Mathematical Surface Representation for Conceptual Design

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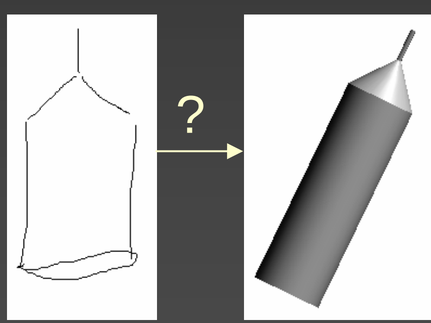
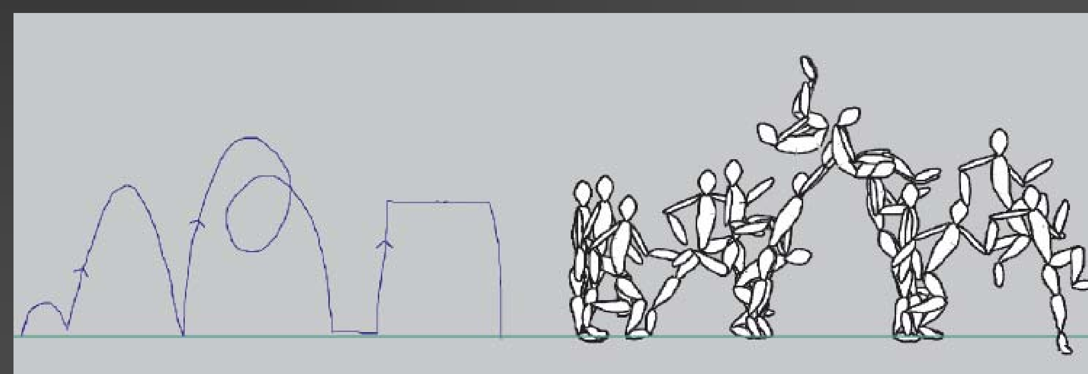
Richard (Hao) Zhang (SFU)

Key Question

How quickly and effectively can a designer transform a mental concept into digital form and manipulate it in an intuitive manner?

Example: Sketch-based modeling

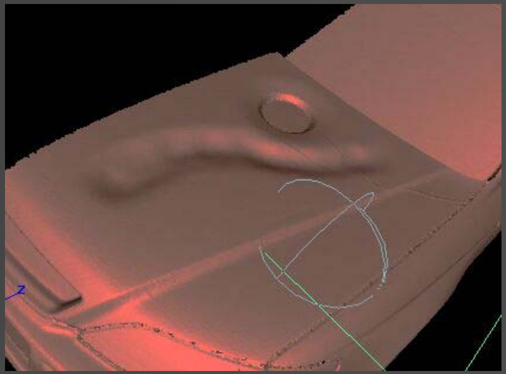




[Thorne, Burke & van de Panne 04]

Industrial Importance

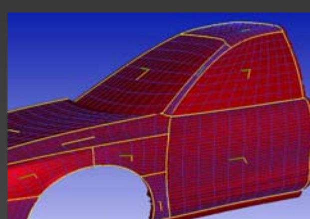
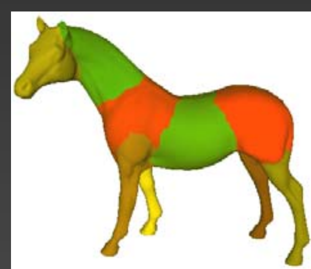
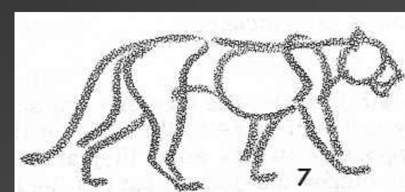
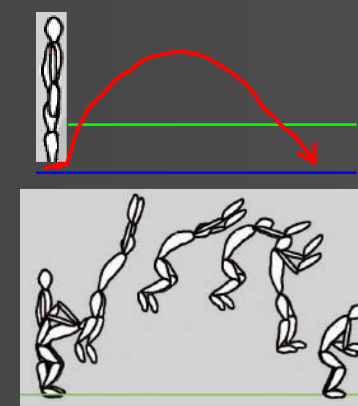
- Designers almost exclusively prefer traditional design techniques, e.g., sculpting, sketching
- Model manipulation, processing, evaluation, manufacturing rely on modeling tools that operate on digital representations
- Our goals are two-fold
  - Develop novel design and control paradigms that are intuitive, effective, and interactive
  - Fundamentally decouple designer's creative process from underlying constraints specific to the digital representation



Feature-based Approach

Focus: Develop new mathematical representations or adapt existing ones to capture the essence of shape as perceived by a designer

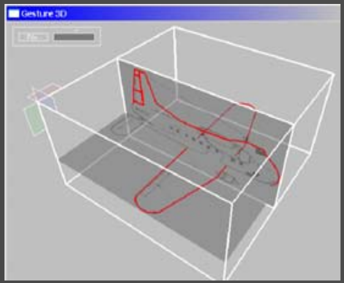
- Features capture essence of shape/movement as we perceive it

