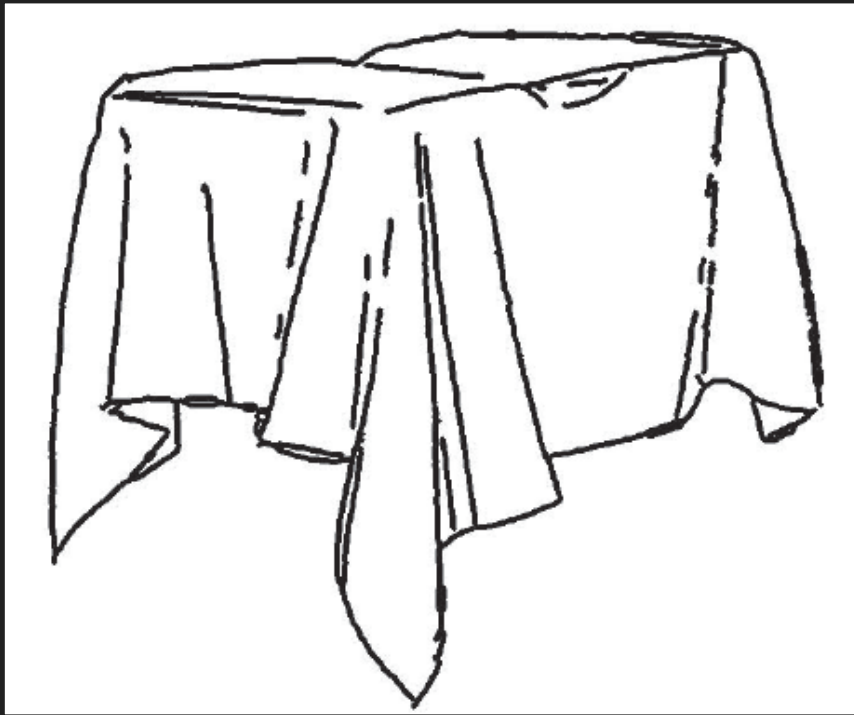
Artist A

Artist B

Artistic Variation

Artist A

Artist B

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

Artistic Variation
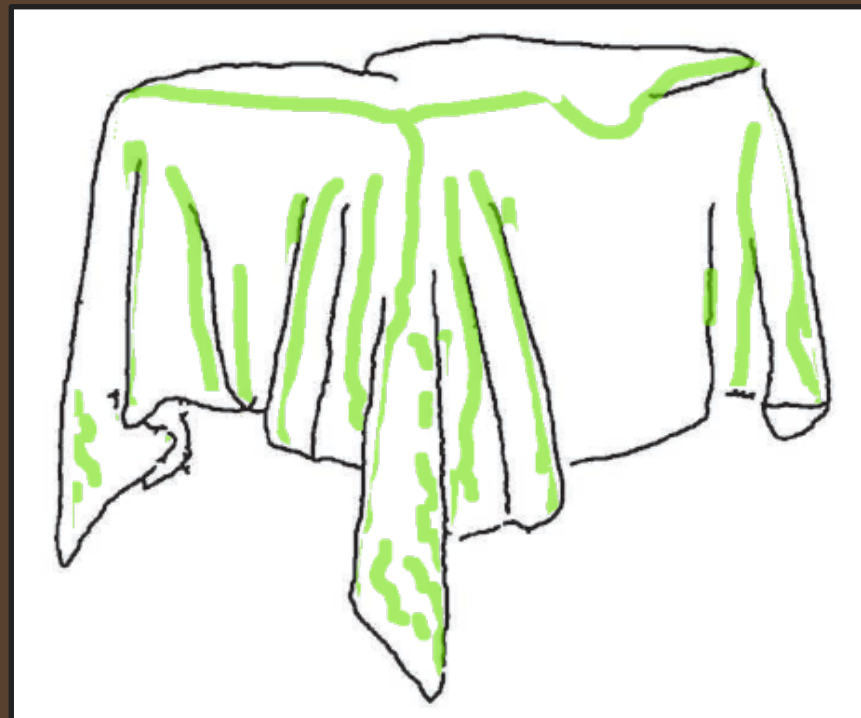
Artist A

Artist B

Other Overlap   RV   RV & AR   AR   SC & AR   SC

Artistic Variation
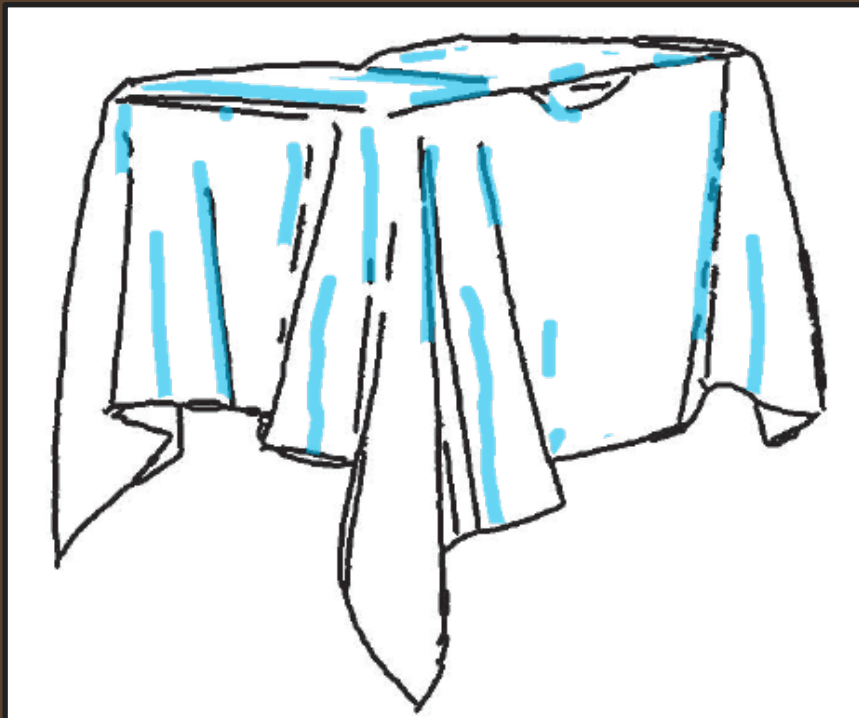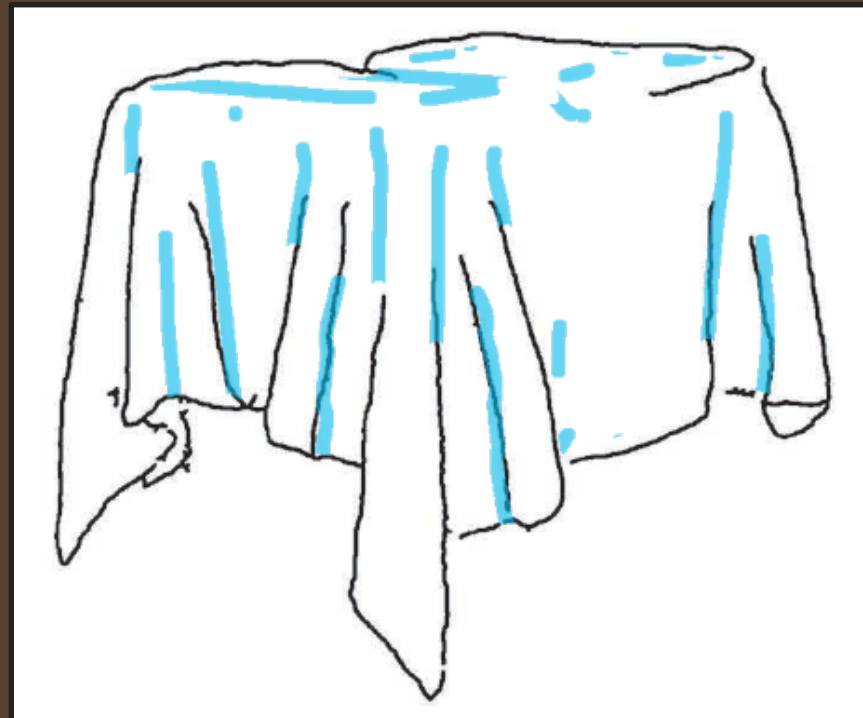
Artist A

