

Visualization Analysis & Design

Half-Day Tutorial

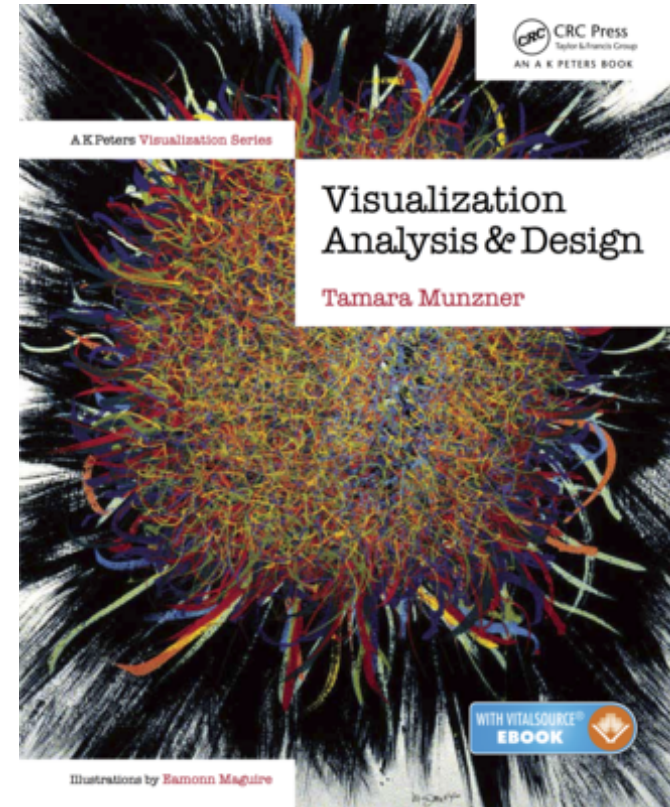
Tamara Munzner

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University of British Columbia

VIS 2025 Tutorial

November 2025, Vienna Austria

<https://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25>



@tamara@cosocial.ca

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

@tamara@cosocial.ca

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Defining visualization (vis)

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

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Why?...

Why have a human in the loop?

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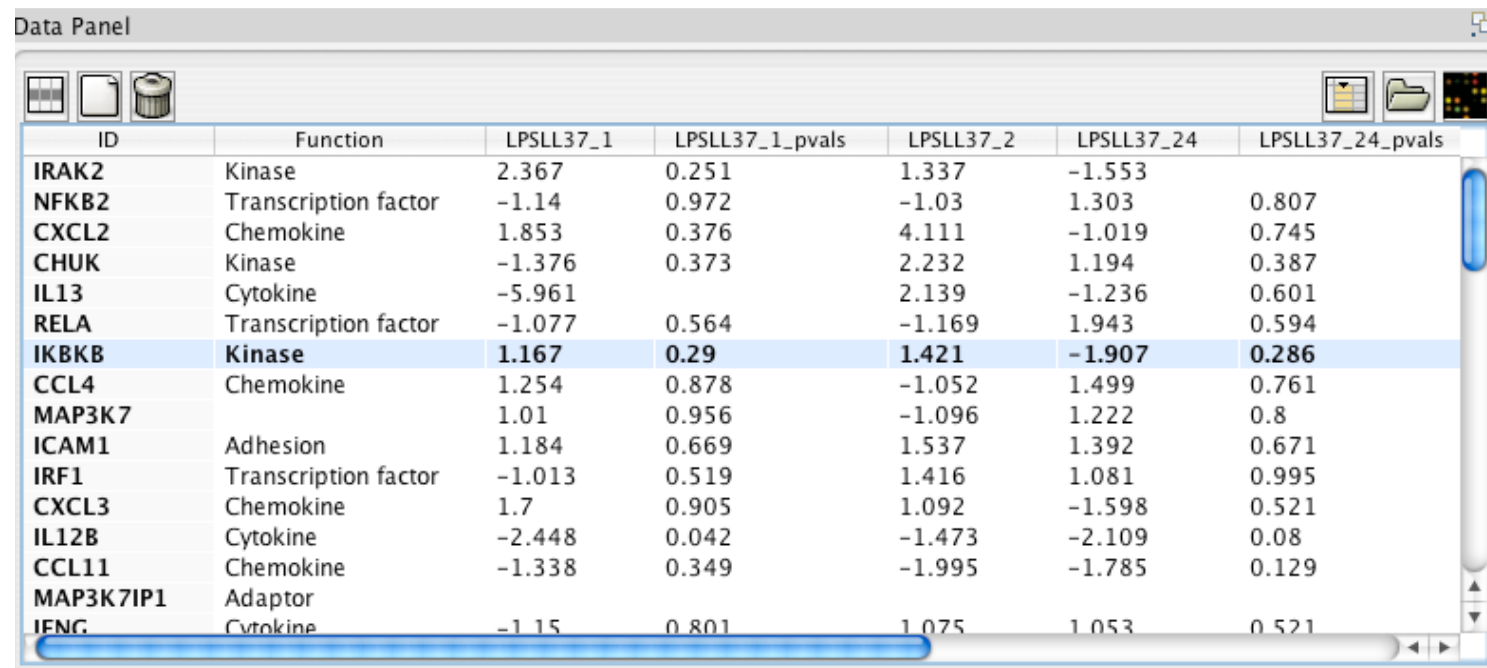
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- 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: data journalism)
 - stepping stone to assess requirements before developing models
 - help automatic solution developers refine & 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



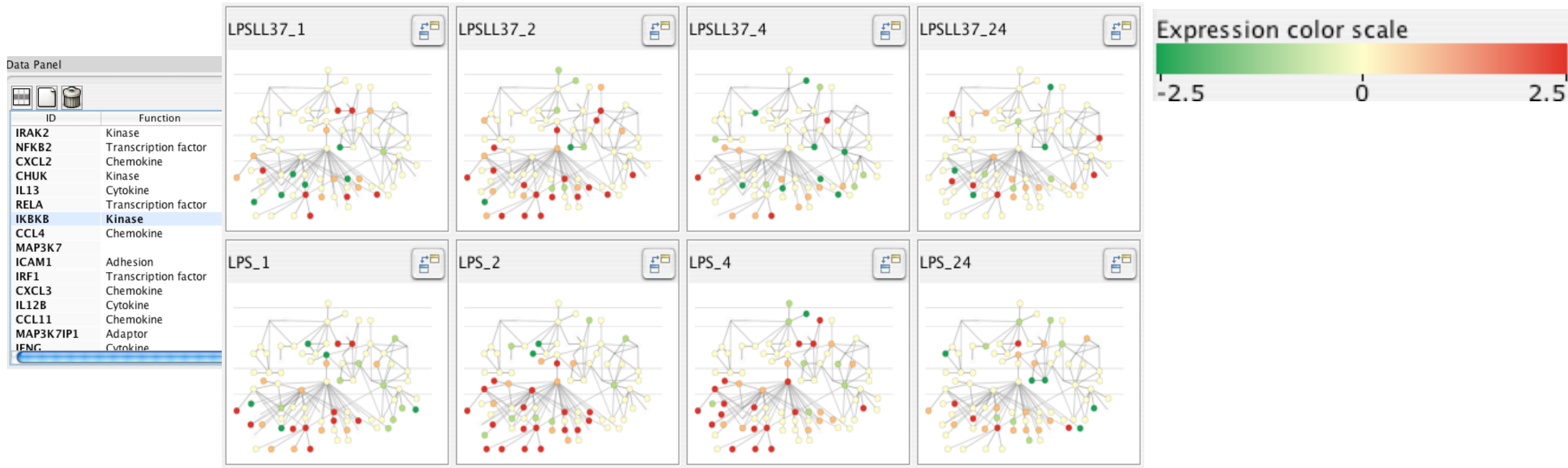
ID	Function	LPSLL37_1	LPSLL37_1_pvals	LPSLL37_2	LPSLL37_24	LPSLL37_24_pvals
IRAK2	Kinase	2.367	0.251	1.337	-1.553	
NFKB2	Transcription factor	-1.14	0.972	-1.03	1.303	0.807
CXCL2	Chemokine	1.853	0.376	4.111	-1.019	0.745
CHUK	Kinase	-1.376	0.373	2.232	1.194	0.387
IL13	Cytokine	-5.961		2.139	-1.236	0.601
RELA	Transcription factor	-1.077	0.564	-1.169	1.943	0.594
IKKB	Kinase	1.167	0.29	1.421	-1.907	0.286
CCL4	Chemokine	1.254	0.878	-1.052	1.499	0.761
MAP3K7		1.01	0.956	-1.096	1.222	0.8
ICAM1	Adhesion	1.184	0.669	1.537	1.392	0.671
IRF1	Transcription factor	-1.013	0.519	1.416	1.081	0.995
CXCL3	Chemokine	1.7	0.905	1.092	-1.598	0.521
IL12B	Cytokine	-2.448	0.042	-1.473	-2.109	0.08
CCL11	Chemokine	-1.338	0.349	-1.995	-1.785	0.129
MAP3K7IP1	Adaptor					
IFNG	Cytokine	-1.15	0.801	1.075	1.053	0.521

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

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Why represent all the data?

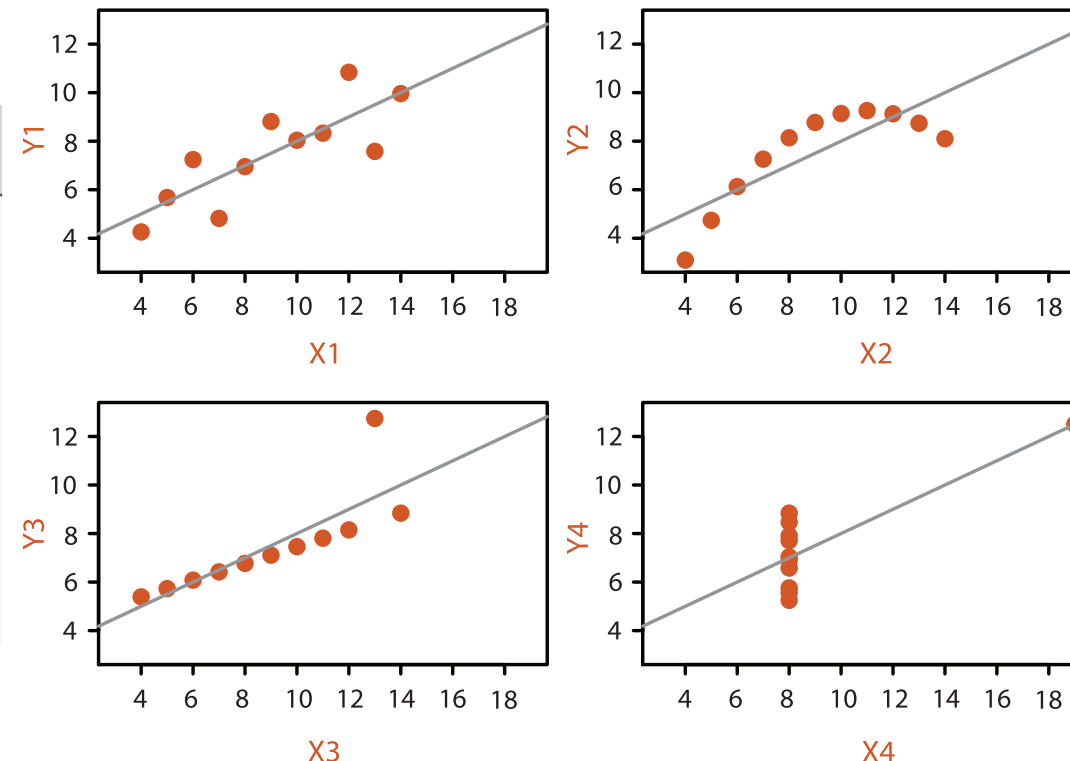
Computer-based visualization systems provide visual representations of datasets designed to help people carry out tasks more effectively:

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

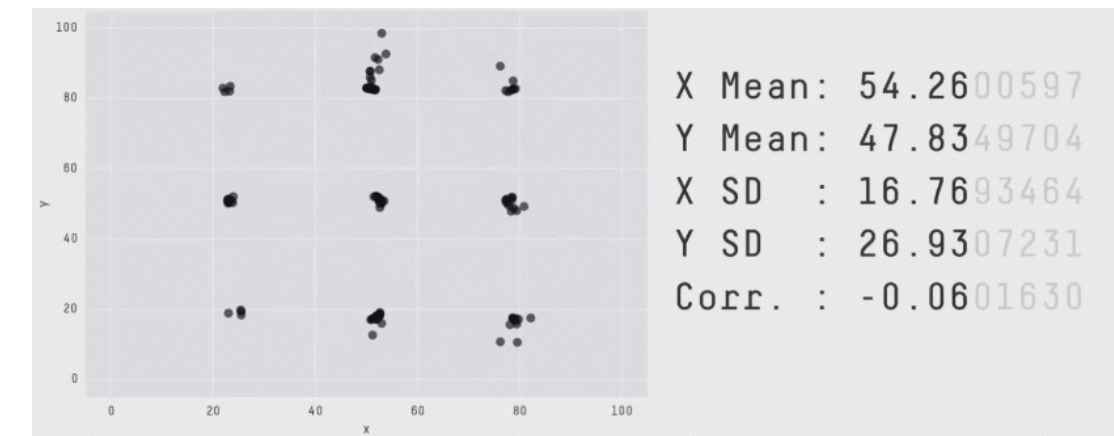
Anscombe's Quartet

Identical statistics

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



Datasaurus Dozen



Same Stats, Different Graphs: Generating Datasets with Varied Appearance and Identical Statistics through Simulated Annealing. CHI 2017. Matejka & Fitzmaurice

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

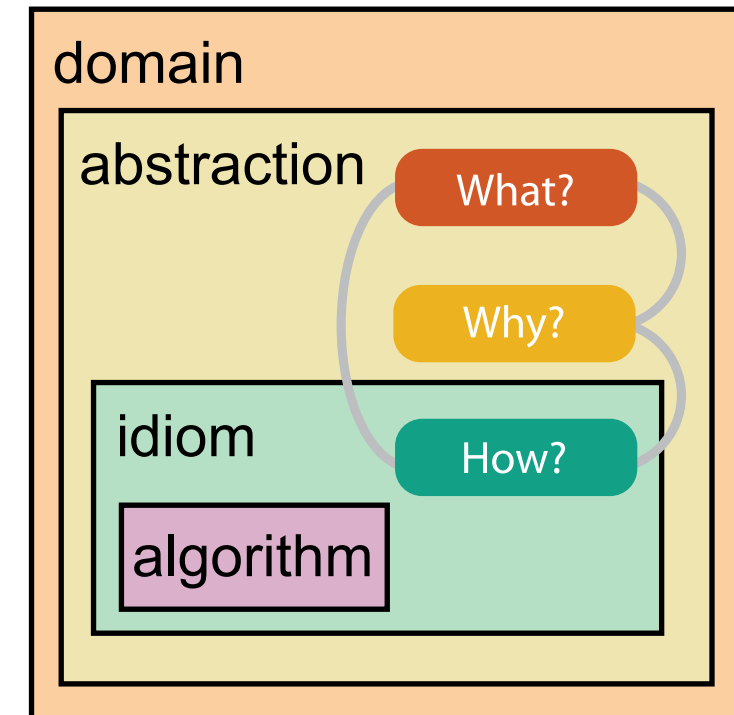
Analysis framework: Four levels, three questions

- *domain situation*
 - who are the target users?

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 - **why** is the user looking at it? **task** abstraction

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

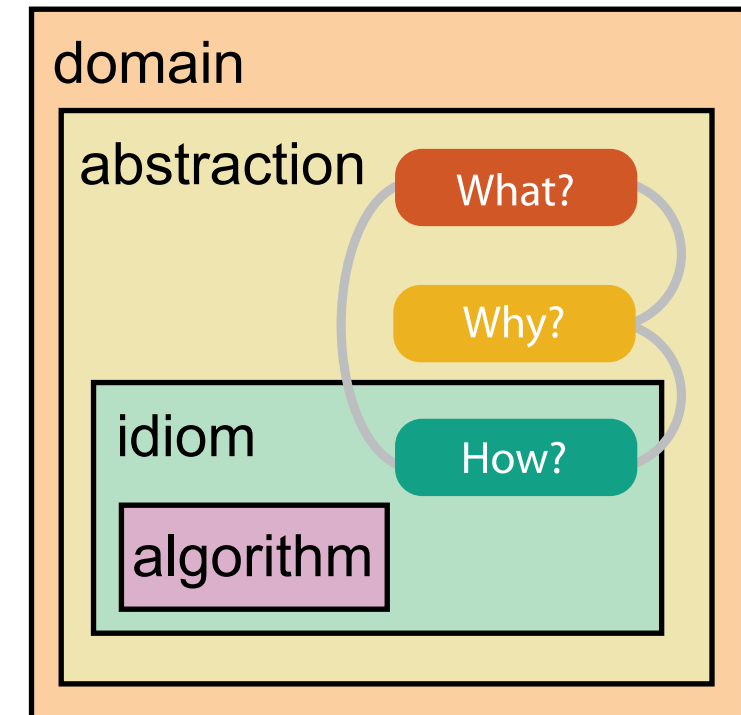


[A Multi-Level Typology of Abstract Visualization Tasks
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- *idiom*
 - **how** is it shown?
 - **visual encoding** idiom: how to draw
 - **interaction** idiom: how to manipulate

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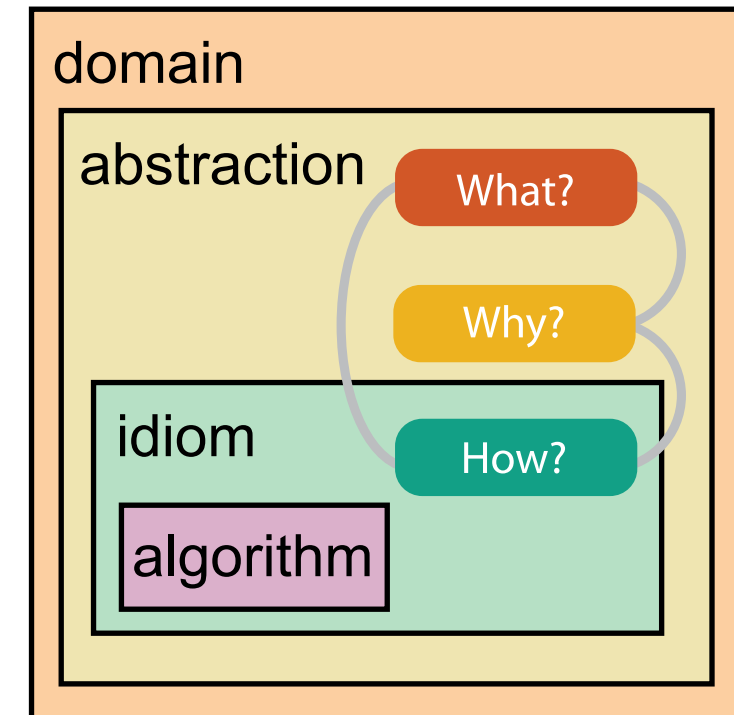


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- *algorithm*
 - efficient computation

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Why is validation difficult?

- different ways to get it wrong at each level



Domain situation

You misunderstood their needs



Data/task abstraction

You're showing them the wrong thing



Visual encoding/interaction idiom

The way you show it doesn't work

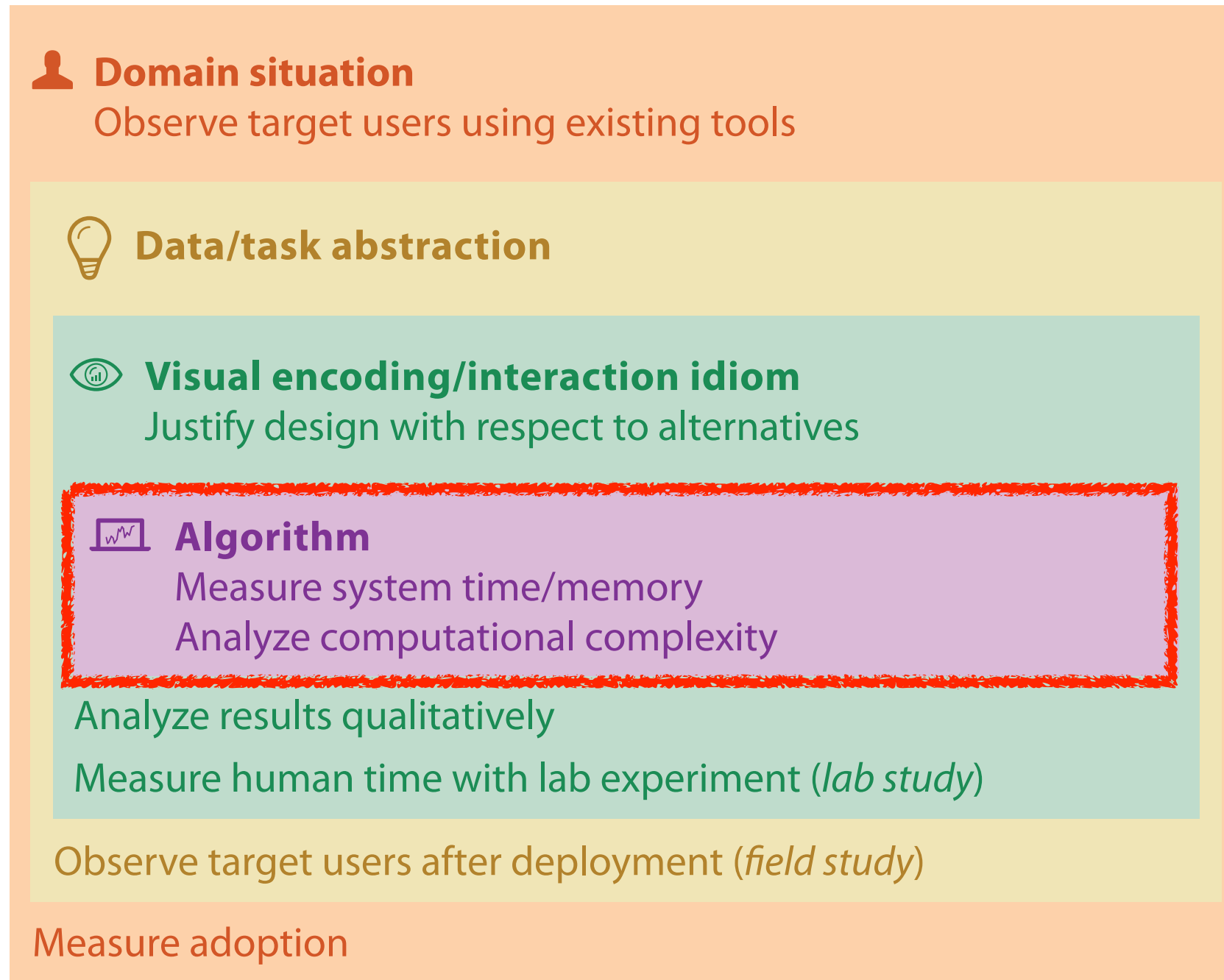


Algorithm

Your code is too slow

Why is validation difficult?

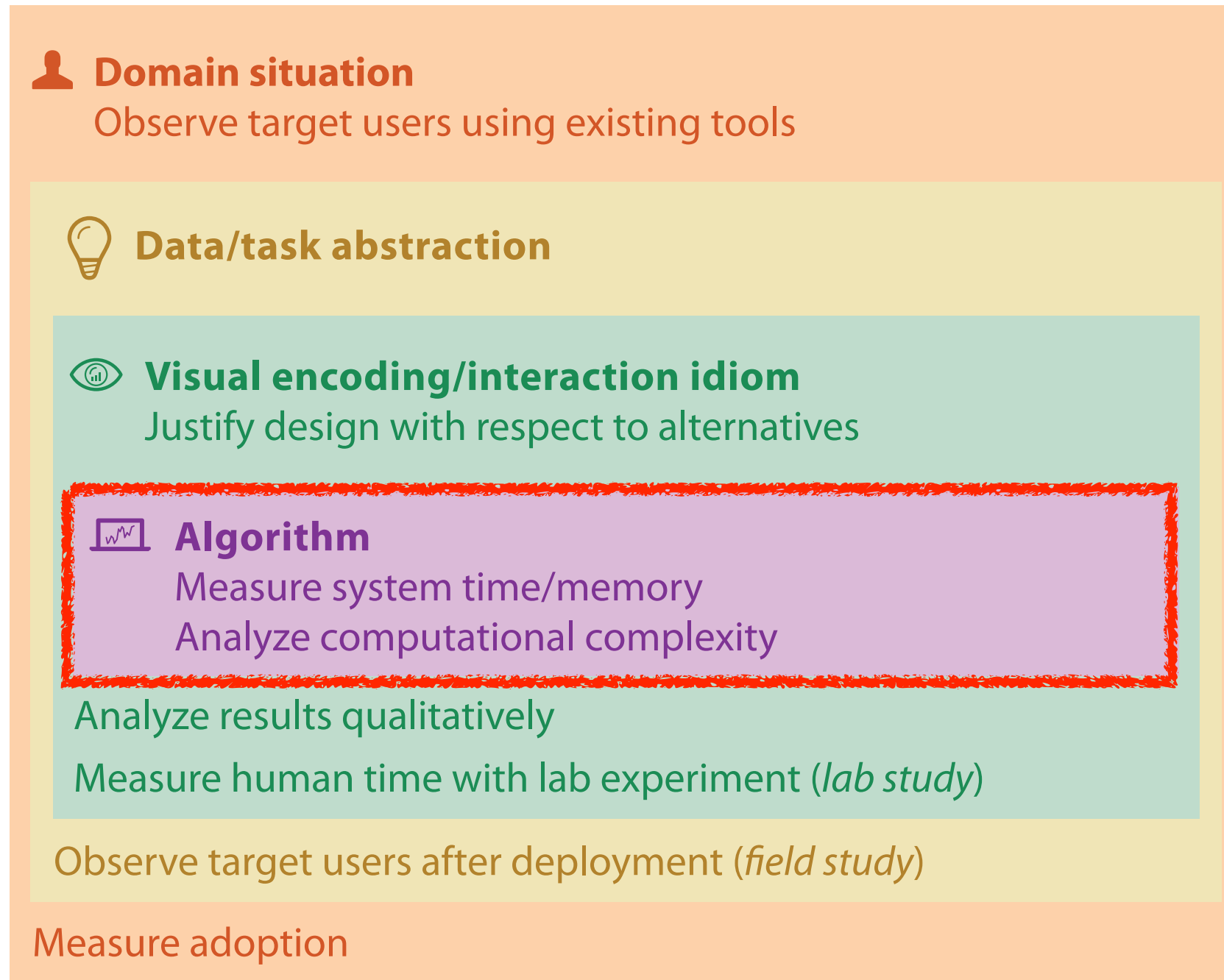
- solution: use methods from different fields at each level



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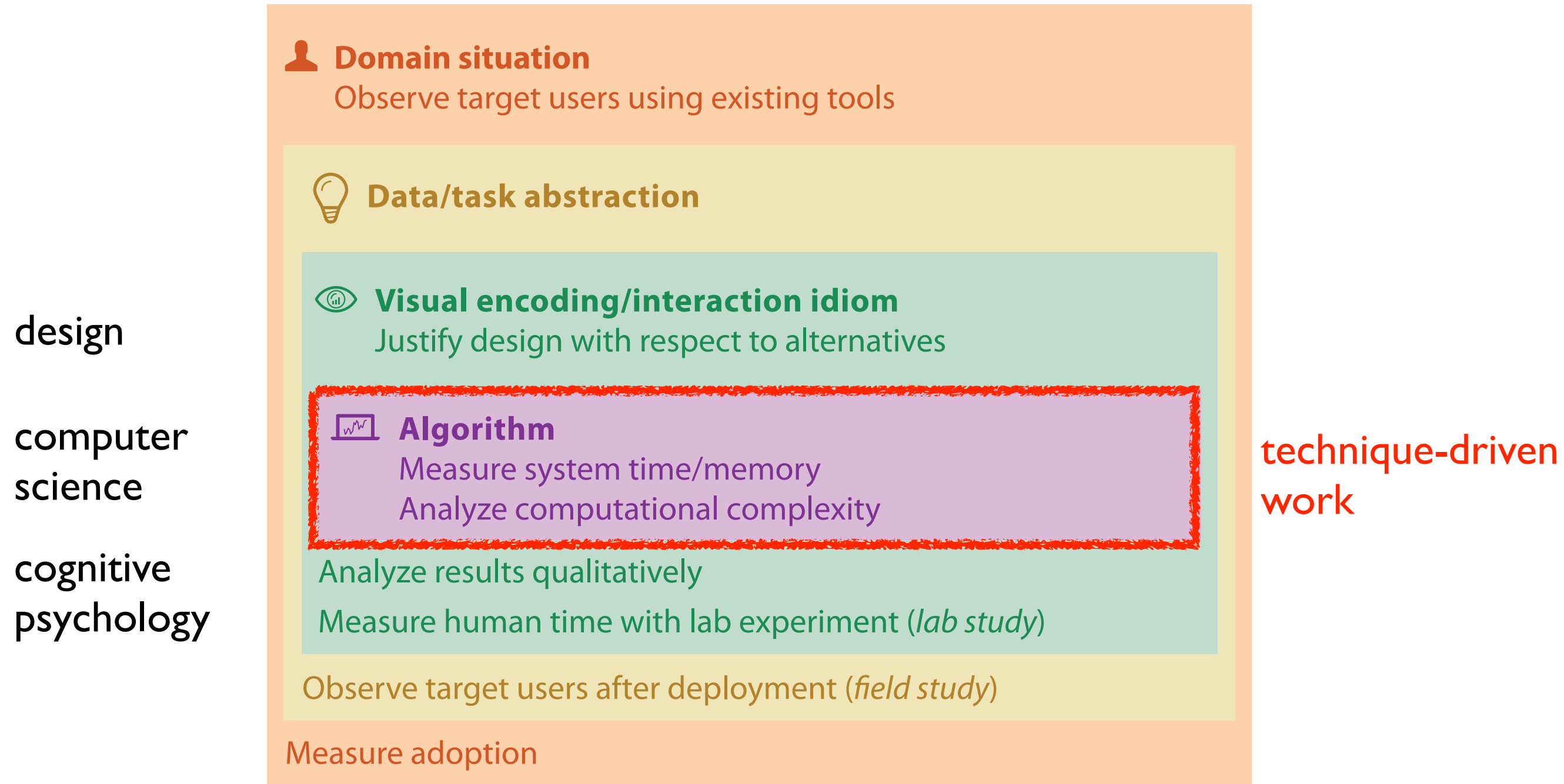
computer
science



technique-driven
work

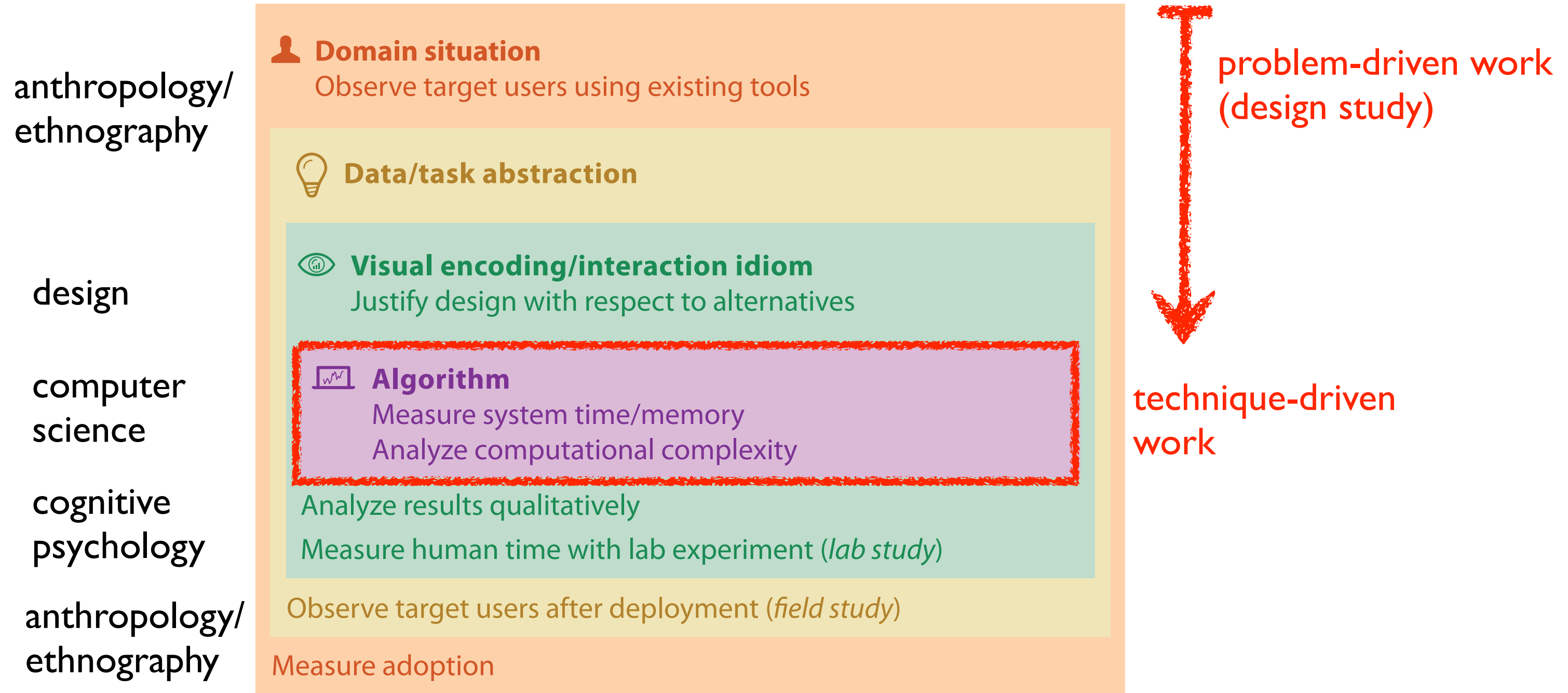
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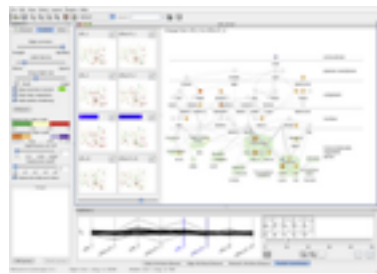


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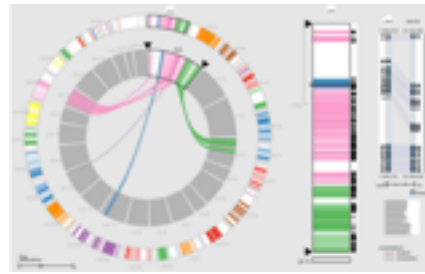
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Design Study Methodology: Reflections from the Trenches and the Stacks



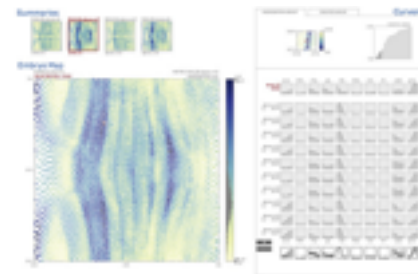
Cerebral
genomics



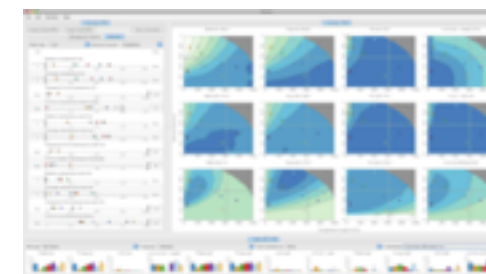
MizBee
genomics



Pathline
genomics



MulteeSum
genomics



Vismon
fisheries management



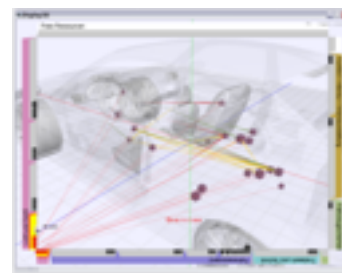
QuestVis
sustainability



WiKeVis
in-car networks



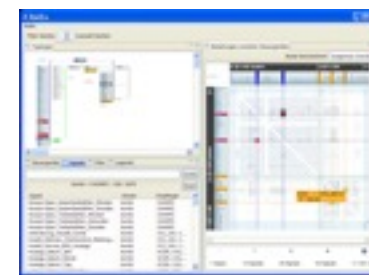
MostVis
in-car networks



Car-X-Ray
in-car networks



ProgSpy2010
in-car networks



ReEx
in-car networks



Cardiogram
in-car networks



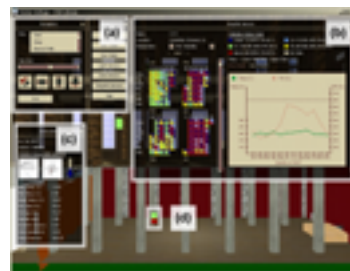
AutobahnVis
in-car networks



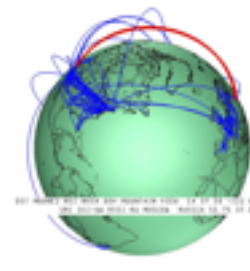
VisTra
in-car networks



Constellation
linguistics



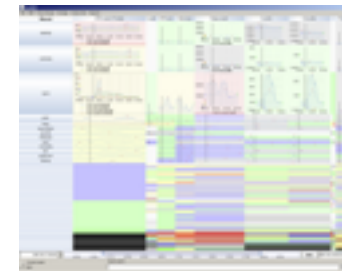
LibVis
cultural heritage



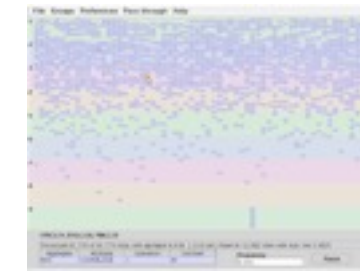
Caidants
multicast



SessionViewer
web log analysis

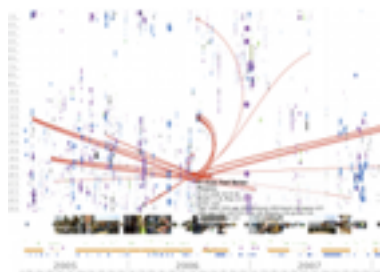


LiveRAC
server hosting

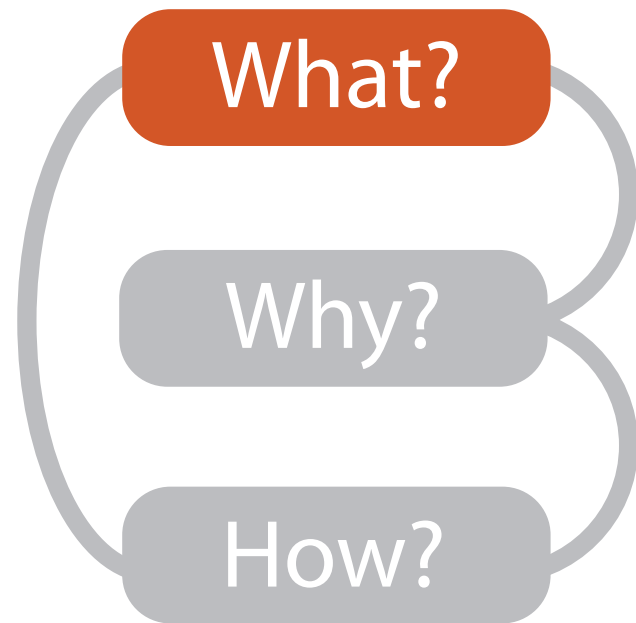


PowerSetViewer
data mining

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



LastHistory
music listening



What?

Datasets Attributes

➔ Data Types

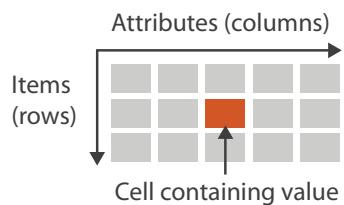
➔ Items ➔ Attributes ➔ Links ➔ Positions ➔ Grids

➔ Data and Dataset Types

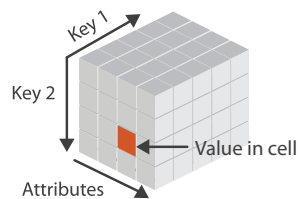
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

➔ Dataset Types

➔ Tables



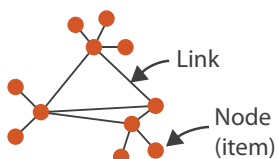
➔ *Multidimensional Table*



➔ Geometry (Spatial)



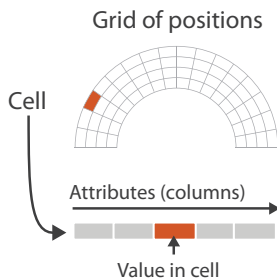
➔ Networks



➔ *Trees*



➔ Fields (Continuous)



➔ Dataset Availability

➔ Static



➔ Dynamic



➔ Attribute Types

➔ Categorical



➔ Ordered

➔ *Ordinal*



➔ *Quantitative*



➔ Ordering Direction

➔ Sequential



➔ Diverging



➔ Cyclic

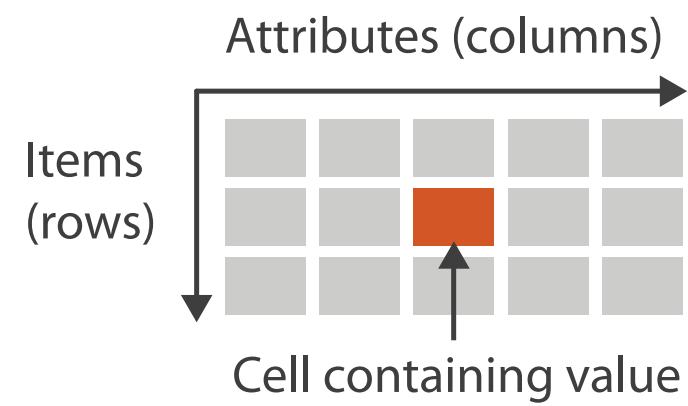


Three major datatypes

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➔ Dataset Types

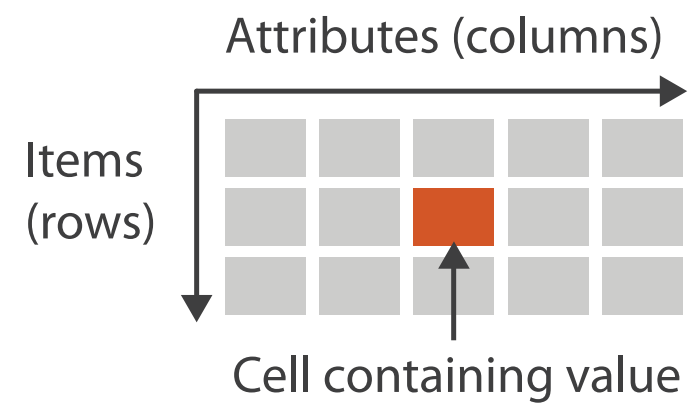
➔ Tables



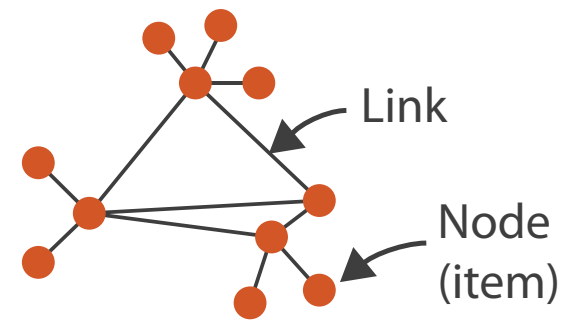
Three major datatypes

➔ Dataset Types

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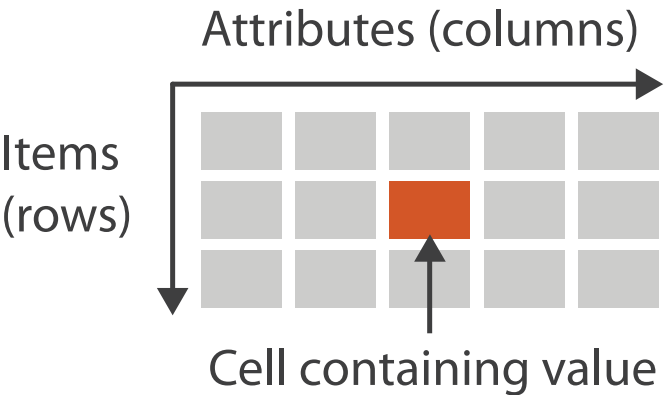
➔ Networks



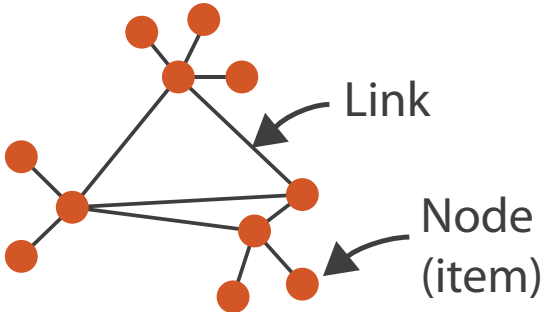
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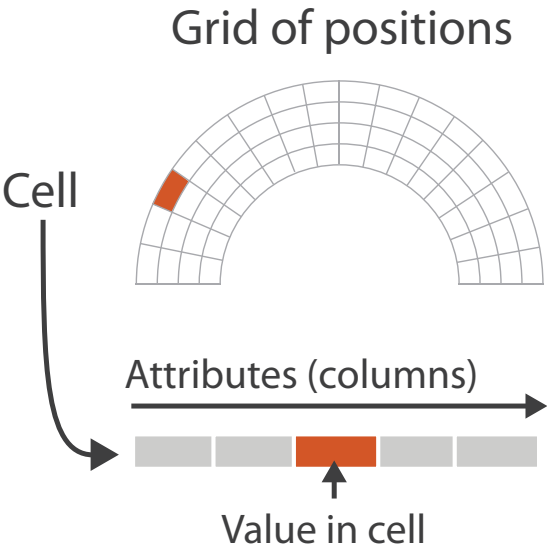


➔ Networks

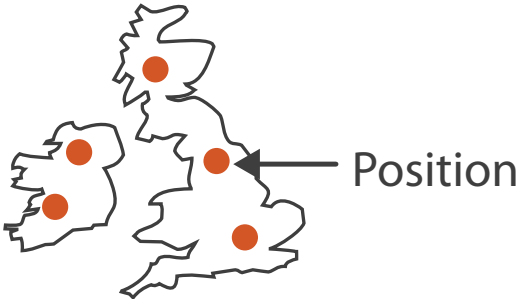


➔ Spatial

➔ Fields (Continuous)



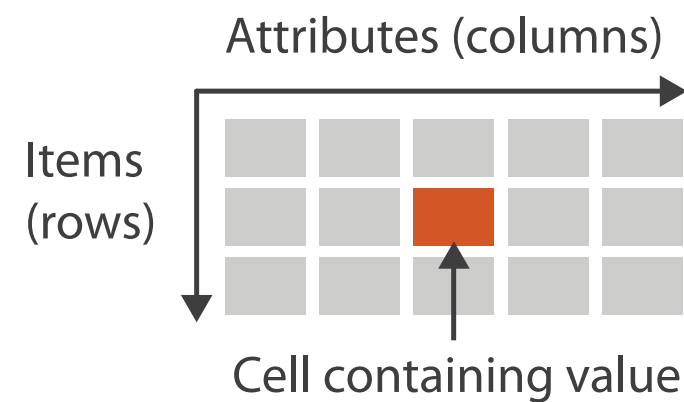
➔ Geometry (Spatial)



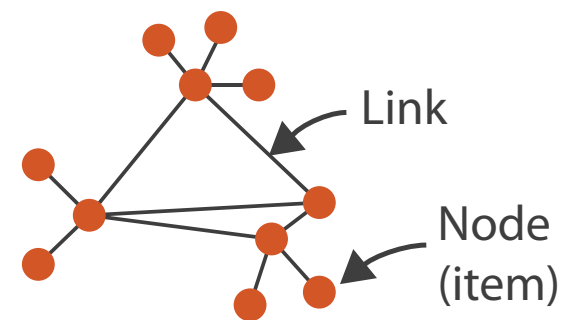
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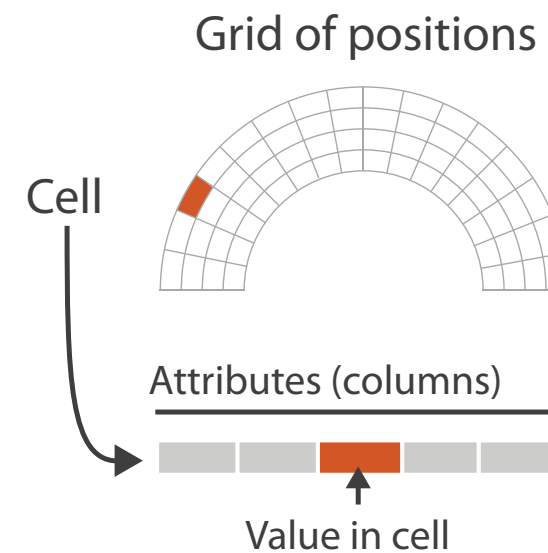


➔ Networks

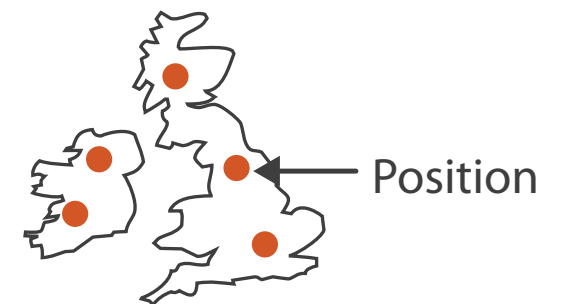


➔ Spatial

➔ Fields (Continuous)



➔ Geometry (Spatial)



- visualization vs computer graphics
 - geometry is design decision

Attribute types

➔ Attribute Types

➔ Categorical

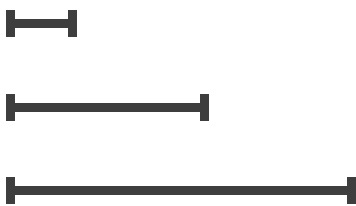


➔ Ordered

➔ *Ordinal*



➔ *Quantitative*



➔ Ordering Direction

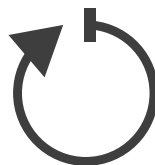
➔ Sequential

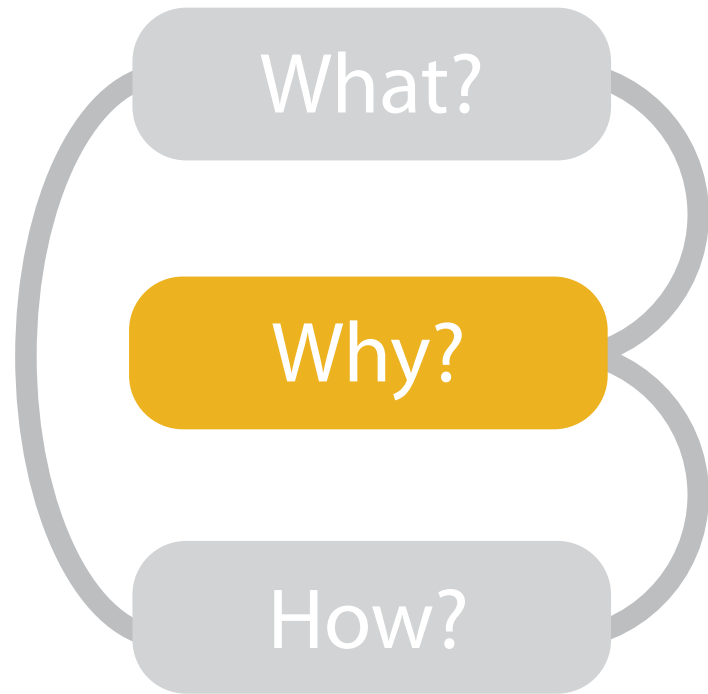


➔ Diverging



➔ Cyclic





Why?

Actions

Targets

➔ Analyze

➔ Consume

➔ Discover



➔ Present



➔ Enjoy

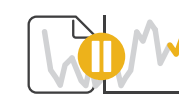


➔ Produce

➔ Annotate



➔ Record



➔ Derive

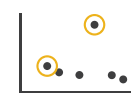


➔ Search

	Target known	Target unknown
Location known	Lookup	Browse
Location unknown	Locate	Explore

➔ Query

➔ Identify



➔ Compare

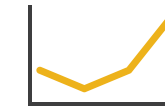


➔ Summarize



➔ All Data

➔ Trends



➔ Outliers



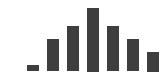
➔ Features



➔ Attributes

➔ One

➔ Distribution



➔ Extremes

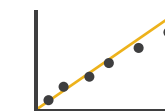


➔ Many

➔ Dependency



➔ Correlation

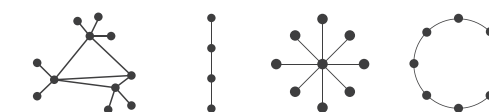


➔ Similarity



➔ Network Data

➔ Topology



➔ Paths



➔ Spatial Data

➔ Shape



👉 Actions

🎯 Targets

➔ **Analyze**

➔ Consume

➔ Discover  ➔ Present  ➔ Enjoy 

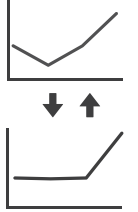
➔ Produce

➔ Annotate  ➔ Record  ➔ Derive 

➔ **Search**

	Target known	Target unknown
Location known	 <i>Lookup</i>	 <i>Browse</i>
Location unknown	 <i>Locate</i>	 <i>Explore</i>

➔ **Query**

➔ Identify  ➔ Compare  ➔ Summarize 

➔ **All Data**

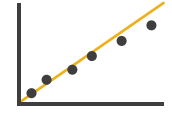
➔ Trends  ➔ Outliers  ➔ Features 

➔ **Attributes**

➔ One

➔ Distribution  ➔ Extremes 

➔ Many

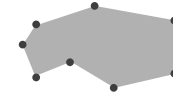
➔ Dependency  ➔ Correlation  ➔ Similarity 

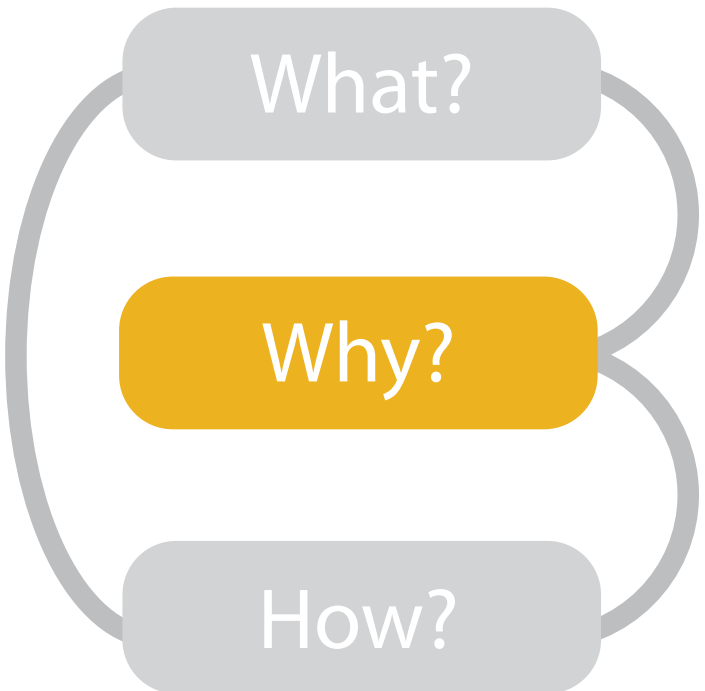
➔ **Network Data**

➔ Topology 

➔ Paths 

➔ **Spatial Data**

➔ Shape 



- {action, target} pairs
 - discover distribution
 - compare trends
 - locate outliers
 - browse topology

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)

➔ Analyze

➔ Consume

➔ Discover



➔ Present

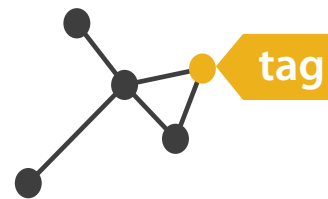


➔ Enjoy



➔ Produce

➔ Annotate



➔ Record

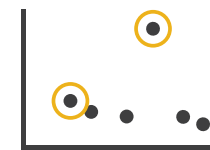


➔ Derive



➔ Query

➔ Identify



➔ Compare



➔ Summarize



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)

➔ Analyze

➔ Consume

➔ Discover



➔ Present

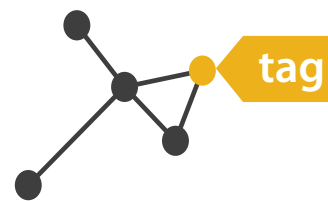


➔ Enjoy



➔ Produce

➔ Annotate



➔ Record

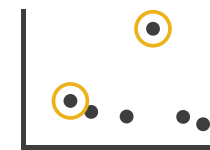


➔ Derive



➔ Query

➔ Identify



➔ Compare

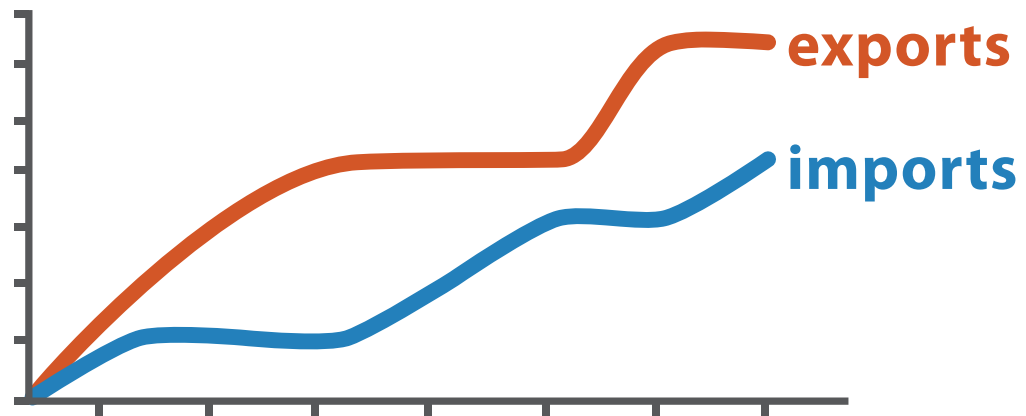


➔ Summarize

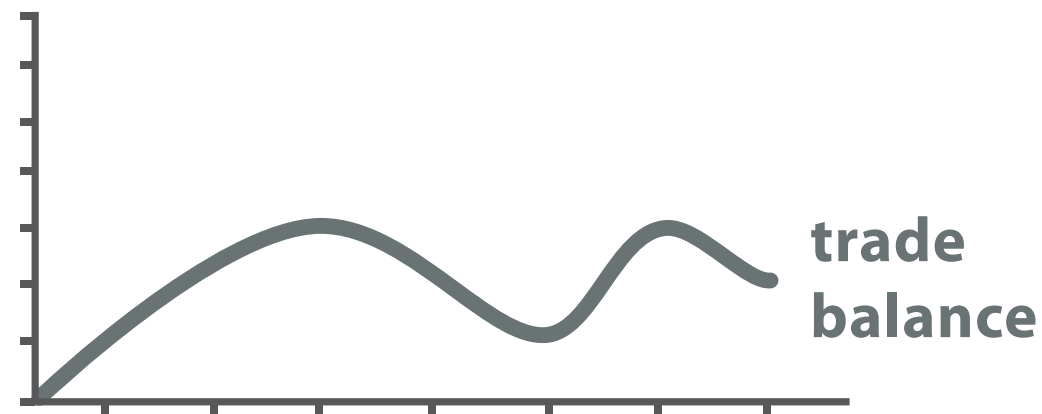


Derive

- 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



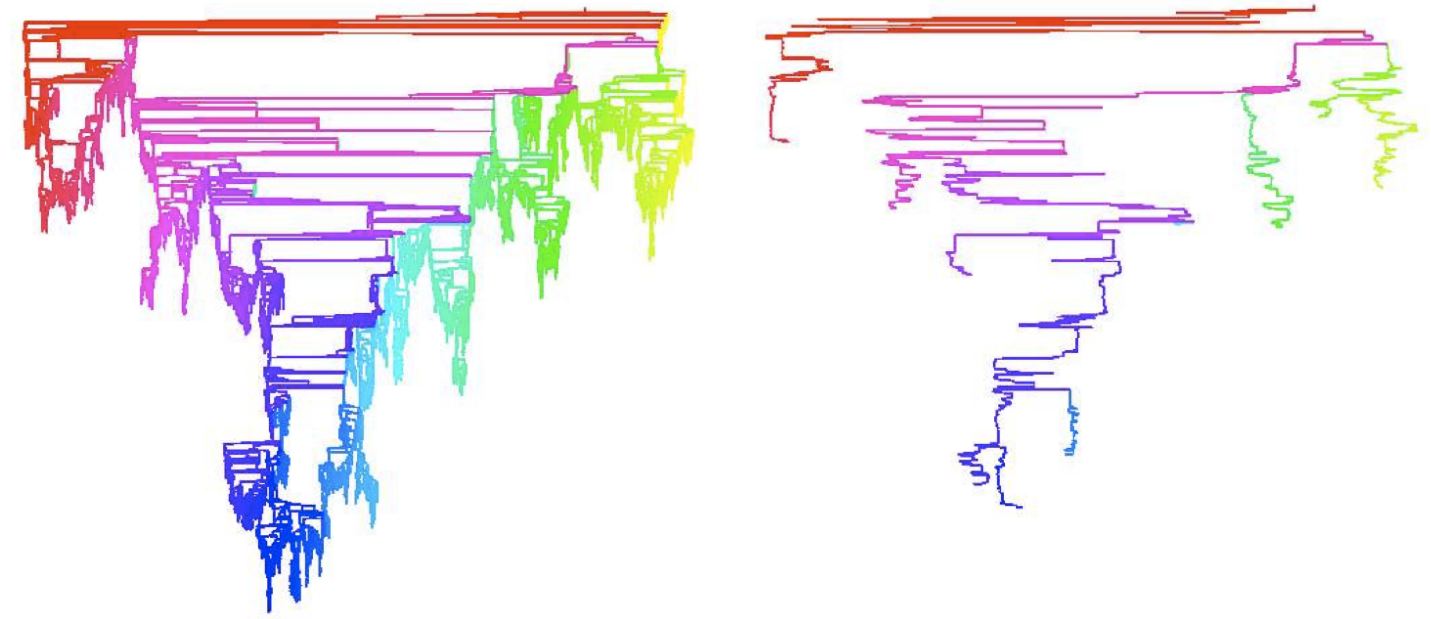
$$\text{trade balance} = \text{exports} - \text{imports}$$

Derived Data

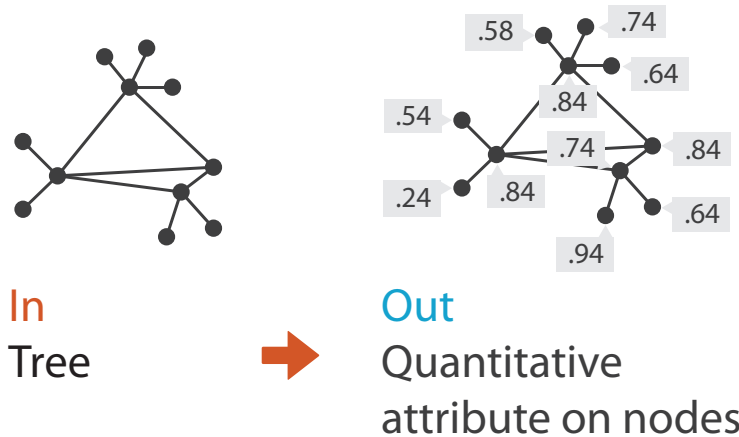
Analysis example: Derive one attribute

- 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



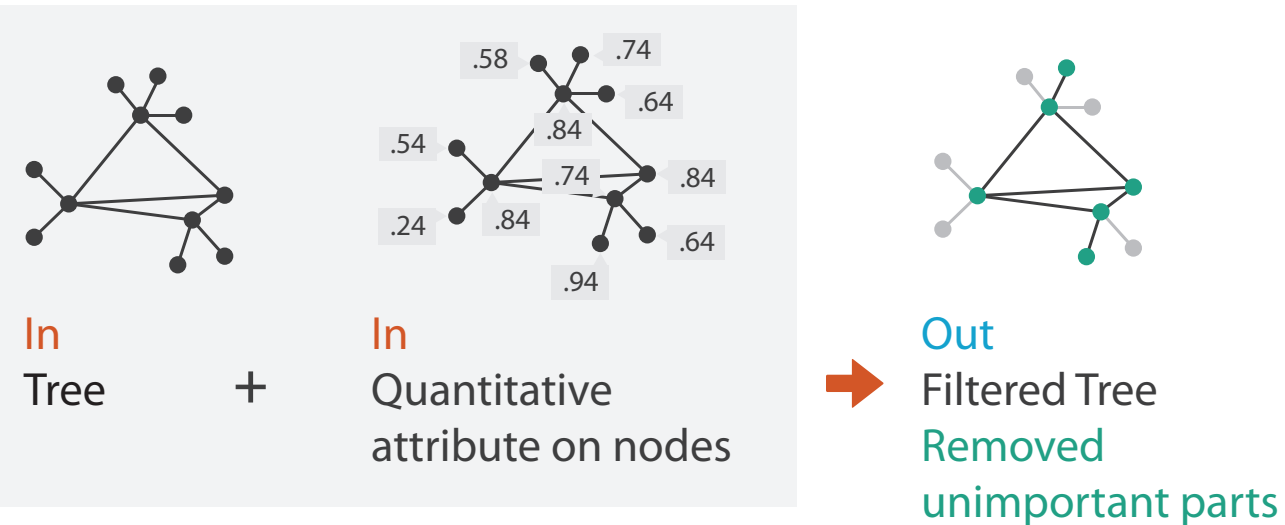
What?