- Features can be sketched out or extracted
- In our work, features will be used to *abstract, describe, infer, differentiate, and control* our digital models

On-going Projects

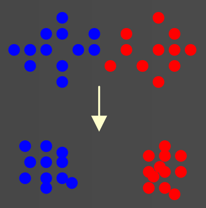
- Sketch-based modeling & animation (UBC + Toronto)
  - *Sketched motions* [Thorne, Burke, van de Panne 04]
  - *Suggestive interface for wireframe 3D sketching* [Tsang, Balakrishnan, Singh 04]
  - *Sketch classification and 3D shape inference*
- Intuitive control of shape & motion (Toronto)
  - High DOF input device [Grossman, Balakrishnan, Singh 03]
  - *Cords – keyframe curve control with physical properties* [Coleman & Singh 04]

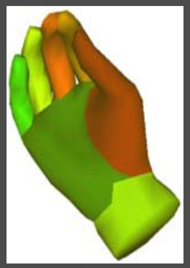


Ryan

On-going Projects

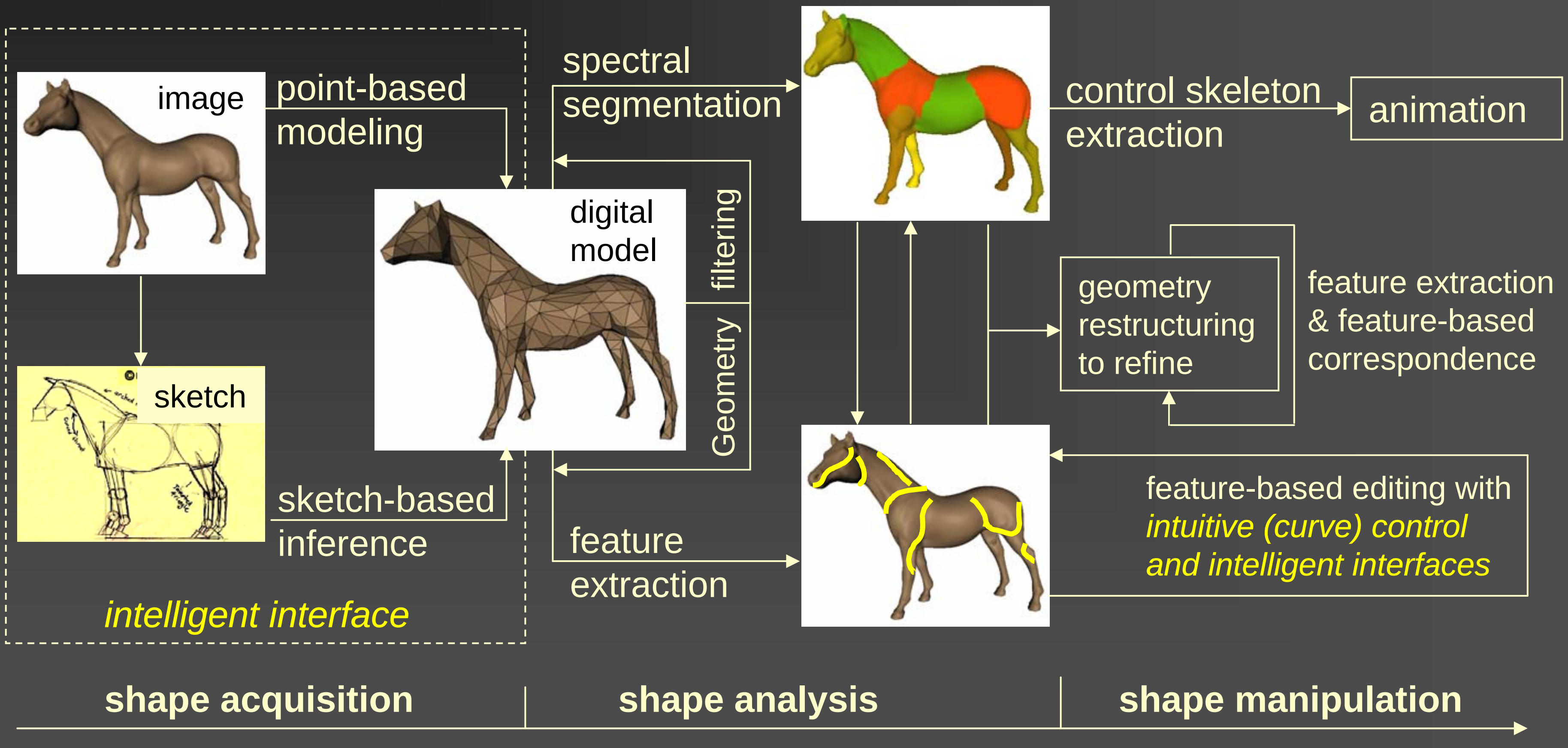
- Geometric signal processing & feature analysis (SFU + Toronto)
  - *Spectral mesh segmentation* [Liu & Zhang 04]
  - Geometry filtering [Zhang 04, Zhang & Fiume 03]
  - Feature-based 3D shape correspondence





