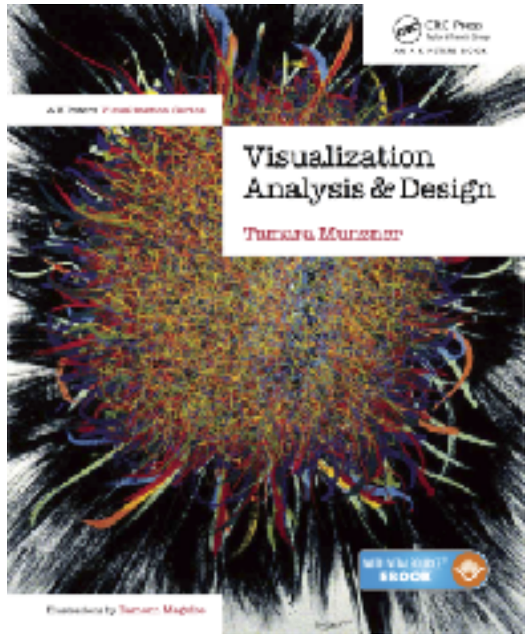

Visualization Analysis & Design

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

Tamara Munzner
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@tamaramunzner

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.

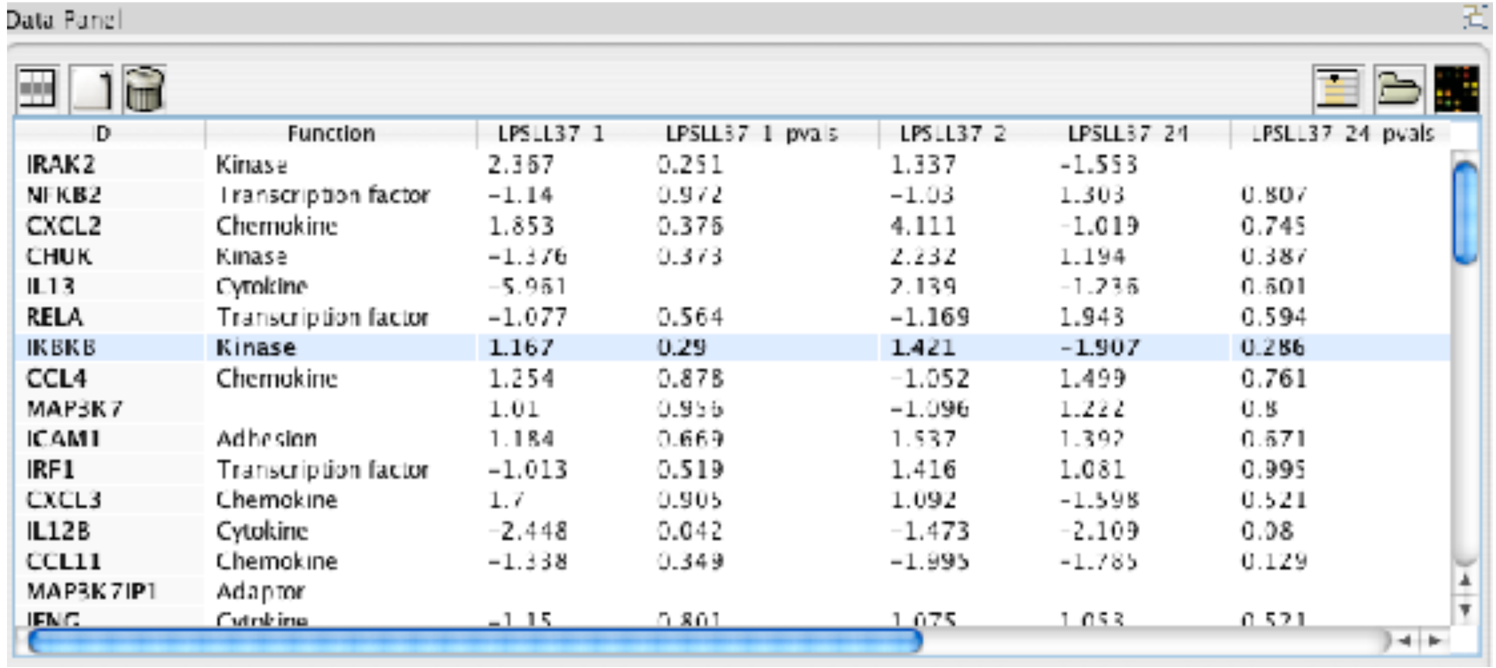
Visualization is suitable when there is a need to augment human capabilities rather than replace people with computational decision-making methods.

- 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



Data Panel

ID	Function	LPSLL37 1	LPSLL37 1 pvals	LPSLL37 2	LPSLL37 24	LPSLL37 24 pvals
IRAK2	Kinase	2.367	0.251	1.337	-1.553	
NFKB2	Transcription factor	-1.14	0.972	-1.03	1.303	0.807
CXCL2	Chemokine	1.853	0.376	4.111	-1.019	0.745
CHUK	Kinase	-1.376	0.373	2.232	1.194	0.387
IL13	Cytokine	-5.961		2.139	-1.236	0.601
RELA	Transcription factor	-1.077	0.564	-1.169	1.943	0.594
IKBKB	Kinase	1.167	0.29	1.421	-1.907	0.286
CCL4	Chemokine	1.254	0.878	-1.052	1.499	0.761
MAP3K7		1.01	0.956	-1.096	1.222	0.8
ICAM1	Adhesion	1.184	0.669	1.537	1.392	0.671
IRF1	Transcription factor	-1.013	0.519	1.416	1.081	0.995
CXCL3	Chemokine	1.7	0.905	1.092	-1.598	0.521
IL12B	Cytokine	-2.448	0.042	-1.473	-2.109	0.08
CCL11	Chemokine	-1.338	0.349	-1.995	-1.785	0.129
MAP3K7IP1	Adaptor					
IFNG	Cytokine	-1.15	0.801	1.075	1.053	0.521

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

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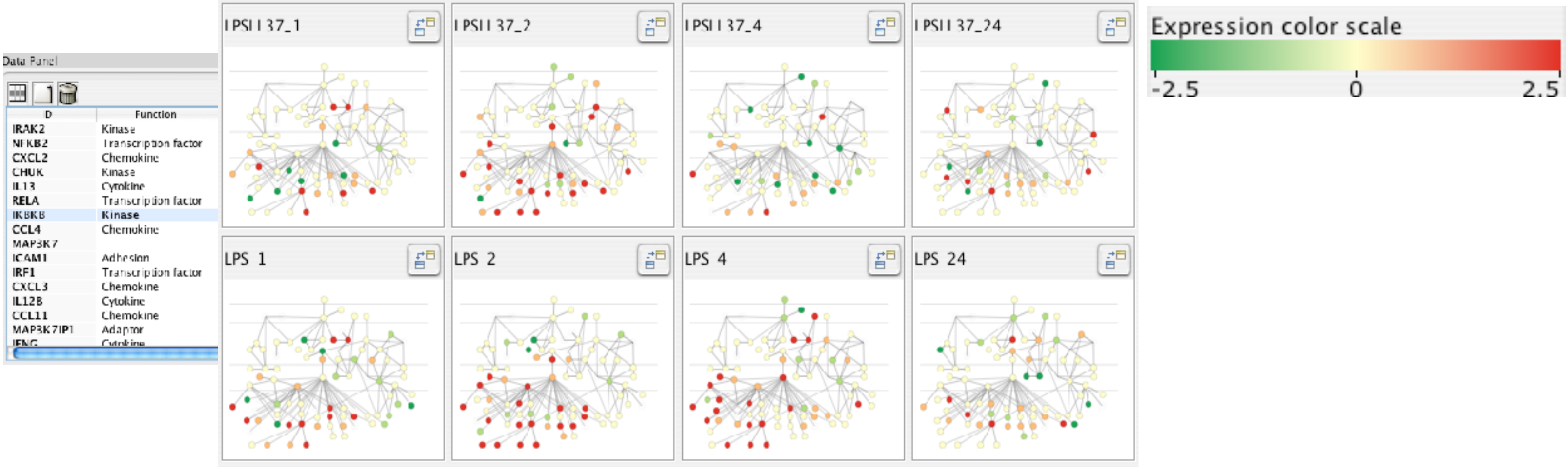

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Why depend on vision?

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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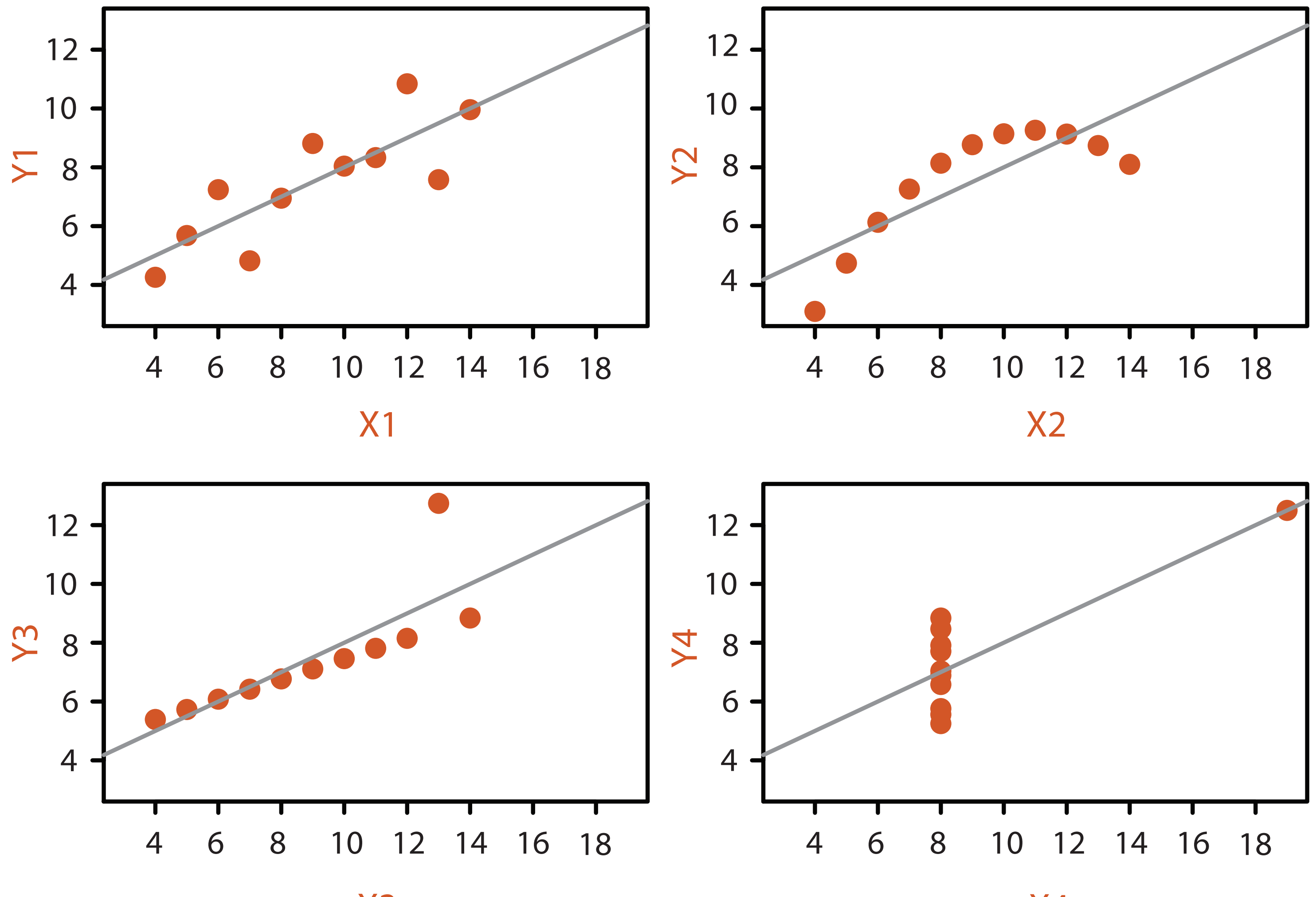

Anscombe's Quartet

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x mean	9
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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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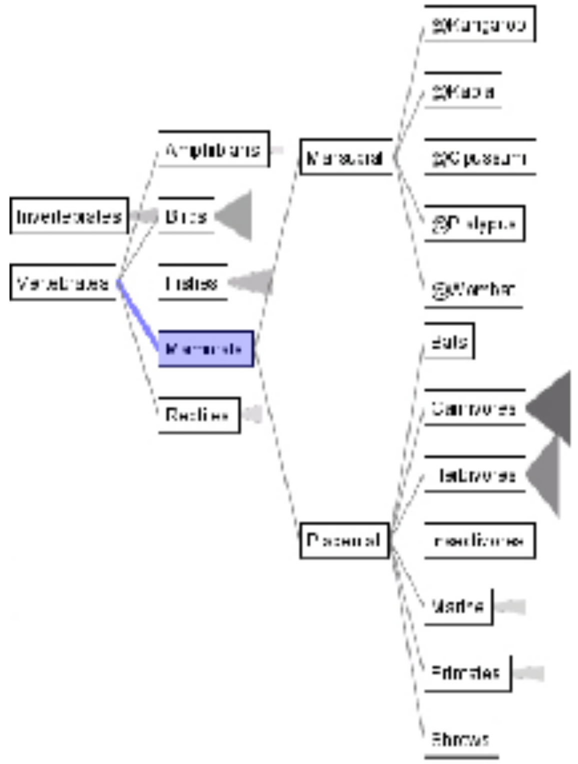
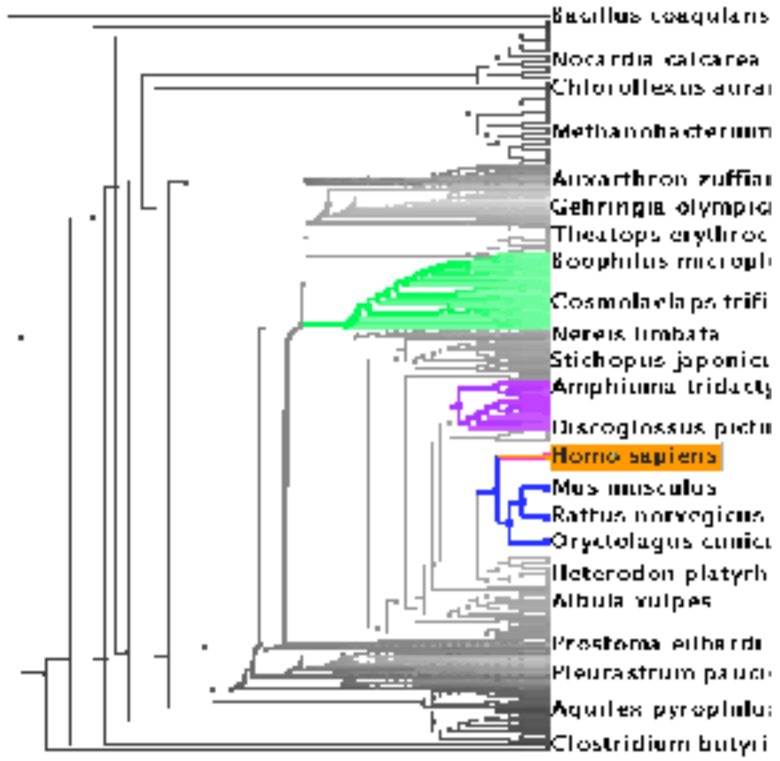
SpaceTree



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

TreeJuxtaposer



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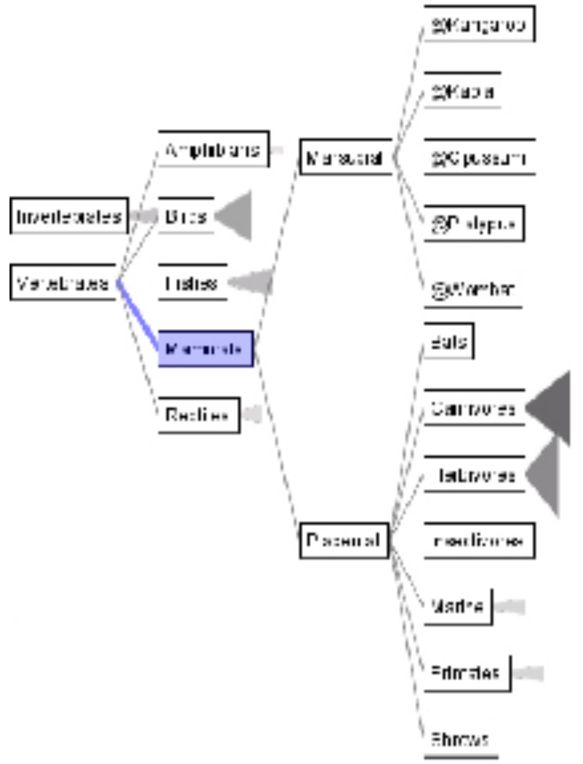

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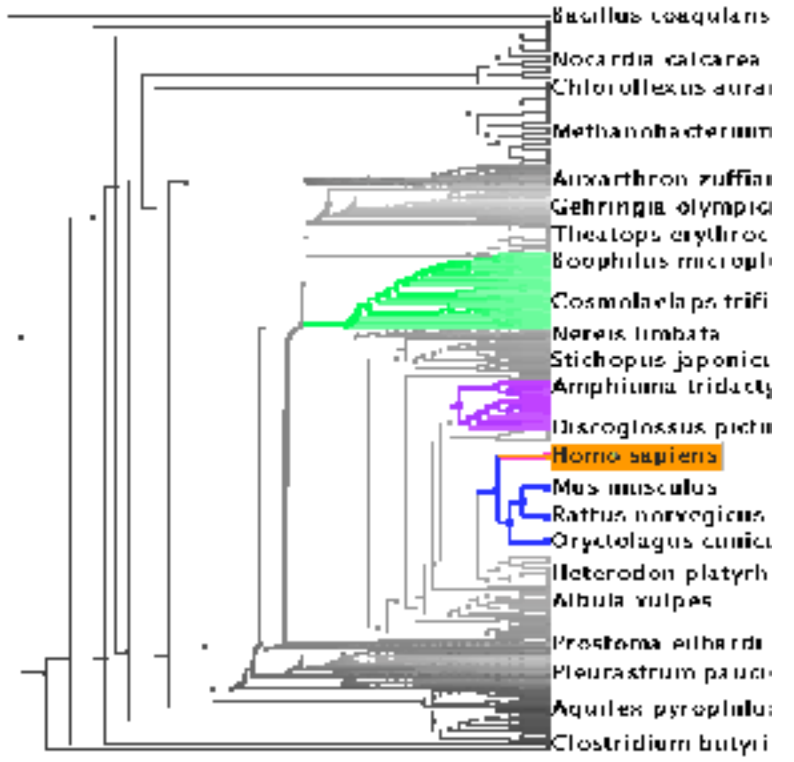

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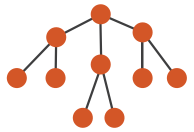
What?

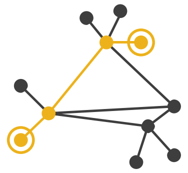
→ Tree



Why?

→ Actions
- → Present → Locate → Identify

→ Targets
- → Path between two nodes

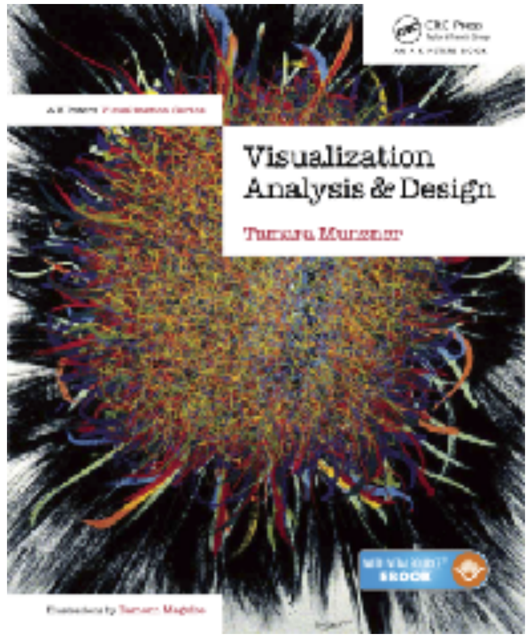


How?

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

→ TreeJuxtaposer
- → Encode → Navigate → Select → Arrange

Visualization Analysis & Design



Analysis: Nested Model (Ch 4)

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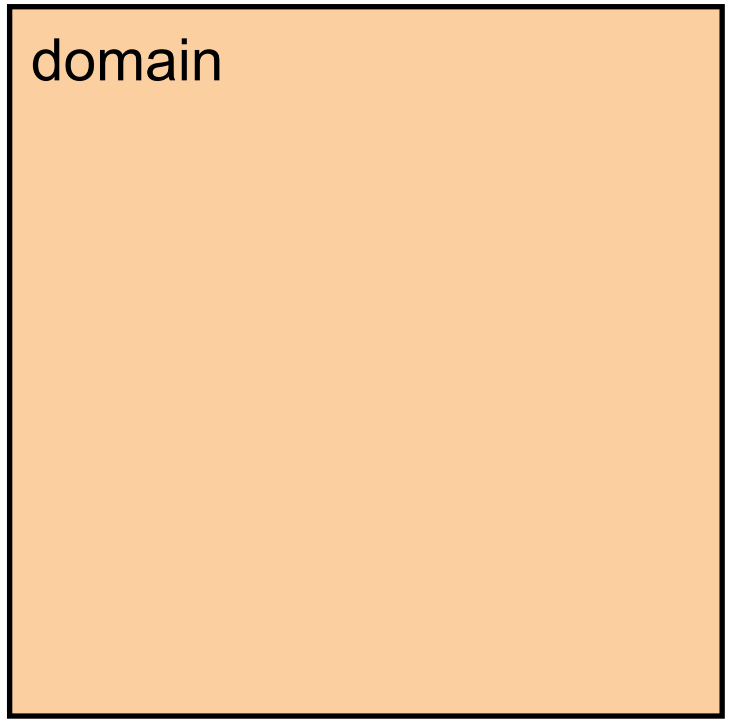
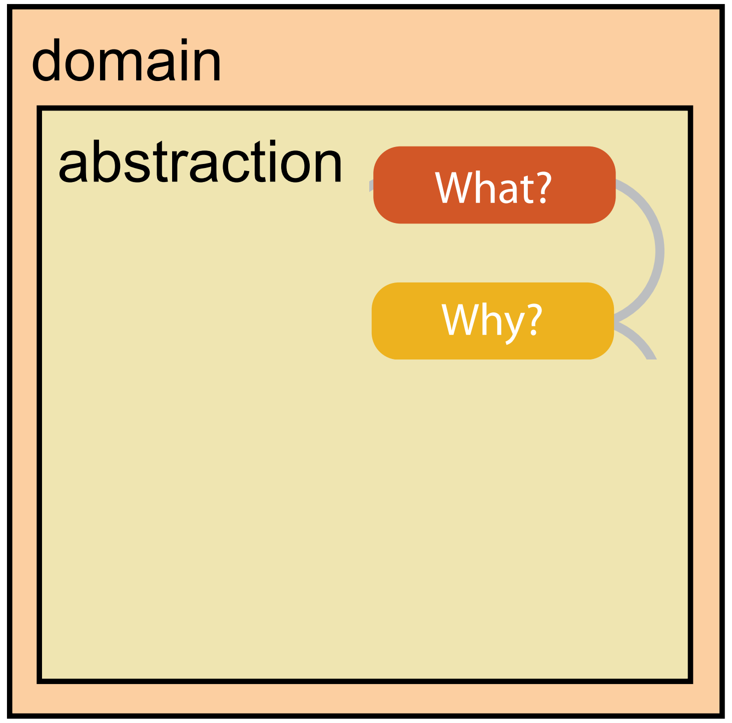
Analysis framework: Four levels, three questions

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



Analysis framework: Four levels, three questions

- *domain situation*
  - who are the target users?
- *abstraction*
  - translate from specifics of domain to vocabulary of vis
    - **what** is shown? **data** abstraction
    - **why** is the user looking at it? **task** abstraction



[A Multi-Level Typology of Abstract Visualization Tasks. Brehmer and Munzner. IEEE TVCG 19(12):2376-2385, 2013 (Proc. InfoVis 2013).]
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    - **what** is shown? **data** abstraction
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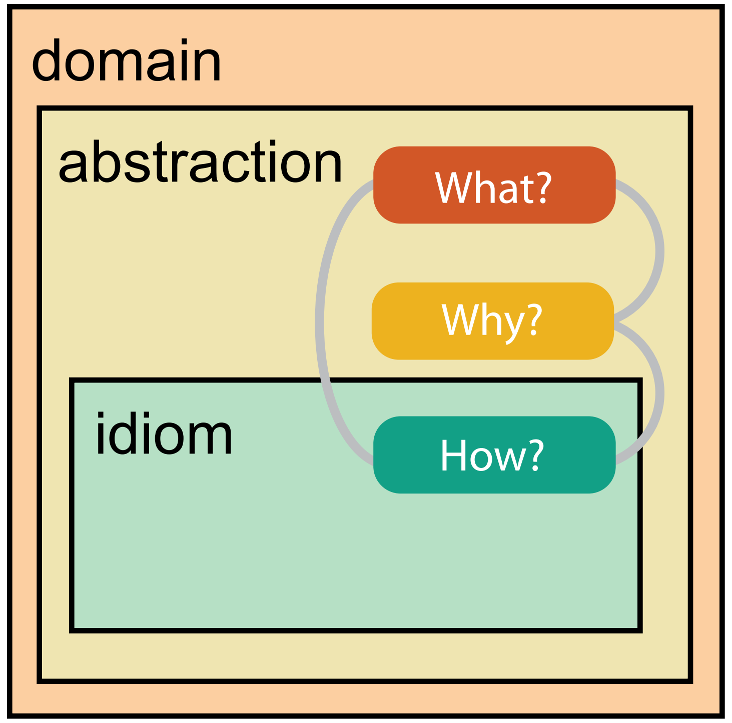
- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate



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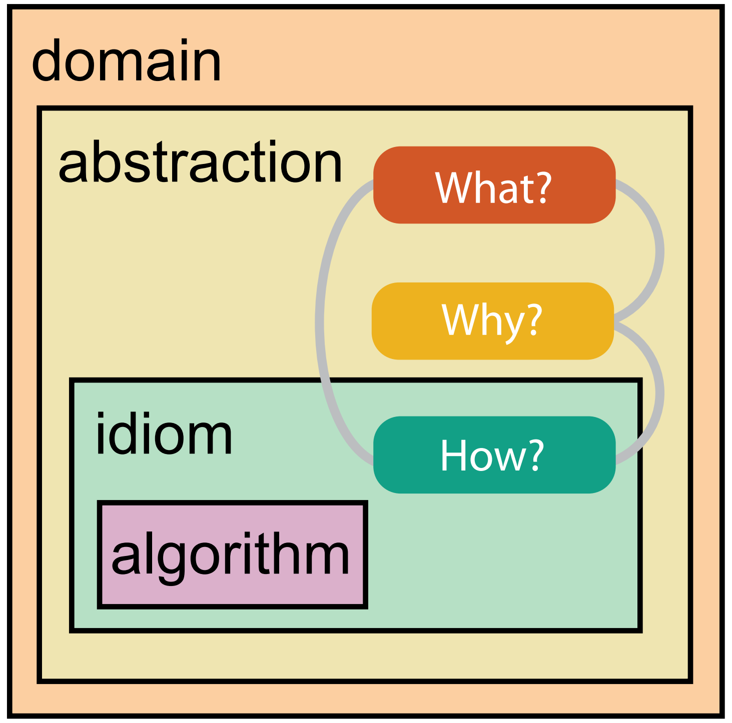
- *idiom*
  - **how** is it shown?
    - **visual encoding** idiom: how to draw
    - **interaction** idiom: how to manipulate
- *algorithm*
  - efficient computation



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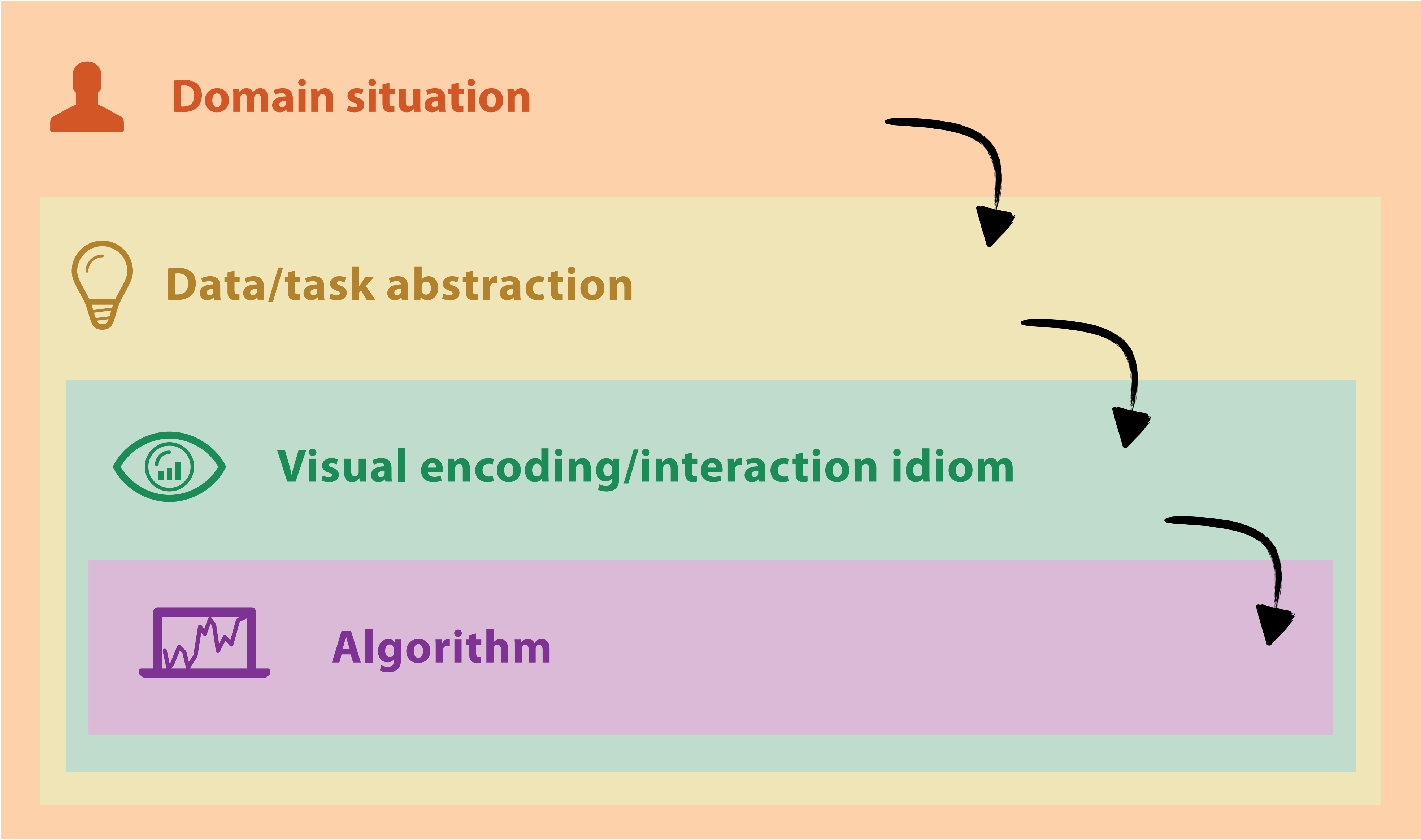
Nested model

- downstream: cascading effects



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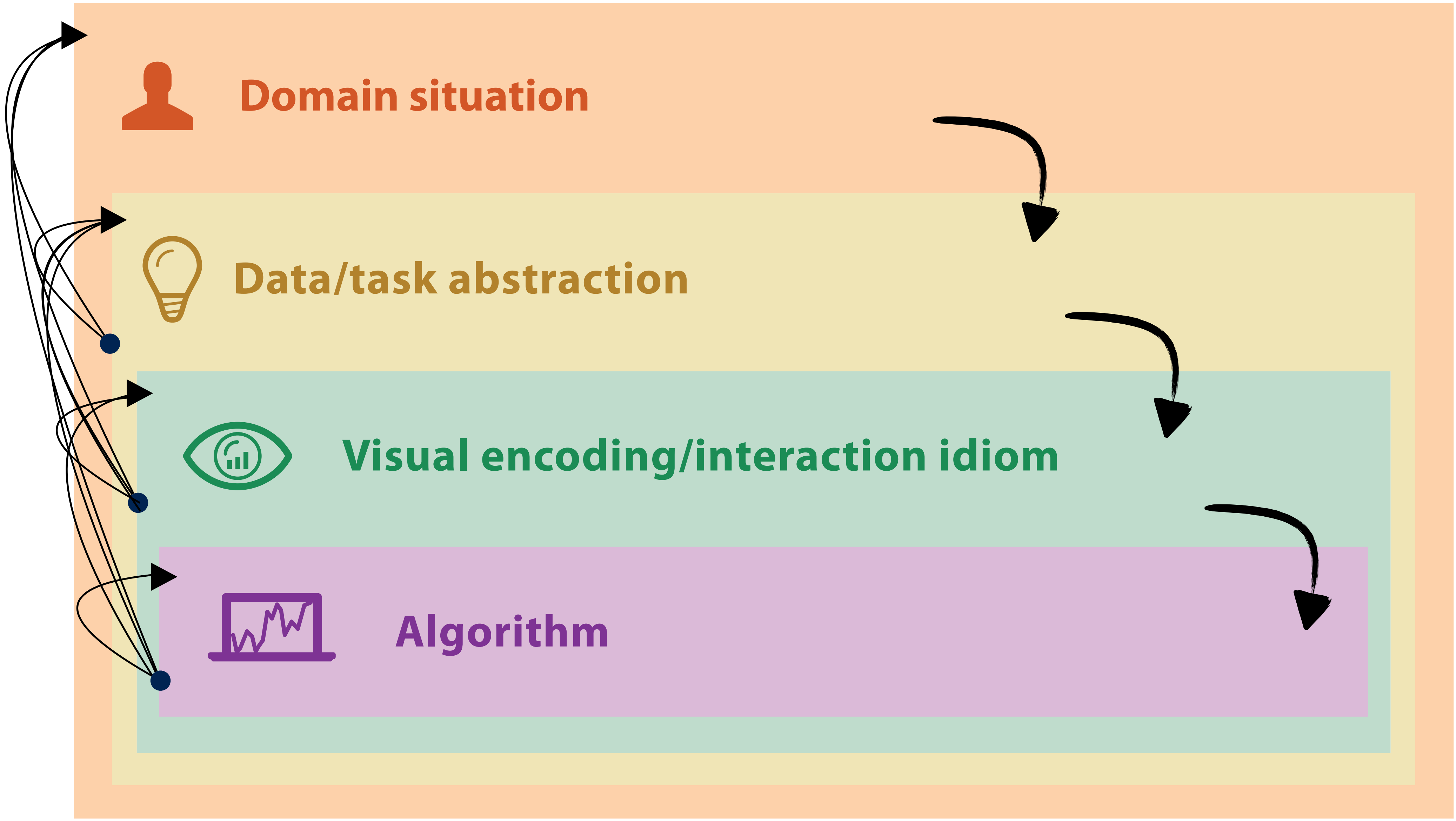
Nested model

- downstream: cascading effects
- upstream: iterative refinement



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

Why is validation difficult?

- different ways to get it wrong at each level

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Why is validation difficult?

- solution: use methods from different fields at each level

Algorithm
Measure system time/memory
Analyze computational complexity

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Why is validation difficult?

- solution: use methods from different fields at each level

computer science

Algorithm
Measure system time/memory
Analyze computational complexity

→ technique-driven work

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Why is validation difficult?

- solution: use methods from different fields at each level

design

computer science

cognitive psychology

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*)

technique-driven work

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Why is validation difficult?

- solution: use methods from different fields at each level

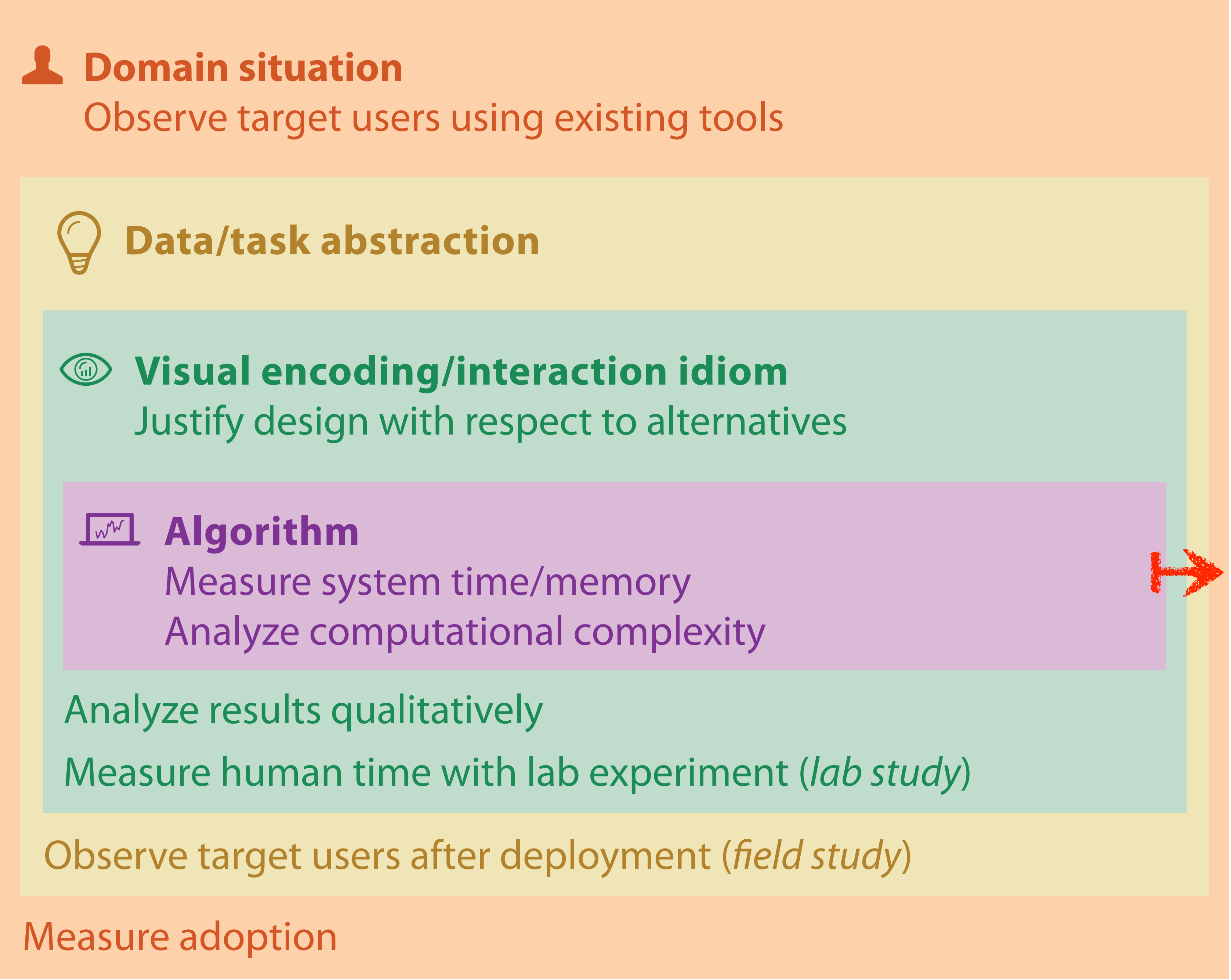
anthropology/ ethnography

design

computer science

cognitive psychology

anthropology/ ethnography



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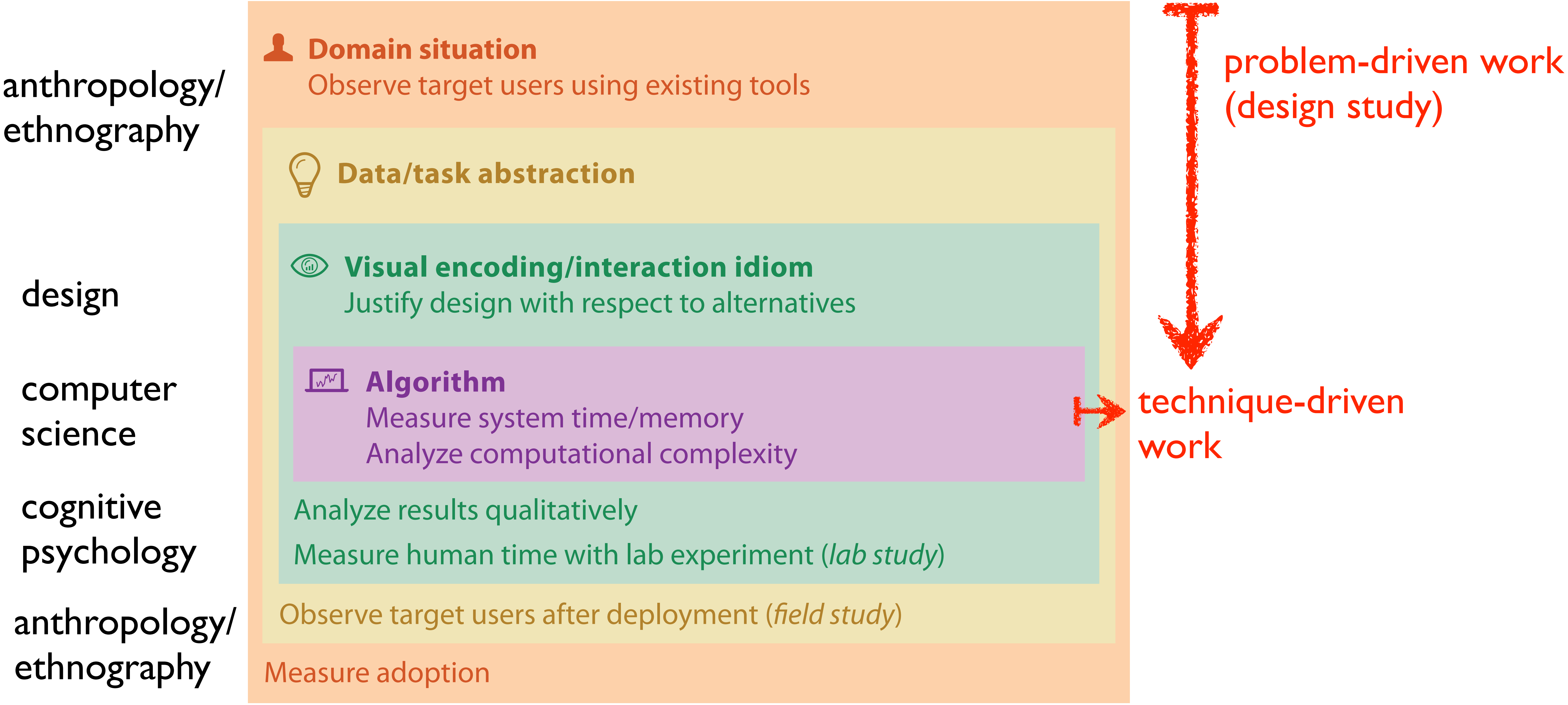

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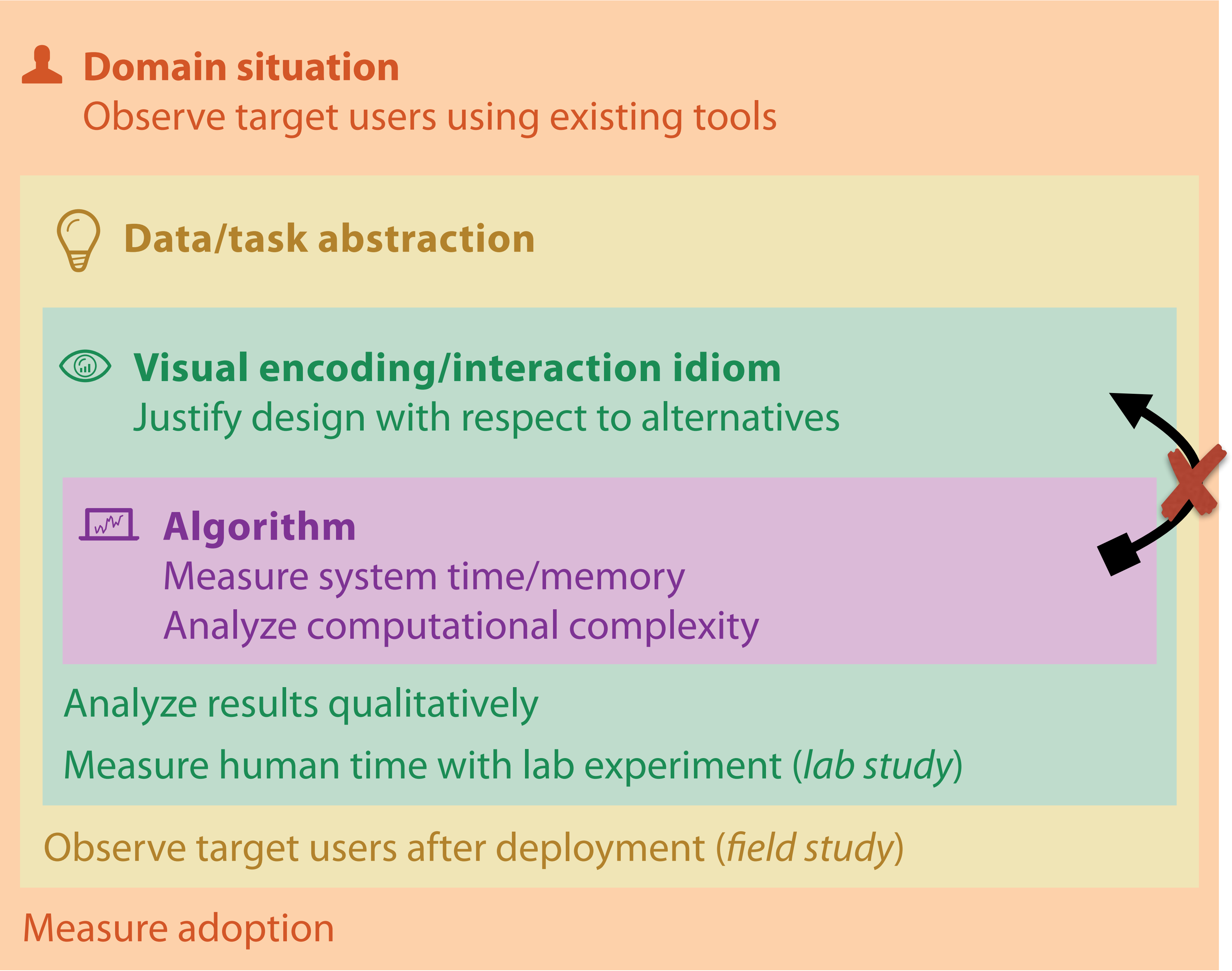
Avoid mismatches



computational benchmarks do not confirm idiom design

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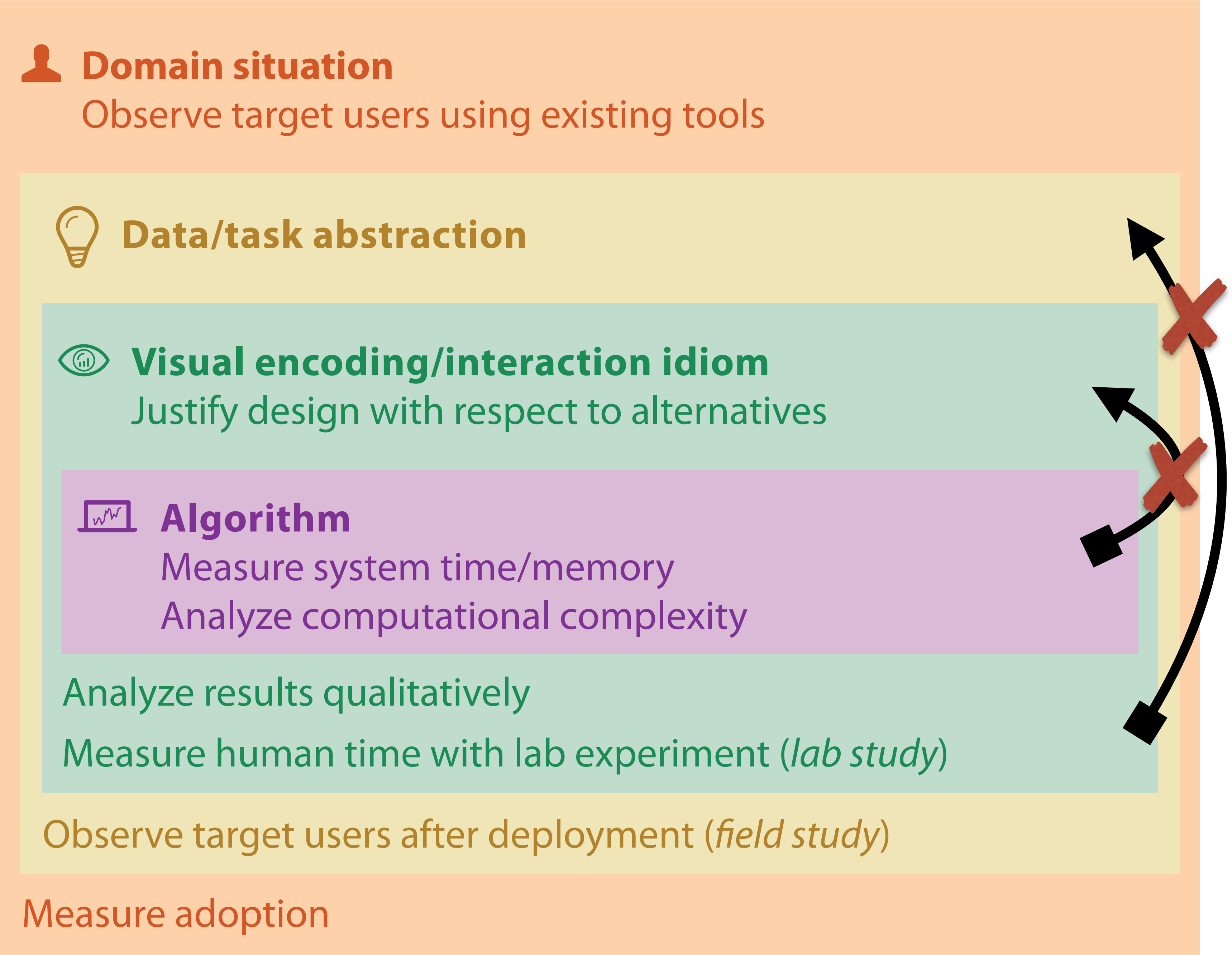

lab studies do not confirm task abstraction

computational benchmarks do not confirm idiom design

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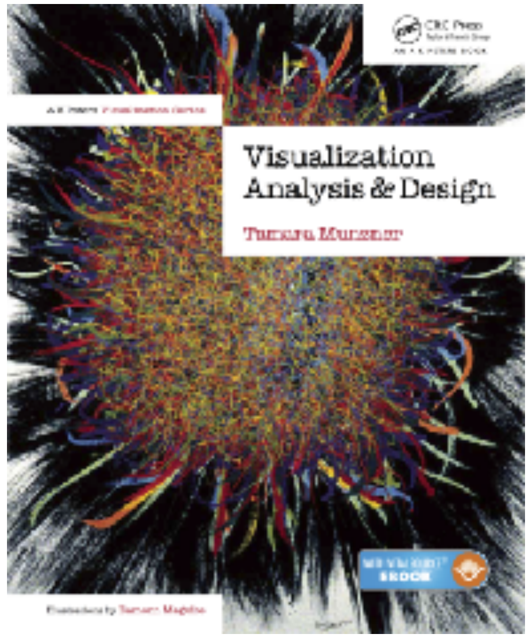
Visualization Analysis & Design

Data Abstraction (Ch 2)



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What does data mean?

What does data mean?

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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  - something else??

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Basil, 7, S, Pear

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  - something else??

Basil, 7, S, Pear

- What about this data?

What does data mean?

14, 2.6, 30, 30, 15, 100001

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Basil, 7, S, Pear

- What about this data?
  - food shipment of produce (basil & pear) arrived in satisfactory condition on 7th day of month

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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?

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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
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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
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Items & Attributes

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

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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"

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  - "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
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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

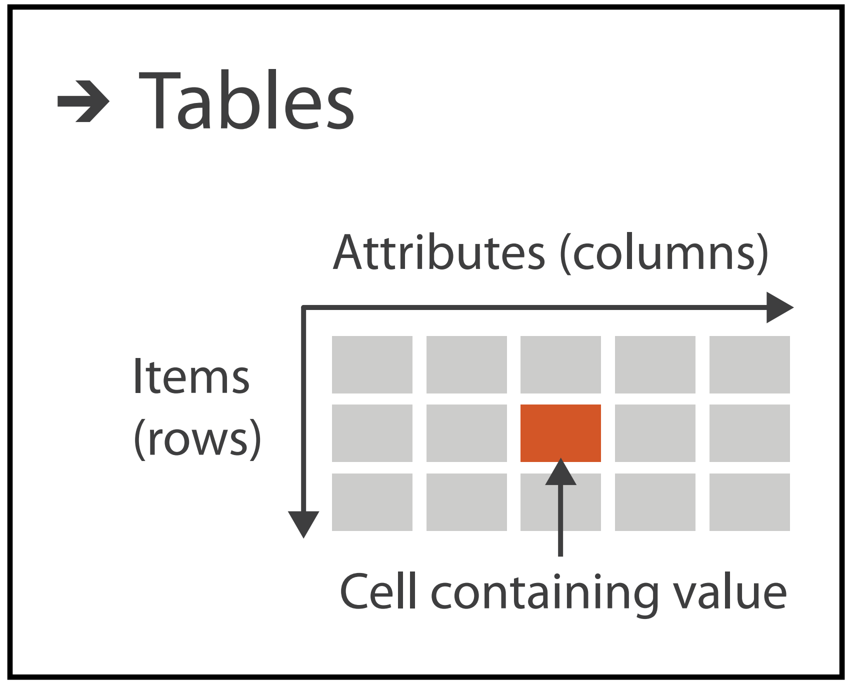
Dataset types

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

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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

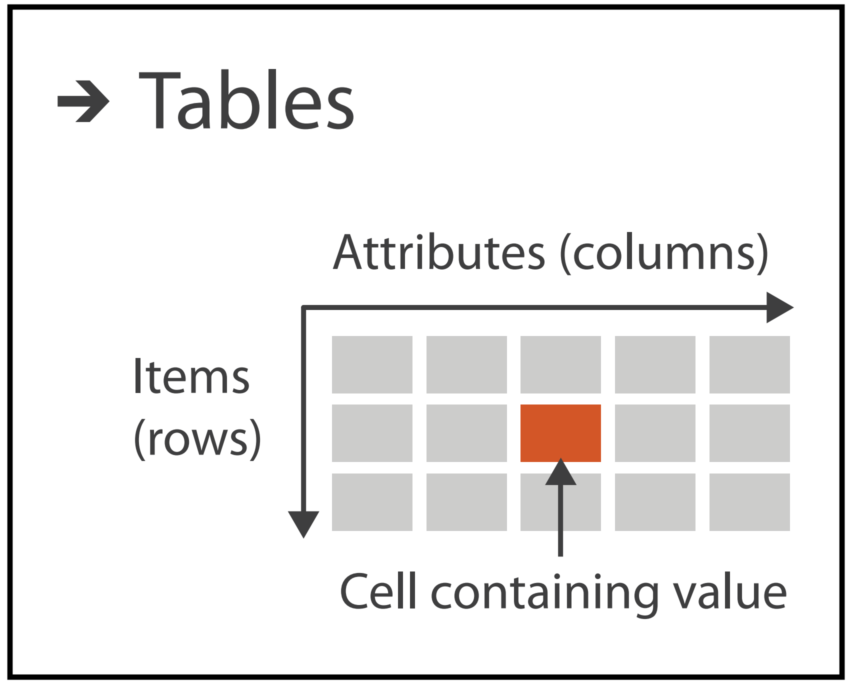
Dataset types

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
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

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

item

attribute

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

item

cell

attribute

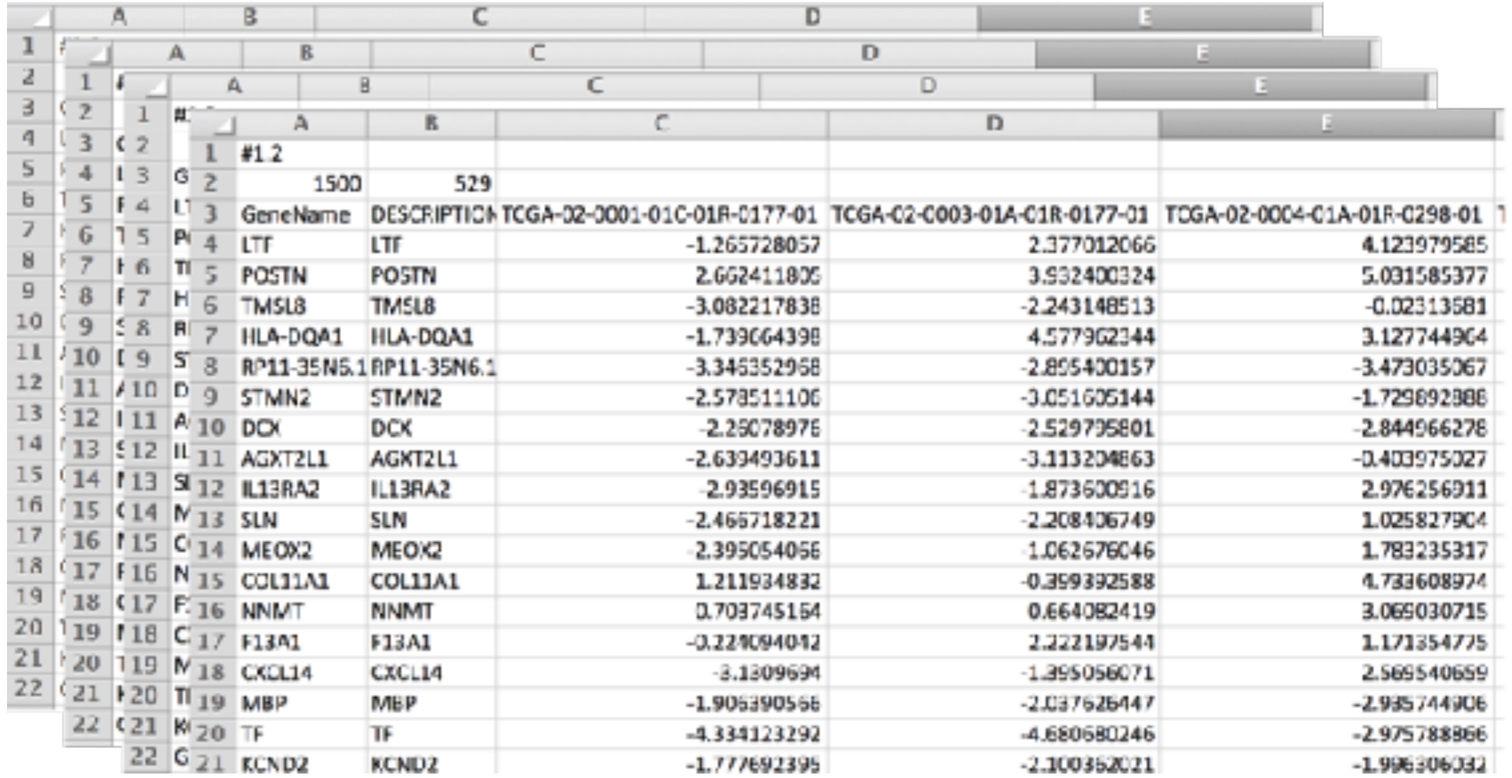
Dataset types

Tables

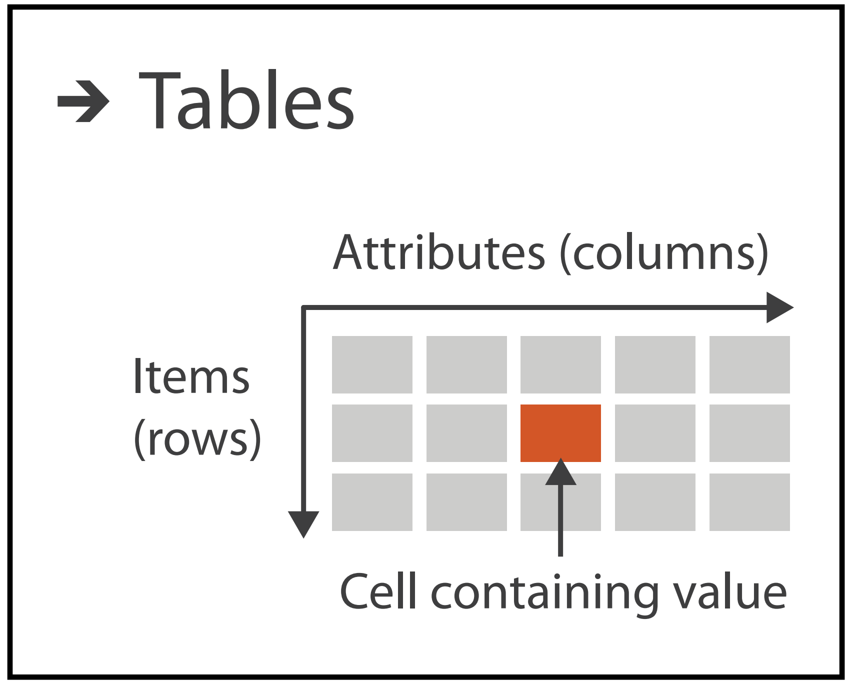
Items

Attributes

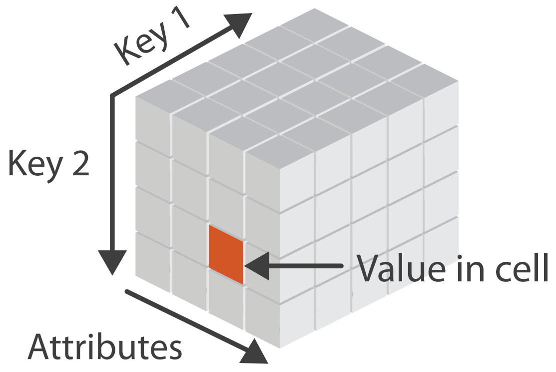
- multidimensional tables
  - –indexing based on multiple keys
    - eg genes, patients



	A	B	C	D	E
1	#1.2				
2	1500	529			
3	GeneName	DESCRIPTION	TCGA-02-0001-01C-01R-0177-01	TCGA-02-0003-01A-01R-0177-01	TCGA-02-0004-01A-01R-0298-01
4	LTF	LTF	-1.265728057	2.377012066	4.123979585
5	POSTN	POSTN	2.662411805	3.932400324	5.031585377
6	TMSL8	TMSL8	-3.082217838	-2.243148513	-0.02313581
7	HLA-DQA1	HLA-DQA1	-1.739664398	4.577962344	3.127744964
8	RP11-35N6.1	RP11-35N6.1	-3.346352968	-2.895400157	-3.473035067
9	STMN2	STMN2	-2.578511106	-3.051605144	-1.729892888
10	DCX	DCX	-2.25078976	-2.529795801	-2.844966278
11	AGXT2L1	AGXT2L1	-2.639493611	-3.113204863	-0.403975027
12	IL13RA2	IL13RA2	-2.93596915	-1.873600916	2.976256911
13	SLN	SLN	-2.466718221	-2.208406749	1.025827904
14	MEOX2	MEOX2	-2.395054056	-1.062676046	1.783235317
15	COL11A1	COL11A1	1.211934832	-0.359392588	4.733608974
16	NNMT	NNMT	0.703745164	0.664082419	3.069030715
17	F13A1	F13A1	-0.224094042	2.222197544	1.171354775
18	CXCL14	CXCL14	-3.1309694	-1.395056071	2.569540659
19	MBP	MBP	-1.906390566	-2.037626447	-2.985744906
20	TF	TF	-4.334123292	-4.680680246	-2.975788866
21	KCND2	KCND2	-1.777692395	-2.100362021	-1.996306032



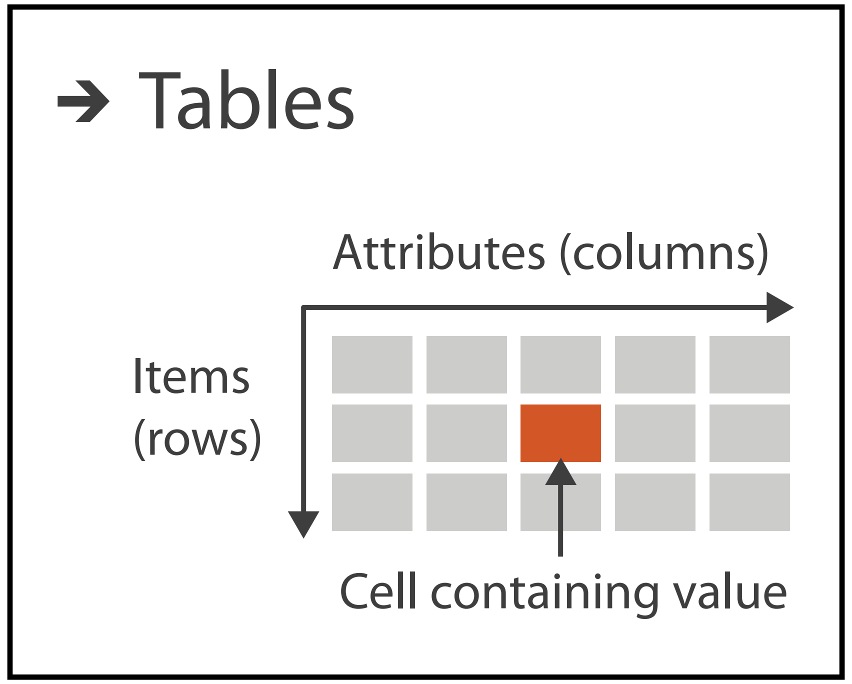
→ *Multidimensional Table*

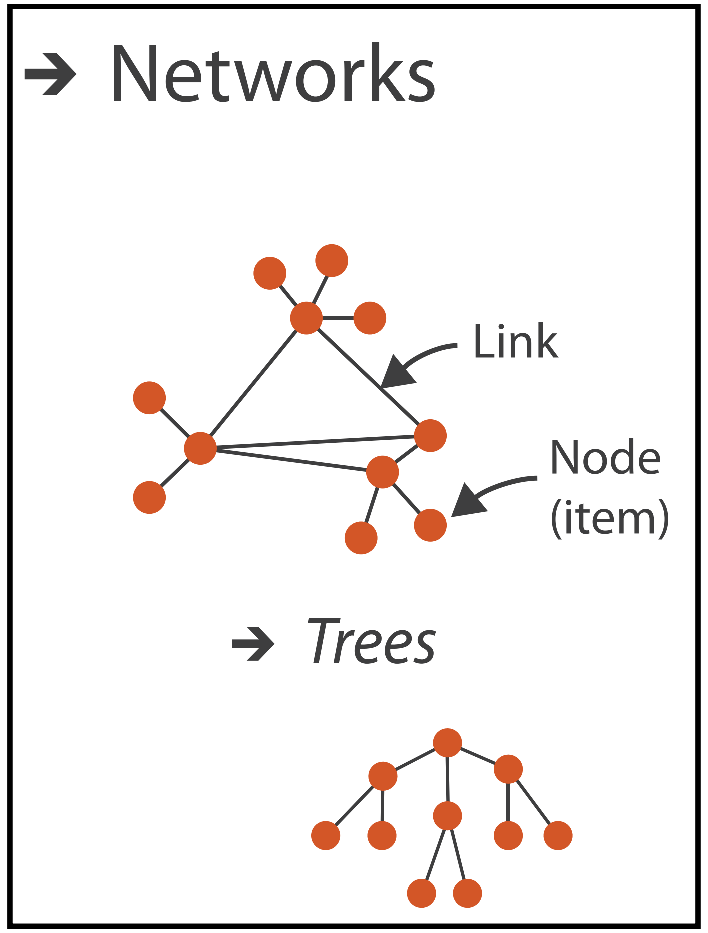


Dataset types

Tables	Networks & Trees
Items	Items (nodes)
Attributes	Links
	Attributes

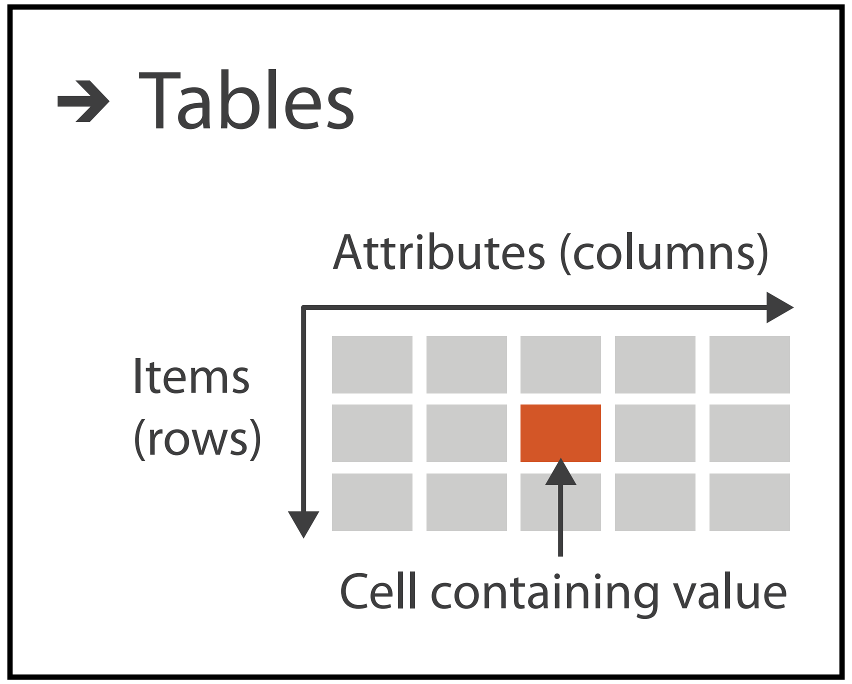
- network/graph
  - –nodes (vertices) connected by links (edges)
  - –tree is special case: no cycles
    - often have roots and are directed

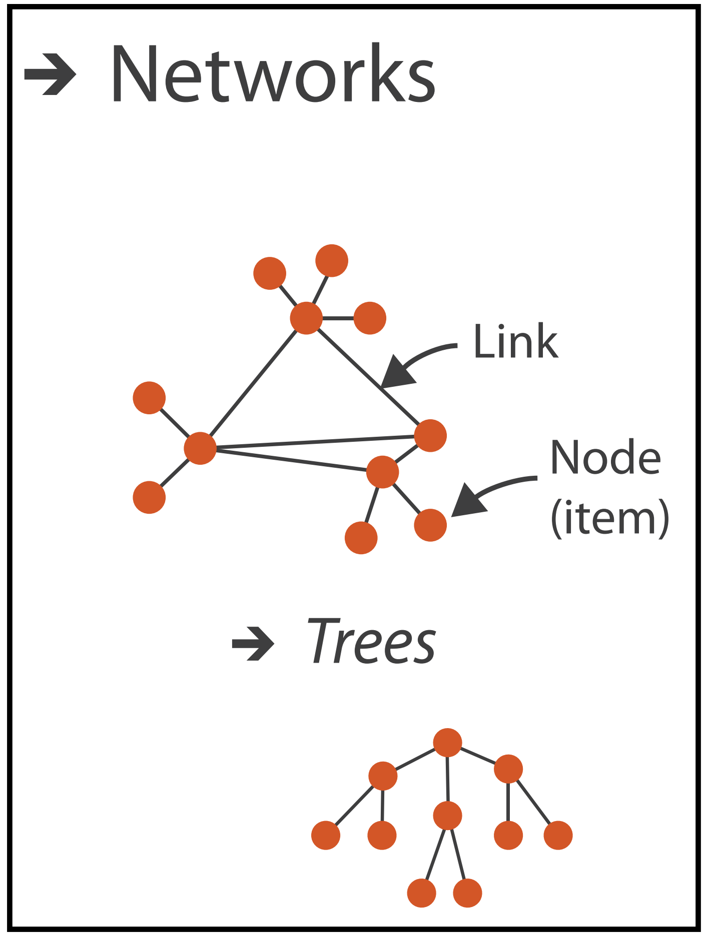


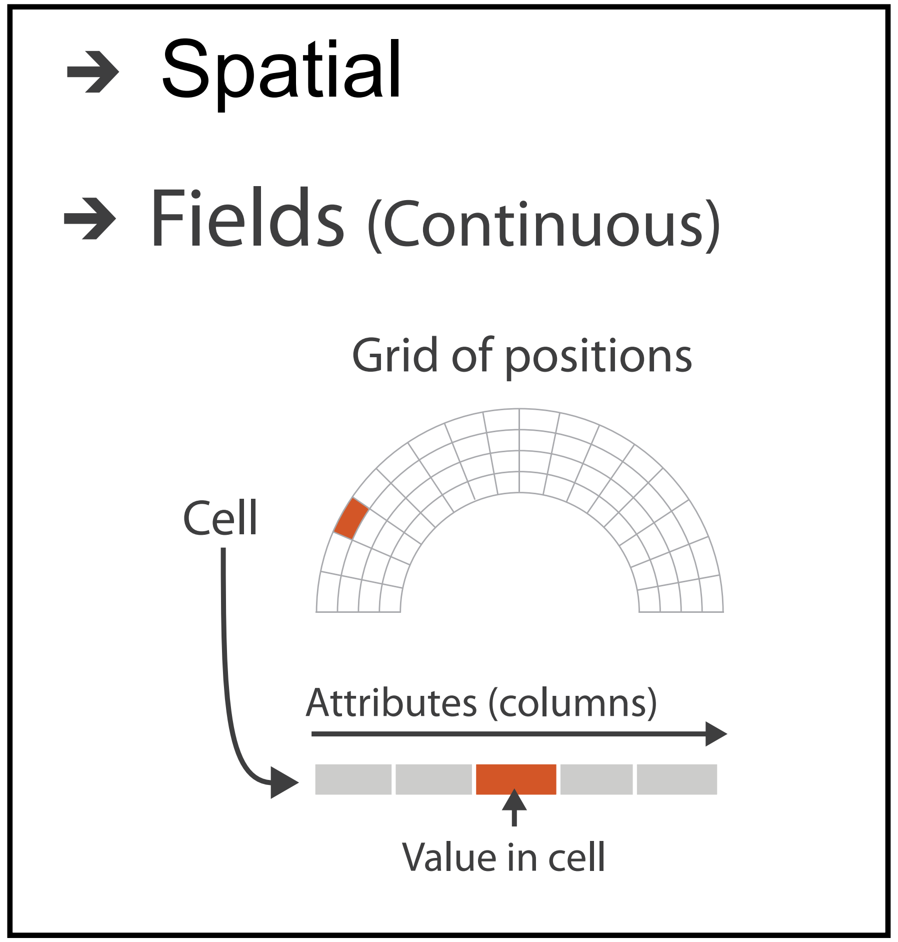


Dataset types

Tables	Networks & Trees	Fields
Items	Items (nodes)	Grids
Attributes	Links	Positions
	Attributes	Attributes

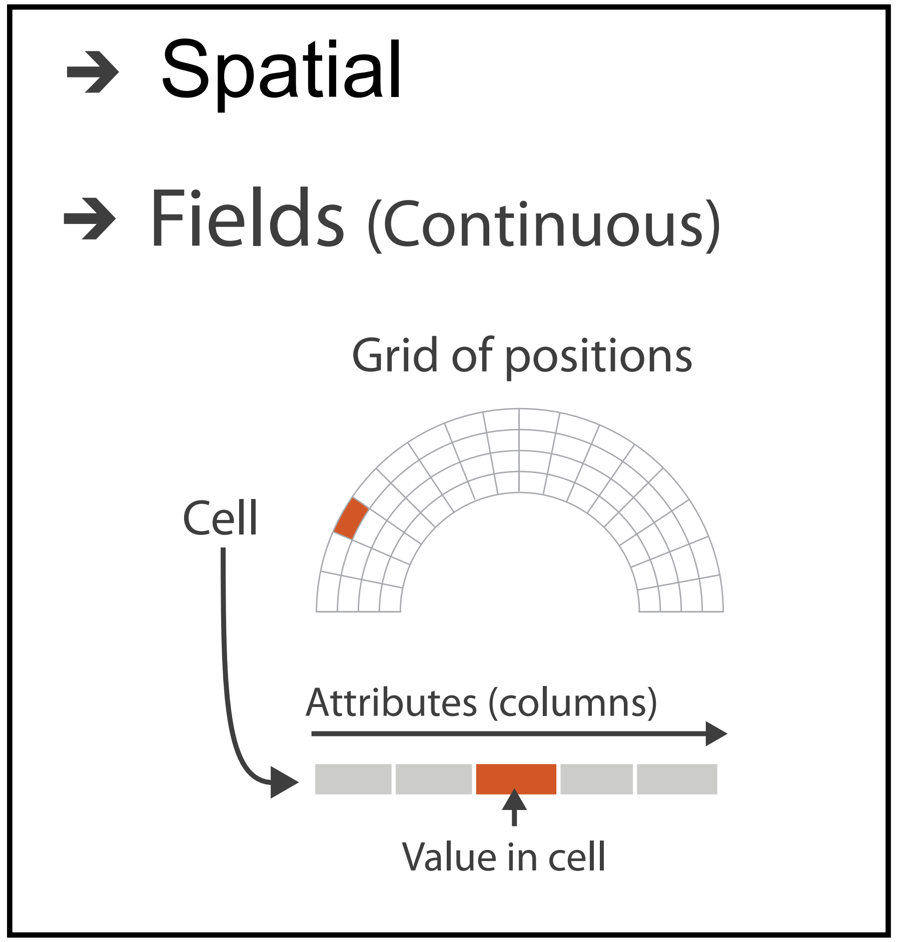


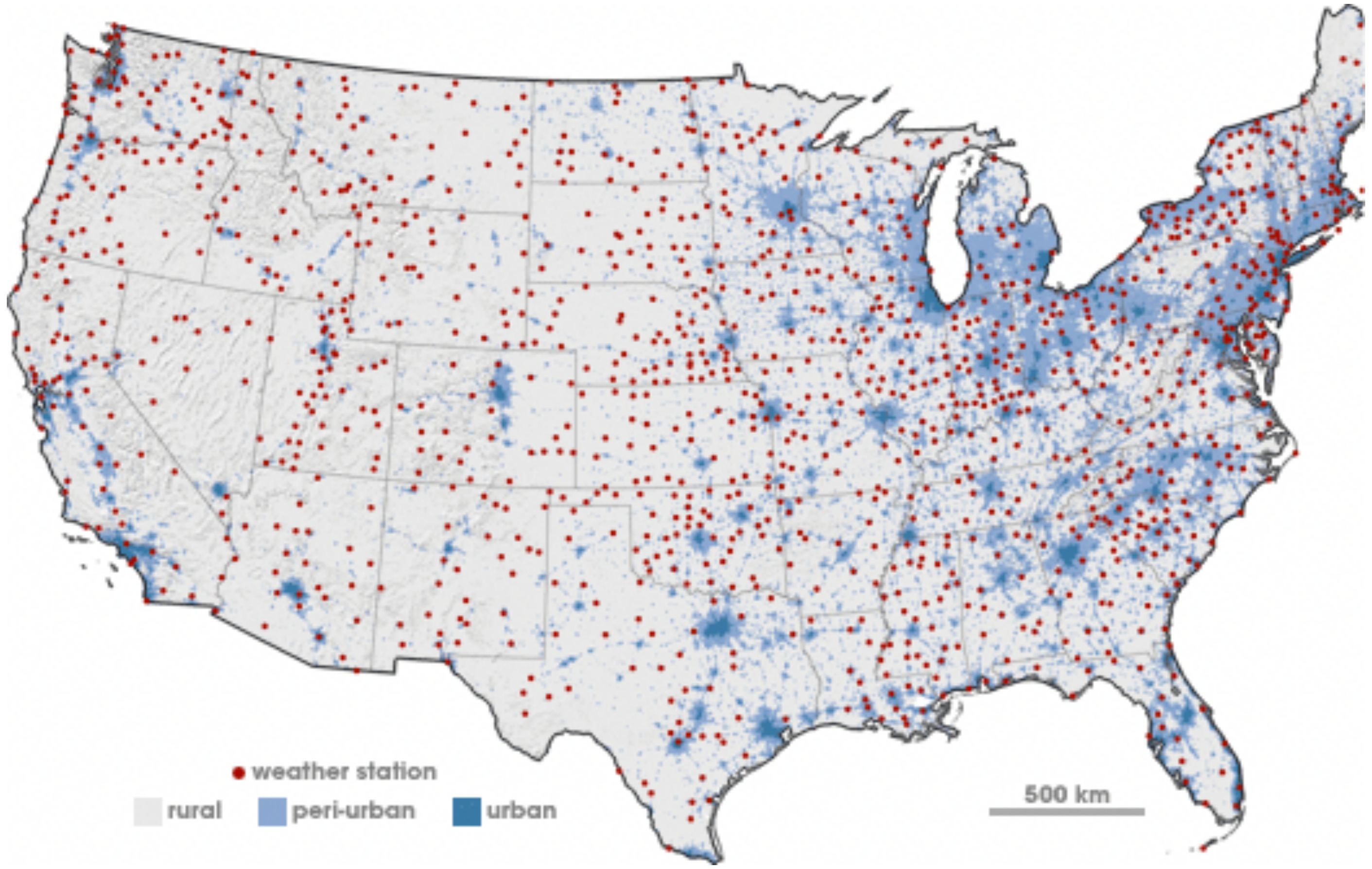




Spatial fields

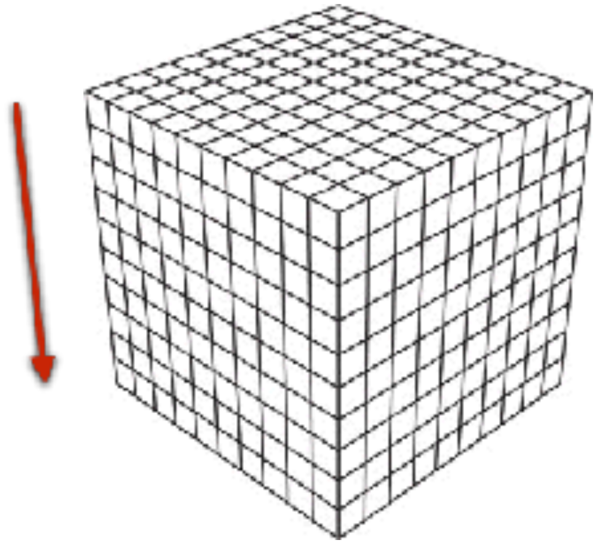
- attribute values associated w/ cells
- cell contains value from continuous domain
  - eg temperature, pressure, wind velocity
- measured or simulated

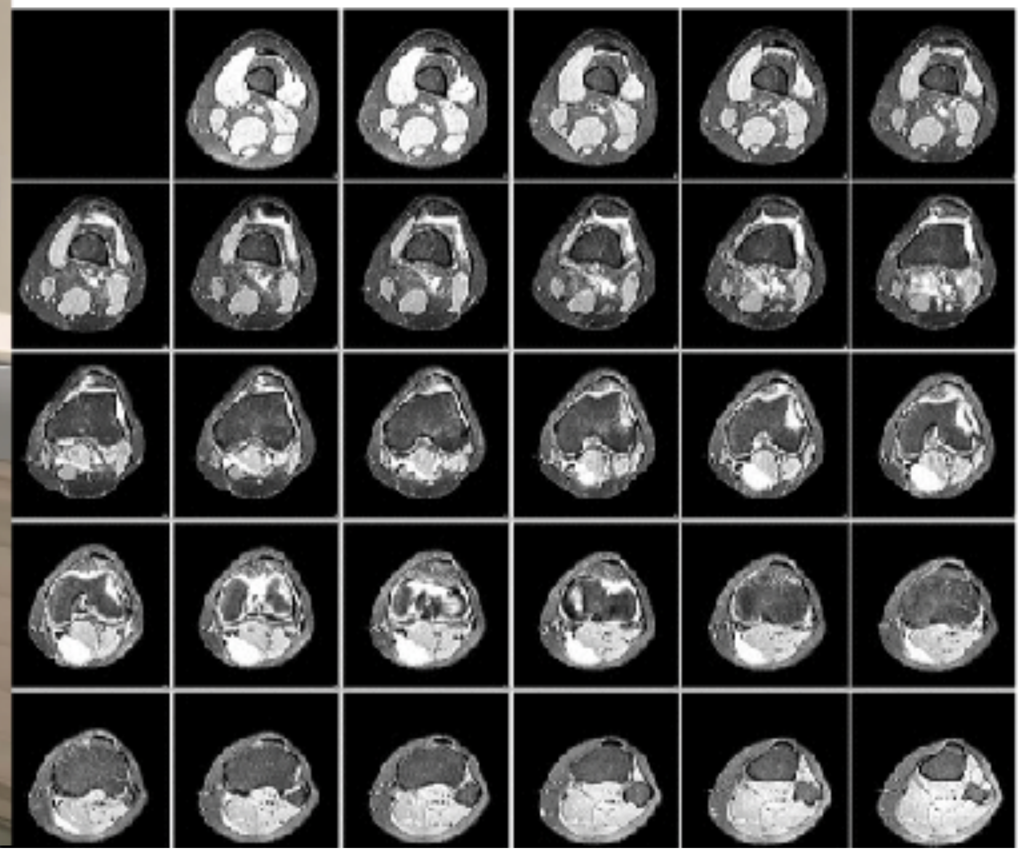




Spatial fields

- 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

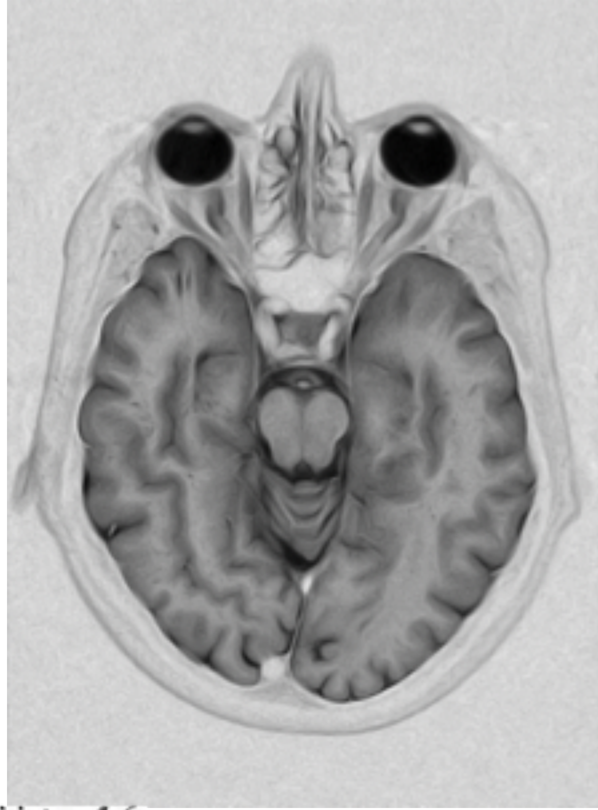




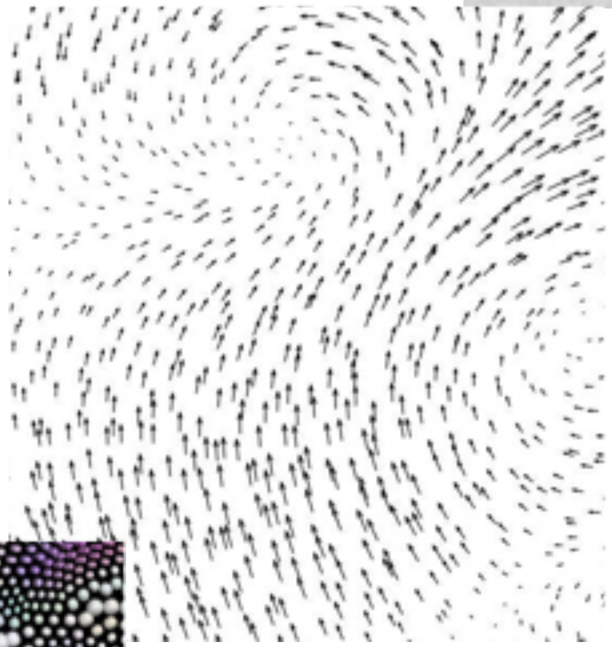
Spatial fields

- 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)

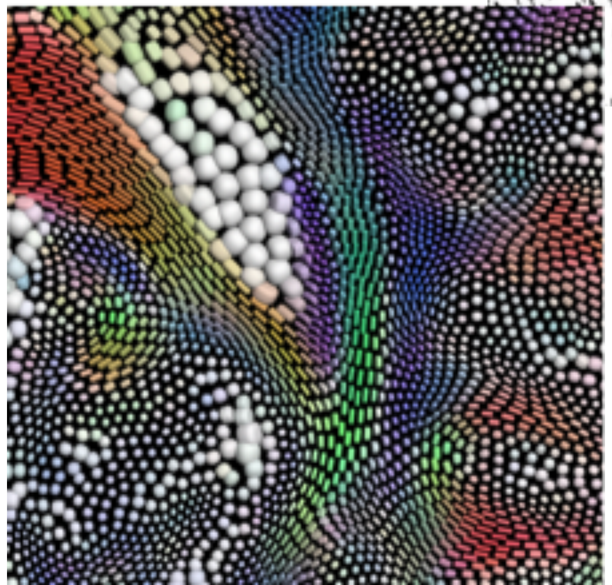
scalar



vector



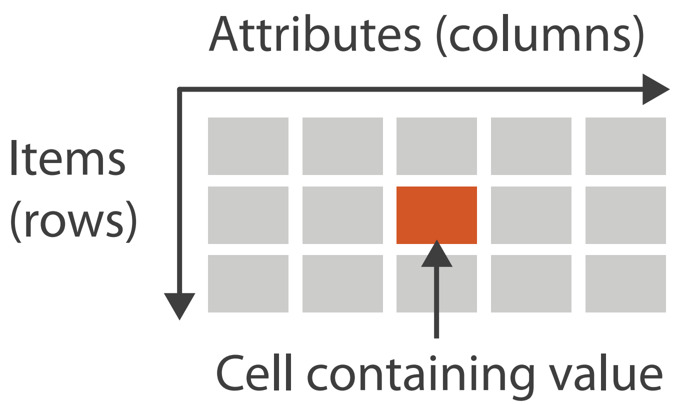
tensor



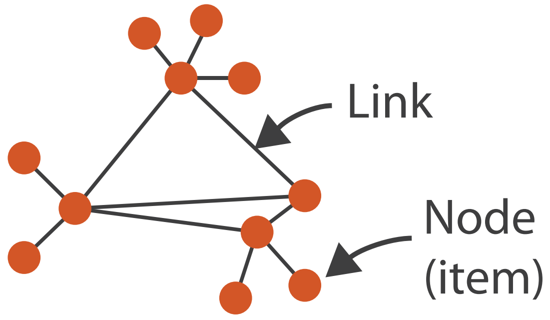
Dataset types

Tables	Networks & Trees	Fields	Geometry
Items	Items (nodes)	Grids	Items
Attributes	Links	Positions	Positions
	Attributes	Attributes	

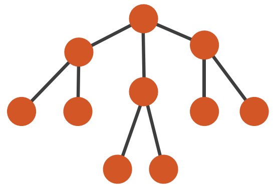
➔ Tables



➔ Networks

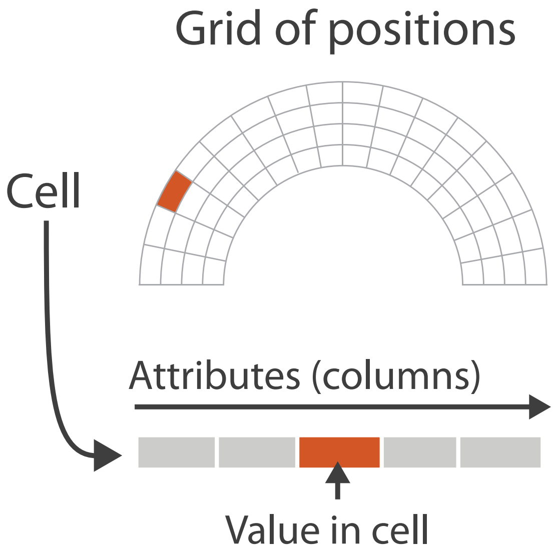


➔ *Trees*

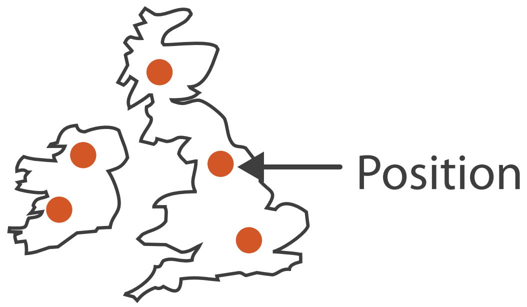


➔ Spatial

➔ Fields (Continuous)

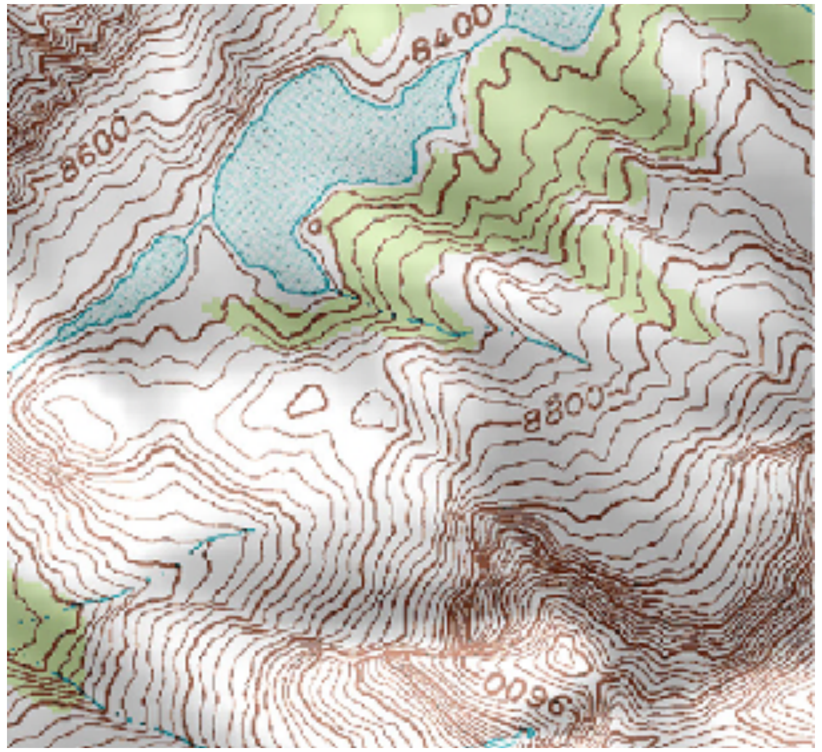


➔ Geometry (Spatial)



Geometry

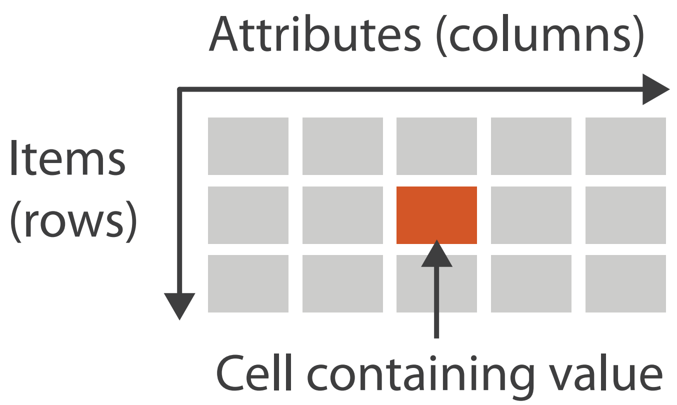
- shape of items
- explicit spatial positions / regions
  - points, lines, curves, surfaces, volumes
- boundary between computer graphics and visualization
  - graphics: geometry taken as given
  - vis: geometry is result of a design decision



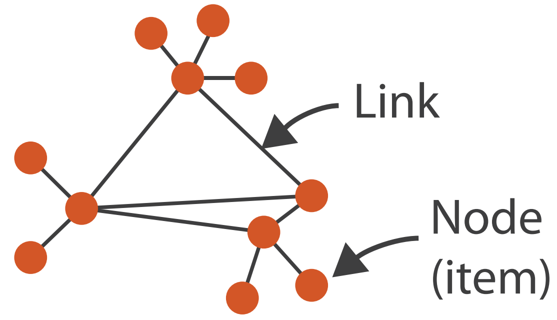
Dataset types

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

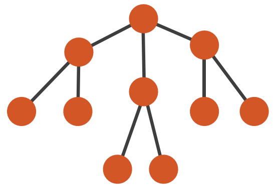
→ Tables



→ Networks

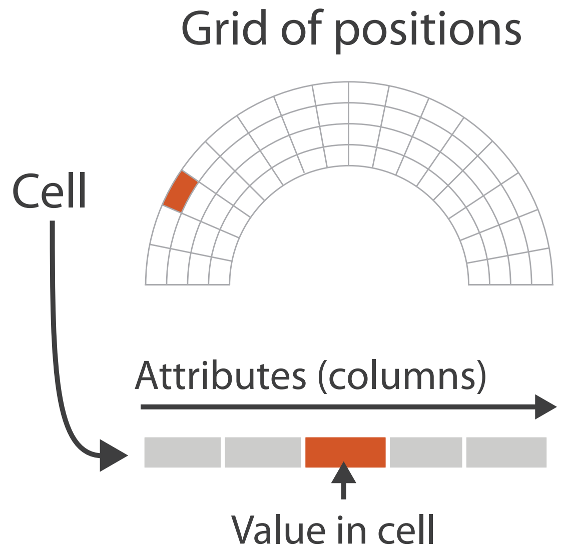


→ *Trees*

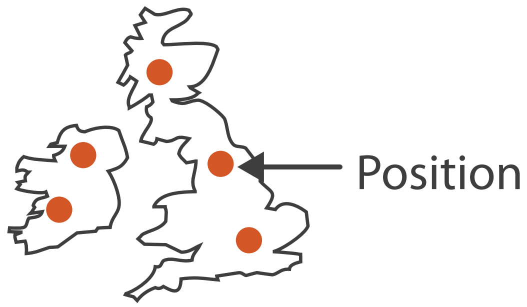


→ Spatial

→ Fields (Continuous)



→ Geometry (Spatial)

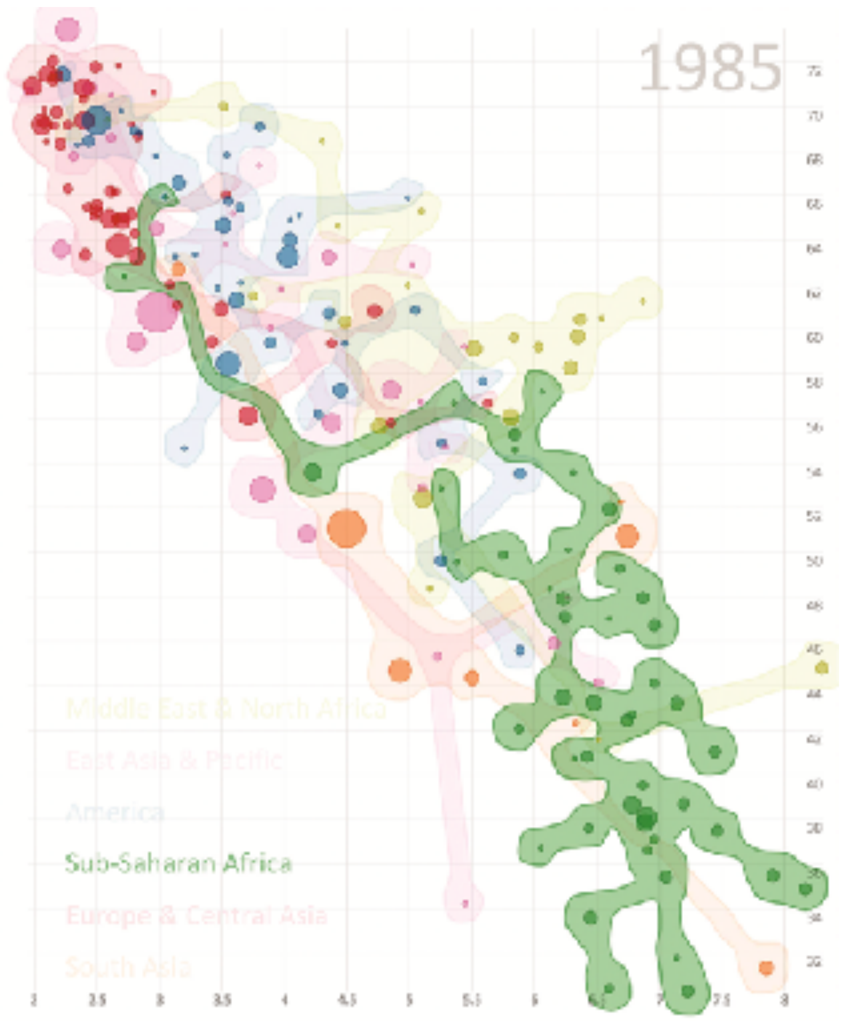


Collections

- how we group items

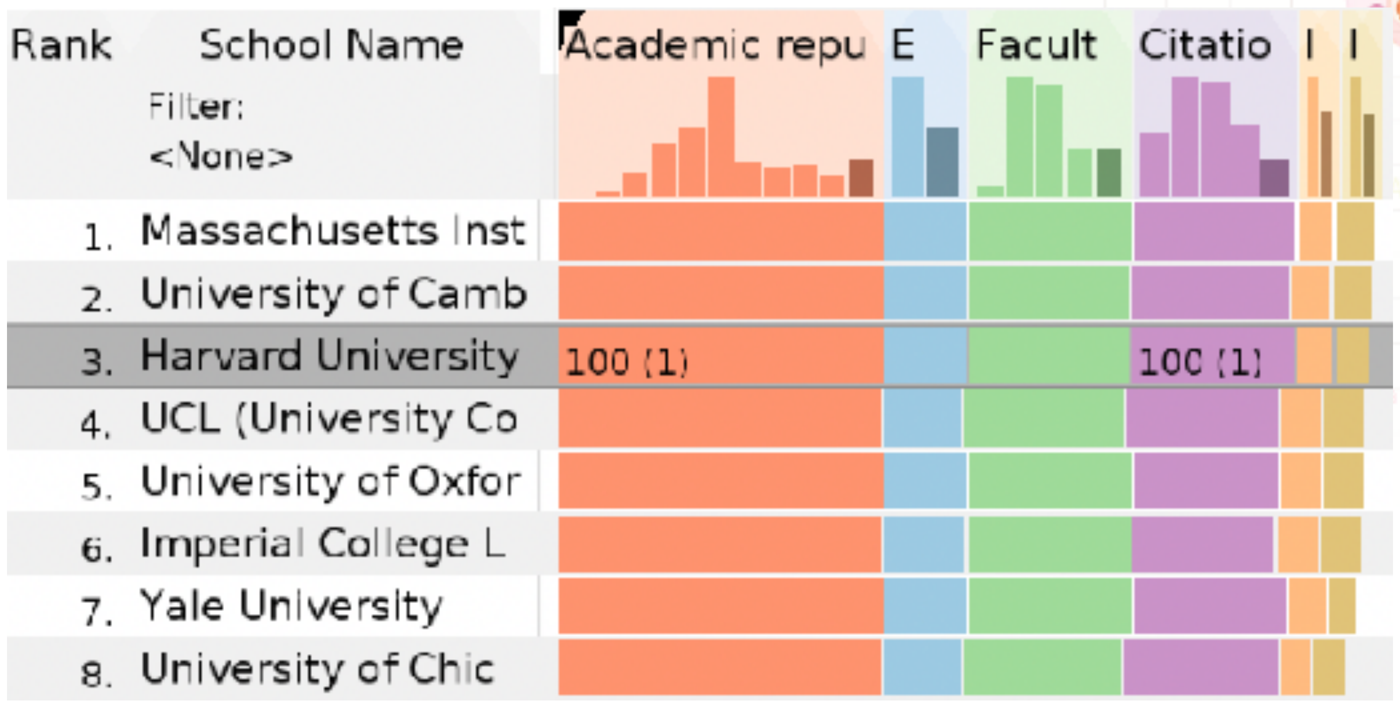
Collections

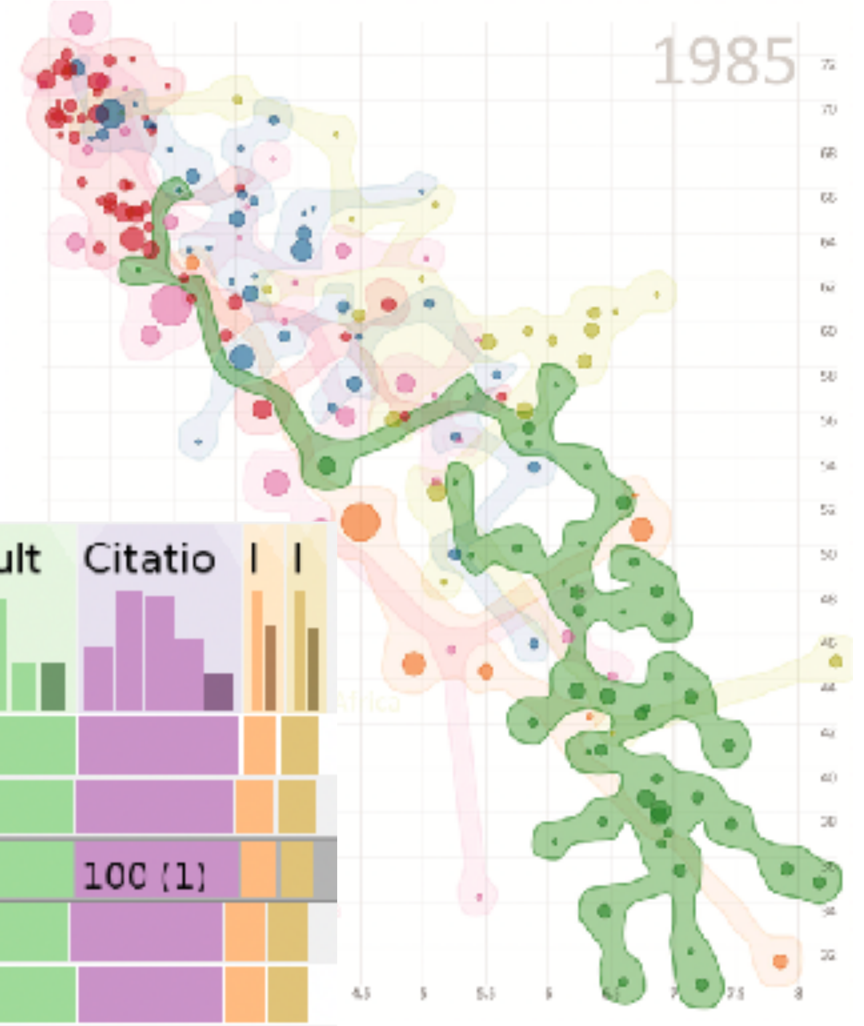
- how we group items
- sets
  - unique items, unordered



Collections

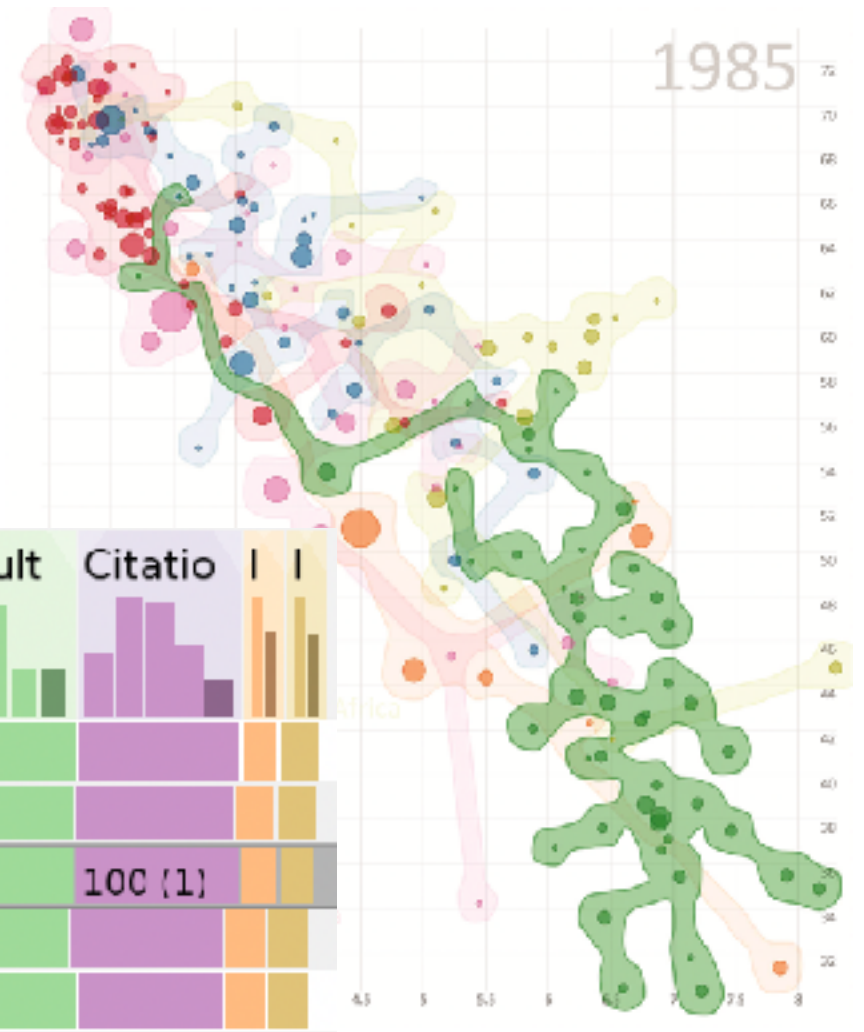
- how we group items
- sets
  - unique items, unordered
- lists
  - ordered, duplicates possible

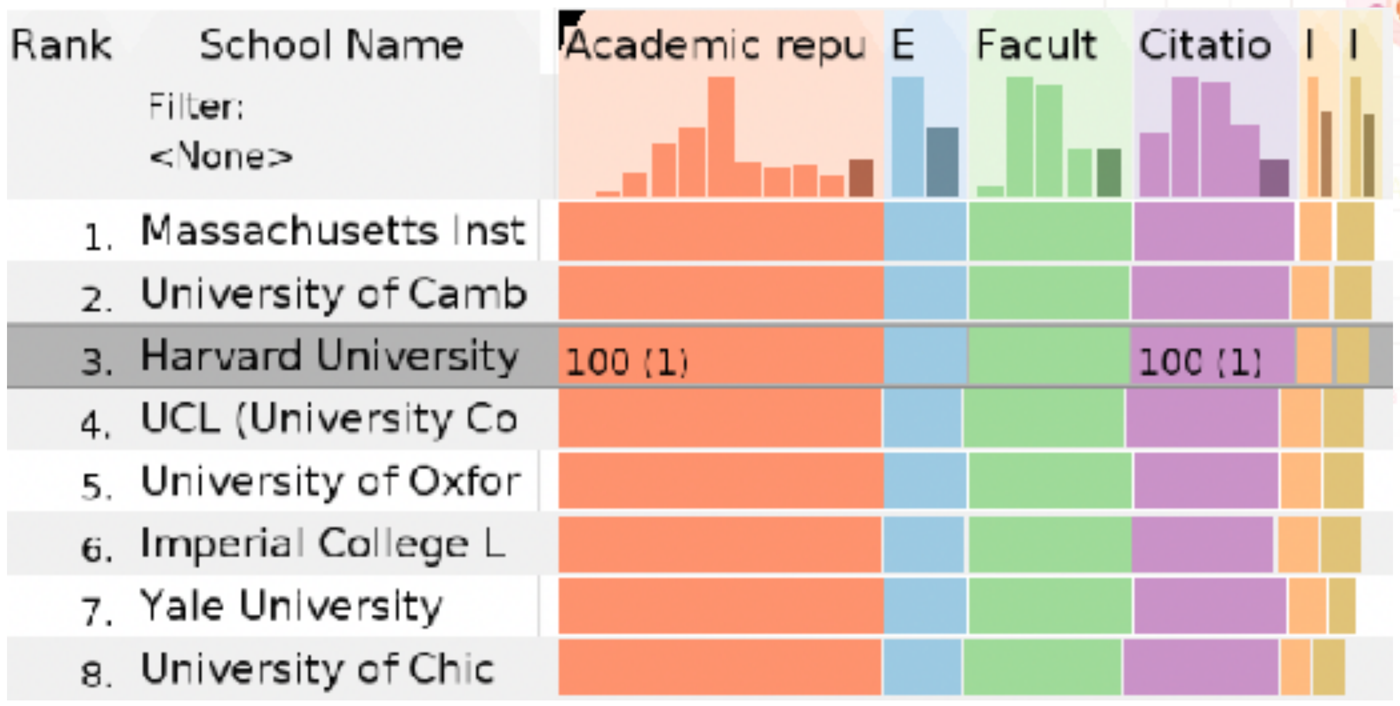


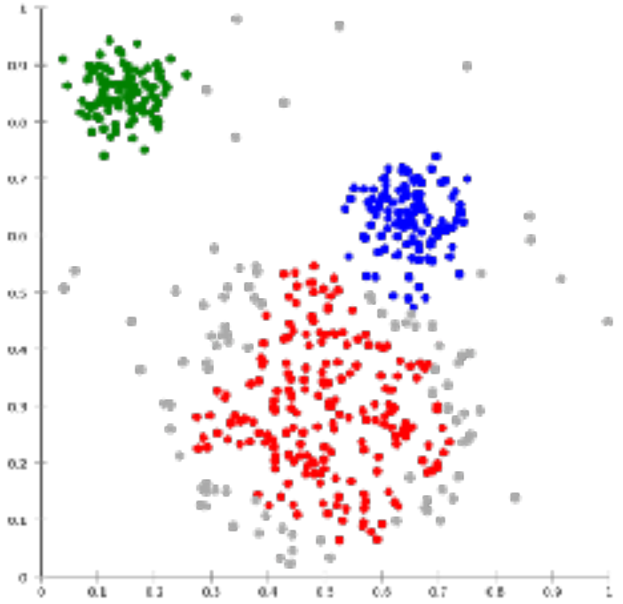


Collections

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







Dataset and data types

➔ Data and Dataset Types

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

➔ Data Types

➔ Items ➔ Attributes ➔ Links ➔ Positions ➔ Grids

Attribute types

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

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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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
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132	6/11/06	3-Medium	Medium Box	0.6	6/12/06
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134	5/1/08	4-Not Specified	Large Box	0.82	5/3/08
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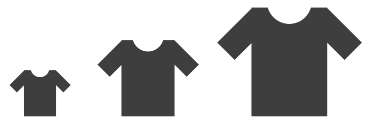
193	8/8/06	1-Urgent	Medium Box	0.57	8/10/06

Other data concerns

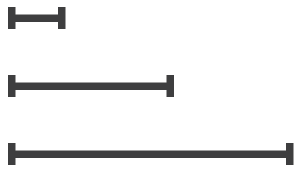
Attribute Types

- Categorical

- Ordered
  - *Ordinal*



  - *Quantitative*

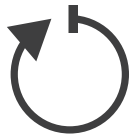


Ordering Direction

- Sequential

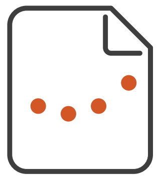
- Diverging

- Cyclic

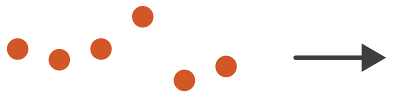


Dataset Availability

- Static



- Dynamic



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
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature

Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions

Data vs conceptual model, example

- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather

Data vs conceptual model, example

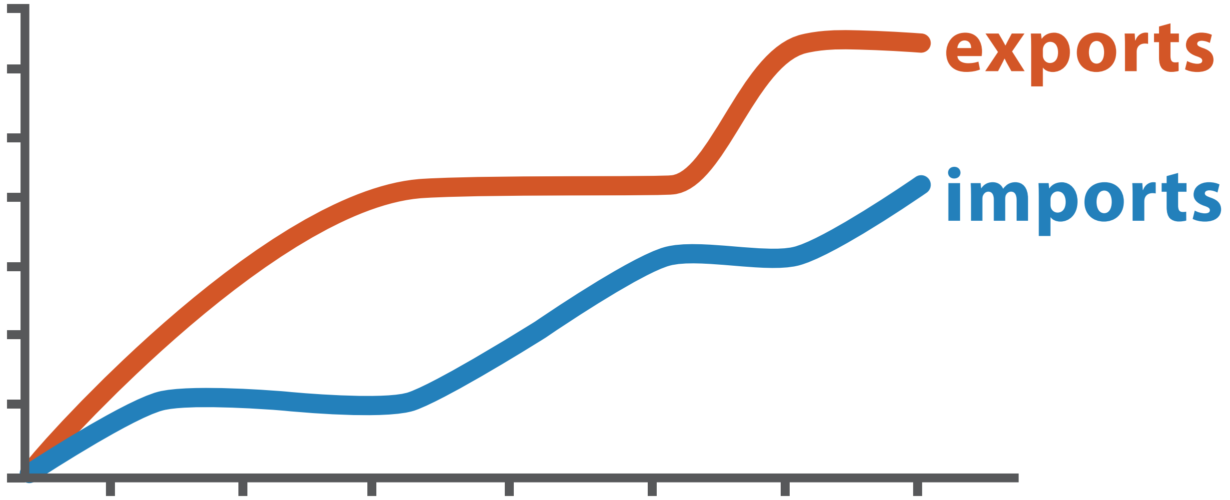
- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready

Data vs conceptual model, example

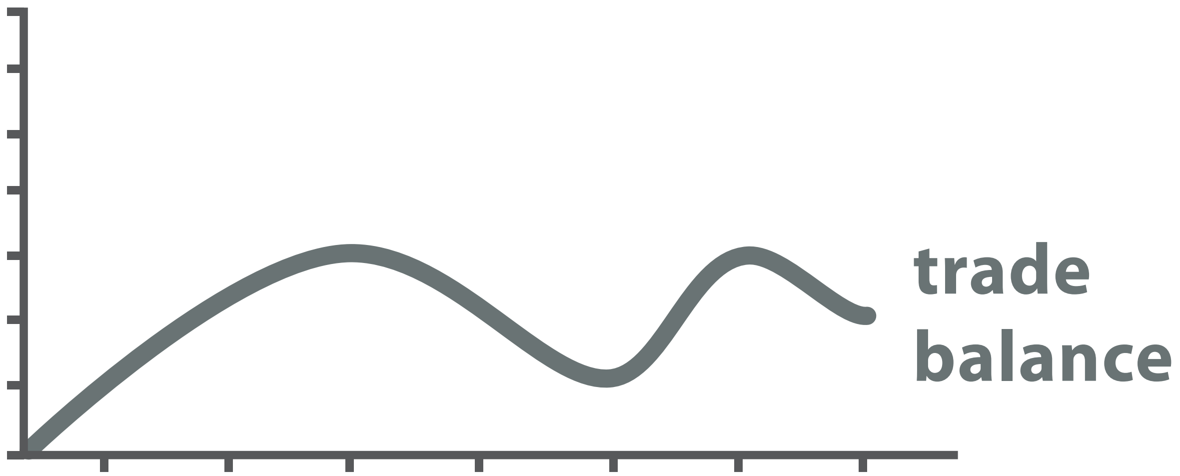
- data model: floats
  - 32.52, 54.06, -14.35, ...
- conceptual model
  - temperature
- multiple possible data abstractions
  - continuous to 2 significant figures: quantitative
    - task: forecasting the weather
  - hot, warm, cold: ordinal
    - task: deciding if bath water is ready
  - above freezing,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

Derived attributes

- derived attribute: compute from originals
  - simple change of type
  - acquire additional data
  - complex transformation



Original Data



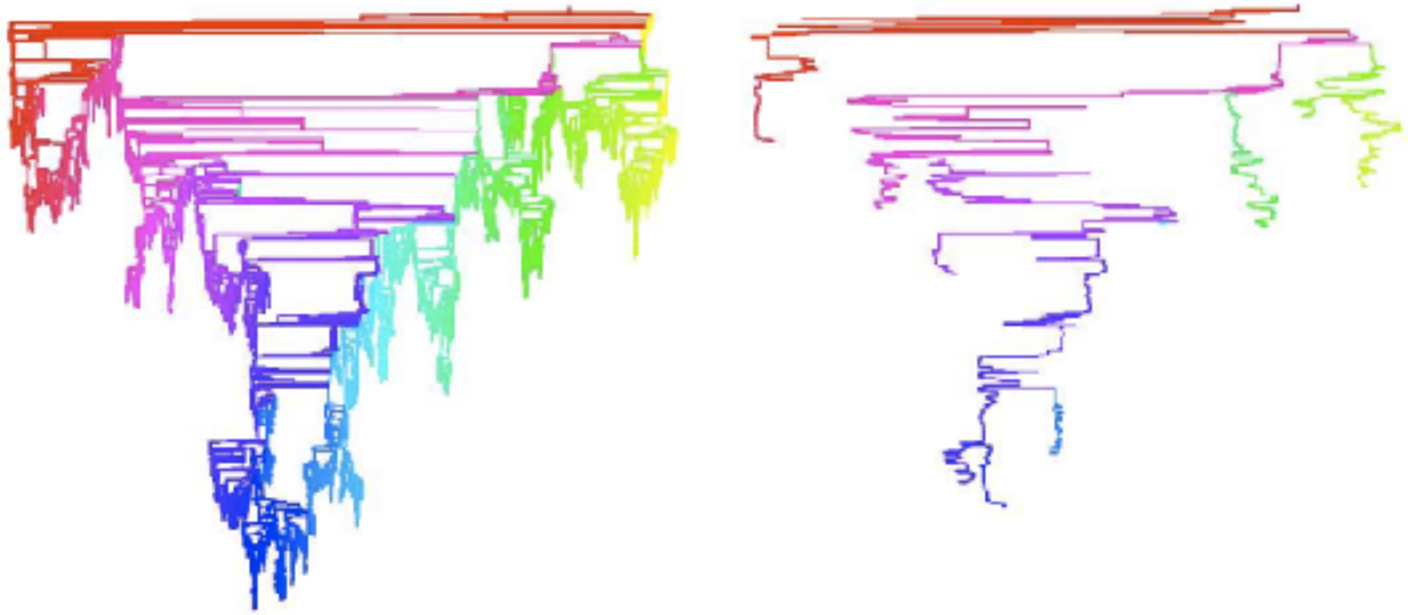
trade balance = exports − imports

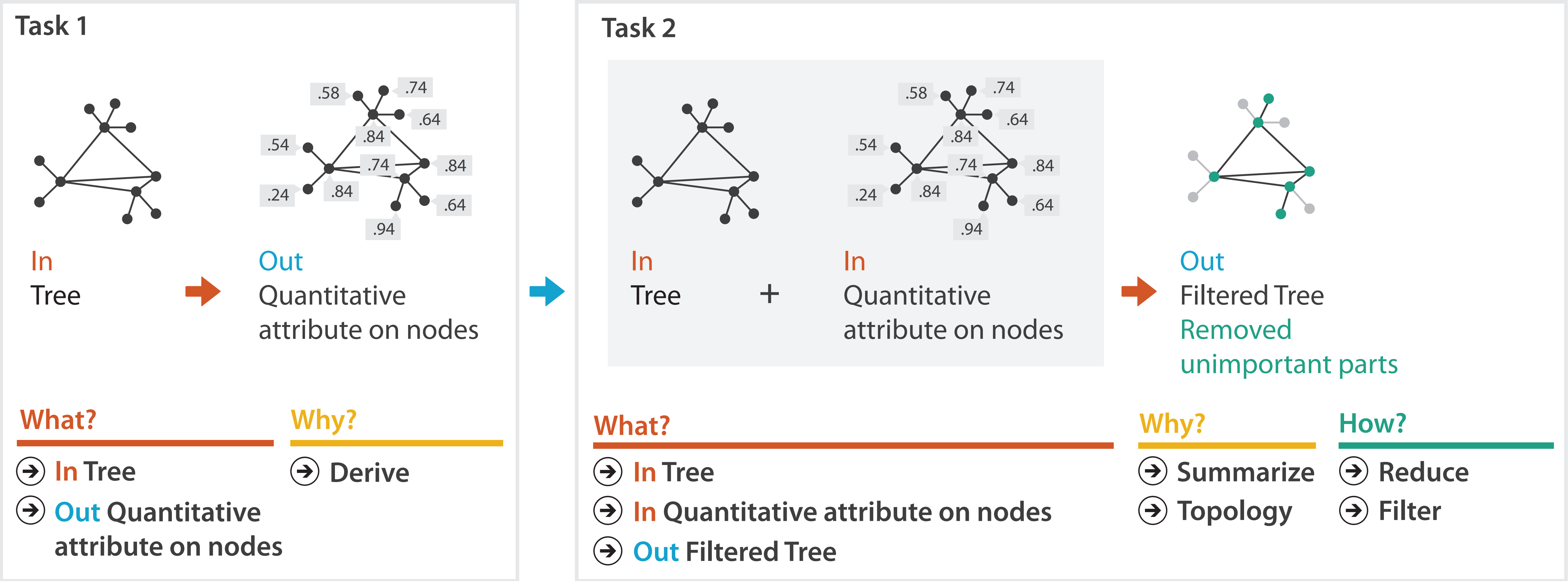
Derived Data

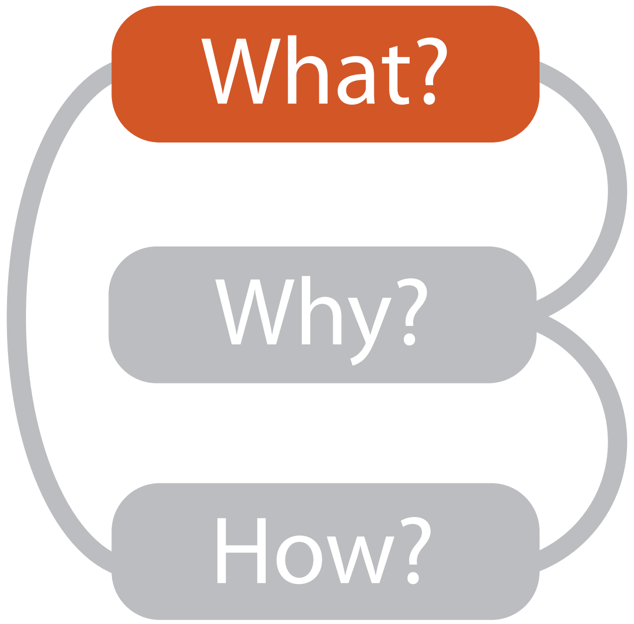
Analysis example: Derive one attribute

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

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







What?

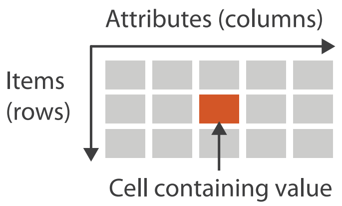
Datasets

Data Types
- Items
- Attributes
- Links
- Positions
- Grids

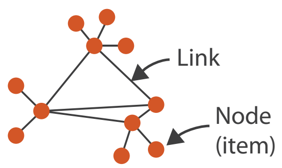
Data and Dataset Types

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

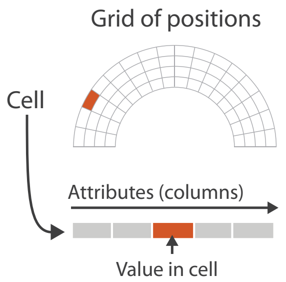
Dataset Types
- Tables



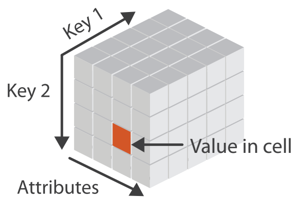
- Networks



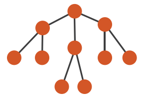
- Fields (Continuous)



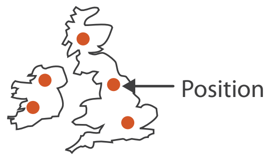
- *Multidimensional Table*



- *Trees*



- Geometry (Spatial)



Dataset Availability
- Static

- Dynamic

Attributes

Attribute Types
- Categorical

- Ordered
  - *Ordinal*

  - *Quantitative*

Ordering Direction
- Sequential

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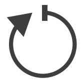
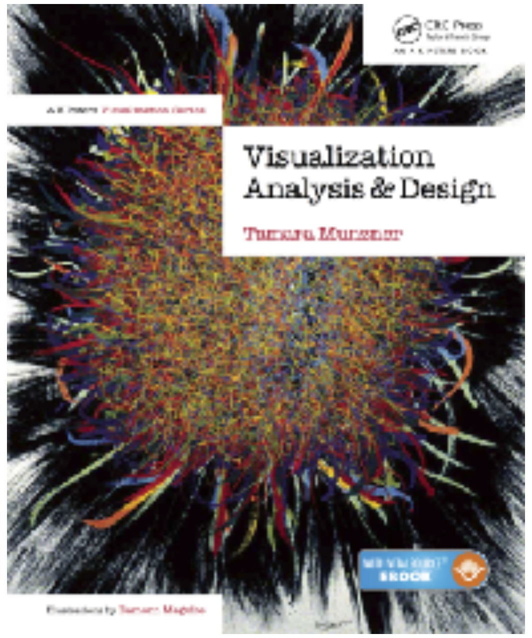


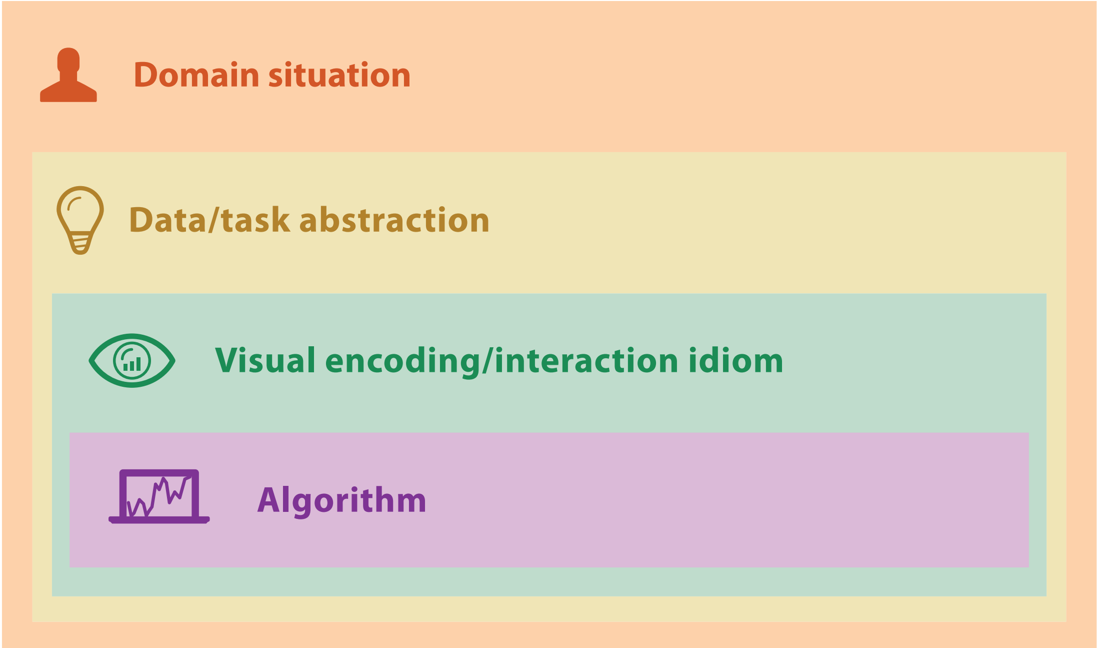


Visualization Analysis & Design

Task Abstraction (Ch 3)

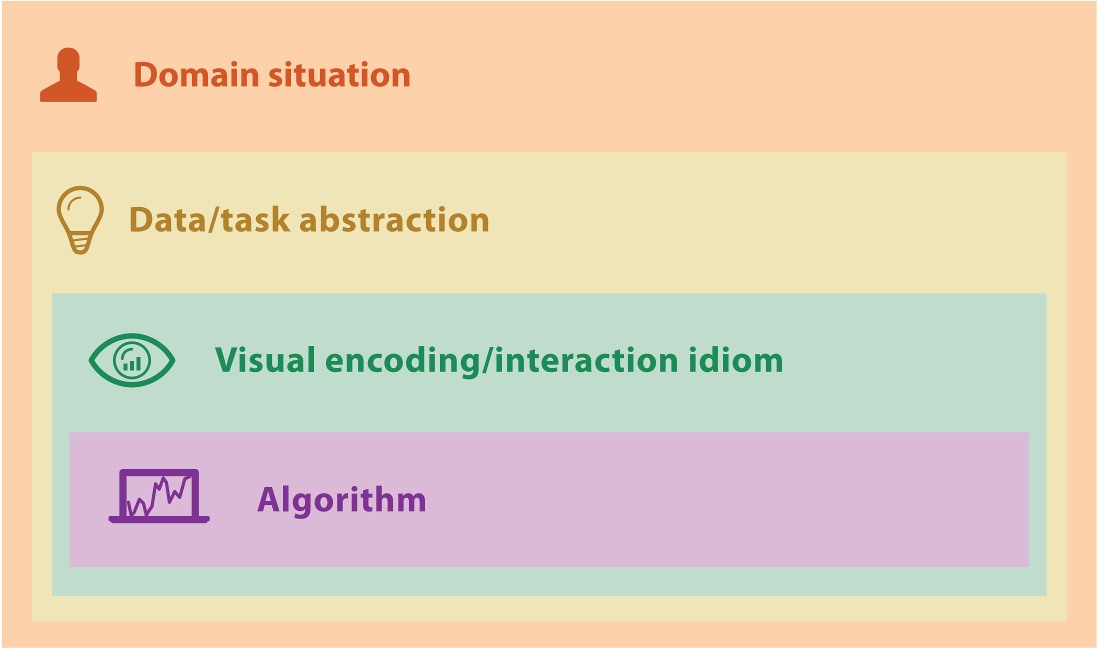
Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

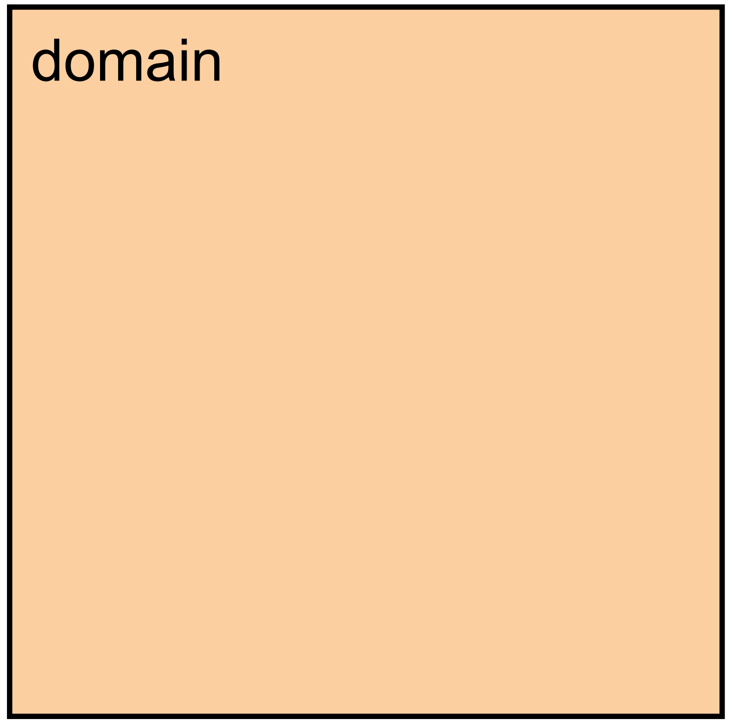
From domain to abstraction



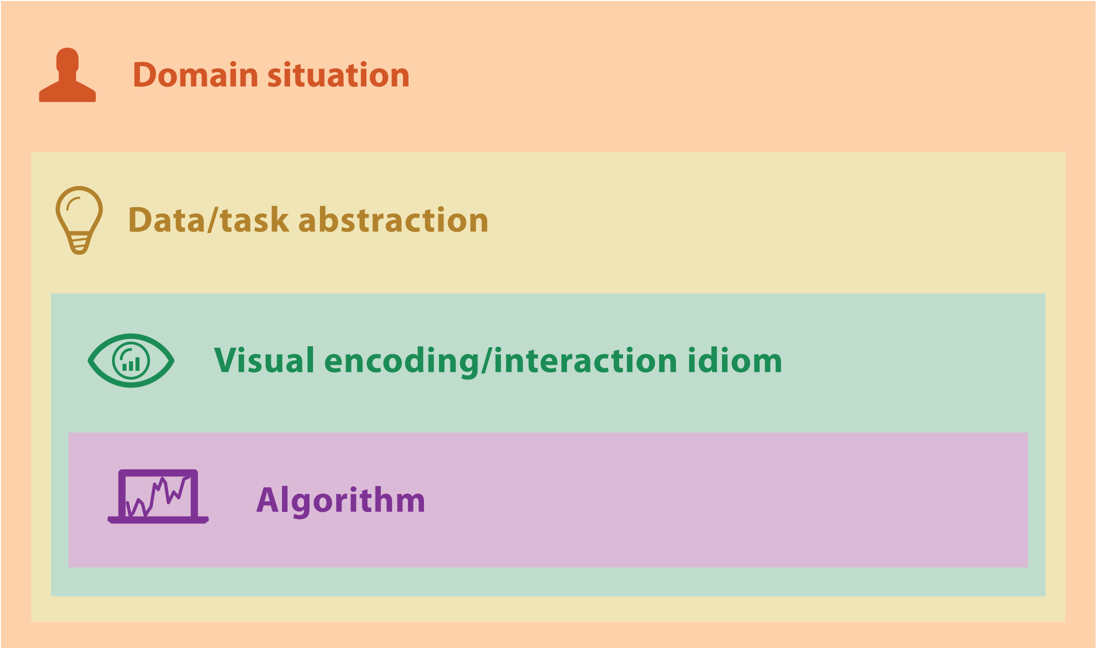
From domain to abstraction

- domain characterization:
  details of application domain

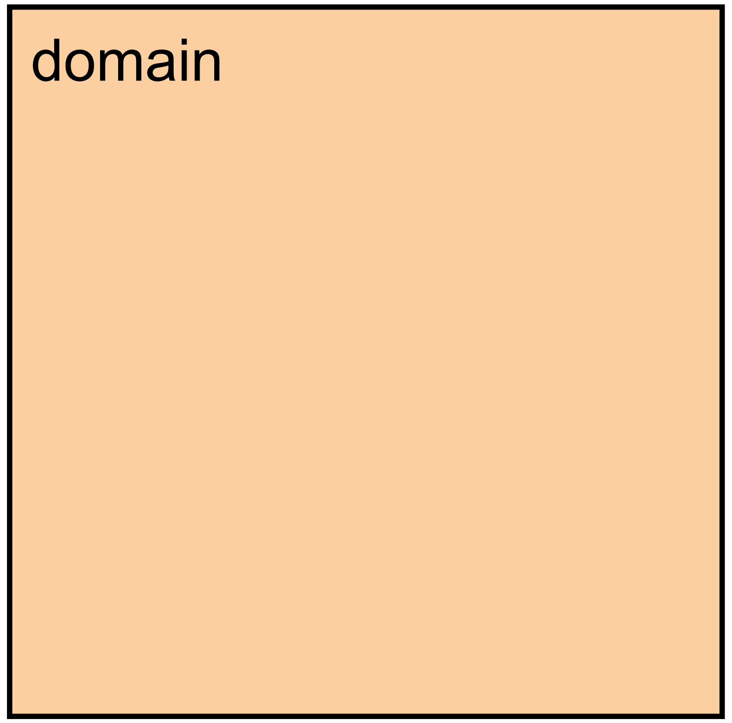




From domain to abstraction



- 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



From domain to abstraction

- domain characterization:
  details of application domain
  - group of users, target domain, their questions & data
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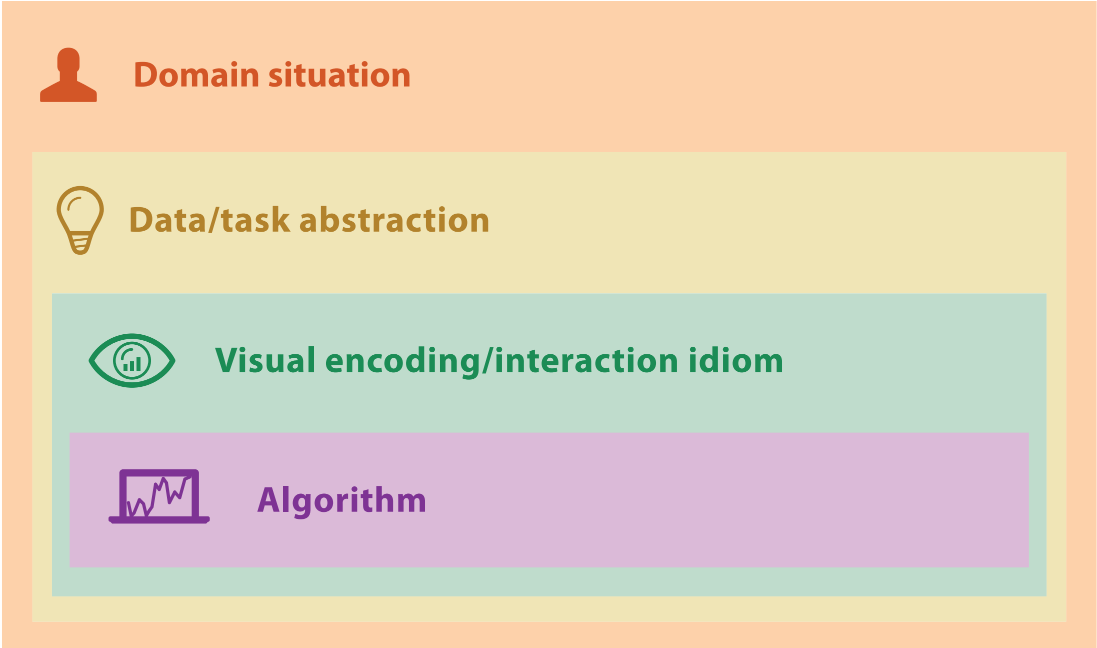
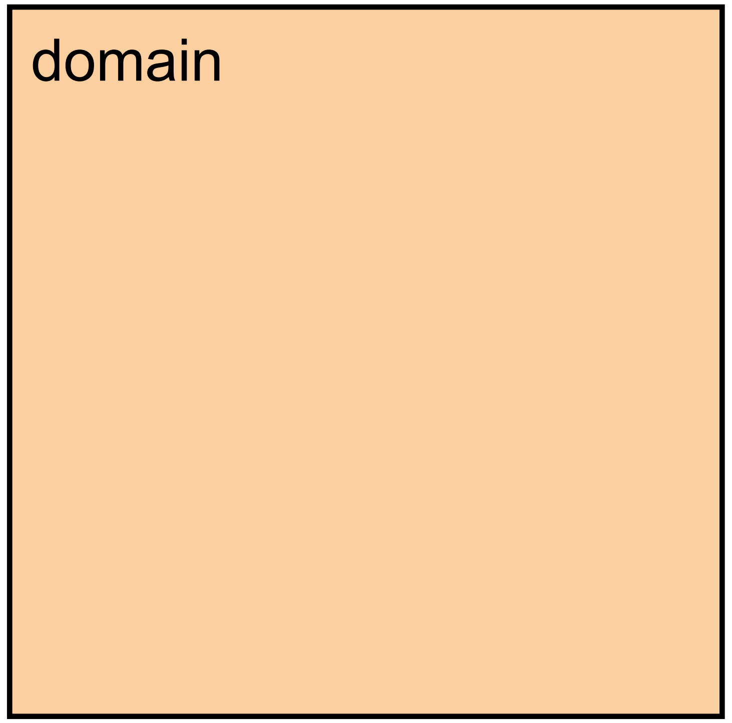
  - domain questions/problems
    - break down into simpler abstract tasks





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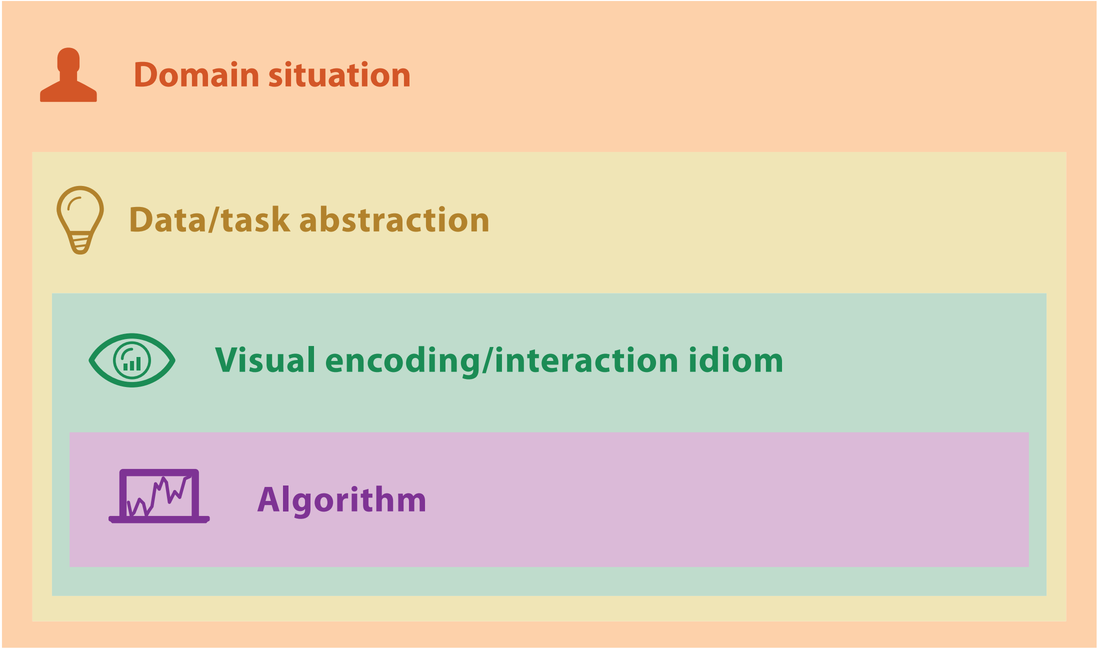
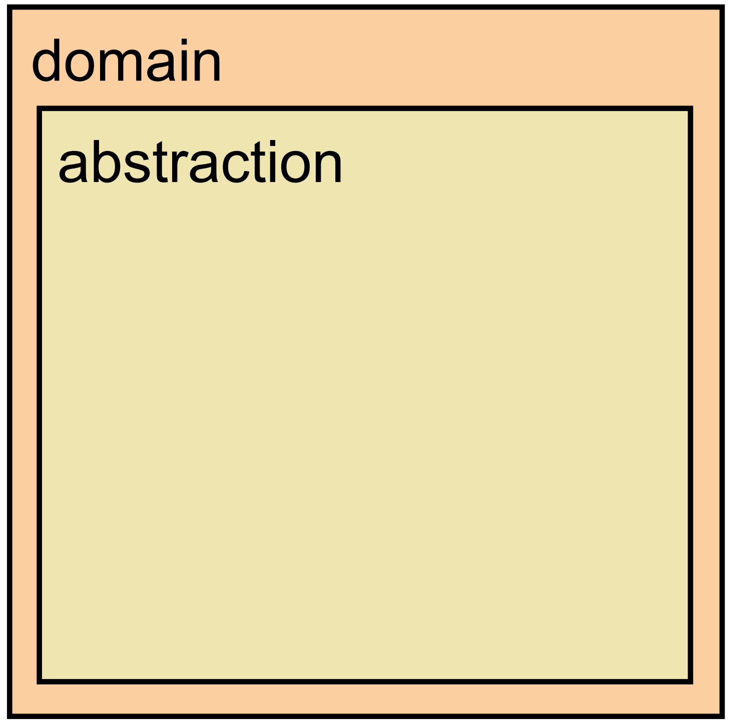
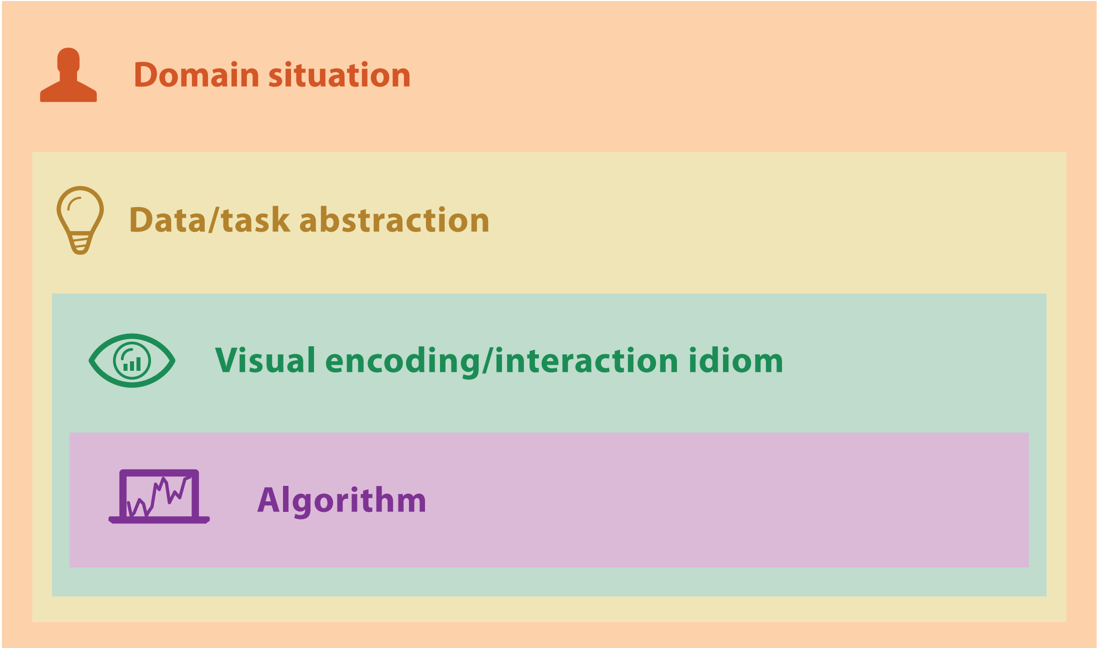
    - break down into simpler abstract tasks
- abstraction: data & task
  - map *what* and *why* into generalized terms

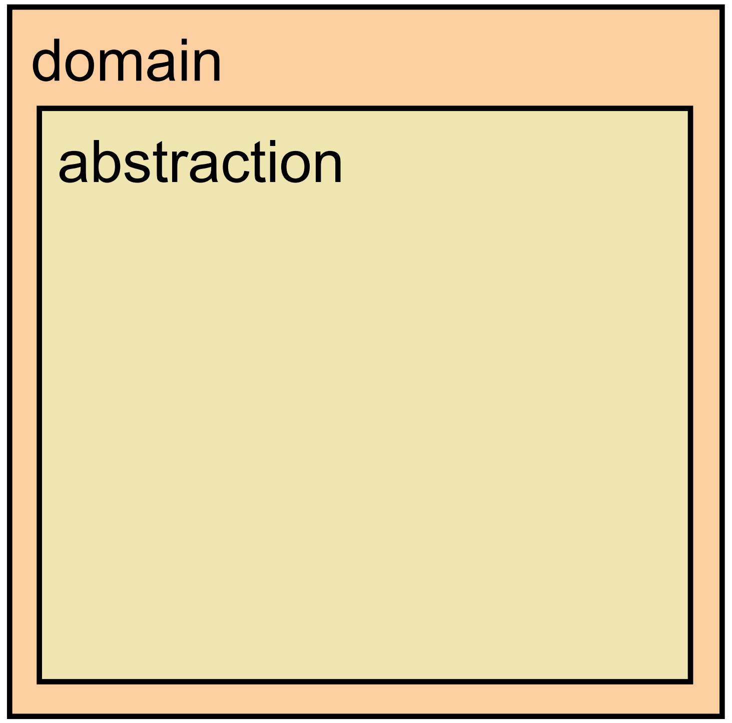




From domain to abstraction

- 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

Characterize Domain Situation

Map Domain-Language Data Description to Data Abstraction

Map Domain-Language Task to Abstract Task

Identify/Create Suitable Idiom/Technique

Identify/Create Suitable Algorithm

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*
  - *compare trends*
  - *locate outliers*
  - *browse topology*

Task abstraction: Actions and targets

- very high-level pattern

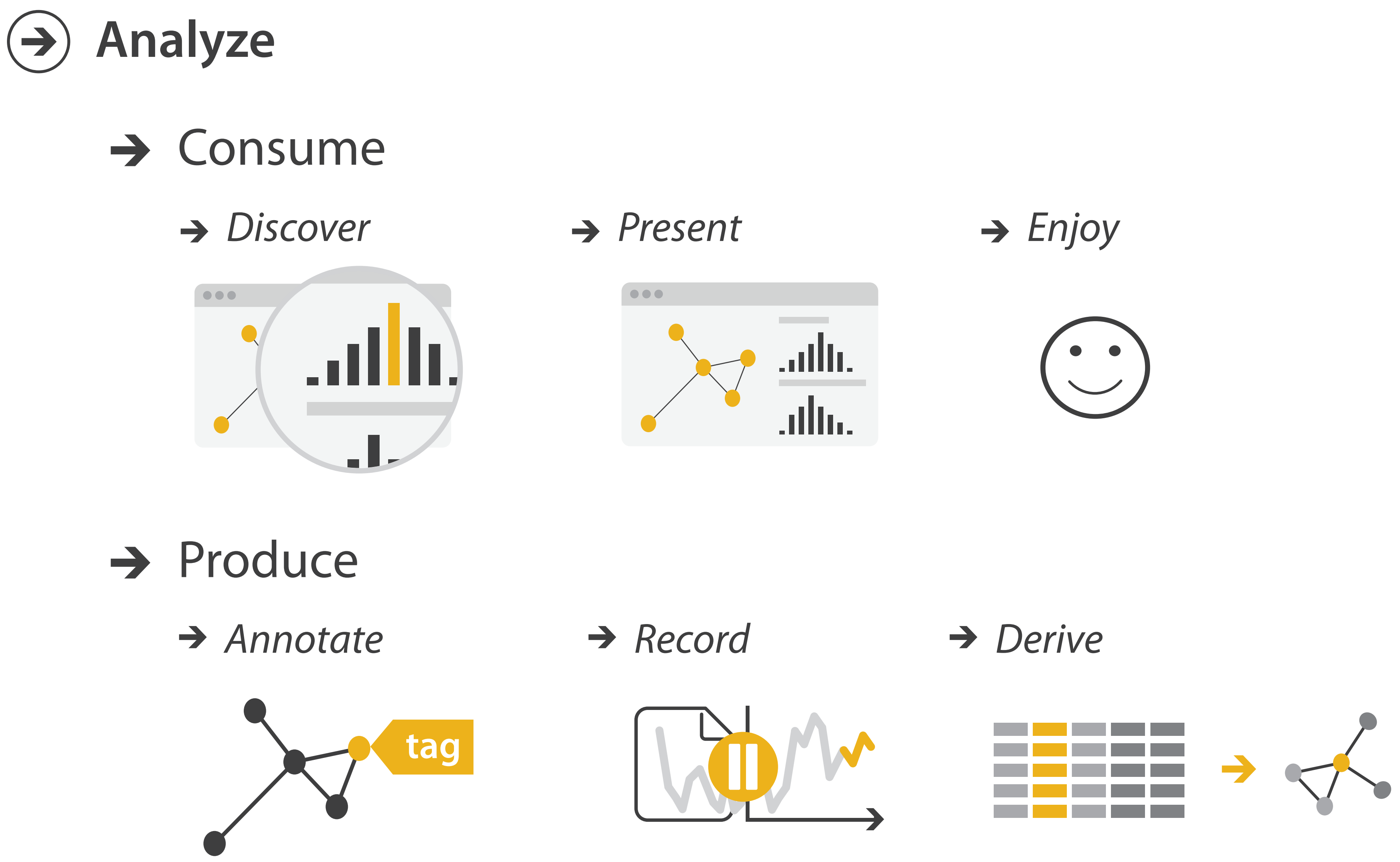
- actions
  - analyze
    - high-level choices
  - search
    - find a known/unknown item
  - query
    - find out about characteristics of item

- 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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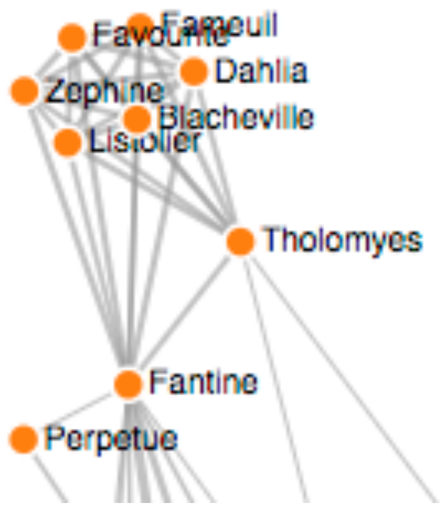
Actions: Search

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

Search

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



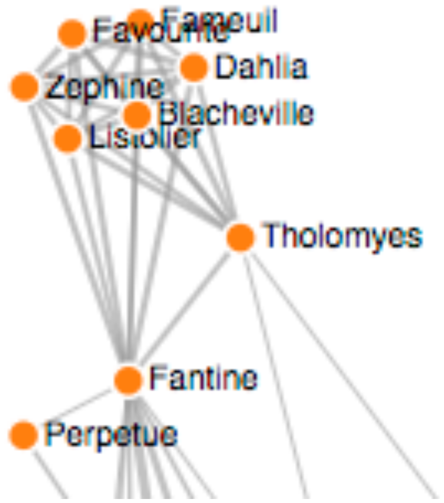
https://bl.ocks.org/heybignick/3faf257bbbbc7743bb72310d03b86ee8

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
- browse
  - ex: books in bookstore

Search

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



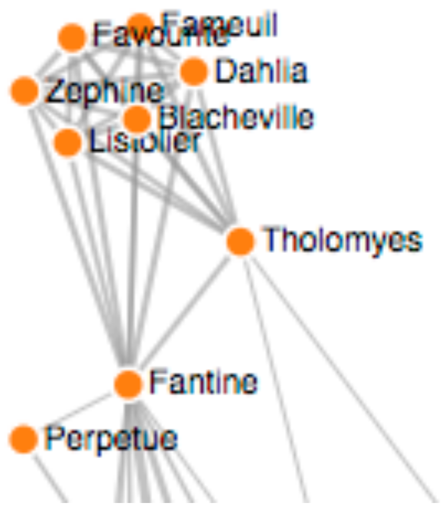
https://bl.ocks.org/heybignick/3faf257bbbbc7743bb72310d03b86ee8

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
- browse
  - ex: books in bookstore
- explore
  - ex: find cool neighborhood in new city

Search

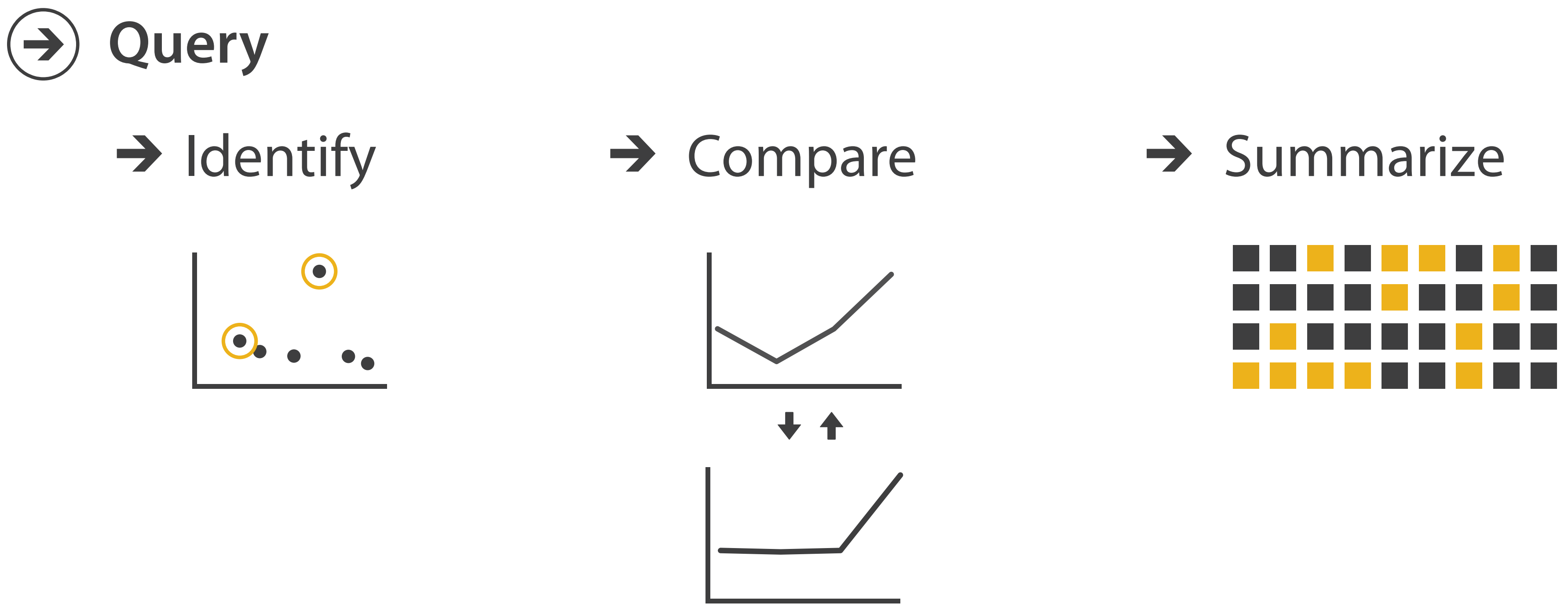
	Target known	Target unknown
Location known	*Lookup*	*Browse*
Location unknown	*Locate*	*Explore*



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

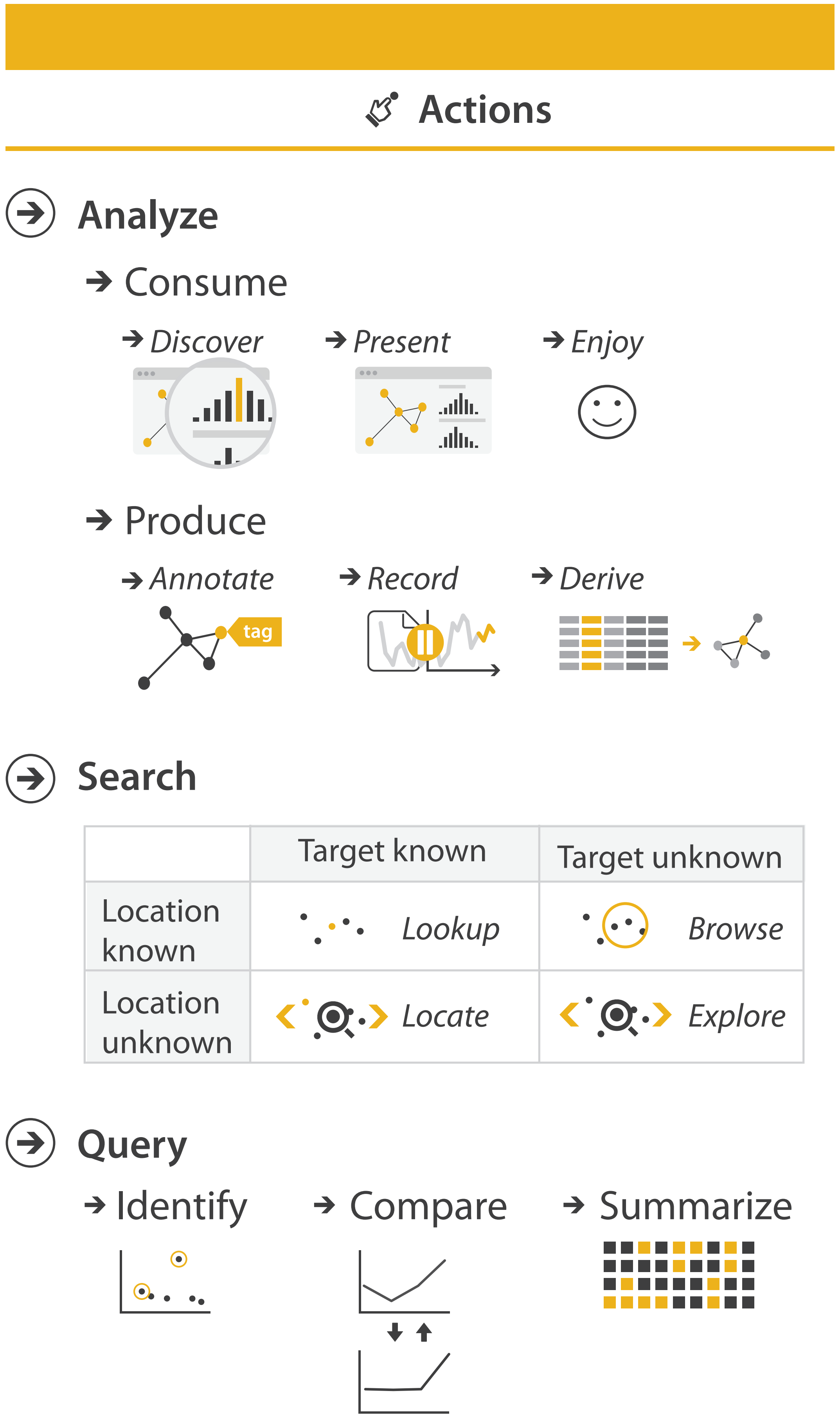
Actions: Query

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



Actions

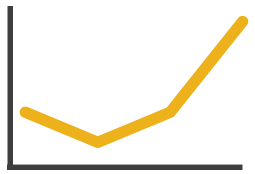
- independent choices for each of these three levels
  - analyze, search, query
  - mix and match

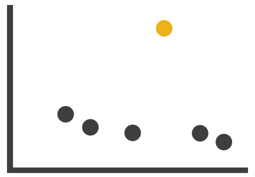


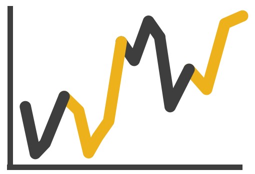
Task abstraction: Targets

Task abstraction: Targets

➔ **All Data**

➔ Trends 

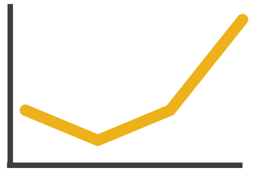
➔ Outliers 

➔ Features 

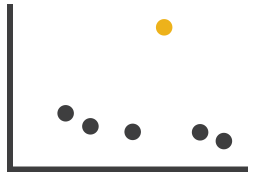
Task abstraction: Targets

➔ All Data

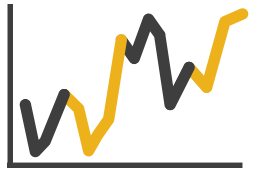
➔ Trends



➔ Outliers



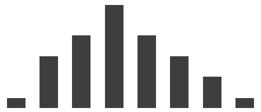
➔ Features



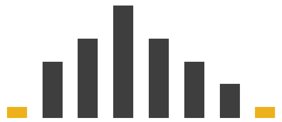
➔ Attributes

➔ One

➔ *Distribution*



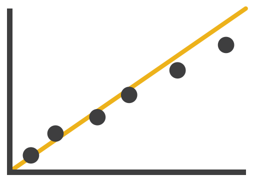
➔ *Extremes*



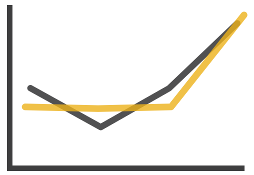
➔ Many

➔ *Dependency*

➔ *Correlation*



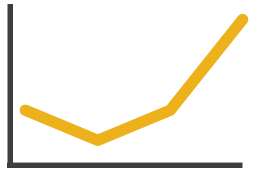
➔ *Similarity*



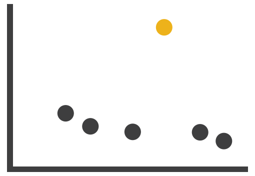
Task abstraction: Targets

➔ All Data

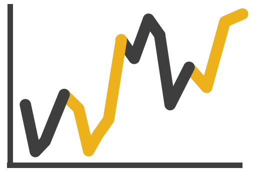
- ➔ Trends



- ➔ Outliers

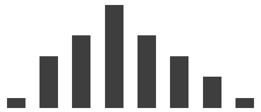


- ➔ Features

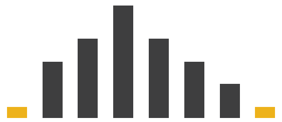


➔ Attributes

- ➔ One
  - ➔ *Distribution*

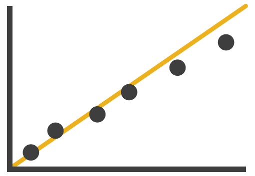


  - ➔ *Extremes*

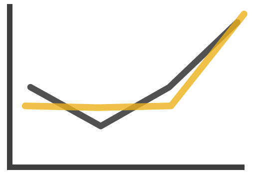


- ➔ Many
  - ➔ *Dependency*

  - ➔ *Correlation*

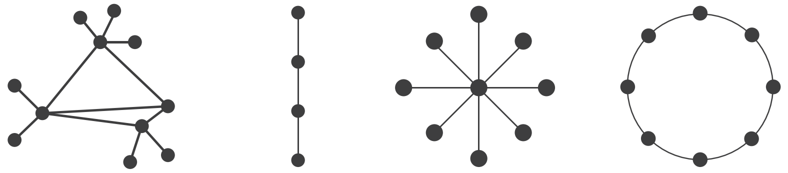


  - ➔ *Similarity*

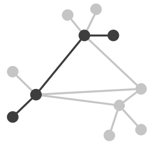


➔ Network Data

- ➔ Topology



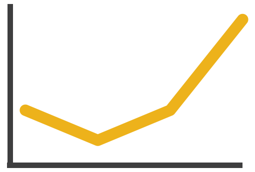
  - ➔ *Paths*



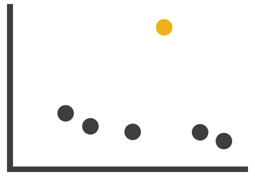
Task abstraction: Targets

➔ All Data

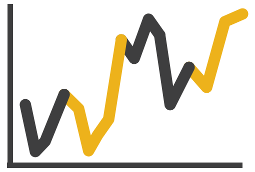
➔ Trends



➔ Outliers



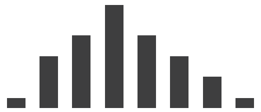
➔ Features



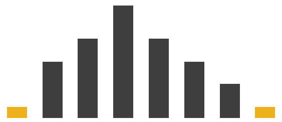
➔ Attributes

➔ One

➔ *Distribution*



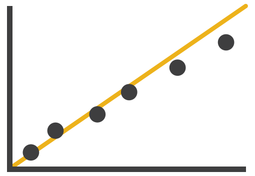
➔ *Extremes*



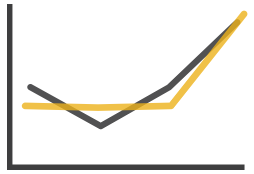
➔ Many

➔ *Dependency*

➔ *Correlation*

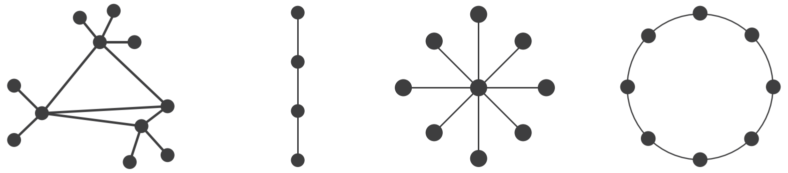


➔ *Similarity*

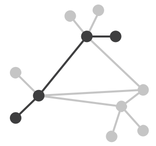


➔ Network Data

➔ Topology

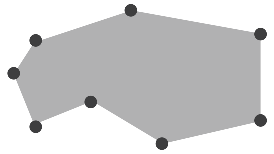


➔ *Paths*



➔ Spatial Data

➔ Shape

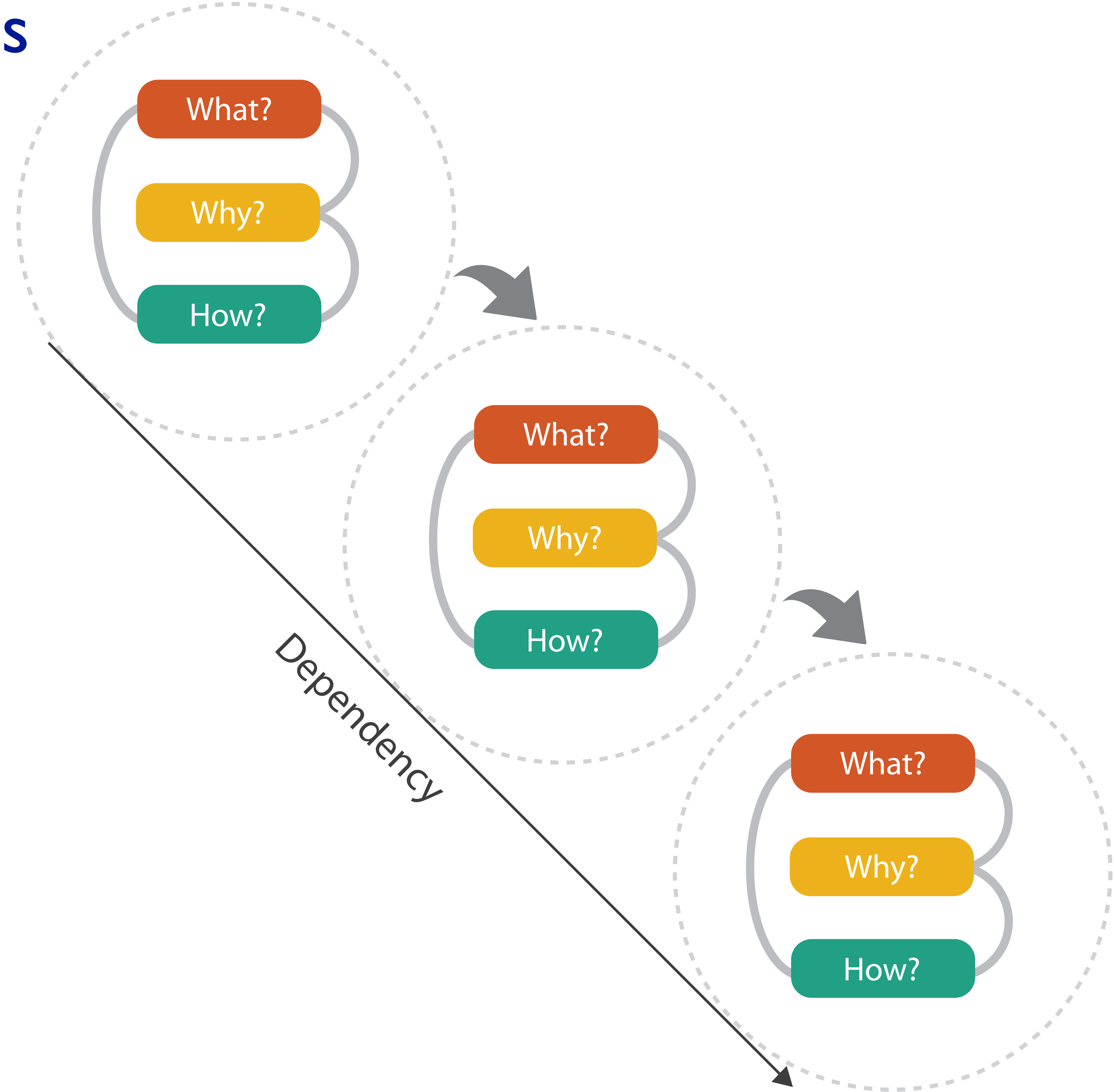


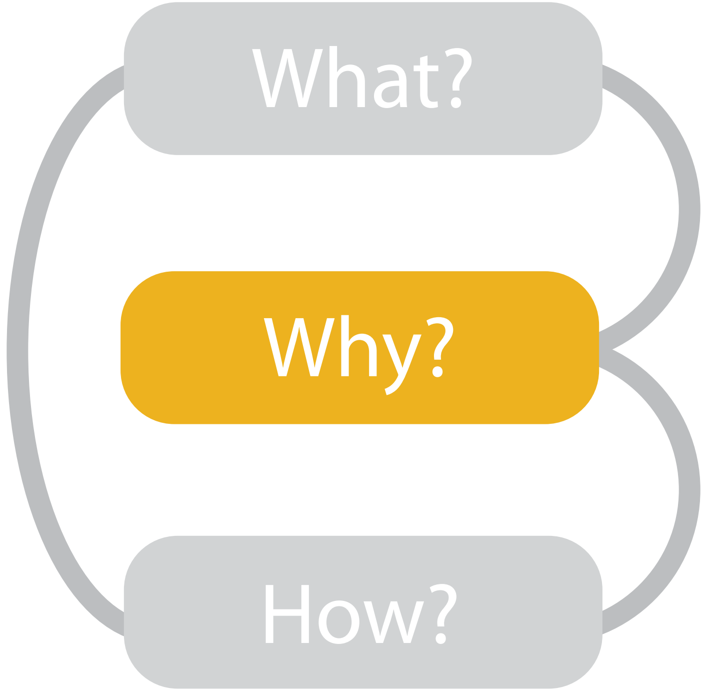
Abstraction

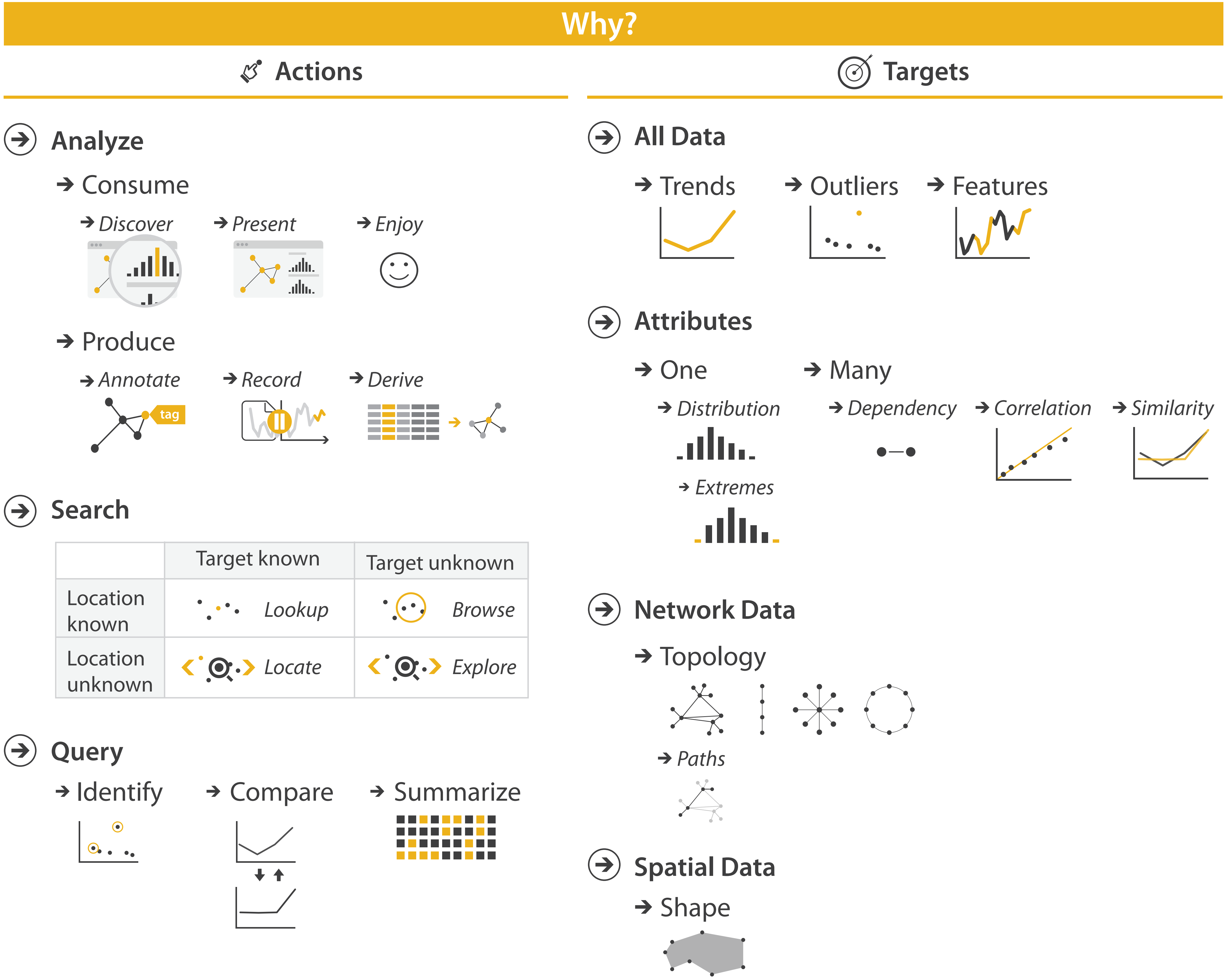
- these {action, target} pairs are good starting point for vocabulary
  - but sometimes you'll need more precision!
- rule of thumb
  - systematically remove all domain jargon

- 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, ...

