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# CPT208 Human-Centric Computing

Introduction to Visualization

Lingyun Yu

# INTRODUCTION

# Why Visualization?

# How many "6"s

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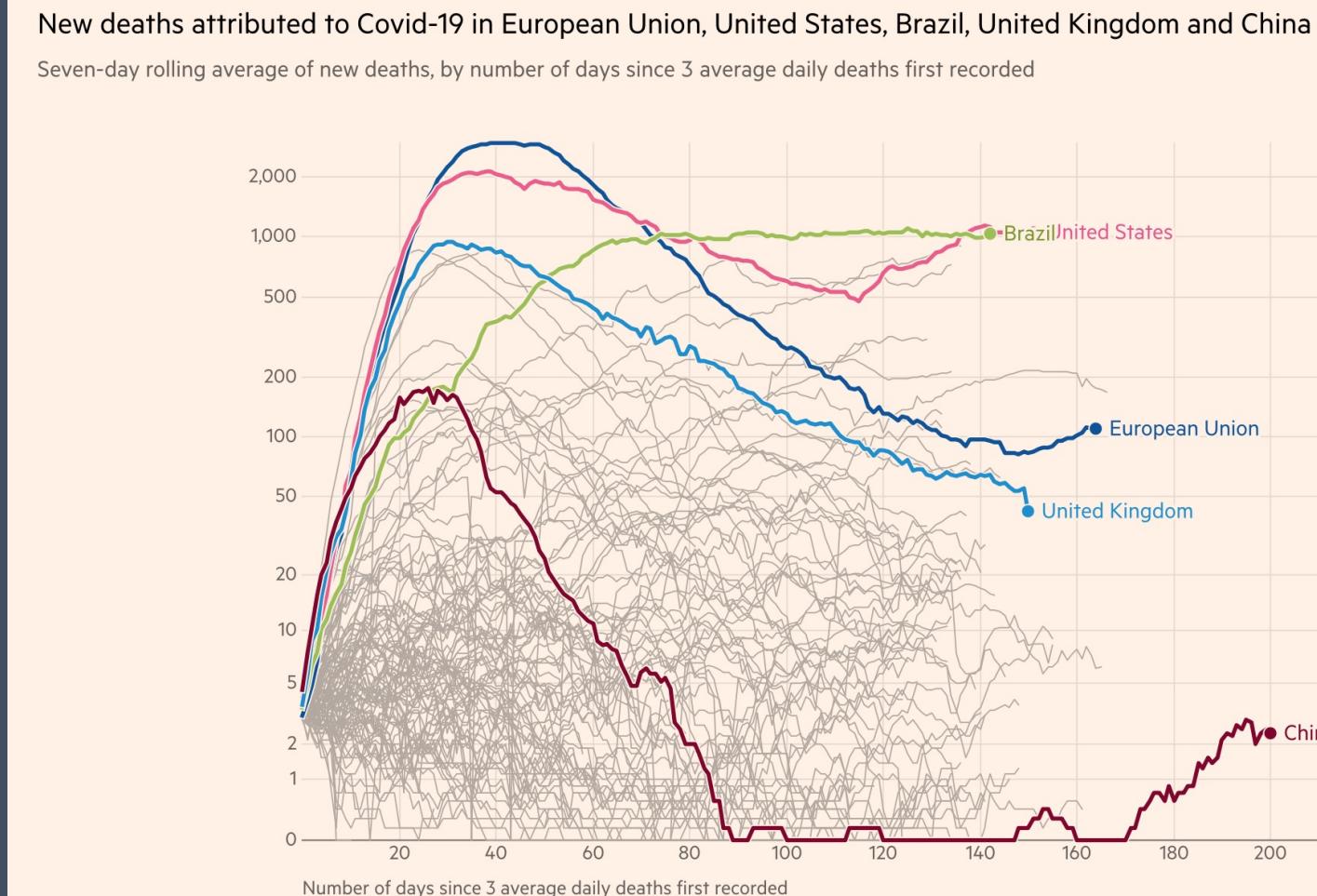
198003847593026749302oefje8fm37494  
o3495736294050kf9v7850275629202039  
48272949572825194kf9v0mv8408g7450  
204957362940fmecure94ks0495ikvm87is  
mznfhg73hrio3p000192838485jf9382549  
4029r9f847v84050848274962940f0v9b8j  
0398b847mb7362bc82940v204lv93mviw

# Pre-Attentive Pattern (Pops out)

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19800384759302**6**749302oefje8fm37494  
o349573**6**294050kf9v7850275**6**29202039  
48272949572825194kf9v0mv8408g7450  
2049573**6**2940fmecure94ks0495ikvm87is  
mznfhg73hrio3p000192838485jf9382549  
4029r9f847v840508482749**6**2940f0v9b8j  
0398b847mb73**6**2bc82940v204lv93mviw

# Graph



<https://ig.ft.com/coronavirus-chart/?areas=eur&areas=usa&areas=bra&areas=gbr&areasRegional=usny&areasRegional=usca&areasRegional=usfl&areasRegional=ustx&cumulative=0&logScale=1&perMillion=0&values=deaths>

# Why Statistics May Not Work

Set A		Set B		Set C		Set D	
X	Y	X	Y	X	Y	X	Y
10	8.04	10	9.14	10	7.46	8	6.58
8	6.95	8	8.14	8	6.77	8	5.76
13	7.58	13	8.74	13	12.74	8	7.71
9	8.81	9	8.77	9	7.11	8	8.84
11	8.33	11	9.26	11	7.81	8	8.47
14	9.96	14	8.1	14	8.84	8	7.04
6	7.24	6	6.13	6	6.08	8	5.25
4	4.26	4	3.1	4	5.39	19	12.5
12	10.84	12	9.11	12	8.15	8	5.56
7	4.82	7	7.26	7	6.42	8	7.91
5	5.68	5	4.74	5	5.73	8	6.89

**Summary Statistics**

$$\mu_X = 9.0 \quad \sigma_X = 3.317$$

$$\mu_Y = 7.5 \quad \sigma_Y = 2.03$$

**Linear Regression**

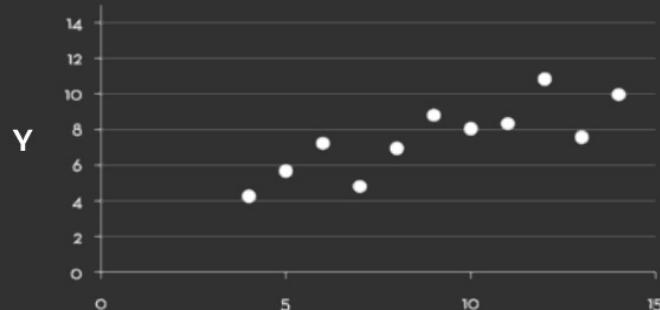
$$Y = 3 + 0.5 X$$

$$R^2 = 0.67$$

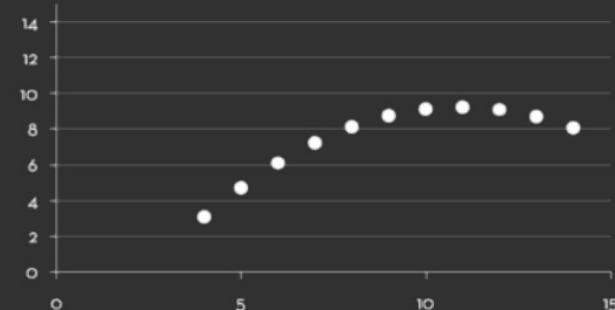
[Anscombe 73]

# Limits of Cognition

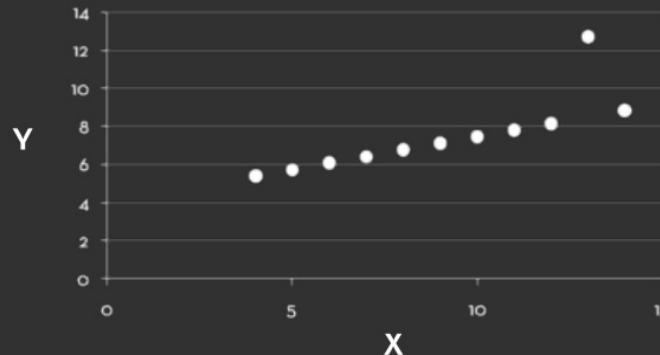
**Set A**



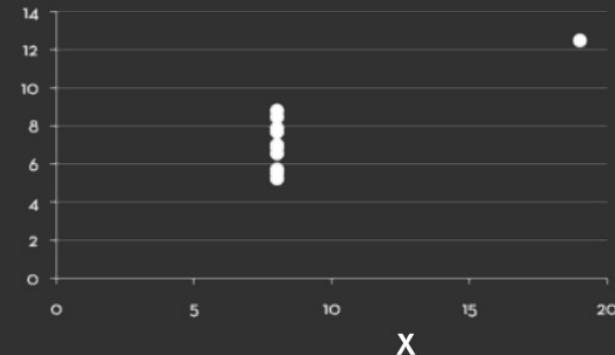
**Set B**



**Set C**



**Set D**



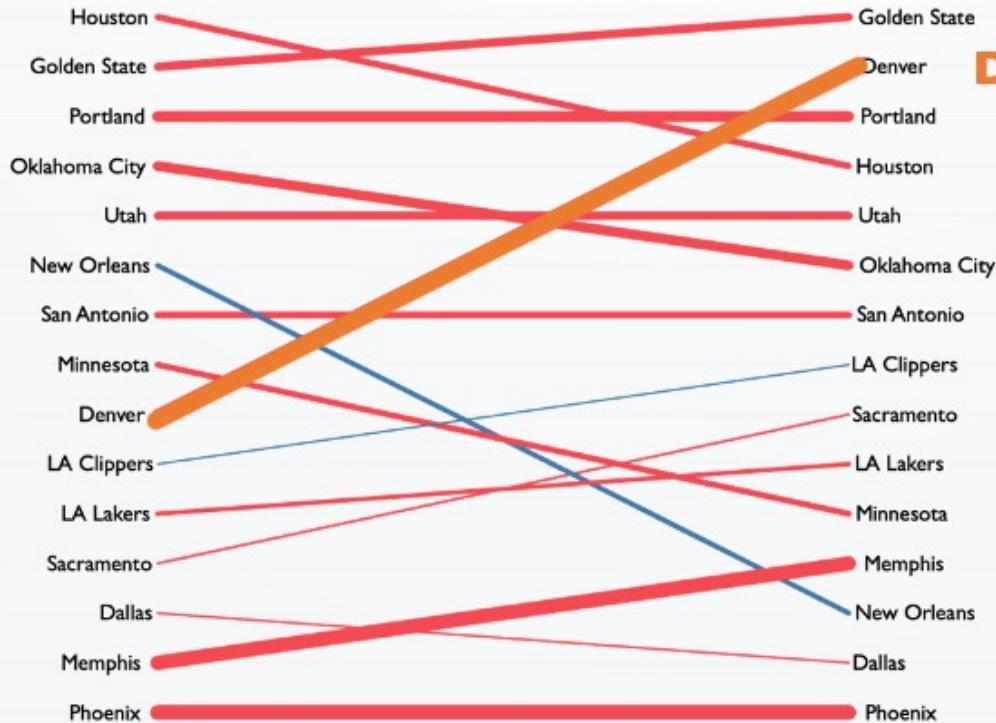
# A Small Quiz

- Which NBA team has achieved better standings after investing more?

