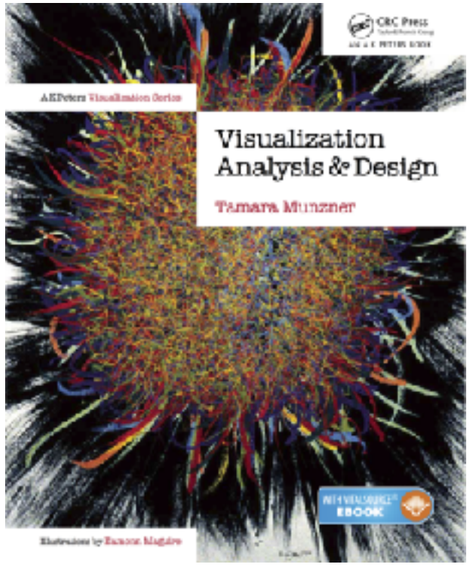
Visualization Analysis & Design



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Bio+Med+Vis Spring School
May 19 2021, virtual

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

@tamaramunzner

Visualization: definition & motivation

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

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

- human in the loop needs the details & no trusted automatic solution exists
  - doesn't know exactly what questions to ask in advance
  - exploratory data analysis
    - ***speed up*** through human-in-the-loop visual data analysis
  - present known results to others
  - stepping stone towards automation
    - before model creation to provide understanding
    - during algorithm creation to refine, debug, set parameters
    - before or during deployment to build trust and monitor

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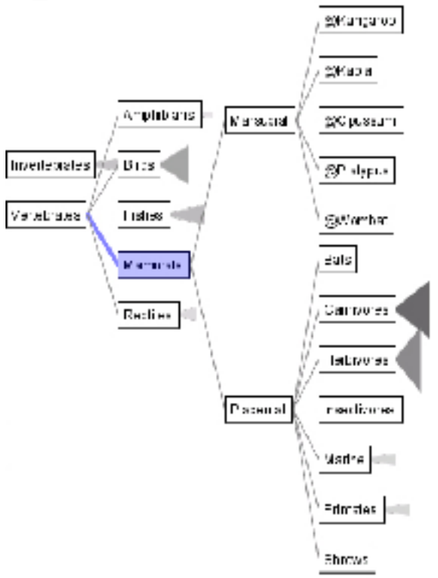
more at:
Visualization Analysis and Design.
Munzner. CRC Press, 2014.

Why analyze?

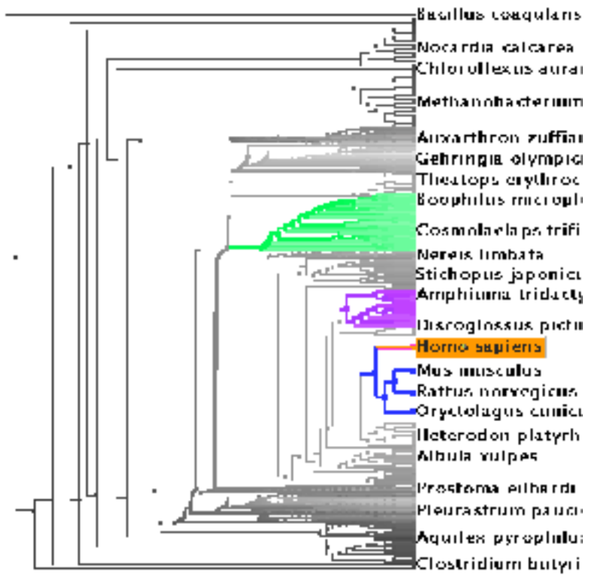
- imposes a structure on huge design space
  - scaffold to help you think systematically about choices
  - analyzing existing as stepping stone to designing new

SpaceTree



[SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation. Grosjean, Plaisant, and Bederson. Proc. InfoVis 2002, p 57–64.]

TreeJuxtaposer



[TreeJuxtaposer: Scalable Tree Comparison Using Focus+Context With Guaranteed Visibility. ACM Trans. on Graphics (Proc. SIGGRAPH) 22:453– 462, 2003.]

What?

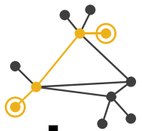
- Tree

Why?

- Actions
  - Present
  - Locate
  - Identify



- Targets
  - Path between two nodes



How?

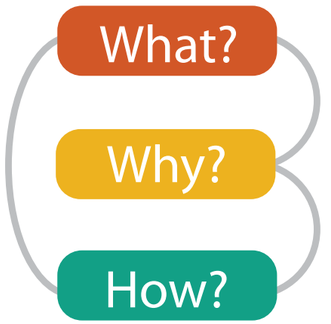
- SpaceTree
  - Encode
  - Navigate
  - Select
  - Filter
  - Aggregate





- TreeJuxtaposer
  - Encode
  - Navigate
  - Select
  - Arrange



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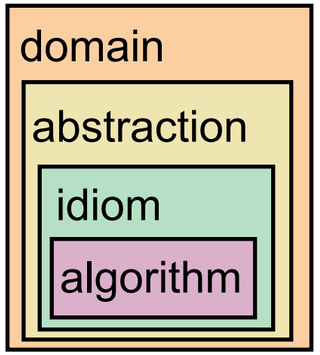
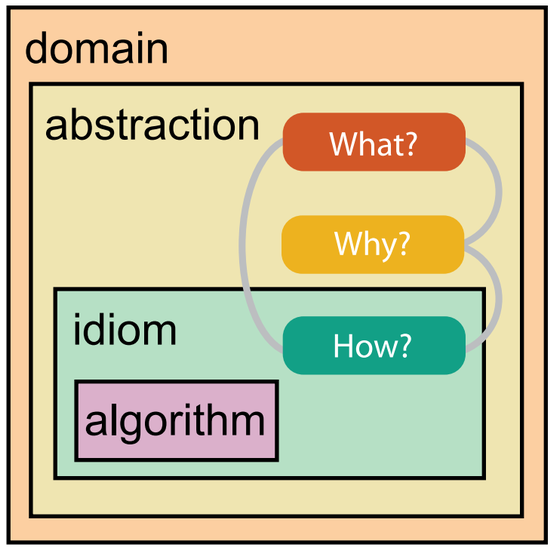
Analysis framework: Four levels, three questions

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



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

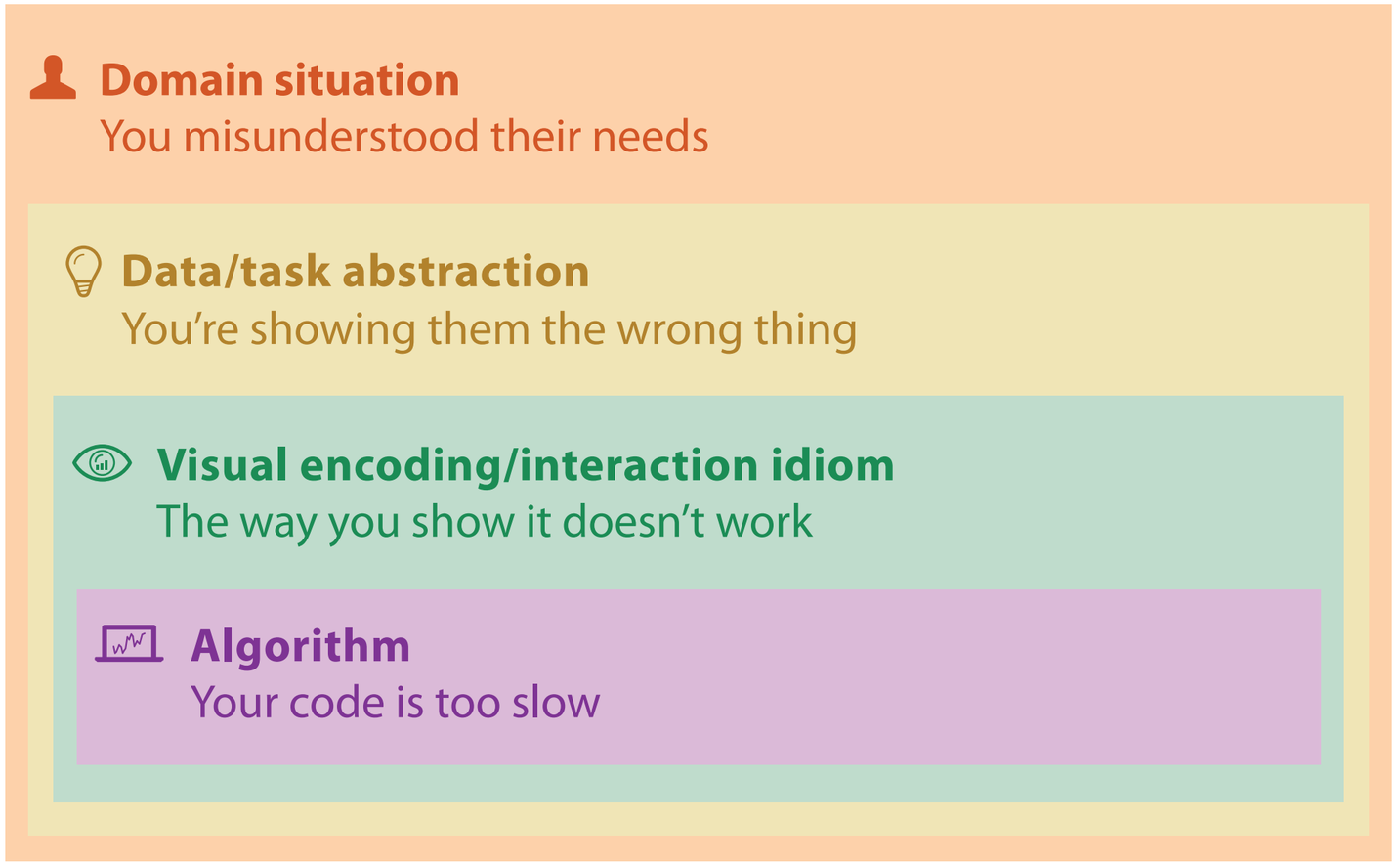


[A Multi-Level Typology of Abstract Visualization Tasks *Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).*]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Why is validation difficult?

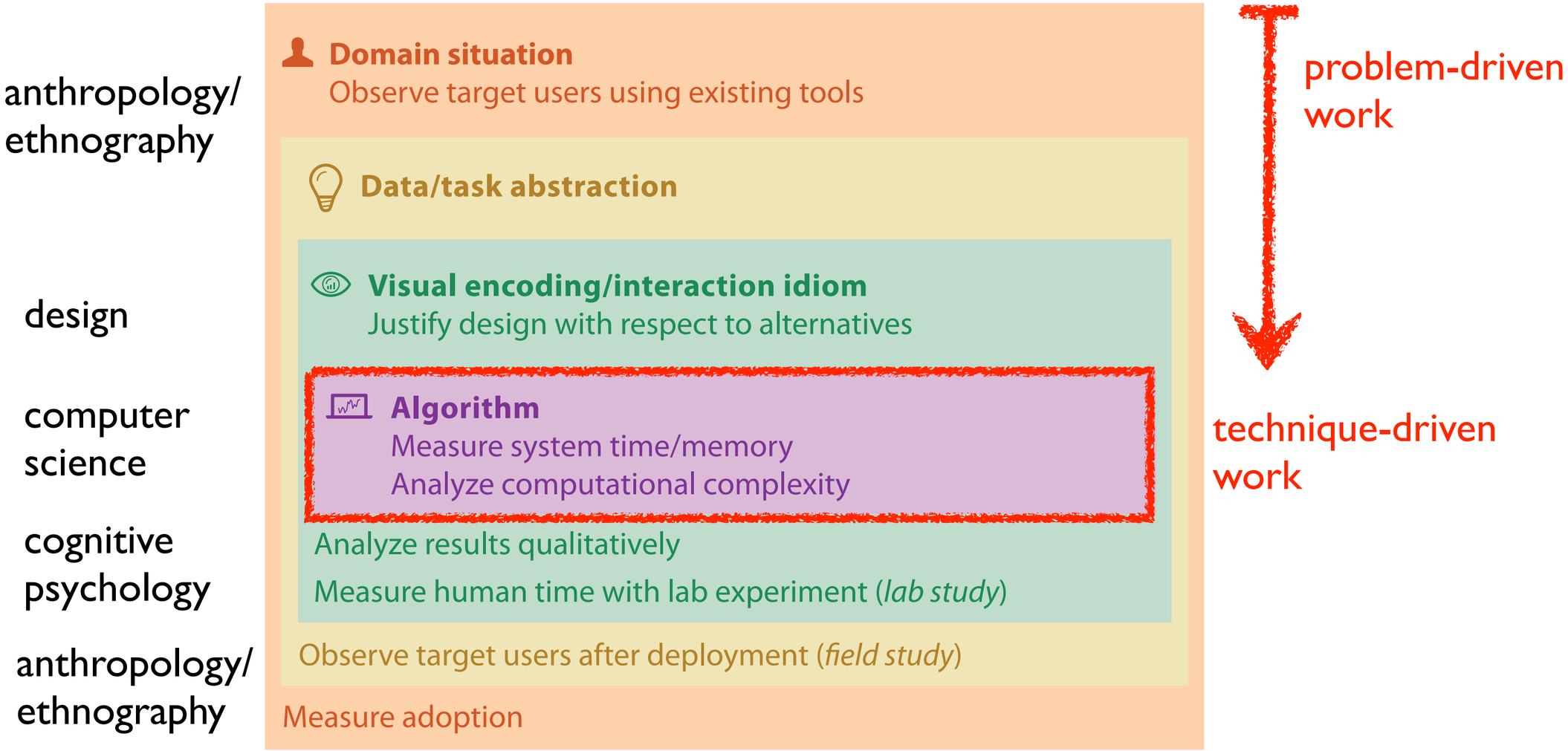
- different ways to get it wrong at each level



http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Why is validation difficult?