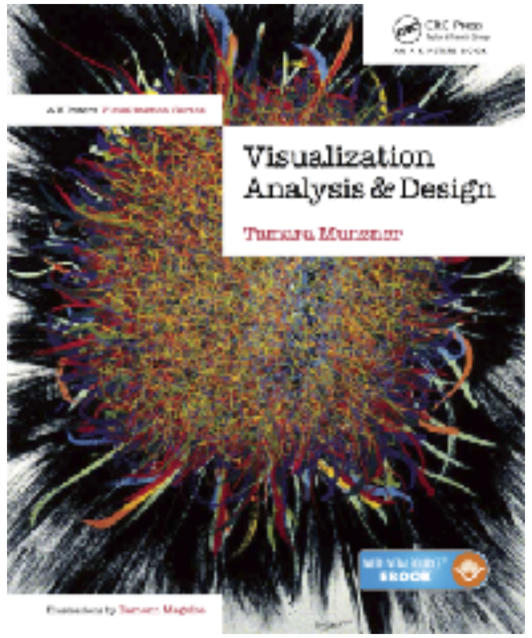
Means and ends







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



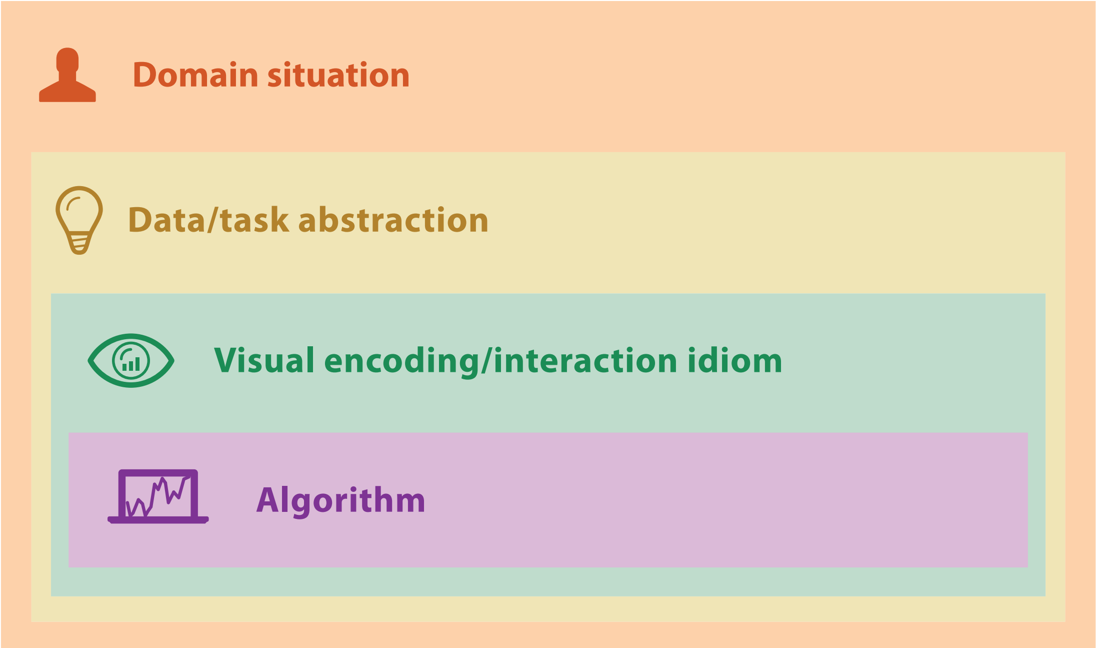
Visualization Analysis & Design

Marks & Channels (Ch 5) I

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

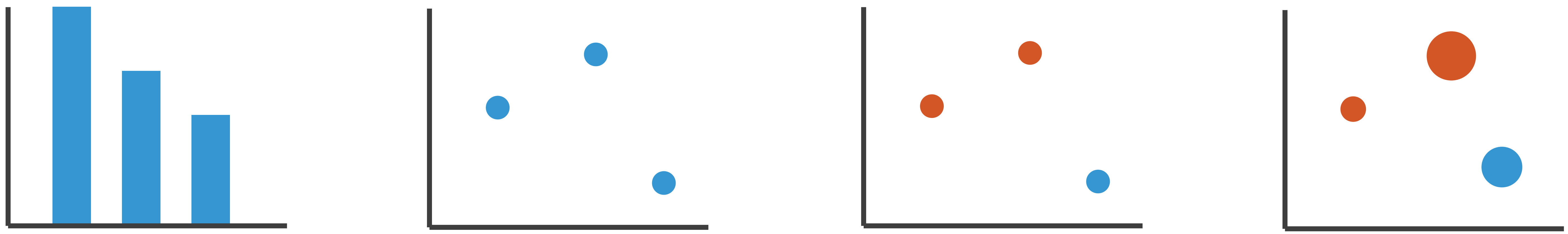
Visual encoding

- how to systematically analyze idiom structure?



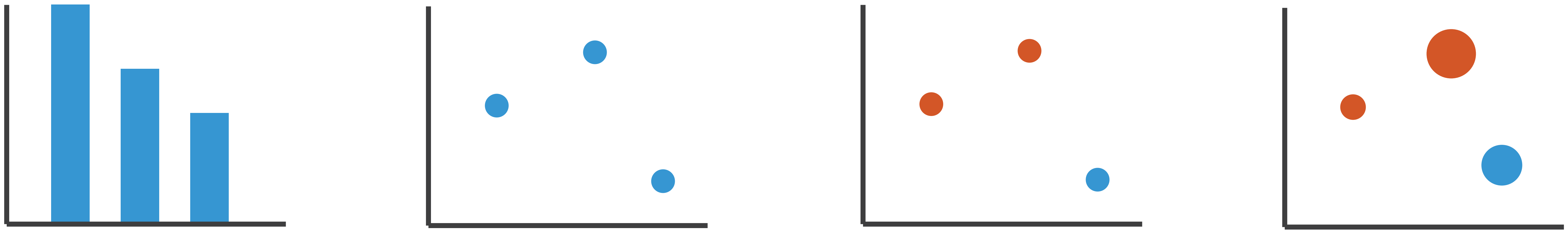
Visual encoding

- how to systematically analyze idiom structure?



Visual encoding

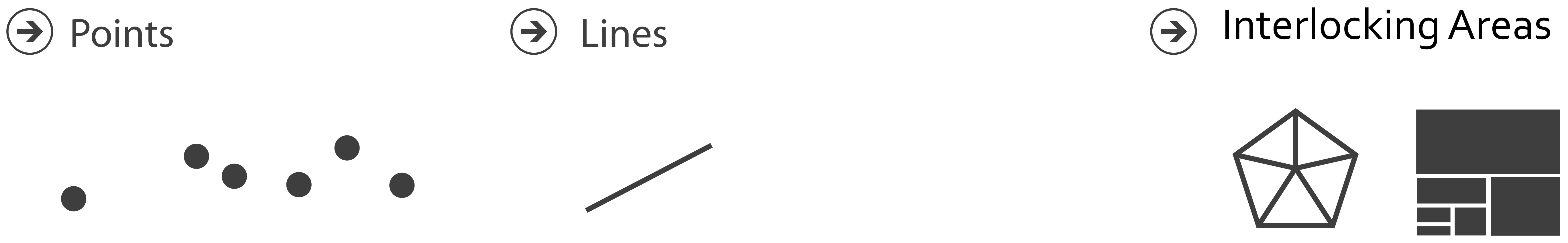
- how to systematically analyze idiom structure?



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

Marks for items

- basic geometric elements

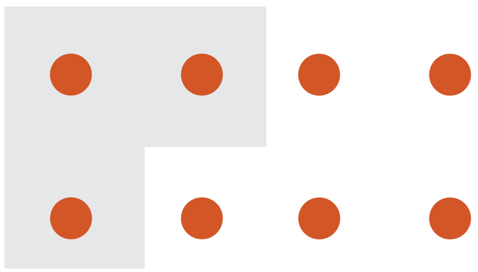


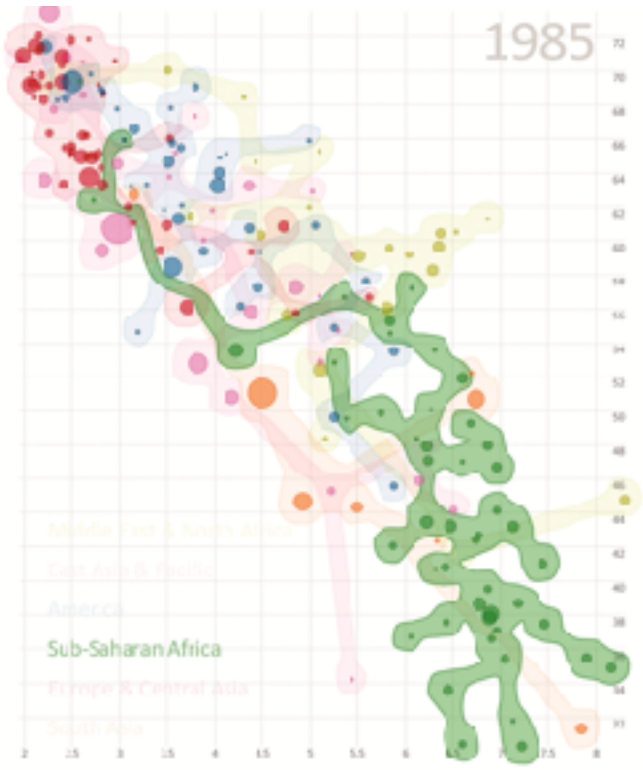
0D 1D 2D

- 3D mark: volume, rarely used

Marks for links

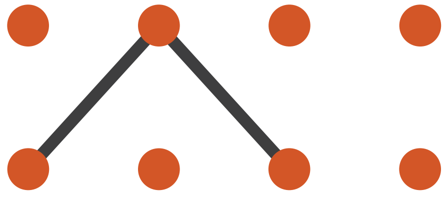
➔ Containment





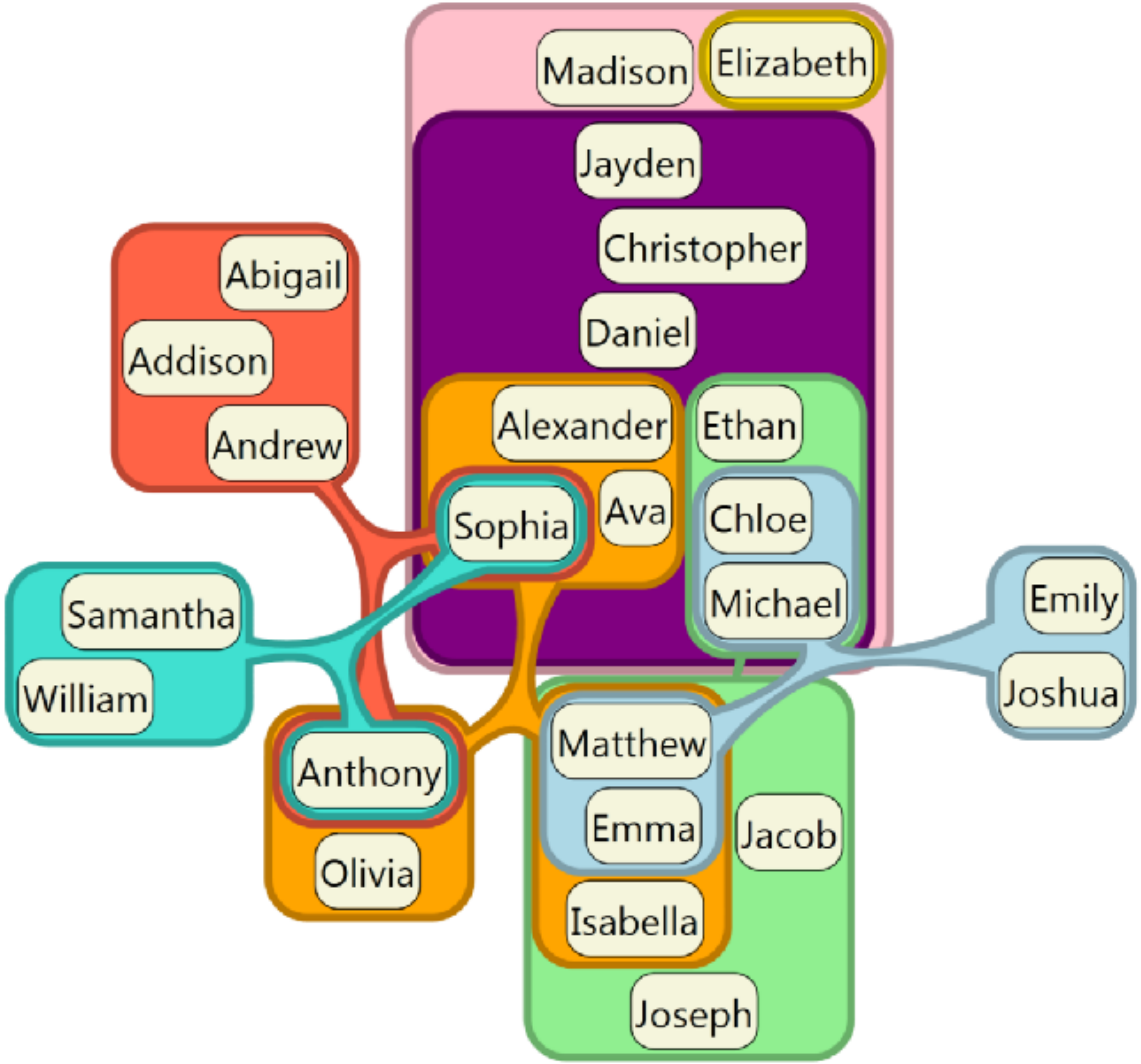
vialab.science.uoit.ca/portfolio/bubblesets

➔ Connection



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

Containment can be nested

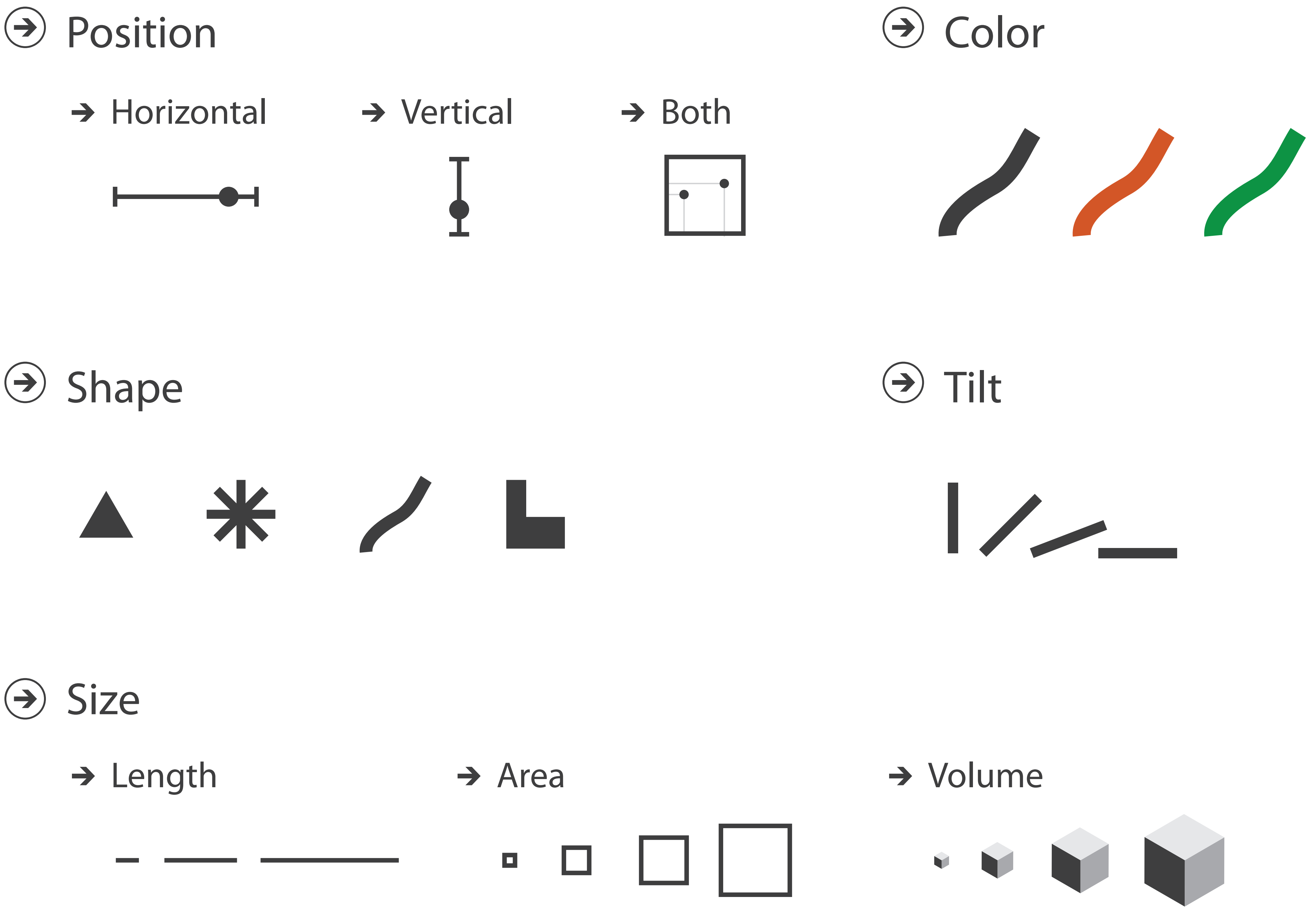


[Untangling Euler Diagrams, Riche and Dwyer, 2010]

Channels

- control appearance of marks
  - proportional to or based on attributes

- many names
  - **visual channels**
  - visual variables
  - retinal channels
  - visual dimensions
  - ...

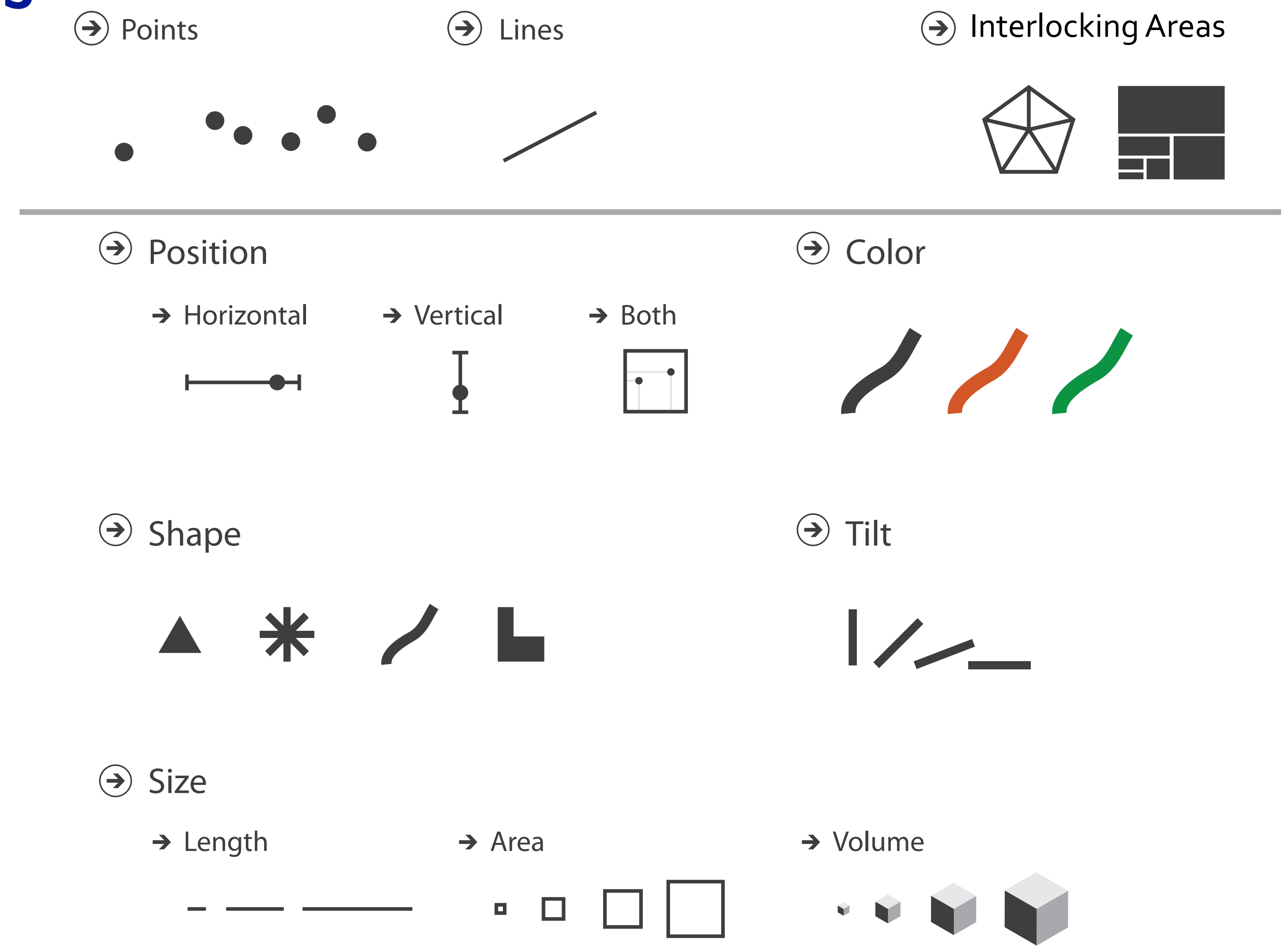


Definitions: Marks and channels

- marks
  - geometric primitives

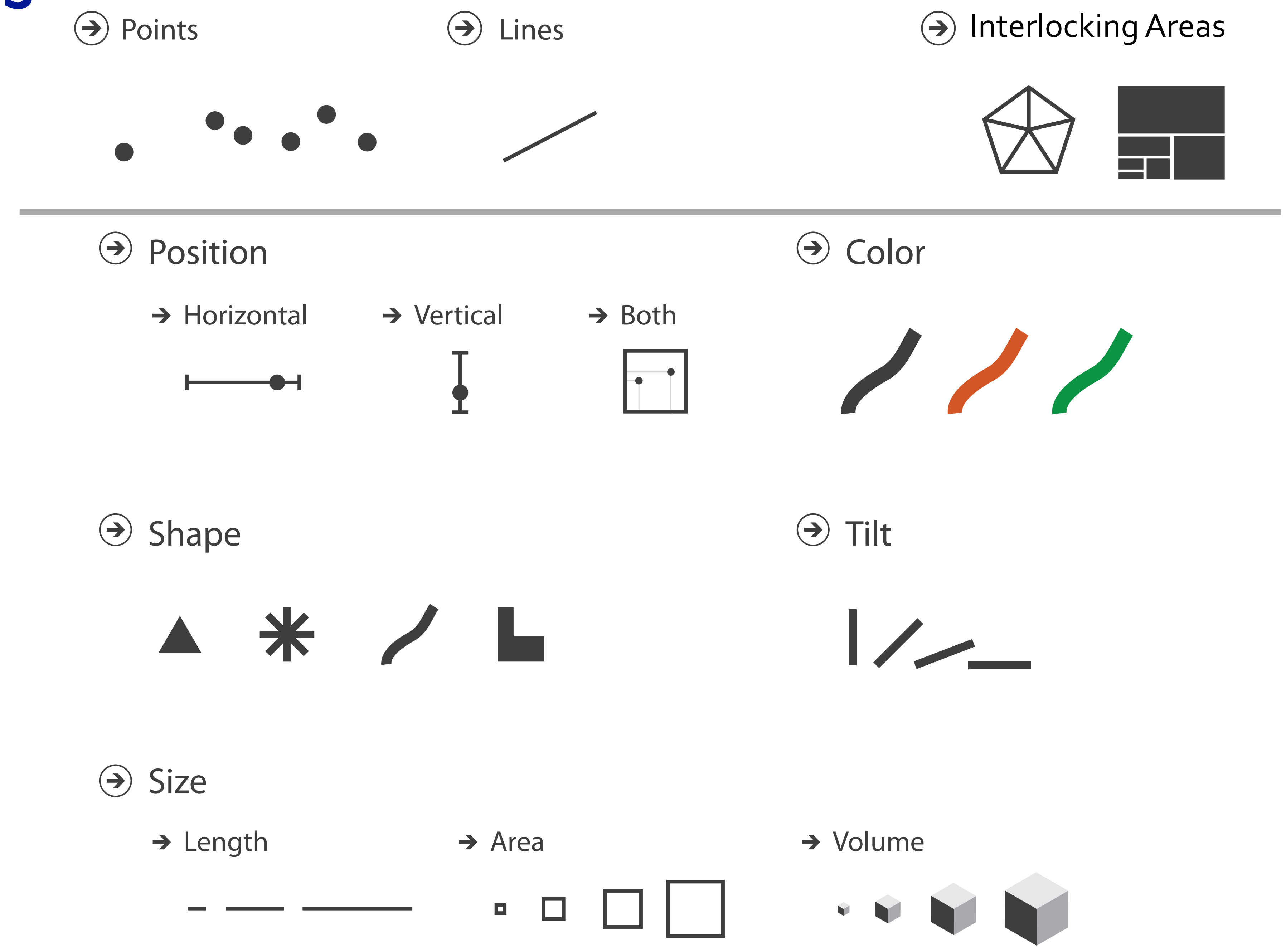
Definitions: Marks and channels

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



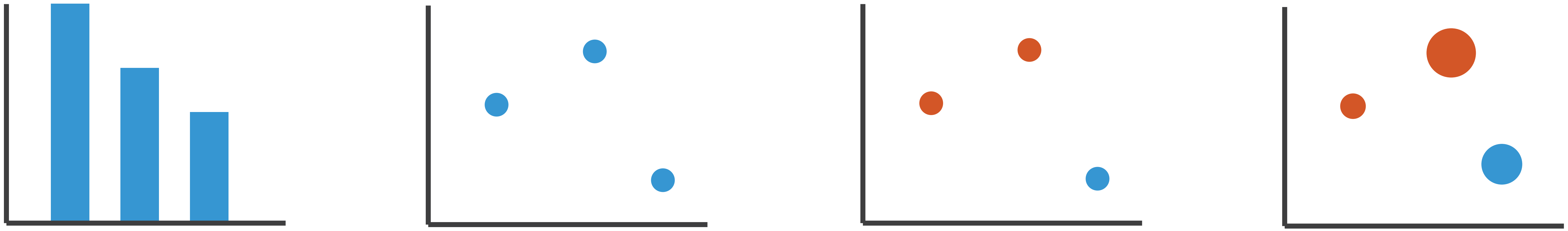
Definitions: Marks and channels

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



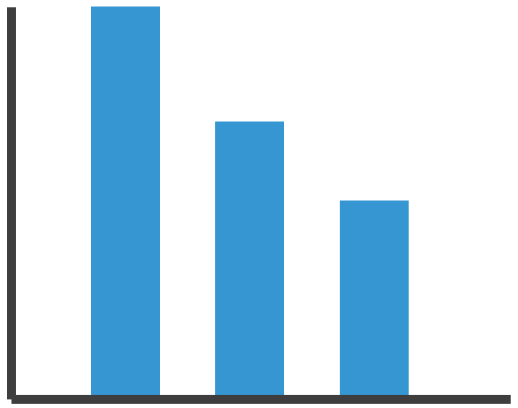
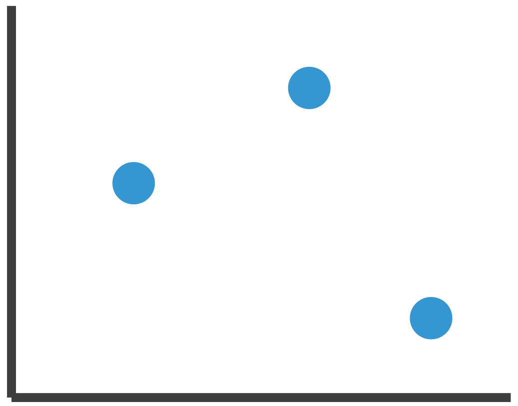
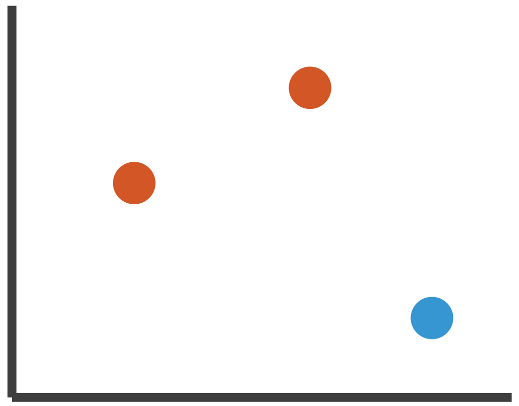
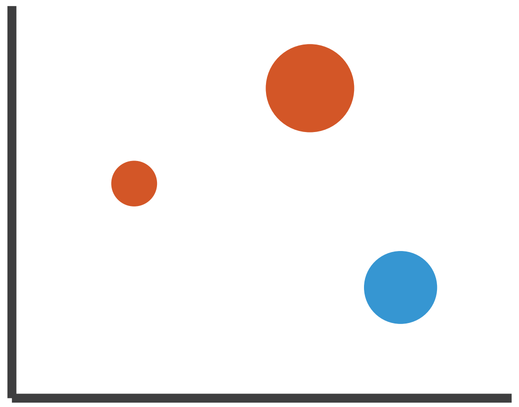
Visual encoding

- analyze idiom structure as combination of marks and channels



Visual encoding

- analyze idiom structure as combination of marks and channels

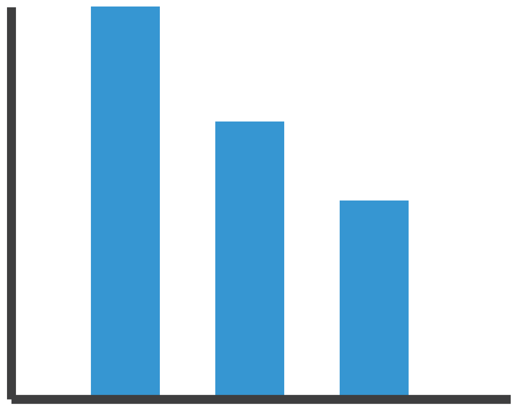





1:
vertical position

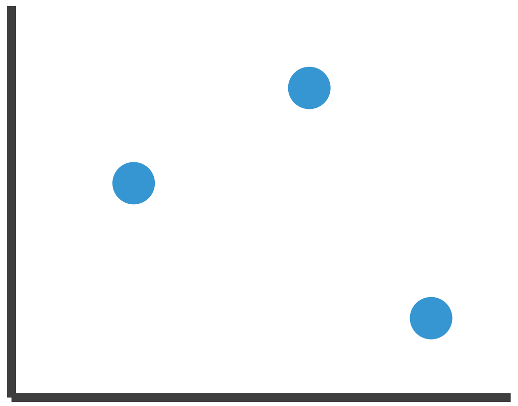
mark: line

Visual encoding

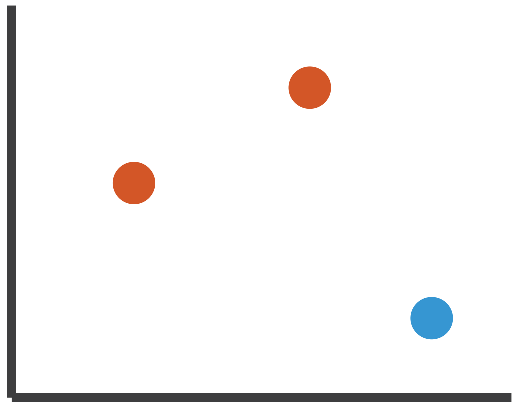
- analyze idiom structure as combination of marks and channels

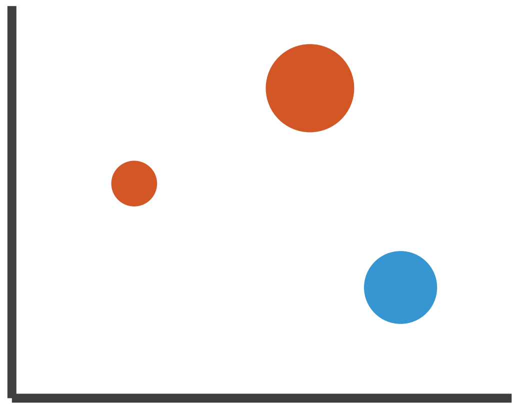


1:
vertical position



2:
vertical position
horizontal position



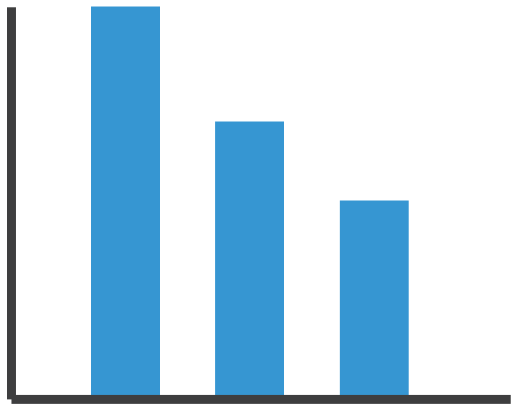


mark: line

mark: point

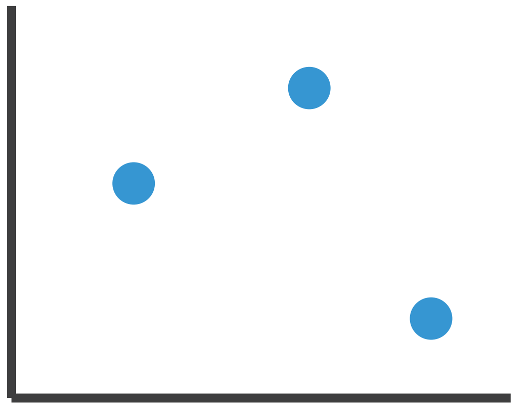
Visual encoding

- analyze idiom structure as combination of marks and channels



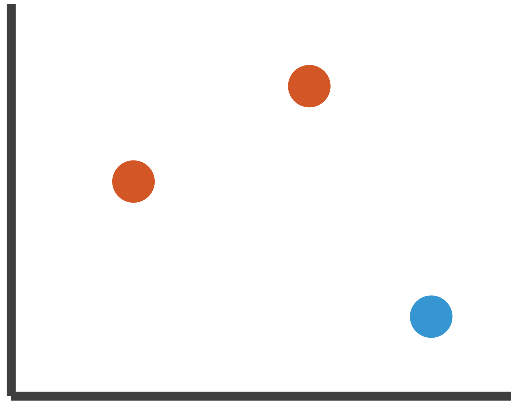
1:
vertical position

mark: line



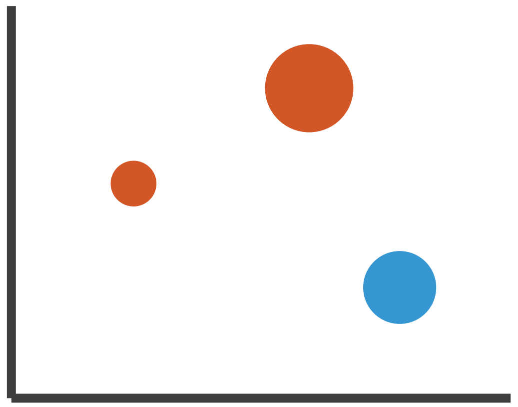
2:
vertical position
horizontal position

mark: point



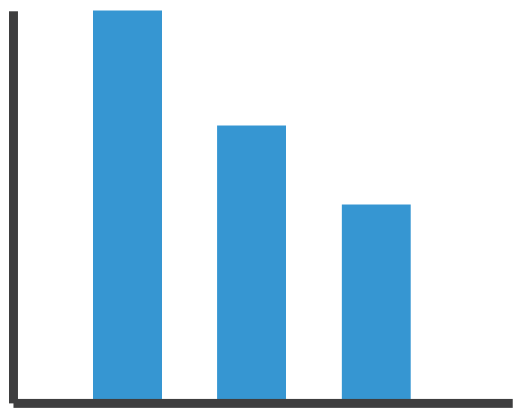
3:
vertical position
horizontal position
color hue

mark: point



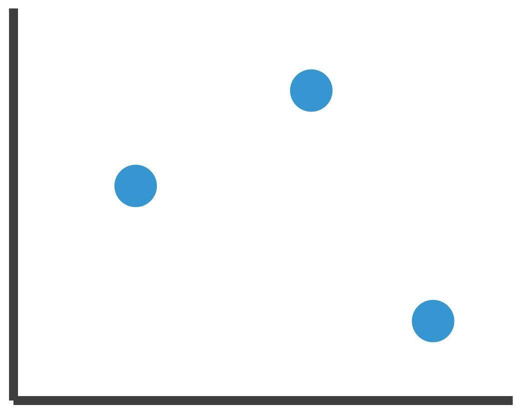
Visual encoding

- analyze idiom structure as combination of marks and channels



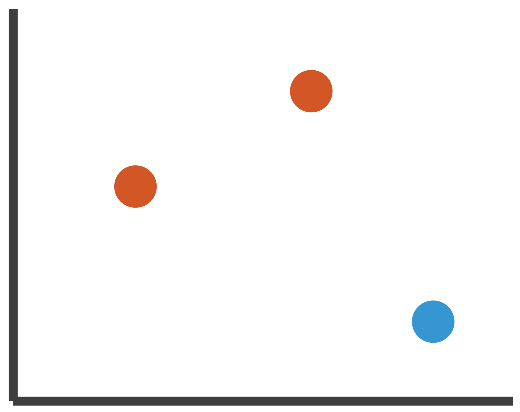
1:
vertical position

mark: line



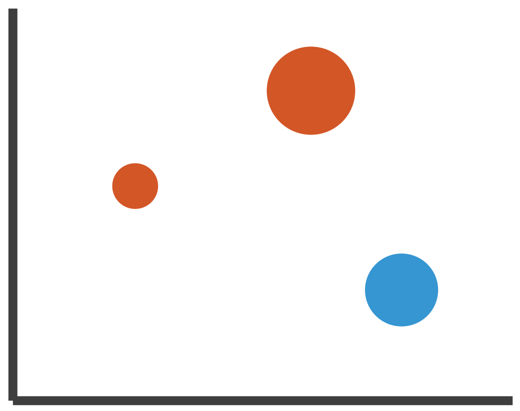
2:
vertical position
horizontal position

mark: point



3:
vertical position
horizontal position
color hue

mark: point

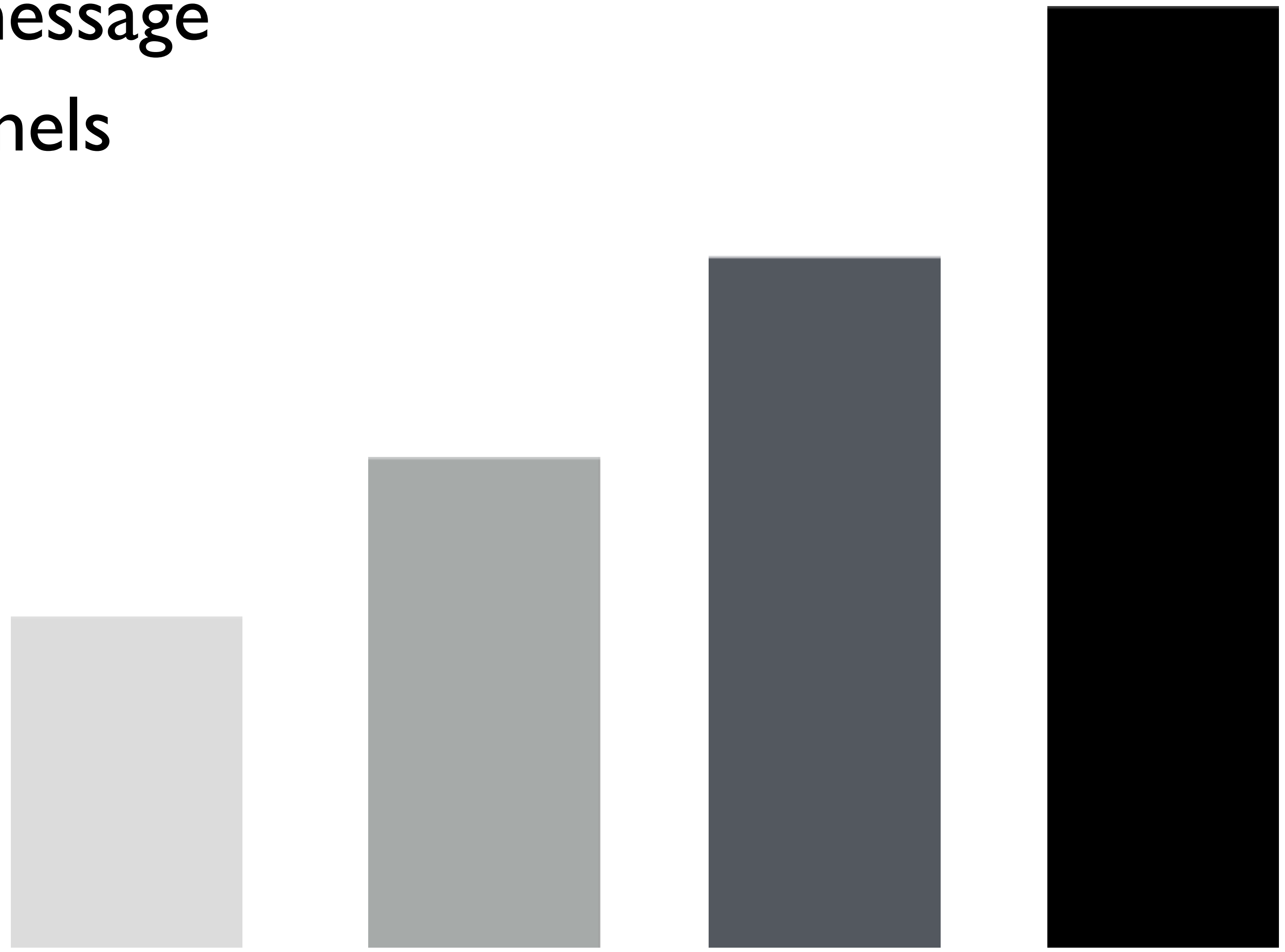


4:
vertical position
horizontal position
color hue
size (area)

mark: point

Redundant encoding

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

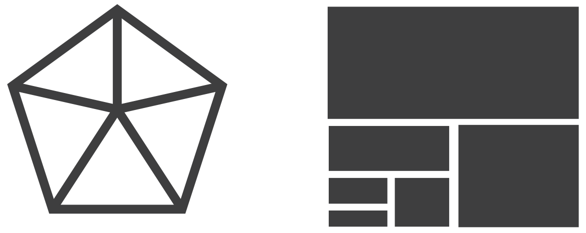


Length and Luminance

Marks as constraints

- math view: geometric primitives have dimensions

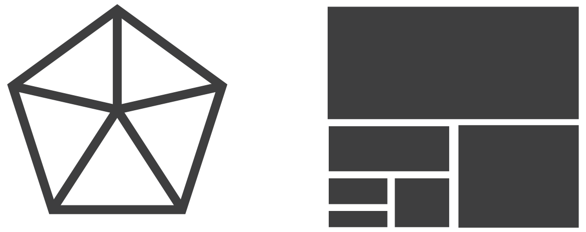
Points 0D Lines 1D Interlocking Areas 2D



Marks as constraints

- math view: geometric primitives have dimensions

Points 0D — Lines 1D — Interlocking Areas 2D

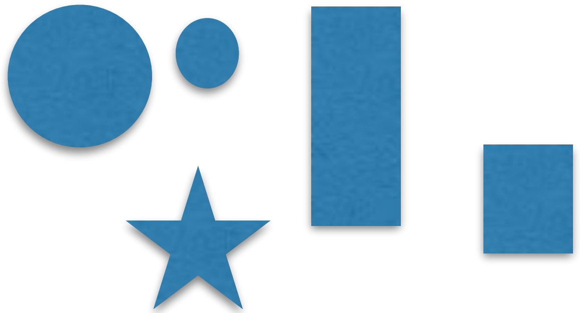


- constraint view: mark type constrains what else can be encoded
  - points: 0 constraints on size, can encode more attributes w/ size & shape
  - lines: 1 constraint on size (length), can still size code other way (width)
  - interlocking areas: 2 constraints on size (length/width), cannot size or shape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

Marks as constraints

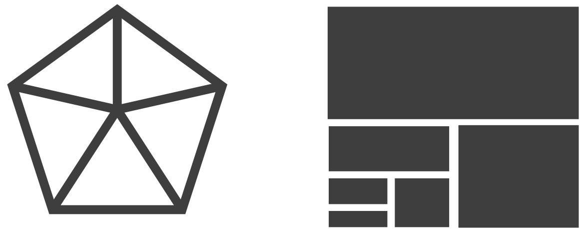
- math view: geometric primitives have dimensions

Points 0D



Lines 1D

Interlocking Areas 2D



- 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?

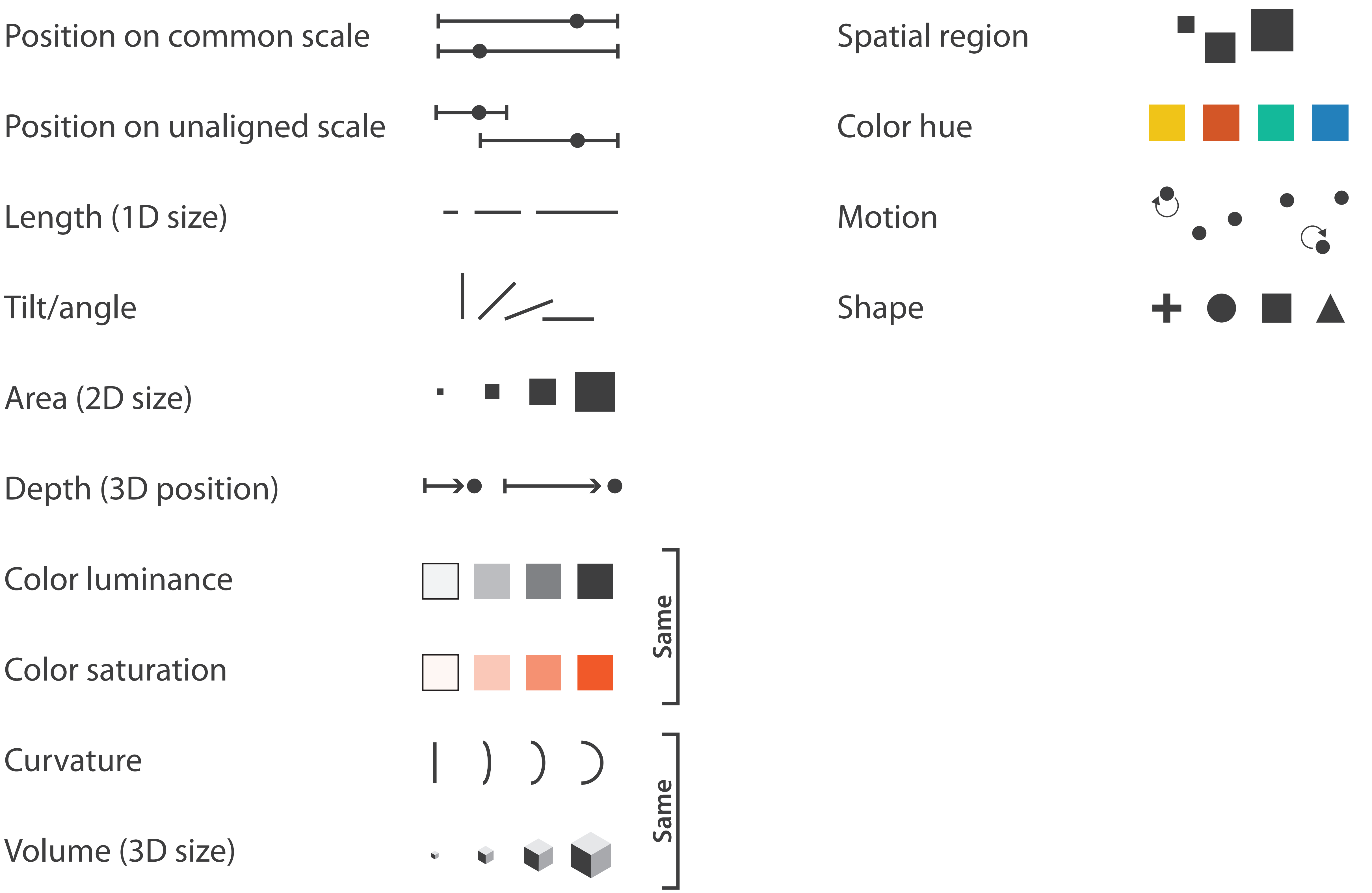
expressiveness

match channel type to data type

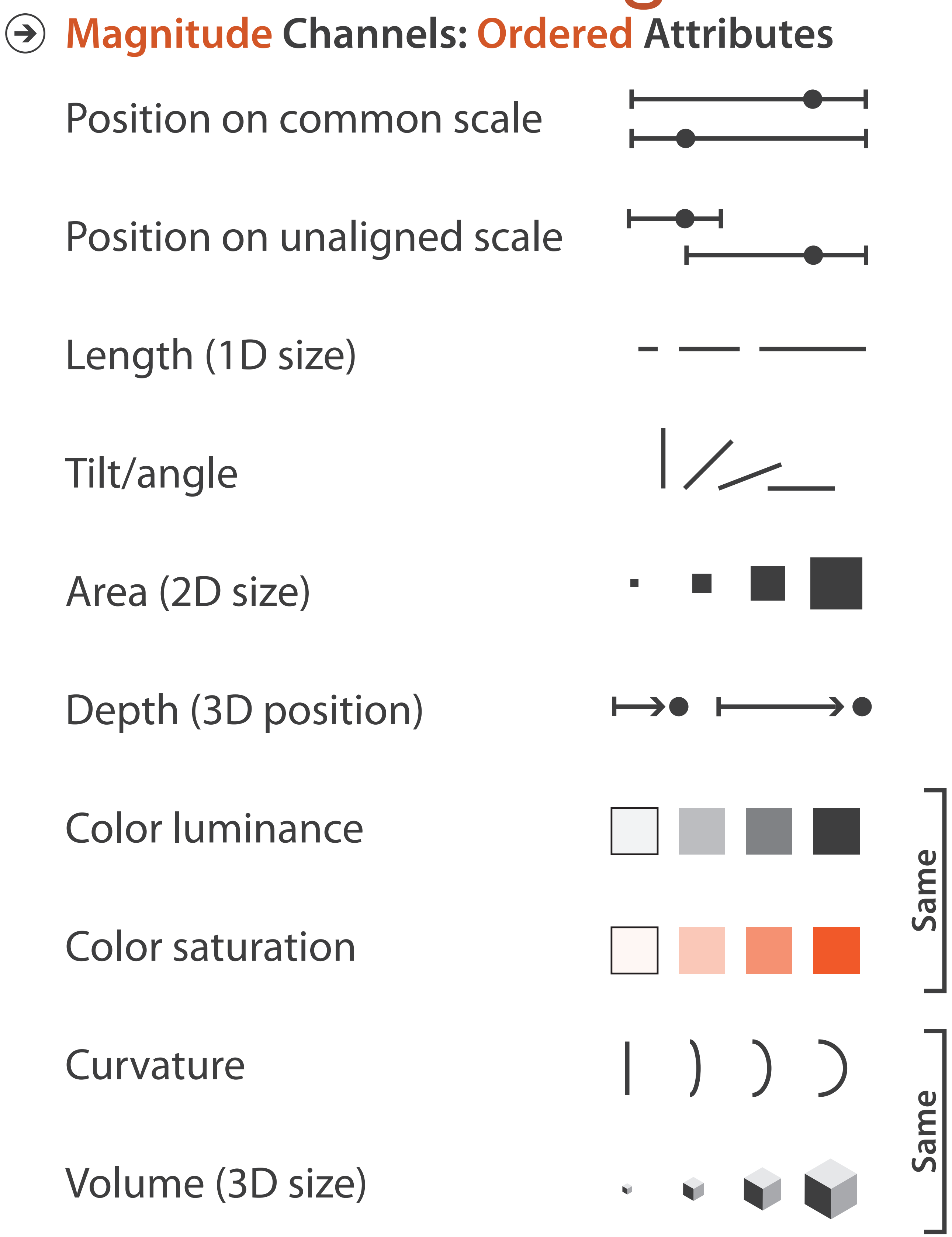
effectiveness

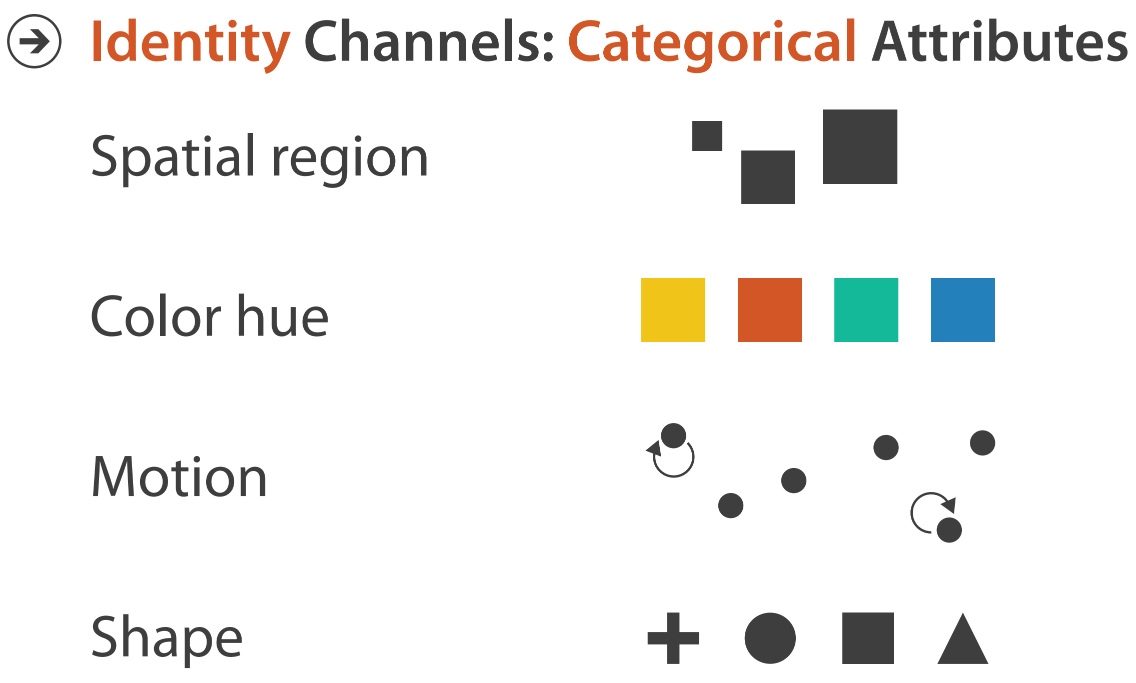
some channels are better than others

Channels: Rankings



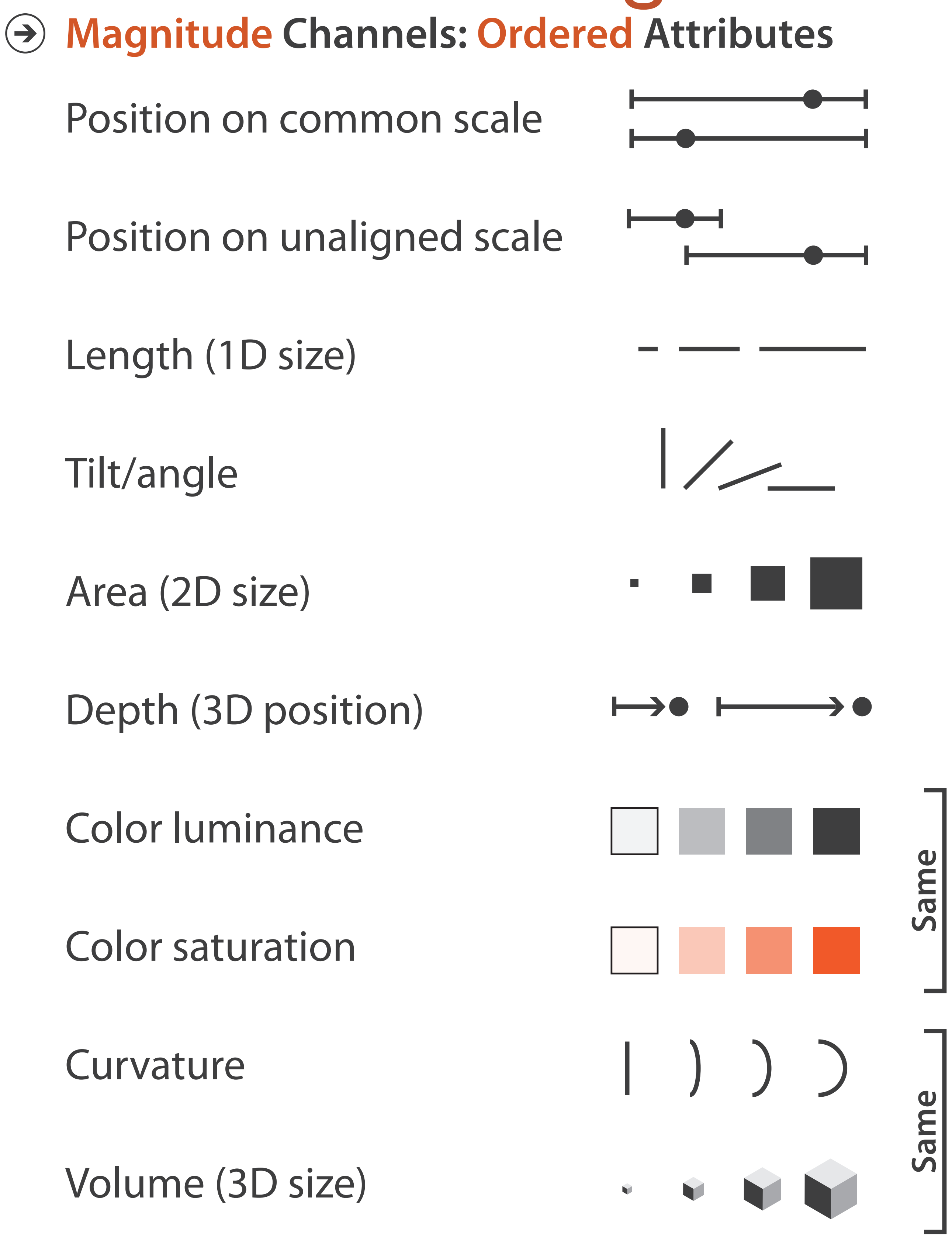
Channels: Rankings

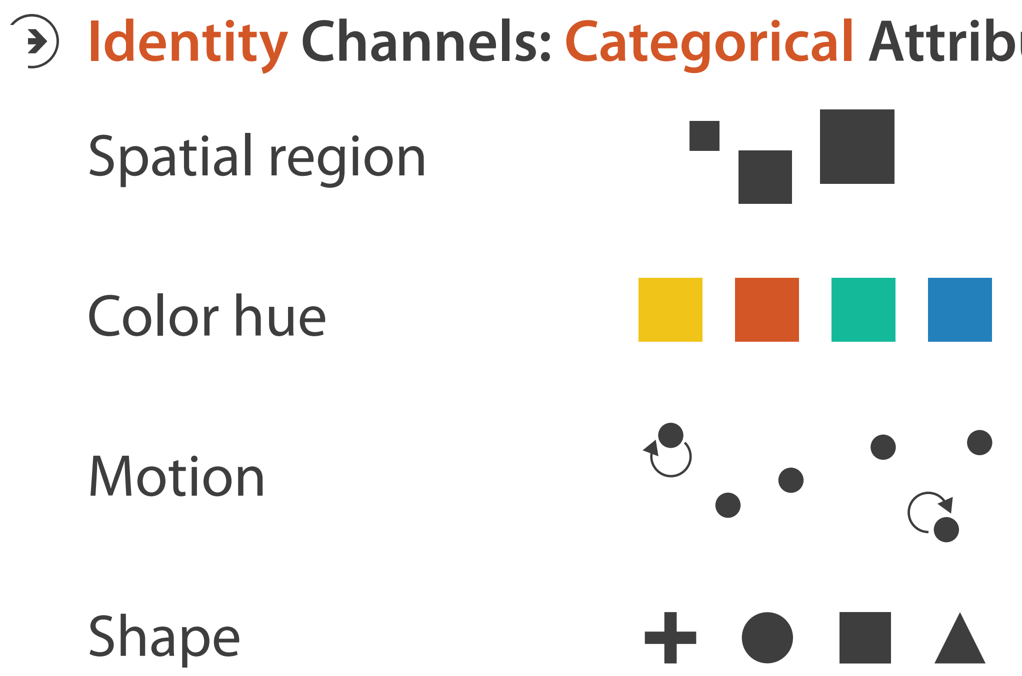


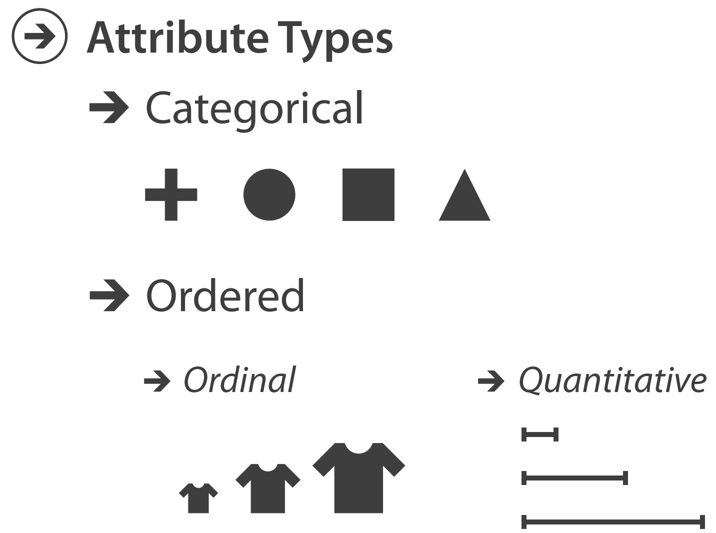


- expressiveness
  – match channel and data characteristics

Channels: Rankings

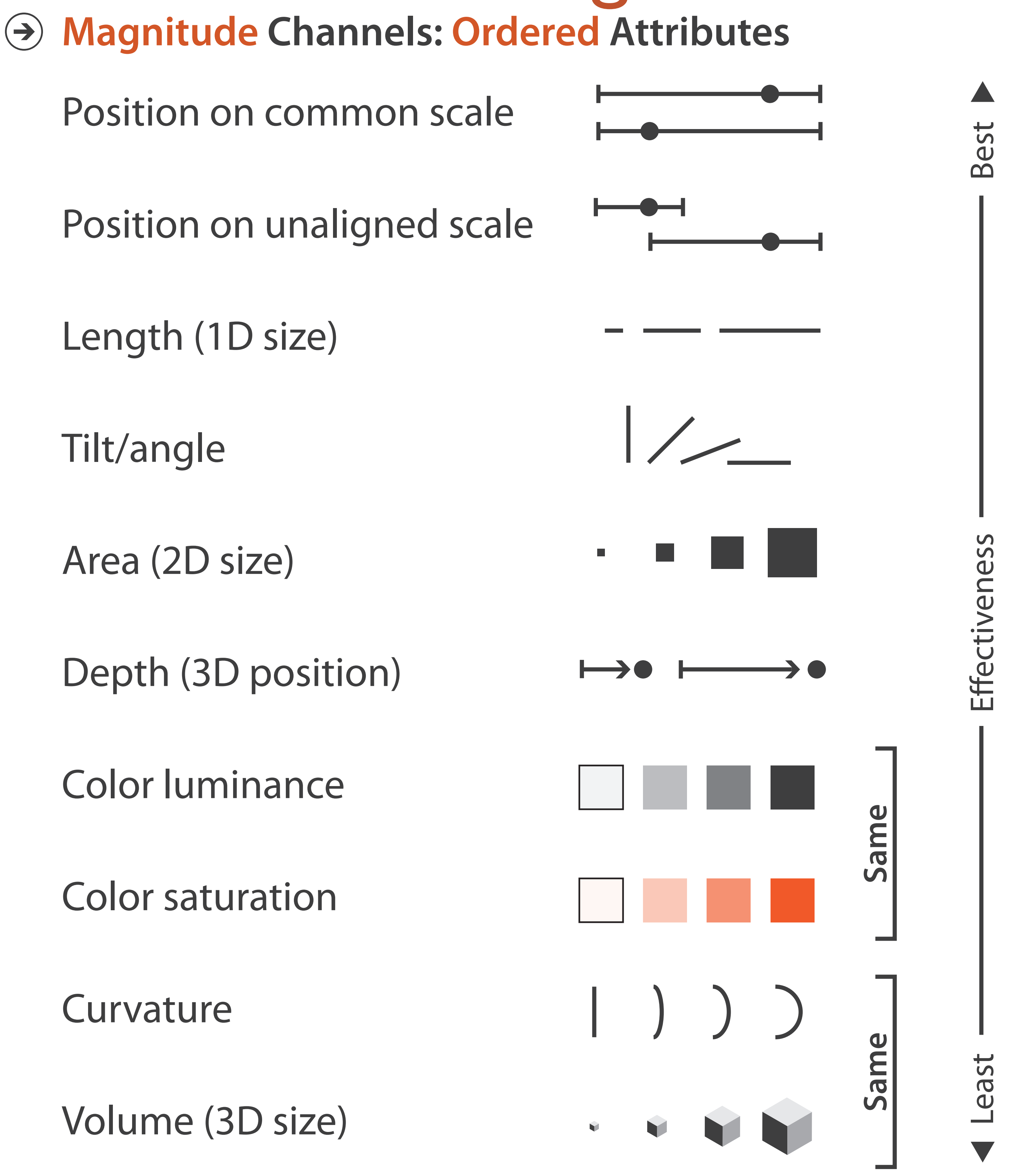


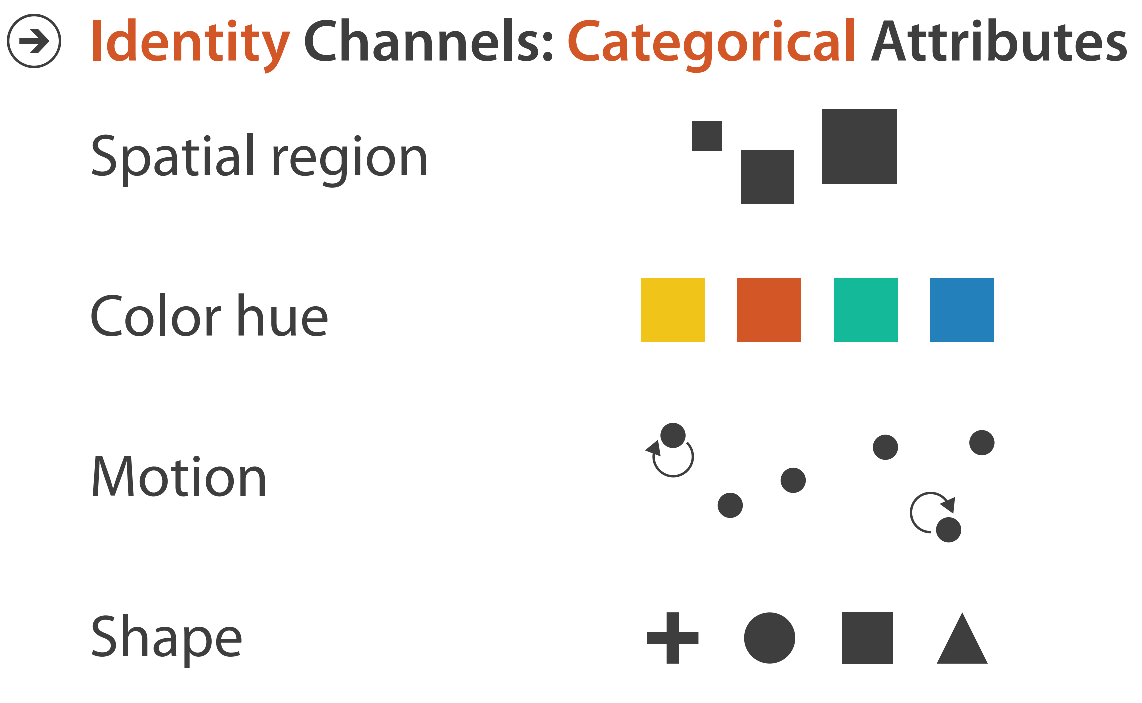




- expressiveness
  - match channel and data characteristics
  - magnitude for ordered
    - how much? which rank?
  - identity for categorical
    - what?

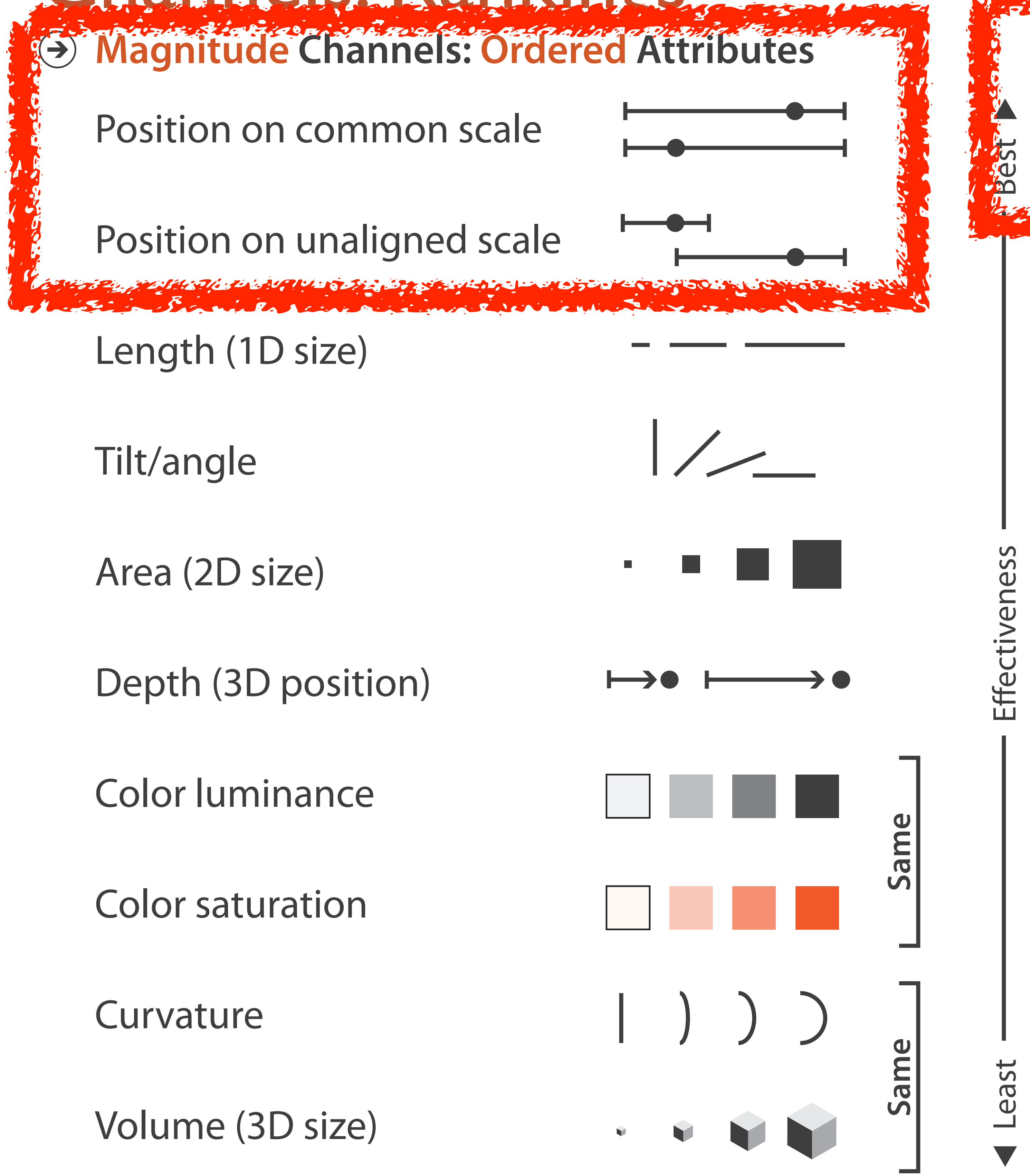
Channels: Rankings

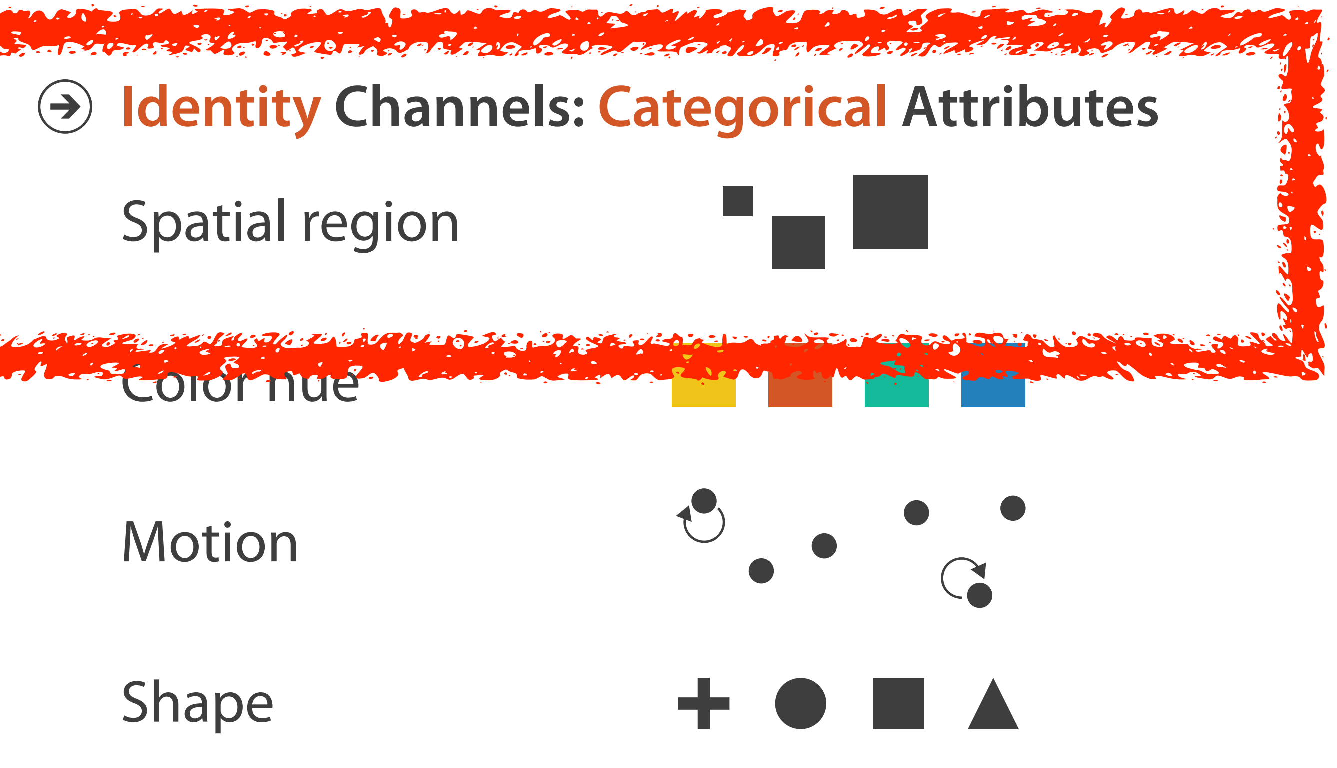




- expressiveness
  - match channel and data characteristics
- effectiveness
  - channels differ in accuracy of perception

Channels: Rankings





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

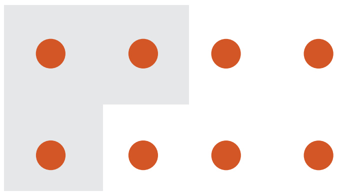
Grouping

- containment
- connection

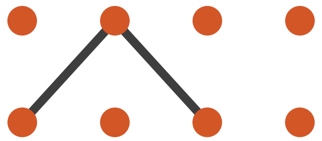
- proximity
  – same spatial region
- similarity
  – same values as other categorical channels

Marks as Links

Containment



Connection

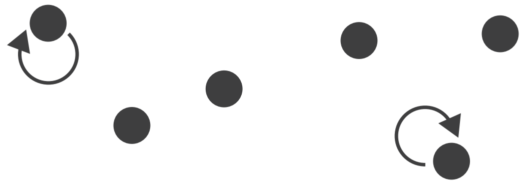


Identity Channels: Categorical Attributes

Spatial region

Color hue

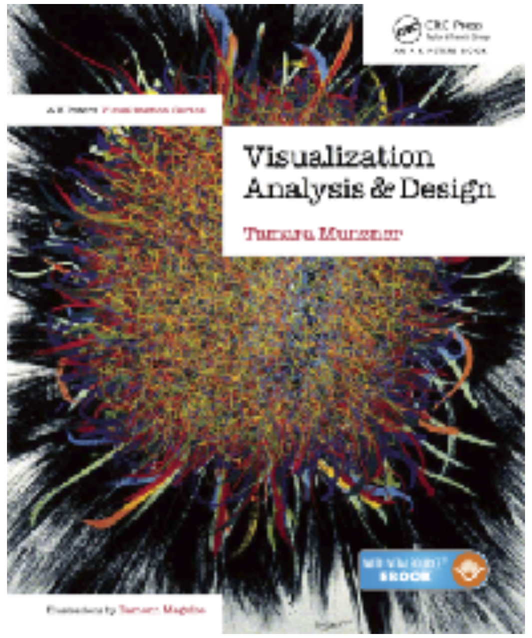
Motion



Shape

Visualization Analysis & Design

Marks & Channels (Ch 5) II



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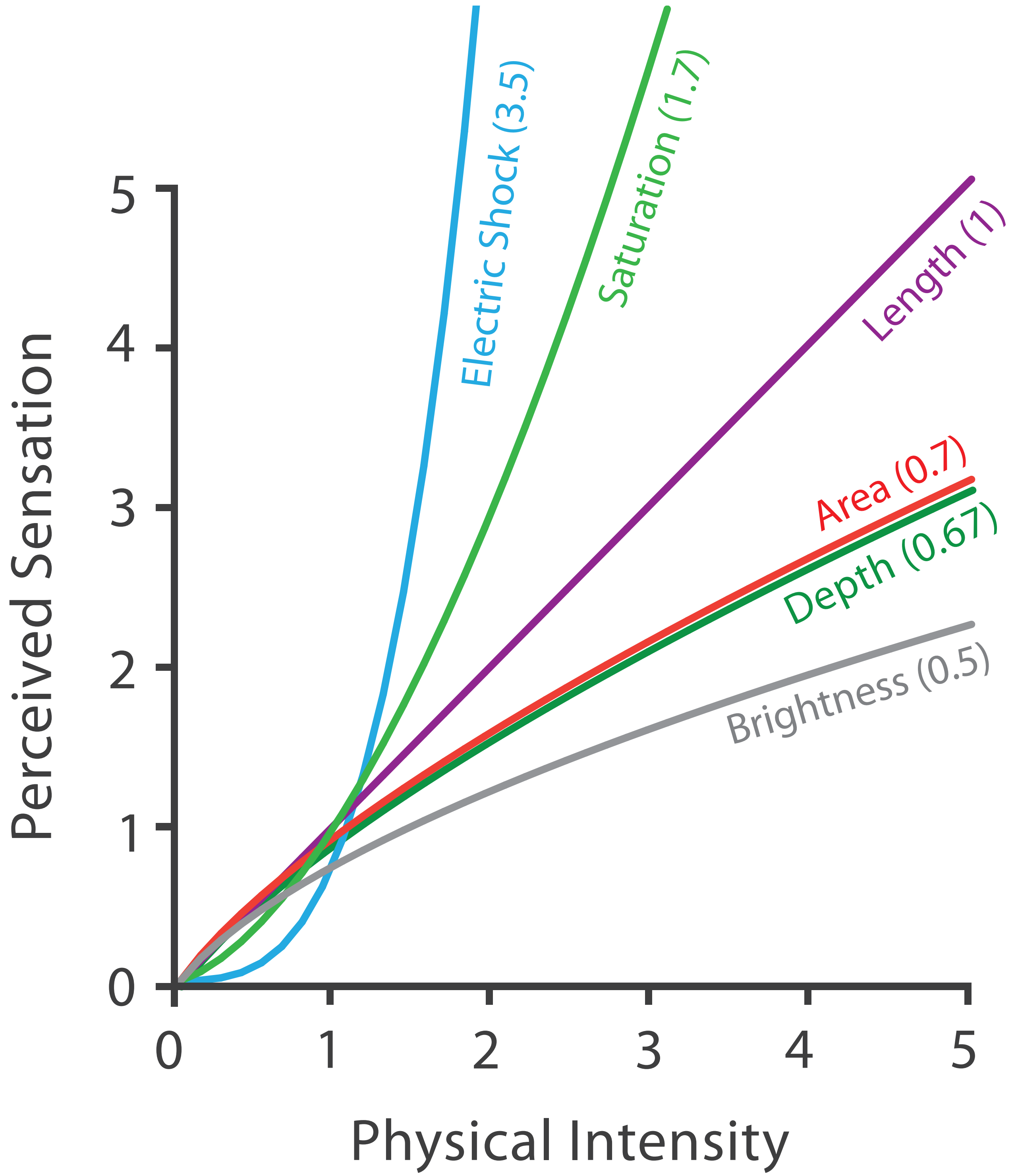
Channel effectiveness

- 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

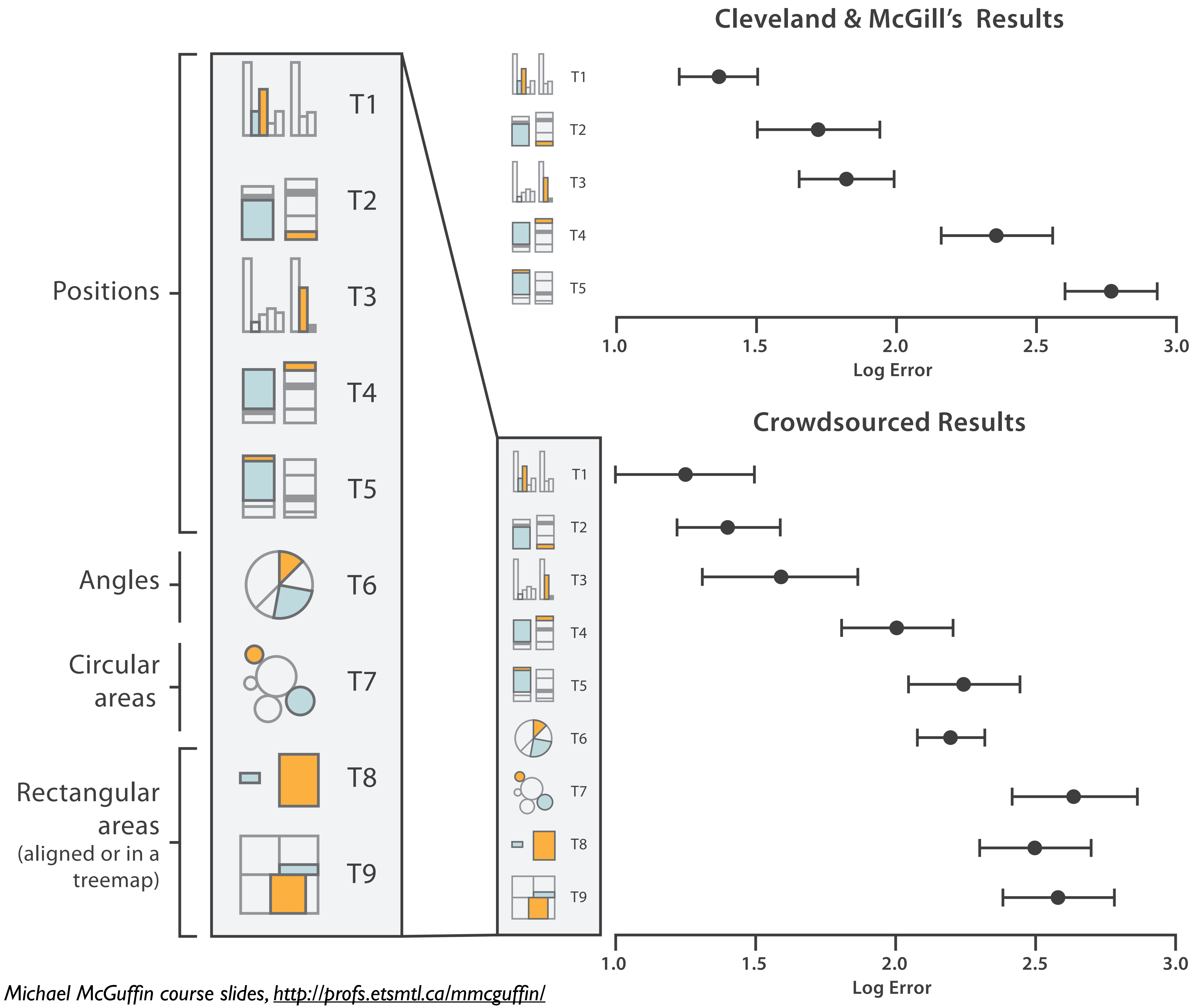
Steven's Psychophysical Power Law: $S = I^N$



S = sensation

I = intensity

Accuracy: Vis experiments

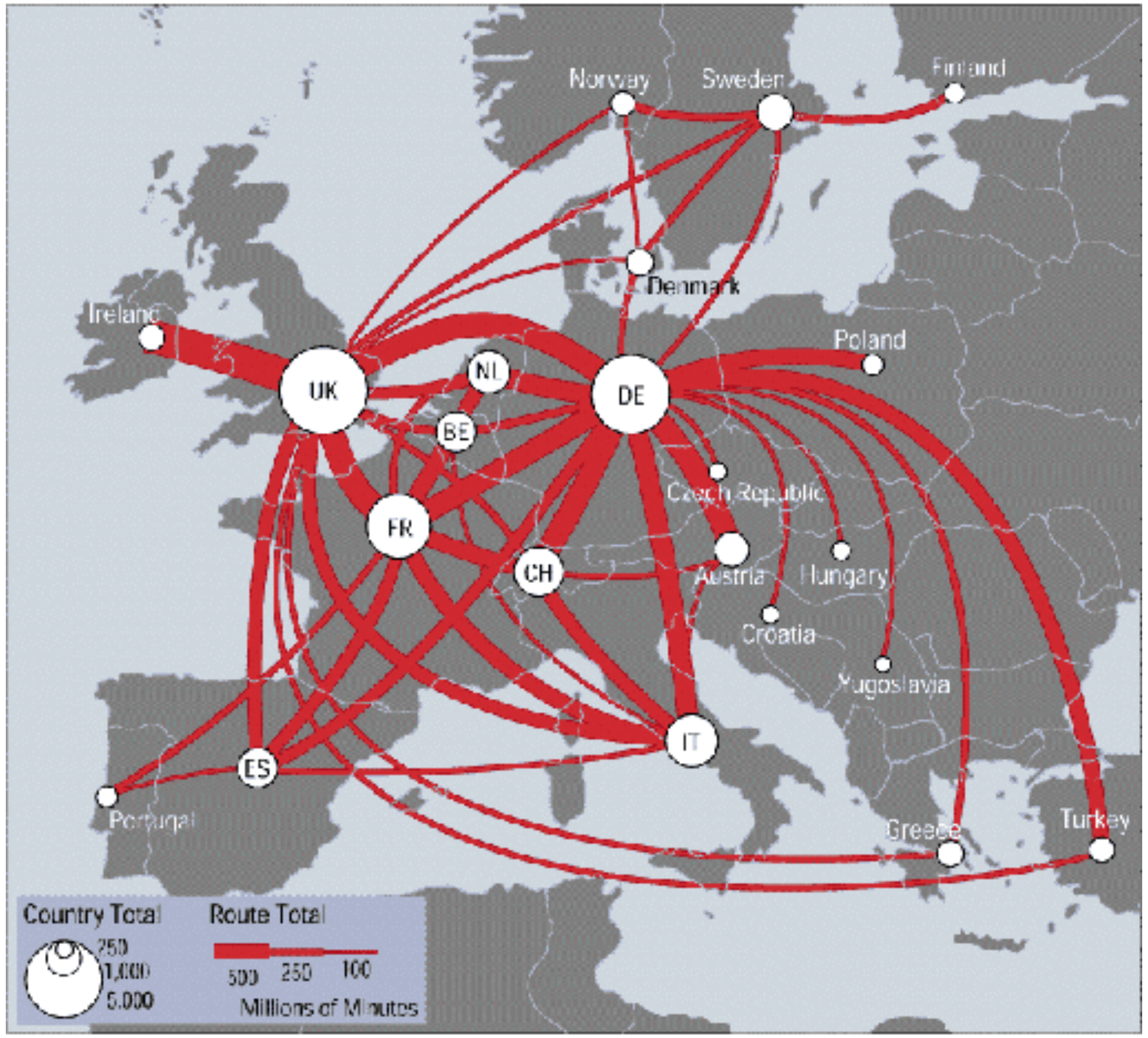


[Crowdsourcing Graphical Perception: Using Mechanical Turk to Assess Visualization Design. Heer and Bostock. Proc ACM Conf. Human Factors in Computing Systems (CHI) 2010, p. 203–212.]

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

Discriminability: How many usable steps?

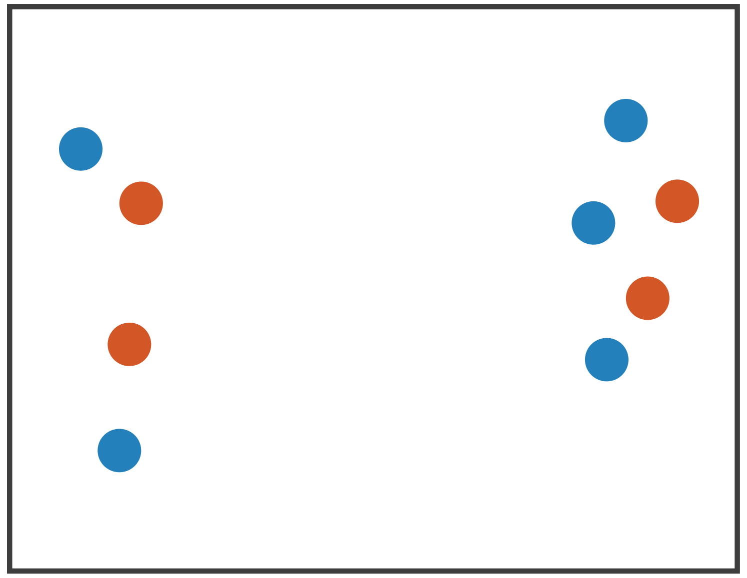
- must be sufficient for number of attribute levels to show
  - linewidth: few bins



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

Separability vs. Integrality

Position
+ Hue (Color)

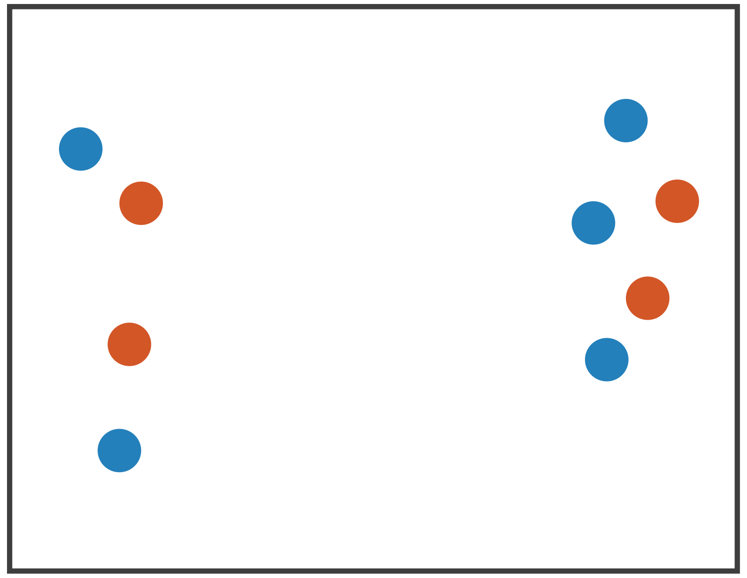


Fully separable

2 groups each

Separability vs. Integrality

Position
+ Hue (Color)



Fully separable

2 groups each

Size
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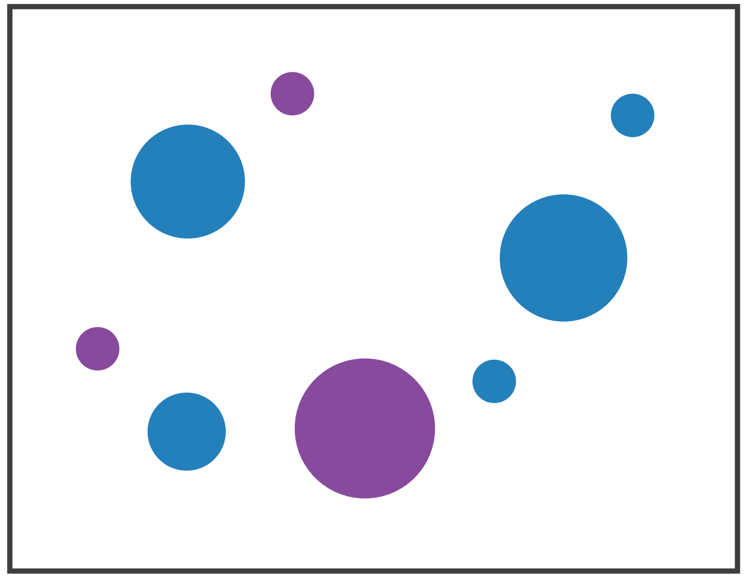
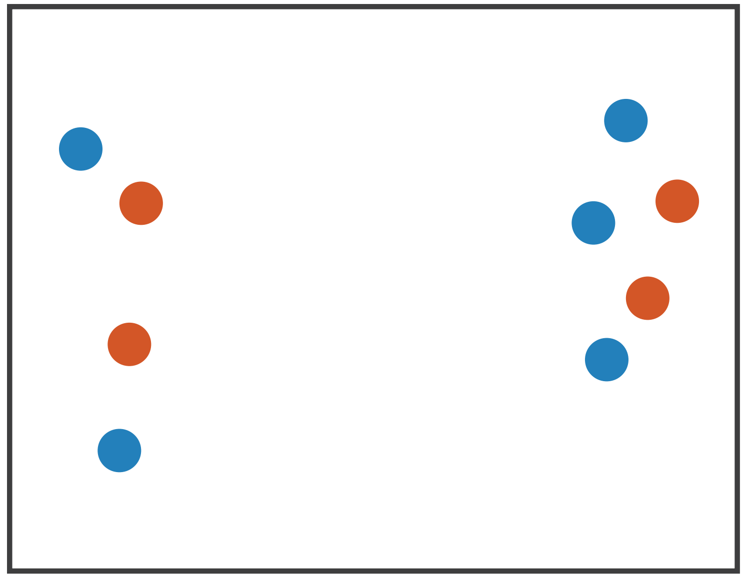


Some interference

2 groups each

Separability vs. Integrality

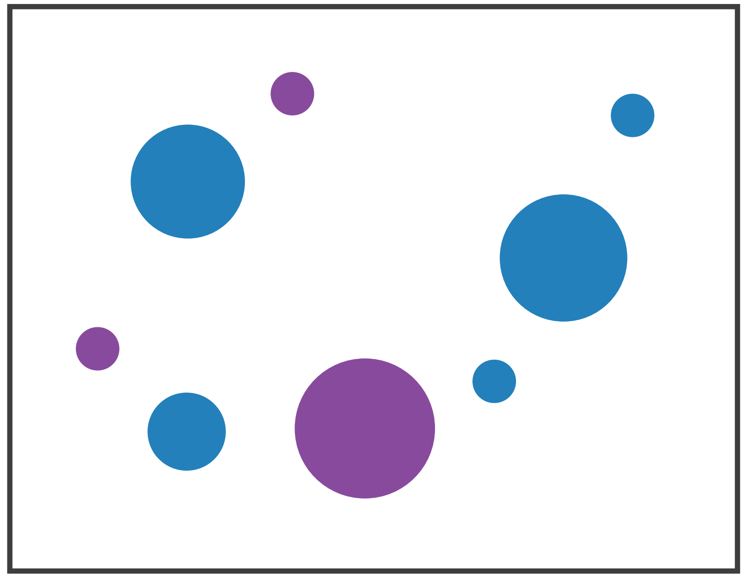
Position
+ Hue (Color)



Fully separable

2 groups each

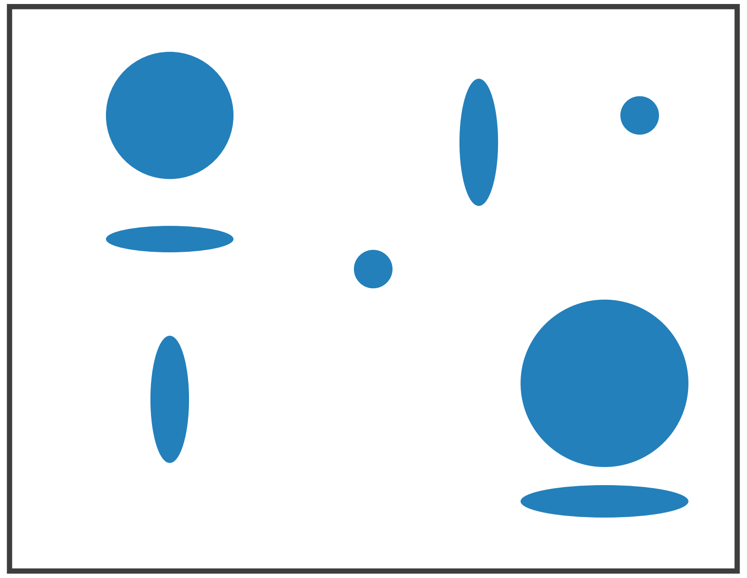
Size
+ Hue (Color)



Some interference

2 groups each

Width
+ Height

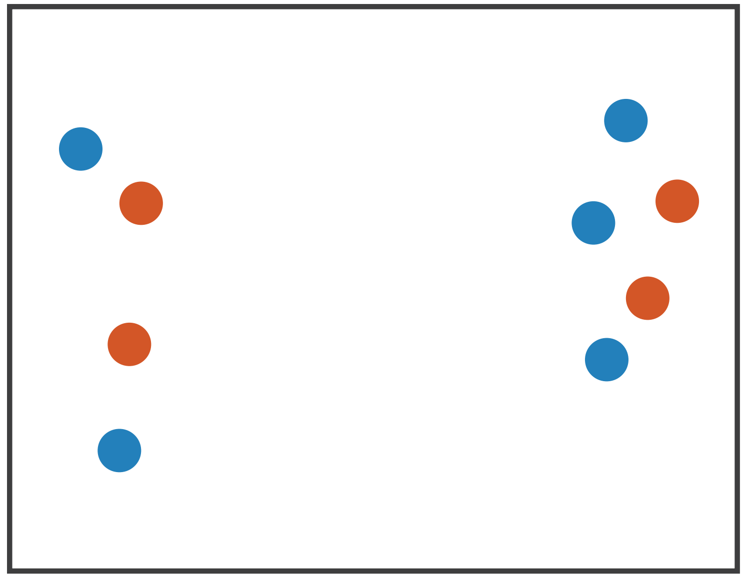


Some/significant interference

3 groups total: integral area

Separability vs. Integrality

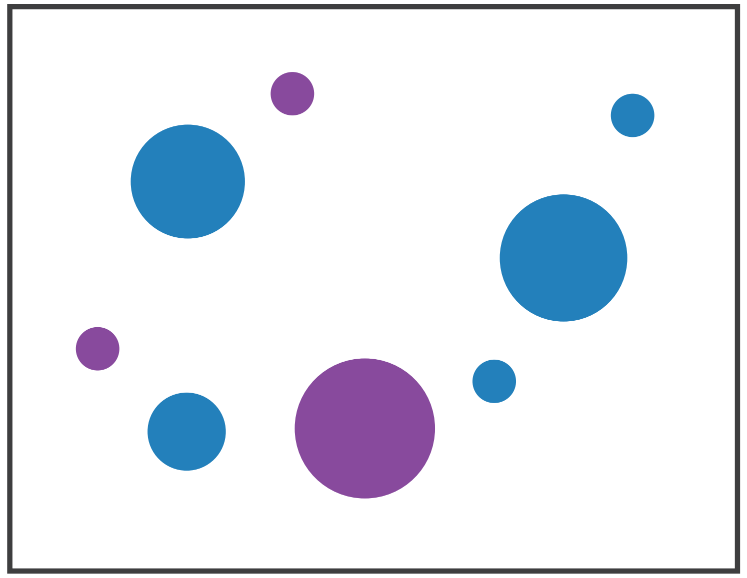
Position
+ Hue (Color)



Fully separable

2 groups each

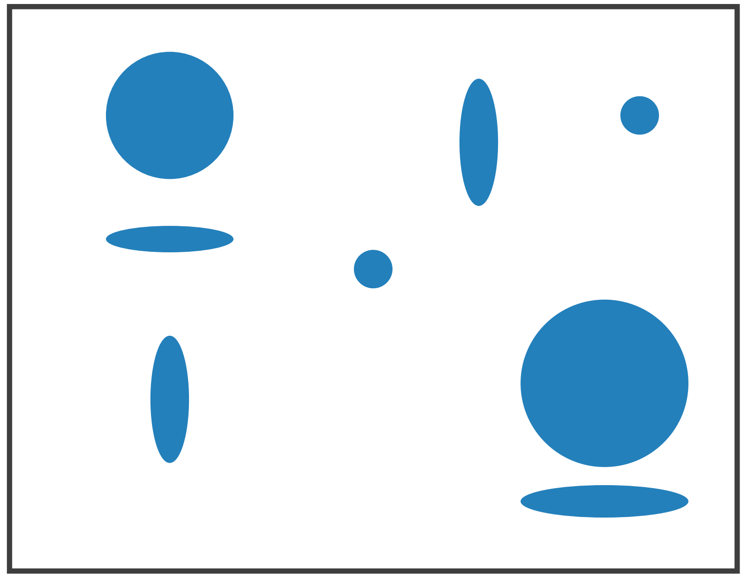
Size
+ Hue (Color)



Some interference

2 groups each

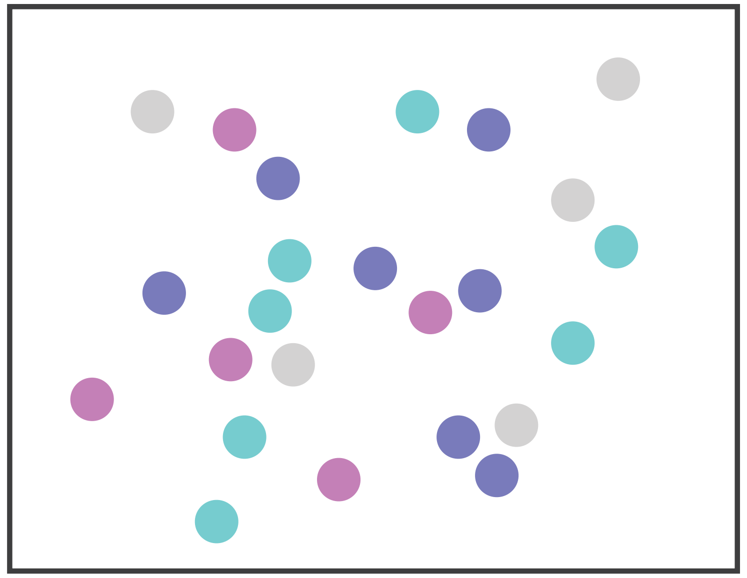
Width
+ Height



Some/significant interference

3 groups total: integral area

Red
+ Green



Major interference

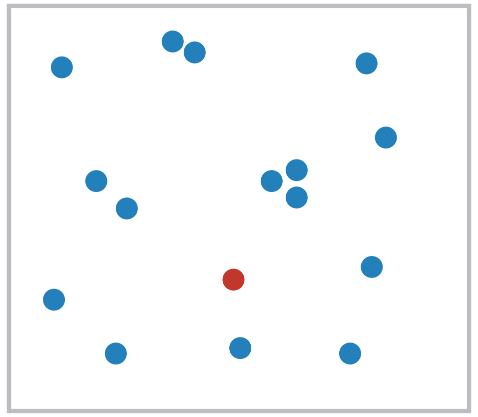
4 groups total: integral hue

Popout

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

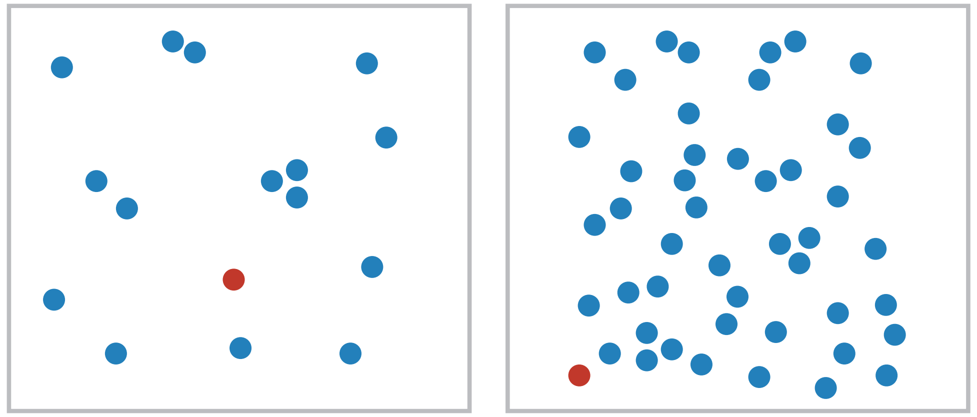
Popout

- 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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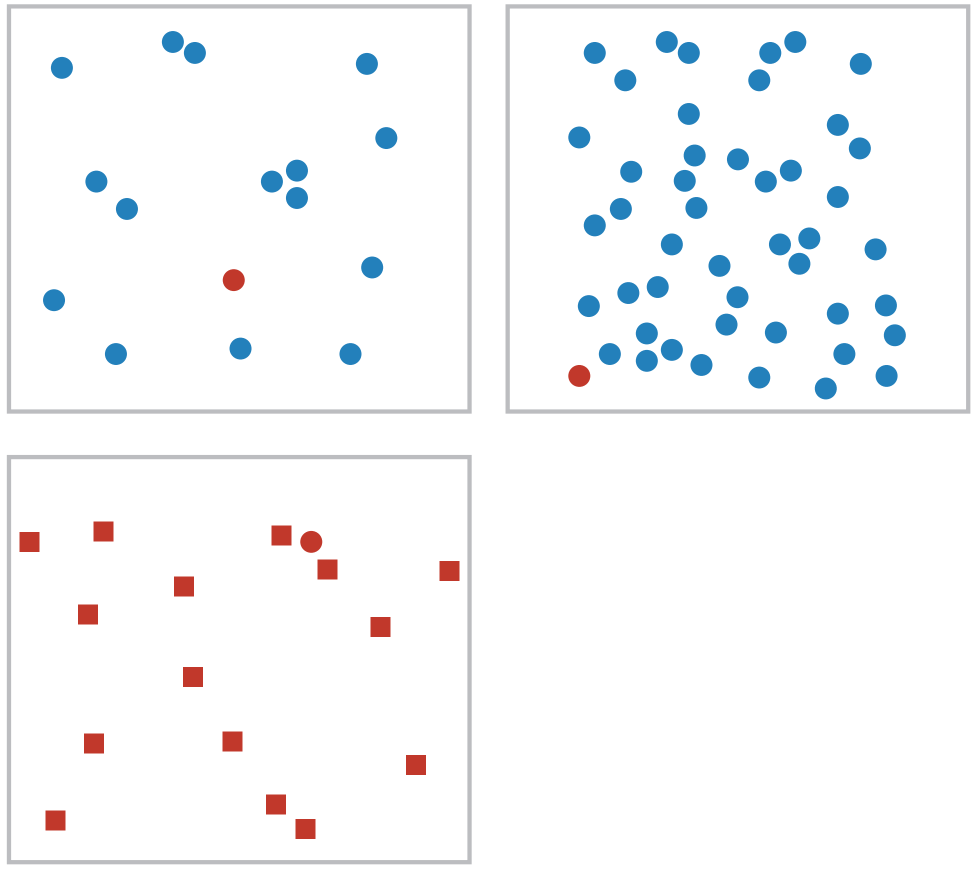
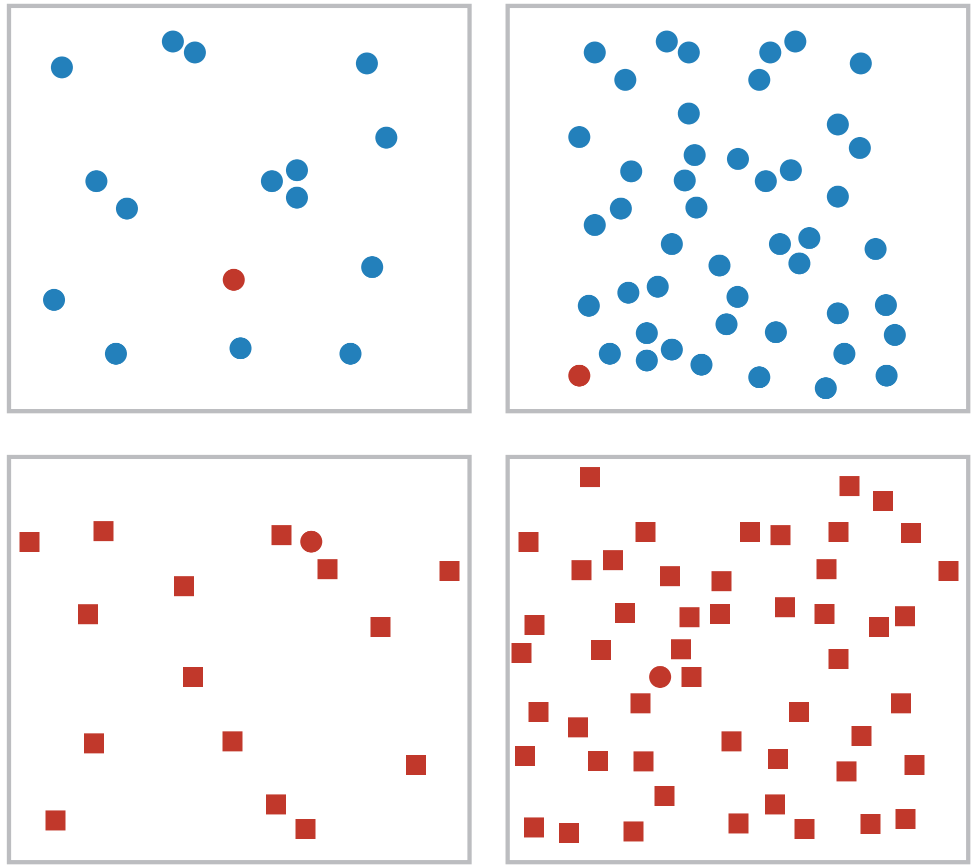


Popout

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



Popout

- find the red dot
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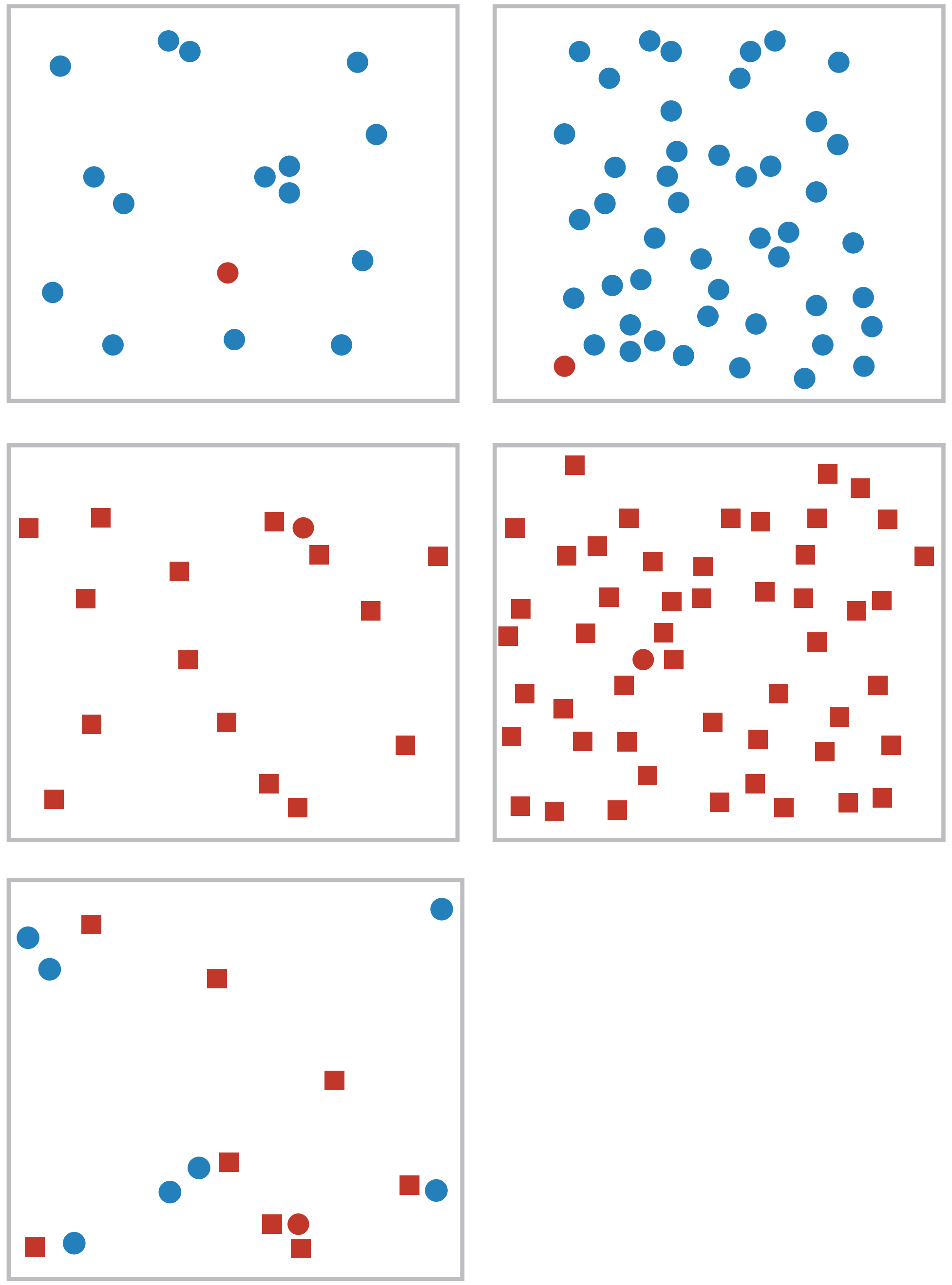
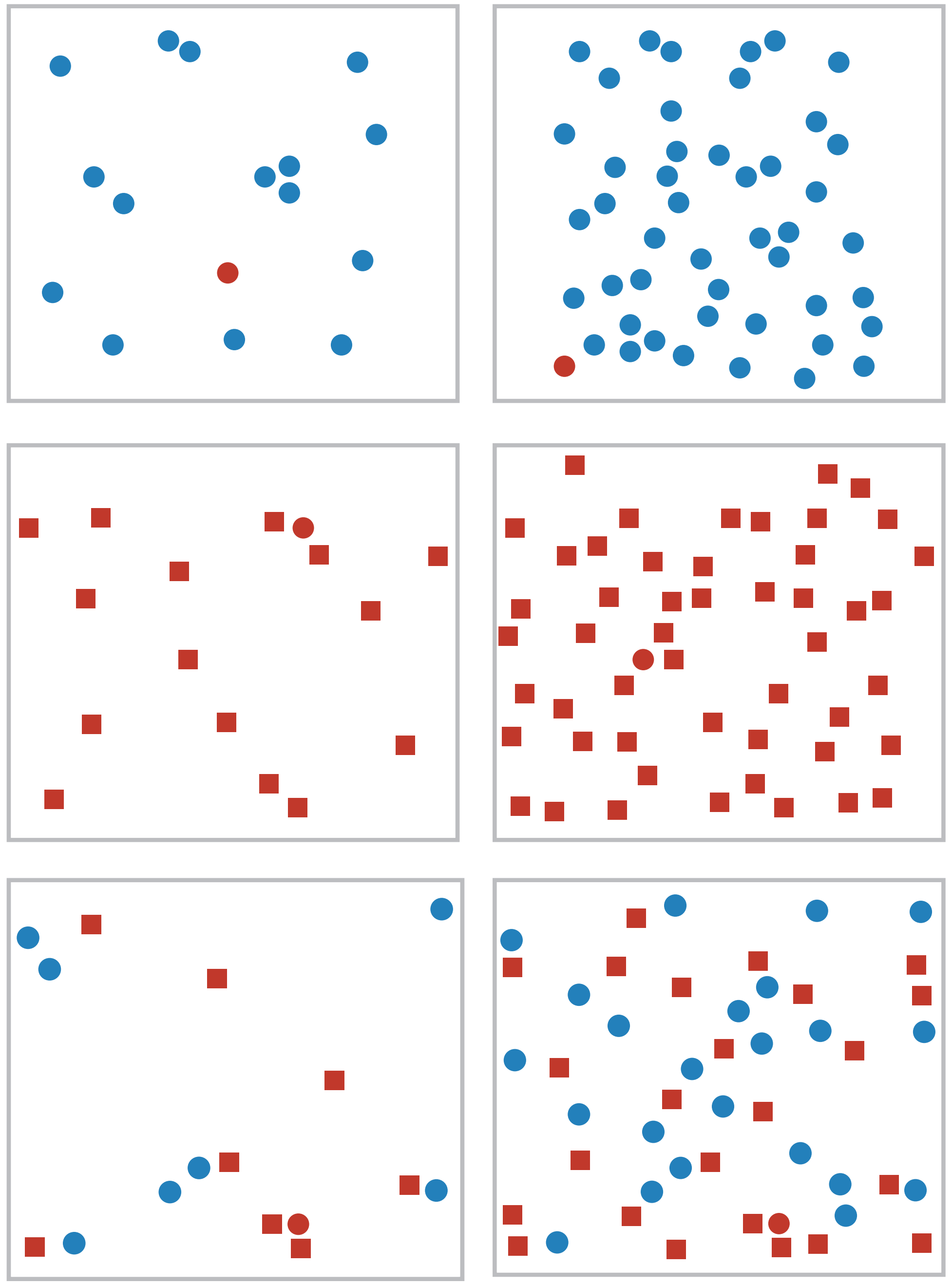


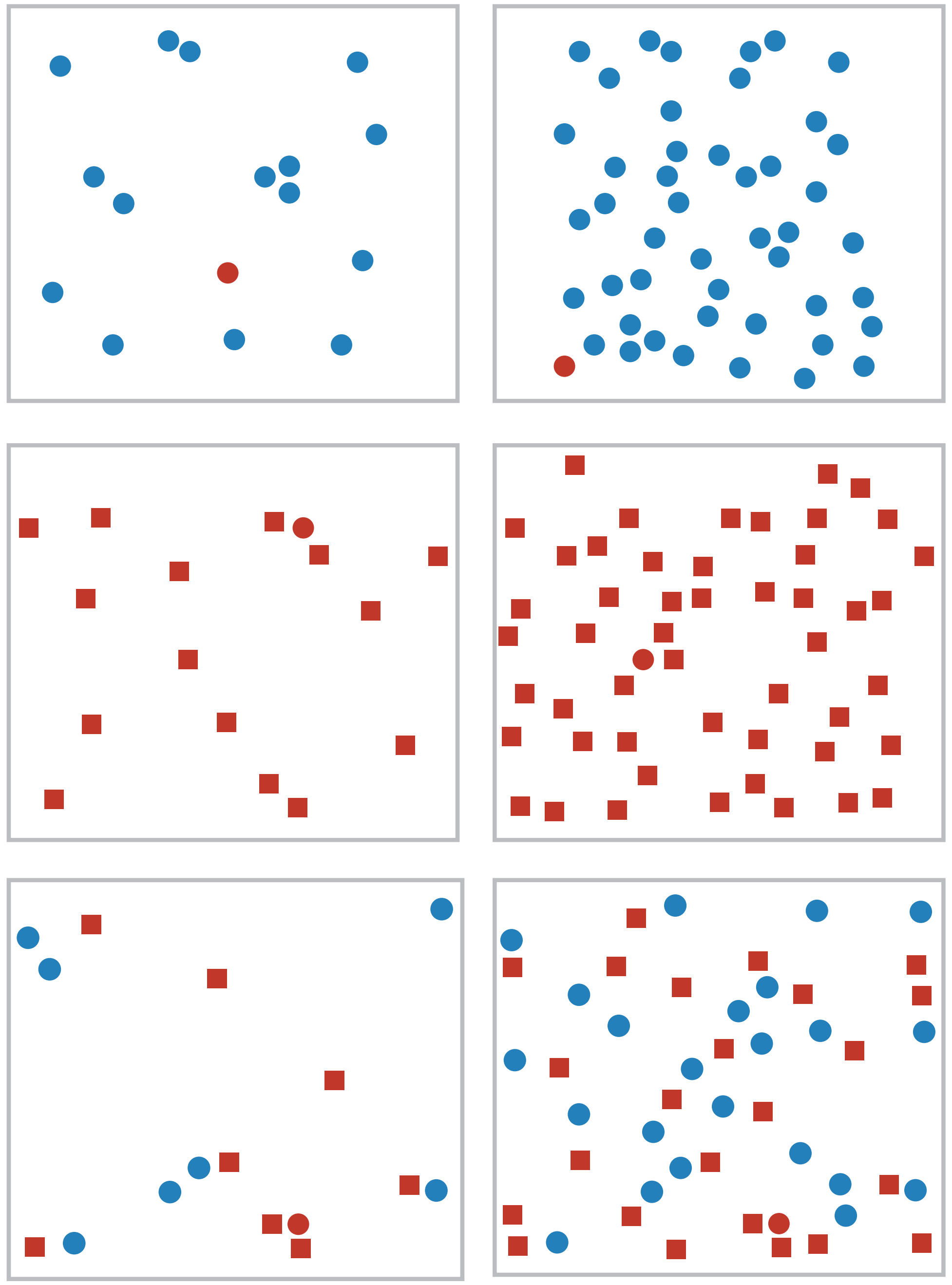
Popout

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

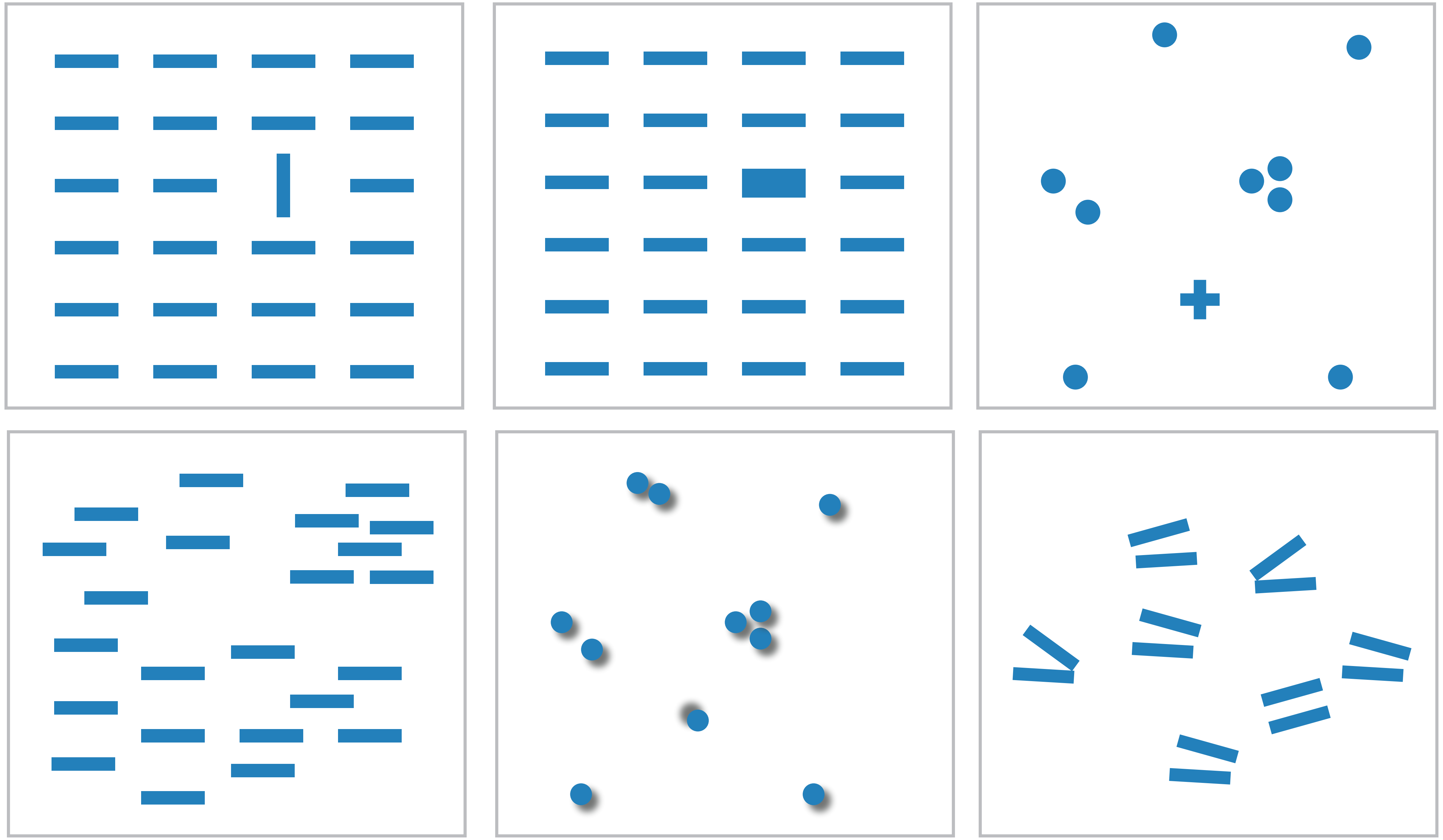


Popout

- 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

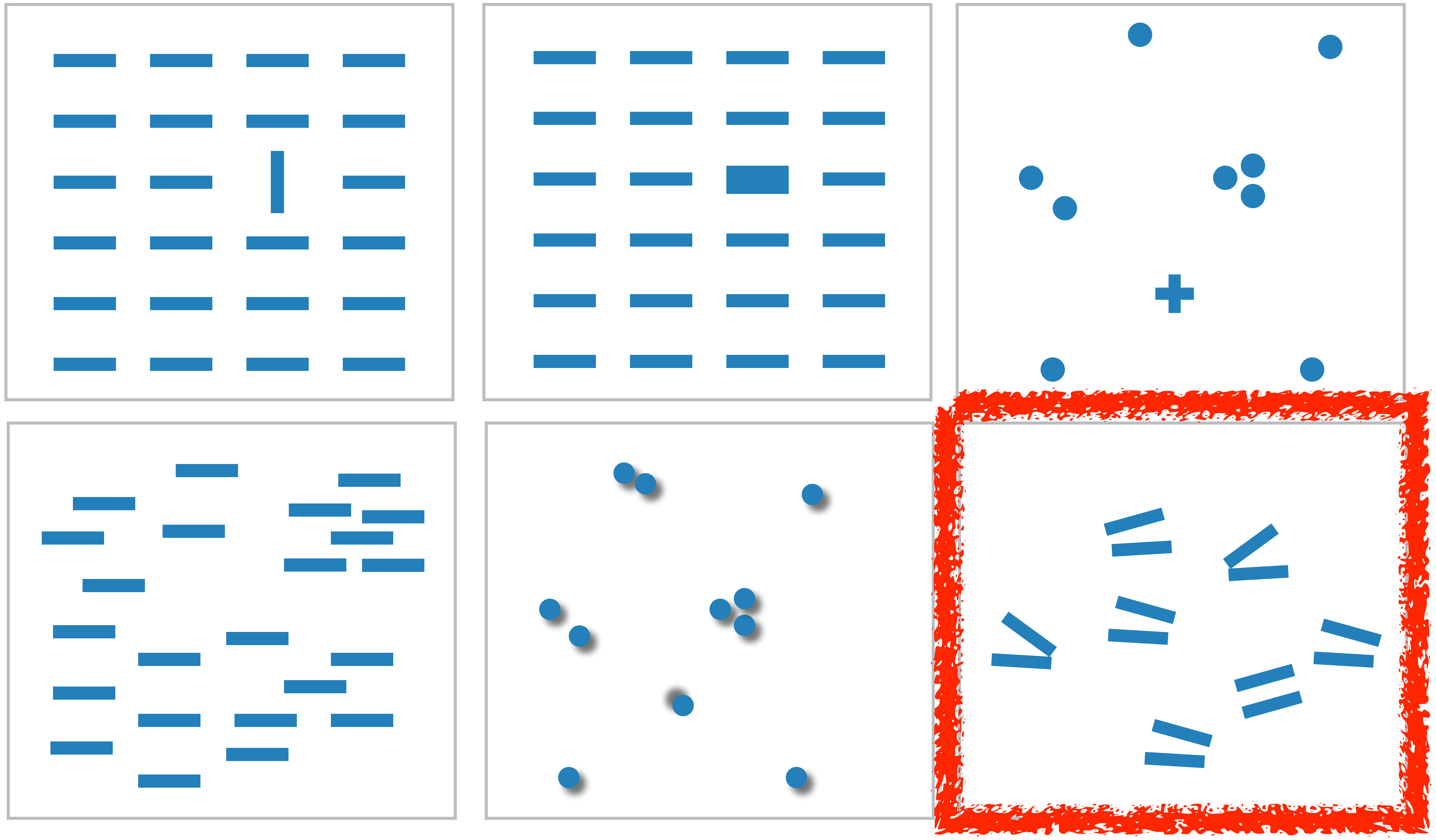


Popout



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

Popout



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

Factors affecting accuracy

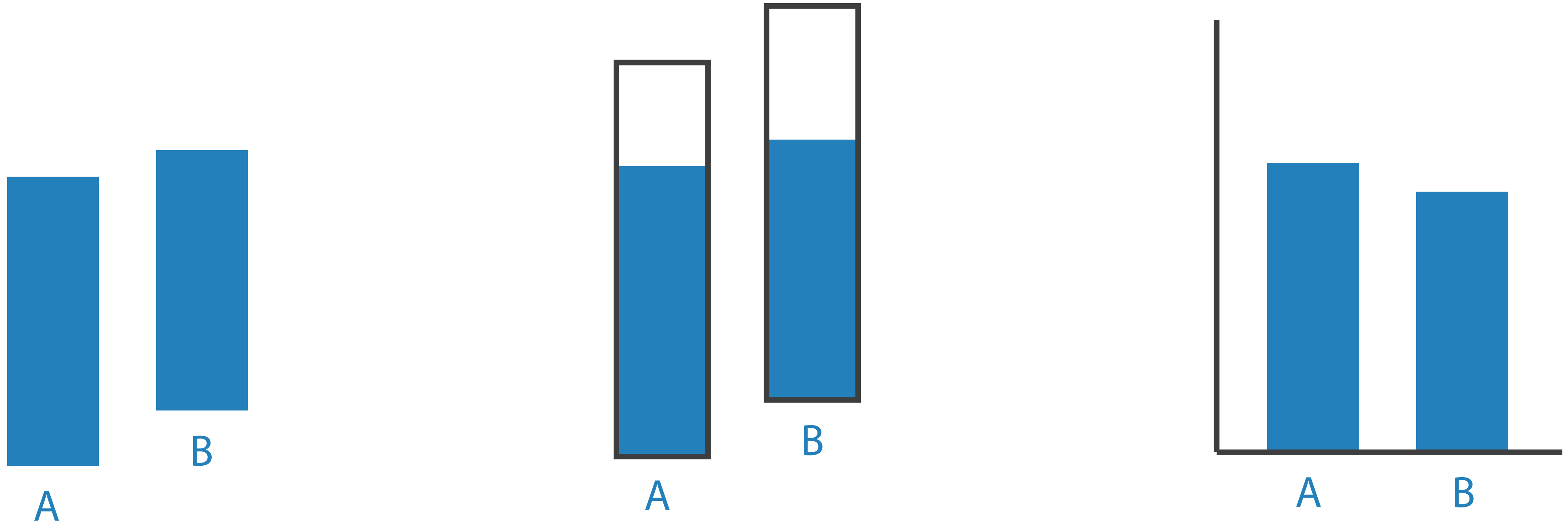
- alignment
- distractors
- distance
- common scale / alignment

Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute

Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment



length

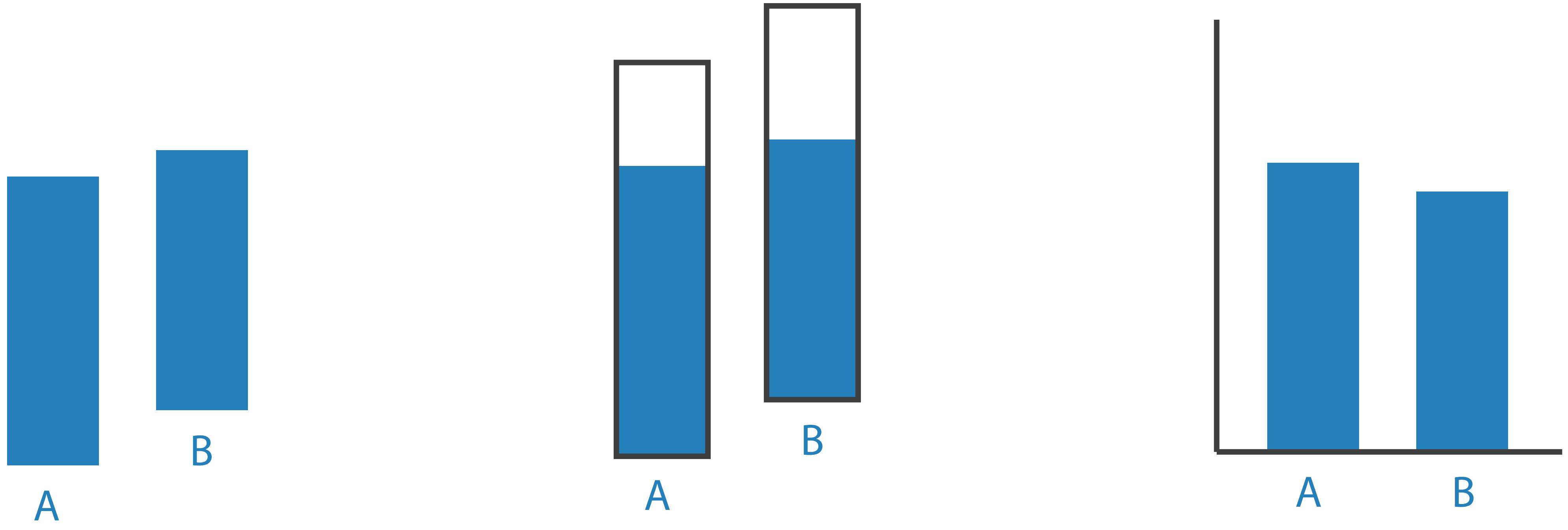
position along unaligned common scale

position along aligned scale

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.]

Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment
  - Weber's Law: ratio of increment to background is constant



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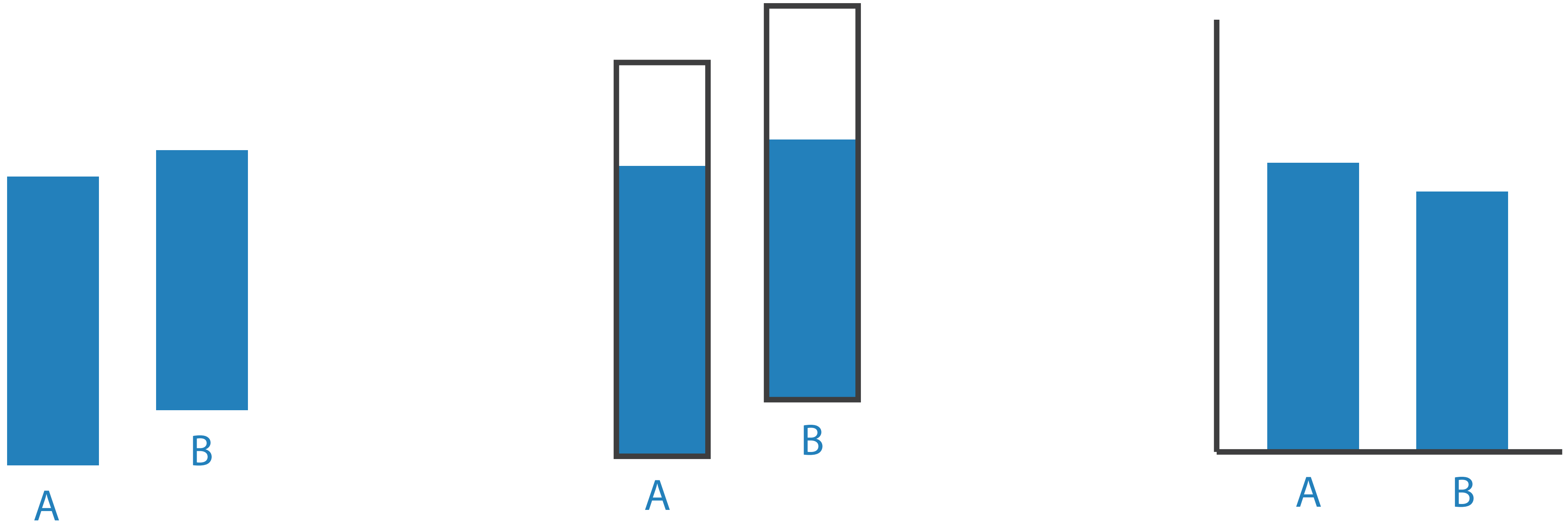
Relative vs. absolute judgements

- perceptual system mostly operates with relative judgements, not absolute
  - that's why accuracy increases with common frame/scale and alignment
  - Weber's Law: ratio of increment to background is constant
    - filled rectangles differ in length by 1:9, difficult judgement
    - white rectangles differ in length by 1:2, easy judgement



length

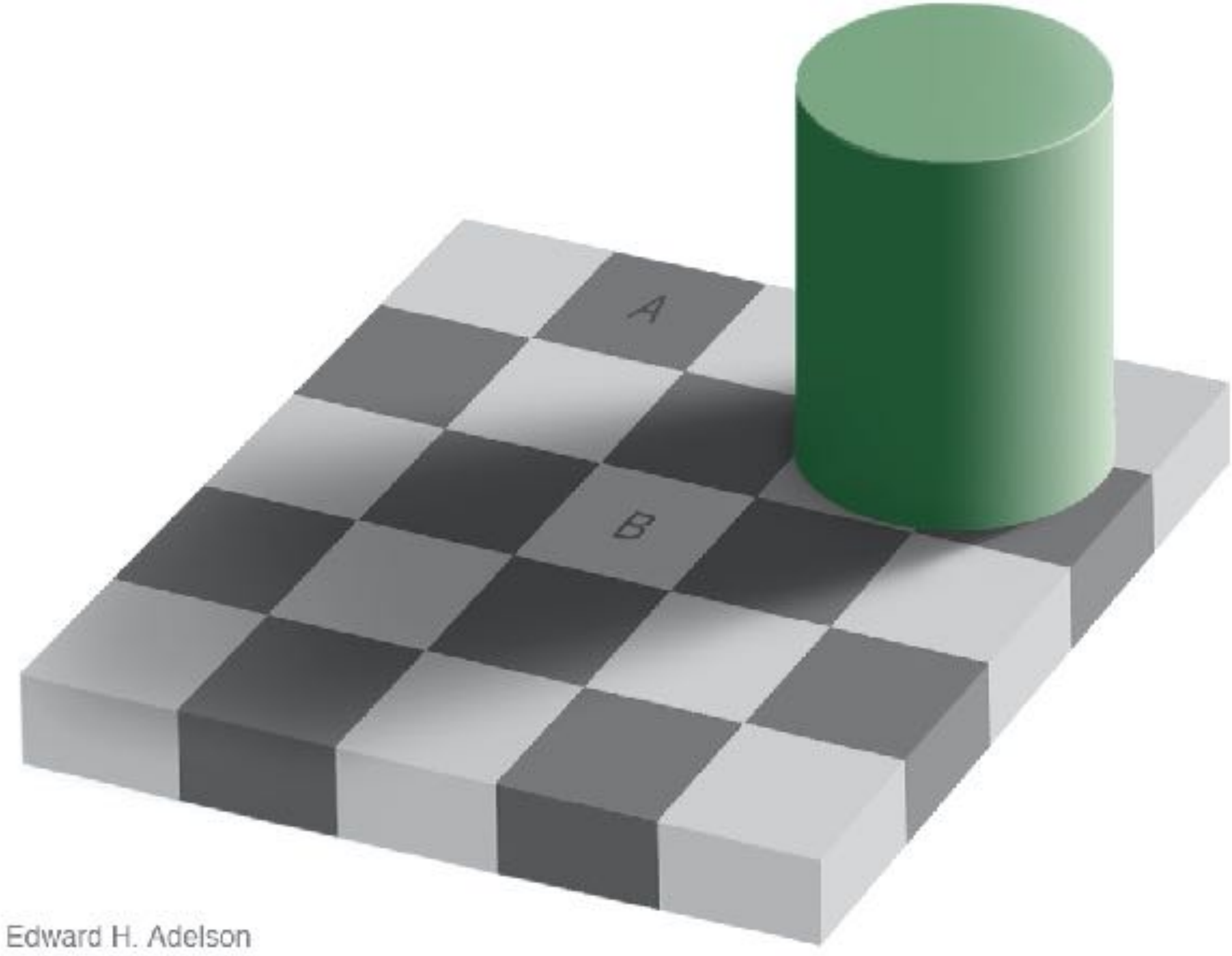
position along unaligned common scale

position along aligned scale

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.]

Relative luminance judgements

- perception of luminance is contextual based on contrast with surroundings



http://persci.mit.edu/gallery/checkershadow

Relative luminance judgements

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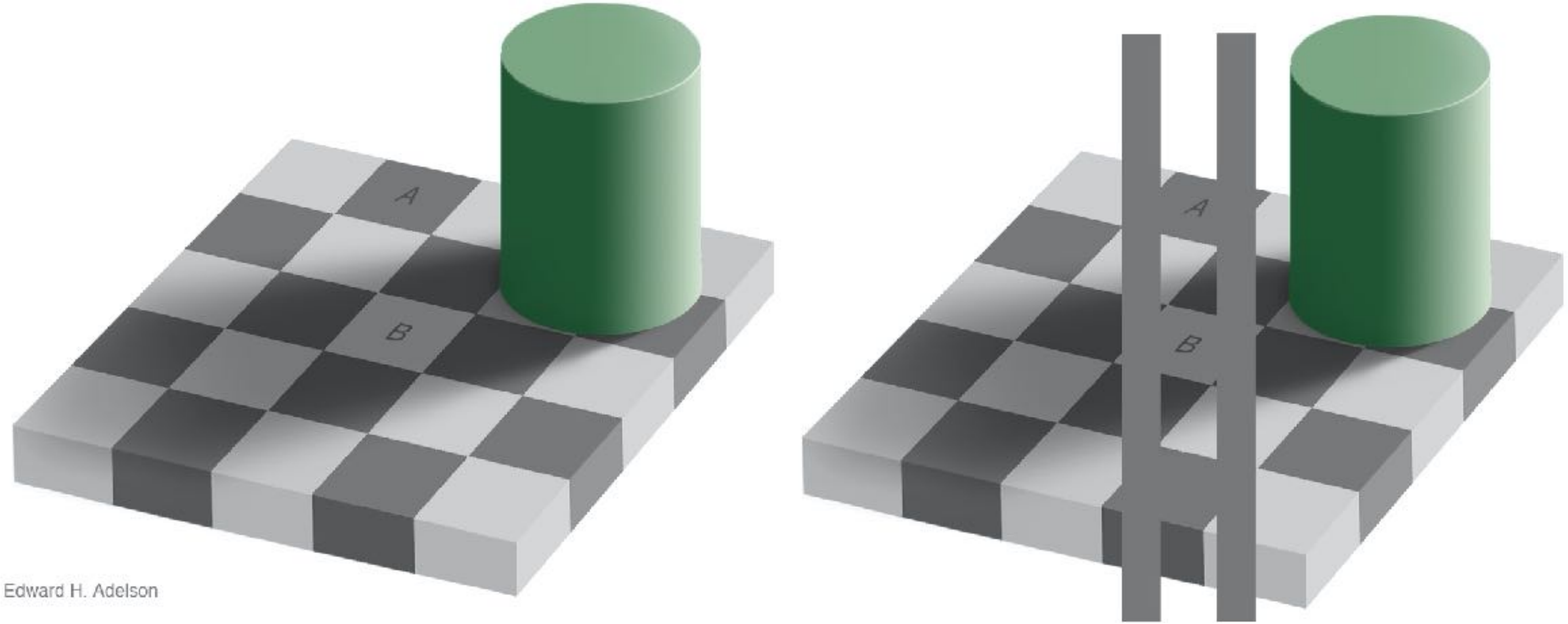
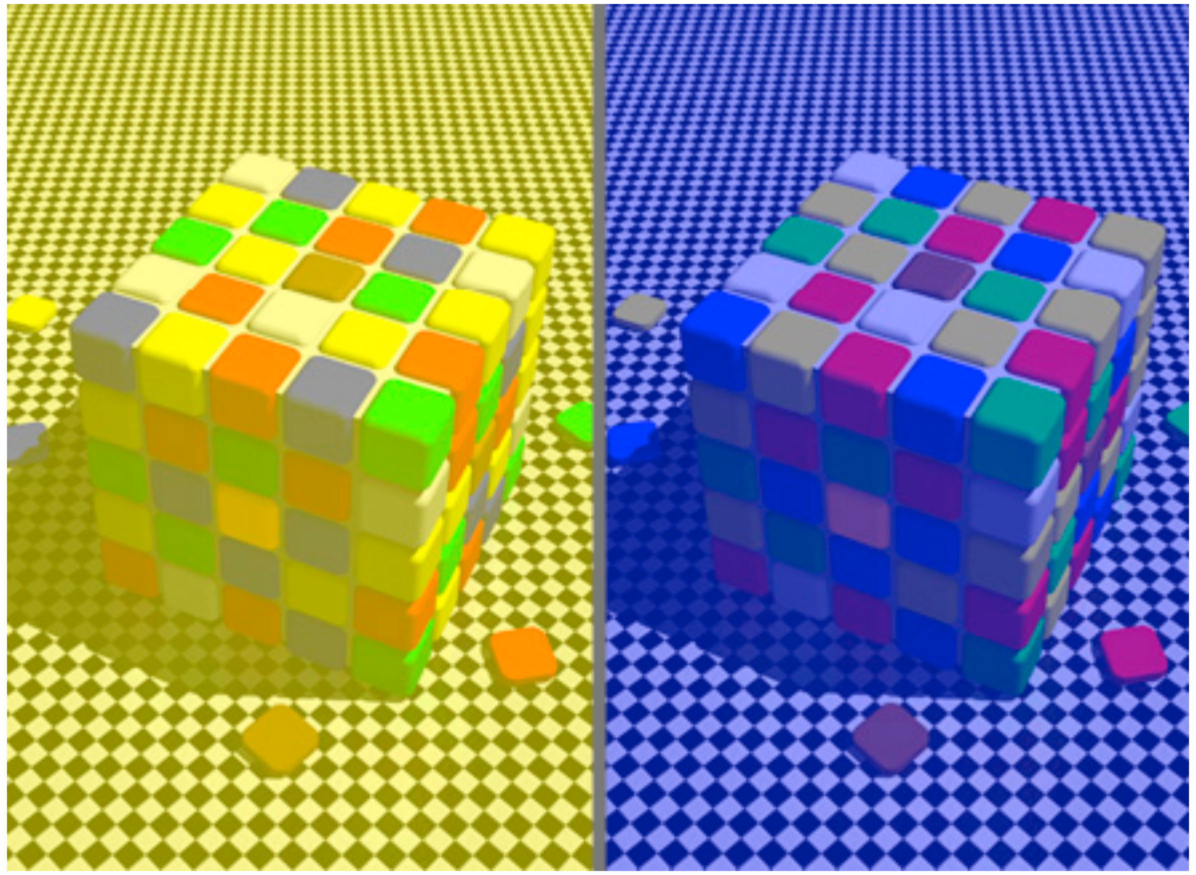


http://persci.mit.edu/gallery/checkershadow

Relative color judgements

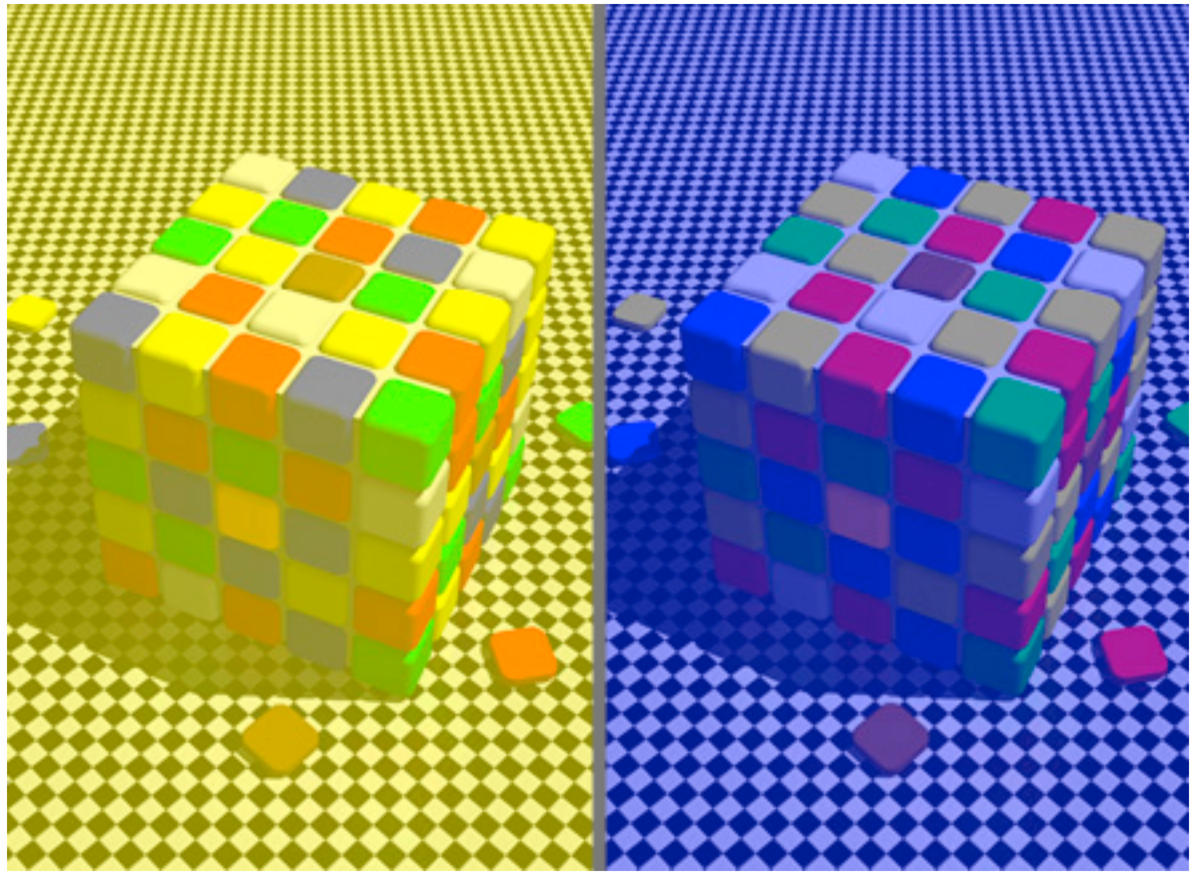
- color constancy across broad range of illumination conditions

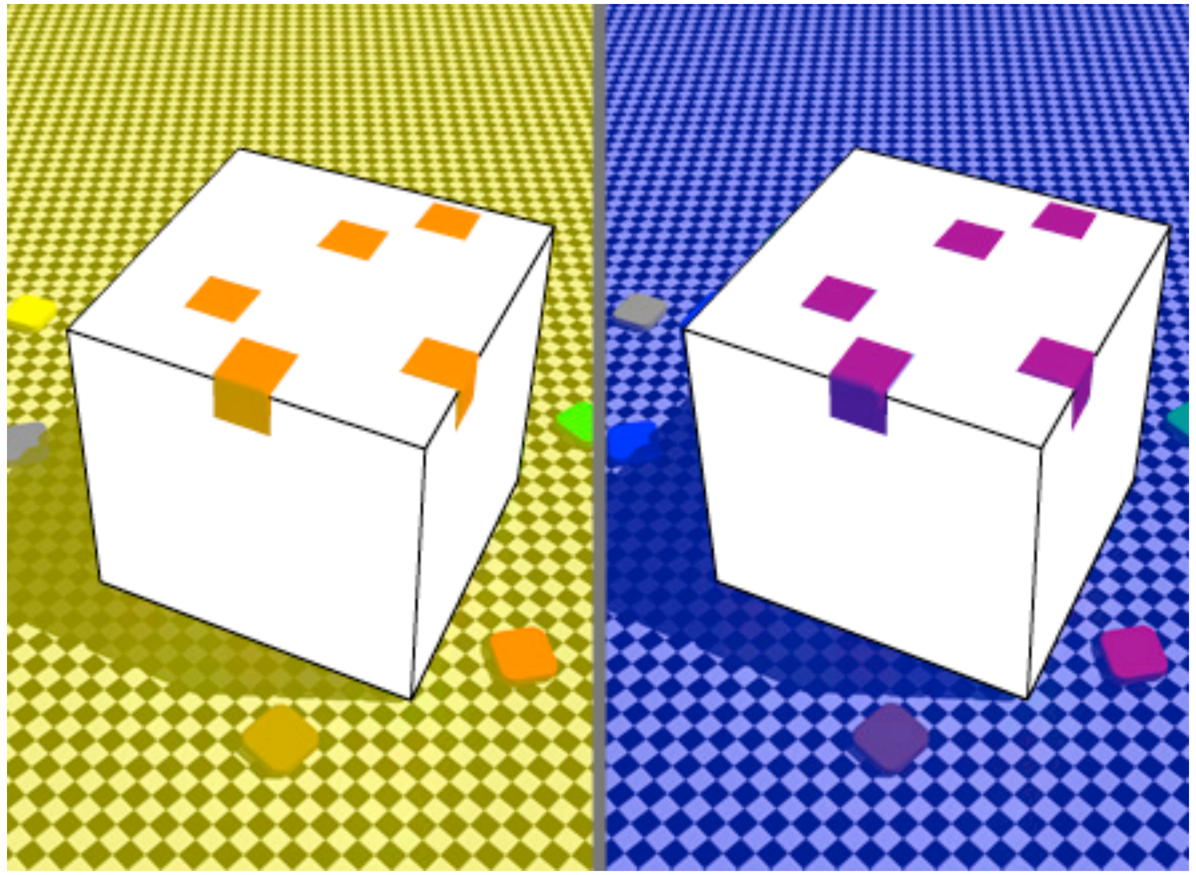


http://www.purveslab.net/seeforyourself/

Relative color judgements

- color constancy across broad range of illumination conditions





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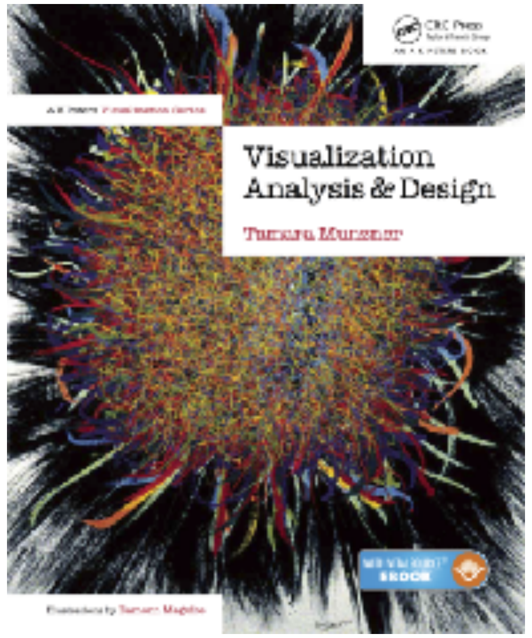

Visualization Analysis & Design

Arrange Tables (Ch 7) I

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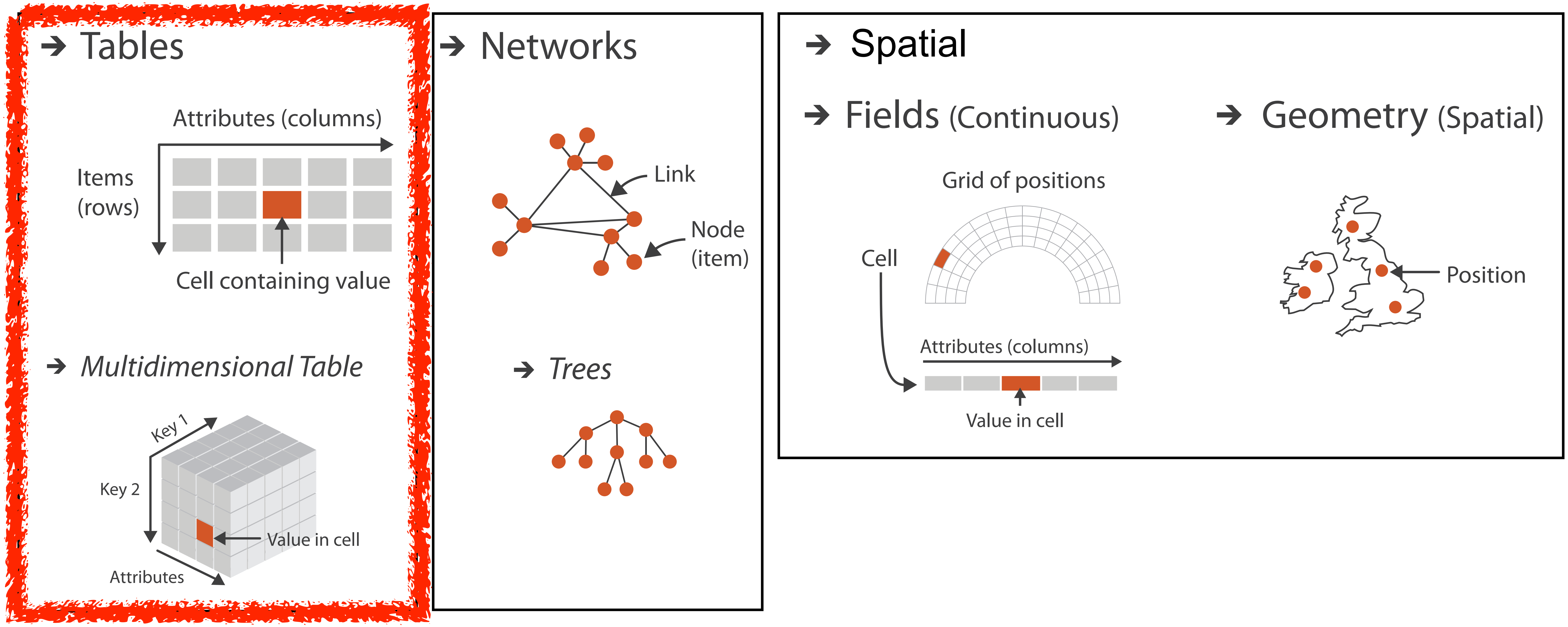
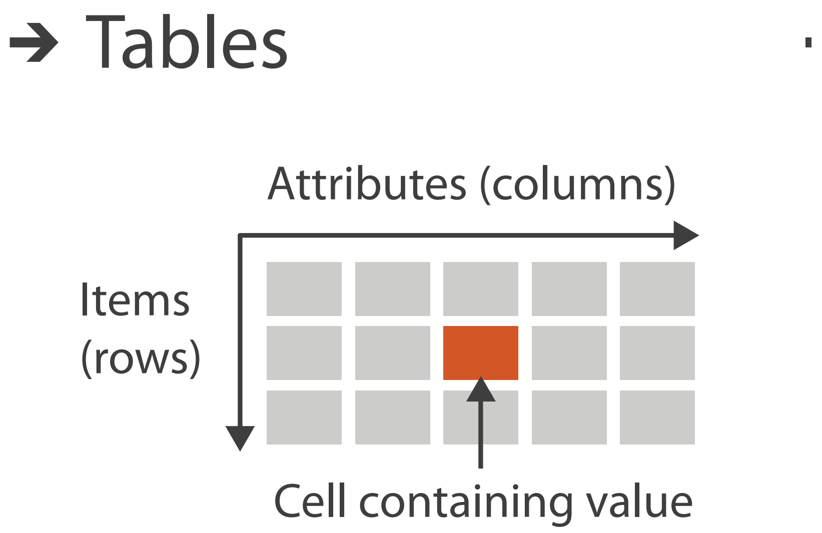
Focus on Tables

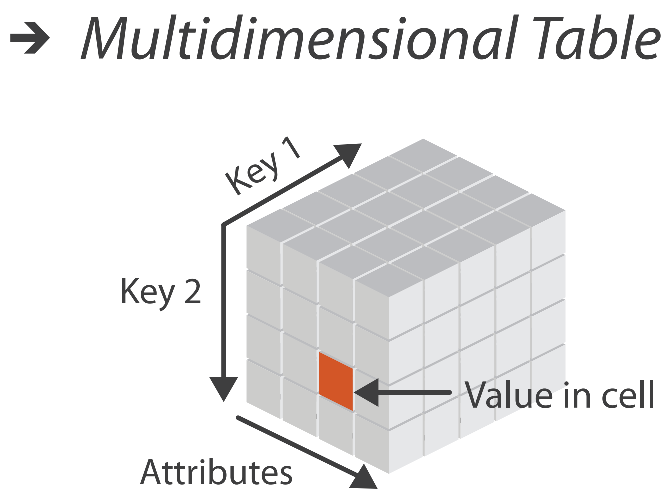
Dataset Types



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

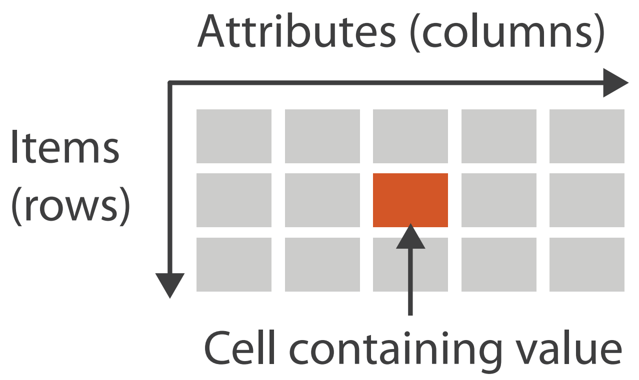




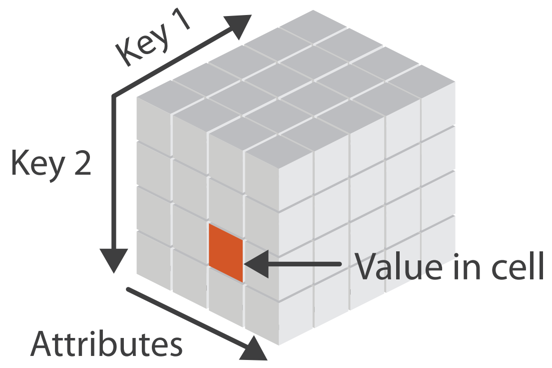
Keys and values

- 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, ...

