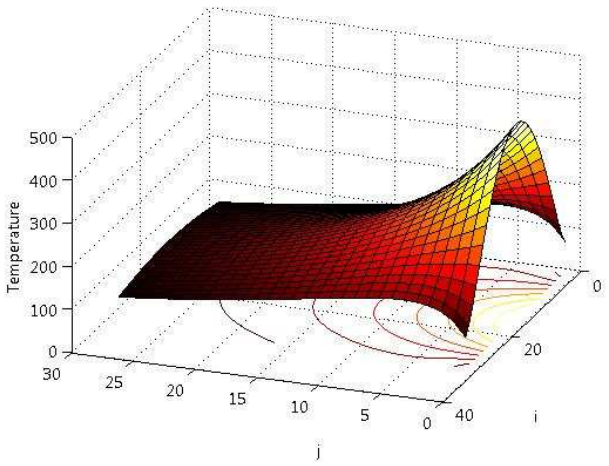
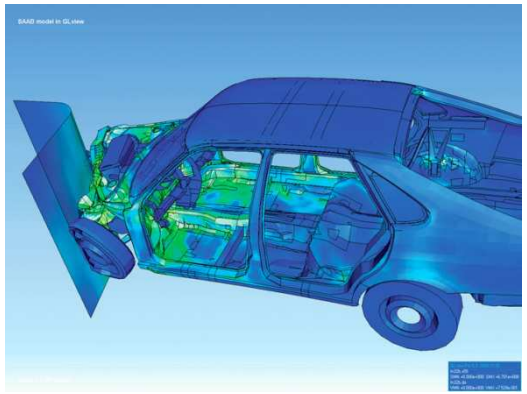
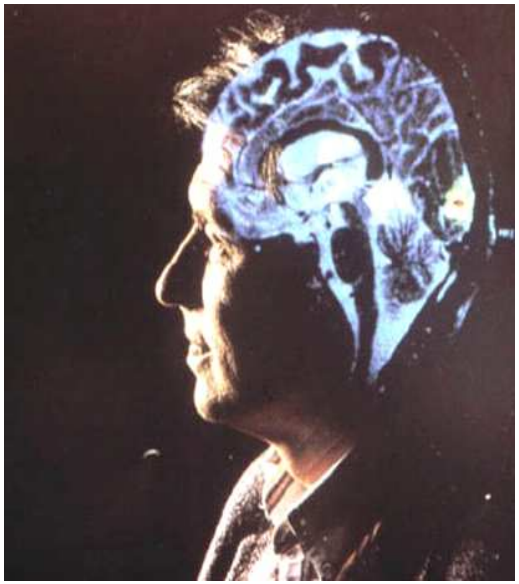




Perception for Visualization

Nicholas F. Polys Ph.D.

VT Research Computing



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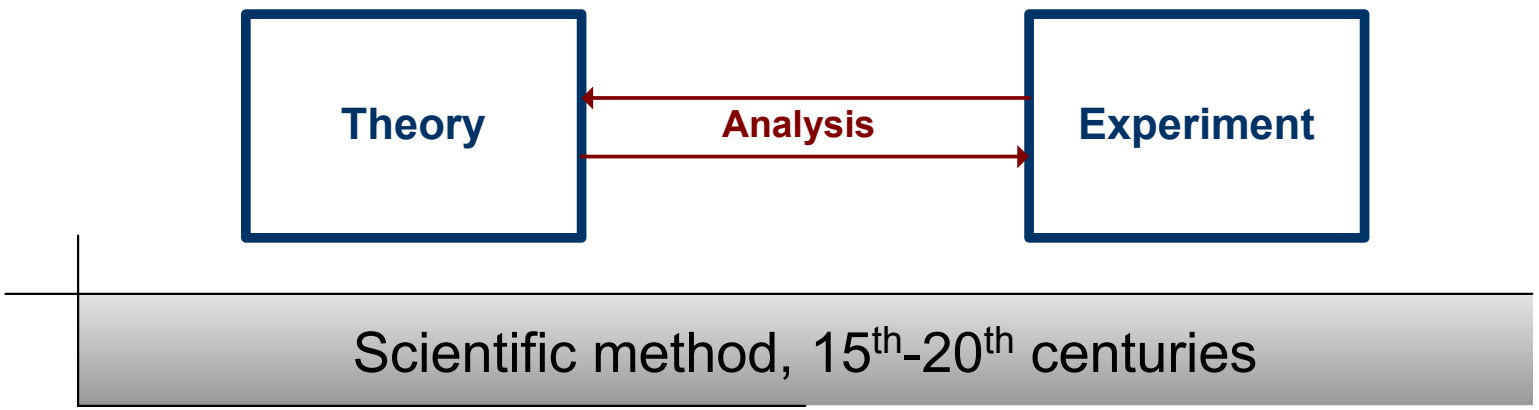
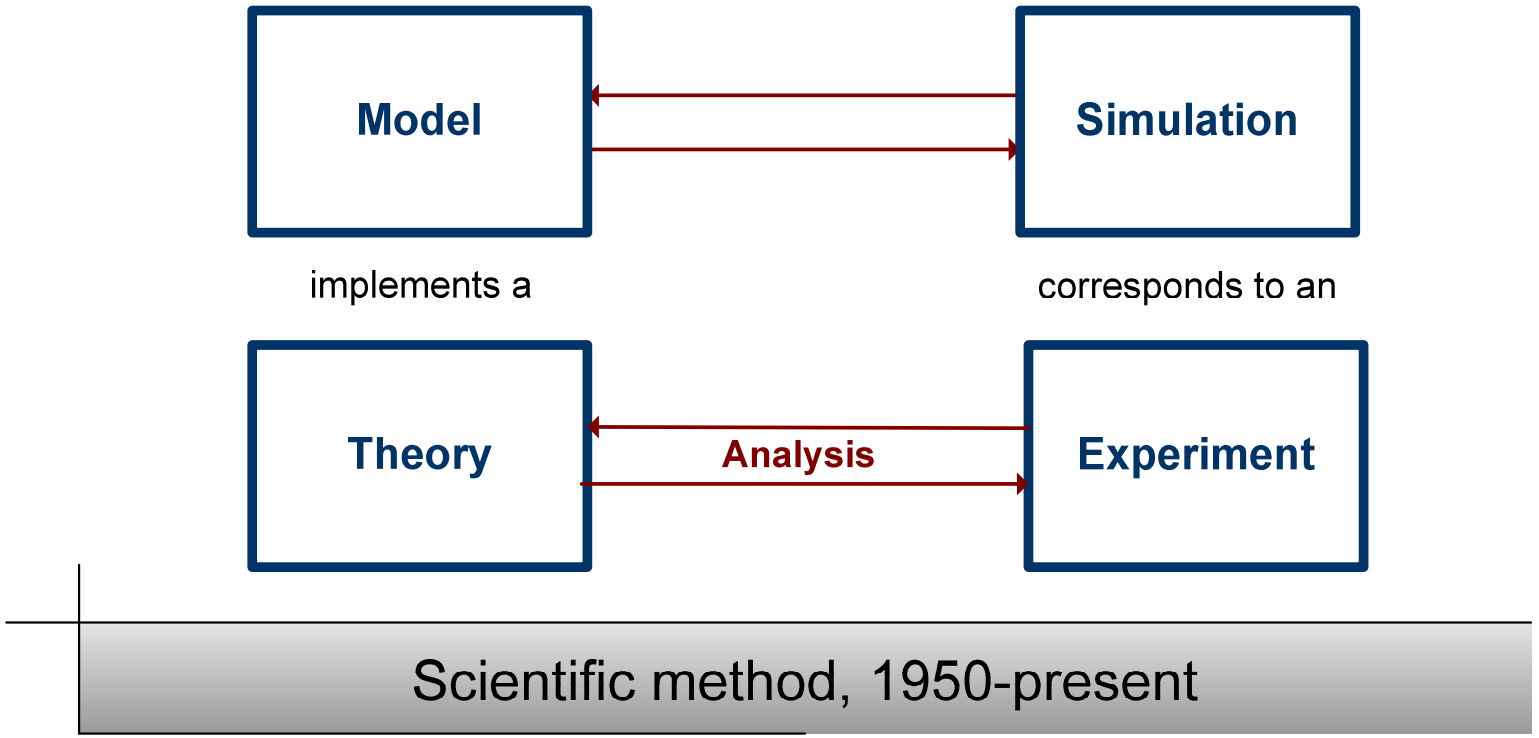
theory = conceptual description of reality

experiment = test theory in physical world



model = formal representation of reality

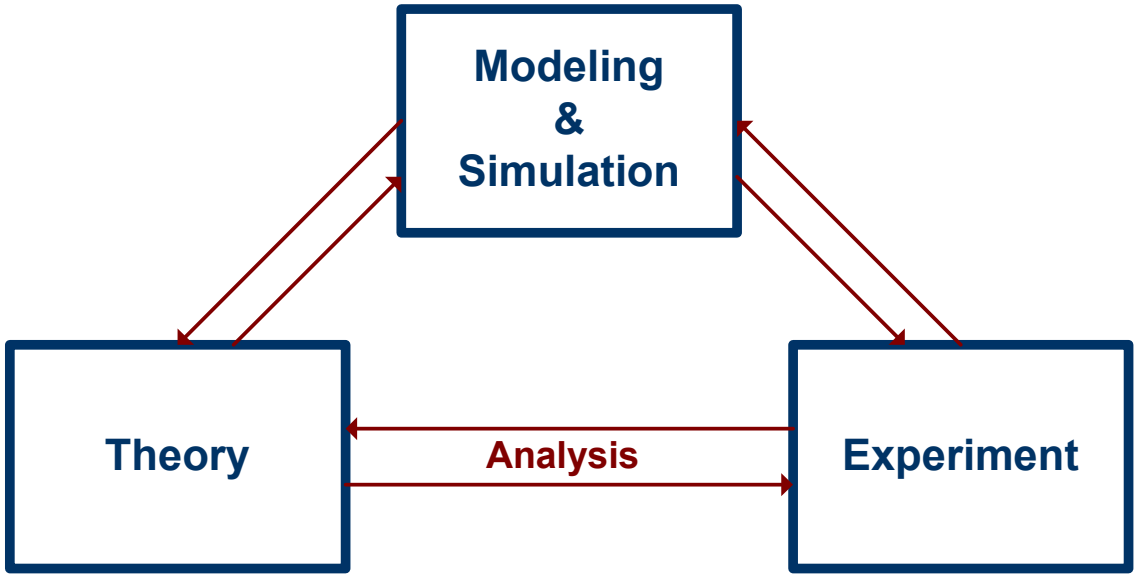
simulation = behavior of model over time



running together

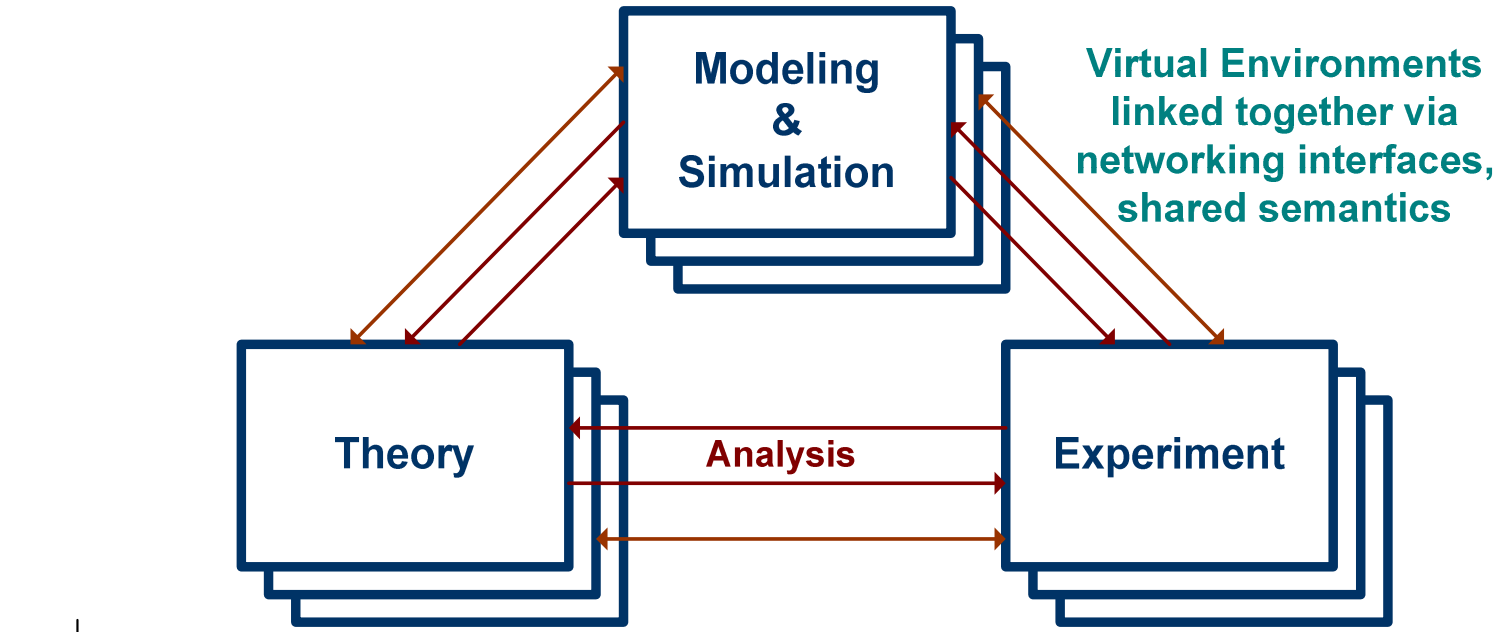
model = formal representation of reality

simulation = behavior of model over time



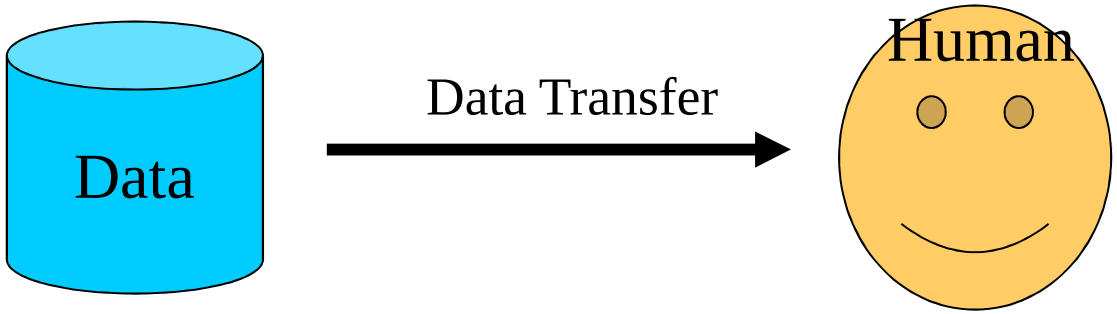
Scientific method, 1950-present

Virtual environments can connect all models and simulations together



Scientific method, emerging 21st century

The Big Problem



How?

Vision:
Aural:
Smell:
Haptics
Taste
esp

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Human Vision

- Highest bandwidth sense
- Fast, parallel
- Pattern recognition
- Pre-attentive
- Extends memory and cognitive capacity
    - (Multiplication test)
- People think visually
- Brain = 8 lbs, vision = 3 lbs

Impressive. Lets use it!

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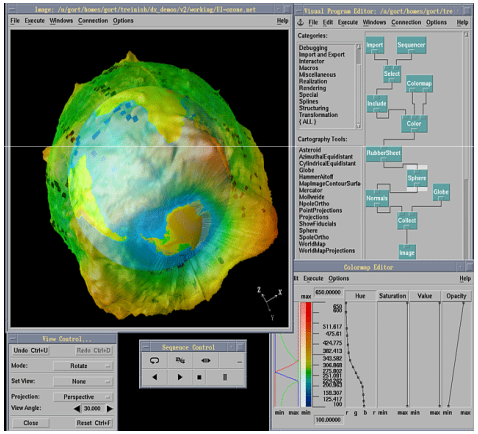
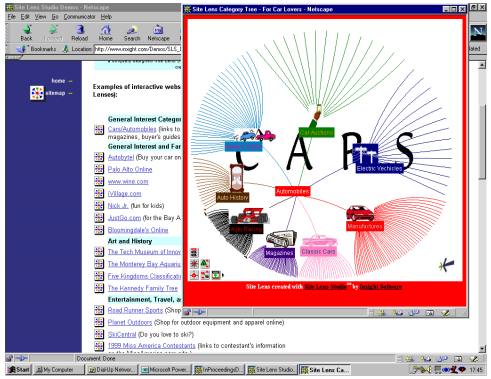
A definition

- Generally:
  - The use of computer-supported, interactive, visual representations of data to amplify cognition

Card, McKinlay and Schneiderman





  - Scientific Visualization
  - Information Visualization
  - Virtual Environments

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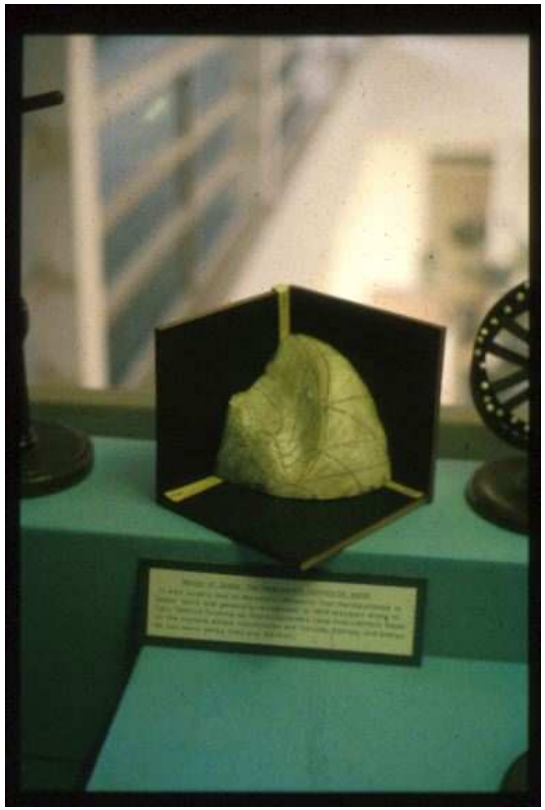
Visual Thinking

- Many of the great scientists were good at visual thinking:
  - Leonardo da Vinci
  - James Clerk Maxwell
  - Michael Faraday
  - Albert Einstein
- This was often at the expense of verbal skills
- Tom West : “In the Mind’s Eye”
  - See also http://www.krasnow.gmu.edu/twest/maxwell_visual.html



Maxwell’s clay model now in
New Cavendish Laboratory, Cambridge
(picture by Tom West)

