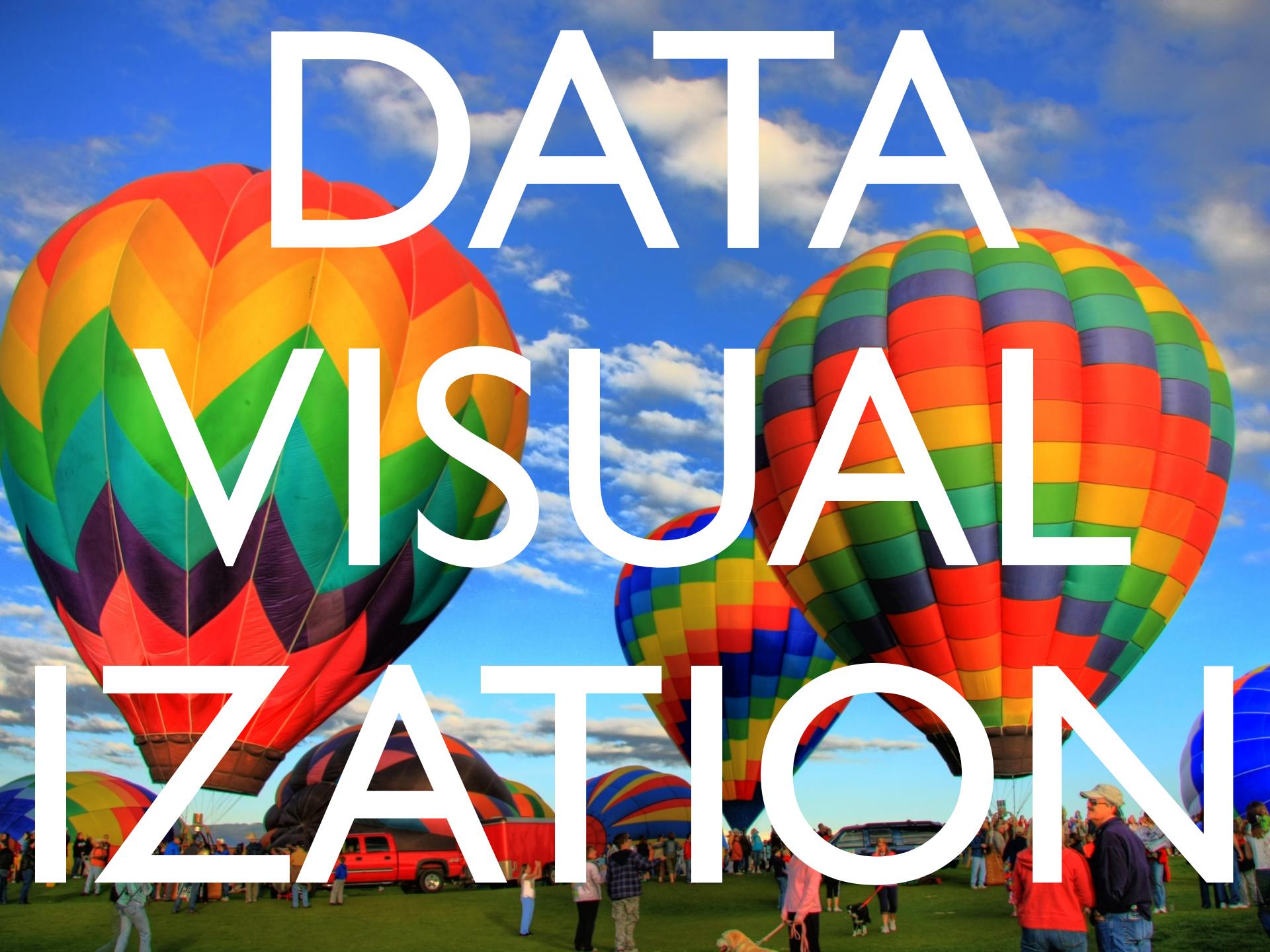


# DATA VISUAL- IZATION

The background of the image is a vibrant hot air balloon festival. Numerous colorful hot air balloons of various sizes are visible against a bright blue sky with scattered white clouds. In the foreground, there's a green grassy field where many people are gathered, some walking and talking, others standing near their balloons. A red pickup truck is parked on the left side. The overall atmosphere is festive and colorful.

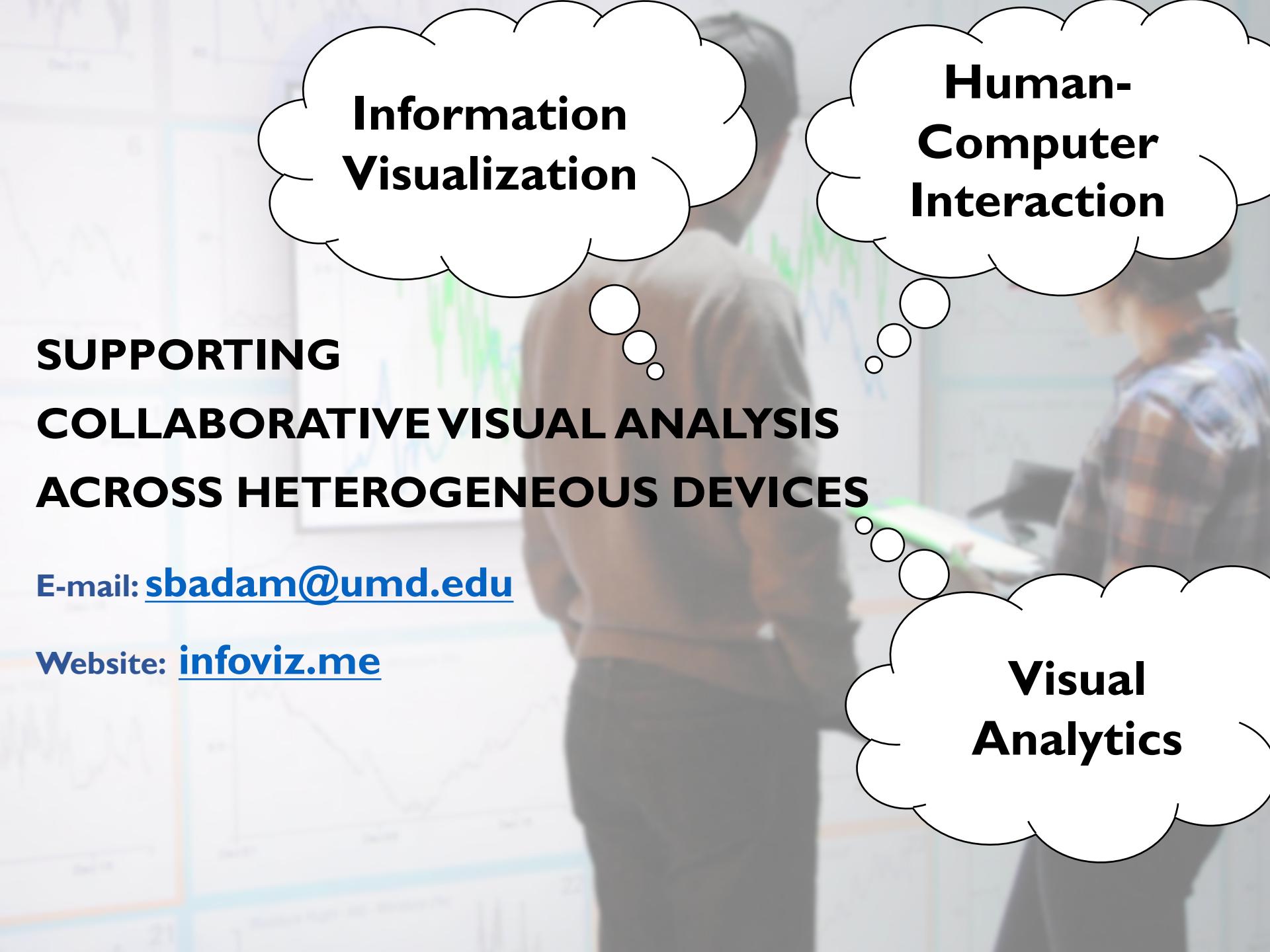
# DATA VISUALIZATION

**Karthik Badam, Niklas Elmquist**

Dept. of Computer Science, College of Information Studies  
University of Maryland, College Park



UNIVERSITY OF  
**MARYLAND**



**Information  
Visualization**

**Human-  
Computer  
Interaction**

**SUPPORTING  
COLLABORATIVE VISUAL ANALYSIS  
ACROSS HETEROGENEOUS DEVICES**

E-mail: [sbadam@umd.edu](mailto:sbadam@umd.edu)

Website: [infoviz.me](http://infoviz.me)

