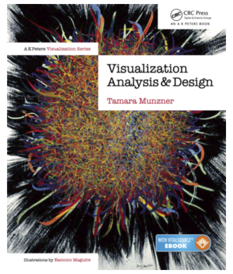
Visualization Analysis & Design
All Book/Teaching Slides



Tamara Munzner
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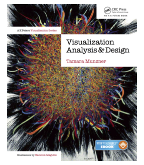
All Book/Teaching Slides
Last change: 4 Oct 2021

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

@tamaramunzner

Contents



Visualization Analysis & Design

What's Vis, and Why Do It? (Ch 1)

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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.

Why have a human in the loop?

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

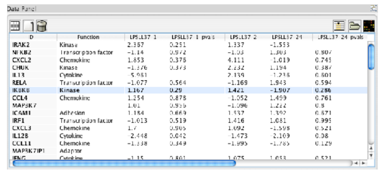
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- don't need vis when fully automatic solution exists and is trusted
- many analysis problems ill-specified
  - don't know exactly what questions to ask in advance
- possibilities
  - long-term use for end users (ex: exploratory analysis of scientific data)
  - presentation of known results (ex: New York Times Upshot)
  - stepping stone to 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



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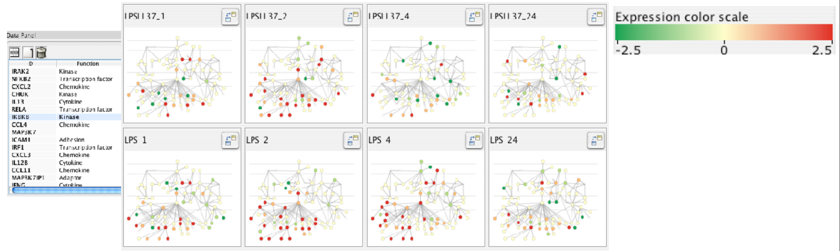

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Why depend on vision?

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

- human visual system is high-bandwidth channel to brain
  - overview possible due to background processing
    - subjective experience of seeing everything simultaneously
    - significant processing occurs in parallel and pre-attentively
- sound: lower bandwidth and different semantics
  - overview not supported
    - subjective experience of sequential stream
- touch/haptics: impoverished record/replay capacity
  - only very low-bandwidth communication thus far
- taste, smell: no viable record/replay devices

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

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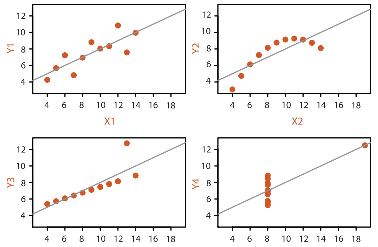

Anscombe's Quartet

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What resource limitations are we faced with?

Vis designers must take into account three very different kinds of resource limitations: those of computers, of humans, and of displays.

- computational limits
  - computation time, system memory
- display limits
  - pixels are precious & most constrained resource
  - **information density**: ratio of space used to encode info vs unused whitespace
    - tradeoff between clutter and wasting space
    - find sweet spot between dense and sparse
- human limits
  - human time, human memory, human attention

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

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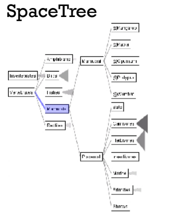
SpaceTree



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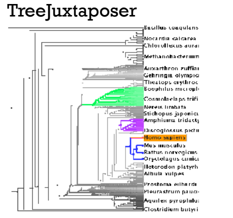
TreeJuxtaposer



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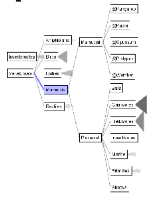

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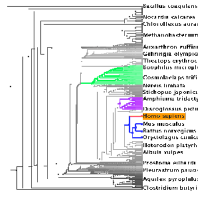

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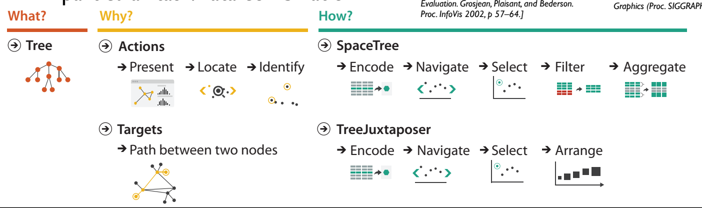

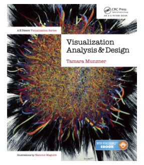

Visualization Analysis & Design

Analysis: Nested Model (Ch 4)

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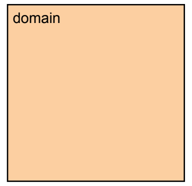
Analysis framework: Four levels, three questions

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



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    - **what** is shown? **data** abstraction
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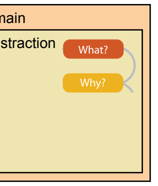

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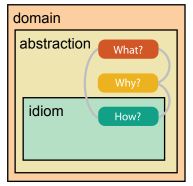
- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate



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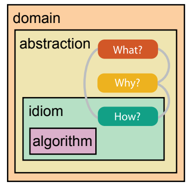
- *algorithm*
  - efficient computation



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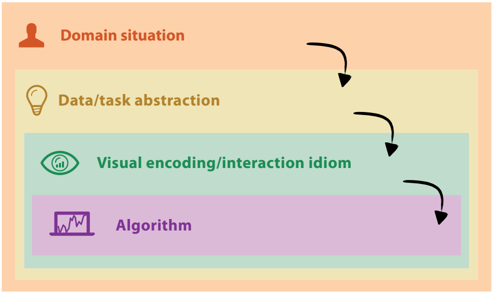
Nested model

- downstream: cascading effects



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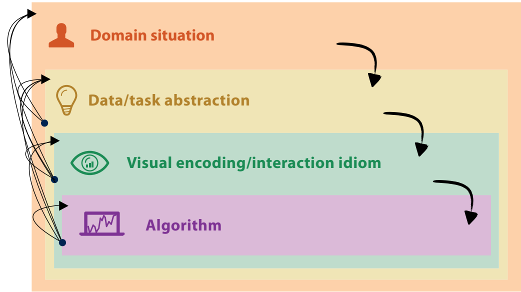
Nested model

- downstream: cascading effects
- upstream: iterative refinement



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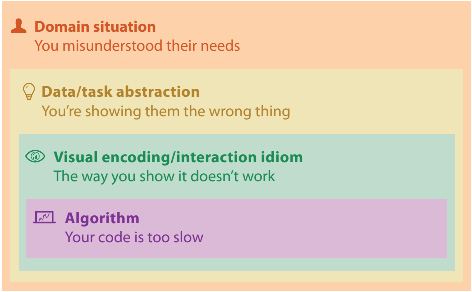
Why is validation difficult?

- different ways to get it wrong at each level



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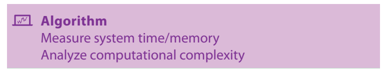

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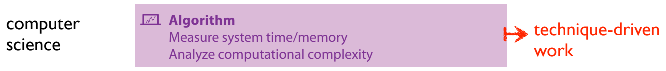

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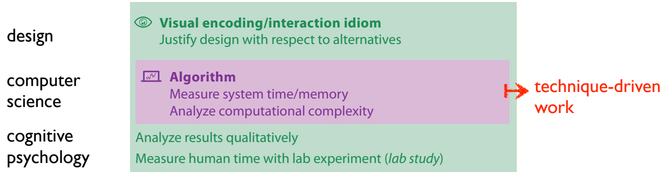

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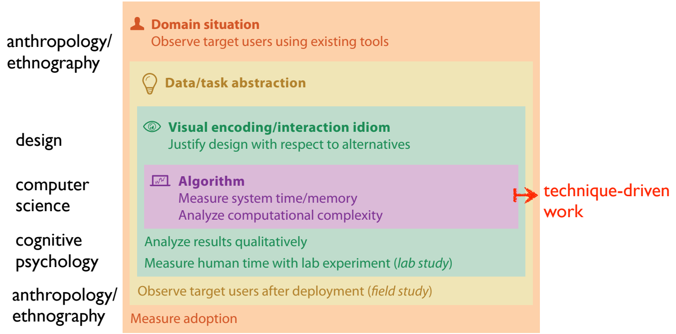

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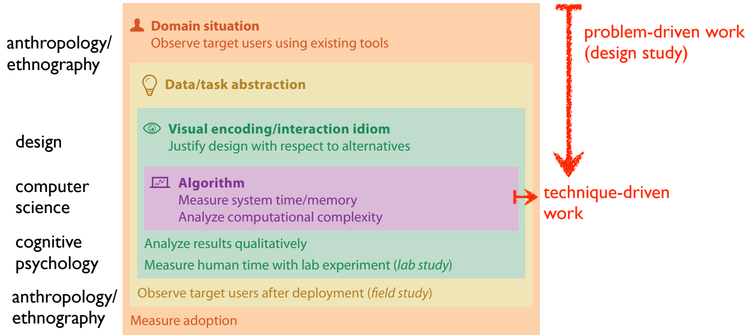

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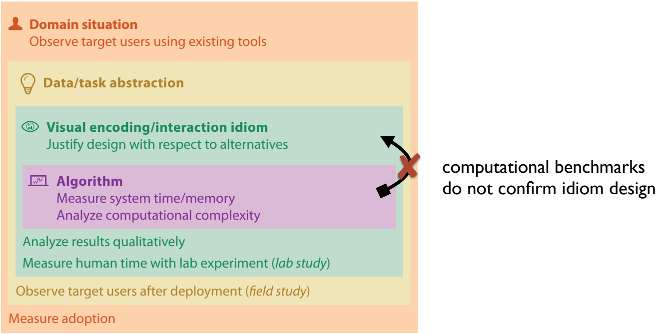

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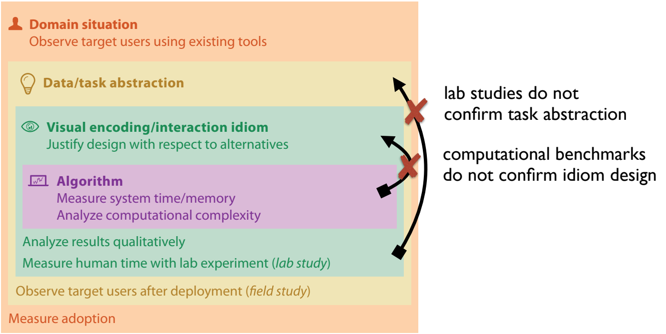

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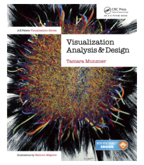

Visualization Analysis & Design

Analysis: Nested Model (Ch 4) II

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Analysis examples: Single paper includes only subset of methods

- 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

Analysis examples: Single paper includes only subset of methods

MatrixExplorer. Henry and Fekete. InfoVis 2006.
- observe and interview target users
- justify encoding/interaction design
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- qualitative result image analysis

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Flow map layout. Phan et al. InfoVis 2005.
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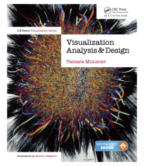

Visualization Analysis & Design

Data Abstraction (Ch 2): In Brief

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Three major datatypes

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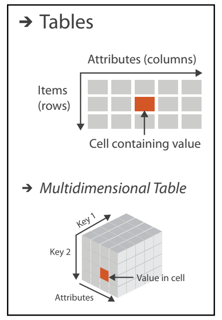

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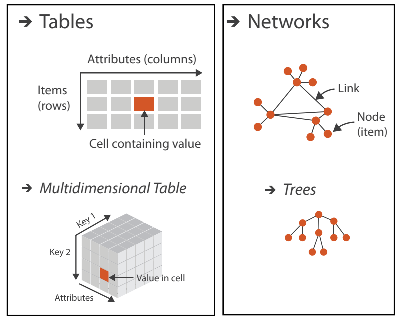

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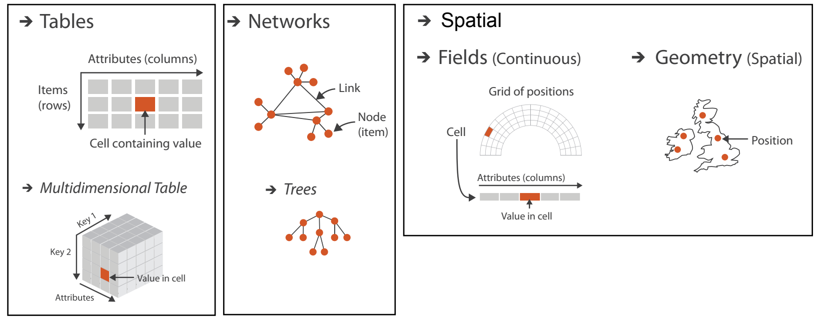

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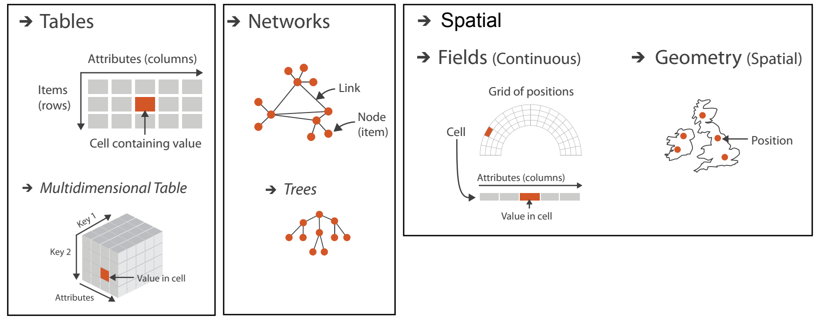
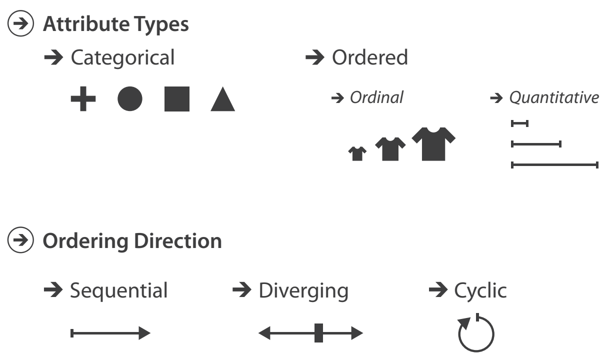
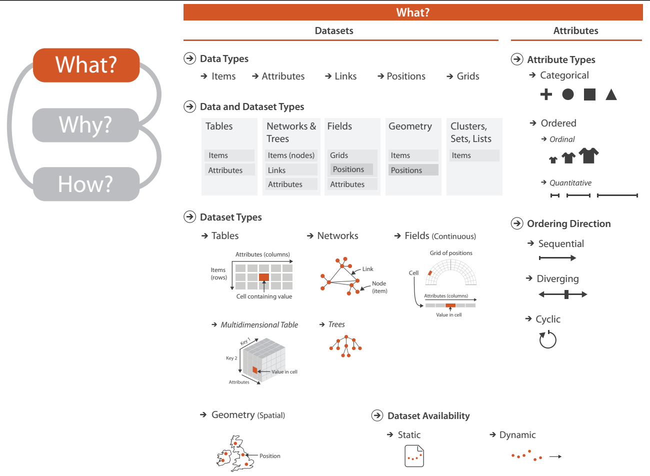


- visualization vs computer graphics
  – geometry is design decision

Attribute types





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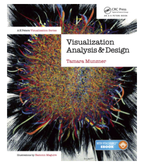

Data Abstraction (Ch 2)

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What does data mean?

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14, 2.6, 30, 30, 15, 100001

- What does this sequence of six numbers mean?

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?

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Basil, 7, S, Pear

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Basil, 7, S, Pear

- What about this data?

What does data mean?

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- 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

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

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"

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"

Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
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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

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"

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

Items & Attributes

- item: individual entity, discrete
  - eg patient, car, stock, city
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- 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

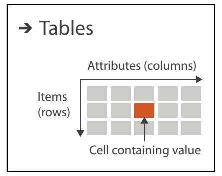
Other data types

- 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 for item-attribute pair



attributes: name, age, shirt size, fave fruit

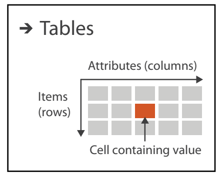
Name	Age	Shirt Size	Favorite Fruit
Amy	8	S	Apple
Basil	7	S	Pear
Clara	9	M	Durian
Desmond	13	L	Elderberry
Ernest	12	L	Peach
Fanny	10	S	Lychee
George	9	M	Orange
Hector	8	L	Loquat
Ida	10	M	Pear
Amy	12	M	Orange

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

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
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129	11/19/08	5-Low	Small Box	0.37	11/28/08
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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
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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

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
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
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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
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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
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
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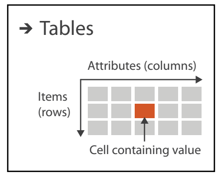
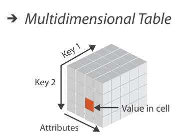
65	3/18/07	1-Urgent	Small Pack	0.49	3/19/07
66	1/20/05	5-Low	Wrap Bag	0.56	1/20/05
69	6/4/05	4-Not Specified	Small Pack	0.44	6/6/05
69	6/4/05	4-Not Specified	Wrap Bag	0.6	6/6/05
70	12/18/06	5-Low	Small Box	0.59	12/23/06
70	12/18/06	5-Low	Wrap Bag	0.82	12/23/06
96	4/17/05	2-High	Small Box	0.55	4/19/05
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

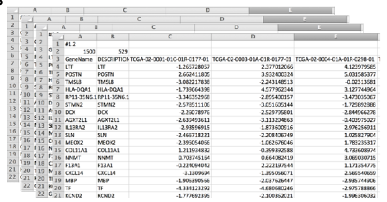
Dataset types

Tables
Items
Attributes

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





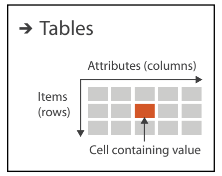


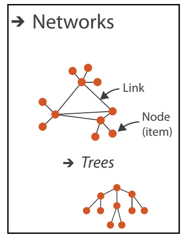
Dataset types

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



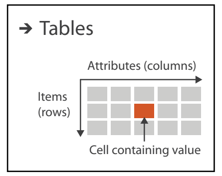


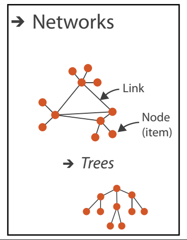
Dataset types

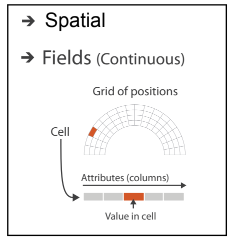
Tables
Items
Attributes

Networks & Trees
Items (nodes)
Links
Attributes

Fields
Grids
Positions
Attributes

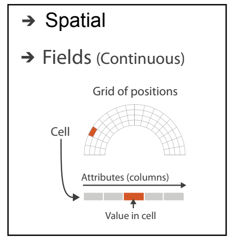


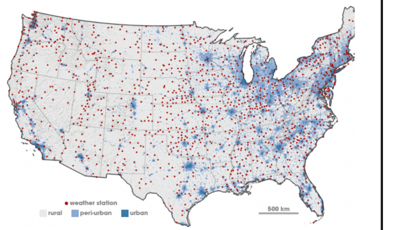




Spatial fields

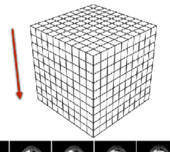
- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated

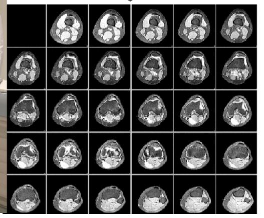




Spatial fields

- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- major concerns
  - sampling: where attributes are measured
  - interpolation: how to model attributes elsewhere
  - grid types

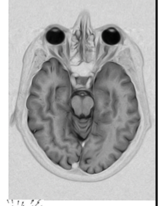




Spatial fields

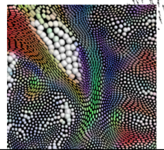
- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated
- major concerns
  - sampling: where attributes are measured
  - interpolation: how to model attributes elsewhere
  - grid types
- major divisions
  - attributes per cell: scalar (1), vector (2), tensor (many)

scalar



vector

tensor



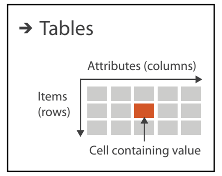
Dataset types

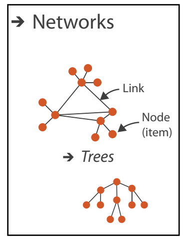
Tables
Items
Attributes

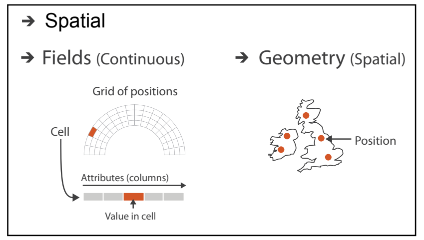
Networks & Trees
Items (nodes)
Links
Attributes

Fields
Grids
Positions
Attributes

Geometry
Items
Positions

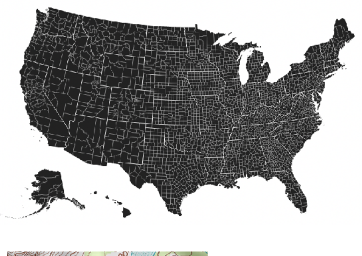


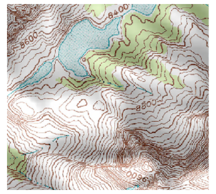




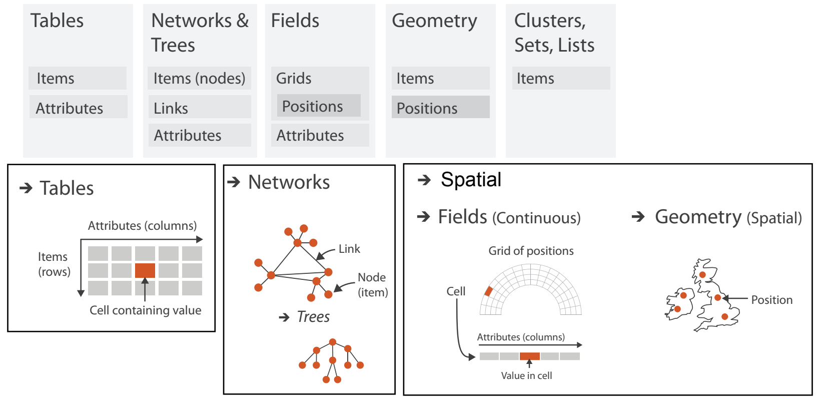
Geometry

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





Dataset types

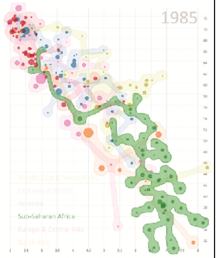


Collections

- how we group items

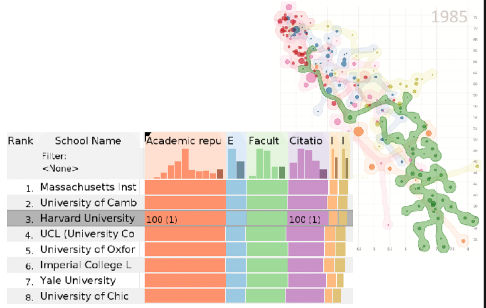
Collections

- how we group items
- sets
  - unique items, unordered



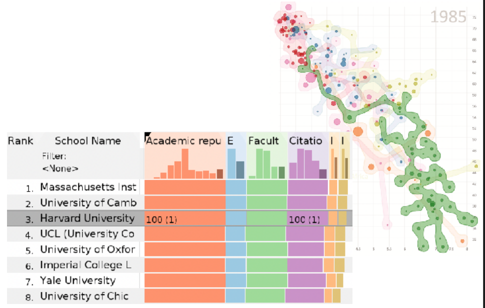
Collections

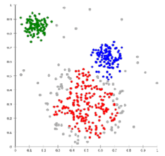
- how we group items
- sets
  - unique items, unordered
- lists
  - ordered, duplicates possible



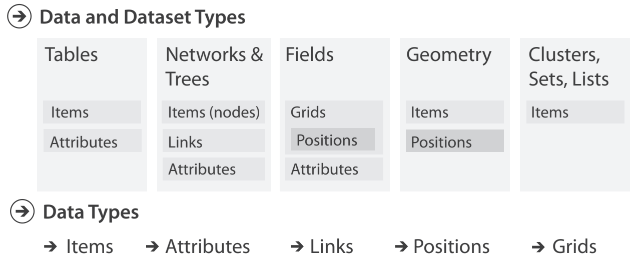
Collections

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





Dataset and data types



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

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
Order ID	Order Date	Order Priority	Product Container	Product Base Margin	Ship Date
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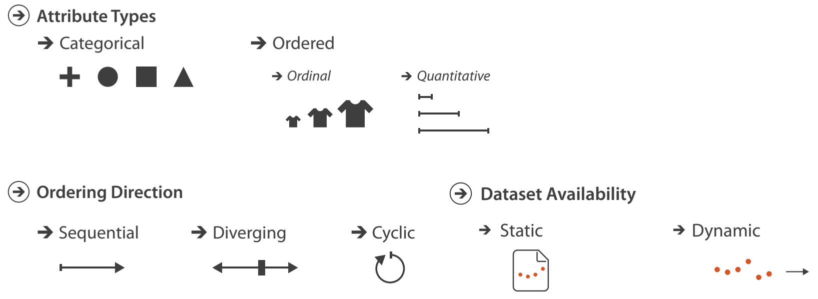
Other data concerns



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!]
- data abstraction process relies on conceptual model
  - for transforming data if needed

Data vs conceptual model, example

Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...

Data vs conceptual model, example

- data model: floats
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- conceptual model
  - temperature

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- multiple possible data abstractions

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  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather

Data vs conceptual model, example

- data model: floats
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    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready

Data vs conceptual model, example

- data model: floats
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- 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

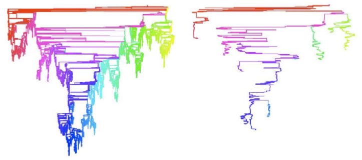
Original Data

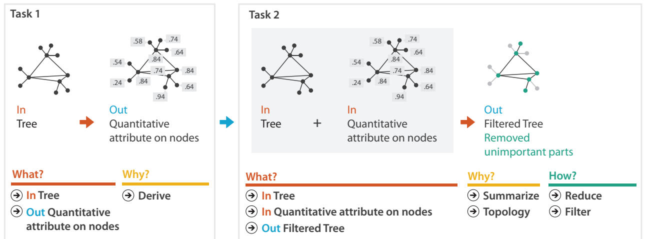
Derived Data

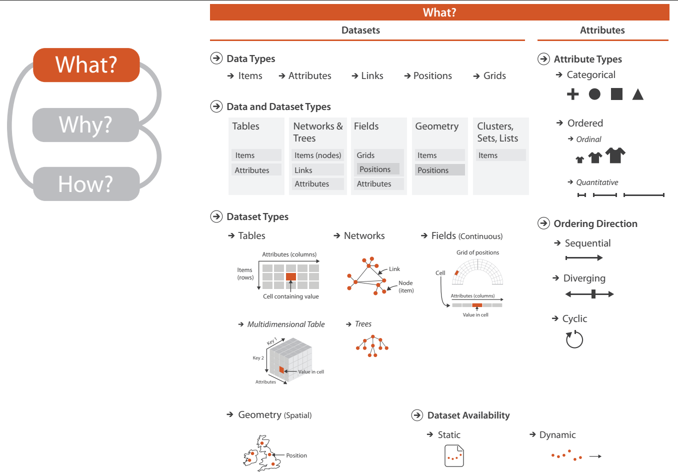
Analysis example: Derive one attribute

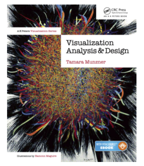
- Strahler number
  - centrality metric for trees/networks
  - derived quantitative attribute
  - draw top 5K of 500K for good skeleton

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





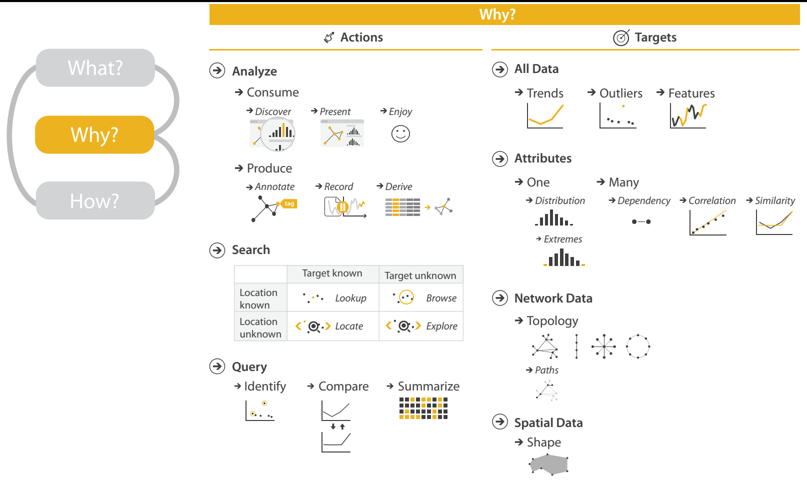


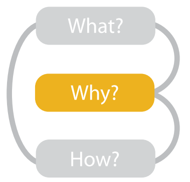


Visualization Analysis & Design

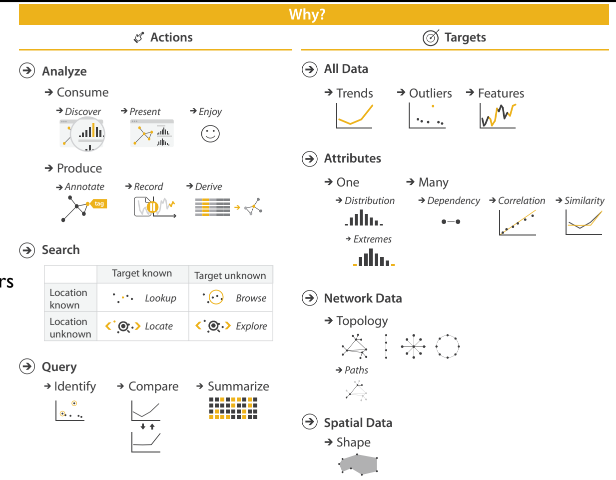
Task Abstraction (Ch 3): In Brief

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner



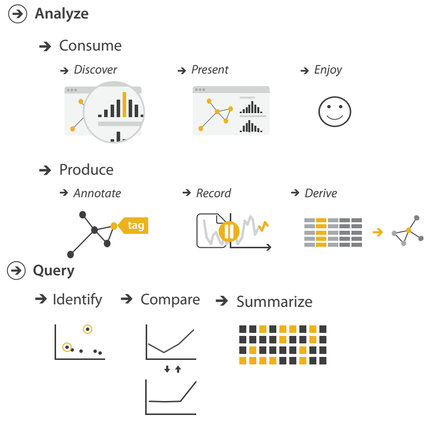


- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*



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)



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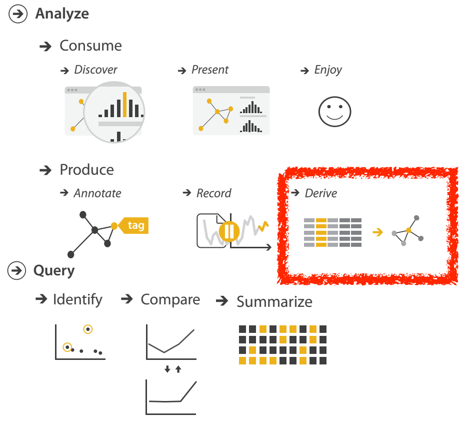


Derive

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

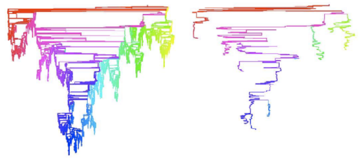
Original Data

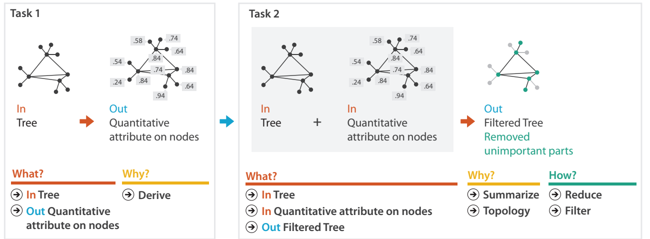
Derived Data

Analysis example: Derive one attribute

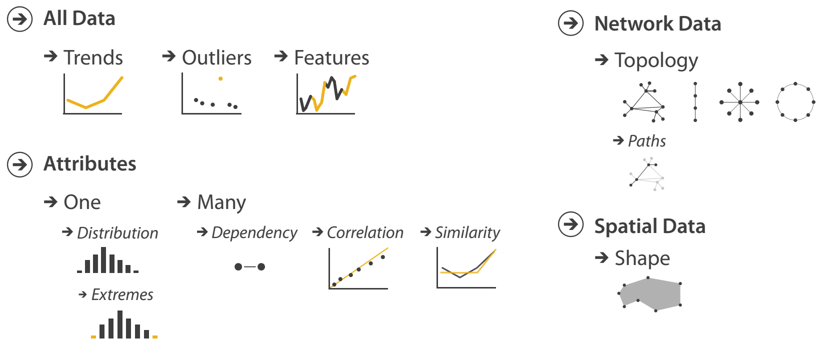
- Strahler number
  - centrality metric for trees/networks
  - derived quantitative attribute
  - draw top 5K of 500K for good skeleton

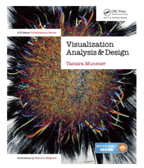
[Using Strahler numbers for real time visual exploration of huge graphs. Auber. Proc. Intl. Conf. Computer Vision and Graphics, pp. 56–69, 2002.]





Why: Targets





Visualization Analysis & Design

Task Abstraction (Ch 3)

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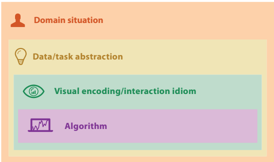
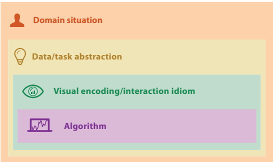
@tamaramunzner

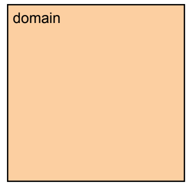
From domain to abstraction



From domain to abstraction

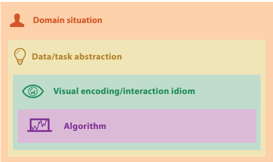
- domain characterization: details of application domain

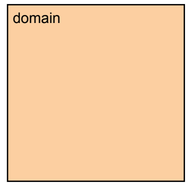




From domain to abstraction

- domain characterization: details of application domain
  - group of users, target domain, their questions & data
    - varies wildly by domain
    - must be specific enough to get traction





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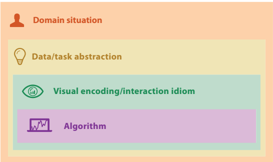
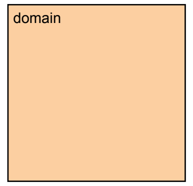
    - break down into simpler abstract tasks





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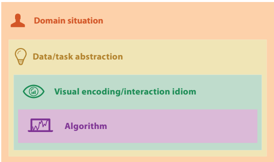
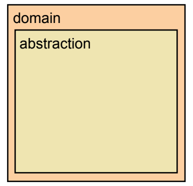
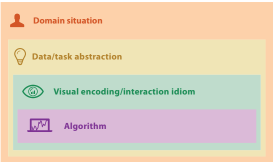
    - break down into simpler abstract tasks
- abstraction: data & task
  - map *what* and *why* into generalized terms

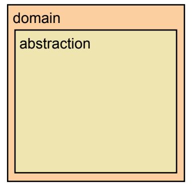




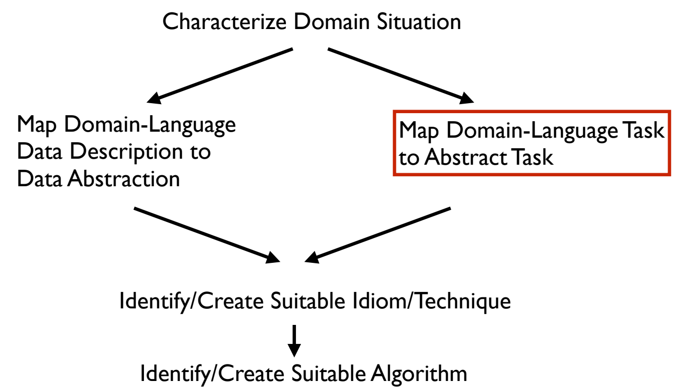
From domain to abstraction

- domain characterization: details of application domain
  - group of users, target domain, their questions & data
    - varies wildly by domain
    - must be specific enough to get traction
  - domain questions/problems
    - break down into simpler abstract tasks
- abstraction: data & task
  - map *what* and *why* into generalized terms
    - identify tasks that users wish to perform, or already do
    - find data types that will support those tasks
      - possibly transform /derive if need be





Design process



Task abstraction: Actions and targets

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

Task abstraction: Actions and targets

- very high-level pattern
- actions
  - analyze
    - high-level choices
  - search
    - find a known/unknown item
  - query
    - find out about characteristics of item
- {action, target} pairs
  - *discover distribution*
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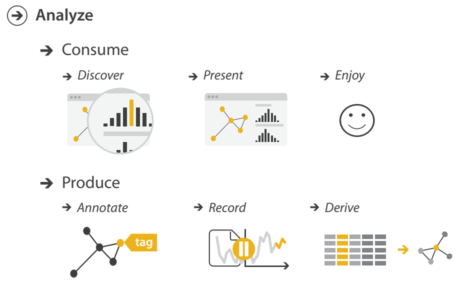
Task abstraction: Actions and targets

- very high-level pattern
- actions
  - analyze
    - high-level choices
  - search
    - find a known/unknown item
  - query
    - find out about characteristics of item
- targets
  - what is being acted on
- {action, target} pairs
  - *discover distribution*
  - *compare trends*
  - *locate outliers*
  - *browse topology*

Actions: Analyze

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



Actions: Search

Actions: Search

- what does user know?
  - target, location

Search

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

Actions: Search

- what does user know?
  - target, location
- lookup
  - ex: word in dictionary
    - alphabetical order

Search

	Target known	Target unknown
Location known	*Lookup*	*Browse*
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Actions: Search

- what does user know?
  - target, location
- lookup
  - ex: word in dictionary
    - alphabetical order
- locate
  - ex: keys in your house
  - ex: node in network

Search

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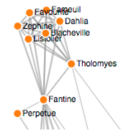

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  - ex: books in bookstore

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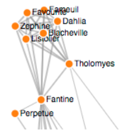

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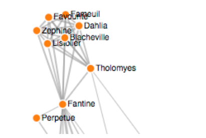
  - target, location
- lookup
  - ex: word in dictionary
    - alphabetical order
- locate
  - ex: keys in your house
  - ex: node in network
- browse
  - ex: books in bookstore
- explore
  - ex: find cool neighborhood in new city

Search

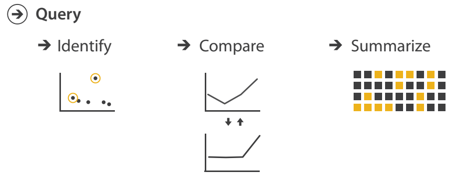
	Target known	Target unknown
Location known	Lookup	Browse
Location unknown	Locate	Explore



https://bl.ocks.org/heybignick/3faf257bbbbc7743bb72310d03b86ee8

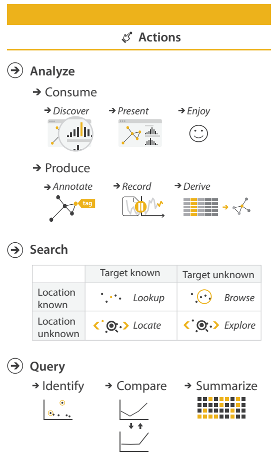
Actions: Query

- how much of the data matters?
  - one: identify
  - some: compare
  - all: summarize



Actions

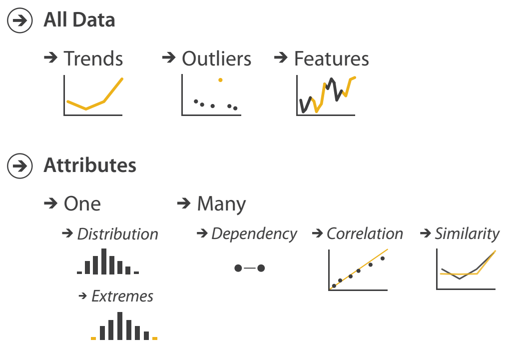
- independent choices for each of these three levels
  - analyze, search, query
  - mix and match



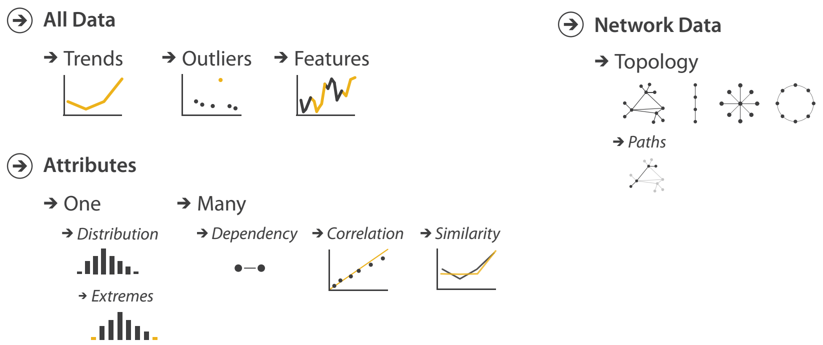
Task abstraction: Targets

Task abstraction: Targets

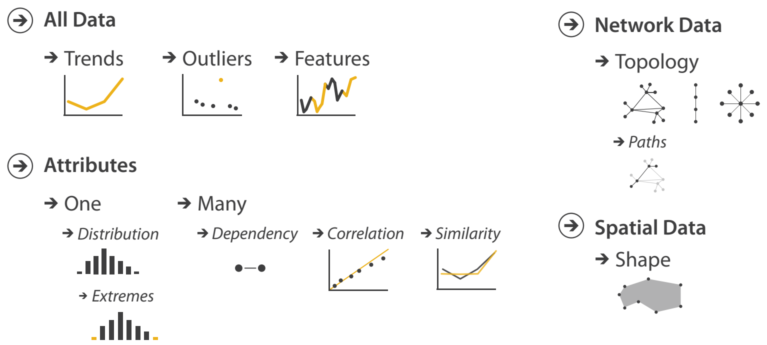
Task abstraction: Targets



Task abstraction: Targets



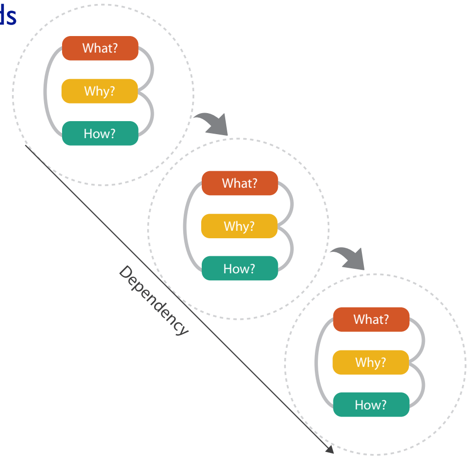
Task abstraction: Targets

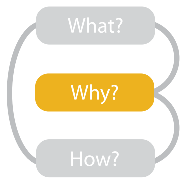


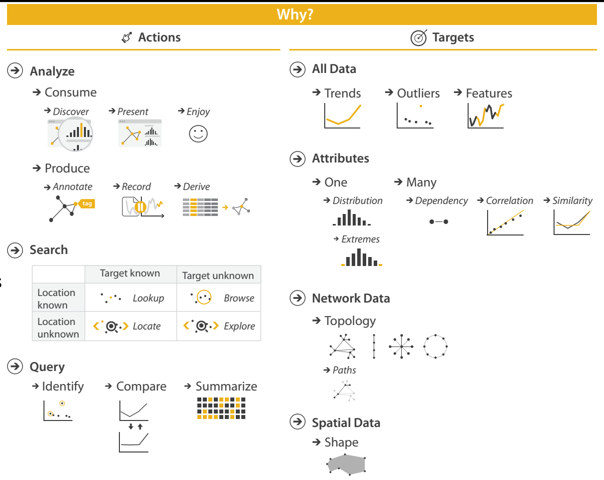
Abstraction

- these {action, target} pairs are good starting point for vocabulary
  - but sometimes you'll need more precision!
- rule of thumb
  - systematically remove all domain jargon
- interplay: task and data abstraction
  - need to use data abstraction within task abstraction
    - to specify your targets!
    - but task abstraction can lead you to transform the data
  - iterate back and forth
    - first pass data, first pass task, second pass data, ...

