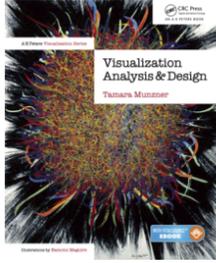


Visualization Analysis & Design

Half-Day Tutorial



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University of British Columbia

IEEE VIS 2019 Tutorial
October 2019, Vancouver BC Canada
<http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse19>

@tamaramunzner

Outline

- Session 1 9:00-10:30am**
 - Analysis: What, Why, How
 - Marks and Channels
 - Arrange Tables
 - Arrange Spatial Data
 - Arrange Networks and Trees
- Session 2 10:50am-12:20pm**
 - Map Color and Other Channels
 - Manipulate: Change, Select, Navigate
 - Facet: Juxtapose, Partition, Superimpose
 - Reduce: Filter, Aggregate
 - Embed: Focus+Context

<http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse19>

@tamaramunzner

Defining visualization (vis)

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

Why?...

Why have a human in the loop?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

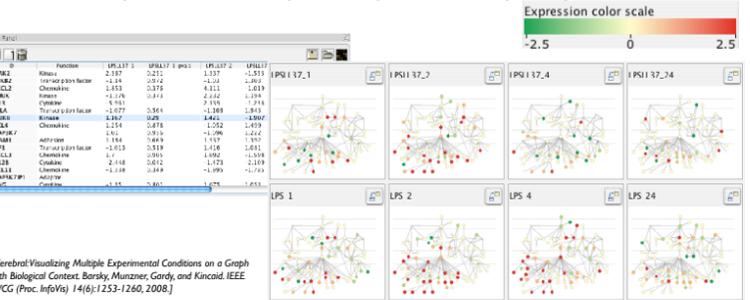
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- don't need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
 - don't know exactly what questions to ask in advance
- possibilities
 - long-term use for end users (ex: exploratory analysis of scientific data)
 - presentation of known results (ex: New York Times Upshot)
 - stepping stone to better understanding of requirements before developing models
 - help developers of automatic solution refine/debug, determine parameters
 - help end users of automatic solutions verify, build trust

Why use an external representation?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- external representation: replace cognition with perception



[Cerebra] Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Bersky, Munzner, Gady, and Kincaid. IEEE TVCG (Proc. InfoVis) 14(6):1253-1260, 2008.

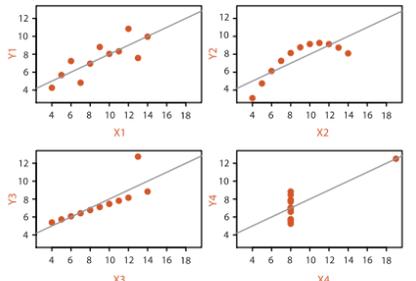
Why represent all the data?

Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively.

- summaries lose information, details matter
 - confirm expected and find unexpected patterns
 - assess validity of statistical model

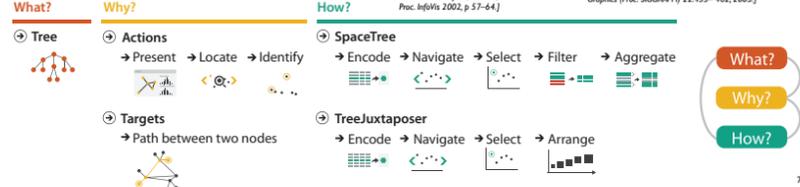
Anscombe's Quartet

Identical statistics	
x mean	9
x variance	10
y mean	7.5
y variance	3.75
x/y correlation	0.816



Why analyze?

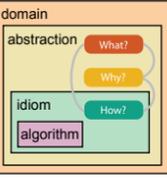
- imposes structure on huge design space
 - scaffold to help you think systematically about choices
 - analyzing existing as stepping stone to designing new
 - most possibilities ineffective for particular task/data combination



Analysis framework: Four levels, three questions

[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

- domain situation
 - who are the target users?
- abstraction
 - translate from specifics of domain to vocabulary of vis
 - what is shown? data abstraction
 - why is the user looking at it? task abstraction
- idiom
 - how is it shown?
 - visual encoding idiom: how to draw
 - interaction idiom: how to manipulate
- algorithm
 - efficient computation



[A Multi-Level Typology of Abstract Visualization Tasks. Behrmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).]

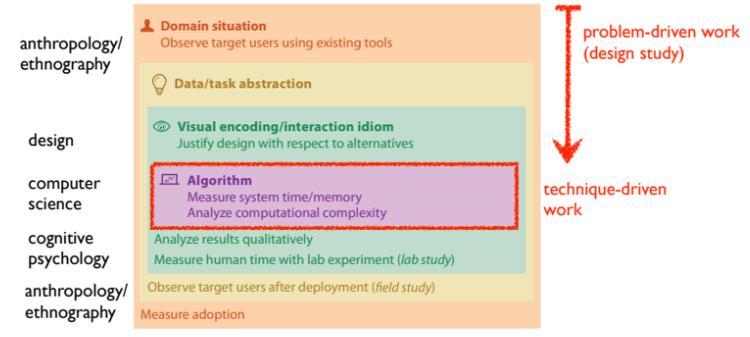
Why is validation difficult?

- different ways to get it wrong at each level



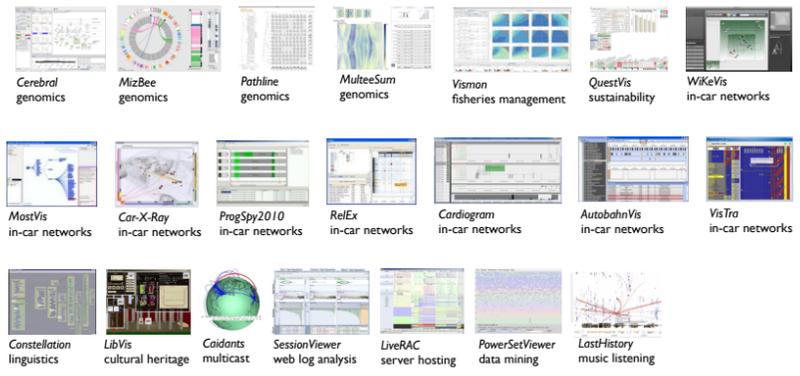
Why is validation difficult?

- solution: use methods from different fields at each level



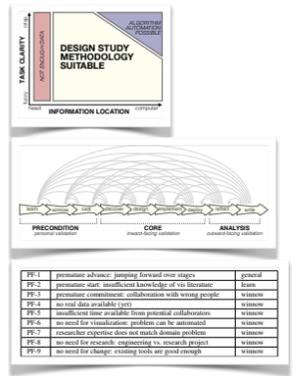
[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

Design Studies: Lessons learned after 21 of them

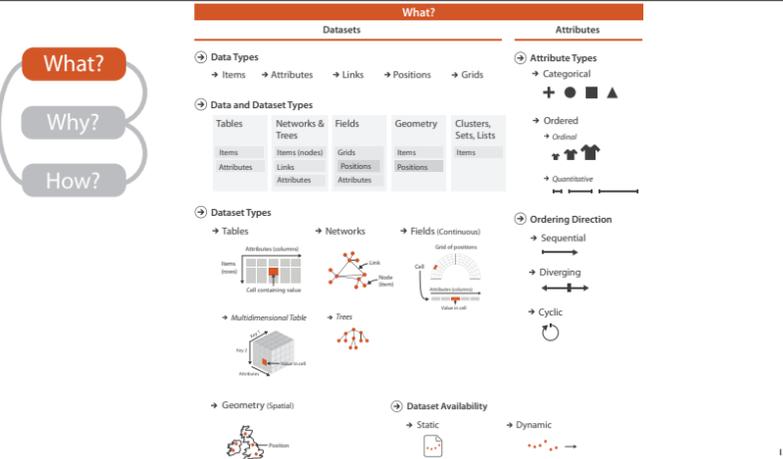


Design Study Methodology: Reflections from the Trenches and the Stacks

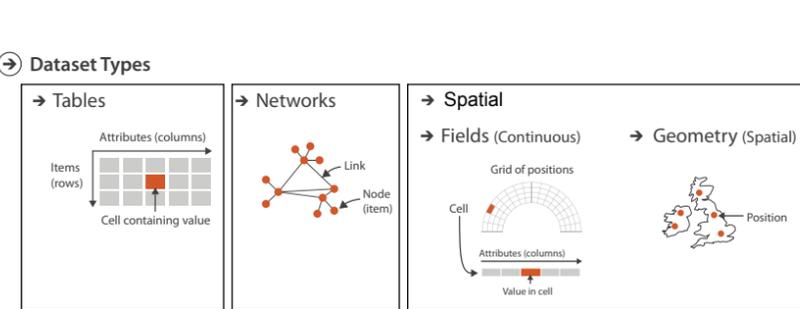
- definitions
- 9-stage framework
- 32 pitfalls and how to avoid them



[Sedlmair, Meyer, Munzner. IEEE Trans. Visualization and Computer Graphics 18(12): 2431-2440, 2012 (Proc. InfoVis 2012).]