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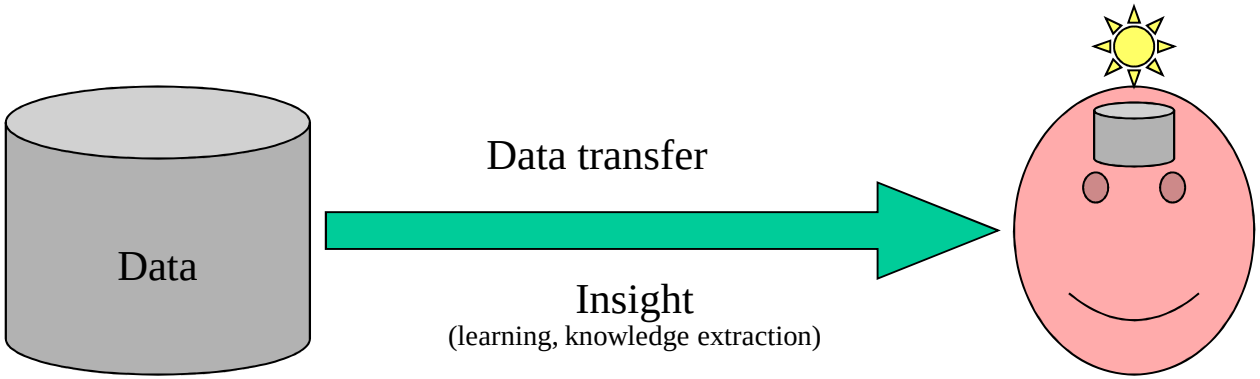
Goal



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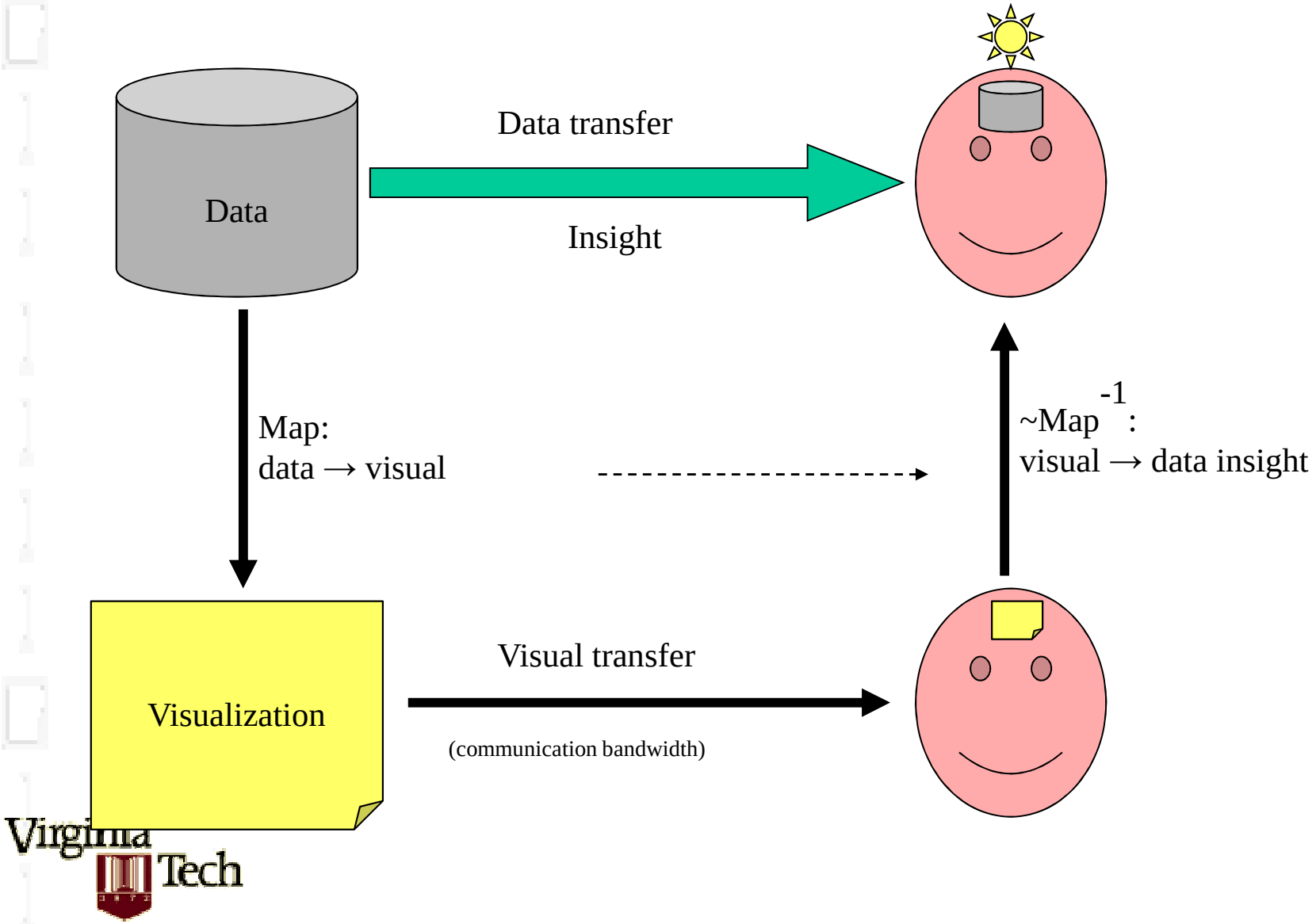
Method



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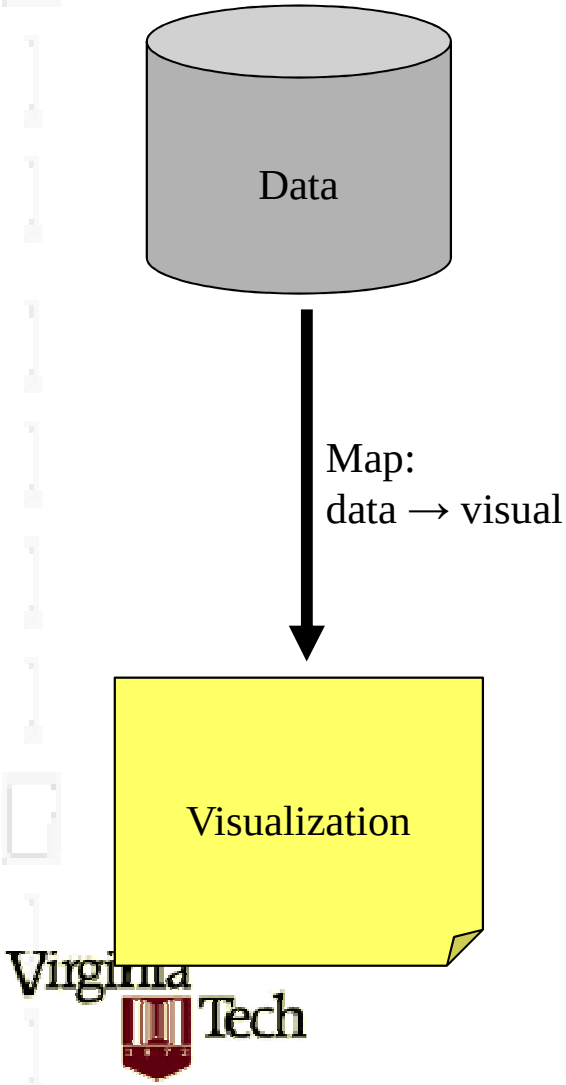
Visual Mappings



Visual Mappings must be:

- Computable (math)

  visual = f(data)

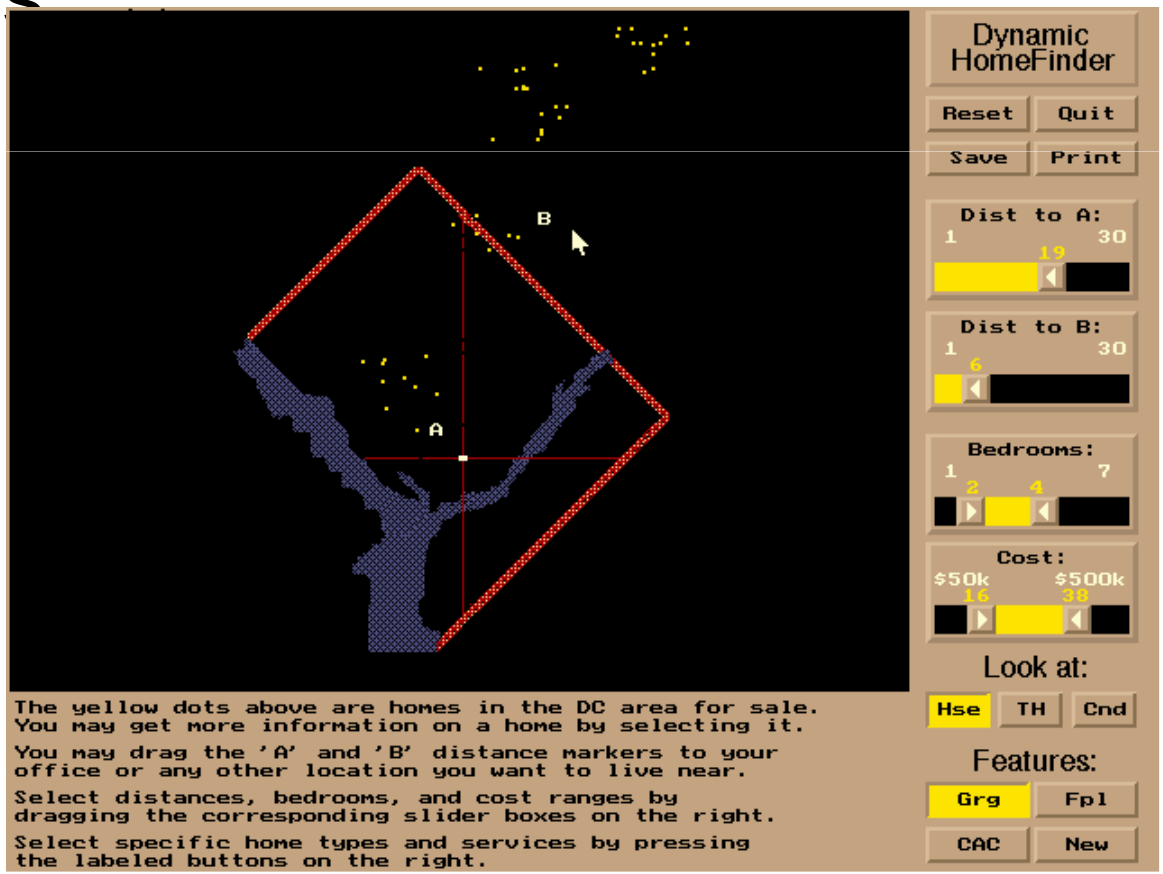
- Comprehensible (invertible)

  $data = f^{-1}(visual)$

- *Creative!*

Visual Structure

- Spatial substrate
- Visual marks
- Visual properties



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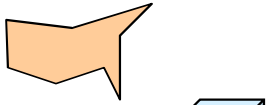
Visual Mapping: Step 1

1. Map: data items → visual marks

Visual marks:

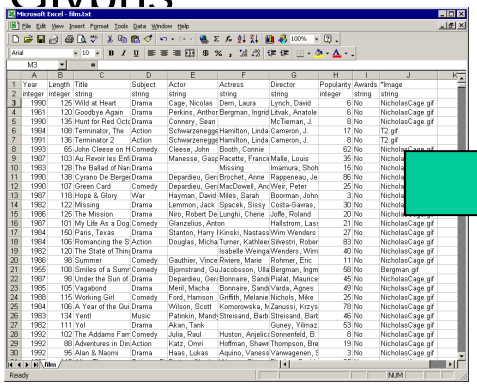
- Points
- Lines

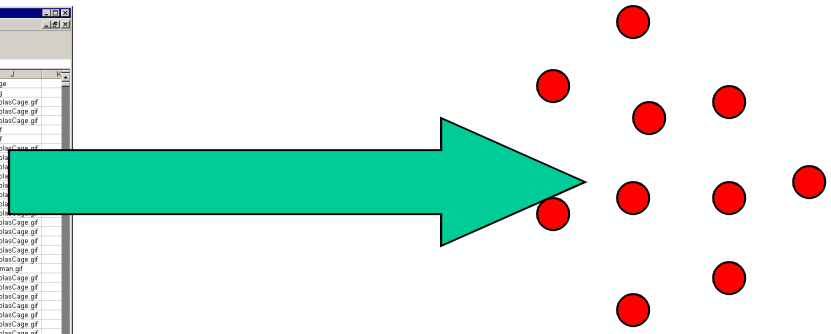


- Areas

- Volumes

- Glyphs





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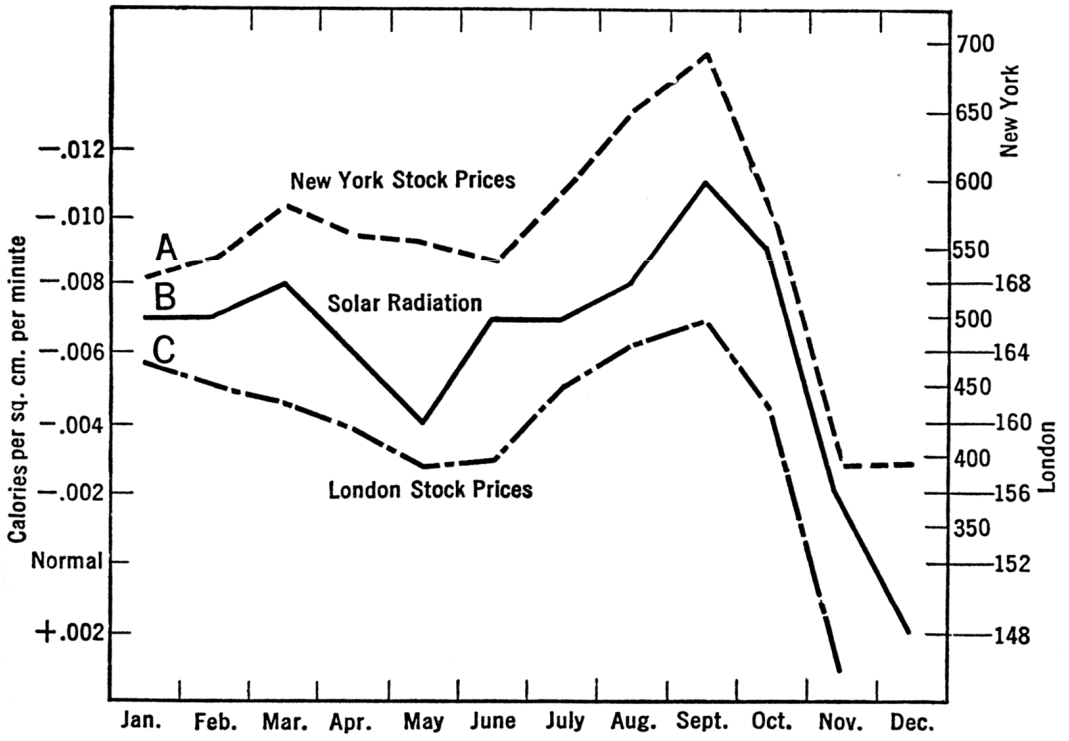
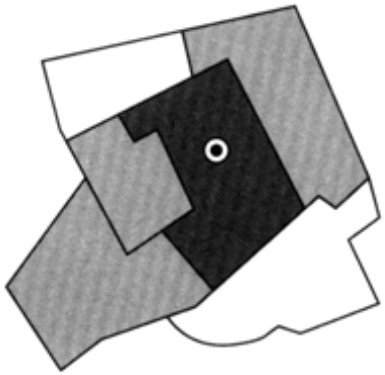
Of course, statistical graphics, just like statistical calculations, are only as good as what goes into them. An ill-specified or preposterous model or a puny data set cannot be rescued by a graphic (or by calculation), no matter how clever or fancy. A silly theory means a silly graphic:



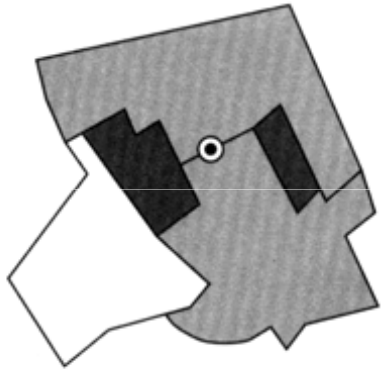
SOLAR RADIATION AND STOCK PRICES

A. New York stock prices (Barron's average). B. Solar Radiation, inverted, and C. London stock prices, all by months, 1929 (after Garcia-Mata and Shaffner).

Edward Tufte

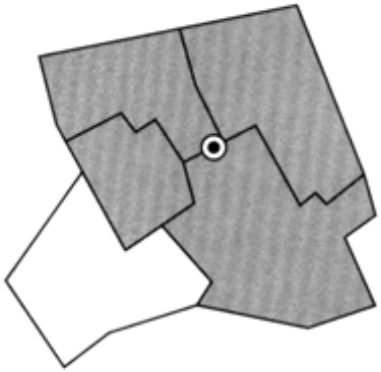


In this aggregation of individual deaths into six areas, the greatest number is concentrated at the Broad Street pump.



In this aggregation of the deaths, the two areas with the most deaths do not even include the infected pump!

[18] Mark Monmonier, *How to Lie with Maps* (Chicago, 1991), pp. 142–143.



Using different geographic subdivisions, the cholera numbers are nearly the same in four of the five areas.

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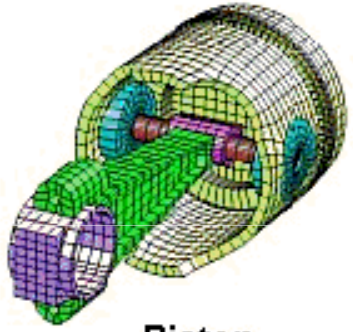
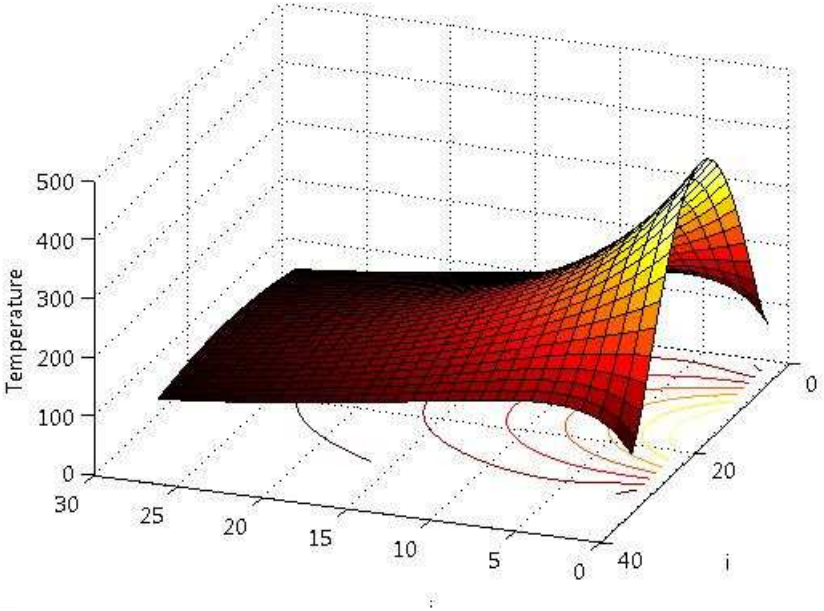
Spatial Domain Reprise

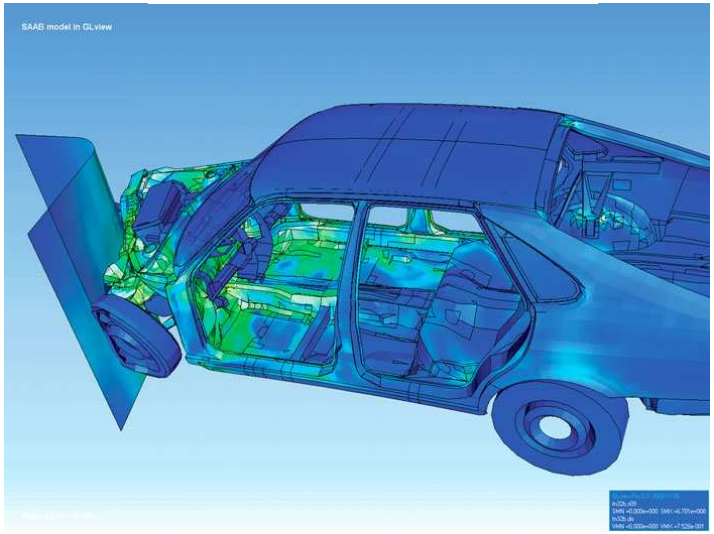
What is the difference and when would you use one or the other?

