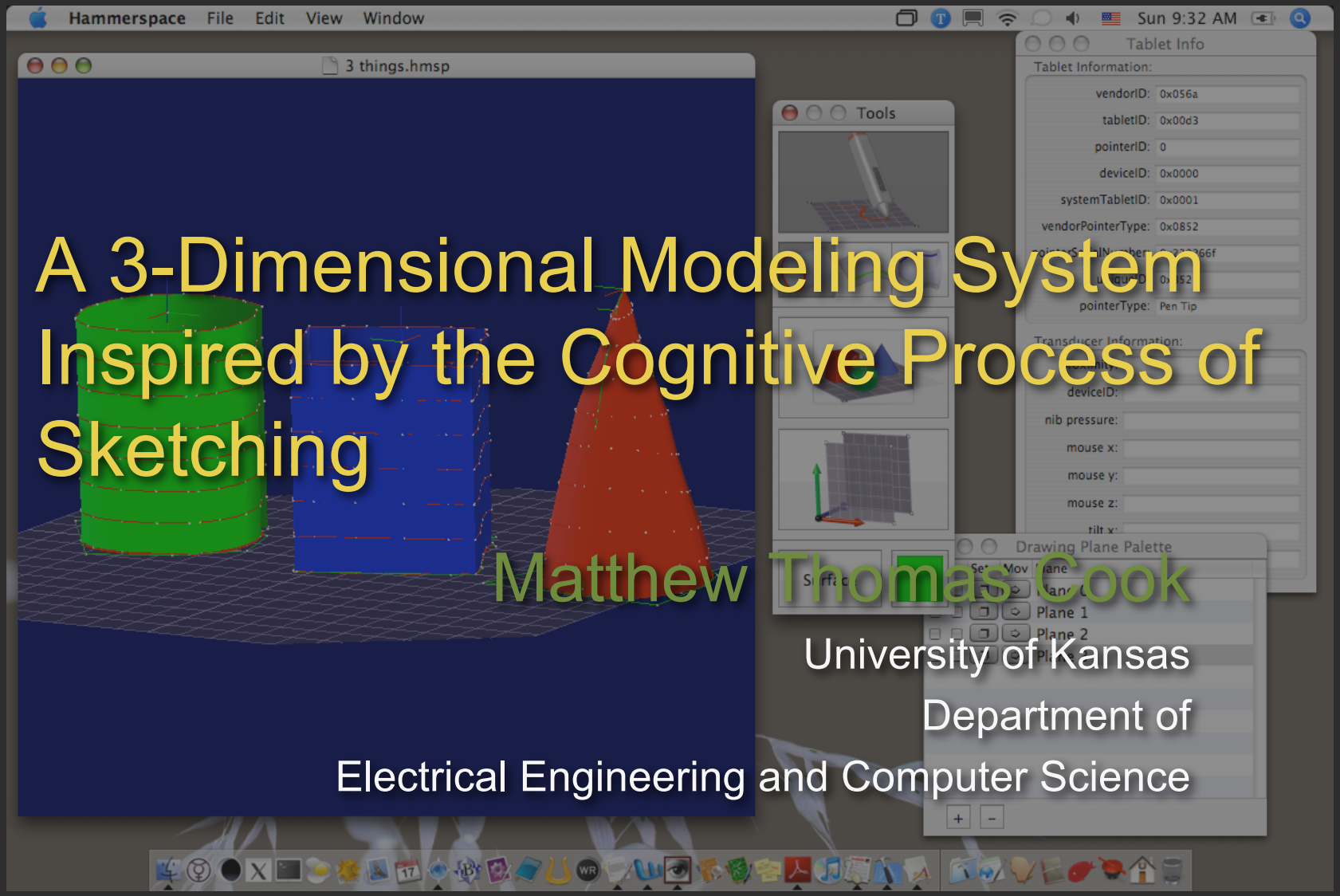


A 3-Dimensional Modeling System Inspired by the Cognitive Process of Sketching

Matthew Thomas Cook

University of Kansas

Department of

Electrical Engineering and Computer Science

Introduction

- 3-D modeling is an increasingly important application, *however…*
- Modeling software is not widely used outside industry.

The Trouble with Current Systems

- For Consumers:
  - Complex modeling methods require expertise.
  - Too expensive.
- For Artists / Designers:
  - Unintuitive interfaces based on underlying representations and engineering tools.
- For Researchers / Engineers:
  - Difficult to generate simple experimental or preparatory models quickly.
- For Everyone:
  - Difficult to interact with the 3-D environment through the 2-D interface.

Research Response: Sketch-Based Modeling

- Develop more intuitive modeling interfaces.
- Often based on physical artistic techniques.
- Focus on preparatory designs and early planning stages of modeling.
- Utilize a variety of modeling methods and interfaces.

- Three areas of weakness in sketch-based modeling.

(1) Trying to Mimic Physical Technique

- Problem:
  - Frustrates users who are expecting a familiar experience.
  - Provides system with impoverished 3-D information.

(2) Result Is 3-D but the Interface is 2-D

- Problem:
  - User's experience is necessarily 2-D
    - 2-D display device.
    - 2-D input devices (mouse, tablet, etc.)
  - 3-D Artistic techniques do not translate.
    - Clay sculpture.
    - Carving.
  - Navigating 3-D environment is challenging.

(3) Digitizing Tablets are Underutilized

- Problem:
  - Tablets also provide dynamic physical information.
    - Stylus position above the tablet's surface.
    - Pressure exerted on the stylus tip.
    - Angle of the stylus in relation to the tablet.
  - This information is largely ignored by other systems.

The Present Work

- Developed a prototype sketch-based modeling interface and modeling method:
  - Based on how artists *think* about sketching.
  - Generate 3-D models from user's 2-D strokes.
- Developed system of tablet gestures:
  - Inspired by natural hand and drawing gestures.
  - Demonstrates the utility of this information.
  - Provides a more intuitive means of controlling the system and navigating 3-D environment.

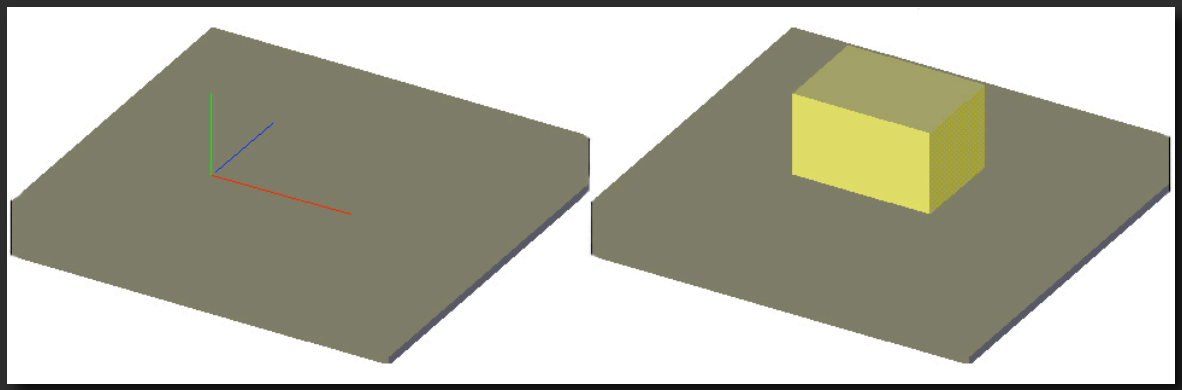
Our Agenda

- Introduction / Background
- Related Work
- Design of the Present System
- Implementation Details
- Preliminary Assessment
- Conclusions

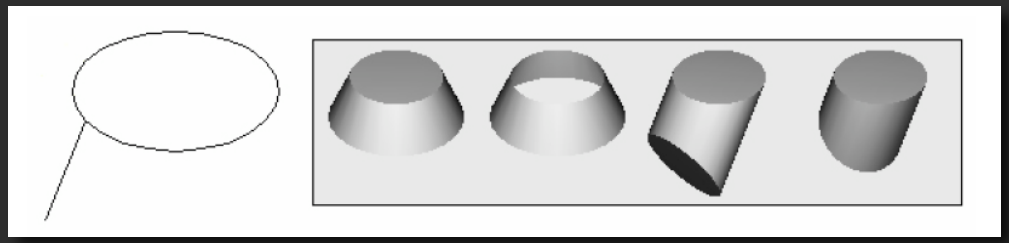
Sketch-Based Modeling Approaches

- Gesture Created Primitives
- AI and Machine Learning
- Height-Field and Shape-from-Shading
- Line Labeling
- Blobby Inflation
- Deformation
- Contour Curves and Drawing Surfaces
- Stroke-Based Constructions

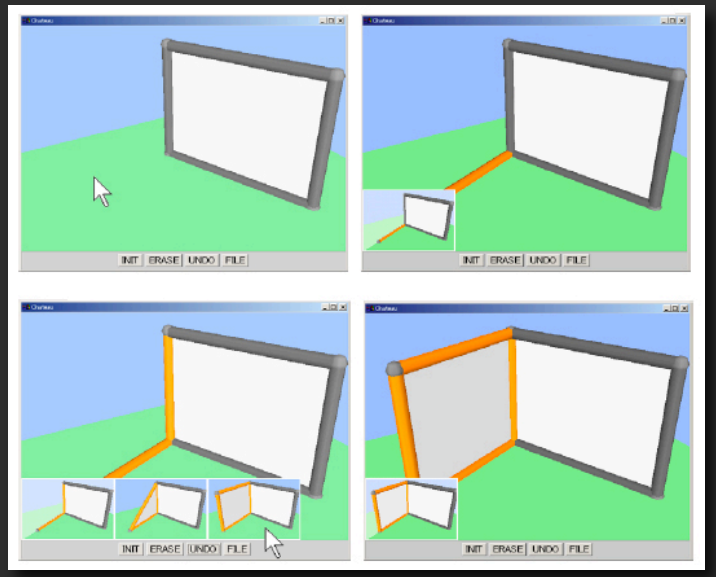
Gesture Created Primitives



Java version of SKETCH
[Zeleznik *et al.*, 1996]
[Doppelt, 1997]

