Conveying Structure

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CS 294-10: Visualization
Spring 2010

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

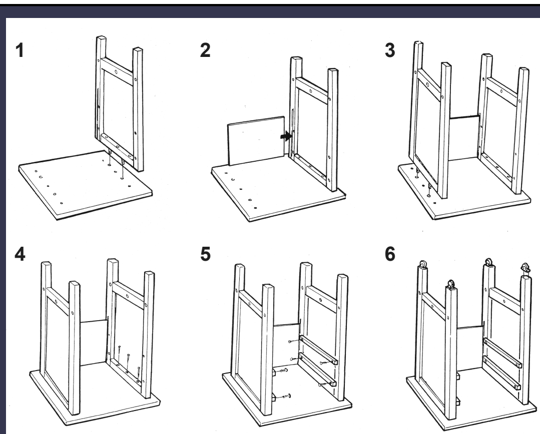
Schedule
- Project proposal: 3/29
- Initial problem presentation: 3/31 (Wed)
- Midpoint design discussion: TBD
- Final paper and presentation: TBD

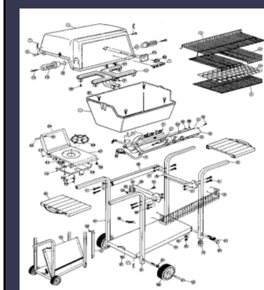
Grading
- Groups of up to 3 people, graded individually
- Clearly report responsibilities of each member

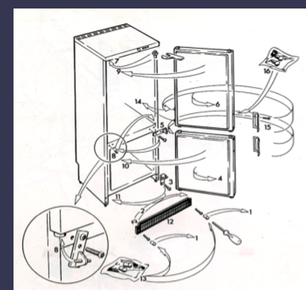
Initial Presentations

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





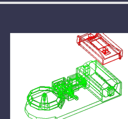


Previous Work

Planning

- Choose sequence of assembly operations
- Robotics / AI / Mechanical Engineering

[Wolter 89], [de Mello 91], [Wilson 92], [Romney 95]



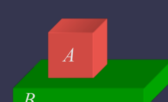
Presentation

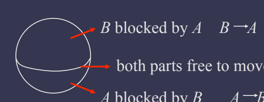
- Visually convey assembly operations
- Visualization / Computer Graphics

[Seligmann 91], [Rist 94], [Butz 97], [Strothotte 98]

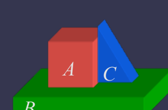
Jointly optimize plan and presentation

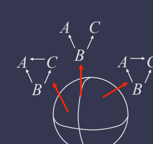
Geometric Analysis [Romney 95]



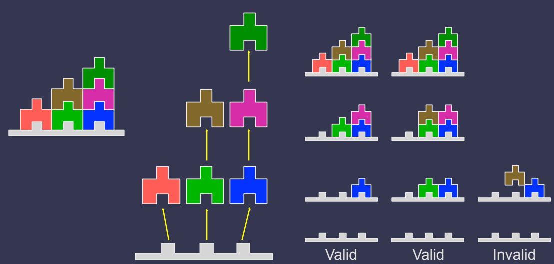


Input Parts **Blocking Graph**





Geometric Assembly Planning



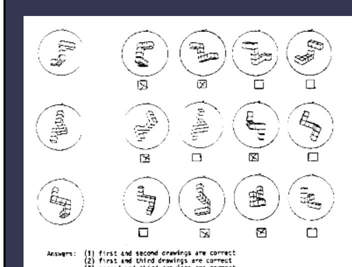
Many Geometrically Valid Sequences

How do we choose the best sequence?

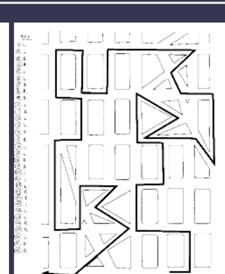
Identifying Design Principles

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

Spatial Ability Tests



Mental Rotation [Vandenburg 78]



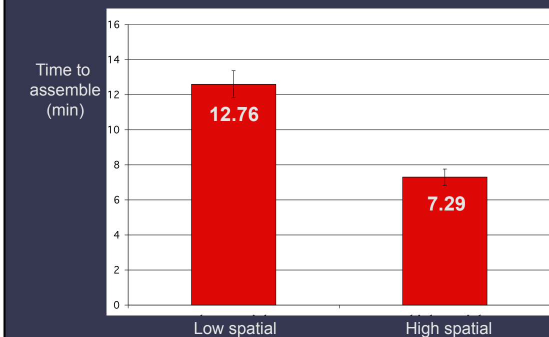
Navigation [Money 78]

Separate high and low spatial ability

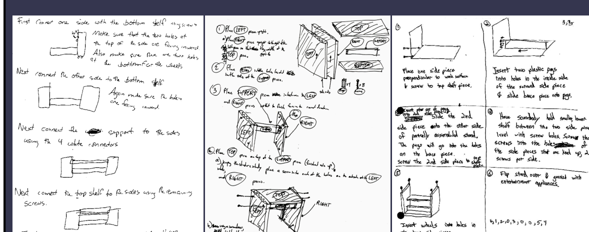
Stage 1: Production

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

Stage 1: Mean completion time

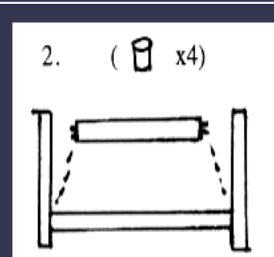


Stage 1: Instructions produced



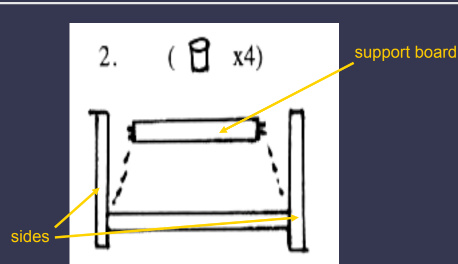
- Almost all contained diagrams 98%
- Text redundant with diagrams 62%

