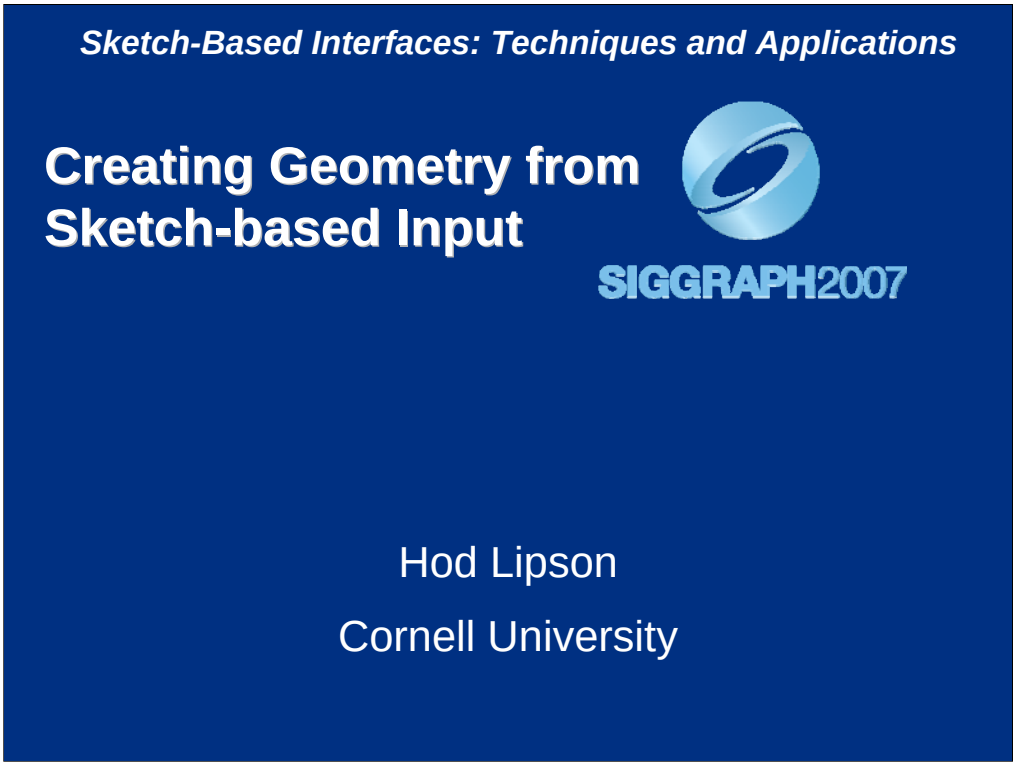
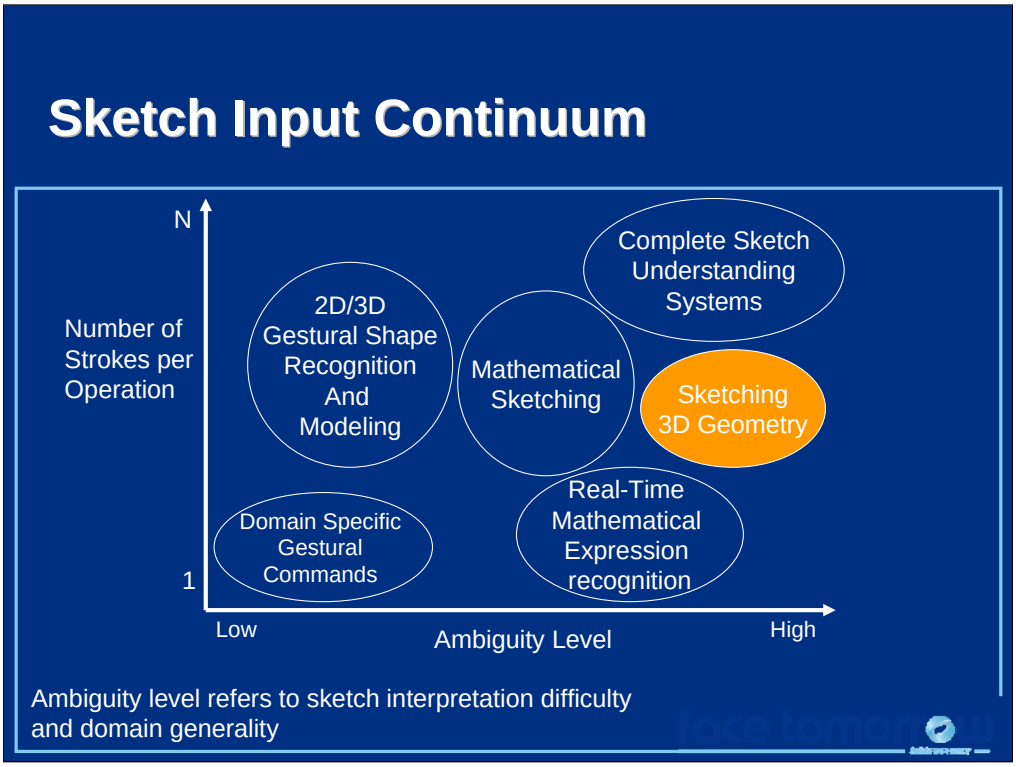



**Creating Geometry from Sketch-based Input (60 min)**

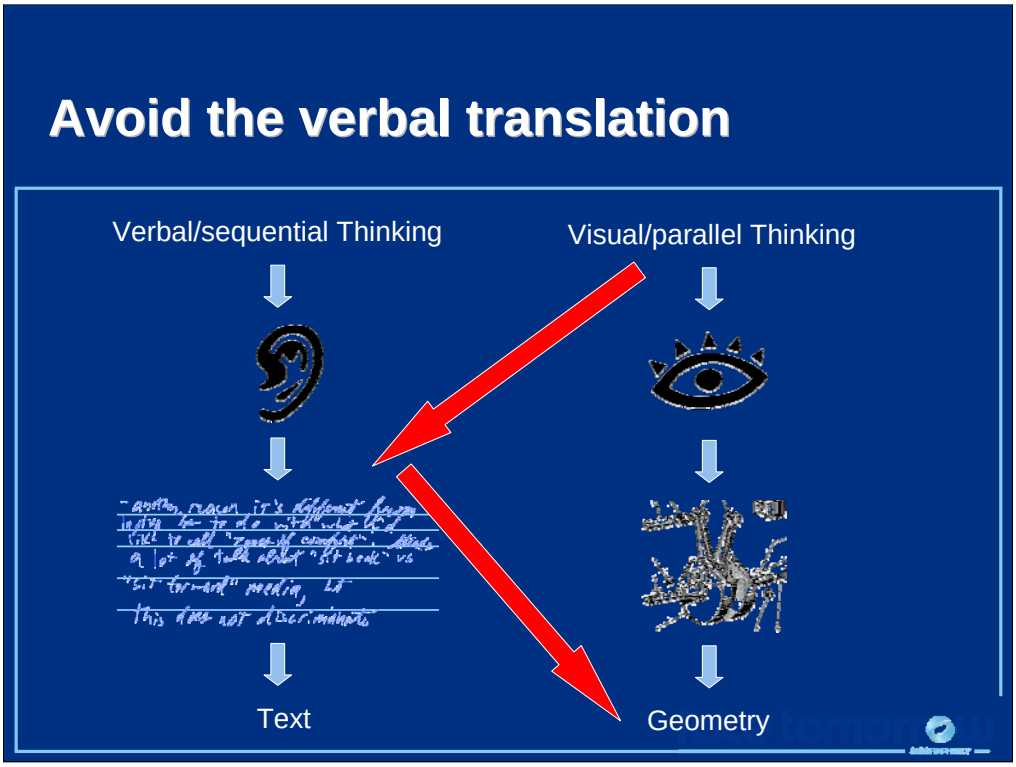
Hod Lipson, Assistant Professor
Department of Mechanical & Aerospace Engineering
216 Upson Hall, Cornell University
Ithaca NY 14853, USA

Email: hod.lipson@cornell.edu
http://www.mae.cornell.edu/lipson

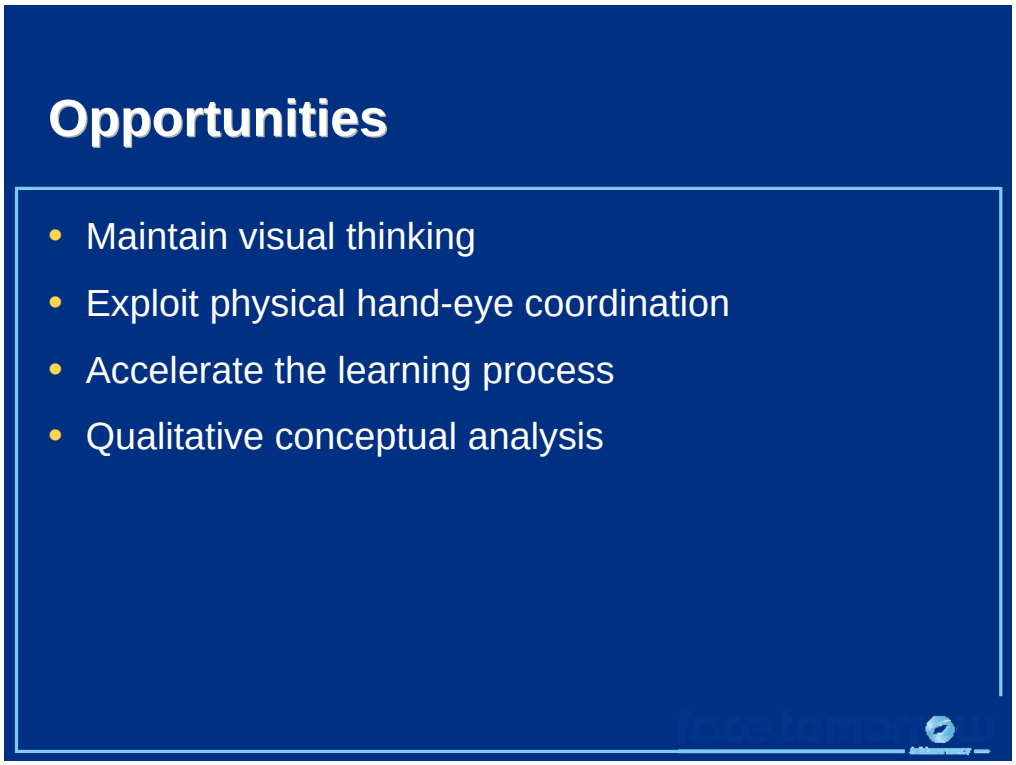



Earlier today we outlined a number of concepts for using sketch-based interfaces for modeling and design. I'd like to return to talk about one particular application and the challenges and opportunities involved in this application area.

