Scientific Volume and Flow Illustration

(How Do I Make a Data Set Look Like an Artist's Drawing?)

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The purpose of computing is insight, not numbers.

Hamming

Numbers

What information consumes is rather obvious: it consumes the attention of its recipients. Hence a wealth of information creates a poverty of attention, and a need to allocate that attention efficiently among the overabundance of information source that might consume it.

Herb Simon

Numbers

218 218 217 217 216 216 215 214 214 213 213 212 211 211 210 210 209 209 208 206 205 203 202 202 201 200 199 198 198 197
197 197 197 197 197 198 198 198 199 200 201 201 202 204 205 206 207 209 210 212 214 215 217 219 221 223 225 227 229 231
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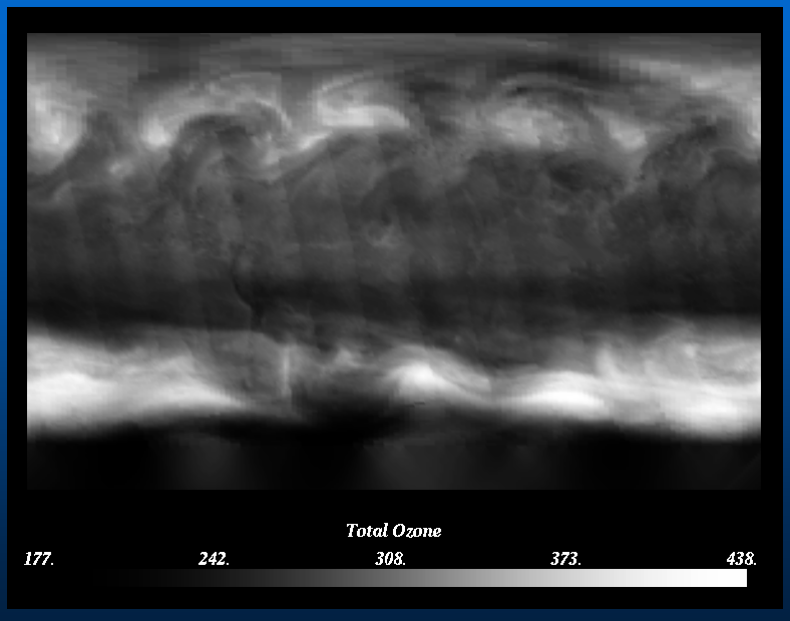
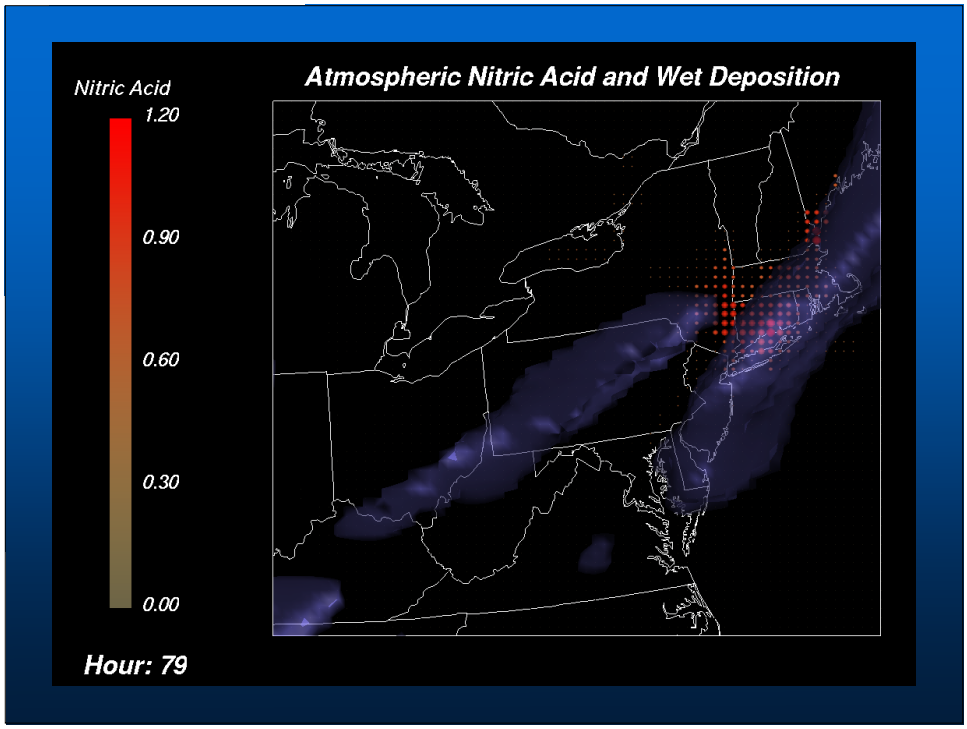


Visualization

- What?
  - Def: visual representation of data
  - Connotations:
    - » computer generated (mostly)
    - » LOTS of data
  - Transforms the abstract and symbolic into the geometric
  - Harnesses the human visual perception system
- When?
  - Presentation
    - » communicate concept to peer, student, policy -maker
  - Exploration
    - » rapidly construct and test many informal hypotheses

Visualization Tasks

- See values
  - extrema
  - anomalies
  - boundaries/thresholds
  - distribution / structure / pattern
- See multiple variables
  - relationships
- See flow/change
- Understand process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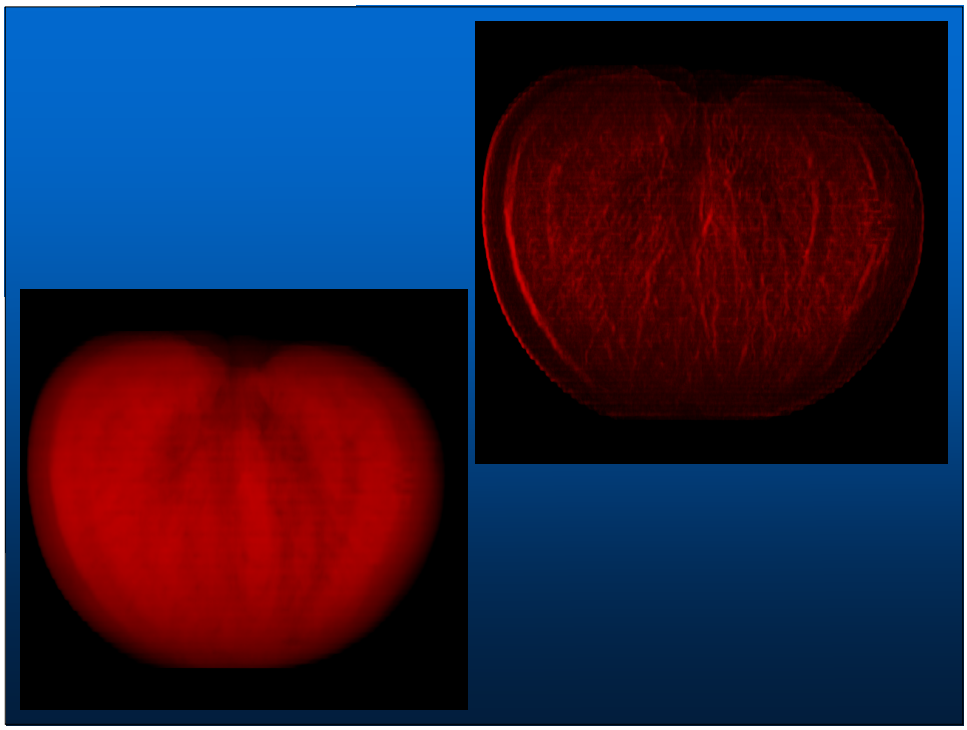
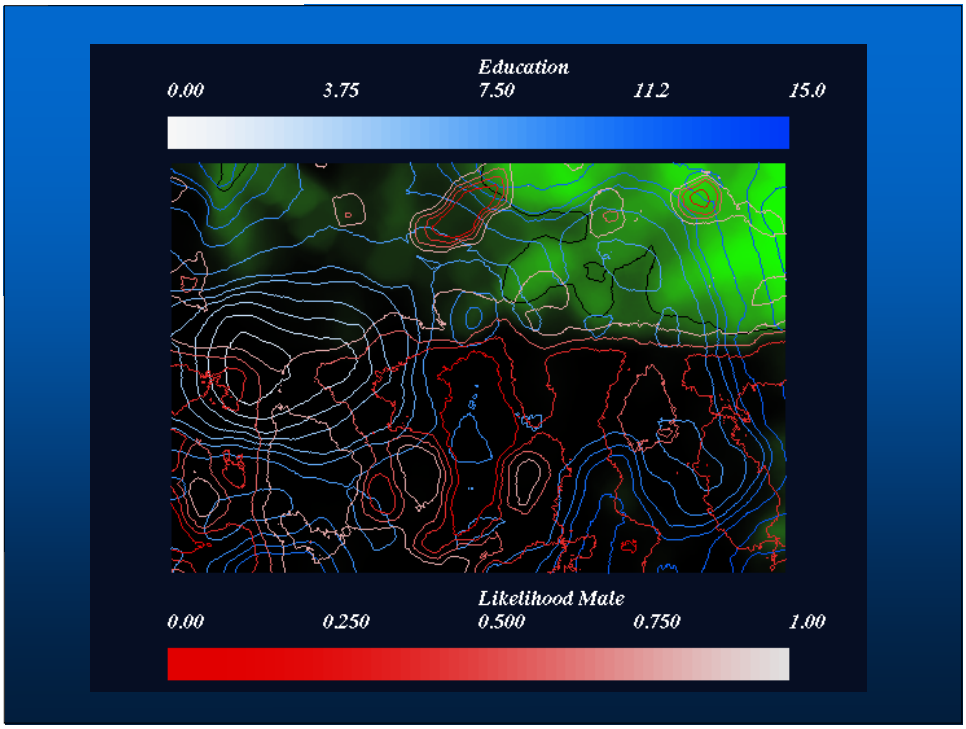
0.60
0.30
0.00
Hour: 79