Stage 1: Errors in instructions



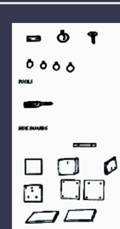
- Errors in low spatial instructions 86%
- Errors in high spatial instructions 12%

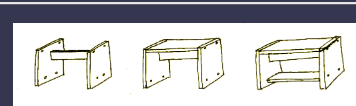
Stage 1: Errors in instructions

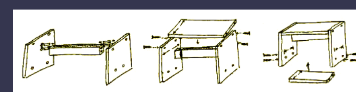


- Errors in low spatial instructions 86%
- Errors in high spatial instructions 12%

Stage 1: Classes of Diagrams

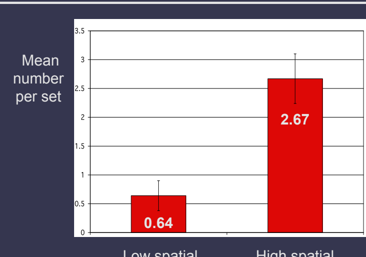

Parts menu


Structural diagrams


Action diagrams

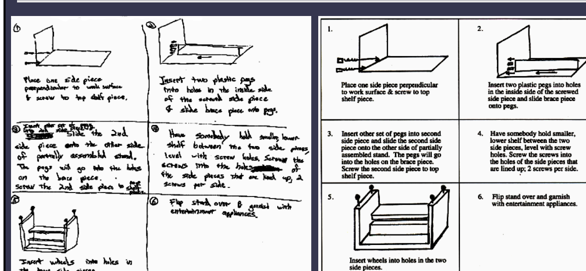
- Parts menu to differentiate parts
- Structural diagrams depict completed step
- Action diagrams show assembly action/operation

Stage 1: Action diagrams



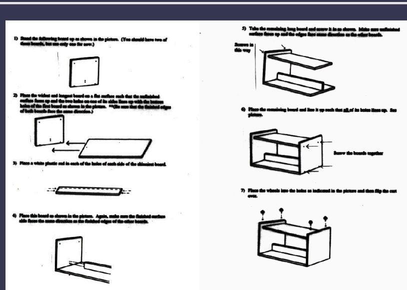
- High spatial
  - More action diagrams
  - More 3D diagrams
  - Less text

Stage 2: Preference



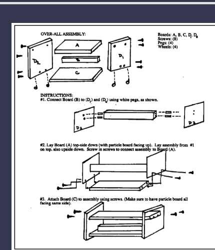
- 21 Participants
- Assemble TV Stand without instructions
- Rated 39 sets of redrawn instructions

Stage 2: Highest Rated

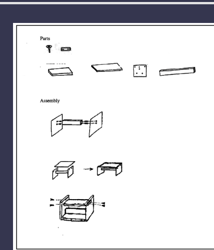


- Ratings similar across all participants
- Spatial ability does not affect preference

Stage 3: Comprehension



Set 1: Text + Action



Set 3: Parts menu + Structural + Action

- 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

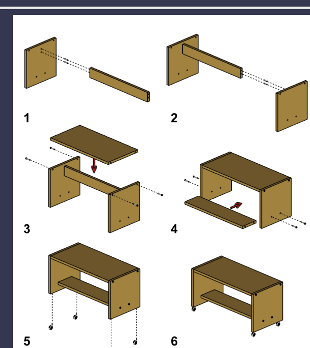
- Should show relevant parts and attachments
- Structural diagrams and exploded view hard to use
- Text not very useful

Design Principles

Step-by-Step

Action diagrams

Good visibility



TV stand instructions generated by our system

Input

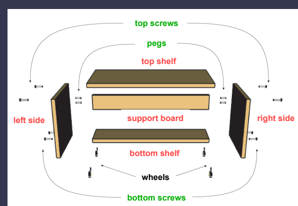
Geometry: Parts in assembled configuration

Orientations: Default viewpoint / orientation
Preferred orientation for each part

Groupings: Fasteners, significant parts, similar actions, symmetry

required
optional

Assembled geometry in default orientation



Parts grouped as fasteners and significant parts

All parts

Search

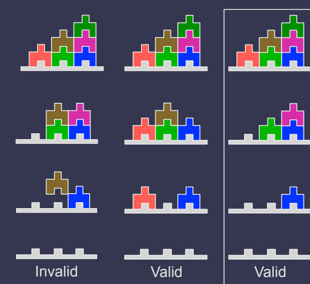
Subdivide Steps

Reorientation

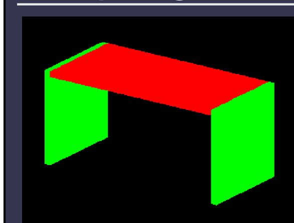
Step-by-step assembly sequence

Find best assembly sequence

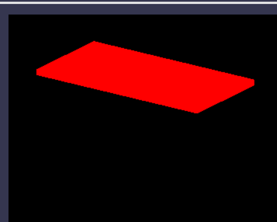
- Planning: Geometric feasibility
- Presentation: Visibility