Sketching to produce 3D geometry is particularly challenging because it involves several levels of ambiguity: Ambiguity inherent in any sketch based application due to inaccuracy of the sketch strokes and lack of a direct interface, but then also ambiguity related to the 2D to 3D mapping. Compounded to this, we have a scaling problem due to the relatively complexity of objects to be inferred. And so we end up being at the upper-right corner of the complexity-ambiguity space.

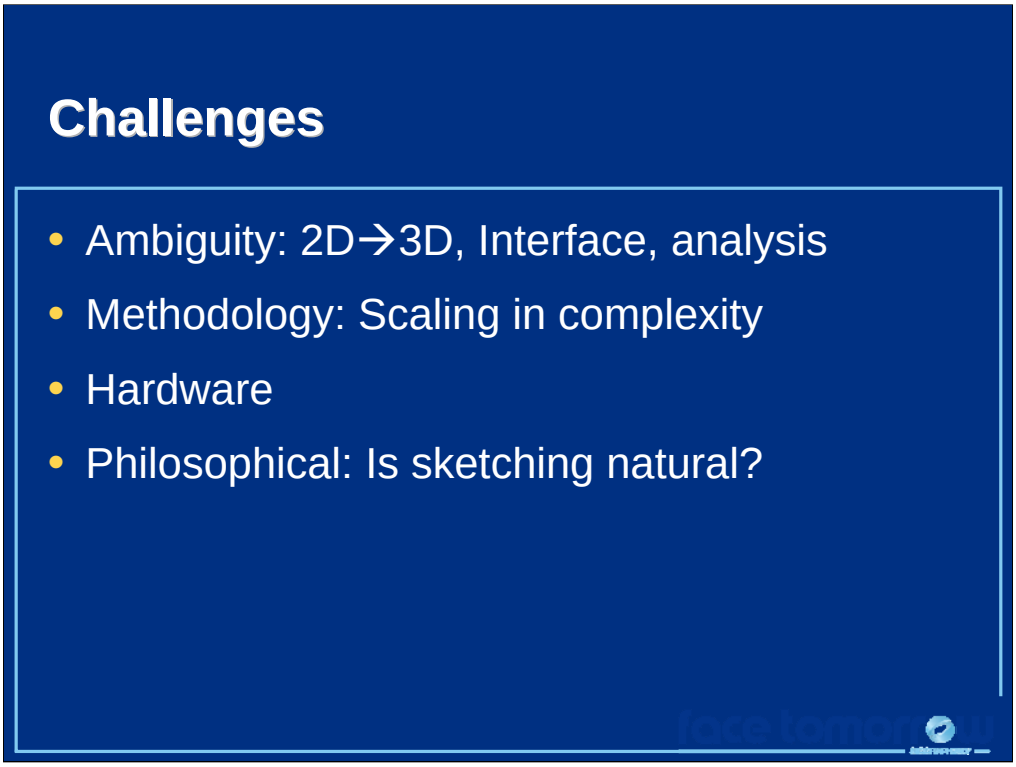



Let's recall that sketch understanding is really about skipping the "forced" translation from the parallel, visual thinking mode which characterizes design, into the verbal, sequential process that is typically needed to enter it into a computer.



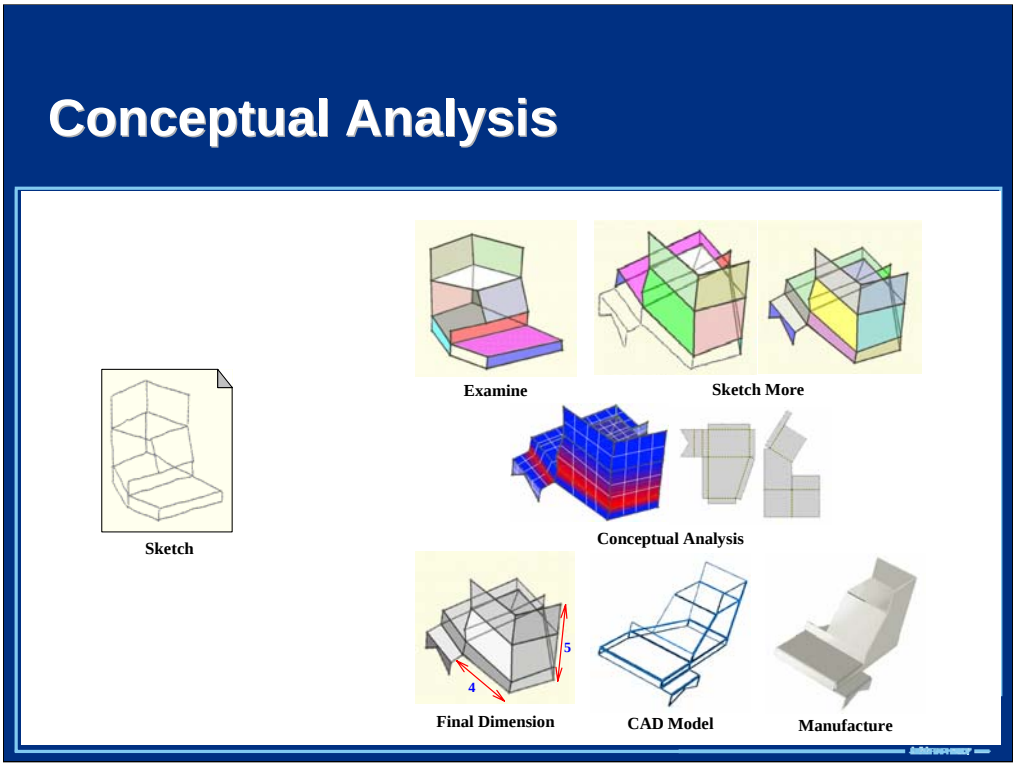

Done well, staying at the “visual side” of the brain could have several profound advantages, such as exploiting the rich-hand-eye coordination, thereby flattening the learning curve. Takeo Igarashi showed how even untrained children can design relatively complex 3D shapes.

In engineering, this has an additional advantage: We can bring computer aided engineering (CAE) tools to bear at the initial stages of design – where most of the critical decisions are made. Today most, of these types of analyses are done at a fairly late stage of the design when a considerable amount of effort has already been invested in creating detailed models.

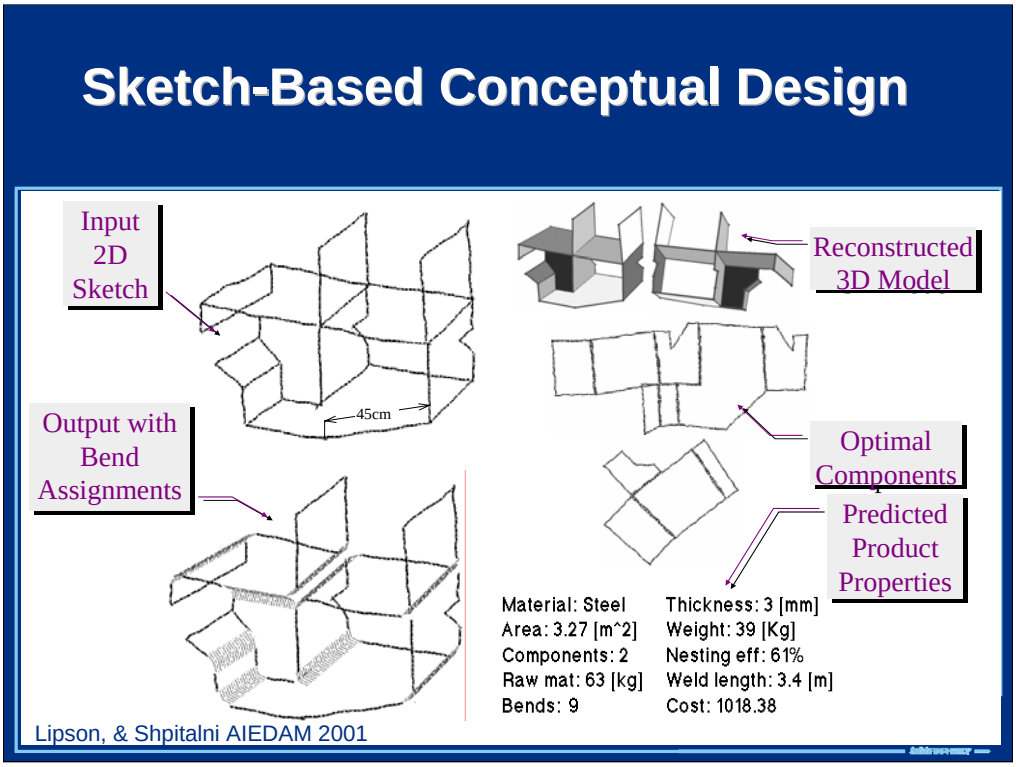



The two main challenges are those outlined on the first slide: Dealing with ambiguity and dealing with complexity.

