

Information Visualization

Introduction

Petra Isenberg

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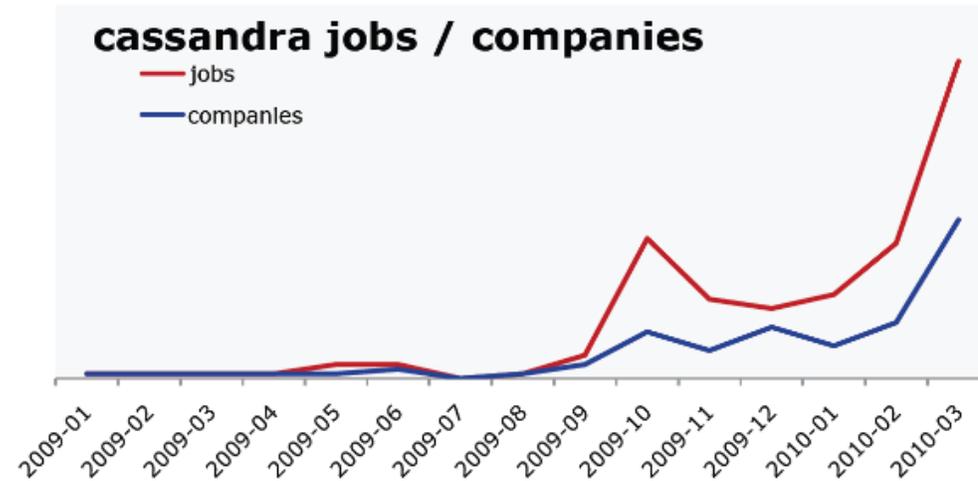
After today you will...

- have gained an overview of the research area
- learned basic principles of data representation and interaction

Why

INFORMATION VISUALIZATION

Hiring trends for data science



It's not easy to get a handle on jobs in data science. However, data from [O'Reilly Research](#) shows a steady year-over-year increase in Hadoop and Cassandra job listings, which are good proxies for the "data science" market as a whole. This graph shows the increase in Cassandra jobs, and the companies listing Cassandra positions, over time.

"The ability to take data -- to be able to understand it, to process it, to extract value from it, to visualize it, to communicate it - that's going to be a hugely important skill in the next decades."

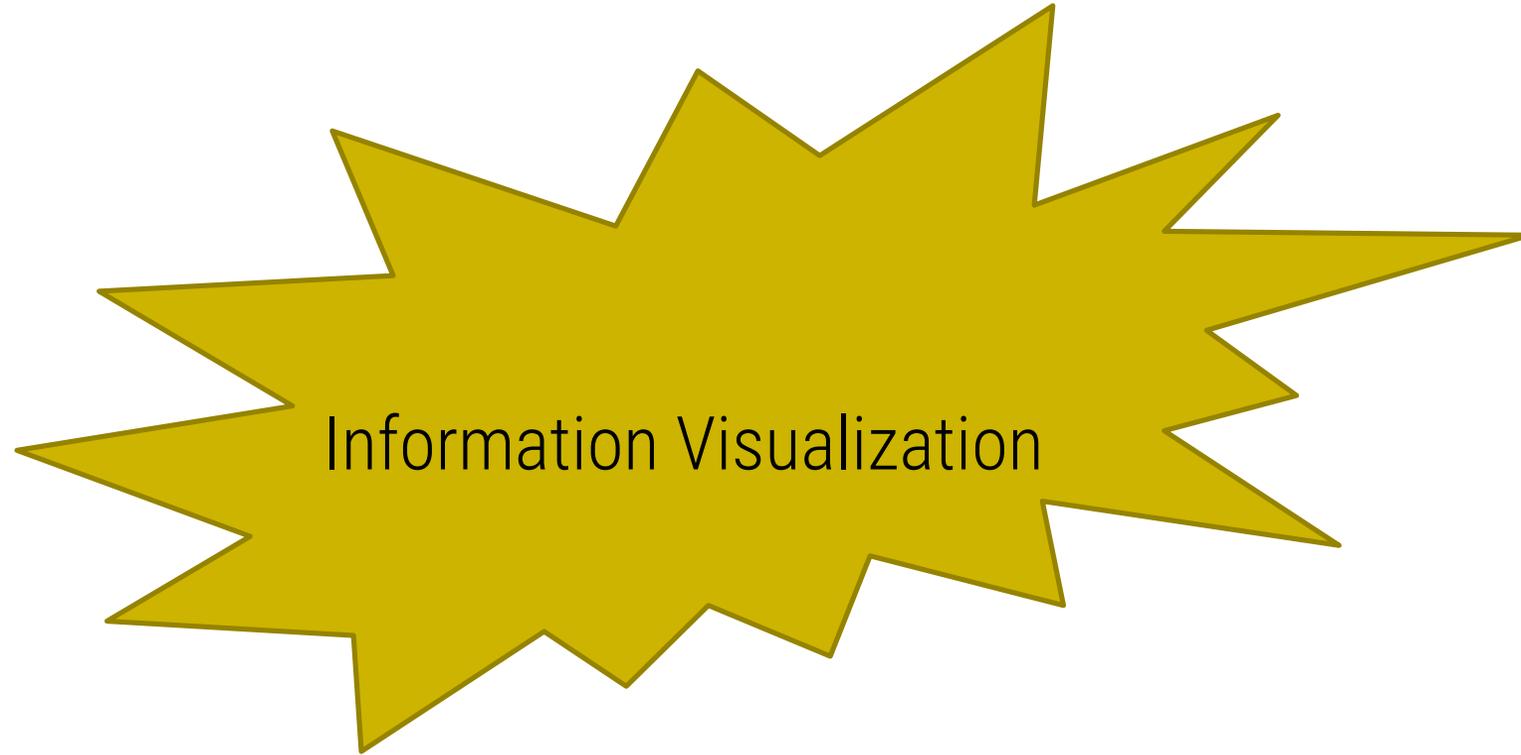
Hal Varian, chief economist at Google

Question

how can we effectively access data?

- understand its structure?
- make comparisons?
- make decisions?
- gain new knowledge?
- convince others?
- ...

Many possible ways to address...



Example

I		II		III		IV	
x	y	x	y	x	y	x	y
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

Raw Data from Anscombe's Quartet

Statistical Analysis

For all four columns, the statistics are identical

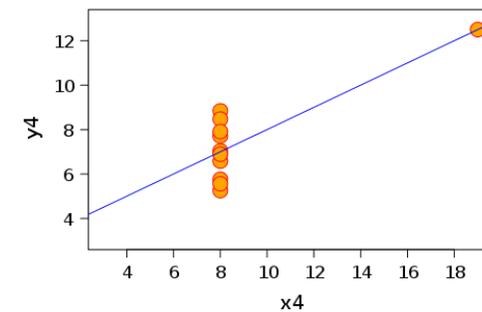
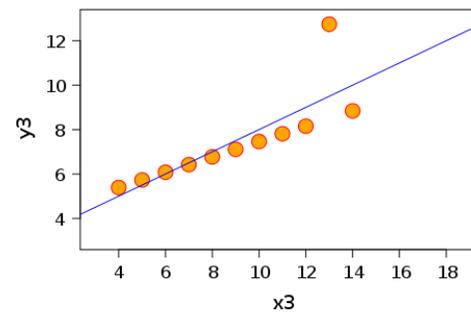
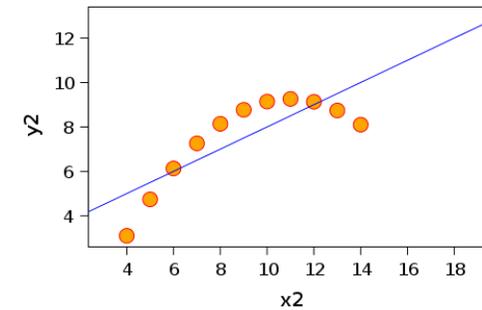
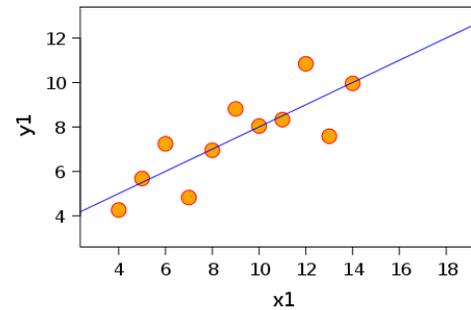
I		II		III		IV	
x	y	x	y	x	y	x	y
10.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
8.0	6.95	8.0	8.14	8.0	6.77	8.0	5.76
13.0	7.58	13.0	8.74	13.0	12.74	8.0	7.71
9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	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
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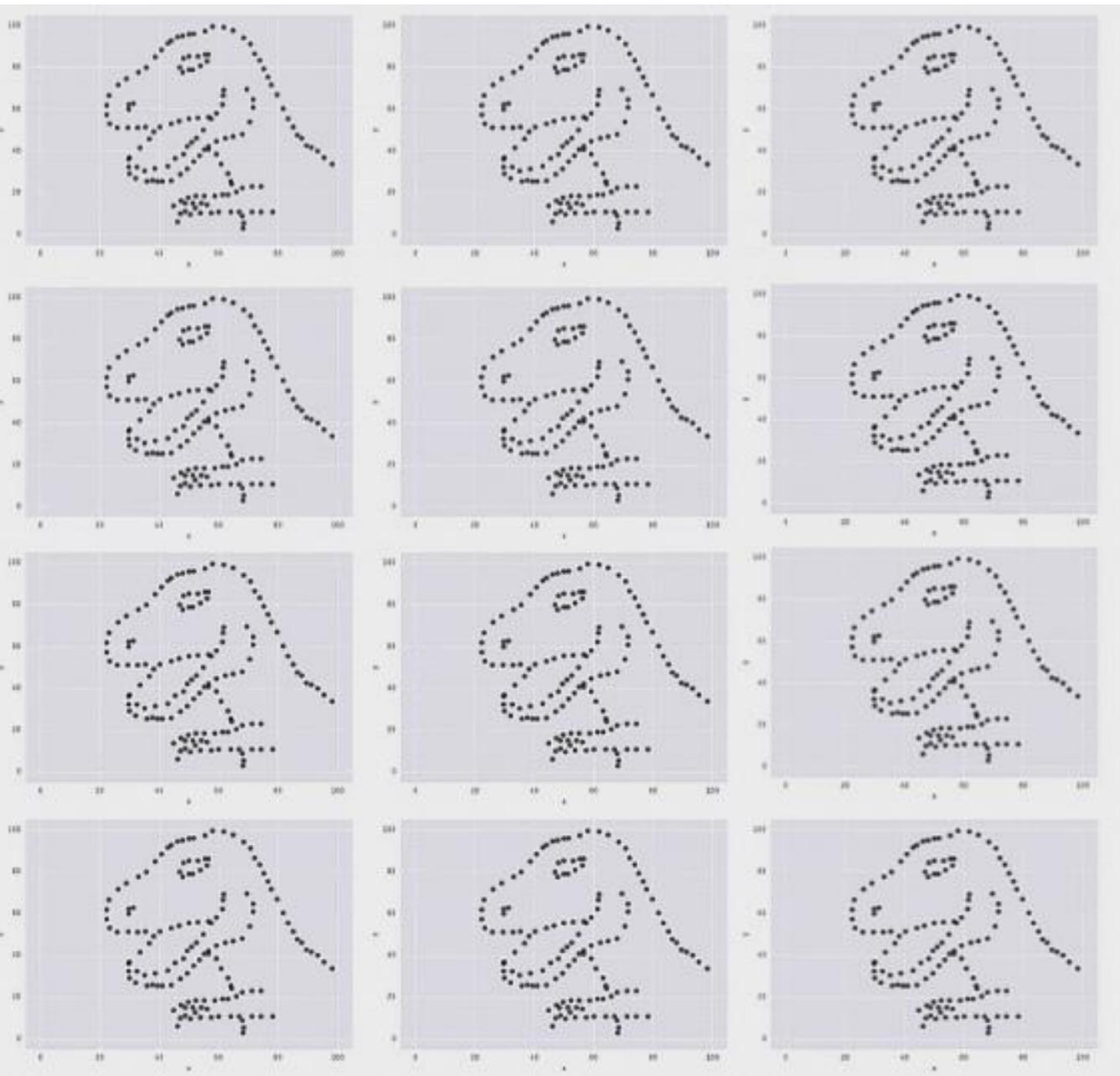
Mean of x	9.0
Variance of x	11.0
Mean of y	7.5
Variance of y	4.12
Correlation between x and y	0.816
Linear regression line	$y = 3 + 0.5x$

Visual Representation of the Data

Visual representation reveals a different story

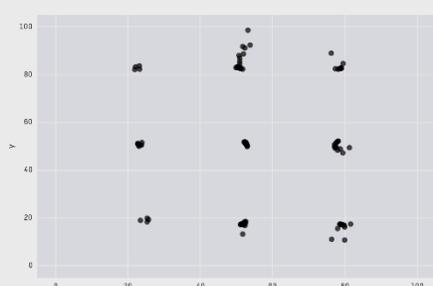
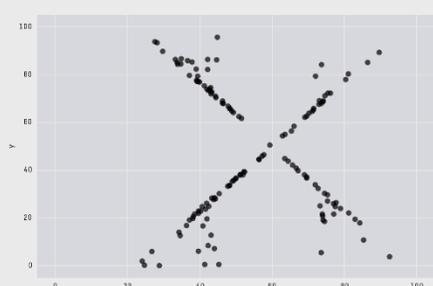
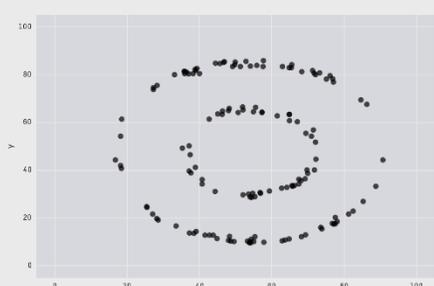
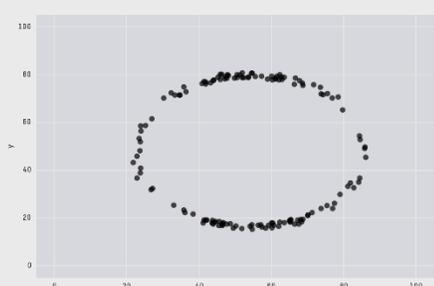
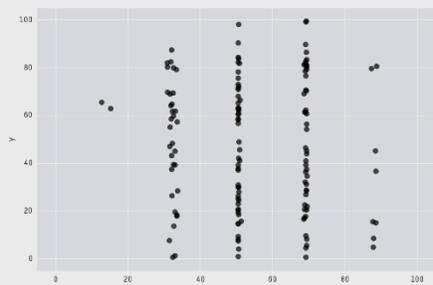
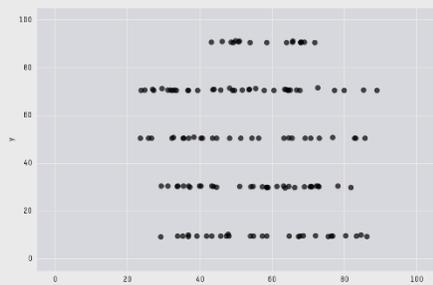
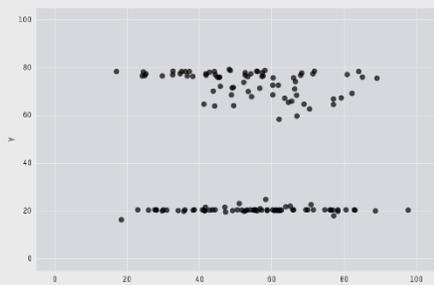
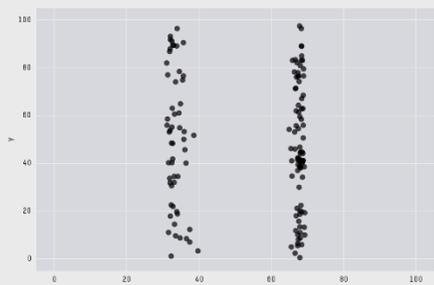
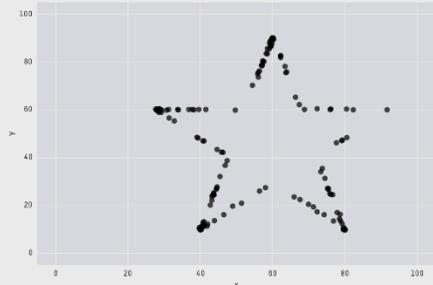
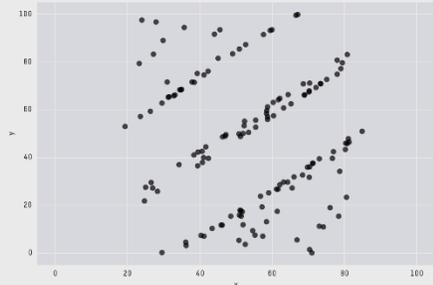
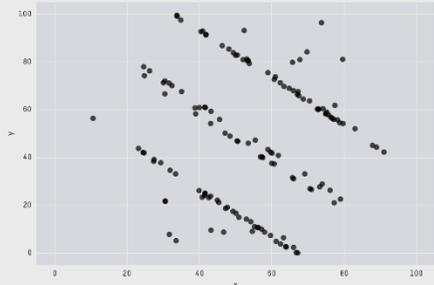
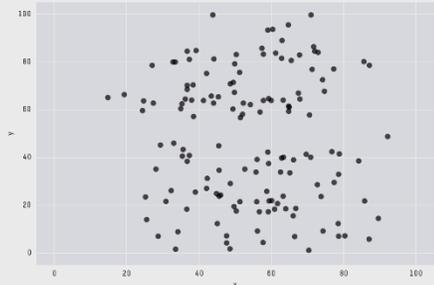
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x	y	x	y	x	y	x	y
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9.0	8.81	9.0	8.77	9.0	7.11	8.0	8.84
11.0	8.33	11.0	9.26	11.0	7.81	8.0	8.47
14.0	9.96	14.0	8.10	14.0	8.84	8.0	7.04
6.0	7.24	6.0	6.13	6.0	6.08	8.0	5.25
4.0	4.26	4.0	3.10	4.0	5.39	19.0	12.50
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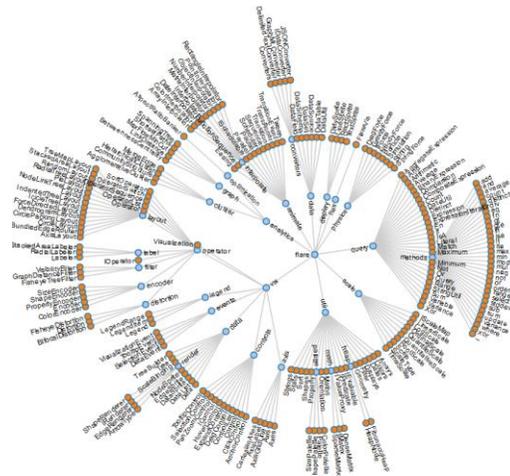
X Mean: 54.26
Y Mean: 47.83
X SD : 16.76
Y SD : 26.93
Corr. : -0.06