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7.50
11.2
15.0
Likelihood Male
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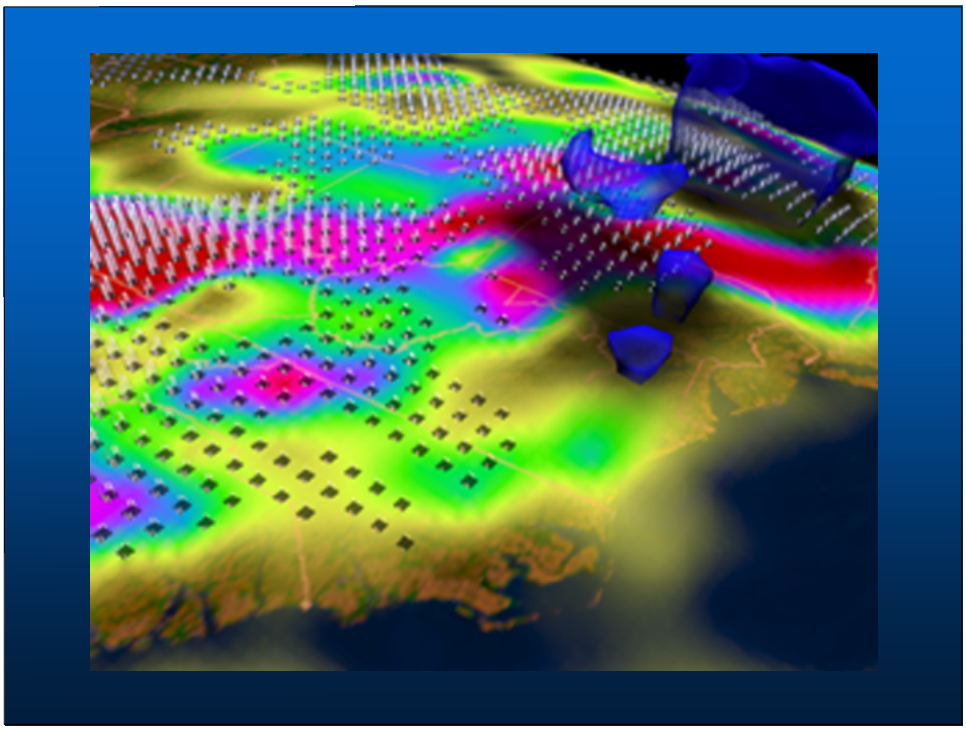
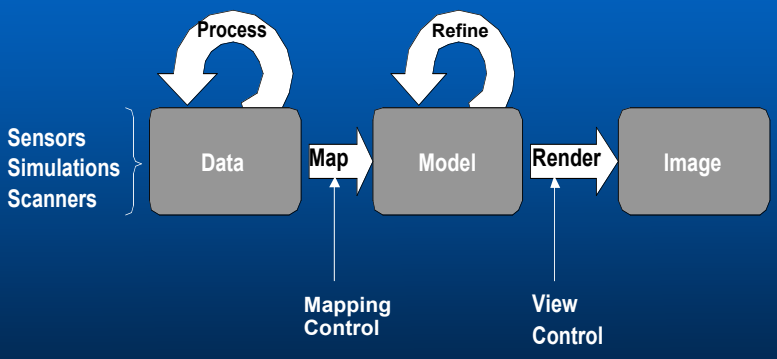
0.250
0.500
0.750
1.00

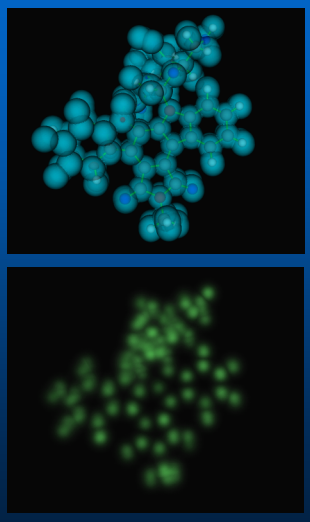


The Visualization Process



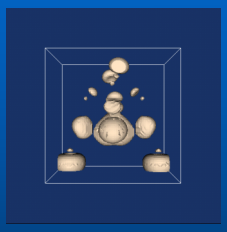
Volume Visualization

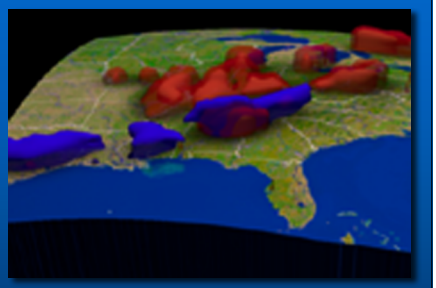
- Isosurface
  - Pick important isolevel and render threshold surface
- Direct volume rendering
  - Accumulate contributions of voxels
  - Realistic rendering
    - » Use physics-based illumination, accumulation, shadowing to enhance perception of data
  - Transfer function design
    - » Arbitrary mappings from scalar value to opacity



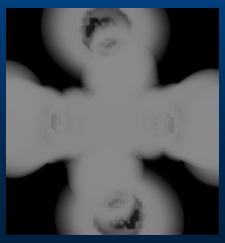
Volume Rendering

- Threshold surfaces





- Direct volume rendering



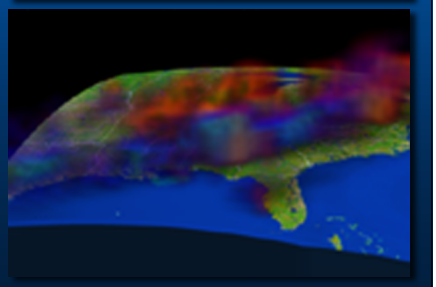


Photo by Pavel Machotka, painting by Paul Cézanne, in Machotcha96, pgs 96-97.