- In Tree
- Out Quantitative attribute on nodes

Why?

- Derive

Task 2



What?

- In Tree
- In Quantitative attribute on nodes
- Out Filtered Tree

Why?

- Summarize
- Topology

How?

- Reduce
- Filter

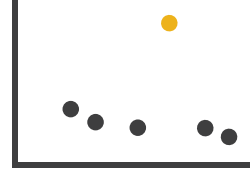
Why: Targets

→ All Data

→ Trends



→ Outliers



→ Features



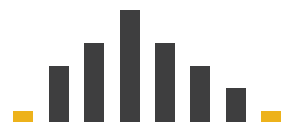
→ Attributes

→ One

→ *Distribution*



→ *Extremes*

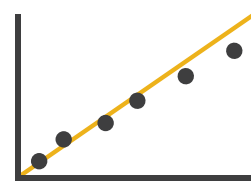


→ Many

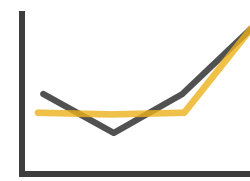
→ *Dependency*



→ *Correlation*

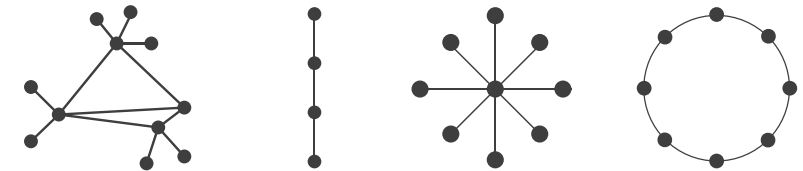


→ *Similarity*



→ Network Data

→ Topology

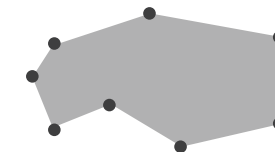


→ *Paths*



→ Spatial Data

→ Shape



How?

Encode

➔ Arrange

➔ Express



➔ Separate



➔ Order



➔ Align



➔ Use



➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue



➔ Saturation



➔ Luminance



➔ Size, Angle, Curvature, ...



➔ Shape



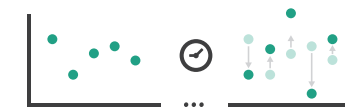
➔ Motion

Direction, Rate, Frequency, ...

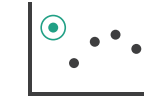


Manipulate

➔ Change



➔ Select



➔ Navigate



Facet

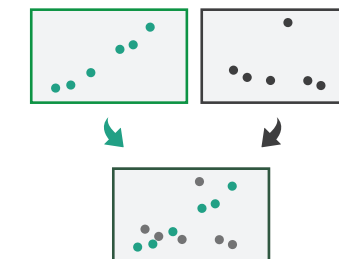
➔ Juxtapose



➔ Partition



➔ Superimpose



Reduce

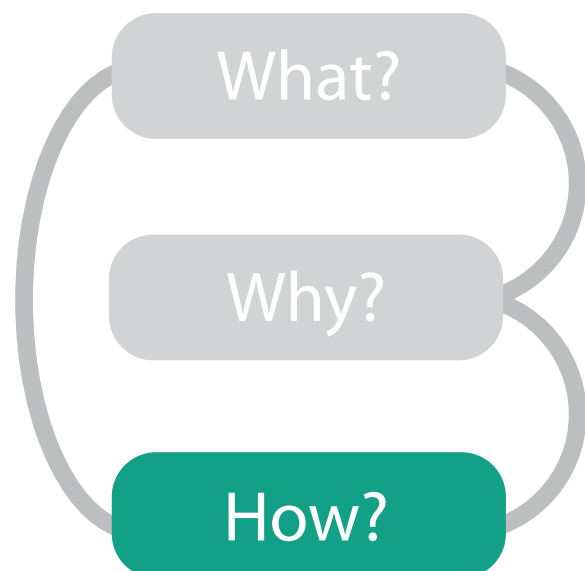
➔ Filter



➔ Aggregate



➔ Embed



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*
 - *Ch 4.Analysis: Four Levels for Validation*
- *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.

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

@tamara@cosocial.ca

<https://www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25>

How?

Encode

➔ Arrange

➔ Express



➔ Separate



➔ Order



➔ Align



➔ Use



➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue



➔ Saturation



➔ Luminance



➔ Size, Angle, Curvature, ...



➔ Shape



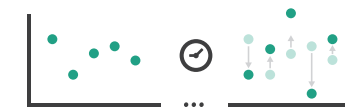
➔ Motion

Direction, Rate, Frequency, ...

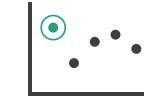


Manipulate

➔ Change



➔ Select



➔ Navigate



Facet

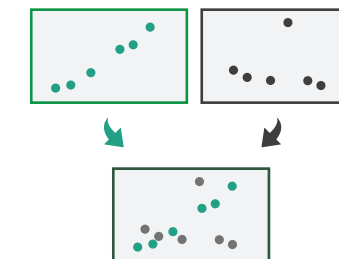
➔ Juxtapose



➔ Partition



➔ Superimpose



Reduce

➔ Filter



➔ Aggregate



➔ Embed



What?

Why?

How?

How?

Encode

➔ Arrange

➔ Express



➔ Separate



➔ Order



➔ Align



➔ Use



➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue



➔ Saturation



➔ Luminance



➔ Size, Angle, Curvature, ...



➔ Shape



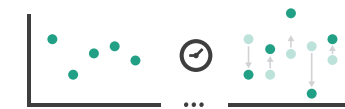
➔ Motion

Direction, Rate, Frequency, ...

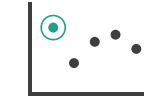


Manipulate

➔ Change



➔ Select



➔ Navigate



Facet

➔ Juxtapose



➔ Partition



➔ Superimpose



Reduce

➔ Filter



➔ Aggregate



➔ Embed



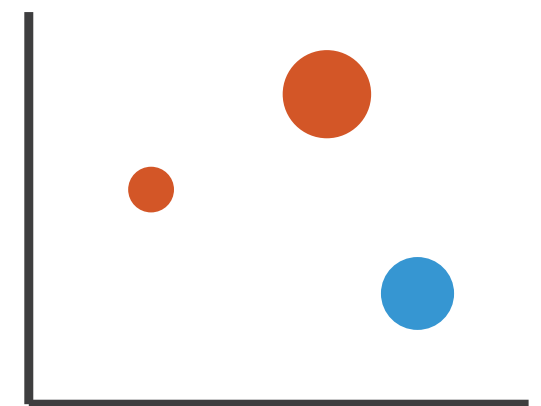
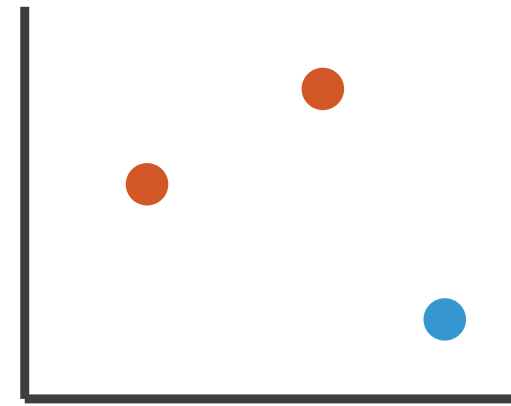
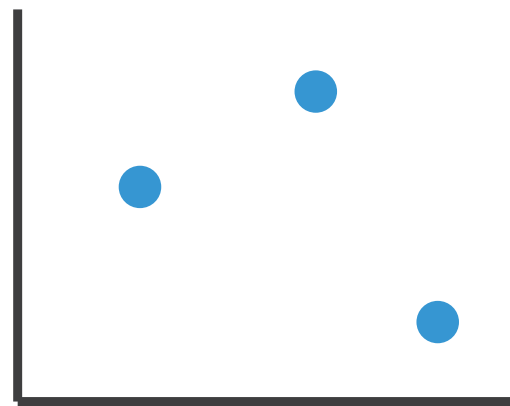
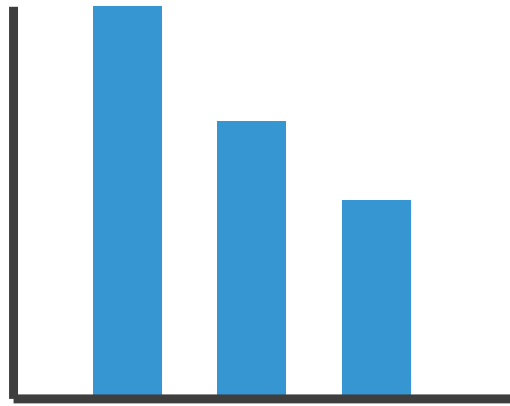
What?

Why?

How?

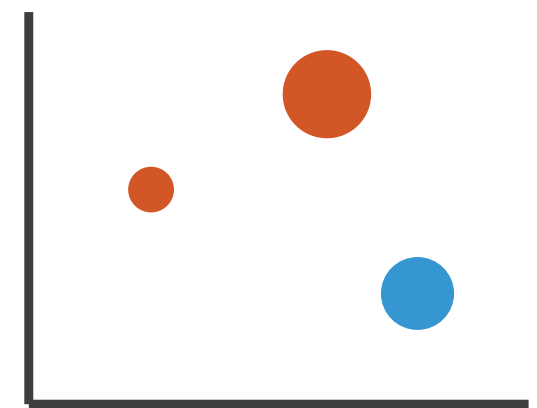
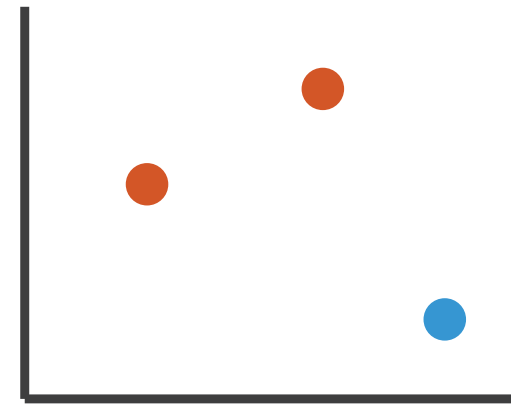
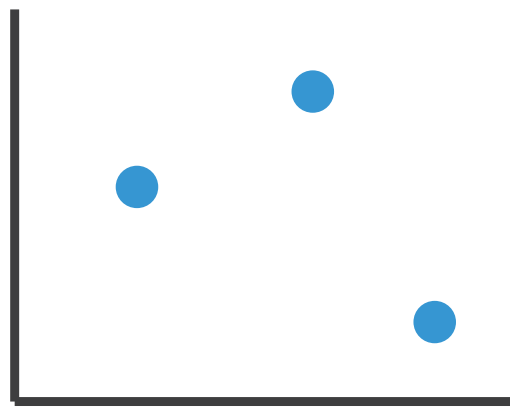
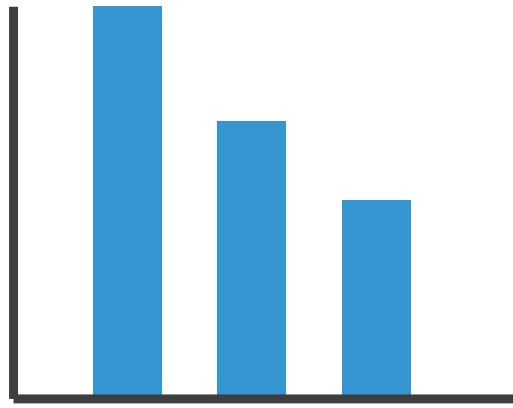
Visual encoding

- how to systematically analyze idiom structure?



Visual encoding

- how to systematically analyze idiom structure?



- marks & channels
 - marks: represent items or links
 - channels: change appearance of marks based on attributes

Marks for items

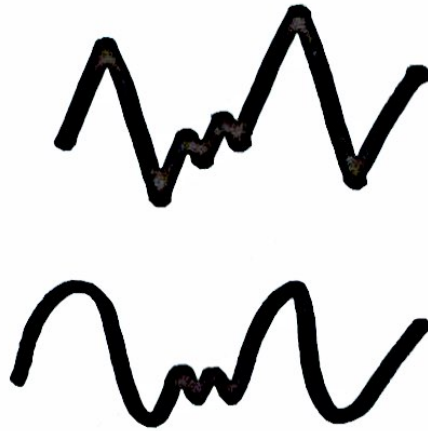
- basic geometric elements

point



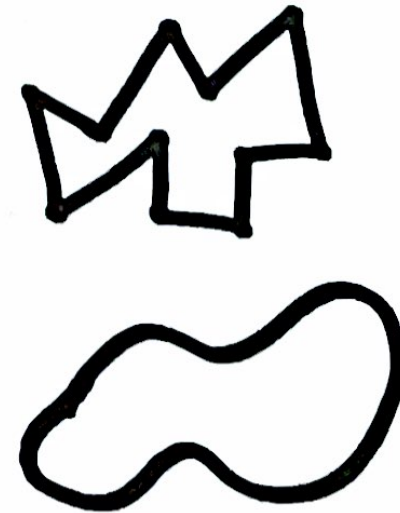
0D

path



1D

poly



2D

Marks for items

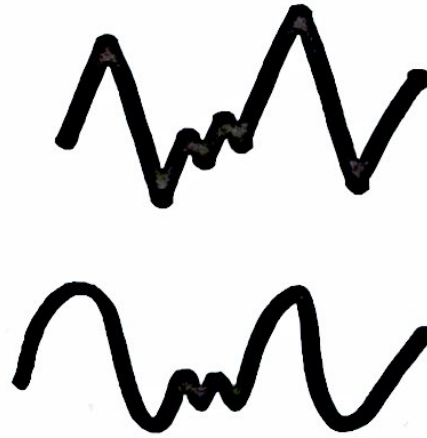
- basic geometric elements

point



1 item

path



many
items

poly



boundary
(closed path)

many
items

Marks for items

- basic geometric elements

point



1 item

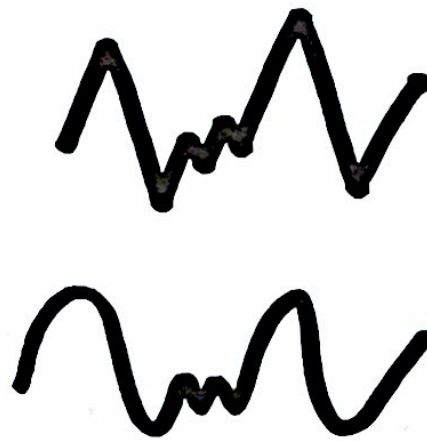
segment



special case
of path:
2 items

2 items

path



many
items

poly



boundary
(closed path)

many
items

- 3D volumes: trickier case

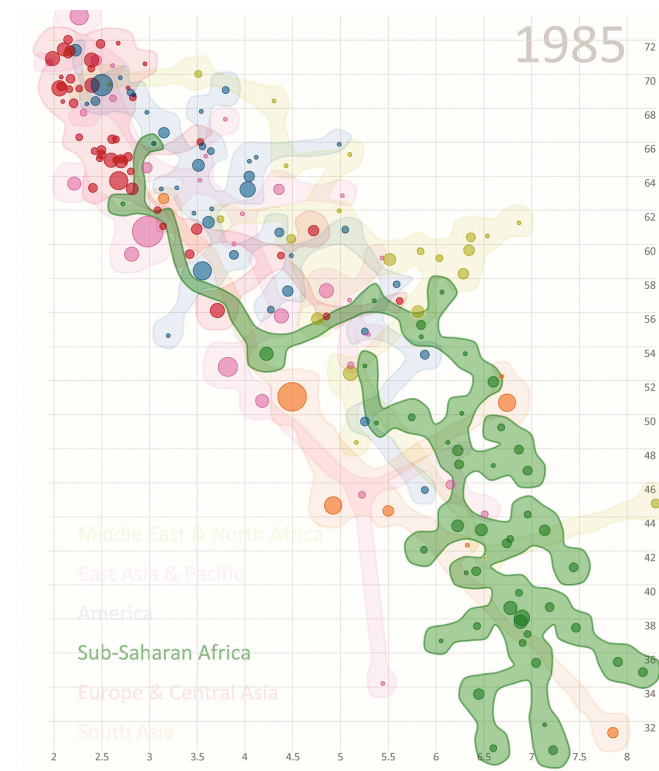
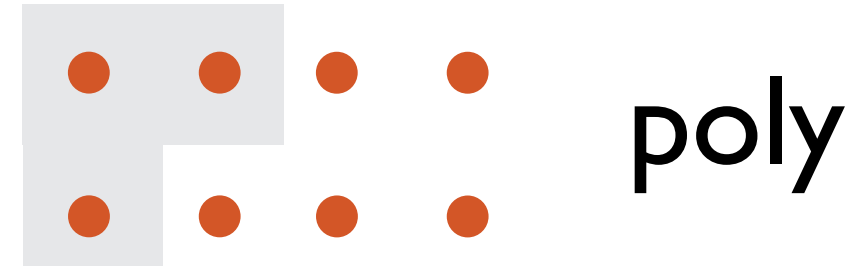
Marks for links

➞ Connection



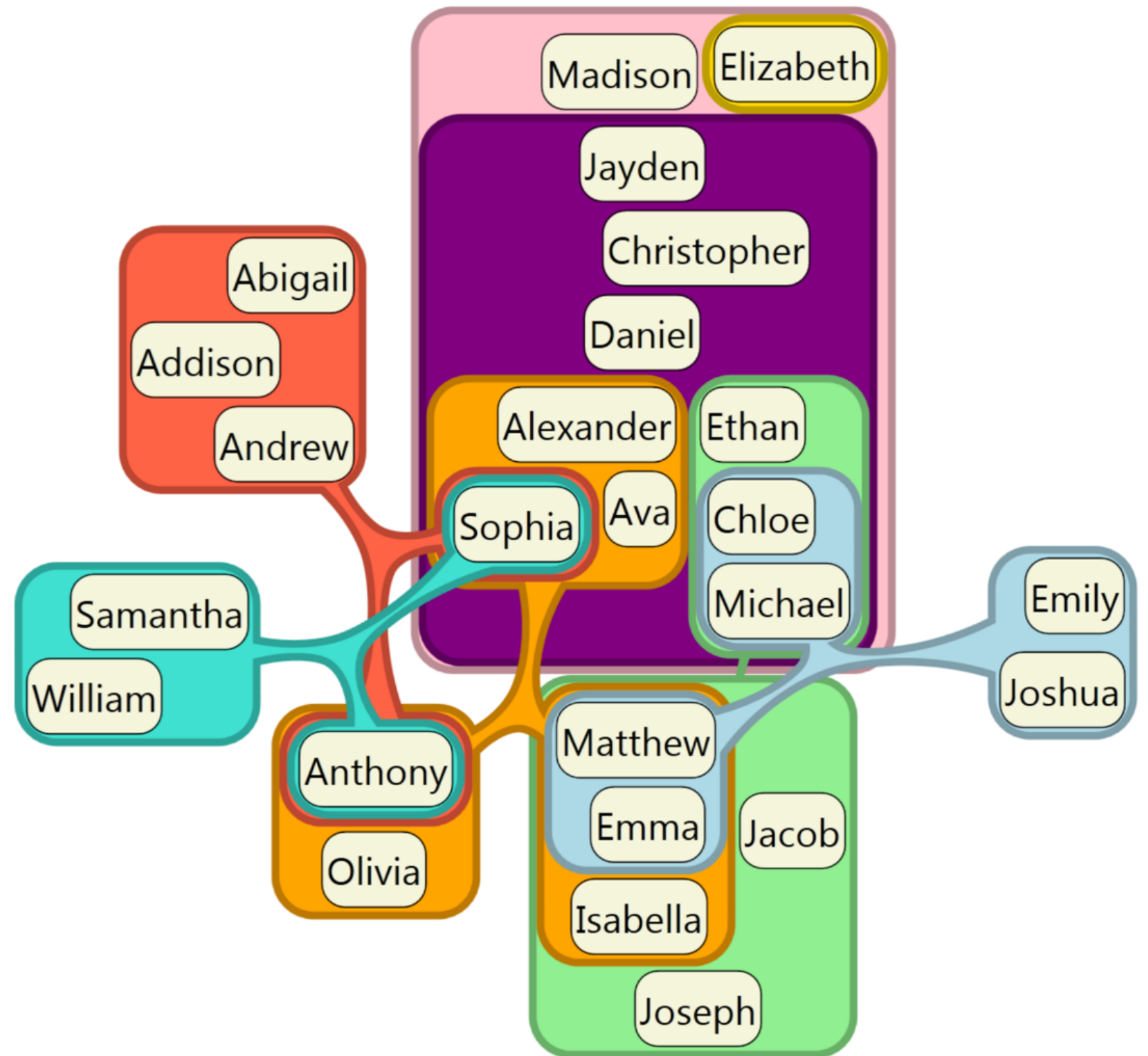
<https://observablehq.com/@d3/force-directed-graph>

➞ Containment



vialab.science.uoit.ca/portfolio/bubblesets

Containment can be nested



[Untangling Euler Diagrams, Riche and Dwyer, 2010]

Channels

- control appearance of marks
 - proportional to or based on attributes
- many names
 - **visual channels**
 - visual variables
 - retinal channels
 - visual dimensions
 - ...

➞ Position

➞ Horizontal (1D) ➞ Vertical (1D) ➞ 2D



➞ Symbol



➞ Size

➞ Length / Width (1D) ➞ Area (2D)



➞ Color



➞ Orientation



Definitions: Marks and channels

- marks
 - geometric primitives

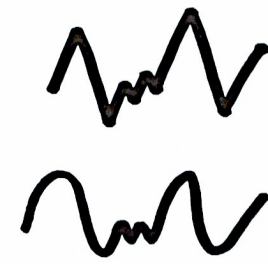
point



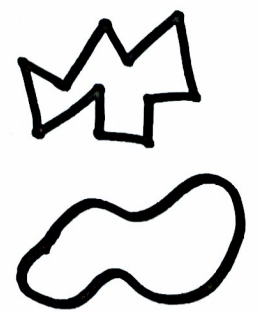
segment



path

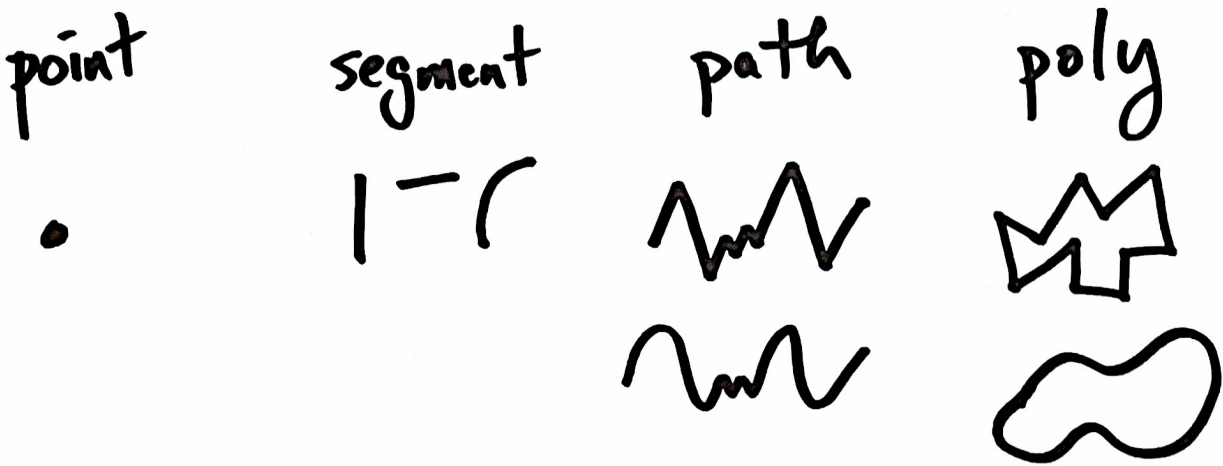


poly



Definitions: Marks and channels

- marks
 - geometric primitives
- channels
 - control appearance of marks



➔ Position

➔ Horizontal (1D) ➔ Vertical (1D) ➔ 2D

➔ Color

➔ Symbol

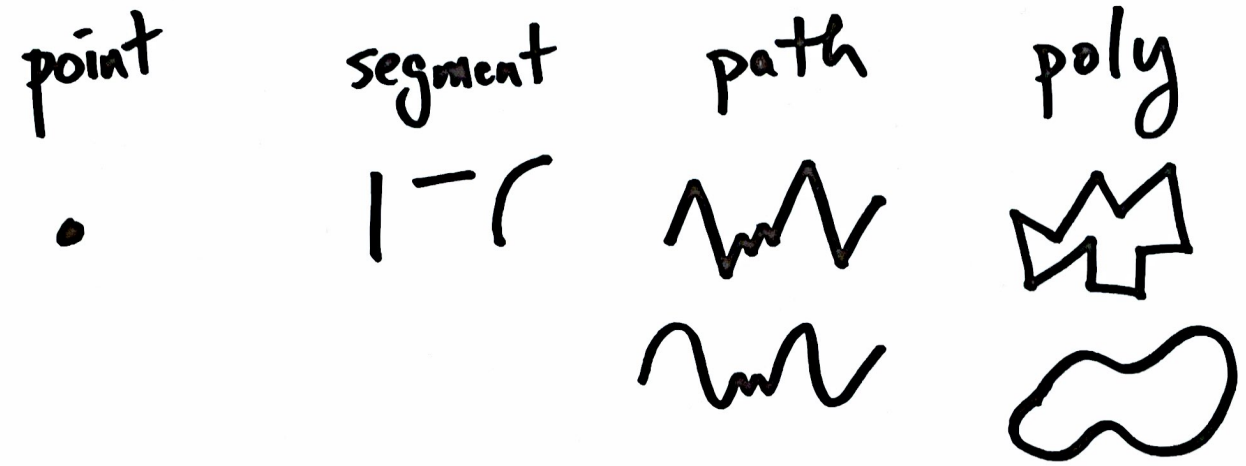
➔ Orientation

➔ Size

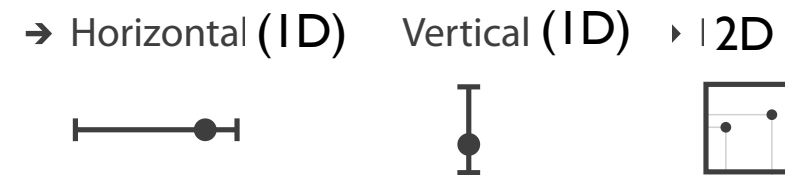
➔ Length/Width (1D) ➔ Area (2D)

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



➔ Position



➔ Color



➔ Symbol



➔ Orientation



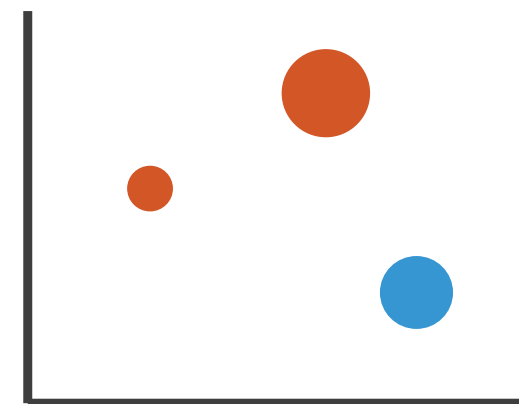
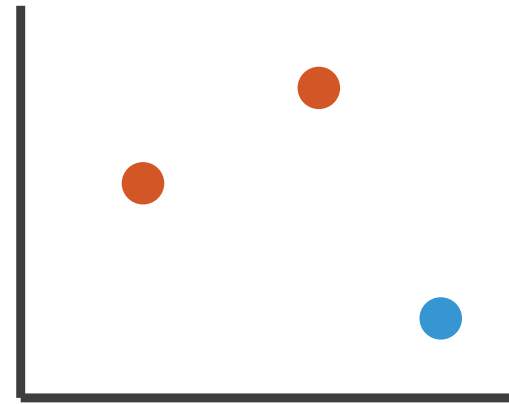
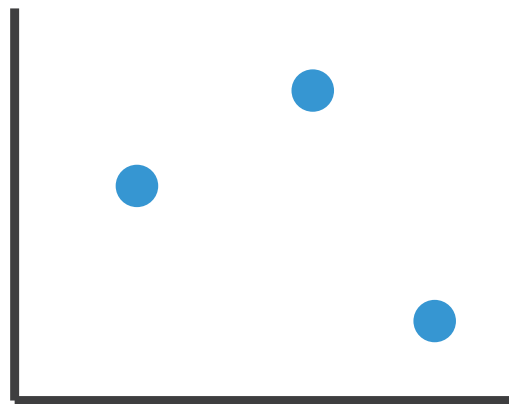
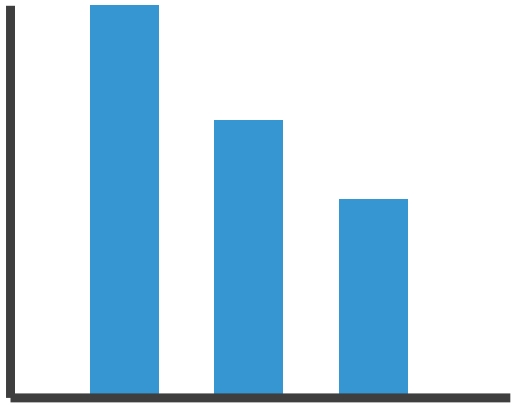
➔ Size

➔ Length/Width (1D) ➔ Area (2D)



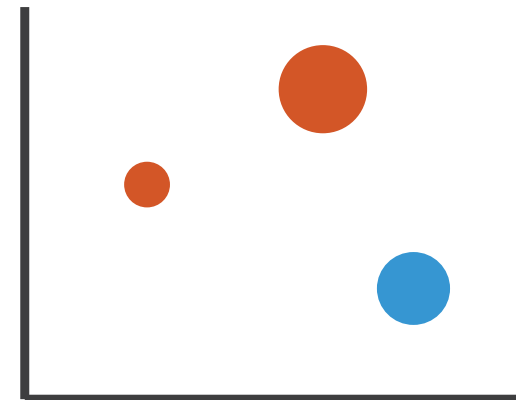
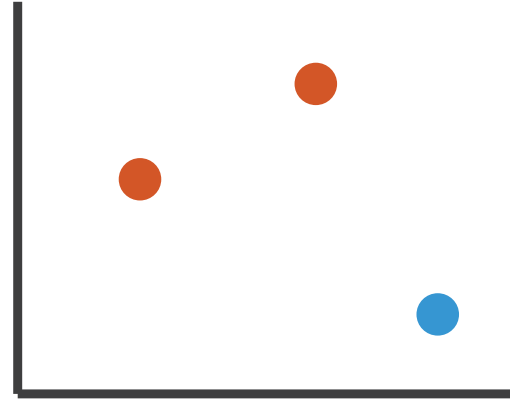
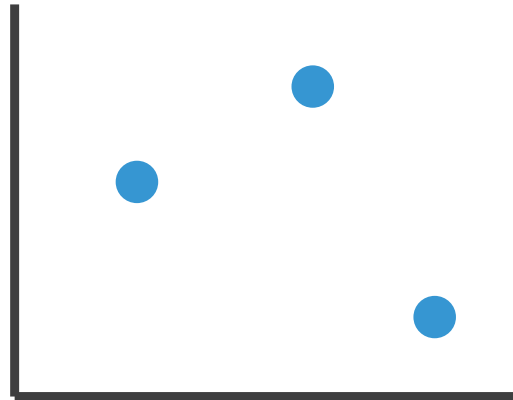
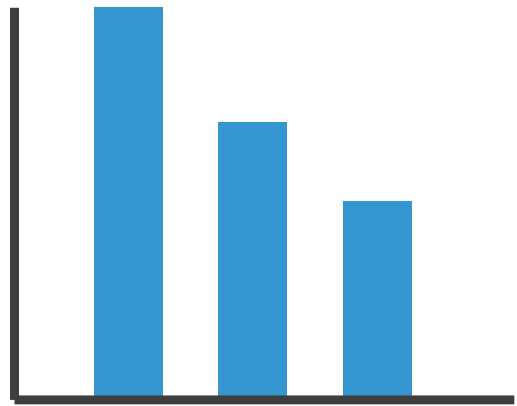
Visual encoding

- analyze idiom structure as combination of marks and channels



Visual encoding

- analyze idiom structure as combination of marks and channels

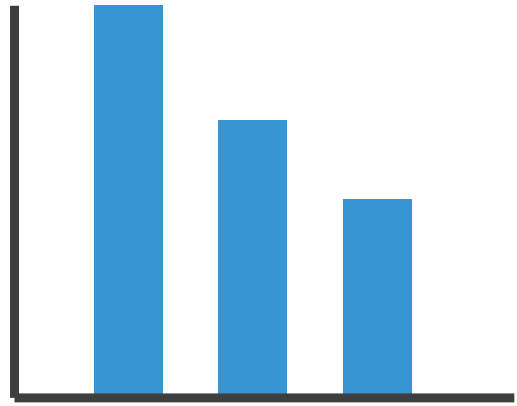


1:
vertical position

mark: segment

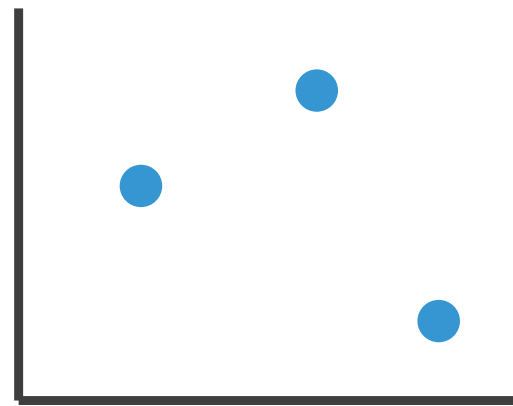
Visual encoding

- analyze idiom structure as combination of marks and channels



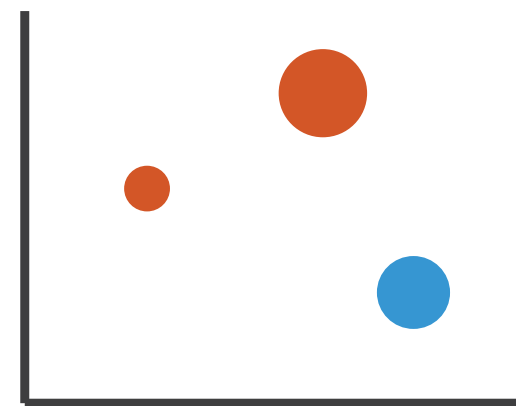
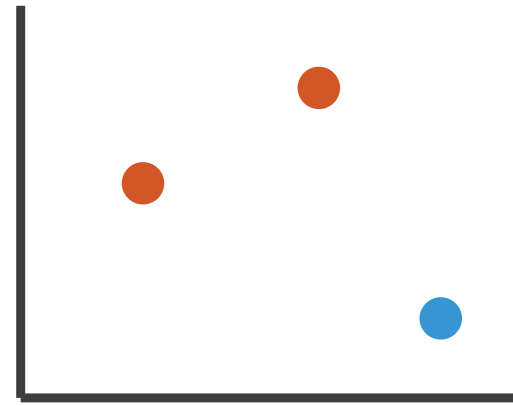
1:
vertical position

mark: segment



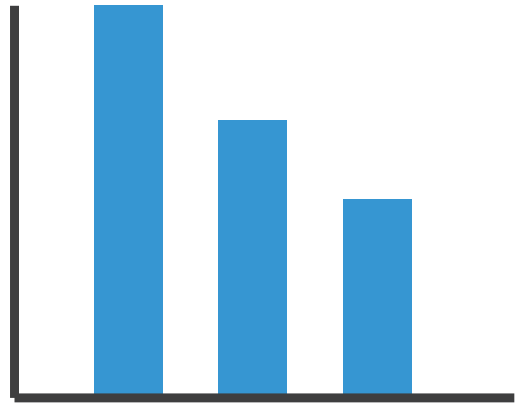
2:
vertical position
horizontal position

mark: point



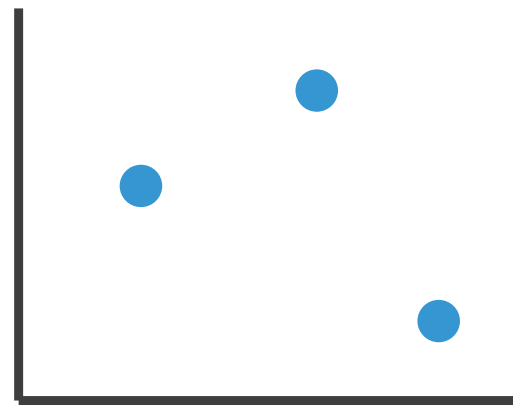
Visual encoding

- analyze idiom structure as combination of marks and channels



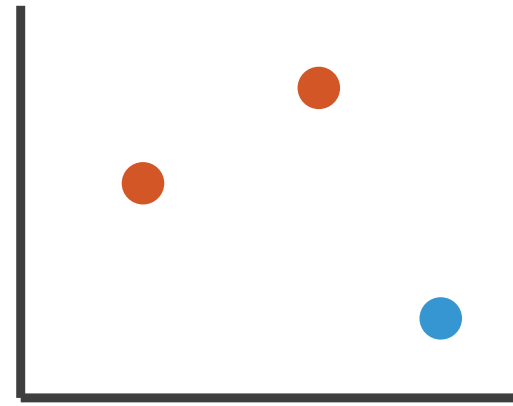
1:
vertical position

mark: segment



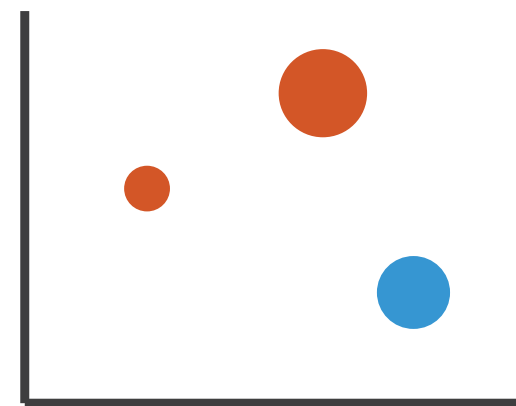
2:
vertical position
horizontal position

mark: point



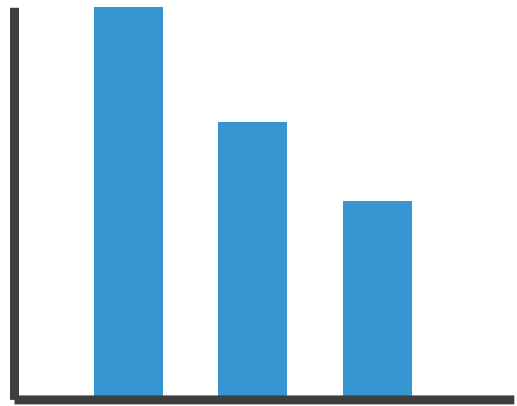
3:
vertical position
horizontal position
color (hue)

mark: point



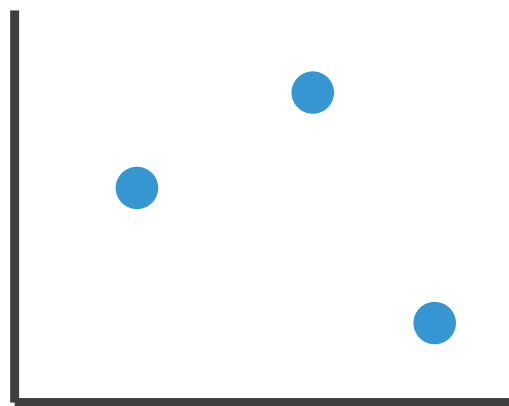
Visual encoding

- analyze idiom structure as combination of marks and channels



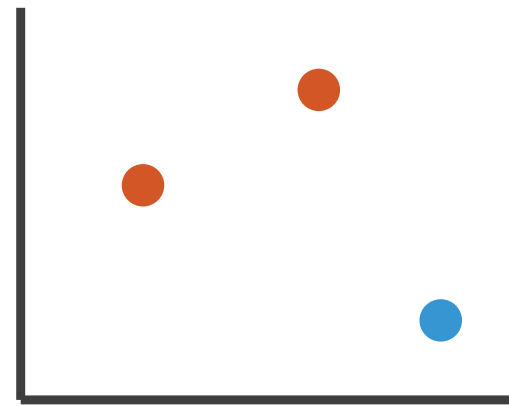
1:
vertical position

mark: segment



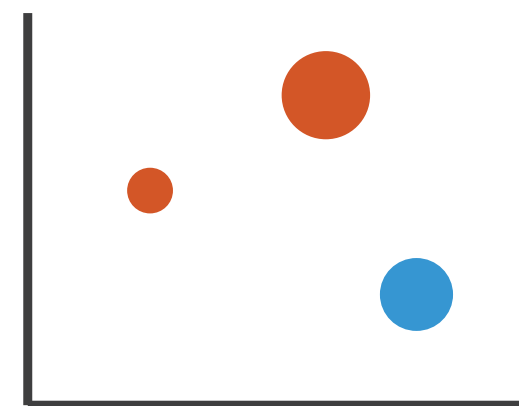
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color (hue)

mark: point

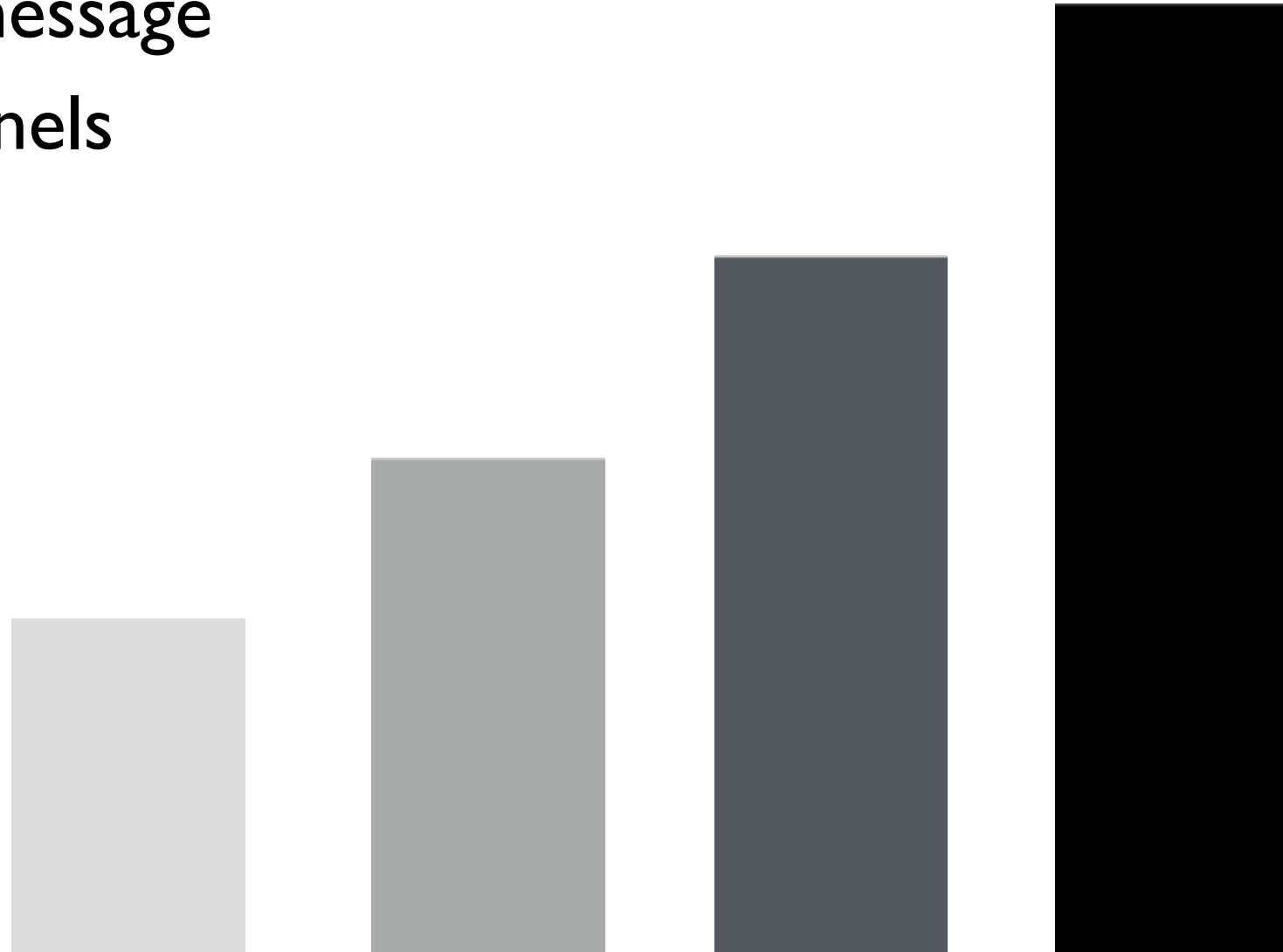


4:
vertical position
horizontal position
color (hue)
2D size (area)

mark: point

Redundant encoding

- multiple channels
 - sends stronger message
 - but uses up channels



Length and Luminance

When to use which channel?

expressiveness

match channel type to data type

effectiveness

some channels are better than others

Channels: Rankings

Position on common scale



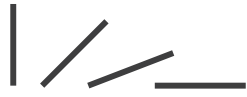
Position on unaligned scale



Length (1D size)



Orientation



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



Same

Spatial region



Color hue



Motion



Symbol



Channels: Rankings

➔ **Magnitude** Channels: **Ordered** Attributes

Position on common scale



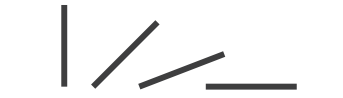
Position on unaligned scale



Length (1D size)



Orientation



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



Same

Same

➔ **Identity** Channels: **Categorical** Attributes

Spatial region



Color hue



Motion



Symbol



- **expressiveness**
 - match channel and data characteristics

Channels: Rankings

➔ **Magnitude** Channels: **Ordered** Attributes

Position on common scale



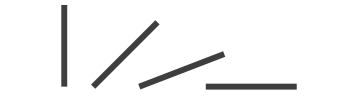
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Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



Same

Same

➔ **Identity** Channels: **Categorical** Attributes

Spatial region



Color hue



Motion



Symbol



➔ **Attribute Types**

➔ Categorical



➔ Ordered

➔ Ordinal



➔ Quantitative



- **expressiveness**

- match channel and data characteristics

- magnitude for ordered

- how much? which rank?

- identity for categorical

- what?

Channels: Rankings

➔ **Magnitude** Channels: **Ordered** Attributes



➔ **Identity** Channels: **Categorical** Attributes



- **expressiveness**
 - match channel and data characteristics
- **effectiveness**
 - channels differ in accuracy of perception

Channels: Rankings

➔ Magnitude Channels: Ordered Attributes

Position on common scale



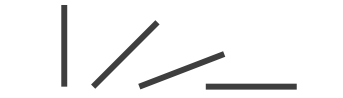
Position on unaligned scale



Length (1D size)



Orientation



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



Same

Same

Best

Effectiveness

Least

➔ Identity Channels: Categorical Attributes

Spatial region



Color hue



Motion



Symbol



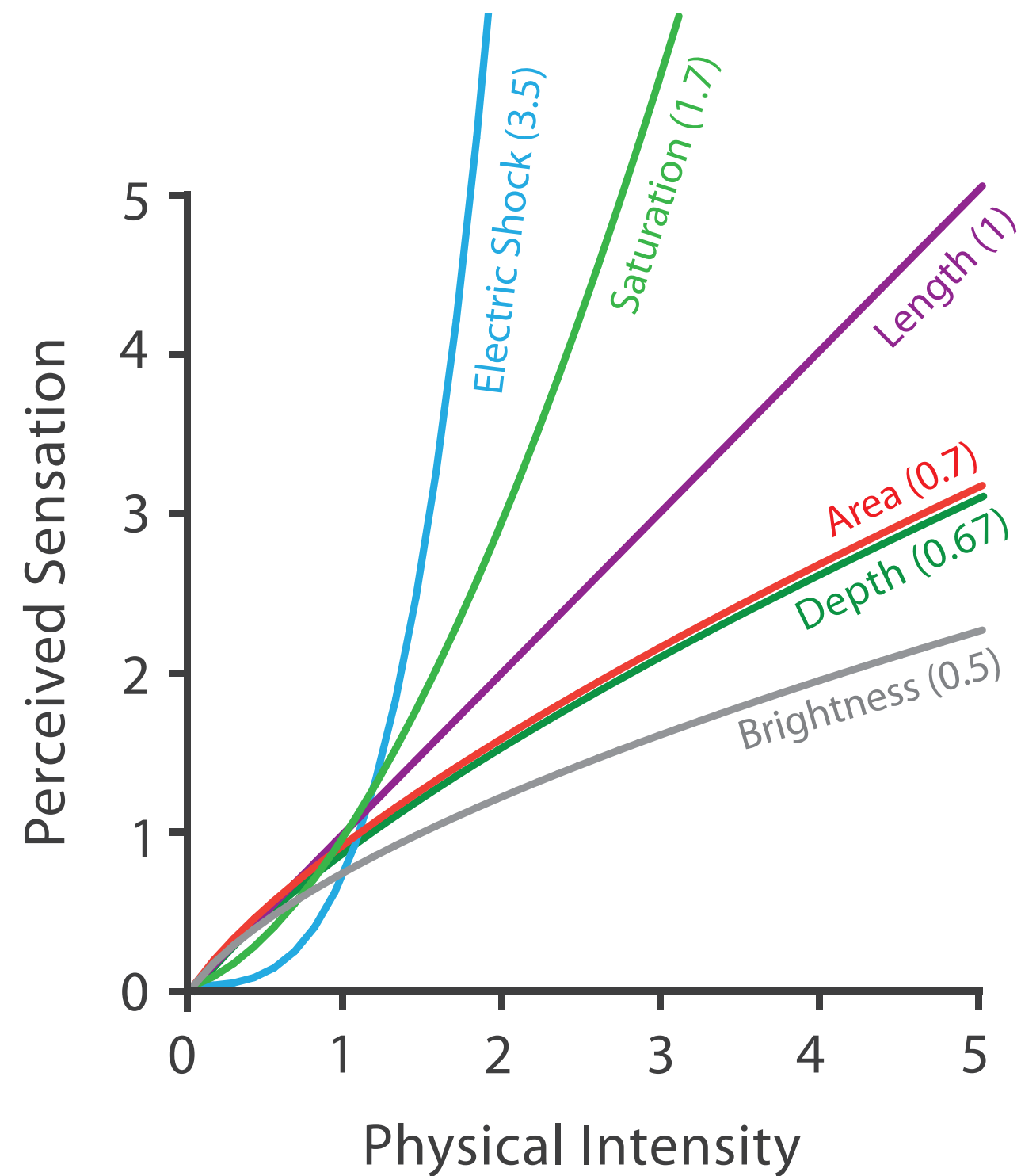
- **expressiveness**
 - match channel and data characteristics
- **effectiveness**
 - channels differ in accuracy of perception
 - spatial position ranks high for both

Channel effectiveness

- accuracy: how precisely can we tell the difference between encoded items?
- discriminability: how many unique steps can we perceive?
- separability: is our ability to use this channel affected by another one?
- popout: can things jump out using this channel?