These are compounded by fundamental hardware issues and deeper questions about the naturalness of sketching – is it really natural, or is it an artifact of the way technology evolved.

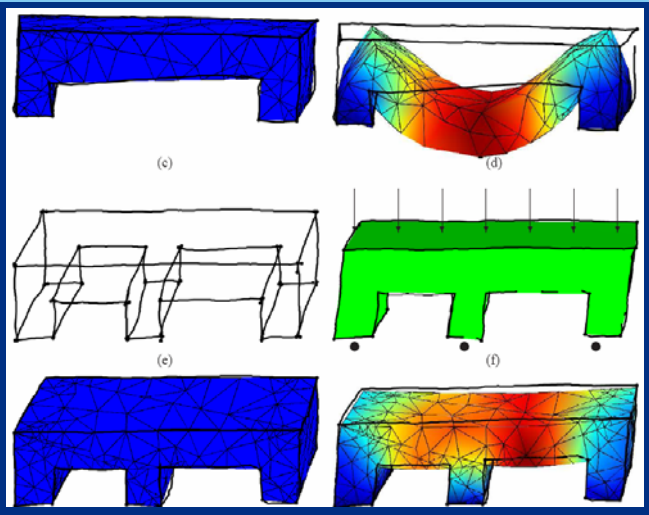



So lets go back to the ideal sketch-based design. We'd like a CAD system to act like an "expert colleague" at a whiteboard. We'd like to get feedback on our design before investing much into it. For example, imagine you can sketch an object, and you asked an expert to look at your sketch and provide feedback on potential manufacturing and stress issues before you invested in details. If a colleague expert could do it, why can't a computer do it? That's not the case now for a number of issues: Sketch interpretation is one, and another is how to analyze "rough" models: How to provide reliable analysis from an unreliable model.




Here is an example…

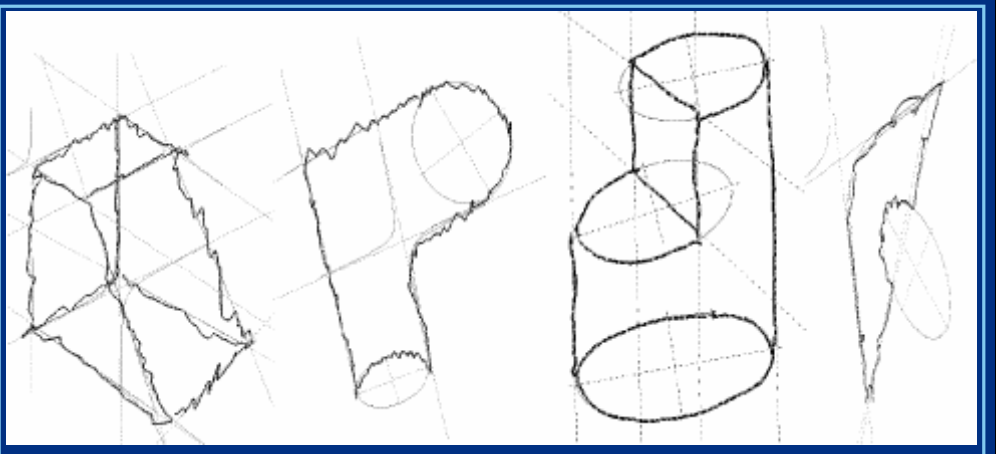
## Perform structural analysis




Masry & Lipson, C&G 2006

And another one…

## Analyzing Strokes



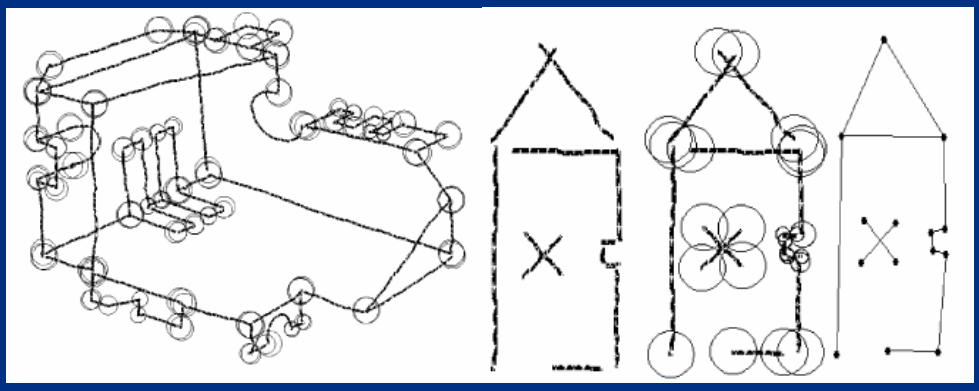
Conic sections use for classification

Shpitalni, M. and Lipson, H., 1996, "Classification of Sketch Strokes and Corner Detection Using Conic Sections and Adaptive Clustering," ***Trans. of ASME J. of Mechanical Design***

Lets look at the way it works.

First, there is an issue of stroke recording and classification. These issues are addressed by many systems, but here we have a particular interest in straight lines and conic sections.

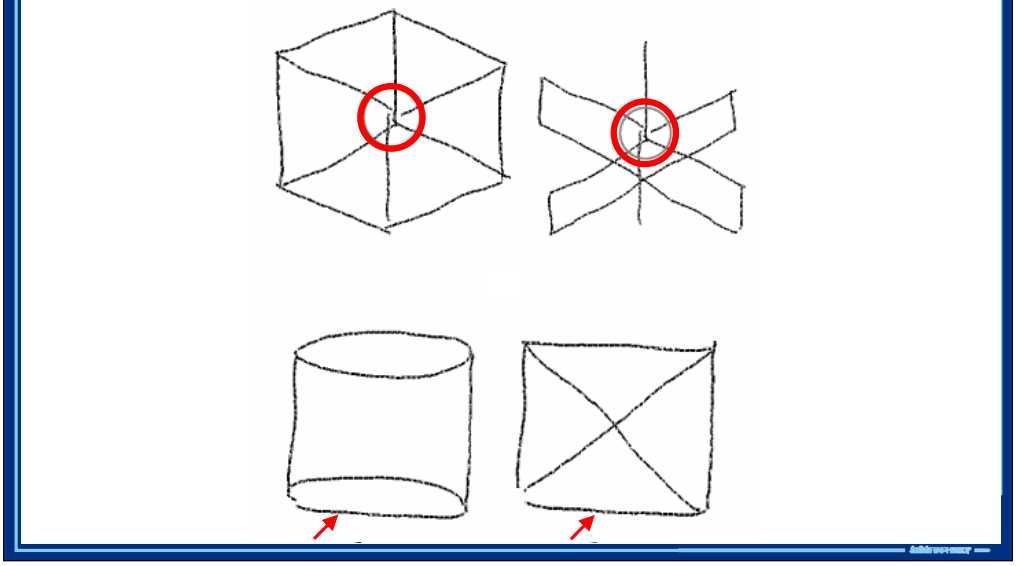
## Analyzing Strokes



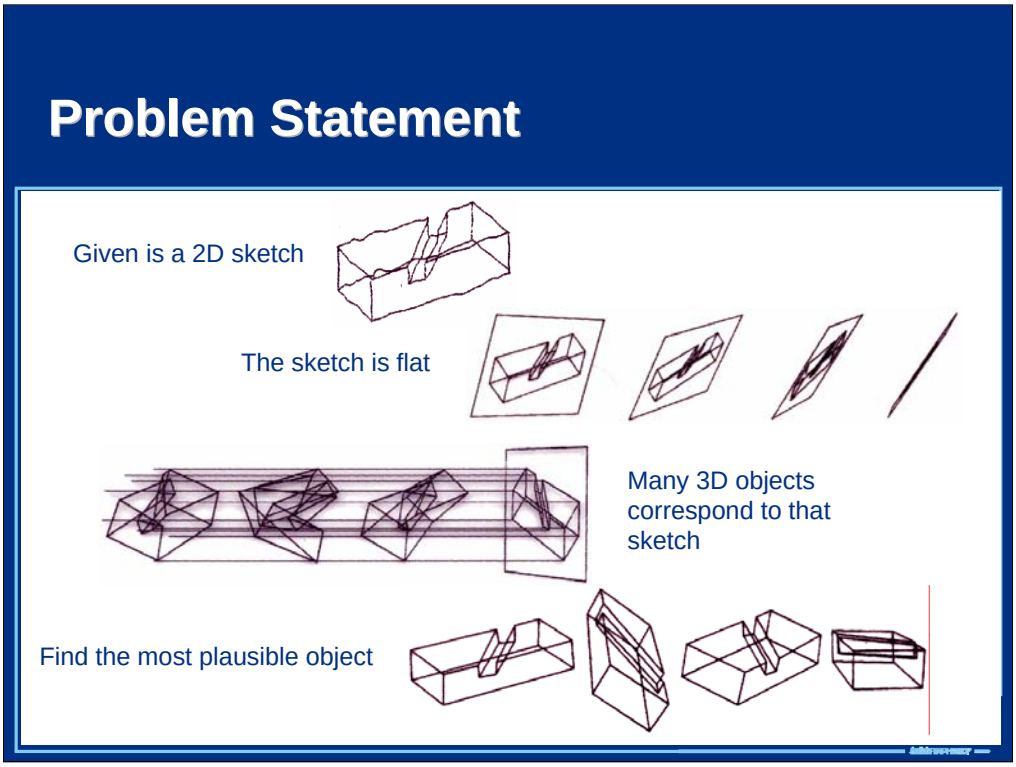
Adaptive tolerance used to join edges into a graph

Evan linking the strokes at their ends is a challenge, as several other speakers have alluded to. There are multi-resolution decisions that need to be made adaptively…

## Interpretation is context dependent



And possibly based on context.