Photograph vs. Illustration

Alice Tangerini, in Hodges89, pg 191

Illustration vs. Volume Rendering

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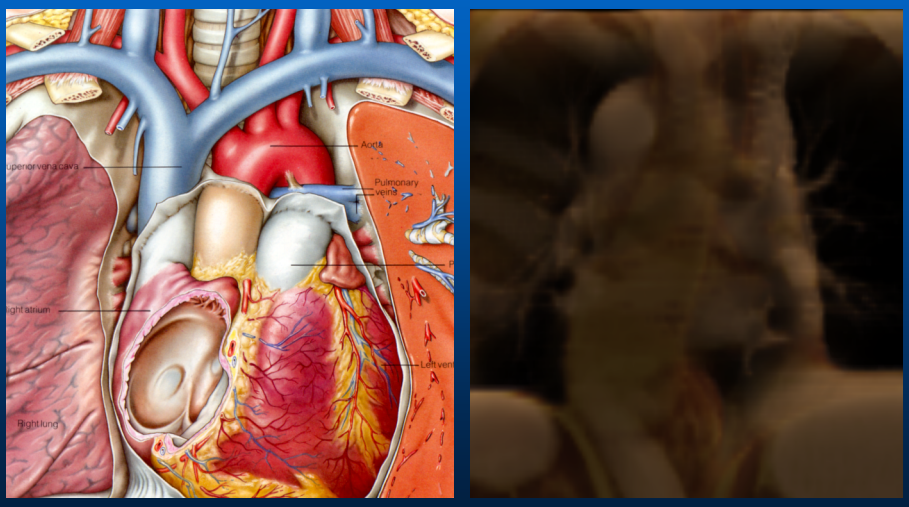
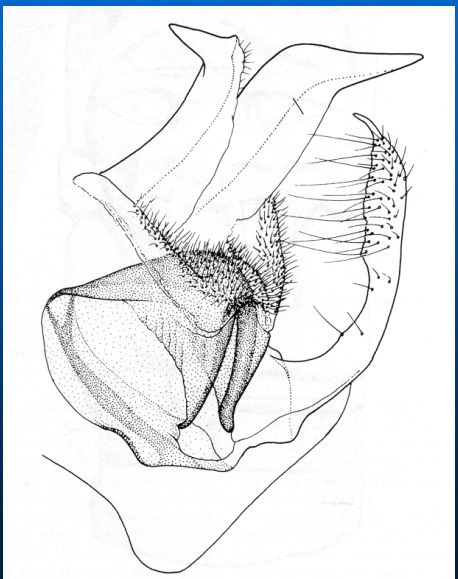


Illustration Goals

- Direct Attention
- Convey Shape
- Convey Depth
- Convey Translucence

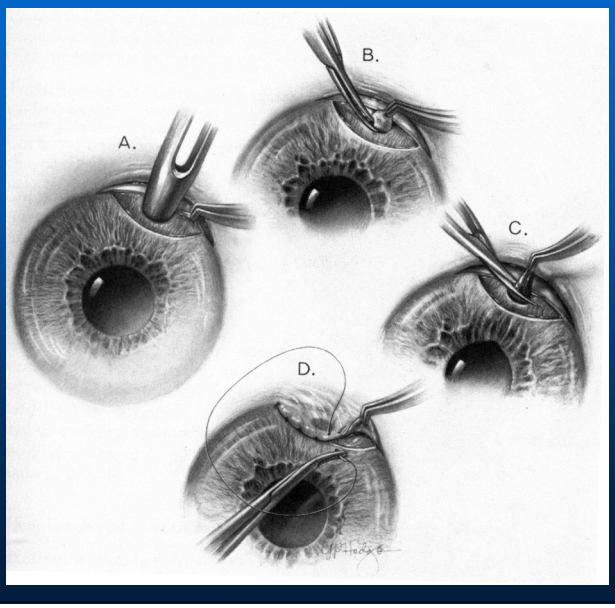
Focus: Levels of Detail



- Only most important areas stippled
- Focal point rendered in detail
- Other structure is simplified

Biruta Akerbergs Hansen, in Hodges89, pg 109

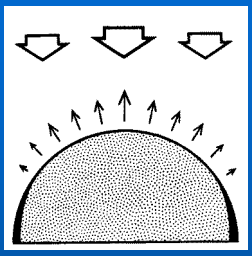
Focus: Vignetting

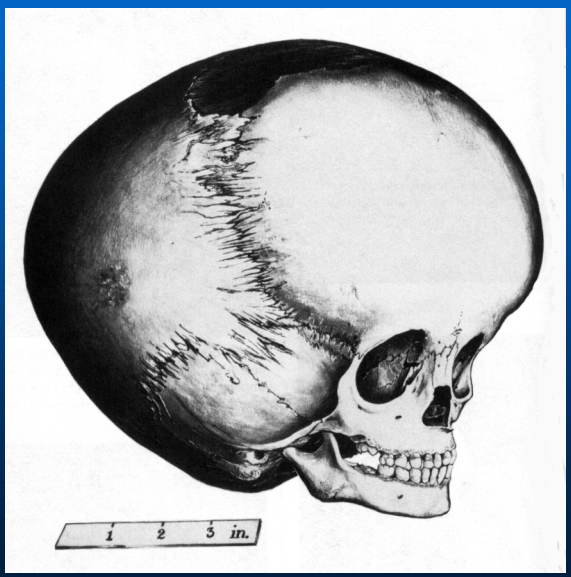


- Allow edges or unimportant structure to fade away to nothing

Gerald Hodge, in Hodges89, pg 137

Shape Cues: Rim Shadow





- Periphery in shadow
- Distant areas darkened
- Simulates beam of light from front
- William Brudon, in Hodges89, pg 86

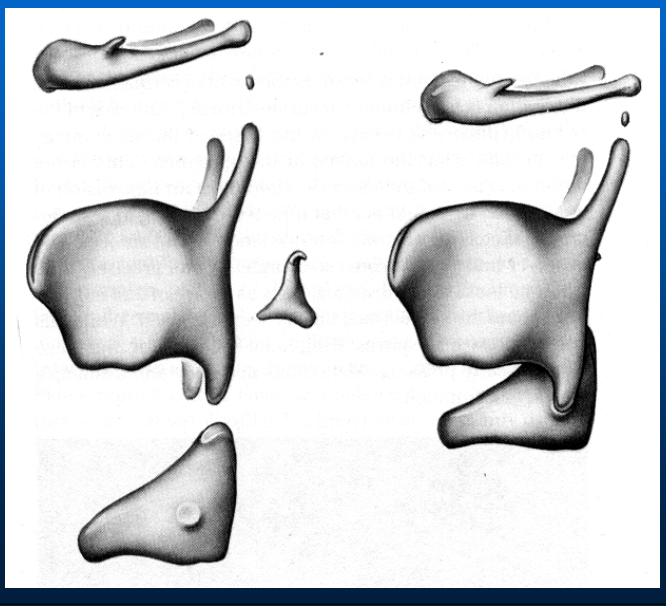
Conveying Shape: Tone Shading

Gail Browne, in
Griffel94, pg 35

Aerial Perspective

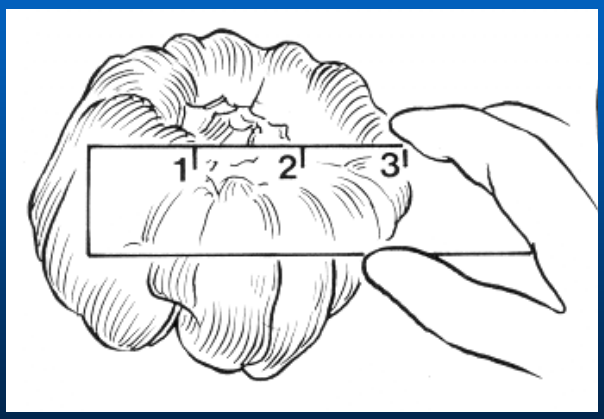
Peter Guest, in Griffel94, pg 44

Depth Cues: Atmospheric Perspective



Robert Demarest, in Wood94, pg 7

Translucence: Detail Cues

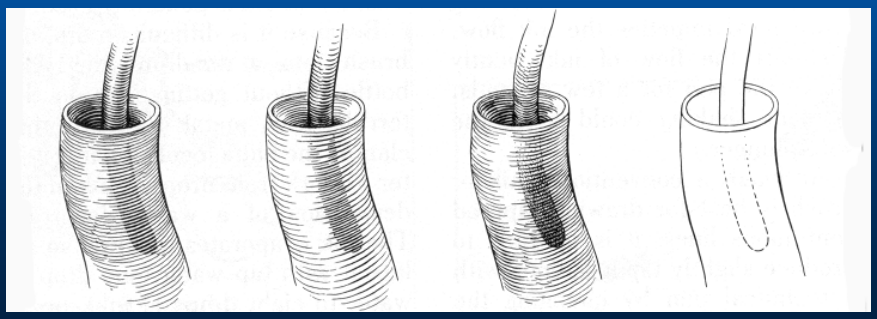


- Top layer seen clearly
- Underlying part is muted and shows less detail

Phyllis Wood in Wood94, pg. 16

Translucence: Obscuration Cues

- Technique
  - Strengthen object before it enters another,
  - then eliminate all traces briefly,
  - then fade back in