Team	2017~2018 Season		2018~2019 Season	
	Salaries	Standings	Salaries	Standings
Golden State	\$137,610,134	2	\$146,291,276	1
Denver	\$107,543,599	9	\$118,327,016	2
Memphis	\$110,700,149	14	\$126,107,461	12
Houston	\$119,905,532	1	\$126,474,100	4
LA Clippers	\$119,093,010	10	\$118,026,816	8
Oklahoma City	\$134,534,640	4	\$144,916,427	6

# The Power of Visualization

2017~2019 Salary vs Standing of NBA Western Conference



Denver Nuggets

Absolute Change of Salary

- 1,066,194
- 5,000,000
- 10,000,000
- 16,008,752

Salary Change

- Decrease
- Increase

# Visualization

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- Helps us think
- Uses perception to offload cognition
- Serves as an external aid to augment working memory
- Boosts our cognitive abilities

# Examples



Aaron Koblin, TED 2006

<http://www.aaronkoblin.com/work/flightpatterns/>

# What is Visualization?

# What is Visualization?

- Visualization is the creation and study of the visual representation of data

Input: data   Output: visual form   Goal: insight



# What can visualization do?

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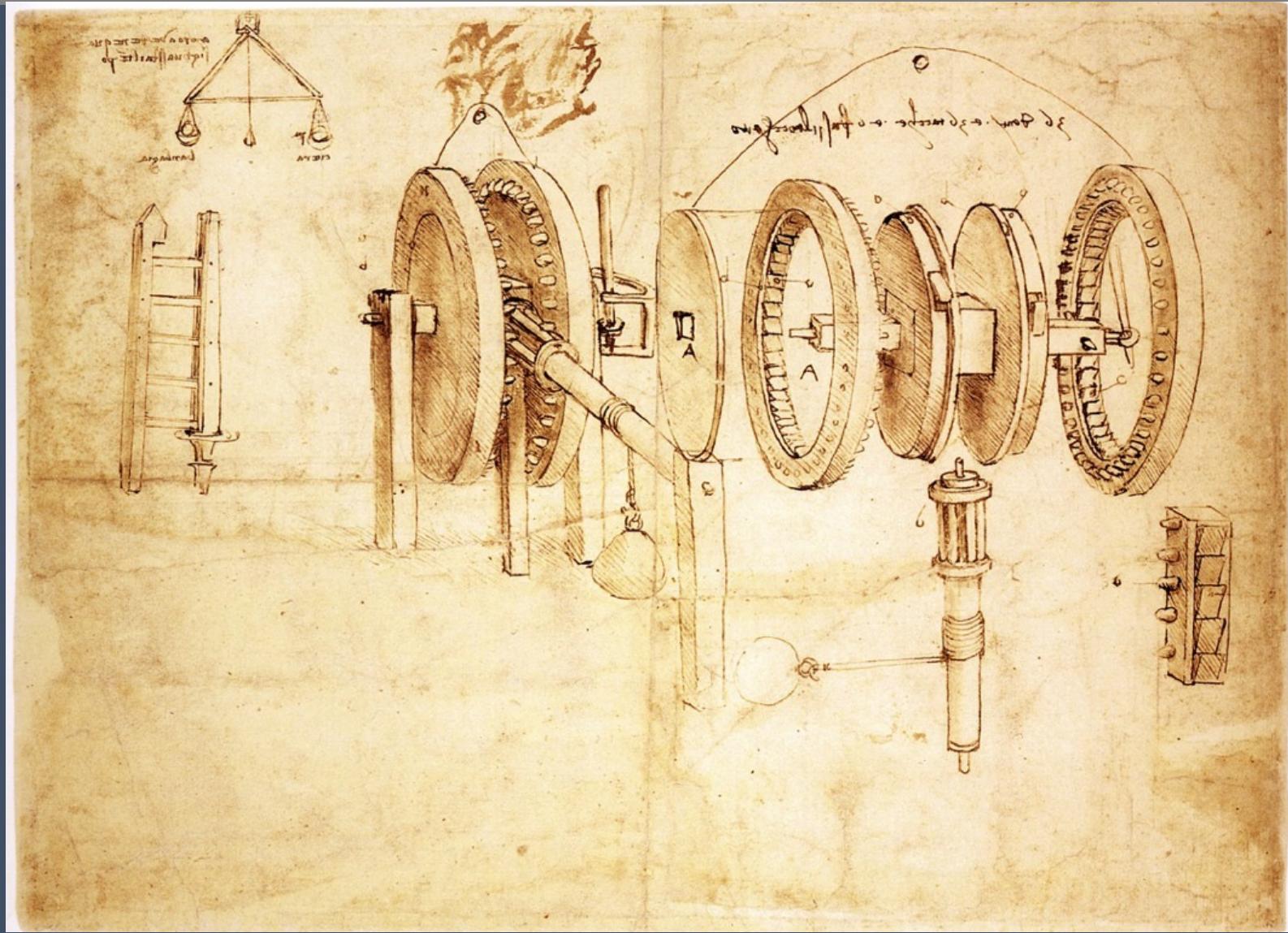
- Represent information
- Analyze data
- Communicate data

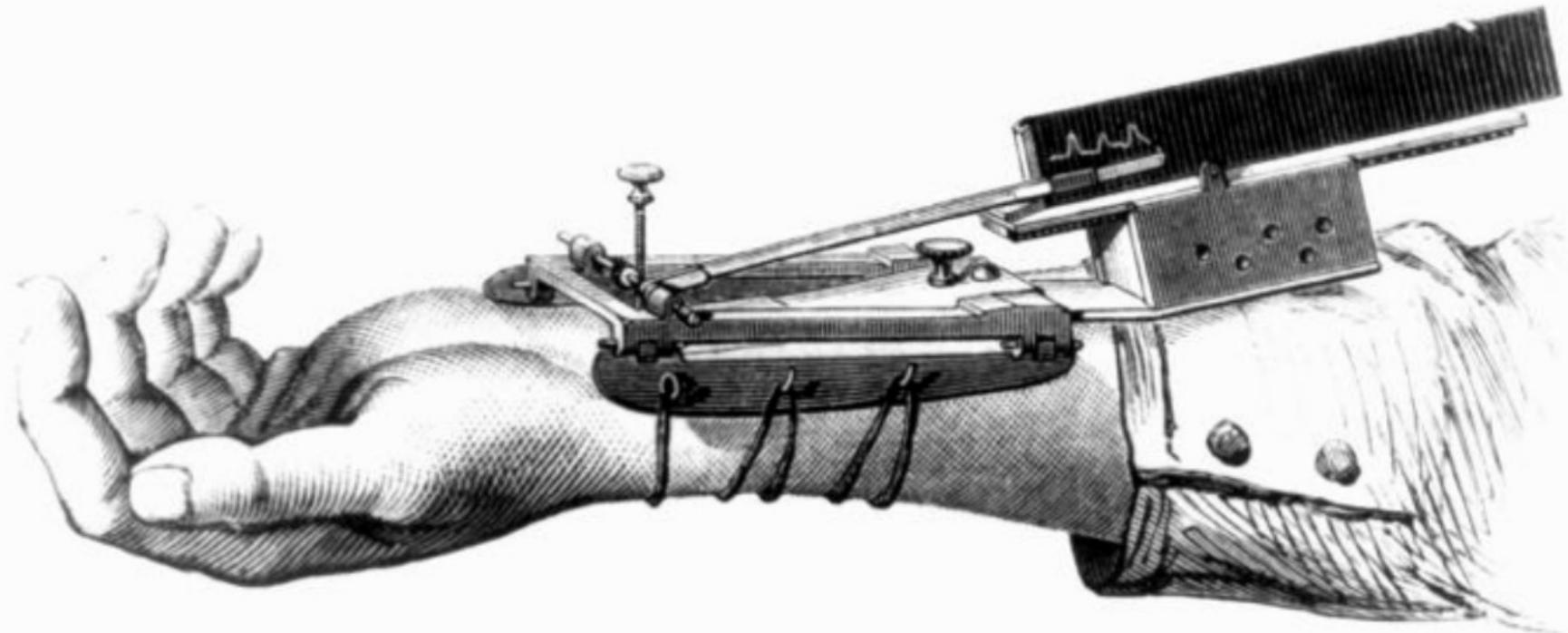
# What can visualization do?

---

- Represent information
- Analyze data
- Communicate data

# Represent Information





1.

**Marey's** **biological** **invention.**

1860. *La méthode graphique dans les sciences expérimentales et principalement en physiologie et en médecine.*

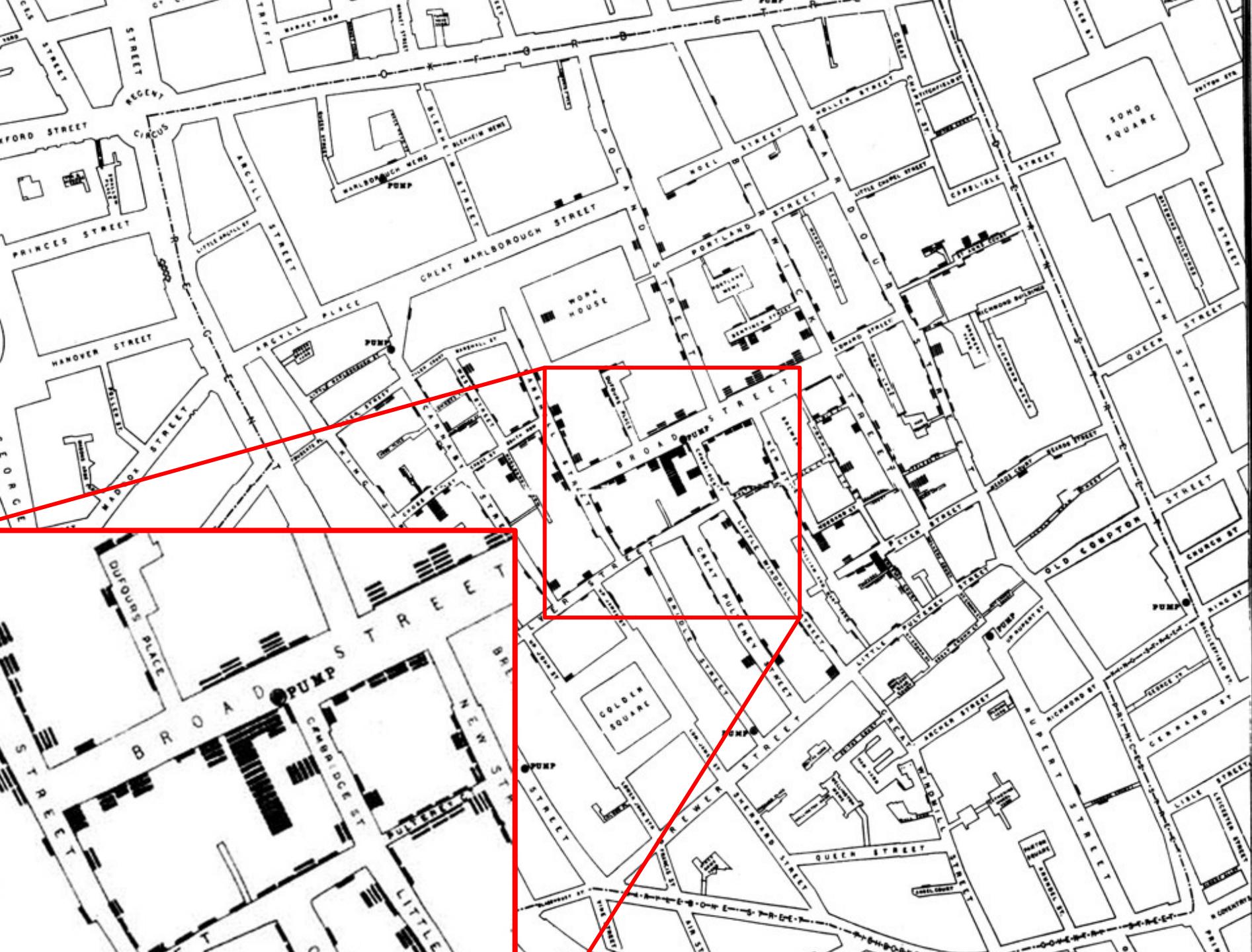
positioned on the patient's radial artery (the artery that parallels the radius bone in the arm).