- Finite Difference
- Finite Element



Piston





Visual Analysis Overview

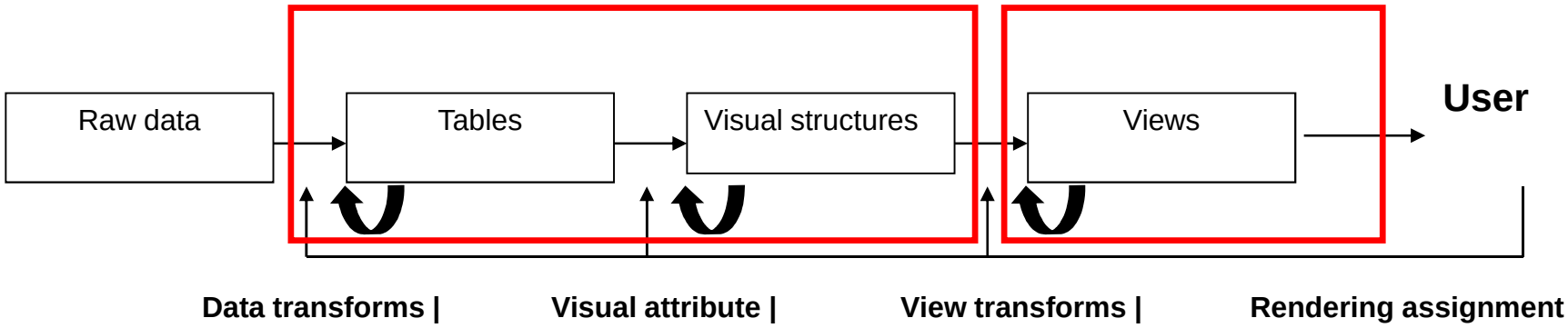


Figure 2.1: Processing in a typical visualization pipeline (from Card et al, 1999)

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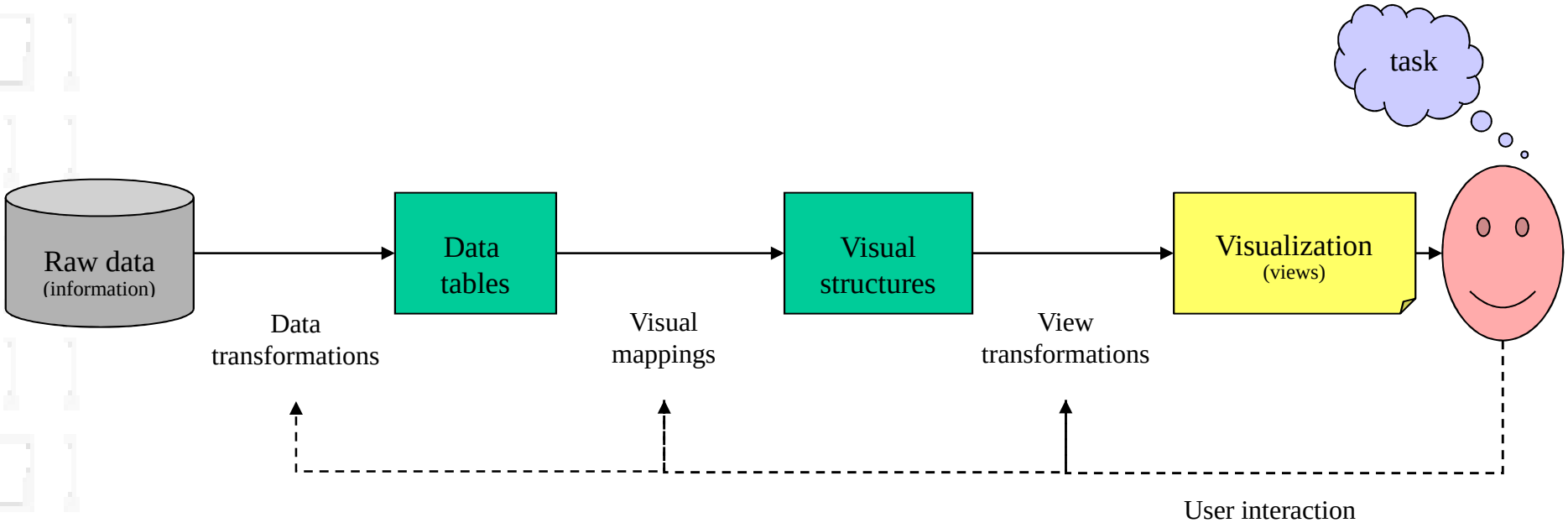
Visualization Pipeline



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Data Table

Attributes (aka: dimensions, variables, fields, columns, …)

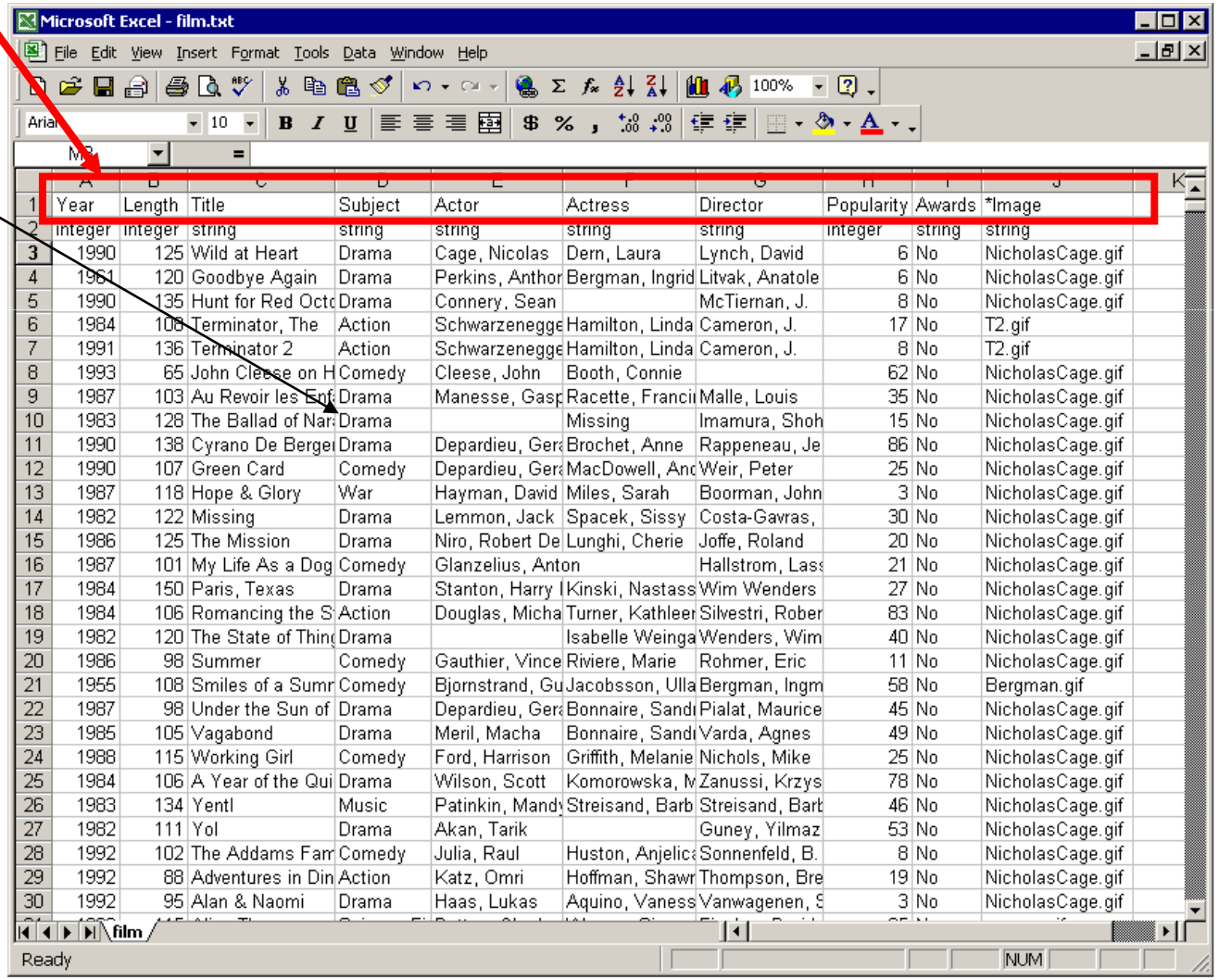
Values

Data Types:

- Quantitative
- Ordinal
- Categorical
- Nominal

Items

(aka:
tuples, cases, records,
data points, rows, …)



	A	B	C	D	E	F	G	H	I	J
1	Year	Length	Title	Subject	Actor	Actress	Director	Popularity	Awards	*Image
2	integer	integer	string	string	string	string	string	integer	string	string
3	1990	125	Wild at Heart	Drama	Cage, Nicolas	Dern, Laura	Lynch, David	6	No	NicholasCage.gif
4	1961	120	Goodbye Again	Drama	Perkins, Anthor	Bergman, Ingrid	Litvak, Anatole	6	No	NicholasCage.gif
5	1990	135	Hunt for Red Octo	Drama	Connery, Sean		McTiernan, J.	8	No	NicholasCage.gif
6	1984	108	Terminator, The	Action	Schwarzenegge	Hamilton, Linda	Cameron, J.	17	No	T2.gif
7	1991	136	Terminator 2	Action	Schwarzenegge	Hamilton, Linda	Cameron, J.	8	No	T2.gif
8	1993	65	John Cleese on H	Comedy	Cleese, John	Booth, Connie		62	No	NicholasCage.gif
9	1987	103	Au Revoir les Enf	Drama	Manesse, Gasp	Racette, Franci	Malle, Louis	35	No	NicholasCage.gif
10	1983	128	The Ballad of Nar	Drama		Missing	Imamura, Shoh	15	No	NicholasCage.gif
11	1990	138	Cyrano De Berger	Drama	Depardieu, Ger	Brochet, Anne	Rappeneau, Je	86	No	NicholasCage.gif
12	1990	107	Green Card	Comedy	Depardieu, Ger	MacDowell, And	Weir, Peter	25	No	NicholasCage.gif
13	1987	118	Hope & Glory	War	Hayman, David	Miles, Sarah	Boorman, John	3	No	NicholasCage.gif
14	1982	122	Missing	Drama	Lemmon, Jack	Spacek, Sissy	Costa-Gavras,	30	No	NicholasCage.gif
15	1986	125	The Mission	Drama	Niro, Robert De	Lunghi, Cherie	Joffe, Roland	20	No	NicholasCage.gif
16	1987	101	My Life As a Dog	Comedy	Glanzelius, Anton		Hallstrom, Lass	21	No	NicholasCage.gif
17	1984	150	Paris, Texas	Drama	Stanton, Harry I	Kinski, Nastass	Wim Wenders	27	No	NicholasCage.gif
18	1984	106	Romancing the S	Action	Douglas, Micha	Turner, Kathleer	Silvestri, Rober	83	No	NicholasCage.gif
19	1982	120	The State of Thin	Drama		Isabelle Weinga	Wenders, Wim	40	No	NicholasCage.gif
20	1986	98	Summer	Comedy	Gauthier, Vince	Riviere, Marie	Rohmer, Eric	11	No	NicholasCage.gif
21	1955	108	Smiles of a Sumr	Comedy	Bjornstrand, Gu	Jacobsson, Ulla	Bergman, Ingm	58	No	Bergman.gif
22	1987	98	Under the Sun of	Drama	Depardieu, Ger	Bonnaire, Sandi	Pialat, Maurice	45	No	NicholasCage.gif
23	1985	105	Vagabond	Drama	Meril, Macha	Bonnaire, Sandi	Varda, Agnes	49	No	NicholasCage.gif
24	1988	115	Working Girl	Comedy	Ford, Harrison	Griffith, Melanie	Nichols, Mike	25	No	NicholasCage.gif
25	1984	106	A Year of the Qui	Drama	Wilson, Scott	Komorowska, M	Zanussi, Krzys	78	No	NicholasCage.gif
26	1983	134	Yentl	Music	Patinkin, Mandy	Streisand, Barb	Streisand, Barb	46	No	NicholasCage.gif
27	1982	111	Yol	Drama	Akan, Tarik		Guney, Yilmaz	53	No	NicholasCage.gif
28	1992	102	The Addams Fam	Comedy	Julia, Raul	Huston, Anjelica	Sonnenfeld, B.	8	No	NicholasCage.gif
29	1992	88	Adventures in Din	Action	Katz, Omri	Hoffman, Shawr	Thompson, Bre	19	No	NicholasCage.gif
30	1992	95	Alan & Naomi	Drama	Haas, Lukas	Aquino, Vaness	Vanwagenen, S	3	No	NicholasCage.gif

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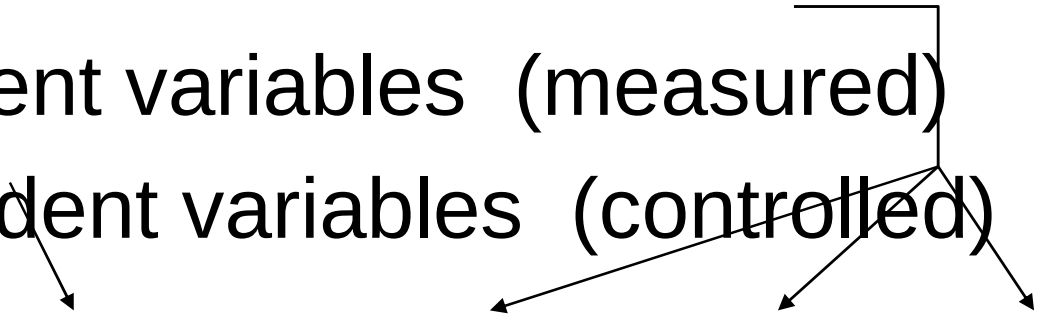
Attributes

- Dependent variables (measured)
- Independent variables (controlled)



ID	Year	Length	Title
0	1986	128	Terminator
1	1993	120	T2
2	2003	142	T3
…	…	…	…

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Fundamental Data Types

- Spatial / perceptual data:

  geometry, colors, textures, lighting

- Abstract data / world & object attributes:

  nominal, ordinal, quantitative

- Temporal data / behaviors:

  states, dynamics

Data Transformations

- Data table operations:
  - Selection
  - Projection
  - Aggregation
    - r = f(rows)
    - c = f(cols)
  - Join
  - Transpose
  - Sort
  - …

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First Steps

Extract data and Map

- **Data transformation**
  - Raw data -> attributes of interest
  - File formats or scripts are usually employed
- **Visual attributes**
  - Assign attributes -> visual representation
  - Typically use some tool (e.g. Paraview, Excel, Gnuplot)

Second Steps

Publish and Deliver

- **View transformation**
  - ‘Camera’ location and properties
- **Rendering assignment**
  - Print vs. interactive
  - Resolution, size
  - Stereo, immersion

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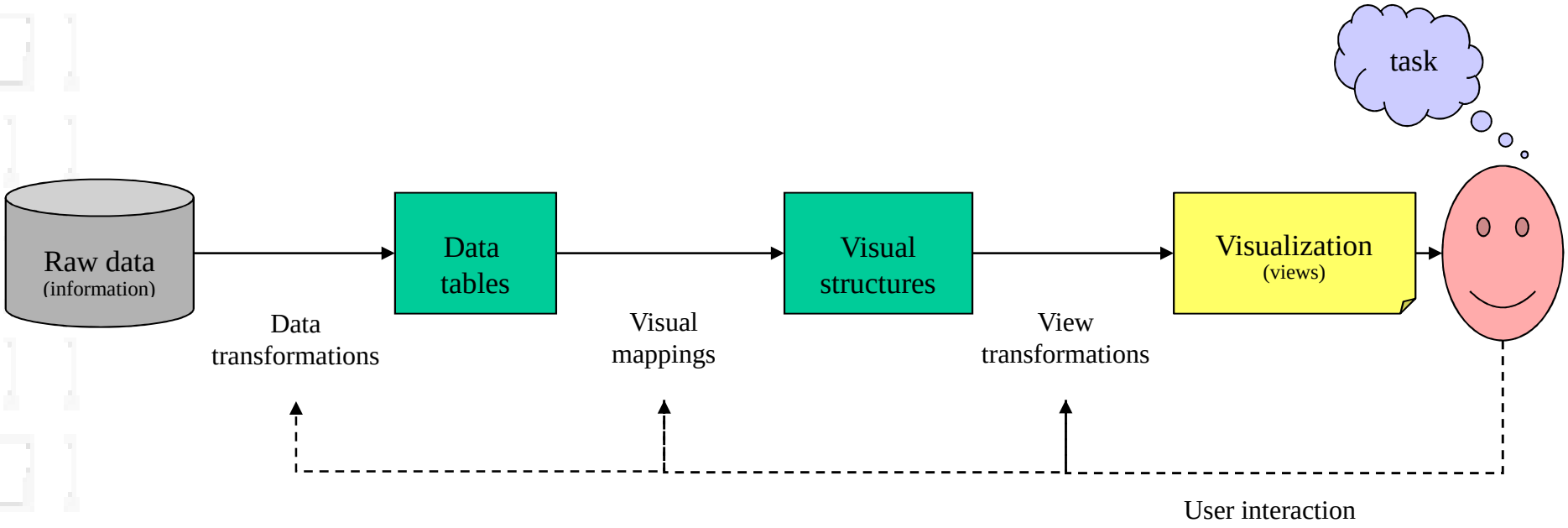
Visualization Pipeline



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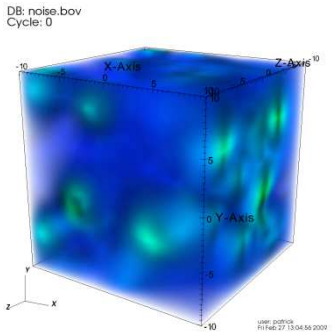
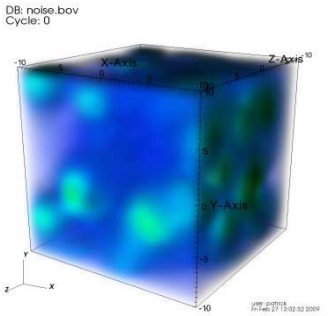
Visual Encoding Examples

Sci Vis

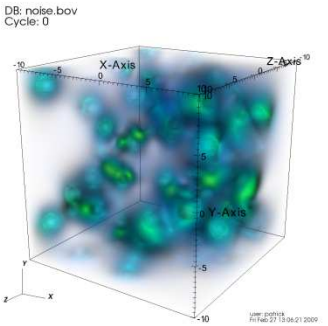
- Spatial substrate
- Visual ‘marks’
  - Visual properties
  - Time-varying