Computing Visibility



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



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

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

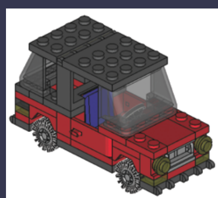
Visibility Constraints

1. Parts being attached R $\min_{r \in R} (Vis(r, R-r)) * W_R$
- Check that each part is visible

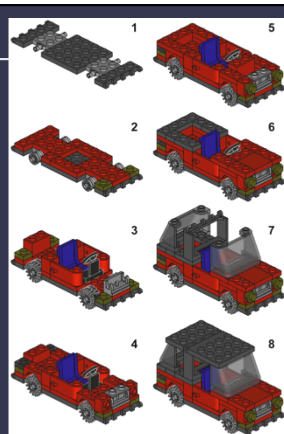
2. Previously attached parts A $Vis(A, R) * W_A$
- Check that context is visible

3. Future unattached parts U $\min_{u \in U} (Vis(u,R)) * W_U$
- Check that future parts will be visible

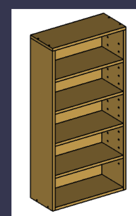
Lego Car



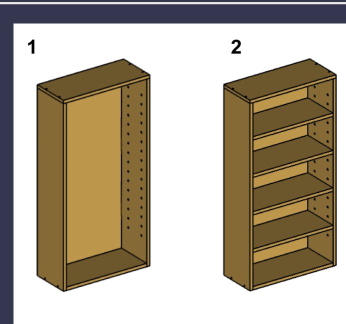
Input model



Bookcase



Input model



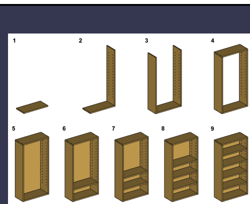
All parts

Search

Subdivide Steps

Reorientation

Step-by-step assembly sequence



Sequentially add parts

- Least visible to most visible
- Distance to viewer

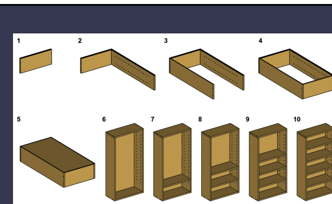
All parts

Search

Subdivide Steps

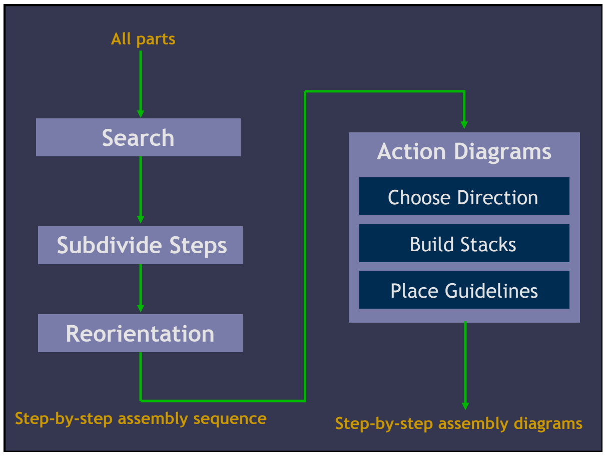
Reorientation

Step-by-step assembly sequence

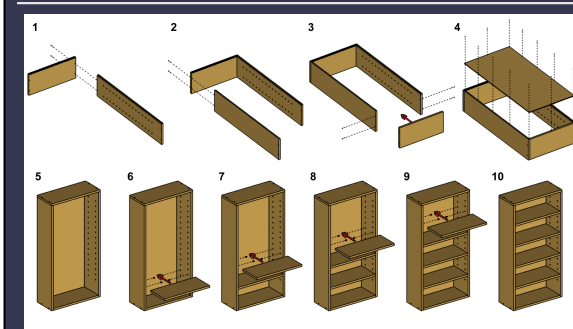


Reorient

- Set preferred orientation
- If poor visibility try alternate orientations

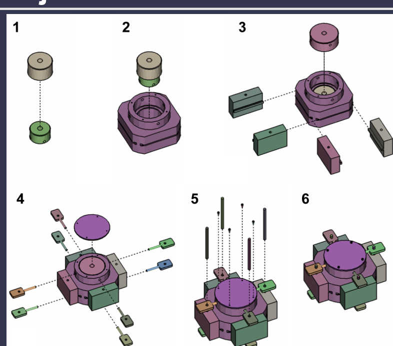


Bookcase



9 Parts Design: 48s

Test Object

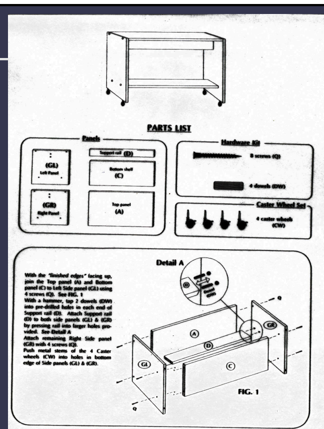


25 Parts Design: 53s

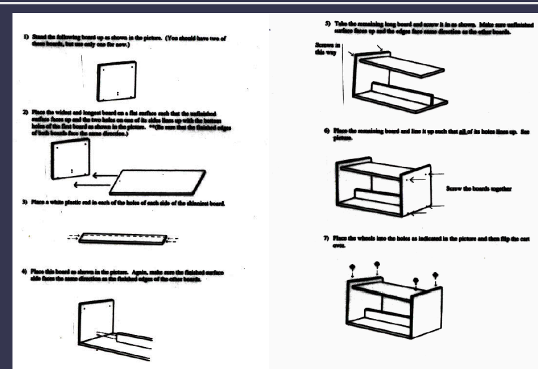
Evaluation

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

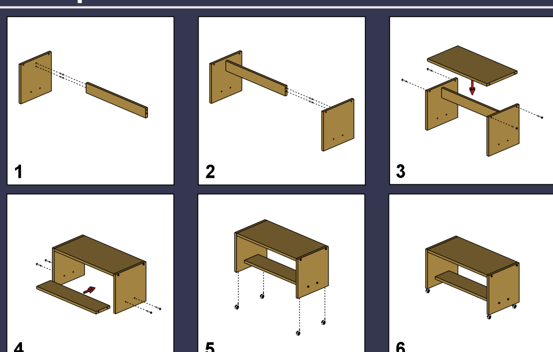
Factory



