Data Visualisation

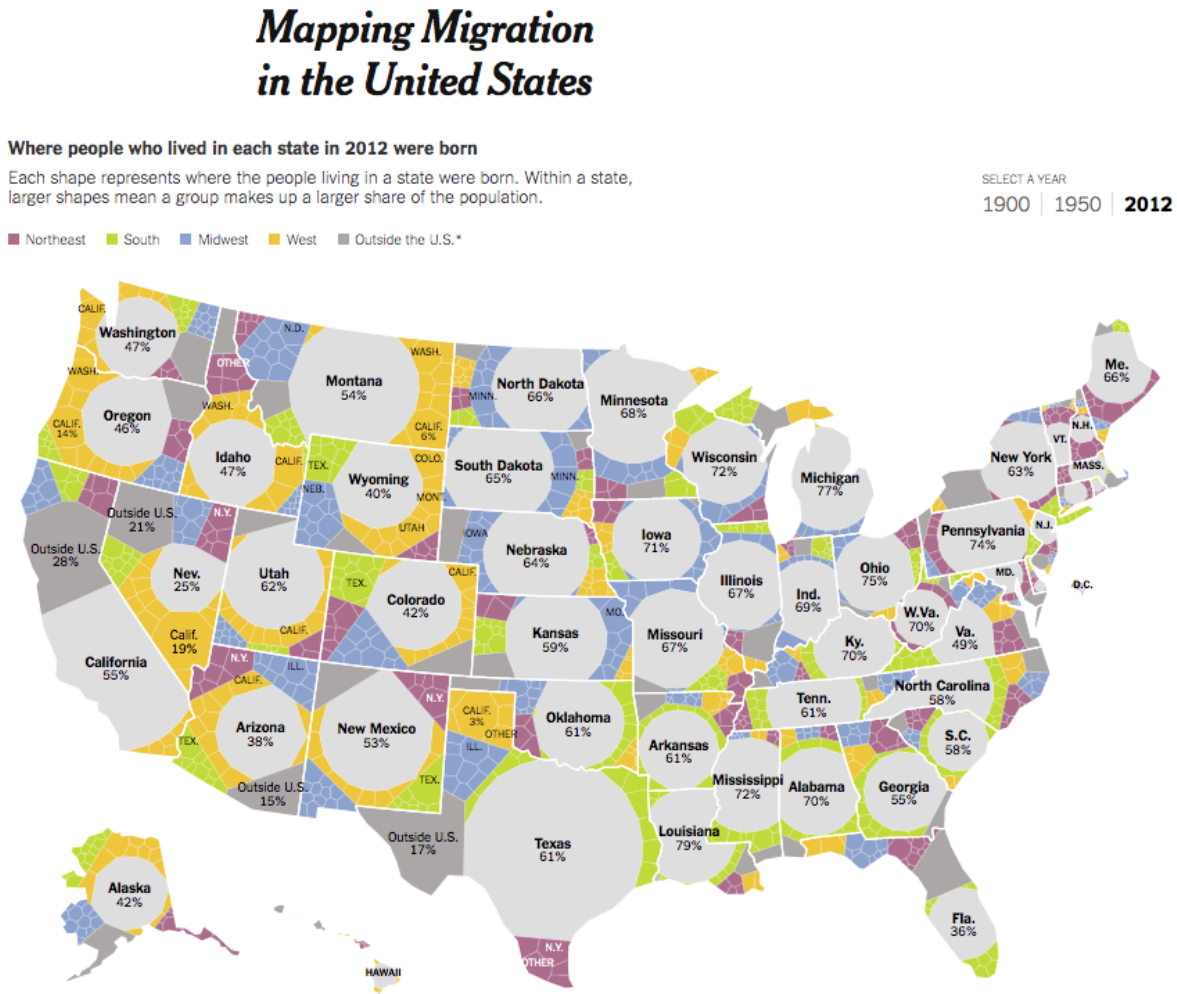
Kamal Karlapalem

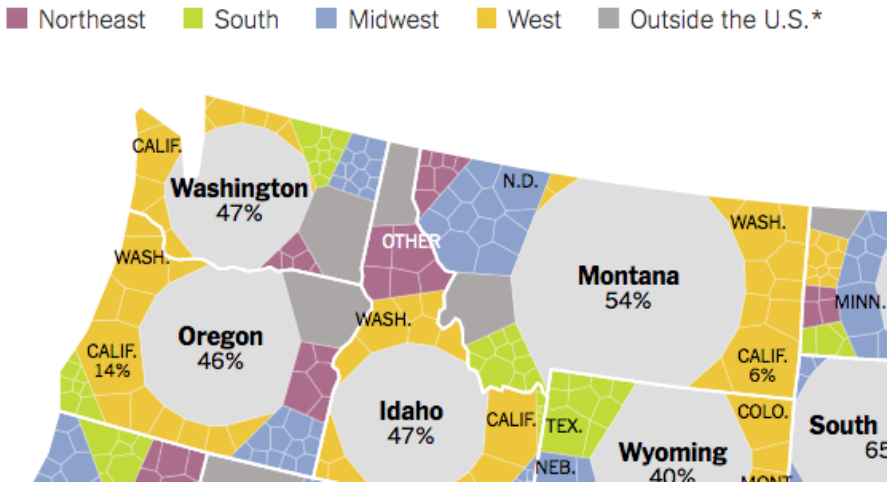
Slides taken and reformatted

from Prof. Tamara Munzner (University of British Columbia, Canada) and

Prof. Dr. Alexandru Telea University of Groningen, the Netherlands

Why create visualisations?

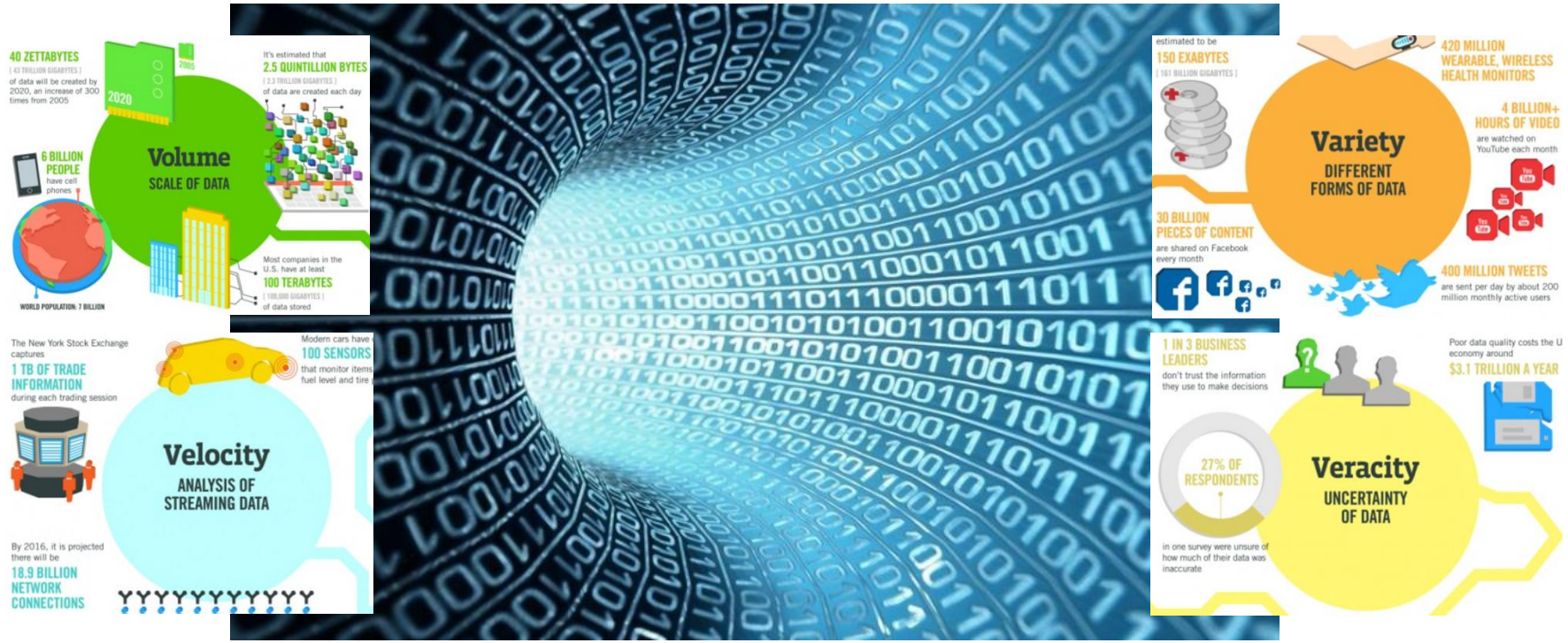




https://www.nytimes.com/2014/08/16/upshot/mapping-migration-in-the-united-states-since-1900.html

Why is Visualization Needed?

The ‘four V’ challenges of big data



Volume: in 2010-2012, the humanity has created more data than it has previously in its history*

Velocity: the speed of generating data already exceeds storage capacities and processing power

Variety: data is numbers, text, images, maps, sounds, video, networks, relations, … anything

Veracity: more data = more noise = more trouble: How do we know we found all is in it?

If data is the modern-age oil…**
visualization is an exploitation engine

* www.emc.com/leadership/programs/digital-universe.htm

** A. Kirk (2012) Visualization: A success design story, Packt Publ.

How is Visualization Useful?

1. Confirm the known:

- (in)validate the fit of a *given model* with a dataset
  - find the distribution of values over a given domain
  - find the correlation (or lack thereof) of several variables
  - answer precise (quantitative) questions
  - “show the best stocks to buy in the market”

2. Discover the unknown:

- find support for a *new model* in the data
  - find which model best fits a dataset
  - find the phenomenon behind the data
  - answer more vague (qualitative) questions
  - “which anomalies does this medical image show?”

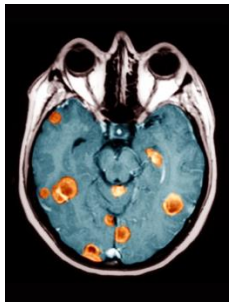
Quantitative questions:

- “which are the strained parts of this car part?”

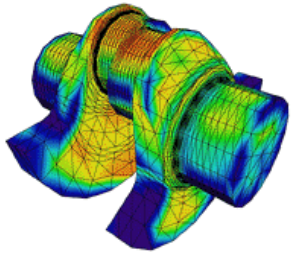
Qualitative questions:

- “is this software system modular or spaghetti code?”

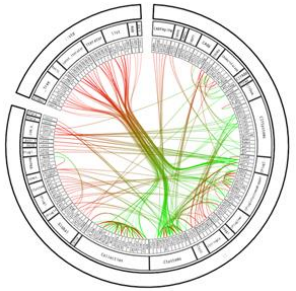
Code colored by test reports



Color coded MRI with tumor



Strain colored car part



Software call graph

Which Scenarios does Visualization address?

1. Exploration:

- ***find*** a story hidden in the data
  - start searching without a goal in mind
  - explore different facets, look for patterns, outliers, unexpected things
  - once you found something interesting, go to step 2 (explanation)

2. Explanation:

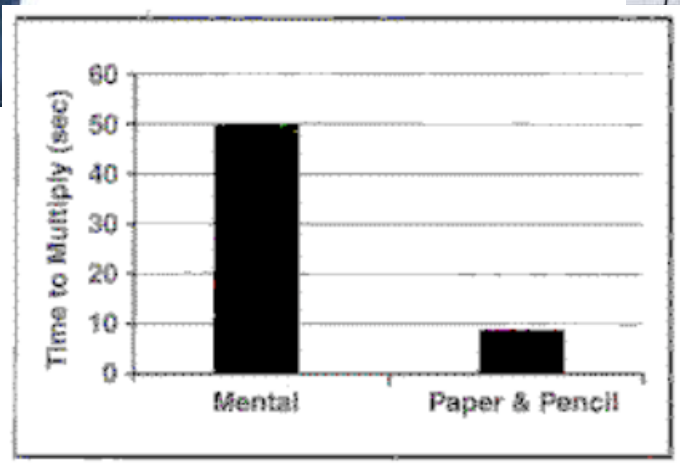
- ***tell*** a story to an audience
  - once you know what the data is hiding…
  - …analyze that to get a clear understanding of it
  - …simplify the explanation to its essence
  - …pack the explanation into a visual narrative

Example Scenario 1: Visualization for Amplifying Cognition

Experiment

- multiply 35 x 95 in your mind *vs* doing it with pen and paper
- study done on tens of participants*
- times are compared in the end

externalize model



Pen-and-paper solution: **5 times faster**

* S. Card, J. Mackinlay, B. Shneiderman (1999) Readings in information visualization: Using vision to think, M. Kaufman Publ.

Example Scenario 2: Visualization for Insight Gathering

Dataset: a table with sales amounts and profits

Month of Year	Sales Amount	Total Product C...	Gross Profit Ma...	Gross Profit
January	1309863.2511	1046855.0401	0.20079058694...	263008.211
February	2451605.6244	2161789.71439...	0.11821473532...	289815.910000...
March	2099415.6158	1781531.84109...	0.15141536164...	317883.774700...
April	1546592.2292	1250946.0643	0.19115973772...	295646.164900...
May	2942672.90960...	2583467.20809...	0.12206783170...	359205.701500...
June	1678567.4193	2010739.61289...	-0.19789029012...	-332172.193599...
July	962716.741700...	754715.7636	0.21605625942...	208000.978100...
August	2044600.0034	1771778.75389...	0.13343502349...	272821.249500...
September	1639840.109	1393936.67389...	0.14995573882...	245903.43510001
October	1358050.4703	1124337.2647	0.17209463912...	233713.205600...
November	2868129.20330...	2561131.77409...	0.10703751729...	306997.42920002
December	2458472.4342	2085375.78659...	0.15175954076...	373096.647600...

from data to visualization

Visualization: a bar chart of sales/profits evolution

✓ contains all *information*
✗ doesn't tell any *story*

✗ shows only data *summary*
✓ shows a clear *insight*

✓ means: desirable
✗ means: limitation

Example Scenario 3: Visualization for problem solving

Mystery: What caused a cholera epidemic in London, 1854?
Dataset: Location of deaths in the London map

zoom in

death counts represented by bar charts

Discover the unknown: deaths correlated with proximity to water pump

Hand drawing by J. Snow, surgeon, London, approx. 1854

Example Scenario 4: Visualization for extracting knowledge

Questions: How does education correlate with income?
Are there any outliers (exceptions)?

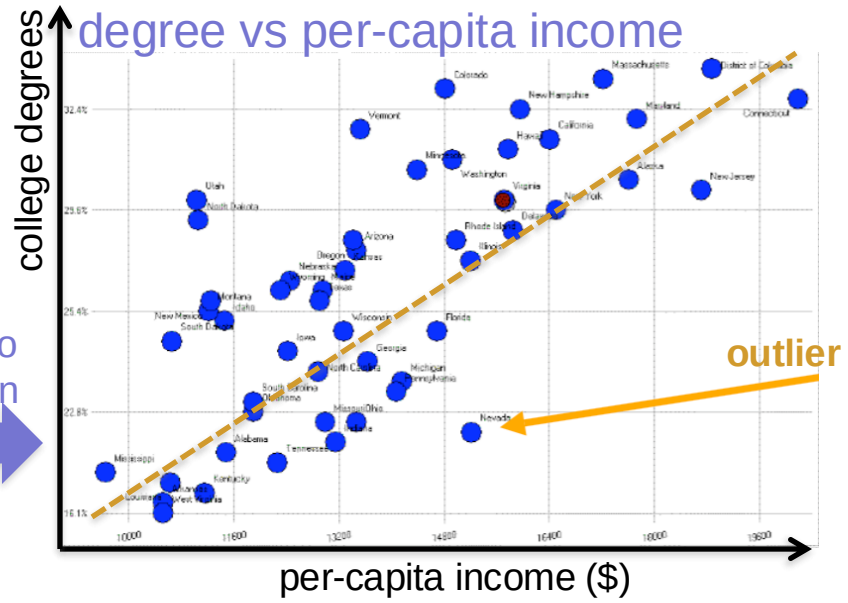
Dataset: US states with aggregated college degrees and per-capita income

Table - StateData ()

State	College Degree %	Per Capita Income
Alabama	20.6%	11486
Alaska	30.3%	17610
Arizona	27.1%	13461
Arkansas	17.0%	10520
California	31.3%	16409
Colorado	33.9%	14821
Connecticut	33.8%	20189
Delaware	27.9%	15854
District of Columbia	36.4%	18881
Florida	24.9%	14698
Georgia	24.3%	13631
Hawaii	31.2%	15770
Idaho	25.2%	11457
Illinois	26.8%	15201
Indiana	20.9%	13149
Iowa	24.5%	12422
Kansas	26.5%	13300
Kentucky	17.7%	11153
Louisiana	19.4%	10635
Maine	25.7%	12957
Maryland	31.7%	17730
Massachusetts	34.5%	17224
Michigan	24.1%	14154
Minnesota	30.4%	14389
Mississippi	19.9%	9648
Missouri	22.3%	12989
Montana	25.4%	11213
Nebraska	26.0%	12452
Nevada	21.5%	15214
New Hampshire	32.4%	15959
New Jersey	30.1%	18714
New Mexico	25.5%	11246
New York	29.6%	16501
North Carolina	24.2%	12885
North Dakota	26.1%	11051
Ohio	22.3%	13461
Oklahoma	22.8%	11893
Oregon	27.5%	13418
Pennsylvania	23.2%	14068
Rhode Island	27.5%	14901
South Carolina	23.0%	11897
South Dakota	24.6%	10661
Tennessee	20.1%	12255
Texas	25.5%	12904
Utah	30.0%	11029
Vermont	31.5%	13527
Virginia	30.0%	15713
Washington	30.9%	14923
West Virginia	16.1%	10520
Wisconsin	24.9%	13276
Wyoming	25.7%	12311

from data to visualization

Visualization: scatterplot of college degree vs per-capita income



Answers:

- per-capita income is roughly proportional with education
- it's easy to find outlier states (e.g., Nevada, see right picture)

Example Scenario 5: Visualization for clarification

Question: How can we show the connections on a metro map more clearly?