→ Tables



→ *Multidimensional Table*

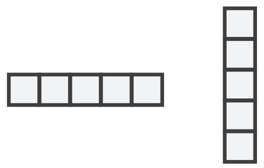


→ *0 Keys*

→ **Express Values**

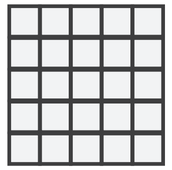
→ *1 Key*

List



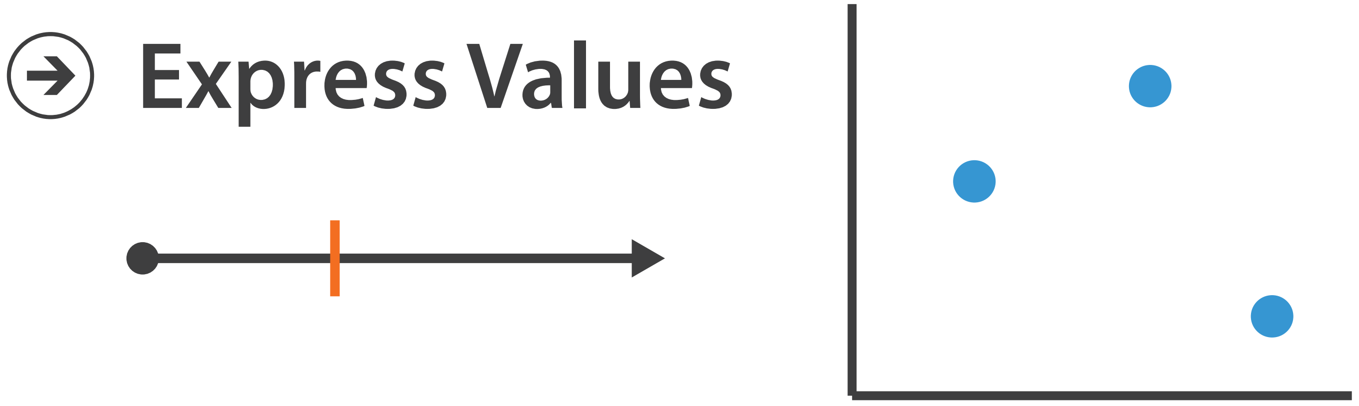
→ *2 Keys*

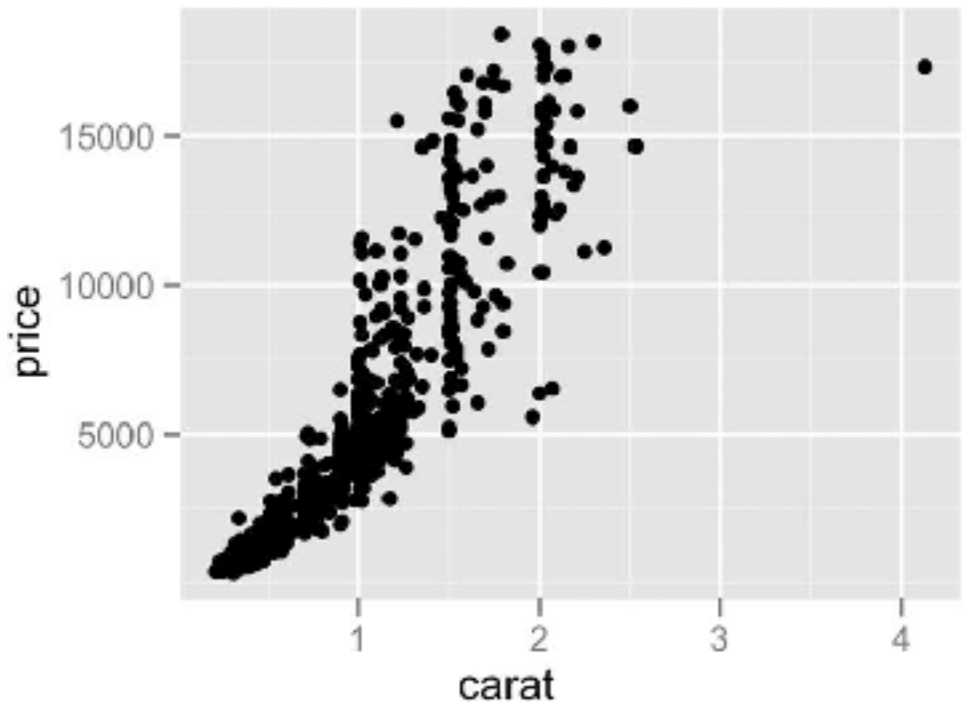
Matrix

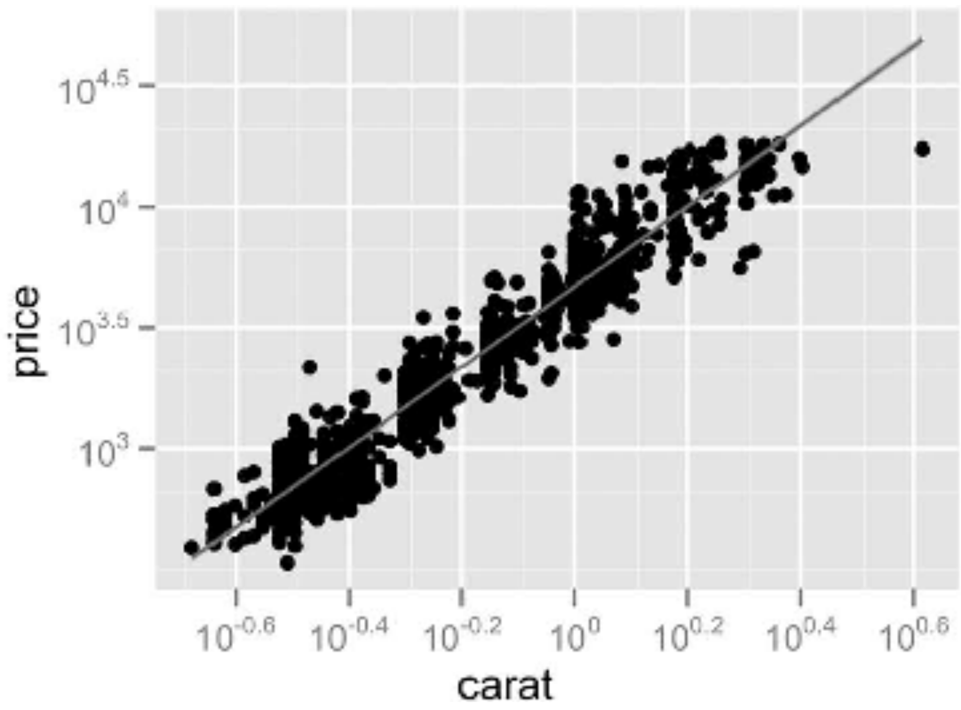


Idiom: **scatterplot**

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



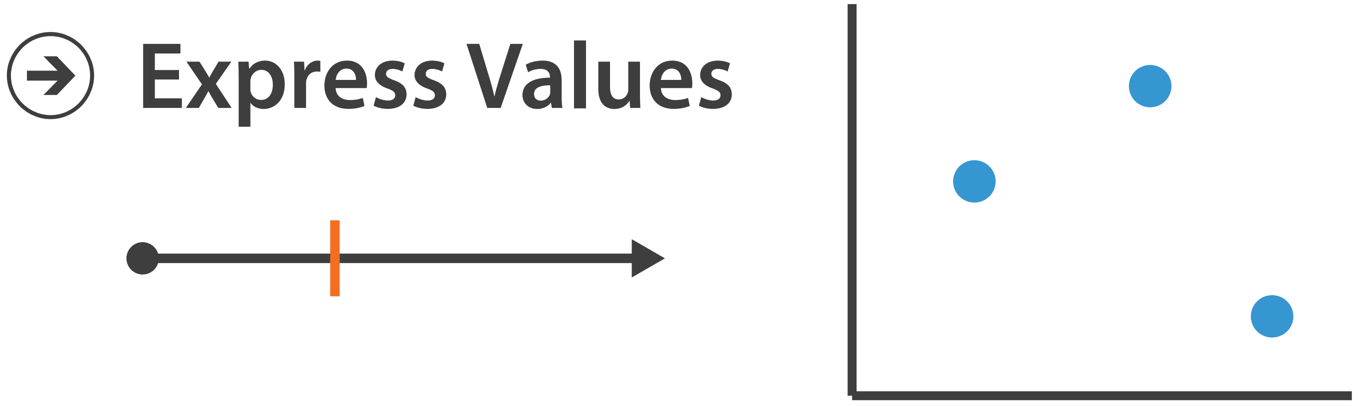


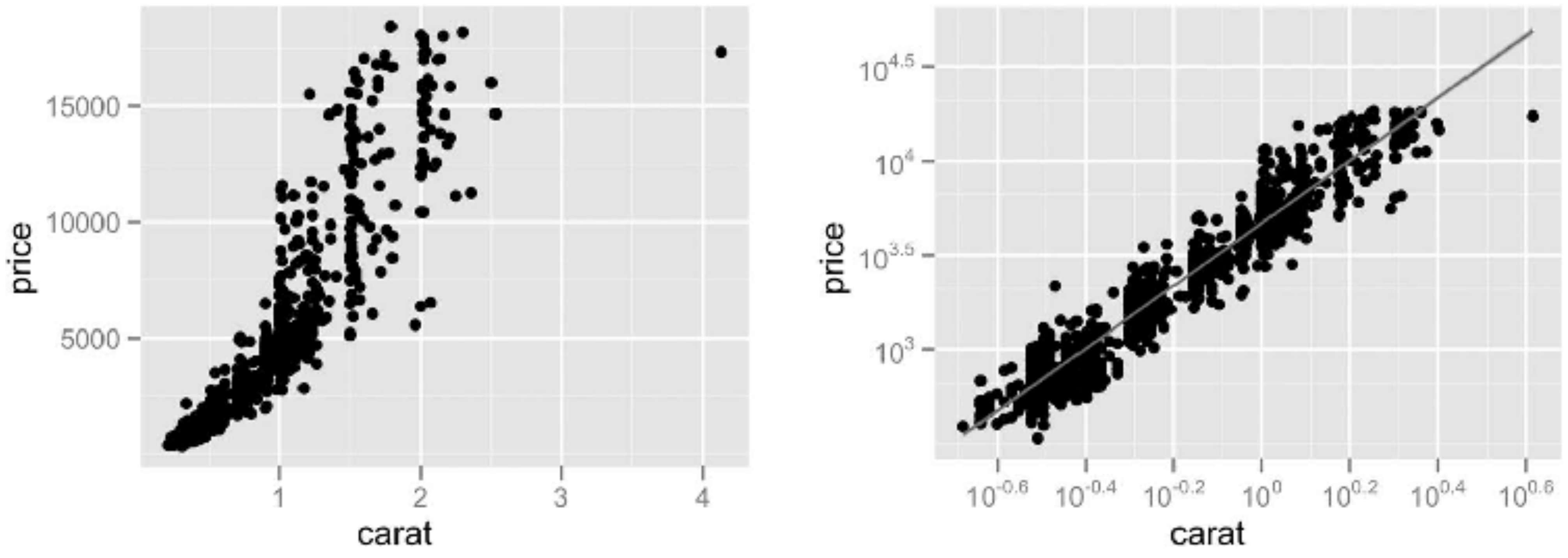


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Idiom: **scatterplot**

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





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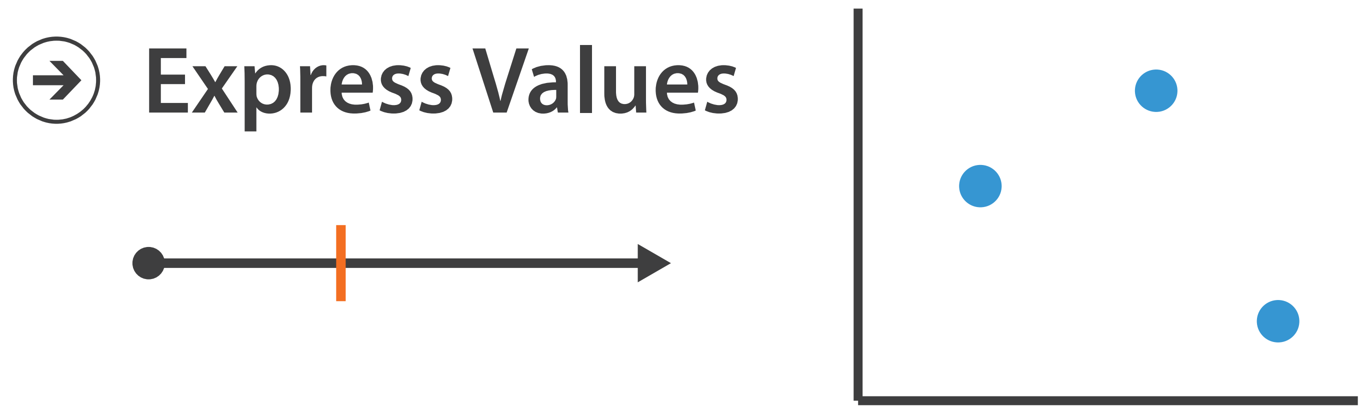
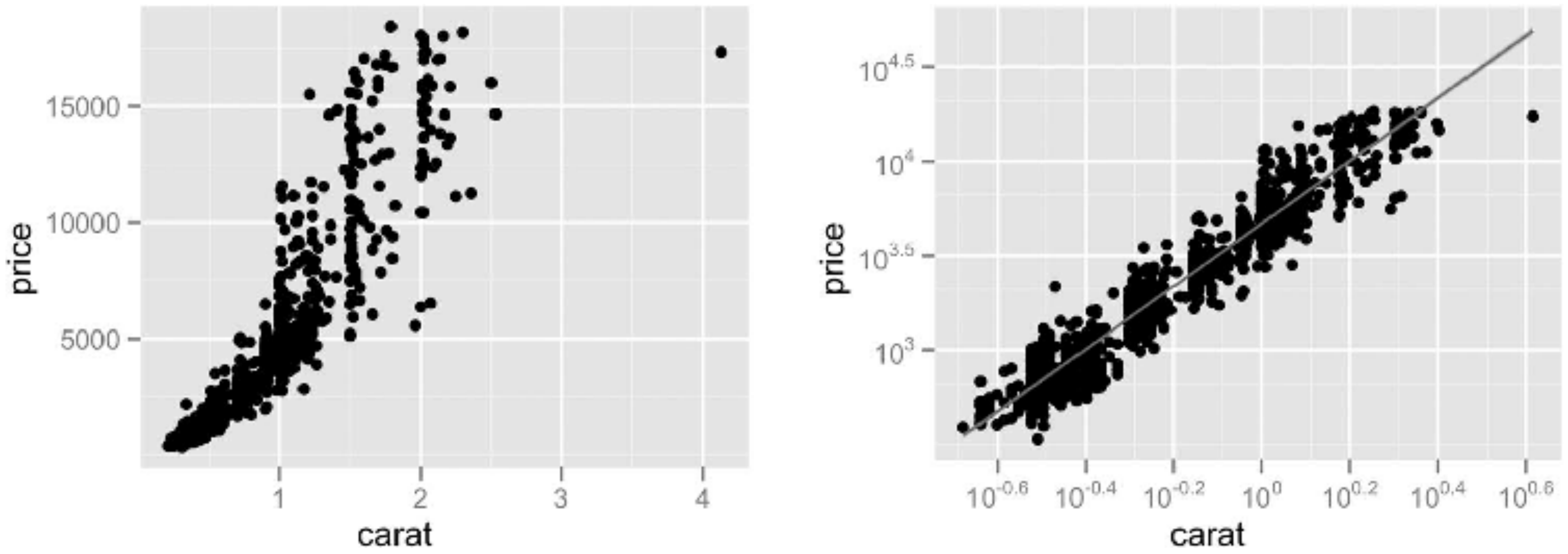


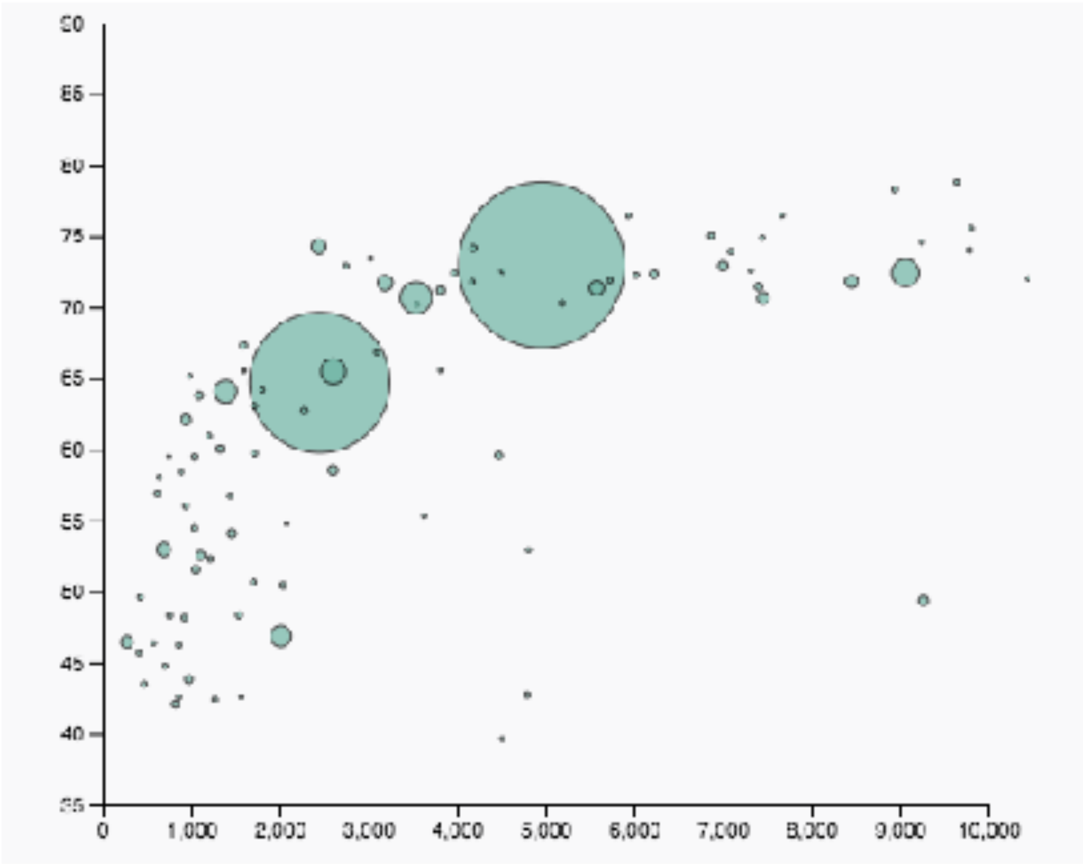
- **express** values (magnitudes)
  - quantitative attributes
- no keys, only values
  - data
    - 2 quant attribs
  - mark: points
  - channels
    - horiz + vert position
  - tasks
    - find trends, outliers, distribution, correlation, clusters
  - scalability
    - hundreds of items

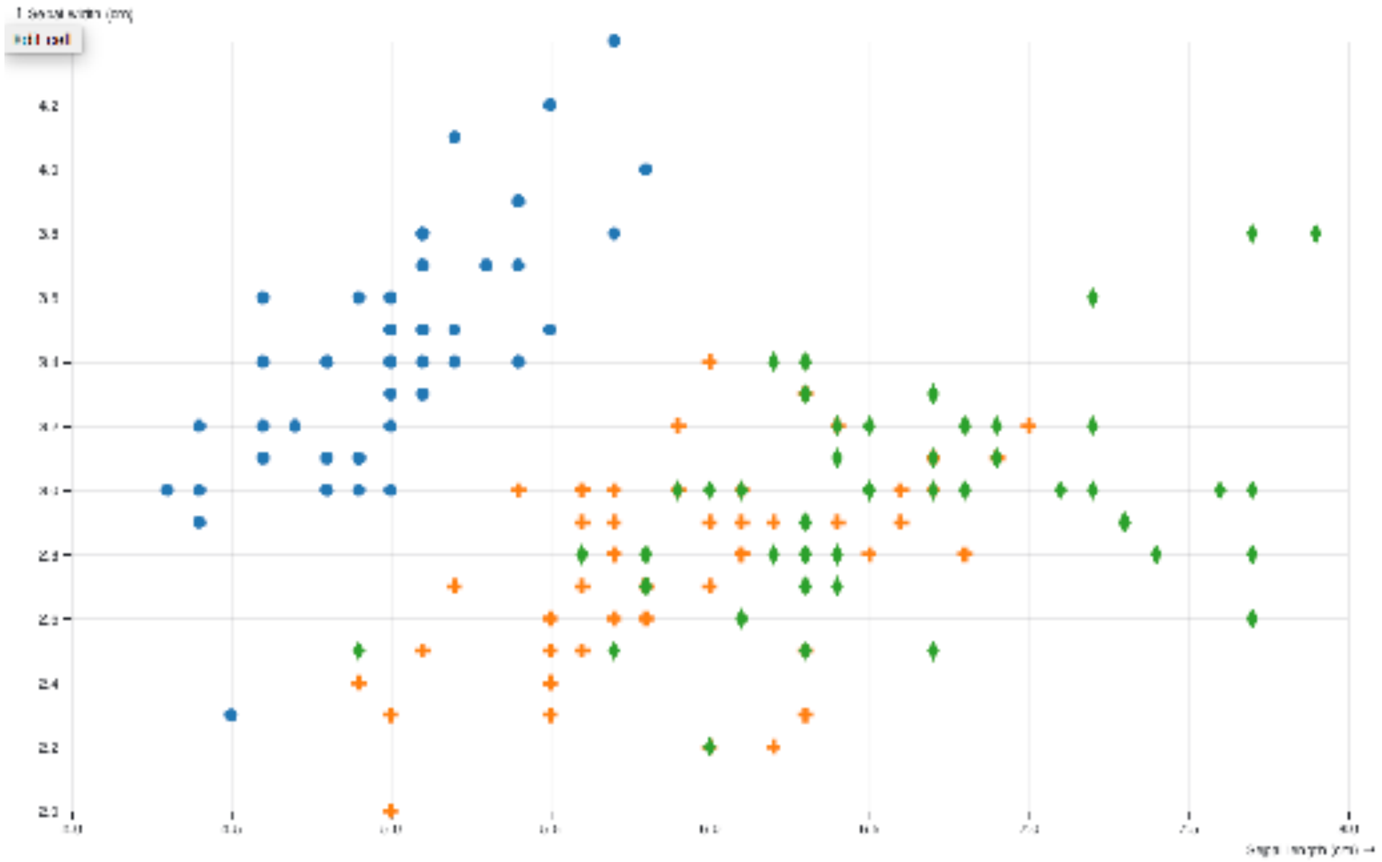


[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

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





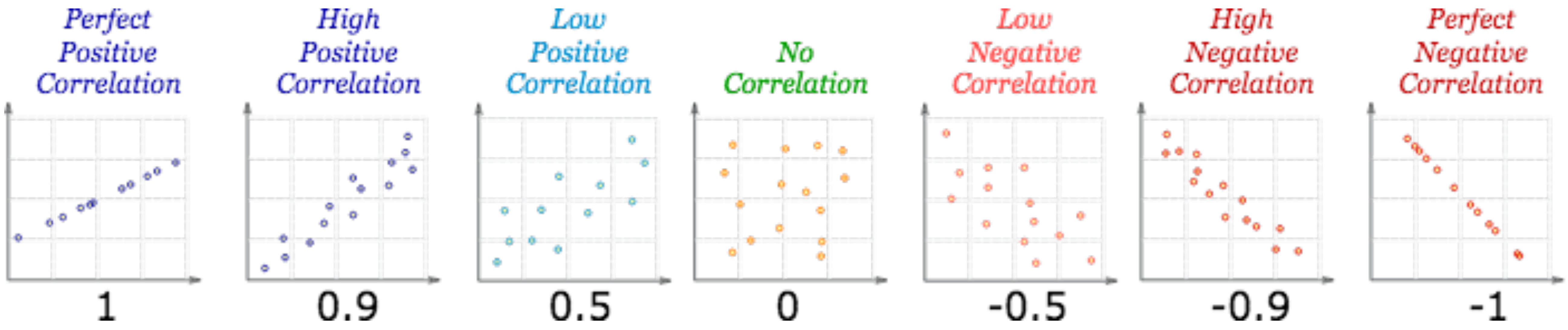
https://www.d3-graph-gallery.com/graph/bubble_basic.html

https://observablehq.com/@d3/scatterplot-with-shapes

Scatterplot tasks

Scatterplot tasks

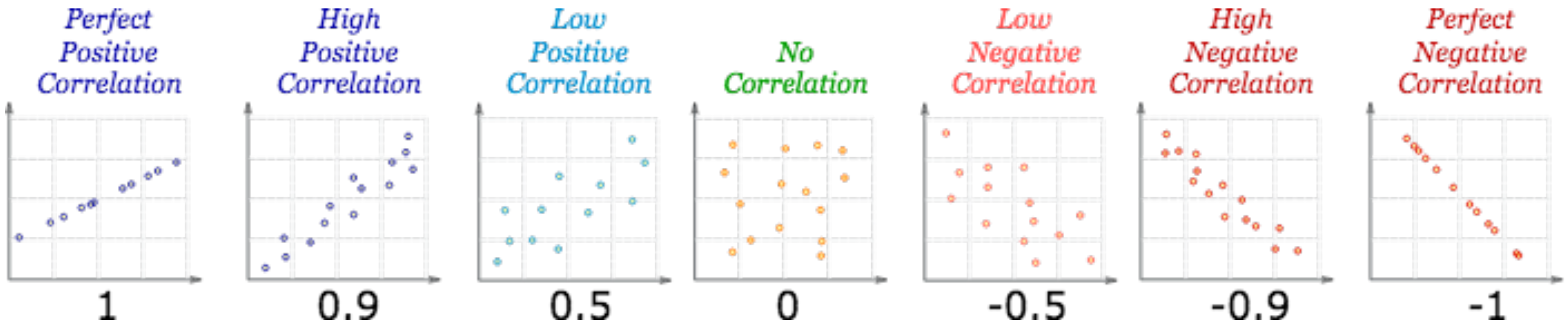
- correlation



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

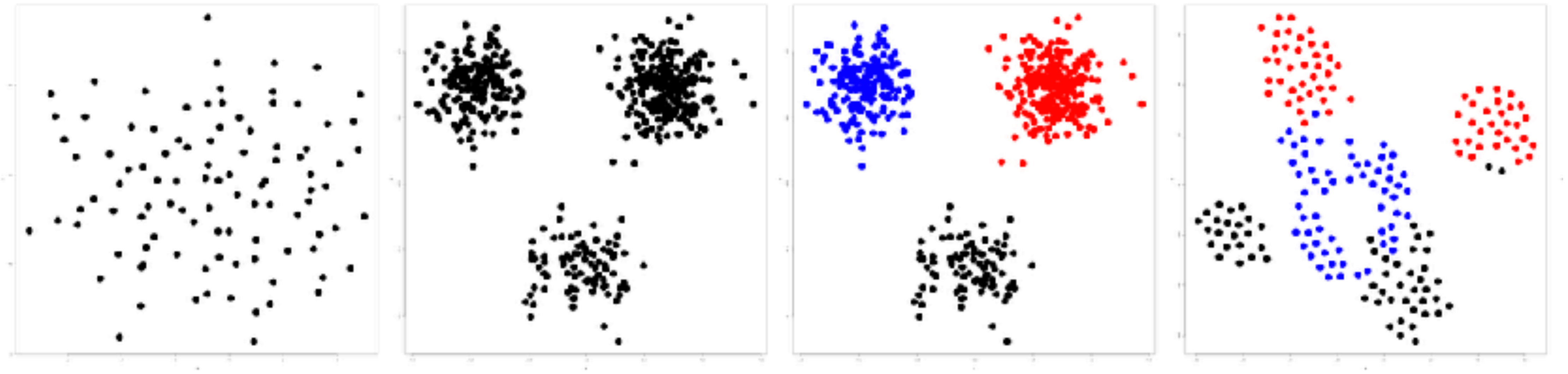
Scatterplot tasks

- correlation



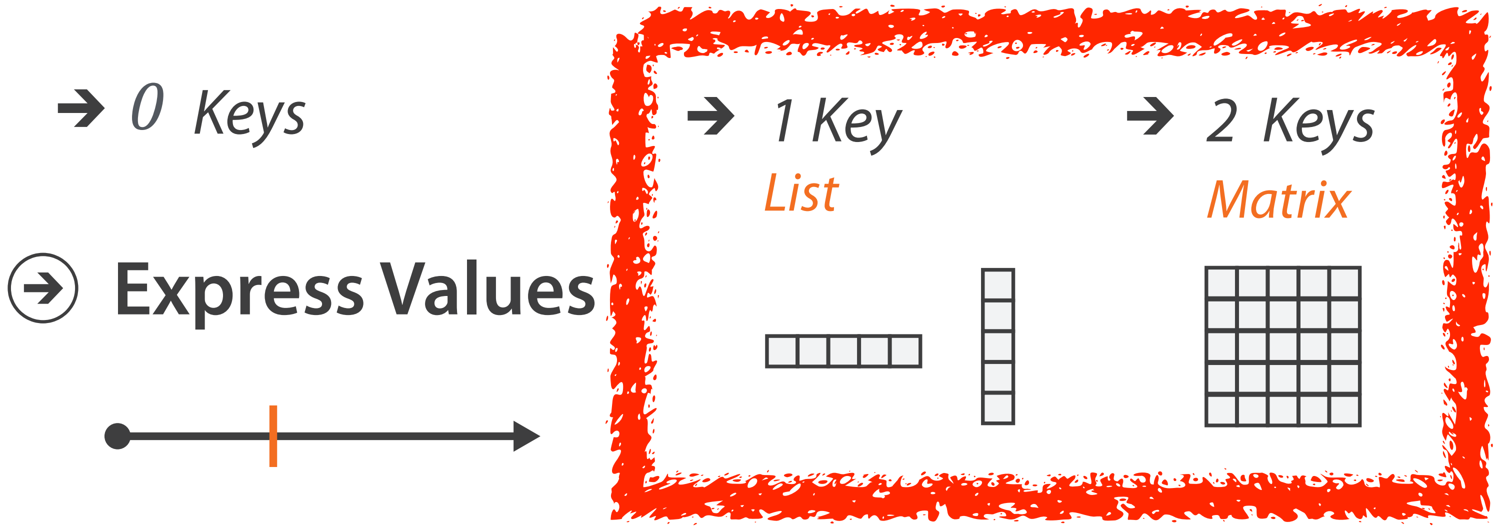
https://www.mathsisfun.com/data/scatter-xy-plots.html

- clusters/groups, and clusters vs classes



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

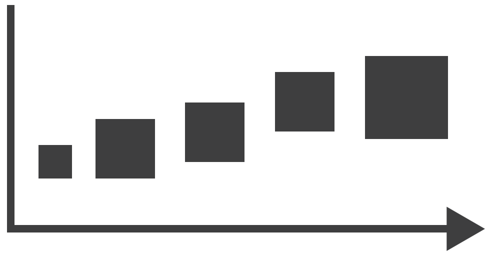
Some keys



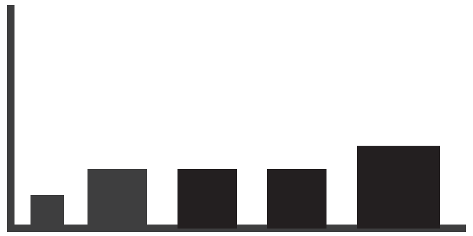
Some keys: Categorical regions

- ➔ Separate

- ➔ Order



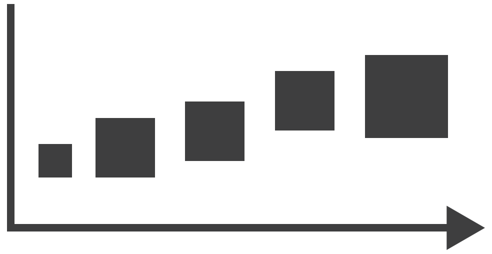
- ➔ Align



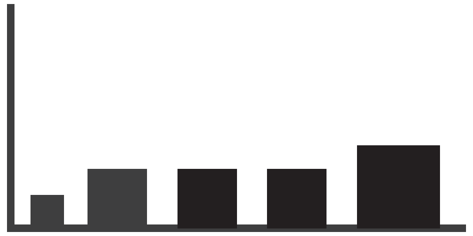
Regions: Separate, order, align

→ Separate

→ Order

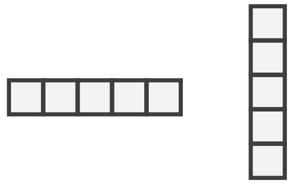


→ Align

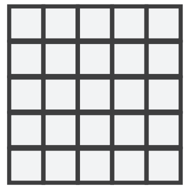


- regions: contiguous bounded areas distinct from each other
  - separate into spatial regions: one mark per region (for now)
- use categorical or ordered attribute to separate into regions
  - no conflict with expressiveness principle for categorical attributes
- use ordered attribute to order and align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

→ *1 Key*
List

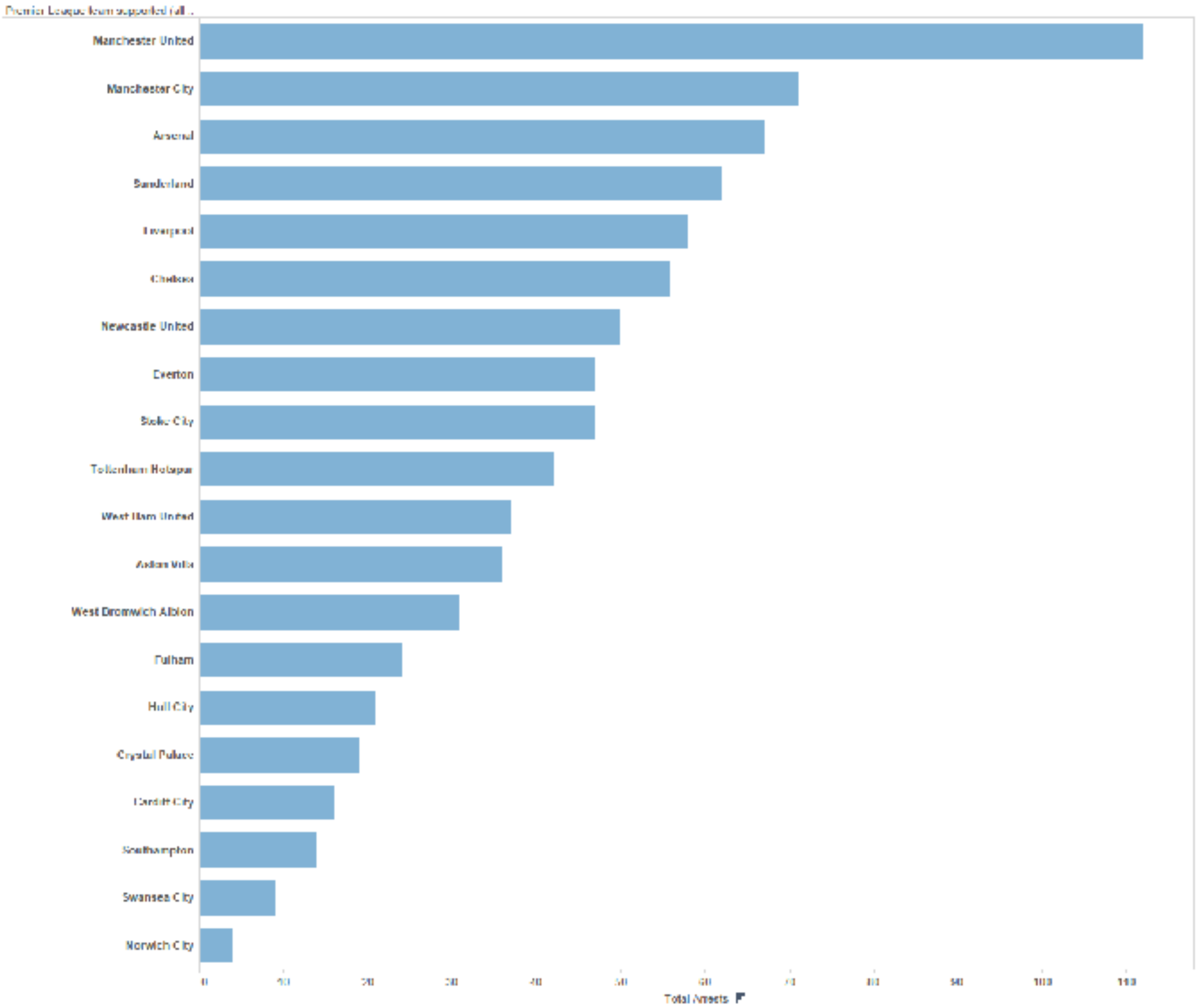


→ *2 Keys*
Matrix



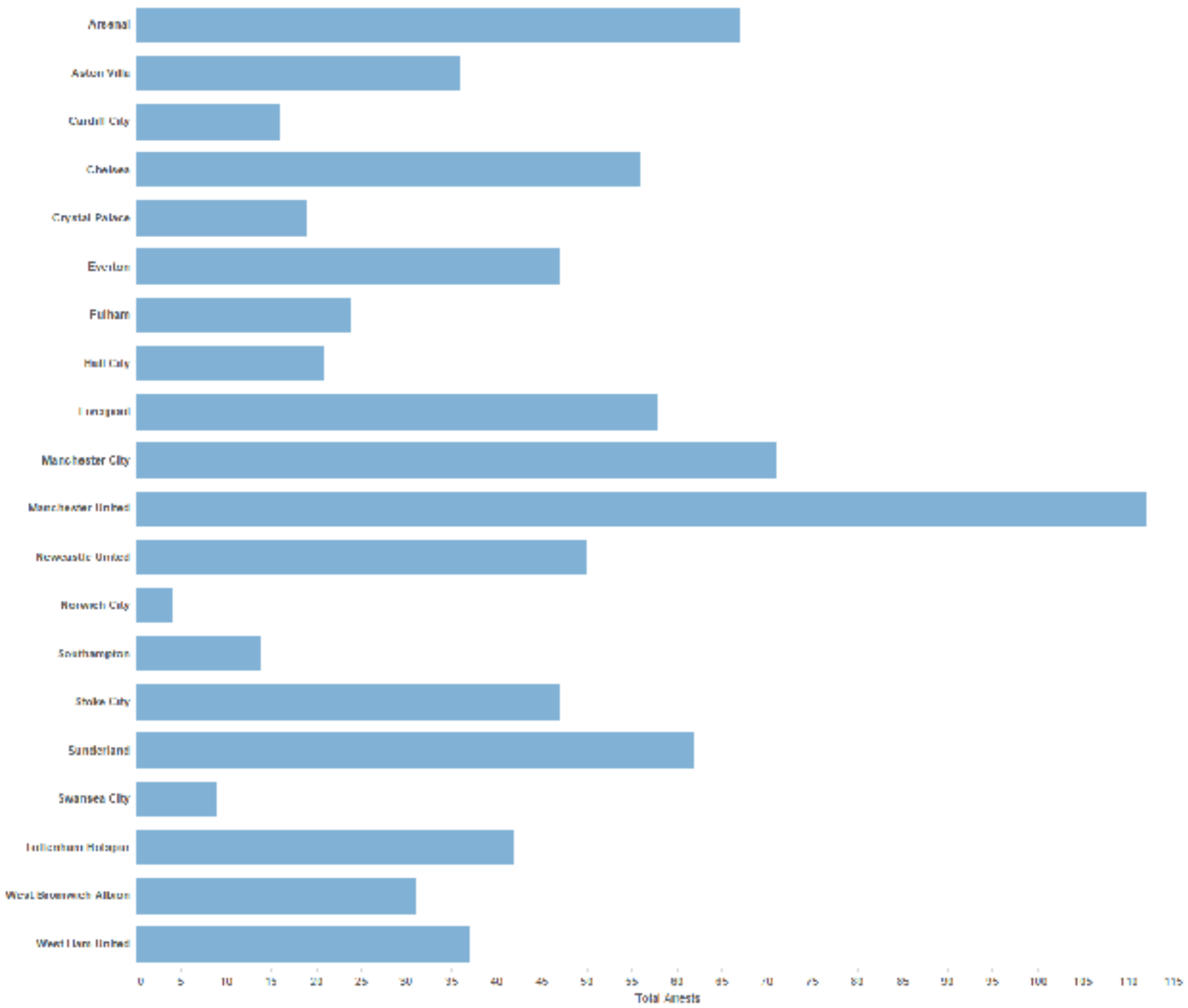
Separated and aligned and ordered

- best case



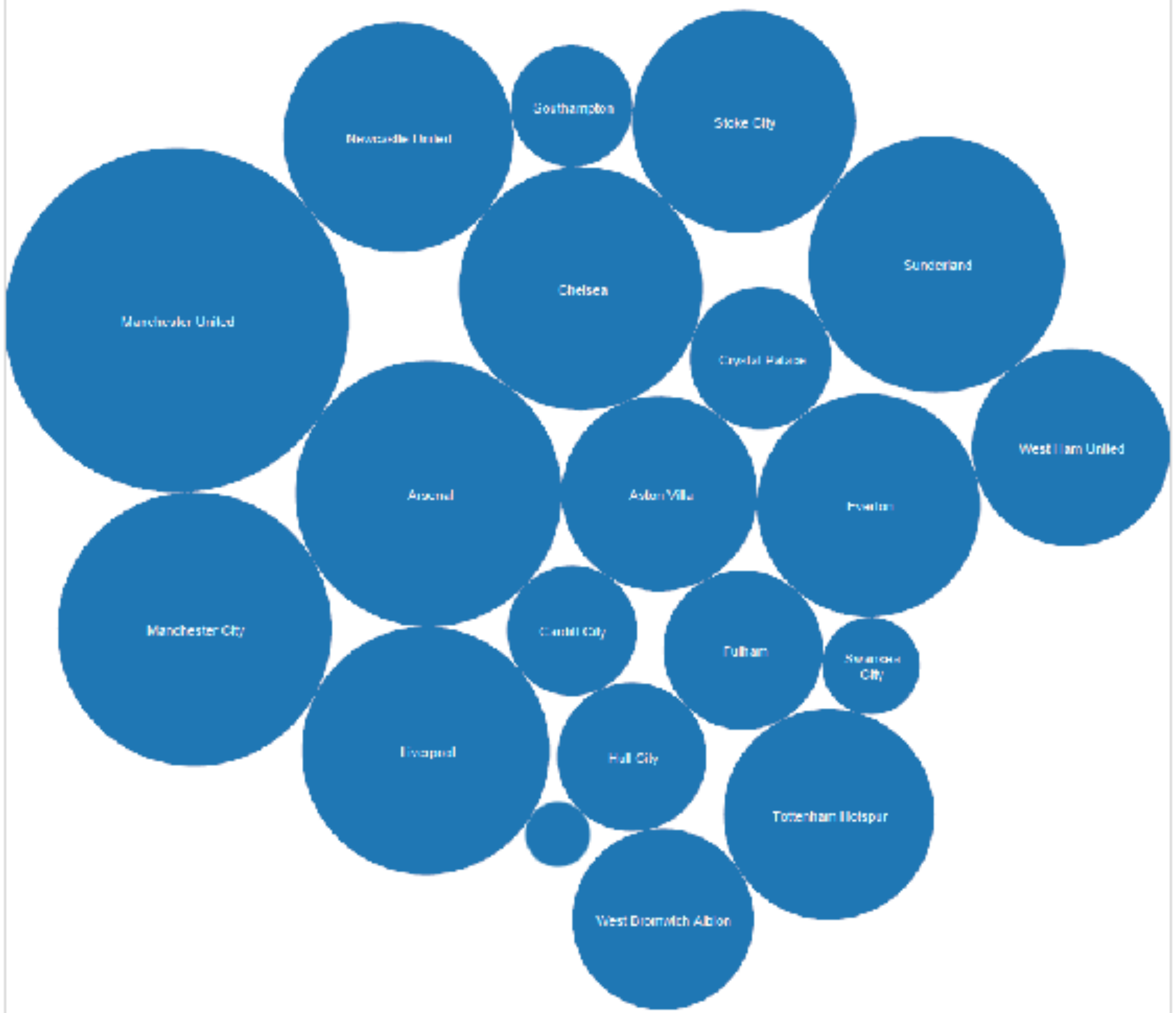
Separated and aligned but not ordered

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

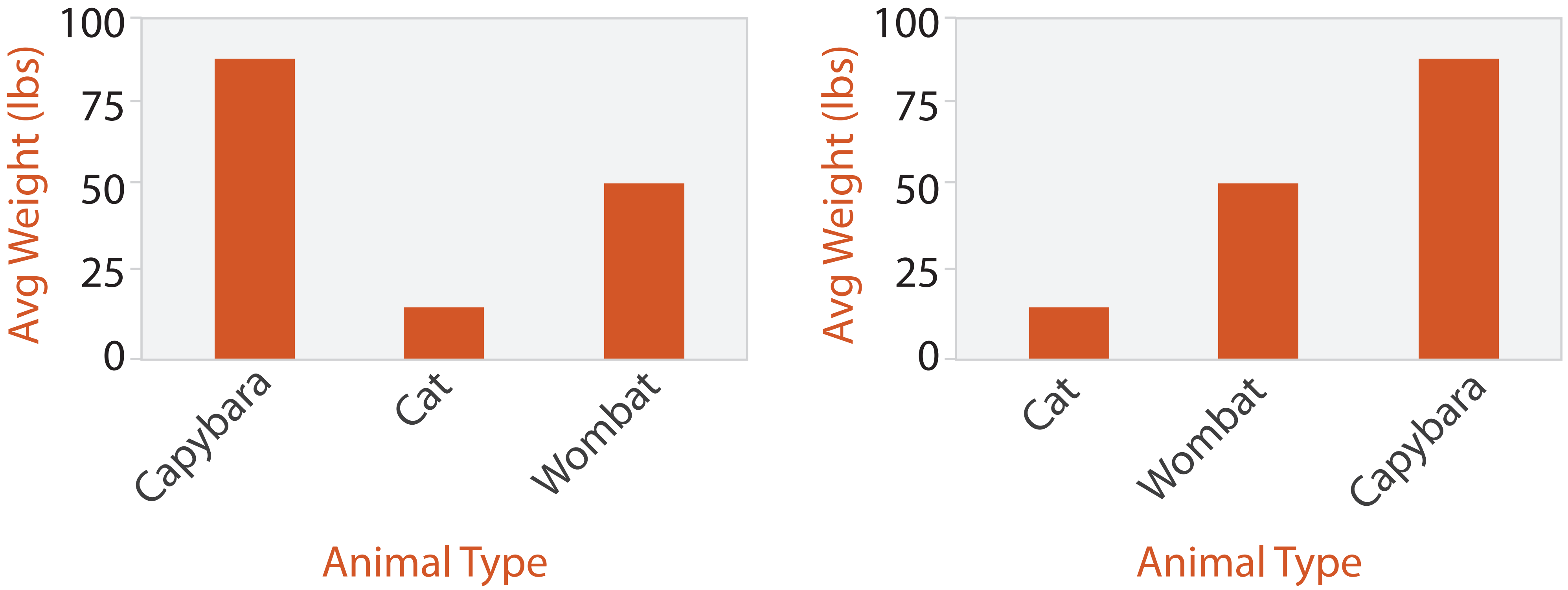


Separated but not aligned or ordered

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



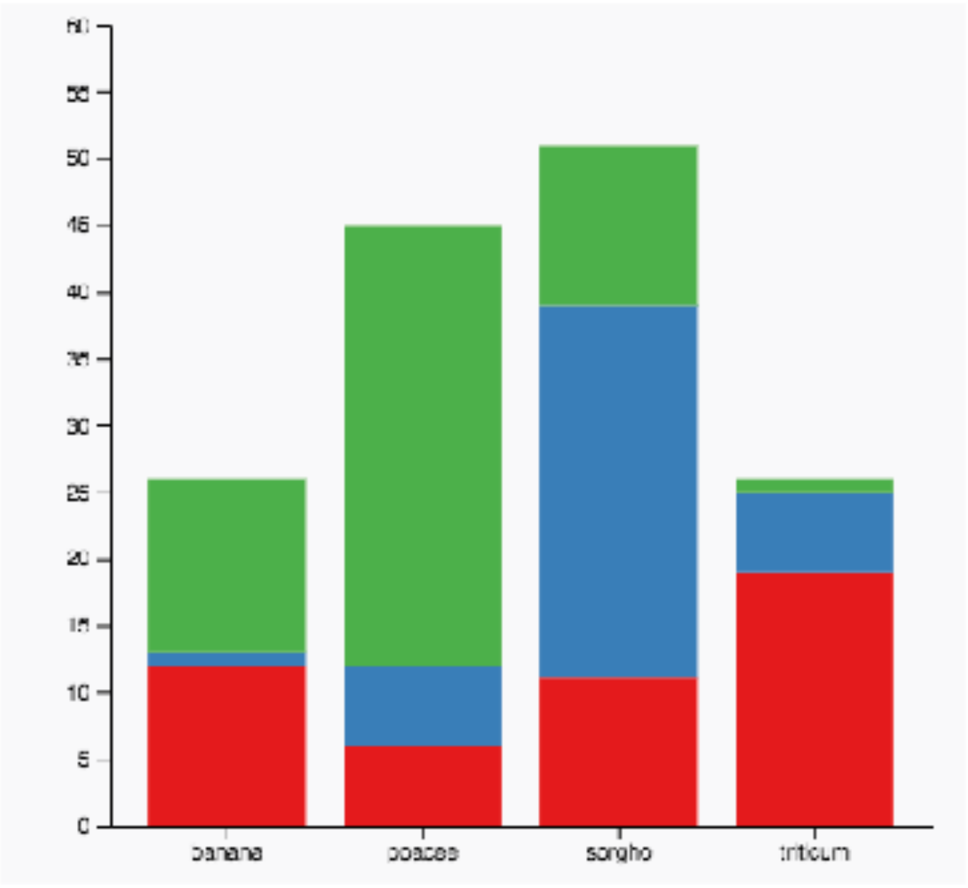
Idiom: **bar chart**



- 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**

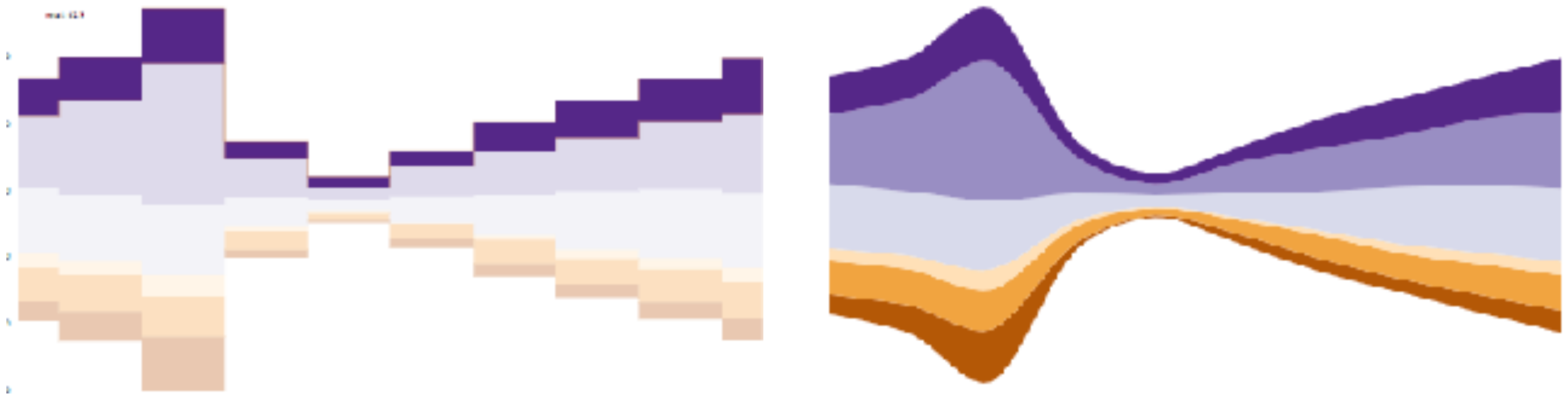
- one more key
  - data
    - 2 categ attrib, 1 quant attrib
  - mark: vertical stack of line marks
    - **glyph**: composite object, internal structure from multiple marks
  - channels
    - length and color hue
    - spatial regions: one per glyph
      - aligned: full glyph, lowest bar component
      - 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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  - data
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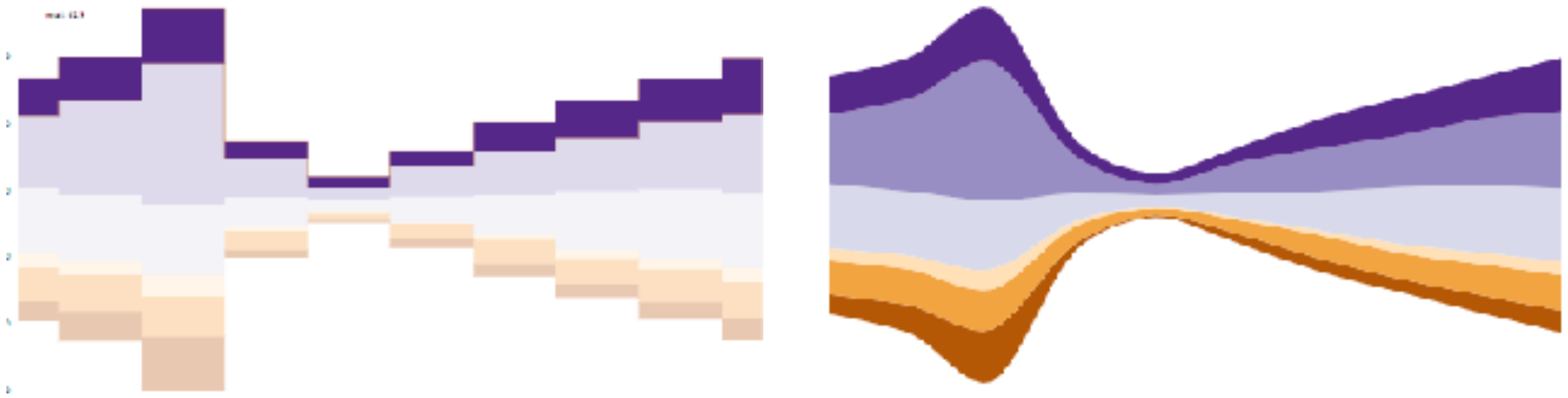
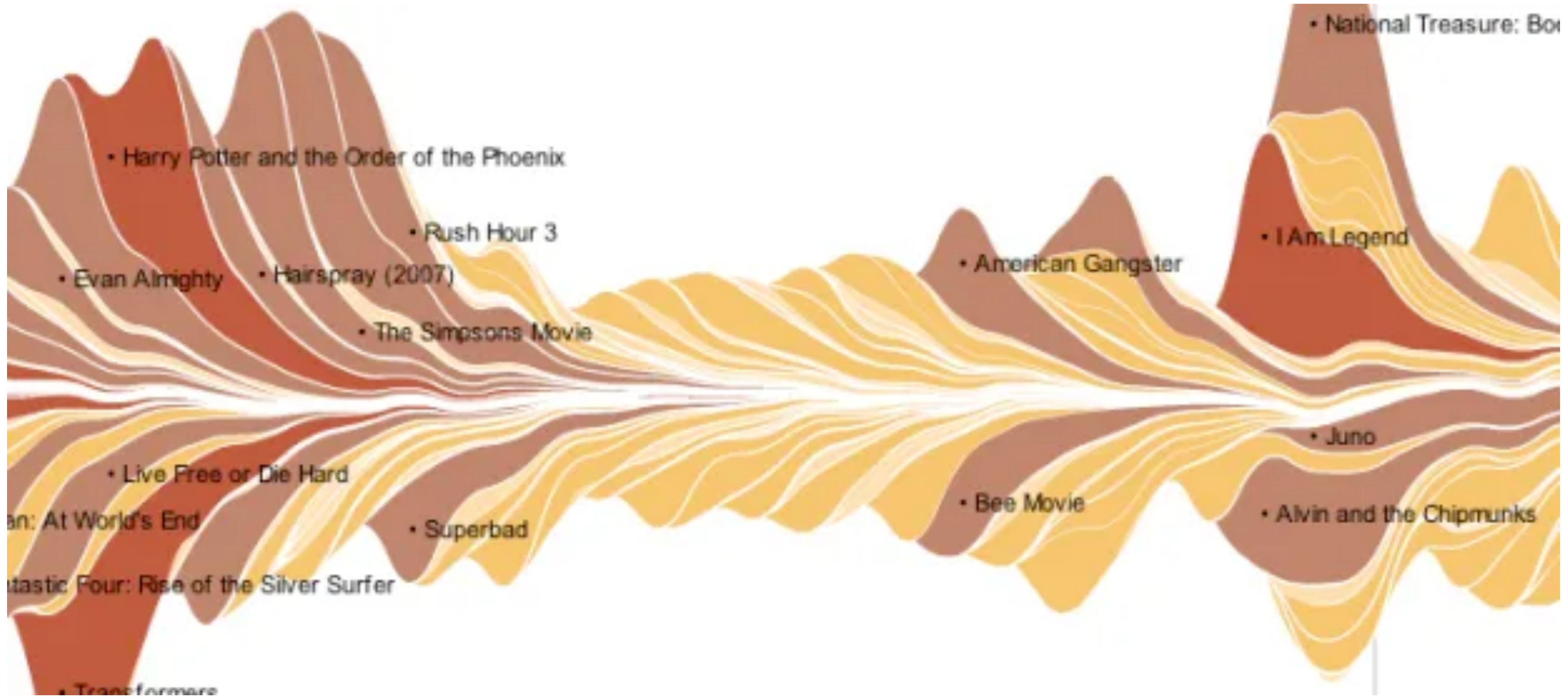
    - 1 quant value attrib (counts)
  - derived data
    - geometry: layers, where height encodes counts
    - 1 quant attrib (layer ordering)
  - scalability
    - hundreds of time keys
    - dozens to hundreds of movies keys
      - more than stacked bars: most layers don't extend across whole chart



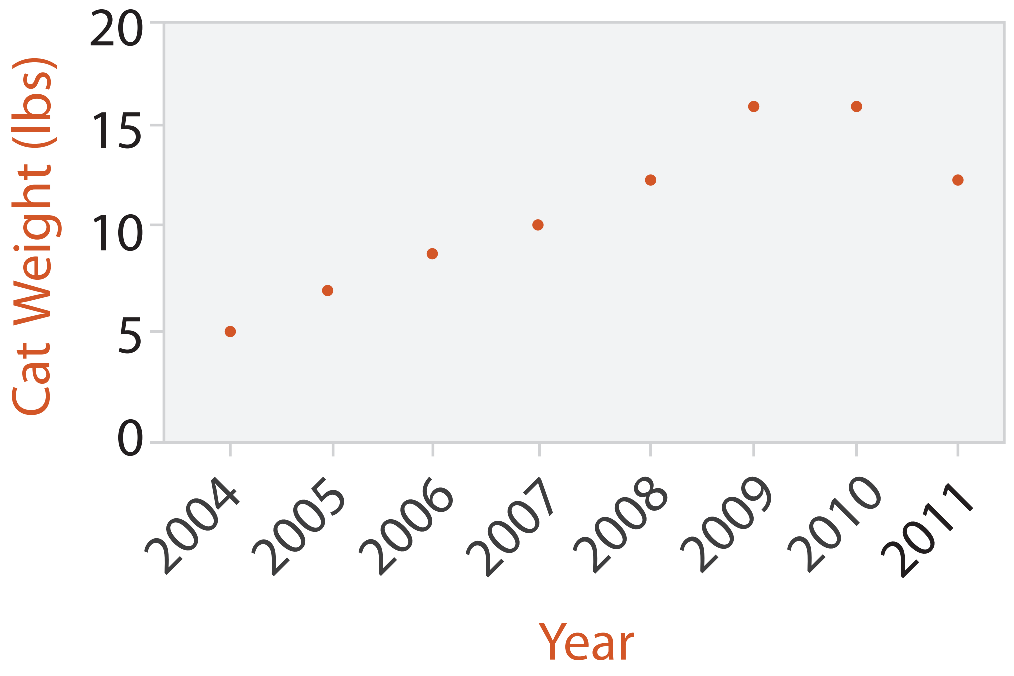
[Stacked Graphs Geometry & Aesthetics. Byron and Wattenberg. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2008) 14(6): 1245–1252, (2008).]

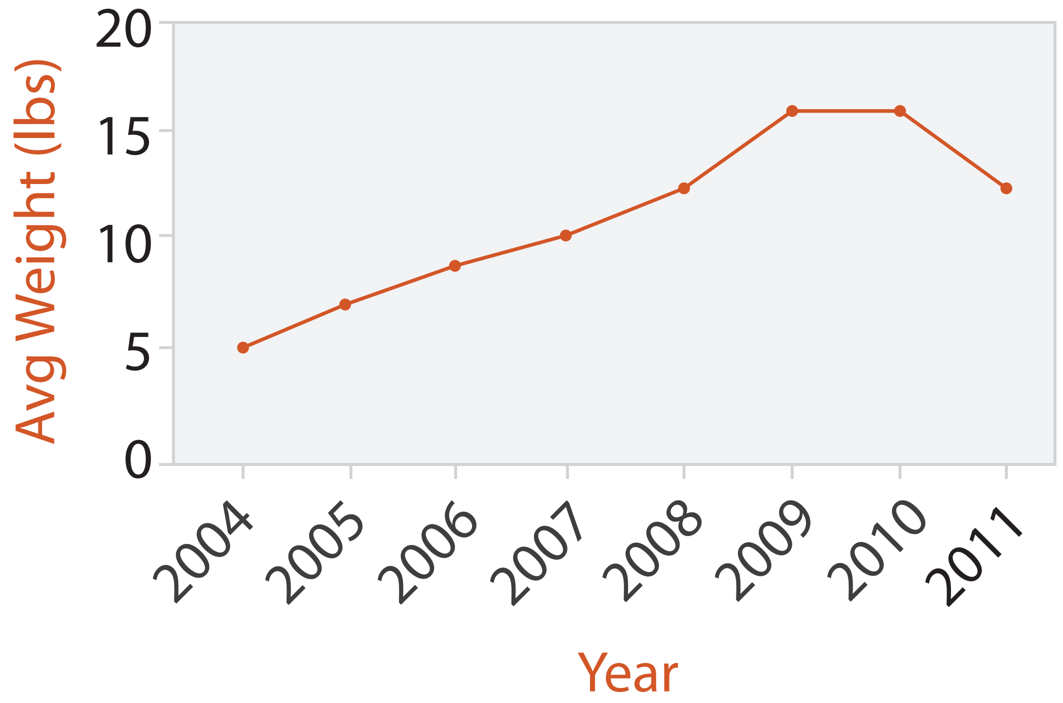


https://flowingdata.com/2008/02/25/ebb-and-flow-of-box-office-receipts-over-past-20-years/

Idiom: **dot / line chart**

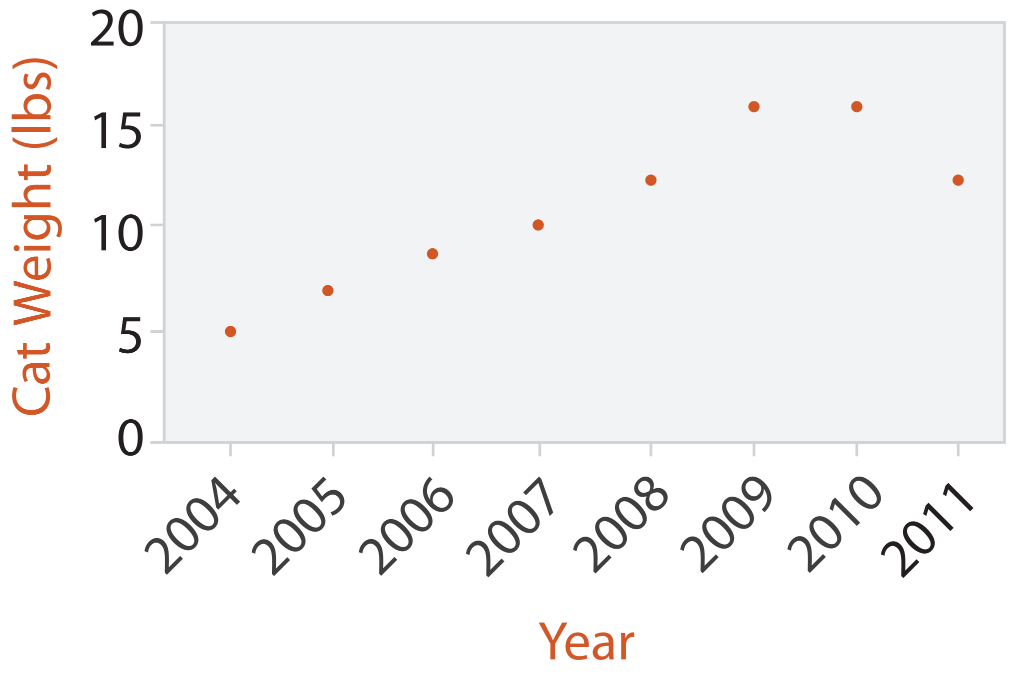
- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    AND line connection marks between them
  - channels
    - aligned lengths to express quant value
    - separated and ordered by key attrib into horizontal regions

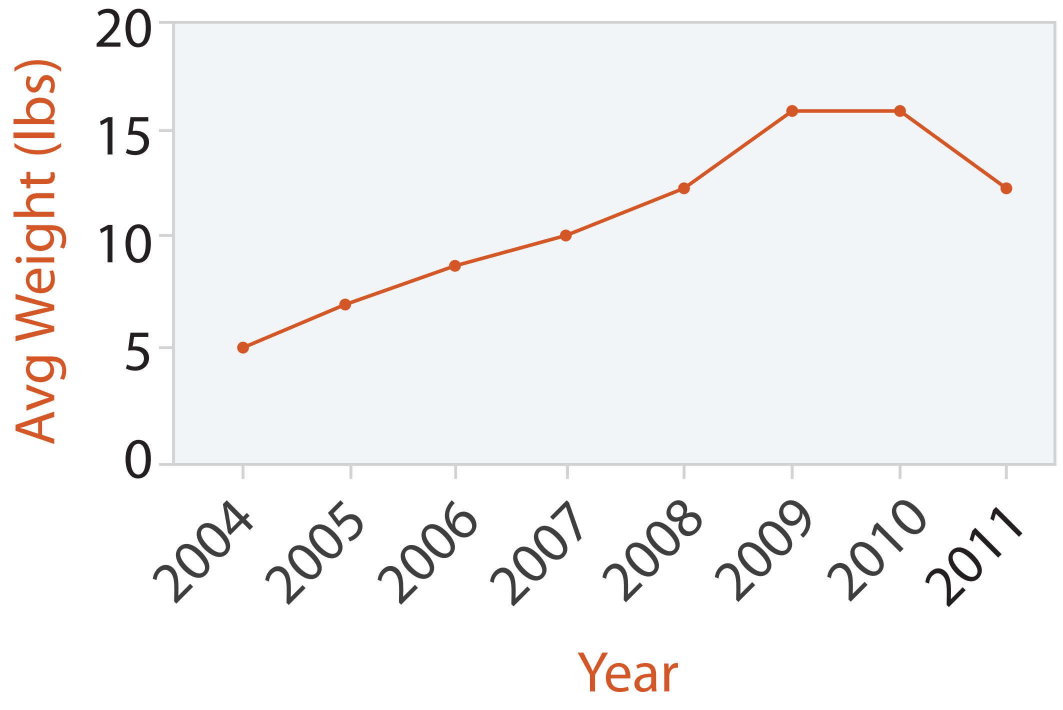




Idiom: **dot / line chart**

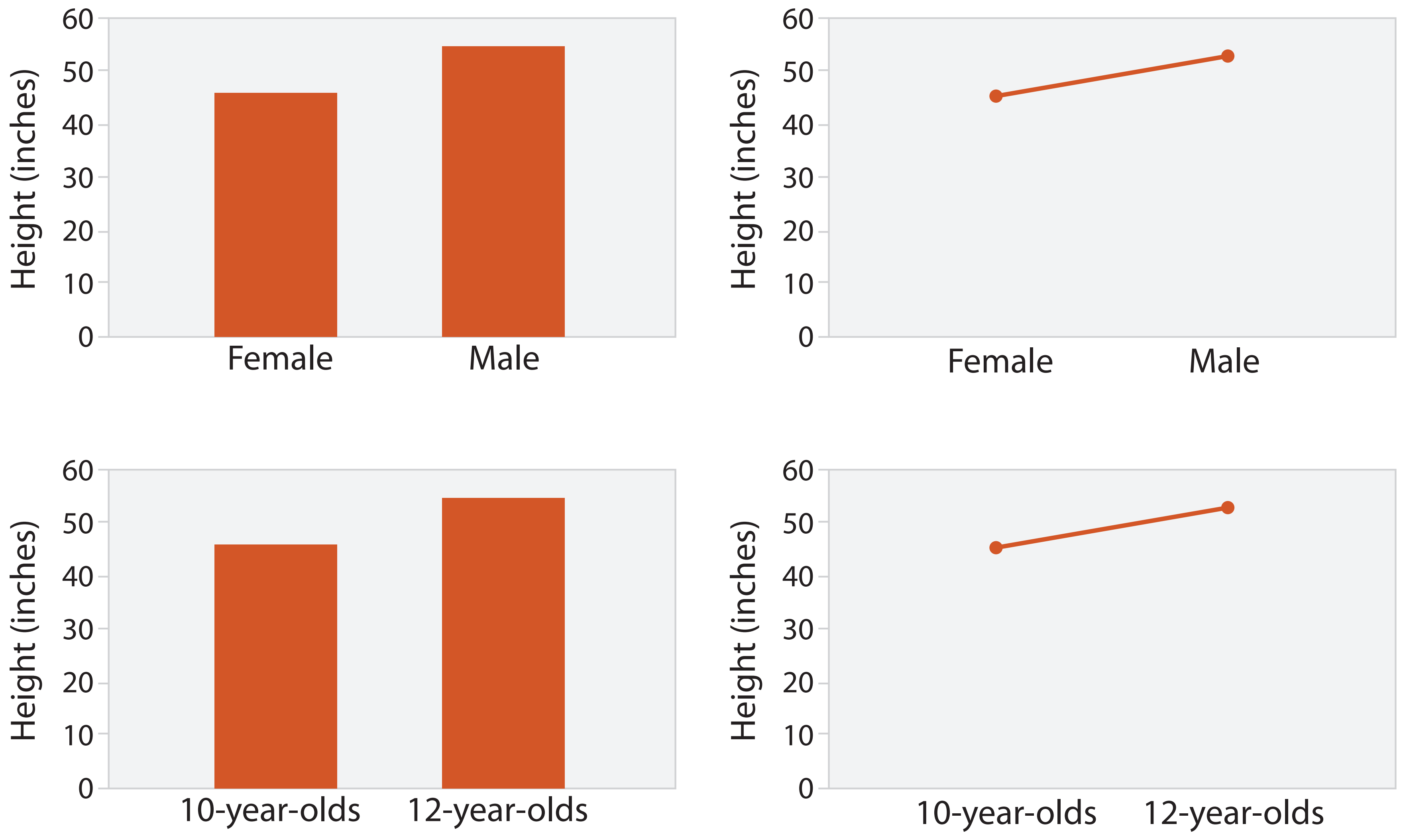
- one key, one value
  - data
    - 2 quant attribs
  - mark: points
    AND line connection marks between them
  - channels
    - aligned lengths to express quant value
    - separated and ordered by key attrib into horizontal regions
  - task
    - find trend
      - connection marks emphasize ordering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

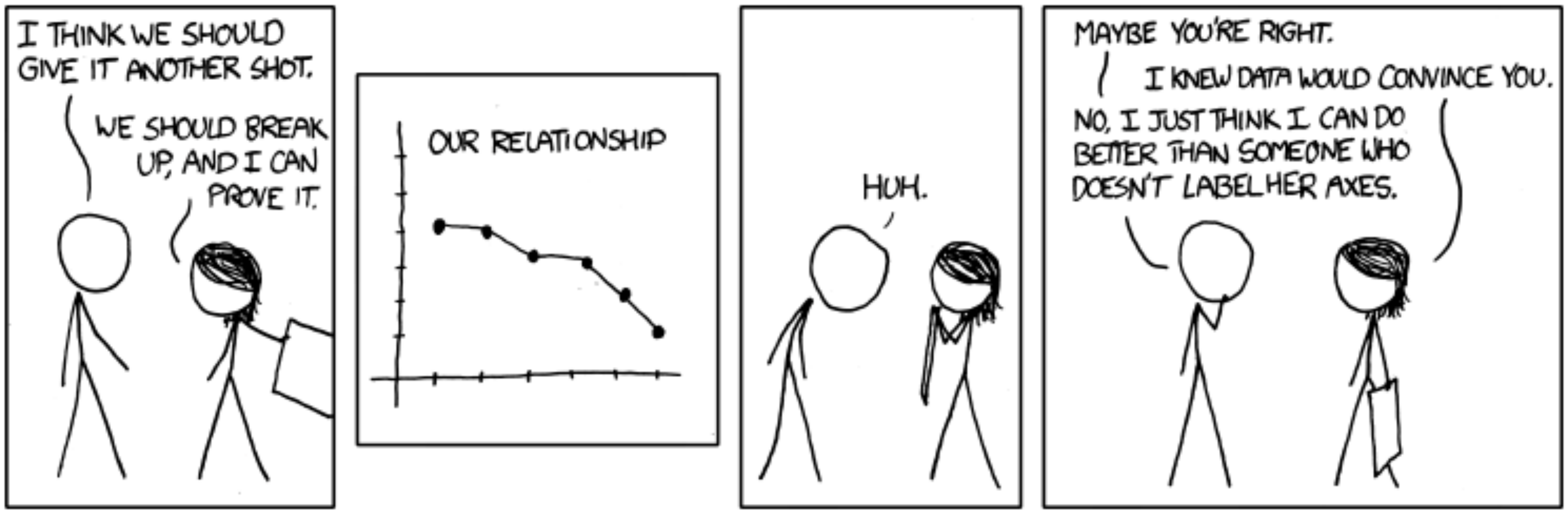
- depends on type of key attrib
  - bar charts if categorical
  - line charts if ordered
- do not use line charts for categorical key attribs
  - violates expressiveness principle
    - implication of trend so strong that it overrides semantics!
      - "The more male a person is, the taller he/she is"



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

Chart axes: label them!

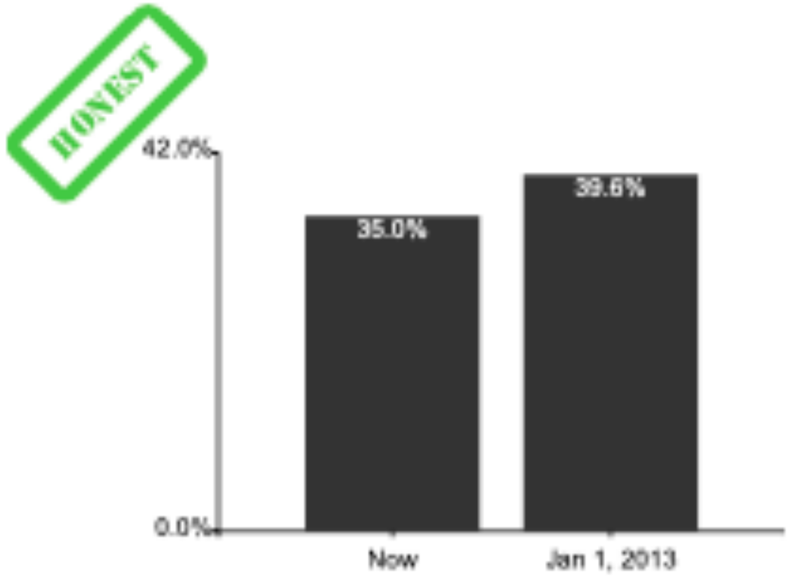
- best practice to label
  - few exceptions: individual small multiple views could share axis label

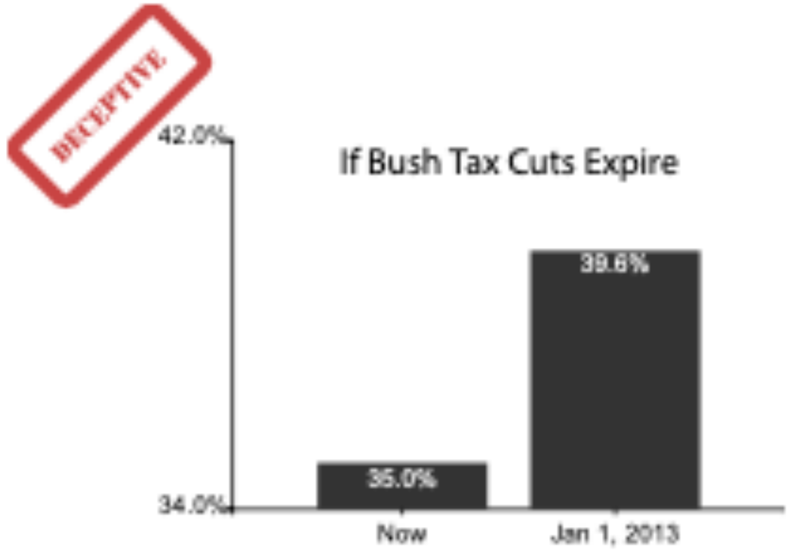


https://xkcd.com/833/

Chart axes: avoid cropping y axis

- include 0 at bottom left or slope misleads

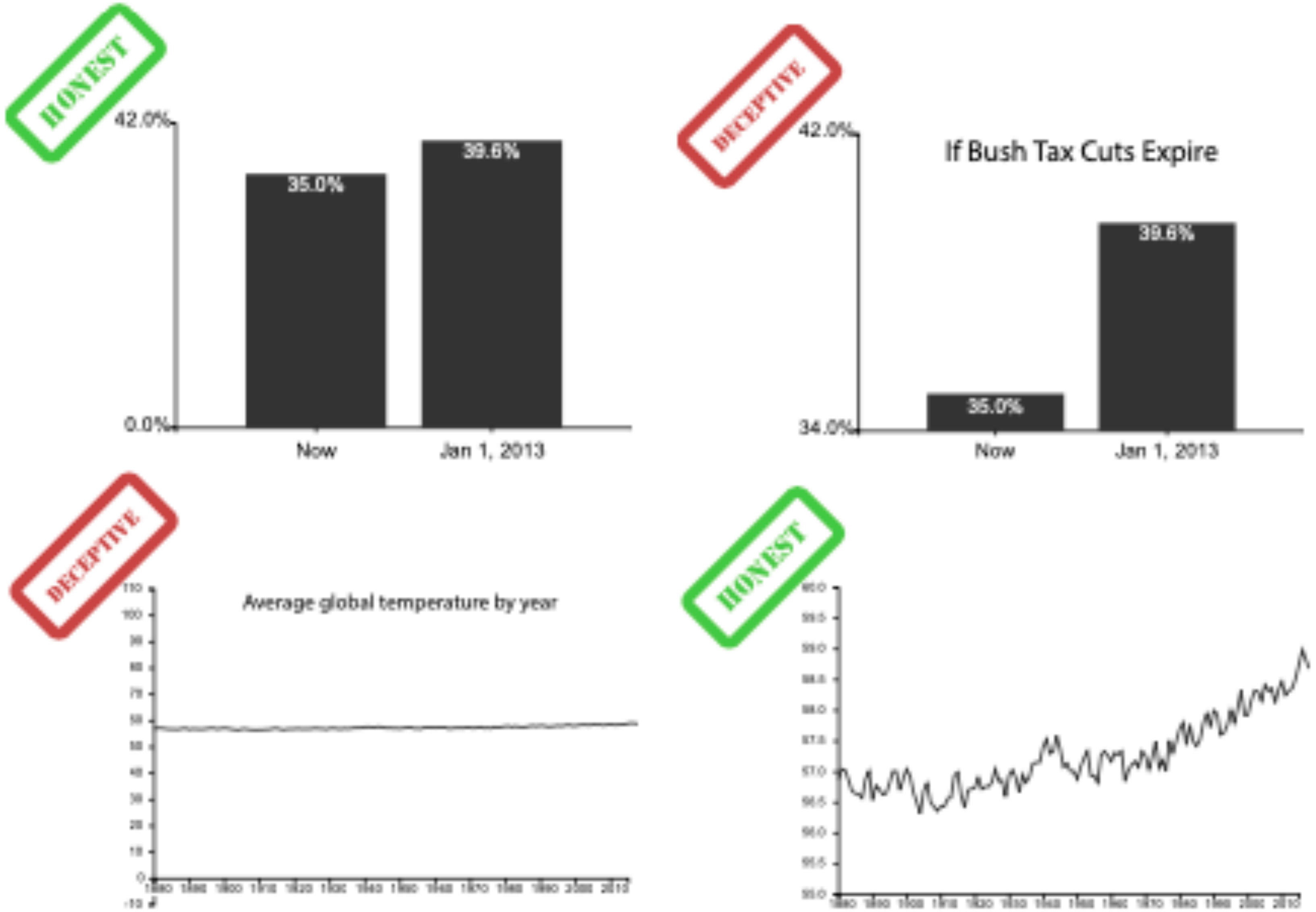




[Truncating the Y-Axis: Threat or Menace? Correll, Bertini, & Franconeri, CHI 2020.]

Chart axes: avoid cropping y axis

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



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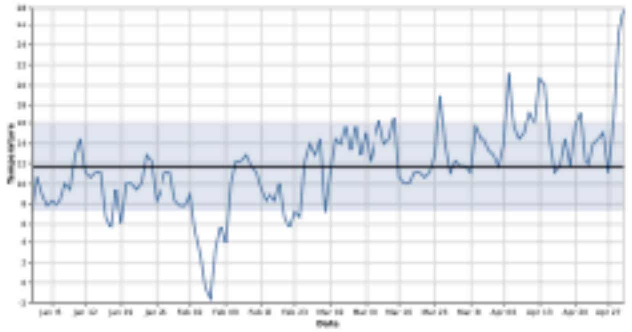
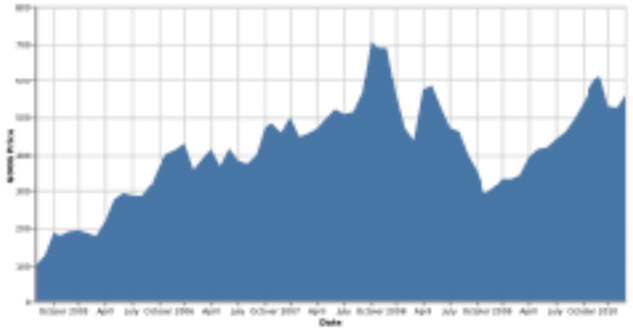
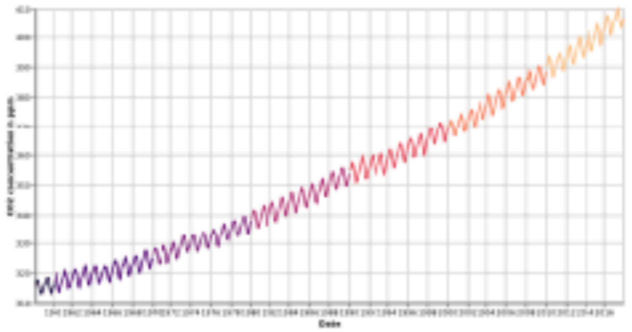


(a) Statistical process charts rely on comparison to an expected value, and so deviations from that value, not from zero, are important

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



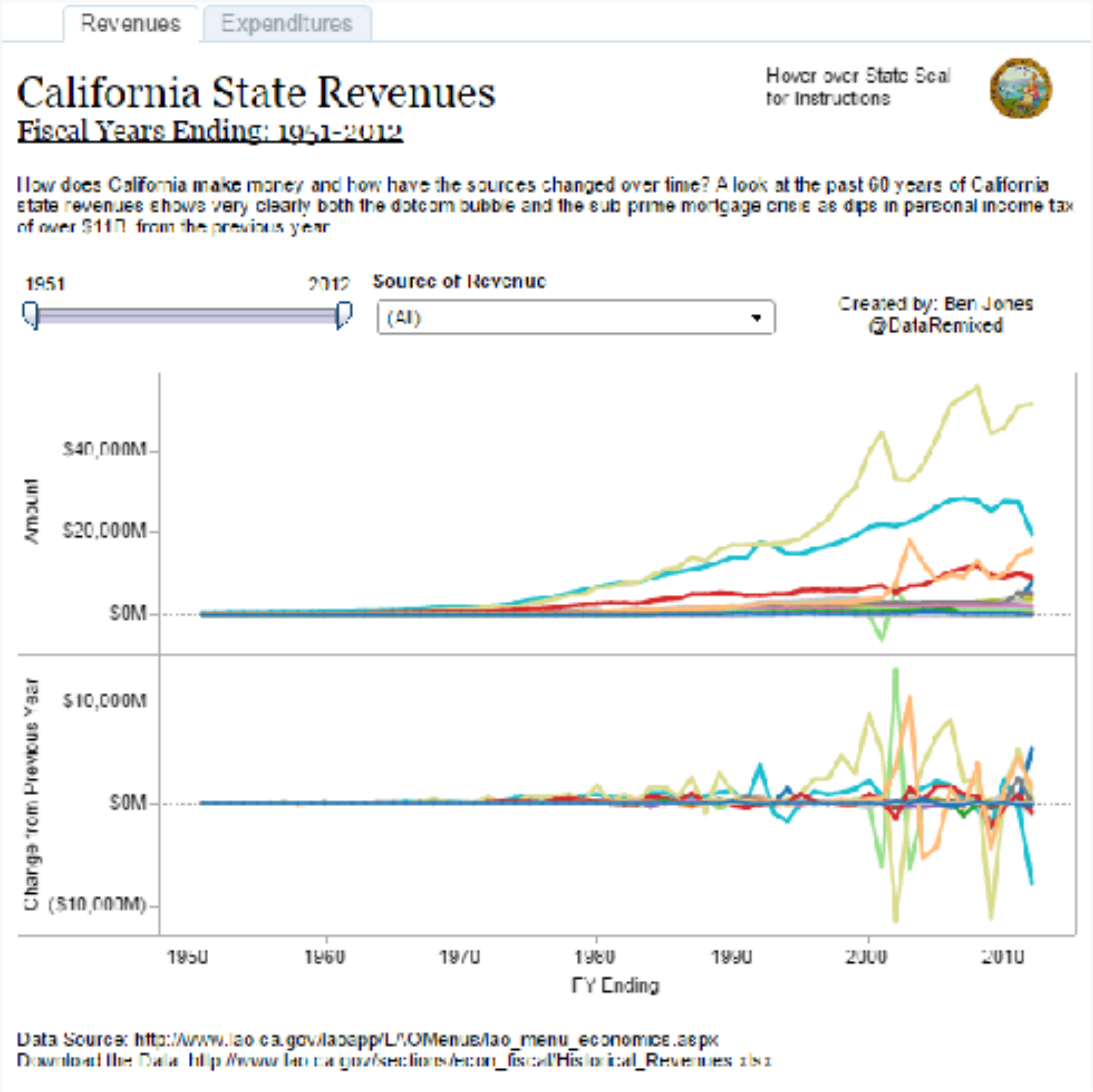
(c) Stock charts must show small differences in stock value, as these can translate to enormous monetary gains or losses.



(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**

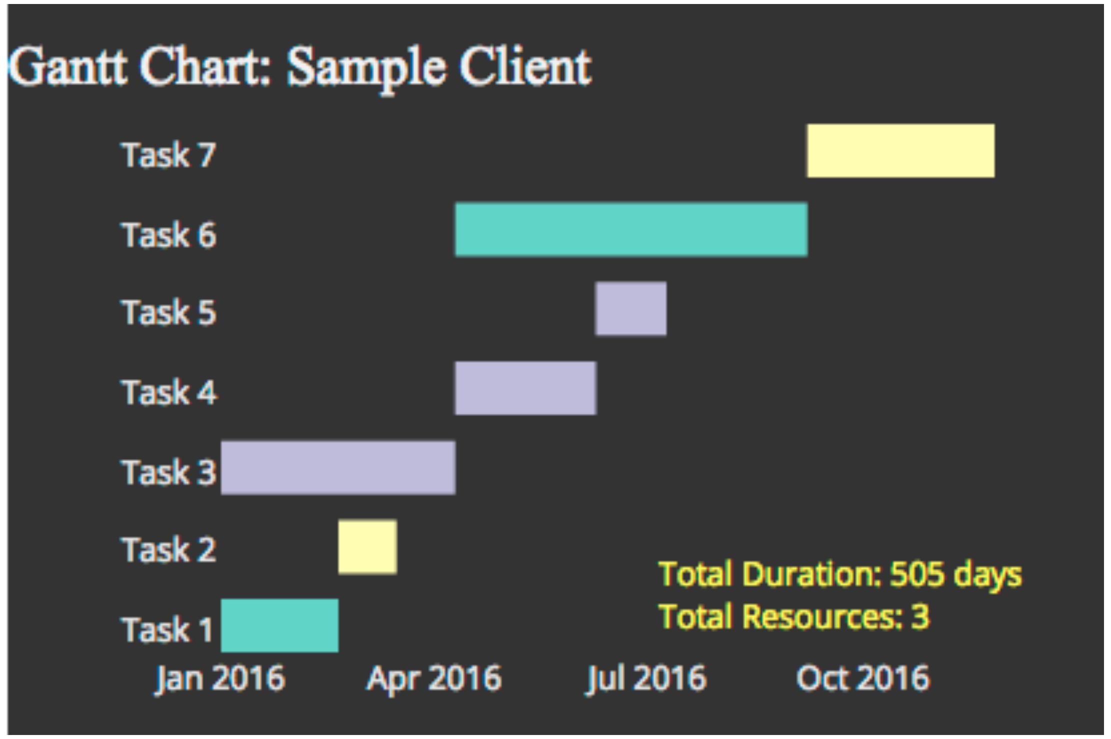
- data: 2 quant attribs
  - 1 key + 1 value
- derived data: new quant value attrib
  - index
  - plot instead of original value
- task: show change over time
  - principle: normalized, not absolute
- scalability
  - same as standard line chart



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

Idiom: **Gantt charts**

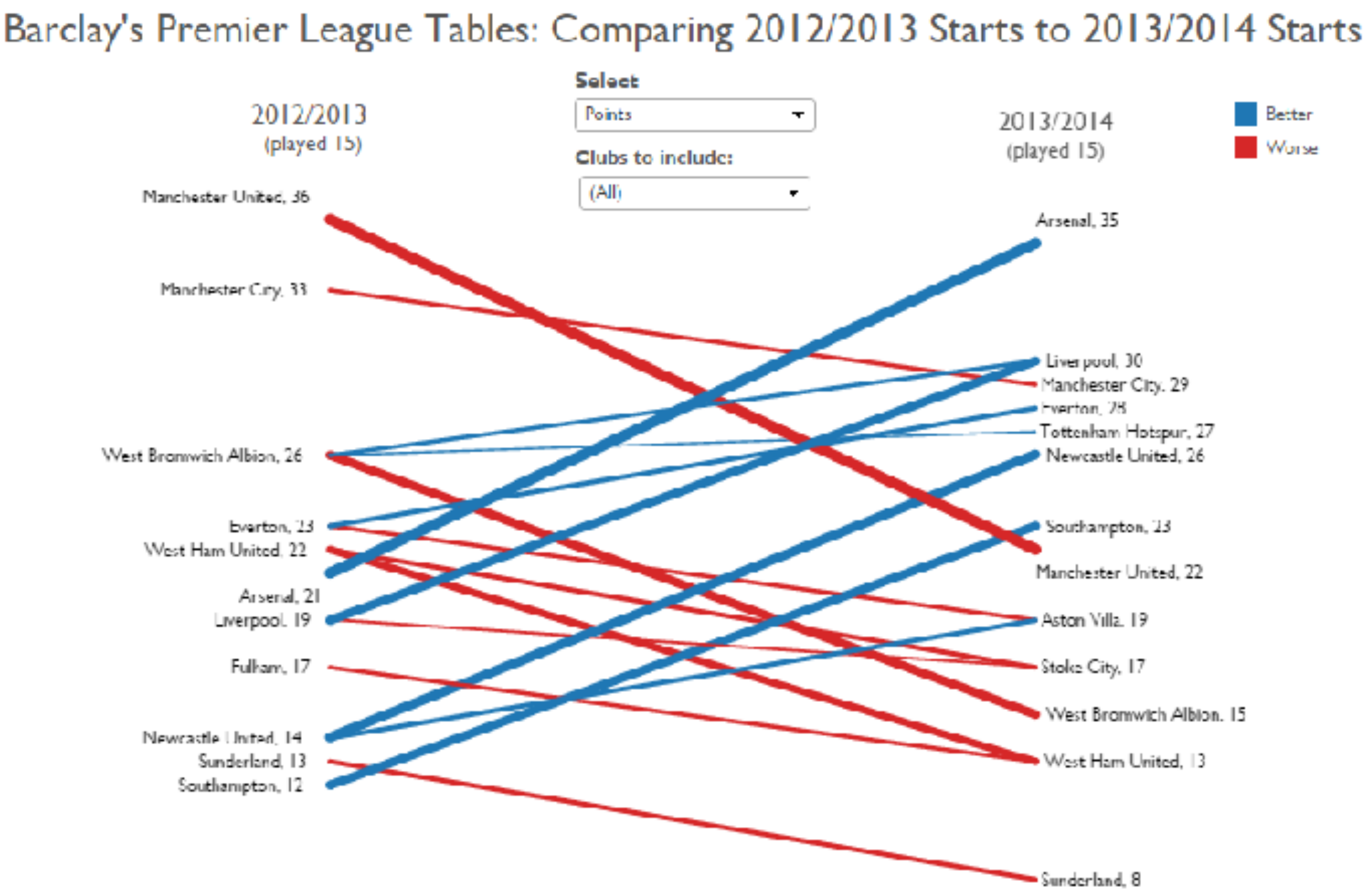
- one key, two (related) values
  - data
    - 1 categ attrib, 2 quant attribs
  - mark: line
    - length: duration
  - channels
    - horiz position: start time (+end from duration)
  - task
    - emphasize temporal overlaps & start/end dependencies between items
  - scalability
    - dozens of key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



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

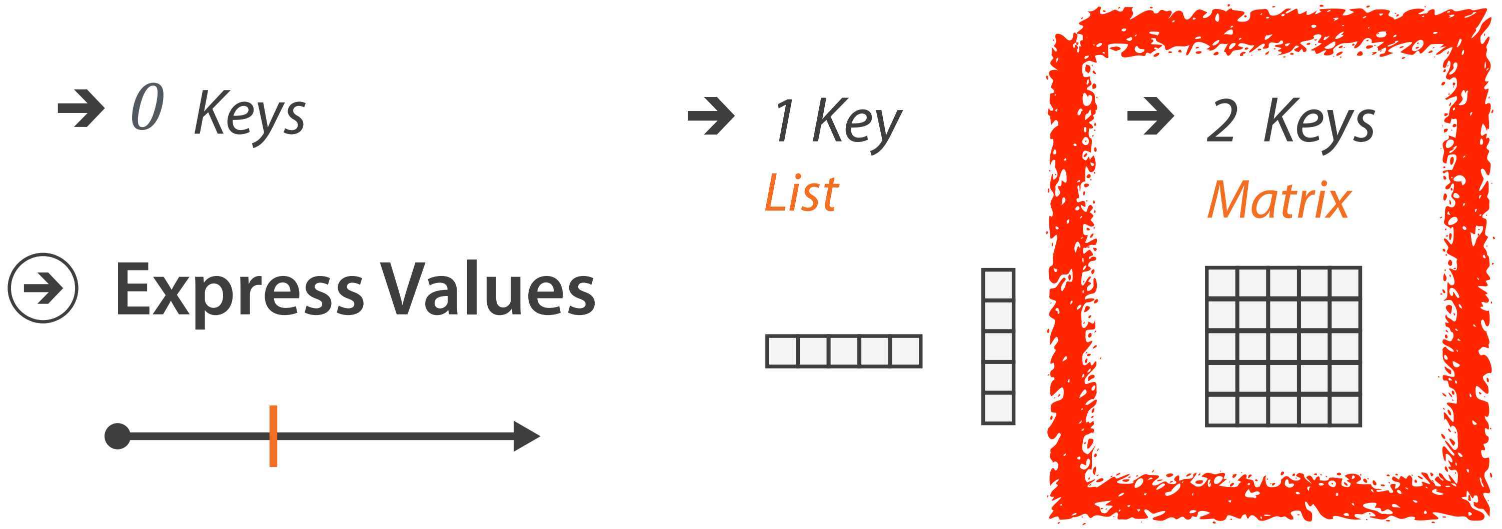
Idiom: **Slopegraphs**

- 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

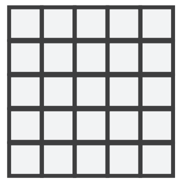
2 Keys

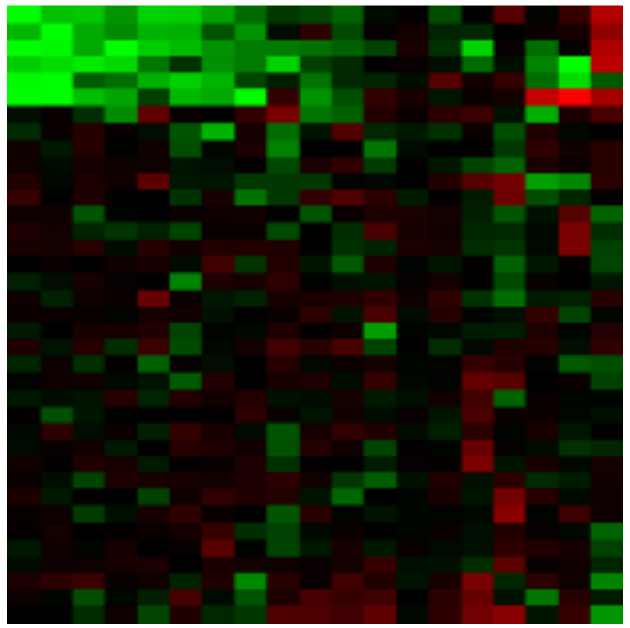


Idiom: **heatmap**

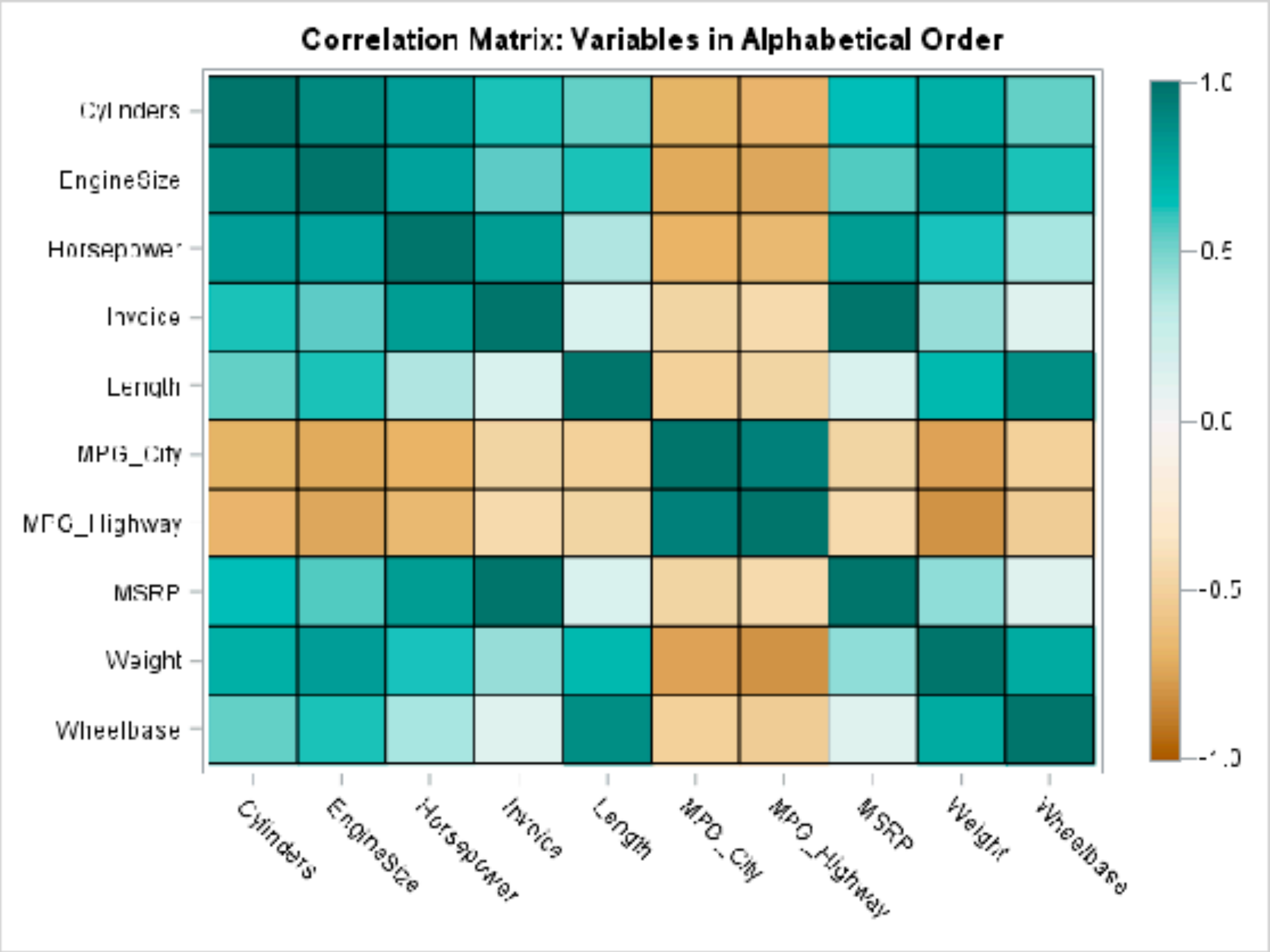
- two keys, one value
  - data
    - 2 categ attribs (gene, experimental condition)
    - 1 quant attrib (expression levels)
  - marks: point
    - separate and align in 2D matrix
      - indexed by 2 categorical attributes
  - channels
    - color by quant attrib
      - (ordered diverging colormap)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

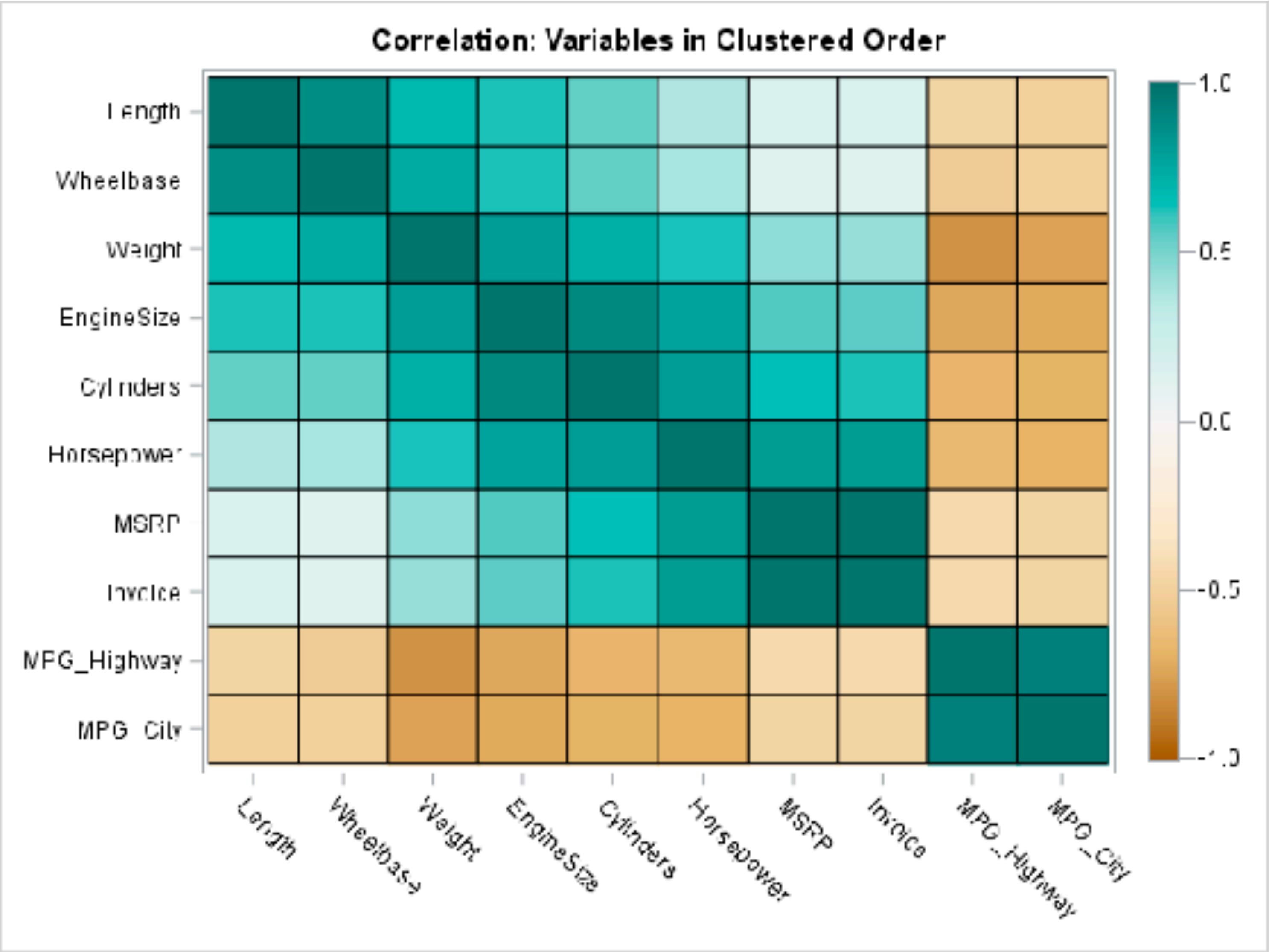
➔ *2 Keys*
Matrix





Heatmap reordering

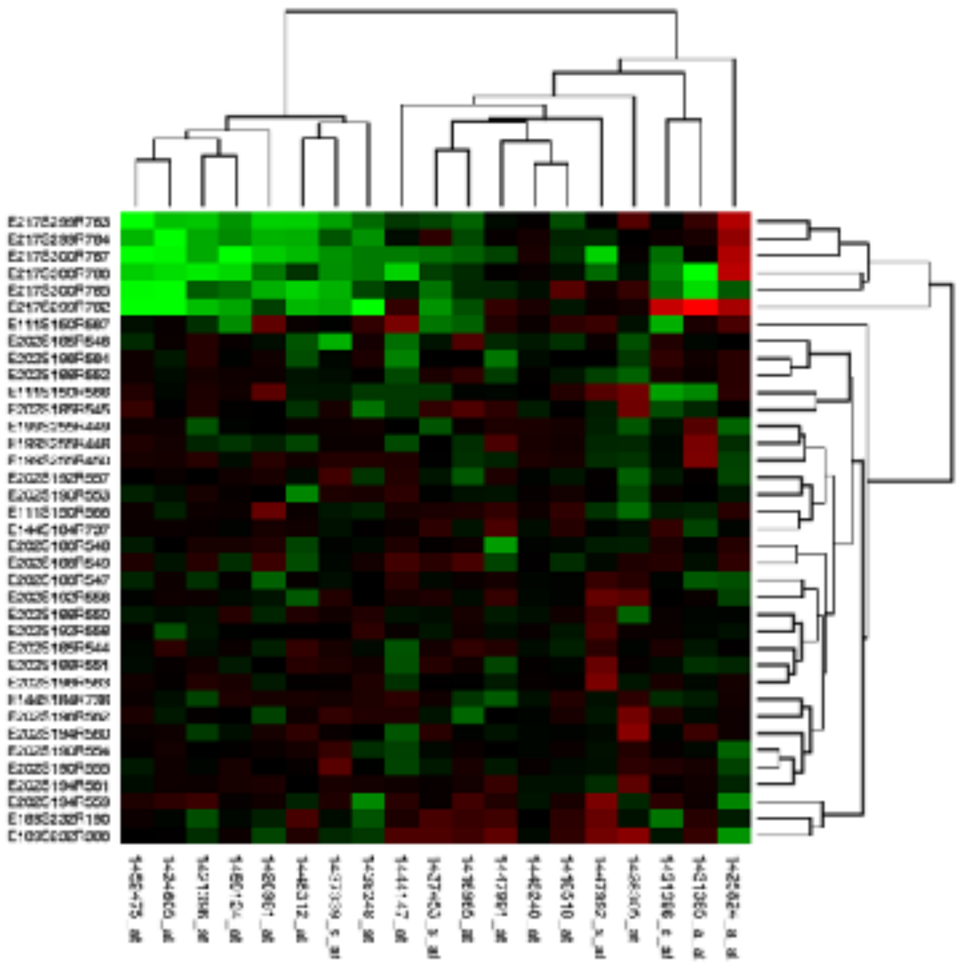


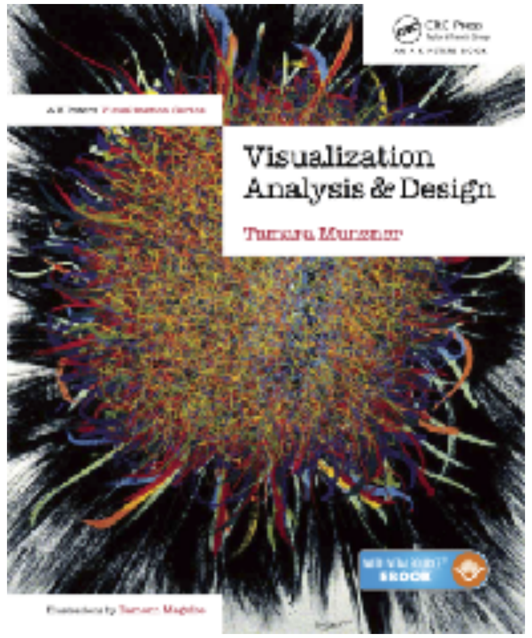


https://blogs.sas.com/content/iml/2018/05/02/reorder-variables-correlation-heat-map.html

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





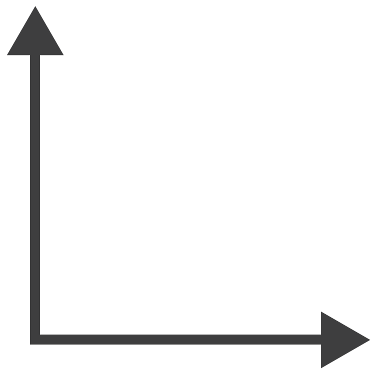
Visualization Analysis & Design

Tables (Ch 7) II

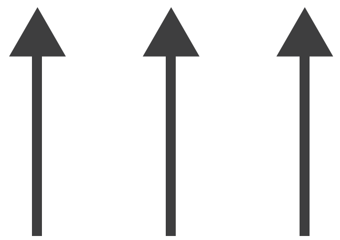
Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

Axis Orientation

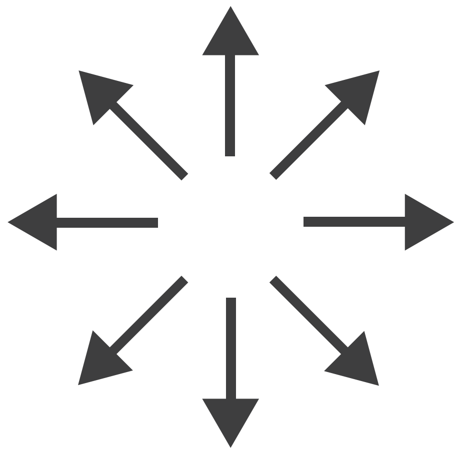
- Rectilinear



- Parallel

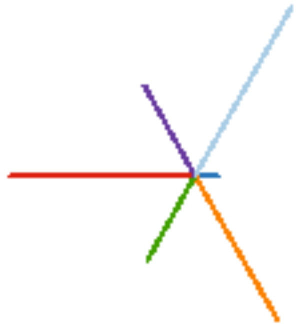


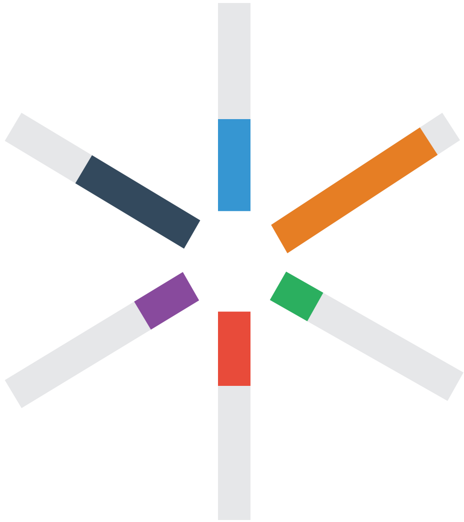
- Radial

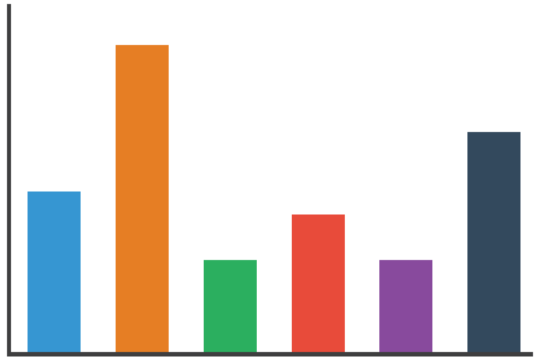


Idioms: **radial bar chart, star plot**

- 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







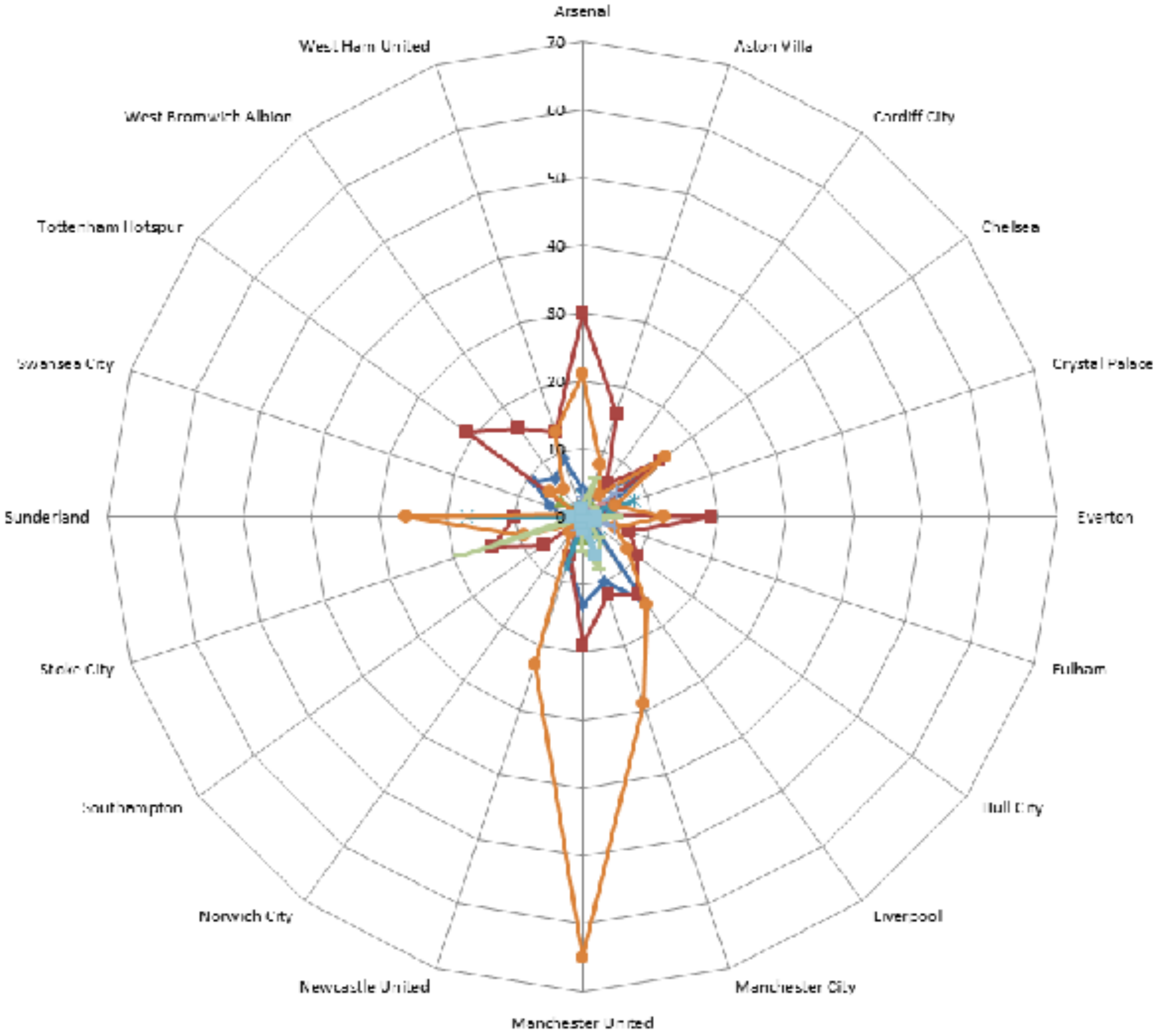
- accuracy
  - length not aligned with radial layouts
    - less accurately perceived than rectilinear aligned

[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.]

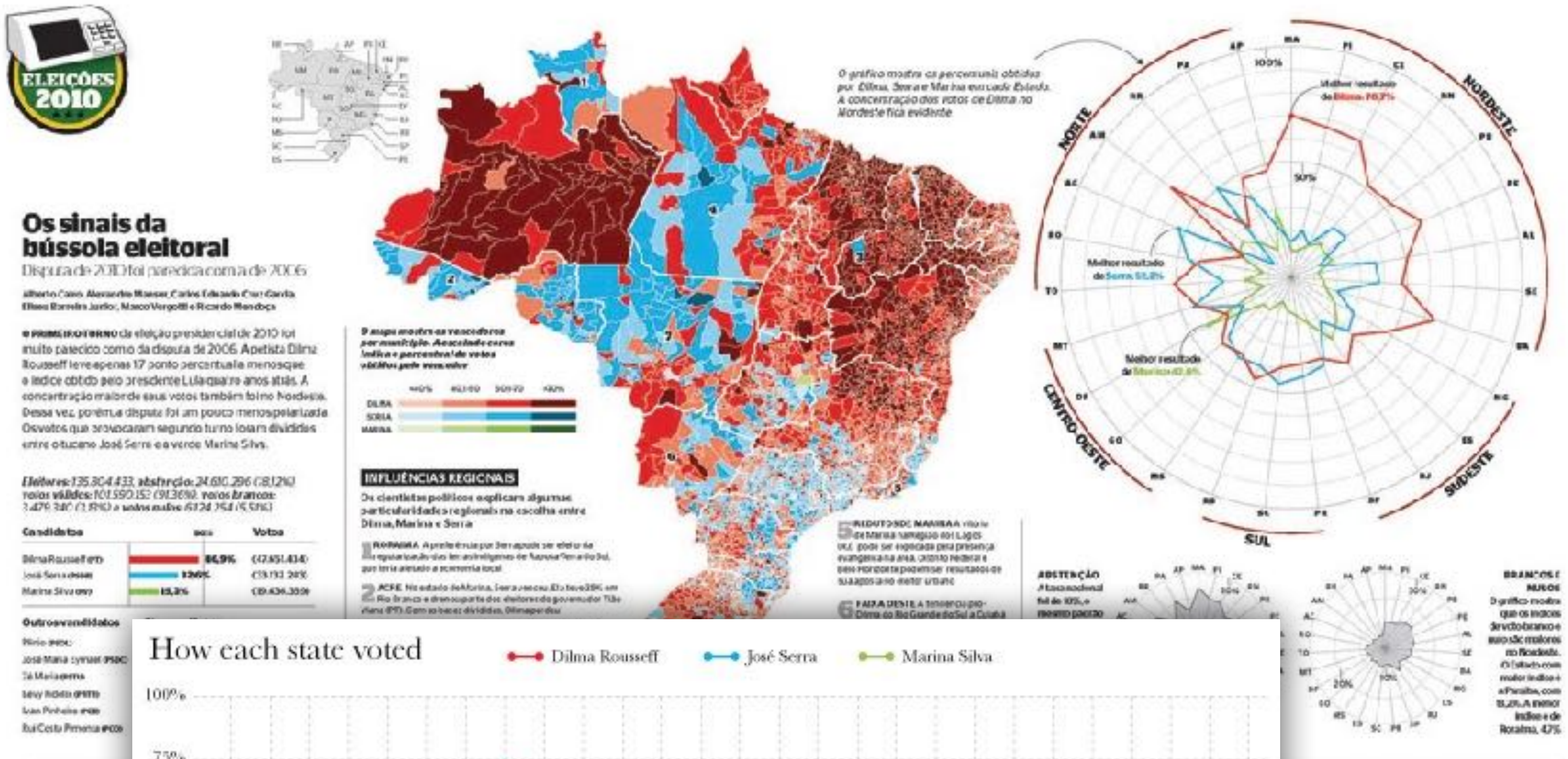
Idiom: **radar plot**

- radial line chart
  - point marks, radial layout
  - connecting line marks

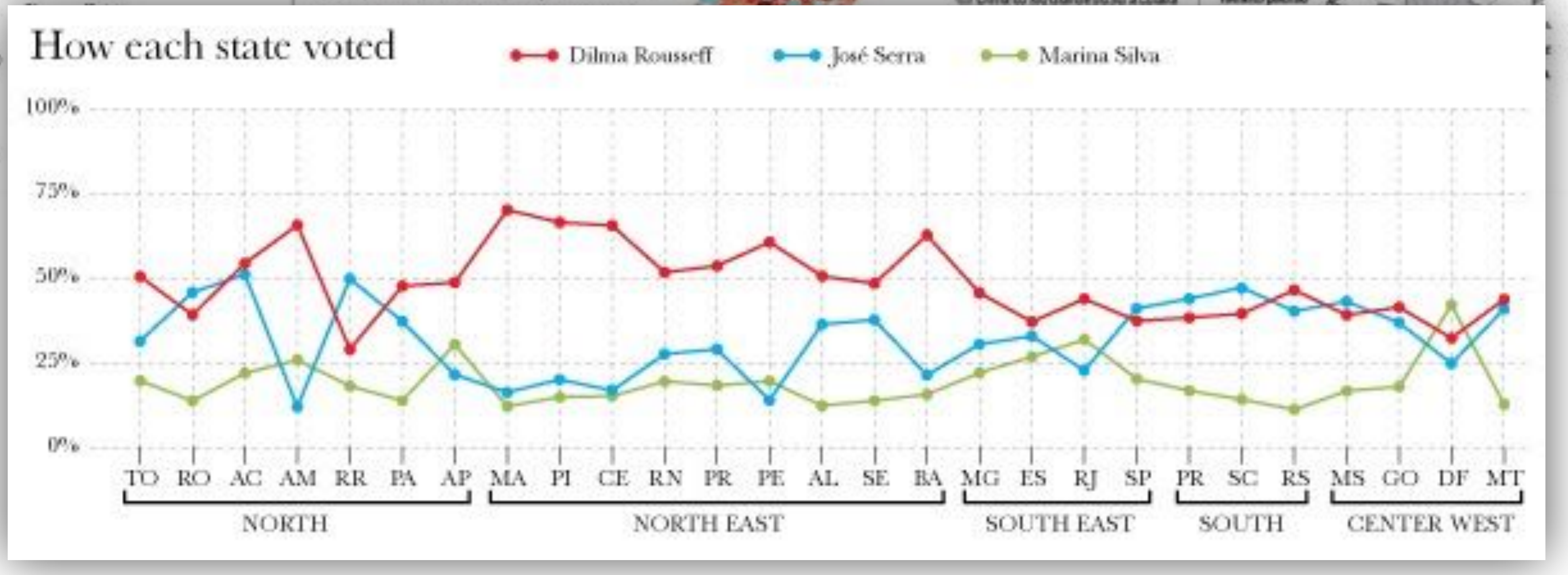
- avoid unless data is cyclic



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



original
difficult to interpret

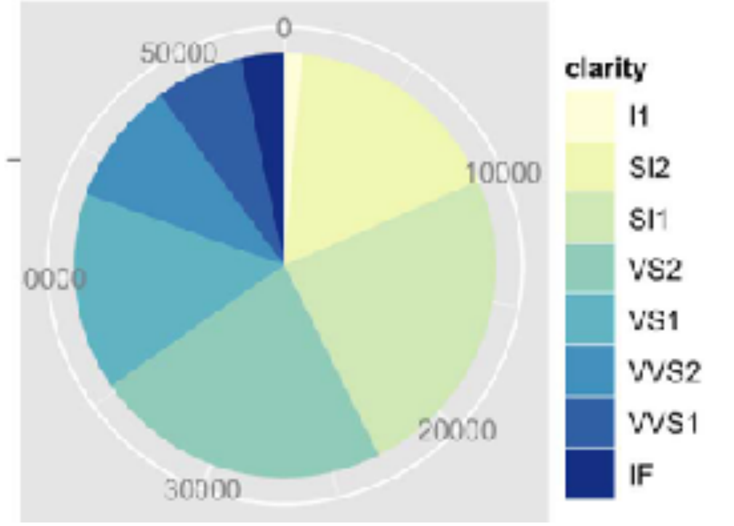


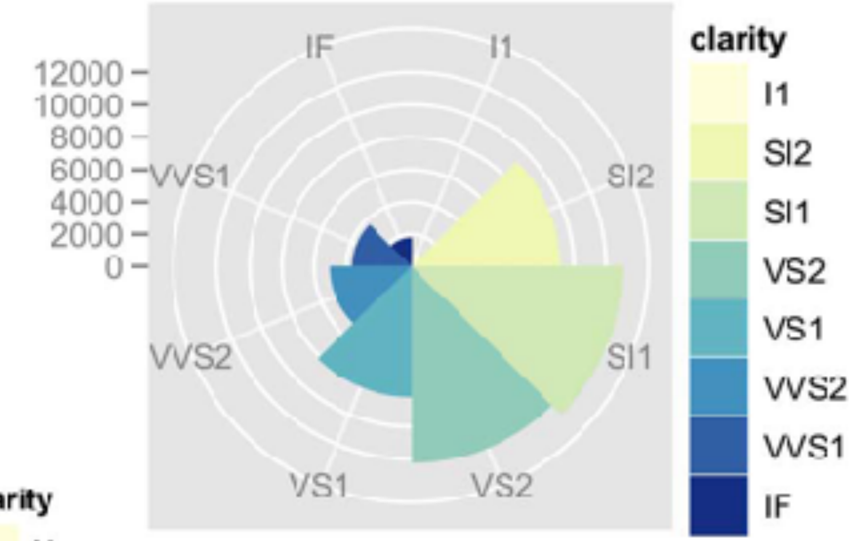
redesign for rectilinear

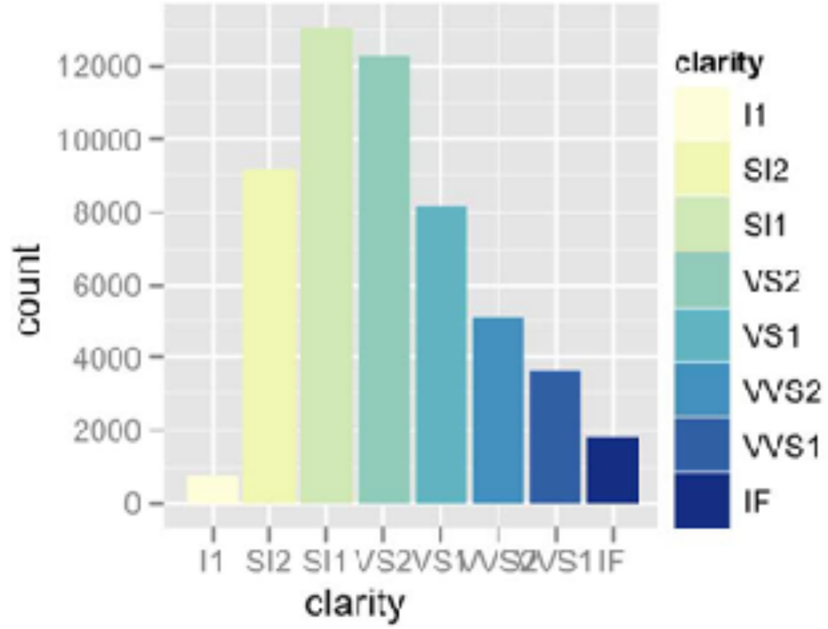
http://www.thefunctionalart.com/2012/11/radar-graphs-avoid-them-999-of-time.html

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



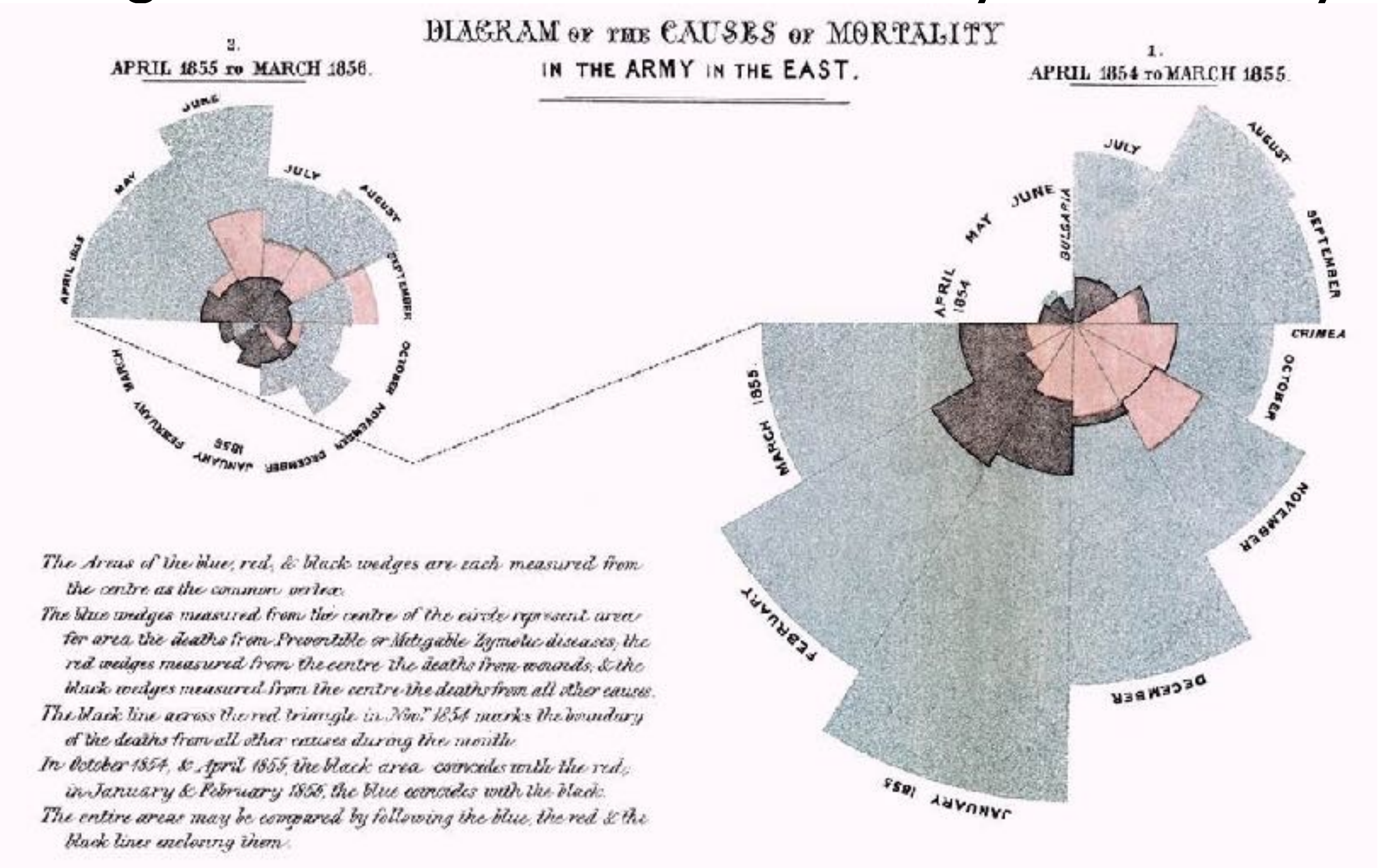




[A layered grammar of graphics. Wickham. Journ. Computational and Graphical Statistics 19:1 (2010), 3–28.]

Coxcomb / nightingale rose / polar area chart

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

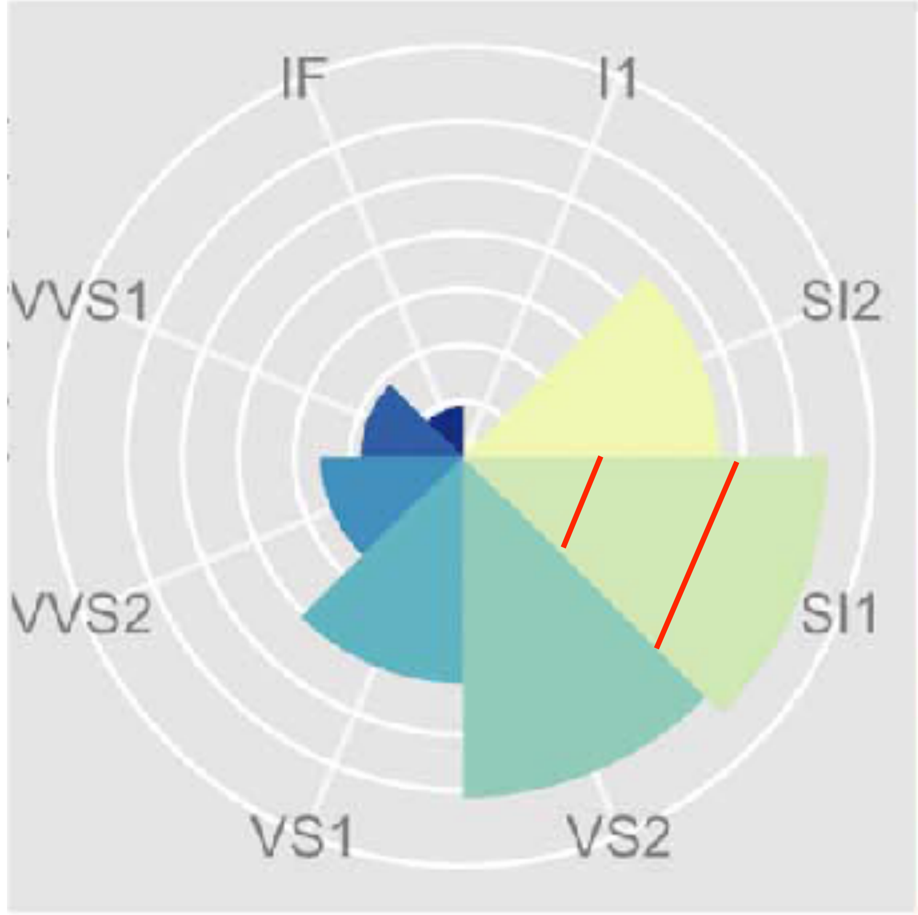


Coxcomb: perception

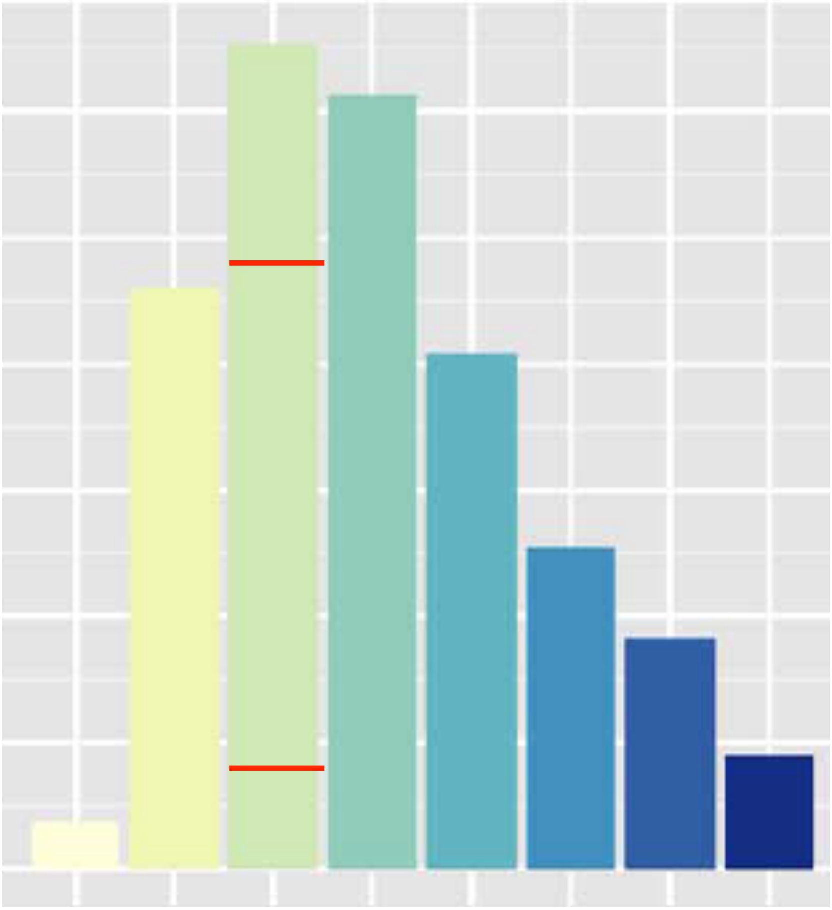
- encode: 1D length
- decode/perceive: 2D area

- nonuniform line/sector width as length increases
  - so area variation is nonlinear wrt line mark length!

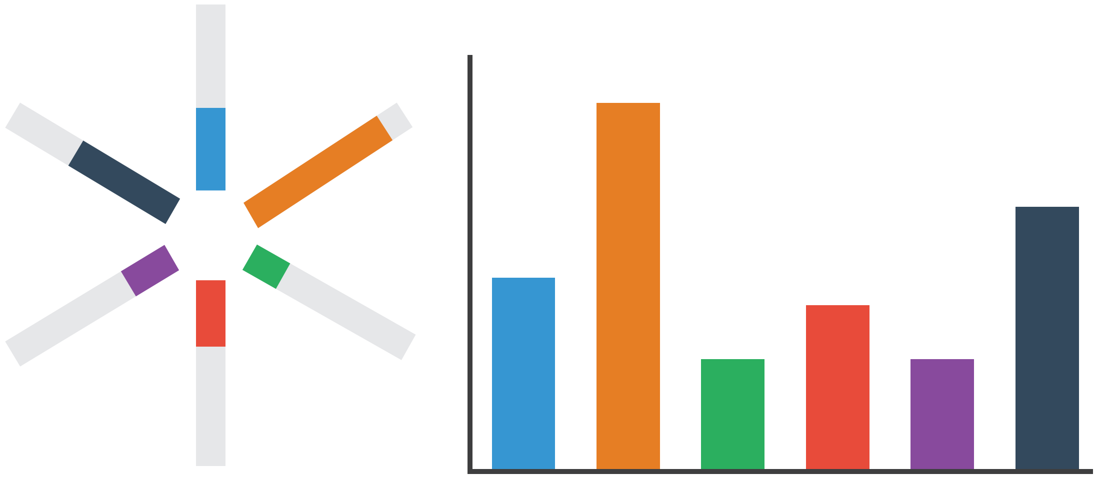
- bar chart safer: uniform width, so area is linear with line mark length
  - both radial & rectilinear cases



nonuniform width as length increases



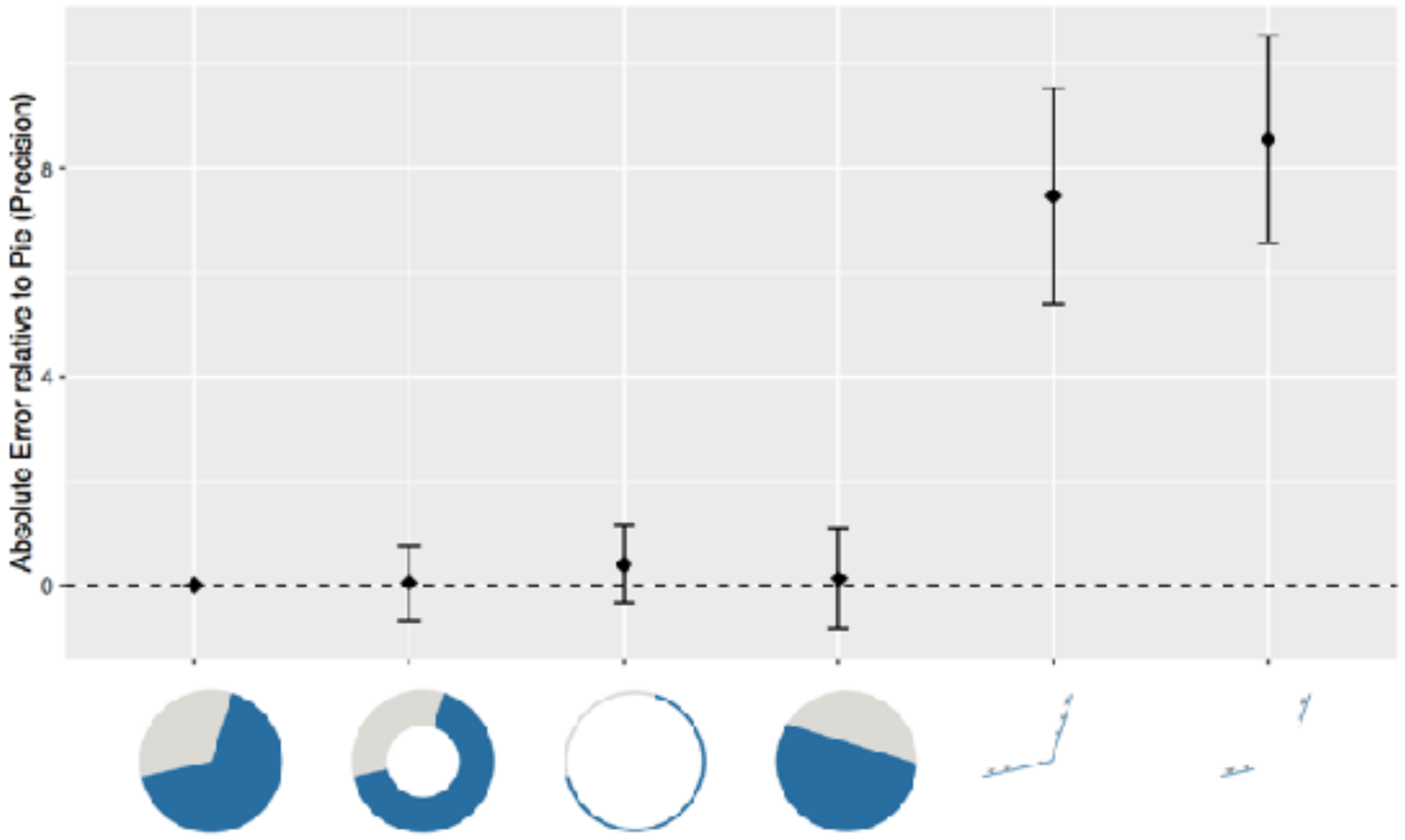
uniform width as length increases



radial & rectilinear bars: uniform width as length increases

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

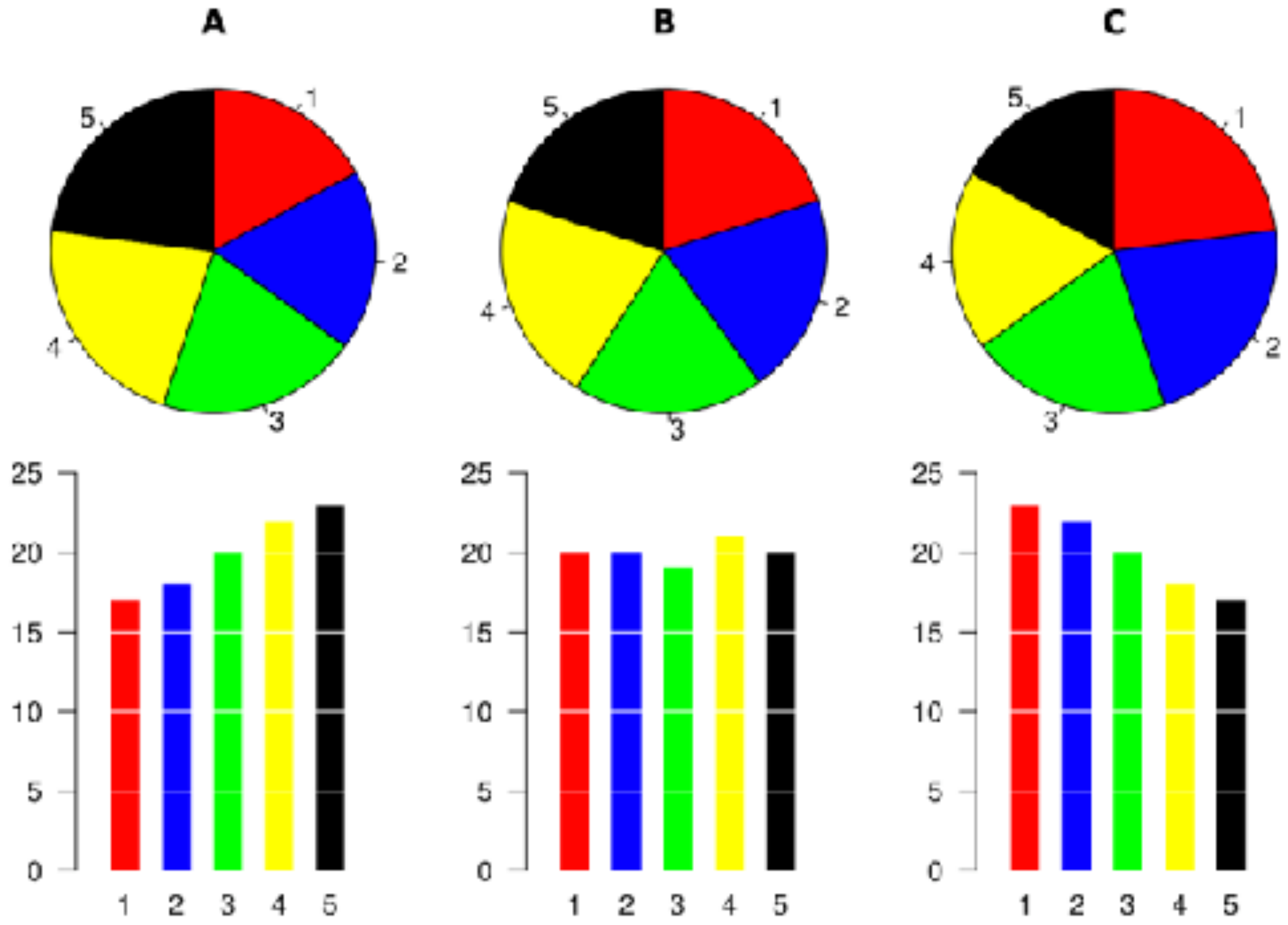
Pie charts: best practices

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

https://eagereyes.org/pie-charts

Pie charts: best practices

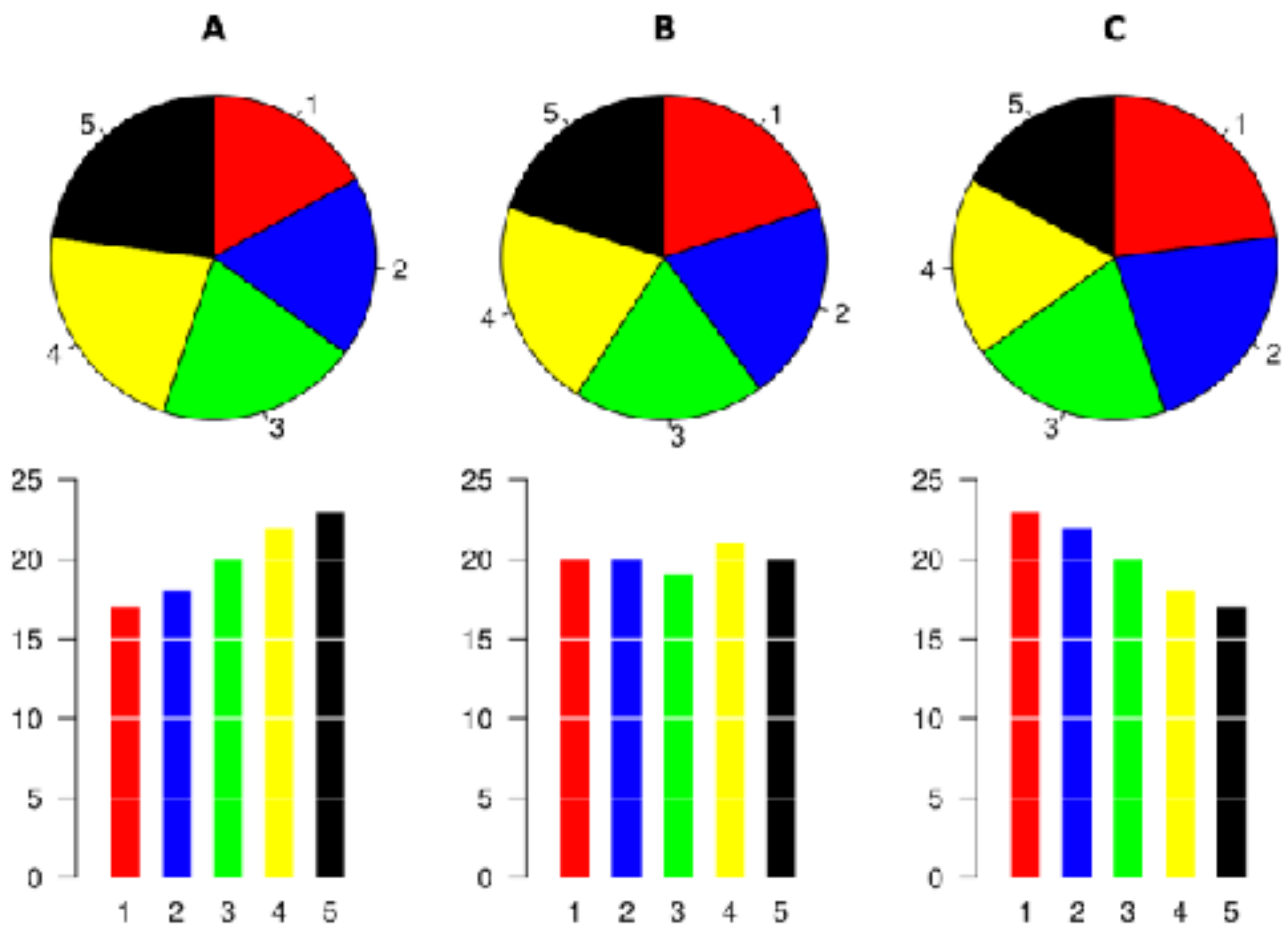
- not so bad for two (or few) levels, for part-to-whole task
- dubious for several levels if details matter

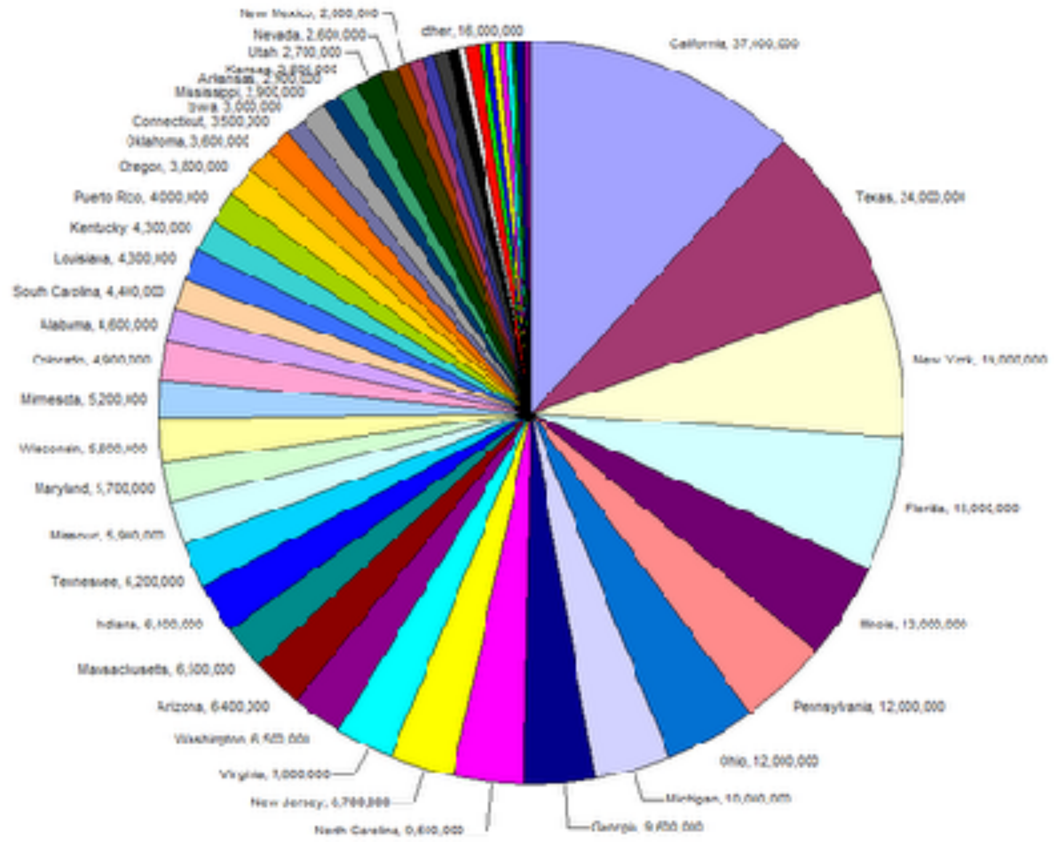


https://eagereyes.org/pie-charts

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

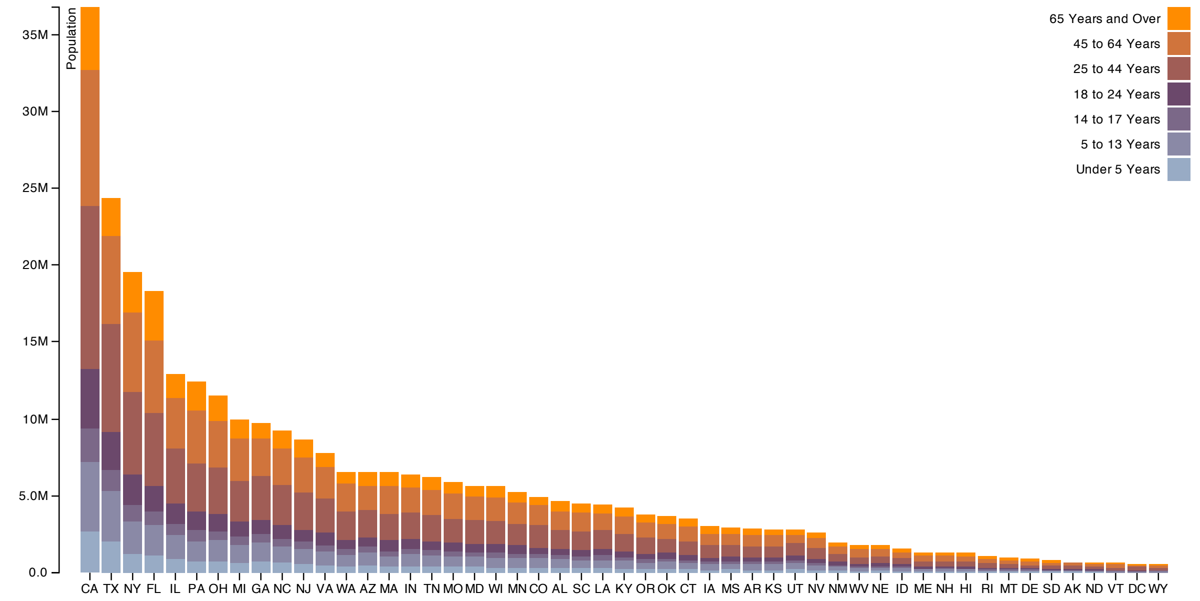


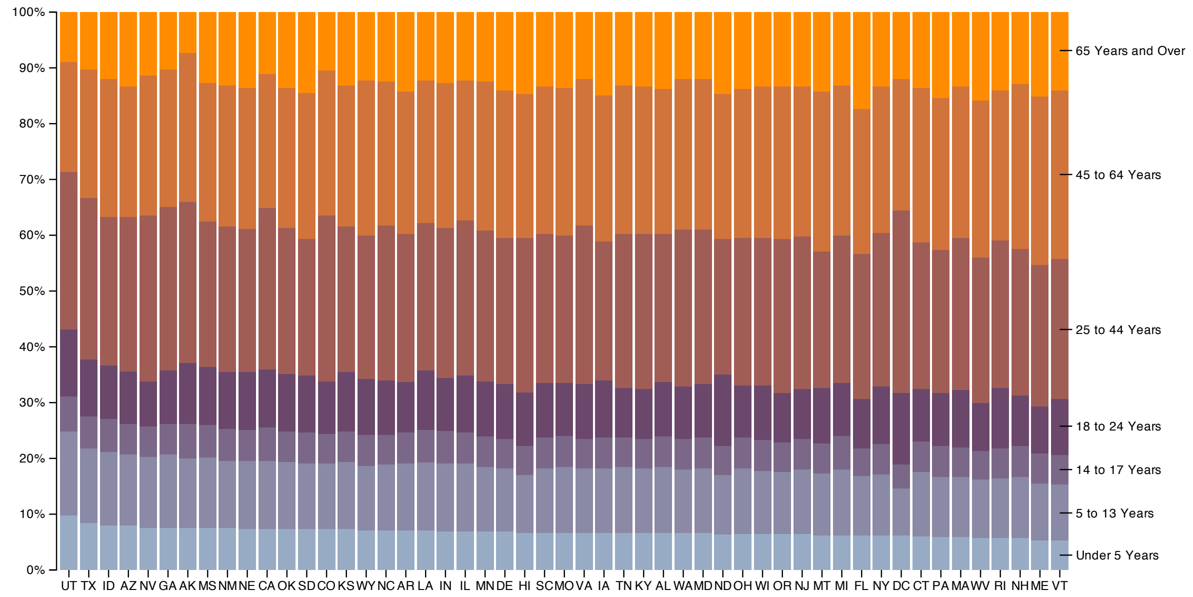


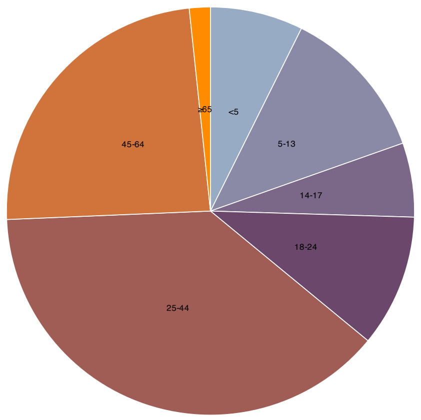
https://eagereyes.org/pie-charts

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,

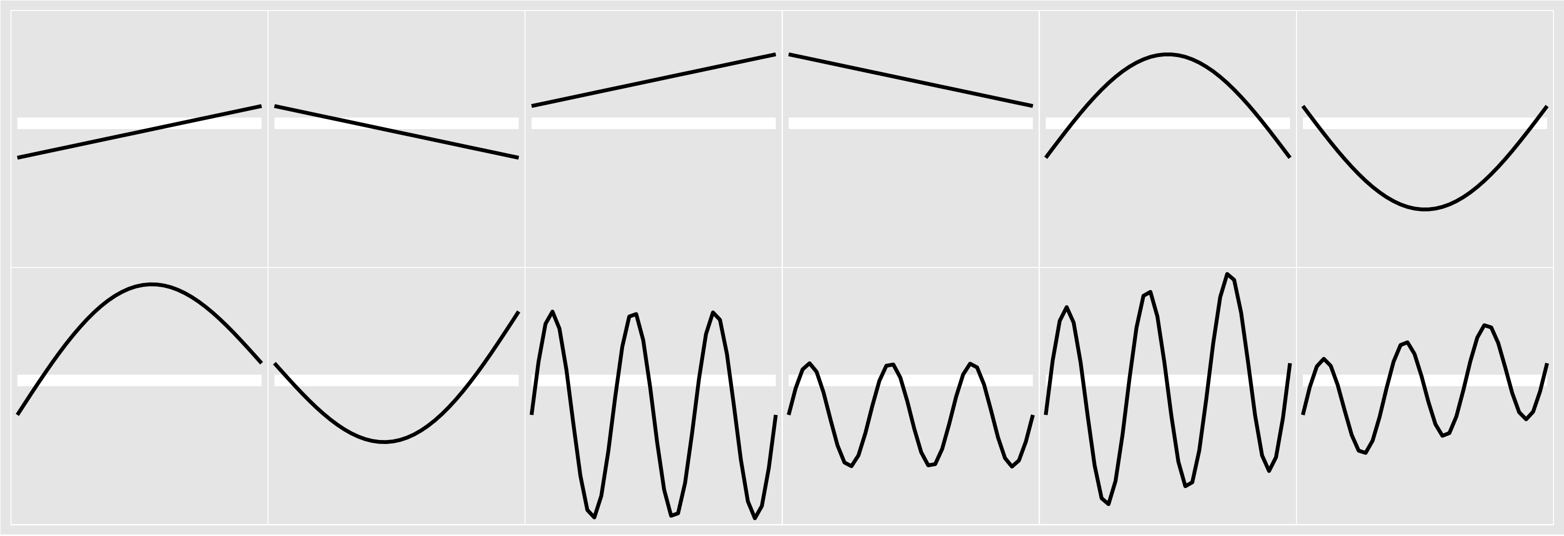
http://bl.ocks.org/mbostock/3887235,

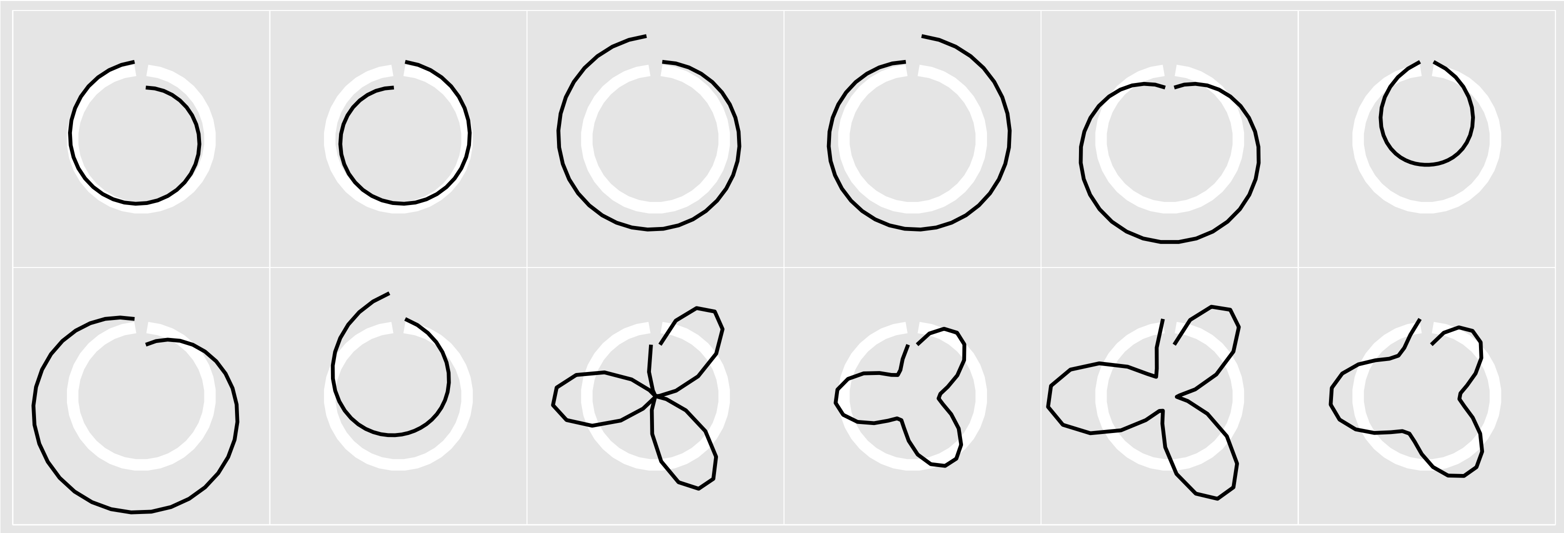
http://bl.ocks.org/mbostock/3886394.