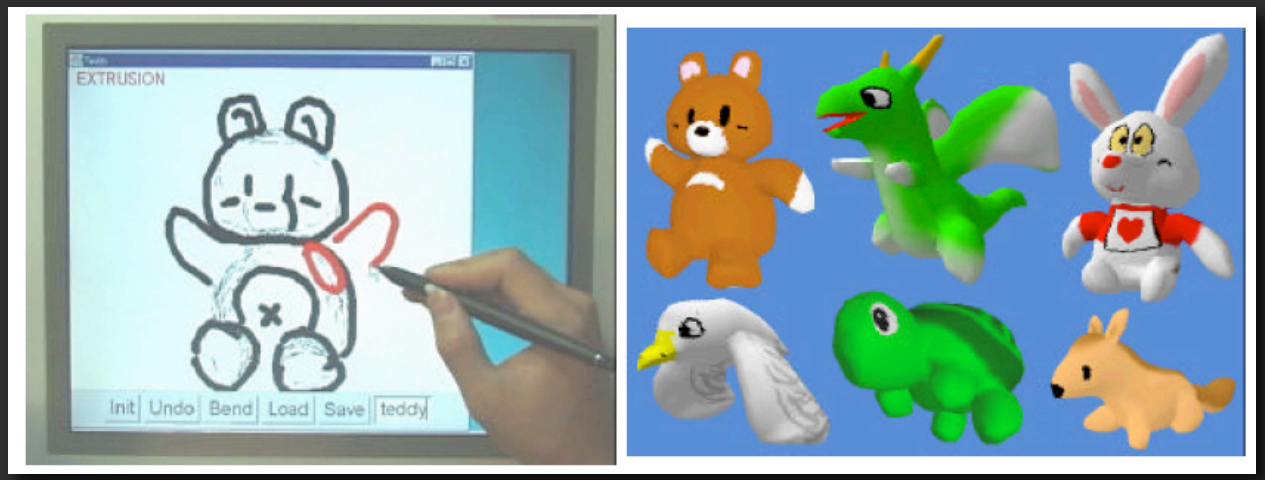


Expectation Lists
[Pereira *et al.*, various]



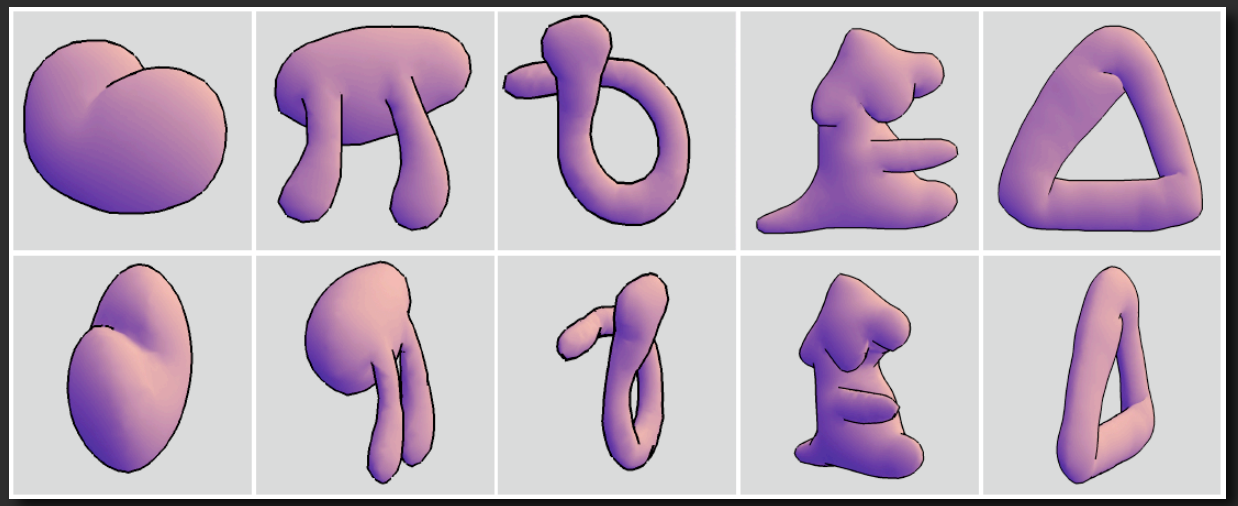
Suggestive Interface
[Igarashi & Hughes, 2001]

Blobby Inflation

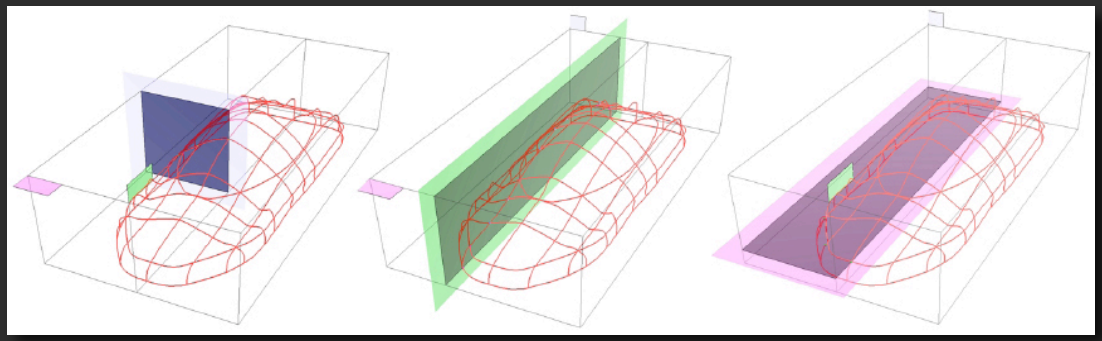


Teddy
[Igarashi *et al.*, 1999]

SmoothSketch
[Karpenko *et al.*, 2002

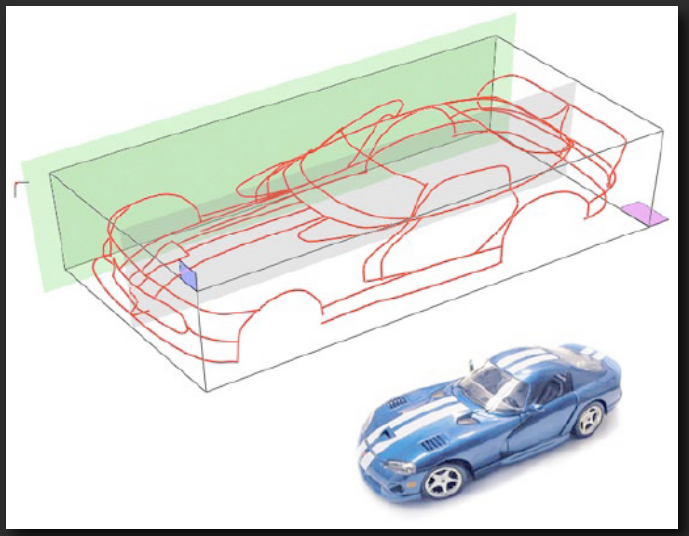


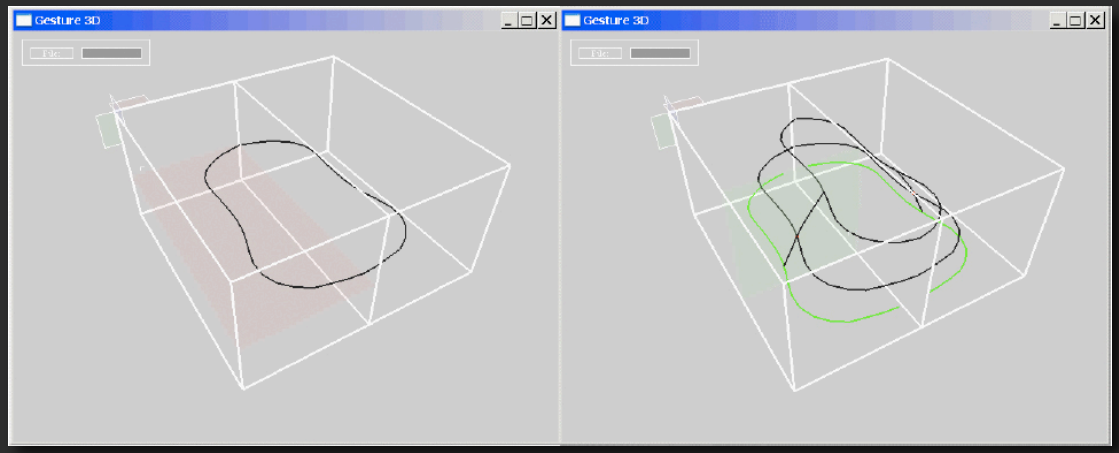
Contour Curves and Drawing Surfaces



Modeling Stage and 2-D Construction Planes
[Grossman *et al.*, 2001]

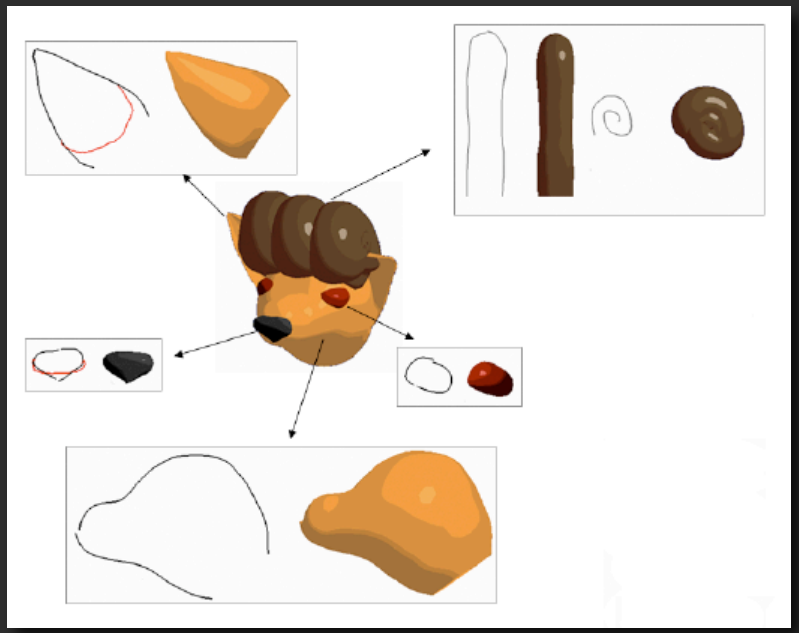
Principle 3-D Curves
[Grossman *et al.*, 2002]





