Information Visualization
Data Abstraction

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http://www.cs.ubc.ca/~tmm/courses/436V-20

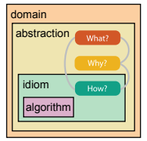
Nested Model

How to evaluate a visualization: So many methods, how to pick?

- Computational benchmarks?
  - quant: system performance, memory
- User study in lab setting?
  - quant: (human) time and error rates, preferences
  - qual: behavior/strategy observations
- Field study of deployed system?
  - quant: usage logs
  - qual: interviews with users, case studies, observations
- Analysis of results?
  - quant: metrics computed on result images
  - qual: consider what structure is visible in result images
- Justification of choices?
  - qual: perceptual principles, best practices

Nested model: Four levels of visualization design

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

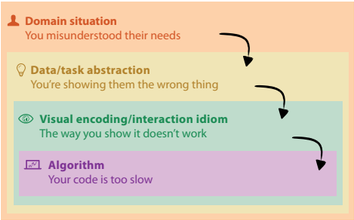


[A Nested Model of Visualization Design and Validation. Munzner. IEEE TVCG 15(6):921-928, 2009 (Proc. InfoVis 2009).]

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

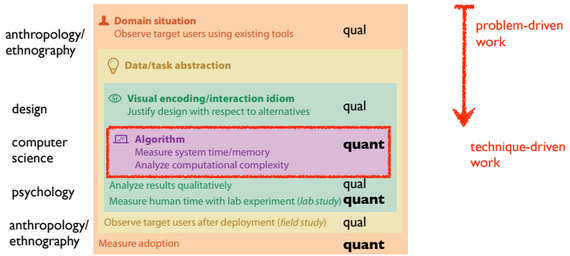
Different threats to validity at each level

- cascading effects downstream



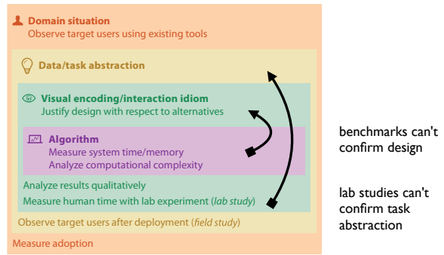
Interdisciplinary: need methods from different fields at each level

- mix of qual and quant approaches (typically)



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

Mismatches: Common problem



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What: Data Abstraction

What does data mean?

14, 2.6, 30, 30, 15, 100001

- What does this sequence of six numbers mean?
  - two points far from each other in 3D space?
  - two points close to each other in 2D space, with 15 links between them, and a weight of 100001 for the link?
  - something else??

Basil, 7, S, Pear

- What about this data?
  - food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month
  - Basil Point neighborhood of city had 7 inches of snow cleared by the Pear Creek Limited snow removal service
  - lab rat Basil made 7 attempts to find way through south section of maze, these trials used pear as reward food

Now what?

- semantics: real-world meaning

Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

Now what?

- semantics: real-world meaning

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

Now what?

- semantics: real-world meaning
- data types: structural or mathematical interpretation of data
  - item, link, attribute, position, (grid)
  - different from data types in programming!

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

Items & Attributes

- item: individual entity, discrete
  - eg patient, car, stock, city
  - "independent variable"
- attribute: property that is measured, observed, logged...
  - eg height, blood pressure for patient
  - eg horsepower, make for car
  - "dependent variable"

attributes: name, age, shirt size, fave fruit

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

item: person

Other data types

- links
  - express relationship between two items
  - eg friendship on facebook, interaction between proteins
- positions
  - spatial data: location in 2D or 3D
  - pixels in photo, voxels in MRI scan, latitude/longitude
- (grids)
  - sampling strategy for continuous data

