Sketch-based modeling

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Introduction

- Method of creating 3D models
- The user draws a 2D shape which is converted to 3D automatically

Introduction

- Existing 3D modeling programs have a high learning curve
- The purpose of sketch based modeling: making 3D modeling as simple as making a drawing

Introduction

The speakers:

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Introduction

Course topics:

- Sketch stroke acquisition and processing
- Multi-view sketch-based modeling of 3D curves and surfaces
- Sketch-based modeling using prior knowledge
- Single-view sketch-based modeling of 3D curves and surfaces
- Sketch-based editing

Sketch stroke acquisition & processing

Karan Singh

Issues in digital sketching

- Stroke filtering *fairing, curve-fitting.*
- Stroke processing *segmentation, recognition, regularization.*
- Stroke dynamics *pressure, tilt, speed, temporal order.*
- Stroke appearance *NPR, stylization, perception.*
- Stroke-based UI Control *widgets, crossing, gestures.*

Stroke filtering: noise & error sources

- User error
 - Intent (wants a square but draws a rectangle).
 - Execution (unsteady hand).
 - Ergonomic (awkward drawing posture).
- Device error
 - Input (tablets better than mice or trackpads).
 - Resolution (projected better than surface capacitance).
 - Signal Noise.

What are desirable strokes?

Smoothness: *“tangent and perhaps curvature continuous curves”*
[Farin et al. 87].

Simple smoothing approaches

- Laplacian. (neighbour averaging).
- Bi-Laplacian.
- LSQ spline fitting.

Simple smoothing: Laplacian

$$lap(C) = (B+D)/2 - C$$

$$C' = C + d * lap(C) \quad 0 < d < 1$$

Best to run many iterations with
A small d , for eg. 5 iterations $d=0.2$.

Simple smoothing: Bi-Laplacian

Find a C' such that:

$$\begin{aligned} lap(C') &= (lap(B) + lap(D)) / 2 \\ (B+D)/2 - C' &= (((A+C')/2 - B) + ((E+C')/2 - D)) / 2 \end{aligned}$$

$$C' = 2/3 (B+D-A/4-E/4)$$

$$bi-lap(C) = C' - C$$

Simple smoothing: LSQ fitting

$f(t)=(x,y)$ from points (x_i, y_i)

Simple smoothing: LSQ fitting

LSQ solves for f to minimize error $\sum_i |f(t_i) - (x_i, y_i)|^2$

Approach: guess t_i ;
 LSQ solve for f ;
 refine t_i for current f ;

iterate...

What are desirable strokes?

- **Fairness:** “*curvature continuous curves with a small number of segments of almost piecewise linear curvature*” [Farin et al. 87].
- Lines, circles and clothoids are the simplest primitives in curvature space.

Comparative approaches to fairing

[McCrae & Singh, Sketching Piecewise Clothoid Curves, *SBIM 2008*]

source code: <http://www.dgp.toronto.edu/~mccrae/clothoid/>

Desirable strokes

- **Neatness:** *“a combination of fairness and fine detail as intended by the user”.*
- Requires either implicit knowledge of user-intent, or an explicit neatening directive by the user.

Stroke neatening: French curves

Physical tools, used to model curves.

French curves +
smooth shape priors,
specify a style/standard

sketch interface

fluid free-form

Stroke neatenening: French curves

[McCrae & Singh, *Neatening sketched strokes using piecewise French Curves*, SBIM 2011]

Stroke neatening: French curves

Stroke neatening & dynamics: elasticurves

[Thiel, Singh, Balakrishnan Elasticurves: Exploiting Stroke Dynamics and Inertia for the Real-time Neatening of Sketched 2D Curves, *UIST 2011*]
java applet: <http://www.dgp.toronto.edu/~ythiel/Elasticurves/>

Elasticcurve

Input q_i 's sampled at a time interval of dt

responsiveness = connector arc-length fraction extending an elasticcurve.

Elasticurve Properties

- **Explicit and real-time:** neatness is directly correlated to drawing speed and *responsiveness*.
- **Analytic:** resilience to dt sampling variation.
- **Precise:** embodies desirable shapes as connectors.

Elasticurve evaluation & curve quality

Intermediate user, trackpad,
visual best of 7 attempts.