Artist B

Other Overlap   RV   RV & AR   AR   SC & AR   SC

Artistic Variation

Artist A

Artist B
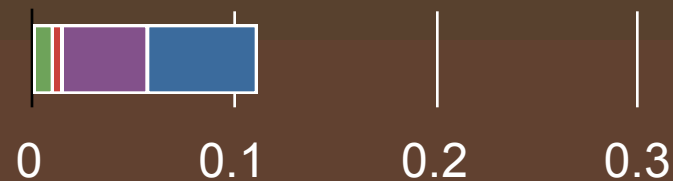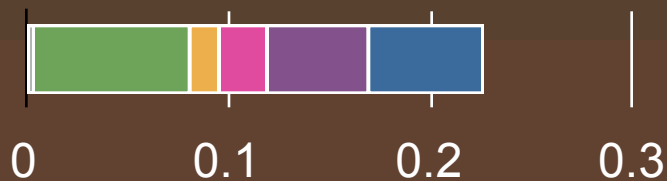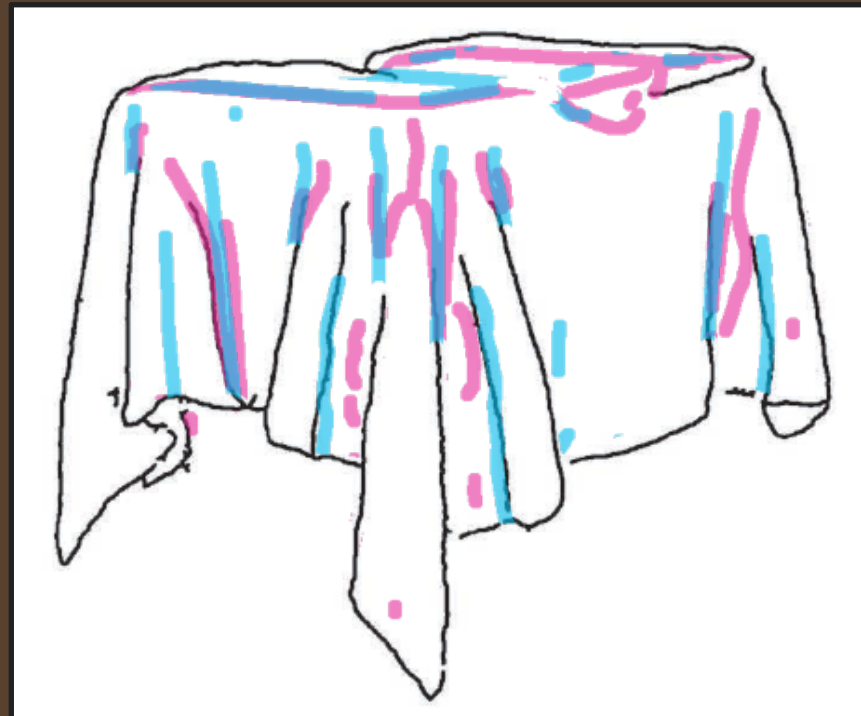
Other Overlap | RV | RV & AR | AR | SC & AR | SC

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
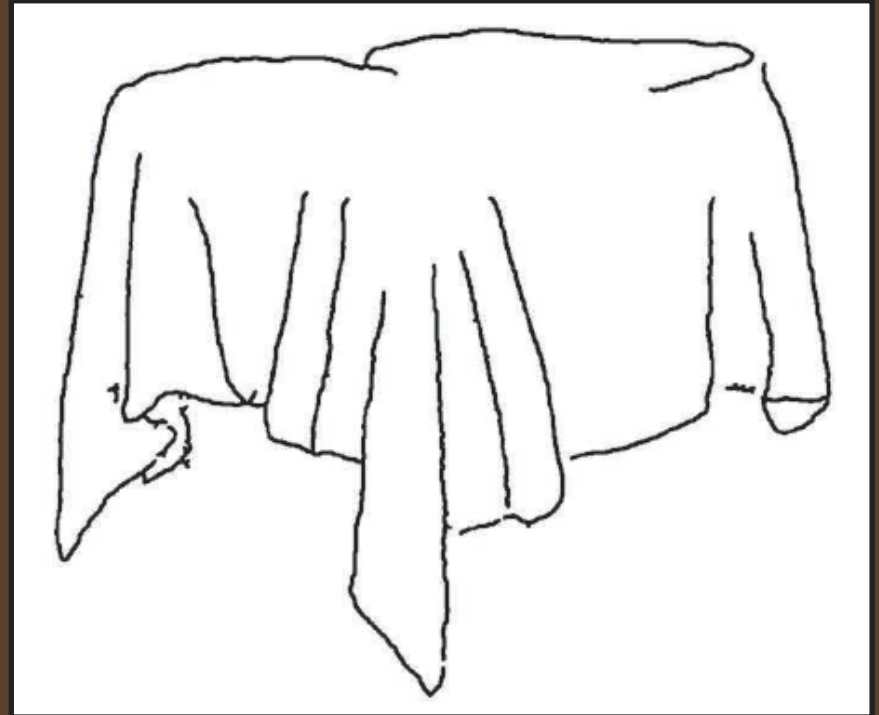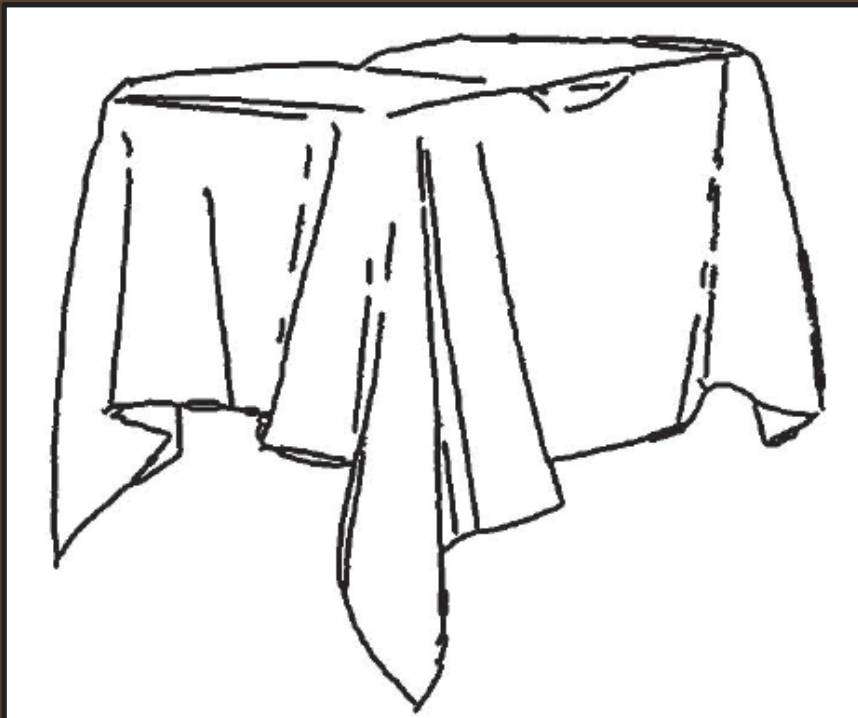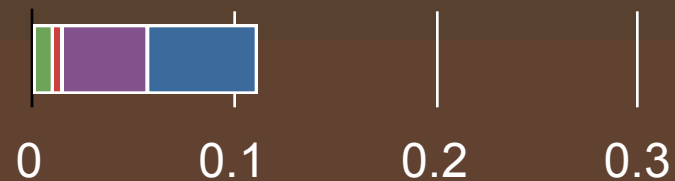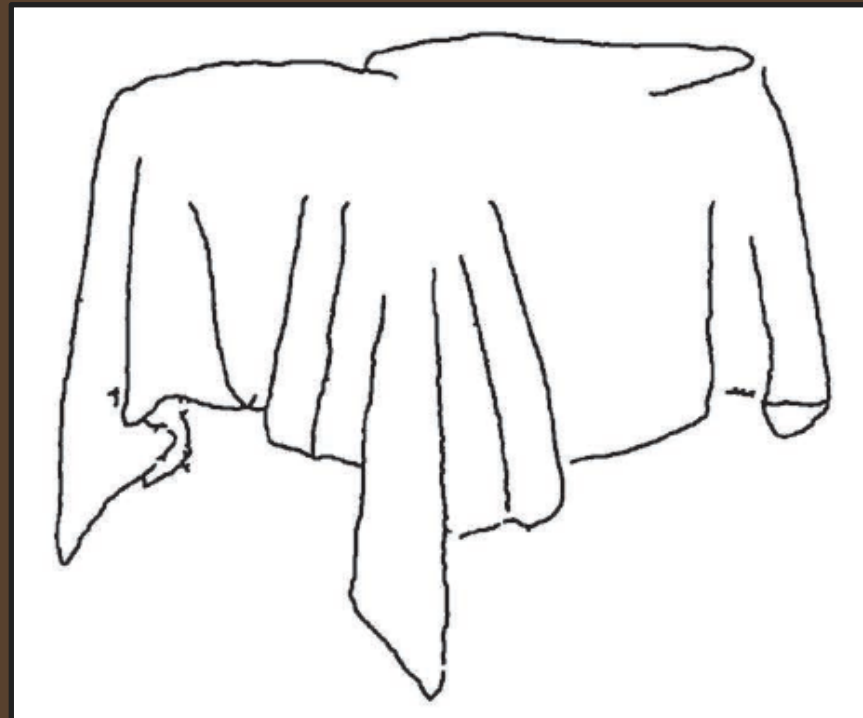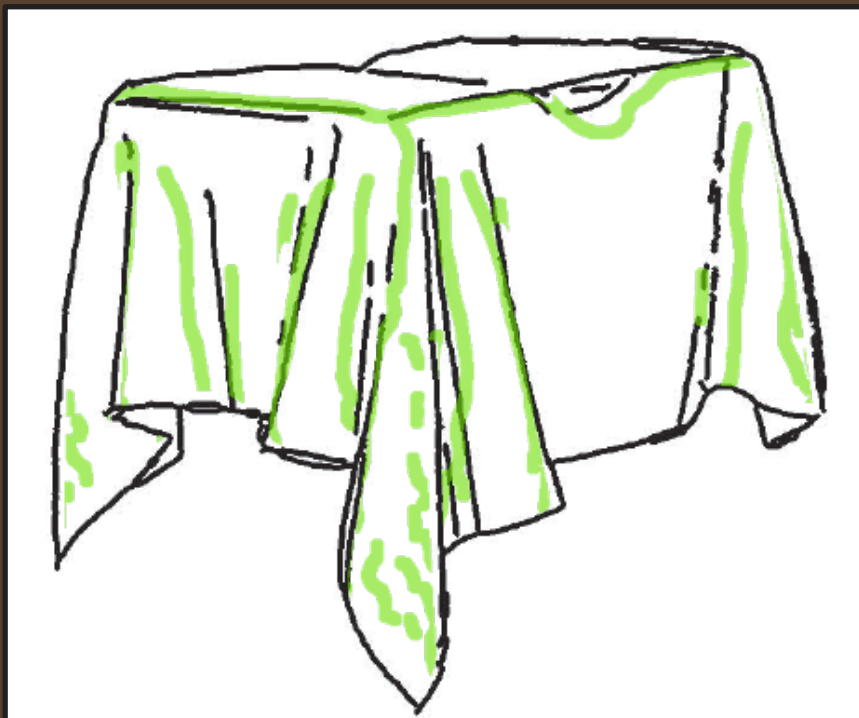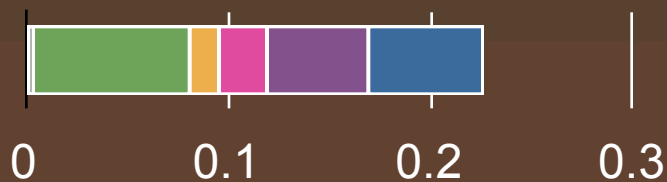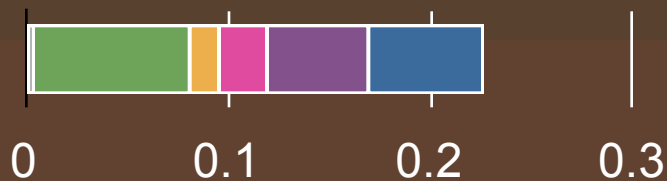- What about other possible definitions?