E.J. Marey's sphygmograph [from Braun 83]

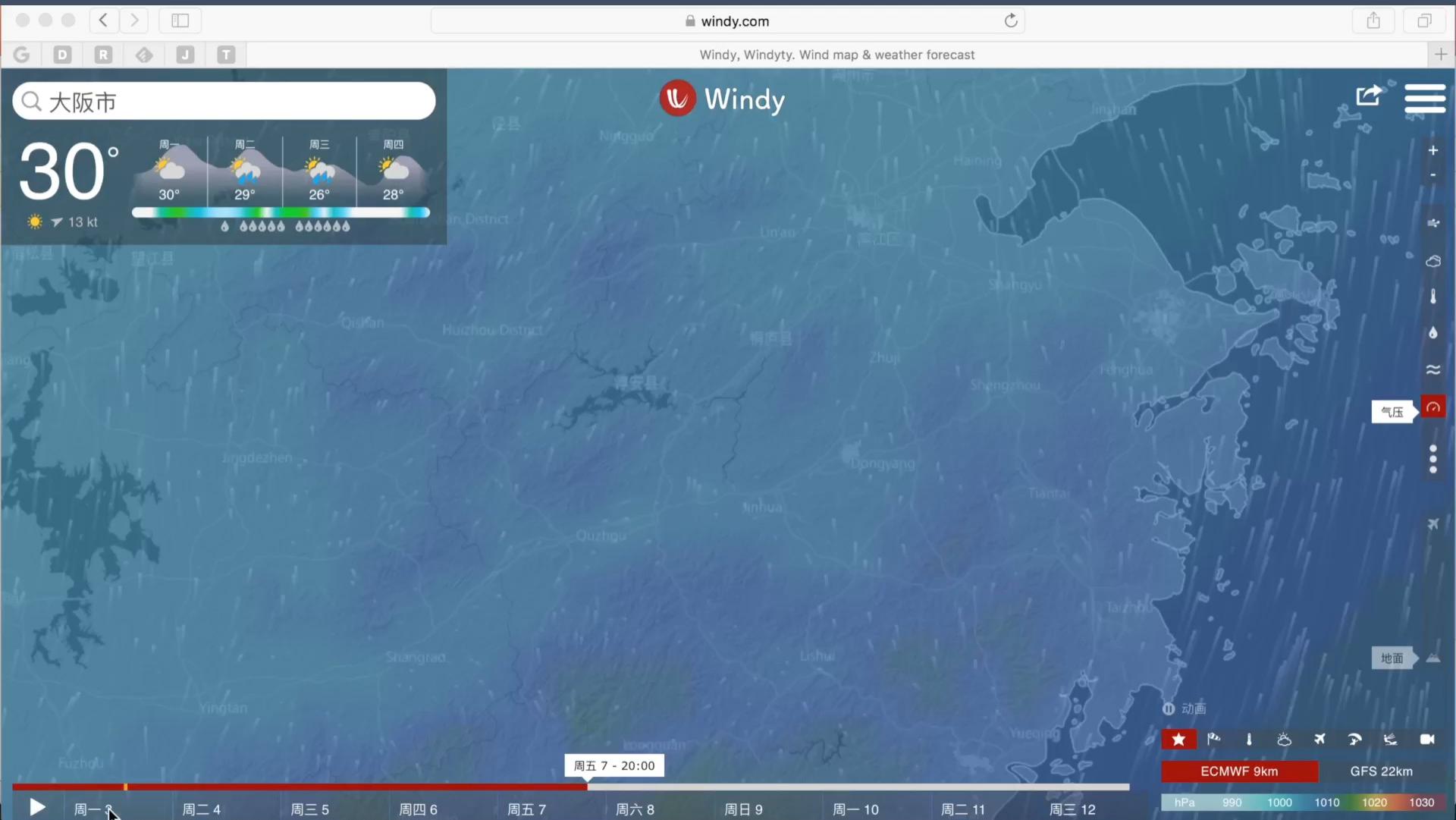
# What can visualization do?

---

- Represent information
- Analyze data
- Communicate data

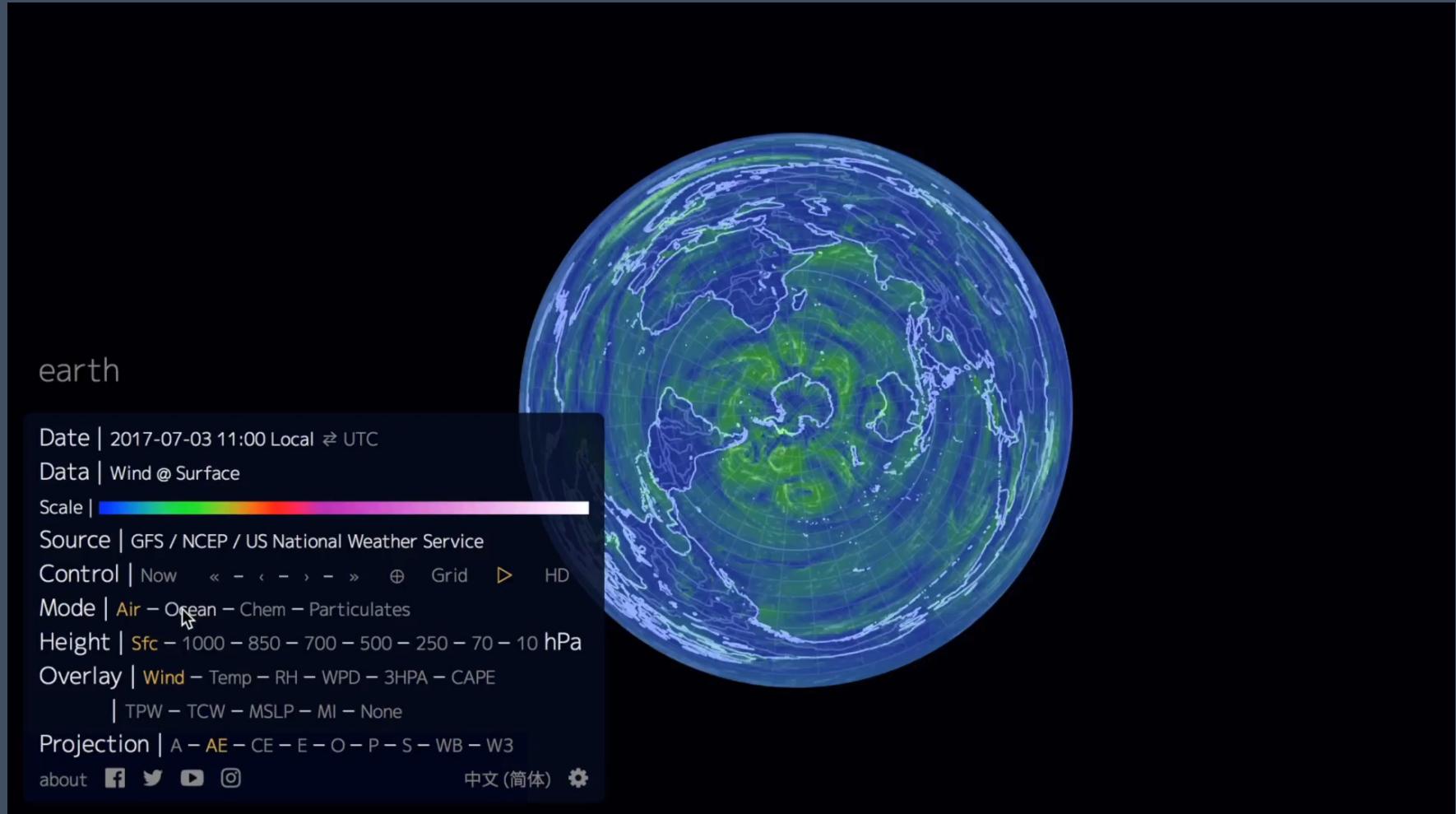


# Reveal Patterns



# Reveal Patterns

- Earth Nullschool

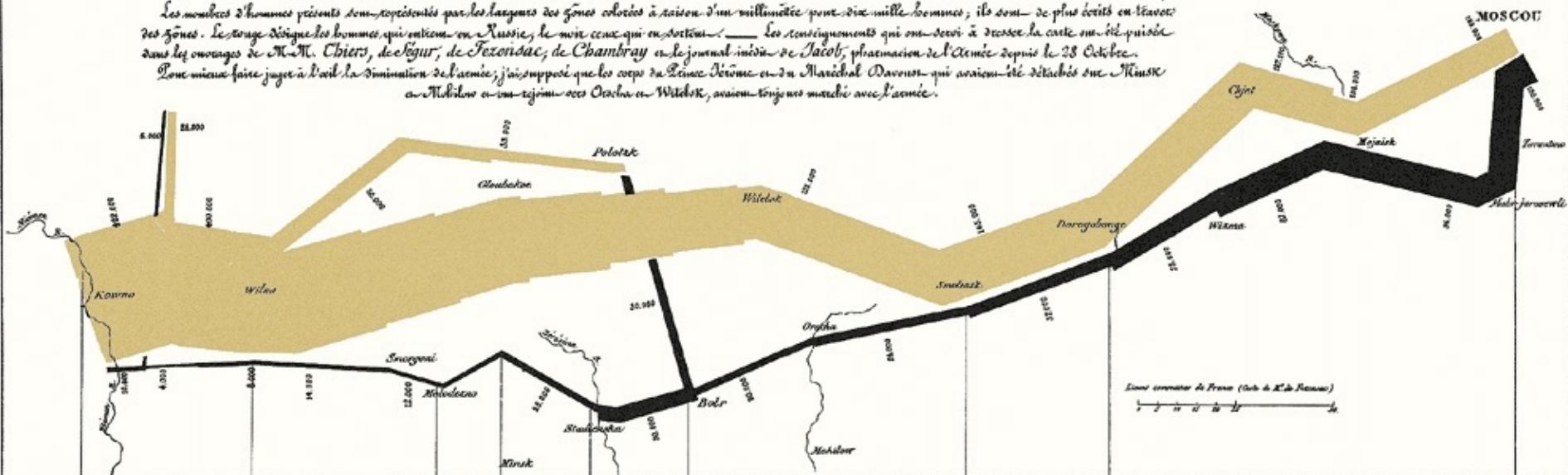


# Reveal Patterns

*Carte Figurative des pertes successives en hommes de l'Armée Française dans la Campagne de Russie 1812-1813.*  
Dessiné par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite.

Paris, le 20 Novembre 1869  
Les nombres d'hommes perdus sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix-mille hommes; ils sont de plus écrits en lettres les zones. Le rouge désigne les hommes qui entrent en Russie, le noir ceux qui en sortent. — Les renseignements qui ont servi à dresser la carte me sont pris dans les ouvrages de M. Chiers, de Ségur, de Fezodac, de Chambray et le journal intime de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

Une autre fois j'ai jugé à l'ail la diminution de l'armée; j'ai supposé que les corps de l'Armée Romaine et du Maréchal Davout qui avaient été détachés sur Moscou et Malibor aient agi avec Olska et Witebsk, auquel temps marchaient avec l'armée.