Stroke Processing

- *Filtering, neatening, beautification* can also be considered as stroke processing.
- Segmentation, classification, recognition.
- Regularization.
- Abstraction.

Stroke segmentation: finding corners

Corner detection features:

- direction discontinuity
- speed minima
- curvature maxima

[T. Sezgin et al., *Sketch Based Interfaces: Early Processing for Sketch Understanding*, Workshop on Perceptive User Interfaces, 2001.]

Stroke classification: pentamenti

[G. Orbay & L. Kara., *Beautification of Design Sketches Using Trainable Stroke Clustering and Curve Fitting*. IEEE Transactions on Visualization and Computer Graphics 17, 5 (May 2011).]

Geometric Stroke Features

Proximity

$$d_{AB} = \|\mathbf{x}_i - \mathbf{x}_j\| \quad a_{AB} = \frac{|\angle(\mathbf{n}_A, \mathbf{n}_B)|}{\pi/2}$$

Alignment

Continuity

$$c_{AB} = \frac{\|(\mathbf{n}_A \times \mathbf{n}_B)\| + \|(\mathbf{n}_A \times \mathbf{n}_s)\| + \|(\mathbf{n}_B \times \mathbf{n}_s)\|}{3} |s|$$

- Pairwise features
- Stroke proximity
- Local learning

Group Strokes by Affinity

Affinity = Proximity + Alignment + Continuity

learning approaches with or without examples:

- neural network

- spectral clustering

- greedy grouping (single-link clustering)

Stroke grouping and regularization

Gestalt Principle

“The whole is greater than the sum of its parts”

Gestalt grouping and regularization

- Similarity
- Symmetry
- Continuation
- Closure
- Proximity

Regularization makes strokes that are nearly isometric, parallel, symmetric, perpendicular etc. precisely so!

Stroke recognition

Stroke Abstraction

Stroke neatening that captures the essence of the stroke.

[X. Mi, D. DeCarlo and M. Stone *Abstraction of 2D Shapes in Terms of Parts*, NPAR 2009.]

Stroke Appearance: NPR

3D model

silhouettes

brushes

ink color
brush width
brush texture
paper texture

strokes

Stroke Perception

[**Wolfe, Maloney & Tam**, Distortions of perceived length in the frontoparallel plane: tests of perspective theories, *Perception & psychophysics*, 2005]

[**Taylor & Mitchell**, Judgements of apparent shape contaminated by knowledge of reality: viewing circles obliquely, *British Jnl. of Psych.*, 1997]

40%

[**Schmidt, Khan, Kurtenbach, Singh**, On expert performance in 3D curve drawing tasks. *SBIM* 2009]

Stroke UI: crossing

[Apitz, G. and Guimbretière, F. *CrossY: A Crossing-Based Drawing Application* ACM UIST, 2004]

Stroke UI: widgets

suggested axes

crossing interaction and composition

[Schmidt, Singh & Balakrishnan Sketching and Composing Widgets for 3D Manipulation, *Eurographics 2008*]

Stroke UI: gestures

- Ad-hoc or pre-defined:
 - Application specific: shorthand, chinese Brush Painting, musical scores, chemical formulas.
 - Platform specific: gesture libraries.
- Template-based:
 - Toolkit or framework.
 - Simple algorithm based on geometric matching.

Ad-hoc vs. template-based

- Ad-hoc can recognize more complex gestures.
- Better consistency and collision handling of gestures in ad-hoc systems.
- Ad-hoc doesn't allow new gestures and limited customization.
- Template-based are easier for a user to specify and customize.

GRANDMA

1. Encode gestures as a linear function of 13 features.
2. Draw a gesture ~15 times.
3. Train asset of feature weights for each gesture.
4. Classify gestures based on highest feature function score.

[D. Rubine. *Specifying gestures by example*. SIGGRAPH 1991]

\$1 recognizer goals

- Resilience to sampling.
- Require no advance math.
- Small code.
- Fast.
- 1-gesture training.
- Return an N-best list with scores.

[J. Wobbrock, A. Wilson & Y. Li. 2007. *Gestures without libraries, toolkits or training: a \$1 recognizer for user interface prototypes*. ACM UIST '07.]