Once the basic classification and joining of strokes is complete, we end up having a graph embedded in 2D, the real problem begins:

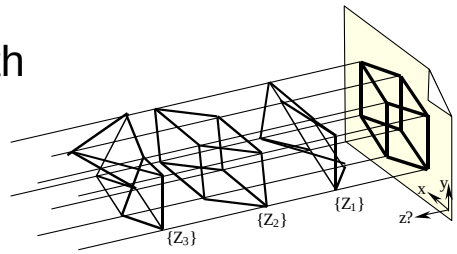
The sketch is flat, and it represents, in theory, and infinite set of 3D objects. Yet we can easily reach a consensus about the most plausible object it represents. How do we do this? There are clearly som interesting issues here that have to do with the human visual system. We make some assumptions.

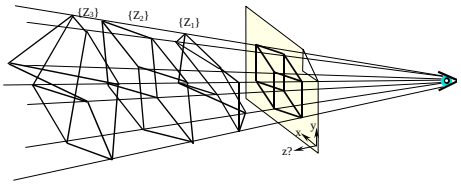
## Approaches

- **Line labeling** is a form of interpretation through junction constraints (Huffman, 1971; Clowes, 1971).
- **The gradient space** constrains line slopes to face gradients (Mackworth, 1973; Wei 1987).
- **The linear System** forms linear (in)equalities in terms of the vertex coordinates and plane equations (Sugihara, 1986; Grimstead and Martin, 1995).
- **Interactive methods** gradually build up the 3D structure (Fukui, 1988; Lamb and Bandopadhay, 1990).
- **The primitive identification** approach assumes known shape instances, CSG (e.g. Wang and Grinstein, 1989).
- **The minimum standard deviation approach** focuses on simple "inflating" (Marill, 1991; Leclerc and Fiscler, 1992).
- **Analytical Heuristics** (Kanade, 1980; Lipson and Shpitalni, 1996).

## Quantifying the solution

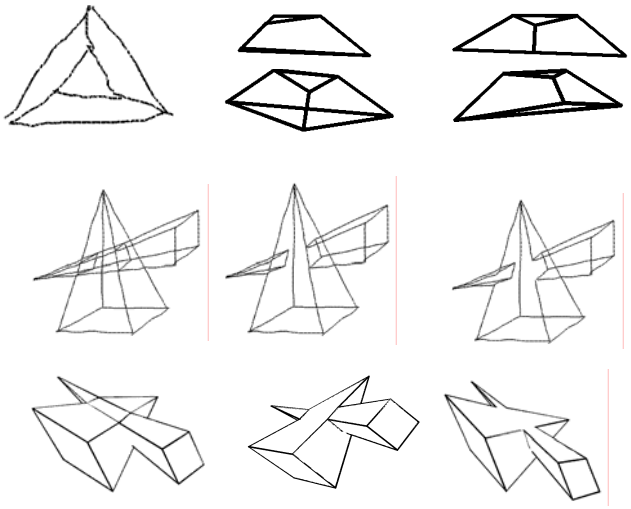
- Each vertex has an unknown depth (z) with respect to the sketch plane (x-y).
- Each vertex has one degree of freedom.
- Find the z-values and a reconstruction is obtained.



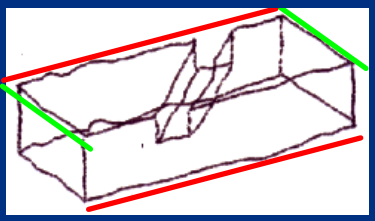
We can quantify the question as an optimization/search problem.

## Tolerating sketching errors



## The first source: Geometric correlations

Statistical correlations provide **soft** constraints between ***z*** coordinates of vertices

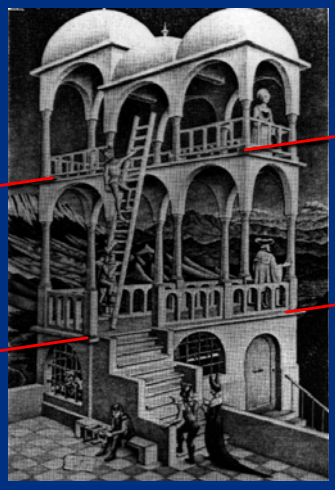


| | |
|---|---|
| Isometry | 1st order |
| Colinearity | |
| Verticality | |
| Corner span | 2nd order |
| Skewed symmetry | |
| Skewed orthogonality | High order |
| Planarity | |

## The first source: Geometric correlations

We interpret drawings by known correlations.

Images not conforming with the correlations confuse us.

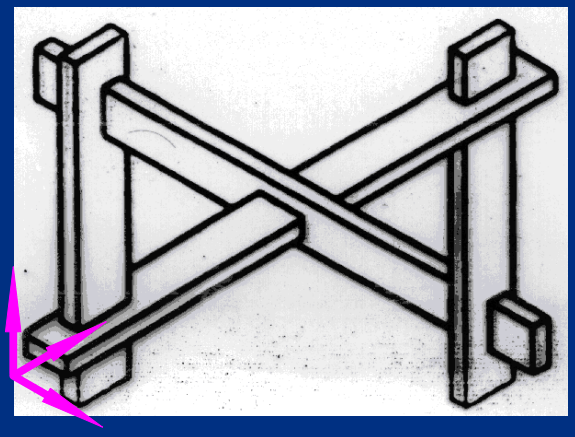


M. C. Escher, *Belvedere*, 1958

## The first source: Geometric correlations

We interpret drawings by known correlations.

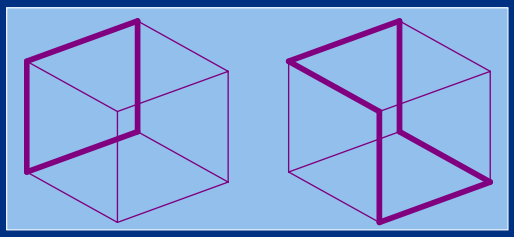
Images not conforming with the correlations confuse us.



M. C. Escher

## The second source: Topology

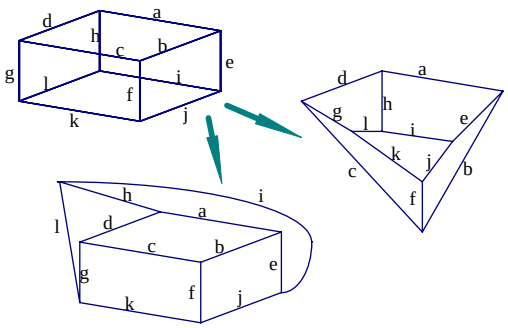
Identify edge circuits corresponding to faces of the depicted objects