Examining Local Features

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

Image-Space	Object-Space	
	View-Dependent	View-Independent
`ImgGradMag`	`N·V`	`SurfMaxCurv`
`ImgMaxCurv`	`ViewDepCurv`	`SurfMaxCurvDeriv`
`ImgMinCurv`	`ViewDepCurvDeriv`	`SurfMinCurv`
`ImgLuminance`	`RadialCurv`	`SurfMeanCurv`
	`RadialCurvDeriv`	`SurfGaussianCurv`
	`RadialTorsion`	

Individual Local Features

- Compare pixels near artists' lines to remainder

probability

N•V

ImgGradMag

0   0.5   1

0   0.0375   0.075

Near Line   Not near line
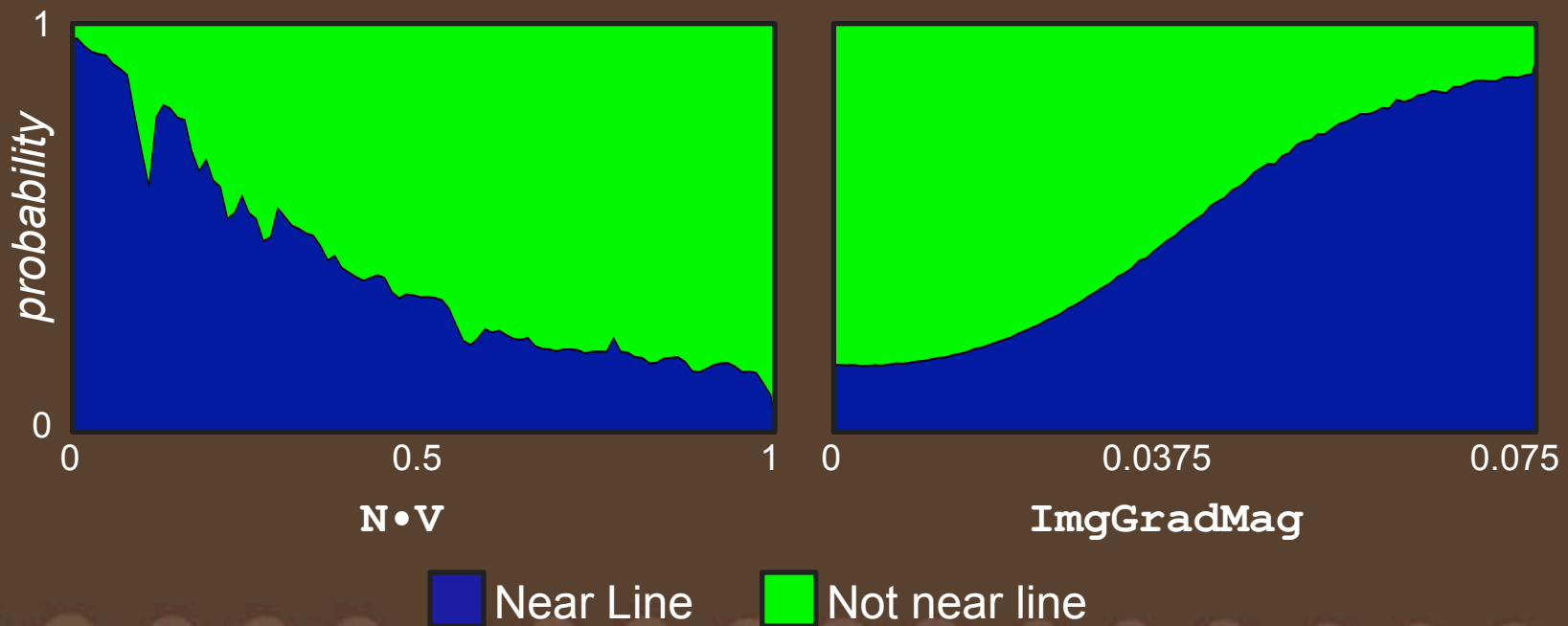
Features in Combination