\$1 algorithm

- Resample the input
 - N evenly spaced points
- Rotate
 - “Indicative” angle between centroid and start point
- Scale
 - Reference square
- Re-rotate and Score
 - Score built from average distance between candidate and template points

\$1 limitations

- Cannot distinguish aspect ratios, orientations.
 - Square from rectangle
 - Up arrow from down arrow
- Cannot be distinguished based on speed.
- Only single strokes.
- Stroke order is important.
- Closed strokes?
- Gestalt gestures!

Take-aways

- Understand your application:
 - Does it need strokes?
 - Are strokes natural and of low-complexity, 2D or 3D?
- Understand source of stroke error before filtering?
- Ensure users can control stroke dynamics before you exploit it.
- Both clean and sketchy stroke appearances are useful.
- Understand perceptual bias in drawn strokes.
- Develop a GUI suited to stroke interaction.

Multi-view sketch-based modeling of 3D curves and surfaces

Yotam Gingold

How can we turn sketch strokes into 3D shapes?

- Interpreting them as gestures
 - Interpreting them as silhouettes
 - Projecting them in 3D
-
- General principle: Drawing from different points of view.

Interpreting stokes as gestures

SKETCH

SKETCH: An Interface for Sketching 3D Scenes [Zelevnik et al. 1996]

Interpreting strokes as silhouettes

Teddy

Teddy: A Sketching Interface for 3D Freeform Design [Igarashi et al. 1999]

More freeform inflation approaches

Implicit functions

Matisse [Bernhardt et al.
2008]

ShapeShop
[Schmidt et al. 2005-
8]

Curvature optimization

FiberMesh [Nealen et al.
2007]

[Andrews et al. 2011]

Inflation (Teddy)

- Step 1

- Step 2

Extrusion (Teddy)

a) projection of the stroke

b) sweep along the projected stroke

[Igarashi et al. 1999]

Inflation (implicit surface)

Inflation (surface optimization)

initial mesh

minimum variation of curvature

FiberMesh [Nealen et al.
2007]

Painting (Teddy)

Before

After

Cutting (Teddy)

Before

Cutting stroke

After

Projecting strokes in 3D

Ambiguity

Figure 1: A single stroke creates the initial curve.

Figure 2: A second stroke defines the curve's shadow and hence its 3D shape.

An Interface for Sketching 3D Curves [Cohen et al. 1999]

Ambiguity

Figure 3: The dashed line indicates an overdrawing stroke.

Figure 4: The system blends the overdrawing with the original curve to get the final result.

An Interface for Sketching 3D Curves [Cohen et al. 1999]

Ambiguity

Figure 7: The shadow defines a ruled surface with a silhouette above the interior critical point of the shadow, B .

An Interface for Sketching 3D Curves [Cohen et al. 1999]

Ambiguity

Figure 8: The curve must turn around at B to stay on the surface.

Figure 9: The curve may have more critical points than the shadow and still be valid.

An Interface for Sketching 3D Curves [Cohen et al. 1999]

Ambiguity

Figure 10: There is no way to project this curve onto the surface to get a continuous 3D curve.

An Interface for Sketching 3D Curves [Cohen et al. 1999]

iLoveSketch

iLoveSketch: As-natural-as-possible sketching system for creating 3D curve models [Bae et al 2008]

Takeaways

- We can remove the ambiguity in depth in several ways:
 - with assumptions (rotund surfaces)
 - by projecting onto other surfaces
 - by sketching from multiple points of view

LABORATOIRE
JEAN KUNTZMANN
MATHÉMATIQUES APPLIQUÉES - INFORMATIQUE

Sketch-based modelling using prior knowledge

Marie-Paule Cani

Grenoble University & Inria

Use of prior knowledge : Motivation

Why do we “see” 3D shapes when we look at a sketch?

Use of prior knowledge : Motivation

Unknown shape

- We infer the simplest one

Well known shapes

- We use prior knowledge

Use of prior knowledge : Motivation

Well known shapes

- Model prior knowledge
- Use it to fill in the missing data

Benefits

- 3D models from a single sketch !
- Constraints maintained !