- solution: use methods from different fields at each level



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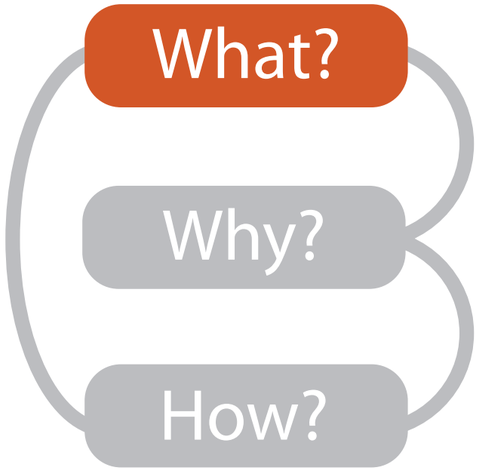


What?

Datasets

Data Types

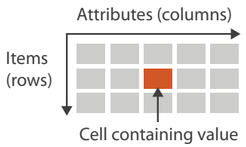
→ Items → Attributes → Links → Positions → Grids

Data and Dataset Types

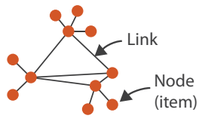
Tables	Networks & Trees	Fields	Geometry	Clusters, Sets, Lists
Items	Items (nodes)	Grids	Items	Items
Attributes	Links	Positions	Positions	
	Attributes	Attributes		

Dataset Types

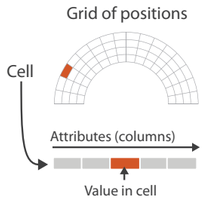
→ Tables



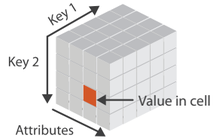
→ Networks



→ Fields (Continuous)



→ *Multidimensional Table*



→ *Trees*

→ Geometry (Spatial)

Attributes

Attribute Types

→ Categorical

→ Ordered

→ *Ordinal*

→ *Quantitative*

Ordering Direction

→ Sequential

→ Diverging

→ Cyclic

Dataset Availability

→ Static

→ Dynamic

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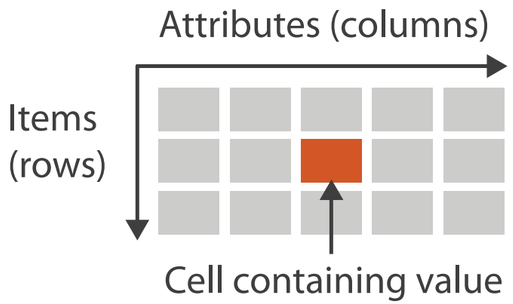
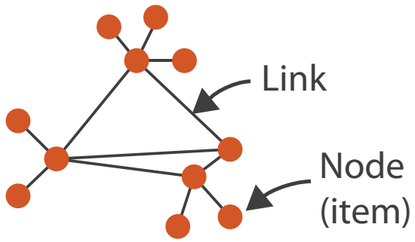
Types: Datasets and data

Dataset Types

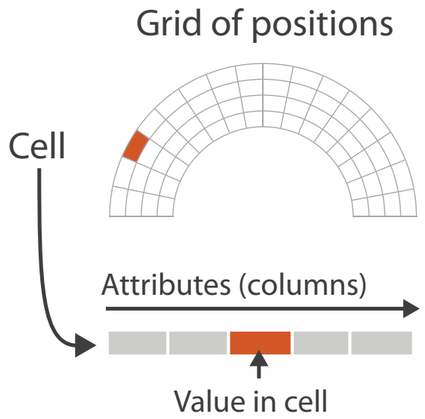
- Tables



- Networks



- Spatial
- Fields (Continuous)



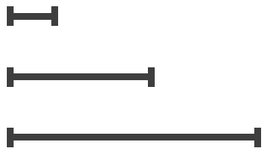
- Geometry (Spatial)

Attribute Types

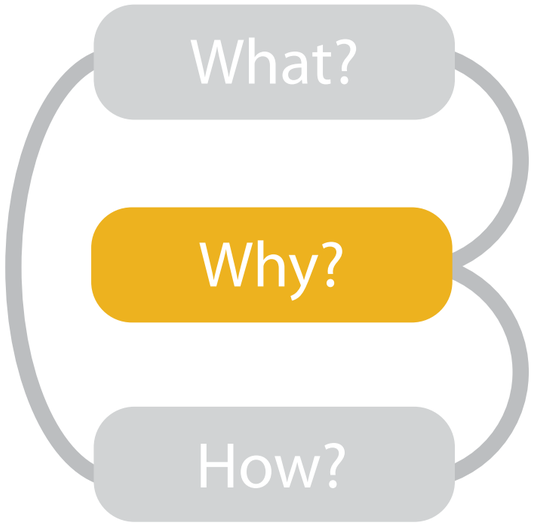
- Categorical

- Ordered
  - *Ordinal*

  - *Quantitative*



http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis



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

Why?

Actions

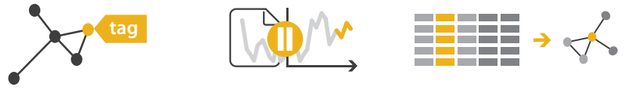
Analyze

→ Consume

→ *Discover* → *Present* → *Enjoy*

→ Produce

→ *Annotate* → *Record* → *Derive*

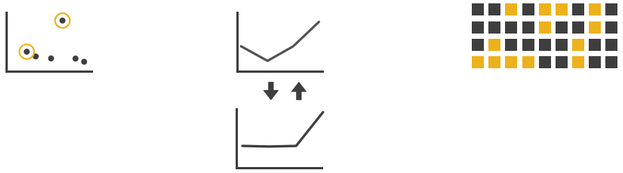


Search

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

Query

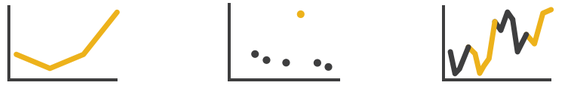
→ Identify → Compare → Summarize



Targets

All Data

→ Trends → Outliers → Features

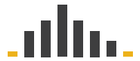


Attributes

→ One → Many

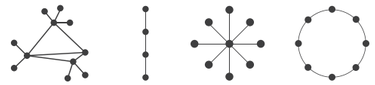
→ *Distribution* → *Dependency* → *Correlation* → *Similarity*

→ *Extremes*



Network Data

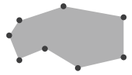
→ Topology

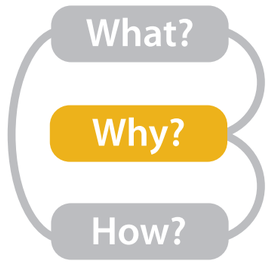


→ *Paths*

Spatial Data

→ Shape





http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

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

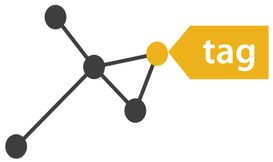
→ *Discover*

→ *Present*

→ *Enjoy*

→ Produce

→ *Annotate*

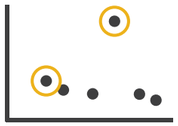


→ *Record*

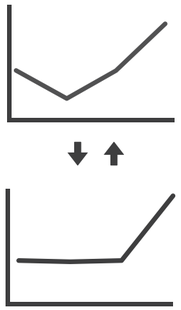
→ *Derive*

Query

→ Identify



→ Compare



→ Summarize

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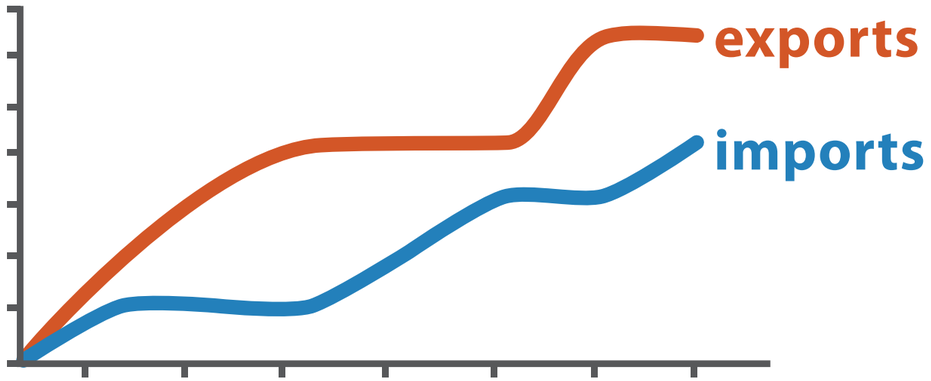
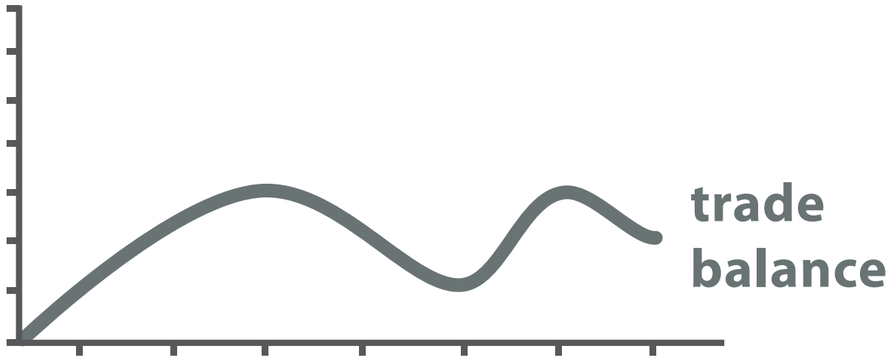
Derive: Crucial Design Choice

- don't 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



trade balance = *exports* – *imports*

Derived Data

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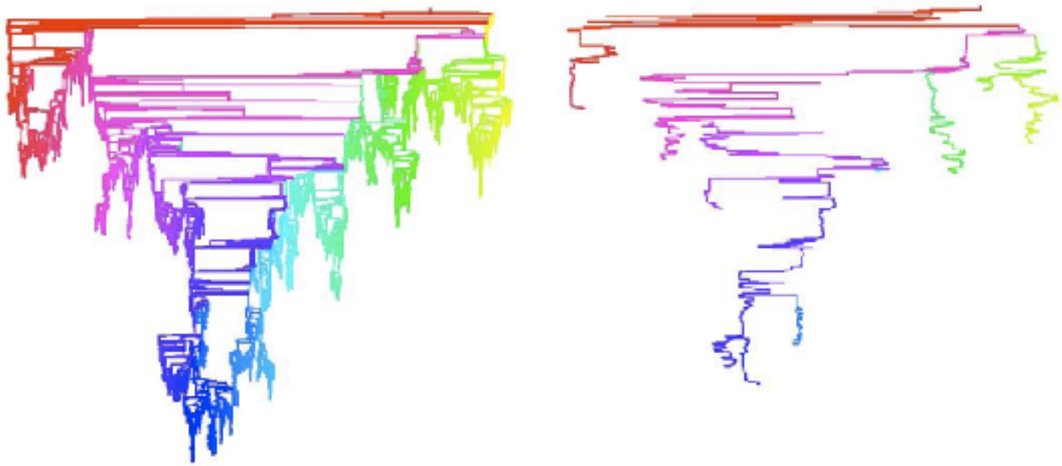
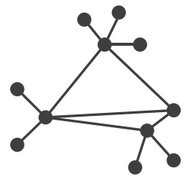
Analysis example: Derive one attribute

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

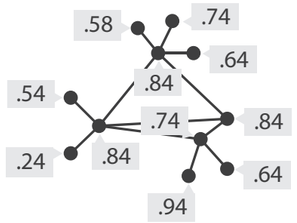
[Using Strahler numbers for real time visual exploration of huge graphs. Auber. Proc. Intl. Conf. Computer Vision and Graphics, pp. 56–69, 2002.]



Task 1



In
Tree



Out
Quantitative attribute on nodes

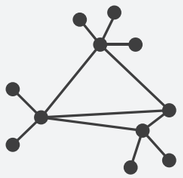
What?

- In Tree
- Out Quantitative attribute on nodes

Why?

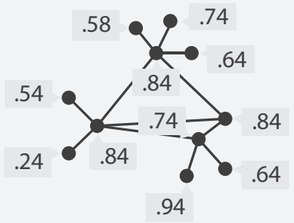
- Derive

Task 2



In
Tree

+



In
Quantitative attribute on nodes

Out
Filtered Tree
Removed unimportant parts

What?

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

Why?

- Summarize
- Topology

How?