Dataset 1: London metro map (1927)

simplify visualization

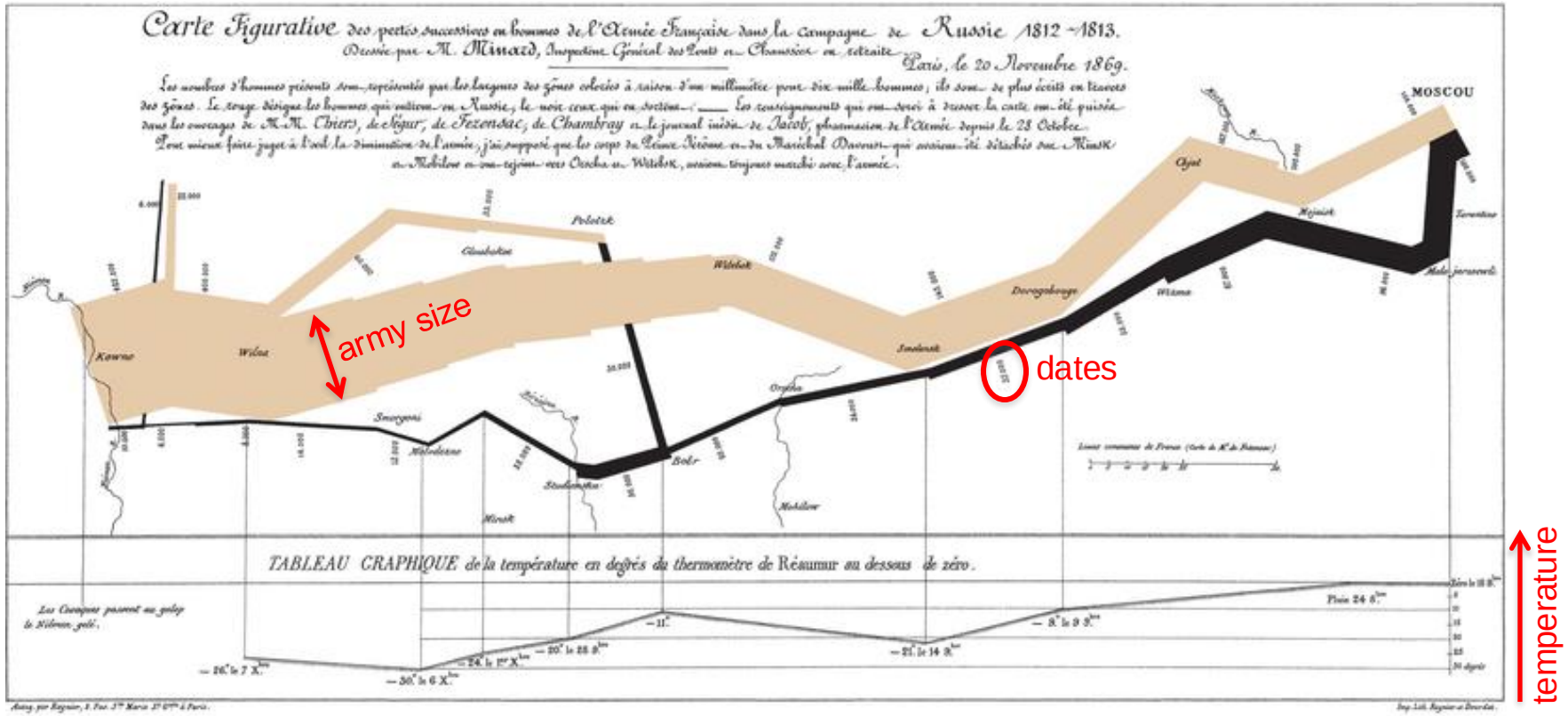
Dataset 2: London metro map (1993)

Answers:

- throw away non-essential information (exact positions of stations/tracks)
- schematize the drawing so that it's easier to read it

Example Scenario 6: Visualization for storytelling

Question: How did Napoleon's campaign in Russia go?



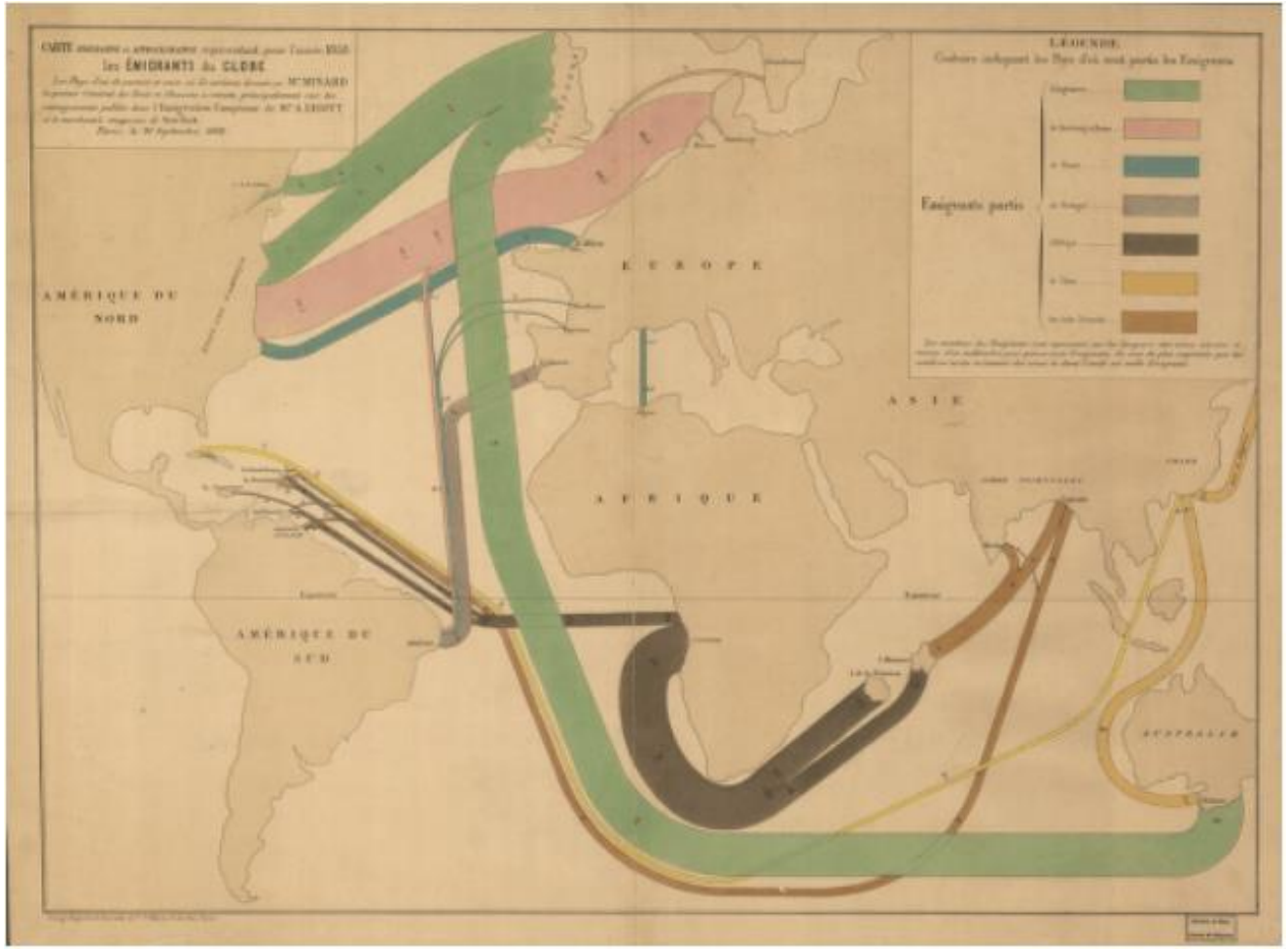
J. Minard's hand-drawn map (1869)

- shows 5 types of data (army size, temperature, position, direction, time)
- storytelling and main message are (painfully) clear…
- note however this is not fully historically accurate*

* J. De Caulaincourt, Mémoires, 1933, Eds. Plon

Example Scenario 7: Visualization for storytelling

Question: How did emigration affect the 19th century world?



J. Minard's hand-drawn map (1869)

- shows key emigration flows, color-coded by emigrants' origins
- we see where from emigrants started, where they went, and how many they were

When is visualization useful?

1. Too much **data**:
   - do not have time to analyze it all (or read the analysis results)
   - show an overview, discover which issues are relevant
   - refine search either visually or analytically

2. Qualitative / complex **questions**:
   - cannot capture question compactly/exactly in a query
   - question/goal is inherently qualitative: understand what is going on
   - show an overview, answer the question by seeing relevant patterns

3. **Communication/Story-telling**:
   - transfer results to different (non technical) stakeholders
   - emphasize a message
   - learn about a new domain or problem

When is visualization NOT useful?

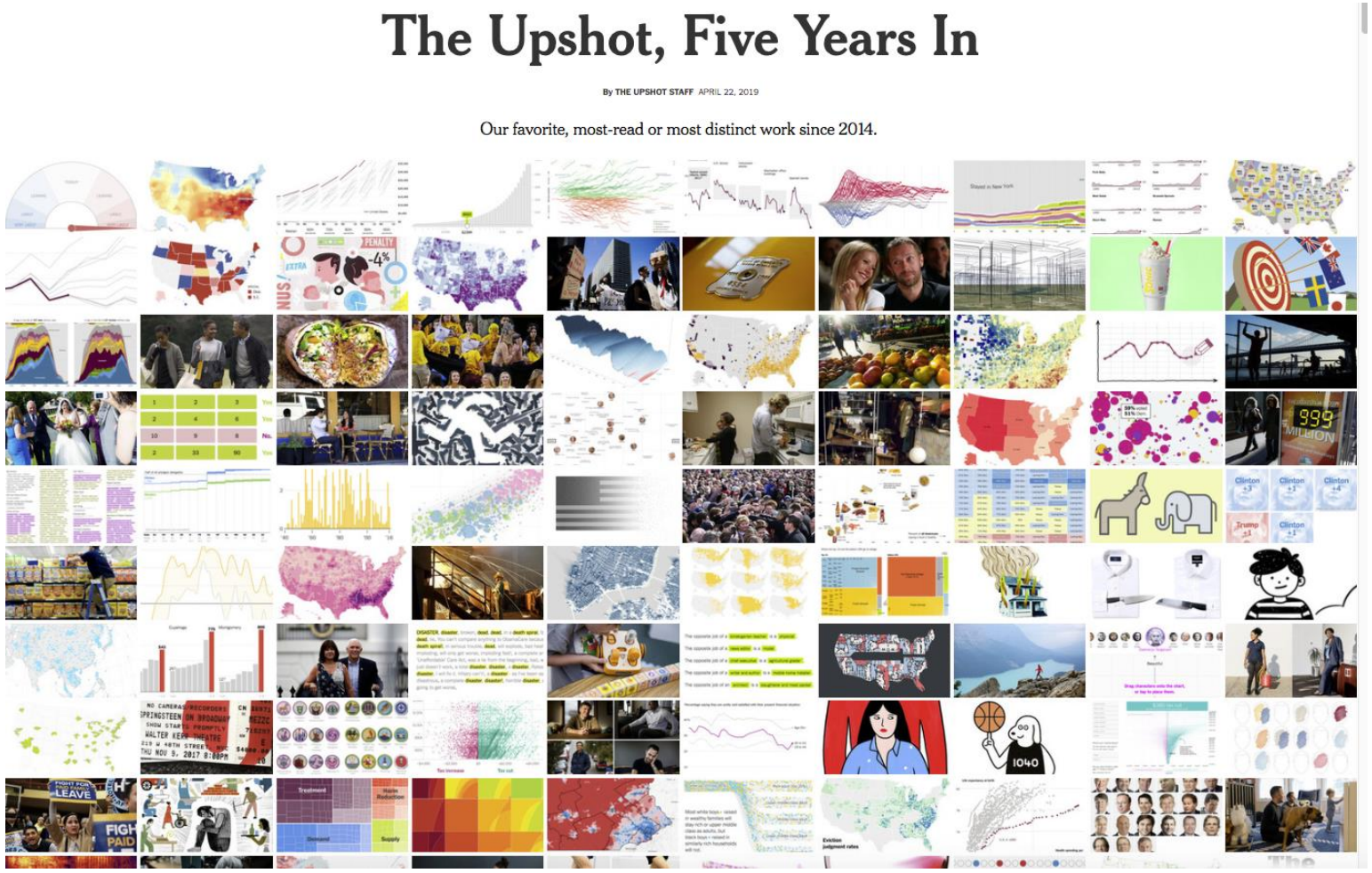
1. Queries:
   - if a question can be answered by a compact, precise query, why visualize?
   - “what is the largest value of a collection of numbers?”

2. Automatic decision-making:
   - if a decision can be automated, why use a human in the loop?
   - “how to optimize a numerical simulation?”

Key thing to remember:
   - visualization is *mainly* a cost *vs* benefits (or value *vs* waste) proposal
     - cost: effort to create and interpret the images
     - benefits: problem solved by interpreting the images
     - similar discussion in software engineering: lean development*

✗ B. Lorensen, On the Death of Visualization, Proc. NIH/NSF Fall Workshop on Visualization Research Challenges, 2004
✗ S. Charters, N. Thomas, M. Munro, The end of the line for Software Visualisation? Proc. IEEE VISSOFT, 2003
✗ S. Reiss, The paradox of software visualization, Proc. IEEE VISSOFT, 2005
✓ J. J. van Wijk, The Value of Visualization, Proc. IEEE Visualization, 2005
* M. Poppendieck, T. Poppendieck, Lean Software Development, Addison-Wesley, 2006

Communicate to others



https://www.nytimes.com/interactive/2019/04/22/upshot/upshot-at-five-years.html

Why create visualisations?

- Analyse data to support reasoning
- Answer questions
- Communicate ideas to others
- Confirm hypothesis
- Expand memory
- Find/reveal patterns
- Generate hypothesis
- Inspire
- Make decisions
- Record information
- See data in the context
- Support computational analysis
- Tell a story

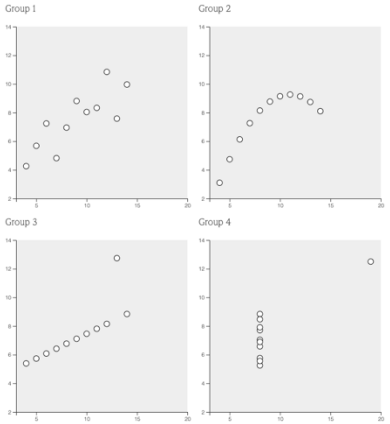
Two big themes

- Foundations
  - Building visualisations is fundamentally about trade-offs
  - Foundations help us understand these tradeoffs and make informed decisions
    - Principles: why should I design it this way vs. that way?
    - Techniques: what kinds of designs are possible?
- Mechanics
  - How to build a visualisation programmatically
  - D3, Javascript, CSS, HTML

Visualisation Techniques

- The way the data is presented changes how we consume it
  - Table of numbers is a (simple) visualisation – consider 200+ rows

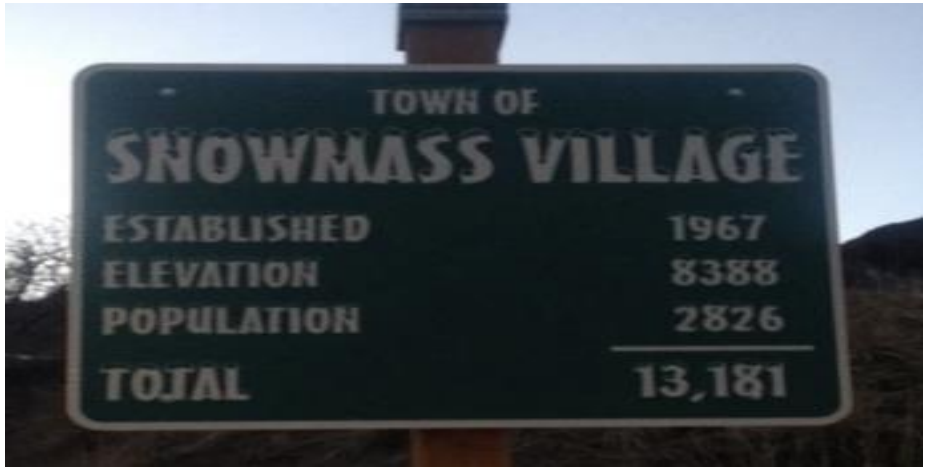
X1	Y1	X2	Y2	X3	Y3	X4	Y4
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89



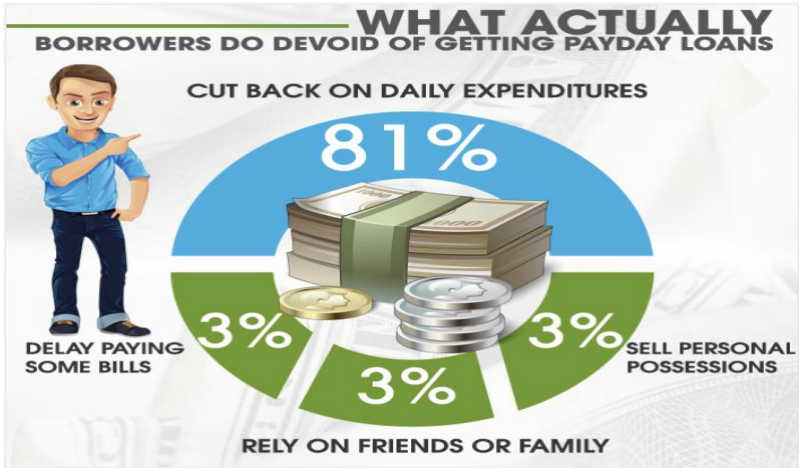
  - Learn how to, and how not to, build interactive data visualisations

Respect the math in the data

- Semantics matter
- Not everything you can do with data makes sense.



https://imgur.com/gNefvUG/



https://viz.wtf/post/107440754050/how-payday-loans-add-up

Data Visualisation

- Data
  - Any kind
  - Any size
  - Any application domain
- Visualisation
  - Fit within a screen
  - Image (heavy) representation
  - Comprehension, analysis, and decision making
- The code/algorithms/ for visualization – not the focus of the course
- The focus of the course is what are decisions, considerations, and rules to follow when we go from Data to its visualisation – **and this is not trivial**

Defining Visualisation

Computer-base visualization systems (mostly software, using hardware user interface devices) that provide visual representations (think images, sequence of images – video) of data sets designed to help people carry out – comprehension, analysis, decision making tasks **more effectively**.

Visualisation is suitable when there is a need to augment human capabilities rather than replace people with computational-decision making – **human in the loop**.

Why is there a human in the loop?

