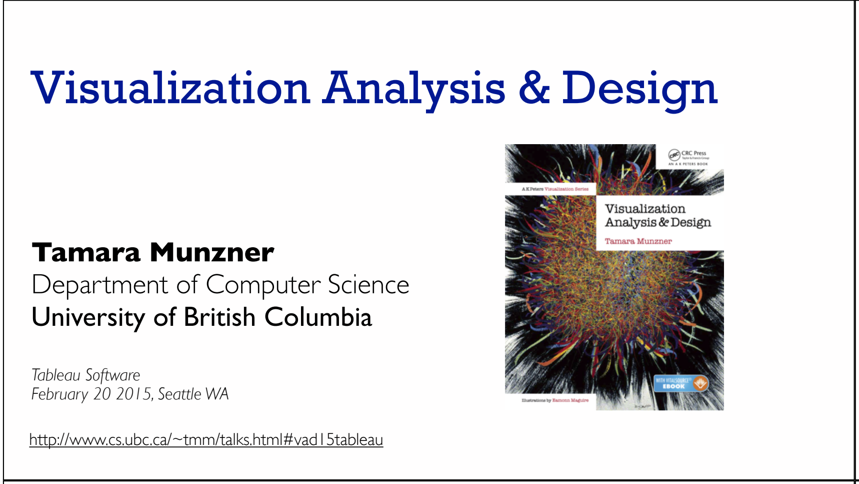
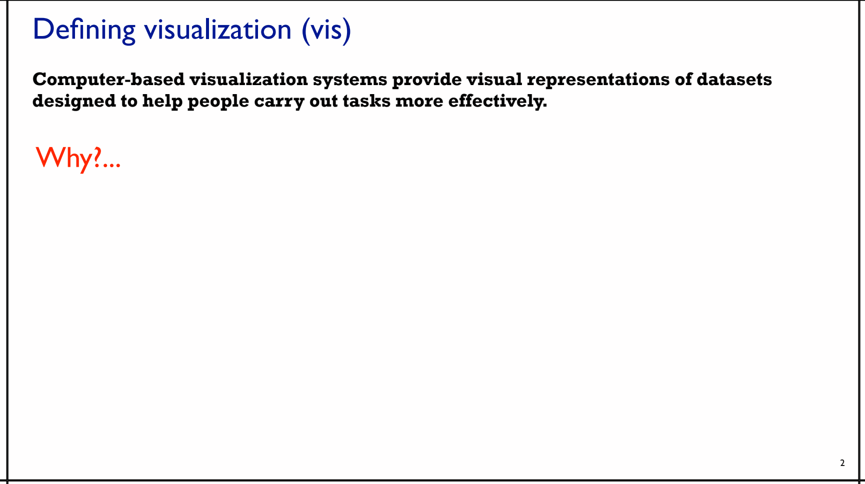


Visualization Analysis & Design

Tamara Munzner
Department of Computer Science
University of British Columbia

Tableau Software
February 20 2015, Seattle WA

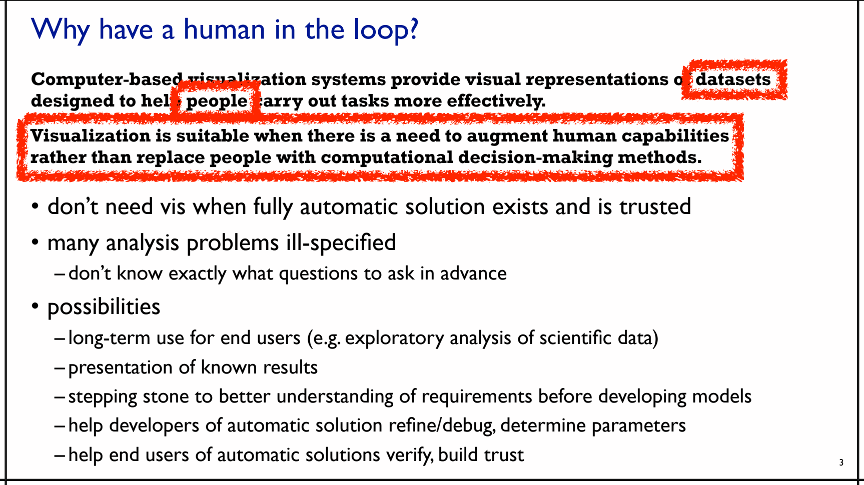
http://www.cs.ubc.ca/~tmm/talks.html#vad15tableau



Defining visualization (vis)

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

Why?...

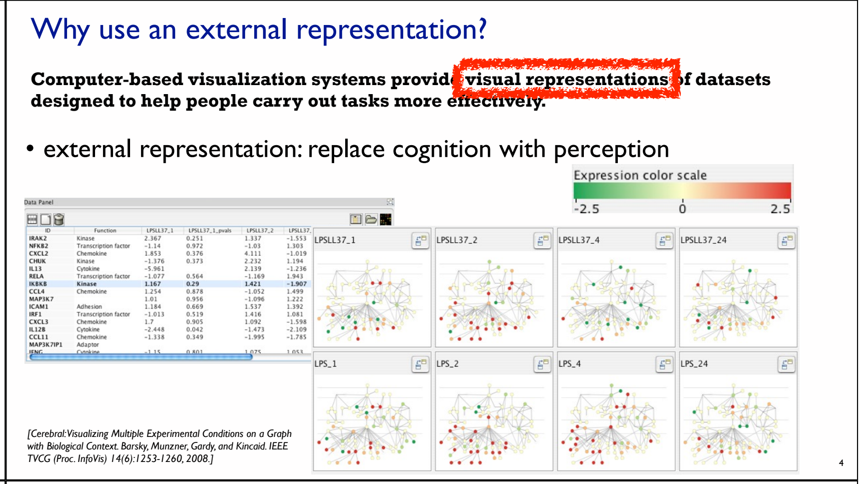


Why have a human in the loop?