Idiom: **glyphmaps**

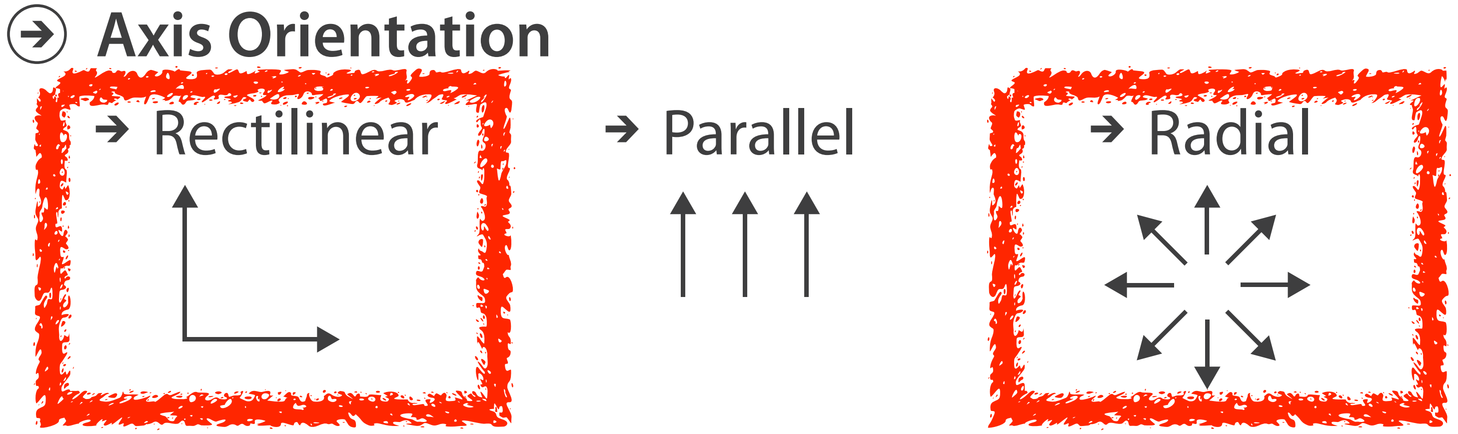
- rectilinear good for linear vs nonlinear trends

- radial good for cyclic patterns
  - evaluating periodicity



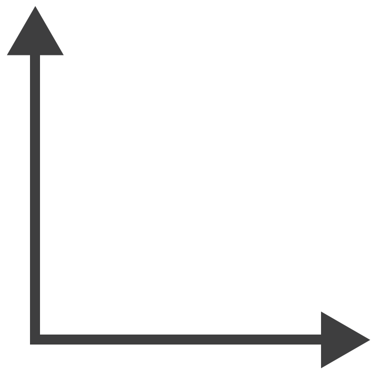


[Glyph-maps for Visually Exploring Temporal Patterns in Climate Data and Models. Wickham, Hofmann, Wickham, and Cook. Environmetrics 23:5 (2012), 382–393.]

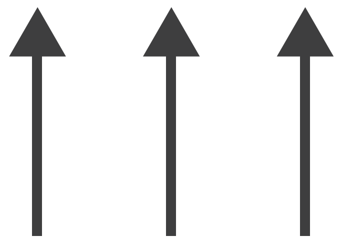


Axis Orientation

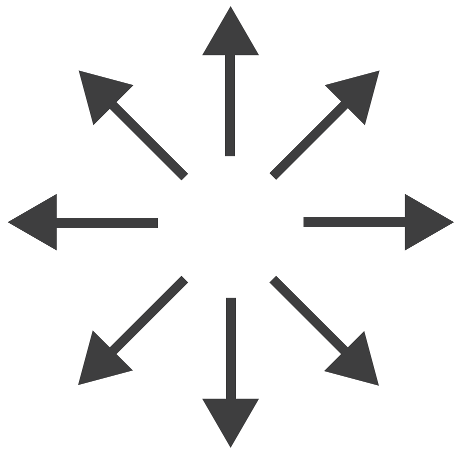
- Rectilinear



- Parallel

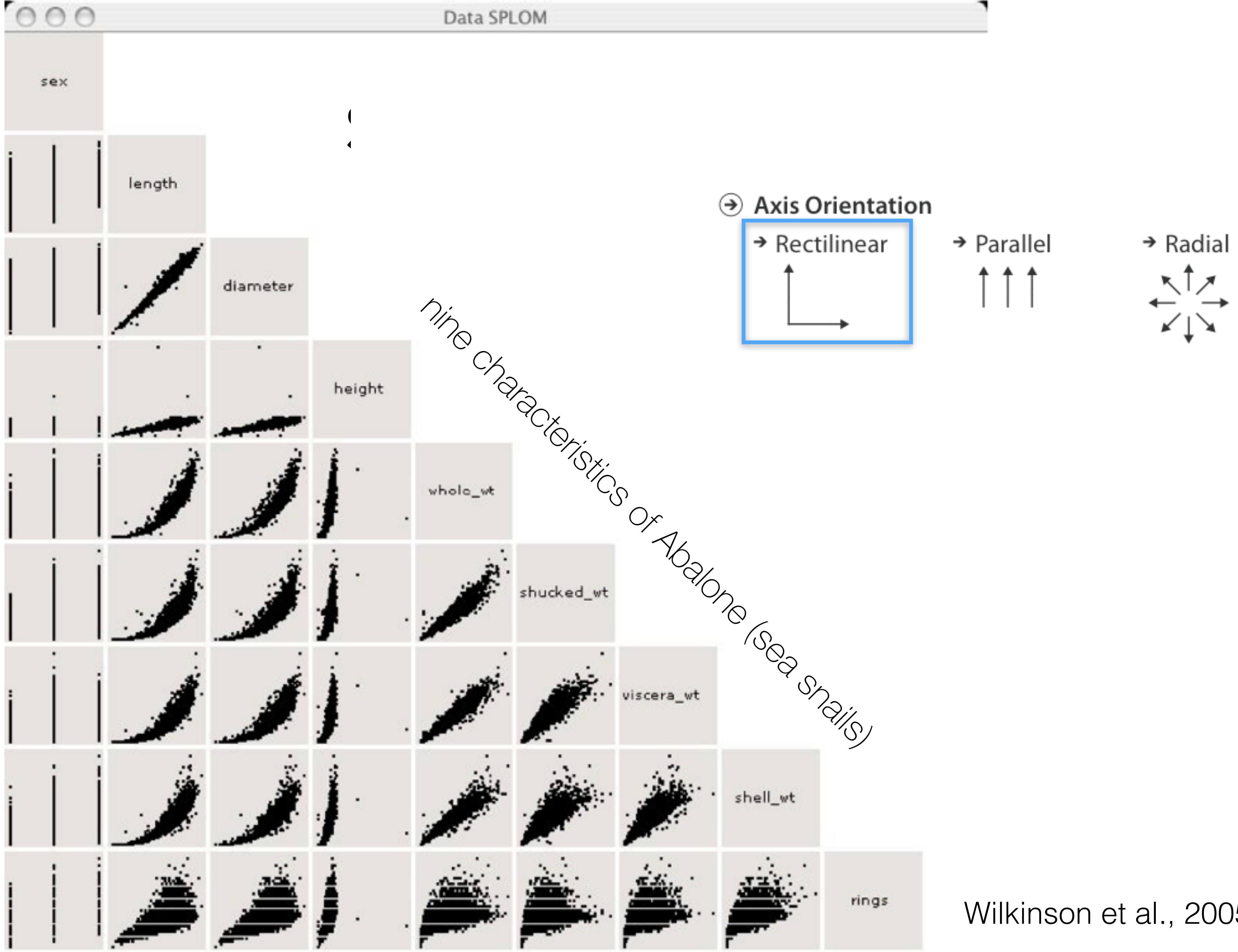


- Radial



Idiom: **SPLOM**

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

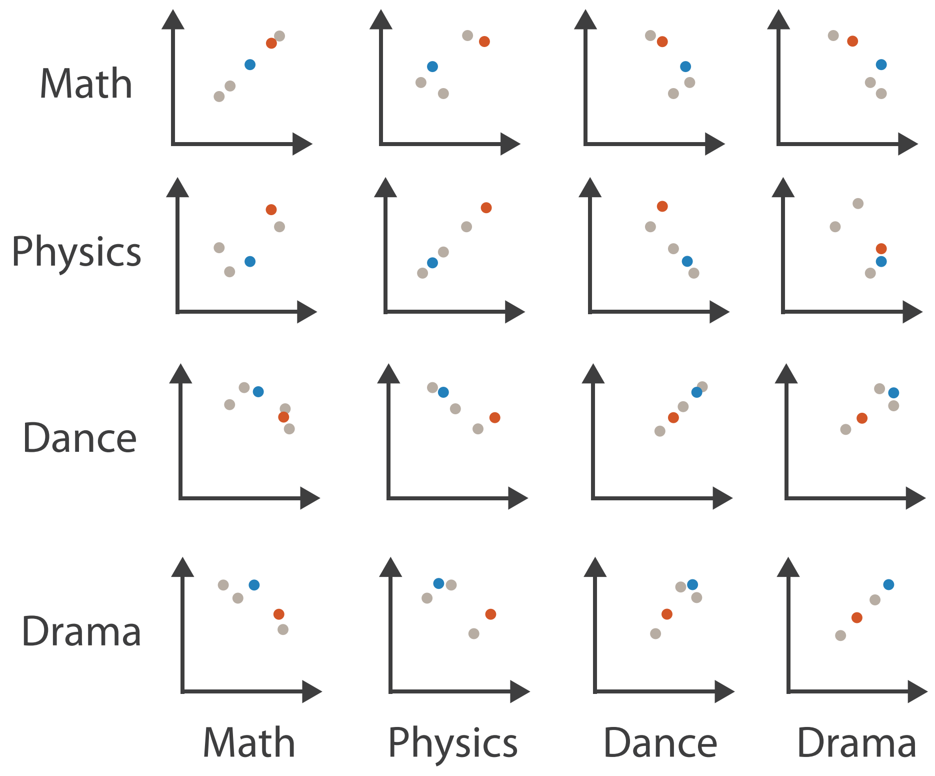


Wilkinson et al., 2005

Idioms: **parallel coordinates**

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

Scatterplot Matrix



Table

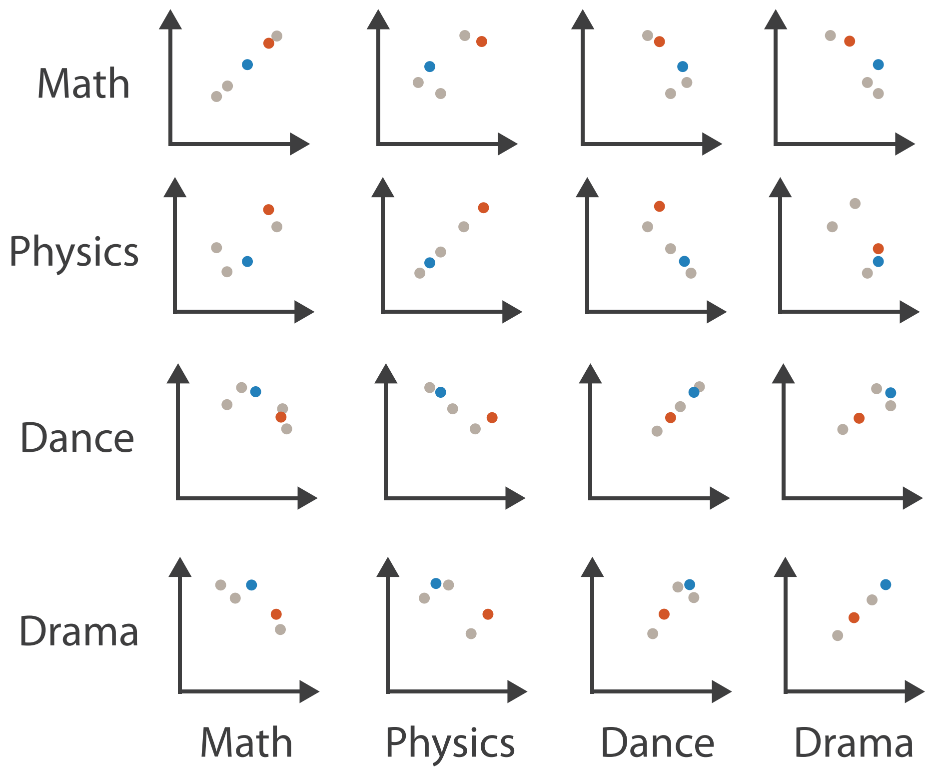
Math	Physics	Dance	Drama
85	95	70	65
90	80	60	50
65	50	90	90
50	40	95	80
40	60	80	90

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

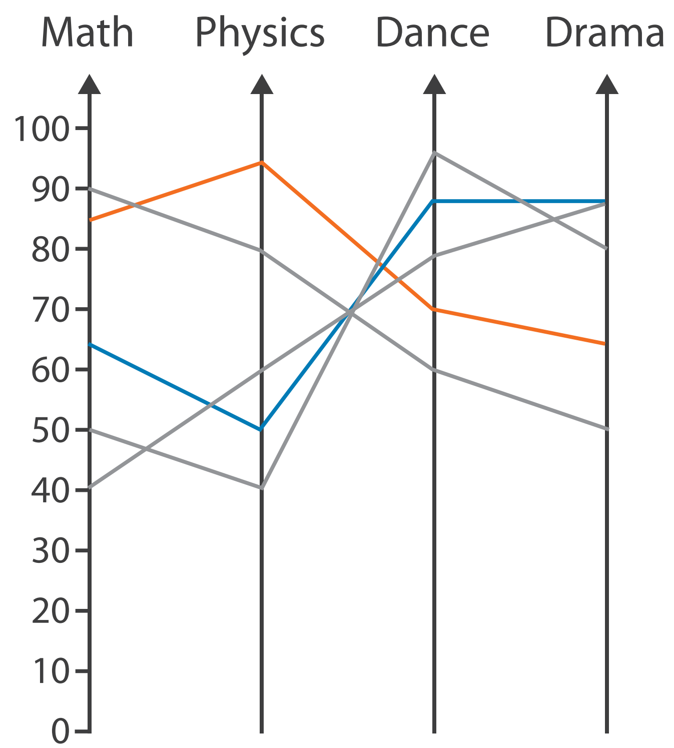
Idioms: **parallel coordinates**

- 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

Scatterplot Matrix



Parallel Coordinates



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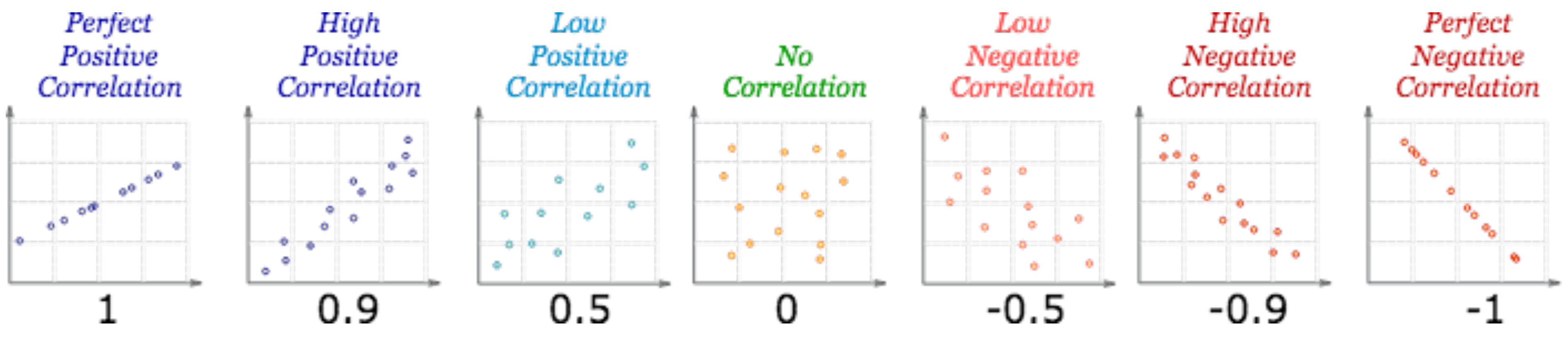
after [Visualization Course Figures. McGuffin, 2014. http://www.michaelmcguffin.com/courses/vis/]

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

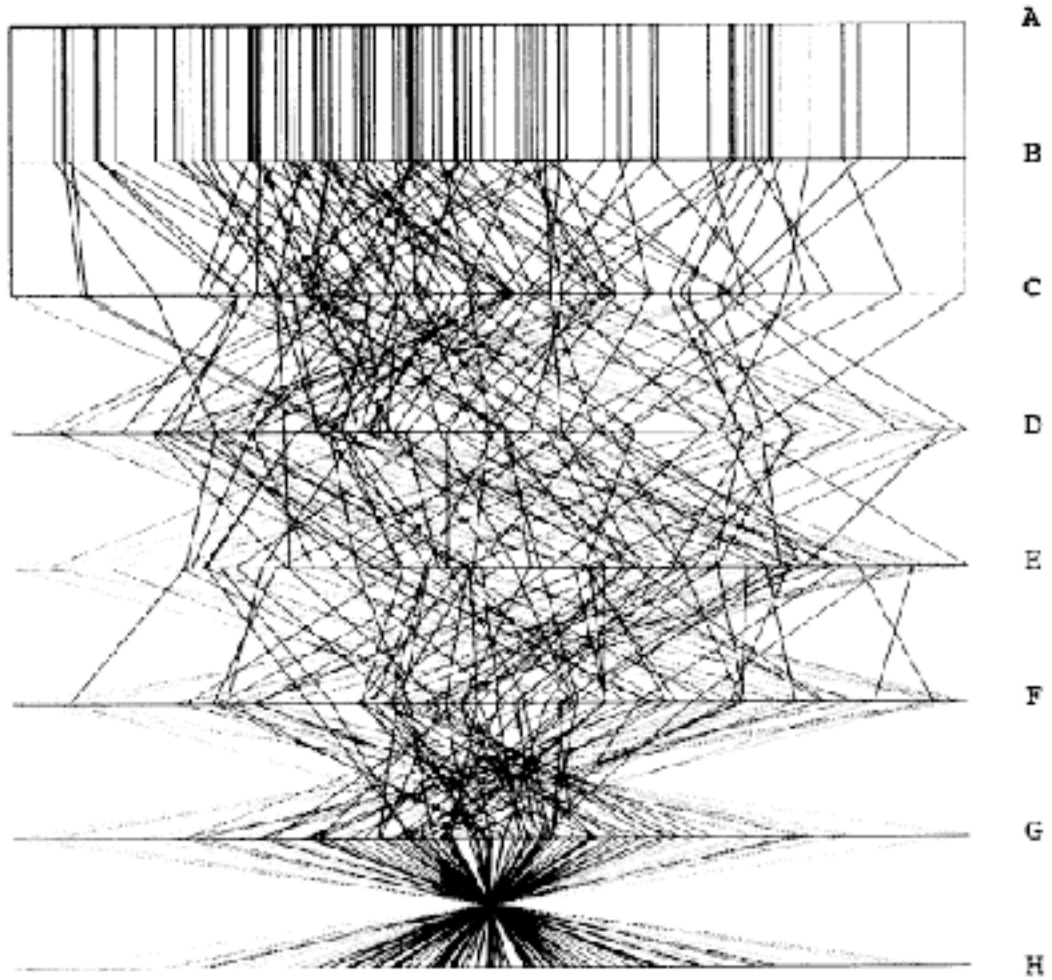
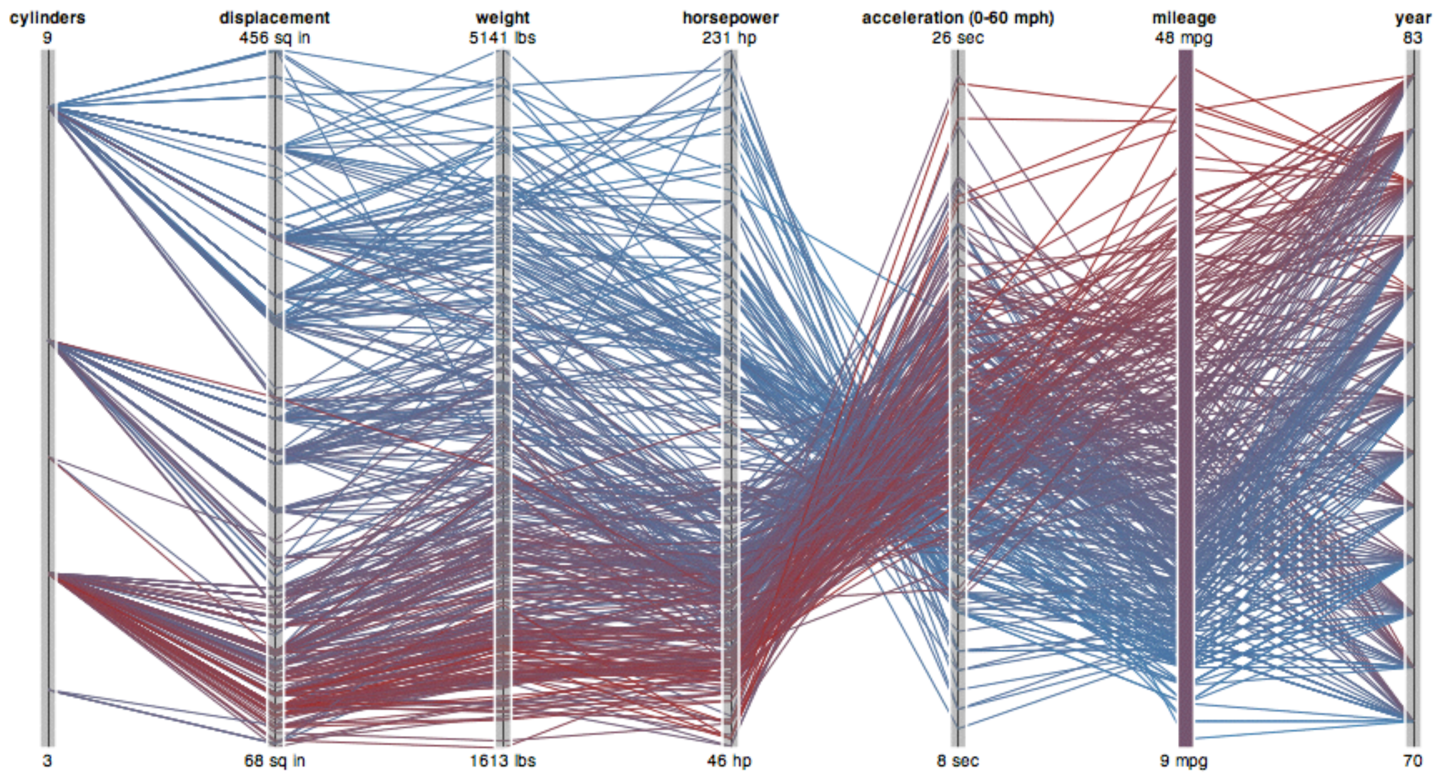


Figure 3. Parallel Coordinate Plot of Six-Dimensional Data Illustrating Correlations of ρ = 1, .8, .2, 0, −.2, −.8, and −1.

[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

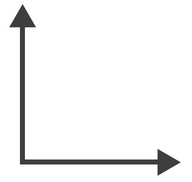


Orientation limitations

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

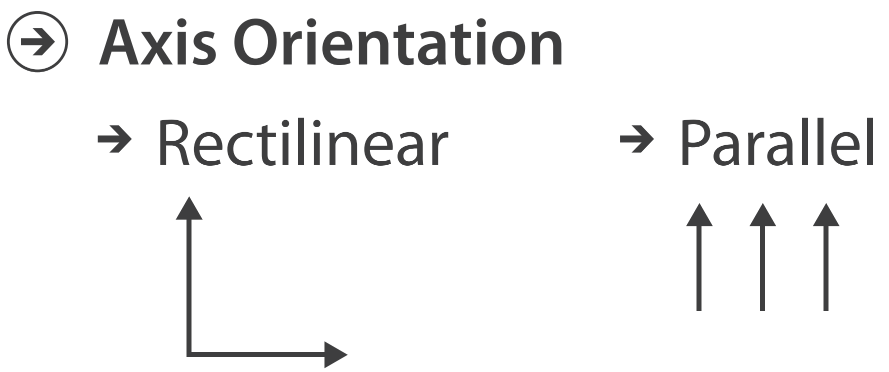
Axis Orientation

→ Rectilinear

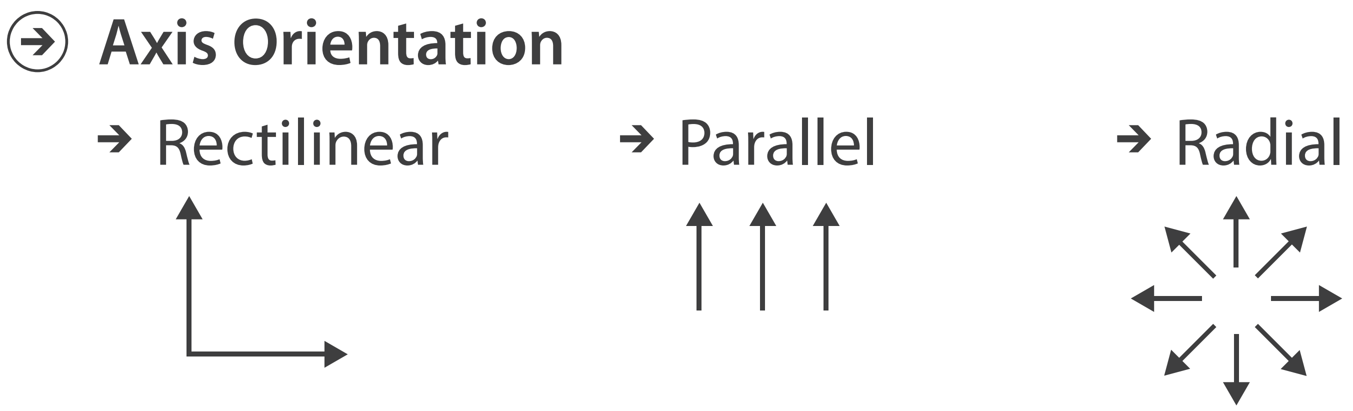


Orientation limitations

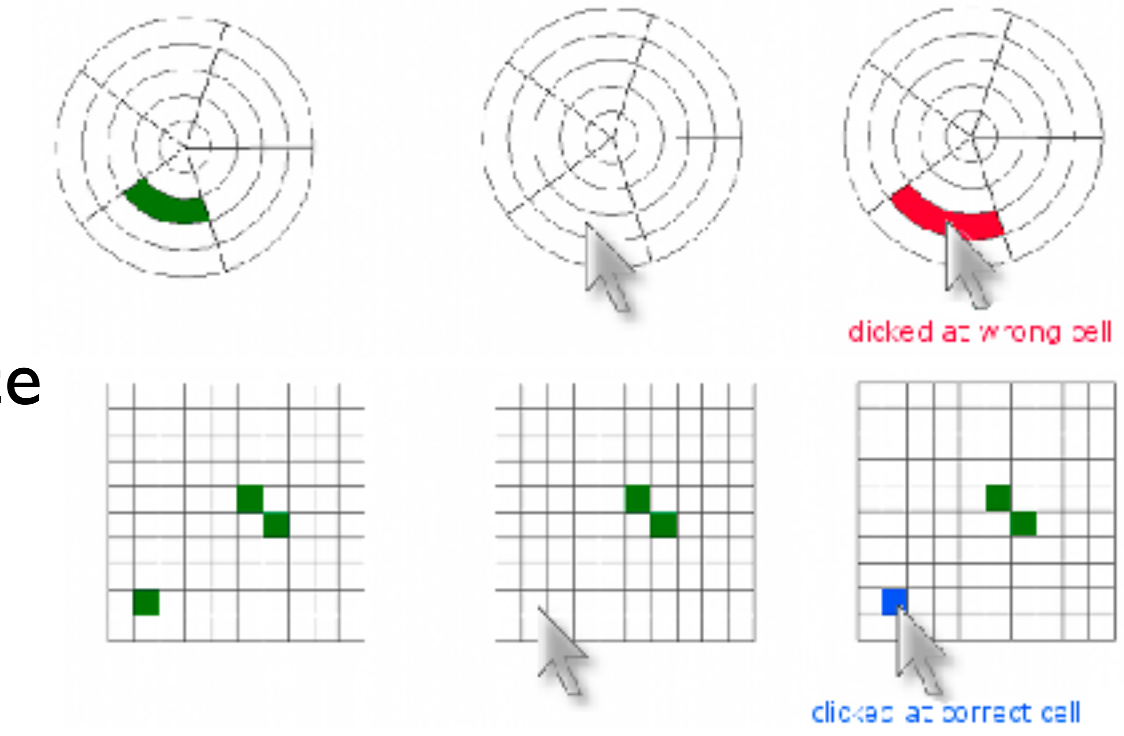
- rectilinear: scalability wrt #axes
  - 2 axes best, 3 problematic, 4+ impossible
- parallel: unfamiliarity, training time



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

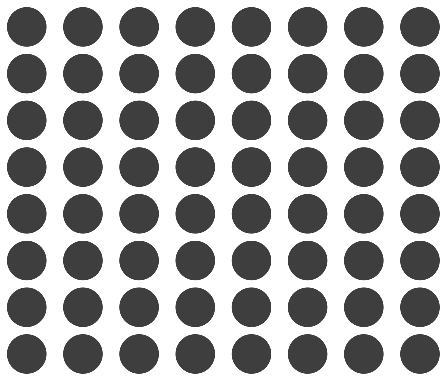


[Uncovering Strengths and Weaknesses of Radial Visualizations - an Empirical Approach. Diehl, Beck and Burch. IEEE TVCG (Proc. InfoVis) 16(6):935–942, 2010.]

Layout density

Layout Density

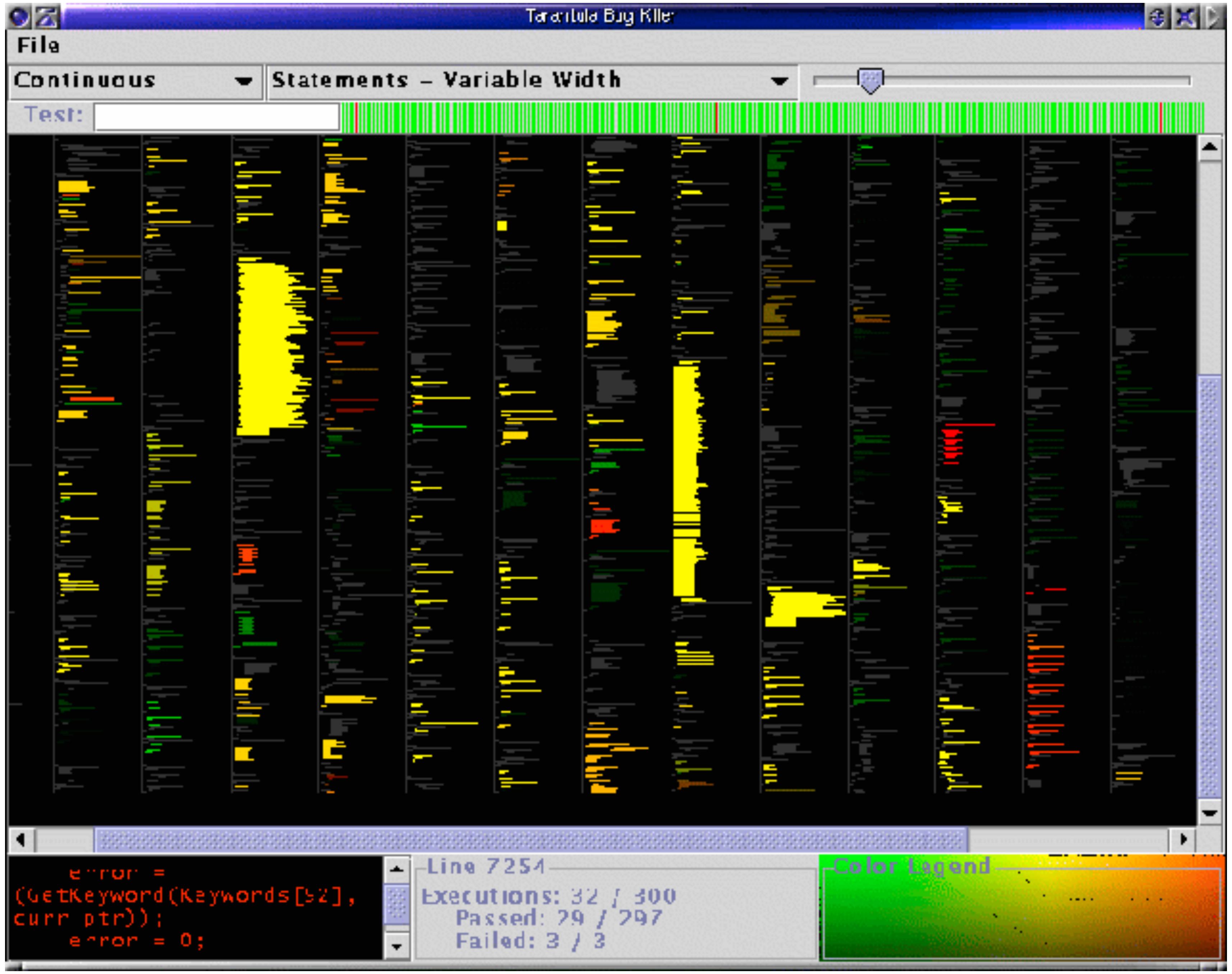
- Dense



- Space-Filling

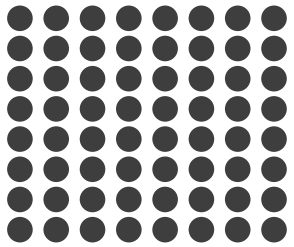
Idiom: Dense software overviews

- 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



→ Layout Density

→ Dense



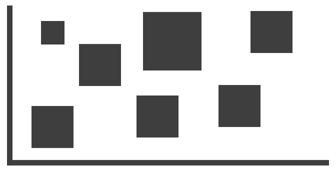
[Visualization of test information to assist fault localization. Jones, Harrold, Stasko. Proc. ICSE 2002, p 467-477.]

Arrange tables

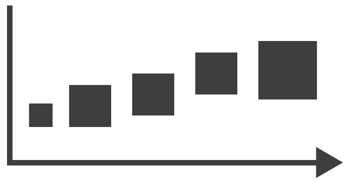
Express Values

Separate, Order, Align Regions

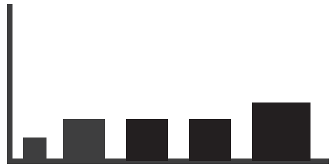
- Separate



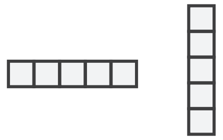
- Order



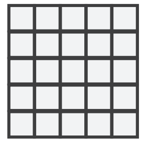
- Align



- *1 Key*
  List

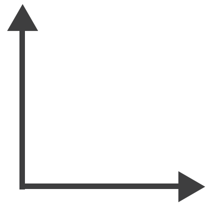


- *2 Keys*
  Matrix

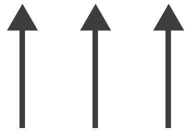


Axis Orientation

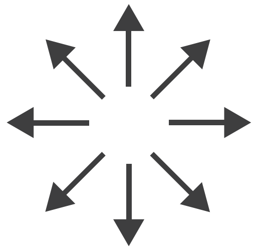
- Rectilinear



- Parallel

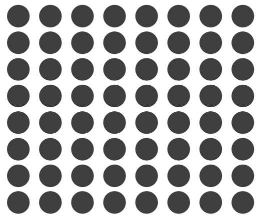


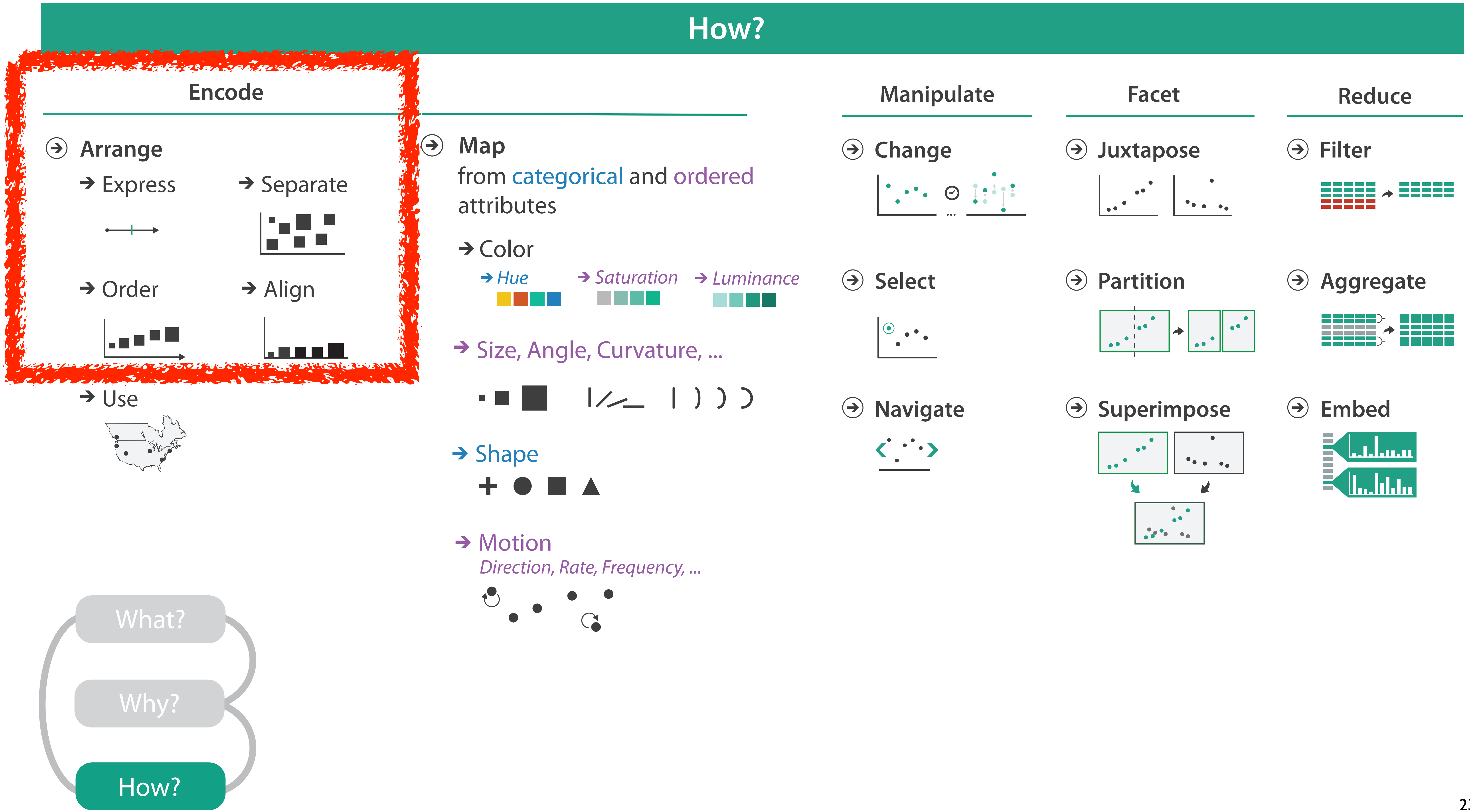
- Radial

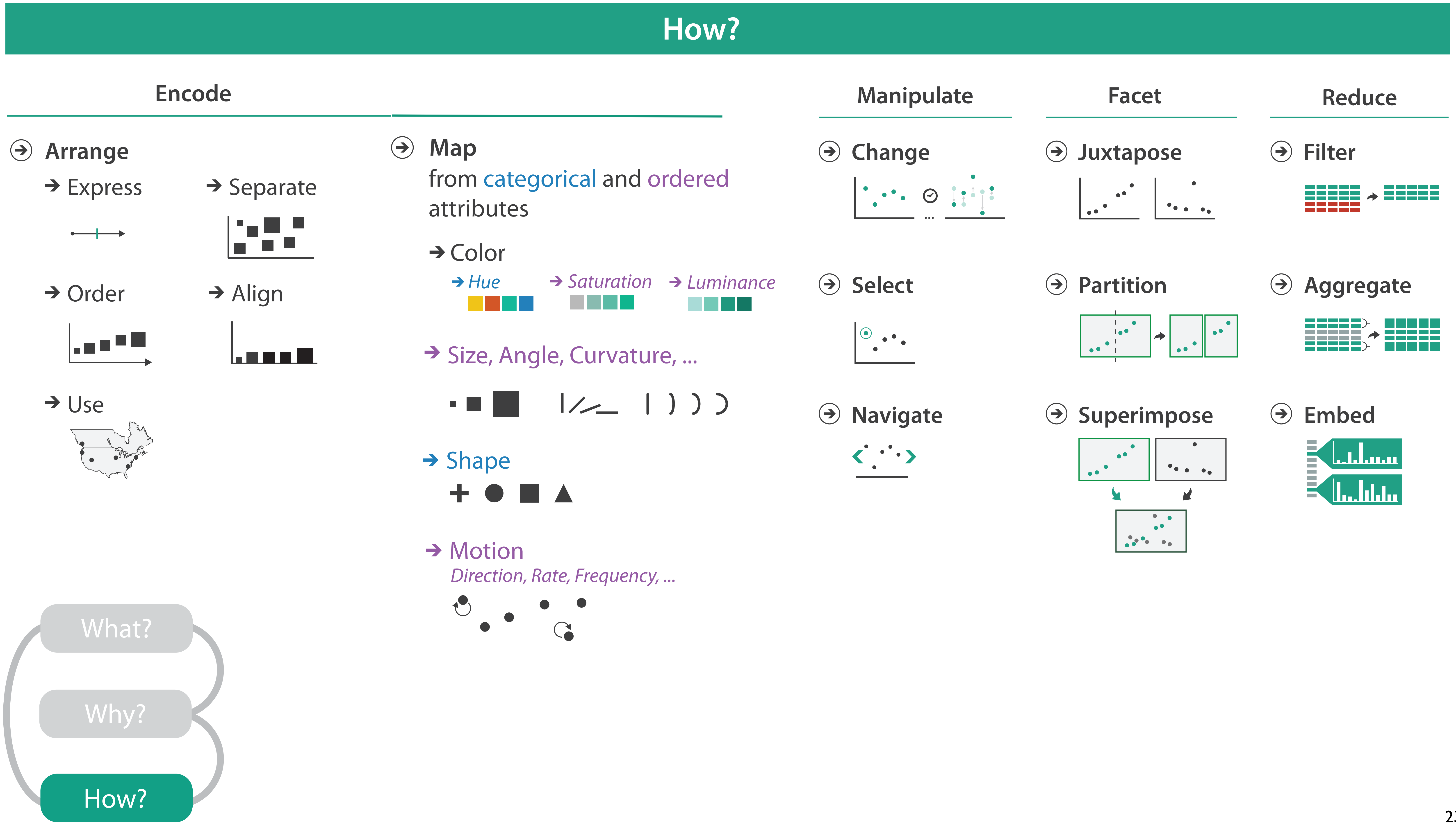


Layout Density

- Dense




How?
Encode
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Manipulate
Change
Select
Navigate
Facet
Juxtapose
Partition
Superimpose
Reduce
Filter
Aggregate
Embed
What?
Why?
How?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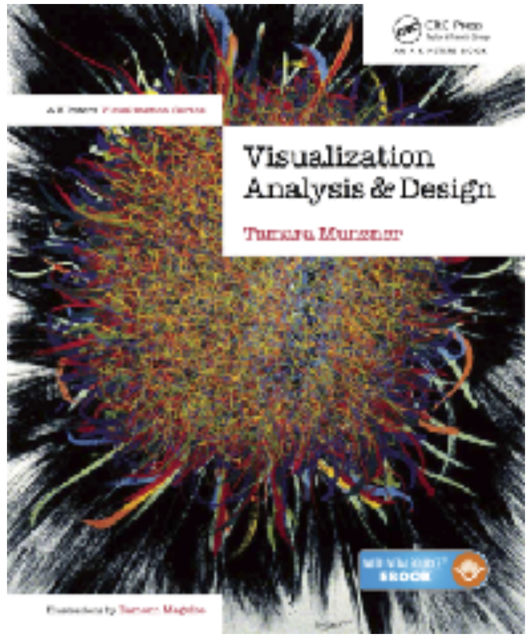


Visualization Analysis & Design

Interactive Views (Ch 11/12)

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

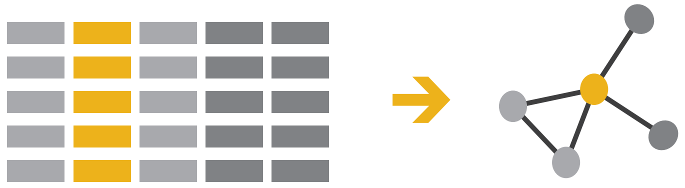
How to handle complexity: 1 previous strategy

➔ *Derive*

- derive new data to show within view

How to handle complexity: 1 previous strategy + 2 more

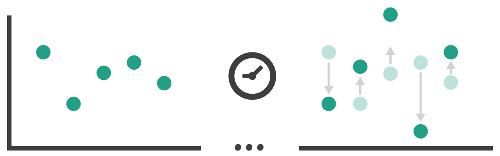
➔ *Derive*



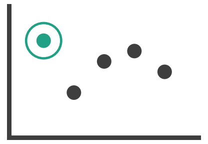
- derive new data to show within view
- change view over time
- facet across multiple views

Manipulate

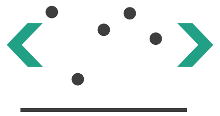
➔ Change



➔ Select

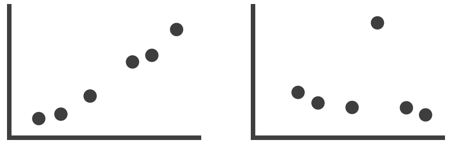


➔ Navigate

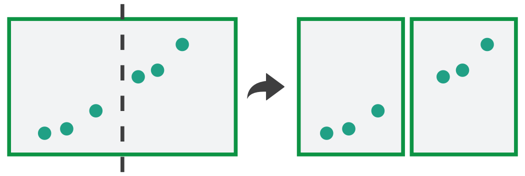


Facet

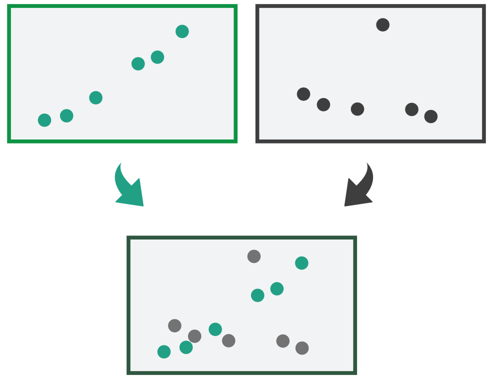
➔ Juxtapose



➔ Partition



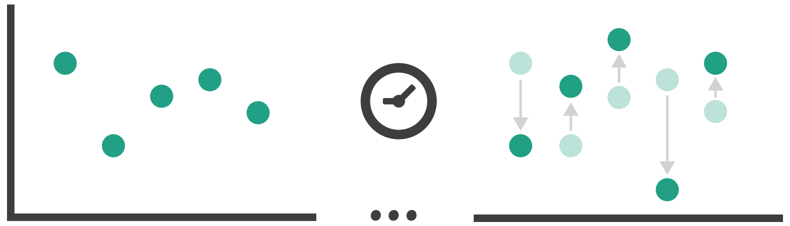
➔ Superimpose



Manipulate View

Manipulate

➔ Change over Time



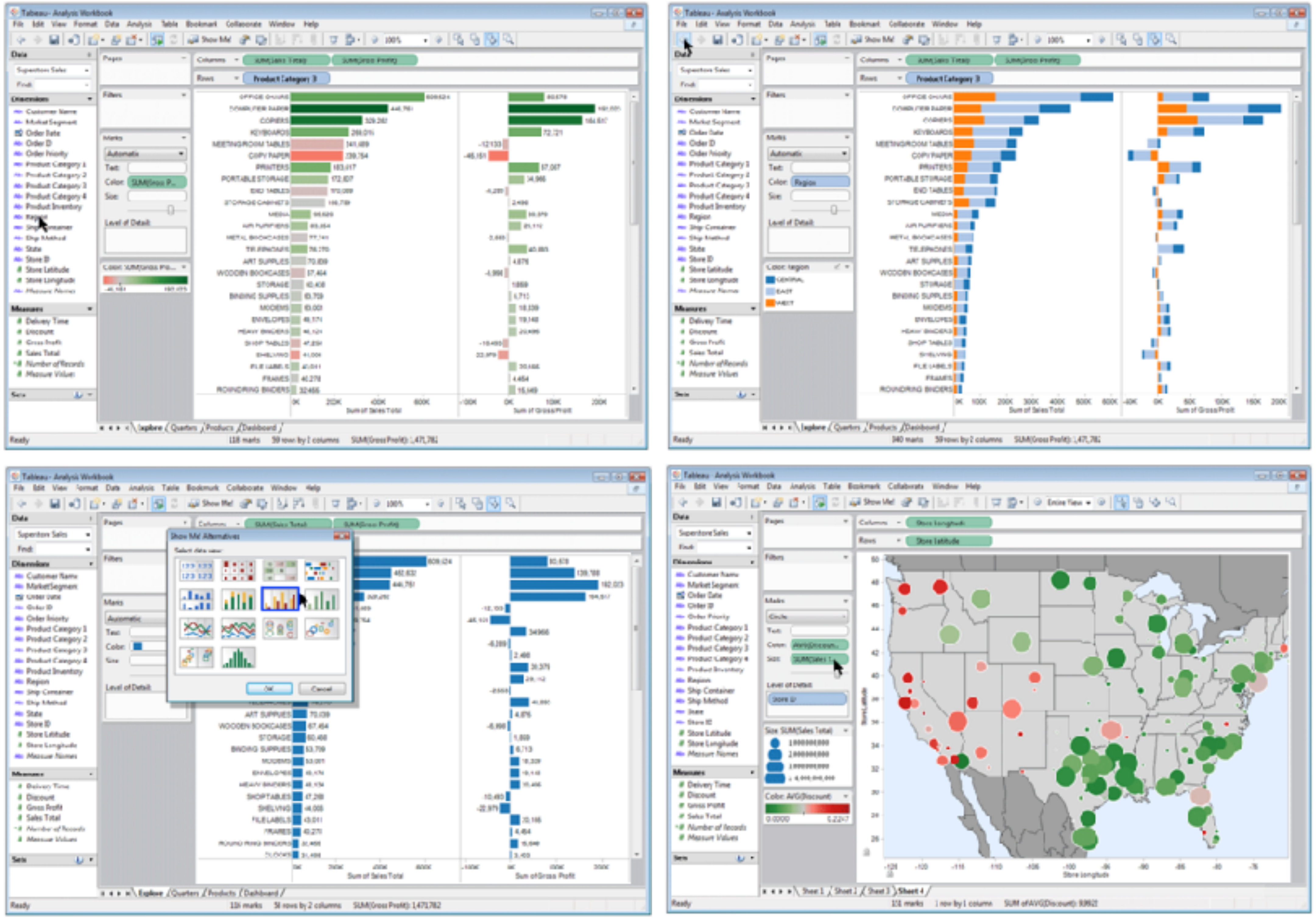
Change over time

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

  - interaction entails change

- powerful & flexible

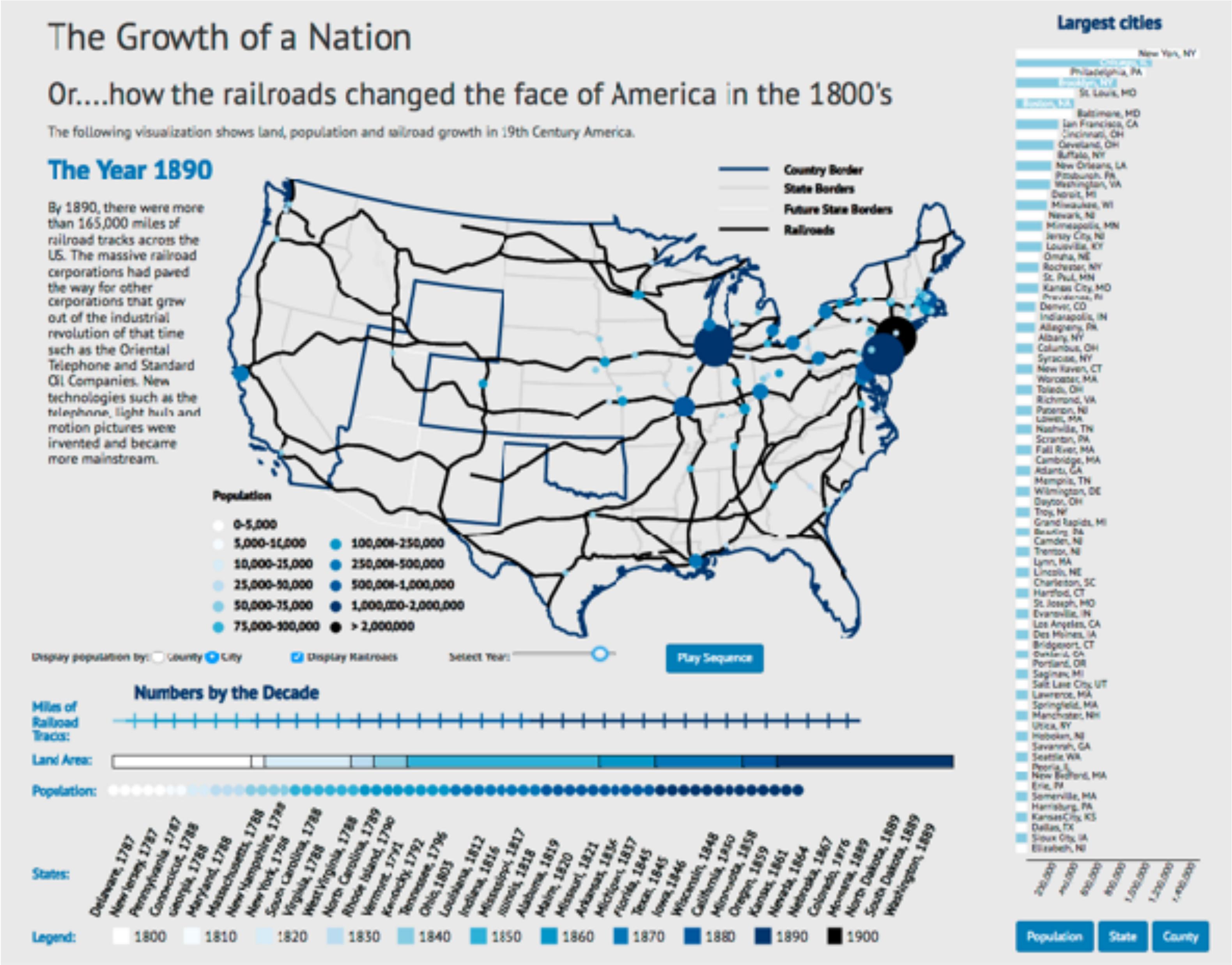
Idiom: **Re-encode**



made with Tableau, http://tableausoftware.com

Idiom: **Change parameters**

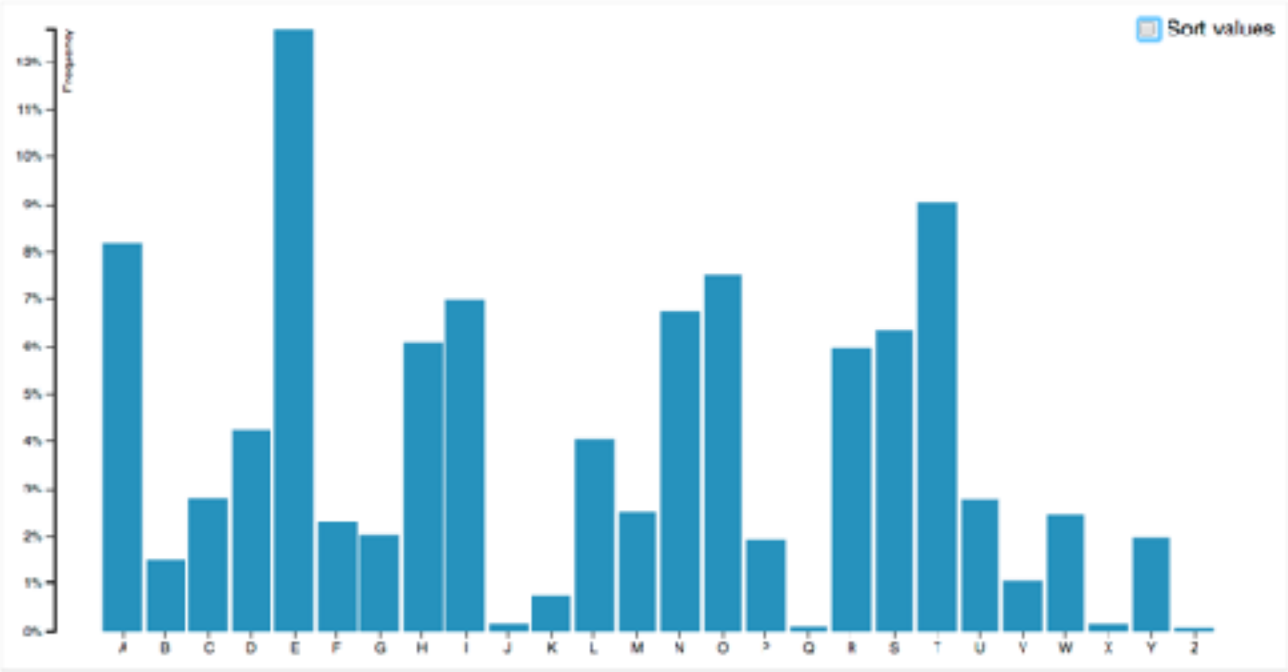
- widgets and controls
  - sliders, buttons, radio buttons, checkboxes, dropdowns/comboboxes
- pros
  - clear affordances, self-documenting (with labels)
- cons
  - uses screen space
- design choices
  - separated vs interleaved
    - controls & canvas

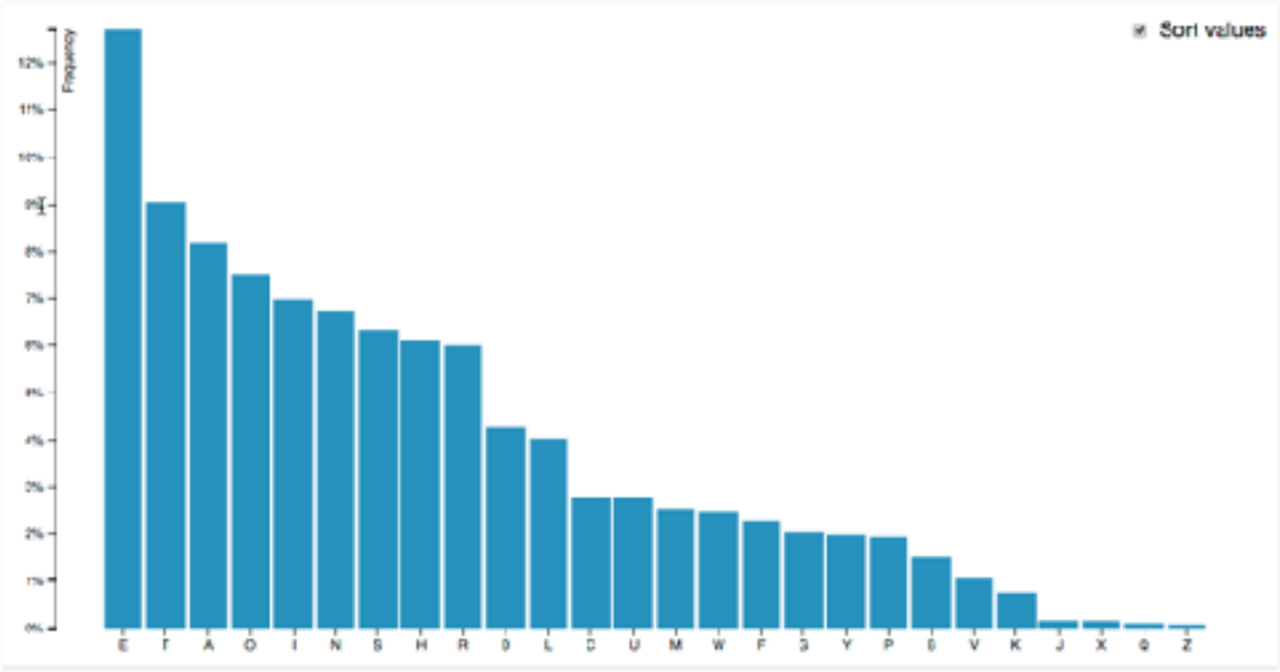


[Growth of a Nation](http://laurenwood.github.io/)
made with D3

Idiom: **Change order/arrangement**

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





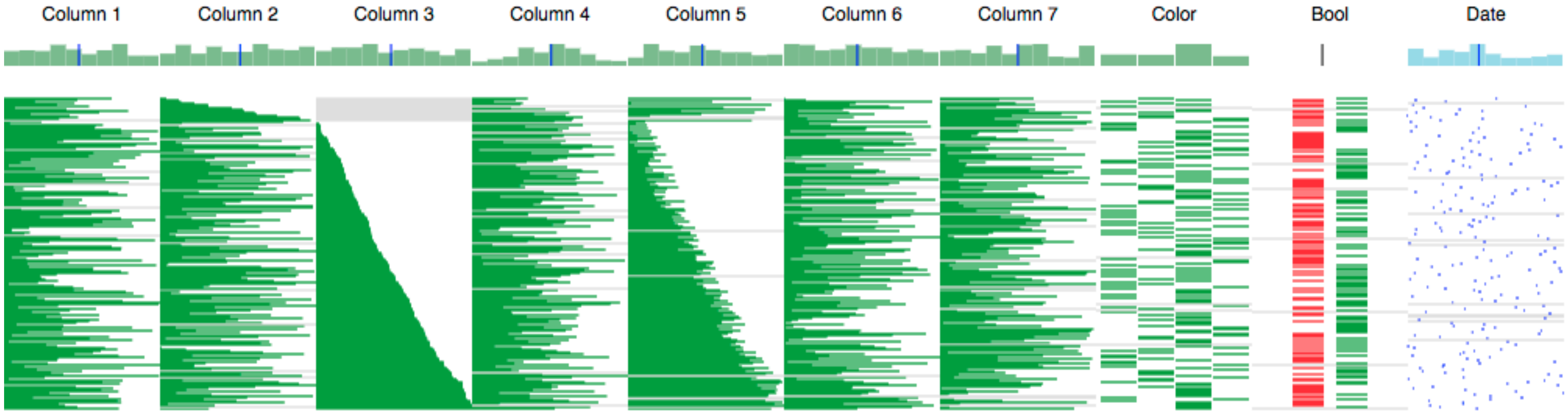
[Sortable Bar Chart] https://observablehq.com/@d3/sortable-bar-chart

made with D3

Idiom: **Reorder**

System: **DataStripes**

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

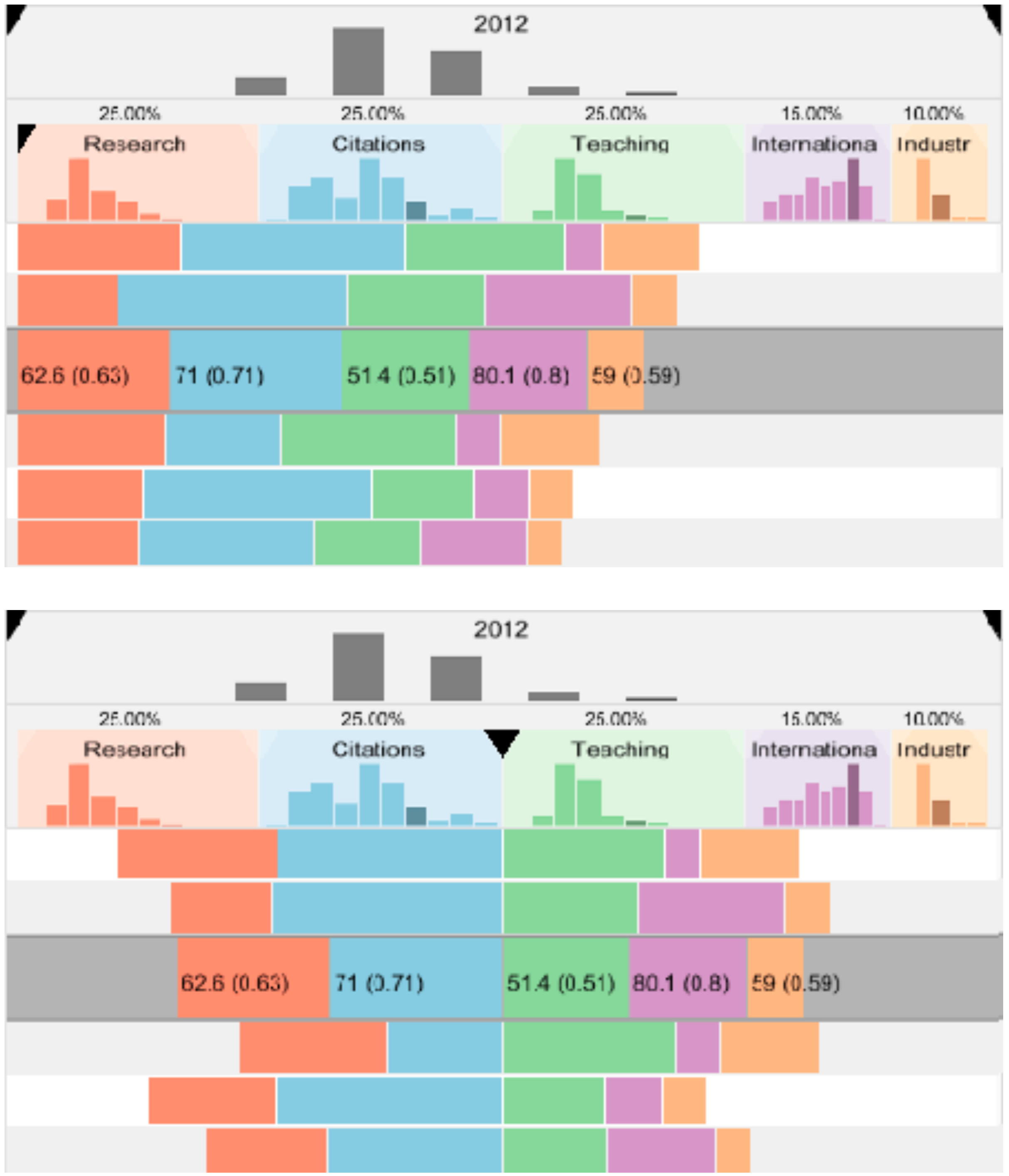


[http://carlmanaster.github.io/datastripes/]

made with D3

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

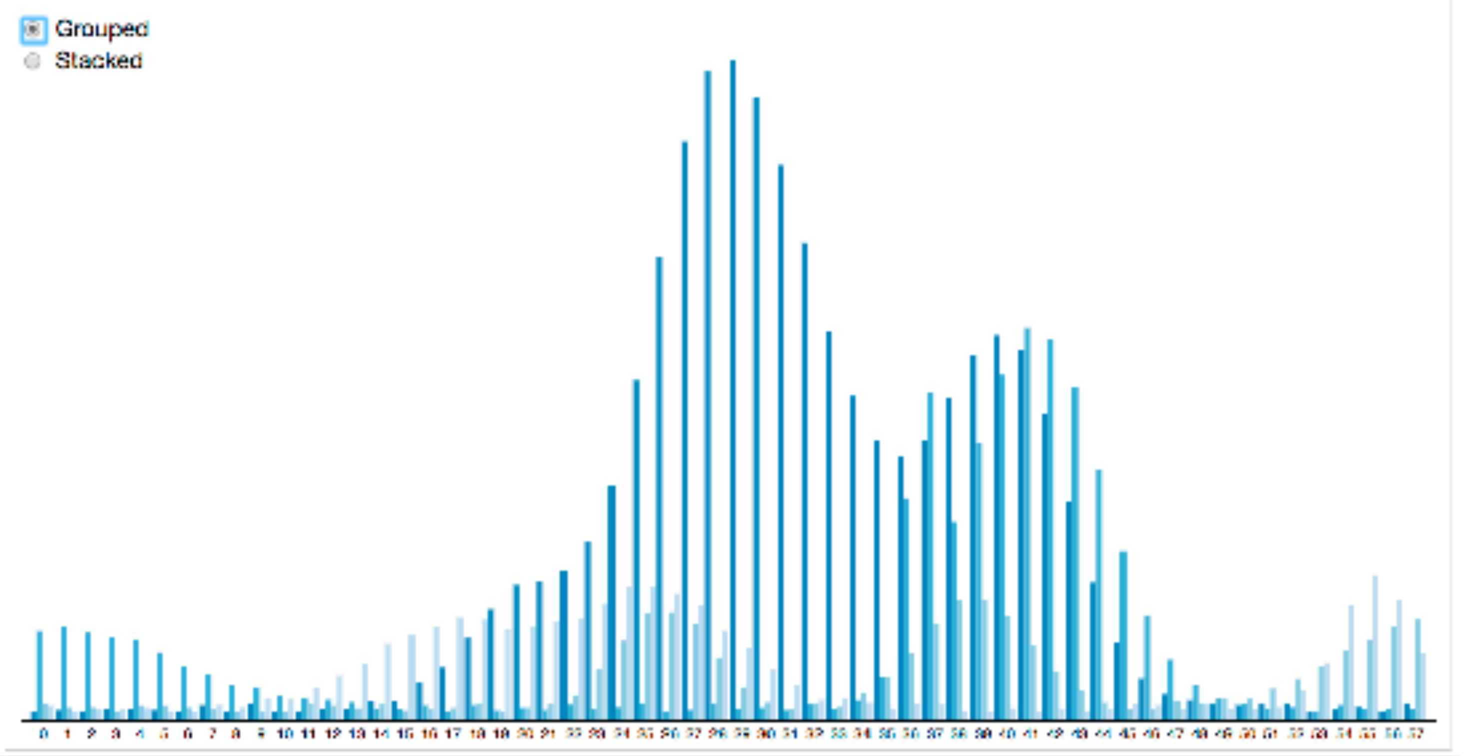
- stacked bars
  - easy to compare
    - first segment
    - total bar
- align to different segment
  - supports flexible comparison

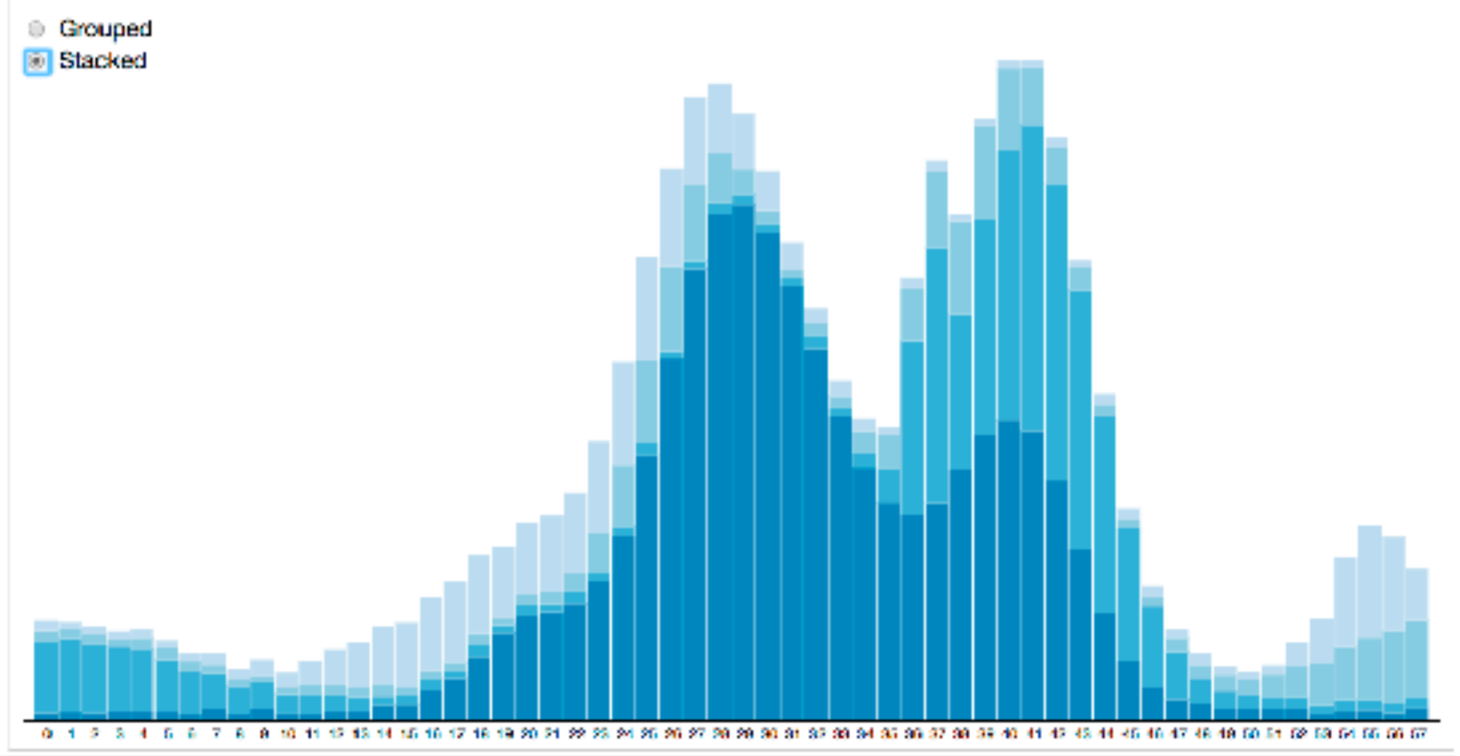


[LineUp: Visual Analysis of Multi-Attribute Rankings. Gratzl, Lex, Gehlenborg, Pfister, and Streit. IEEE Trans. Visualization and Computer Graphics (Proc. InfoVis 2013) 19:12 (2013), 2277–2286.]

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

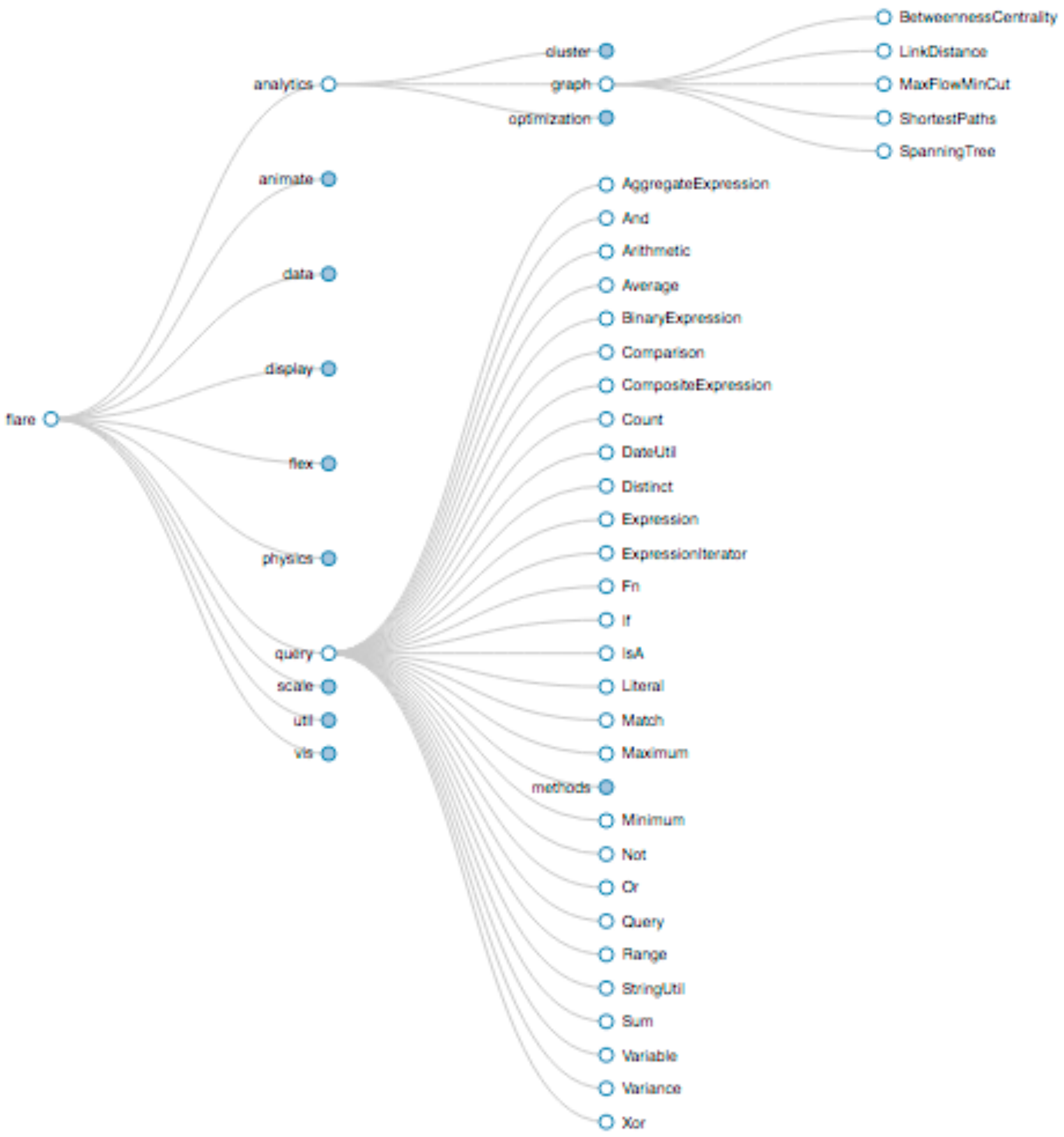




[Stacked to Grouped Bars] https://observablehq.com/@d3/stacked-to-grouped-bars

Idiom: **Animated transition - tree detail**

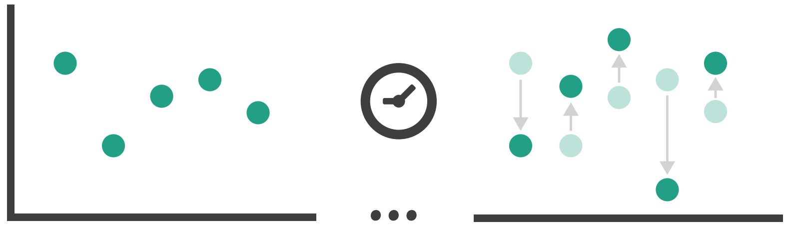
- animated transition
  - network drilldown/rollup



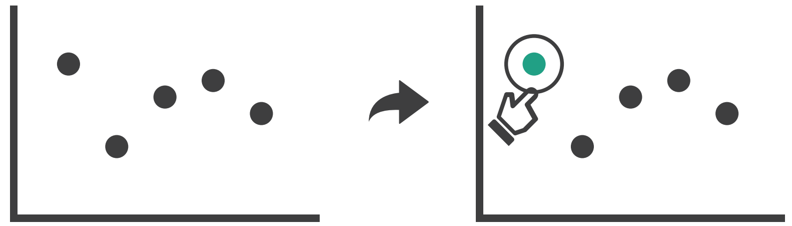
[Collapsible Tree] https://observablehq.com/@d3/collapsible-tree

Manipulate

➔ Change over Time

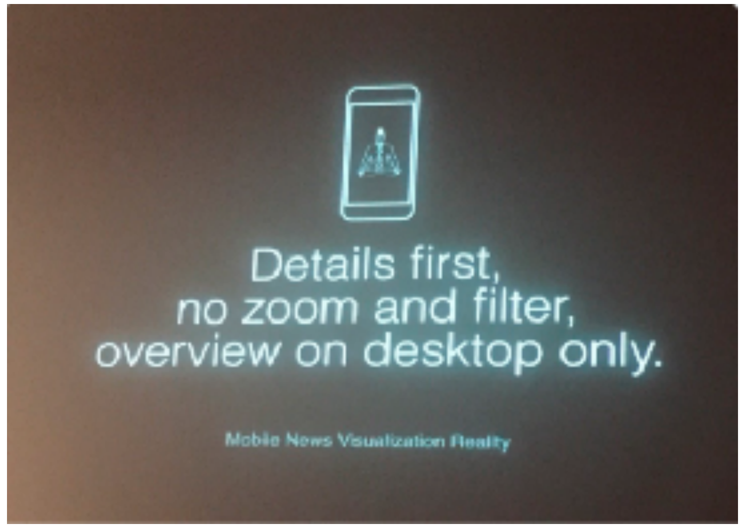


➔ Select



Interaction technology

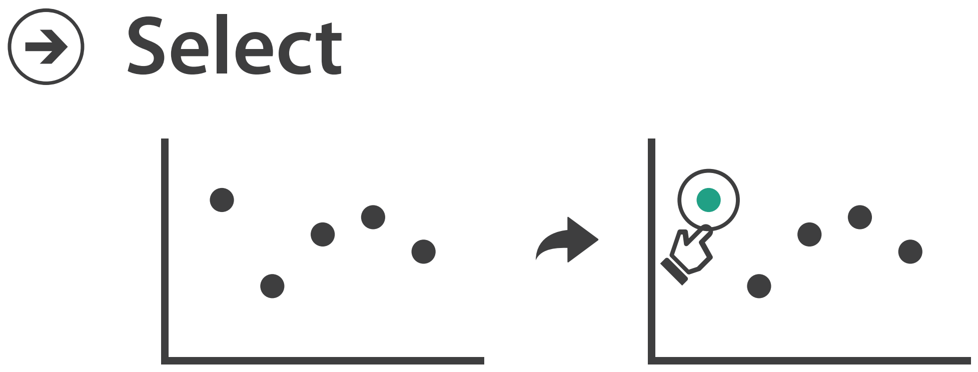
- what do you design for?
  - mouse & keyboard on desktop?
    - large screens, hover, multiple clicks
  - touch interaction on mobile?
    - small screens, no hover, just tap
  - gestures from video / sensors?
    - ergonomic reality vs movie bombast
  - eye tracking?



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

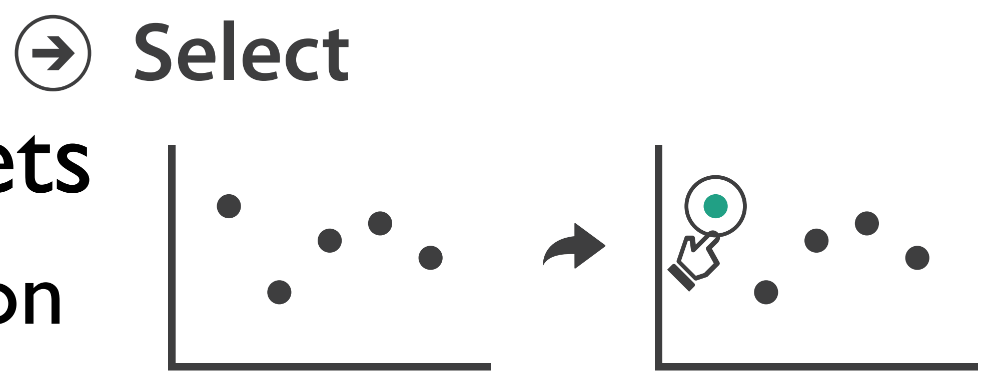
I Hate Tom Cruise - Alex Kauffmann (5 min)
www.youtube.com/watch?v=QXLfT9sFcbc

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, …)

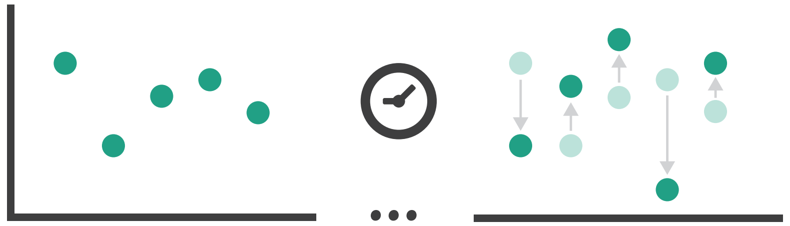
Highlighting



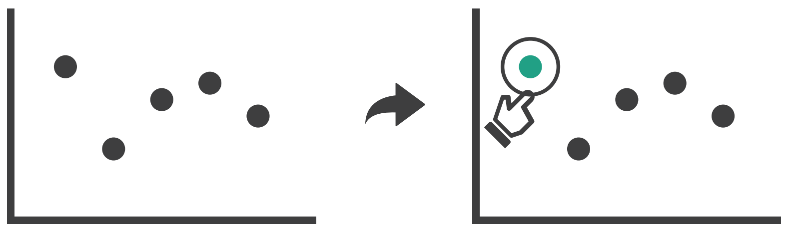
- highlight: change visual encoding for selection targets
  - visual feedback closely tied to but separable from selection (interaction)
- design choices: typical visual channels
  - change item color
    - but hides existing color coding
  - add outline mark
  - change size (ex: increase outline mark 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

➔ Change over Time



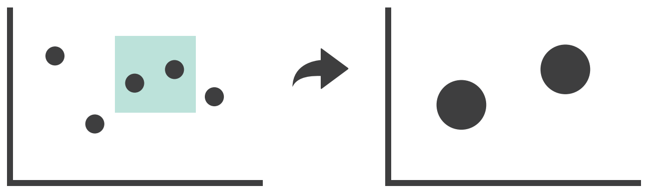
➔ Select



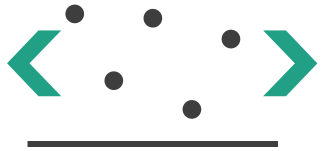
➔ Navigate

➔ Item Reduction

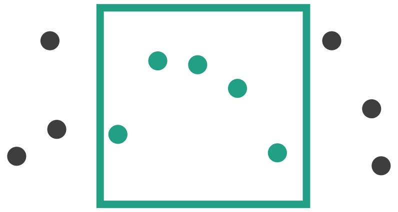
➔ *Zoom*
Geometric or *Semantic*



➔ *Pan/Translate*

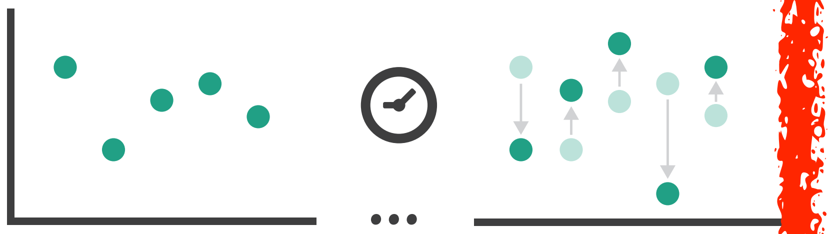


➔ *Constrained*

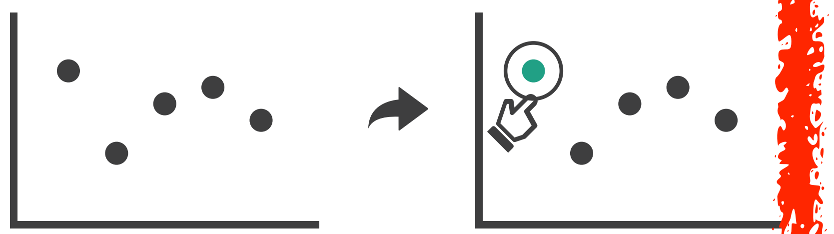


Manipulate

Change over Time

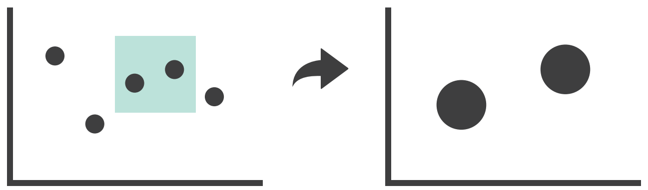


Select

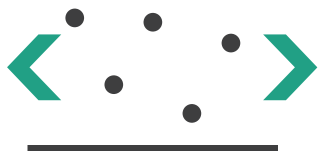


Navigate

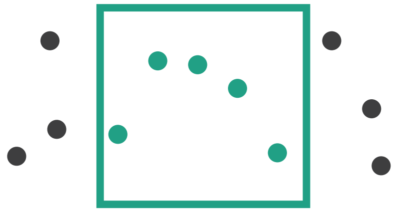
→ *Zoom*
Geometric



→ *Pan/Translate*



→ *Constrained*

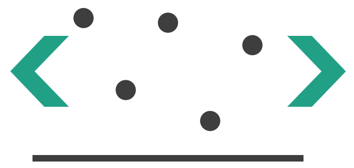


Navigate: Changing viewpoint/visibility

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

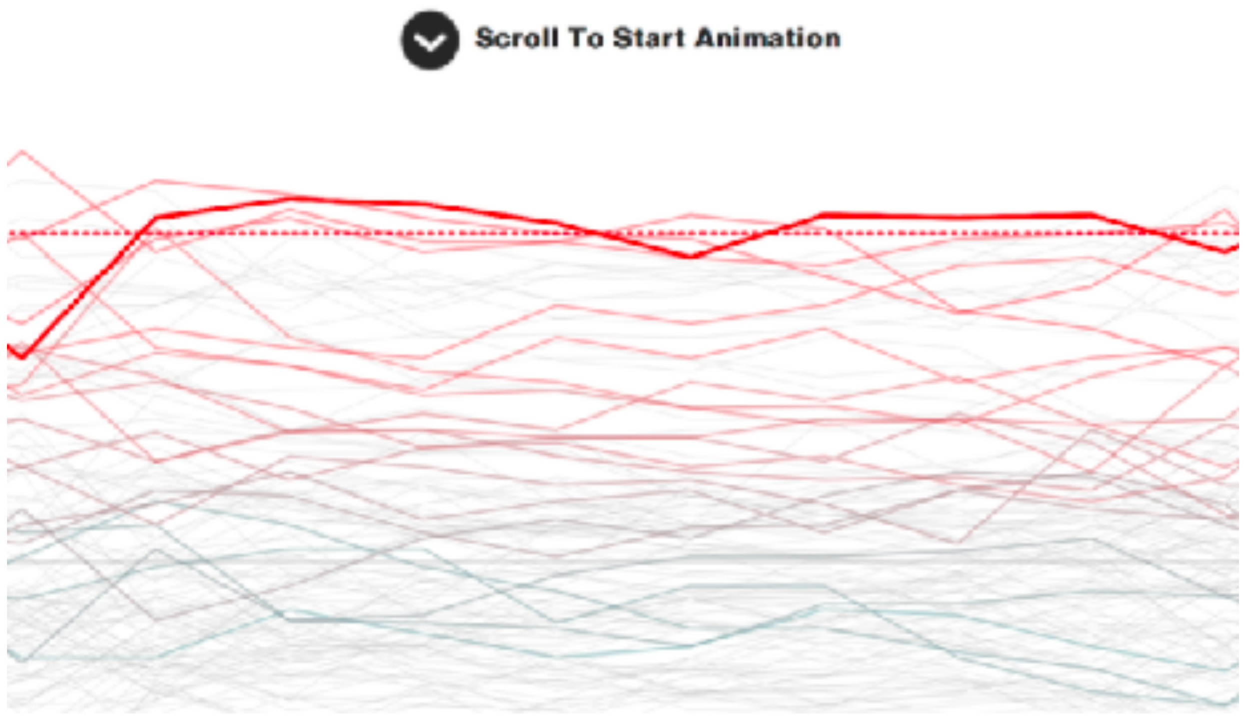
➔ **Navigate**

➔ *Pan/Translate*



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

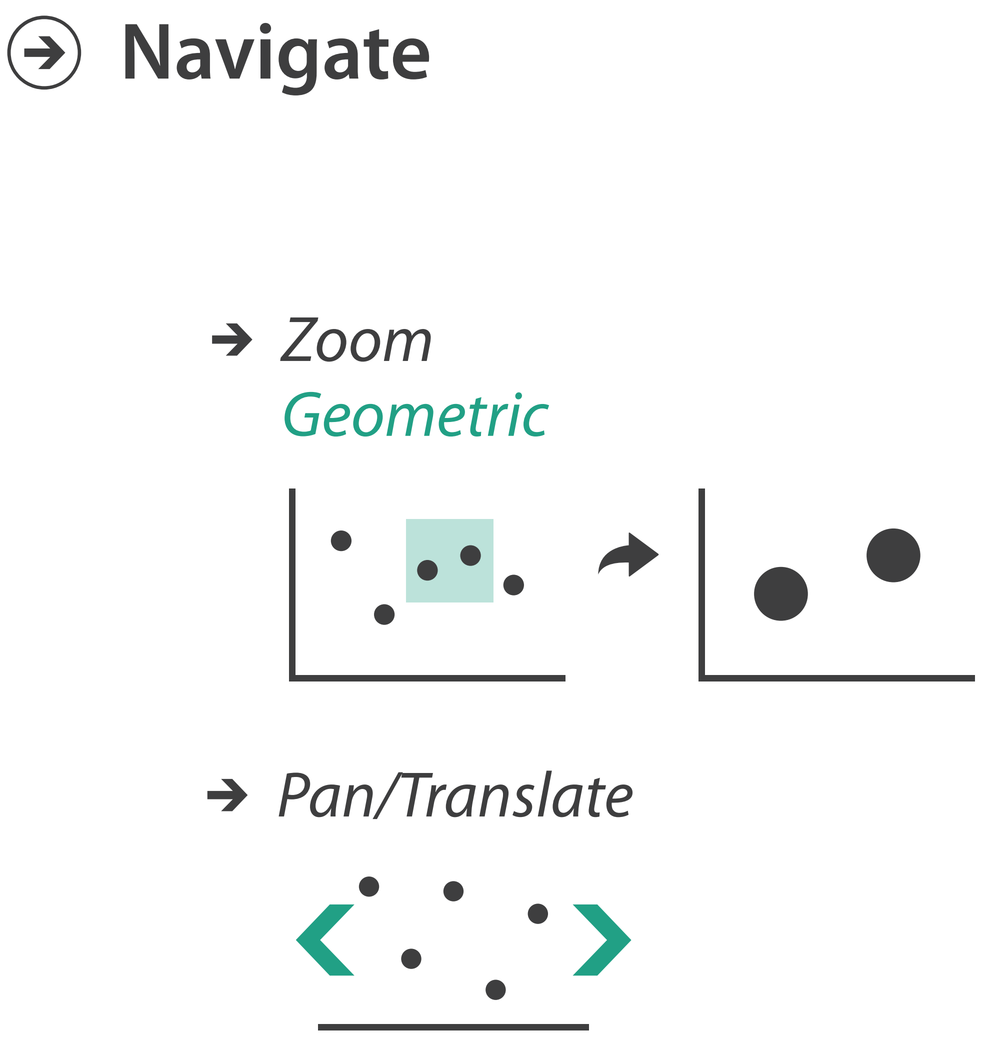


[How to Scroll, Bostock](https://bost.ocks.org/mike/scroll/)

https://eagereyes.org/blog/2016/the-scrollytelling-scourge

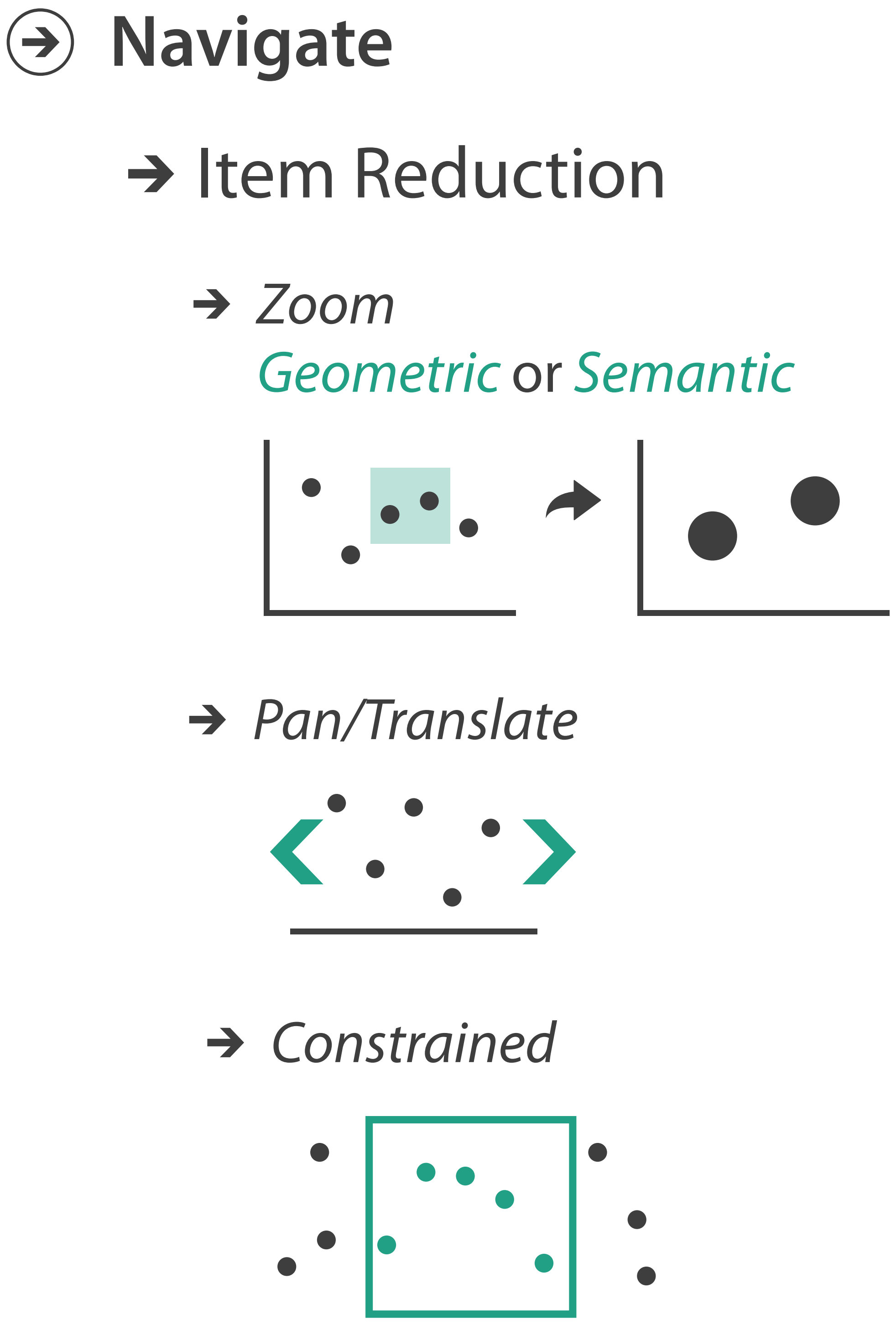
Navigate: Changing viewpoint/visibility

- 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



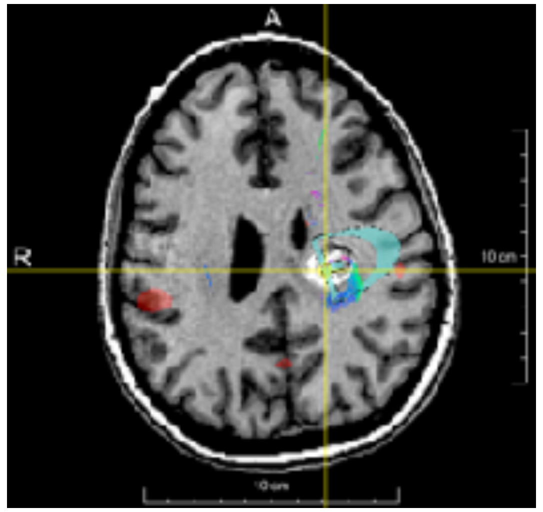
Idiom: **Animated transition + constrained navigation**

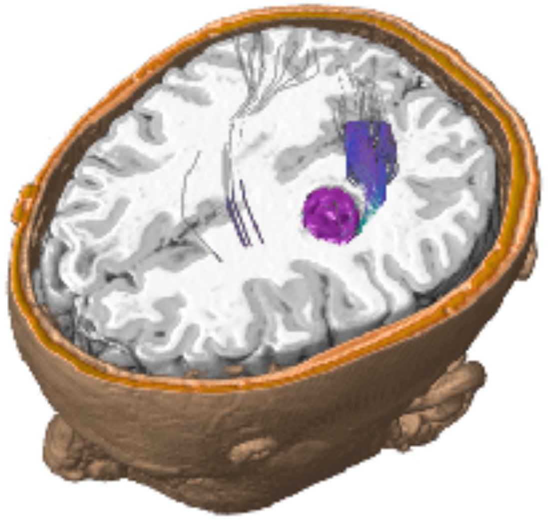
- example: geographic map
  - simple zoom, only viewport changes, shapes preserved

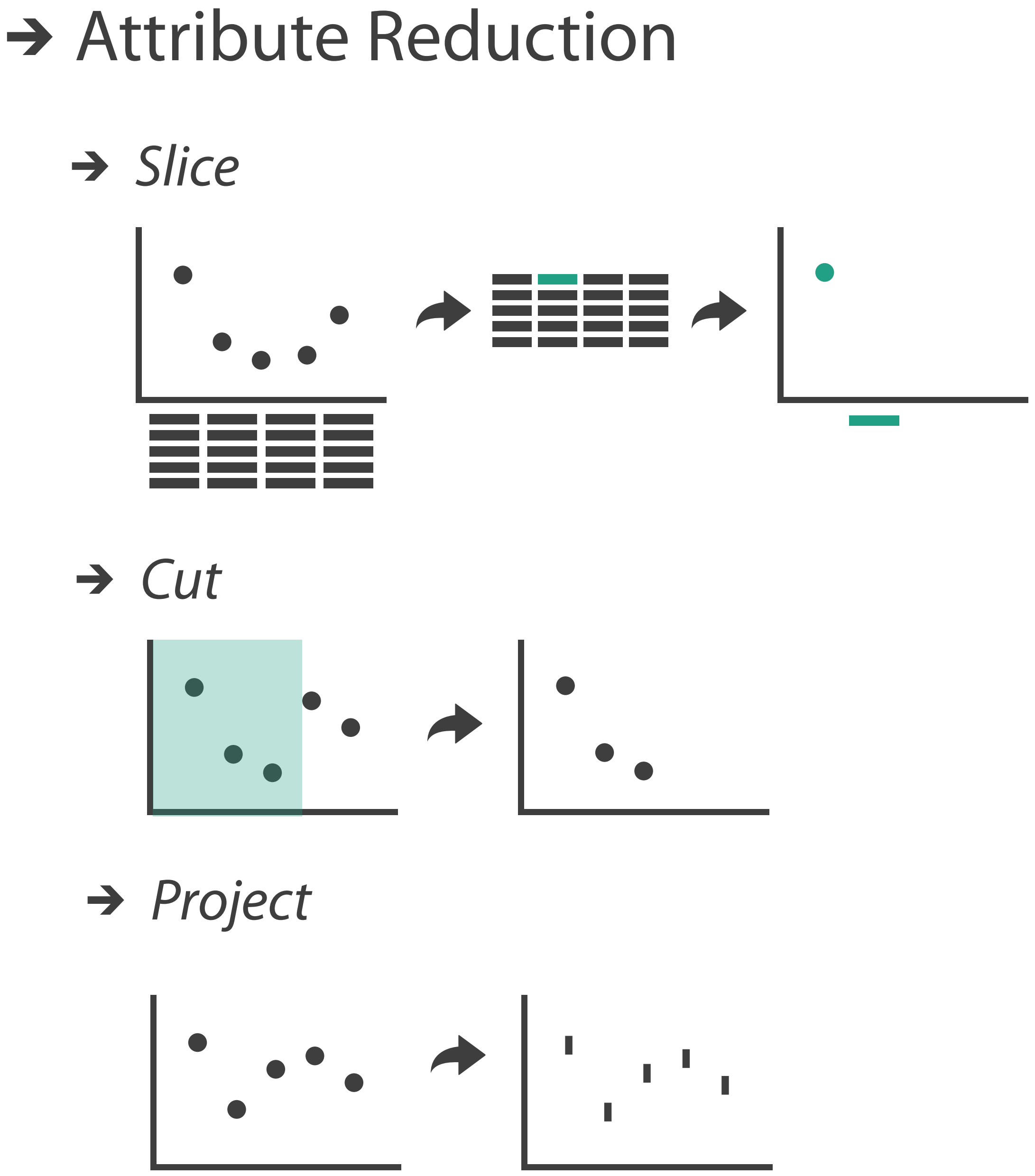
[Zoom to Bounding Box] https://observablehq.com/@d3/zoom-to-bounding-box

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, ...







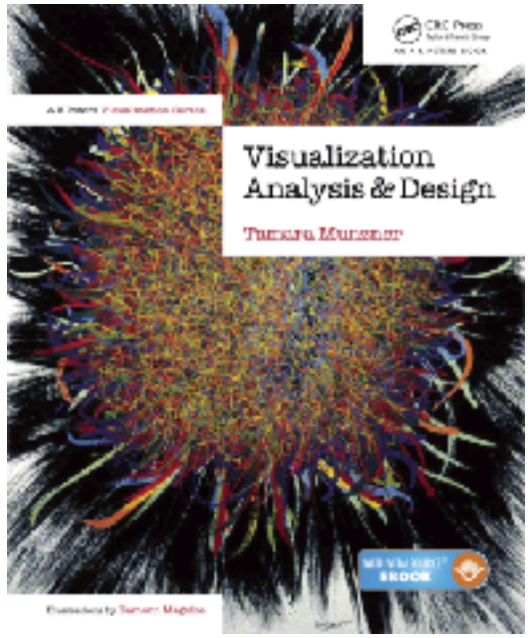
[Interactive Visualization of Multimodal Volume Data for Neurosurgical Tumor Treatment. Rieder, Ritter, Raspe, and Peitgen. Computer Graphics Forum (Proc. EuroVis 2008) 27:3 (2008), 1055–1062.]

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



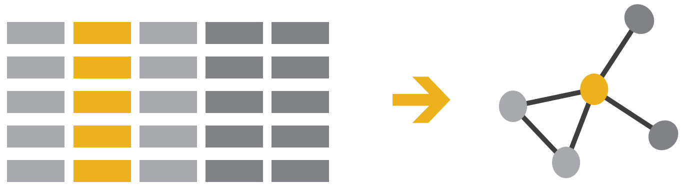
Visualization Analysis & Design

Interactive Views (Ch 11/12) II

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

How to handle complexity: 1 previous strategy + 2 more

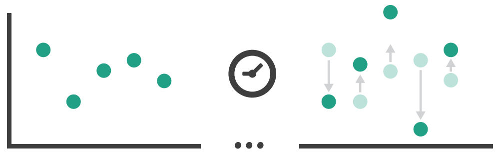
→ *Derive*



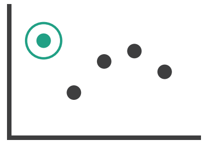
- derive new data to show within view
- change view over time
- facet across multiple views

Manipulate

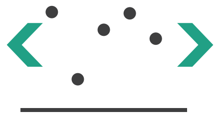
Change



Select

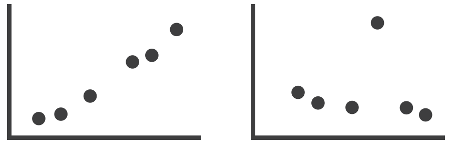


Navigate

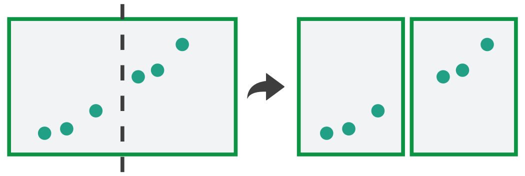


Facet

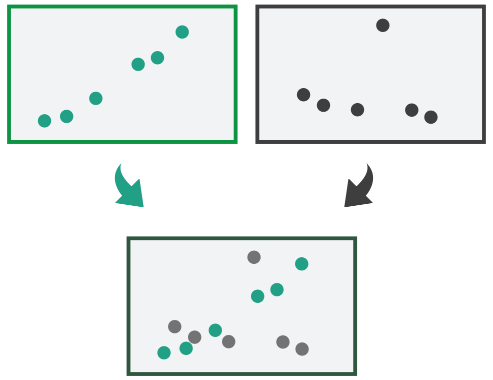
Juxtapose



Partition



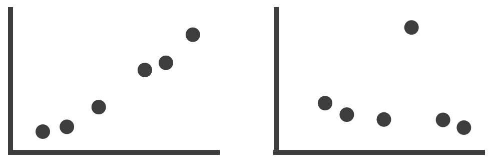
Superimpose



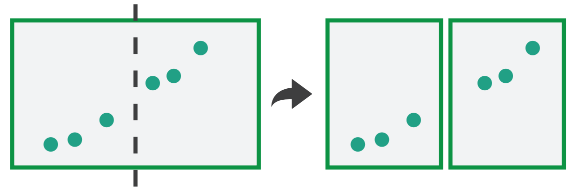
Multiple Views

Facet

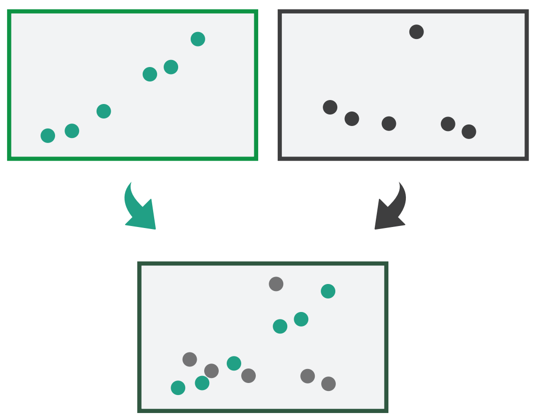
- Juxtapose



- Partition

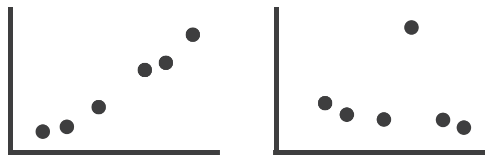


- Superimpose

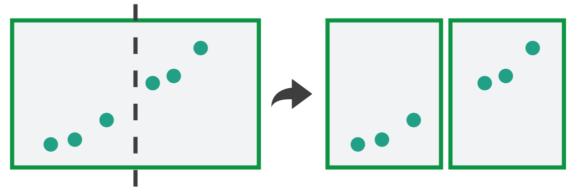


Facet

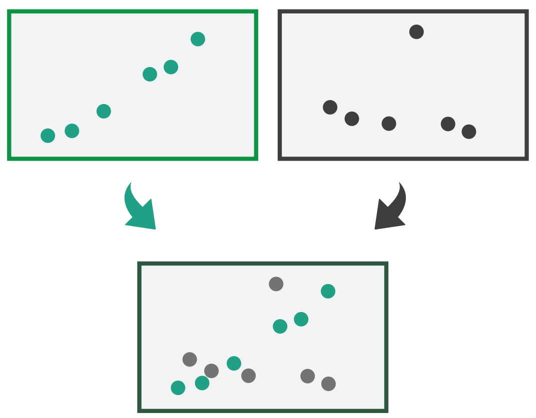
Juxtapose



Partition



Superimpose

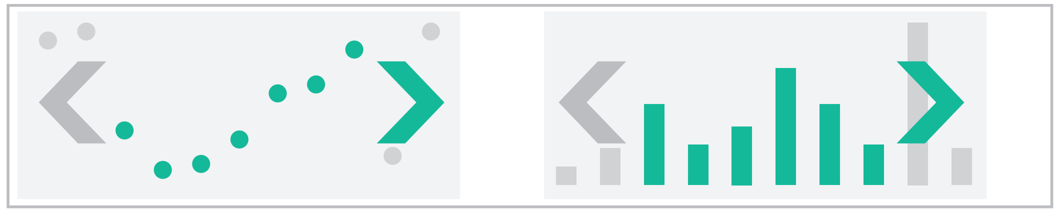


Juxtapose and coordinate views

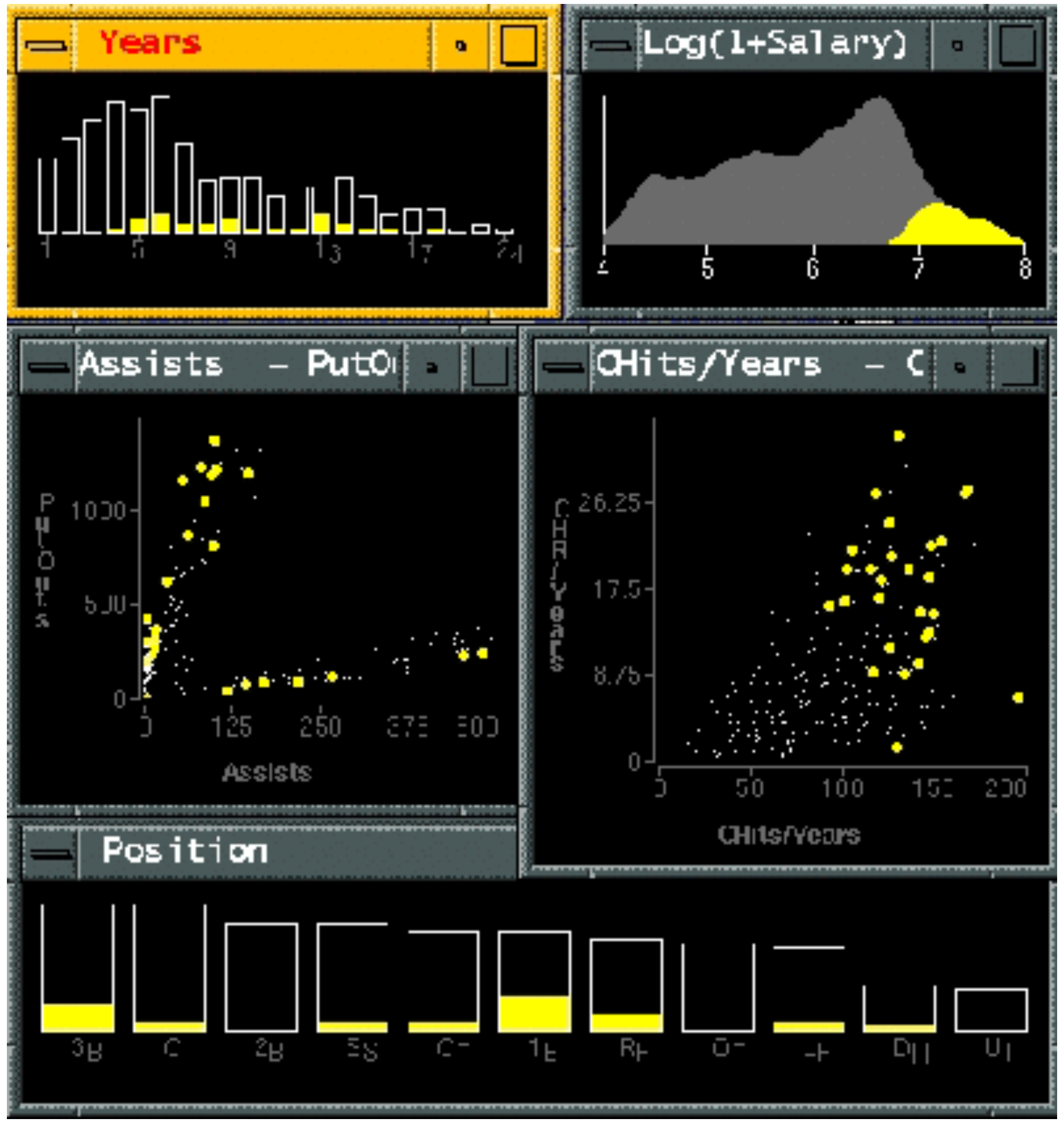
- Share Encoding: Same/Different
  - *Linked Highlighting*

- Share Data: All/Subset/None

- Share Navigation



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

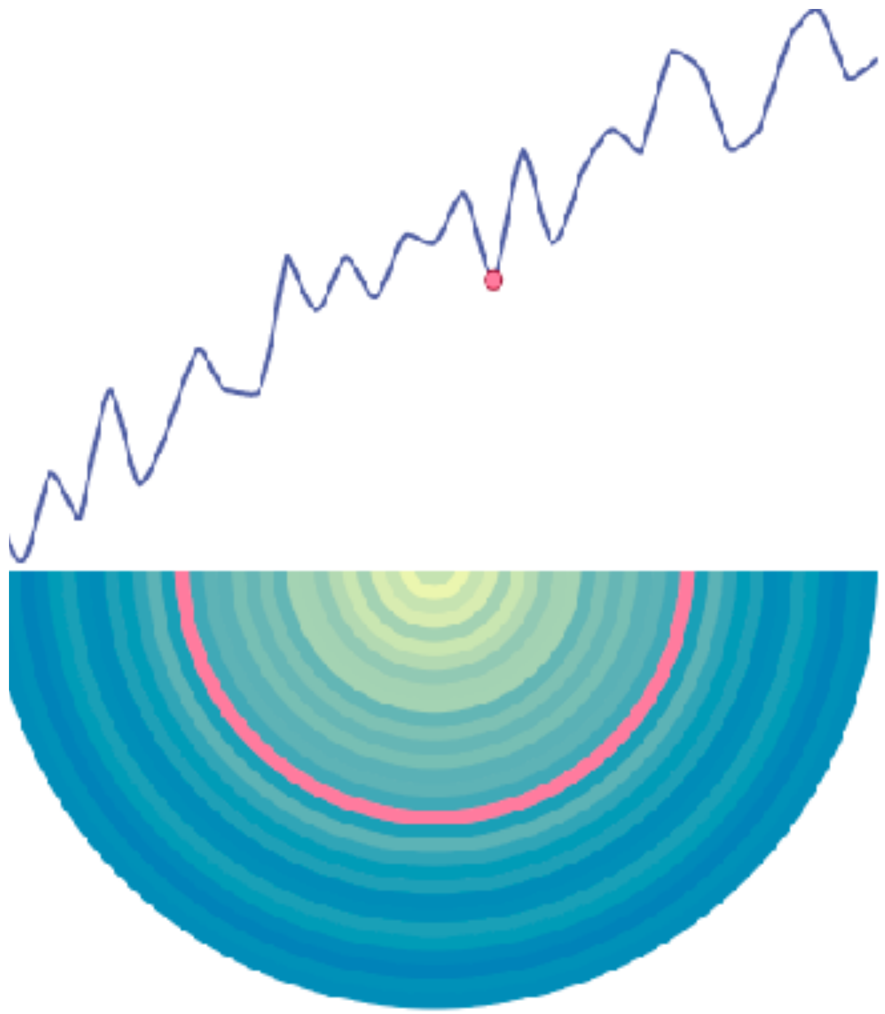


- see how regions contiguous in one view are distributed within another
  - powerful and pervasive interaction idiom
- encoding: different
  - *multiform*
- data: all shared
  - all **items** shared
  - different **attributes** across the views
- aka: brushing and linking

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

Linked views: 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**

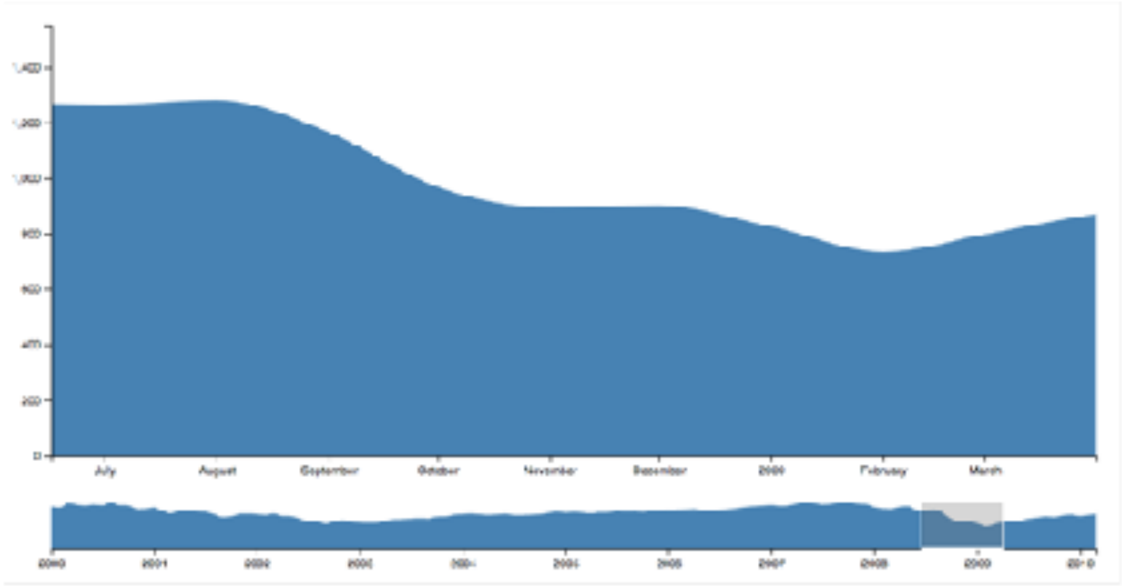
System: **Google Maps**

- 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

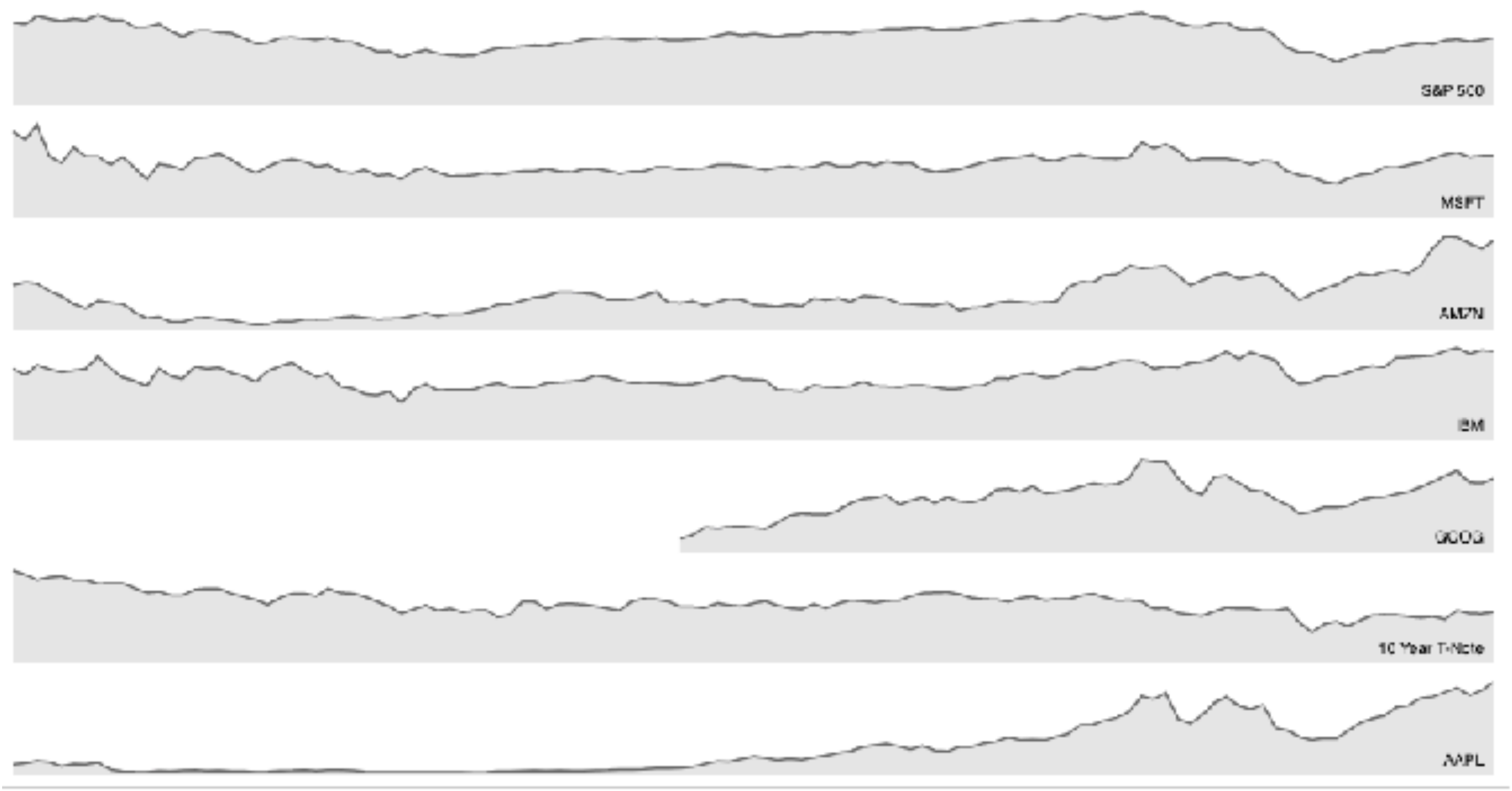
Idiom: **Tooltips**

- 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**

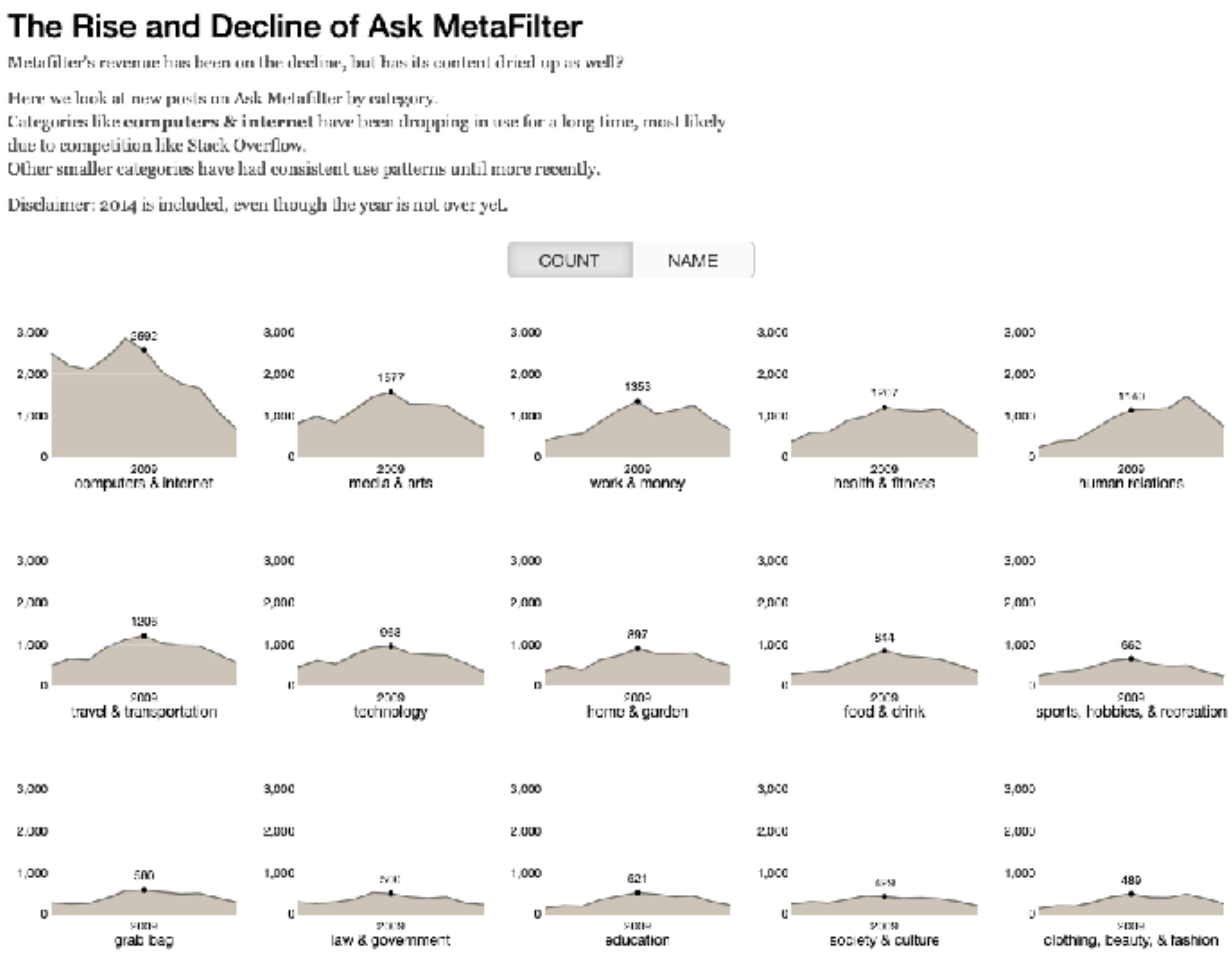
- encoding: same
  - ex: line charts
- data: none shared
  - different slices of dataset
    - items or attributes
    - ex: stock prices for different companies



[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



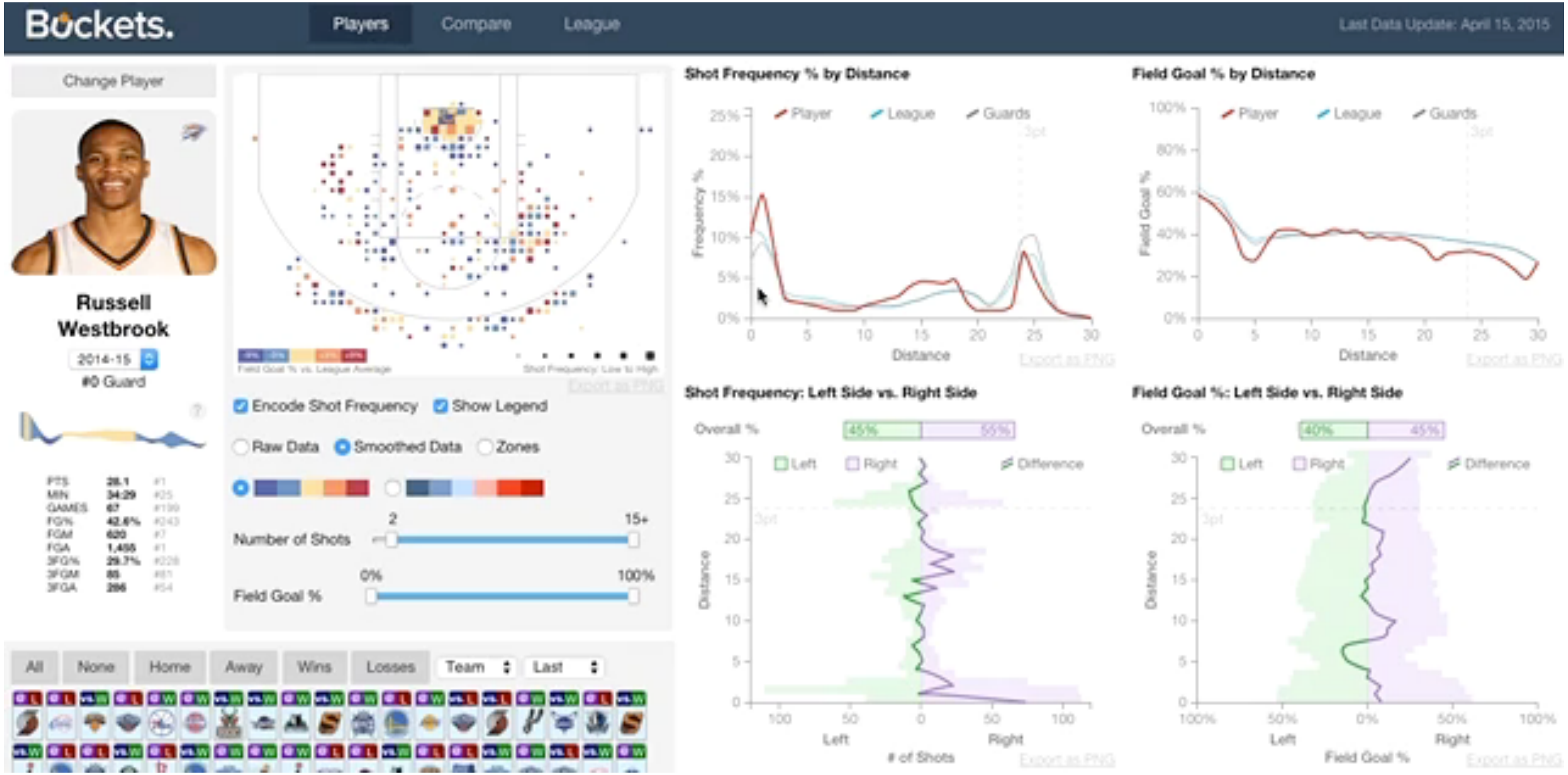
[https://bl.ocks.org/ColinEberhardt/3c780088c363d1515403f50a87a87121]

[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

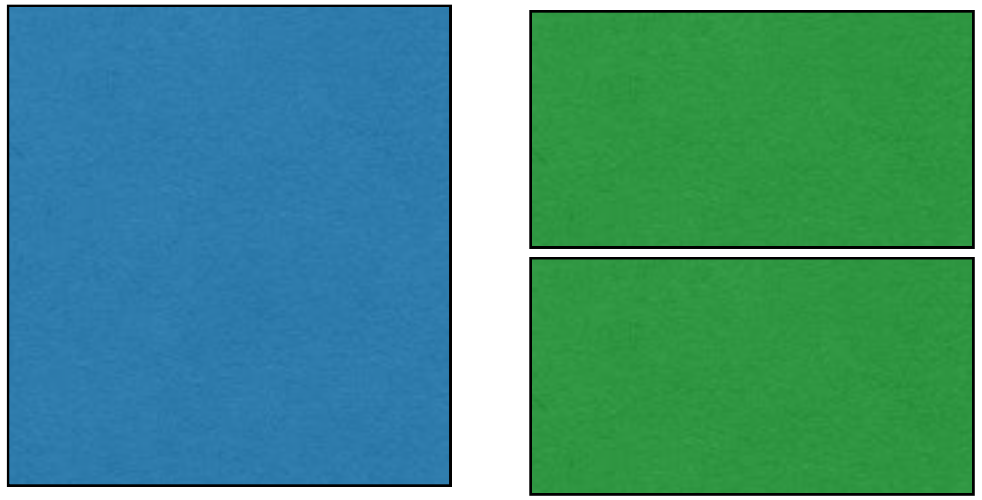
System: **Buckets**



- multiform
- multidirectional linked highlighting of small multiples
- tooltips

http://buckets.peterbeshai.com/

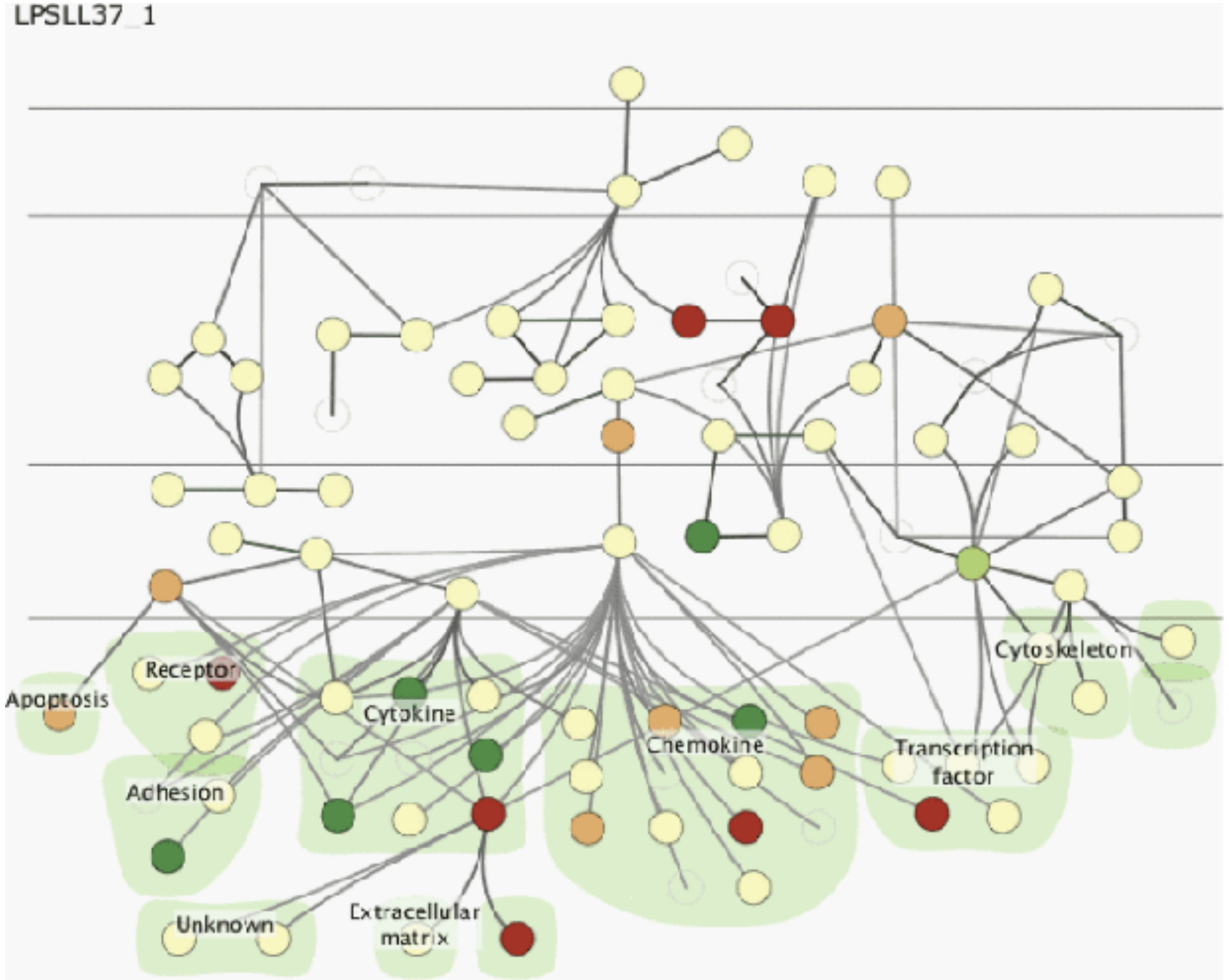
Juxtapose views: tradeoffs



- 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

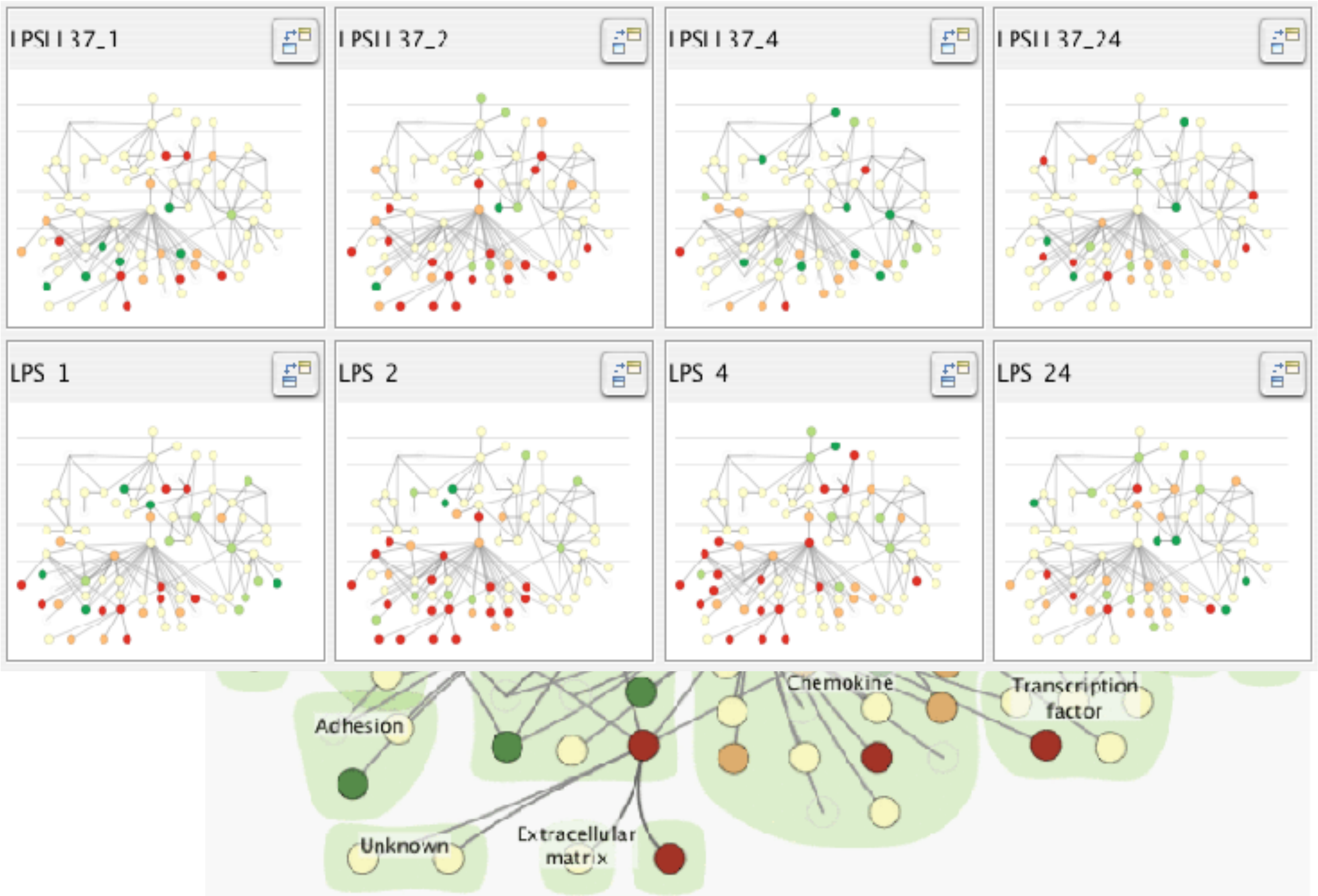
- animate: hard to follow if many scattered changes or many frames
  - vs easy special case: animated transitions



[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.]

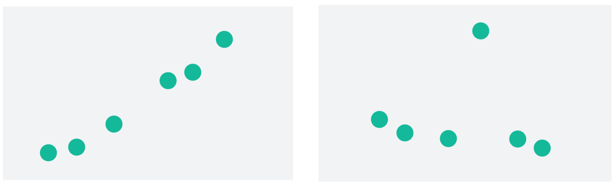
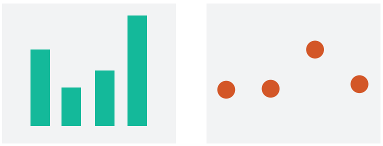
Juxtapose vs animate

- 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.]

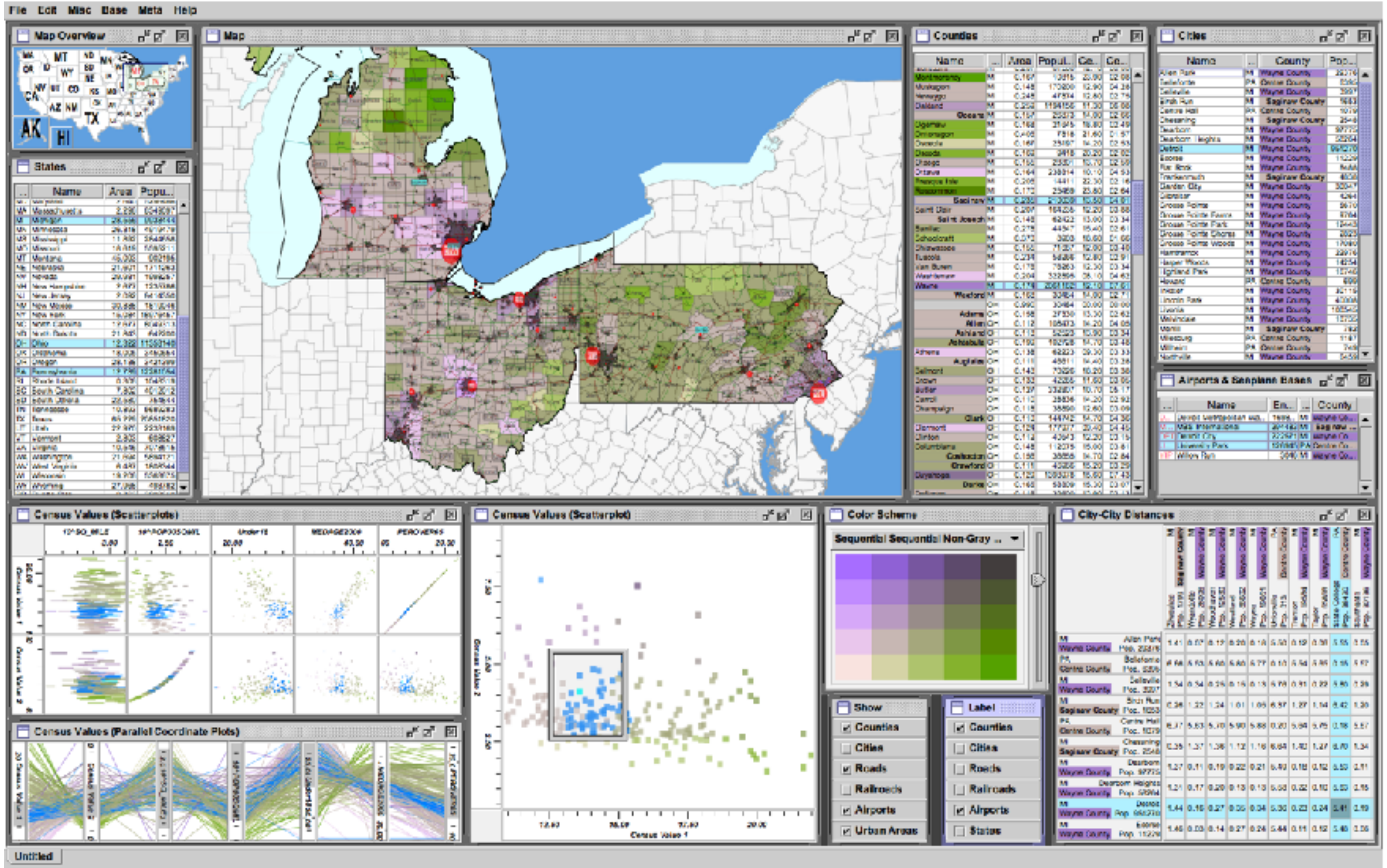
View coordination: Design choices

		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

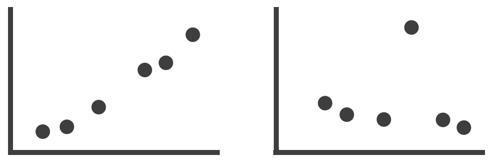
- how many views is ok vs too complex?
  - open research question



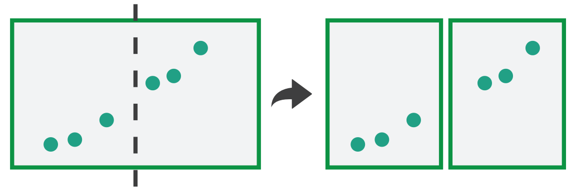
[Building Highly-Coordinated Visualizations In Improvise. Weaver. Proc. IEEE Symp. Information Visualization (InfoVis), pp. 159–166, 2004.]

Facet

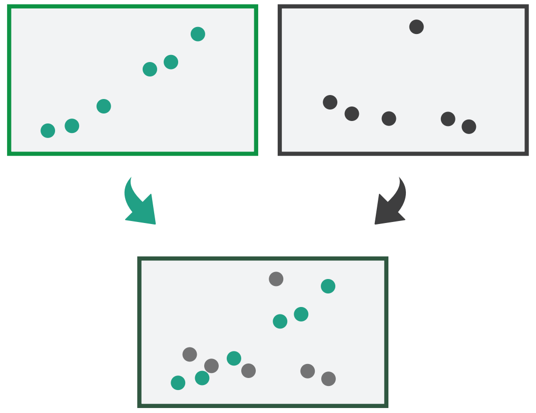
Juxtapose



Partition



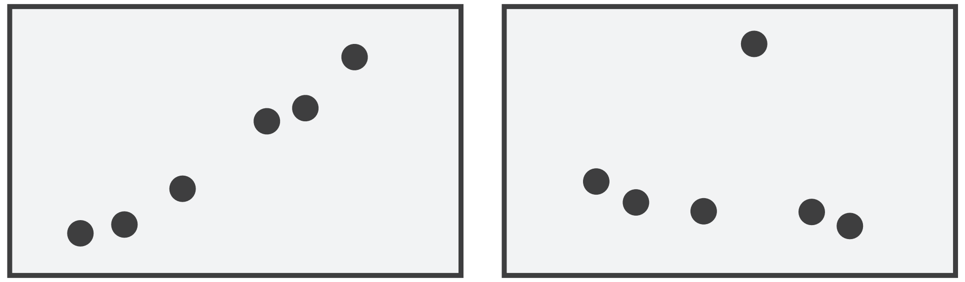
Superimpose



Partition into views

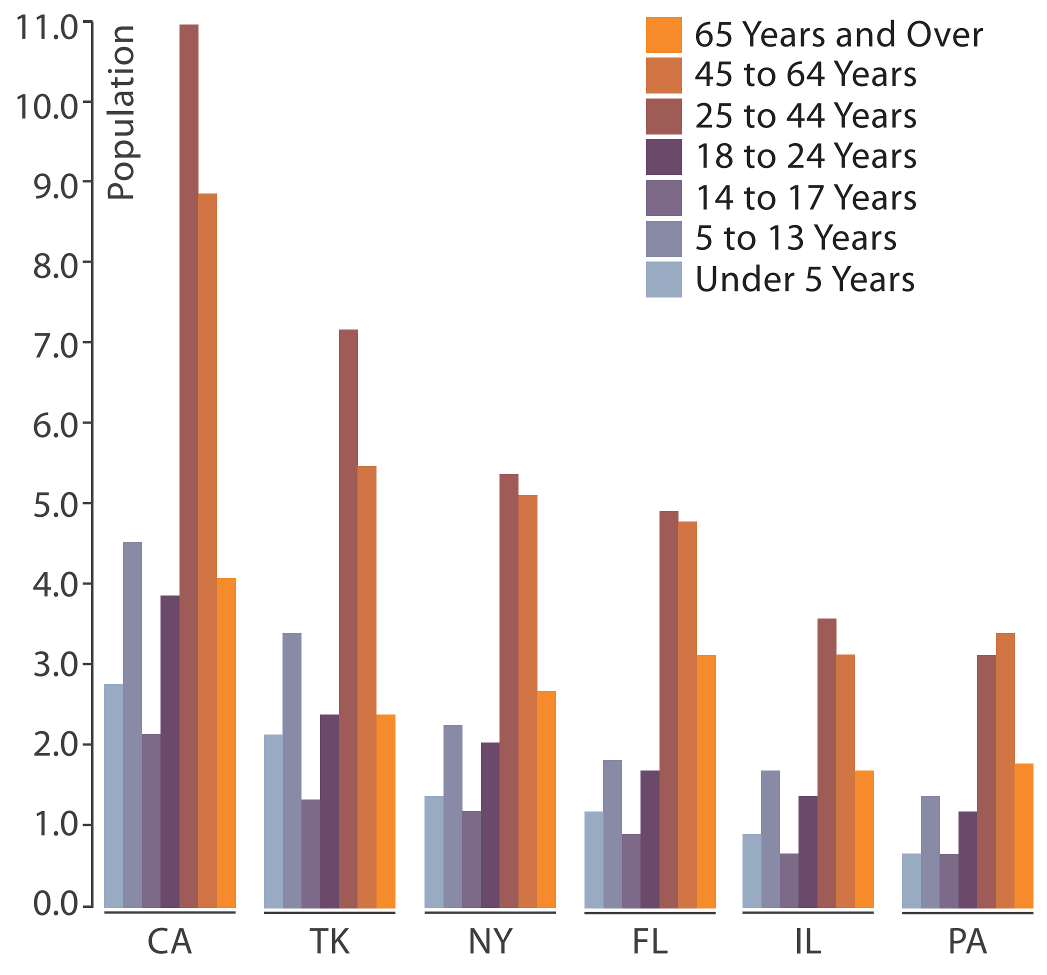
- how to divide data between views
  - split into regions by attributes
  - encodes association between items using spatial proximity
  - order of splits has major implications for what patterns are visible

➔ Partition into Side-by-Side Views



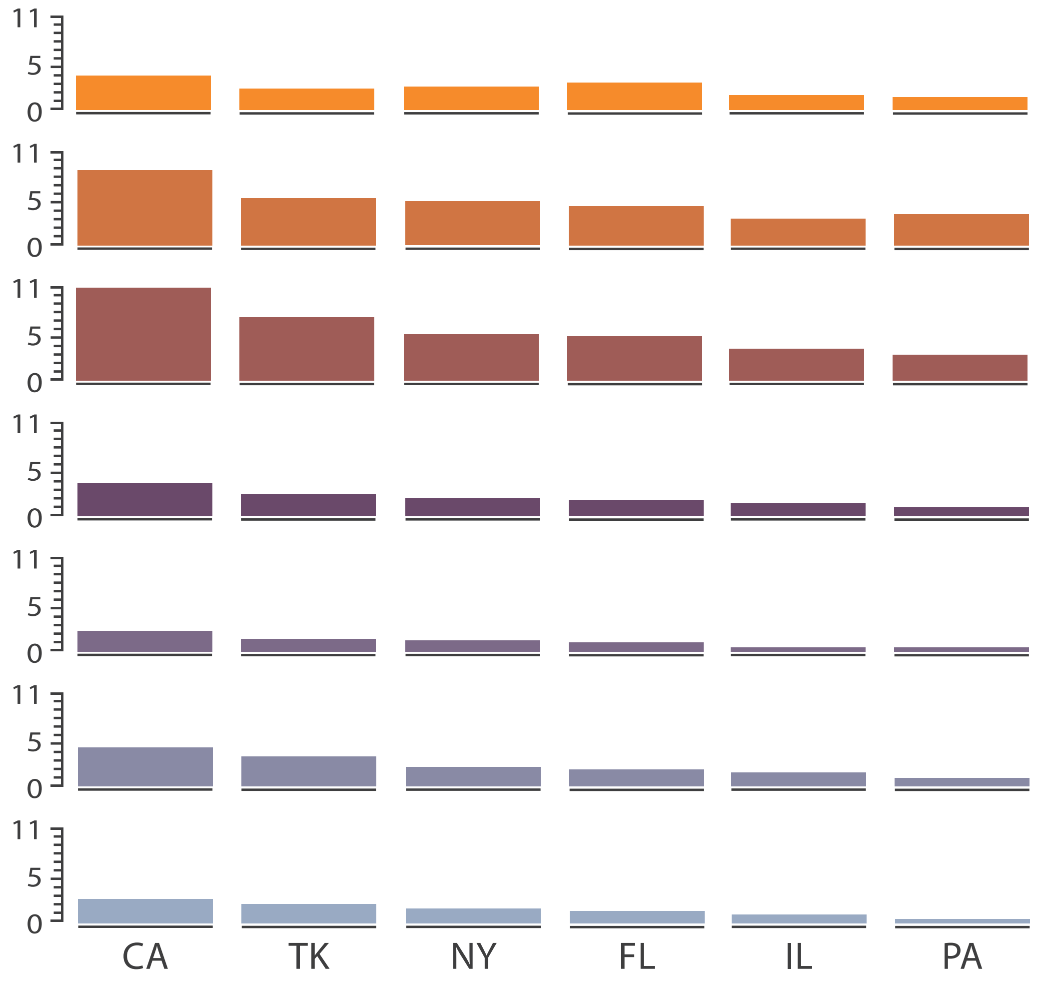
Partitioning: Grouped vs small-multiple bars

- 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



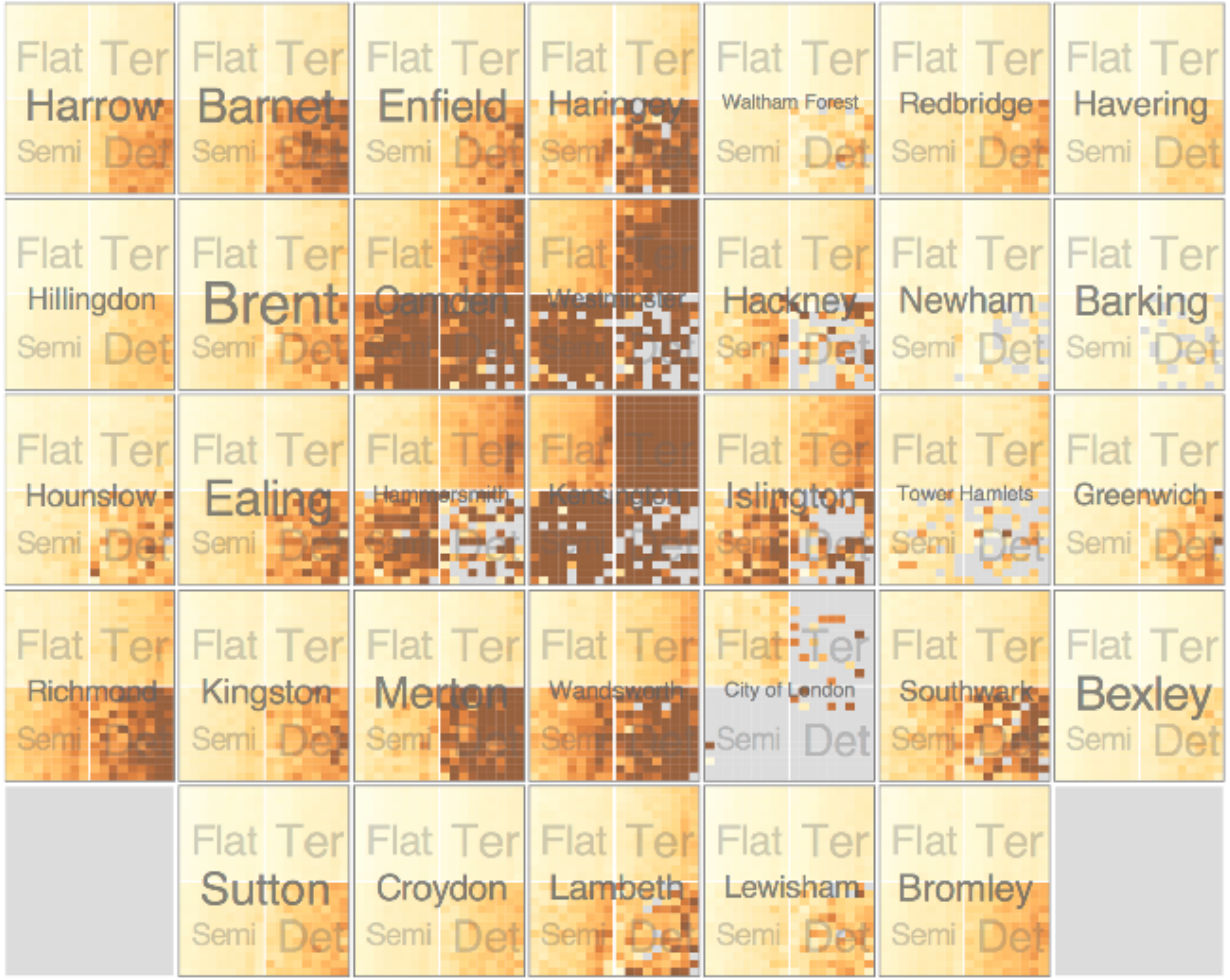
[https://bl.ocks.org/mbostock/4679202]

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

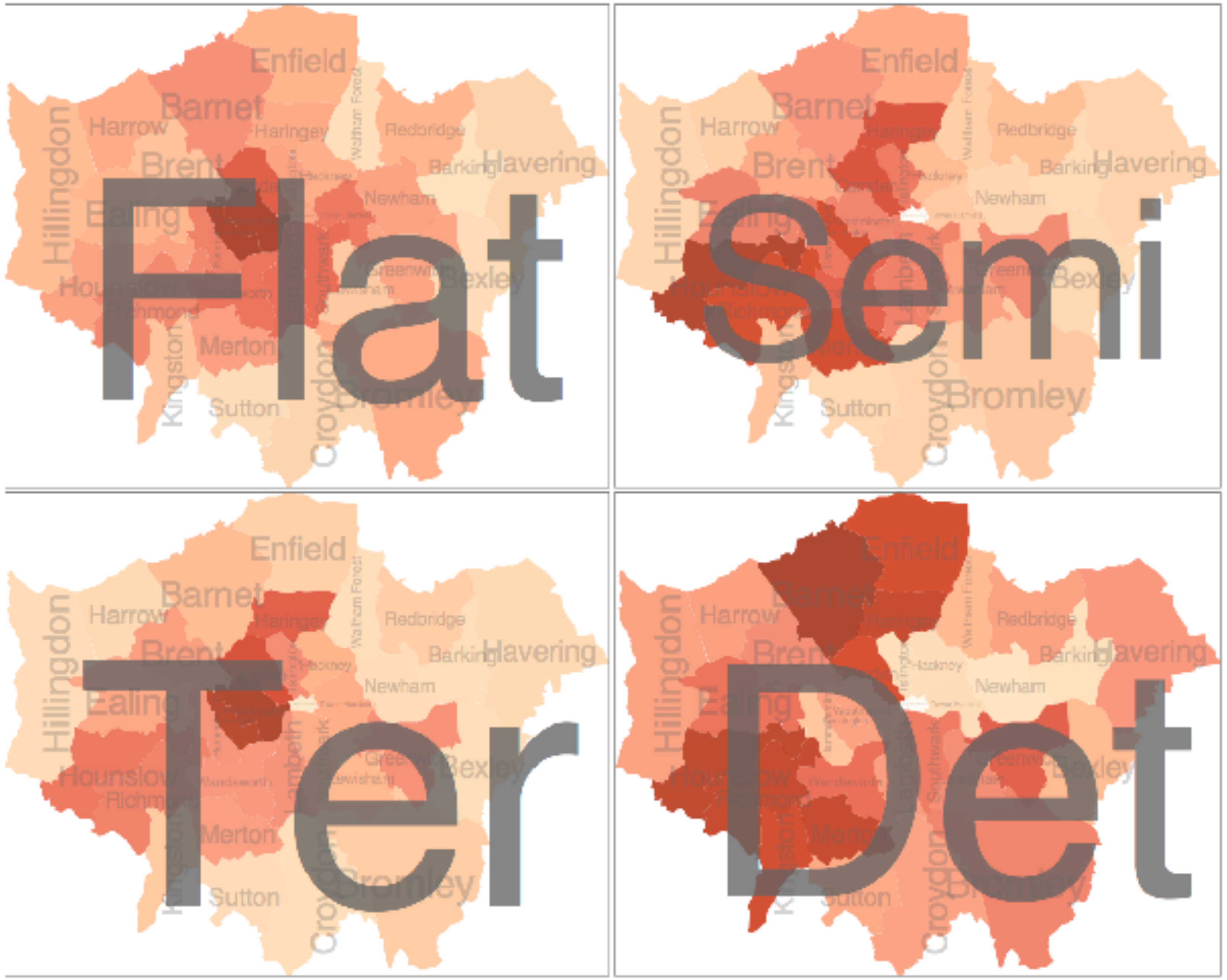
- type patterns
  - within specific type, which neighborhoods inconsistent

[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**

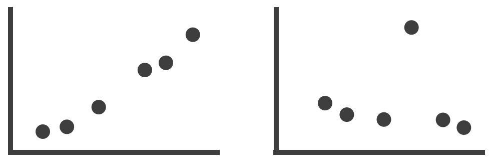
- different encoding for second-level regions
  - choropleth maps



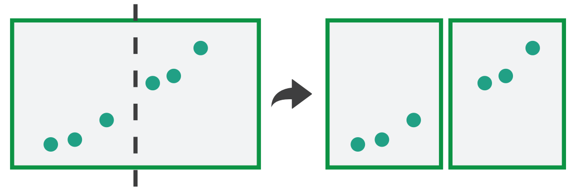
[Configuring Hierarchical Layouts to Address Research Questions. Slingsby, Dykes, and Wood. IEEE Transactions on Visualization and Computer Graphics (Proc. InfoVis 2009) 15:6 (2009), 977–984.]