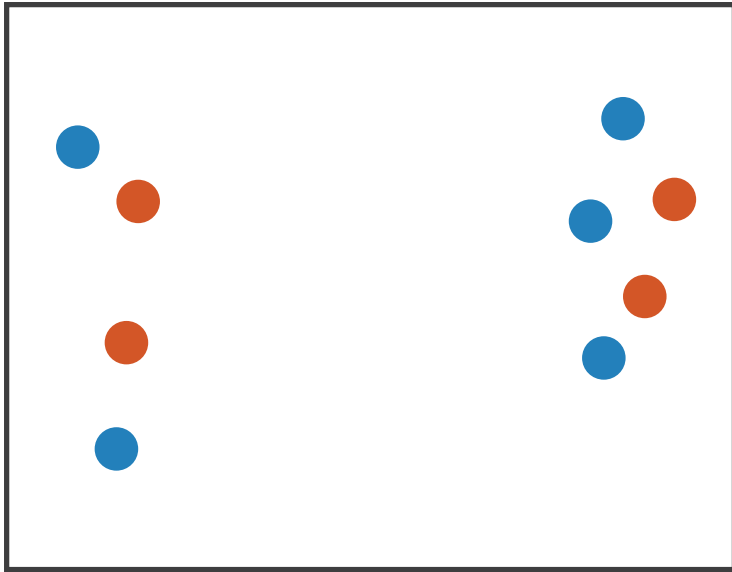
Accuracy: Fundamental Theory

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



Separability vs. Integrality

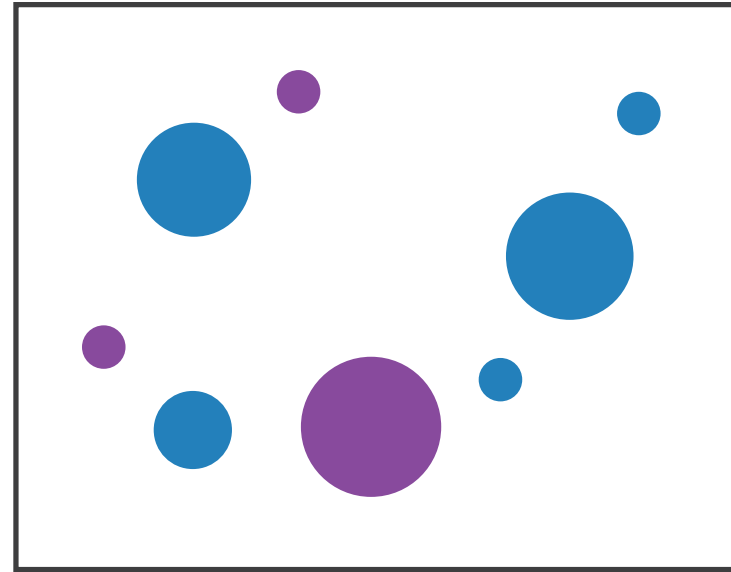
Position
+ Hue (Color)



Fully separable

2 groups each

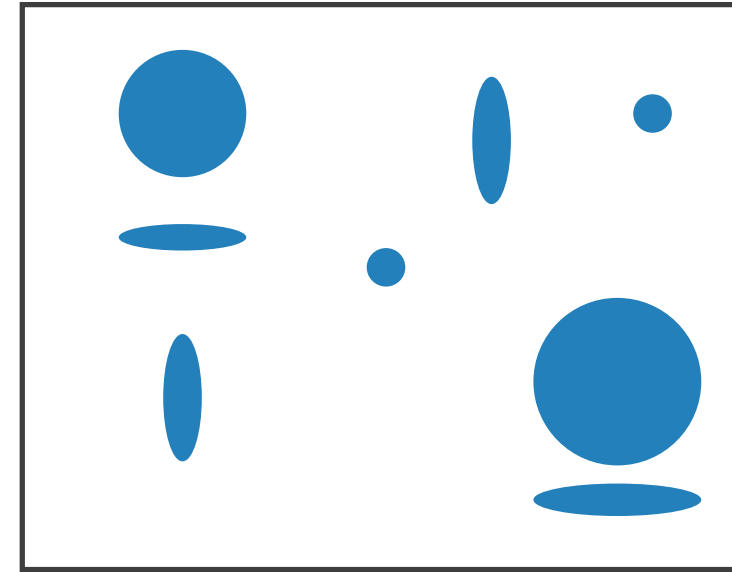
Size
+ Hue (Color)



Some interference

2 groups each

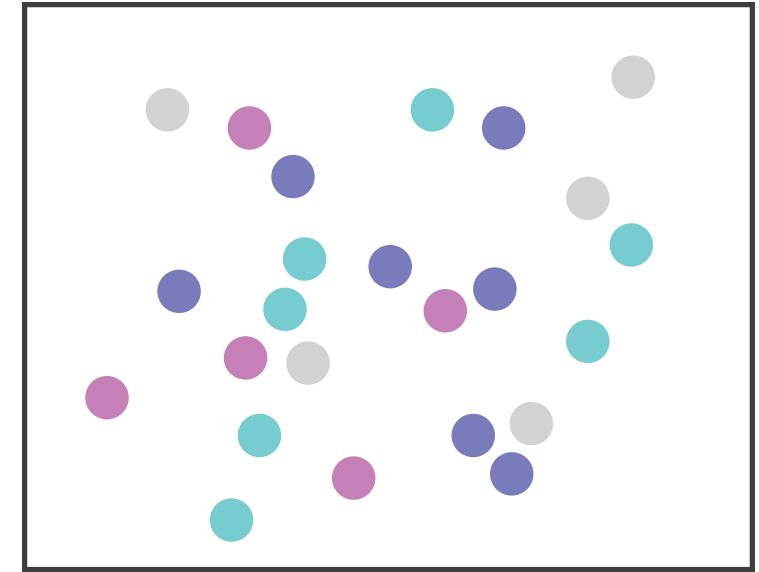
Width
+ Height



Some/significant
interference

3 groups total:
integral area

Red
+ Green



Major interference

4 groups total:
integral hue

Grouping

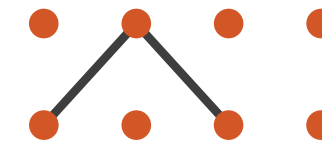
- containment
- connection
- proximity
 - same spatial region
- similarity
 - same values as other categorical channels

Marks as Links

➔ Containment



➔ Connection



➔ Identity Channels: Categorical Attributes

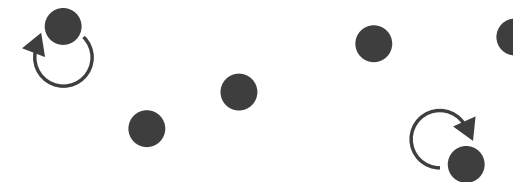
Spatial region



Color hue



Motion

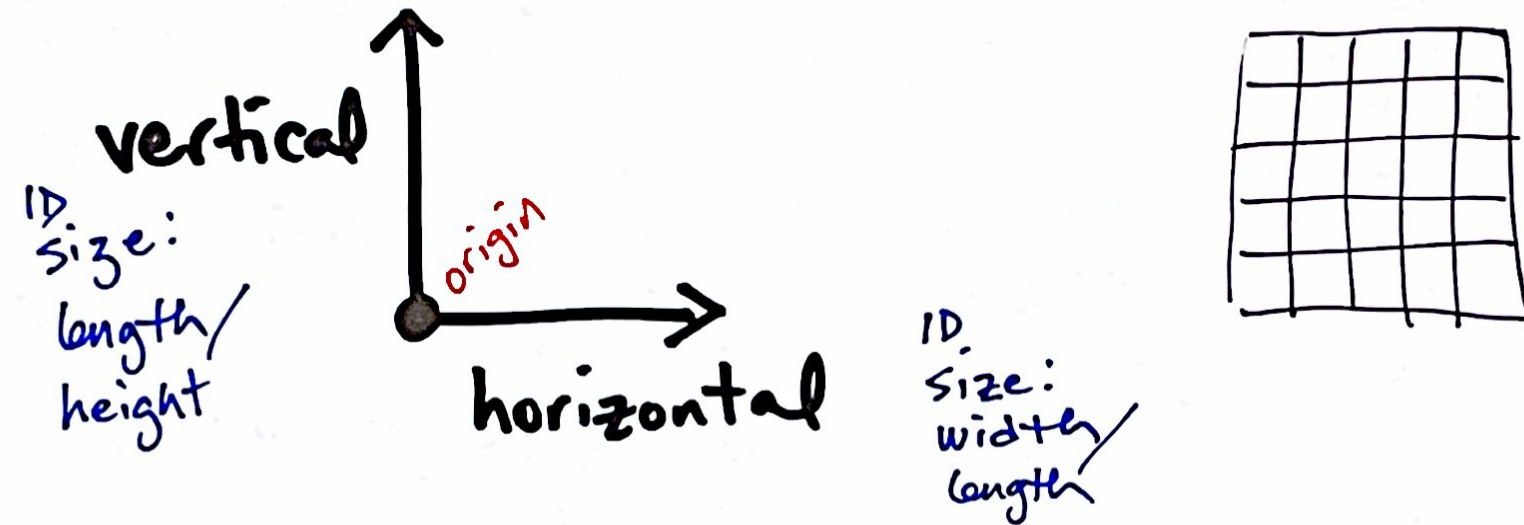


Shape

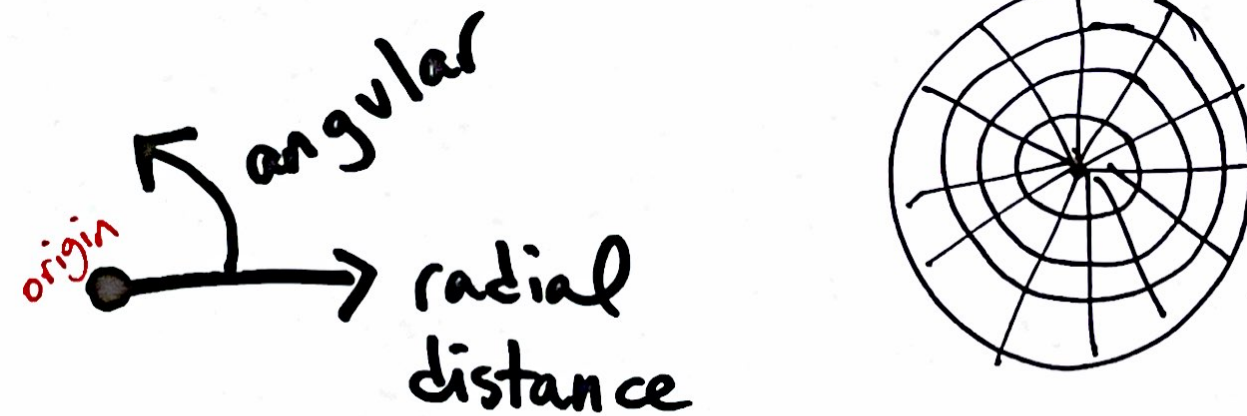


Position: Two possible coordinate systems

- Cartesian/rectilinear



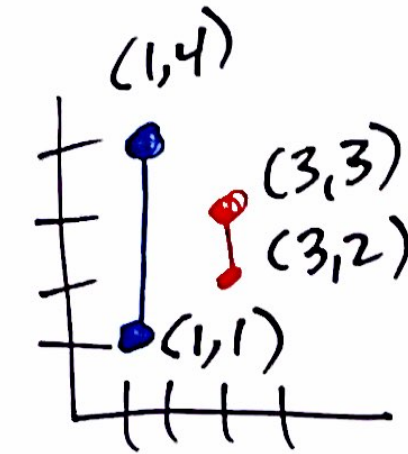
- Polar/radial



- mutually exclusive, can't use both at once

Absolute vs relative

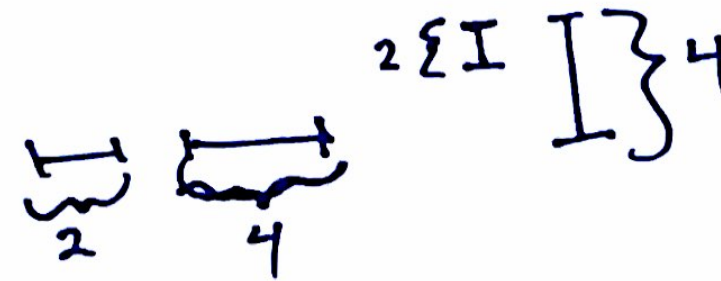
- position is absolute
 - position: absolute position that marks have in common within coordinate frame (rectilinear or radial)
- order and size are relative
 - order: relative locations
 - size: relative distances
 - can be used without absolute position
 - but follow position when that is used
 - always for order
 - with path/segment or poly types for size



position:
implies
order
(+ size for non-point marks)

above left right
below

order
(without position)



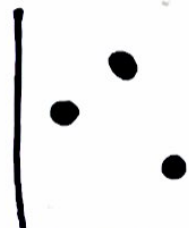
size
(without position)



vertical:
position + order + size
all show same attribute

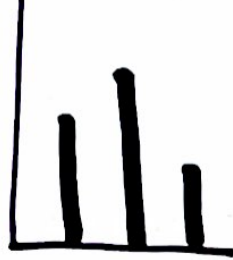
Visual encoding analysis, more examples

scatterplot



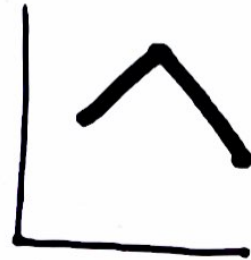
points: H&V
pos/order,

bar/lollipop chart



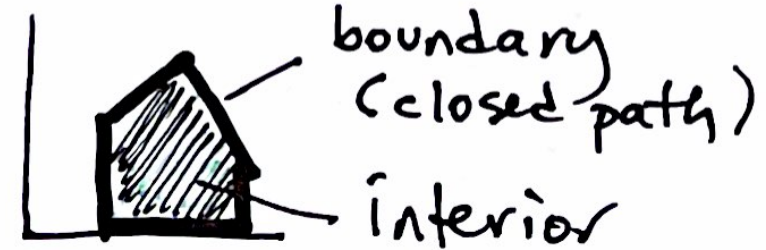
segments: V
pos/order/size

line chart

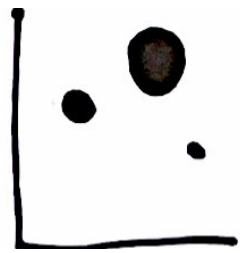


path: H&V pos/order

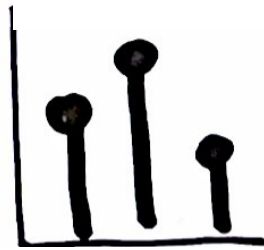
filled area chart



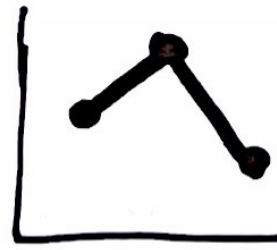
poly: H&V pos/order



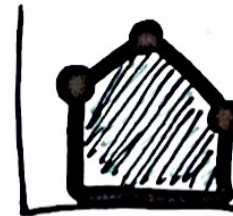
points: H&V
pos/order, size (2D)



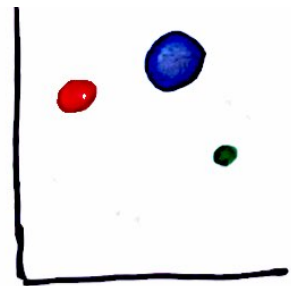
segments: V
pos/order/size.
points: H&V pos/order



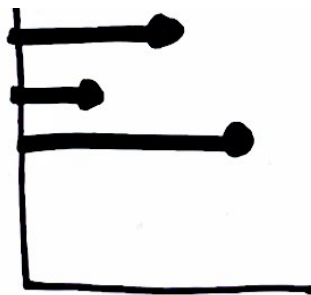
path: H&V pos/order.
points: H&V pos/order



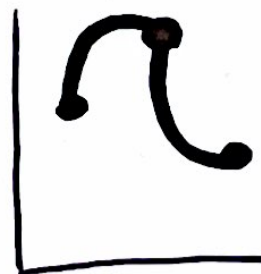
poly: H&V pos/order.
points: H&V pos/order



points: H&V
pos/order, size (2D),
color



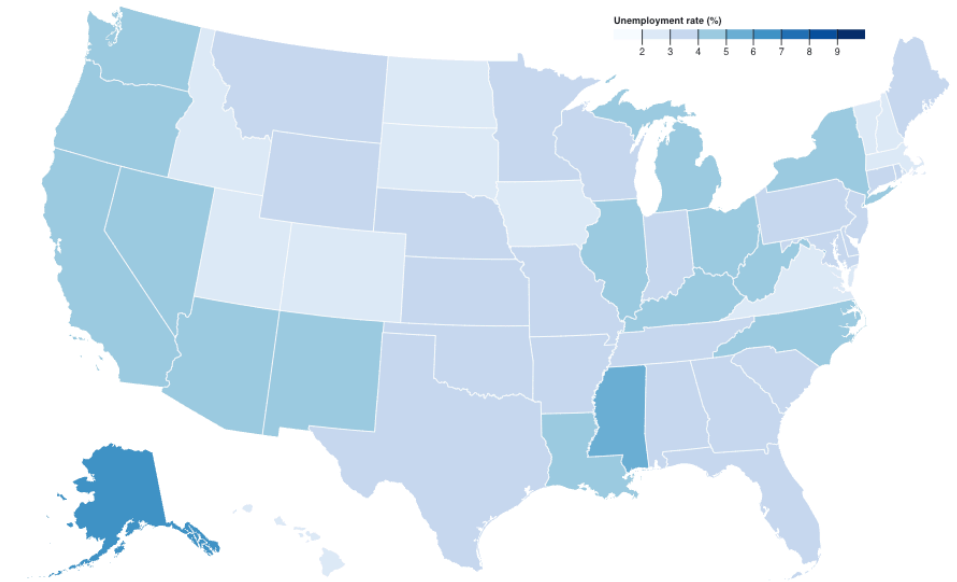
segments: H
pos/order/size.
points: H&V pos/order



path: H&V pos/order.
points: H&V pos/order

Constraints

- geographic example: choropleth maps
- what can we do to California? could we encode additional data?
 - cannot shrink/grow (size channel)
 - cannot translate (position channel)
 - cannot rotate (orientation channel)
 - cannot reshape (symbol channel)
 - why not?
 - would lose meaning of that mark: boundary encodes meaning
 - also lose meaning for other occluded marks
- constraints arise from shared boundaries between marks
 - can't independently change position, order, size, orientation, (symbol)
 - could change all simultaneously, typically through algorithm

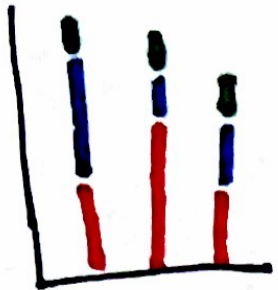


<https://observablehq.com/@d3/us-state-choropleth>

Shared boundary constraints

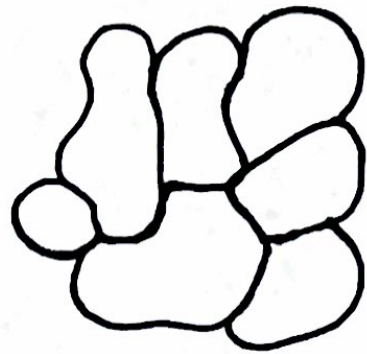
- marks that touch by design:
shared boundary constraints
 - cannot change independently,
moving one would affect the others

stacked bar chart



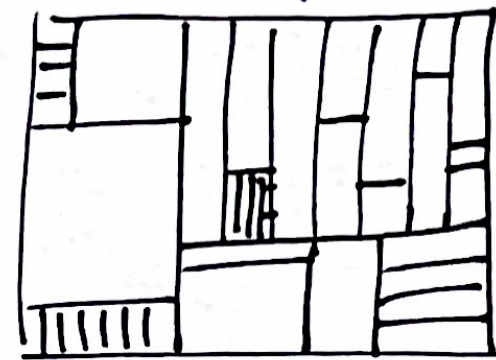
glyphs:
multiple segments

channel: vert shared

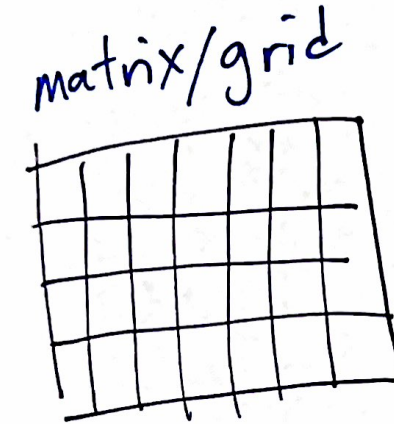


channel:
2D position shared

tree map



channel:
2D position shared



1D horizontal shared positions
1D vertical shared positions

Constraints & Channel Availability

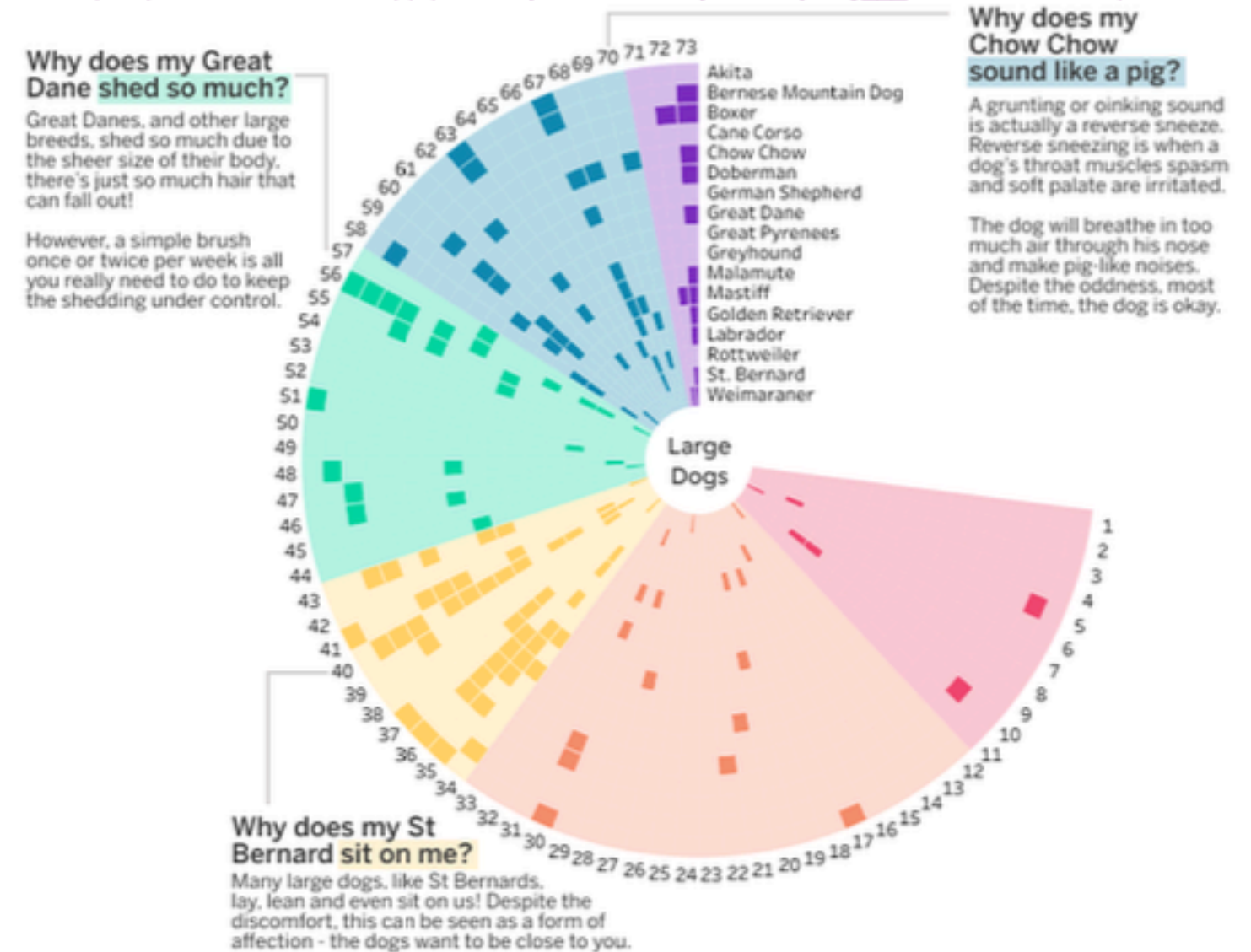
- consider marks and channels as imposing constraints
 - when does mark type constrain channel use?
 - when does using one channel constrain another channel?
- Channel Availability Model
 - Encoded: which channels directly used to encode attributes?
 - clear meaning
 - multiple channels can be directly used for redundant encoding
 - Free: which channels free to encode another attribute?
 - without changing usability of existing encoding
 - Unavailable: which channels unavailable / precluded / taken?
 - because of mark type or characteristics?
 - because of idiom/algorithm design specifics?
 - because other channels used?

Channel use: what does it mean?

- Does channel size encode attribute?
 - yes? sizes differ
 - according to dog name in alphabetical order
 - no! size differences not meaningful
 - just emerges from choice of layout, radial vs rectilinear
 - not a "real" attribute encoding
- Can we use size channel to encode another attribute?
 - no! not free
 - it's "taken" already, would change meaning
- Size channel is Unavailable

Q5 Marks & Channels: Why Does My Dog [4 pts]

Credit: https://public.tableau.com/app/profile/wjsutton/viz/WhyDoesMyDog_IronQuest/DesktopVersion



https://public.tableau.com/app/profile/wjsutton/viz/WhyDoesMyDog_IronQuest/DesktopVersion

Beyond simple marks: glyphs & levels

glyphs:

more than one mark for each item



levels:

hierarchical structure of marks: show info at multiple scales



WorkflowVisualizer



[Maguire et al. Taxonomy-based Glyph Design – with a Case Study on Visualizing Workflows of Biological Experiments. TVCG 2012](#)

Scope of analysis

- simplifying assumptions
 - at least one mark per item
 - single view
- later on
 - some items not represented by marks:
aggregation and filtering
 - multiple views
 - beyond glyphs

one : many
mark items

aggregation
filtering

Reducing Items and Attributes

➔ Filter

→ Items



→ Attributes

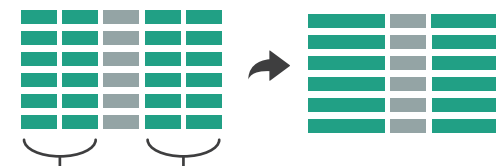


➔ Aggregate

→ Items



→ Attributes



Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 2014.
– *Chap 5: Marks and Channels*
- *On the Theory of Scales of Measurement*. Stevens. Science 103:2684 (1946), 677–680.
- Psychophysics: Introduction to its Perceptual, Neural, and Social Prospects. Stevens. Wiley, 1975.
- *Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods*. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.
- *Perception in Vision*. Healey. <http://www.csc.ncsu.edu/faculty/healey/PP>
- Visual Thinking for Design. Ware. Morgan Kaufmann, 2008.
- Information Visualization: Perception for Design, 3rd edition. Ware. Morgan Kaufmann /Academic Press, 2004.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch5marks>

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

@tamara@cosocial.ca

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

Visualization Analysis & Design, Tutorial

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How?

Encode

➔ Arrange

➔ Express



➔ Separate



➔ Order



➔ Align



➔ Use



➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue



➔ Saturation



➔ Luminance



➔ Size, Angle, Curvature, ...



➔ Shape



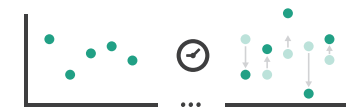
➔ Motion

Direction, Rate, Frequency, ...

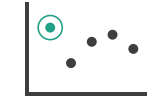


Manipulate

➔ Change



➔ Select



➔ Navigate

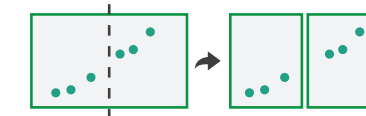


Facet

➔ Juxtapose



➔ Partition



➔ Superimpose



Reduce

➔ Filter



➔ Aggregate



➔ Embed



What?

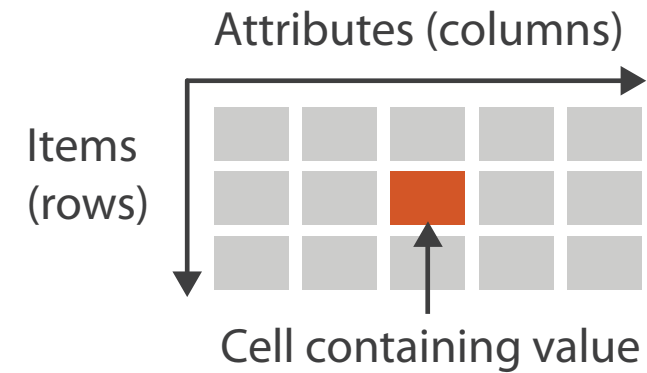
Why?

How?

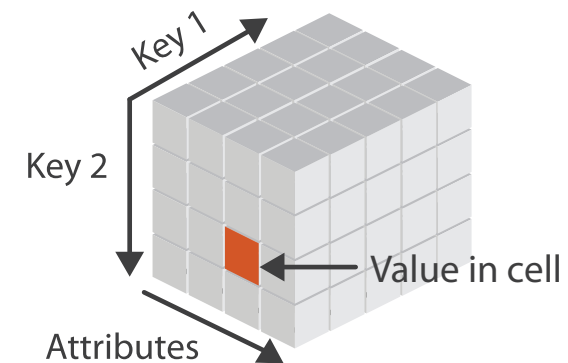
Keys and values

- key
 - independent attribute
 - used as unique index to look up items
 - simple tables: 1 key
 - multidimensional tables: multiple keys
- value
 - dependent attribute, value of cell
- classify arrangements by key count
 - 0, 1, 2, many...

→ Tables



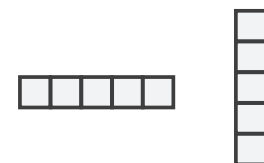
→ *Multidimensional Table*



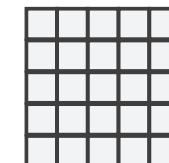
⊕ Express Values



→ 1 Key
List



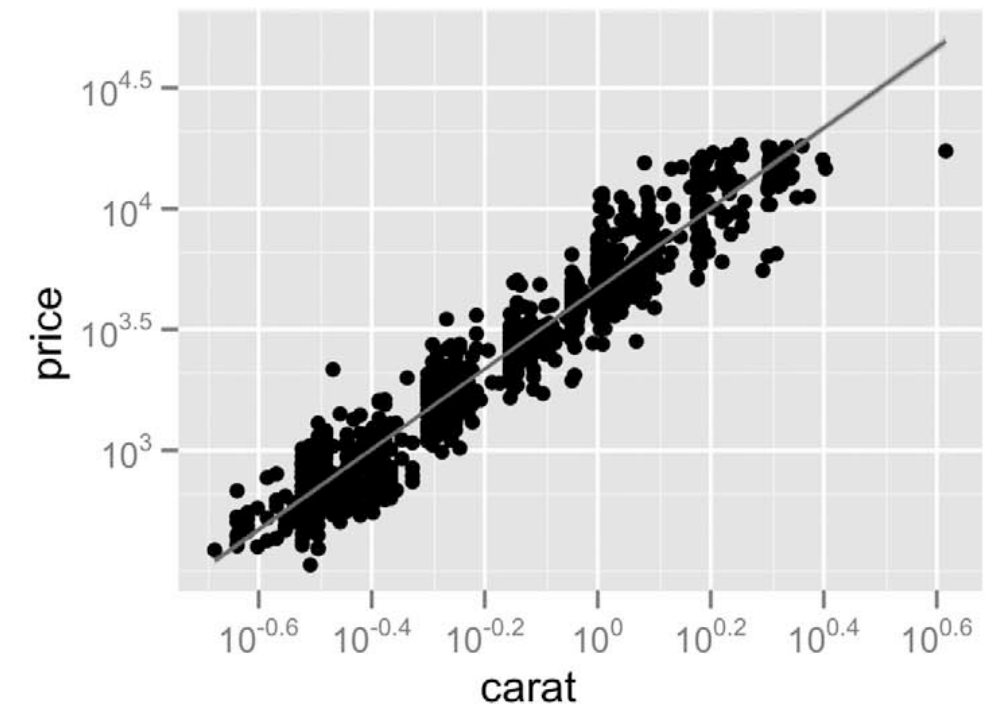
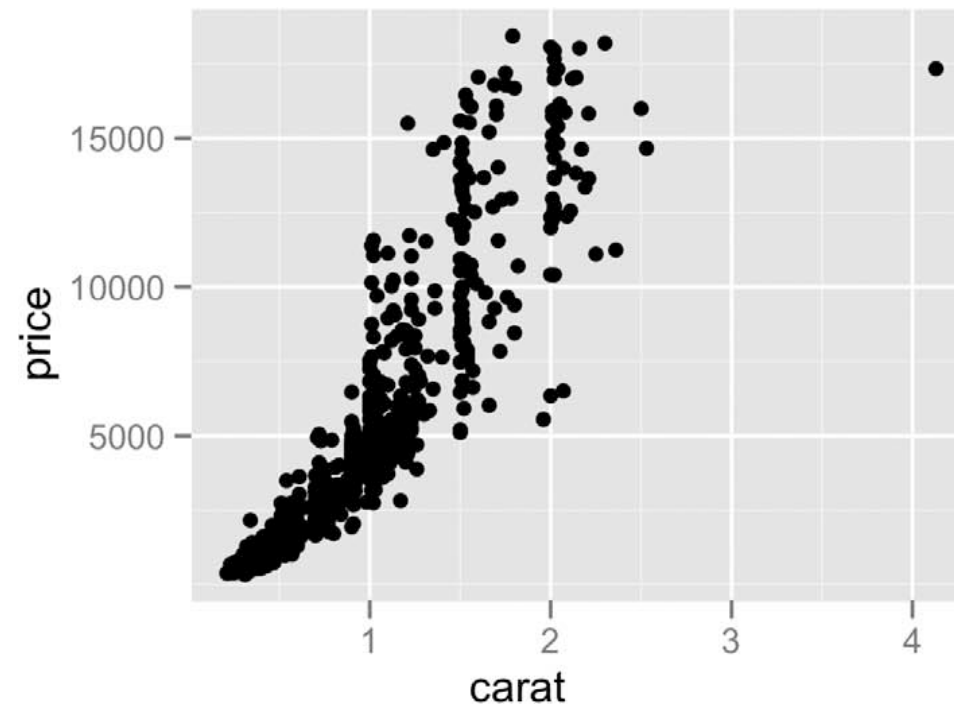
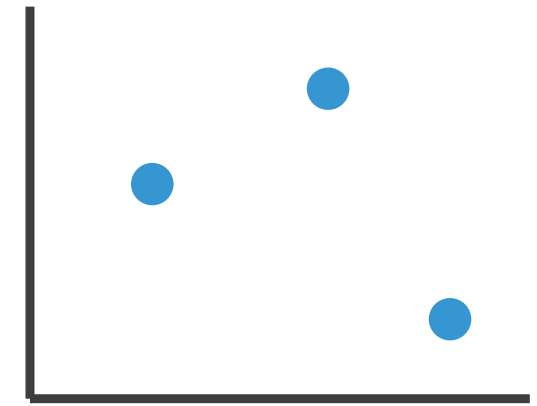
→ 2 Keys
Matrix



Idiom: scatterplot

- **express** values (magnitudes)
 - quantitative attributes
- no keys, only values

➔ Express Values

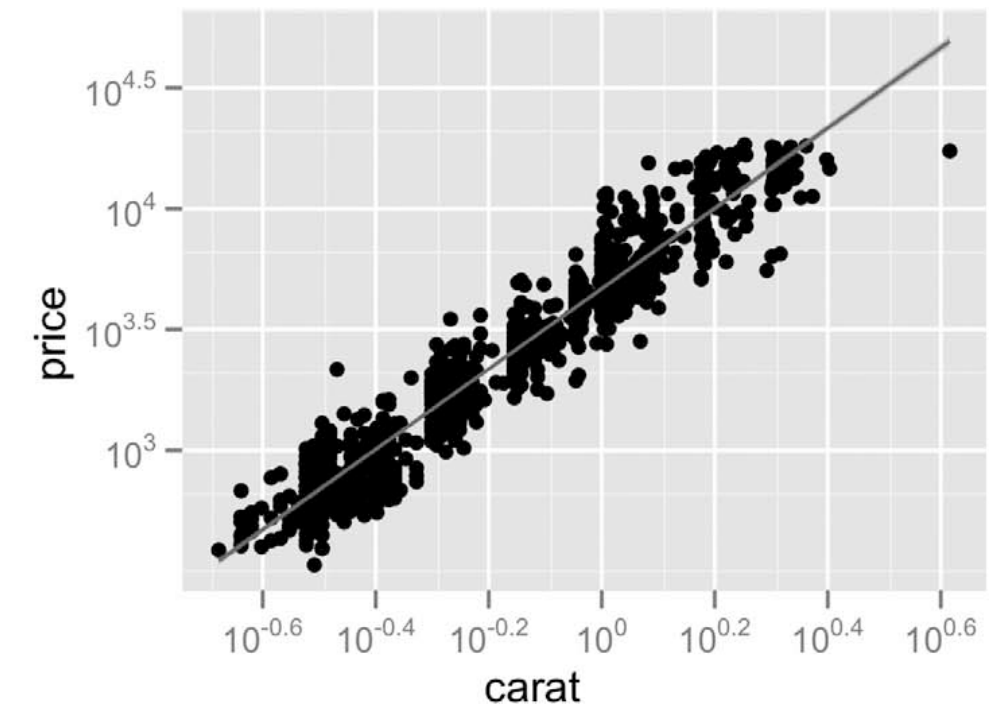
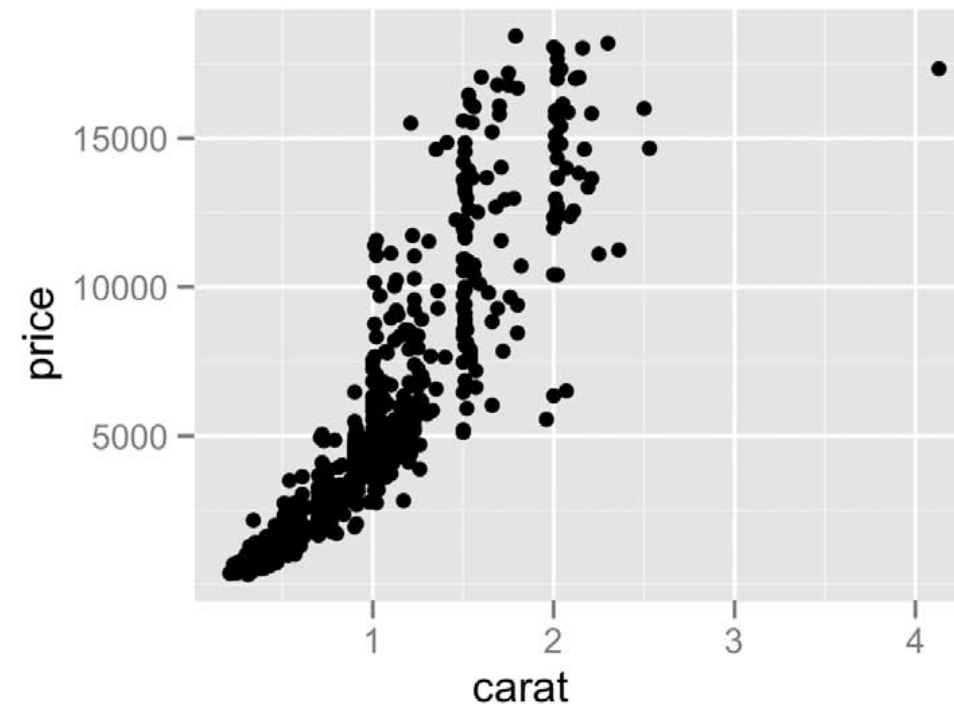
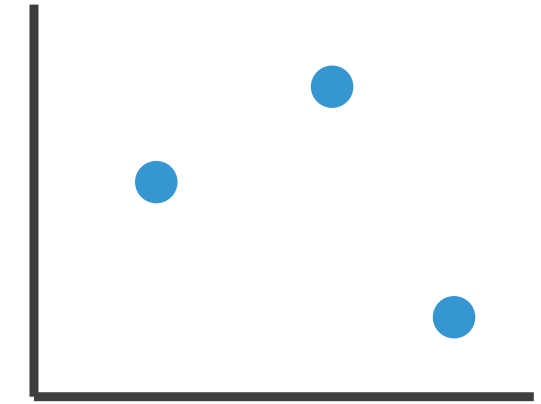


[A layered grammar of graphics. Wickham. *Journ. Computational and Graphical Statistics* 19:1 (2010), 3–28.]

Idiom: scatterplot

- **express** values (magnitudes)
 - quantitative attributes
- no keys, only values
 - data
 - 2 quant attribs
 - mark: points
 - channels
 - horiz position/order
 - vert position/order

➔ Express Values

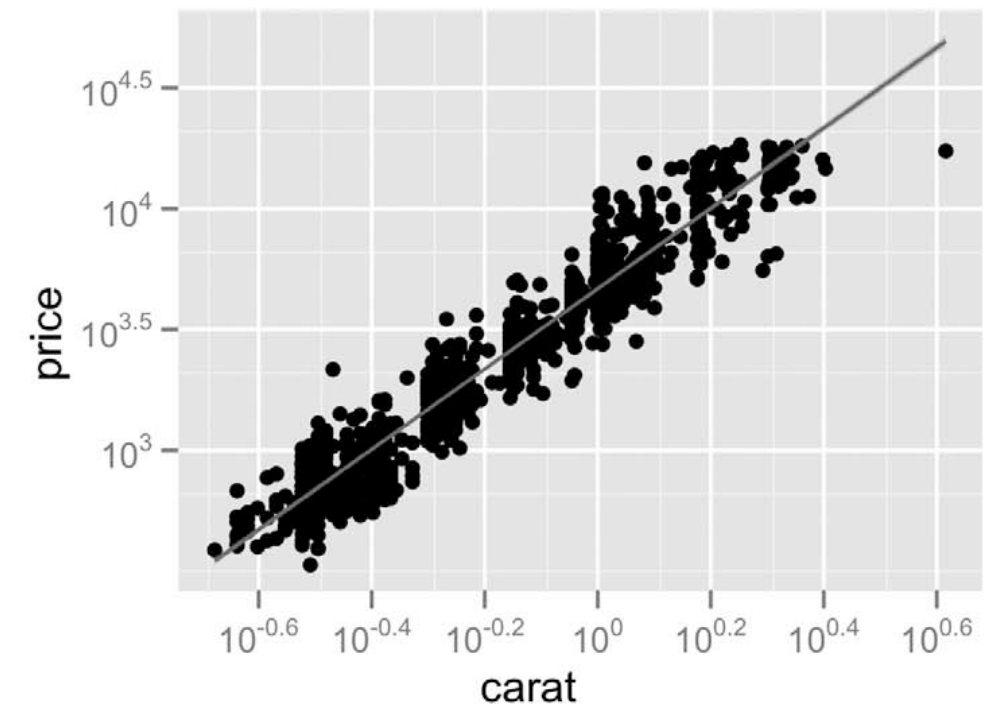
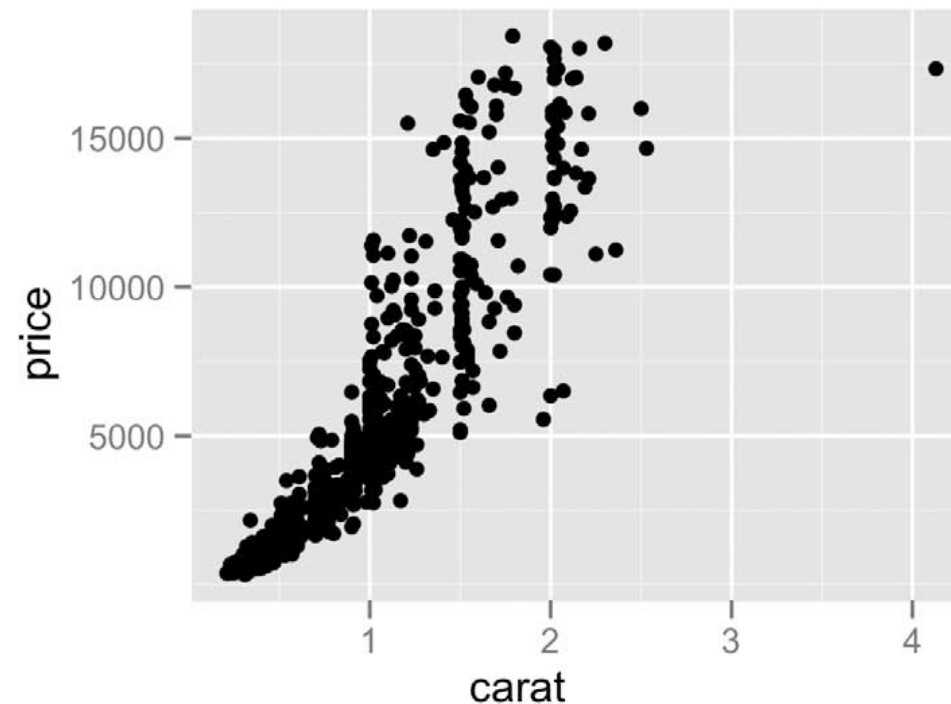
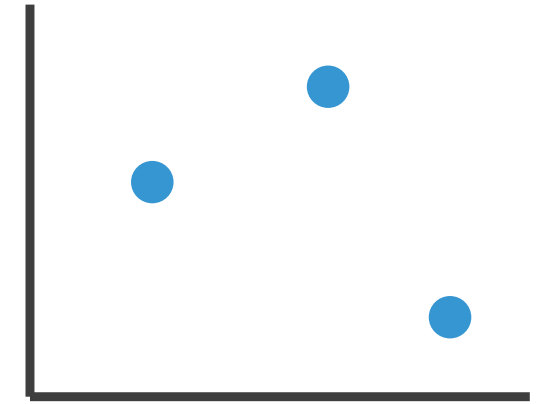


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idiom: scatterplot

- **express** values (magnitudes)
 - quantitative attributes
- no keys, only values
 - data
 - 2 quant attribs
 - mark: points
 - channels
 - horiz position/order
 - vert position/order
 - tasks
 - find trends, outliers, distribution, correlation, clusters
 - scalability
 - 1K items

➞ Express Values



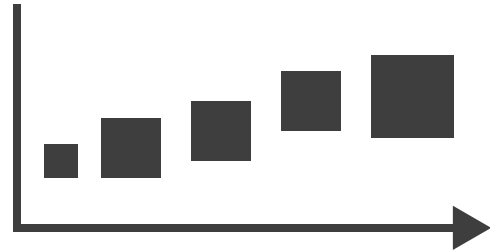
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Some keys: Categorical regions

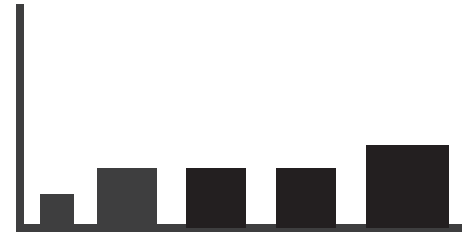
→ Separate



→ Order



→ Align



Regions: Separate, order, align

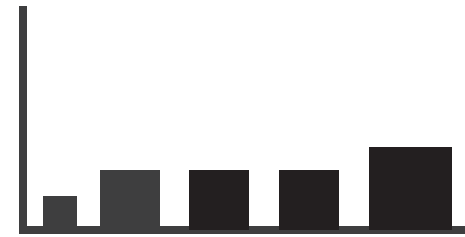
→ Separate



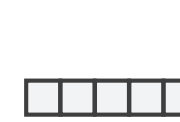
→ Order



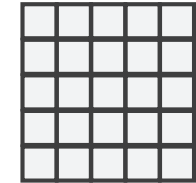
→ Align



→ 1 Key
List



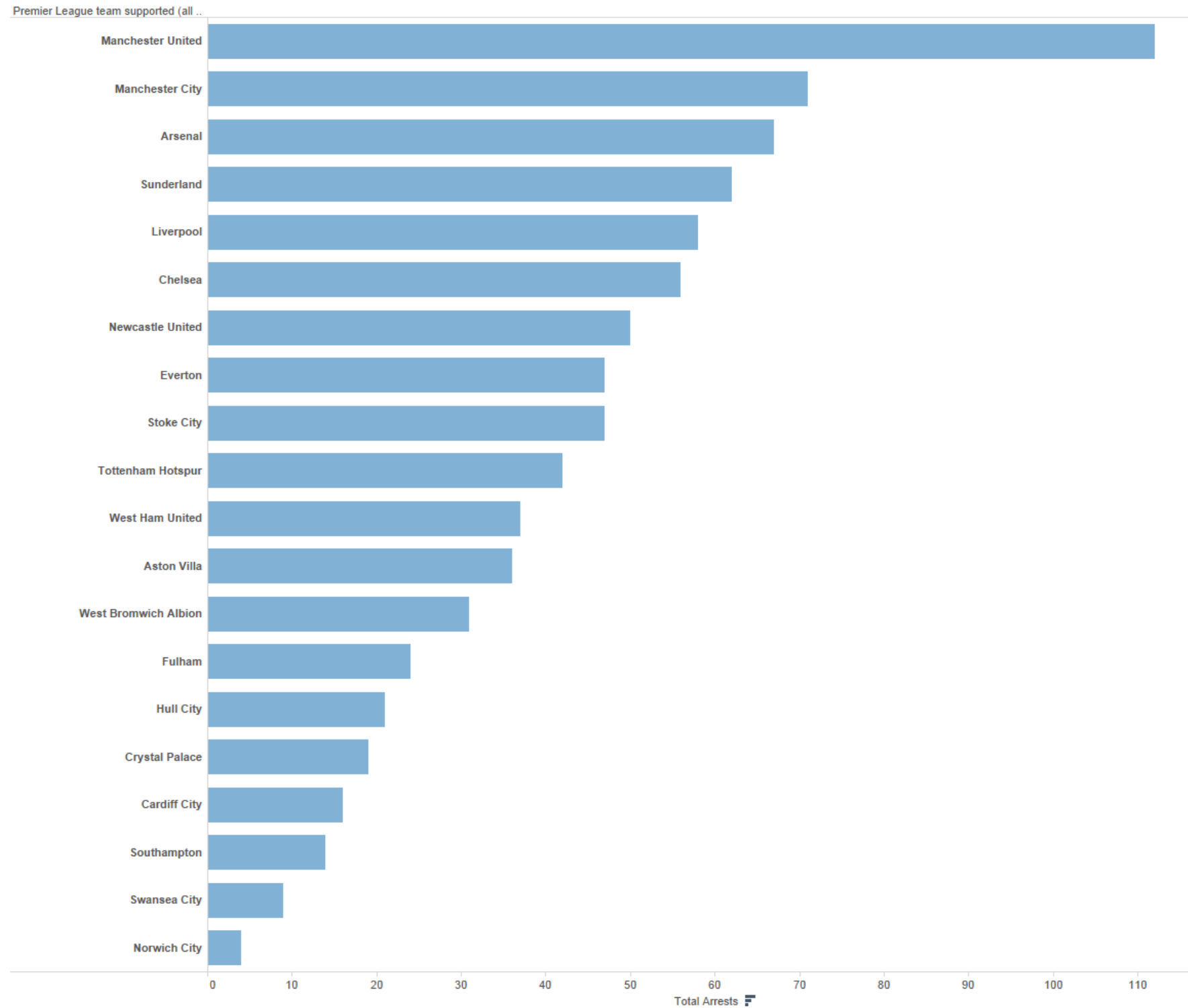
→ 2 Keys
Matrix



- separate into regions by any attribute: categorical or ordered
 - **regions**: contiguous bounded areas distinct from each other
 - no conflict with expressiveness principle for categorical attributes
 - one glyph/mark per region
- then can use ordered attribute to order and align regions
 - order in one direction (eg horiz), then align in other direction (eg vert)
 - align: impose shared coordinate frame so absolute position has meaning
 - difference between value and 0 point along axis

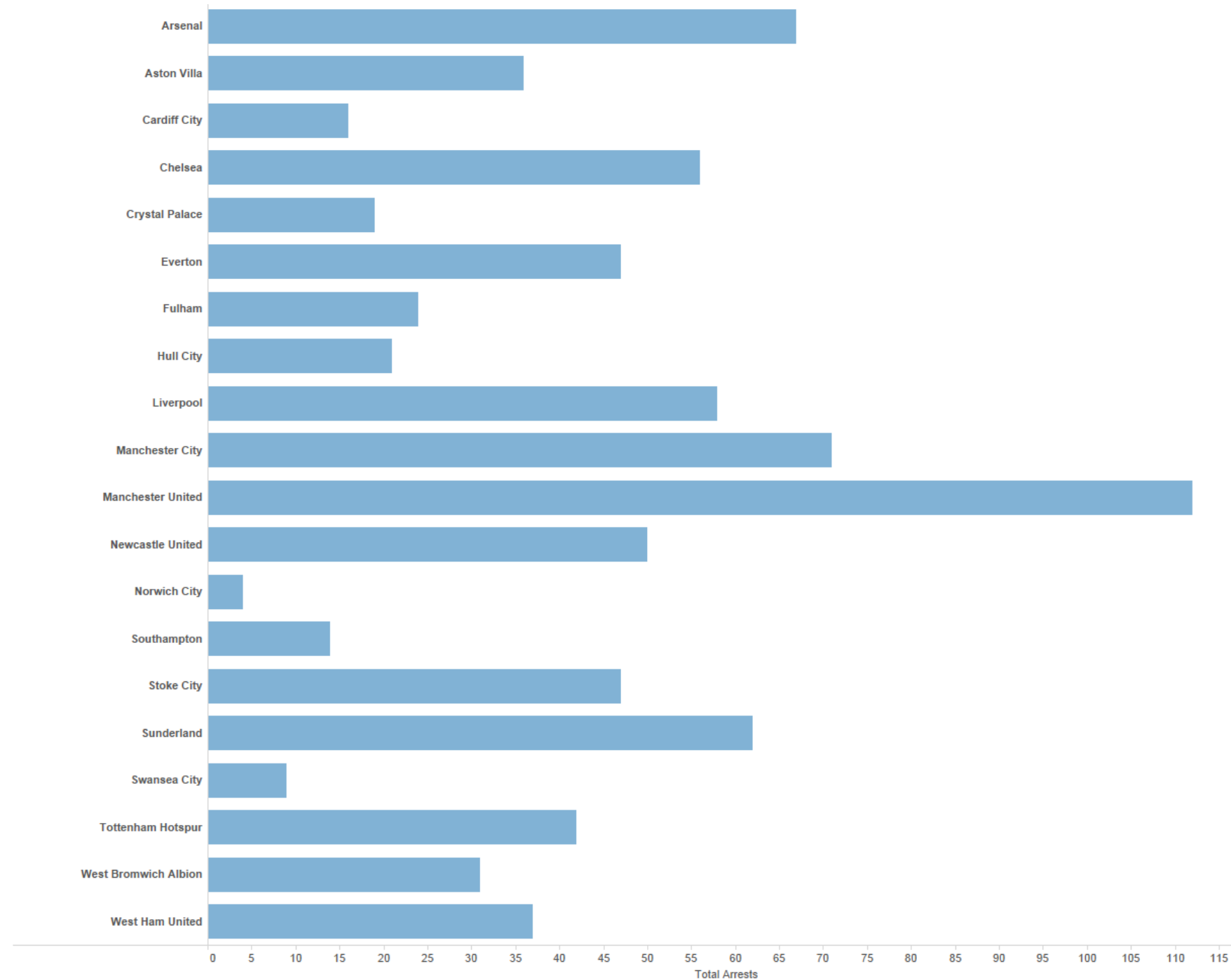
Separated and aligned and ordered

- best case



Separated and aligned but not ordered

- limitation: hard to know rank. what's 4th? what's 7th?



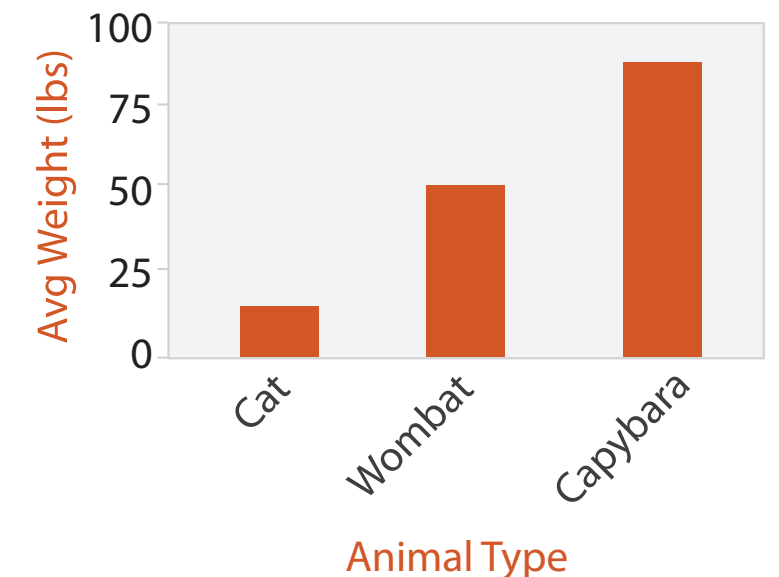
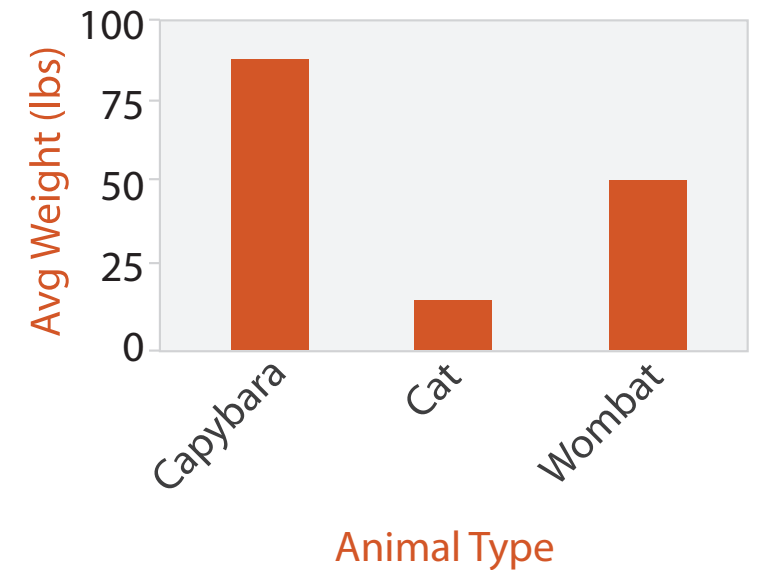
Separated but not aligned or ordered

- limitation: hard to make comparisons with 2D size (vs aligned 1D position)



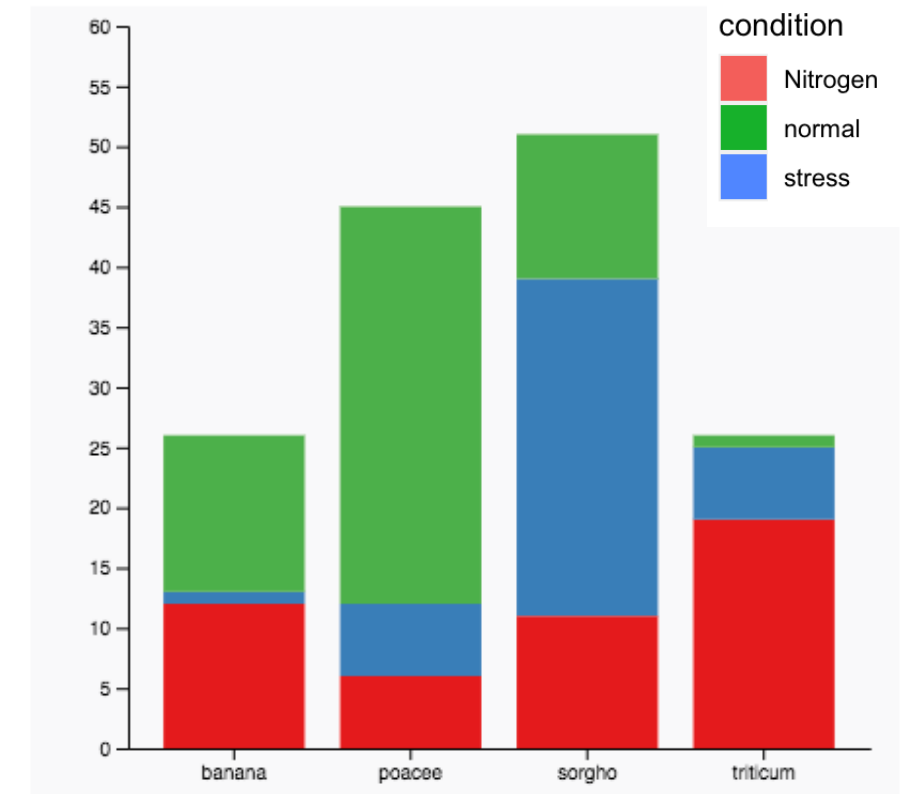
Idiom: **bar chart** (vertical)

- one key, one value
 - data: 1 categ attrib, 1 quant attrib
 - mark: segments (or length-coded points)
 - channels
 - separate by type into one mark per region
 - order horizontally by some quant attrib
 - » alphabetical by attrib name (easy lookup)
 - » by same attrib as vert size (easy to see distributions, find extremes)
 - horiz: position according to order, distribute at equal intervals along axis
 - align vertically: express quant value with
 - vert position/order, vert size
 - segment: emphasize distance between value & 0 point on axis below
 - task: compare, lookup values
 - scalability
 - dozens to hundreds of levels for key [# bars], 1K values [lengths]



Idiom: stacked bar chart

- one more key
 - data: 2 categ attrib (both keys), 1 quant attrib
 - quant value indexed by categ pair {species, condition}
 - multi-level encoding: 2 levels
 - **glyph**: composite object, internal structure from multiple marks
 - entire-glyph level (full bar, by species)
 - within-glyph level (stacked components, by condition for each species)
 - channels
 - entire glyph (level 2): just like normal bar chart
 - separate by species, horiz order by species name, horiz position from order at equal intervals
 - vert position/order/size by value (for whole species)
 - within-glyph (level 1)
 - separate & color by condition, vert order alphabetical (by condition name)
 - vert ID size (length) is value, vertical shared boundary
 - vert position: **unavailable** except for lowest component
 - mark: segment (or length-coded point mark)
 - task: + part-to-whole relationship [components]
 - scalability: asymmetric
 - for *stacked* key attrib, 10-12 levels [components]
 - for *main* key attrib, dozens to hundreds of levels [bars]

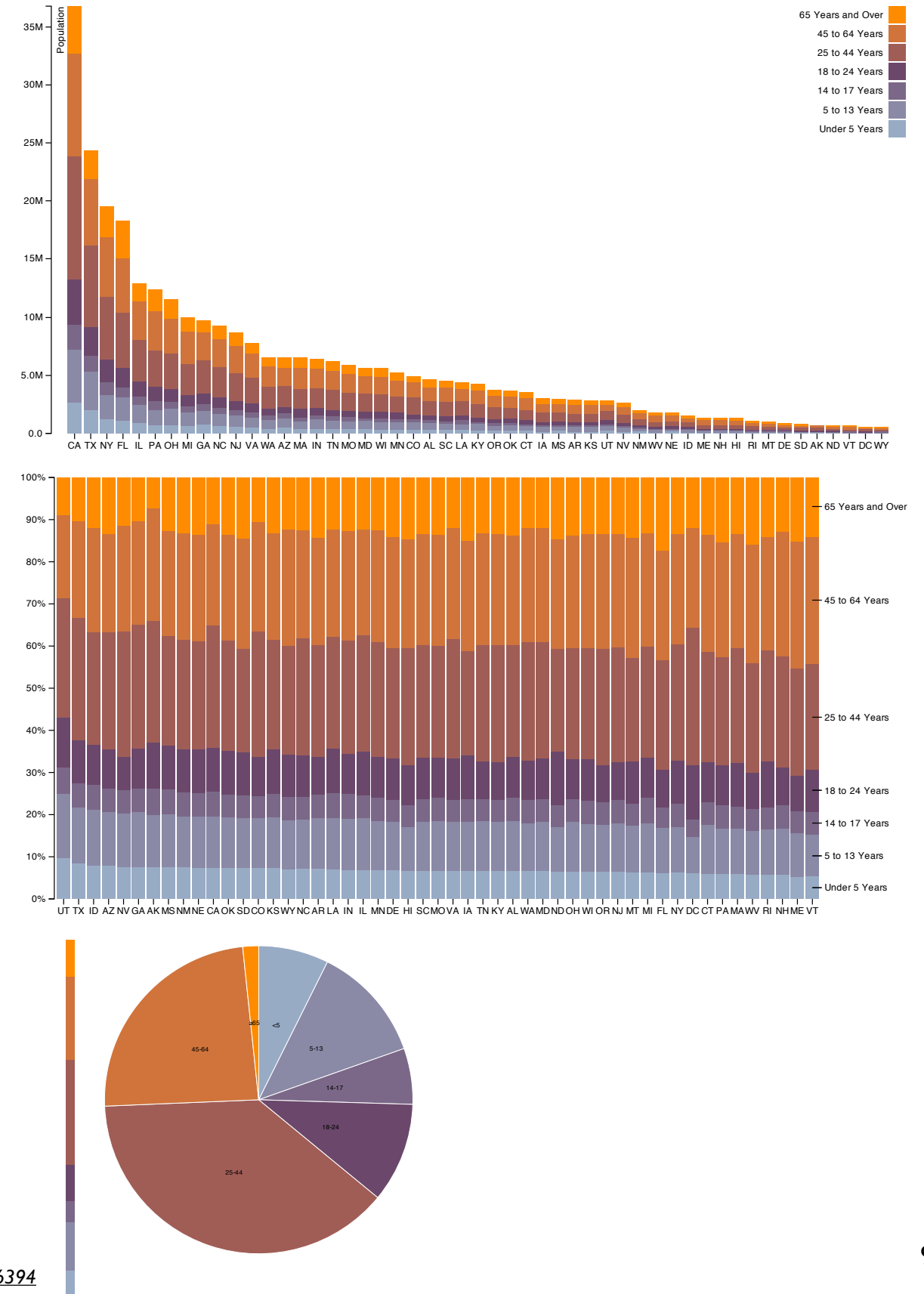


https://www.d3-graph-gallery.com/graph/barplot_stacked_basicWide.html

<https://r-graph-gallery.com/48-grouped-barplot-with-ggplot2.html>

Idioms: **normalized stacked bar chart**

- task: part-to-whole judgements
- normalized stacked bar chart
 - stacked bar chart, normalized to full vert height
 - relative sizes show proportions
 - analysis of differences
 - level 2 (bar): vert ID pos/size uniform & **unavailable**
 - vert pos meaningful for different 2 numbers
 - top & bottom components
 - vs bottom component & whole bar for unnormalized
- information density
 - single stacked bar equivalent to full pie
 - high info density: narrow rectangle vs large circle



Idioms: pie chart, coxcomb chart

- pie chart

- poly marks with angular position/order/size (shared boundaries)
- radial position/order/size is uniform and unavailable
- accuracy: less accurate than rectilinear aligned position

- data

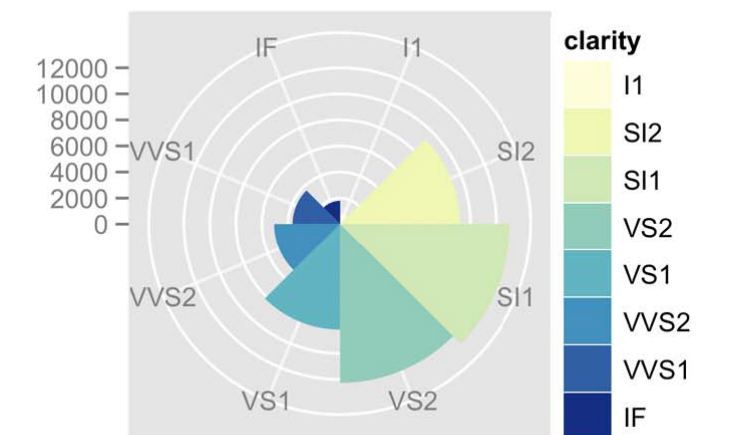
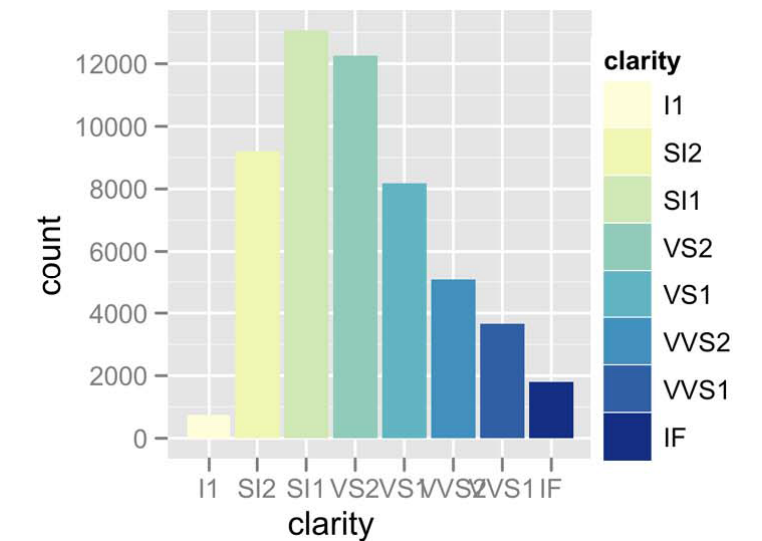
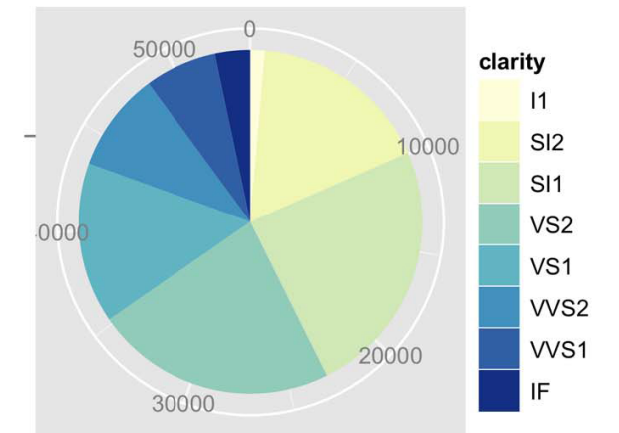
- 1 categ key attrib, 1 quant value attrib