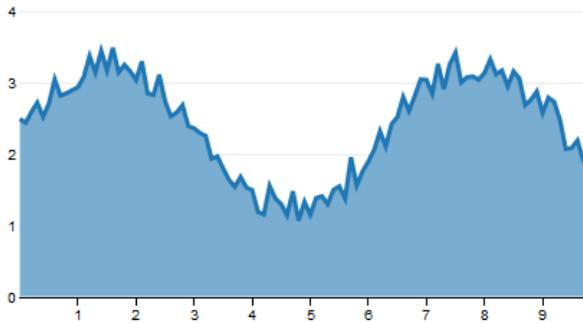
Why visual data representations?

- Vision is our most dominant sense
- We are very good at recognizing visual patterns
- We need to see and understand in order to explain, reason, and make decisions

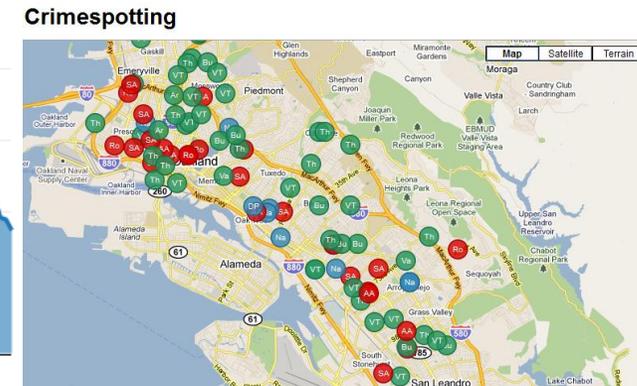
common examples:



graphs / hierarchies



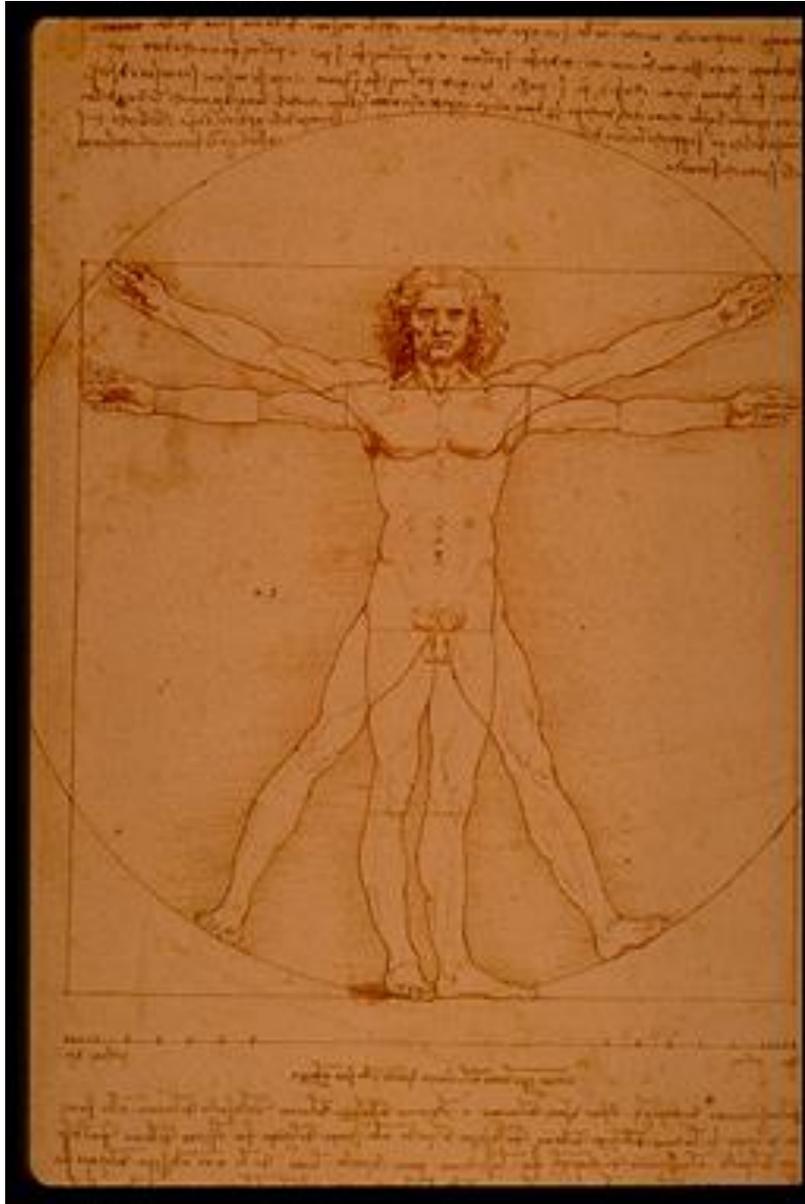
charts



maps

Other benefits of visualization

- expand human working memory
 - offload cognitive resources to the visual system,
- reduce search
 - by representing a large amount of data in a small space,
- enhance the recognition of patterns
 - by making them visually explicit
- aid monitoring of a large number of potential events
- provides a manipulable medium & allows exploration of a space of parameter values.



L'occhio,
che si dice finestra dell'anima,
è la principale via donde il comune
senso può piú copiosamente e
magnificamente considerare
le infinite opere di natura.

Leonardo da Vinci
(1452 - 1519)

The eye...
the window of the soul,
is the principal means
by which the central sense
can most completely and
abundantly appreciate
the infinite works of nature.

百聞不如一見

"One hundred rumors are not comparable to one look."

An Old Chinese Inscription

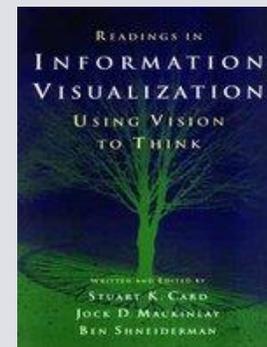
Information visualization

- Create visual representation
- Concentrates on abstract data
- Includes interaction

Official Definition:

The use of computer-supported, interactive, visual representations of abstract data to amplify cognition.

[Card et al., 1999]



Functions of Visualizations

- Recording information
 - Tables, blueprints, satellite images
- Processing information
 - needs feedback and interaction
- Presenting information
 - share, collaborate, revise
 - for oneself, for one's peers and to teach
- Seeing the unseen

Visualization of abstract data has been practiced for hundreds of years...

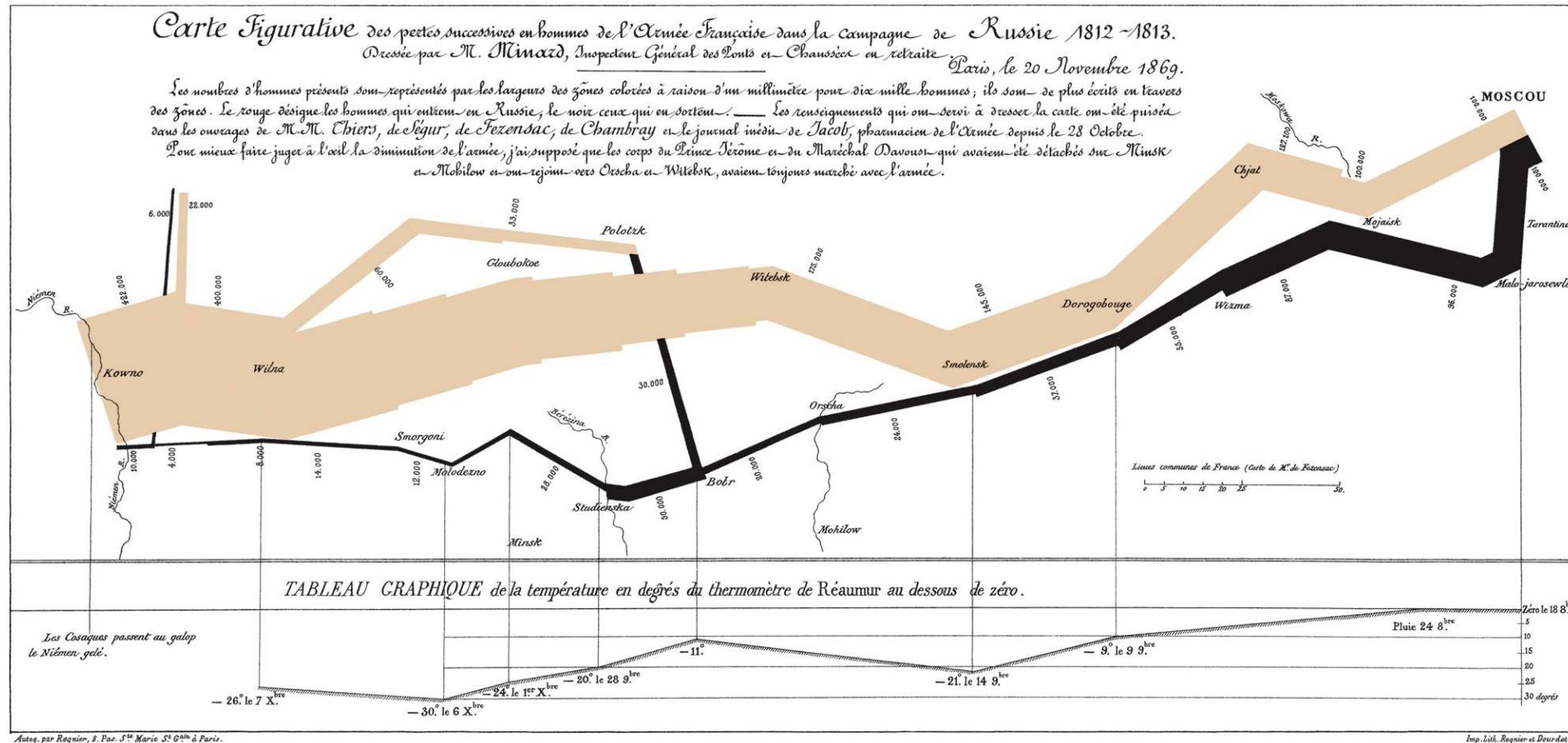
HISTORICAL EXAMPLES

Napoleon's March on Moscow

Charles Minard, 1869

Named the best statistical graphic ever drawn (by Edward Tufte)

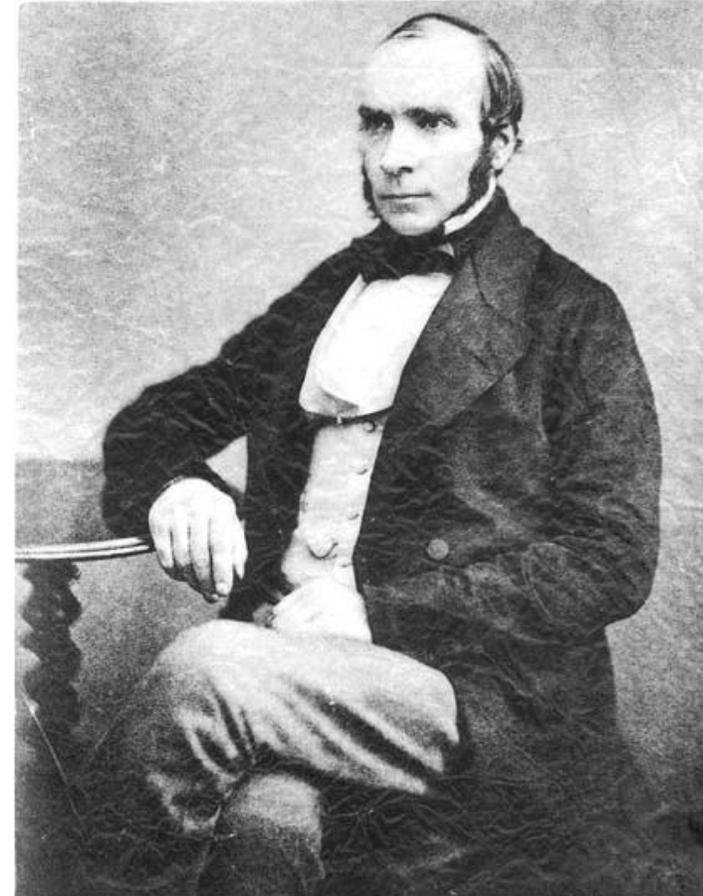
- Includes: spatial layout linked with stats on: army size, temperature, time
- Tells a story in one overview



More info: The Visual Display of Quantitative Information (Tufte)

The Broadway Street Pump

- In 1854 cholera broke out in London
 - 127 people near Broad Street died within 3 days
 - 616 people died within 30 days
- “Miasma in the atmosphere”
- Dr. John Snow was the first to link contaminated water to the outbreak of cholera
- How did he do it?
 - he talked to local residents
 - identified a water pump as a likely source
 - used maps to illustrate his theory
 - convinced authorities to disable the pump