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

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

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

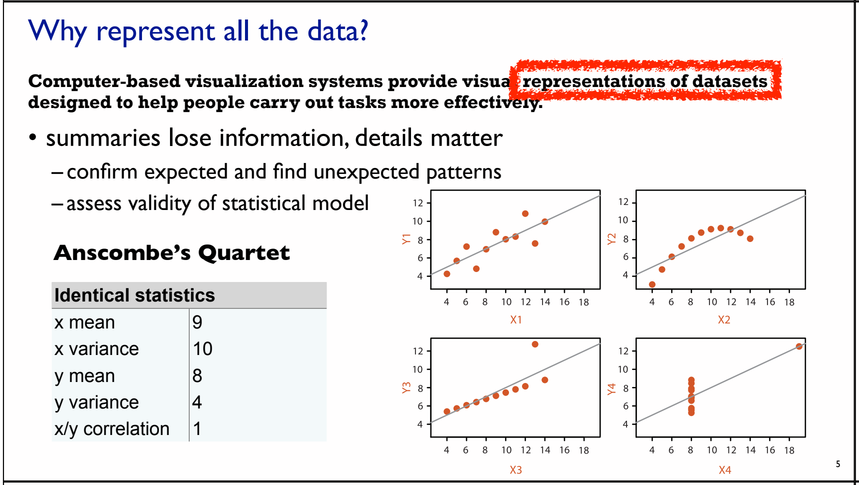


Why use an external representation?

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

- external representation: replace cognition with perception

[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.]



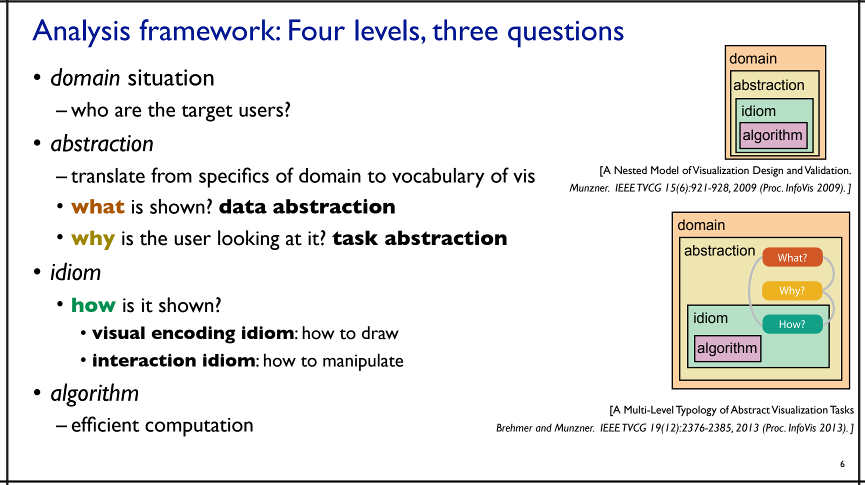
Why represent all the data?

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	8
y variance	4
x/y correlation	1

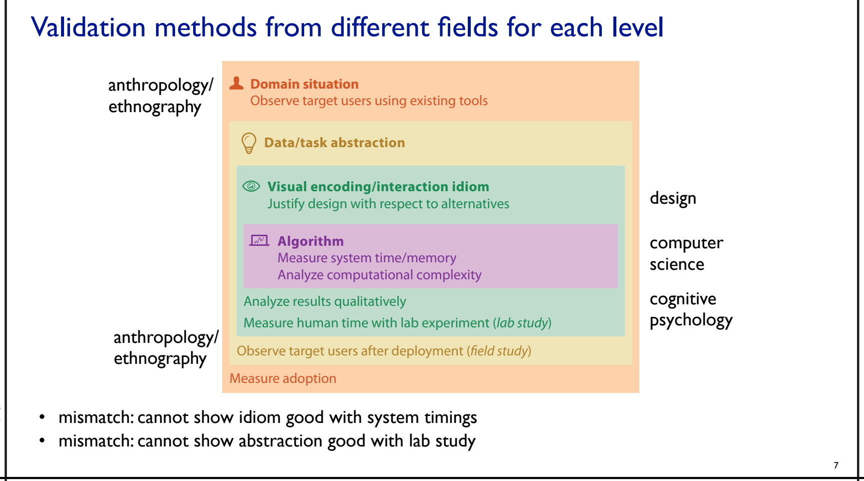


Analysis framework: Four levels, three questions

- *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).*]



Validation methods from different fields for each level

anthropology/ethnography

Domain situation
Observe target users using existing tools

Data/task abstraction

Visual encoding/interaction idiom
Justify design with respect to alternatives

Algorithm
Measure system time/memory
Analyze computational complexity

Analyze results qualitatively
Measure human time with lab experiment (*lab study*)

Observe target users after deployment (*field study*)

Measure adoption

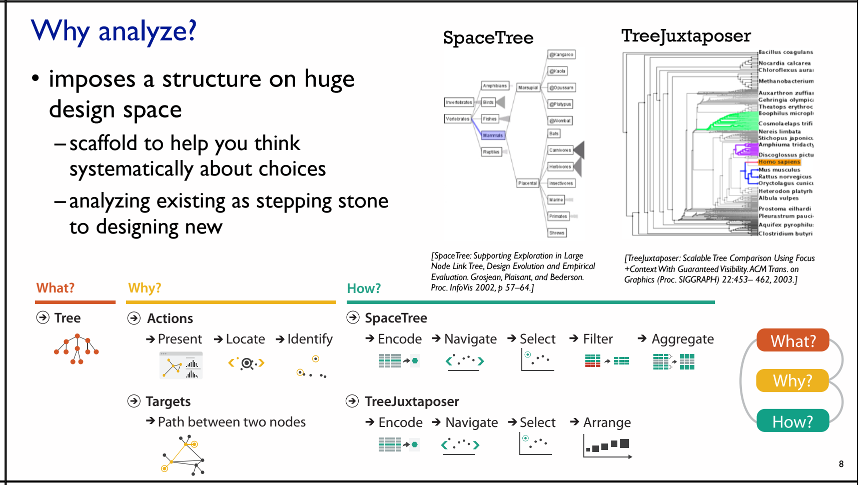
anthropology/ethnography

design

computer science

cognitive psychology

- mismatch: cannot show idiom good with system timings
- mismatch: cannot show abstraction good with lab study