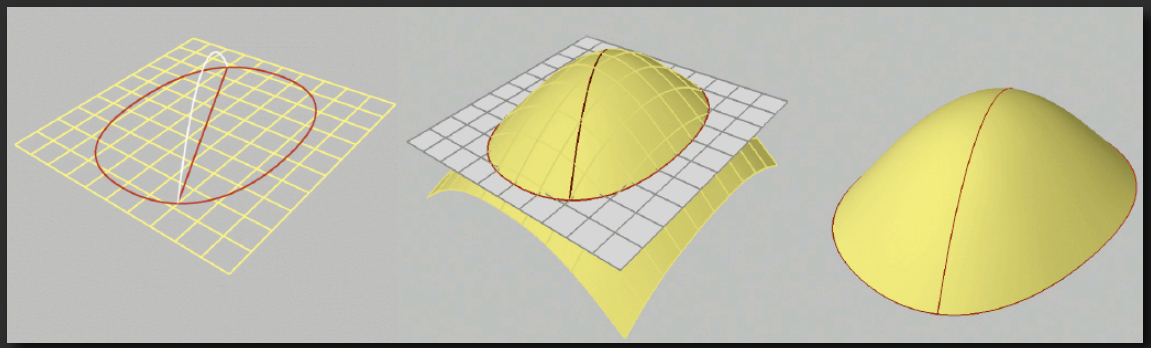
Construction Planes
[Tsang *et al.*, 2004]

Stroke-Based Construction



Rotational and Cross-Sectional
Blending Surfaces
[Cherlin *et al.*, 2005]

Sketch and Constraint Based
B-Spline Surfaces
[Michalik *et al.*, 2002]



Related Work Summary

- Interaction heavy interfaces get in the way of the sketching process.
- Sketching is inherently ambiguous, and defies interpretive systems.
- Inflation and Gesture systems were effective in creating geometry, but too constraining.
- Stroke based systems were more expressive, but difficult to control.

Design of the Present System

- Introduction / Background
- Related Work
- Design of the Present System
  - Approach
  - System Components
- Implementation Details
- Preliminary Assessment
- Conclusions

A New Approach:

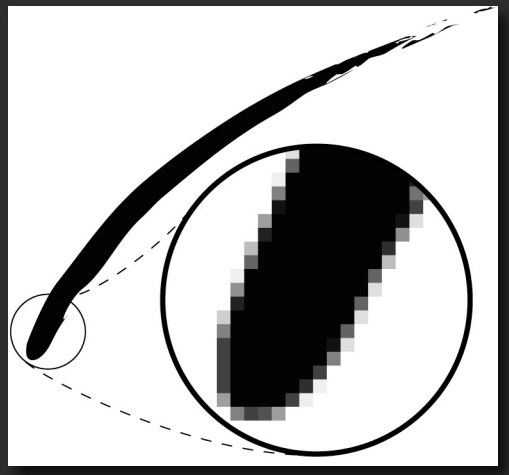
- Input based on 2-D sketching into a 3-D environment.
  - Accept familiar 2-D drawing skills.
  - Expand those to define 3-D objects.
- A construction system based on the way artists *think* about drawing.
  - Cater the the *mental* processes that underlie physical techniques.
  - Skills translate, even when techniques are incongruous.
- Offer system control though tablet gestures.
  - More direct physical means of navigating in 3-D.
  - Based on natural / intuitive physical motions.

Components of the System

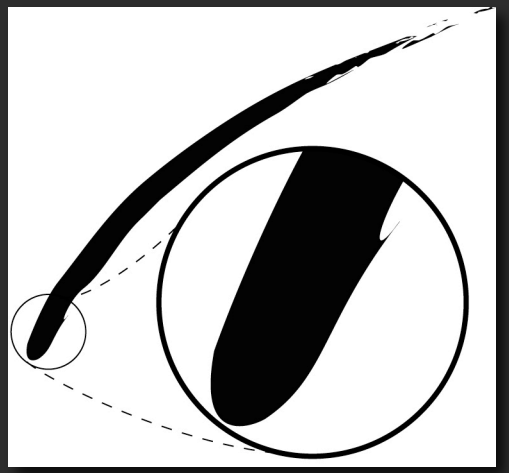
- Stroke System
- Drawing Planes
- 3-D Construction System
- Tablet Gestures

Representing Strokes

- 2-D art systems use raster graphics to mimic natural media.
  - Might encourage 2-D rather than 3-D drawing.
  - Does not provide geometric information.
- Vector graphic representation.
  - Strokes are collected as polyline.
  - Converted to a parametric representation.



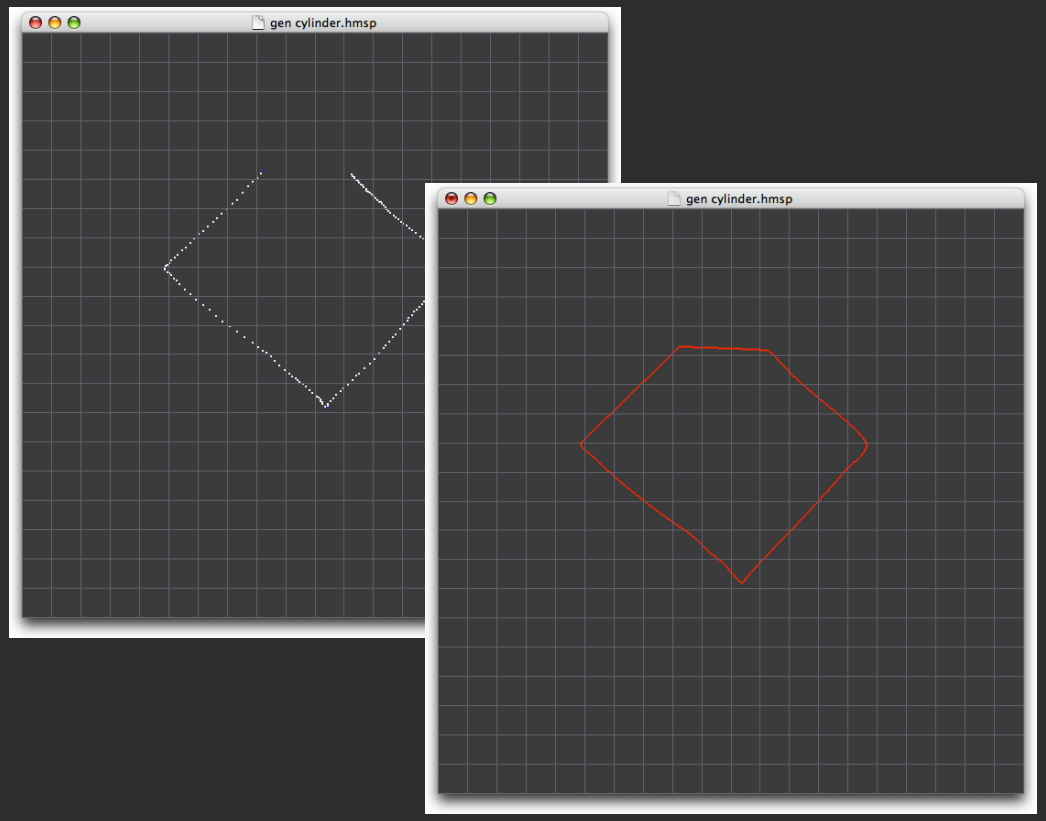
Raster Graphic



Vector Graphic

Collecting Strokes

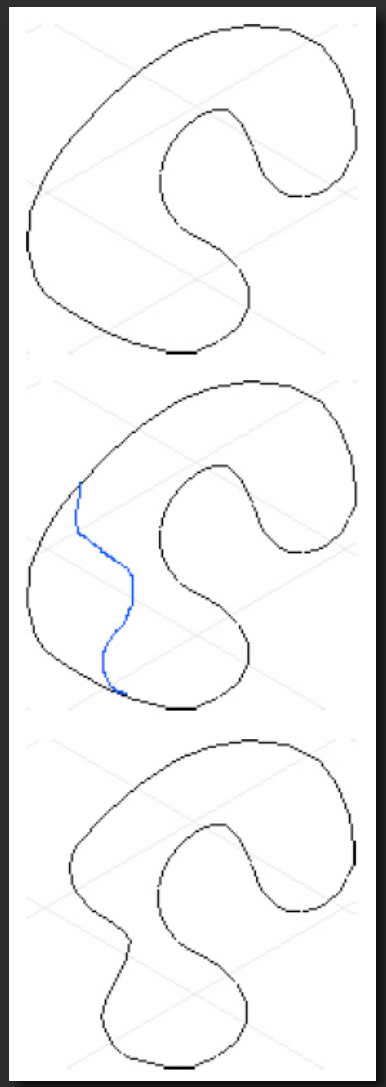
- On-the-fly fitting
  - Very resource intensive.
  - Unsettling to the user.
  - Often unstable results.
- Stepwise fitting
  - Distracting to the user.
  - Occasionally unstable.
- Batch processing
  - Least distracting to user.
  - Highly stable results.