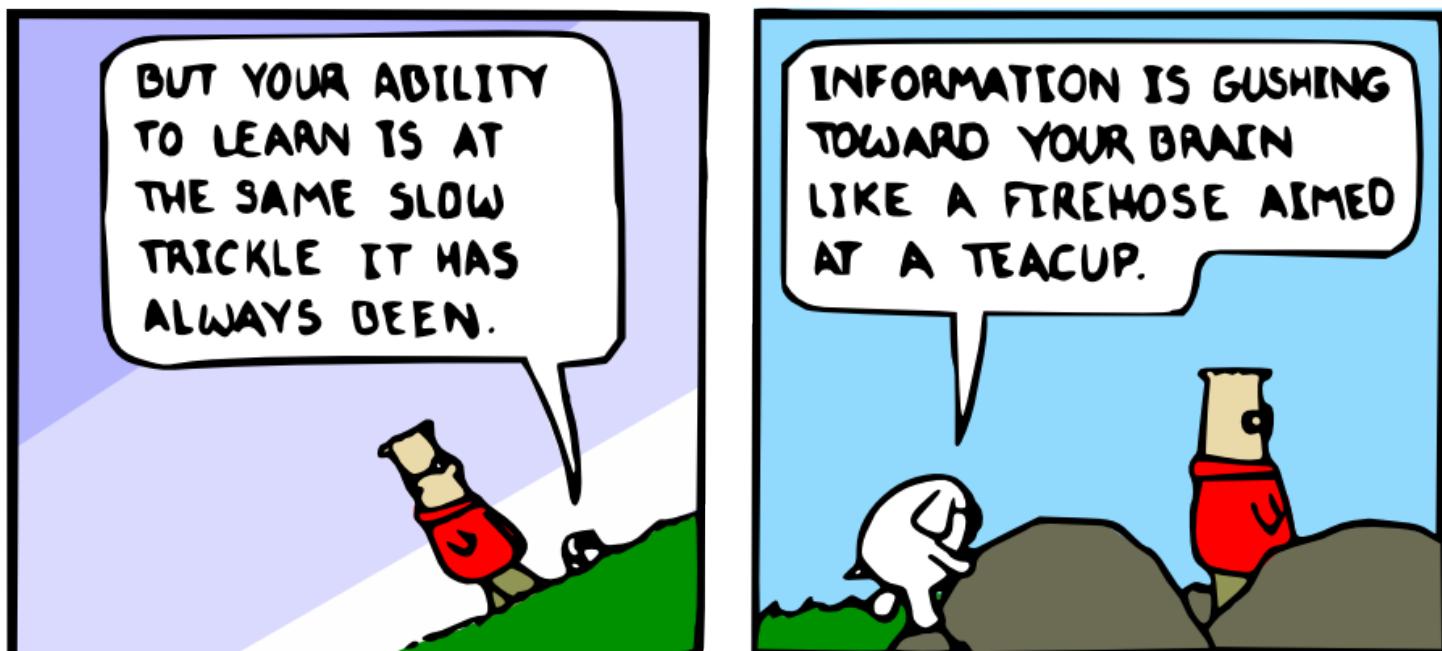
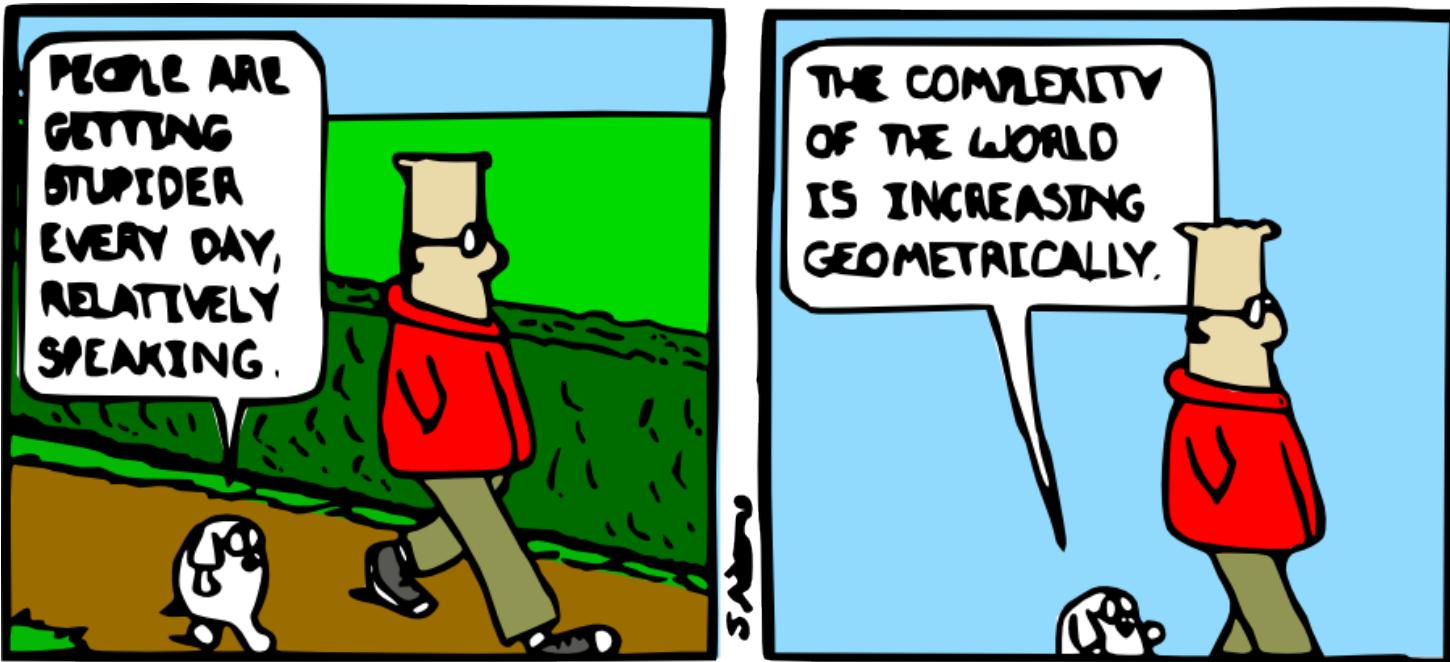
**Visual  
Analytics**

The background of the image shows a close-up of dry, brown soil with a few small green plant sprouts emerging from it. The lighting is warm and suggests a sunny day. Overlaid on this image is the word "INTRODUCTION" in large, white, sans-serif capital letters.

INTRODUCTION

BIG DATA PERMEATES SOCIETY...

VOLUME  
VELOCITY  
VERACITY  
VARIETY

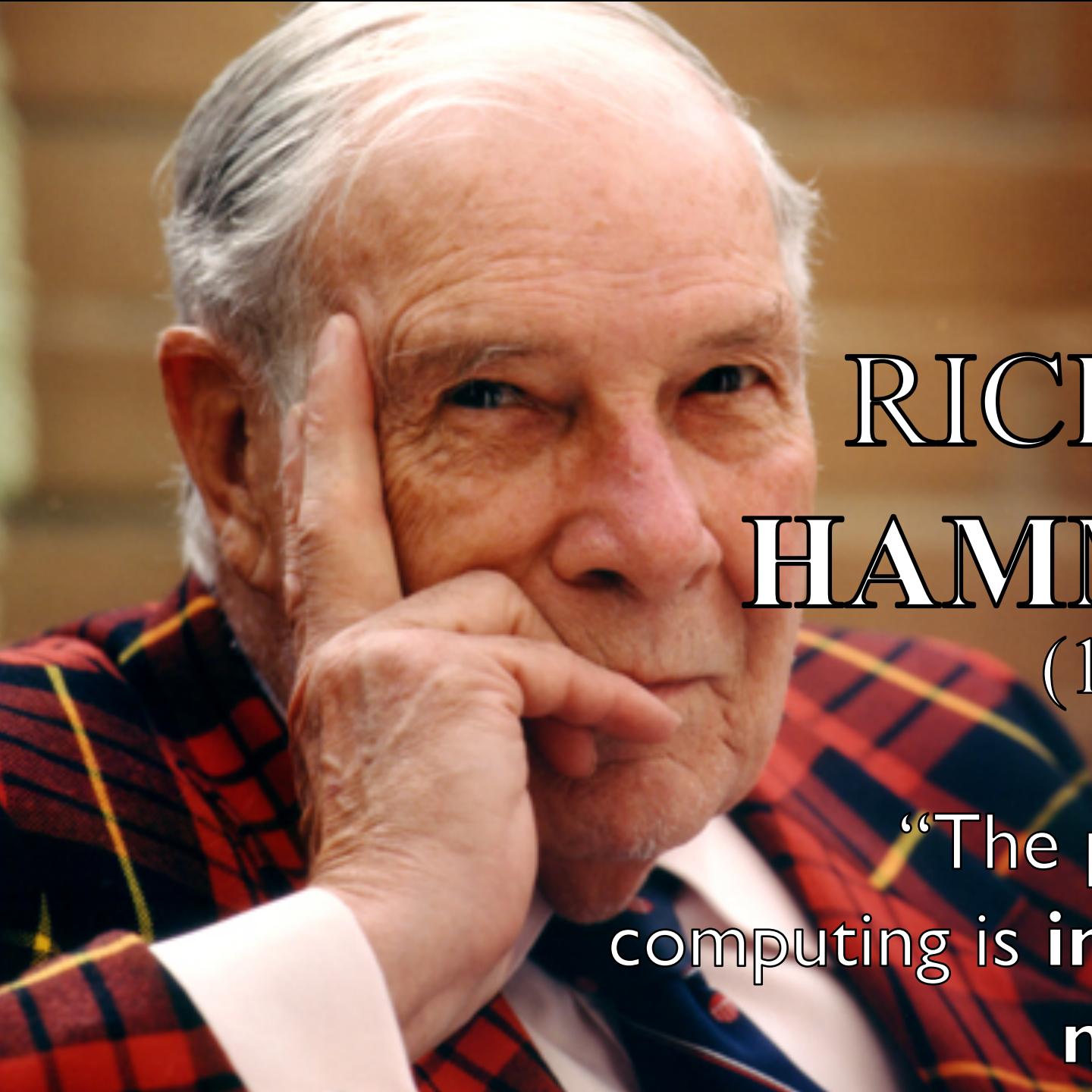


DILBERT © Courtesy

**Mathematics and statistics have been very successful in helping us manage this data...**

1.159	<b>1.40</b>	<b>0.9192</b>	<b>1.90</b>	<b>0.9713</b>	<b>2.40</b>	<b>0.9918</b>	<b>3.39</b>
1.186	<b>1.41</b>	<b>0.9207</b>	<b>1.91</b>	<b>0.9719</b>	<b>2.41</b>	<b>0.9920</b>	<b>3.32</b>
1.112	<b>1.42</b>	<b>0.9222</b>	<b>1.92</b>	<b>0.9726</b>	<b>2.42</b>	<b>0.9922</b>	<b>3.3</b>
1.188	<b>1.43</b>	<b>0.9236</b>	<b>1.93</b>	<b>0.9732</b>	<b>2.43</b>	<b>0.9925</b>	<b>3.</b>
1.14	<b>1.44</b>	<b>0.9251</b>	<b>1.94</b>	<b>0.9738</b>	<b>2.44</b>	<b>0.9927</b>	<b>3</b>
	<b>1.45</b>	<b>0.9265</b>	<b>1.95</b>	<b>0.9744</b>	<b>2.45</b>	<b>0.9929</b>	
	<b>1.46</b>	<b>0.9279</b>	<b>1.96</b>	<b>0.9750</b>	<b>2.46</b>	<b>0.9931</b>	
	<b>1.47</b>	<b>0.9292</b>	<b>1.97</b>	<b>0.9756</b>	<b>2.47</b>	<b>0.9932</b>	
	<b>1.48</b>	<b>0.9306</b>	<b>1.98</b>	<b>0.9761</b>	<b>2.48</b>	<b>0.9933</b>	
	<b>1.49</b>	<b>0.9319</b>	<b>1.99</b>	<b>0.9767</b>	<b>2.49</b>	<b>0.9934</b>	

$$\Phi(-w) = 1 - \Phi(w)$$

A close-up portrait of Richard Hamming, an elderly man with white hair, resting his chin on his hand and looking thoughtfully off-camera.

