Conveying Structure

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CS 294-10: Visualization
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Final project

Design new visualization method
- Pose problem, Implement creative solution

Deliverables
- Implementation of solution
- 8-12 page paper in format of conference paper submission
- 2 design discussion presentations

Schedule
- Project proposal: 3/29
- Initial problem presentation: 3/31 (Wed)
- Midpoint design discussion: TBD
- Final paper and presentation: TBD

Grading
- Groups of up to 3 people, graded individually
- Clearly report responsibilities of each member

Initial Presentations

David Zats and Sushrut
Jon Barron
Zev
Tim Wheeler
Wed: Ryan Greenberg
Wed: Jeff, Akshay and Boaz
Priyanka and Lita
Wed: Shimul, Kerstin and Prahalika
Wed: Jonathan and Aaron
Wed: Steven Chu
Jaeyoung
Wed: Jiamin
Arpad
Ebby
Wed: Paul Oppenheim

Assembly Instructions
Previous Work

Planning
- Choose sequence of assembly operations
  - Robotics / AI / Mechanical Engineering
    - [Victer 89], [da Mello 91], [Wilson 92], [Romney 95]

Presentation
- Visually convey assembly operations
  - Visualization / Computer Graphics
    - [Seligmann 91], [Rist 94], [Butz 97], [Strothotte 98]

Jointly optimize plan and presentation

Geometric Analysis [Romney 95]

Input Parts

Blocking Graph

- $B$ blocked by $A$, $B ightarrow A$
- both parts free to move
- $A$ blocked by $B$, $A ightarrow B$
Geometric Assembly Planning

Valid  Valid  Invalid

How do we choose the best sequence?

Many Geometrically Valid Sequences

Valid  Valid  Valid  Valid

Identifying Design Principles

Stage 1: Production
Stage 2: Preference
Stage 3: Comprehension

Spatial Ability Tests

Mental Rotation [Vandenburg 78]
Navigation [Money 78]

Separate high and low spatial ability
Stage 1: Production

- 43 Participants
- Assemble TV Stand without instructions
- Write instructions for novice assembler

Stage 1: Mean completion time

<table>
<thead>
<tr>
<th>Time to assemble (min)</th>
<th>Low spatial</th>
<th>High spatial</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>12.76</td>
<td>7.29</td>
</tr>
</tbody>
</table>

Stage 1: Instructions produced

- Almost all contained diagrams 98%
- Text redundant with diagrams 62%

Stage 1: Errors in instructions

- Errors in low spatial instructions 86%
- Errors in high spatial instructions 12%
Stage 1: Errors in instructions

- Errors in low spatial instructions: 86%
- Errors in high spatial instructions: 12%

Stage 1: Classes of Diagrams

- Structural diagrams: depict completed step
- Action diagrams: show assembly action/operation

Stage 1: Action diagrams

- Mean number per set:
  - Low spatial: 0.64
  - High spatial: 2.67

- High spatial:
  - More action diagrams
  - More 3D diagrams
  - Less text

Stage 2: Preference

- 21 Participants
- Assemble TV Stand without instructions
- Rated 39 sets of redrawn instructions
Stage 2: Highest Rated

- Ratings similar across all participants
- Spatial ability does not affect preference

Stage 3: Comprehension

- 44 Participants
- Given 1 of 4 instruction sets from Stage 2
- Assemble TV stand using instructions

Stage 3: Results

- No difference in assembly time by condition
- Instruction consultations: Low 8.9 High 7.1
- Box picture consultations: Low 9.1 High 3.4

Comments
- Should show relevant parts and attachments
- Structural diagrams and exploded view hard to use
- Text not very useful

Design Principles

- Step-by-Step
- Action diagrams
- Good visibility

TV stand instructions generated by our system
**Input**

Geometry: Parts in assembled configuration

Orientations: Default viewpoint / orientation

Preferred orientation for each part

Groupings: Fasteners, significant parts, similar actions, symmetry

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**Computing Visibility**

Area(P) = # red pixels
Area of top alone

Area(P,Q) = # red pixels
Area of top not occluded by sides

Vis(P,Q) = Area(P,Q) / Area(P)
% pixels that remain visible when sides are included

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**Visibility Constraints**

1. Parts being attached R
   - Check that each part is visible
   \[ \min_{r \in R} (\text{Vis}(r, R-r)) \times W_r \]

2. Previously attached parts A
   - Check that context is visible
   \[ \text{Vis}(A, R) \times W_A \]

3. Future unattached parts U
   - Check that future parts will be visible
   \[ \min_{u \in U} (\text{Vis}(u, R)) \times W_u \]

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**Find best assembly sequence**

- Planning: Geometric feasibility
- Presentation: Visibility

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**Step-by-step assembly sequence**

Valid

Valid

Invalid
Sequentially add parts
- Least visible to most visible
- Distance to viewer

Reorientation
- Set preferred orientation
- If poor visibility try alternate orientations
**Action Diagrams**
- Choose Direction
- Build Stacks
- Place Guidelines

**Step-by-step assembly diagrams**

**Bookcase**
- 9 Parts
- Design: 48s

**Test Object**
- 25 Parts
- Design: 53s

**Evaluation**
- 30 Participants
- Given 1 of 3 instruction sets: factory, hand-drawn, computer
- Assemble TV stand using instructions
Factory          Hand-drawn         Computer

Mean
time to
assemble
(min)

1.6     0.6     0.5

Errors: Factory 1.6  Hand-drawn 0.6  Computer 0.5
Task rated easiest in computer condition
Summary

Identification of design principles
- Production
- Preference
- Comprehension

Instantiation of design principles

Validation of design principles

Conveying Structure

Complex 3D objects
- Architectural models
- Mechanical assemblies
- Biological specimens
- ...