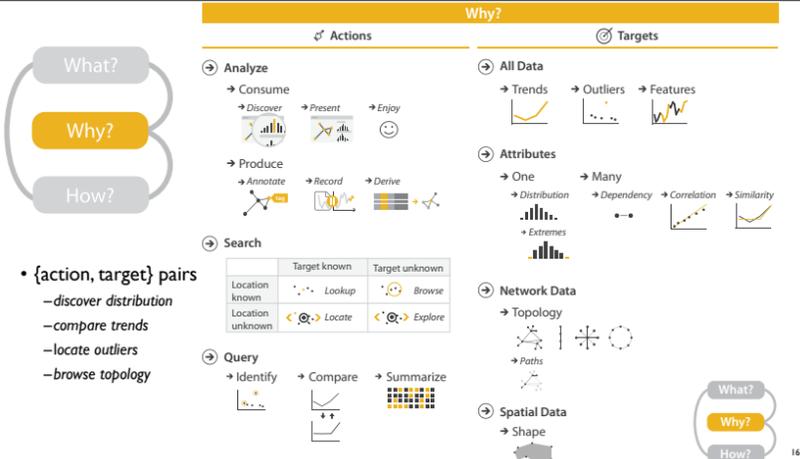
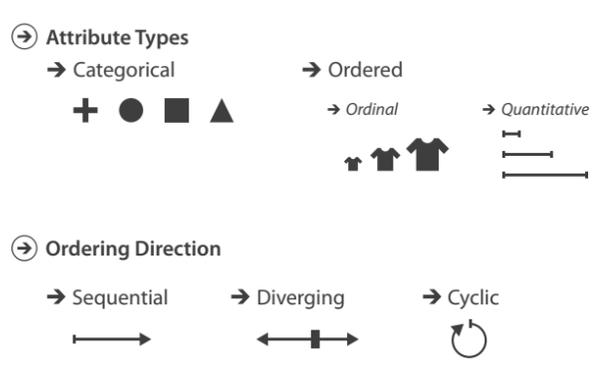


Three major datatypes



- visualization vs computer graphics
 - geometry is design decision

Attribute types



Actions: Analyze, Query

- analyze**
 - consume
 - discover vs present
 - aka explore vs explain
 - enjoy
 - aka casual, social
 - produce
 - annotate, record, derive
- query**
 - how much data matters?
 - one, some, all
- independent choices**
 - analyze, query, (search)

Derive

- don't necessarily just draw what you're given!
 - decide what the right thing to show is
 - create it with a series of transformations from the original dataset
 - draw that
- one of the four major strategies for handling complexity

Original Data Derived Data

Analysis example: Derive one attribute

- Strahler number**
 - centrality metric for trees/networks
 - derived quantitative attribute
 - draw top 5K of 500K for good skeleton

[Using Strahler numbers for real time visual exploration of huge graphs. Auber. Proc. Intl. Conf. Computer Vision and Graphics, pp. 56-69, 2002.]

Task 1: In Tree → Out Quantitative attribute on nodes → Derive

Task 2: In Tree + In Quantitative attribute on nodes → Out Filtered Tree (Removed unimportant parts) → Summarize, Reduce, Topology, Filter

Why: Targets

- All Data**
 - Trends
 - Outliers
 - Features
- Network Data**
 - Topology
 - Paths
- Attributes**
 - One
 - Distribution
 - Extremes
 - Many
 - Dependency
 - Correlation
 - Similarity
- Spatial Data**
 - Shape

How?

Encode	Manipulate	Facet	Reduce
<ul style="list-style-type: none"> Arrange <ul style="list-style-type: none"> Express Order Use Map from categorical and ordered attributes <ul style="list-style-type: none"> Color (Hue, Saturation, Luminance) Size, Angle, Curvature, ... Shape Motion (Direction, Rate, Frequency, ...) 	<ul style="list-style-type: none"> Change Select Navigate 	<ul style="list-style-type: none"> Juxtapose Partition Superimpose 	<ul style="list-style-type: none"> Filter Aggregate Embed

What? Why? How?

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 1: What's Vis, and Why Do It?
 - Chap 2: What: Data Abstraction
 - Chap 3: Why: Task Abstraction
- A Multi-Level Typology of Abstract Visualization Tasks. Brehmer and Munzner. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 19:12 (2013), 2376-2385.
- Low-Level Components of Analytic Activity in Information Visualization. Amar, Eagan, and Stasko. Proc. IEEE InfoVis 2005, p 111-117.
- A taxonomy of tools that support the fluent and flexible use of visualizations. Heer and Shneiderman. Communications of the ACM 55:4 (2012), 45-54.
- Rethinking Visualization: A High-Level Taxonomy. Tory and Möller. Proc. IEEE InfoVis 2004, p 151-158.
- Visualization of Time-Oriented Data. Aigner, Miksch, Schumann, and Tominski. Springer, 2011.

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<http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse19> @tamaramunzner

How?

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What? Why? How?

Visual encoding

- analyze idiom structure

Definitions: Marks and channels

- marks**
 - geometric primitives
- channels**
 - control appearance of marks
- channel properties differ**
 - type & amount of information that can be conveyed to human perceptual system
 - show magnitude vs. identity
 - accuracy of perception
 - number of discriminable bins

Visual encoding

- analyze idiom structure
- as combination of marks and channels

1: vertical position 2: vertical position horizontal position 3: vertical position horizontal position color hue 4: vertical position horizontal position color hue size (area)

mark: line mark: point mark: point mark: point

Channels

Position on common scale	Spatial region
Position on unaligned scale	Color hue
Length (1D size)	Motion
Tilt/angle	Shape
Area (2D size)	
Depth (3D position)	
Color luminance	Same
Color saturation	
Curvature	Same
Volume (3D size)	

Channels: Matching expressiveness

Magnitude Channels: Ordered Attributes	Identity Channels: Categorical Attributes
Position on common scale	Spatial region
Position on unaligned scale	Color hue
Length (1D size)	Motion
Tilt/angle	Shape
Area (2D size)	
Depth (3D position)	
Color luminance	Same
Color saturation	
Curvature	Same
Volume (3D size)	

- expressiveness principle**
 - match channel and data characteristics
- Attribute Types**
 - Categorical: +, ●, ■, ▲
 - Ordered: → Ordinal, → Quantitative

Channels: Ranking effectiveness

Magnitude Channels: Ordered Attributes	Identity Channels: Categorical Attributes
Position on common scale	Spatial region
Position on unaligned scale	Color hue
Length (1D size)	Motion
Tilt/angle	Shape
Area (2D size)	
Depth (3D position)	
Color luminance	Same
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Volume (3D size)	

- expressiveness principle**
 - match channel and data characteristics
- effectiveness principle**
 - encode most important attributes with highest ranked channels

Channels: Ranking effectiveness

Magnitude Channels: Ordered Attributes	Identity Channels: Categorical Attributes
Position on common scale	Spatial region
Position on unaligned scale	Color hue
Length (1D size)	Motion
Tilt/angle	Shape
Area (2D size)	
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Volume (3D size)	

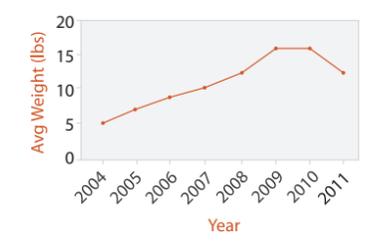
- expressiveness principle**
 - match channel and data characteristics
- effectiveness principle**
 - encode most important attributes with highest ranked channels
 - spatial position ranks high for both

Accuracy: Fundamental Theory

Steven's Psychophysical Power Law: $S = I^N$

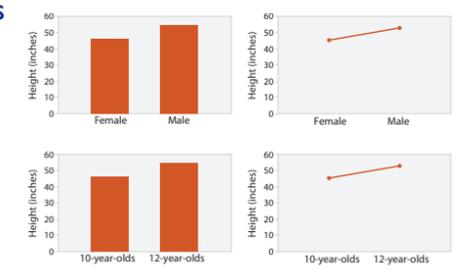
Idiom: line chart / dot plot

- one key, one value
 - data
 - 2 quant attribs
 - mark: points
 - line connection marks between them
 - channels
 - aligned lengths to express quant value
 - separated and ordered by key attrib into horizontal regions
 - task
 - find trend
 - connection marks emphasize ordering of items along key axis by explicitly showing relationship between one item and the next



Choosing bar vs line charts

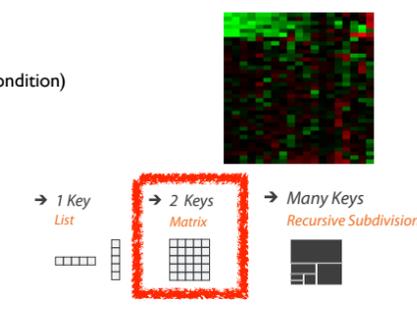
- depends on type of key attrib
 - bar charts if categorical
 - line charts if ordered
- do not use line charts for categorical key attribs
 - violates expressiveness principle
 - implication of trend so strong that it overrides semantics!
 - “The more male a person is, the taller he/she is”



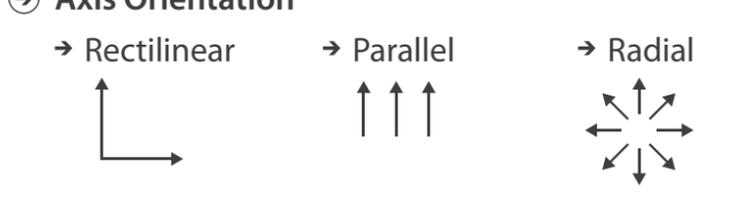
after [Bars and Lines: A Study of Graphic Communication. Zacks and Tversky. Memory and Cognition 27:6 (1999), 1073–1079.]