# RICHARD HAMMING

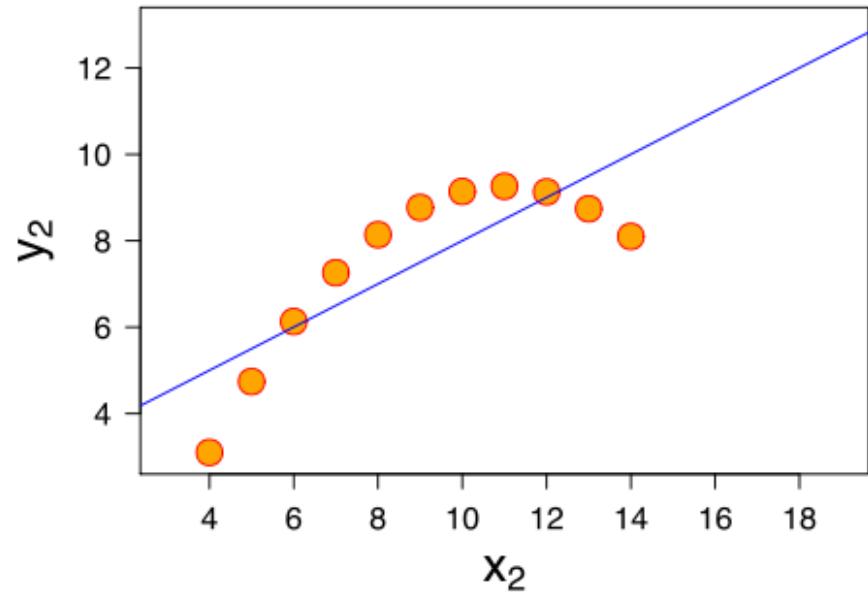
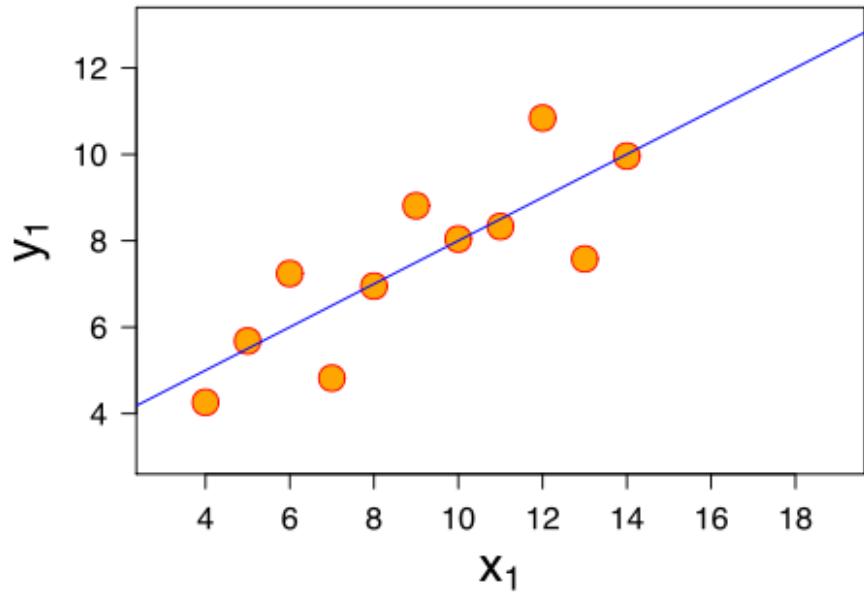
(1915-1998)

“The purpose of computing is **insight**, not numbers.”

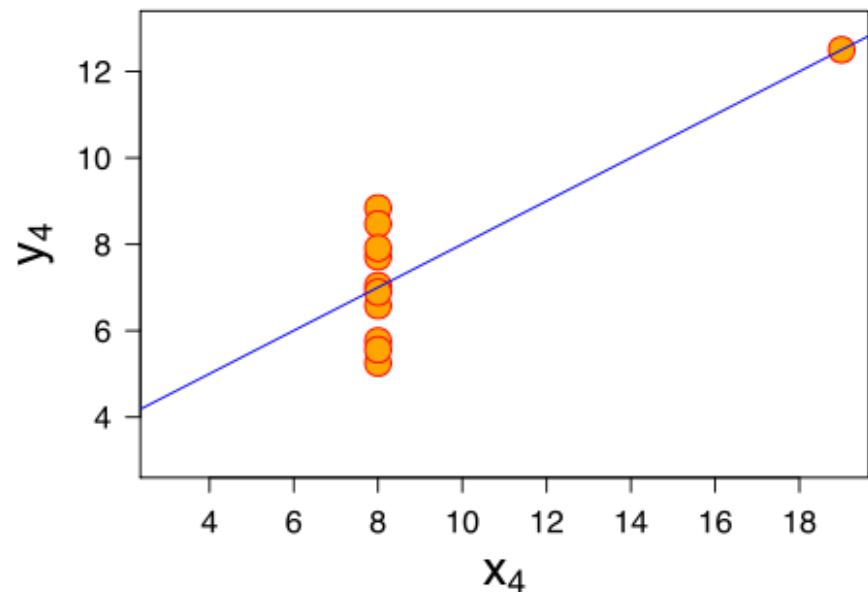
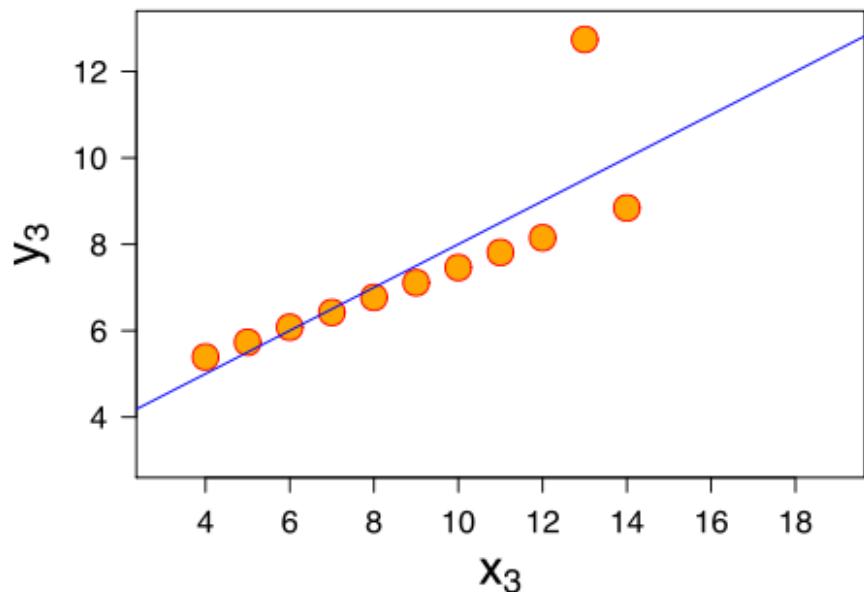
Sometimes **STATISTICS**  
is not **ENOUGH.**

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	9.0	8.14	9.0	6.77	9.0	5.76
13.0	7.58	11.0	8.81	11.0	8.04	11.0	7.11
9.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
11.0	8.04	10.0	9.14	10.0	7.46	8.0	6.58
14.0	7.58	11.0	8.81	11.0	8.04	11.0	7.11
6.0	7.58	10.0	8.81	10.0	8.04	9.0	7.11
4.0	8.04	9.0	9.14	9.0	7.46	8.0	6.58
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

Property	Value
Mean of x	9
Sample variance of x	11
Mean of y	7.50
Sample variance of y	4.122 or 4.127
Correlation between x and y	0.816
Linear regression line	$y = 3.00 + 0.500x$



## ANSCOMBE'S QUARTET

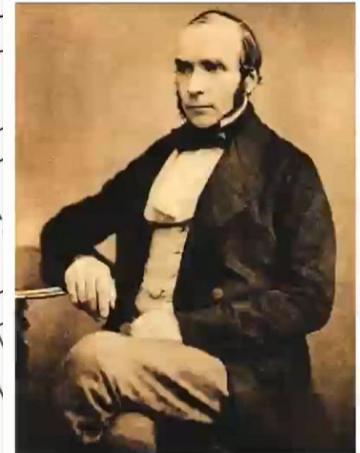




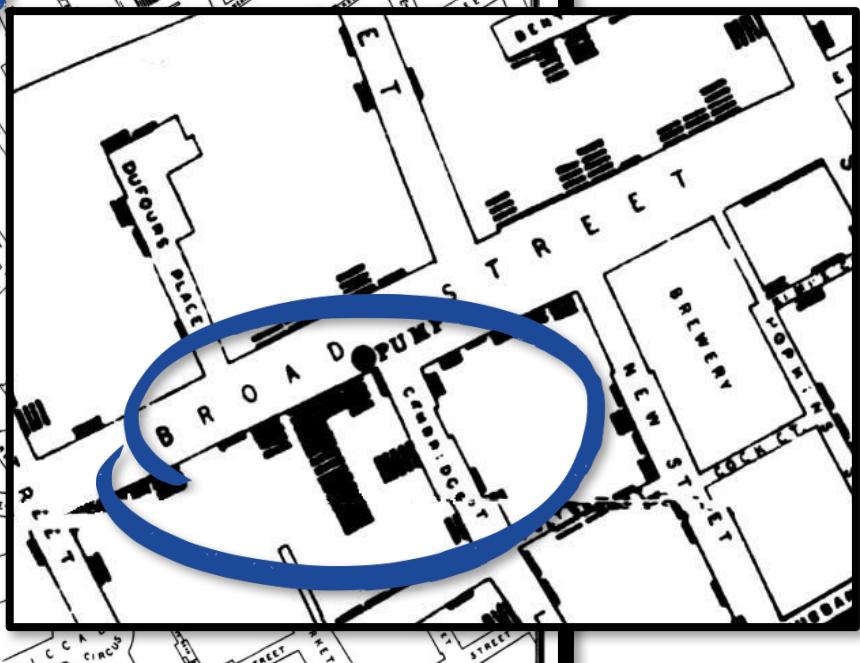
“A picture is worth a thousand words.”

# CONFUCIUS\*

(551-479 B.C.)



John Snow (1813-1858)



# Carte Figurative des pertes successives en hommes de l'Armée Française dans la Campagne de Russie 1812-1813.

Dressée par M. Minard, Inspecteur Général des Ponts et Chaussées en retraite Paris, le 20 Novembre 1869.

Les nombres d'hommes présents sont représentés par les largeurs des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en travers des 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 ont été puisés dans les ouvrages de M. M. Chiers, de Segur, de Fezensac, de Chambray et le journal inédit de Jacob, pharmacien de l'Armée depuis le 28 Octobre.

Pour mieux faire juger à l'œil la diminution de l'armée, j'ai supposé que les corps du Prince Jérôme et du Maréchal Davout, qui avaient été détachés sur Minsk en Mohilow et se rejoignent vers Orscha en Witelsk, avaient toujours marché avec l'armée.