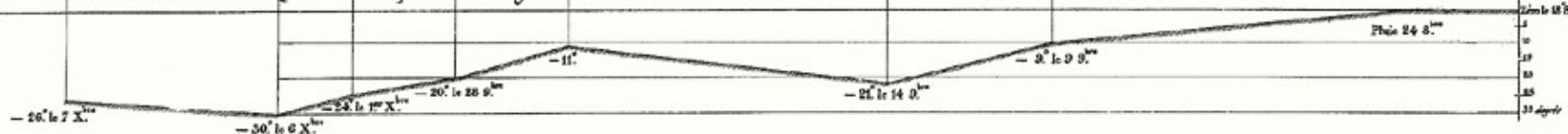


*TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.*

Les Cosaques passent au gelé  
la Siberia gelé.

Avec la permission de l'Académie des Sciences de Paris.

Dép. Natl. Représenté à l'Académie.



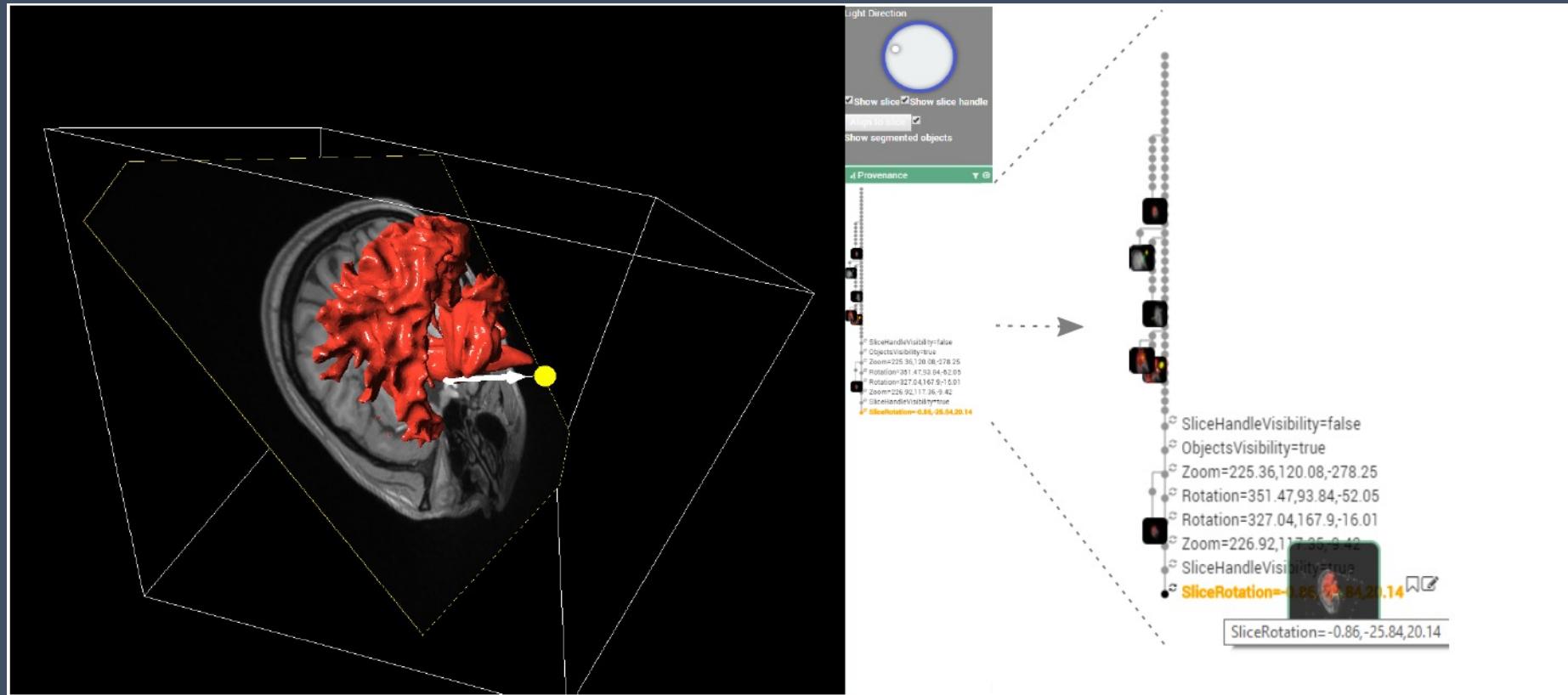
C.J.Minard,1869  
E.Tufte,Writings,Artworks,News

# What can visualization do?

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- Represent information
- Analyze data
- **Communicate data**

# Communicate Data



# Hans Rosling' TED Talk



# Wealth Inequality in America

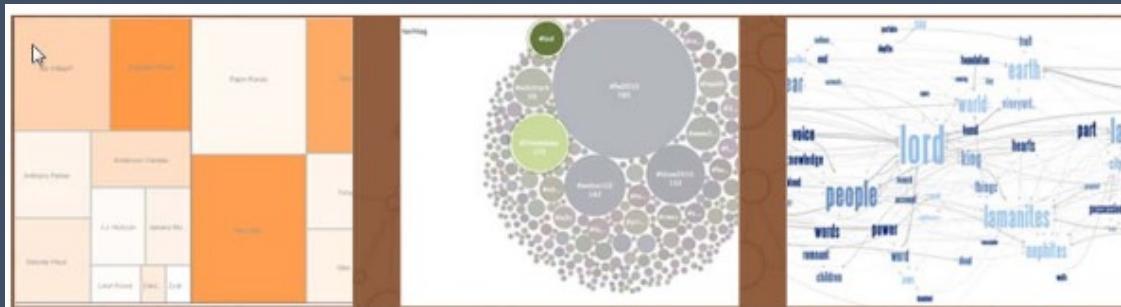
# Visualization Is Young

# VIS - Subfields

- Scientific Visualization (SciVis) – Spatial data



- Information Visualization (InfoVis) – Abstract data

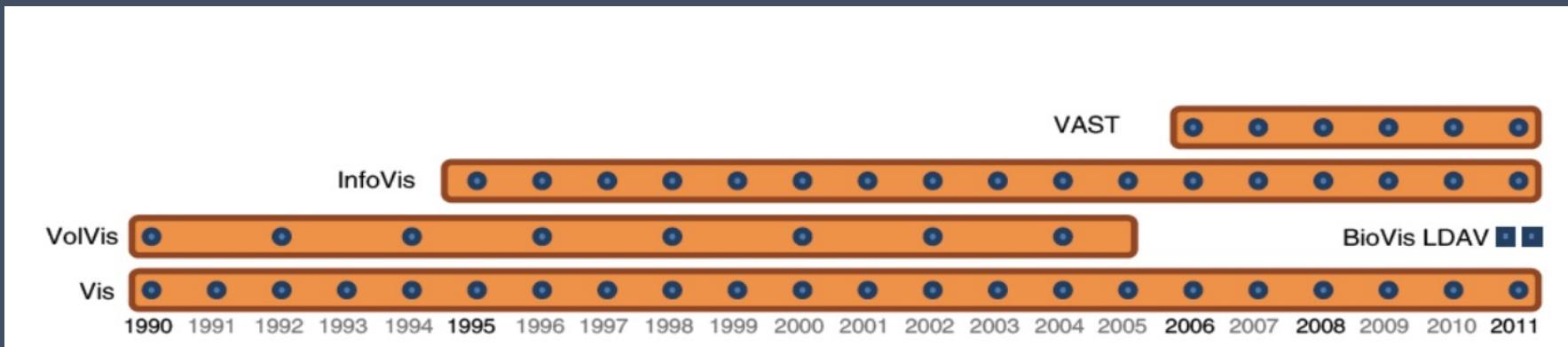


- Visual Analytics (VAST) – Analytical Reasoning



# Top VIS Conferences

- VAST (Visual Analytics Science and Technology)
- InfoVis (Information Visualization)
- SciVis (Scientific Visualization)



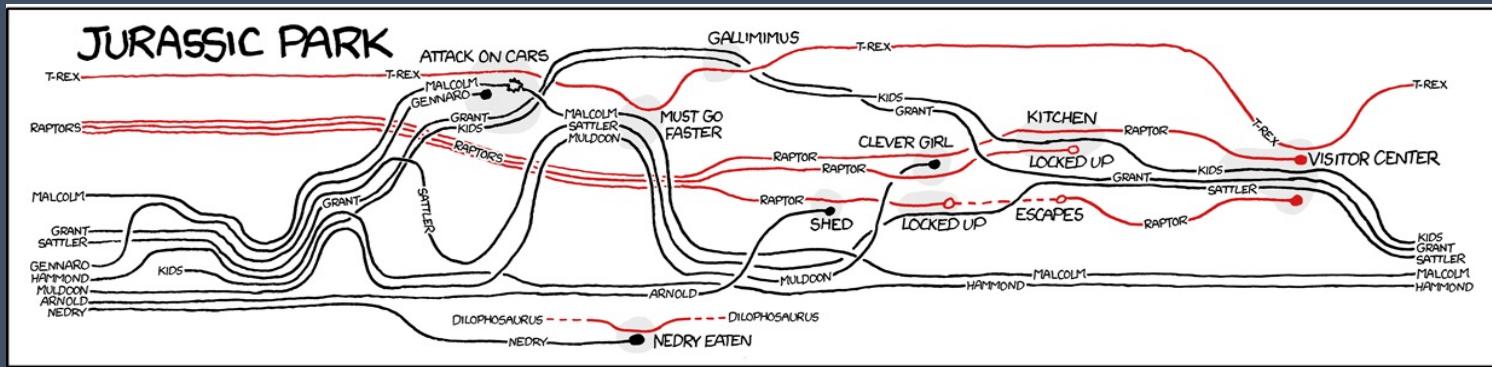
# VIS - Graphics

- **Graphics**
  - Photo-realistic
  - Simulation
  - Real-world
  - Visual media
- **Visualization**
  - Illustrative
  - Understanding
  - Information



# VIS - Infographics

- Infographics is static

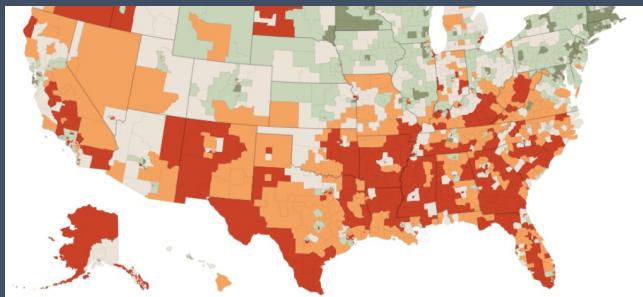
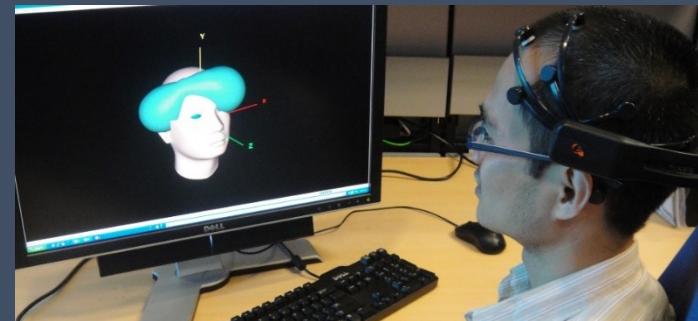
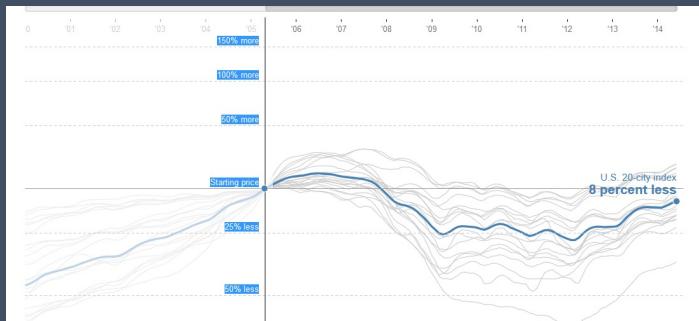