Idiom: heatmap

- two keys, one value
 - data
 - 2 categ attribs (gene, experimental condition)
 - 1 quant attrib (expression levels)
 - marks: area
 - separate and align in 2D matrix
 - indexed by 2 categorical attributes
 - channels
 - color by quant attrib
 - (ordered diverging colormap)
 - task
 - find clusters, outliers
 - scalability
 - 1K categorical levels, 1M items; only ~10 quantitative attribute levels

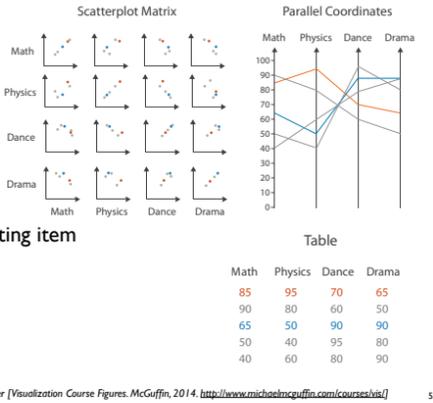


Axis Orientation



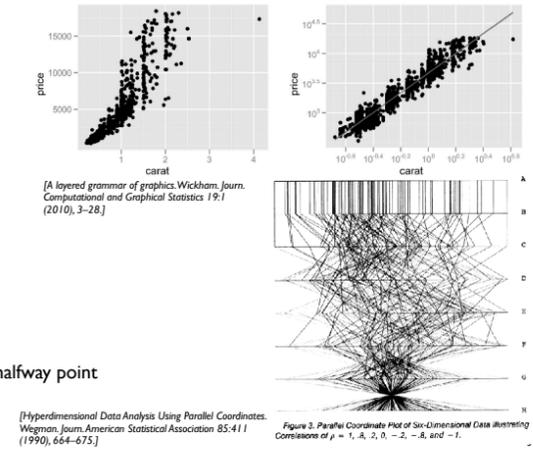
Idioms: scatterplot matrix, parallel coordinates

- scatterplot matrix (SPLOM)
 - rectilinear axes, point mark
 - all possible pairs of axes
 - scalability
 - one dozen attribs
 - dozens to hundreds of items
- parallel coordinates
 - parallel axes, jagged line representing item
 - rectilinear axes, item as point
 - axis ordering is major challenge
 - scalability
 - dozens of attribs
 - hundreds of items



Task: Correlation

- scatterplot matrix
 - positive correlation
 - diagonal low-to-high
 - negative correlation
 - diagonal high-to-low
 - uncorrelated
- parallel coordinates
 - positive correlation
 - parallel line segments
 - negative correlation
 - all segments cross at halfway point
 - uncorrelated
 - scattered crossings



[Hyperdimensional Data Analysis Using Parallel Coordinates. Wegman. Journ. American Statistical Association 85:411 (1990), 664–675.]

Idioms: pie chart, polar area chart

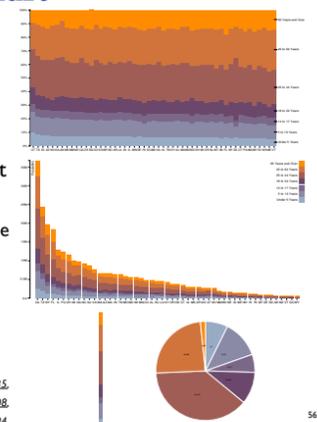
- pie chart
 - area marks with angle channel
 - accuracy: angle/area much less accurate than line length
 - arclength also less accurate than line length
- polar area chart
 - area marks with length channel
 - more direct analog to bar charts
- data
 - 1 categ key attrib, 1 quant value attrib
- task
 - part-to-whole judgements



[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idioms: normalized stacked bar chart

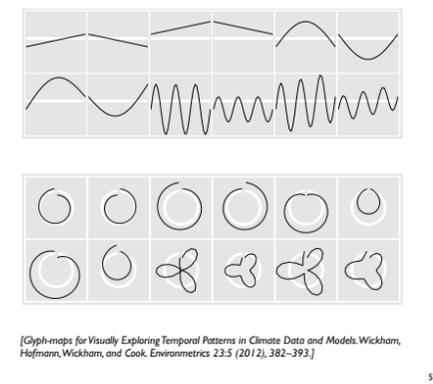
- task
 - part-to-whole judgements
- normalized stacked bar chart
 - stacked bar chart, normalized to full vert height
 - single stacked bar equivalent to full pie
 - high information density: requires narrow rectangle
- pie chart
 - information density: requires large circle



<http://bl.ocks.org/mbostock/2887235>
<http://bl.ocks.org/mbostock/2886208>
<http://bl.ocks.org/mbostock/2886394>

Idiom: glyphmaps

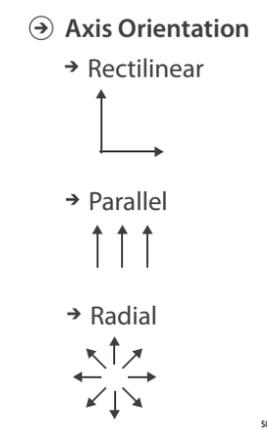
- rectilinear good for linear vs nonlinear trends
 - linear trends
 - nonlinear trends
- radial good for cyclic patterns
 - cyclic patterns



[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. Environmentrics 23:5 (2012), 392–393.]

Orientation limitations

- rectilinear: scalability wrt #axes
 - 2 axes best
 - 3 problematic
 - more in afternoon
 - 4+ impossible
- parallel: unfamiliarity, training time
- radial: perceptual limits
 - angles lower precision than lengths
 - asymmetry between angle and length
 - can be exploited!



[Uncovering Strengths and Weaknesses of Radial Visualizations - an Empirical Approach. Diehl, Beck and Burch. IEEE TVCG (Proc. InfoVis) 16(6):935–942, 2010.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 7: Arrange Tables
- Visualizing Data. Cleveland. Hobart Press, 1993.
- A Brief History of Data Visualization. Friendly. 2008. <http://www.datavis.ca/milestones>

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@tamaramunzner

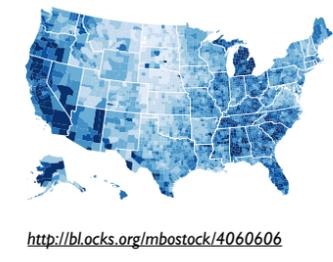
Arrange spatial data

- Use Given
 - Geometry
 - Geographic
 - Other Derived
 - Spatial Fields
 - Scalar Fields (one value per cell)
 - Isocontours
 - Direct Volume Rendering
 - Vector and Tensor Fields (many values per cell)
 - Flow Glyphs (local)
 - Geometric (sparse seeds)
 - Textures (dense seeds)
 - Features (globally derived)



Idiom: choropleth map

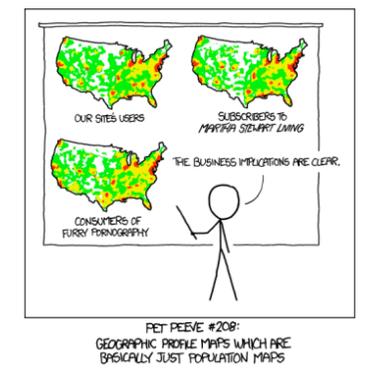
- use given spatial data
 - when central task is understanding spatial relationships
- data
 - geographic geometry
 - table with 1 quant attribute per region
- encoding
 - use given geometry for area mark boundaries
 - sequential segmented colormap [more later]



<http://bl.ocks.org/mbostock/4060606>

Beware: Population maps trickiness!