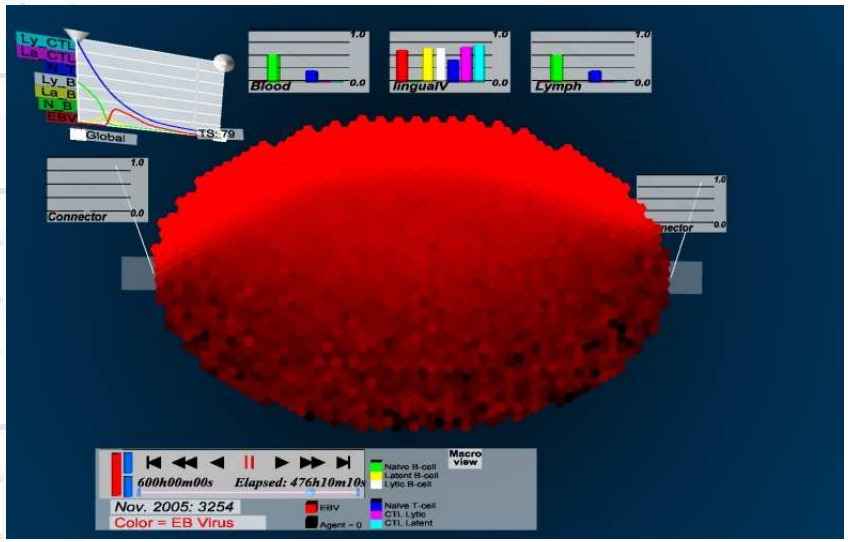
3D Texture method

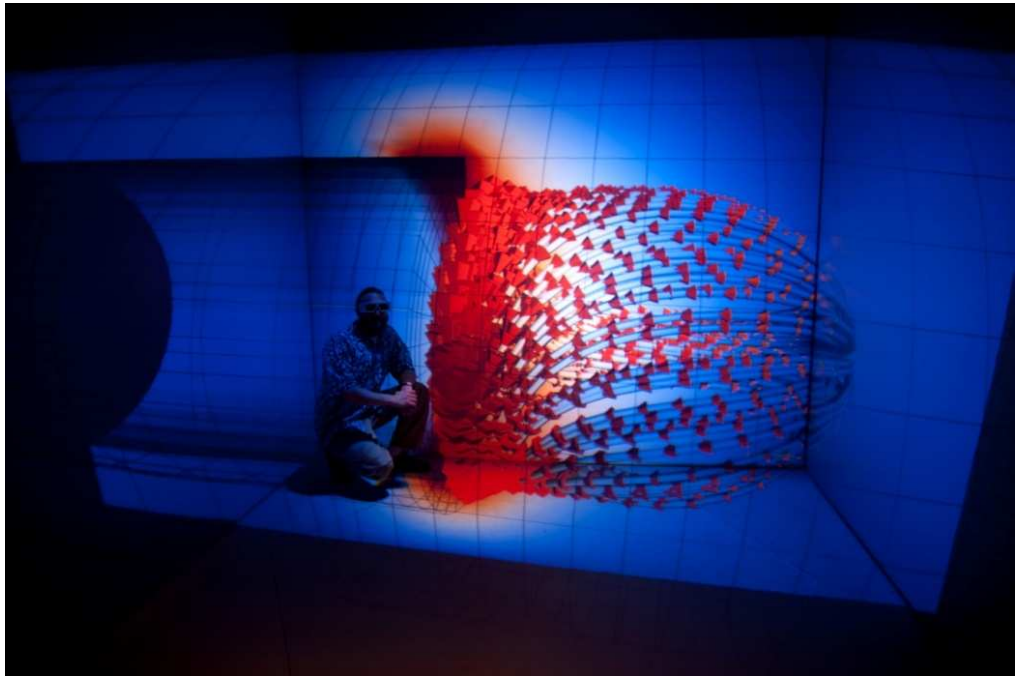


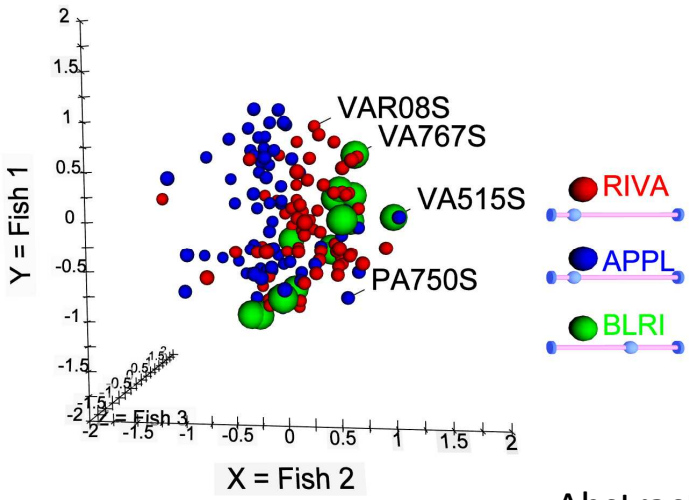
Splatting method

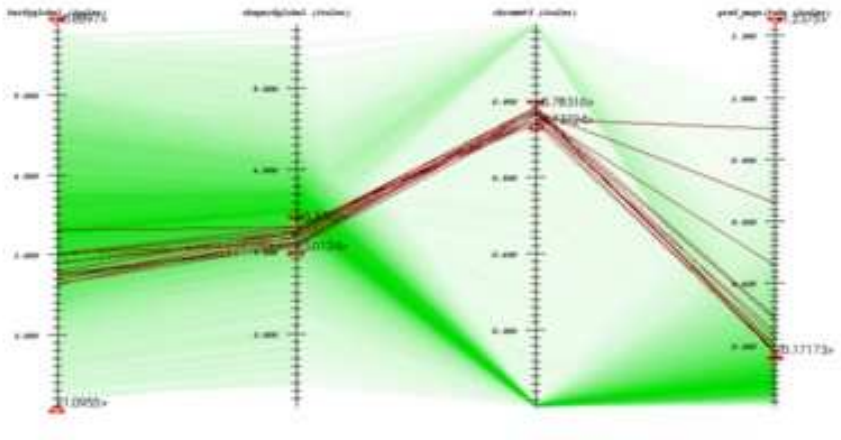


Raycasting method

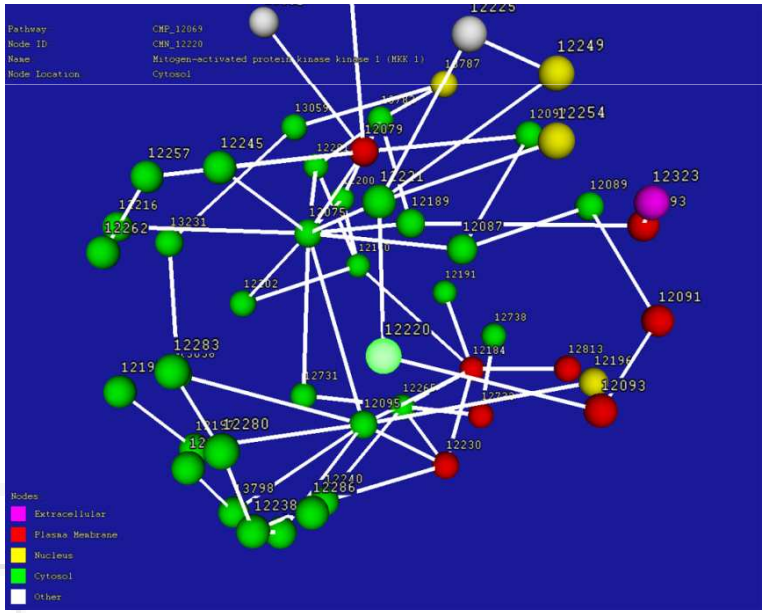








Abstract Data



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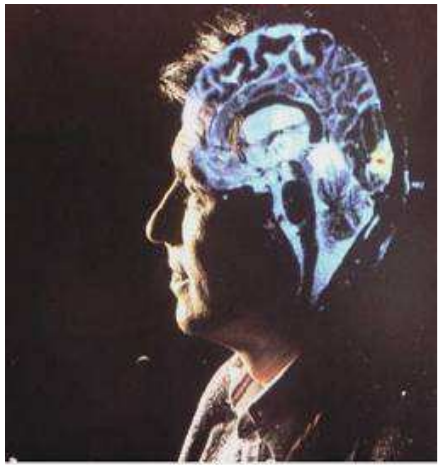
Network Data

Visualization

- An instrument / tool to
  - look at your data and see things otherwise hidden…
  - Amplify Cognition
- 3 key stages:
  - Transforming data
  - Encoding data
  - Delivering / Rendering



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Visual Analysis Overview

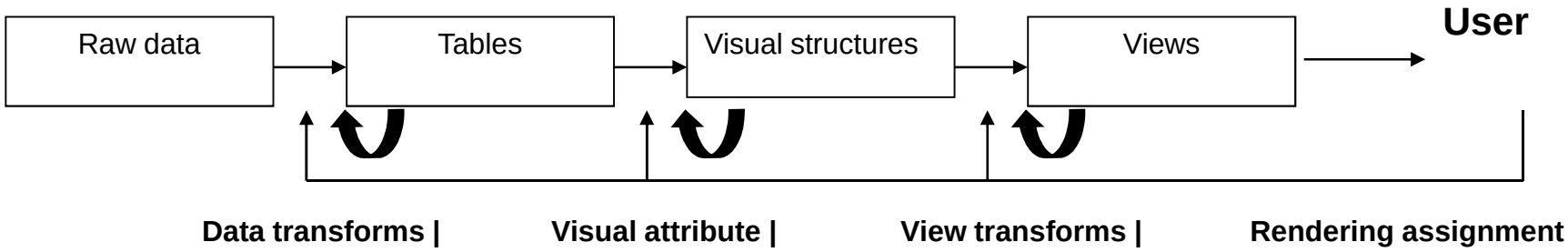

Figure 2.1: Processing in a typical visualization pipeline (from Card et al, 1999)

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Information Visualization Mantra

(Shneiderman)

- Overview first, zoom and filter, then details on demand
- Overview first, zoom and filter, then details on demand
- Overview first, zoom and filter, then details on demand
- Overview first, zoom and filter, then details on demand
- Overview first, zoom and filter, then details on demand

Rewind- to first principles

- The human mind is still the best analyst; how do we:
  - discover trends and relationships
  - communicate concept and results graphically
- How can perception inform design?

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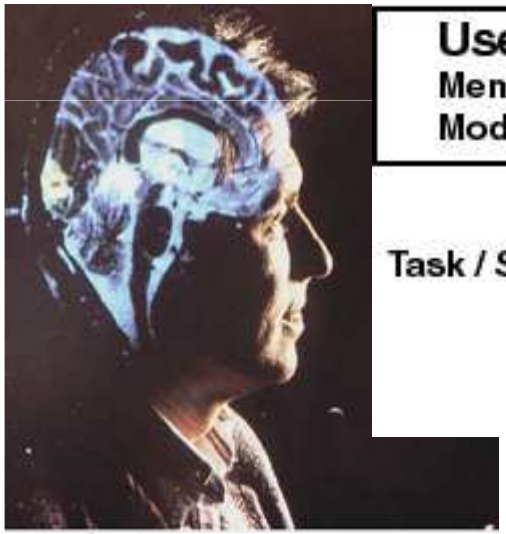
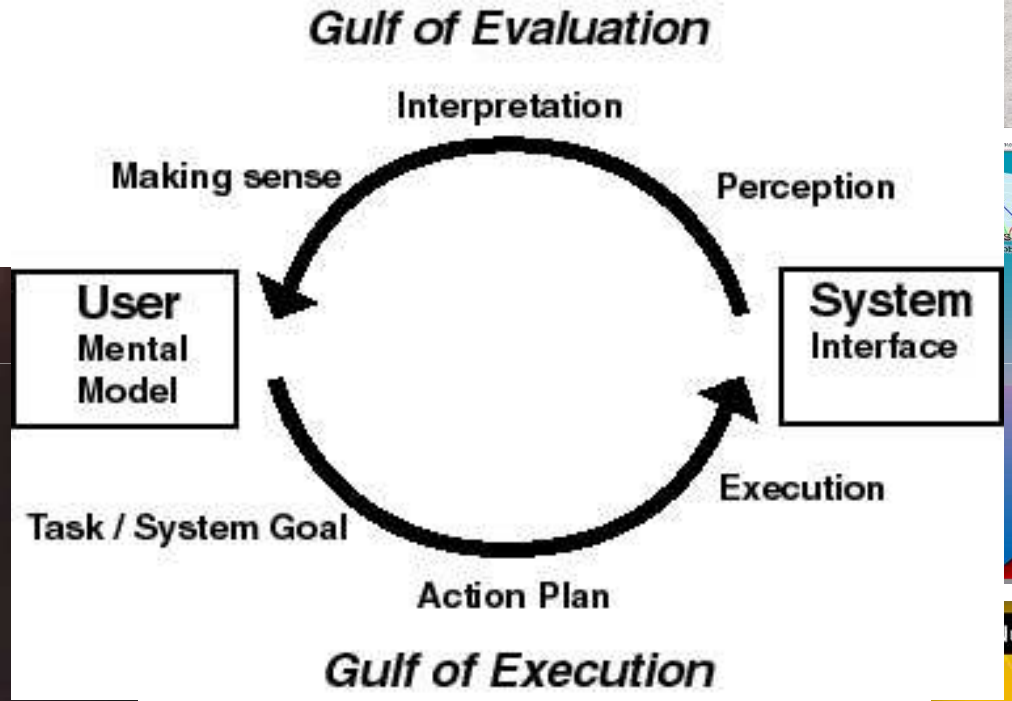
What is HCI?

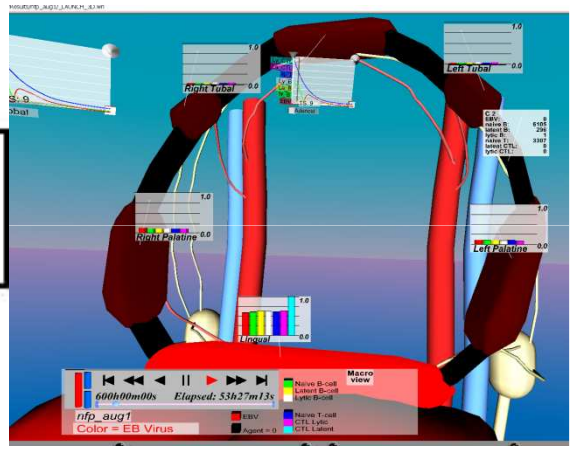
- A multidisciplinary science of the interface: *psychology, design & media, human factors, sociology, computer science*
- Experimental methods to rationalize UI features, design, and software architecture

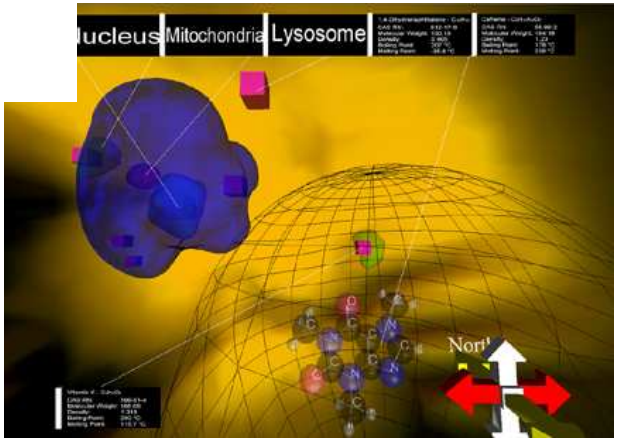
Virginia Tech

Norman's Gulfs









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Communication Across the Gulfs

User-centered design:

- ***Evaluation*** : Information Design
  - What do I see?
  - What does it mean?

- ***Execution*** : Interaction Design
  - What is my next goal?
  - How do I achieve it?
  - Make it happen!

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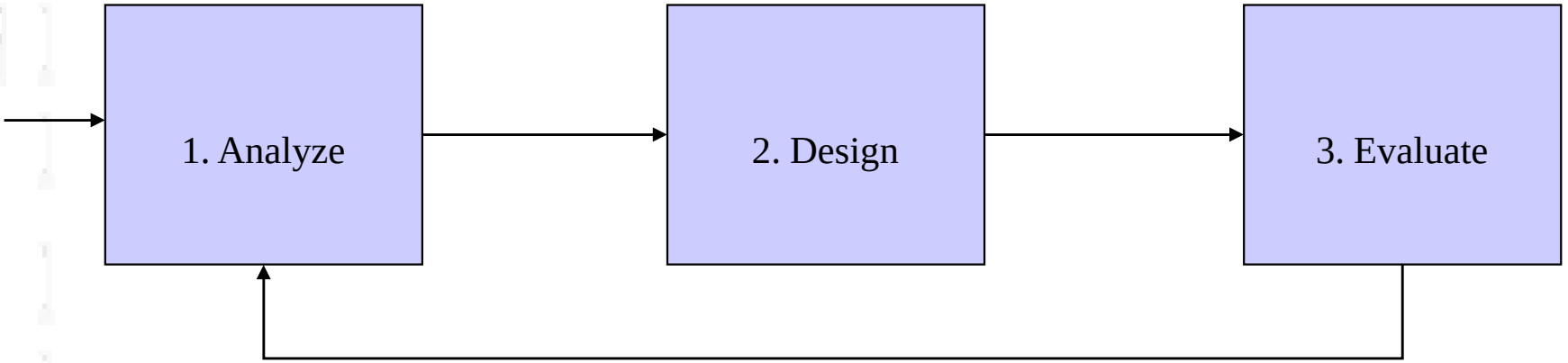
HCI Design Process



- Iterative, progressively concrete

HCI UI Evaluation Metrics

- User learnability:
  - Learning time
  - Retention time
- User performance: ***
  - Performance time
  - Success rates
  - Error rates, recovery
  - Clicks, actions
- User satisfaction:
  - Surveys

Measure while users perform benchmark tasks

Virginia Tech

Not “user friendly”

Visualization Design

- Analyze problem:
  - Data: schema, structures, scalability
  - Tasks/insights
  - Prioritize tasks and data attributes
- Design solutions:
  - Data transformations
  - Mappings: data→visual
  - Overview strategies
  - Navigation strategies
  - Interaction techniques
  - multiple views vs. integrated views
- Evaluate solutions:
  - Analytic: Claims analysis, tradeoffs
  - Empirical: Usability studies, controlled experiments

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Information Design

Goal: identify methods for representing and arranging the objects and actions possible in a system in a way that facilitates perception and understanding

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Information Design

- Define and arrange the visual (and other modality) elements of a user interface
  - Screen layout, icon design, vocabulary selection
  - But also the “big picture” or overall info model
  - Models of perception, psychology guide this
- Engineering an information design
  - Make sure what people see (hear, etc.) makes sense, and helps them to pursue meaningful goals
  - Depends on *what they are doing*, hence the important role of user interaction scenarios

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Good Graphics

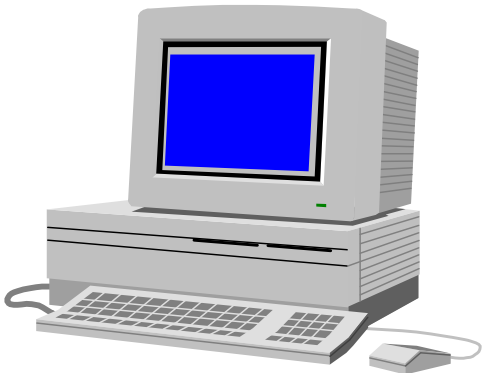
- Precision
- Clarity
- Maximize Data-to-ink ratio
  - Data Ink Ratio = (data ink) / (total ink in the plot)
- Minimize Lie factor
  - Lie factor = (size of graphic) / (size of data)