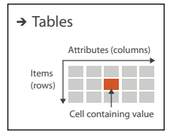
Dataset types

Tables

Items

Attributes

- flat table
  - one item per row
  - each column is attribute
  - cell holds value



attributes: name, age, shirt size, fave fruit

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

item: person

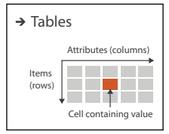
Dataset types

Tables

Items

Attributes

- flat table
  - one item per row
  - each column is attribute
  - cell holds value for item-attribute pair
  - unique key (could be implicit)



attributes: name, age, shirt size, fave fruit

ID	Name	Age	Shirt Size	Favorite Fruit
1	Amy	8	S	Apple
2	Basil	7	S	Pear
3	Clara	9	M	Durian
4	Desmond	13	L	Elderberry
5	Ernest	12	L	Peach
6	Fanny	10	S	Lychee
7	George	9	M	Orange
8	Hector	8	L	Loquat
9	Ida	10	M	Pear
10	Amy	12	M	Orange

item: person

Table

A	B	C	S	T	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
32	7/16/07	2-High	Medium Box	0.6	7/18/07
32	7/16/07	2-High	Medium Box	0.65	7/18/07
35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05
97	1/29/06	3-Medium	Small Box	0.38	1/30/06
129	11/19/08	5-Low	Small Box	0.37	11/28/08
130	5/8/08	2-High	Small Box	0.37	5/9/08
130	5/8/08	2-High	Medium Box	0.38	5/10/08
130	5/8/08	2-High	Small Box	0.6	5/11/08
132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06
134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07
166	9/12/07	2-High	Small Box	0.55	9/14/07
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06
194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08

Table

item

cell

attribute

A	B	C	S	T	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
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130	5/8/08	2-High	Small Box	0.37	5/9/08
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193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06
194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08

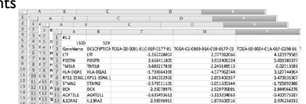
Dataset types

Tables

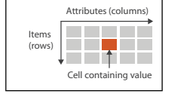
Items

Attributes

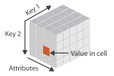
- multidimensional tables
  - indexing based on multiple keys
    - eg genes, patients



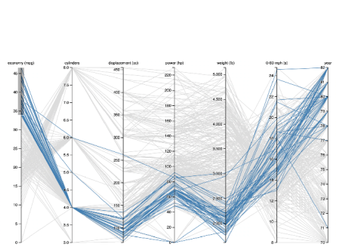
→ Tables

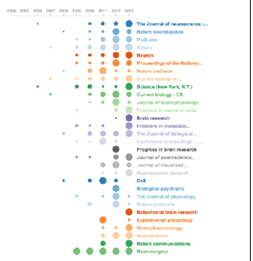


→ *Multidimensional Table*



Visualizing tables





Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

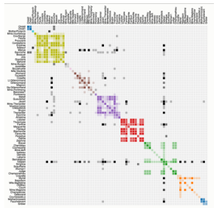
- network/graph
  - nodes (vertices) connected by links (edges)
  - tree is special case: no cycles
    - often have roots and are directed

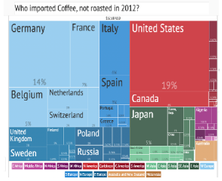
→ Tables

→ Networks

→ *Trees*

Visualizing networks





Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

Fields

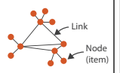
Grids

Positions

Attributes

→ Tables

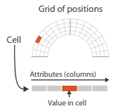
→ Networks



→ *Trees*

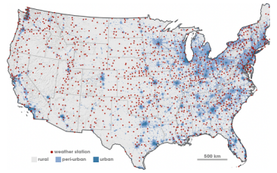
→ Spatial

→ Fields (Continuous)



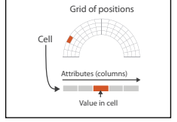
Spatial fields

- attribute values associated with cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated



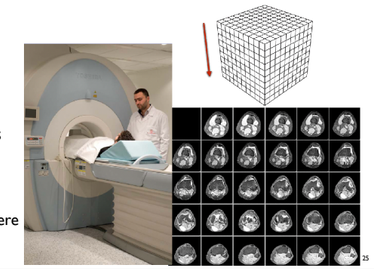
→ Spatial

→ Fields (Continuous)