- Do not need visualization when a fully automatic solution exists and is trusted
- Many analysis problems are ill-specified – data is unknown
  - Do not know what questions to as in advance
- Possibilities
  - Long-term use for end users (ex: exploratory analysis of scientific data)
  - Presentation of known results (ex: New York Times Upshot)
  - Steppingstone to assess requirements before developing models
  - Help automatic solution developers refine and determine parameters
  - Help end users of automatic solutions verify and build trust

Why visualisation

	LeBron James	Kareem Abdul-Jabbar
Total points	38,390	38,387
3-pointers	2,237	1
2-pointers	11,816	15,836
Free throws	8,047	6,712
Total baskets	22,100	22,549

Source: Basketball-reference.com Note: Data is through Feb. 7. By The New York Times

https://www.nytimes.com/interactive/2023/02/07/sports/basketball/lebron-james-kareem-abdul-jabbar-points.html

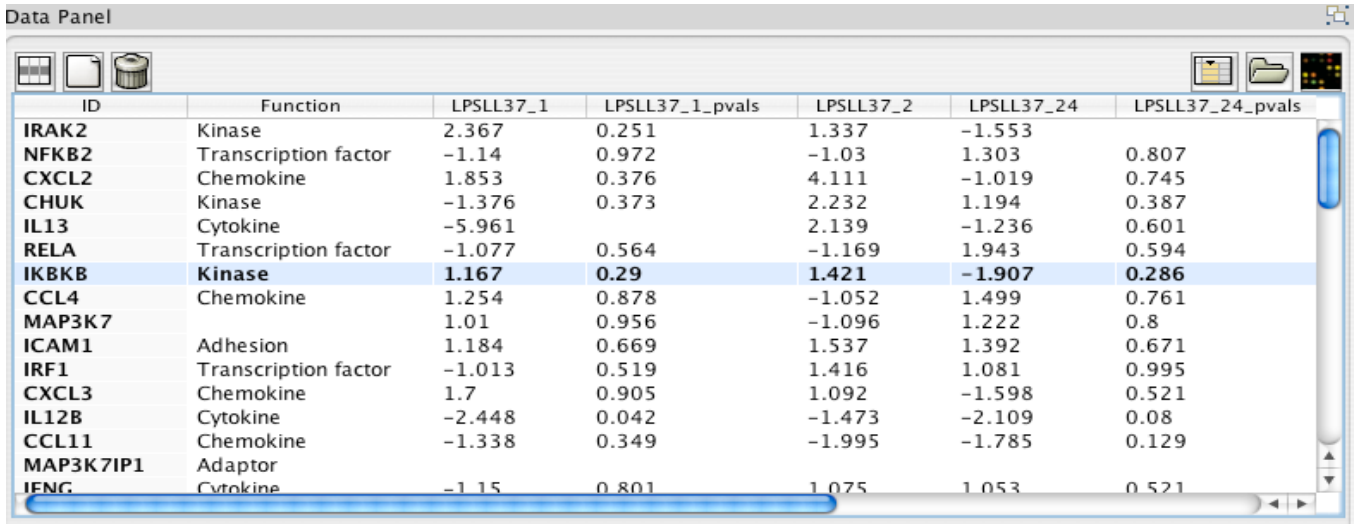
Why depend on visualization?

- Human visual system is the high-bandwidth channel to the 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: improvised record/replay capacity
  - Only very low-bandwidth communication this far
- Taste/smell: no viable record/play devices

Why use an external representation?

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

- external representation: replace cognition with perception



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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.]

Data Panel

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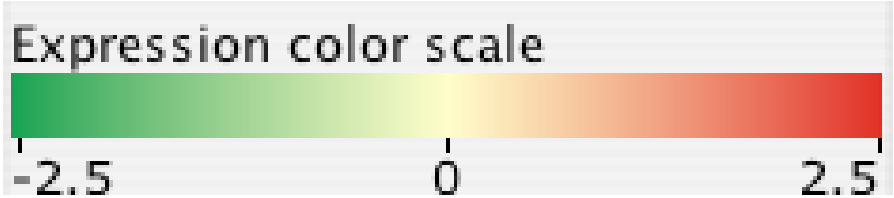

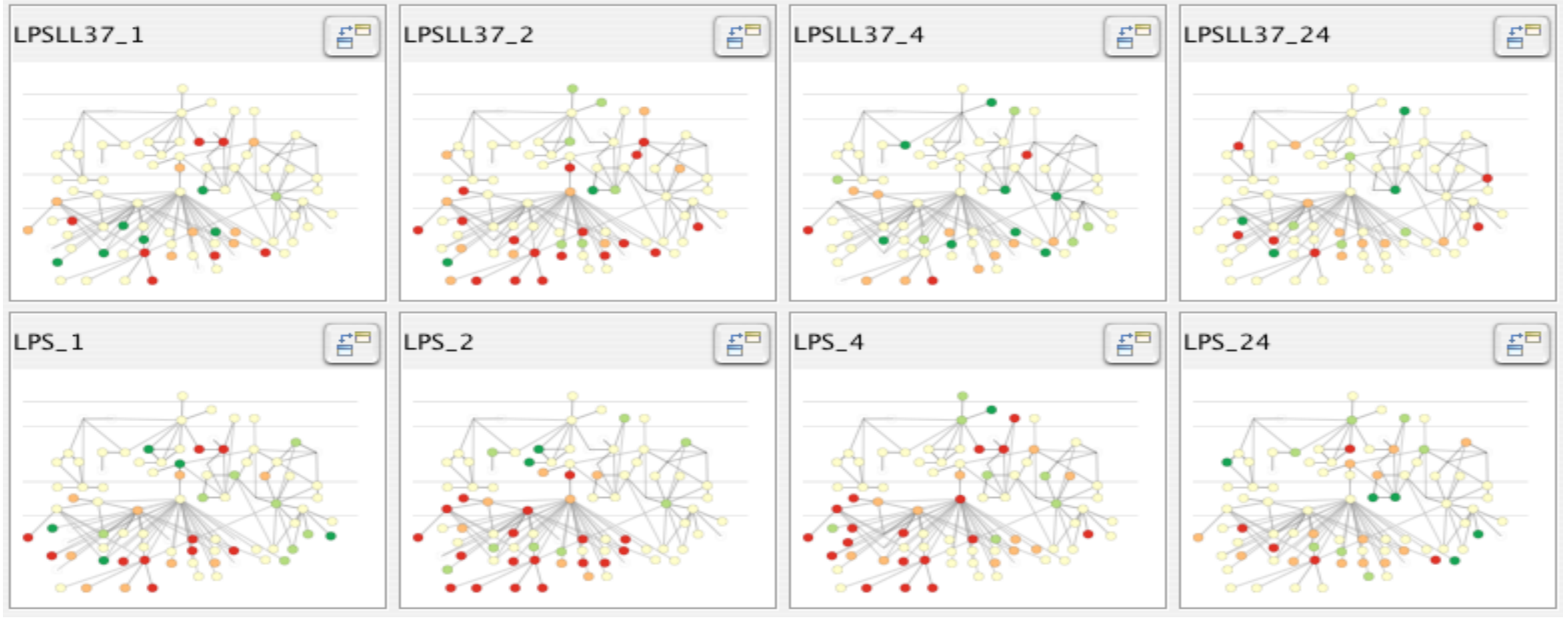

Some Datasets

- How would you visualize this table of numbers?

X1	Y1	X2	Y2	X3	Y3	X4	Y4
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
12.0	10.84	12.0	9.13	12.0	8.15	8.0	5.56
7.0	4.82	7.0	7.26	7.0	6.42	8.0	7.91
5.0	5.68	5.0	4.74	5.0	5.73	8.0	6.89

Why represent all the data?

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

- Summaries lose information; details matter
  - Confirm expected and final 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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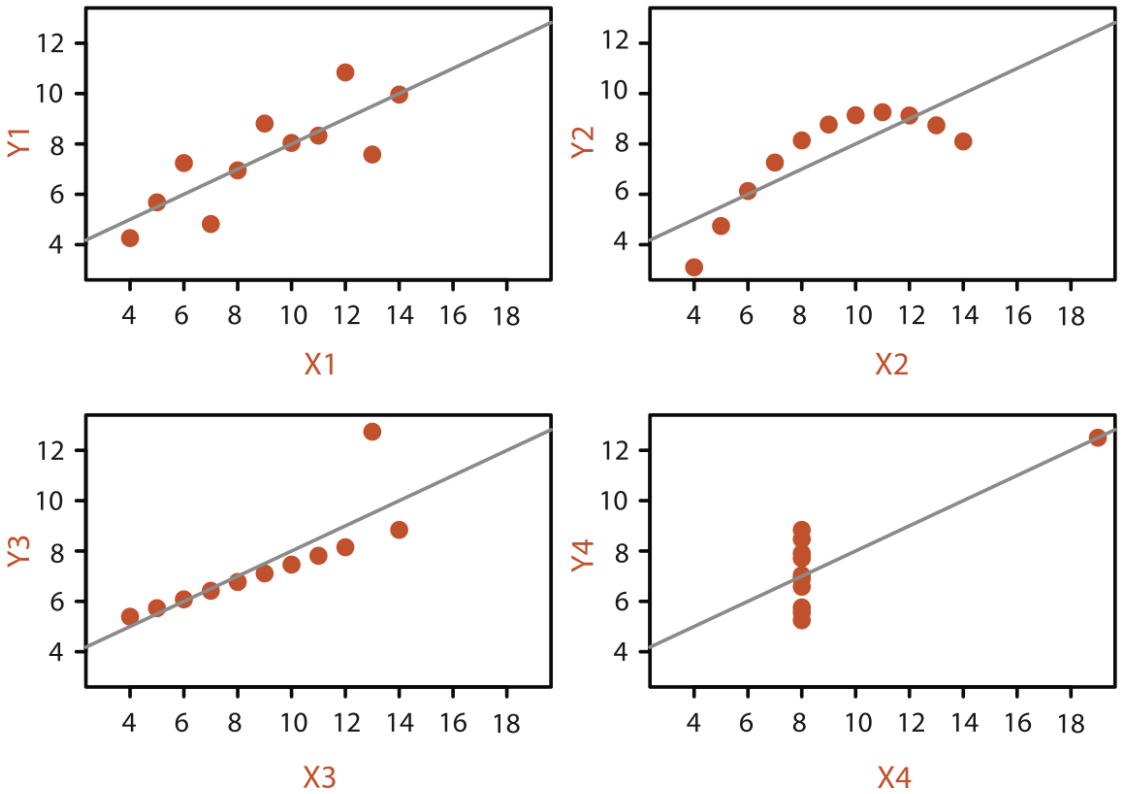

X1	Y1	X2	Y2	X3	Y3	X4	Y4
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
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Anscombe's Quartet

Identical statistics	
x mean	9
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What resource limitations are we faced with?

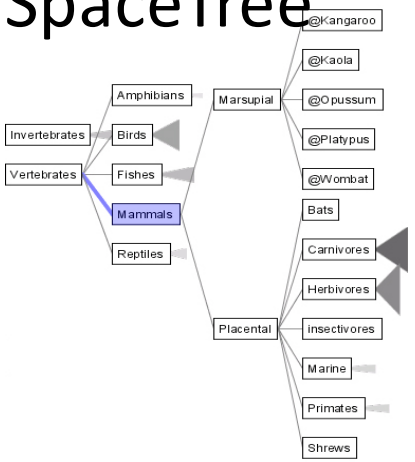
Vis designers must consider three very different kinds of resource limitations: those of computers, humans, and displays.

- Computational limits
  - Computation time, system memory (user interaction, scale)
- Display limits
  - Pixels are precious and the most constrained resource
  - Information density: ratio of space used to encode info vs. unused whitespace
    - Tradeoff between clutter and wasting space
    - Find a sweet spot between dense and sparse
- Human limits
  - Human time, human memory, human attention

Why analyse?

- Imposes structure on huge design space
  - Scaffold to help you think systematically about choices
  - Analysing existing as a stepping stone to designing new
  - Most possibilities ineffective for a particular task/data combination

SpaceTree



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

TreeJuxtaposer

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

What?

- Tree

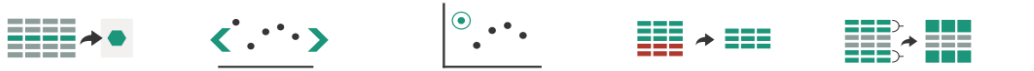
Why?

- Actions
  - → Present → Locate → Identify

- Targets
  - → Path between two nodes

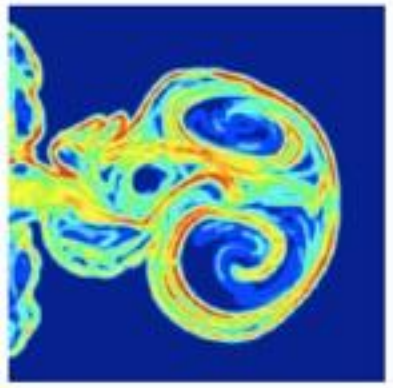
How?

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

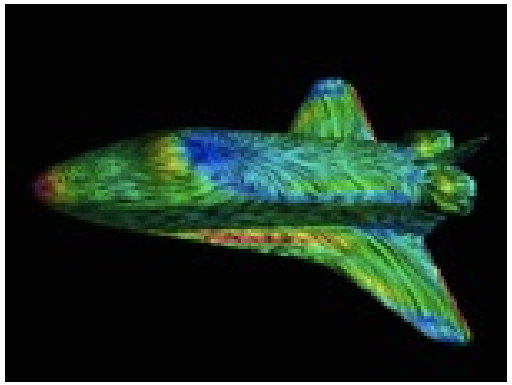


- TreeJuxtaposer
  - → Encode → Navigate → Select → Arrange

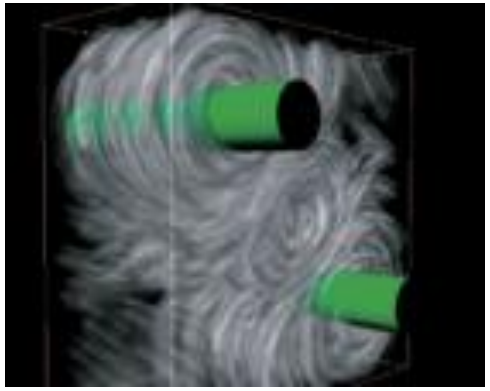
Visualization examples: Engineering sciences



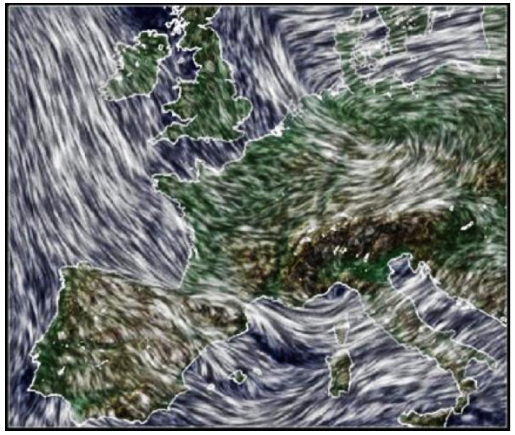
mixing of substances
(chemistry)



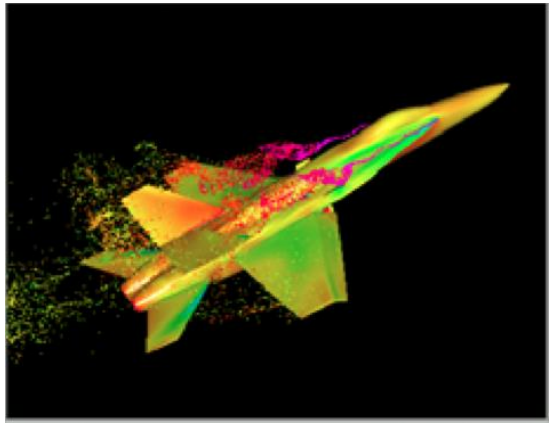
flow on surface
(aircraft design)



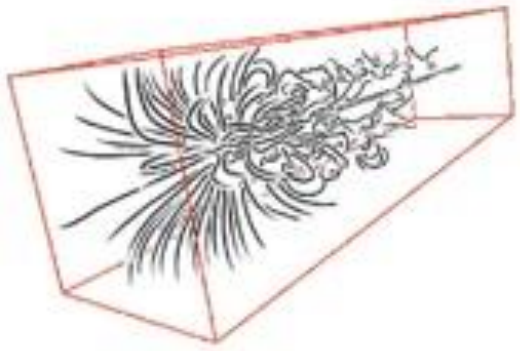
flow in volume
(engine design)



wind flow atop geo map
(weather forecast)

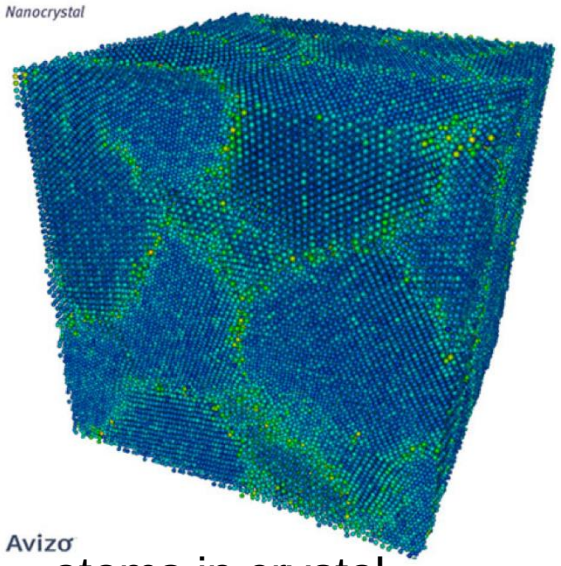


particle flow close to surface
(aircraft design 2)

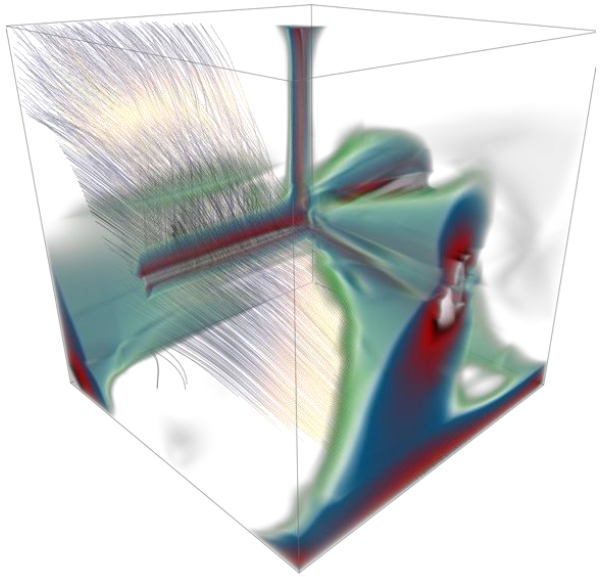


sketch of flow in volume
(illustrative/communication)

