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

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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.
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.
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.
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.
**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.
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.
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.
Generalized Cylinder 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
  • Generate the alignment frame.
  • Generate a profile curve.
  • Position and scale the profile curve.
  • Evaluate the profile over the parametric parameters.
  • Extend the mesh with the resulting surface points.
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.
Questions?