- Visualization is interactive

Evaluation

# VIS - HCI

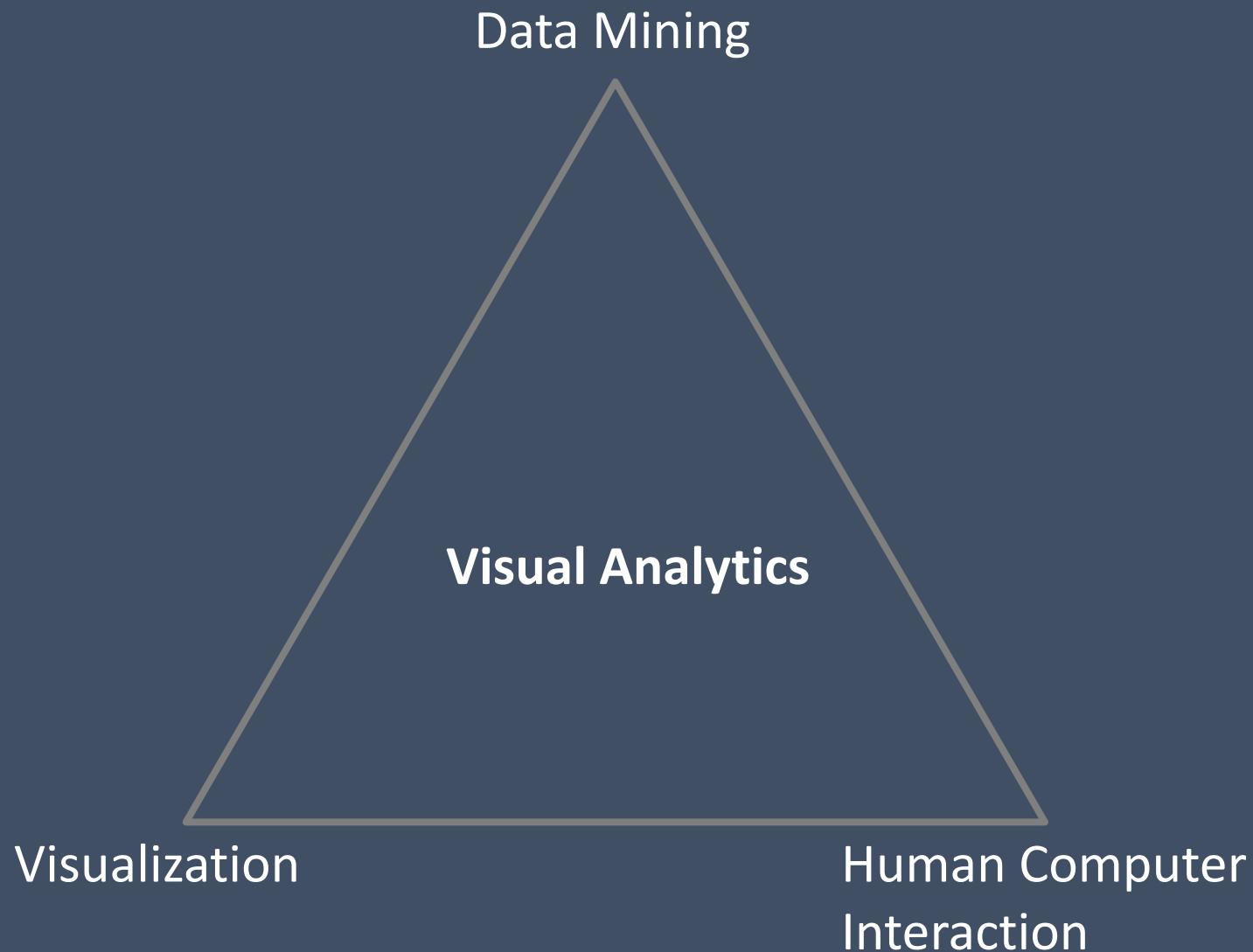
- Visualization deals with **data**
- HCI deals with everything involving **human & computer interaction**



# VIS - Data Mining

- Data mining focuses more on **automatic algorithms**
- Visualization keeps **human in the loop** and focuses more on **interactive analysis**





# **PERCEPTION & COGNITION**

# What is visual?

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- Perception: about the nature of the signals coming in; what you see
- Cognition: about how you understand and interpret what you see

# Visual Perception

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- Perception is the organization, identification and interpretation of **sensory** information in order to represent and understand the environment.

# Cognition

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- In science, cognition is a group of **mental processes** that includes attention, memory, producing and understanding language, solving problems, and making decisions.

# Task one

- This example requires sustained attention and concentration
- 3 players in white and 3 players in black passing a different basketball to each other



Count the total number of times people wearing white are passing the ball



Do not count passes by the players in black



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© Viscog Productions, [www.viscog.com](http://www.viscog.com)



natgeotv.com

© National Geographic <https://www.youtube.com/watch?v=iiEzf3J4iFk>

# Fact

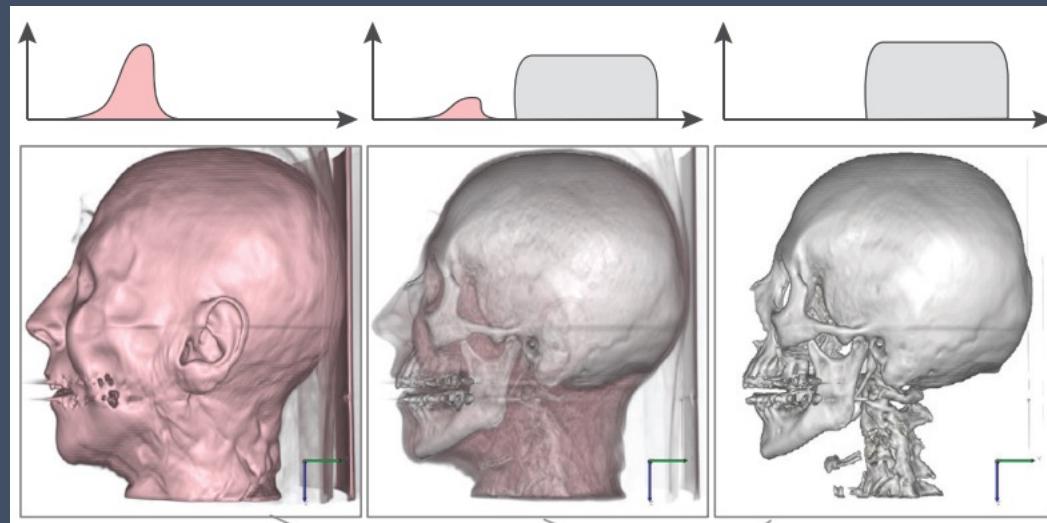
- Memory plays an important role in human cognition, but working memory is extremely limited.



# Fact

- Memory plays an important role in human cognition, but working memory is extremely limited.