Regression Tree Model:

```
ImgGradMag > 2433.08
|  ImgGradMag > 4706.19
|  |  0.181
|  |  0.0341
|  RadialCurvDeriv > 0.02
|  |  ViewDepCurvDeriv > 0.044
|  |  |  0.0455
|  |  |  0.0175
|  |  SurfGaussianCurv > -0.004
|  |  |  ViewDepCurv > 0.076
|  |  |  |  N dot V > 0.782
|  |  |  |  |  0.0113
|  |  |  |  |  0.0252
|  |  |  |  SurfMaxCurvDeriv > 0.014
|  |  |  |  |  SurfMinCurv > 0.022
|  |  |  |  |  |  0.0044
|  |  |  |  |  |  0.0125
|  |  |  |  |  |  0.0023
...
```
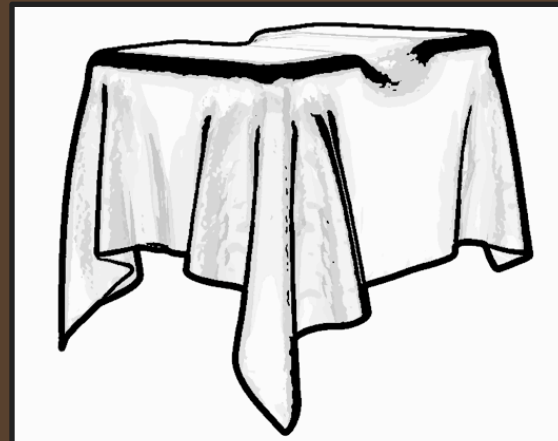

Predicted Probability

Artists' Average

Feature Importance

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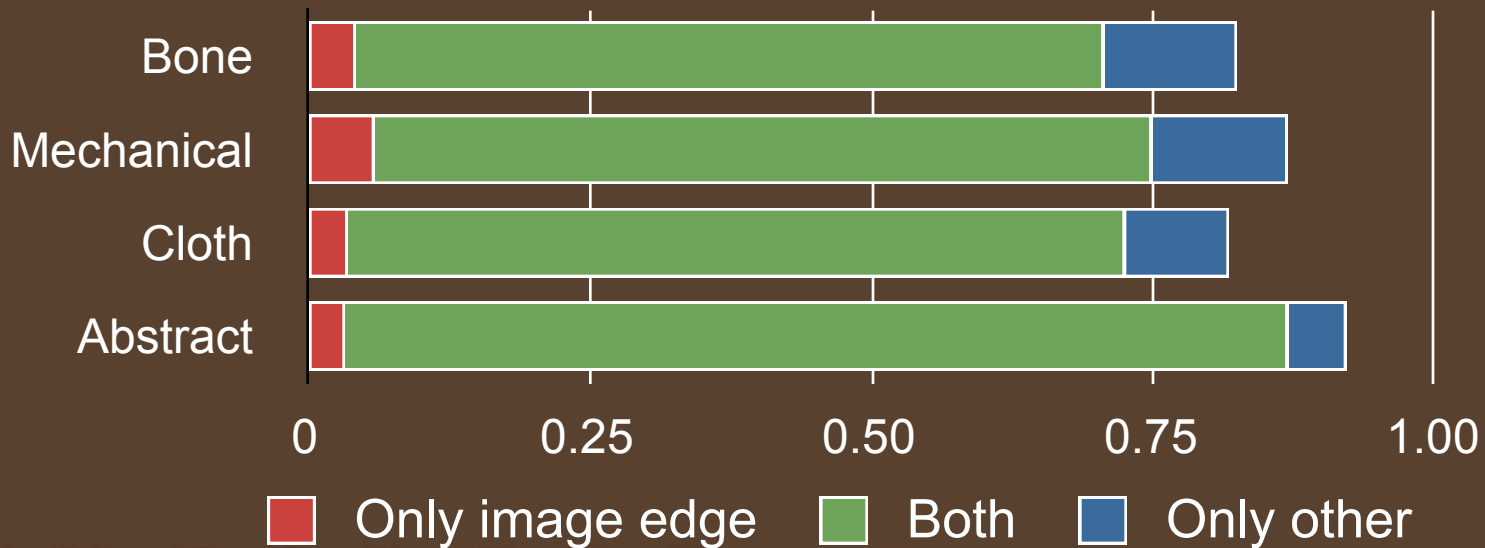 - View-independent object space

Image Edges vs. Others

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

Bar chart showing proportions for Bone, Mechanical, Cloth, and Abstract across categories "Only image edge" (red), "Both" (green), and "Only other" (blue), with x-axis from 0 to 1.00.

Legend: ■ Only image edge ■ Both ■ Only other

Overview

- Background

- Study Design

- Analysis and Results

- Conclusion
  - Summary of Results
  - Future Work

- Dataset Demo

SIGGRAPH2008

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
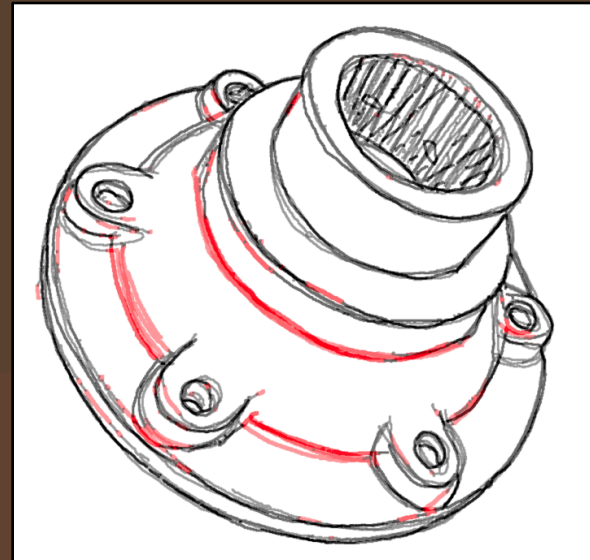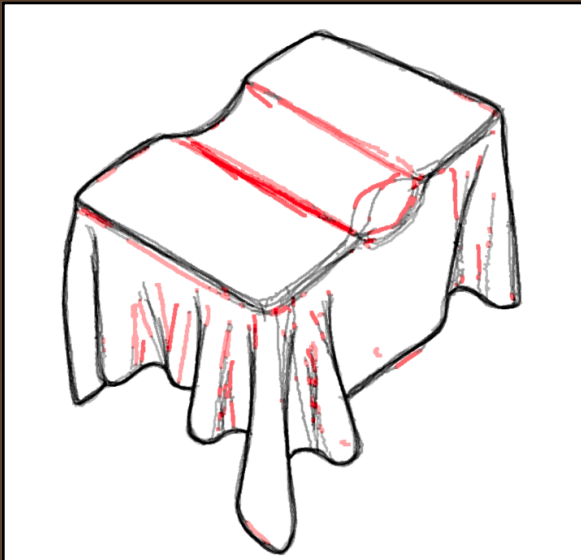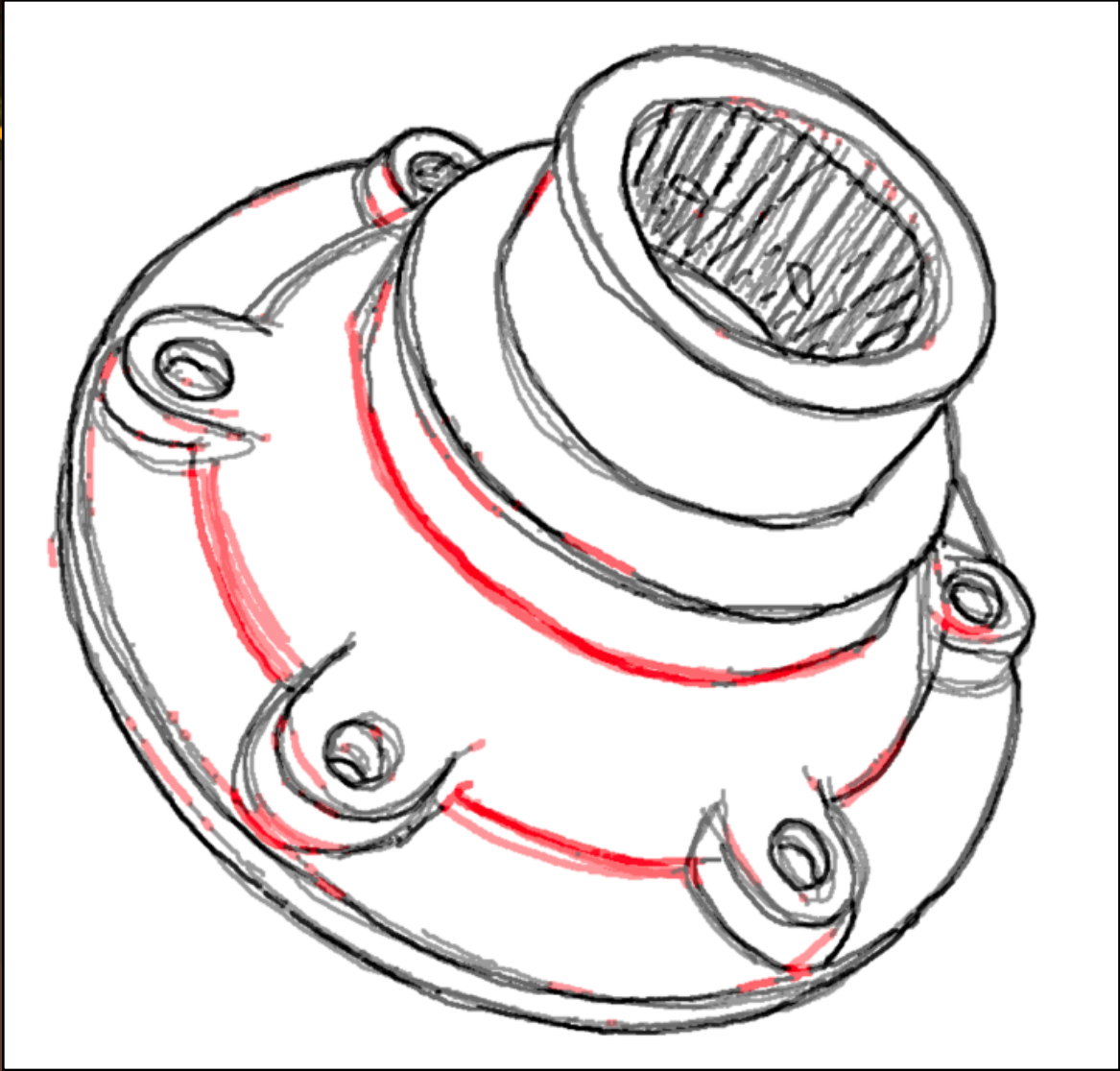
Unexplained Lines