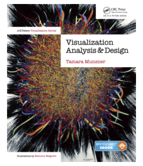
Means and ends







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



Visualization Analysis & Design

Marks & Channels (Ch 5) I

Tamara Munzner
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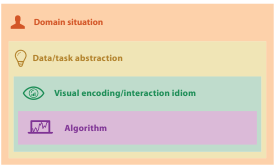
University of British Columbia
@tamaramunzner

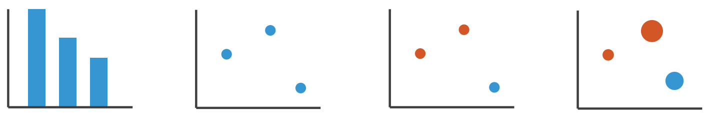
Visual encoding

- how to systematically analyze idiom structure?



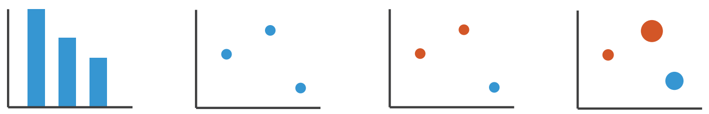
Visual encoding

- how to systematically analyze idiom structure?



Visual encoding

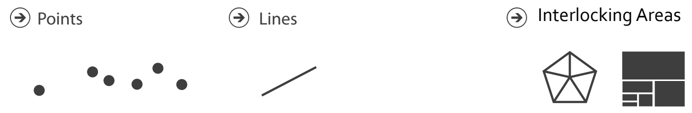
- how to systematically analyze idiom structure?



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

Marks for items

- basic geometric elements

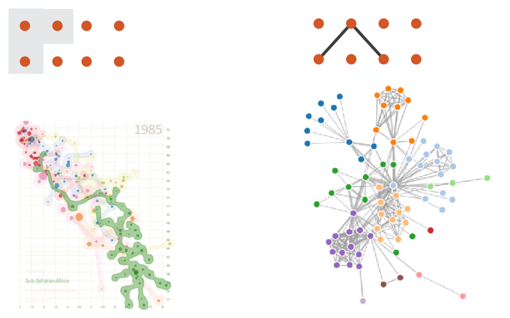


0D 1D 2D

- 3D mark: volume, rarely used

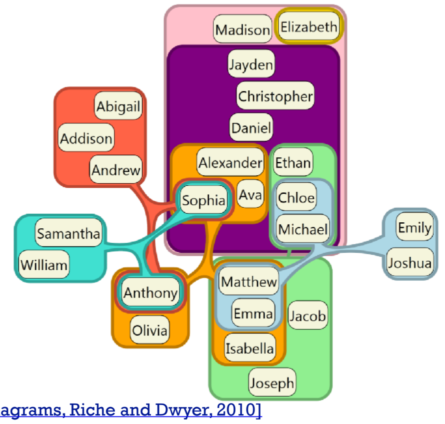
Marks for links

- Containment
- Connection



vialab.science.uoit.ca/portfolio/bubblesets https://observablehq.com/@d3/force-directed-graph

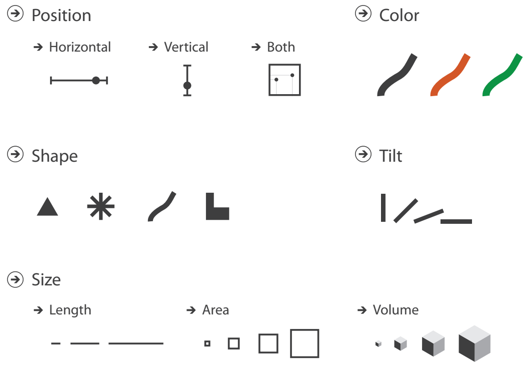
Containment can be nested



[Untangling Euler Diagrams, Riche and Dwyer, 2010]

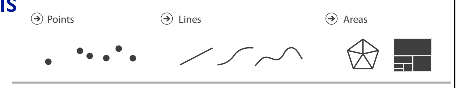
Channels

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



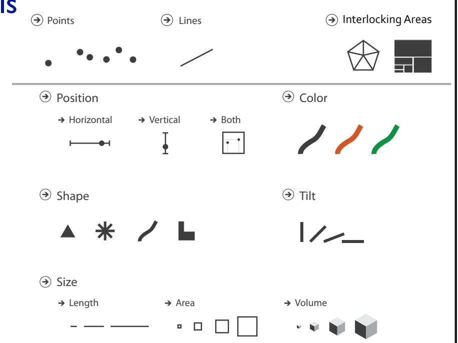
Definitions: Marks and channels

- marks
  - geometric primitives



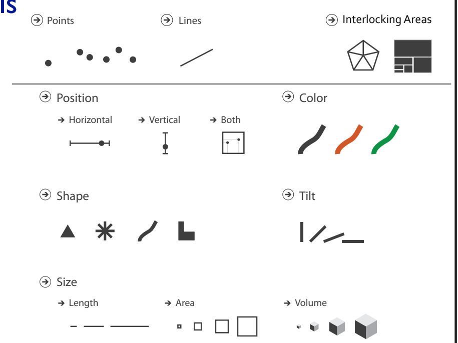
Definitions: Marks and channels

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



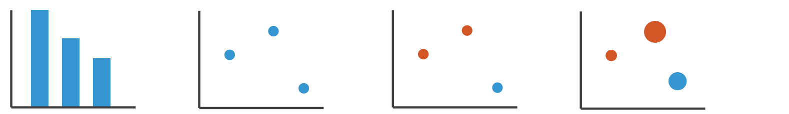
Definitions: Marks and channels

- marks
  - geometric primitives
- channels
  - control appearance of marks
- channel properties differ
  - type & amount of information that can be conveyed to human perceptual system



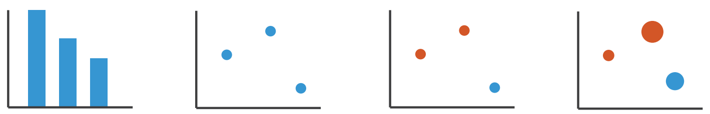
Visual encoding

- analyze idiom structure as combination of marks and channels



Visual encoding

- analyze idiom structure as combination of marks and channels

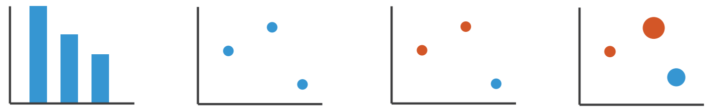


1:
vertical position

mark: line

Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

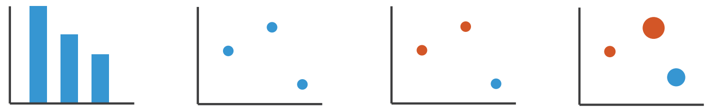
2:
vertical position
horizontal position

mark: line

mark: point

Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

2:
vertical position
horizontal position

3:
vertical position
horizontal position
color hue

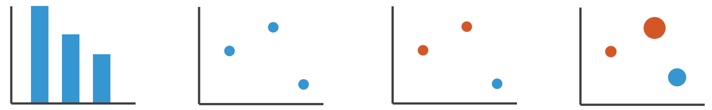
mark: line

mark: point

mark: point

Visual encoding

- analyze idiom structure as combination of marks and channels



1:
vertical position

2:
vertical position
horizontal position

3:
vertical position
horizontal position
color hue

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

mark: line

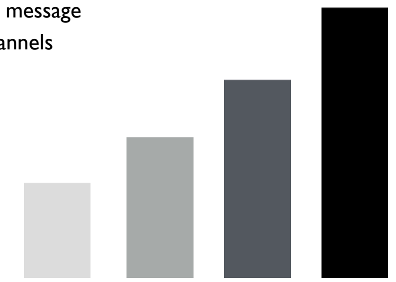
mark: point

mark: point

mark: point

Redundant encoding

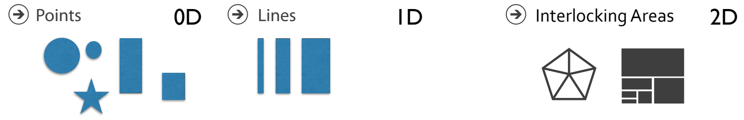
- multiple channels
  - sends stronger message
  - but uses up channels



Length and Luminance

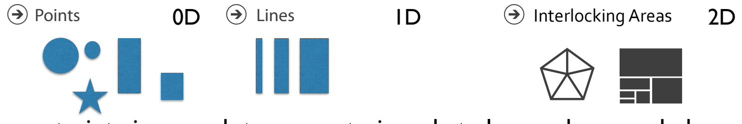
Marks as constraints

- math view: geometric primitives have dimensions



Marks as constraints

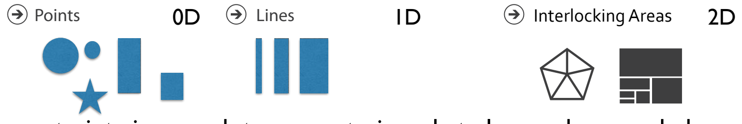
- math view: geometric primitives have dimensions



- constraint view: mark type constrains what else can be encoded
  - points: 0 constraints on size, can encode more attributes w/ size & shape
  - lines: 1 constraint on size (length), can still size code other way (width)
  - interlocking areas: 2 constraints on size (length/width), cannot size or shape code
    - interlocking: size, shape, position

Marks as constraints

- math view: geometric primitives have dimensions



- constraint view: mark type constrains what else can be encoded
  - points: 0 constraints on size, can encode more attributes w/ size & shape
  - lines: 1 constraint on size (length), can still size code other way (width)
  - interlocking areas: 2 constraints on size (length/width), cannot size or shape code
    - interlocking: size, shape, position
- quick check: can you size-code another attribute
  - or is size/shape in use?

Scope of analysis

- simplifying assumptions: one mark per item, single view
- later on
  - multiple views
  - multiple marks in a region (glyph)
  - some items not represented by marks (aggregation and filtering)

When to use which channel?

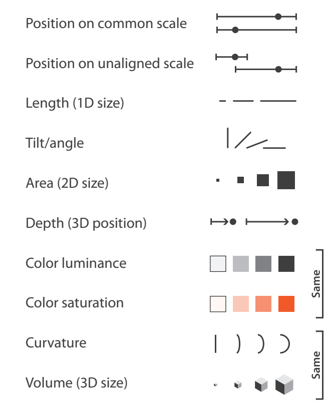
expressiveness

match channel type to data type

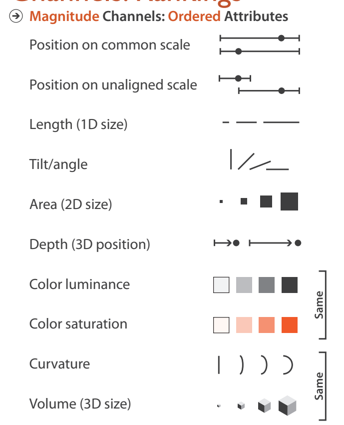
effectiveness

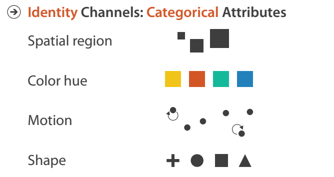
some channels are better than others

Channels: Rankings



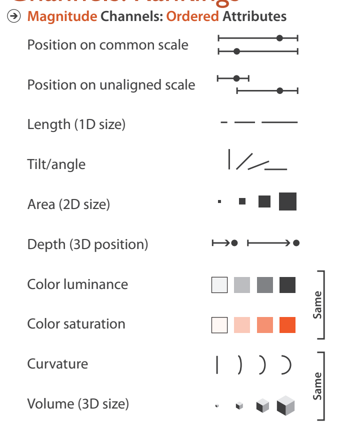
Channels: Rankings

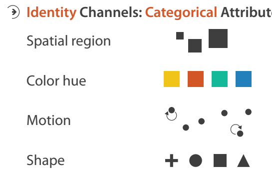


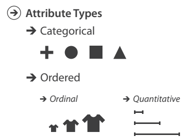


- expressiveness
  - match channel and data characteristics

Channels: Rankings

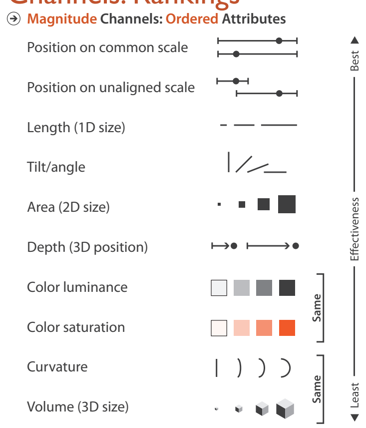


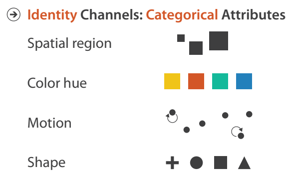




- expressiveness
  - match channel and data characteristics
  - magnitude for ordered
    - how much? which rank?
  - identity for categorical
    - what?

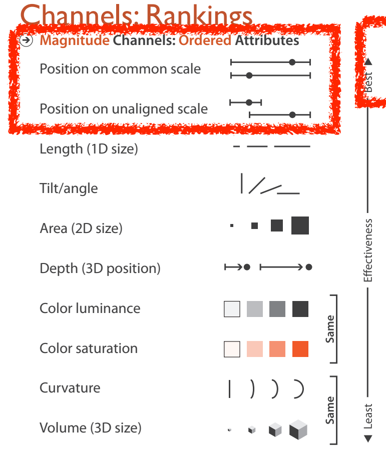
Channels: Rankings

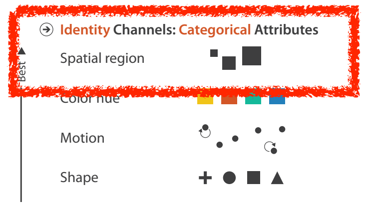




- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception

Channels: Rankings



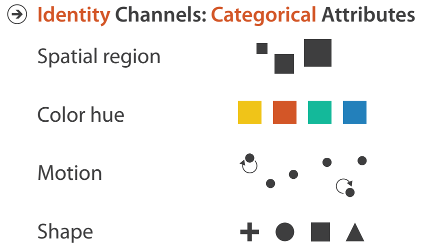


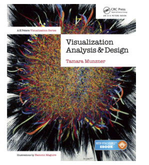
- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception
  - spatial position ranks high for both

Grouping

- containment
- connection

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





Visualization Analysis & Design

Marks & Channels (Ch 5) II

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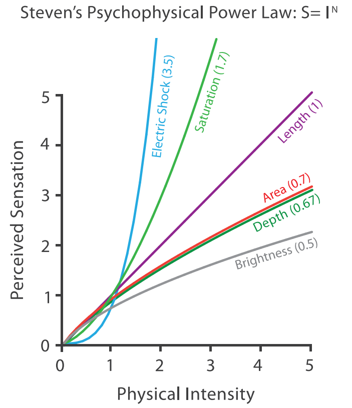
Channel effectiveness

- 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

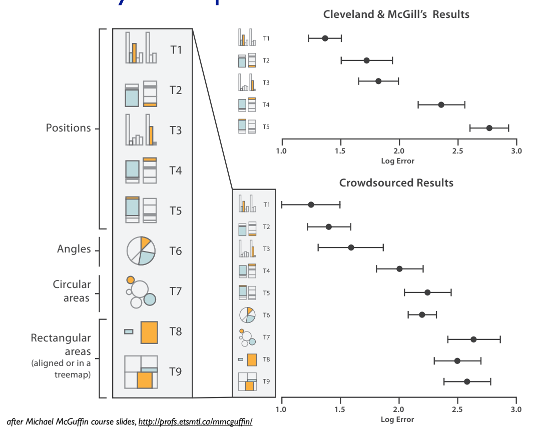
- length is accurate: linear
- others magnified or compressed
  - exponent characterizes



S = sensation

I = intensity

Accuracy: Vis experiments

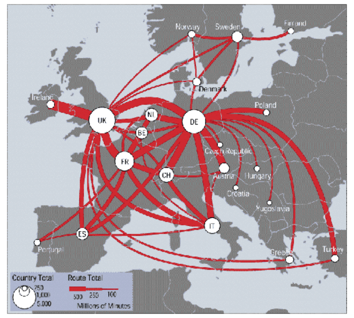


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

after Michael McGuffin course slides, http://profs.etsmtl.ca/mmcguffin/

Discriminability: How many usable steps?

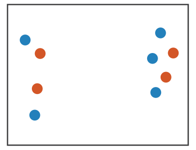
- must be sufficient for number of attribute levels to show
  - linewidth: few bins



[mappa.mundi.net/maps/maps 014/telegeography.html]

Separability vs. Integrality

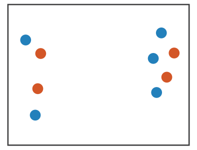
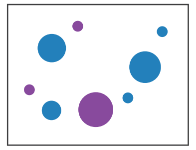
Position
+ Hue (Color)



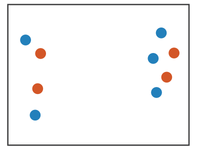
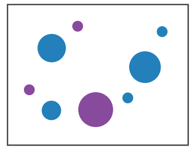
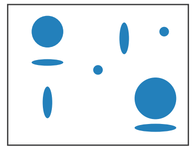
Fully separable

2 groups each

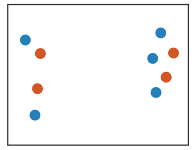
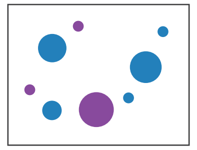
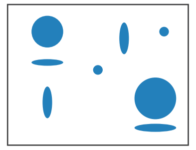
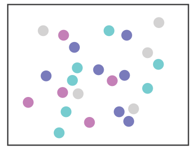
Separability vs. Integrality

Position + Hue (Color)	Size + Hue (Color)
	
Fully separable	Some interference
2 groups each	2 groups each

Separability vs. Integrality

Position + Hue (Color)	Size + Hue (Color)	Width + Height
		
Fully separable	Some interference	Some/significant interference
2 groups each	2 groups each	3 groups total: integral area

Separability vs. Integrality

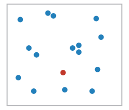
Position + Hue (Color)	Size + Hue (Color)	Width + Height	Red + Green
			
Fully separable	Some interference	Some/significant interference	Major interference
2 groups each	2 groups each	3 groups total: integral area	4 groups total: integral hue

Popout

- find the red dot
  - how long does it take?

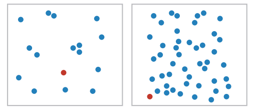
Popout

- find the red dot
  - how long does it take?



Popout

- find the red dot
  - how long does it take?



Popout

- find the red dot
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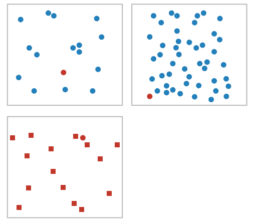
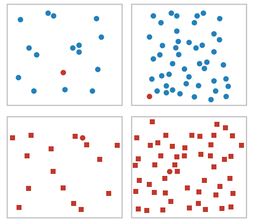


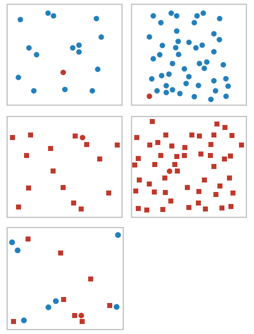
Popout

- find the red dot
  - how long does it take?



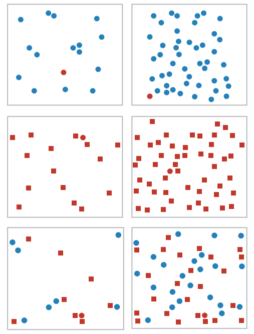
Popout

- find the red dot
  - how long does it take?



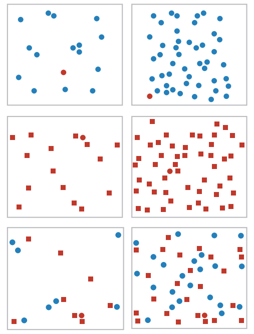
Popout

- find the red dot
  - how long does it take?

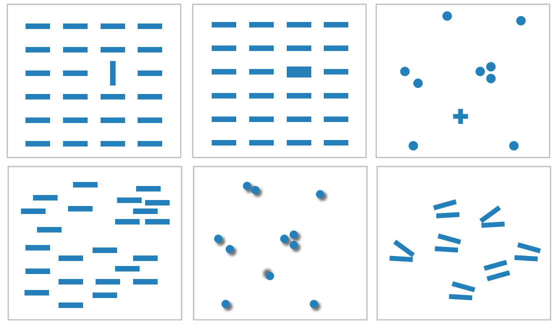


Popout

- find the red dot
  - how long does it take?
- parallel processing on many individual channels
  - speed independent of distractor count
  - speed depends on channel and amount of difference from distractors
- serial search for (almost all) combinations
  - speed depends on number of distractors



Popout



- many channels
  - tilt, size, shape, proximity, shadow direction, ...

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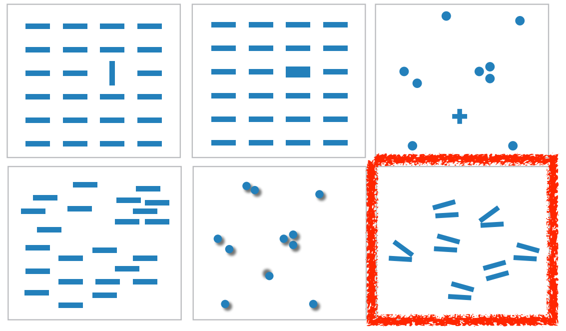

- many channels
  - tilt, size, shape, proximity, shadow direction, ...
- but not all!
  - parallel line pairs do not pop out from tilted pairs

Factors affecting accuracy

- alignment
- distractors
- distance
- common scale / alignment

Relative vs. absolute judgements

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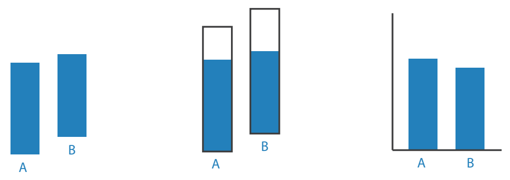

after [Graphical Perception: Theory, Experimentation, and Application to the Development of Graphical Methods. Cleveland and McGill. Journ. American Statistical Association 79:387 (1984), 531–554.]

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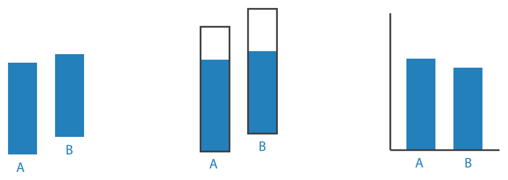

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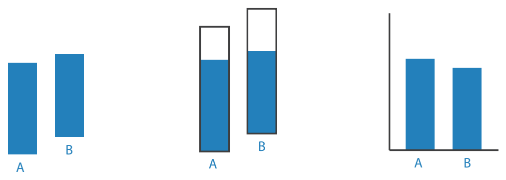
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement



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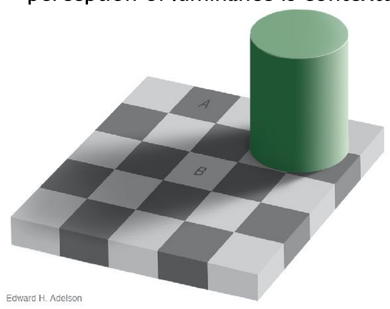

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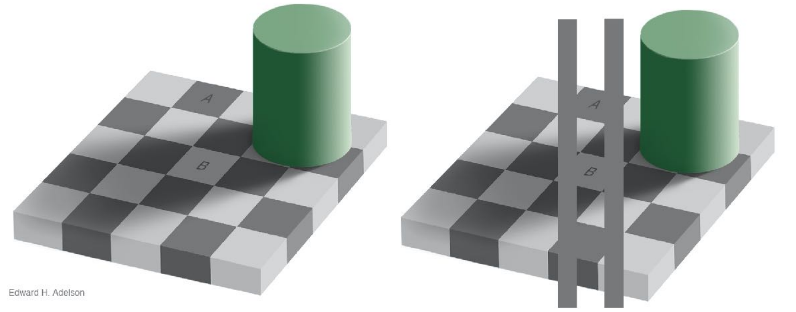

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Relative color judgements

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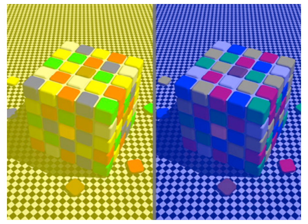

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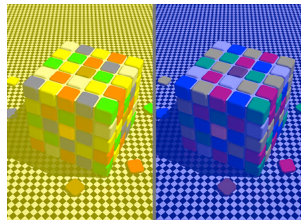

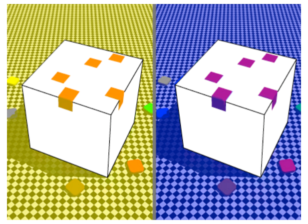

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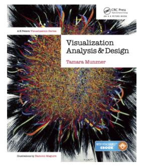


Visualization Analysis & Design

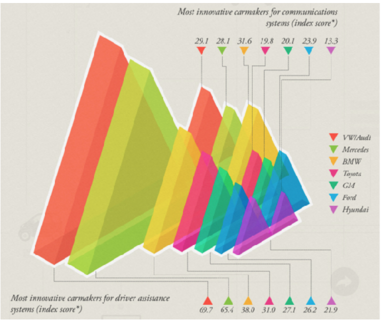
Rules of Thumb (Ch 6)

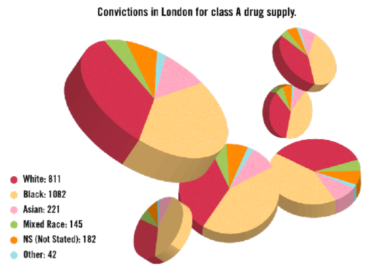
Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

Rules of Thumb

- Guidelines and considerations, not absolute rules
  - when to use 3D? when to use 2D?
  - when to use eyes instead of memory?
  - when does immersion help?
  - when to use overviews?
  - how long is too long?
  - which comes first, form or function?

Unjustified 3D all too common, in the news and elsewhere

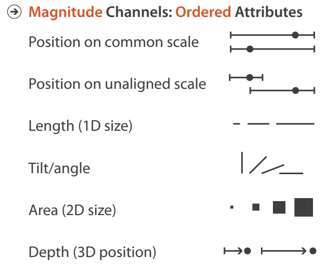




http://viz.wtf/post/137826497077/eye-popping-3d-triangles
http://viz.wtf/post/139002022202/designer-drugs-ht-ducqn

Depth vs power of the plane

- high-ranked spatial position channels: **planar** spatial position
  - not depth!



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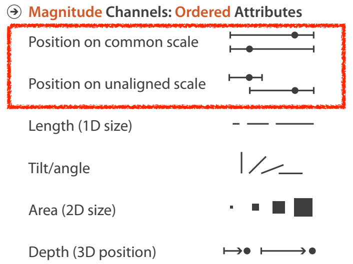

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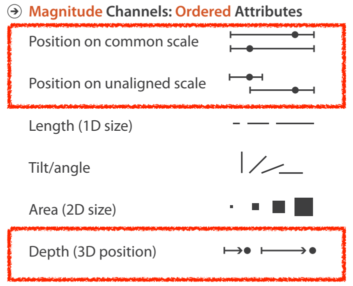

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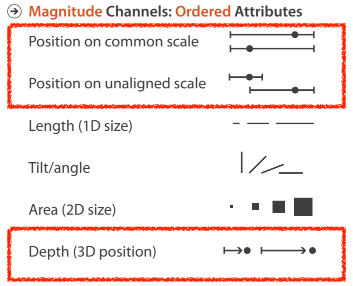
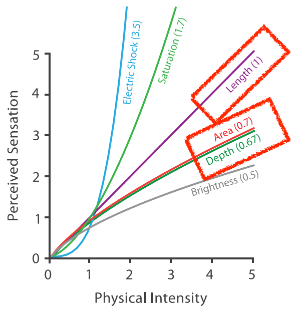
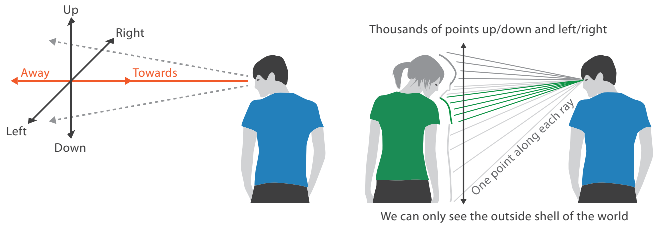


Steven's Psychophysical Power Law: $S= I^N$



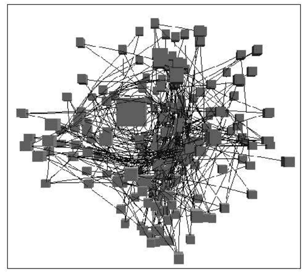
No unjustified 3D: Danger of depth

- we don't really live in 3D: we **see** in 2.05D
  - acquire more info on image plane quickly from eye movements
  - acquire more info for depth slower, from head/body motion



Occlusion hides information

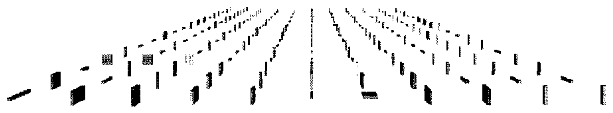
- occlusion
- interaction can resolve, but at cost of time and cognitive load



[Distortion Viewing Techniques for 3D Data. Carpendale et al. InfoVis1996.]

Perspective distortion loses information

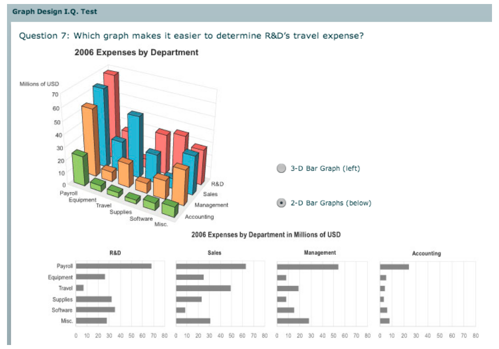
- perspective distortion
  - interferes with all size channel encodings
  - power of the plane is lost!



[Visualizing the Results of Multimedia Web Search Engines. Mukherjea, Hirata, and Hara. InfoVis 96]

3D vs 2D bar charts

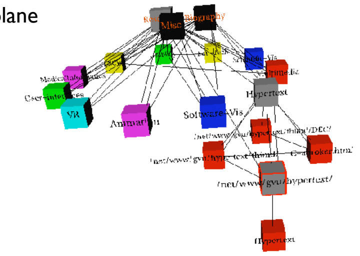
- 3D bars: very difficult to justify!
  - perspective distortion
  - occlusion
- faceting into 2D almost always better choice



[http://perceptualedge.com/files/GraphDesignIQ.html]

Tilted text isn't legible

- text legibility
  - far worse when tilted from image plane



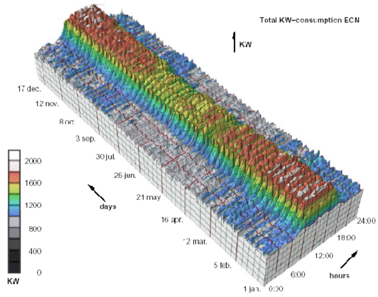
- further reading

Exploring and Reducing the Effects of Orientation on Text Readability in Volumetric Displays. Grossman et al. CHI 2007

[Visualizing the World-Wide Web with the Navigational View Builder. Mukherjea and Foley. Computer Networks and ISDN Systems, 1995.]

No unjustified 3D example: Time-series data

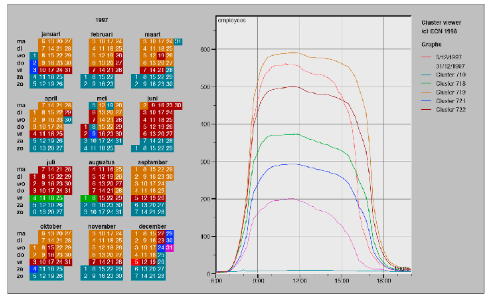
- extruded curves: detailed comparisons impossible



[Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc. InfoVis 99.]

No unjustified 3D example: Transform for new data abstraction

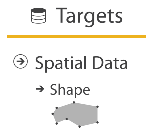
- derived data: cluster hierarchy
- juxtapose multiple views: calendar, superimposed 2D curves

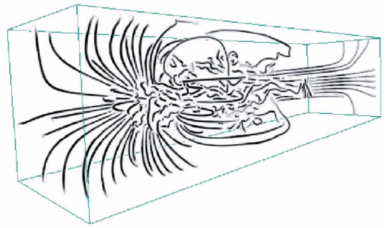


[Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc. InfoVis 99.]

Justified 3D: shape perception

- benefits outweigh costs when task is shape perception for 3D spatial data
  - interactive navigation supports synthesis across many viewpoints

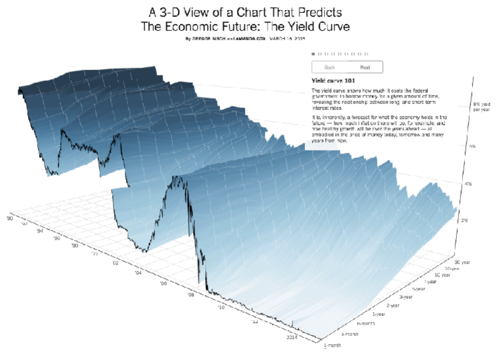




[Image-Based Streamline Generation and Rendering. Li and Shen. IEEE Trans. Visualization and Computer Graphics (TVCG) 13:3 (2007), 630–640.]

Justified 3D: Economic growth curve

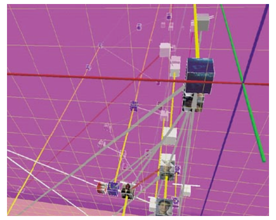
- constrained navigation steps through carefully designed viewpoints



http://www.nytimes.com/interactive/2015/03/19/upshot/3d-yield-curve-economic-growth.html

No unjustified 3D

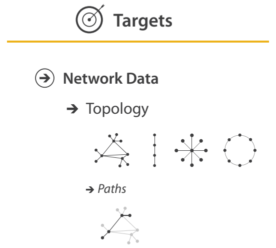
- 3D legitimate for true 3D spatial data
- 3D needs very careful justification for abstract data
  - enthusiasm in 1990s, but now skepticism
  - be especially careful with 3D for point clouds or networks



[WEBPATH-a three dimensional Web history. Frecon and Smith. Proc. InfoVis 1999]

No unjustified 2D

- consider whether network data requires 2D spatial layout
  - especially if reading text is central to task!
  - arranging as network means lower information density and harder label lookup compared to text lists
- benefits outweigh costs when topological structure/context important for task
  - be especially careful for search results, document collections, ontologies



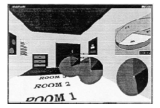
Eyes beat memory

- principle: external cognition vs. internal memory
  - easy to compare by moving eyes between side-by-side views
  - harder to compare visible item to memory of what you saw
- implications for animation
  - great for choreographed storytelling
  - great for transitions between two states
  - poor for many states with changes everywhere
    - consider small multiples instead

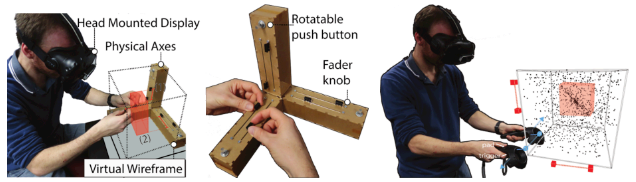
literal	abstract
animation	small multiples
show time with time	show time with space

Resolution beats immersion

- immersion typically not helpful for abstract data
  - do not need sense of presence or stereoscopic 3D
  - desktop also better for workflow integration
- resolution much more important: pixels are the scarcest resource
- first wave: virtual reality for abstract data difficult to justify
- second wave: AR/MR (augmented/mixed reality) has more promise



[Development of an information visualization tool using virtual reality. Kirner and Martins. Proc. Symp. Applied Computing 2000]



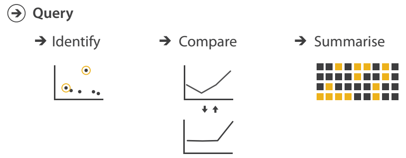
[A Design Space for Spatio-Data Coordination: Tangible Interaction Devices for Immersive Information Visualisation. Cordeil, Bach, Li, Elliott, and Dwyer. Proc. PacificVis 2017 Notes.]

Overview first, zoom and filter, details on demand

- influential mantra from Shneiderman

[The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations. Shneiderman. Proc. IEEE Visual Languages, pp. 336–343, 1996.]

- overview = summary
  - microcosm of full vis design problem



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  - rendering speed when item count is large (guaranteed frame rate)

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- dangerous to start with aesthetics
  - usually impossible to add function retroactively

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- dangerous to start with aesthetics
  - usually impossible to add function retroactively
- start with focus on functionality
  - possible to improve aesthetics later on, as refinement
  - if no expertise in-house, find good graphic designer to work with
  - aesthetics do matter! another level of function
    - visual hierarchy, alignment, flow
    - Gestalt principles in action

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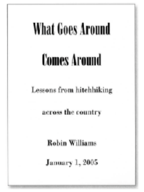

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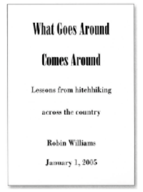

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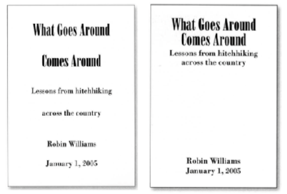

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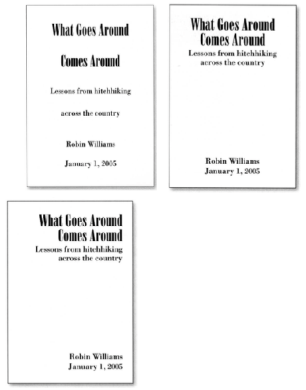

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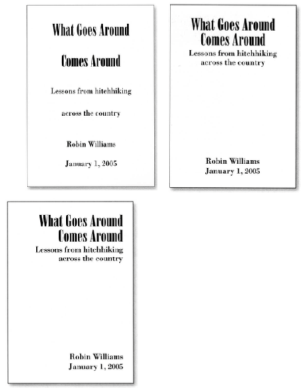

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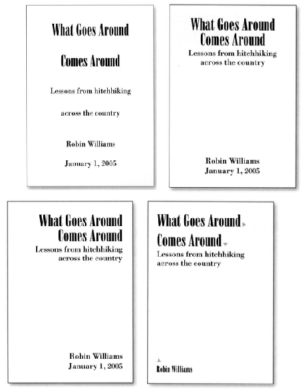

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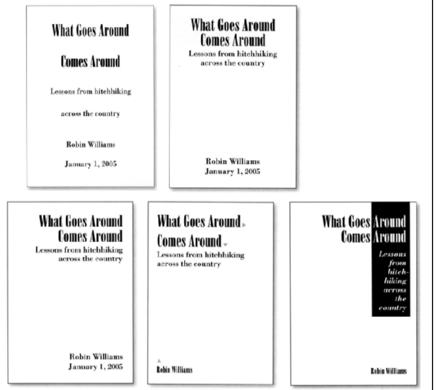

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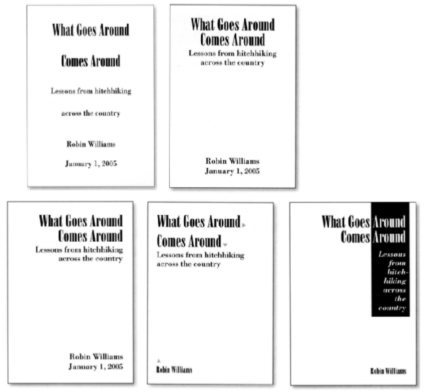
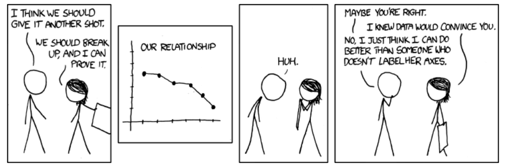


- *The Non-Designer's Design Book, 4th ed. Robin Williams, Peachpit Press, 2015.*
  - fast read, very practical to work through whole thing

Best practices: Labelling

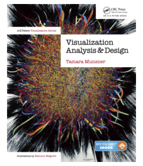
- make visualizations as self-documenting as possible
  - meaningful & useful title, labels, legends
    - axes and panes/subwindows should have labels
      - and axes should have good mix/max boundary tick marks
    - everything that's plotted should have a legend
      - and own header/labels if not redundant with main title
    - use reasonable numerical format
      - avoid scientific notation in most cases



[https://xkcd.com/833/]

Rules of Thumb Summary

- No unjustified 3D
  - Power of the plane
  - Disparity of depth
  - Occlusion hides information
  - Perspective distortion dangers
  - Tilted text isn't legible
- No unjustified 2D
- Eyes beat memory
- Resolution over immersion
- Overview first, zoom and filter, details on demand
- Responsiveness is required
- Function first, form next



Visualization Analysis & Design

Arrange Tables (Ch 7) I

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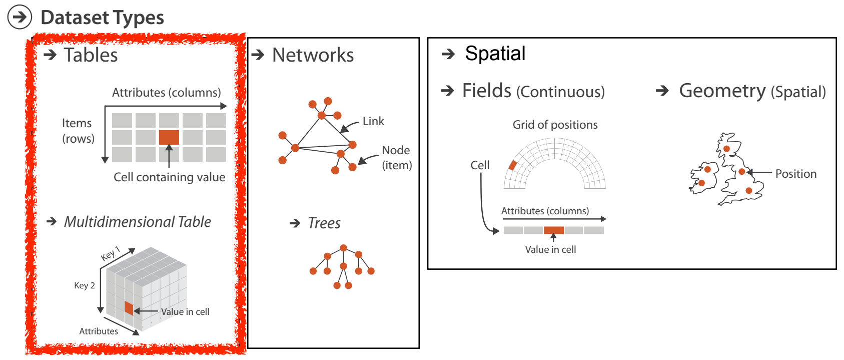
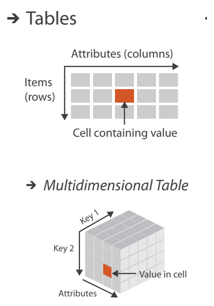
@tamaramunzner

Focus on Tables



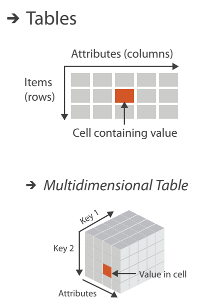
Keys and values

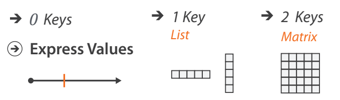
- key
  - independent attribute
  - used as unique index to look up items
  - simple tables: 1 key
  - multidimensional tables: multiple keys
- value
  - dependent attribute, value of cell



Keys and values

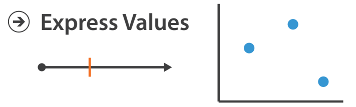
- key
  - independent attribute
  - used as unique index to look up items
  - simple tables: 1 key
  - multidimensional tables: multiple keys
- value
  - dependent attribute, value of cell
- classify arrangements by keys used
  - 0, 1, 2, ...