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

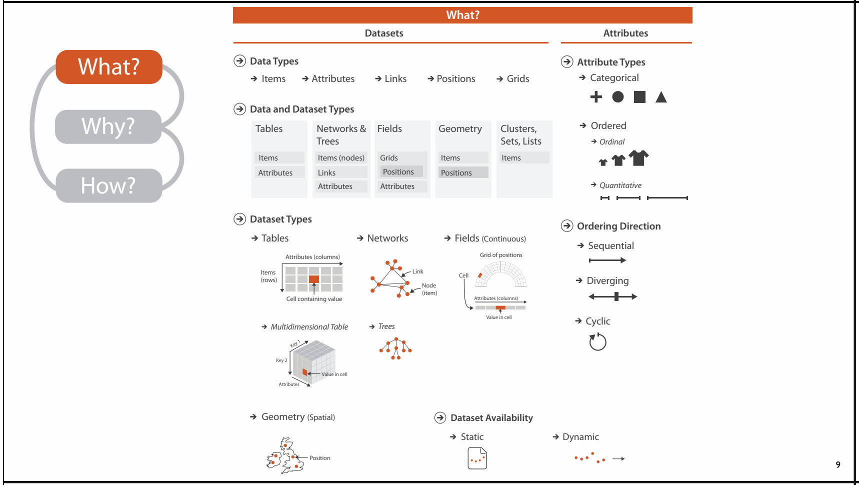
[TreeJuxtaposer: Scalable Tree Comparison Using Focus +Context With Guaranteed Visibility. ACM Trans. on Graphics (Proc. SIGGRAPH) 22:453– 462, 2003.]

What?
- Tree

Why?
- Actions
  - Present → Locate → Identify
- Targets
  - Path between two nodes

How?
- SpaceTree
  - Encode → Navigate → Select → Filter → Aggregate
- TreeJuxtaposer
  - Encode → Navigate → Select → Arrange

What? Why? How?



What? Why? How?

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		

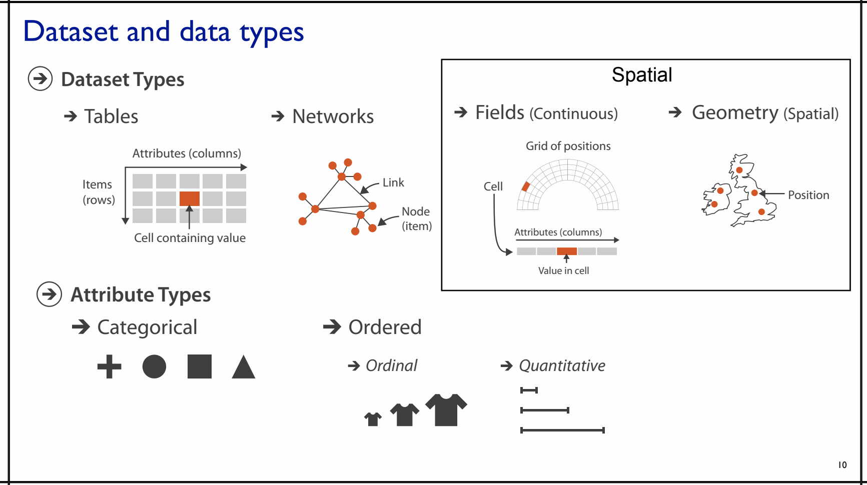
Dataset Types
- Tables
- Networks
- Fields (Continuous)
- *Multidimensional Table*
- *Trees*
- Geometry (Spatial)

Dataset Availability
- Static
- Dynamic

Attributes

Attribute Types
- Categorical
- Ordered
  - *Ordinal*
  - *Quantitative*

Ordering Direction
- Sequential
- Diverging
- Cyclic

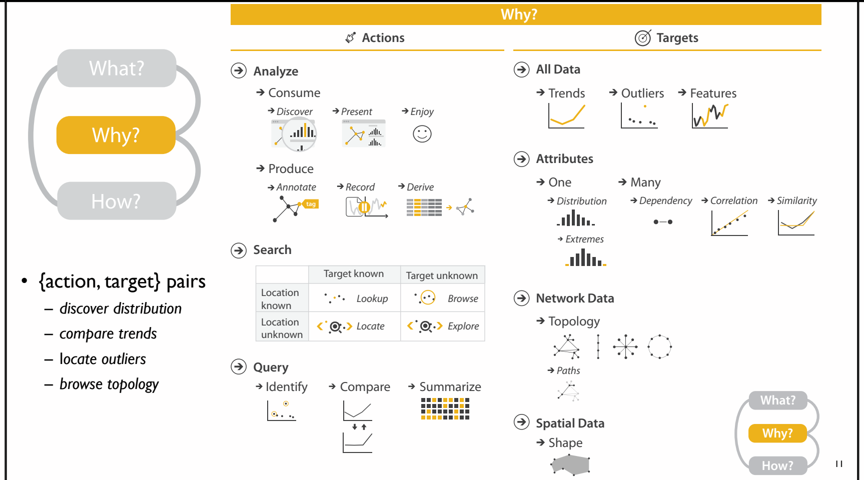


Dataset and data types

Dataset Types
- Tables
- Networks

Spatial
- Fields (Continuous)
- Geometry (Spatial)

Attribute Types
- Categorical
- Ordered
  - *Ordinal*
  - *Quantitative*



What? Why? How?