Batch Processing
Temporary (top) and Final (bottom) Visualization

Dealing with Strokes

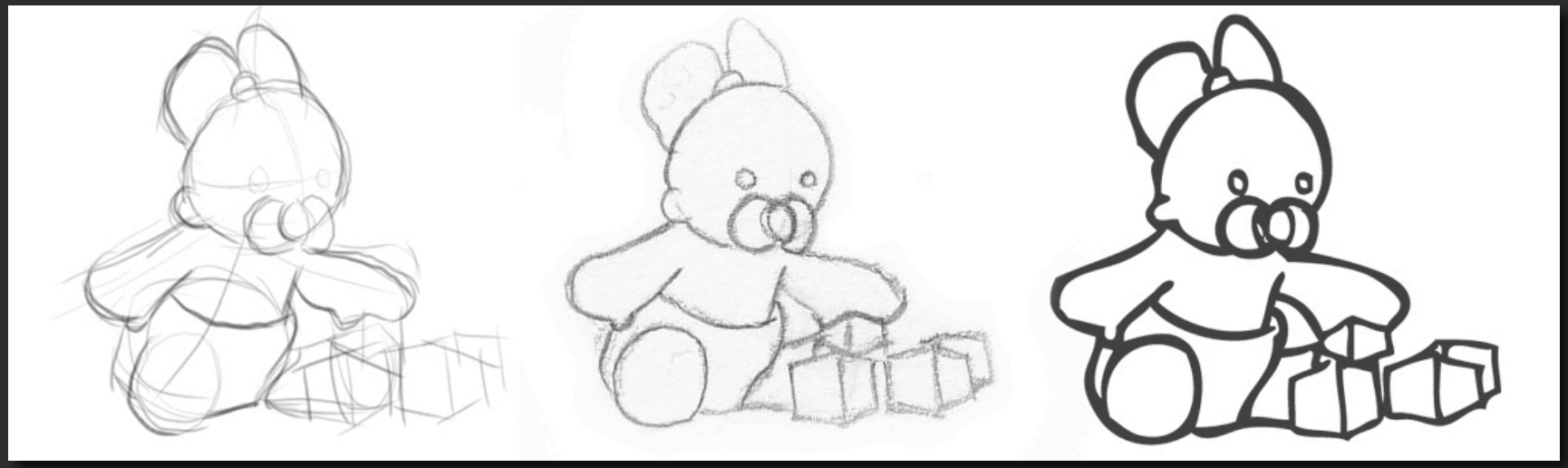
- `mark-based' or `stroke-based' editing systems.
  - Overdrawing replaces segment. *OR…*
  - Additional curves act as attractors.
- Drawbacks:
  - Interpreting the meaning of a correction is non-trivial.
  - Frustrating for users.
  - Curve degradation.
  - Lose extraneous and contemplative strokes.



Editing with Overdrawing
[Pereira *et al.*, 2003]

Traditional Technique: The Cleanup Artist

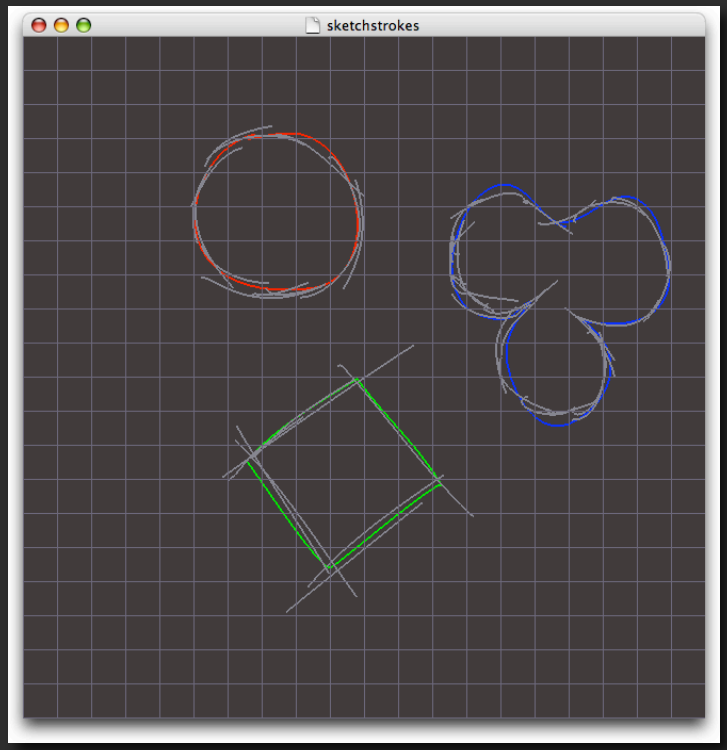
- In the world of hand-drawn animation:
  - Original animators' messy sketches are traced to clean lines by a *cleanup artist*.



Rough Sketch | Cleaned Sketch | Inked Drawing

The Stroke Tool

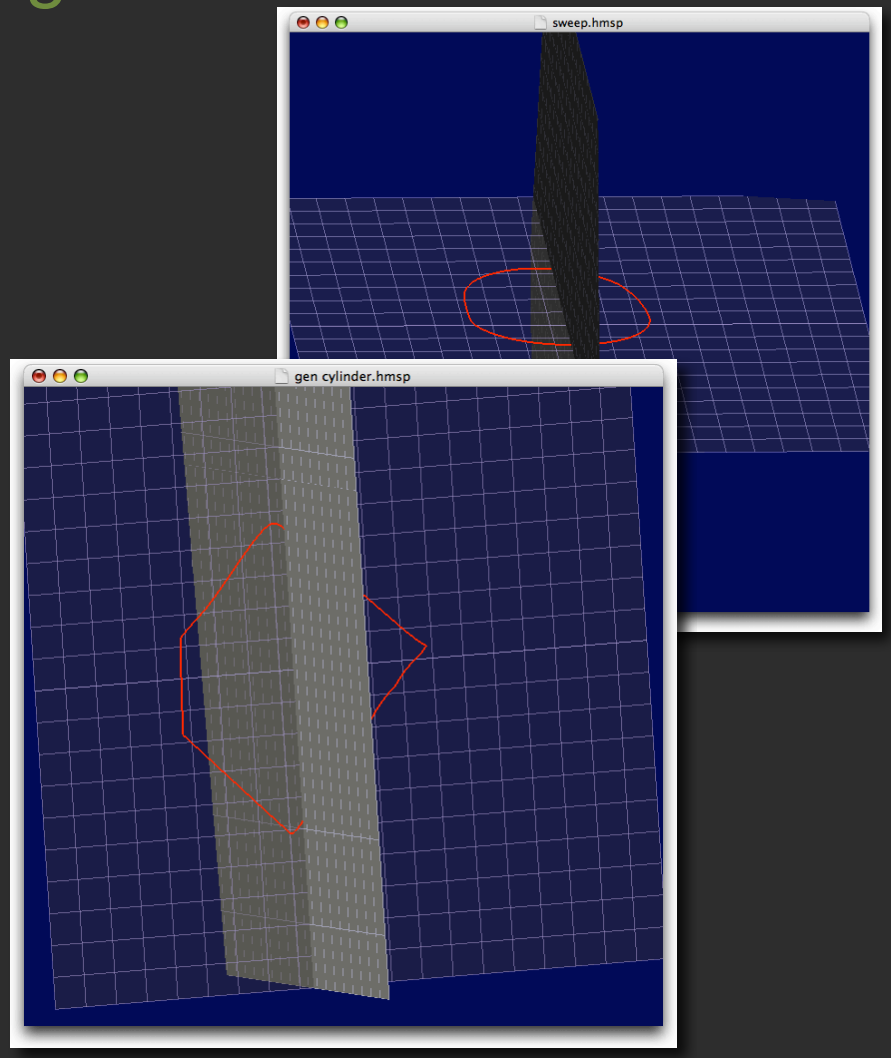
- Stroke tool with 3 pens - indicate system interpretation of strokes.
  - Last stroke created with each pen is color coded.
  - Historical strokes are muted.
- Direct control of final stroke.
- No need for an interpretive system.



Tool Palette: Stroke Tool

Drawing Planes: Placing 2-D strokes in 3-D

- 2-D drawing surfaces in 3-D space.
- User adjustable position, orientation.
- Draw geometry in place.
- Planes automatically created as user works.
  - Adjustment to a clean plane - adjust plane.
  - Adjustment to an active plane - clone plane and adjust clone.

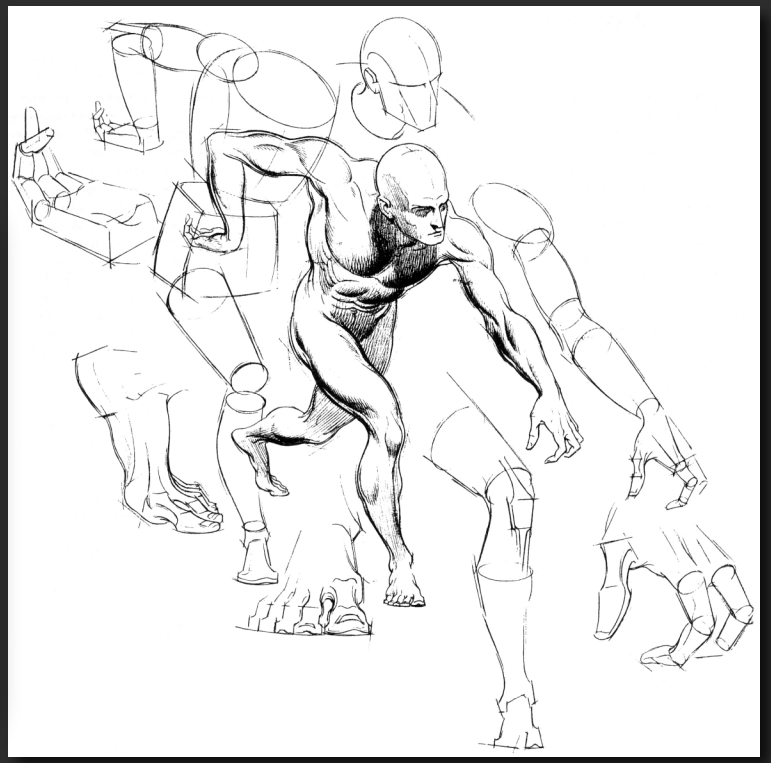


Drawing Planes

3-D Construction System: Artistic Basis

- Artists deconstruct subjects into basic shapes.