- task

- part-to-whole judgements

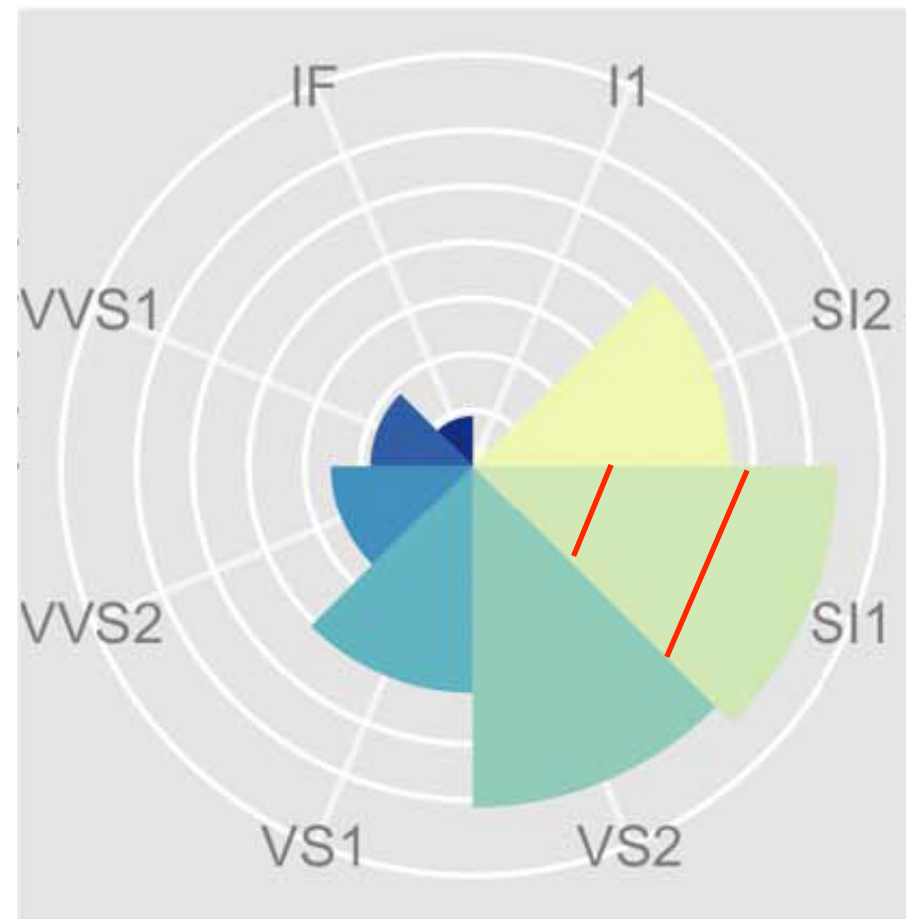
- coxcomb chart

- more direct analog to bar charts
- poly marks, but inverse: radial encodes & angular uniform

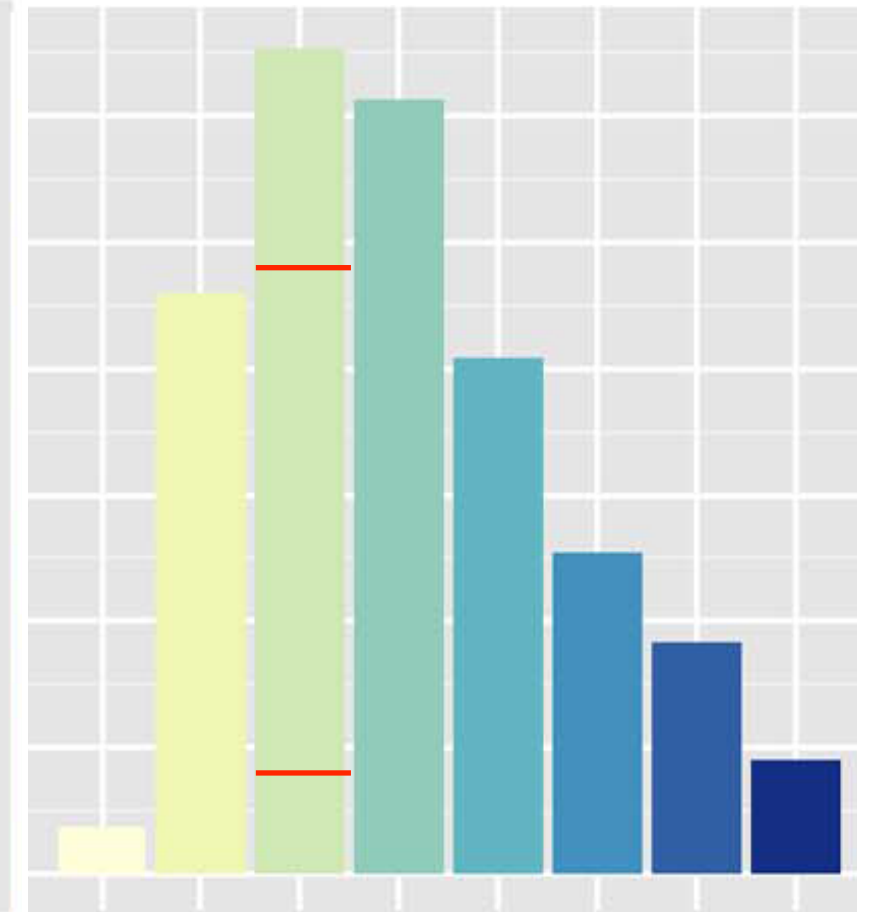


Coxcomb: perception

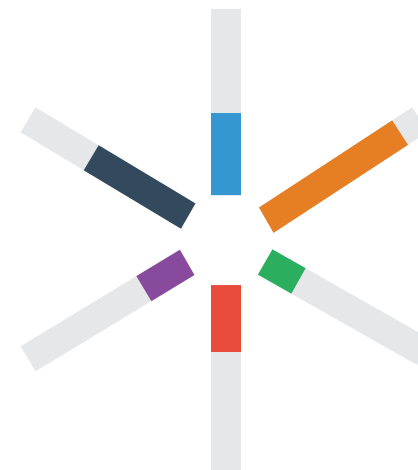
- nonuniform sector width as length increases
 - so area variation is nonlinear wrt mark length!
- encode: length
 - ID angular size
- decode/perceive: area
 - 2D size
- bar chart safer: uniform width, so area is linear w/ mark length
 - both radial & rectilinear cases



nonuniform width as length increases



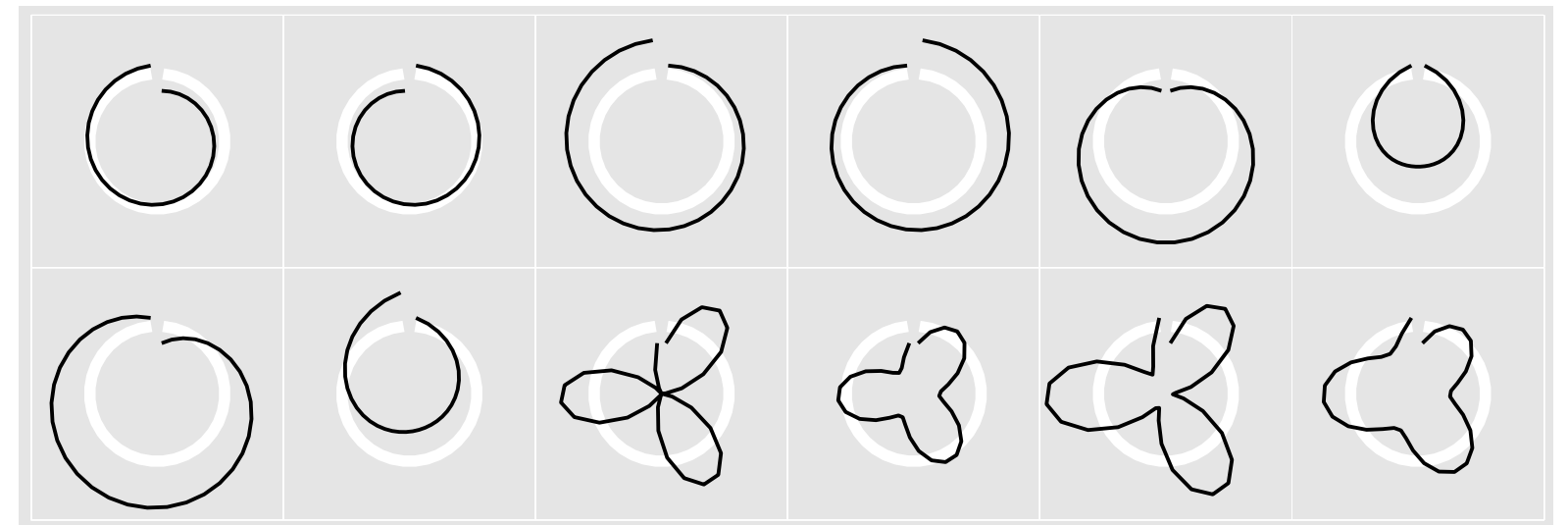
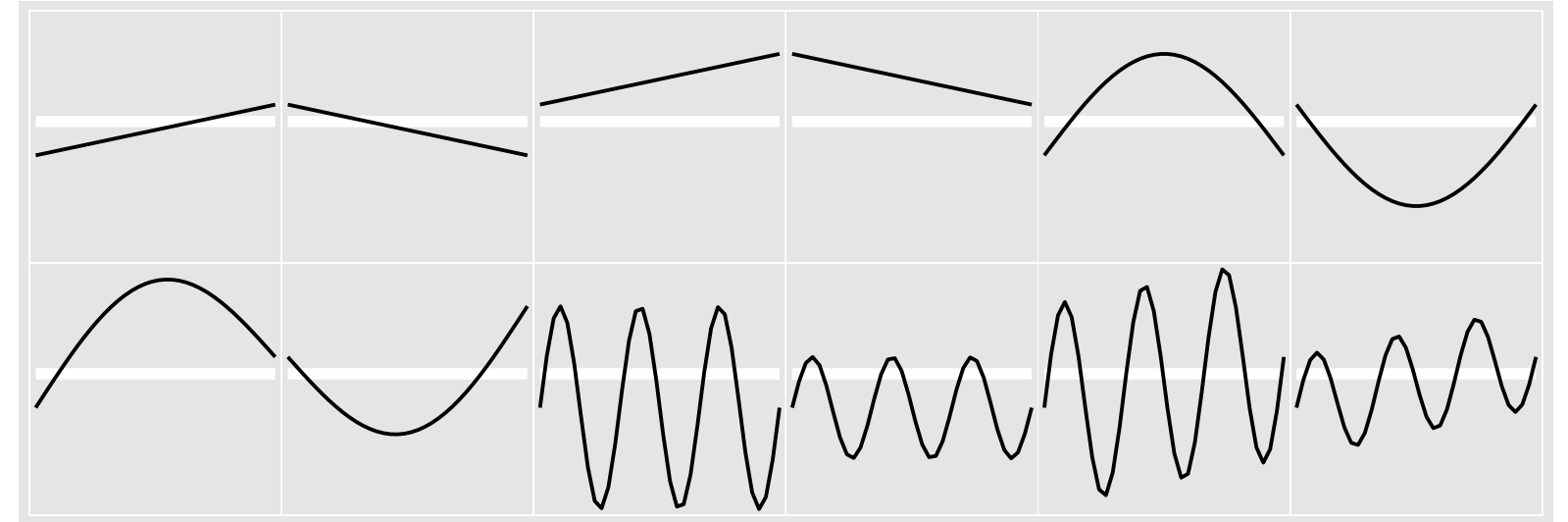
uniform width as length increases



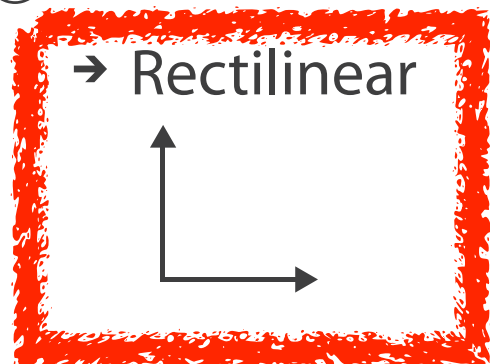
radial & rectilinear bars: uniform width as length increases

Idiom: **glyphmaps**

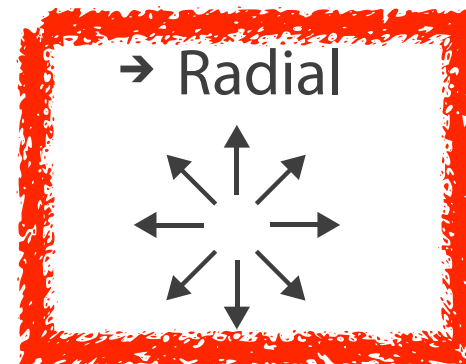
- rectilinear good for linear vs nonlinear trends
- radial good for cyclic patterns



➔ Axis Orientation



→ Parallel
↑ ↑ ↑



[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. *Environmetrics* 23:5 (2012), 382–393.]

Idiom: heatmap

- two keys, one value

- data

- 2 categ attribs (gene, experimental condition)
 - 1 quant attrib (expression levels)

- marks: point

- indexed by 2 categorical key attributes
 - rectilinear: position/order, shared boundaries
 - size, orientation **unavailable**

- channels

- color by quant attrib (ordered diverging colormap)

- task: find outliers, find clusters (if ordered well)

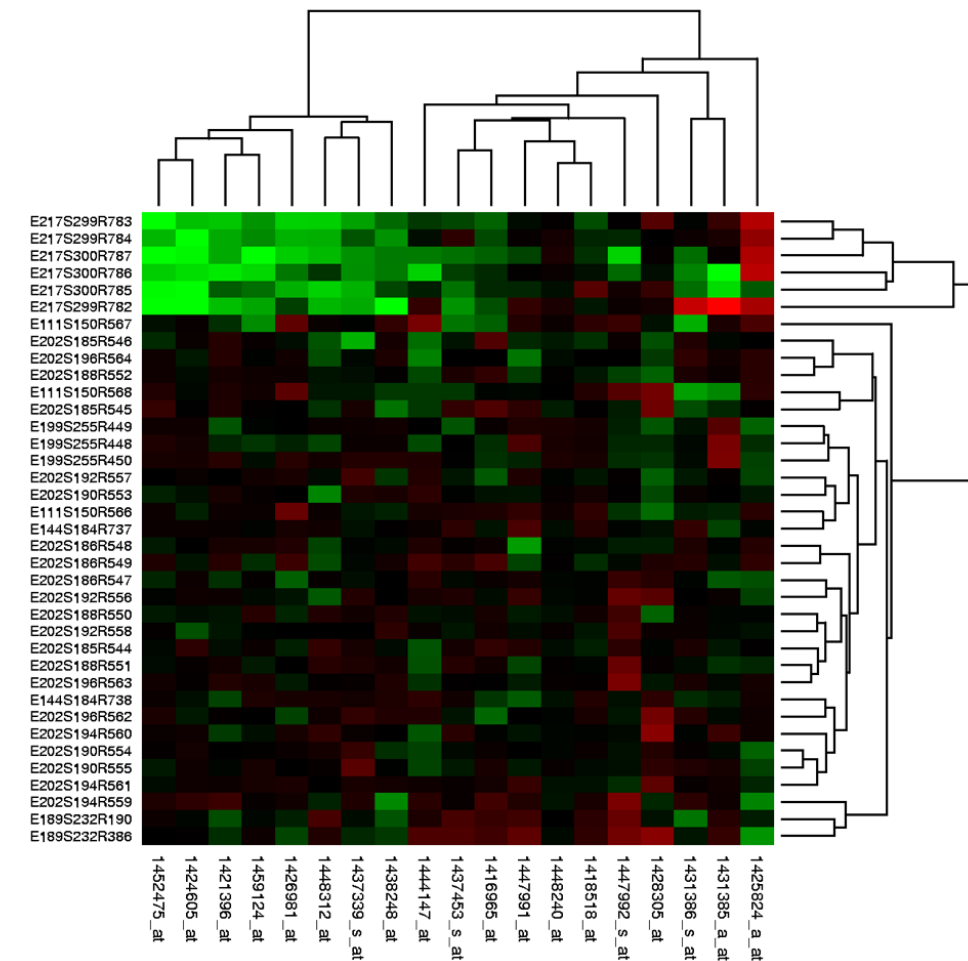
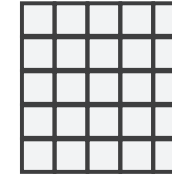
- dendrogram from cluster hierarchy traversal: order by derived attribute, to assess cluster quality

- scalability: asymmetric

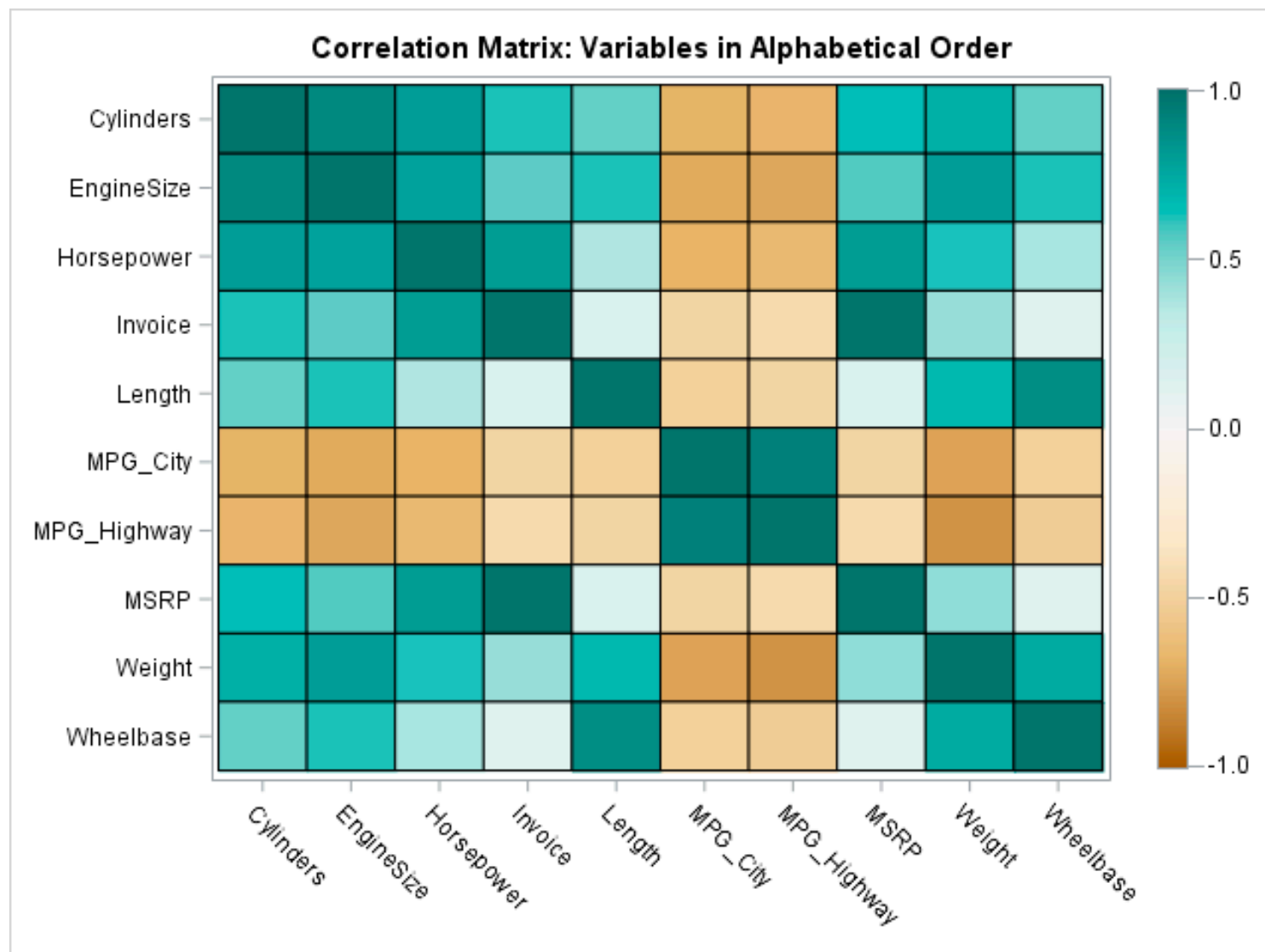
- 100s of categ levels, up to 1M items, but ~10 quant attrib levels

→ 2 Keys

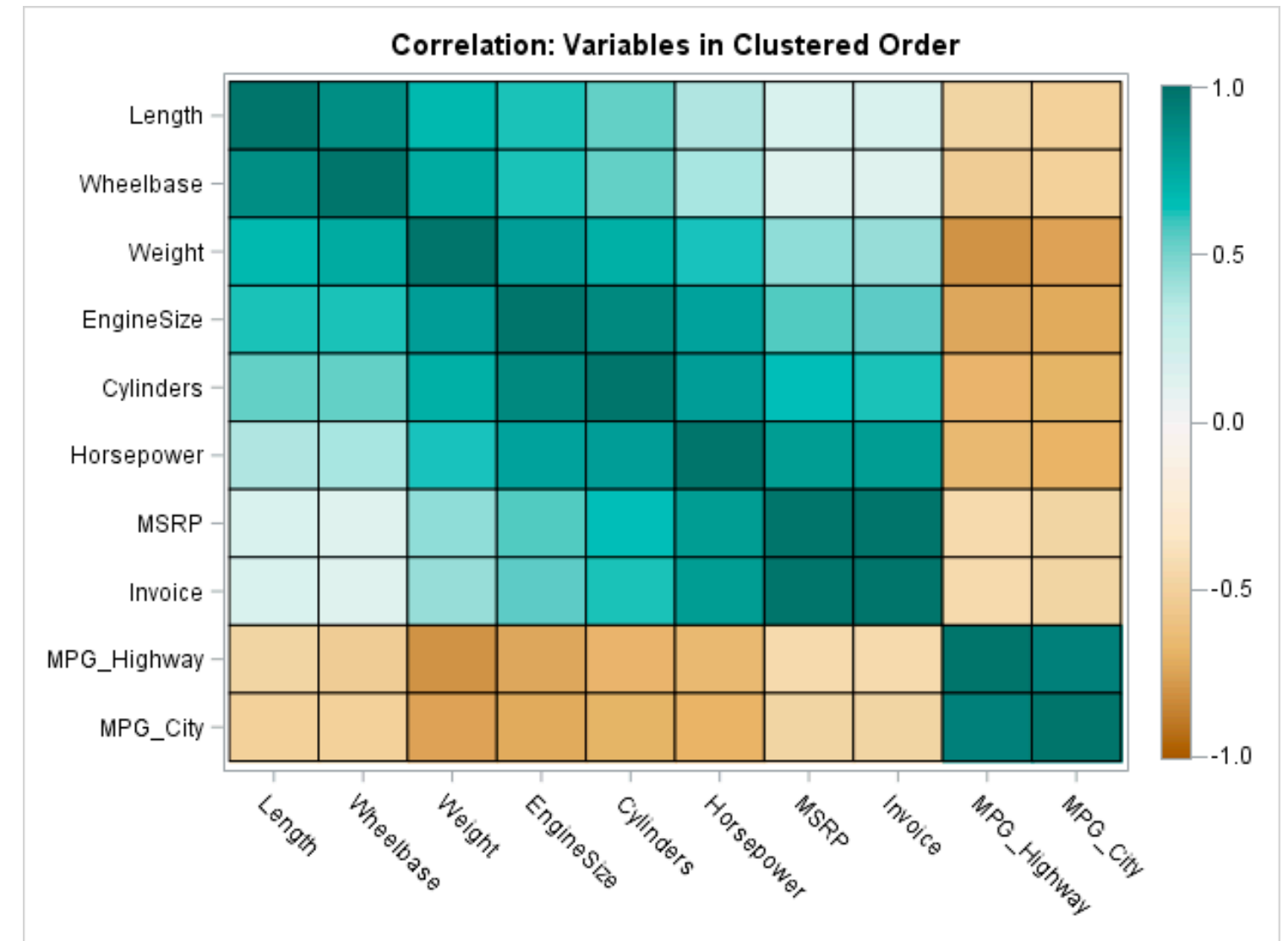
Matrix



Heatmap reordering



order by attrib name (alphabetical)

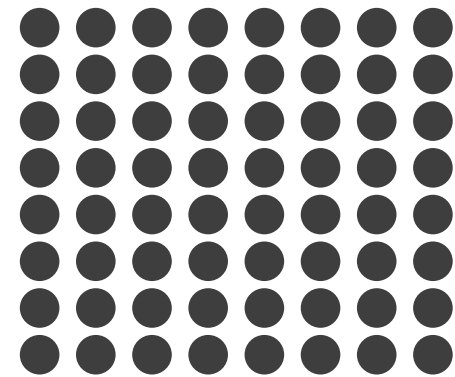


order by derived attribute (data-driven clustering)

Layout density

➔ Layout Density

➔ Dense



➔ Space-Filling

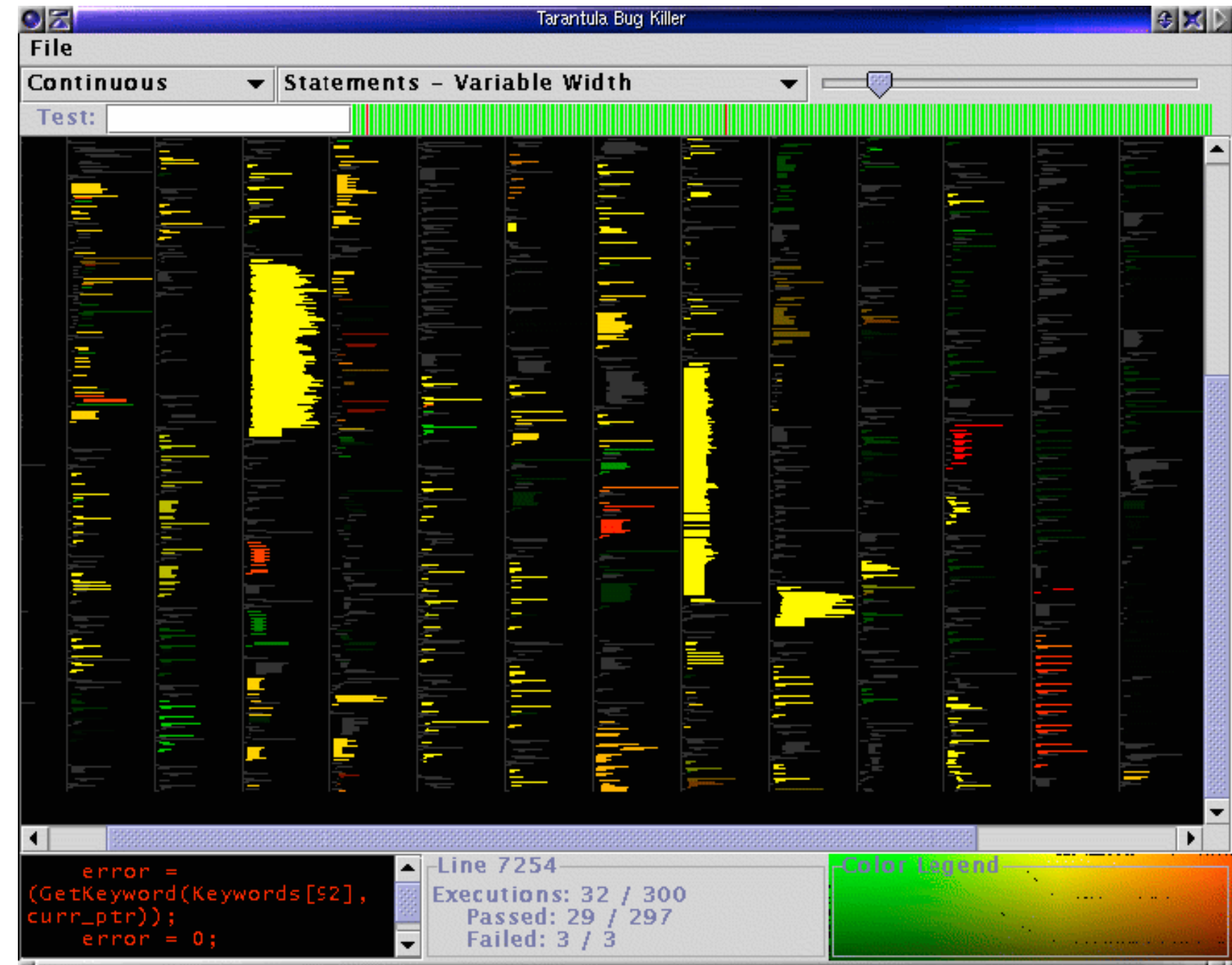
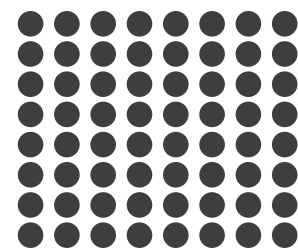


Idiom: Dense software overviews

- data: text
 - text + 1 quant attrib per line
- derived data: table of line lengths
- encoding
 - length coded lines, one pixel high
 - wrap long list into many columns
 - color line by attribute
- scalability
 - 10K+ lines

➔ Layout Density

➔ Dense



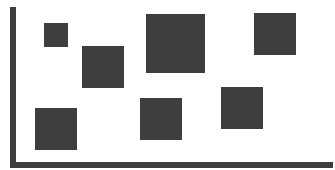
Arrange tables

② Express Values

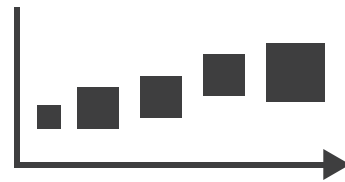


② Separate, Order, Align Regions

→ Separate



→ Order



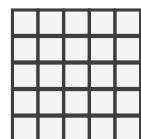
→ Align



→ 1 Key
List

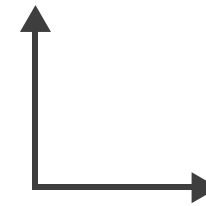


→ 2 Keys
Matrix

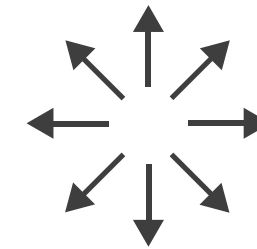


② Axis Orientation

→ Rectilinear

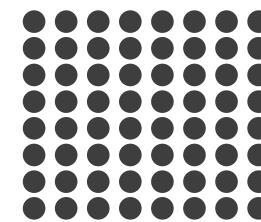


→ Radial



② Layout Density

→ Dense



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>
- The History of the Cluster Heat Map. Leland Wilkinson and Michael Friendly. The American Statistician 63:2 (2009), 179-184.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch7tables>

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

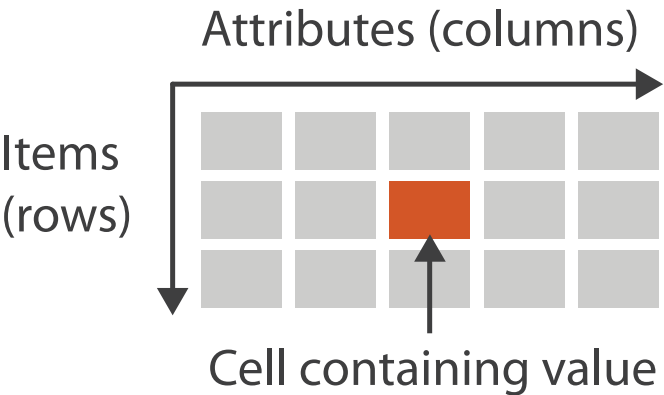
@tamara@cosocial.ca

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

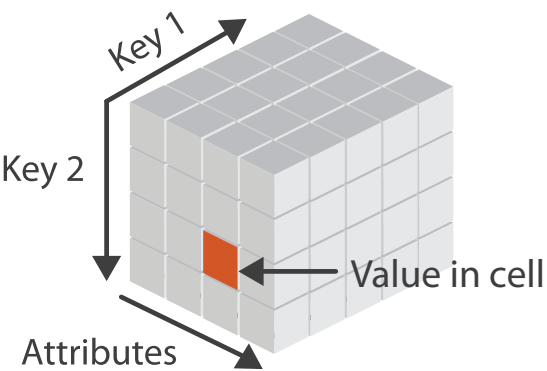
Focus on Spatial

→ Dataset Types

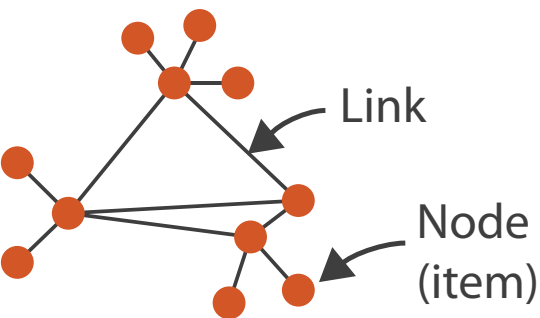
→ Tables



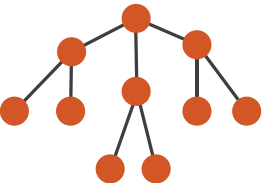
→ Multidimensional Table



→ Networks

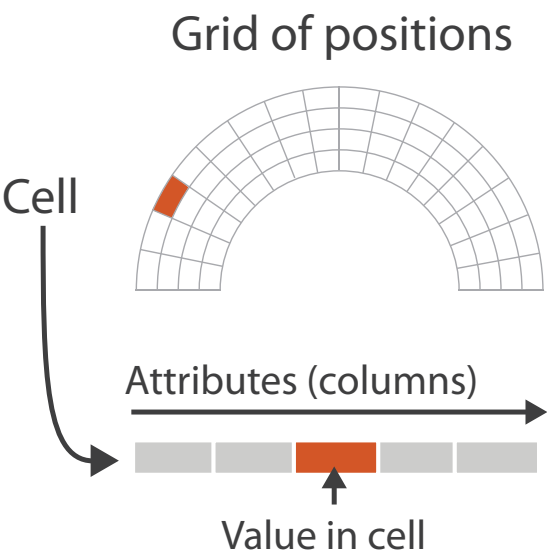


→ Trees

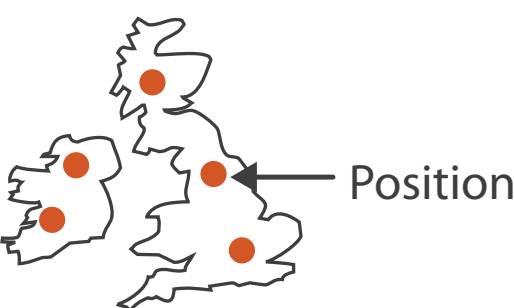


→ Spatial

→ Fields (Continuous)



→ Geometry (Spatial)



- when central task is understanding spatial relationships
 - use given spatial data

How?

Encode

➔ Arrange

➔ Express



➔ Separate



➔ Order



➔ Align



➔ Use



➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue



➔ Saturation



➔ Luminance



➔ Size, Angle, Curvature, ...



➔ Shape



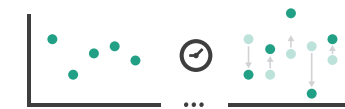
➔ Motion

Direction, Rate, Frequency, ...

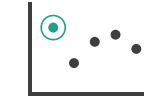


Manipulate

➔ Change



➔ Select



➔ Navigate



Facet

➔ Juxtapose



➔ Partition



➔ Superimpose



Reduce

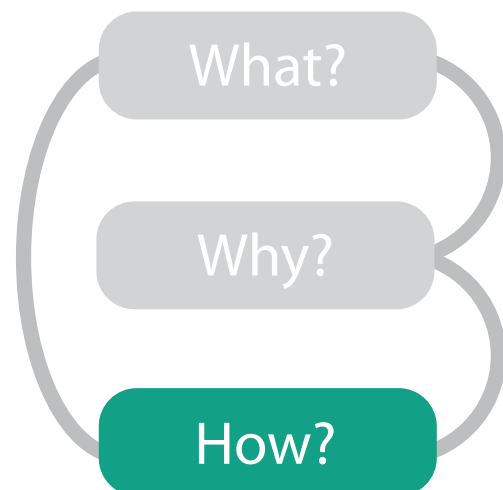
➔ Filter



➔ Aggregate



➔ Embed



Geographic Map

poly marks with 2D shared boundaries,
encode:

- position / order channels,
using given spatial data

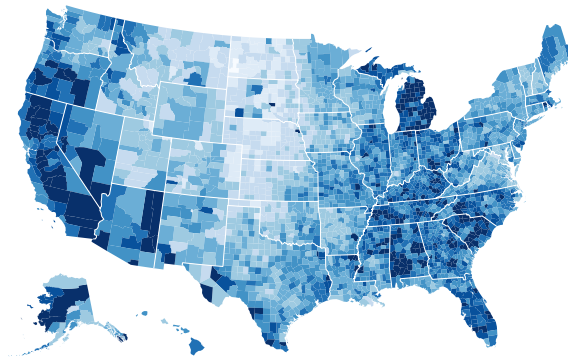
cannot use other channels to show other
attributes, locked down as unavailable:

- size
- orientation
- symbol/shape



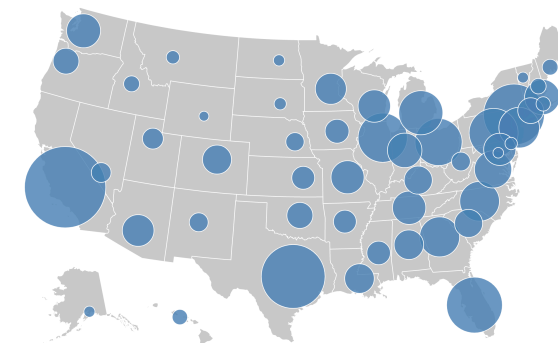
Thematic maps

- show spatial variability of attribute ("theme")
 - combine geographic / reference map with (simple, flat) tabular data, joining
 - region: shared-boundary poly marks (eg provinces, countries) or point marks (eg cities)
 - region: categorical key attribute in table, use to look up value attributes
- major idioms
 - choropleth: color
 - but salience depends on size
 - symbol maps: add mark
 - but occlusion possible
 - dot maps: add many marks
 - but same non-uniform size issue
 - cartograms: recompute all
 - but requires familiarity



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

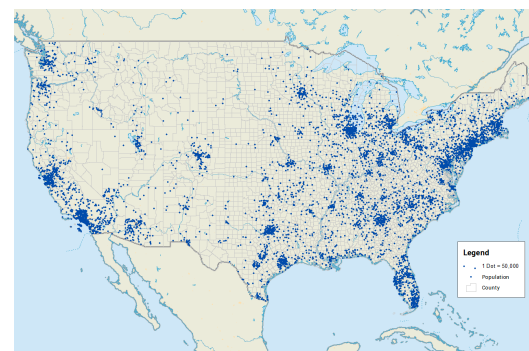
choropleth



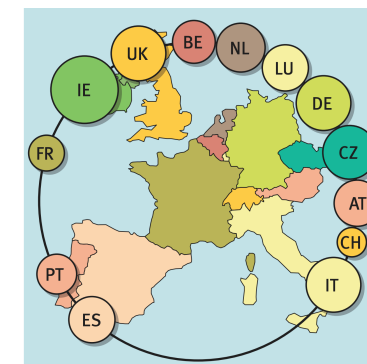
symbol map



non-contiguous

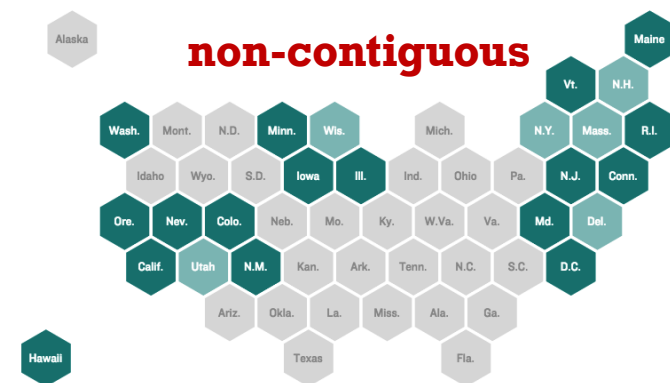


dot map



necklace map

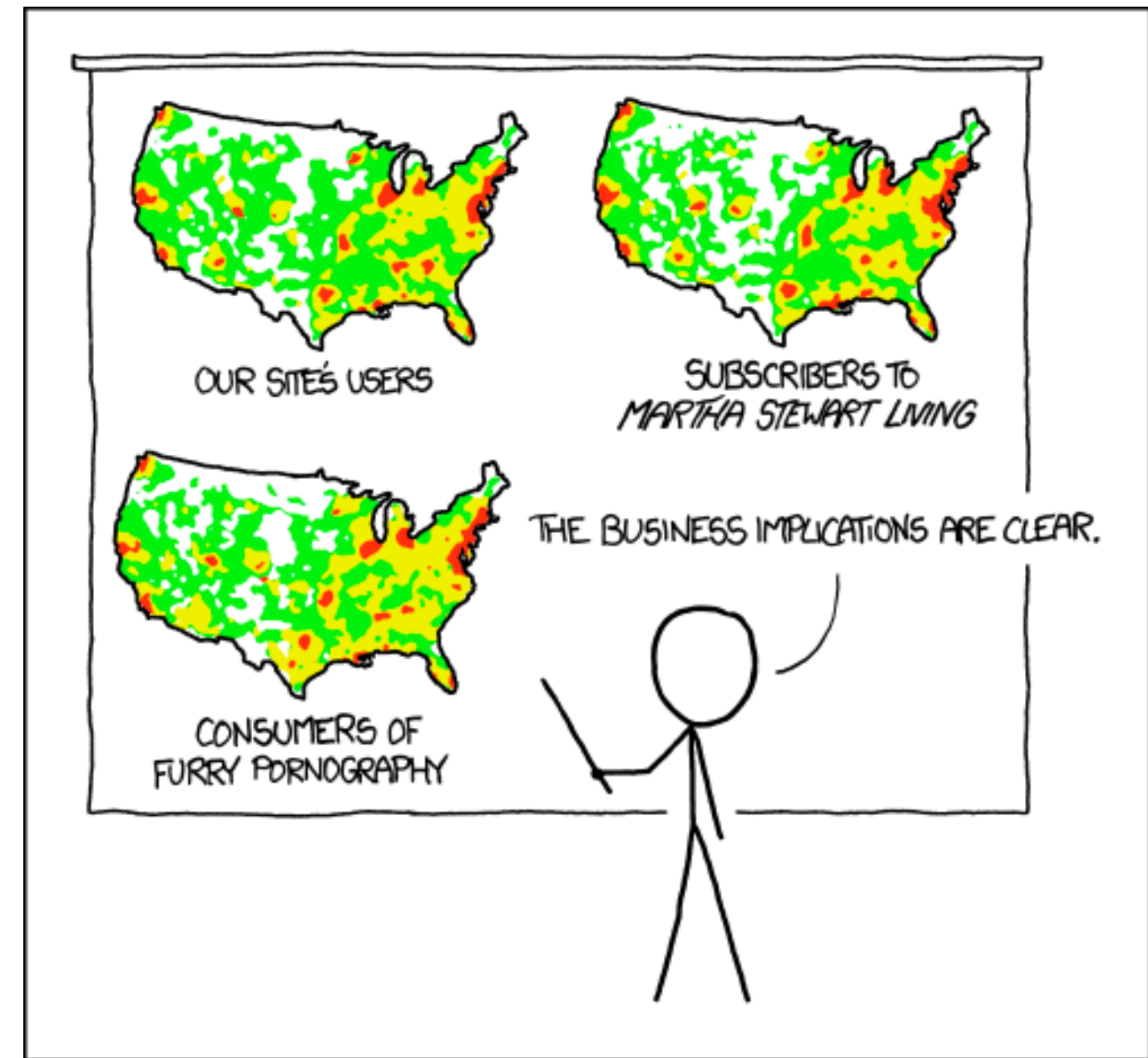
Necklace Maps. Bettina Speckmann and Kevin Verbeek. TVCG (16)6:881-889, 2010.
<https://bspeckmann.win.tue.nl/papers/NecklaceMapsFinal.pdf>



cartogram

Beware: Population maps trickiness!

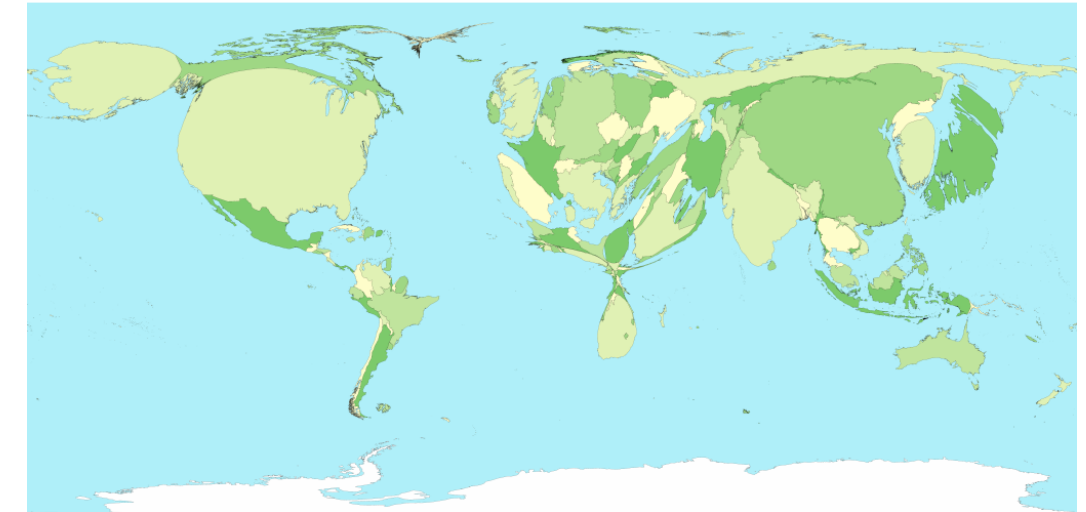
- spurious correlations: most attributes just show where people live
- consider when to normalize by population density
 - encode raw data values
 - tied to underlying population
 - but should use normalized values
 - eg unemployed people per 100 citizens
- general issue, even beyond maps
 - absolute counts vs relative/normalized data
 - failure to normalize is common error



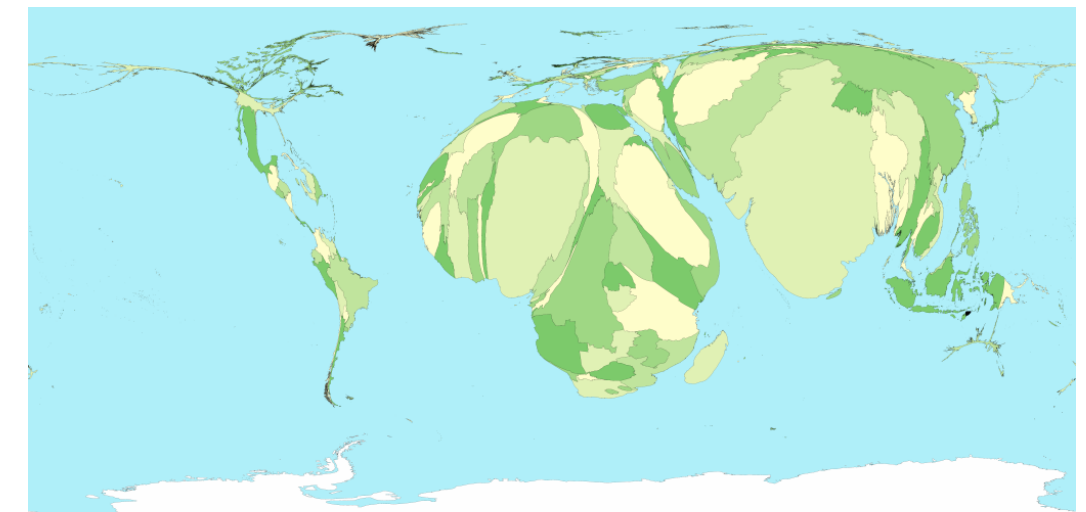
[<https://xkcd.com/1138>]

Idiom: **Contiguous cartogram**

- poly marks with 2D shared boundaries
 - aka *area-proportional continuous cartogram*
- derive new interlocking polys
 - based on combination of original interlocking marks and new quantitative attribute
 - encode: area (2D size) for new quant attribute
 - encode: order, maintaining relative position of polys
 - unavailable: position, orientation, shape/symbol
- algorithm to create new marks
 - input: target size (quant attribute)
 - goal: keep shape, position, orientation as close as possible to given spatial data for original polys
 - requirement: maintain constraints
 - order (relative position)
 - contiguous shared boundaries with neighbours



Greenhouse Emissions



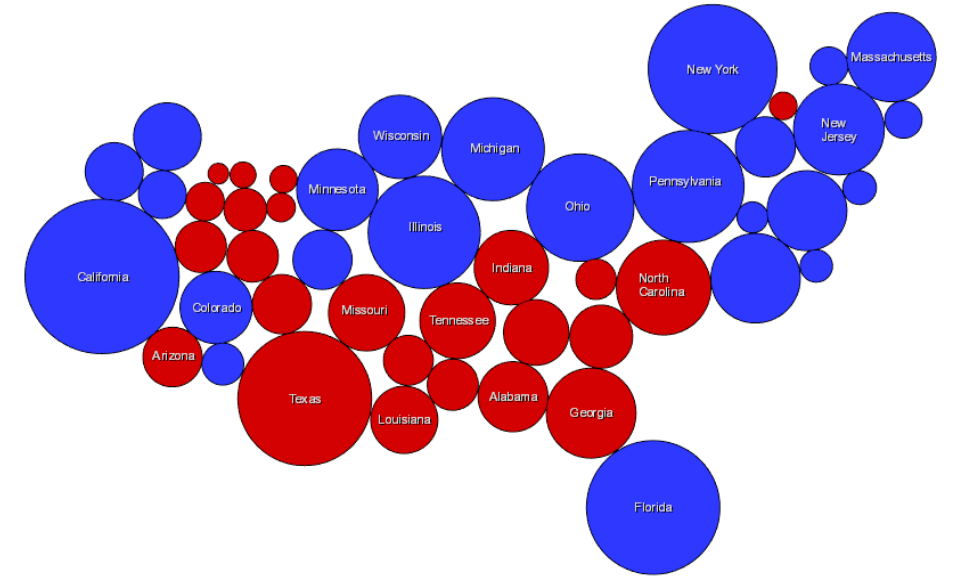
Child Mortality

D. Area-proportional
continuous cartogram



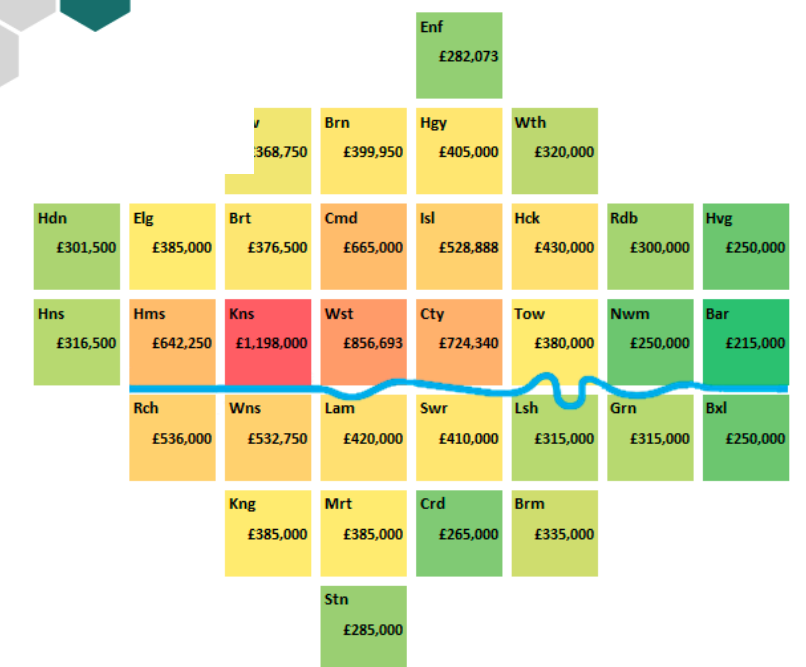
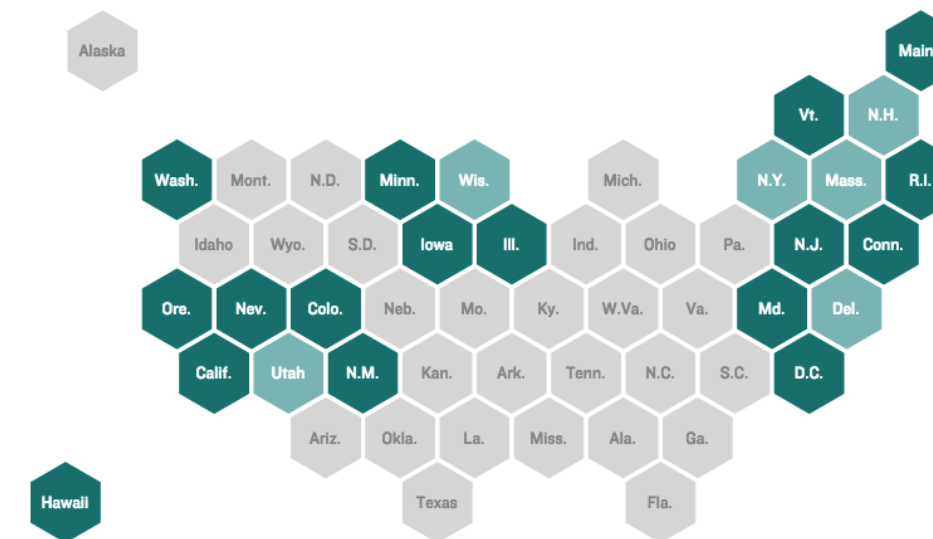
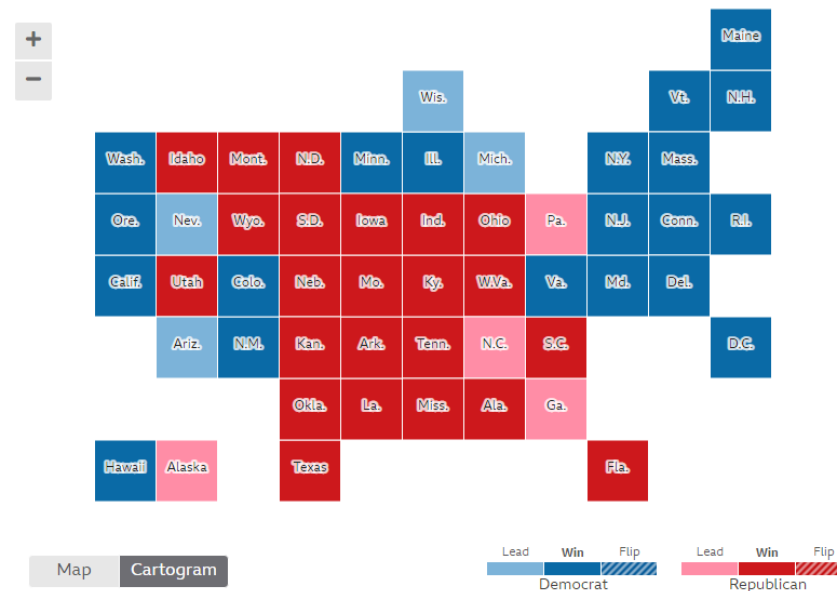
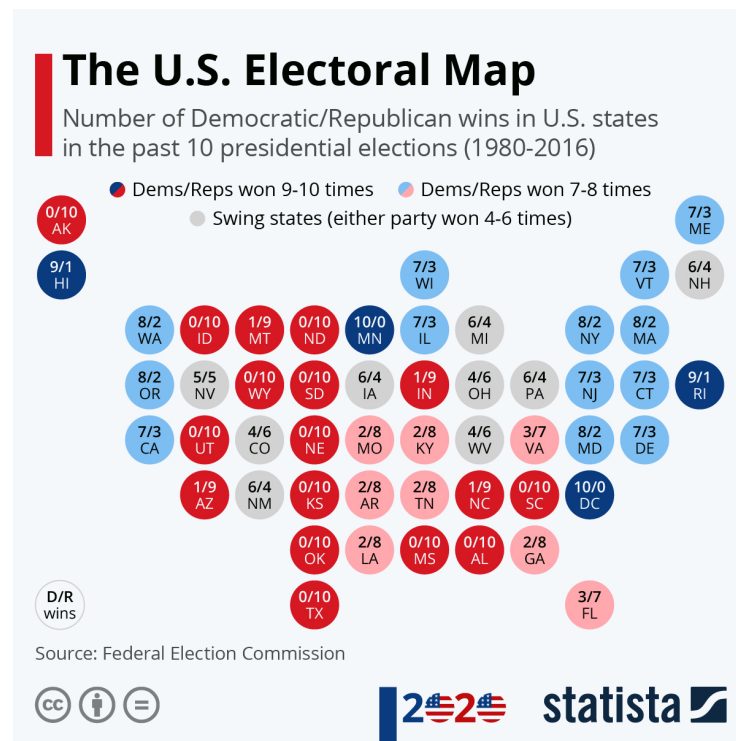
Idiom: **Dorling (circle) cartogram**

- Dorling cartogram
 - throw away shape by regularizing to circles
 - point marks, with shared 2D boundaries
 - encode quant attribute with 2D size
 - encode relative locations of old polys with order
 - unavailable:
 - position: algorithm constraint to be as close as possible to original geographic locations (given spatial data)
 - orientation: meaningless since circles are symmetric
 - symbol/shape: must be circle, by definition
 - free: color
 - can treat as special case of circle packing, with quasi-geographic position constraints



<https://www.arcgis.com/apps/StorytellingTextLegend/index.html?appid=b686a7679cb747e9825d1d1bb6b26046>

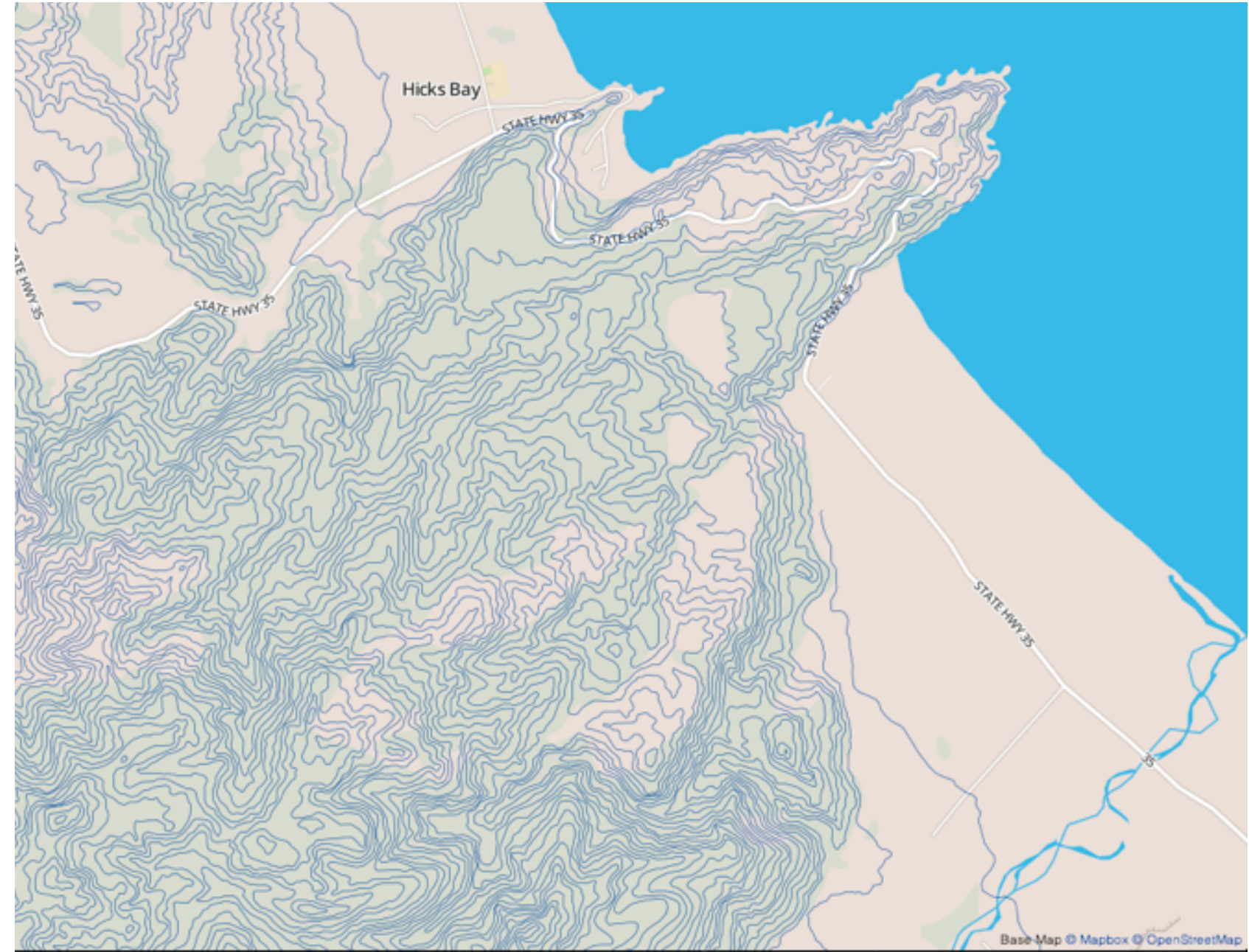
Idiom: Equal-area (Grid) Cartogram



- regularize shape & size, arranged in grid
 - derive new point marks with 2D shared boundaries
 - unavailable channels: size, shape/symbol, orientation
 - possible shapes: circles, squares, hexagons
 - unavailable: position, algorithm constraint to keep as close as possible to given spatial data
 - encode relative location/arrangement of original polys with order
 - encode quant attribute with color, just like with choropleth
- aka: *grid map*, *mosaic cartogram*, *pseudo-Demers cartogram*, *geofacets*, *geogrid*, *tile grid map*, *tile map*

Idiom: **topographic map**

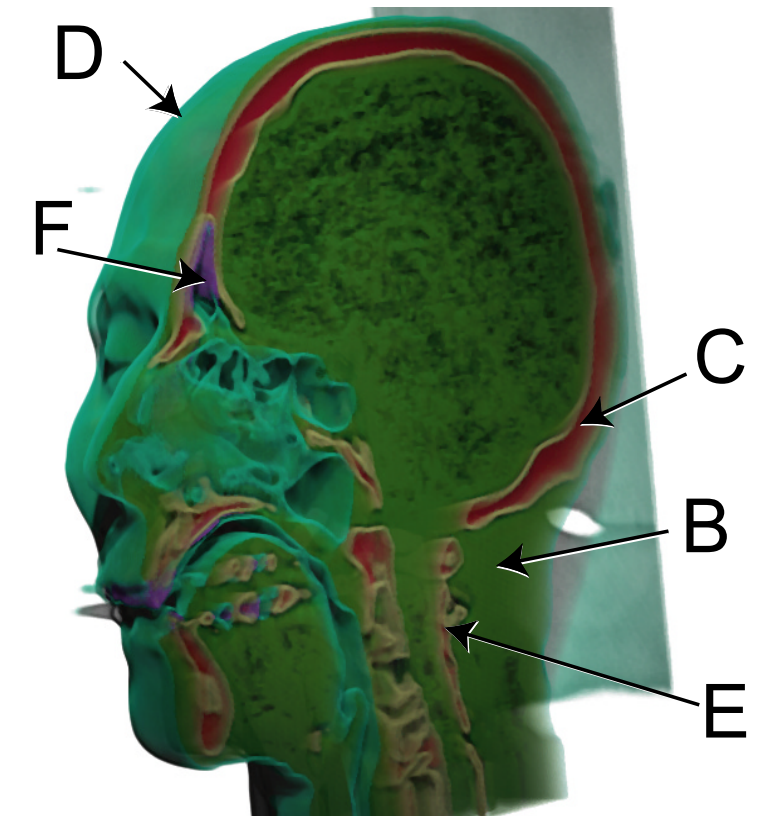
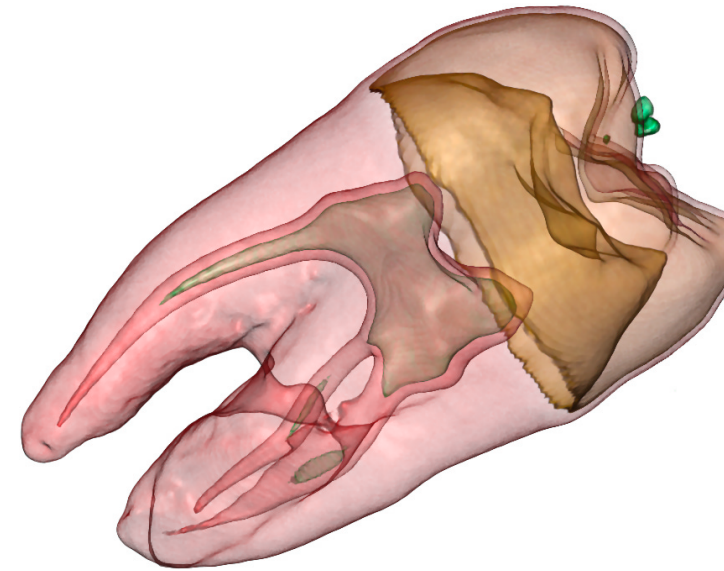
- data
 - geographic geometry
 - scalar spatial field
 - 1 quant attribute per grid cell
- derived data
 - isoline geometry
 - isocontours computed for specific levels of scalar values



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

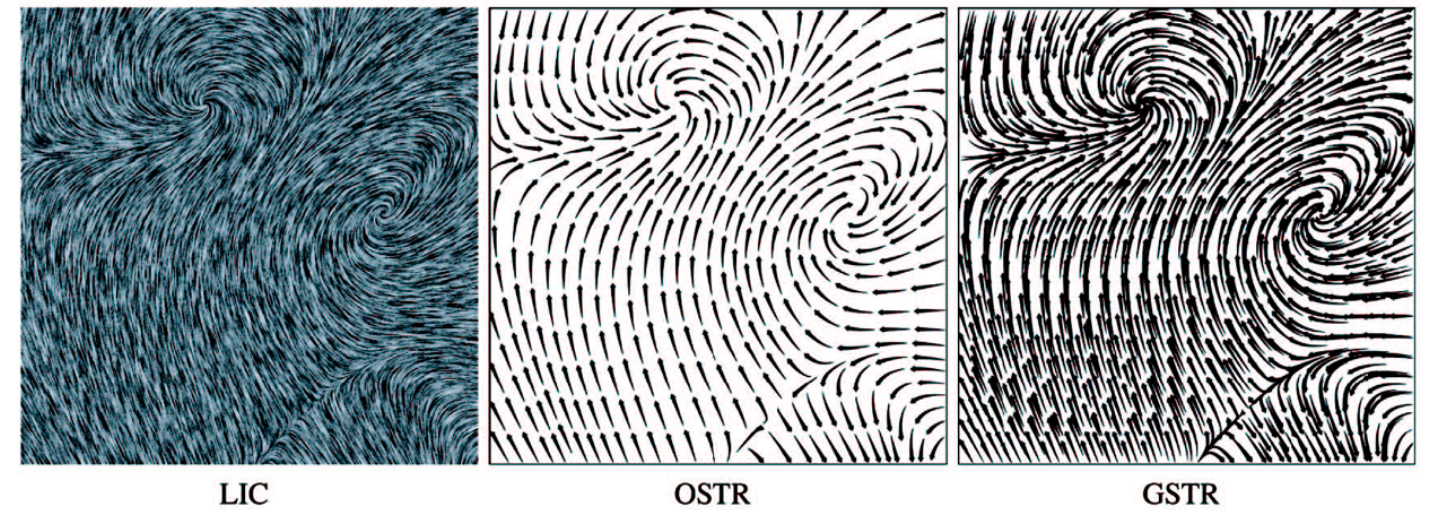
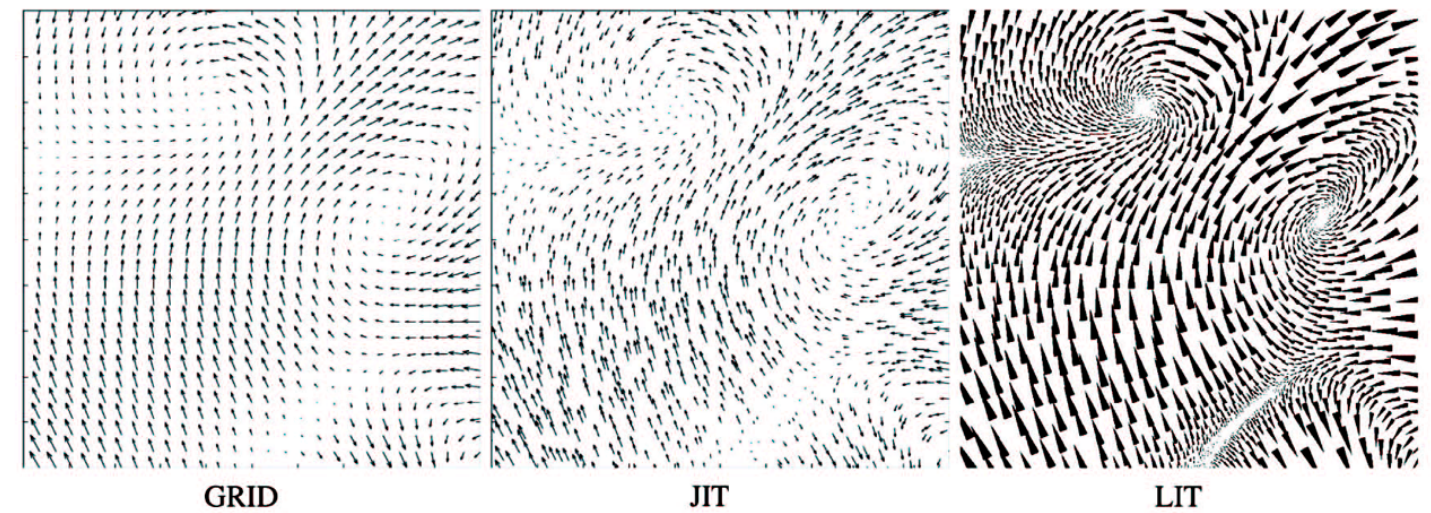


[Interactive Volume Rendering Techniques. Kniss. Master's thesis, University of Utah Computer Science, 2002.]