Gerald Hodge, in Hodges89, pg 101

Illustration vs. Volume Rendering

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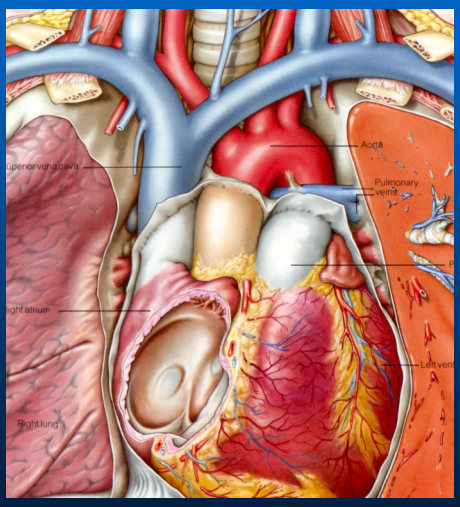
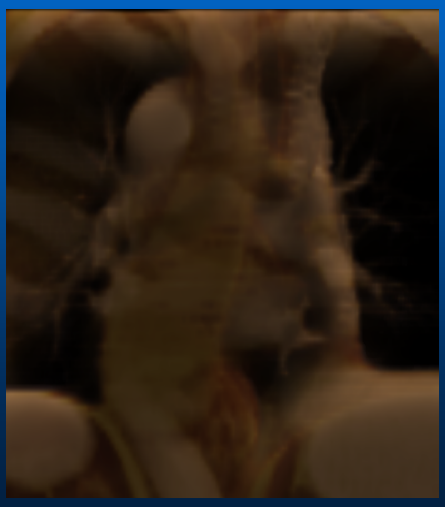




Volume Illustration

- Joint work with David Ebert, now at Purdue Univ. and our students (Aidong Lu, Chris Morris, Nik Svakhine, Alark Joshi, Jesus Caban)
- Approach
  - Apply expressive-level NPR techniques to volume models to improve comprehensibility
- Issues
  - What to show?
  - How to show it?
  - How to implement it?

Features

- Surface Rendering
  - Surfaces
  - Silhouettes, high curvature regions, CFD
- Volume Rendering
  - Surfaceness
  - Indicators
    - » Gradient, higher-order properties
    - » Variability
    - » Local structure

Toolbox of Techniques

- Feature enhancement
  - Boundary enhancement
  - Silhouette enhancement
  - Oriented fading
  - Tone shading
- Depth enhancement
  - Aerial perspective
  - Halos
- Directing focus
  - Regional enhancement

Boundary/Silhouette Enhancement

- Silhouette voxels where
  - there is a feature (boundary)
  - feature normal ortho to view

- Enhance boundary opacity by function of gradient

where $o_g = o_v\left(k_{gc} + \left(k_{gs}\|\nabla_f\|\right)^{k_{ge}}\right)$

$k_{gc} = 1$, $k_{gs} = 0$ yields no gradient enhancement
$k_{gs} >= 1$ yields full gradient enhancement
$k_{gc} = 0$ yields only areas with large gradients

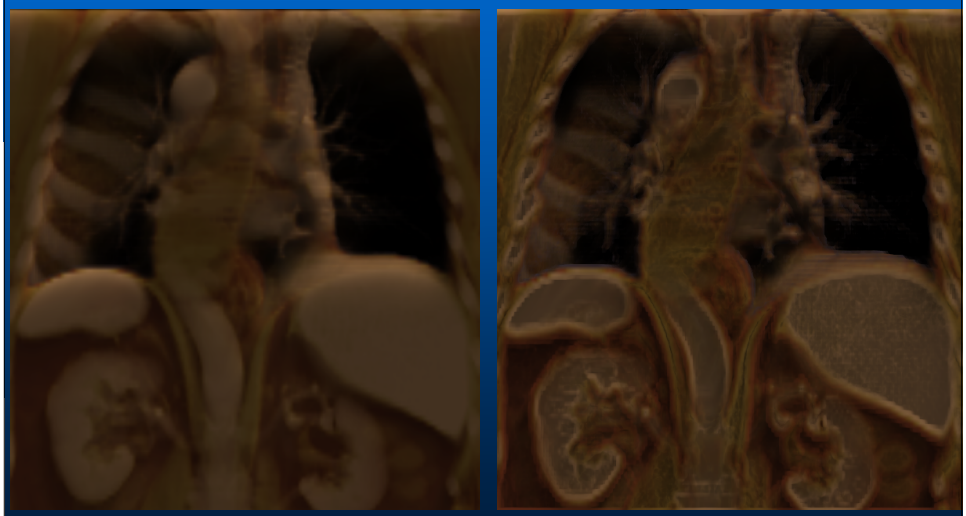
- Enhance silhouettes based on gradient direction

where $o_s = o_v\left(k_{sc} + k_{ss}\left(1 - abs\left(\nabla_f \cdot V\right)\right)^{k_{se}}\right)$

k_{sc} scales opacity of unenhanced features
k_{ss} controls size of maximum enhancement
k_{se} controls rate of enhancement