- Reduce
- Filter

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Targets

All Data

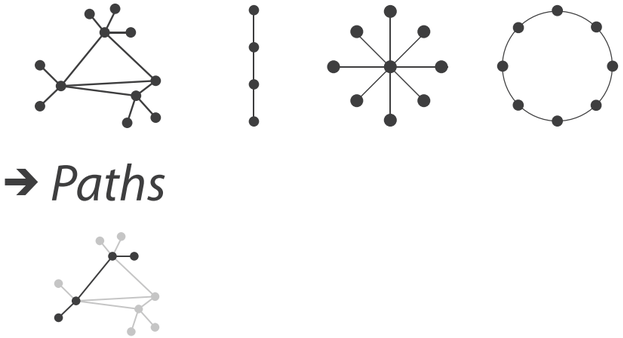
- Trends
- Outliers
- Features

Attributes

- One
  - *Distribution*
  - *Extremes*
- Many
  - *Dependency*
  - *Correlation*
  - *Similarity*

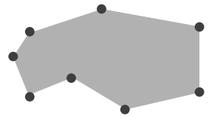
Network Data

- Topology
- *Paths*



Spatial Data

- Shape



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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

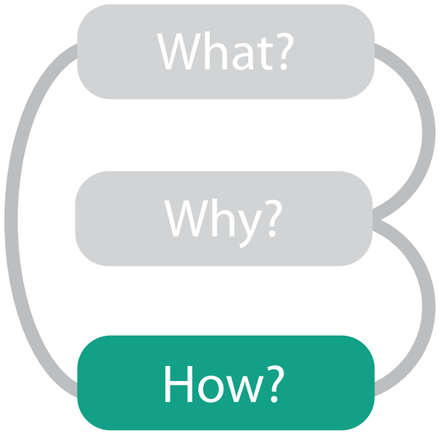
- **Change**
- **Select**
- **Navigate**

Facet

- **Juxtapose**
- **Partition**
- **Superimpose**

Reduce

- **Filter**
- **Aggregate**
- **Embed**

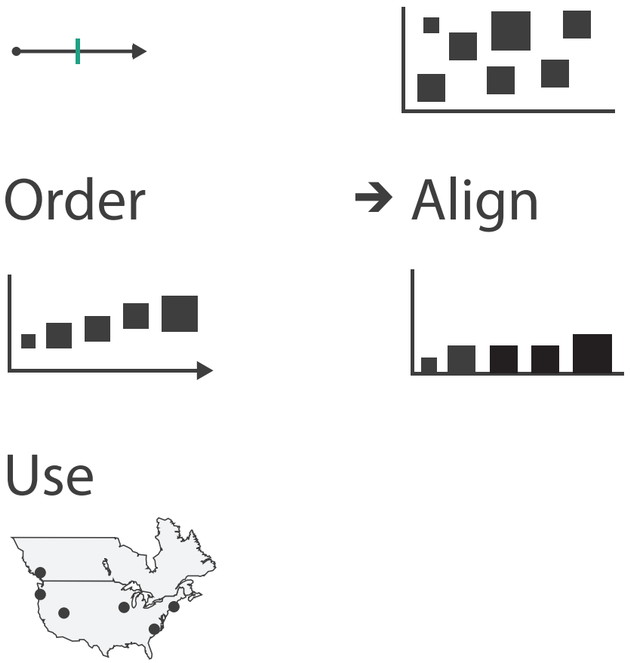


http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

How to encode: Arrange space, map channels

Encode

- **Arrange**
  - Express
  - Separate
  - Order
  - Align
  - Use



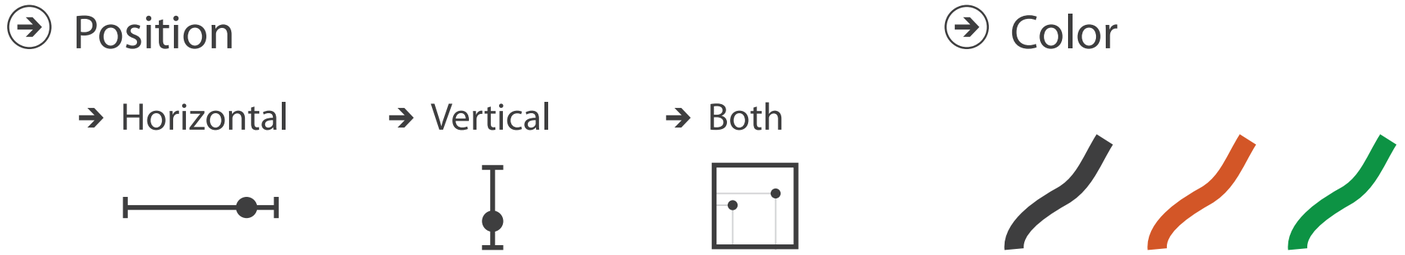
- **Map**
  from categorical and ordered attributes
  - Color
    - *Hue*
    - *Saturation*
    - *Luminance*
  - Size, Angle, Curvature, ...
  - Shape
  - Motion
    Direction, Rate, Frequency, ...

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Definitions: Marks and channels

- marks
  - geometric primitives
  - one per item

- channels
  - control appearance of marks



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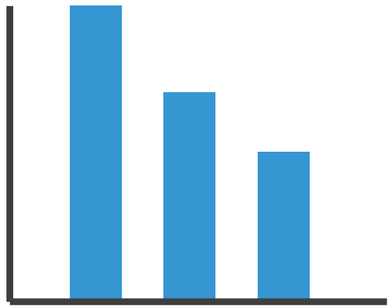
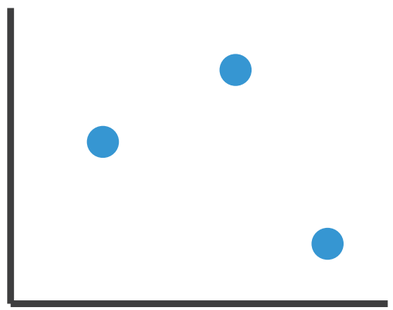
Encoding visually with marks and channels

- analyze idiom structure
  - as combination of marks and channels



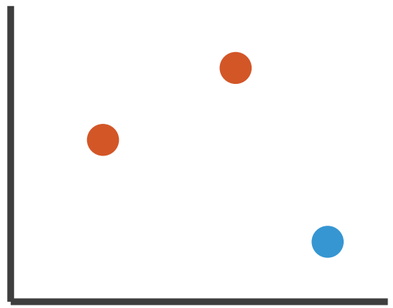
1:
vertical position

mark: line



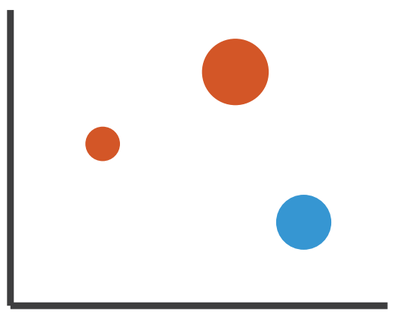
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

mark: point



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

mark: point

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Channels

Position on common scale

Position on unaligned scale

Length (1D size)

Tilt/angle

Area (2D size)

Depth (3D position)

Color luminance

Color saturation

Curvature

Volume (3D size)

Same

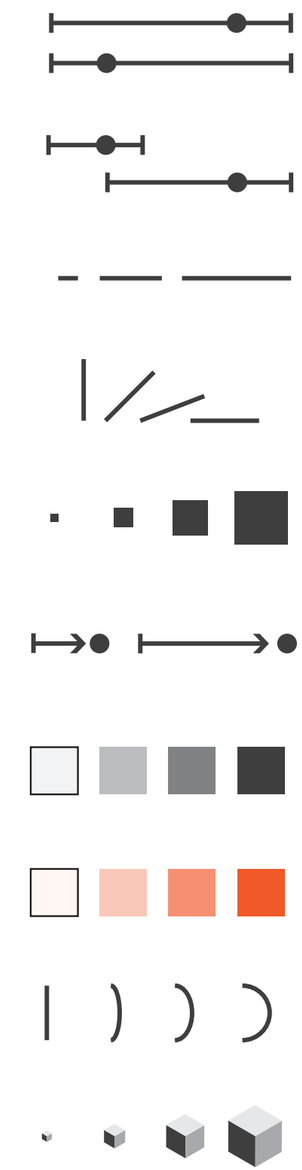
Same

Spatial region

Color hue

Motion

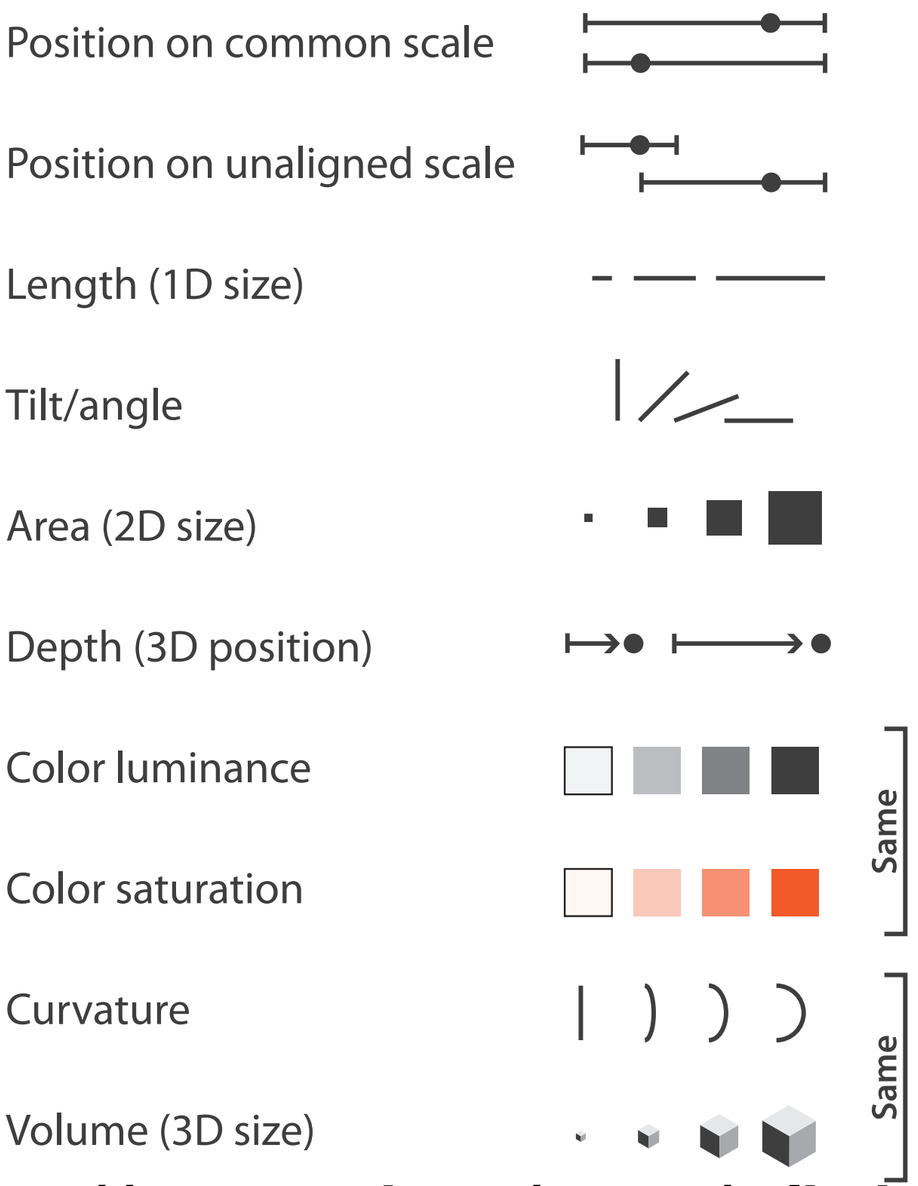
Shape



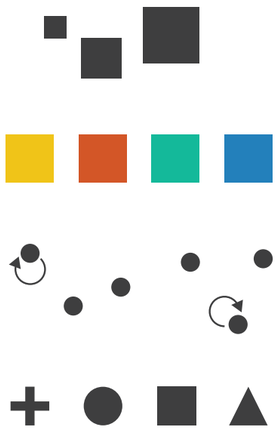
http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Channels: Matching Types

Magnitude Channels: Ordered Attributes



Identity Channels: Categorical Attributes

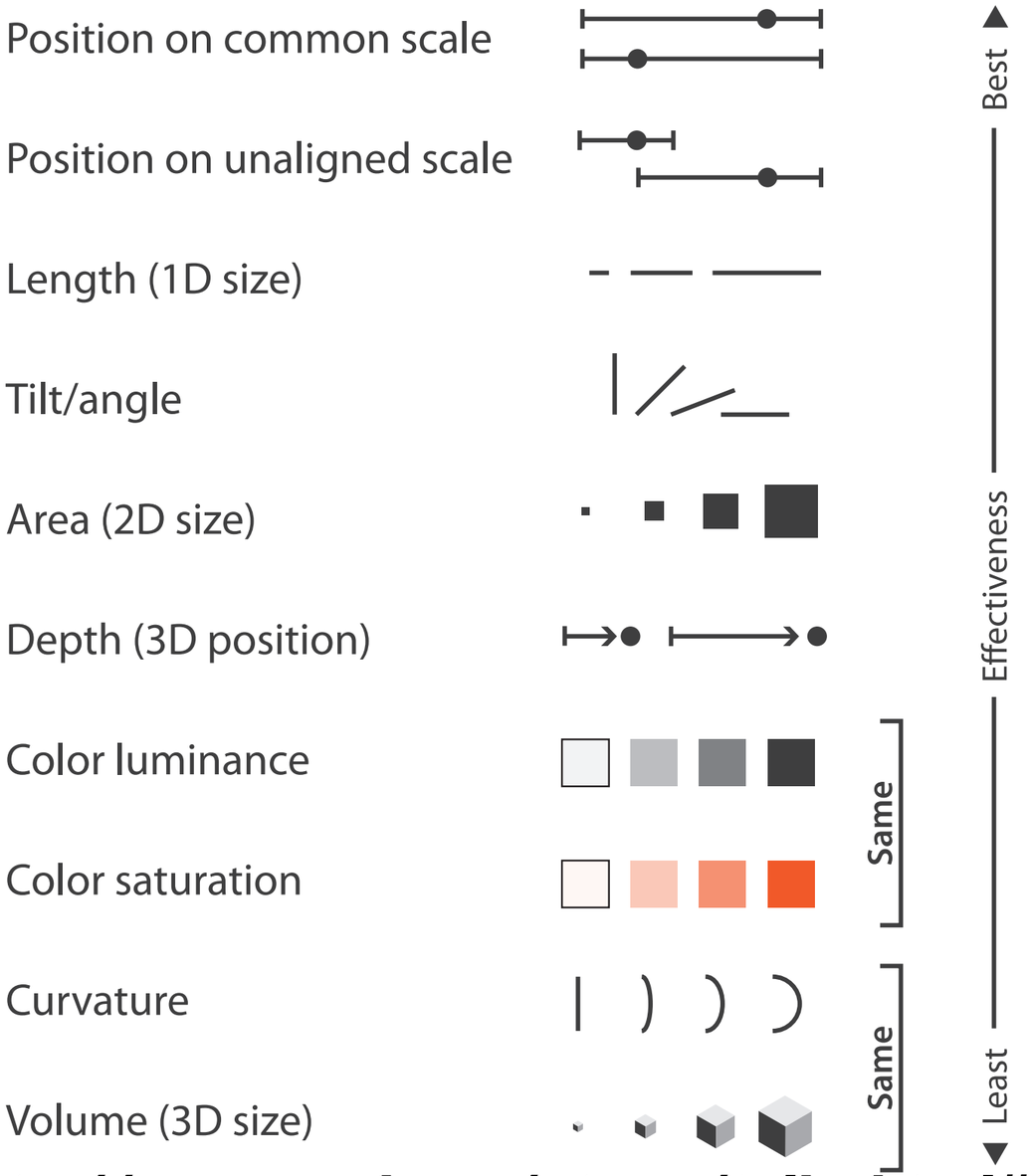


- expressiveness principle
  - match channel and data characteristics

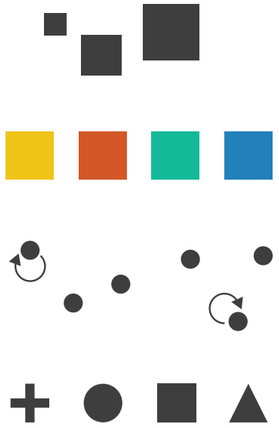
http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Channels: Rankings