- consider when to normalize by population density
- general issue
 - absolute counts vs relative/normalized data



PET PEEVE #208: GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS
<https://xkcd.com/1138/>

Idiom: topographic map

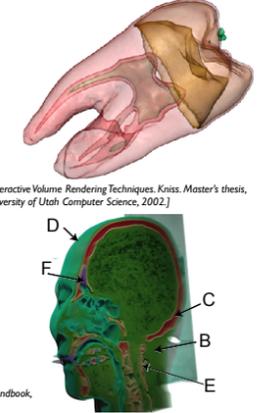
- data
 - geographic geometry
 - scalar spatial field
 - 1 quant attribute per grid cell
- derived data
 - isoline geometry
 - isocontours computed for specific levels of scalar values



Land Information New Zealand Data Service

Idioms: isosurfaces, direct volume rendering

- data
 - scalar spatial field
 - 1 quant attribute per grid cell
- task
 - shape understanding, spatial relationships
- isosurface
 - derived data: isocontours computed for specific levels of scalar values
- direct volume rendering
 - transfer function maps scalar values to color, opacity
 - no derived geometry

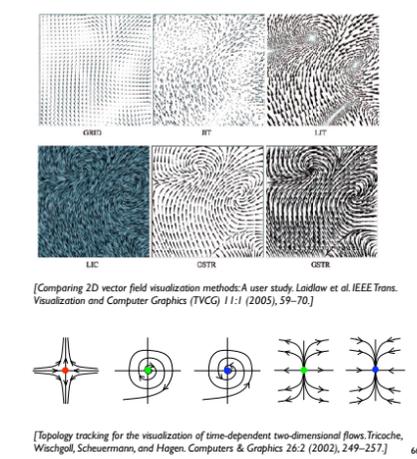


[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

Vector and tensor fields

- data
 - many attribs per cell
- idiom families
 - flow glyphs
 - purely local
 - geometric flow
 - derived data from tracing particle trajectories
 - sparse set of seed points
 - texture flow
 - derived data, dense seeds
 - feature flow
 - global computation to detect features
 - encoded with one of methods above

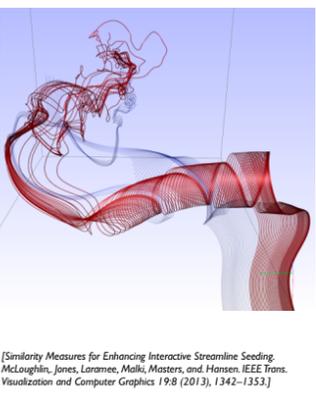


[Comparing 2D vector field visualization methods: A user study. Laidlow et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]

[Topology tracking for the visualization of time-dependent two-dimensional flows. Tricoche, Wischgoll, Scheuermann, and Hagen. Computers & Graphics 26:2 (2002), 249–257.]

Idiom: similarity-clustered streamlines

- data
 - 3D vector field
- derived data (from field)
 - streamlines: trajectory particle will follow
- derived data (per streamline)
 - curvature, torsion, tortuosity
 - signature: complex weighted combination
 - compute cluster hierarchy across all signatures
 - encode: color and opacity by cluster
- tasks
 - find features, query shape
- scalability
 - millions of samples, hundreds of streamlines



[Similarity Measures for Enhancing Interactive Streamline Seeding. McLaughlin, Jones, Laramée, Malki, Masters, and Hansen. IEEE Trans. Visualization and Computer Graphics 19:8 (2013), 1342–1353.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Oct 2014.
 - Chap 8: Arrange Spatial Data
- How Maps Work: Representation, Visualization, and Design. MacEachren. Guilford Press, 1995.
- Overview of visualization. Schroeder and Martin. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 3–39. Elsevier, 2005.
- Real-Time Volume Graphics. Engel, Hadwiger, Kniss, Reza-Salama, and Weiskopf. AK Peters, 2006.
- Overview of flow visualization. Weiskopf and Erlebacher. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 261–278. Elsevier, 2005.

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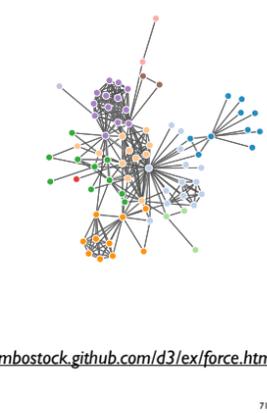
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Arrange networks and trees

- Node-Link Diagrams
 - Connection Marks
 - ✓ NETWORKS ✓ TREES
- Adjacency Matrix
 - Derived Table
 - ✓ NETWORKS ✓ TREES
- Enclosure
 - Containment Marks
 - ✗ NETWORKS ✓ TREES

Idiom: force-directed placement

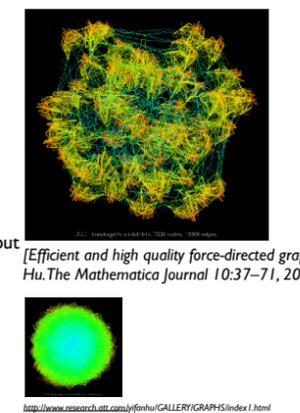
- visual encoding: node-link diagram
 - link connection marks, node point marks
- algorithm: energy minimization
 - analogy: nodes repel, links draw together like springs
 - optimization problem: minimize crossings
- spatial position: no meaning directly encoded
 - sometimes proximity meaningful
 - sometimes proximity arbitrary, artifact of layout algorithm
- tasks
 - explore topology; locate paths, clusters
- scalability
 - node/edge density $E < 4N$



<http://mbostock.github.com/d3/ex/force.html>

Idiom: sfdp (multi-level force-directed placement)

- data
 - original: network
 - derived: cluster hierarchy atop it
- considerations
 - better algorithm for same encoding technique
 - same: fundamental use of space
 - hierarchy used for algorithm speed/quality but not shown explicitly
- scalability
 - nodes, edges: 1K-10K
 - hairball problem still hits eventually

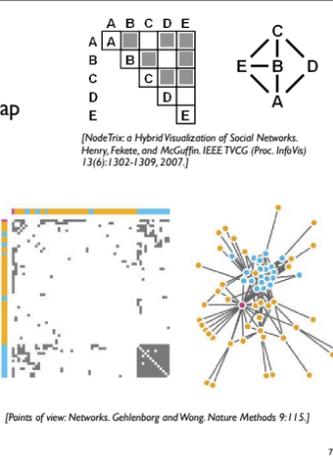


[Efficient and high quality force-directed graph drawing. Hu. The Mathematica Journal 10:37–71, 2005.]

<http://www.research.att.com/~fhu/GALLERY/GRAPH/index.html>

Idiom: adjacency matrix view

- data: network
 - transform into same data/encoding as heatmap
- derived data: table from network
 - 1 quant attrib
 - weighted edge between nodes
 - 2 categ attribs: node list x 2
- visual encoding
 - cell shows presence/absence of edge
- scalability
 - 1K nodes, 1M edges

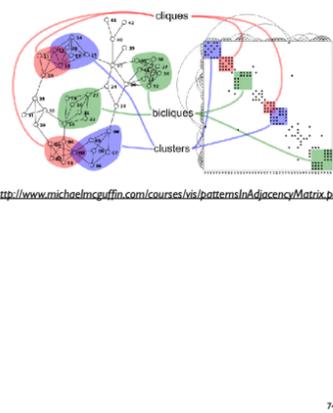


[NodeTrix: a Hybrid Visualization of Social Networks. Henry, Fekete, and McGuffin. IEEE TVCG (Proc. InfoVis) 13(6):1302-1309, 2007.]

[Points of view: Networks. Gehlenborg and Wang. Nature Methods 9:115.]

Connection vs. adjacency comparison

- adjacency matrix strengths
 - predictability, scalability, supports reordering
 - some topology tasks trainable
- node-link diagram strengths
 - topology understanding, path tracing
 - intuitive, no training needed
- empirical study
 - node-link best for small networks
 - matrix best for large networks
 - if tasks don't involve topological structure!

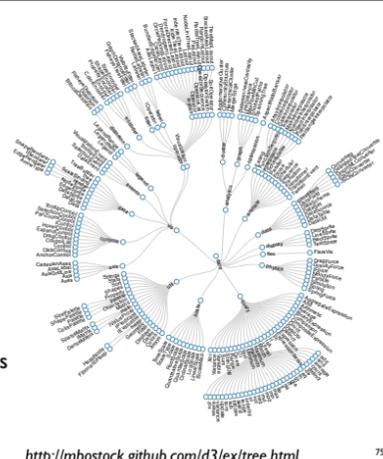


<http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png>

[On the readability of graphs using node-link and matrix-based representations: a controlled experiment and statistical analysis. Ghoniem, Fekete, and Castagliola. Information Visualization 4:2 (2005), 114–135.]