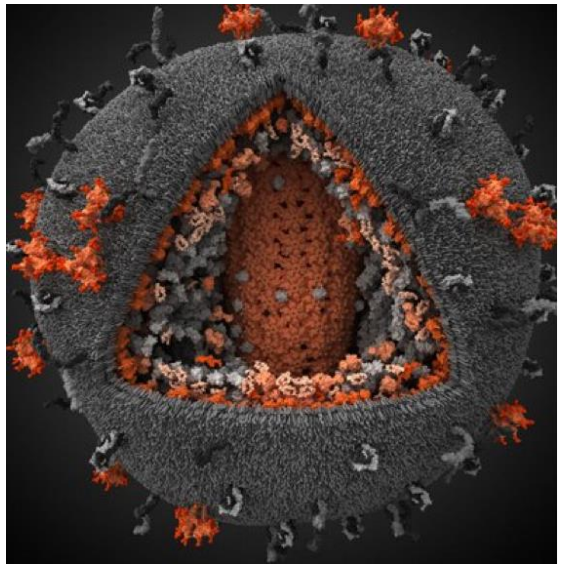
Visualization examples: Material/biosciences



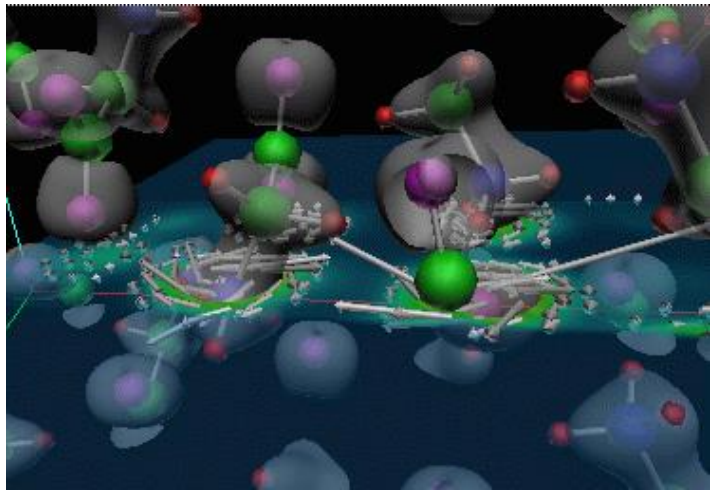
atoms in crystal (crystallography)



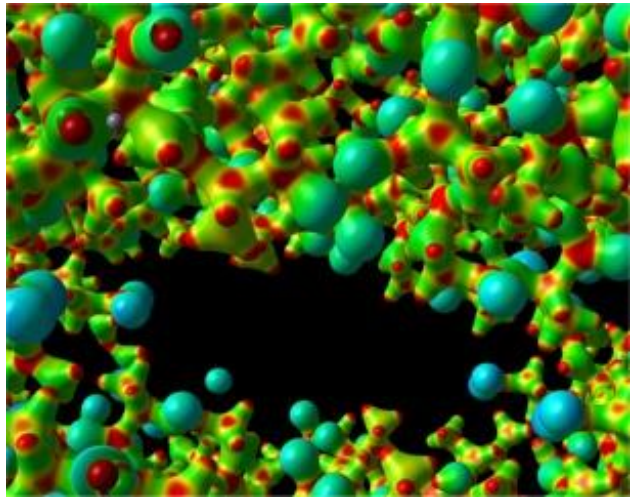
stress tensors



3D HIV model

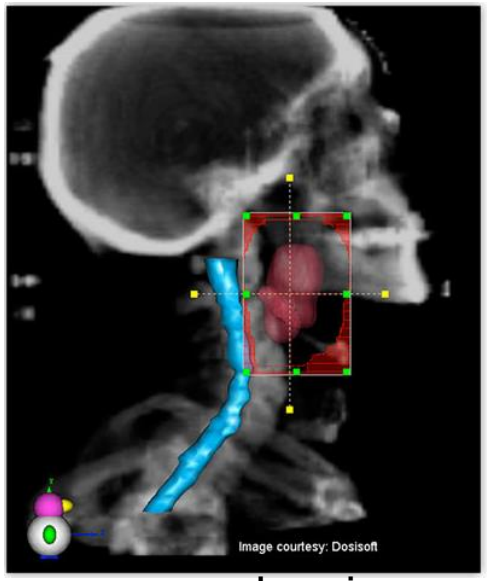


glycine crystal simulation

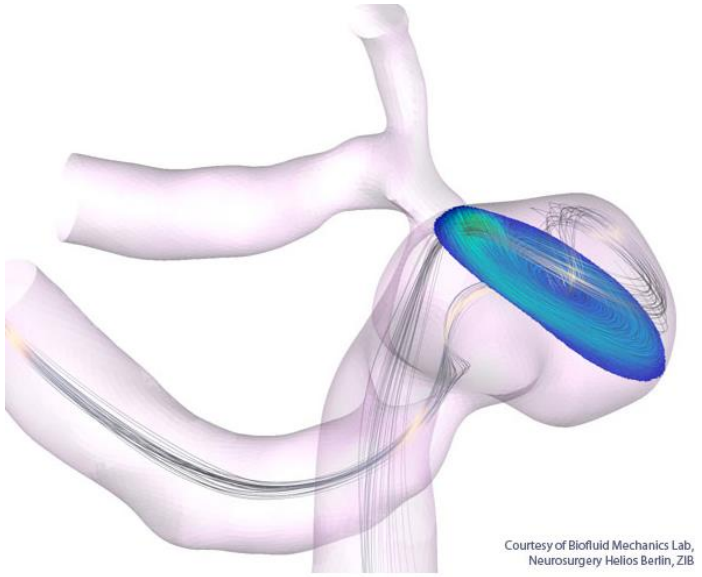


potential field in crystal structure

Visualization examples: Medical sciences

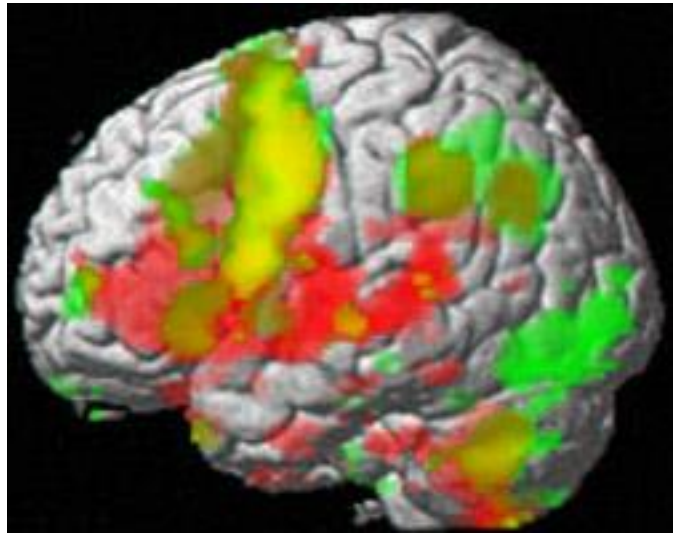


surgery planning

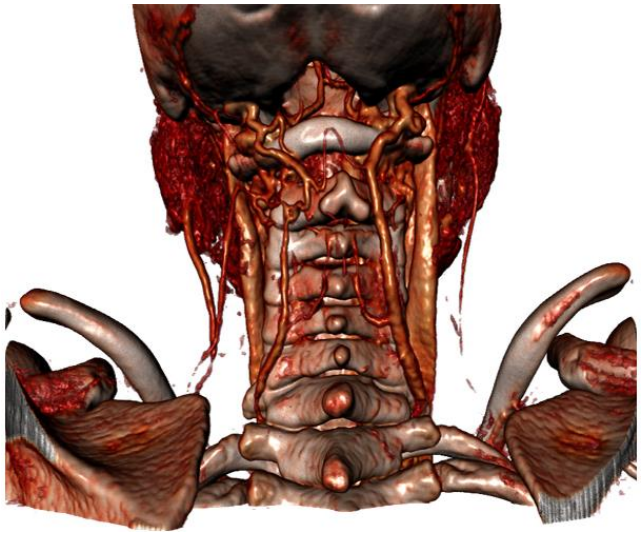


blood flow in aneurysm

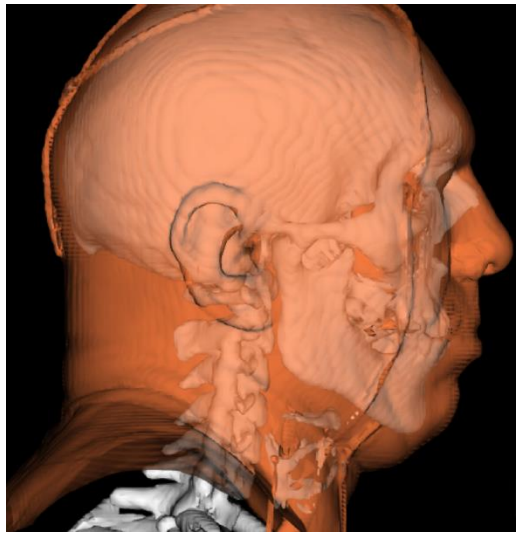
bone tissue density



brain activity (fMRI)

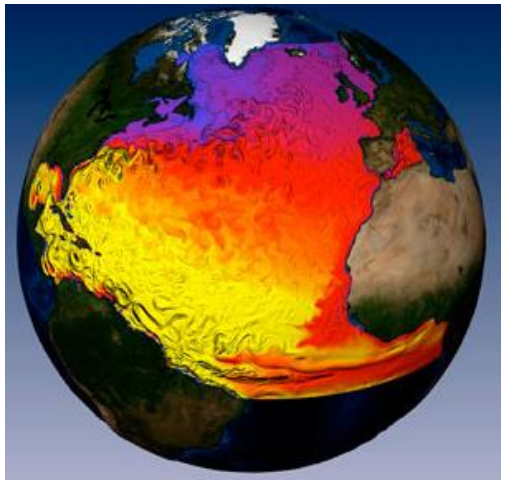


MRI scan - tissues

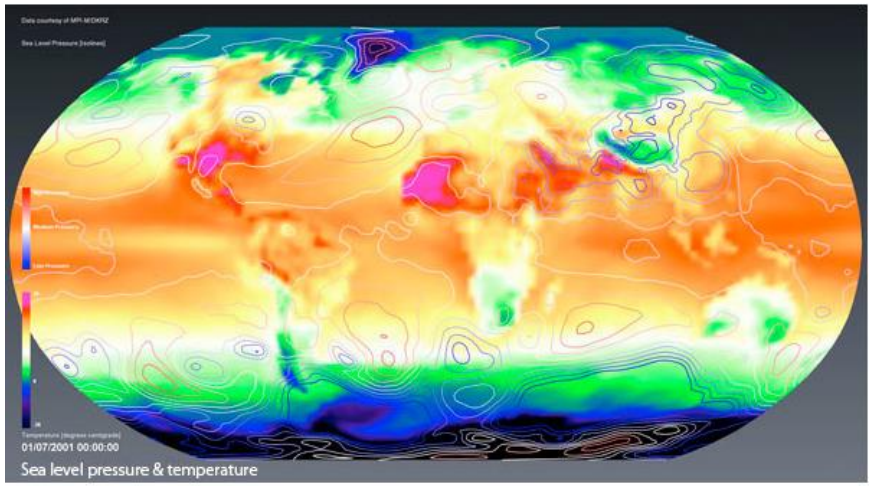


bone + skin surface

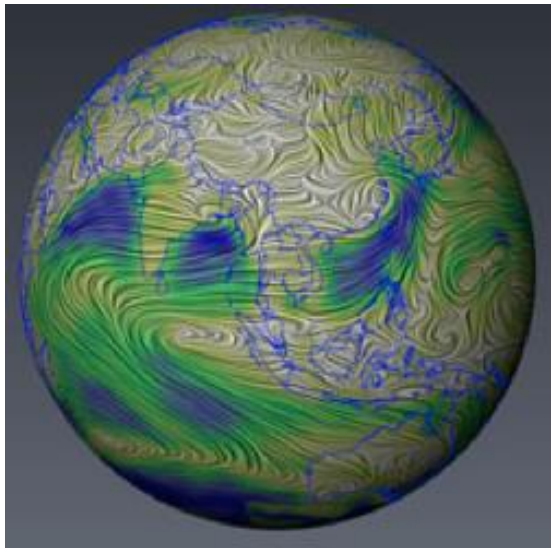
Visualization examples: Geosciences



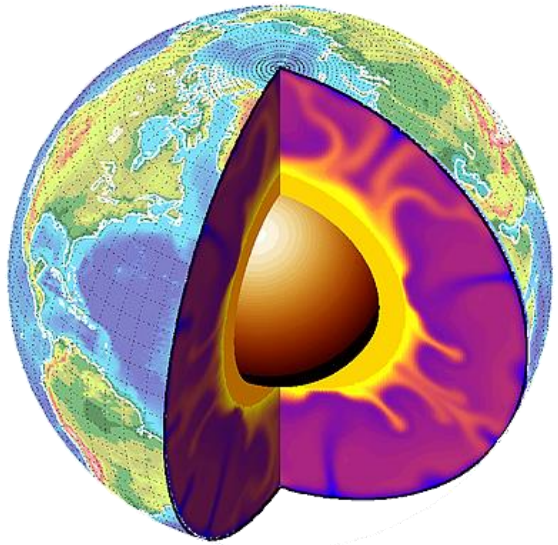
ocean velocity
and surface temperature



sea level pressure and temperature



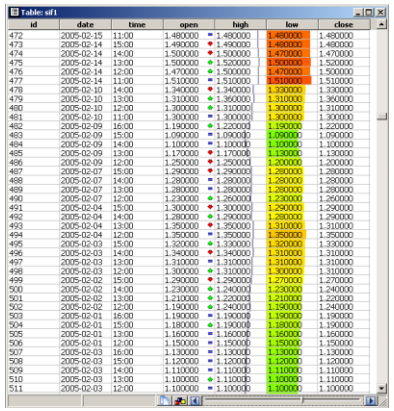
wind flow paths over
Earth's surface



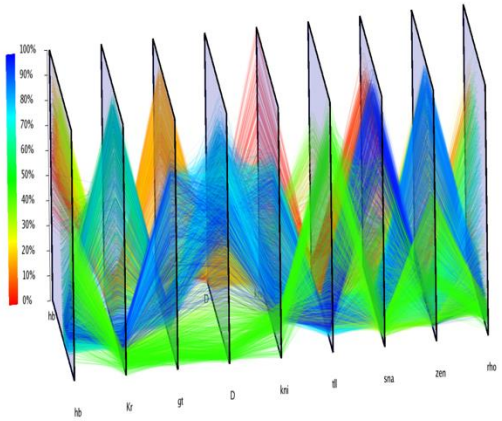
Earth surface and inner temperature

Visualization examples: Abstract data (infovis)

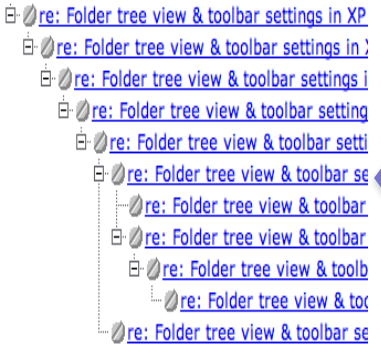
- mapping is not ‘neutral’ or natural, but reflects the problem/question to be solved



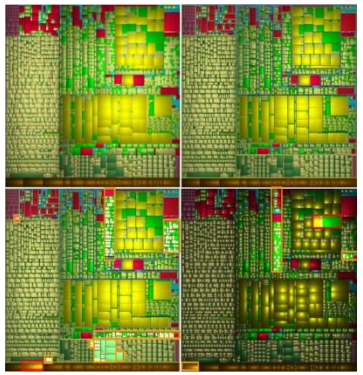
data table: classical view



data table: parallel coordinates view



tree: explorer view

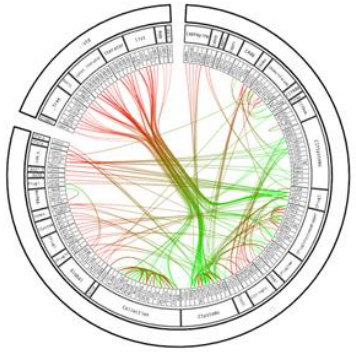


tree: cushion treemap view

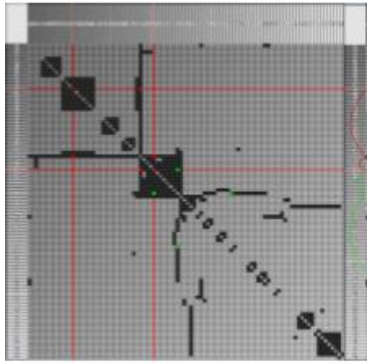
```
void ASTVisitor::traverse(ASTNode &obj)
{
  ASTNodeStack stack;
  static ASTNode sentinelNode(0); //put on the bottom of the s
  stack.push(StackItem(sentinelNode, SHOULD_IGNORE));
  stack.push(StackItem(obj, SHOULD_VISIT)); //the node that wi
  while(!stack.empty())
  {

    ASTNode &curNode(stack.top().astNode);
    if (stack.top().postVisit == SHOULD_IGNORE)
    {
      stack.pop();
    }
    else if (stack.top().postVisit == SHOULD_POSTVISIT)
    {
      const Visit visitResult(postVisitASTNode(curNode));
      if (visitResult == VISIT_STOP)
        return;
      stack.pop();
      if (visitResult == VISIT_POSTPARENT)
```

source code: classical view

source code: dense pixel view



graph: bundled view

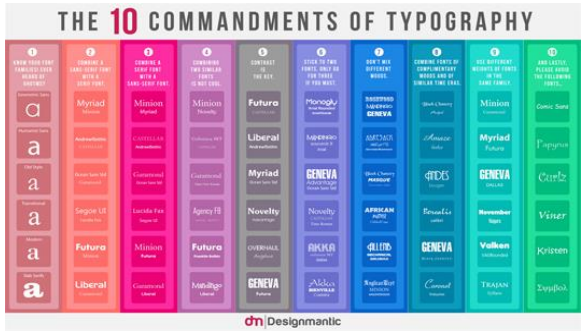


graph: adjacency matrix

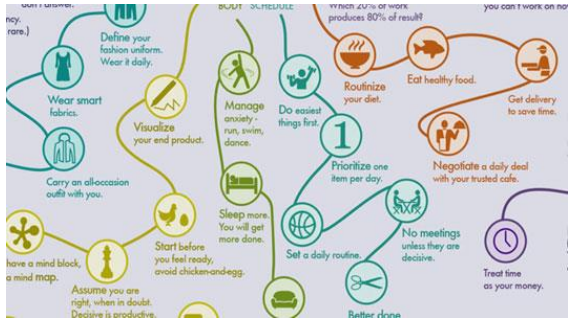
Visualization examples: Infographics

- basically information visualization displays, carefully set into (artistic) graphic design

