Scientific Visualization

Topics

- **Motivation**
- Color
- InfoVis vs. SciVis
- VisTrails
- Core Techniques
- Advanced Techniques

Check Assumptions: Why Visualize?

- Problem:
  - How do you apprehend 100k tuples?
  - …when your short-term memory is 7-10 items.
- Solution:
  - Harness the visual acuity of the eye to convey enormous amounts of information very quickly
  - Use color, space, depth, icons, patterns to increase information bandwidth
- Caveat:
  - Easy to misrepresent the data with so many visual dimensions available

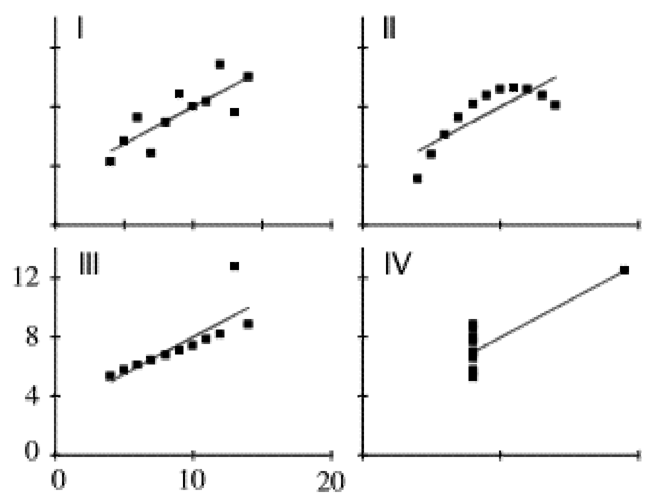
Anscombe's Quartet

I		II		III		IV	
x	y	x	y	x	y	x	y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	10.84	12	9.13	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

Anscombe's Quartet (2)

- mean of the x values = 9.0
- mean of the y values = 7.5
- equation of the least-squared regression line:
  y = 3 + 0.5x
- sums of squared errors (about the mean) = 110.0
- regression sums of squared errors
  (variance accounted for by x) = 27.5
- residual sums of squared errors
  (about the regression line) = 13.75
- correlation coefficient = 0.82
- coefficient of determination = 0.67

Anscombe's Quartet (3)



Benefits of Visualization

- More precise and revealing
  - Anscombe's Quartet
- Data density: numbers / cm^2
  - Galaxy Map
- Human eye is a very efficient pattern detector

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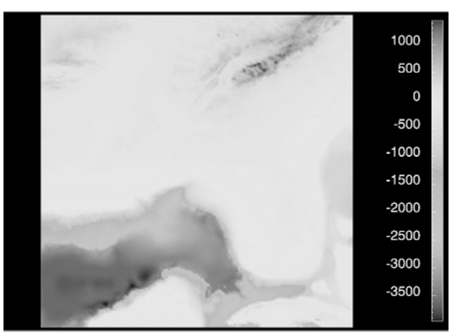
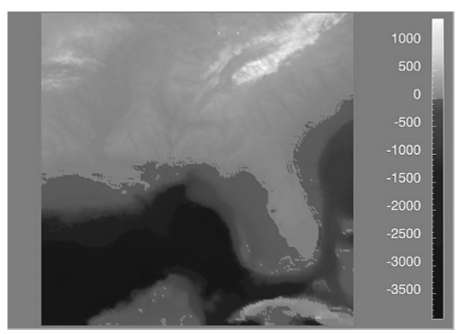
- Advanced Techniques

Color Matters

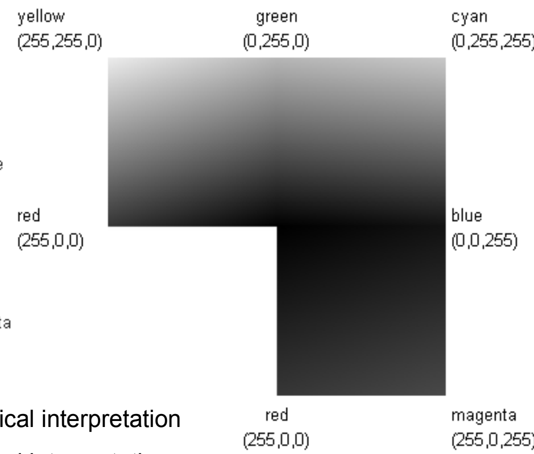




Lloyd Treinish, IBM Research, http://www.research.ibm.com/people/l/lloydt/

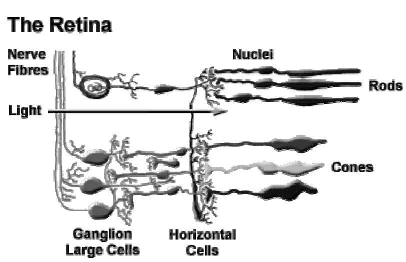
Color: RGB

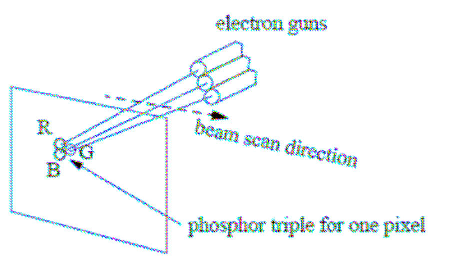
- (0, 0, 0) is black
- (255, 255, 255) is white
- (255, 0, 0) is red
- (0, 255, 0) is green
- (0, 0, 255) is blue
- (255, 255, 0) is yellow
- (0, 255, 255) is cyan
- (255, 0, 255) is magenta