- Geometry restructuring (Toronto + Montreal)
  - Feature-based retargeting of geometry [Singh et al. 04]
- 3D shape inference & reconstruction
  - *Point-based modeling from images* [Poulin et al. 03] [Epstein, M. Granger-Piché, and P. Poulin 04]
  - Interactive space carving for 3D shape construction [Granger-Piché, Epstein, Poulin 04]

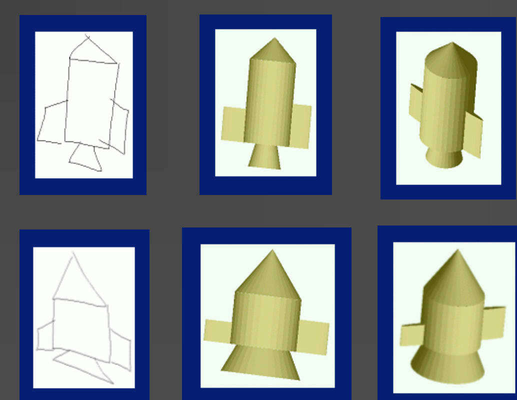
How do these fit together?



Sketch-based Modeling

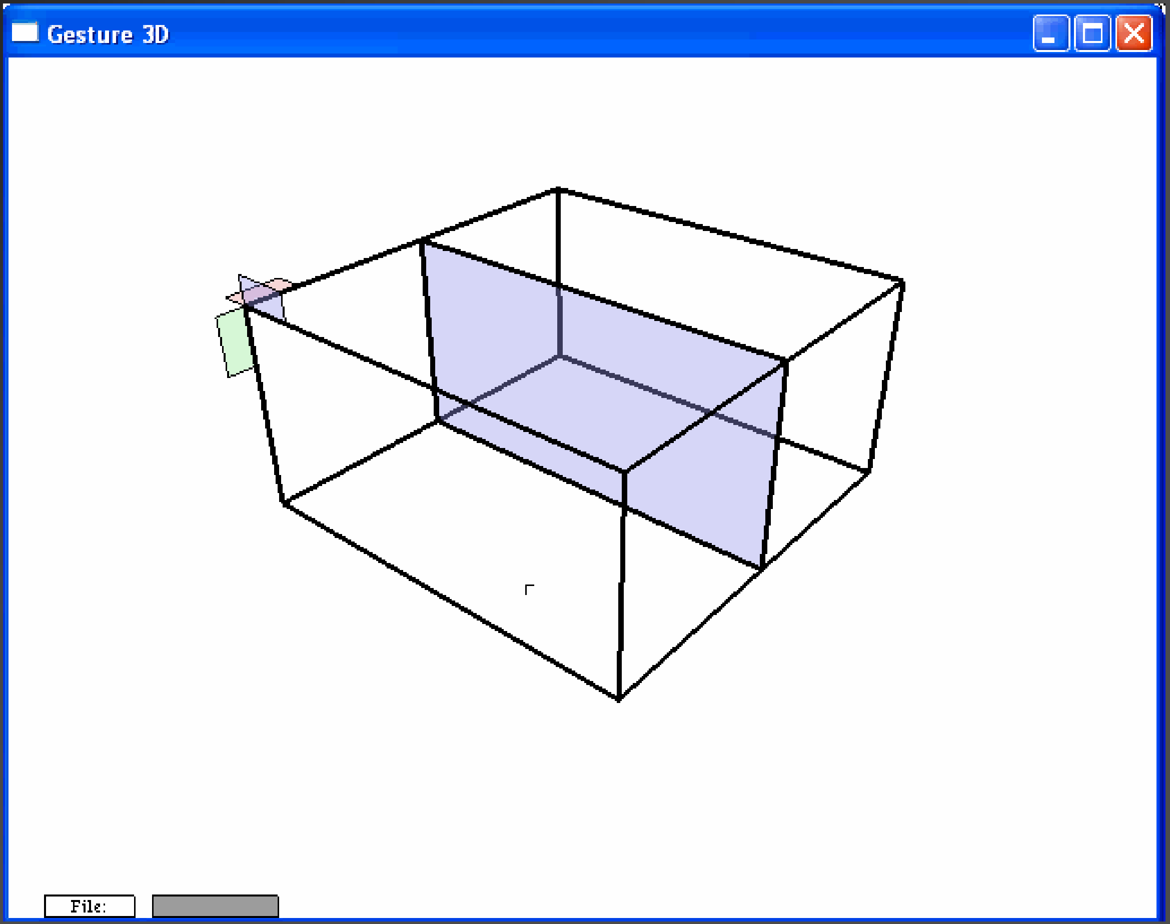
Question: How to go from a sketch to a digital representation?