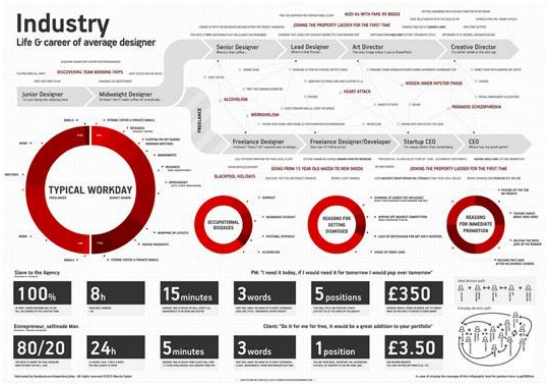
time series



categorical trees

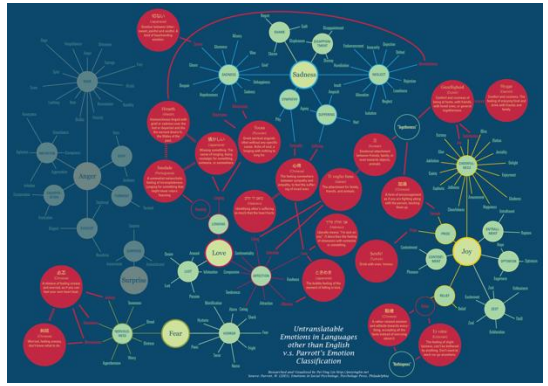


path lines

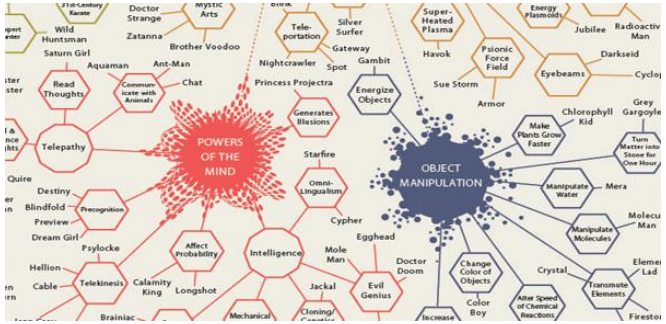


time lines

density maps



graphs and networks



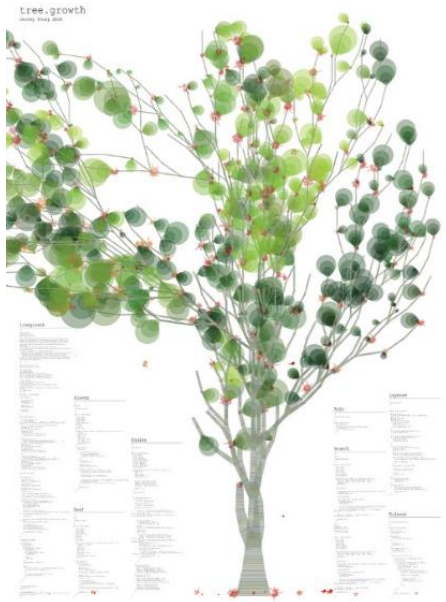
more graphs and networks

multivariate data

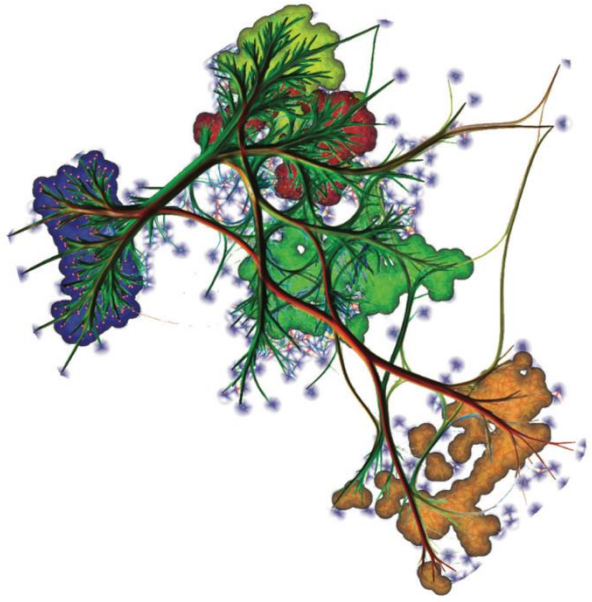
stacked bar charts

Visualization examples: Intriguing art

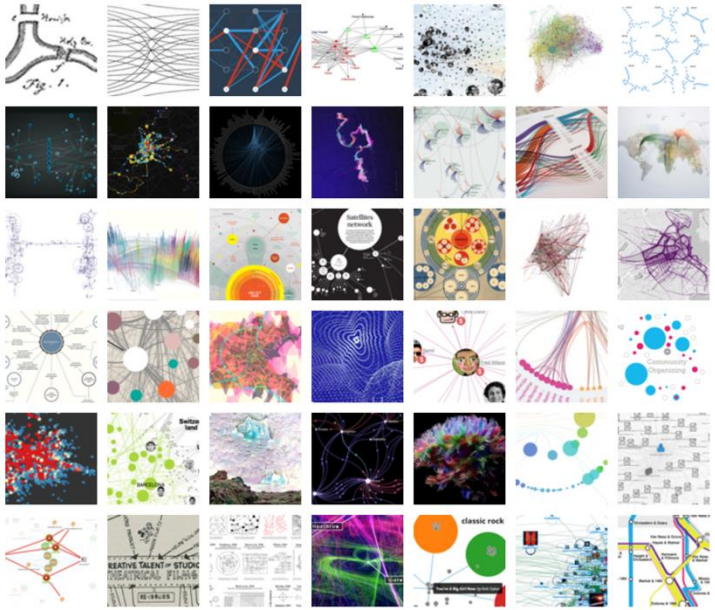
•nice/intriguing images generated from data with the aim of provoking thought/interest



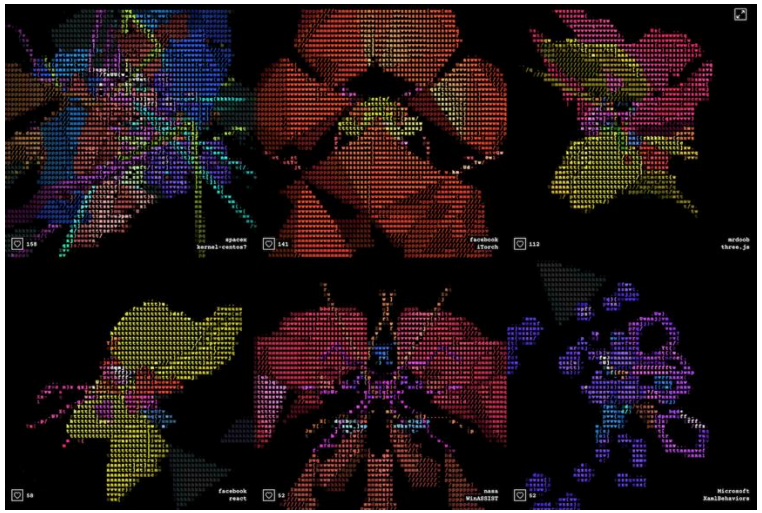
tree and program code



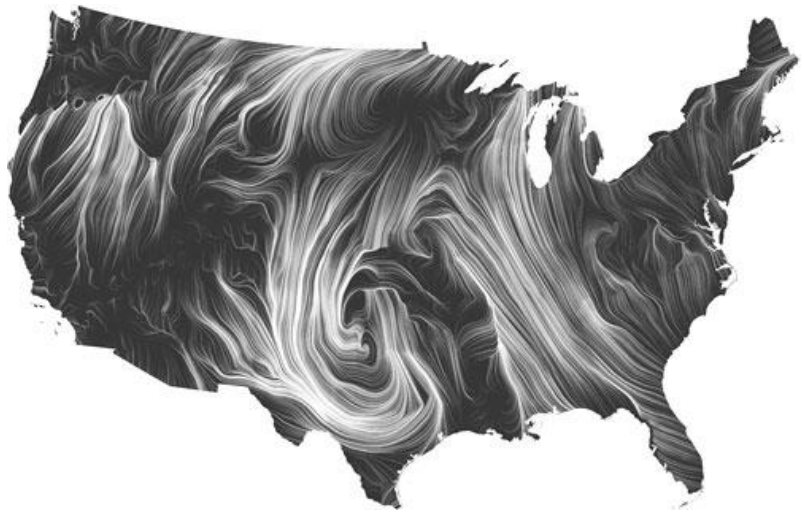
multidimensional projections



visualcomplexity.com

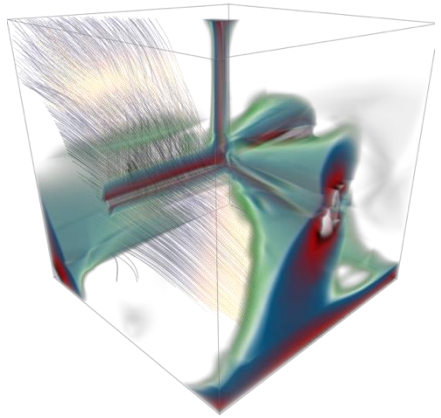
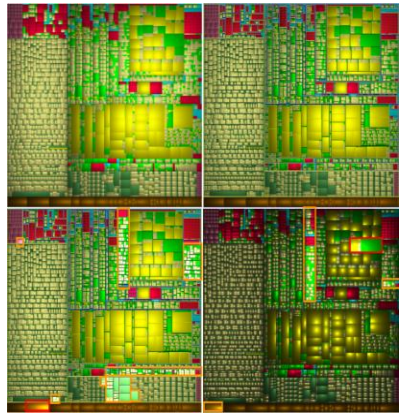
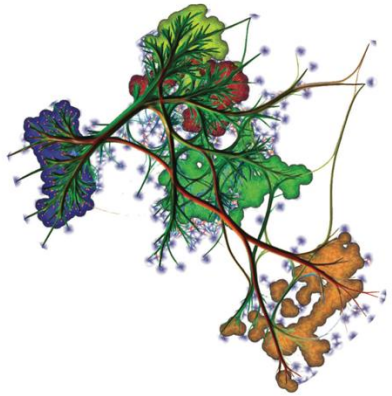


activity of programmers/language (GitHub)

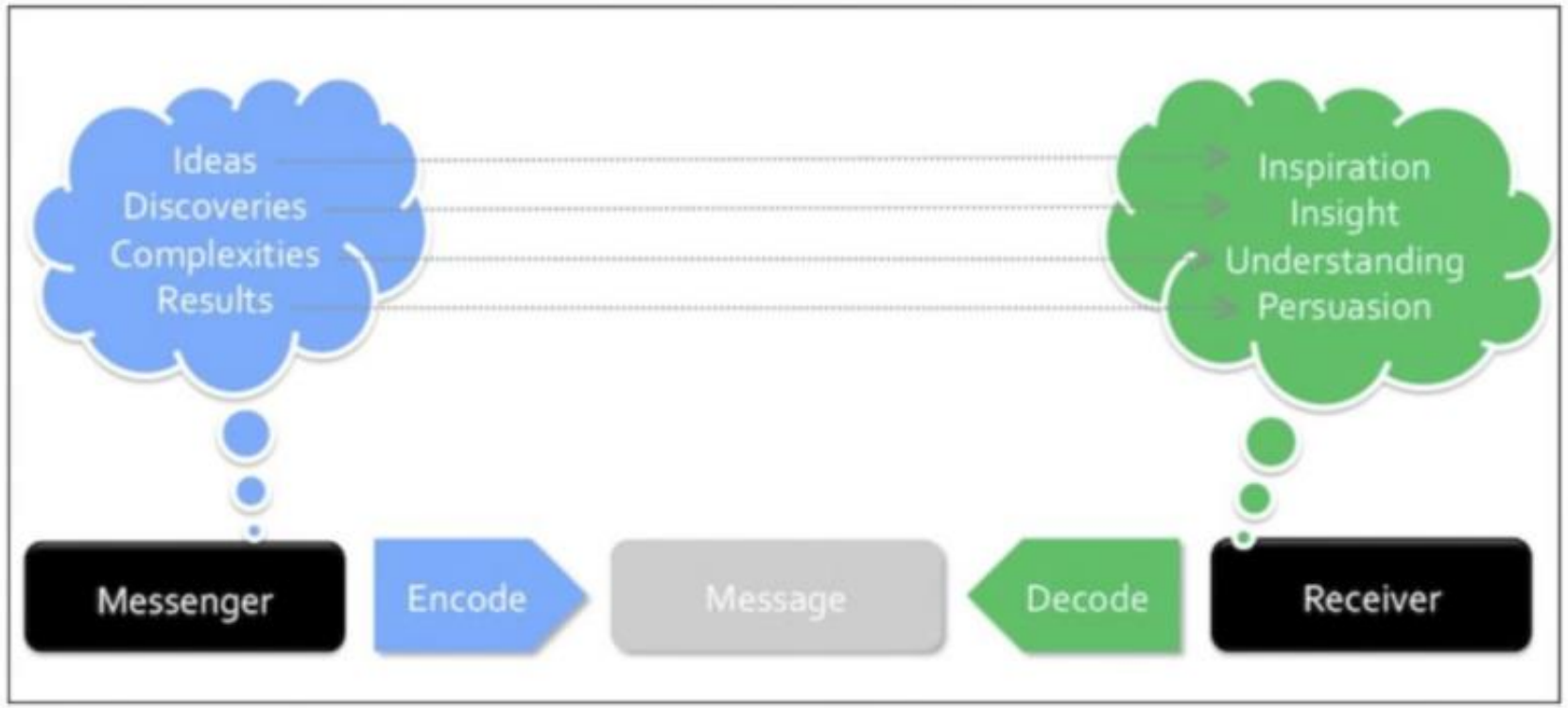


wind map over the US

SciVis *vs* InfoVis *vs* Infographics *vs* VizArt

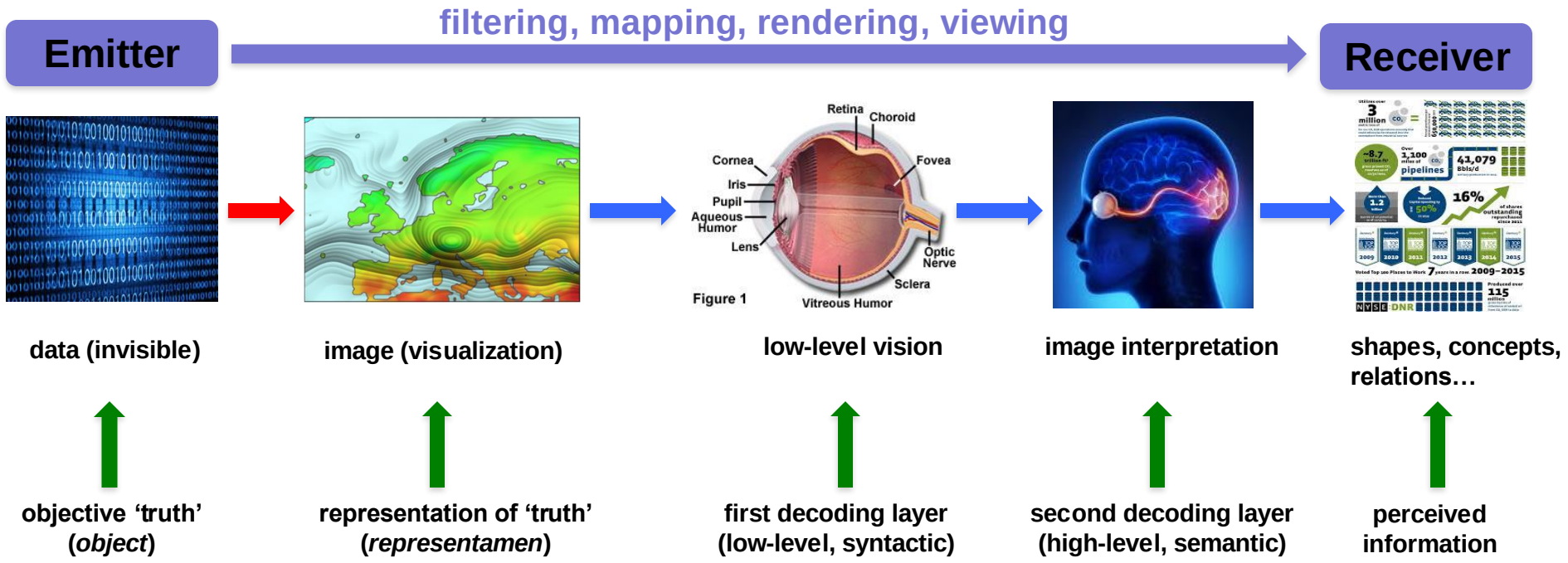
	SciVis	InfoVis	Infographics	VizArt
				
Content	highly scientific	less scientific	general purpose	anything
Audience	scientists	professionals	grand public	grand public
Display	interactive	interactive	static	static
Precision	very exact	less exact	often qualitative	irrelevant
Detail	high level	more aggregated	summaries	irrelevant
Goals	problem-solving	discovery	presentation	entertainment

The Visualization Pipeline: A Communication View



- **messenger:** visualization designer or, more generally, the **data** itself
- **receiver:** the customer (**user**) of the visualization
- **message:** the visualization **image** itself
- **encoding:** translating the data into an image
- **decoding:** getting the data from the image

The Visualization Pipeline: A Perceptual View



Interpretation challenges

- low-level vision: must know how the **eye** sees colors, contrasts, textures, …
- pattern recognition: must know how the **brain** assigns meaning to shapes
- high-level sensemaking: must know how the user **decides** based on semantics

How to *design* a visualization so it's *interpreted* the way we want?