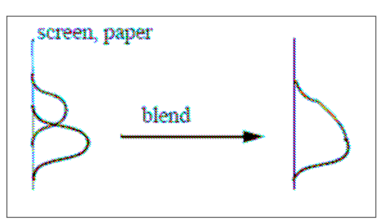


- Carries a natural biological interpretation
- as well as a techonolgical interpretation

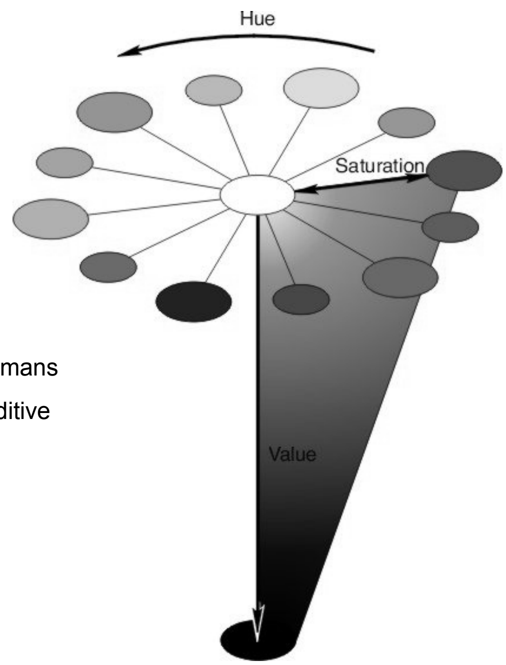
RGB Justified







HSV

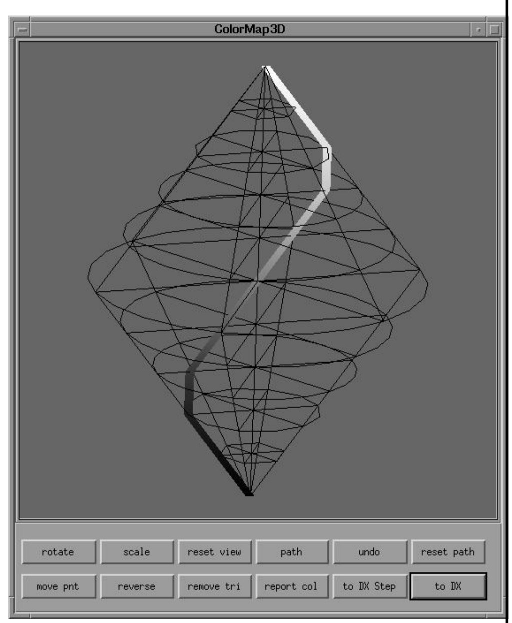


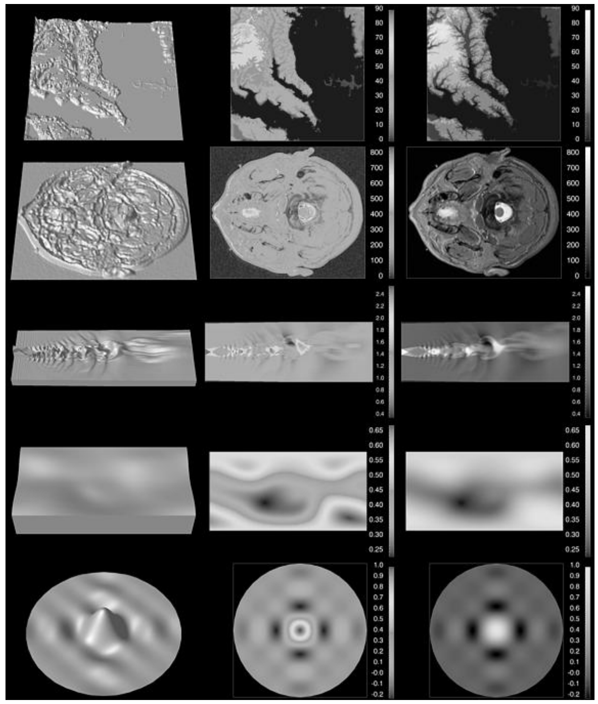
• More intuitive model for humans

• Difficult to compute the additive RGB values "in your head"

Color Map Tools

- Helps define a curve through the color space
- Common shapes:
  - Linear
  - S-Curve
- Common paths:
  - "Rainbow"