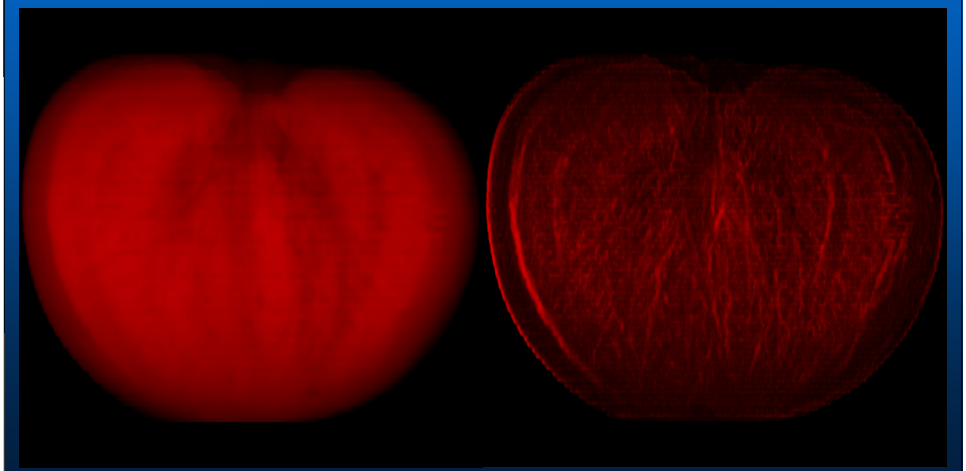
Illuminated Gas

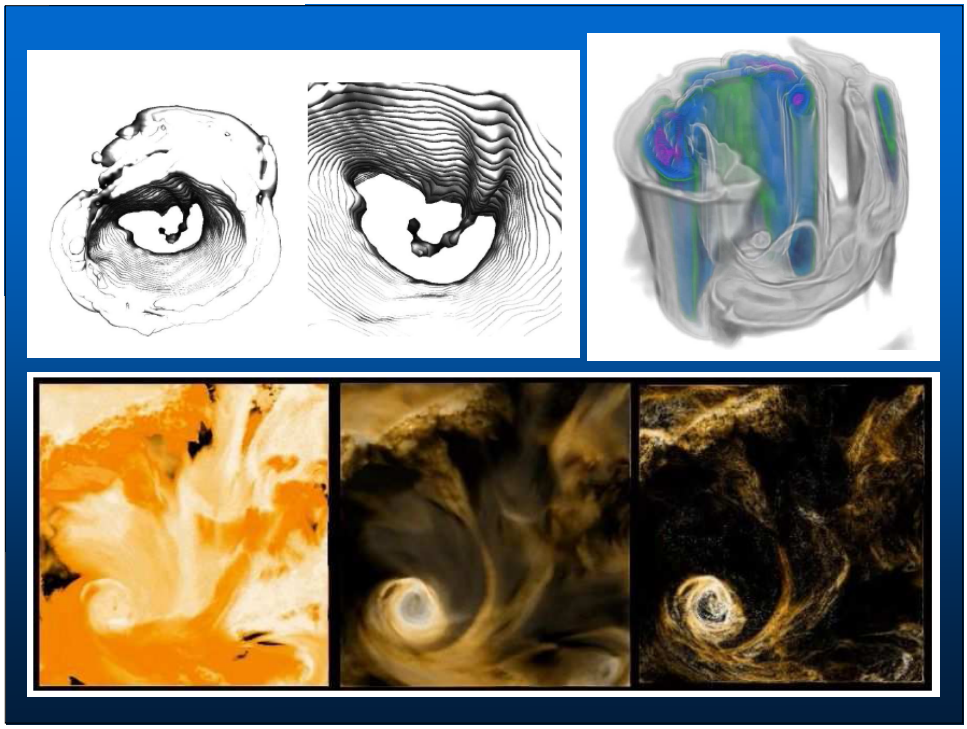
Silhouette and Boundary Enhanced Image



Illuminated Gas

Boundary and Silhouette Enhancement





Tone Shading

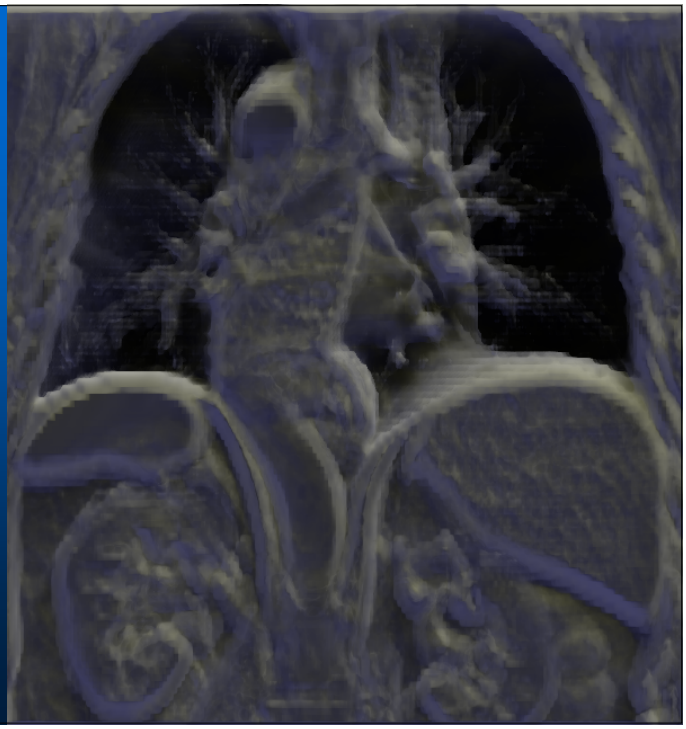
- Artistic technique:
  - change tone of color with orientation to light
  - mimics illumination by warm light source
- Gooch et al. [S98] introduced synthetic illumination model for automatic tone shading
  - linear interpolation between warm and cool color for surface using N•L as parameter
- Computed as

$$c = k_{ta} I_G + \sum_{i}^{N_L} \left(I_t + k_{td} I_o \right)$$

- with tone contribution

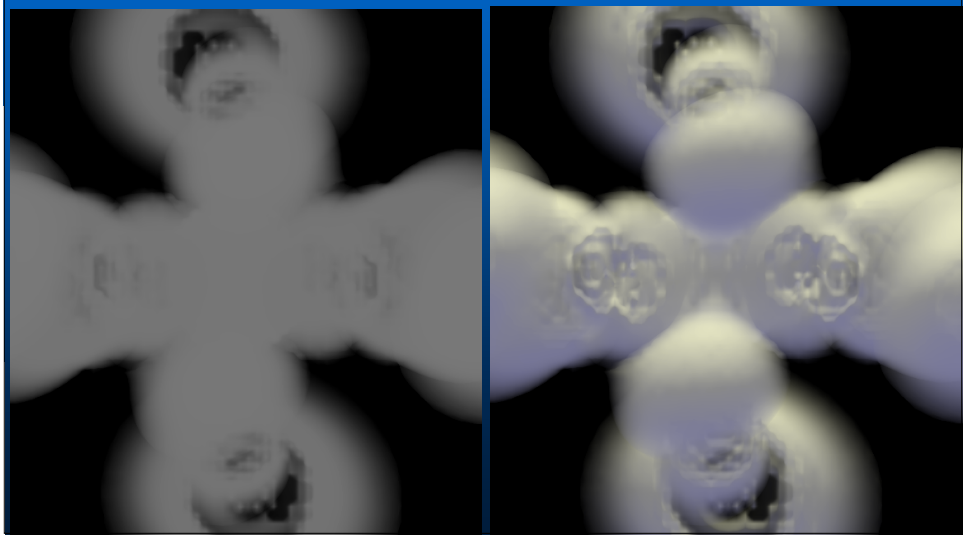
$$I_t = \left(\left(1.0 + \nabla_f \cdot L \right) / 2 \right) c_w + \left(1 - \left(1.0 + \nabla_f \cdot L \right) / 2 \right) c_c$$

Tone shading

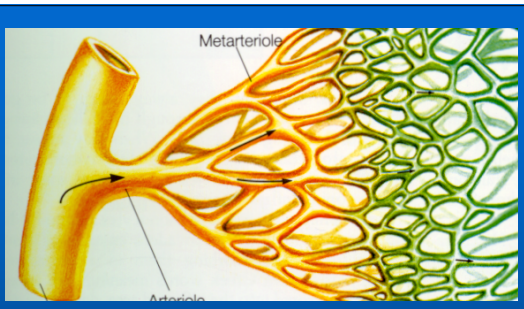


Illuminated Gas

Tone Shaded



Feature Halos



- Concept
  - Null halos
  - Clarify depth
- Feature haloed by neighbors
  - most strongly for close neighbors of weak pixels

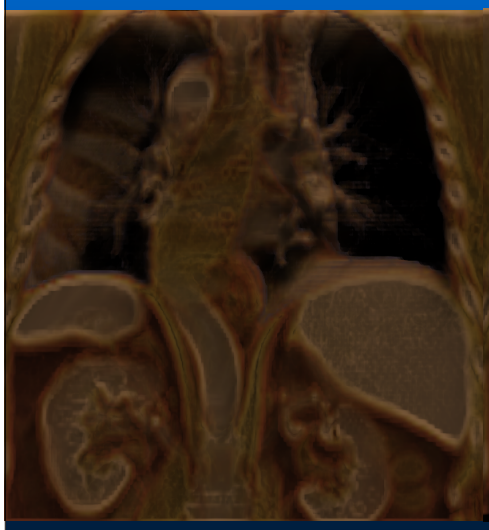
$$h_i = \left(\sum_{n}^{neighbors} \frac{h_n}{\|P_i - P_n\|^2} \right) \left(1 - \|\nabla_f(P_i)\| \right)$$

- Halo potential of each voxel
  - highest for silhouette voxels with strong gradient to this voxel

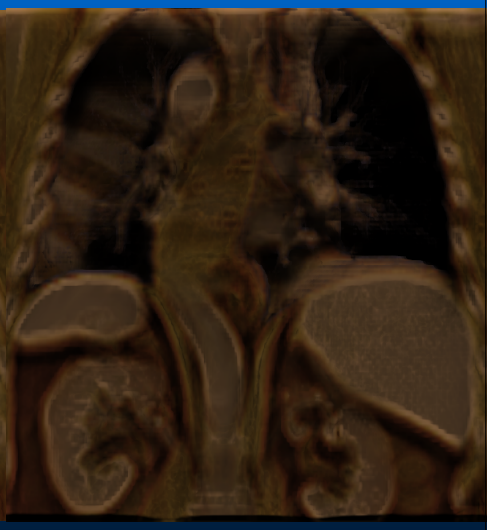
$$h_n = \left(\nabla_{fn}(P_n) \cdot \left(\frac{(P_i - P_n)}{\|P_i - P_n\|} \right) \right)^{k_{hpe}} \left(1 - \nabla_{fn}(P_n) \cdot V \right)^{k_{hse}}$$