When do we have a good visualization? Non-technical view

Simple in theory…

•when the targeted users can **easily** accomplish what they **want** using the visualization

In practice, complicated…

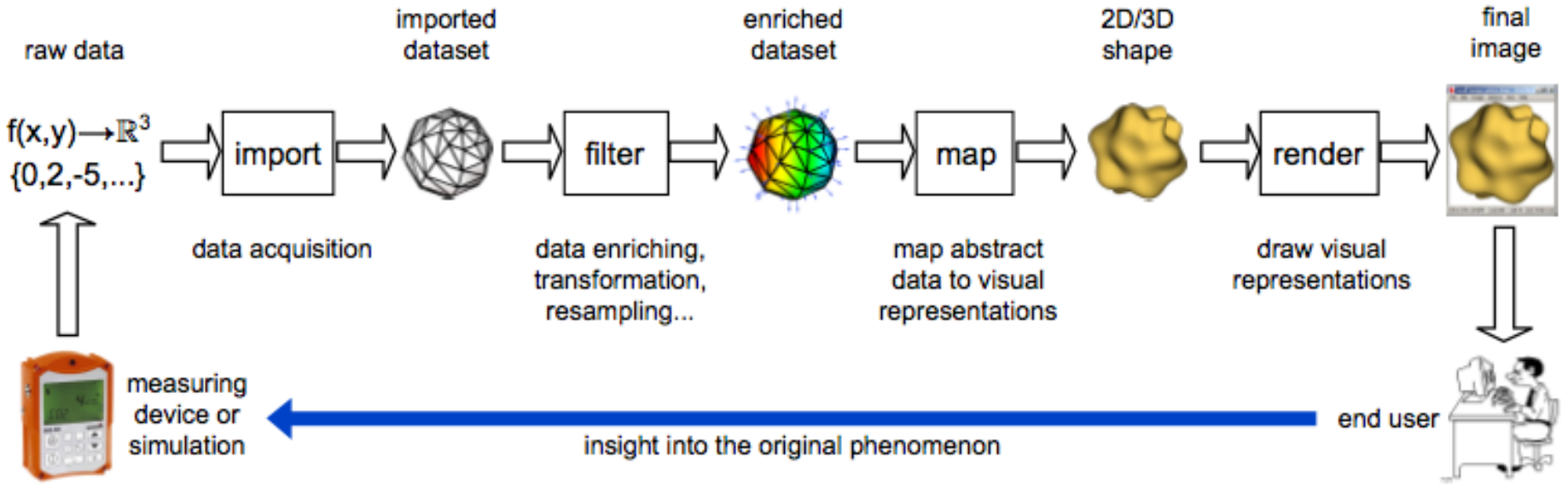
•**what** information do readers/users need to get to accomplish their tasks?
•**how much** detail info do users need?
•how do we surely know what users **want**?
•how are we sure the users **get** what the visualization encodes?
•how to avoid **misinterpretations**?
•what is the effort users must **pay** to read a visualization?

What's so hard? Interdisciplinarity!

•skills needed to design a good visualization are not evident/intuitive
•they must be learned (that's what we're trying to do here)
•crafting a good visualization requires skills in (at least)

- perception, vision, cognition
- (computer) graphics
- data science
- programming
- interaction

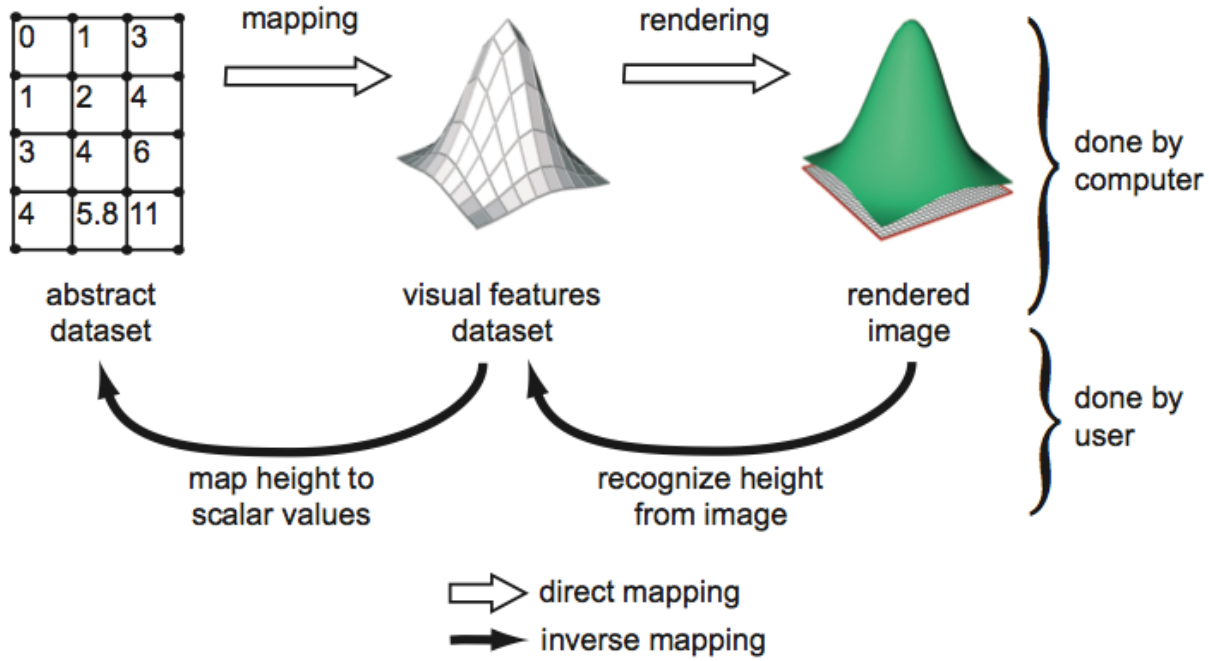
The Visualization Pipeline: A Technical View*



- transform raw data into insightful answers
- sequence of **steps**
  - data acquisition (conversion, formatting, cleaning)
  - data enrichment (transformation, resampling, filtering)
  - data mapping (produce visible shapes from data)
  - rendering (draw and interact with the shapes)

* A. Telea (2004) *Data Visualization – Principles and Practice,* 2nd ed., CRC Press

The Visualization Pipeline: A Functional View*

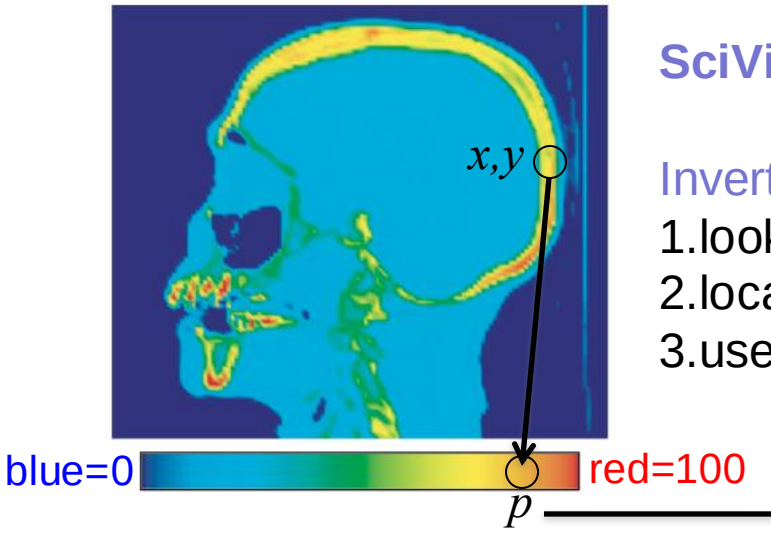


- input: dataset in some high-dimensional space
- output: color image, e.g. displayed on computer screen
- visualization: function mapping **data** to **images**
- analysis: inverse function mapping **images** to **data**

* A. Telea, Data Visualization – Principles and Practice, 2nd ed., CRC Press, 2014

When do we have a good visualization? Technical view

How to **invert** the mapping (function) from data to images?



SciVis example: CT-scan density slice s mapped to color

Invert mapping:

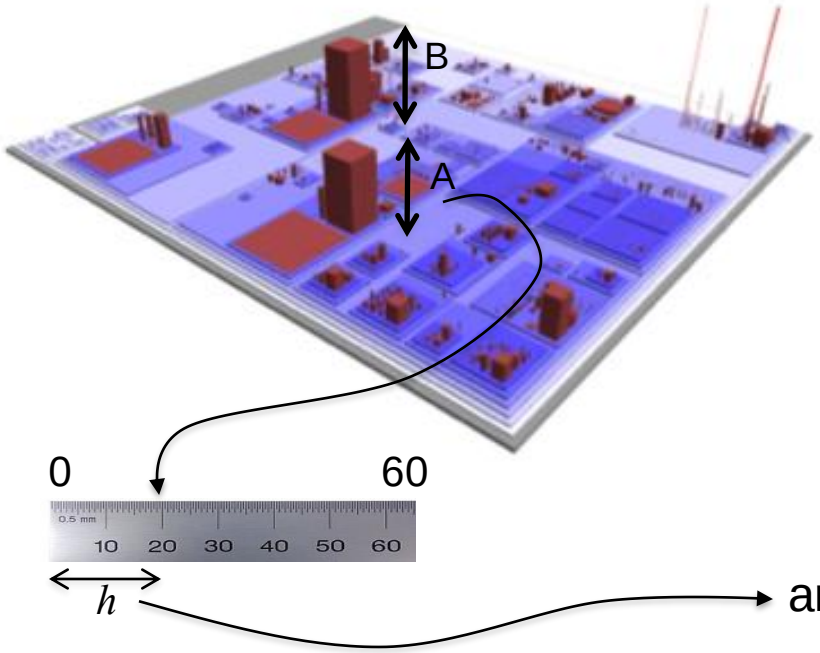
1. look at some point (x,y) in the image $\rightarrow$ color c
2. locate c in colormap at some position p
3. use the colormap legend to derive data value s from p

Problems

- what if we cannot distinguish colors well? (step 1)
- what if we cannot compare colors well? (step 2)
- what if the colormap is bad? (step 3, *e.g.* more values s_1, s_2 map to same color c)
- what if there's no color legend?
- what if there's no colormap?
- …

When do we have a good visualization? (cont'd)

How to **invert** the mapping (function) from data to images?



InfoVis example:
software quality q mapped to bar height

Invert mapping:
1.look at some bar (A) in the image$\rightarrow$ height h
2.locate h in in the length-legend
3.use the legend to derive data value s from h

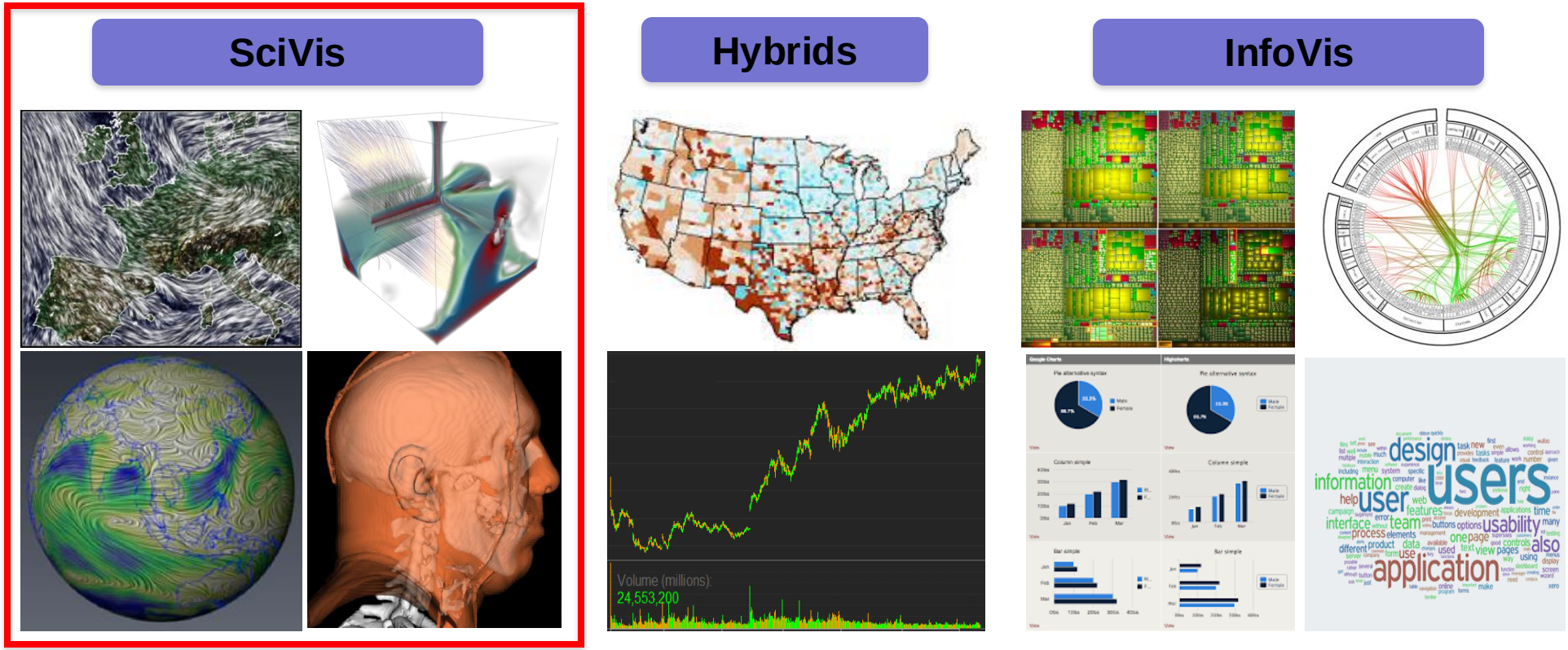
Problems
- what if we have a distorting projection in 3D (perspective)? (step 1)
- what if we cannot compare lengths well? (step 2)
- what if the length-legend is non-linear or not starting at zero? (step 3)
- what if there's no length-legend?
- …

SciVis *vs* InfoVis, revisited

SciVis | **Hybrids** | **InfoVis**

What are the differences you see between the three types in terms of visualization but also displayed data?

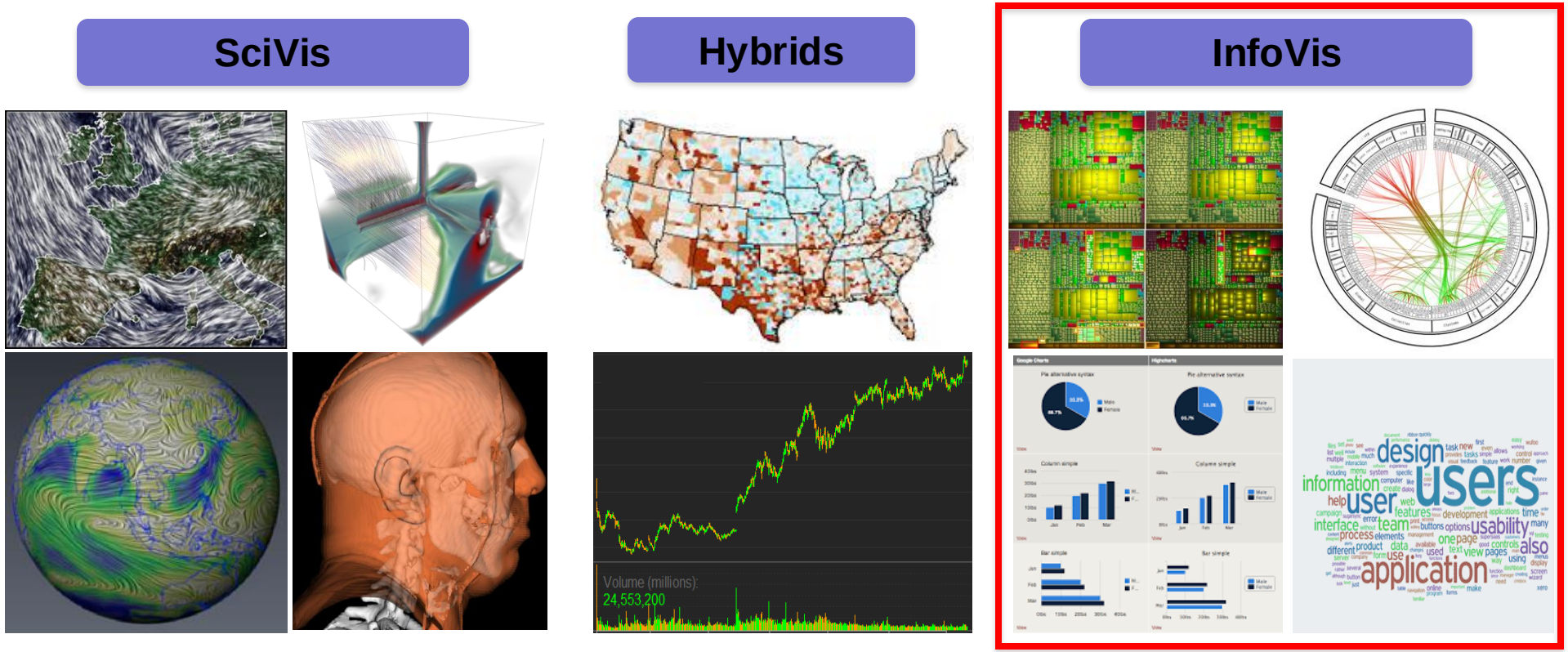
SciVis *vs* InfoVis, revisited: Focus on SciVis



SciVis

- 2D and 3D displays
- physical quantities (temperature, pressure, velocity, density, etc)
- data is *numerical* and *continuous*
- data is defined over a 2D or 3D spatial domain (location is *given*)
- every point in this domain carries a data value (data is *dense*)

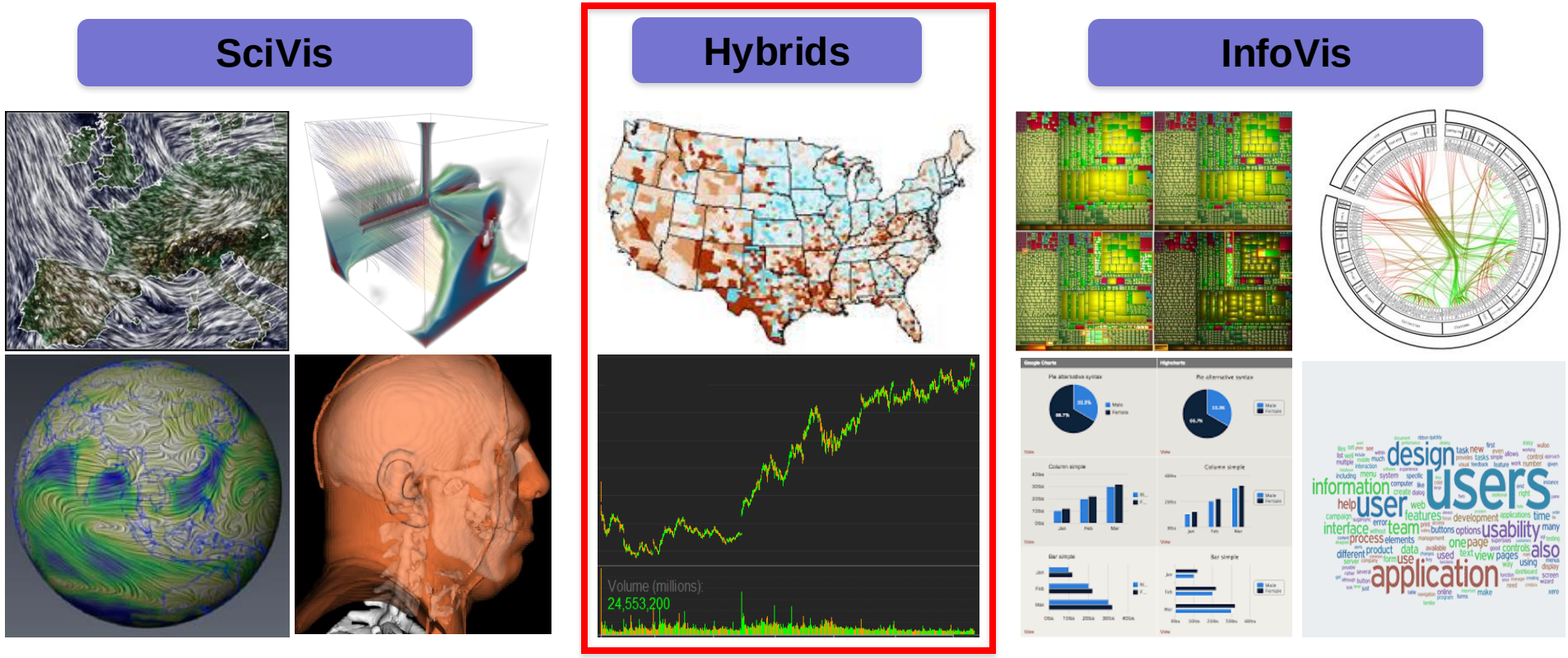
SciVis *vs* InfoVis, revisited: Focus on InfoVis