Idiom: radial node-link tree

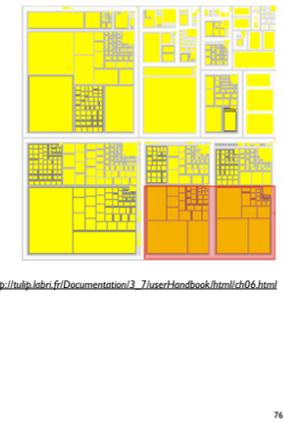
- data
 - tree
- encoding
 - link connection marks
 - point node marks
 - radial axis orientation
 - angular proximity: siblings
 - distance from center: depth in tree
- tasks
 - understanding topology, following paths
- scalability
 - 1K - 10K nodes



<http://mbostock.github.com/d3/ex/tree.html>

Idiom: treemap

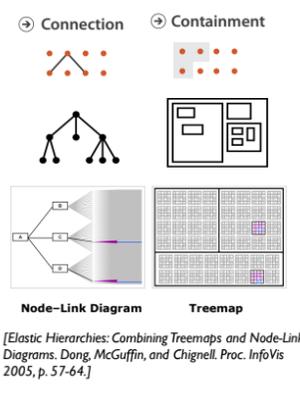
- data
 - tree
 - 1 quant attrib at leaf nodes
- encoding
 - area containment marks for hierarchical structure
 - rectilinear orientation
 - size encodes quant attrib
- tasks
 - query attribute at leaf nodes
- scalability
 - 1M leaf nodes



http://uiplib.lebr.fr/Documentation/3_UserHandbook/html/ch06.html

Link marks: Connection and containment

- marks as links (vs. nodes)
 - common case in network drawing
 - 1D case: connection
 - ex: all node-link diagrams
 - emphasizes topology, path tracing
 - networks and trees
 - 2D case: containment
 - ex: all treemap variants
 - emphasizes attribute values at leaves (size coding)
 - only trees



[Elastic Hierarchies: Combining Treemaps and Node-Link Diagrams. Dong, McGuffin, and Chignell. Proc. InfoVis 2005, p. 57-64.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 9: Arrange Networks and Trees
- Visual Analysis of Large Graphs: State-of-the-Art and Future Research Challenges. von Landesberger et al. Computer Graphics Forum 30:6 (2011), 1719–1749.
- Simple Algorithms for Network Visualization: A Tutorial. McGuffin. Tsinghua Science and Technology (Special Issue on Visualization and Computer Graphics) 17:4 (2012), 383–398.
- Drawing on Physical Analogies. Brandes. In Drawing Graphs: Methods and Models, LNCS Tutorial, 2025, edited by M. Kaufmann and D. Wagner, LNCS Tutorial, 2025, pp. 71–86. Springer-Verlag, 2001.
- <http://www.treevis.net> Treevis.net: A Tree Visualization Reference. Schulz. IEEE Computer Graphics and Applications 31:6 (2011), 11–15.
- Perceptual Guidelines for Creating Rectangular Treemaps. Kong, Heer, and Agrawala. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 16:6 (2010), 990–998.

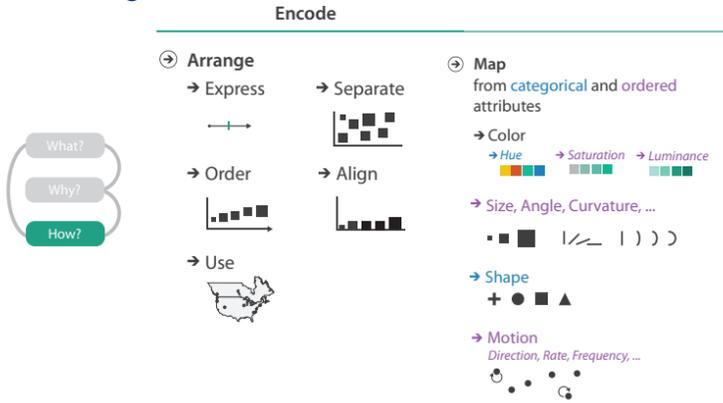
Outline

- **Session 1 9-10:30am**
 - Analysis: What, Why, How
 - Marks and Channels
 - Arrange Tables
 - Arrange Spatial Data
 - Arrange Networks and Trees
- **Session 2 10:50am-12:20pm**
 - Map Color and Other Channels
 - Manipulate: Change, Select, Navigate
 - Facet: Juxtapose, Partition, Superimpose
 - Reduce: Filter, Aggregate
 - Embed: Focus+Context
- **Break 10:30-10:50am**

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Idiom design choices: First half



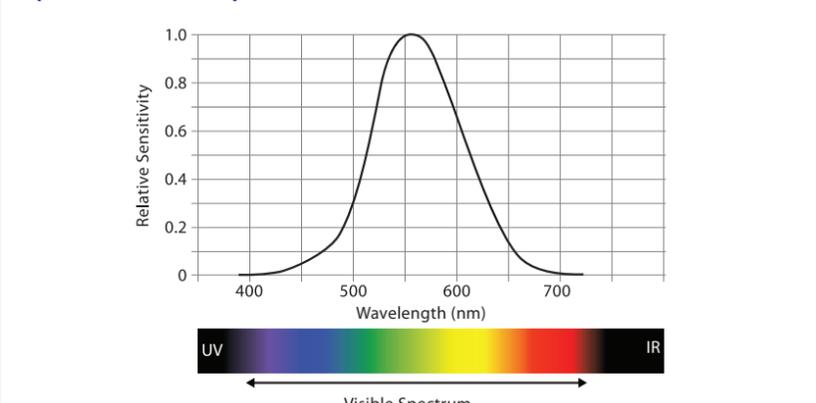
Decomposing color

- first rule of color: do not talk about color!
 - color is confusing if treated as monolithic
- decompose into three channels
 - ordered can show magnitude
 - luminance
 - saturation
 - categorical can show identity
 - hue

Luminance

- need luminance for edge detection
 - fine-grained detail only visible through luminance contrast
 - legible text requires luminance contrast!
- HLS better than RGB for encoding but beware
 - L lightness ≠ L* luminance

Spectral sensitivity



Colormaps

- Categorical
 - Binary
 - Categorical
- Ordered
 - Sequential
 - Diverging
- Bivariate

Colormaps

- Categorical
 - Binary
 - Categorical
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 - Sequential
 - Diverging
- Bivariate

Colormaps

- Categorical
 - Binary
 - Categorical
- Ordered
 - Sequential
 - Diverging
- Bivariate

use with care if more than two levels (binary)!

Colormaps

- Categorical
 - Binary
 - Categorical
- Ordered
 - Sequential
 - Diverging
- Bivariate

- color channel interactions
 - size heavily affects salience
 - small regions need high saturation
 - large need low saturation
 - saturation & luminance: 3-4 bins max
 - also not separable from transparency

Categorical color: Discriminability constraints

- noncontiguous small regions of color: only 6-12 bins

Ordered color: Rainbow is poor default

- problems
 - perceptually unordered
 - perceptually nonlinear
- benefits
 - fine-grained structure visible and nameable
- alternatives
 - large-scale structure: fewer hues

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 - large-scale structure: fewer hues
 - fine structure: multiple hues with monotonically increasing luminance [eg viridis]

Viridis / Magma

- monotonically increasing luminance, perceptually uniform
- colorful, colourblind-safe
- R, python, D3

Ordered color: Rainbow is poor default

- problems
 - perceptually unordered
 - perceptually nonlinear
- benefits
 - fine-grained structure visible and nameable
- alternatives
 - large-scale structure: fewer hues
 - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
 - categorical: segmented saturated rainbow is good!

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 10: Map Color and Other Channels
- ColorBrewer, Brewer.
 - <http://www.colorbrewer2.org>
- Color In Information Display. Stone. IEEE Vis Course Notes, 2006.
 - <http://www.stonesc.com/Vis06>
- A Field Guide to Digital Color. Stone. AK Peters, 2003.
- Rainbow Color Map (Still) Considered Harmful. Borland and Taylor. IEEE Computer Graphics and Applications 27:2 (2007), 14-17.
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann / Academic Press, 2004.
- <http://www.r-bloggers.com/using-the-new-viridis-colormap-in-r-thanks-to-simon-garnier/>

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- <http://www.cs.ubc.ca/~trmm/talks.html#halfdaycourse19> @tamaramunzner

How?

Encode

- Arrange
 - Express
 - Order
 - Use
- Map from categorical and ordered attributes
 - Color
 - Hue
 - Saturation
 - Luminance
 - Size, Angle, Curvature, ...
 - Shape
 - +
 -
 - ▲
 - Motion
 - Direction, Rate, Frequency, ...

Manipulate

- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed

What? Why? How?

How to handle complexity: 1 previous strategy + 3 more

→ Derive

Manipulate

- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed

- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view

Manipulate

→ Change over Time

→ Navigate

- Item Reduction
- Zoom
 - Geometric
 - Semantic
- Pan/Translate
- Constrained

→ Attribute Reduction

- Slice
- Cut
- Project

Idiom: Realign System: LineUp

- stacked bars
 - easy to compare
 - first segment
 - total bar
- align to different segment
 - supports flexible comparison

[LineUp: Visual Analysis of Multi-Attribute Rankings. Gatz, Lex, Gehlborg, Pfister, and Streit. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2013) 19:12 (2013), 2277–2286.]