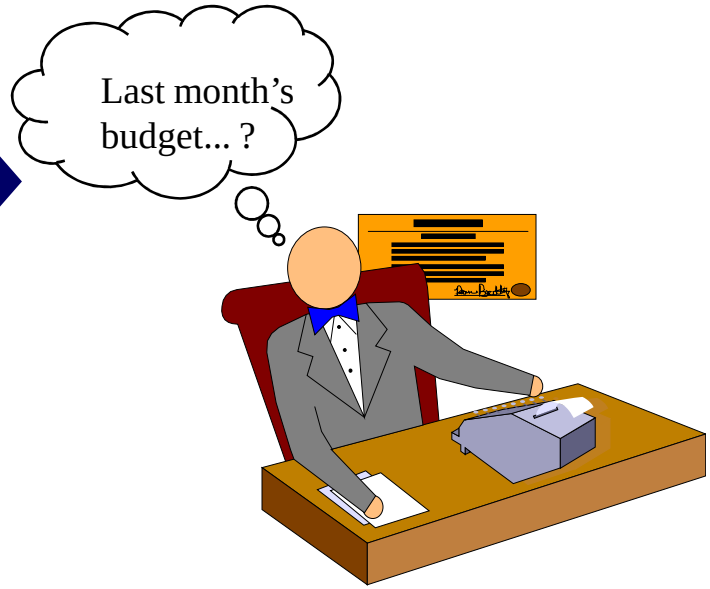
Making Sense of an Information Display

Perception
color, shading, lines
characters, squares,
spatial organization

Interpretation
Excel worksheet, a cell
is selected, formula is
displayed at top

Making Sense
Income worksheet,
Total tax income is being
calculated, the wrong
multipler is being used





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Perception for Design

- Using our understanding of the human perceptual systems to guide design
  - Visual system
  - Auditory system
  - Vestibular system
- Leverage pre-attentive facilities
- Reduce cognitive overhead

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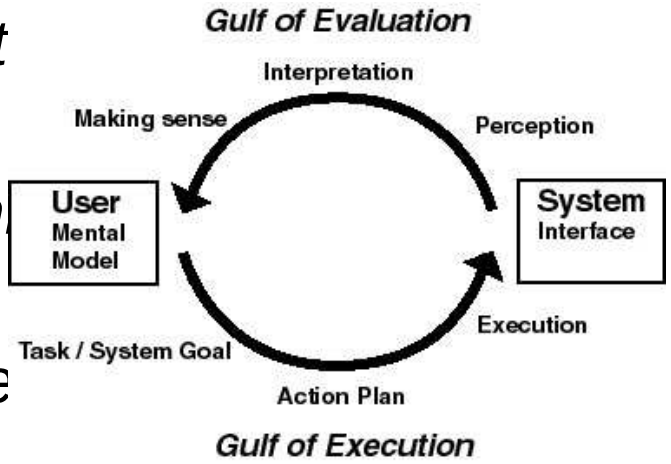
Perception

- Organize and encode sensory data in the mind
  - Lines, shapes, colors are “extracted”
  - Very fast, generally with no conscious thought
  - May be influenced by expectations, “top-down”
- Low-level units then grouped and organized
  - Perceived as rows, columns, grids, figures
  - Seeing the relationships among different elements
- Design goal: make this perceptual process rapid and accurate

Background: Information Psychophysics

- Edward Tufte, *Envisioning Informat*
  (1983, 1990)
- Jaques Bertin, *Semiology of Graph*
  (1983)
- Donald Norman, *Cognitive Enginee*
  (1986)
- Joseph Goguen, *Semiotic Morphisms*
  (2000)
- Colin Ware, *Perception for Design*
  (2003)



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Pre-attentive Processing

- Involuntary, do not require conscious attention
- Parallel
- Efficient
- Resistant to instruction

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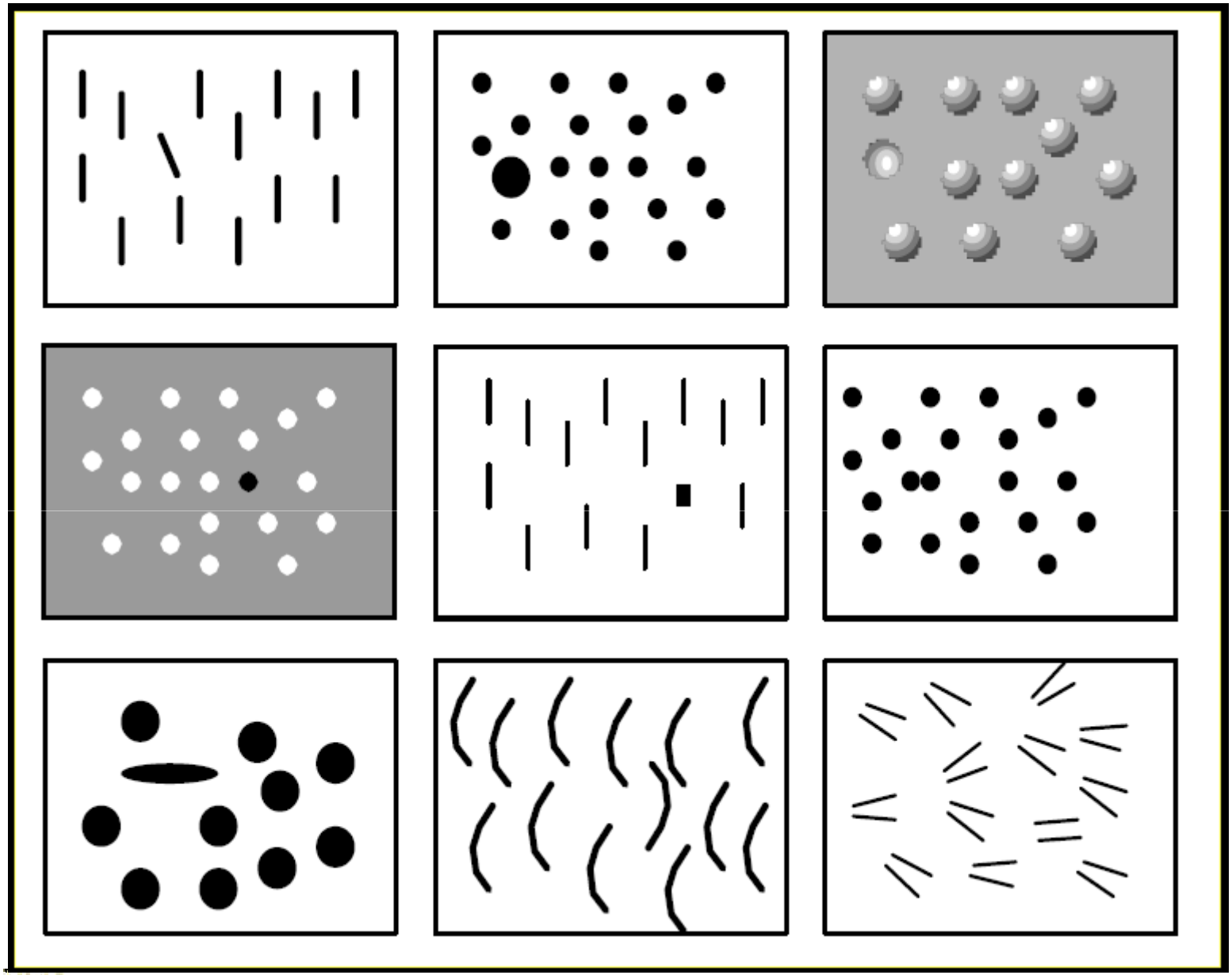
Attention

- Pop out effects ‘stand out’ in some simple dimension (conjunctions don’t):
  - Rapid visual search
  - Form, color, simple motion/blinking, spatial stereo depth, shading, position

1298762190902374 8
5943290870654839 4
0560248595437289 0
0989050987463223 4

Virginia Tech



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Frame Rate

- Threshold for perceiving continuity:
  - flicker < 50 Hz
  - > 24 fps looks smooth & plenty interactive
- Flicker & Attention can lead to change blindness (Simmons, 2000)

- Browser.getCurrentFrameRate()
- Implementing X3DPerFrameObserverScript
  - public void prepareEvents (){}

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Attention and blindness

- http://viscog.beckman.uiuc.edu/djs_lab/demos.html
- http://www.psych.ubc.ca/~rensink/flicker/
  - http://www.psych.ubc.ca/~rensink/flicker/download/index.html

Virginia Tech

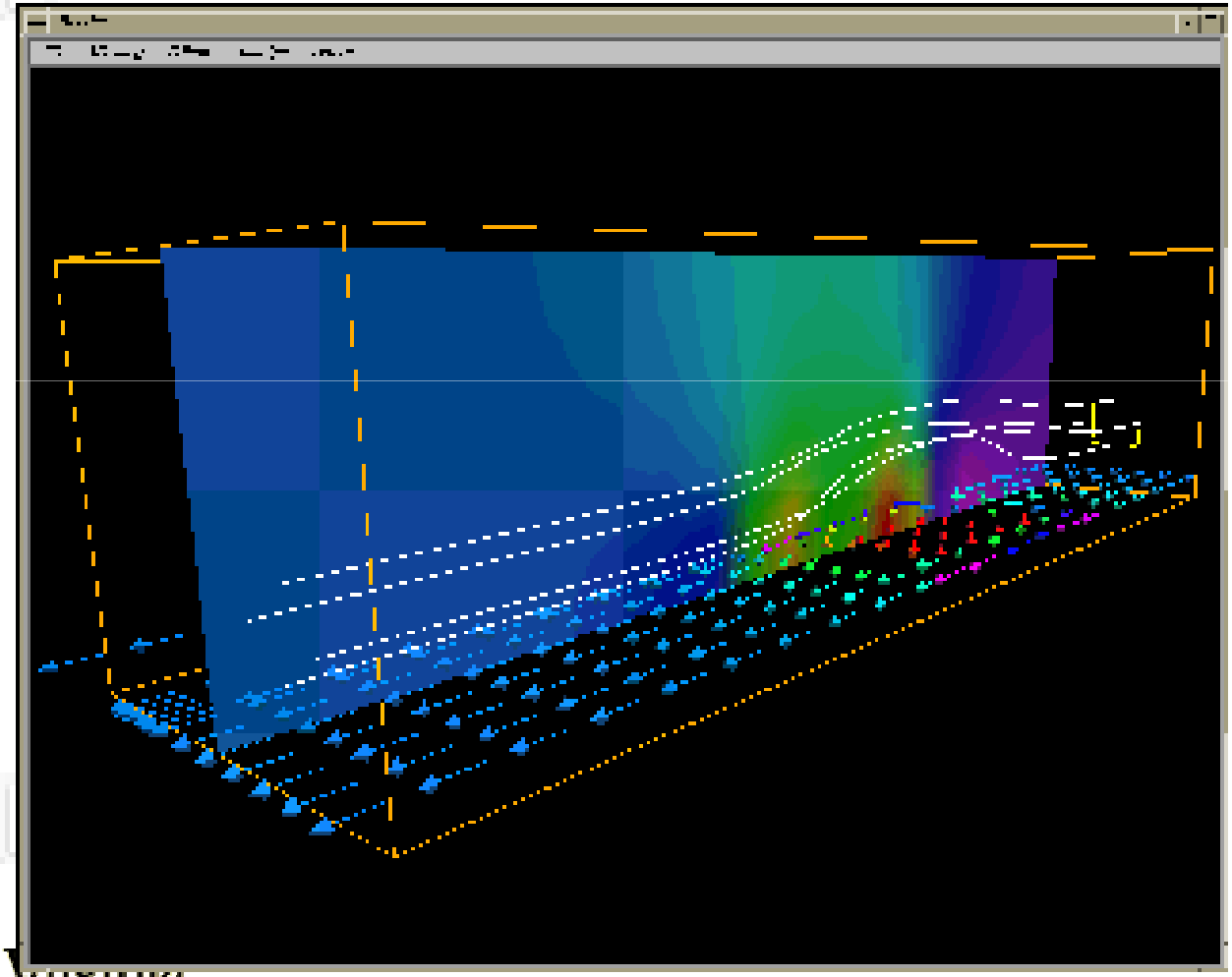
Animation Guidelines

- The higher the frame-rate the better
- Beware data assumptions:

  Interpolation versus Sequencing
- Provide user control over time ?

  (e.g. DVDTimeController)

Representing multiple properties



- Flow of air around a car
  - Vectors and particle paths illustrate flow
  - Coloured slice indicates pressure

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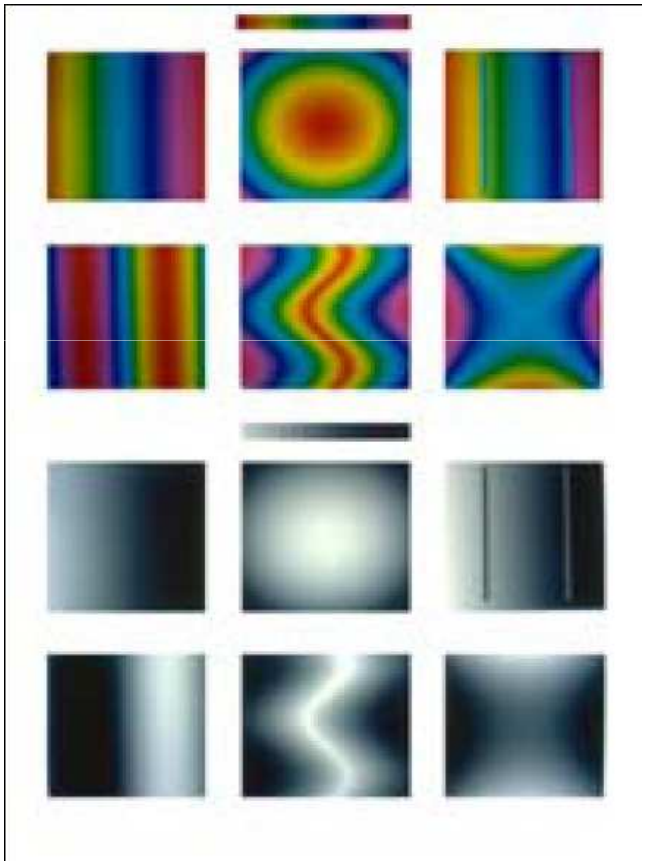
Features: Color

- Luminance channel
  (3x spatial accuity)
- Red / Green channel
- Yellow / Blue channel

The spectrum is not a perceptually linear sequence (not pre-attentive)!
(Keller 1993; Ware, 2000)



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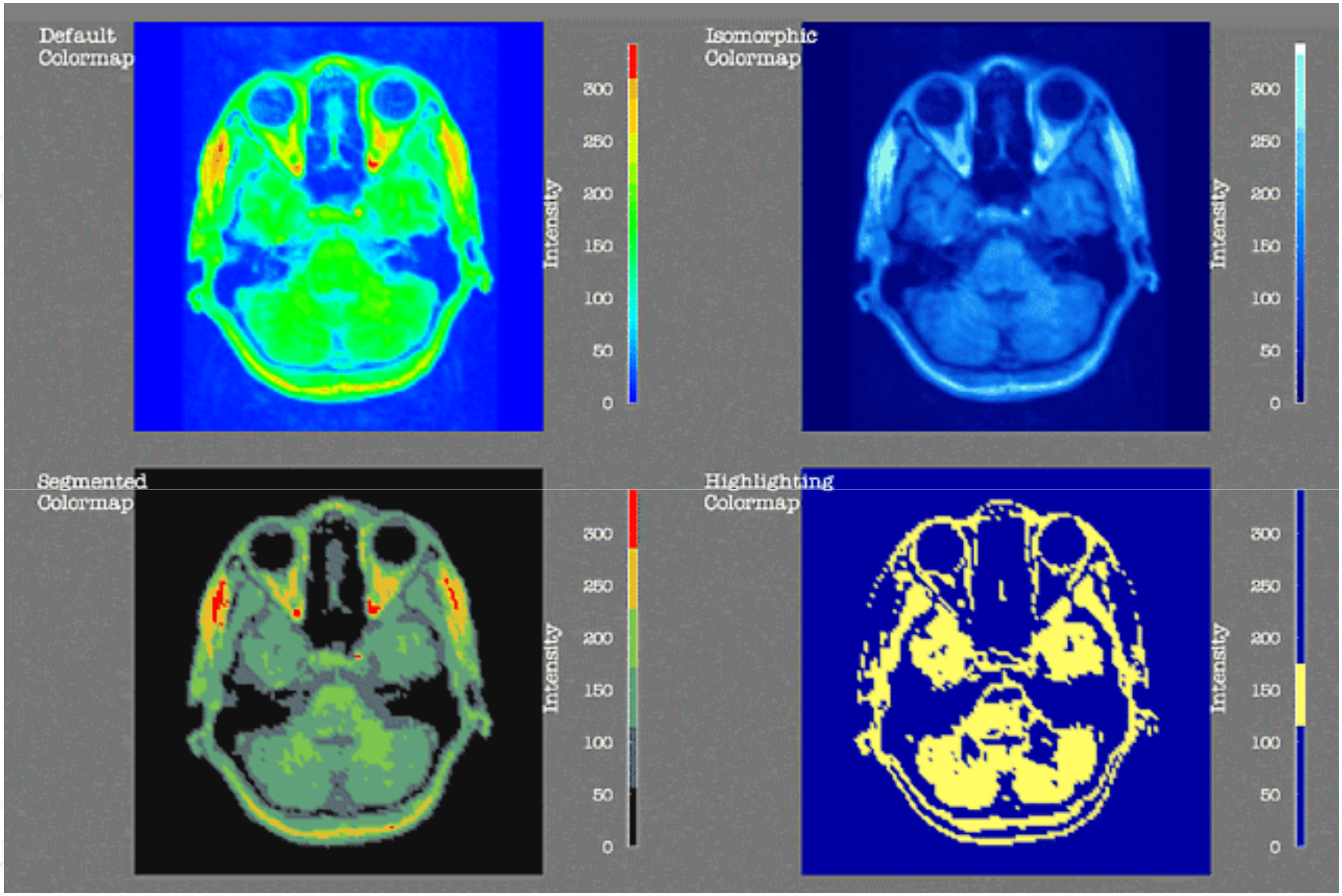

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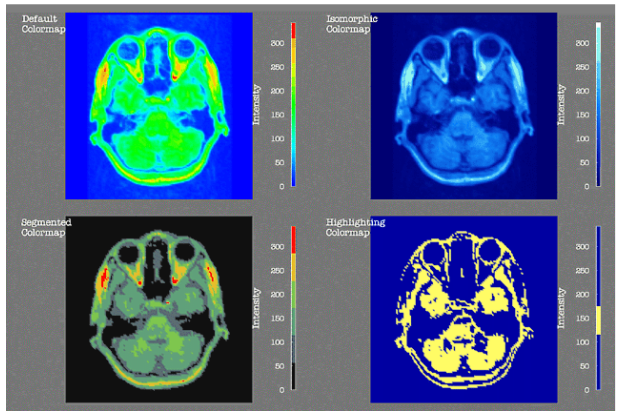
IBM

Color (again)



- **IBM Research and color maps:**
  http://www.research.ibm.com/dx/proceedings/pravda/truevis.htm