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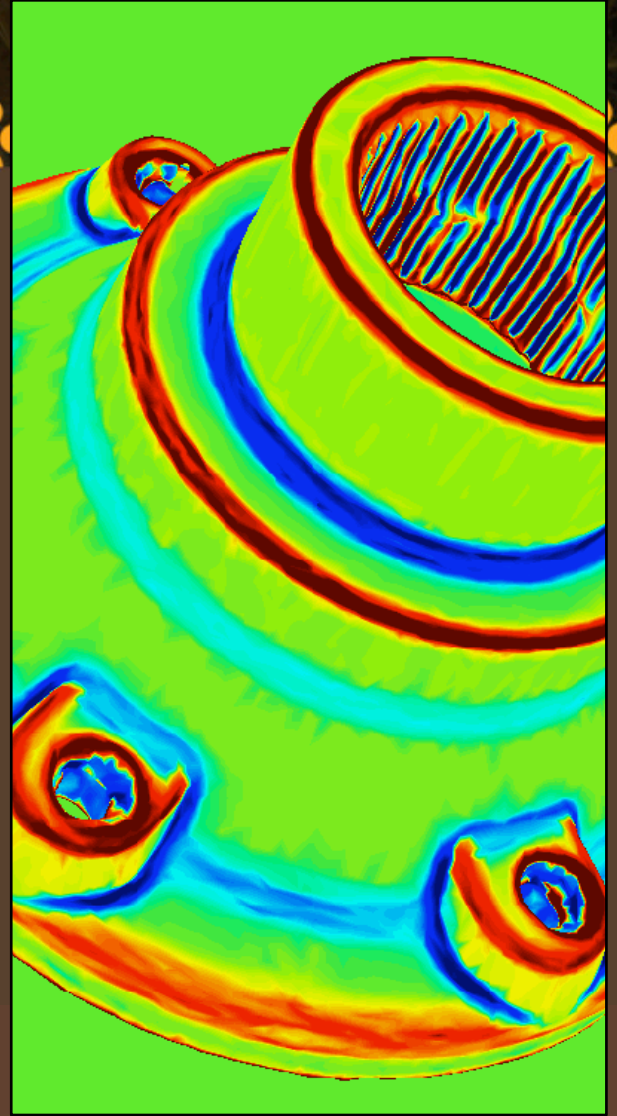 - Choices based on global features