Spatial fields

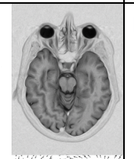
- attribute values associated with cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- beyond the scope of this class
  - sampling
    where attributes are measured
  - interpolation
    how to model attributes elsewhere
  - grid types



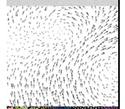
Spatial fields

- attribute values associated with cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- beyond the scope of this class
  - sampling
    where attributes are measured
  - interpolation
    how to model attributes elsewhere
  - grid types, tensors

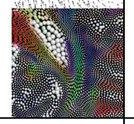
scalar



vector



tensor



Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

Fields

Grids

Positions

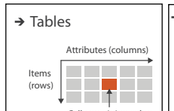
Attributes

Geometry

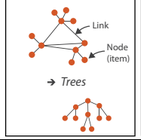
Items

Positions

→ Tables



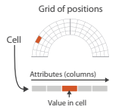
→ Networks



→ *Trees*

→ Spatial

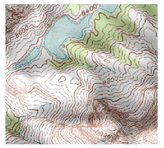
→ Fields (Continuous)



→ Geometry (Spatial)

Geometry

- shape of items
- explicit spatial positions
- points, lines, curves, surfaces, regions
  - (volumes outside scope of class)
- boundary between computer graphics and visualization
  - graphics: geometry taken as given
  - vis: geometry is result of a design decision



Dataset types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

Fields

Grids

Positions

Attributes

Geometry

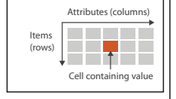
Items

Positions

Clusters, Sets, Lists

Items

→ Tables

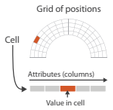


→ Networks

→ *Trees*

→ Spatial

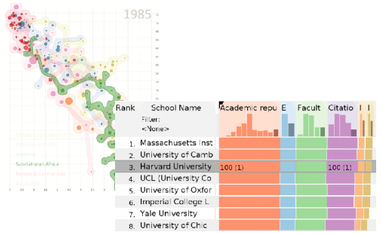
→ Fields (Continuous)

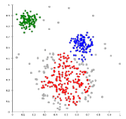


→ Geometry (Spatial)

Collections

- how we group items
- sets
  - unique items, unordered
- lists
  - ordered, duplicates possible
- clusters
  - groups of similar items





Dataset and data types

Data and Dataset Types

Tables

Items

Attributes

Networks & Trees

Items (nodes)

Links

Attributes

Fields

Grids

Positions

Attributes

Geometry

Items

Positions

Clusters, Sets, Lists

Items

Data Types

→ Items → Attributes → Links → Positions → Grids

Attribute types

- which classes of values & measurements?
- categorical (nominal)
  - compare equality
  - no implicit ordering
- ordered
  - ordinal
    - less/greater than defined
  - quantitative
    - meaningful magnitude
    - arithmetic possible

Attribute Types

→ Categorical

→ Ordered

→ *Ordinal*

→ *Quantitative*

Table

A	B	C	S	T	U
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
3	10/14/06	5-Low	Large Box	0.8	10/21/06
6	2/21/08	4-Not Specified	Small Pack	0.55	2/22/08
32	7/16/07	2-High	Small Pack	0.79	7/17/07
32	7/16/07	2-High	Jumbo Box	0.72	7/17/07
32	7/16/07	2-High	Medium Box	0.6	7/18/07
32	7/16/07	2-High	Medium Box	0.65	7/18/07
35	10/23/07	4-Not Specified	Wrap Bag	0.52	10/24/07
35	10/23/07	4-Not Specified	Small Box	0.58	10/25/07
36	11/3/07	1-Urgent	Small Box	0.55	11/3/07
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05
97	1/29/06	3-Medium	Small Box	0.38	1/30/06
129	11/19/08	5-Low	Small Box	0.37	11/28/08
130	5/8/08	2-High	Small Box	0.37	5/9/08
130	5/8/08	2-High	Medium Box	0.38	5/10/08
130	5/8/08	2-High	Small Box	0.6	5/11/08
132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
132	6/11/06	3-Medium	Jumbo Box	0.69	6/14/06
134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
135	10/21/07	4-Not Specified	Small Pack	0.64	10/23/07
166	9/12/07	2-High	Small Box	0.55	9/14/07
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06
194	4/5/08	3-Medium	Wrap Bag	0.42	4/7/08