Features Halos

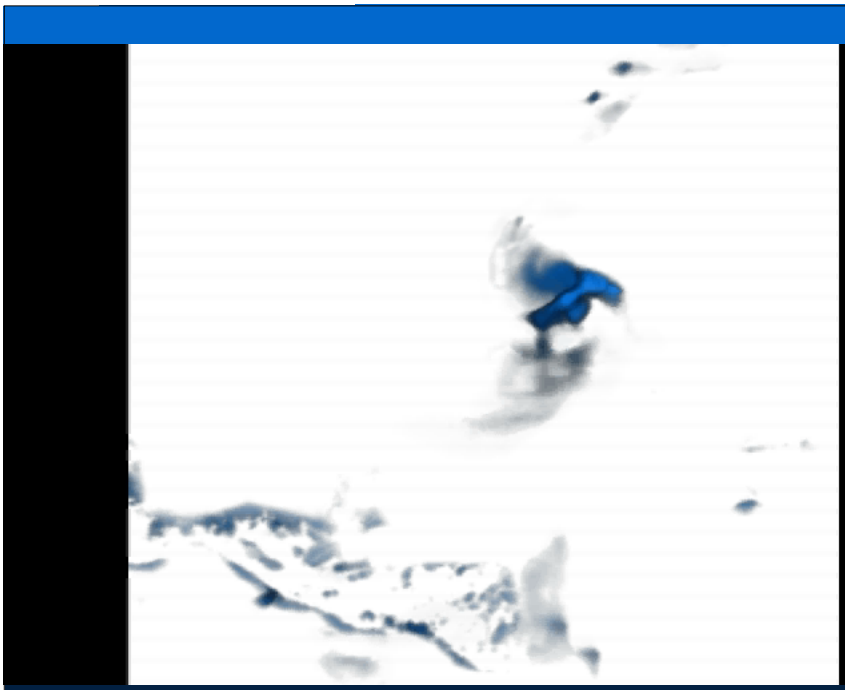
Without



With

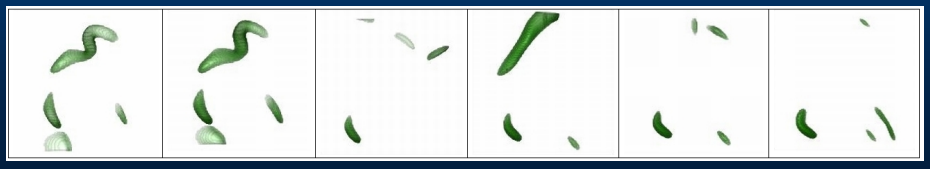


Understanding Change and Process



Flow Illustration

- Research done primarily by Alark Joshi
- Adding a dimension
  - Volume: What's inside this surface?
  - Temporal: How did it get this way?
- Questions
  - Where was this feature before?
  - What is pattern of motion of features?
  - How has this feature changed?