- {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

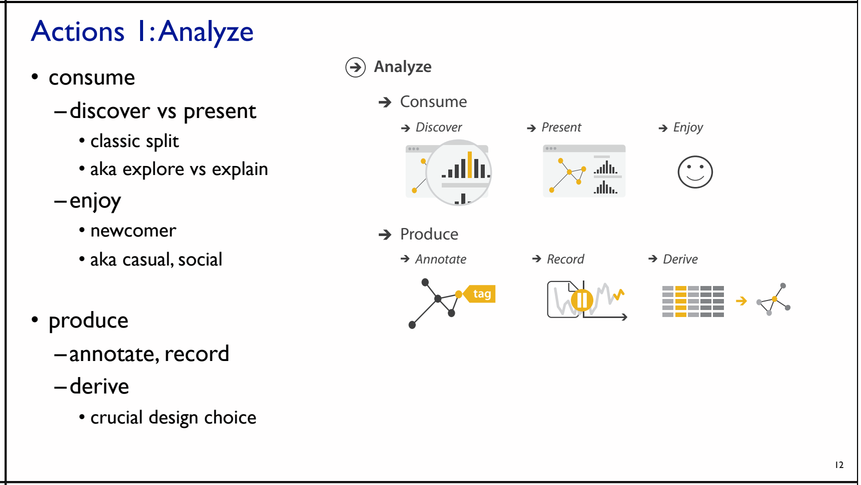
All Data
- Trends → Outliers → Features

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

Network Data
- Topology
  - *Paths*

Spatial Data
- Shape

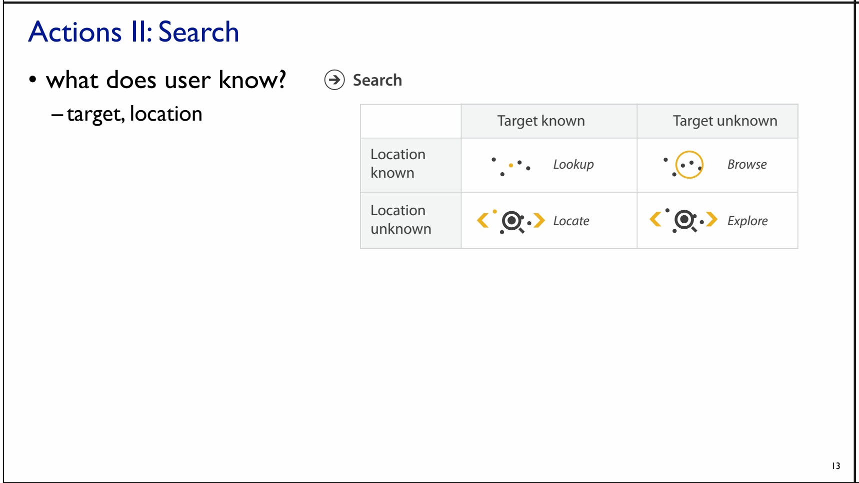
What? Why? How?



Actions I: Analyze

- consume
  - discover vs present
    - classic split
    - aka explore vs explain
  - enjoy
    - newcomer
    - aka casual, social
- produce
  - annotate, record
  - derive
    - crucial design choice

Analyze
- Consume
  - *Discover* → *Present* → *Enjoy*
- Produce
  - *Annotate* → *Record* → *Derive*

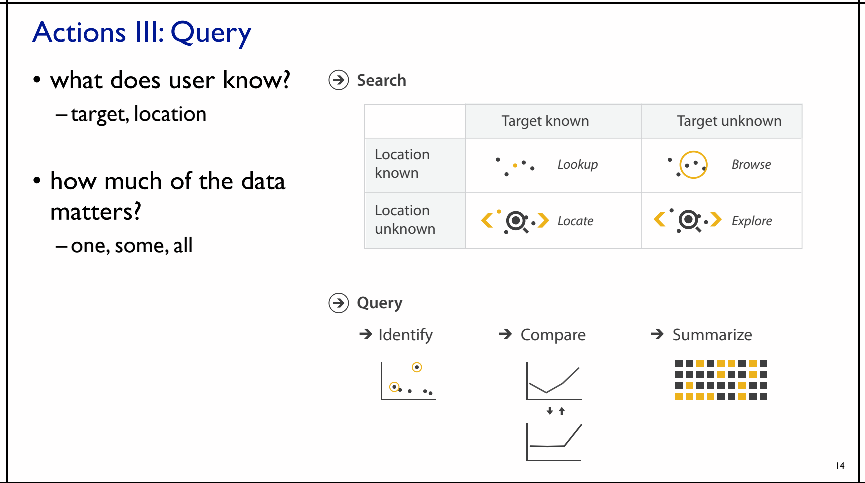


Actions II: Search

- what does user know?
  - target, location

Search

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



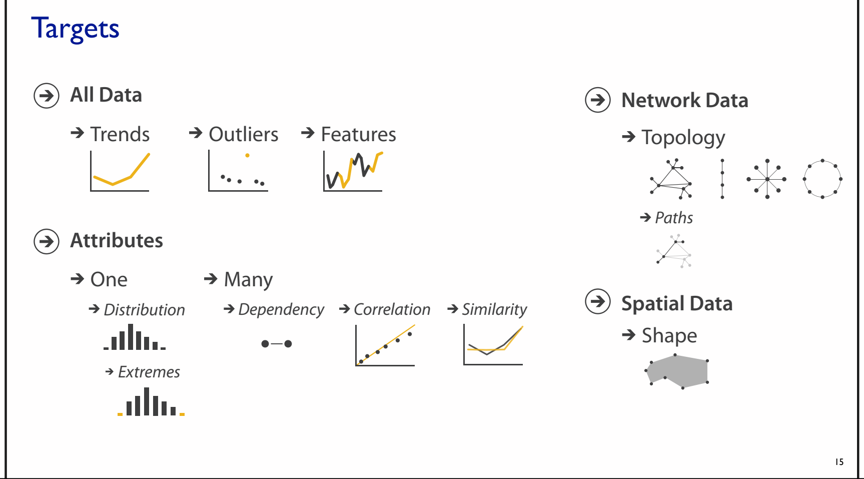
Actions III: Query

- what does user know?
  - target, location
- how much of the data matters?
  - one, some, all