Magnitude Channels: Ordered Attributes



Identity Channels: Categorical Attributes



- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception
- distinguishability
  - match available levels in channel w/ data

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

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

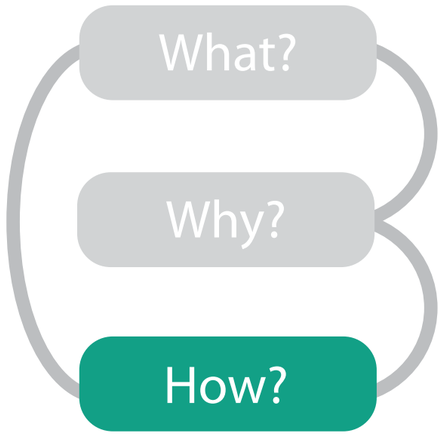
- **Change**
- **Select**
- **Navigate**

Facet

- **Juxtapose**
- **Partition**
- **Superimpose**

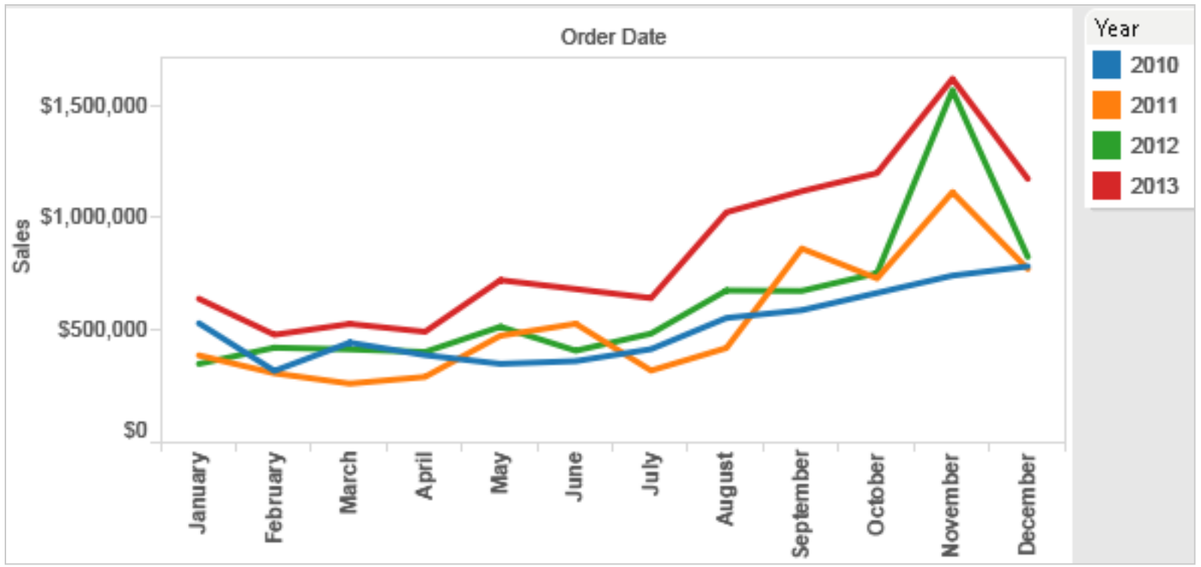
Reduce

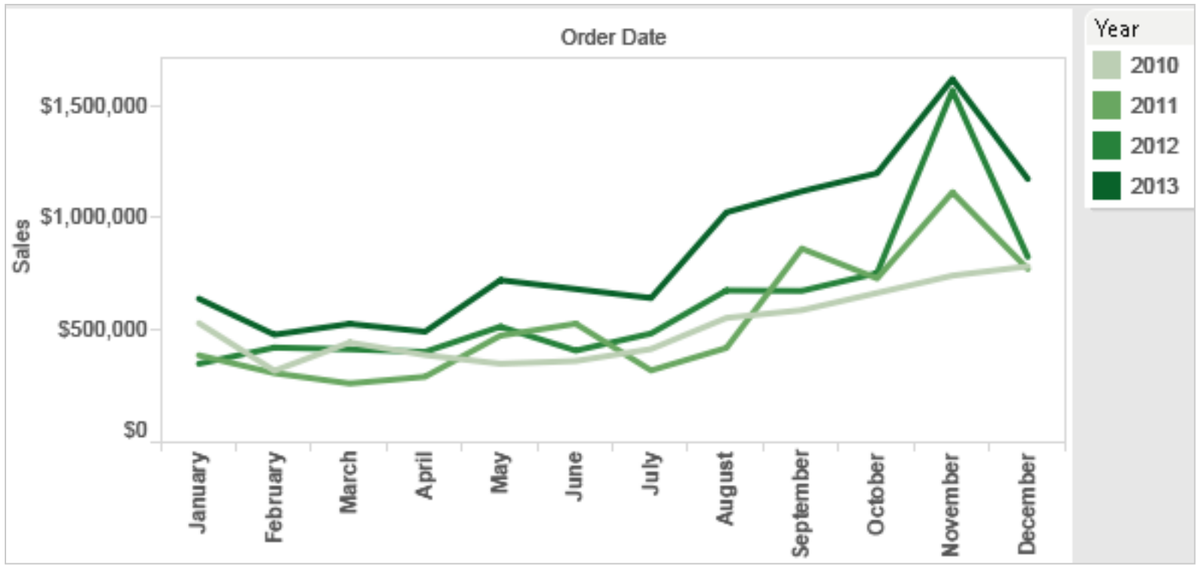
- **Filter**
- **Aggregate**
- **Embed**

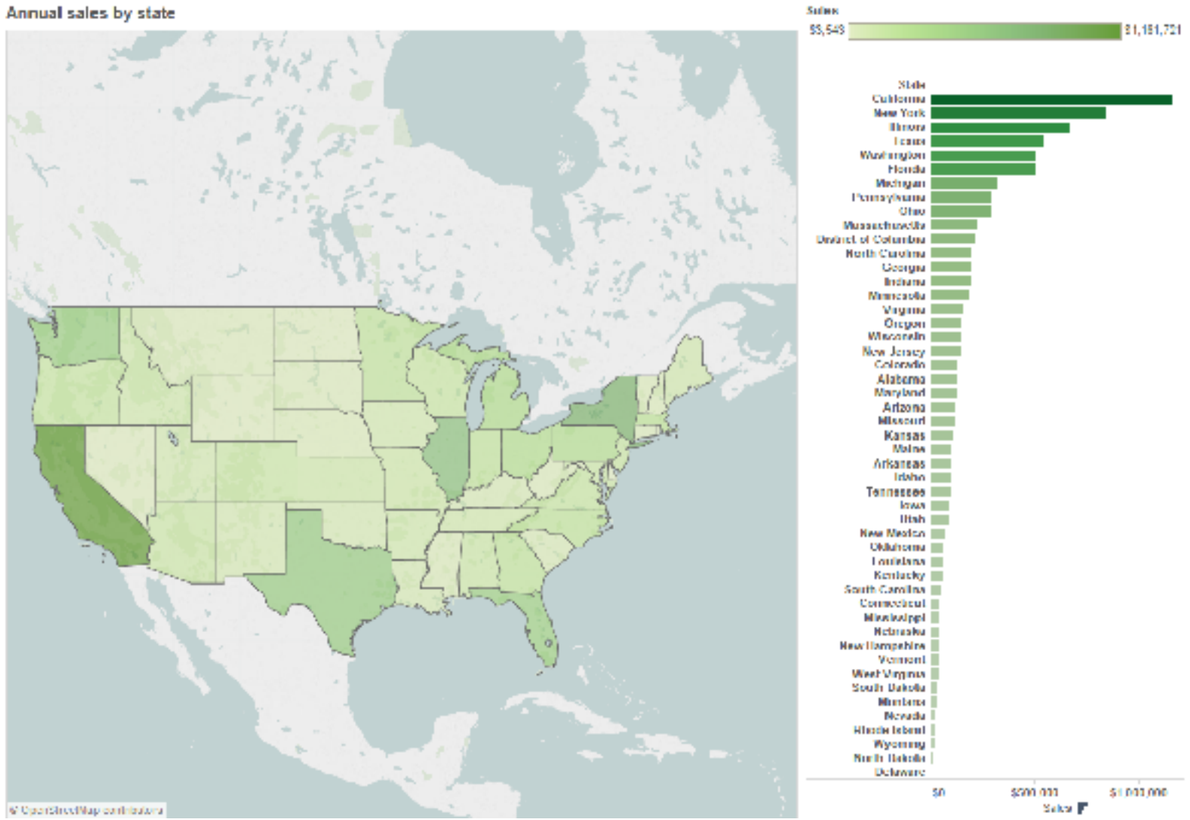


http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Categorical vs ordered color





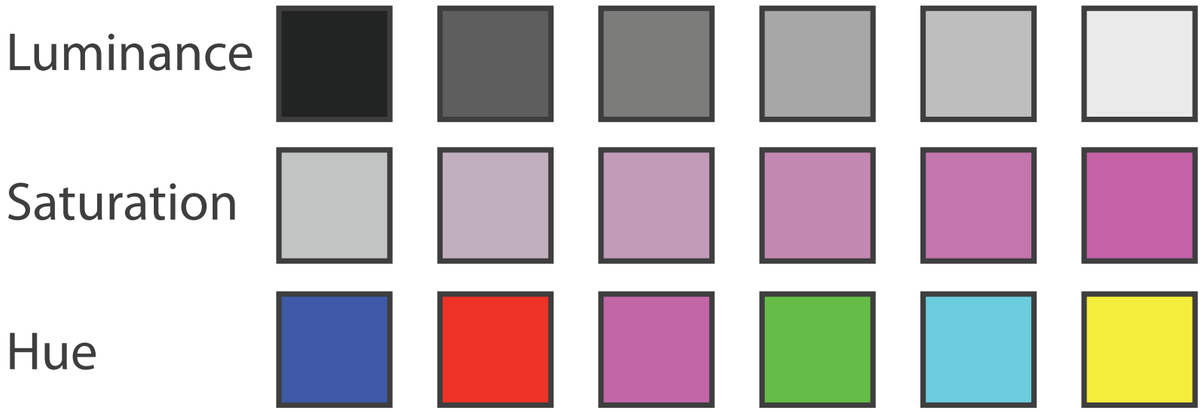


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

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: how bright
    - saturation: how colorful
  - categorical can show identity
    - hue: what color
  - caveat: not well supported by current tools