In this talk

- Animals, trees and garments

Sketching specific shapes

Example 1: Animals from a side-view sketch

Goal: Modeling animals and other creatures from a single sketch

A priori knowledge

- Organic shapes: Mostly smooth, volumetric shapes
- Anatomic principles : sagittal plane symmetry, pairs of limbs
- Structural symmetry of the sketch (limbs in arbitrary postures)

Animals from a side-view sketch

Choice of 3D shape representation

- Polygon meshes inflated from contours ?

- ~ Enables flat areas and full control of geometry
- Post-editing is not user-friendly

- Skeleton-based implicit surfaces ?

- + Smooth, volumetric shapes
- + Easy progressive blending
- + 3D line skeletons suited for post-editing

[Bernhardt et al., SBIM 2008]

Animals from a side-view sketch

Choice of 3D shape representation

Implicit surface $S = \{P / f(P) = c\}$, $f(P) = \sum f_i(P)$

SCALIS: SCALE Invariant integral Surfaces

- Extension of convolution surfaces
- Scale invariant
- Exact contour matching

Animals from a side-view sketch

Overview of the method

1. Sub-parts detection, contours closing
2. Using structural symmetries to clean the sketch
3. Depth positioning and implicit reconstruction

1. Identifying subparts from the sketch

Perceptual process

- Subparts are partially/fully bounded by curves
- They may be partially occluded
- Depth ordering from cues (“T-junctions” and inclusions)

-> Semantic curve classification

- Silhouette contours
- Suggestive contours (red)
 - Internal silhouettes

Animals from a side-view sketch

2. Cleaning the sketch

Knowledge on structural symmetries

- Standing pose hypothesis: pairing based on angle
- Enables to remove background limbs

3. Generating the implicit 3D model

- Skeletons of shape-parts : Medial-Axis
- 3D parts : SCALIS surfaces
- Relative depths from a priori knowledge
 - “flesh around bones” hypothesis
- Blending

Animals from a side-view sketch

*[Entem, Barthe,
Cordier, Cani,
Van de Panne,
SMI'2014]*

Sketching specific shapes

Example 2: Designing a tree

Challenges

- Need to control a specific shape
- Too many branches for interactive modelling!
- Distributions matching laws from biology

Inspiration

Idea

- Combine multi-resolution sketches with procedural generation!

Designing a tree

- Structure from silhouette!
- Use rules from botanic and probability
 - Infer sub-structures
 - Adapt branching style
 - Extend branches to 3D

Creating lots of elements

Designing a tree

- Silhouette analysis

- Medial axis?

- Add knowledge on branching arrangements

- Find shortest branch

Creating lots of elements

Designing a tree

- Inferring substructures

- Inferring 3D branch distributions

Example 2

Designing a tree

Eucalyptus tree

[Wither, Boudon, Cani, Godin, Eurographics 2009]

Sketching using prior knowledge

Example 3: Clothing design

Standard method to create garments

- Design & place patterns
- Run a simulation
- Iterate!

Idea

- 3D garment from a single sketch?

→ automatic 3D + patterns!

?

Clothing design

Using silhouette information only

Virtual clothing from a sketch?

- Sketch on a view of a 3D model
- **Knowledge? Rule of thumb**
 - Fitting is the same in all directions!

Sketch in
a distance
field!

Clothing design

Using silhouette information only

Results lack folds!

- Allow the designer to sketch them?

[Turquin, Cani, Hughes IEEE CG&A 2007]

- Requires specific skills!

Clothing design

Using silhouette information only

Results lack folds!

- Use more a priori knowledge?
 - Cloth is a developable material
 - Folds can be simulated

Clothing design

Developable surfaces from a sketch

Developable surface from sketch?

- **Solution 1:** increase developability

- Start with the rough surface
- Locally optimize the shape (1D normal map)

- **Solution 2:** smooth developable surface from contours

Convex edges?

Recursively split
& triangulate the
convex hull

Clothing design

Developable surfaces from a sketch

Results

Folds from simulation

- Physically-based parameters required
- Stiff system for un-extensible cloth
- Ideal fold-free surface to be drawn at the design stage!

Clothing design

Sketching folds?

Folds may be part of design!

Challenge: Handling non-flat silhouettes !