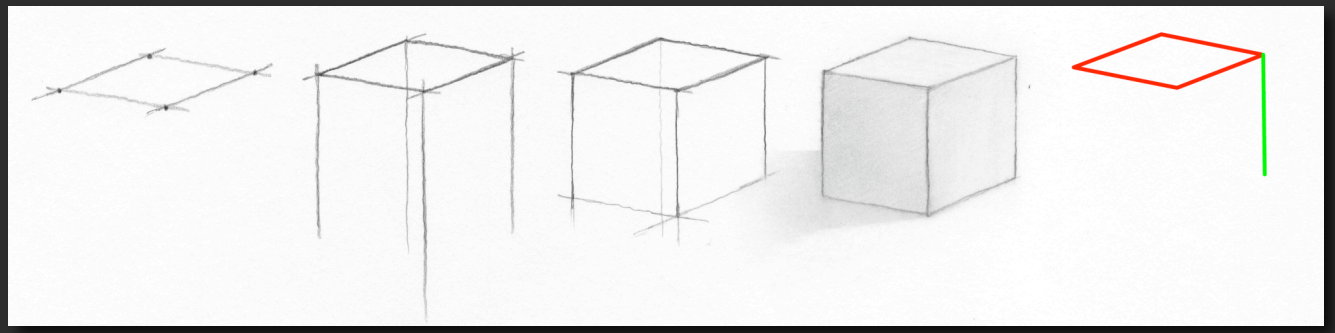
[Roberts & Reardon, 1991]

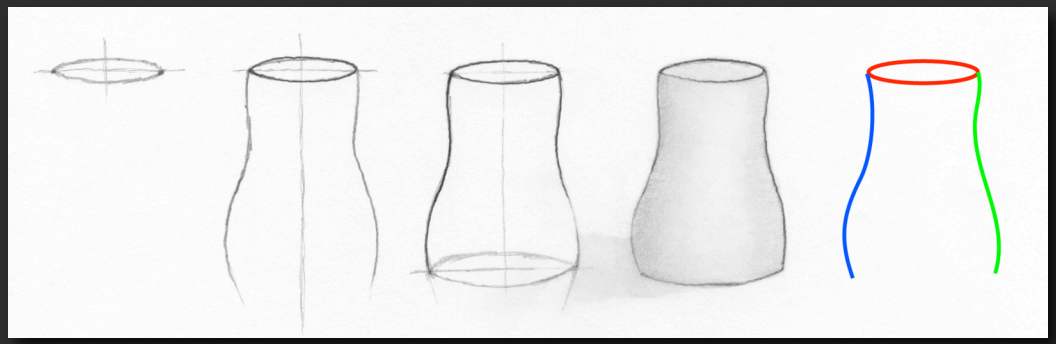


[Hogarth, 1996]

Artistic Basis (cont.)

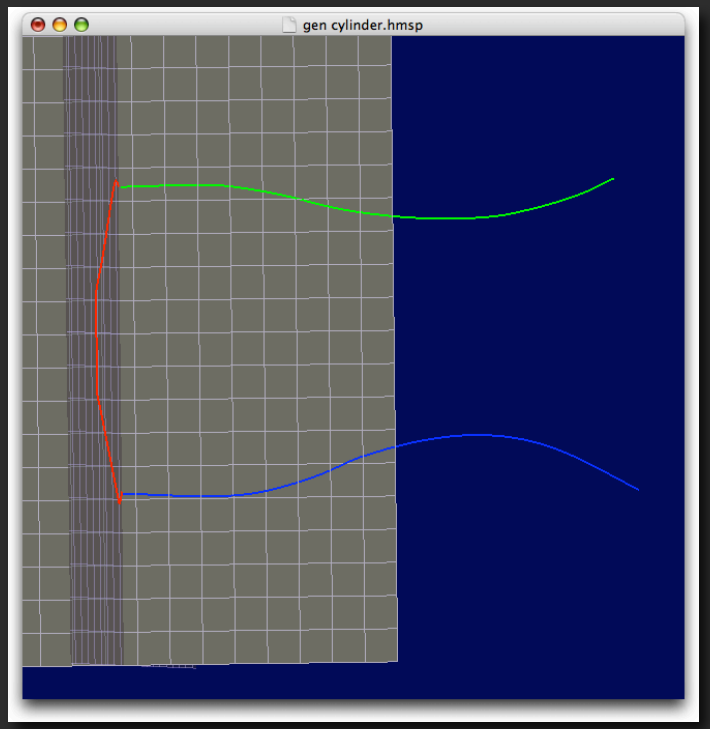
- Basic shapes rendered with silhouette lines.
  - Define a basic cross section.
  - Sweep or manipulate 2-D shape through space.





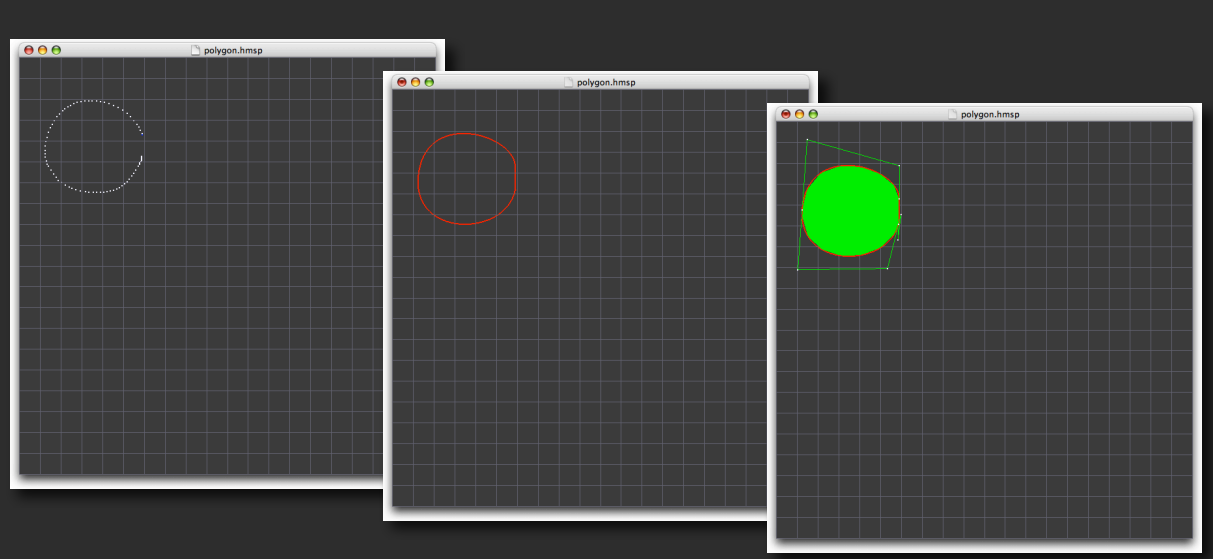
How does this translate to a modeling interface?

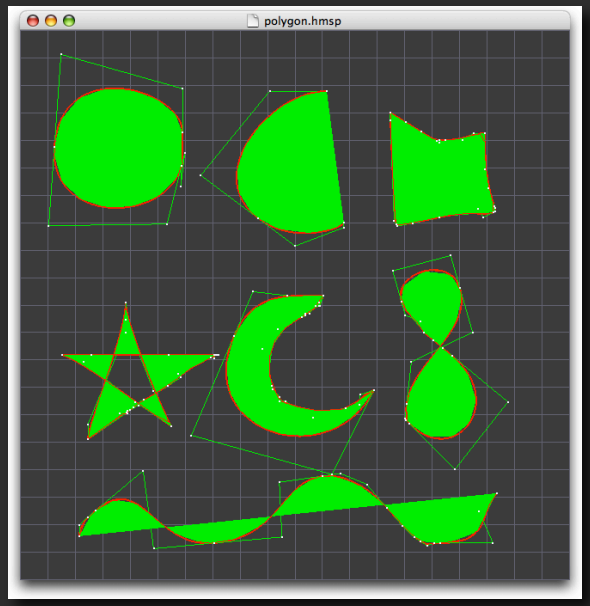
- Strokes are tagged for interpretation by the pen used to make them.
  - Die stroke - end shape swept through space.
  - Path stroke - extension outline defining the sweep path.
  - Size Stroke - variation in size along the sweep.
- These serve as input to 3 construction methods.



Closed Polygon

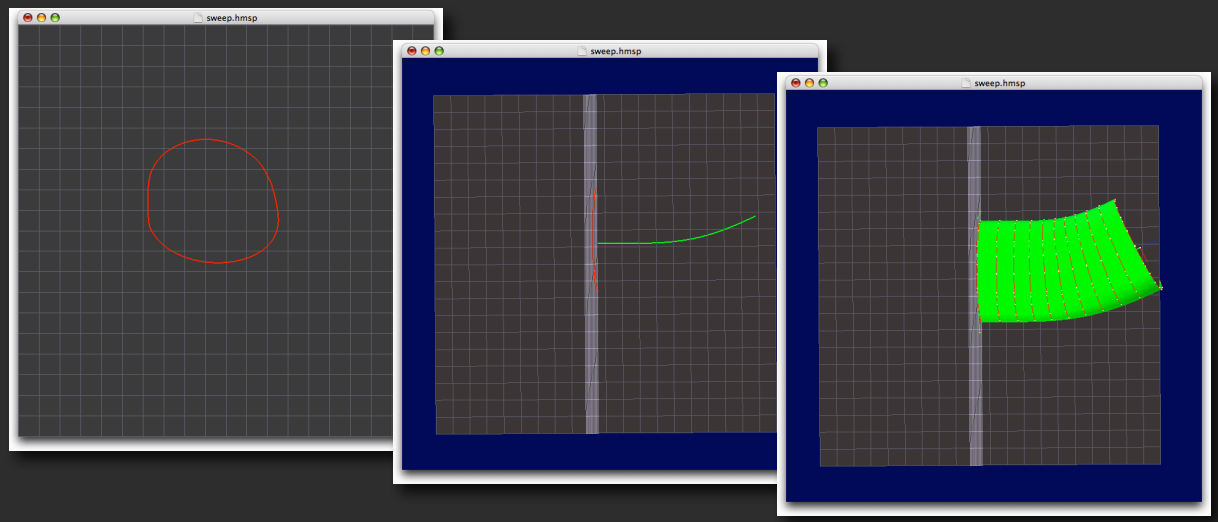
- Defined by a single die stroke.
- Forms a 2-dimensional closed polygon.
  - Represent flat shapes.
  - Place solid caps at the end of other 3-D components.