- User-friendly sketch interface
- Model easy to refine and reuse
- Interface should be *suggestive*
  - *Incorporate prior knowledge*: e.g., assume object class is known *a priori* — “I am drawing a car”
  - Suggestion search should be robust

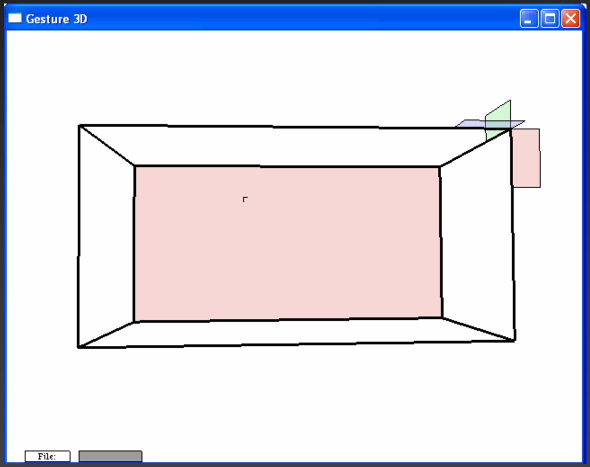


Suggestive wireframe 3D sketching

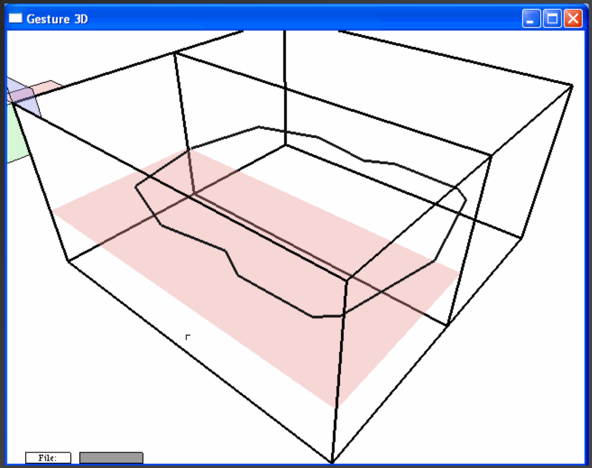
- Intuitive drawing on spatially integrated planes
- *Image-guided sketching*: e.g., curve pinning, snapping, …
- *Gesture inputs*
- *Suggestions*



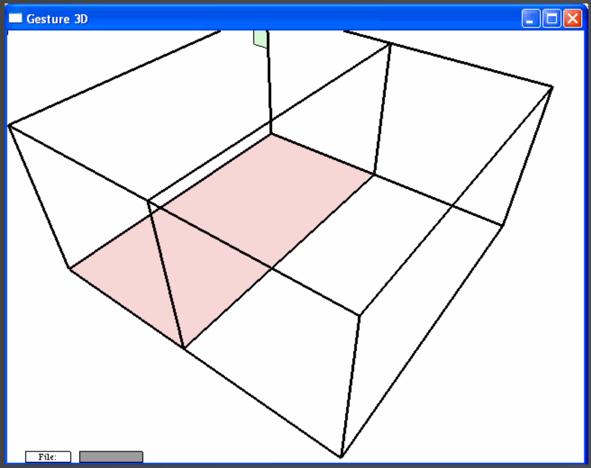
Specific System Features



“Closure” suggestion

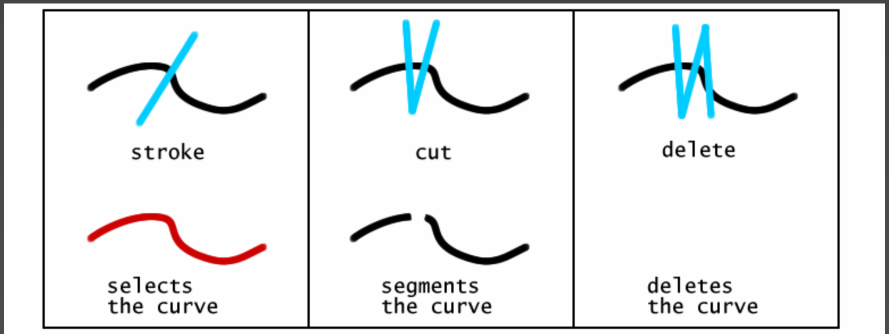


“Extrusion” suggestion



Database suggestion

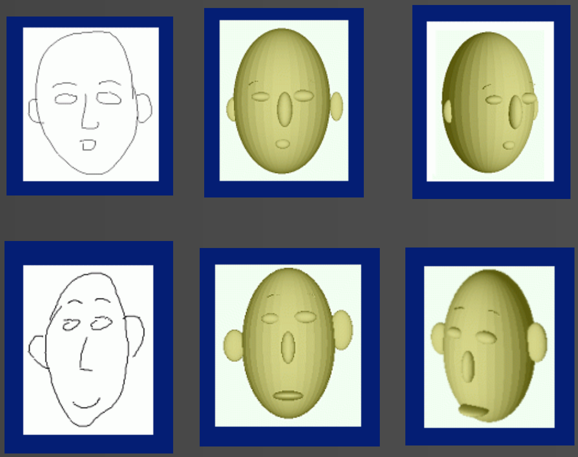
Gestures



Sketch Classification and 3D Inference

- Sketch-based shape descriptors + similarity metric
  - *Discriminative* yet *robust* descriptors
  - Include context information
  - Model less dependent on stroke structures