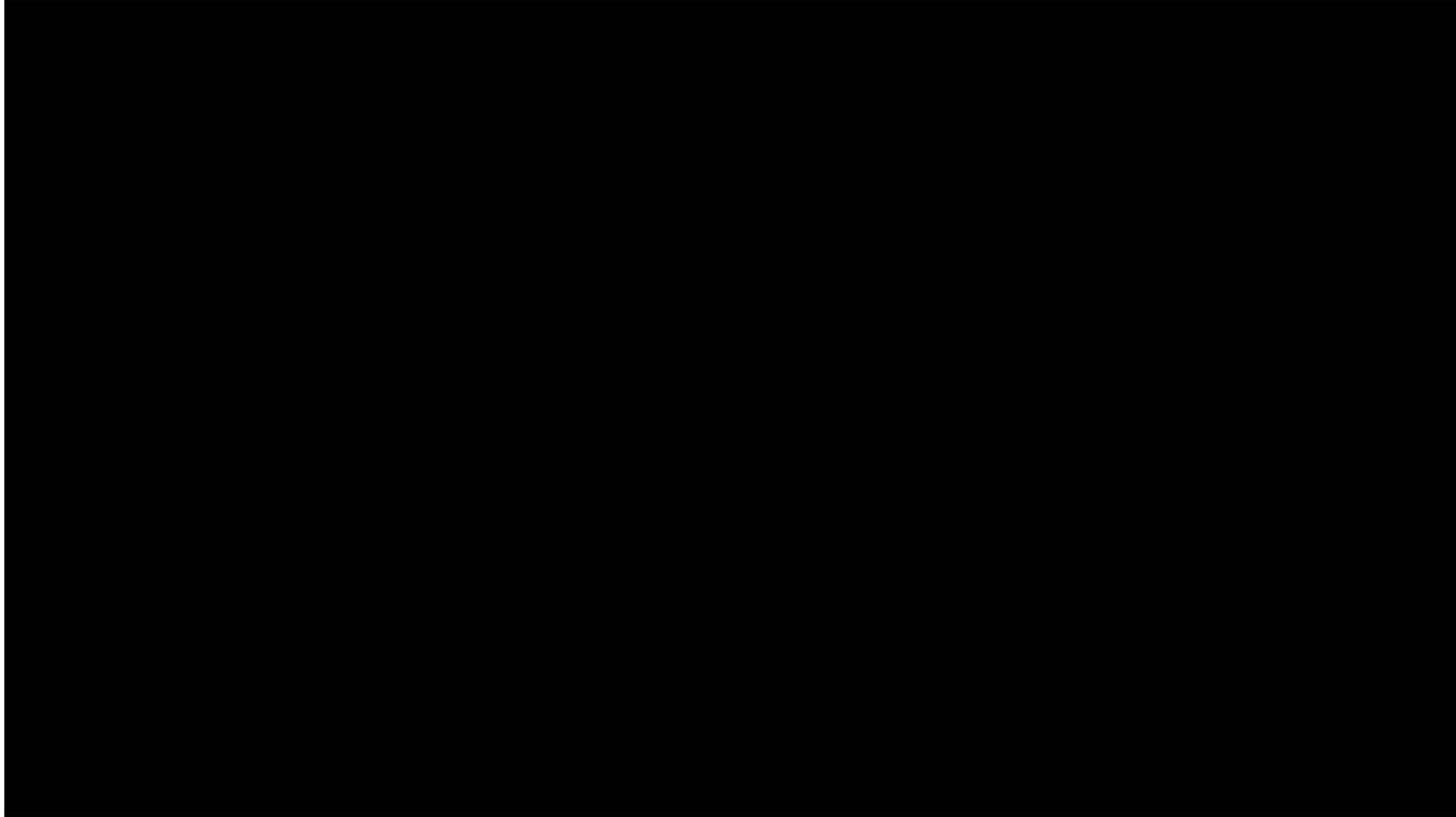




John Snow, 1854

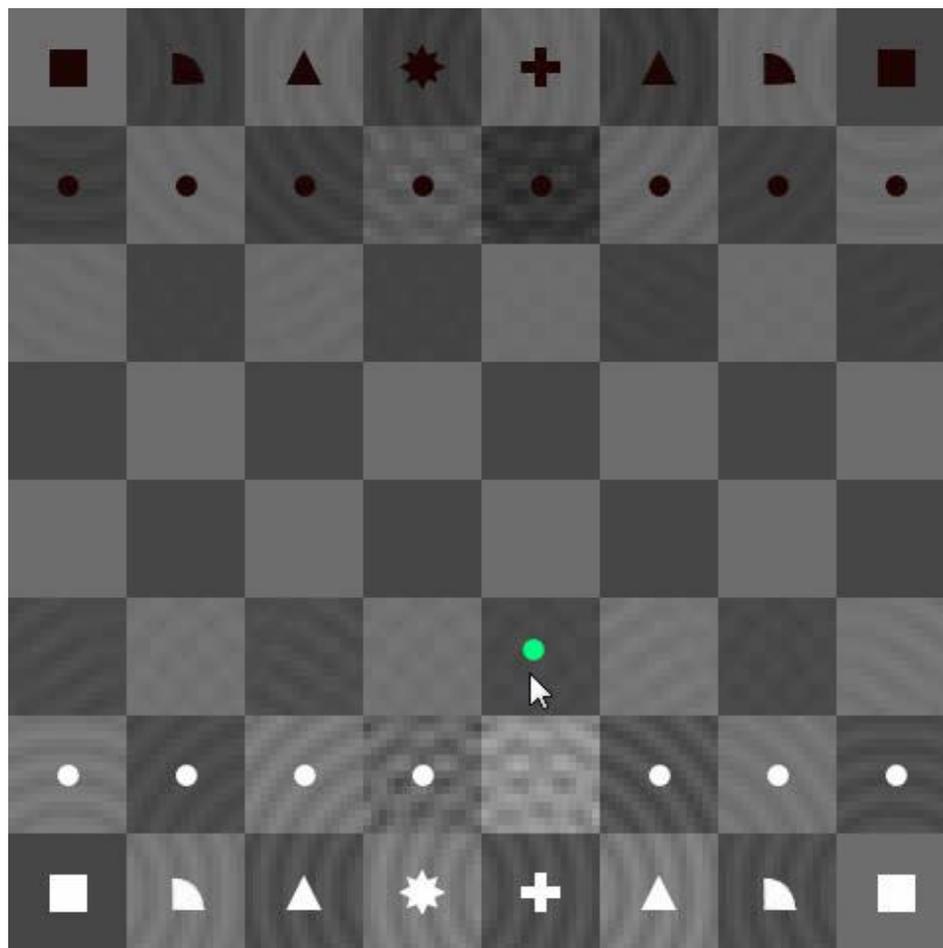
... AND MORE RECENTLY

TrashTrack



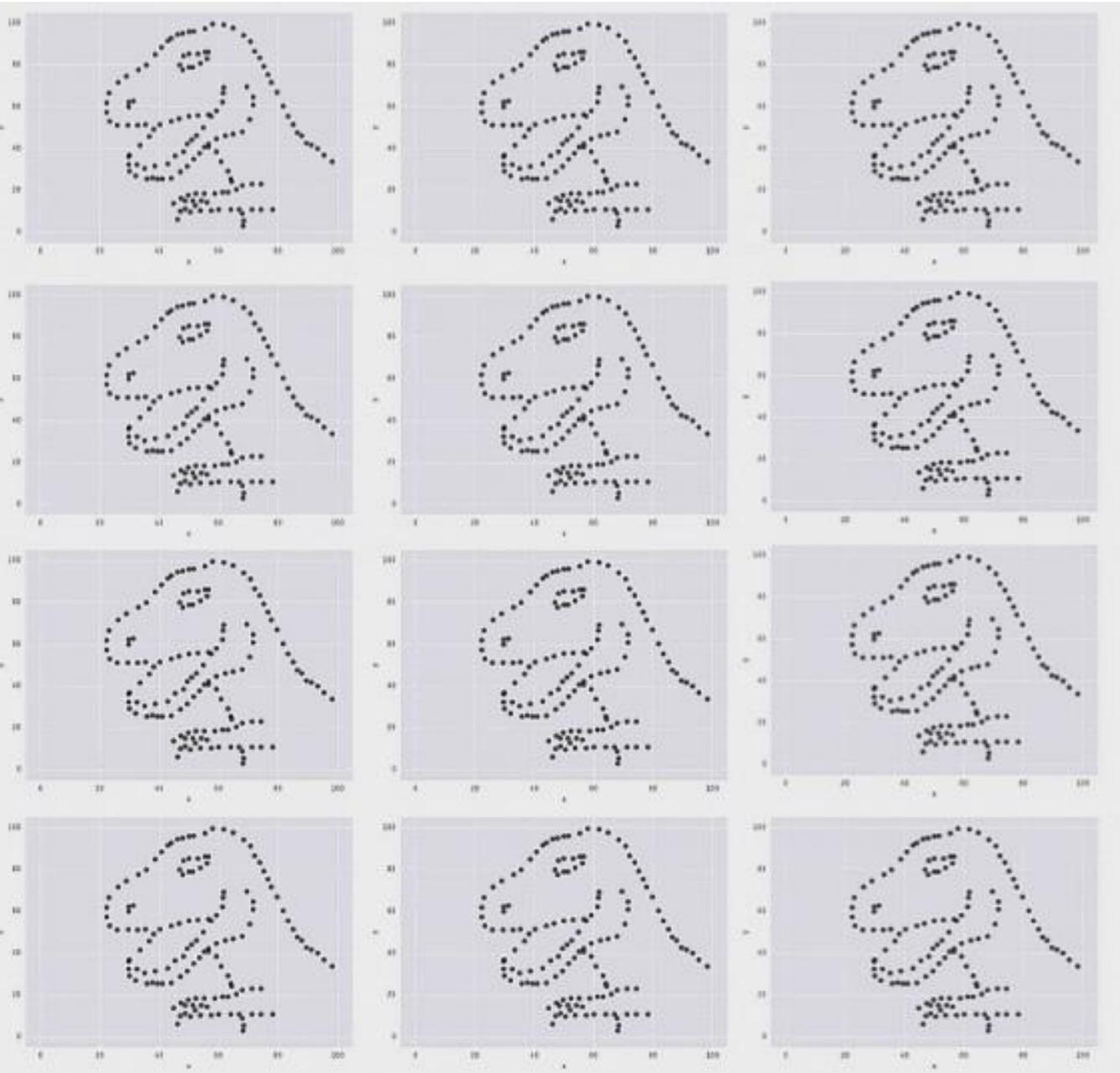
Winner of the NSF International Science & Engineering Visualization Challenge!
<http://senseable.mit.edu/trashtrack/>

Artificial Intelligence



<http://www.turbulence.org/spotlight/thinking/chess.html>

Information is Beautiful





[Awards](#) [Challenges](#)

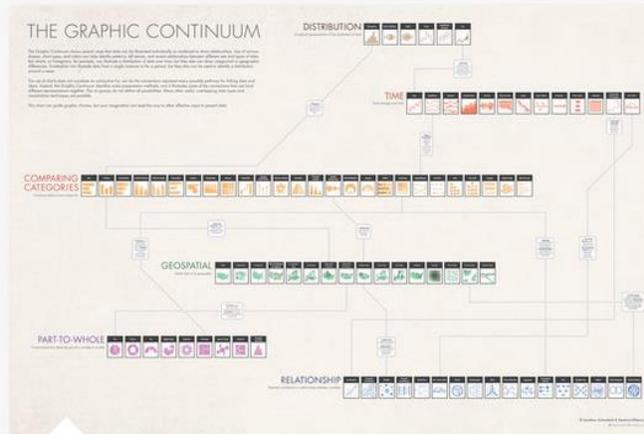
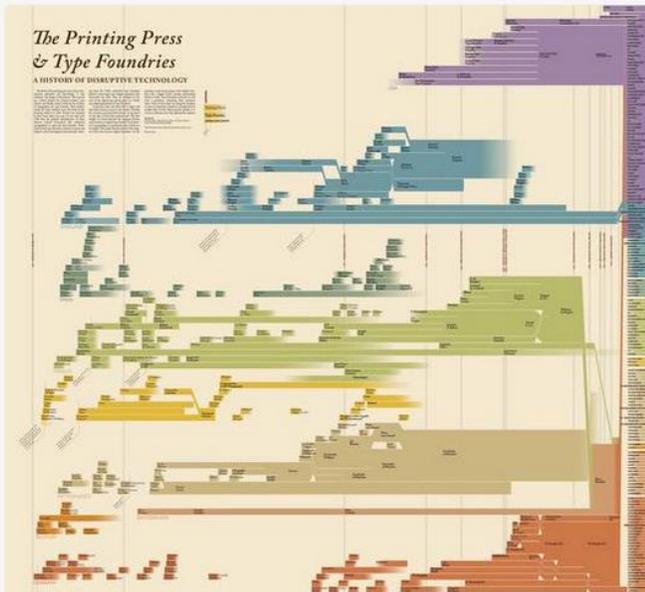
[All](#) [2019](#) [2018](#) [2017](#) [2016](#) [2015](#) [2014](#) [2013](#) [2012](#)

[All](#) [Shortlist](#) [★ Winners](#) [Gold](#) [Silver](#) [Bronze](#) [Rising Star](#) [Outstanding Individual](#) [Best-Non-English-Language](#) [Outstanding Outfit](#) [Student](#)

[Community](#) [Most Beautiful](#)

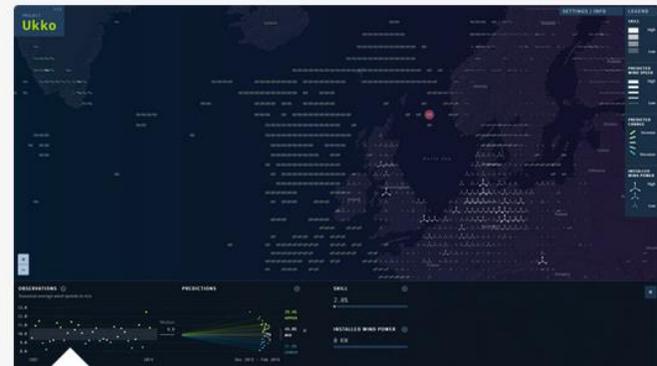
[All](#) [Arts, Entertainment & Culture](#) [Breaking News](#) [Humanitarian](#) [Leisure, Games & Sport](#) [Maps, Places & Spaces](#) [News & Current Affairs](#)

[People, Language & Identity](#) [Politics & Global](#) [Visualization & Information Design](#) [Science & Technology](#) [Unusual](#)



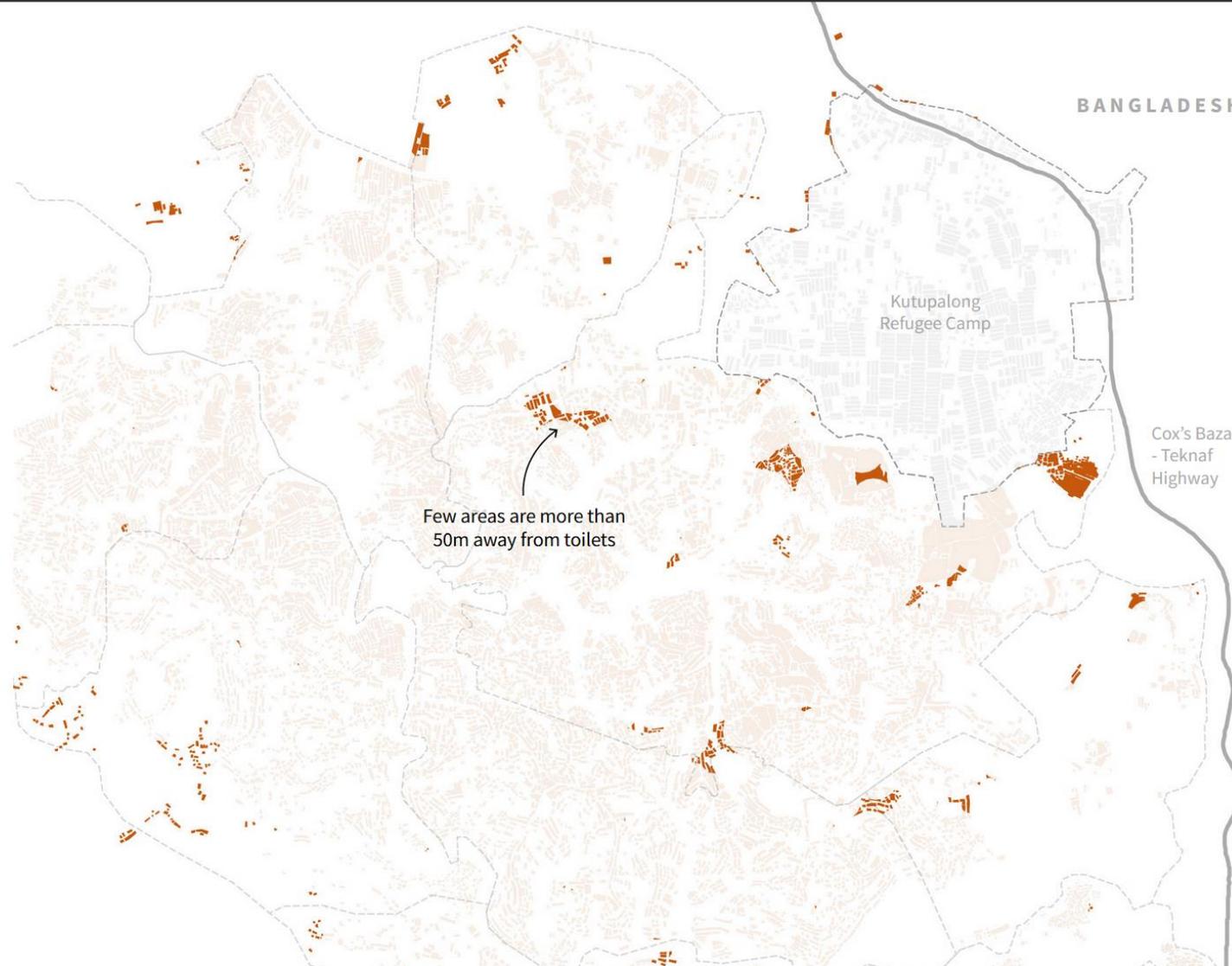
The Graphic Continuum

The Graphic Continuum is our view of the many different types of visualizations available to us



Project Ukko - Seasonal Wind Predictions for the Energy Sector

Weather forecasts predict future wind conditions only in the range of weeks. Climate predictions look at big changes over years and decades



Too far from a latrine

Refugee households should be within 50 metres of a latrine. "Close enough to encourage their use but far enough to prevent problems with smells and pests," the UNHCR guideline says. This map shows refugee shelters that are too far from a latrine.