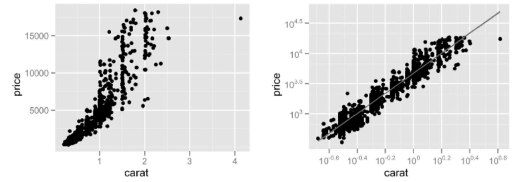




Idiom: **scatterplot**

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

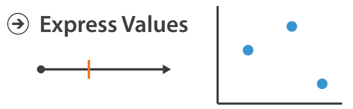


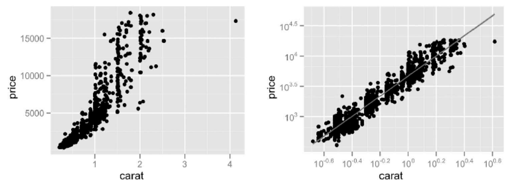


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idiom: **scatterplot**

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

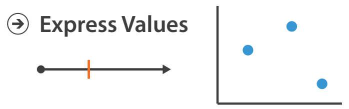


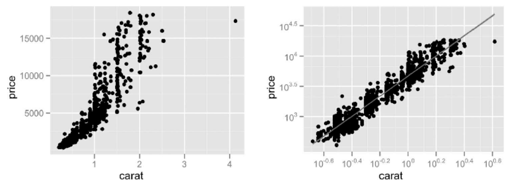


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idiom: **scatterplot**

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

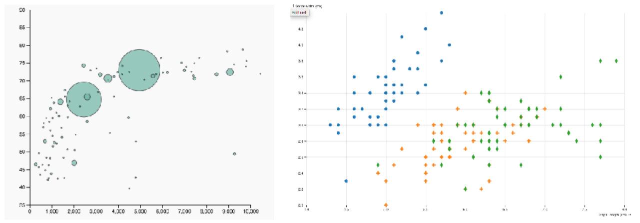




[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Scatterplots: Encoding more channels

- additional channels viable since using point marks
  - color
  - size (1 quant attribute, used to control 2D area)
    - note radius would mislead, take square root since area grows quadratically
  - shape

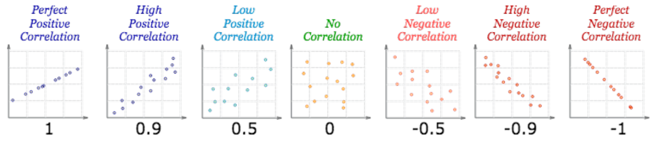


https://www.d3-graph-gallery.com/graph/bubble_basic.html https://observablehq.com/@d3/scatterplot-with-shapes

Scatterplot tasks

Scatterplot tasks

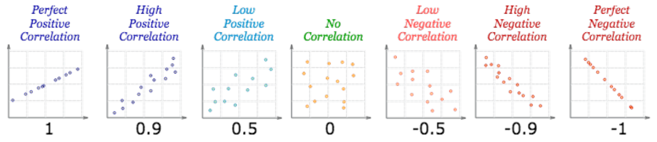
- correlation



https://www.mathsisfun.com/data/scatter-xy-plots.html

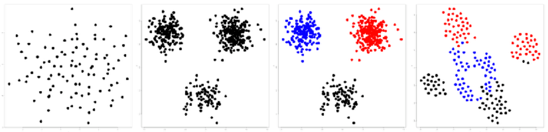
Scatterplot tasks

- correlation



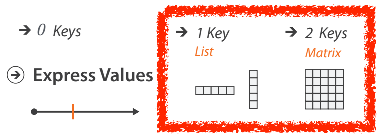
https://www.mathsisfun.com/data/scatter-xy-plots.html

- clusters/groups, and clusters vs classes



https://www.cs.ubc.ca/labs/imager/tr/2014/DRVisTasks/

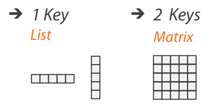
Some keys



Some keys: Categorical regions

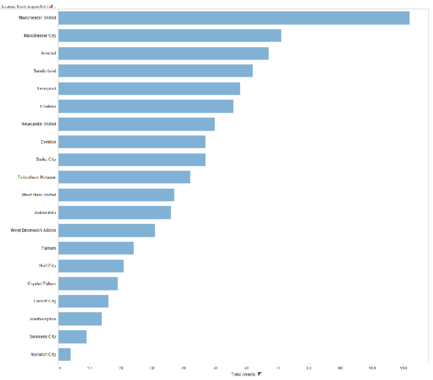
Regions: Separate, order, align

- regions: contiguous bounded areas distinct from each other
  - separate into spatial regions: one mark per region (for now)
- use categorical or ordered attribute to separate into regions
  - no conflict with expressiveness principle for categorical attributes
- use ordered attribute to order and align regions



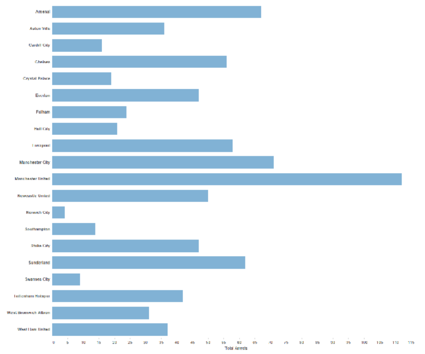
Separated and aligned and ordered

- best case



Separated and aligned but not ordered

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

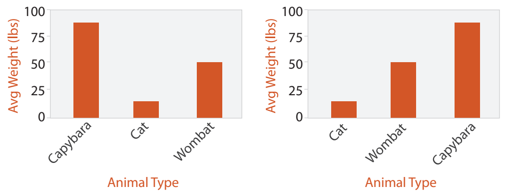


Separated but not aligned or ordered

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

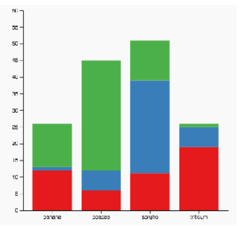
Idiom: **bar chart**

- one key, one value
  - data
    - 1 categ attrib, 1 quant attrib
  - mark: lines
  - channels
    - length to express quant value
    - spatial regions: one per mark
      - separated horizontally, aligned vertically
      - ordered by quant attrib
        - » by label (alphabetical), by length attrib (data-driven)
  - task
    - compare, lookup values
  - scalability
    - dozens to hundreds of levels for key attrib [bars], hundreds for values



Idiom: **stacked bar chart**

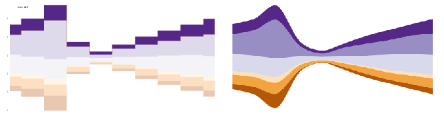
- one more key
  - data
    - 2 categ attrib, 1 quant attrib
  - mark: vertical stack of line marks
    - **glyph**: composite object, internal structure from multiple marks
  - channels
    - length and color hue
    - spatial regions: one per glyph
      - aligned: full glyph, lowest bar component
      - unaligned: other bar components
  - task
    - part-to-whole relationship
  - scalability: asymmetric
    - for *stacked* key attrib, 10-12 levels [segments]
    - for *main* key attrib, dozens to hundreds of levels [bars]



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

Idiom: **streamgraph**

- generalized stacked graph
  - emphasizing horizontal continuity
    - vs vertical items
  - data
    - 1 categ key attrib (movies)
    - 1 ordered key attrib (time)
    - 1 quant value attrib (counts)
  - derived data
    - geometry: layers, where height encodes counts
    - 1 quant attrib (layer ordering)



[Stacked Graphs Geometry & Aesthetics. Byron and Wattenberg. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14(6): 1245–1252, (2008).]

Idiom: **streamgraph**

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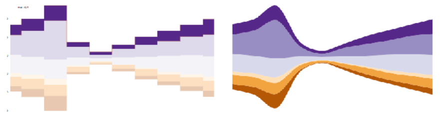
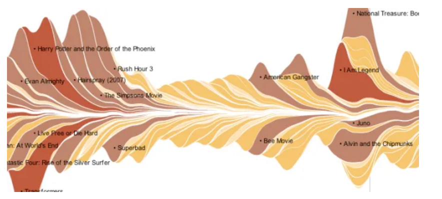
    - 1 categ key attrib (movies)
    - 1 ordered key attrib (time)
    - 1 quant value attrib (counts)
  - derived data
    - geometry: layers, where height encodes counts
    - 1 quant attrib (layer ordering)
  - scalability
    - hundreds of time keys
    - dozens to hundreds of movies keys
      - more than stacked bars: most layers don't extend across whole chart



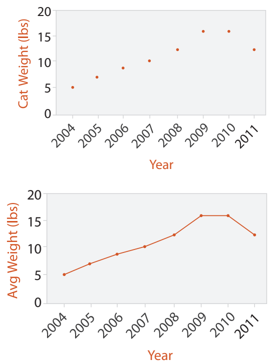
[Stacked Graphs Geometry & Aesthetics. Byron and Wattenberg. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14(6): 1245–1252, (2008).]



https://flowingdata.com/2008/02/25/ebb-and-flow-of-box-office-receipts-over-past-20-years/

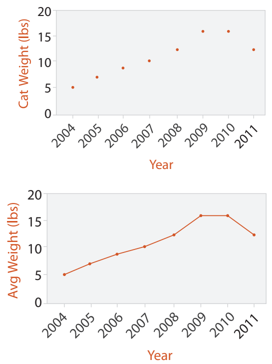
Idiom: **dot / line chart**

- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    AND line connection marks between them
  - channels
    - aligned lengths to express quant value
    - separated and ordered by key attrib into horizontal regions



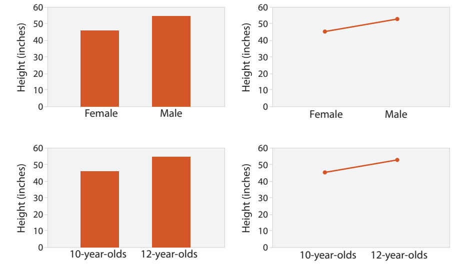
Idiom: **dot / line chart**

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



Choosing bar vs line charts

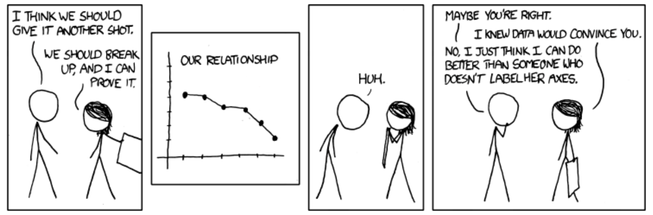
- depends on type of key attrib
  - bar charts if categorical
  - line charts if ordered
- do not use line charts for categorical key attribs
  - violates expressiveness principle
    - implication of trend so strong that it overrides semantics!
      - "The more male a person is, the taller he/she is"



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

Chart axes: label them!

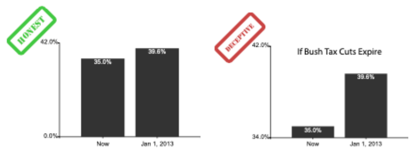
- best practice to label
  - few exceptions: individual small multiple views could share axis label



https://xkcd.com/833/

Chart axes: avoid cropping y axis

- include 0 at bottom left or slope misleads

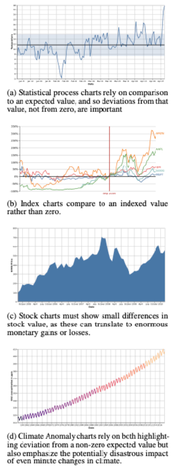


[Truncating the Y-Axis: Threat or Menace? Correll, Bertini, & Franconeri, CHI 2020.]

Chart axes: avoid cropping y axis

- include 0 at bottom left or slope misleads
  - some exceptions (arbitrary 0, small change matters)

[Truncating the Y-Axis: Threat or Menace? Correll, Bertini, & Franconeri, CHI 2020.]



(a) Statistical process charts rely on comparison to an expected value, and so deviations from that value, not from zero, are important

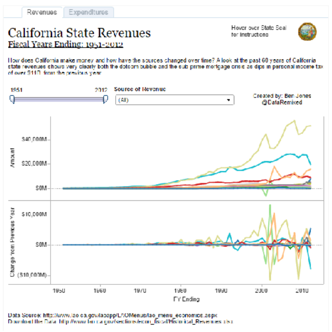
(b) Index charts compare to an indexed value rather than zero.

(c) Stock charts must show small differences in stock value, as these can translate to enormous monetary gains or losses.

(d) Climate Anomaly charts rely on both highlighting deviation from a non-zero expected value but also emphasize the potentially disastrous impact of even minute changes in climate.

Idiom: **Indexed line charts**

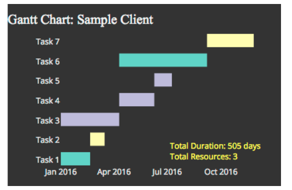
- data: 2 quant attribs
  - 1 key + 1 value
- derived data: new quant value attrib
  - index
  - plot instead of original value
- task: show change over time
  - principle: normalized, not absolute
- scalability
  - same as standard line chart



https://public.tableau.com/profile/ben.jones#!/vizhome/CAStateRevenues/Revenues

Idiom: **Gantt charts**

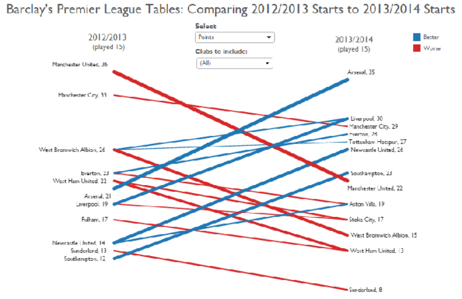
- one key, two (related) values
  - data
    - 1 categ attrib, 2 quant attribs
  - mark: line
    - length: duration
  - channels
    - horiz position: start time (+end from duration)
  - task
    - emphasize temporal overlaps & start/end dependencies between items
  - scalability
    - dozens of key levels [bars]
    - hundreds of value levels [durations]



https://www.r-bloggers.com/gantt-charts-in-r-using-plotly/

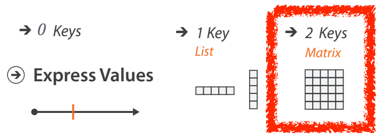
Idiom: **Slopegraphs**

- two values
  - data
    - 2 quant value attribs
    - (1 derived attrib: change magnitude)
  - mark: point + line
    - line connecting mark between pts
  - channels
    - 2 vertical pos: express attrib value
    - (linewidth/size, color)
  - task
    - emphasize changes in rank/value
  - scalability
    - hundreds of value levels
    - dozens of items



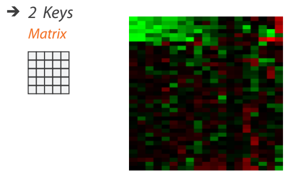
https://public.tableau.com/profile/ben.jones#!/vizhome/Slopegraphs/Slopegraphs

2 Keys

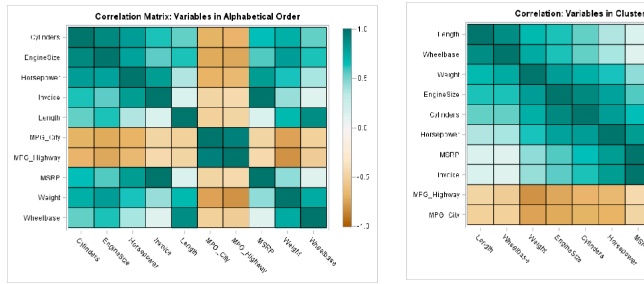


Idiom: **heatmap**

- two keys, one value
  - data
    - 2 categ attribs (gene, experimental condition)
    - 1 quant attrib (expression levels)
  - marks: point
    - separate and align in 2D matrix
      - indexed by 2 categorical attributes
  - channels
    - color by quant attrib
      - (ordered diverging colormap)
  - task
    - find clusters, outliers
  - scalability
    - 1M items, 100s of categ levels, ~10 quant attrib levels

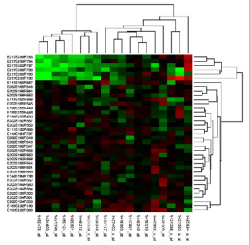


Heatmap reordering



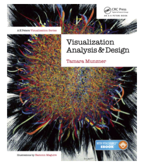
https://blogs.sas.com/content/iml/2018/05/02/reorder-variables-correlation-heat-map.html

Idiom: **cluster heatmap**



- in addition
  - derived data
    - 2 cluster hierarchies
  - dendrogram
    - parent-child relationships in tree with connection line marks
    - leaves aligned so interior branch heights easy to compare
  - heatmap
    - marks (re-)ordered by cluster hierarchy traversal
    - task: assess quality of clusters found by automatic methods

Visualization Analysis & Design



Tables (Ch 7) II

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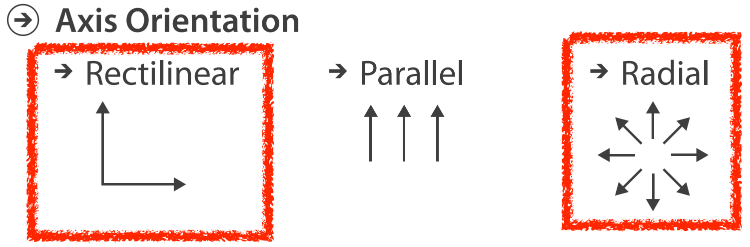
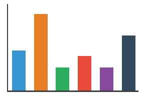


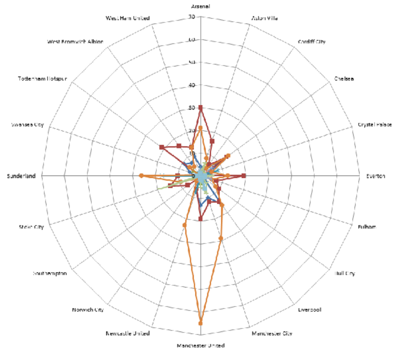
Idioms: **radial bar chart, star plot**



- star plot
  - line mark, radial axes meet at central point
- radial bar chart
  - line mark, radial axes meet at central ring
  - channels: length, angle/orientation
- bar chart
  - rectilinear axes, aligned vertically
- accuracy
  - length not aligned with radial layouts
    - less accurately perceived than rectilinear aligned

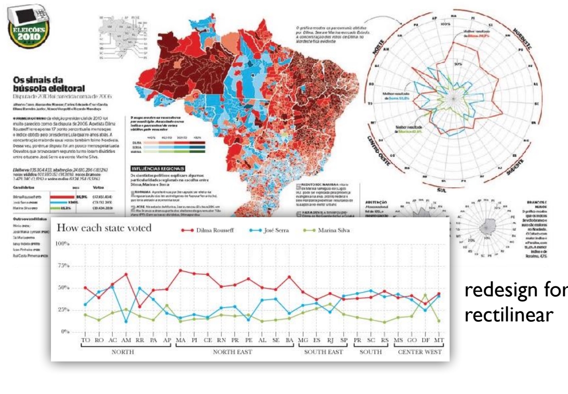
[Vismon: Facilitating Risk Assessment and Decision Making In Fisheries Management. Booshehrian, Möller, Peterman, and Munzner. Technical Report TR 2011-04, Simon Fraser University, School of Computing Science, 2011.]

Idiom: **radar plot**



- radial line chart
  - point marks, radial layout
  - connecting line marks
- avoid unless data is cyclic

"Radar graphs: Avoid them (99.9% of the time)"

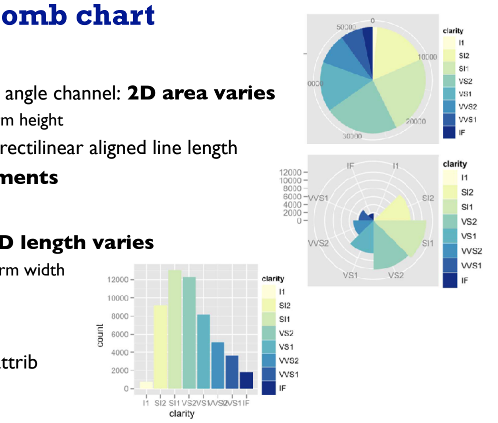


original
difficult to interpret

redesign for
rectilinear

http://www.thefunctionalart.com/2012/11/radar-graphs-avoid-them-999-of-time.html

Idioms: **pie chart, coxcomb chart**

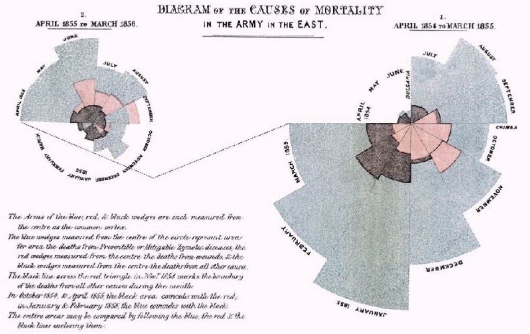


- pie chart
  - **interlocking area** marks with angle channel: **2D area varies**
    - separated & ordered radially, uniform height
  - accuracy: area less accurate than rectilinear aligned line length
  - **task: part-to-whole judgements**
- coxcomb chart
  - line marks with length channel: **1D length varies**
    - separated & ordered radially, uniform width
  - direct analog to radial bar charts
- data
  - 1 categ key attrib, 1 quant value attrib

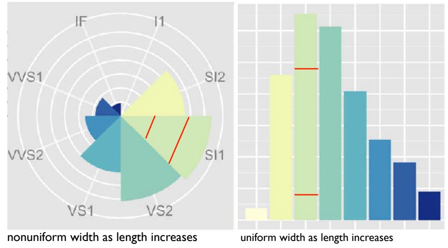
[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Coxcomb / nightingale rose / polar area chart

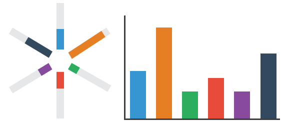
- invented by Florence Nightingale: Diagram of the Causes of Mortality in the Army in the East



Coxcomb: perception

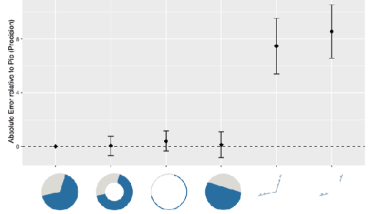


- encode: 1D length
- decode/perceive: 2D area
- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt line mark length!
- bar chart safer: uniform width, so area is linear with line mark length
  - both radial & rectilinear cases



Pie charts: perception

- some empirical evidence that people respond to arc length
  - decode/perceive: not angles
  - maybe also areas?...
- donut charts no worse than pie charts



[Arcs, Angles, or Areas: Individual Data Encodings in Pie and Donut Charts. Skau and Kosara. Proc. EuroVis 2016.]

https://eagereyes.org/blog/2016/an-illustrated-tour-of-the-pie-chart-study-results

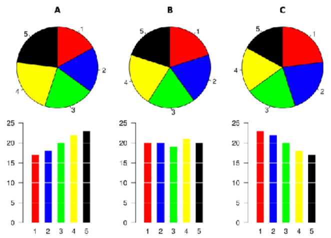
Pie charts: best practices

- not so bad for two (or few) levels, for part-to-whole task

https://eagereyes.org/pie-charts

Pie charts: best practices

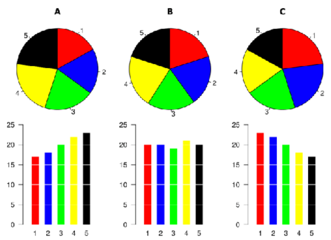
- not so bad for two (or few) levels, for part-to-whole task
- dubious for several levels if details matter

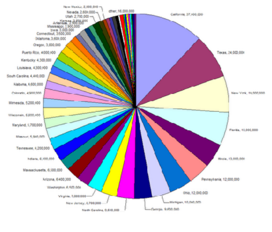


https://eagereyes.org/pie-charts

Pie charts: best practices

- not so bad for two (or few) levels, for part-to-whole task
- dubious for several levels if details matter
- terrible for many levels

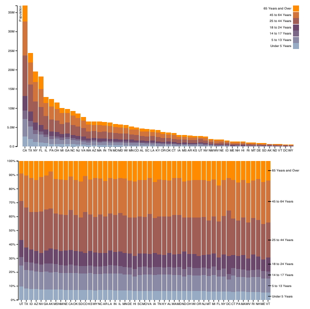


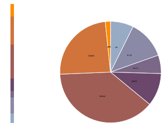


https://eagereyes.org/pie-charts

Idioms: **normalized stacked bar chart**

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

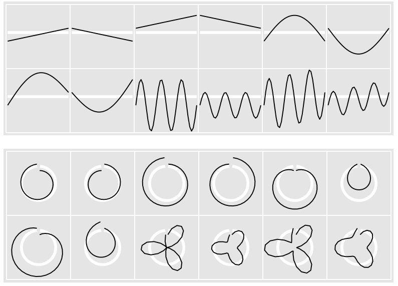




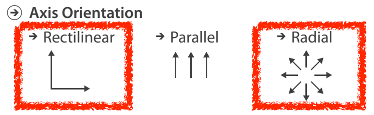
http://bl.ocks.org/mbostock/3886208,
http://bl.ocks.org/mbostock/3887235,
http://bl.ocks.org/mbostock/3886394.

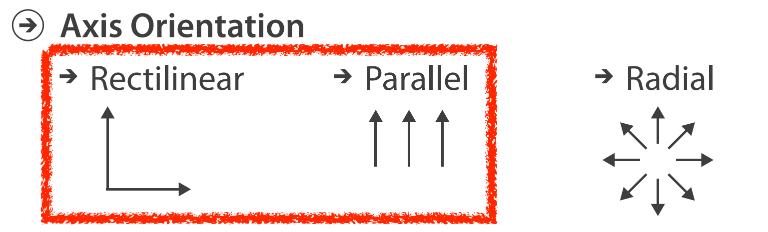
Idiom: **glyphmaps**

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



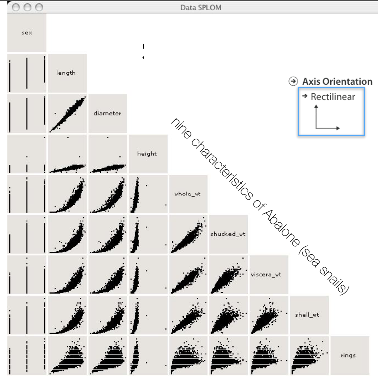
[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. Environmetrics 23:5 (2012), 382–393.]

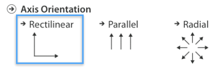




Idiom: **SPLOM**

- scatterplot matrix (SPLOM)
  - rectilinear axes, point mark
  - all possible pairs of axes
  - scalability
    - one dozen attribs
    - dozens to hundreds of items

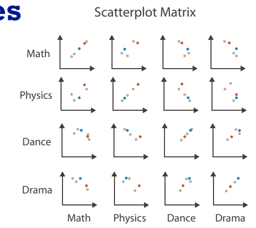




Wilkinson et al., 2005

Idioms: **parallel coordinates**

- scatterplot limitation
  - visual representation with orthogonal axes
  - can show only two attributes with spatial position channel



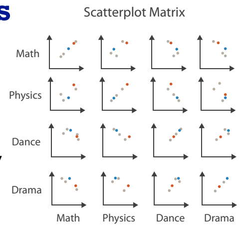
Table

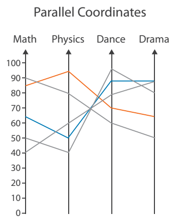
Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

after [Visualization Course Figures. McGuffin, 2014. http://www.michaelmcguffin.com/courses/vis/]

Idioms: **parallel coordinates**

- scatterplot limitation
  - visual representation with orthogonal axes
  - can show only two attributes with spatial position channel
- alternative: line up axes in parallel to show many attributes with position
  - item encoded with a line with n segments
  - n is the number of attributes shown
- parallel coordinates
  - parallel axes, jagged line for item
  - rectilinear axes, item as point
    - axis ordering is major challenge
  - scalability
    - dozens of attribs
    - hundreds of items





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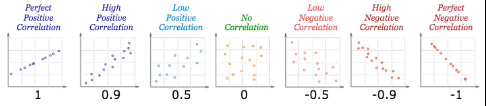
after [Visualization Course Figures. McGuffin, 2014. http://www.michaelmcguffin.com/courses/vis/]

Task: Correlation

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



https://www.mathsisfun.com/data/scatter-xy-plots.html

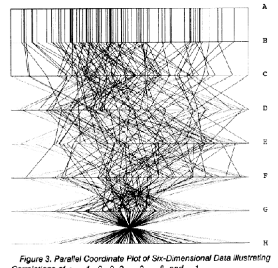
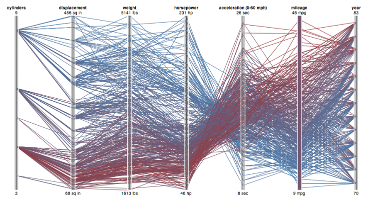


Figure 3. Parallel Coordinate Plot of Six-Dimensional Data Illustrating Correlations of ρ = 1, .8, .2, 0, −.2, −.8, and −1.

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

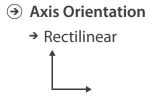
Parallel coordinates, limitations

- visible patterns only between neighboring axis pairs
- how to pick axis order?
  - usual solution: reorderable axes, interactive exploration
  - same weakness as many other techniques
    - downside of interaction: human-powered search
  - some algorithms proposed, none fully solve



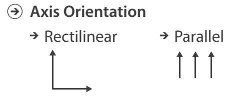
Orientation limitations

- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible



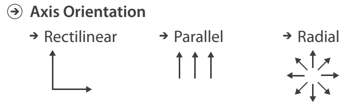
Orientation limitations

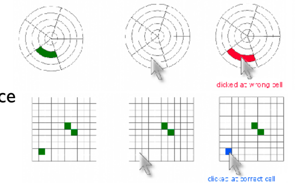
- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible
- parallel: unfamiliarity, training time



Orientation limitations

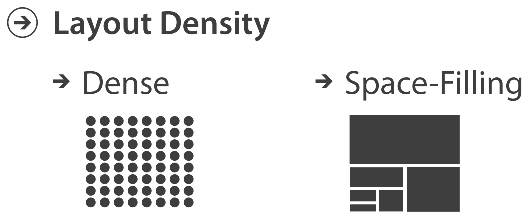
- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible
- parallel: unfamiliarity, training time
- radial: perceptual limits
  - polar coordinate asymmetry
    - angles lower precision than length
    - nonuniform sector width/size depending on radial distance
  - frequently problematic
    - but sometimes can be deliberately exploited!
      - for 2 attribs of very unequal importance





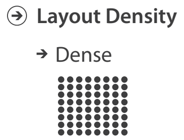
[Uncovering Strengths and Weaknesses of Radial Visualizations - an Empirical Approach. Diehl, Beck and Burch. IEEE TVCG (Proc. InfoVis) 16(6):935–942, 2010.]

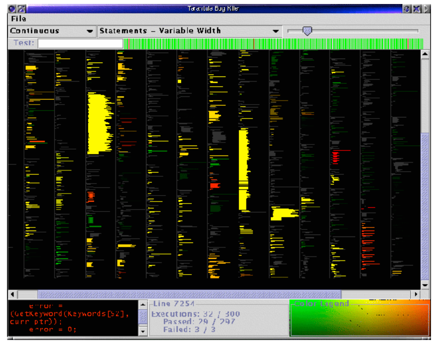
Layout density



Idiom: Dense software overviews

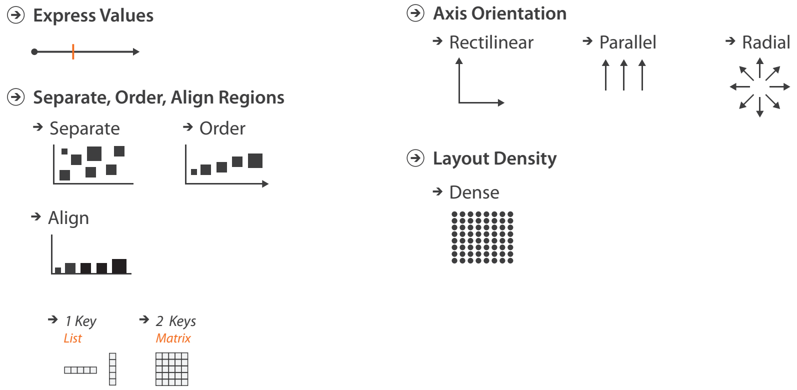
- data: text
  - text + 1 quant attrib per line
- derived data:
  - one pixel high line
  - length according to original
- color line by attrib
- scalability
  - 10K+ lines

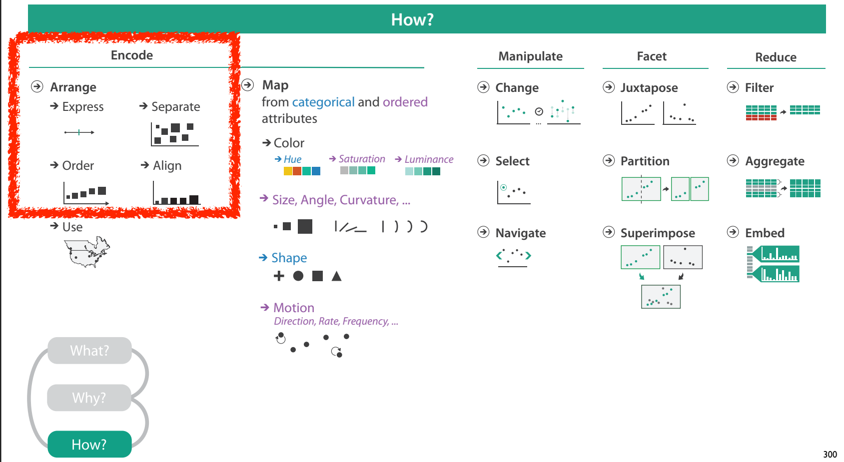


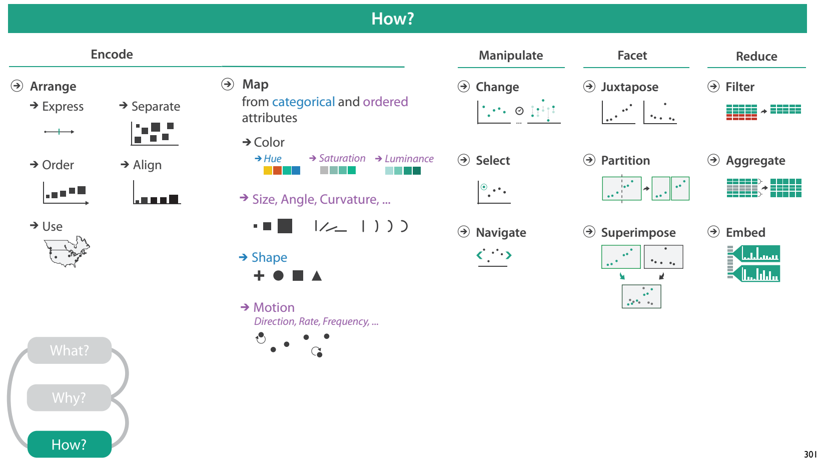


[Visualization of test information to assist fault localization. Jones, Harrold, Stasko. Proc. ICSE 2002, p 467-477.]

Arrange tables

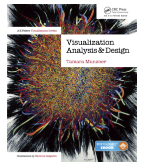






Visualization Analysis & Design

Tables (Ch 7) III



Tamara Munzner
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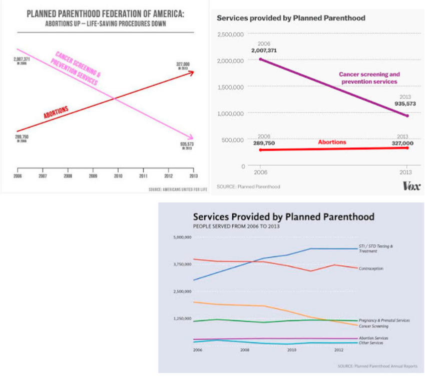
Chart axes

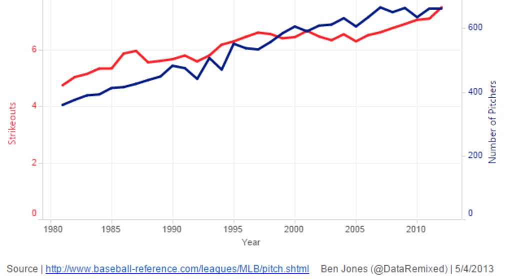
- labelled axis is critical
- avoid cropping y-axis
  - include 0 at bottom left
  - or slope misleads



http://www.thefunctionalart.com/2015/10/if-you-see-bullshit-say-bullshit.html

Idiom: **dual-axis line charts**

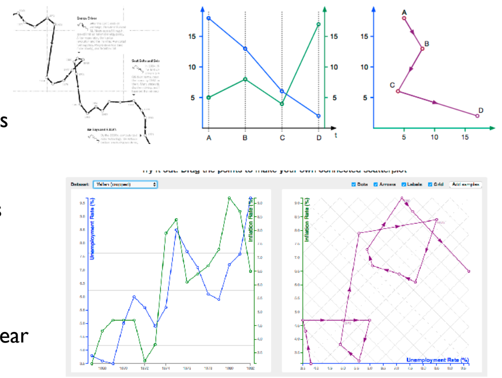
- controversial
  - acceptable if commensurate
  - beware, very easy to mislead!



Source | http://www.baseball-reference.com/leagues/MLB/pitch.shtml   Ben Jones (@DataRemixed) | 5/4/2013

Idiom: **connected scatterplots**

- scatterplot with line connection marks
  - popular in journalism
  - horiz + vert axes: value attribs
  - line connection marks: temporal order
  - alternative to dual-axis charts
    - horiz: time
    - vert: two value attribs
- empirical study
  - engaging, but correlation unclear

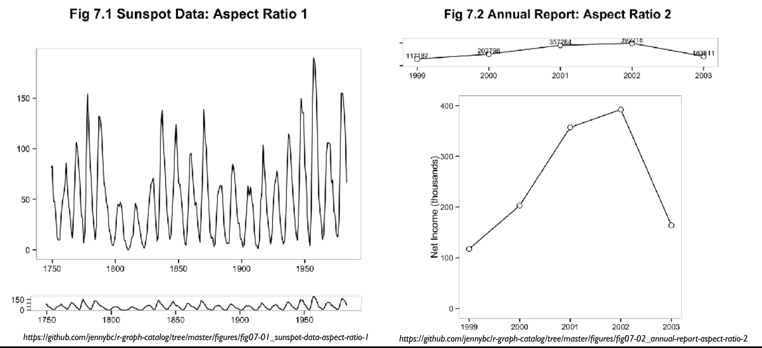


[The Connected Scatterplot for Presenting Paired Time Series. Haroz, Kosara and Franconeri. IEEE TVCG 22(9):2174-86, 2016.]

http://steveharoz.com/research/connected_scatterplot/

Choosing line chart aspect ratios

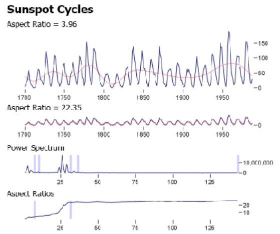
- 1: banking to 45 (1980s)
  - Cleveland perceptual argument: most accurate angle judgement at 45

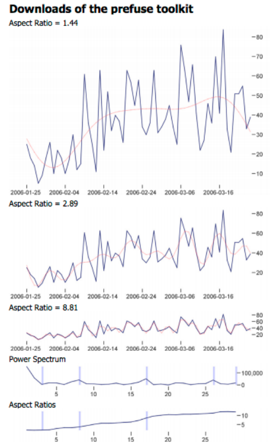


https://github.com/jennybc/r-graph-catalog/tree/master/figures/fig07-01_sunspot-data-aspect-ratio-1
https://github.com/jennybc/r-graph-catalog/tree/master/figures/fig07-02_annual-report-aspect-ratio-2

Choosing line chart aspect ratios

- 2: multi scale banking to 45 (2006)
  - frequency domain analysis to find ratios
    - FFT the data, convolve with Gaussian to smooth
  - find interesting spikes/ranges in power spectrum
    - cull nearby regions if similar, ensure overview
  - create trend curves (red) for each aspect ratio

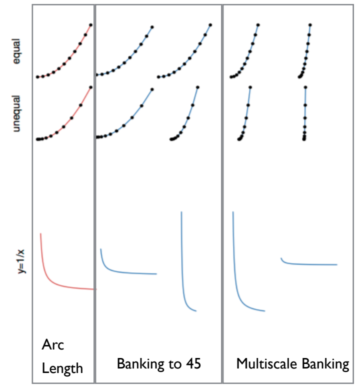




[Multi-Scale Banking to 45 Degrees. Heer and Agrawala, Proc InfoVis 2006]

Choosing line chart aspect ratios

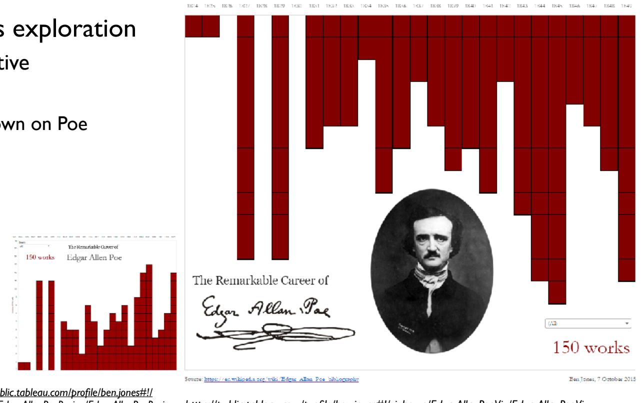
- 3: arc length based aspect ratio (2011)
  - minimize the arc length of curve while keeping the area of the plot constant
  - parametrization and scale invariant
  - symmetry preserving
  - robust & fast to compute
- meta-points from this progression
  - young field; prescriptive advice changes rapidly
  - reasonable defaults required deep dive into perception meets math



[Arc Length-Based Aspect Ratio Selection. Talbot, Gerth, and Hanrahan. Proc InfoVis 2011]

Breaking conventions

- presentation vs exploration
  - engaging/evocative
  - inverted y axis
    - blood drips down on Poe

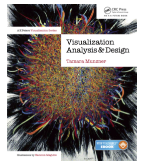


https://public.tableau.com/profile/ben.jones#!/vizhome/EdgarAllanPoeBoring/EdgarAllenPoeBoring https://public.tableau.com/profile/ben.jones#!/vizhome/EdgarAllanPoeViz/EdgarAllanPoeViz

[Slide inspired by Ben Jones]

Visualization Analysis & Design

Network Data (Ch 9)



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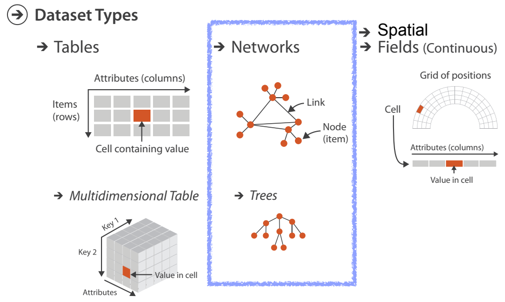
@tamaramunzner

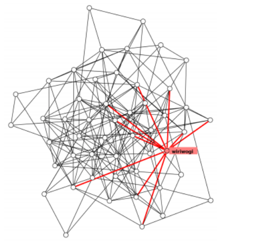
Network data

- 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



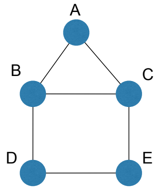
Network tasks: topology-based and attribute-based

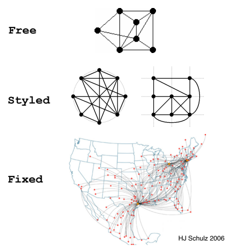
- topology based tasks
  - find paths
  - find (topological) neighbors
  - compare centrality/importance measures
  - identify clusters / communities
- attribute based tasks (similar to table data)
  - find distributions, ...
- combination tasks, incorporating both
  - example: find friends-of-friends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

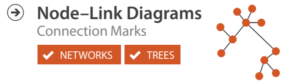


Node-link diagrams

- nodes: point marks
- links: line marks
  - straight lines or arcs
  - connections between nodes
- intuitive & familiar
  - most common
  - many, many variants

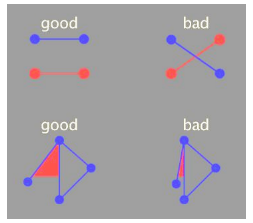






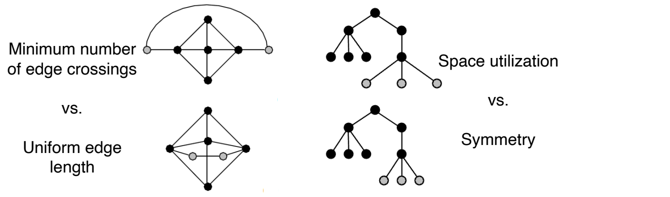
Criteria for good node-link layouts

- minimize
  - edge crossings, node overlaps
  - distances between topological neighbor nodes
  - total drawing area
  - edge bends
- maximize
  - angular distance between different edges
  - aspect ratio disparities
- emphasize symmetry
  - similar graph structures should look similar in layout



Criteria conflict

- most criteria NP-hard individually
- many criteria directly conflict with each other



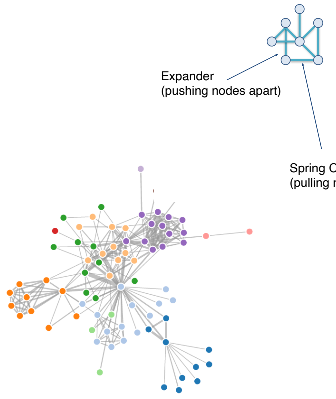
Schulz 2004

Optimization-based layouts

- formulate layout problem as optimization problem
- convert criteria into weighted cost function
  - F(layout) = a*[crossing counts] + b*[drawing space used]+...
- use known optimization techniques to find layout at minimal cost
  - energy-based physics models
  - force-directed placement
  - spring embedders

Force-directed placement

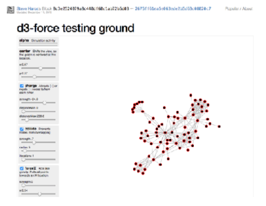
- physics model
  - links = springs pull together
  - nodes = magnets repulse apart
- algorithm
  - place vertices in random locations
  - while not equilibrium
    - calculate force on vertex
      - sum of
        - » pairwise repulsion of all nodes
        - » attraction between connected nodes
    - move vertex by c * vertex_force



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

Force-directed placement properties

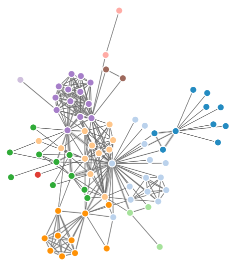
- strengths
  - reasonable layout for small, sparse graphs
  - clusters typically visible
  - edge length uniformity
- weaknesses
  - nondeterministic
  - computationally expensive: O(n^3) for n nodes
    - each step is n^2, takes ~n cycles to reach equilibrium
  - naive FD doesn't scale well beyond 1K nodes
  - iterative progress: engaging but distracting



https://bl.ocks.org/steveharoz/8c3e2524079a8c440df60c1ab72b5d03

Idiom: **force-directed placement**

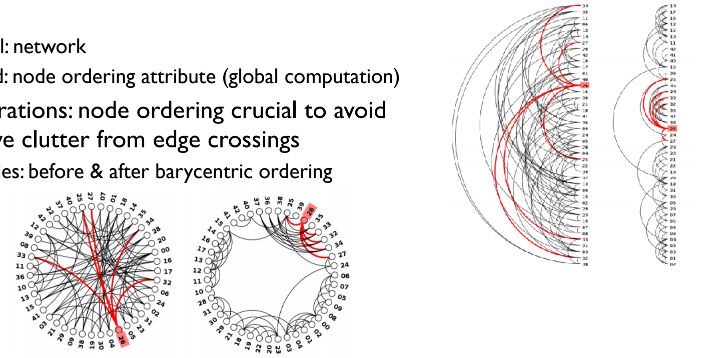
- visual encoding
  - link connection marks, node point marks
- considerations
  - spatial position: no meaning directly encoded
    - left free to minimize crossings
  - proximity semantics?
    - sometimes meaningful
    - sometimes arbitrary, artifact of layout algorithm
    - tension with length
      - long edges more visually salient than short
- tasks
  - explore topology; locate paths, clusters
- scalability
  - node/edge density E < 4N



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

Idiom: **circular layouts / arc diagrams (node-link)**

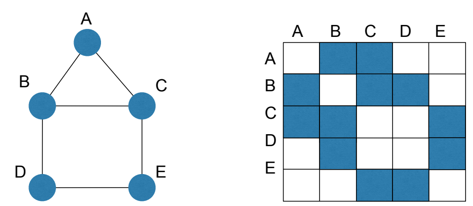
- restricted node-link layouts: lay out nodes around circle or along line
- data
  - original: network
  - derived: node ordering attribute (global computation)
- considerations: node ordering crucial to avoid excessive clutter from edge crossings
  - examples: before & after barycentric ordering

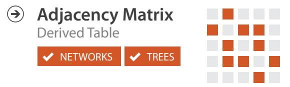


http://profs.etsmtl.ca/mmcguffin/research/2012-mcguffin-simpleNetVis/mcguffin-2012-simpleNetVis.pdf

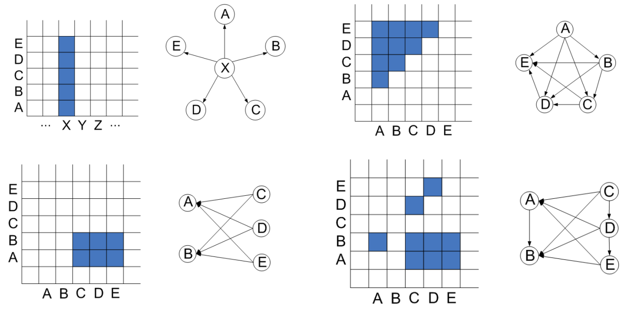
Adjacency matrix representations

- derive adjacency matrix from network



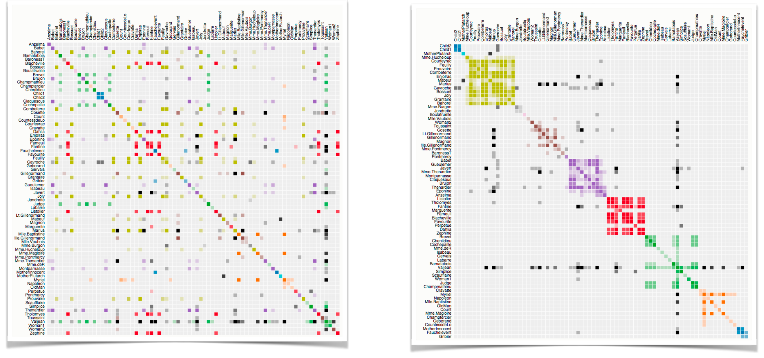


Adjacency matrix examples



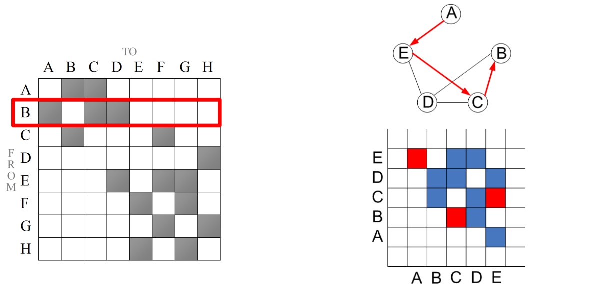
HJ Schulz 2007

Node order is crucial: Reordering



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

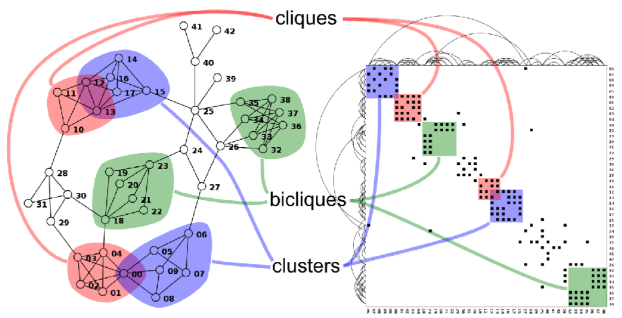
Adjacency matrix



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

bad for topology tasks related to paths

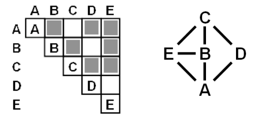
Structures visible in both



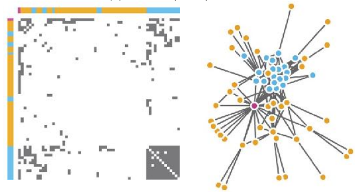
http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png

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.]