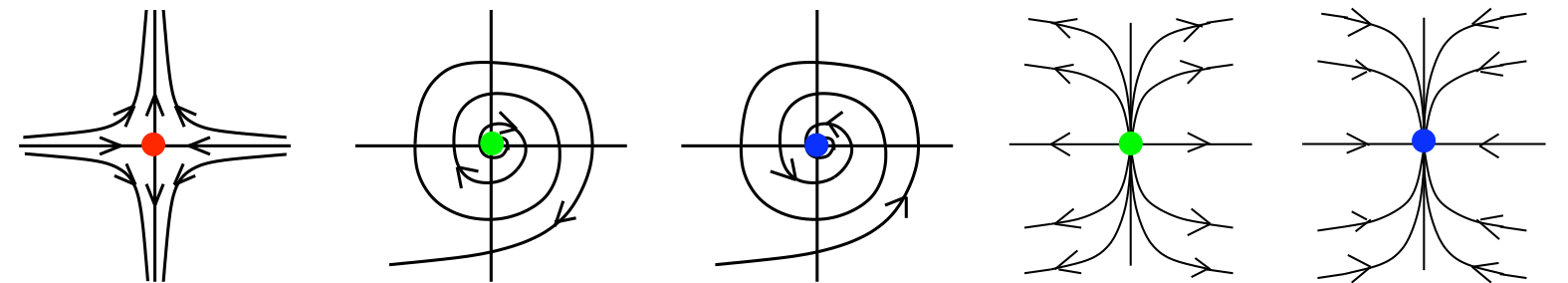
[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

Vector and tensor fields

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



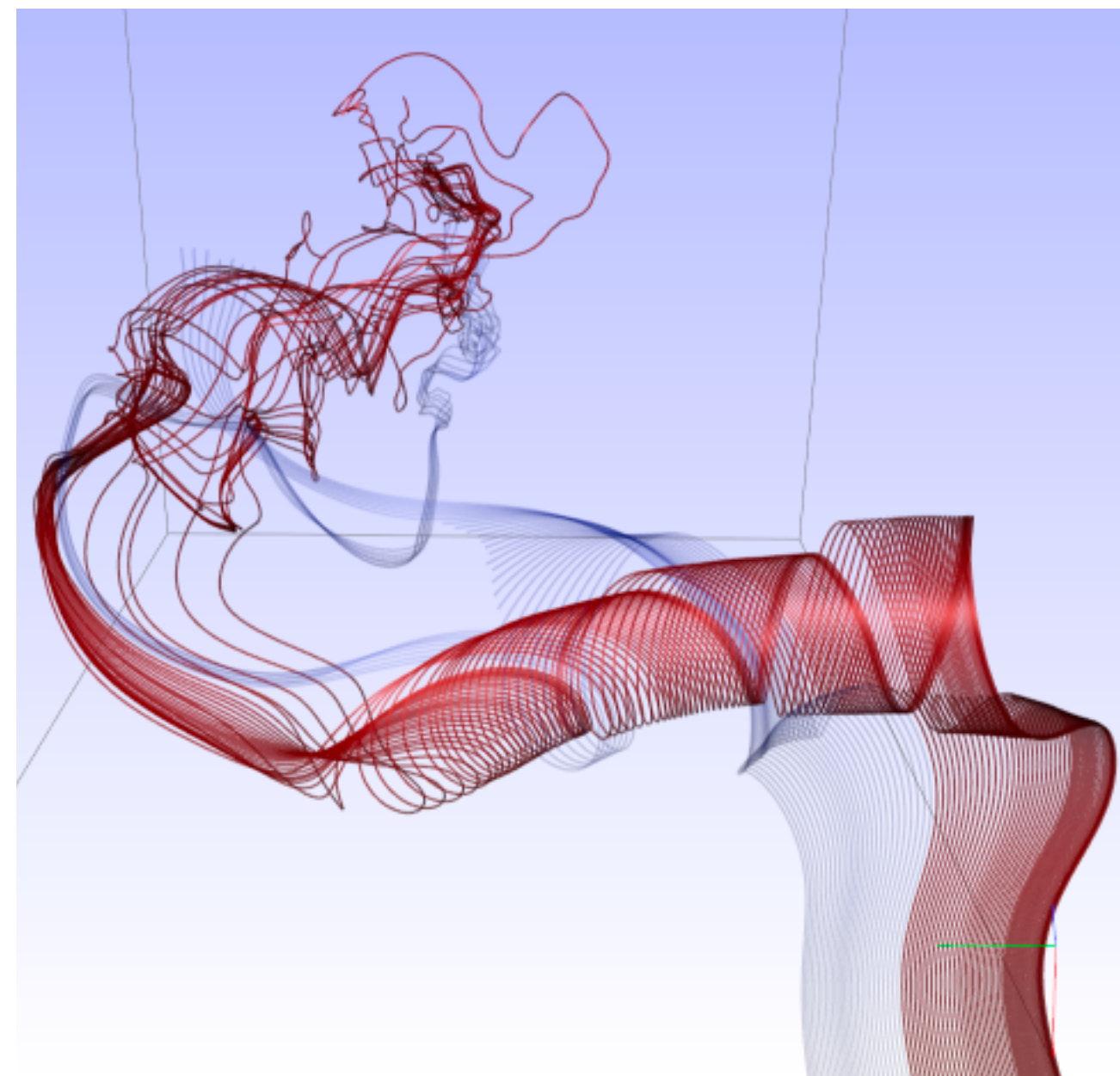
[Comparing 2D vector field visualization methods: A user study. Laidlaw et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]



[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



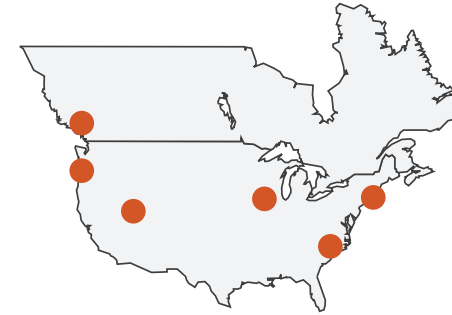
[Similarity Measures for Enhancing Interactive Streamline Seeding. McLoughlin, Jones, Laramee, Malki, Masters, and Hansen. IEEE Trans. Visualization and Computer Graphics 19:8 (2013), 1342–1353.]

Arrange spatial data

➔ Use Given

➔ Geometry

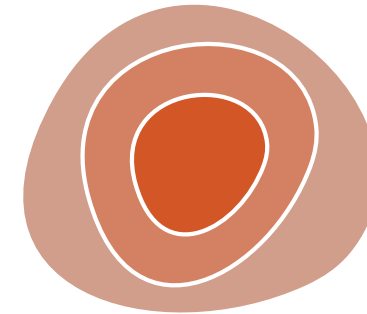
- ➔ *Geographic*
- ➔ *Other Derived*



➔ Spatial Fields

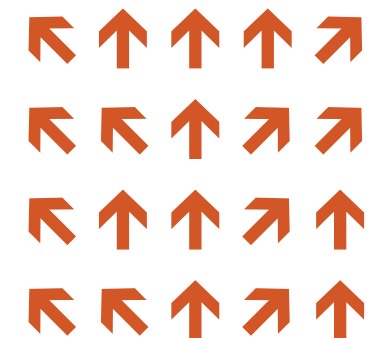
➔ *Scalar Fields (one value per cell)*

- ➔ *Isocontours*
- ➔ *Direct Volume Rendering*



➔ *Vector and Tensor Fields (many values per cell)*

- ➔ *Flow Glyphs (local)*
- ➔ *Geometric (sparse seeds)*
- ➔ *Textures (dense seeds)*
- ➔ *Features (globally derived)*



Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, Nov 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.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch8spatial>

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

@tamara@cosocial.ca

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

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- BREAK 10:30-11

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Network data

- networks

- model relationships between things

- aka graphs

- two kinds of items, both can have attributes

- nodes

- links

- tree

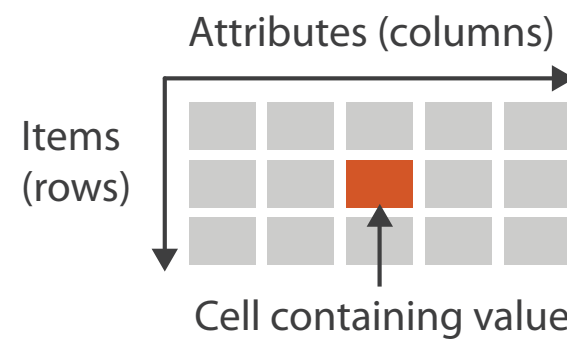
- special case

- no cycles

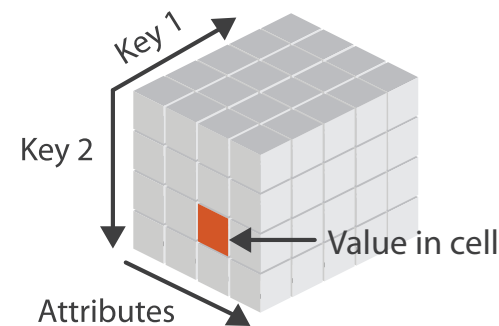
- one parent per node

➔ Dataset Types

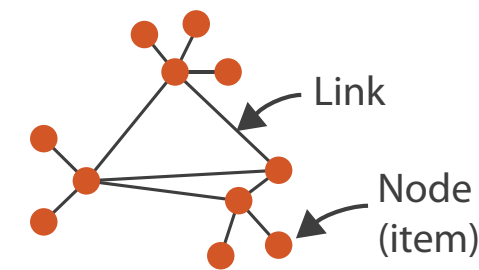
➔ Tables



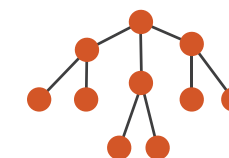
➔ *Multidimensional Table*



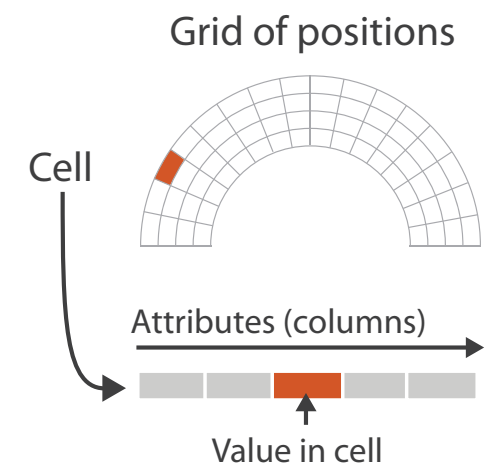
➔ Networks



➔ Trees



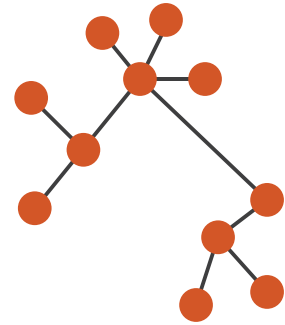
➔ Spatial
➔ Fields (Continuous)



Arrange networks and trees

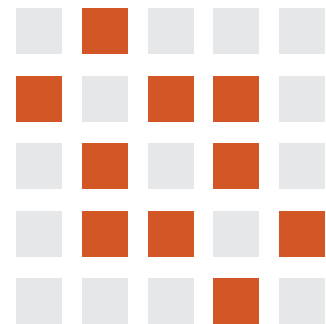
→ Node–Link Diagrams Connection Marks

✓ NETWORKS ✓ TREES



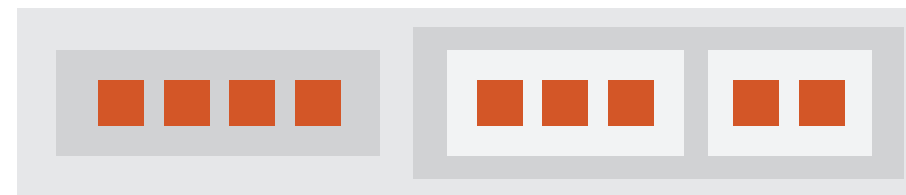
→ Adjacency Matrix Derived Table

✓ NETWORKS ✓ TREES



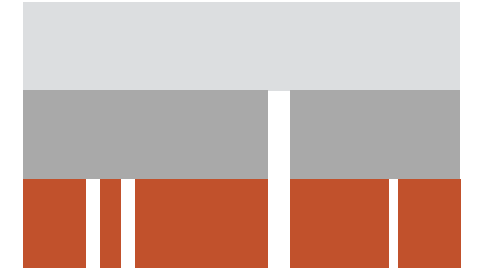
→ Enclosure Containment Marks

✗ NETWORKS ✓ TREES



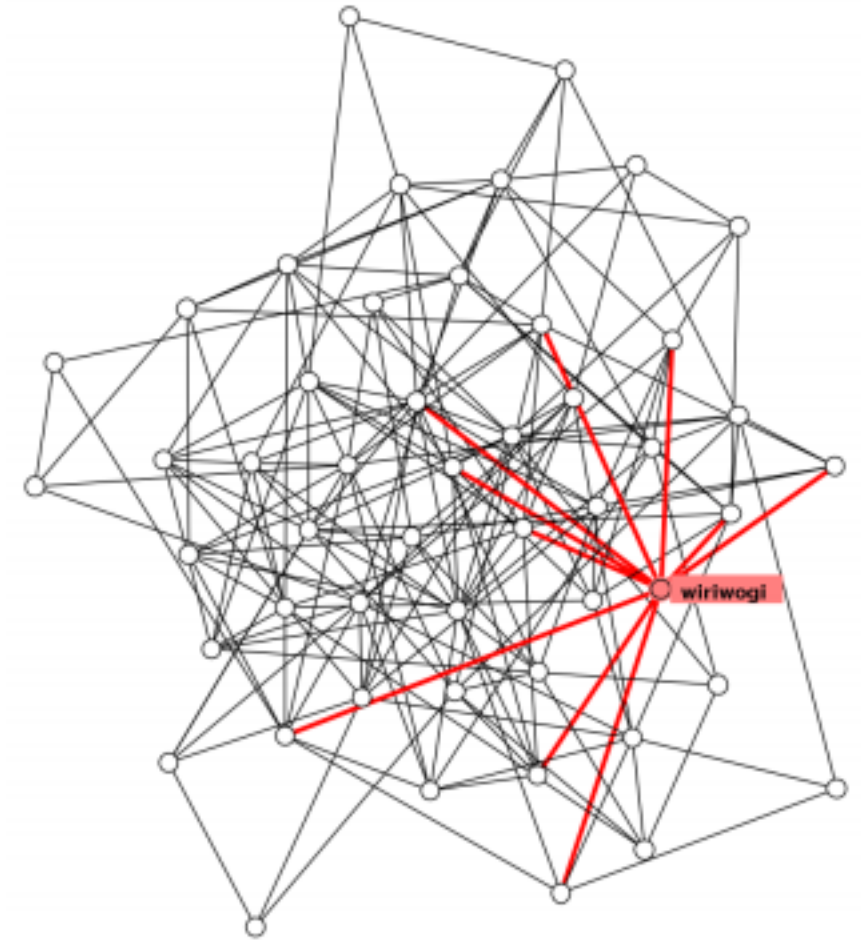
→ Implicit Spatial Position

✗ NETWORKS ✓ TREES



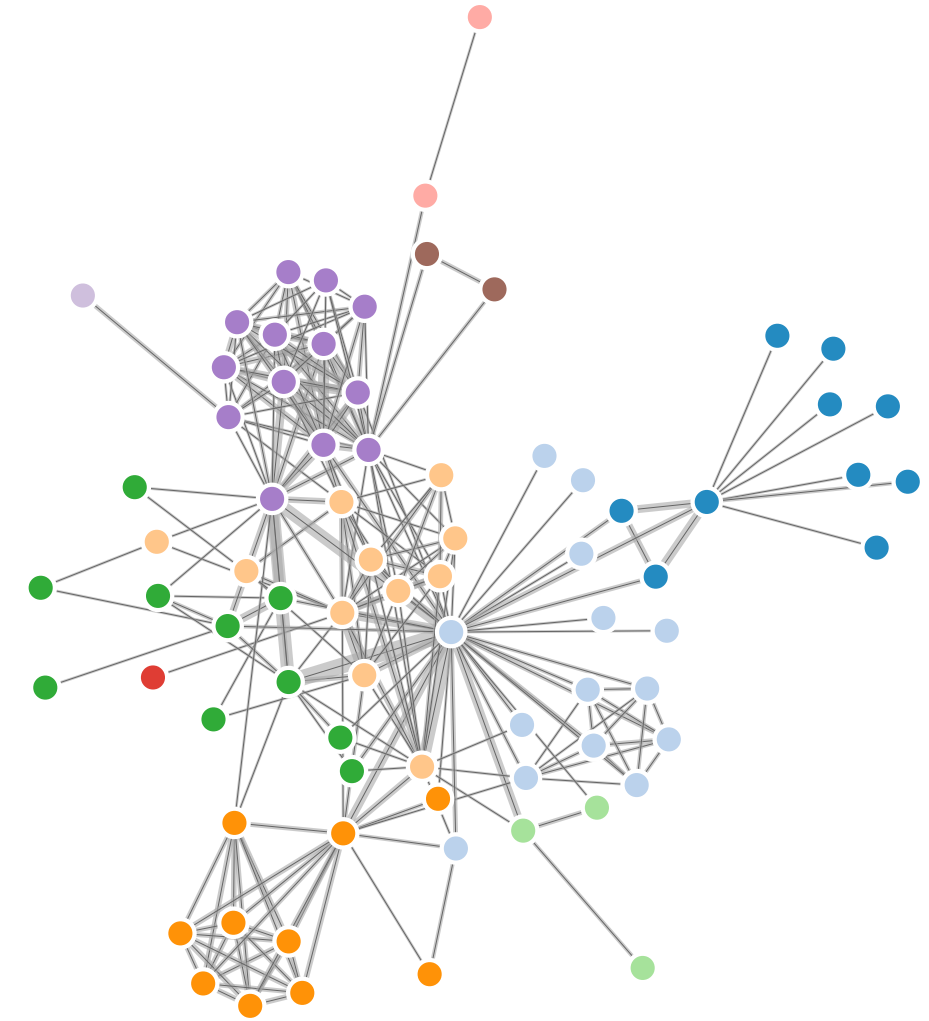
Network tasks: topology-based and attribute-based

- topology based tasks
 - find paths
 - find (topological) neighbors
 - compare centrality/importance measures
 - identify clusters / communities
- attribute based tasks (similar to table data)
 - find distributions, ...
- combination tasks, incorporating both
 - example: find friends-of-friends who like cats
 - topology: find all adjacent nodes of given node
 - attributes: check if has-pet (node attribute) == cat



Idiom: **force-directed placement**

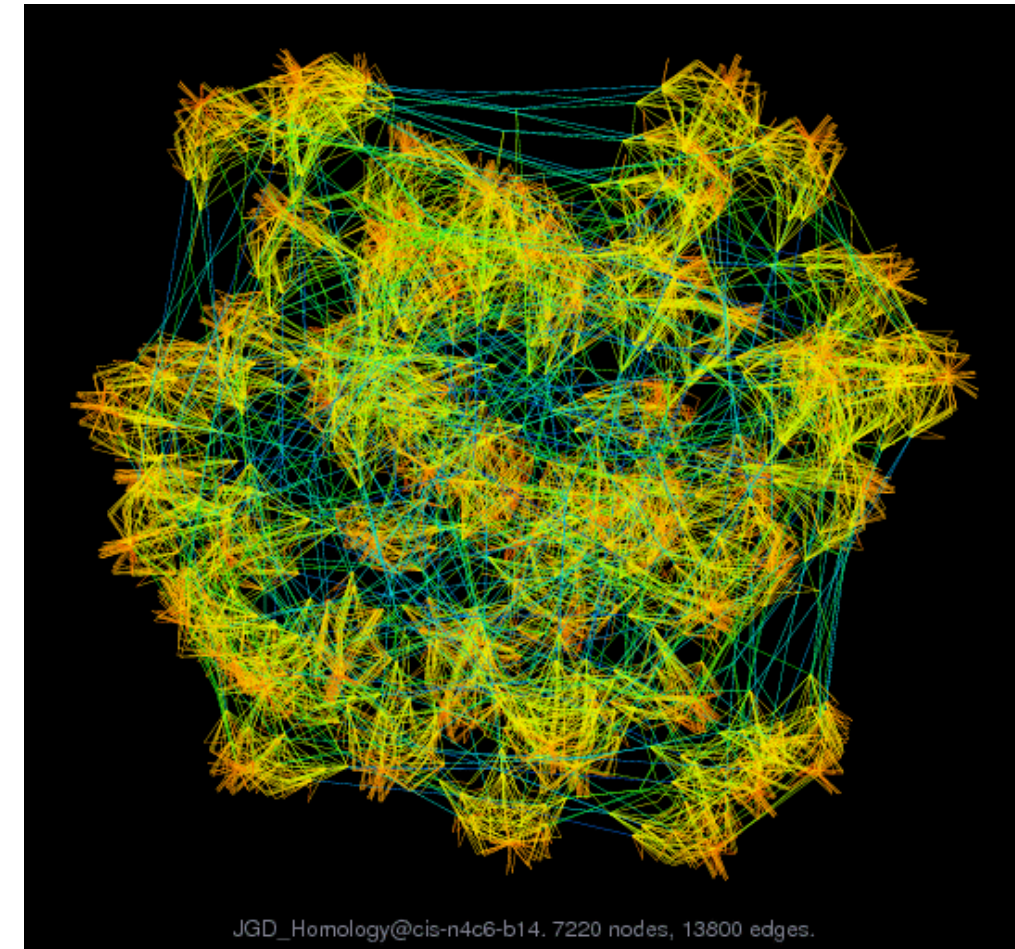
- visual encoding: node-link diagram
 - node point marks, link connection marks
- algorithm: energy minimization
 - analogy: nodes repel, links draw together like springs
 - optimization problem: minimize crossings
- spatial position/order: no meaning directly encoded
 - sometimes proximity meaningful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



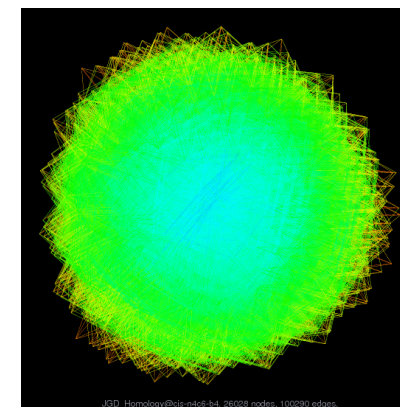
<https://observablehq.com/@d3/force-directed-graph/2>

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 eventually hits



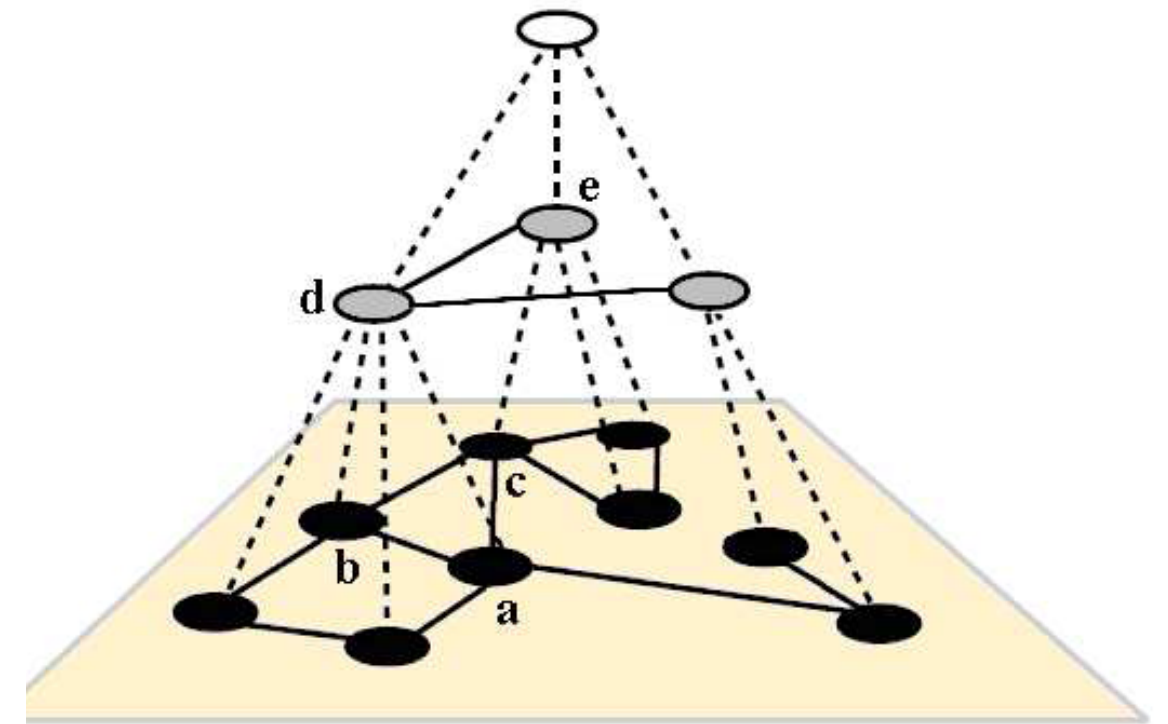
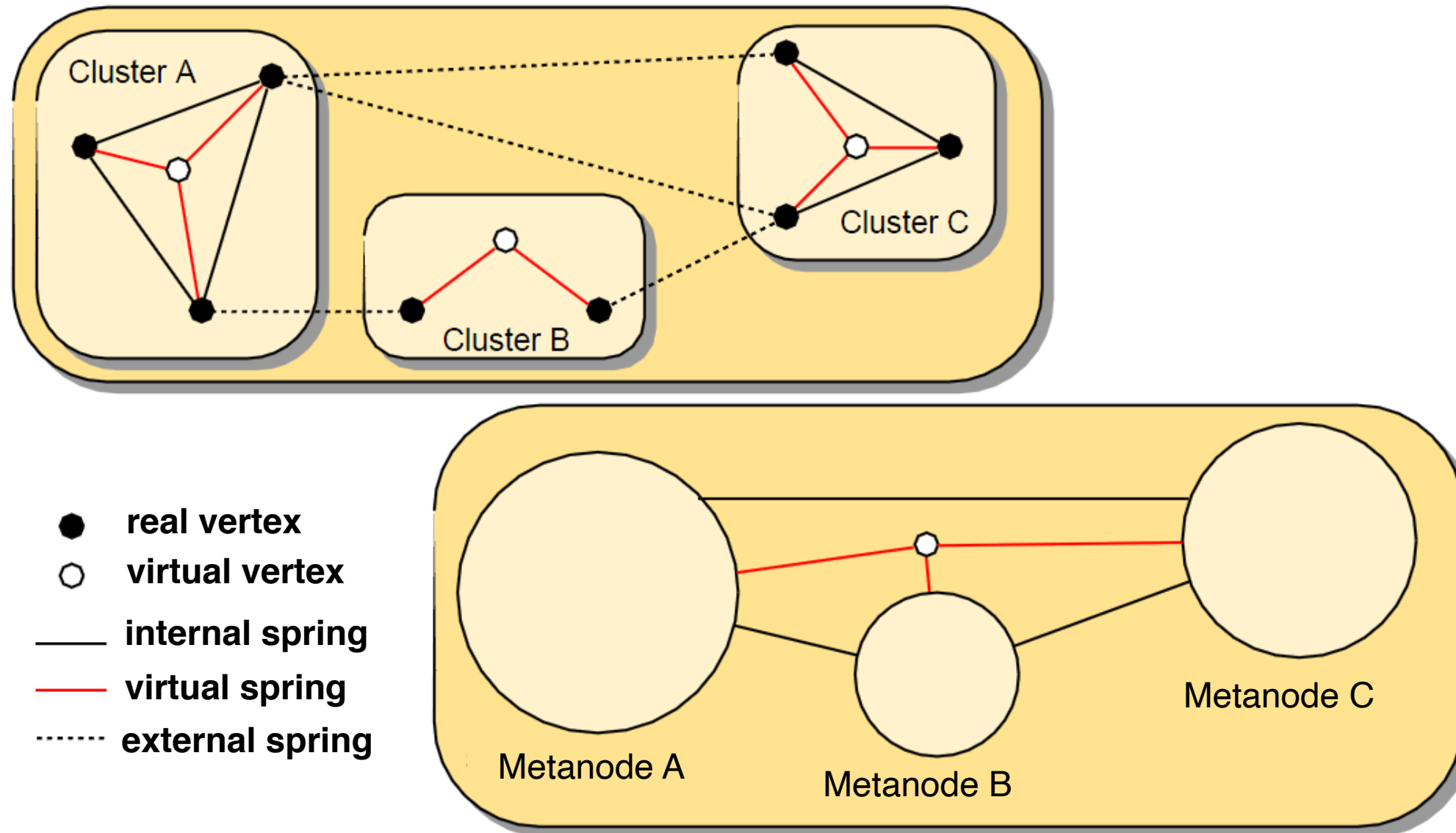
[Efficient and high quality force-directed graph drawing. Hu. The Mathematica Journal 10:37–71, 2005.]



<http://www.research.att.com/yifanhu/GALLERY/GRAPHS/index1.html>

Multilevel networks

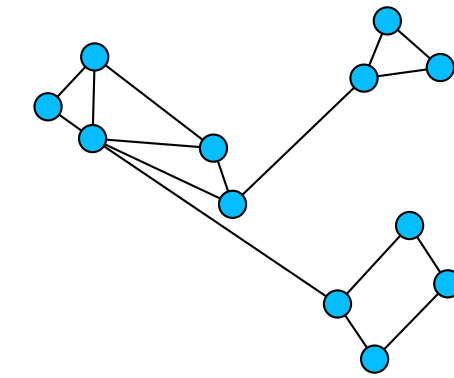
- derive cluster hierarchy of metanodes on top of original graph nodes



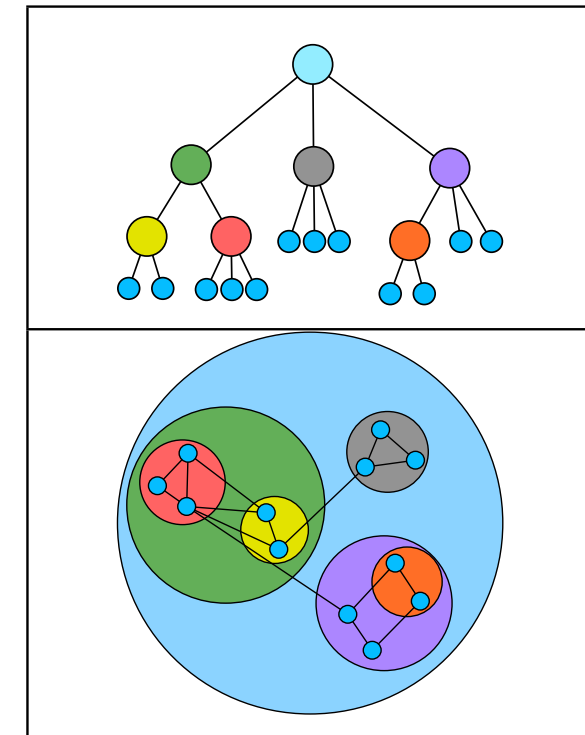
[Schulz 2004]

Idiom: **GrouseFlocks**

- data: compound network
 - network
 - cluster hierarchy atop it
 - derived or interactively chosen
- visual encoding
 - connection marks for network links
 - containment marks for hierarchy
 - point marks for nodes
- dynamic interaction
 - select individual metanodes in hierarchy to expand/contract



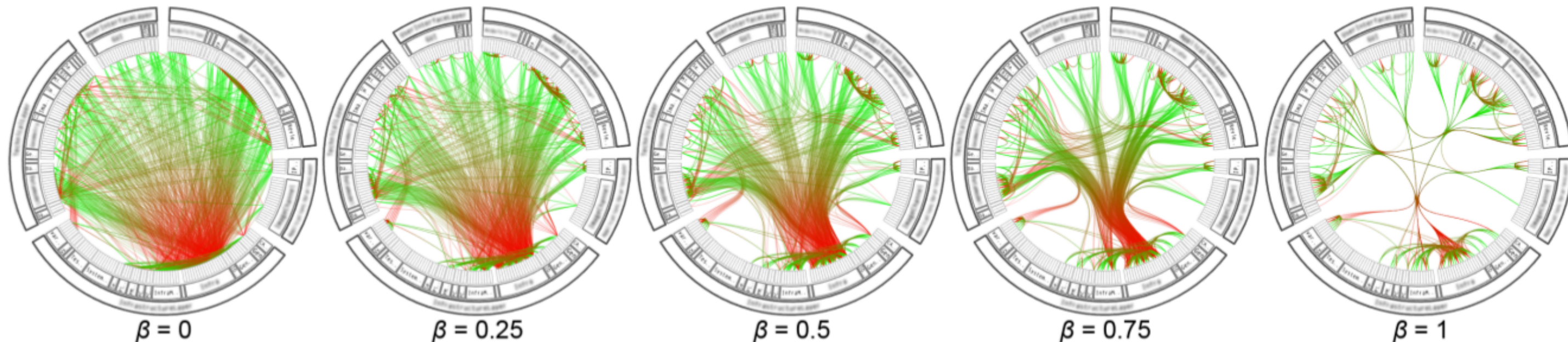
Graph Hierarchy 1



[*GrouseFlocks: Steerable Exploration of Graph Hierarchy Space*. Archambault, Munzner, and Auber. *IEEE TVCG* 14(4):900-913, 2008.]

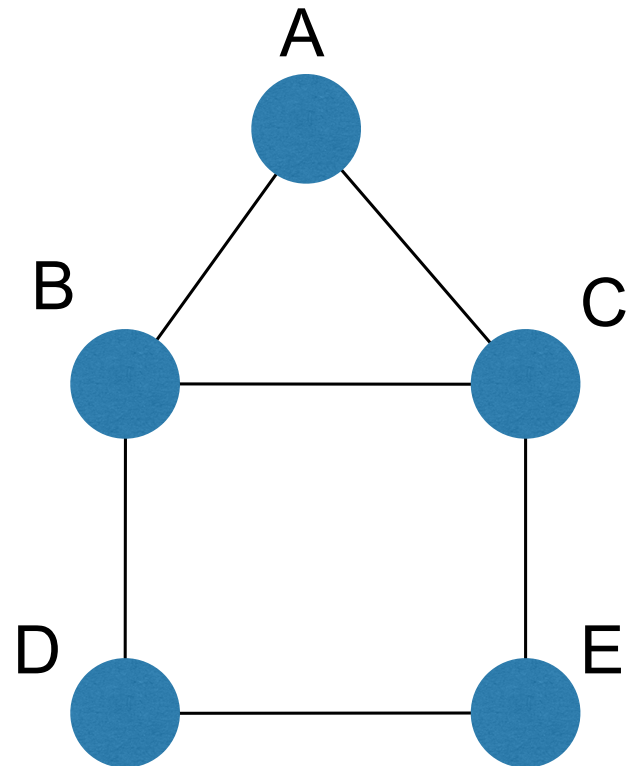
Idiom: hierarchical edge bundling

- data
 - any layout of compound network
 - network: software classes (nodes), import/export between classes (links)
 - cluster hierarchy: class package structure
 - derived: bundles of edges with same source/destination (multi-level)
- idiom: curve edge routes according to bundles
- task: edge clutter reduction



Adjacency matrix representations

- derive adjacency matrix from network



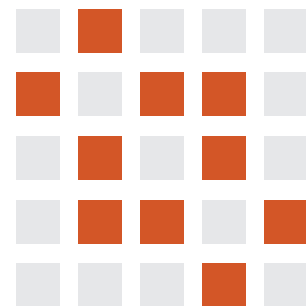
	A	B	C	D	E
A					
B					
C					
D					
E					



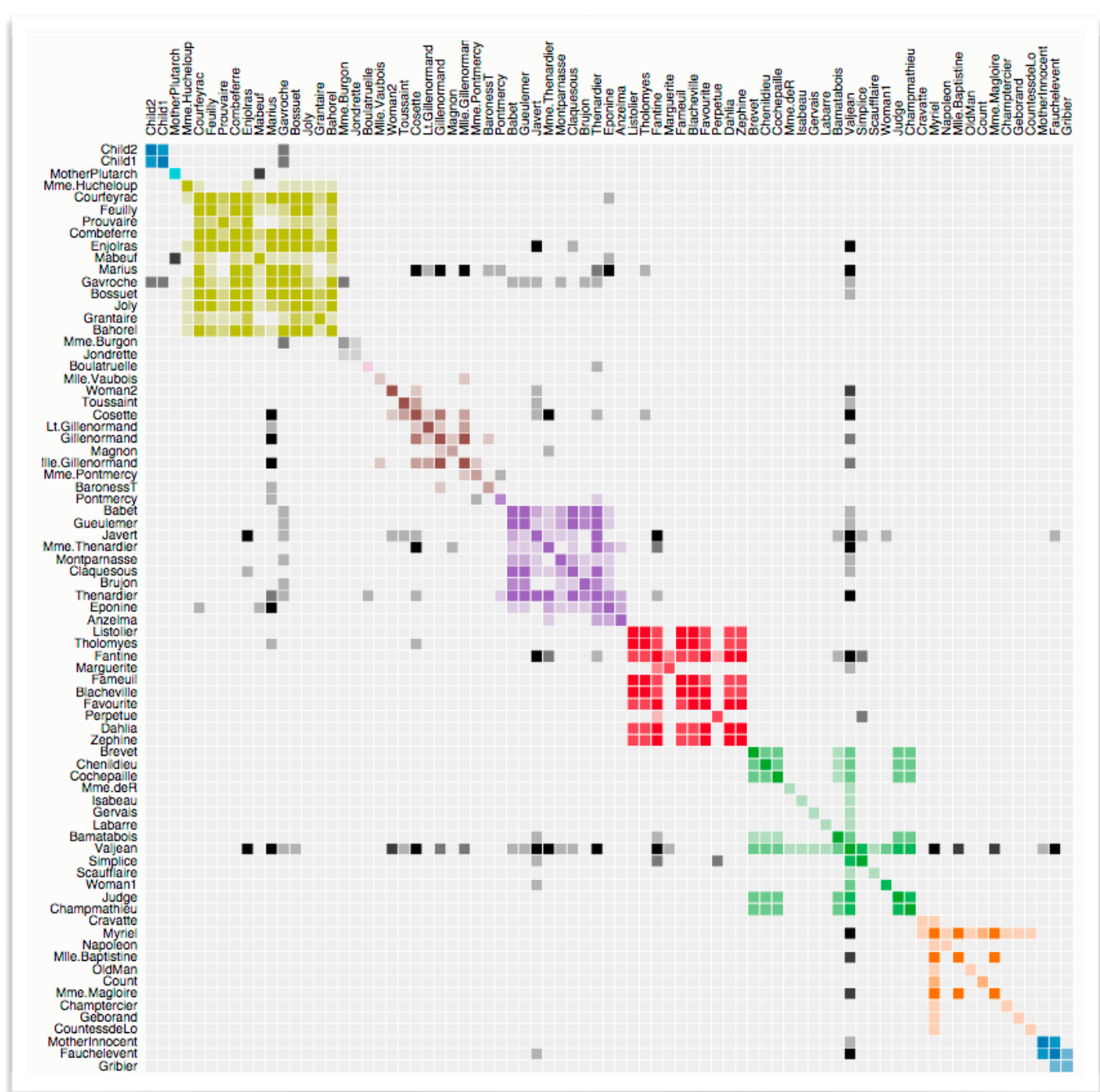
Adjacency Matrix
Derived Table

✓ NETWORKS

✓ TREES



Node order is crucial: Reordering

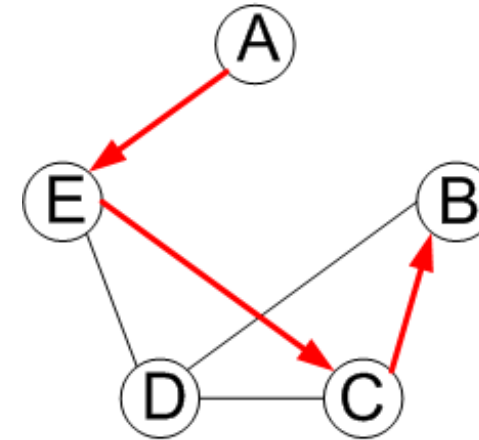


<https://bost.ocks.org/mike/miserables/>

Adjacency matrix

		TO							
		A	B	C	D	E	F	G	H
FROM	A								
	B								
	C								
	D								
	E								
	F								
	G								
	H								

good for topology tasks
related to neighborhoods
(node 1-hop neighbors)

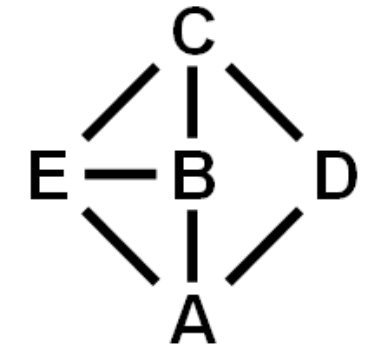
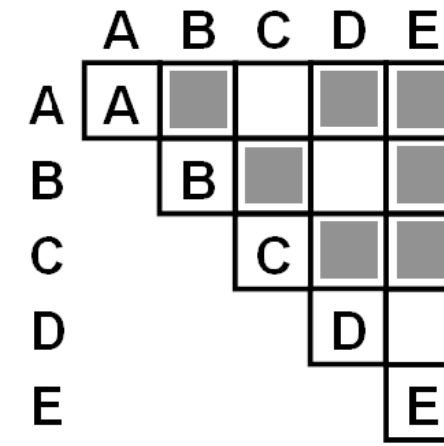


	A	B	C	D	E
E					
D					
C					
B					
A					

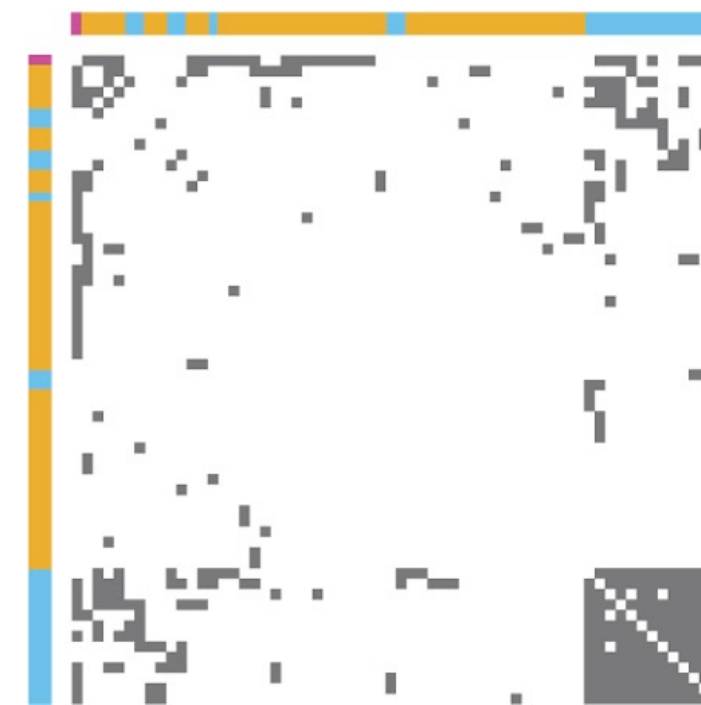
bad for topology tasks
related to paths

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



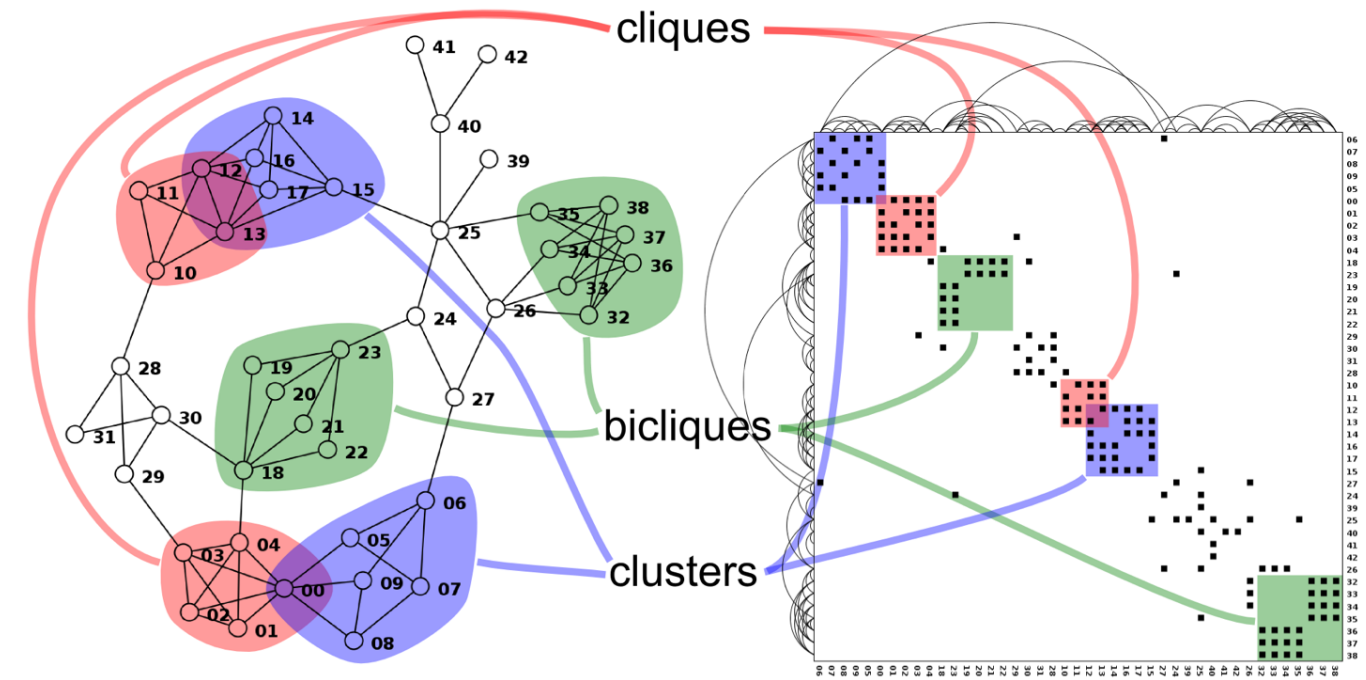
[NodeTrix: a Hybrid Visualization of Social Networks. Henry, Fekete, and McGuffin. IEEE TVCG (Proc. InfoVis) 13(6):1302-1309, 2007.]



[Points of view: Networks. Gehlenborg and Wong. 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!

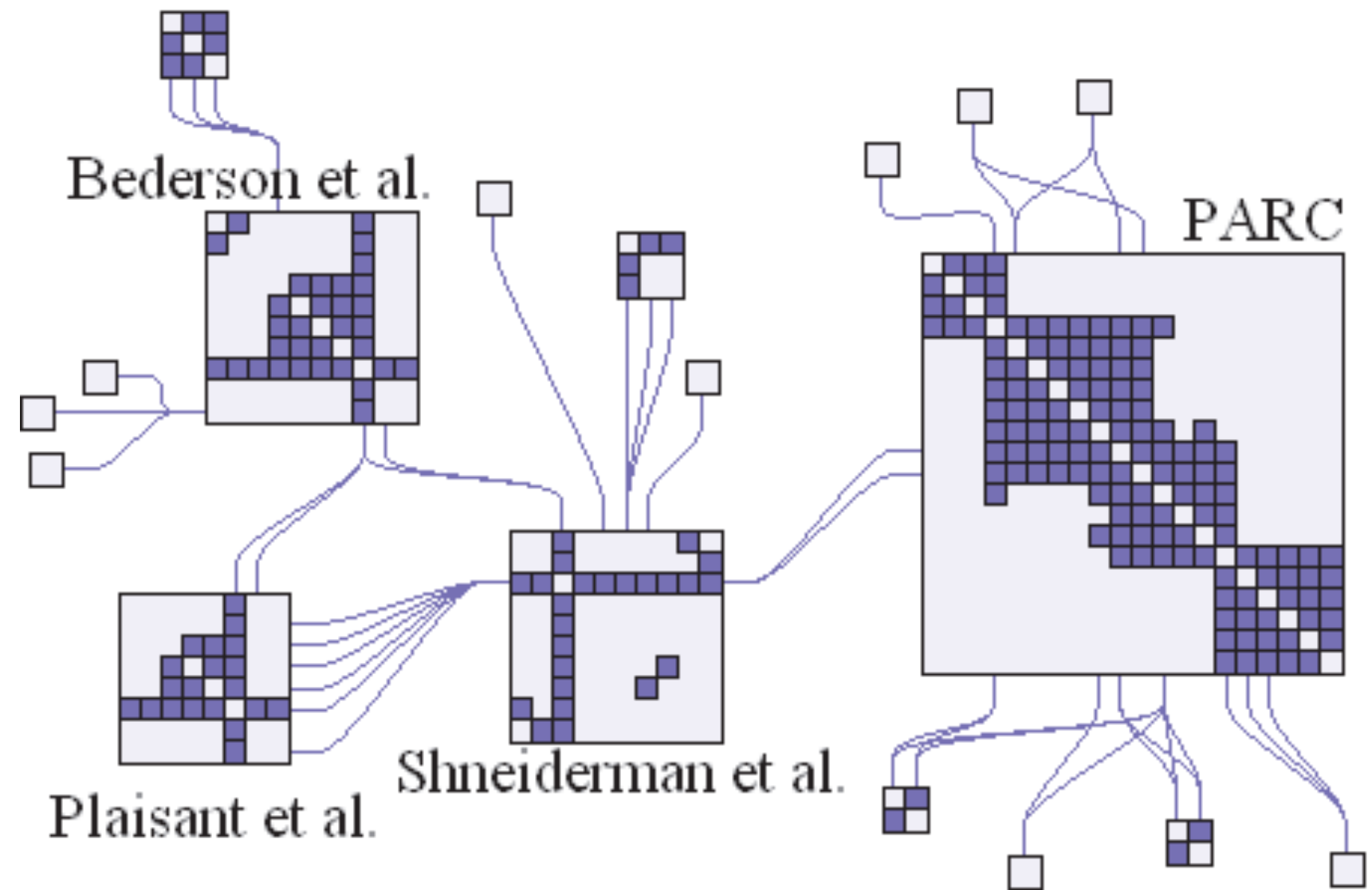


<https://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png>

[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: **NodeTrix**

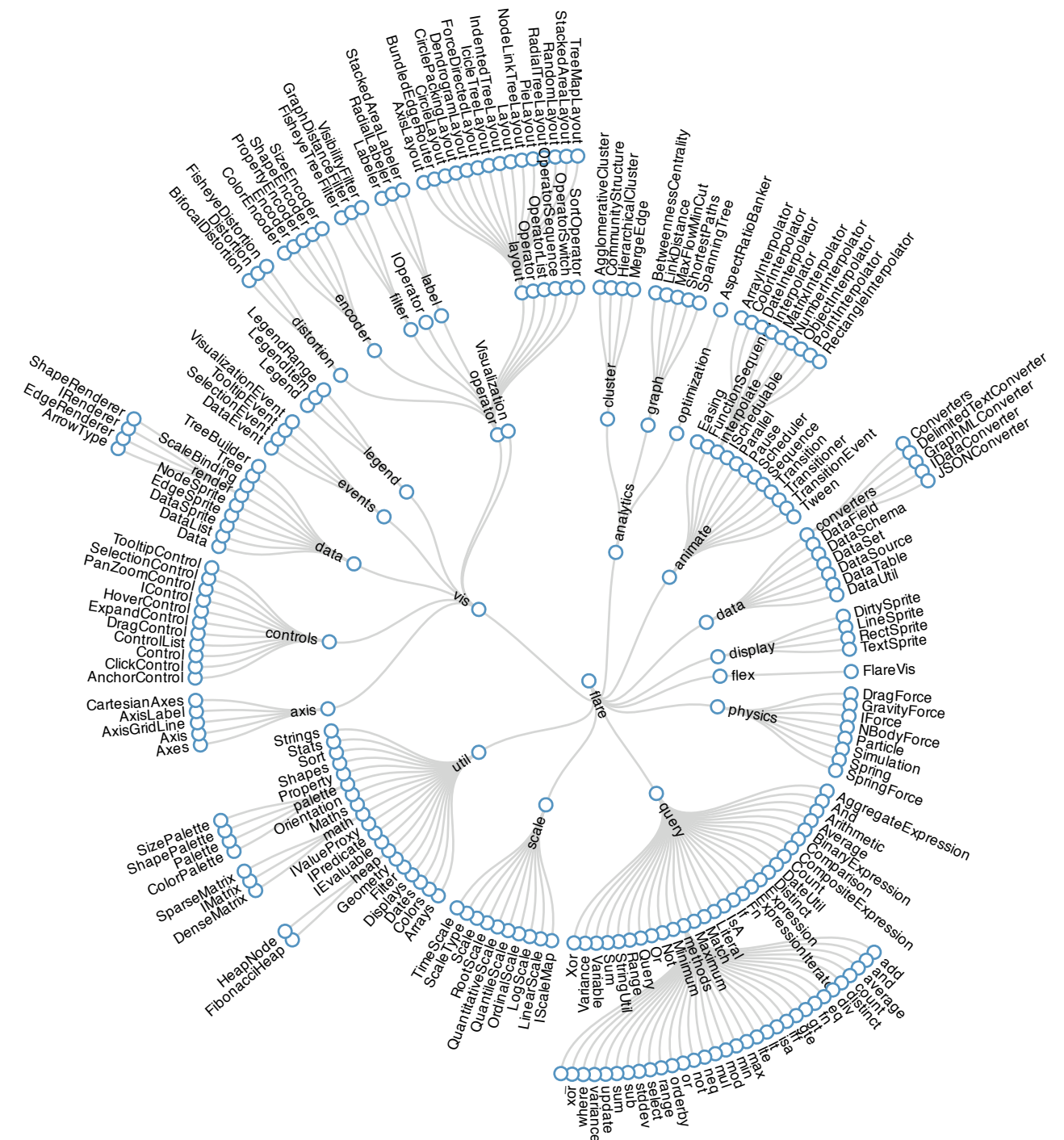
- hybrid nodelink/matrix
- capture strengths of both



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

Idiom: radial node-link tree

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

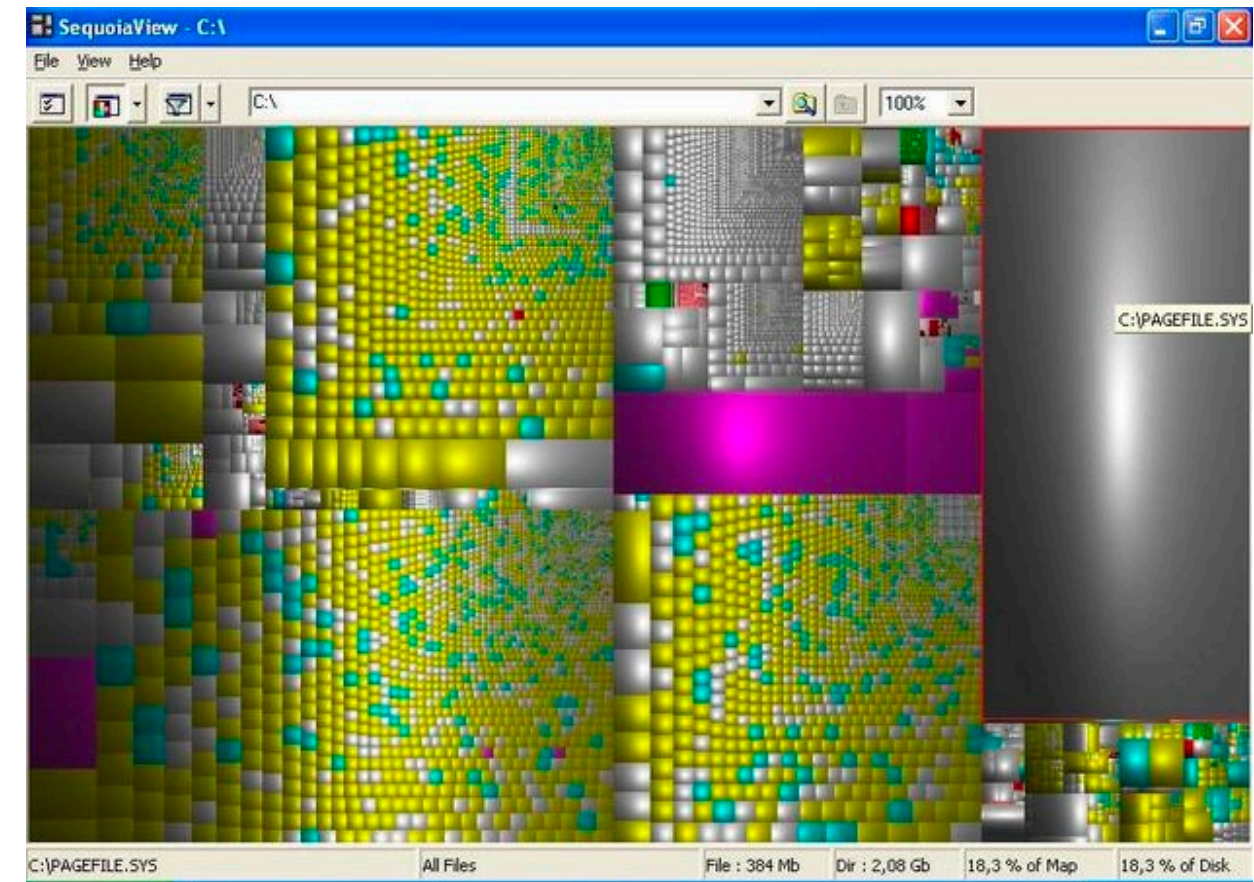
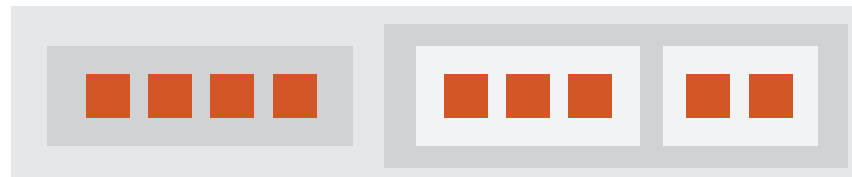


Idiom: **treemap**

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

➔ **Enclosure**
Containment Marks

✕ NETWORKS ✓ TREES



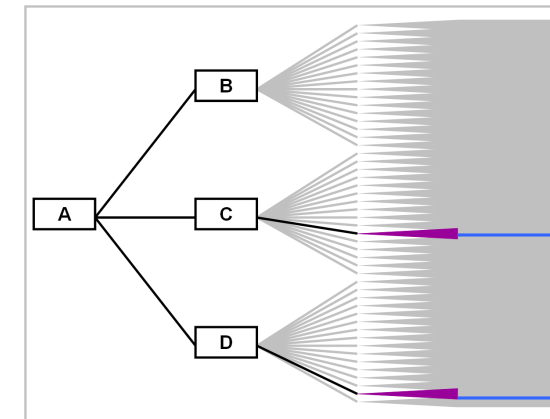
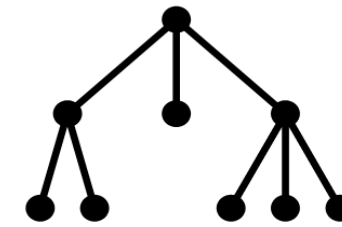
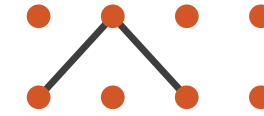
<https://www.win.tue.nl/sequoiaview/>

[Cushion Treemaps. van Wijk and van de Wetering.
Proc. Symp. InfoVis 1999, 73-78.]