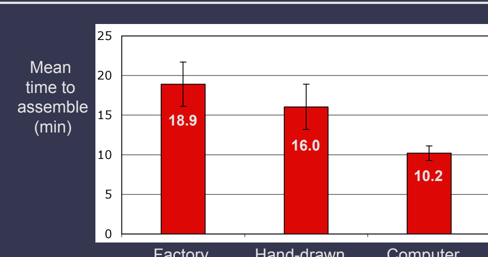
Hand-drawn



Computer Generated



Results

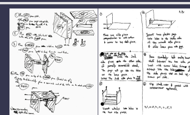


Errors: Factory **1.6** Hand-drawn **0.6** Computer **0.5**

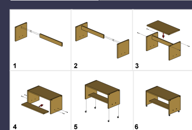
Task rated easiest in computer condition

Summary

Identification of design principles
- Production
- Preference
- Comprehension



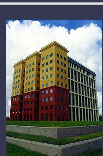
Instantiation of design principles

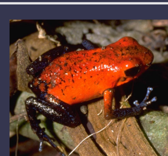


Validation of design principles

Conveying Structure

Complex 3D objects

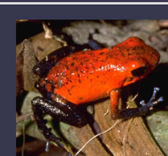
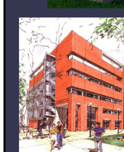
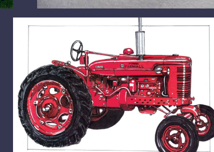
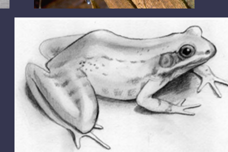




- **Architectural models**
- **Mechanical assemblies**
- **Biological specimens**
- **…**

Photographs and illustrations



Reveal external shape, do not expose internal structure

Problem: Occlusion

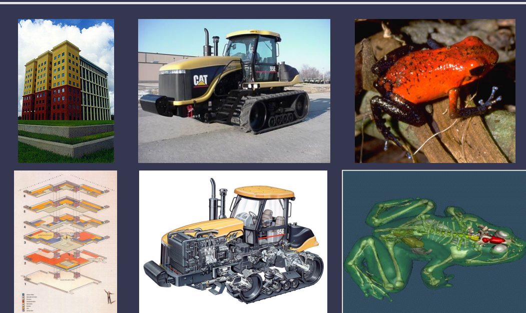
Can't see beyond frontmost surface

- 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

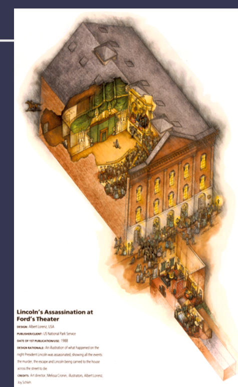
- Internal features
- Viewpoint
- Blockers

Procedure

- Transform blockers so internal features visible

Internal Features

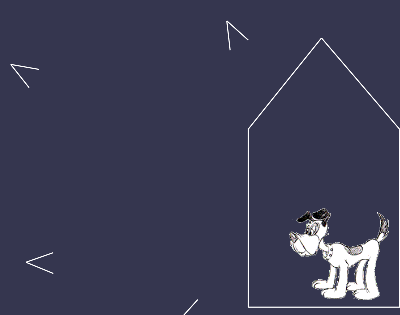
- **Which internal features should be visible?**
  - **Presentation**
    - Features support story
  - **Exploration**
    - Show all internal parts
    - All of the important features may not be known *a priori*



Lincoln's assassination at Ford's theater [Lorenz 88]