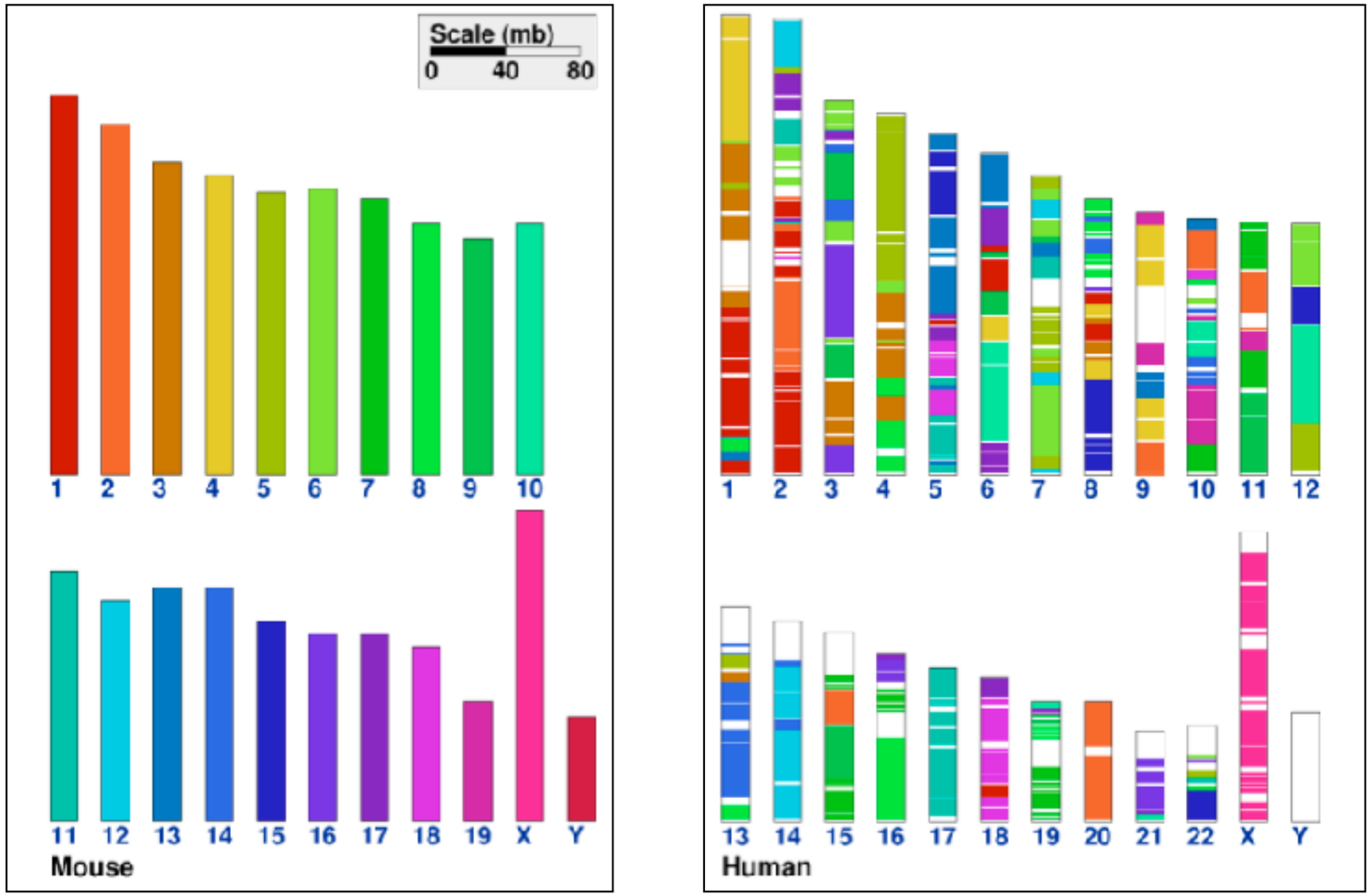


- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey: how many discriminable bins can we use?

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Categorical color: limited number of discriminable bins

- human perception built on relative comparisons
  - great if color contiguous
  - surprisingly bad for absolute comparisons
- noncontiguous small regions of color
  - fewer bins than you want
  - rule of thumb: 6-12 bins, including background and highlights
- alternatives? other talks!

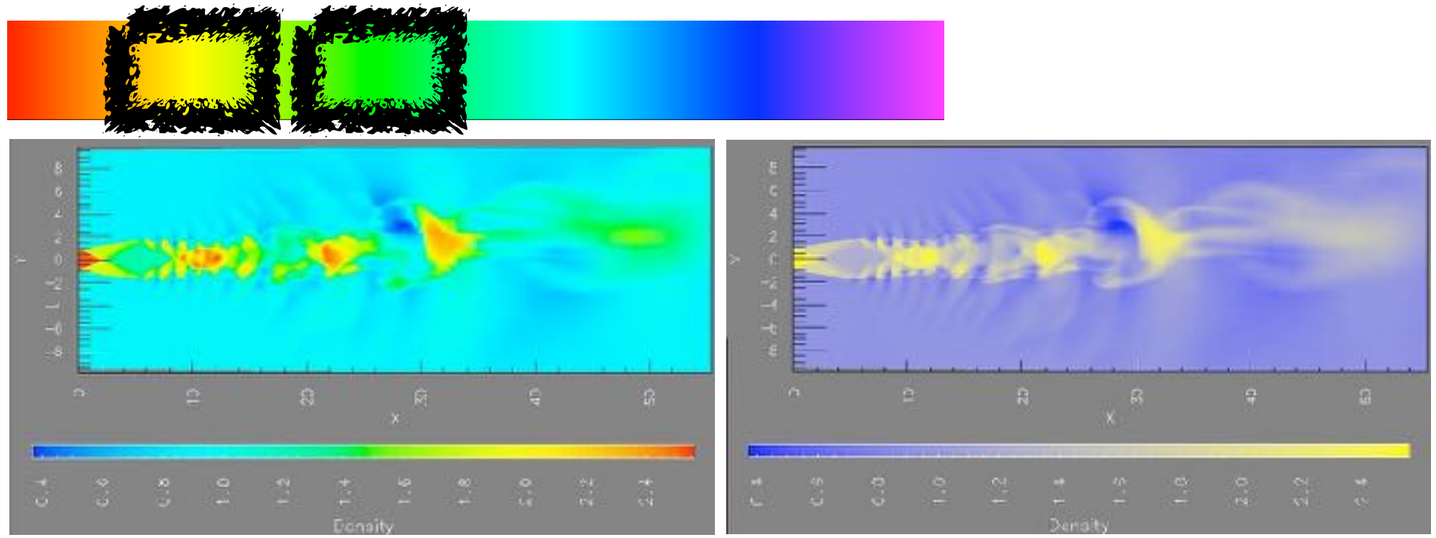


[Cinteny: flexible analysis and visualization of synteny and genome rearrangements in multiple organisms. Sinha and Meller. BMC Bioinformatics, 8:82, 2007.]

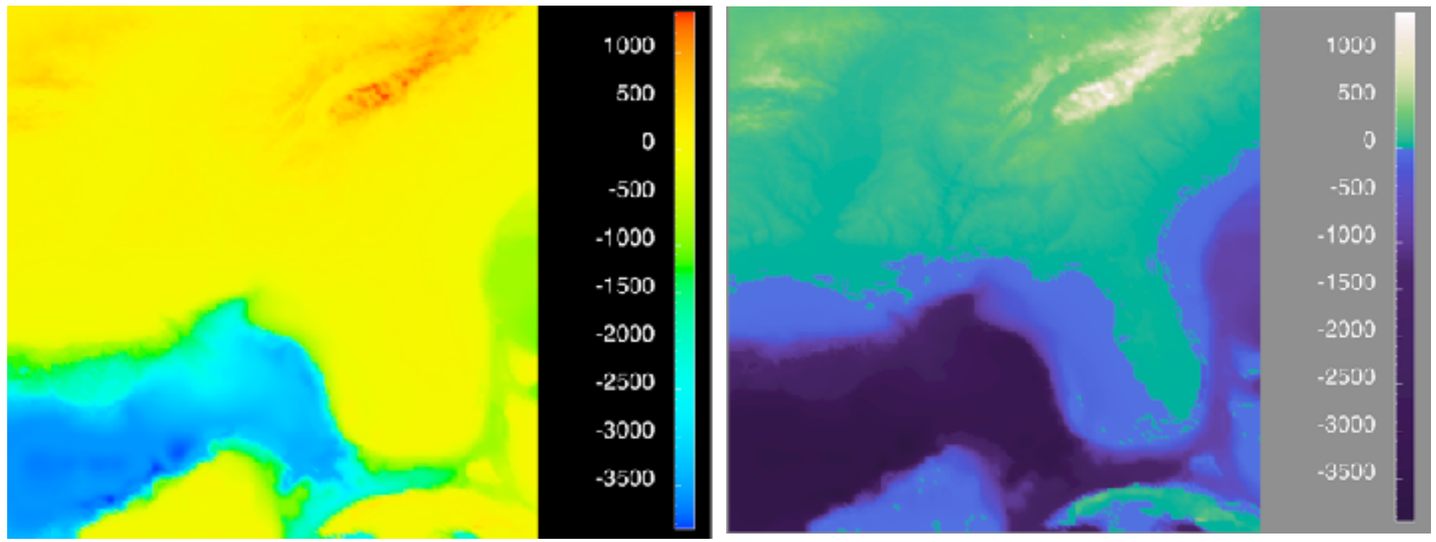
http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear
- benefits
  - small-scale structure: see & name
- alternatives
  - large-scale structure: fewer hues
  - known structure: segmented
  - have it both ways, small+large:
    - multiple hues
    - monotonically increasing luminance



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



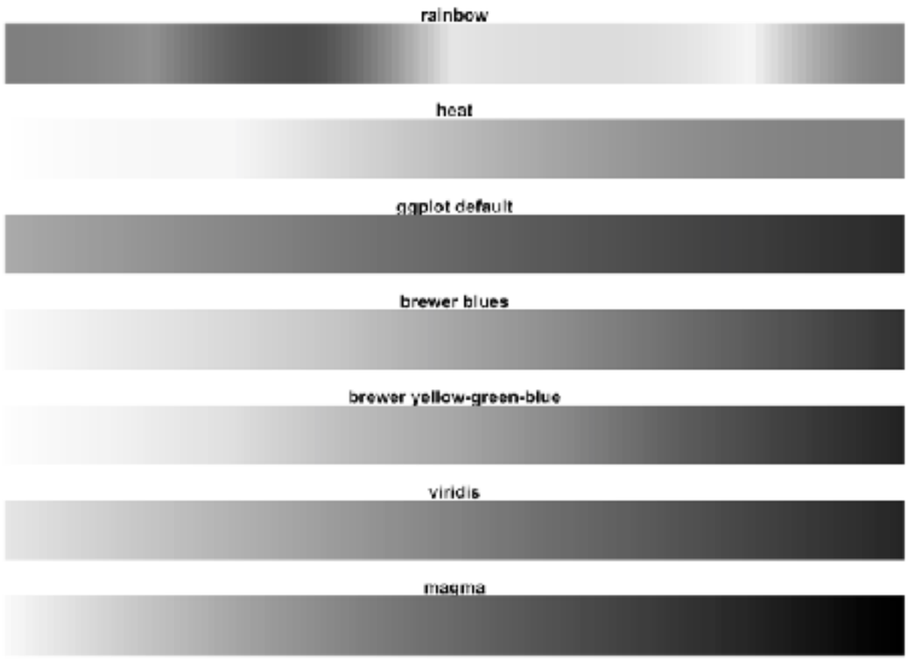
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Viridis / Magma

- colorful, perceptually uniform, colorblind-safe, monotonically increasing luminance

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



http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

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

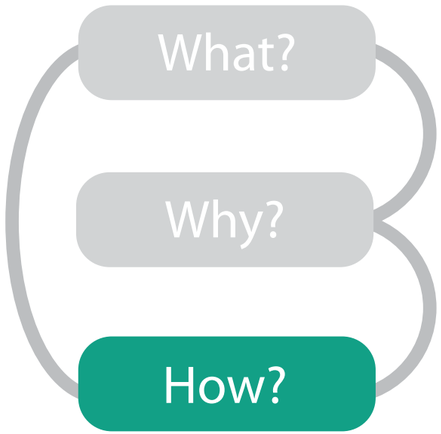
- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed



http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

How to handle complexity: 3 more strategies + 1 previous

Manipulate	Facet	Reduce
Change	Juxtapose	Filter
Select	Partition	Aggregate
Navigate	Superimpose	Embed

→ *Derive*

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

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

How to handle complexity: 3 more strategies + 1 previous

Manipulate

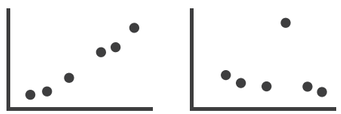
- Change

- Select

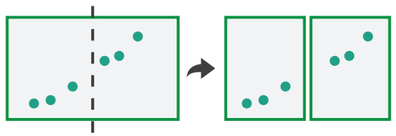
- Navigate

Facet

- Juxtapose



- Partition

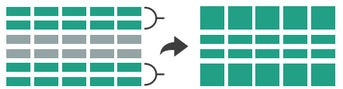


- Superimpose

Reduce

- Filter

- Aggregate



- Embed

- → *Derive*

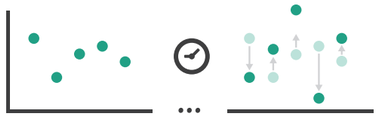
- change over time
  - most obvious & flexible of the 4 strategies

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

How to handle complexity: 3 more strategies + 1 previous

Manipulate

- Change



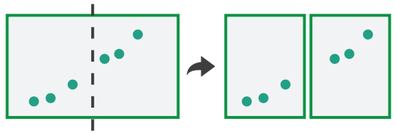
- Select

- Navigate

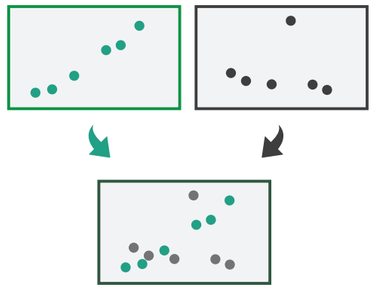
Facet

- Juxtapose

- Partition



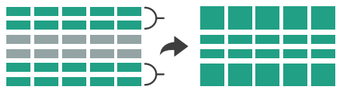
- Superimpose



Reduce

- Filter

- Aggregate



- Embed

- *Derive*

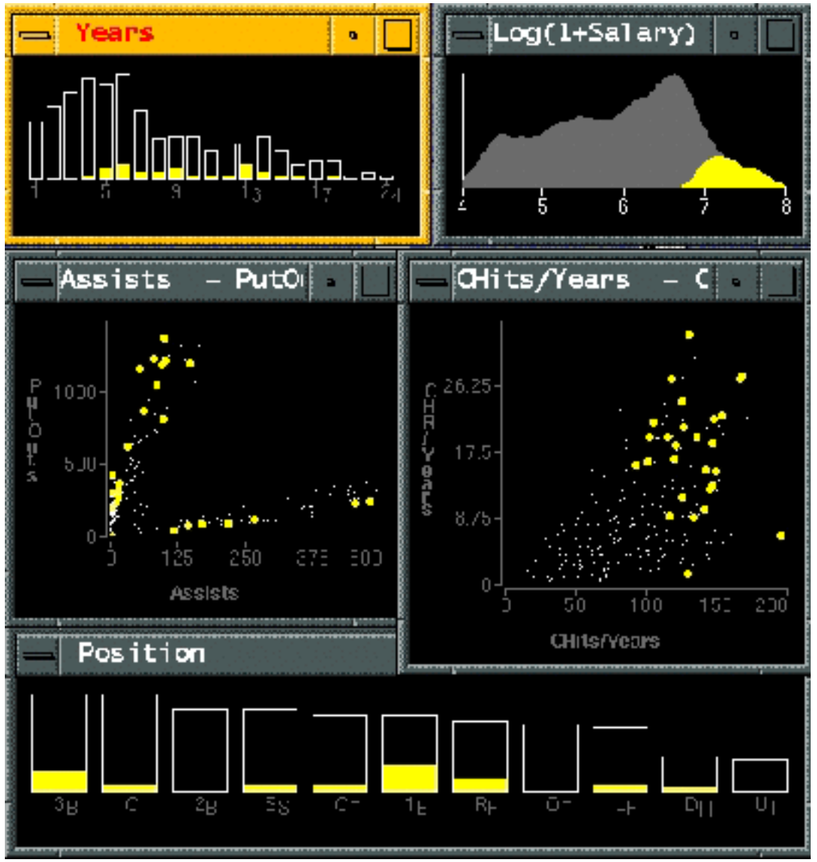
- facet data across multiple views

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Idiom: **Linked highlighting**