For polyhedral objects, constrain planarity among vertices of each circuit

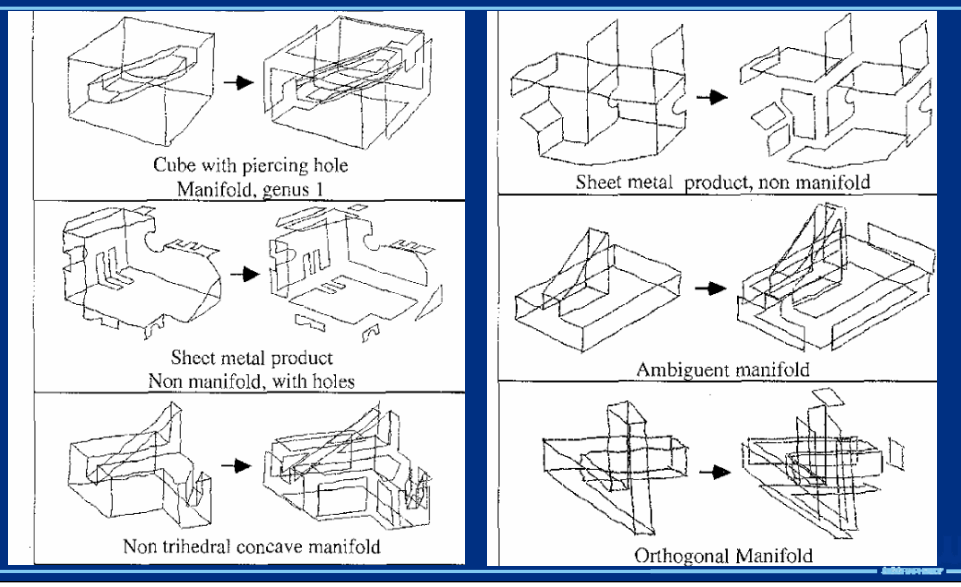
***How to identify circuits?***

## For Manifold Objects with Genus 0

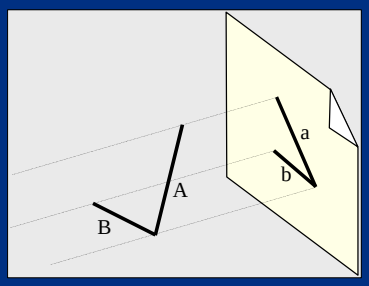



**Face A: {a,b,c,d}**
**Face B: {b,e,j,f}**
**Face C: {c,f,k,g}**
**...**

## Non-manifold use local analysis



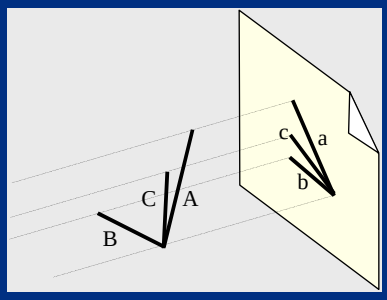
## Geometric correlations




- Learn to correlate 2D with 3D

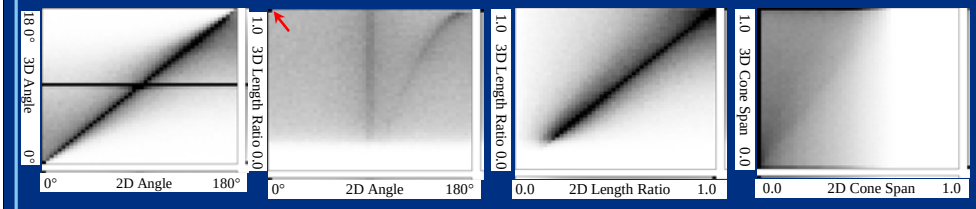
$$p(\alpha_{3d} / \alpha_{2d}) = \frac{pdf(\alpha_{3d}, \alpha_{2d}) \cdot \delta\alpha_{3d} \cdot \delta\alpha_{2d}}{pdf(\alpha_{2d}) \cdot \delta\alpha_{2d}}$$

## Higher order correlations




- Learn patterns in all permutations of lengths and angles of segment groups of various sizes

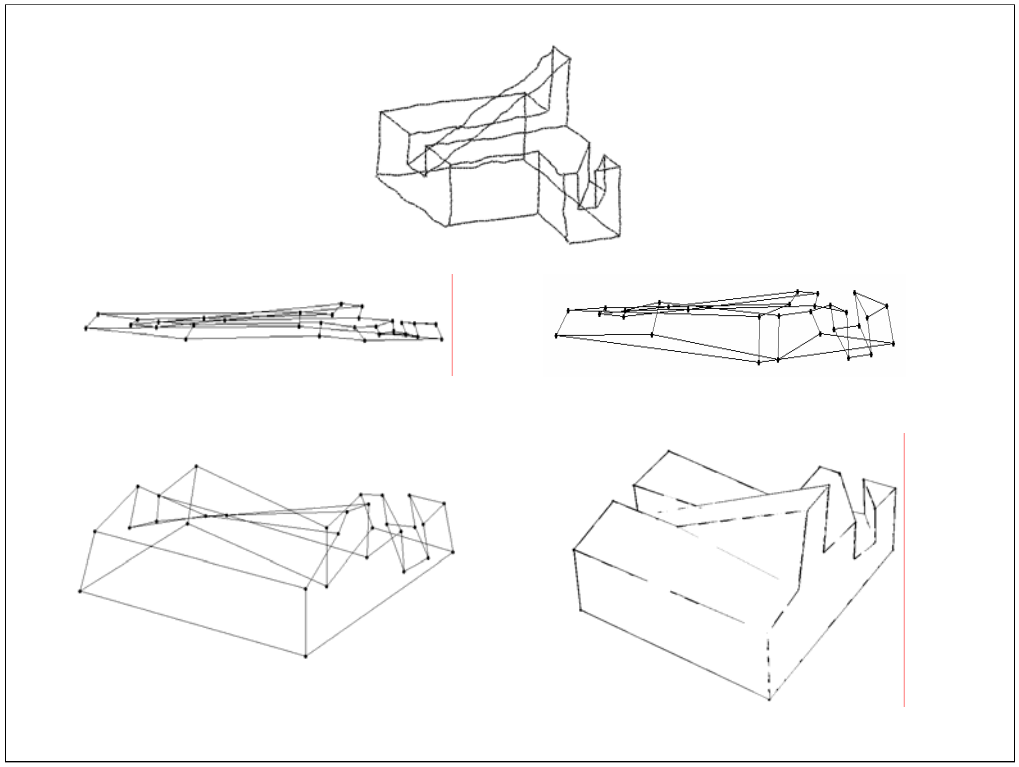
# Measuring 2D-3D second order correlations

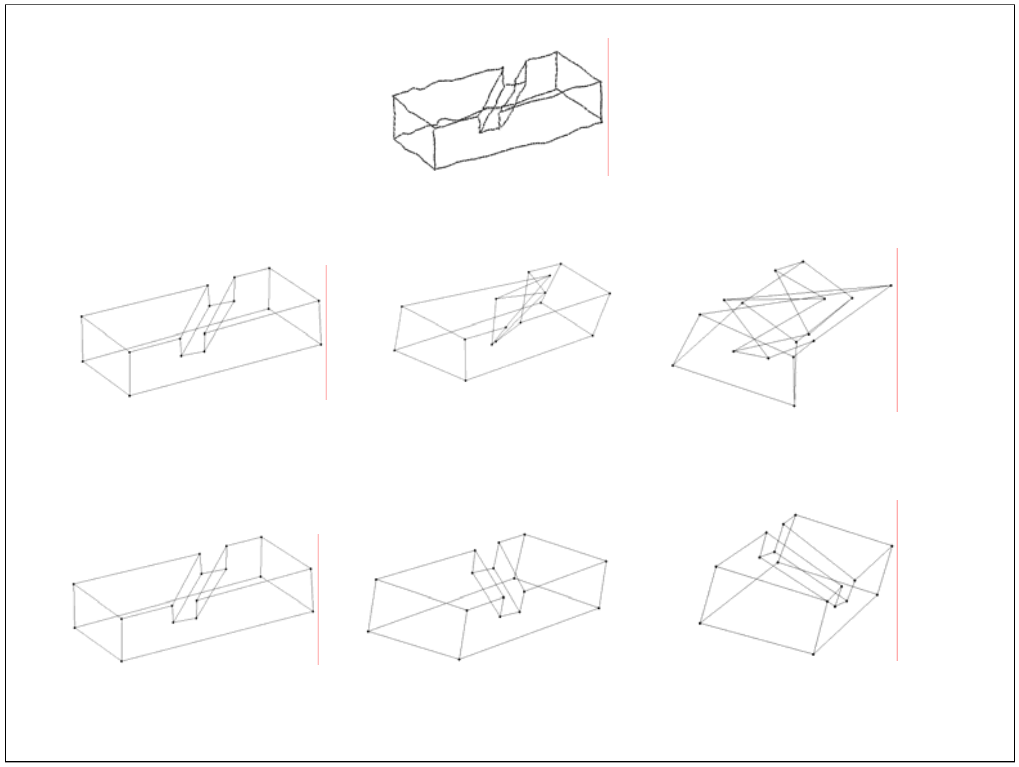


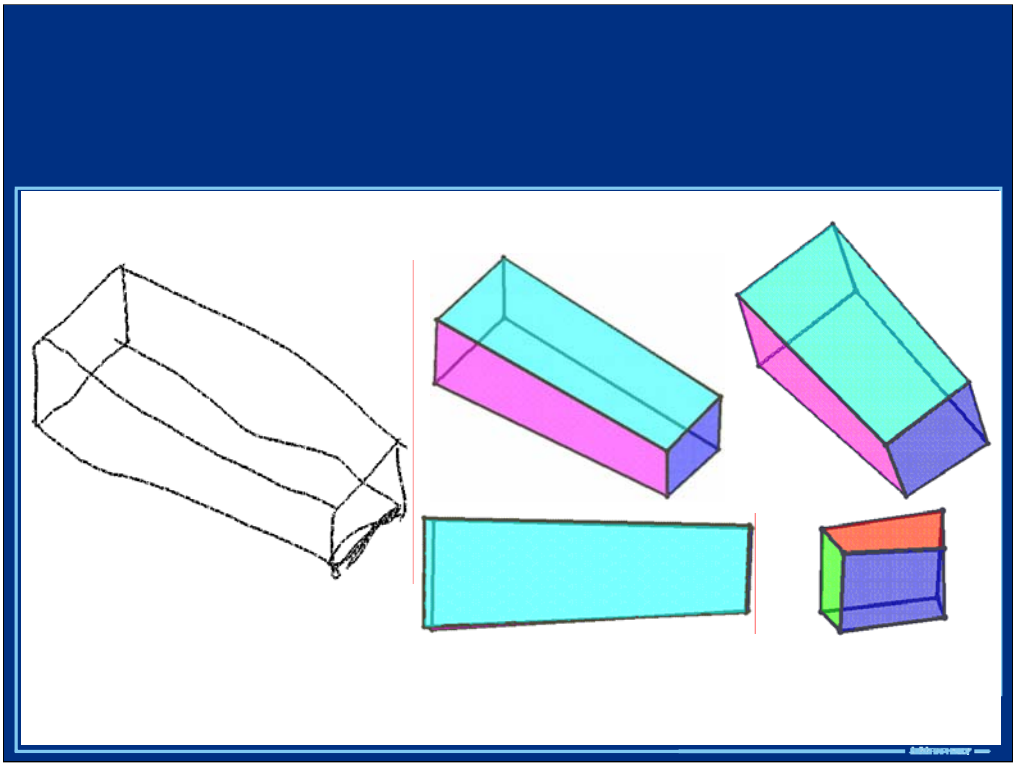

Dark areas show high correlation. Strips on right and bottom of each table show marginal probabilities. Note dark top-left corner of bottom-left plot.