Visualization must serve as an external aid to augment working memory



# Task two



Find the one thing in the image that is changing

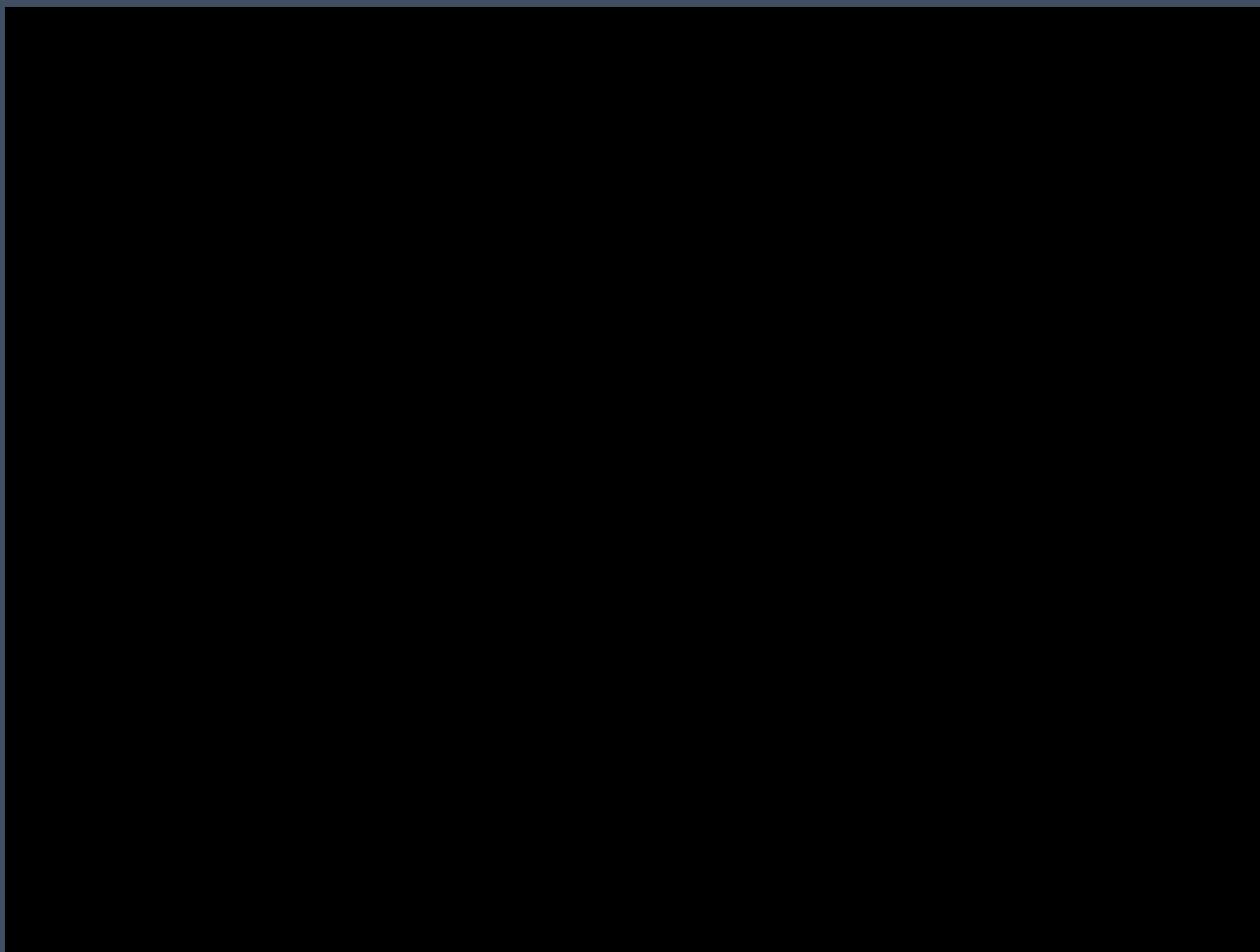


Raise your hand once you detect the change



Remain quiet while others continue to look

# Task two



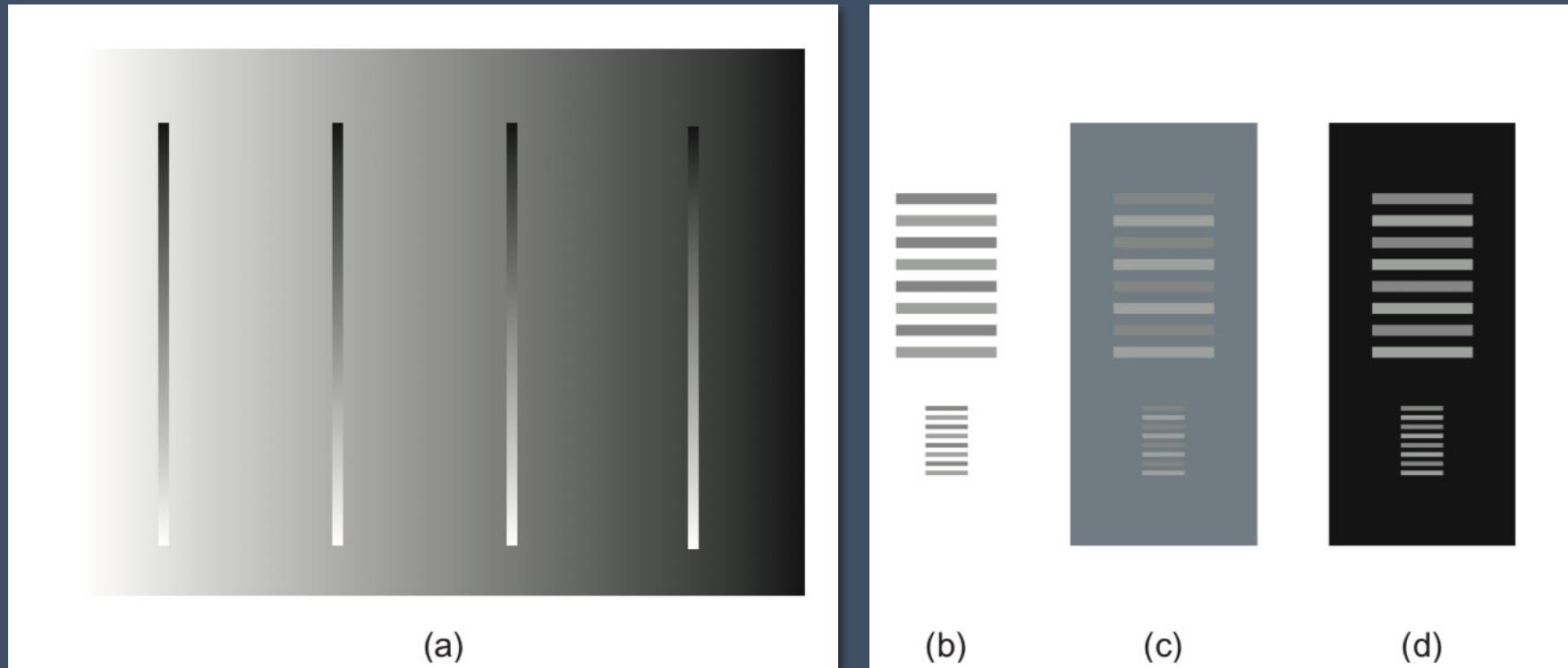
# Fact

- To see an object change, it is necessary to attend to it.

Make changes visible in visualizations to reduce the cognitive load

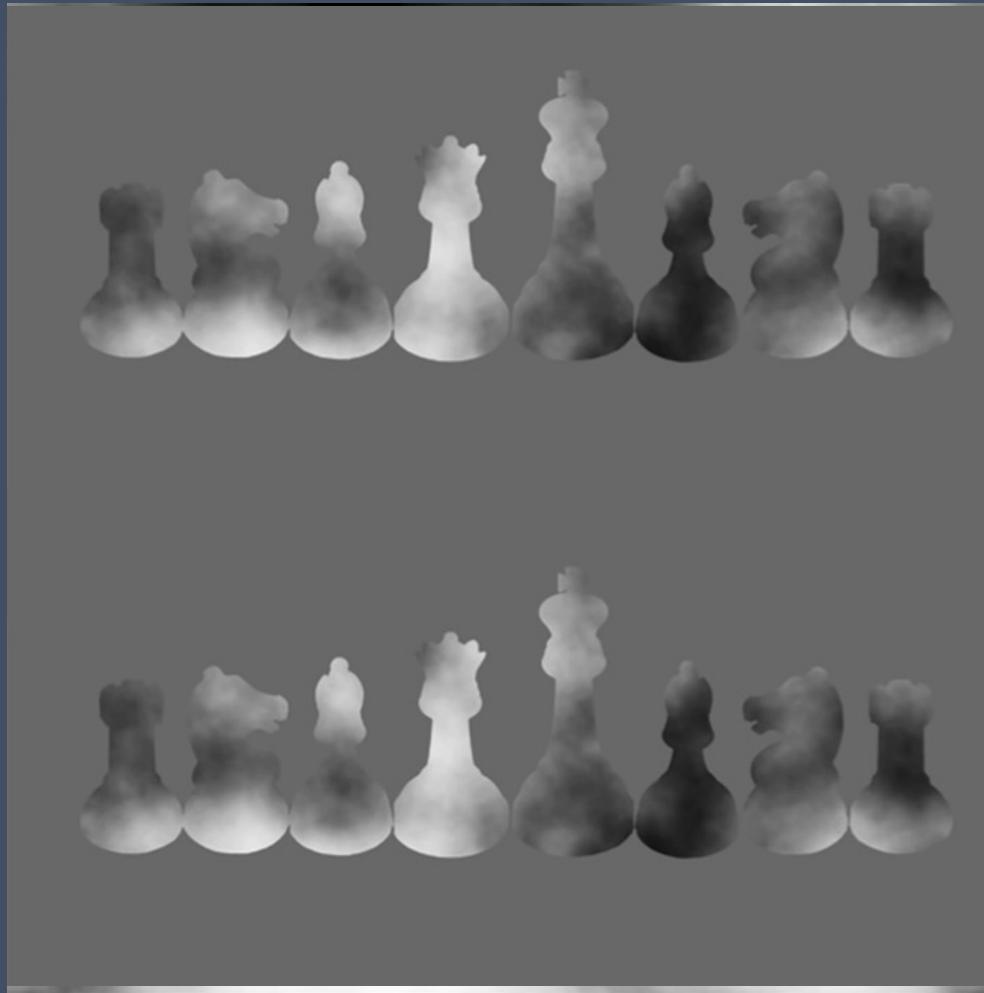
# Case three

- Simultaneous Contrast



**Figure 3.20** (a) All the gray strips are the same. Perceived differences between gray-scale values are enhanced where the values are close to the background gray value, an effect known as crispening. (b, c, d) The differences in the grays of the gray lattice are more evident (c) than with either the white (b) or the black (d) backgrounds, another example of crispening.

# Simultaneous Contrast



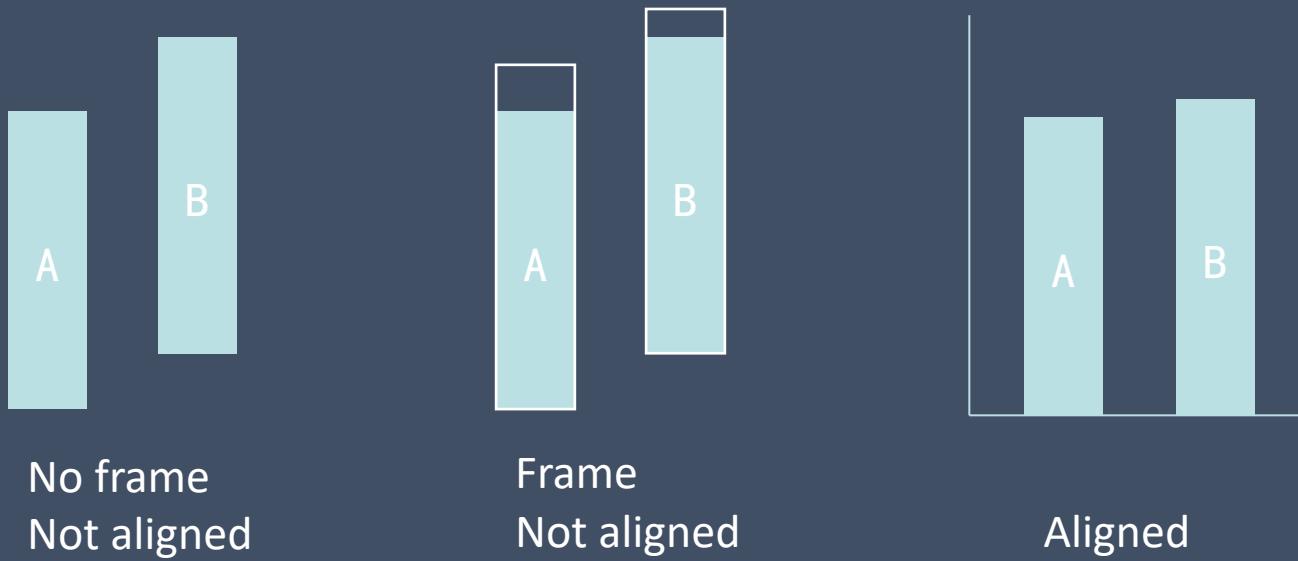
# Fact

- Our visual system sees differences, not absolute values.

Use high contrast between objects that should be distinguishable

# A simple visualization example

- A and B, which one has bigger size?

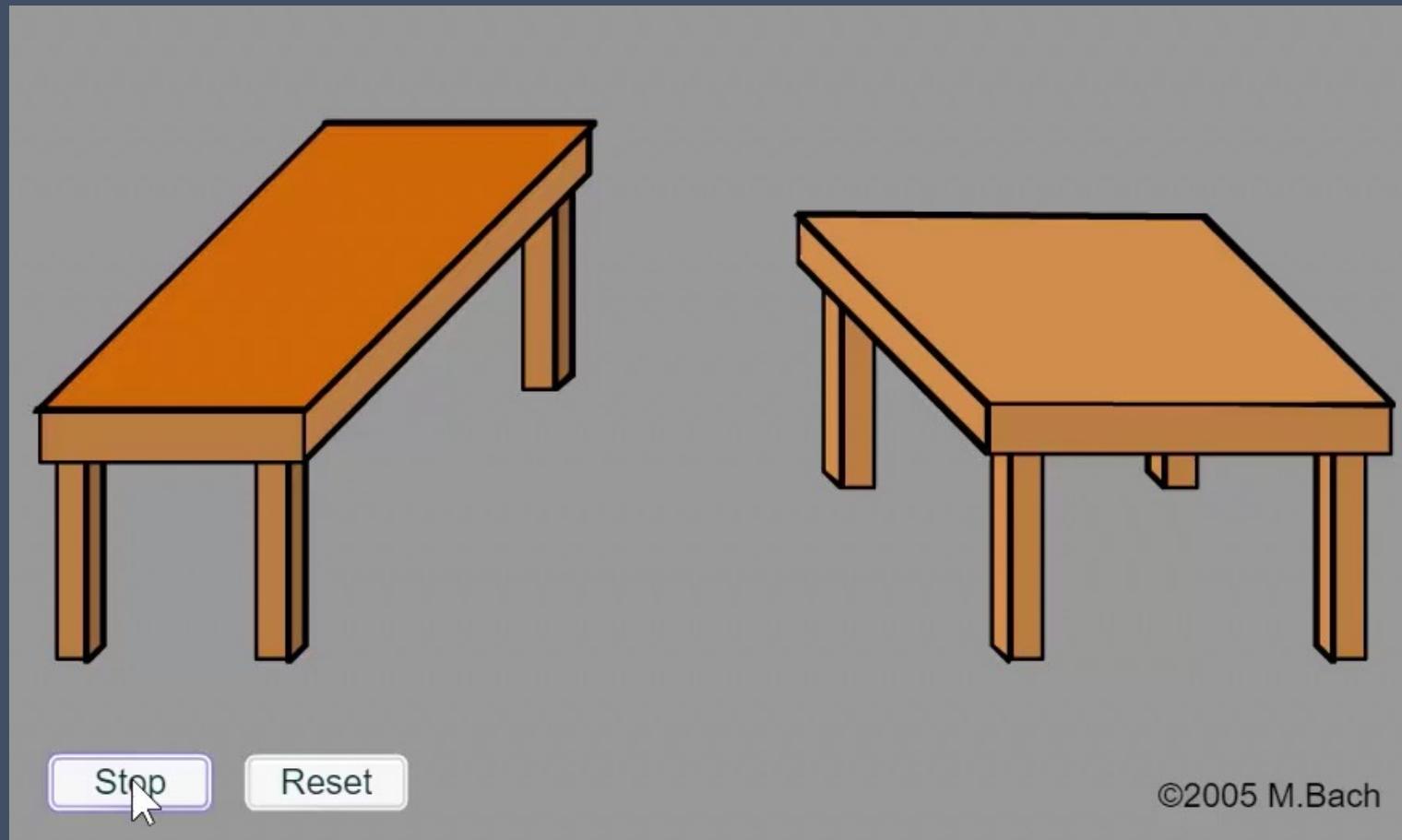


# Depth Perception

- Linear Perspective
- Interposition
- Relative size
- Texture gradient
- Shadowing