Clothing design

Sketching a folded surface

Iterate

- Optimize developability
- Match the sketch

Initialization

Visual hull from silhouettes

Clothing design

Sketching a folded surface: Results

[Jung, Hahmann, Rohmer, Bégault, Boissieux, Cani, ACM TOG 2015]

Conclusion

Sketch-based modelling using prior knowledge

- + Knowledge helps filling in missing data
- + High quality modeling (constraints met)
 - Fast 3D from a single sketch!
- A system for each application...

Next: more general methods!

[Wither Bouthors Cani 2008]

[Wither Bertails Cani 2007]

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Thanks to my students and collaborators!

Single-view sketch-based modeling of 3D curves and surfaces Part I

Yotam Gingold

© Satoshi Kako

© Kei Acedera, Imaginism Studios 2008

© 2009 Chris Onstad :: achewood.com

Lévrier persan.

oldbookillustrations.com

© Alex Rosmarin

© Glenn Vilppu

Goals

- Model by “describing” an existing 2D image with primitives and annotations.
- Usable by novices, including those with poor drawing skills.
- Create structured models.

Sketch-based modeling with few strokes

[Cherlin et al. 2005]

- Generalized cylinders with varying cross sections and “spines”

Inspiration

2D Drawing Approaches

[Glenn Vilppu
1997]

[Preston Blair
1994]

Primitives

Generalized Cylinders & Ellipsoids

Primitives

Generalized Cylinder

Ellipsoid

Primitive: Generalized Cylinder

Generalized Cylinder

Annotations

Same-length

Connection curve

Same-tilt

Mirror

Same-scale

Alignment

Demo

Modeling Session

5x Speed

Results

Guide images: © Preston Blair; © Alex Rosmarin; © Kei Acedera, Imaginism Studios 2008; © Björn Hurri, www.bjornhurri.com; © Alex Rosmarin; © Alex Rosmarin; © Satoshi Kako; © Satoshi Kako

Limitations

Limited range of models

Can't be used for certain drawings

Doesn't actually use the guide image

Single-View Sketch-Based Modeling

[Andre and Saito 2011]

- Two perpendicular cross sections form the projection of a cubic corner (which is well-defined)

Single-View Sketch-Based Modeling

[Andre and Saito 2011]

- Two perpendicular cross sections form the projection of a cubic corner (which is well-defined)

Single-View Sketch-Based Modeling

[Andre and Saito 2011]

- That gives us 3D axes for the shape

Single-View Sketch-Based Modeling

[Andre and Saito 2011]

- Which we can use to sweep out a surface

Single-View Sketch-Based Modeling

[Andre and Saito 2011]

A suggestive interface for image guided 3D sketching [Tsang et al. 2004]

- Use the guide sketch to snap strokes.

User sketch

Automatically snapped to the guide image

Challenges

Challenges

Segmentation

Challenges

Segmentation
Recognition

Challenges

An automatic solution entails solving a **complex, non-convex** optimization problem with **many local minima**.

Interactive Approach

Overview

input
sketch

semantic
classification

interactive
matching

real-time
Snapping

geosemantic
Snapping

Primitives: Feature Curves

sphere

box

straight cylinder

truncated cone

straight
generalized
cylinder

bent
generalized
cylinder

Primitives: Feature Curves

sphere

box

straight cylinder

truncated cone

straight
generalized
cylinder

bent
generalized
cylinder

Primitives: Silhouette Curves

sphere

box

straight cylinder

truncated cone

straight
generalized
cylinder

bent
generalized
cylinder

Tagging

Tagging

Tagging

Drag-and-Drop

Anatomy of a Drag: Curve Matching

Anatomy of a Drag: Curve Matching

Anatomy of a Drag: Curve Matching

Anatomy of a Drag: Curve Matching

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Anatomy of a Drag: Curve Matching

Anatomy of a Drag: Curve Matching

Anatomy of a Drag: Curve Matching

Anatomy of a Drag: Primitive Fitting

Anatomy of a Drag: Primitive Fitting

$$\begin{aligned} \min : & \phi_p(x_p) \\ \text{s.t.} : & C_p(x_p) = 0 \end{aligned}$$