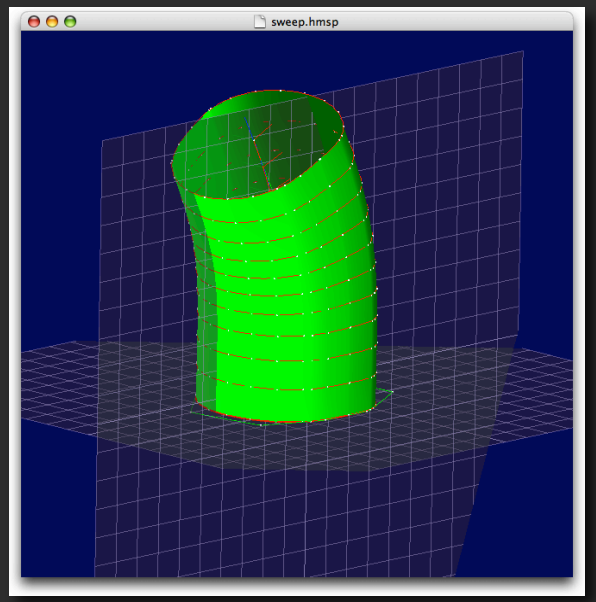




Sweep

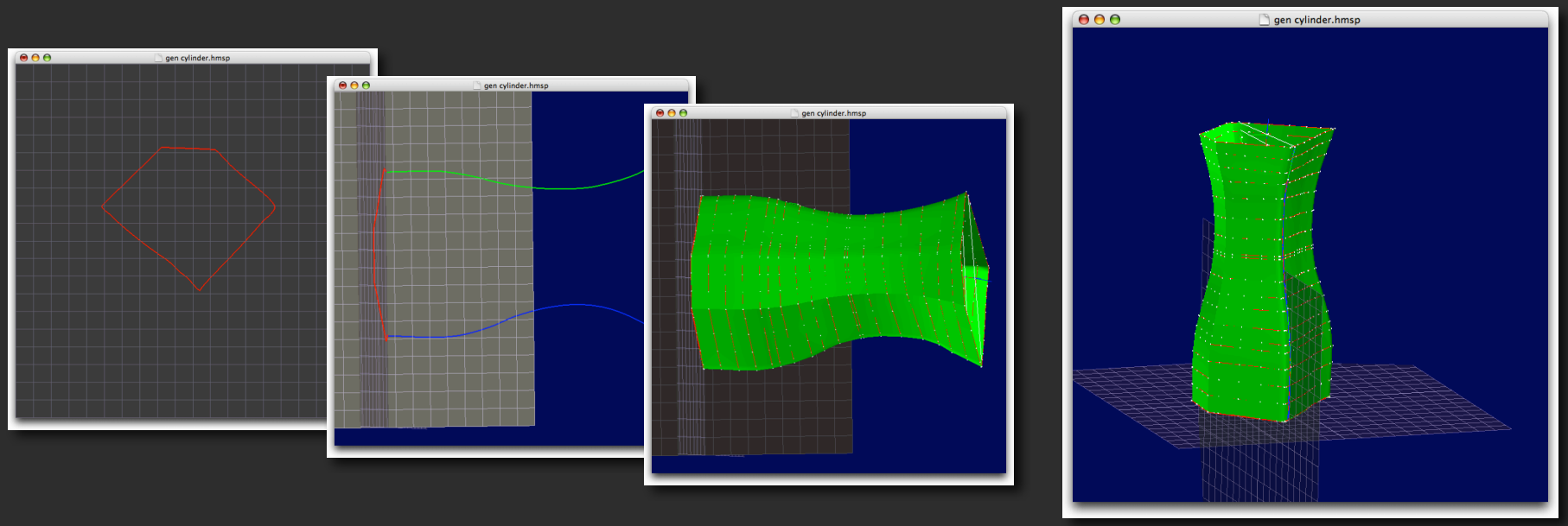
- Defined by a die stroke and path stroke.
- Die stroke is swept along the path stroke.
- Construct shapes that maintain a consistent cross section.
  - Connected - Tubes boxes, cylinder, and ducts.
  - Unconnected - Sheets, ribbons, hulls, walls, and flags.





Generalized Cylinder

- Defined by die, path, and size strokes.
- Die shape varies along path.
- Shape is swept along average of path and size strokes.
- Construct modeling components with variably sized cross section.
  - Closed - pyramids, cones, balloons, lampshades, dishes, and vases.
  - Abstract or open - leaves, sword blades, fruit, fish bodies, character heads, plant stalks, beveled letters, and mechanical parts.



Interacting With the System: Tablet Gestures

- Brush Off / Rehearsal
- Lift and Lead
- Pounce
- Joystick
- Flick
- Low-Angle Push

Lift-and-Lead

- Reposition hand, drawing surface, or both to improve dexterity.
- Hovering stylus leads movement in 3-D Environment.
  - While hovering, barrel button activates system.
  - Tilt of the stylus selects the parameter to adjust.
  - Positional movement above the tablet surfaces adjusts the parameter.
- Lift-and-Lead controls the user's viewpoint.
  - Translation - tilt stylus to the right.
  - Zoom - keep stylus vertical.
  - Rotation - tilt stylus to the left.

Pounce

- A quick, isolated, high-pressure event used to signal a modal transition.
  - Detected by a brief high pressure event.
  - Remains in contact with surface to provide further input.
- Advantages
  - No need to maintain a pressure level over a long period.
  - Less need to tune pressure for individual users.
  - System is free to interpret variable pressure levels in other tools.
- Used to define constraint axis for plane rotation.

Flick

- Resembles a flicking or flip through motion.
  - Cycle though a series of options in 2 directions.
  - Activated with upper barrel button.
- Advantages
  - Simple and intuitive.
  - Works in 2 directions.
  - Ambidextrous.
- Used to switch stroke pens while drawing.

Implementing the System

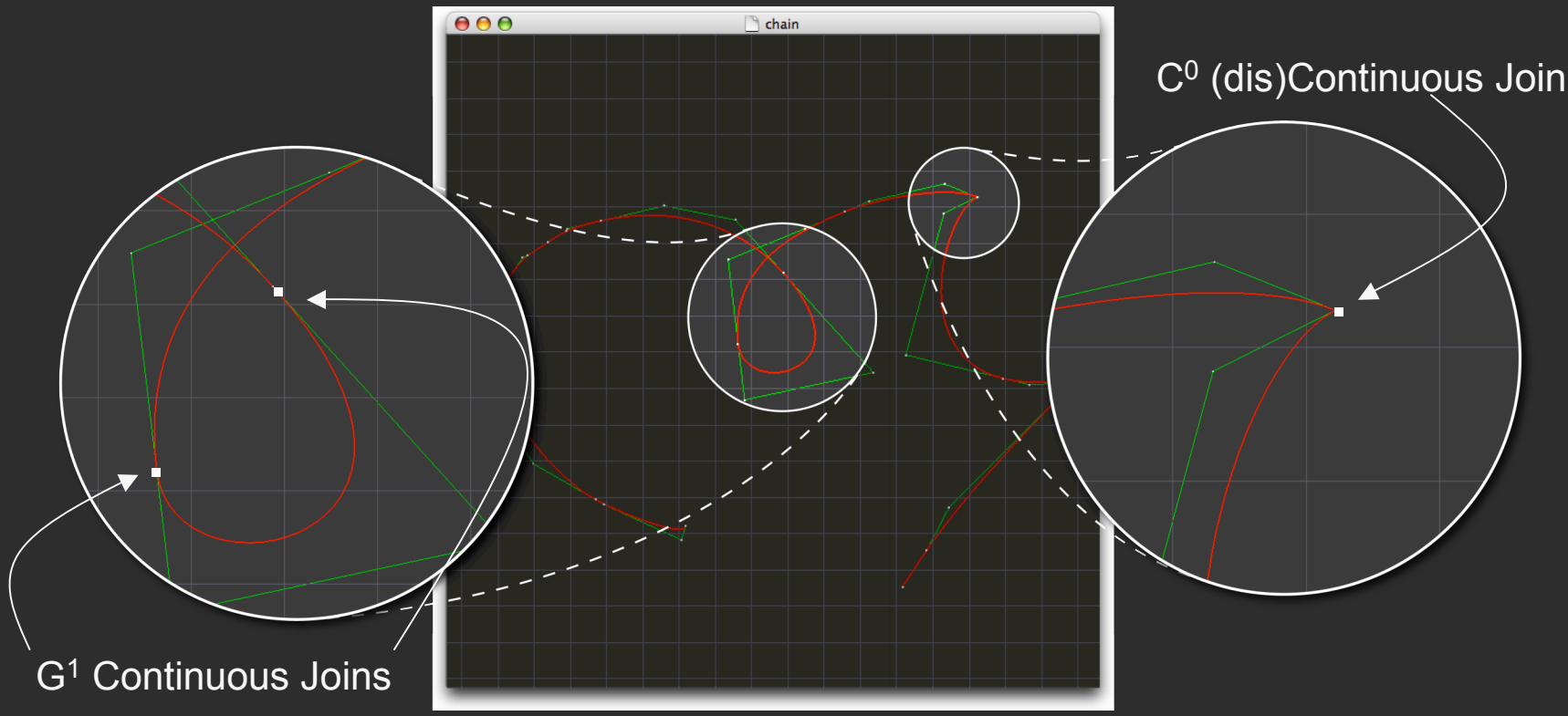
- Introduction / Background
- Related Work
- Design of the Present System
- Implementation Details
  - Stroke System
  - Constructing Models from Strokes
- Preliminary Assessment
- Conclusions

Implementing the Stroke System

- Strokes are collected as raw sample points.
- Converted into a parametric curve representation.
- A 3 stage process:
  - Filtration - simple distance filter.
  - Classification - find the corners.
  - Conversion - stroke fitting.

Stroke Fitting

- Recursive least-squares fitting algorithm based on [Schneider, 1990].
  - Generates a chain of cubic Bézier curves.
  - Smooth segments: G^1 geometric continuity.
  - Corner segments: C^0 parametric continuity.