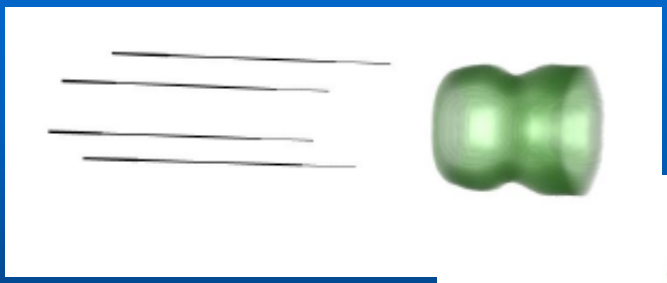


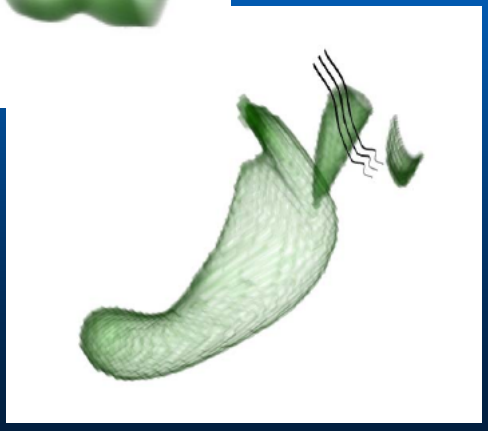
daVinci

Inspiration: Flow Paths

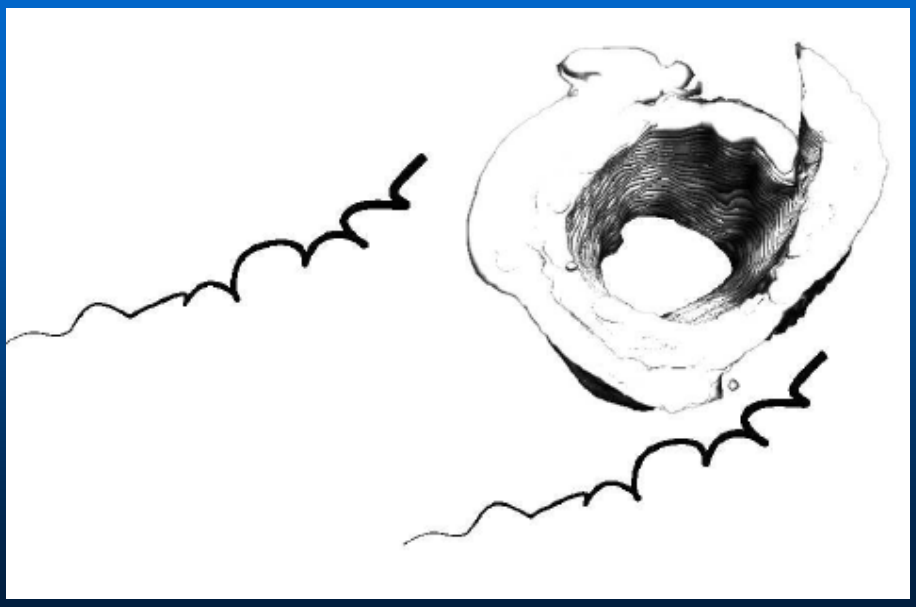
- McCloud

Adaptation: Flow Paths



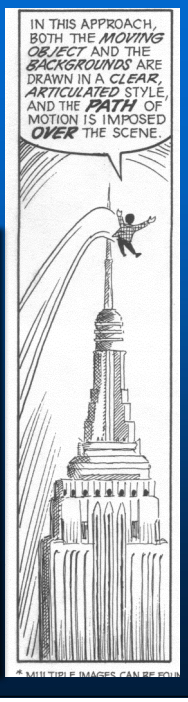


Application: Flow Paths

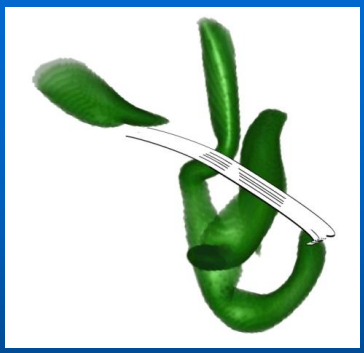


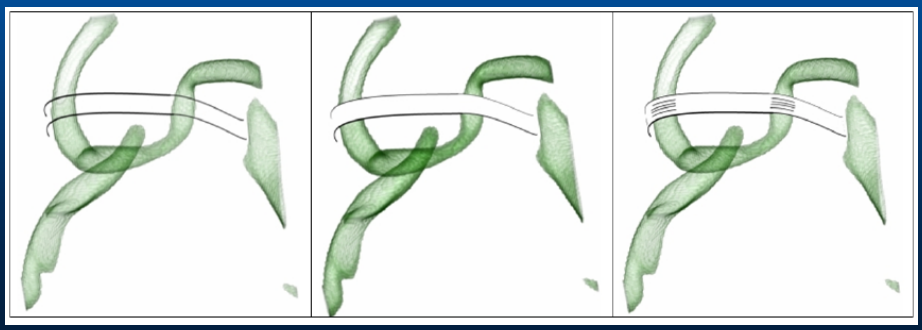
Inspiration: Flow Ribbons

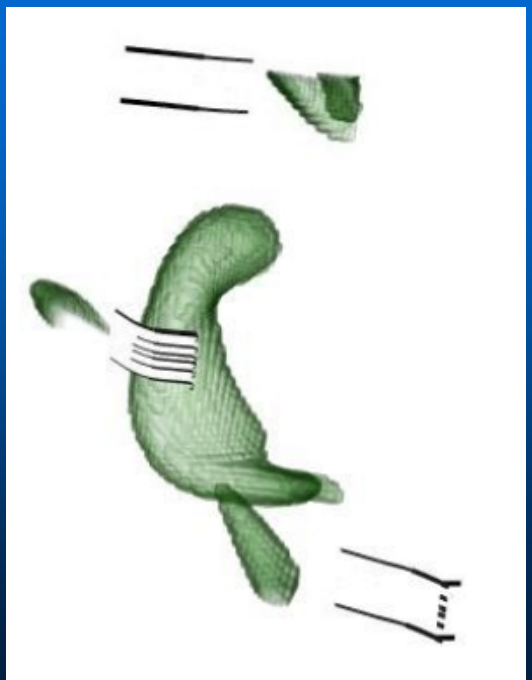
- McCloud



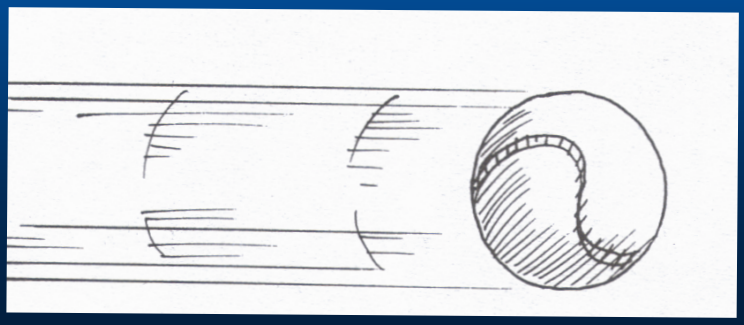
Adaptation: Flow Ribbons





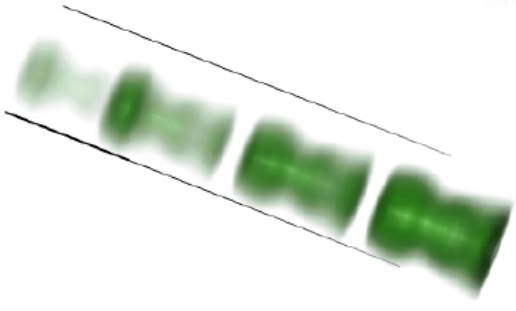


Inspiration: Strobe Silhouettes

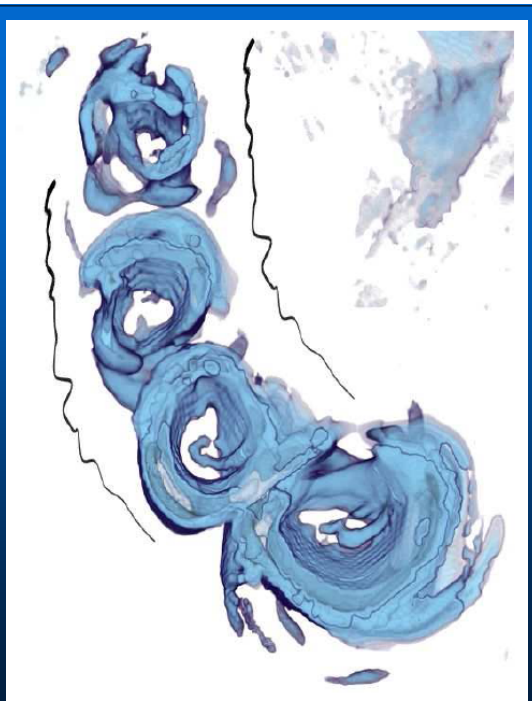


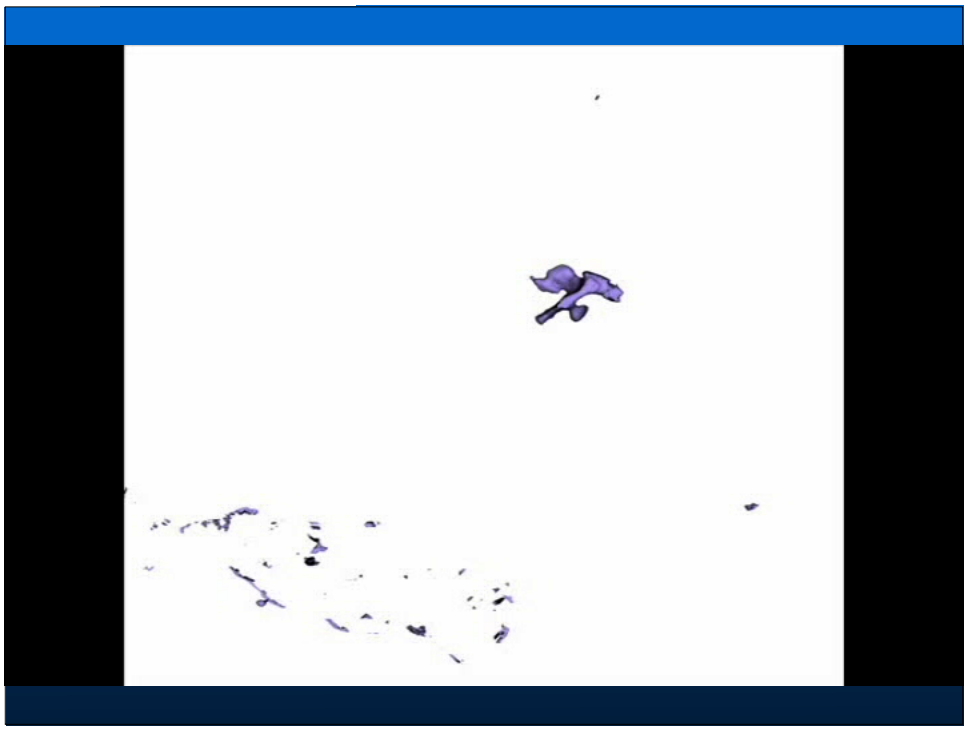
McCloud

Adaptation: Strobe Silhouettes



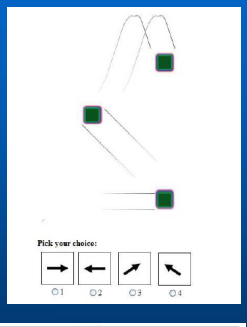
Application: Strobe Silhouettes

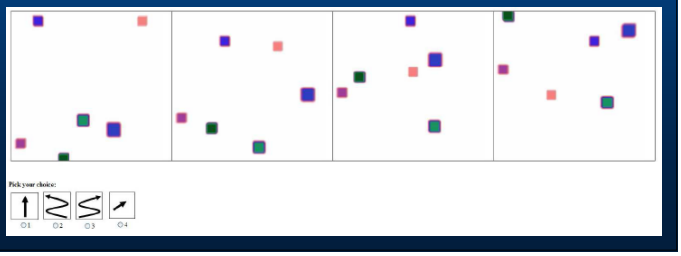




Flow Illustration Evaluation

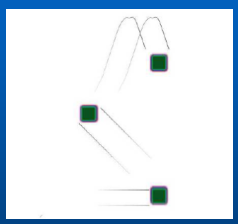
- Conducted user study to compare
  - Snapshots
  - Augmented snapshots
  - Animation
  - Augmented animation
- Measured
  - Accuracy
  - Speed
  - Confidence





Datasets

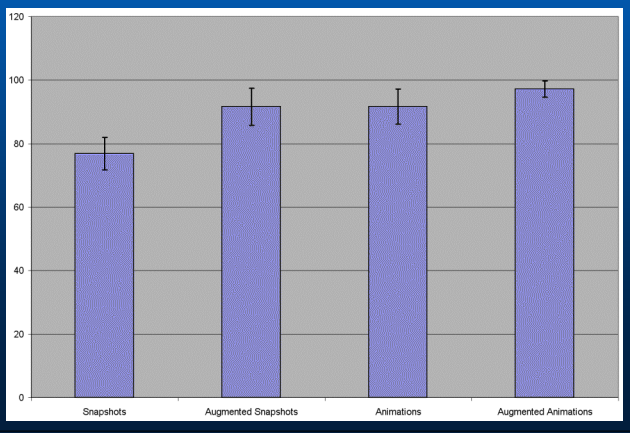
- Both synthetic and real-world data were presented in all four representations.
- The synthetic datasets consisted of
  - A single feature tracing a simple path (linear or circular)
  - Multiple features tracing simple paths (linear, circular, spiral)
  - Multiple features tracing complex paths.
- Our real-world dataset was the turbulent vortex dataset courtesy of Rutgers university