Anatomy of a Drag: Primitive Fitting

Anatomy of a Drag: Geosemantic Relations

Anatomy of a Drag: Geosemantic Relations

$$\begin{array}{ll} \min_x : & \sum_{p \in P} \phi_p(x_p) \\ \text{s.t.} : & C_p(x_p) = 0 \quad \forall p \in P \\ & \psi_g(x_g) = 0 \quad \forall g \in G \end{array}$$

Geosemantic Relations

Constraints linking two or more feature curves:

- Parallelism
- Orthogonality
- Collinear centers (three or more)
- Concentric
- Coplanar

Limitations & Future Work

More primitives

Operate directly on raster sketches

Eliminate sketch curve classification

Sketched occlusions

More geosemantic relations

Lifting curve networks into 3D

- Interactively
 - Analytic drawing of 3D scaffolds [Schmidt et al. 2009]
- Automatically
 - CrossShade: Shading Concept Sketches Using Cross-Section Curves [Shao et al. 2012]
 - True2Form: 3D curve networks from 2D sketches via selective regularization [Xu et al. 2014]

Analytic drawing of 3D scaffolds

[Schmidt et al. 2009]

- Draw precise scaffold lines by connecting them to 2-point perspective vanishing points

Analytic drawing of 3D scaffolds

[Schmidt et al. 2009]

- The scaffolds make it possible to draw complex curves

Analytic drawing of 3D scaffolds

[Schmidt et al. 2009]

- ... and complex shapes

CrossShade: Shading Concept Sketches Using Cross-Section Curves [Shao et al. 2012]

- Leverage properties of designer-drawn cross sections:
 - intersect on orthogonal planes
 - are aligned with principal curvature (and therefore are orthogonal themselves)
 - are geodesics
 - intersect with minimal foreshortening

CrossShade: Shading Concept Sketches Using Cross-Section Curves [Shao et al. 2012]

- With these cues, we can propagate normals everywhere:

CrossShade: Shading Concept Sketches Using Cross-Section Curves [Shao et al. 2012]

True2Form: 3D curve networks from 2D sketches via selective regularization [Xu et al. 2014]

- Given 2D curves, we can selectively apply the constraints in an optimization to get 3D curves

True2Form: 3D curve networks from 2D sketches via selective regularization [Xu et al. 2014]

True2Form: 3D curve networks from 2D sketches via selective regularization [Xu et al. 2014]

Inspiration

Input curves

3D Reconstruction

Inspiration

Input curves

3D Reconstruction

Inspiration

Input curves

3D Reconstruction

Takeaways

- Make “intractable” problems tractable with perceptually grounded assumptions or by asking the user to help.
 - Don’t ask the user for too much. Separate that which is easy for a **human** and challenging for a **computer**.
- Consult artistic practice and perceptual psychology for inspiration.

Single-view sketch-based modeling of 3D curves and surfaces

Part II

Frederic Cordier

Free-Form Sketching of Self-Occluding Objects

Frederic Cordier, Hyewon Seo: Free-Form Sketching of Self-Occluding Objects. IEEE Computer Graphics and Applications 27(1): 50-59 (2007)

Sketching of Mirror-Symmetric Shapes

Frederic Cordier, Hyewon Seo, Jinho Park, Jun-yong Noh: Sketching of Mirror-Symmetric Shapes. IEEE Trans. Vis. Comput. Graph. 17(11): 1650-1662 (2011)

Reconstruction of helices from their orthogonal projection

Frederic Cordier, Mahmoud Melkemi, Hyewon Seo: Reconstruction of helices from their orthogonal projection. Computer Aided Geometric Design, Volume 46, August 2016, Pages 1–15

Reconstruction of helices from their orthogonal projection

- Reconstruction of curves of constant curvature

Reconstruction of helices from their orthogonal projection

Parametric equation of a helix of radius r and pitch p :

$$H(t) = \begin{bmatrix} r \cos(t) \\ pt \\ r \sin(t) \end{bmatrix}$$

Computing r , p and the projection matrix requires non-linear optimization !