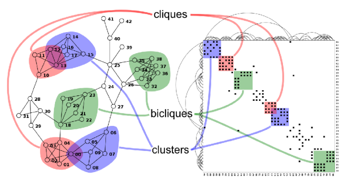


[Points of view: Networks. Gehlenborg and Wong. Nature Methods 9:115.]

Node-link vs. matrix comparison

- node-link diagram strengths
  - topology understanding, path tracing
  - intuitive, flexible, no training needed
- adjacency matrix strengths
  - focus on edges rather than nodes
  - layout straightforward (reordering needed)
  - predictability, scalability
  - some topology tasks trainable
- empirical study
  - node-link best for small networks
  - matrix best for large networks
    - if tasks don't involve path tracing!

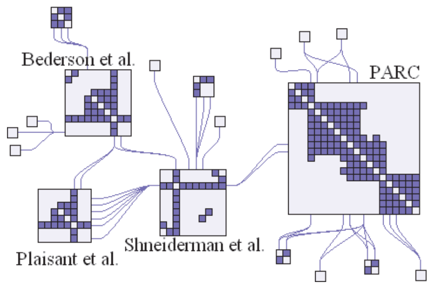
[On the readability of graphs using node-link and matrix-based representations: a controlled experiment and statistical analysis. Ghoniem, Fekete, and Castagliola. Information Visualization 4:2 (2005), 114–135.]



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

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.]

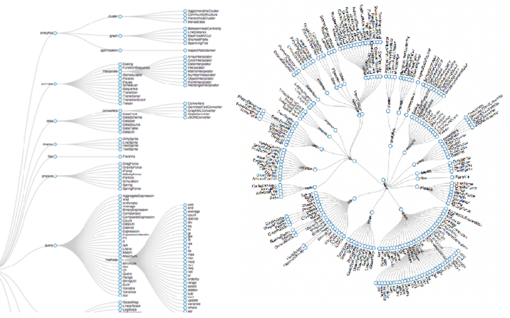
Trees

Node-link trees

- Reingold-Tilford
  - tidy drawings of trees
    - exploit parent/child structure
  - allocate space: compact but without overlap
    - rectilinear and radial variants

[Tidier drawing of trees. Reingold and Tilford. IEEE Trans. Software Eng., SE-7(2):223–228, 1981.]

  - nice algorithm writeup
    http://billmill.org/pymag-trees/

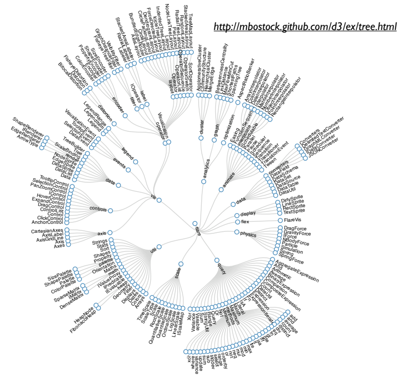


http://bl.ocks.org/mbostock/4339184 http://bl.ocks.org/mbostock/4063550

Idiom: **radial node-link tree**

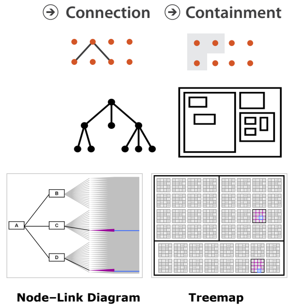
- data
  - tree
- encoding
  - link connection marks
  - point node marks
  - radial axis orientation
    - angular proximity: siblings
    - distance from center: depth in tree
- tasks
  - understanding topology, following paths
- scalability
  - 1K - 10K nodes (with/without labels)

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



Link marks: Connection and containment

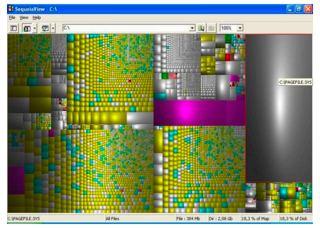
- marks as links (vs. nodes)
  - common case in network drawing
  - 1D case: connection
    - ex: all node-link diagrams
    - emphasizes topology, path tracing
    - networks and trees
  - 2D case: containment
    - ex: all treemap variants
    - emphasizes attribute values at leaves (size coding)
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



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

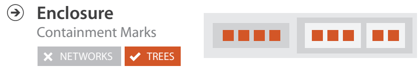
Idiom: **treemap**

- data
  - tree
  - 1 quant attrib at leaf nodes
- encoding
  - area containment marks for hierarchical structure
  - rectilinear orientation
  - size encodes quant attrib
- tasks
  - query attribute at leaf nodes
  - ex: disk space usage within filesystem
- scalability
  - 1M leaf nodes



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

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



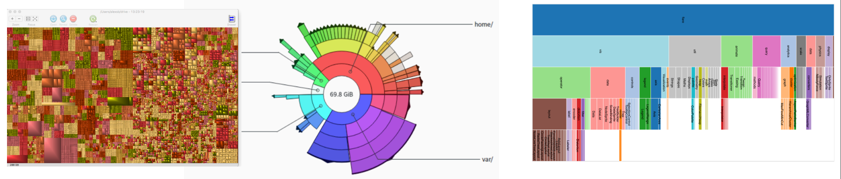
Idiom: implicit tree layouts (sunburst, icicle plot)

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

Treemap — containment

Sunburst — position (radial)

Icicle Plot — position (rectilinear)



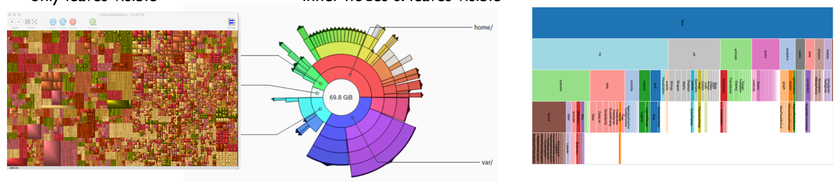
Idiom: implicit tree layouts (sunburst, icicle plot)

- 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



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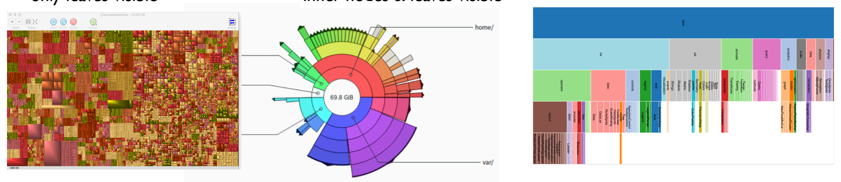
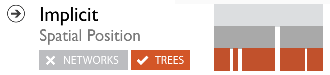
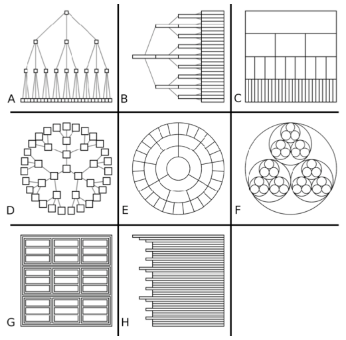




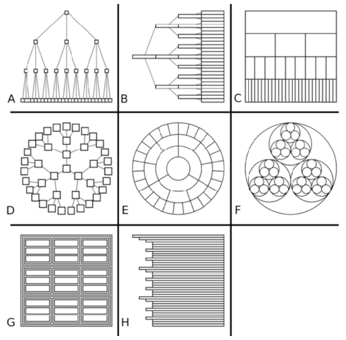
Tree drawing idioms comparison



[Quantifying the Space-Efficiency of 2D Graphical Representations of Trees. McGuffin and Robert. Information Visualization 9:2 (2010), 115–140.]

Comparison: tree drawing idioms

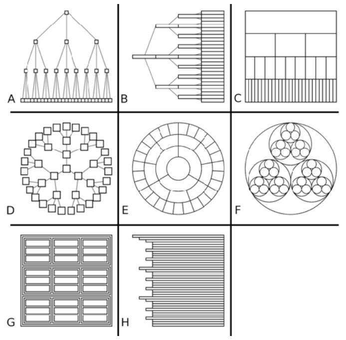
- data shown
  - link relationships
  - tree depth
  - sibling order



[Quantifying the Space-Efficiency of 2D Graphical Representations of Trees. McGuffin and Robert. Information Visualization 9:2 (2010), 115–140.]

Comparison: tree drawing idioms

- data shown
  - link relationships
  - tree depth
  - sibling order
- design choices
  - connection vs containment link marks
  - rectilinear vs radial layout
  - spatial position channels



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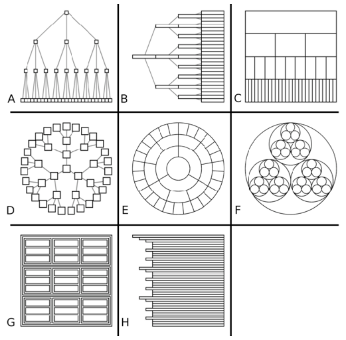
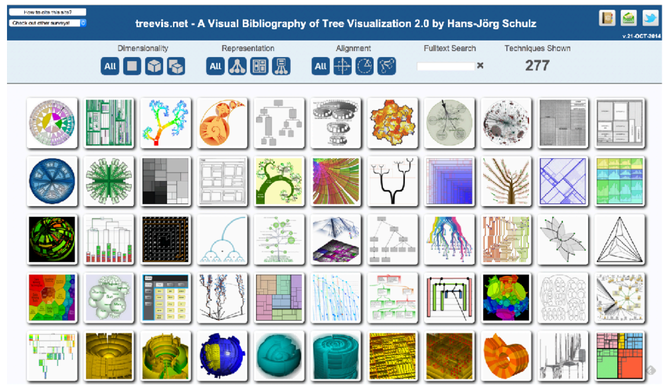
Comparison: tree drawing idioms

- data shown
  - link relationships
  - tree depth
  - sibling order
- design choices
  - connection vs containment link marks
  - rectilinear vs radial layout
  - spatial position channels
- considerations
  - redundant? arbitrary?
  - information density?
    - avoid wasting space
    - consider where to fit labels!



[Quantifying the Space-Efficiency of 2D Graphical Representations of Trees. McGuffin and Robert. Information Visualization 9:2 (2010), 115–140.]

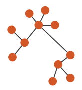
treevis.net: Many, many options!



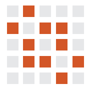
https://treevis.net/

Arrange networks and trees

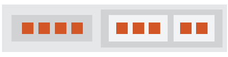
Node–Link Diagrams
Connection Marks
NETWORKS TREES



Adjacency Matrix
Derived Table
NETWORKS TREES

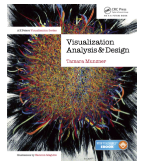


Enclosure
Containment Marks
NETWORKS TREES



Implicit
Spatial Position
NETWORKS TREES

Visualization Analysis & Design



Network Data (Ch 9) II

Tamara Munzner
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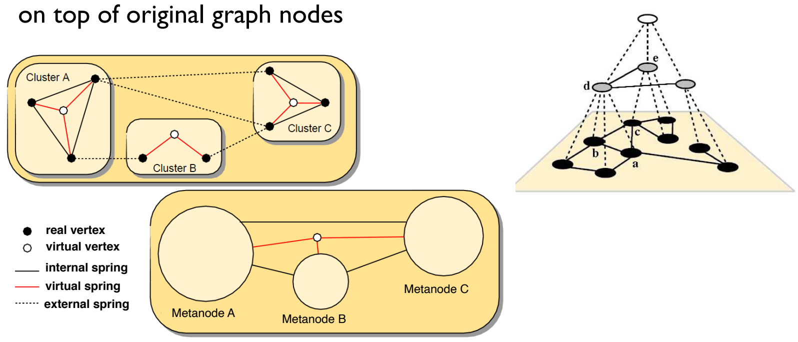
Multilevel networks

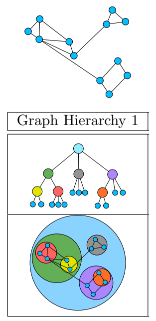
- derive cluster hierarchy of metanodes on top of original graph nodes



[Schulz 2004]

Idiom: **GrouseFlocks**

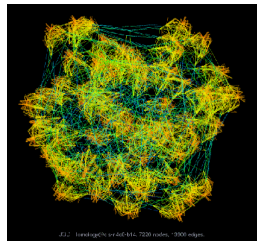
- data: compound network
  - network
  - cluster hierarchy atop it
    - derived or interactively chosen
- visual encoding
  - connection marks for network links
  - containment marks for hierarchy
  - point marks for nodes
- dynamic interaction
  - select individual metanodes in hierarchy to expand/contract



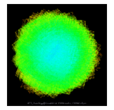
[GrouseFlocks: Steerable Exploration of Graph Hierarchy Space. Archambault, Munzner, and Auber. IEEE TVCG 14(4):900-913, 2008.]

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

- data: compound graph
  - 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



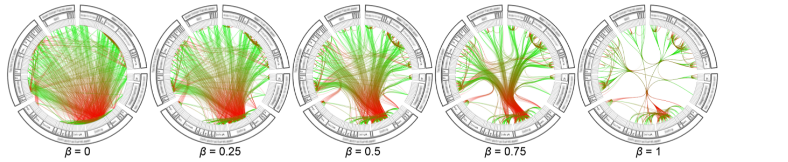
[Efficient and high quality force-directed graph drawing. Hu. The Mathematica Journal 10:37–71, 2005.]



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

Idiom: **hierarchical edge bundling**

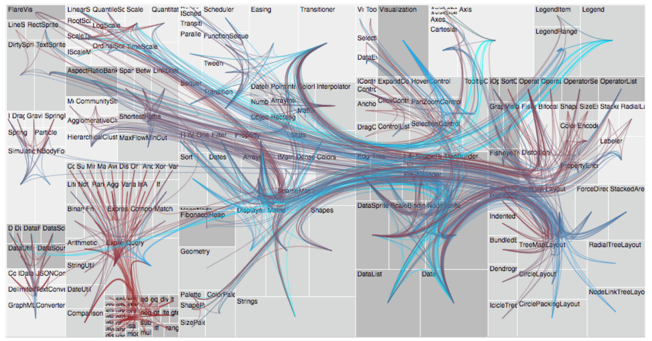
- data
  - any layout of compound network
    - network: software classes (nodes), import/export between classes (links)
    - cluster hierarchy: class package structure
  - derived: bundles of edges with same source/destination (multi-level)
- idiom: curve edge routes according to bundles
- task: edge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

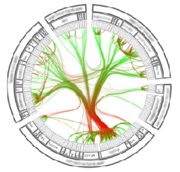


[Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data. Danny Holten. TVCG 12(5):741-748 2006]

Hierarchical edge bundling

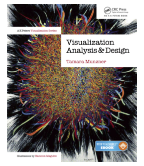
- works for any layout: treemap vs radial





[Hierarchical Edge Bundles: Visualization of Adjacency Relations in Hierarchical Data. Danny Holten. TVCG 12(5):741-748 2006]

Visualization Analysis & Design



Spatial Data (Ch 9)

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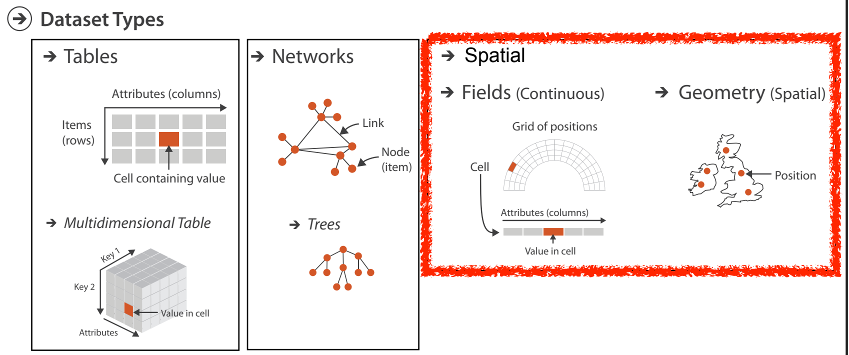
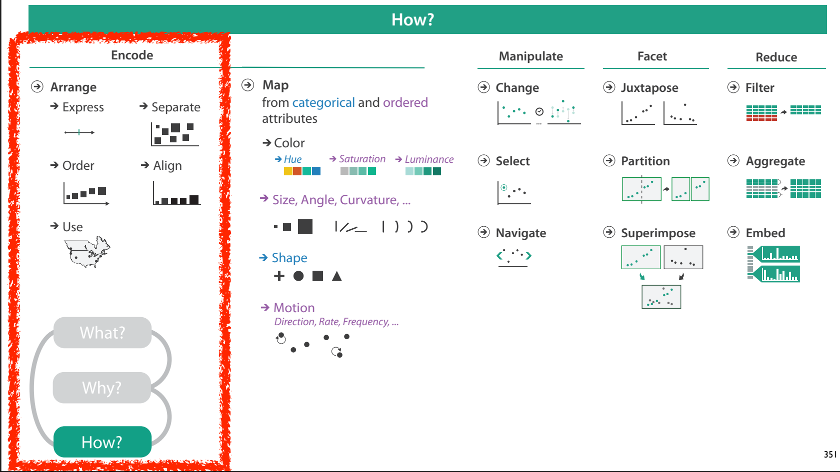
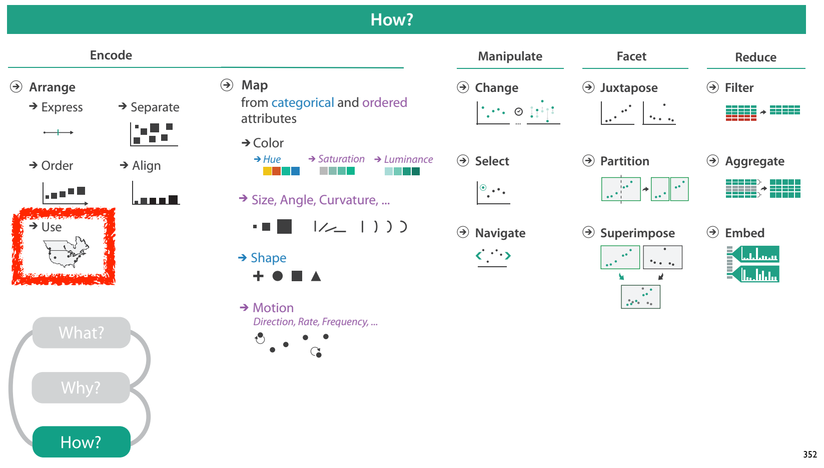
Focus on Spatial







Spatial data

- use given spatial position
- when?
  - dataset contains spatial attributes and they have primary importance
  - central tasks revolve around understanding spatial relationships
- examples
  - geographical/cartographic data
  - sensor/simulation data

Geographic Maps

Geographic Map

Interlocking marks

- shape coded
- area coded
- position coded

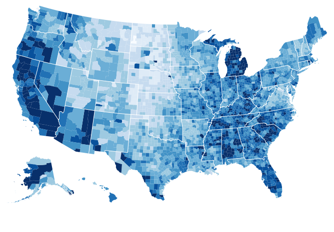
- cannot encode another attribute with these channels, they're "taken"

Thematic maps

- show spatial variability of attribute ("theme")
  - combine geographic / reference map with (simple, flat) tabular data
  - join together
    - region: interlocking area marks (provinces, countries with outline shapes)
      - also could have point marks (cities, locations with 2D lat/lon coords)
    - region: categorical key attribute in table
      - use to look up value attributes
- major idioms
  - choropleth
  - symbol maps
  - cartograms
  - dot density maps

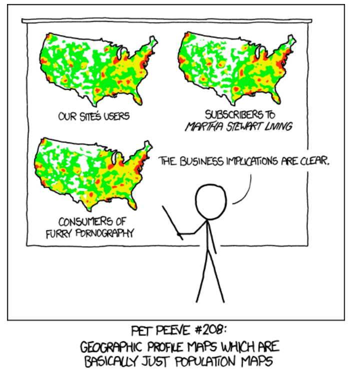
Idiom: **choropleth map**

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



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

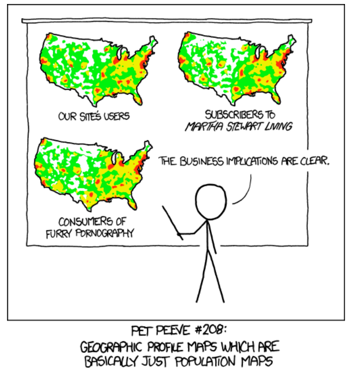
Beware: Population maps trickiness!



[https://xkcd.com/1138]

Beware: Population maps trickiness!

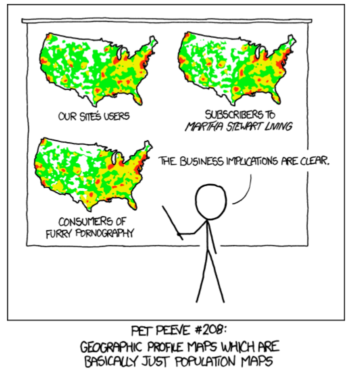
- spurious correlations: most attributes just show where people live



[https://xkcd.com/1138]

Beware: Population maps trickiness!

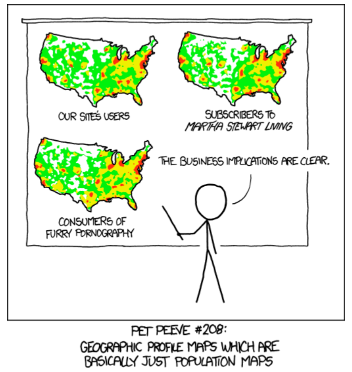
- spurious correlations: most attributes just show where people live
- consider when to normalize by population density
  - encode raw data values
    - tied to underlying population
  - but should use normalized values
    - unemployed people per 100 citizens, mean family income



[https://xkcd.com/1138]

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
    - unemployed people per 100 citizens, mean family income
- general issue
  - absolute counts vs relative/normalized data
  - failure to normalize is common error



[https://xkcd.com/1138]

Choropleth maps: Recommendations

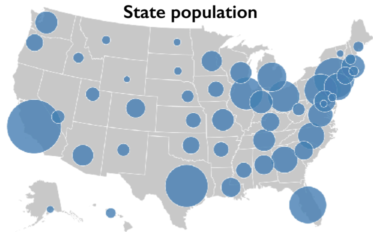
- only use when central task is understanding spatial relationships
- show only one variable at a time
- normalize when appropriate
- be careful when choosing colors & bins
- best case: regions are roughly equal sized

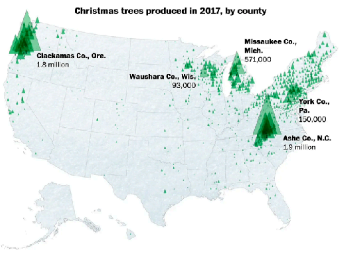
Choropleth map: Pros & cons

- pros
  - easy to read and understand
  - well established visualization (no learning curve)
  - data is often collected and aggregated by geographical regions
- cons
  - most effective visual variable used for geographic location
  - visual salience depends on region size, not true importance wrt attribute value
    - large regions appear more important than small ones
  - color palette choice has a huge influence on the result

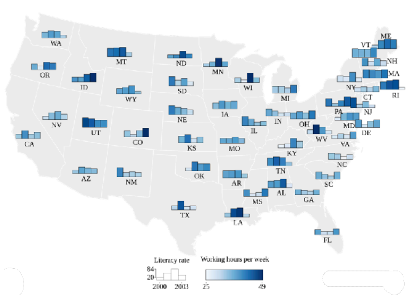
Idiom: **Symbol maps**

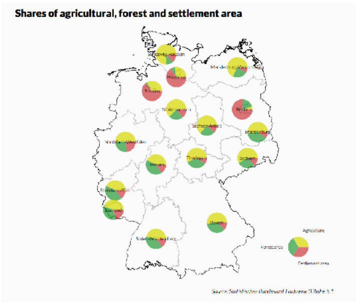
- symbol is used to represent aggregated data (mark or glyph)
  - allows use of size and shape and color channels
    - aka proportional symbol maps, graduated symbol maps
- keep original spatial geometry in the background
- often a good alternative to choropleth maps





Symbol maps with glyphs



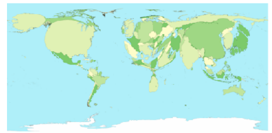


Symbol map: Pros & cons

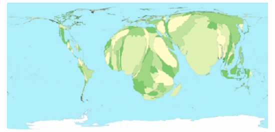
- pros
  - somewhat intuitive to read and understand
  - mitigate problems with region size vs data salience
    - marks: symbol size follows attribute value
    - glyphs: symbol size can be uniform
- cons
  - possible occlusion / overlap
    - symbols could overlap each other
    - symbols could occlude region boundaries
  - complex glyphs may require explanation / training

Idiom: **Contiguous cartogram**

- interlocking marks: shape, area, and position coded
- derive new interlocking marks
  - based on combination of original interlocking marks and new quantitative attribute
- algorithm to create new marks
  - input: target size
  - goal: shape as close to the original as possible
  - requirement: maintain constraints
    - relative position
    - contiguous boundaries with their neighbours



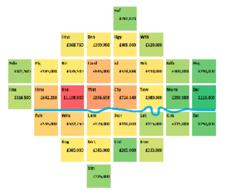
Greenhouse Emissions

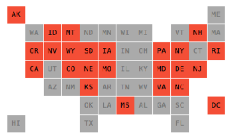


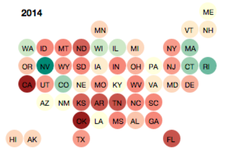
Child Mortality

Mark Newman, Univ. Michigan

Idiom: **Grid Cartogram**







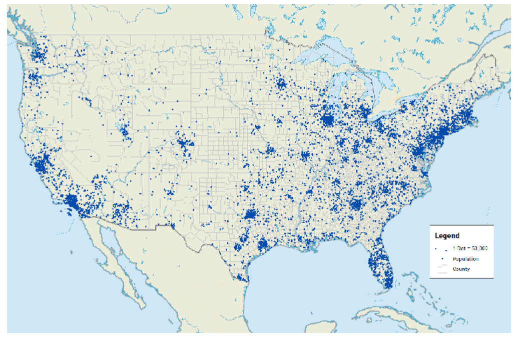
- uniform-sized shapes arranged in rectilinear grid
- maintain approximate spatial position and arrangement

Cartogram: Pros & cons

- pros
  - can be intriguing and engaging
  - best case: strong and surprising size disparities
  - non-contiguous cartograms often easier to understand
- cons
  - require substantial familiarity with original dataset & use of memory
    - compare distorted marks to memory of original marks
    - mitigation strategies: transitions or side by side views
  - major distortion is problematic
    - may be aesthetically displeasing
    - may result in unrecognizable marks
  - difficult to extract exact quantities

Idiom: **Dot density maps**

- visualize distribution of a phenomenon by placing dots
- one symbol represents a constant number of items
  - dots have uniform size & shape
  - allows use of color channel
- task: show spatial patterns, clusters

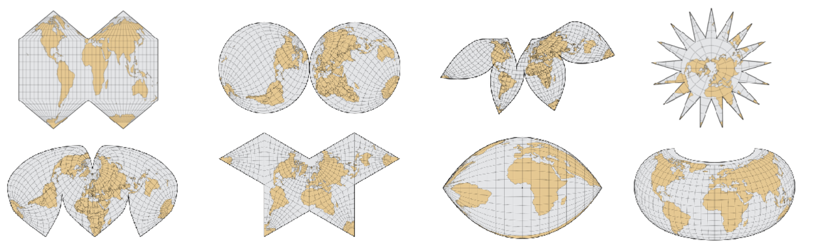


Dot density maps: Pros and cons

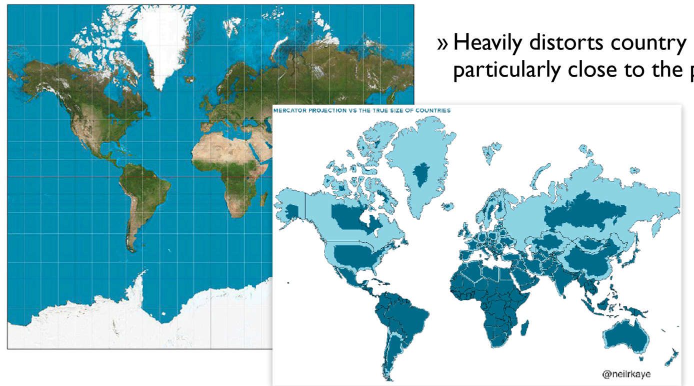
- pros
  - straightforward to understand
  - avoids choropleth non-uniform region size problems
- cons
  - challenge: normalization, just like choropleths
    - show population density (correlated with attribute), not effect of interest
  - perceptual disadvantage: difficult to extract quantities
  - performance disadvantage: rendering many dots can be slow

Map Projections

- mathematical functions that map 3D surface geometry of the Earth to 2D maps
- all projections of sphere on plane necessarily distort surface in some way
- interactive: philogb.github.io/page/myriahedral/ and jasondavies.com/maps/

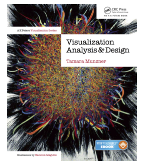


Mercator Projection



» Heavily distorts country sizes; particularly close to the poles.

Visualization Analysis & Design



Spatial Data (Ch 9) II

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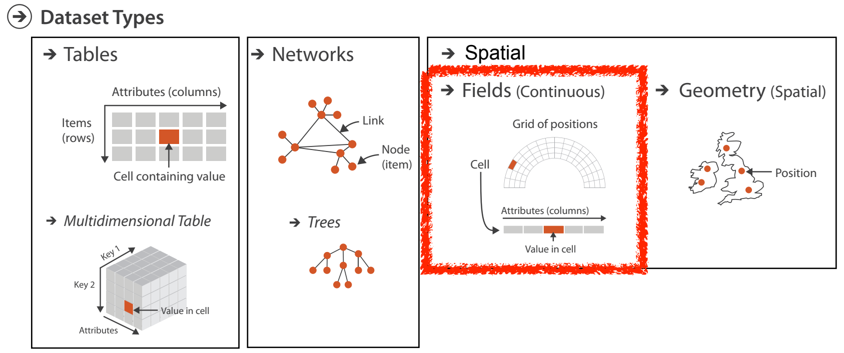
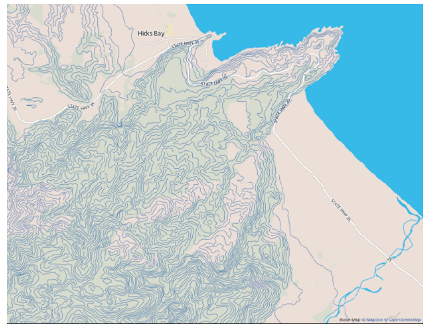
Focus on Spatial



Spatial Fields

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
- task
  - understanding terrain shape
    - densely lined regions = steep
- pros
  - use only 2D position, avoid 3D challenges
  - color channel available for other attributes
- cons
  - significant clutter from additional lines



Land Information New Zealand Data Service

Idioms: **isosurfaces, direct volume rendering**

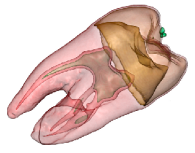
- data
  - scalar spatial field (3D volume)
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships

[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.]

Idioms: **isosurfaces, direct volume rendering**

- data
  - scalar spatial field (3D volume)
    - 1 quant attribute per grid cell
- task
  - shape understanding, spatial relationships
- isosurface
  - derived data: isocontours computed for specific levels of scalar values



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

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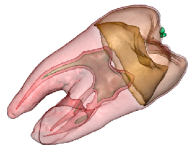
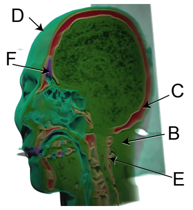
Idioms: **isosurfaces, direct volume rendering**

- data
  - scalar spatial field (3D volume)
    - 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





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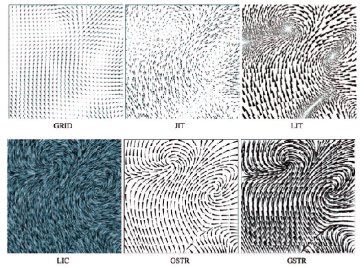
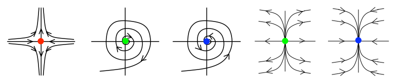
[Multidimensional Transfer Functions for Volume Rendering. Kniss, Kindlmann, and Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189–210. Elsevier, 2005.]

Vector and tensor fields

- data
  - multiple attribs per cell (vector: 2)
- idiom families
  - *flow glyphs*
    - purely local
  - *geometric flow*
    - derived data from tracing particle trajectories
    - sparse set of seed points
  - *texture flow*
    - derived data, dense seeds
  - *feature flow*
    - global computation to detect features



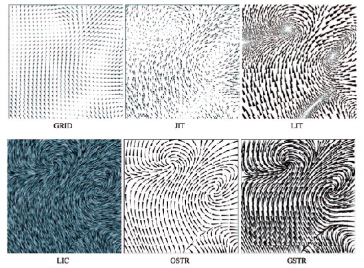
[Comparing 2D vector field visualization methods: A user study. Laidlaw et al. IEEE Trans. Visualization and Computer Graphics (TVCG) 11:1 (2005), 59–70.]



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

Vector fields

- empirical study tasks
  - finding critical points, identifying their types
  - identifying what type of critical point is at a specific location
  - predicting where a particle starting at a specified point will end up (advection)



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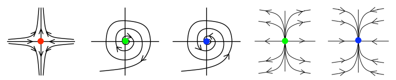
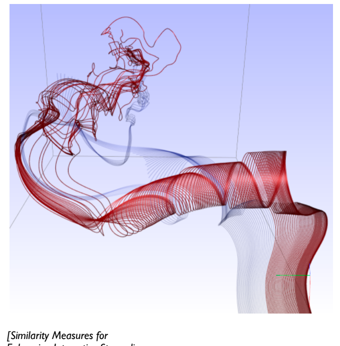


[Topology tracking for the visualization of time-dependent two-dimensional flows. Tricoche, Wischgoll, Scheuermann, and Hagen. Computers & Graphics 26:2 (2002), 249–257.]

Idiom: **similarity-clustered streamlines**

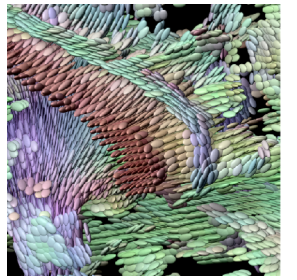
- data
  - 3D vector field
- derived data (from field)
  - streamlines: trajectory particle will follow
- derived data (per streamline)
  - curvature, torsion, tortuosity
  - signature: complex weighted combination
  - compute cluster hierarchy across all signatures
  - encode: color and opacity by cluster
- 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.]

Idiom: Ellipsoid Tensor Glyphs

- data
  - tensor field: multiple attributes at each cell (entire matrix)
    - stress, conductivity, curvature, diffusivity...
  - derived data:
    - shape (eigenvalues)
    - orientation (eigenvectors)
- visual encoding
  - glyph: 3D ellipsoid



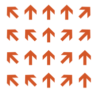
[Superquadric Tensor Glyphs. Kindlmann. Proc. VisSym04, p147-154, 2004.]

Arrange spatial data

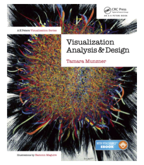
- Use Given
  - Geometry
    - *Geographic*

  - 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)*



Visualization Analysis & Design



Color (Ch 10)

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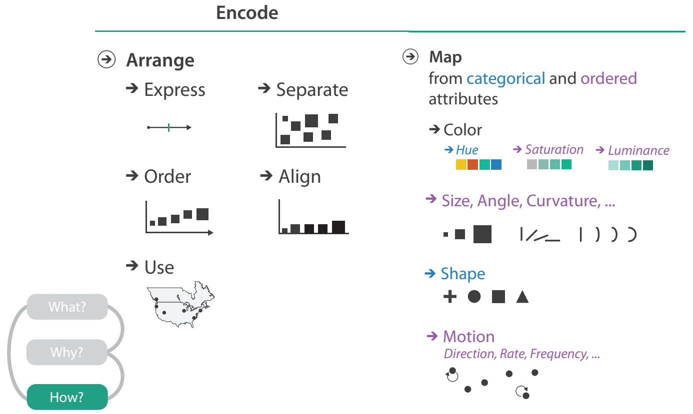
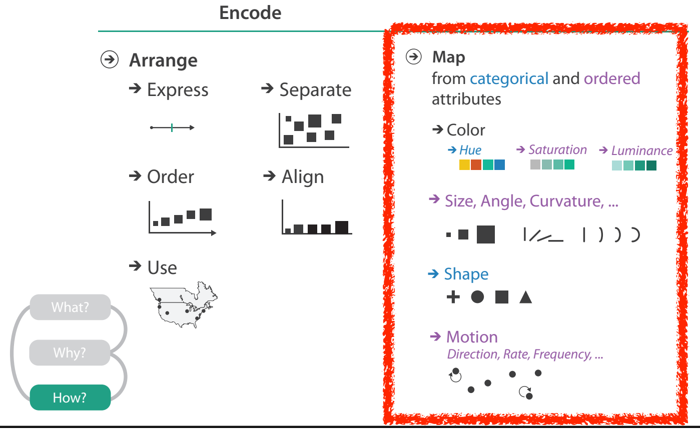
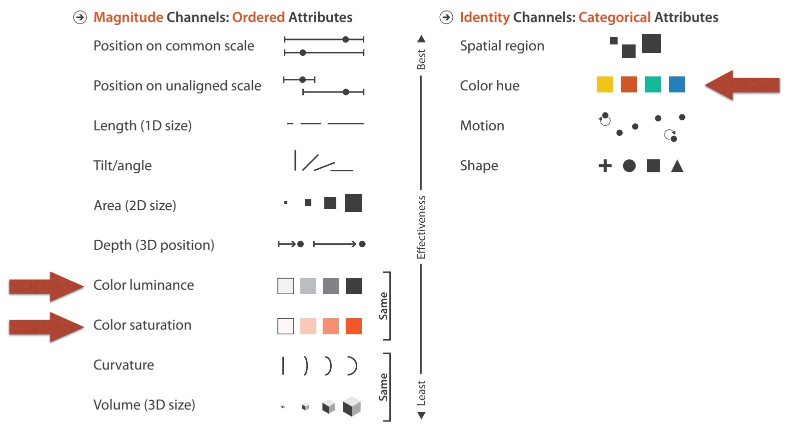
Idiom design choices: Visual encoding



Idiom design choices: Beyond spatial arrangement



Channels: What's up with color?



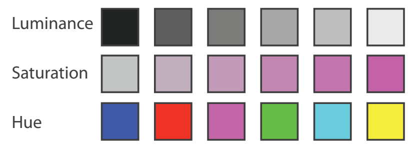
Decomposing color

Decomposing color

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

Decomposing color

- first rule of color: do not (just) talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



Decomposing color

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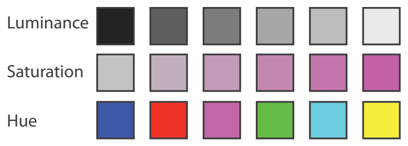
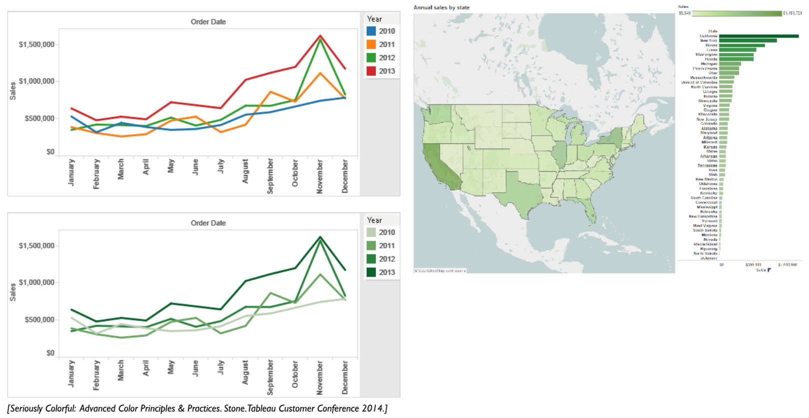


- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey
    - how many discriminable bins can we use?