Facet

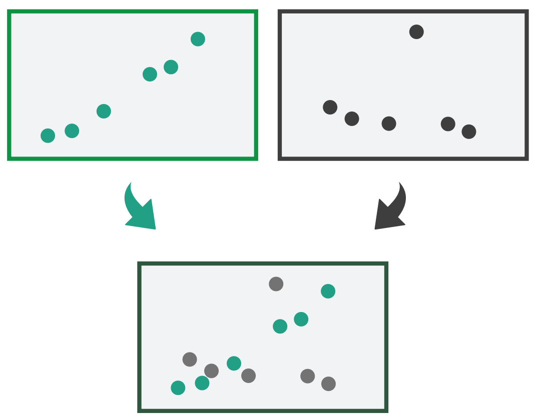
- Juxtapose



- Partition

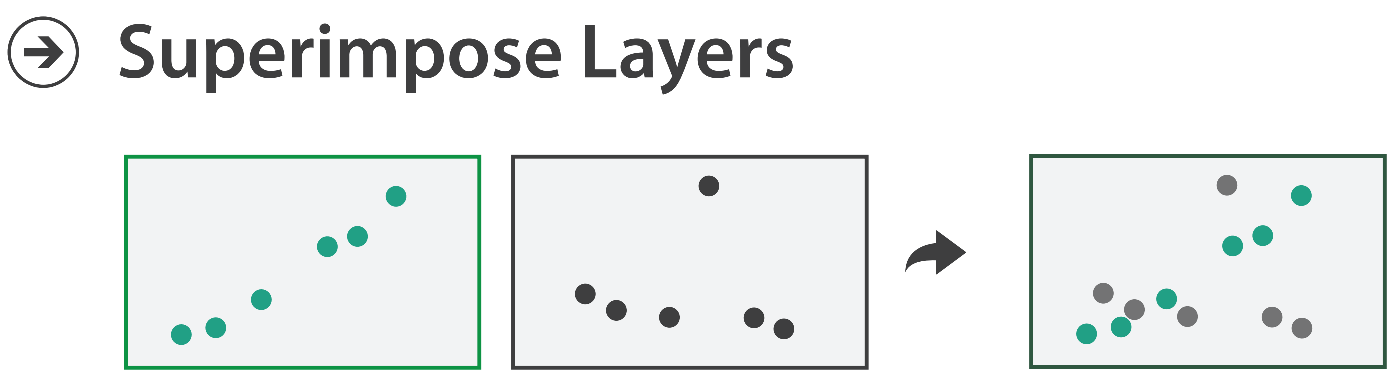


- Superimpose



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?



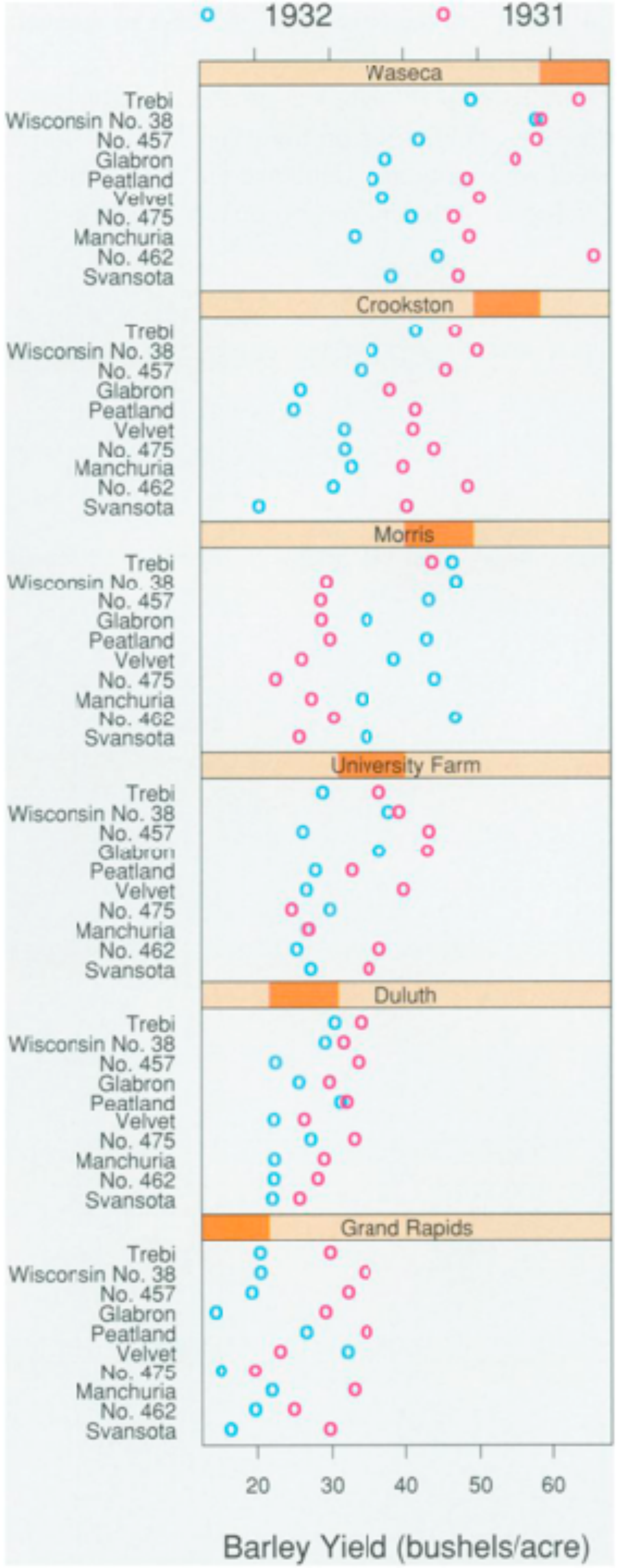
Static visual layering

- 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**

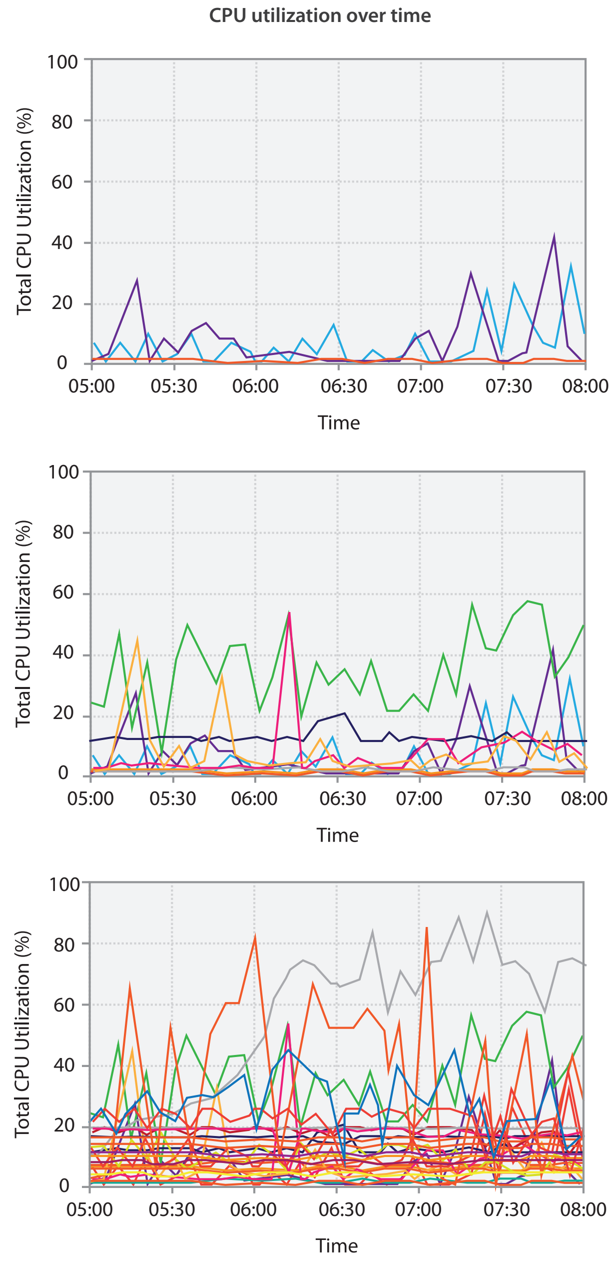
- superimpose within same frame
  - color code by year
- partitioning
  - split by site, rows are barley varieties
- main-effects ordering
  - derive value of median for group
  - order rows within view by variety median
  - order views themselves by site median

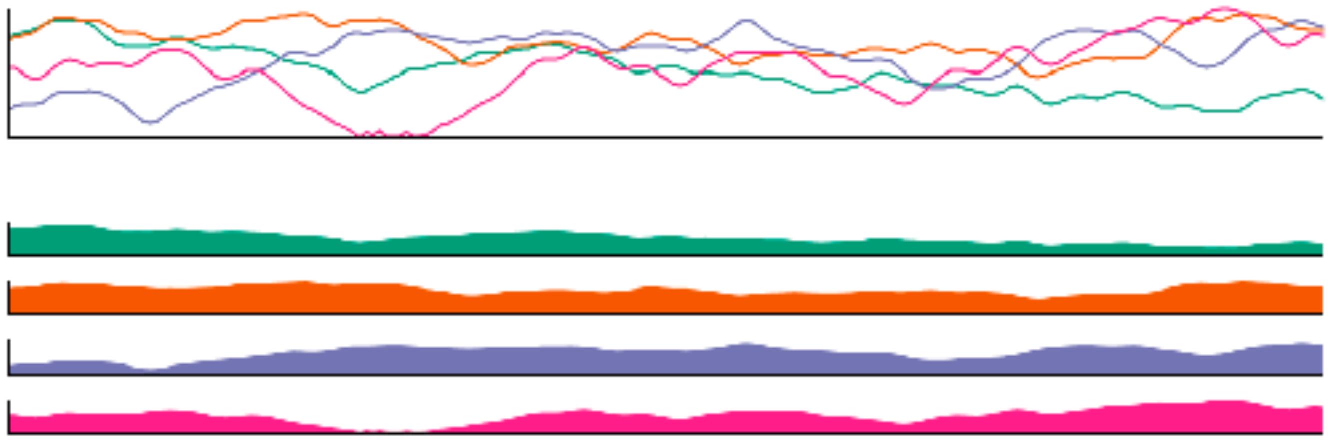


[The Visual Design and Control of Trellis Display. Becker, Cleveland, & Shyu. Journal of Computational and Graphical Statistics 5(2):123-155 1996.]

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



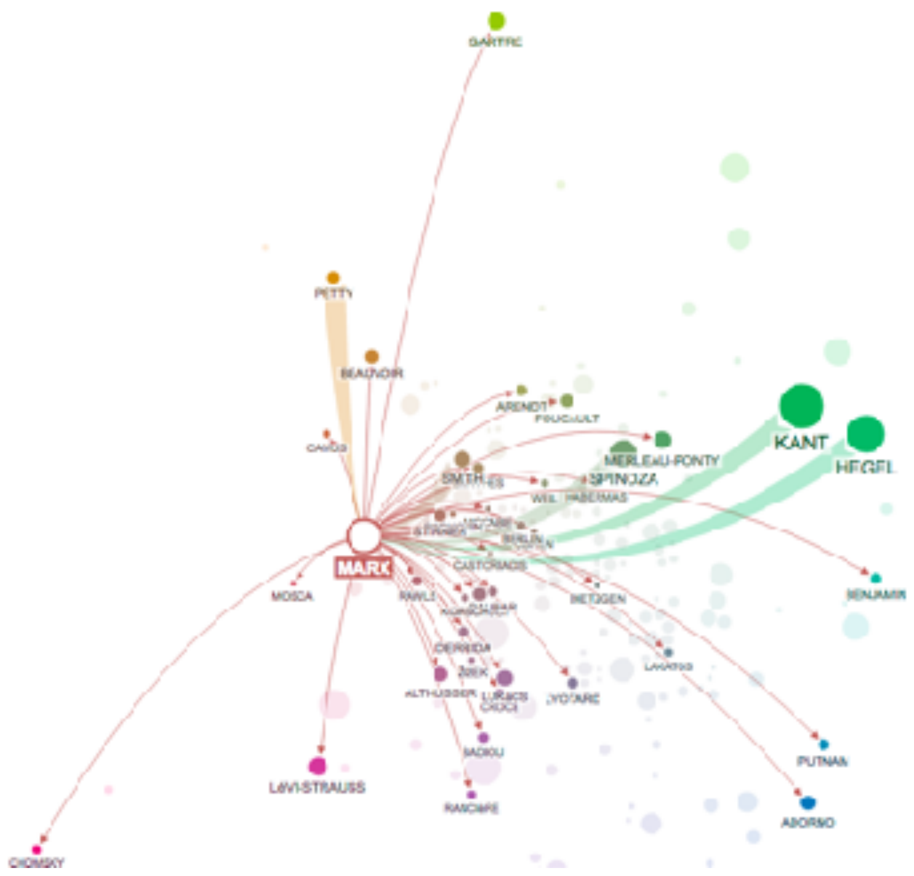


[Graphical Perception of Multiple Time Series. Javed, McDonnel, and Elmqvist. IEEE Transactions on Visualization and Computer Graphics (Proc. IEEE InfoVis 2010) 16:6 (2010), 927–934.]

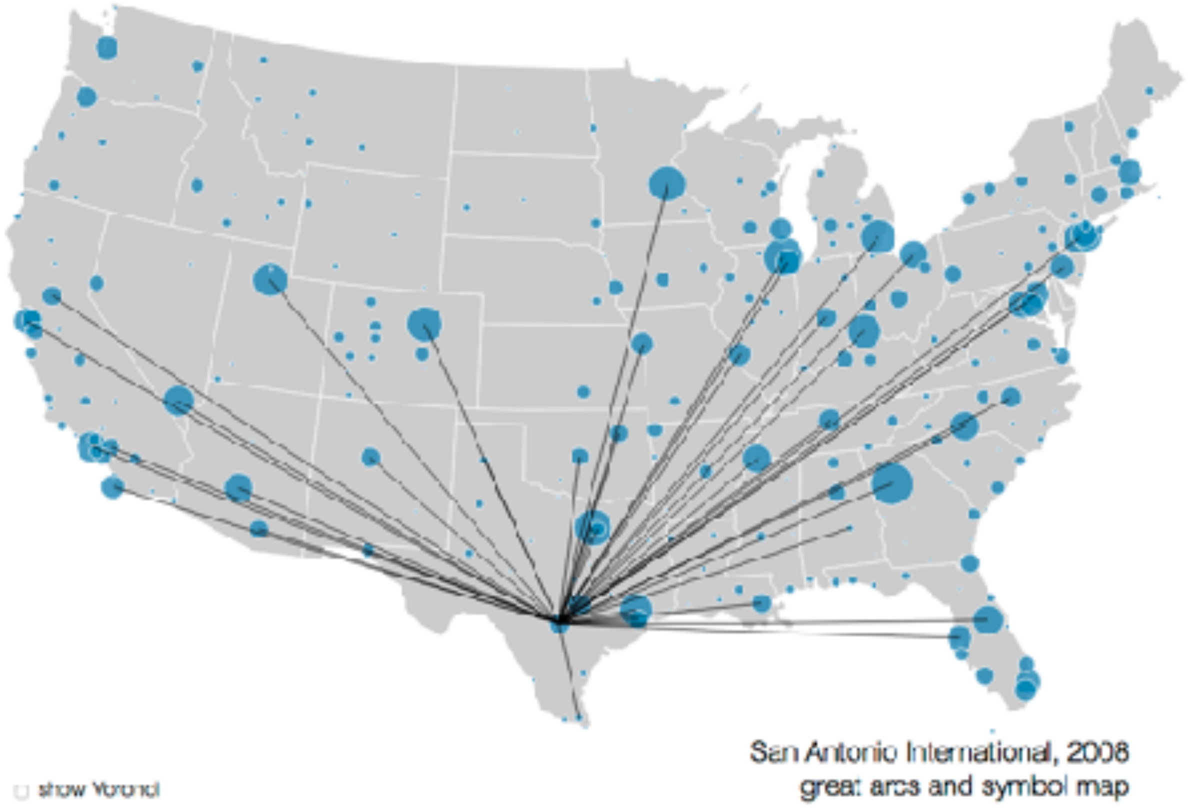
Dynamic visual layering

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

click (heavyweight)

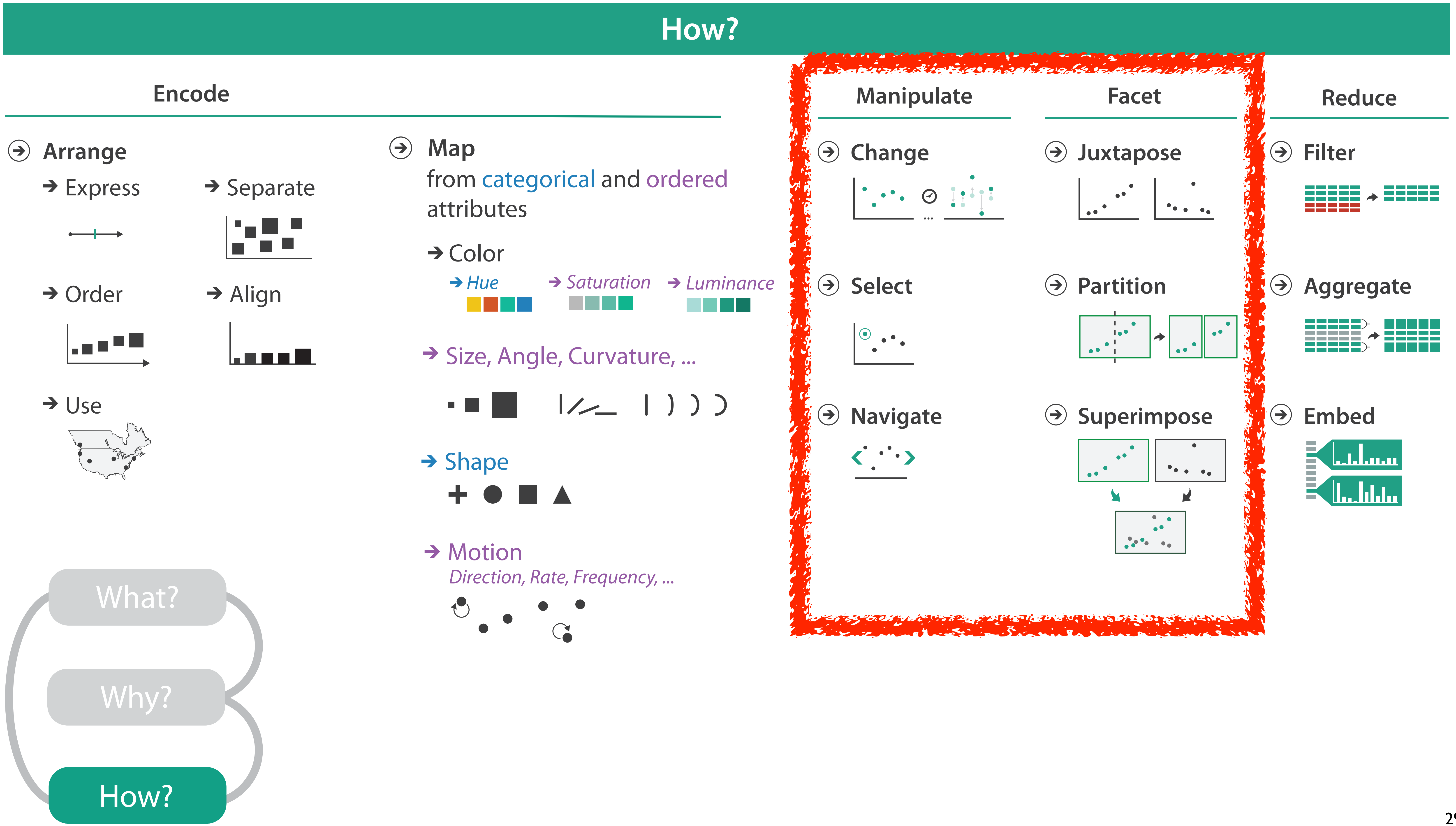


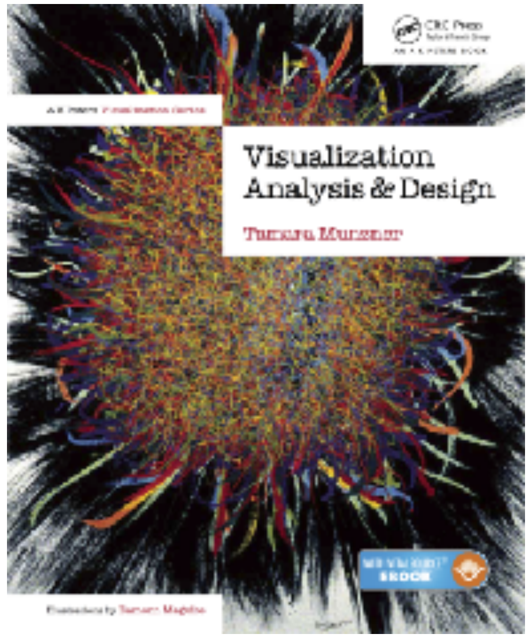
hover (fast)



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

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


How?
Encode
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Manipulate
Change
Select
Navigate
Facet
Juxtapose
Partition
Superimpose
Reduce
Filter
Aggregate
Embed
What?
Why?
How?



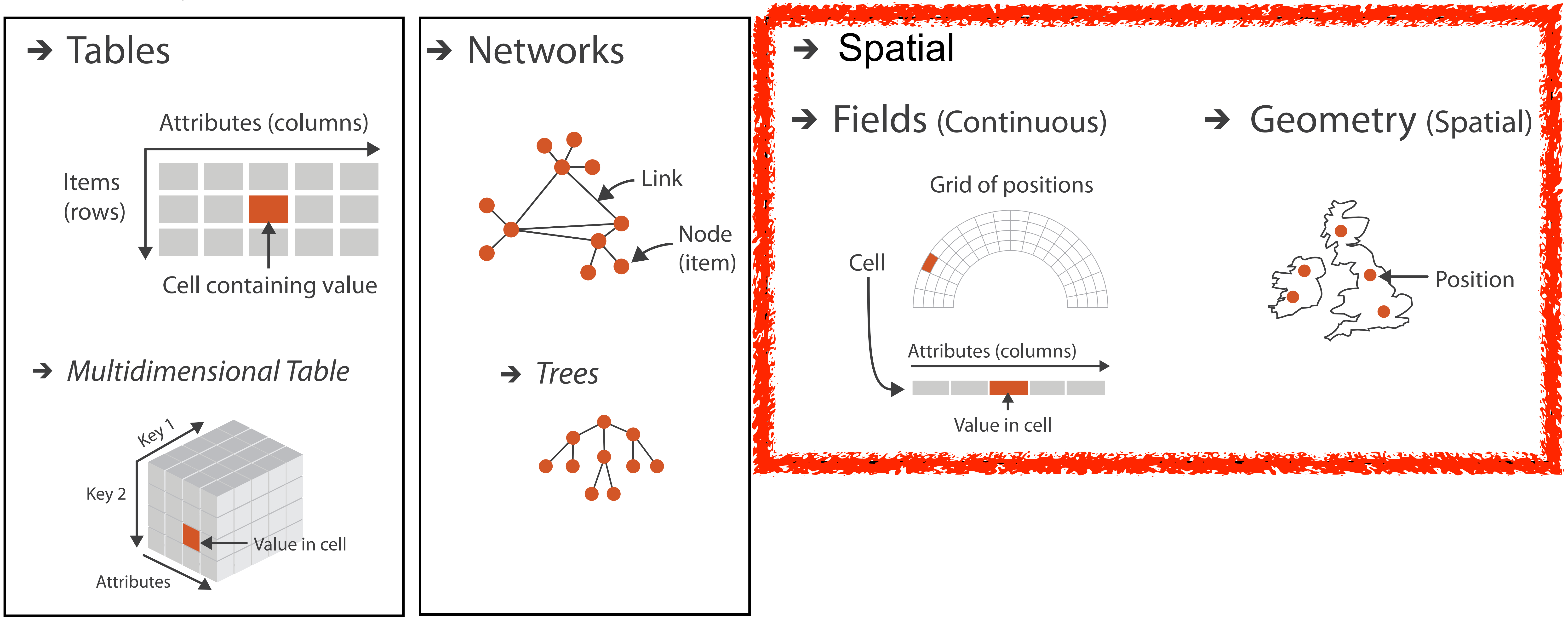
Visualization Analysis & Design

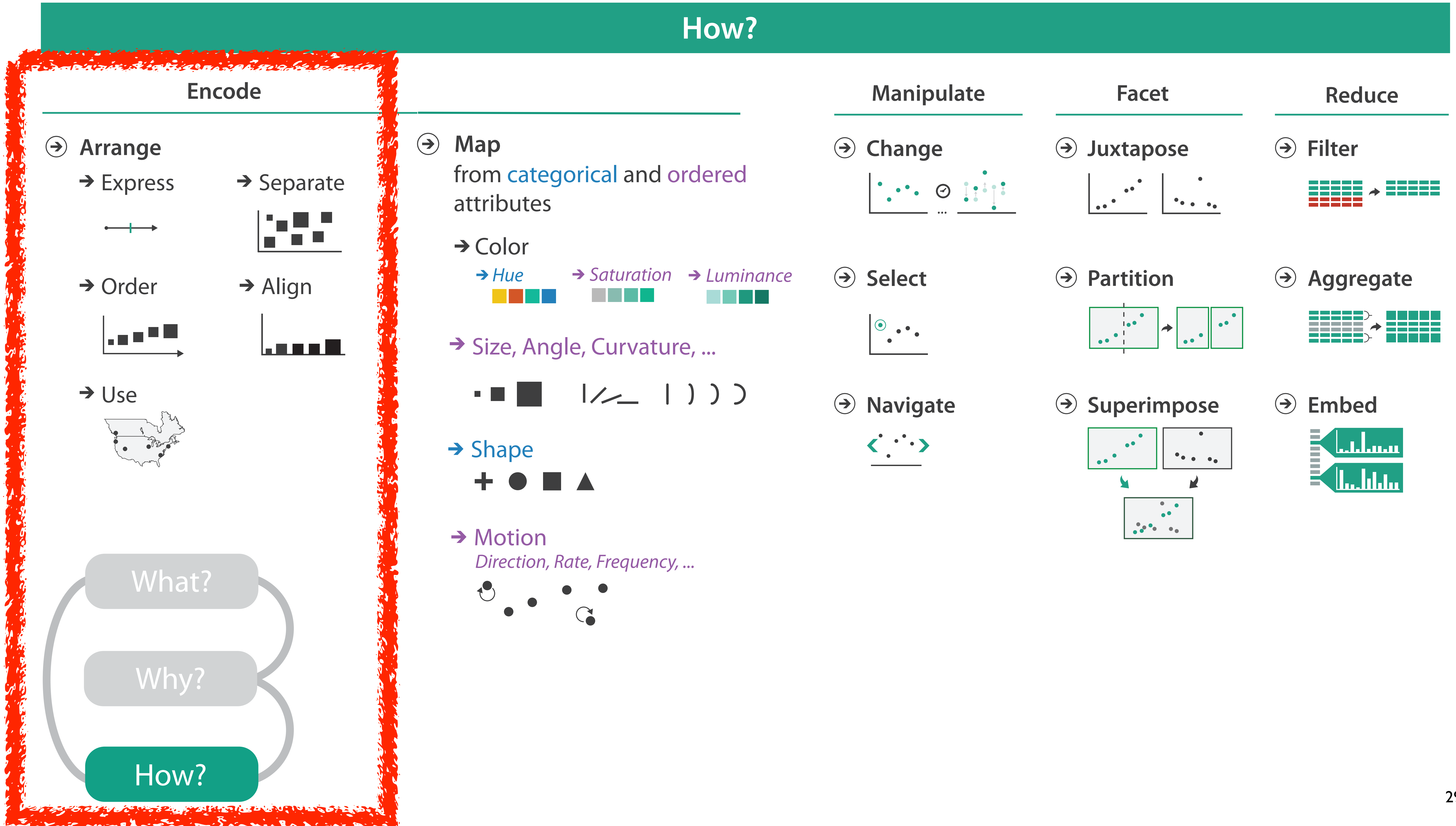
Spatial Data (Ch 9)

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

Focus on Spatial

➔ Dataset Types





How?
Encode
Arrange
Express
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Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Manipulate
Change
Select
Navigate
Facet
Juxtapose
Partition
Superimpose
Reduce
Filter
Aggregate
Embed
What?
Why?
How?

How?

Encode

Arrange
- Express
- Separate
- Order
- Align
- Use

Map
from categorical and ordered attributes

- Color
  - Hue
  - Saturation
  - Luminance
- Size, Angle, Curvature, ...
- Shape
- Motion
  - *Direction, Rate, Frequency, ...*

Manipulate

Change

Select

Navigate

Facet

Juxtapose

Partition

Superimpose

Reduce

Filter

Aggregate

Embed

What?

Why?

How?

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

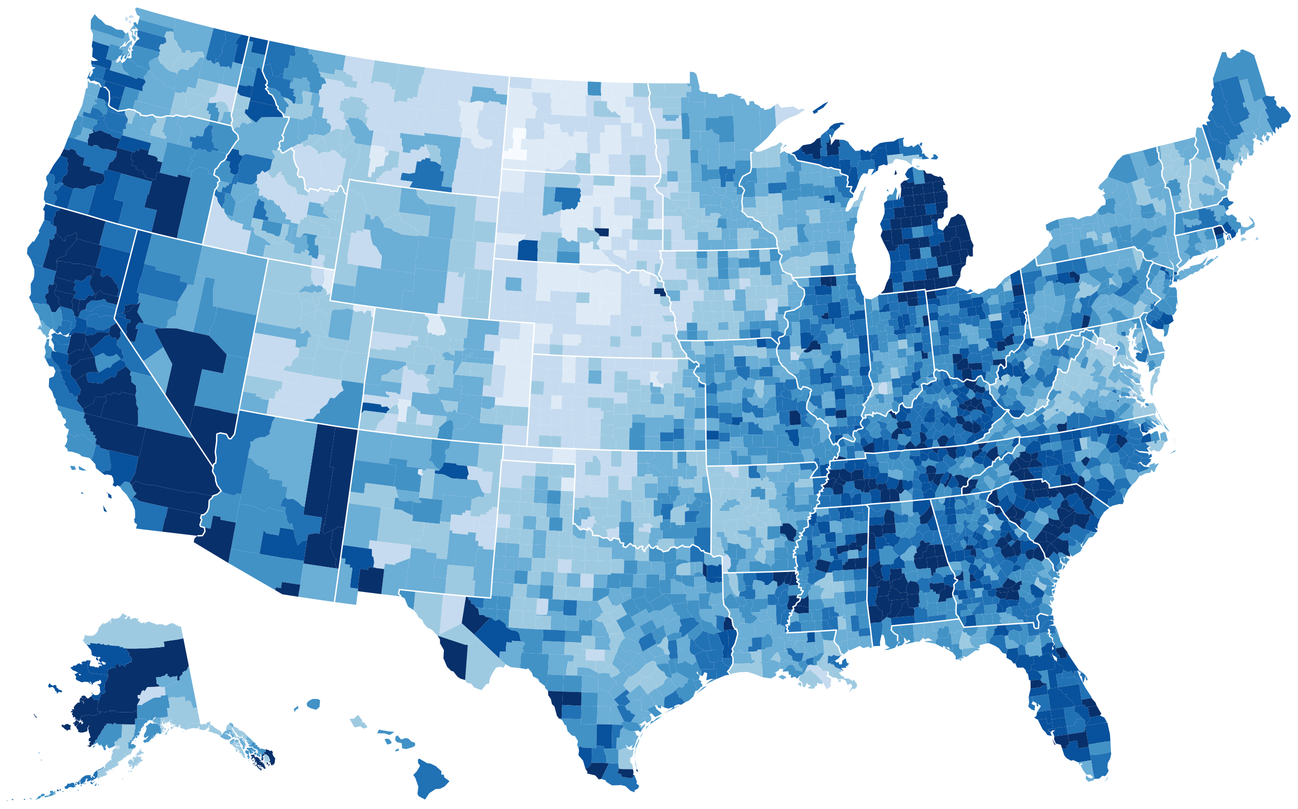
- cannot encode another attribute with these channels, they're "taken"

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

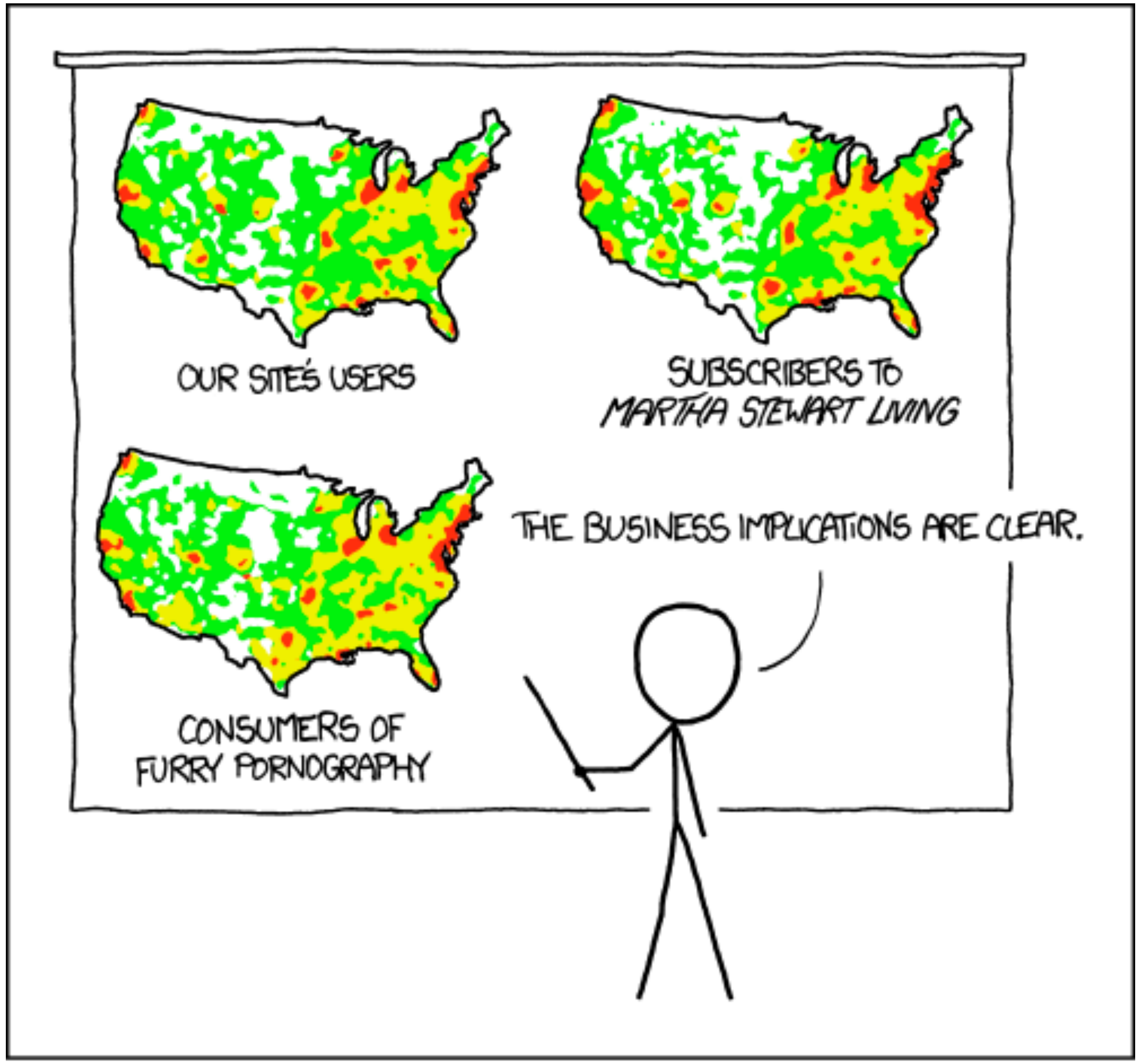
Idiom: **choropleth map**

- 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!

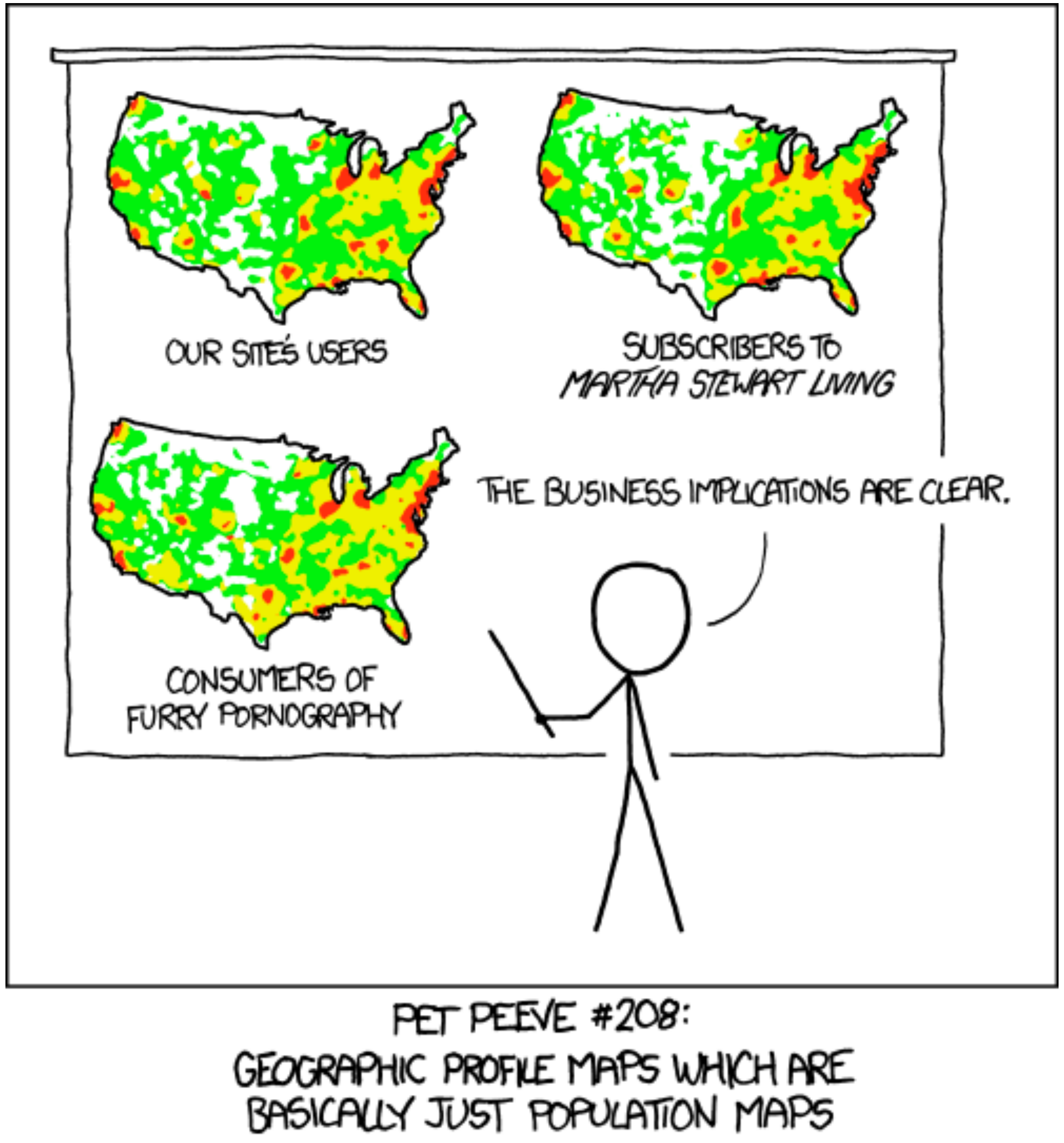


PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

[*https://xkcd.com/1138*]

Beware: Population maps trickiness!

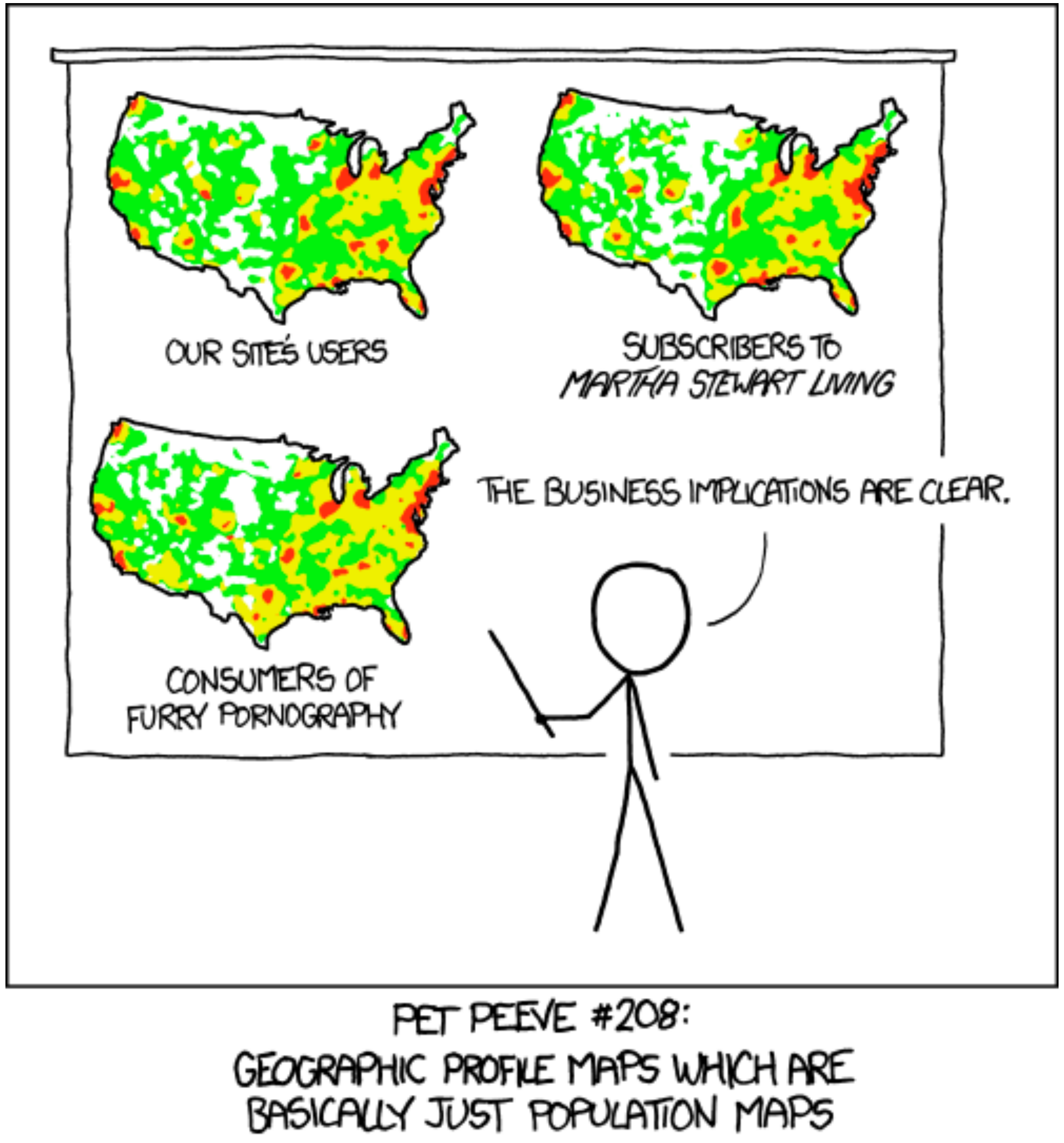
- spurious correlations: most attributes just show where people live



[https://xkcd.com/1138]

Beware: Population maps trickiness!

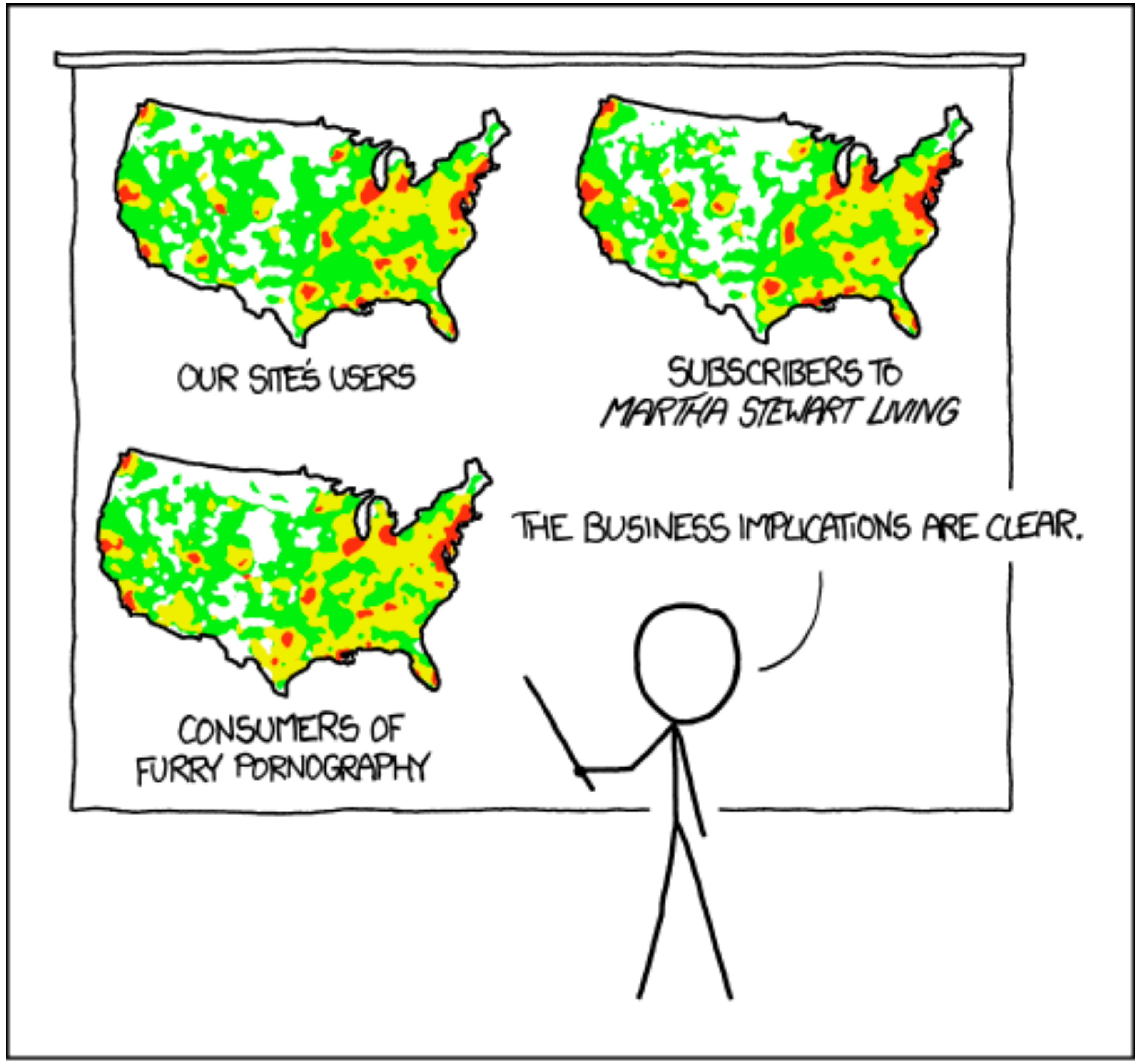
- spurious correlations: most attributes just show where people live
- consider when to normalize by population density
  - encode raw data values
    - tied to underlying population
  - but should use normalized values
    - unemployed people per 100 citizens, mean family income



[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



PET PEEVE #208:
GEOGRAPHIC PROFILE MAPS WHICH ARE BASICALLY JUST POPULATION MAPS

[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

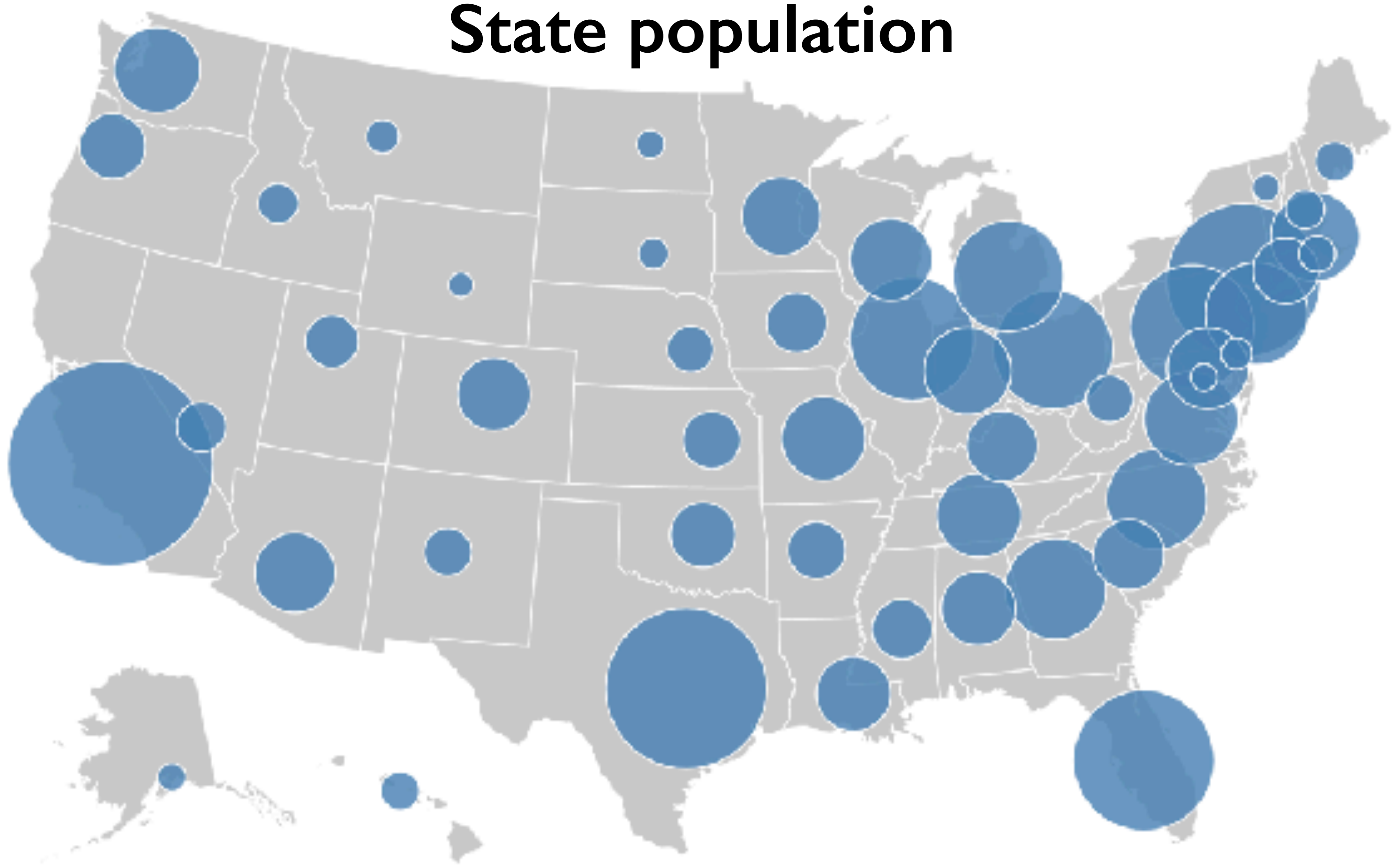
Choropleth map: Pros & cons

- 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

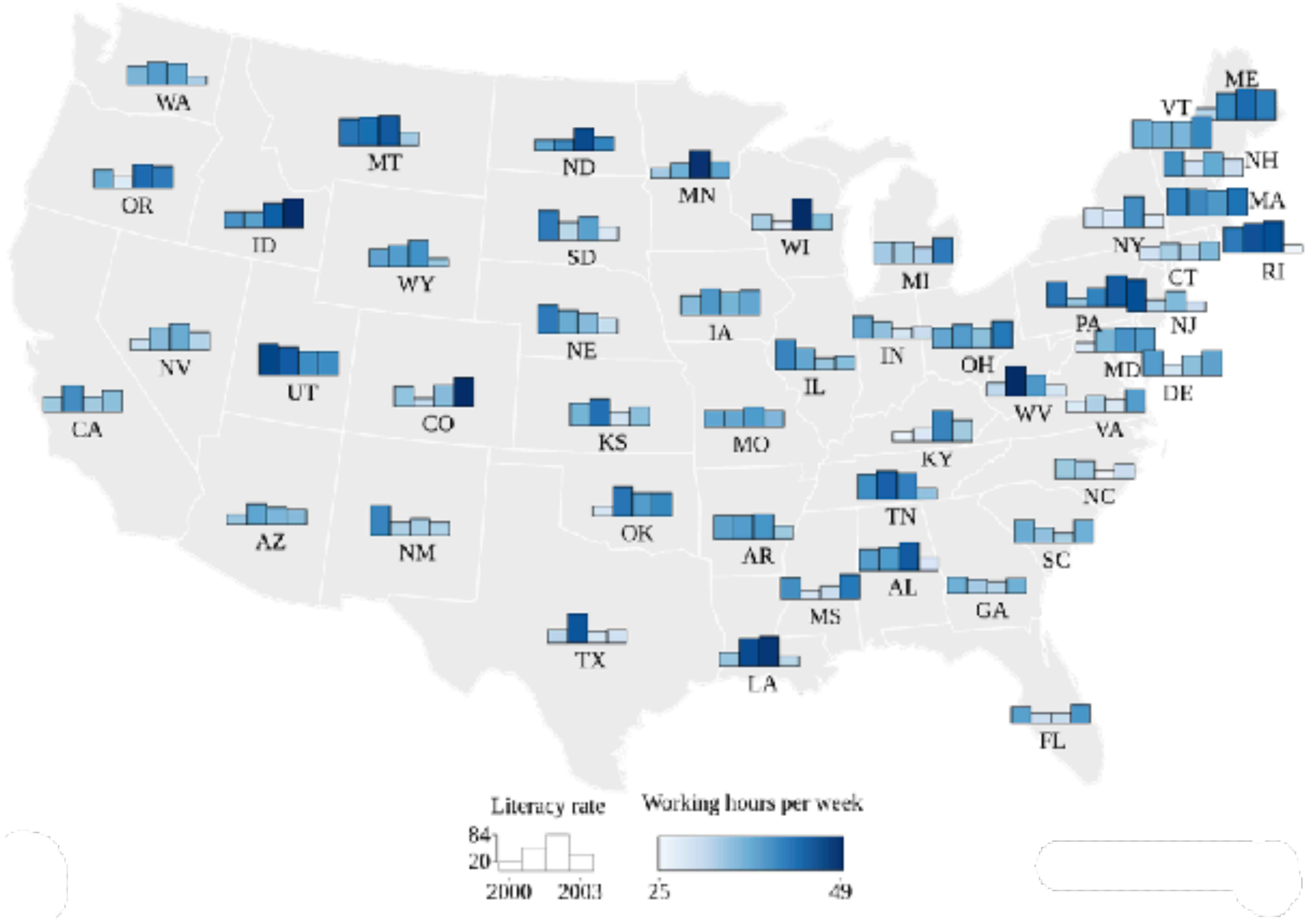
Idiom: **Symbol maps**

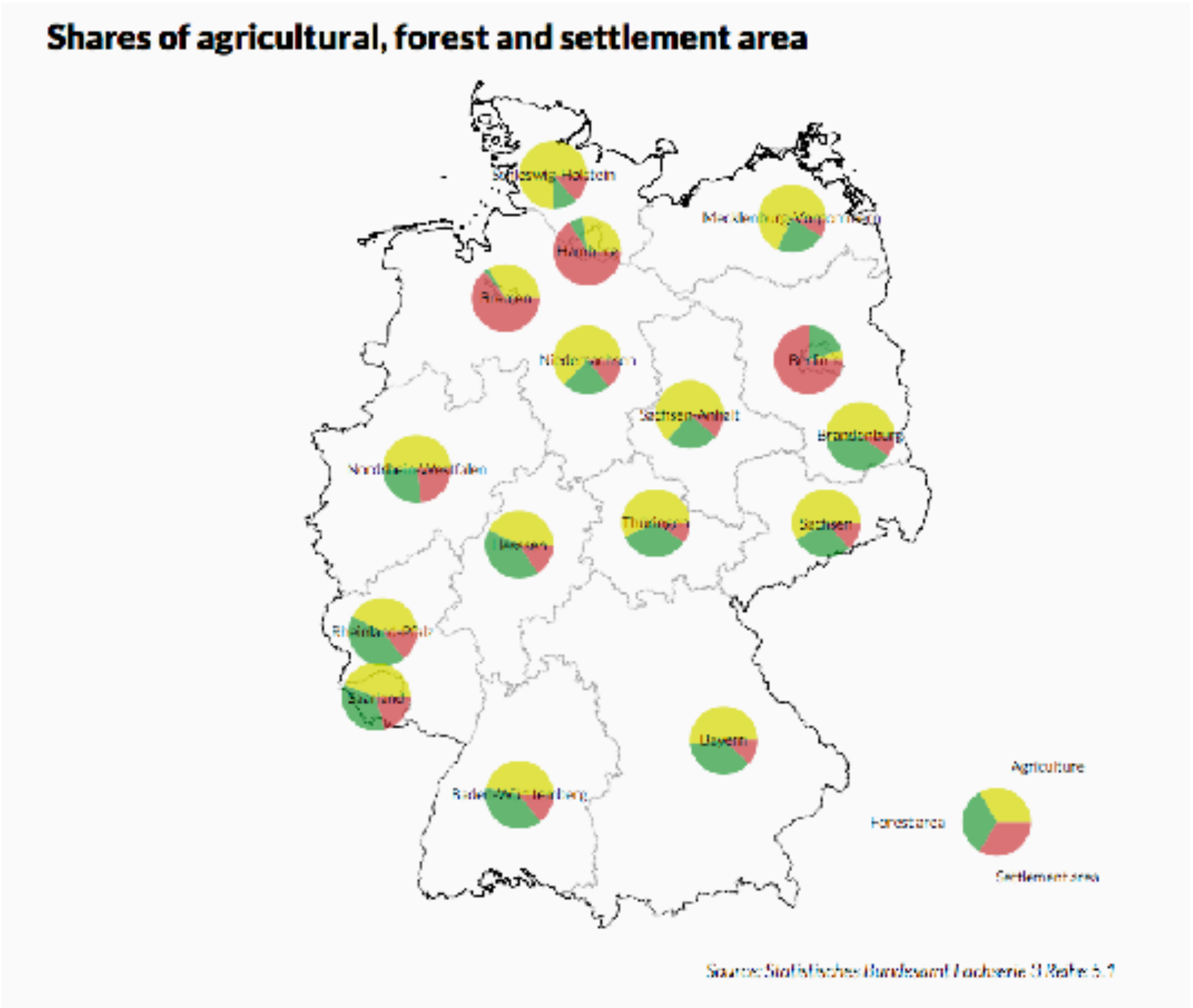
- symbol is used to represent aggregated data (mark or glyph)
  - allows use of size and shape and color channels
    - aka proportional symbol maps, graduated symbol maps
- keep original spatial geometry in the background
- often a good alternative to choropleth maps

State population



Symbol maps with glyphs



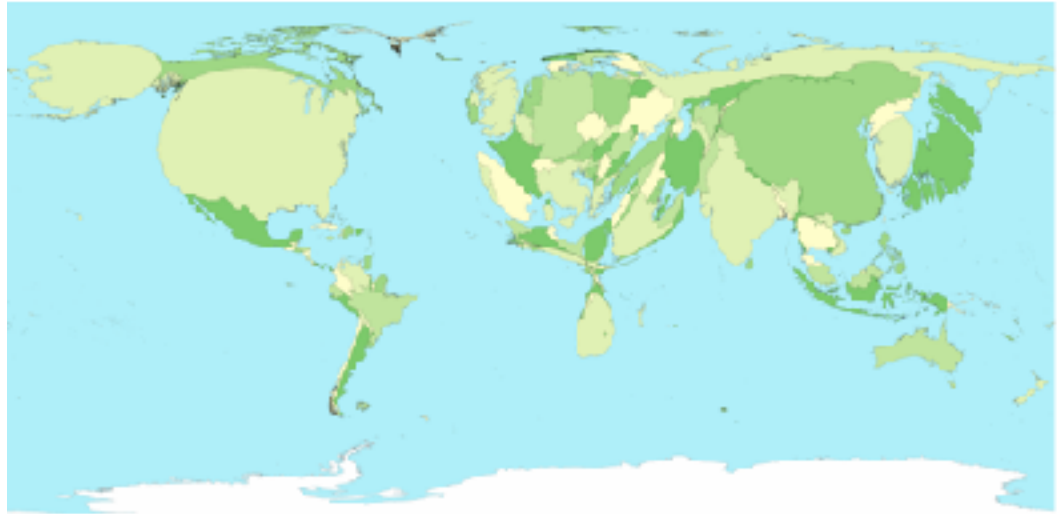


Symbol map: Pros & cons

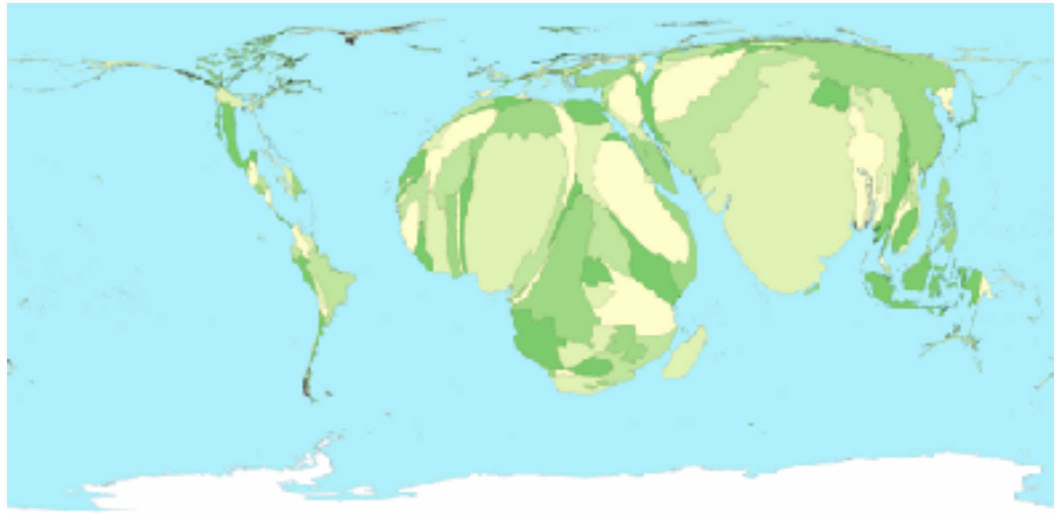
- pros
  - somewhat intuitive to read and understand
  - mitigate problems with region size vs data salience
    - marks: symbol size follows attribute value
    - glyphs: symbol size can be uniform
- cons
  - possible occlusion / overlap
    - symbols could overlap each other
    - symbols could occlude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

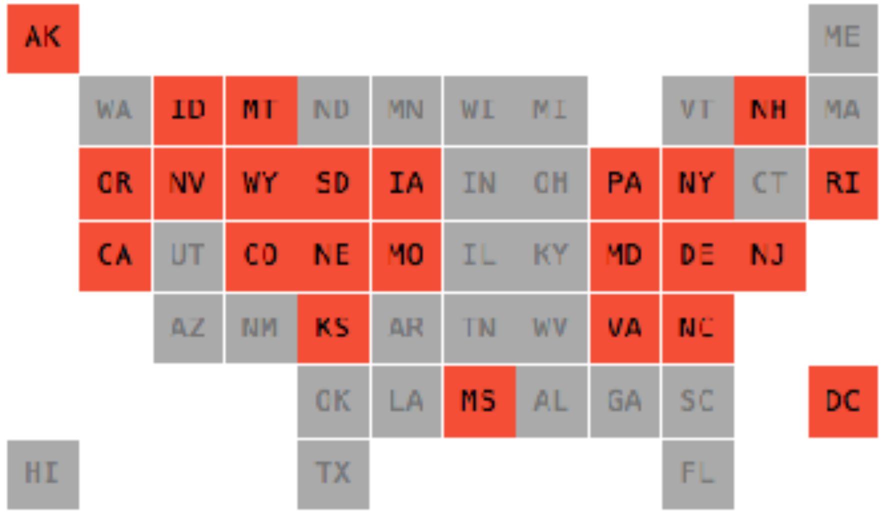


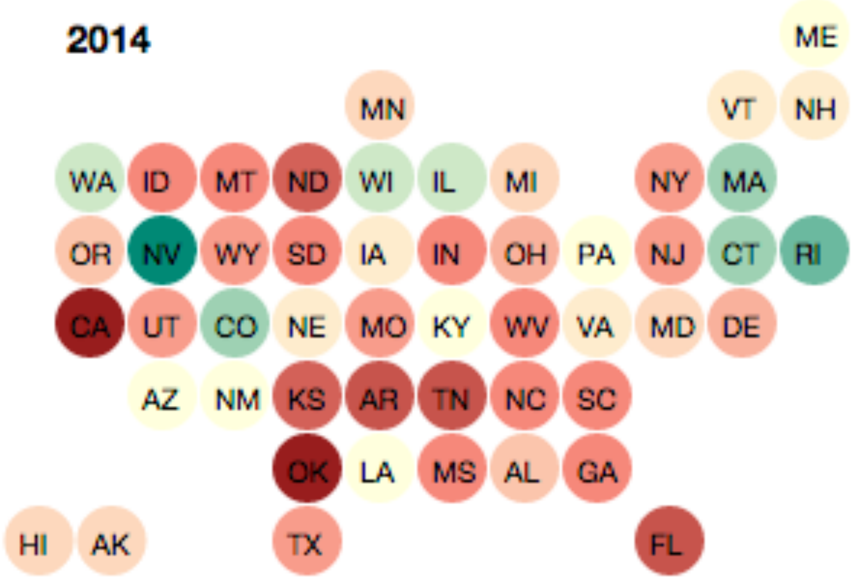
Greenhouse Emissions



Child Mortality

Idiom: **Grid Cartogram**





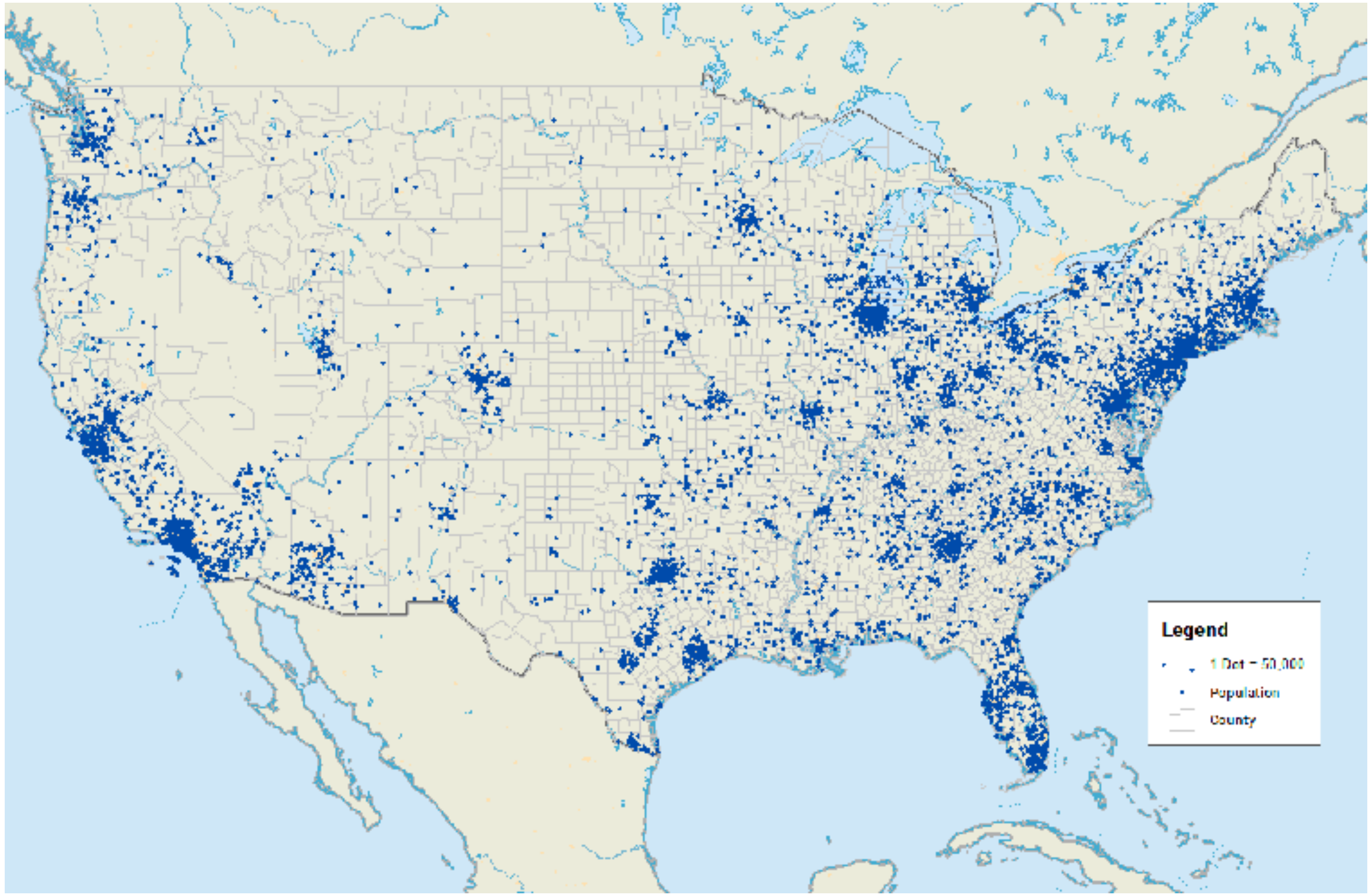
- uniform-sized shapes arranged in rectilinear grid
- maintain approximate spatial position and arrangement

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

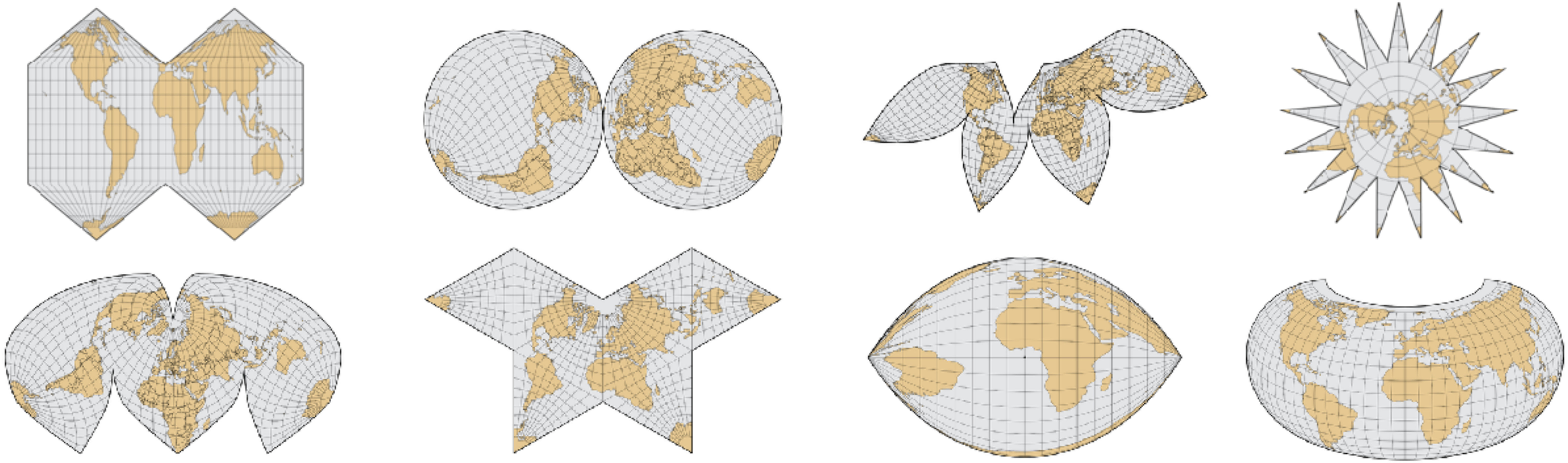


Dot density maps: Pros and cons

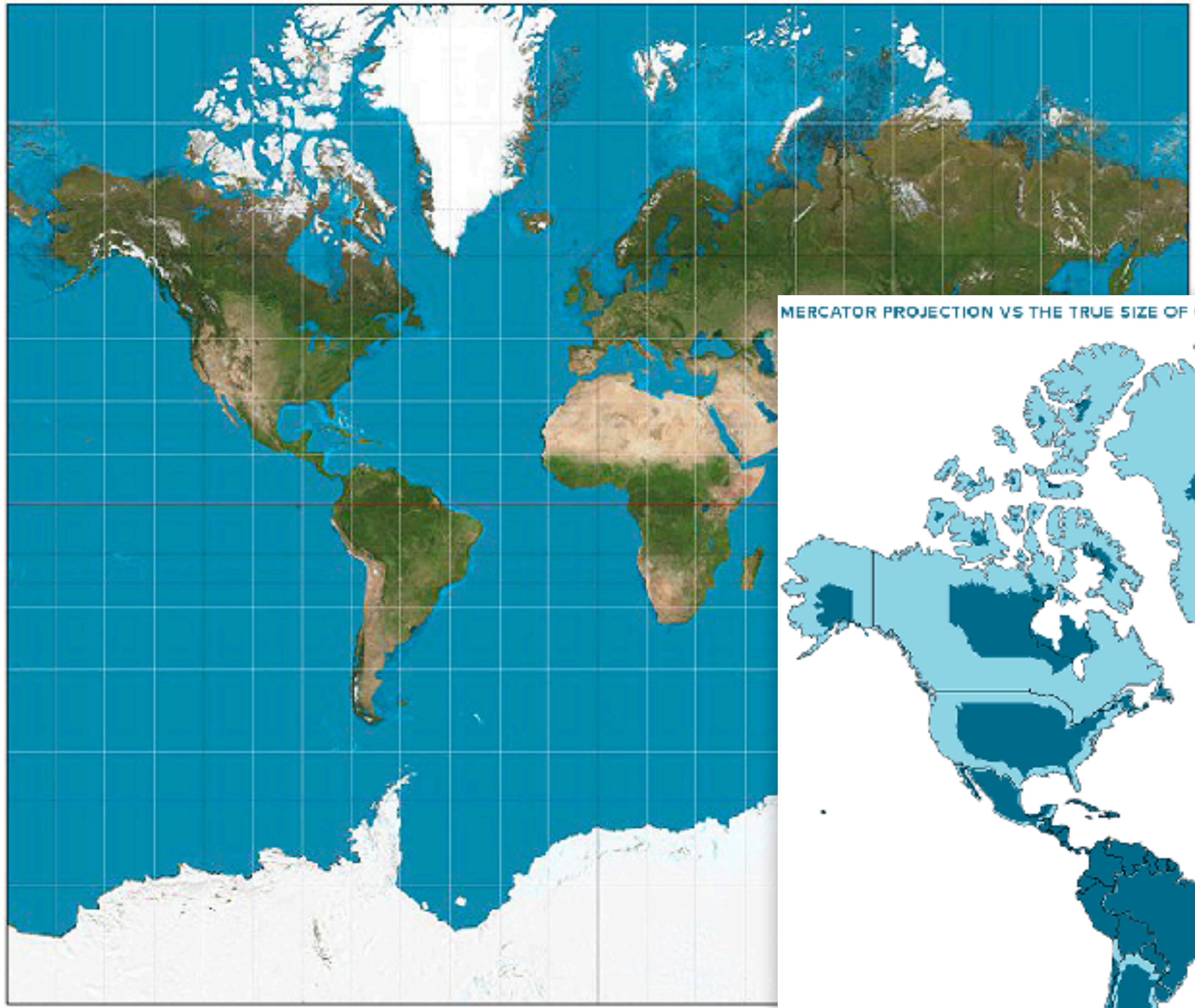
- pros
  - straightforward to understand
  - avoids choropleth non-uniform region size problems
- cons
  - challenge: normalization, just like choropleths
    - show population density (correlated with attribute), not effect of interest
  - perceptual disadvantage:
    difficult to extract quantities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

Map Projections

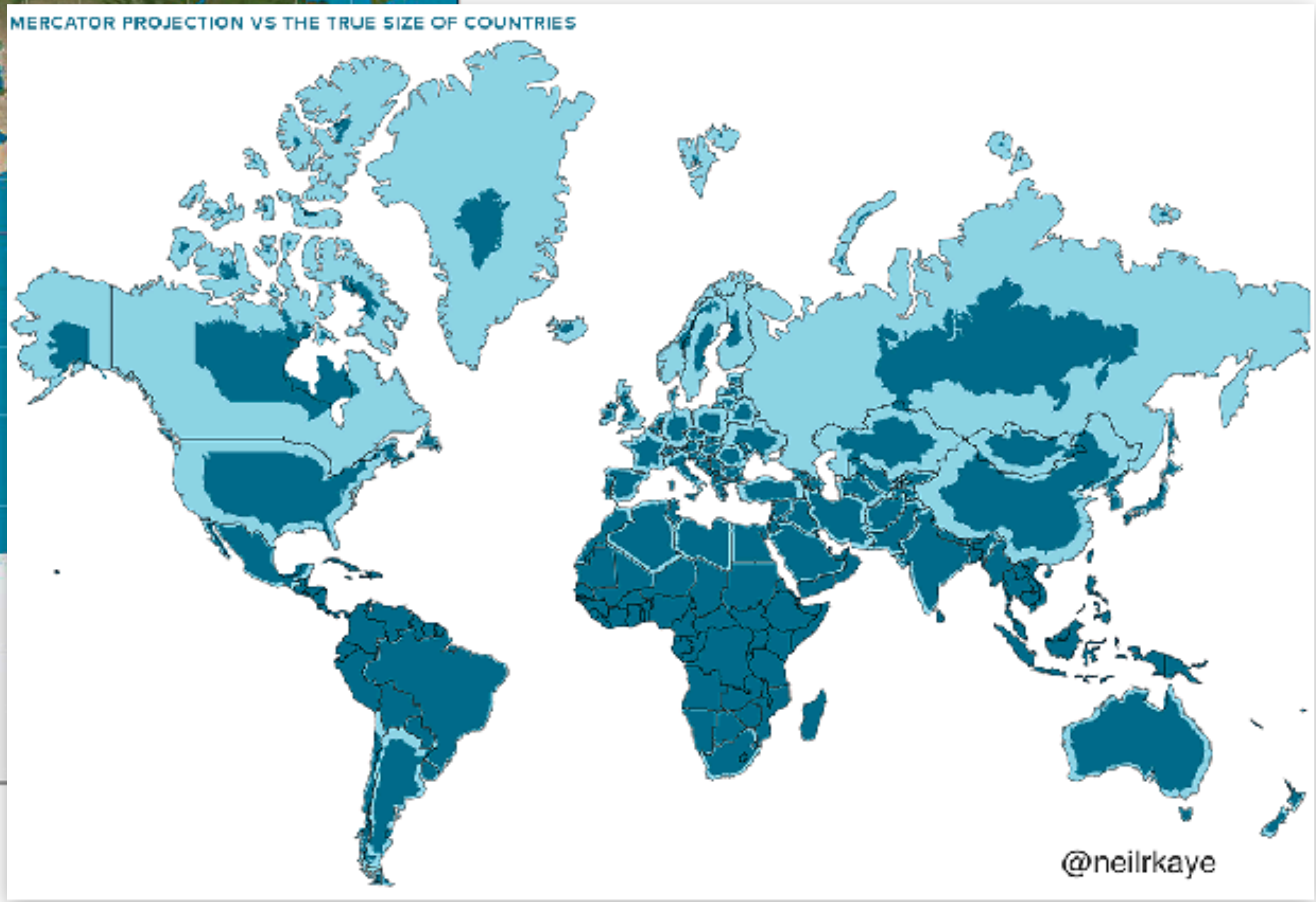
- mathematical functions that map 3D surface geometry of the Earth to 2D maps
- all projections of sphere on plane necessarily distort surface in some way
- interactive: philogb.github.io/page/myriahedral/ and jasondavies.com/maps/

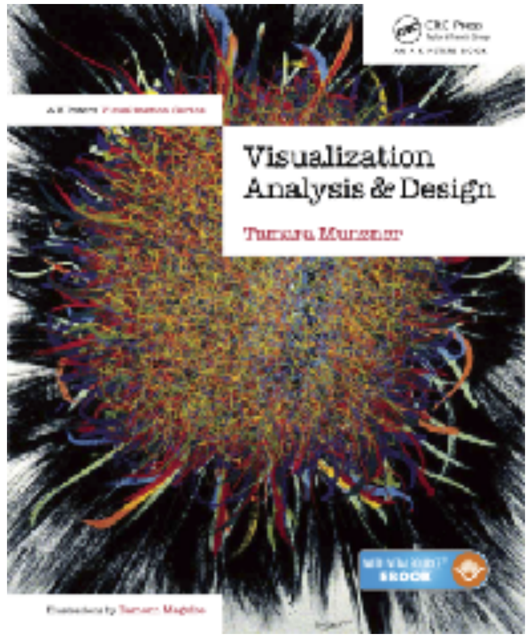


Mercator Projection



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



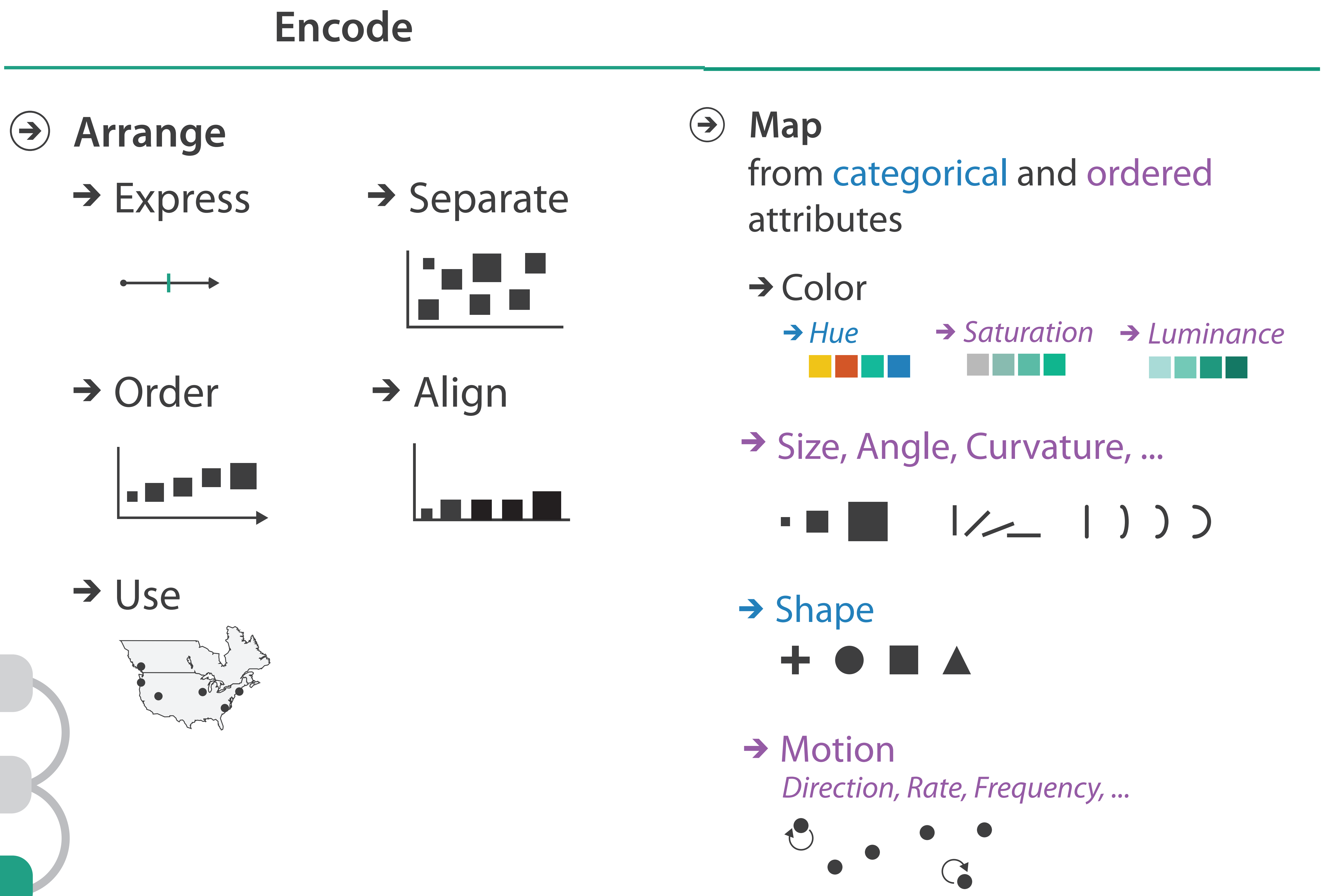


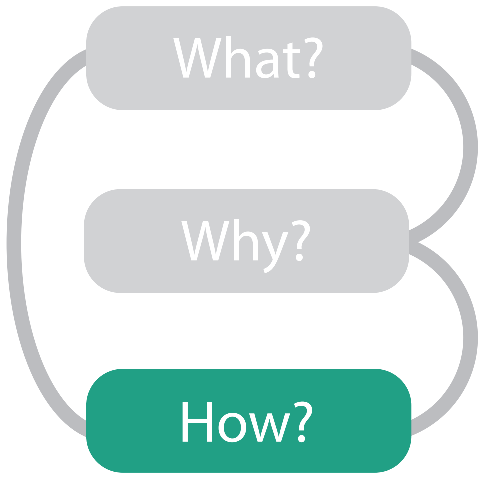
Visualization Analysis & Design

Color (Ch 10)

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

Idiom design choices: Visual encoding





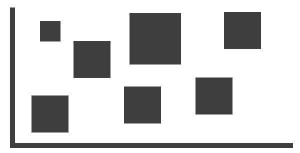
Idiom design choices: Beyond spatial arrangement

Encode

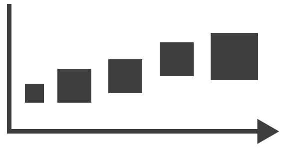
Arrange

→ Express

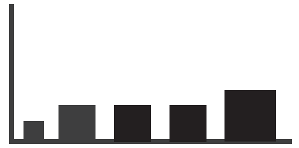
→ Separate



→ Order



→ Align



→ Use

Map

from categorical and ordered attributes

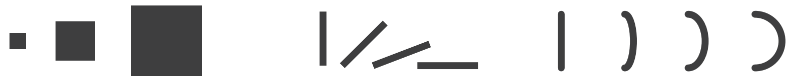
→ Color

→ *Hue*

→ *Saturation*

→ *Luminance*

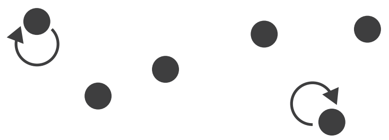
→ Size, Angle, Curvature, ...

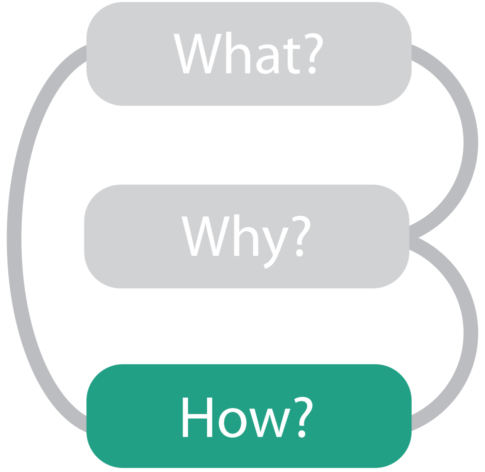


→ Shape

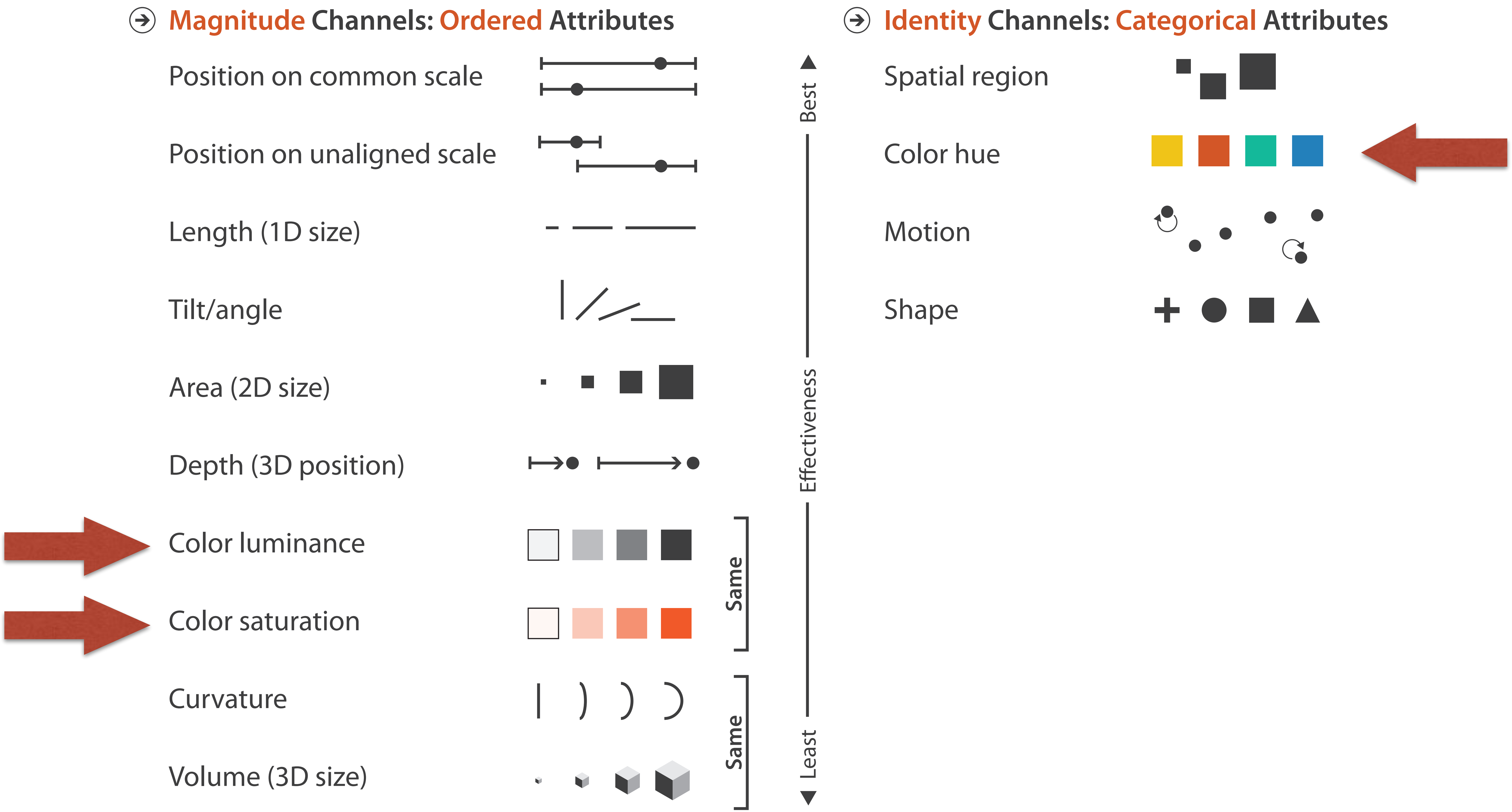
→ Motion

Direction, Rate, Frequency, ...





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

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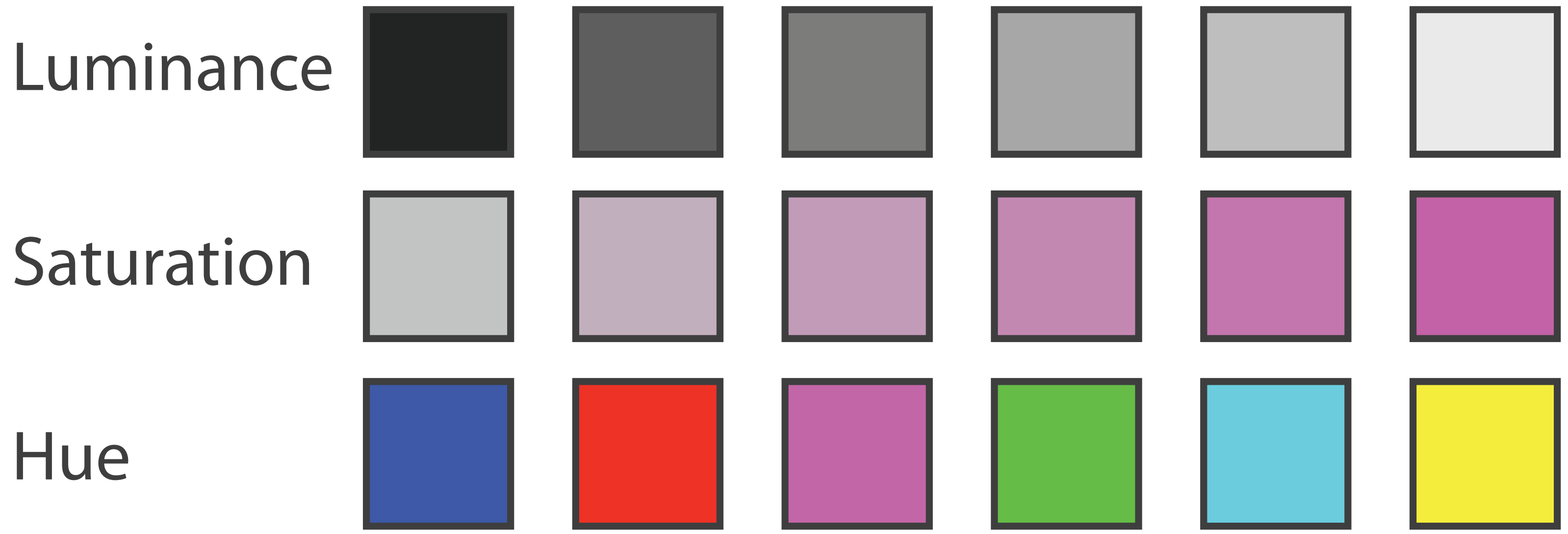
- first rule of color: do not (just) talk about color!
  - color is confusing if treated as monolithic
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



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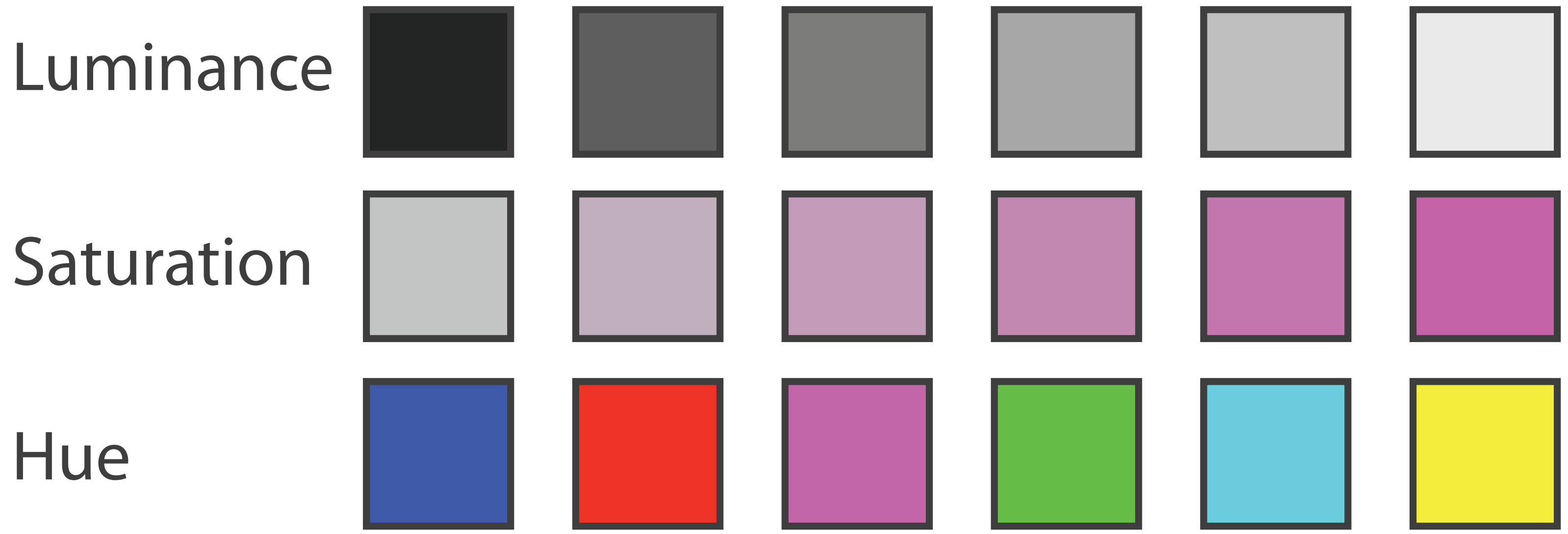
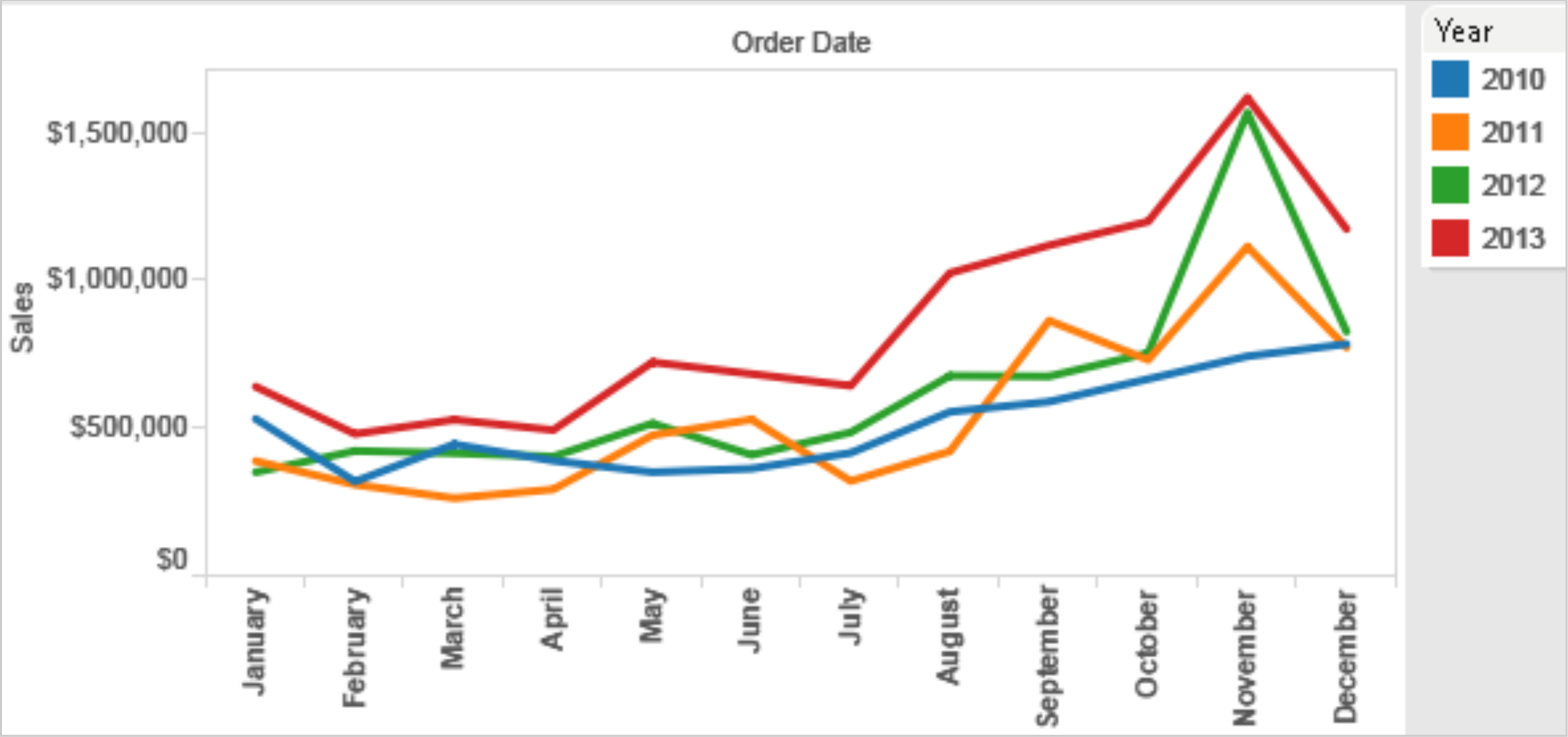
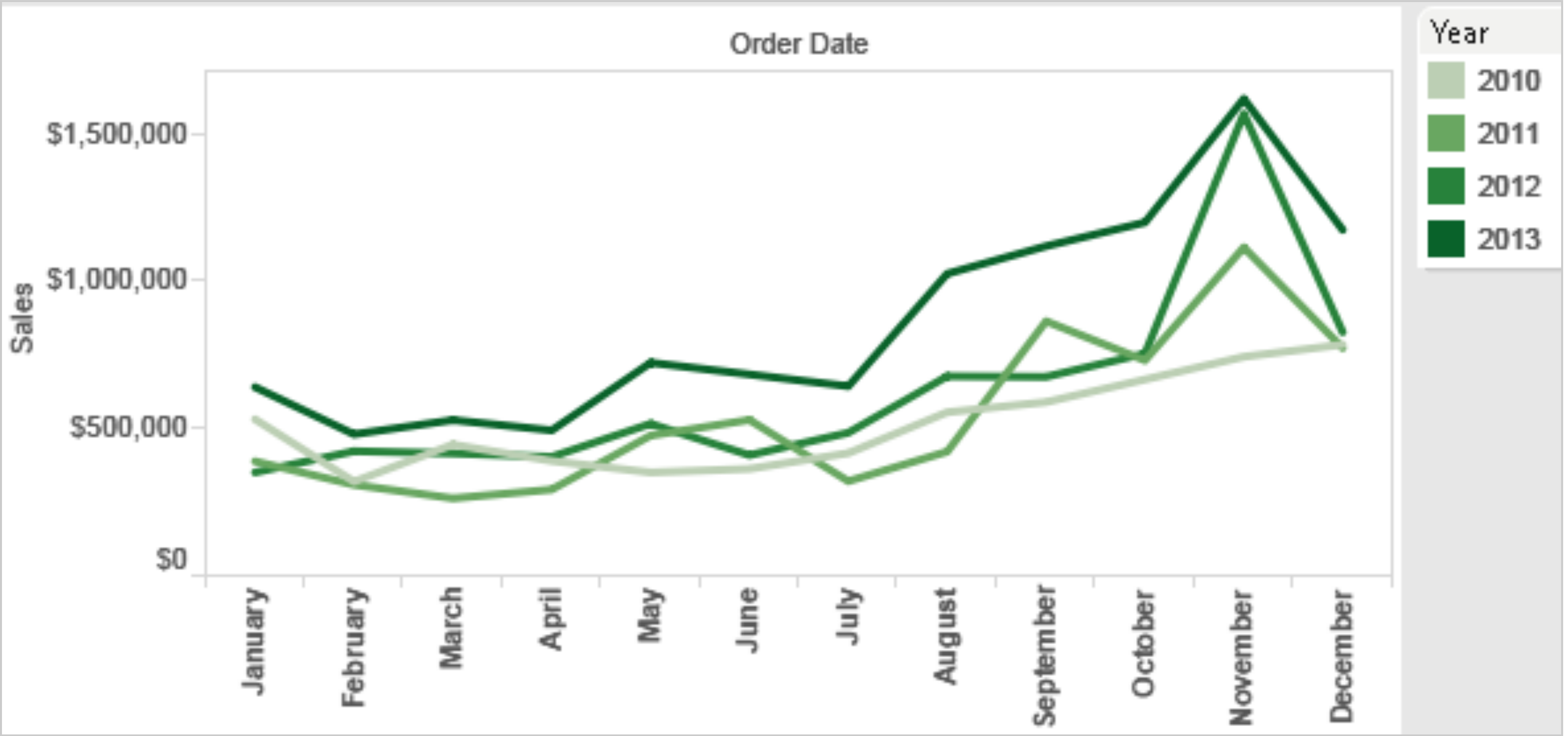


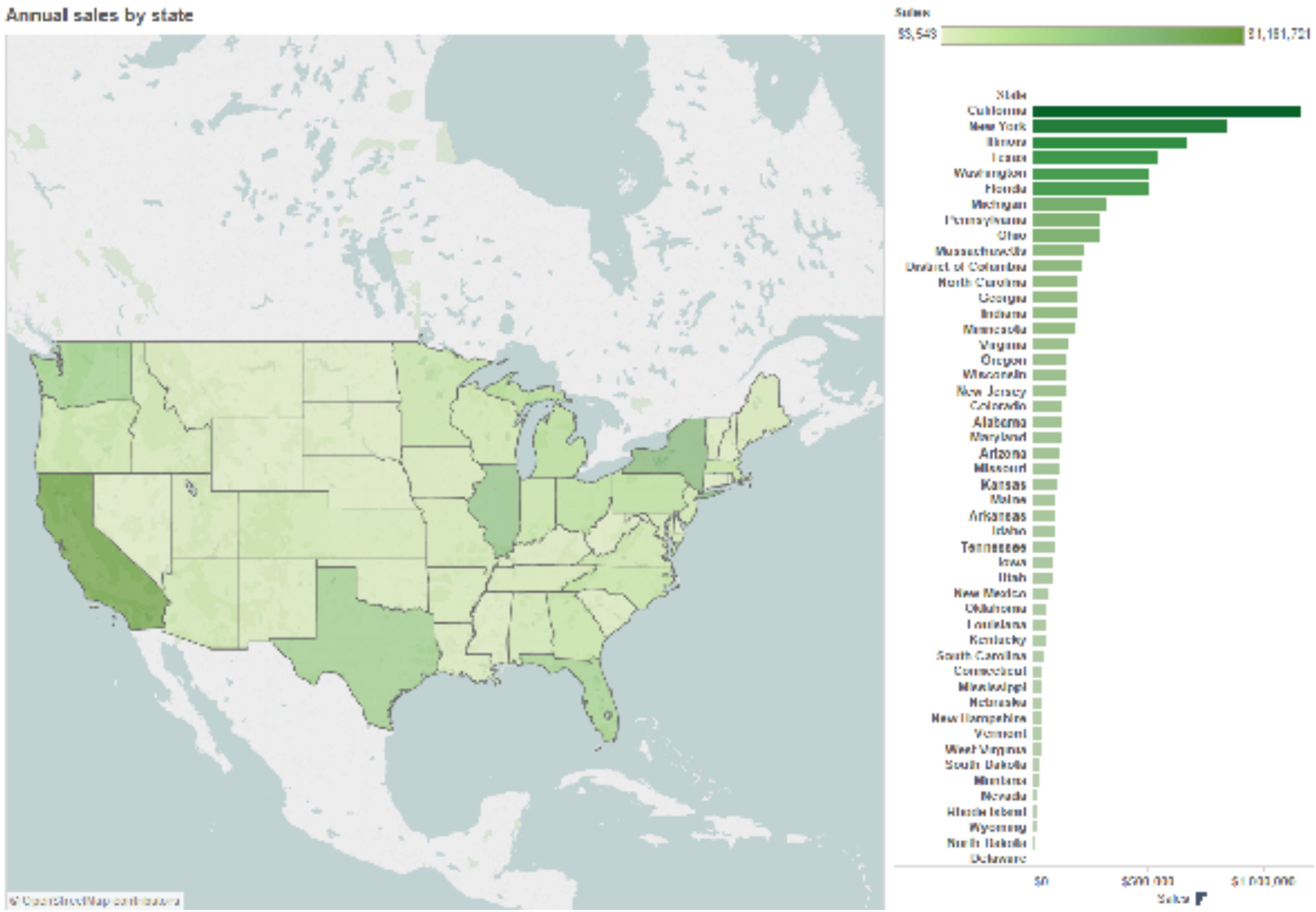
- channels have different properties
  - what they convey directly to perceptual system
  - how much they can convey
    - how many discriminable bins can we use?

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

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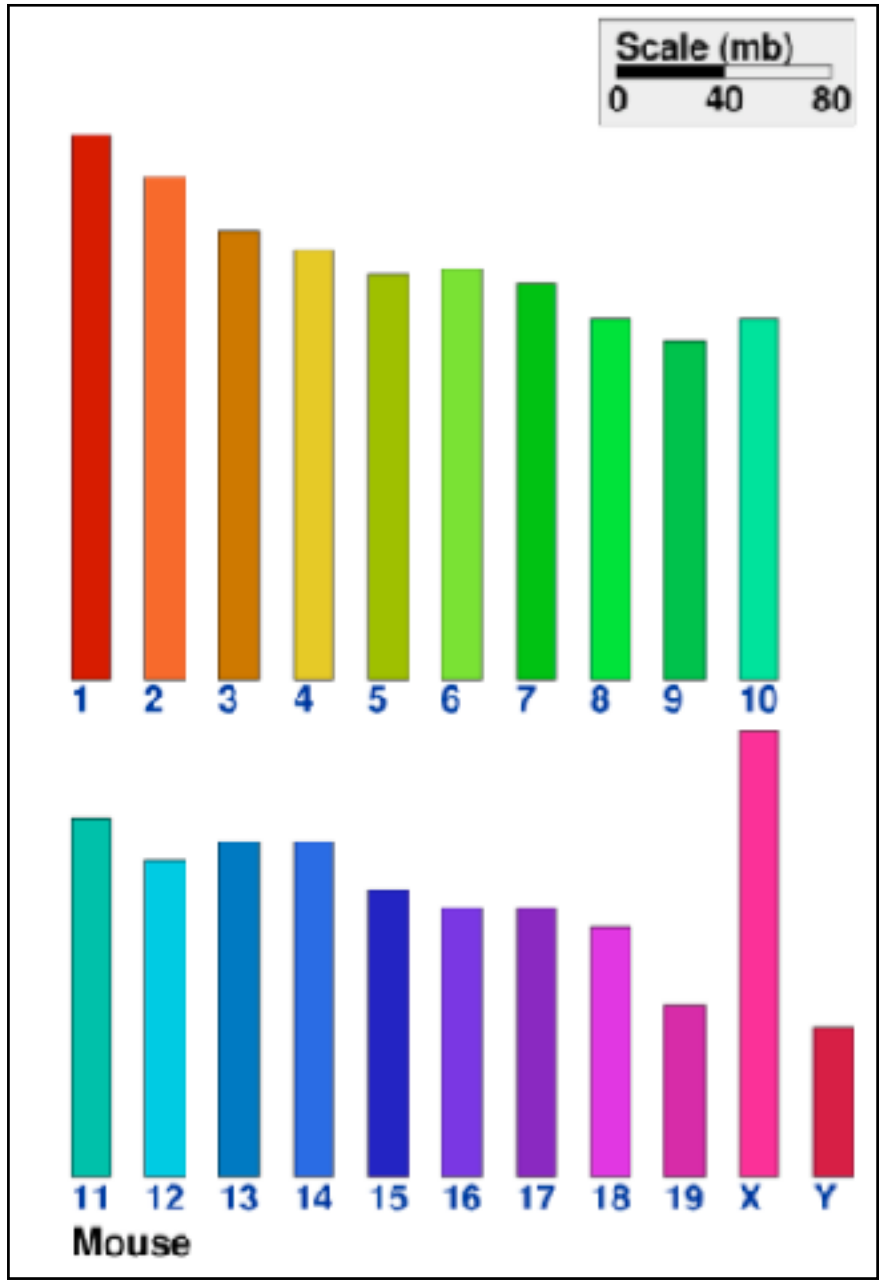
  - great if color contiguous



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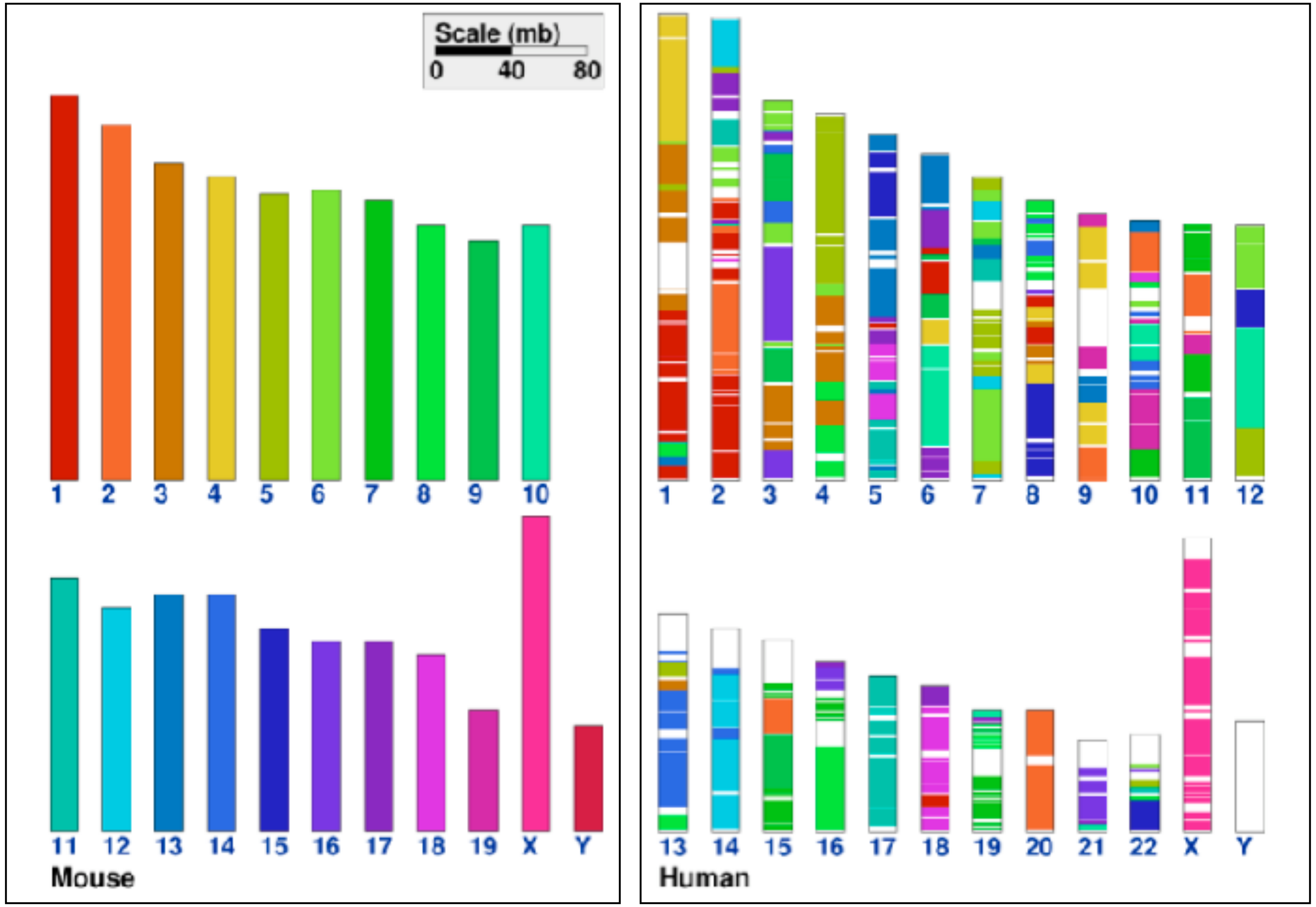

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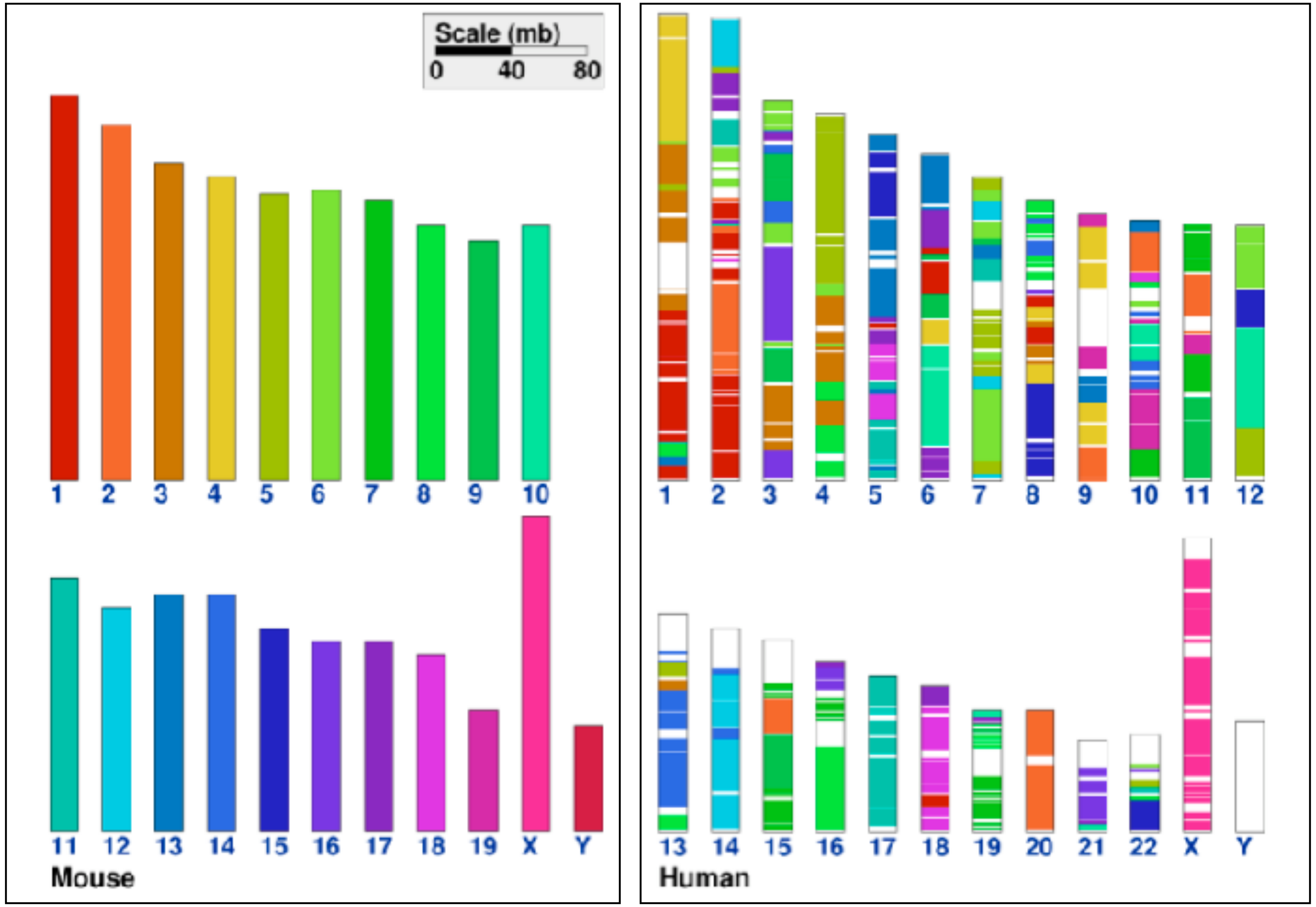
Categorical color: limited number of discriminable bins

- 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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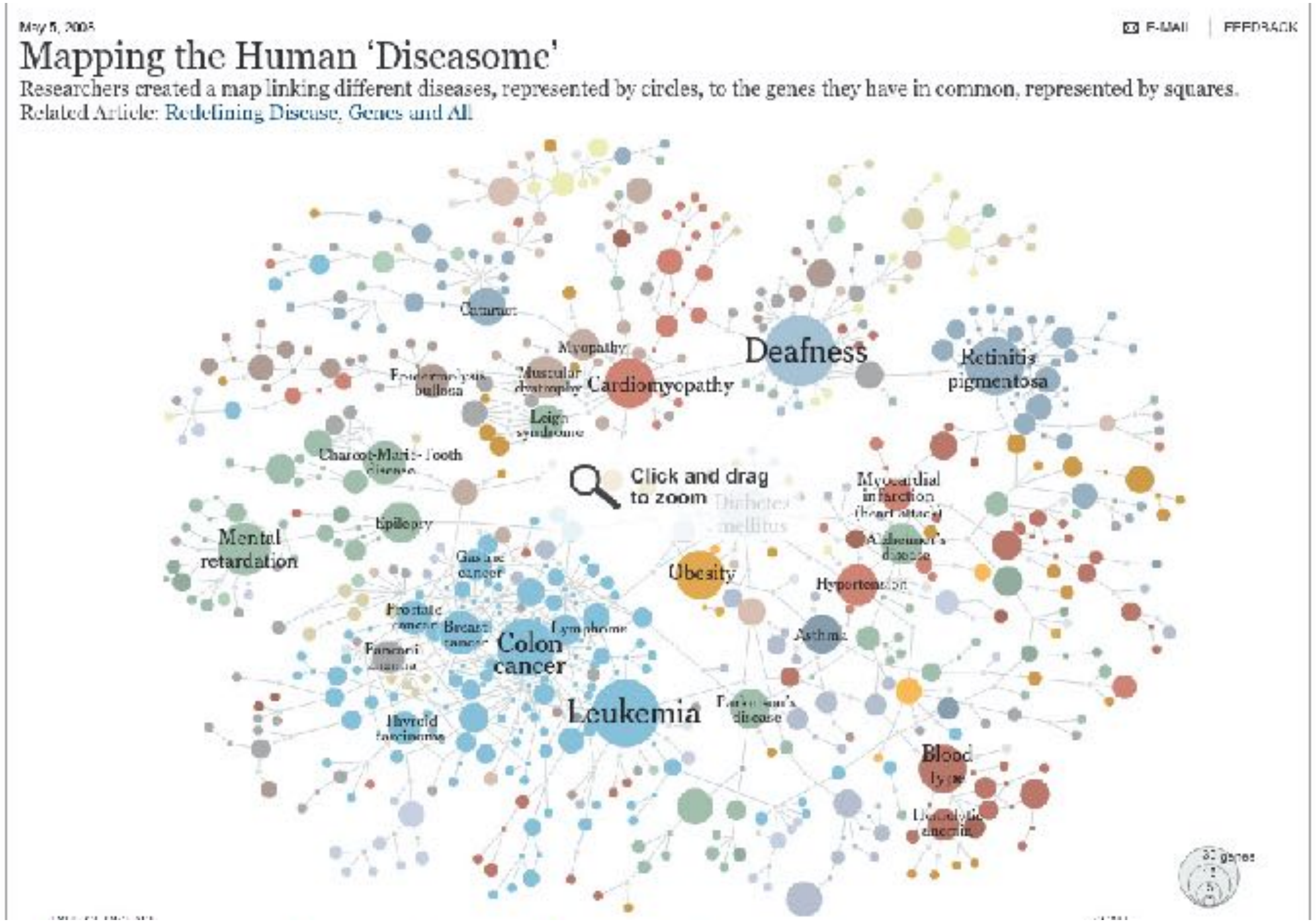
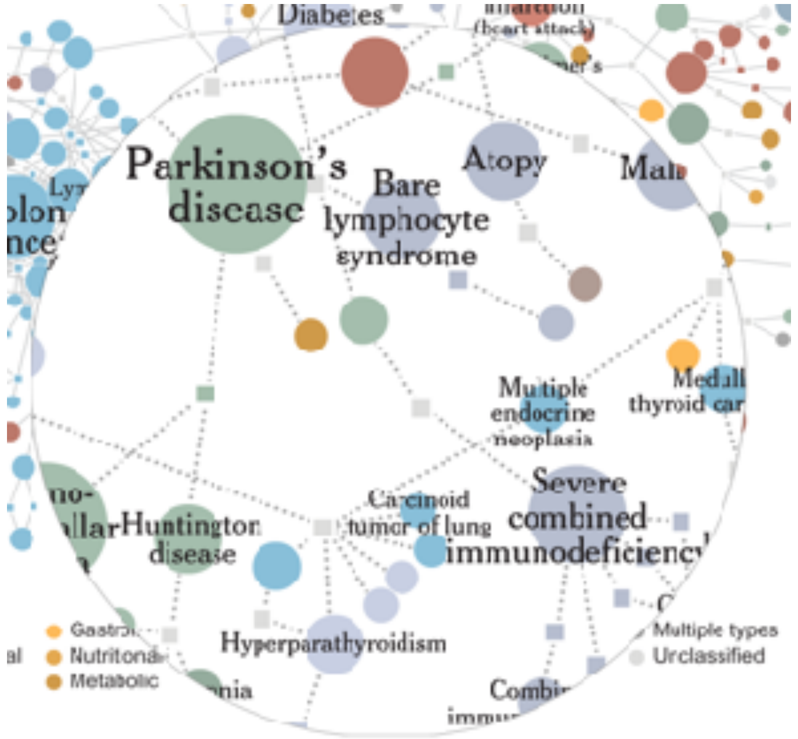
Categorical color: limited number of discriminable bins

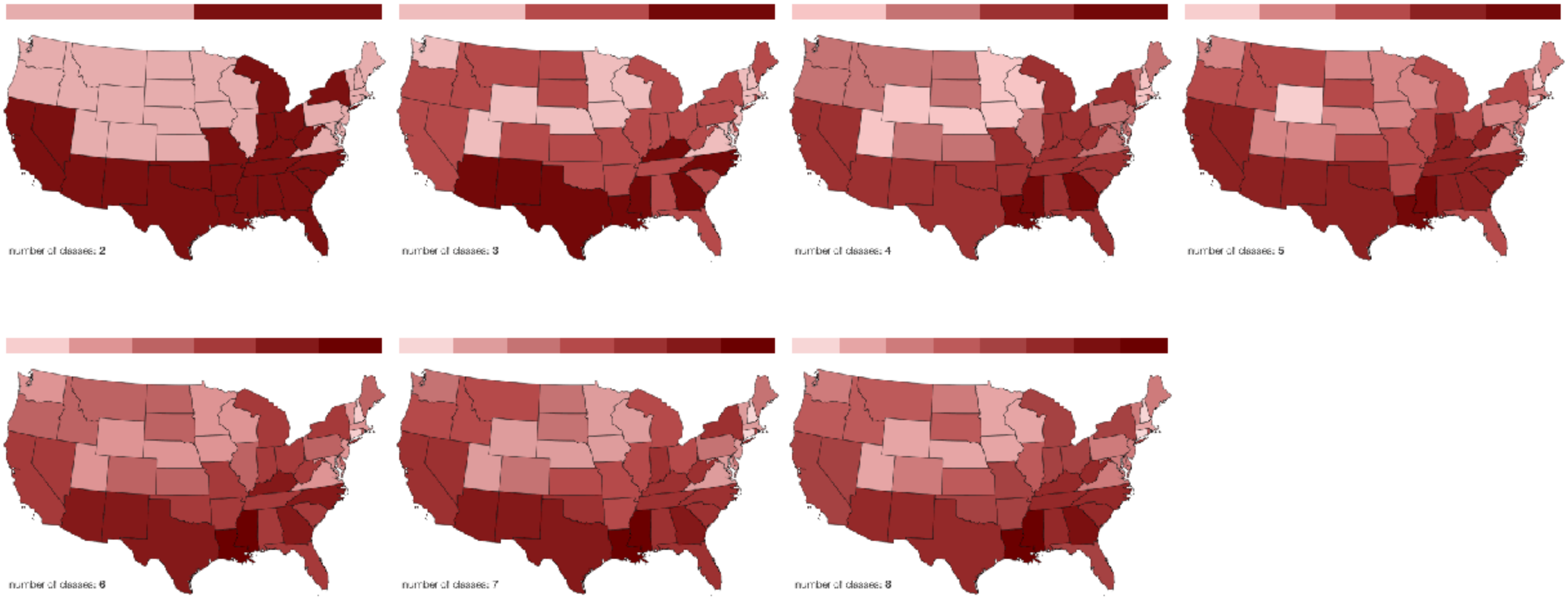
Cancer	Connective tissue	Cardiovascular	Endocrine	Gastrointestinal	Ear, nose, throat	Developmental	Multiple types
Bone	Muscular	Hematological	Immunological	Nutritional	Ophthalmological	Neurological	Unclassified
Skeletal	Dermatological	Renal		Metabolic	Respiratory	Psychiatric	





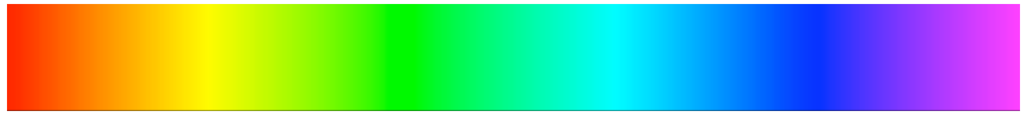
https://archive.nytimes.com/www.nytimes.com/interactive/2008/05/05/science/20080506_DISEASE.html

Ordered color: limited number of discriminable bins



[Gregor Aisch, vis4.net/blog/posts/choropleth-maps/](vis4.net/blog/posts/choropleth-maps/)

Ordered color: Rainbow is poor default



- problems
  - perceptually unordered
  - perceptually nonlinear

Ordered color: Rainbow is poor default

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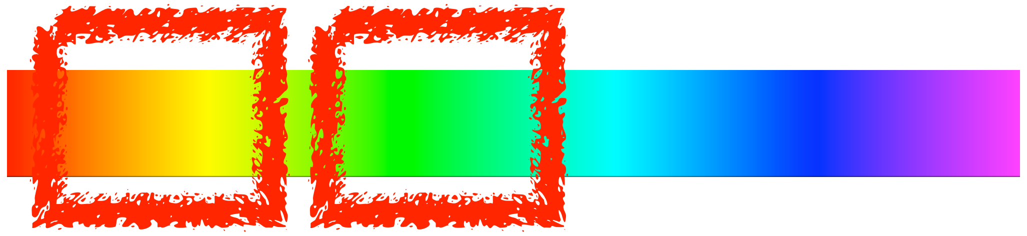

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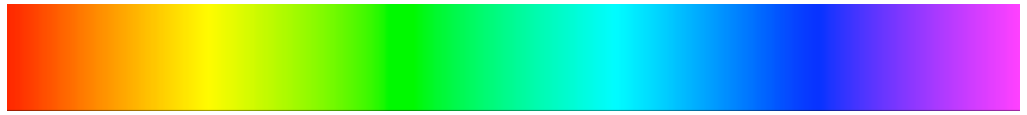
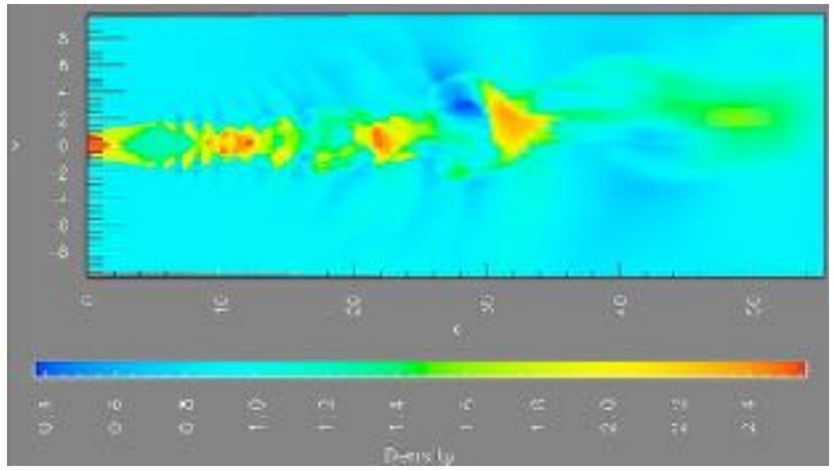
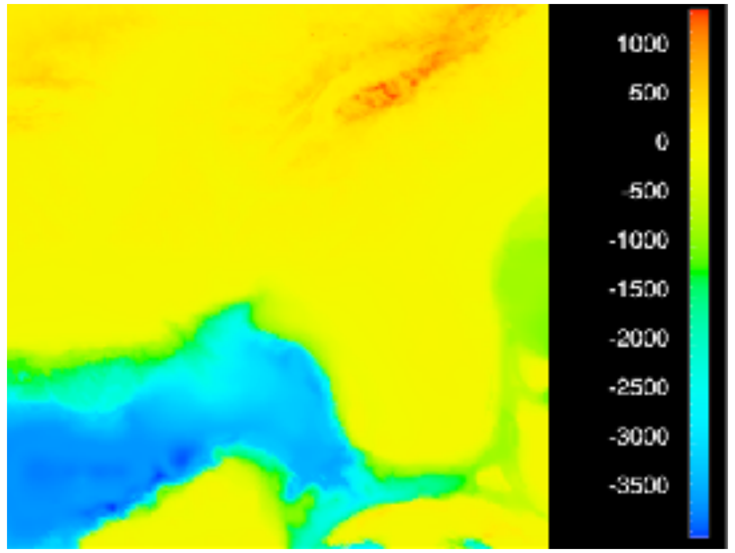
  - fine-grained structure visible and nameable





[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]

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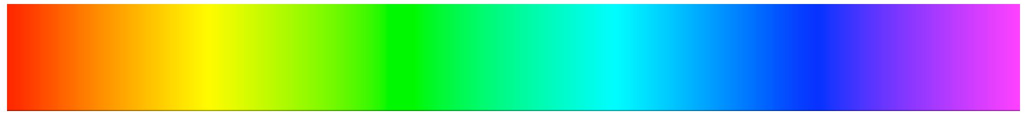

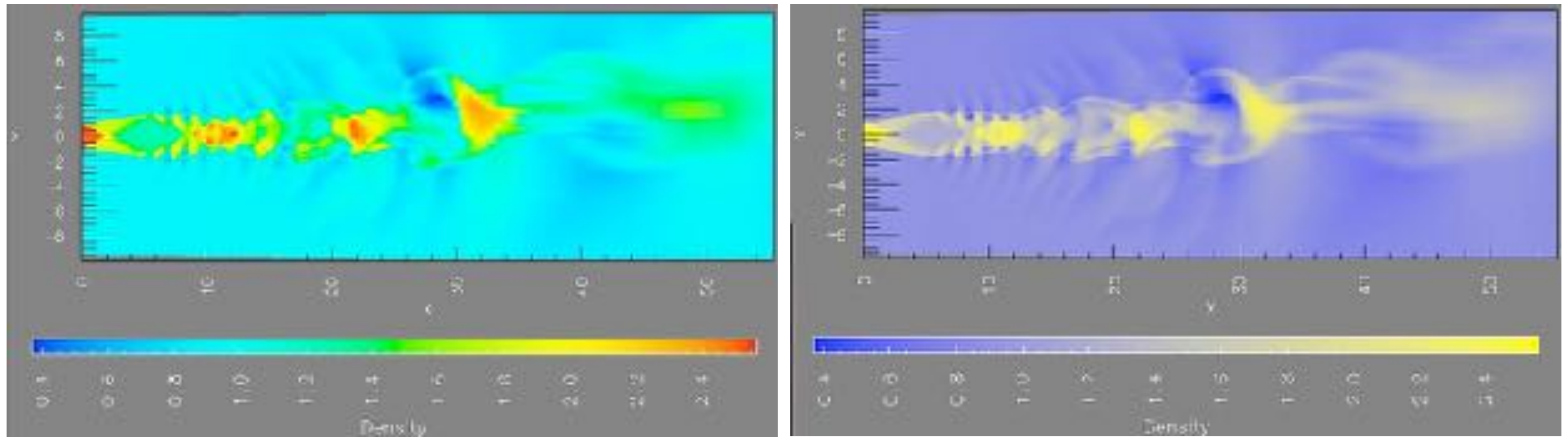

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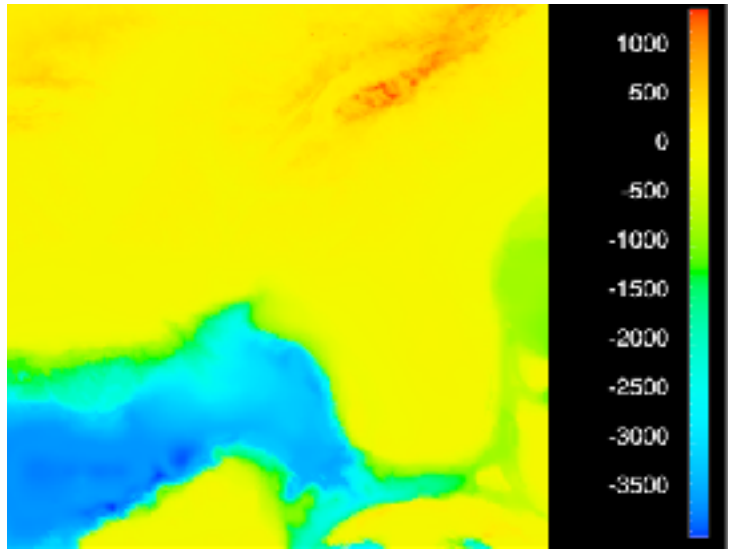

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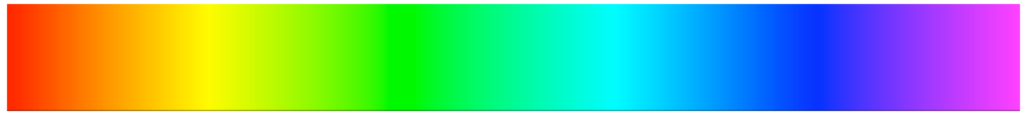
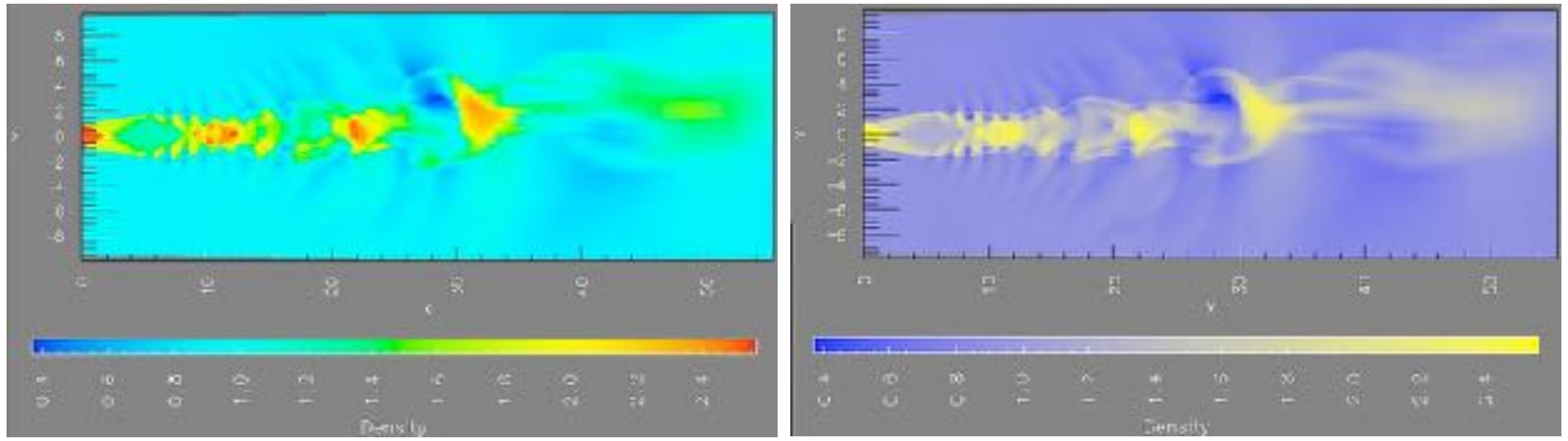
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]





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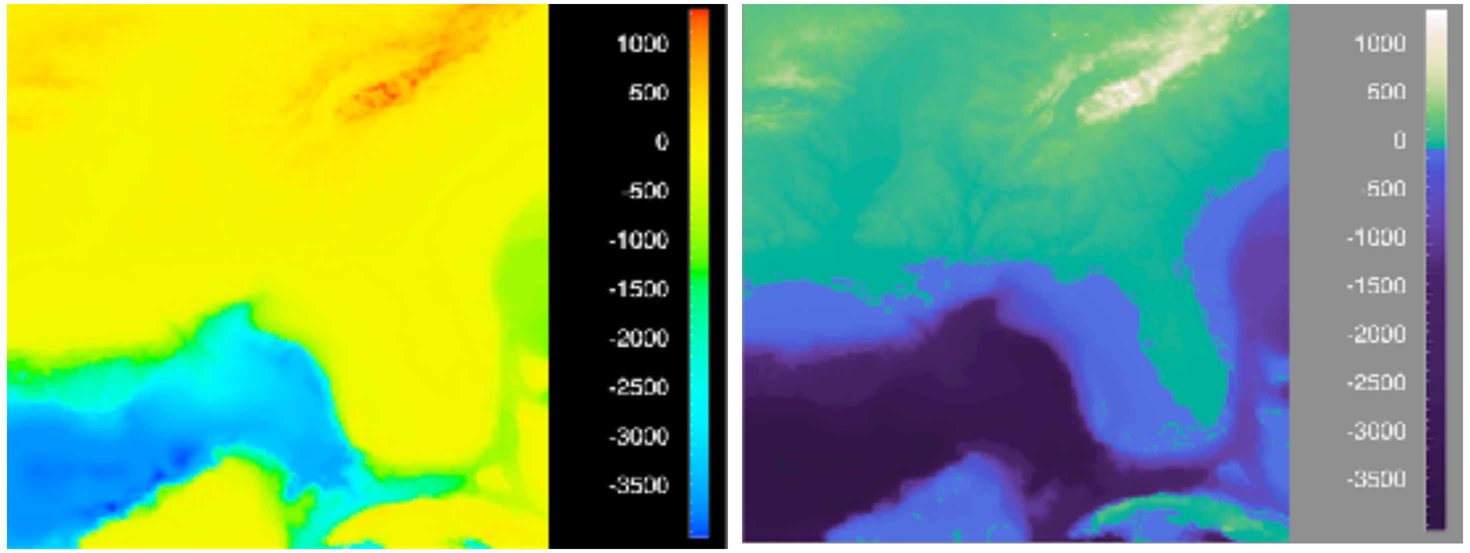
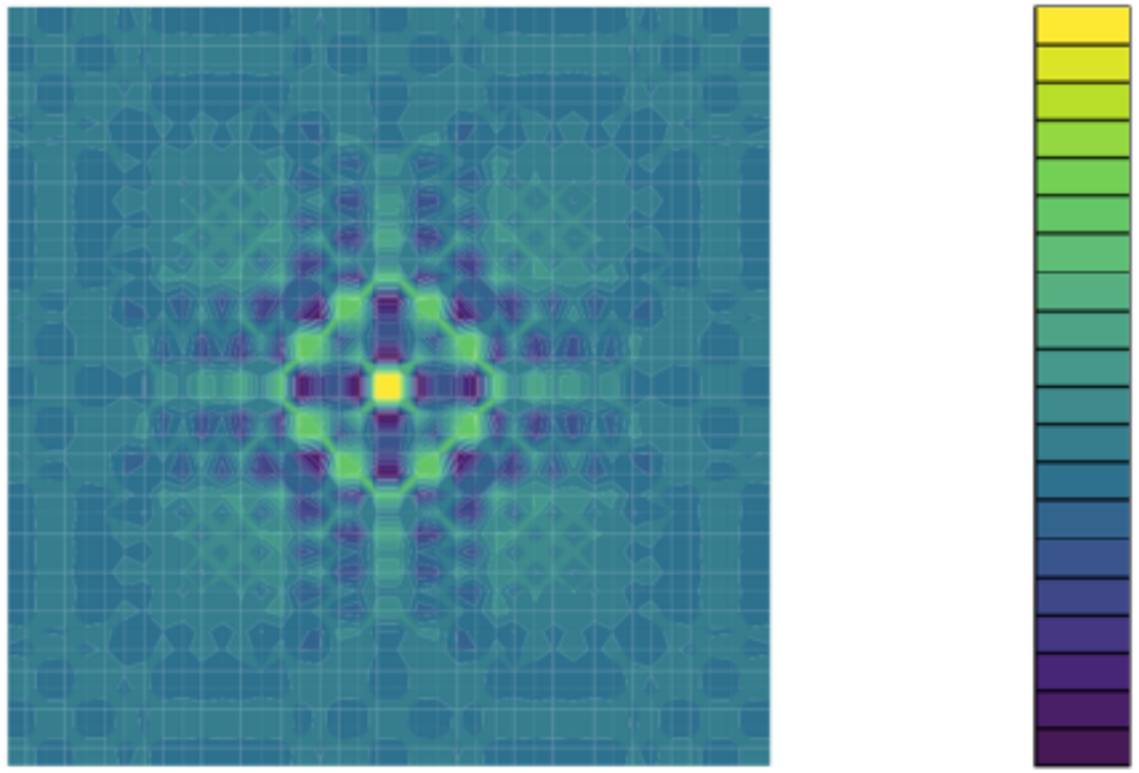
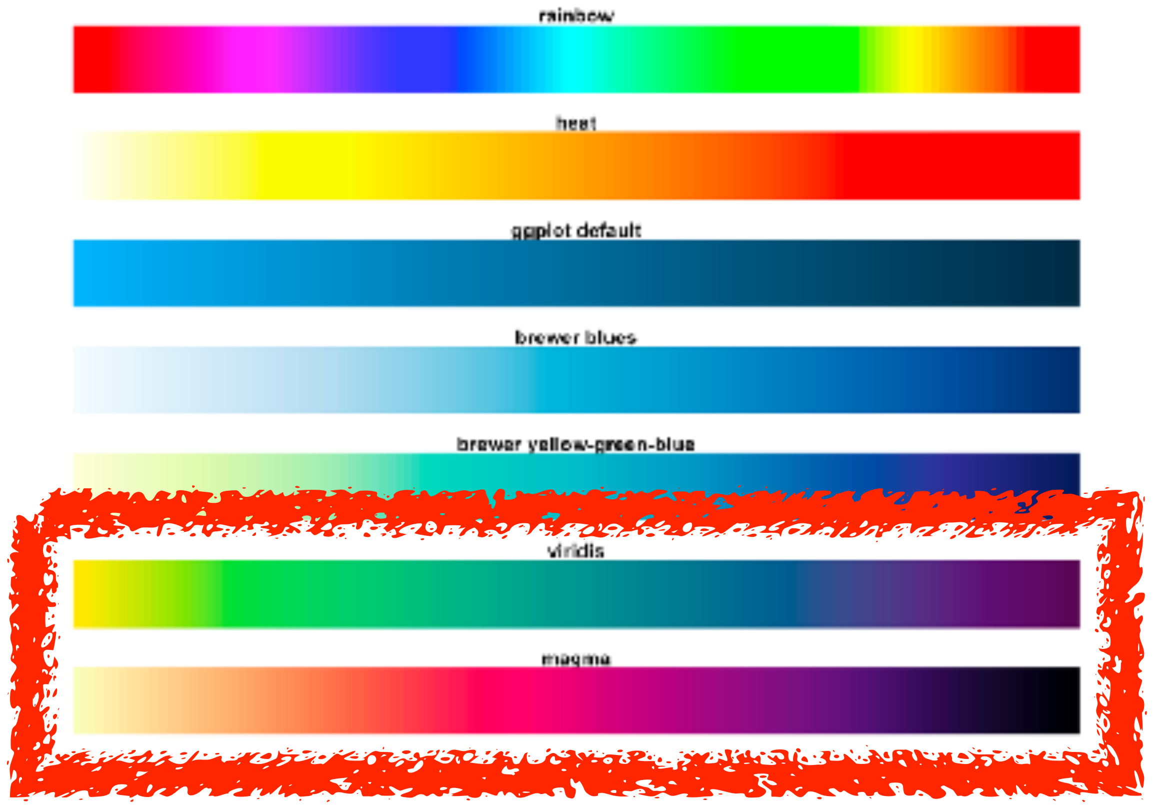


[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

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

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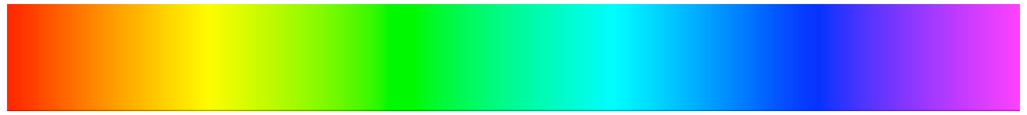

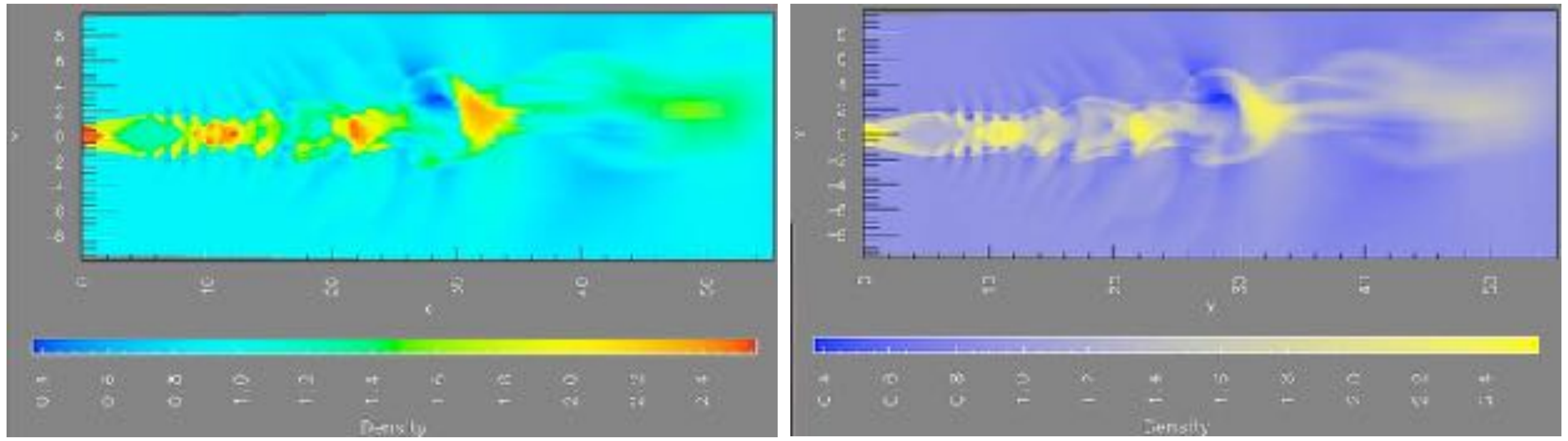

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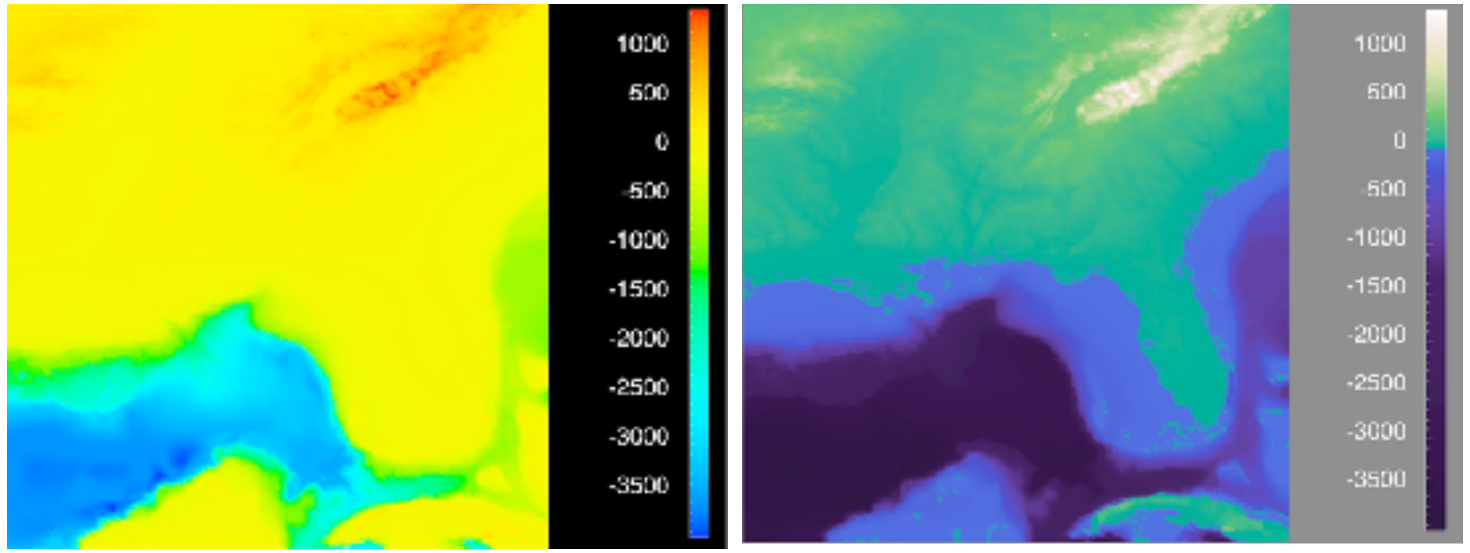
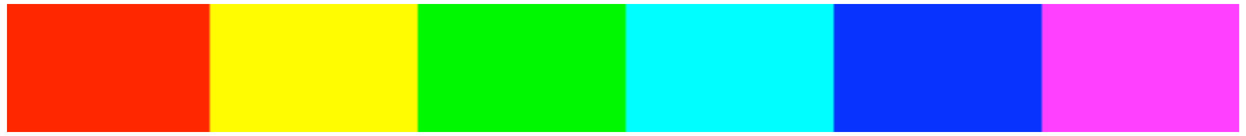
- benefits
  - fine-grained structure visible and nameable
- alternatives
  - large-scale structure: fewer hues
  - fine structure: multiple hues with monotonically increasing luminance [eg viridis]
- legit for categorical
  - segmented saturated rainbow is good!