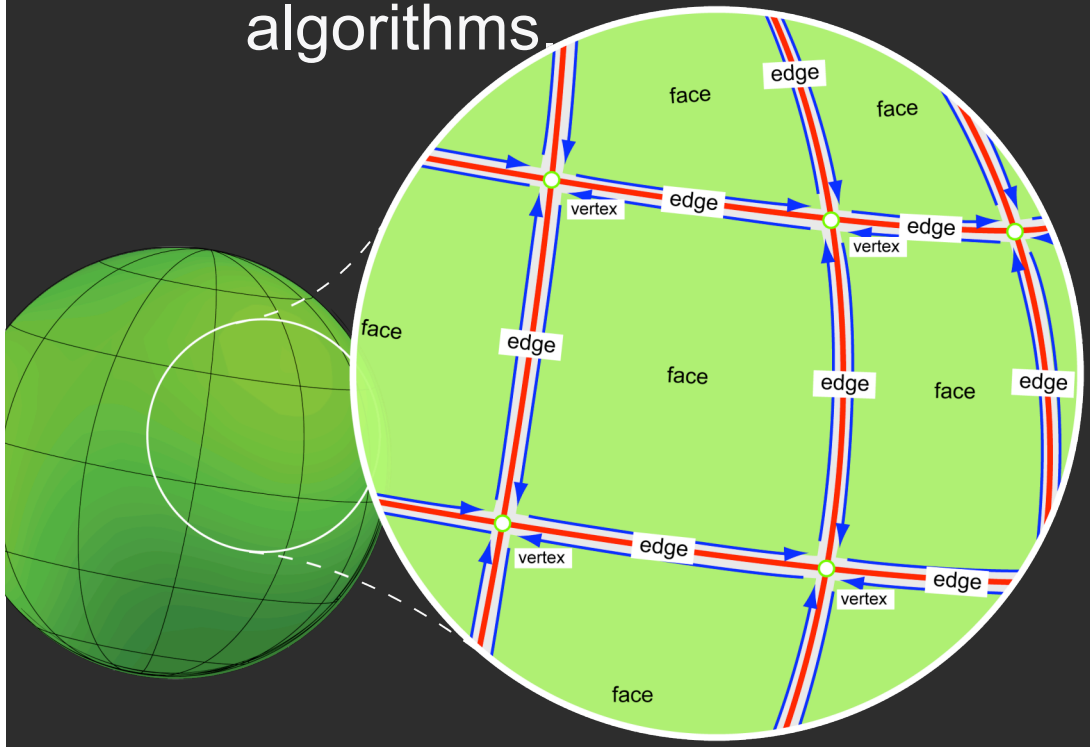


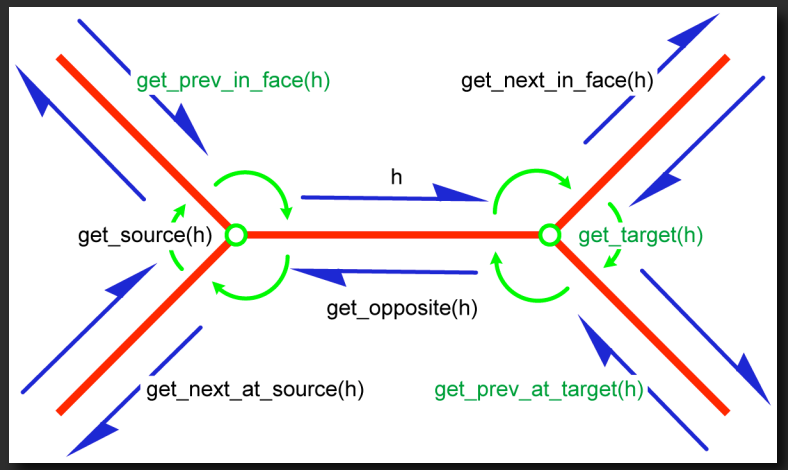
Constructing Models from Strokes

- Model Representation
- Sweep Construction
- Generalized Cylinder Construction

Model Representation

- Data is stored in 2 parallel structures
  - Vertex Array - memory efficient geometric structure for hardware.
  - Halfedge Mesh - complex topological structure for algorithms.

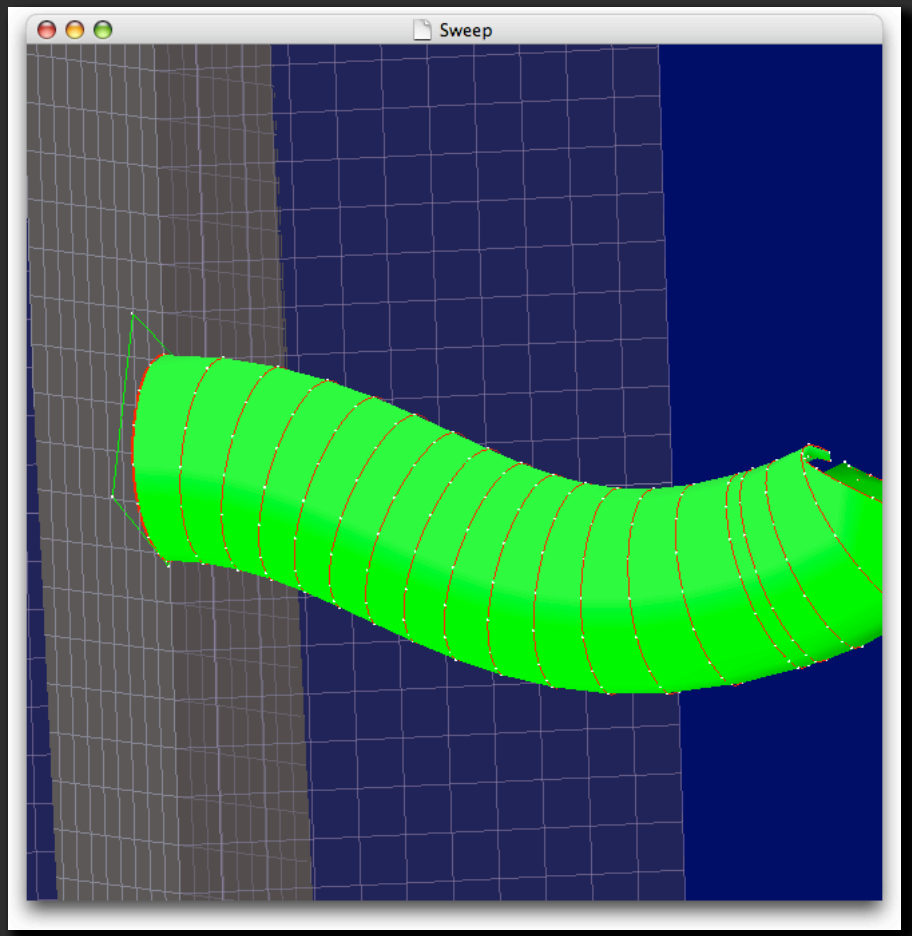


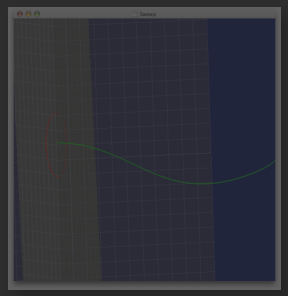
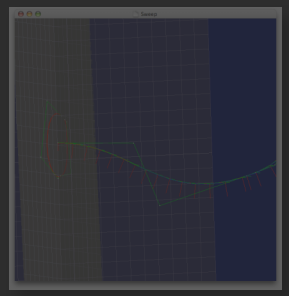
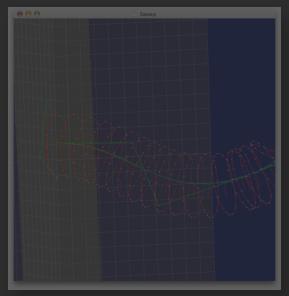
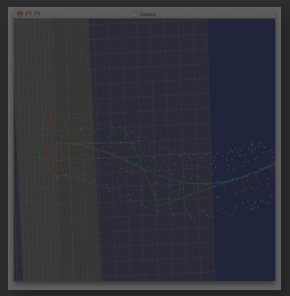
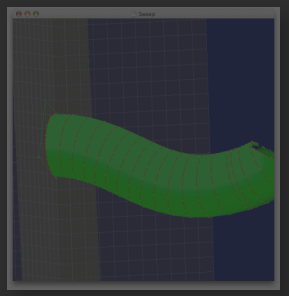


Halfedge Structure

Sweep Construction

- Preparation Process
  - Calculate stroke lengths.
  - Convert the input strokes into construction curves.
  - Orient the construction curves.
  - Generate the parametric parameters that will define the surface.
  - Prepare for the iteration.
- Iteration
  - Propagate the alignment frame.
  - Generate a profile curve.
  - Position the profile curve.
  - Evaluate the profile over the parametric parameters.
  - Extend the mesh with the resulting surface points.