System: **EDV**

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



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

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Idiom: **bird's-eye maps**

System: **Google Maps**

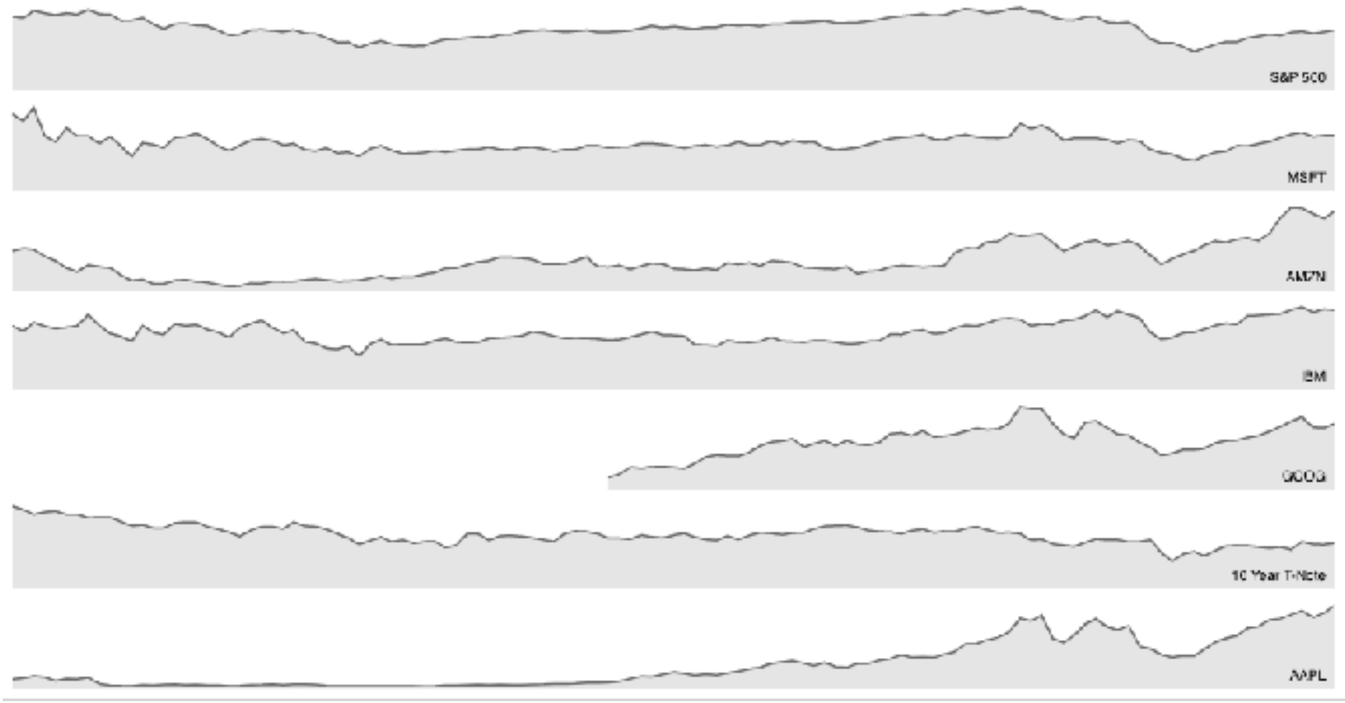
- encoding: same
- data: subset shared
- navigation: shared
  - bidirectional linking
- differences
  - viewpoint
  - (size)
- ***overview-detail***

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

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Idiom: **Small multiples**

- encoding: same
  - ex: line charts
- data: none shared
  - different slices of dataset
    - items or attributes
    - ex: stock prices for different companies

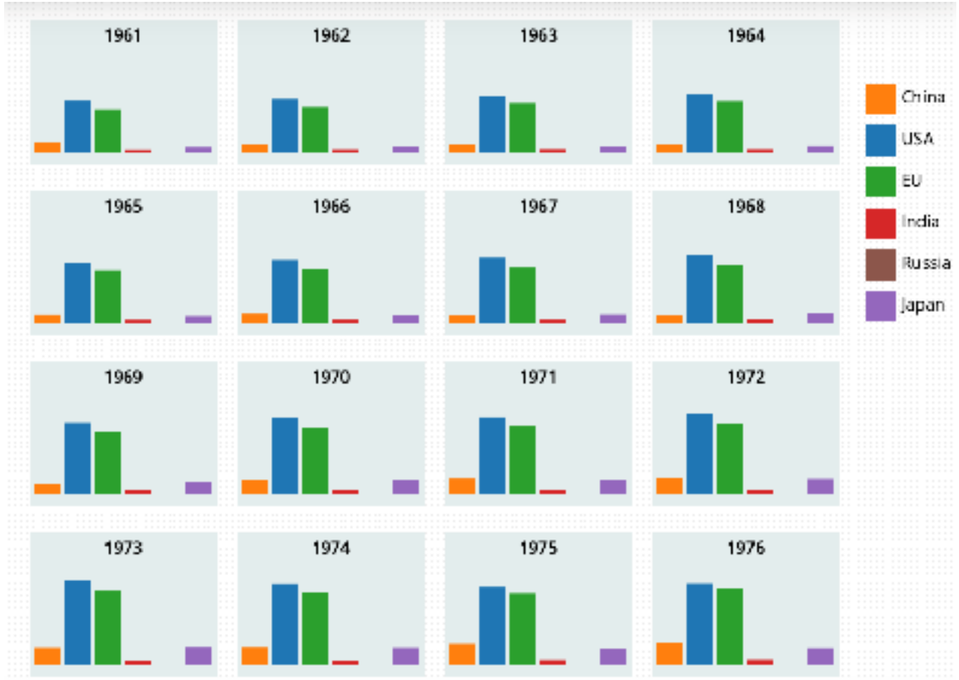


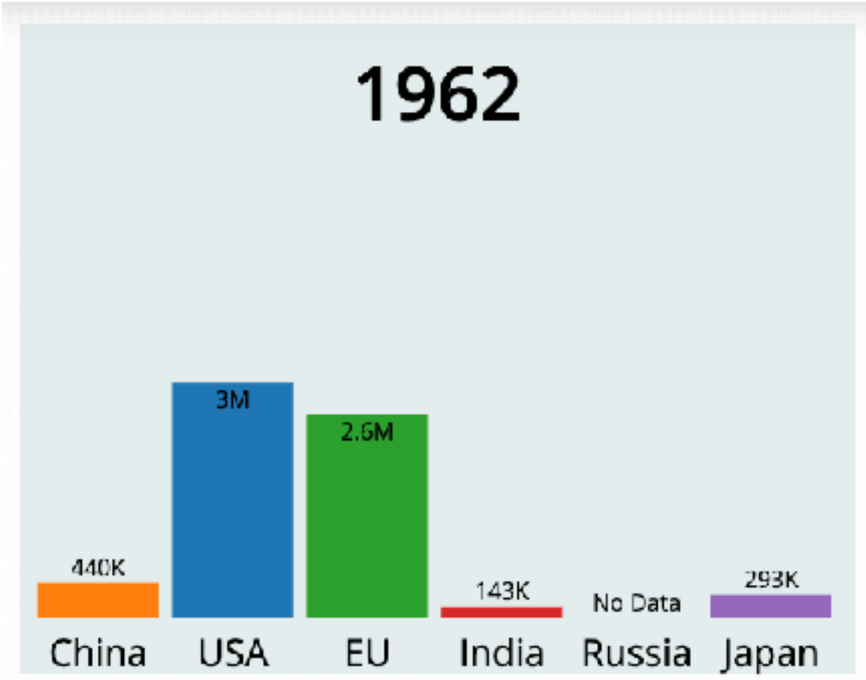
[https://bl.ocks.org/mbostock/1157787]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Idiom: **Small multiples + details on demand**

- combining idioms





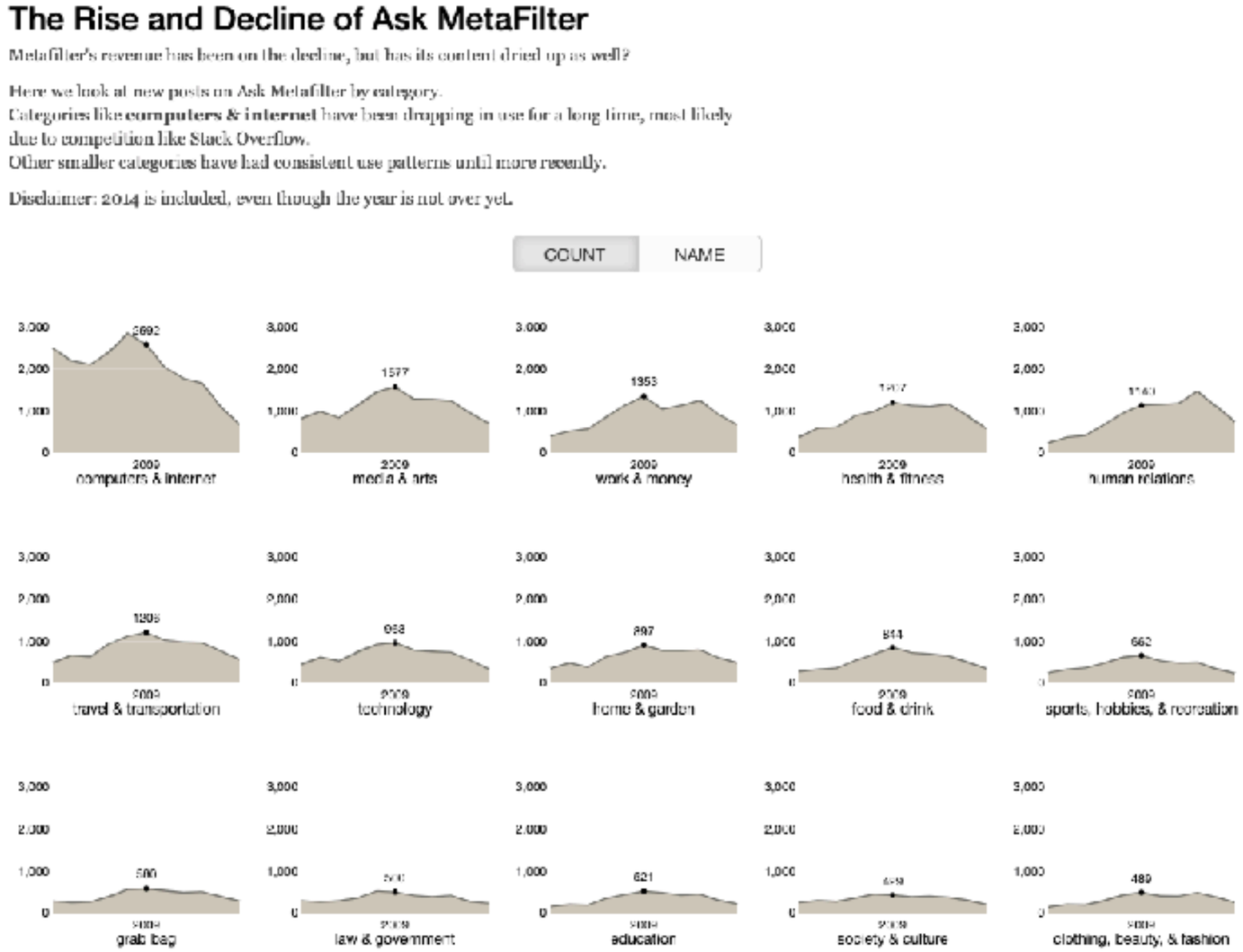
[http://vallandingham.me/co2_small_multiple]

[https://vallandingham.me/small_multiples_with_details.html]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Interactive small multiples

- linked highlighting: analogous item/attribute across views
  - same year highlighted across all charts if hover within any chart