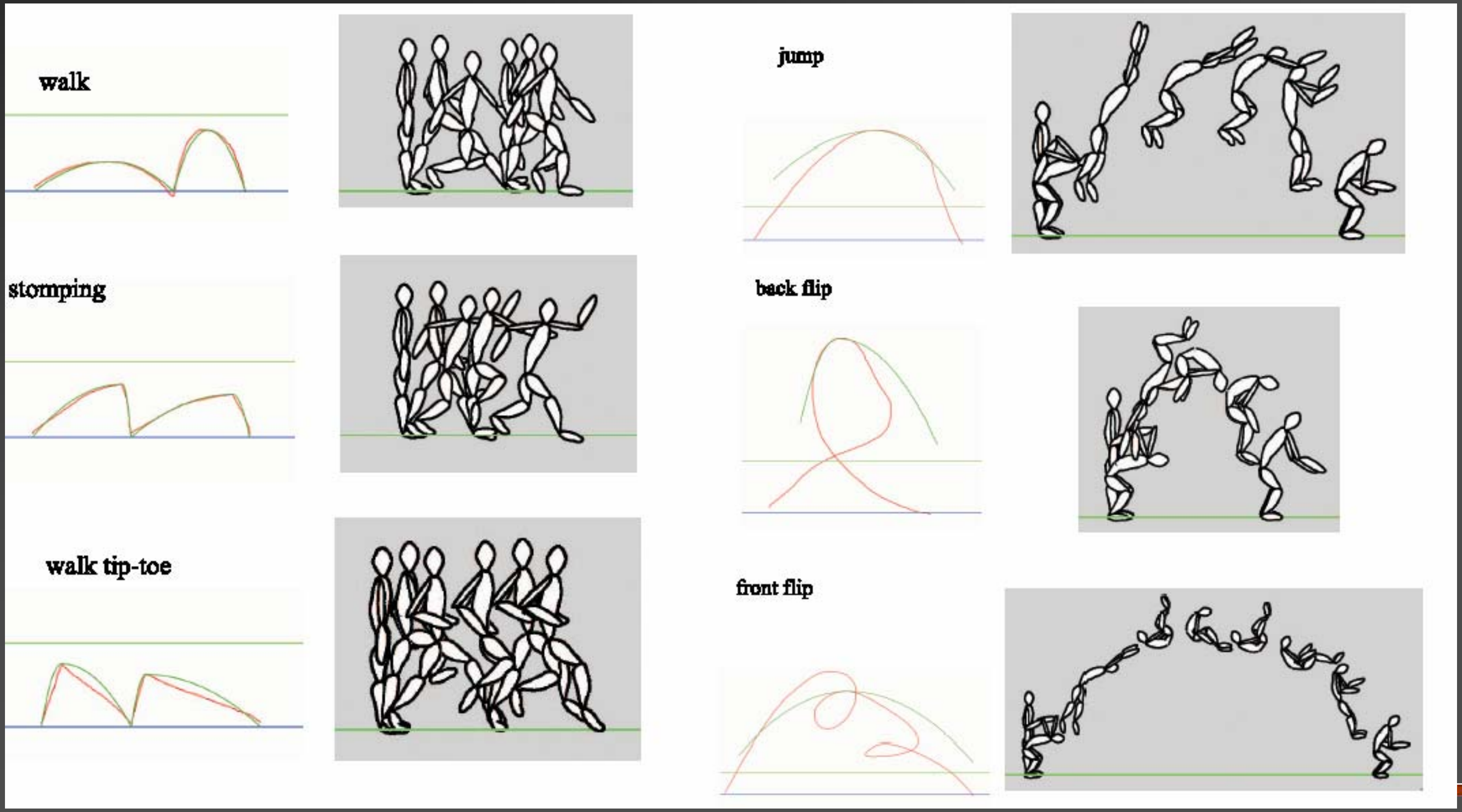
  → *K-means feature classifiers* (current)



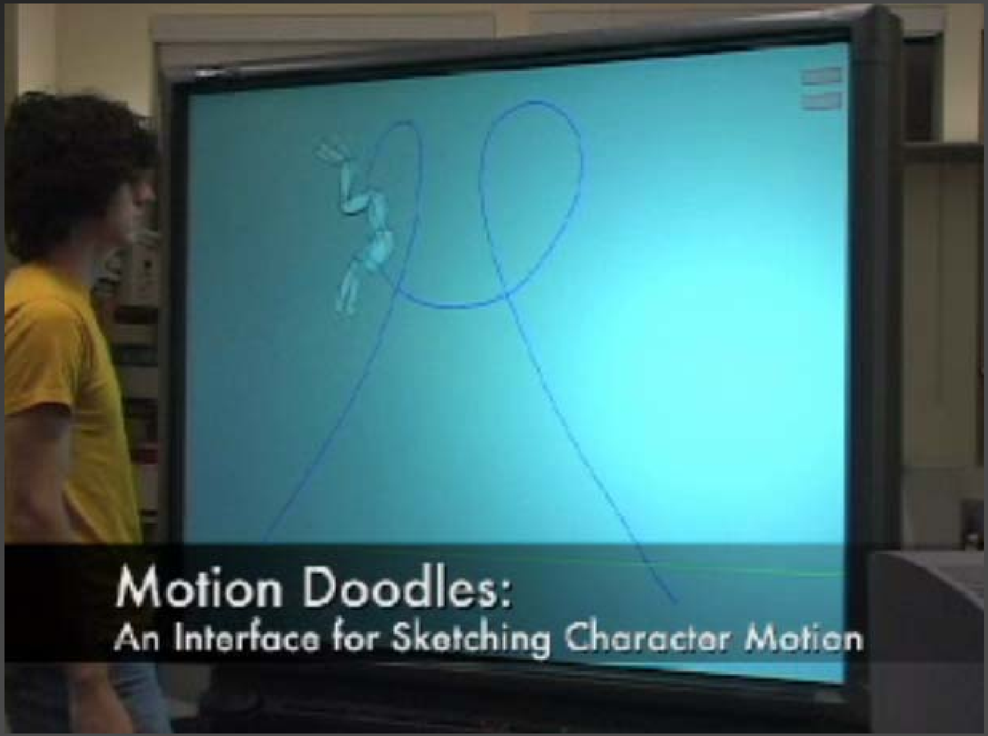
- Relying on training set of free-form sketches
- Find "most likely" parsing of sketch into known model
  - *Maximum likelihood parsing of full sketch*, instead of just local features
  - Conditional Random Fields (future work)