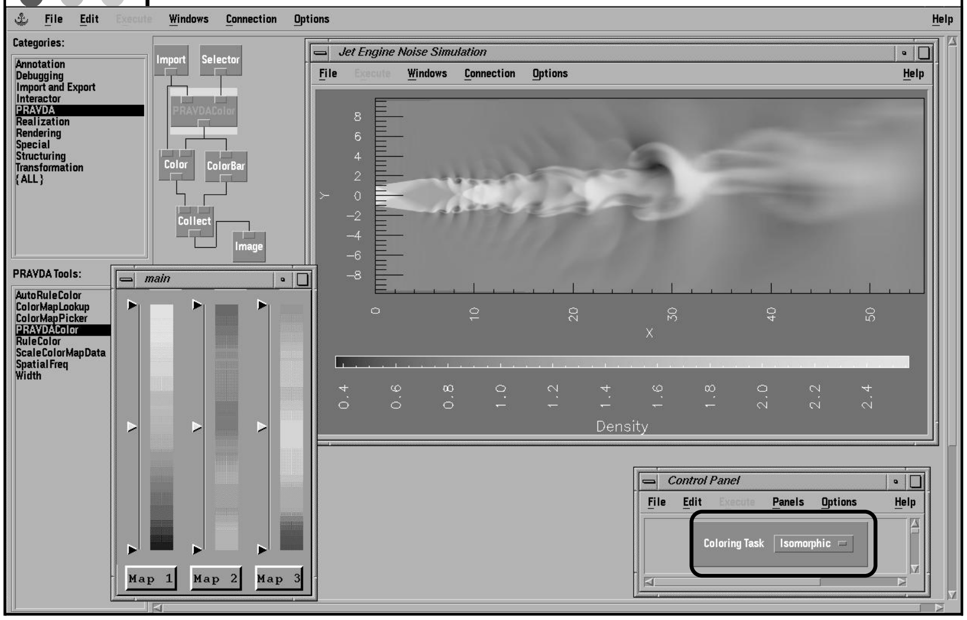


Lloyd Treinish, IBM Research, http://www.research.ibm.com/people/l/lloydt/

PRAVDA

- Perceptual Rule-based Architecture for Visualizing Data Accurately
- Guides color map selection based on human perception
- Specifically, choices pruned using
  - spatial frequency
  - data type
    - (ordinal, interval, ratio)
  - user-selected visualization goal
    - (isomorphic, segmentation, highlighting)

PRAVDA



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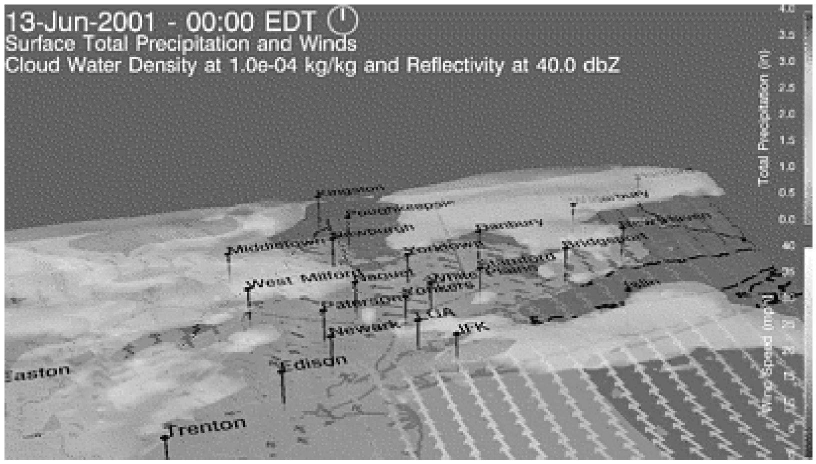
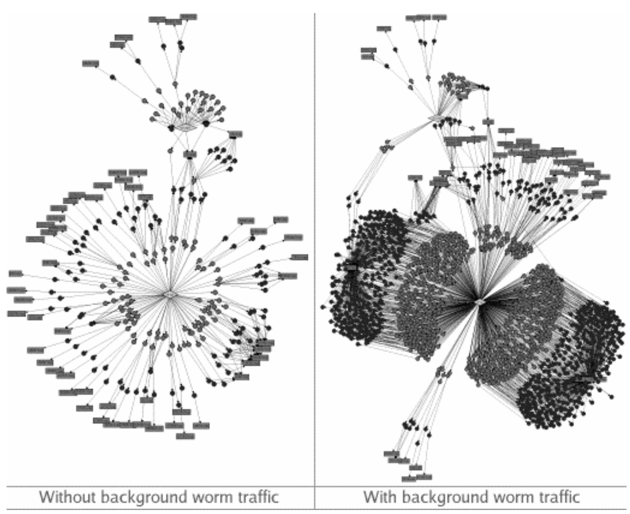
- **SciVis vs. InfoVis**
- VisTrails
- Core Techniques
- Advanced Techniques

Scientific Visualization



Information Visualization



InfoVis vs. SciVis

SciVis: Scientific & physically based

InfoVis: Abstract

[Card, Mackinlay, & Shneiderman 1999]

SciVis: Spatialization given

InfoVis: Spatialization chosen

[Munzner 2003]

Melanie Tory, Visualization 2003, used with permission

Problems with these categories

- SciVis or InfoVis?
  - Scientific, but not physically based
    - Bioinformatics
    - Math equations:
      e.g., $f(i, j, k, w) = i^2 + j^2 + k^2 + w^2$
  - Physically based, but not necessarily scientific
    - Air traffic control systems
    - Maps

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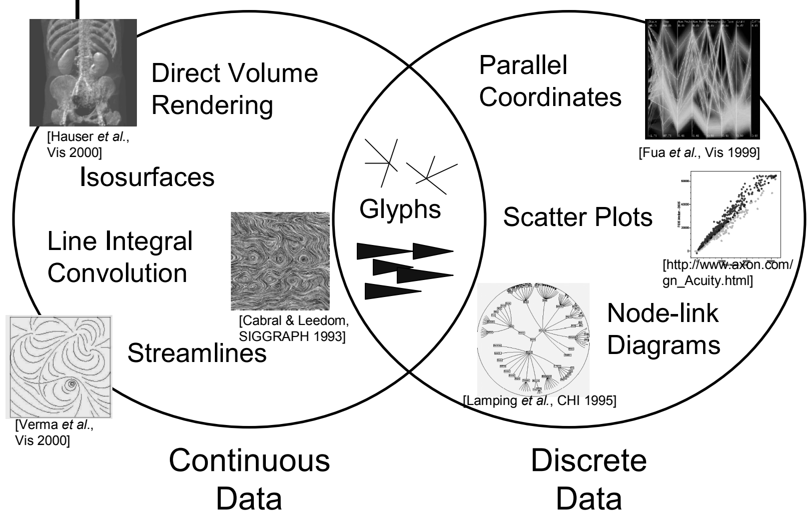
1st Attempt: Continuous & Discrete Data