Color Channels in Visualization

Categorical vs ordered color



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

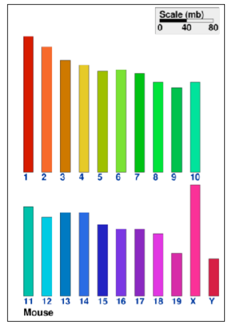
Categorical color: limited number of discriminable bins

- human perception built on relative comparisons

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

Categorical color: limited number of discriminable bins

- human perception built on relative comparisons
  - great if color contiguous



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

Categorical color: limited number of discriminable bins

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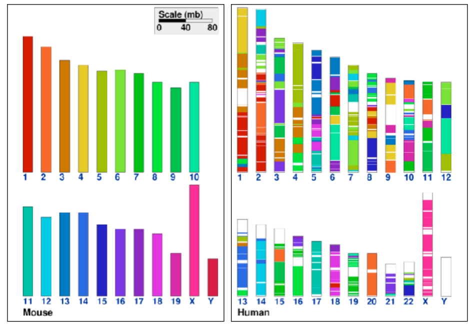
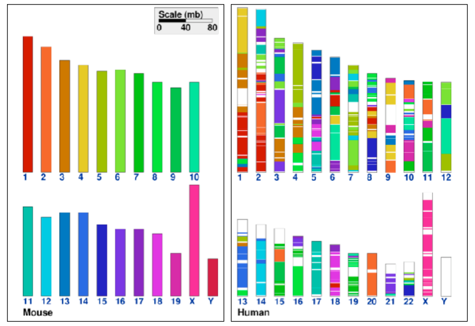
  - great if color contiguous
  - surprisingly bad for absolute comparisons



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

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



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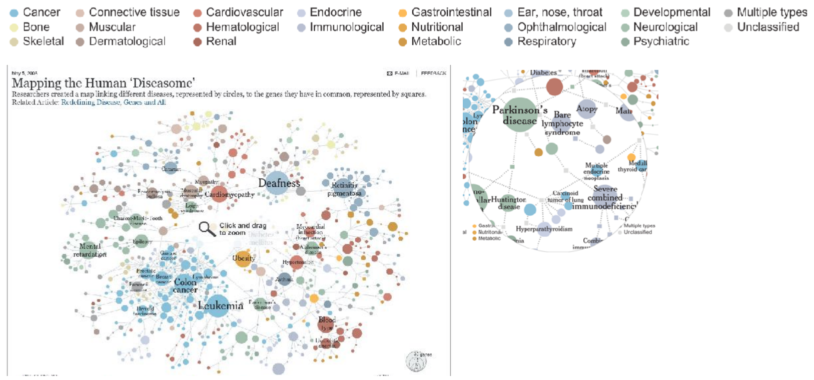
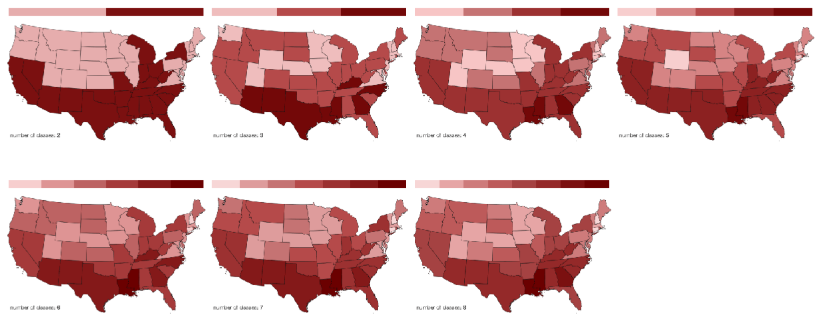
Categorical color: limited number of discriminable bins



https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

Ordered color: limited number of discriminable bins

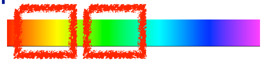


Gregor Aisch, vis4.net/blog/posts/choropleth-maps/

Ordered color: Rainbow is poor default

- problems
  - perceptually unordered
  - perceptually nonlinear

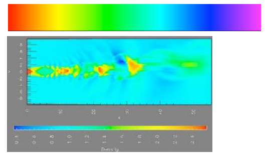
Ordered color: Rainbow is poor default



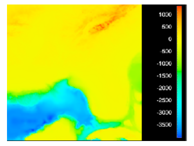
- problems
  - perceptually unordered
  - perceptually nonlinear

Ordered color: Rainbow is poor default

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



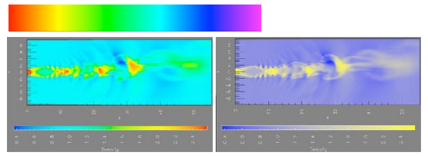
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



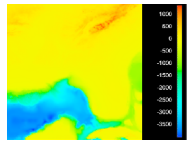
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Ordered color: Rainbow is poor default

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



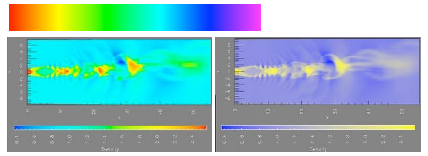
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]



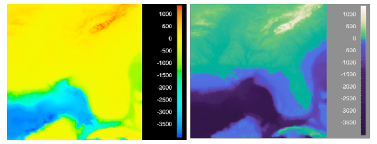
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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]



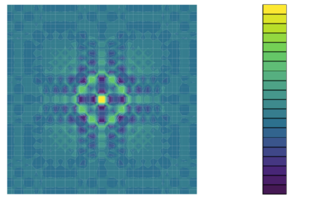
[A Rule-based Tool for Assisting Colormap Selection. Bergman, Rogowitz, and Treinish. Proc. IEEE Visualization (Vis), pp. 118–125, 1995.]

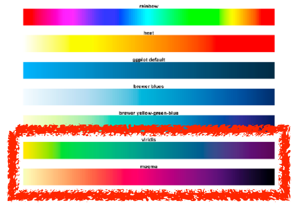


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

Viridis / Magma: sequential colormaps

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

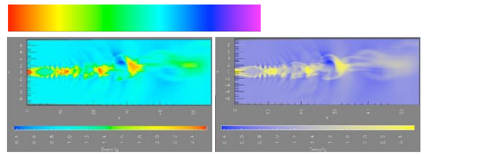




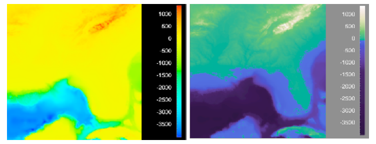
https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

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]
- legit for 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.]

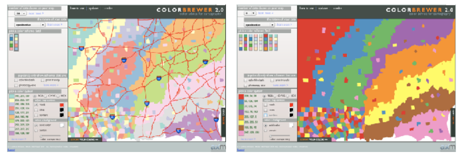


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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

Interaction between channels: Not fully separable

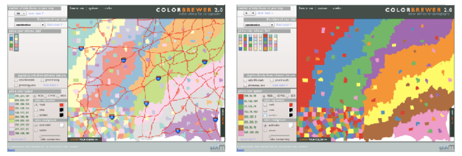
- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation

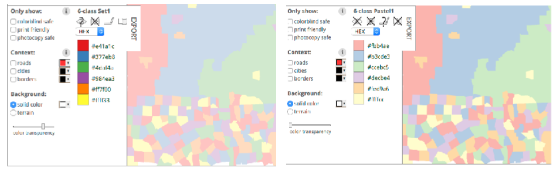


http://colorbrewer2.org/

Interaction between channels: Not fully separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency

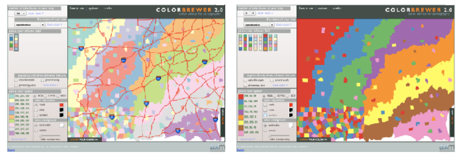


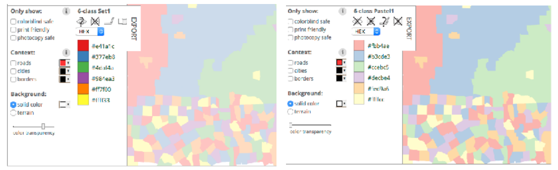


http://colorbrewer2.org/

Interaction between channels: Not fully separable

- color channel interactions
  - size heavily affects salience
  - small regions need high saturation
  - large regions need low saturation
- saturation & luminance:
  - not separable from each other!
  - also not separable from transparency
  - small separated regions: 2 bins safest (use only one of these channels), 3-4 bins max
  - contiguous regions: many bins (use only one of these channels)





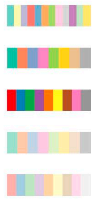
http://colorbrewer2.org/

Color Palettes

Color palettes: univariate

→ Categorical

Categorical



categorical

- categorical
  - aim for maximum distinguishability
  - aka *qualitative*, *nominal*

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

Color palettes: univariate

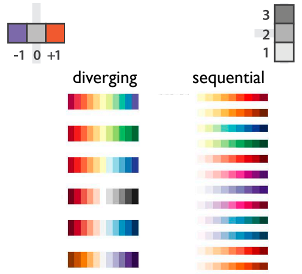
→ Categorical

→ Ordered
→ *Sequential* → *Diverging*

Categorical

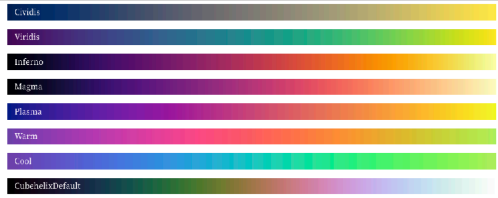
- diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints
- sequential
  - ramp luminance or saturation

Diverging -1 0 +1 / Sequential 3 2 1



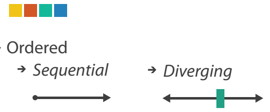
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Color palettes: univariate



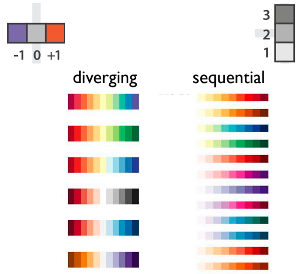
→ Categorical

→ Ordered
→ *Sequential* → *Diverging*



- diverging
  - useful when data has meaningful "midpoint"
  - use neutral color for midpoint
    - white, yellow, grey
  - use saturated colors for endpoints
- sequential
  - ramp luminance or saturation
  - if multi-hue, good to order by luminance

Diverging -1 0 +1 / Sequential 3 2 1

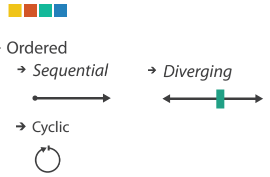


after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Color palettes: univariate

→ Categorical

→ Ordered
→ *Sequential* → *Diverging*
→ Cyclic



cyclic multihue

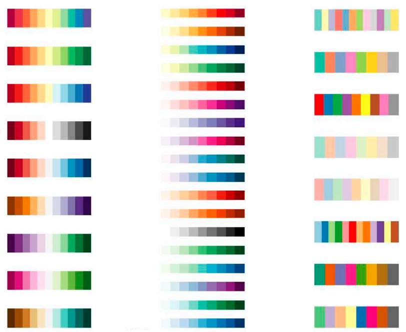
https://github.com/d3/d3-scale-chromatic

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

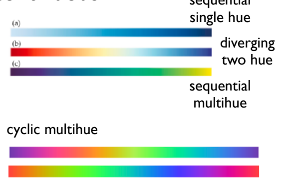
Color palette design considerations: univariate

segmented

diverging sequential categorical



continuous



- segmented or continuous?
- diverging or sequential or cyclic?
- single-hue or two-hue or multi-hue?
- perceptually linear?
- ordered by luminance?
- colorblind safe?

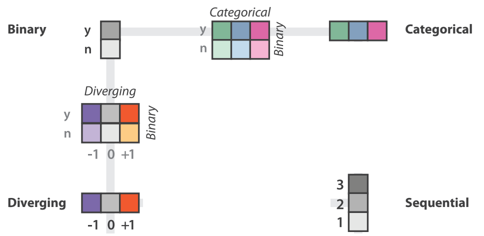
[A Study of Colormaps in Network Visualization. Karim et al. Appl. Sci. 2019, 9, 4228; doi:10.3390/app9204228] https://github.com/d3/d3-scale-chromatic

Colormaps: bivariate

→ Categorical

→ Ordered
  → *Sequential* → *Diverging*

→ Bivariate



- bivariate best case
  - binary in one of the directions

d3.schemePaired <>

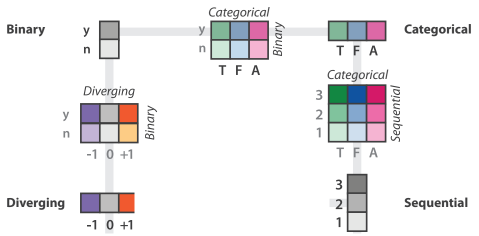
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps: bivariate

→ Categorical

→ Ordered
  → *Sequential* → *Diverging*

→ Bivariate



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

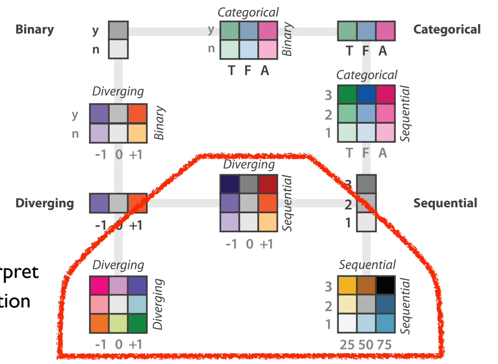
Colormaps

→ Categorical

→ Ordered
  → *Sequential* → *Diverging*

→ Bivariate

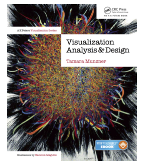
use with care!



- bivariate can be very difficult to interpret
  - when multiple levels in each direction

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

Visualization Analysis & Design



Color (Ch 10) II

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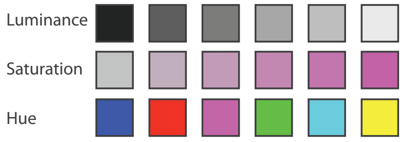
Decomposing color

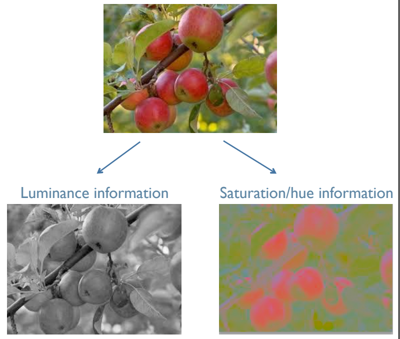
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



Color Deficiency

Luminance

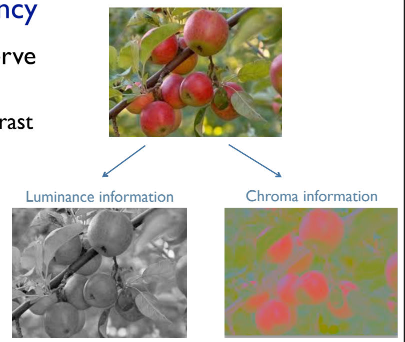
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!



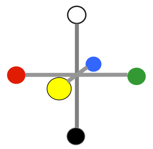
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Opponent color and color deficiency

- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)

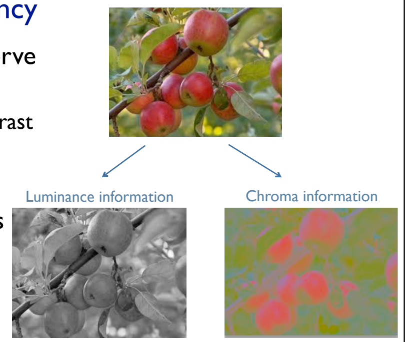


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

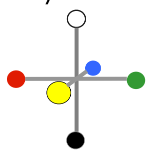


Opponent color and color deficiency

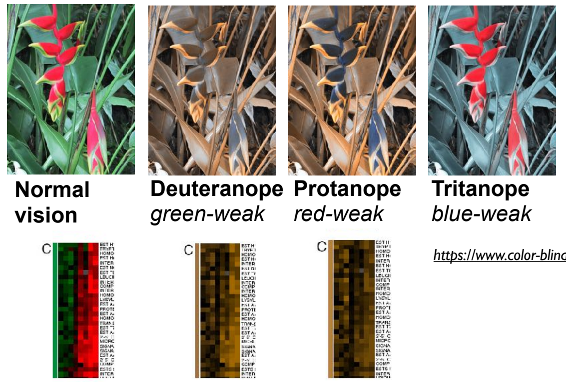
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- "colorblind": degraded acuity, one axis
  - 8% of men are red/green color deficient
  - blue/yellow is rare



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



Designing for color deficiency: Check with simulator

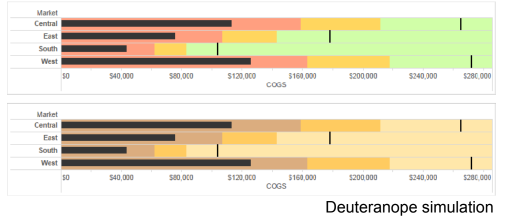


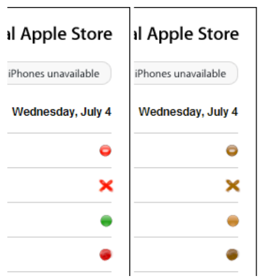
https://www.color-blindness.com/coblis-color-blindness-simulator/

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

Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape



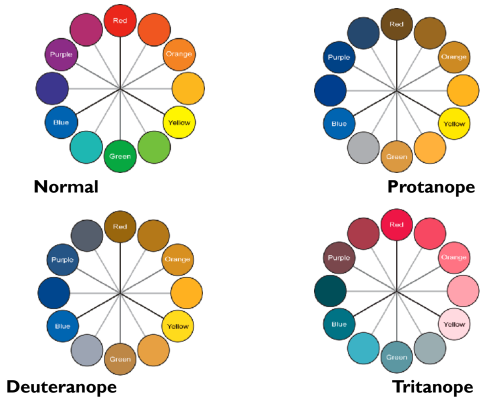


Change the shape

Vary luminance

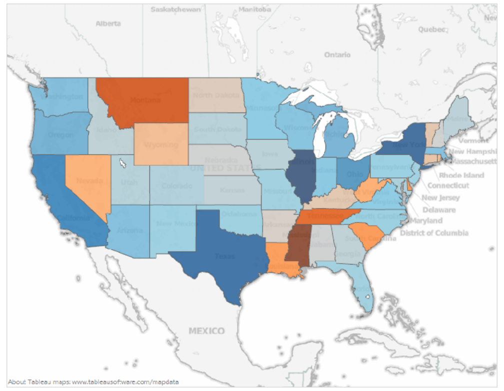
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Color deficiency: Reduces color to 2 dimensions



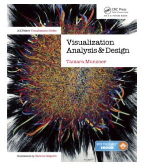
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Designing for color deficiency: Blue-Orange is safe



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

Visualization Analysis & Design



Color (Ch 10) III

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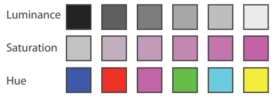
Color Spaces

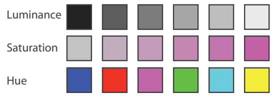
Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding



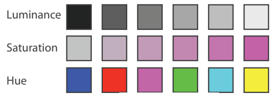
Many color spaces

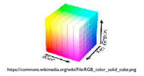
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace



Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware

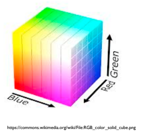


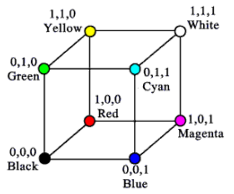


RGB

- RGB: good for display hardware

Corners of the RGB color cube

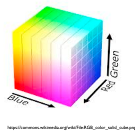


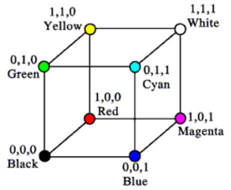


RGB

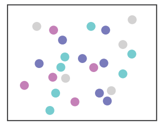
- RGB: good for display hardware
  - poor for encoding & interpolation

Corners of the RGB color cube





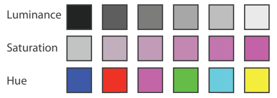
Red
+ Green

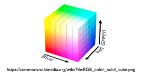


Major interference

Many color spaces

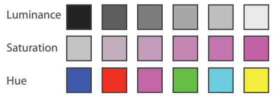
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation

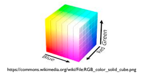




Many color spaces

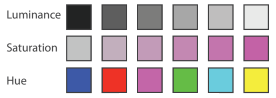
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation

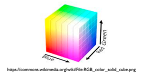




Many color spaces

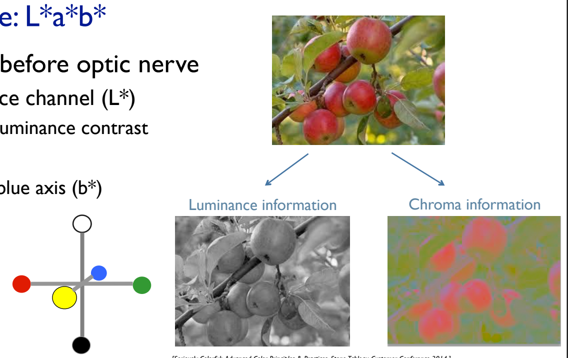
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding





Perceptual colorspace: L*a*b*

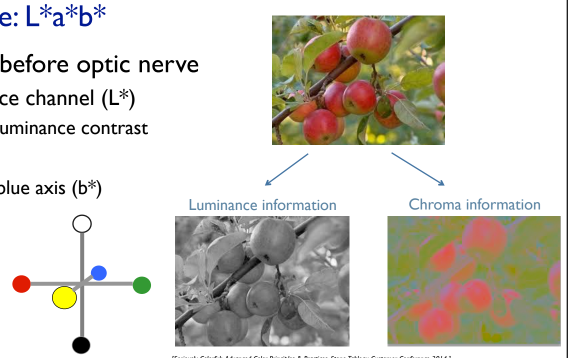
- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)



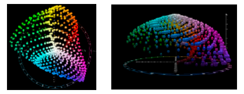
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

Perceptual colorspace: L*a*b*

- perceptual processing before optic nerve
  - one achromatic luminance channel (L*)
    - edge detection through luminance contrast
  - 2 chroma channels
    - red-green (a*) & yellow-blue axis (b*)
- CIE LAB
  - perceptually uniform
    - great for interpolating
  - complex shape
    - poor for encoding



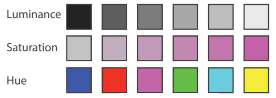
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

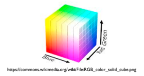


https://en.wikipedia.org/wiki/CIELAB_color_space

Many color spaces

- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace
- RGB: good for display hardware
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding





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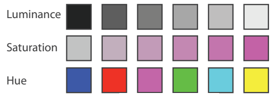
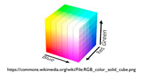
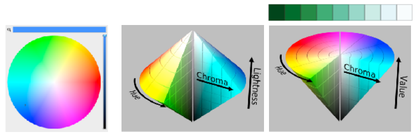
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding

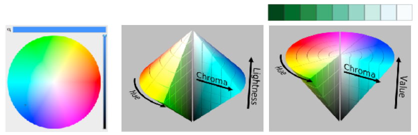


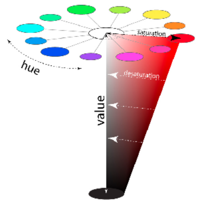




HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
-

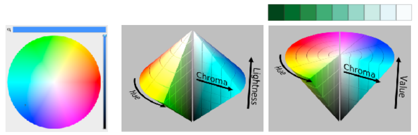


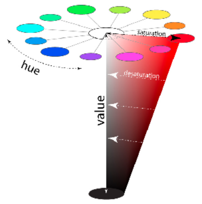


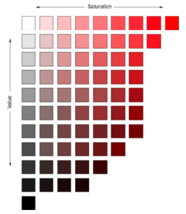
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

HSL/HSV

- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
- saturation
  - in HSV (single-cone) desaturated = white
  - in HSL (double-cone) desaturated = grey
- luminance vs saturation
  - channels **not** very separable
  - typically not crucial to distinguish between these with encoding/decoding
  - key point is hue vs luminance/saturation





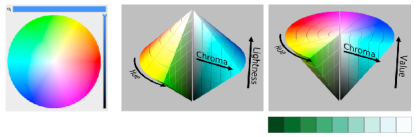


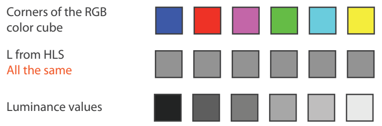
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

HSL/HSV: Pseudo-perceptual colorspace

- HSL better than RGB for encoding **but beware**
  - L lightness ≠ L* luminance





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

Many color spaces

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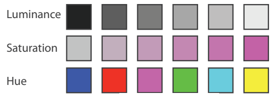
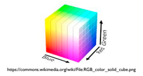
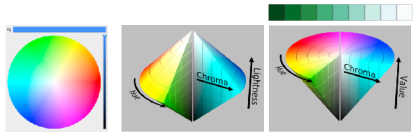
  - poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  - hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  - hue/saturation wheel intuitive
  - beware: only pseudo-perceptual!
  - lightness (L) or value (V) ≠ luminance (L*)

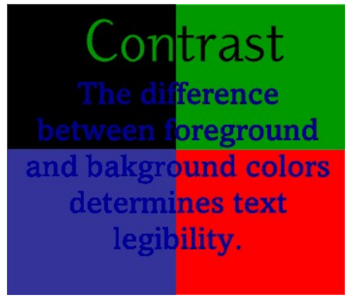


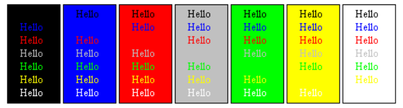




Color Constrast & Naming

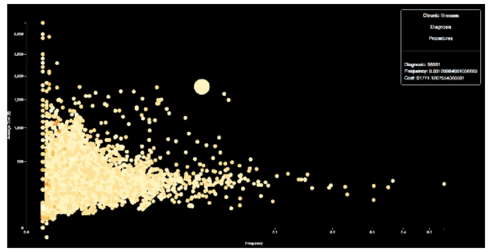
Interaction with the background





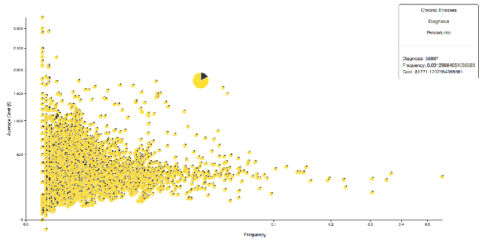
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



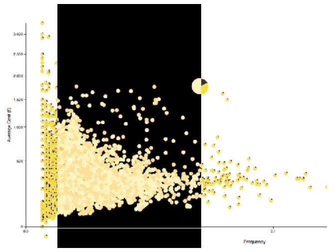
Interaction with the background: tweaking yellow for visibility

- marks with medium luminance on a background with high luminance



Interaction with the background: tweaking yellow for visibility

- change luminance of marks depending on background



Color/Lightness constancy: Illumination conditions

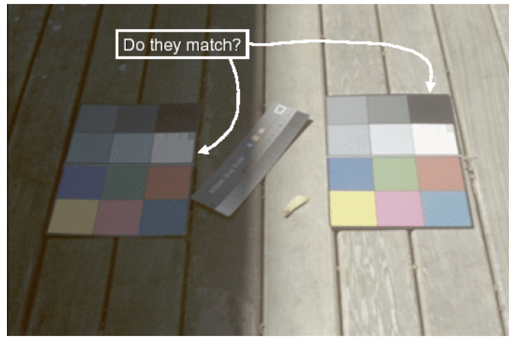


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

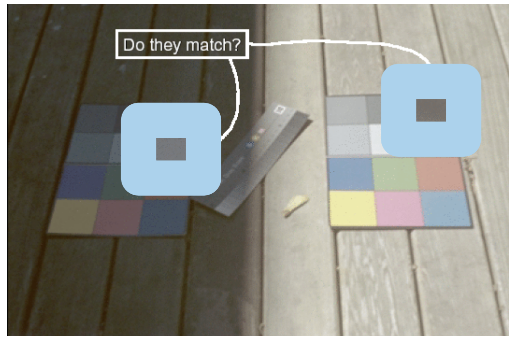
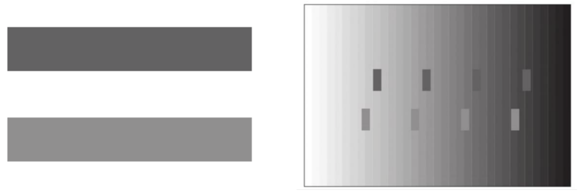


Image courtesy of John McCann via Maureen Stone

Contrast with background



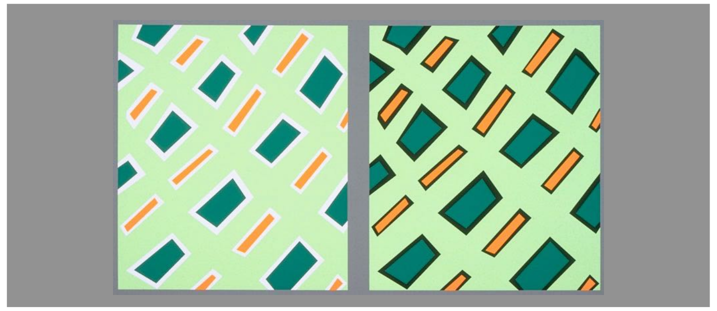
Contrast with background

Black and blue? White and gold?

https://imgur.com/hxJjUQB

https://en.wikipedia.org/wiki/The_dress

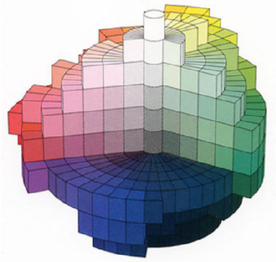
Bezold Effect: Outlines matter



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

Color Appearance

- given L, a*, b*, can we tell what color it is?
  - no, it depends
- chromatic adaptation
- luminance adaptation
- simultaneous contrast
- spatial effects
- viewing angle
- …



Color naming

Color naming

http://www.thedoghousediaries.com/1406

Color naming

https://blog.xkcd.com/2010/05/03/color-survey-results/

Color naming

- nameability affects
  - communication
  - memorability
- can integrate into color models
  - in addition to perceptual considerations

https://blog.xkcd.com/2010/05/03/color-survey-results/

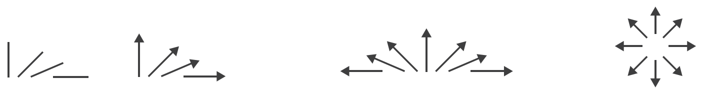
Color is just part of vision system

- Does not help perceive
  - Position
  - Shape
  - Motion
  - …

Map Other Channels

Angle / tilt / orientation channel

- different mappings depending on range used



Sequential ordered
line mark or arrow glyph

Diverging ordered
arrow glyph

Cyclic ordered
arrow glyph

- nonlinear accuracy
  - high: exact horizontal, vertical, diagonal (0, 45, 90 degrees)
  - lower: other orientations (eg 37 vs 38 degrees)

Map other channels

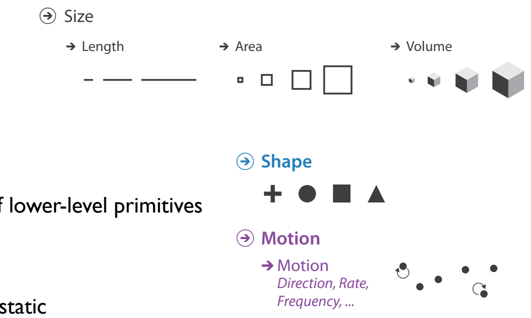
- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor

Map other channels

- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins

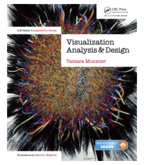
Map other channels

- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins
- motion
  - highly separable against static
    - great for highlighting (binary)
  - use with care to avoid irritation



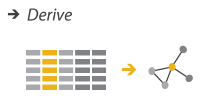
Visualization Analysis & Design

Interactive Views (Ch 11/12)



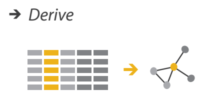
Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

How to handle complexity: 1 previous strategy

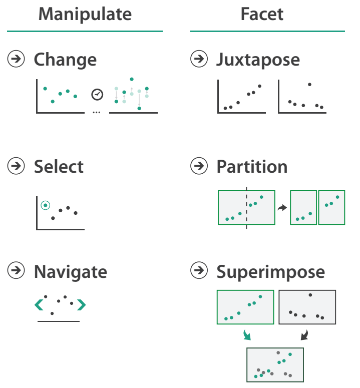


- derive new data to show within view

How to handle complexity: 1 previous strategy + 2 more

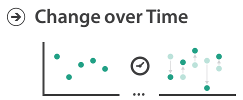


- derive new data to show within view
- change view over time
- facet across multiple views



Manipulate View

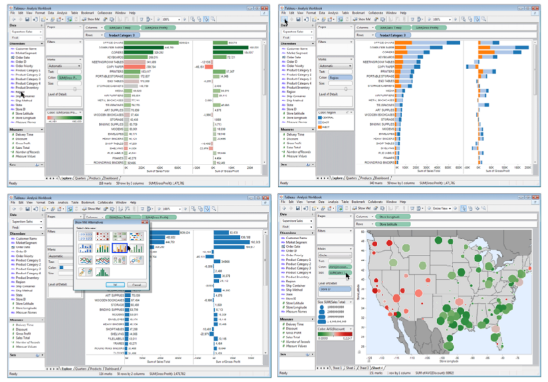
Manipulate



Change over time

- change any of the other choices
  - encoding itself
  - parameters
  - arrange: rearrange, reorder
  - aggregation level, what is filtered...
  - interaction entails change
- powerful & flexible

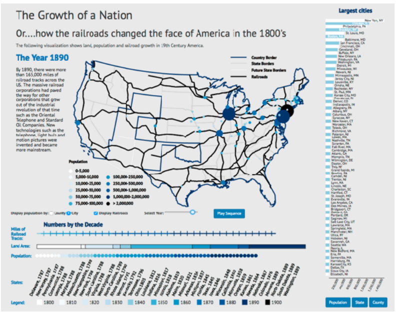
Idiom: **Re-encode**



made with Tableau, http://tableausoftware.com

Idiom: **Change parameters**

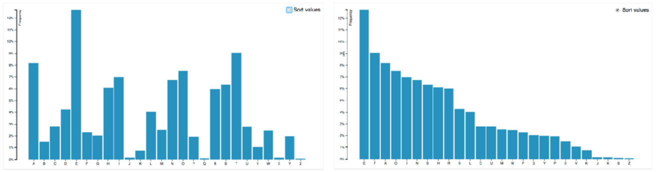
- widgets and controls
  - sliders, buttons, radio buttons, checkboxes, dropdowns/comboboxes
- pros
  - clear affordances, self-documenting (with labels)
- cons
  - uses screen space
- design choices
  - separated vs interleaved
    - controls & canvas



[Growth of a Nation](http://laurenwood.github.io/)
made with D3

Idiom: **Change order/arrangement**

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



[Sortable Bar Chart] https://observablehq.com/@d3/sortable-bar-chart
made with D3

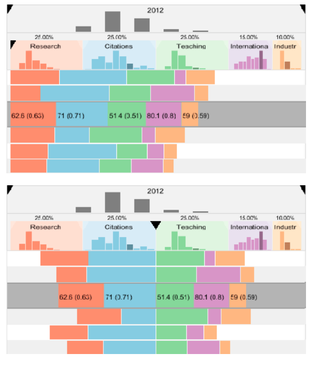
Idiom: **Reorder** System: **DataStripes**

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

[http://carlmanaster.github.io/datastripes/]
made with D3

Idiom: **Change alignment** System: **LineUp**

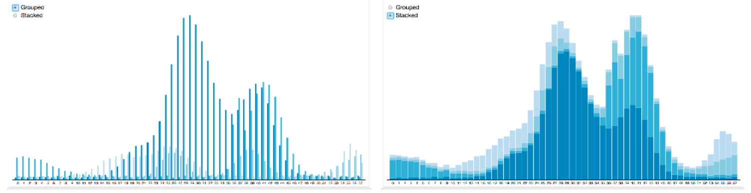
- stacked bars
  - easy to compare
    - first segment
    - total bar
- align to different segment
  - supports flexible comparison



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

Idiom: **Animated transitions - visual encoding change**

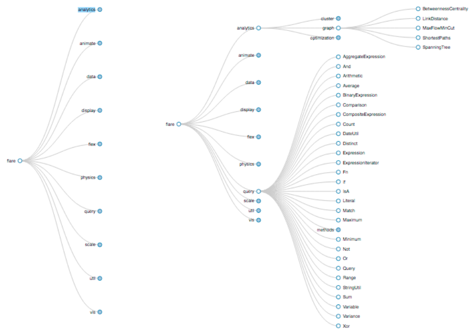
- smooth transition from one state to another
  - alternative to jump cuts, supports item tracking
    - best case for animation
  - staging to reduce cognitive load



[Stacked to Grouped Bars] https://observablehq.com/@d3/stacked-to-grouped-bars

Idiom: **Animated transition - tree detail**

- animated transition
  - network drilldown/rollup

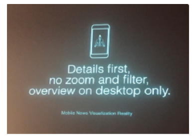


[Collapsible Tree] https://observablehq.com/@d3/collapsible-tree

Manipulate

Interaction technology

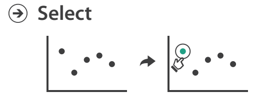
- what do you design for?
  - mouse & keyboard on desktop?
    - large screens, hover, multiple clicks
  - touch interaction on mobile?
    - small screens, no hover, just tap
  - gestures from video / sensors?
    - ergonomic reality vs movie bombast
  - eye tracking?



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

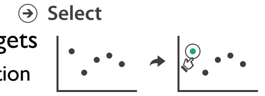
I Hate Tom Cruise - Alex Kauffmann (5 min)
www.youtube.com/watch?v=QXLfT9sFcbc

Selection



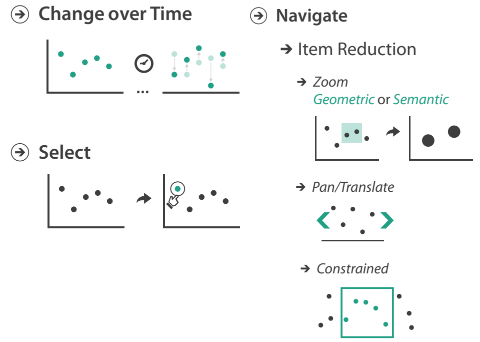
- selection: basic operation for most interaction
- design choices
  - how many selection types?
    - interaction modalities
      - click/tap (heavyweight) vs hover (lightweight but not available on most touchscreens)
      - multiple click types (shift-click, option-click, …)
      - proximity beyond click/hover (touching vs nearby vs distant)
    - application semantics
      - adding to selection set vs replacing selection
      - can selection be null?
        - ex: toggle so nothing selected if click on background
      - primary vs secondary (ex: source/target nodes in network)
      - group membership (add/delete items, name group, …)

Highlighting

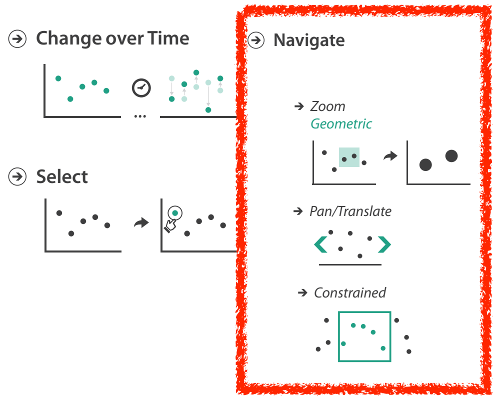


- highlight: change visual encoding for selection targets
  - visual feedback closely tied to but separable from selection (interaction)
- design choices: typical visual channels
  - change item color
    - but hides existing color coding
  - add outline mark
  - change size (ex: increase outline mark linewidth)
  - change shape (ex: from solid to dashed line for link mark)
- unusual channels: motion
  - motion: usually avoid for single view
    - with multiple views, could justify to draw attention to other views

Manipulate



Manipulate

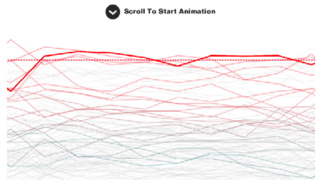


Navigate: Changing viewpoint/visibility

- change viewpoint
  - changes which items are visible within view
- camera metaphor
  - pan/translate/scroll
    - move up/down/sideways

Idiom: **Scrollytelling**

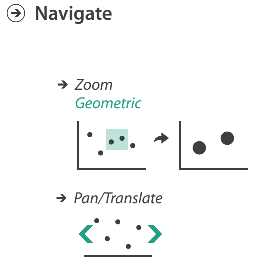
- how: navigate page by scrolling (panning down)
- pros:
  - familiar & intuitive, from standard web browsing
  - linear (only up & down) vs possible overload of click-based interface choices
- cons:
  - full-screen mode may lack affordances
  - scrolljacking, no direct access
  - unexpected behaviour
  - continuous control for discrete steps



[How to Scroll, Bostock](https://bost.ocks.org/mike/scroll/)
https://eagereyes.org/blog/2016/the-scrollytelling-scourge

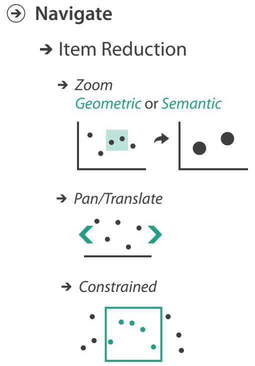
Navigate: Changing viewpoint/visibility

- change viewpoint
  - changes which items are visible within view
- camera metaphor
  - pan/translate/scroll
    - move up/down/sideways
  - rotate/spin
    - typically in 3D
  - zoom in/out
    - enlarge/shrink world == move camera closer/further
    - geometric zoom: standard, like moving physical object



Navigate: Unconstrained vs constrained

- unconstrained navigation
  - easy to implement for designer
  - hard to control for user
    - easy to overshoot/undershoot
- constrained navigation
  - typically uses animated transitions
  - trajectory automatically computed based on selection
    - just click; selection ends up framed nicely in final viewport



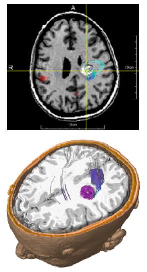
Idiom: **Animated transition + constrained navigation**

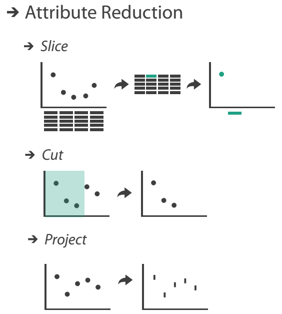
- example: geographic map
  - simple zoom, only viewport changes, shapes preserved

[Zoom to Bounding Box] https://observablehq.com/@d3/zoom-to-bounding-box

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 slide of plane from camera
  - project
    - change mathematics of image creation
      - orthographic
      - perspective
      - many others: Mercator, cabinet, ...