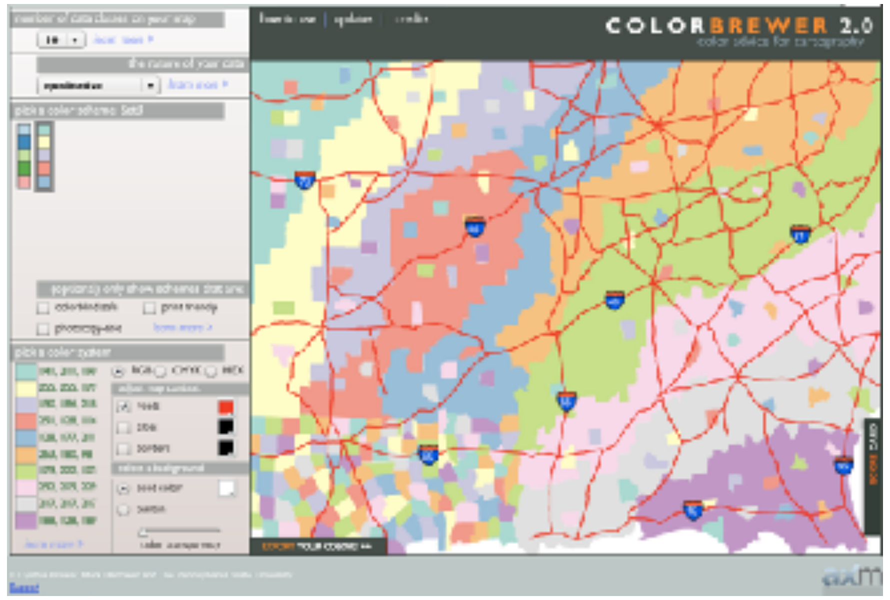
[Why Should Engineers Be Worried About Color? Treinish and Rogowitz 1998. http://www.research.ibm.com/people/l/lloydt/color/color.HTM]

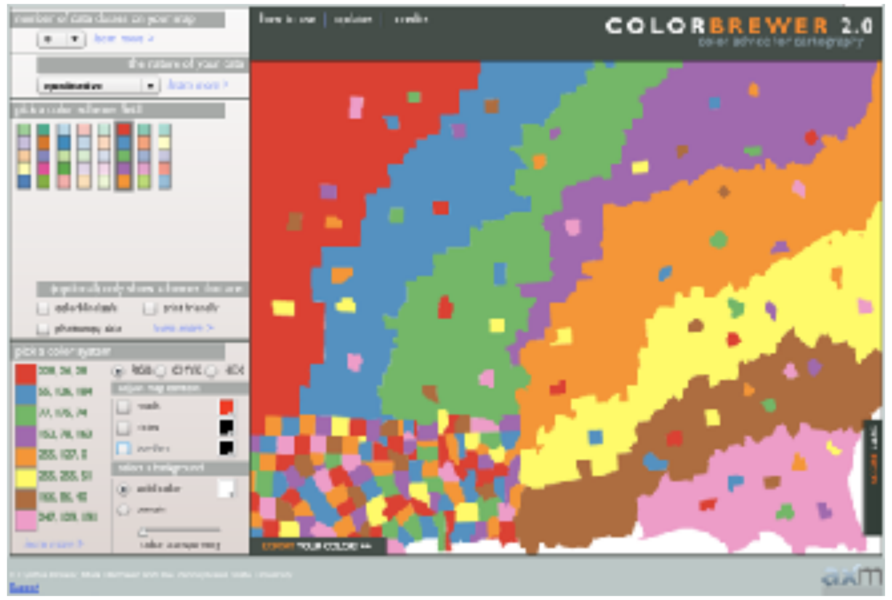


[Transfer Functions in Direct Volume Rendering: Design, Interface, Interaction. Kindlmann. SIGGRAPH 2002 Course Notes]

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/

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- saturation & luminance:
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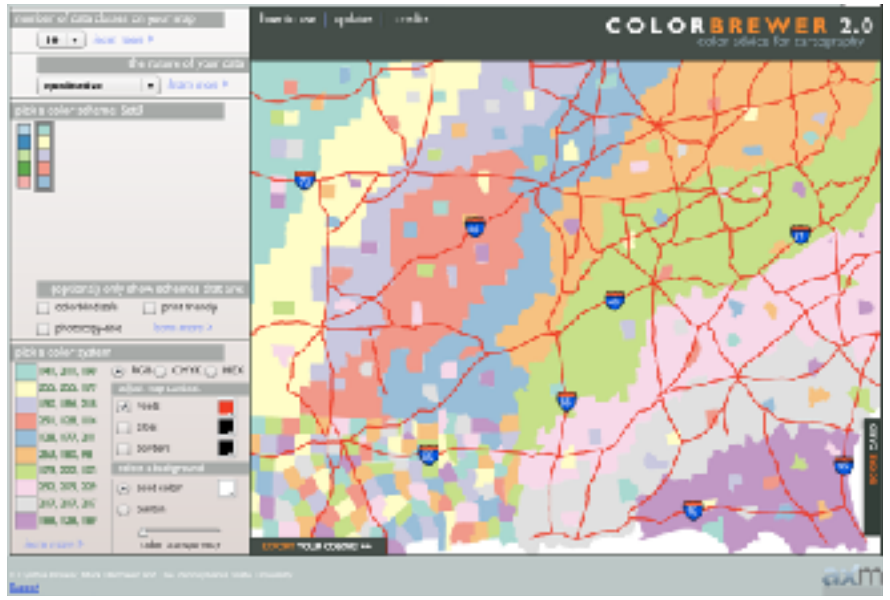
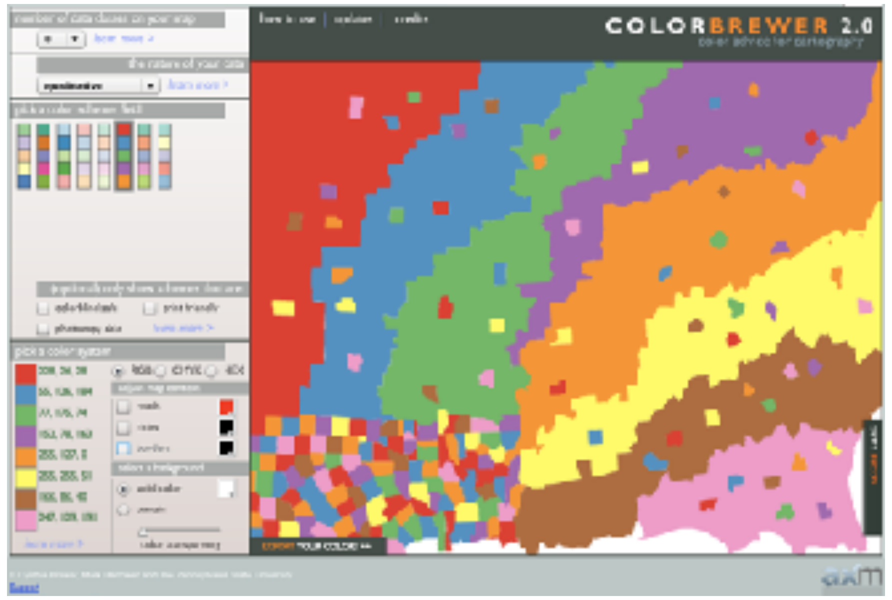
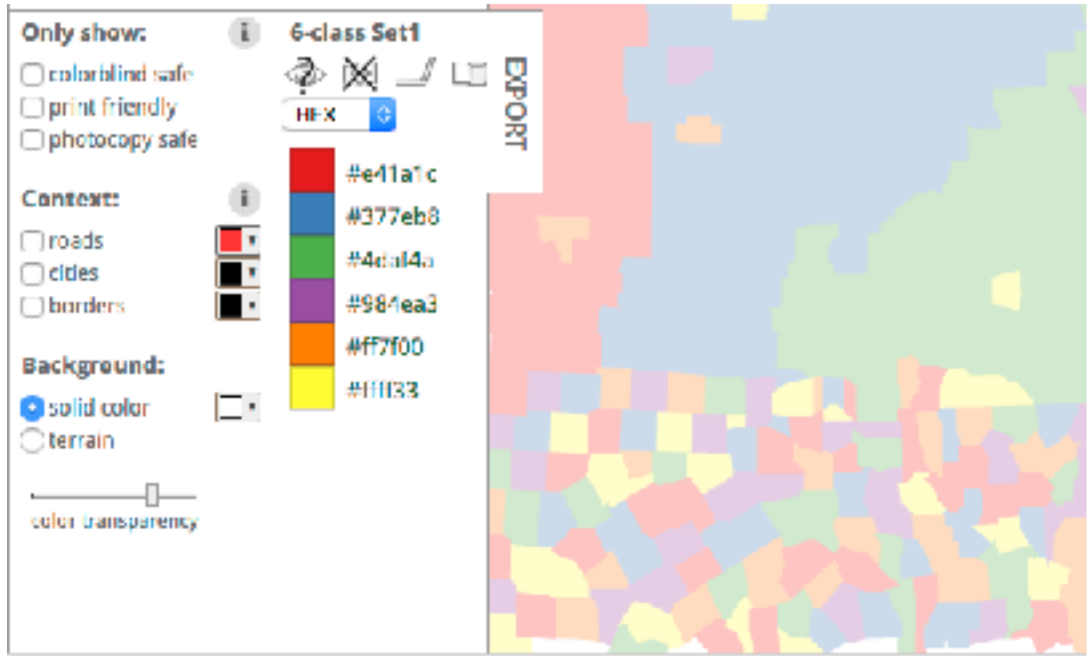
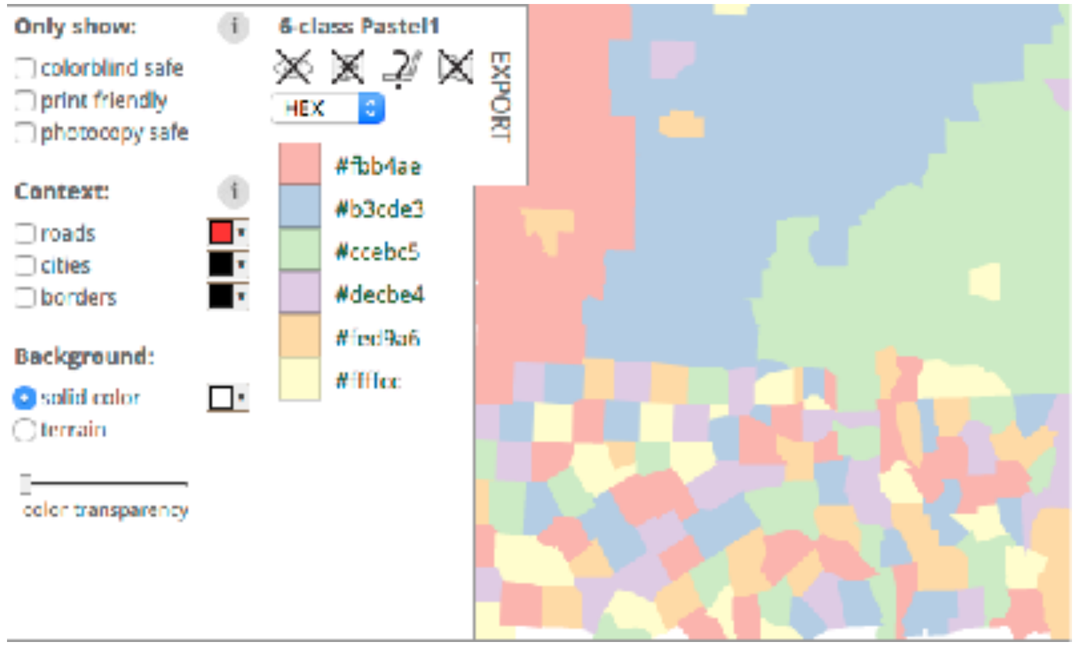
  - also not separable from transparency









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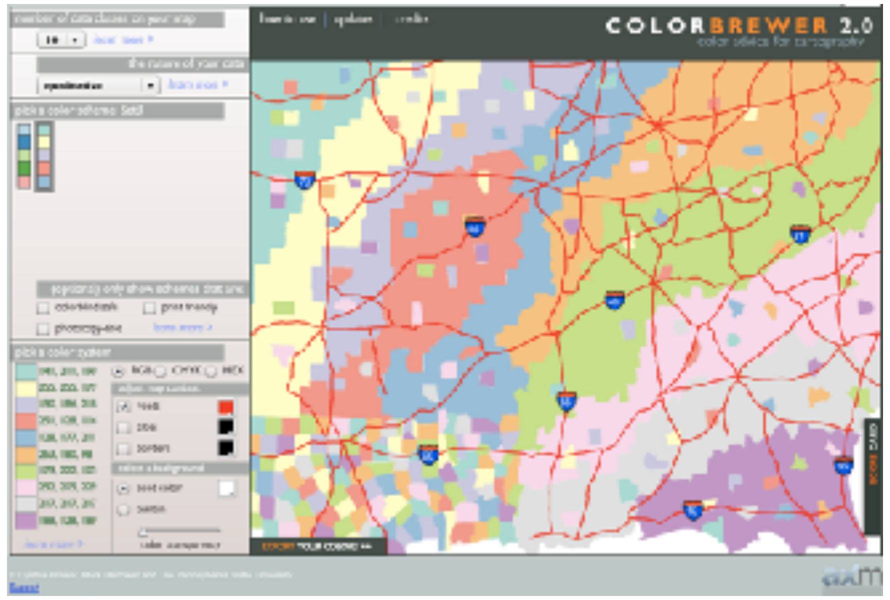
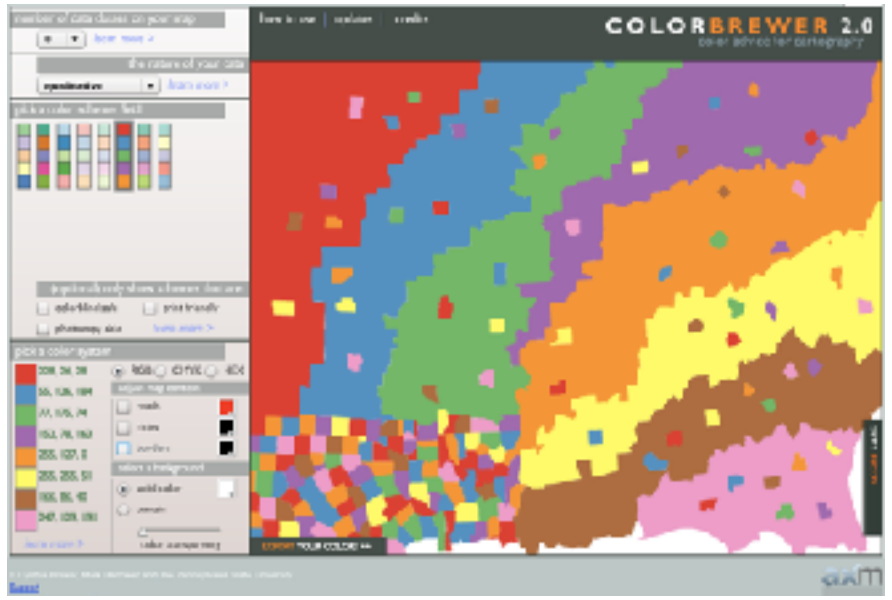
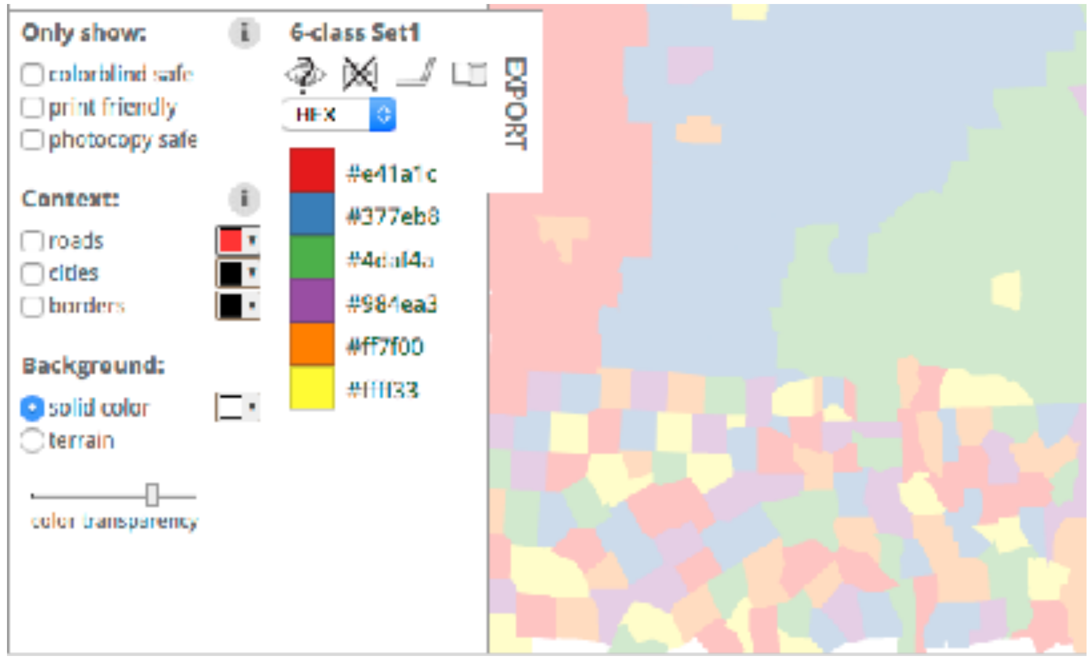
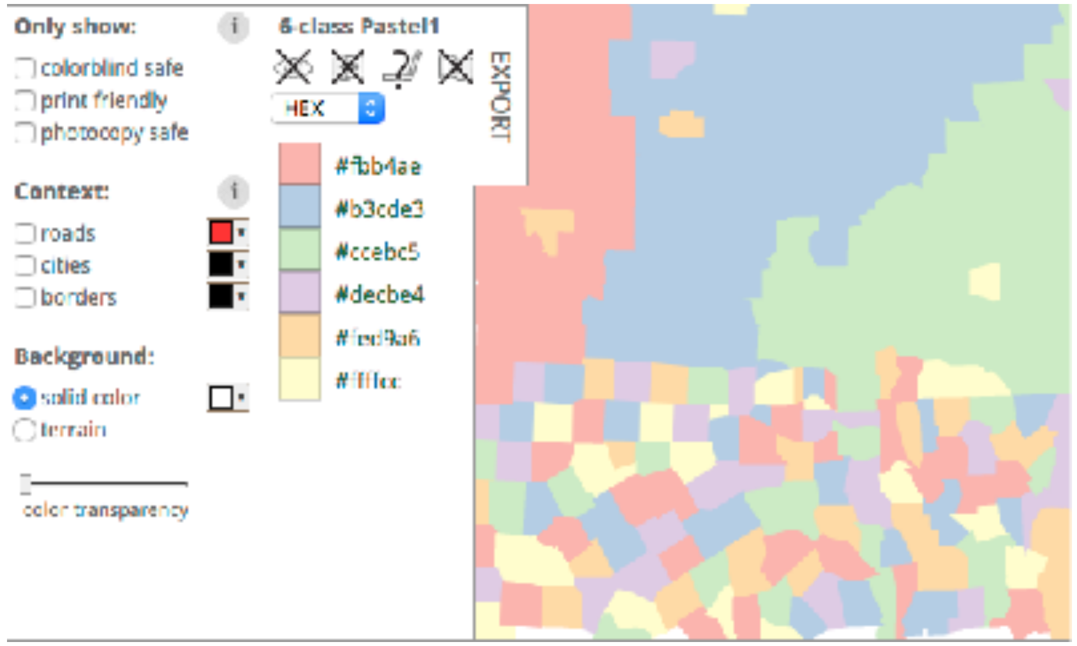
Interaction between channels: Not fully separable

- 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)







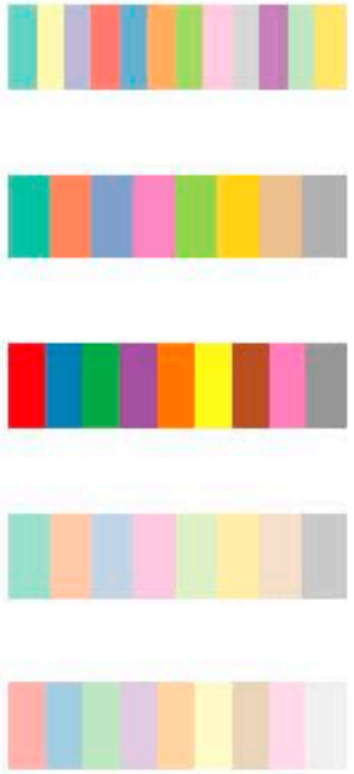


http://colorbrewer2.org/

Color Palettes

Color palettes: univariate

➔ Categorical



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

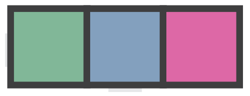
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

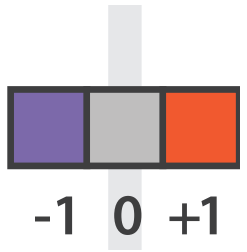
Color palettes: univariate

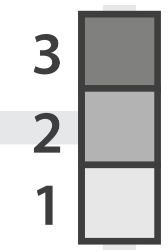
➔ Categorical

➔ Ordered

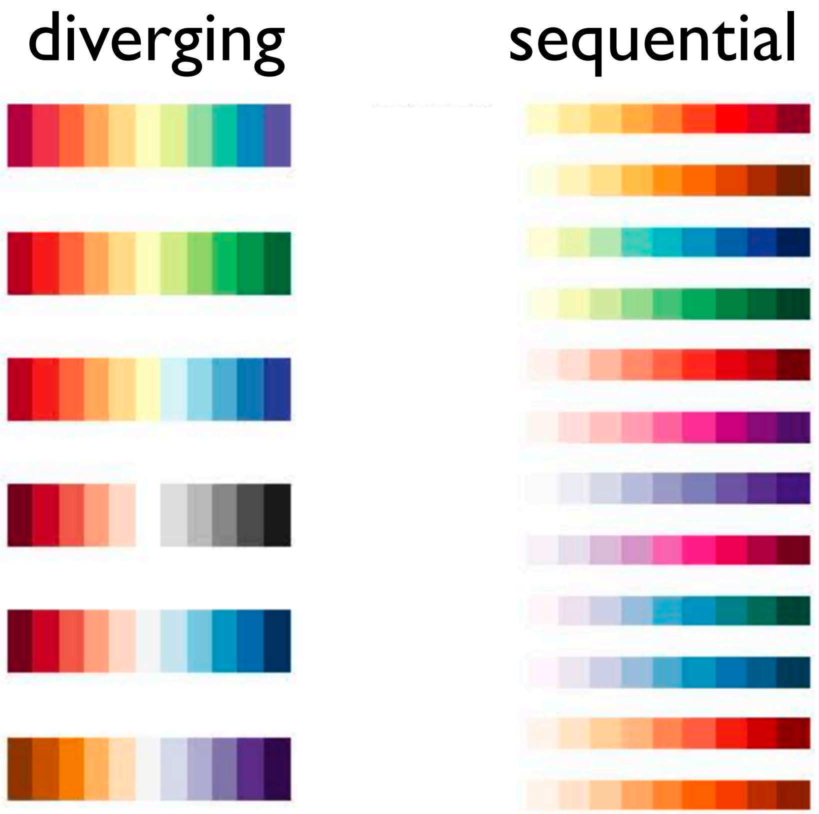
➔ *Sequential* ➔ *Diverging*







- 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

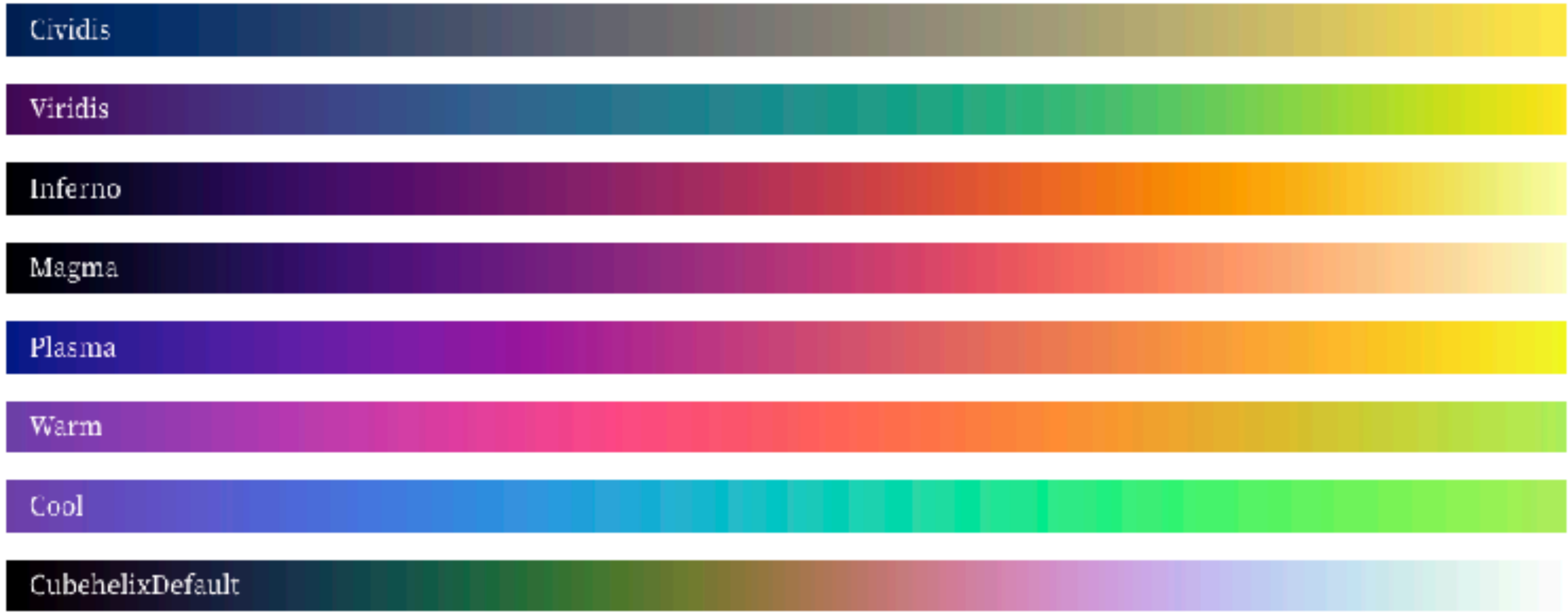


after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

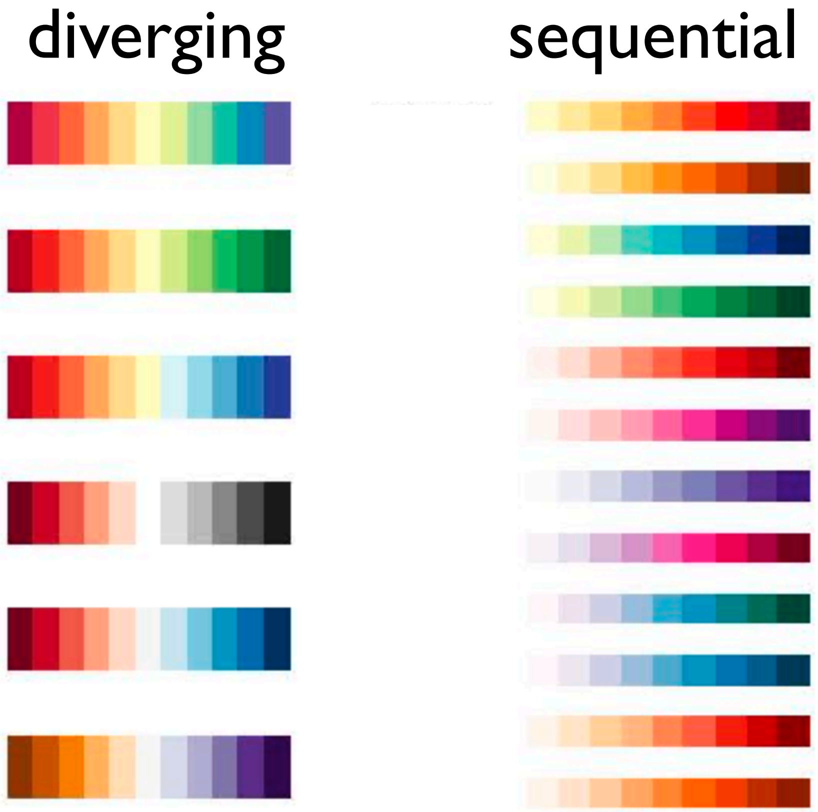
Color palettes: univariate

- 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



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

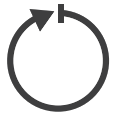
➔ Categorical

➔ Ordered

➔ *Sequential*

➔ *Diverging*

➔ Cyclic



cyclic multihue

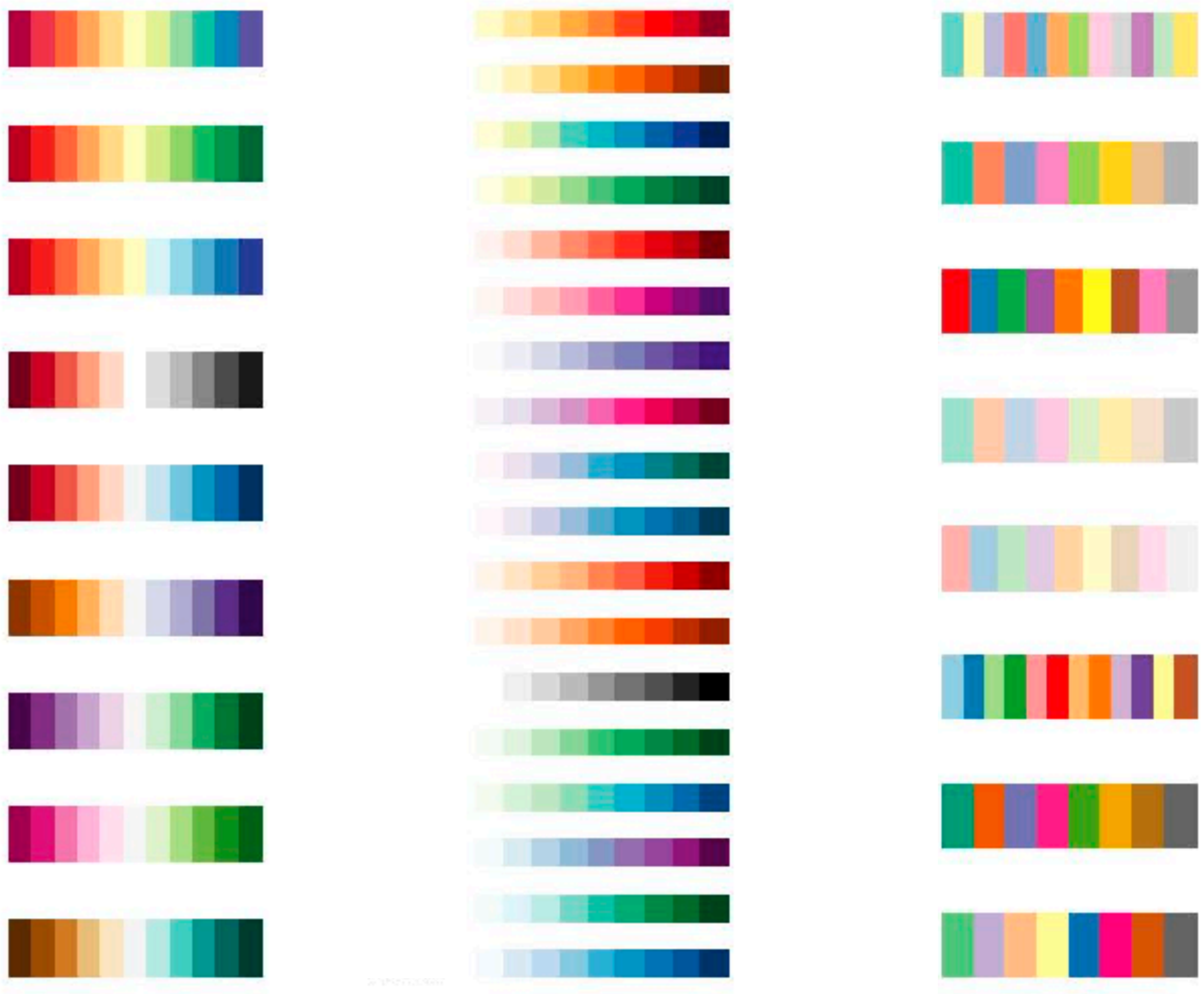
https://github.com/d3/d3-scale-chromatic

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

sequential single hue

diverging two hue

sequential multihue

cyclic multihue

- 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

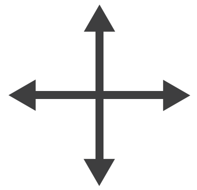
Colormaps: bivariate

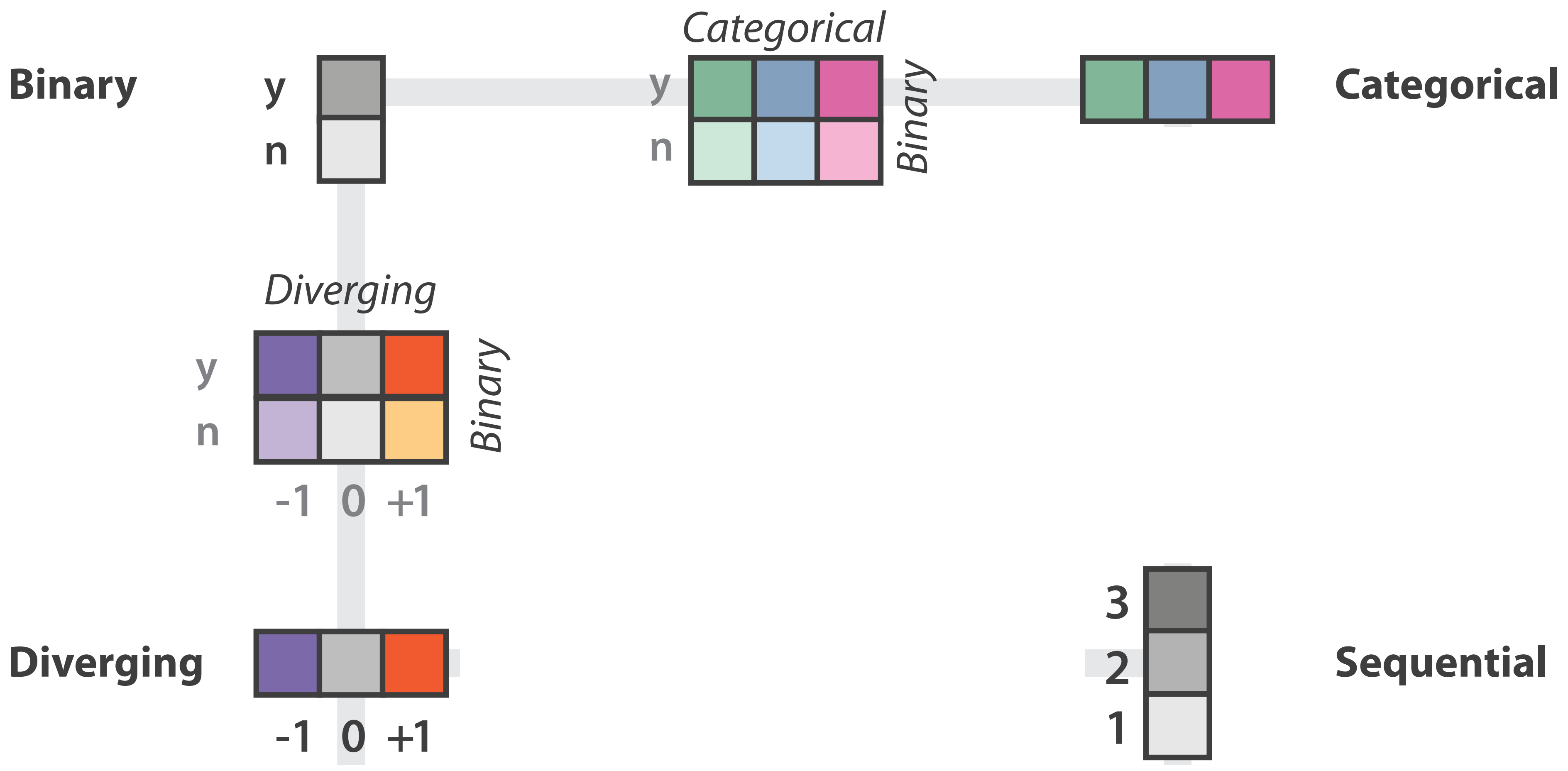
- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*

  - ➔ *Diverging*

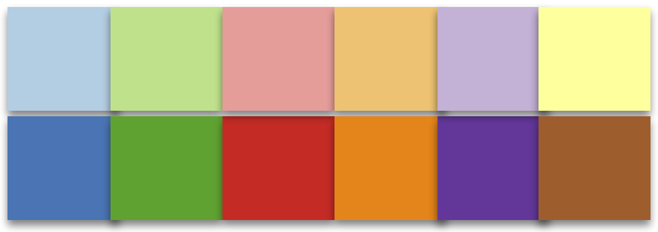
- ➔ Bivariate





- bivariate best case
  - binary in one of the directions

d3.schemePaired <>



binary saturation

categorical hue

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

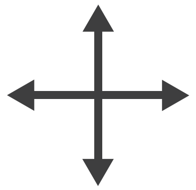
Colormaps: bivariate

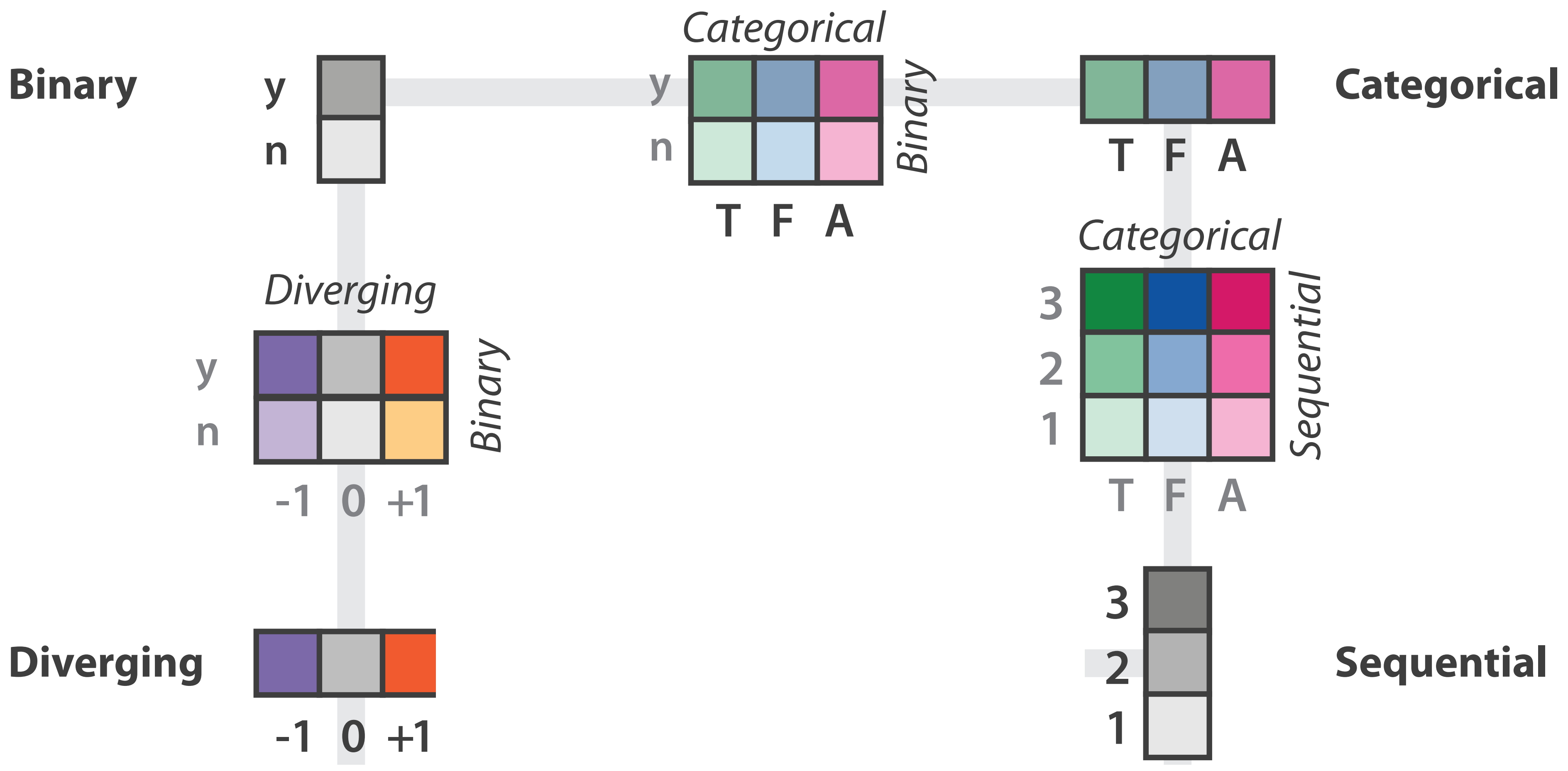
- ➔ Categorical

- ➔ Ordered
  - ➔ *Sequential*

  - ➔ *Diverging*

- ➔ Bivariate





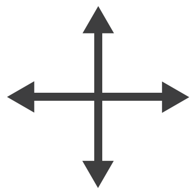
after [Color Use Guidelines for Mapping and Visualization. Brewer, 1994. http://www.personal.psu.edu/faculty/c/a/cab38/ColorSch/Schemes.html]

Colormaps

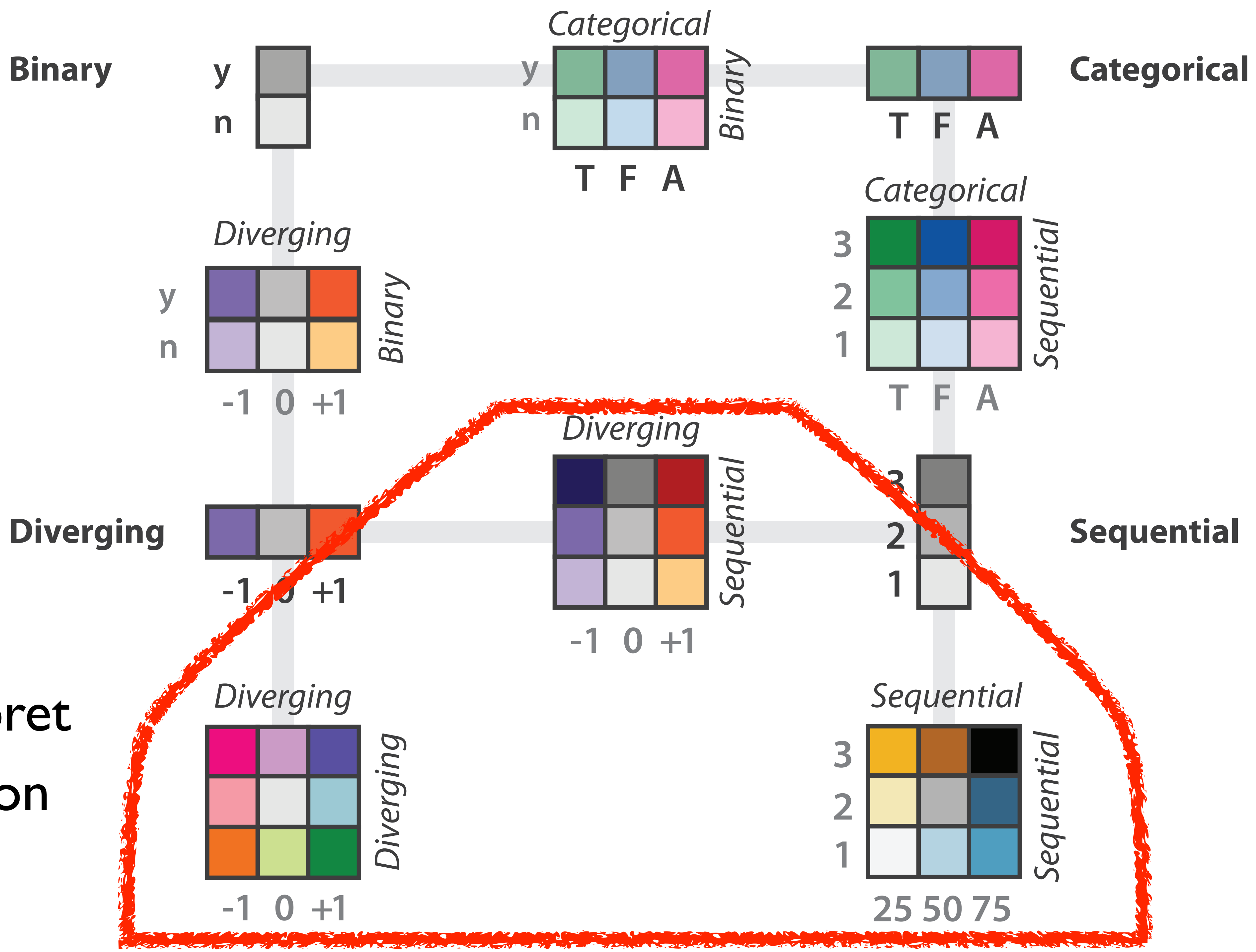
- Categorical

- Ordered
  - *Sequential*
  - *Diverging*

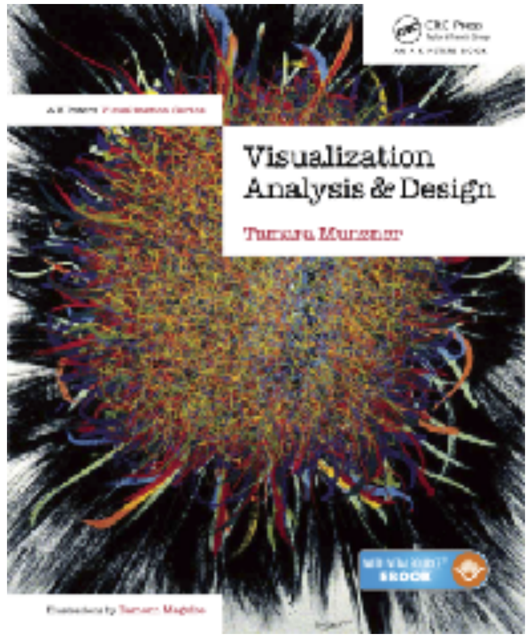
- Bivariate



use with care!



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



Visualization Analysis & Design

Color (Ch 10) II

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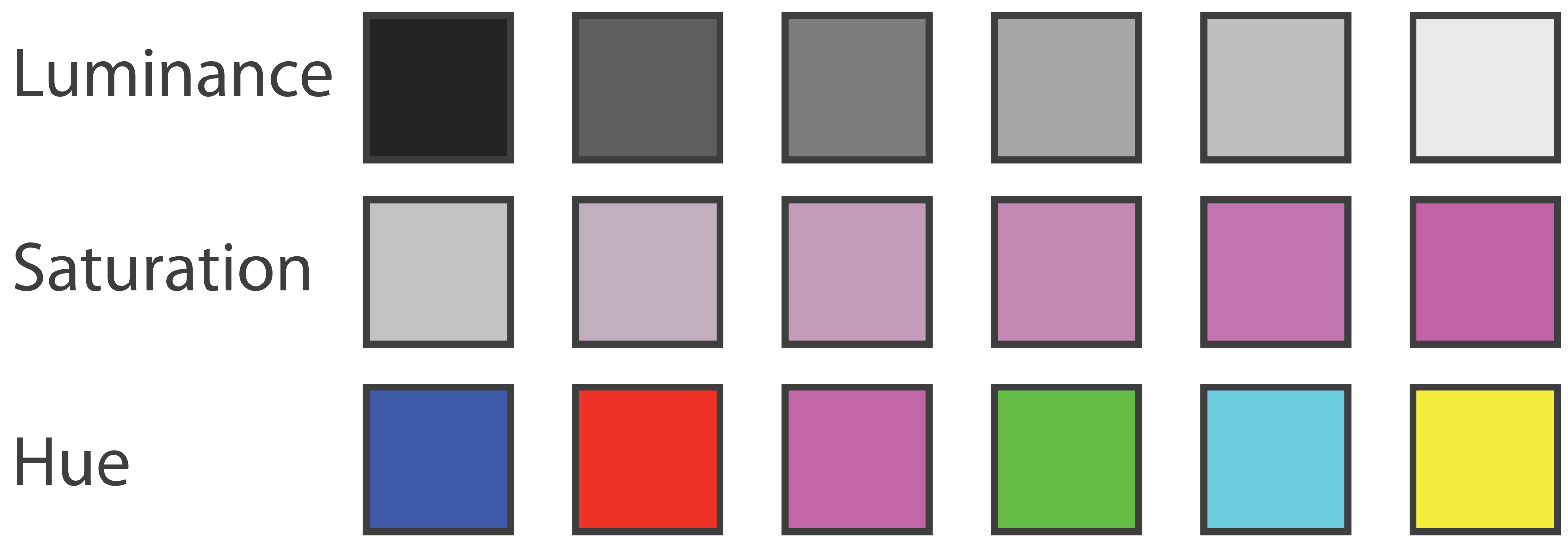
Decomposing color

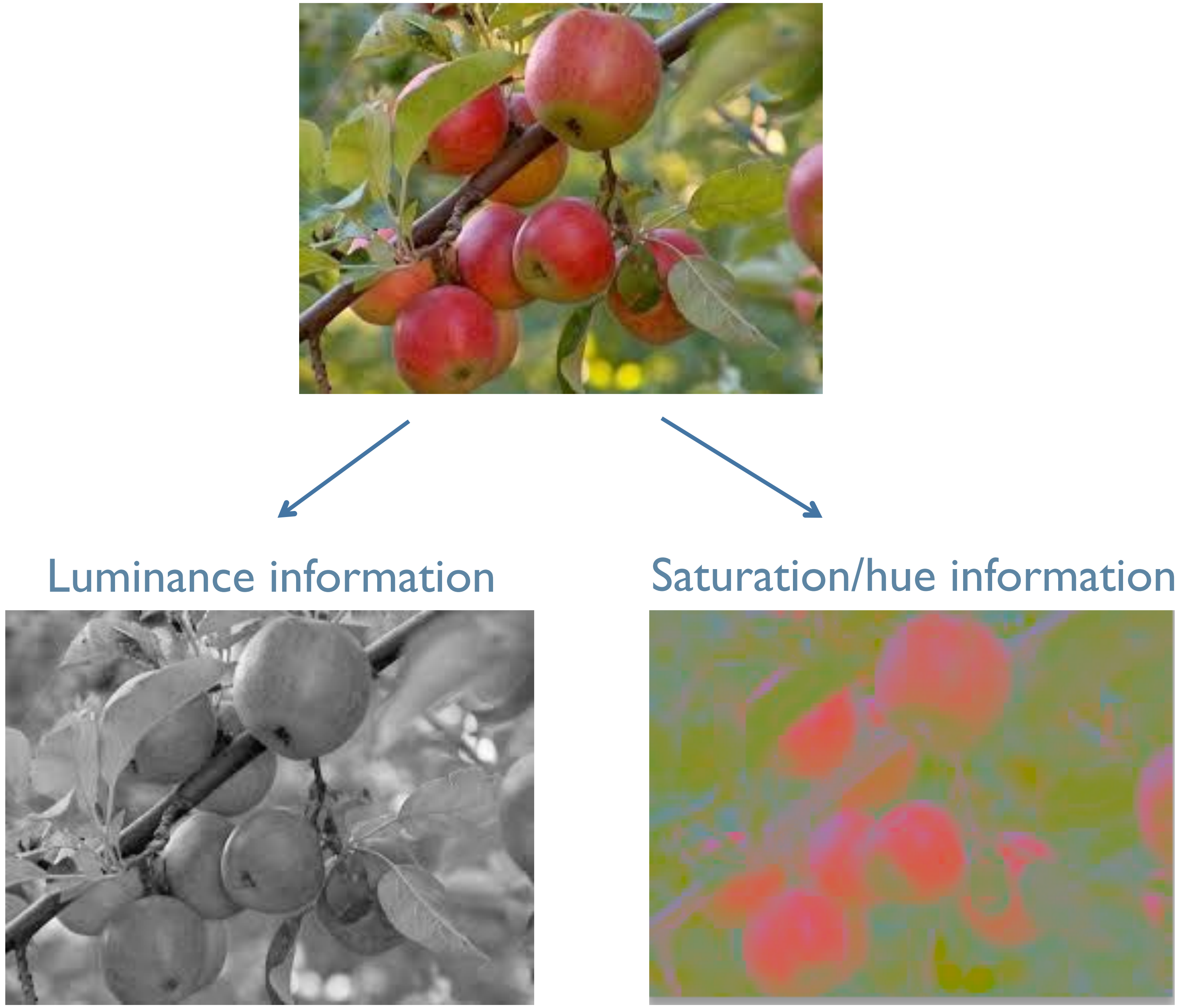
- decompose into three channels
  - ordered can show magnitude
    - **luminance**: how bright (B/W)
    - **saturation**: how colourful
  - categorical can show identity
    - **hue**: what color



Color Deficiency

Luminance

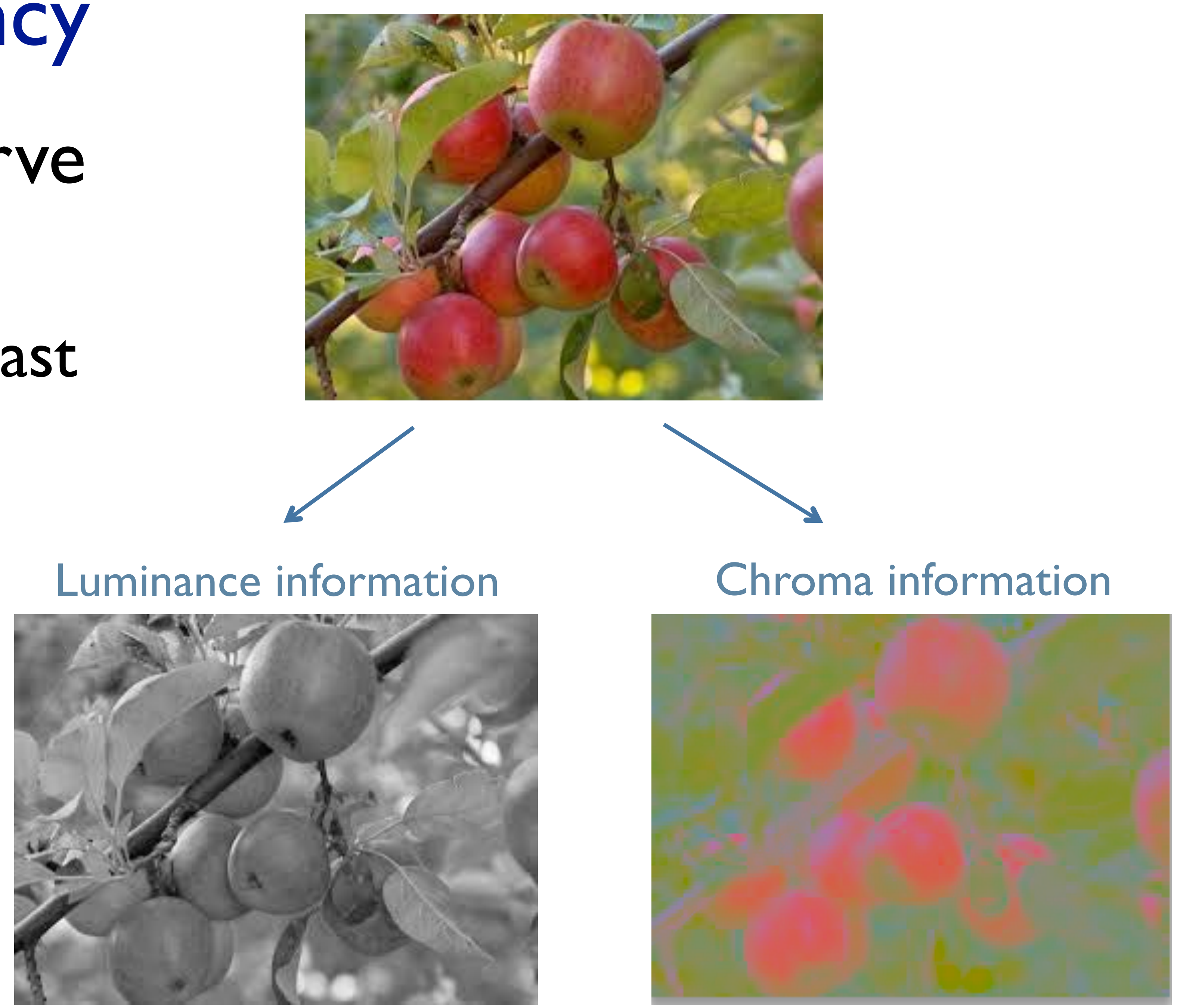
- need luminance for edge detection
  - fine-grained detail only visible through luminance contrast
  - legible text requires luminance contrast!



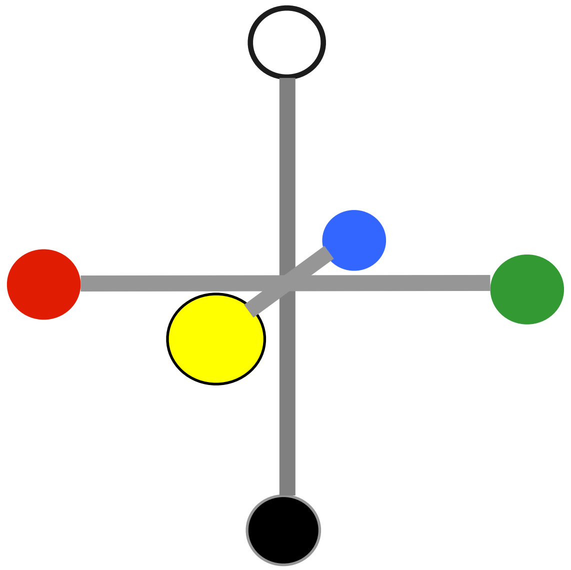
[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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*)

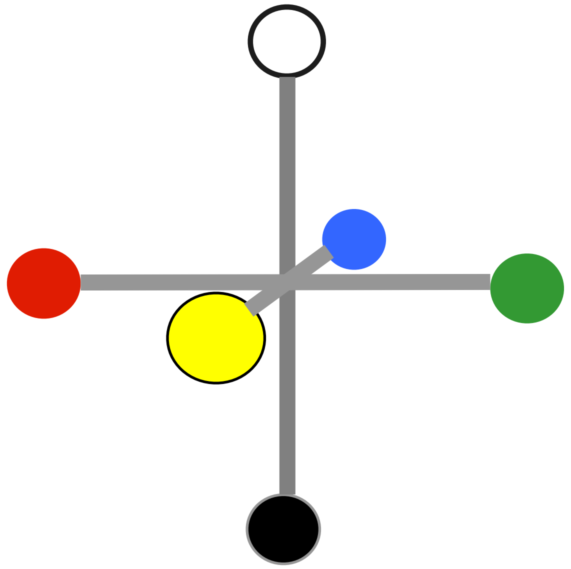


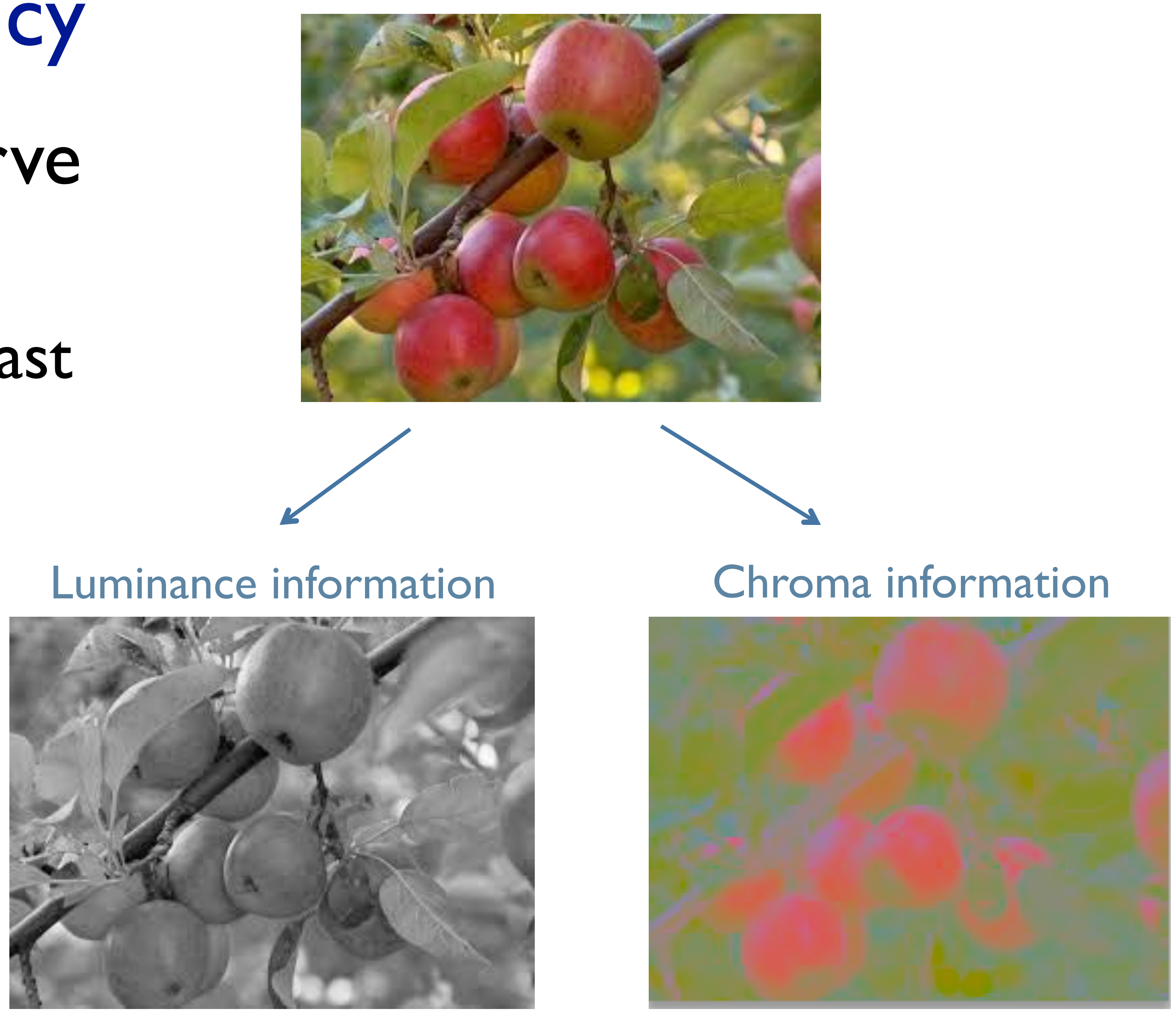
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]



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



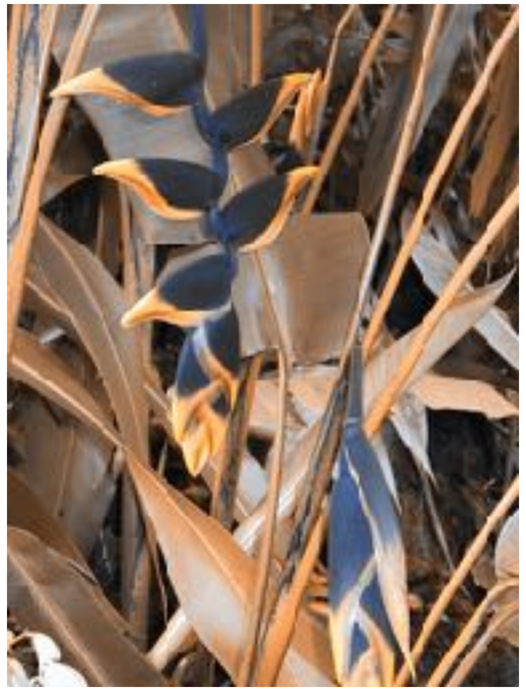


[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

Designing for color deficiency: Check with simulator

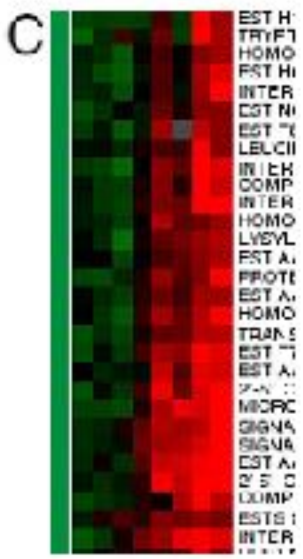
Normal vision

Deuteranope
green-weak



Protanope
red-weak

Tritanope
blue-weak

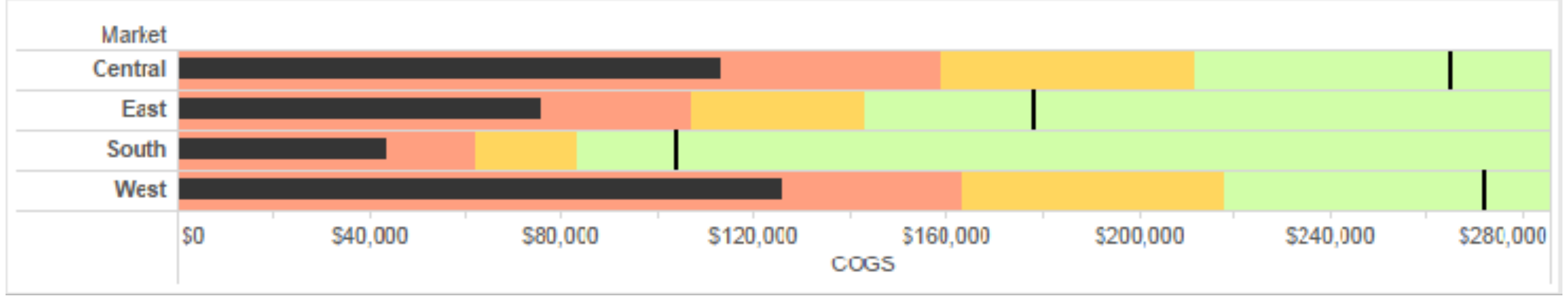


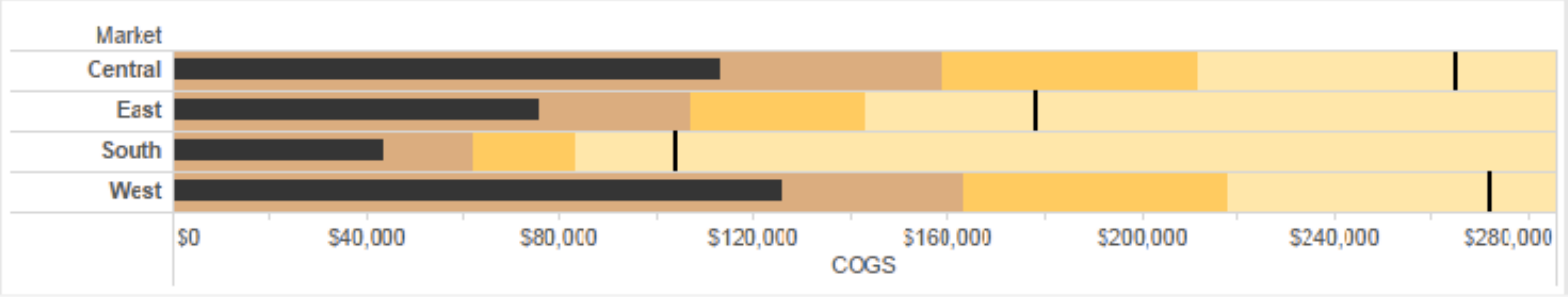
https://www.color-blindness.com/coblis-color-blindness-simulator/

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

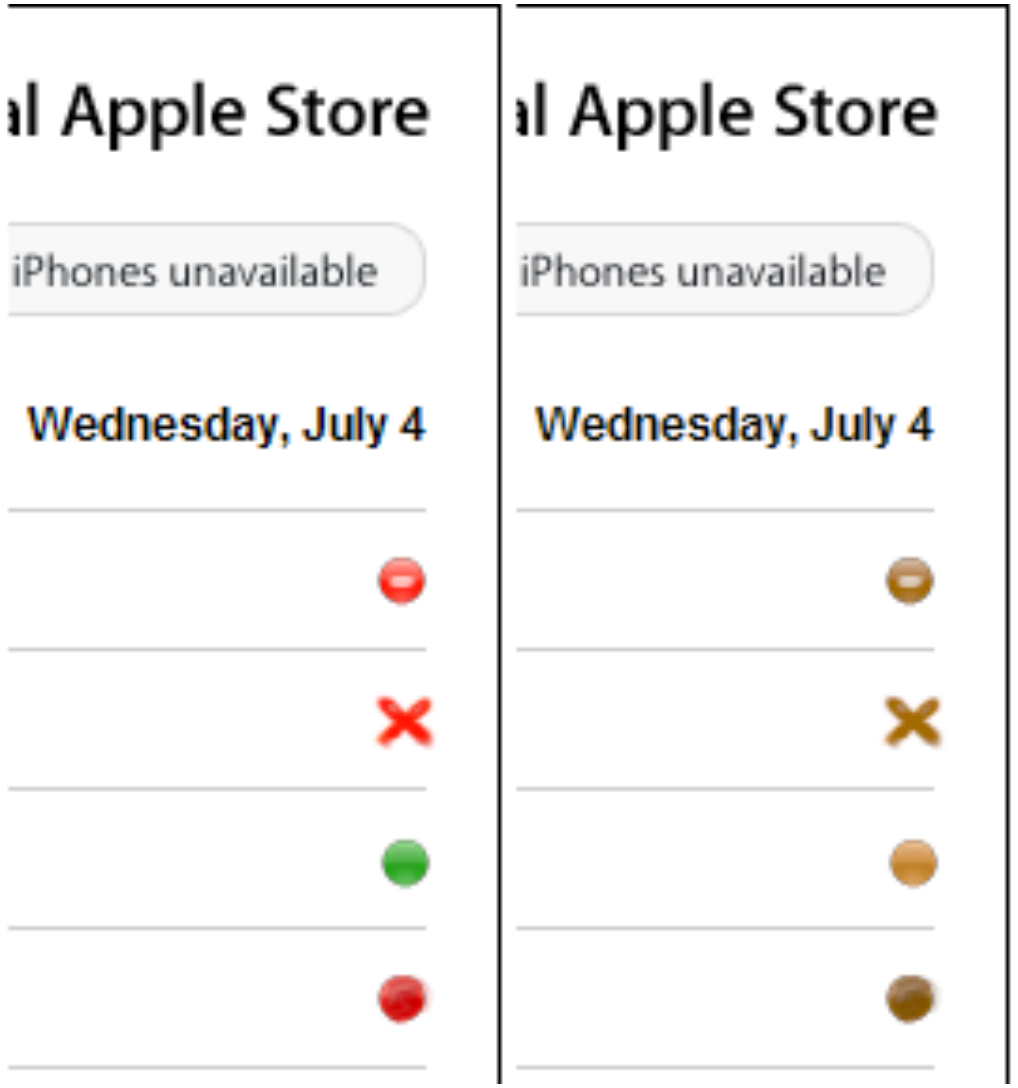
Designing for color deficiency: Avoid encoding by hue alone

- redundantly encode
  - vary luminance
  - change shape





Deuteranope simulation

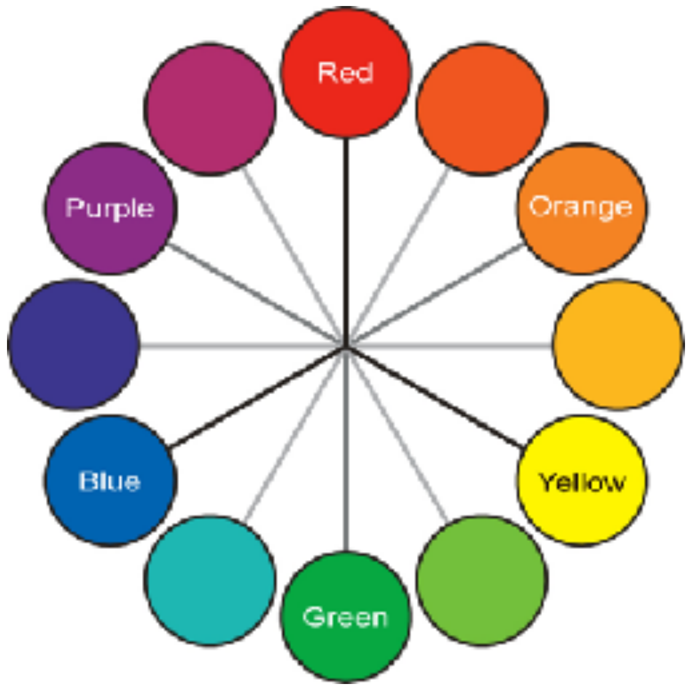


Change the shape

Vary luminance

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

Color deficiency: Reduces color to 2 dimensions



Normal

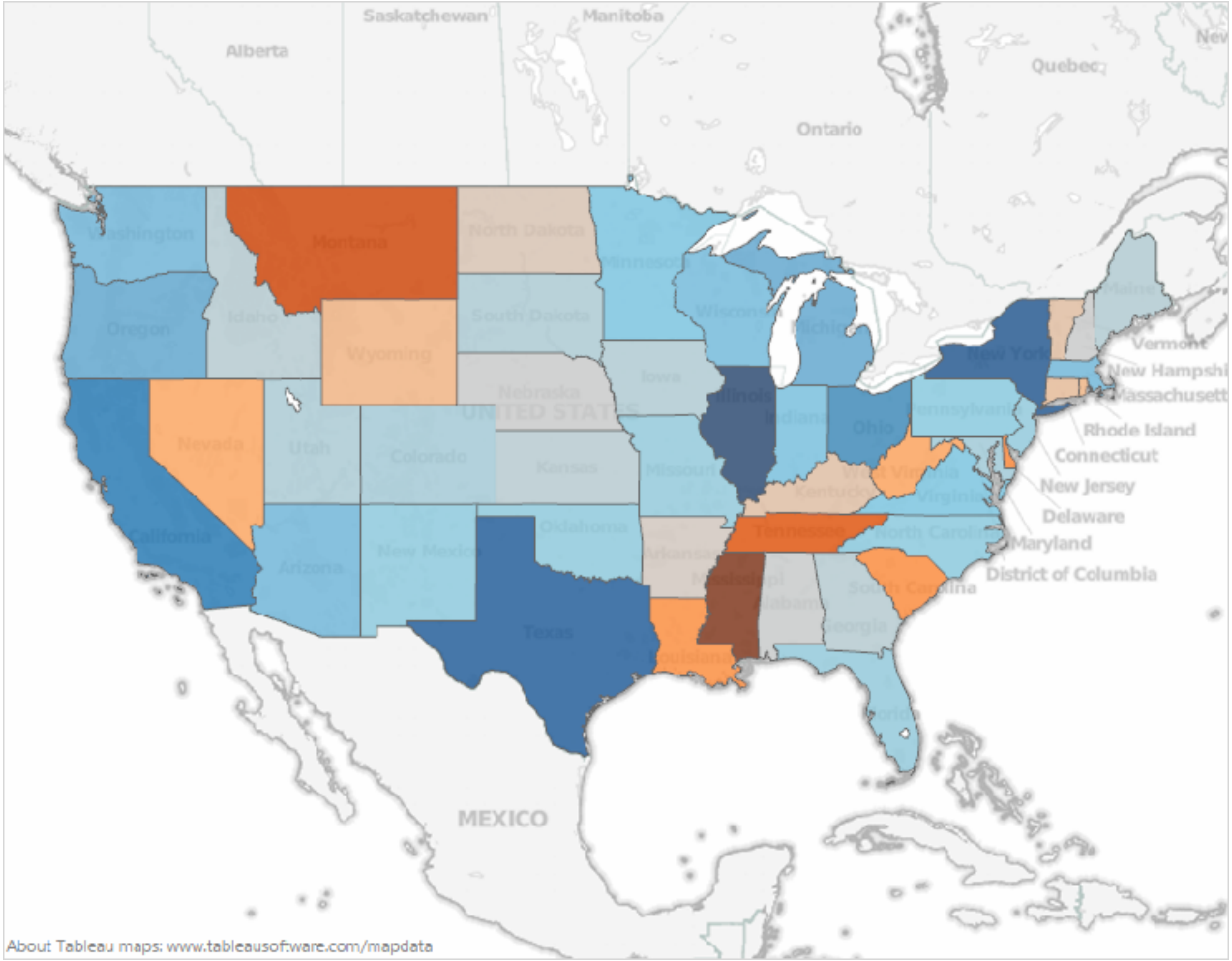
Protanope

Deuteranope

Tritanope

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

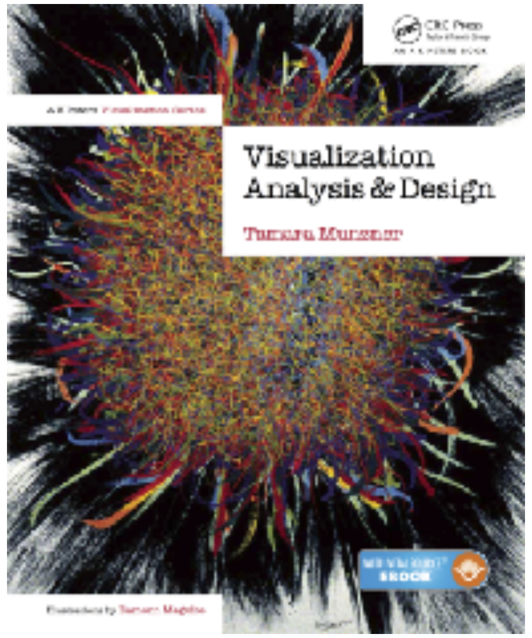
Designing for color deficiency: Blue-Orange is safe



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

Visualization Analysis & Design

Color (Ch 10) III



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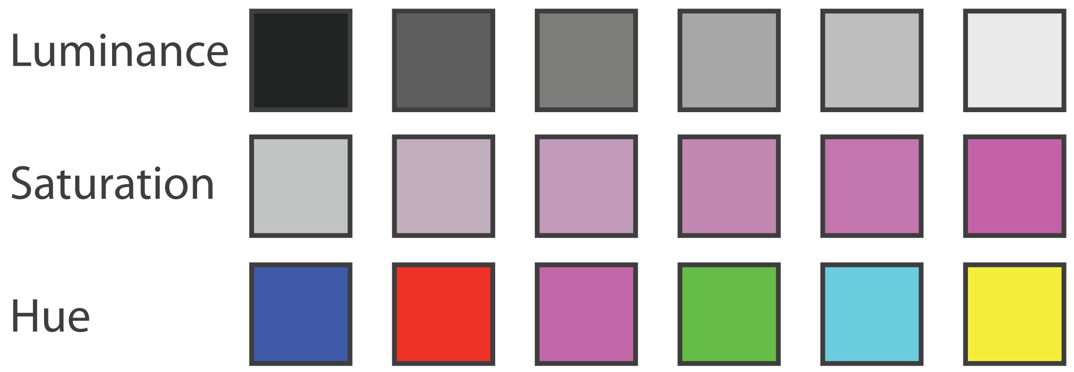
@tamaramunzner

Color Spaces

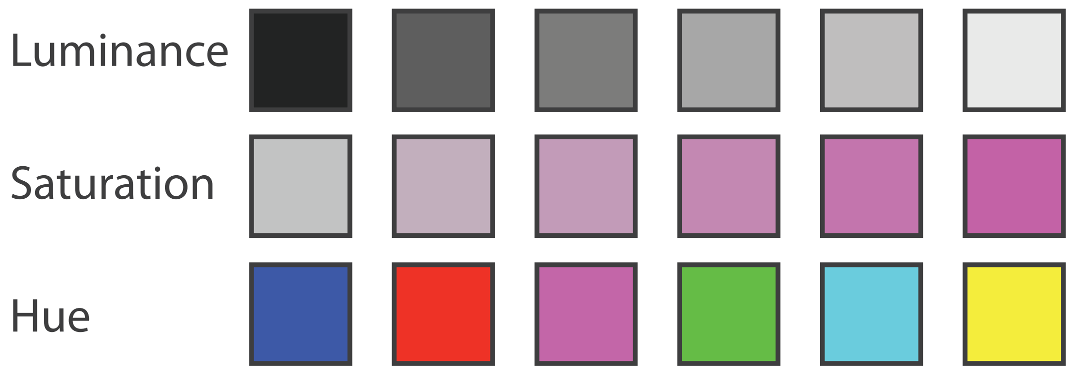
Many color spaces

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



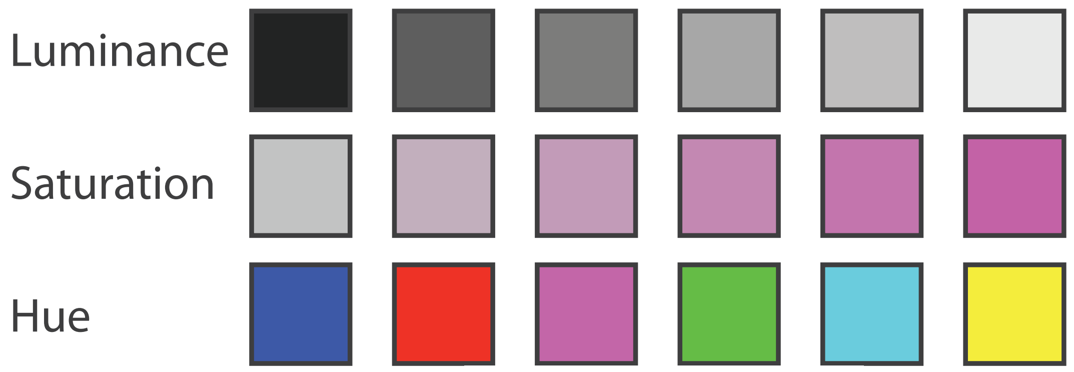
Many color spaces

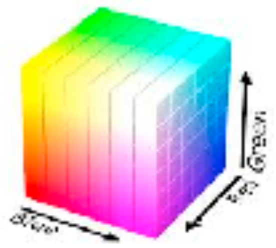
- Luminance (L*), hue (H), saturation (S)
  - good for encoding
  - but not standard graphics/tools colorspace



Many color spaces

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



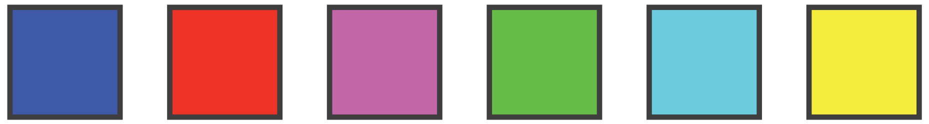


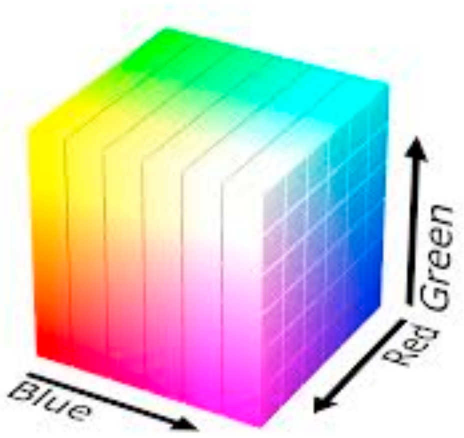
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

RGB

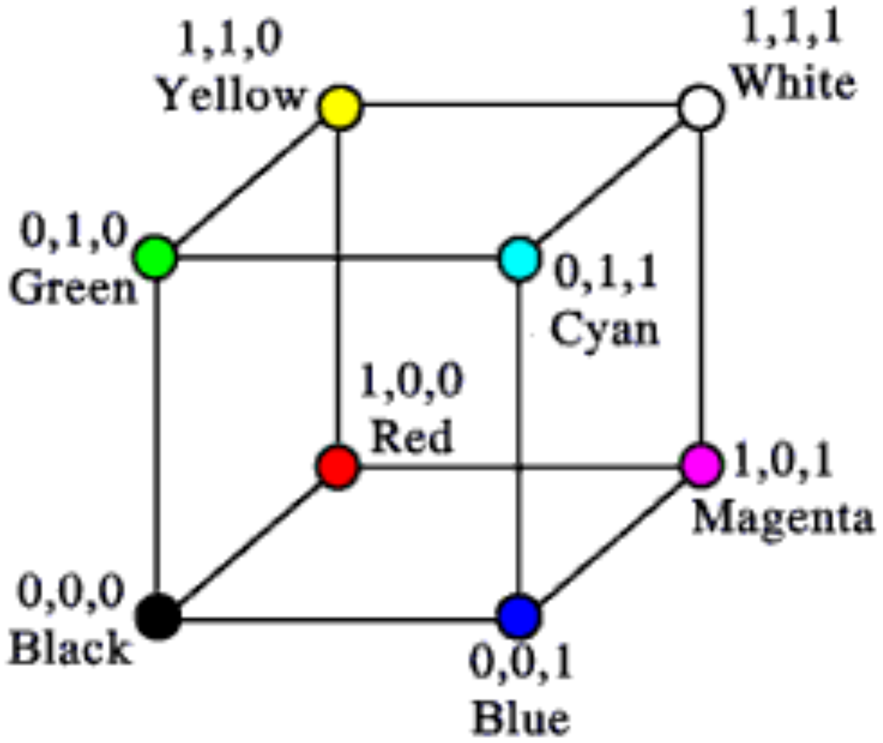
- RGB: good for display hardware

Corners of the RGB color cube





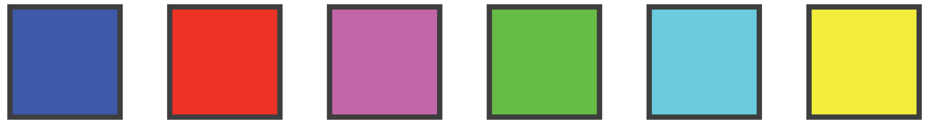
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

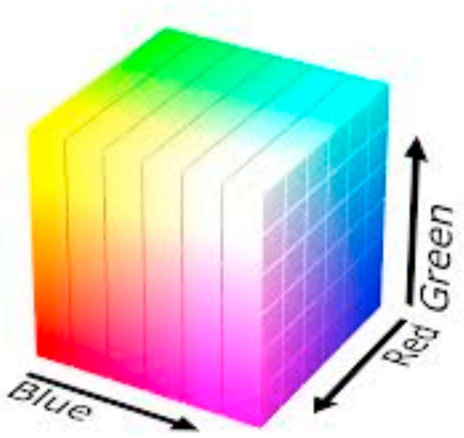


RGB

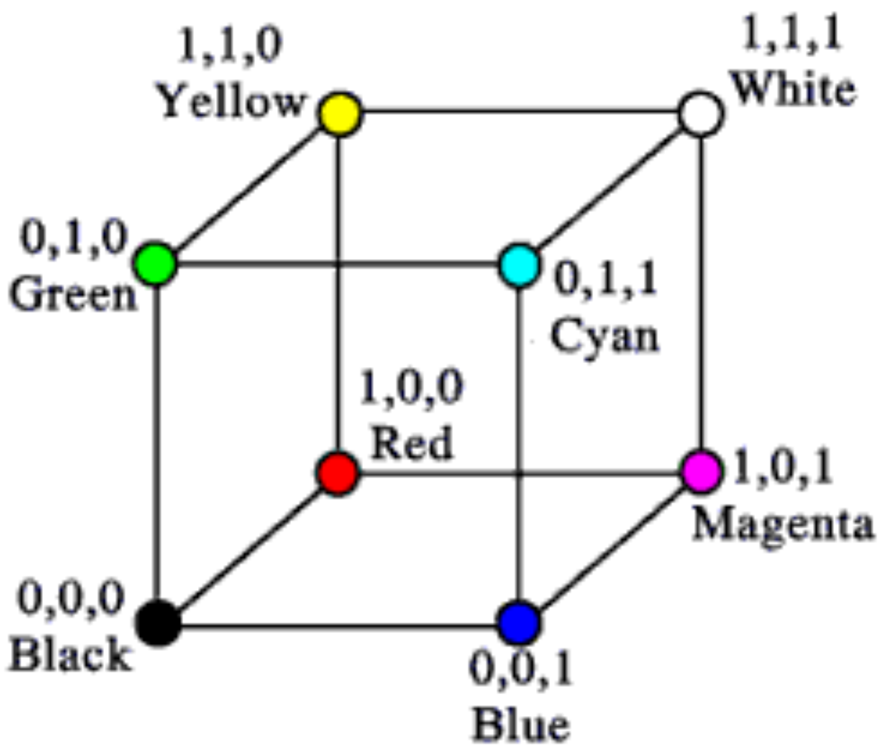
- RGB: good for display hardware
  - poor for encoding & interpolation

Corners of the RGB color cube

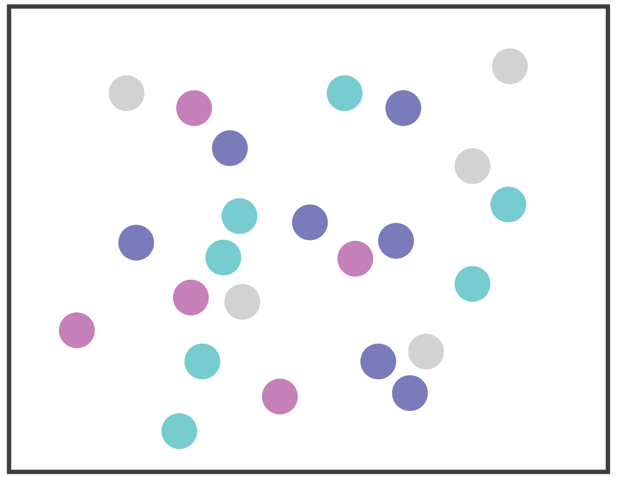




https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png



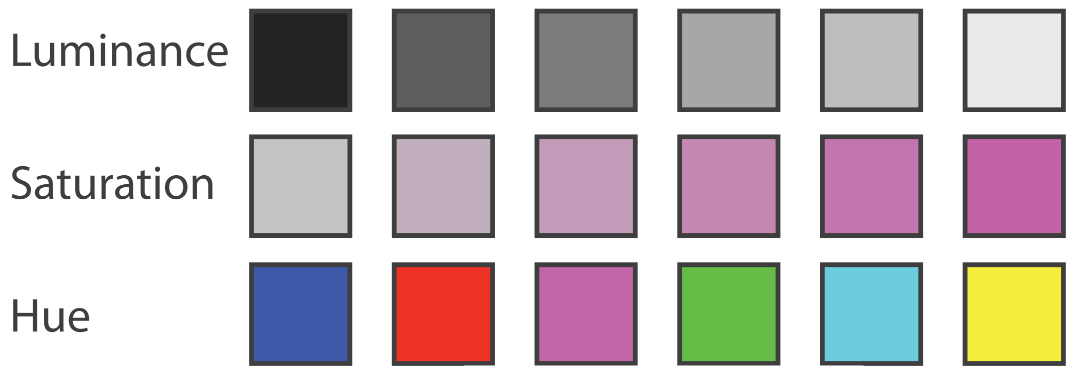
Red
+ Green

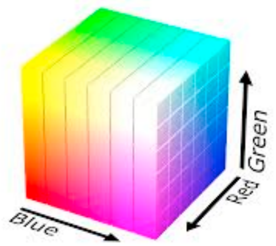


Major interference

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

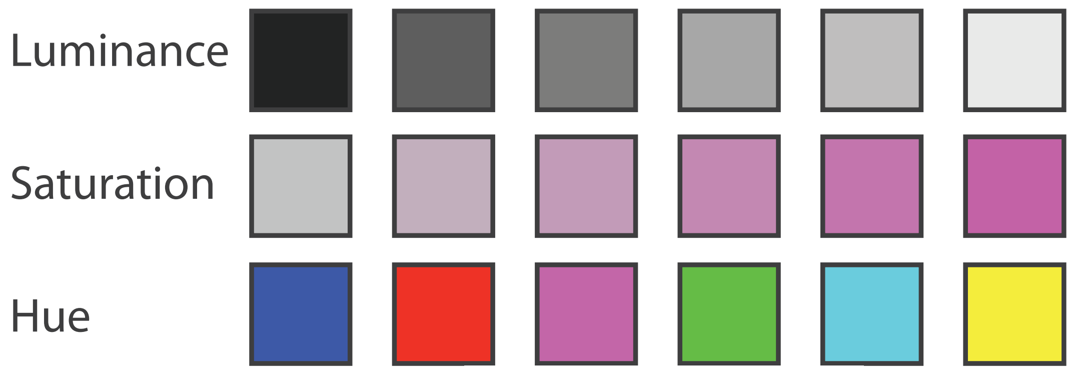


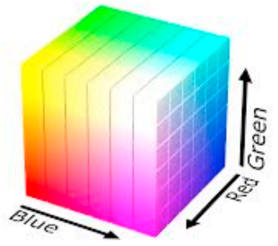


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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

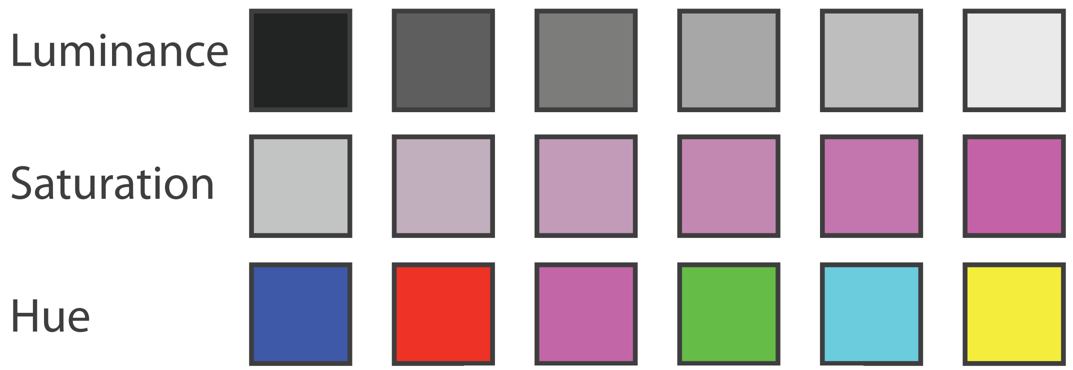


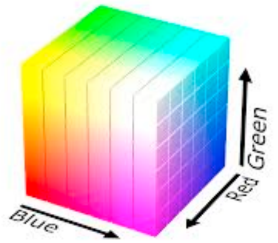


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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

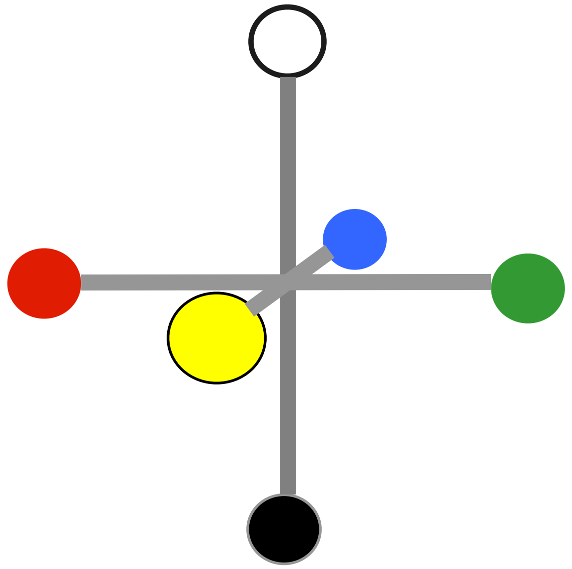


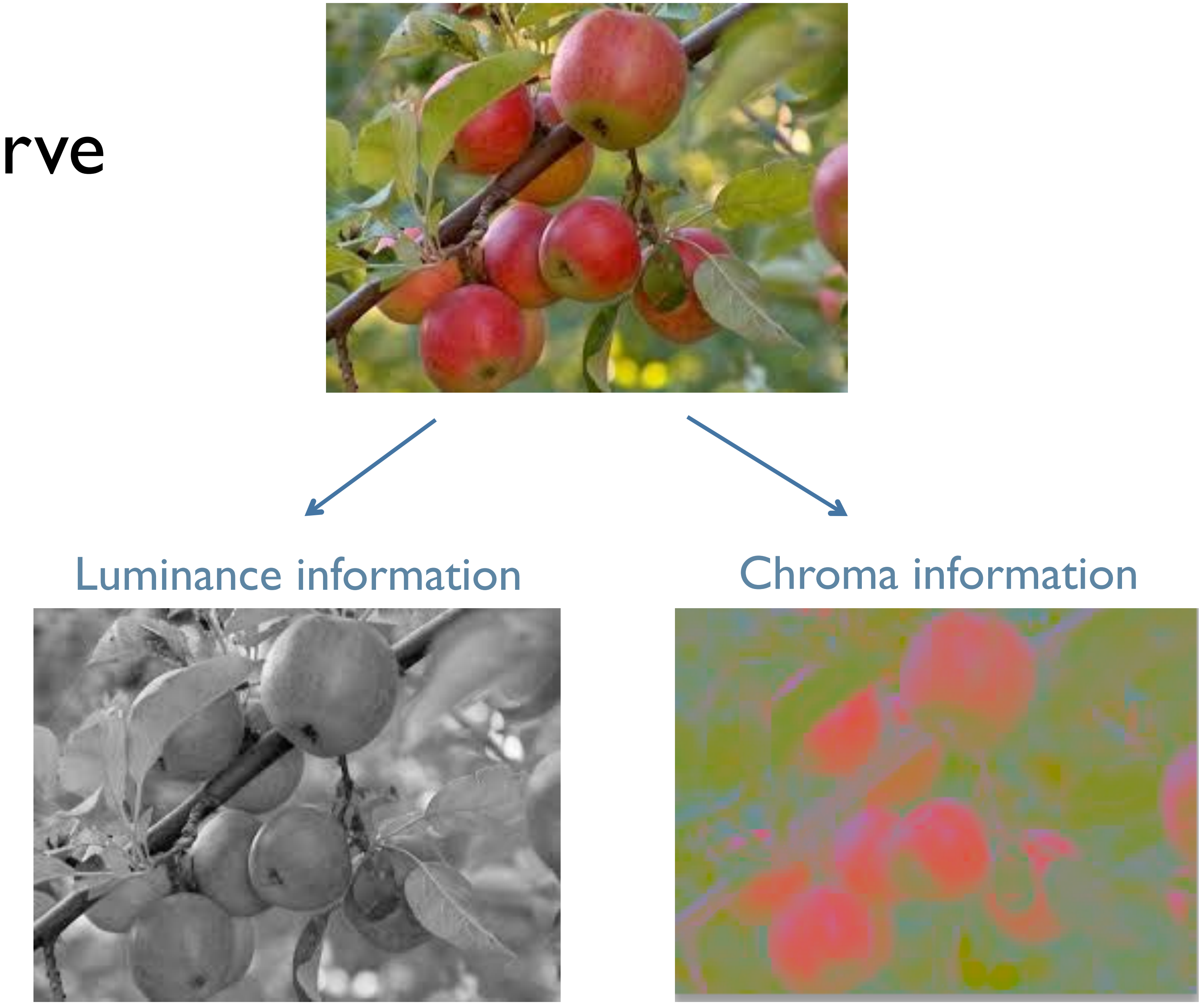


https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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*)

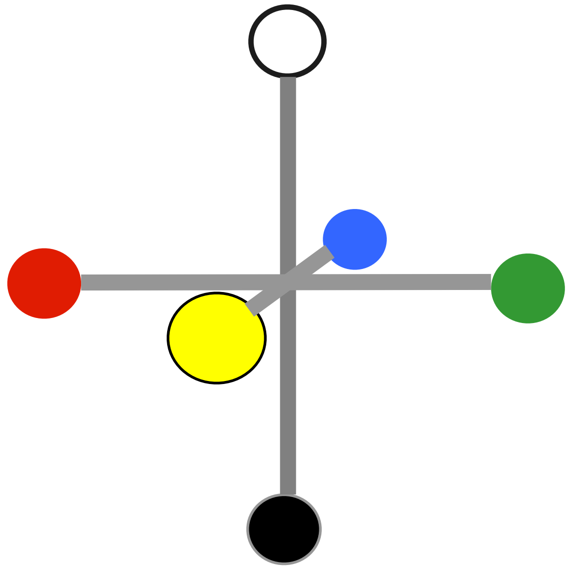


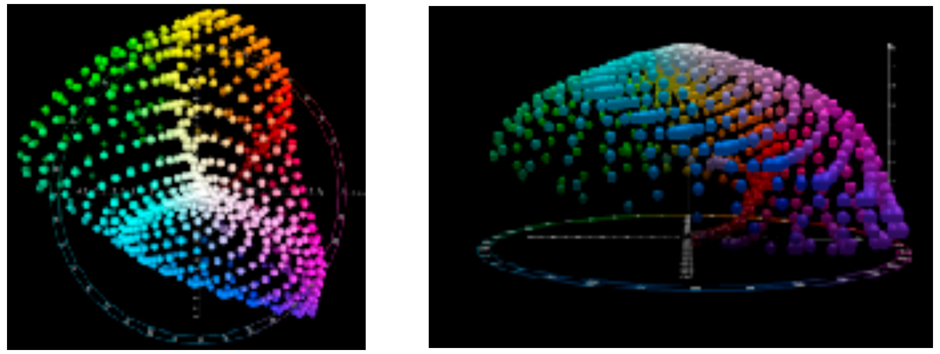


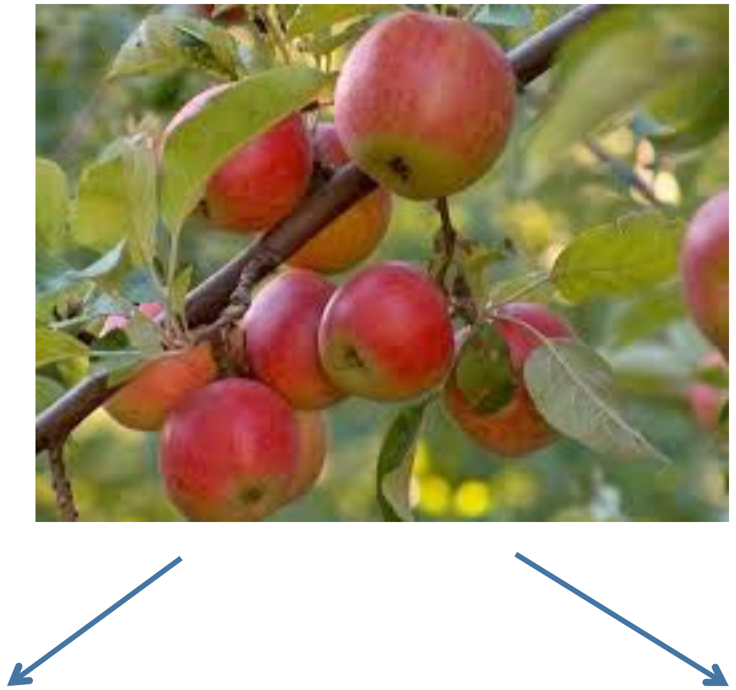
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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







Luminance information

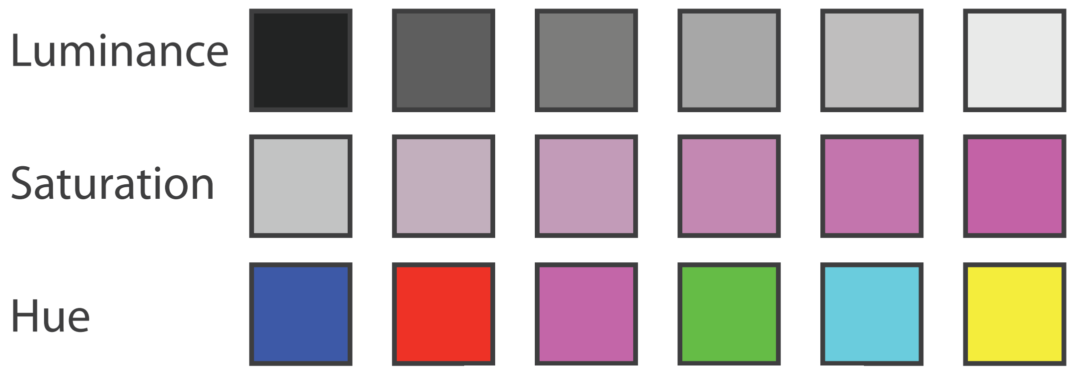
Chroma information

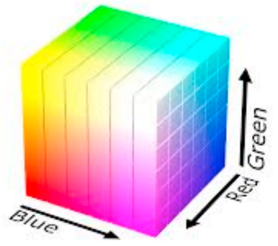
[Seriously Colorful: Advanced Color Principles & Practices. Stone.Tableau Customer Conference 2014.]

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





https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png

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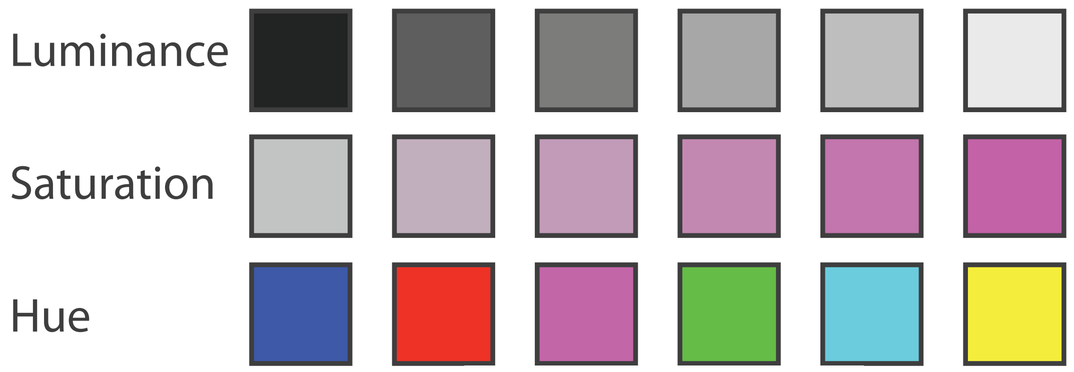
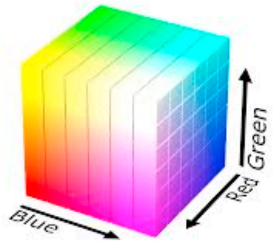
- HSL/HSV: somewhat better for encoding





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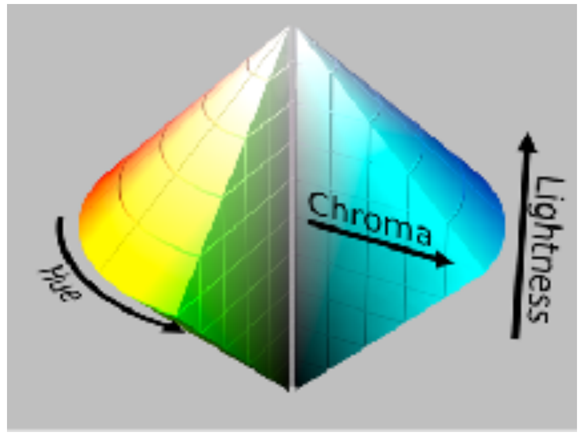
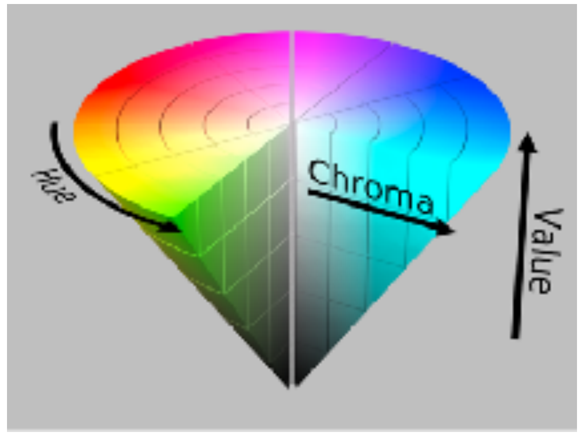
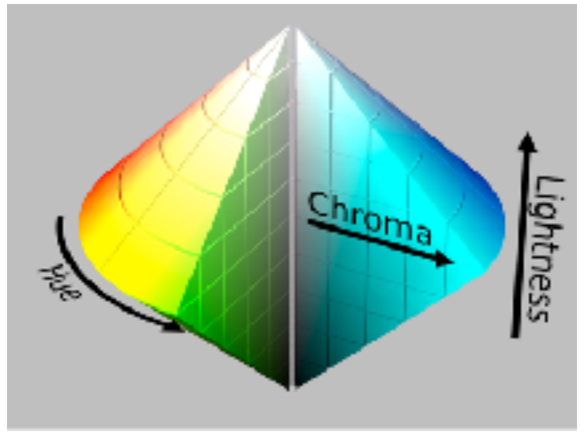
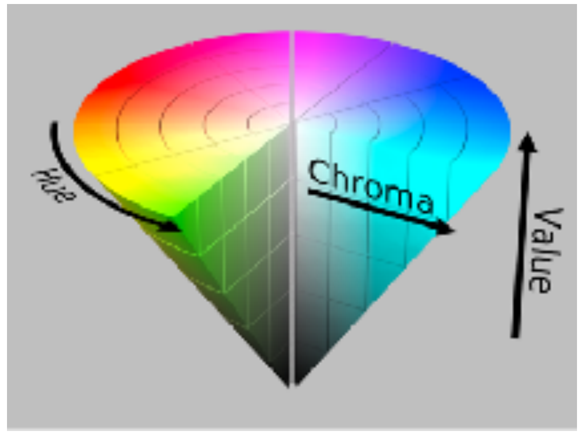


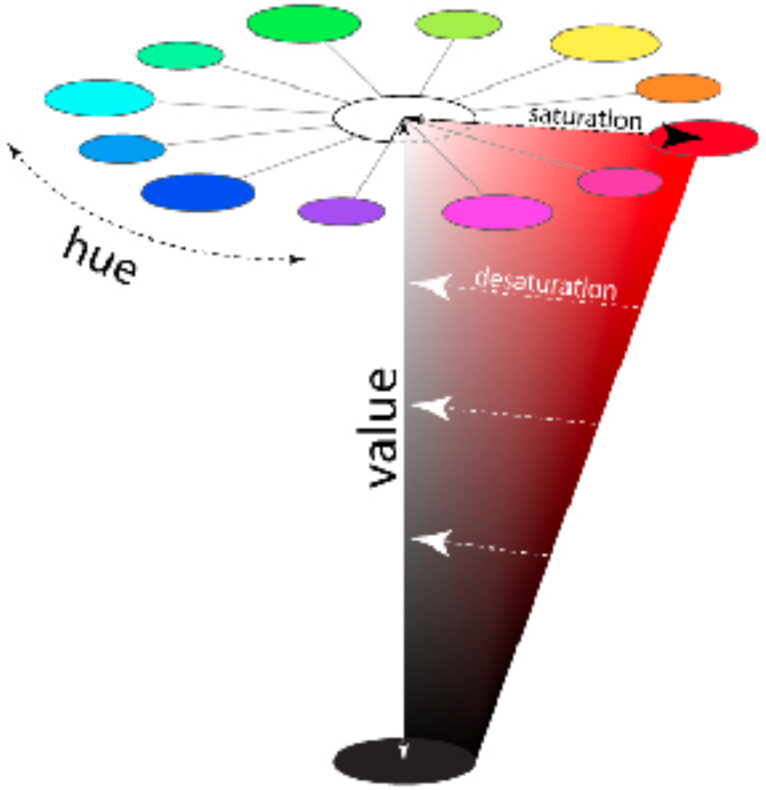


HSL/HSV

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



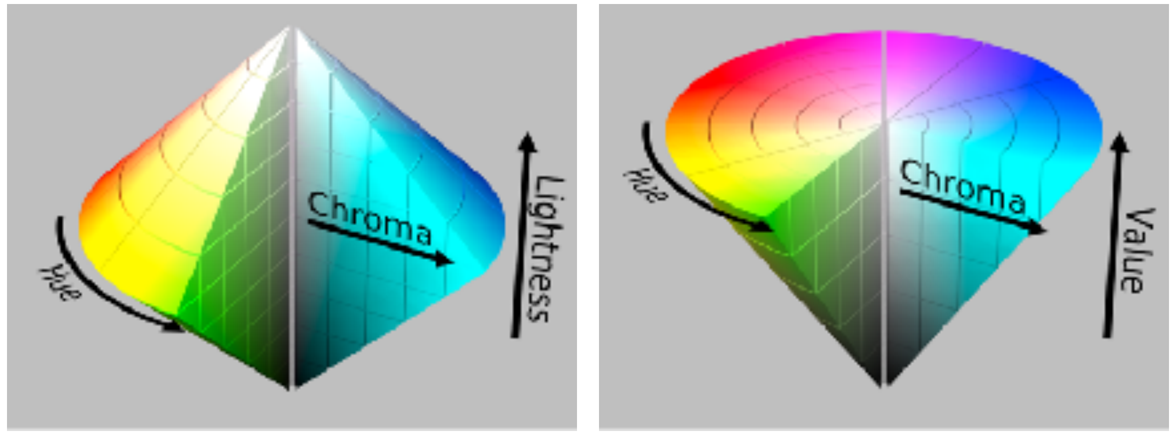


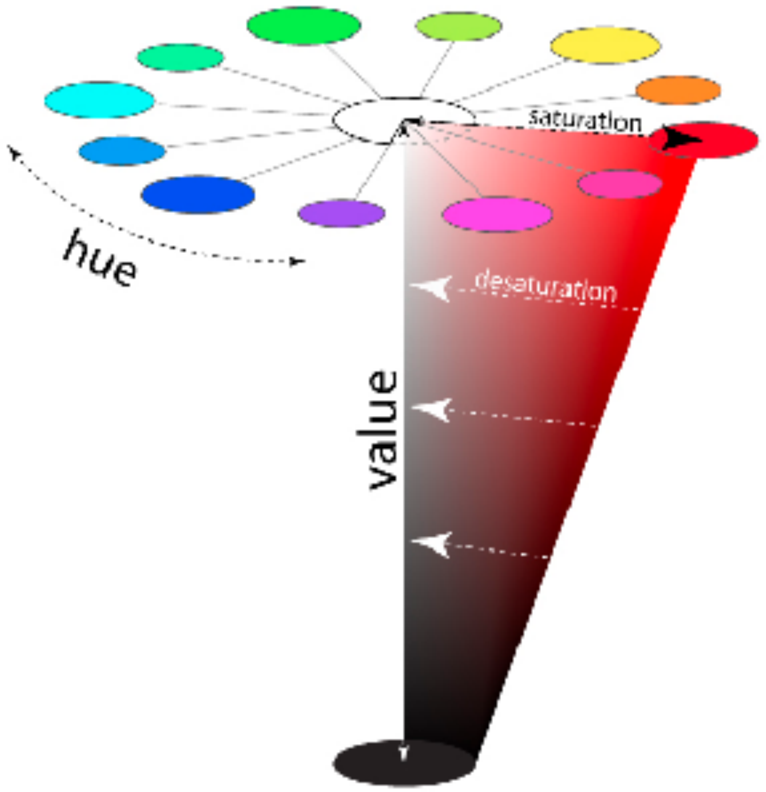


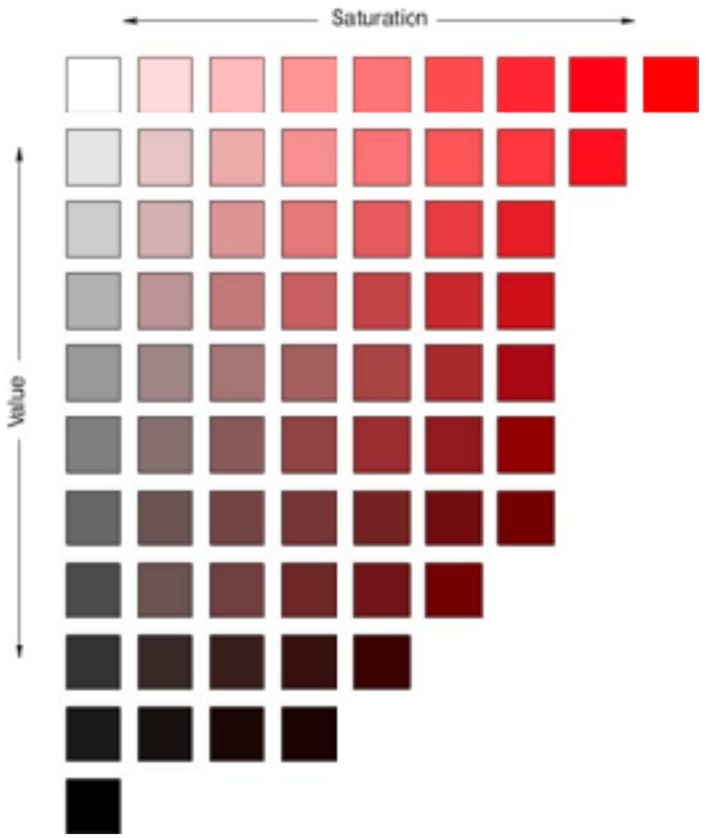
http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

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



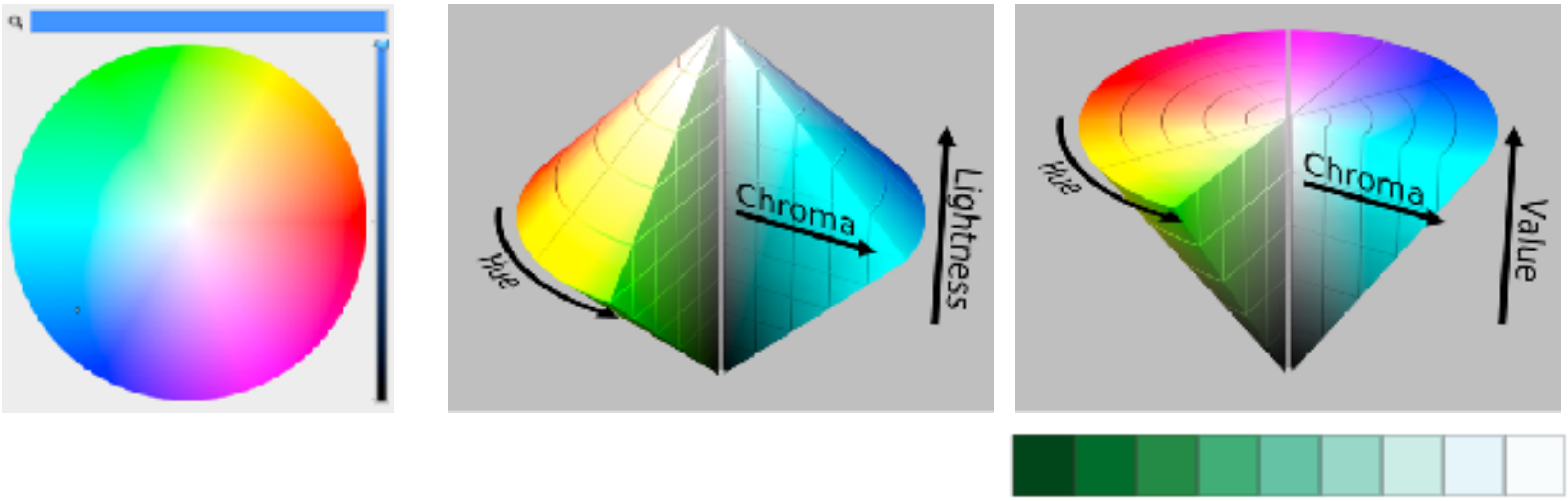




http://learn.leighcotnoir.com/artspeak/elements-color/hue-value-saturation/hsv8/

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

HSL/HSV: Pseudo-perceptual colorspace

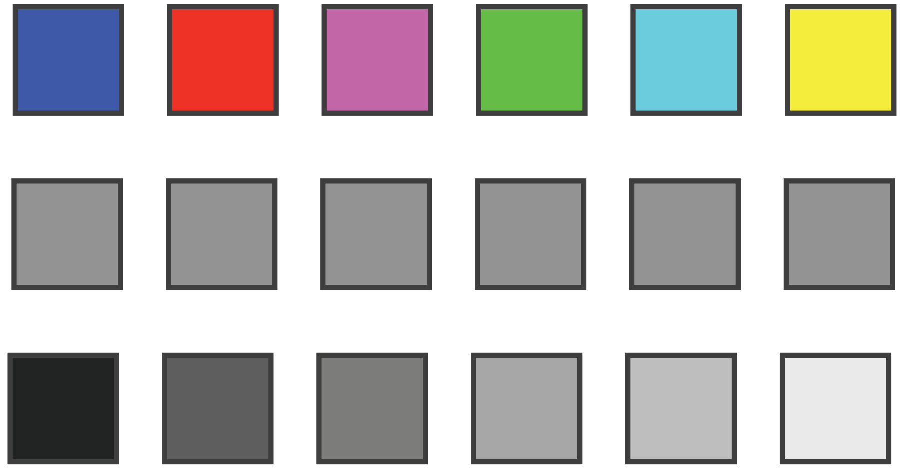


- HSL better than RGB for encoding **but beware**
  - L lightness ≠ L* luminance

Corners of the RGB color cube

L from HLS
All the same

Luminance values



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

Many color spaces

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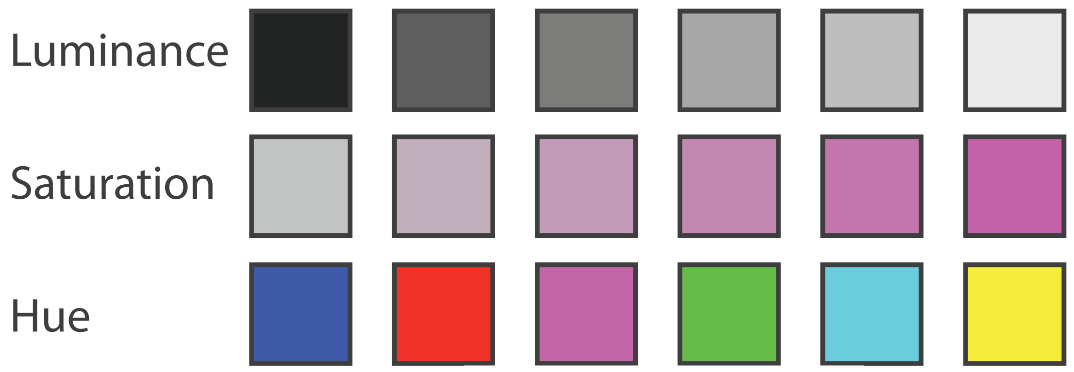
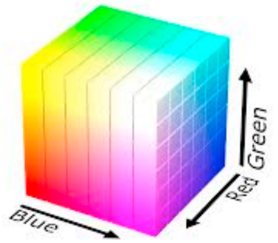
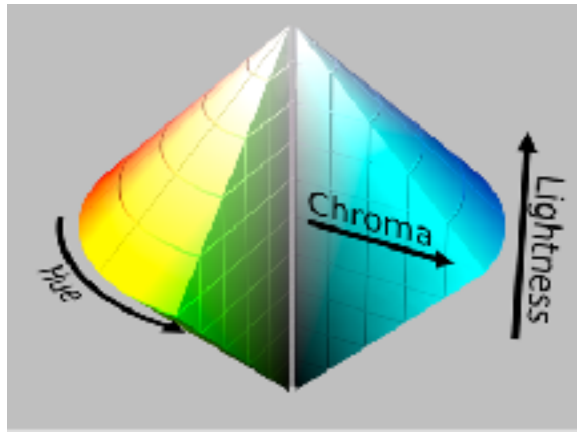
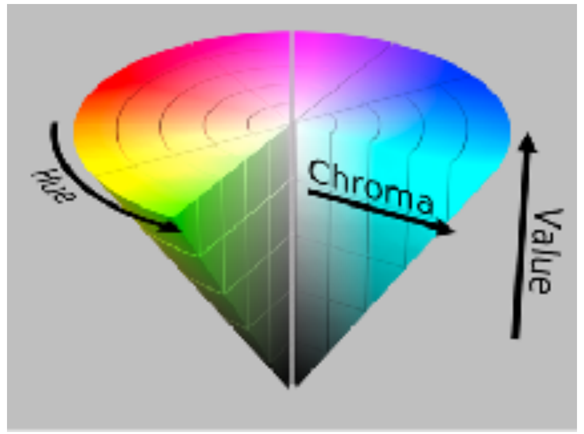
- RGB: good for display hardware
  – poor for encoding & interpolation
- CIE LAB (L*a*b*): good for interpolation
  – hard to interpret, poor for encoding
- HSL/HSV: somewhat better for encoding
  – hue/saturation wheel intuitive
  – beware: only pseudo-perceptual!
  – lightness (L) or value (V) ≠ luminance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





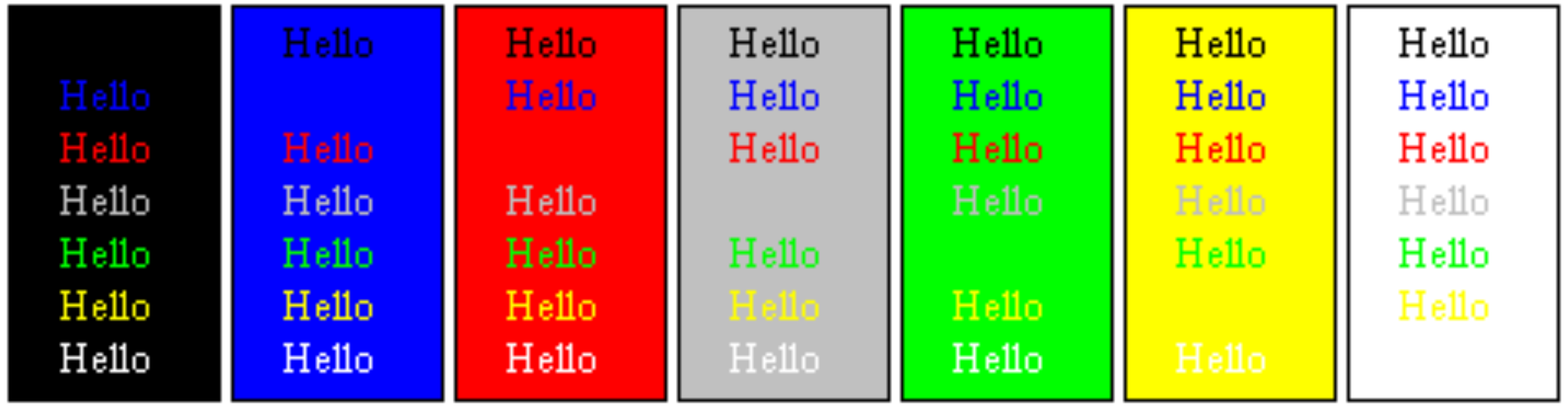
https://commons.wikimedia.org/wiki/File:RGB_color_solid_cube.png





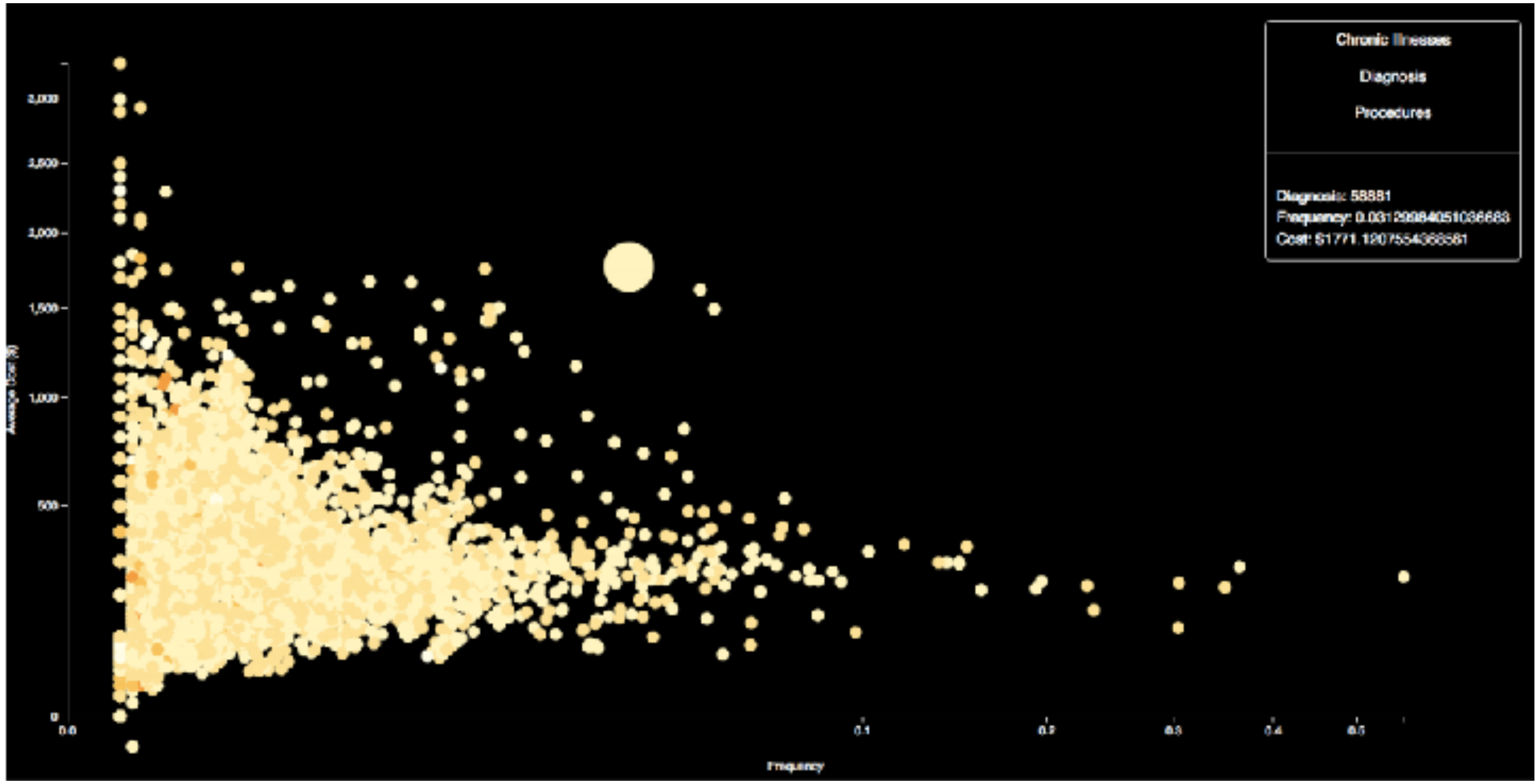
Color Constrast & Naming

Interaction with the background



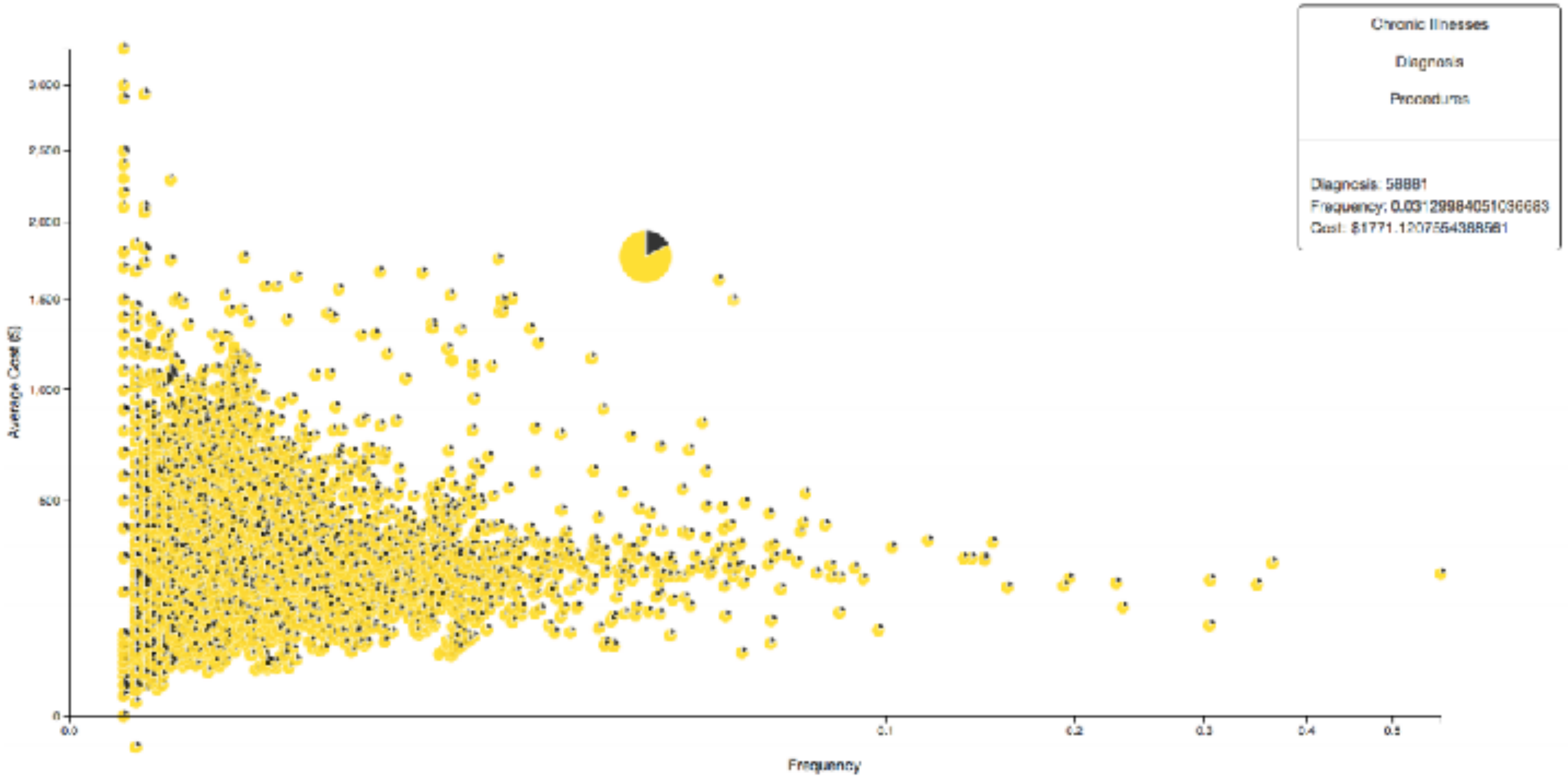
Interaction with the background: tweaking yellow for visibility

- marks with high luminance on a background with low luminance



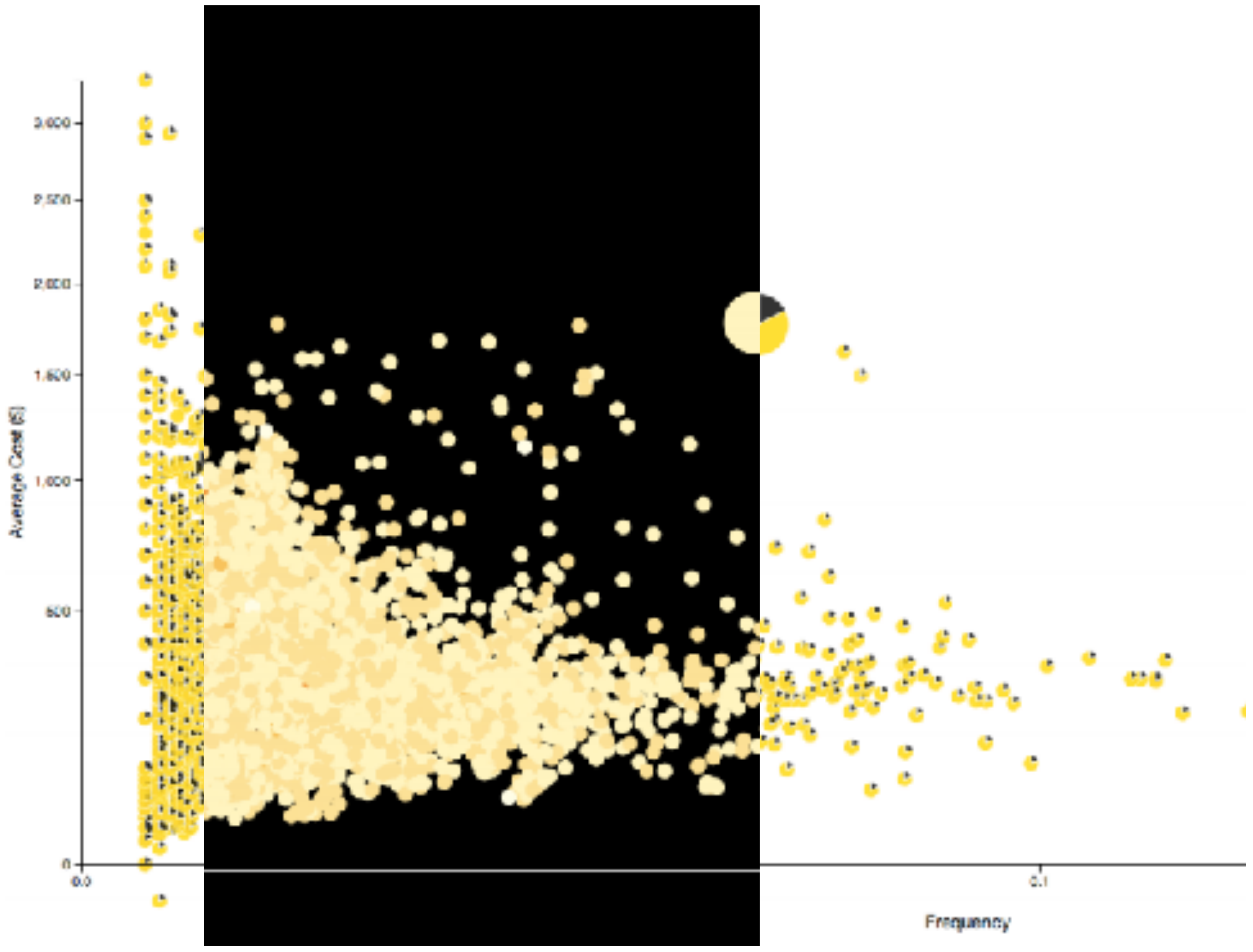
Interaction with the background: tweaking yellow for visibility

- 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

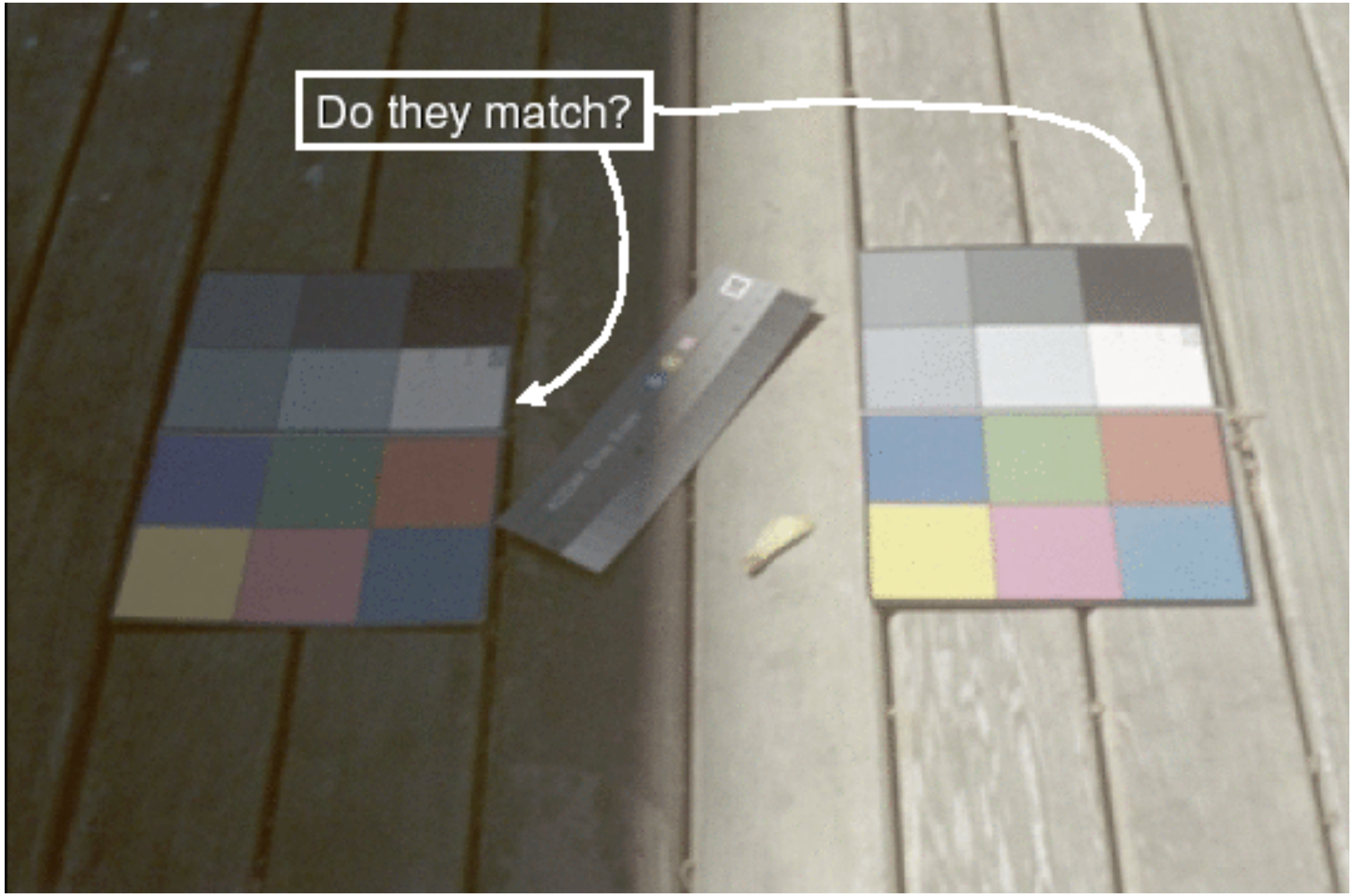


Image courtesy of John McCann via Maureen Stone

Color/Lightness constancy: Illumination conditions

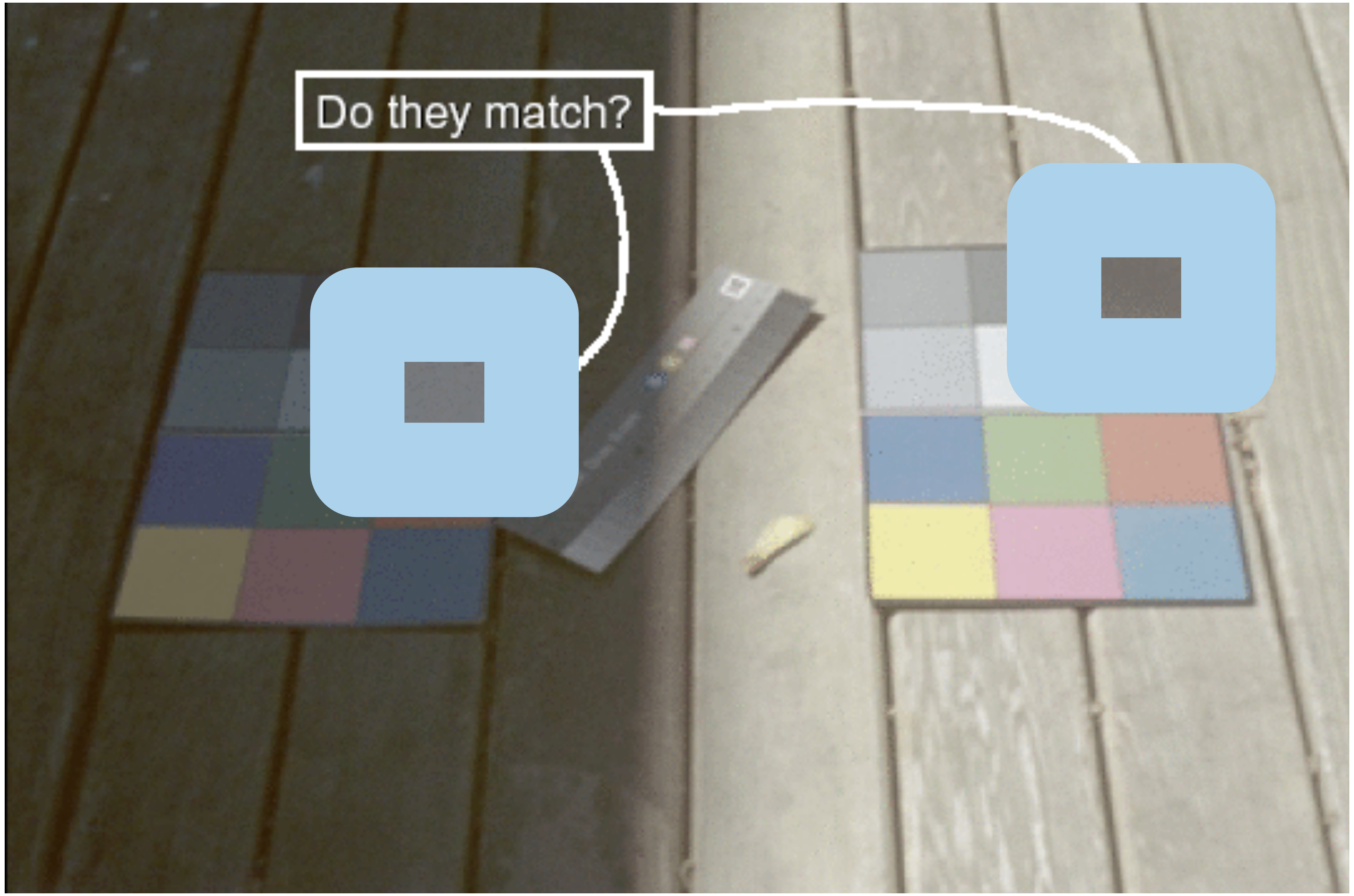
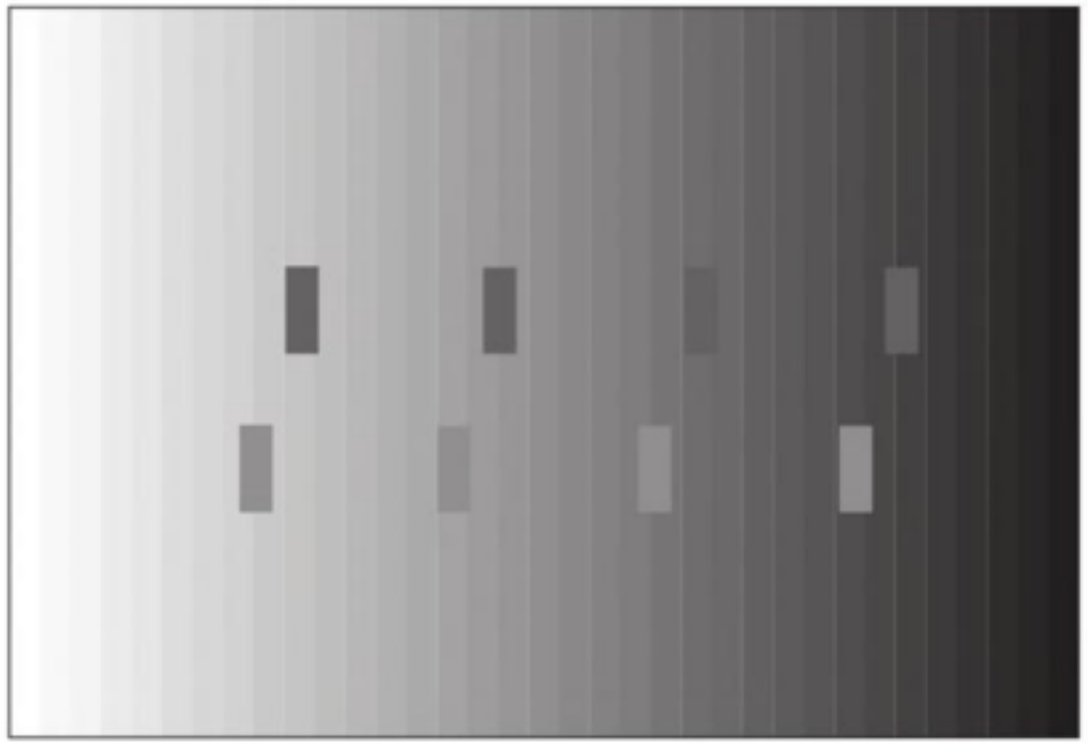
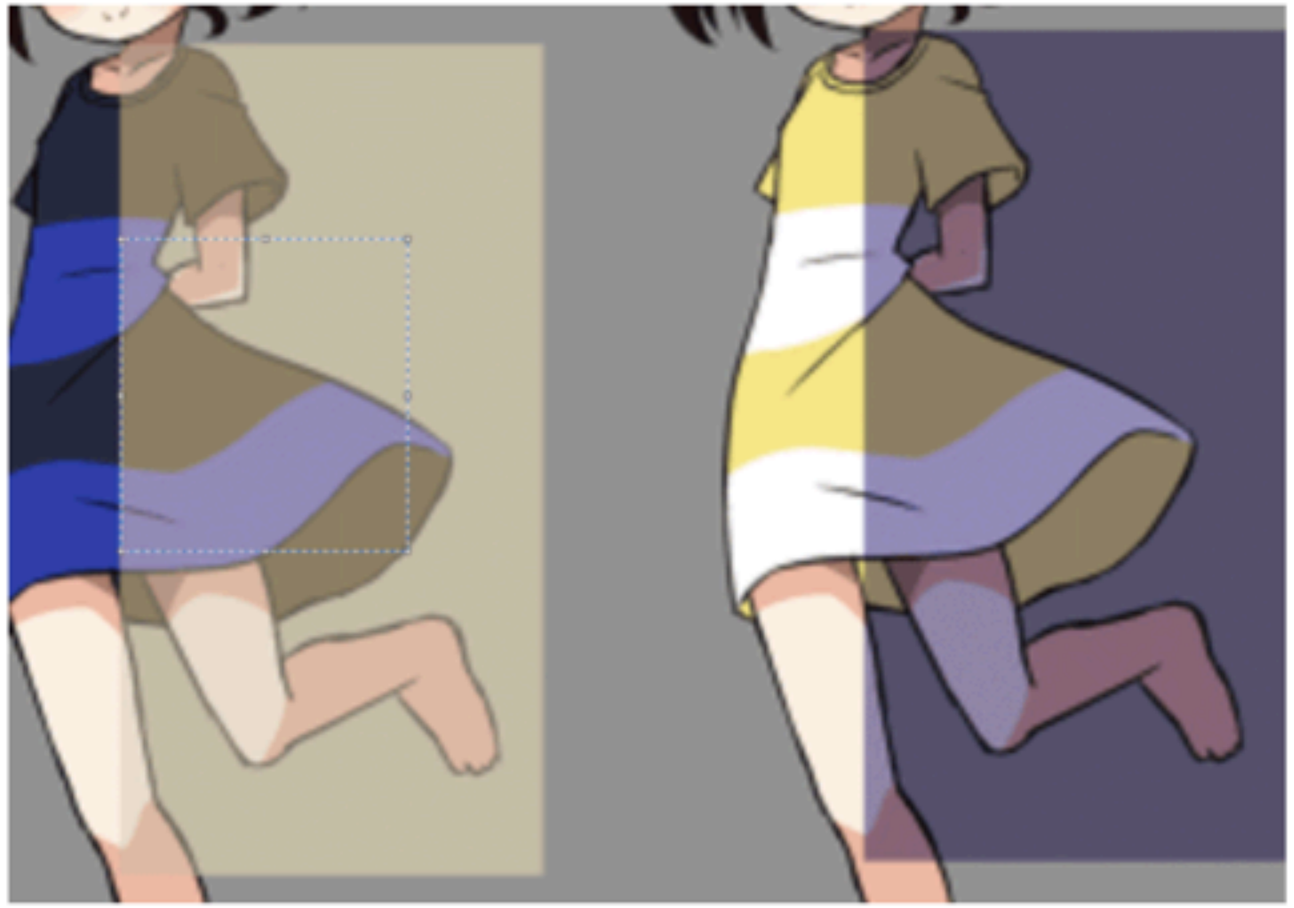


Image courtesy of John McCann via Maureen Stone

Contrast with background



Contrast with background

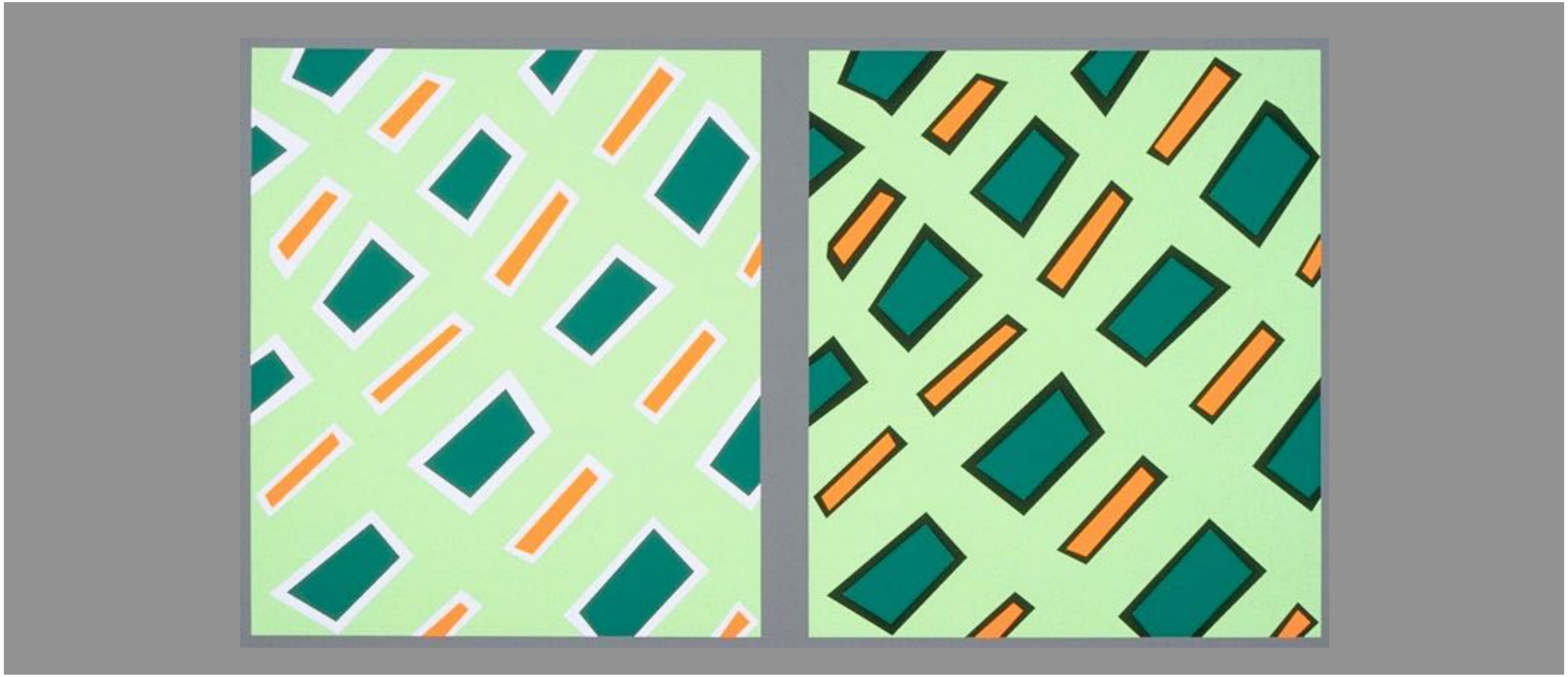
 

Black and blue? White and gold?

https://imgur.com/hxJjUQB

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

Bezold Effect: Outlines matter

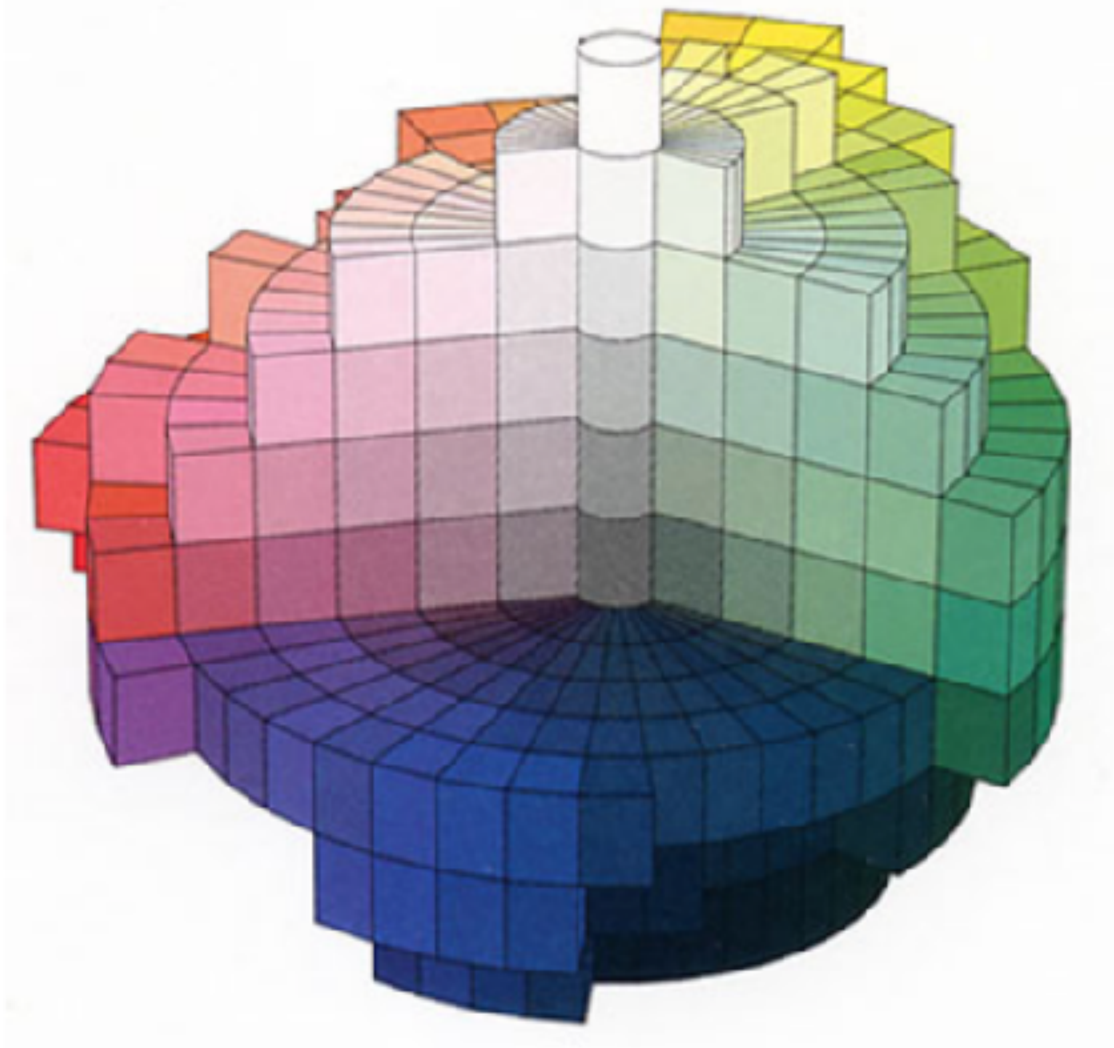


[Seriously Colorful: Advanced Color Principles & Practices. Stone. Tableau Customer Conference 2014.]