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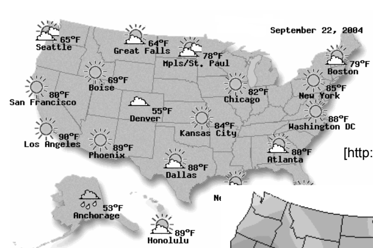
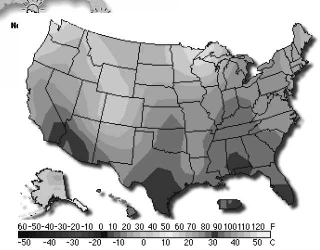
Problems with 1st Attempt

BUT…

- The same data can be visualized discretely or continuously



[http://www.tvweather.com]



[http://www.wunderground.com]

- So, our *interpretation* of data is more important than characteristics of data

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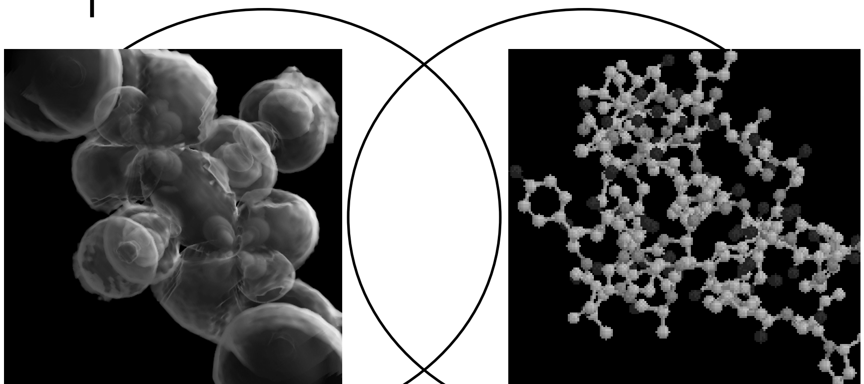
2nd Attempt: Model not Data



[Simeon Potts]

[http://www.chem.swin.edu.au/modules/mod2/formats.html]

Continuous Model

Discrete Model

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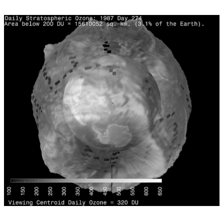
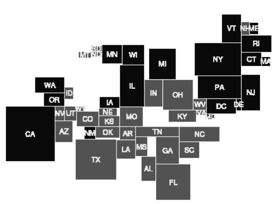
3rd Attempt: What about spatialization?

- Visualization can be categorized according to whether the spatial layout is given or chosen [Munzner 2003]
- We extend this idea to a continuum:

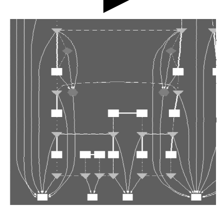
Given — Decreasing constraints → Chosen



[Llyod Treinish]



[Heilmann *et al.*, InfoVis 2004]



[http://www.graphviz.org]

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- SciVis vs. InfoVis
- **VisTrails**
- Core Techniques
- Advanced Techniques

VisTrails

Juliana Freire and Claudio T. Silva
University of Utah
http://www.sci.utah.edu/~vgc/vistrails
with
Steven P. Callahan
Emanuelle Santos
Carlos E. Scheidegger
Huy T. Vo

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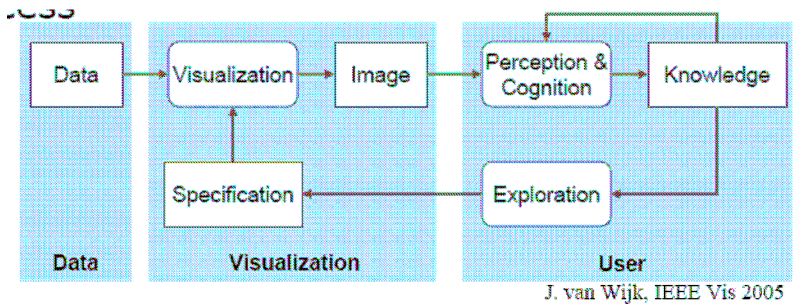
VisTrails

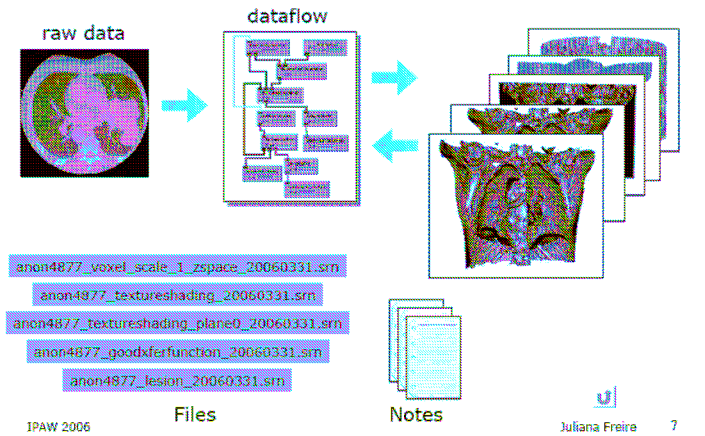
- Visualization is a difficult, interactive, iterative process