Sketching Motion: Motion Doodles

Gestures controlled by sketches



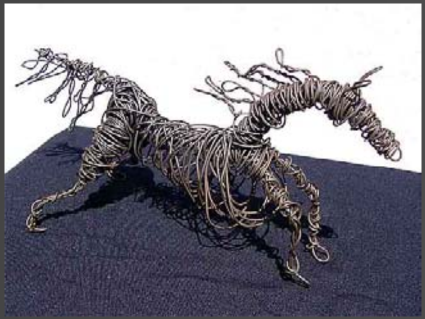
Video: Motion Doodles



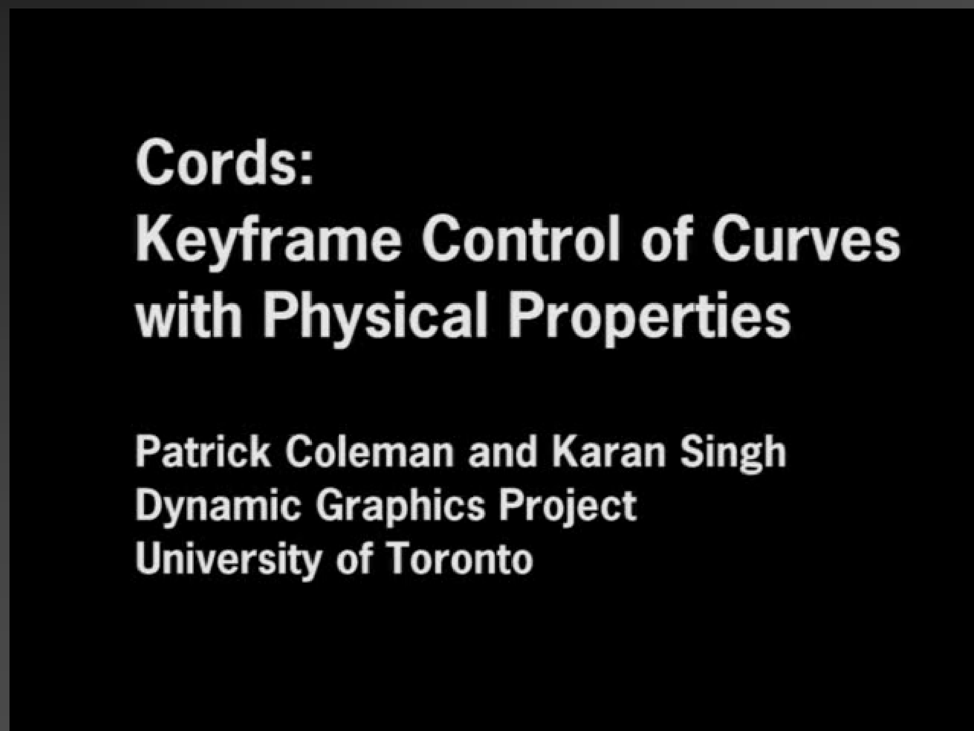
[Thorne, Burke, van de Panne, *SIGGRAPH 2004*]

Cords: Keyframe Control of Curves

- Motivation: *precise and interactive* control of strings, wires, rubber bands, etc., with *physical appearance* properties
- Contributions:
  - Precise control for keyframe animation
  - Automatic bending and wrapping around 3D scene geometry
  - Models length, stiffness, and elasticity
  - Intuitive parameter space for predictable response
  - Easy to code algorithms