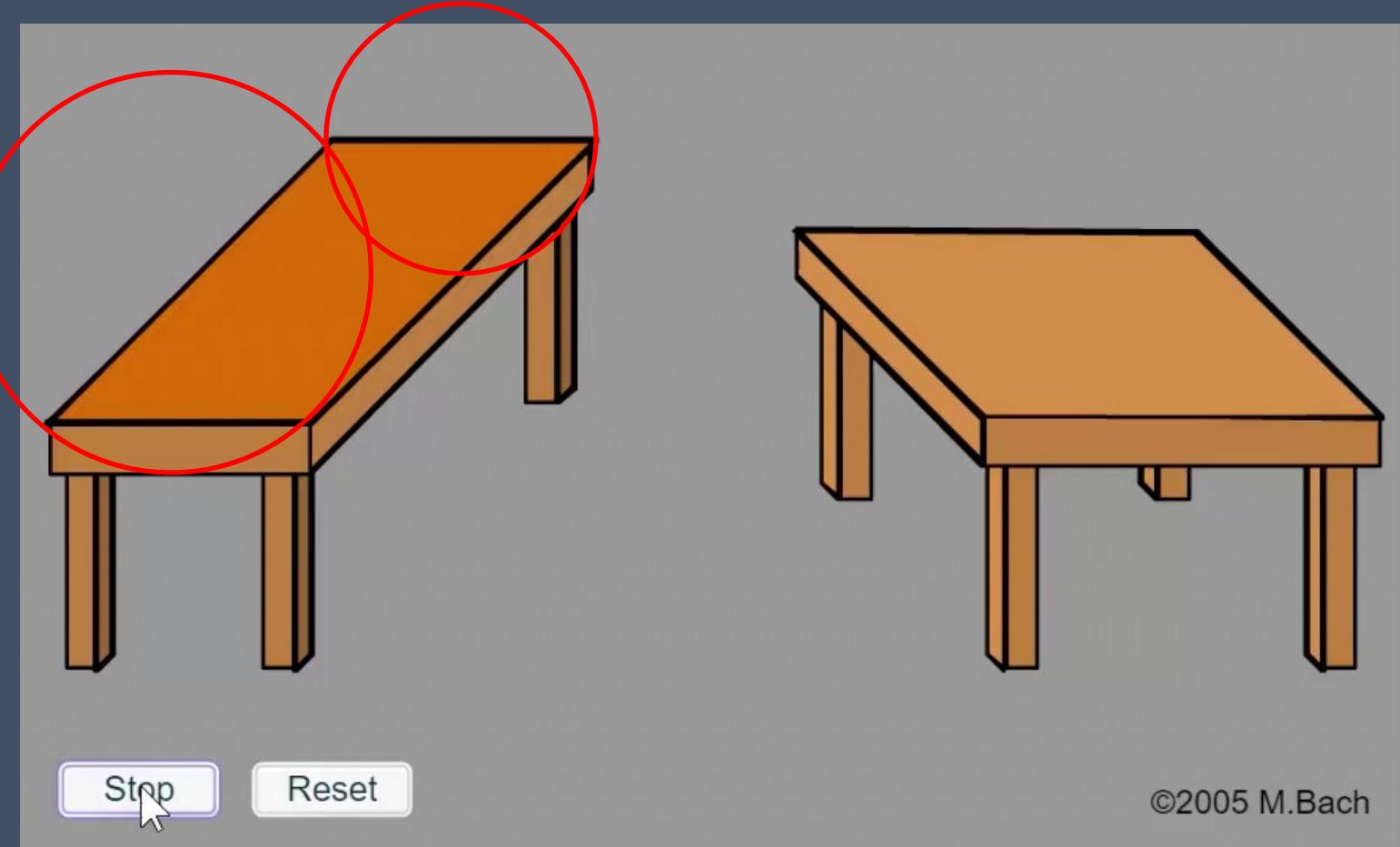


# Shepard's Rotated Table



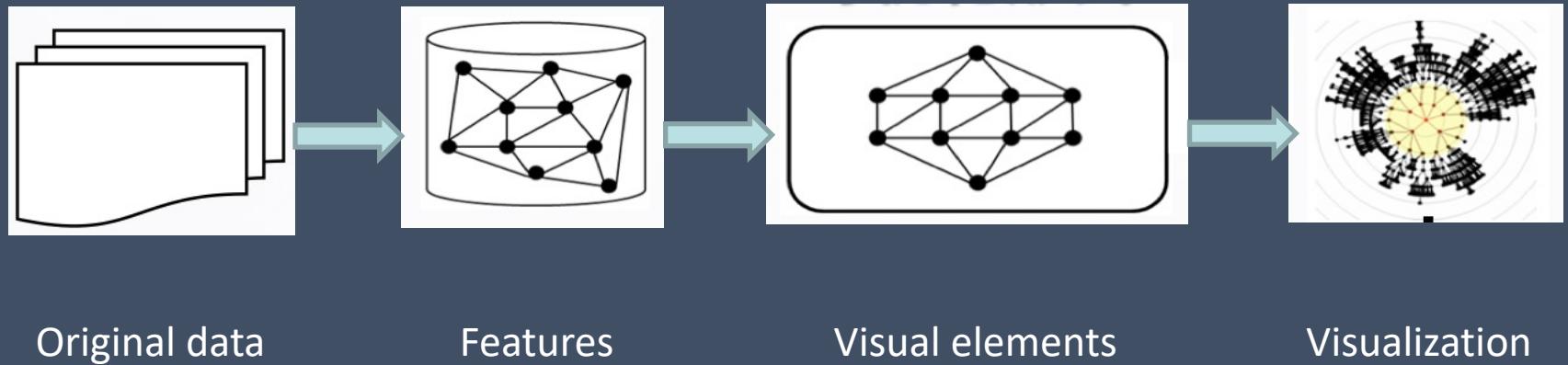
© [http://www.michaelbach.de/ot/sze\\_shepardTables](http://www.michaelbach.de/ot/sze_shepardTables)

# Shepard's Rotated Table



© [http://www.michaelbach.de/ot/sze\\_shepardTables](http://www.michaelbach.de/ot/sze_shepardTables)

# How do we visualize the data



Original data

Features

Visual elements

Visualization

# VISUAL ENCODING

# Visual encoding

---

- Data/ Dataset Types and Attributes
- Marks and Channels

# What?

## Datasets

### ④ Data Types

- Items
- Attributes
- Links
- Positions
- Grids

### ④ Data and Dataset Types

Tables

Items

Attributes

Networks &amp; Trees

Items (nodes)

Links

Fields

Grids

Attributes

Geometry

Items

Positions

Clusters, Sets, Lists

Items

### ④ Attribute Types

- Categorical



- Ordered

- Ordinal

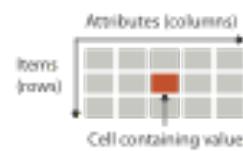


- Quantitative

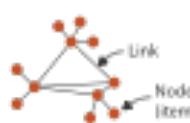


### ④ Dataset Types

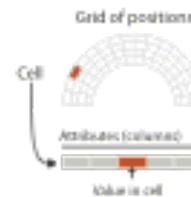
#### → Tables



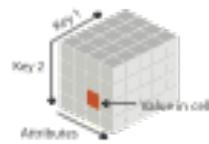
#### → Networks



#### → Fields (Continuous)



#### → Multi-dimensional Table



#### → Trees



#### → Geometry (Spatial)



### ④ Ordering Direction

#### → Sequential



#### → Diverging



#### → Cyclic



### ④ Dataset Availability

#### → Static



#### → Dynamic



# Data types

What?

## Datasets

### → Data Types

→ Items    → Attributes    → Links    → Positions    → Grids

### → Data and Dataset Types

Tables

Items

Attributes

Networks &  
Trees

Items (nodes)

Links

Attributes

Fields

Grids

Positions

Attributes

Geometry

Items

Positions

Clusters,  
Sets, Lists

Items

# Data and Dataset Types

④ Data Types

- Items
- Attributes
- Links
- Positions
- Grids

⑤ Data and Dataset Types

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

⑥ Dataset Types

- Tables
  - Attributes (columns)
  - Items (rows)
  - Cell containing value
- Networks
  - Link
  - Node (item)
- Fields (Continuous)
  - Grid of positions
  - Cell
  - Attribute (column)
  - Value in cell
- Multidimensional Table
  - Key 1
  - Key 2
  - Value in cell
  - Attributes
- Trees
  -
- Geometry (Spatial)
  - Position

④ Attribute Types

- Categorical



→ Ordered

- Ordinal



→ Quantitative



④ Ordering Direction

- Sequential



- Diverging



- Cyclic



⑥ Dataset Availability

- Static



- Dynamic

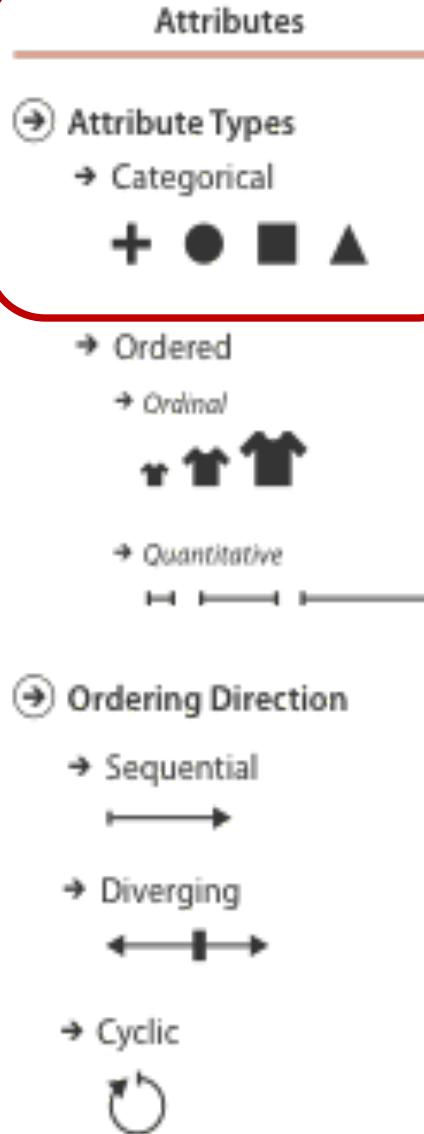


CPT208 Human-Centric Computing

Lingyun Yu

Visualization and Representation

# Data and Dataset Types



- Or nominal (labels)
- Can be counted
- Examples:
  - Fruits (apple, oranges, ...)
  - Car makers (Audi, BMW, ...)
- Operations:
  - $=, \neq$

# Data and Dataset Types

Attributes

Attribute Types

- Categorical
  - +
  - 
  - 
  - ▲
- Ordered
  - Ordered
  - Ordinal
  - ↔ T-shirt icons
- Quantitative
  - ↔

Ordering Direction

- Sequential
  - ↔
- Diverging
  - ↔
- Cyclic
  - ↻

- Can be counted, ordered
- Examples:
  - 5-star rating scheme (★ ★ ★ ★ ★)
  - Shirt size (XS, S, M, L, XL, ...)
- Operations:
  - =, ≠, <, >

# Data and Dataset Types

Attributes

Attribute Types

- Categorical
  - +
  - 
  - 
  - ▲
- Ordered
  - Ordered
  - Ordinal
  - ↔ T-shirt icons
- Quantitative
  - ↔

Ordering Direction

- Sequential
  - ↔
- Diverging
  - ↔
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- Can be counted, ordered
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  - Shirt size (XS, S, M, L, XL, ...)
- Operations:
  - =, ≠, <, >

# Data and Dataset Types

Attributes

Attribute Types

- Categorical
  - +
  - 
  - 
  - ▲
- Ordered
  - 
  - Ordinal
    - ↑
    - ↑
    - ↑
- Quantitative
  - ↔
  - ↔
  - ↔

Ordering Direction

- Sequential
  -
- Diverging
  - ←
  -
- Cyclic
  - ↻

- can be counted, ordered, measured
- interval: no clear zero, or an arbitrary one
  - examples:
    - dates
    - lat/lon
  - operations:
    - $=, \neq, <, >, +, -$   
(will usually compare differences)
- ratio: meaningful zero
  - examples:
    - Physical measurements: mass, luminance...
    - Money
  - operations:
    - $=, \neq, <, >, +, -, \times, \div$   
(can measure proportions)

# Data and Dataset Types

## Attributes

### Attribute Types

#### Categorical



#### Ordered

##### Ordinal



##### Quantitative



### Ordering Direction

#### Sequential



altitudes, speeds, ...