Search

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

Query
- Identify → Compare → Summarize



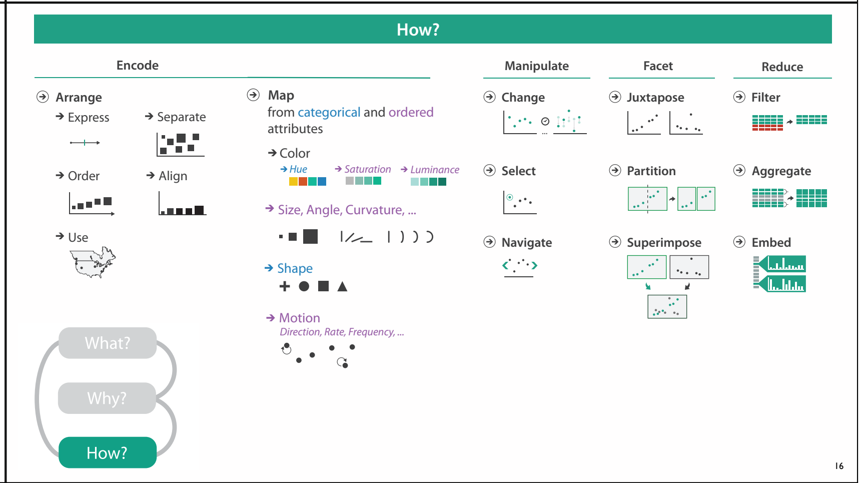
Targets

All Data
- Trends → Outliers → Features

Attributes
- One
  - *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, ...

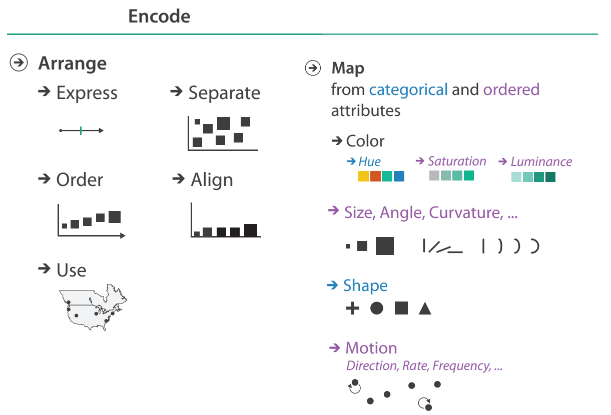
Manipulate
- Change
- Select
- Navigate

Facet
- Juxtapose
- Partition
- Superimpose

Reduce
- Filter
- Aggregate
- Embed

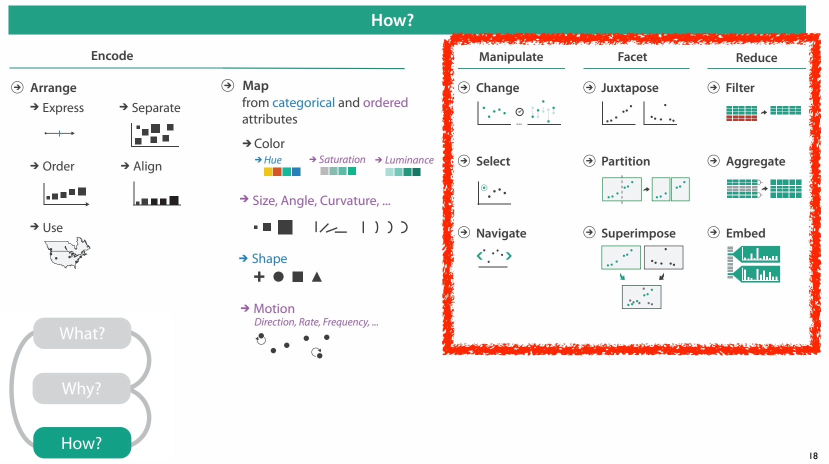
What? Why? How?

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, ...


How?

Encode

Arrange
- Express
- Separate
- Order
- Align
- Use

Map
from categorical and ordered attributes
- Color
  - Hue
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- Size, Angle, Curvature, ...
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What?

Why?

How?

Manipulate
- Change
- Select
- Navigate

Facet
- Juxtapose
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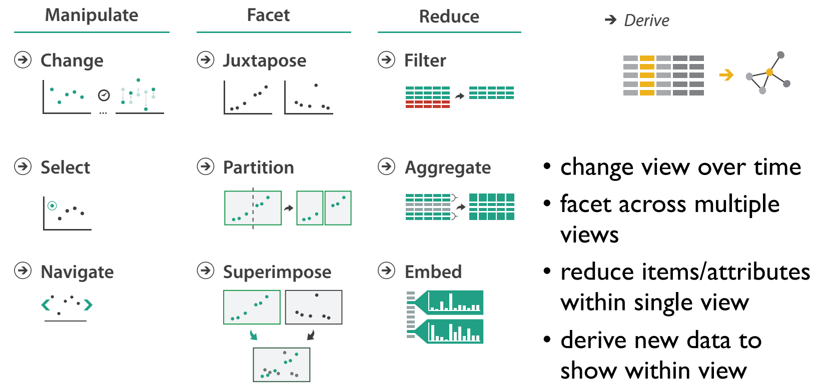
- Superimpose