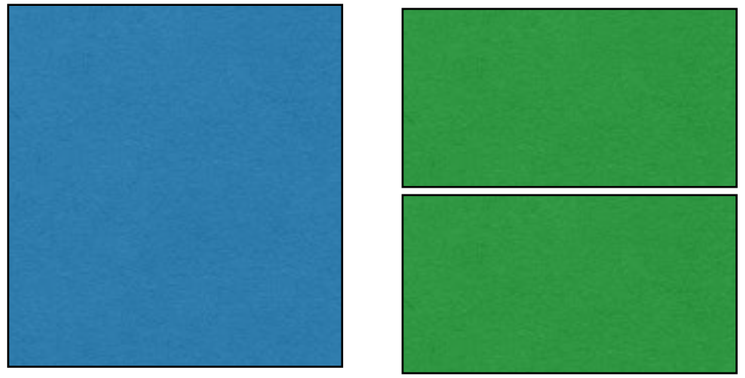
[https://bl.ocks.org/ColinEberhardt/3c780088c363d1515403f50a87a87121]

[https://blog.scottlogic.com/2017/04/05/interactive-responsive-small-multiples.html]

[http://projects.flowingdata.com/tut/linked_small_multiples_demo/]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Juxtapose views: tradeoffs

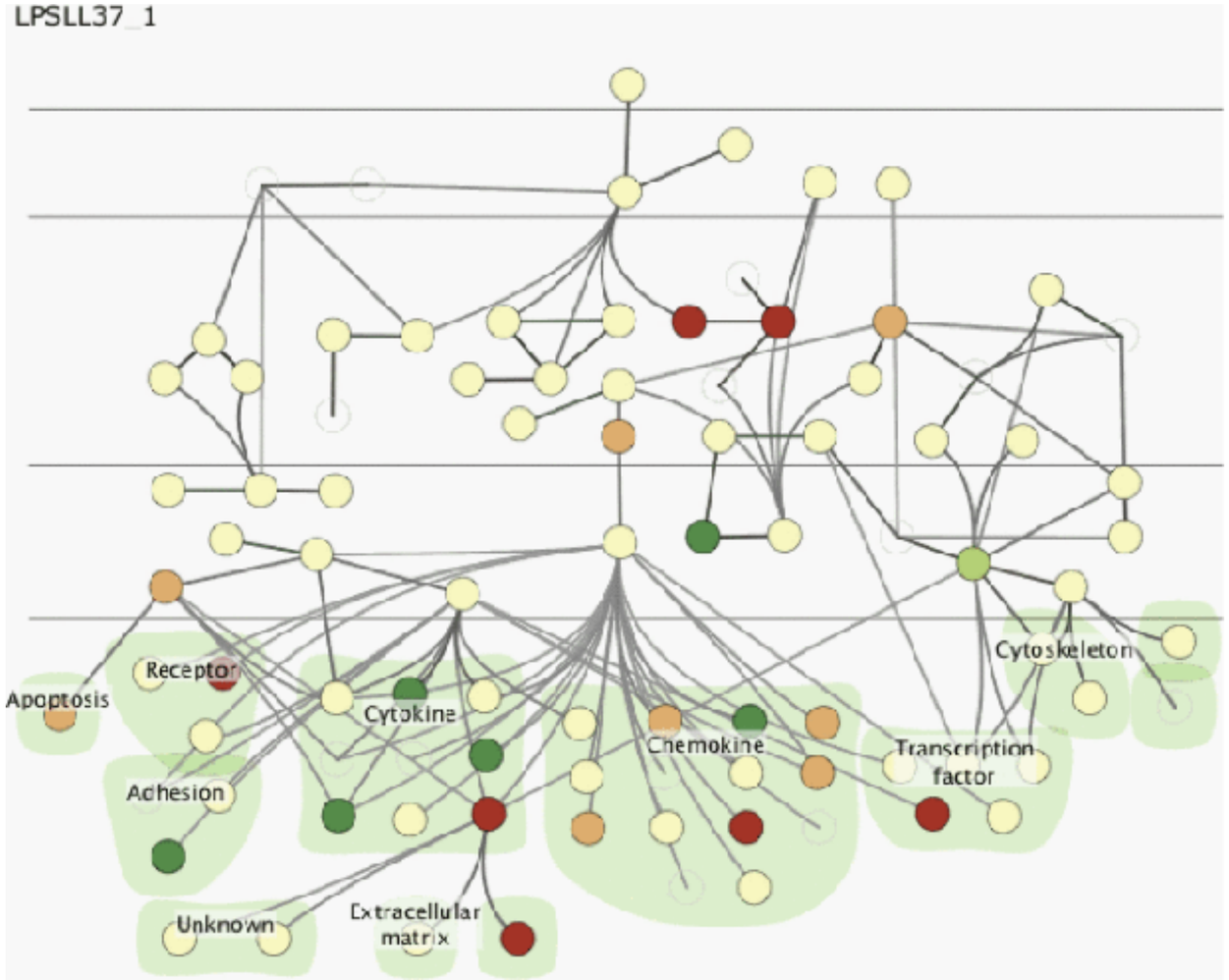


- juxtapose costs
  - display area
    - 2 views side by side: each has only half the area of one view
- juxtapose benefits
  - cognitive load: eyes vs memory
    - lower cognitive load: move eyes between 2 views
    - higher cognitive load: compare single changing view to memory of previous state

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Juxtapose vs animate

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

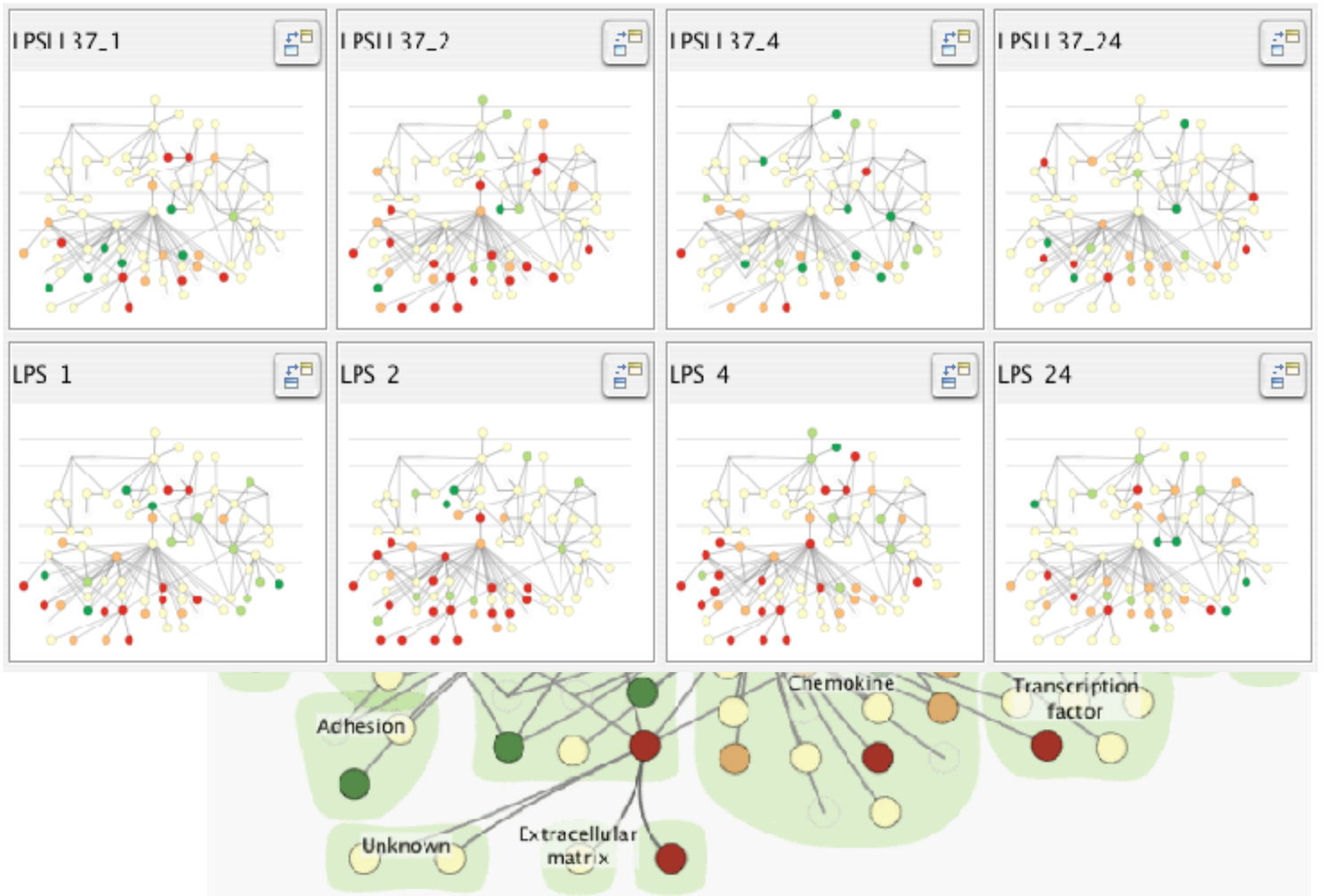


[Cerebral:Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans.Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Juxtapose vs animate

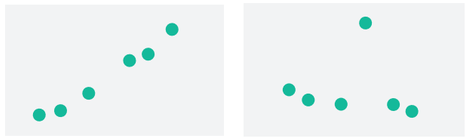
- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions
- juxtapose: easier to compare across small multiples
  - different conditions (color), same gene (layout)



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

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

View coordination: Design choices

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

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

How to handle complexity: 3 more strategies + 1 previous

Manipulate

- Change
- Select
- Navigate

Facet

- Juxtapose
- Partition
- Superimpose

Reduce

- Filter
- Aggregate
- Embed

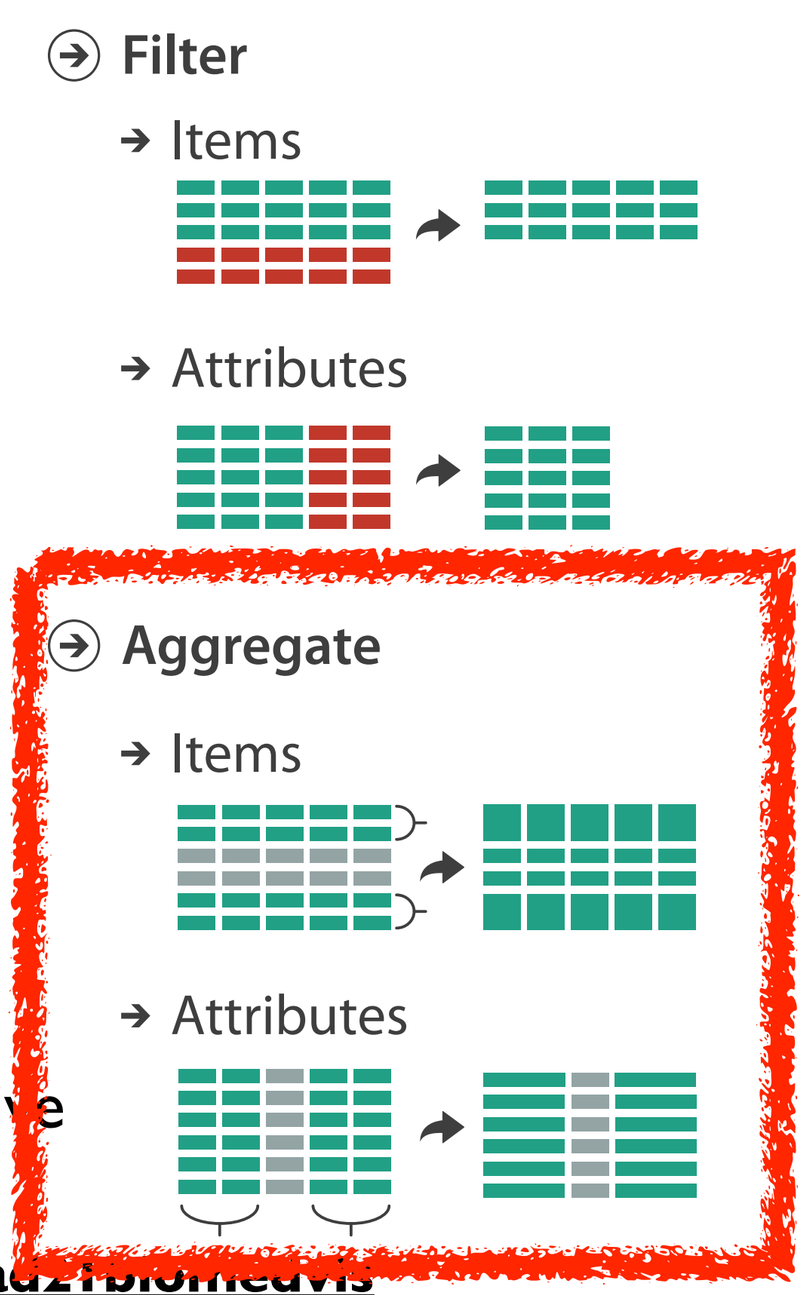
→ *Derive*

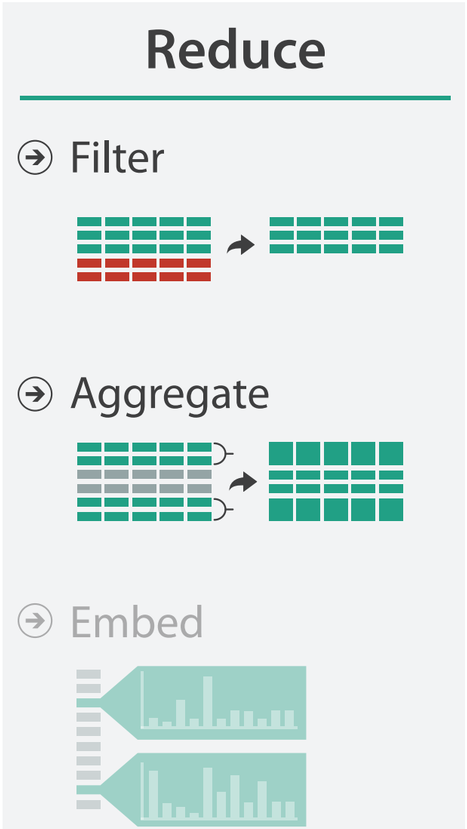
- reduce what is shown within single view