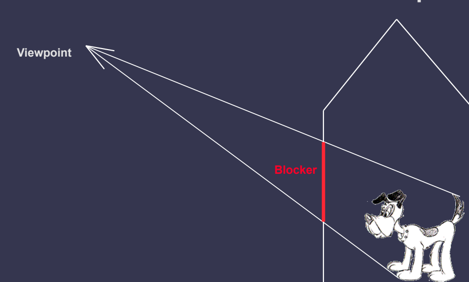
Viewpoint

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

Choosing Good Views

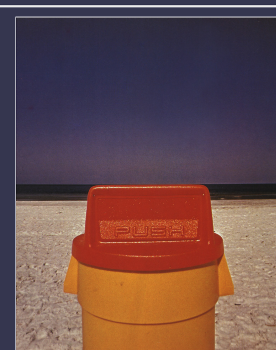
Generic vs. accidental views

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

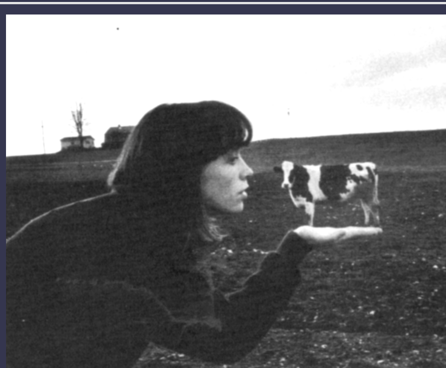
Accidental view

Alignment of trash and sea



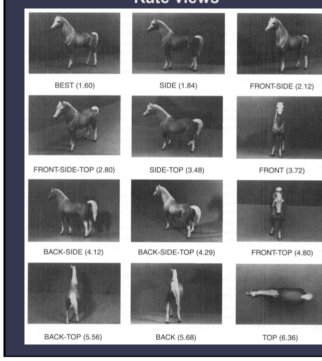
[Turner]

Generic vs. accidental view



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

Rate views



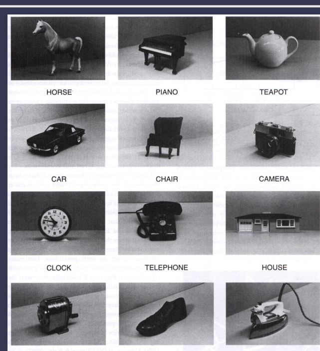
Canonical view [Palmer, Rosch, Chase 81]

Features must be salient

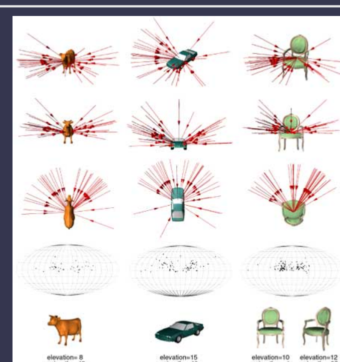
Generic view

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

Street level view

Overhead view

Sometimes a good viewpoint will expose features

- Street view does not show overall city plan
- Overhead view exposes more of the city plan

Layering

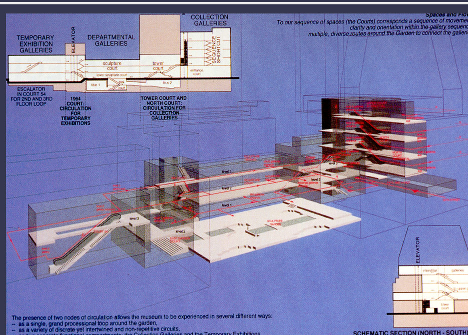
Transparency

Blocker completely transparent

Blocker semi-transparent

Location of battery in army radio [Feiner & Seligmann 92]

Transparency



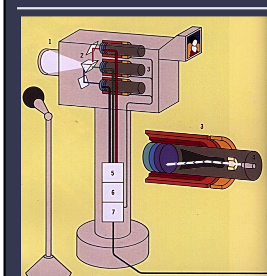
MoMA design entry [Tschumi 99]

Ghosting

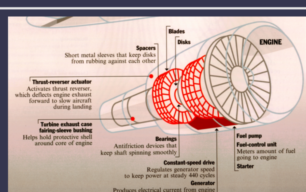
Army radio [Feiner & Seligmann 92]

Bus [Thomas www.jttechart.com]

Draw blockers as wireframes

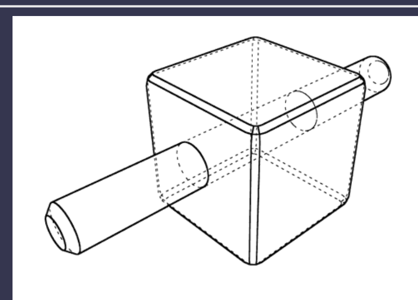


Video camera [from Homes 93]



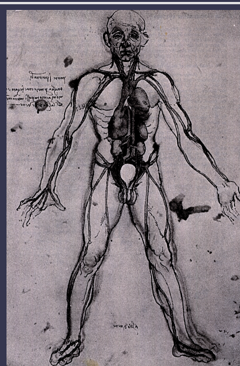
Airplane engine [from Holmes 93]