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/

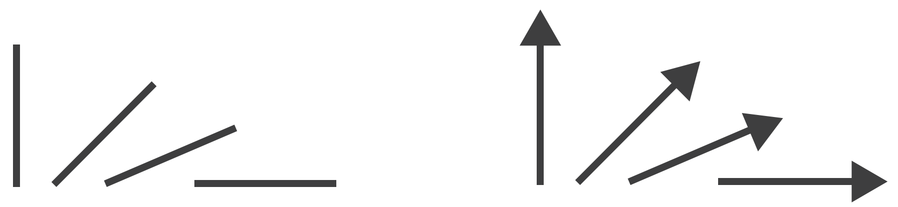
Color is just part of vision system

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

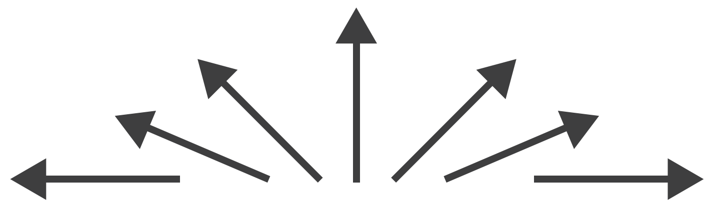
Map Other Channels

Angle / tilt / orientation channel

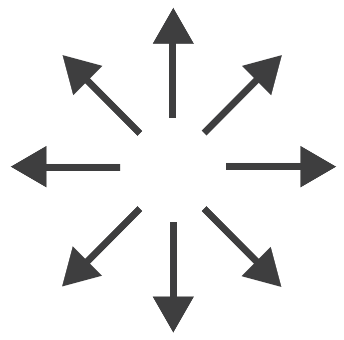
- different mappings depending on range used



Sequential ordered
line mark or arrow glyph



Diverging ordered
arrow glyph

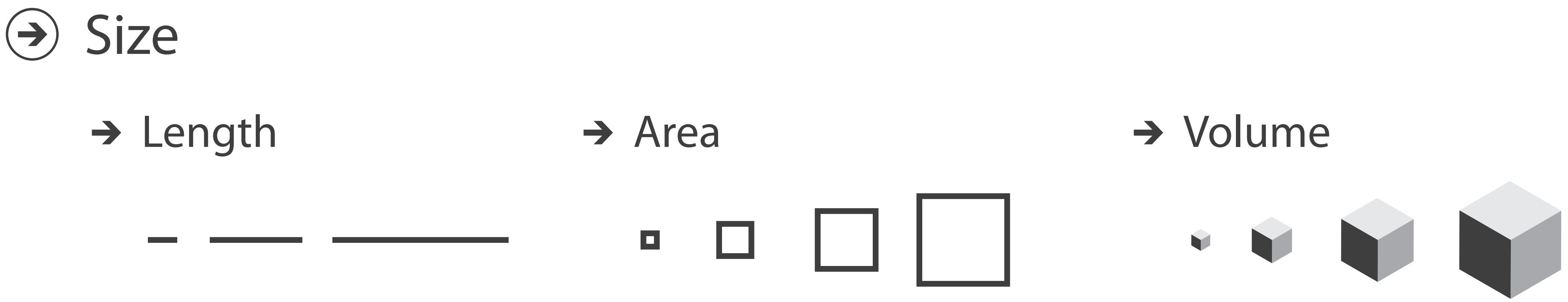


Cyclic ordered
arrow glyph

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

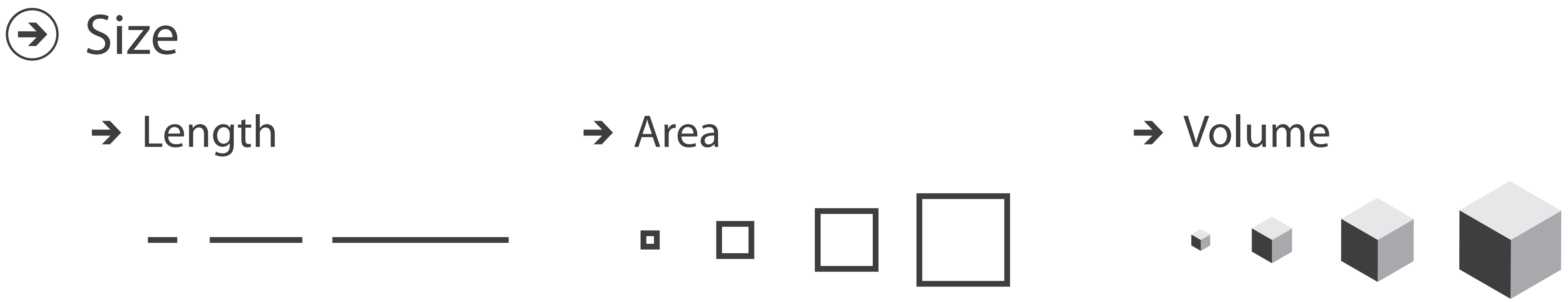
Map other channels

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



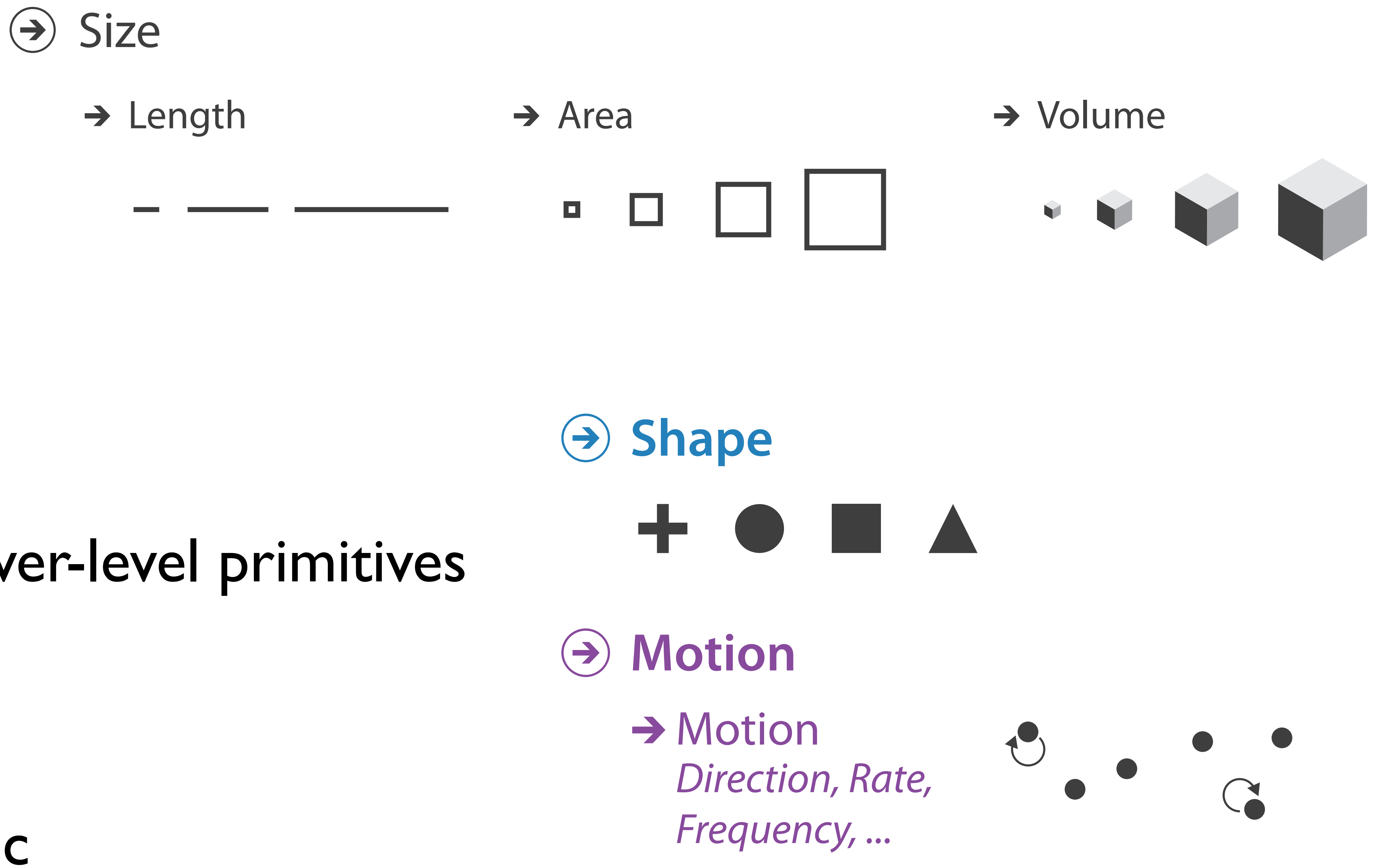
Map other channels

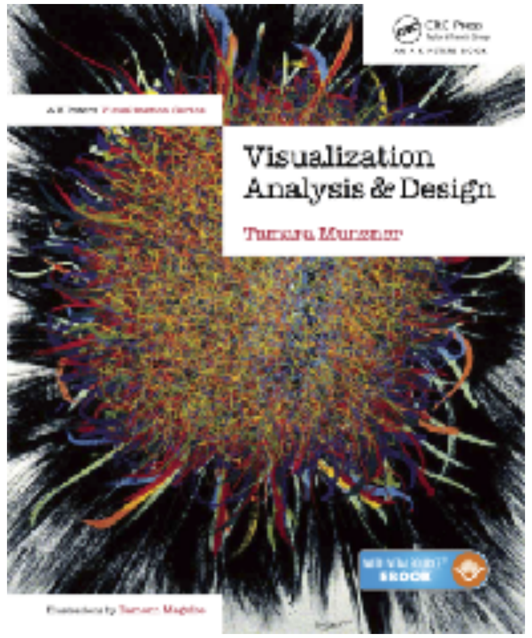
- size
  - aligned length best
  - length accurate
  - 2D area ok
  - 3D volume poor
- shape
  - complex combination of lower-level primitives
  - many bins



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

Reduce: Aggregation & Filtering (Ch 13)

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

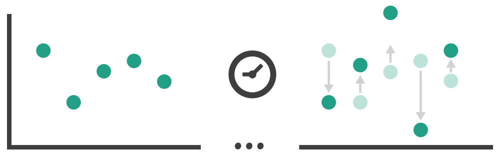
How to handle complexity: 3 previous strategies

→ *Derive*

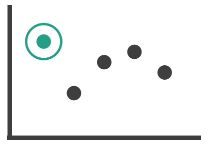
- derive new data to show within view
- change view over time
- facet across multiple views

Manipulate

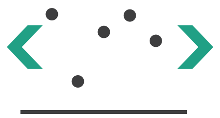
→ Change



→ Select

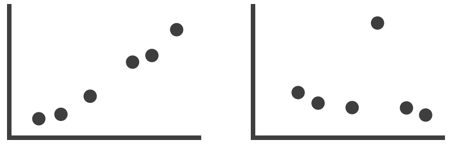


→ Navigate

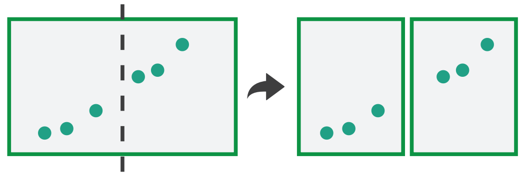


Facet

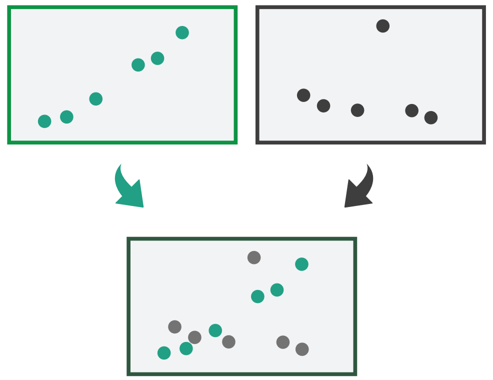
→ Juxtapose



→ Partition



→ Superimpose



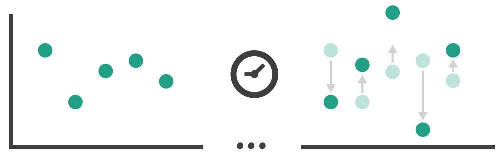
How to handle complexity: 3 previous strategies + 1 more

→ *Derive*

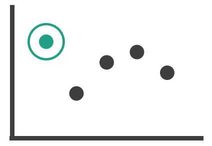
- derive new data to show within view
- change view over time
- facet across multiple views
- reduce items/attributes within single view

Manipulate

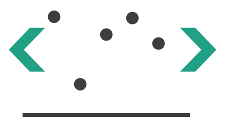
→ Change



→ Select

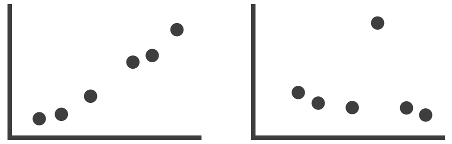


→ Navigate

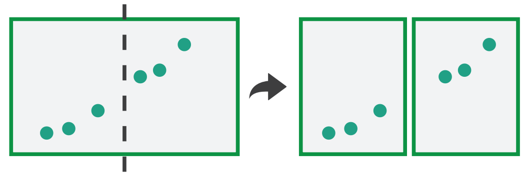


Facet

→ Juxtapose



→ Partition



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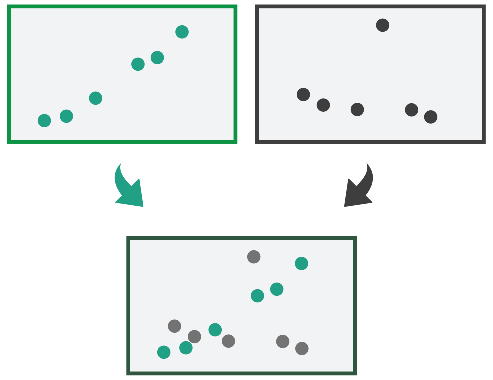
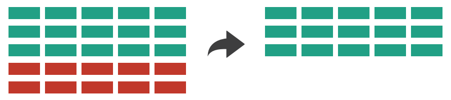
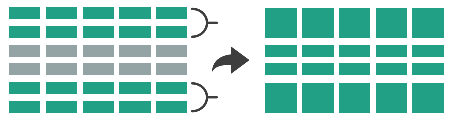


Reduce

→ Filter



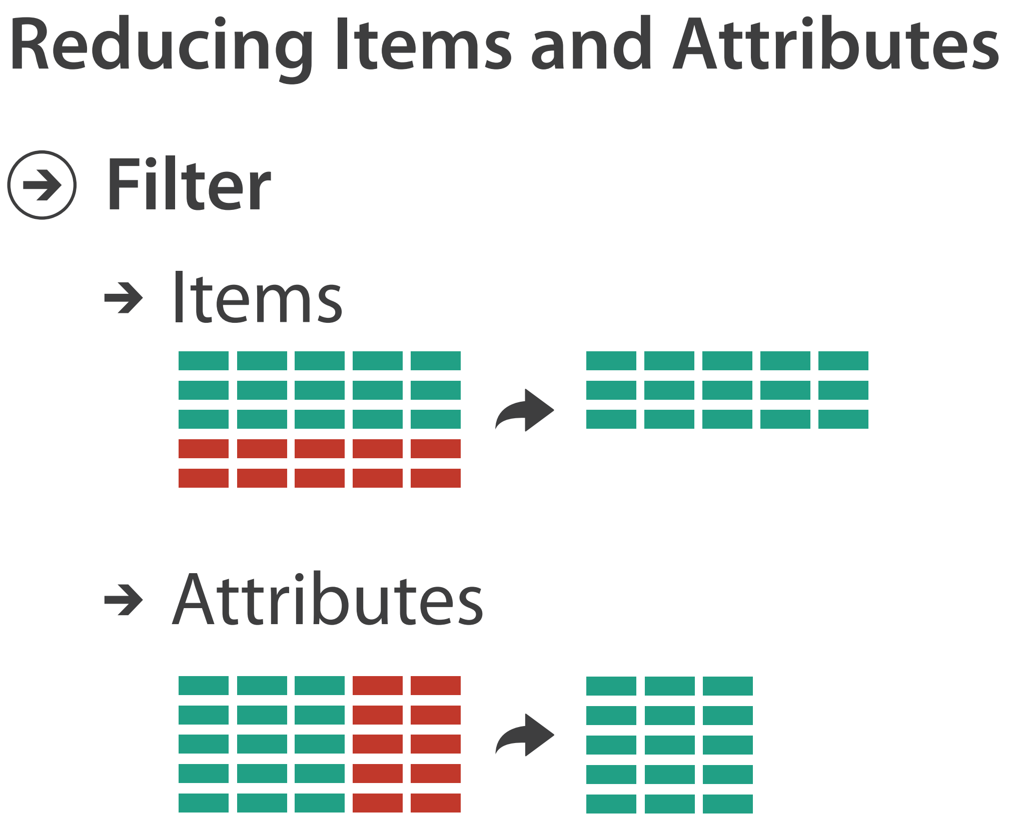
→ Aggregate



→ Embed

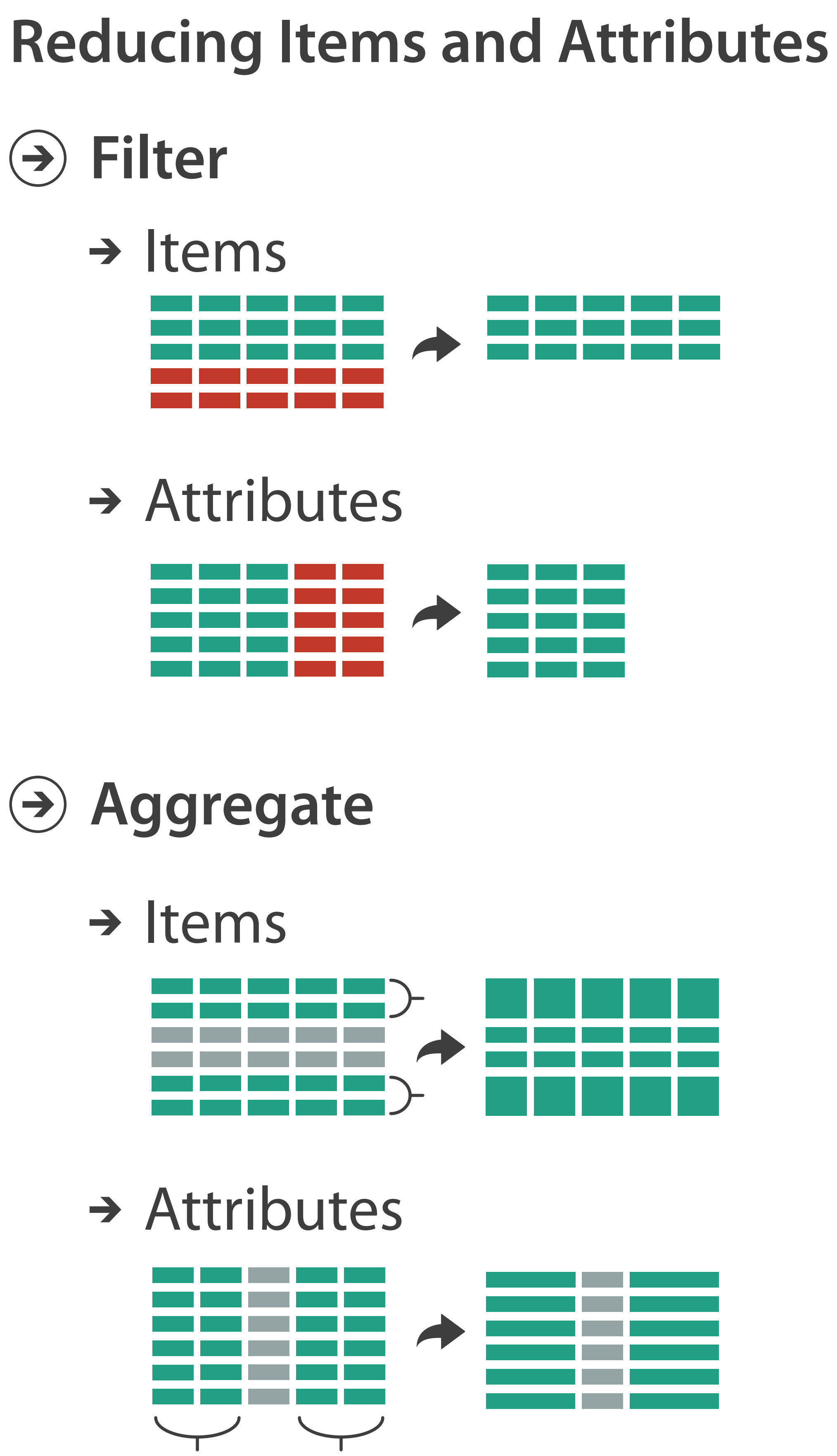
Reduce items and attributes

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



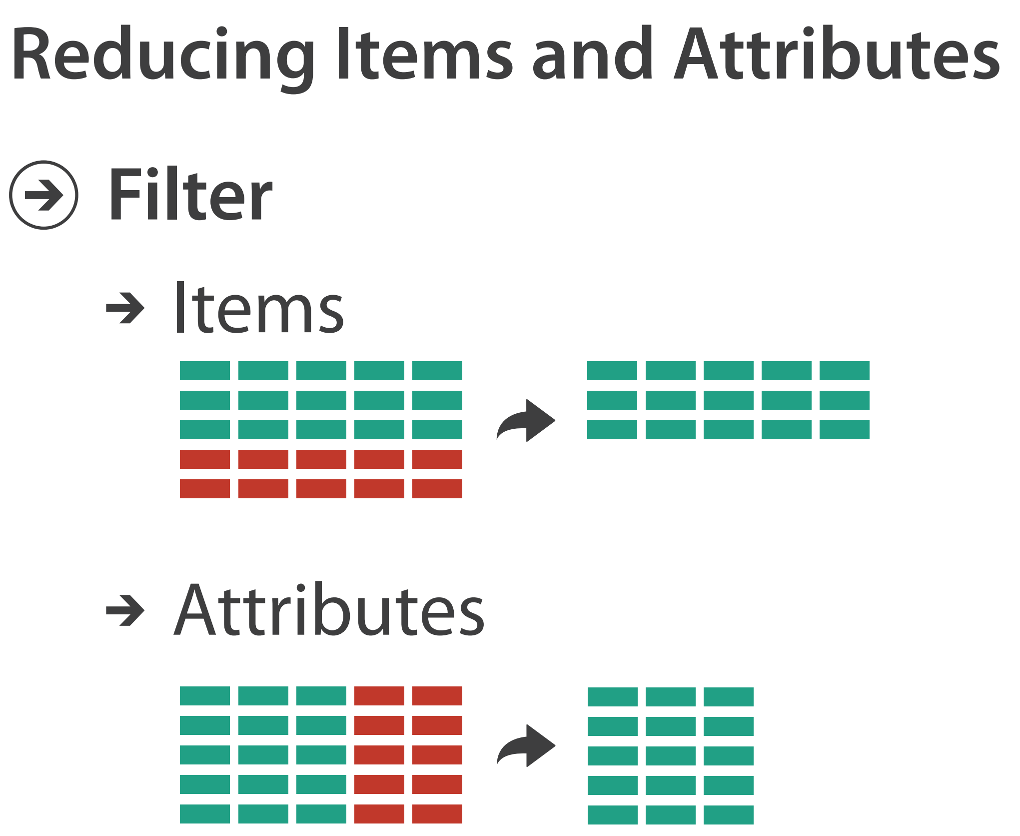
Reduce items and attributes

- 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



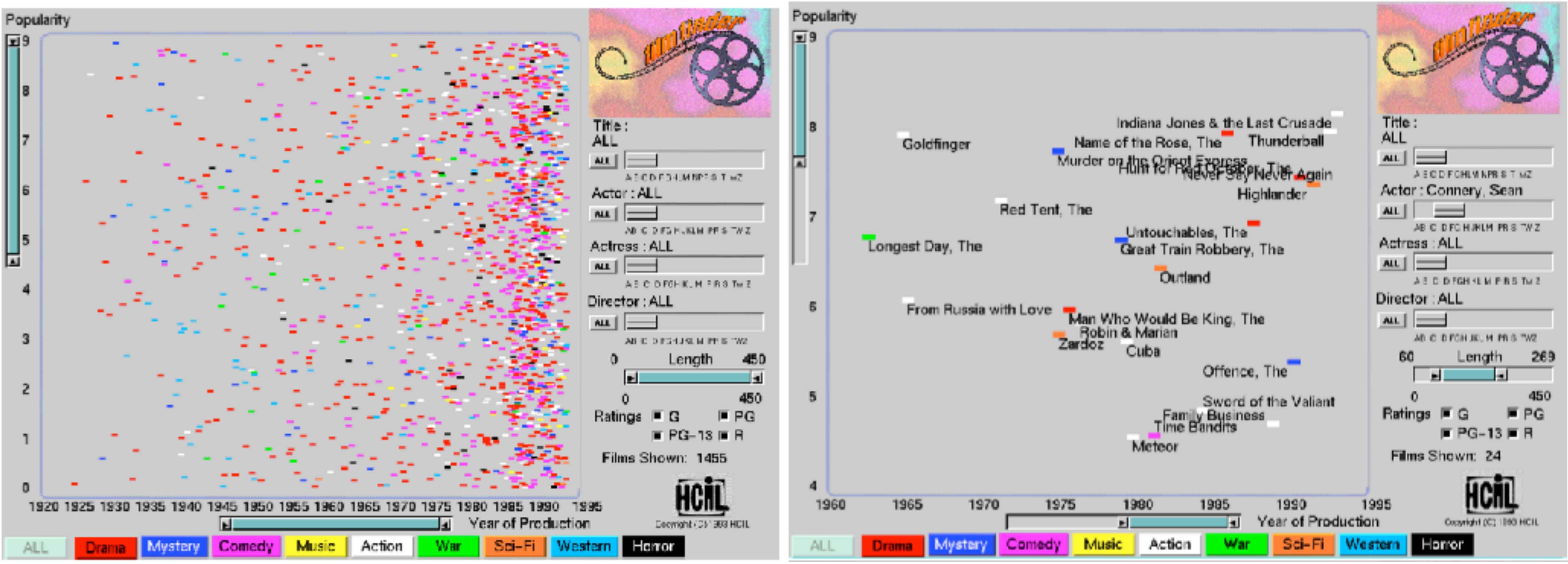
Filter

- 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**

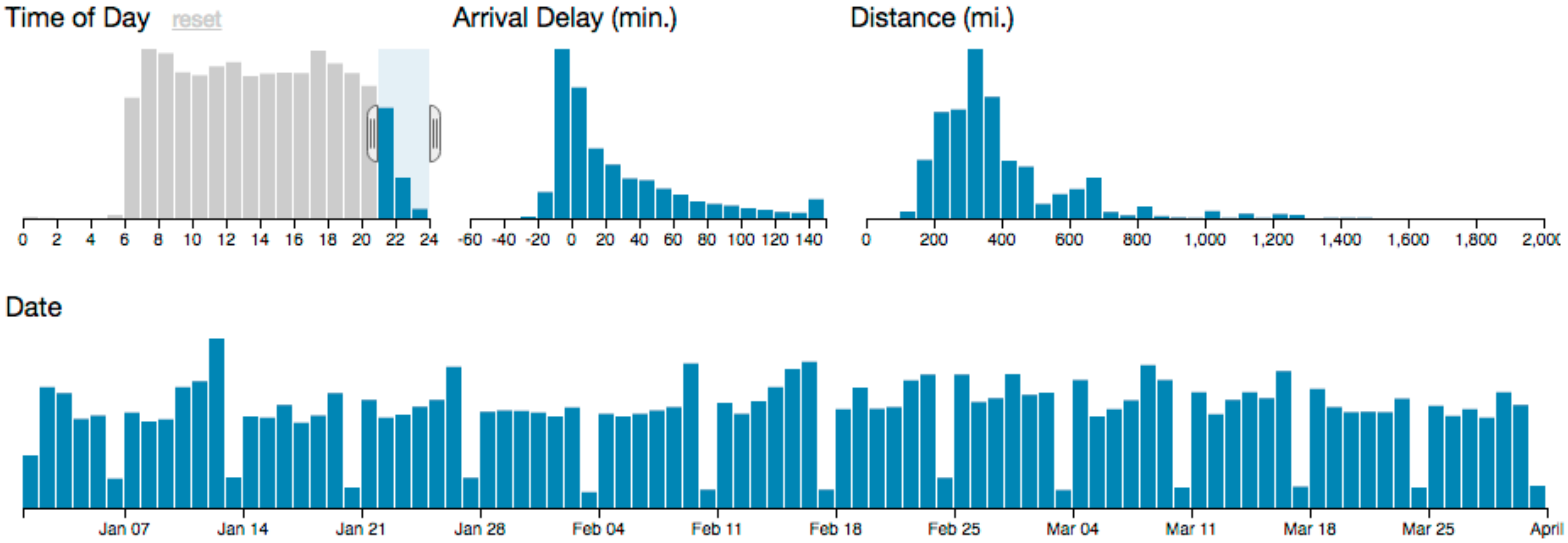
- dynamic queries/filters for items
  - tightly coupled interaction and visual encoding idioms, so user can immediately see results of action



[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

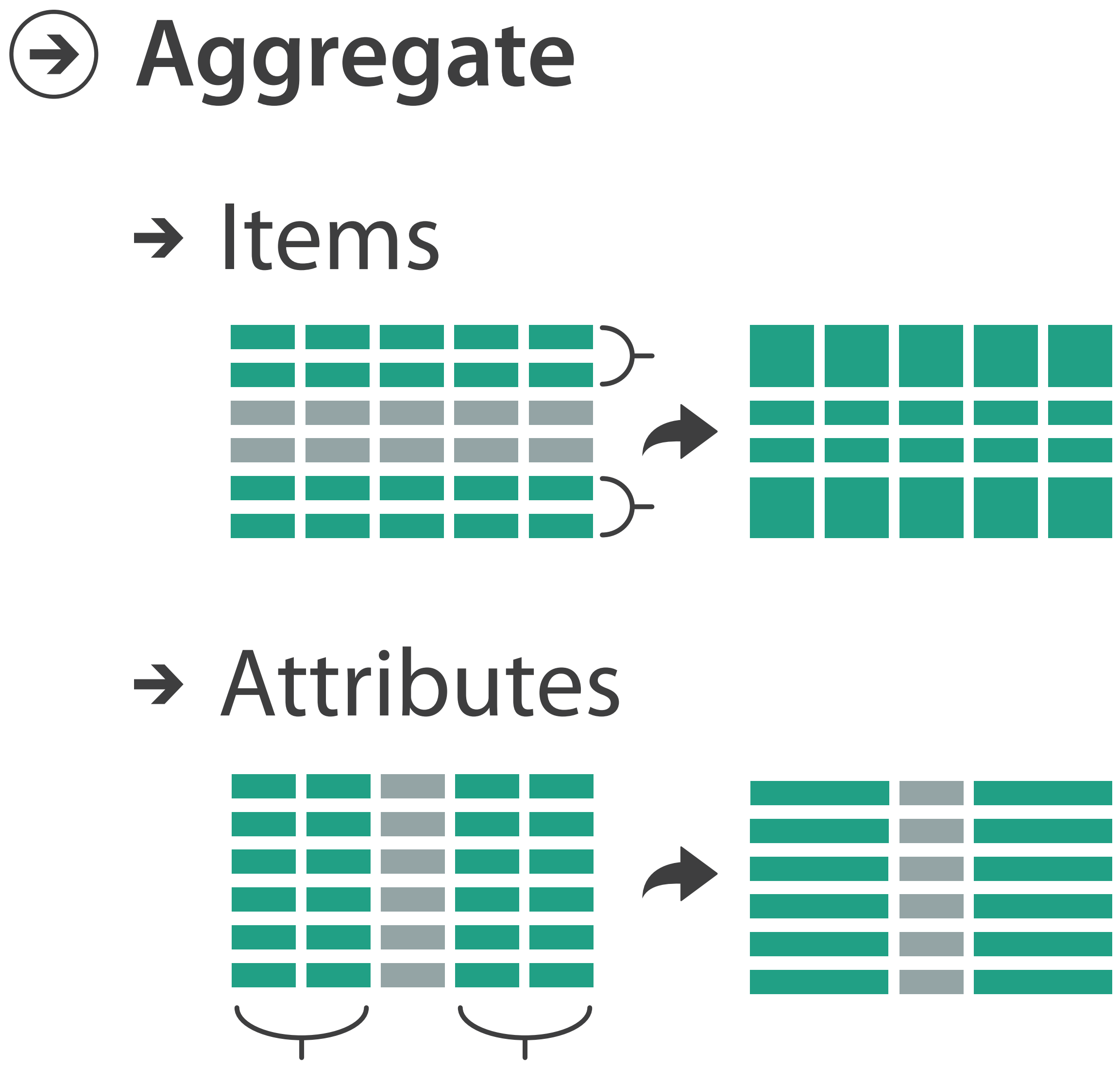


http://square.github.io/crossfilter/

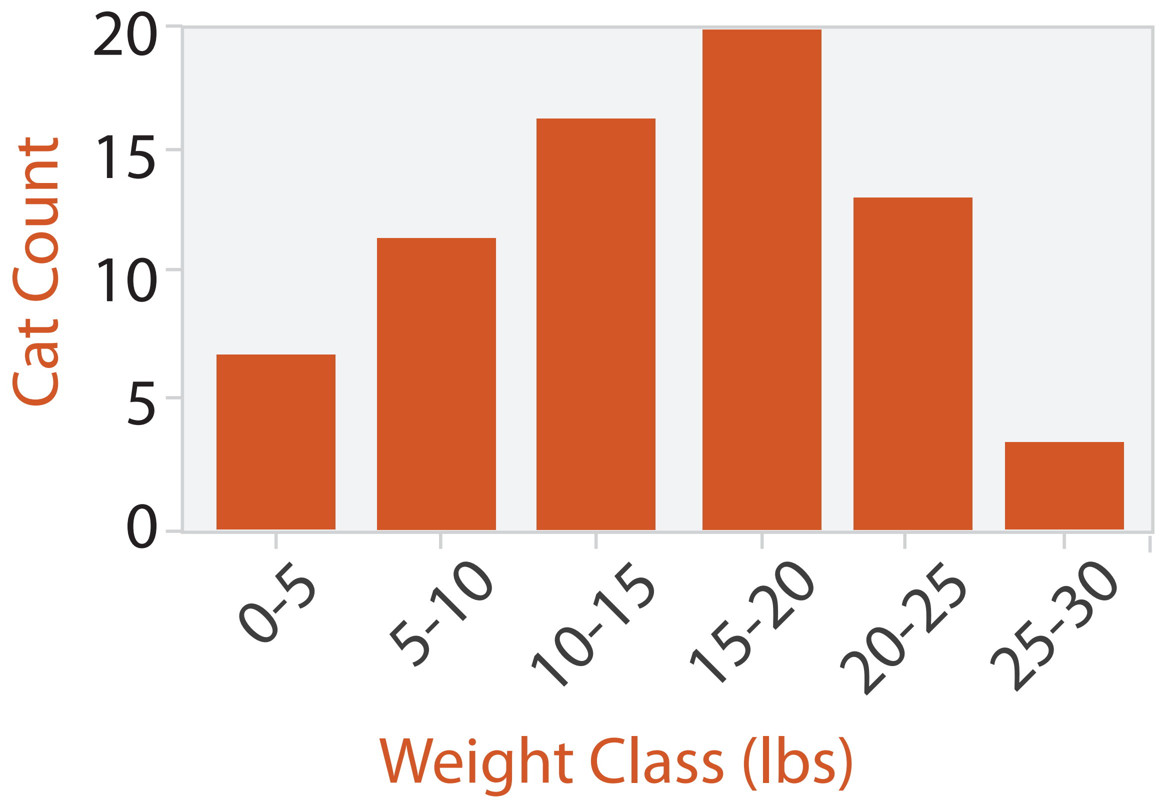
https://observablehq.com/@uwdata/interaction

Aggregate

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



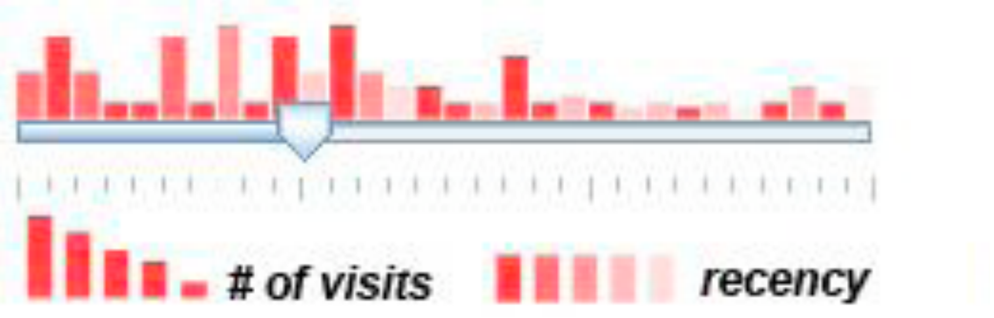
Idiom: **histogram**



- 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.]

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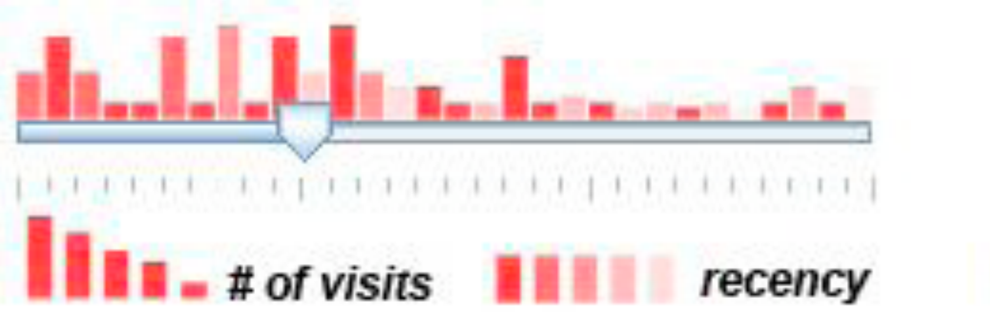

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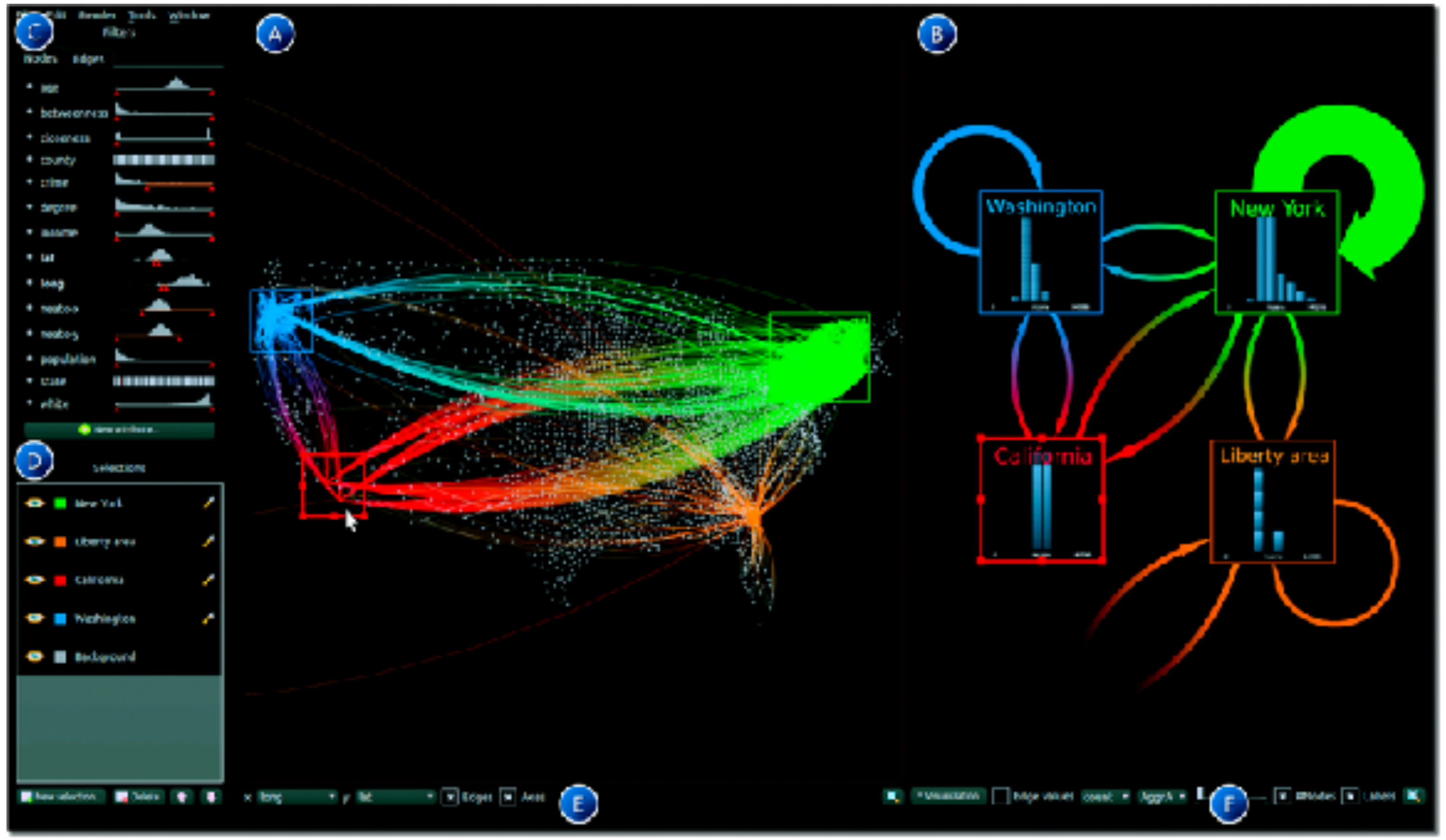

[Multivariate Network Exploration and Presentation: From Detail to Overview via Selections and Aggregations. van den Elzen, van Wijk, IEEE TVCG 20(12): 2014 (Proc. InfoVis 2014).]

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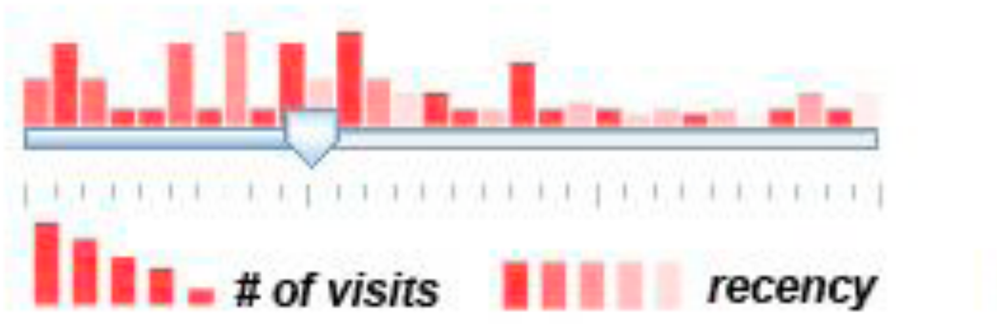

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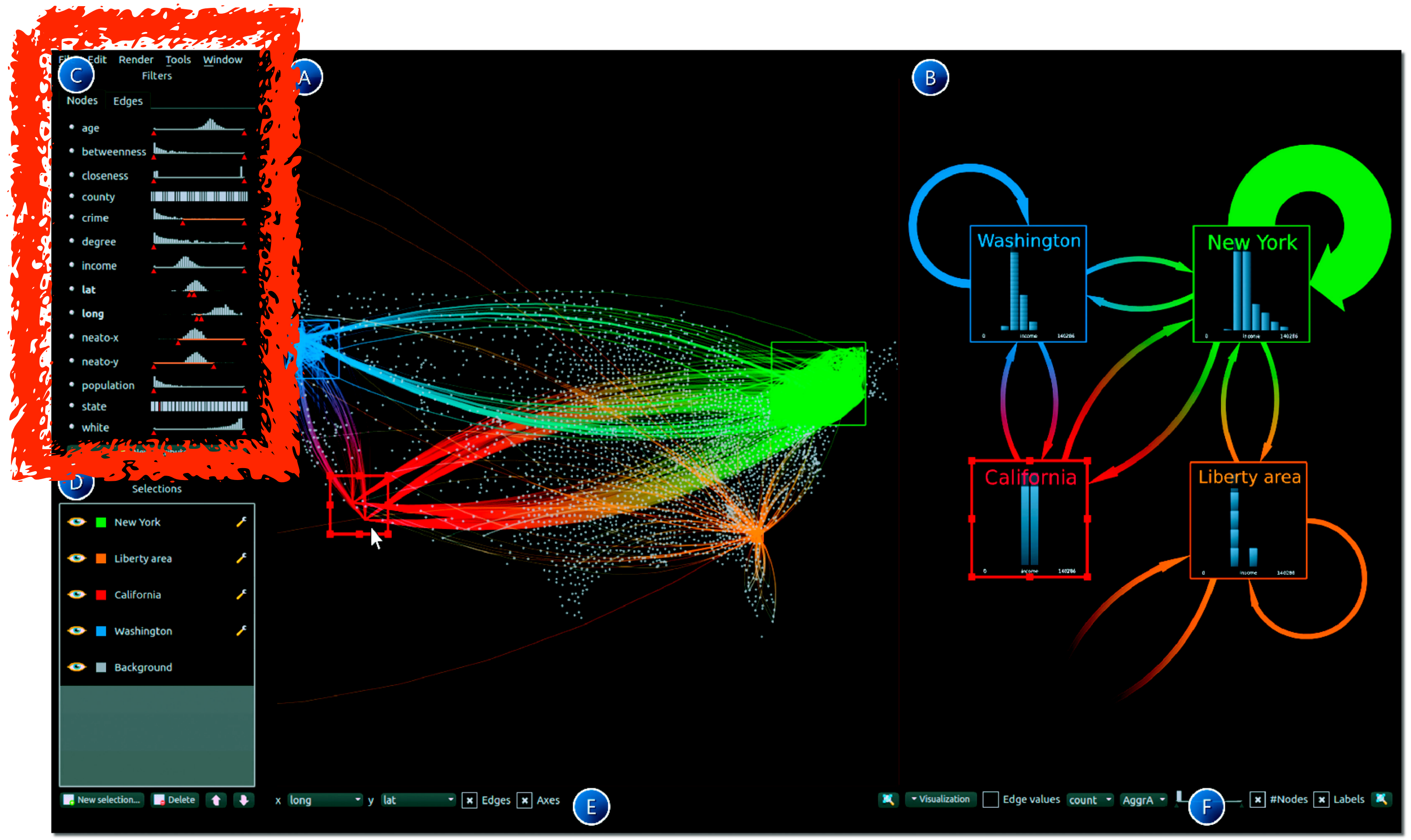

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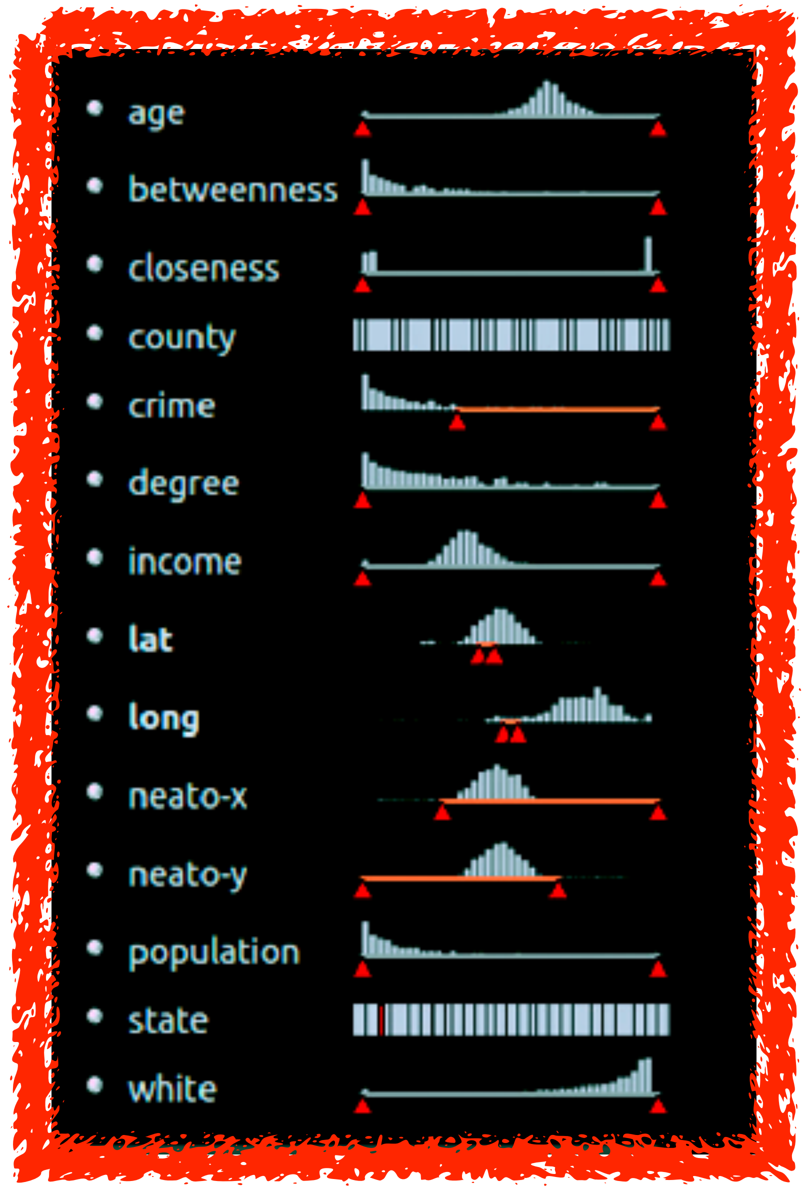
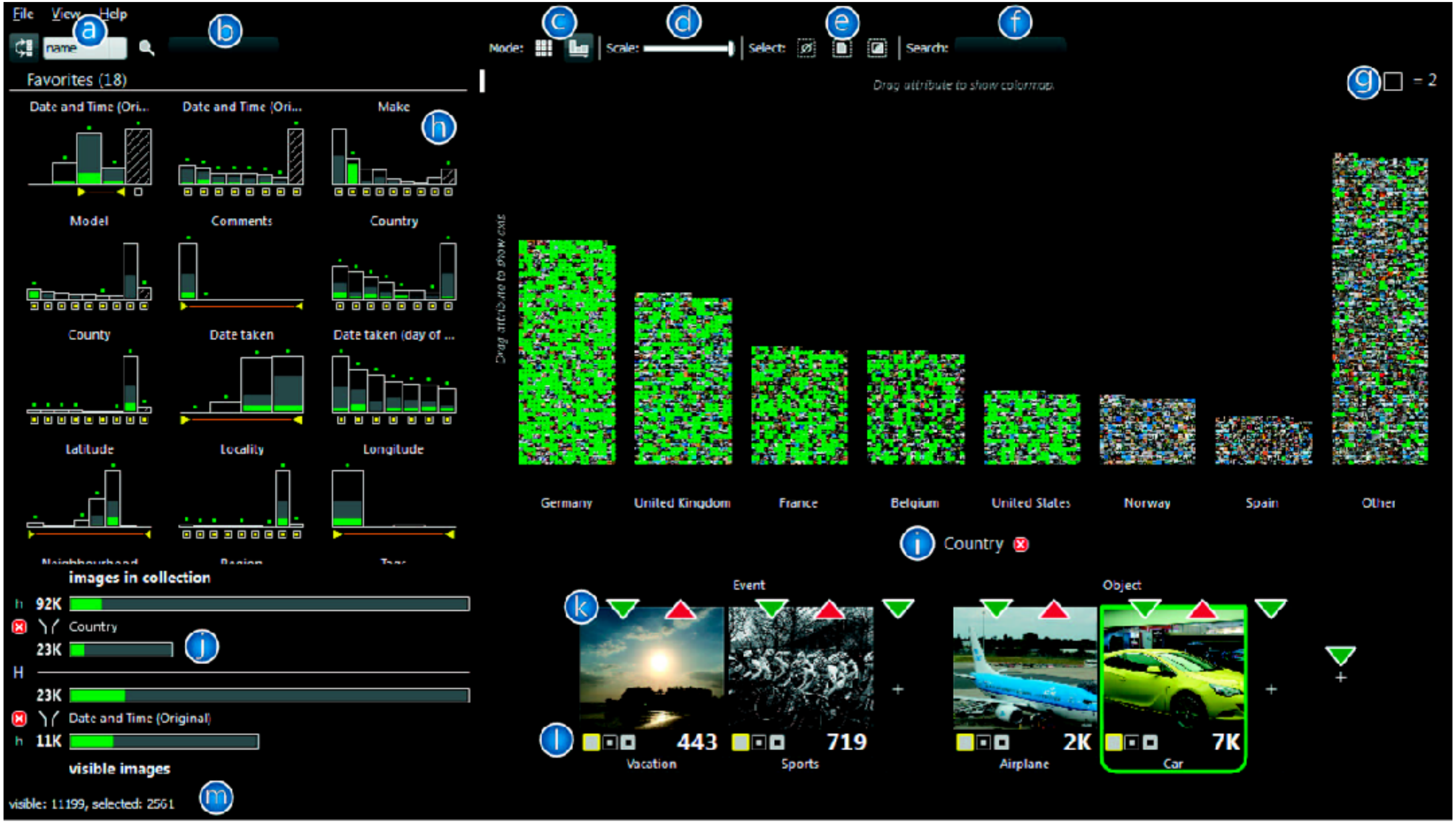


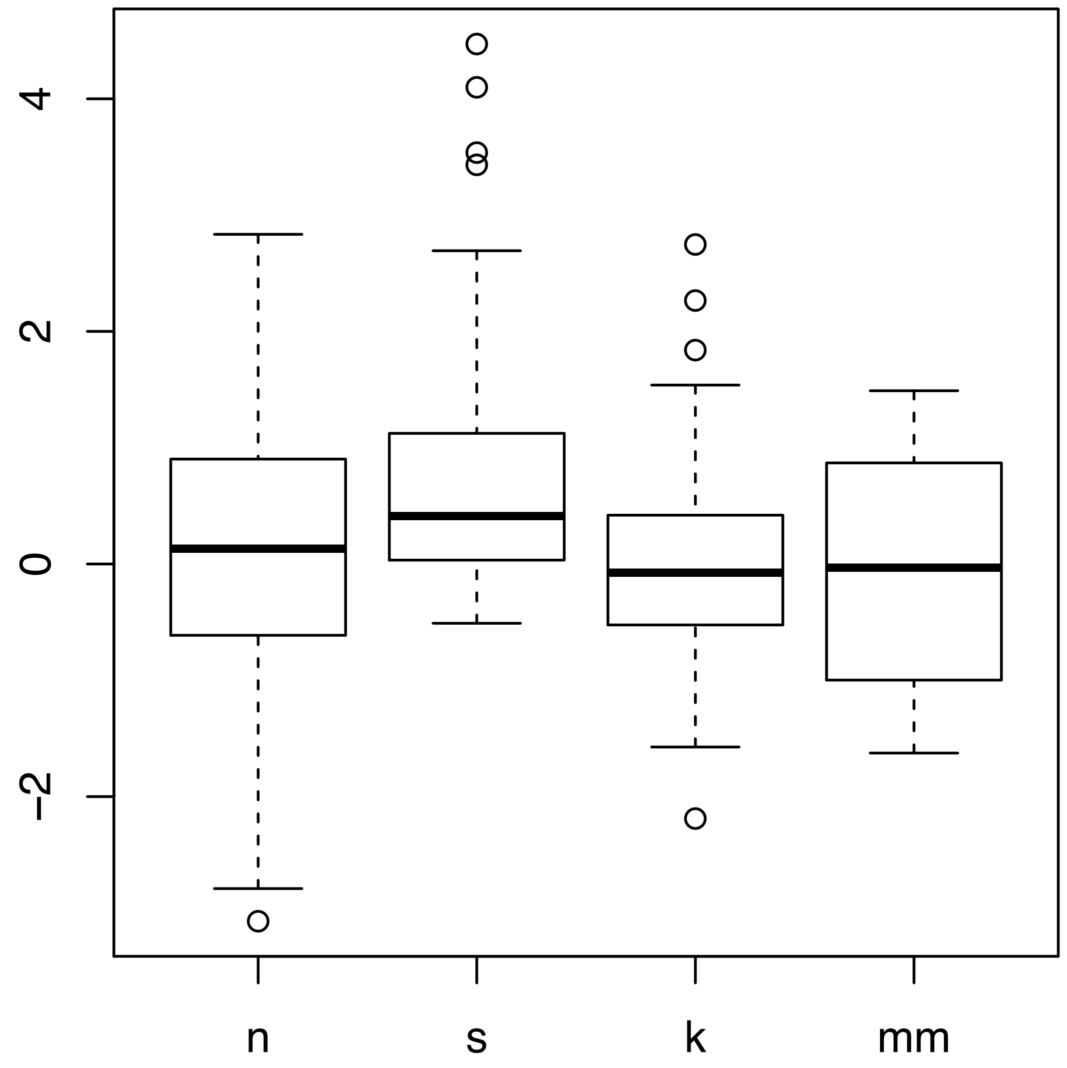
Scented histogram bisliders: detailed



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

Idiom: **boxplot**

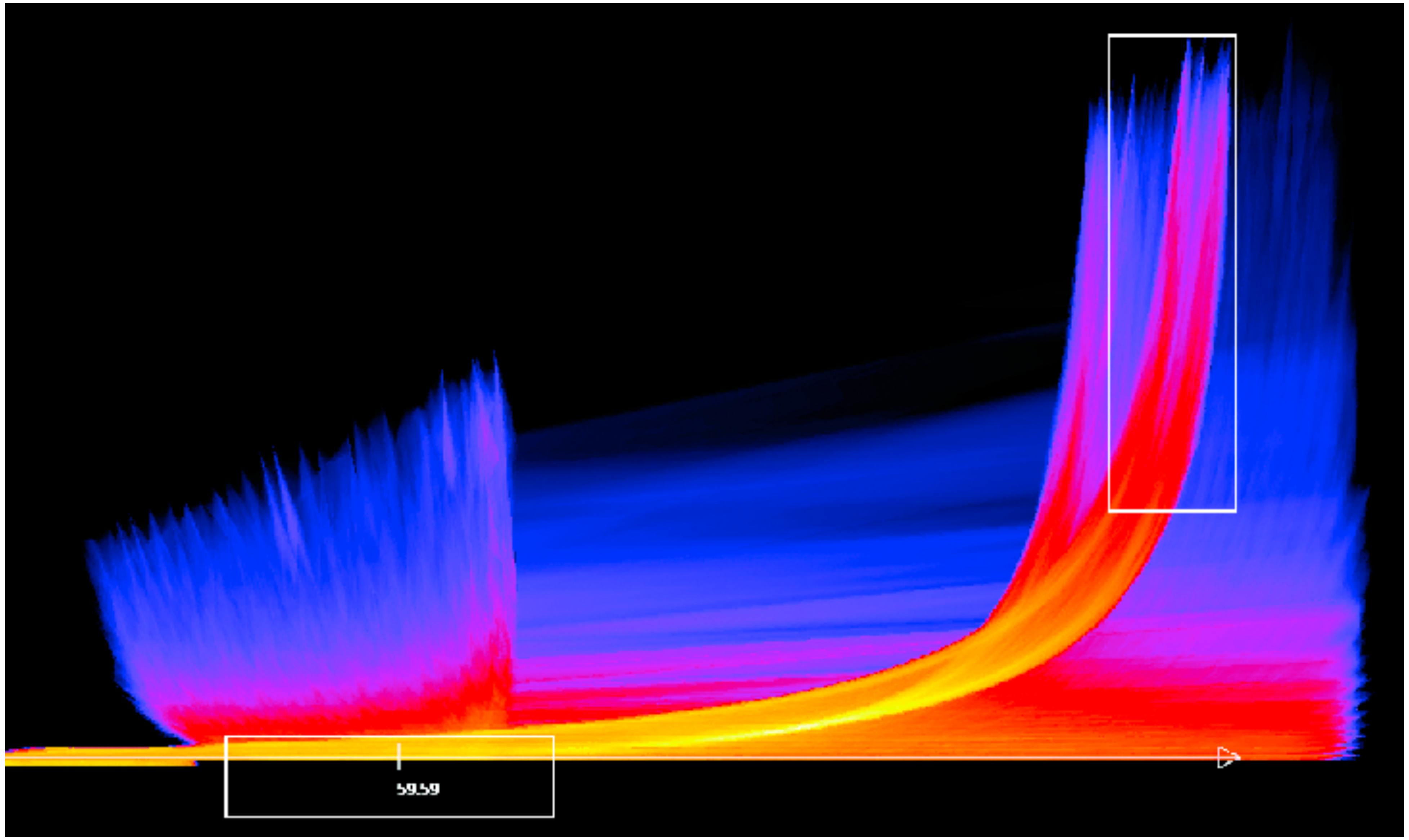
- static item aggregation
- task: find distribution
- data: table
- derived data
  - 5 quant attribs
    - median: central line
    - lower and upper quartile: boxes
    - lower upper fences: whiskers
      - values beyond which items are outliers
  - outliers beyond fence cutoffs explicitly shown
-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



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

Idiom: **Continuous scatterplot**

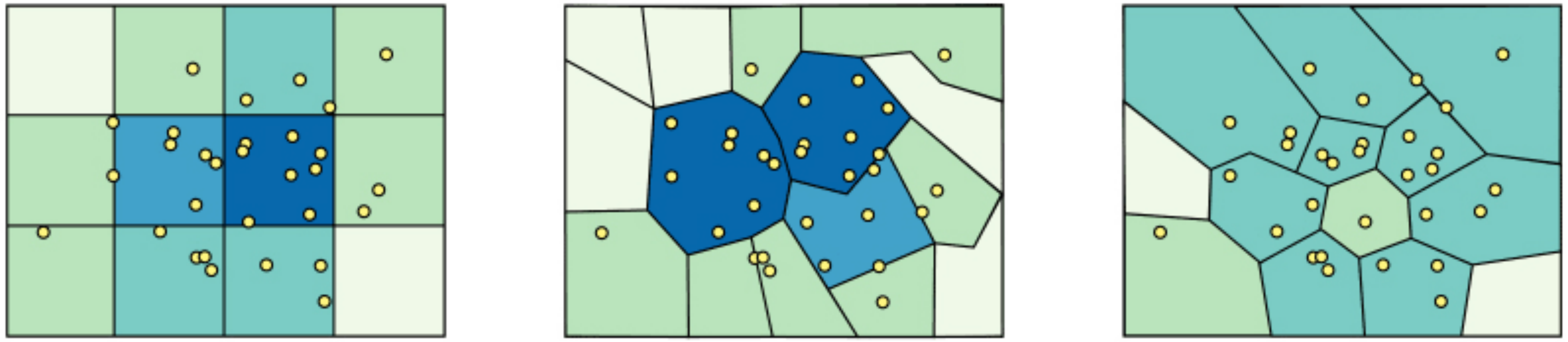
- static item aggregation
- data: table
- derived data: table
  - key attribs x,y for pixels
  - quant attrib: overplot density
- dense space-filling 2D matrix
- color:
  sequential categorical hue +
  ordered luminance colormap
- scalability
  - no limits on overplotting:
    millions of items



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

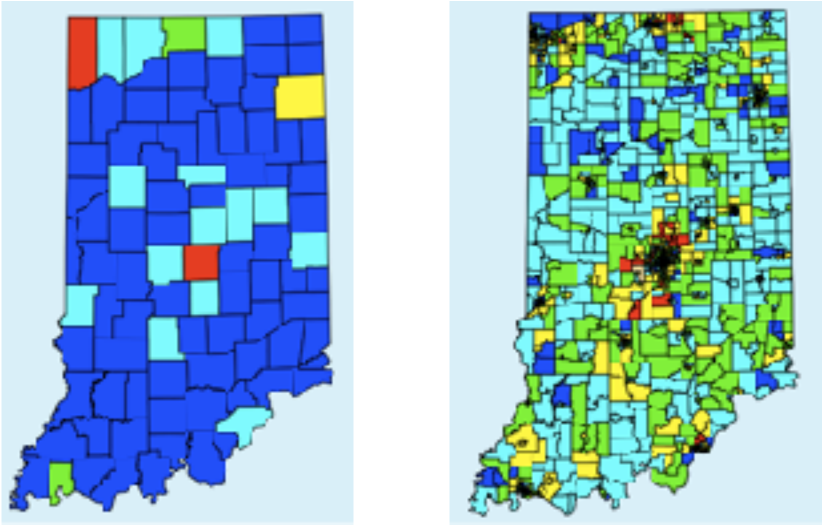
Spatial aggregation

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



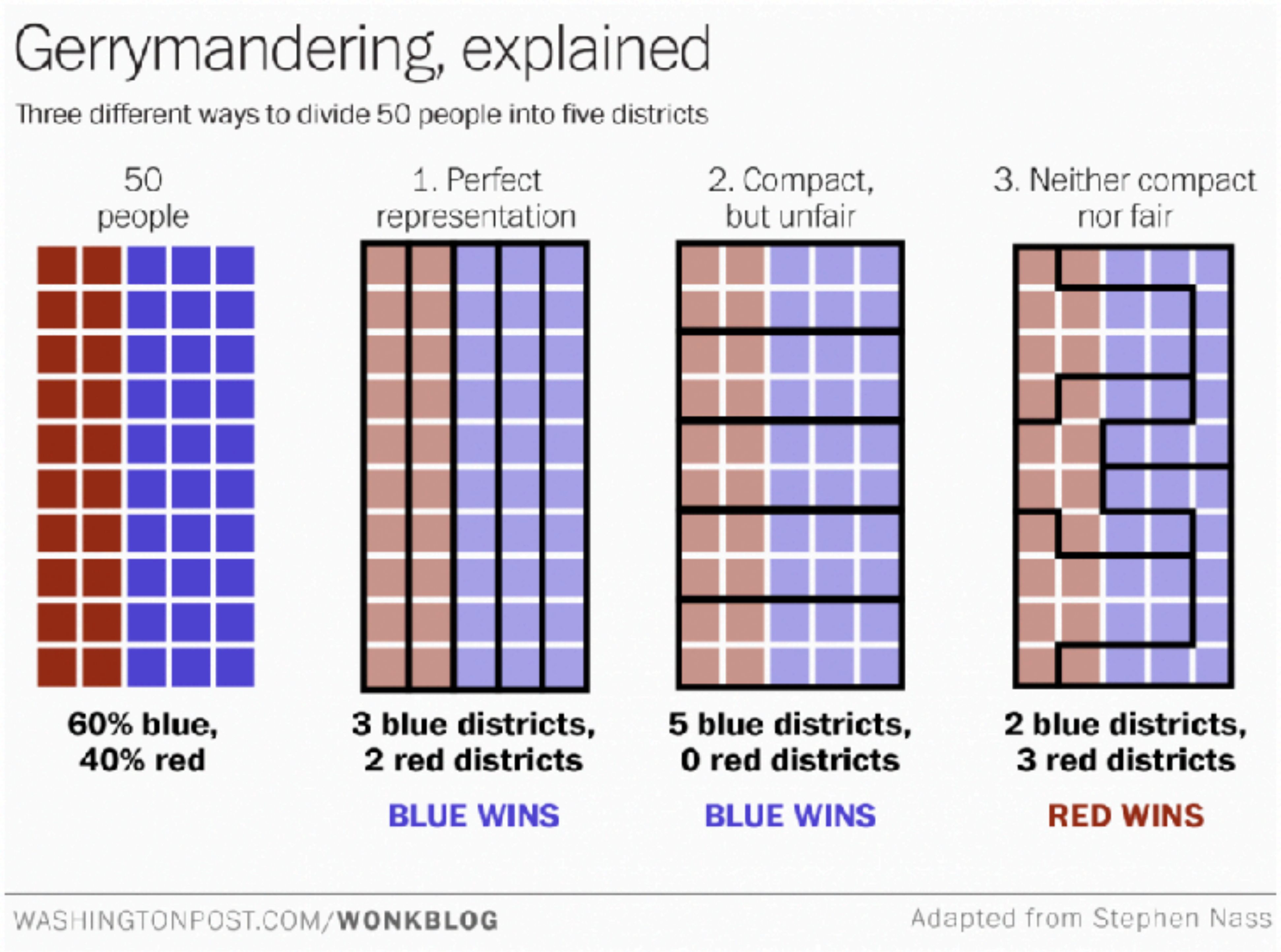
[http://www.e-education.psu/edu/geog486/l4_p7.html, Fig 4.cg.6]

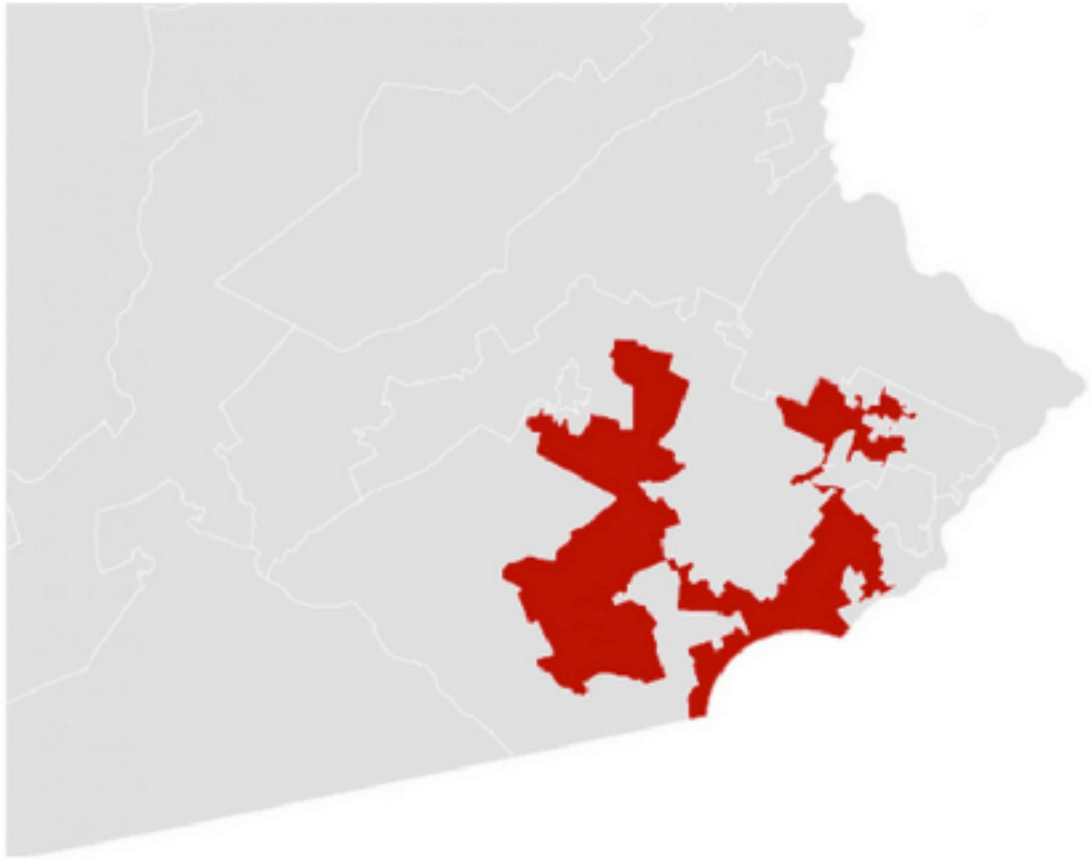
  - scale effects



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

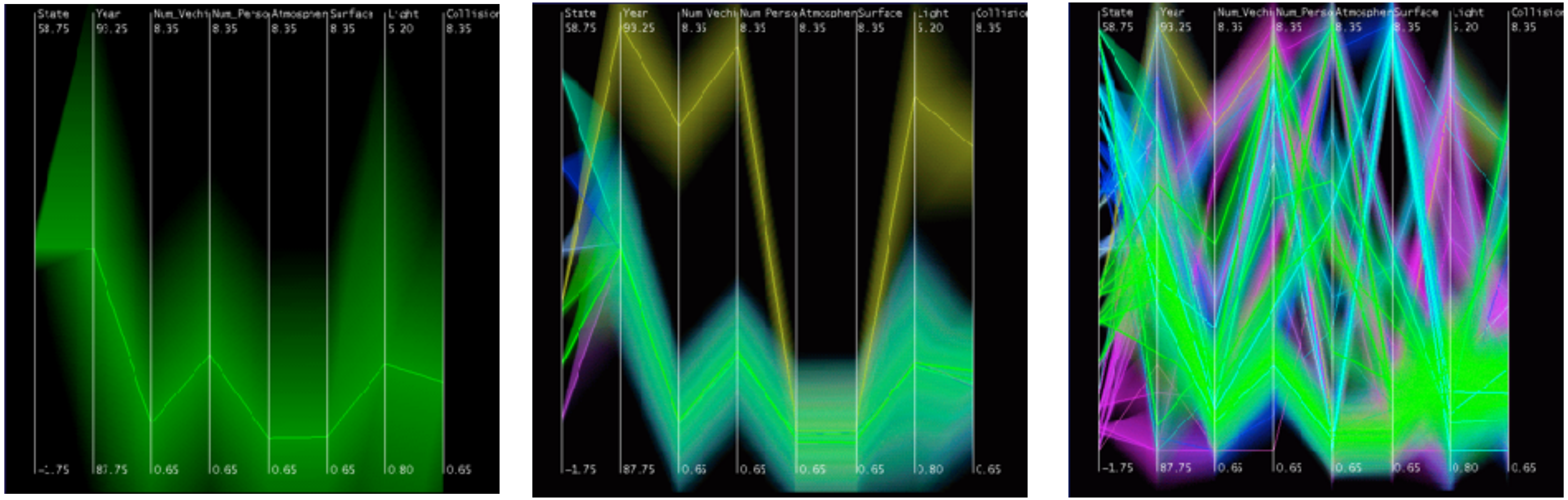
https://www.washingtonpost.com/news/wonk/wp/2015/03/01/this-is-the-best-explanation-of-gerrymandering-you-will-ever-see/

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

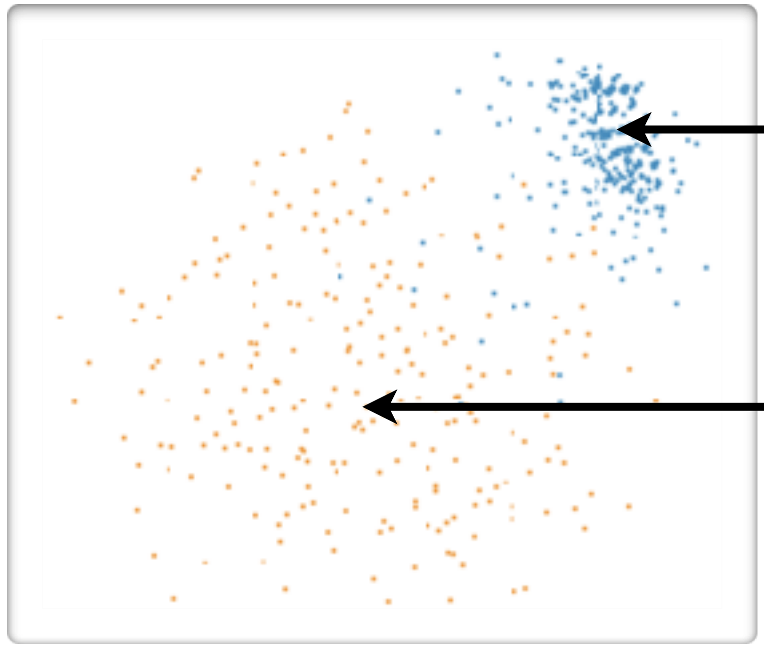


[Hierarchical Parallel Coordinates for Exploration of Large Datasets. Fua, Ward, and Rundensteiner. Proc. IEEE Visualization Conference (Vis '99), pp. 43– 50, 1999.]

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

tumor measurement data → DR →

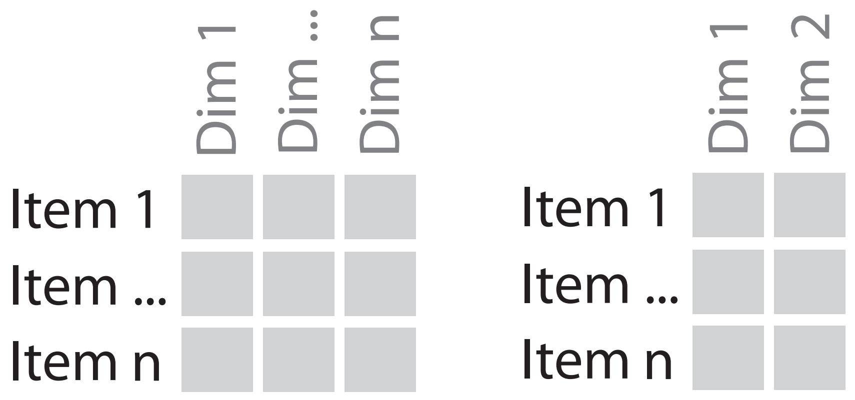


data:
9D measured space

derived data:
2D target space

Idiom: **Dimensionality reduction for documents**

Task 1



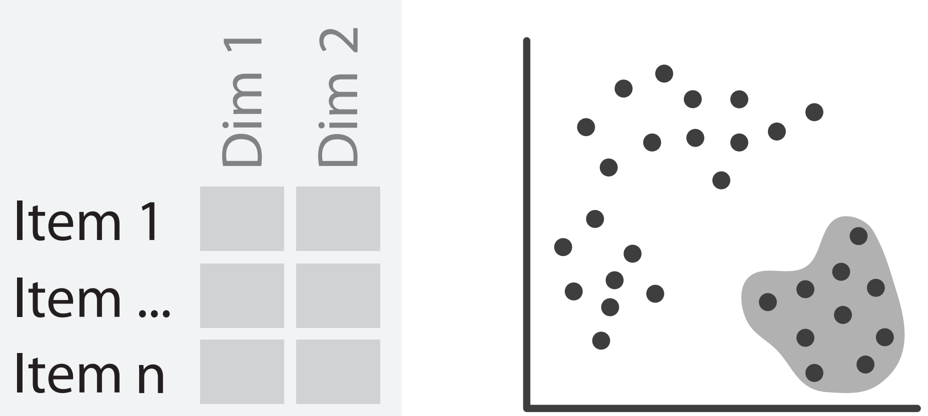
In
HD data → Out
2D data

What?
- In High-dimensional data
- Out 2D data

Why?
- Produce
- Derive

→

Task 2



In
2D data → Out
Scatterplot
Clusters & points

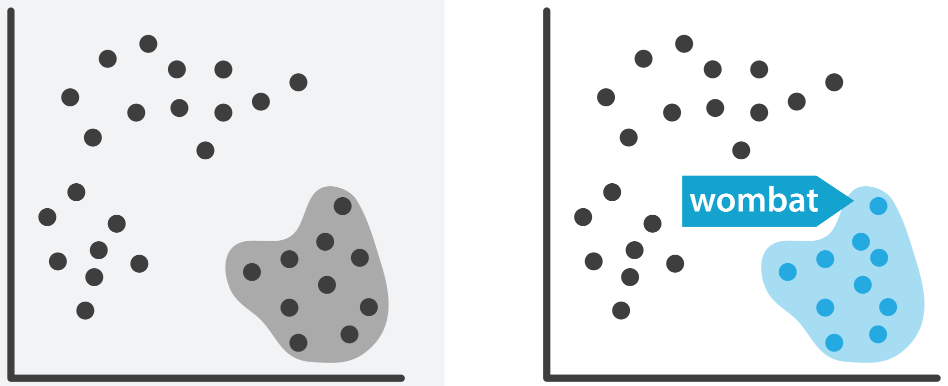
What?
- In 2D data
- Out Scatterplot
- Out Clusters & points

Why?
- Discover
- Explore
- Identify

How?
- Encode
- Navigate
- Select

→

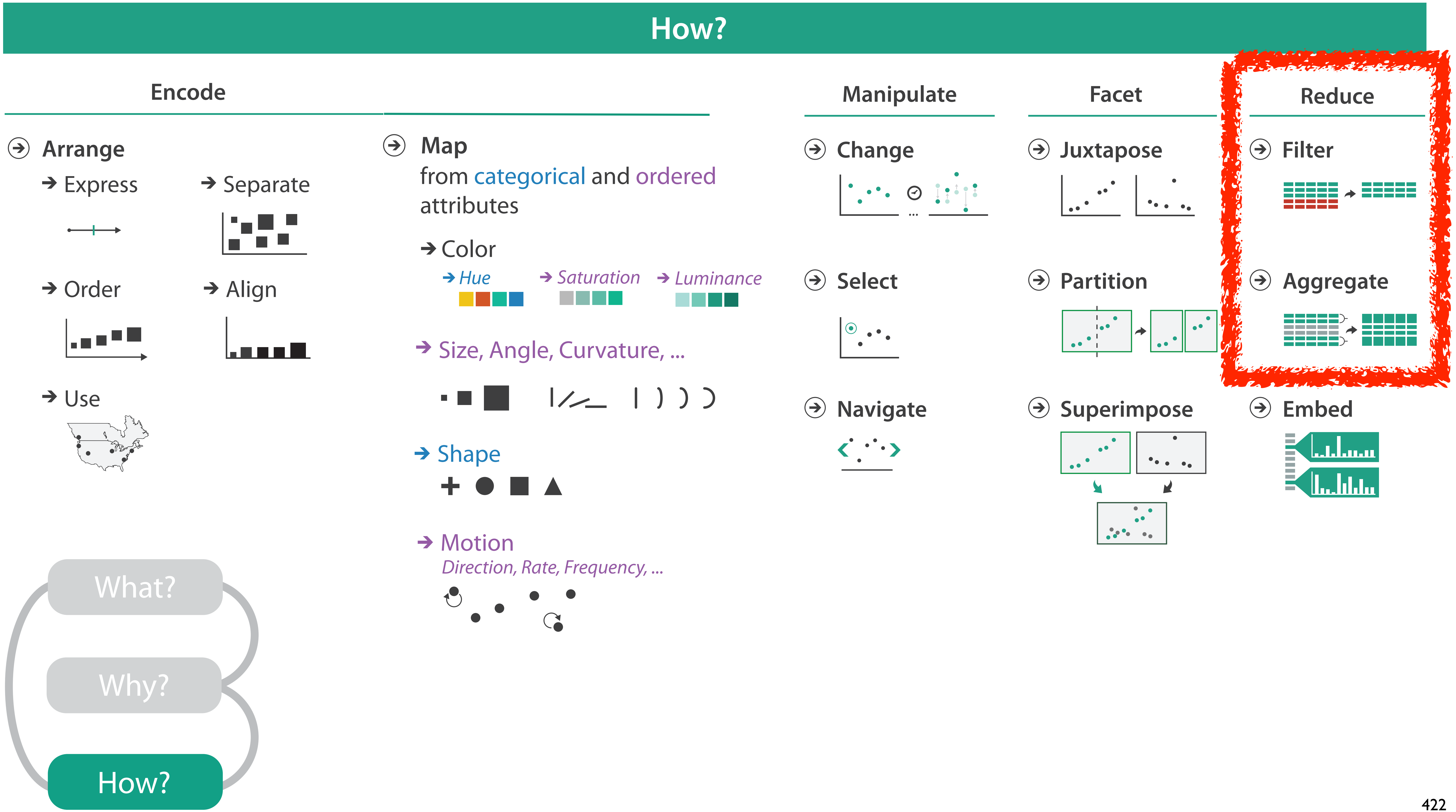
Task 3

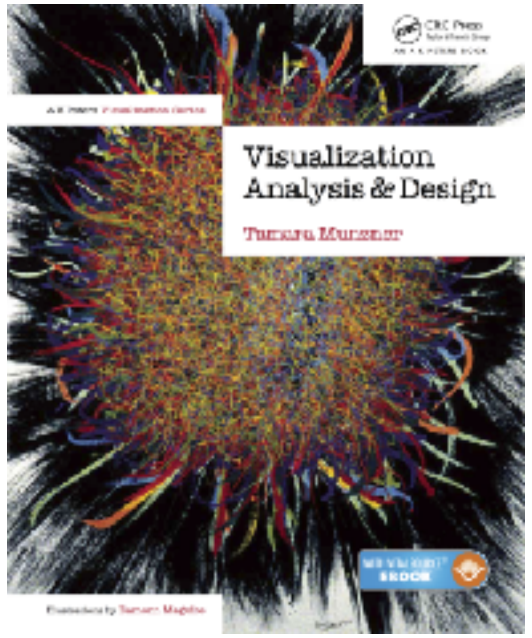


In
Scatterplot
Clusters & points → Out
Labels for clusters

What?
- In Scatterplot
- In Clusters & points
- Out Labels for clusters

Why?
- Produce
- Annotate


How?
Encode
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Manipulate
Change
Select
Navigate
Facet
Juxtapose
Partition
Superimpose
Reduce
Filter
Aggregate
Embed
What?
Why?
How?

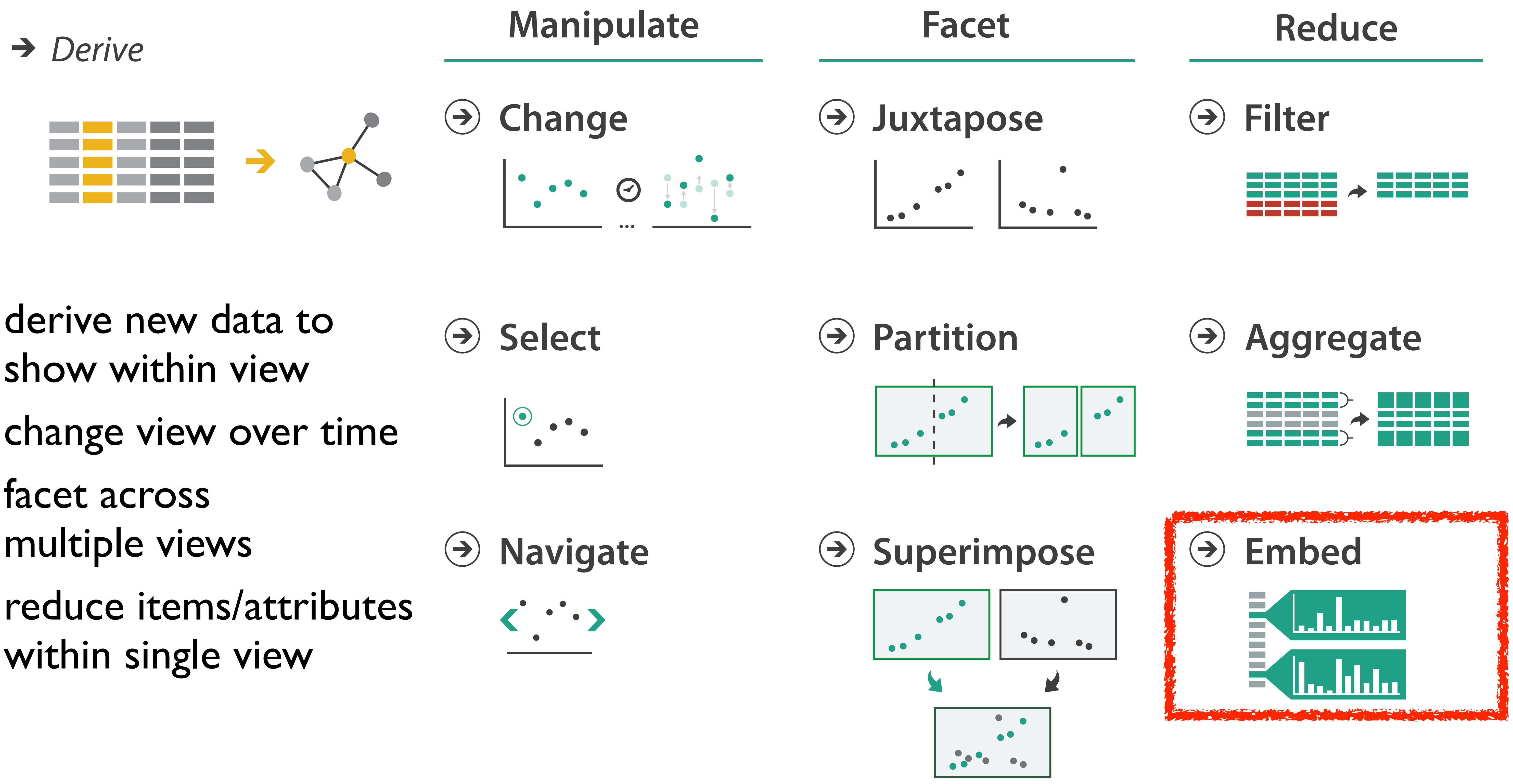


Visualization Analysis & Design

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

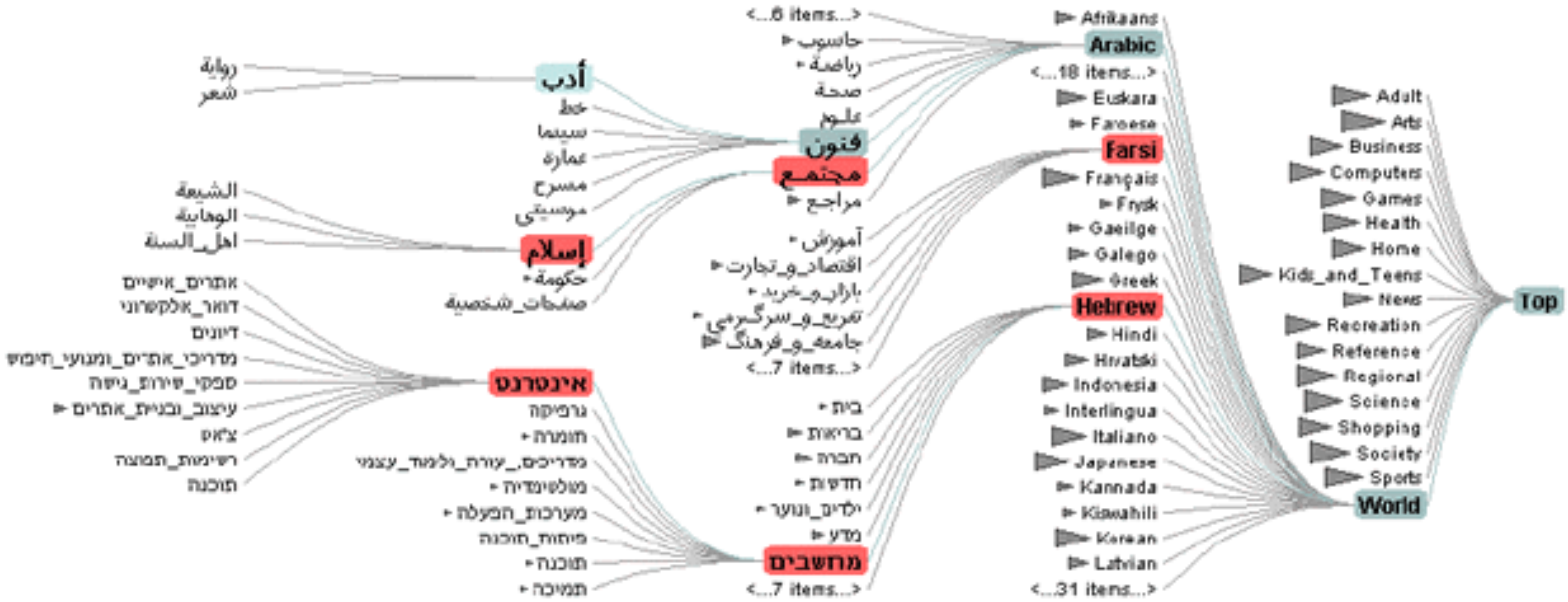
- combine focus + context info within single view
  – vs standard navigation within view
  – vs multiple views
- elide data
  – selectively filter and aggregate

➔ **Embed**

➔ Elide Data

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.]

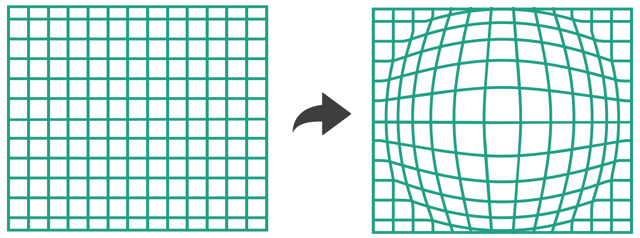
Embed: Focus+Context

- 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

Embed

→ Elide Data

→ Distort Geometry



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/

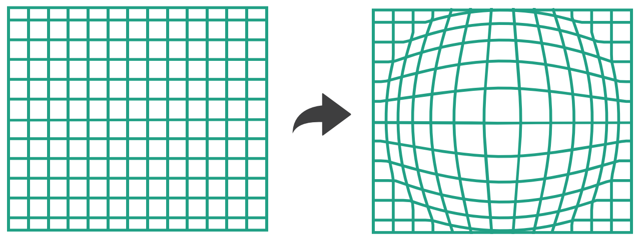
Embed: Focus+Context

- 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

Embed

→ Elide Data

→ Distort Geometry

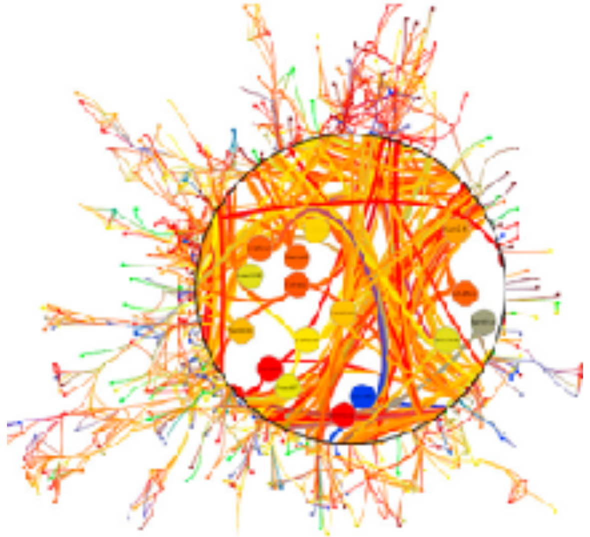


Distortion costs and benefits

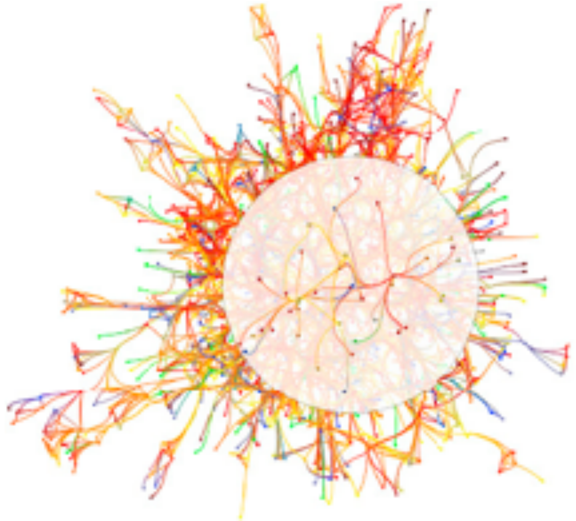
- benefits
  - combine focus and context information in single view
- costs
  - length comparisons impaired
    - topology comparisons unaffected: connection, containment
  - effects of distortion unclear if original structure unfamiliar
  - object constancy/tracking may be impaired

fisheye lens

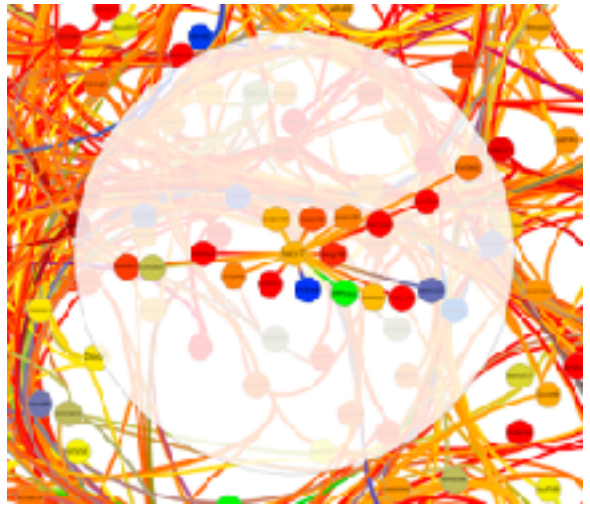
magnifying lens



neighborhood layering



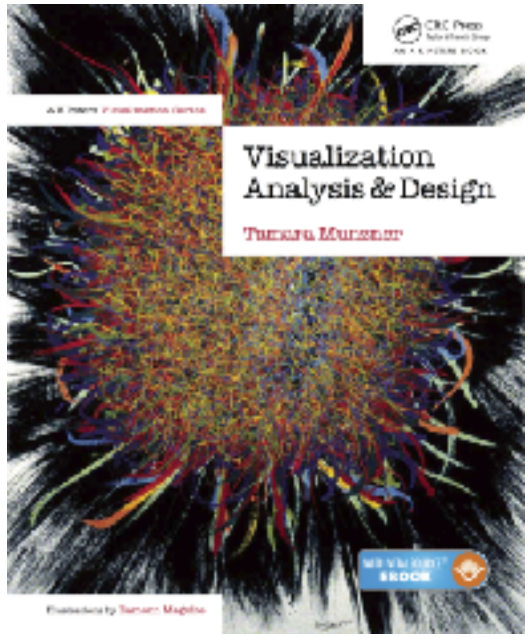
Bring and Go



[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.]

Visualization Analysis & Design

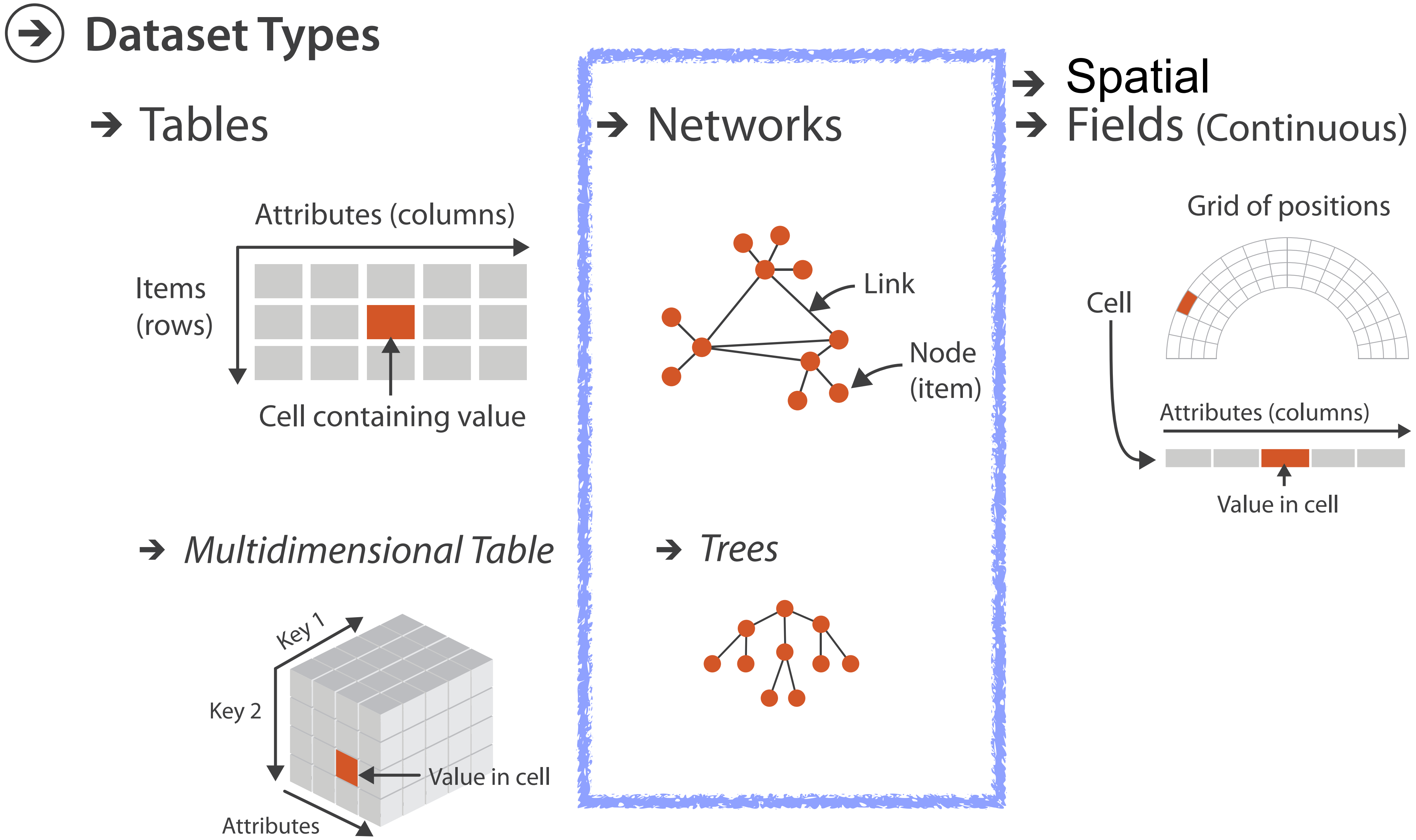
Network Data (Ch 9)



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

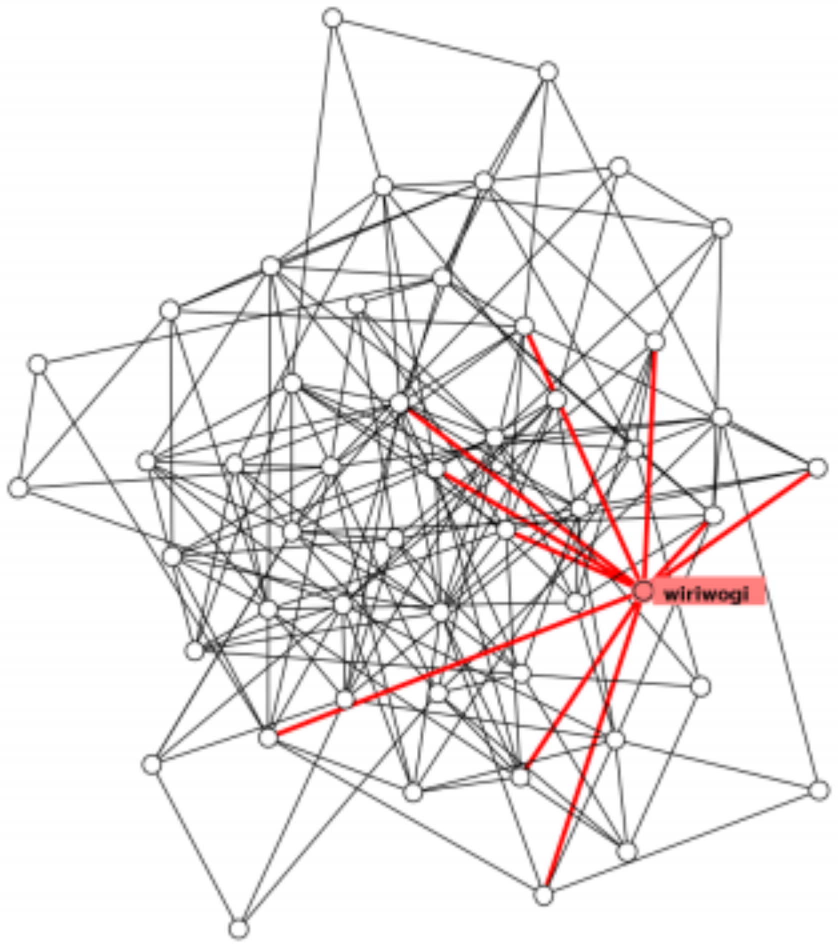
Network data

- 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



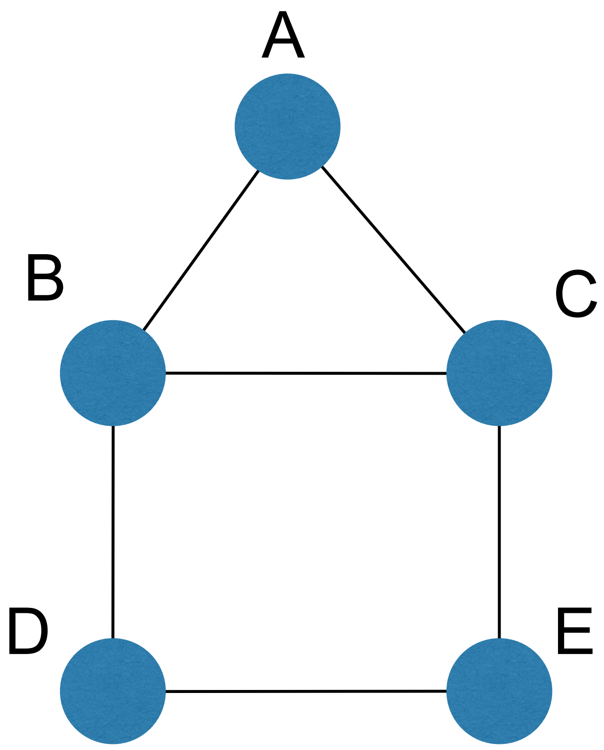
Network tasks: topology-based and attribute-based

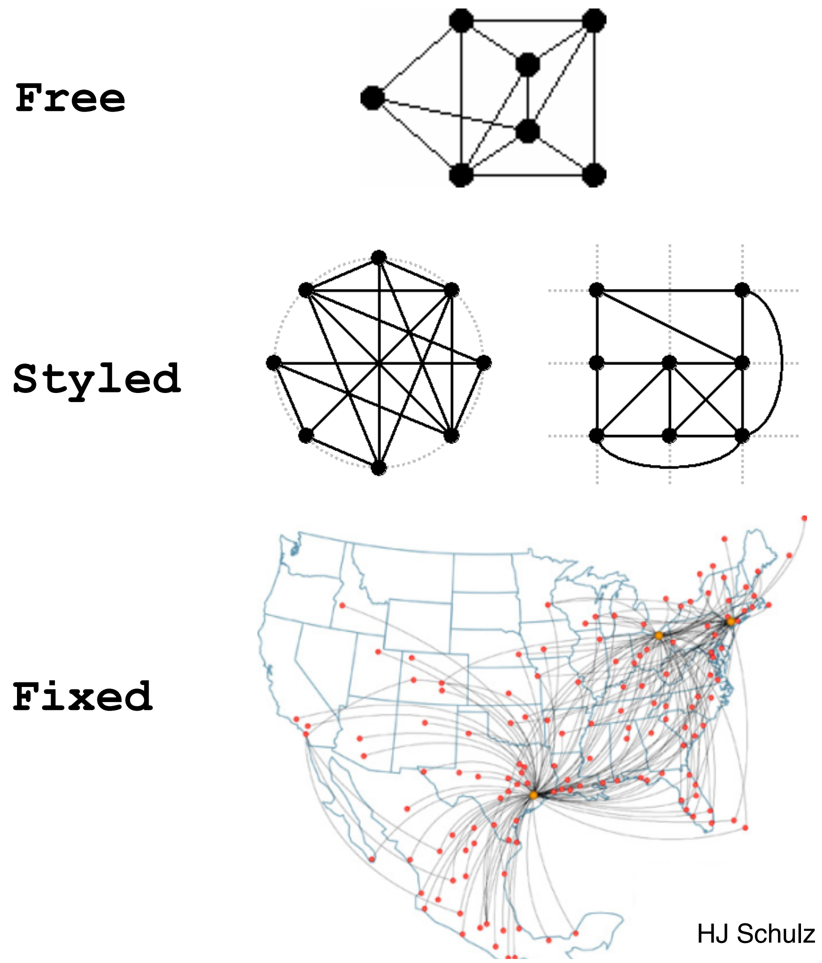
- topology based tasks
  - find paths
  - find (topological) neighbors
  - compare centrality/importance measures
  - identify clusters / communities
- attribute based tasks (similar to table data)
  - find distributions, ...
- combination tasks, incorporating both
  - example: find friends-of-friends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



Node-link diagrams

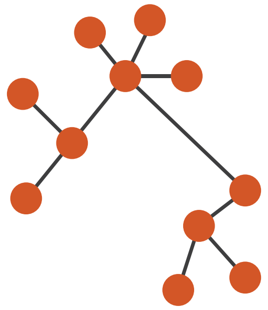
- nodes: point marks
- links: line marks
  - straight lines or arcs
  - connections between nodes
- intuitive & familiar
  - most common
  - many, many variants





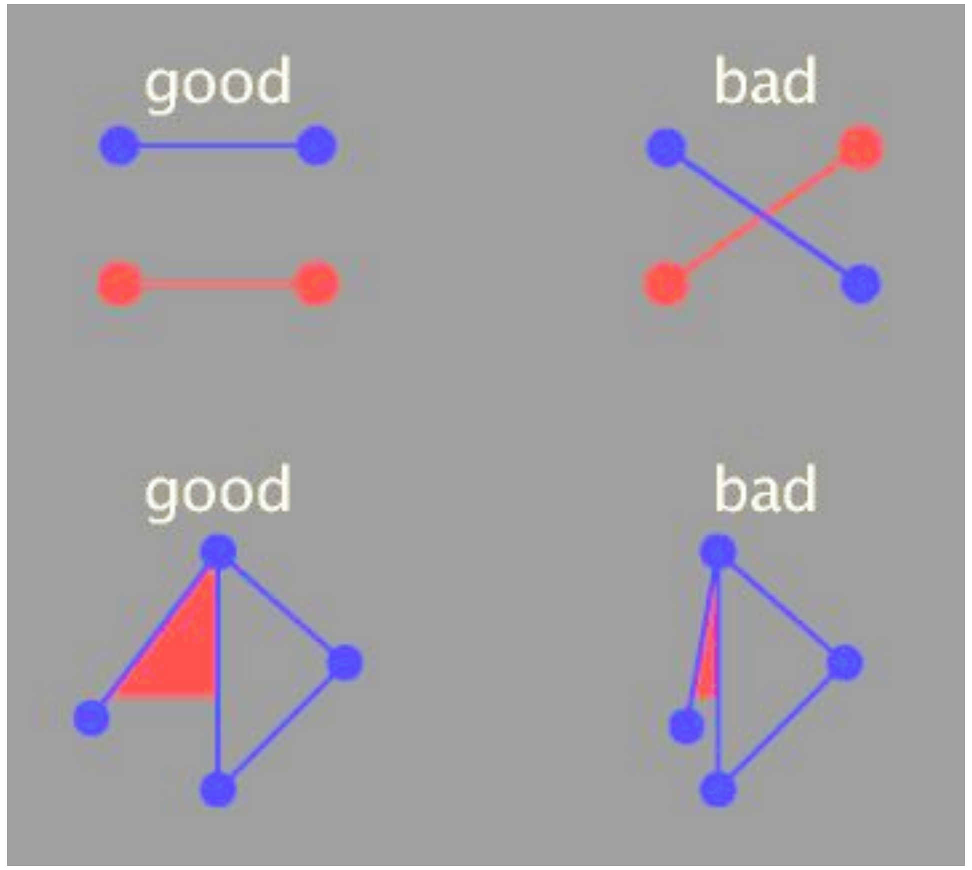
HJ Schulz 2006

Node–Link Diagrams
Connection Marks
✔ NETWORKS ✔ TREES



Criteria for good node-link layouts

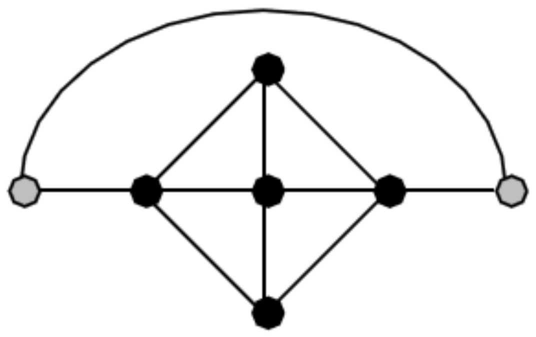
- minimize
  - edge crossings, node overlaps
  - distances between topological neighbor nodes
  - total drawing area
  - edge bends
- maximize
  - angular distance between different edges
  - aspect ratio disparities
- emphasize symmetry
  - similar graph structures should look similar in layout



Criteria conflict

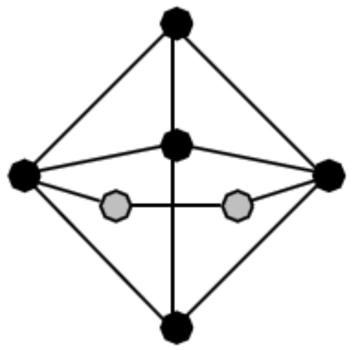
- most criteria NP-hard individually
- many criteria directly conflict with each other

Minimum number of edge crossings

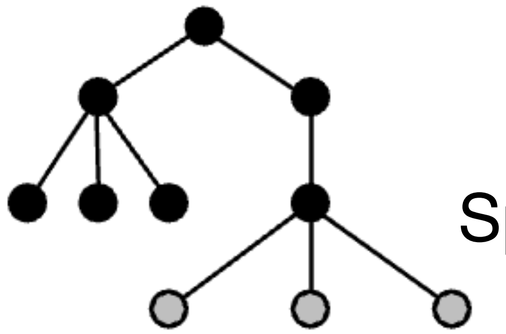


vs.

Uniform edge length

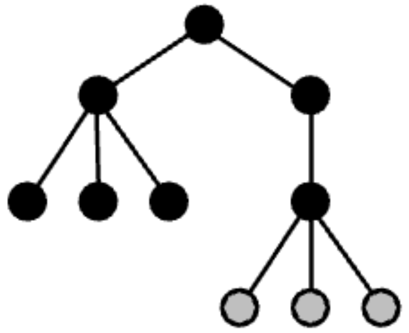


Space utilization



vs.

Symmetry



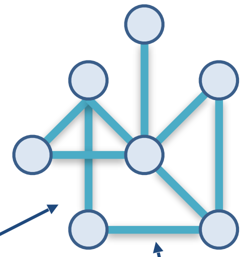
Schulz 2004

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



Expander
(pushing nodes apart)

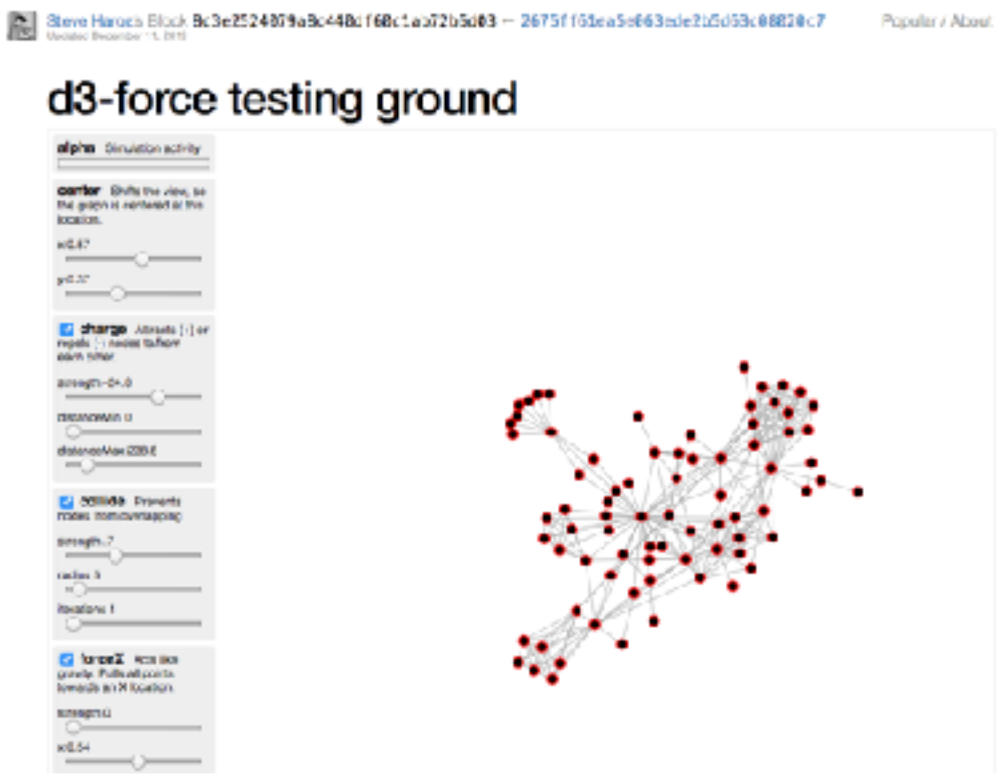
Spring Coil
(pulling nodes together)

- 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

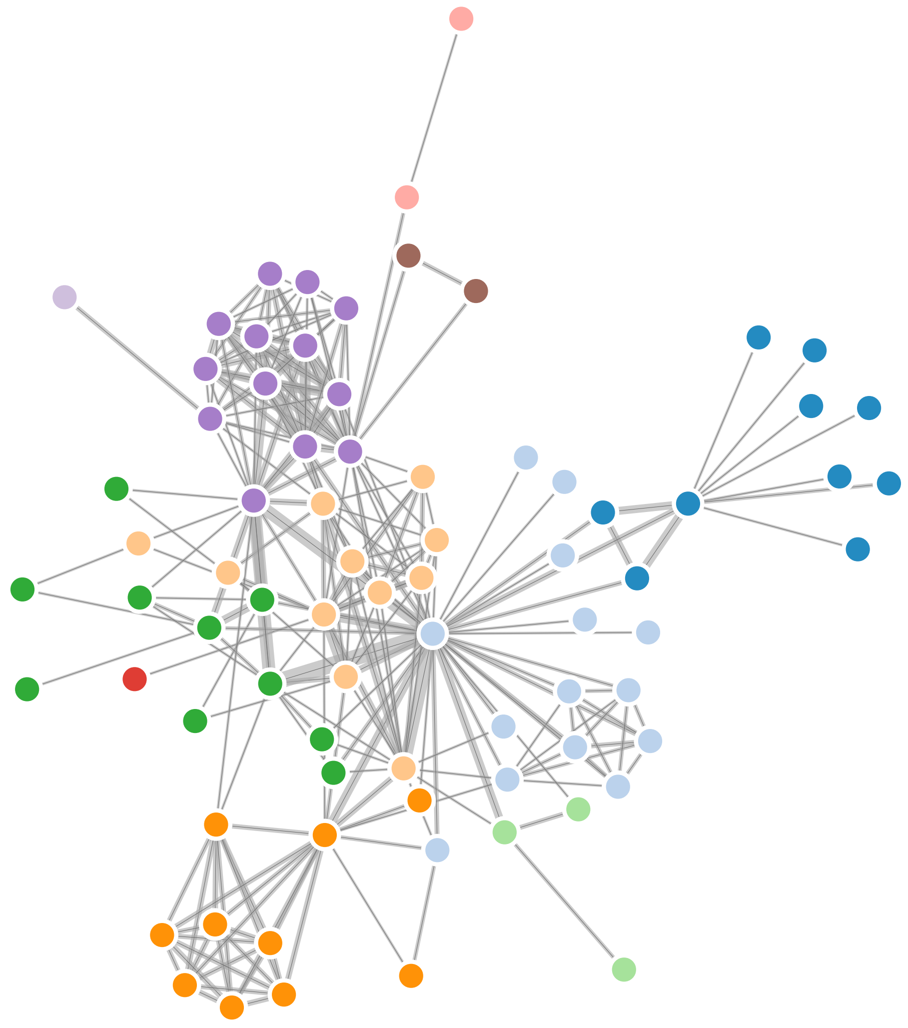
- strengths
  - reasonable layout for small, sparse graphs
  - clusters typically visible
  - edge length uniformity
- weaknesses
  - nondeterministic
  - computationally expensive: O(n^3) for n nodes
    - each step is n^2, takes ~n cycles to reach equilibrium
  - naive FD doesn't scale well beyond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



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

Idiom: **force-directed placement**

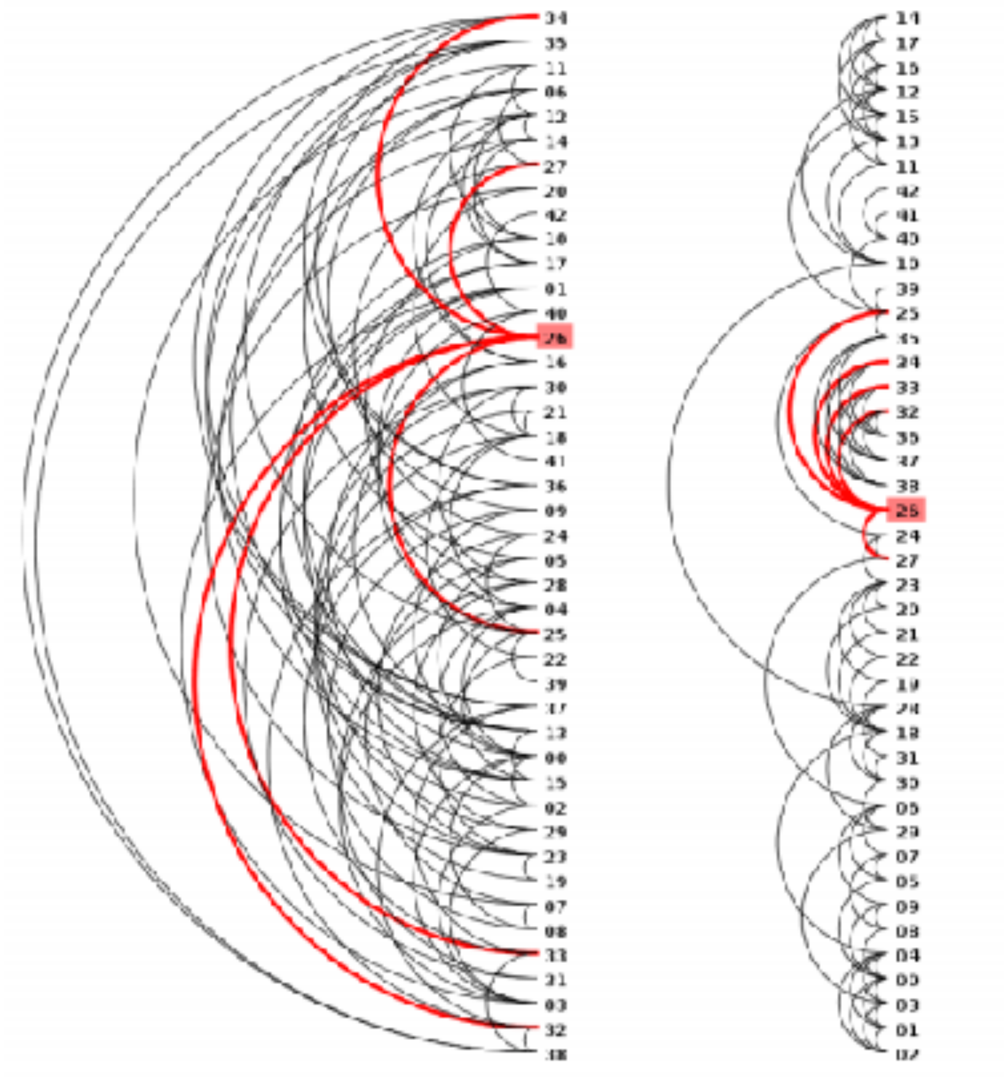
- visual encoding
  - link connection marks, node point marks
- considerations
  - spatial position: no meaning directly encoded
    - left free to minimize crossings
  - proximity semantics?
    - sometimes meaningful
    - sometimes arbitrary, artifact of layout algorithm
    - tension with length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

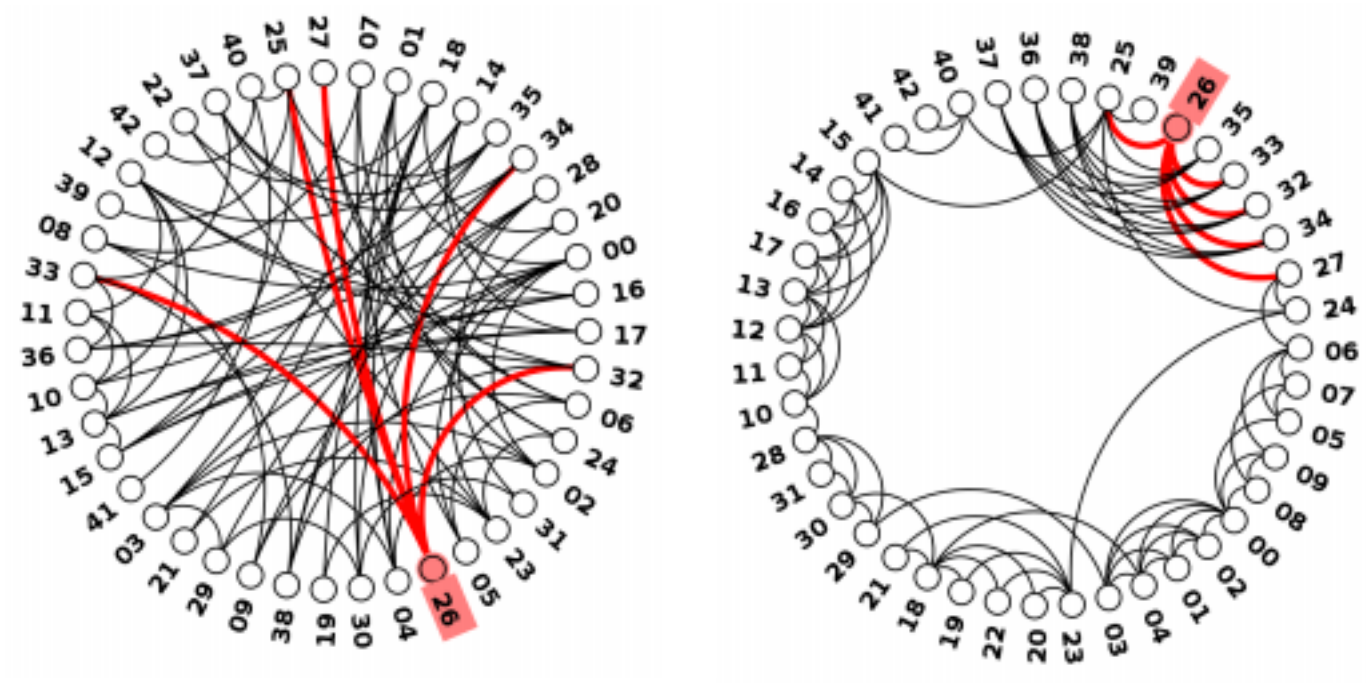


http://mbostock.github.com/d3/ex/force.html

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

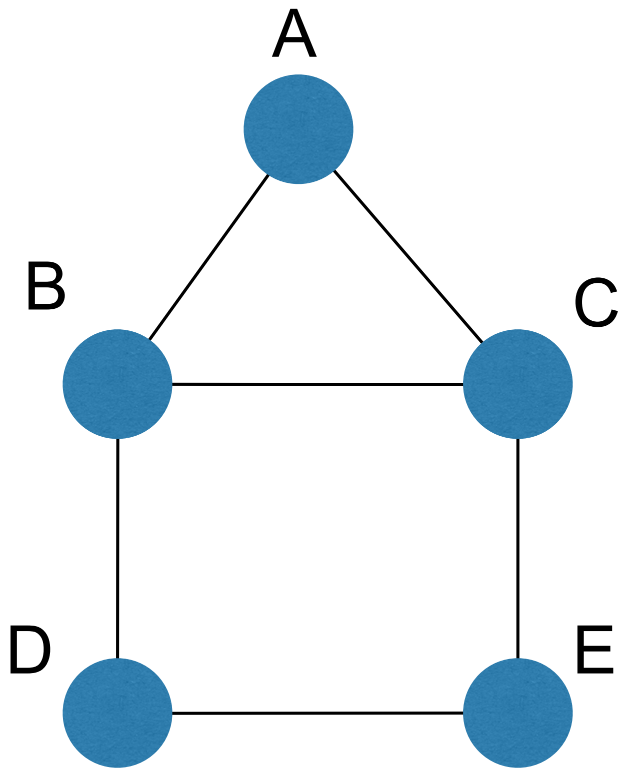


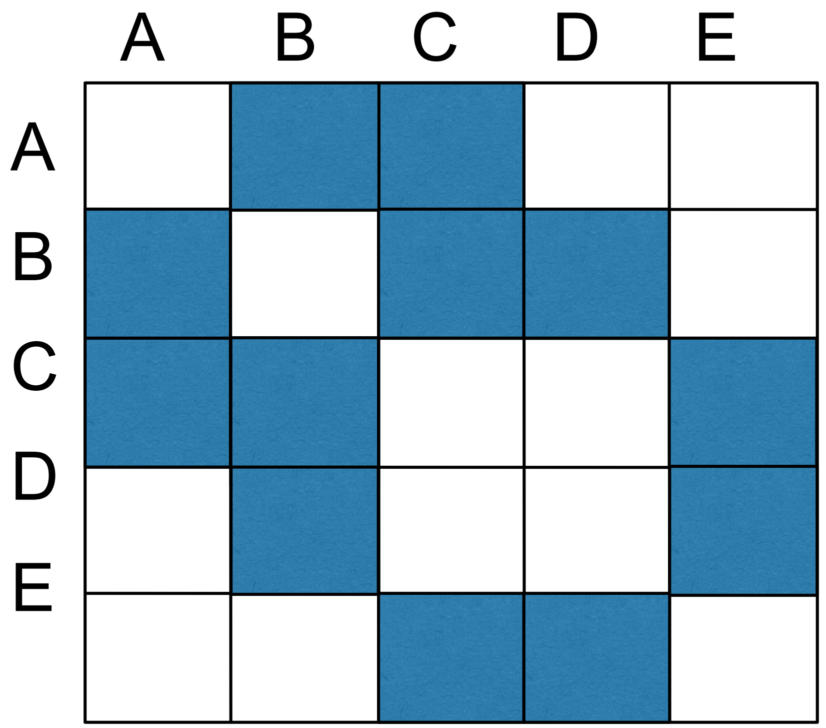


http://profs.etsmtl.ca/mmcguffin/research/2012-mcguffin-simpleNetVis/mcguffin-2012-simpleNetVis.pdf

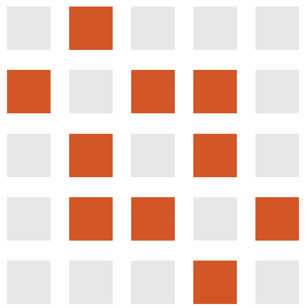
Adjacency matrix representations

- derive adjacency matrix from network

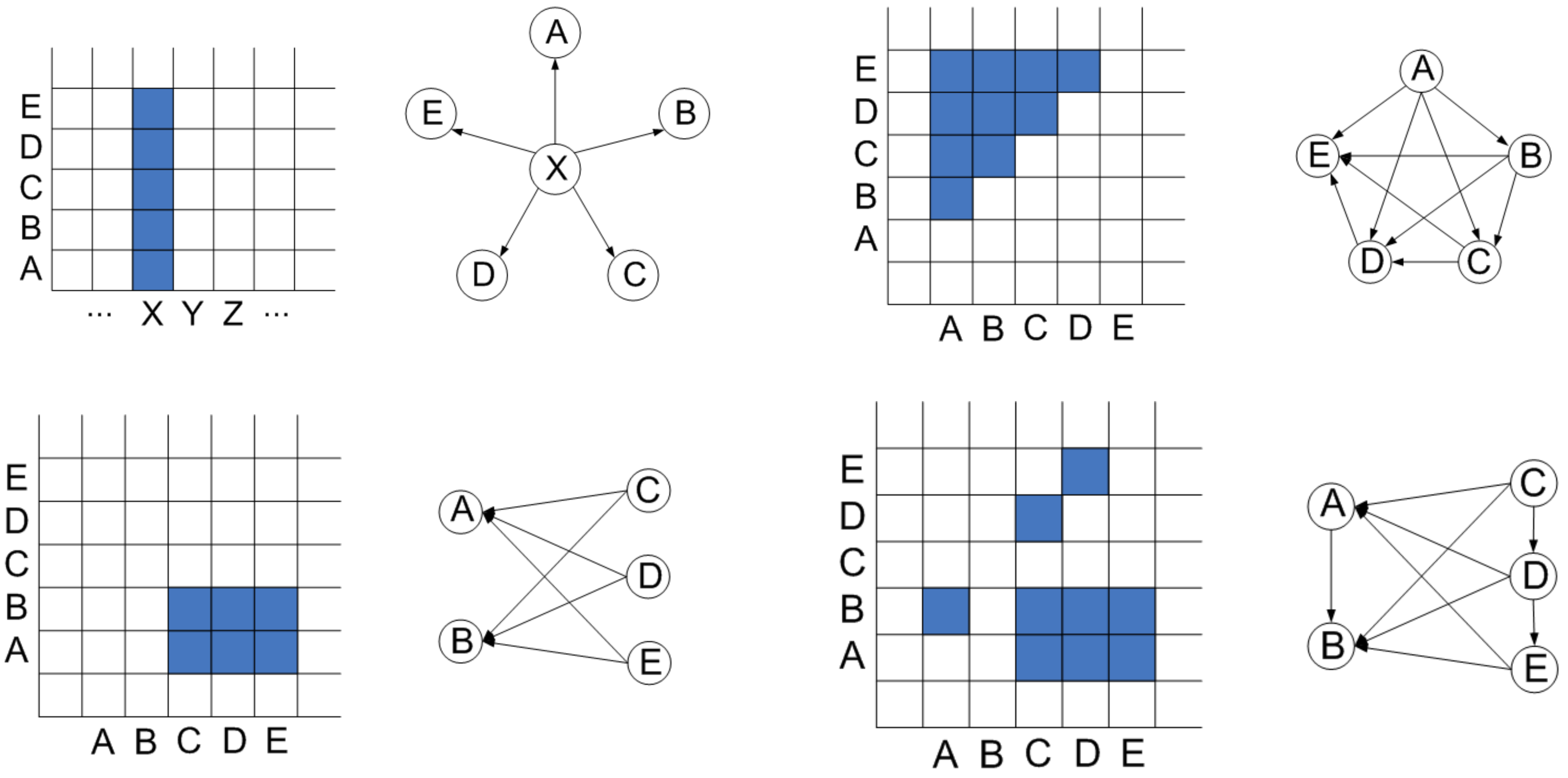




Adjacency Matrix
Derived Table
✔ NETWORKS ✔ TREES

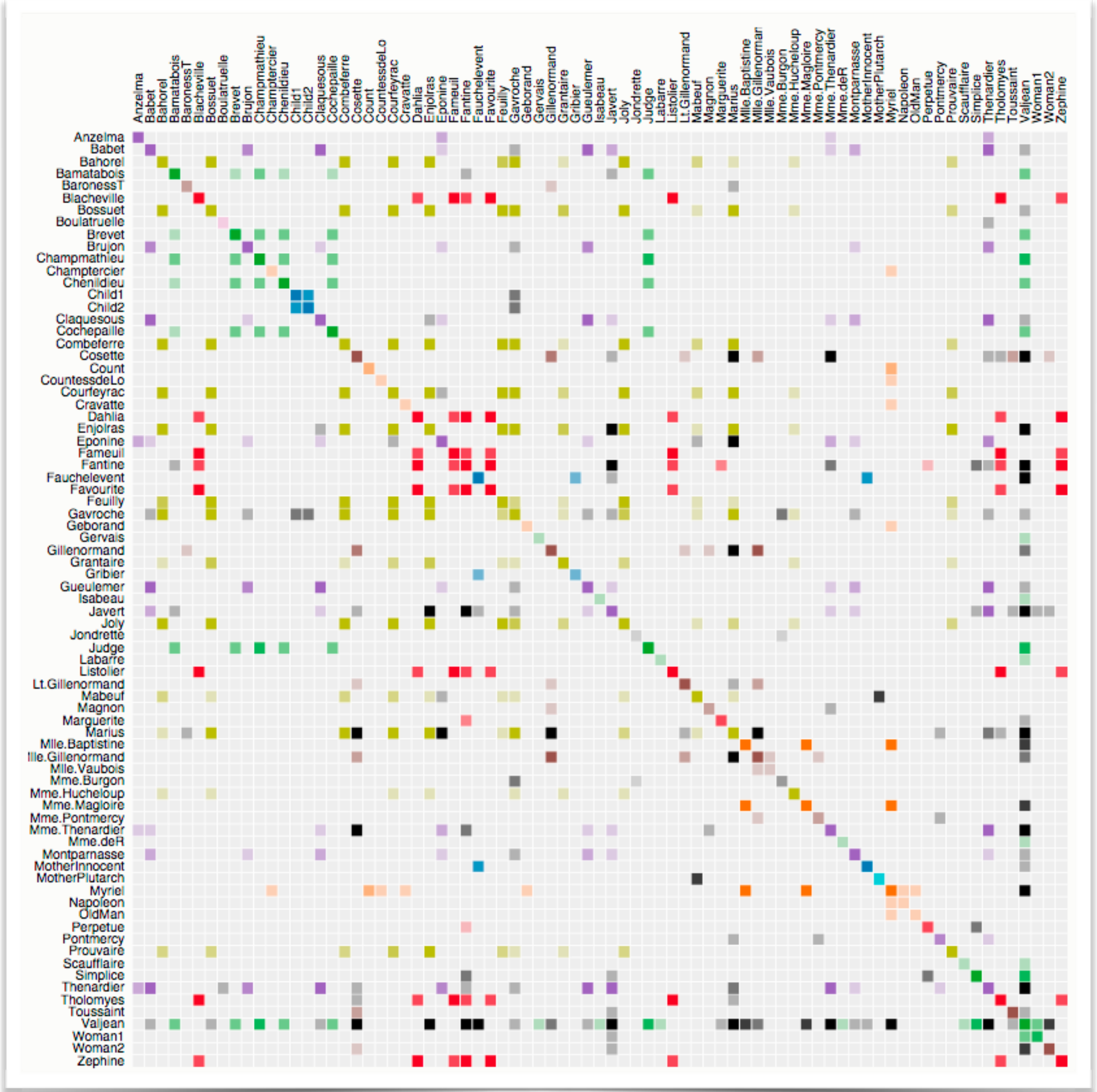


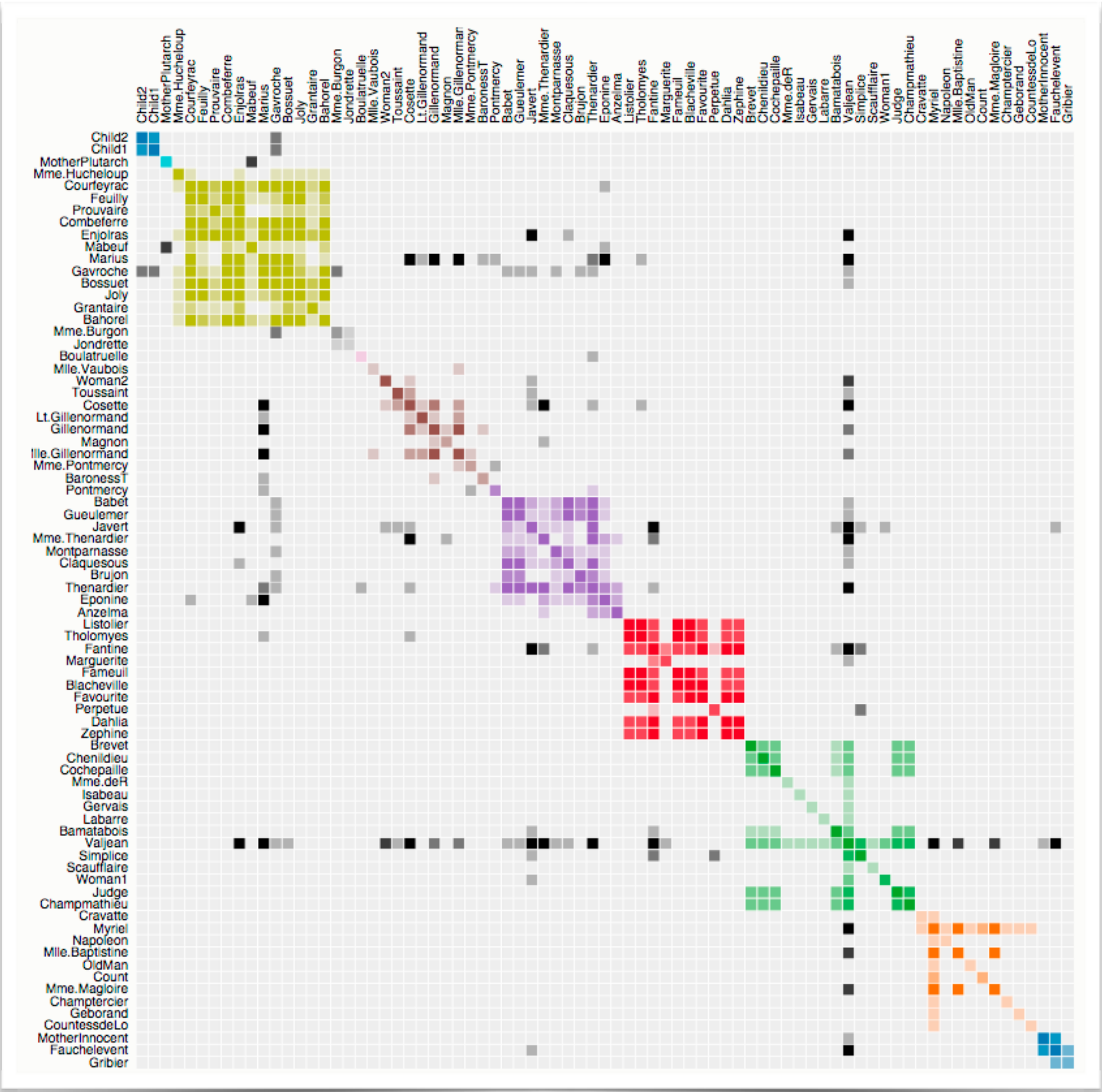
Adjacency matrix examples



HJ Schulz 2007

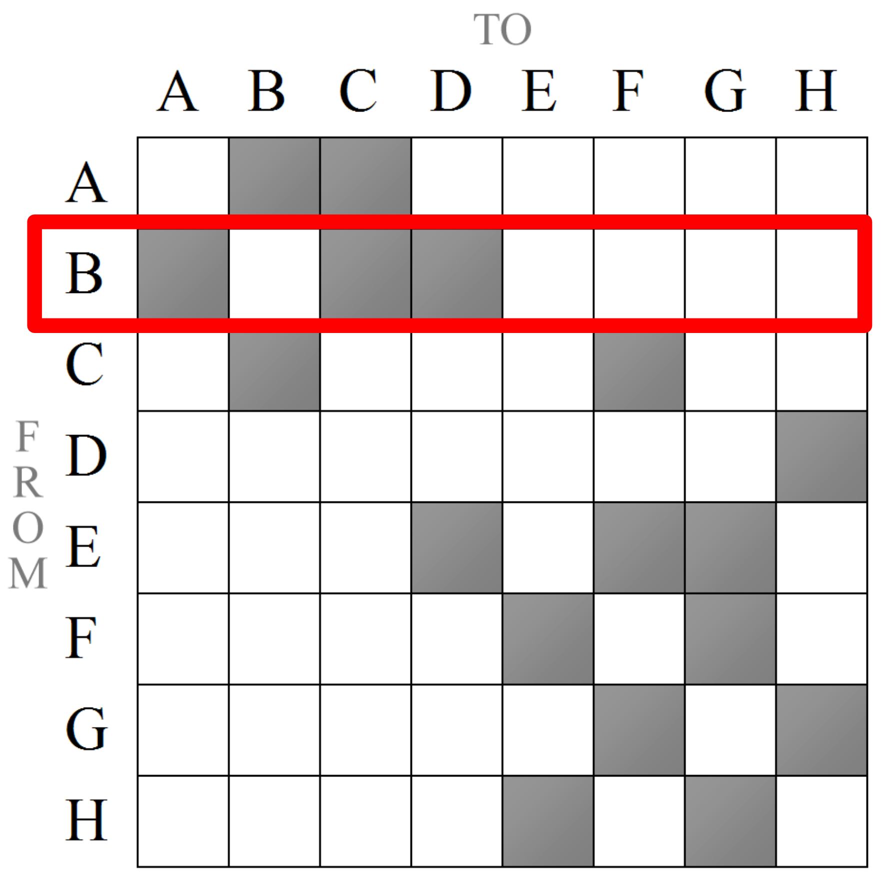
Node order is crucial: Reordering



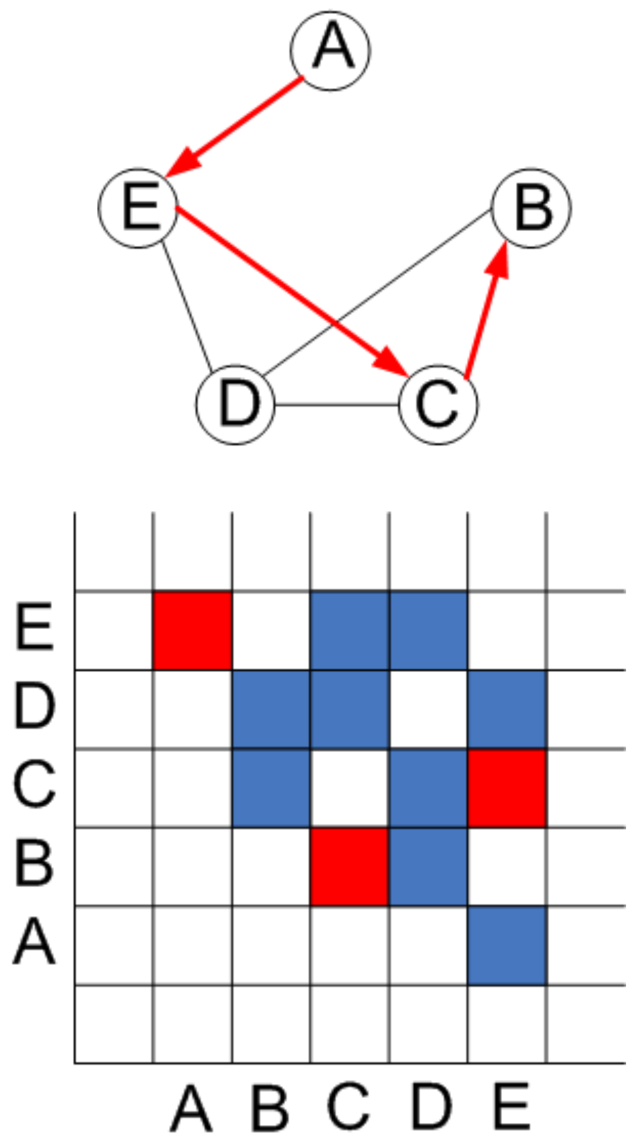


https://bost.ocks.org/mike/miserables/

Adjacency matrix

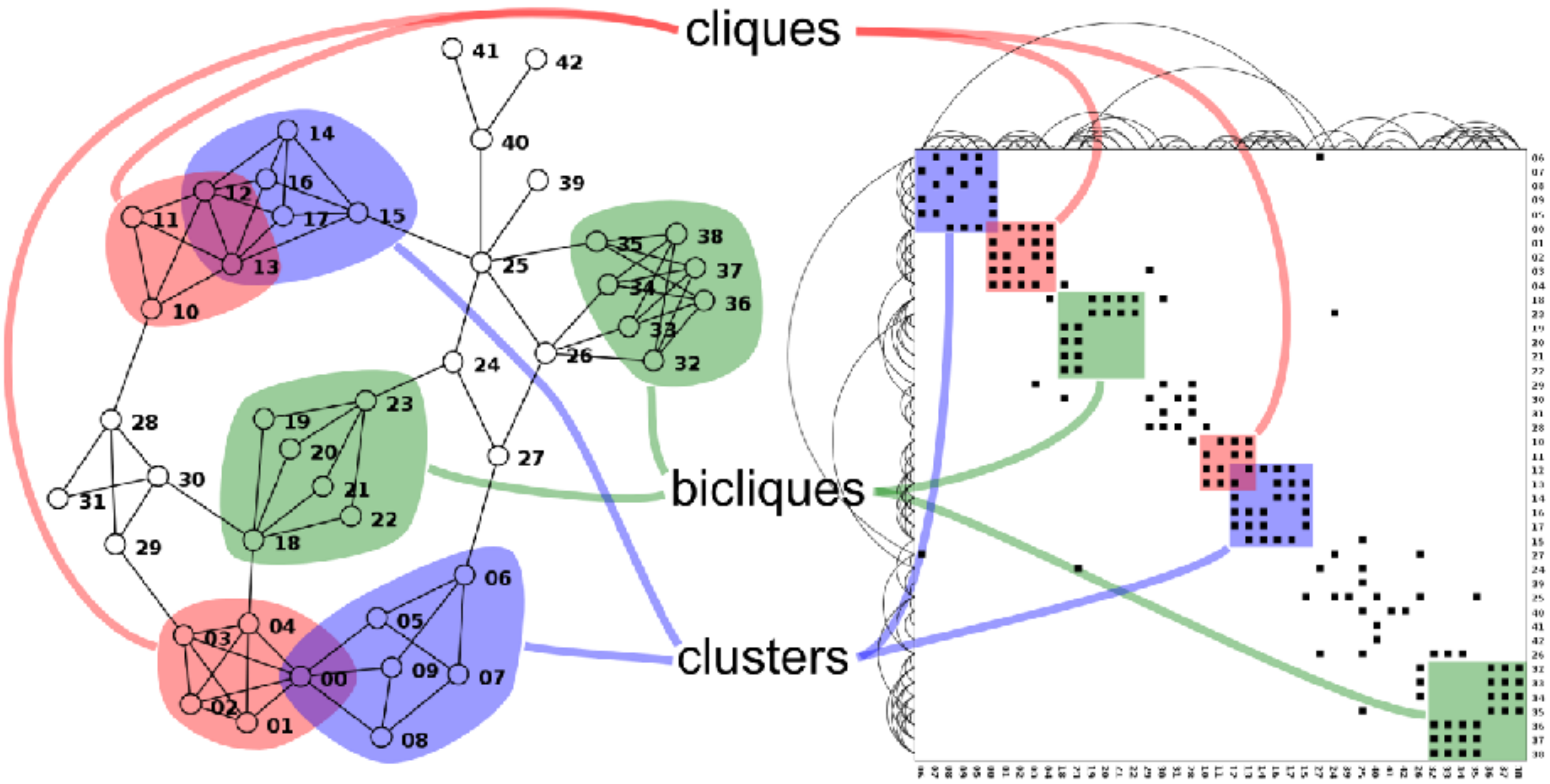


good for topology tasks related to neighborhoods (node 1-hop neighbors)



bad for topology tasks related to paths

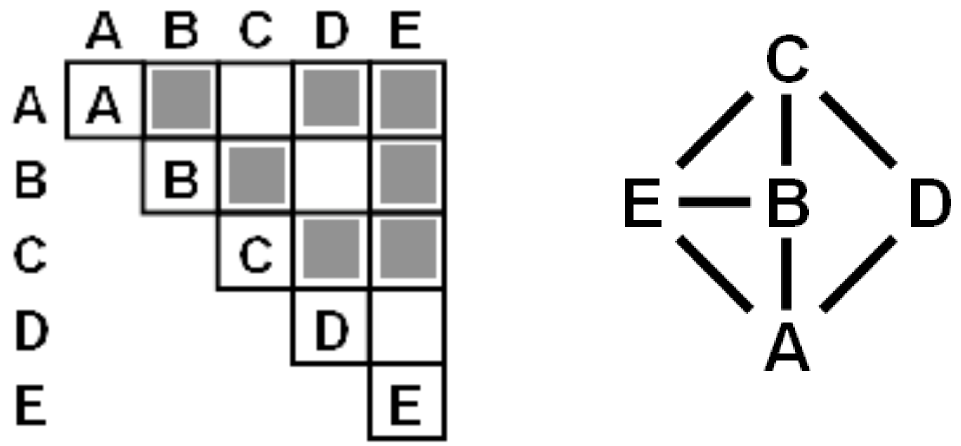
Structures visible in both



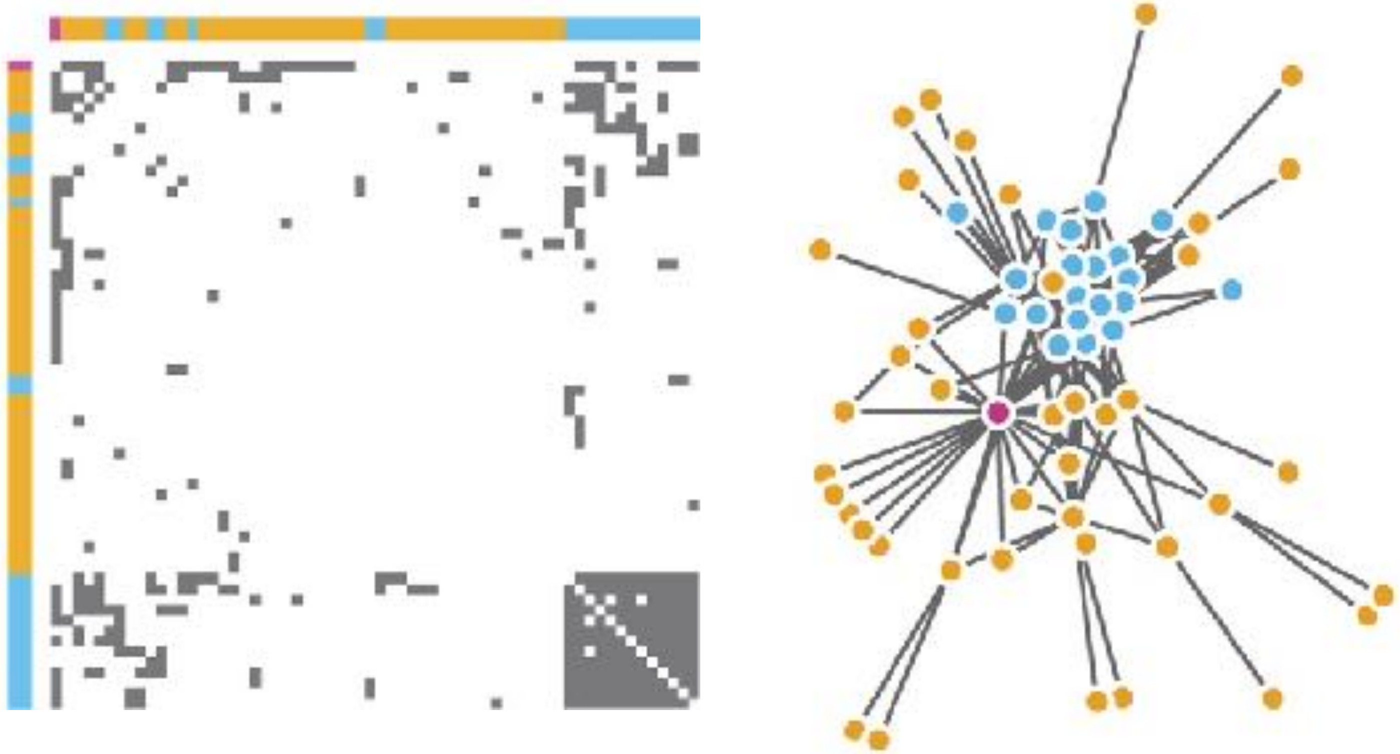
http://www.michaelmcguffin.com/courses/vis/patternsInAdjacencyMatrix.png

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.]

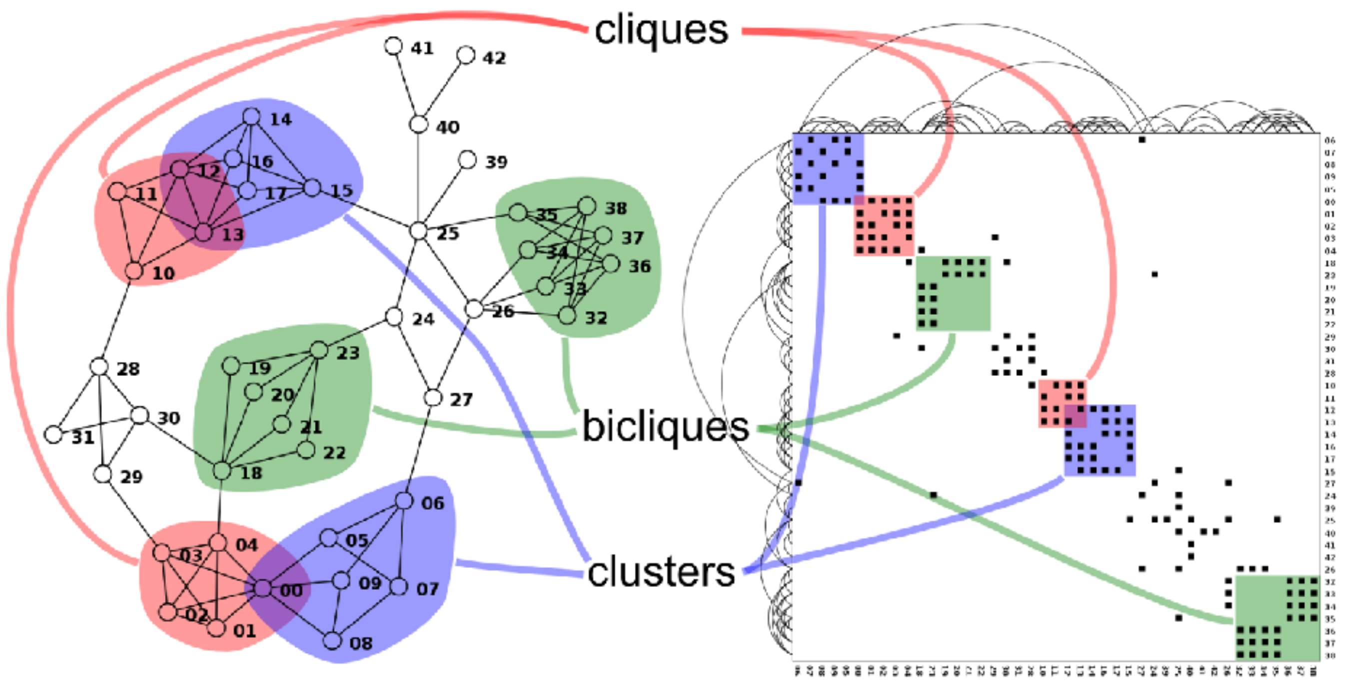


[Points of view: Networks. Gehlenborg and Wong. Nature Methods 9:115.]

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!

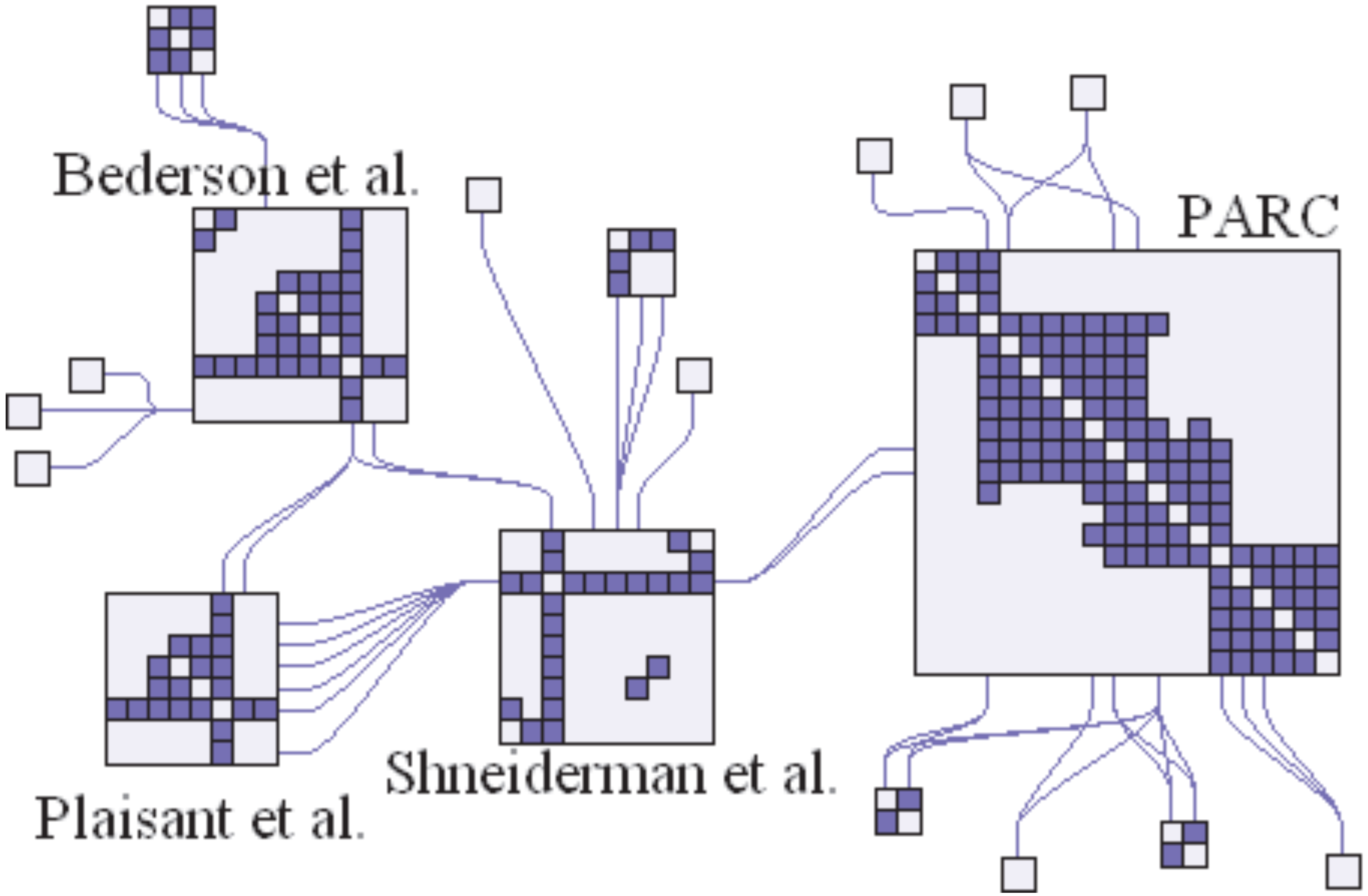
[On the readability of graphs using node-link and matrix-based representations: a controlled experiment and statistical analysis. Ghoniem, Fekete, and Castagliola. Information Visualization 4:2 (2005), 114–135.]



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

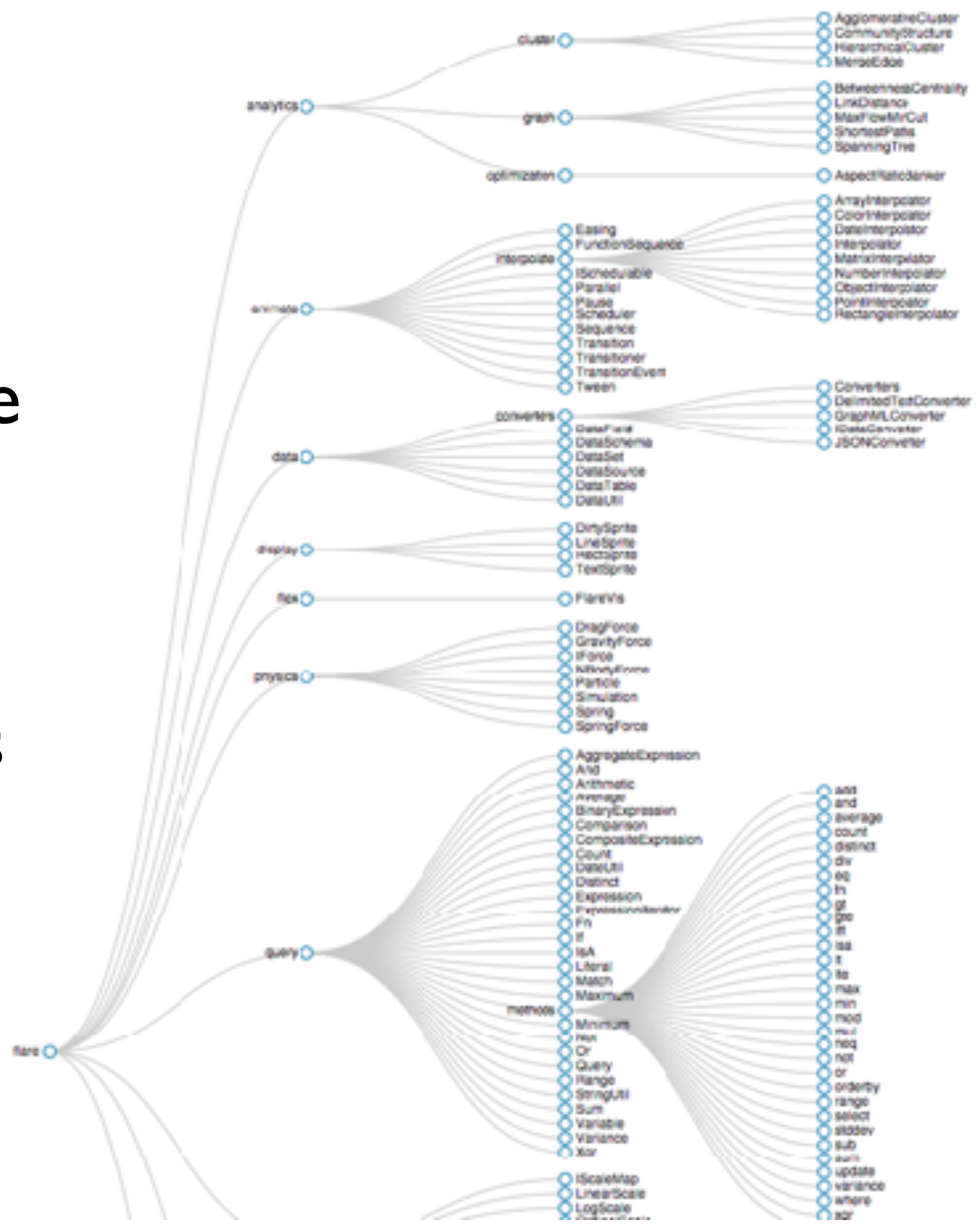
Node-link trees

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

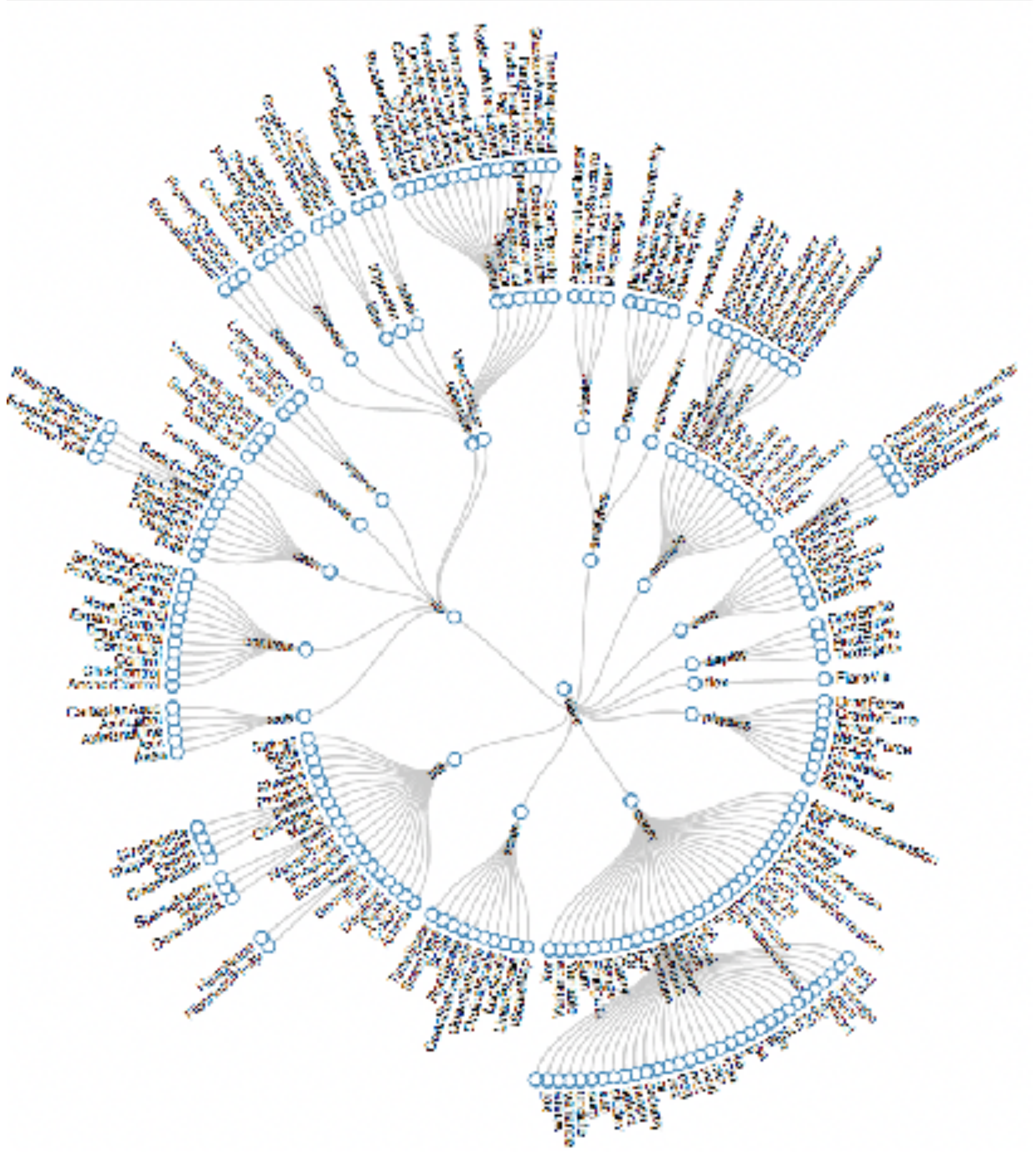
[Tidier drawing of trees. Reingold and Tilford. IEEE Trans. Software Eng., SE-7(2):223–228, 1981.]

  - nice algorithm writeup

    http://billmill.org/pymag-trees/



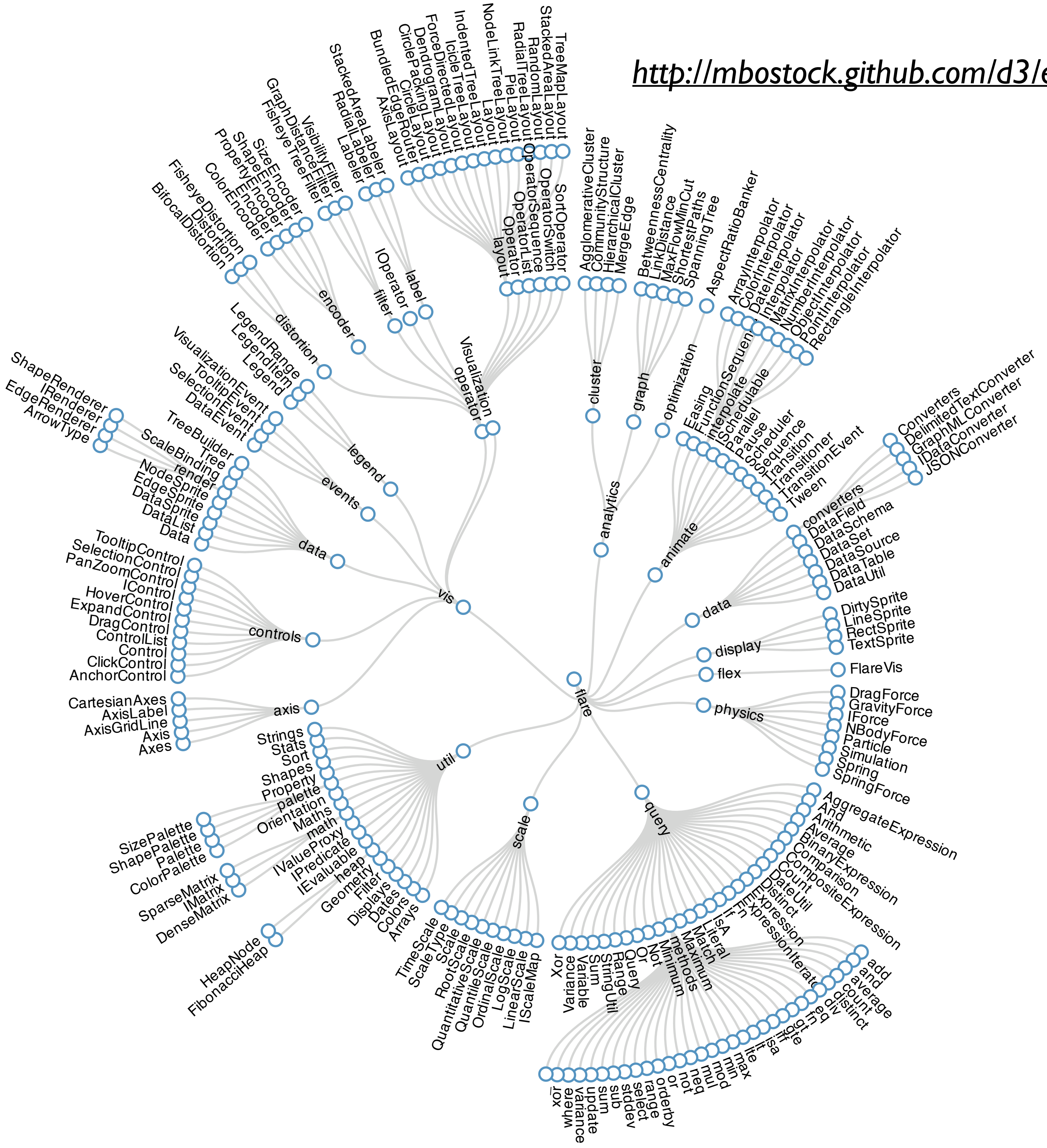
http://bl.ocks.org/mbostock/4339184



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

Idiom: **radial node-link tree**

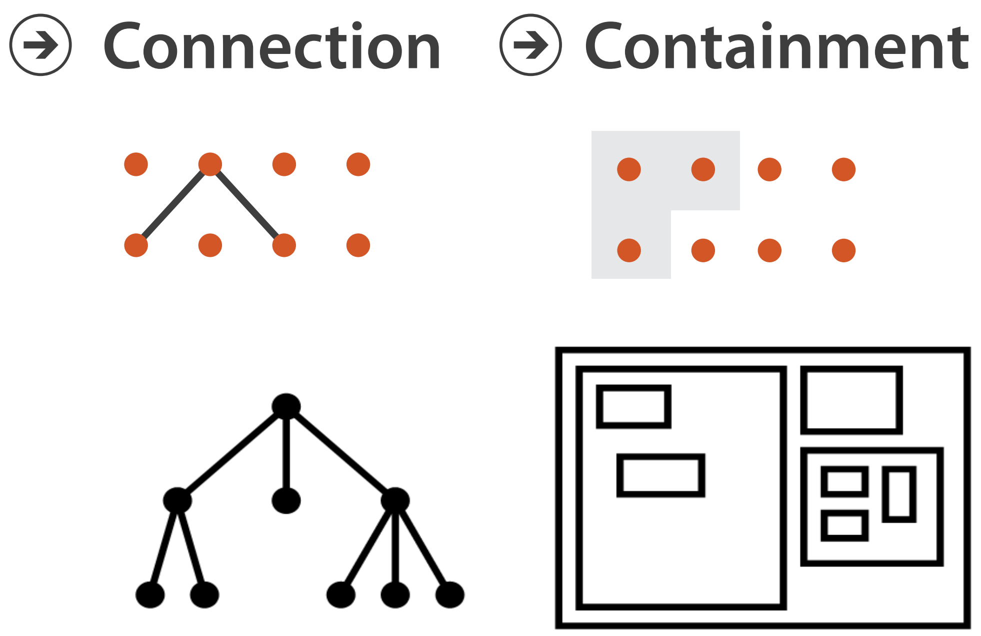
- data
  - tree
- encoding
  - link connection marks
  - point node marks
  - radial axis orientation
    - angular proximity: siblings
    - distance from center: depth in tree
- tasks
  - understanding topology, following paths
- scalability
  - 1K - 10K nodes (with/without labels)

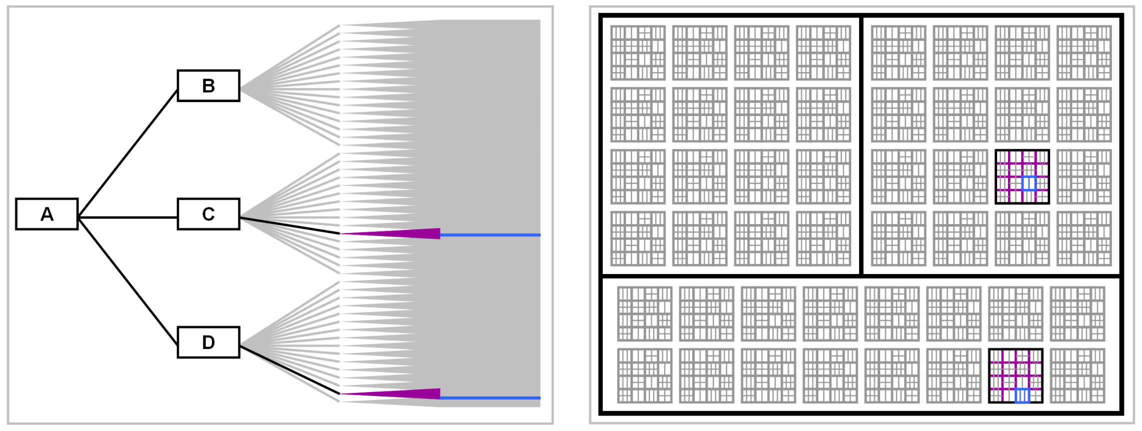


http://mbostock.github.com/d3/ex/tree.html

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



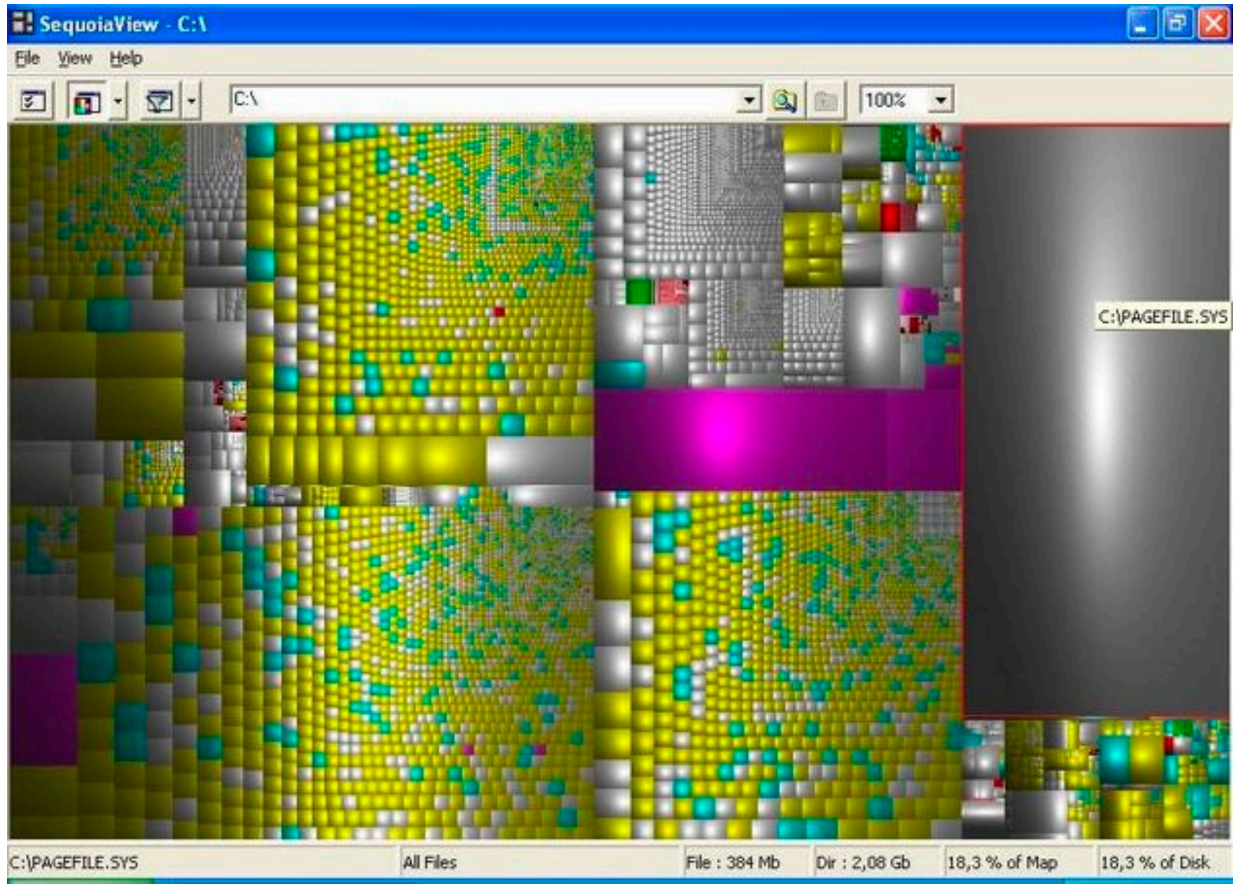


Node–Link Diagram Treemap

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

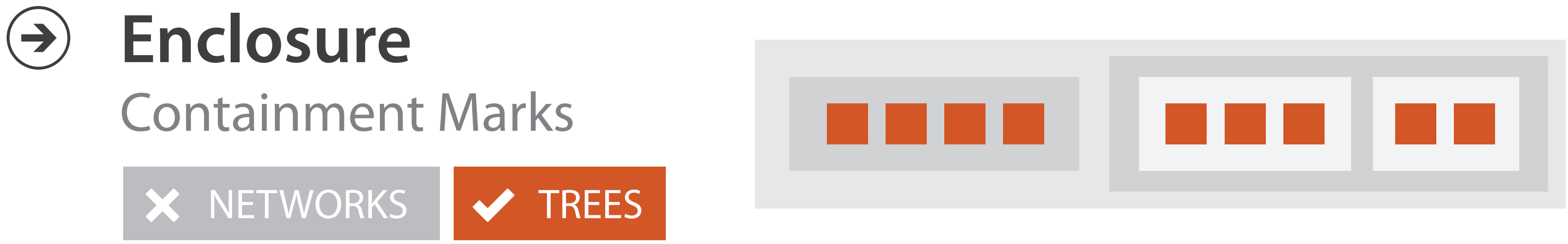
Idiom: **treemap**

- 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/

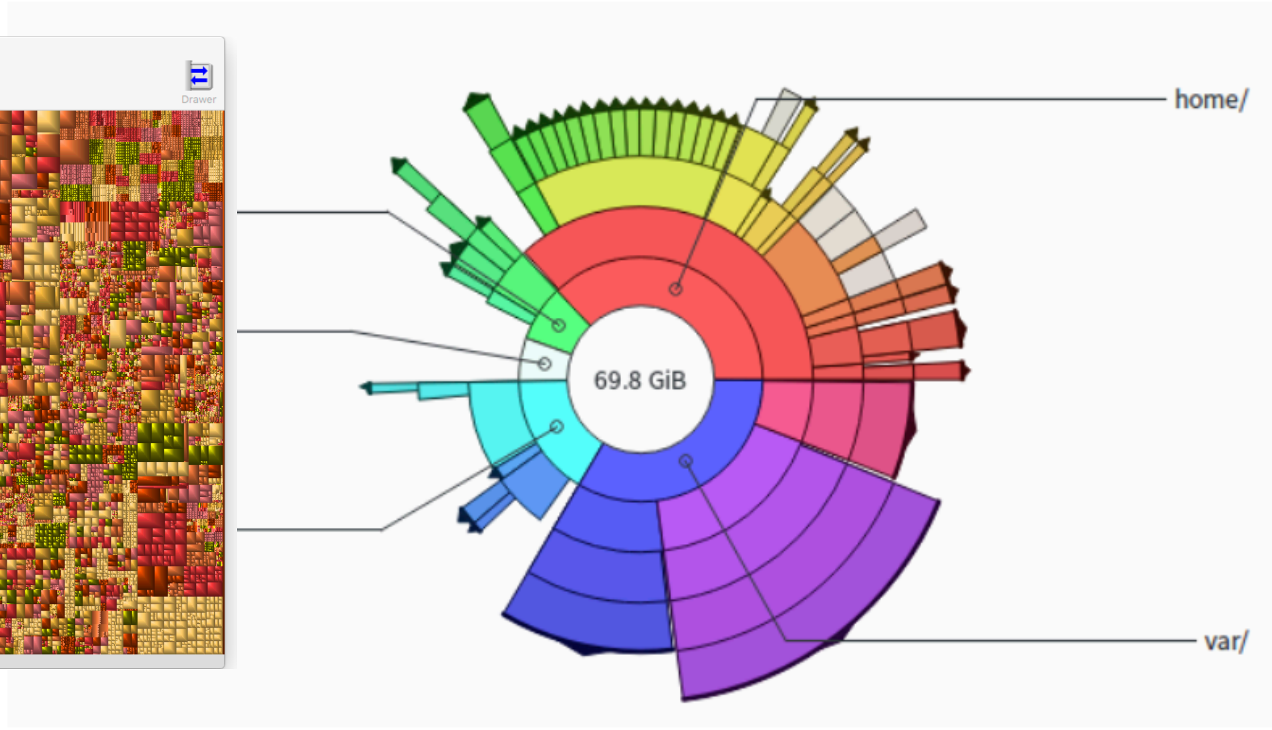
[Cushion Treemaps. van Wijk and van de Wetering. Proc. Symp. InfoVis 1999, 73-78.]