VisTrails

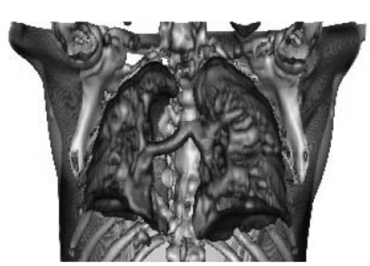
- Claim:
  - “Generation and management of visualizations is a major bottleneck in the scientific process”
- More data, more collaboration, more interdisciplinary work…

Manual Provenance

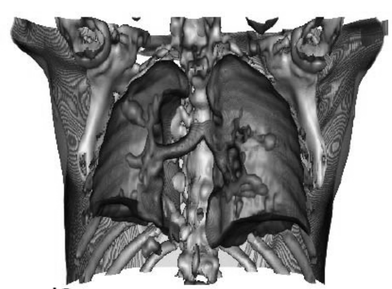


What’s the difference?

anon4877_base_20060331.srn



anon4877_lesion_20060401.srn



How were these images created?

Are they really from the same patient?

Do they use the same colormaps?

VisTrails: Key Ideas

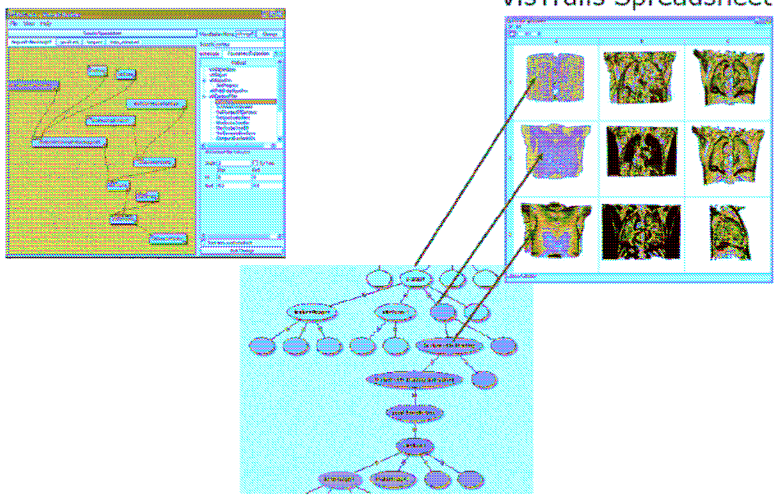
- Track the interactive development of visualizations
- Store these “VisTrails” in as XML
  - Query, Analyze, Reuse
- Provide an interface for creating, composing, comparing, and dissecting VisTrails simply and efficiently

VisTrails: Techniques

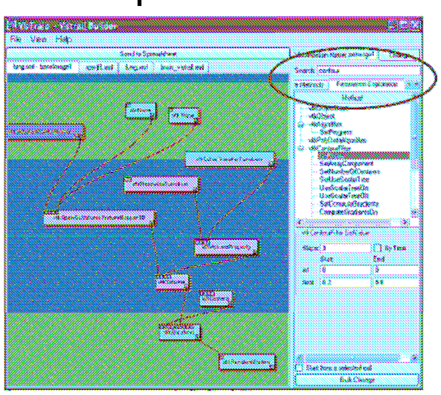
- Convenience:
  - Track all changes in the GUI automatically
  - Spreadsheet interface
- Efficiency:
  - Cache manager
- Collaboration:
  - Share and reuse VisTrails, not just finished scripts