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

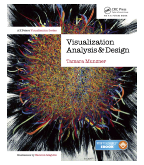
Interaction benefits

- interaction pros
  - major advantage of computer-based vs paper-based visualization
  - flexible, powerful, intuitive
    - exploratory data analysis: change as you go during analysis process
    - fluid task switching: different visual encodings support different tasks
  - animated transitions provide excellent support
    - empirical evidence that animated transitions help people stay oriented

Interaction limitations

- interaction has a time cost
  - sometimes minor, sometimes significant
  - degenerates to human-powered search in worst case
- remembering previous state imposes cognitive load
- controls may take screen real estate
  - or invisible functionality may be difficult to discover (lack of affordances)
- users may not interact as planned by designer
  - NYTimes logs show ~90% don't interact beyond scrollytelling - Aisch, 2016

Visualization Analysis & Design



Interactive Views (Ch 11/12) II

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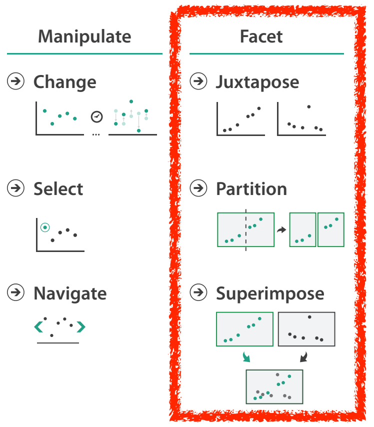
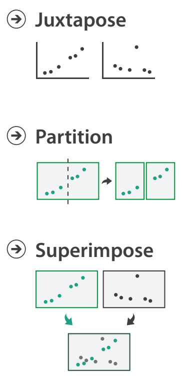
How to handle complexity: 1 previous strategy + 2 more

- derive new data to show within view
- change view over time
- facet across multiple views

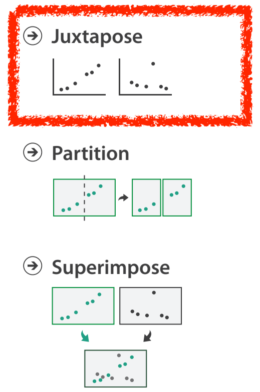


Multiple Views

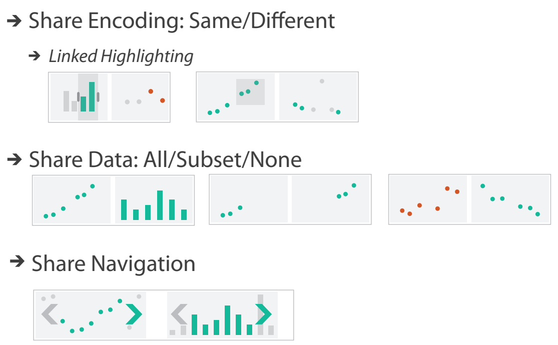
Facet



Facet

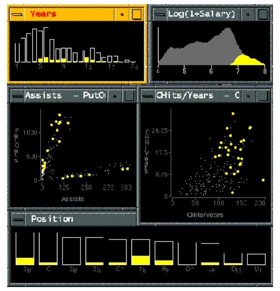


Juxtapose and coordinate views



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

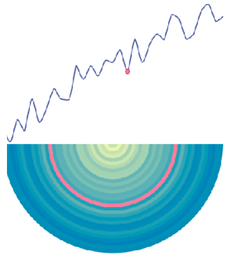
- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - *multiform*
- data: all shared
  - all **items** shared
  - different **attributes** across the views
- aka: brushing and linking



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

Linked views: Directionality

- unidirectional vs bidirectional linking
  - bidirectional almost always better!



http://pbeshai.github.io/linked-highlighting-react-vega-redux/
https://medium.com/@pbesh/linked-highlighting-with-react-d3-js-and-reflux-16e9c0b2210b

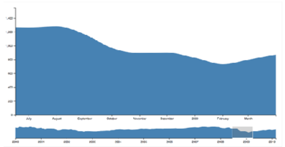
Idiom: **Overview-detail views** System: **Google Maps**

- 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**

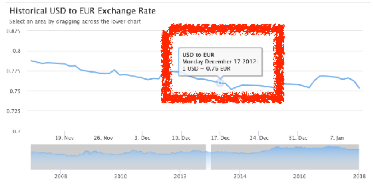
- encoding: same or different
- data: subset shared
- navigation: shared
  - unidirectional linking
  - select in small overview, change extent in large detail view



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

Idiom: **Tooltips**

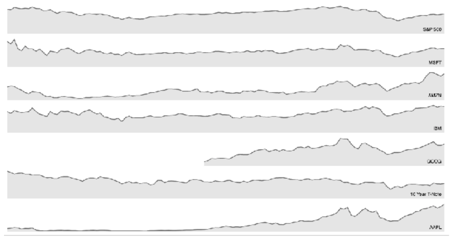
- popup information for selection
  - hover or click
  - specific case of detail view: provide useful additional detail on demand
  - beware: does not support overview!
    - always consider if there's a way to visually encode directly to provide overview
    - "If you make a rollover or tooltip, assume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



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

Idiom: **Small multiples**

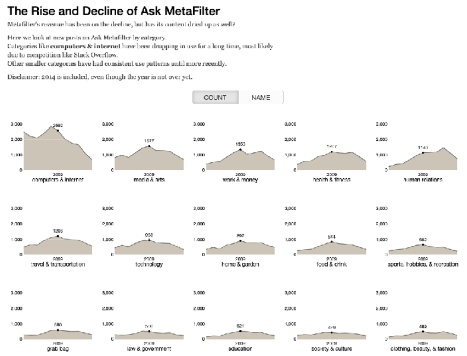
- encoding: same
  - ex: line charts
- data: none shared
  - different slices of dataset
    - items or attributes
    - ex: stock prices for different companies



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

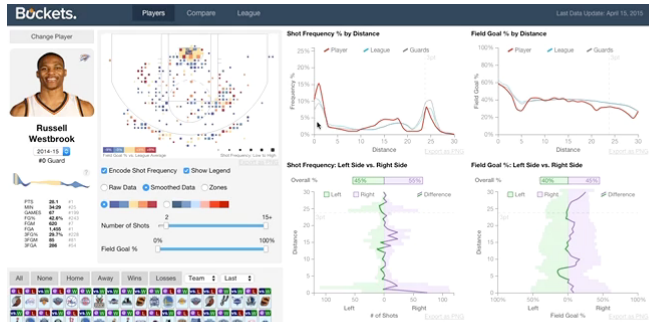
Interactive small multiples

- 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/]

Example: Combining many interaction idioms System: **Buckets**

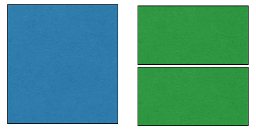


- multiform
- multidirectional linked highlighting of small multiples
- tooltips

http://buckets.peterbeshai.com/

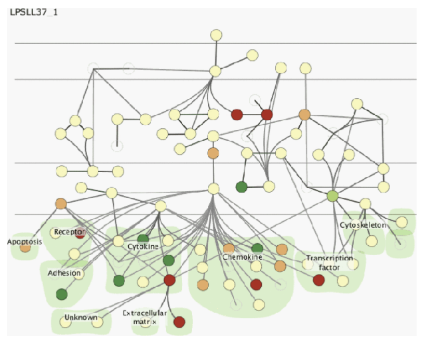
Juxtapose views: tradeoffs

- 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

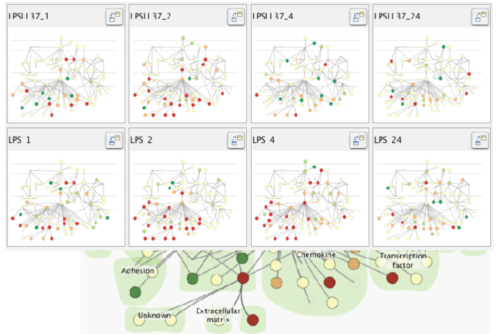
- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions



[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.]

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)



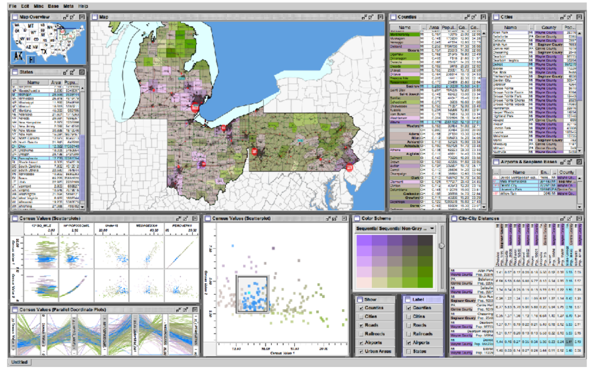
[Cerebral: Visualizing Multiple Experimental Conditions on a Graph with Biological Context. Barsky, Munzner, Gardy, and Kincaid. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14:6 (2008), 1253–1260.]

View coordination: Design choices

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

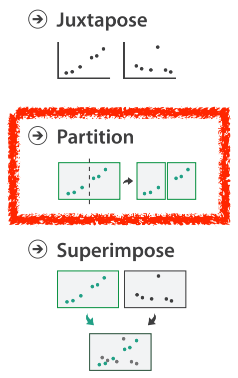
Idiom: **Reorderable lists** System: **Improvise**

- list views
  - easy lookup
  - useful when linked to other views
- how many views is ok vs too complex?
  - open research question



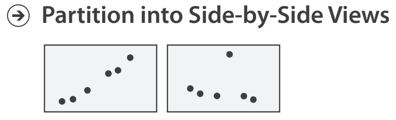
[Building Highly-Coordinated Visualizations In Improvise. Weaver. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 159–166, 2004.]

Facet



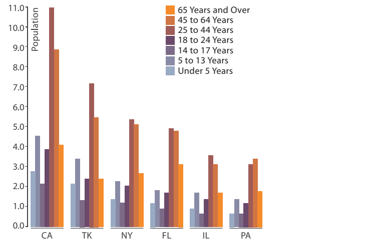
Partition into views

- 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



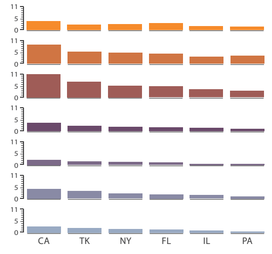
Partitioning: Grouped vs small-multiple bars

- 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



[https://observablehq.com/@d3/grouped-bar-chart]

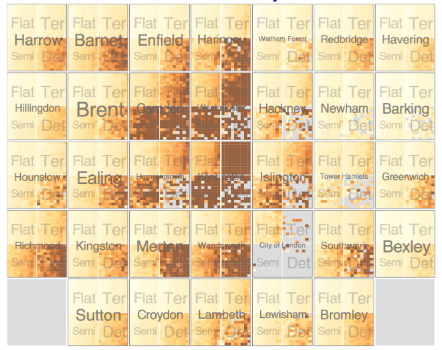
- small-multiple bar charts
  - split by age into regions
    - one chart per region
  - compare: easy within age, harder across states



[https://bl.ocks.org/mbostock/4679202]

Partitioning: Recursive subdivision System: **HIVE**

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



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

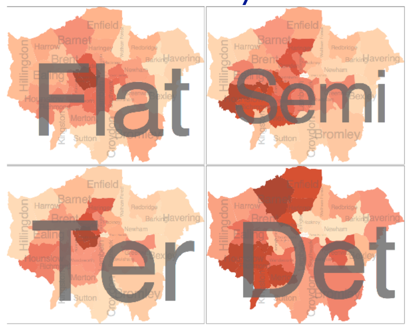
Partitioning: Recursive subdivision System: **HIVE**

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

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

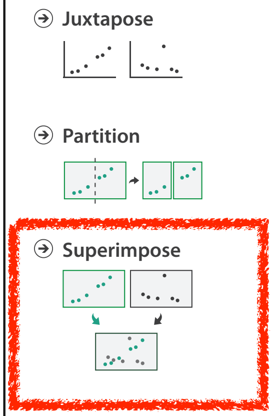
Partitioning: Recursive subdivision System: **HIVE**

- different encoding for second-level regions
  - choropleth maps



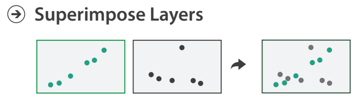
[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Facet



Superimpose layers

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



Static visual layering

- foreground layer: roads
  - hue, size distinguishing main from minor
  - high luminance contrast from background
- background layer: regions
  - desaturated colors for water, parks, land areas
- user can selectively focus attention

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

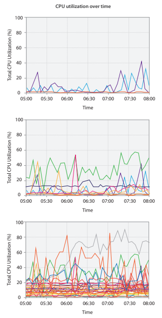
Idiom: **Trellis plots**

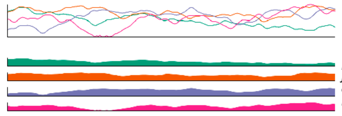
- superimpose within same frame
  - color code by year
- partitioning
  - split by site, rows are barley varieties
- main-effects ordering
  - derive value of median for group
  - order rows within view by variety median
  - order views themselves by site median

[The Visual Design and Control of Trellis Display. Becker, Cleveland, & Shyu. Journal of Computational and Graphical Statistics 5(2):123-155 1996.]

Superimposing limits (static)

- few layers, more lines
  - up to a few dozen lines
  - but not hundreds
- superimpose vs juxtapose: empirical study
  - same size: all multiples, vs single superimposed
    - superimposed: local tasks
    - juxtaposed: global tasks, esp. for many charts



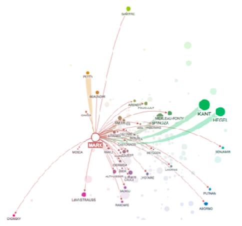


[Graphical Perception of Multiple Time Series. Javed, McDonnel, and Elmqvist. IEEE Transactions on Visualization and Computer Graphics (Proc. IEEE InfoVis 2010) 16:6 (2010), 927–934.]

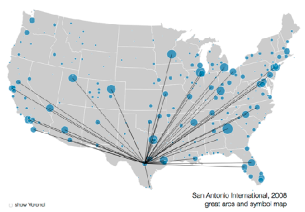
Dynamic visual layering

- interactive, based on selection
- one-hop neighbour highlighting

click (heavyweight)

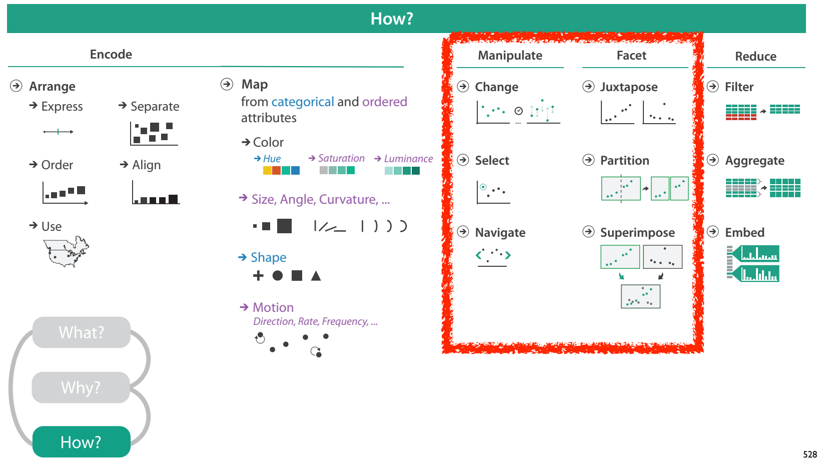


hover (fast)

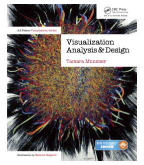


https://mariandoerk.de/edgemaps/demo/

http://mbostock.github.io/d3/talk/20111116/airports.html



Visualization Analysis & Design



Reduce: Aggregation & Filtering (Ch 13)

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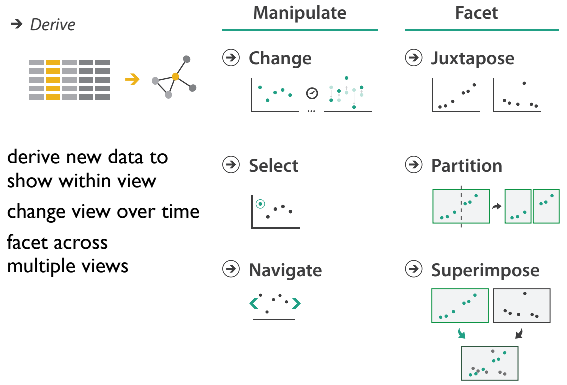
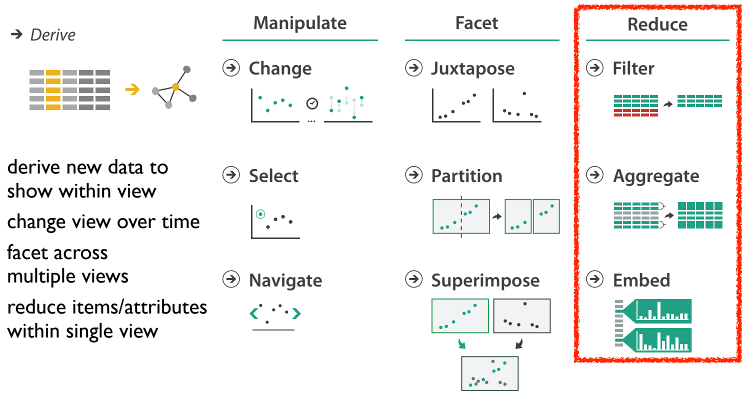
How to handle complexity: 3 previous strategies



- derive new data to show within view
- change view over time
- facet across multiple views

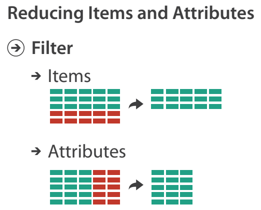
How to handle complexity: 3 previous strategies + 1 more



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

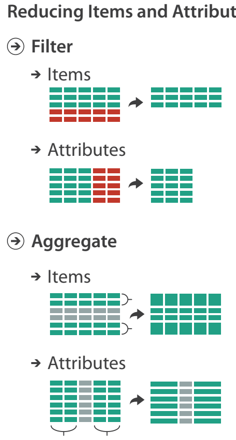
Reduce items and attributes

- reduce/increase: inverses
- filter
  - pro: straightforward and intuitive
    - to understand and compute
  - con: out of sight, out of mind



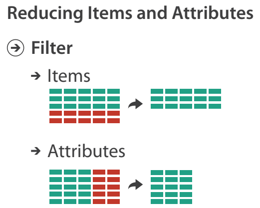
Reduce items and attributes

- 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



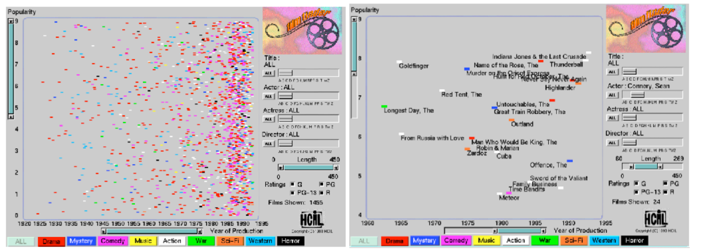
Filter

- eliminate some elements
  - either items or attributes
- according to what?
  - any possible function that partitions dataset into two sets
    - attribute values bigger/smaller than x
    - noise/signal
- filters vs queries
  - query: start with nothing, add in elements
  - filters: start with everything, remove elements
  - best approach depends on dataset size



Idiom: **FilmFinder**

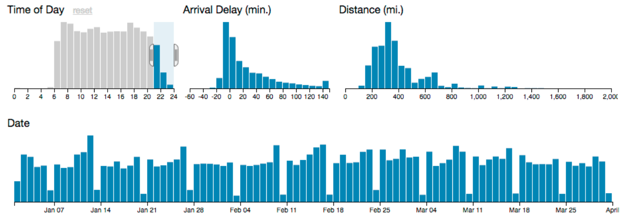
- dynamic queries/filters for items
  - tightly coupled interaction and visual encoding idioms, so user can immediately see results of action



[Ahlberg & Shneiderman, Visual Information Seeking: Tight Coupling of Dynamic Query Filters with Starfield Displays. CHI 1994.]

Idiom: **cross filtering** System: **Crossfilter**

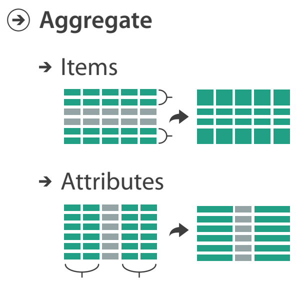
- item filtering
- coordinated views/controls combined
  - all scented histogram bisliders update when any ranges change



http://square.github.io/crossfilter/
https://observablehq.com/@uwdata/interaction

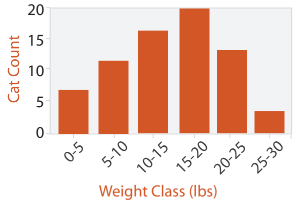
Aggregate

- a group of elements is represented by a smaller number of derived elements



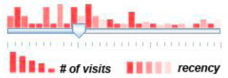
Idiom: **histogram**

- 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.]

Idiom: **scented widgets**

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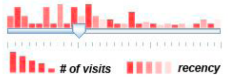
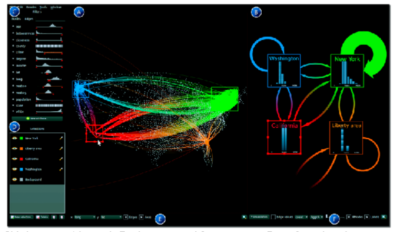
  - better cues for *information foraging*: show whether value in drilling down further vs looking elsewhere
- concise use of space: histogram on slider



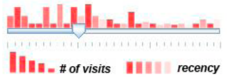
[Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Willett, Heer, and Agrawala. IEEE TVCG (Proc. InfoVis 2007) 13:6 (2007), 1129–1136.]



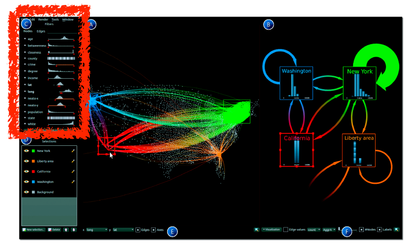
[Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. van den Elzen, van Wijk, IEEE TVCG 20(12): 2014 (Proc. InfoVis 2014).]

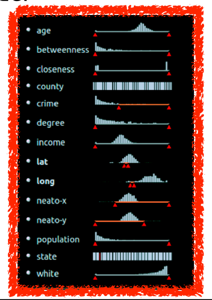
Idiom: **scented widgets**

- 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



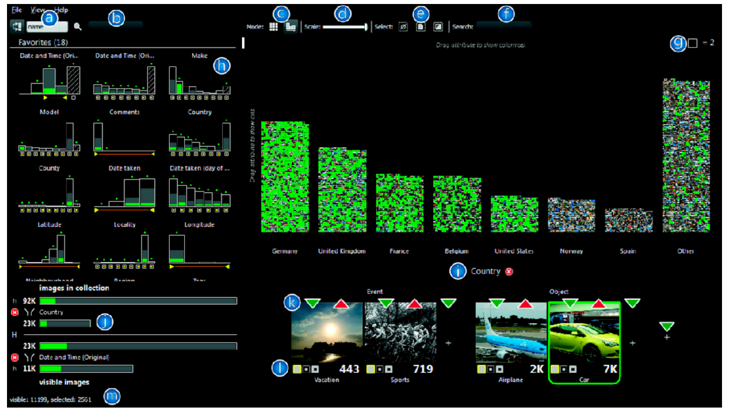
[Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Willett, Heer, and Agrawala. IEEE TVCG (Proc. InfoVis 2007) 13:6 (2007), 1129–1136.]





[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).]

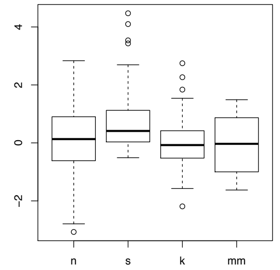
Scented histogram bisliders: detailed



[ICLIC: Interactive categorization of large image collections. van der Corput and van Wijk. Proc. PacificVis 2016.]

Idiom: **boxplot**

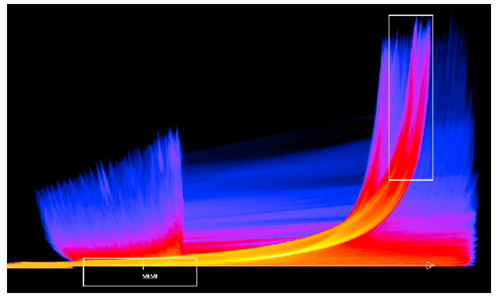
- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown
-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



[40 years of boxplots. Wickham and Stryjewski. 2012]

Idiom: **Continuous scatterplot**

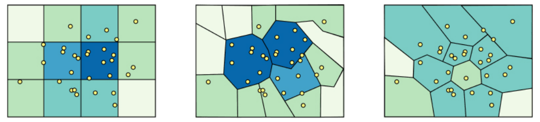
- static item aggregation
- data: table
- derived data: table
  - key attribs x,y for pixels
  - quant attrib: overplot density
- dense space-filling 2D matrix
- color: sequential categorical hue + ordered luminance colormap
- scalability
  - no limits on overplotting: millions of items



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

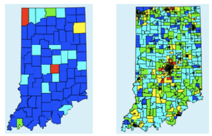
Spatial aggregation

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



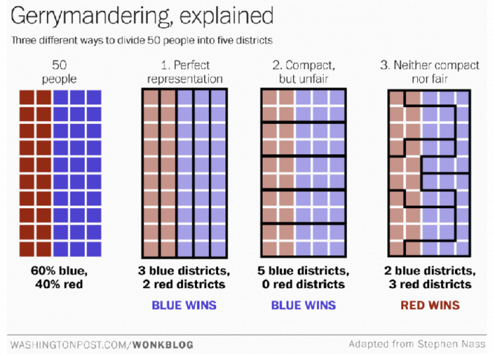
[http://www.e-education.psu/edu/geog486/l4_p7.html, Fig 4.cg.6]

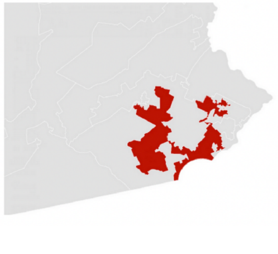
  - scale effects



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

Gerrymandering: MAUP for political gain





A real district in Pennsylvania: Democrats won 51% of the vote but only 5 out of 18 house seats

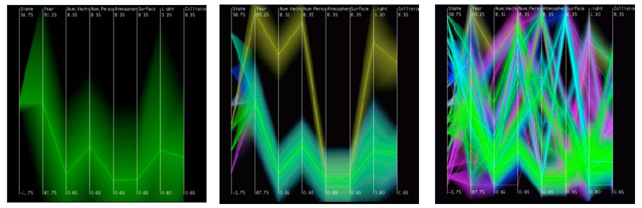
https://www.washingtonpost.com/news/wonk/wp/2015/03/01/this-is-the-best-explanation-of-gerrymandering-you-will-ever-see/

Dynamic aggregation: Clustering

- clustering: classification of items into similar bins
  - based on similiarity measure
  - hierarchical algorithms produce "similarity tree": cluster hierarchy
    - agglomerative clustering: start w/ each node as own cluster, then iteratively merge
- cluster hierarchy: derived data used w/ many dynamic aggregation idioms
  - cluster more homogeneous than whole dataset
    - statistical measures & distribution more meaningful

Idiom: **Hierarchical parallel coordinates**

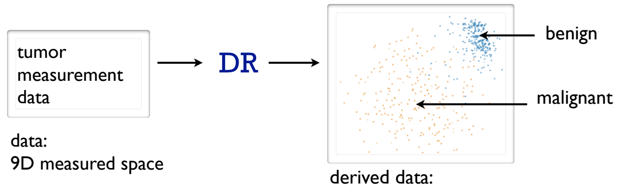
- dynamic item aggregation
- derived data: **cluster hierarchy**
- encoding:
  - cluster band with variable transparency, line at mean, width by min/max values
  - color by proximity in hierarchy



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

Attribute aggregation: Dimensionality reduction

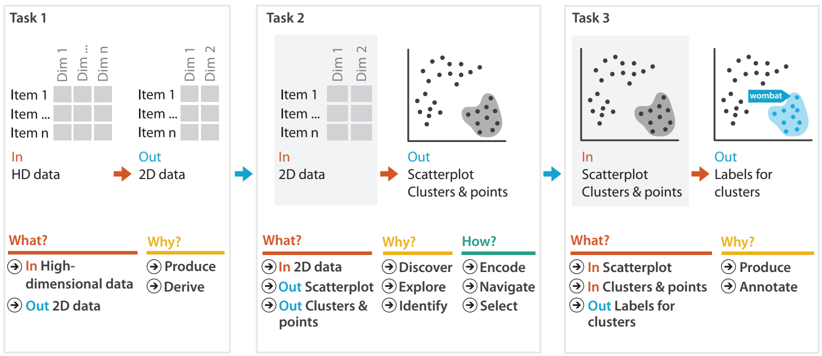
- attribute aggregation
  - derive low-dimensional target space from high-dimensional measured space
    - capture most of variance with minimal error
  - use when you can't directly measure what you care about
    - true dimensionality of dataset conjectured to be smaller than dimensionality of measurements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

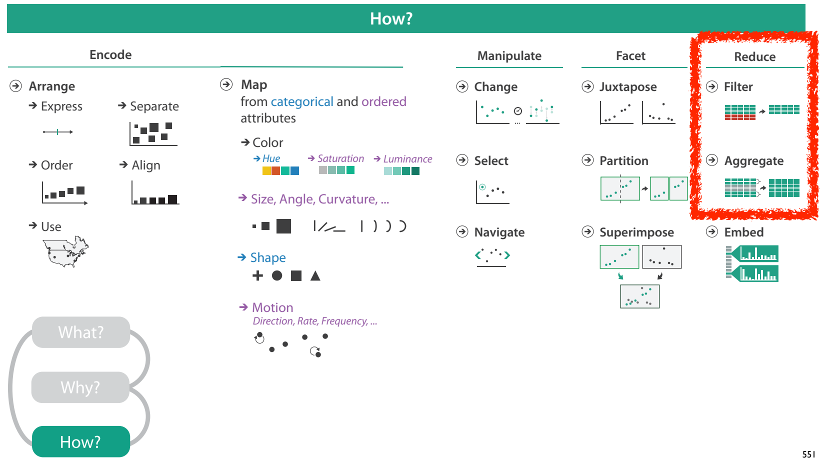


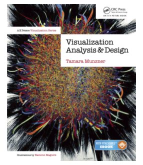
data:
9D measured space

derived data:
2D target space

Idiom: **Dimensionality reduction for documents**





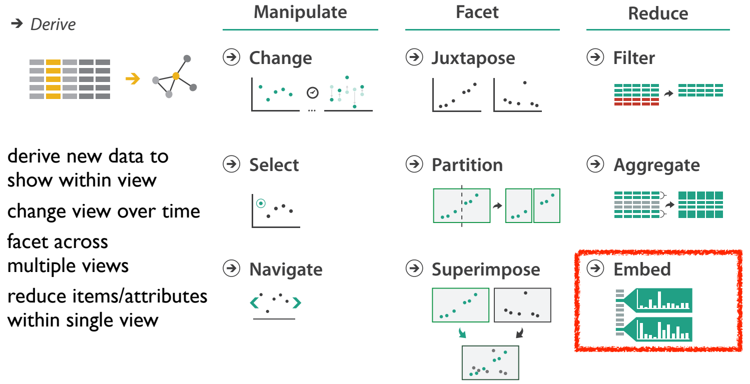


Visualization Analysis & Design

Embed: Focus+Context (Ch 14)

Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

How to handle complexity: 4 strategies



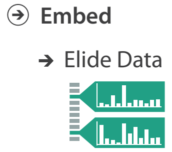
- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view

Embed: Focus+Context

- combine focus + context info within single view
  - vs standard navigation within view
  - vs multiple views

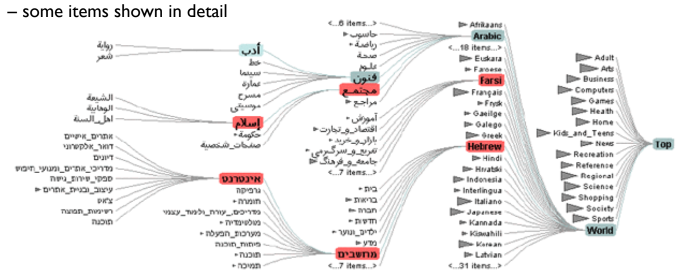
Embed: Focus+Context

- combine focus + context info within single view
  - vs standard navigation within view
  - vs multiple views
- elide data
  - selectively filter and aggregate



Idiom: **DOITrees Revisited**

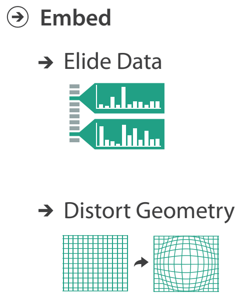
- focus+context choice: elide
  - some items dynamically filtered out
  - some items dynamically aggregated together
  - some items shown in detail



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

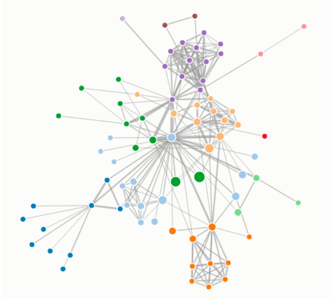
Embed: Focus+Context

- combine focus + context info within single view
  - vs standard navigation within view
  - vs multiple views
- elide data
  - selectively filter and aggregate
- distort geometry
  - carefully chosen to integrate F+C



Idiom: **Fisheye Lens**

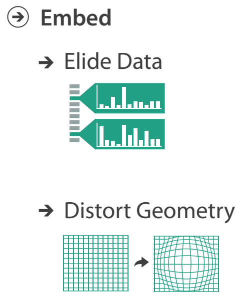
- F+C choice: distort geometry
  - shape: radial
  - focus: single extent
  - extent: local
  - metaphor: draggable lens



[D3 Fisheye Lens] https://bost.ocks.org/mike/fisheye/

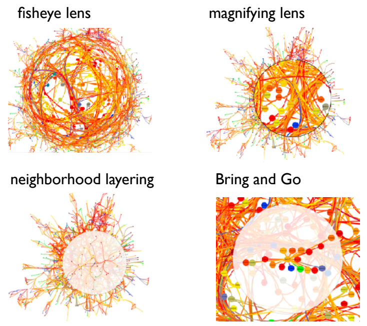
Embed: Focus+Context

- combine focus + context info within single view
  - vs standard navigation within view
  - vs multiple views
- elide data
  - selectively filter and aggregate
- distort geometry: design choices
  - region shape: radial, rectilinear, complex
  - how many regions: one, many
  - region extent: local, global
  - interaction metaphor

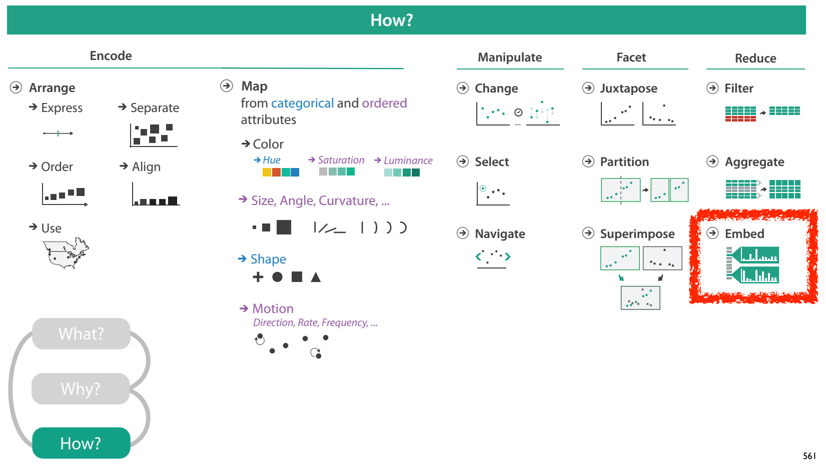


Distortion costs and benefits

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

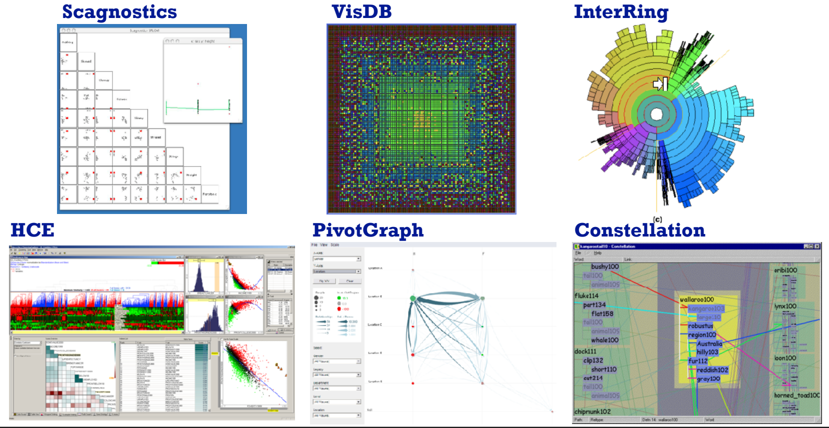


[Living Flows: Enhanced Exploration of Edge-Bundled Graphs Based on GPU-Intensive Edge Rendering. Lambert, Auber, and Melançon. Proc. Intl. Conf. Information Visualisation (IV), pp. 523–530, 2010.]



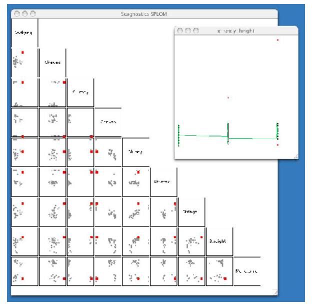
Ch 15: Analysis Case Studies

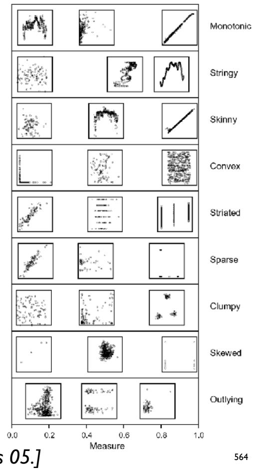
Analysis Case Studies



Graph-Theoretic Scagnostics

- scatterplot diagnostics
  - scagnostics SPLOM: each point is one original scatterplot





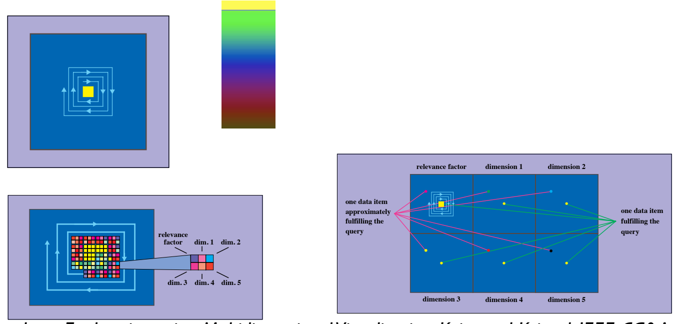
[Graph-Theoretic Scagnostics Wilkinson, Anand, and Grossman. Proc InfoVis 05.]

Scagnostics analysis

System	Scagnostics
What: Data	Table.
What: Derived	Nine quantitative attributes per scatterplot (pairwise combination of original attributes).
Why: Tasks	Identify, compare, and summarize; distributions and correlation.
How: Encode	Scatterplot, scatterplot matrix.
How: Manipulate	Select.
How: Facet	Juxtaposed small-multiple views coordinated with linked highlighting, popup detail view.
Scale	Original attributes: dozens.

VisDB

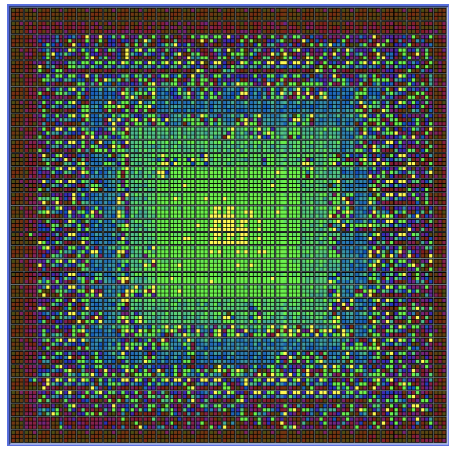
- table: draw pixels sorted, colored by relevance
- group by attribute or partition by attribute into multiple views



[VisDB: Database Exploration using Multidimensional Visualization, Keim and Kriegel, IEEE CG&A, 1994]

VisDB Results

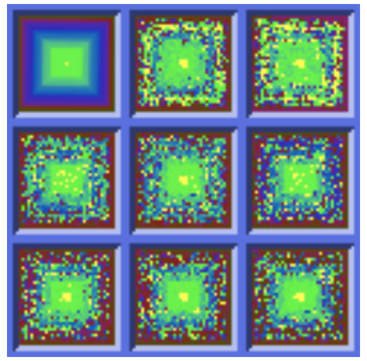
- partition into many small regions: dimensions grouped together



[VisDB: Database Exploration using Multidimensional Visualization, Keim and Kriegel, IEEE CG&A, 1994]

VisDB Results

- partition into small number of views
  - inspect each attribute



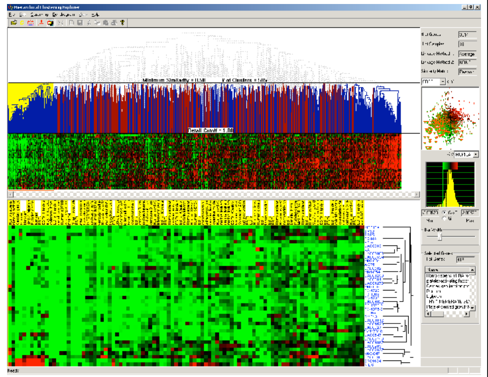
[VisDB: Database Exploration using Multidimensional Visualization, Keim and Kriegel, IEEE CG&A, 1994]

VisDB Analysis

System	VisDB
What: Data	Table (database) with k attributes; query returning table subset (database query).
What: Derived	$k + 1$ quantitative attributes per original item: query relevance for the k original attributes plus overall relevance.
Why: Tasks	Characterize distribution within attribute, find groups of similar values within attribute, find outliers within attribute, find correlation between attributes, find similar items.
How: Encode	Dense, space-filling; area marks in spiral layout; colormap: categorical hues and ordered luminance.
How: Facet	Layout 1: partition by attribute into per-attribute views, small multiples. Layout 2: partition by items into per-item glyphs.
How: Reduce	Filtering
Scale	Attributes: one dozen. Total items: several million. Visible items (using multiple views, in total): one million. Visible items (using glyphs): 100,000

Hierarchical Clustering Explorer

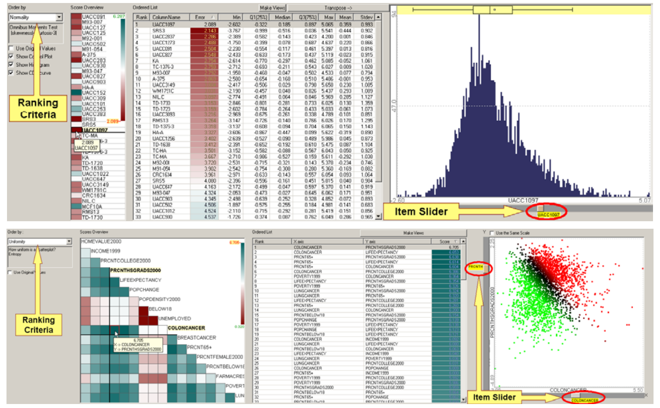
- heatmap, dendrogram
- multiple views



[Interactively Exploring Hierarchical Clustering Results. Seo and Shneiderman, IEEE Computer 35(7): 80-86 (2002)]

HCE

- rank by feature idiom
  - 1D list
  - 2D matrix



A rank-by-feature framework for interactive exploration of multidimensional data. Seo and Shneiderman. Information Visualization 4(2): 96-113 (2005)

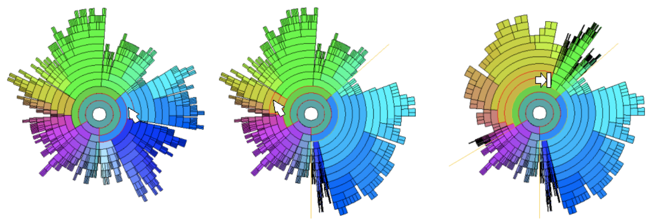
HCE

A rank-by-feature framework for interactive exploration of multidimensional data. Seo and Shneiderman. Information Visualization 4(2): 96-113 (2005)

HCE Analysis

System	Hierarchical Clustering Explorer (HCE)
What: Data	Multidimensional table: two categorical key attributes (genes, conditions); one quantitative value attribute (gene activity level in condition).
What: Derived	Hierarchical clustering of table rows and columns (for cluster heatmap); quantitative derived attributes for each attribute and pairwise attribute combination; quantitative derived attribute for each ranking criterion and original attribute combination.
Why: Tasks	Find correlation between attributes; find clusters, gaps, outliers, trends within items.
How: Encode	Cluster heatmap, scatterplots, histograms, boxplots. Rank-by-feature overviews: continuous diverging colormaps on area marks in reorderable 2D matrix or 1D list alignment.
How: Reduce	Dynamic filtering; dynamic aggregation.
How: Manipulate	Navigate with pan/scroll.
How: Facet	Multiform with linked highlighting and shared spatial position; overview–detail with selection in overview populating detail view.
Scale	Genes (key attribute): 20,000. Conditions (key attribute): 80. Gene activity in condition (quantitative value attribute): $20,000 \times 80 = 1,600,000$.

InterRing



original hierarchy

blue subtree expanded

tan subtree expanded

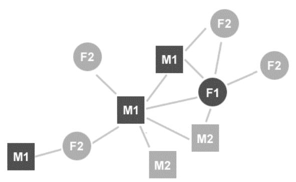
[InterRing: An Interactive Tool for Visually Navigating and Manipulating Hierarchical Structures. Yang, Ward, Rundensteiner. Proc. InfoVis 2002, p 77-84.]