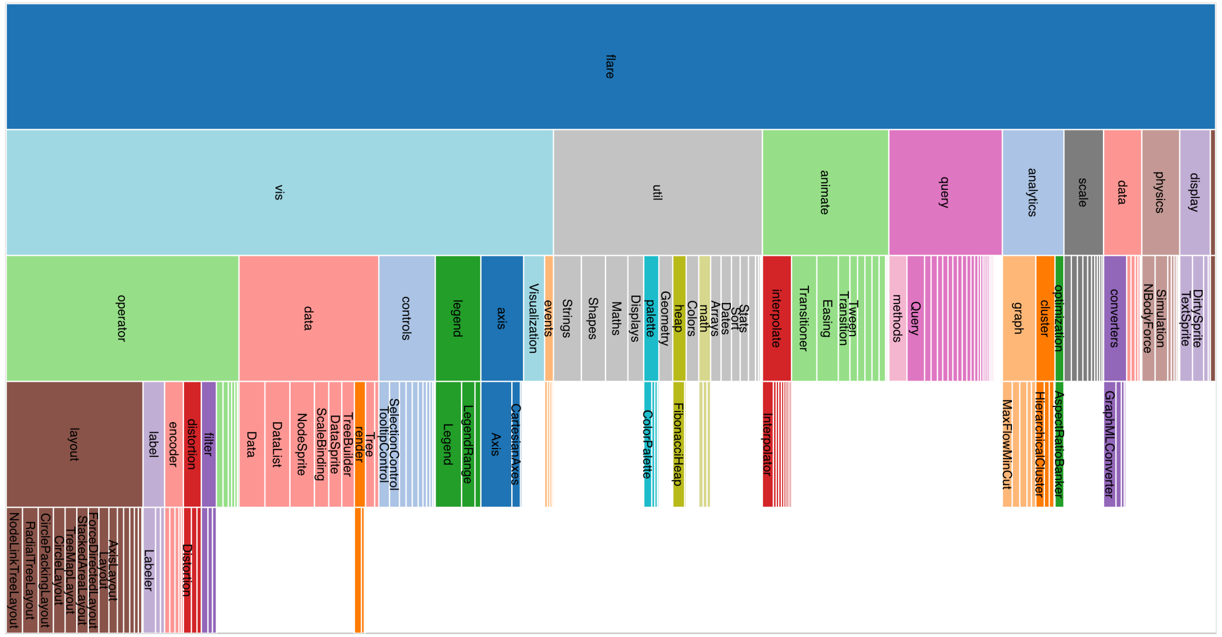


Idiom: implicit tree layouts (sunburst, icicle plot)

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

Treemap	Sunburst	Icicle Plot
containment	position (radial)	position (rectilinear)





Idiom: implicit tree layouts (sunburst, icicle plot)

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

Treemap

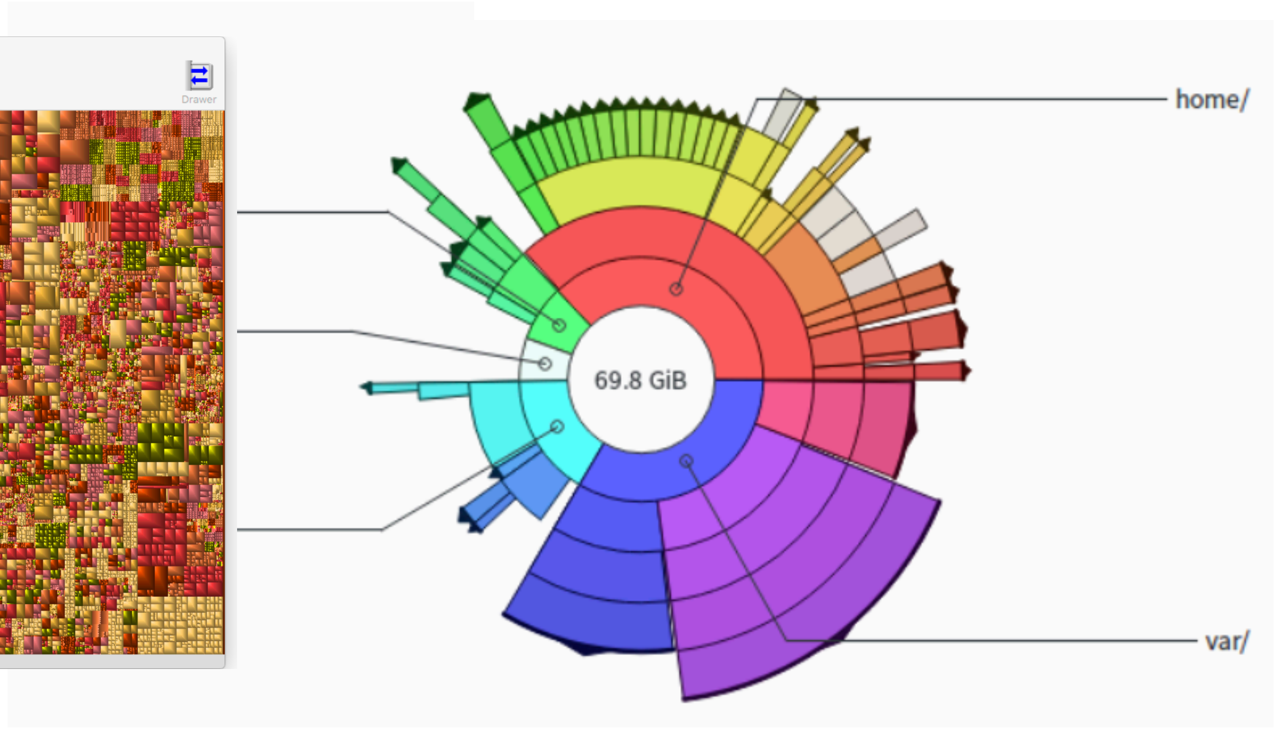
containment

only leaves visible

Sunburst

position (radial)

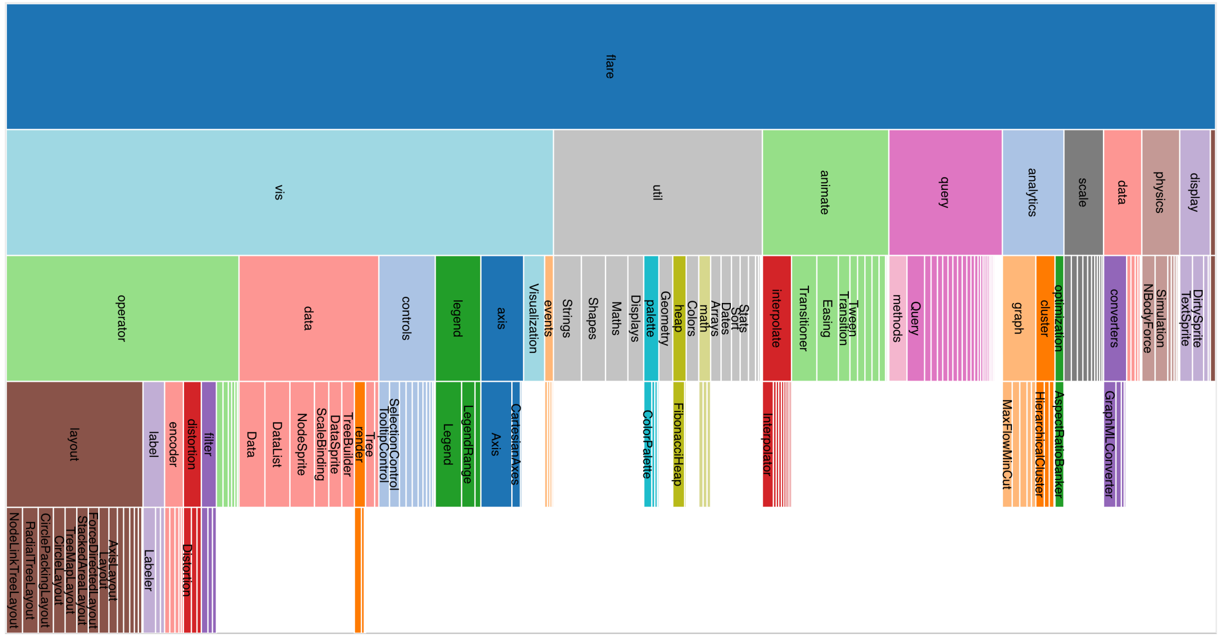
inner nodes & leaves visible



Icicle Plot

position (rectilinear)

inner nodes & leaves visible



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Treemap

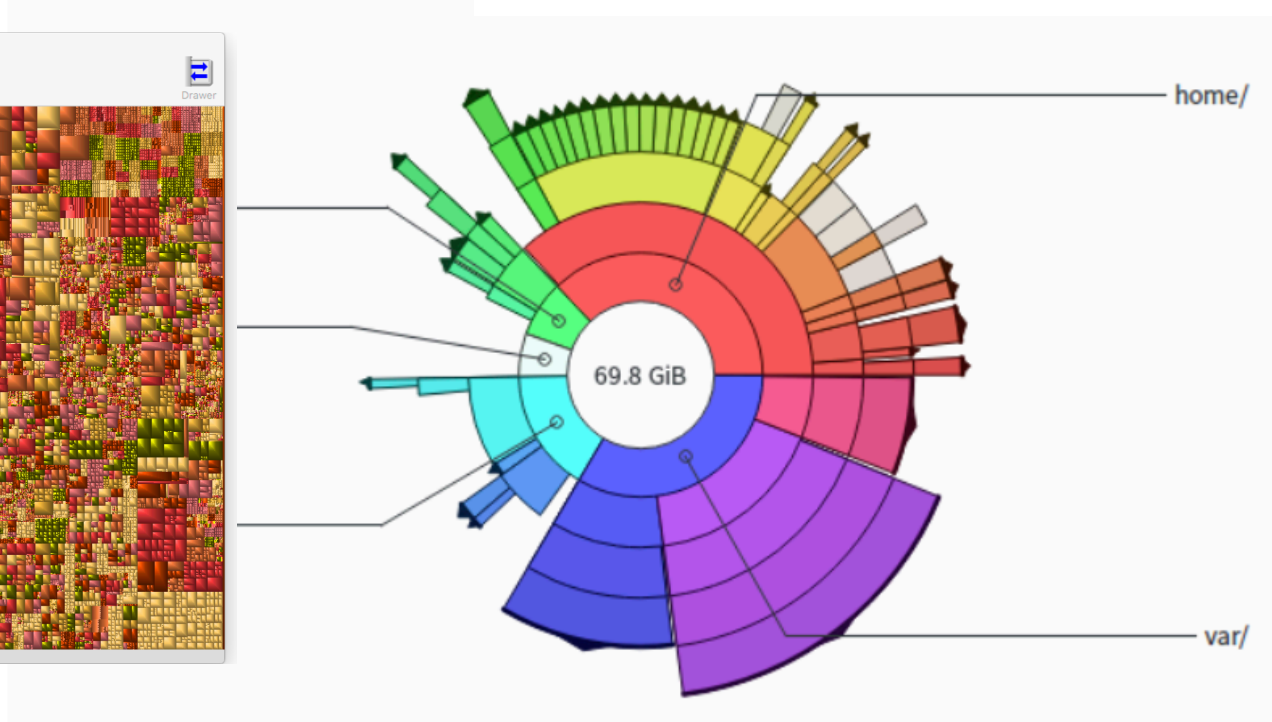
containment

only leaves visible

Sunburst

position (radial)

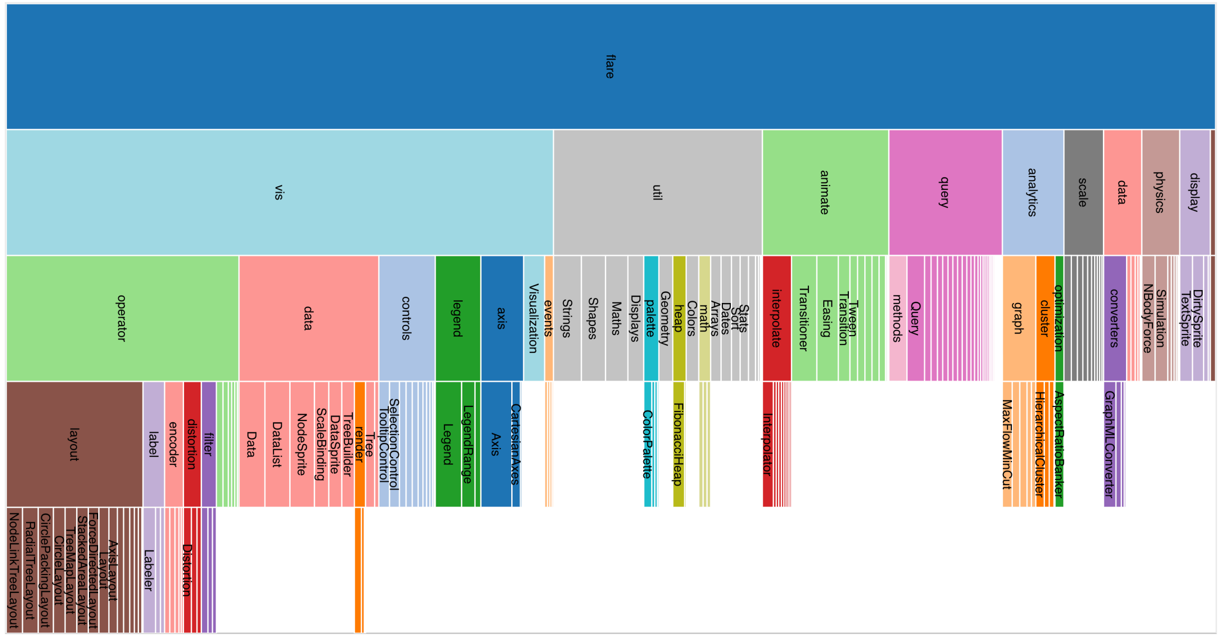
inner nodes & leaves visible



Icicle Plot

position (rectilinear)

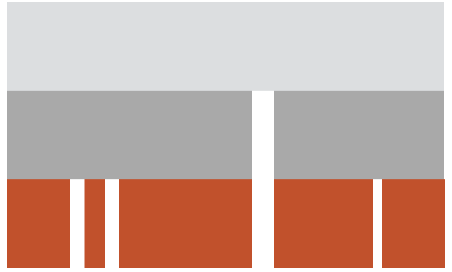
inner nodes & leaves visible



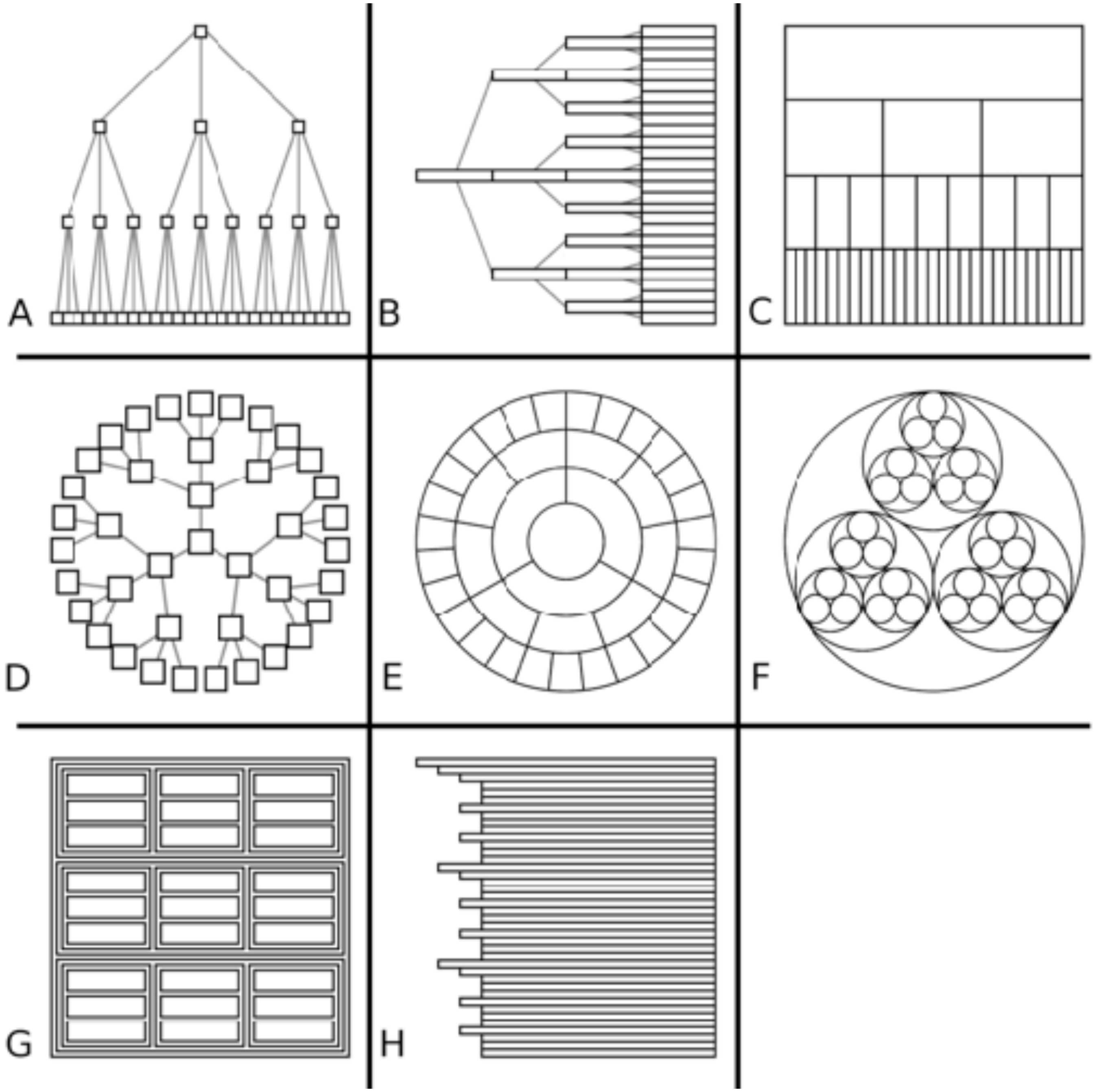
➔ **Implicit**

Spatial Position

✕ NETWORKS ✔ TREES



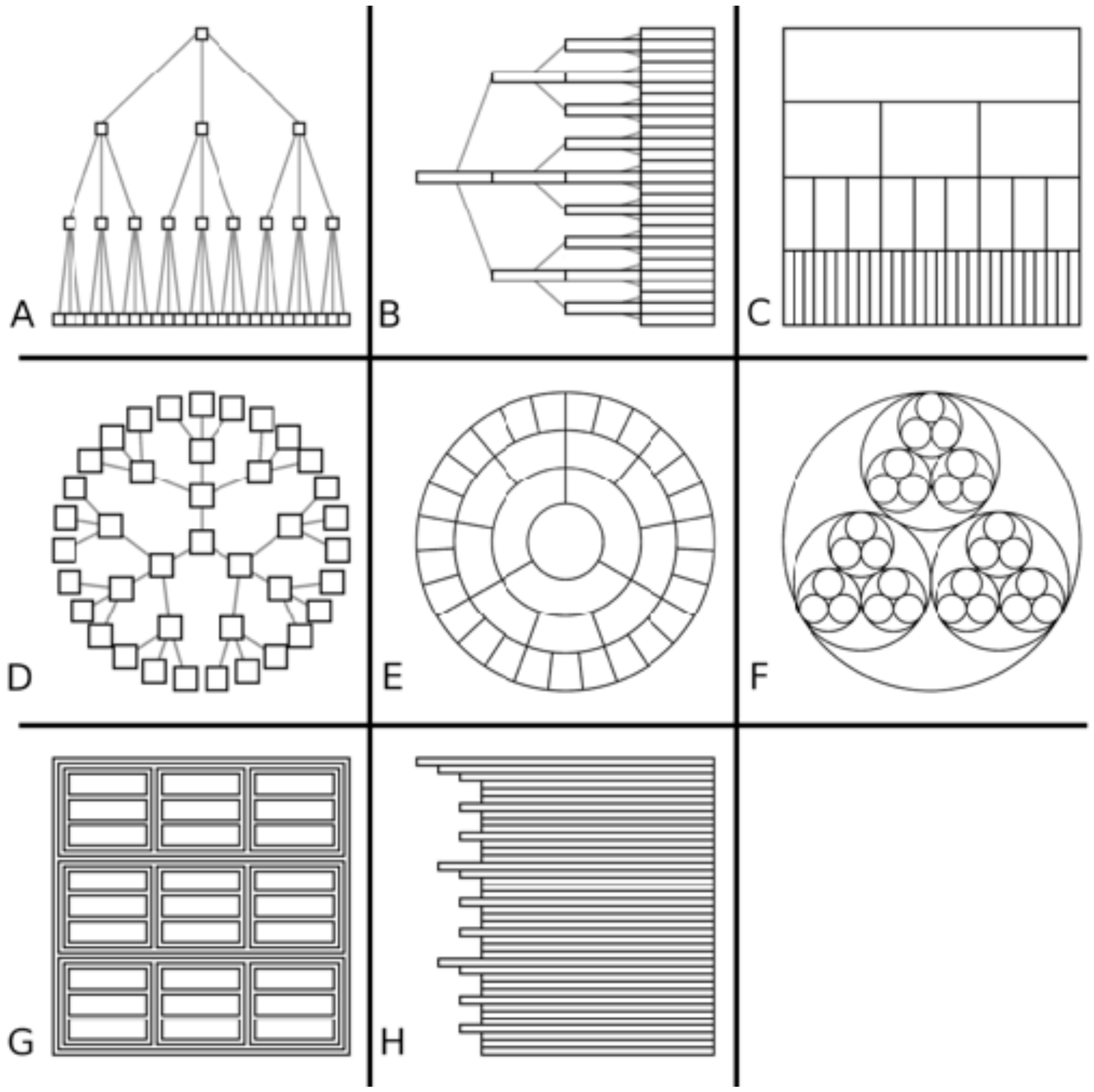
Tree drawing idioms comparison



[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



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Comparison: tree drawing idioms

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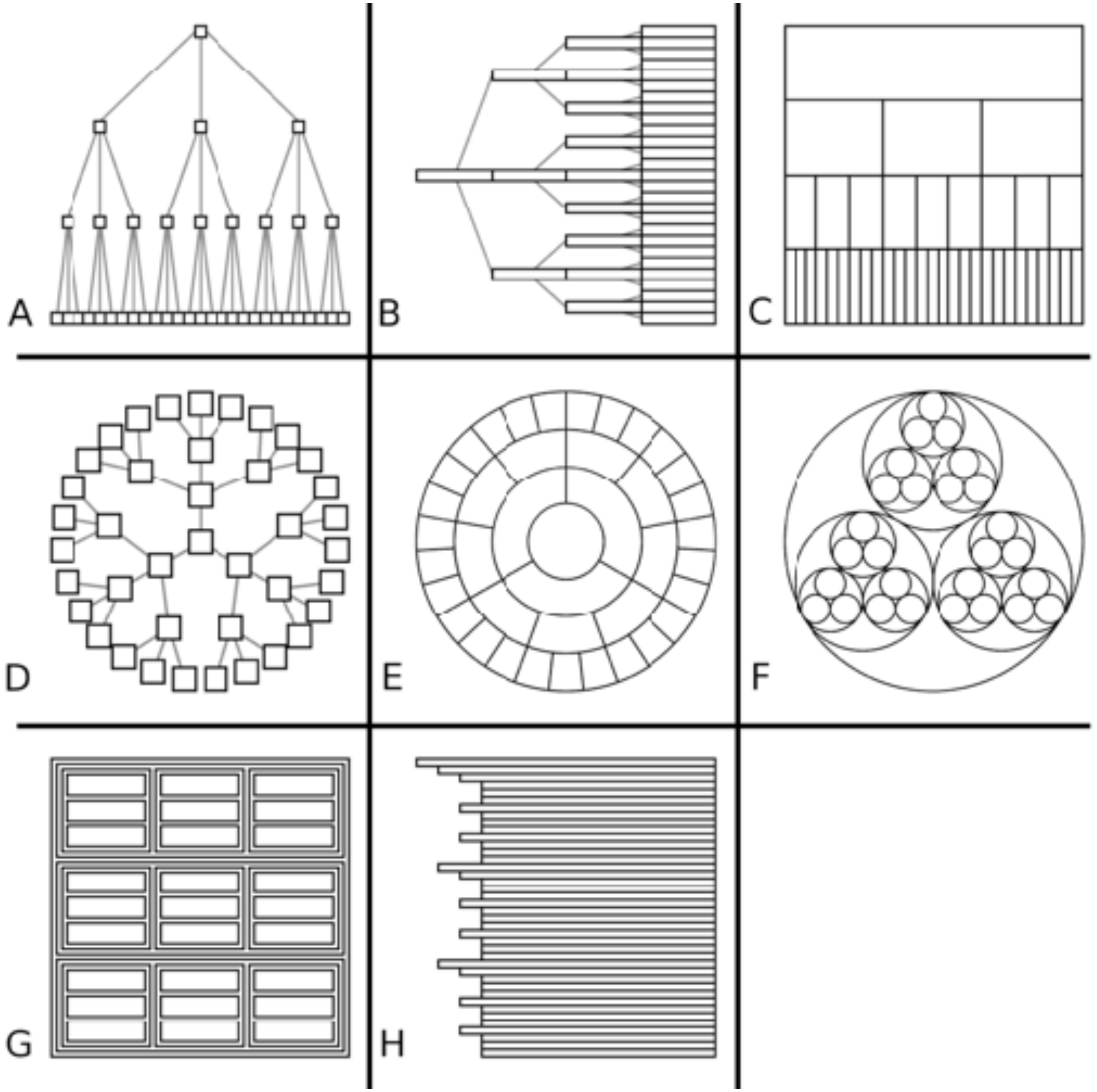
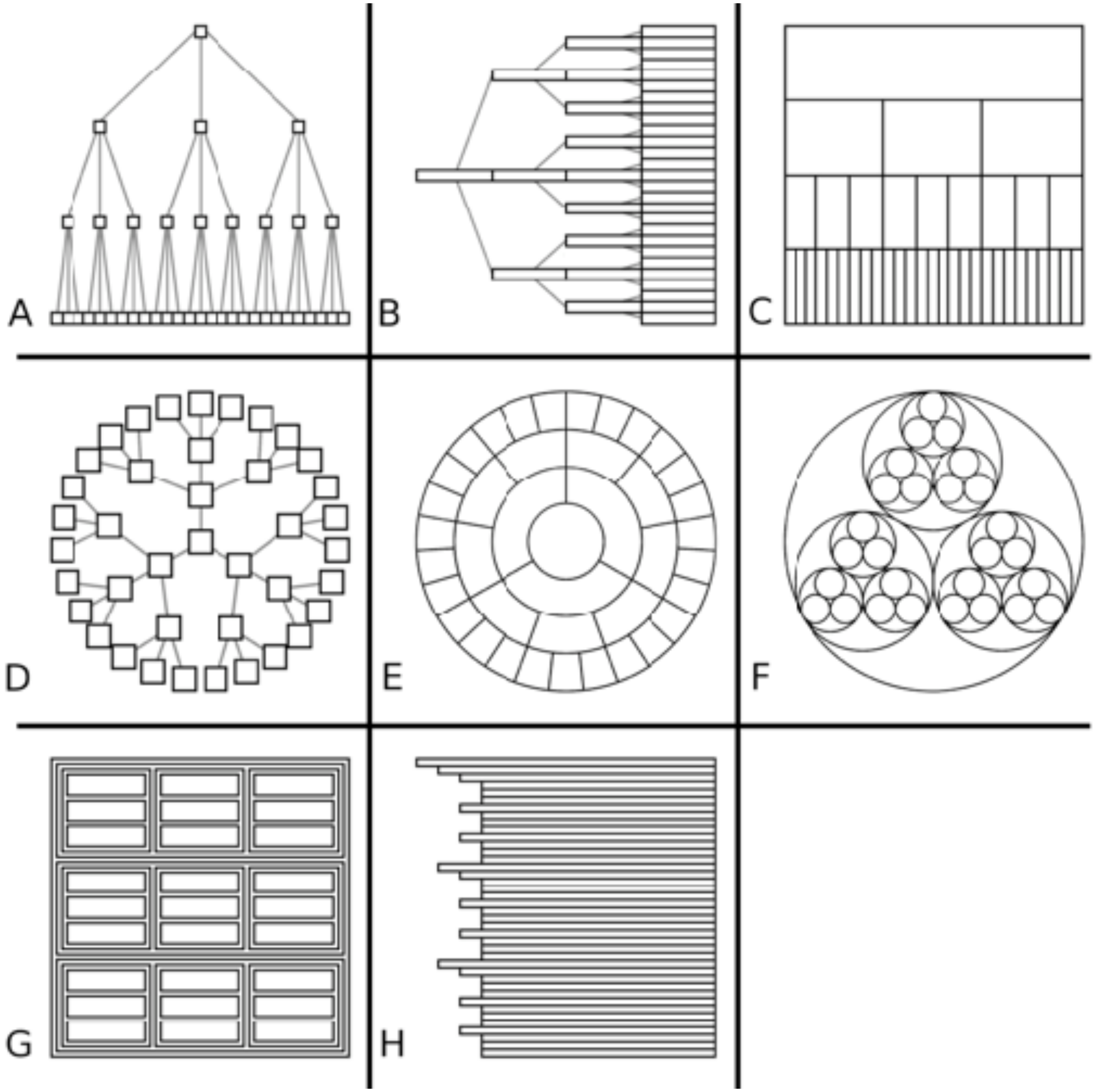
  - link relationships
  - tree depth
  - sibling order
- design choices
  - connection vs containment link marks
  - rectilinear vs radial layout
  - spatial position channels



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

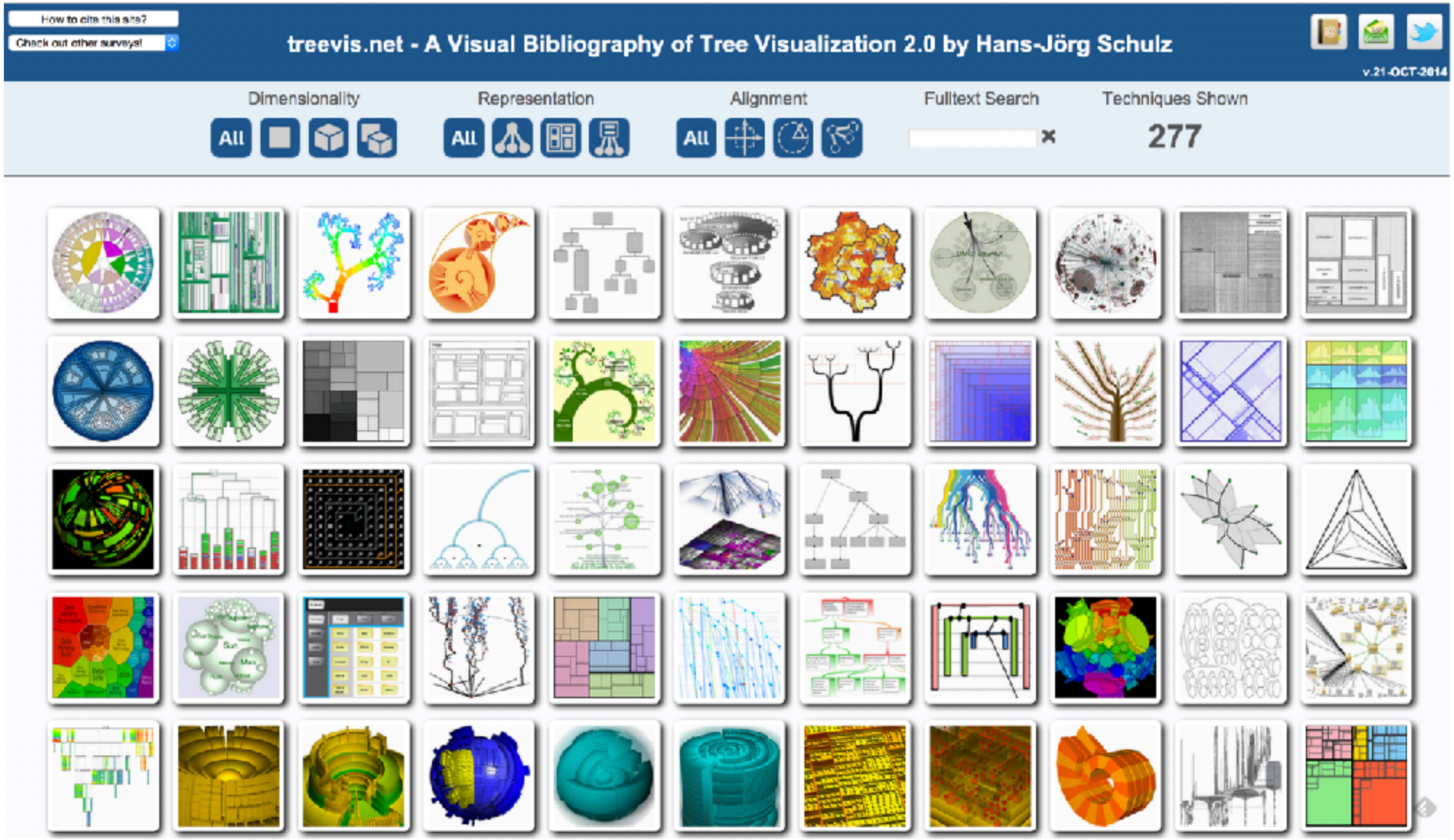
Comparison: tree drawing idioms

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

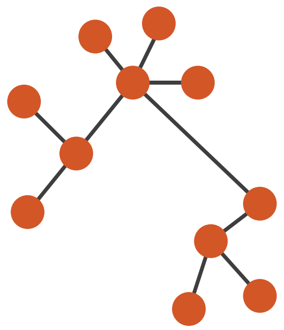


https://treevis.net/

Arrange networks and trees

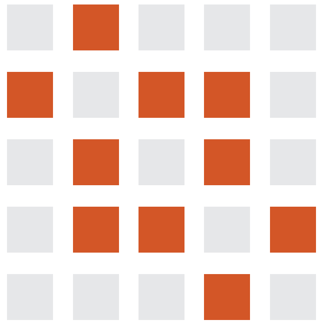
Node–Link Diagrams
Connection Marks

✔ NETWORKS ✔ TREES



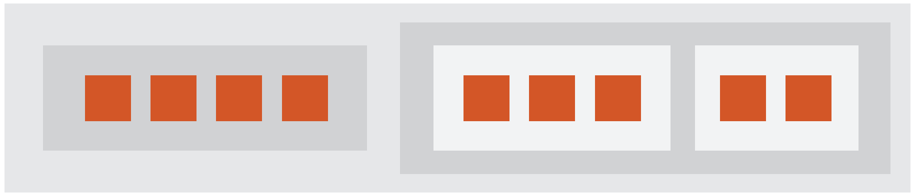
Adjacency Matrix
Derived Table

✔ NETWORKS ✔ TREES



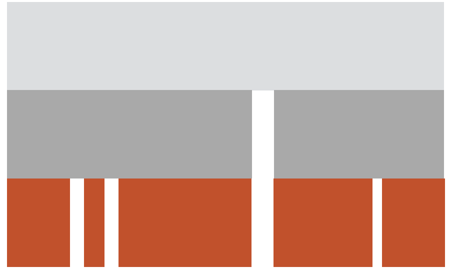
Enclosure
Containment Marks

✖ NETWORKS ✔ TREES



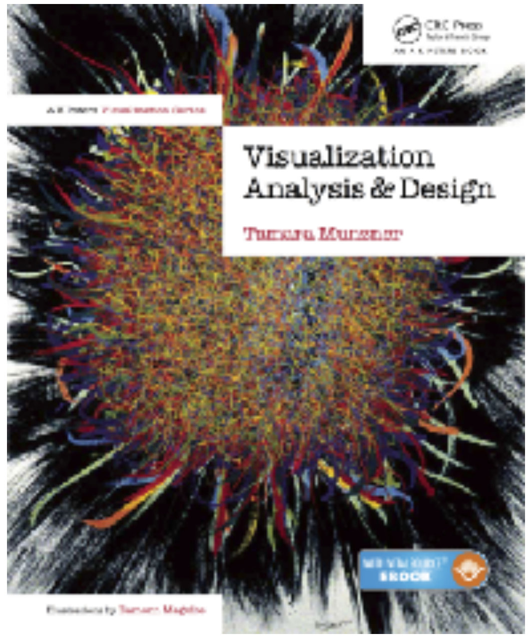
Implicit
Spatial Position

✖ NETWORKS ✔ TREES



Visualization Analysis & Design

Rules of Thumb (Ch 6)

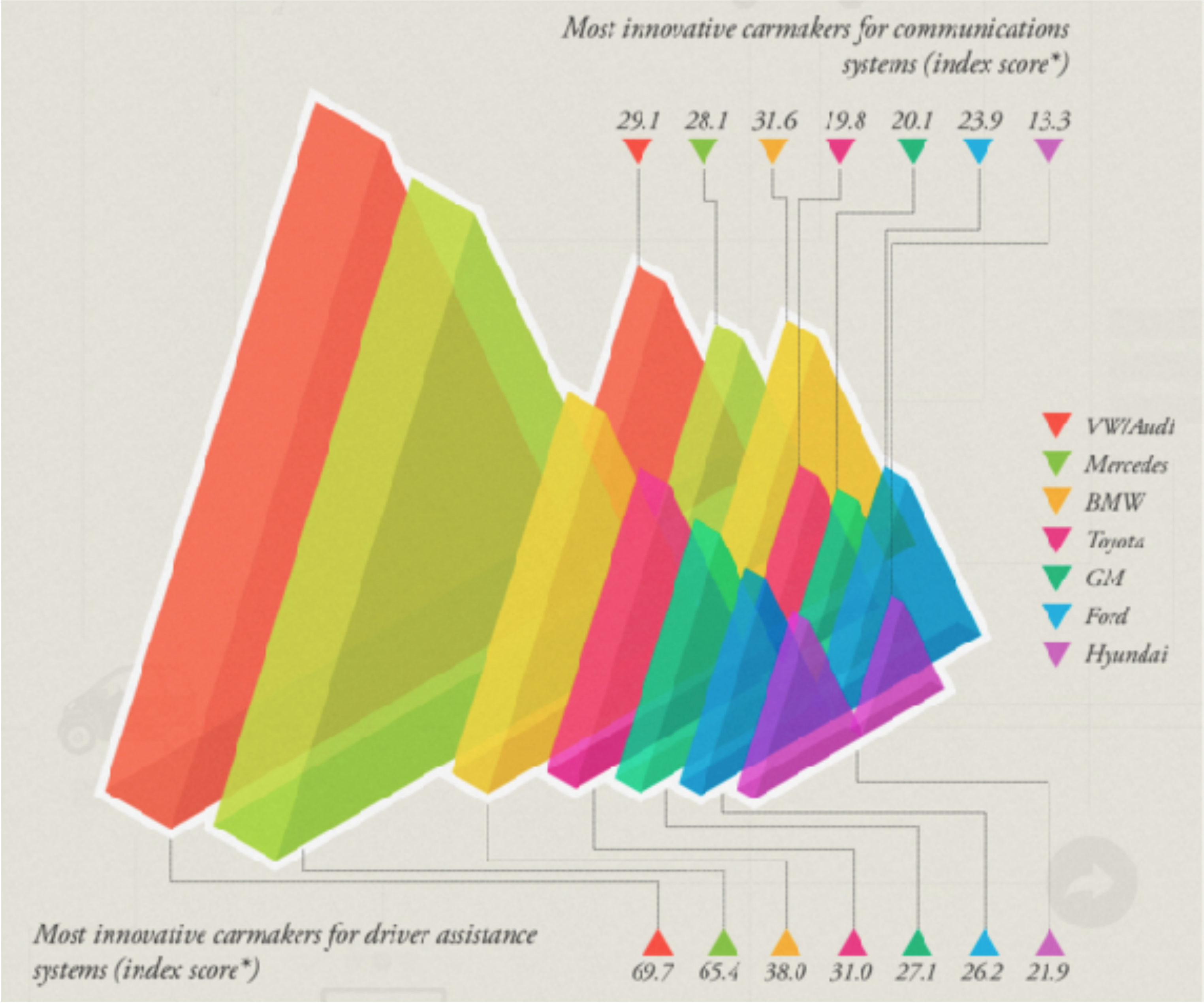


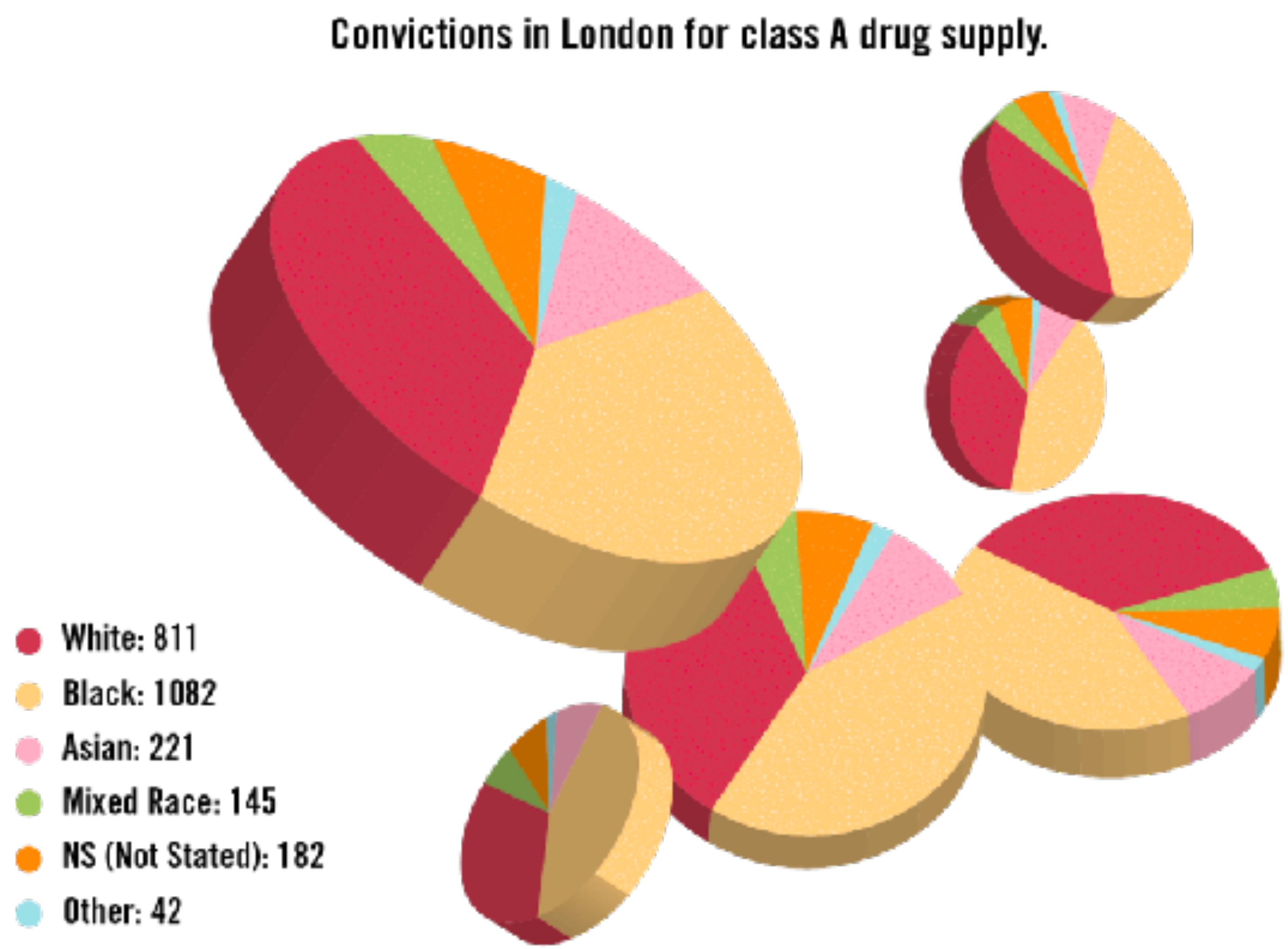
Tamara Munzner
Department of Computer Science
University of British Columbia
@tamaramunzner

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



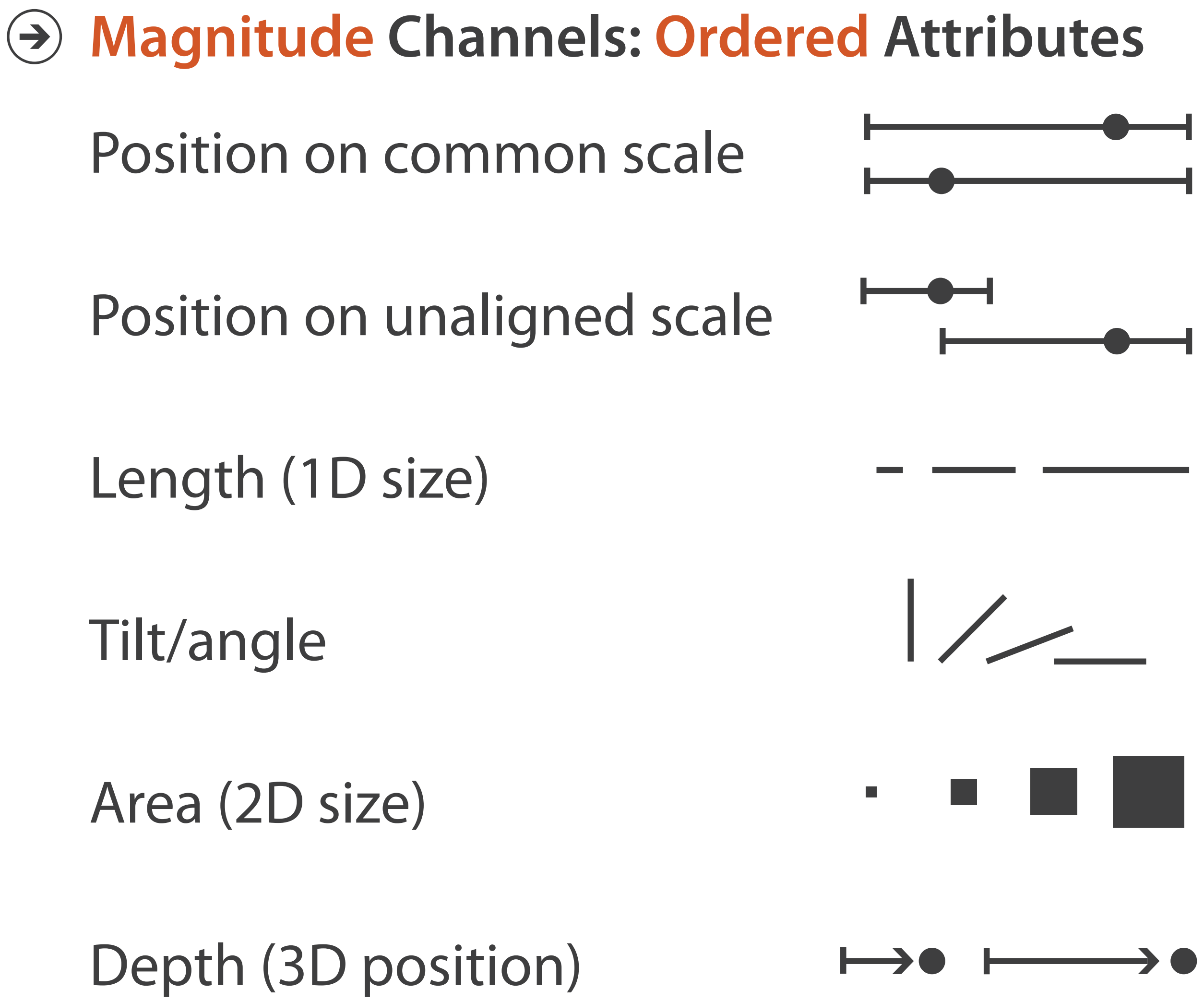


http://viz.wtf/post/137826497077/eye-popping-3d-triangles

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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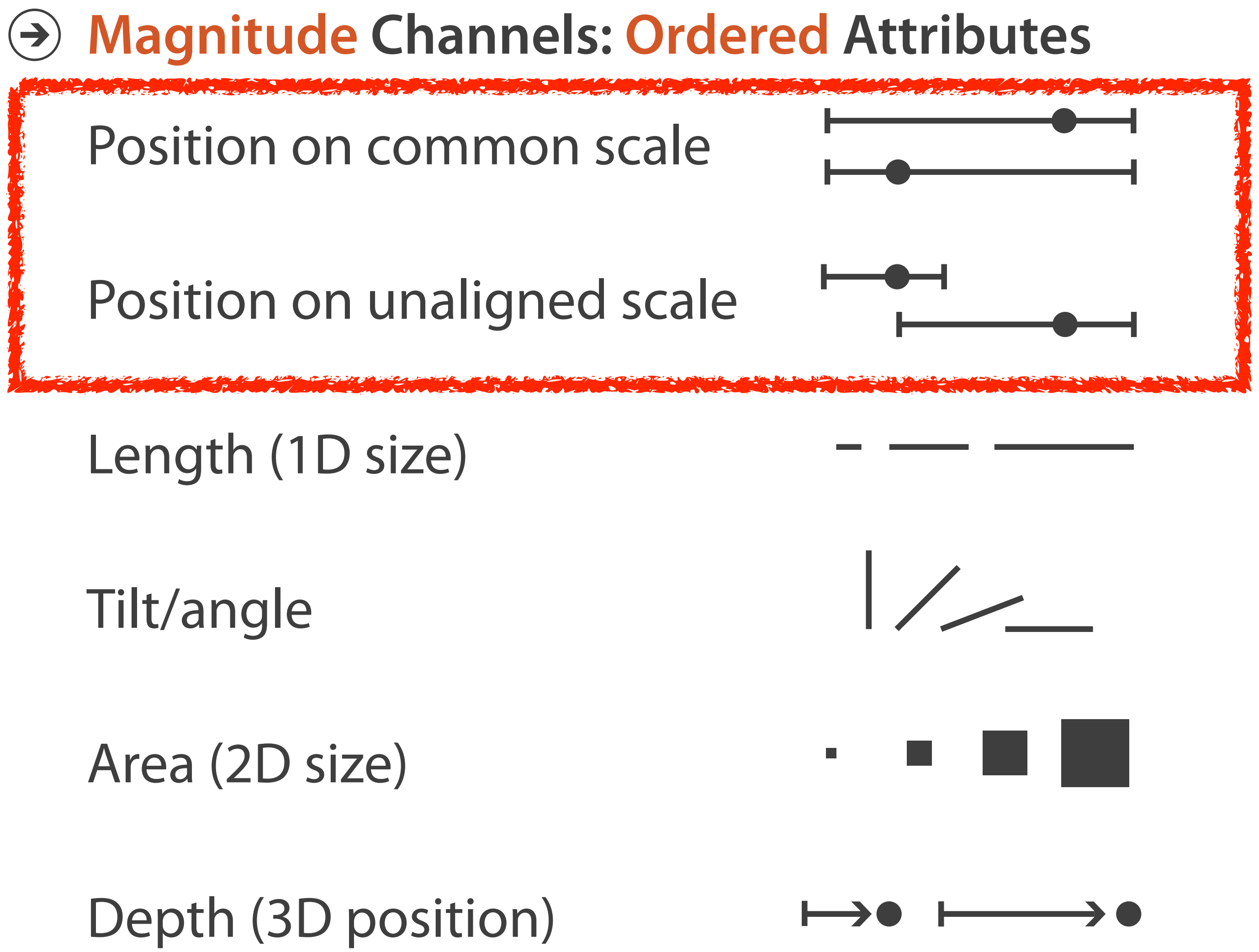

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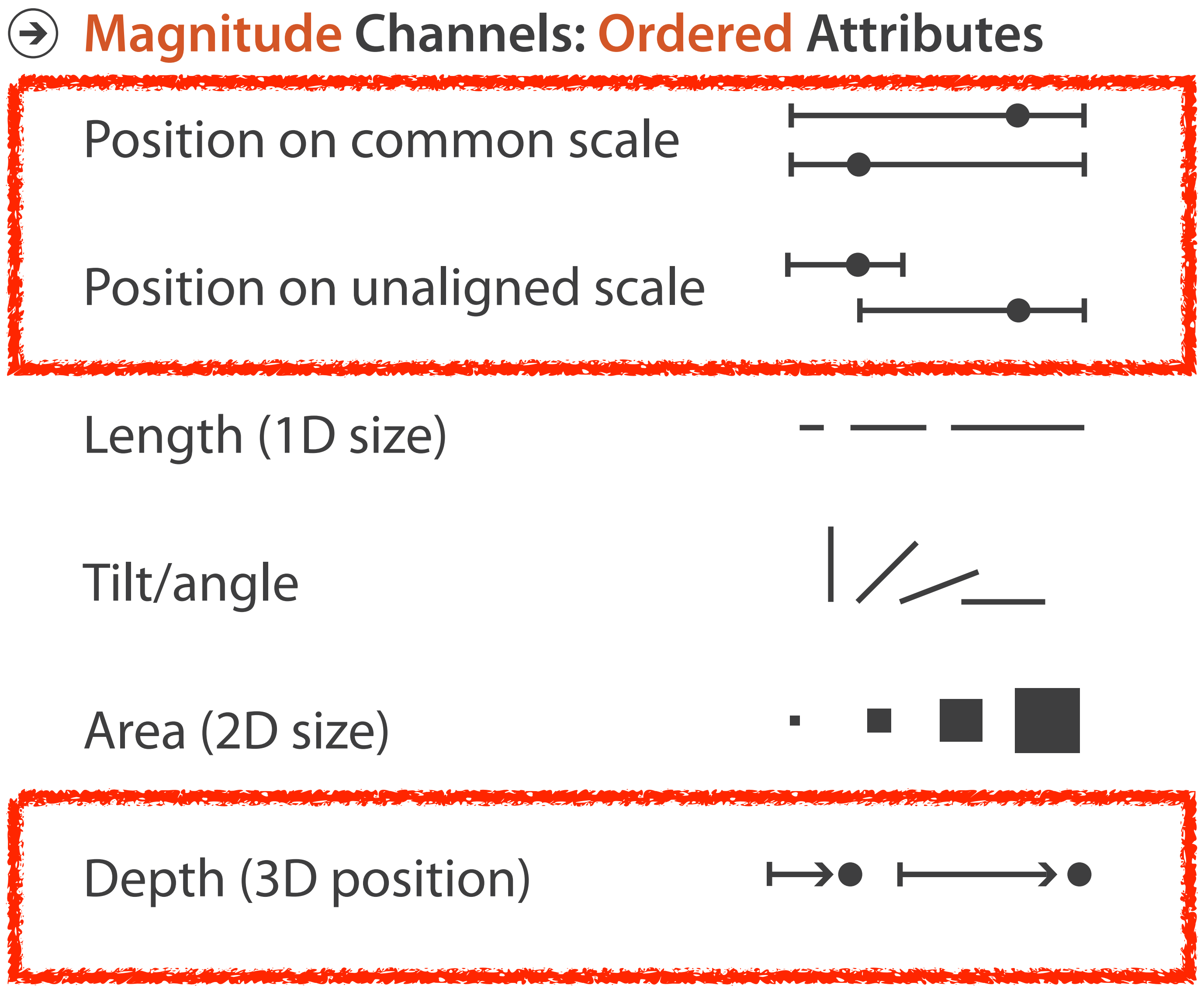

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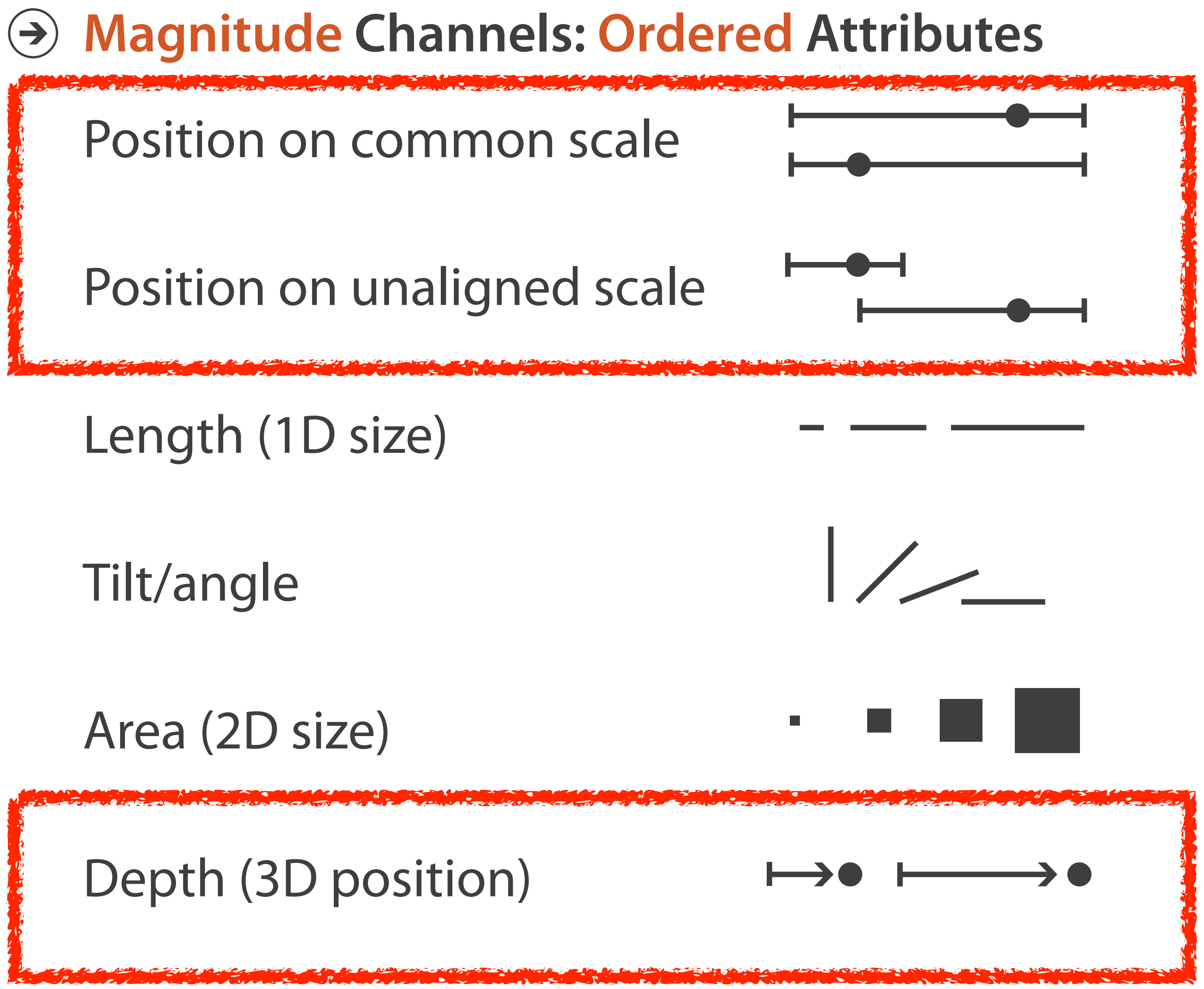
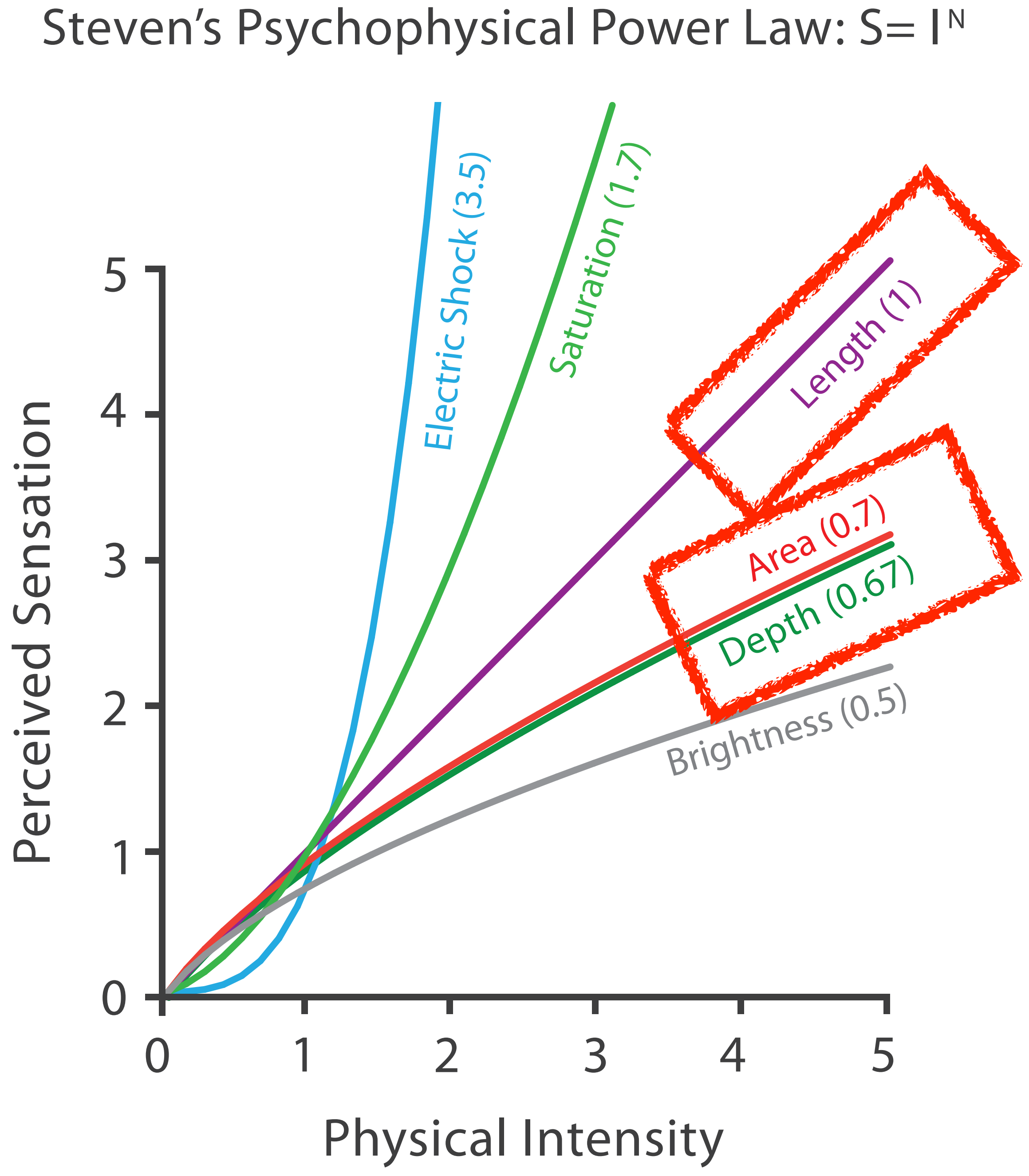
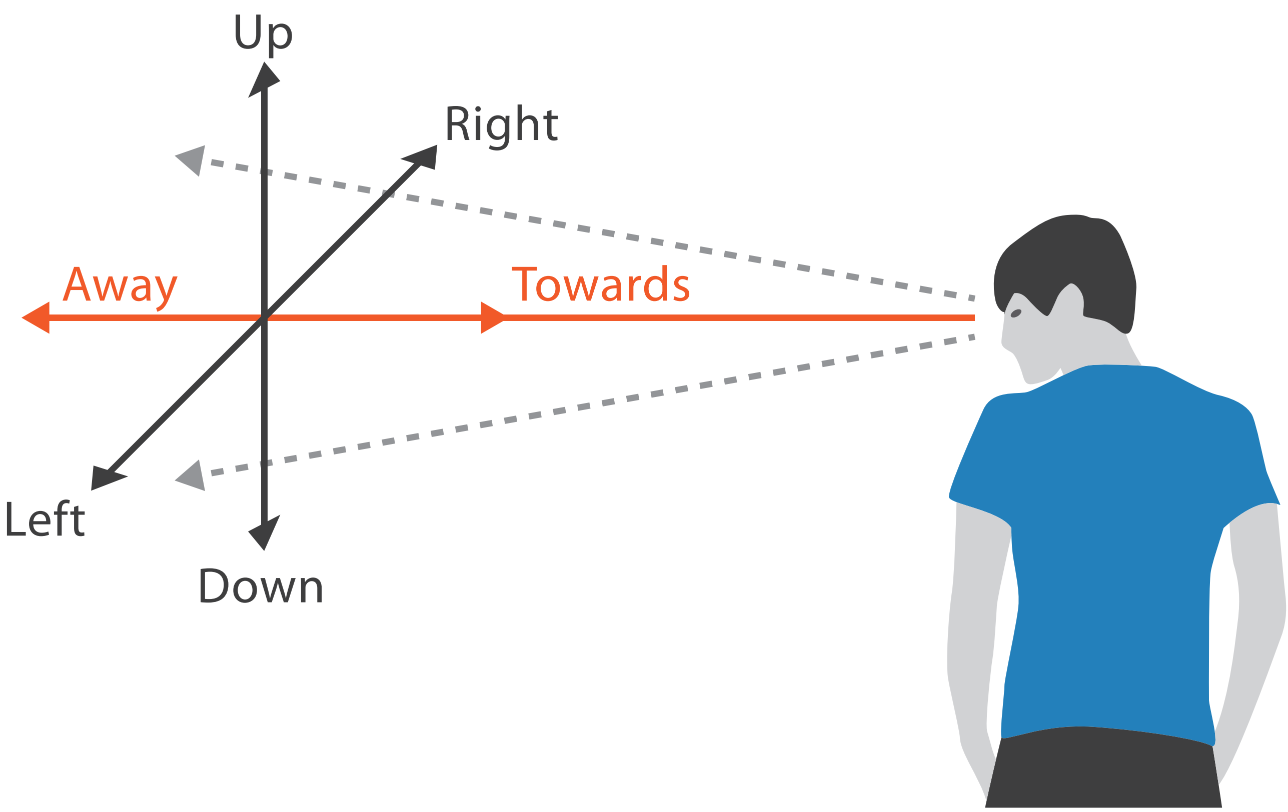


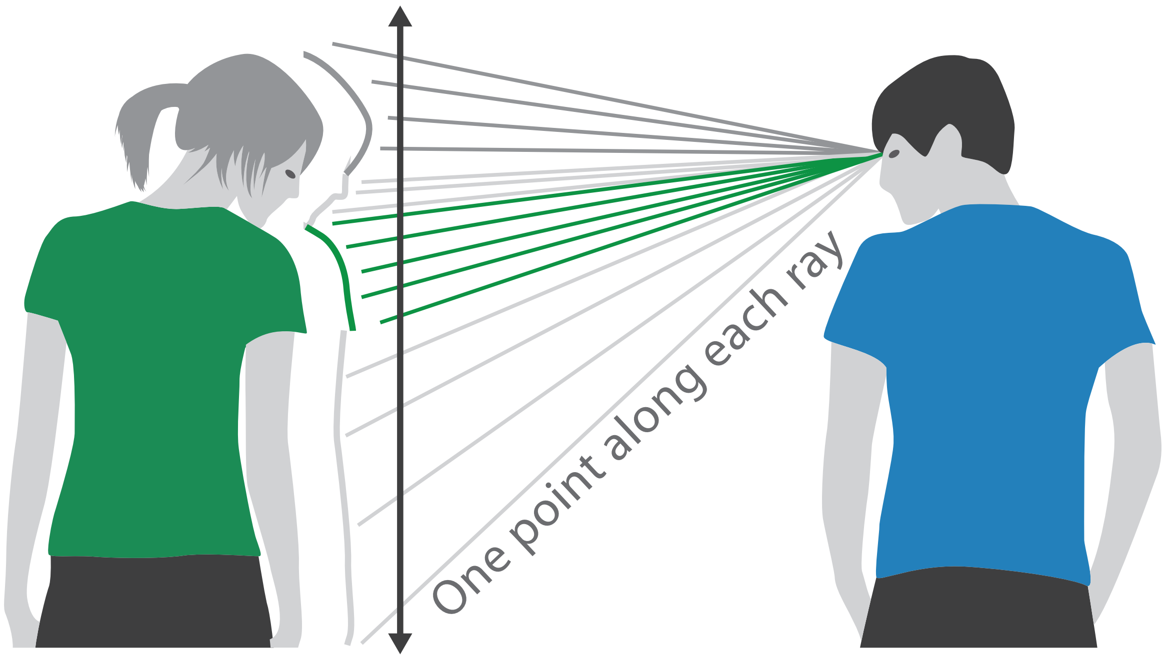


No unjustified 3D: Danger of depth

- 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



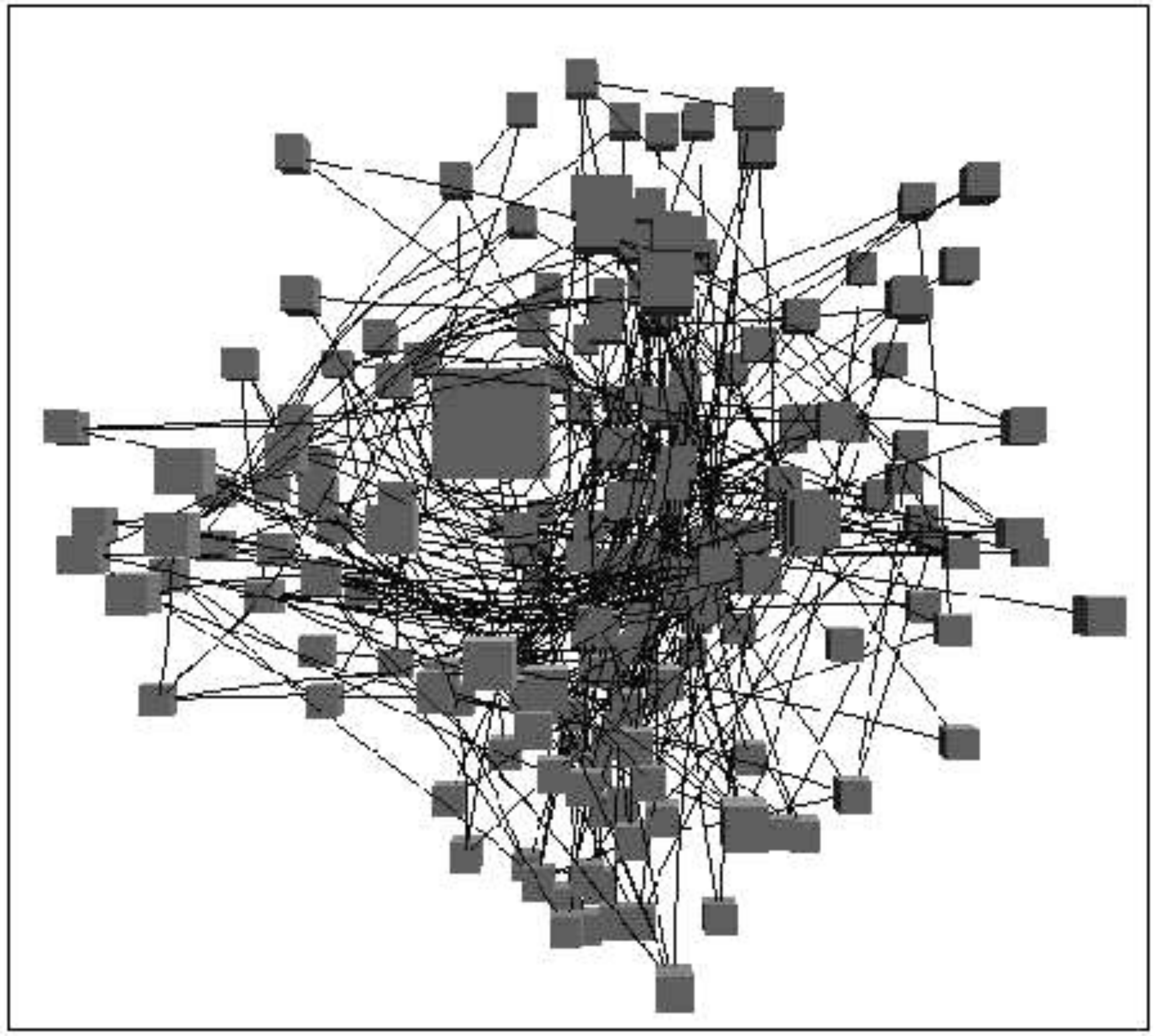
Thousands of points up/down and left/right



We can only see the outside shell of the world

Occlusion hides information

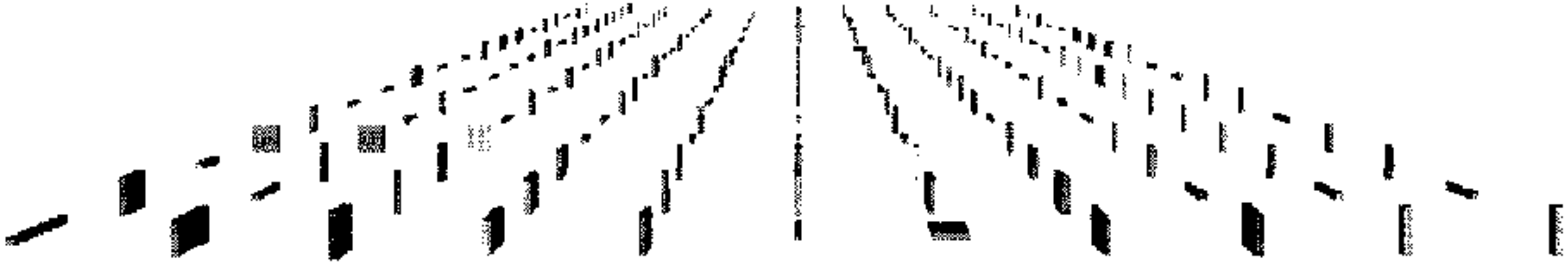
- occlusion
- interaction can resolve, but at cost of time and cognitive load



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

Perspective distortion loses information

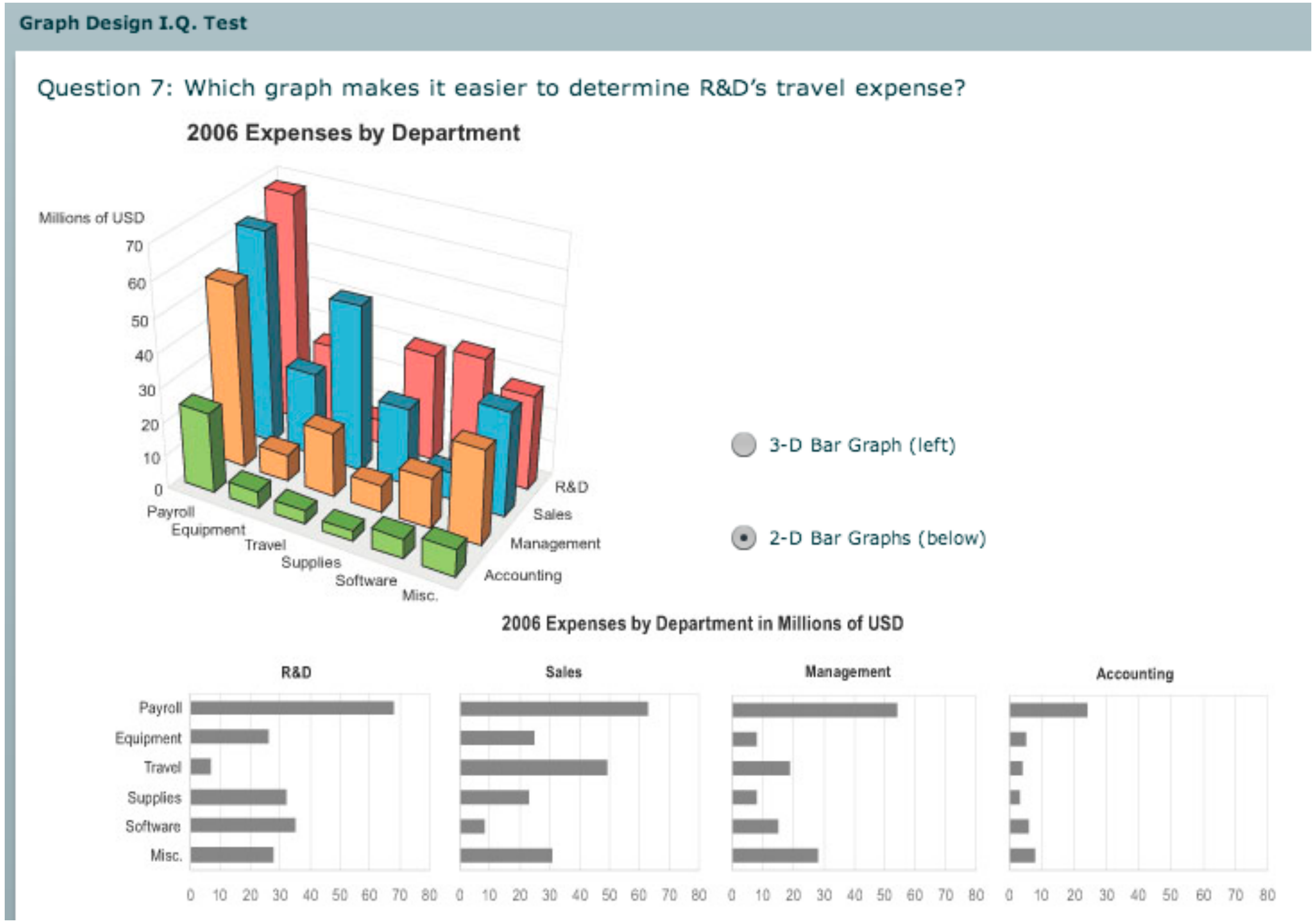
- perspective distortion
  - interferes with all size channel encodings
  - power of the plane is lost!



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

3D vs 2D bar charts

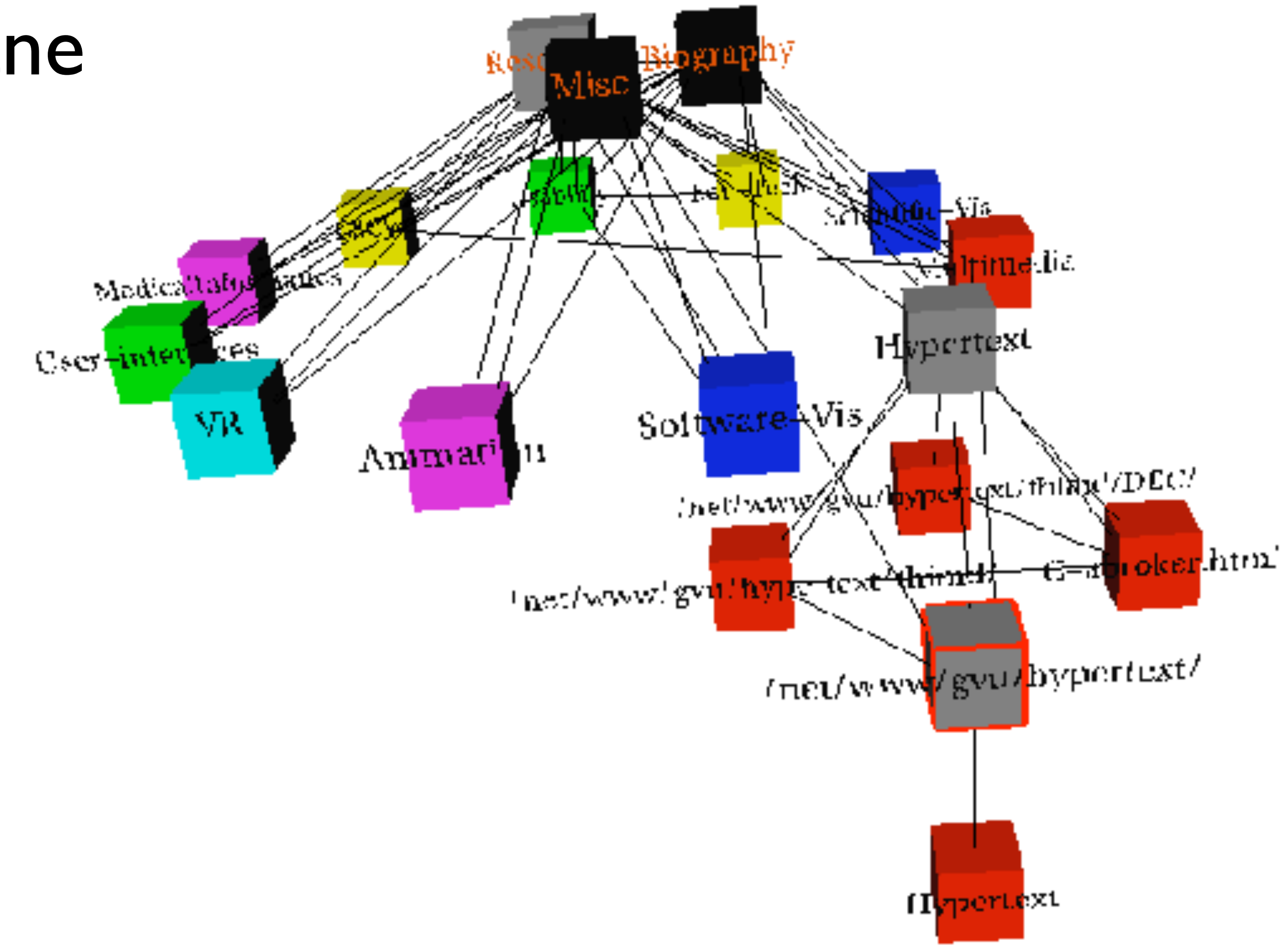
- 3D bars:
  very difficult to justify!
  - perspective distortion
  - occlusion
- faceting into 2D almost always better choice



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

Tilted text isn't legible

- text legibility
  - far worse when tilted from image plane



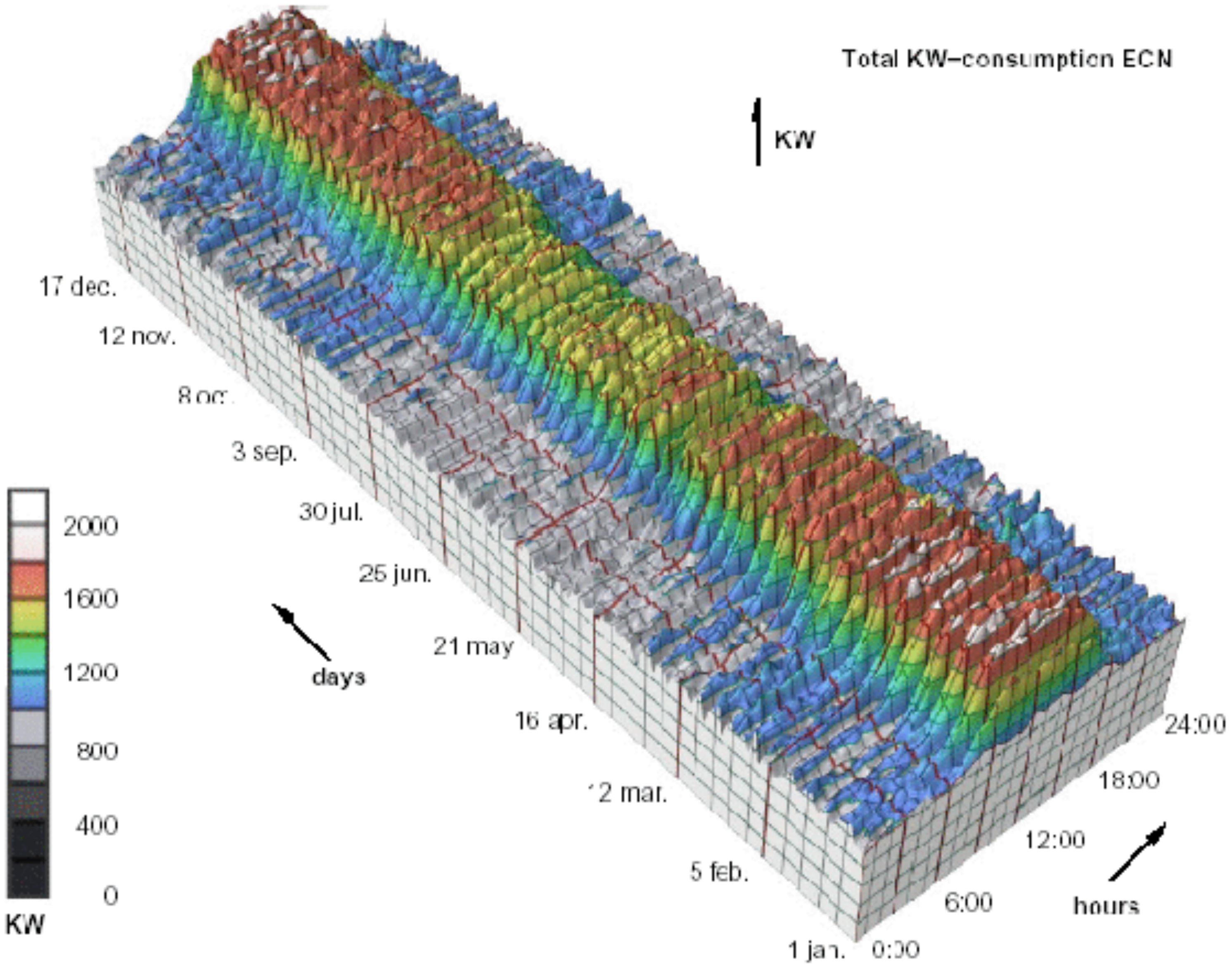
- further reading

  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

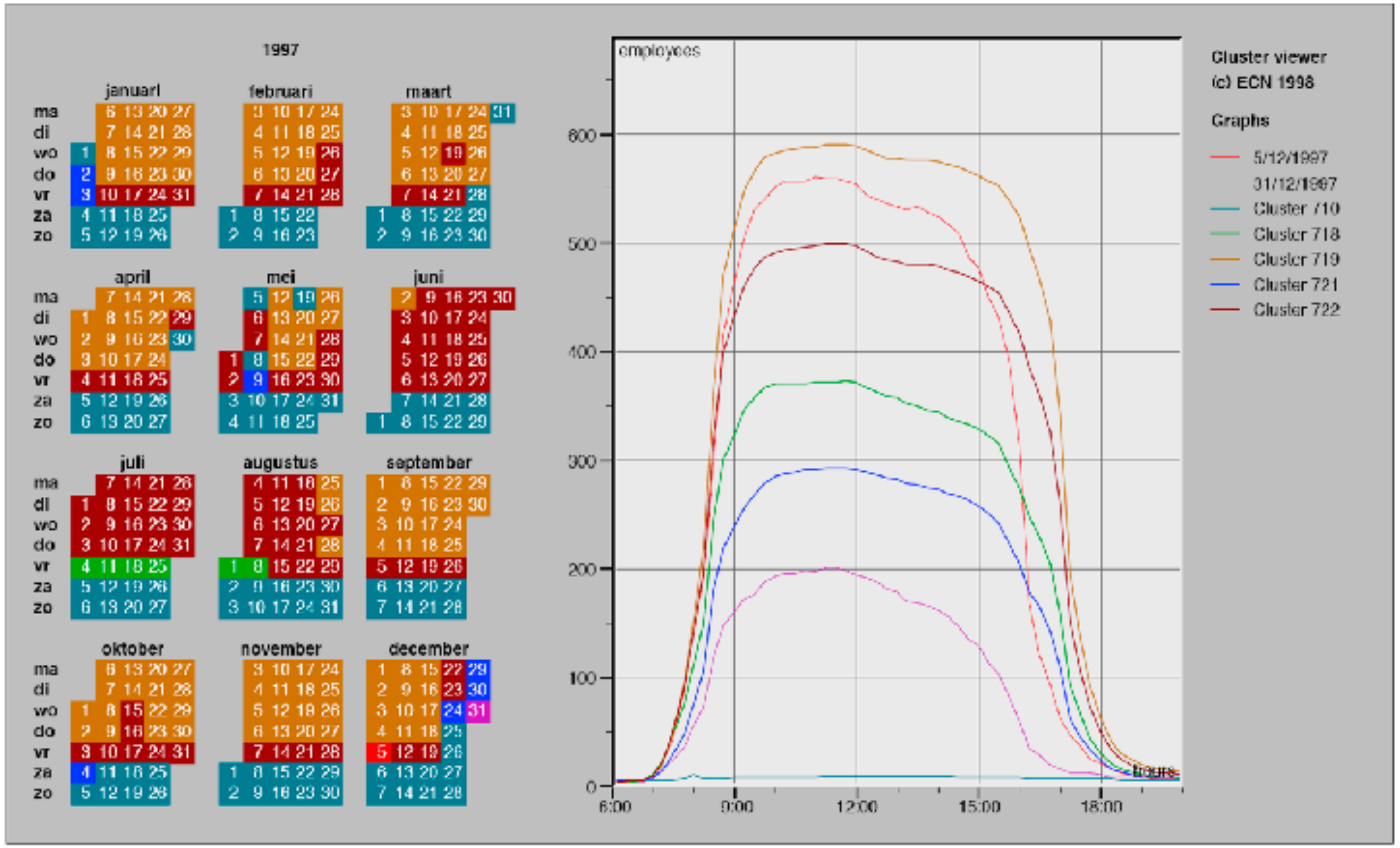
- extruded curves: detailed comparisons impossible



[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

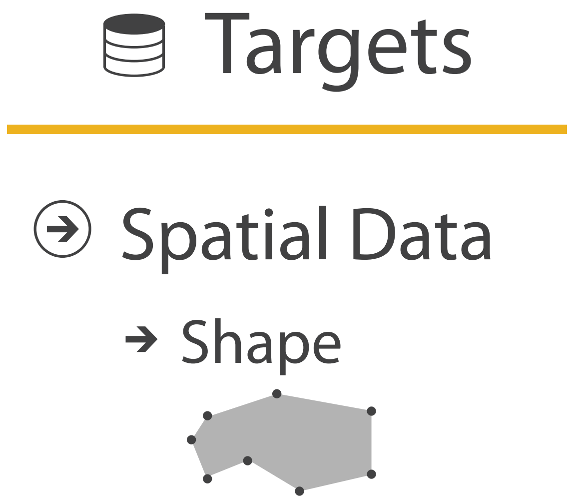
- derived data: cluster hierarchy
- juxtapose multiple views: calendar, superimposed 2D curves

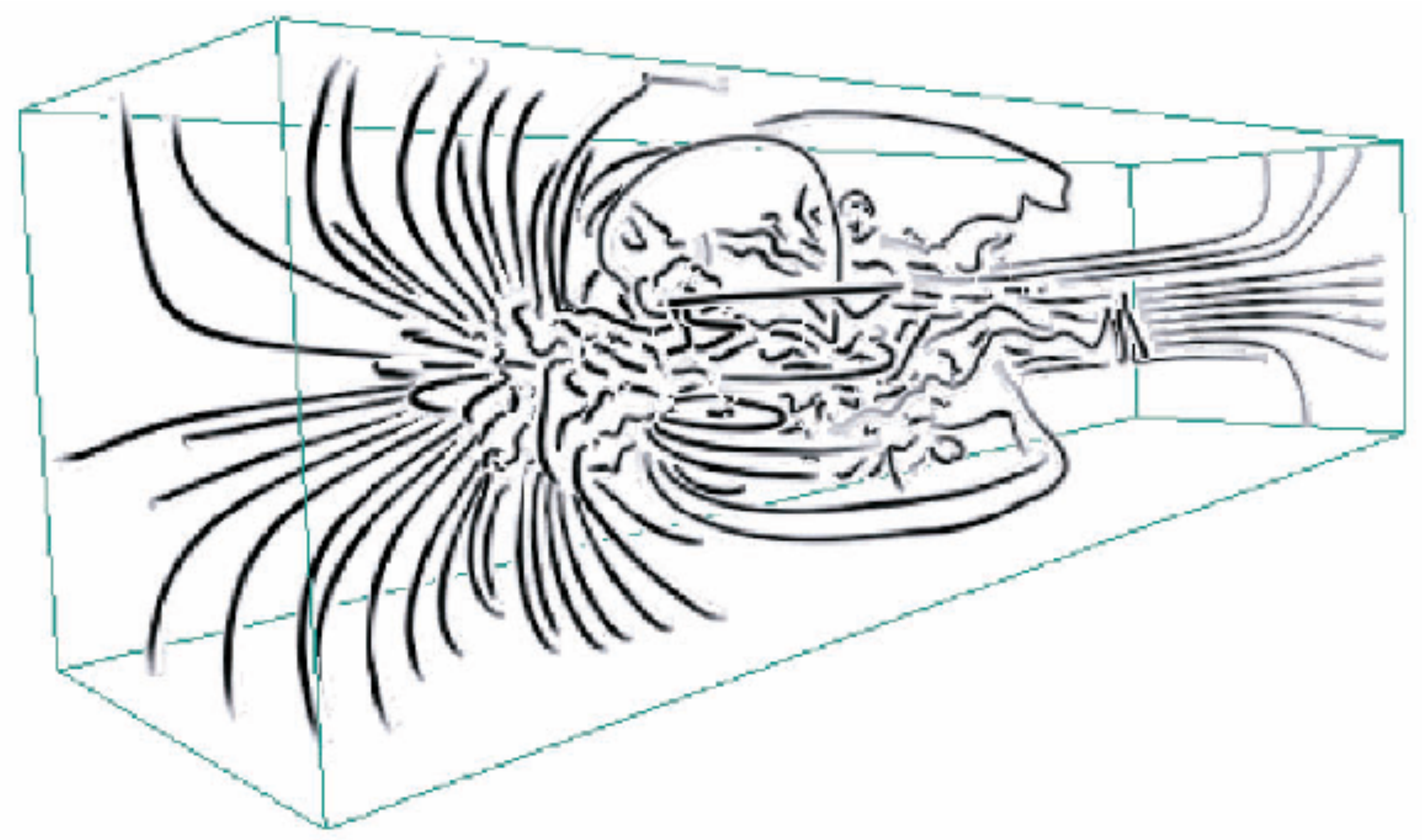


[Cluster and Calendar based Visualization of Time Series Data. van Wijk and van Selow, Proc. InfoVis 99.]

Justified 3D: shape perception

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

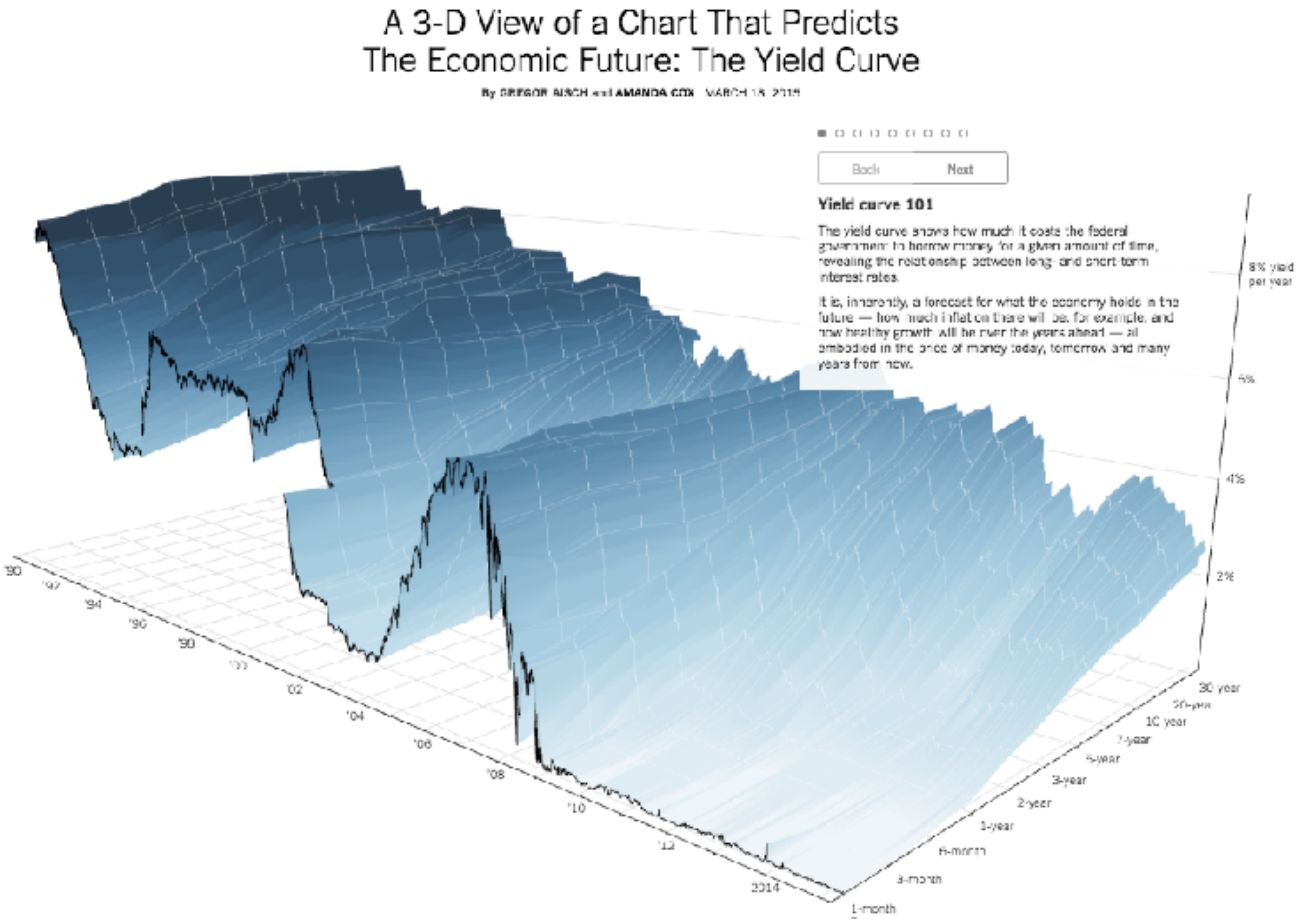




[Image-Based Streamline Generation and Rendering. Li and Shen.
IEEE Trans. Visualization and Computer Graphics (TVCG) 13:3 (2007), 630–640.]

Justified 3D: Economic growth curve

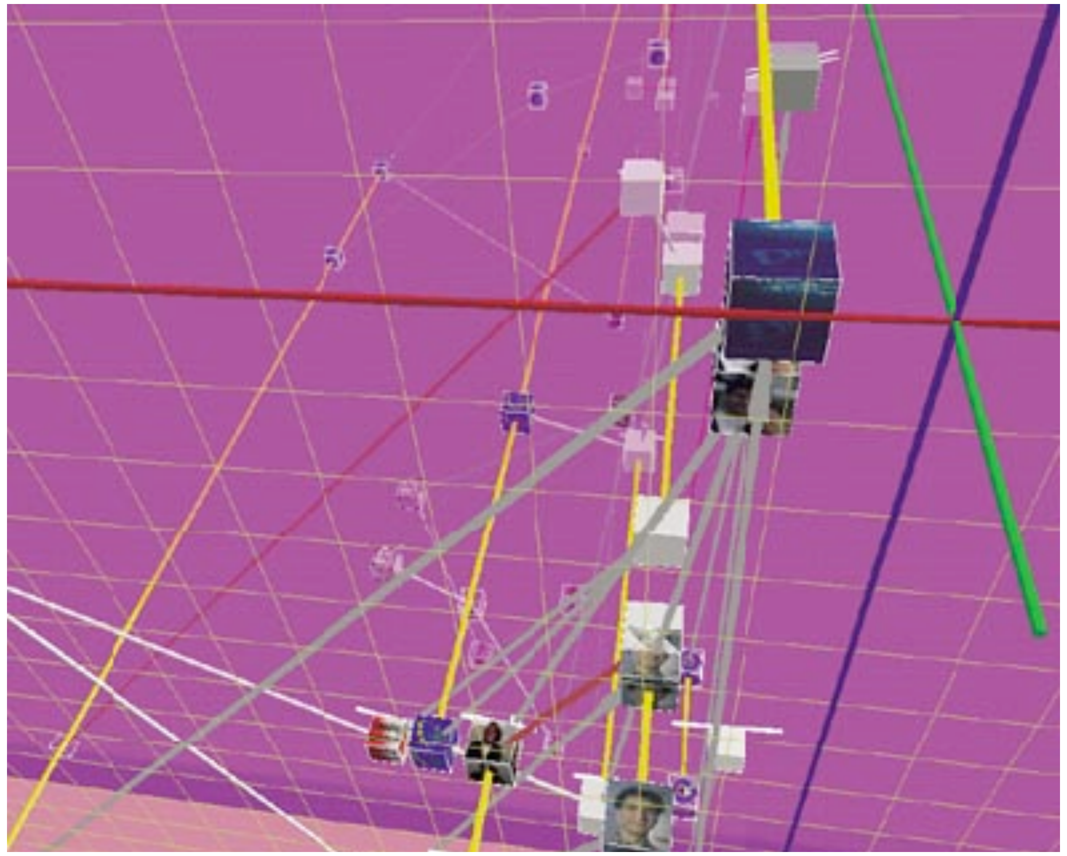
- constrained navigation steps through carefully designed viewpoints



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

No unjustified 3D

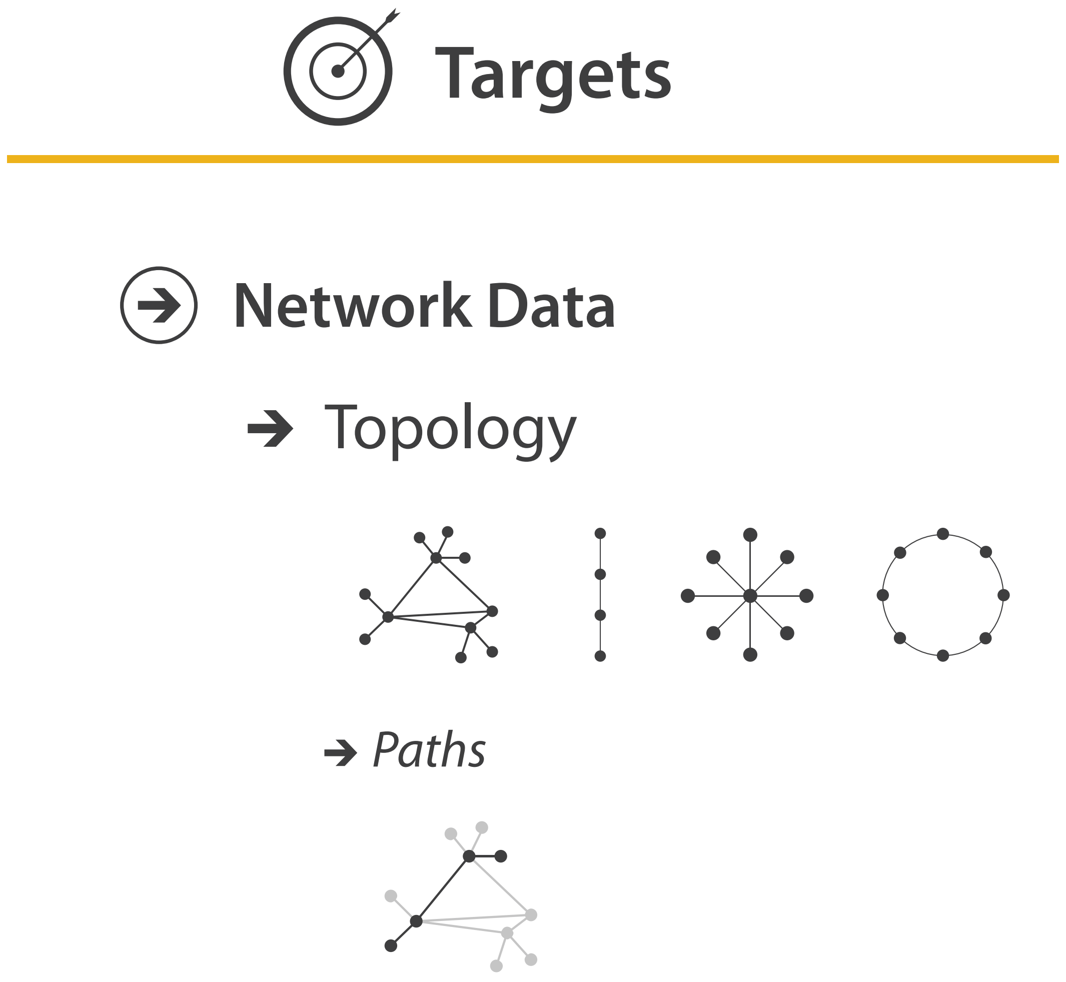
- 3D legitimate for true 3D spatial data
- 3D needs very careful justification for abstract data
  - enthusiasm in 1990s, but now skepticism
  - be especially careful with 3D for point clouds or networks



[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

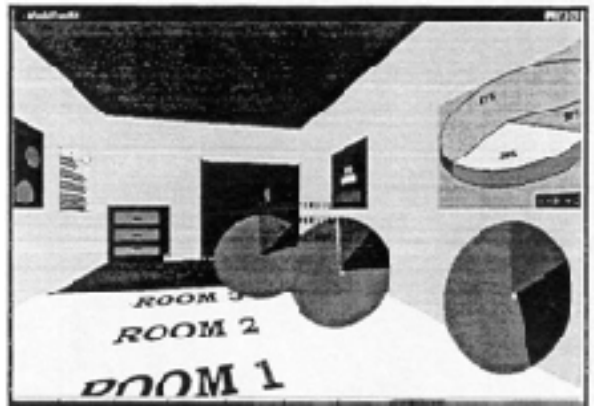
literal ⟷ abstract

animation ⟷ small multiples

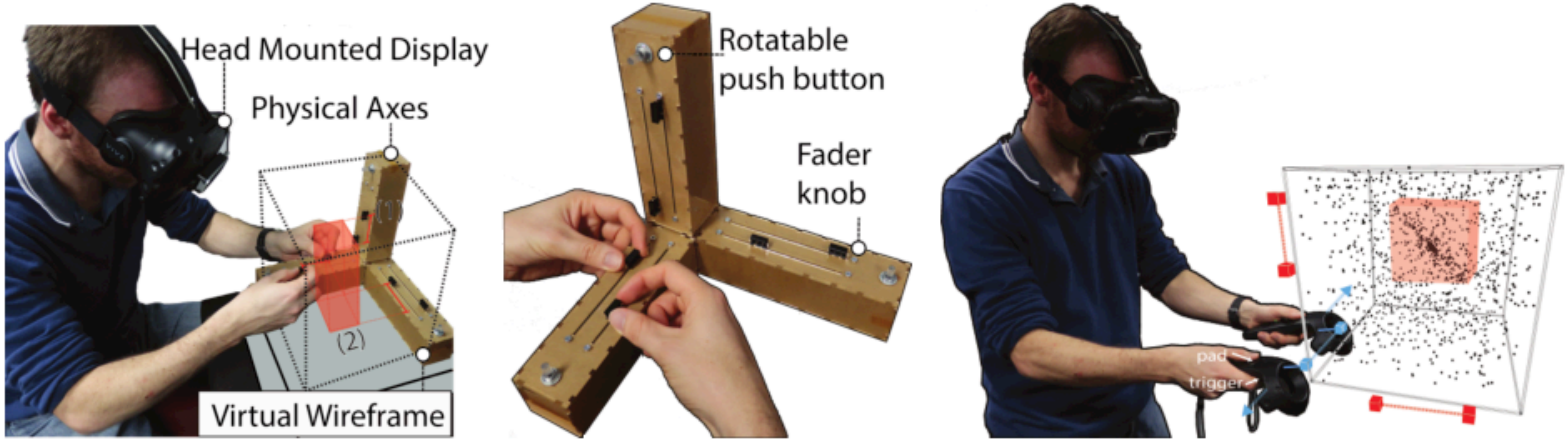
show time with time ⟷ show time with space

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]



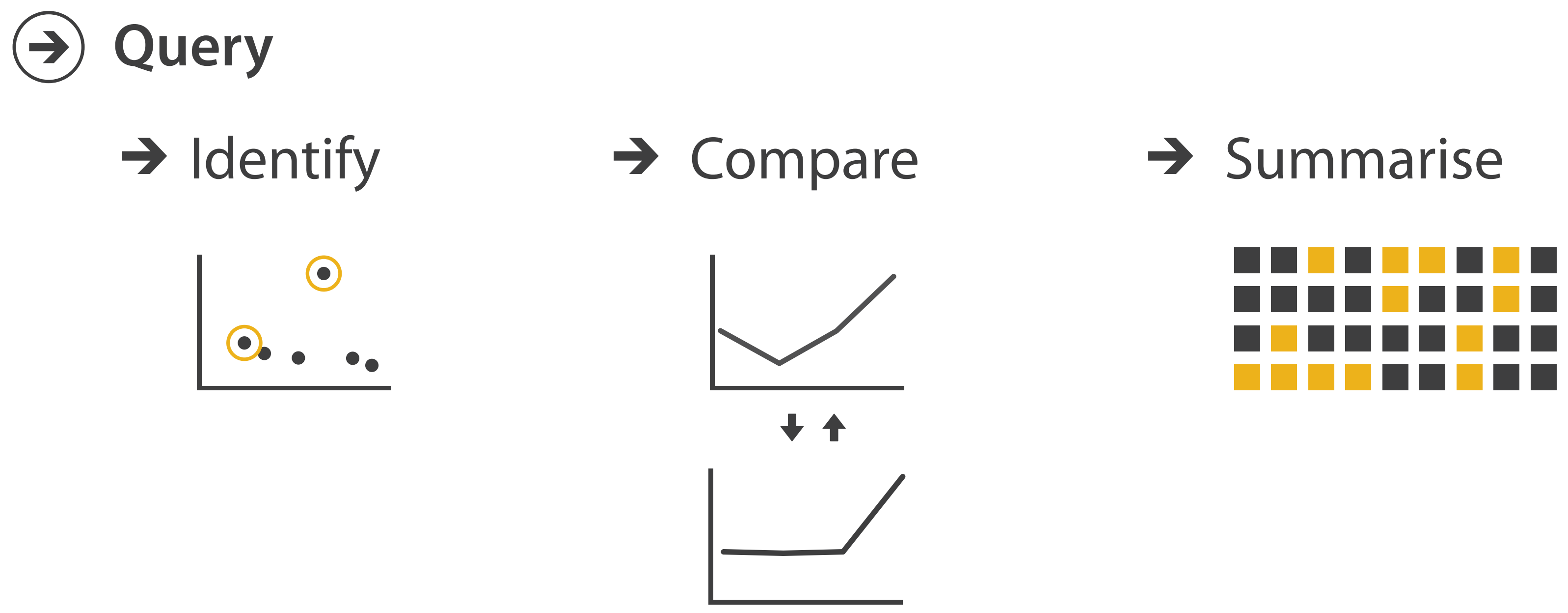
[A Design Space for Spatio-Data Coordination: Tangible Interaction Devices for Immersive Information Visualisation. Cordeil, Bach, Li, Elliott, and Dwyer. Proc. PacificVis 2017 Notes.]

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



Rule of thumb: **Responsiveness is required**

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

Function first, form next

- 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

Form: Basic graphic design ideas

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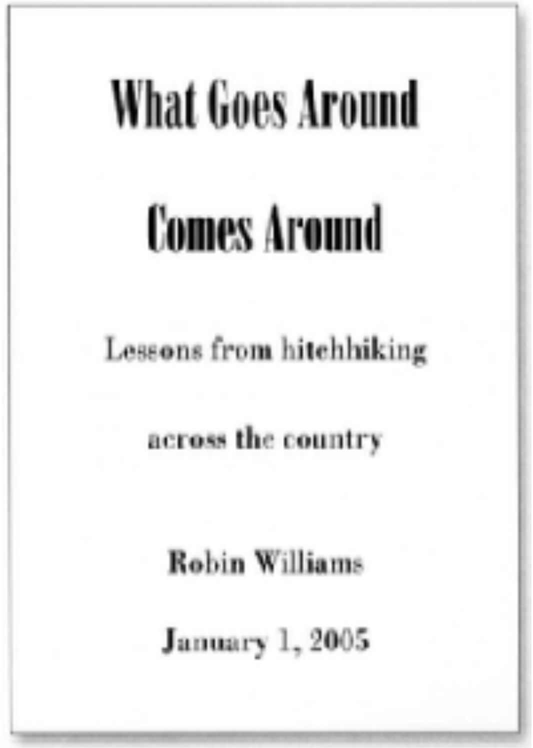
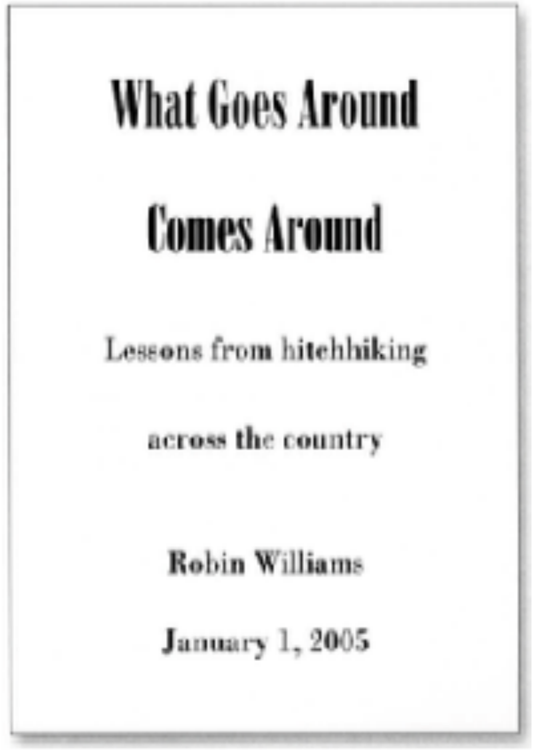


Form: Basic graphic design ideas

- proximity
  - – do group related items together
  - – avoid equal whitespace between unrelated



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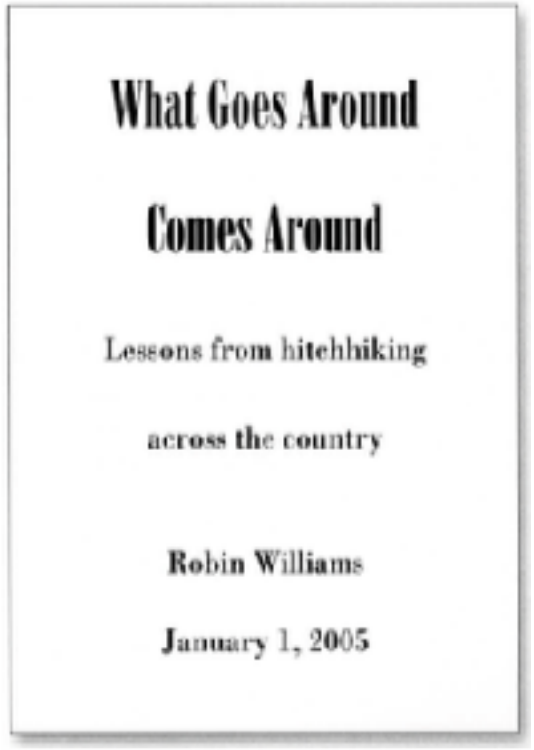

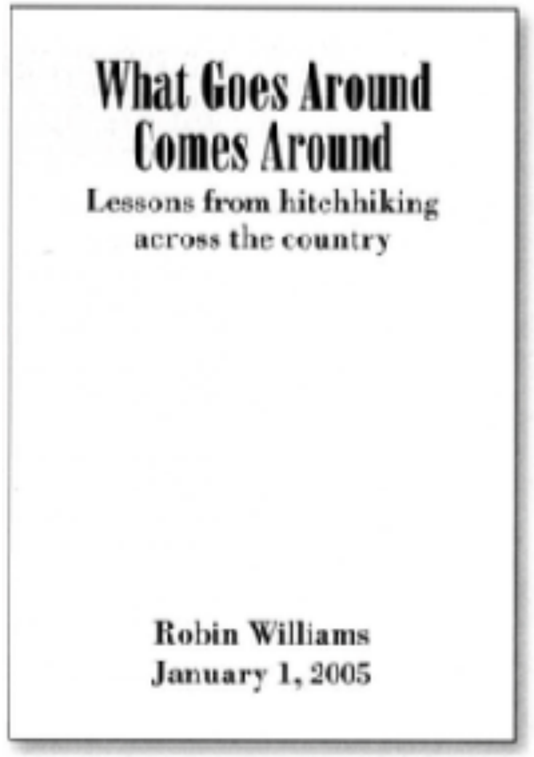

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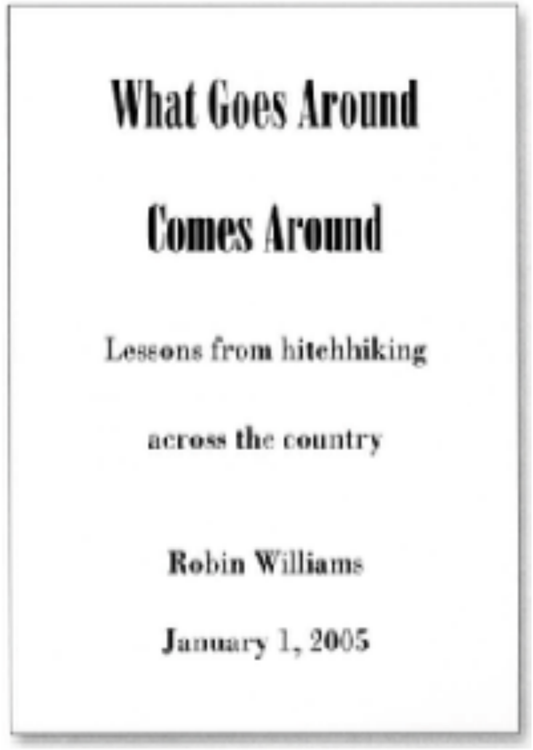

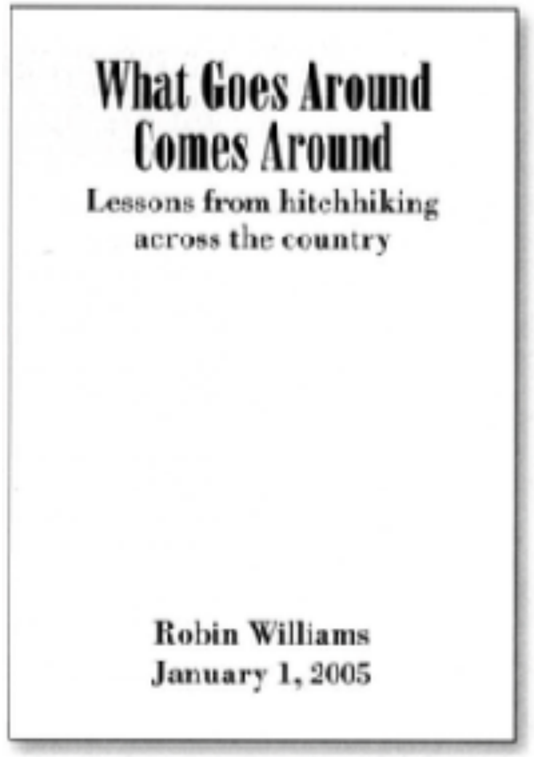

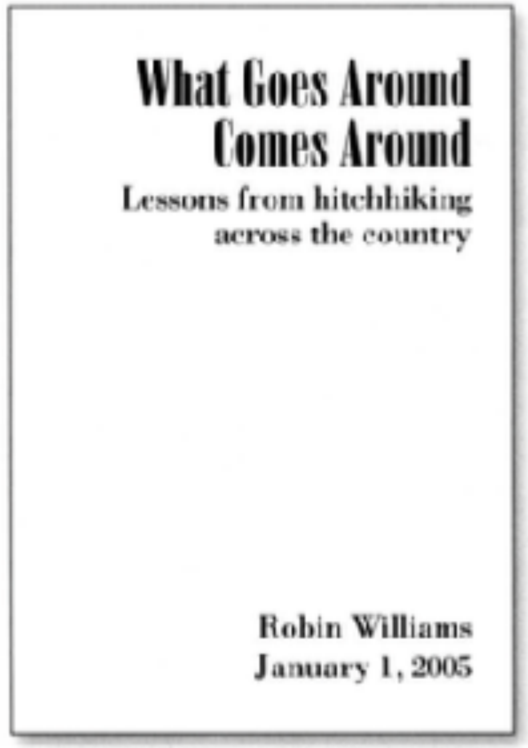

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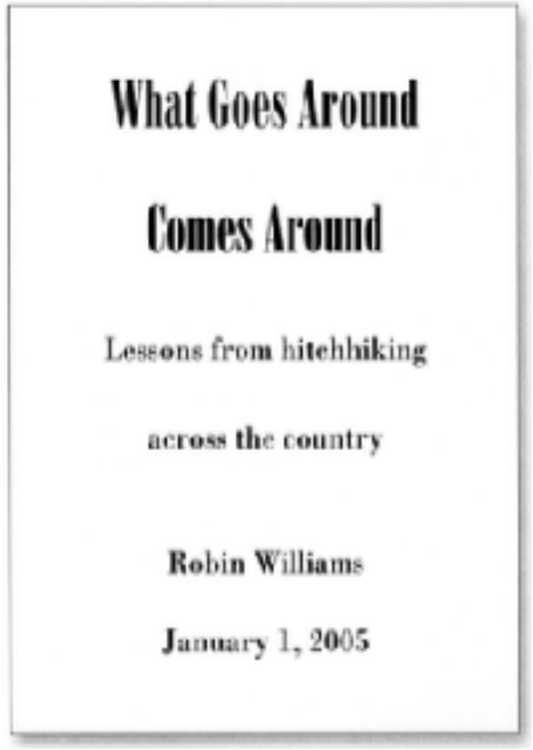

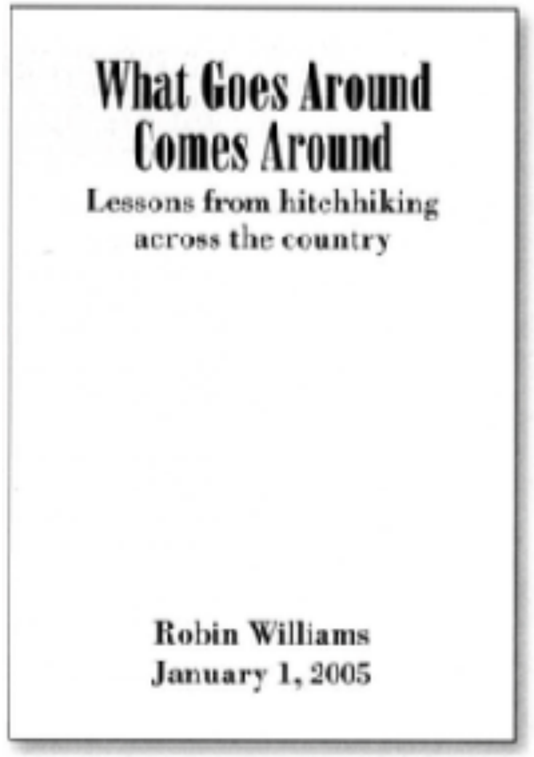

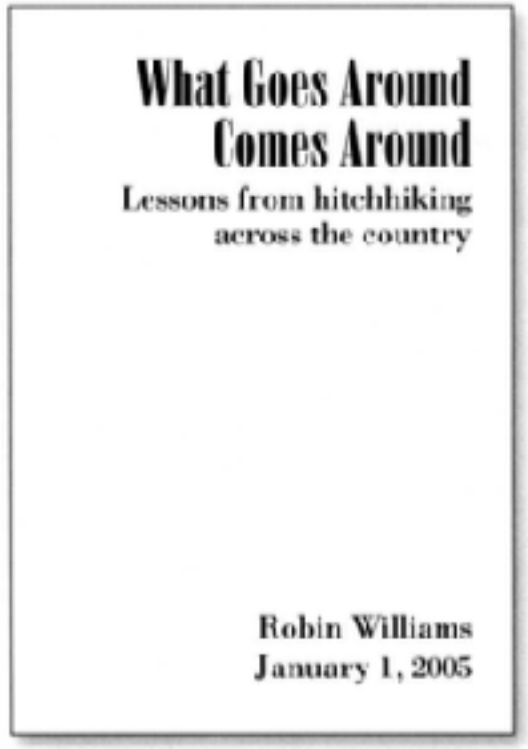

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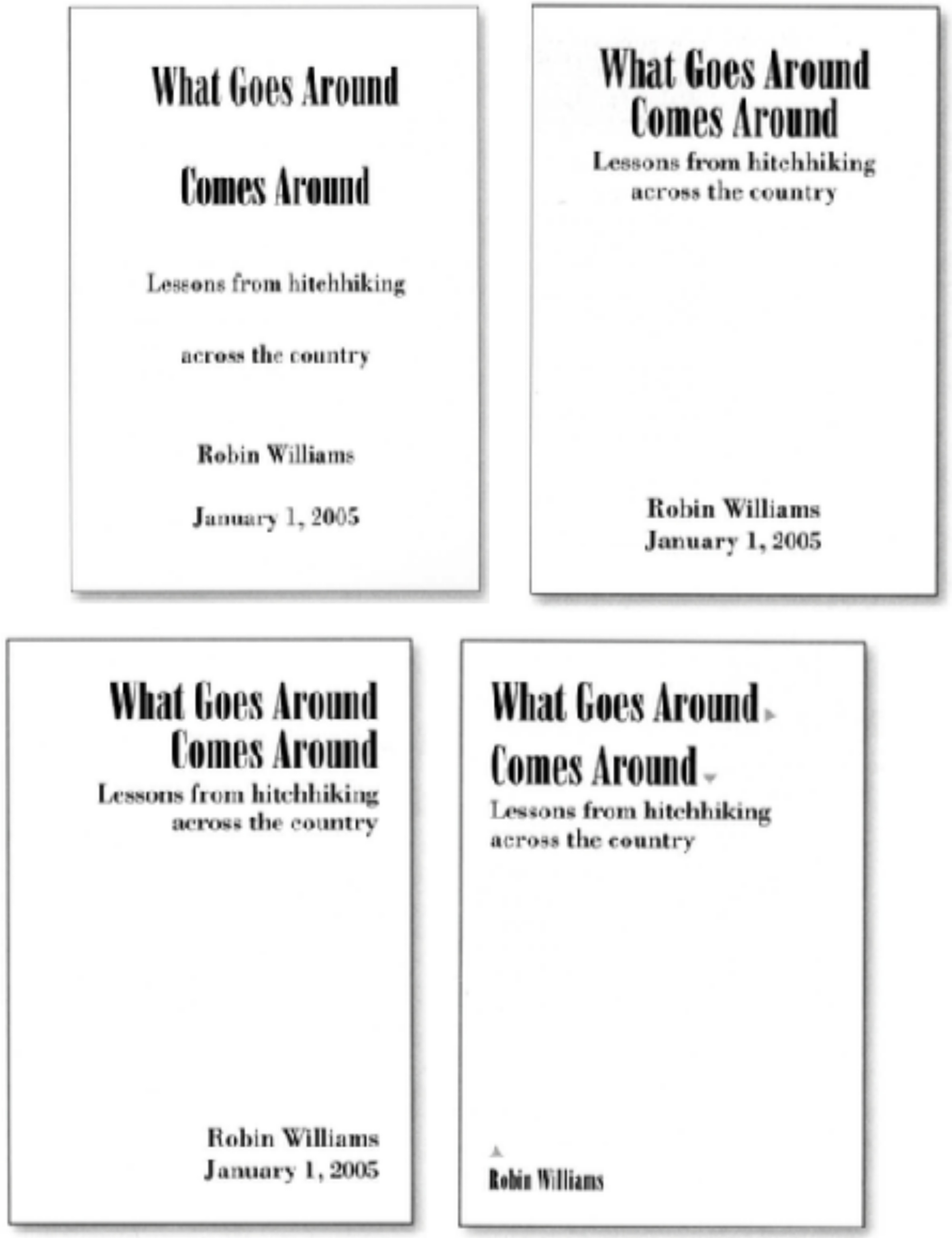

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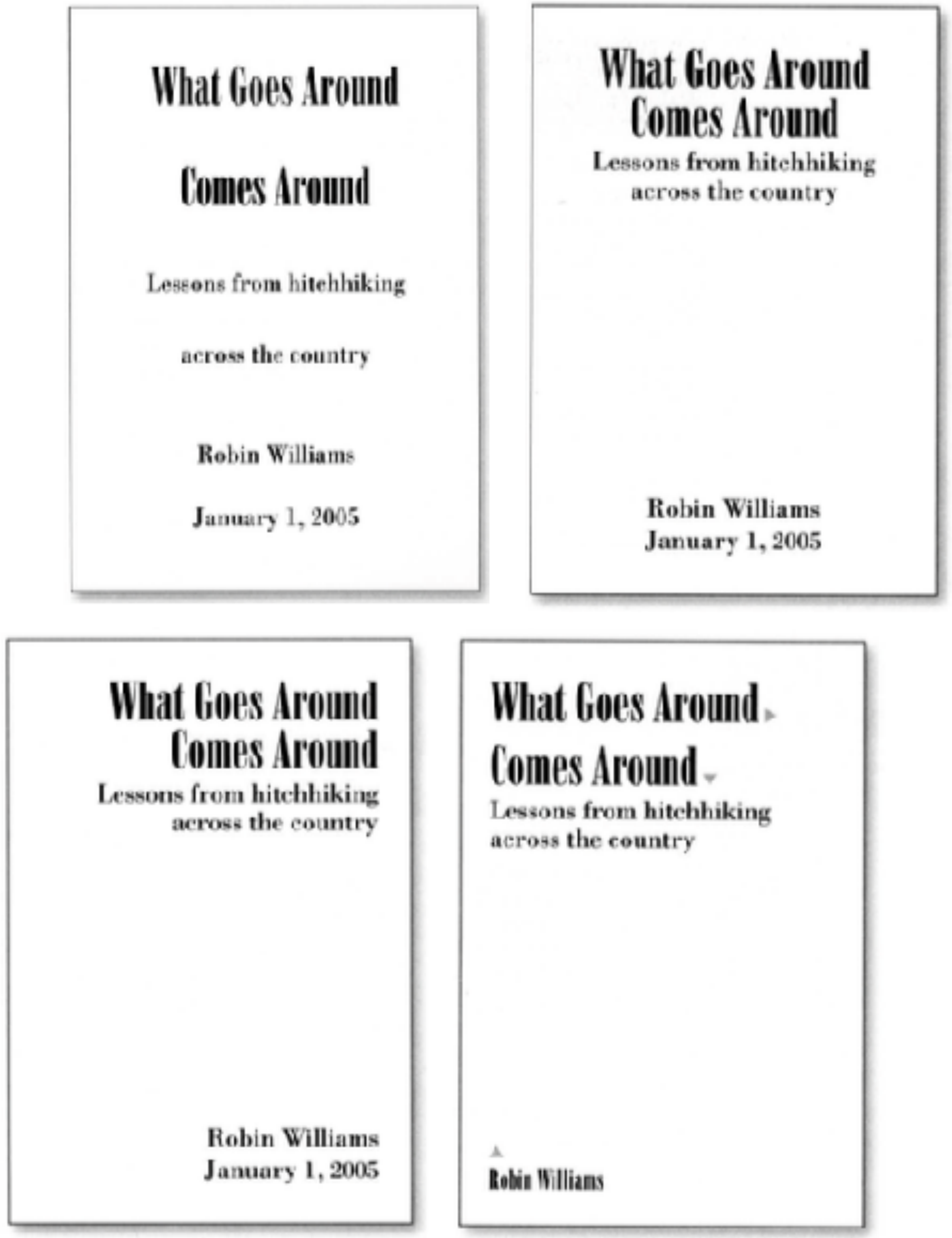
- contrast
  - if not identical, then very different
  - avoid not quite the same



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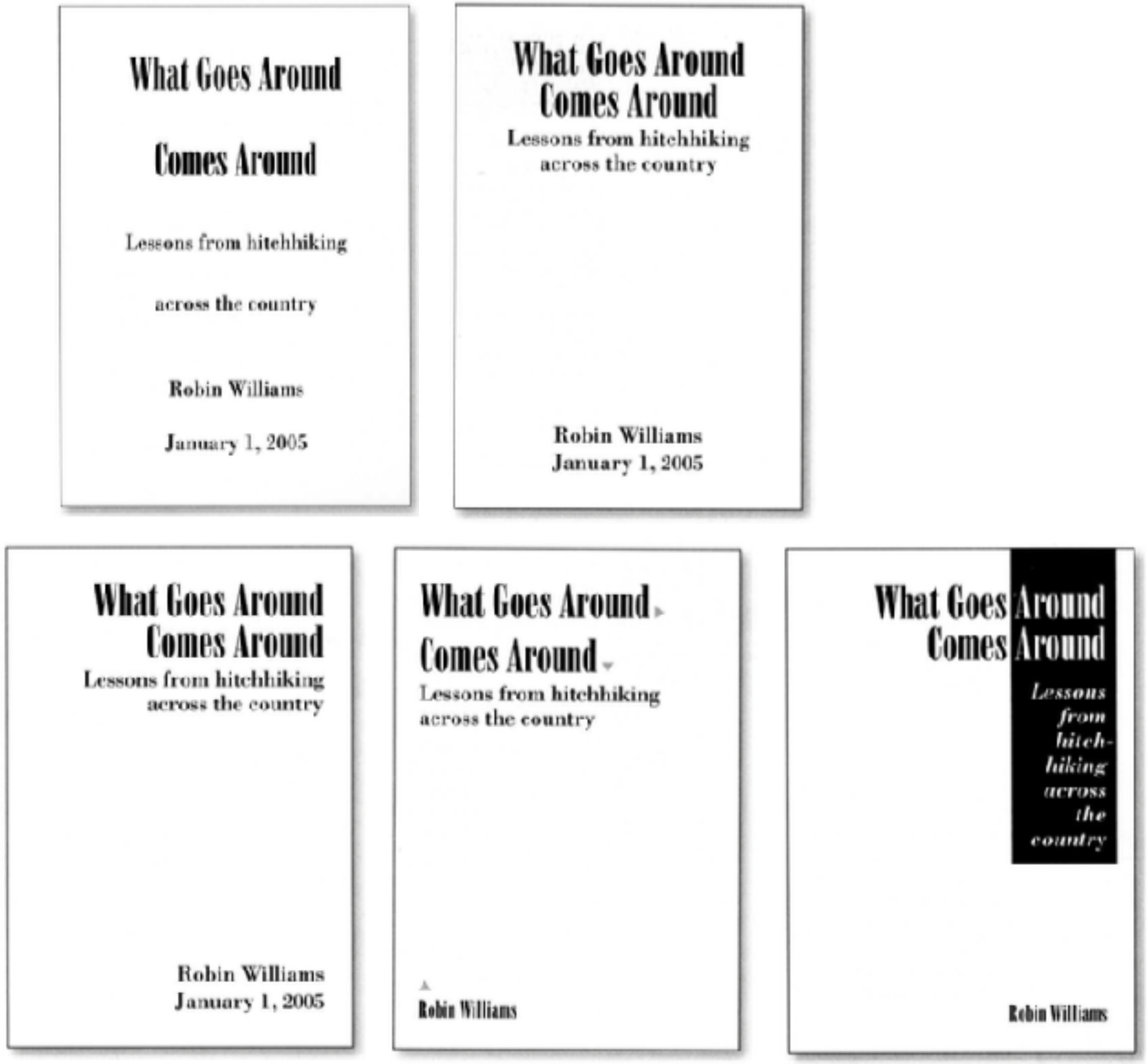

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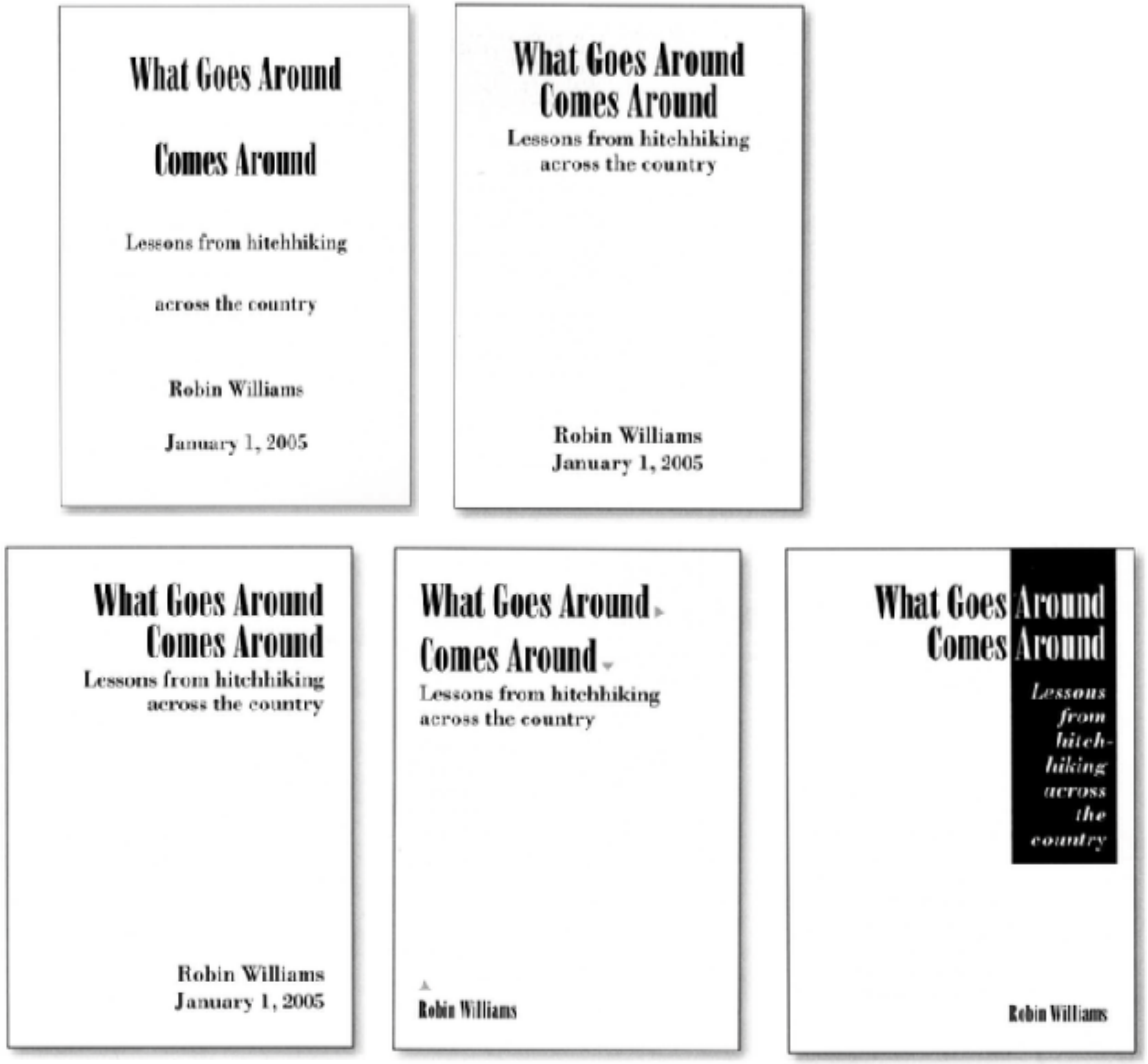
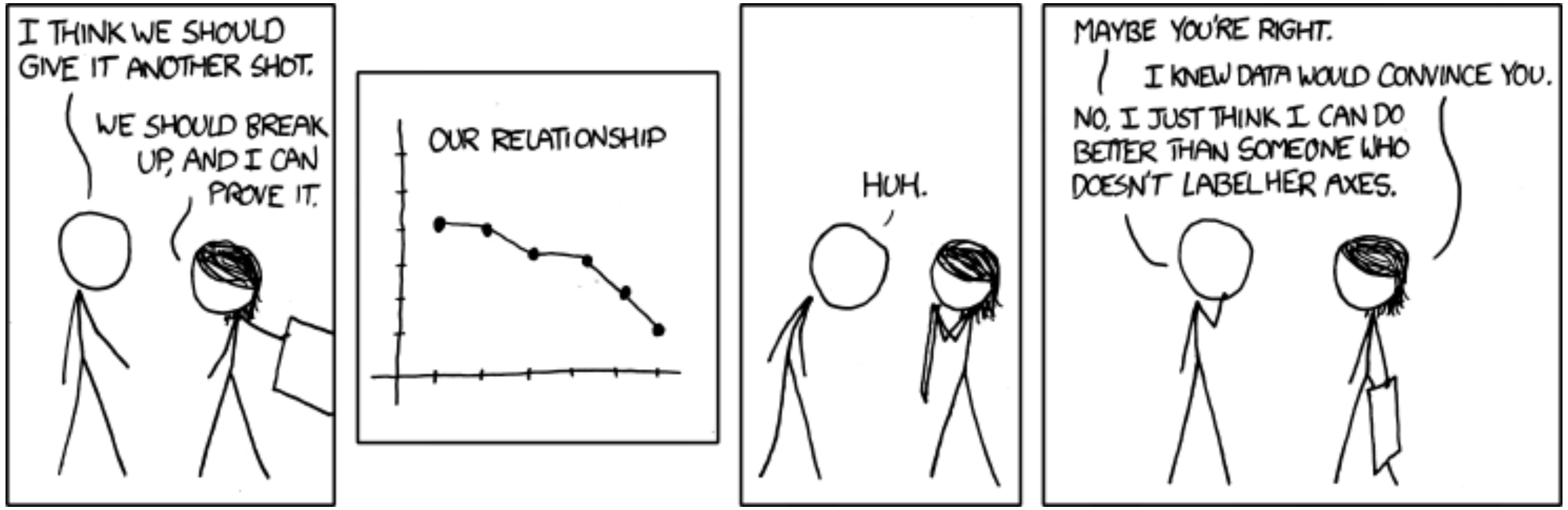


- *The Non-Designer's Design Book, 4th ed. Robin Williams, Peachpit Press, 2015.*
  - fast read, very practical to work through whole thing

Best practices: Labelling

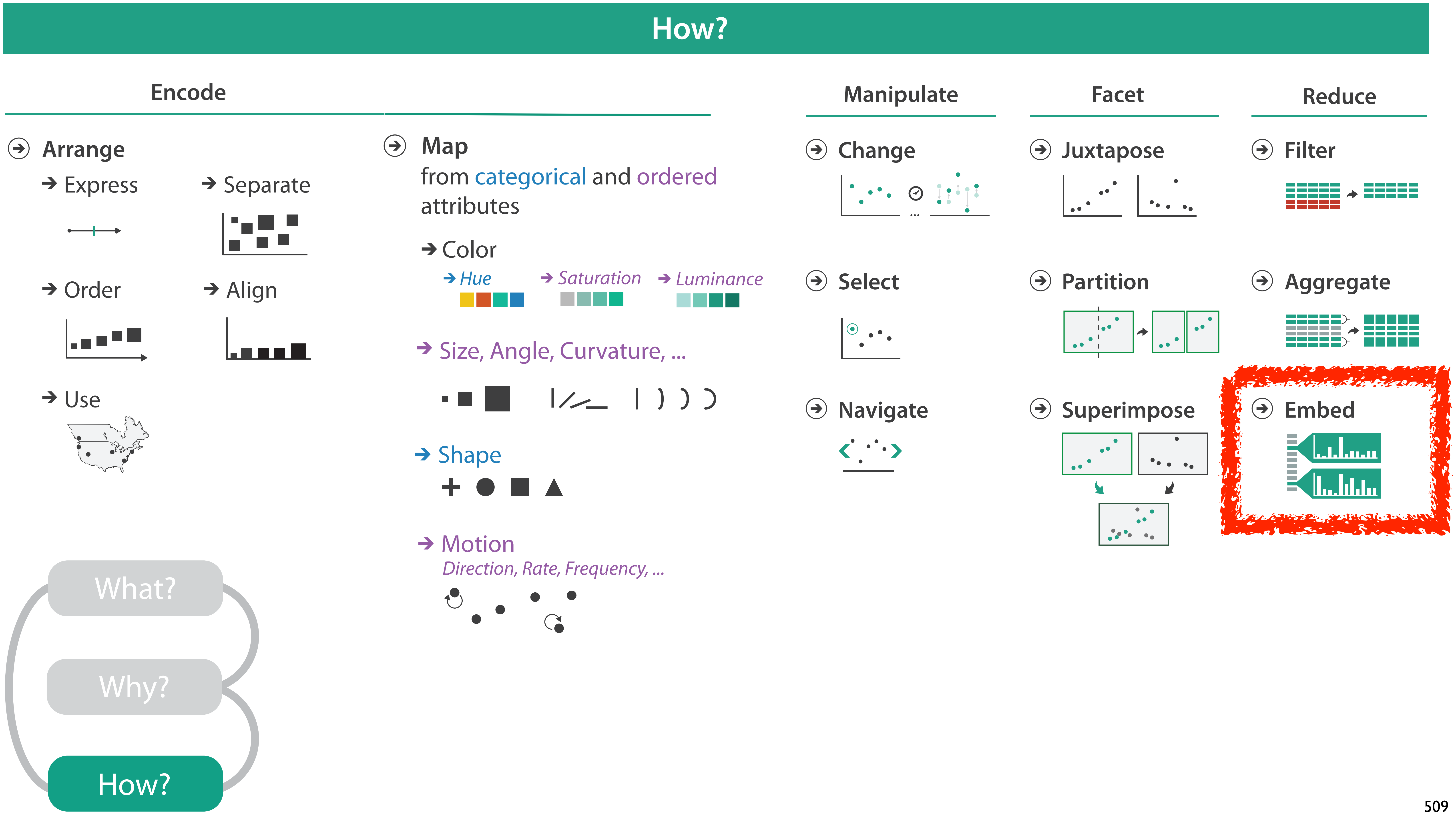
- make visualizations as self-documenting as possible
  - meaningful & useful title, labels, legends
    - axes and panes/subwindows should have labels
      - and axes should have good mix/max boundary tick marks
    - everything that's plotted should have a legend
      - and own header/labels if not 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


How?
Encode
Arrange
Express
Separate
Order
Align
Use
Map
from categorical and ordered attributes
Color
Hue
Saturation
Luminance
Size, Angle, Curvature, ...
Shape
Motion
Direction, Rate, Frequency, ...
Manipulate
Change
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Navigate
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Partition
Superimpose
Reduce
Filter
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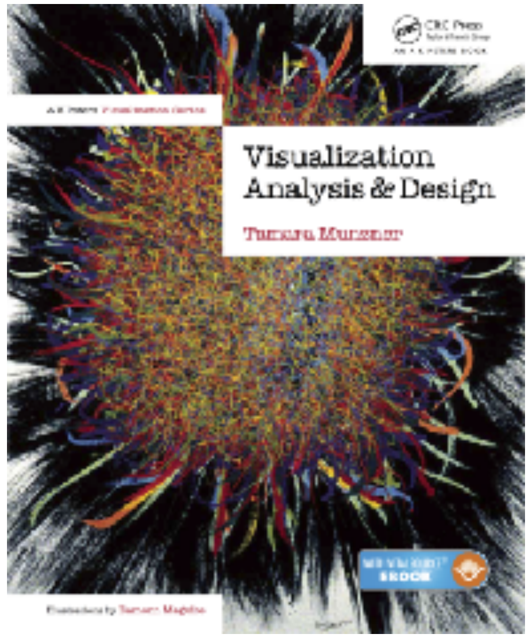
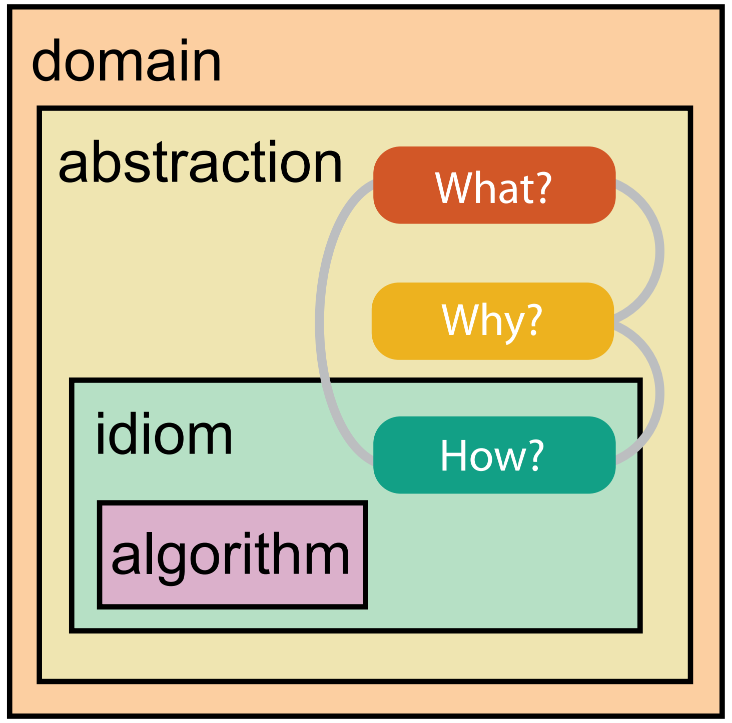
What?
Why?
How?



Visualization Analysis & Design

Wrapup

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


domain
abstraction
What?
Why?
idiom
How?
algorithm

What?

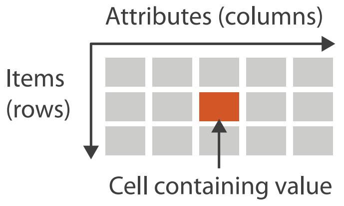
Datasets

Data Types
- Items
- Attributes
- Links
- Positions
- Grids

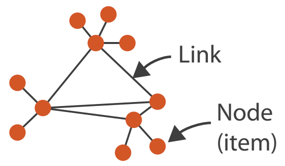
Data and Dataset Types

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

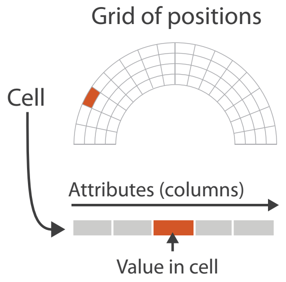
Dataset Types
- Tables



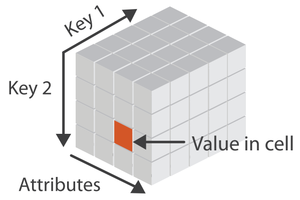
- Networks



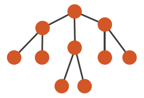
- Fields (Continuous)



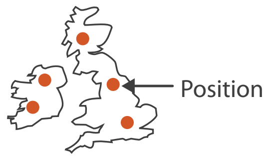
- *Multidimensional Table*



- *Trees*



- Geometry (Spatial)

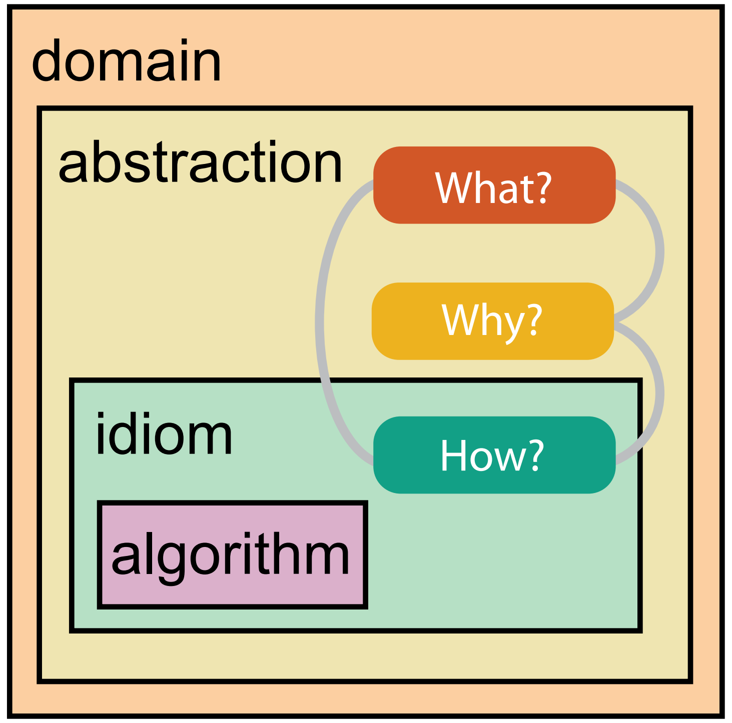


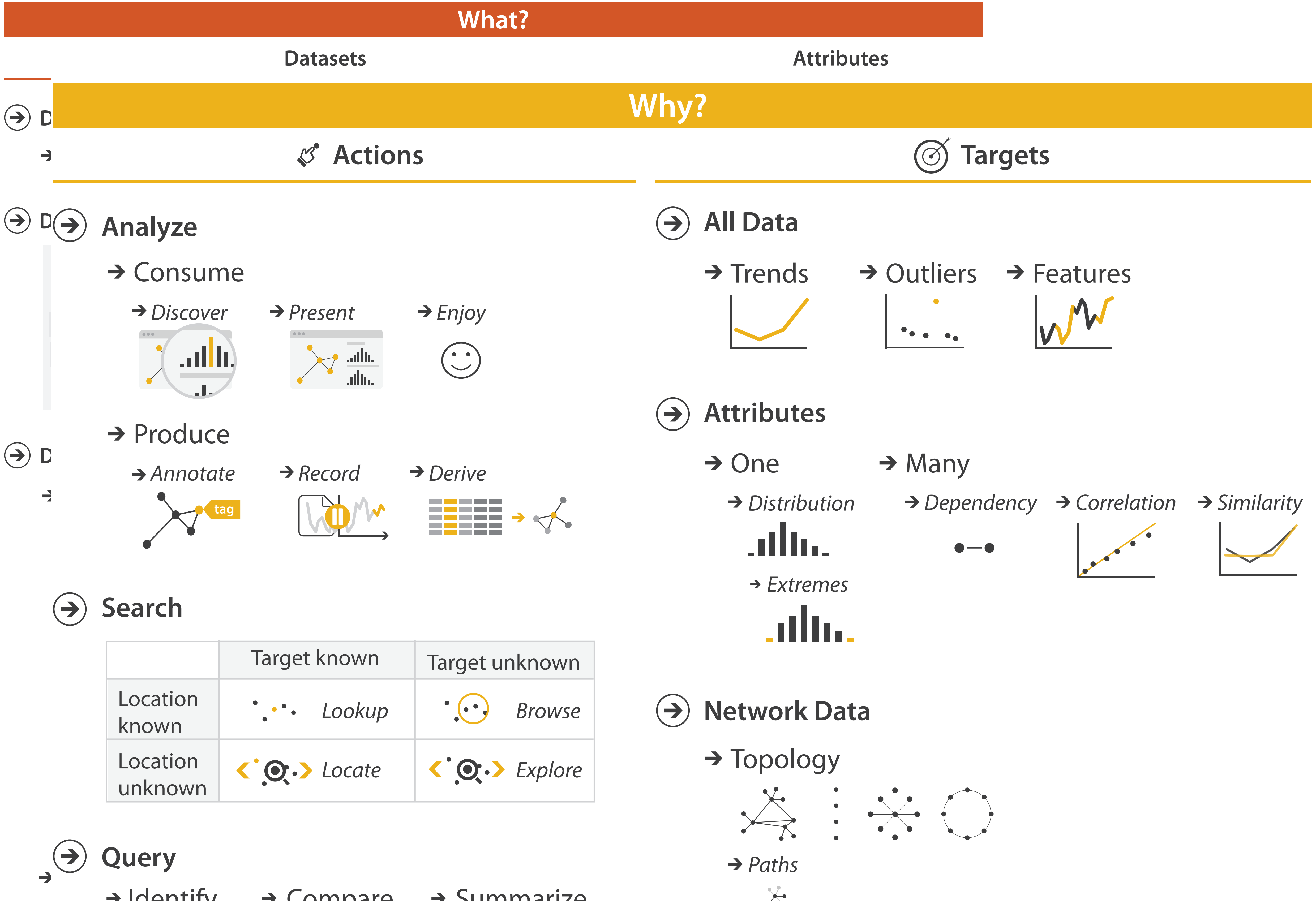
Attributes

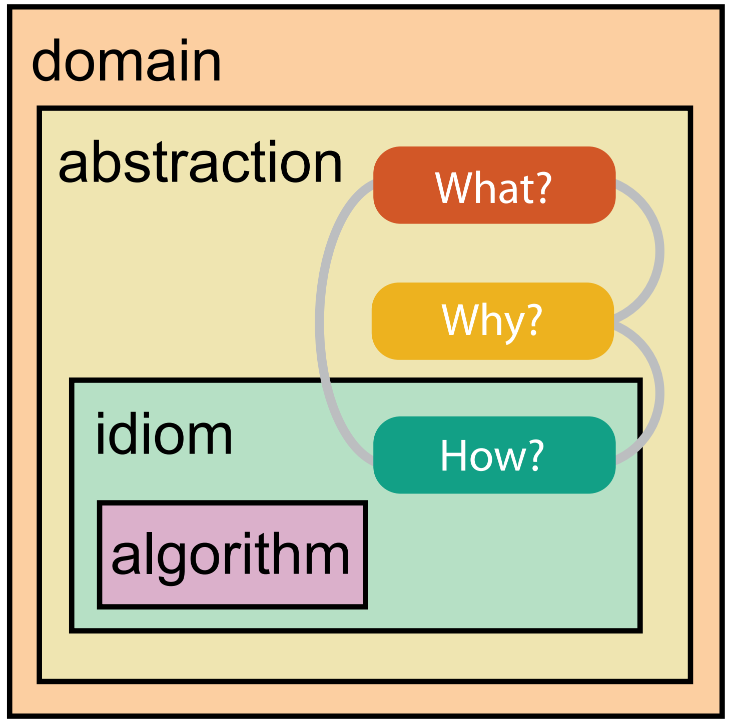
Attribute Types
- Categorical
- Ordered
  - *Ordinal*

  - *Quantitative*

Ordering Direction
- Sequential
- Diverging
- Cyclic




What?
Datasets
Attributes
Why?
Actions
Targets
Analyze
Consume
Discover
Present
Enjoy
Produce
Annotate
tag
Record
Derive
Search
Target known
Target unknown
Location known
Lookup
Browse
Location unknown
Locate
Explore
Query
Identify
Compare
Summarize
All Data
Trends
Outliers
Features
Attributes
One
Many
Distribution
Dependency
Correlation
Similarity
Extremes
Network Data
Topology
Paths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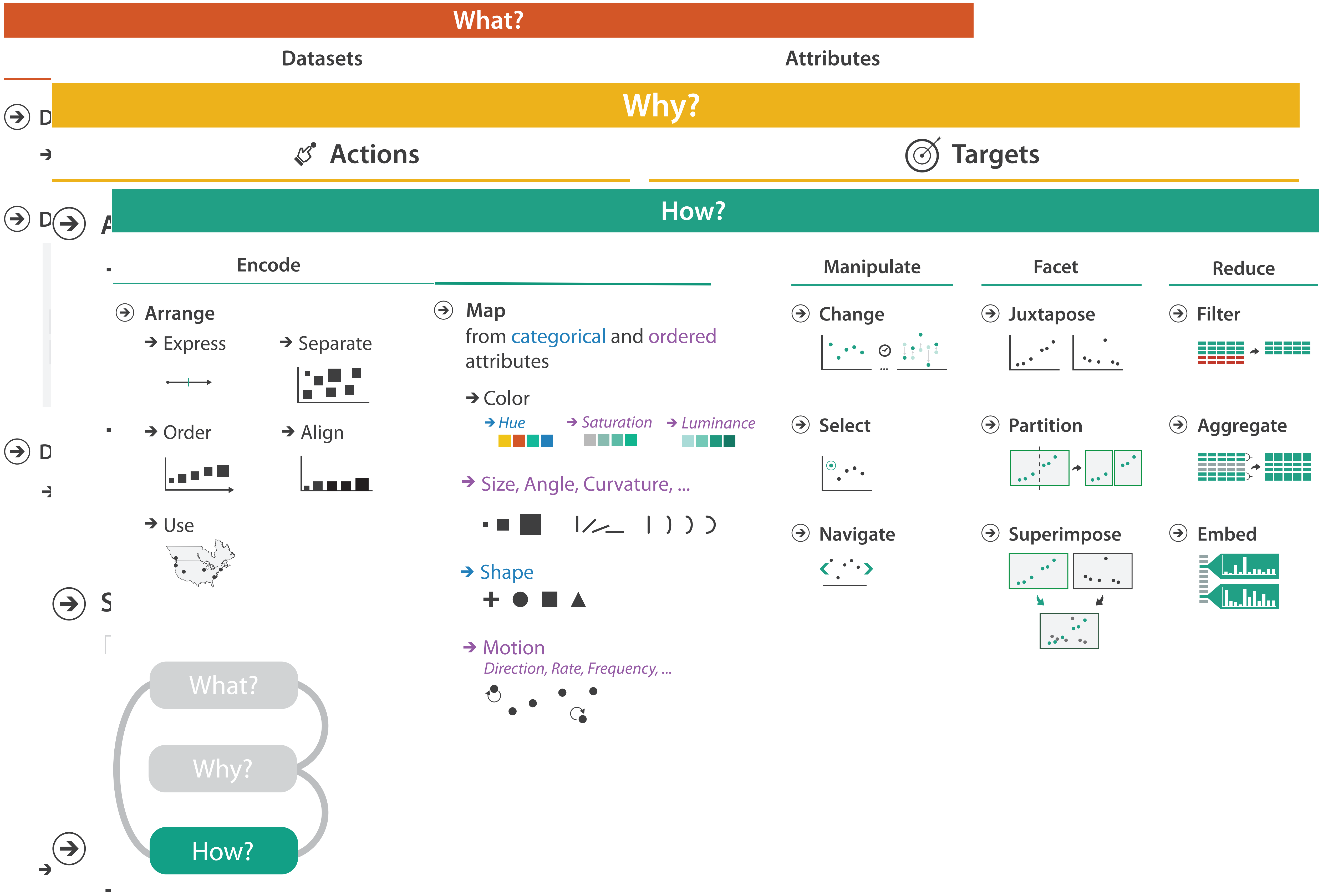
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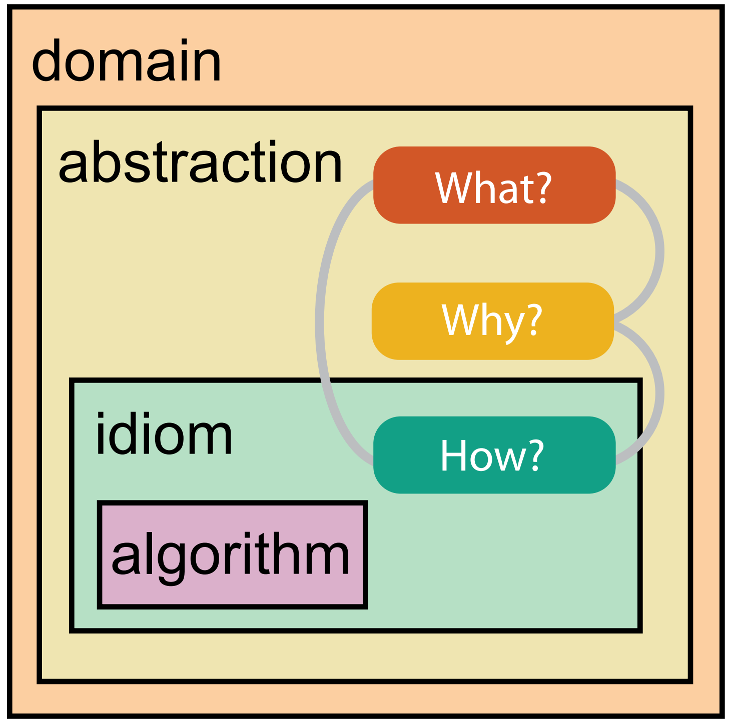
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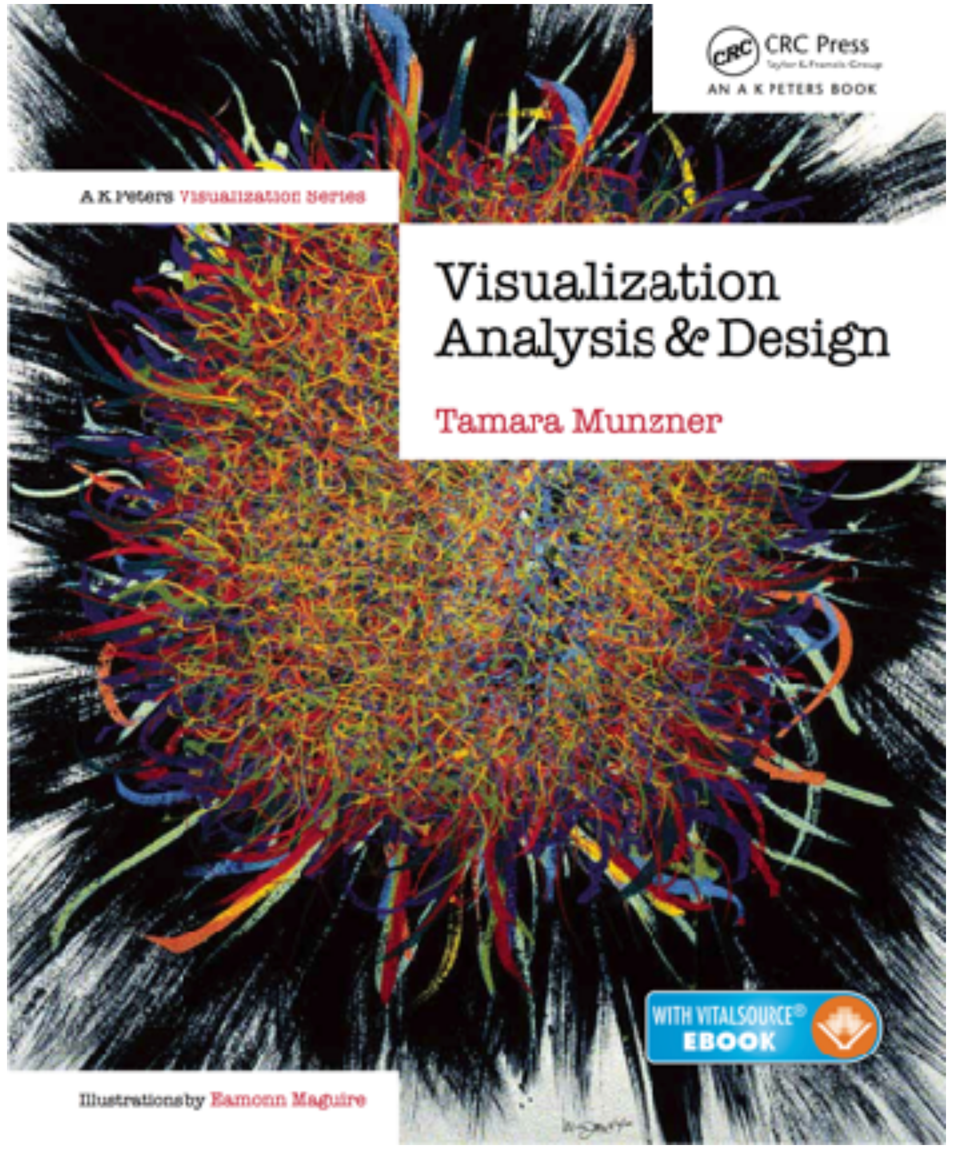
More information

- 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

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



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

@tamaramunzner