Link marks: Connection and containment

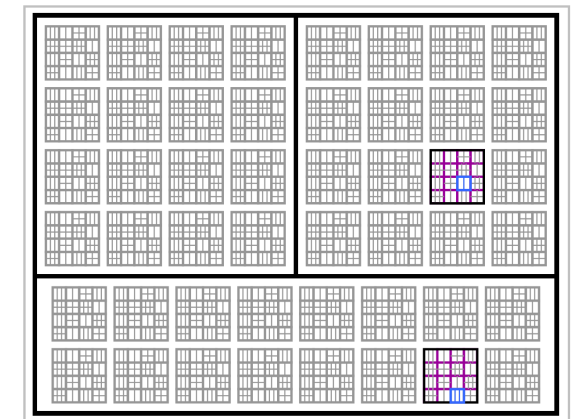
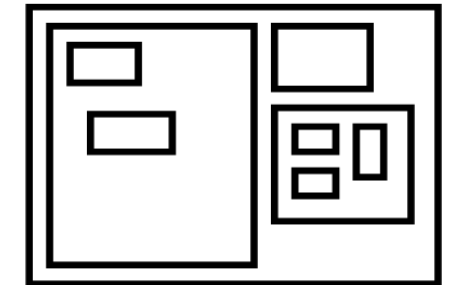
- marks as links (vs. nodes)
 - common case in network drawing
 - 1D case: connection
 - ex: all node-link diagrams
 - emphasizes topology, path tracing
 - networks and trees
 - 2D case: containment
 - ex: all treemap variants
 - emphasizes attribute values at leaves (size coding)
 - only trees

➞ Connection



Node-Link Diagram

➞ Containment



Treemap

Idiom: implicit tree layouts (sunburst, icicle plot)

- alternative to connection and containment: position
 - show parent-child relationships only through relative positions

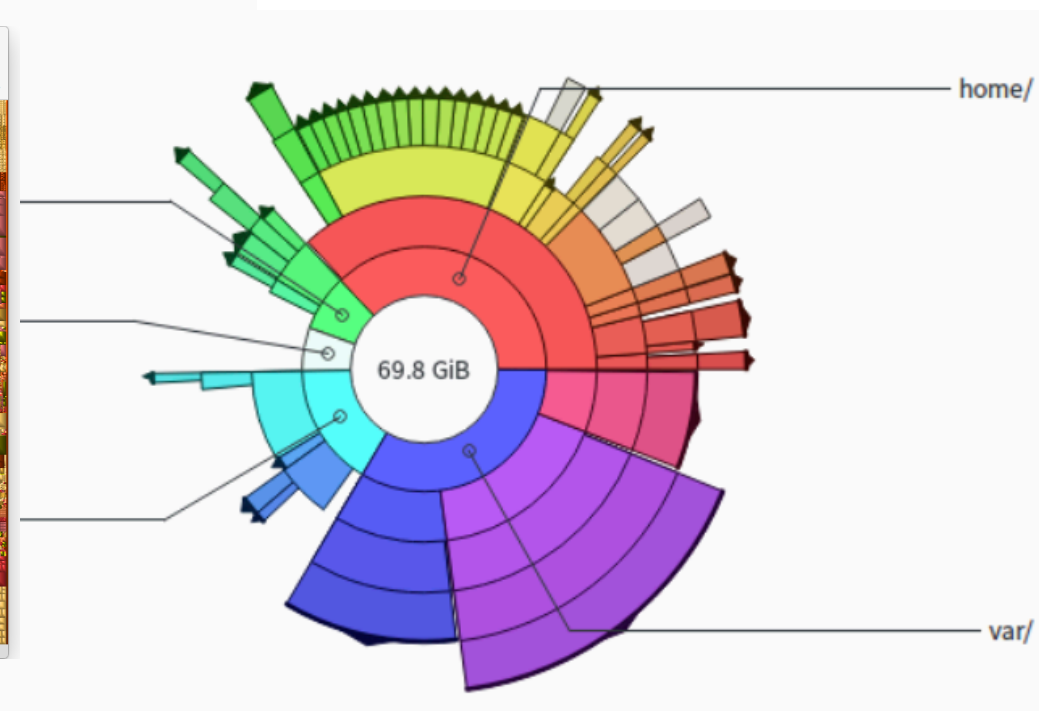
Treemap

containment
only leaves visible



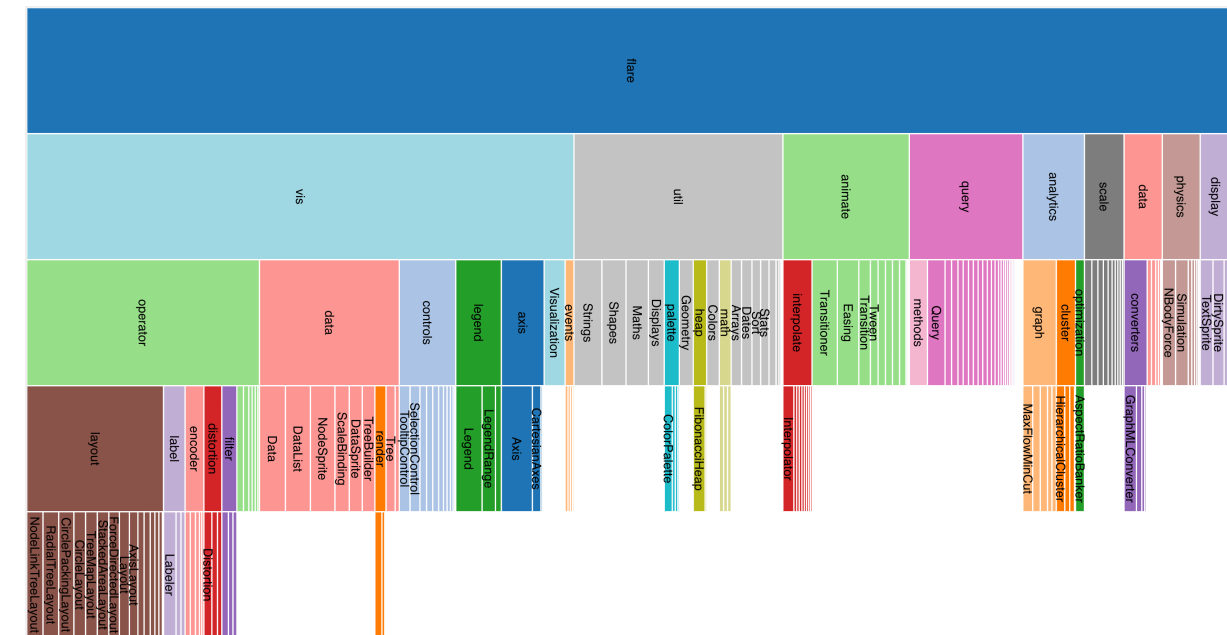
Sunburst

position (radial)
inner nodes & leaves visible



Icicle Plot

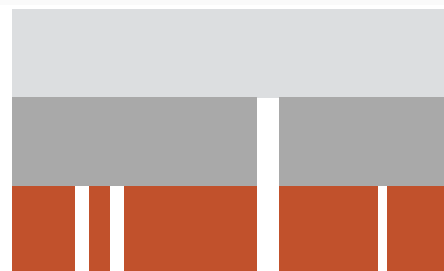
position (rectilinear)
inner nodes & leaves visible



Implicit
Spatial Position

✗ NETWORKS

✓ TREES



treevis.net: Many, many options!

How to cite this site?

Check out other surveys!

treevis.net - A Visual Bibliography of Tree Visualization 2.0 by Hans-Jörg Schulz

v.21-OCT-2014

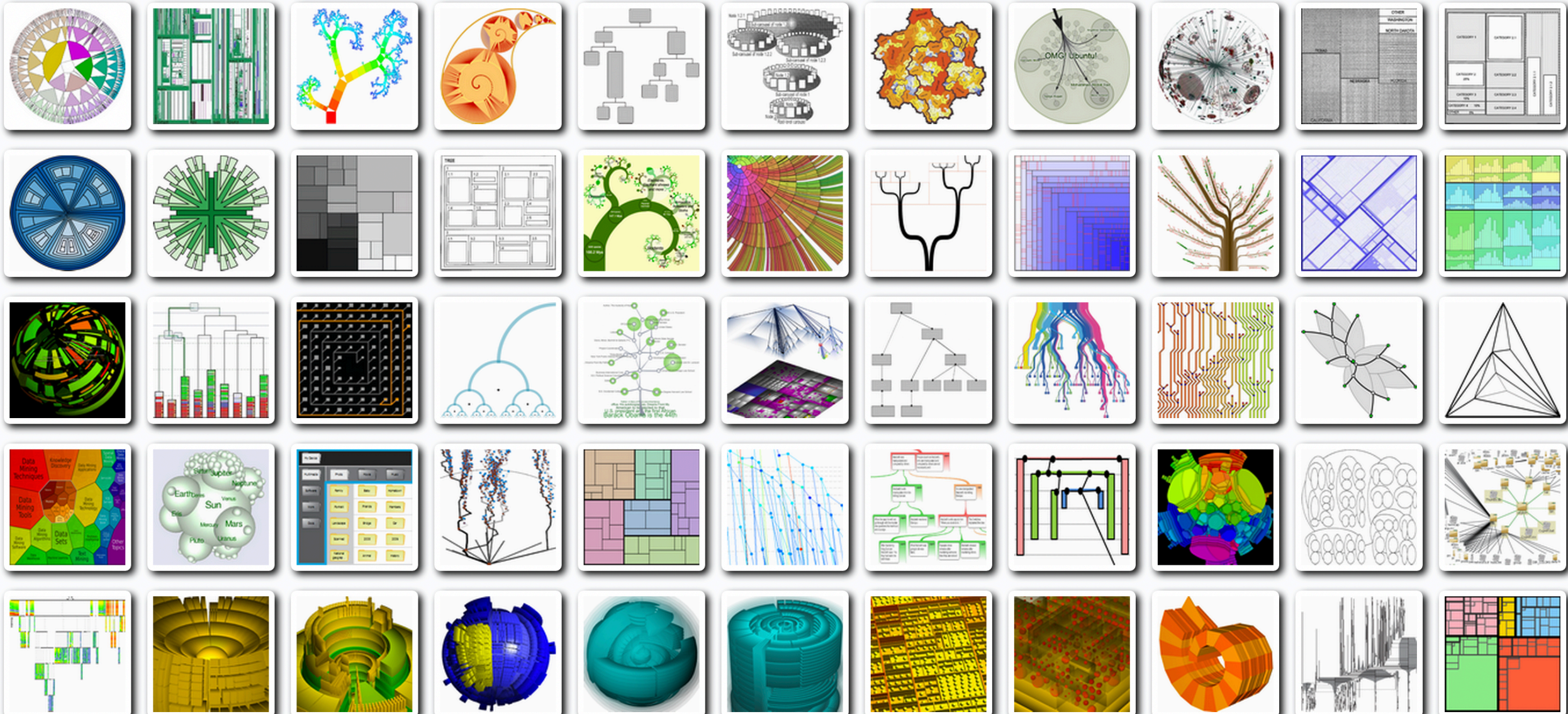
Dimensionality: All

Representation: All

Alignment: All

Fulltext Search: ×

Techniques Shown: 277



The grid displays a wide variety of tree visualization techniques. Some examples include: a circular tree with a color gradient, a tree with a sun-like head, a tree with a circuit-like structure, a tree with a 3D structure, a tree with a circular structure, a tree with a rectangular structure, a tree with a triangular structure, a tree with a square structure, a tree with a pentagonal structure, a tree with a hexagonal structure, a tree with a heptagonal structure, a tree with an octagonal structure, a tree with a nonagonal structure, a tree with a decagonal structure, a tree with an undecagonal structure, a tree with a dodecagonal structure, a tree with a trapezoidal structure, a tree with a parallelogram structure, a tree with a rhombus structure, a tree with a rectangle structure, a tree with a square structure, a tree with a circle structure, a tree with a triangle structure, a tree with a quadrilateral structure, a tree with a pentagon structure, a tree with a hexagon structure, a tree with a heptagon structure, a tree with an octagon structure, a tree with a nonagon structure, a tree with a decagon structure, a tree with an undecagon structure, a tree with a dodecagon structure, a tree with a trapezoid structure, a tree with a parallelogram structure, a tree with a rhombus structure, a tree with a rectangle structure, a tree with a square structure, a tree with a circle structure, a tree with a triangle structure, a tree with a quadrilateral structure, a tree with a pentagon structure, a tree with a hexagon structure, a tree with a heptagon structure, a tree with an octagon structure, a tree with a nonagon structure, a tree with a decagon structure, a tree with an undecagon structure, a tree with a dodecagon structure.

<https://treevis.net/>

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.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch9networks>

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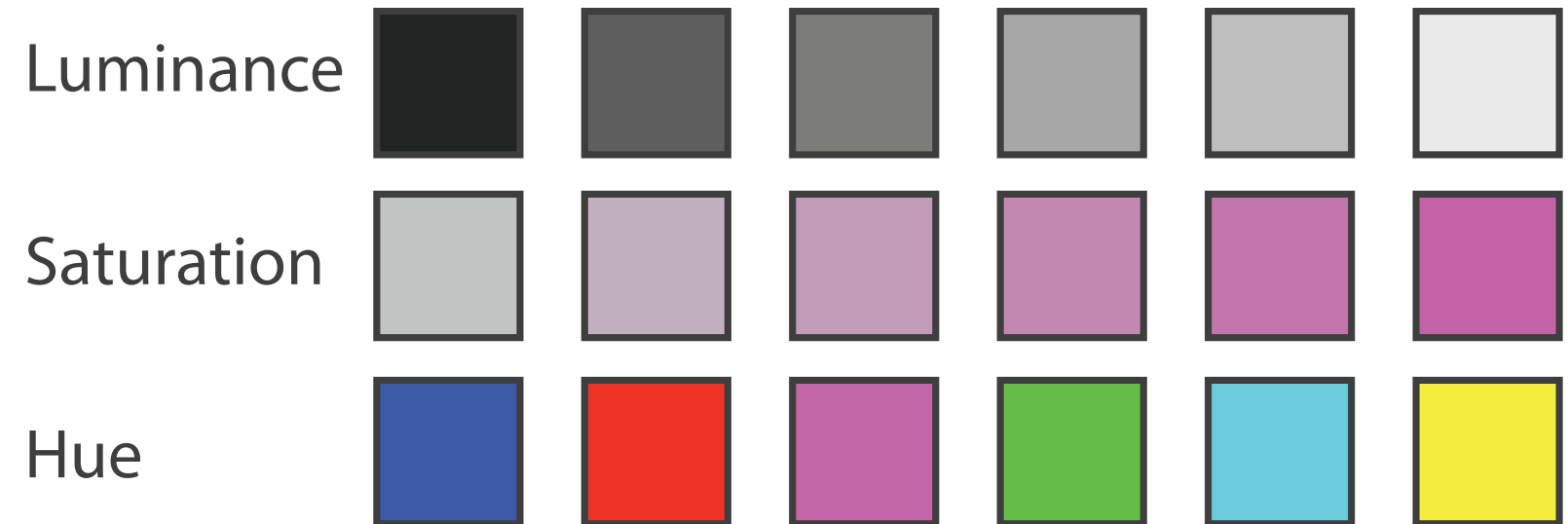
www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

Decomposing color

- first rule of color: do not talk about color!
 - color is confusing if treated as monolithic

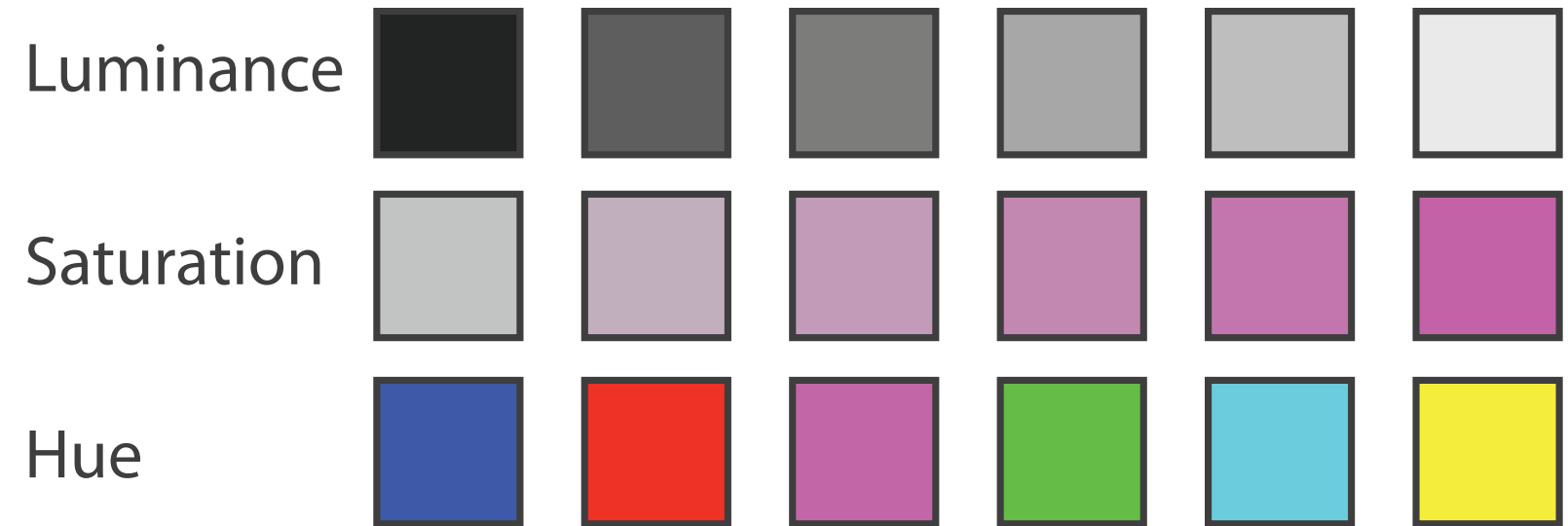
Decomposing color

- first rule of color: do not talk about color!
 - color is confusing if treated as monolithic
- decompose into three channels



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



Decomposing color

- first rule of color: do not talk about color!
 - color is confusing if treated as monolithic

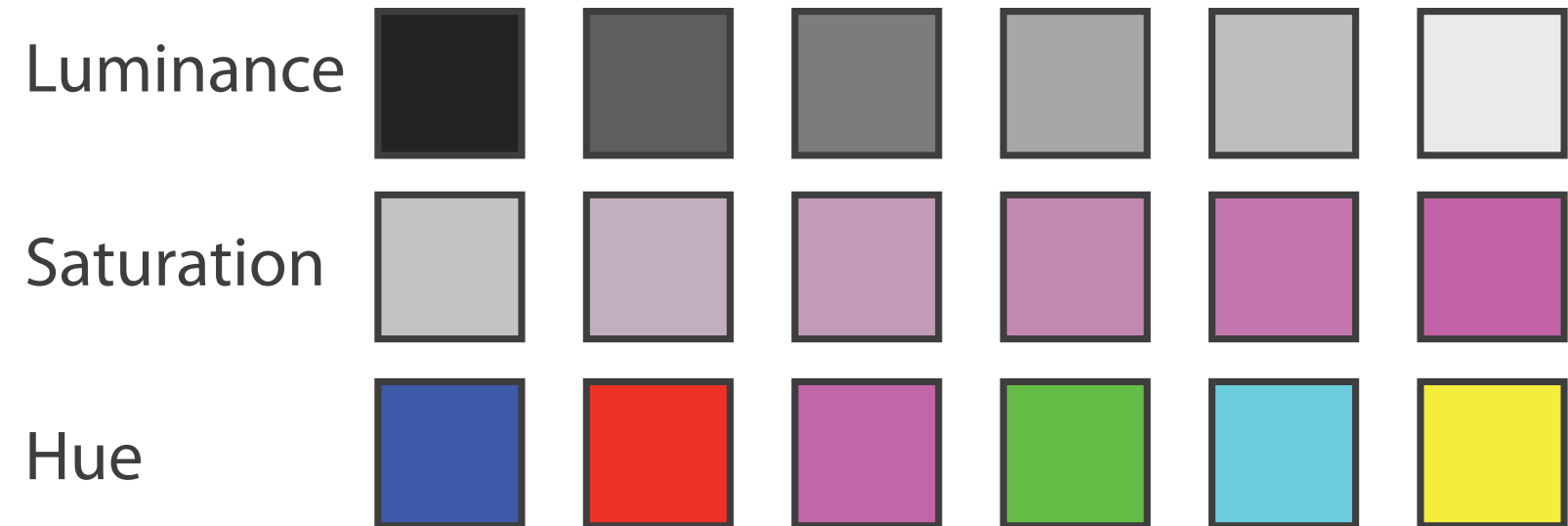
- decompose into three channels

- ordered can show magnitude

- luminance
 - saturation

- categorical can show identity

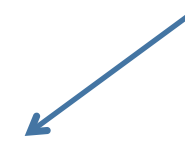
- hue



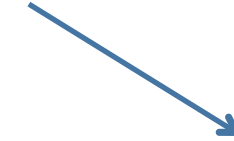
- perceptual colorspace, in contrast to three channels of RGB

Luminance

- need luminance for edge detection
 - fine-grained detail only visible through luminance contrast
 - legible text requires luminance contrast!



Luminance information



Color information



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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 $\neq$ L^* luminance

Corners of the RGB color cube

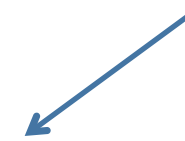


L from HLS

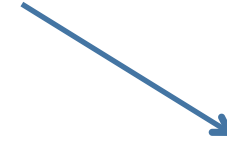
All the same



Luminance values



Luminance information



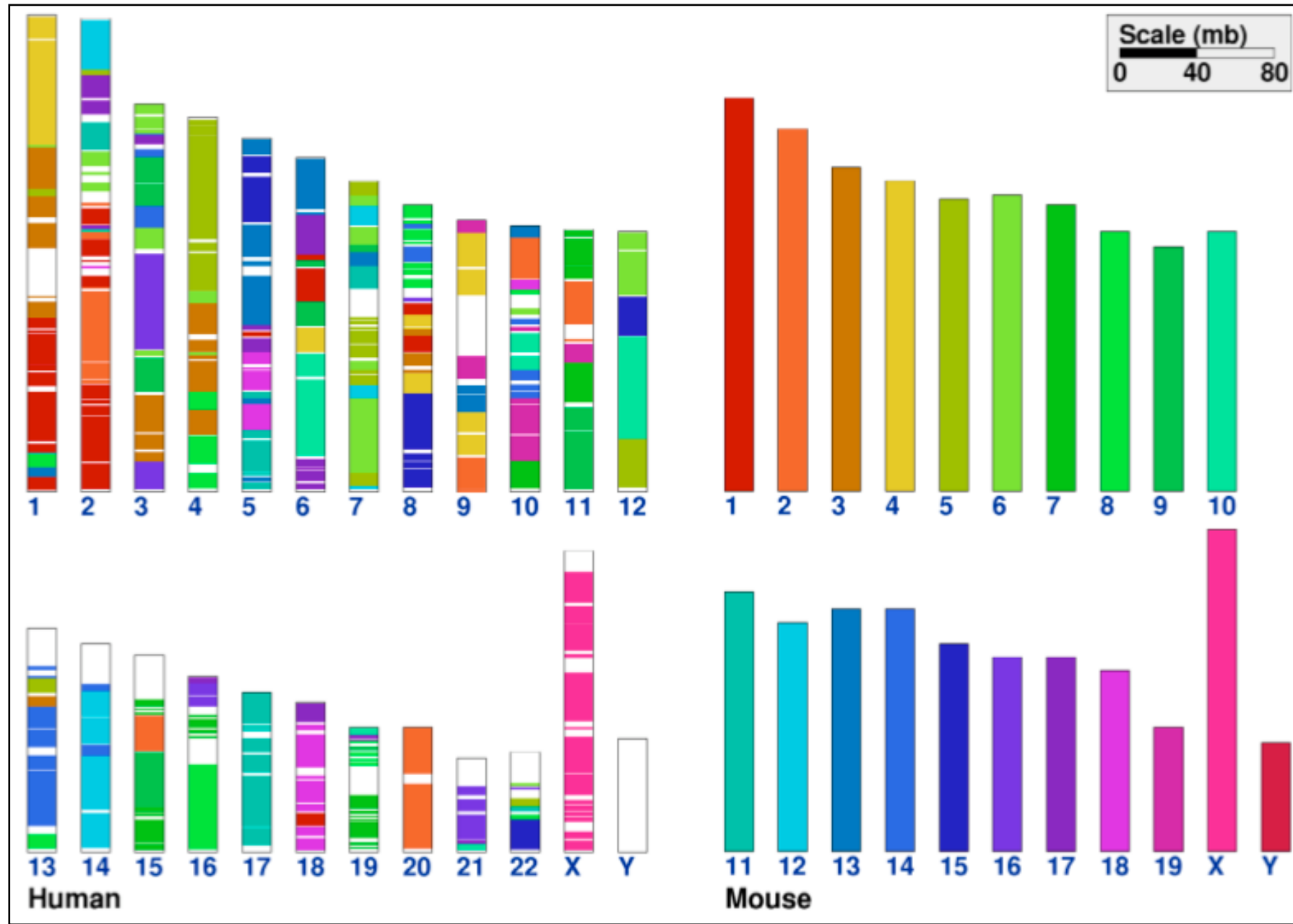
Color information



[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Categorical color: Discriminability constraints

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



[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

Ordered color: Rainbow is poor default

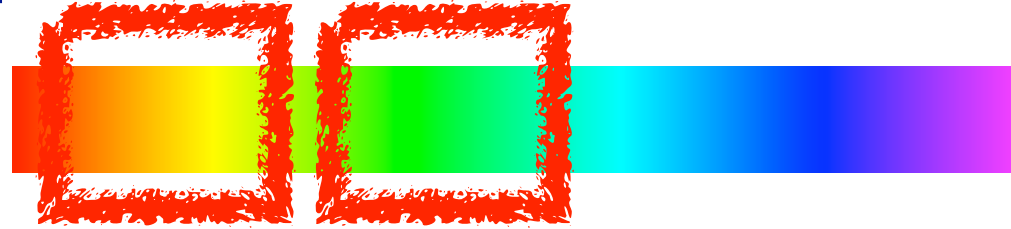
- problems

- perceptually unordered
- perceptually nonlinear



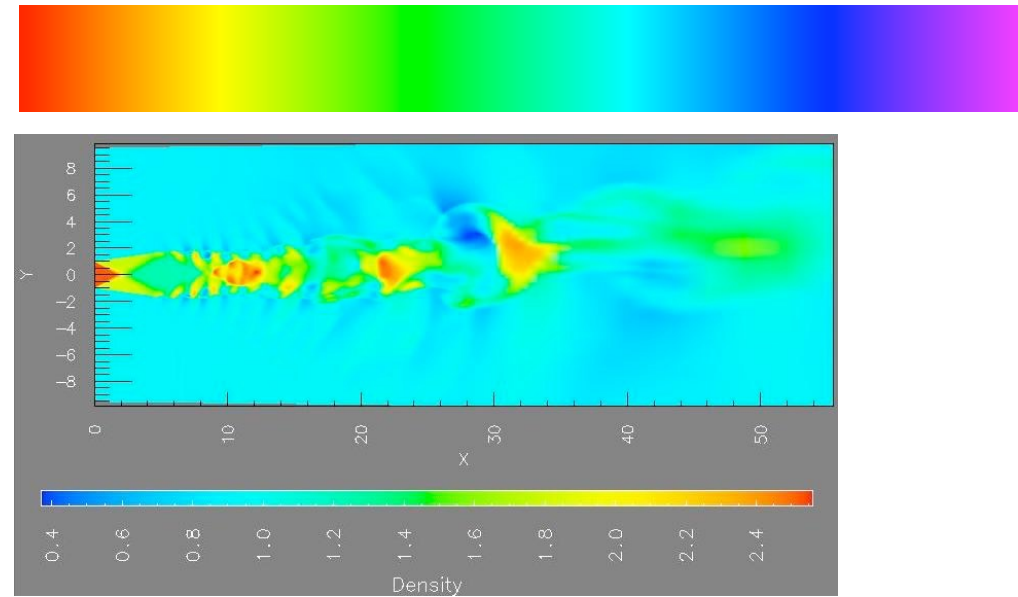
Ordered color: Rainbow is poor default

- problems
 - perceptually unordered
 - perceptually nonlinear

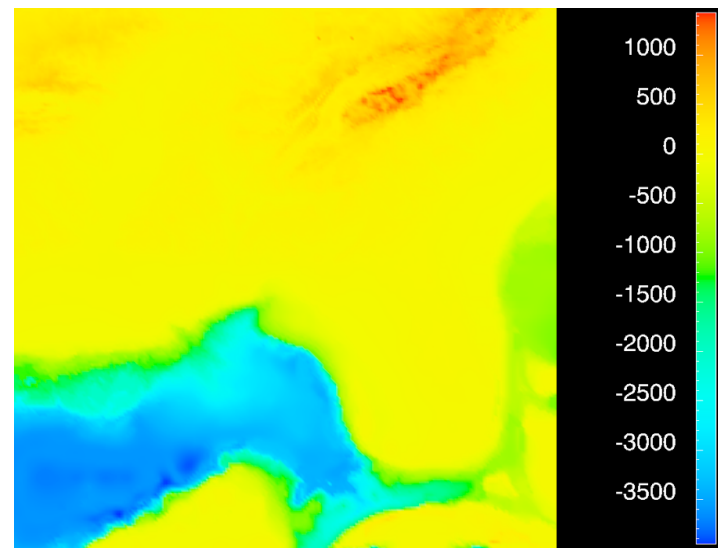


Ordered color: Rainbow is poor default

- problems
 - perceptually unordered
 - perceptually nonlinear
- benefits
 - fine-grained structure visible and nameable



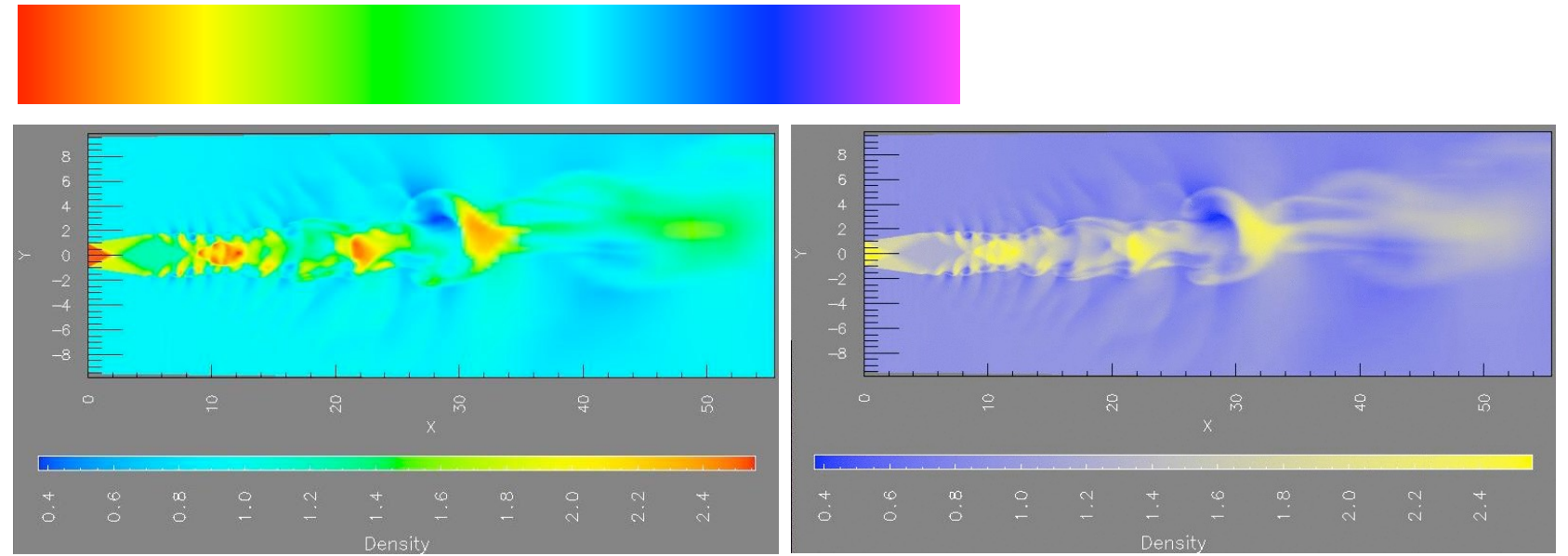
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. *Proc. IEEE Visualization (Vis)*, pp. 118–125, 1995.]



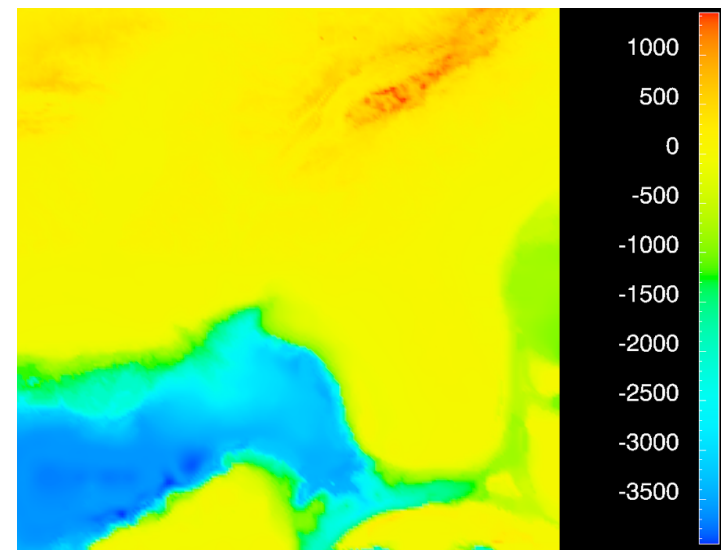
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. <http://www.research.ibm.com/people/lloyd/color/color.HTM>]

Ordered color: Rainbow is poor default

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



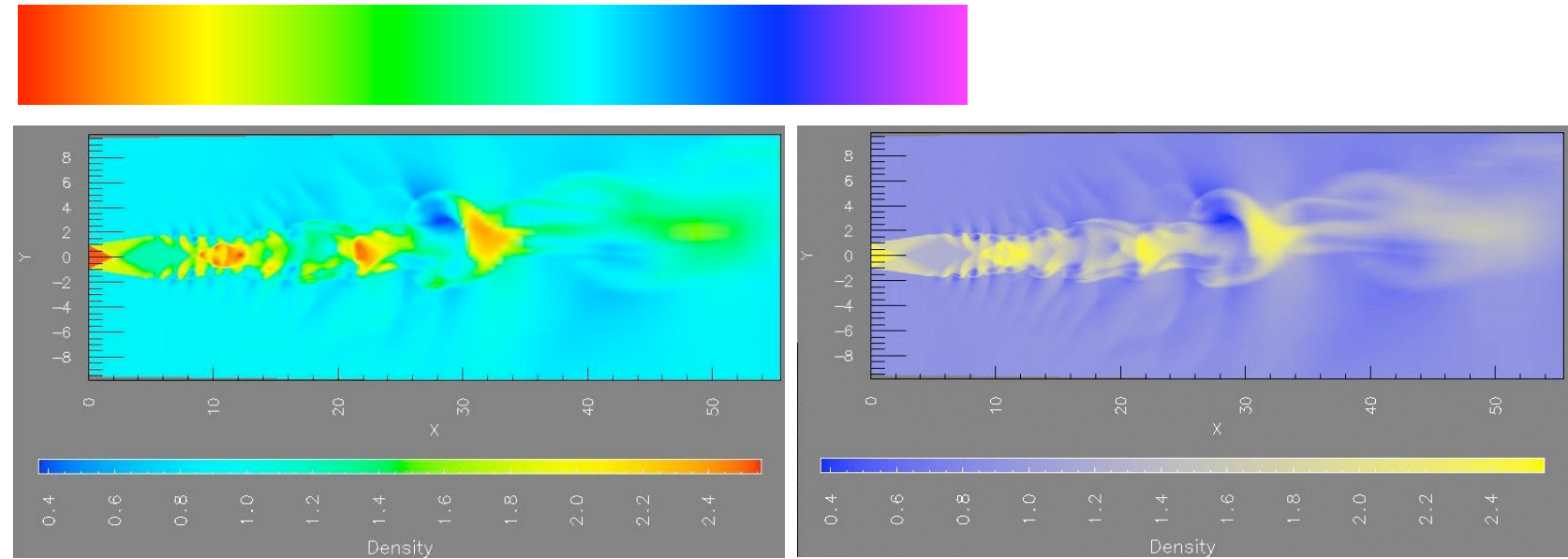
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. *Proc. IEEE Visualization (Vis)*, pp. 118–125, 1995.]



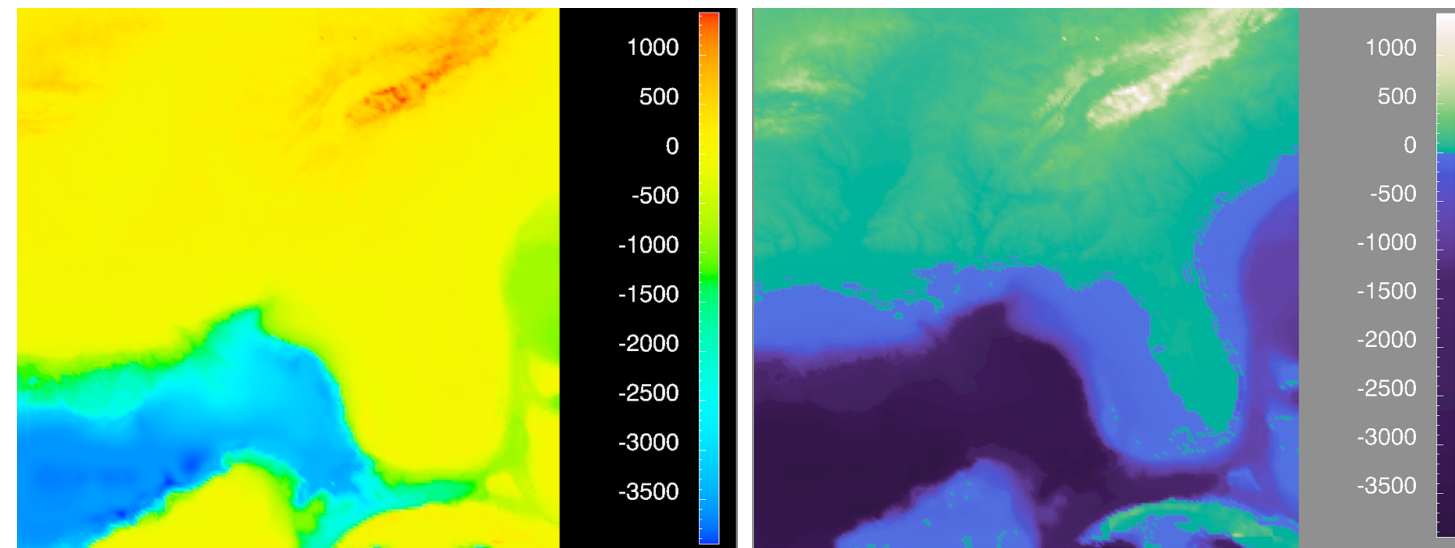
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. <http://www.research.ibm.com/people/lloyd/color/color.HTM>]

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]



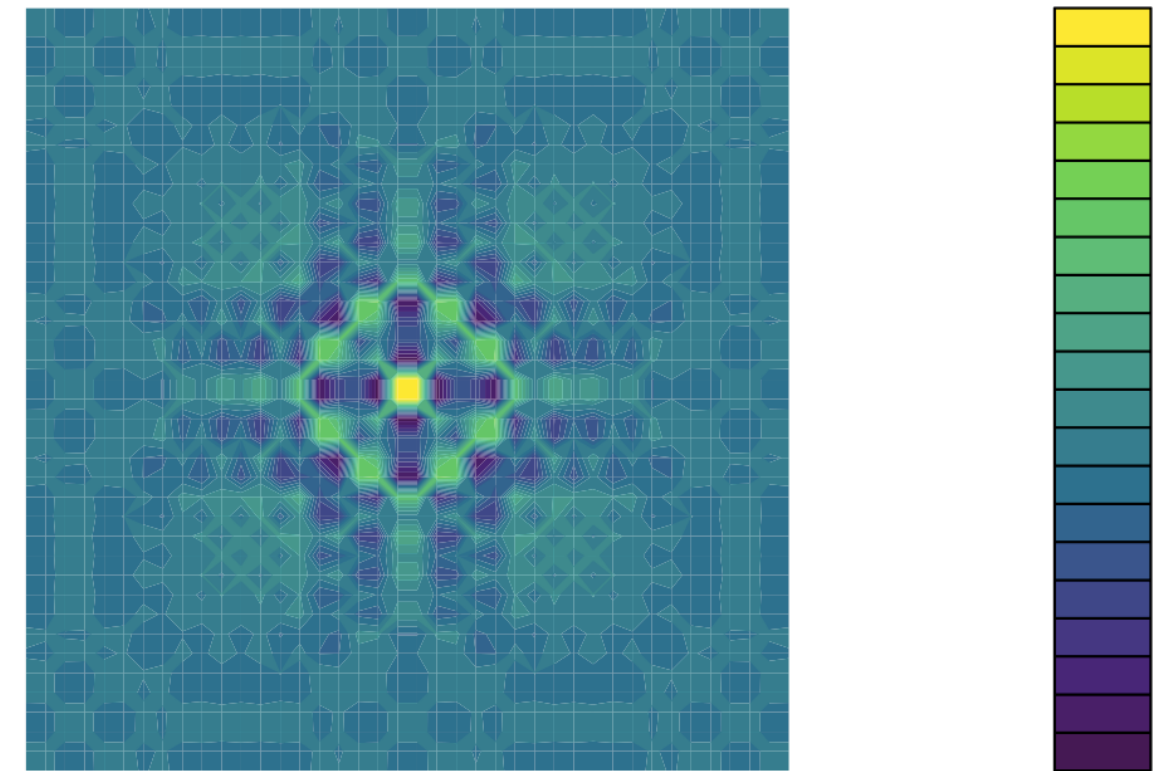
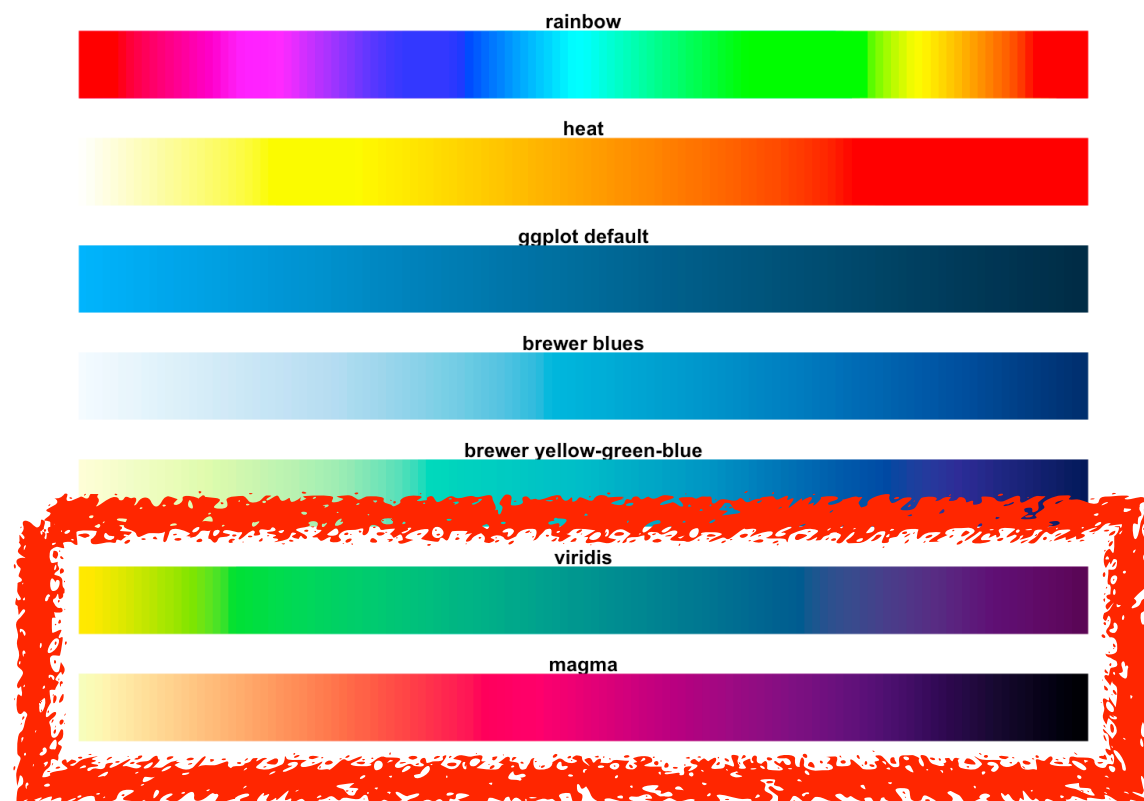
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. *Proc. IEEE Visualization (Vis)*, pp. 118–125, 1995.]



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. <http://www.research.ibm.com/people/lloyd/color/color.HTM>]

Viridis / Magma

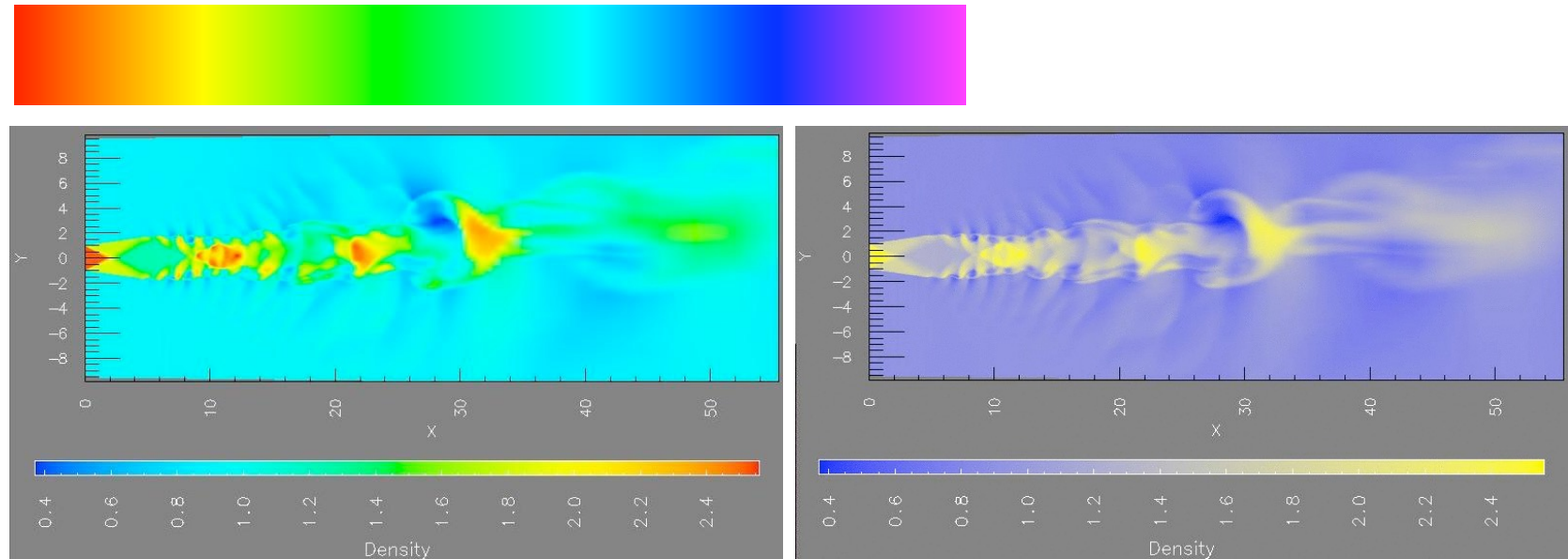
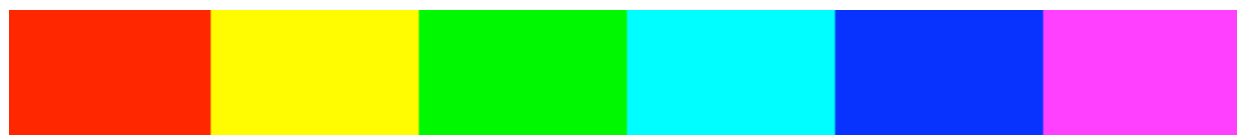
- monotonically increasing luminance, perceptually uniform
- colorful, colourblind-safe
 - R, python, D3



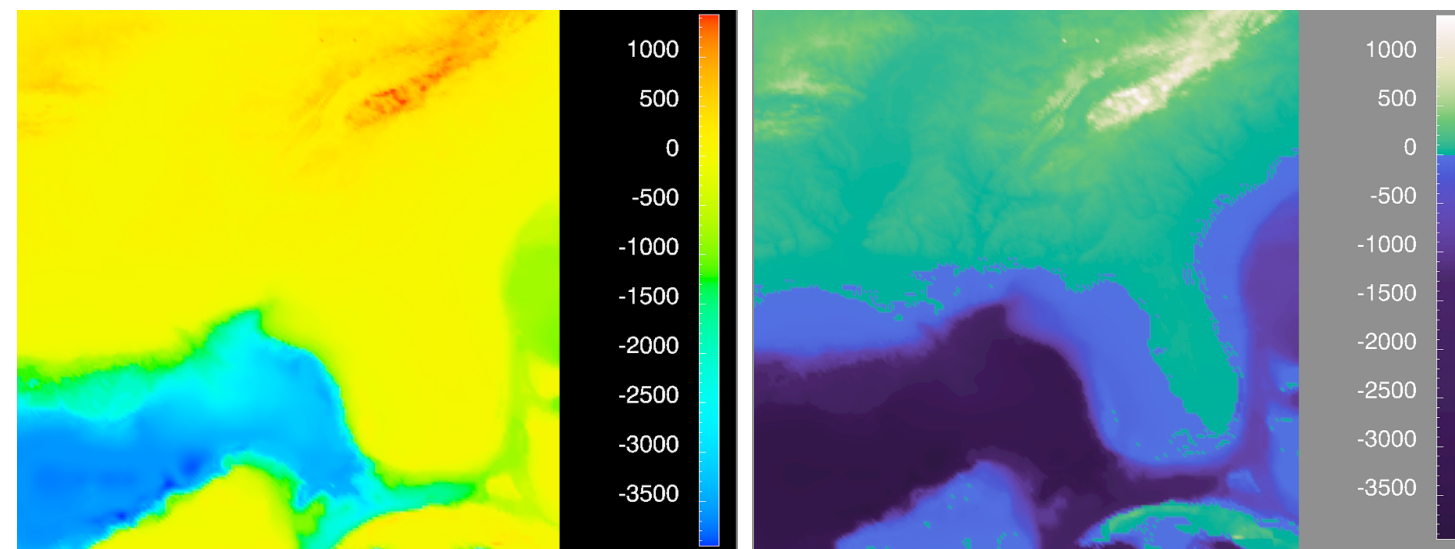
<https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html>

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!



[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. *Proc. IEEE Visualization (Vis)*, pp. 118–125, 1995.]



[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998.]

[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. *SIGGRAPH 2002 Course Notes*]

but...

Rainbow Colormaps Are Not All Bad.

Ware, Stone, & Szafir. *IEEE CG&A* 43(3):88-93, 2023

Colormaps

→ Categorical



→ Ordered

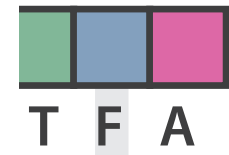
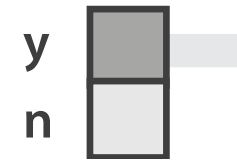
→ *Sequential*



→ *Diverging*

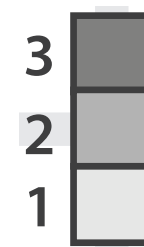
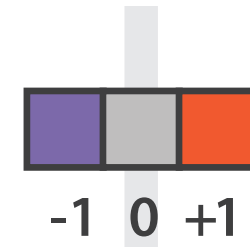


Binary



Categorical

Diverging



Sequential

after [Color Use Guidelines for Mapping
and Visualization. Brewer, 1994. [http://
www.personal.psu.edu/faculty/c/a/cab38/
ColorSch/Schemes.html](http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html)]

Colormaps

→ Categorical



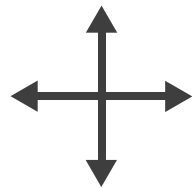
→ Ordered

→ *Sequential*

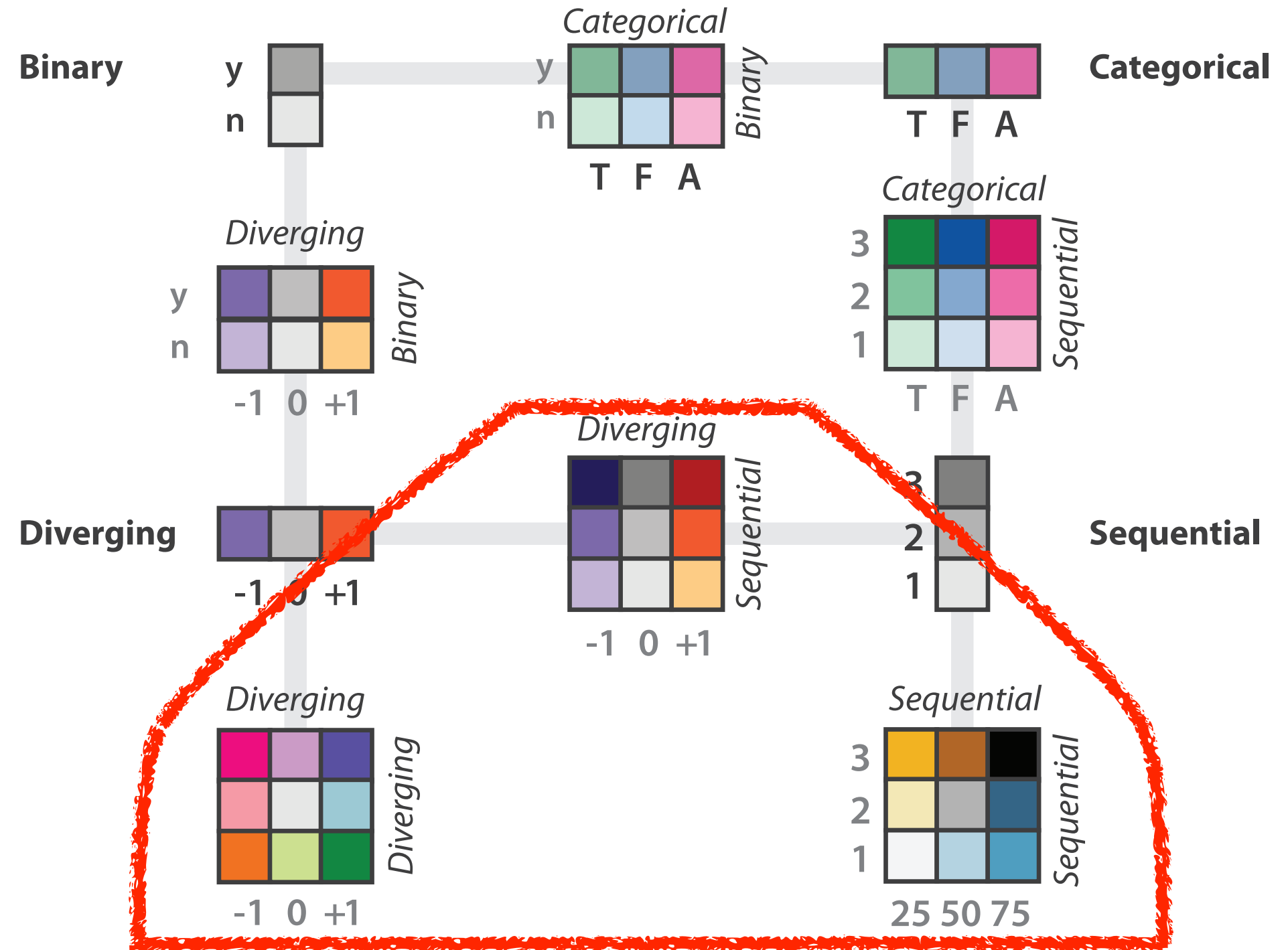
→ *Diverging*



→ Bivariate



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



after [Color Use Guidelines for Mapping
and Visualization. Brewer, 1994. [http://
www.personal.psu.edu/faculty/c/a/cab38/
ColorSch/Schemes.html](http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html)]

Colormaps

→ Categorical



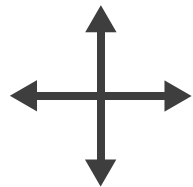
→ Ordered

→ *Sequential*

→ *Diverging*



→ Bivariate



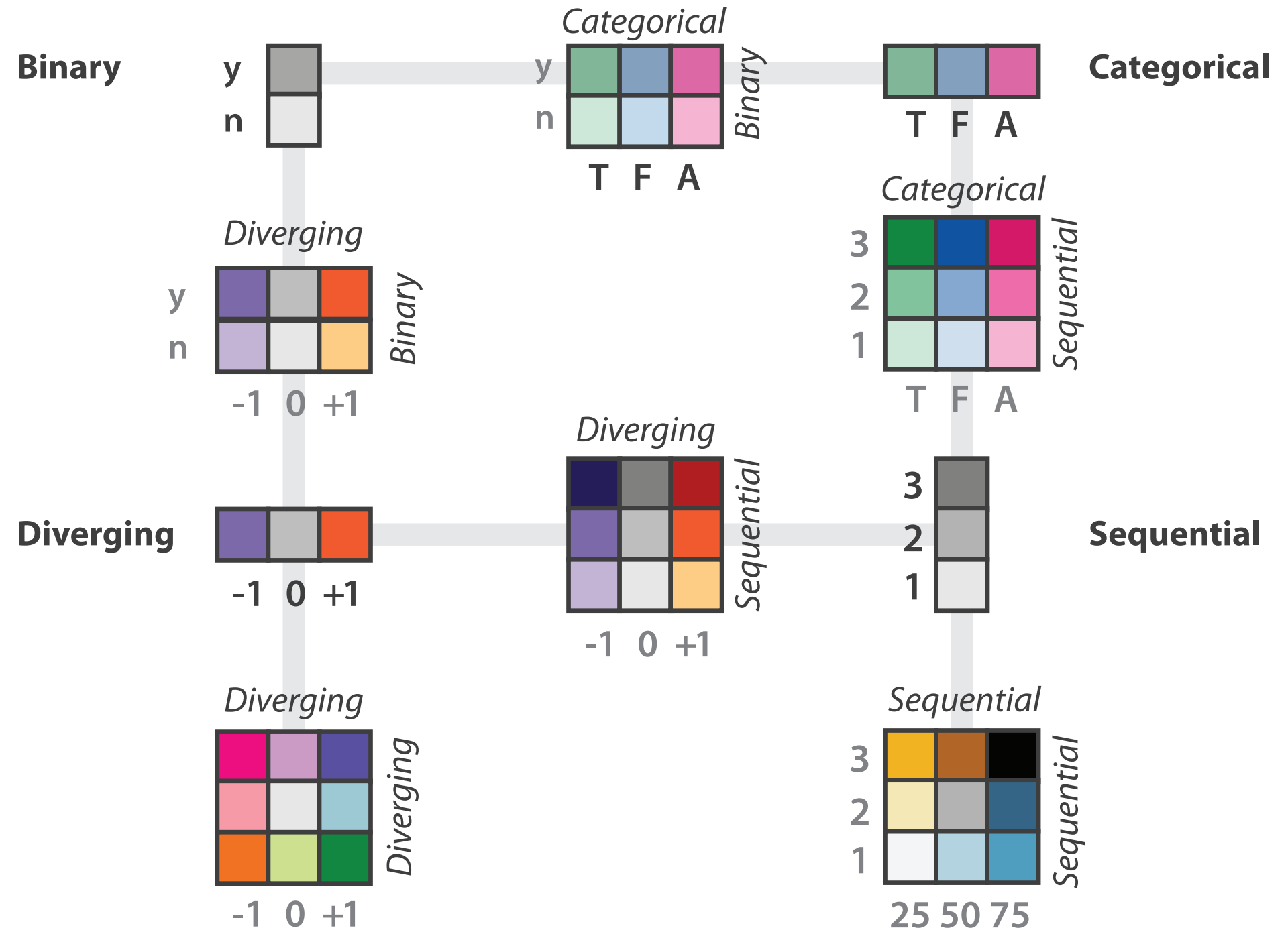
- color channel interactions

- size heavily affects salience

- small regions need high saturation
- large need low saturation

- saturation & luminance: 3-4 bins max

- also not separable from transparency



after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. <http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html>]

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/>
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch10color>

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

@tamara@cosocial.ca

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

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How?