InfoVis

- 2D displays (mostly)
- any quantities (physical, text, categories, prices, relations)
- data is not necessarily *numerical* and usually *discontinuous* (e.g. relations)
- data has no spatial association (location is *chosen* by design)
- not every point in the visualization has a data value (data is *discrete*)

SciVis *vs* InfoVis, revisited: Hybrids



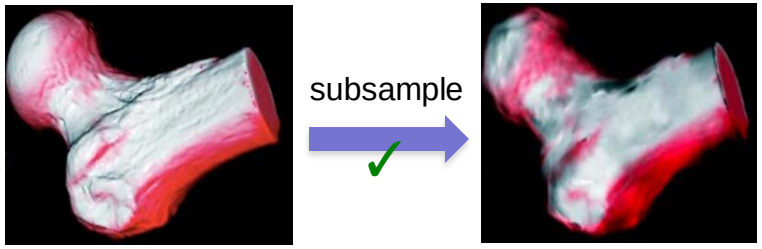
Hybrids

- 2D or 2 1/2D displays
- any quantities (like in InfoVis)
- at least one quantity is numerical and continuous (e.g. space in a map, time in a stock chart) and at least one is not (e.g. population measured per county)
- examples: geovisualization, timeline charts

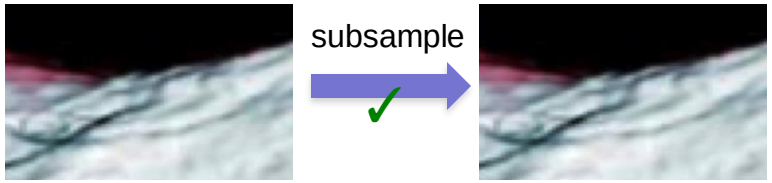
SciVis *vs* InfoVis data

SciVis

Continuous, numerical, spatial data



bone dataset, 80K points — bone dataset, 20K points



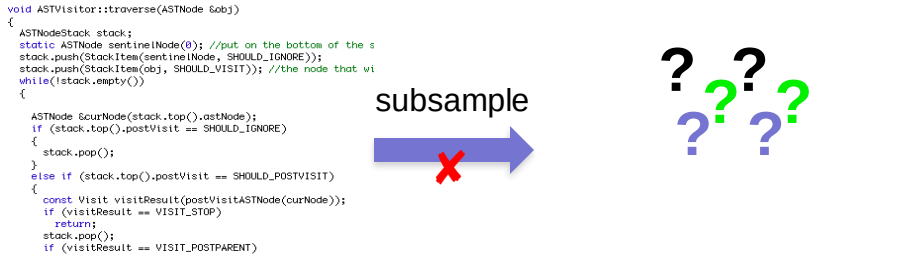
bone detail, 88 polygons — bone detail, 87 polygons

- we throw away 75% of the data
- the semantics stays the same

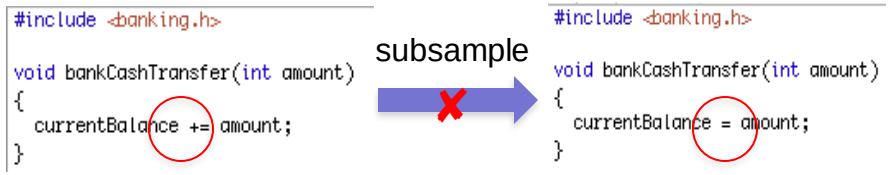
- interpolation: simple
- resampling: **Cauchy-continuous** ☺

InfoVis

Discrete, non-numerical, non-spatial data



C++ text, 80K lines — C++ text, 20K lines



C++ text, 88 chars — C++ text, 87 chars

- we throw away one single character
- the semantics becomes fully different!

- interpolation: often not possible
- resampling: **not Cauchy continuous** ☹

How to treat *volume* and *variety* for all data types?

When do we have a good visualization? Technical view

Simple in theory…

•when the the user **can invert the mapping** from the image to the underlying data

In practice, complicated…

•do we need to **precisely** invert the mapping?
•do we need to invert the mapping for **all** data points?
•how **easily** should it be possible to invert the mapping?
•even if we can invert the mapping, do we get all our **questions** being solved?

Practical approach

•try to make the mapping **as invertible as possible**
•measure inversion precision/speed/ease by **user studies**
•see if the obtained mapping (visualization) answers our questions
- if so, great, we have an effective visualization
- if not, discover areas to improve and refine the visualization

•synthesize lessons learned into **design guidelines**
•use these when constructing **new** visualizations

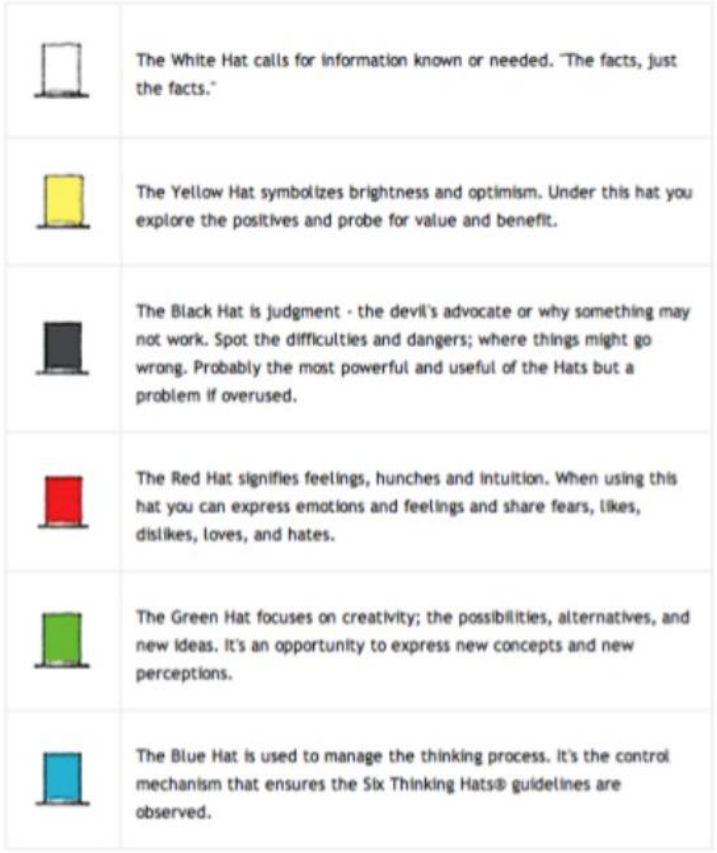
We'll discuss these in detail in Modules 3 and 4

Roles in Visualization

Who are the stakeholders?

•data visualization involves many types of people
•we need to know them all to create something effective

Use De Bono's user-model*



- multiple user types = multiple 'hats'
- same person may wear several hats
- a good design must cover all hats
- different hats = different concerns
- this way, we (dis)cover interdisciplinary problems

* E. de Bono (1985) *Six Thinking Hats: An Essential Approach to Business Management*. Little, Brown, & Company

8 Roles in Visualization

start: we have
a **problem**…

end: we use
a **solution**

Role 1: Initiator

- identifies a **problem** in some application domain
- typically **owns** the problem (needs to get it solved)
- typically is not a visualization, but an application-domain, expert
- knows the problem requirements well
- mindset
  - researcher: seeks evidence, wants to discover the known
  - business: seeks solution, knows its value
- way of working
  - initiates the project
  - sets requirements
  - evaluates final results

Role 2: Data Scientist

- translates from problem domain and requirements to a **data model**
- a data model
  - describes what should be measured
  - specifies the required accuracy
  - tells how data items are related
  - specifies data storage and access (e.g. database)
- addresses data for quality (cleaning, auditing, versioning)
- consolidates the data (filtering, aggregation)
- has strong analytical/statistical skills
- can or can not have implementation skills

Role 3: Journalist

- is the **storyteller** of the project
- establishes the analytical narrative (how to go from questions to answers)
- **before** results are available
  - refines the main questions (from the initiator)
  - finds key angles to look at the problem from
- **after** results are available
  - refines these to link them to questions
  - synthesizes answers
  - assembles the whole into an easy-to-follow presentation
- knows languages of all other roles (so can translate between them)

"What questions/curiosities do **you** hope to answer by this visualization?"
"What stories should **users/readers** be able to derive?"

Role 4: Computer Scientist

- is the **executor** of the project
- creates/uses programs to
  - query, aggregate, filter the data (for the data scientist)
  - generate full stories (for the journalist)
  - support the presentation/interaction modes (proposed by the designer)
  - encode data into images (as specified by the cognitive scientist)
- strong skills in programming, computer graphics, image processing
- typically fewer skills in communication
- does not need to be an application domain expert
- executes **all** what others are requiring….
  ...and tells them the **price** they need to pay for what they want

Role 5: Designer

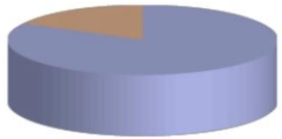
- **links** data and questions to interactive images
- two types of design
  - **visual:** from data to images
  - **interaction:** from user input to queries
- similar role to application architect in software engineering
- understands the requirements (from initiator)
- understands the techniques (from data analyst, computer scientist)
- explores/defends alternative designs
- balances form *vs* function
- skills: UI design, interaction, graphics design, ergonomics, presentation

Role 6: Cognitive Scientist

- **supports** designer with effective visual encodings
- **evaluates** the proposed solution (e.g. via user studies)
- similar to a ‘low-level designer’ (less artistic, more scientific)
- understands how decision-making works
- skills: computer vision, cognitive science, perception, Gestalt principles, usability

Example: Which pie chart is better?

visible pixels:
blue:82%
yellow: 18%



visible pixels:
blue:91%
yellow: 9%

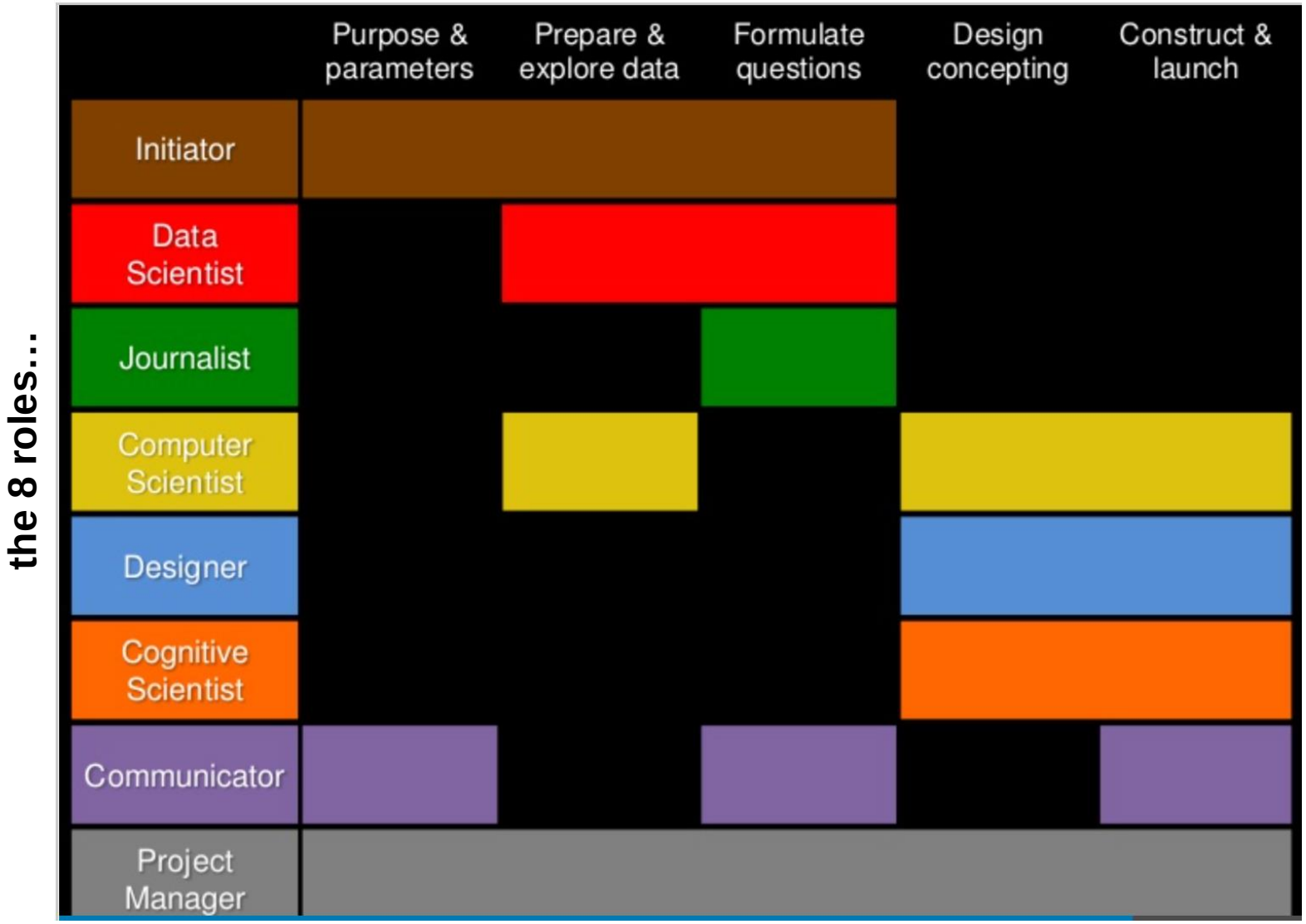
Role 7: Communicator

- **negotiates** between problem owner (client) and all other roles
- manages expectations
- presents possibilities to all roles
- launches, publicizes, markets final product
- role can overlap with initiator and project manager, but not identical
  - communicator is not the **owner** of the problem (that's the initiator)
  - communicator does not take **decisions**, only mediates

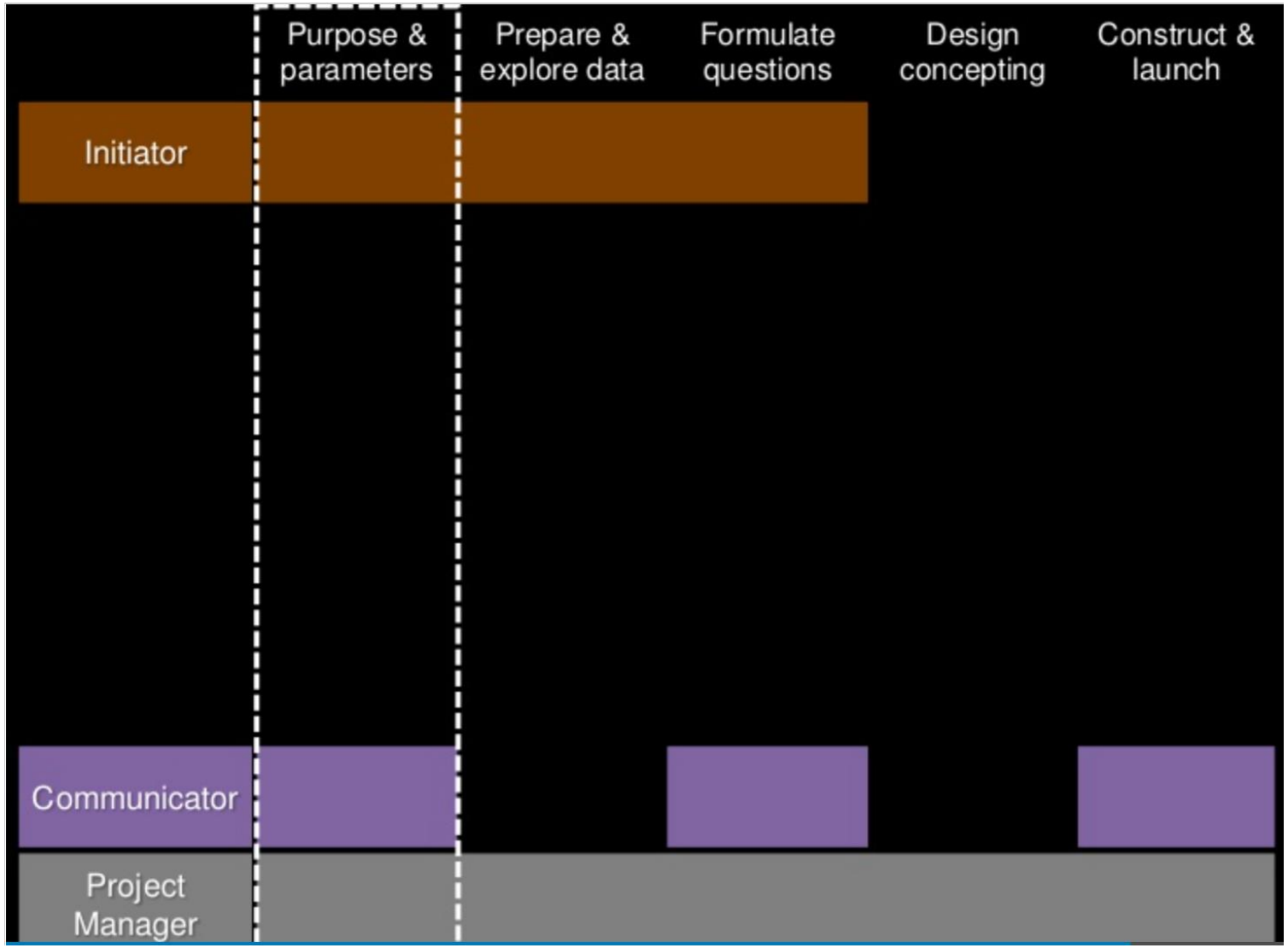
Role 8: Project Manager

- **looks after** the project during its entire execution
- manages progress (milestones, deliverables)
- thinks in terms of cost *vs* benefits (or value *vs* waste, see earlier slides)
- checks correctness and completeness *vs* requirements
- assigns people to the other 6 roles (initiator is given)
- specific to visualization
  - checks data usage **ethics** (privacy, anonymization, etc)
  - checks visualization **correctness** (together with designer/cognitive scientist)
- typically not an application-domain expert, nor a scientist