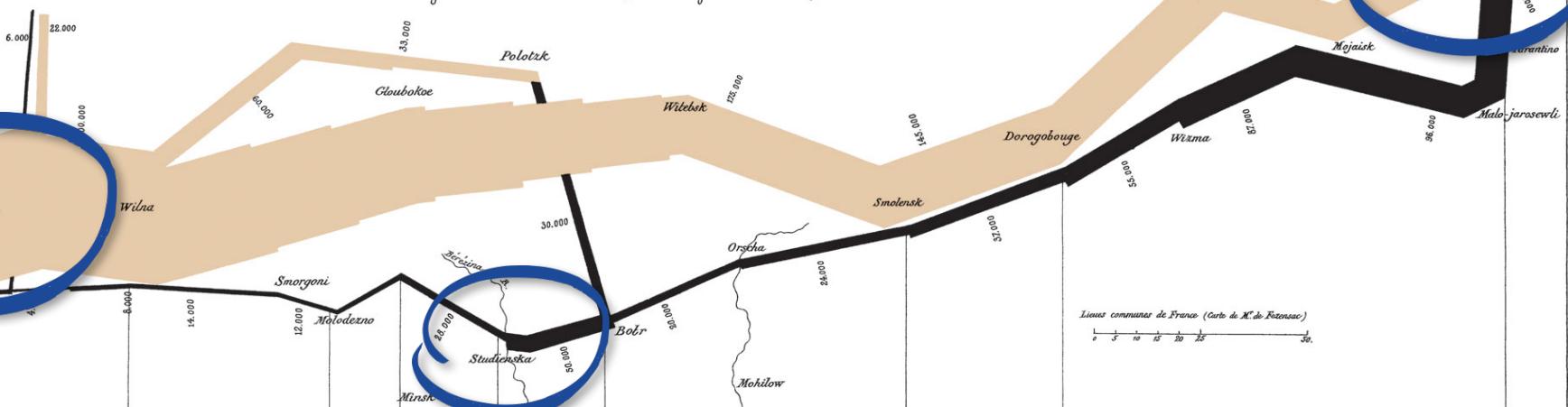
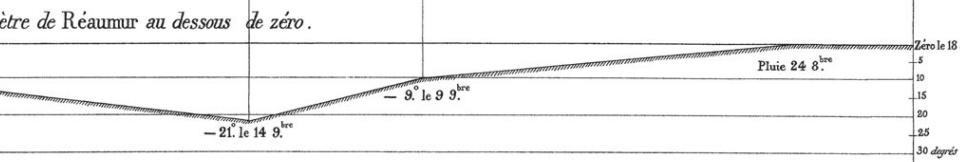


TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.

Les cosaques passent au galop  
le Niémen gelé.

-26° le 7 X.<sup>bre</sup>  
-30° le 6 X.<sup>bre</sup>

-24° le 1<sup>er</sup> X.<sup>bre</sup>  
-20° le 28 9.<sup>bre</sup>



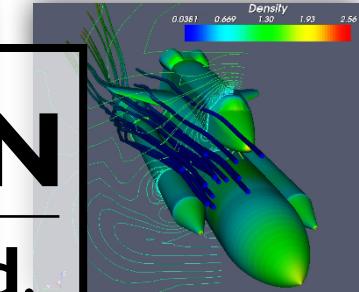
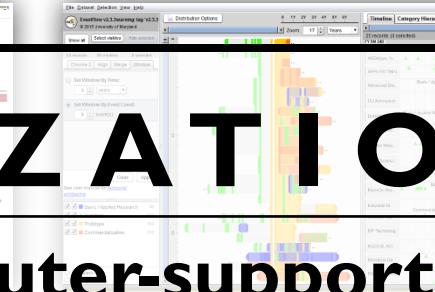
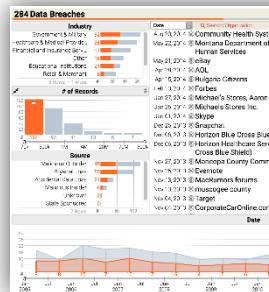
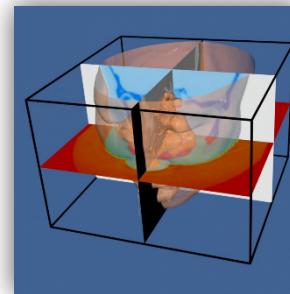
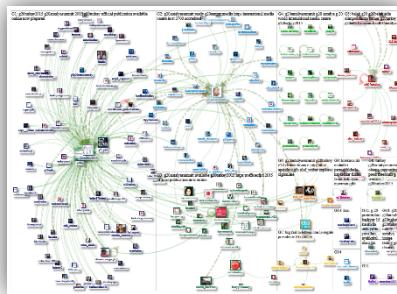
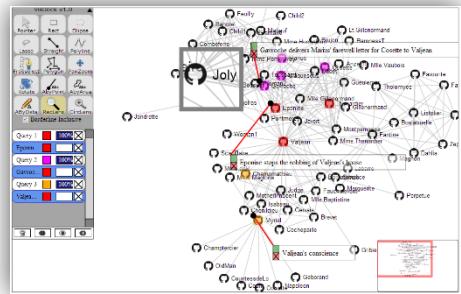
Imp. Lith. Regnier et Dourdet.

# SCIENTIFIC DEFINITION

# VISUALIZATION – DEFINITION!

- “*Transformation of the symbolic into the geometric*”
  - [McCormick et al. 1987]
- “*... finding the artificial memory that best supports our natural means of perception.*”
  - [Bertin 1967]
- “*The use of computer-generated, interactive, visual representations of data to amplify cognition.*”
  - [Card, Mackinlay, & Shneiderman 1999]

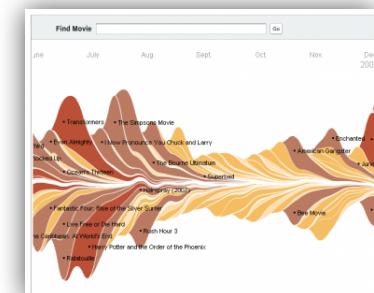
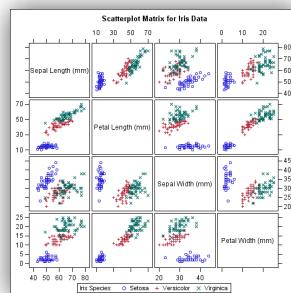
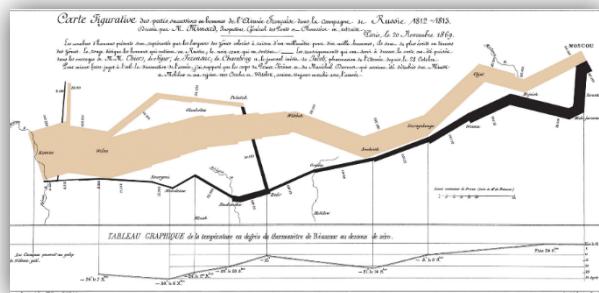
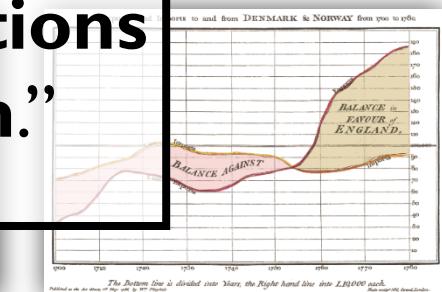
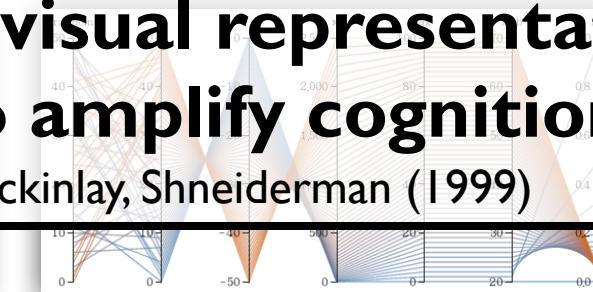
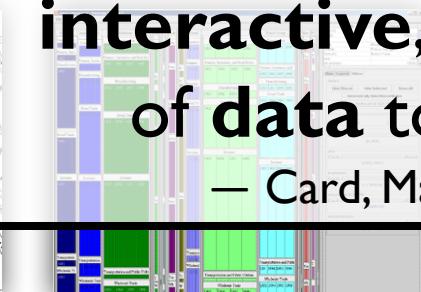
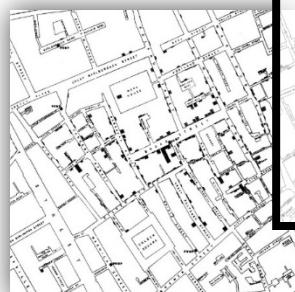




# VISUALIZATION

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

— Card, Mackinlay, Shneiderman (1999)