Unexplained Lines

- How to explain remaining lines?
  - Artistic license
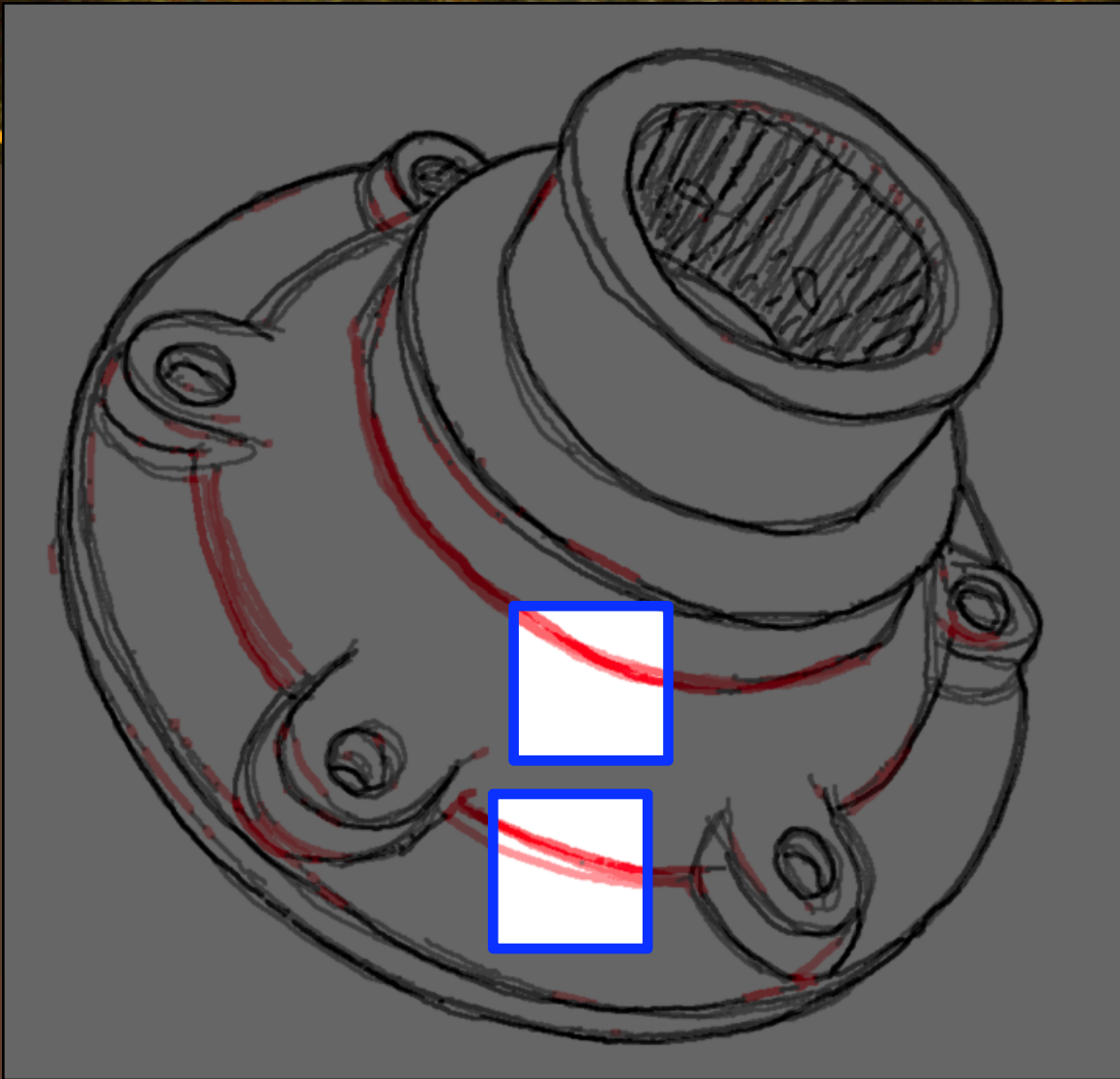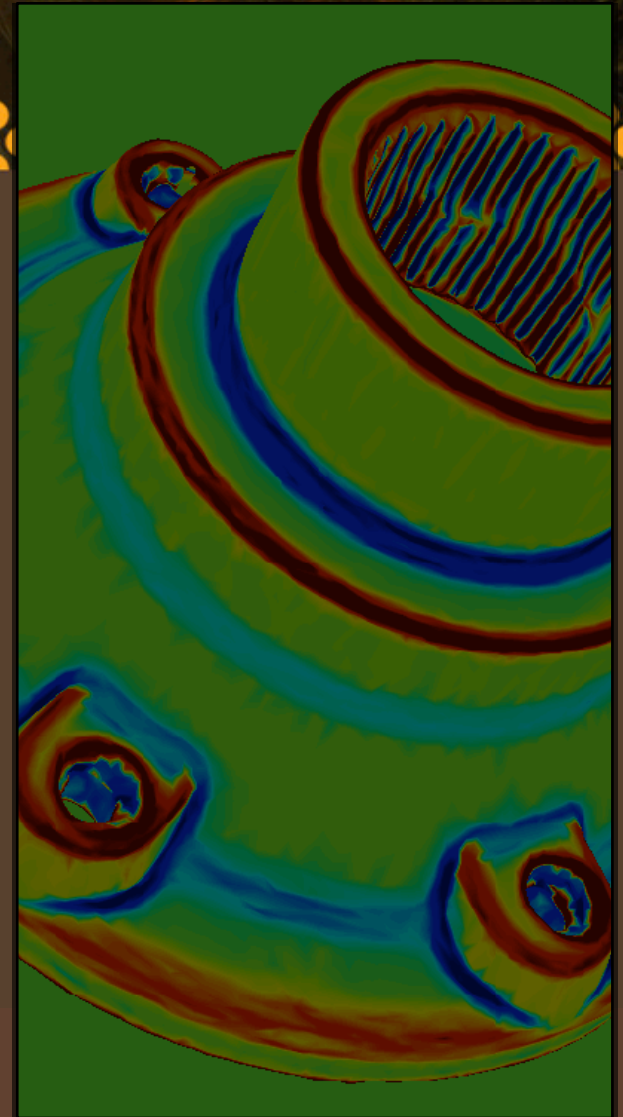 - Need better local feature definitions