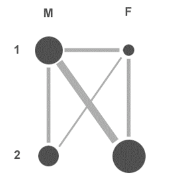
InterRing Analysis

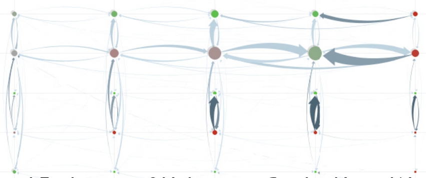
System	InterRing
What: Data	Tree.
Why: Tasks	Selection, rollup/drilldown, hierarchy editing.
How: Encode	Radial, space-filling layout. Color by tree structure.
How: Facet	Linked coloring and highlighting.
How: Reduce	Embed: distort; multiple foci.
Scale	Nodes: hundreds if labeled, thousands if dense. Levels in tree: dozens.

PivotGraph

- derived rollup network

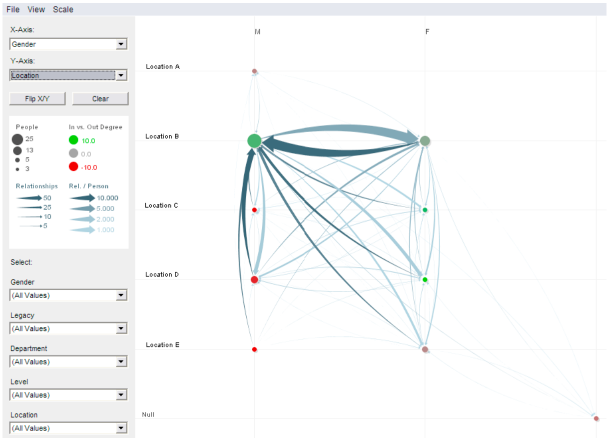






[Visual Exploration of Multivariate Graphs, Martin Wattenberg, CHI 2006.]

PivotGraph



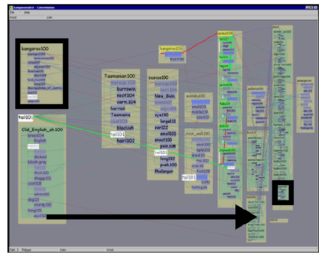
[Visual Exploration of Multivariate Graphs, Martin Wattenberg, CHI 2006.]

PivotGraph Analysis

Idiom	PivotGraph
What: Data	Network.
What: Derived	Derived network of aggregate nodes and links by roll-up into two chosen attributes.
Why: Tasks	Cross-attribute comparison of node groups.
How: Encode	Nodes linked with connection marks, size.
How: Manipulate	Change: animated transitions.
How: Reduce	Aggregation, filtering.
Scale	Nodes/links in original network: unlimited. Roll-up attributes: 2. Levels per roll-up attribute: several, up to one dozen.

Analysis example: Constellation

- data
  - multi-level network
    - node: word
    - link: words used in same dictionary definition
    - subgraph for each definition
      - not just hierarchical clustering
  - paths through network
    - query for high-weight paths between 2 nodes
      - quant attrib: plausibility

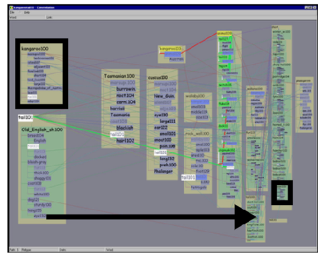


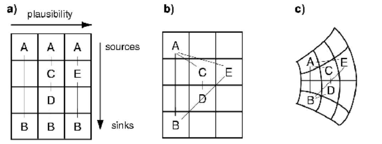
[Interactive Visualization of Large Graphs and Networks. Munzner. Ph.D. Dissertation, Stanford University, June 2000.]

[Constellation: A Visualization Tool For Linguistic Queries from MindNet. Munzner, Guimbretière and Robertson. Proc. IEEE Symp. InfoVis 1999, p.132-135.]

Using space: Constellation

- visual encoding
  - link connection marks between words
  - link containment marks to indicate subgraphs
  - encode plausibility with horiz spatial position
  - encode source/sink for query with vert spatial position
- spatial layout
  - curvilinear grid: more room for longer low-plausibility paths

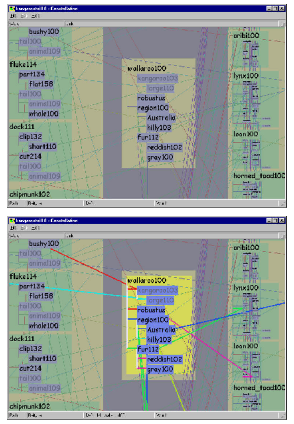




[Interactive Visualization of Large Graphs and Networks. Munzner. Ph.D. Dissertation, Stanford University, June 2000.]

Using space: Constellation

- edge crossings
  - cannot easily minimize instances, since position constrained by spatial encoding
  - instead: minimize perceptual impact
- views: superimposed layers
  - dynamic foreground/background layers on mouseover, using color
  - four kinds of constellations
    - definition, path, link type, word
      - not just 1-hop neighbors



https://youtu.be/7sJC3QVpSkQ

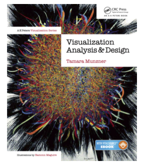
[Interactive Visualization of Large Graphs and Networks. Munzner. Ph.D. Dissertation, Stanford University, June 2000.]

Constellation Analysis

System	Constellation
What: Data	Three-level network of paths, subgraphs (definitions), and nodes (word senses).
Why: Tasks	Discover/verify: browse and locate types of paths, identify and compare.
How: Encode	Containment and connection link marks, horizontal spatial position for plausibility attribute, vertical spatial position for order within path, color links by type.
How: Manipulate	Navigate: semantic zooming. Change: Animated transitions.
How: Reduce	Superimpose dynamic layers.
Scale	Paths: 10–50. Subgraphs: 1–30 per path. Nodes: several thousand.

Visualization Analysis & Design

Wrapup



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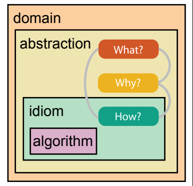

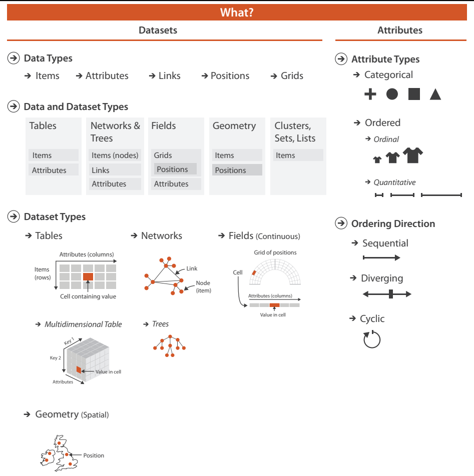

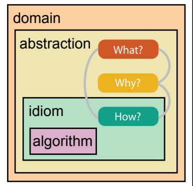

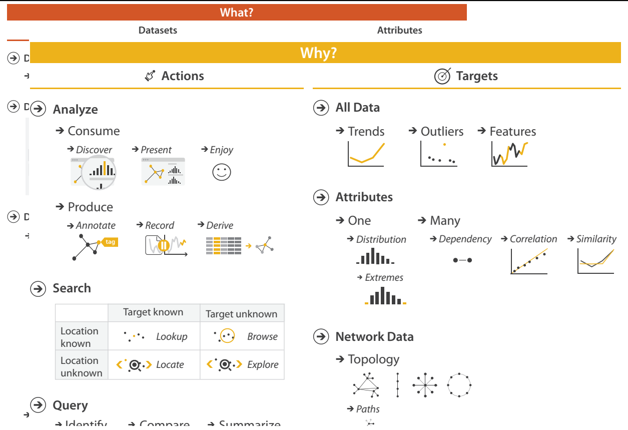

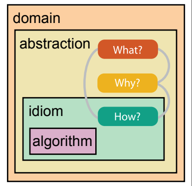

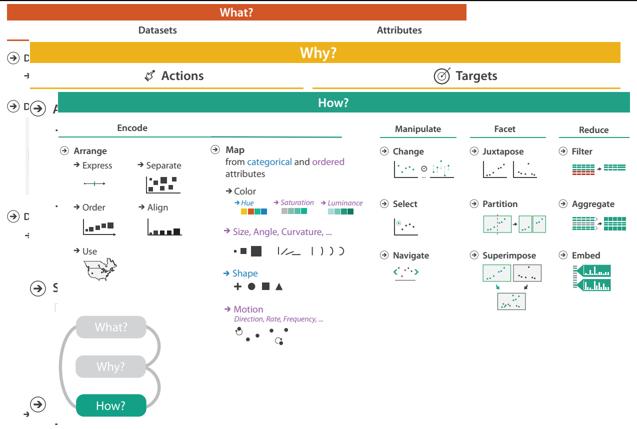

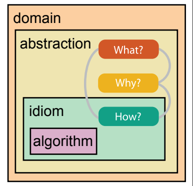

More information

- book
  http://www.cs.ubc.ca/~tmm/vadbook
  - 20% promo code for book+ebook combo: HVN17
  - http://www.crcpress.com/product/isbn/9781466508910
  - illustration acknowledgement: Eamonn Maguire
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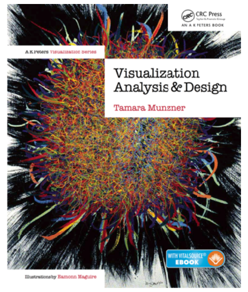


Visualization Analysis and Design. Munzner. CRC Press, AK Peters Visualization Series, 2014.

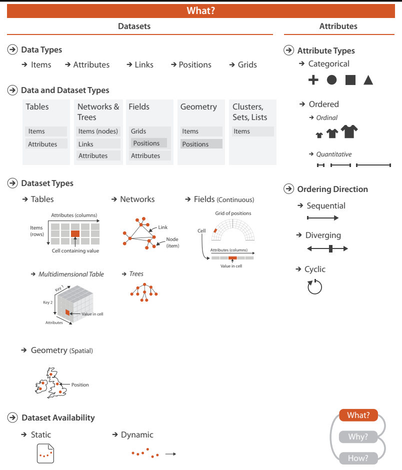
@tamaramunzner

Credits

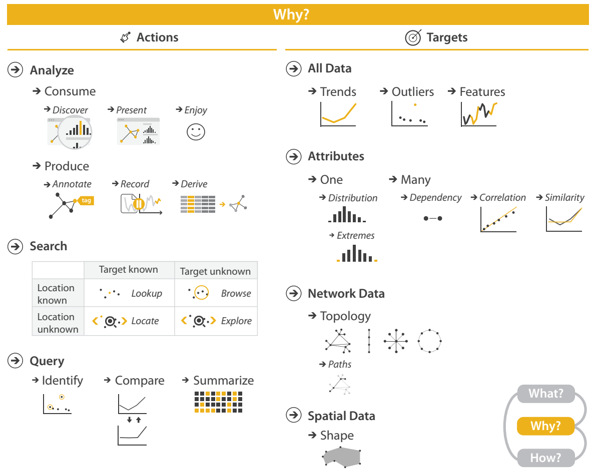
- Drawing on lectures from many others including
  - Alex Lex & Miriah Meyer, Utah, http://dataviscourse.net/
  - Maureen Stone, StoneSoup/Tableau, Color in Information Display (VIS 2006)
  - Ben Jones, UW/Tableau
  - Hanspeter Pfister, Harvard, http://cs171.org/
  - Jeff Heer, Washington
  - Enrico Bertini, NYU Tandon
  - Marti Hearst, UC Berkeley
  - Pat Hanrahan, Stanford

Big Picture & Other Synthesis

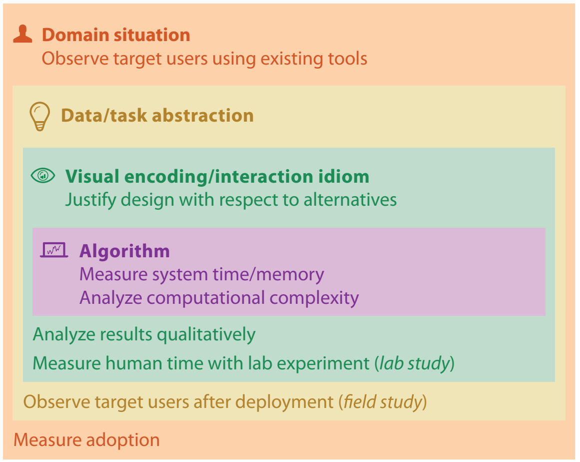
Ch 2



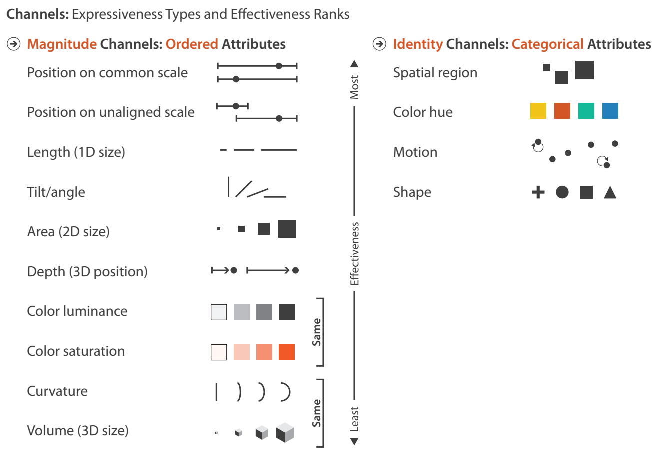
Ch 3



Ch 4



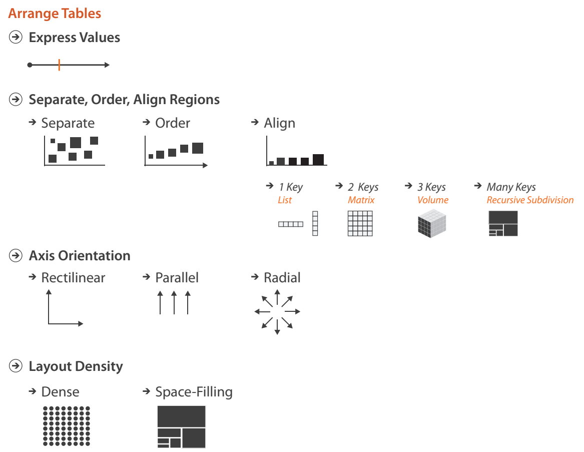
Ch 5



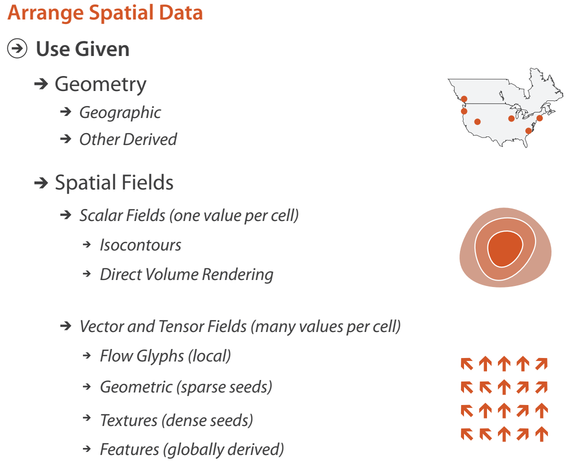
Ch 6

- No unjustified 3D
  - Power of the plane
  - Disparity of depth
  - Occlusion hides information
  - Perspective distortion dangers
  - Tilted text isn't legible
- No unjustified 2D
- Eyes beat memory
- Resolution over immersion
- Overview first, zoom and filter, details on demand
- Responsiveness is required
- Function first, form next

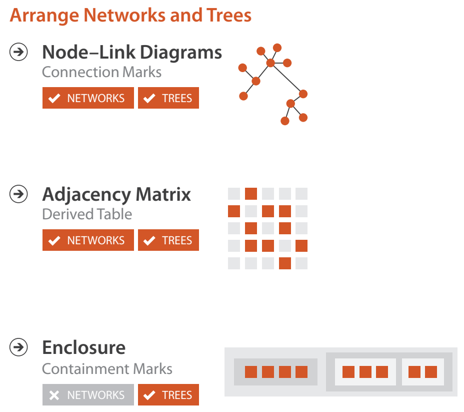
Ch 7



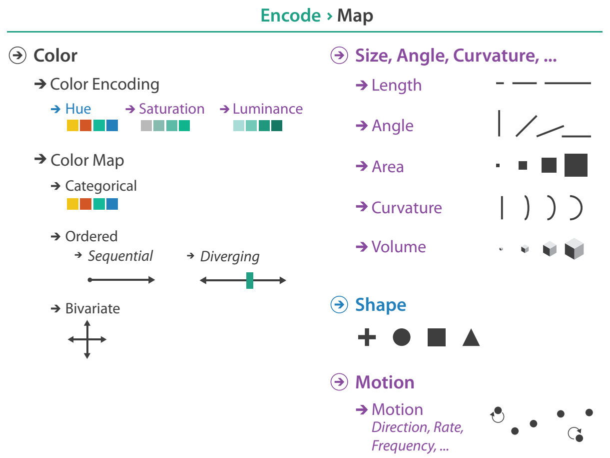
Ch 8



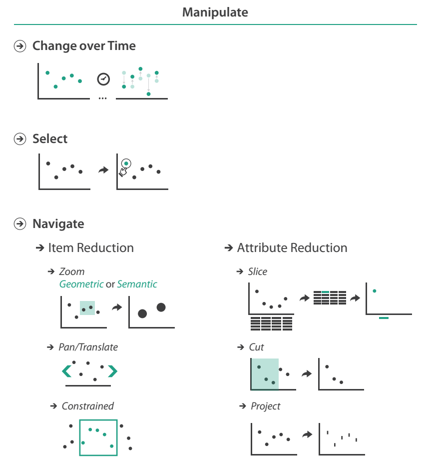
Ch 9



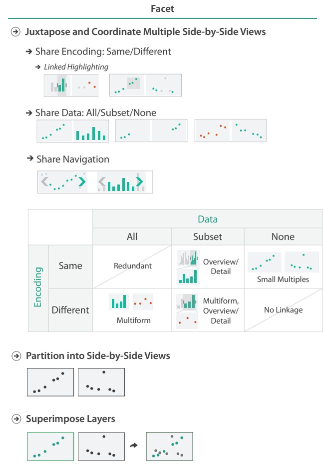
Ch 10



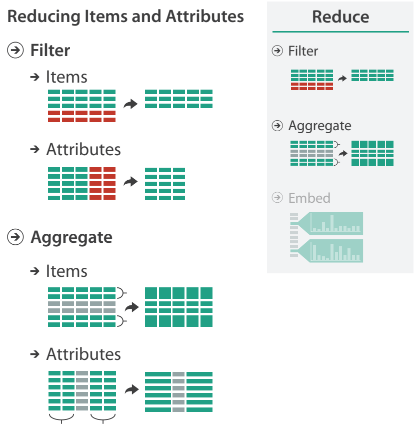
Ch 11



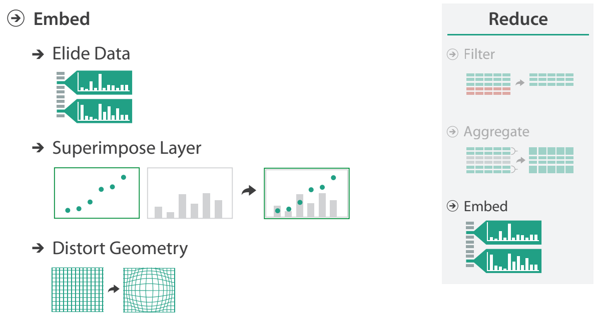
Ch 12



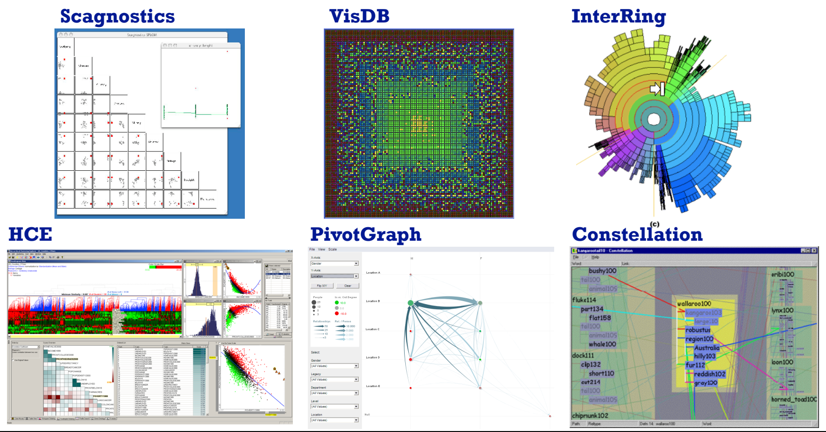
Ch 13



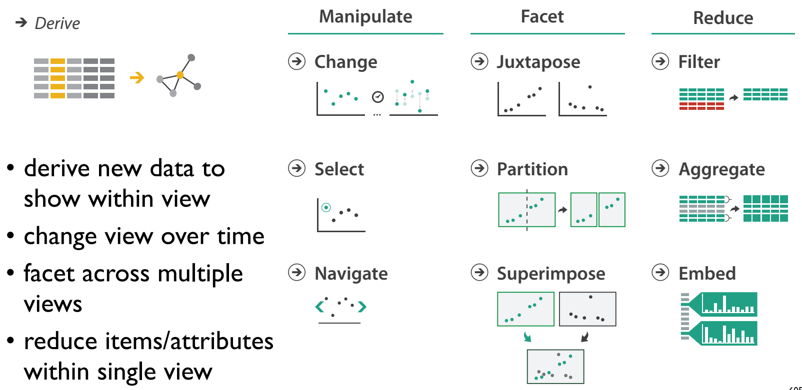
Ch 14



Ch 15



How to handle complexity: 4 families of strategies



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

Further Reading

Further reading: Ch 1

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - Chap 1: What's Vis, and Why Do It?
- The Nature of External Representations in Problem Solving. Jiajie Zhang. Cognitive Science 21:2 (1997), 179-217.
- A Representational Analysis of Numeration Systems. Jiajie Zhang and Donald A. Norman. Cognition 57 (1995), 271-295.
- Why a Diagram Is (Sometimes) Worth Ten Thousand Words.. Jill H. Larkin and Herbert A. Simon. Cognitive Science 11:1 (1987), 65-99.
- Graphs in Statistical Analysis. F.J. Anscombe. American Statistician 27 (1973), 17-21.
- Design Study Methodology: Reflections from the Trenches and the Stacks. Michael Sedlmair, Miriah Meyer, and Tamara Munzner. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2012), 18(12):2431-2440, 2012.
- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013.
- Current approaches to change blindness Daniel J. Simons. Visual Cognition 7, 1/2/3 (2000), 1-15.
- Semiology of Graphics, Jacques Bertin, Gauthier-Villars 1967, EHESS 1998
- The Visual Display of Quantitative Information. Edward R. Tufte. Graphics Press, 1983.

Further reading: Ch 2/3 selected

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

Further reading, Ch 2 full

- Readings in Information Visualization: Using Vision To Think, Chapter 1. Stuart K. Card, Jock Mackinlay, and Ben Shneiderman. Morgan Kaufmann, 1999.
- Rethinking Visualization: A High-Level Taxonomy. InfoVis 2004, p 151-158, 2004.
- The Eyes Have It: A Task by Data Type Taxonomy for Information Visualizations Ben Shneiderman, Proc. 1996 IEEE Visual Languages
- Data Visualization: Principles and Practice, 2nd ed. Alexandru Telea, CRC Press, 2014.
- Interactive Data Visualization: Foundations, Techniques, and Applications, 2nd ed. Matthew O. Ward, Georges Grinstein, Daniel Keim. CRC Press, 2015.
- The Visualization Handbook. Charles Hansen and Chris Johnson, eds. Academic Press, 2004.
- Visualization Toolkit: An Object-Oriented Approach to 3D Graphics, 4th ed. Will Schroeder, Ken Martin, and Bill Lorensen. Kitware 2006.
- The Structure of the Information Visualization Design Space. Stuart Card and Jock Mackinlay, Proc. InfoVis 97.
- Polaris: A System for Query, Analysis and Visualization of Multi-dimensional Relational Databases (extended paper) Chris Stolte, Diane Tang and Pat Hanrahan. IEEE TVCG 8(1):52-65 2002.
- Visualization of Time-Oriented Data. Wolfgang Aigner, Silvia Miksch, Heidrun Schumann, Chris Tominski. Springer 2011.

Further reading, Ch 3 full

- A Multi-Level Typology of Abstract Visualization Tasks.. Matthew Brehmer and Tamara Munzner. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 13) 19:12 (2013), 2376-2385.
- A characterization of the scientific data analysis process. Rebecca R. Springmeyer, Meera M. Blattner, and Nelson M. Max. Proc. Vis 1992, p 235-252.
- Low-Level Components of Analytic Activity in Information Visualization. Robert Amar, James Eagan, and John Stasko. Proc. InfoVis 05, pp. 111-117.
- Task taxonomy for graph visualization. Bongshin Lee, Catherine Plaisant, Cynthia Sims Parr, Jean-Daniel Fekete, and Nathalie Henry. Proc. BELIV 2006.
- Interactive Dynamics for Visual Analysis. Jeffrey Heer and Ben Shneiderman. Communications of the ACM, 55(4), pp. 45-54, 2012.
- What does the user want to see?: what do the data want to be? A. Johannes Pretorius and Jarke J. van Wijk. Information Visualization 8(3):153-166, 2009.
- Chapter 1, Readings in Information Visualization: Using Vision to Think. Stuart Card, Jock Mackinlay, and Ben Shneiderman, Morgan Kaufmann 1999.
- An Operator Interaction Framework for Visualization Systems. Ed H. Chi and John T. Riedl. Proc. InfoVis 1998, p 63-70.
- Nominal, Ordinal, Interval, and Ratio Typologies are Misleading. Paul F. Velleman and Leland Wilkinson. The American Statistician 47(1):65-72, 1993.
- Rethinking Visualization: A High-Level Taxonomy. Melanie Tory and Torsten Möller, Proc. InfoVis 2004, pp. 151-158.
- SpaceTree: Supporting Exploration in Large Node Link Tree, Design Evolution and Empirical Evaluation. Catherine Plaisant, Jesse Grosjean, and Ben B. Bederson. Proc. InfoVis 2002.
- TreeJuxtaposer: Scalable Tree Comparison using Focus+Context with Guaranteed Visibility Tamara Munzner, Francois Guimbretiere, Serdar Tasiran, Li Zhang, and Yunhong Zhou. SIGGRAPH 2003.
- Feature detection in linked derived spaces. Chris Henze. Proc. Visualization (Vis) 1998, p 87-94.
- Using Strahler numbers for real time visual exploration of huge graphs. David Auber. Intl Conf. Computer Vision and Graphics, 2002, p 56-69.

Further reading: Ch 4

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 4: Analysis: Four Levels for Validation*
- Storks Deliver Babies (p= 0.008). Robert Matthews. Teaching Statistics 22(2):36-38, 2000.
- The Earth is spherical ($p < 0.05$): alternative methods of statistical inference. Kim J. Vicente and Gerard L. Torenvliet. Theoretical Issues in Ergonomics Science, 1(3):248-271, 2000.
- The Prospects for Psychological Science in Human-Computer Interaction. Allen Newell and Stuart K. Card. Journal Human-Computer Interaction 1(3):209-242, 1985.
- How to do good research, get it published in SIGKDD and get it cited!, Eamonn Keogh, SIGKDD Tutorial 2009.
- False-Positive Psychology: Undisclosed Flexibility in Data Collection and Analysis Allows Presenting Anything as Significant. Joseph P. Simmons, Leif D. Nelson and Uri Simonsohn. Psychological Science 22(11):1359-1366, 2011.
- Externalisation - how writing changes thinking.. Alan Dix. Interfaces, Autumn 2008.

Guerilla/Discount Usability

- grab a few people and watch them use your interface
  - even 3-5 gives substantial coverage of major usability problems
  - agile/lean qualitative, vs formal quantitative user studies
    - goal is not statistical significance!
- think-aloud protocol
  - contextual inquiry (conversations back and forth) vs fly on the wall (you're silent)

Further reading, usability

- 7 Step Guide to Guerrilla Usability Testing, Markus Piper
  - https://userbrain.net/blog/7-step-guide-guerrilla-usability-testing-diy-usability-testing-method
- The Art of Guerrilla Usability Testing, David Peter Simon
  - http://www.uxbooth.com/articles/the-art-of-guerrilla-usability-testing/
- Discount Usability: 20 Years, Jakob Nielsen
  - https://www.nngroup.com/articles/discount-usability-20-years/
- Interaction Design: Beyond Human-Computer Interaction
  - Preece, Sharp, Rogers. Wiley, 4th edition, 2015.
- About Face: The Essentials of Interaction Design
  - Cooper, Reimann, Cronin, Noessel. Wiley, 4th edition, 2014.
- Task-Centered User Interface Design. Lewis & Rieman, 1994
  - http://hcibib.org/tcuid/
- Designing with the Mind in Mind. Jeff Johnson. Morgan Kaufmann, 2nd, 2014.

Further Reading: Ch 5

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series. CRC Press. 2014
  - Chap 5: Marks and Channels
- Semiology of Graphics, Jacques Bertin, Gauthier-Villars 1967, EHESS 1998.
- Graphical Perception: Theory, Experimentation and the Application to the Development of Graphical Models. William S. Cleveland, Robert McGill, J. Am. Stat. Assoc. 79:387, pp. 531-554, 1984.
- A Model for Studying Display Methods of Statistical Graphics (with Discussion). William S. Cleveland. Journal of Computational and Statistical Graphics 2(4):323-364 1993.
- Automating the Design of Graphical Presentations of Relational Information. Jock Mackinlay, ACM Transaction on Graphics, vol. 5, no. 2, April 1986, pp. 110-141.
- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013.
- How Maps Work: Representation, Visualization, and Design. Alan M. MacEachren. Guilford Press, 1995.
- Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Jeffrey Heer and Michael Bostock. Proc. CHI 2010.
- Taxonomy-Based Glyph Design---With a Case Study on Visualizing Workflows of Biological Experiments. Eamonn Maguire, Philippe Rocca-Serra, Susanna-Assunta Sansone, Jim Davies, and Min Chen. IEEE TVCG (Proc. InfoVis 12) 18(12):2603-2612 2012.
- Glyph-Based Visualization: Foundations, Design Guidelines, Techniques and Applications. Rita Borgo, Johannes Kehrer, David H.S. Chung, Eamonn Maguire, Robert S. Laramee, Helwig Hauser, Matthew Ward, and Min Chen. Eurographics State of the Art Reports (STAR):39-63 2013.
- On the Theory of Scales of Measurement. S. S. Stevens. Science 103(2684):677-680, 1946.
- Psychophysics: Introduction to Its Perceptual, Neural, and Social Prospects, S. S. Stevens, Wiley 1975.
- Visual Thinking for Design, Colin Ware, Morgan Kaufmann 2008.
- Perception in Vision web page with demos, Christopher Healey. (see also Attention and Visual Memory in Visualization and Computer Graphics, Christopher G. Healey and James T. Enns, IEEE TVCG 18(7):1170-1188 2012.)
- Feature Analysis in Early Vision: Evidence from Search Asymmetries. Treisman and Gormican. Psychological Review 95(1):15-48, 1988.

Further reading: Ch 6 selected

- Visualization Analysis and Design. Tamara Munzner. CRC Press, 2014.
  - *Chap 6: Rules of Thumb*
- Designing with the Mind in Mind: Simple Guide to Understanding User Interface Design Rules. Jeff Johnson. Morgan Kaufmann, 2010.
  - *Chap 12: We Have Time Requirements*
- The Non-Designer's Design Book. 3rd edition. Robin Williams. Peachpit Press, 2008.

Further reading, Ch 6 full

- Visual Thinking for Design, Colin Ware, Morgan Kaufmann 2008.
- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013.
- The Use of 2-D and 3-D Displays for Shape Understanding versus Relative Position Tasks. Mark St. John, Michael B. Cowen, Harvey S. Smallman, and Heather M. Oonk. Human Factors 43:1 (2001), 79-98.
- An Evaluation of Cone Trees. Andy Cockburn and Bruce McKenzie. In People and Computers XIV: Usability or Else. British Computer Society Conference on Human Computer Interaction, pp. 425-436. Springer, 2000.
- 3D or Not 3D? Evaluating the Effect of the Third Dimension in a Document Management System. Andy Cockburn and Bruce McKenzie. Proc. CHI 2003, p 434-441.
- Evaluating Spatial Memory in Two and Three Dimensions. Andy Cockburn and Bruce McKenzie. International Journal of Human-Computer Studies. 61(30):359-373.
- Supporting and Exploiting Spatial Memory in User Interfaces. Joey Scarr, Andy Cockburn, and Carl Gutwin. Foundations and Trends in Human-Computer Interaction. 2013. 6:1 1-84.
- Principles of Traditional Animation Applied to Computer Animation John Lasseter, Proceedings of SIGGRAPH 87, Computer Graphics, 21(4), pp. 35-44, July 1987.
- Animation: Can It Facilitate? Barbara Tversky, Julie Morrison, Mireille Betrancourt. International Journal of Human Computer Studies 57:4, pp 247-262, 2002.
- Structuring information interfaces for procedural learning. Jeffrey M. Zacks and Barbara Tversky. Journal of Experimental Psychology: Applied, Vol 9(2), Jun 2003, 88-100.
- Effectiveness of Animation in Trend Visualization. George Robertson and Roland Fernandez and Danyel Fisher and Bongshin Lee and John Stasko. IEEE Trans. on Visualization and Computer Graphics 14(6):1325-1332, 2008 (Proc. InfoVis08).
- Current Approaches to Change Blindness. Daniel J. Simons. Visual Cognition 7:1/2/3 (2000), 1-15.
- The eyes have it: A task by data type taxonomy for information visualizations. Ben Shneiderman. Proc. Conf. Visual Languages 1996, p 336-343.
- The Notion of Overview in Information Visualization. Kaspar Hornbaek and Morten Hertzum. International Journal of Human-Computer Studies 69:7-8 (2011), 509-525.
- The Information Visualizer, an Information Workspace. Stuart Card, George Robertson, and Jock Mackinlay. Proc. CHI 1991, p 181-186.
- Designing with the Mind in Mind: Simple Guide to Understanding User Interface Design Rules. Jeff Johnson. Morgan Kaufmann, 2010.
- A Framework of Interaction Costs in Information Visualization. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 08) 14:6 (2008), 1149-1156.
- Toward a Deeper Understanding of the Role of Interaction in Information Visualization. Ji Soo Yi, Youn Ah Kang, John T. Stasko, and Julie A. Jacko. TVCG (Proc. InfoVis 07) 13:6 (2007), 1224-1231.
- Get It Right in Black and White. Maureen Stone. Functional Color, 2010.
- The Non-Designer's Design Book. Robin Williams. Peachpit Press, 2008.

Further reading: Ch 7 selected

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

Further reading, Ch 7 full

- The Structure of the Information Visualization Design Space. Stuart K. Card and Jock D. Mackinlay. Proc InfoVis 1999, pp. 92-99.
- Visual Techniques for Exploring Databases.. Daniel A. Keim. KDD 1997 Tutorial Notes, 1997.
- The Grammar of Graphics, 2nd edition. Leland Wilkinson. Springer, 2005.
- Visualization Course Figures. Michael McGuffin, 2014
- The Generalized Pairs Plot. John W. Emerson, Walton A. Green, Barret Schloerke, Dianne Cook, Heike Hofmann, and Hadley Wickham. Journal of Computational and Graphical Statistics 22:1 (2012), 79-91.
- Interactive Dynamics for Visual Analysis: A Taxonomy of Tools That Support the Fluent and Flexible Use of Visualizations. Jeffrey Heer and Ben Shneiderman. Queue 10:2 (2012), 30-55.
- Sémiologie Graphique: Les diagrammes - Les réseaux - Les cartes. Jacques Bertin. Gauthier-Villard, 1967. Reissued by Editions de l'Ecole des Hautes Etudes en Sciences in 1999.
- web site: A Brief History of Data Visualization.. Michael Friendly. article: A Brief History of Data Visualization. Michael Friendly. In Handbook of Data Visualization, Computational Statistics, edited by Antony Unwin, Chun-houh Chen, and Wolfgang K. HÃ¤rdle, pp. 15-56. Springer, 2008.
- Visualizing Data. William S. Cleveland. Hobart Press, 1993.
- ThemeRiver: Visualizing Theme Changes over Time. Susan Havre, Beth Hetzler, and Lucy Nowell. Proc. InfoVis 2000, pp. 9-20.
- Stacked Graphs Geometry & Aesthetics.. Lee Byron and Martin Wattenberg. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 08) 14:6 (2008), 1245-1252.
- Bars and Lines: A Study of Graphic Communication.. Jeff Zacks and Barbara Tversky. Memory and Cognition 27:6 (1999), 1073-1079.
- The Shape Parameter of a Two-Variable Graph. William S. Cleveland, Marylyn E. McGill, and Robert McGill. Journal of the American Statistical Association 83:402 (1988), 289-300.
- Multi-Scale Banking to 45 Degrees.. Jeffrey Heer and Maneesh Agrawala. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 06) 12:5 (2006), 701-708.
- The History of the Cluster Heat Map.. Leland Wilkinson and Michael Friendly. The American Statistician 63:2 (2009), 179-184.
- Seriation and Matrix Reordering Methods: An Historical Overview.. Innar Liiv. Journal of Statistical Analysis and Data Mining 3:2 (2010), 70-91.
- Parallel Coordinates: A Tool for Visualizing Multi-Dimensional Geometry. Alfred Inselberg and Bernard Dimsdale. Proc. IEEE Conf. Visualization (Vis), 1990.
- Parallel Coordinates: Visual Multidimensional Geometry and Its Applications.. Alfred Inselberg. Springer, 2009.
- Uncovering Strengths and Weaknesses of Radial Visualizations - An Empirical Approach. Stephan Diehl, Fabian Beck, and Michael Burch. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 10) 16:6 (2010), 935-942.
- A Survey of Radial Methods for Information Visualization.. Geoffrey M. Draper, Yarden Livnat, and Richard F. Riesenfeld. IEEE Transactions on Visualization and Computer Graphics 15:5 (2009), 759-776.
- Designing Pixel-Oriented Visualization Techniques: Theory and Applications. Daniel A. Keim. IEEE Transactions on Visualization and Computer Graphics 6:1 (2000), 59-78.
- Seesoft - A Tool for Visualizing Line Oriented Software Statistics. Stephen G. Eick, Joseph L. Steffen, and Eric E Sumner, Jr. IEEE Transactions on Software Engineering 18:11 (1992), 957-968.
- Visualization of Test Information to Assist Fault Localization.. James A. Jones, Mary Jean Harrold, and John Stasko. Proc. International Conference on Software Engineering (ICSE), pp. 467-477. ACM, 2002.

Further reading: Ch 8 selected

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

Further reading, Ch 8 full

- web site: A Brief History of Data Visualization, http://www.datavis.ca/milestones, Michael Friendly. article: A Brief History of Data Visualization. Michael Friendly. In Handbook of Data Visualization, Computational Statistics, edited by Antony Unwin, Chun-houh Chen, and Wolfgang K. Härdle, pp. 15-56. Springer, 2008.
- The Evolution of Thematic Cartography/A Research Methodology and Historical Review.. Alan M. MacEachren. The Canadian Cartographer 16:1 (1979), 17-33.
- Thematic Cartography and Geovisualization, Third edition. Terry A. Slocum, Robert B. McMaster, Fritz C. Kessler, and Hugh H. Howard. Prentice Hall, 2008.
- Overview of Visualization. William J. Schroeder and Kenneth M. Martin. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 3-39. Elsevier, 2005.
- Overview of Volume Rendering.. Arie Kaufman and Klaus Mueller. In The Visualization Handbook, edited by Charles C. Hansen and Christopher R. Johnson, pp. 127-174. Elsevier, 2005.
- Marching Cubes: A High Resolution 3D Surface Construction Algorithm.. William E. Lorensen and Harvey E. Cline. Computer Graphics (Proc. SIGGRAPH 87) 21:4 (1987), 163-169.
- A Survey of the Marching Cubes Algorithm. Timothy S. Newman and Hong Yi. Computers & Graphics 30:5 (2006), 854-879.
- Simplifying Flexible Isosurfaces Using Local Geometric Measures. Hamish Carr, Jack Snoeyink, and Michiel van de Panne. Proc. IEEE Conf. Visualization (Vis) 2004, pp. 497-504.
- Real-Time Volume Graphics. Klaus Engel, Markus Hadwiger, Joe Kniss, Christof Reza-Salama, and Daniel Weiskopf. A K Peters, 2006.
- Volume Rendering.. Robert A. Drebin, Loren C. Carpenter, and Pat Hanrahan. Computer Graphics (Proc. SIGGRAPH 88) 22:4 (1988), 65-74.
- Display of Surfaces from Volume Data. Marc Levoy. IEEE Computer Graphics and Applications 8:3 (1988), 29-37.
- Interactive Volume Rendering Techniques. Joe Kniss. Master's thesis, University of Utah, Department of Computer Science, 2002. a
- Multidimensional Transfer Functions for Volume Rendering. Joe Kniss, Gordon Kindlmann, and Charles Hansen. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 189-210. Elsevier, 2005.
- Overview of Flow Visualization. Daniel Weiskopf and Gordon Erlebacher. In The Visualization Handbook, edited by Charles Hansen and Christopher Johnson, pp. 261-278. Elsevier, 2005.
- Over Two Decades of Integration-Based Geometric Flow Visualization. Tony McLoughlin, Robert S. Laramee, Ronald Peikert, Frits H. Post, and Min Chen. Computer Graphics Forum (Proc. Eurographics 09, State of the Art Reports) 6:29 (2010), 1807-1829.
- The State of the Art in Flow Visualization: Dense and Texture-Based Techniques. Robert S. Laramee, Helwig Hauser, Helmut Doleisch, Benjamin Vrolijk, Frits H. Post, and Daniel Weiskopf. Computer Graphics Forum (Proc. Eurographics 04) 23:2 (2004), 203-221.
- The State of the Art in Flow Visualisation: Feature Extraction and Tracking. Frits H. Post, Benjamin Vrolijka, Helwig Hauser, Robert S. Laramee, and Helmut Doleisch. Computer Graphics Forum (Proc. Eurographics 03) 22:4 (2003), 1-17.
- Imaging Vector Fields Using Line Integral Convolution. Brian Cabral and Leith Casey Leedom. SIGGRAPH 1993, pp. 263-270.
- Visualization and Processing of Tensor Fields. Joachim Weickert and Hans Hagen, editors. Springer, 2006.
- An Introduction to Visualization of Diffusion Tensor Imaging and Its Applications. A. Vilanova, S. Zhang, G. Kindlmann, and D. Laidlaw. In Visualization and Processing of Tensor Fields, pp. 121-153. Springer, 2006.
- Superquadric Tensor Glyphs. Gordon Kindlmann. Proc. Eurographics/IEEE Conference on Visualization (VisSym), pp. 147-154. Eurographics, 2004.

Further reading: Ch 9 selected

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

Further reading, Ch 9 full

- Graph Visualisation in Information Visualisation: A Survey. Ivan Herman, Guy Melançon, and M. Scott Marshall. IEEE Transactions on Visualization and Computer Graphics (TVCG) 6:1 (2000), 24-44.
- 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.
- Just How Dense Are Dense Graphs in the Real World?: A Methodological Note. Guy Melançon. Proc AVI Workshop BEyond time and errors: novel evaLuation methods for Information Visualization (BELIV). ACM, 2006.
- Drawing on Physical Analogies. Ulrik 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.
- A Fast Adaptive Layout Algorithm for Undirected Graphs. A. Frick, A. Ludwig, and H. Mehldau. Proc. International Symposium on Graph Drawing (GD 94), Lecture Notes in Computer Science, 894, pp. 388-403. Springer, 1995.
- Efficient and High Quality Force-Directed Graph Drawing. Yifan Hu. The Mathematica Journal 10 (2005), 37-71.
- Drawing Large Graphs with a Potential-Field-Based Multilevel Algorithm. S. Hachul and M. Jünger. Proc International Symposium on Graph Drawing (GD 04), Lecture Notes in Computer Science, 3383, pp. 285-295. Springer, 2004.
- TopoLayout: Multilevel Graph Layout by Topological Features. Daniel Archambault, Tamara Munzner, and David Auber. IEEE Transactions on Visualization and Computer Graphics 13:2 (2007), 305-317.
- MatrixExplorer: A Dual-Representation System to Explore Social Networks. Nathalie Henry and Jean-Daniel Fekete. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 06) 12:5 (2006), 677-684.
- NodeTrix: A Hybrid Visualization of Social Networks. Nathalie Henry, Jean-Daniel Fekete, and Michael McGuffin. IEEE Transactions on Computer Graphics and Visualization (Proc. InfoVis 07) 13:6 (2007), 1302-1309.
- On the Readability of Graphs Using Node-Link and Matrix-Based Representations: A Controlled Experiment and Statistical Analysis. Mohammad Ghoniem, Jean-Daniel Fekete, and Philippe Castagliola. Information Visualization 4:2 (2005), 114-135.
- Quantifying the Space-Efficiency of 2D Graphical Representations of Trees. Michael J. McGuffin and Jean-Marc Robert. Information Visualization 9:2 (2010), 115-140.
- web site: treevis.net. article: A Tree Visualization Reference. Hans-Jö rg Schulz. IEEE Computer Graphics and Applications 31:6 (2011), 11-15.
- The Design Space of Implicit Hierarchy Visualization: A Survey. Hans-J&oouml;rg Schulz, Steffen Hadlak, and Heidrun Schumann. IEEE Transactions on Visualization and Computer Graphics 17:4(2011), 393-411.
- Treemaps: A Space-Filling Approach to the Visualization of Hierarchical Information. Brian Johnson and Ben Shneiderman. Proc IEEE Conference on Visualization (Vis) 1991, pp. 284-291.
- Perceptual Guidelines for Creating Rectangular Treemaps. Kong, Heer, and Agrawala. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis) 16:6 (2010), 990-998.