# VISUALIZATION PIPELINE

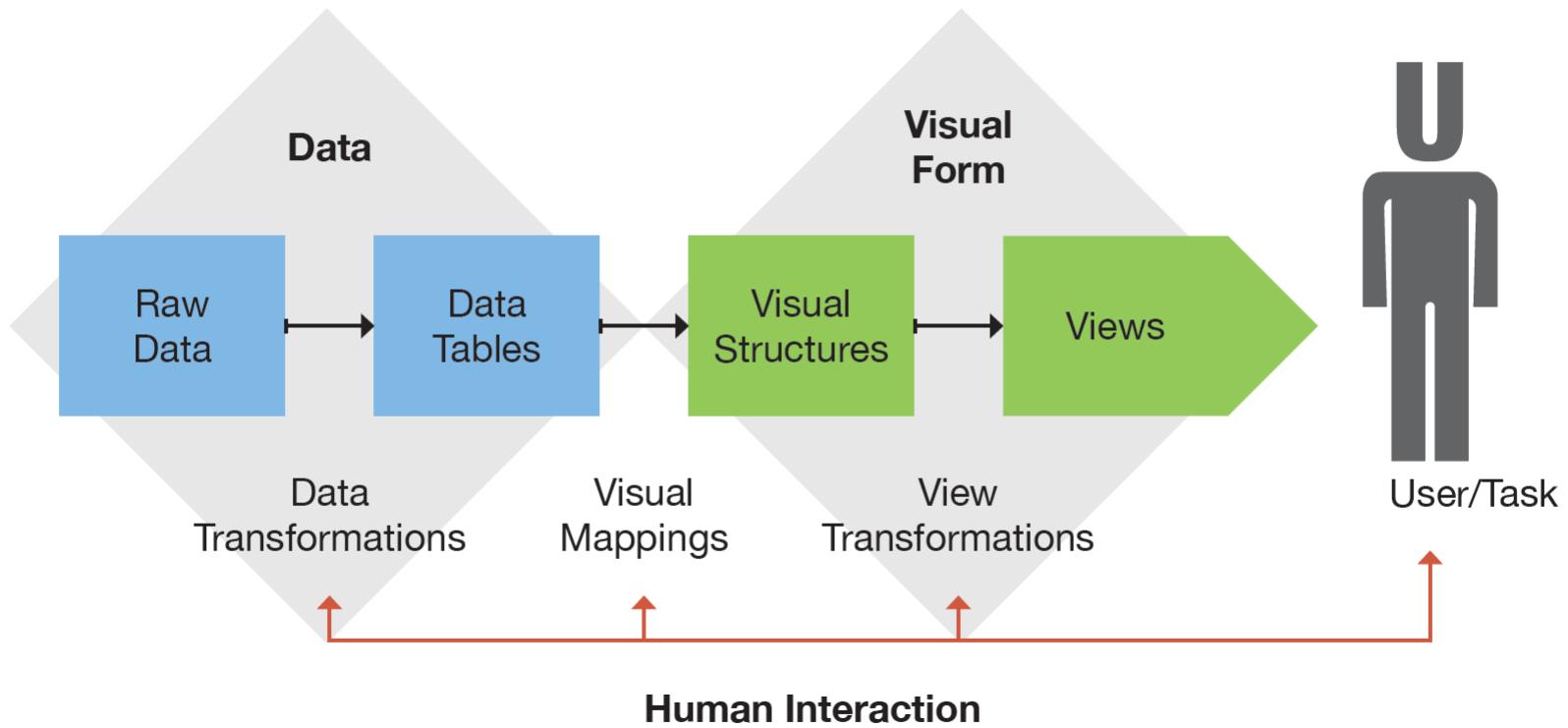


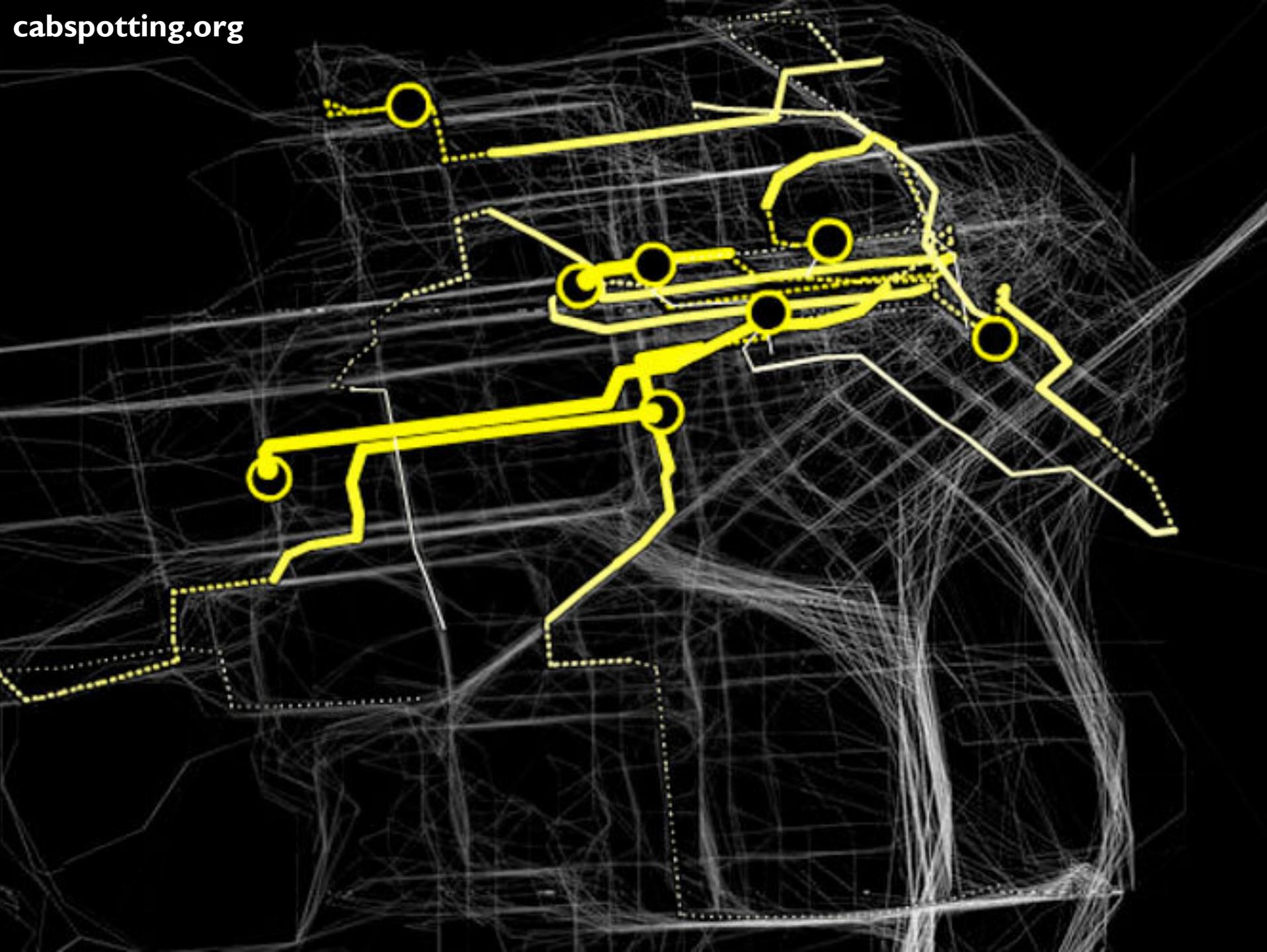
# VISUALIZATION PIPELINE

- Visualization transforms data to visual form
- Useful to think about a **pipeline**
  - Raw data goes in
  - Visualization comes out
- Feedback loop: interaction (not for static)
- Reference model: **visualization pipeline**
  - From Card, Mackinlay, Shneiderman