VisTrails Builder

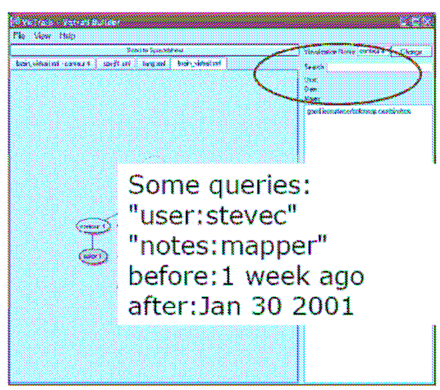
VisTrails Spreadsheet



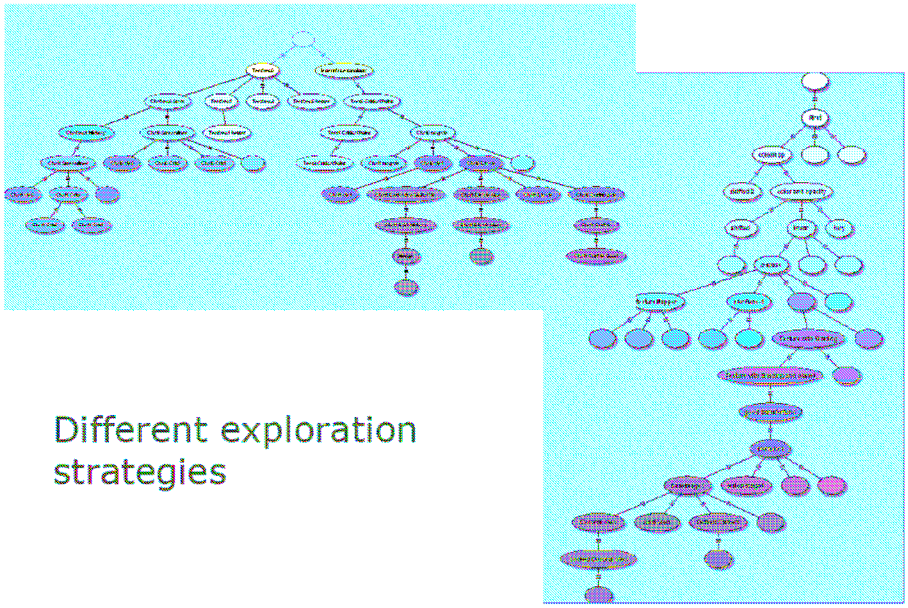
VisTrails Version Tree



Searching for modules



Searching for dataflows



Different exploration strategies

IPAW 2006 Juliana Freire 59

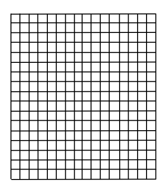
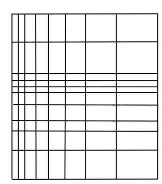
Tangible Benefits

- Reproducible Science
- Visualization by Analogy
- Reduce “Time to Insight”

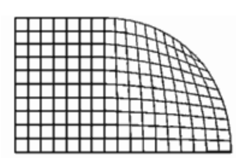
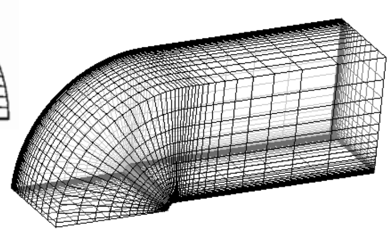
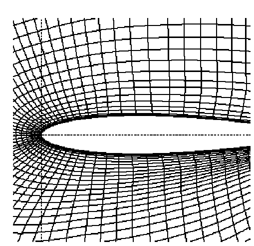
Visualization Techniques

- Scalars
  - Glyphs
  - Color
  - Slices
  - Isosurface
- Vectors
  - Barbs
  - Streamlines
- Volume Rendering

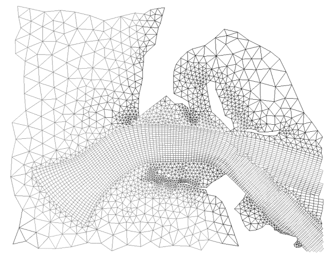
Structured Grids

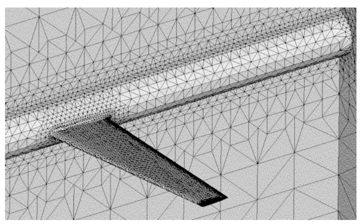
- Regular topology
- Potentially irregular geometry
- *Fast, but difficult to construct for complex domains*