The Winners of the World Data Visualization Prize

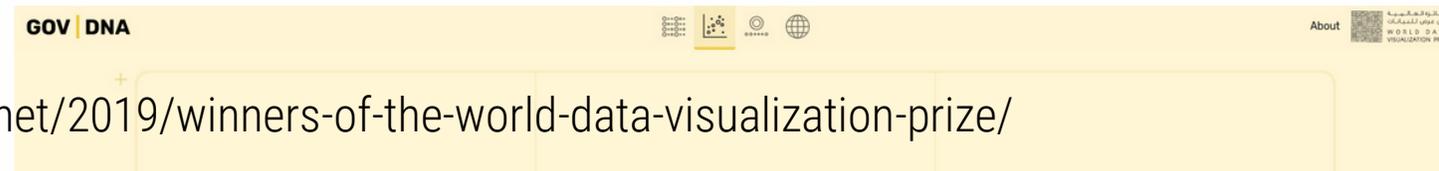
The results are in. After combing through hundreds of impressive, insightful and creative entries, we've decided on the winners of the [World Data Visualization Prize 2019](#).

Conducted in partnership with the [World Government Summit](#), the prize focuses on how governments are improving citizens' lives. We asked entrants to use the power of data-visualization to illuminate data on the innovations and decisions – seen and unseen – that drive progress.

Scroll through the interactive, static and hand-drawn “napkin” category winners to see who took the grand prize of \$25,000.

Interactive

Winner – \$6,000



<https://informationisbeautiful.net/2019/winners-of-the-world-data-visualization-prize/>



<

RANKING

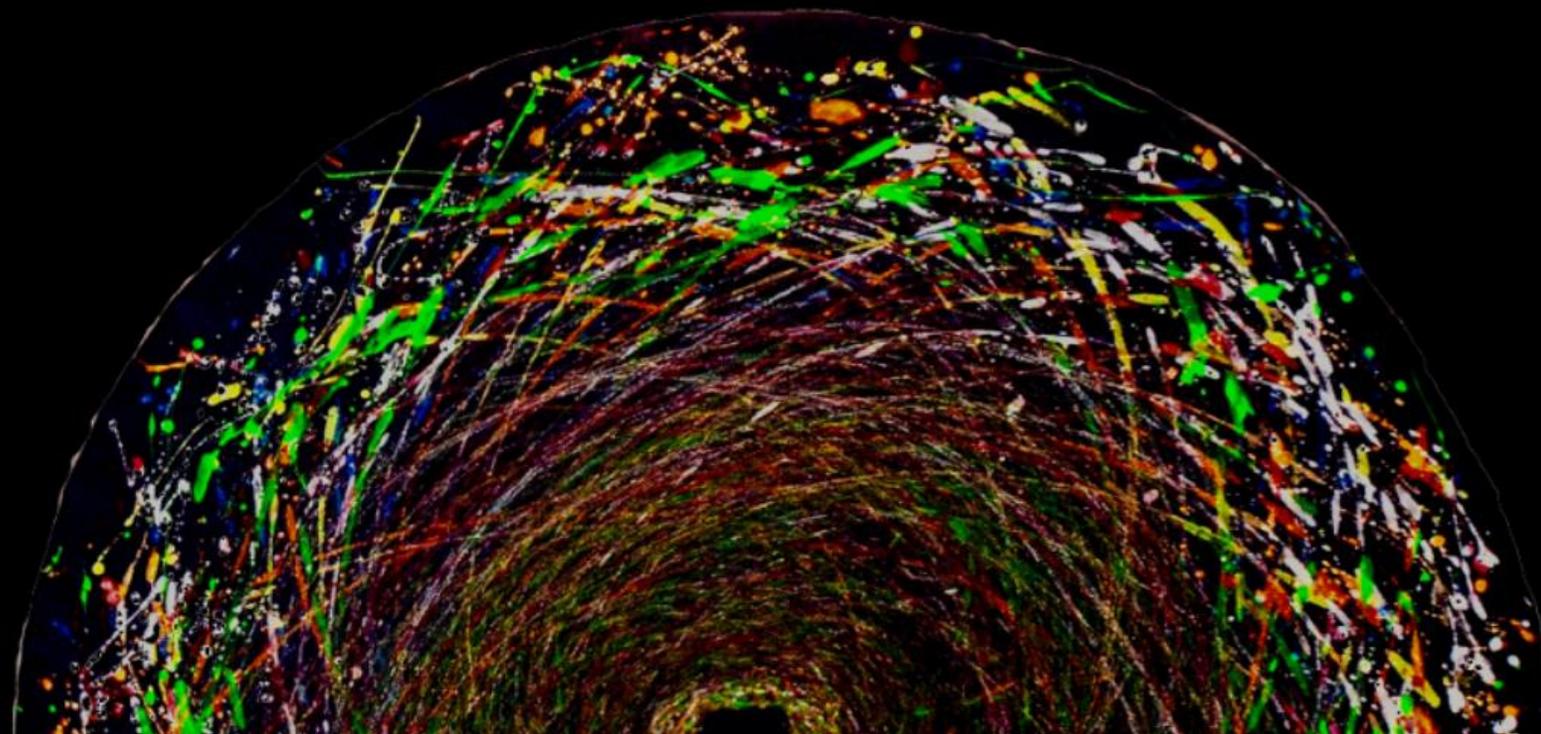
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VISUALIZATION CHALLENGE

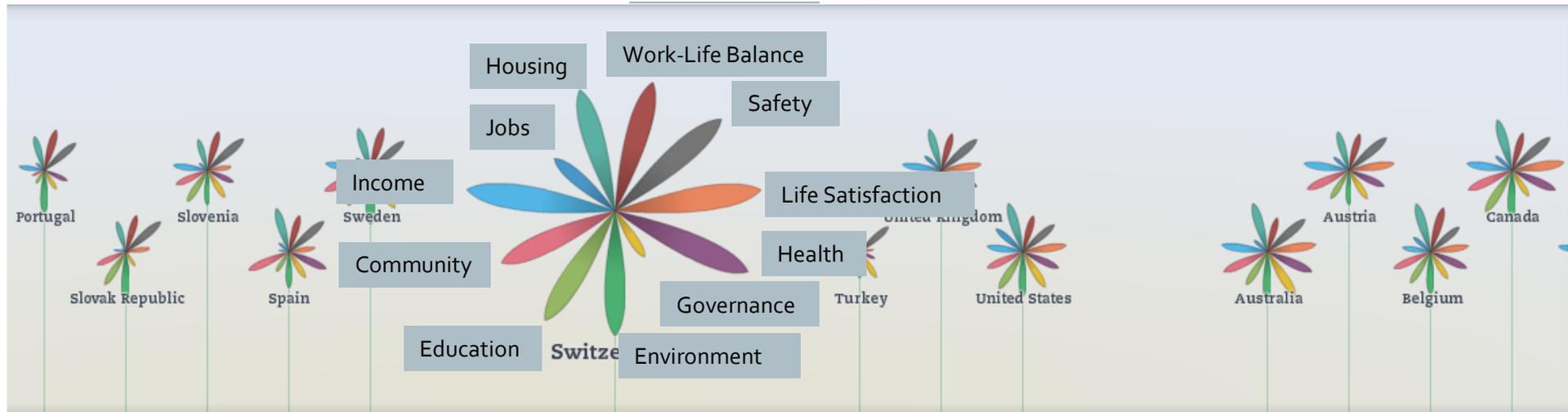
[About](#) [Participants' Guide](#) [Rules and Eligibility](#) [Entry Requirements](#) [Winners](#) [FAQ](#) [Blog](#)

The most beautiful visualizations from the worlds of science and engineering
2018 Winners Announced!



Open Data

- Movement making government data freely available
- Encourage participation by everyone



Specific Visualization Environments



Molecular visualisation in the Reality Cube
University of Groningen, NL



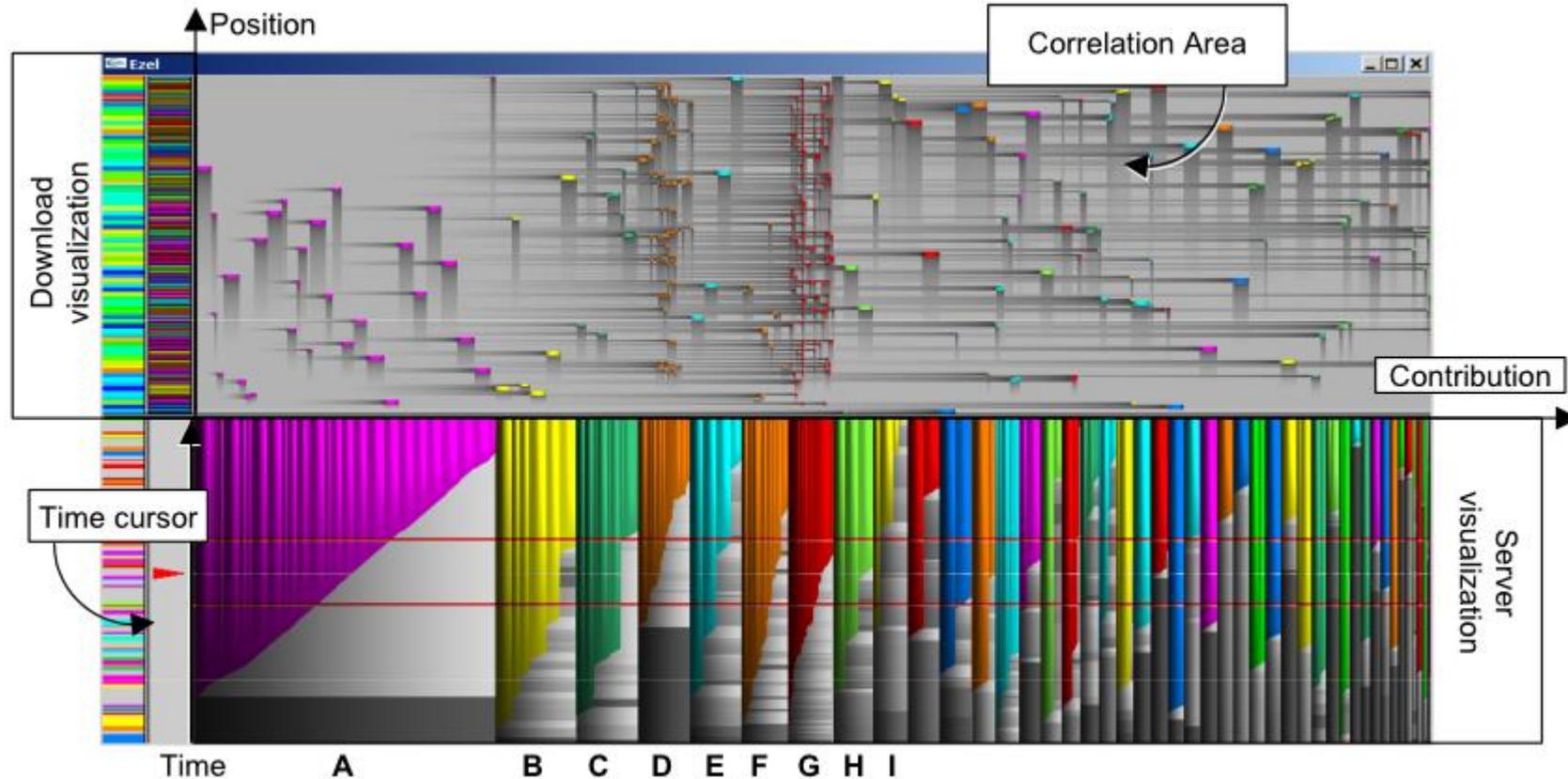
Tabletops for Visualization
University of Calgary



WILD Wall, INRIA

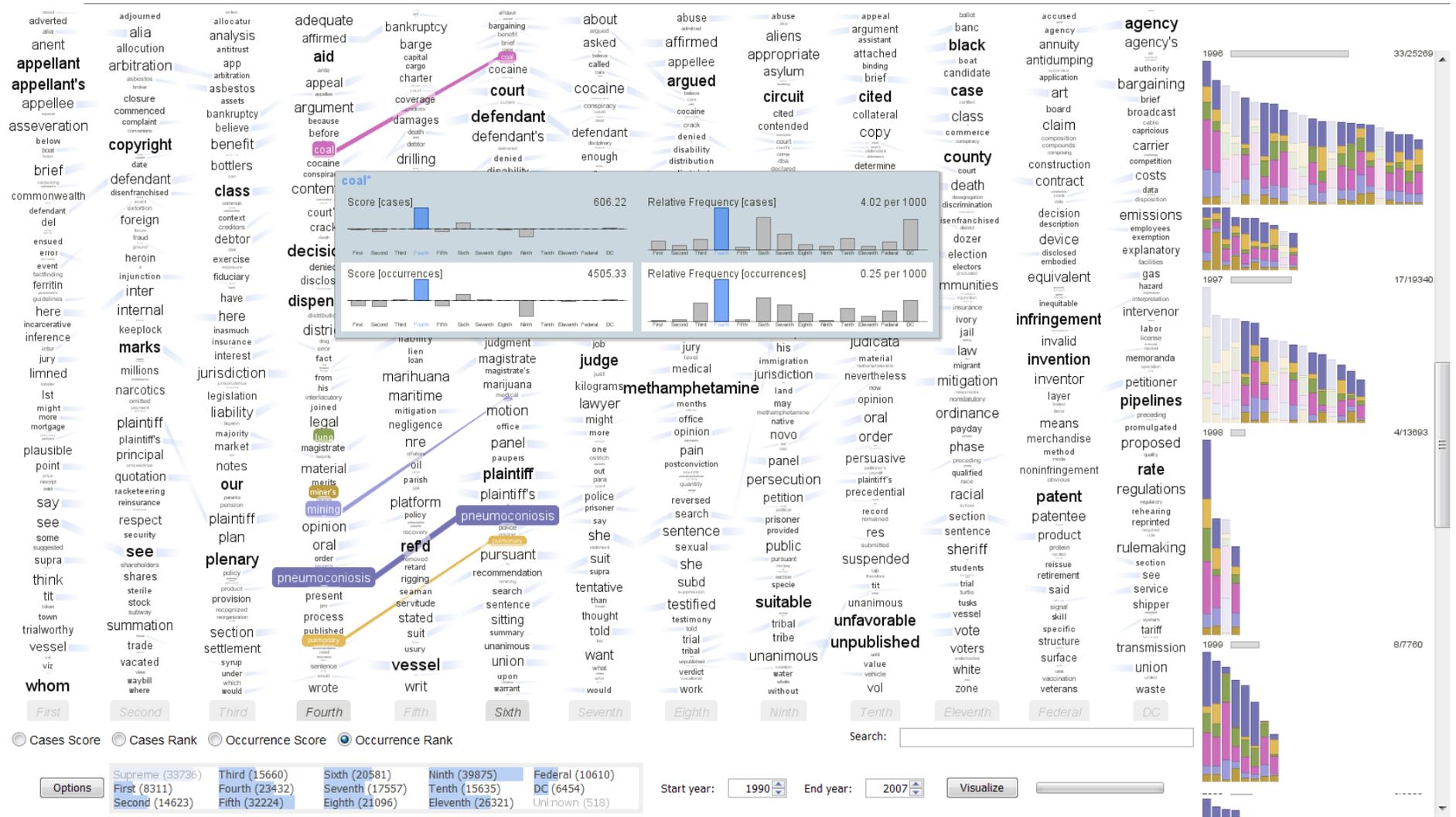
Software Visualization

EZEL: a Visual Tool for Performance Assessment of Peer-to-Peer File-Sharing Networks
(Voinea et al., InfoVis, 2004)



Text Visualization

Parallel Tag Clouds to Explore Faceted Text Corpora (Collins et al., VAST 2009)