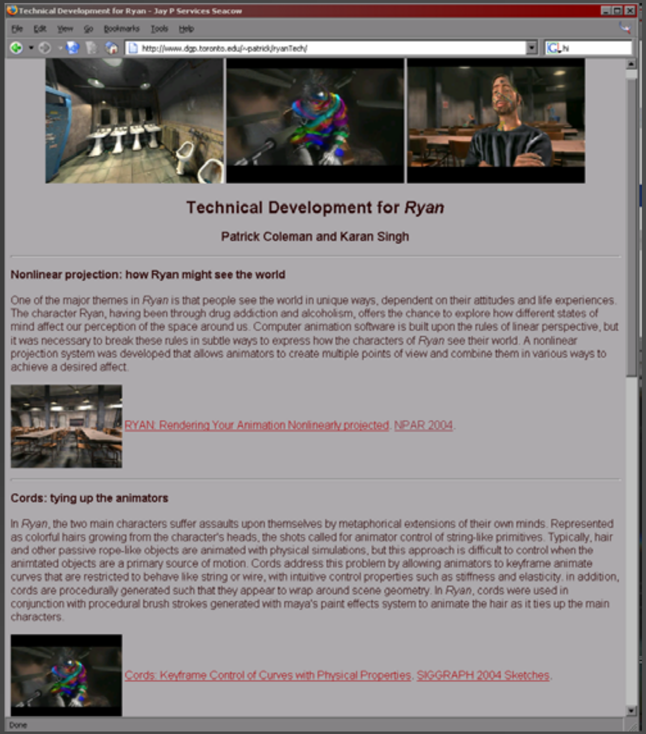
Video: Cords (in *Ryan*)



Ryan: *SIGGRAPH 2004* Electronic Theater Jury Prize

Cords — Future Work

- Generation algorithms incorporating the analytic form
- Higher order continuity along cords
- Modeling of surfaces
- Hybrid models incorporating physical simulation



Technical Development for Ryan - Jay P Services Seacow

http://www.dgp.toronto.edu/~patrick/ryanTech/

Technical Development for *Ryan*

Patrick Coleman and Karan Singh

Nonlinear projection: how Ryan might see the world

One of the major themes in *Ryan* is that people see the world in unique ways, dependent on their attitudes and life experiences. The character Ryan, having been through drug addiction and alcoholism, offers the chance to explore how different states of mind affect our perception of the space around us. Computer animation software is built upon the rules of linear perspective, but it was necessary to break these rules in subtle ways to express how the characters of *Ryan* see their world. A nonlinear projection system was developed that allows animators to create multiple points of view and combine them in various ways to achieve a desired affect.

RYAN: Rendering Your Animation Nonlinearly projected. NPAR 2004.

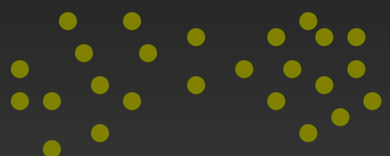
Cords: tying up the animators

In *Ryan*, the two main characters suffer assaults upon themselves by metaphorical extensions of their own minds. Represented as colorful hairs growing from the character's heads, the shots called for animator control of string-like primitives. Typically, hair and other passive rope-like objects are animated with physical simulations, but this approach is difficult to control when the animtated objects are a primary source of motion. Cords address this problem by allowing animators to keyframe animate curves that are restricted to behave like string or wire, with intuitive control properties such as stiffness and elasticity. in addition, cords are procedurally generated such that they appear to wrap around scene geometry. In *Ryan*, cords were used in conjunction with procedural brush strokes generated with maya's paint effects system to animate the hair as it ties up the main characters.

Cords: Keyframe Control of Curves with Physical Properties. SIGGRAPH 2004 Sketches.

For more information:
www.dgp.toronto.edu/~patrick
/ryanTech

Spectral Geometry Processing



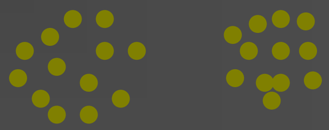
original space

Affinity matrix:
$W \in \mathbf{R}^{N \times N}$

Eigenvalue
Decomposition:
$W = E \Lambda E^T$

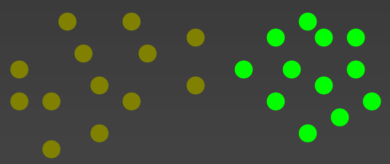
Find m-dimensional
embedding

$U = [e_1, e_2, \ldots e_m]$



embedding space

k-means
clustering on
rows of U

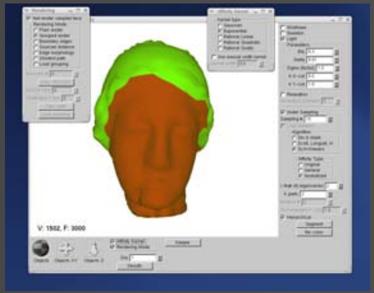


Spectral clustering

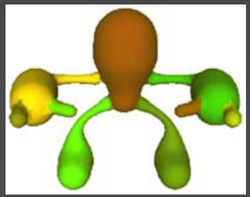
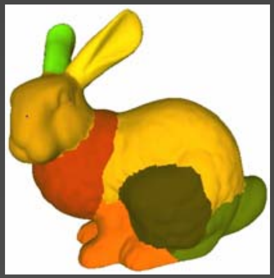
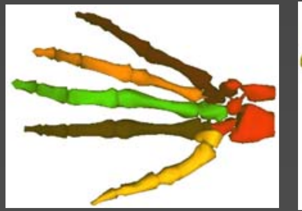
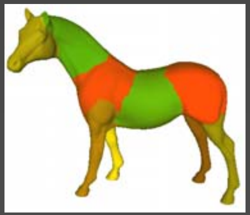
Polarization theorem
[Brand & Huang 03]