Reconstruction of helices from their orthogonal projection

Sampling of the helix

Compute the affine transformation L

Compute the rotation matrix and the helix parameters

Reconstruction of helices from their orthogonal projection

The key idea:

Pitch equal to **1**
Scale along y equal to **2**

Pitch equal to **2**
Scale along y equal to **1**

Reconstruction of helices from their orthogonal projection

Sampling of the helix

$$M_{r,p} = \begin{bmatrix} r \cos(t_1) & pt_1 & r \sin(t_1) \\ r \cos(t_2) & pt_2 & r \sin(t_2) \\ \vdots & \vdots & \vdots \\ r \cos(t_n) & pt_n & r \sin(t_n) \end{bmatrix} = M_U S_{rp}$$

$$M_U = \begin{bmatrix} \cos(t_1) & t_1 & \sin(t_1) \\ \cos(t_2) & t_2 & \sin(t_2) \\ \vdots & \vdots & \vdots \\ \cos(t_n) & t_n & \sin(t_n) \end{bmatrix} \quad S_{rp} = \begin{bmatrix} r & 0 & 0 \\ 0 & p & 0 \\ 0 & 0 & r \end{bmatrix}$$

Reconstruction of helices from their orthogonal projection

$$\min_L \|M_U L - M_C\|_F^2$$

Affine transformation

- Rotation
- Shear
- Scale...

$$\|M_U L - M_C\|_F^2 = \left\| \left(M_U S_{rp} \right) \underbrace{\left(S_{rp}^{-1} L \right)}_{\text{Should be close to orthonormal (i.e. rotation matrix)}} - M_C \right\|_F^2$$

Should be close to orthonormal
(i.e. rotation matrix)

Key idea: changing the **scaling transformation** of the helix is equivalent to changing its **radius** and **pitch**

Reconstruction of helices from their orthogonal projection

$\left(S_{rp}^{-1}L\right)$ is a matrix with orthonormal columns if

$$\left(S_{rp}^{-1}L\right)^T \left(S_{rp}^{-1}L\right) = I$$

We solve

$$\min_{r,p} \left\| \left(S_{rp}^{-1}L\right)^T \left(S_{rp}^{-1}L\right) - I \right\|_F^2$$

Reconstruction of helices from their orthogonal projection

Advantages:

- Method that requires solving simple linear systems
- Much faster than using non-linear optimization
- Provides an approximate solution which is very close to the exact solution

Reconstruction of helices from their orthogonal projection

Reconstruction of helices from their orthogonal projection

Inferring mirror symmetric 3D curves from sketches

- Input: the 2D sketch of a mirror-symmetric 3D shape
- Output: a set of 3D curves such that their orthogonal projection matches the input sketch

Inferring mirror symmetric 3D curves from sketches

- Assumptions:
- Mirror-symmetric shape composed of curves
- Orthogonal projection

Inferring mirror symmetric 3D curves from sketches

Overview

- Finding pairs of symmetric curves:
- 3D reconstruction:

Inferring mirror symmetric 3D curves from sketches

Properties of symmetric polygons

- P and P' are the orthogonal projections of a pair of symmetric 3D polygonal curves:

Inferring mirror symmetric 3D curves from sketches

How to find that P_1 is symmetric to P_2 ?

Inferring mirror symmetric 3D curves from sketches

- A turn vertex is a vertex such that the two adjacent vertices are located in the same half-plane delimited by l .

Inferring mirror symmetric 3D curves from sketches

- A turn vertex is a vertex such that the two adjacent vertices are located in the same half-plane delimited by l .

Inferring mirror symmetric 3D curves from sketches

Inferring mirror symmetric 3D curves from sketches

Finding the symmetric curves

P_1 and P_2 symmetric
 P_3 self-symmetric
 P_4 non-symmetric

P_1 and P_4 symmetric
 P_3 and P_2 non-symmetric

P_2 self-symmetric
 P_1 , P_3 and P_4 non-symmetric

Inferring mirror symmetric 3D curves from sketches

Computing the symmetry relationship

- Unnatural 3D reconstruction

Inferring mirror symmetric 3D curves from sketches

- Exploiting the curve connectivity and the generic viewpoint assumption

Inferring mirror symmetric 3D curves from sketches

- The curve connectivity is not sufficient to uniquely define the symmetry relationship.