Encode

➔ Arrange

➔ Express



➔ Separate



➔ Order



➔ Align



➔ Use



➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue



➔ Saturation



➔ Luminance



➔ Size, Angle, Curvature, ...



➔ Shape



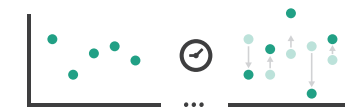
➔ Motion

Direction, Rate, Frequency, ...

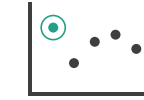


Manipulate

➔ Change



➔ Select



➔ Navigate



Facet

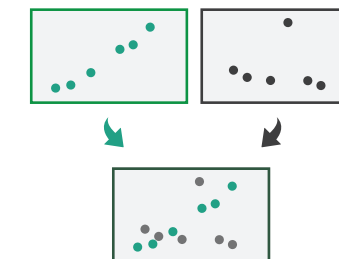
➔ Juxtapose



➔ Partition



➔ Superimpose



Reduce

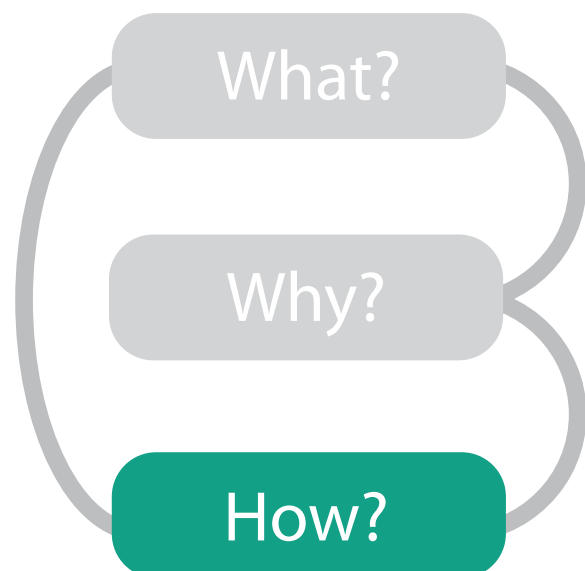
➔ Filter



➔ Aggregate



➔ Embed



How?

Encode

→ Arrange

→ Express



→ Separate



→ Order



→ Align



→ Use



→ Map

from **categorical** and **ordered** attributes

→ Color

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→ Size, Angle, Curvature, ...



→ Shape



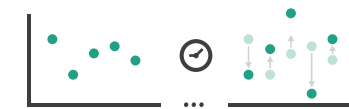
→ Motion

Direction, Rate, Frequency, ...

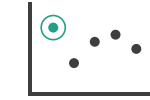


Manipulate

→ Change



→ Select



→ Navigate

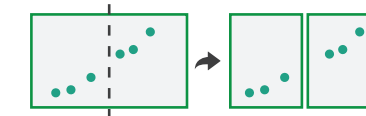


Facet

→ Juxtapose



→ Partition



→ Superimpose



Reduce

→ Filter



→ Aggregate



→ Embed



What?

Why?

How?

How to handle complexity: 2 more strategies

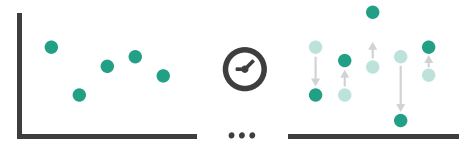
→ *Derive*



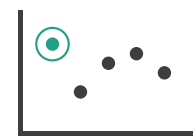
- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view

Manipulate

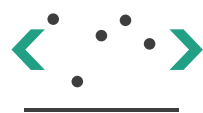
② Change



② Select

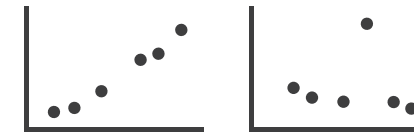


② Navigate

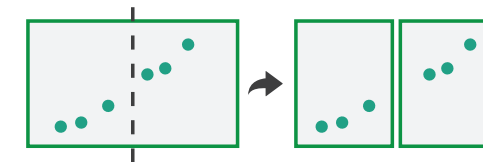


Facet

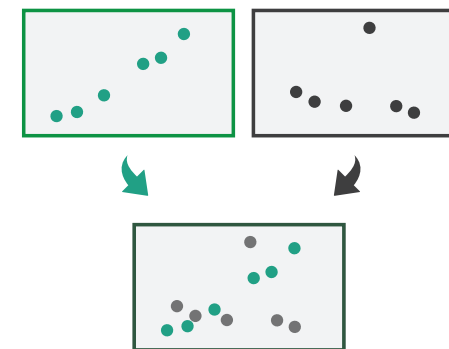
② Juxtapose



② Partition



② Superimpose

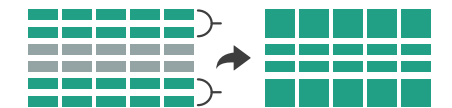


Reduce

② Filter



② Aggregate

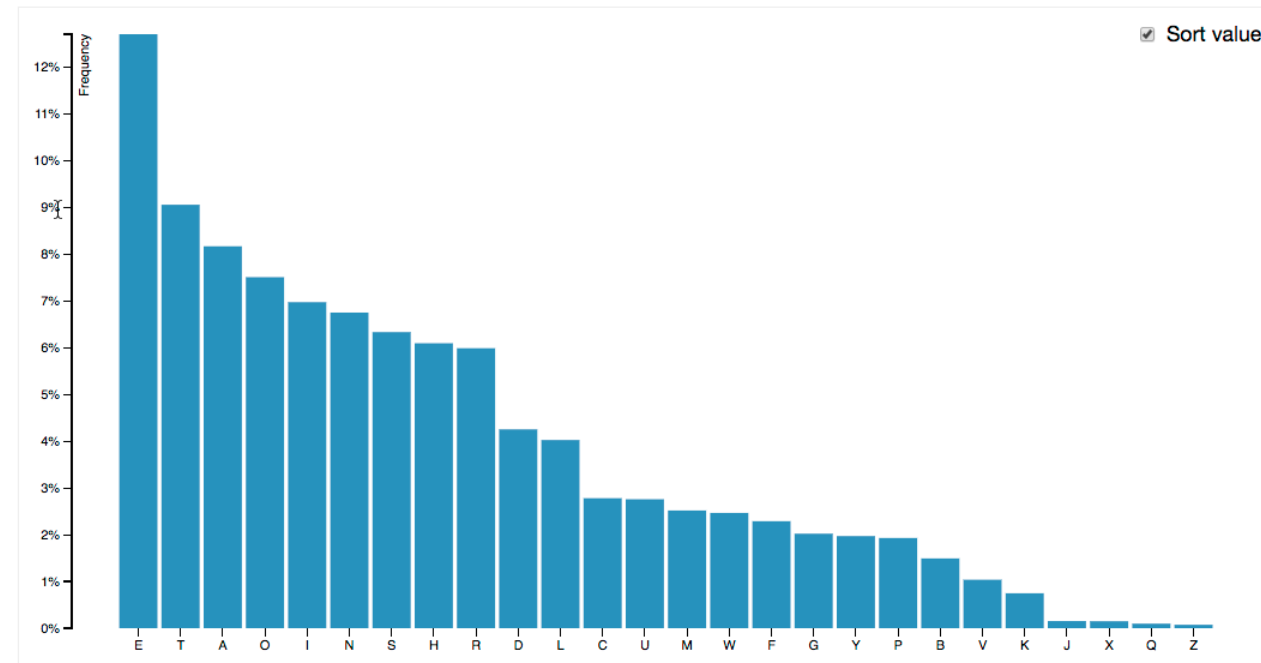
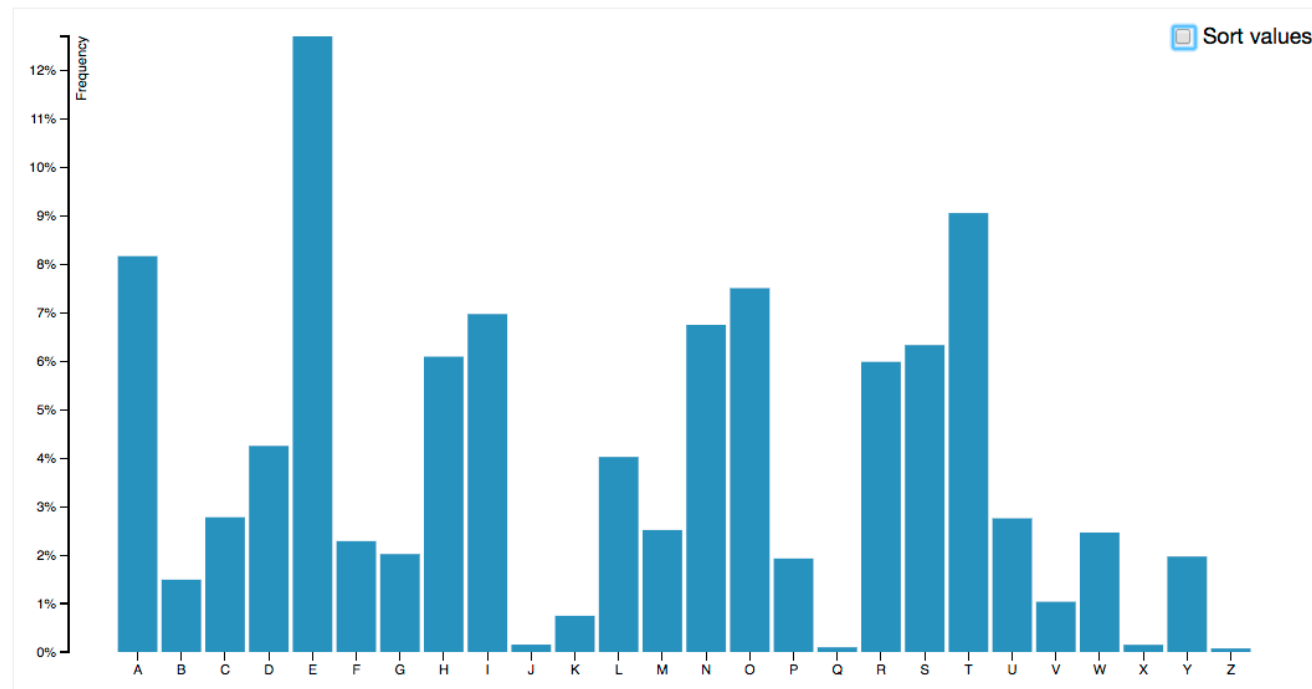


② Embed



Idiom: **Change order/arrangement**

- what: simple table
- how: data-driven reordering
- why: find extreme values, trends

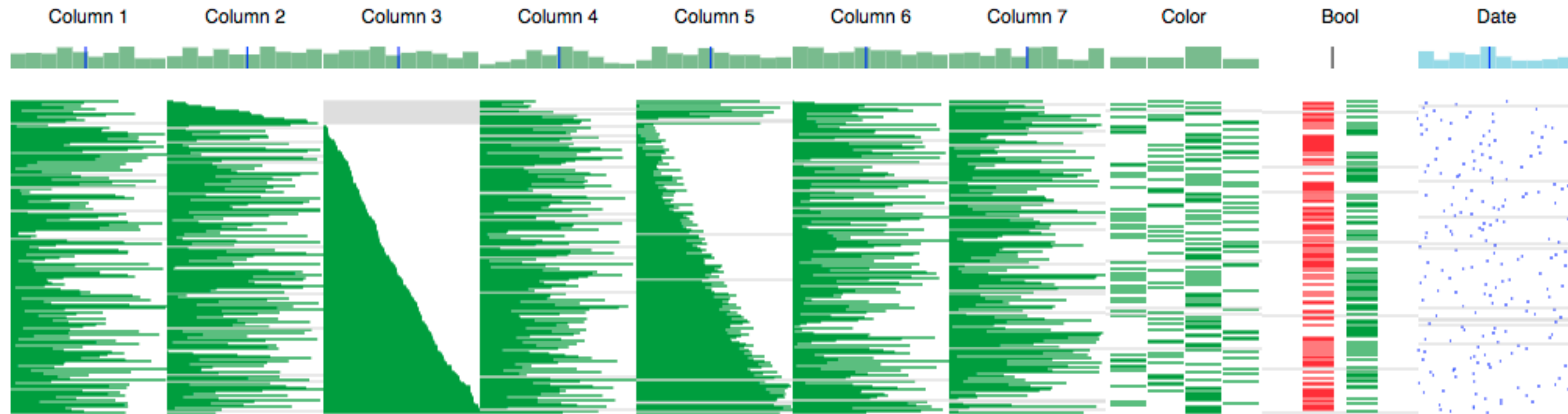


[Sortable Bar Chart](<https://blocks.roadtolarissa.com/mbostock/3885705>)

Idiom: **Change order**

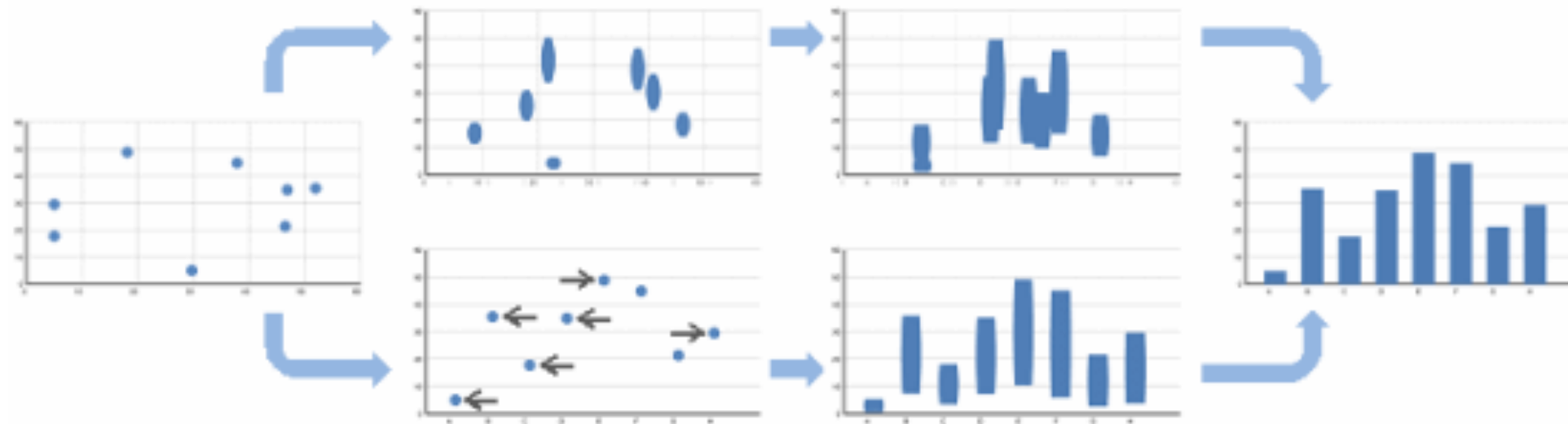
System: **DataStripes**

- what: table with many attributes
- how: data-driven reordering by selecting column
- why: find correlations between attributes



Idiom: **Animated transitions**

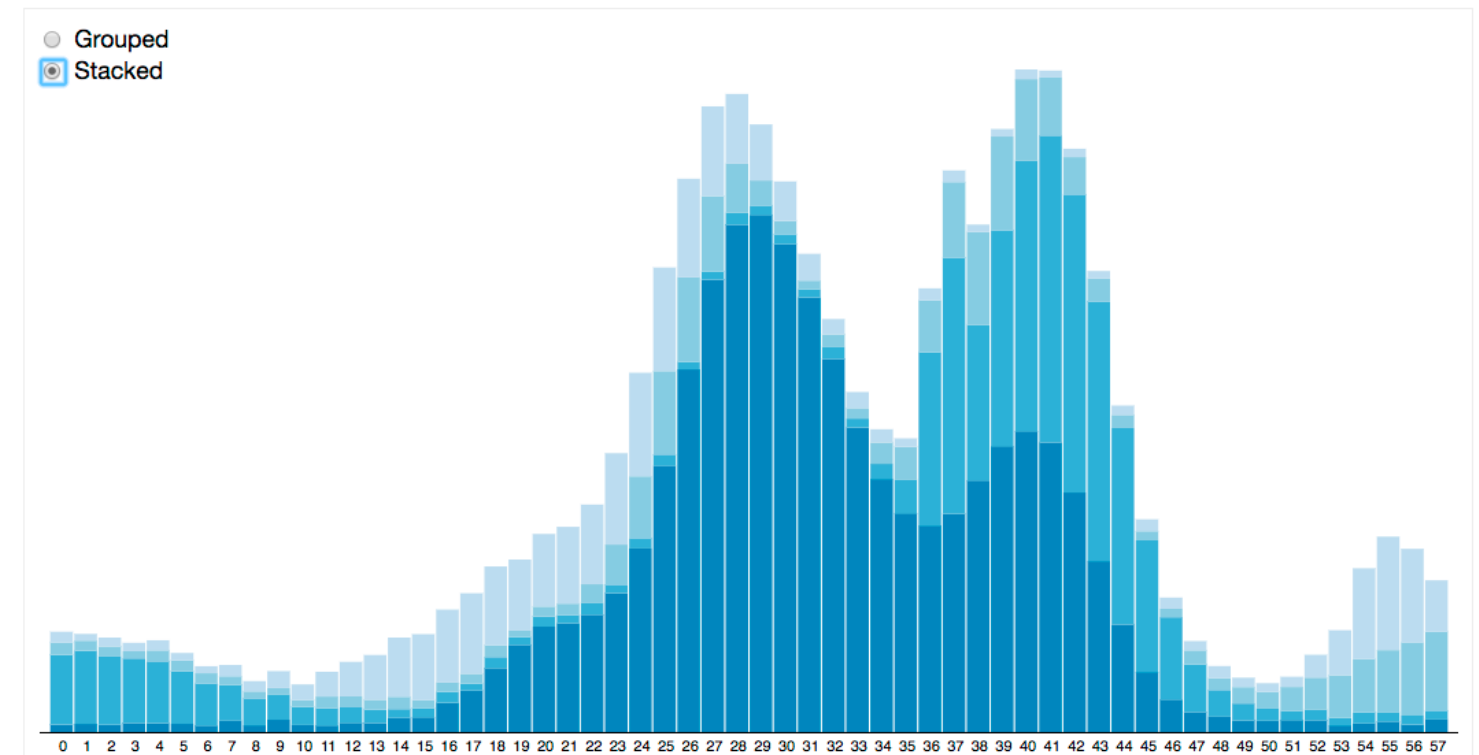
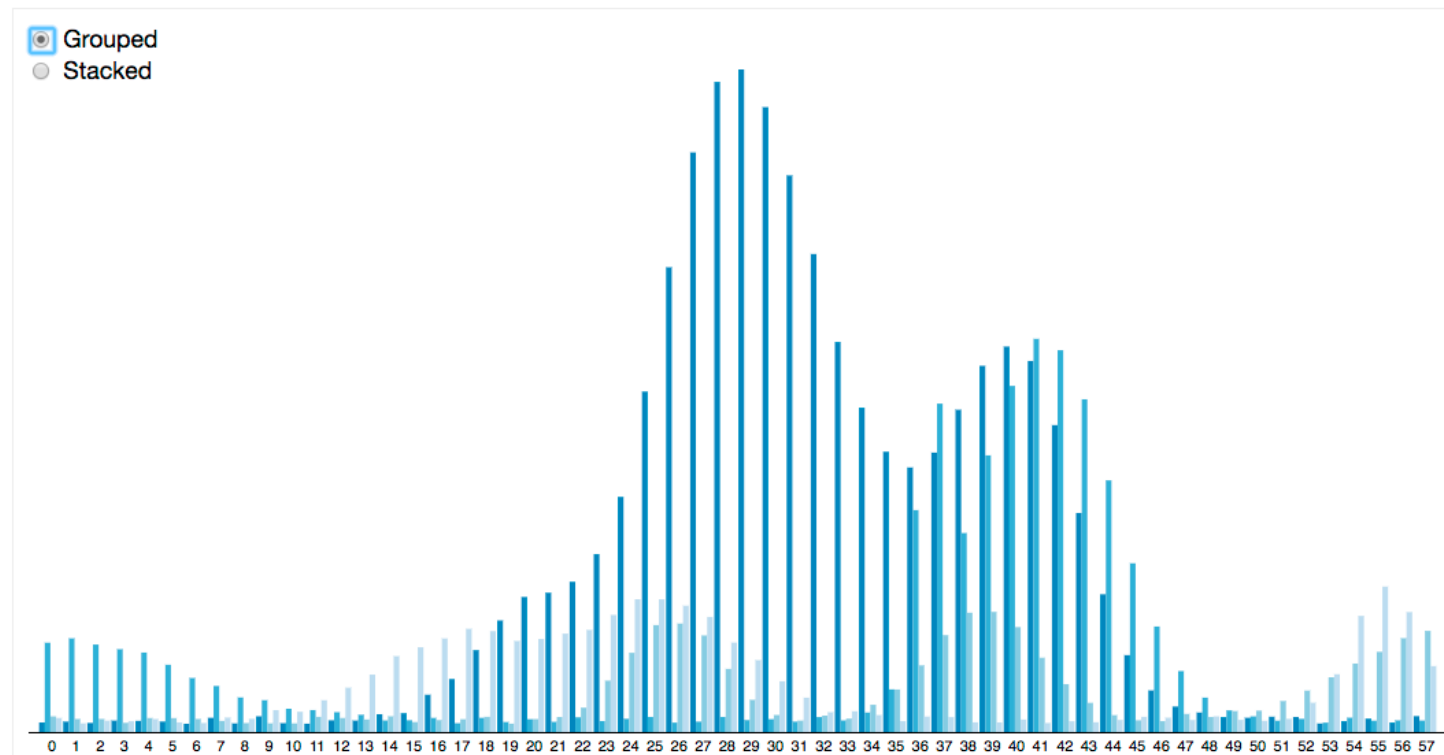
- smooth interpolation from one state to another
 - alternative to jump cuts, supports item tracking
 - best case for animation
 - staging to reduce cognitive load
- example: animated transitions in statistical data graphics



video: vimeo.com/19278444

Idiom: **Animated transitions - visual encoding**

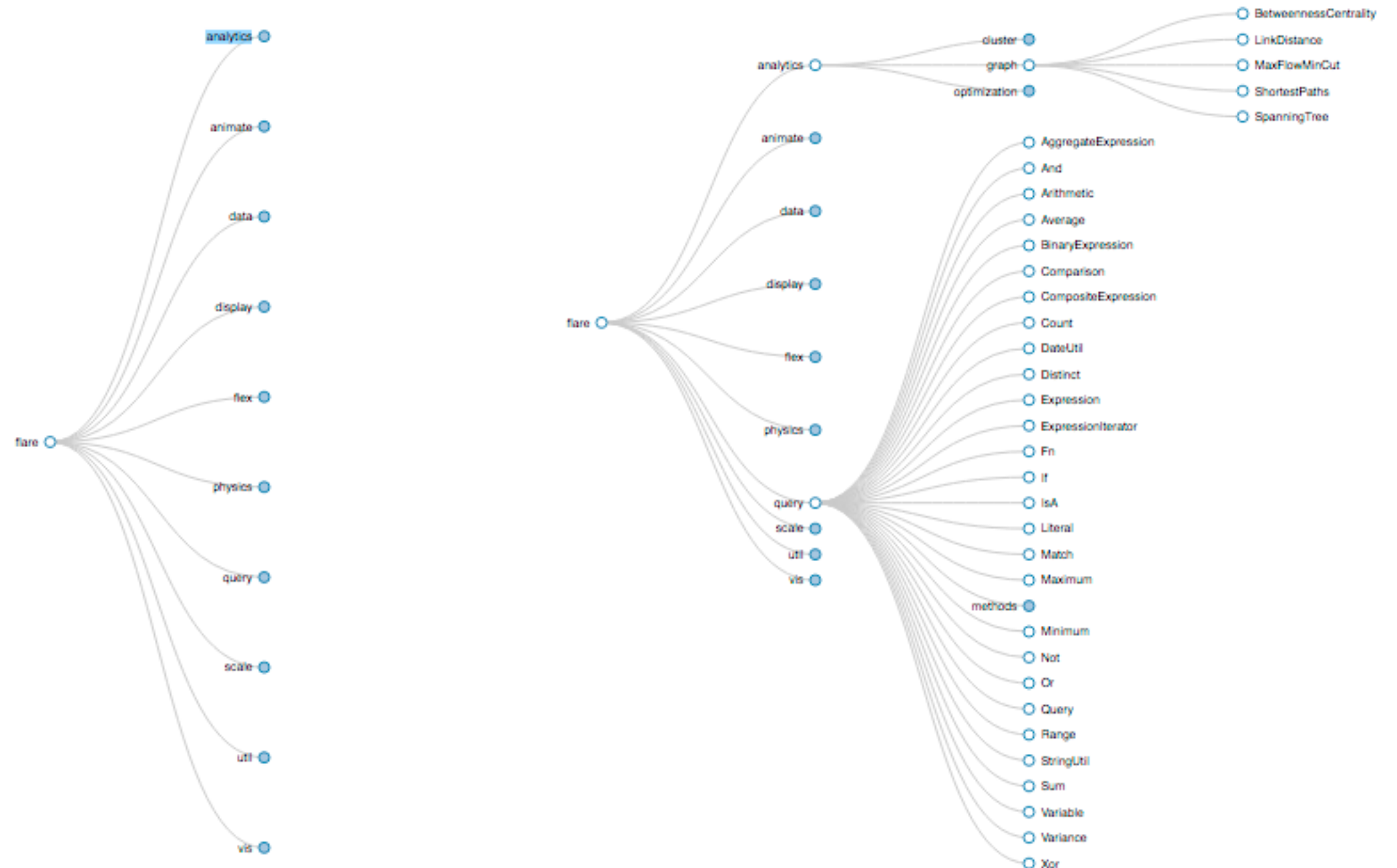
- smooth transition from one state to another
 - alternative to jump cuts, supports item tracking
 - best case for animation
 - staging to reduce cognitive load



[Stacked to Grouped Bars](<http://bl.ocks.org/mbostock/3943967>)

Idiom: **Animated transition** - tree detail

- animated transition
 - network drilldown/rollup



[Collapsible Tree](<https://blocks.org/mbostock/4339083>)

Tooltips

- popup information for selection
 - hover or click
 - can provide useful additional detail on demand
 - beware: does not support overview!
 - always consider if there's a way to visually encode directly to provide overview
 - “If you make a rollover or tooltip, assume nobody will see it. If it's important, make it explicit.”
 - Gregor Aisch, NYTimes

Interaction technology

- what do you design for?
 - mouse & keyboard on desktop?
 - large screens, hover, multiple clicks
 - touch interaction on mobile?
 - small screens, no hover, just tap
 - gestures from video / sensors?
 - ergonomic reality vs movie bombast
 - eye tracking?

slide inspired by: Alexander Lex, Utah



Data visualization and the news - Gregor Aisch (37 min)
vimeo.com/182590214



I Hate Tom Cruise - Alex Kauffmann (5 min)
www.youtube.com/watch?v=QXLfT9sFcbbc

Rule of thumb: **Responsiveness is required**

- *visual feedback: three rough categories*
 - *0.1 seconds: perceptual processing*
 - subsecond response for mouseover highlighting - ballistic motion
 - *1 second: immediate response*
 - fast response after mouseclick, button press - Fitts' Law limits on motor control
 - *10 seconds: brief tasks*
 - bounded response after dialog box - mental model of heavyweight operation (file load)
- **scalability considerations**
 - highlight selection without complete redraw of view (graphics frontbuffer)
 - show hourglass for multi-second operations (check for cancel/undo)
 - show progress bar for long operations (process in background thread)
 - rendering speed when item count is large (guaranteed frame rate)

Navigate: Changing item visibility

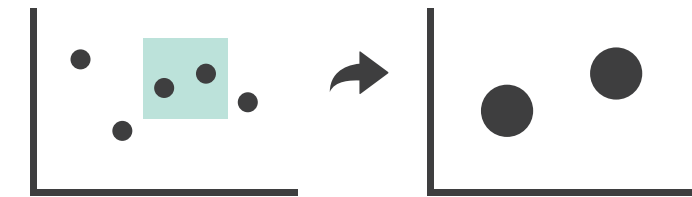
- change viewpoint
 - changes which items are visible within view
 - camera metaphor
 - zoom
 - geometric zoom: familiar semantics
 - semantic zoom: adapt object representation based on available pixels
 - » dramatic change, or more subtle one
 - pan/translate
 - rotate
 - especially in 3D
 - constrained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

➔ Navigate

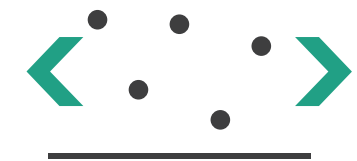
➔ Item Reduction

➔ Zoom

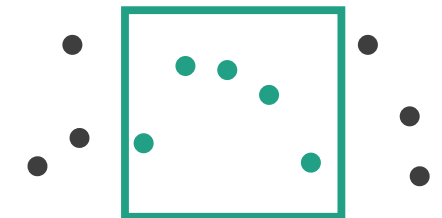
Geometric or *Semantic*



➔ Pan/Translate

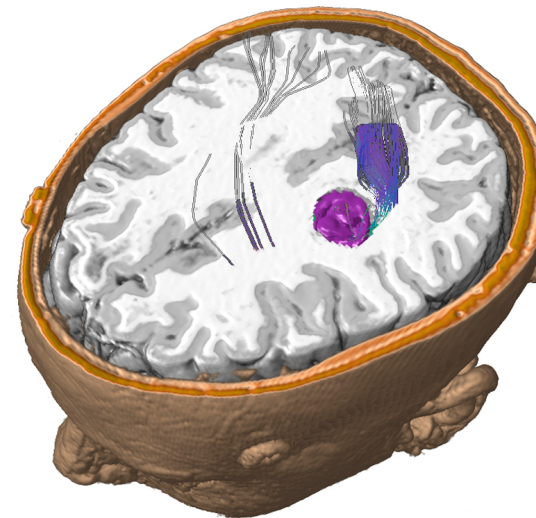
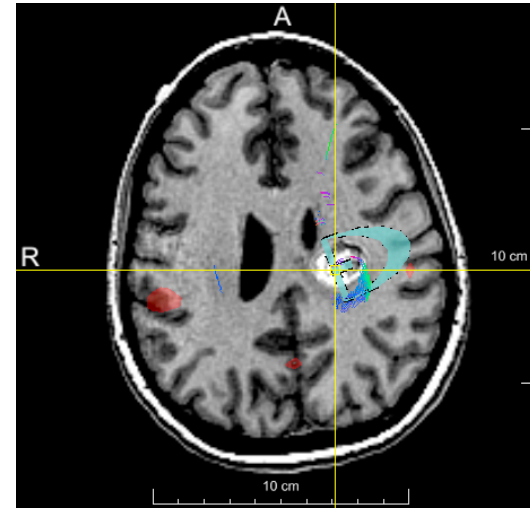


➔ Constrained



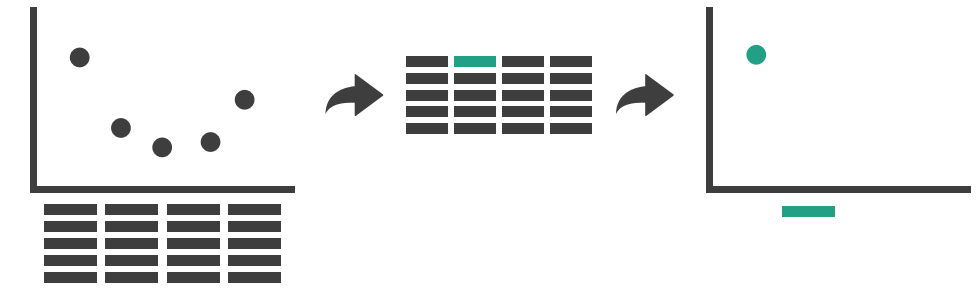
Navigate: Reducing attributes

- 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, ...

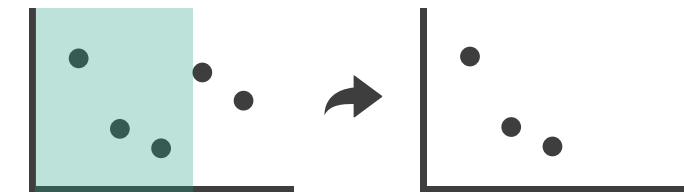


→ Attribute Reduction

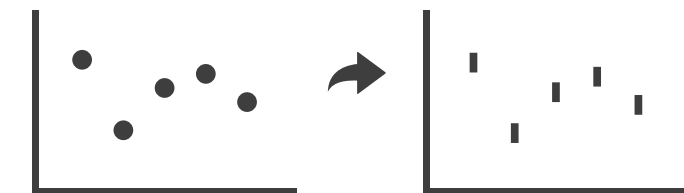
→ Slice



→ Cut



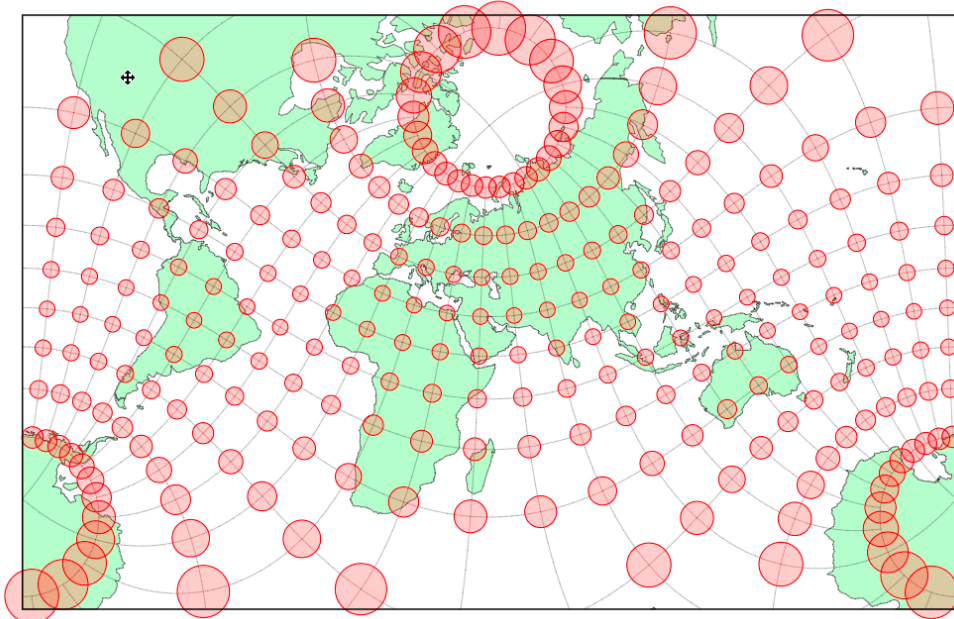
→ Project



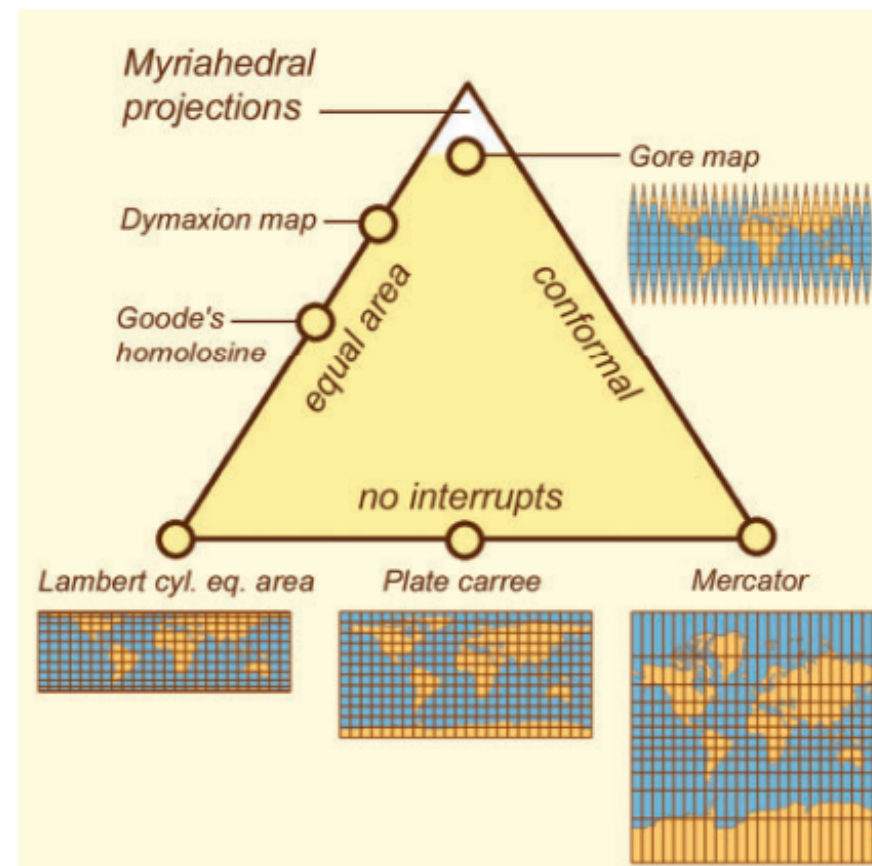
Navigate: Cartographic projections

- project from 2D sphere surface to 2D plane
 - can only fully preserve 2 out of 3
 - angles: conformal
 - area: equal area
 - contiguity: no interruptions

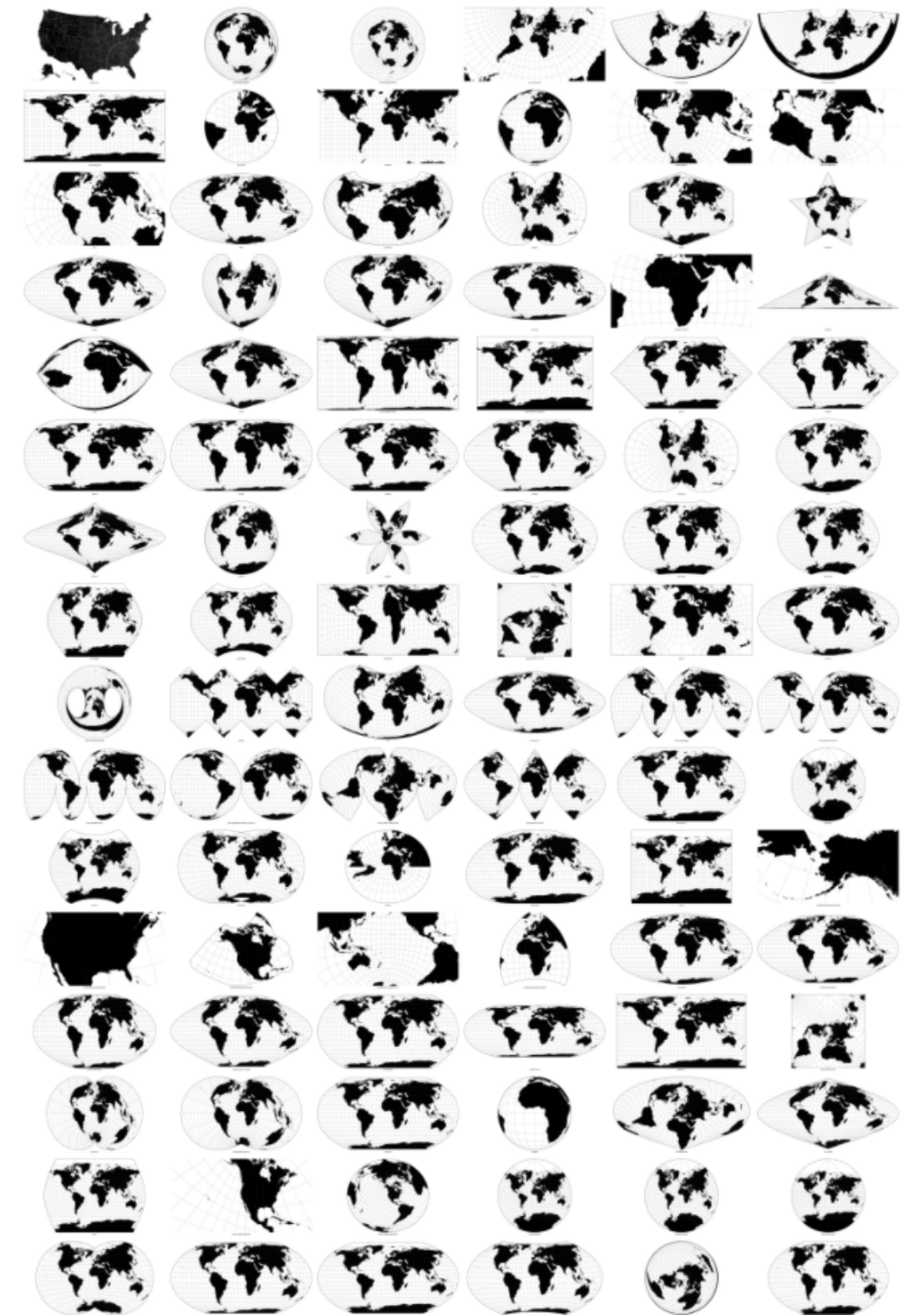
Tissot's Indicatrix



<https://www.jasondavies.com/maps/tissot/>



<https://www.win.tue.nl/~vanwijk/myriahedral/>



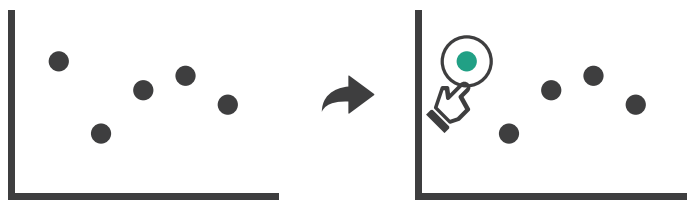
[Every Map Projection](<https://bl.ocks.org/mbostock/29cddc0006f8b98eff12e60dd08f59a7>)

Manipulate

➔ Change over Time



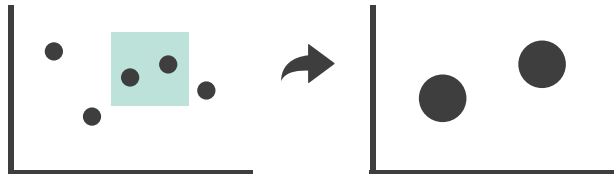
➔ Select



➔ Navigate

➔ Item Reduction

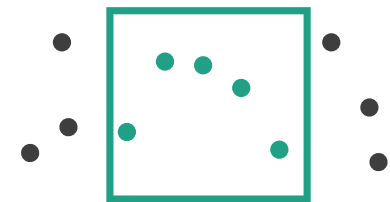
➔ Zoom
Geometric or *Semantic*



➔ Pan/Translate

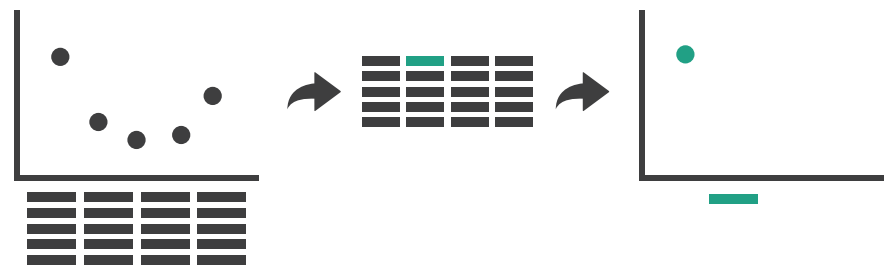


➔ Constrained

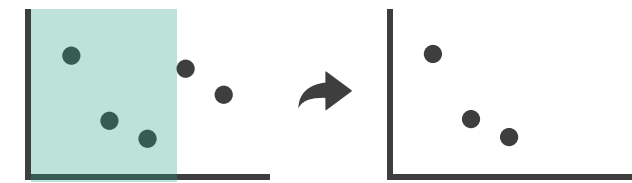


➔ Attribute Reduction

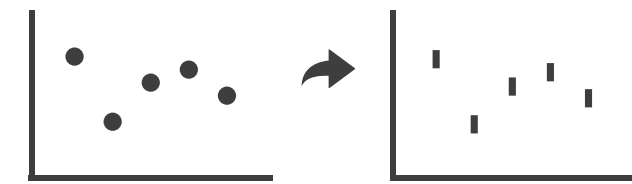
➔ Slice



➔ Cut

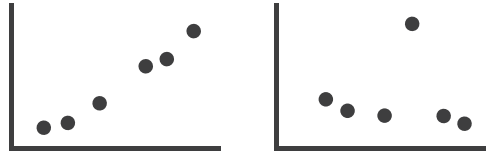


➔ Project

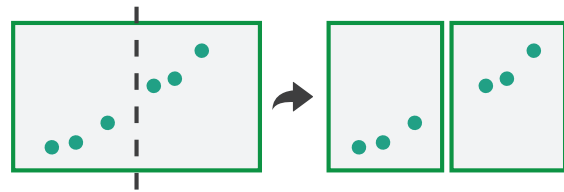


Facet

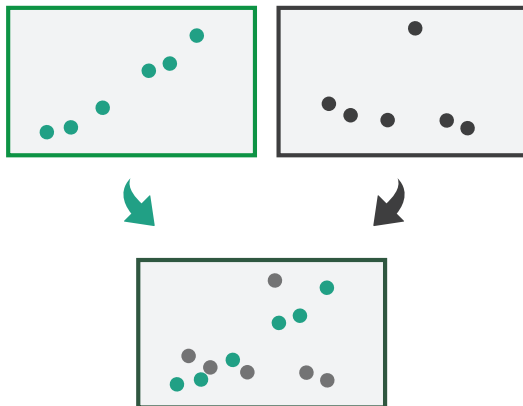
➔ Juxtapose



➔ Partition



➔ Superimpose



Juxtapose and coordinate views

→ Share Encoding: Same/Different

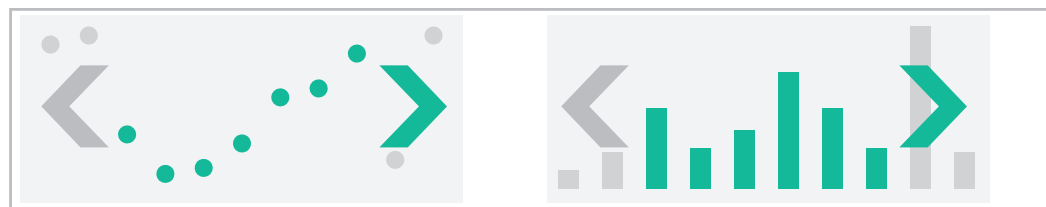
→ *Linked Highlighting*



→ Share Data: All/Subset/None



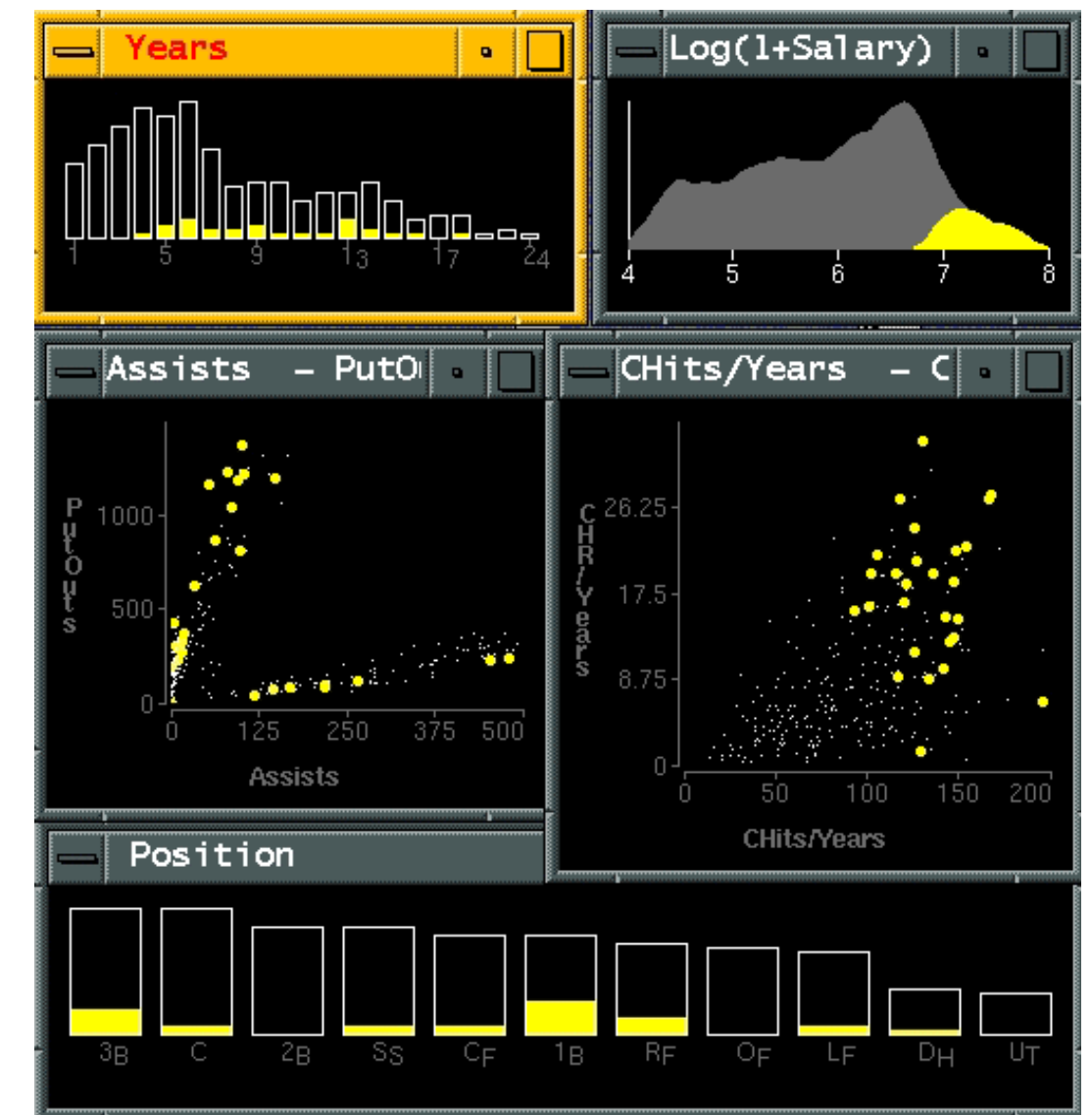
→ Share Navigation



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
 - all **items** shared
 - different **attributes** across the views
- aka: brushing and linking



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

Linked views: Multidirectional linking

System: **Buckets**

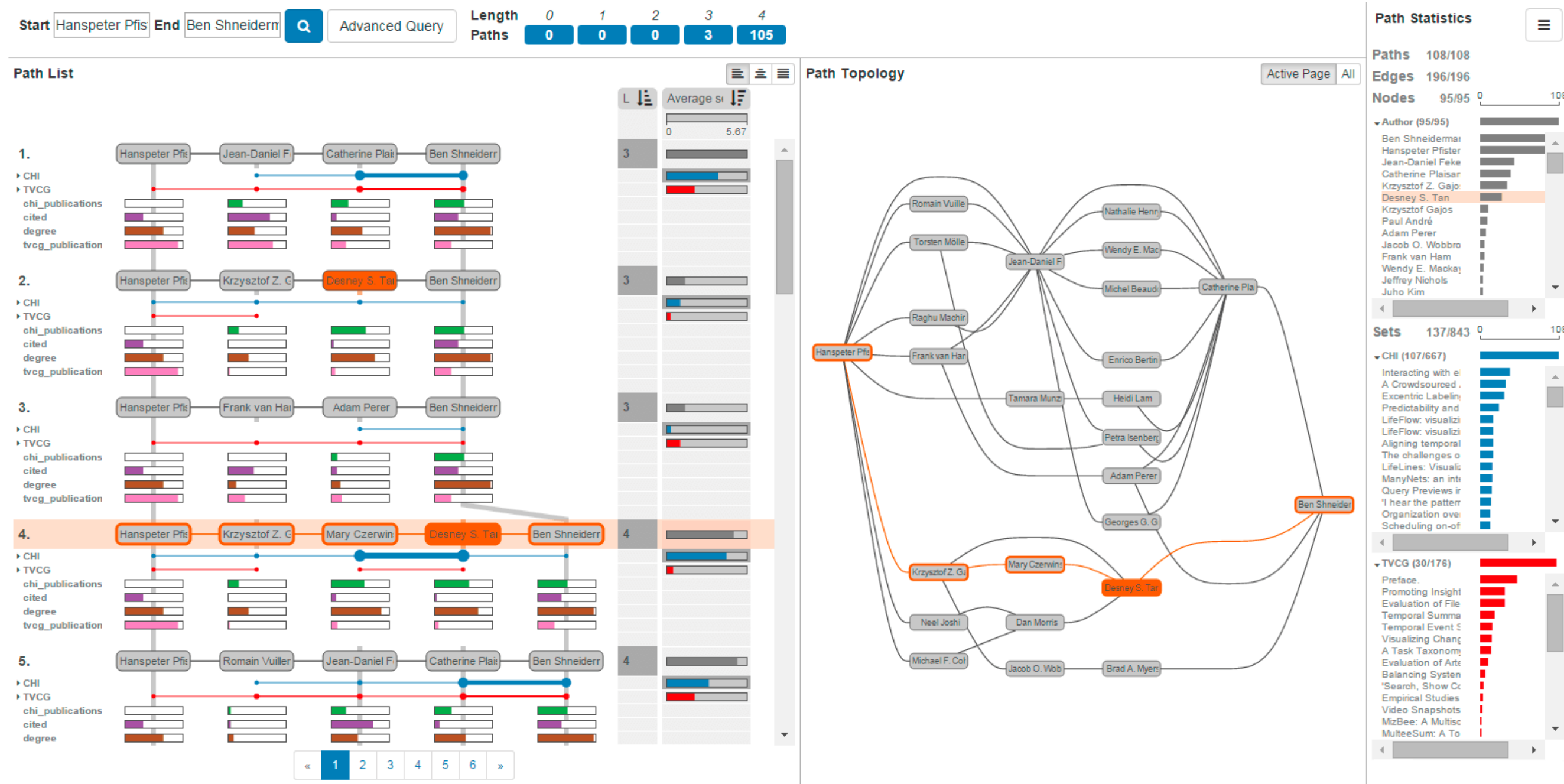


<http://buckets.peterbeshai.com/>

<https://medium.com/@pbesh/linked-highlighting-with-react-d3-js-and-reflux-16e9c0b2210b>

Complex linked multiform views

System: Pathfinder



<https://www.youtube.com/watch?v=aZF7AC8aNXo>

Idiom: **Overview-detail views**

System: **Google Maps**

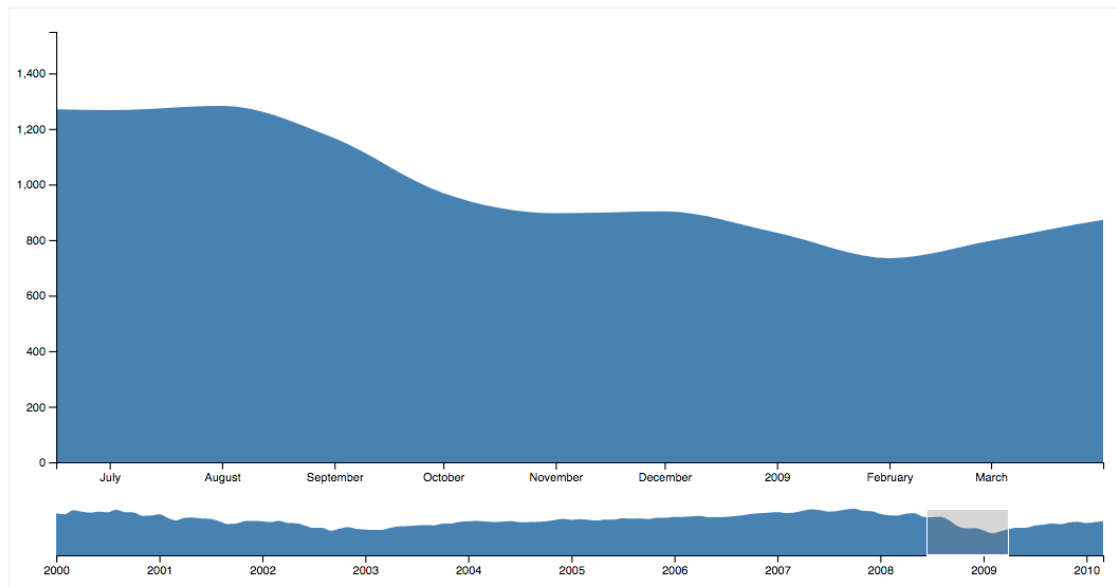
- encoding: same or different
 - ex: same (birds-eye map)
- data: subset shared
 - viewpoint differences: subset of data items
- navigation: shared
 - bidirectional linking
- other differences
 - (window size)



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

Idiom: Overview-detail navigation

- encoding: same or different
- data: subset shared
- navigation: shared
 - unidirectional linking
 - select in small overview, change extent in large detail view



<https://observablehq.com/@uwdata/interaction>

Idiom: Tooltips

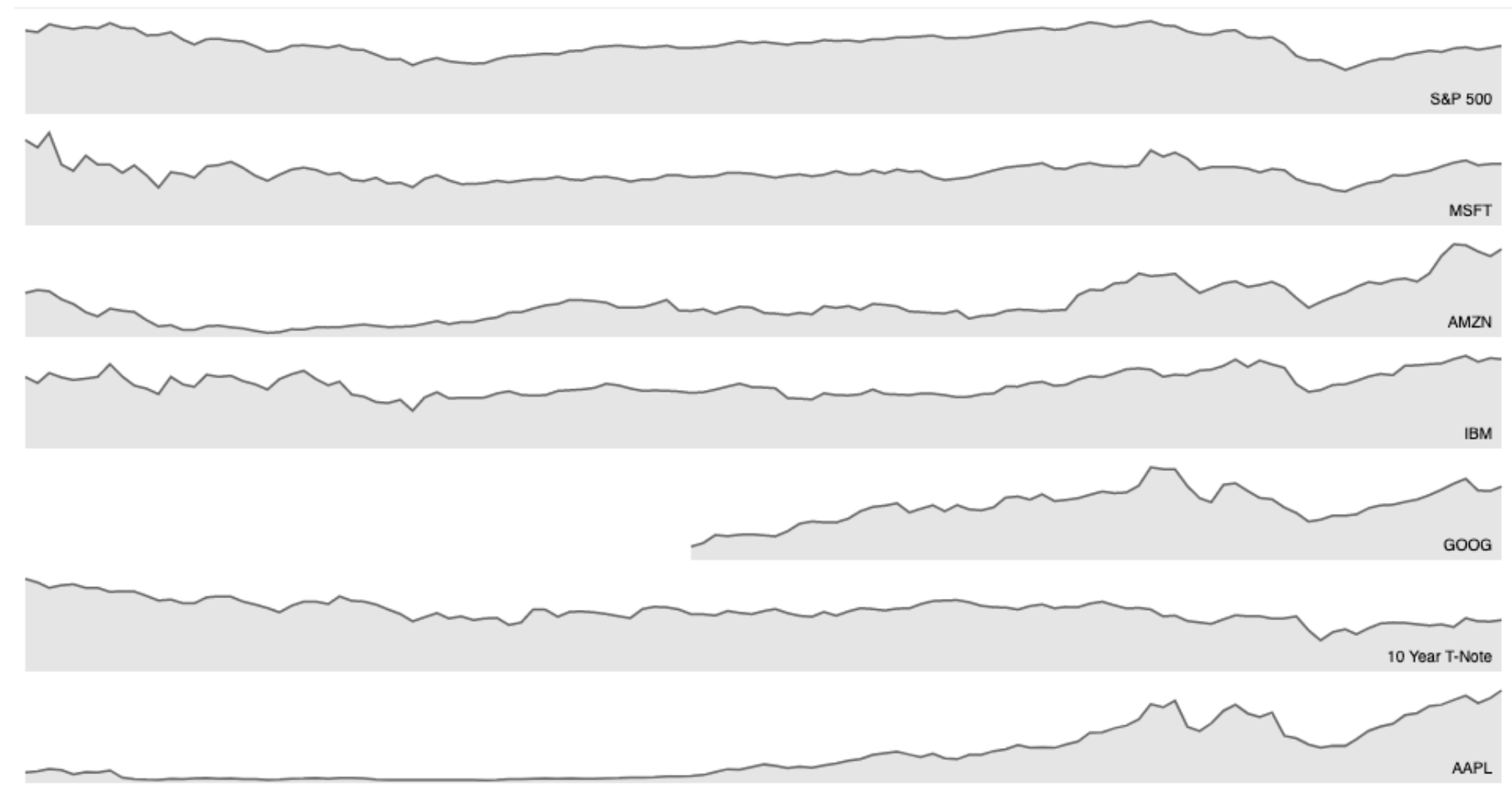
- popup information for selection
 - hover or click
 - specific case of detail view:
provide useful additional detail on demand
 - beware: does not support overview!
 - always consider if there's a way to visually encode directly to provide overview
 - “If you make a rollover or tooltip, assume nobody will see it. If it's important, make it explicit.”
 - Gregor Aisch, NYTimes



[\[https://www.highcharts.com/demo/dynamic-master-detail\]](https://www.highcharts.com/demo/dynamic-master-detail)

Idiom: **Small multiples**

- encoding: same
 - ex: line charts
- data: none shared
 - different slices of dataset
 - items or attributes
 - ex: stock prices for different companies
- linked highlighting:
analogous item/attribute
across views
 - same year highlighted across all charts if hover within any chart



[\[blocks.roadtolarissa.com/mbostock/1157787/\]](https://blocks.roadtolarissa.com/mbostock/1157787/)

The Rise and Decline of Ask MetaFilter

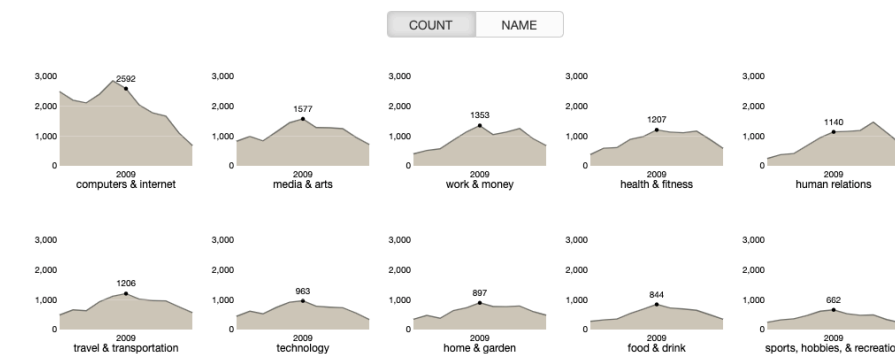
Metafilter's revenue has been on the decline, but has its content dried up as well?