Navigate: Changing item visibility

- change viewpoint
 - changes which items are visible within view
 - camera metaphor
 - zoom
 - geometric zoom: familiar semantics
 - semantic zoom: adapt object representation based on available pixels
 - dramatic change, or more subtle one
 - pan/translate
 - rotate
 - especially in 3D
 - constrained navigation
 - often with animated transitions
 - often based on selection set

Idiom: Semantic zooming System: LiveRAC

- visual encoding change
 - colored box
 - sparkline
 - simple line chart
 - full chart: axes and tickmarks

[LiveRAC - Interactive Visual Exploration of System Management Time-Series Data. McLachlan, Munzner, Koutsoufios, and North. Proc. ACM Conf. Human Factors in Computing Systems (CHI), pp. 1483–1492, 2008.]

Navigate: Reducing attributes

- continuation of camera metaphor
- slice
 - show only items matching specific value for given attribute: slicing plane
 - axis aligned, or arbitrary alignment
- cut
 - show only items on far side of plane from camera
- project
 - change mathematics of image creation
 - orthographic
 - perspective
 - many others: Mercator, cabinet, ...

[Interactive Visualization of Multimodal Volume Data for Neurosurgical Tumor Treatment. Rieder, Ritter, Raspe, and Peitgen. Computer Graphics Forum (Proc. EuroVis 2008) 27:3 (2008), 1055–1062.]

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 11: Manipulate View
- Animated Transitions in Statistical Data Graphics. Heer and Robertson. IEEE Trans. on Visualization and Computer Graphics (Proc. InfoVis07) 13:6 (2007), 1240–1247.
- Selection: 524,288 Ways to Say "This is Interesting". Wills. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 54–61, 1996.
- Smooth and efficient zooming and panning. van Wijk and Nuij. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 15–22, 2003.
- Starting Simple - adding value to static visualisation through simple interaction. Dix and Ellis. Proc. Advanced Visual Interfaces (AVI), pp. 124–134, 1998.

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<http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse19> @tamaramunzner

Facet

- Juxtapose
- Partition
- Superimpose

Juxtapose and coordinate views

- Share Encoding: Same/Different
 - Linked Highlighting
- Share Data: All/Subset/None
- Share Navigation

Idiom: Linked highlighting System: EDV

- see how regions contiguous in one view are distributed within another
 - powerful and pervasive interaction idiom
- encoding: different
 - multiform
- data: all shared

[Visual Exploration of Large Structured Datasets. Wills. Proc. New Techniques and Trends in Statistics (NTTS), pp. 237–246. IOS Press, 1995.]

Idiom: bird's-eye maps System: Google Maps

- encoding: same
- data: subset shared
- navigation: shared
 - bidirectional linking
- differences
 - viewpoint
 - size
- overview-detail

[A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.]

Idiom: Small multiples System: Cerebral

- encoding: same
- data: none shared
 - different attributes for node colors
 - (same network layout)
- navigation: shared

[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

Coordinate views: Design choice interaction

		Data		
		All	Subset	None
Encoding	Same	Redundant	Overview/Detail	Small Multiples
	Different	Multiform	Multiform, Overview/Detail	No Linkage

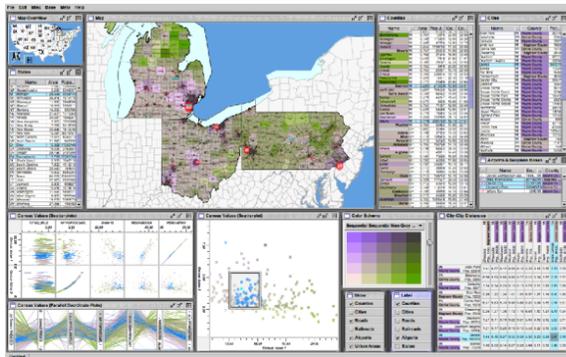
- why juxtapose views?
 - benefits: eyes vs memory
 - lower cognitive load to move eyes between 2 views than remembering previous state with single changing view
 - costs: display area, 2 views side by side each have only half the area of one view

Why not animation?

- disparate frames and regions: comparison difficult
 - vs contiguous frames
 - vs small region
 - vs coherent motion of group
- safe special case
 - animated transitions

System: **Improvise**

- investigate power of multiple views
 - pushing limits on view count, interaction complexity
 - how many is ok?
 - open research question
 - reorderable lists
 - easy lookup
 - useful when linked to other encodings

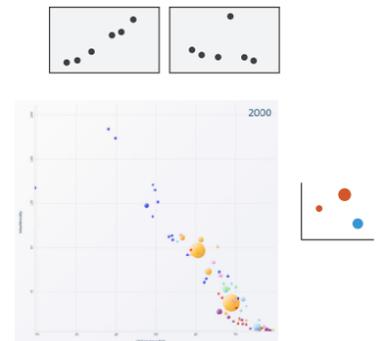


[Building Highly-Coordinated Visualizations In Improvise. Weaver. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 159–166, 2004.]

Partition into views

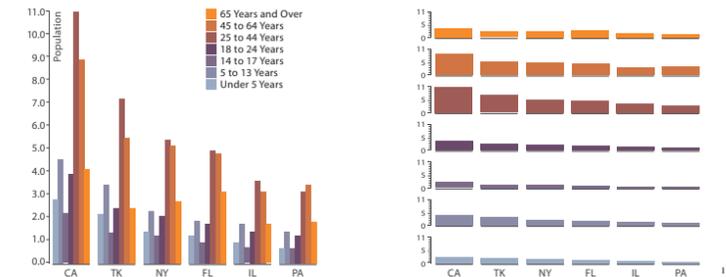
- how to divide data between views
 - split into regions by attributes
 - encodes association between items using spatial proximity
 - order of splits has major implications for what patterns are visible
- no strict dividing line
 - view**: big/detailed
 - contiguous region in which visually encoded data is shown on the display
 - glyph**: small/iconic
 - object with internal structure that arises from multiple marks

Partition into Side-by-Side Views



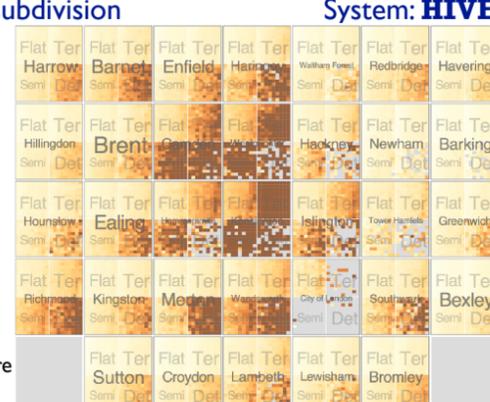
Partitioning: List alignment

- single bar chart with grouped bars
 - split by state into regions
 - complex glyph within each region showing all ages
 - compare: easy within state, hard across ages
- small-multiple bar charts
 - split by age into regions
 - one chart per region
 - compare: easy within age, harder across states



Partitioning: Recursive subdivision

- split by neighborhood
- then by type
 - years as rows
 - months as columns
- then time
- color by price
- neighborhood patterns
 - where it's expensive
 - where you pay much more for detached type



[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- switch order of splits
 - type then neighborhood
- switch color
 - by price variation
- type patterns
 - within specific type, which neighborhoods inconsistent

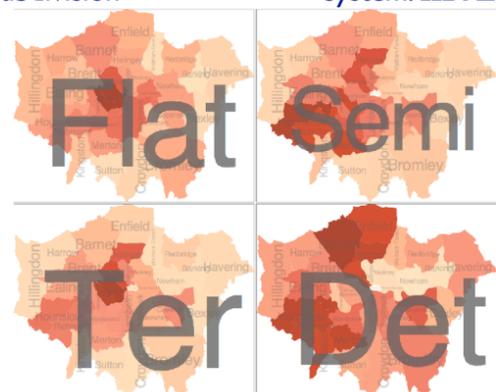


[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- different encoding for second-level regions
 - choropleth maps

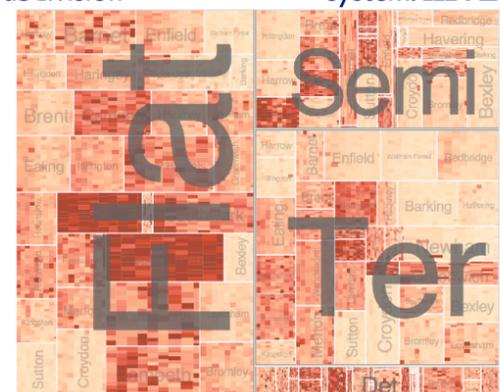


[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Partitioning: Recursive subdivision

System: **HIVE**

- size regions by sale counts
 - not uniformly
- result: treemap



[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

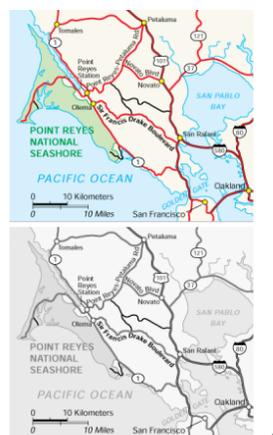
Superimpose layers

- layer**: set of objects spread out
 - superimpose layers over region
 - each set is visually distinguishable group
 - extent: whole view
- design choices
 - how many layers, how to distinguish?
 - encode with different, nonoverlapping channels
 - two layers achievable, three with careful design
 - small static set, or dynamic from many possible?