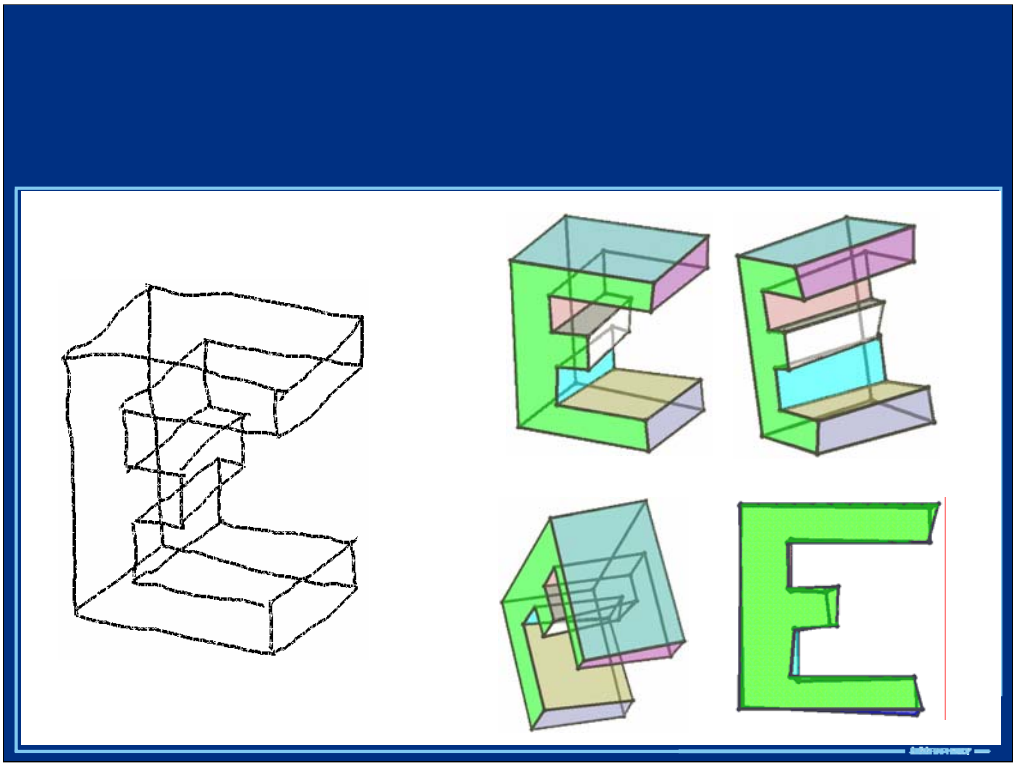
## To reconstruct:

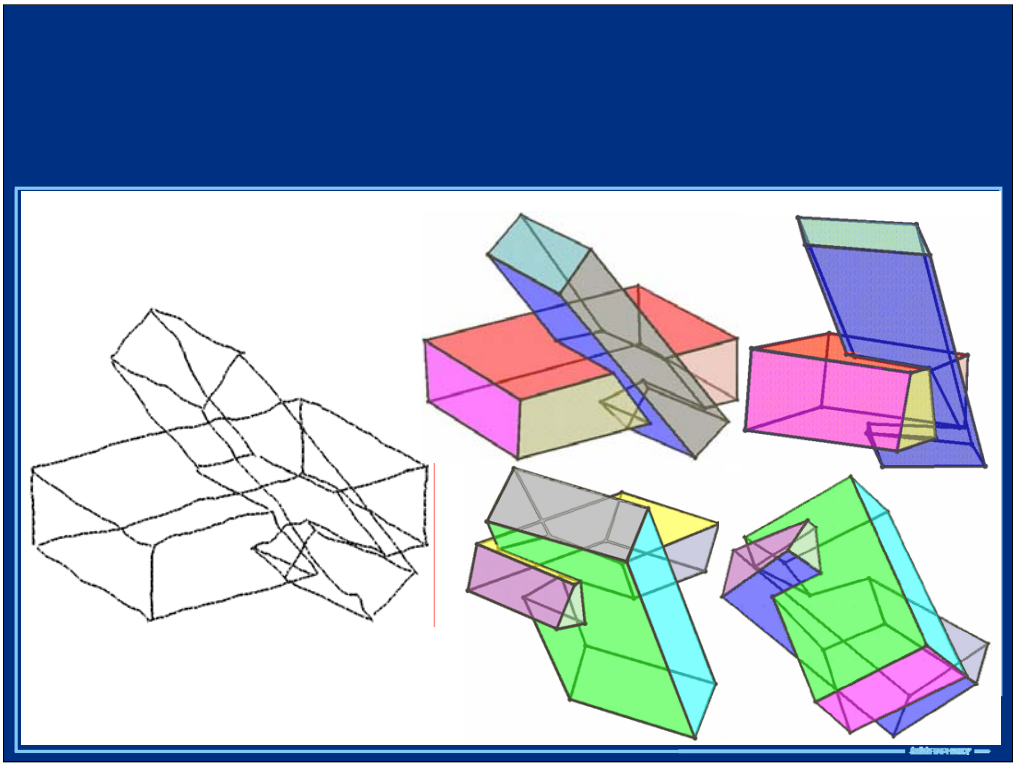
- Optimize z's so that they comply as much of the soft constraints,
  - Gradient Methods
  - Stochastic Methods (Genetic, Annealing)
- Select a consistent subset with highest certainty, and solve, by Variational Geometry