- **Human factors in visualization research**
  Tory, M.; Moller, T.;
  Visualization and Computer Graphics, IEEE Transactions on
  Volume 10, Issue 1, Jan-Feb 2004 Page(s):72 - 84
  http://doi.ieeecomputersociety.org/10.1109/TVCG.2004.1260759

- **Color Spectra and Scales**
  http://geography.uoregon.edu/datagraphics/EOS/Light&Bartlein_EOS2004.pdf

- **Some guidelines for Sci Vis:**

http://www-ugrad.cs.colorado.edu/~csci4576/SciVis/SciVisColor.html#ColorGuidelines

- **More detail about CG color models**

http://www.ncsu.edu/scivis/lessons/colormodels/color_models2.html

Making Sense of an Information Display

Interpretation
Excel worksheet, a cell is selected, formula is displayed at top

Perception
color, shading, lines characters, squares, spatial organization

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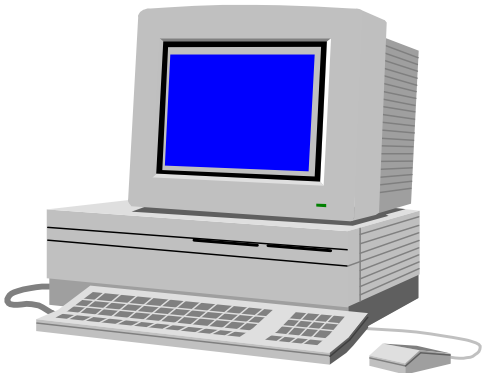

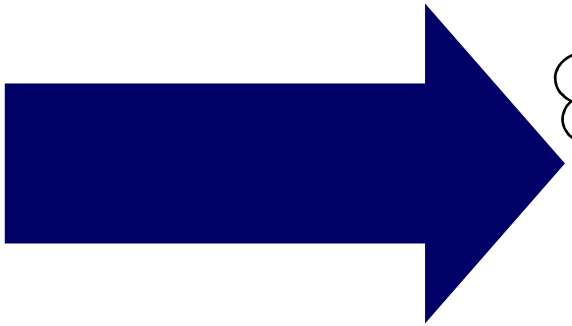

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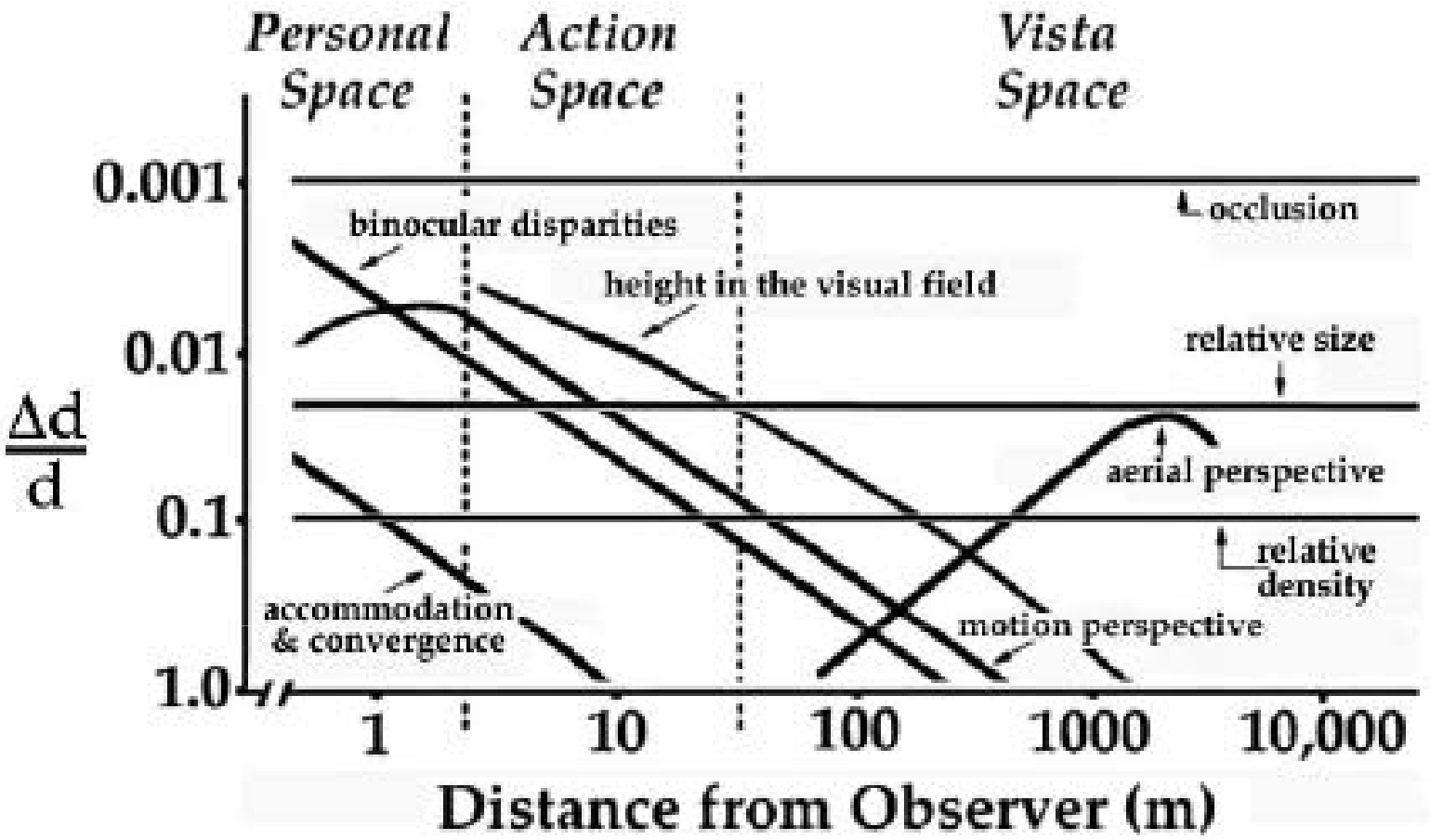
Interpretation

- Perceiving enables interpretation
  - Perceptual processing identifies major display structures (rectangles, text strings, etc)
  - Users must interpret what these display structures mean in the system
- Designers must anticipate and support user reactions to interface elements
  - Choosing familiar images, symbols, words
  - Refining elements through abstraction
  - Promoting affordances that users can recognize

Depth Cues

Structure the world- locating objects and relationships in space

- Stereoscopy
- Motion parallax
- Relative size / scale
- Fog / atmosphere…



Cutting, J.E., and Vishton, P.M. (1995). Perceiving layout and knowing distances: The integration, relative potency, and contextual use of different information about depth. In: Epstein, W., and Rogers, S. (Eds.) *Perceptual Space. New York: Academic Press.*

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Patterns & Grouping

- Gestalt principles

- Also: continuation, closure, common fate
- Guiding Law of Pragnanz (simplest, most stable configuration)

Gestalt principles

- Palmer & Rock, 1990– review & update principles; grouping based on perceived proximity in 3D space (not 2D proximity on retina)
- Quinlan & Wilton, 1998 – study involving Gestalt conflict; proposed resolution mechanisms

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Objects

- Feature Binding – putting the streams together for internal represenation
  - color, form, motion
  - Just in time?
- 2.5 D sketch (Marr, 1982)
- Geons (Biederman, 1993)

Fundamental Data Types

- Spatial / perceptual data:

  geometry, colors, textures, lighting

- Abstract data / world & object attributes:

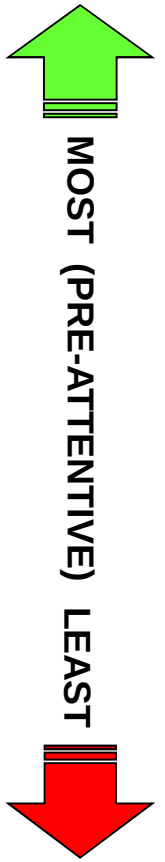
  nominal, ordinal, quantitative

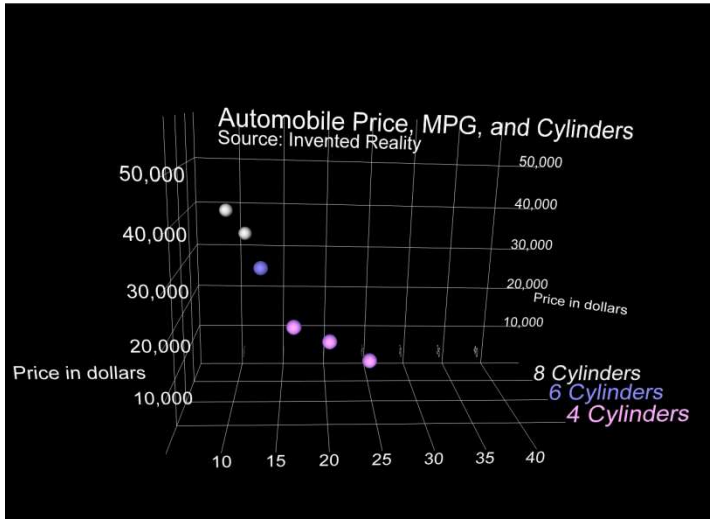
- Temporal data / behaviors:

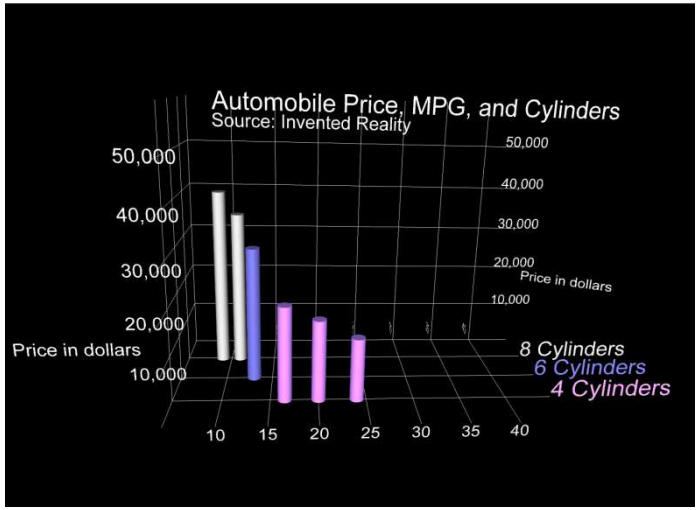
  states, dynamics

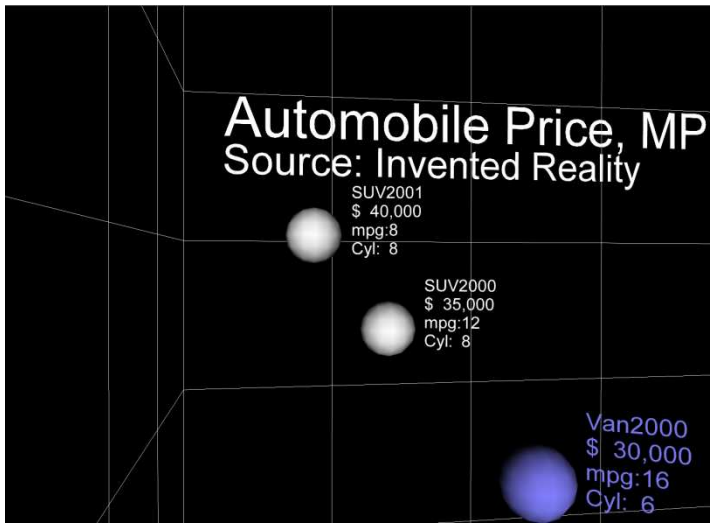
InfoVis: Visual Markers

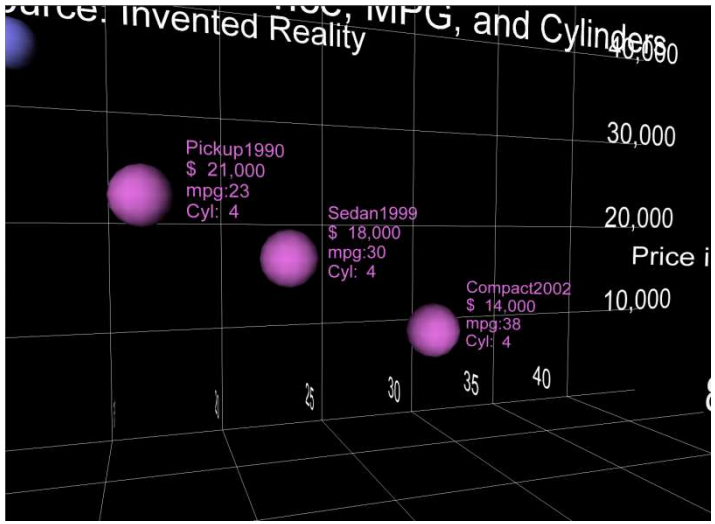
Data Type	Quantitative	Ordinal	Nominal
Graphical Representation	position length angle / slope area volume color / density (Cleveland and McGill, 1980)	position density color texture connection containment length angle slope area volume (Mackinlay, 1986)	position color texture connection containment density shape length angle slope area volume (Mackinlay, 1986)











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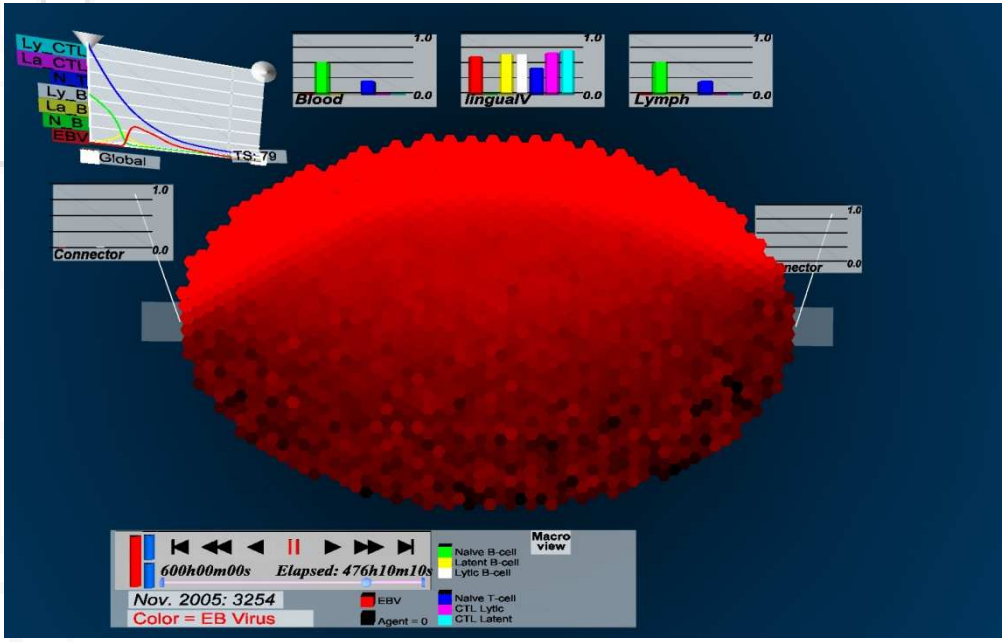
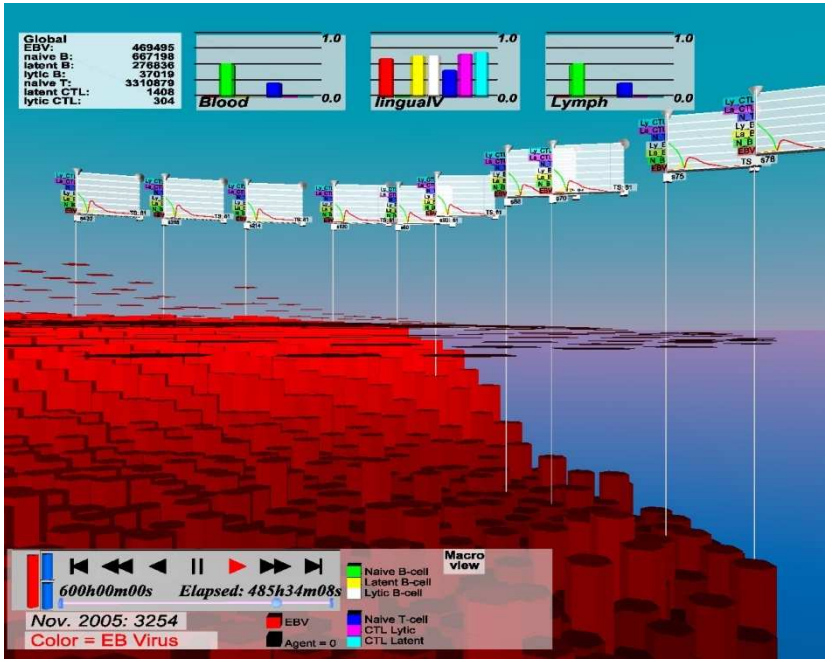
PathSim example





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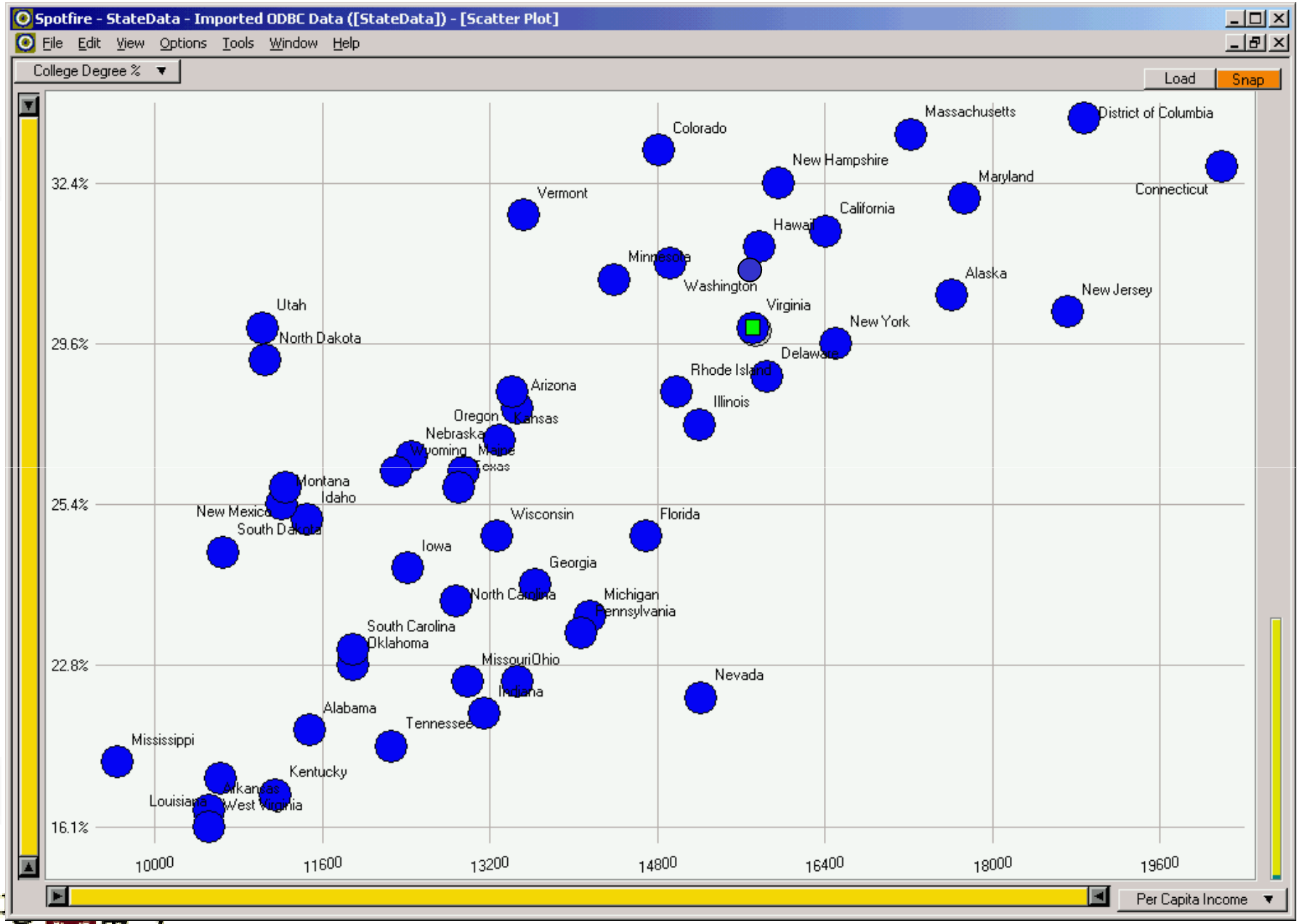
- Which state has highest income?
- Relationship between income and education?
- Outliers?