  - Choices based on global features
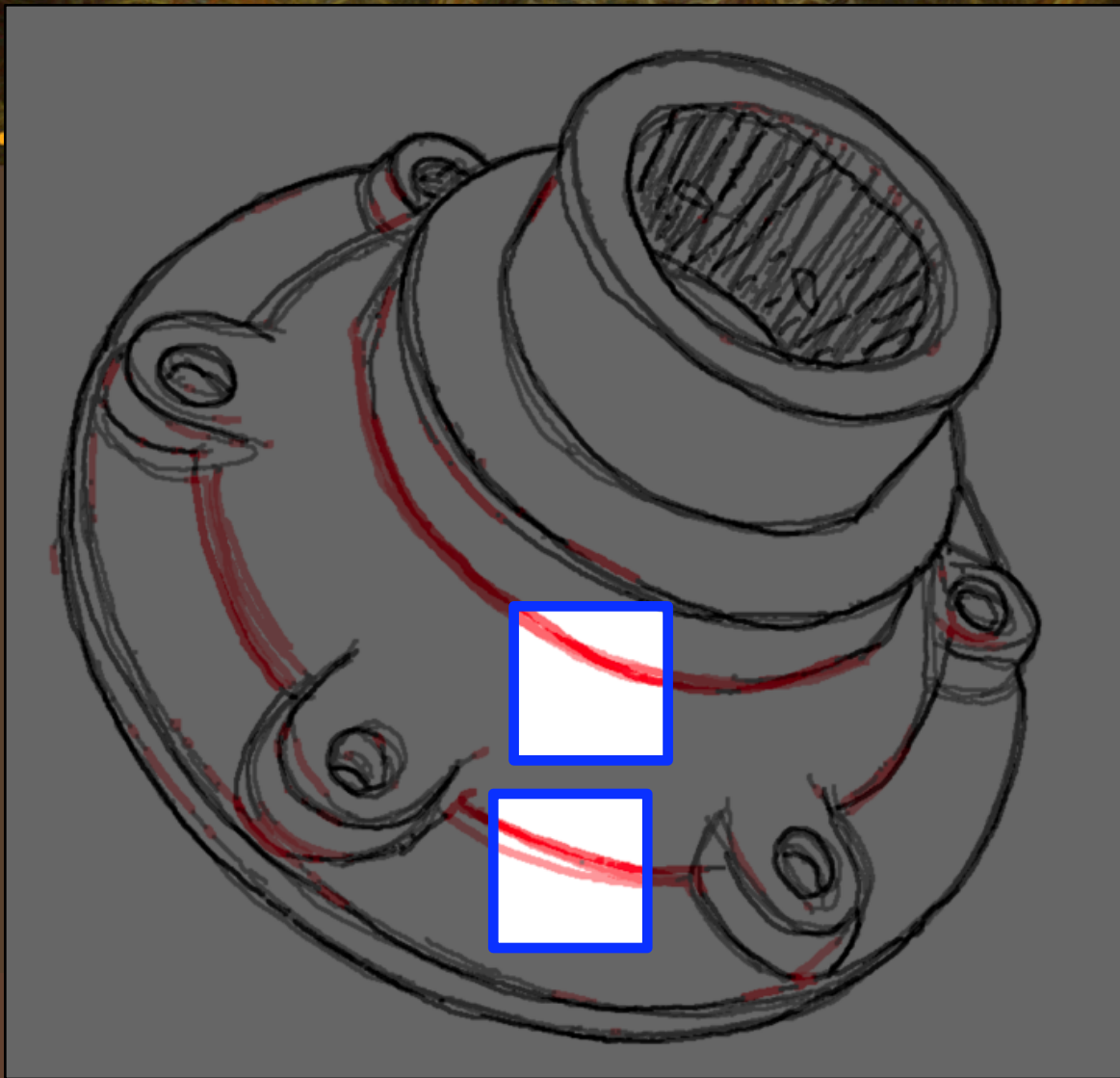
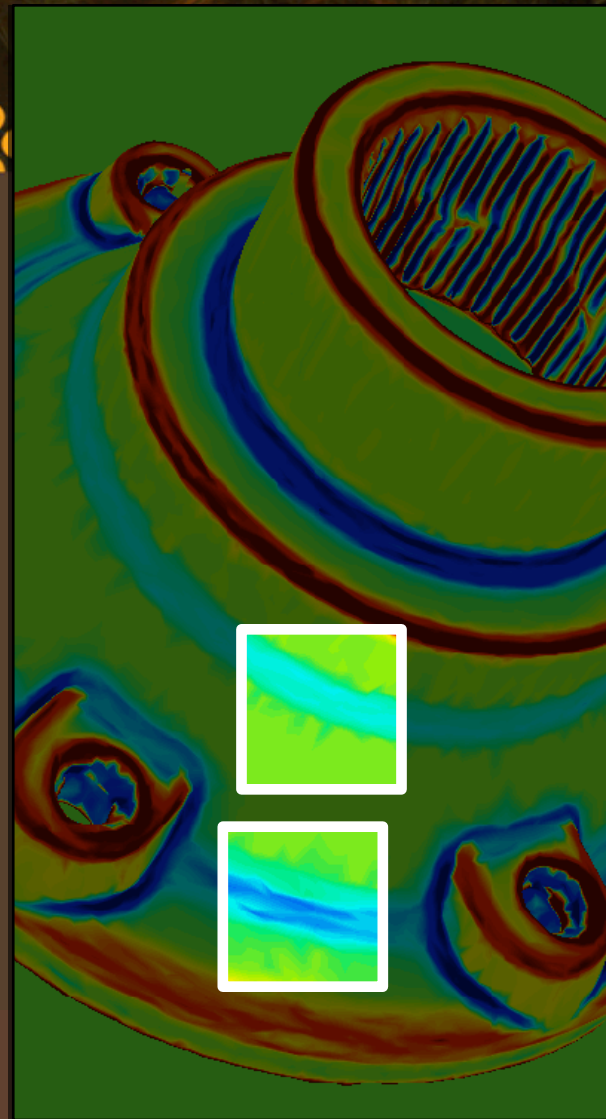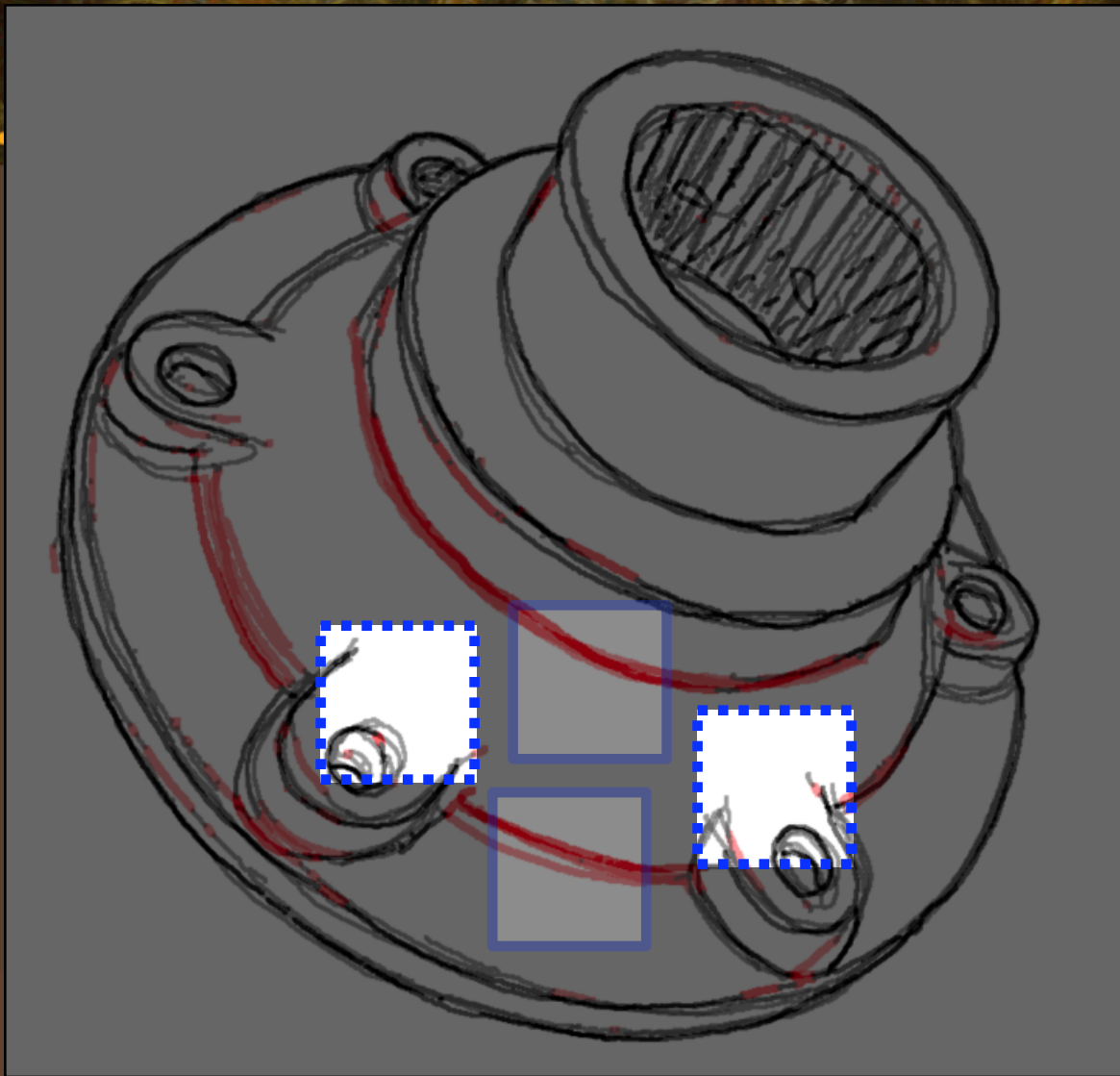Composite Drawing