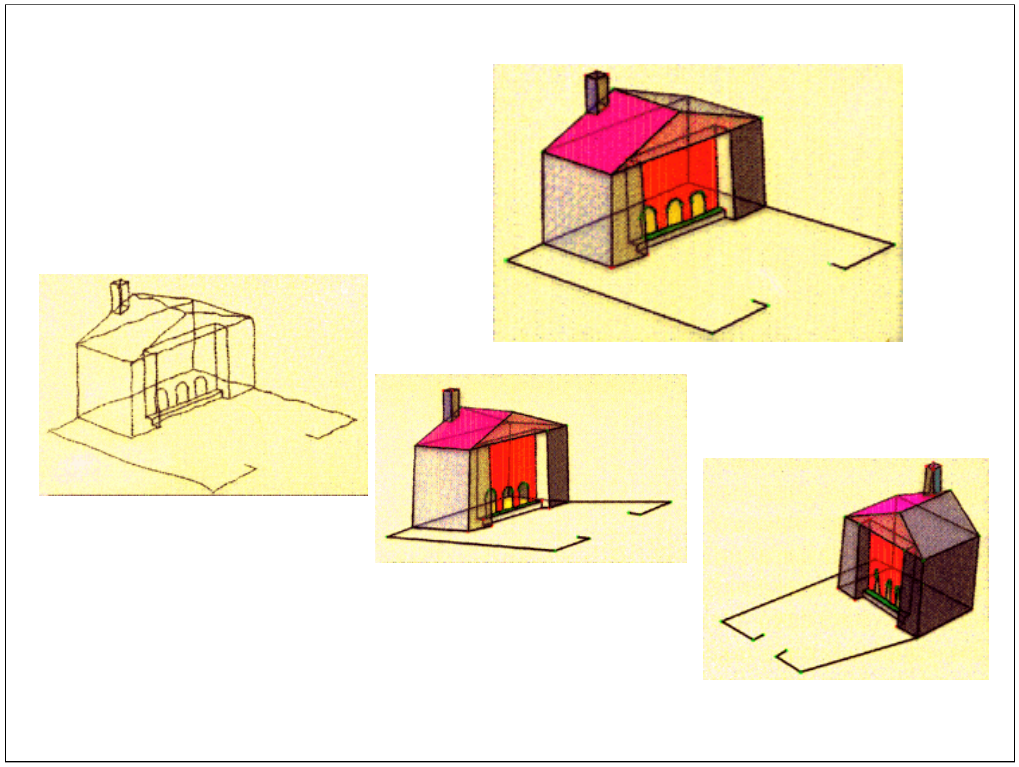


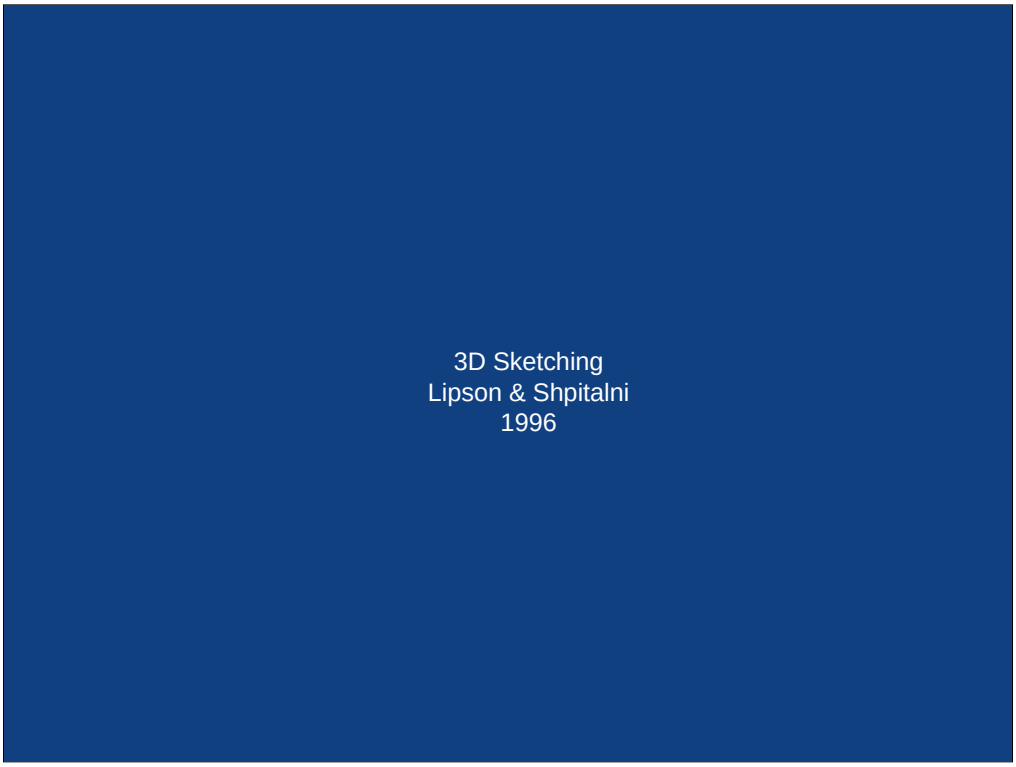


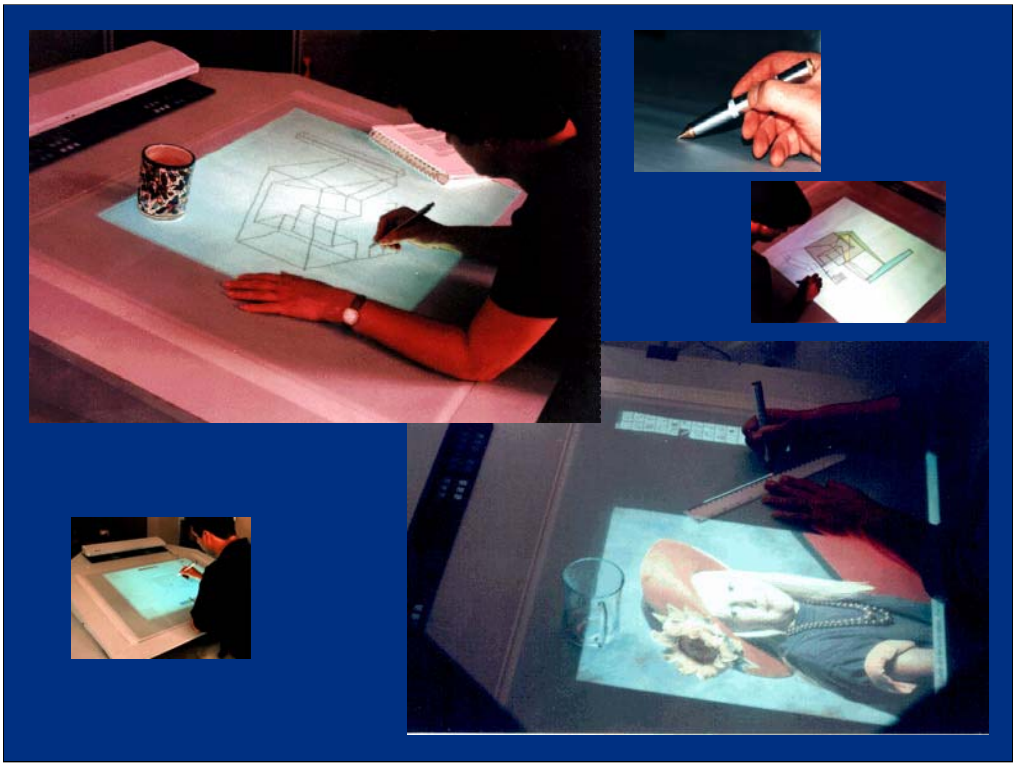


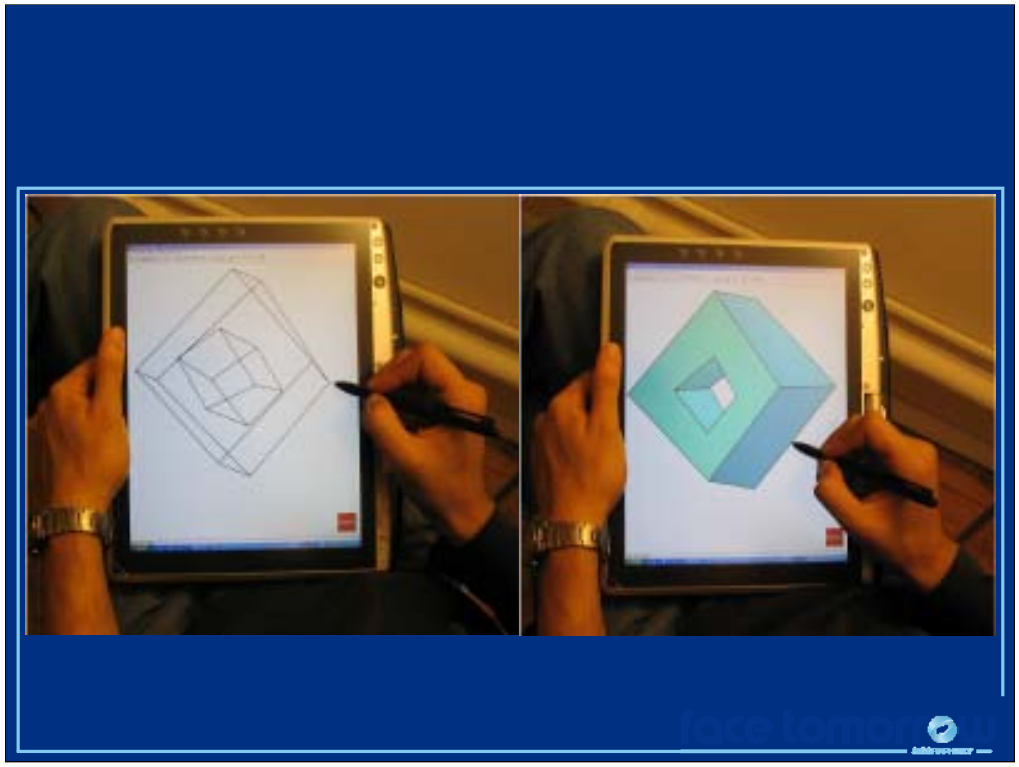


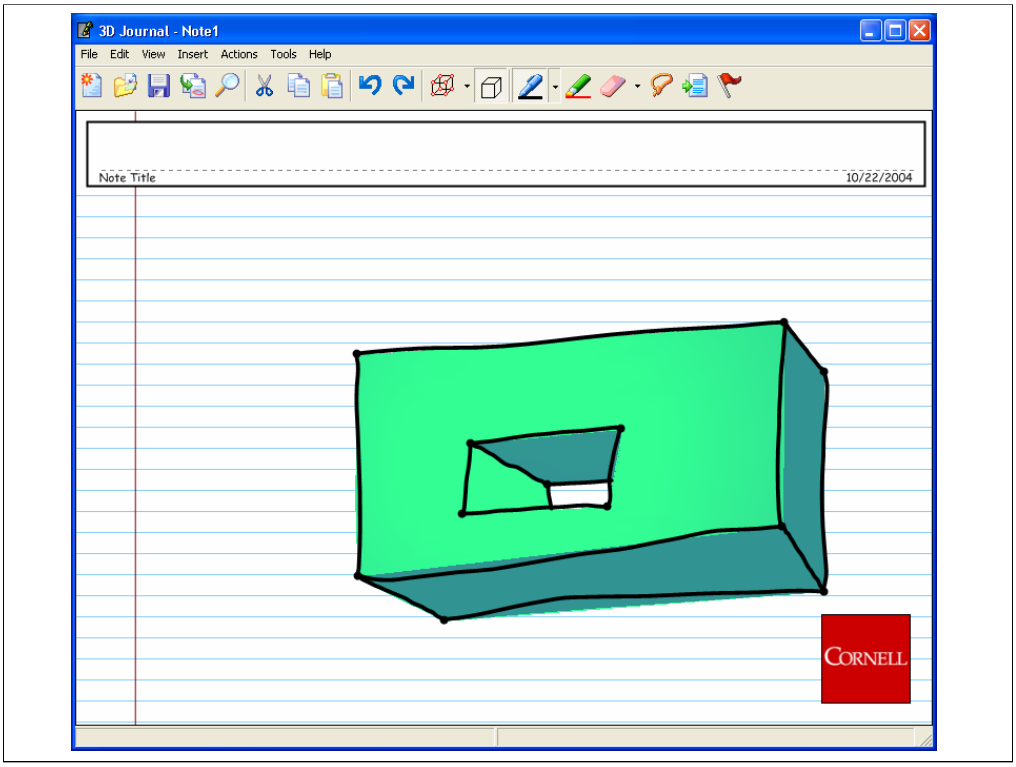


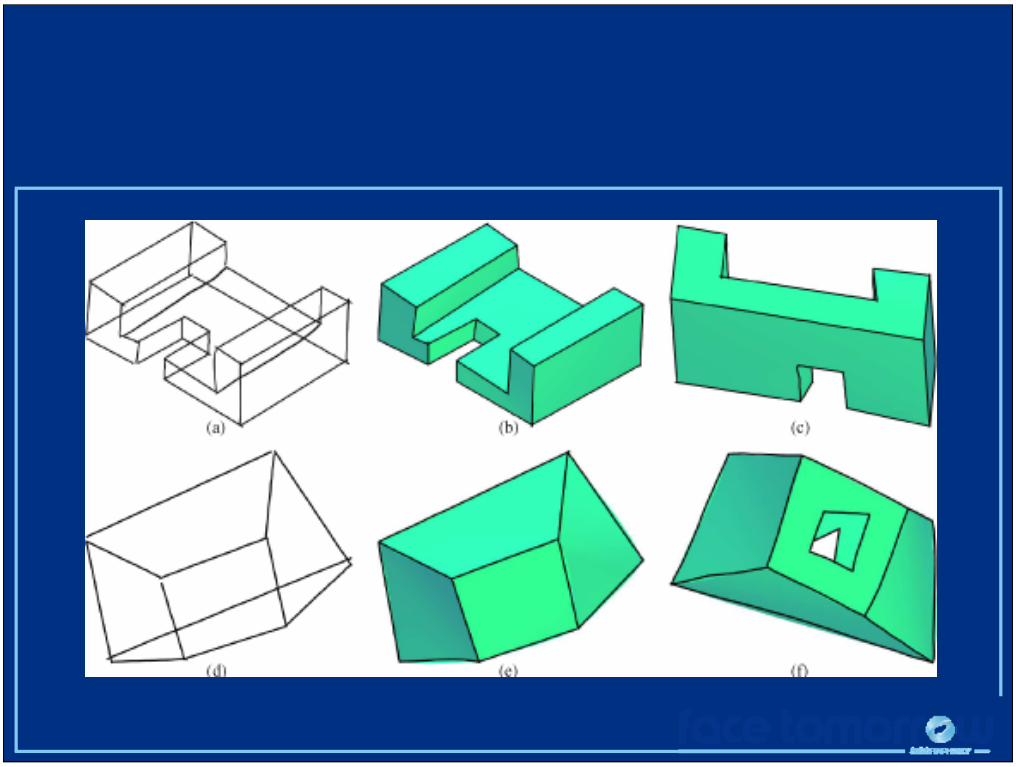



3D Sketching
Lipson & Shpitalni
1996



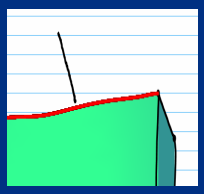



3D Journal - Note1
File Edit View Insert Actions Tools Help
Note Title
10/22/2004
CORNELL

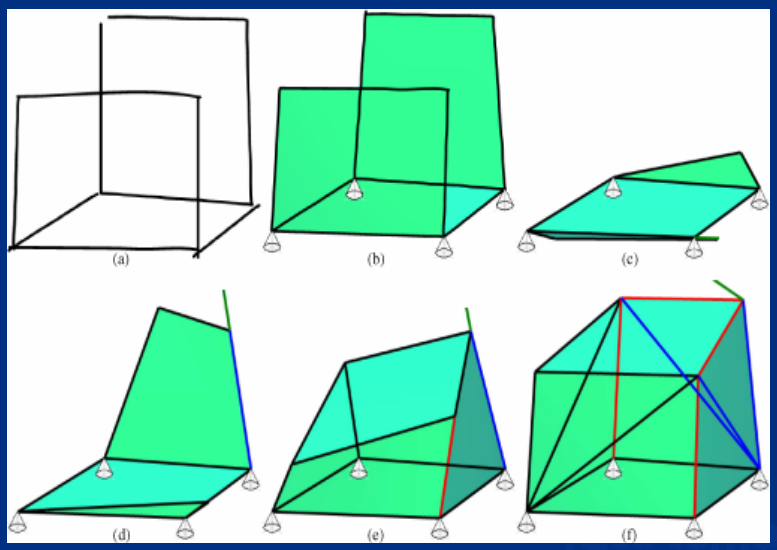

(a)
(b)
(c)
(d)
(e)
(f)

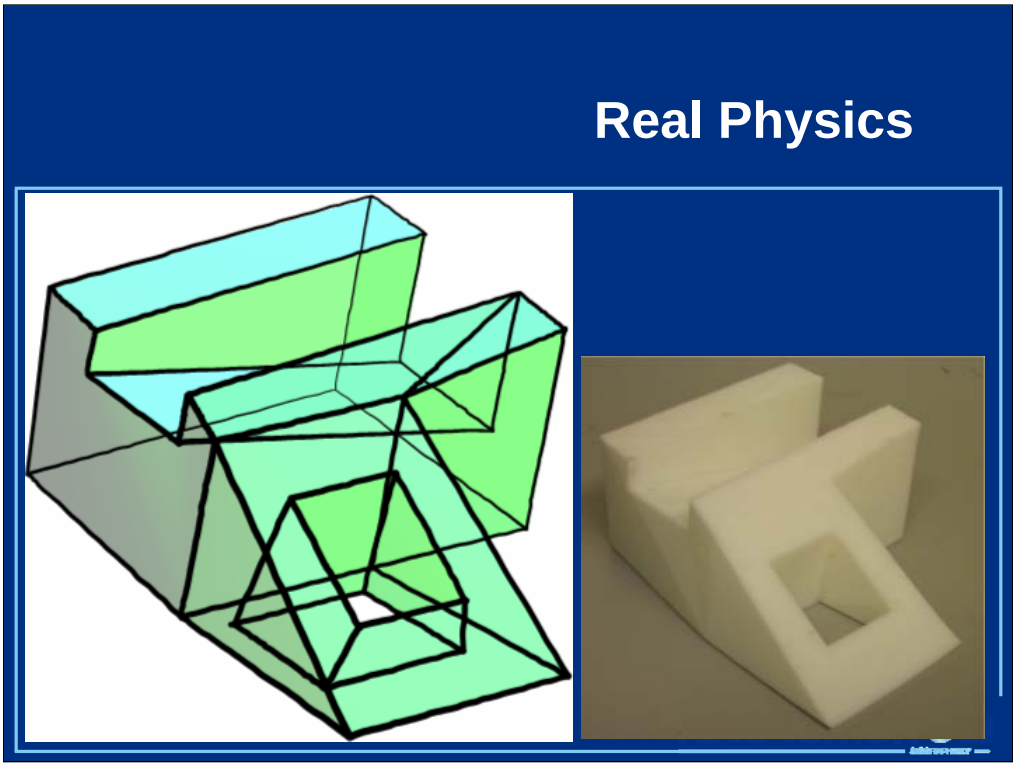
## Interactive Interface

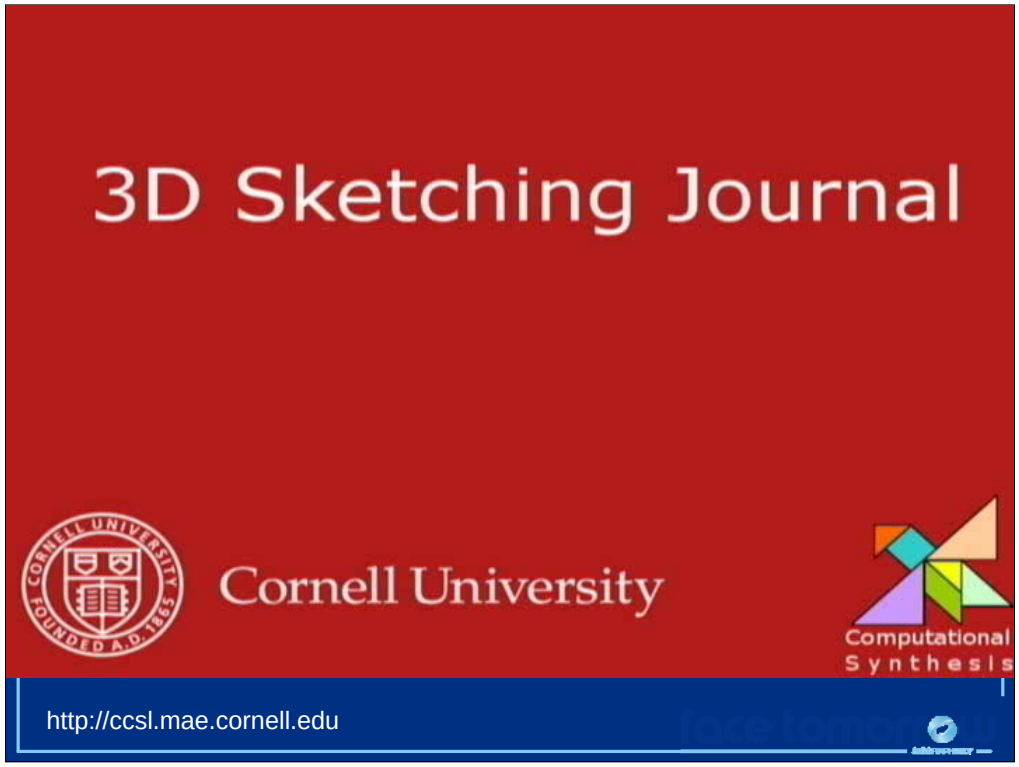
- Incremental “real-time” reconstruction
  - When the user tries to “spin” the object
- De-clutter the scene
  - Hidden stroke removal
  - Draw on faces
- Interpretation cues
  - Snap-to edges and vertices are highlighted
  - Tolerances dependent on pen
- Undo, Pen-Tip Erase, Edit



## Adding Physics




Real Physics


3D Sketching Journal
Cornell University
Computational
Synthesis
http://ccsl.mae.cornell.edu

## Conclusions

- 3D sketching + physics would be very useful in engineering
  - Incremental “sketch & spin”
- Main (unique) challenges are
  - 2D to 3D reconstruction
  - Spatial navigation
- Next Steps
  - Less ambiguity
  - More Physics