Reduce
- Filter
- Aggregate
- Embed

How to handle complexity: 3 more strategies + 1 previous


Manipulate
- Change
- Select
- Navigate

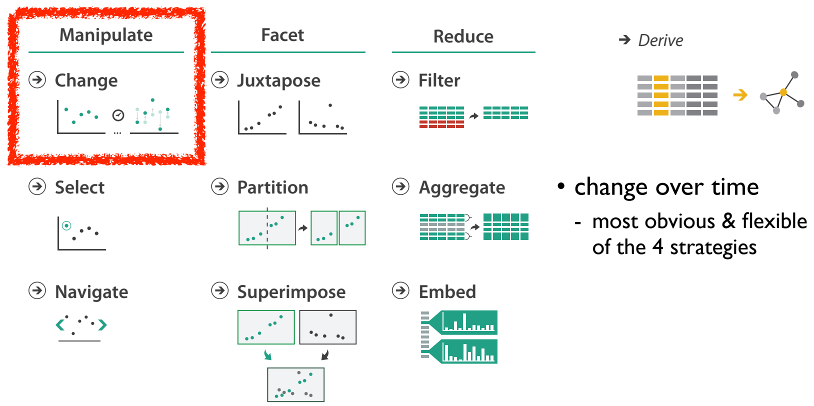
Facet
- Juxtapose
- Partition
- Superimpose

Reduce
- Filter
- Aggregate
- Embed

Derive

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

How to handle complexity: 3 more strategies + 1 previous


Manipulate
- Change
- Select
- Navigate

Facet
- Juxtapose
- Partition
- Superimpose

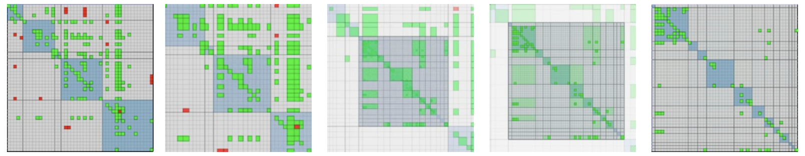
Reduce
- Filter
- Aggregate
- Embed

Derive

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

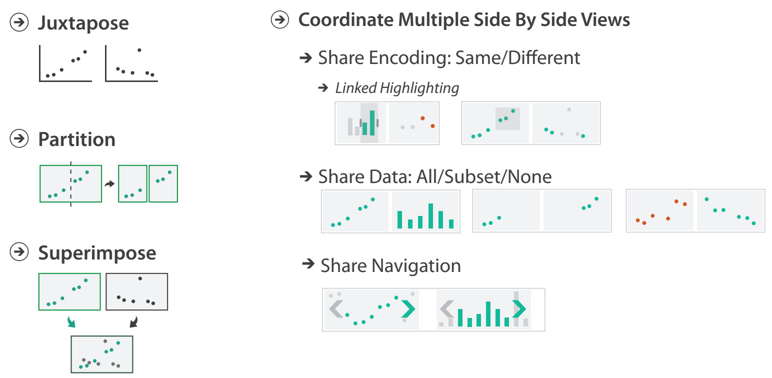
Idiom: **Animated transitions**

- smooth transition from one state to another
  - alternative to jump cuts
  - support for item tracking when amount of change is limited
- example: multilevel matrix views
  - scope of what is shown narrows down
    - middle block stretches to fill space, additional structure appears within
    - other blocks squish down to increasingly aggregated representations



[Using Multilevel Call Matrices in Large Software Projects. van Ham. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 227–232, 2003.]

Facet

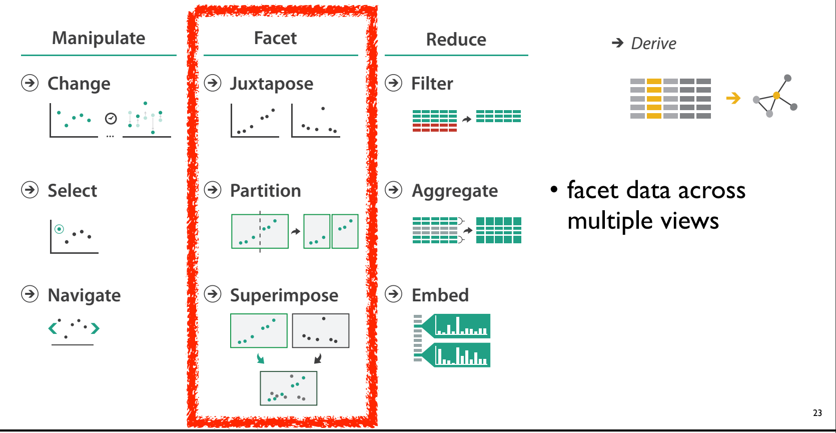

Juxtapose

Partition

Superimpose

Coordinate Multiple Side By Side Views
- Share Encoding: Same/Different
  - Linked Highlighting
- Share Data: All/Subset/None
- Share Navigation

How to handle complexity: 3 more strategies + 1 previous


Manipulate
- Change
- Select
- Navigate

Facet
- Juxtapose
- Partition
- Superimpose

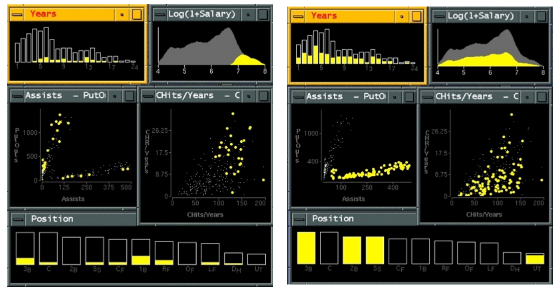
Reduce
- Filter
- Aggregate
- Embed

Derive

- facet data across multiple views

Idiom: **Linked highlighting** System: **EDV**

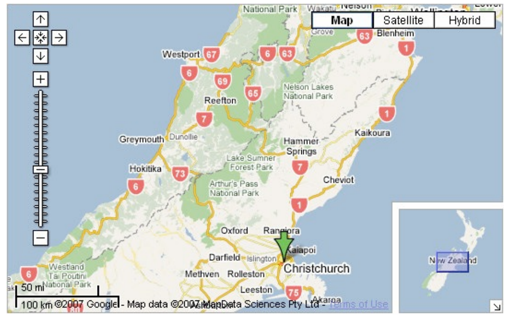
- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - ***multiform***
- data: all shared