Dotted lines

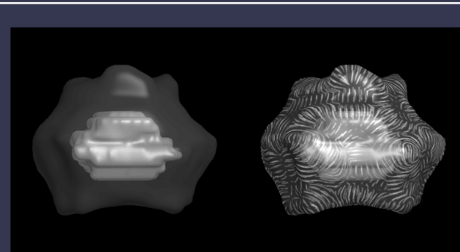


Dotted lines expose hidden features

Leonardo Da Vinci circa 1490



Interrante – Siggraph 97



Blocker surface indicated via thin lines in direction of principal curvature

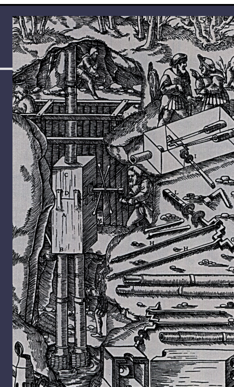
Cutaways and Sections

Cutaways

Blockers partially visible

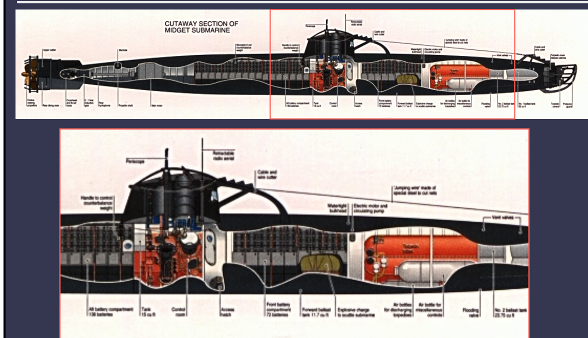
Edges

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



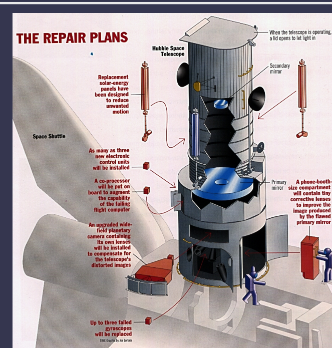
Manually operated reciprocating water pump [Agricola 1556]

Cutaways: Example



Midget submarine [from Holmes 93]

Cutaways: Example



Hubble repair [from Holmes 93]

Sections

Split along cutting surface

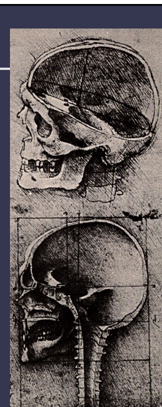
- Usually planar cut
- May not cut all objects in plane

Orientation

- Principal planes
- Symmetry planes
- Structural elements

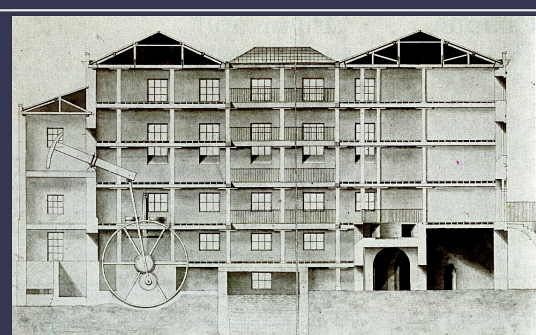
Convey shape

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



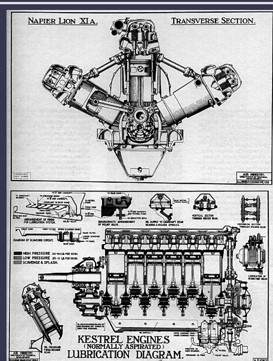
Skulls [Da Vinci ca 1490]

Architecture



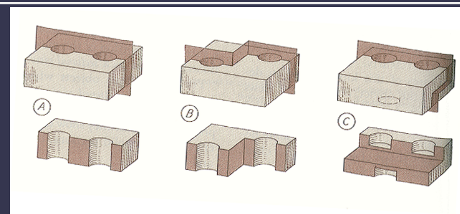
Engine in a large building [Boulton & Watt]

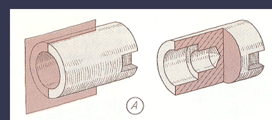
Technical illustration



Two sections of engine

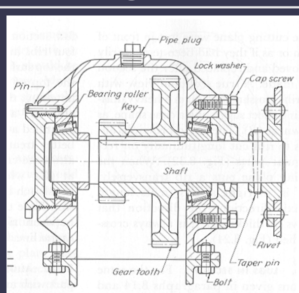
Showing cut location





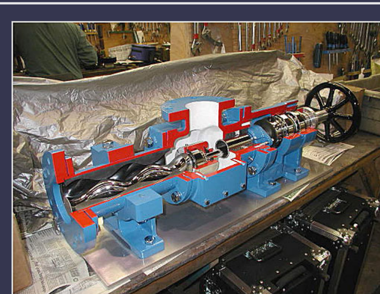
[French & Vierck 60]

Shape of cutting surface



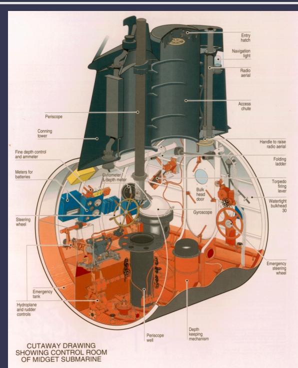
[French & Vierck 60]

Shape of cutting surface



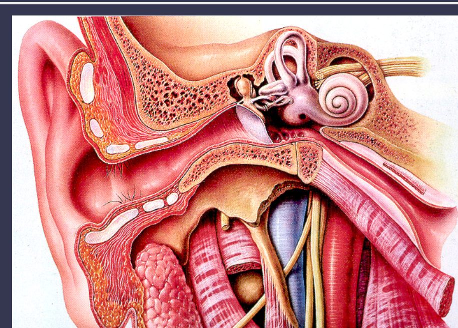
Physical cutaway [CalCo www.calcocutaways.com]

Shape of blocking surface



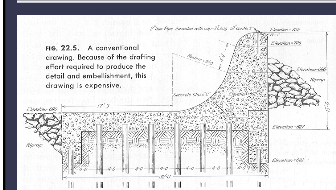
Control room of Midget Submarine [from Holmes 93]

Material of cut volume

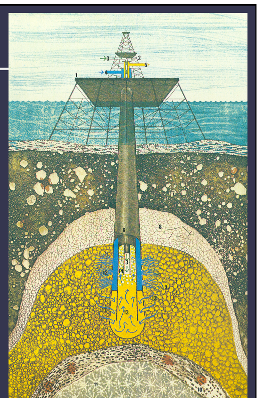


Ear canal [from Mijksenaar 99]

Material of cut vol.