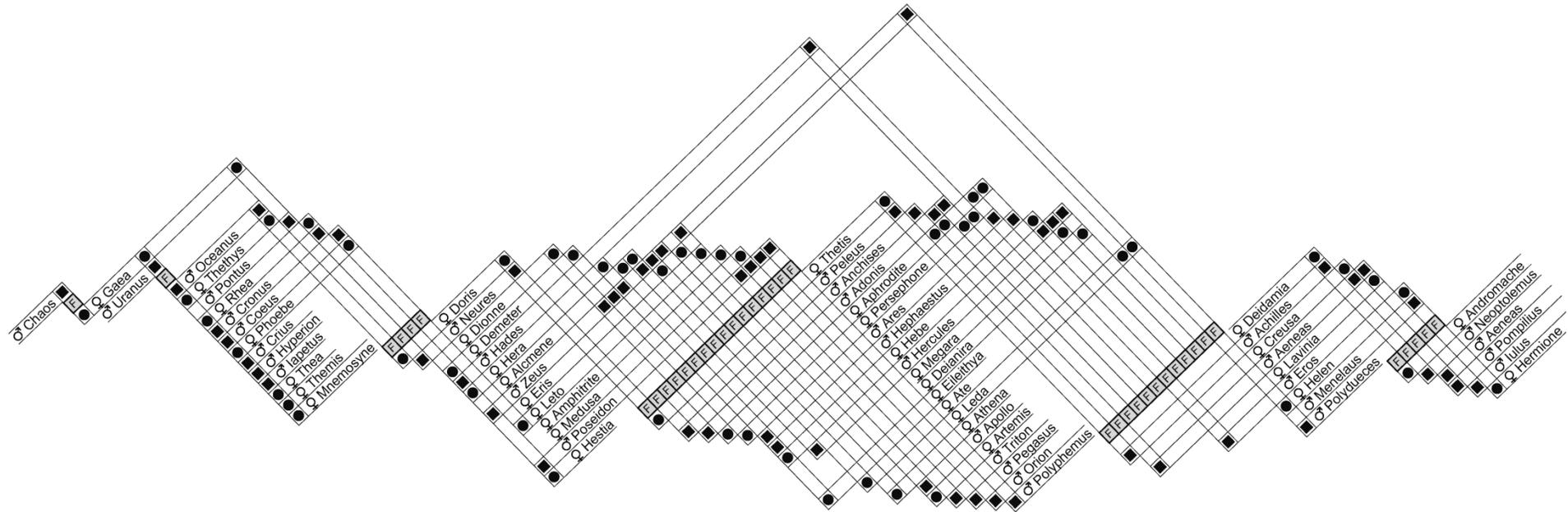
Graphs



http://www.facebook.com/note.php?note_id=469716398919

Visualizing Friendships by [Paul Butler](#) on Tuesday, December 14, 2010

Family Trees



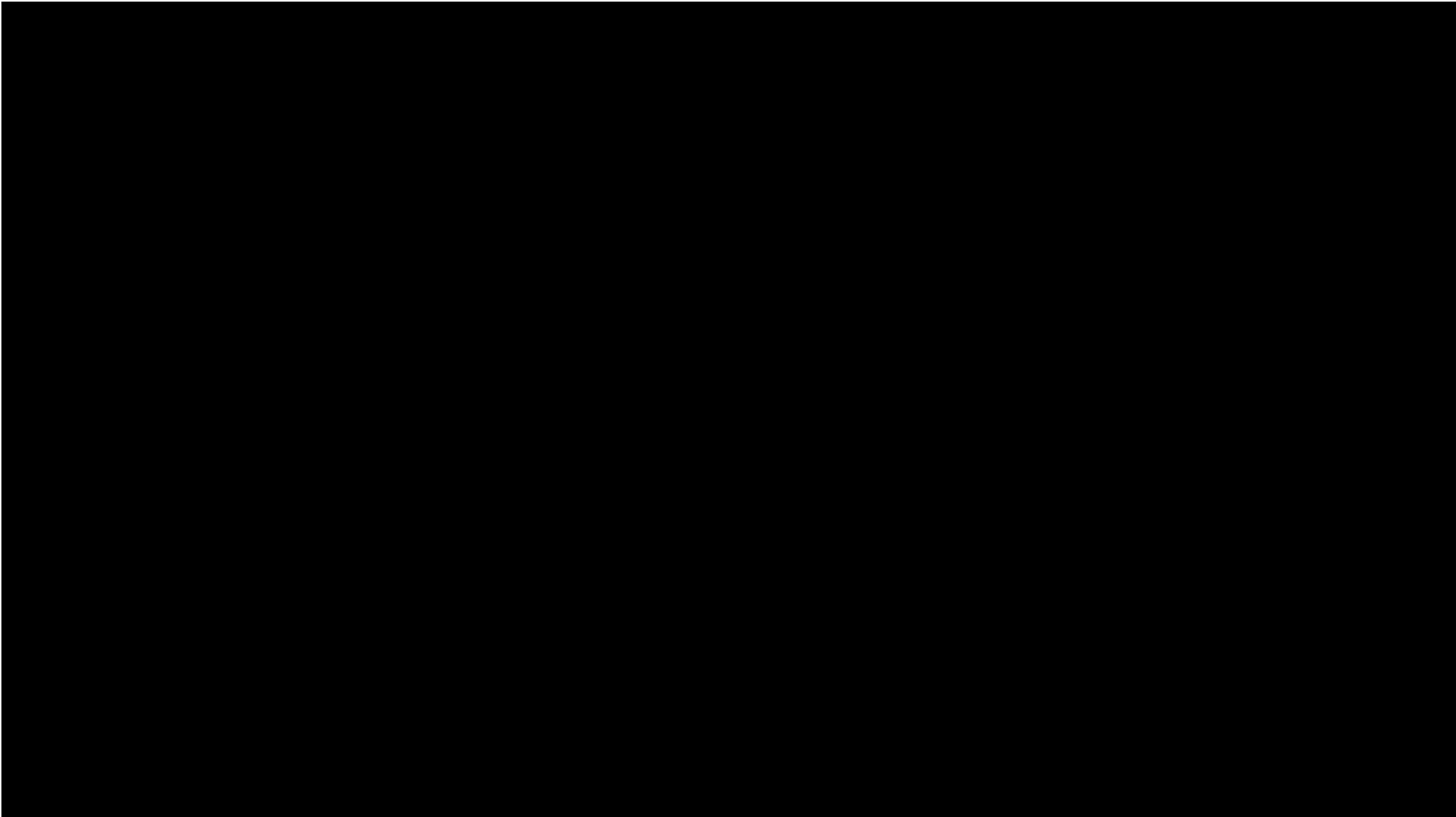
Data Videos

https://players.brightcove.net/679256133001/NkgrDczuol_default/index.html?videoId=5859936437001

The first
Earth Day
was in **1970**



What's changed since?



Weather



Resources for more examples

- Visualization conferences
- Blogs
 - <http://infosthetics.com/>
 - <http://felinlovewithdata.com/>
 - <http://eagereyes.org/>
 - <http://flowingdata.com/>
 - <http://www.informationisbeautiful.net/>
- Books
 - Textbooks
 - Readings in Information Visualization: Using Vision to Think (a bit old now but good intro)
 - Information Visualization (Robert Spence – a light intro, I recommend as a start)
 - Information Visualization Perception for Design (Colin Ware, focused on perception and cognition)
 - Interactive Data Visualization: Foundations, Techniques, and Applications (Ward et al.)
 - Visualization Analysis and Design (Tamara Munzner, most recent book)
 - Examples
 - Beautiful Data (McCandless)
 - Now You See it (Few)
 - Tufte Books: Visual Display of Quantitative Information (and others)
 - ... (many more, ask me for details)

It is difficult to create

CREATE VISUALIZATIONS

GOOD



What is a representation?

- A representation is
 - a formal system or mapping by which the information can be specified (D. Marr)
 - a sign system in that it stands for something other than its self.
- for example: the number thirty-four

34

decimal

100010

binary

XXXIV

roman

Presentation

- different representations reveal different aspects of the information
 - decimal: counting & information about powers of 10,
 - binary: counting & information about powers of 2,
 - roman: impress your friends (outperformed by positional system)
- presentation
 - how the representation is placed or organized on the screen

34, **34**, 34

Principles of Graphical Excellence

- Well-designed presentation of interesting data – a matter of *substance, statistics, design*
- Complex ideas communicated with clarity, precision, efficiency
- Gives the viewer the greatest number of ideas in the shortest time with the least ink in the smallest space
- Involves almost always multiple variables
- Tell the truth about the data

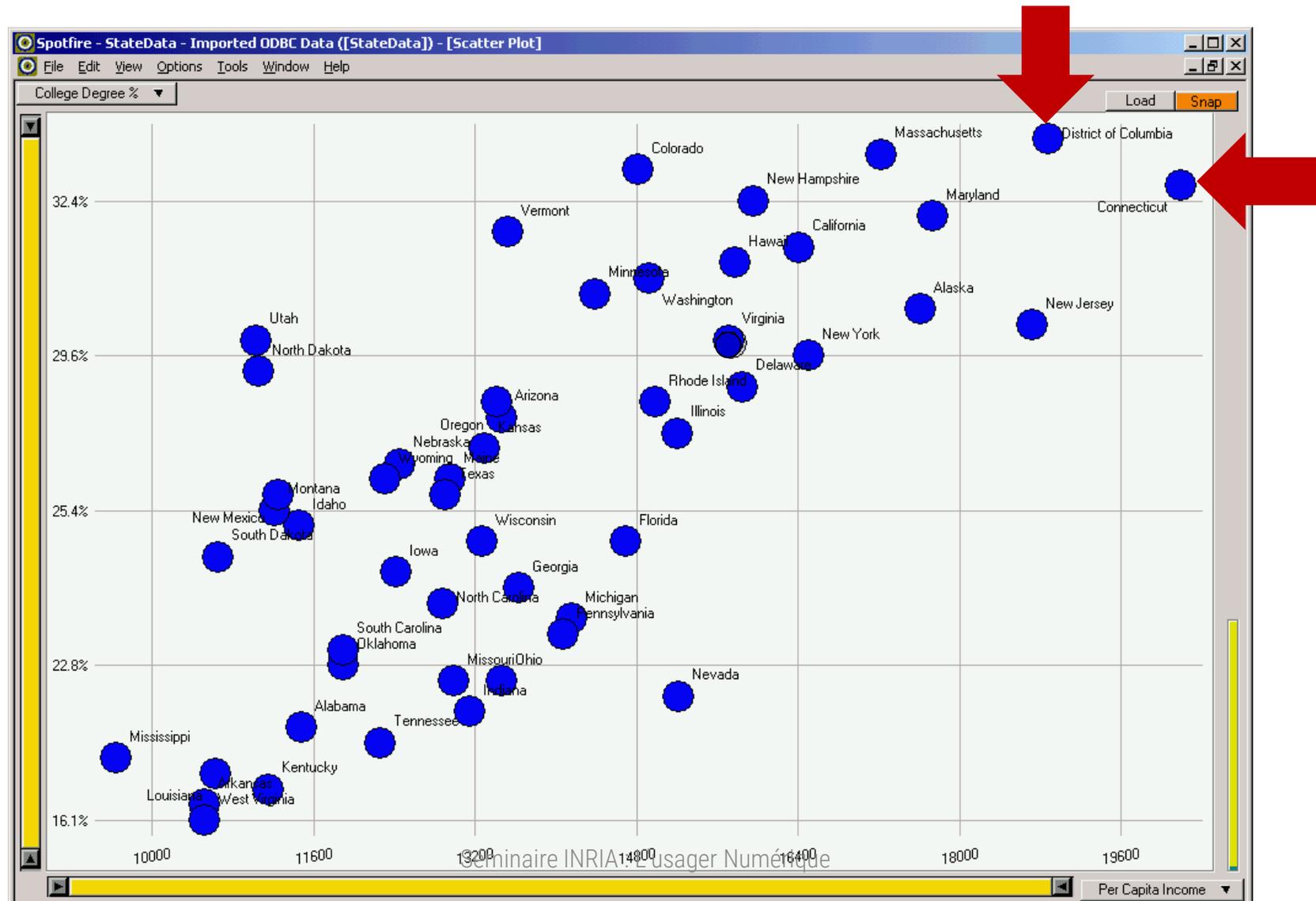
Or a bit more simply...

- Solving a problem simply means representing it so as to make the solution transparent ... (Simon, 1981)
- Good representations:
 - allow people to find relevant information
 - information may be present but hard to find
 - allow people to compute desired conclusions
 - computations may be difficult or “for free” depending on representations

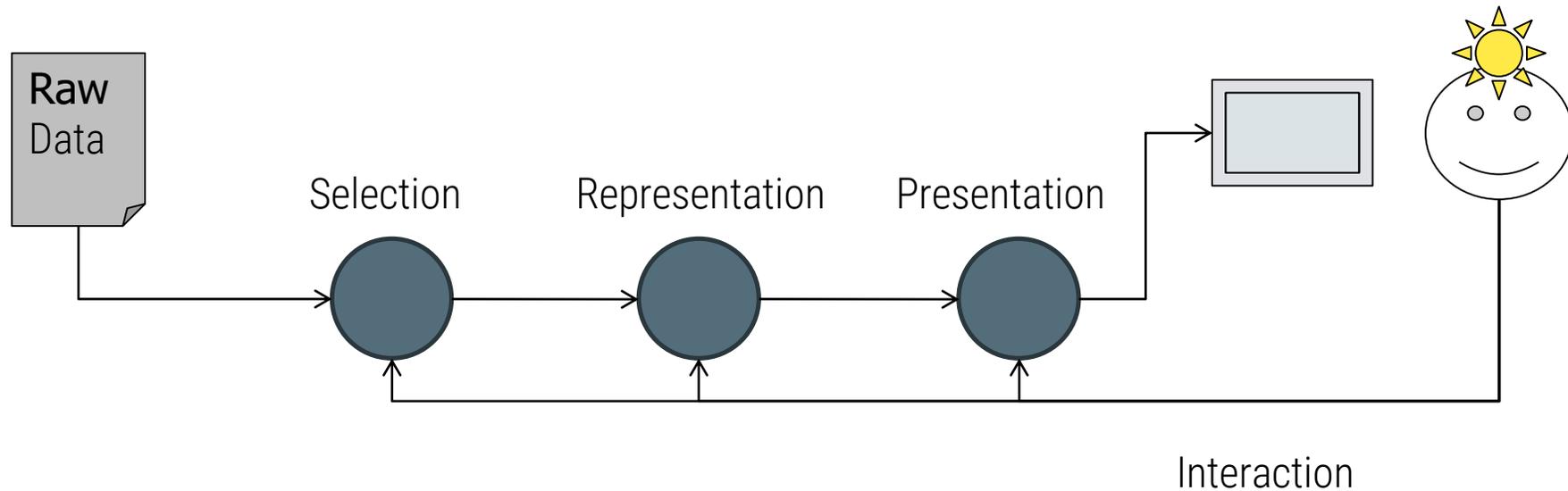
Good representation?

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	28.1%	11051
Ohio	22.3%	13461
Oklahoma	22.8%	11893
Oregon	27.5%	13418
Pennsylvania	23.2%	14068
Rhode Island	27.5%	14981
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

Good representation!



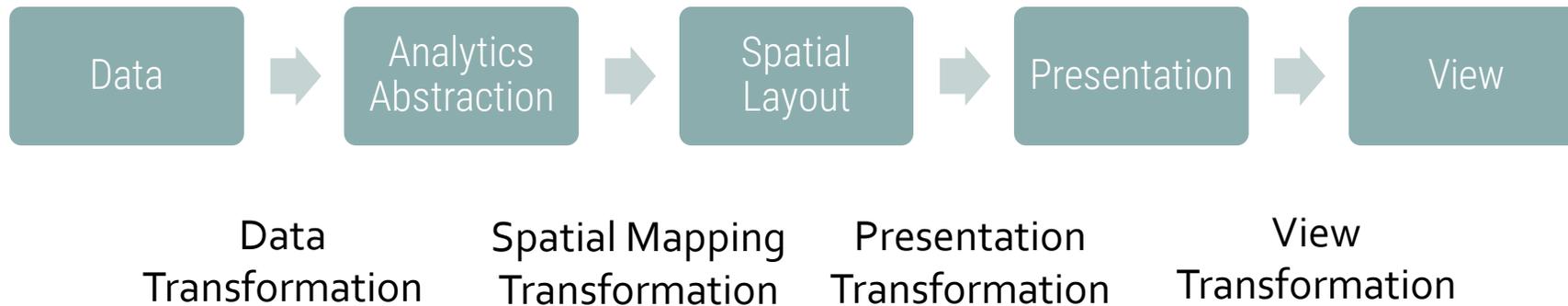
How do we arrive at a visualization?