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

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

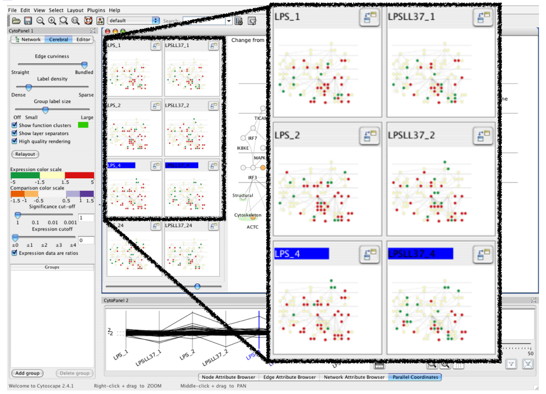
- encoding: same
- data: subset shared
- navigation: shared
  - bidirectional linking
- differences
  - viewpoint
  - (size)
- ***overview-detail***



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

Idiom: **Small multiples** System: **Cerebral**

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



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

Coordinate views: Design choice interaction

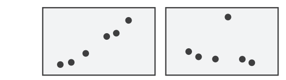
		Data		
		All	Subset	None
Encoding	Same	Redundant	Overview/ Detail	Small Multiples
	Different	Multiform	Multiform, Overview/ Detail	No Linkage

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

Partition into views

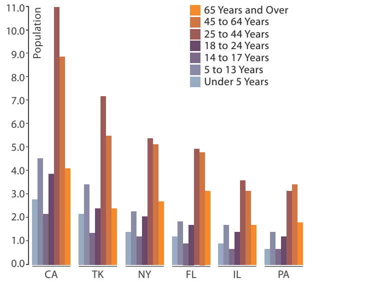
- how to divide data between views
  - encodes association between items using spatial proximity
  - major implications for what patterns are visible
  - split according to attributes
- design choices
  - how many splits
    - all the way down: one mark per region?
    - stop earlier, for more complex structure within region?
  - order in which attribs used to split
  - how many views

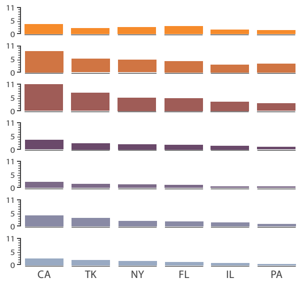
Partition into Side-by-Side Views



Partitioning: List alignment

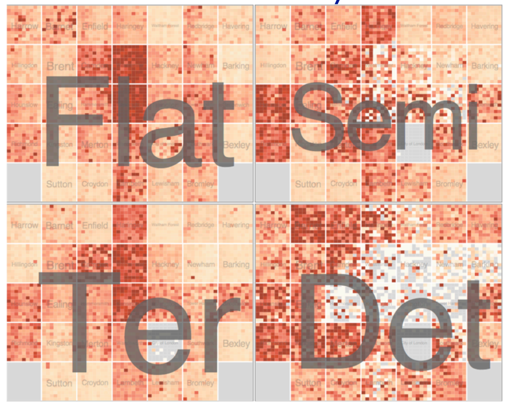
- single bar chart with grouped bars
  - split by state into regions
    - complex glyph within each region showing all ages
  - compare: easy within state, hard across ages
- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across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





Partitioning: Recursive subdivision System: **HIVE**

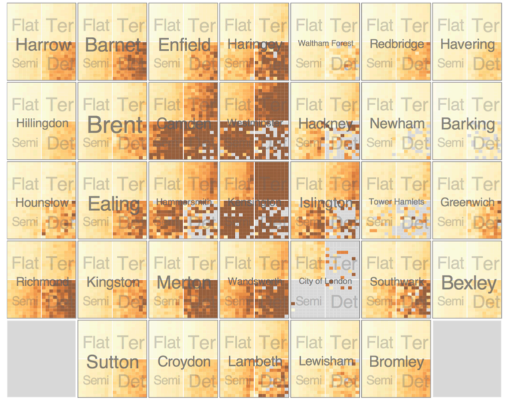
- split by type
- then by neighborhood
- then time
  - years as rows
  - months as columns



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

Partitioning: Recursive subdivision System: **HIVE**

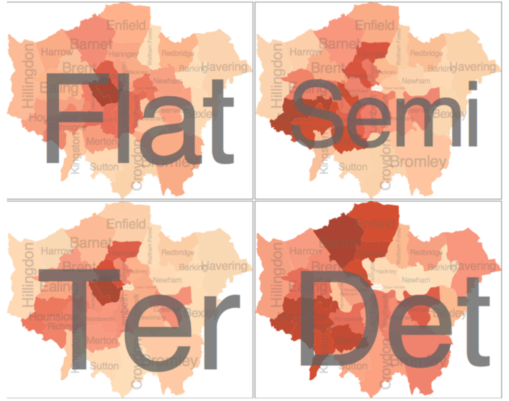
- switch order of splits
  - neighborhood then type
- very different patterns