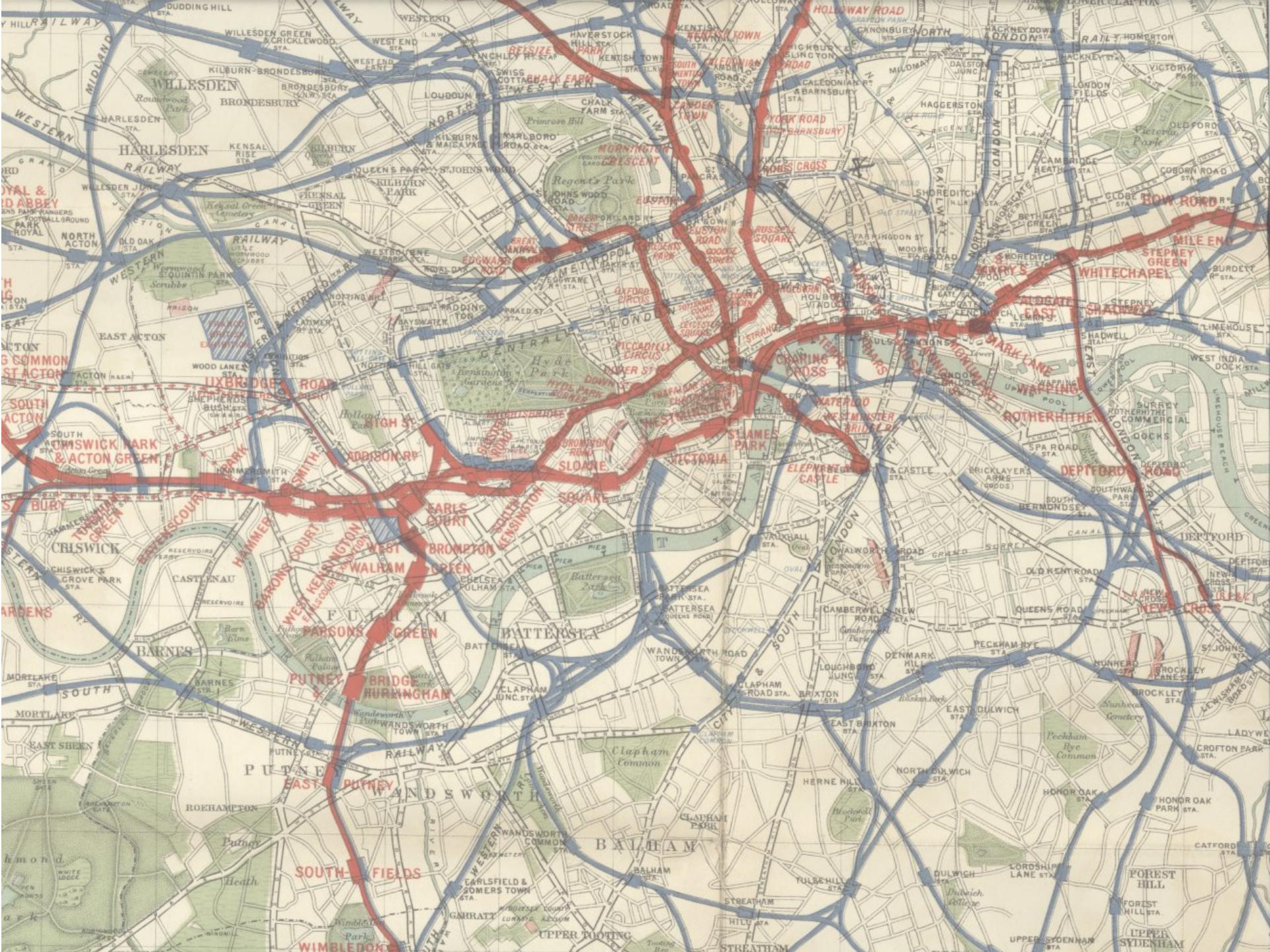


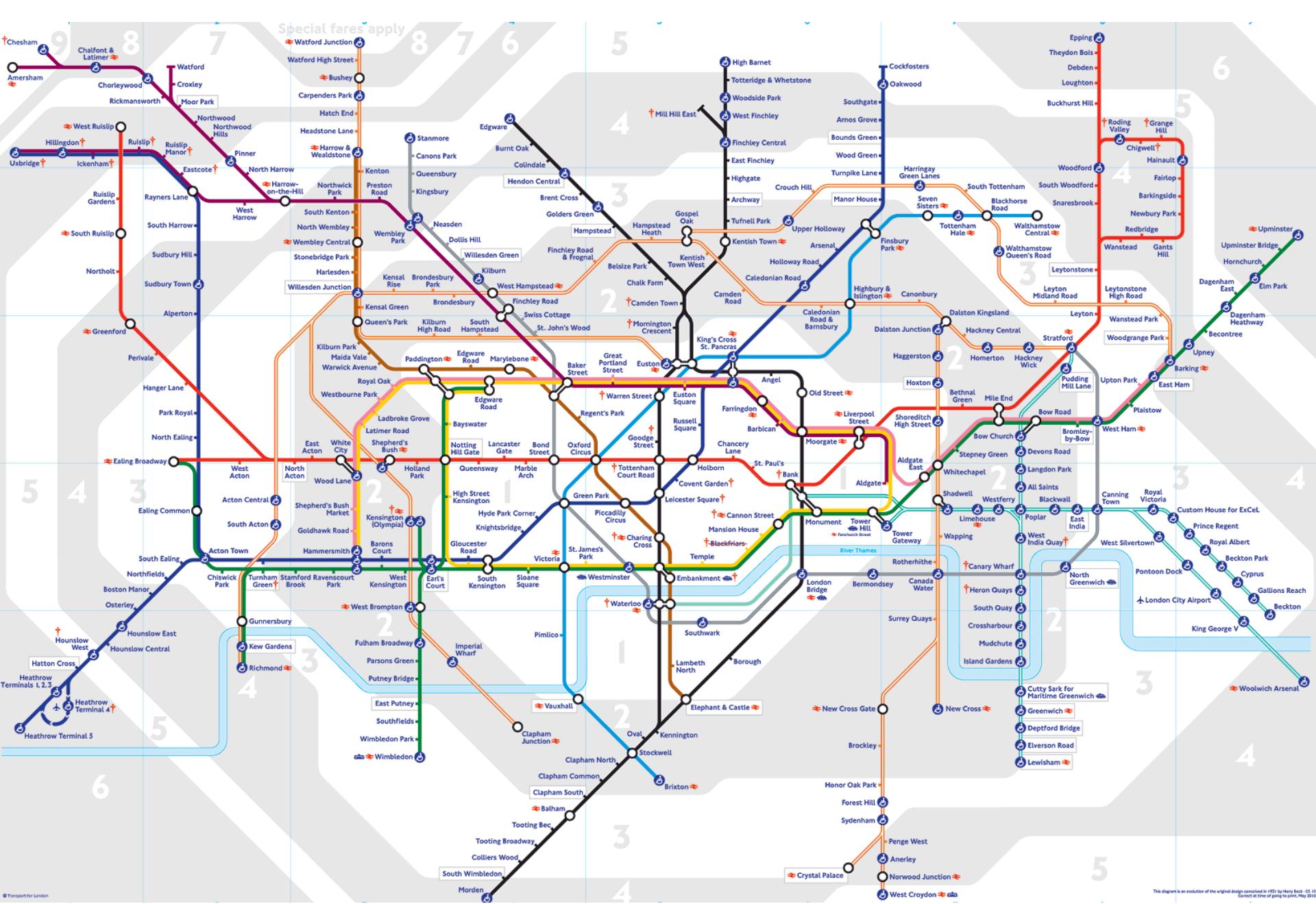
# VISUALIZATION PIPELINE











This diagram is an evolution of the original design conceived in 1931 by Harry Beck - 15.12.2010  
Correct at time of going to print.



# COMMUNICATION

Telling a story

End of the pipeline (after analysis)

Present findings to stakeholders

Pictures are easy to understand



# ANALYSIS

Understanding data

Part of a cycle (not pipeline)

Utilize power of visuals for sensemaking

Pictures allow us to grasp quickly

# VISUALIZATION GUIDELINES

**NO** single theory

Case-by-case basis

**NO** silver bullet

Find the right tool

**NOT** trivial

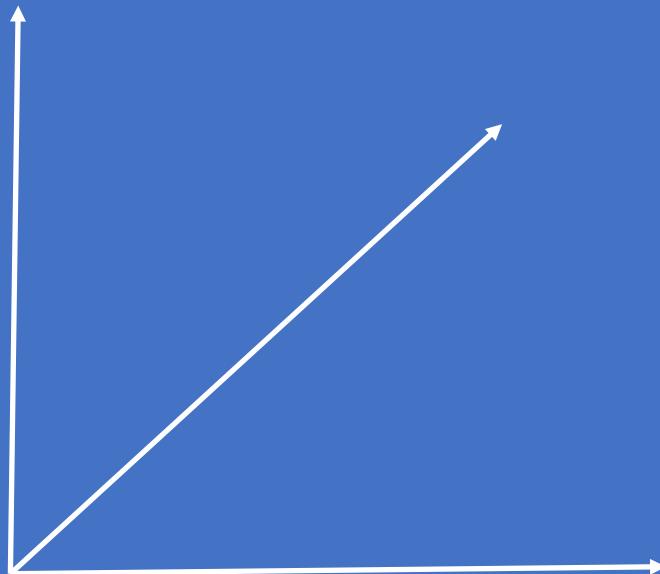
Requires plan + design

**NOT** easy to get started

Need exposure...



# MULTIDIMENSIONAL DATA



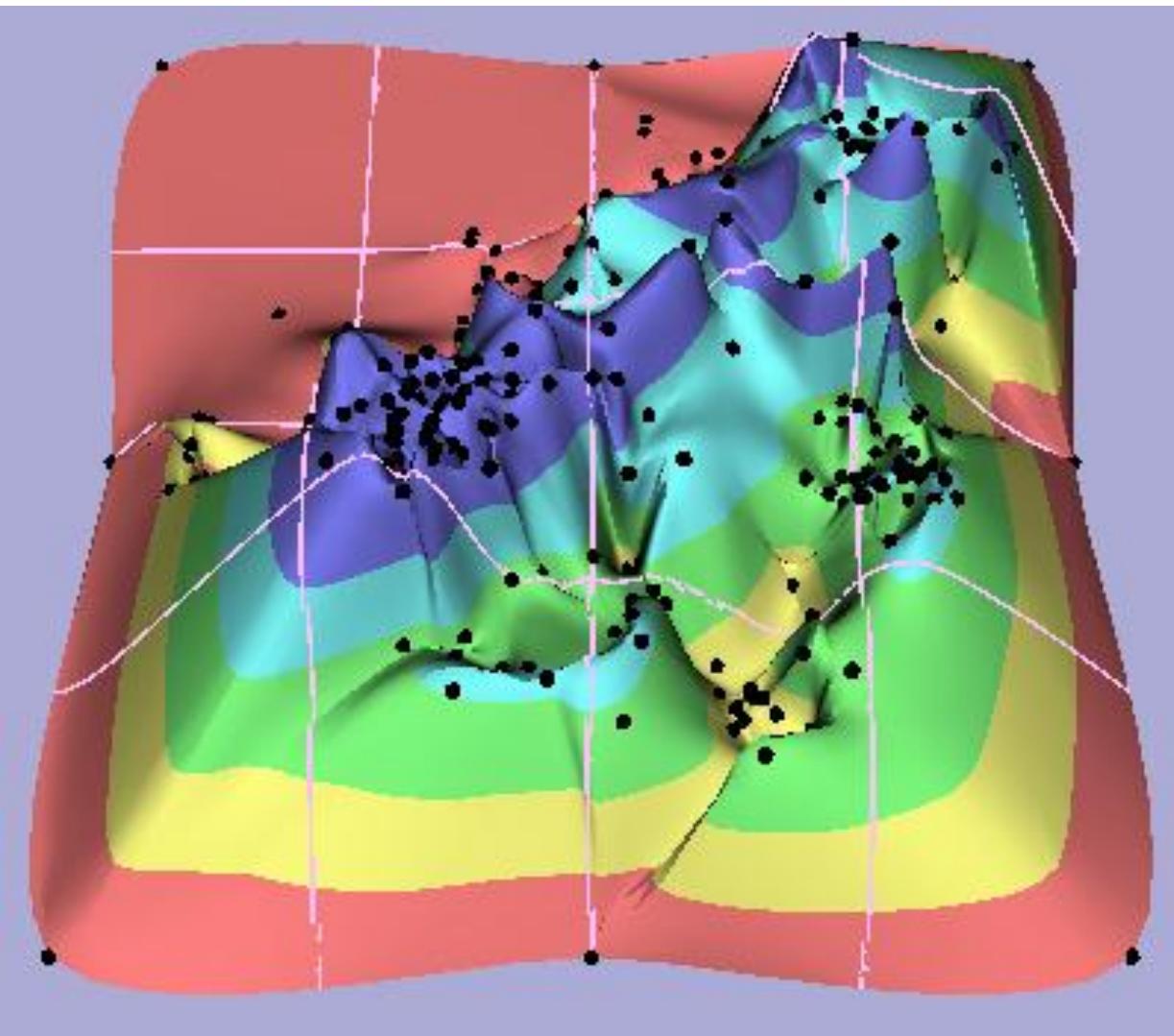
>> 3 dimensions

# MULTIDIMENSIONAL DATA

- Visual variables are limited in number
- Primary ones: space (essentially 2D)
  - 3D for 3D data (scientific visualization)
- **Inspiration:** 3D computer graphics
  - 3D world is projected down to 2D
  - Can we use this idea here?
- **Method:** Dimensional Projection
  - Most basic multidimensional technique
  - Projects n-D data to 2-D data



# DIMENSIONAL PROJECTION

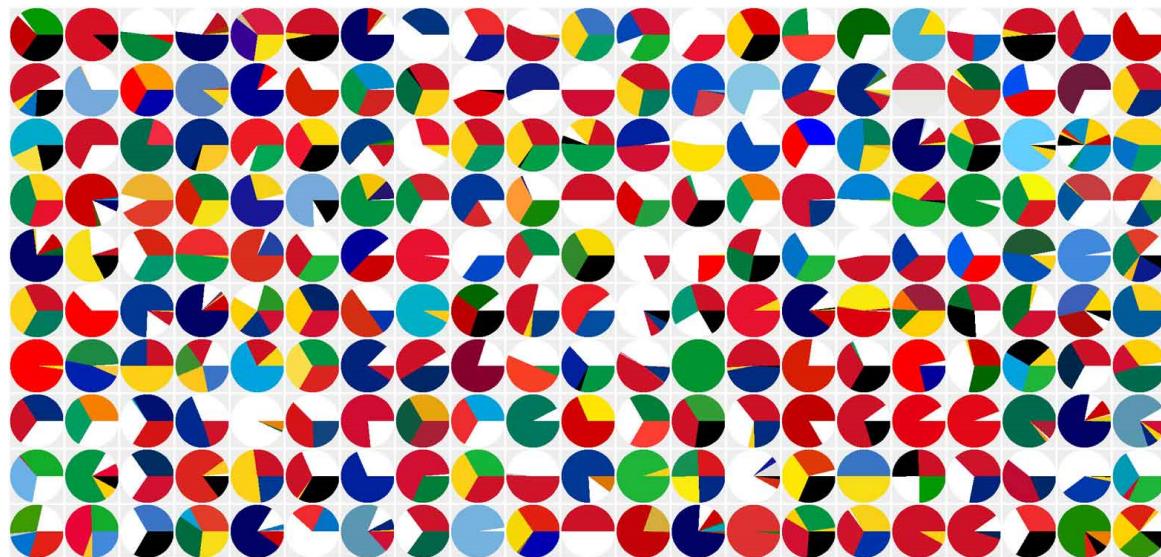


Melanie Tory,  
UVictoria

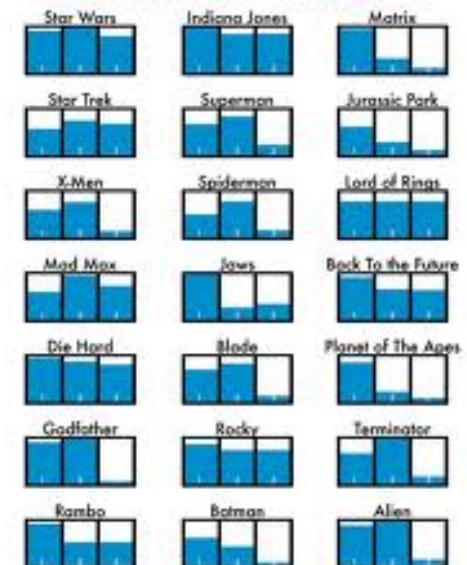


# SMALL MULTIPLES

- Give each variable a graph of its own!