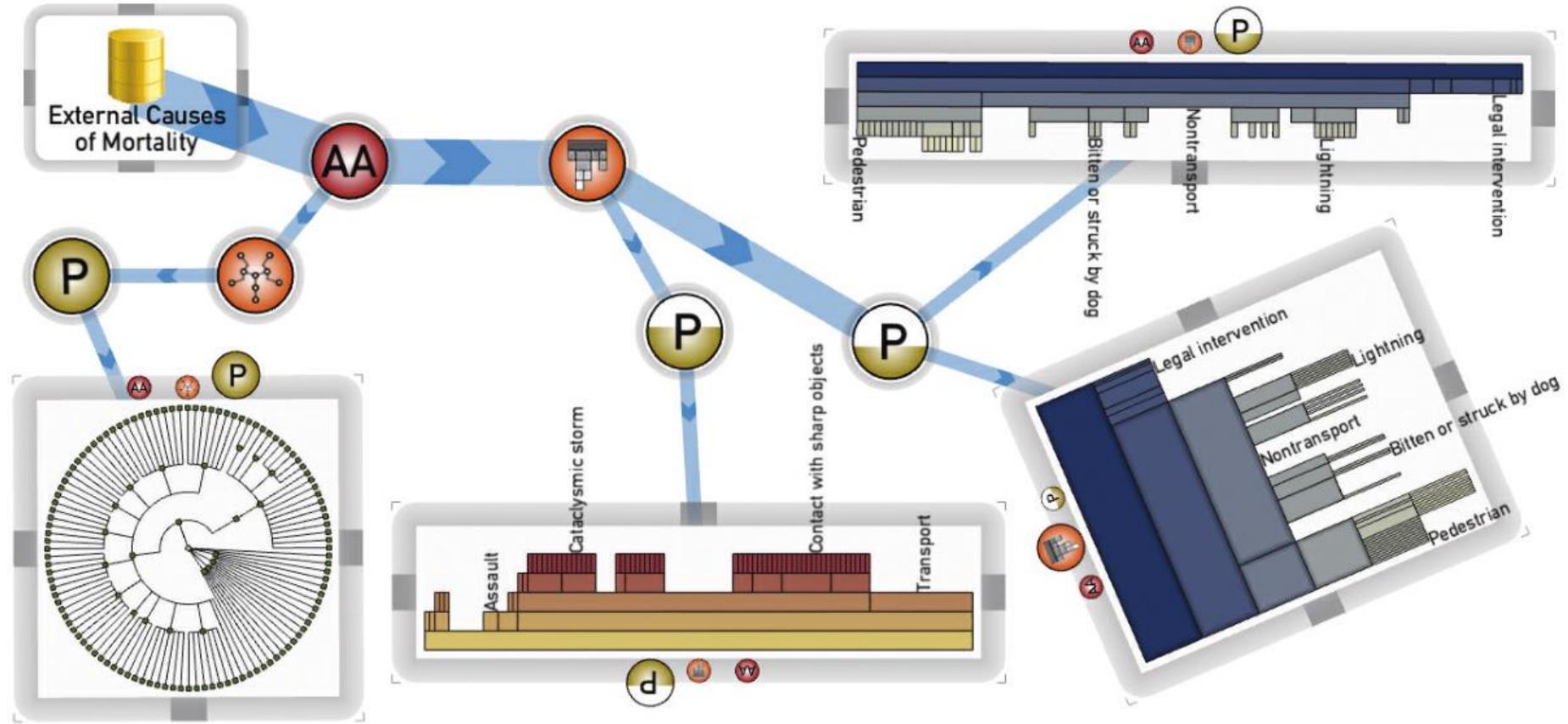
The Visualization Pipeline

Visualization Reference Model

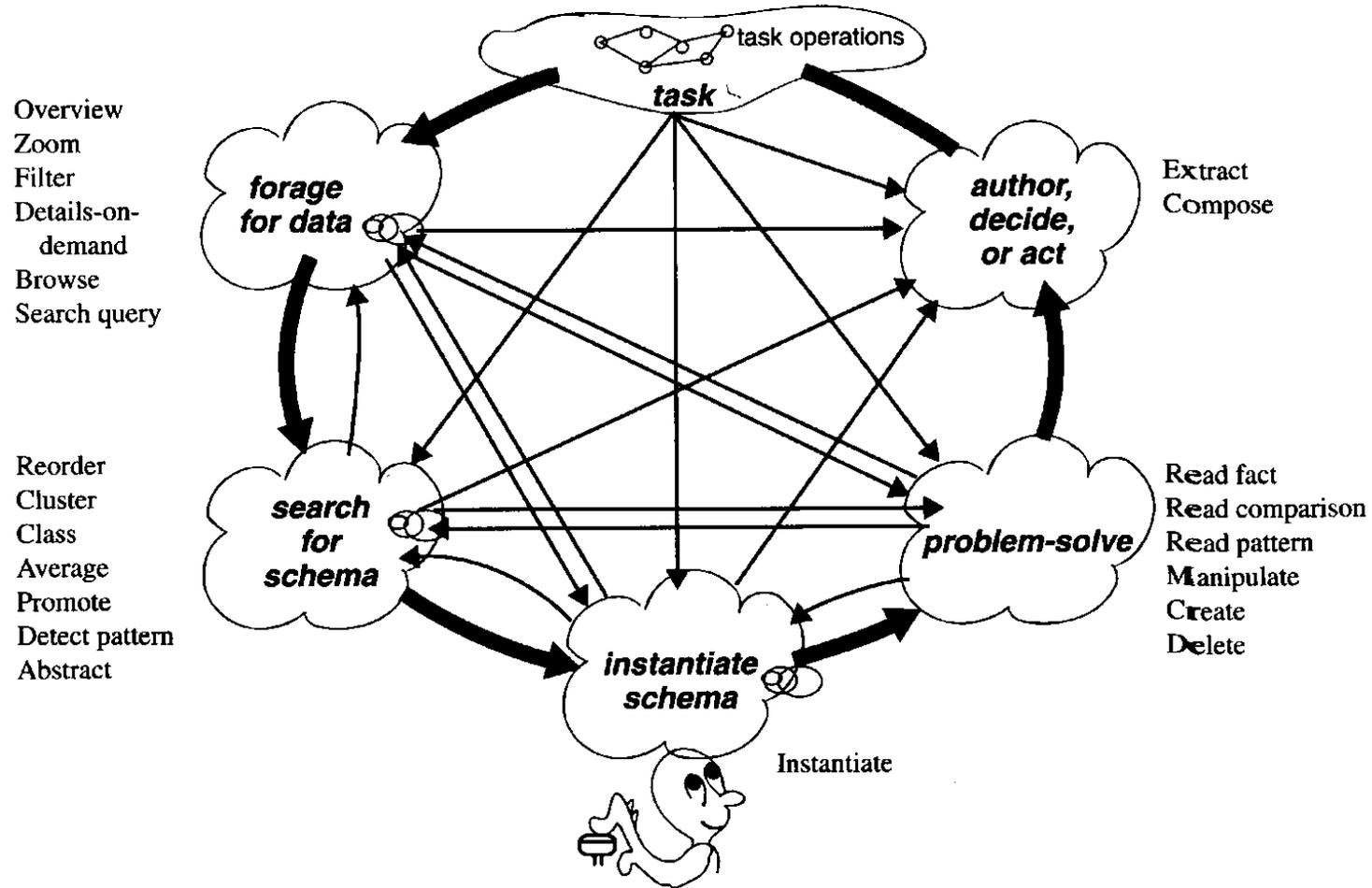
Also a visualization pipeline a bit expanded



Visualization pipeline in an image



Knowledge Crystallization Cycle



Working with visualizations in NOT a linear process

[Card et al., 1999]

Pitfalls

- Selecting the wrong data
- Selecting the wrong data structure
- Filtering out important data
- Failed understanding of the types of things that need to be shown
- Choosing the wrong representation
- Choosing the wrong presentation format
- Inappropriate interactions provided to explore the data

Recap

- So far you
 - learned what information visualization is
 - learned about the advantages of visualization
 - saw a number of examples (historical and new)
- Next
 - you will get to know your data
 - you will learn about the basic components of visualization

Data

- Data is the foundation of any visualization
- The visualization designer needs to understand
 - the data properties
 - know what meta-data is available
 - know what people want from the data

Nominal, Ordinal and Quantitative

- Nominal (labels)
 - Fruits: apples, oranges
- Ordered
 - Quality of meat: grade A, AA, AAA
 - Can be counted and ordered, but not measured
- Quantitative: Interval
 - no clear zero (or arbitrary)
 - e.g. dates, longitude, latitude
 - usually compare differences (intervals)
- Quantitative: Ratio
 - meaningful origin (zero)
 - physical measurements (temperature, mass, length)
 - counts and amounts

Nominal, Ordinal and Quantitative

- Nominal (labels)
 - Operations: =, ≠
- Ordered
 - Operations: =, ≠, <, >
- Quantitative: Interval
 - Operations: =, ≠, <, >, -, +
 - Can measure distances or spans
- Quantitative: Ratio
 - Operations: =, ≠, <, >, -, +, ×, ÷
 - Can measure ratios or proportions

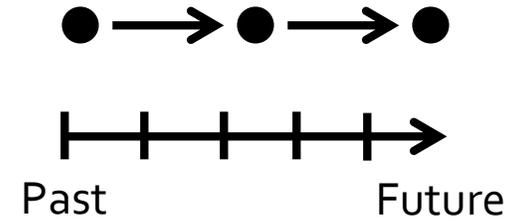


[1989 – 1999] + [2002 – 2012]

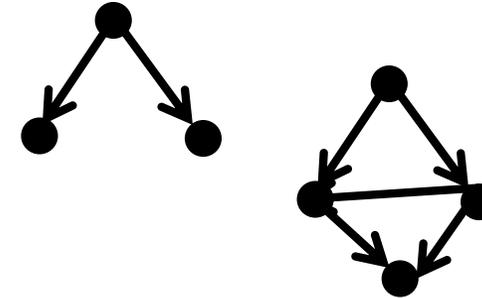
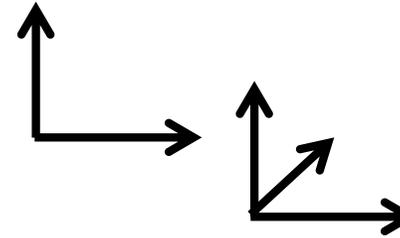
10kg / 5kg

Data-Type Taxonomy

- 1D (linear)
- Temporal
- 2D (maps)
- 3D
- nD (relational)
- Trees (hierarchies)
- Networks (graphs)



vis examples later

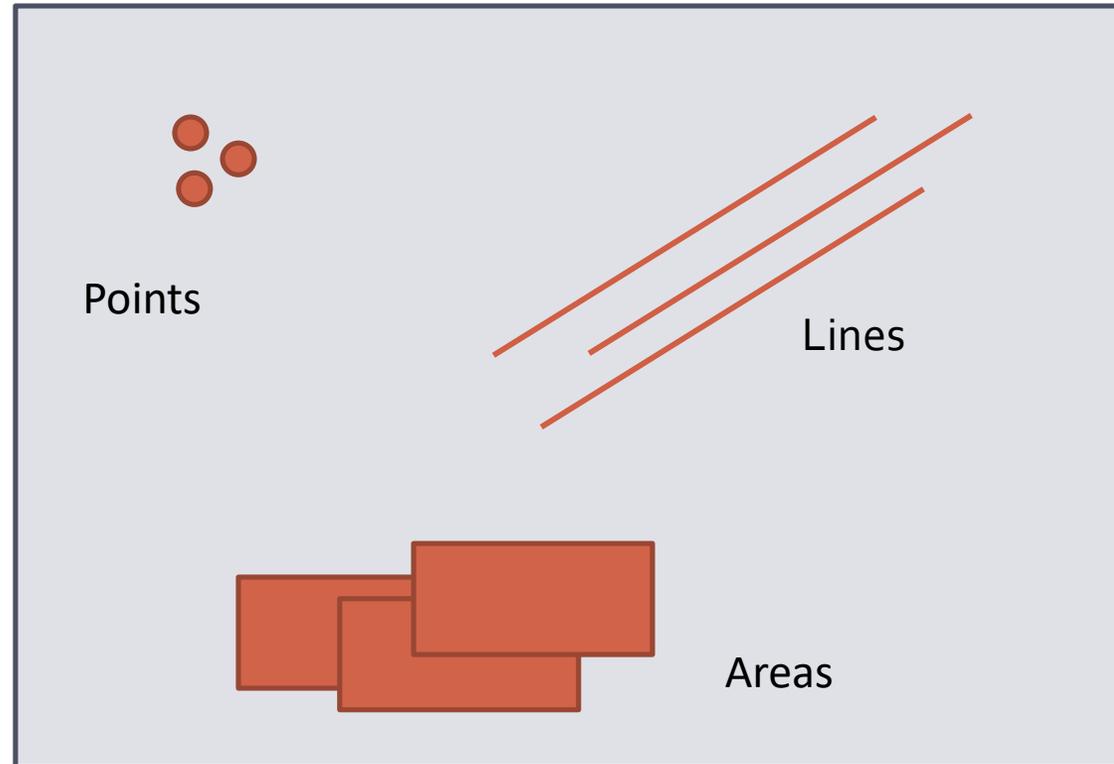


Why is this important?

- Nominal, ordinal, and quantitative data are best expressed in different ways visually
- Data types often have inherent tasks
 - temporal data (comparison of events)
 - trees (understand parent-child relationships)
 - ...
- But:
 - any data type (1D, 2D,...) can be expressed in a multitude of ways!

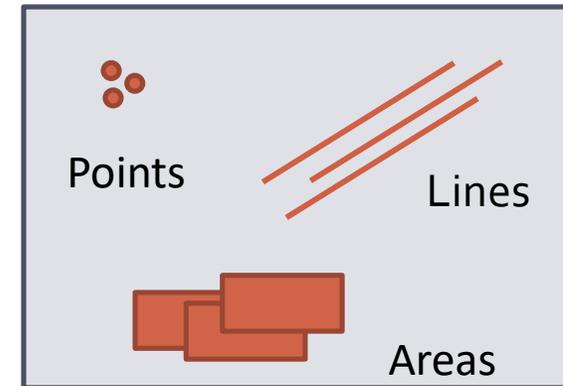
Visualization's Main Building Blocks

Marks which represent:



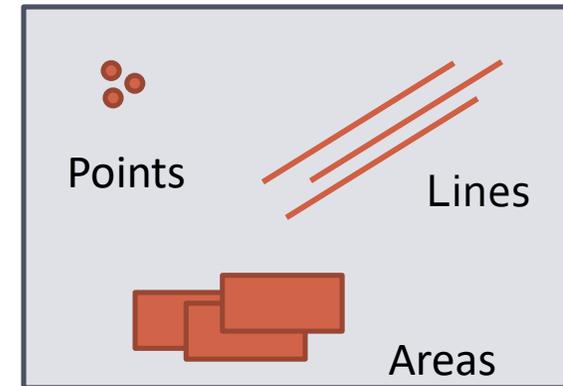
Points

- “A point represents a location on the plane that has **no theoretical length or area.** This signification is independent of the size and character of the mark which renders it visible.”
- a location
- marks that indicate points can vary in all visual variables



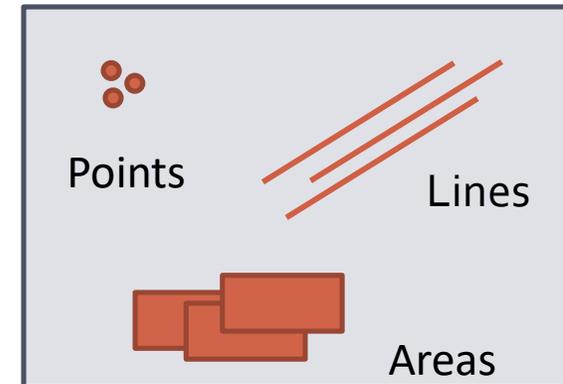
Lines

- “A line signifies a phenomenon on the plane which has **measurable length but no area**. This signification is independent of the width and characteristics of the mark which renders it visible.”
- a boundary, a route, a connection