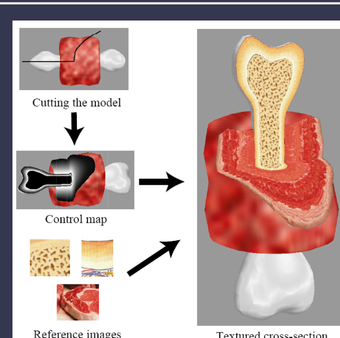


[French and Vierck 60]



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

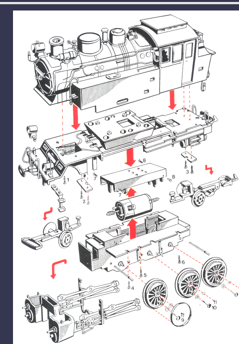
- Reduce / eliminate occlusions

Axonometric projection

- Reduces distortion

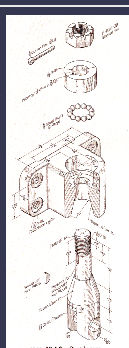
Guidelines

- When?
- Where ?

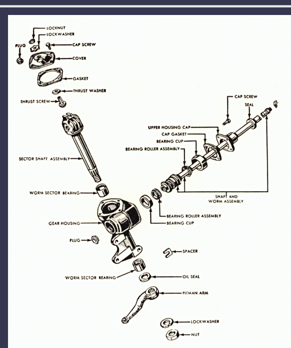


Train [from Mijksenaar 99]

Principal Axes

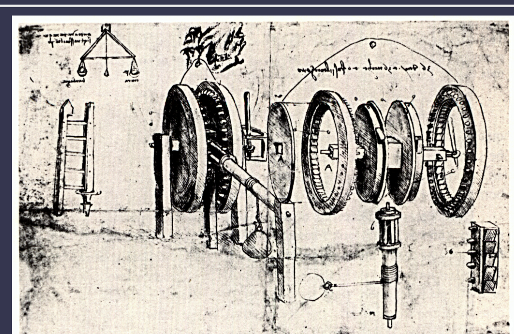


Pivot hanger [French & Vierck 60]



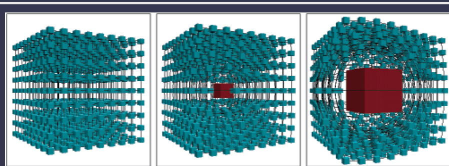
Manual steering gear [from Ferguson 92]

Leonardo Da Vinci

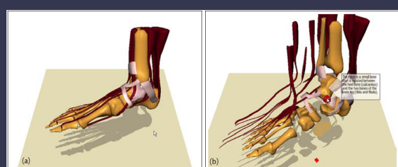


Ratchet device

Radial exploded views

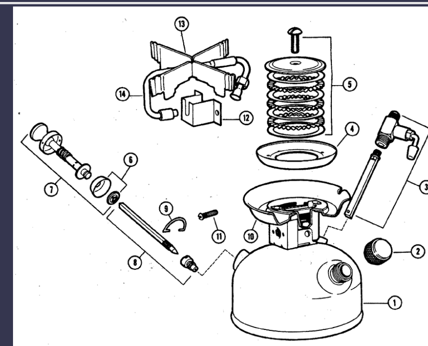


3D Distortion Viewing [Carpendale 97]



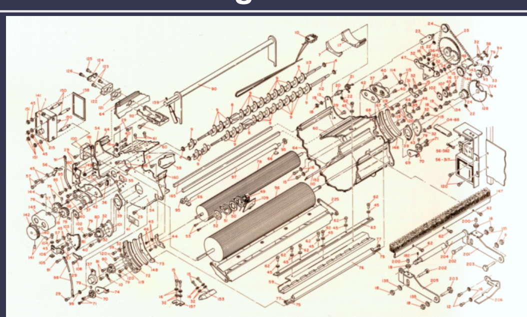
3D Explosion Probe [Sonnet 04]

Zigzag layout



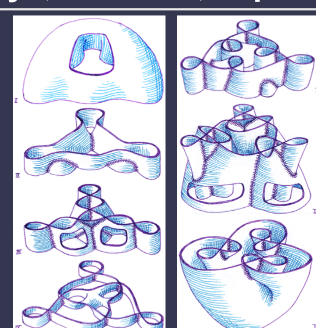
Camping Stove [from Mijksenaar 99]

Occlusion and guidelines



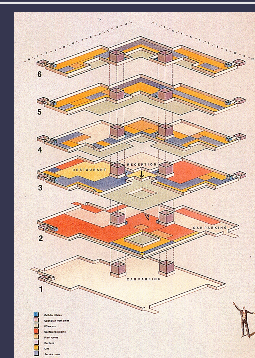
IBM Series III Copies/Duplicator Adjustment Parts Manual [Graham 76]

Cutaways, sections, exploded view



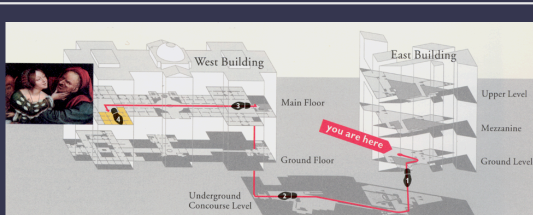
Strange immersion of torus in 3-space
[Curtis 92]