Here we look at new posts on Ask Metafilter by category.

Categories like **computers & internet** have been dropping in use for a long time, most likely due to competition like Stack Overflow.

Other smaller categories have had consistent use patterns until more recently.

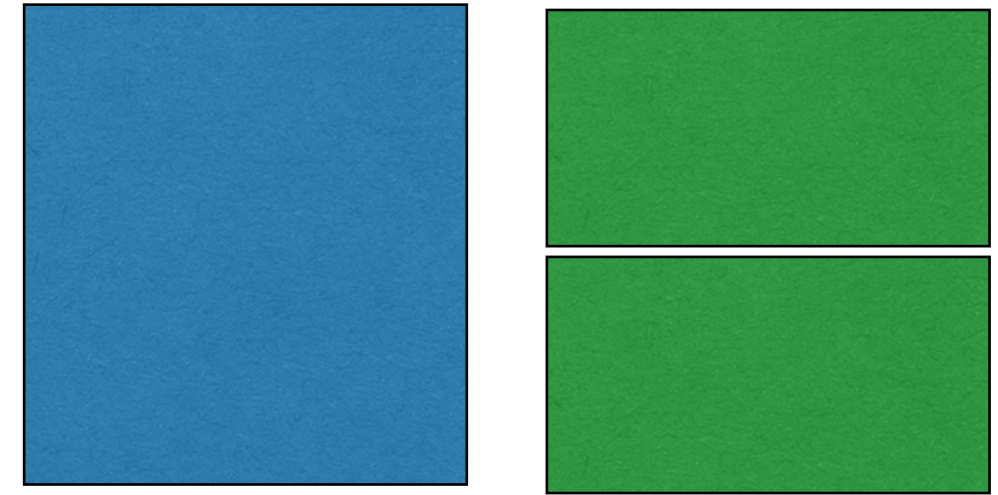
Disclaimer: 2014 is included, even though the year is not over yet.



[\[http://projects.flowingdata.com/tut/linked_small_multiples_demo/\]](http://projects.flowingdata.com/tut/linked_small_multiples_demo/)

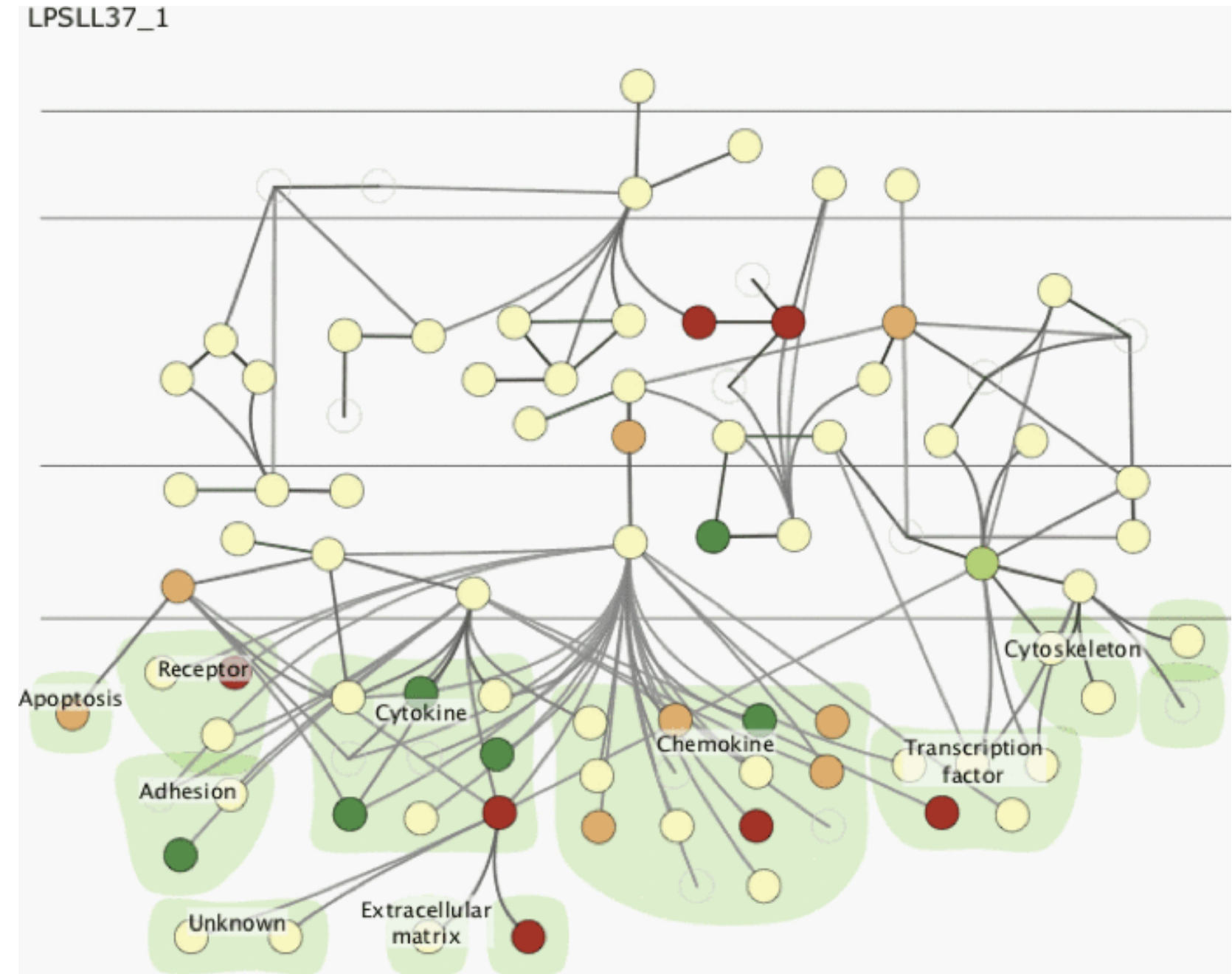
Juxtapose views: tradeoffs

- juxtapose costs
 - display area
 - 2 views side by side: each has only half the area of one view
- juxtapose benefits
 - cognitive load: eyes vs memory
 - lower cognitive load: move eyes between 2 views
 - higher cognitive load: compare single changing view to memory of previous state



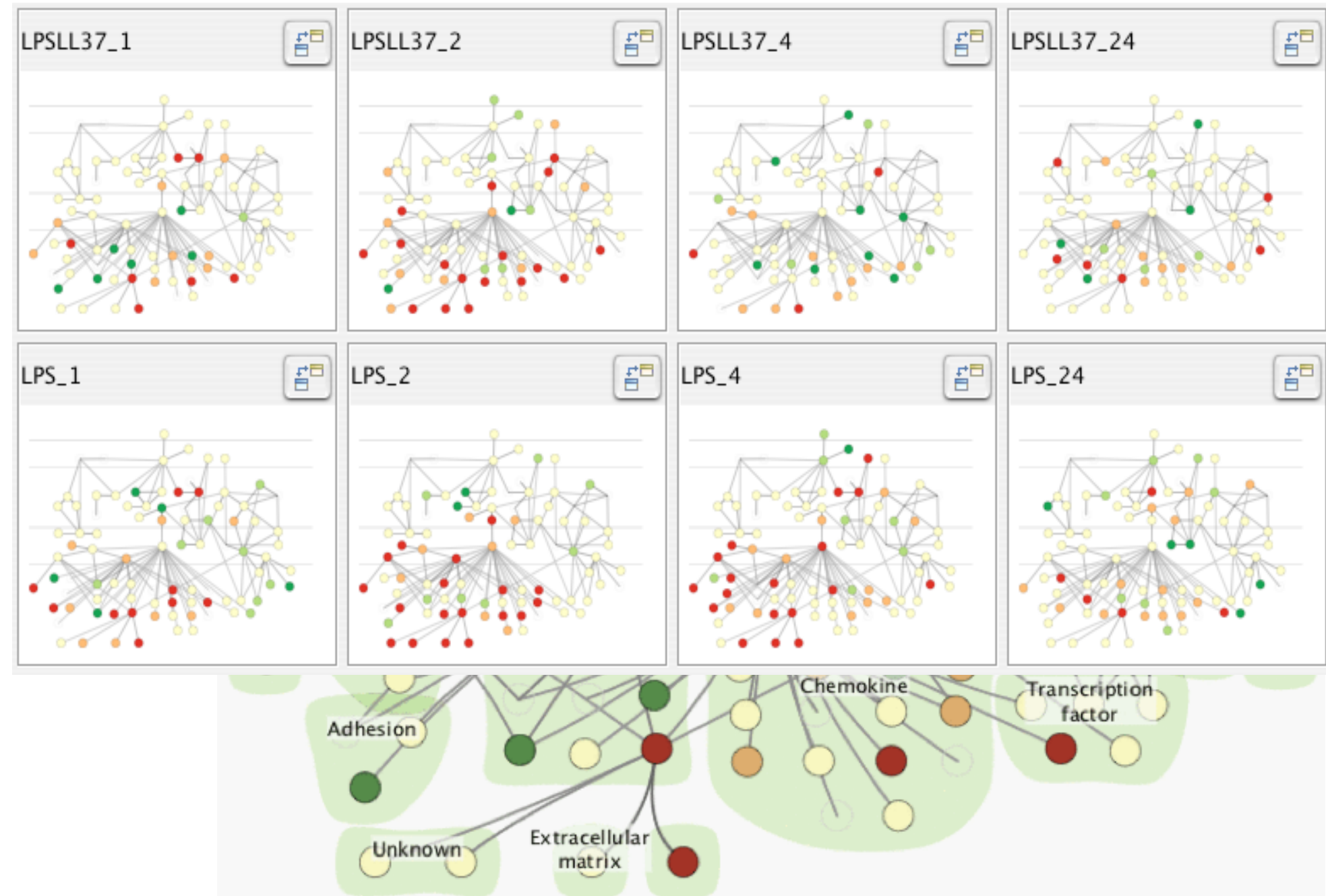
Juxtapose vs animate

- animate: hard to follow if many scattered changes or many frames
 - vs easy special case: animated transitions

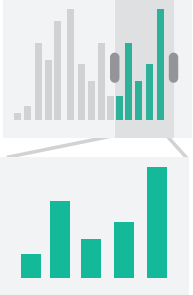
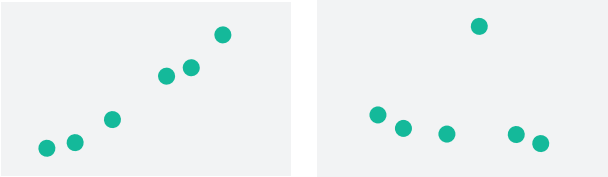


Juxtapose vs animate

- animate: hard to follow if many scattered changes or many frames
 - vs easy special case: animated transitions
- juxtapose: easier to compare across small multiples
 - different conditions (color), same gene (layout)



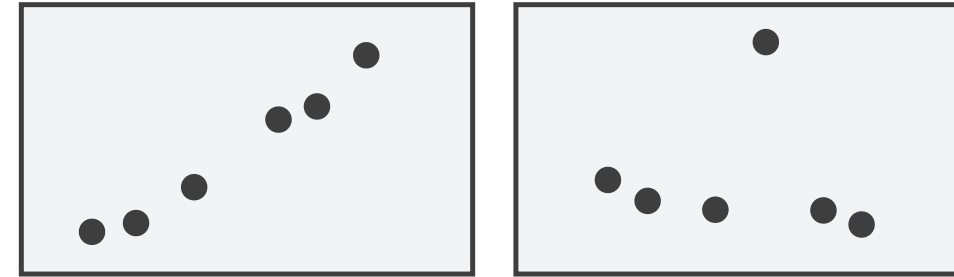
Coordinate views: Design choice interaction

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

Partition into views

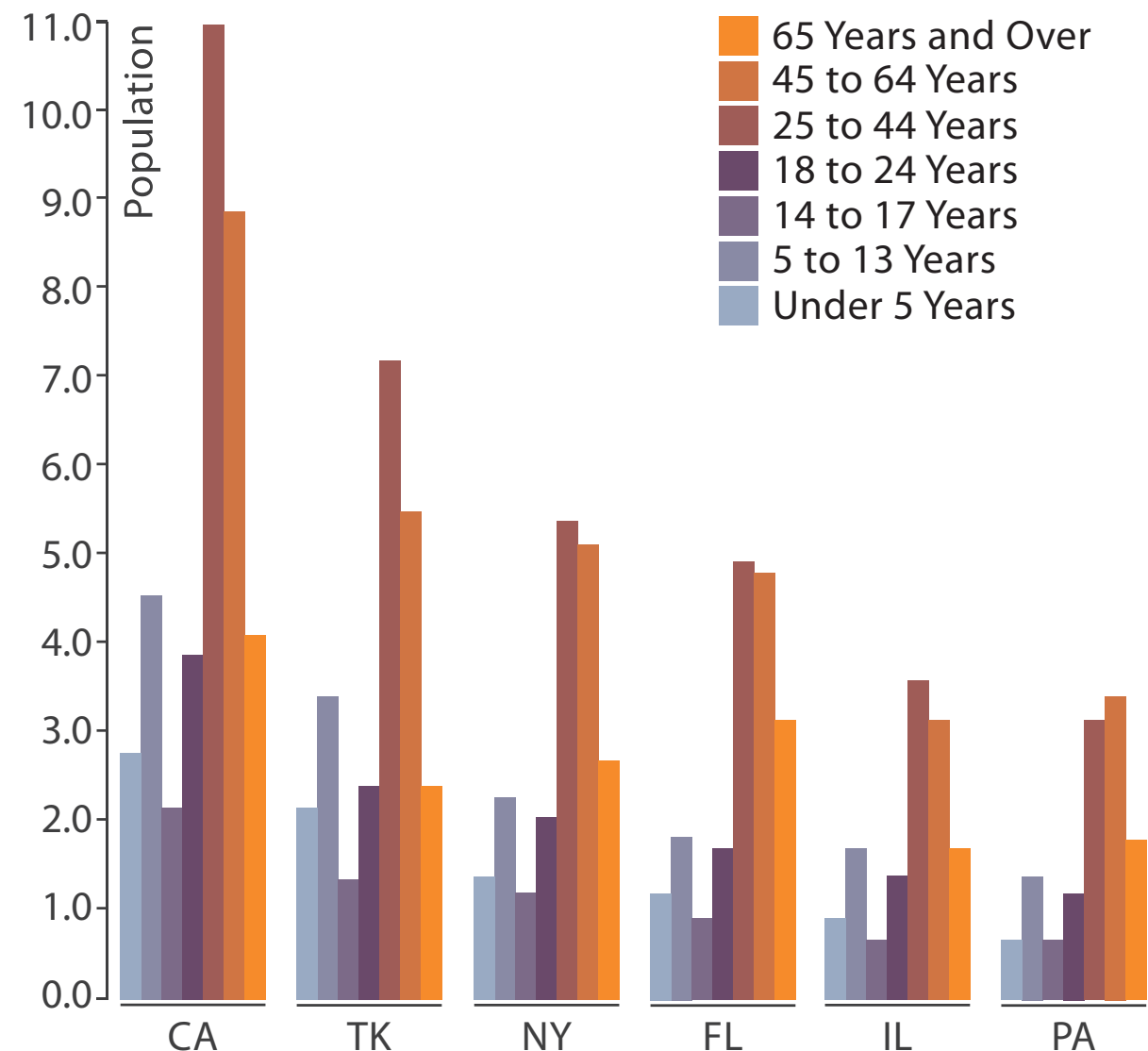
- how to divide data between views
 - split into regions by attributes
 - encodes association between items using spatial proximity
 - order of splits has major implications for what patterns are visible

➔ Partition into Side-by-Side Views

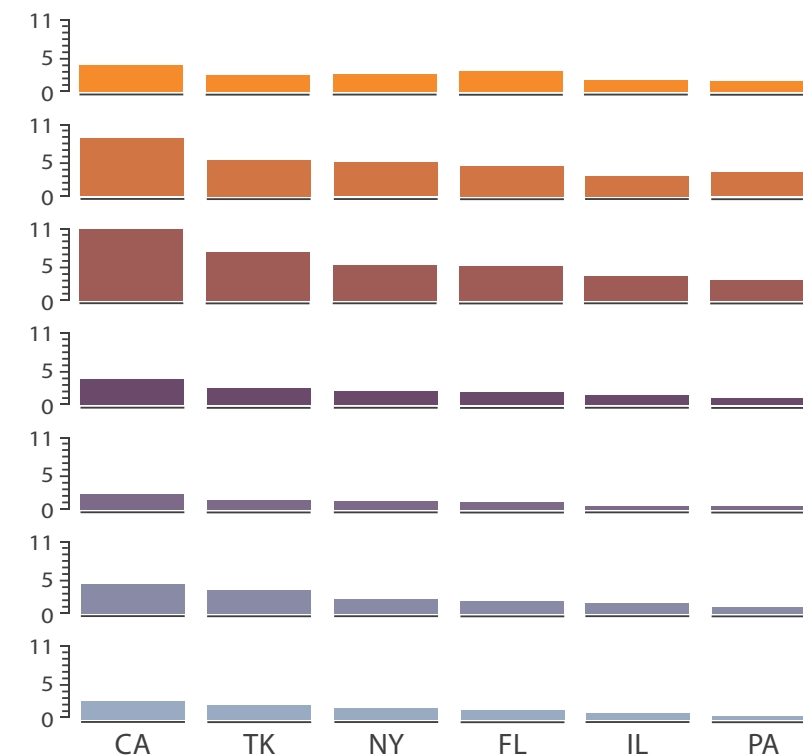


Partitioning: List alignment

- 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

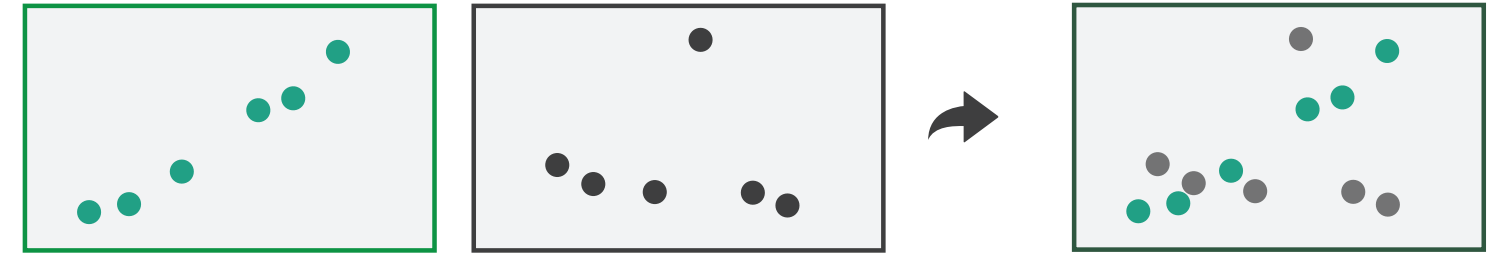


Superimpose layers

- **layer**: set of objects spread out over region

⊕ Superimpose Layers

- 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. Stone. 2010.]

<http://www.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white>

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.stonesc.com/wordpress/2010/03/get-it-right-in-black-and-white>

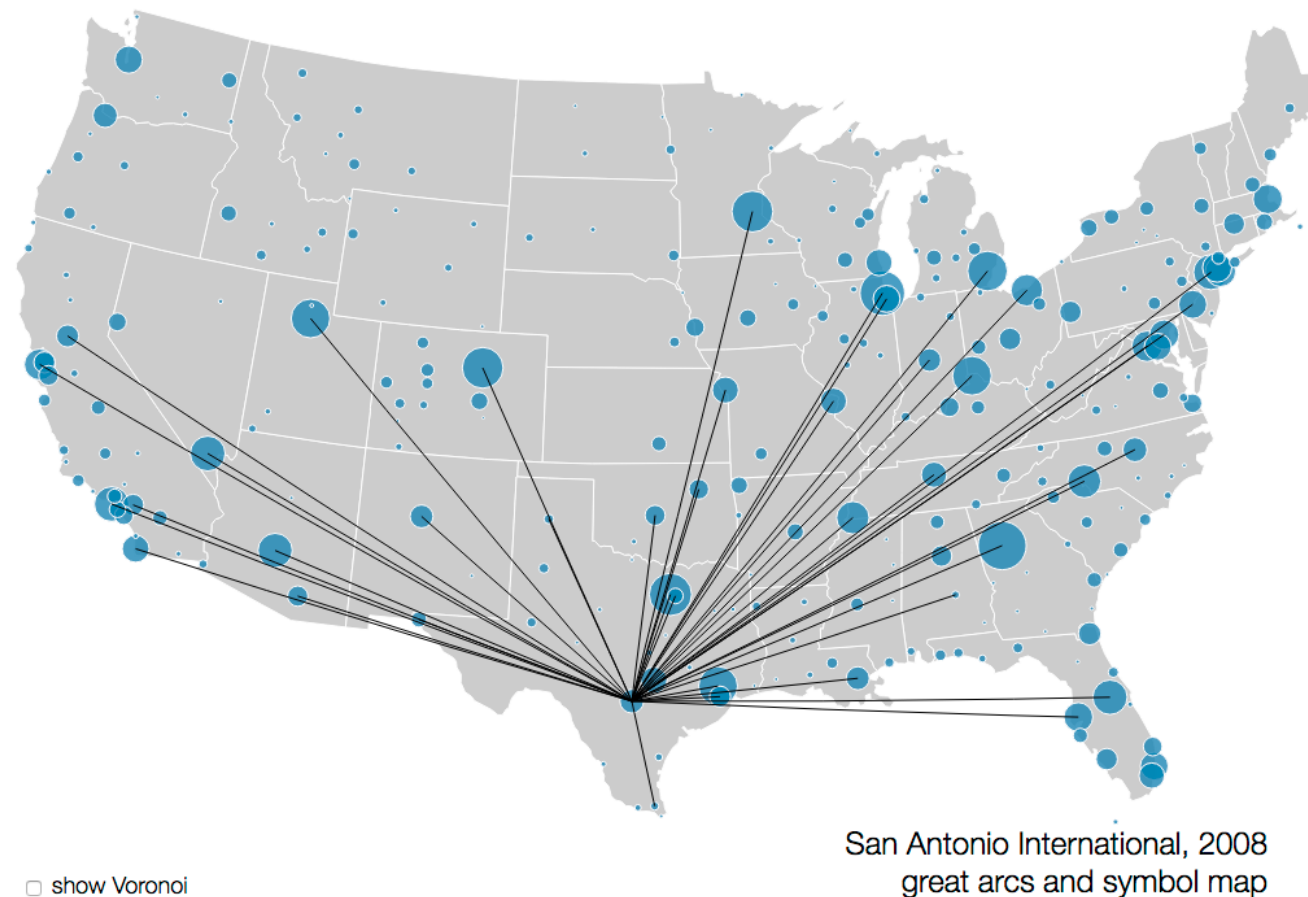
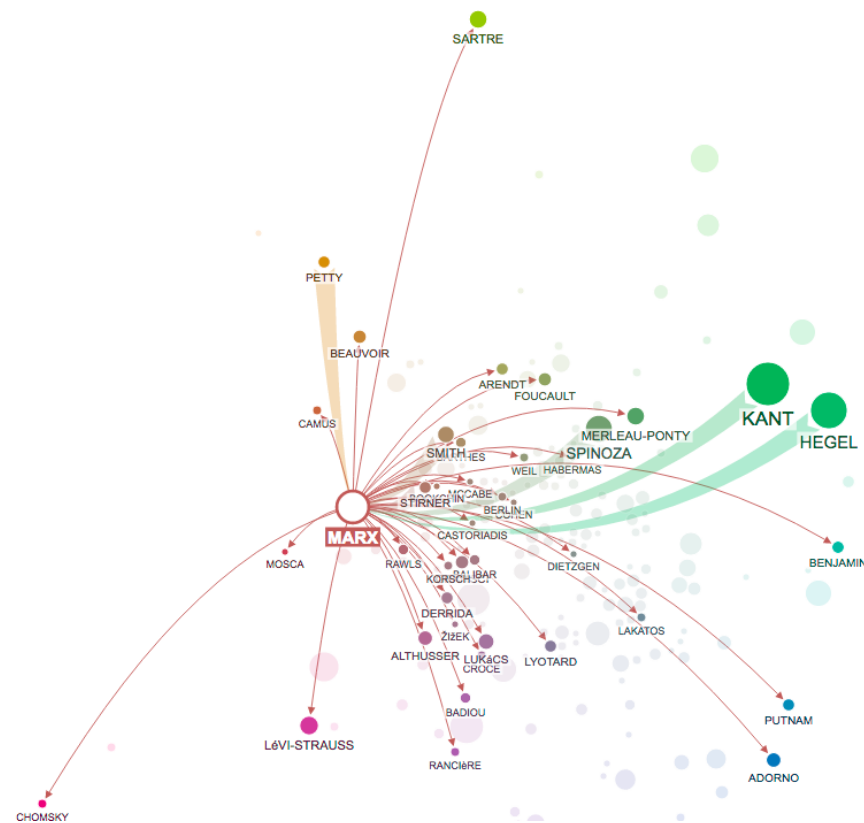
Idiom: Trellis plots

- superimpose within same frame
 - color code by year
- partitioning
 - split by site, rows are wheat varieties
- main-effects ordering
 - derive value of median for group, use to order
 - order rows within view by variety median
 - order views themselves by site median



Dynamic visual layering

- interactive based on selection
- one-hop neighbour highlighting demos: click vs hover (lightweight)



<https://mariandoerk.de/edgemaps/demo/>

<https://mbostock.github.io/d3/talk/20111116/airports.html>

Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
—Chap 11: Manipulate View & Chap 12: Facet Into Multiple Views
- *Animated Transitions in Statistical Data Graphics*. Heer and Robertson. *IEEE Trans. on Visualization and Computer Graphics (Proc. InfoVis 07)* 13:6 (2007), 1240–1247.
- *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.
- *A Review of Overview+Detail, Zooming, and Focus+Context Interfaces*. Cockburn, Karlson, and Bederson. *ACM Computing Surveys* 41:1 (2008), 1–31.
- *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 Elmqvist. *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.
- *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*. Wills. 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, Laramée, Hauser, Ward, and Chen. In *Eurographics State of the Art Reports*, pp. 39–63, 2013.

Visualization Analysis & Design Tutorial

- Session 1

- Analysis: What, Why, How
- Marks and Channels
- Q&A
- Visualizing Tabular Data
- Visualizing Spatial Data
- Q&A

- Session 2

- Visualizing Network Data
- Color
- Q&A
- Interactive & Multiple Views
- Reduce: Filter, Aggregate
- Q&A

@tamara@cosocial.ca

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

Reduce items and attributes

- reduce/increase: inverses
- filter
 - pro: straightforward and intuitive
 - to understand and compute
 - 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

Reducing Items and Attributes

➔ Filter

➔ Items



➔ Attributes

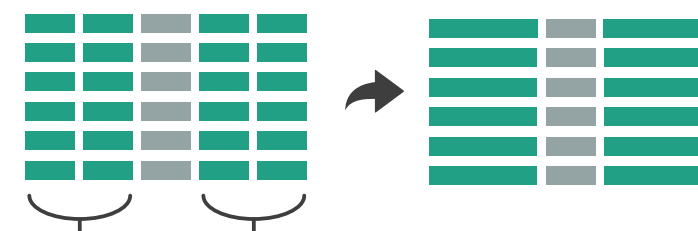


➔ Aggregate

➔ Items



➔ Attributes

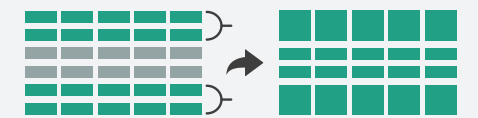


Reduce

➔ Filter



➔ Aggregate



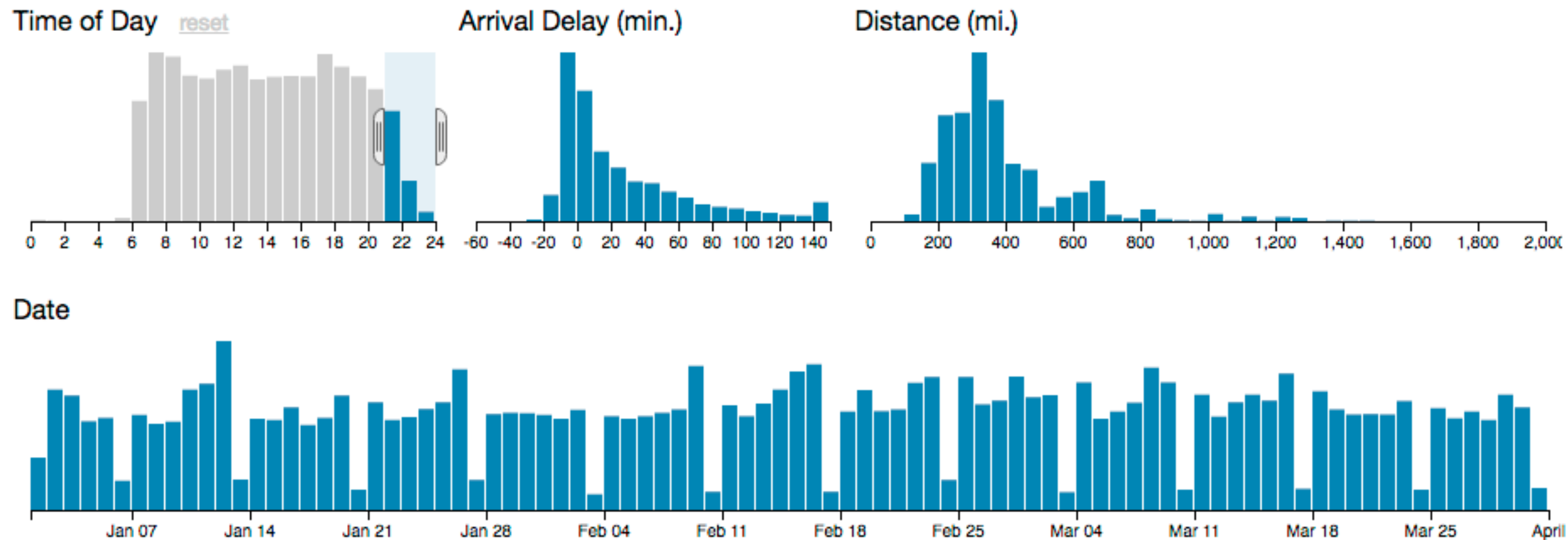
➔ Embed



Idiom: **cross filtering**

System: **Crossfilter**

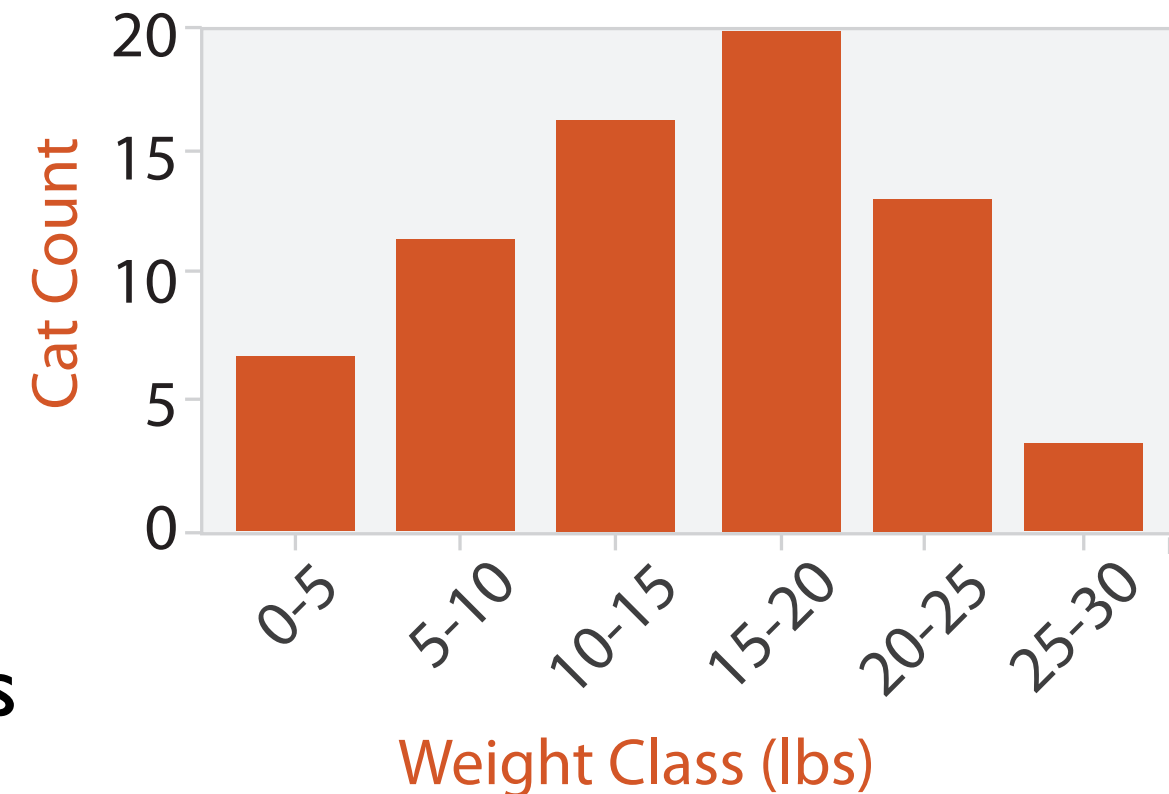
- item filtering
- coordinated views/controls combined
 - all scented histogram bisliders update when any ranges change



[\[https://square.github.io/crossfilter/\]](https://square.github.io/crossfilter/)

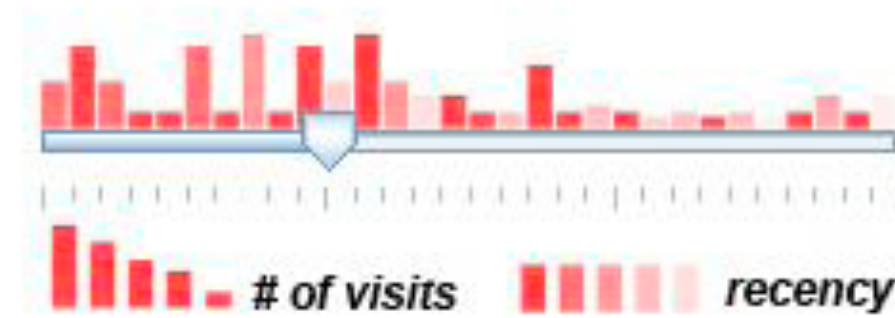
Idiom: **histogram**

- 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

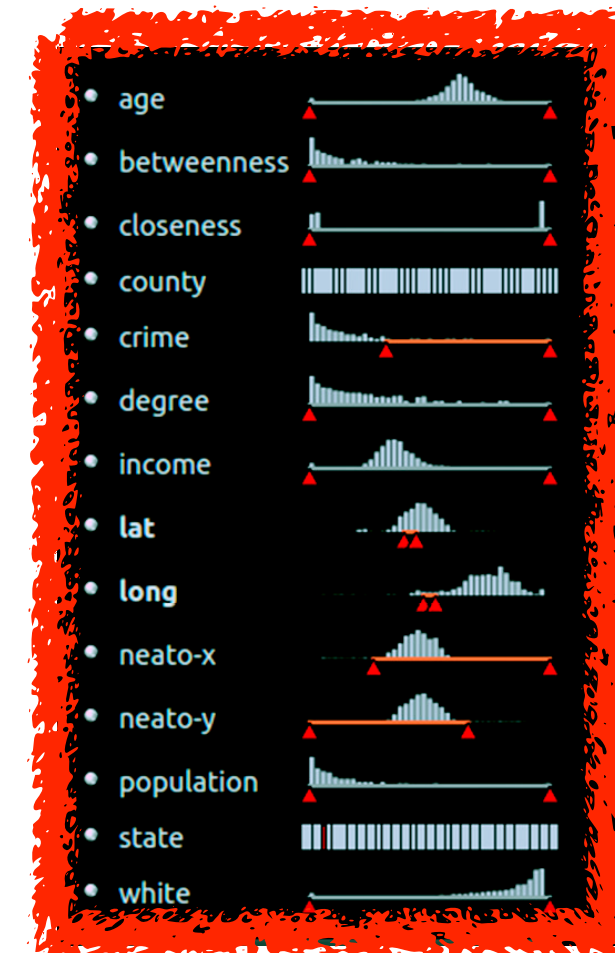
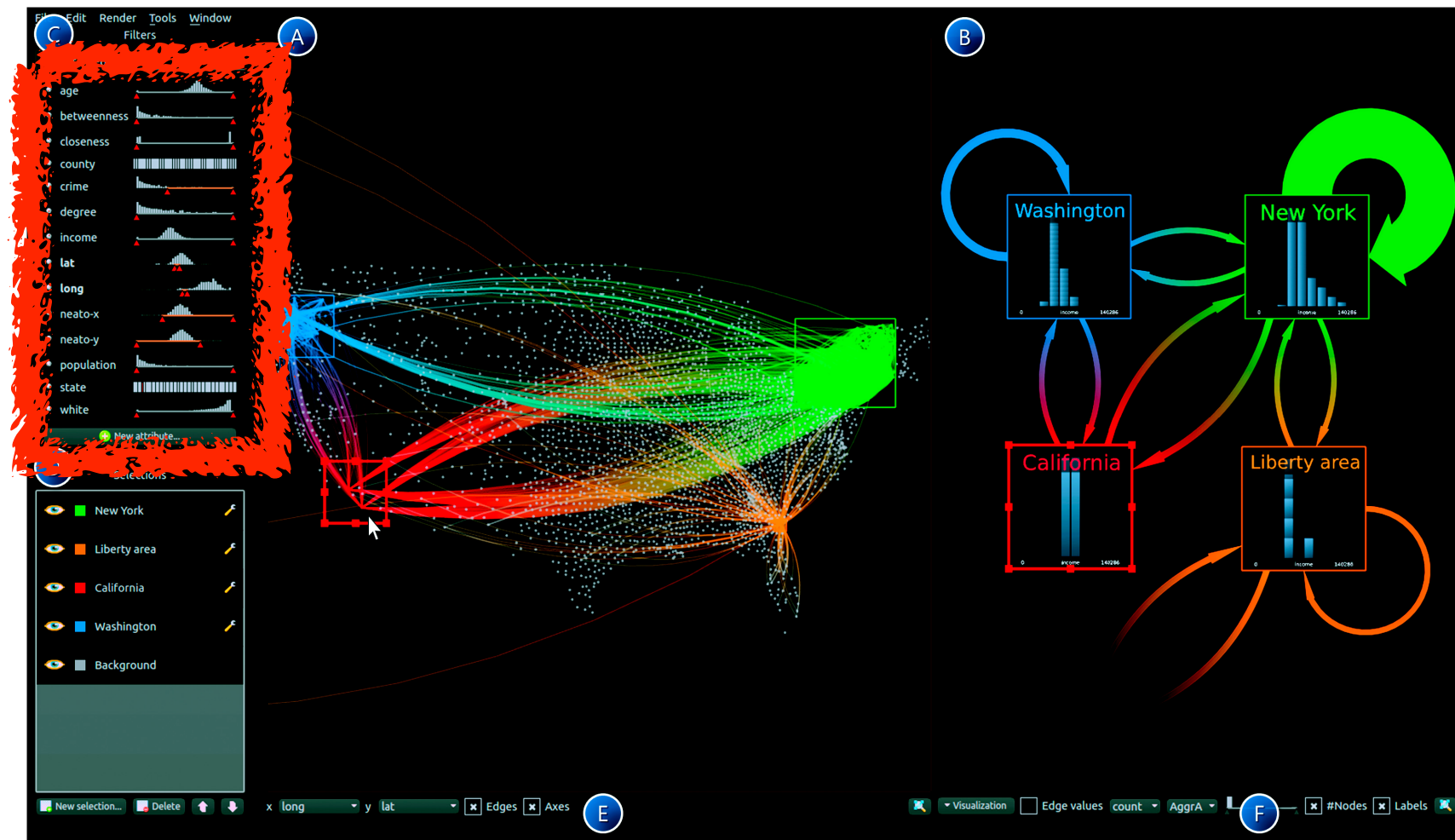


Idiom: scented widgets

- augmented widgets show **information scent**
 - better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider



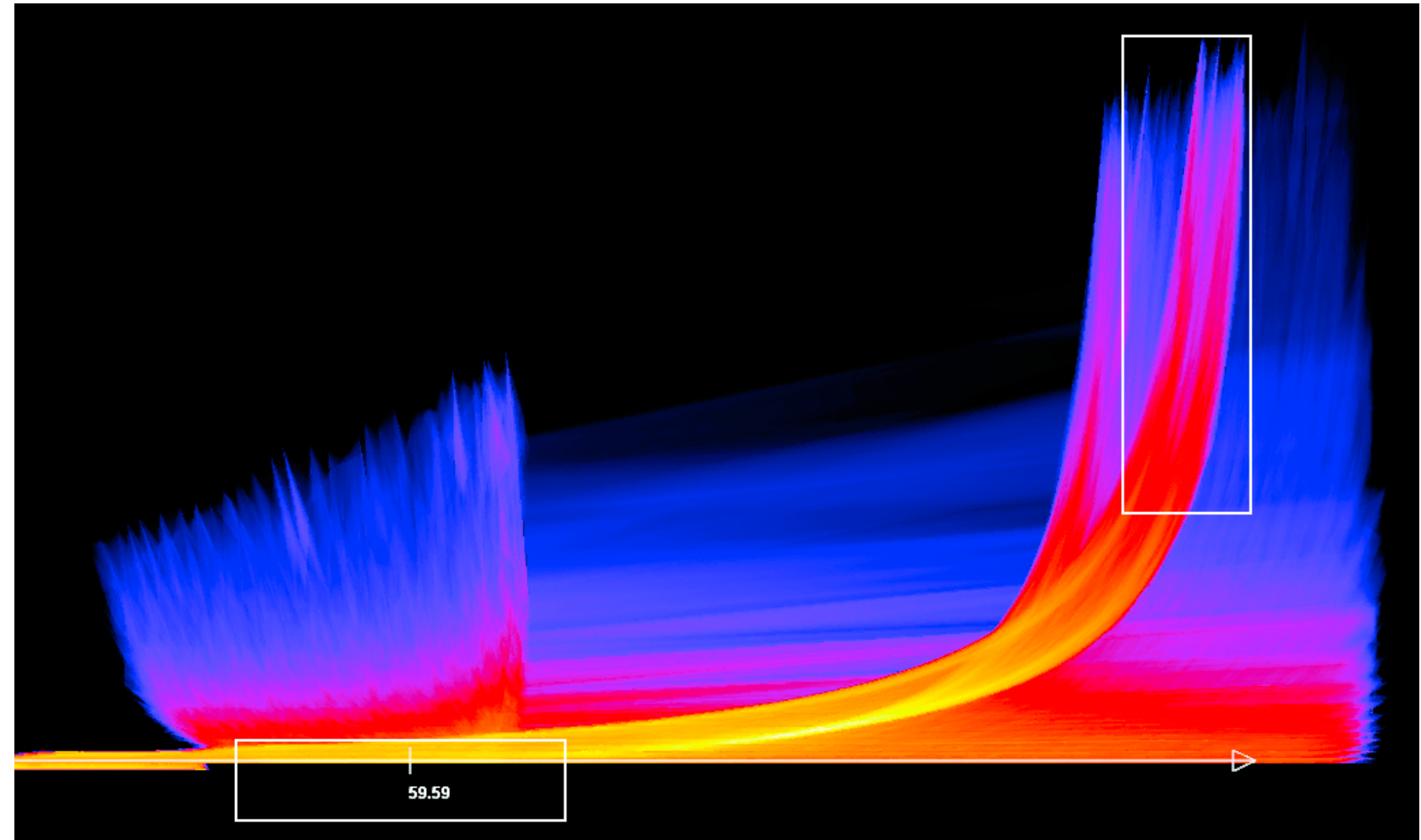
[Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Willett, Heer, and Agrawala. IEEE TVCG (Proc. InfoVis 2007) 13:6 (2007), 1129–1136.]



[Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. van den Elzen, van Wijk, IEEE TVCG 20(12): 2014 (Proc. InfoVis 2014).]

Idiom: Continuous scatterplot

- static item aggregation
- data: table
- derived data: table
 - key attribs x,y for pixels
 - quant attrib: overplot density
- dense space-filling 2D matrix
- color: sequential categorical hue + ordered luminance colormap
- scalability
 - no limits on overplotting: millions of items



[Continuous Scatterplots. Bachthaler and Weiskopf.
IEEE TVCG (Proc.Vis 08) 14:6 (2008), 1428–1435. 2008.]

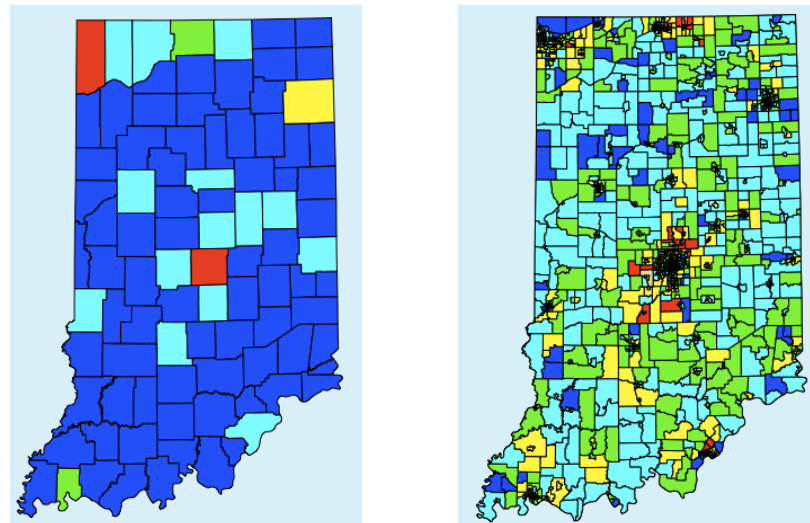
Spatial aggregation

- MAUP: Modifiable Areal Unit Problem
 - changing boundaries of cartographic regions can yield dramatically different results
 - zone effects



[http://www.e-education.psu.edu/geog486/l4_p7.html, Fig 4.cg.6]

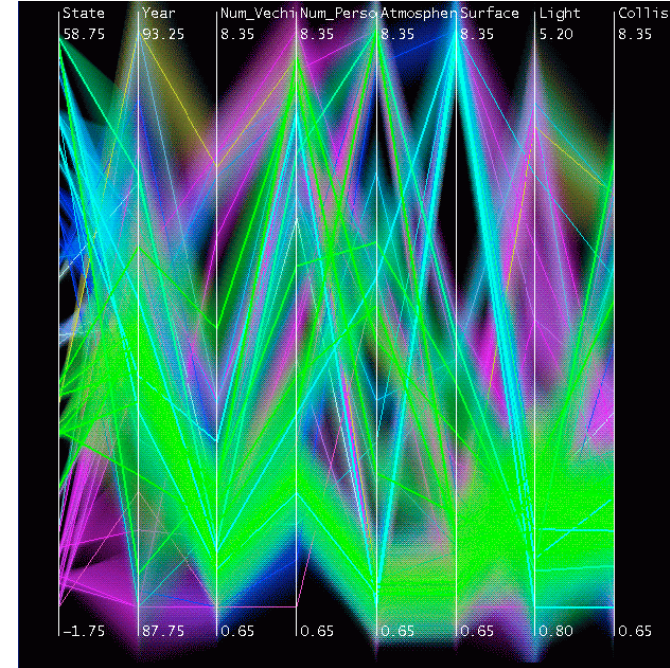
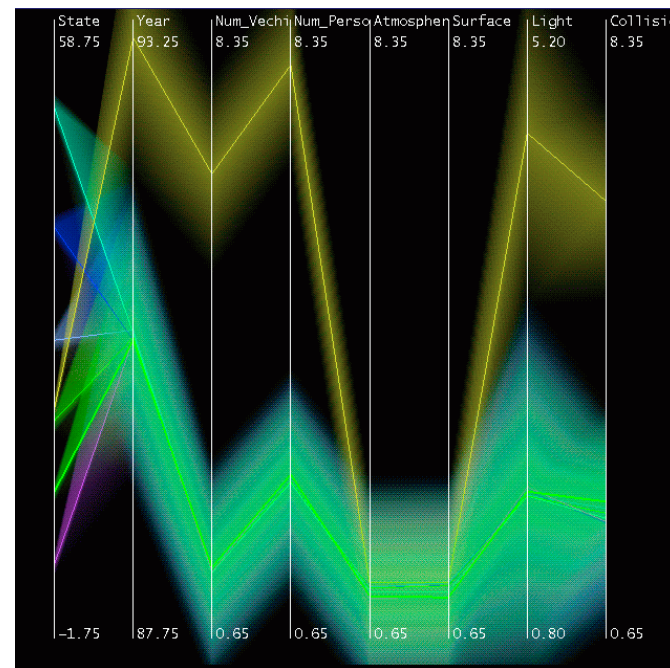
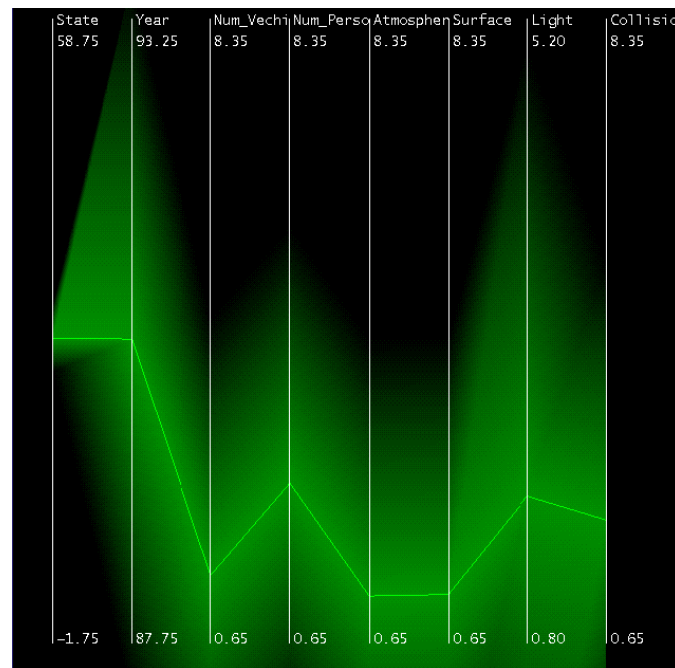
- scale effects



<https://blog.cartographica.com/blog/2011/5/19/the-modifiable-areal-unit-problem-in-gis.html>

Idiom: **Hierarchical parallel coordinates**

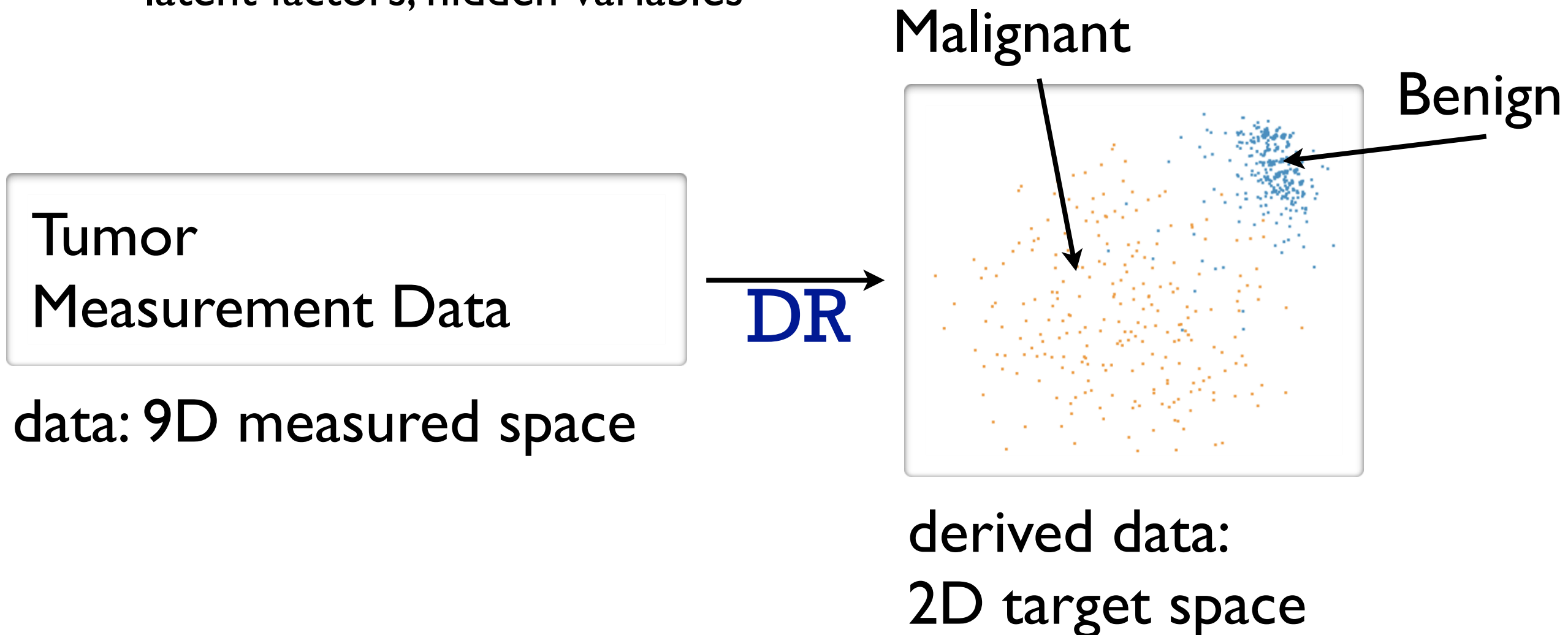
- dynamic item aggregation
- derived data: ***hierarchical clustering***
- encoding:
 - cluster band with variable transparency, line at mean, width by min/max values
 - color by proximity in hierarchy



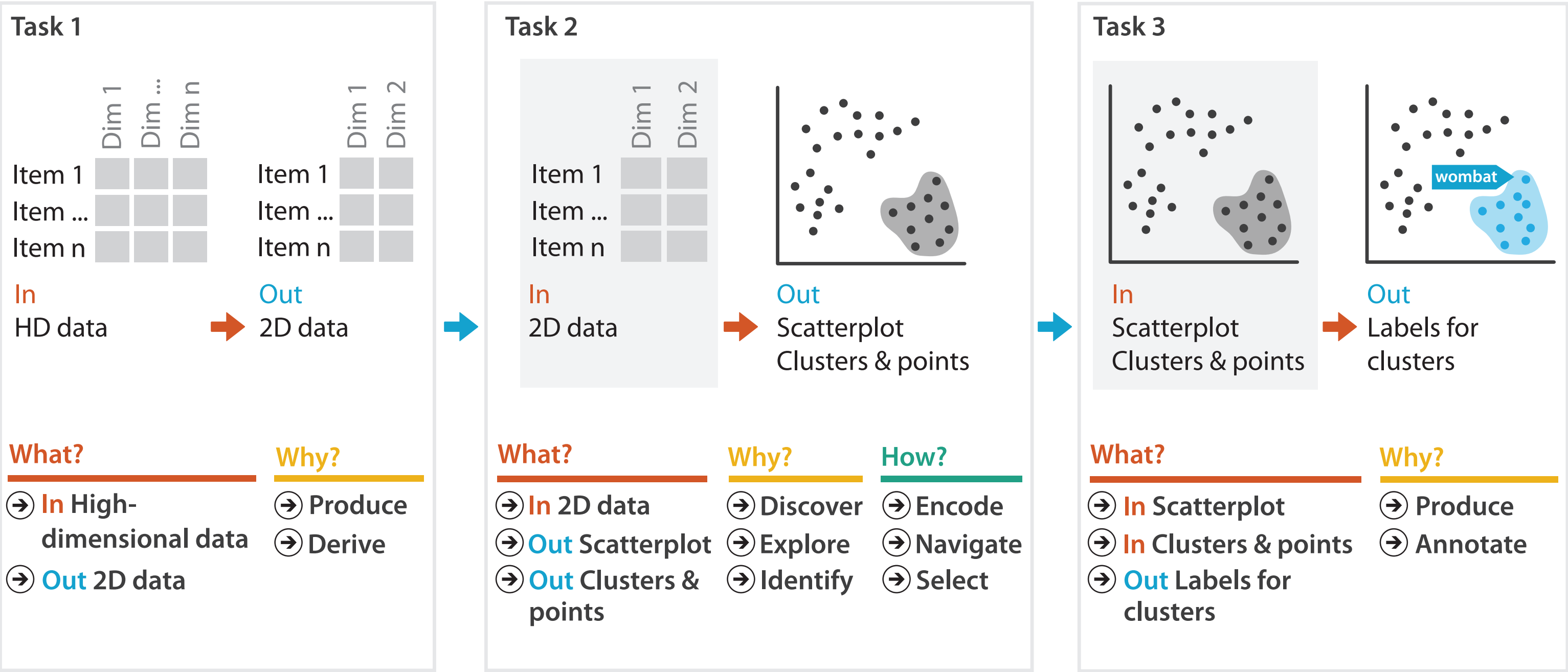
[Hierarchical Parallel Coordinates for Exploration of Large Datasets. Fua, Ward, and Rundensteiner. Proc. IEEE Visualization Conference (Vis '99), pp. 43– 50, 1999.]

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



Idiom: Dimensionality reduction for documents



Further reading

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 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.
- <https://www.cs.ubc.ca/~tmm/vadbook/furtherreading.html#ch13reduce>

What?

Datasets

Attributes

Why?

Actions

Targets

How?

Encode

Manipulate

Facet

Reduce

➔ Arrange

➔ Express

➔ Separate

➔ Map

from **categorical** and **ordered** attributes

➔ Color

➔ Hue

➔ Saturation

➔ Luminance

➔ Size, Angle, Curvature, ...

➔ Shape

➔ Motion

Direction, Rate, Frequency, ...

➔ Change

➔ Select

➔ Navigate

➔ Juxtapose

➔ Partition

➔ Superimpose

➔ Filter

➔ Aggregate

➔ Embed

What?

Why?

How?

domain

abstraction

What?

Why?

How?

idiom

algorithm

More information

- this tutorial

www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25

- book

<http://www.cs.ubc.ca/~tmm/vadbook>

– <https://www.routledge.com/Visualization-Analysis-and-Design/Munzner/p/book/9781466508910>

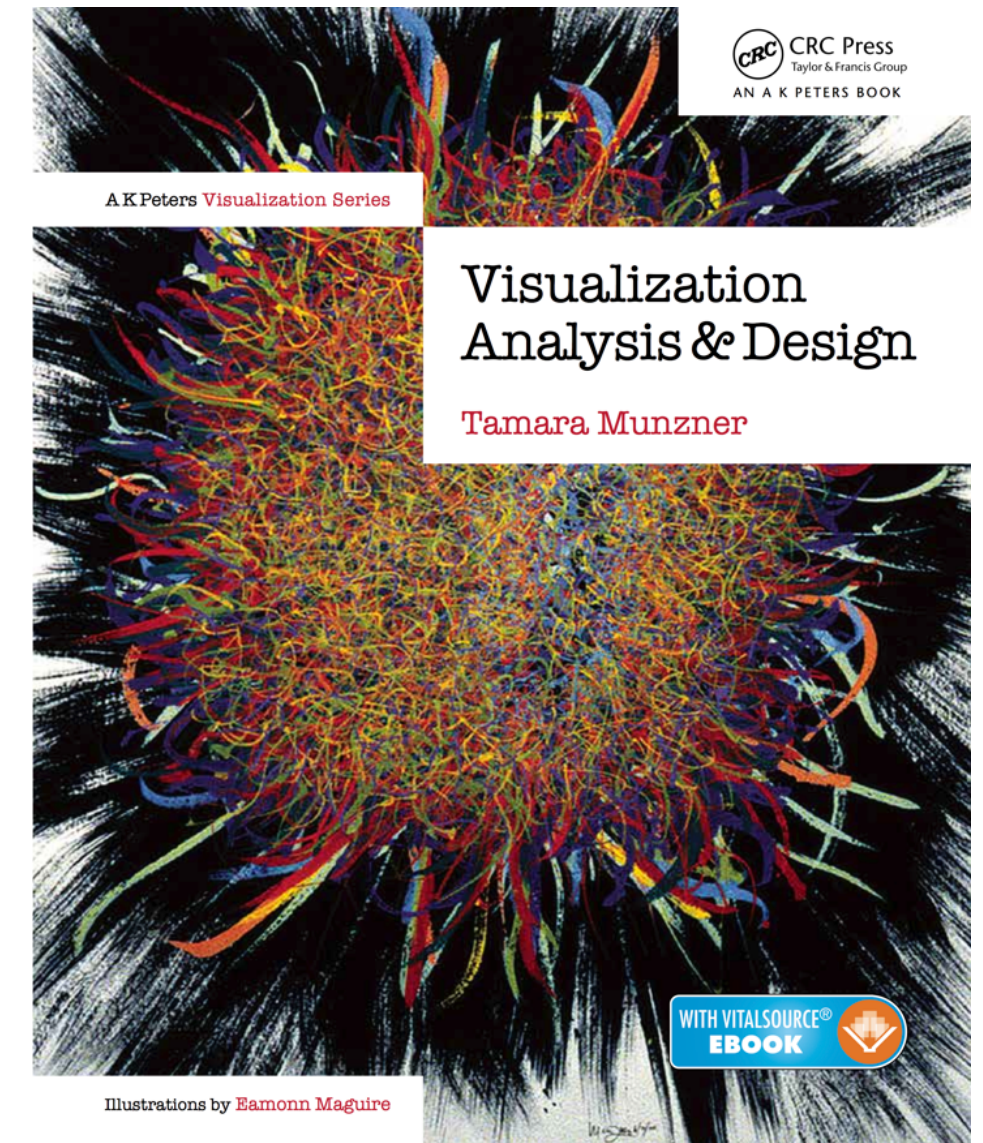
– illustration acknowledgement: Eamonn Maguire

- full courses, papers, videos, software, talks

<http://www.cs.ubc.ca/group/infovis>

<http://www.cs.ubc.ca/~tmm>

 @tamara@cosocial.ca



Visualization Analysis and Design. Munzner.
CRC Press, AK Peters Visualization Series, 2014.

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www.cs.ubc.ca/~tmm/talks.html#halfdaycourse25