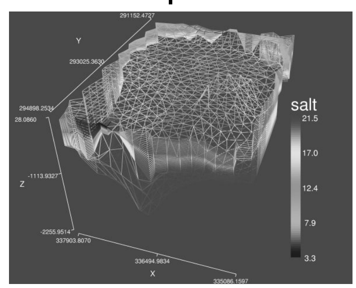




Unstructured Grids

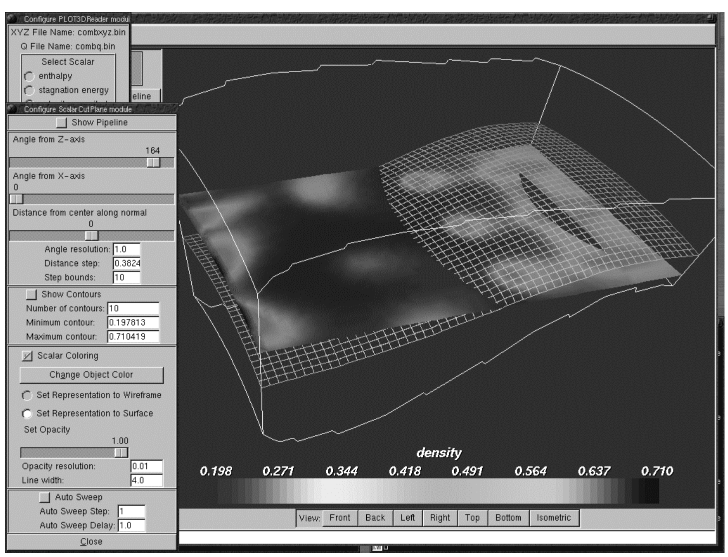


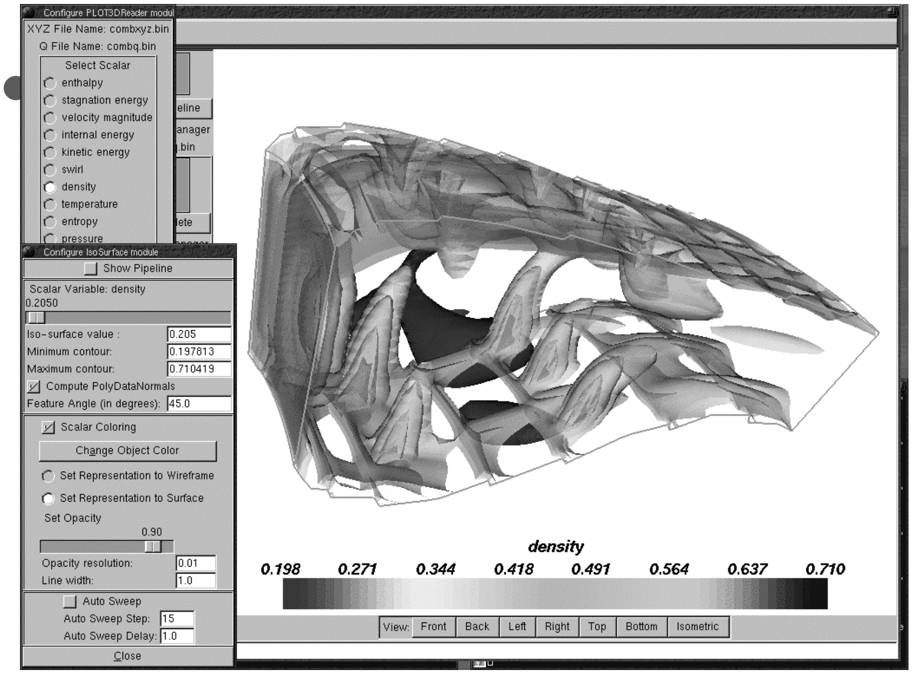
- Irregular Topology
- Irregular Geometry
- Easier to fit to complex domains,
- but algorithms more complicated and slower



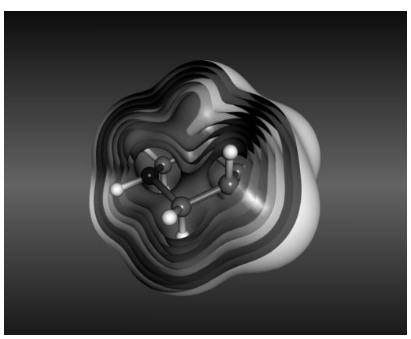


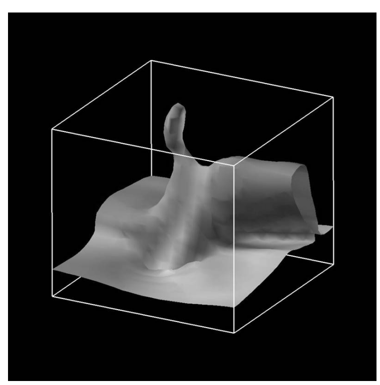
Cutting Planes





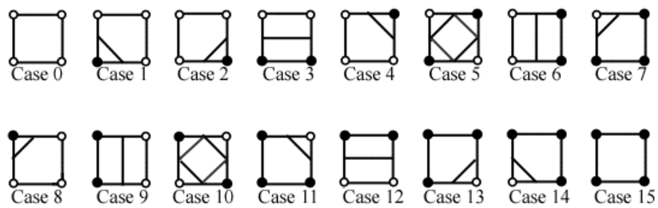
Isosurfaces





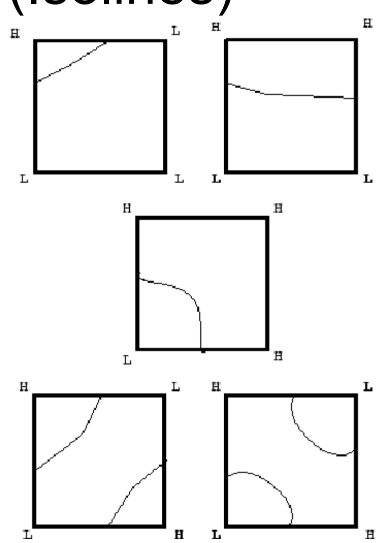
Isosurfaces (Isolines)

- For each cell, mark nodes as above or below the isovalue
- Problem:
  - Desired isosurface intersects cells in many different ways
- Observation:
  - There is only a small number of configurations possible
  - …when considering algebraic equivalences



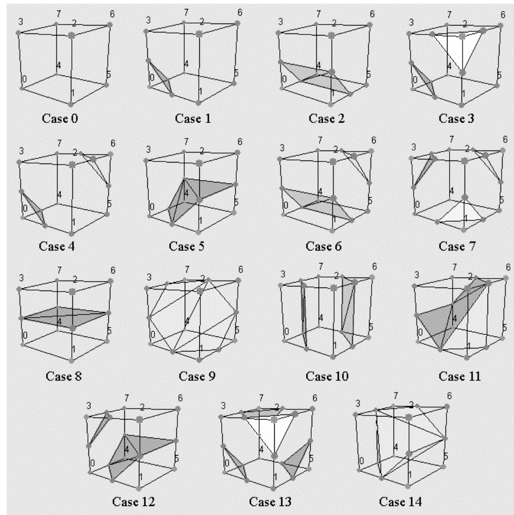
Isosurfaces (Isolines)