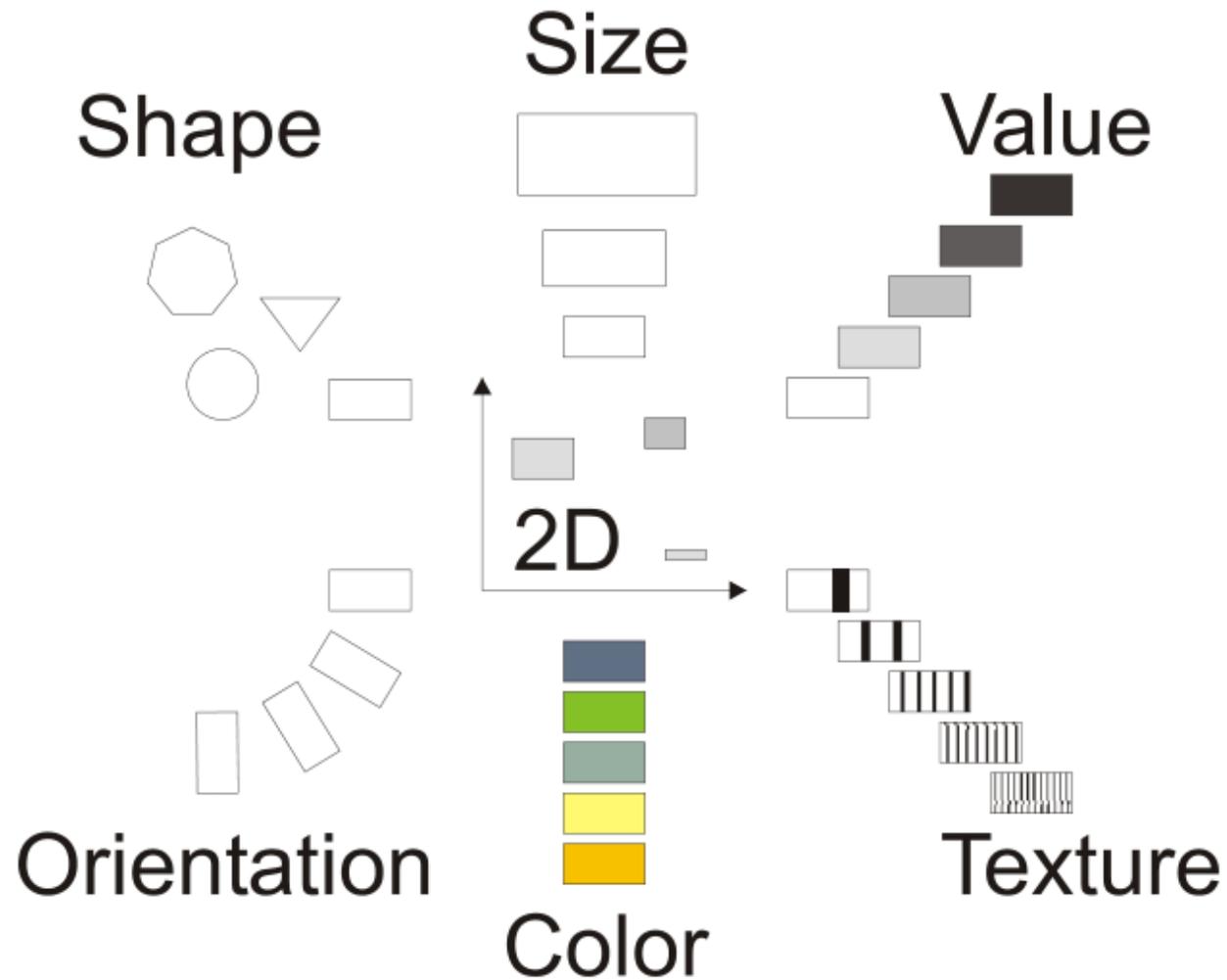


Areas

- “An area signifies something on the plane that **has measurable size**.
This signification applies to the entire area covered by the visible mark.”
- an area can change in position but not in size, shape or orientation without making the area itself have a different meaning



Visual Variables Applicable to Marks



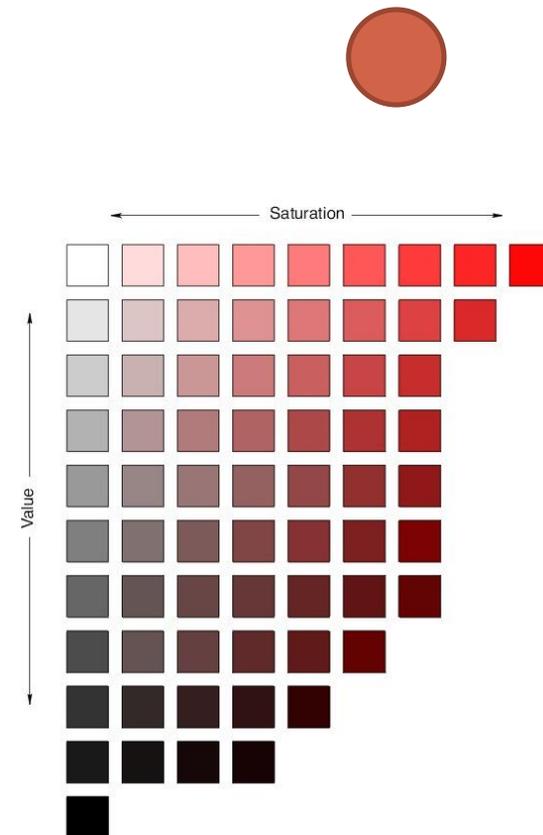
Additional Variables for Computers

- **motion**

- direction, acceleration, speed, frequency, onset, 'personality'

- **saturation**

- colour as Bertin uses largely refers to hue, saturation != value



Extending those from Semiology of Graphics (Bertin)

Additional Variables for Computers

- **flicker**
 - frequency, rhythm, appearance
- **depth? 'quasi' 3D**
 - depth, occlusion, aerial perspective, binocular disparity
- **Illumination**
- **transparency**

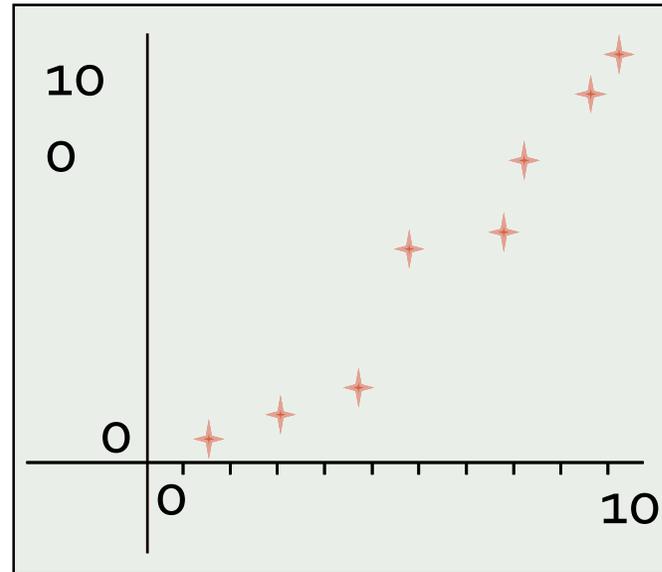
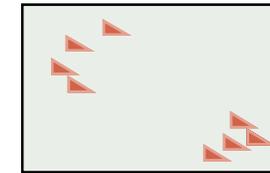
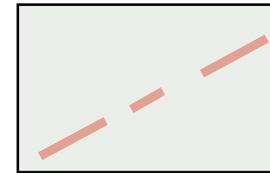
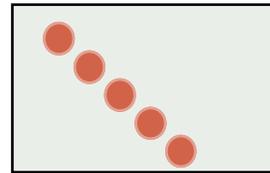
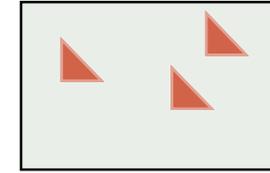
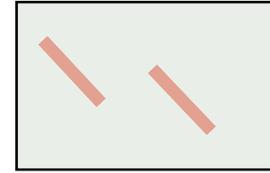
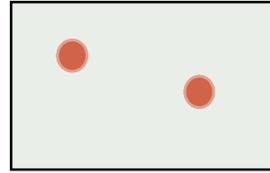


Characteristics of Visual Variables

- **Selective:**
Can this variable allow us to spontaneously differentiate/isolate items from groups?
- **Associative:**
Can this variable allow us to spontaneously group items in a group?
- **Ordered:**
Can this variable allow us to spontaneously perceive an order?
- **Quantitative:**
Can the difference between two marks in this variable be interpreted numerically ?
- **Length (resolution):**
Across how many changes in this variable are distinctions possible?

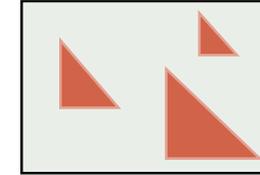
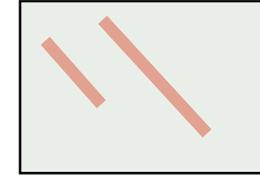
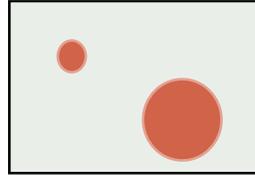
Visual Variable: Position

- ✓ • selective
- ✓ • associative
- ✓ • quantitative
- ✓ • order
- ✓ • length
(resolution)

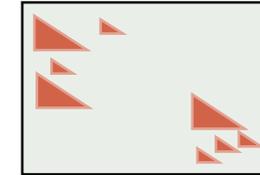
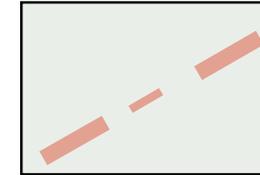
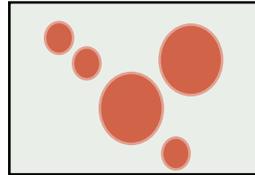


Visual Variable: Size

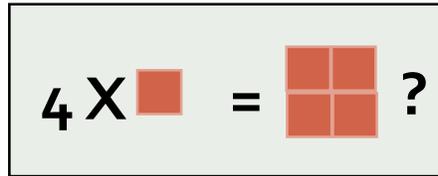
✓ • selective



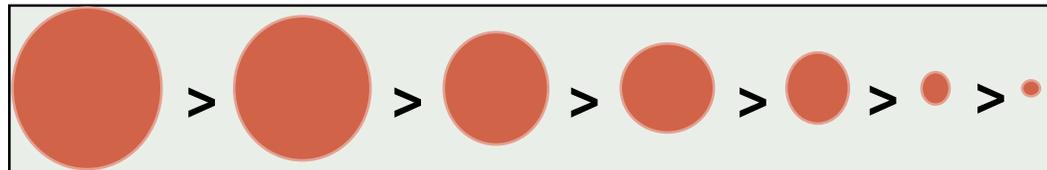
✓ • associative



✓ • quantitative



✓ • order



✓ • length
(resolution)

Size



points



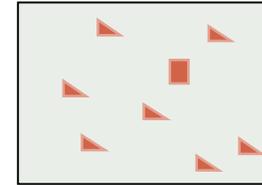
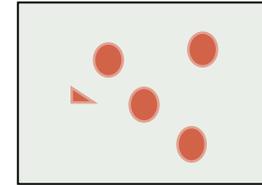
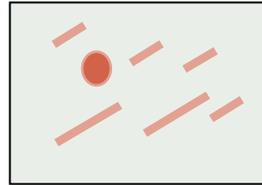
lines



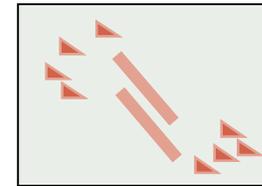
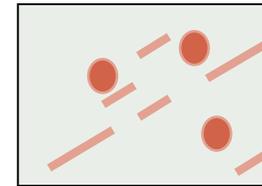
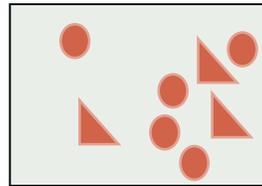
areas

Visual Variable: Shape

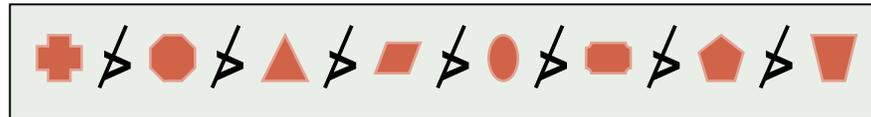
 • selective



 • associative



 • ordered



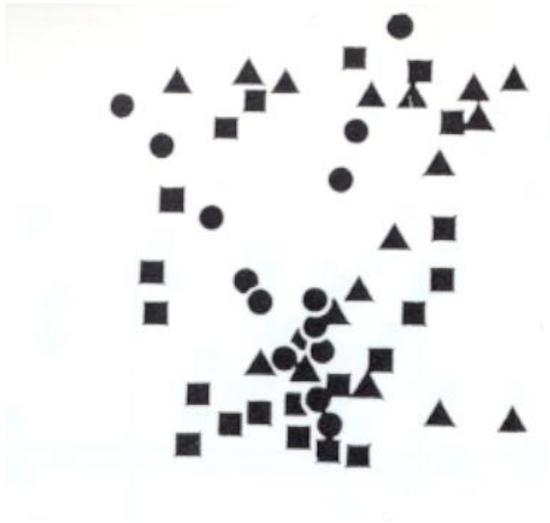
 • quantitative

 • length
(resolution)



– infinite

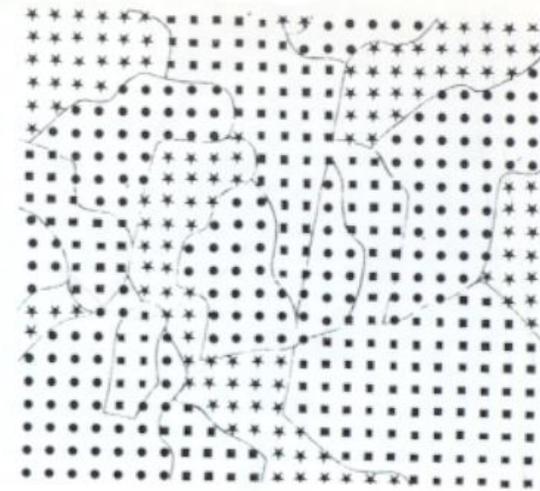
Shape



points



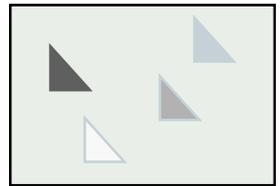
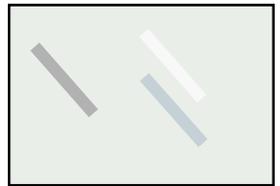
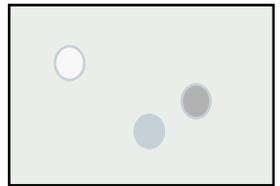
lines



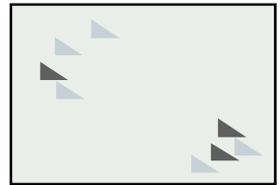
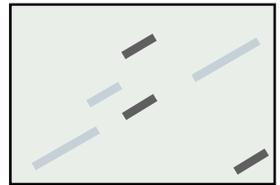
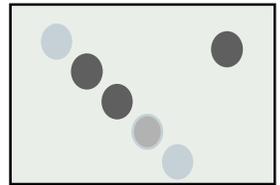
areas

Visual Variable: Value

✓ • selective

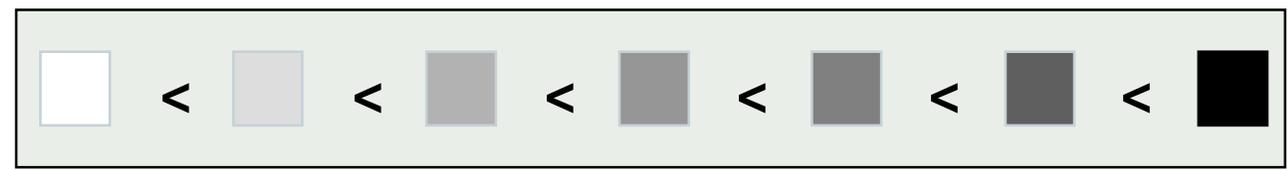


✓ • associative



≠ • quantitative

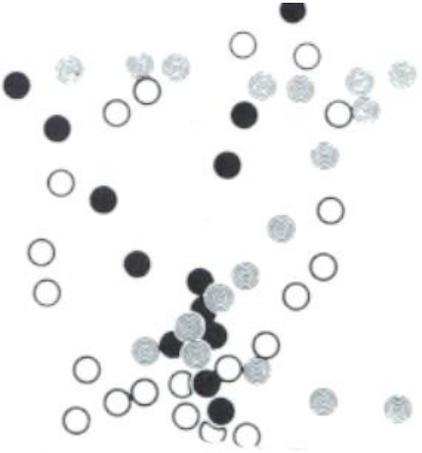
✓ • order



✓ • length (resolution)

- theoretically infinite but practically limited
- association and selection ~ < 7 and distinction ~ 10