User accuracy

- *User accuracy* - number of correct answers per user per technique
- Accuracy was higher for augmented snapshots and augmented animations than for plain snapshots or animations

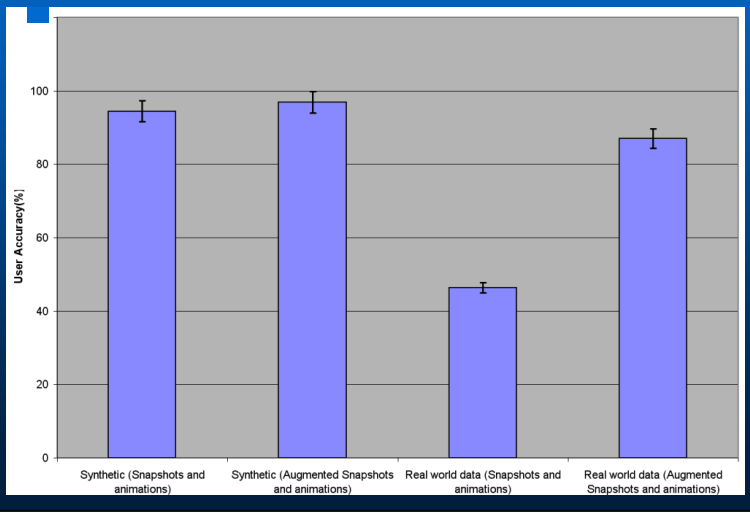
User accuracy (%)



p<0.0001

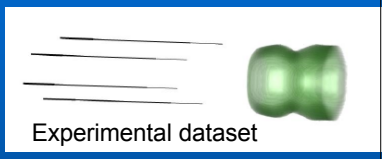
Synthetic vs Real-world data

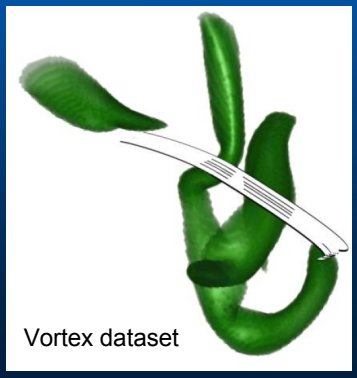
- For synthetic data, subjects were fast and accurate for all four representations.



Synthetic vs Real-world data

- User accuracy for real world data was 30% for snapshots and 66.67% using animation.
- For real-world data, when visualized using augmented snapshots, the user accuracy is much higher at 82%.
- Subjects performed best (user accuracy = 92.66%) with the real world data when visualized using augmented animations.

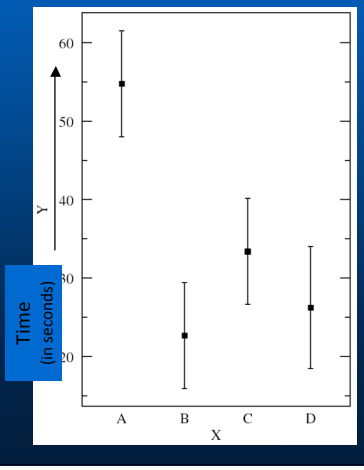

Experimental dataset


Vortex dataset

Task time

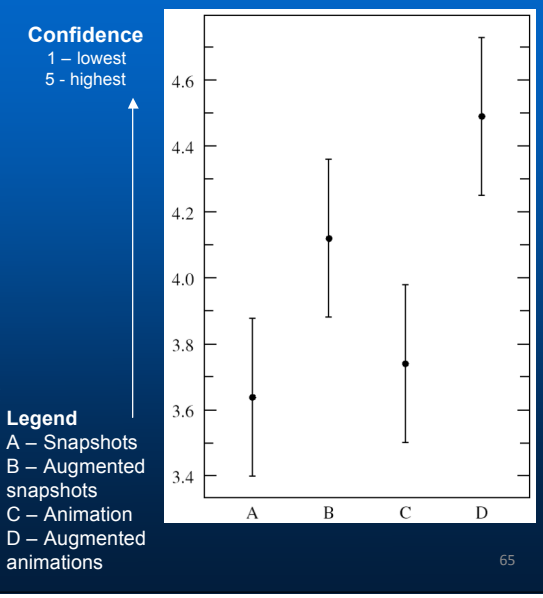
- Task time - the time required to complete each task per visualization technique.
- The subjects required more time when viewing snapshots than in the other three cases.
- Augmented animations helped subjects answer questions faster than just animations.
- The p-value < 0.0001 from the ANOVA test implies that it is a significant result.

Legend
A – Snapshots
B – Augmented snapshots
C – Animation
D – Augmented animations



User confidence

- The subjects were asked to specify a confidence level for each answer.
- Subjects were more confident in their answers when using illustration-inspired techniques
- The p-value<0.0007 from the ANOVA test implies that this is a significant result.

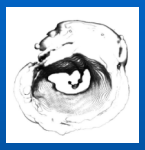
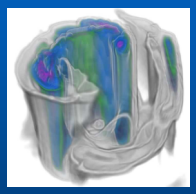


Directions

- Larger toolbox of illustration techniques
  - Structure
  - Motion
  - Attribute change
- Additional applications and evaluation
- More direct visualization of models

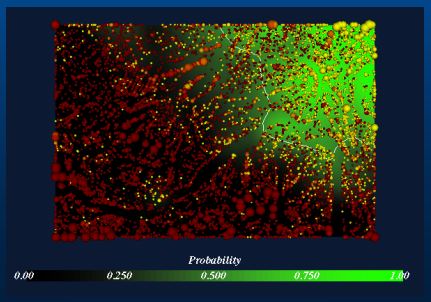
A Very Short History of 3D Visualization

- Where?
- What?
- When?
- Why?

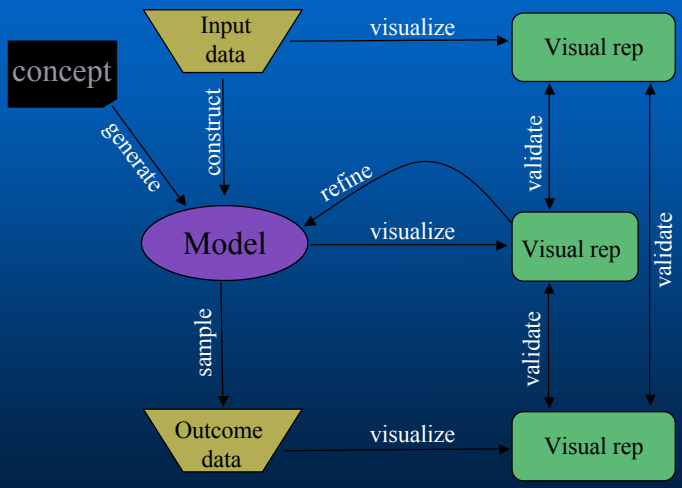




What's a Model?

- A system of postulates, data, and inferences presented as a mathematical description of an entity or state of affairs -- (12) Webster's Ninth Collegiate Dictionary
- Data vs Model
  - Discrete : continuous
  - Deterministic : probabilistic
  - Examples : explanations

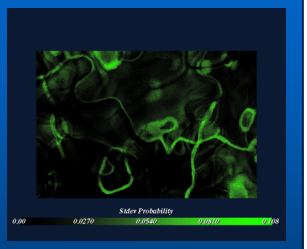


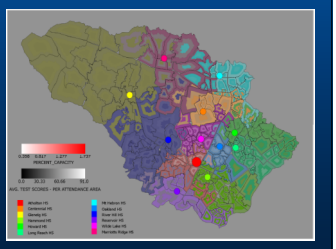
Thinking with Models



Some Challenges

- **Understanding models**
  - Sampling and interrogating
  - High-dimensional structure of model
  - Model sensitivity and variability
- **Comparing models**
  - Validating outcome against reality
  - Validating model against from reality
  - Examining families of models
- **Constructing models**
  - Selecting parameters
  - Incremental construction
  - Abstract specification





Questions?

Image References

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- Elaine Hodges (ed), *The Guild Handbook of Scientific Illustration*, John Wiley & Sons, 1989.
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