Inferring mirror symmetric 3D curves from sketches

Maximizing the compactness of the reconstructed curves:

$$C(O) = \frac{V(O)^2}{S(O)^3}$$

Li Y, Pizlo Z, Steinman RM. A computational model that recovers the 3D shape 33 of an object from a single 2D retinal representation. Vision Research. 2009; 34 49(9):979–91.

Inferring mirror symmetric 3D curves from sketches

Open problems in sketch-based modeling

- 3D reconstruction from sketches

Open problems in sketch-based modeling

Silhouette completion

(a)

(b)

(c)

(d)

(e)

Lance R. Williams: Topological Reconstruction of a Smooth Manifold-Solid from Its Occluding Contour. International Journal of Computer Vision 23(1): 93-108 (1997)

Open problems in sketch-based modeling

3D Reconstruction

- Input: the 2D sketch composed of polygonal curves in a plane
- Output: a shape such that its orthogonal projection matches the input sketch

An infinite number of solutions !

Open problems in sketch-based modeling

- How to select the best solution ?
- According to Li et al., four criteria:
 - Symmetry
 - Planarity
 - Maximum compactness
 - Minimum surface

Li, Y., Pizlo, Z. & Steinman, R.M. "A computational model that recovers the 3D shape of an object from a single 2D retinal representation", Vision Research, Volume 49, Issue 9, 11 May 2009, Pages 979-991

Open problems in sketch-based modeling

- **Symmetry** refers to the mirror-symmetry of the object.

Most of people will interpret this as a sphere

Open problems in sketch-based modeling

- **Planarity** refers to the planarity of the contours of the object.

Open problems in sketch-based modeling

- **Compactness** is defined as V^2/S^3 where V is the object's volume and S is the object's surface area.

3D Reconstruction

- **Minimum surface** is defined as the minimum of the total surface area.

-> Recover a 3D shape, which has the smallest range in depth

Sketch-based editing

Yotam Gingold

Editing operations

- Cutting (we saw earlier)
- Deform by sketching new silhouettes
- Edit relief by sketching shading
- Digital sculpting (ZBrush, etc) — won't talk about

A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

- Silhouette editing

A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

- Silhouette creation

A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

- To edit a silhouette:
 - Parameterize silhouette edges

A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

- To edit a silhouette:
 - Parameterize silhouette edges
 - Parameterize sketch

A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

- To edit a silhouette:
 - Parameterize silhouette edges
 - Parameterize sketch
 - Find correspondences

A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

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A Sketch-Based Interface for Detail-Preserving Mesh Editing [Nealen et al. 2005]

- To edit a silhouette:
 - Parameterize silhouette edges
 - Parameterize sketch
 - Find correspondences
 - Use as xy position constraints (keep z unchanged)
 - Minimize Laplacian Surface Editing energy [Sorkine et al. 2004]

Surface relief editing by sketching shading

Shading-Based Surface Editing [Gingold and Zorin 2008]

Shading

[Michelangelo]

[Dürer]

Shaded 3D Models

FiberMesh [Nealen et al. 2007]

© Miguel Ângelo

Approach

Obtain a new 3D model by shading over an existing one.

Approach

Obtain a new 3D model by shading over an existing one.

Example Session

Shape-from-Shading

Given a shaded image of an object, can we recover its shape?

Shaded Image

Shape (Height Field)

[Durou, Falcone, and Sagona 2008]

User Interface

Shading Strokes

Thin Strokes

Silhouette Stroke

Silhouette Strokes

Results

Why is this hard?

Why is this hard?

The change is
global

Why is this hard?

The change is
global

Rotation about the stroke

Approach

Centerline of stroke: rotate surface about the stroke

- stable, predictable

Elsewhere: Laplacian Editing Energy [Sorkine et al. 2004]

- preserves appearance & shape

Variable vertex weights for our brush parameters

- controllable

Linear Constraints + Quadratic Energy =
sparse linear system of equations

Flip Ambiguity

top

side

Concave/Convex
ambiguity

top

side

Slope
ambiguity

Summary

Limitations

Shading requires expertise.

Speed: modifications aren't local.

Highlight control is limited.

Takeaways

- Familiar curves (silhouettes and shading) are natural candidates for editing operations.
- Sketching is a natural way to input curves.
- It's “easier” to deform than create geometry.