Sections and exploded view



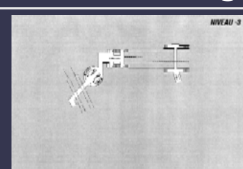
IBM building plan [from Holmes 93]

Exploded view

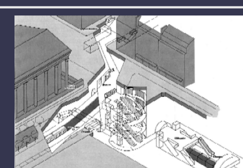


Concept design for museum guide [Tufte 97]

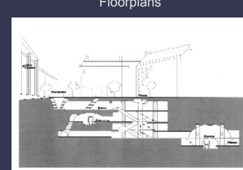
Understanding 3D maps



Floorplans



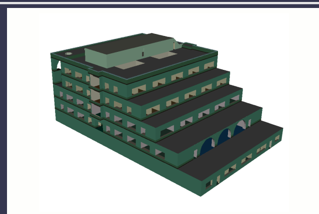
Axonometric View



Floorplans + Front View

Locating landmarks fastest with axonometric view [Fontaine 01]

Generating an exploded view



Soda Hall model from Funkhouser, Séquin, Teller

1. Geometric analysis - Find downward facing *ceiling* polygons
2. Place sectioning planes below ceilings
3. Multi-pass render each story separately

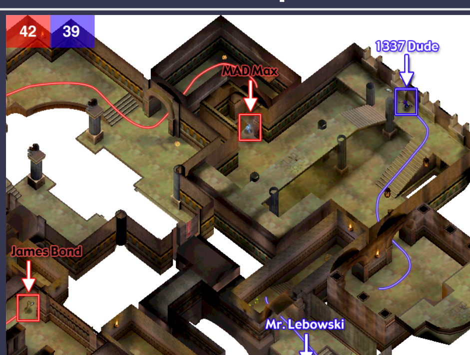
Works with existing 3D applications

Quake III Arena by Id Software

Intercept and modify OpenGL stream

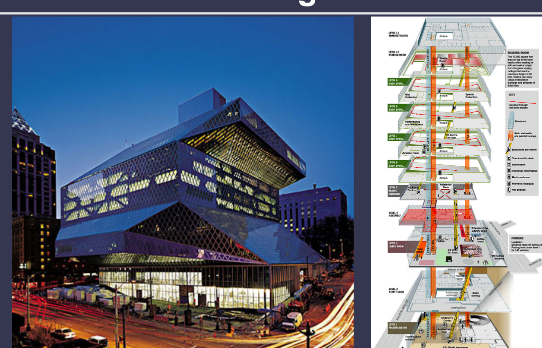
- Non-invasive [Mohr 01]
- Apply to existing OpenGL application without modification

Future: Enhanced spectator mode

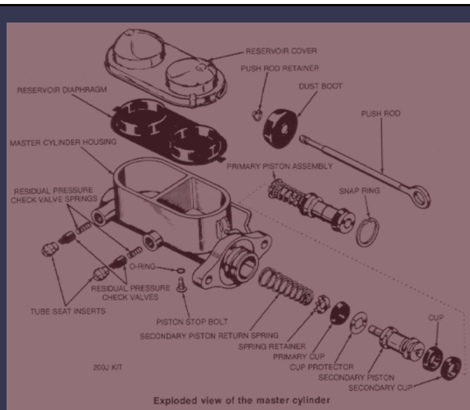


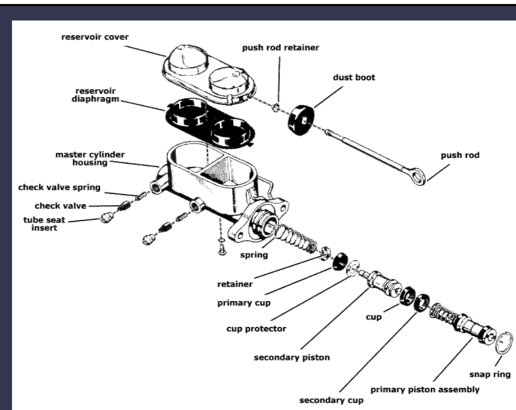
Mock-up design

Real-world buildings

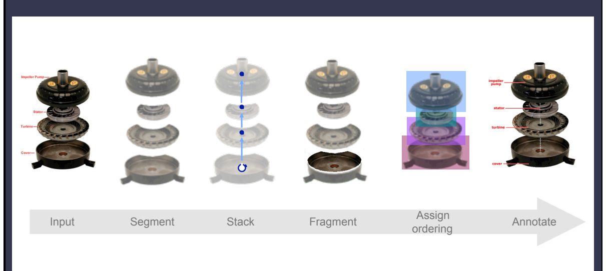


Seattle Public Library [from Seattle Times 04]





Authoring Pipeline

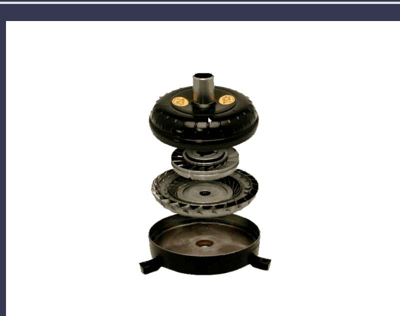


Segmentation

Stacking

Fragmentation and depth assignment

Annotation



Interactive viewing