Static visual layering

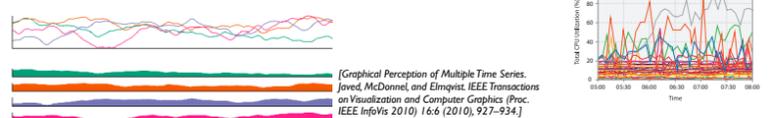
- foreground layer: roads
 - hue, size distinguishing main from minor
 - high luminance contrast from background
- background layer: regions
 - desaturated colors for water, parks, land areas
- user can selectively focus attention
- “get it right in black and white”
 - check luminance contrast with greyscale view



[Get it right in black and white. Stone. 2010. <http://www.stones.com/wordpress/2010/03/get-it-right-in-black-and-white/>]

Superimposing limits

- few layers, but many lines
 - up to a few dozen
 - but not hundreds
- superimpose vs juxtapose: empirical study
 - superimposed for local, multiple for global
 - tasks
 - local: maximum, global: slope, discrimination
 - same screen space for all multiples vs single superimposed

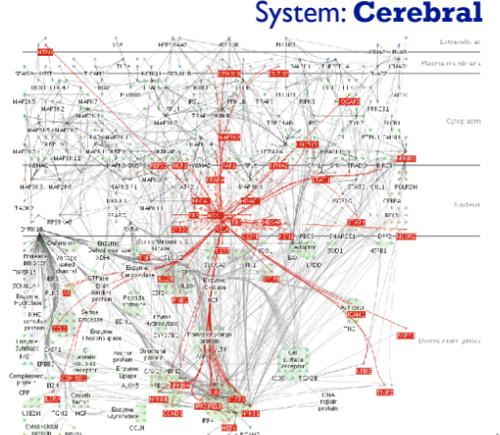


[Graphical Perception of Multiple Time Series. Javed, McDonnell, and Elmquist. IEEE Transactions on Visualization and Computer Graphics (Proc. IEEE InfoVis 2010) 16:6 (2010), 927–934.]

Dynamic visual layering

System: **Cerebral**

- interactive, from selection
 - lightweight: click
 - very lightweight: hover
- ex: I-hop neighbors



[Cerebral: a Cytoscape plugin for layout of and interaction with biological networks using subcellular localization annotation. Barsky, Gardy, Hancock, and Munzner. Bioinformatics 23:8 (2007), 1040–1042.]

Further reading

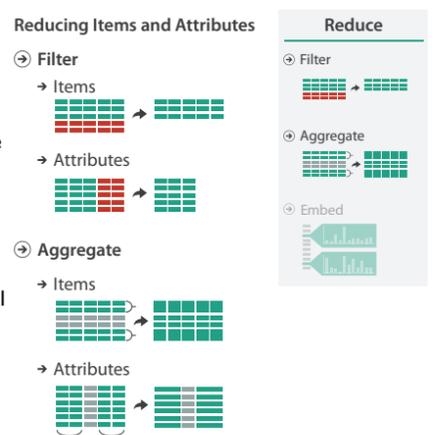
- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 12: Facet Into Multiple Views
- A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence. Lam and Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.
- Zooming versus multiple window interfaces: Cognitive costs of visual comparisons. Plumlee and Ware. ACM Trans. on Computer-Human Interaction (TOCHI) 13:2 (2006), 179–209.
- Exploring the Design Space of Composite Visualization. Javed and Elmquist. Proc. Pacific Visualization Symp. (PacificVis), pp. 1–9, 2012.
- Visual Comparison for Information Visualization. Gleicher, Albers, Walker, Jusufi, Hansen, and Roberts. Information Visualization 10:4 (2011), 289–309.
- Guidelines for Using Multiple Views in Information Visualizations. Baldonado, Woodruff, and Kuchinsky. In Proc. ACM Advanced Visual Interfaces (AVI), pp. 110–119, 2000.
- Cross-Filtered Views for Multidimensional Visual Analysis. Weaver. IEEE Trans. Visualization and Computer Graphics 16:2 (Proc. InfoVis 2010), 192–204, 2010.
- Linked Data Views. Willis. In Handbook of Data Visualization, Computational Statistics, edited by Unwin, Chen, and Härdle, pp. 216–241. Springer-Verlag, 2008.
- Glyph-based Visualization: Foundations, Design Guidelines, Techniques and Applications. Borgo, Kehrer, Chung, Maguire, Laramee, Hauser, Ward, and Chen. In Eurographics State of the Art Reports, pp. 39–63, 2013.

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 - Embed: Focus+Context

Reduce items and attributes

- reduce/increase: inverses
- filter
 - pro: straightforward and intuitive
 - con: out of sight, out of mind
- aggregation
 - pro: inform about whole set
 - con: difficult to avoid losing signal
- not mutually exclusive
 - combine filter, aggregate
 - combine reduce, change, facet

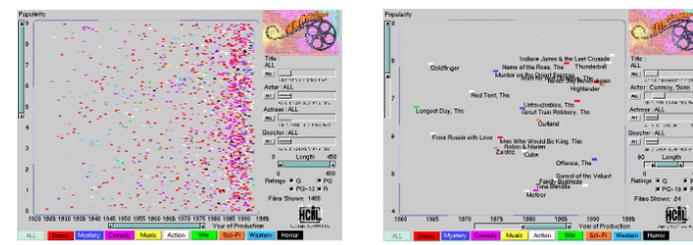


[126]

Idiom: dynamic filtering

System: **FilmFinder**

- item filtering
- browse through tightly coupled interaction
 - alternative to queries that might return far too many or too few



[Visual information seeking: Tight coupling of dynamic query filters with starfield displays. Ahlberg and Shneiderman. Proc. ACM Conf. on Human Factors in Computing Systems (CHI), pp. 313–317, 1994.]

Idiom: scented widgets

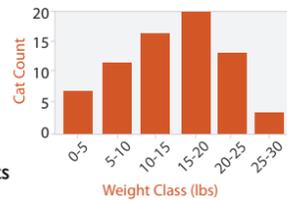
- augment widgets for filtering to show **information scent**
 - cues to show whether value in drilling down further vs looking elsewhere
- concise, in part of screen normally considered control panel



[Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Willett, Heer, and Agrawala. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2007) 13:6 (2007), 1129–1136.]

Idiom: histogram

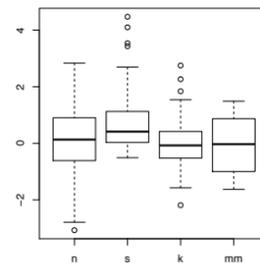
- static item aggregation
- task: find distribution
- data: table
- derived data
 - new table: keys are bins, values are counts
- bin size crucial
 - pattern can change dramatically depending on discretization
 - opportunity for interaction: control bin size on the fly



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Idiom: boxplot

- static item aggregation
- task: find distribution
- data: table
- derived data
 - 5 quant attris
 - median: central line
 - lower and upper quartile: boxes
 - lower upper fences: whiskers
 - values beyond which items are outliers
 - outliers beyond fence cutoffs explicitly shown

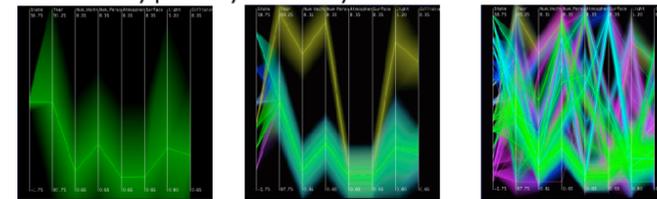


[40 years of boxplots. Wickham and Stryjewski. 2012. had.co.nz]

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Idiom: Hierarchical parallel coordinates

- dynamic item aggregation
- derived data: **hierarchical clustering**
- encoding:
 - cluster band with variable transparency, line at mean, width by min/max values
 - color by proximity in hierarchy

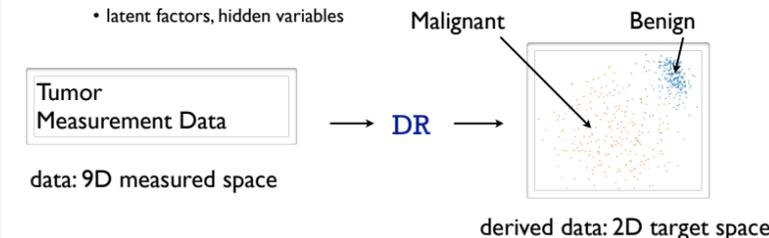


[Hierarchical Parallel Coordinates for Exploration of Large Datasets. Fua, Ward, and Rundensteiner. Proc. IEEE Visualization Conference (Vis '99), pp. 43–50, 1999.]