Table - StateData ()

Load | Snap

State	College Degree %	Per Capita Income
Alabama	20.6%	11486
Alaska	30.3%	17610
Arizona	27.1%	13461
Arkansas	17.0%	10520
California	31.3%	16409
Colorado	33.9%	14821
Connecticut	33.8%	20189
Delaware	27.9%	15854
District of Columbia	36.4%	18881
Florida	24.9%	14698
Georgia	24.3%	13631
Hawaii	31.2%	15770
Idaho	25.2%	11457
Illinois	26.8%	15201
Indiana	20.9%	13149
Iowa	24.5%	12422
Kansas	26.5%	13300
Kentucky	17.7%	11153
Louisiana	19.4%	10635
Maine	25.7%	12957
Maryland	31.7%	17730
Massachusetts	34.5%	17224
Michigan	24.1%	14154
Minnesota	30.4%	14389
Mississippi	19.9%	9648
Missouri	22.3%	12989
Montana	25.4%	11213
Nebraska	26.0%	12452
Nevada	21.5%	15214
New Hampshire	32.4%	15959
New Jersey	30.1%	18714
New Mexico	25.5%	11246
New York	29.6%	16501
North Carolina	24.2%	12885
North Dakota	28.1%	11051
Ohio	22.3%	13461
Oklahoma	22.8%	11893
Oregon	27.5%	13418
Pennsylvania	23.2%	14068
Rhode Island	27.5%	14981
South Carolina	23.0%	11897
South Dakota	24.6%	10661
Tennessee	20.1%	12255
Texas	25.5%	12904
Utah	30.0%	11029
Vermont	31.5%	13527
Virginia	30.0%	15713
Washington	30.9%	14923
West Virginia	16.1%	10520
Wisconsin	24.9%	13276
Wyoming	25.7%	12311

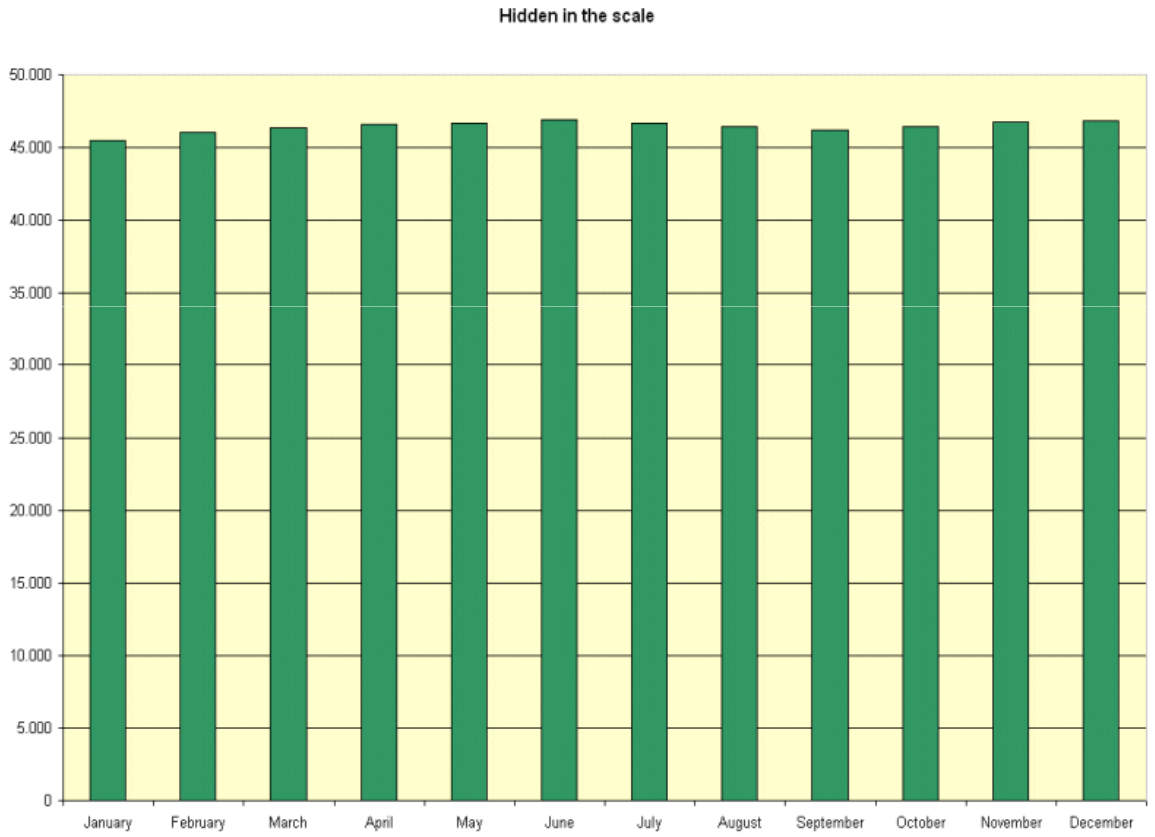


College Degree %

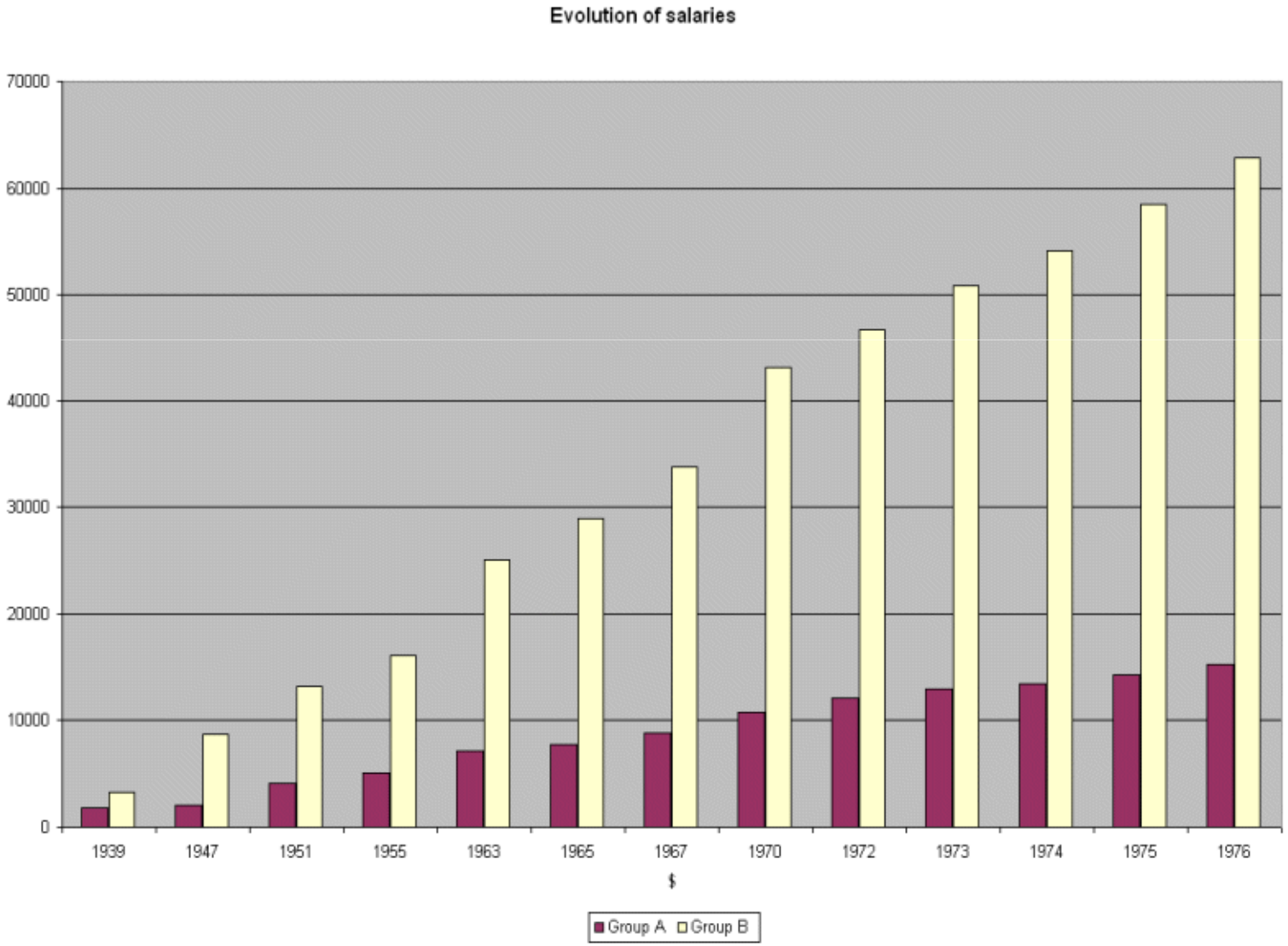
Per Capita Income

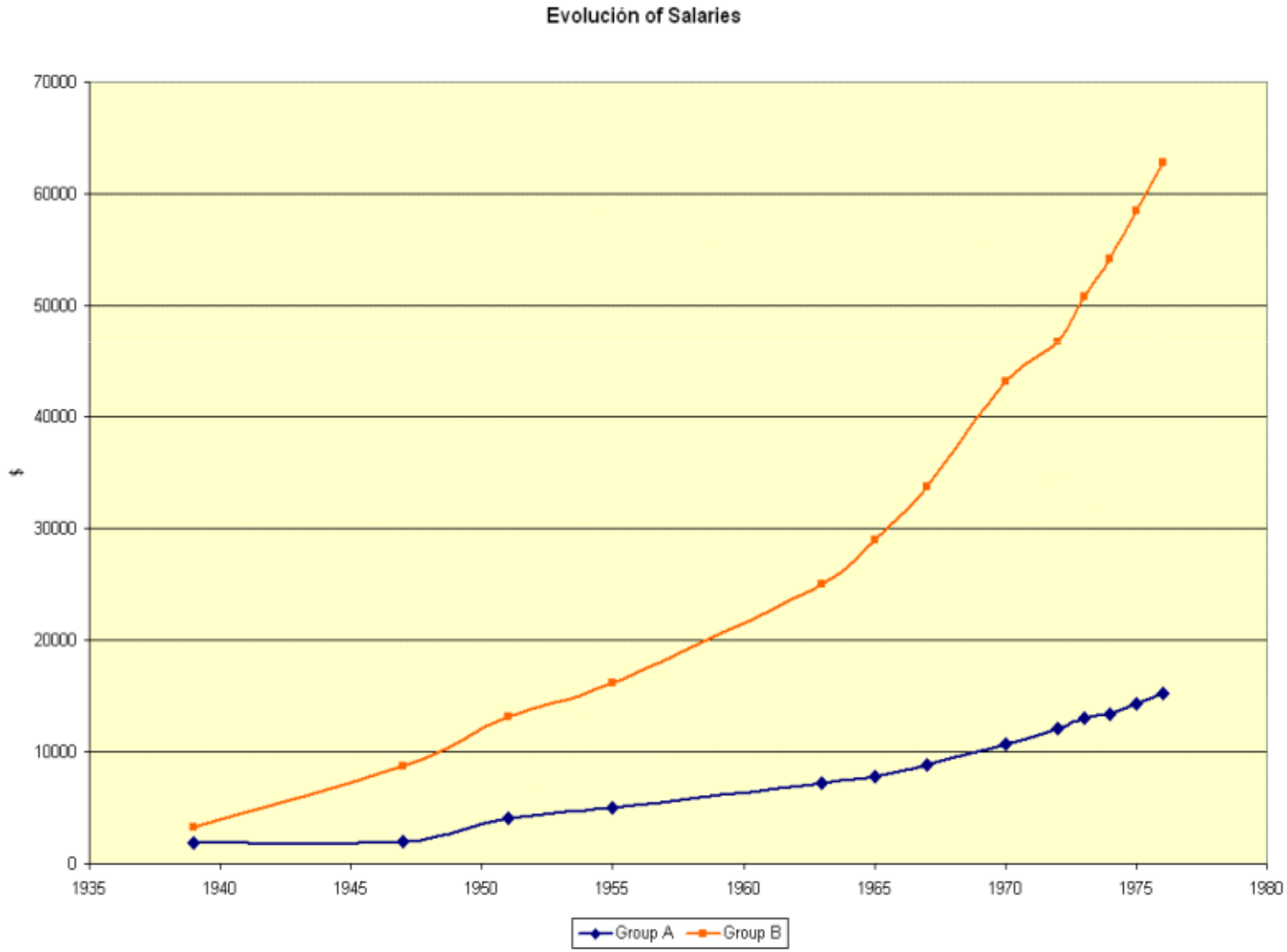
Tech

Scale



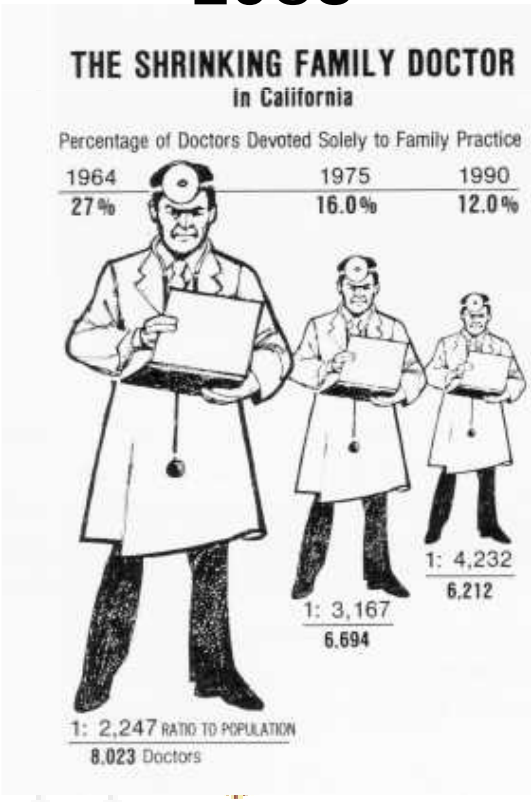
Virginia Tech


Evolution of salaries
70000
60000
50000
40000
30000
20000
10000
0
1939
1947
1951
1955
1963
1965
1967
1970
1972
1973
1974
1975
1976
$
Group A
Group B


Evolución of Salaries
70000
60000
50000
40000
30000
20000
10000
0
$
1935
1940
1945
1950
1955
1960
1965
1970
1975
1980
Group A
Group B

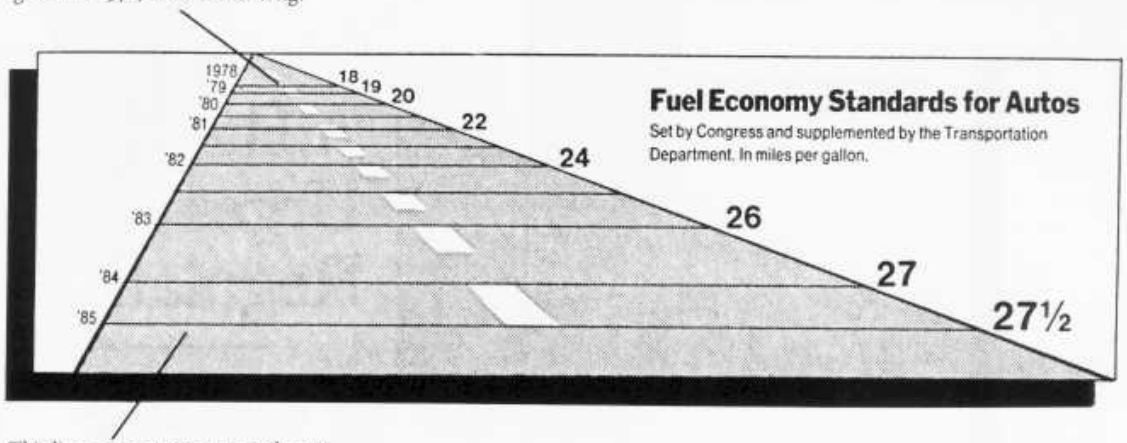
Lying

From Tufte
1983



Los Angeles Times, August 5, 1979, p. 3.

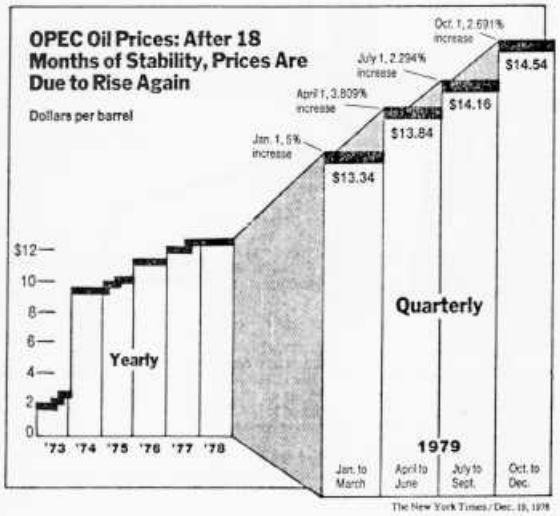
This line, representing 18 miles per gallon in 1978, is 0.6 inches long.



This line, representing 27.5 miles per gallon in 1985, is 5.3 inches long.

New York Times, August 9, 1978, p. D-2.

Design variation corrupts this display:



New York Times, December 19, 1978, p. D-7.

Human Limitations for Short-Term Memory

- Miller's 7 +/- 2 magic number
  - People can recognize 7 +/- 2 chunks of information at a time and hold these chunks in memory for 15-30 seconds
- Chunking
  - Ability to cluster information together
  - Size of chunk depends on knowledge, experience, and familiarity

Virginia Tech

Chunking Example 1

HEC ATR ANU PTH ETR EET

Virginia Tech

Chunking Example 2

THE CAT RAN UP THE TREE

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Other Chunking Examples

- Image sequences
- Facial recognition
- Word/letter familiarity
- Hierarchies of information
- Others?