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

Partitioning: Recursive subdivision System: **HIVE**

- different encoding for second-level regions
  - choropleth maps



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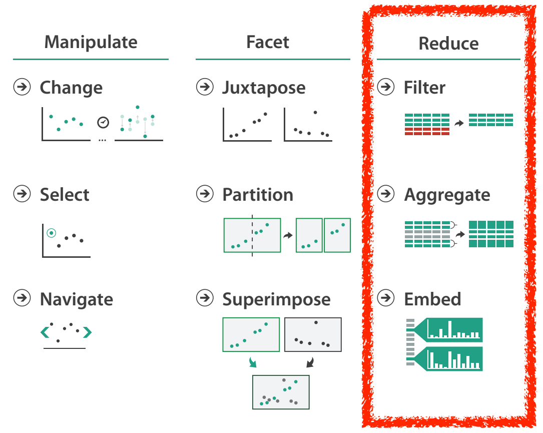
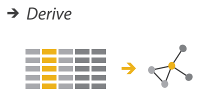
How to handle complexity: 3 more strategies + 1 previous

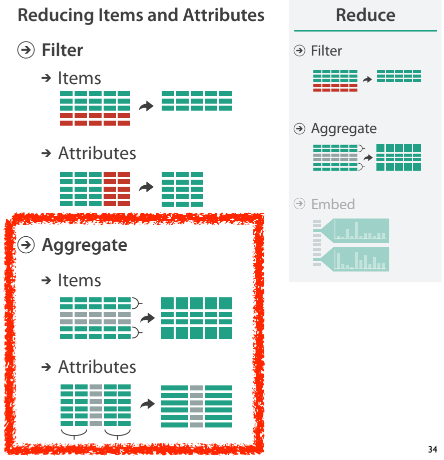

Manipulate
Change
Select
Navigate
Facet
Juxtapose
Partition
Superimpose
Reduce
Filter
Aggregate
Embed


→ *Derive*

- reduce what is shown within single view

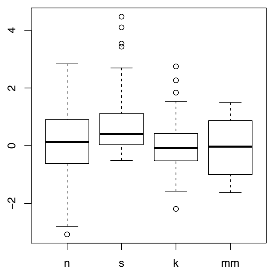
Reduce items and attributes

- 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


Reducing Items and Attributes
Filter
→ Items
→ Attributes
Aggregate
→ Items
→ Attributes
Reduce
Filter
Aggregate
Embed

Idiom: **boxplot**

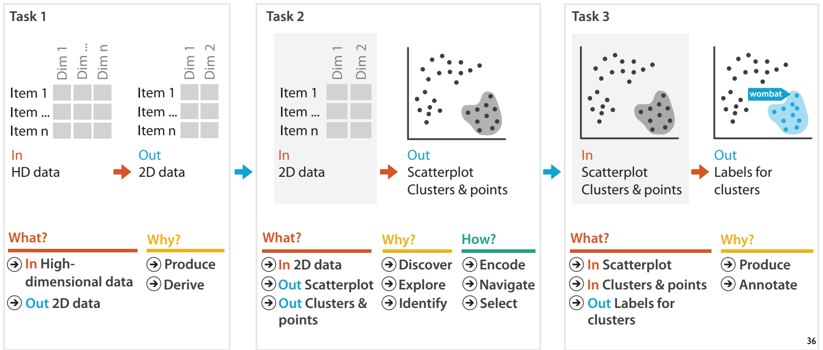
- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown



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

Idiom: **Dimensionality reduction for documents**

- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space


Task 1

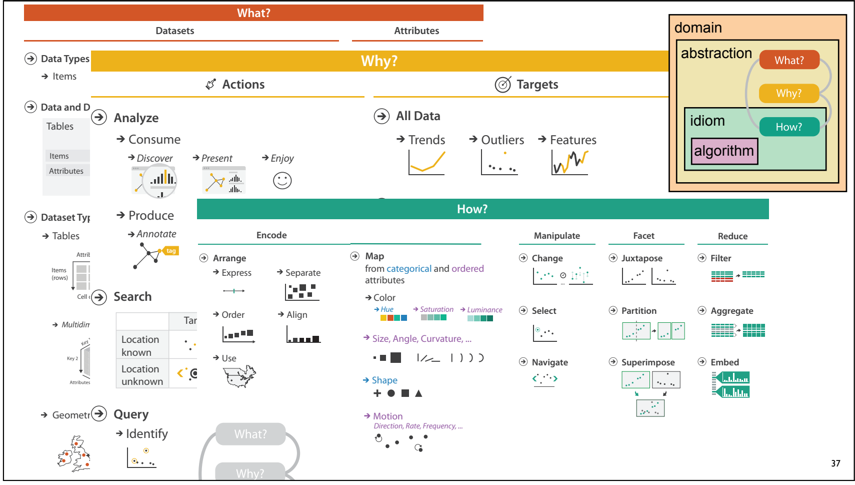
In
HD data
Out
2D data
What?
In High-dimensional data
Out 2D data
Why?
Produce
Derive

Task 2

In
2D data
Out
Scatterplot
Clusters & points
What?
In 2D data
Out Scatterplot
Out Clusters & points
Why?
Discover
Explore
Identify
How?
Encode
Navigate
Select

Task 3

In
Scatterplot
Clusters & points
Out
Labels for clusters
What?
In Scatterplot
In Clusters & points
Out Labels for clusters
Why?
Produce
Annotate


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
Location known
Location unknown
Query
→ Identify
Targets
All Data
→ Trends
→ Outliers
→ Features
domain
abstraction
What?
Why?
idiom
How?
algorithm
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

More Information

- this talk
  http://www.cs.ubc.ca/~tmm/talks.html#vad15tableau
- 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
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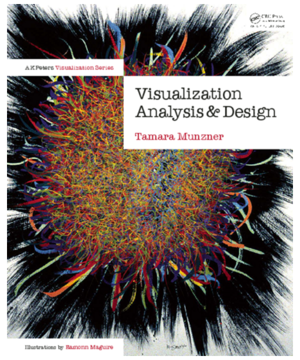
- papers, videos, software, talks, full courses
  http://www.cs.ubc.ca/group/infovis
  http://www.cs.ubc.ca/~tmm


A K Peters Visualization Series
Visualization Analysis & Design
Tamara Munzner
Illustrations by Eamonn Maguire

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