categorical
ordinal
quantitative

A	B	C	S	T	U
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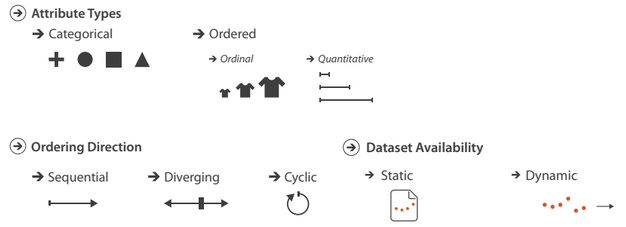
166	9/12/07	2-High	Small Box	0.55	9/14/07
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06

Quiz: What kind of variable?

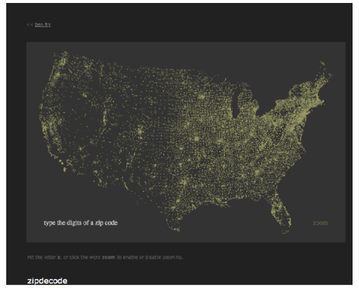
- 50 meter race times
- college major
- Amazon rating for product
- product name

Other data concerns



Hierarchical data

- multi-level structure
  - space
  - time
  - others
- example: zipdecode



https://benfry.com/zipdecode/

Data abstraction: Three operations

- translate from domain-specific language to generic visualization language
- identify dataset type(s), attribute types
- identify cardinality
  - how many items in the dataset?
  - what is cardinality of each attribute?
    - number of levels for categorical data
    - range for quantitative data
- consider whether to transform data
  - guided by understanding of task

Data vs conceptual models

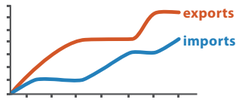
- data model
  - mathematical abstraction
    - sets with operations, eg floats with * / - +
    - variable data types in programming languages
- conceptual model
  - mental construction (semantics)
  - supports reasoning
  - typically based on understanding of tasks [stay tuned, next week]
- data abstraction process relies on conceptual model
  - for transforming data if needed

Data vs conceptual model, example

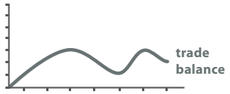
- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready
  - above freezing, below freezing: categorical
    - task: decide if I should leave the house today

Derived attributes

- derived attribute: compute from originals
  - simple change of type
  - acquire additional data
  - complex transformation
- more on this next time



Original Data



trade balance = exports − imports

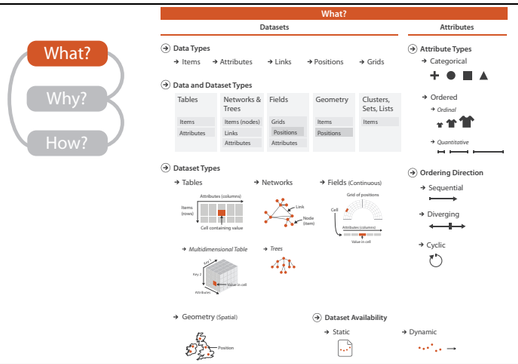
Derived Data

Data abstraction practice

- 2018 Central Park Squirrel Census

https://www.thesquirrelcensus.com/

https://data.cityofnewyork.us/Environment/2018-Central-Park-Squirrel-Census-Squirrel-Data/vfnx-vebw



Todo this week

- D3 videos to watch this week
  - refresher only if you need it: JS/HTML [90 min]
  - Intro to HTML/CSS/SVG [35 min]
  - Intro to D3.js [45 min]
- Quiz 1 to do this week, due by Fri Jan 10, 8am
- remember, no in-person labs this week!
- Foundations Exercise 1 out today (Thu Jan 9)
  - due Wed Jan 15

Credits

- Visualization Analysis and Design (Ch 2)
- Alex Lex & Miriah Meyer, http://dataviscourse.net/