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

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, facet, change, derive

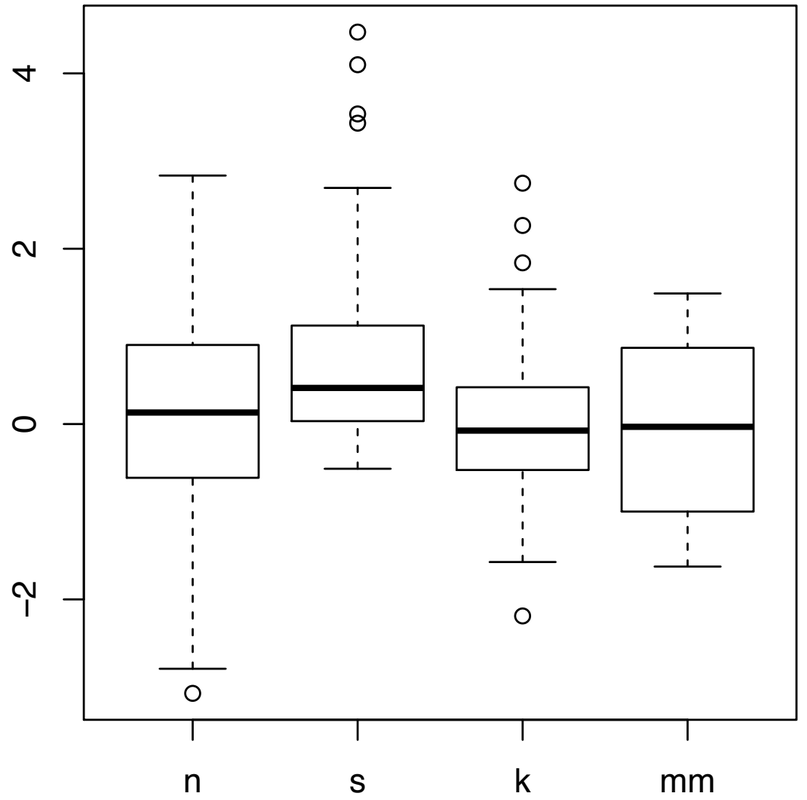




http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Idiom: **boxplot**

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

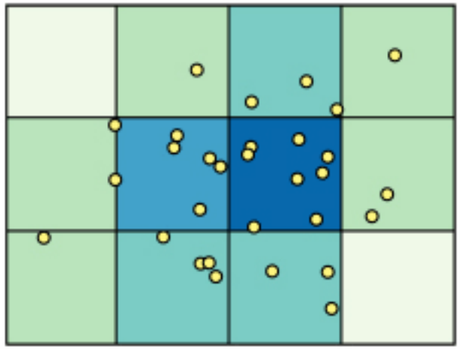
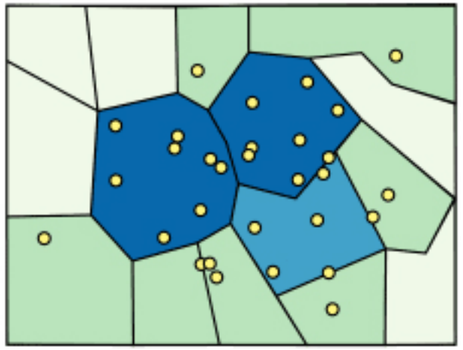
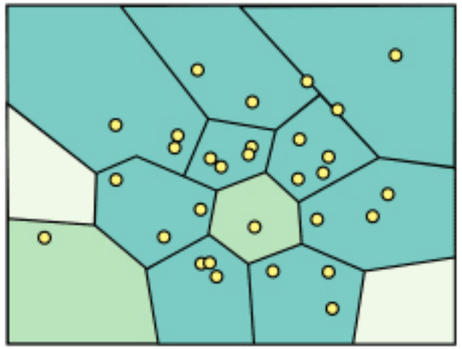


[40 years of boxplots. Wickham and Stryjewski. 2012. had.co.nz]

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

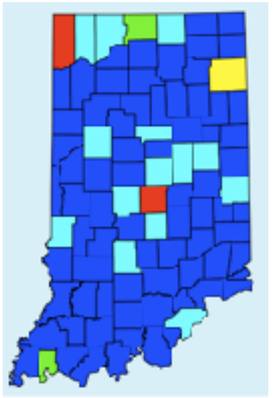
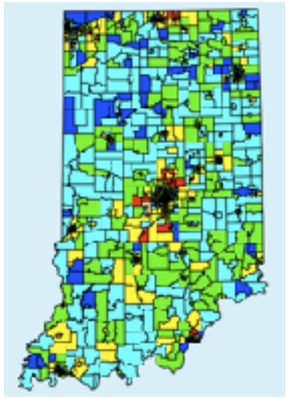
Spatial aggregation

- 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

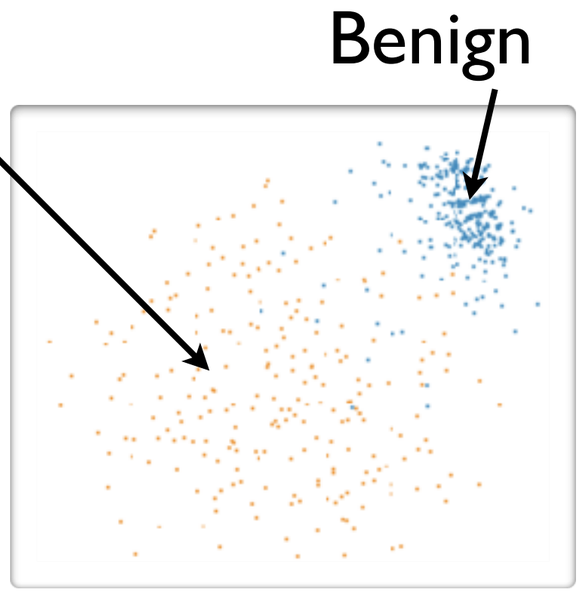
http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Dimensionality reduction

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space
    - capture most of variance with minimal error
  - 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

Tumor
Measurement Data

→ DR →

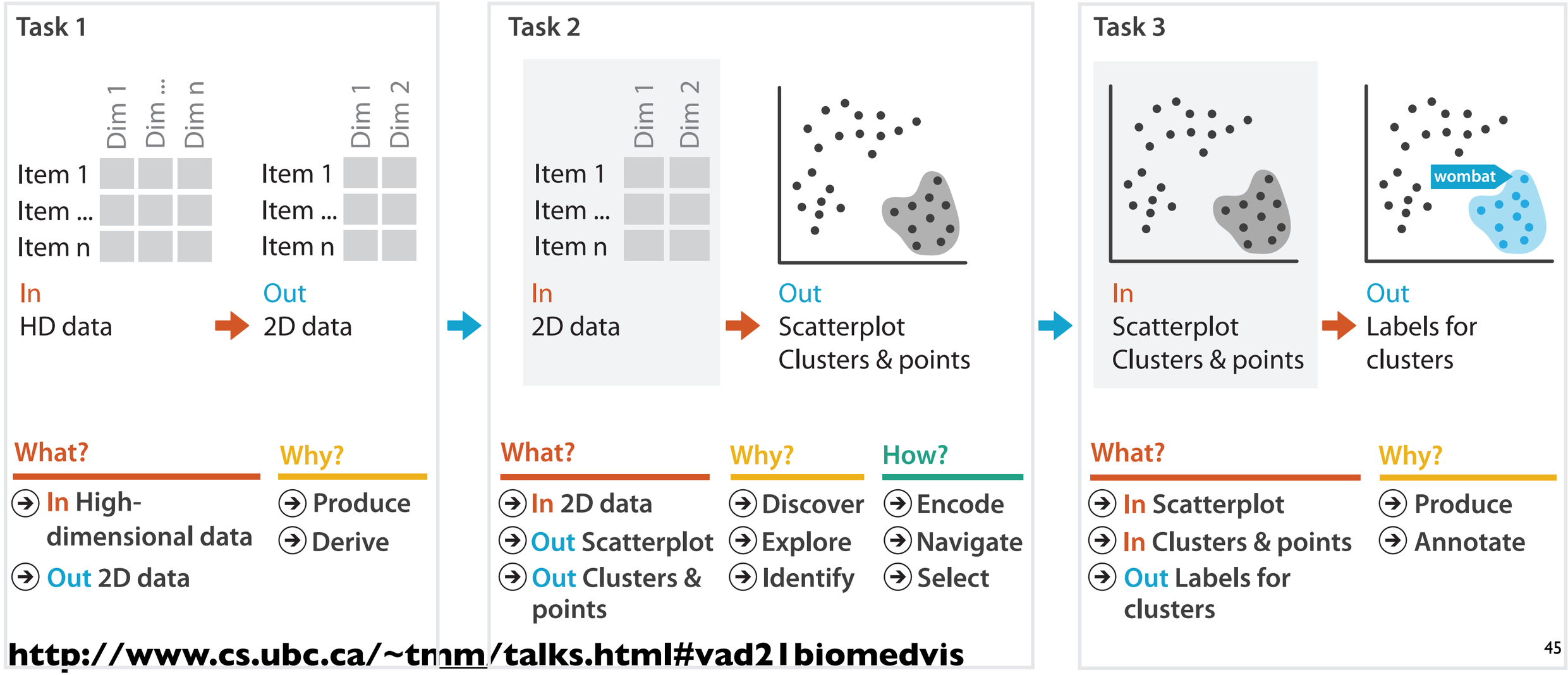


data: 9D measured space

derived data: 2D target space

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

Idiom: **Dimensionality reduction for documents**



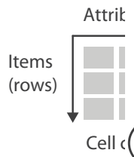
http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

What?

Datasets

Attributes

- Data Types
  - Items
- Data and D
  - Tables
    - Items
    - Attributes
- Dataset Typ
  - Tables
  - Multidim
  - Geometr



Why?

Actions

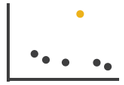
- Analyze
  - Consume
    - Discover
    - Present
    - Enjoy
  - Produce
    - Annotate
  - Search

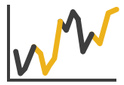
	Tar
Location known	
Location unknown	

- Query
  - Identify

Targets

- All Data
  - Trends
  - Outliers
  - Features





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

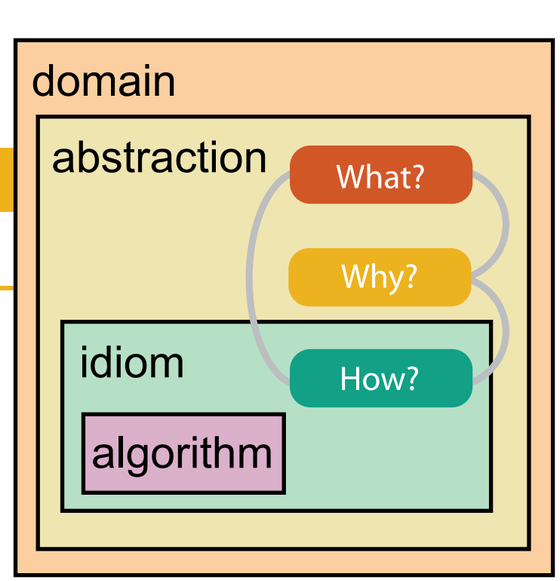
- Superimpose

Reduce

- Filter

- Aggregate

- Embed



http://

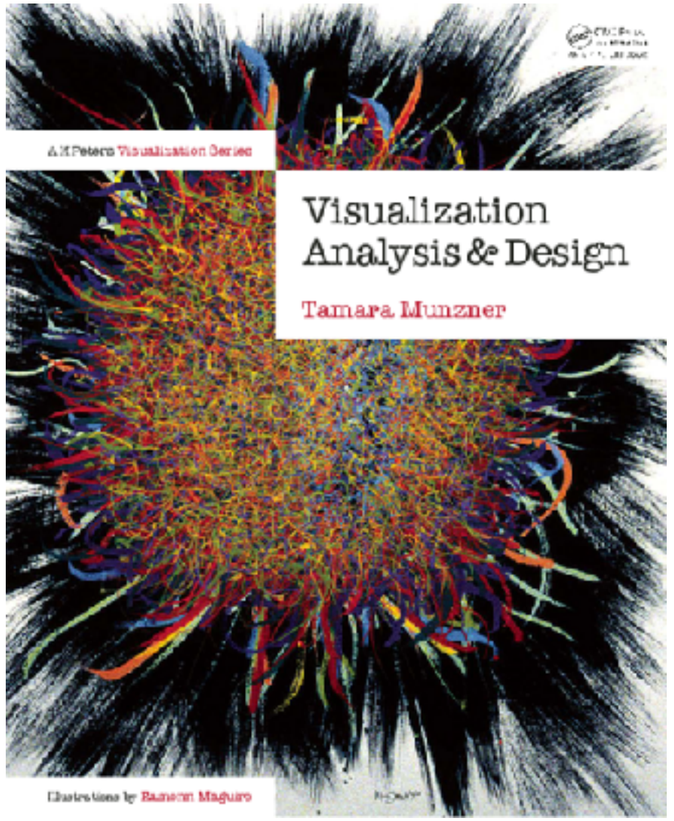
More Information

@tamaramunzner

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis

- book page (including tutorial lecture slides)
  http://www.cs.ubc.ca/~tmm/vadbook
  - 20% promo code for book+ebook combo: HVN17
  - http://www.crcpress.com/product/isbn/9781466508910
  - illustrations: Eamonn Maguire

- papers, videos, software, talks, courses
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm



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

http://www.cs.ubc.ca/~tmm/talks.html#vad21biomedvis