Virginia Tech

Making Sense of an Information Display

Interpretation

Excel worksheet, a cell is selected, formula is displayed at top

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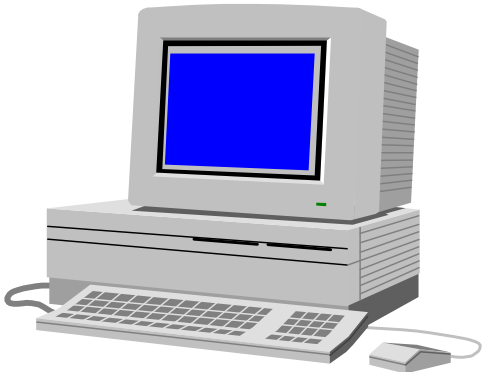
Income worksheet, Total tax income is being calculated, the wrong multipler is being used



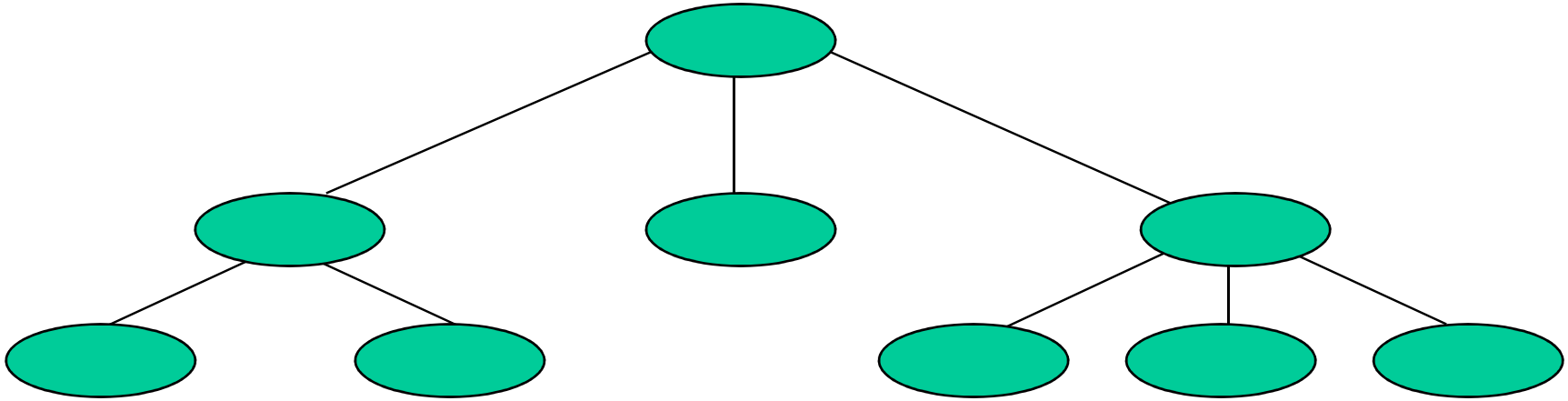
Virginia Tech

Making Sense

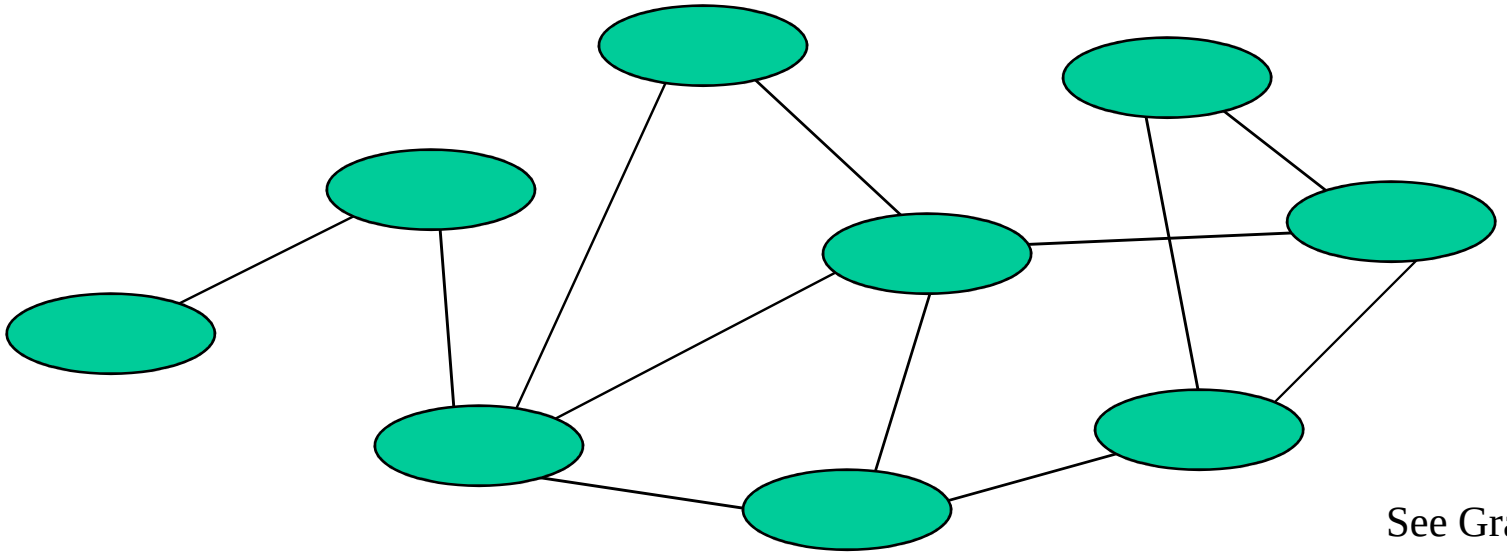
- Last step in crossing the Gulf of Evaluation
  - Information has been perceived and interpreted
  - Users must “make sense” of information by relating it to their tasks, goals, and interests
- Designers must support people’s abilities to detect patterns and relationships
  - Consistent use of shape, size, color, position
  - Information models (e.g., hierarchies) organize data
  - Dynamic displays cue users to structure

Important Considerations

- Understanding the domain
- Understanding the Research Question
- Understanding the purpose of the Vis
  - User and reader tasks



Which network is easier to understand?

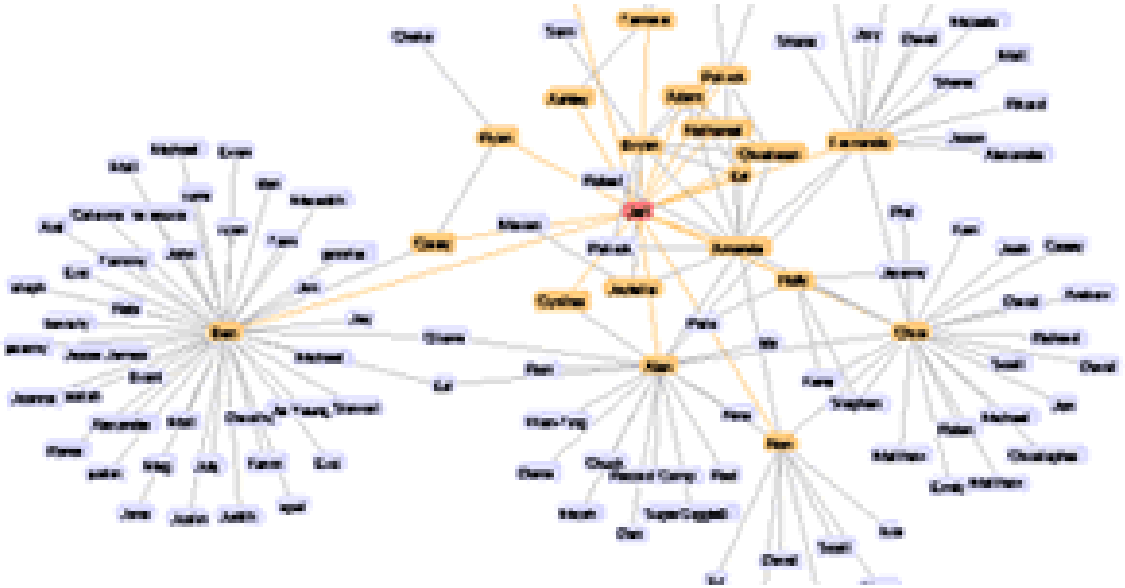


See Graph Vis !

Graph Layout is still hard

- Prefuse.org – GraphML
- GraphVis – dot format
- Network Workbench - nwb

  http://nwb.cns.iu.edu/



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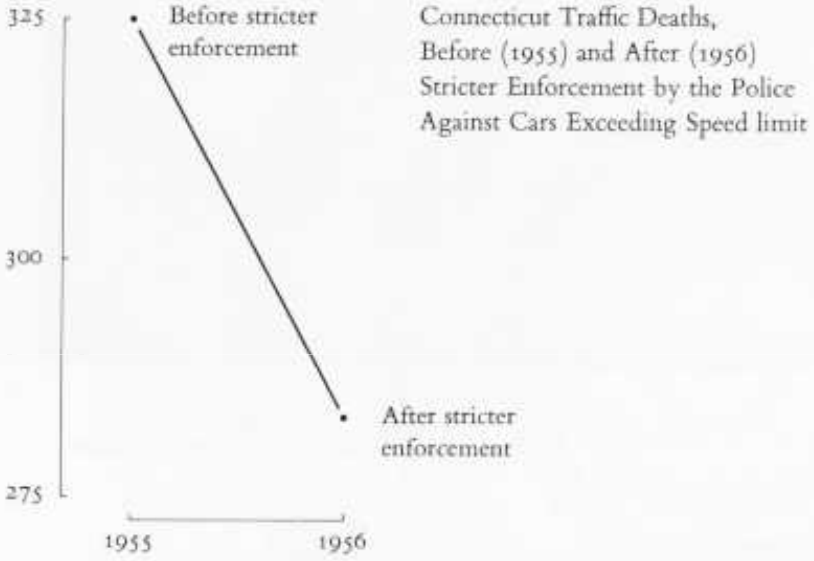
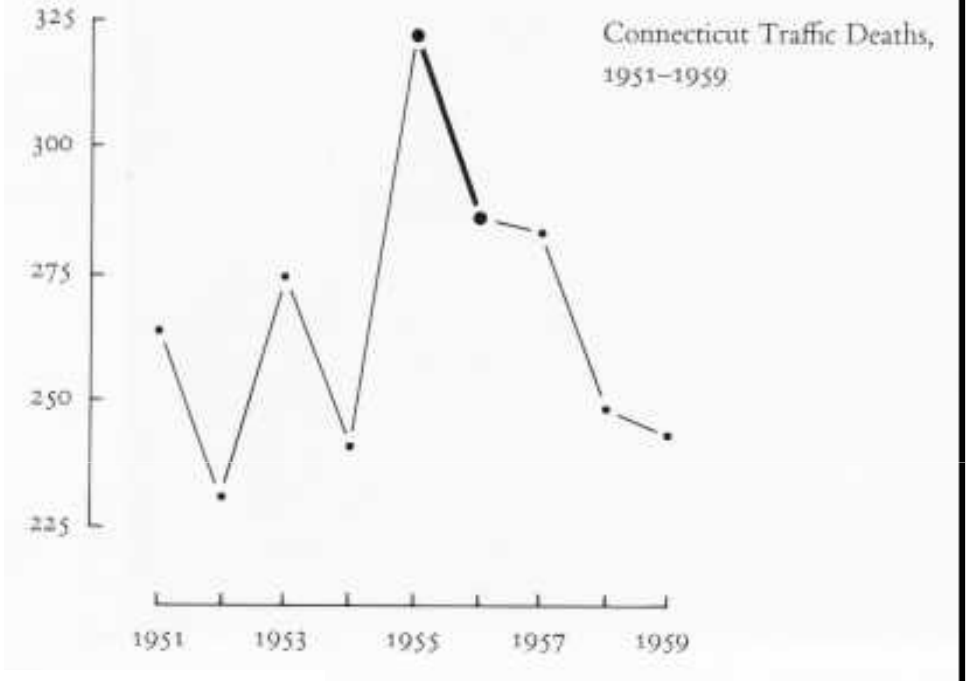
Context Required

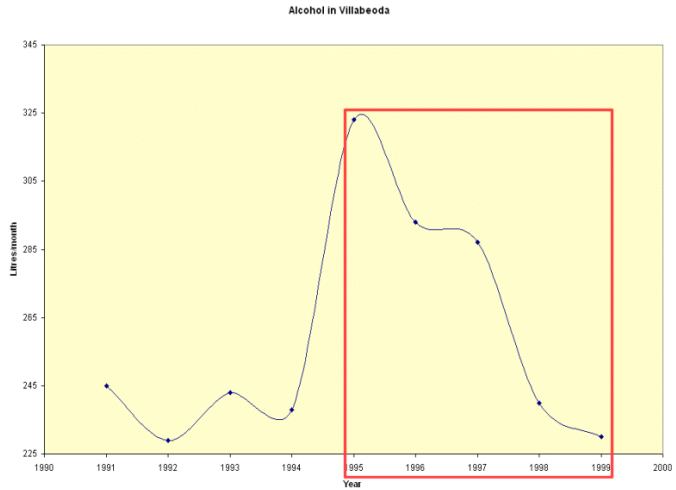
Graphics must not quote data out of context.

Nearly all the important questions are left unanswered by this display:



A few more data points add immensely to the account:





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Immersive Virtual Environments

- Leveraging Spatial perception and knowledge
- Embodied interaction
- Examples
- More at last class!

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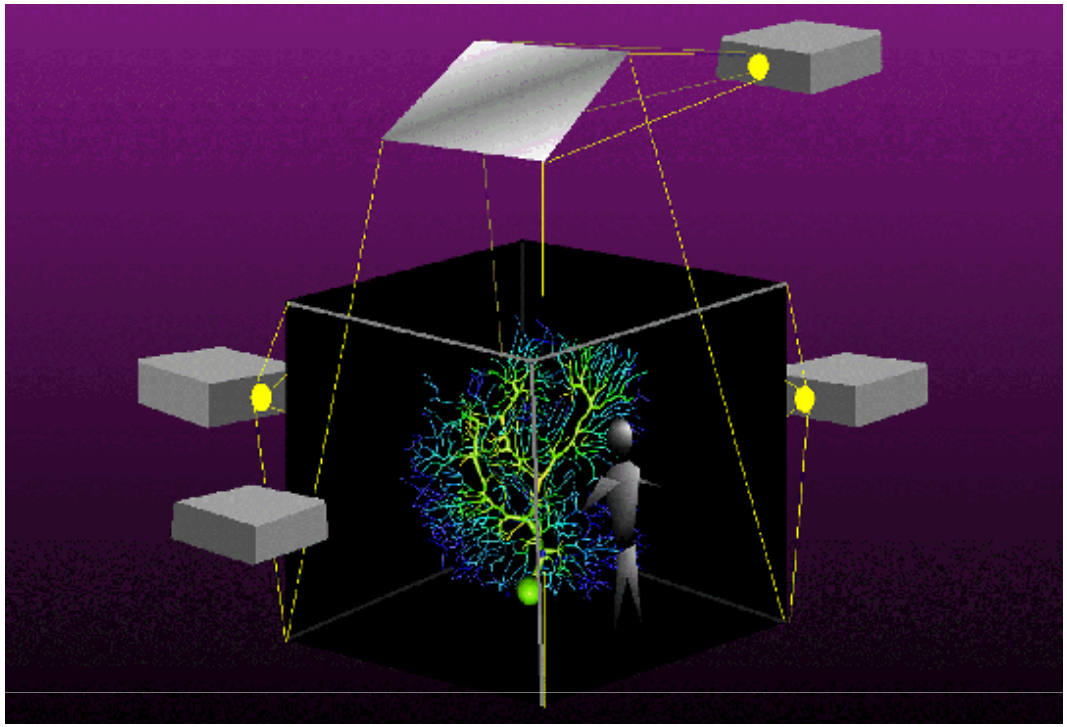
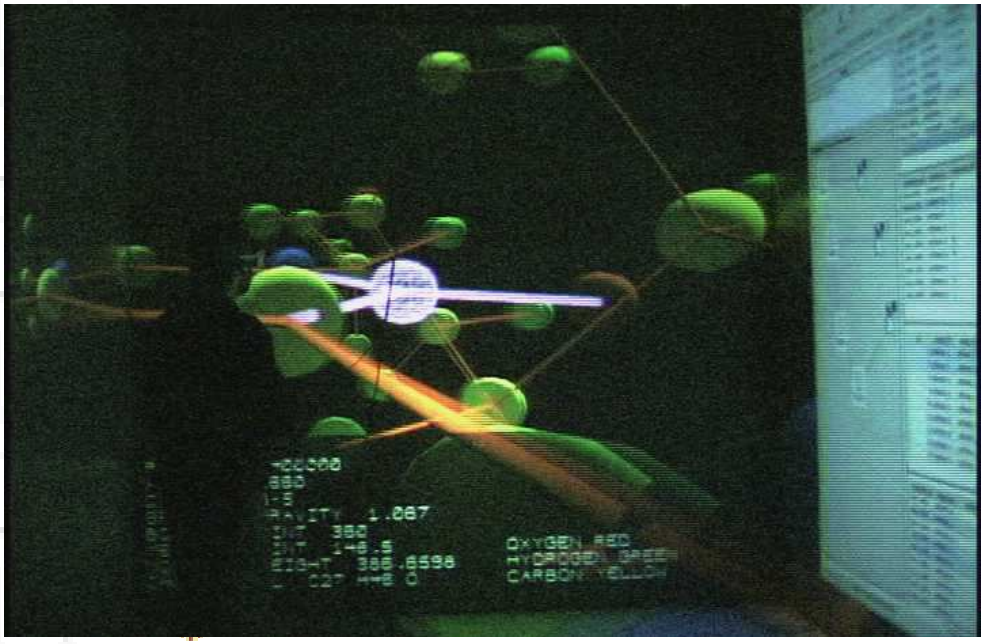
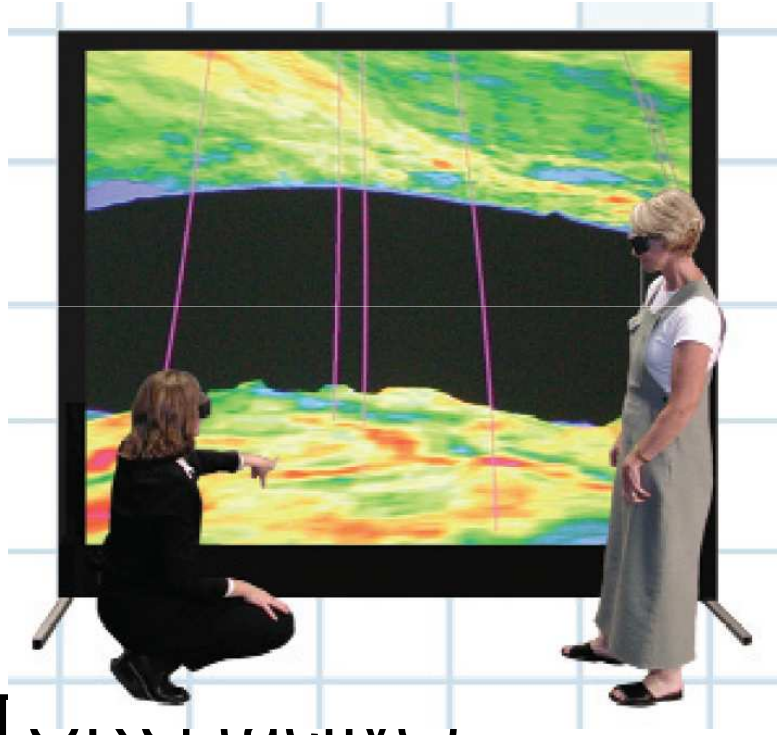



OXYGEN RED
CARBON YELLOW

Stereo Walls



TCRS (active)

Andrews (passive)

3-4 additional in labs around campus

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ParaView

- Use your knowledge to present the important aspects of the simulation data as:
- An image
- A movie

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