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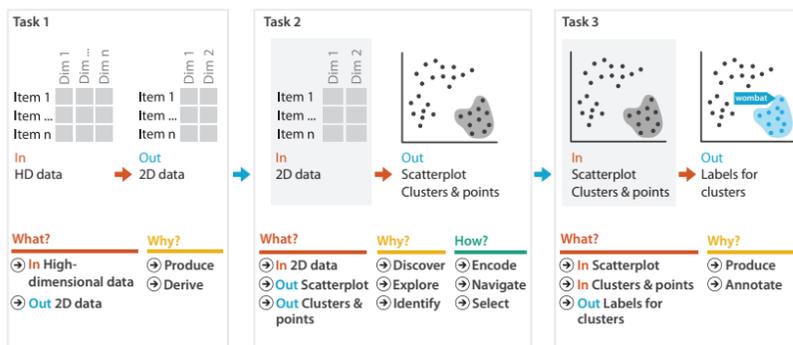
Dimensionality reduction

- attribute aggregation
 - derive low-dimensional target space from high-dimensional measured space
 - use when you can't directly measure what you care about
 - true dimensionality of dataset conjectured to be smaller than dimensionality of measurements
 - latent factors, hidden variables



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Idiom: Dimensionality reduction for documents



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Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 13: Reduce Items and Attributes
- Hierarchical Aggregation for Information Visualization: Overview, Techniques and Design Guidelines. Elmqvist and Fekete. IEEE Transactions on Visualization and Computer Graphics 16:3 (2010), 439–454.
- A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence. Lam and Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.

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Outline

- Session 1 9-10:30am
 - Analysis: What, Why, How
 - Marks and Channels
 - Arrange Tables
 - Arrange Spatial Data
 - Arrange Networks and Trees
- Session 2 10:50am-12:20pm
 - Map Color and Other Channels
 - Manipulate: Change, Select, Navigate
 - Facet: Juxtapose, Partition, Superimpose
 - Reduce: Filter, Aggregate
 - Embed: Focus+Context

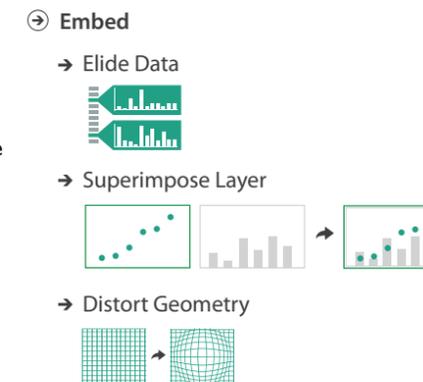
<http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse19>

@tamaramunzner

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Embed: Focus+Context

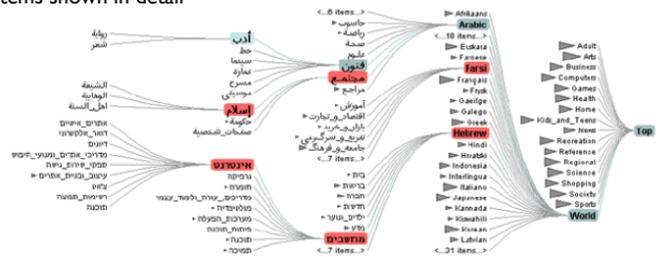
- combine information within single view
- elide
 - selectively filter and aggregate
- superimpose layer
 - local lens
- distort geometry
 - to make room for context



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Idiom: DOITrees Revisited

- elide
 - some items dynamically filtered out
 - some items dynamically aggregated together
 - some items shown in detail

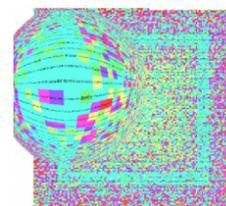


[DOITrees Revisited: Scalable, Space-Constrained Visualization of Hierarchical Data. Heer and Card. Proc. Advanced Visual Interfaces (AVI), pp. 421–424, 2004.]

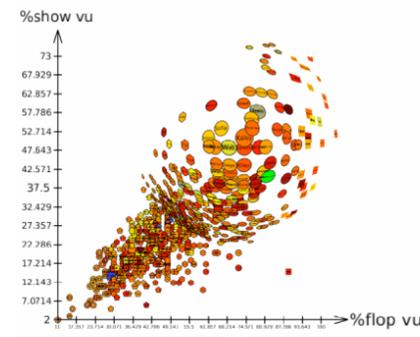
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Idiom: Fisheye Lens

- distort geometry
 - shape: radial
 - focus: single extent
 - extent: local
 - metaphor: draggable lens



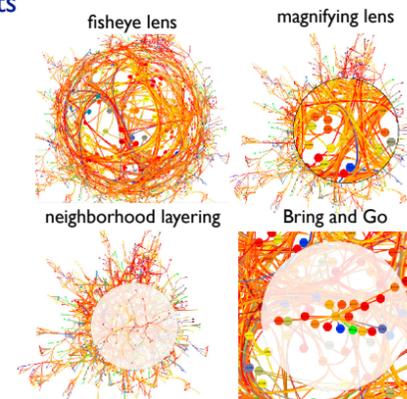
<http://tulip.lbr.fr/TulipDrupal/?q=node/251>
<http://tulip.lbr.fr/TulipDrupal/?q=node/371>



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Distortion costs and benefits

- benefits
 - combine focus and context information in single view
- costs
 - length comparisons impaired
 - network/tree topology comparisons unaffected: connection, containment
 - effects of distortion unclear if original structure unfamiliar
 - object constancy/tracking maybe impaired



[Living Flows: Enhanced Exploration of Edge-Bundled Graphs Based on GPU-Intensive Edge Rendering. Lambert, Auber, and Melançon. Proc. Intl. Conf. Information Visualisation (IV), pp. 523–530, 2010.]

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Further reading

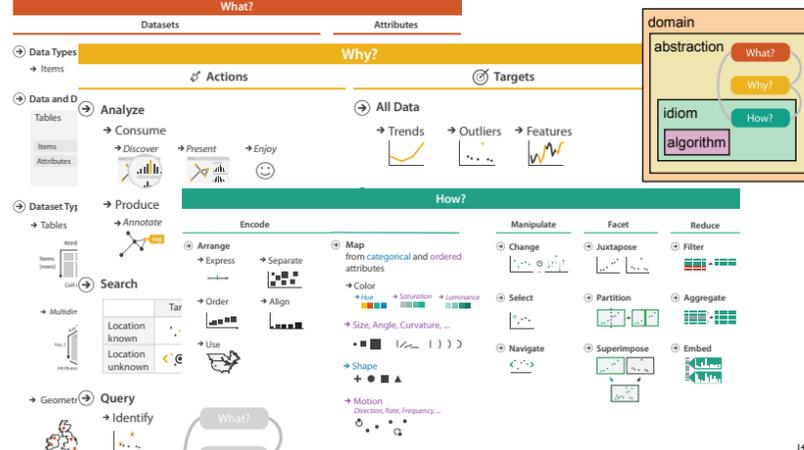
- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
 - Chap 14: Embed: Focus+Context
- A Fisheye Follow-up: Further Reflection on Focus + Context. Furnas. Proc. ACM Conf. Human Factors in Computing Systems (CHI), pp. 999–1008, 2006.
- A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence. Lam and Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.

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Not covered today

- Rules of Thumb
 - No unjustified 3D
 - Power of the plane, dangers of depth
 - Occlusion hides information
 - Perspective distortion loses information
 - Tilted text isn't legible
 - No unjustified 2D
 - Resolution over immersion
 - Overview first, zoom and filter, details on demand
 - Function first, form next

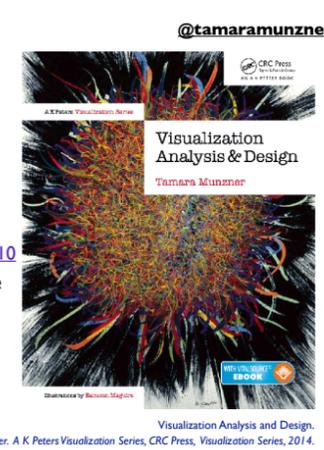
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More Information

- this tutorial
 - <http://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse19>
- book
 - <http://www.cs.ubc.ca/~tmm/vadbook>
 - 20% promo code for book+ebook combo: HVN17
 - <http://www.crcpress.com/product/isbn/9781466508910>
 - illustration acknowledgement: Eamonn Maguire
- full courses, papers, videos, software, talks
 - <http://www.cs.ubc.ca/group/infovis>
 - <http://www.cs.ubc.ca/~tmm>



Munzner. A K Peters Visualization Series, CRC Press, Visualization Series, 2014.

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