Sweep

Generalized Cylinder Construction

- Preparation Process
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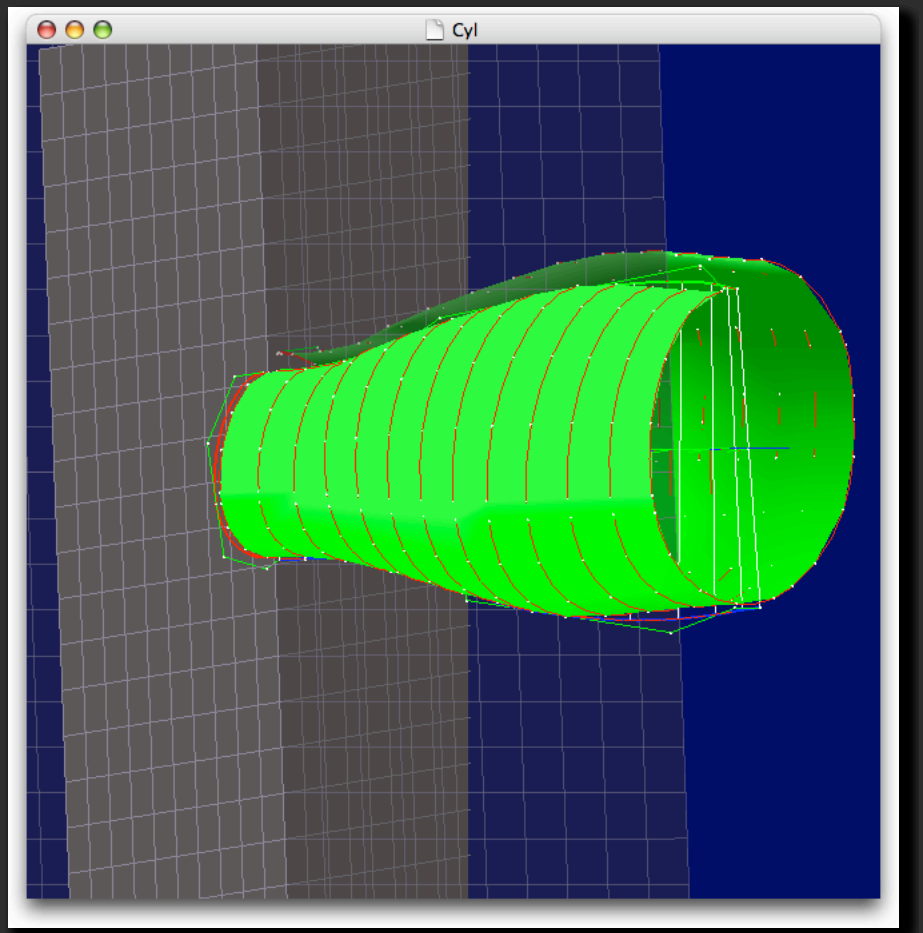
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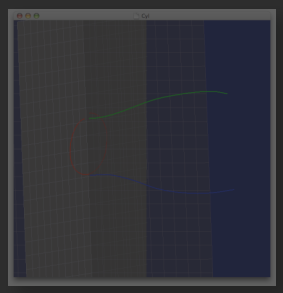
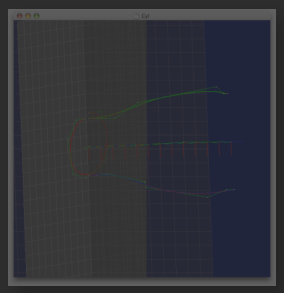
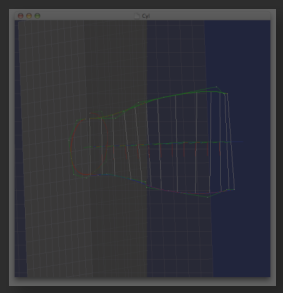
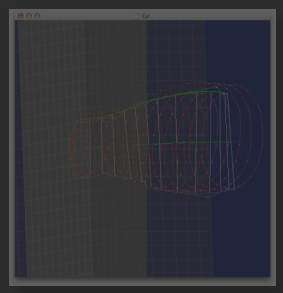
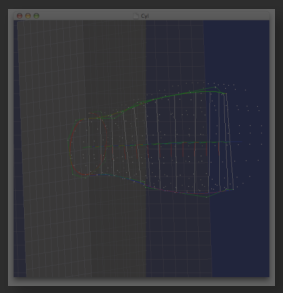
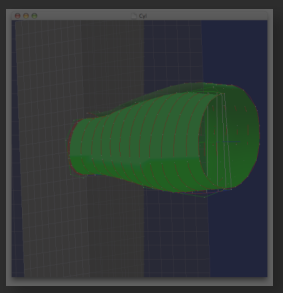







Preliminary Assessment

- Introduction / Background
- Related Work
- Design of the Present System
- Implementation Details
- Preliminary Assessment
  - Stroke and Sketching System
  - Drawing Planes & 3-D Construction
  - Tablet Gestures
- Conclusions

Strokes and Sketching System

- Affordances
  - Unhindered free drawing.
  - Stroke collection is stable and visually comfortable.
  - Allows full variety of sketching strokes.
- Difficulties
  - Contemplative and extraneous strokes are underutilized.
- Future Work
  - Incorporate raster-based visualizations.
  - Limited stroke correction.

Drawing Planes & 3-D Construction

- Affordances
  - Arbitrary plane positioning.
  - Automatic plane creation with user control.
  - 2-D free drawing input.
  - Basis in cognitive artistic technique.
  - Sharp features, open die shapes, flat polygons.
- Difficulties
  - Noisy path strokes.
  - Limited variety of models.
- Future Work
  - Additional construction methods.
  - Grouping and visibility control of planes.

Lift-and-Lead

- Affordances
  - More intuitive physical navigation of 3-D environment.
  - Access to navigation in-context.
- Difficulties
  - Far angle rotation is uncomfortable/unstable.
- Future Work
  - Compress selection range to the comfortable side of vertical.

Pounce

- Affordances
  - In-context access to a related command.
- Difficulties
  - Occasional misinterpretation.
- Future Work
  - Delayed version for novice users.
  - Interactive adjustment interface.

Flick

- Affordances
  - Extremely successful and intuitive.
  - Bidirectional selection from choices.
  - In-context selection.
- Difficulties
  - none
- Future Work
  - Expand into other areas of the program.
  - Basis for other, more involved gestures.

Conclusions

- Introduction / Background
- Related Work
- Design of the Present System
- Implementation Details
- Preliminary Assessment
- Conclusions
  - Contributions
  - Limitations
  - Future Work

Contributions

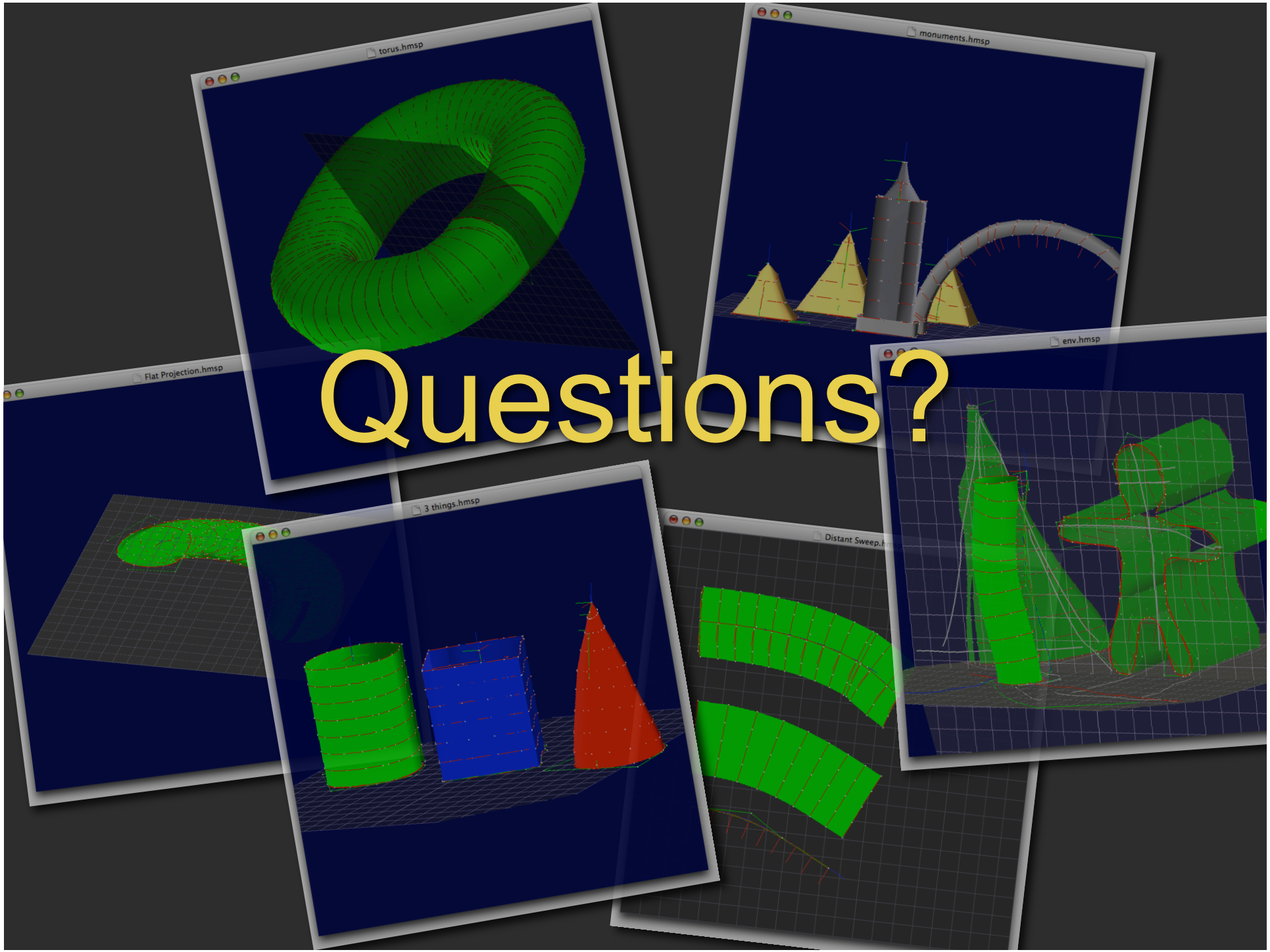
- Developed sketch-based modeling interface.
  - Based on a cognitive model of sketching rather than a physical technique.
  - Accepts 2-D drawing input to construct 3-D models.
- Developed a system of tablet gestures.
  - Demonstrates utility of dynamic physical tablet input.
  - Provides more intuitive navigation of 3-D environment.
  - Allows uninterrupted sketching.

Limitations

- Lacks a full feature set.
  - Export models.
  - Manipulate modeling components after the fact.
  - Combine components beyond adjacency.
- Variety of models that can be created is limited.
  - Generally 2-manifold forms.
  - Some common shapes are difficult to create.
- Some gestures need further development.

Future Work

- User testing.
- Improve cleanup artist system.
- Additional construction methods.
  - Dynamic die shapes.
  - Stroke based deformation.
- Continue to develop gestures.
- Alternative model representations.
  - Implicit modeling.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Questions?