- 2D Case



Isosurfaces

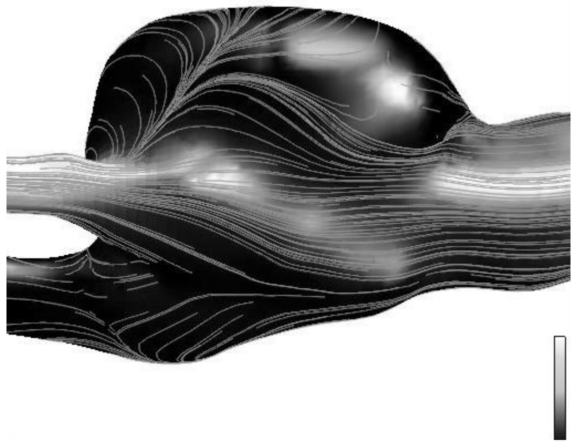
- 3D case



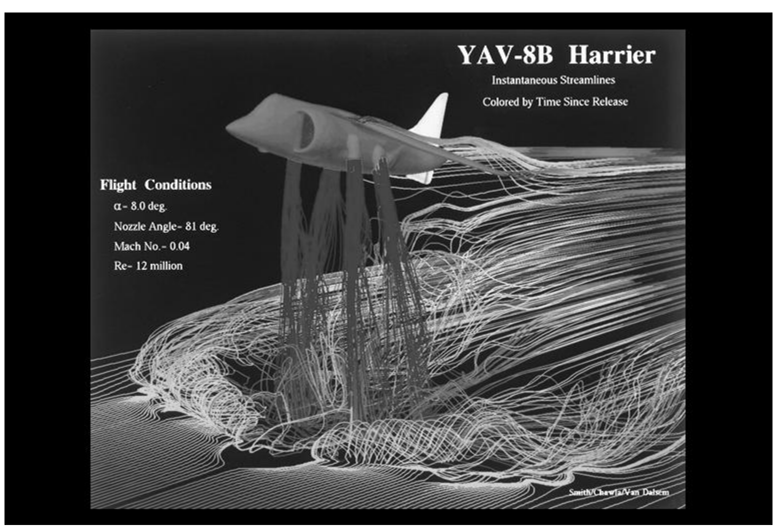
Isosurfaces (done)

- Marching Cubes:
  - Same 16 cases work for larger cubes consisting of many cells
  - Suggests an *Out-of-core* algorithm that works on a block of cells at a time

Streamlines

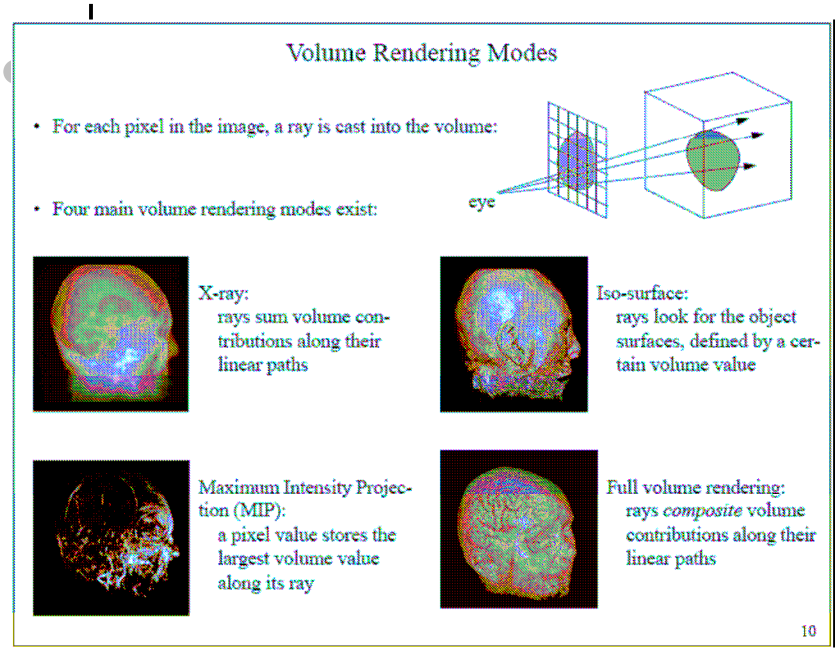


Streamlines

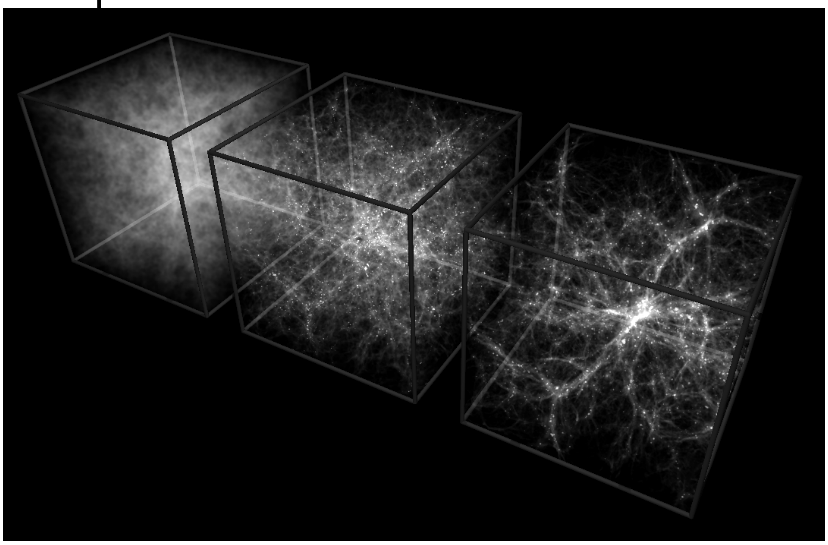


Streamlines

- Algorithm
  - From a seed point, cast a ray in the direction of the vector field, repeat
  - Amounts to integrating the vector field
- Design challenges
  - Evenly spaced streamlines
  - Discontinuities and boundaries



“Full” Volume Rendering



Conclusions

- Visualization matters
- Interactive, iterative, difficult process
  - Automation difficult (Color example)
  - Empower the user instead (VisTrails)
- Terms to remember
  - Structured vs. Unstructured Grids
  - Isosurfaces, Cutting Planes
  - Streamlines, Volume Rendering