Value



points



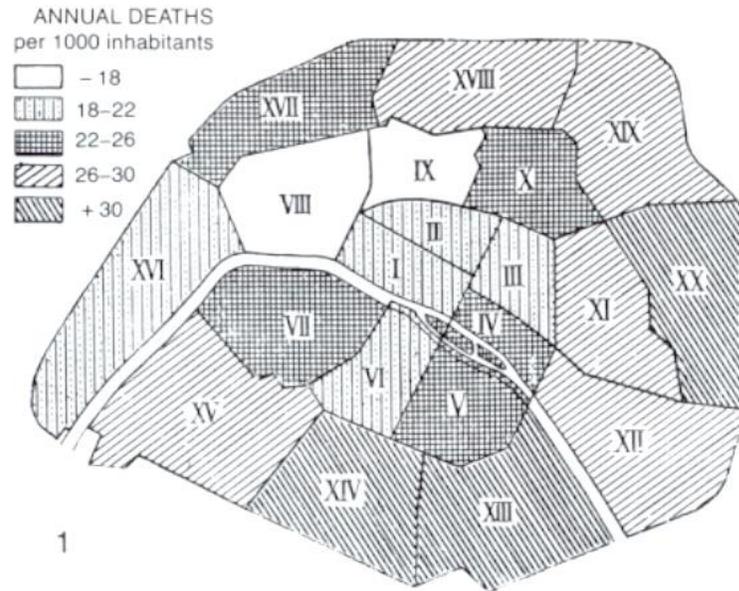
lines



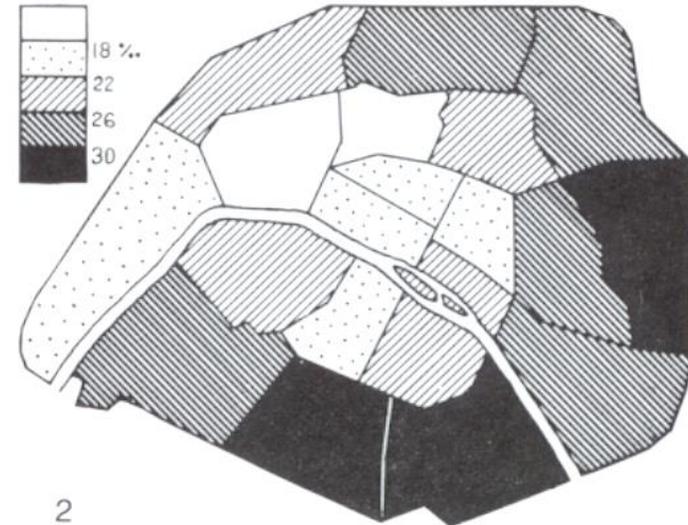
areas

Value

ordered, cannot be reordered



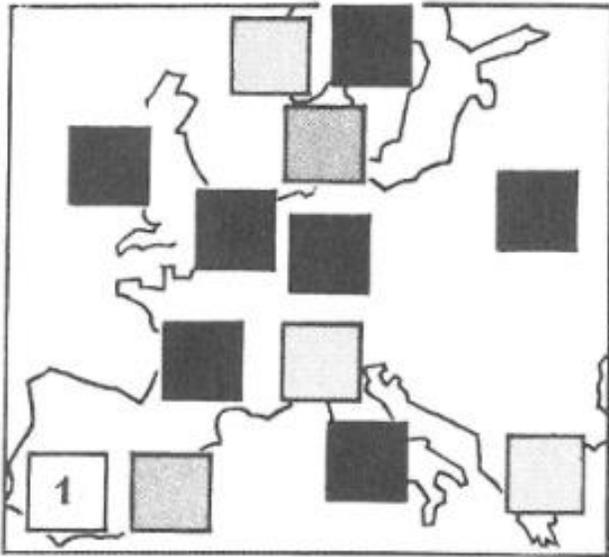
Values not ordered correctly according to scale
Information has to be read point by point



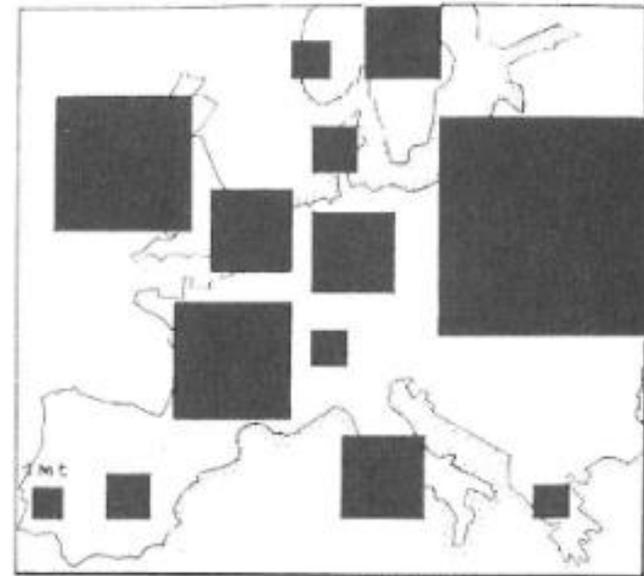
Values ordered correctly
Image much more useful

Value

is not quantitative



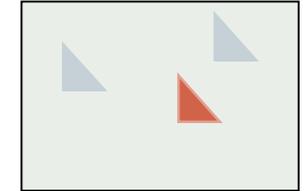
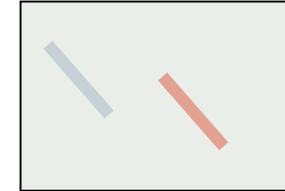
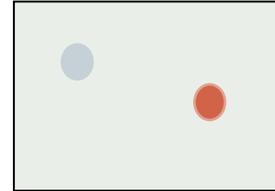
if Portugal is 1, what is France?
you need a legend!



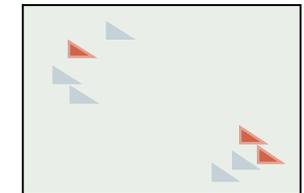
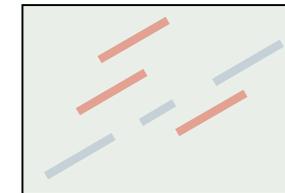
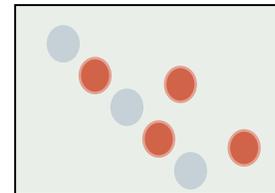
if Portugal is 1, what is France?
still hard, but doable

Visual Variable: Colour

✓ • selective



✓ • associative



≠ • quantitative

≠ • order



✓ • length (resolution)

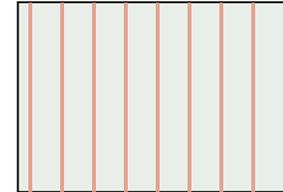
- theoretically infinite but practically limited
- association and selection ~ < 7 and distinction ~ 10

Visual Variable: Orientation

✓ • selective

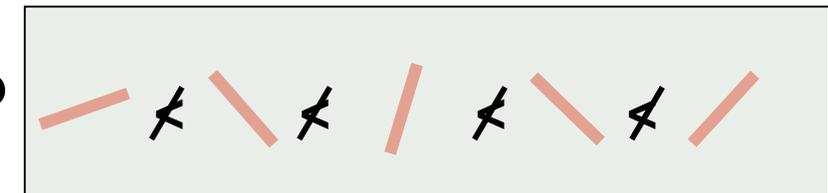
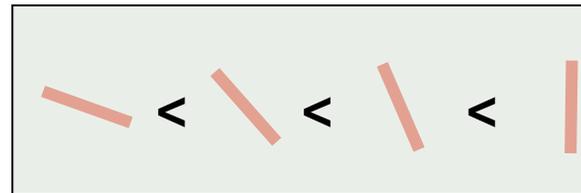


✓ • associative



~~≠~~ • quantitative

~~≠~~ • order



✓ • length (resolution)

• ~5 in 2D; ? in 3D

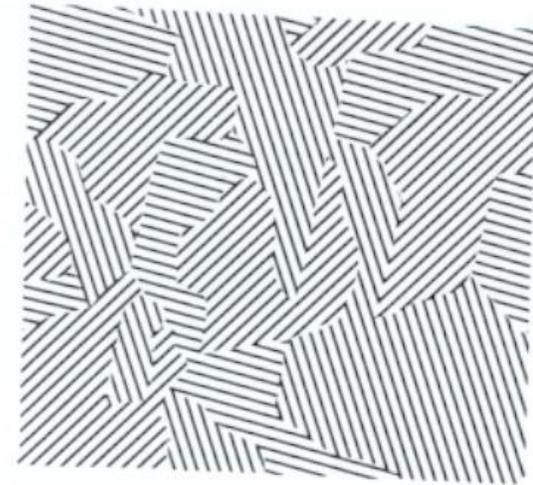
Orientation



points



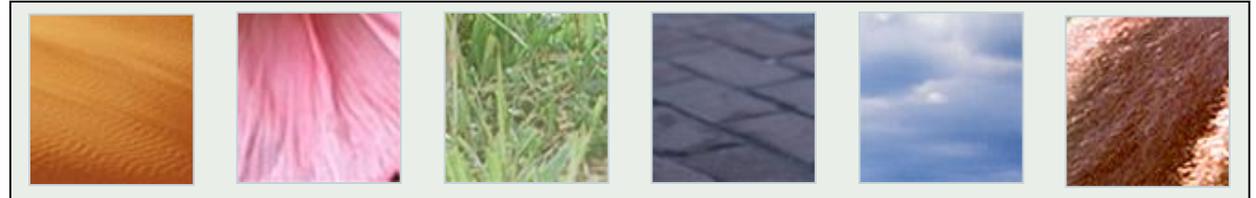
lines



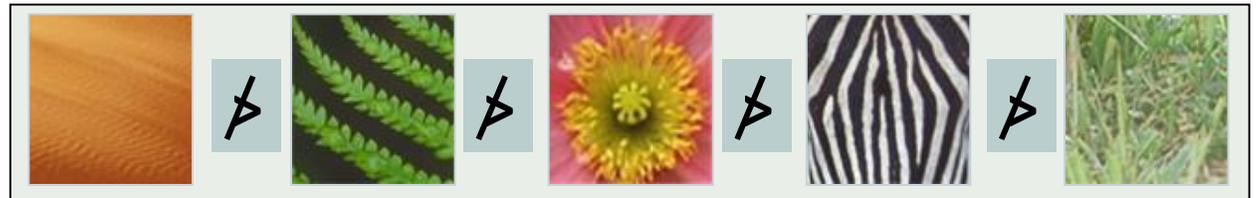
areas

Visual Variable: Texture

- ✓ • selective
- ✓ • associative
- ≠ • quantitative



- ≠ • order



- ✓ • length
(resolution)
 - theoretically infinite

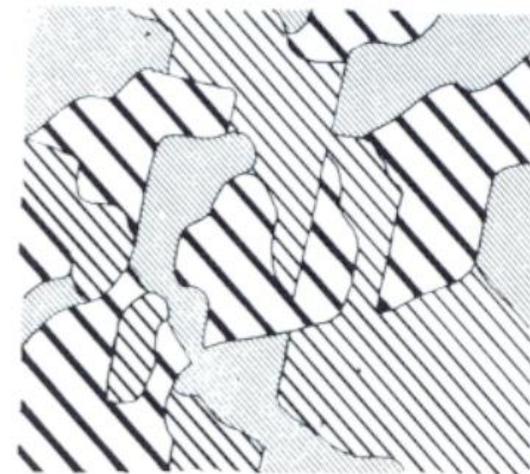
Texture



points



lines

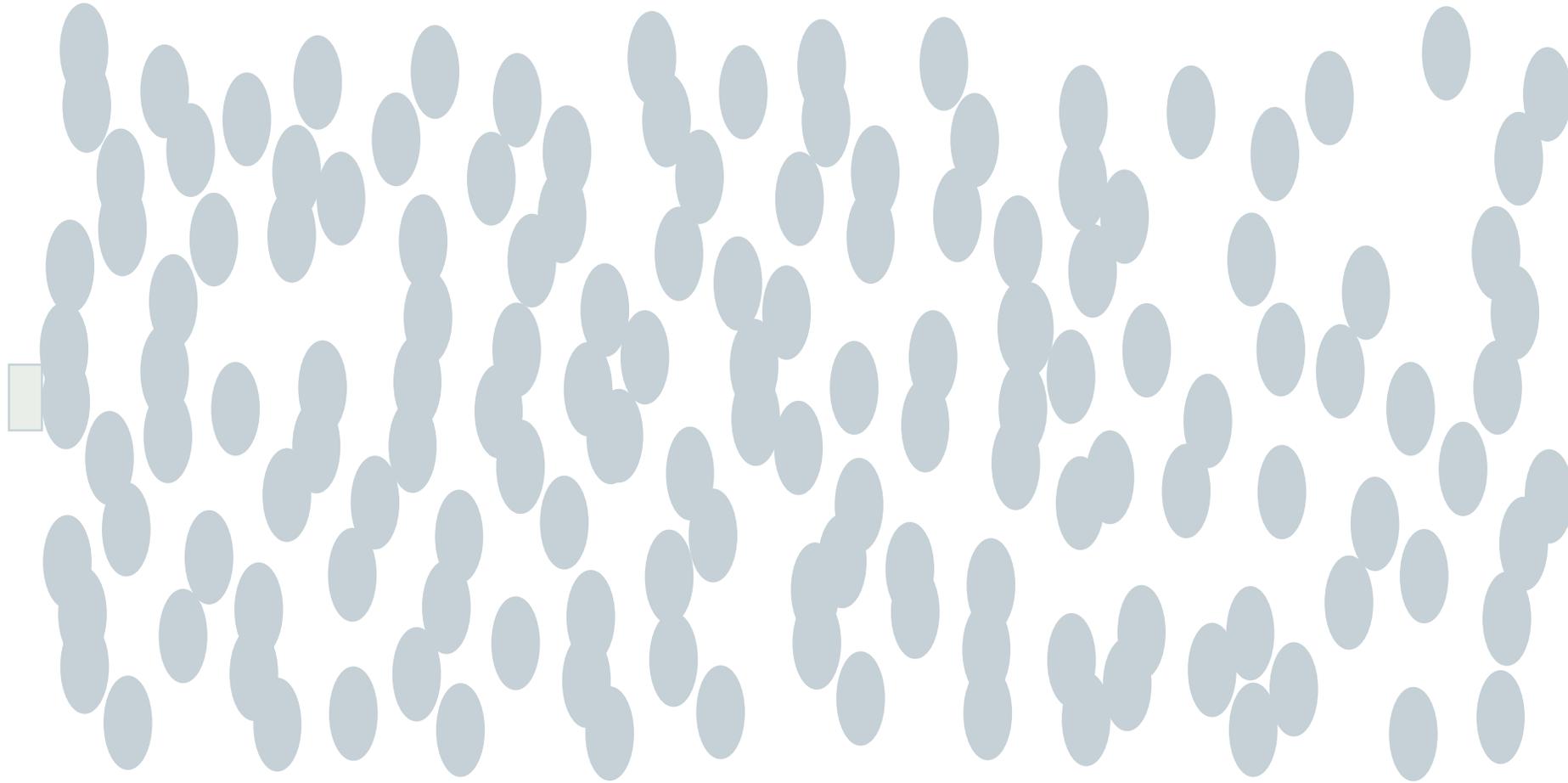


areas

Visual Variable: Motion

- ✓ • selective
 - motion is one of our most powerful attention grabbers
- ✓ • associative
 - moving in unison groups objects effectively
- ≠ • quantitative
 - subjective perception
- ≠ • order
- ? • length (resolution)
 - distinguishable types of motion?

Motion



Visual Variables

Visual Variable	Selective	Associative	Quantitative	Order	Length
Position	Yes	Yes	Yes	Yes	Dependant on resolution
Size	Yes	Yes	Approximate	Yes	Association: 5; Distinction: 20
Shape	With Effort	With Effort	No	No	Infinite
Value	Yes	Yes	No	Yes	Association: 7; Distinction: 10
Hue	Yes	Yes	No	No	Association: 7; Distinction: 10
Orientation	Yes	Yes	No	No	4
Grain	Yes	Yes	No	No	5
Texture	Yes	Yes	No	No	Infinite
Motion	Yes	Yes	No	Yes	Unknown

Summary

	Quantitative	Ordinal	Nominal
More Accurate	Position 	Position 	Position 
	Length 	Density 	Hue 
	Angle 	Saturation 	Density 
	Slope 	Hue 	Saturation 
	Area 	Length 	Shape 
	Density 	Angle 	Length 
	Saturation 	Slope 	Angle 
	Hue 	Area 	Slope 
Less Accurate	Shape 	Shape 	Area 

Jacques Bertin refined by Cleveland&McGill then by Card&Mackinlay

Summary

- Now you know the main building blocks are **marks**
- Marks are modified by **visual variables**
- Visual variables have **specific characteristics**
- These characteristics influence how the data will be perceived