Maximum Curvature

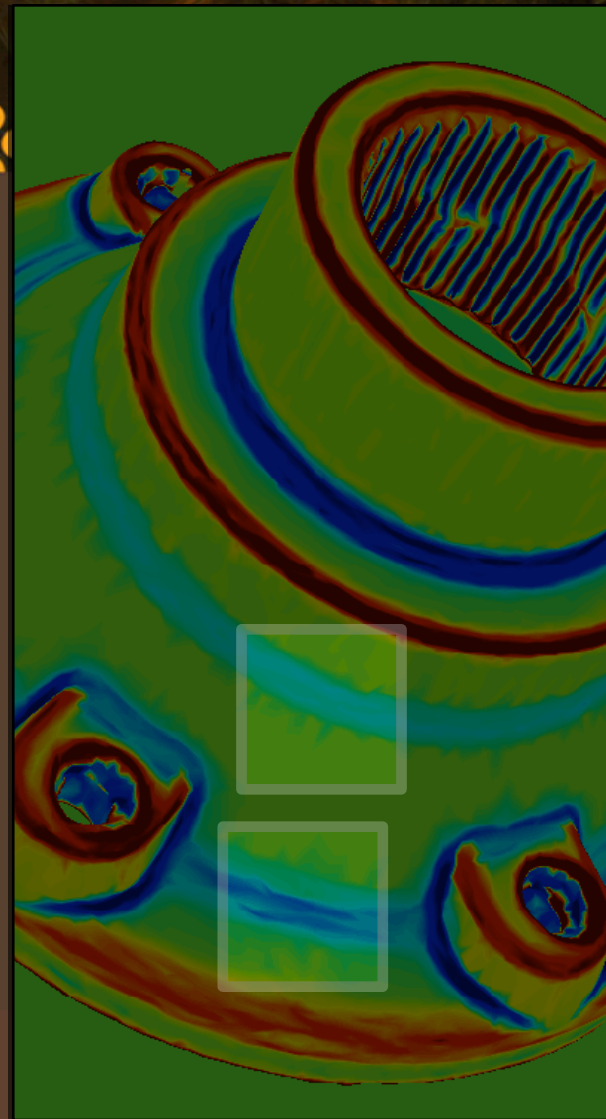Composite Drawing

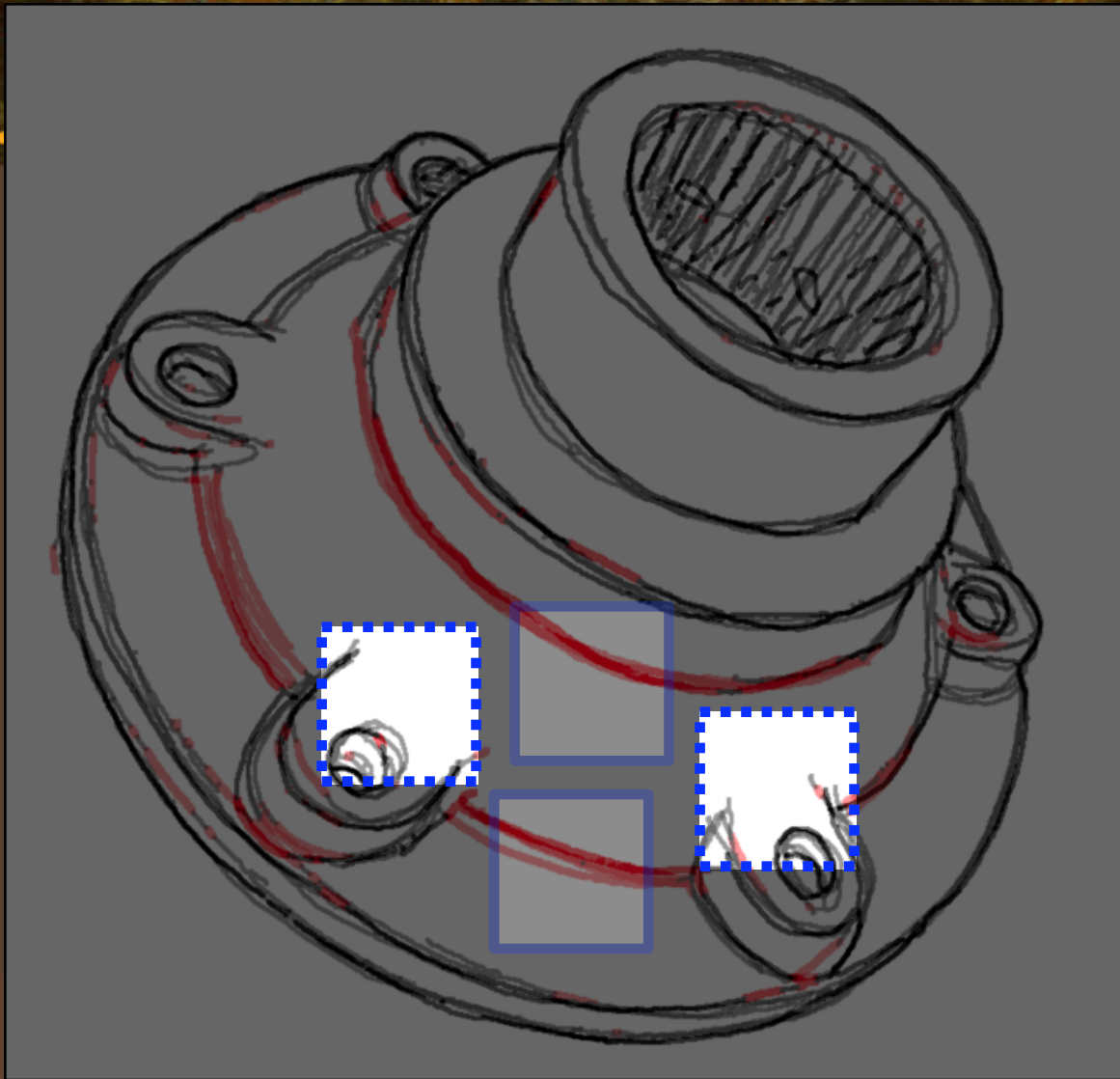Maximum Curvature

Composite Drawing
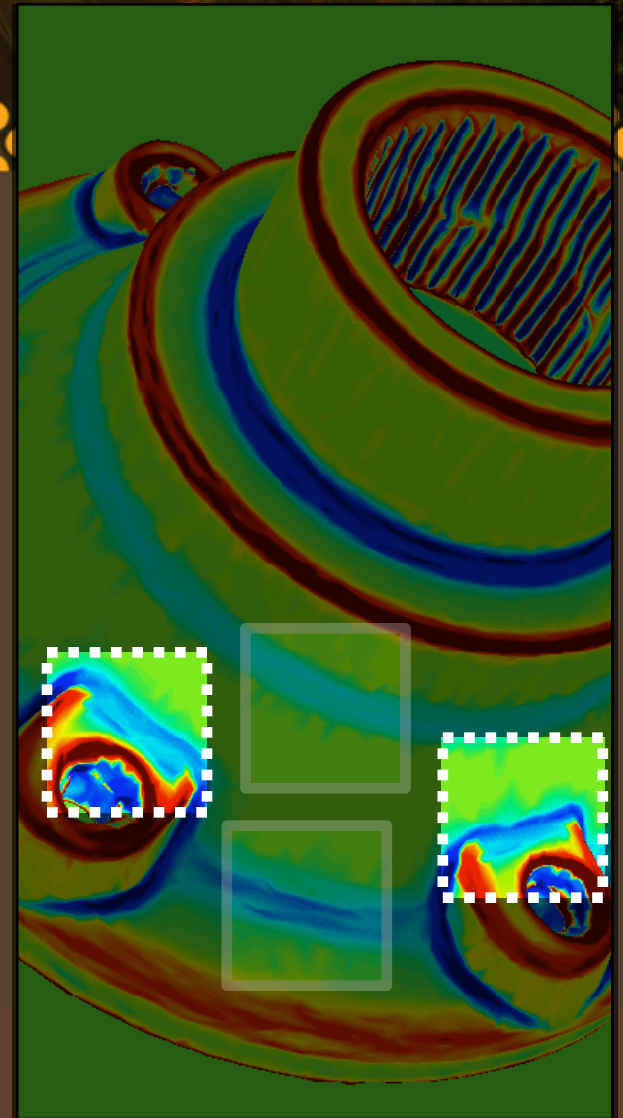
Maximum Curvature

Composite Drawing

Maximum Curvature

Composite Drawing

Maximum Curvature

Future Work

- New studies
  - Shading and stylization effects
  - Perception of shape in artists' drawings
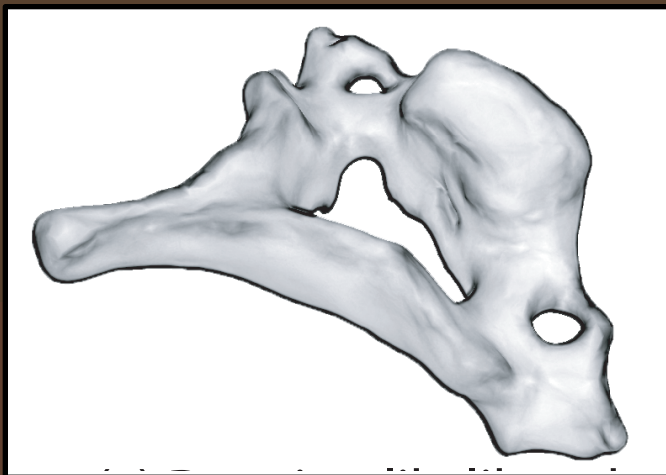- Data-driven line drawing synthesis

Synthesis Future Work

Artists' Composite

Individual Drawing

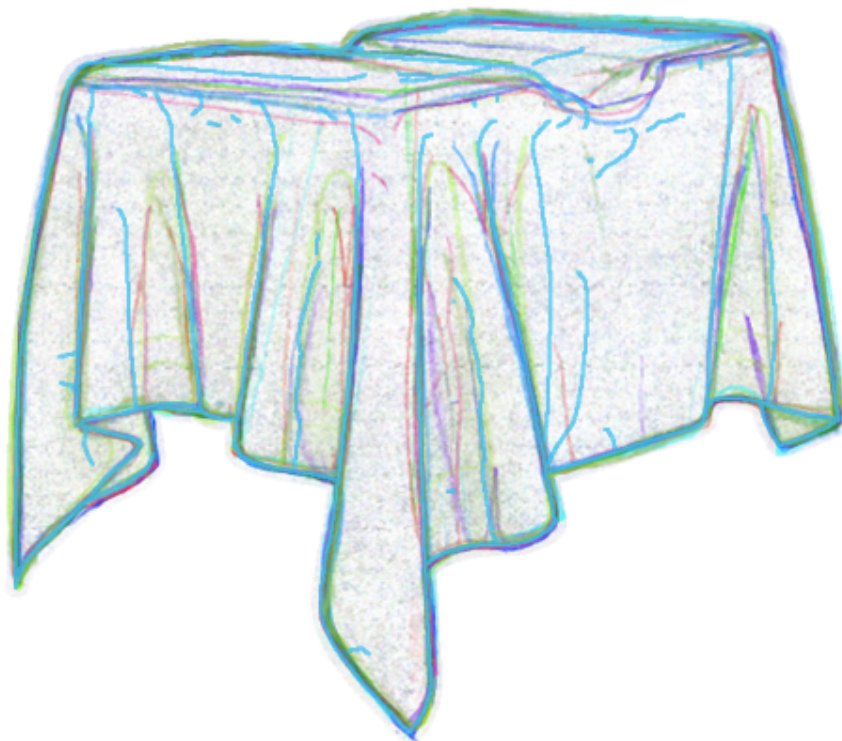Probability Image

Synthesized Lines

Dataset Plug

- You can download the full dataset at:

    www.cs.princeton.edu/gfx/proj

- Viewer demo

Viewer Demo

Acknowledgements

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