#### Diverging



temperature, elevation (terrain+bathymetry),  
profit & loss...

#### Cyclic



time measurements: hour of the day,  
month of the year, ...

# Mark and Channels

Channels Position  
Size  
(Grey)Value  
Texture  
Color  
Orientation  
Shape

	Marks	Points	Lines	Areas
LES VARIABLES DE L'IMAGE				
XY 2 DIMENSIONS DU PLAN	POINTS	LIGNES	ZONES	
Z				
TAILLE				
VALEUR				
LES VARIABLES DE SÉPARATION DES IMAGES				
GRAIN				
COULEUR				
ORIENTATION				
FORME				

Semiology of Graphics [J. Bertin, 67]

# Information in Position

- Good to encode quantitative variables (Q)

C+

B+

A+

BC twice as long as AB

# Information in Color

(Grey)Value is perceived as ordered (O)



Can encode quantitative values (Q) [not as well]



Hue is normally perceived as unordered (N)



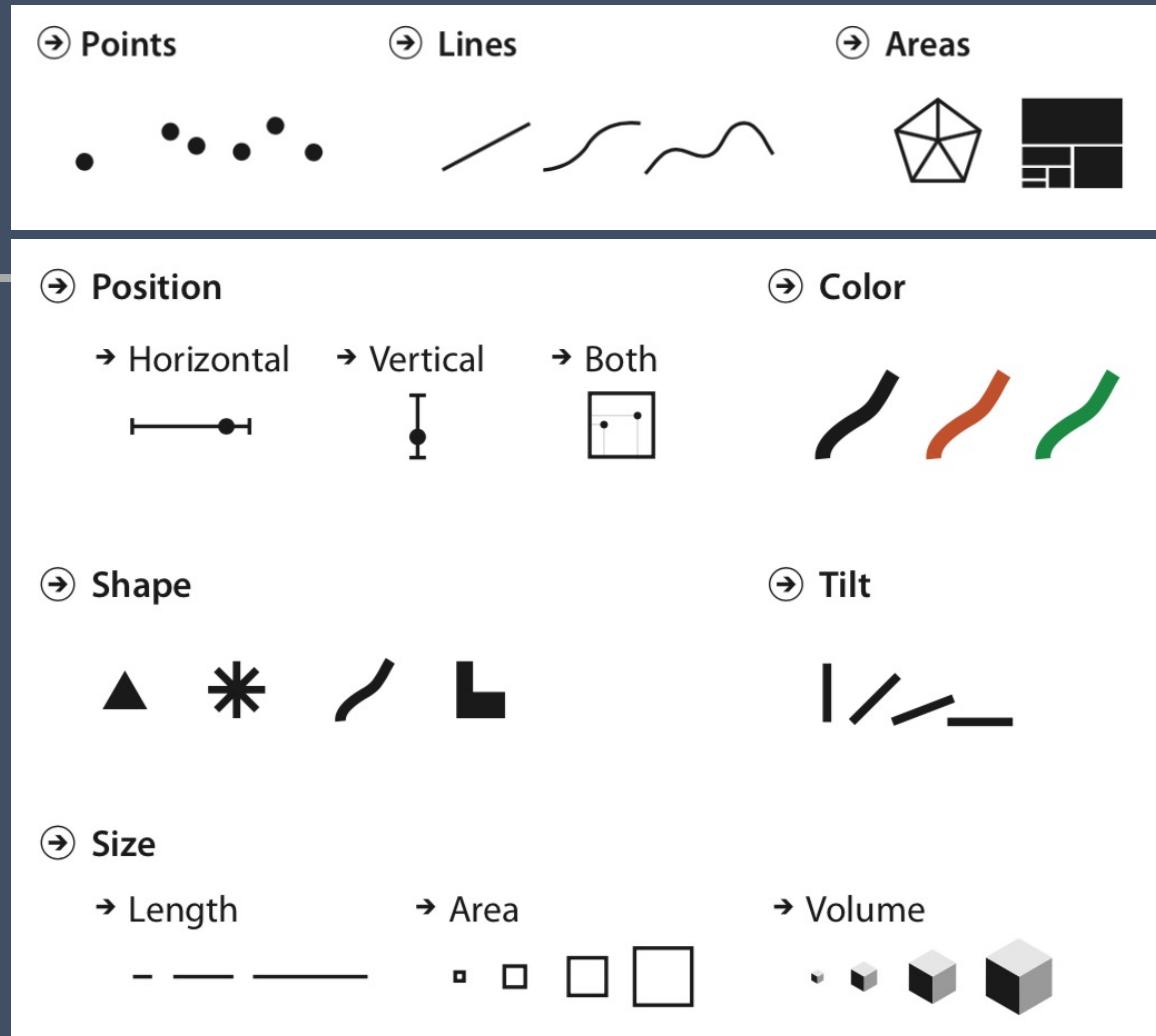
# Definitions: Marks and channels

## Marks

- Geometric primitives

## Channels

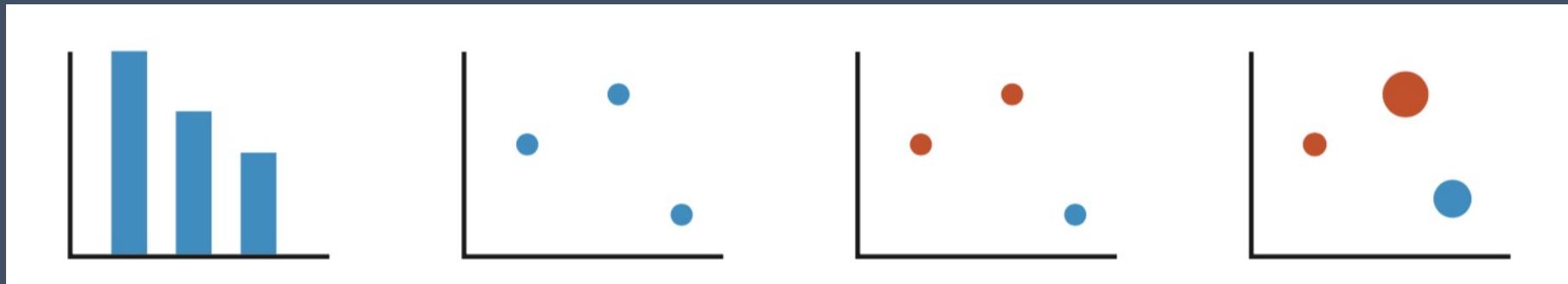
- Control appearance of marks
- Can redundantly code with multiple channels



# Visual encoding

## Analyze idiom structure

- As combination of marks and channels



1:  
vertical position

mark: line

2:  
vertical position  
horizontal position

mark: point

3:  
vertical position  
horizontal position  
color hue

mark: point

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

mark: point

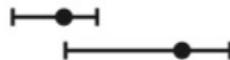
# Channels: expressiveness types and effectiveness rankings

## → Magnitude Channels: Ordered Attributes

Position on common scale



Position on unaligned scale



Length (1D size)



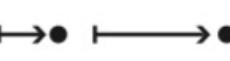
Tilt/angle



Area (2D size)



Depth (3D position)



Color luminance



Color saturation



Curvature



Volume (3D size)



## → Identity Channels: Categorical Attributes

Spatial region



Color hue



Motion



Shape



### Expressiveness principle

- match channel and data characteristics

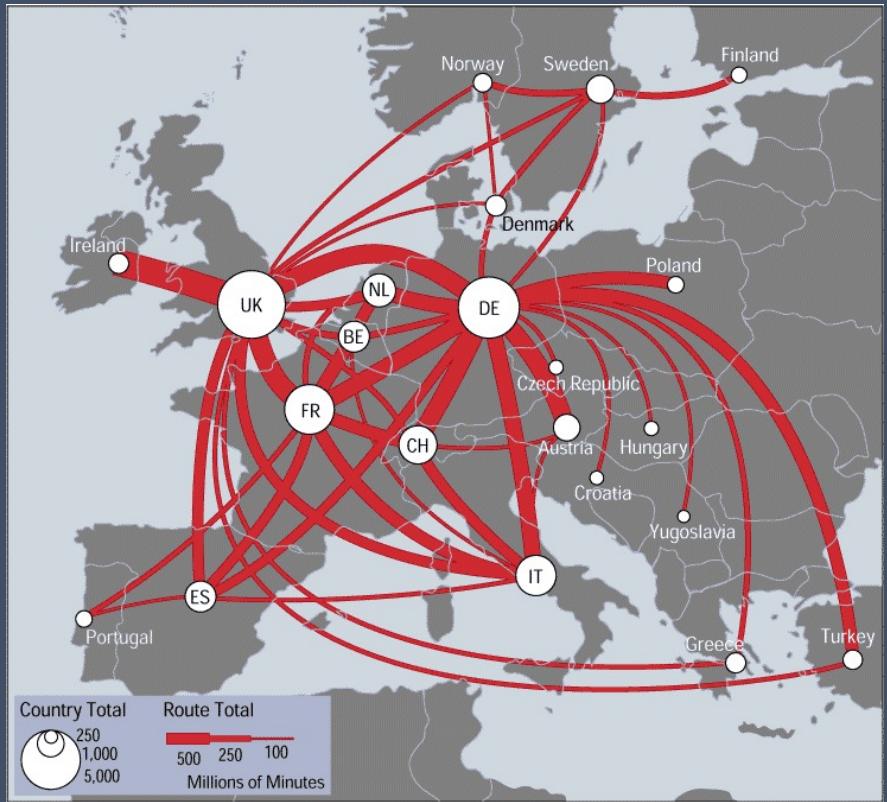
### Effectiveness principle

- encode most important attributes with highest ranked channels
- spatial position ranks high for both

# Discriminability: How many usable steps?

Must be sufficient for the number of attribute levels to show

- **Linewidth:** a few bins



Linewidth has a limited number of discriminable bins

# Summary

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- Visualization
  - Why?
  - What
    - Represent information
    - Analyze data
    - Communicate data
- Perception & Cognition
- Visual Encoding