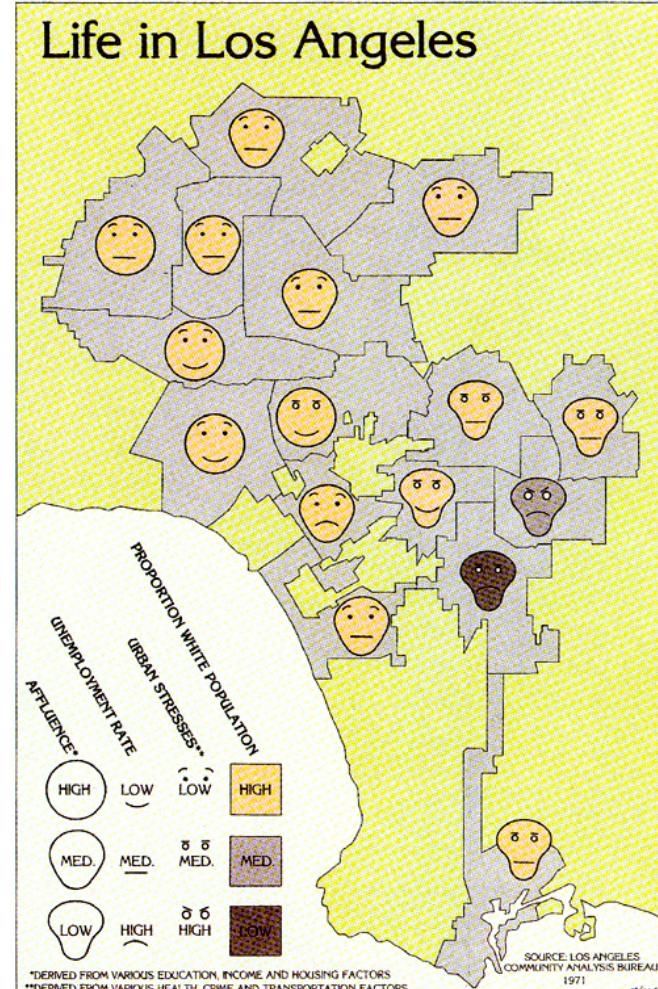
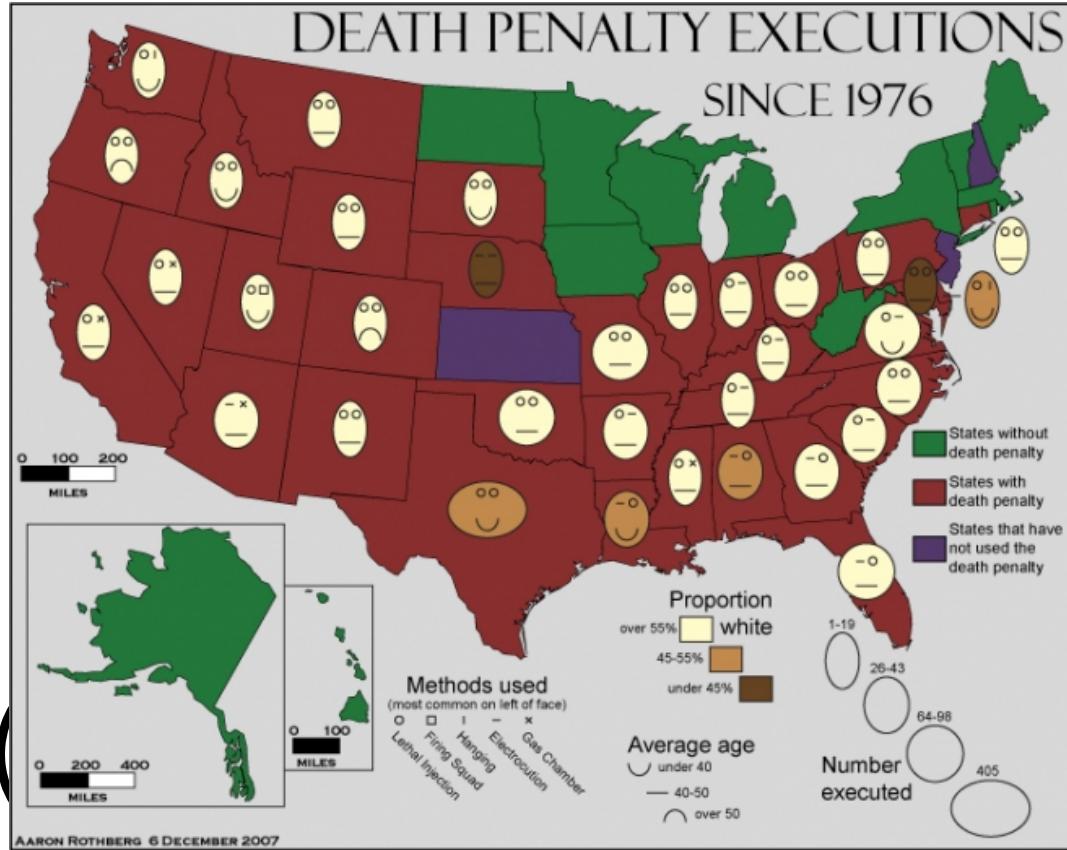
THE TRILOGY METER



DANMETH.COM

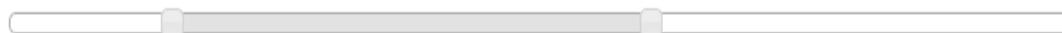
# CHERNOFF FACES (1973)

- Utilize human face recognition
- Visualize n-D data (glyphs)



# DYNAMIC QUERIES

- Ben Shneiderman in 1990s:
  - SQL queries are cumbersome
  - Difficult syntax
  - Conversation, not direct
- Start with sliders, extend them



# HOME FINDER

Video!

The screenshot shows a map of a city area with a red dotted line forming a polygon. Inside this polygon, there are several yellow dots representing homes for sale. Two specific points, 'A' and 'B', are marked with red dashed lines extending from the polygon's boundary. A cursor is positioned near point 'B'. To the right of the map is a control panel with the following settings:

Dynamic HomeFinder	
Reset	Quit
Save	Print
Dist to A:	
1	30
19	(highlighted)
Dist to B:	
1	30
6	(highlighted)
Bedrooms:	
1	7
2	4
4	(highlighted)
Cost:	
\$50k	\$500k
16	38

Below the control panel, the text "Look at:" is followed by three buttons: "Hse" (highlighted), "TH", and "Cnd". Further down, the text "Features:" is followed by four buttons: "Grg" (highlighted), "Fpl", "EAC", and "New".

**Map Instructions:**

The yellow dots above are homes in the DC area for sale. You may get more information on a home by selecting it. You may drag the 'A' and 'B' distance markers to your office or any other location you want to live near. Select distances, bedrooms, and cost ranges by dragging the corresponding slider boxes on the right. Select specific home types and services by pressing the labeled buttons on the right.



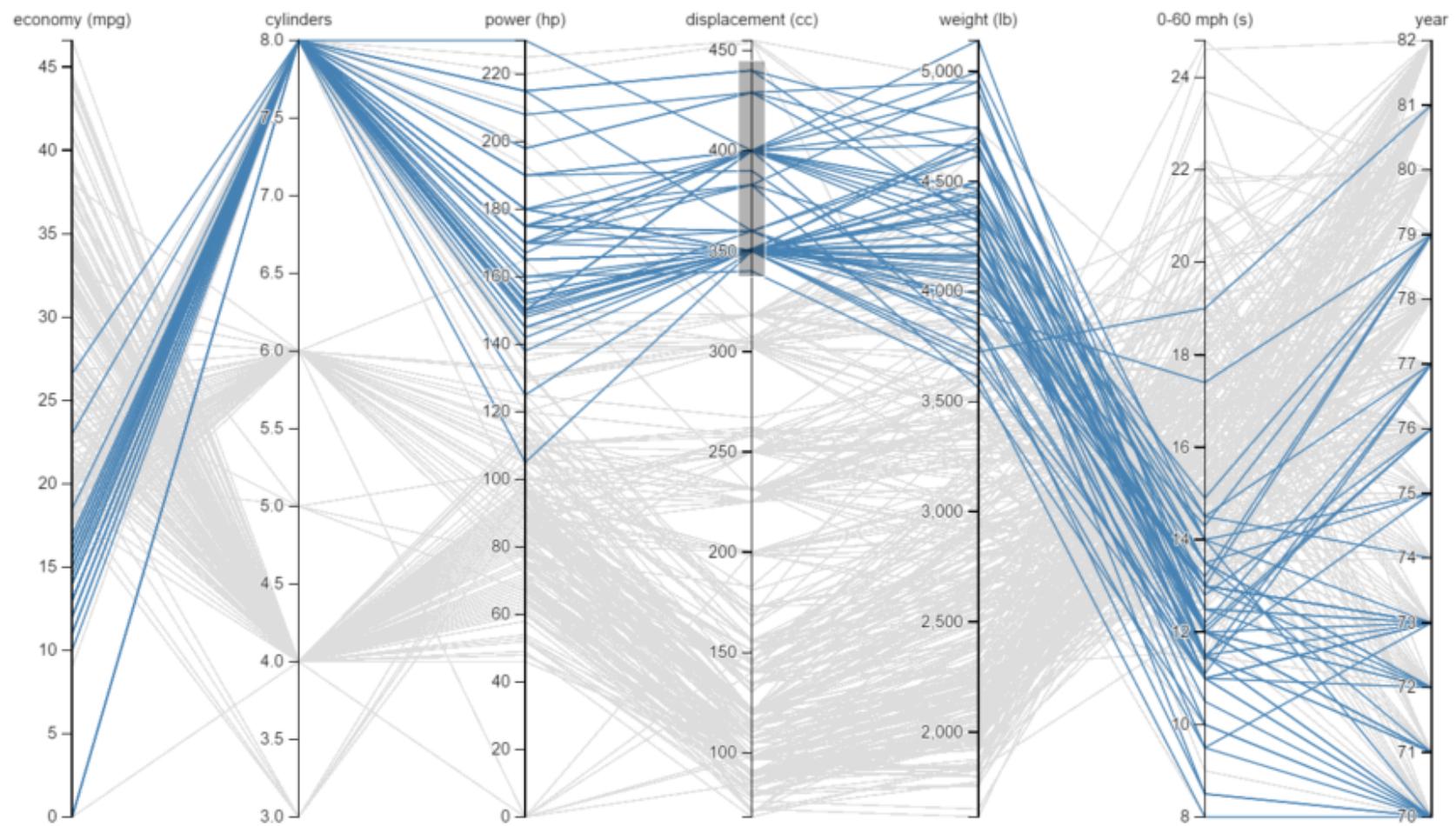
# PARALLEL COORDINATES

- Mapping data dimension to graphical dimensions (axes) quickly consumes space
  - Only 2 dimensions (X + Y) in practice
  - Shape, color, and size = additional 3 dims
- Instead: line up axes in parallel
  - Points in 2D space become polylines
  - Connect positions along parallel axes
- Concept: parallel coordinates
- Designed by Alfred Inselberg in 1985