Photographs and illustrations
Reveal external shape, do not expose internal structure
Problem: Occlusion

Can't see beyond frontmost surface
- Fundamental property / limitation of vision

Exterior surfaces hide internal structure
- Normally we exploit this in computer graphics

Exploded views, cutaways, ghosting...

How it’s built / How it works / What it does

Topics
- Framework for conveying structure
- Choosing good views
- Layering
- Cutaways and sections
- Exploded views

Framework
### Framework for conveying structure

**Goal:** Expose important internal features

**Requirements**
- Internal features
- Viewpoint
- Blockers

**Procedure**
- Transform blockers so internal features visible

### Internal Features

- Which internal features should be visible?
  - Presentation
    - Features support story
  - Exploration
    - Show all internal parts
    - All of the important features may not be known a priori

### Viewpoint

Where is observer looking from?

### Blockers

Blockers are the objects or surfaces that occlude internal features from the viewpoint
**Blocker transformation**

Choose transformations that de-emphasizes blockers and emphasizes internal features?
- Cull
- Move
- Transparency
- Modify drawing style
- Rotate object (or transform viewpoint)

Visualization should clearly indicate transformation

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**Generic vs. accidental views**

**Generic:** A view of an object that does not change drastically under small changes in viewpoint

**Accidental:** A special view of an object for which small perturbations in viewpoint drastically change appearance

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**Accidental view**

Alignment of trash and sea

[Turner]
Generic vs. accidental view

Which view is best? [Palmer, Rosch, Chase 81]

Rate views

Canonical view [Palmer, Rosch, Chase 81]

Features must be salient
Generic view
Oblique view
  - Frontal view from above
  - ¾ up view

Canonical Views [Blanz, Tarr Bulthoff 99]
What is a good view?

Canonical views
- Oblique views from above
- Avoid accidental views

In our case – to reveal internal structure
- Separation of internal features in image plane

Viewpoint transformations

Sometimes a good viewpoint will expose features
- Street view does not show overall city plan
- Overhead view exposes more of the city plan

Layering

Transparency

Location of battery in army radio [Fainer & Seligmann 92]
**Transparency**

MoMA design entry [Tschumi 93]

**Ghosting**

Army radio [Feiner & Seligmann 92]

Bus [Thomas www.jttechart.com]

**Draw blockers as wireframes**

Video camera [from Homes 93]

Airplane engine [from Holmes 93]

**Dotted lines**

Dotted lines expose hidden features
Cutaways and Sections

Cutaways
Blockers partially visible

Edges
- Raggedness emphasizes cut
- Contrast also adds emphasis
- Shape focuses attention
- Spatializes internal stuff

Leonardo Da Vinci circa 1490

Interrante – Siggraph 97
Blocker surface indicated via thin lines in direction of principal curvature

Manually operated reciprocating water pump [Agricola 1556]
Cutaways: Example

Midget submarine [from Holmes 93]

Cutaways: Example

Hubble repair [from Holmes 93]

Sections

Split along cutting surface
- Usually planar cut
- May not cut all objects in plane

Orientation
- Principal planes
- Symmetry planes
- Structural elements

Convey shape
- Shape of cutting surface
- Auxiliary view showing cut location
- Shape & material of cut volume
- Orthogonal view allows measurement

Architecture

Engine in a large building [Boulton & Watt]
Shape of blocking surface

Control room of Midget Submarine [from Holmes 93]

Material of cut volume

Ear canal [from Mijksenaar 99]

Material of cut vol.

[French and Vierck 60]

Extracting sulphur from deposits [from Herdeg 81]

Synthesizing cut material

Volumetric illustration [Owada 04]
Exploded Views

Exploded views

Goal: Show overall structure

Direction
- Principal axes
- Sometimes zigzag to reduce occlusions

Distance
- Reduce / eliminate occlusions

Axonometric projection
- Reduces distortion

Guidelines
- When?
- Where?

Train [from Mijksenaar 99]

Principal Axes

Pivot hanger [French & Vierck 60]  Manual steering gear [from Ferguson 92]

Leonardo Da Vinci

Ratchet device
Sections and exploded view

IBM building plan [from Holmes 93]

Exploded view

Concept design for museum guide [Tufte 97]

Understanding 3D maps

Floorplans

Axonometric View

Locating landmarks fastest with axonometric view [Fontaine 01]
1. Geometric analysis - Find downward facing ceiling polygons
2. Place sectioning planes below ceilings
3. Multi-pass render each story separately

Generating an exploded view

Works with existing 3D applications

Intercept and modify OpenGL stream
- Non-invasive [Mohr 01]
- Apply to existing OpenGL application without modification

Future: Enhanced spectator mode

Real-world buildings

Seattle Public Library [from Seattle Times 04]