Segmentation via Spectral Clustering

- One instance of *context-based 3D shape analysis*
- Point entities become mesh faces or vertex 1-rings
- Affinities honor *minima rule* (emphasize concavity)
- *Nyström method* with specific *subsampling* algorithm improves asymptotic complexity from O($n^2 logn$) to O($sn\ logn$)
- Post-smoothing of cut boundary using *morphological processing*

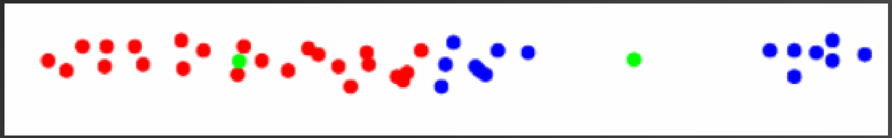


[Liu & Zhang 04]


Current and Future Work

- Replace *k*-means by more advanced clustering



- Careful study of polarization phenomenon
- *Feature extraction* via spectral clustering
- *Context-based shape correspondence*
  - Robust iterative closest point (ICP) in spectral domain
  - Combination of feature estimation, correspondence identification, and rigid or non-rigid transformation search
- Can we handle sketches?

Point-based Modeling from Images

- Capturing complex reality instead of a mental concept
- Utilizing point-sampled geometric representation
  - Points are the simplest possible primitives — increasingly popular
  - Facilitate easy and interactive improvement of object quality
- Tight integration of point-based representation and user interactivity
- User-guided point-shape reconstruction via interactive system for high-quality result and rendering

Video: Points from Images

[Poulin et al. 03]

Publications (2003 – 2004)

- P. Coleman, K. Singh, “Cords: Keyframe Control of Curves with Physical Properties,” *SIGGRAPH 2004 Sketches*.
- E. Epstein, M. Granger-Piché, and P. Poulin, “Exploiting Mirrors in Interactive Reconstruction with Structured Light,” *Proc. Vision, Modeling, and Visualization 2004*, November 2004, to appear.
- M. Granger-Piché, E. Epstein, P. Poulin. “Interactive Hierarchical Space Carving with Projector-based Calibrations.” *Proc. Vision, Modeling and Visualization 2004*, November 2004, to appear.
- T. Grossman, R. Balakrishnan, K. Singh. “An Interface for Creating and Manipulating Curves Using a High Degree-of-Freedom Input Device,” *ACM CHI 2003*, pp. 185-192.
- R. Liu and H. Zhang, “3D Mesh Segmentation through Spectral Clustering,” *Proc. Pacific Graphics* 2004, pp. 298-305.

Publications (2003 – 2004)

- P. Poulin, M. Stamminger, F. Duranleau, M-C. Frasson, G. Drettakis, “Interactive Point-Based Modeling of Complex Objects from Images,” *Proc. Graphics Interface 2003*.
- K Singh, H. K. Pedersen, V. Krishnamurthy, “Feature-Based Retargeting of Parameterized Geometry,” *IEEE 2004 Geometric Modeling and Processing (GMP 2004), Theory and Applications*, pp. 163-172.
- S. Tsang, R. Balakrishnan, K. Singh, A. Ranjan, “A Suggestive Interface for Image Guided 3D Sketching,” *ACM CHI 2004*, pp. 591-598.
- M. Thorne, D. Burke, and M. van de Panne, “Motion Doodles: An Interface for Sketching Character Motion,” *ACM SIGGRAPH 2004.*
- H. Zhang, “Discrete Combinatorial Laplacian Operators for Digital Geometry Processing,” *Proc. SIAM Conference on Geometric Design and Computing*, 2004, to appear.
- H. Zhang and Eugene Fiume, “Butterworth Filtering and Implicit Fairing of Irregular Meshes,” *Proc. Pacific Graphics 2003*, pp. 502-506.

Industrial Partners

Company	Specialty	Headquarter	URL
Alias Systems Corp.	3D Modeling & Animation (Maya)	Toronto, ON, Canada	www.alias.com/
ARANZ Group of Companies	3D scanning and Modeling	New Zealand	www.aranz.com/
Arius 3D Inc.	3D scanning and Modeling	Mississauga, ON, Canada	www.arius3d.com/
Actuality Systems Inc.	Spatial 3D Visualization	Burlington, MA, USA	actualitysystems.com/
Electronic Arts	Computer Games and Entertainment	Redwood City, CA, USA	www.ea.com/
Measureand Inc.	3D Measuring Sensors Tech.	Fredericton, NB, Canada	www.measurand.com/

Acknowledgement

- MITACS for financial support
- Karan Singh, Michiel van de Panne, Pierre Poulin, Patrick Coleman, Steve Tsang for providing slide samples, video, and papers
- SFU graduate students: Frank Liu and Varun Jain
- All the researchers and students involved
- FAS student travel funding

Project URL: http://www.dgp.toronto.edu/~karan/project_website/index.htm