Further reading: Ch 10 selected

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 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.
- https://cran.r-project.org/web/packages/viridis/vignettes/intro-to-viridis.html

Further reading, Ch 10 full

- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013.
- A Field Guide To Digital Color, Maureen Stone, AK Peters 2003.
- Representing Colors as Three Numbers, Maureen Stone, IEEE Computer Graphics and Applications, 25(4), July 2005, pp. 78-85.
- Color use guidelines for data representation C. Brewer, 1999.
- How Not to Lie with Visualization, Bernice E. Rogowitz and Lloyd A. Treinish, Computers In Physics 10(3) May/June 1996, pp 268-273.
- Rainbow Color Map (Still) Considered Harmful. David Borland and Russell M. Taylor, III. IEEE Computer Graphics and Applications 27:2 (2007), 14-17.
- Information Visualization: Perception for Design, 3rd edition, Colin Ware, Morgan Kaufmann, 2013.
- A Rule-Based Tool for Assisting Colormap Selection.. Lawrence D. Bergman, Bernice E. Rogowitz, and Lloyd A. Treinish. Proc. IEEE Visualization (Vis) 1995, 118-125.
- An Empirical Inquiry Concerning Human Understanding of Two-Variable Color Maps.. Howard Wainer and Carl M. Francolini. The American Statistician 34:2 (1980), 81-93.
- Motion to Support Rapid Interactive Queries on Node-Link Diagrams.. Colin Ware and Robert Bobrow. Transactions on Applied Perception (TAP) 1:1 (2004), 3-18.

Further reading: Ch 11 selected

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

Further reading, Ch 11 full

- Starting Simple - Adding Value to Static Visualisation Through Simple Interaction.. A. Dix and G. Ellis. Proc. Advanced Visual Interfaces (AVI) 1998, 124-134.
- Animated Transitions in Statistical Data Graphics Jeffrey Heer and George G. Robertson. IEEE TVCG (Proc. InfoVis 2007) 13(6): 1240-1247, 2007. [Archived version]
- Selection: 524,288 Ways To Say 'This Is Interesting'. Graham J. Wills. Proc. InfoVis 1996, p 54-61.
- Pad++: A Zooming Graphical Interface for Exploring Alternate Interface Physics Ben Bederson, and James D Hollan, Proc UIST 94.
- LiveRAC - Interactive Visual Exploration of System Management Time-Series Data. Peter McLachlan, Tamara Munzner, Eleftherios Koutsofios, Stephen North. Proc. Conf. on Human Factors in Computing Systems (CHI) 2008, 1483-1492.
- Rapid Controlled Movement Through a Virtual 3D Workspace Jock Mackinlay, Stuart Card, and George Robertson. Proc SIGGRAPH '90, pp 171-176.
- Smooth and Efficient Zooming and Panning. Jack J. van Wijk and Wim A.A. Nuij, Proc. InfoVis 2003, p. 15-22.

Further reading: Ch 12 selected

- Visualization Analysis and Design. Munzner. AK Peters Visualization Series, CRC Press, 2014.
  - *Chap 12: Facet Into Multiple Views*
- *A Review of Overview+Detail, Zooming, and Focus+Context Interfaces.* Cockburn, Karlson, and Bederson. ACM Computing Surveys 41:1 (2008), 1–31.
- *A Guide to Visual Multi-Level Interface Design From Synthesis of Empirical Study Evidence.* Lam and Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.
- *Zooming versus multiple window interfaces: Cognitive costs of visual comparisons.* Plumlee and Ware. ACM Trans. on Computer-Human Interaction (ToCHI) 13:2 (2006), 179–209.
- *Exploring the Design Space of Composite Visualization.* Javed and 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.
- *Guidelines for Using Multiple Views in Information Visualizations.* Baldonado, Woodruff, and Kuchinsky. In Proc. ACM Advanced Visual Interfaces (AVI), pp. 110–119, 2000.
- *Cross-Filtered Views for Multidimensional Visual Analysis.* Weaver. IEEE Trans. Visualization and Computer Graphics 16:2 (Proc. InfoVis 2010), 192–204, 2010.
- *Linked Data Views.* 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, Laramee, Hauser, Ward, and Chen. In Eurographics State of the Art Reports, pp. 39–63, 2013.

Further reading, Ch 12 full

- A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Andy Cockburn, Amy Karlson, and Benjamin B. Bederson. Computing Surveys 41:1 (2008), pp. 1-31.
- A Guide to Visual Multi-Level Interface Design from Synthesis of Empirical Study Evidence. Heidi Lam and Tamara Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.
- Zooming versus Multiple Window Interfaces: Cognitive Costs of Visual Comparisons. M. Plumlee and C. Ware. Transactions on Computer-Human Interaction (ToCHI) 13:2 (2006), pp. 179-209.
- Exploring the Design Space of Composite Visualization. Waqas Javed and Niklas Elmqvist. Proc. IEEE Symposium on Pacific Visualization (PacificVis), pp. 1-9. IEEE Computer Society, 2012.
- Visual Comparison for Information Visualization. Michael Gleicher, Danielle Albers, Rick Walker, Ilir Jusufi, Charles D. Hansen, and Jonathan C. Roberts. Information Visualization 10:4 (2011), pp. 289-309.
- Guidelines for Using Multiple Views in Information Visualizations. Michelle Q. Wang Baldonado, Allison Woodruff, and Allan Kuchinsky. Proc. International Working Conference on Advanced Visual Interfaces (AVI), pp. 110-119. ACM, 2000.
- State of the Art: Coordinated & Multiple Views in Exploratory Visualization. Jonathan C. Roberts. Proc. Conference on Coordinated & Multiple Views in Exploratory Visualization (CMV), pp. 61-71. IEEE Computer Society, 2007.
- Building Highly-Coordinated Visualizations in Improvise. Chris Weaver. Proc. IEEE Symposium on Information Visualization (InfoVis), pp. 159-166. IEEE Computer Society, 2004.
- Cross-Filtered Views for Multidimensional Visual Analysis. Chris Weaver. IEEE TVCG (2010), pp. 192-204.
- Configuring Hierarchical Layouts to Address Research Questions. Adrian Slingsby, Jason Dykes, and Jo Wood. IEEE TVCG (Proc. InfoVis 2009), pp. 977-984.
- Spatially Ordered Treemaps. Jo Wood and Jason Dykes. IEEE TVCG (Proc. InfoVis 2008), pp. 1348-1355.
- Glyph-Based Visualization: Foundations, Design Guidelines, Techniques and Applications. Rita Borgo, Johannes Kehrer, David H.S. Chung, Eamonn Maguire, Robert S. Laramee, Helwig Hauser, Matthew Ward, and Min Chen. Eurographics State of the Art Reports, pp. 39-63. Eurographics, 2013.
- Multivariate Data Glyphs: Principles and Practice. Matthew O. Ward. In Handbook of Data Visualization, Computational Statistics, edited by Antony Unwin, Chun-houh Chen, and Wolfgang K. HÃ¤rdle, pp. 179-198.
- Information Visualization: Perception for Design Colin Ware. Third edition. Morgan Kaufmann, 2013.
- A Taxonomy of Glyph Placement Strategies for Multidimensional Data Visualization. Matthew O. Ward. Information Visualization 1:3-4 (2002), pp. 194-210.
- Taxonomy-Based Glyph Design - With a Case Study on Visualizing Workflows of Biological Experiments. Eamonn Maguire, Philippe Rocca-Serra, Susanna-Assunta Sansone, Jim Davies, and Min Chen. IEEE TVCG (Proc. InfoVis 2012), pp. 2603-2612.
- Color Enhanced Star Plot Glyphs - Can Salient Shape Characteristics Be Overcome? Alexander Klippel, Frank Hardisty, Rui Li, and Chris Weaver. Cartographica 44:3 (2009), 217-231.
- Brushing Scatterplots Richard A. Becker and William S. Cleveland. Technometrics 29 (1987), 127-142.
- Linked Data Views Graham J. Wills. Technometrics 29 (1987), 127-142.
- Get It Right in Black and White. Maureen Stone. Functional Color, 2010.
- Dot Plots: A Useful Alternative to Bar Charts. Naomi B. Robbins. 2006.

Further reading: Ch 13 selected

- 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.

Further reading, Ch 13 full

- Visual Information Seeking: Tight Coupling of Dynamic Query Filters with Starfield Displays. Chris Ahlberg and Ben Shneiderman. Proc. CHI, pp. 313-317. ACM, 1994.
- Scented Widgets: Improving Navigation Cues with Embedded Visualizations. Wesley Willett, Jeffrey Heer, and Maneesh Agrawala. IEEE TVCG (Proc. InfoVis 2007), pp. 1129-1136.
- Information Foraging Theory: Adaptive Interaction with Information. Peter Pirolli. Oxford University Press, 2007.
- Exploratory Data Analysis. John W. Tukey. Addison-Wesley, 1977.
- 40 Years of Boxplots Hadley Wickham and Lisa Stryjewski. Technical report, had.co.nz, 2012.
- Hierarchical Aggregation for Information Visualization: Overview, Techniques and Design Guidelines. Niklas Elmqvist and Jean-Daniel Fekete. IEEE TVCG (2010), pp. 439-454.
- Hierarchical Parallel Coordinates for Exploration of Large Datasets. Ying-Huey Fua, Matthew O. Ward, and Elke A. Rundensteiner. Proc. IEEE Conference on Visualization (Vis), pp. 43-50. IEEE Computer Society, 1999.
- The Modifiable Areal Unit Problem (MAUP) David Wong. In The SAGE Handbook of Spatial Analysis, edited by A. Stewart Fotheringham and Peter A. Rogerson, pp. 105-123. Sage, 2009.
- The Modifiable Areal Unit Problem. Stan Openshaw. Number 38 in Concepts and Techniques in Modern Geography, Geo Books, 1984.
- Geographically Weighted Visualization: Interactive Graphics for Scale-Varying Exploratory Analysis. Jason Dykes and Chris Brunsdon. IEEE TVCG (Proc. InfoVis 2007), pp. 1161-1168.
- Interactive Hierarchical Dimension Ordering, Spacing and Filtering for Exploration of High Dimensional Datasets. Jing Yang, Wei Peng, Matthew O. Ward, and Elke A. Rundensteiner. Proc. InfoVis, pp. 105-112. IEEE Computer Society, 2003.
- Clutter Reduction in Multi-Dimensional Data Visualization Using Dimension Reordering. Wei Peng, Matthew O. Ward, and Elke A. Rundensteiner. Proc. InfoVis, pp. 89-96. IEEE Computer Society, 2004.
- Value and Relation Display for Interactive Exploration of High Dimensional Datasets. Jing Yang, Anilkumar Patro, Shiping Huang, Nishant Mehta, Matthew O. Ward, and Elke A. Rundensteiner. Proc. InfoVis, pp. 73-80. IEEE Computer Society, 2004.
- Visual Hierarchical Dimension Reduction for Exploration of High Dimensional Datasets. Jing Yang, Matthew O. Ward, Elke A. Rundensteiner, and Shiping Huang. Proc. Eurographics/IEEE Symposium on Visualization (VisSym), pp. 19-28. Eurographics, 2003.
- DimStiller: Workflows for Dimensional Analysis and Reduction. Stephen Ingram, Tamara Munzner, Veronika Irvine, Melanie Tory, Steven Bergner, and Torsten Moeller. Proc. VAST, pp. 3-10. IEEE Computer Society, 2010.
- Similarity Clustering of Dimensions for an Enhanced Visualization of Multidimensional Data. Michael Ankerst, Stefan Berchtold, and Daniel A. Keim. Proc. InfoVis, pp. 52-60. IEEE Computer Society, 1998.
- Discussion of a Set of Points in Terms of Their Mutual Distances. G. Young and A. S. Householder. Psychometrika 3:1.
- Multidimensional Scaling: I. Theory and Method. W. S. Torgerson. Psychometrika 17 (1952), pp. 401-419.
- A Linear Iteration Time Layout Algorithm for Visualising High Dimensional Data. M. Chalmers. Proc. IEEE VIS, pp. 127-132. IEEE Computer Society, 1996.
- Glimmer: Multilevel MDS on the GPU. Stephen Ingram, Tamara Munzner, and Marc Olano. IEEE TVCG (2009), pp. 249-261.
- Empirical Guidance on Scatterplot and Dimension Reduction Technique Choices. Michael Sedlmair, Tamara Munzner, and Melanie Tory. IEEE TVCG (Proc. InfoVis 2013), pp. 2634-2643.

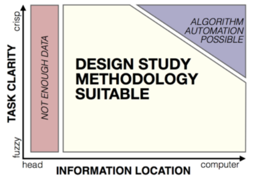
Further reading: Ch 14 selected

- Visualization Analysis and Design. Munzner. AK Peters / CRC Press, Oct 2014.
  - *Chap 14: Embed: Focus+Context*
- *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.
- *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 Fisheye Follow-up: Further Reflection on Focus + Context.* Furnas. Proc. ACM Conf. Human Factors in Computing Systems (CHI), pp. 999–1008, 2006.

Further reading, Ch 14 full

- A Review of Overview+Detail, Zooming, and Focus+Context Interfaces. Andy Cockburn, Amy Karlson, and Benjamin B. Bederson. Computing Surveys 41:1 (2008), pp. 1-31.
- A Guide to Visual Multi-Level Interface Design from Synthesis of Empirical Study Evidence. Heidi Lam and Tamara Munzner. Synthesis Lectures on Visualization Series, Morgan Claypool, 2010.
- Data Base Navigation: An Office Environment for the Professional. Robert Spence and Mark Apperley. Behaviour and Information Technology 1:1 (1982), pp. 43-54.
- A Polyfocal Projection for Statistical Surfaces. Naftali Kadmon and Eli Shlomi. The Cartographic Journal 15:1 (1978), pp. 36-41.
- A Review and Taxonomy of Distortion-Oriented Presentation Techniques. Ying K. Leung and Mark Apperley. Transactions on Computer-Human Interaction (ToCHI) 1:2 (1994), pp. 126-160.
- The FISHEYE View: A New Look at Structured Files. George W. Furnas. Technical report, Bell Laboratories Technical Memorandum No. 82-11221-22, 1982.
- Generalized Fisheye Views. George W. Furnas. Proc. CHI 1986, pp. 16-23.
- A Fisheye Follow-up: Further Reflection on Focus + Context. George W. Furnas. Proc. CHI 2006, pp. 999-1008.
- The Perspective Wall: Detail and Context Smoothly Integrated. Jock D. Mackinlay, George G. Robertson, and Stuart K. Card. Proc. CHI 1991, pp. 173-179.
- Cone Trees: Animated 3D Visualizations of Hierarchical Information. George Robertson, Jock Mackinlay, and Stuart Card. Proc. CHI 1991, pp. 189-194.
- Three-Dimensional Pliable Surfaces: For Effective Presentation of Visual Information. M. Sheelagh T. Carpendale, David J. Cowperthwaite, and F. David Fracchia. Proc. of the Symposium on User Interface Software and Technology (UIST), pp. 217-226. ACM, 1995.
- Distortion Viewing Techniques for 3D Data. M. Sheelagh T. Carpendale, David J. Cowperthwaite, and F. David Fracchia. Proc. InfoVis, pp. 46-53. IEEE Computer Society, 1996.
- Nonlinear Magnification Fields. T. Alan Keahey and Edward L. Robertson. Proc. InfoVis, pp. 51-58. IEEE Computer Society, 1997.
- A Focus+Content Technique Based on Hyperbolic Geometry for Visualizing Large Hierarchies. John Lamping, Ramana Rao, and Peter Pirolli. Proc. CHI, pp. 401-408. ACM, 1995.
- Exploring Large Graphs in 3D Hyperbolic Space. Tamara Munzner. IEEE Computer Graphics and Applications 18:4 (1998), pp. 18-23.
- TreeJuxtaposer: Scalable Tree Comparison Using Focus+Context with Guaranteed Visibility. Tamara Munzner, Francois Guimbretiere, Serdar Tasiran, Li Zhang, and Yunhong Zhou. Proc. SIGGRAPH (2003), pp. 453-462.
- PRISAD: Partitioned Rendering Infrastructure for Scalable Accordion Drawing (Extended Version). James Slack, Kristian Hildebrand, and Tamara Munzner. Information Visualization 5:2 (2006), pp. 137-151.

Design Study Methodology



Michael Sedlmair 

Miriah Meyer 

Design Study Methodology

Reflections from the Trenches and from the Stacks

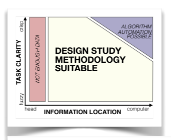
Tamara Munzner
@tamaramunzner 

http://www.cs.ubc.ca/labs/imager/tr/2012/dsm/

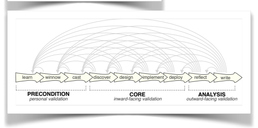
Design Study Methodology: Reflections from the Trenches and from the Stacks.
Sedlmair, Meyer, Munzner. IEEE Trans. Visualization and Computer Graphics 18(12): 2431-2440, 2012 (Proc. InfoVis 2012).

Methodology for problem-driven work

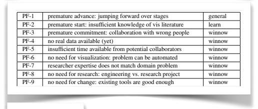
- definitions



- 9-stage framework

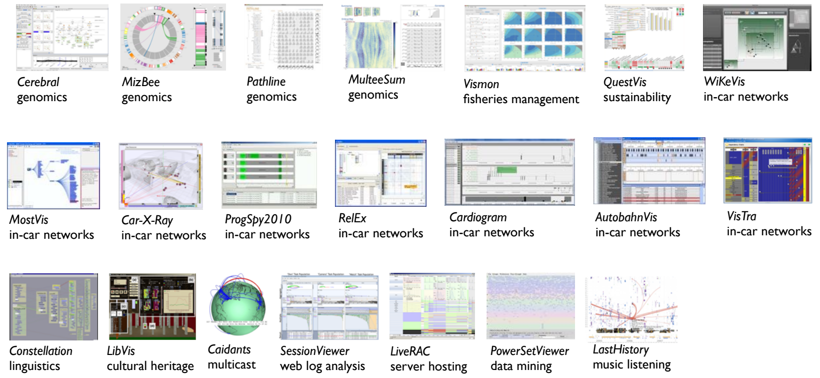


- 32 pitfalls & how to avoid them

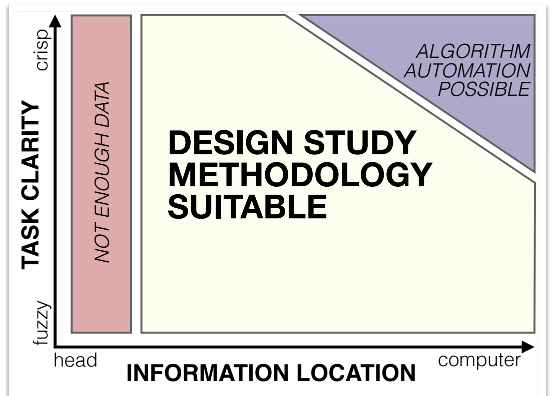


- comparison to related methodologies

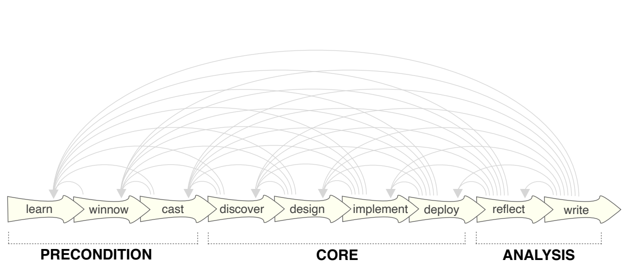
Lessons learned from the trenches: 21 between us



Design study methodology: definitions

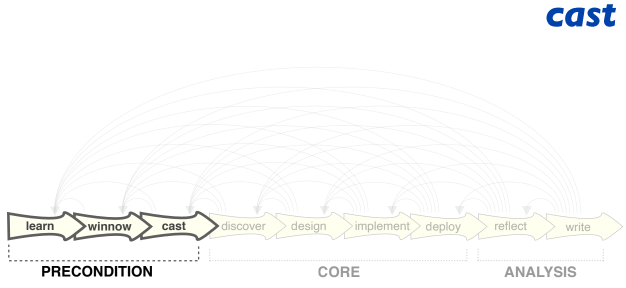


9 stage framework



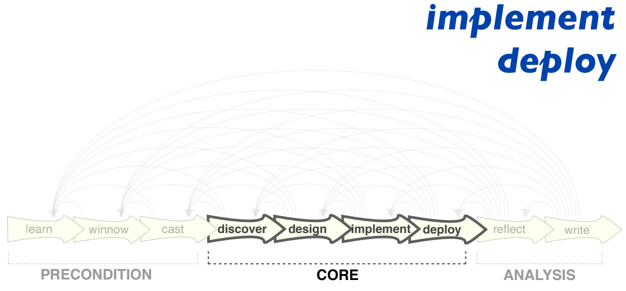
9-stage framework

learn
winnow
cast



9-stage framework

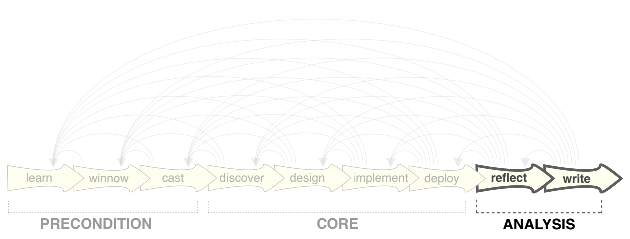
discover
design
implement
deploy



9-stage framework

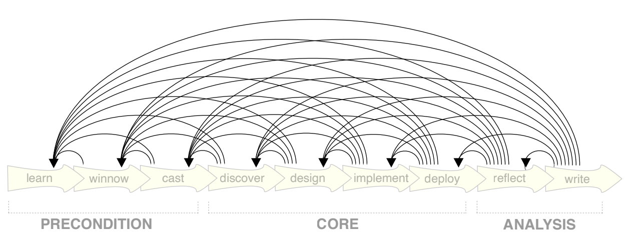
reflect
write

- guidelines: confirm, refine, reject, propose



9-stage framework

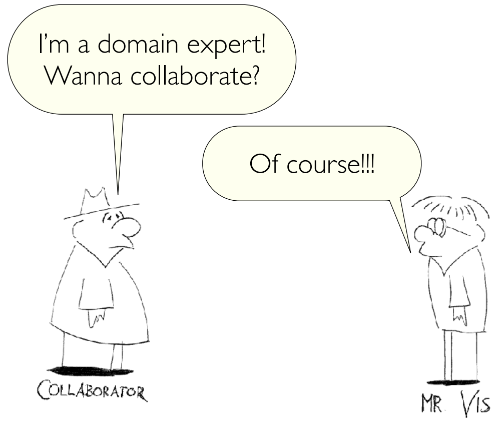
iterative



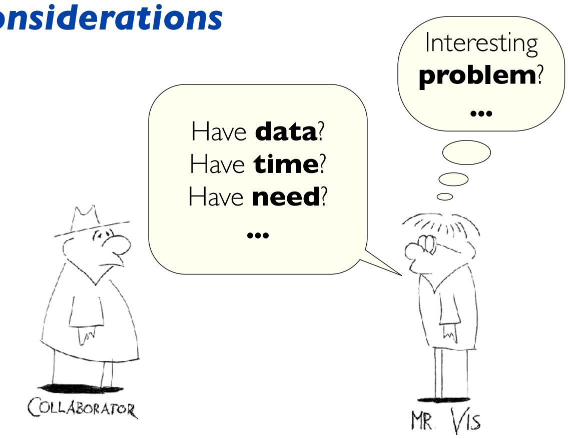
Design study methodology: 32 pitfalls

- and how to avoid them

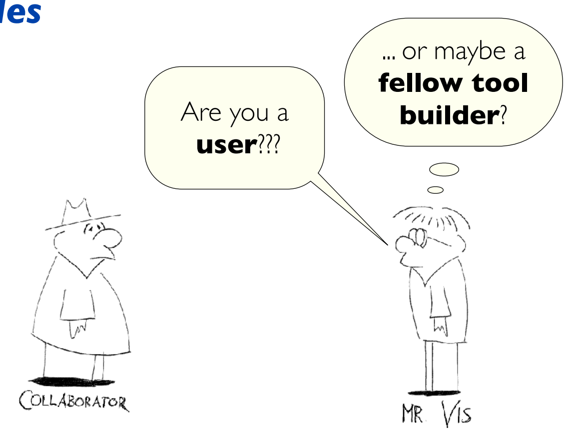
PF-1	premature advance: jumping forward over stages	general
PF-2	premature start: insufficient knowledge of vis literature	learn
PF-3	premature commitment: collaboration with wrong people	winnow
PF-4	no real data available (yet)	winnow
PF-5	insufficient time available from potential collaborators	winnow
PF-6	no need for visualization: problem can be automated	winnow
PF-7	researcher expertise does not match domain problem	winnow
PF-8	no need for research: engineering vs. research project	winnow
PF-9	no need for change: existing tools are good enough	winnow



considerations

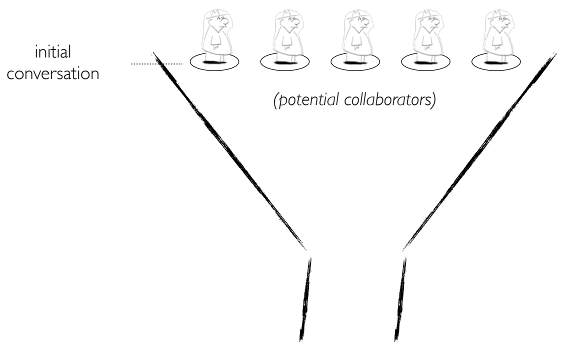


roles

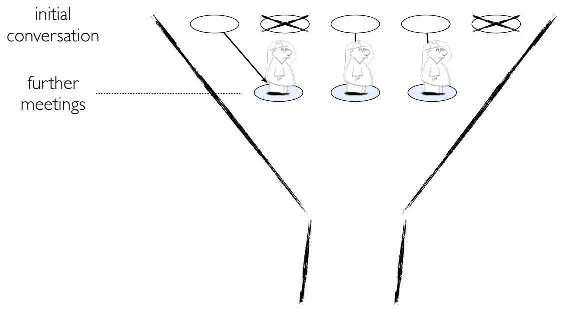


METAPHOR
Winnowing

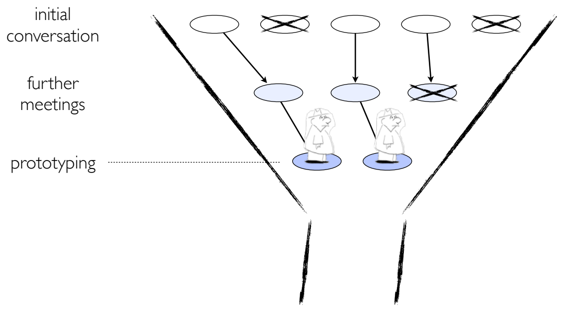
Collaborator winnowing



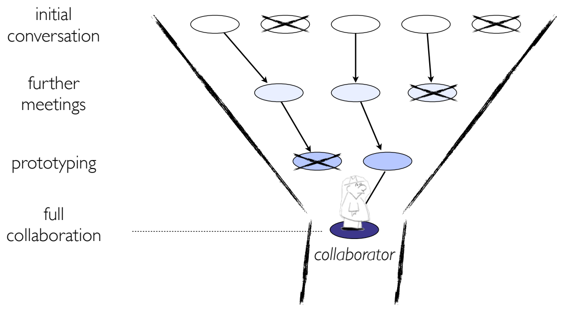
Collaborator winnowing



Collaborator winnowing



Collaborator winnowing



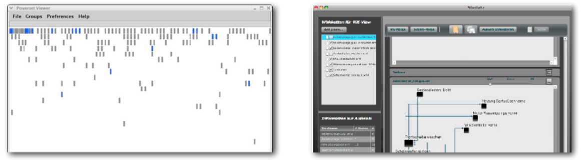
Collaborator winnowing

Talk with many, stay with few!

EXAMPLE FROM THE TRENCHES
Premature Collaboration!

PowerSet Viewer
2 years / 4 researchers

WikeVis
0.5 years / 2 researchers



EXAMPLE FROM THE TRENCHES
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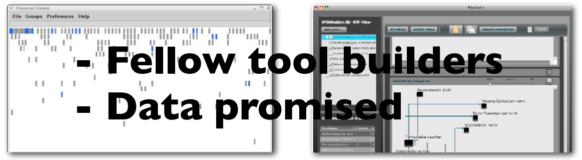


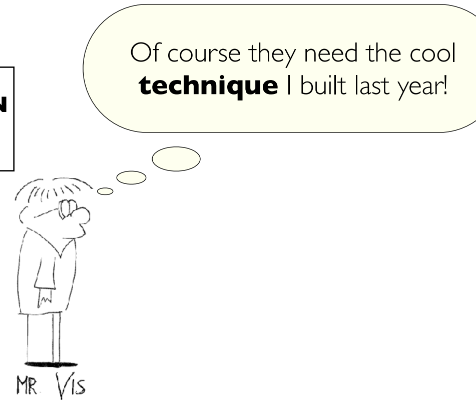
- Fellow tool builders
- Data promised

Design study methodology: 32 pitfalls

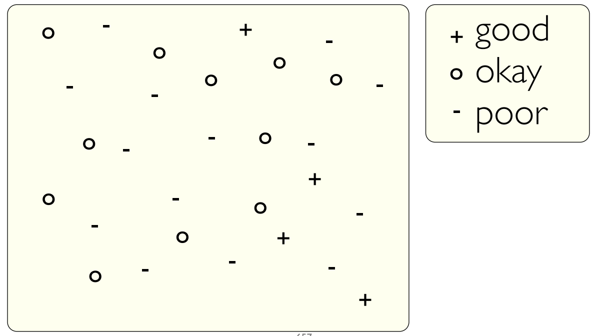
PF-10	no real/important/recurring task	winnow
PF-11	no rapport with collaborators	winnow
PF-12	not identifying front line analyst and gatekeeper before start	cast
PF-13	assuming every project will have the same role distribution	cast
PF-14	mistaking fellow tool builders for real end users	cast
PF-15	ignoring practices that currently work well	discover
PF-16	expecting *just talking* or *fly on wall* to work	discover
PF-17	experts focusing on visualization design vs. domain problem	discover
PF-18	learning their problems/language: too little / too much	discover
PF-19	abstraction: too little	design
PF-20	premature design commitment: consideration space too small	design

PITFALL

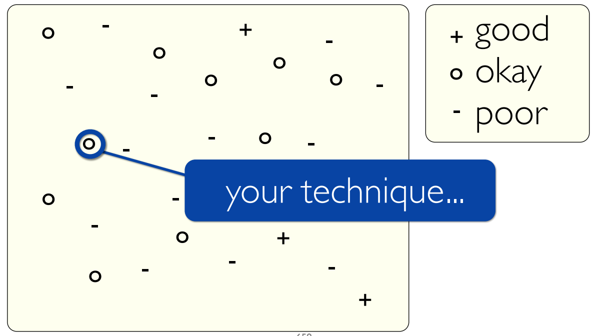
PREMATURE DESIGN COMMITMENT



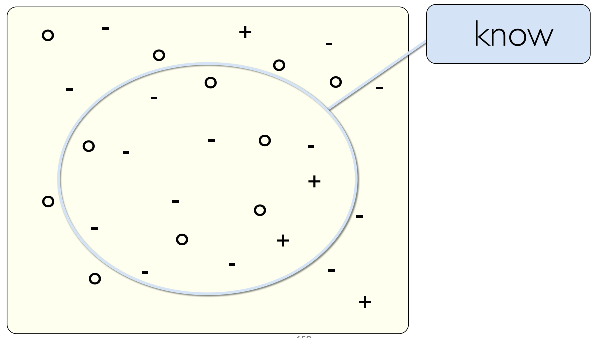
METAPHOR
Design Space



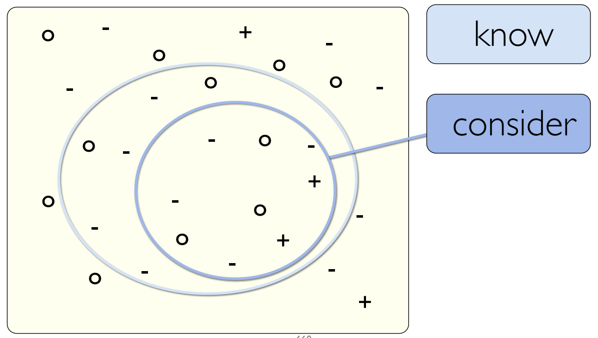
METAPHOR
Design Space



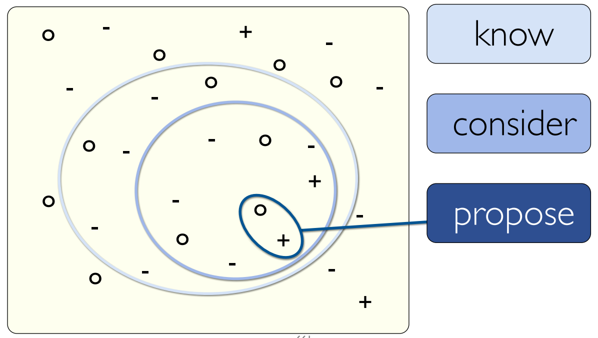
METAPHOR
Design Space



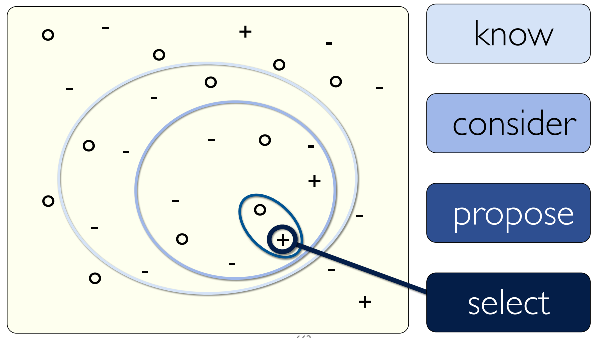
METAPHOR
Design Space



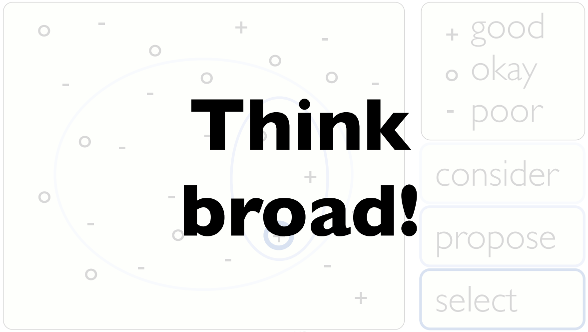
METAPHOR
Design Space



METAPHOR
Design Space



METAPHOR
Design Space

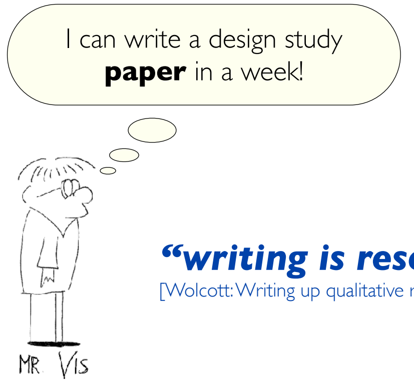


Think broad!

Design study methodology: 32 pitfalls

PF-21	mistaking technique-driven for problem-driven work	design
PF-22	nonrapid prototyping	implement
PF-23	usability: too little / too much	implement
PF-24	premature end: insufficient deploy time built into schedule	deploy
PF-25	usage study not case study: non-real task/data/user	deploy
PF-26	*liking* necessary but not sufficient for validation	deploy
PF-27	failing to improve guidelines: confirm, refine, reject, propose	reflect
PF-28	insufficient writing time built into schedule	write
PF-29	no technique contribution ≠ good design study	write
PF-30	too much domain background in paper	write
PF-31	story told chronologically vs. focus on final results	write
PF-32	premature end: win race vs. practice music for debut	write

PITFALL
PREMATURE PUBLISHING



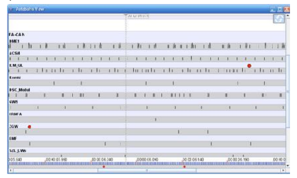
"writing is research"
[Wolcott: Writing up qualitative research, 2009]

METAPHOR
Horse Race vs. Music Debut

technique-driven
problem-driven

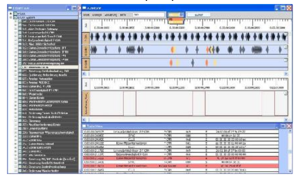
EXAMPLE FROM THE TRENCHES
Don't step on your own toes!

First design round published



AutobahnVis 1.0
[Sedlmair et al., Smart Graphics, 2009]

Subsequent work not stand-alone paper



AutobahnVis 2.0
[Sedlmair et al., Information Visualization 10(3), 2011]

Reflections from the stacks: Wholesale adoption inappropriate

- ethnography
  - rapid, goal-directed fieldwork
- grounded theory
  - not empty slate: vis background is key
- action research
  - aligned
    - intervention as goal
    - transferability not reproducibility
    - personal involvement is key
  - opposition
    - translation of participant concepts into visualization language
    - researcher lead not facilitate design
    - orthogonal to vis concerns: participants as writers, adversarial to status quo, postmodernity

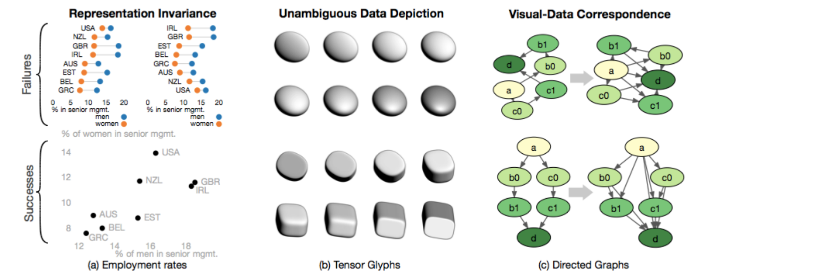
Next Steps

What-Why-How Analysis

- this approach is not the only way to analyze visualizations!
  - one specific framework intended to help you think
  - other frameworks support different ways of thinking
    - following: one interesting example

Algebraic Process for Visualization Design

- which mathematical structures in data are preserved and reflected in vis
  - negation, permutation, symmetry, invariance



[Fig 1. An Algebraic Process for Visualization Design. Carlos Scheidegger and Gordon Kindlmann. IEEE TVCG (Proc. InfoVis 2014), 20(12):2181-2190.]

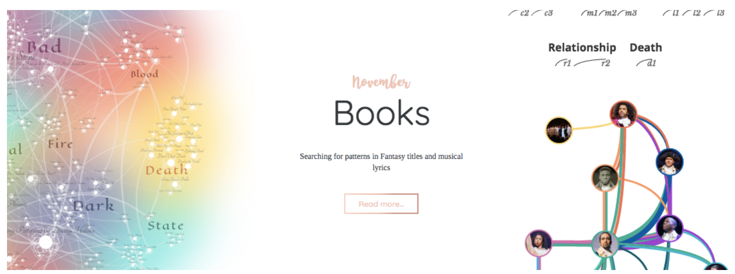
Algebraic process: Vocabulary

- **invariance** violation: single dataset, many visualizations
  - **hallucinator**
- **unambiguity** violation: many datasets, same vis
  - data change invisible to viewer
    - **confuser**
- **correspondence** violation:
  - can't see change of data in vis
    - **jumbler**
  - salient change in vis not due to significant change in data
    - **misleader**
  - match mathematical structure in data with visual perception
- we can X the data; can we Y the image?
  - are important data changes well-matched with obvious visual changes?

Visual Design Process In Depth: **Dear Data**

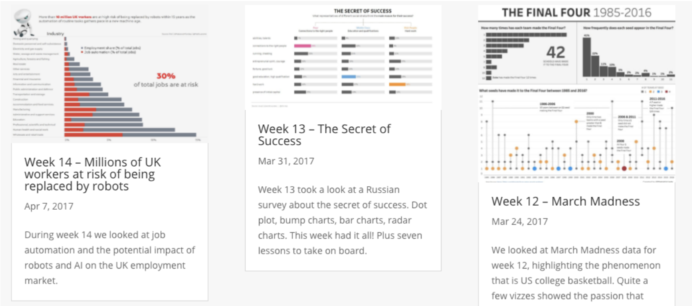
http://www.dear-data.com/by-week/

Visual Design Process In Depth: **Data Sketches**



http://www.datasketch.es/

Redesign En Masse: **Makeover Mondays**



http://www.makeovermonday.co.uk/blog/

In-Class Exercise

Scenario

- data: room occupancy rates
  - 1 room
  - occupancy measured every 5 min, duration 1 day
- task: characterize space usage pattern
- design
  - propose idioms (visual encoding, interaction)
  - justify idiom choice

Consider

- **what's the cardinality of the data?**
- **is a single static chart good enough?**
- **should you derive any useful additional data?**

Cardinality

- Marshall: 68 cities * 40 years * 4 crime types = 10,880
- Wine: 130K * 4 = 650,000
  - spatial (hierarchical), quantitative, categorical, free-form text

Scenario

- data: room occupancy rates
  - 20 rooms
  - measured every 5 min, duration 1 day
- task: compare space usage patterns between rooms
- design
  - propose idioms (visual encoding, interaction)
  - justify idiom choice

Consider

- what's the cardinality of the data?
- is a single static chart good enough?
- should you derive any useful additional data?
- **what are trade-offs between**
  - **filtering to see one chart at a time**
  - **showing all side by side with small multiples**
  - **superimposing all on top of each other**

Scenario

- data: room occupancy rates in building
  - 1 building: 200 rooms across 4 floors
  - measured every 5 min, duration 1 day
  - time series + floor plans
- task: characterize space usage patterns
  - trends, outliers
- design
  - propose & justify idioms

Consider

- what's the cardinality of the data?
- is a single static chart good enough?
- should you derive any useful additional data?
- what are trade-offs between
  - filtering to see one chart at a time
  - showing side by side with small multiples
  - superimposing on top of each other
- **multi-scale structure to exploit? aggregate, zoom, slice/dice, filter?**

Scenario

- data: room occupancy rates in building
  - 1 building: 200 rooms across 4 floors
  - measured every 5 min, duration 1 **year**
  - time series + floor plans **+ room sizes**
- task: characterize space usage patterns
  - trends, outliers
- design
  - propose & justify idioms

Consider

- what's the cardinality of the data?
- is a single static chart good enough?
- should you derive any useful additional data?
- what are trade-offs between
  - filtering to see one chart at a time
  - showing side by side with small multiples
  - superimposing on top of each other
- multi-scale structure to exploit? aggregate, zoom, slice/dice, filter?
- **can you normalize the data? should you - always vs on demand?**
- **how to handle multi-scale space and multi-scale time?**

Scenario

- data: currency exchange rates
  - 30 countries (each against CAD)
  - measured every 5 min, duration 5 years
  - time series + country names + continent names (+ map shapefiles) + country populations
- task: find groups of similarly-performing currencies
- design
  - propose & justify idioms

Consider

- what's the cardinality of the data?
- is a single static chart good enough?
- should you derive any useful additional data?
- what are trade-offs between
  - filtering to see one chart at a time
  - showing side by side with small multiples
  - superimposing on top of each other
- multi-scale structure to exploit? aggregate, zoom, slice/dice, filter?
- can you normalize the data? should you - always vs on demand?
- how to handle multi-scale space and multi-scale time?
- **is spatial information germane or extraneous?**

Scenario

- data: CPU usage across many machines
  - 100 machines, belonging to 20 companies
  - measured every 5 min, duration 1 month
  - time series + company name + company location (country)
- task: capacity planning for machine room
- design
  - propose & justify idioms

Scenario

- data: many metrics across many machines
  - 100 machines, belonging to 20 companies
  - 4 metrics measured every 5 min, duration 1 month
    - CPU, memory, disk I/O, network traffic
  - time series + company name + company sector (finance/tech/entertainment/other)
- task: forensic analysis to determine possible causes of crashes

- design
  - propose & justify idioms