Visualization Construction: Roles *vs* Activities

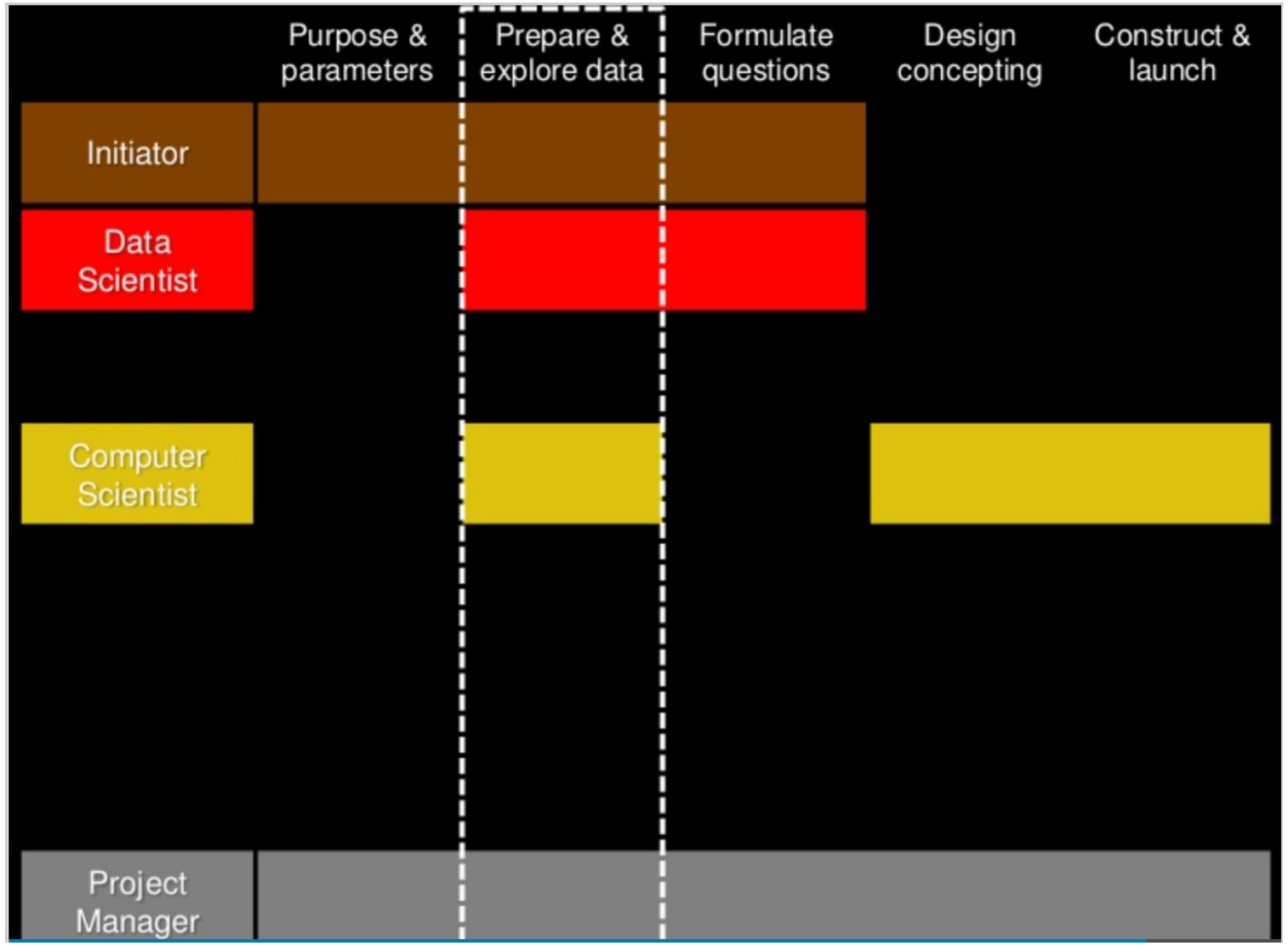


Visualization Construction: Roles *vs* Activities



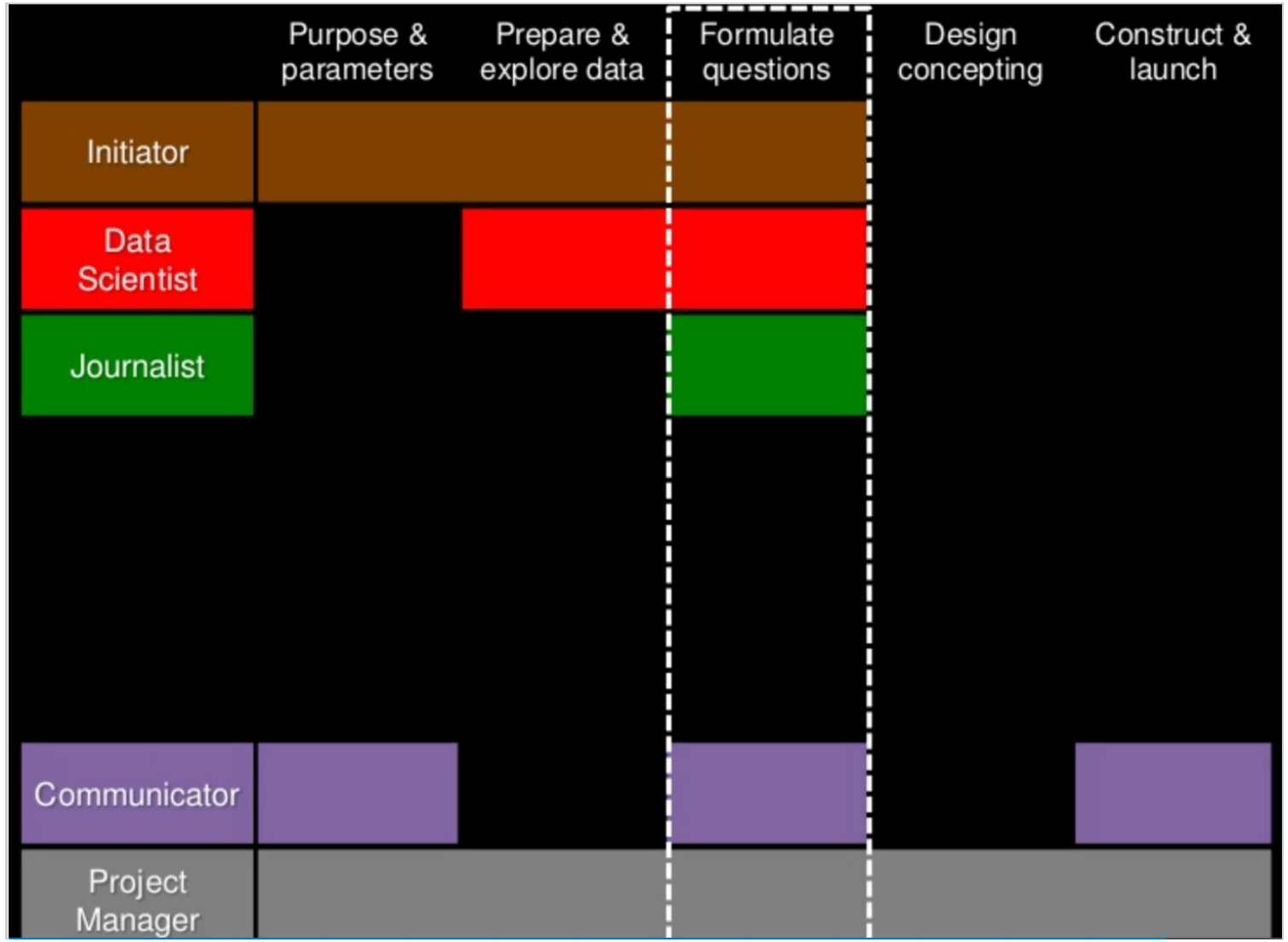
Activity 1: Define what you want to achieve…

Visualization Construction: Roles *vs* Activities



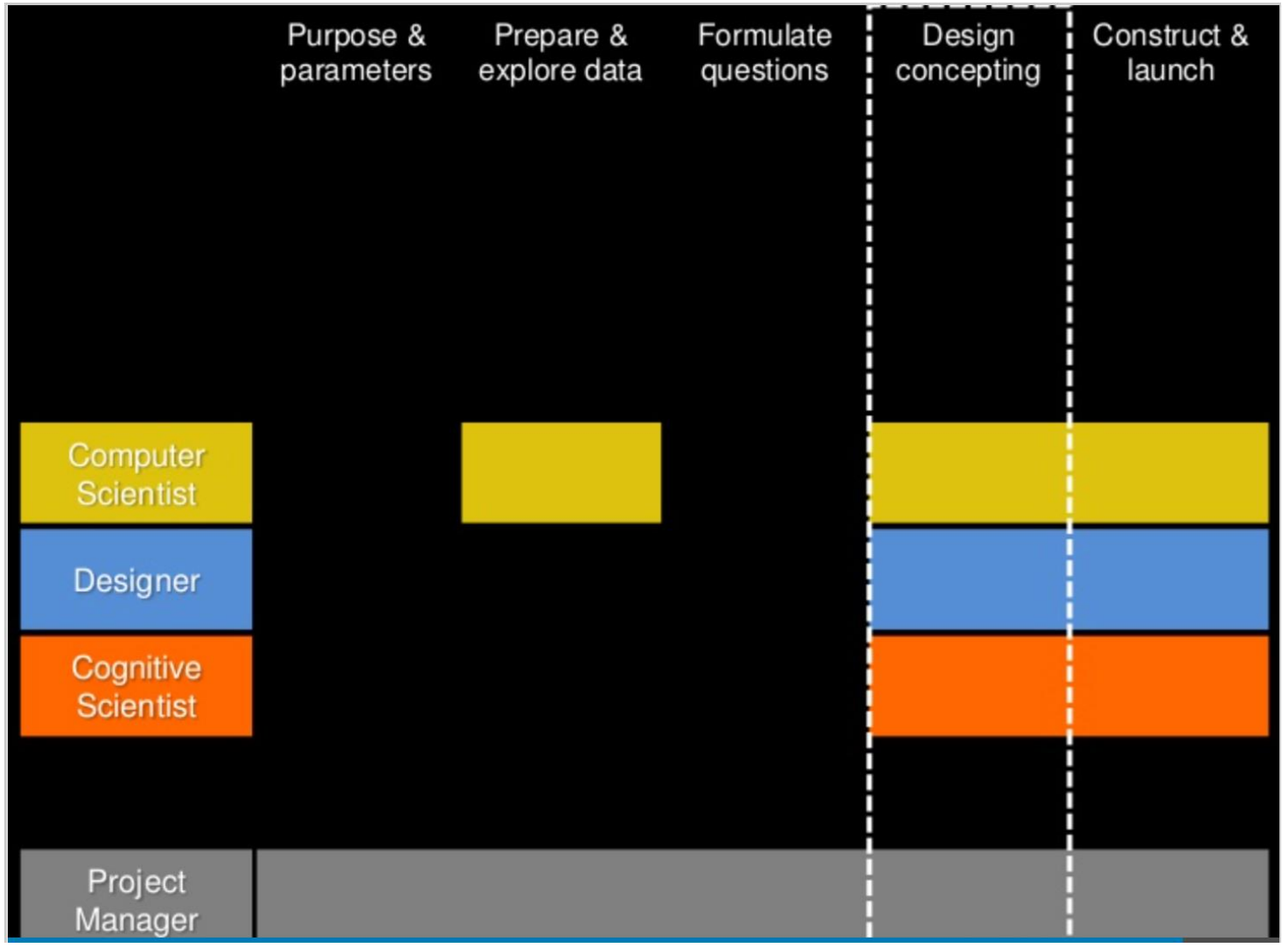
Activity 2: Gather and process the data…

Visualization Construction: Roles *vs* Activities



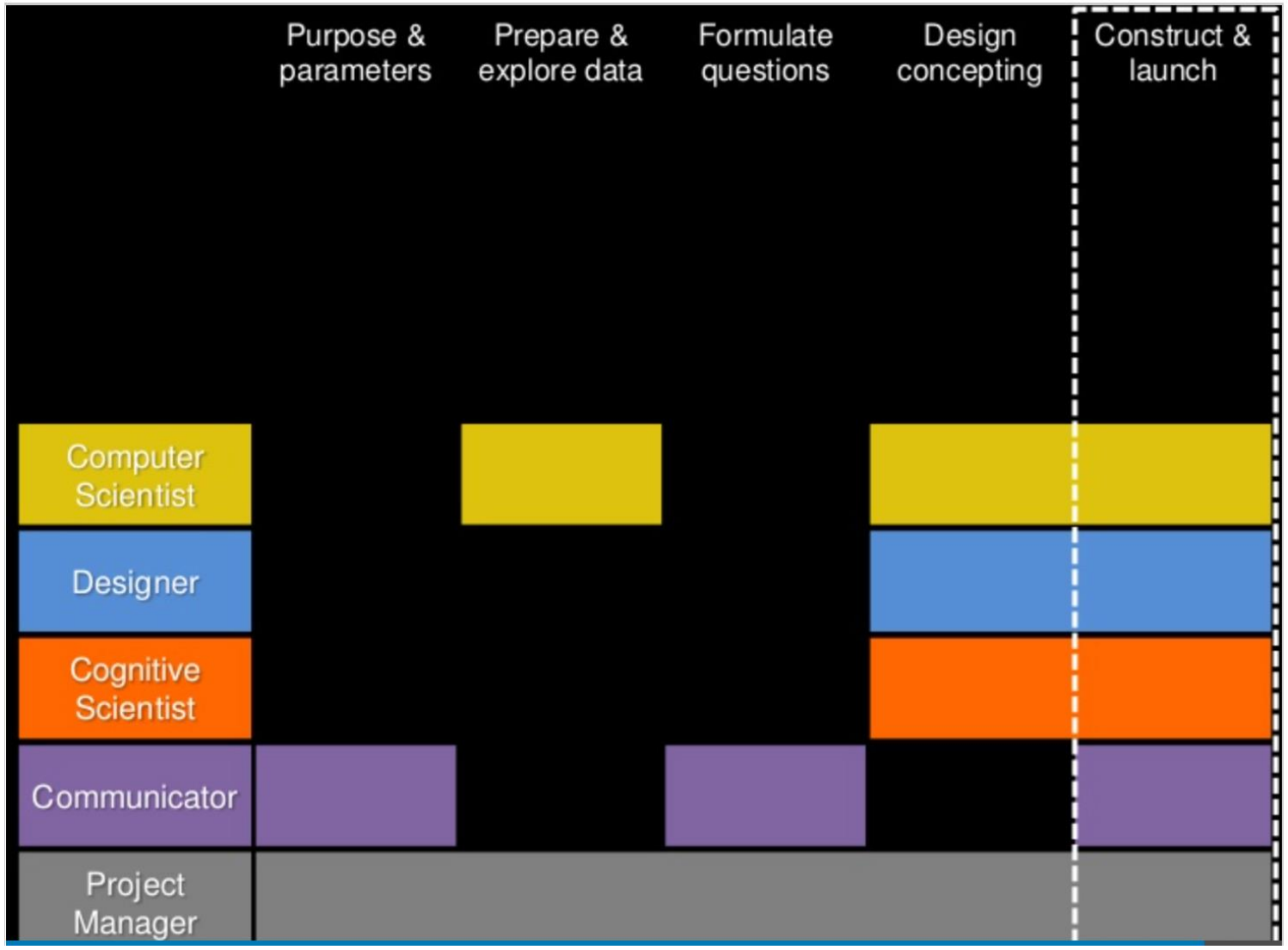
Activity 3: See which questions on the data cover your problem…

Visualization Construction: Roles *vs* Activities



Activity 4: Map questions to data-queries and visualization design…

Visualization Construction: Roles *vs* Activities



Activity 5: Implement it all, test it, deliver the solution

Summary

Data Visualization

- helps getting insight into large, multidimensional, complex datasets

- visualization pipeline
    - data acquisition, filtering, mapping, and rendering

- visualization sub-fields
    - scientific visualization
    - information visualization
    - infographics

- visualization challenges
    - data encoding
    - inverse mapping

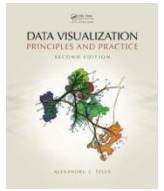
Next module

- data representation

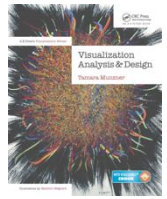
Happy so far?

Further reading

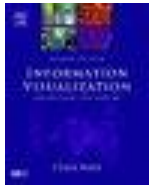
Data Visualization – Principles and practice (A. Telea, CRC Press, 2014)
- main focus: scientific visualization
- for visualization implementers (programmers) and researchers



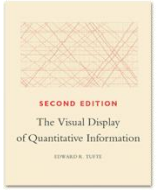
Visualization Analysis and Design (T. Munzner, CRC Press, 2014)
- main focus: information visualization
- for visualization implementers (programmers) and researchers



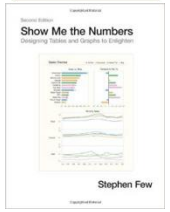
Information Visualization: Perception for Design (C. Ware, Morgan Kaufman, 2012)
- main focus: information visualization, infographics
- for visualization designers and end-user scientists



The Visual Display of Quantitative Information (E. Tufte, Graphics Press, 2001)
- main focus: information visualization, infographics
- for visualization designers and graphics artists



Show Me the Numbers – Designing Tables and Graphs (S. Few, Analytic Press, 2012)
- main focus: information visualization, infographics
- for visualization designers and communication scientists



Data Visualization: A Successful Design Process (A. Kirk, Packt Publishing, 2012)
- main focus: information visualization, infographics
- for visualization designers and communication scientists