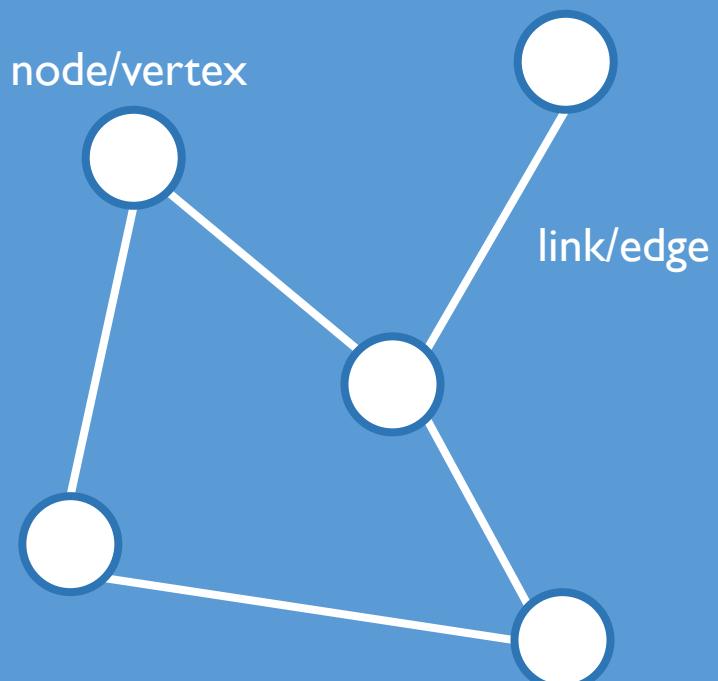


# EXAMPLE: PARALLEL COORDS

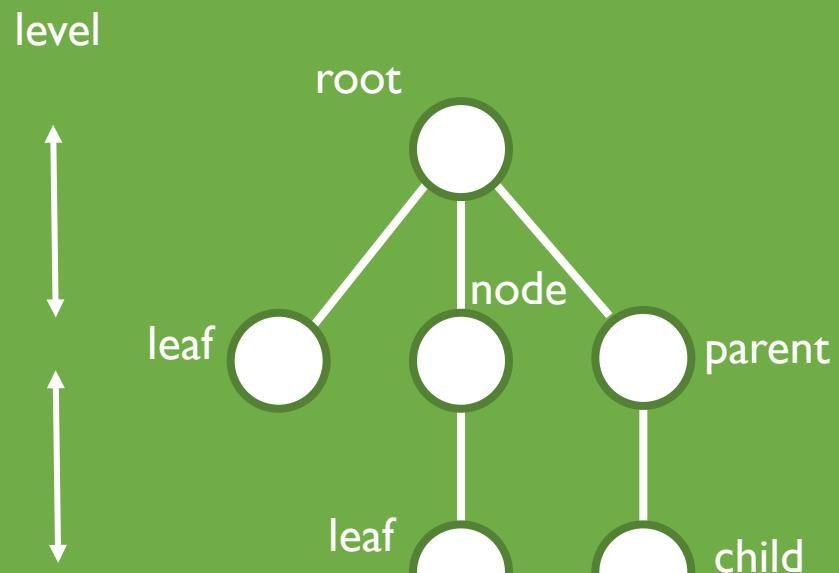
<http://bl.ocks.org/jasondavies/1341281>



# NETWORKS

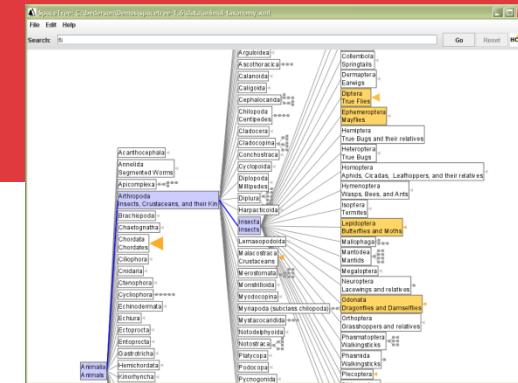


# TREES

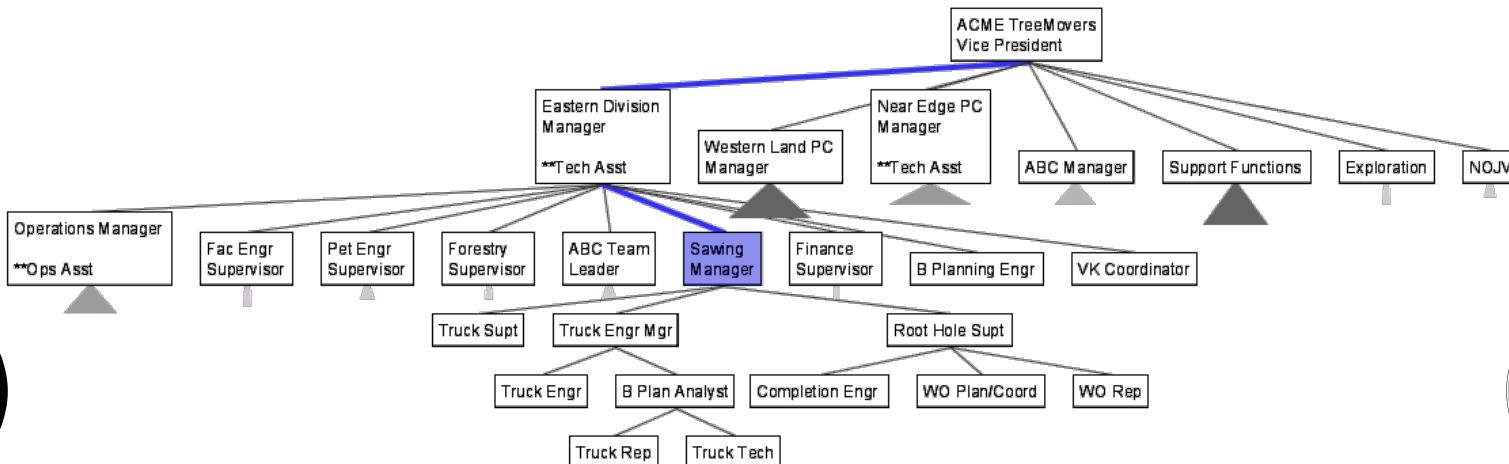


# SPACETREES

- Work with recursive tree layout
- Addresses problems with this layout:
  - Interaction to expand and collapse
  - Optimized camera movement, rescaling of branches
  - Preview icons

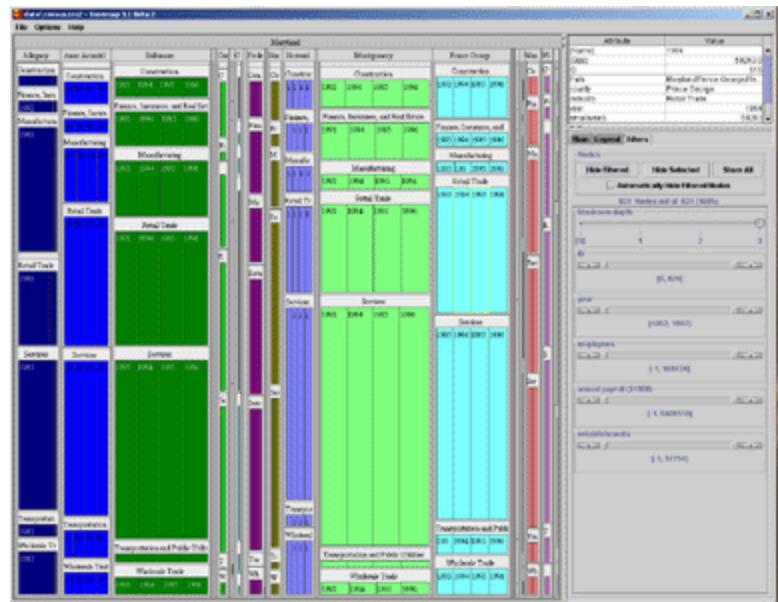
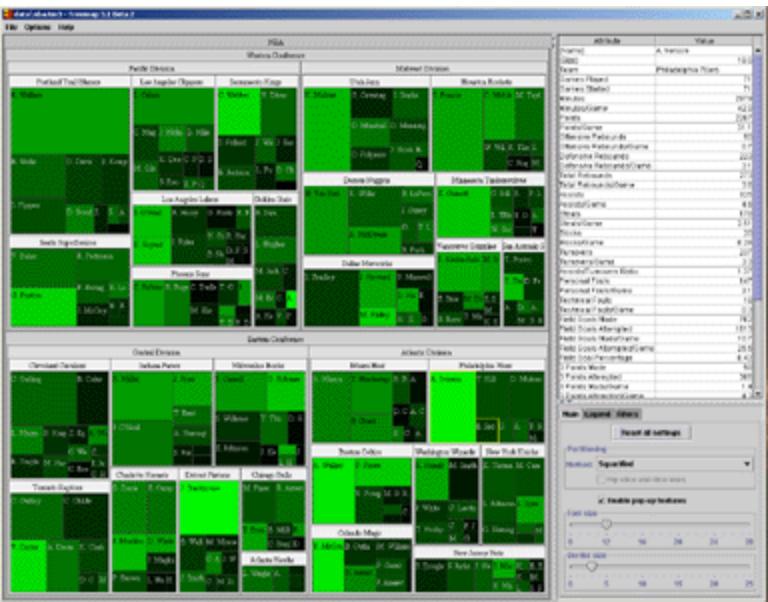


[https://www.youtube.com/watch?v=-vXRJ\\_Ry\\_yE](https://www.youtube.com/watch?v=-vXRJ_Ry_yE)



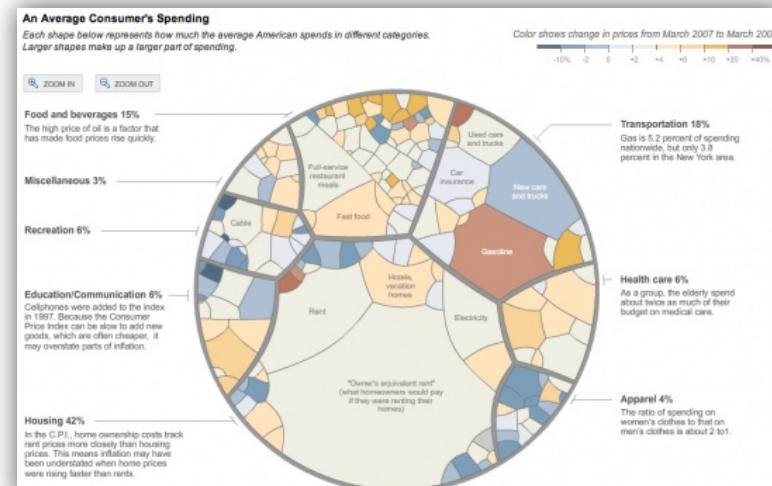
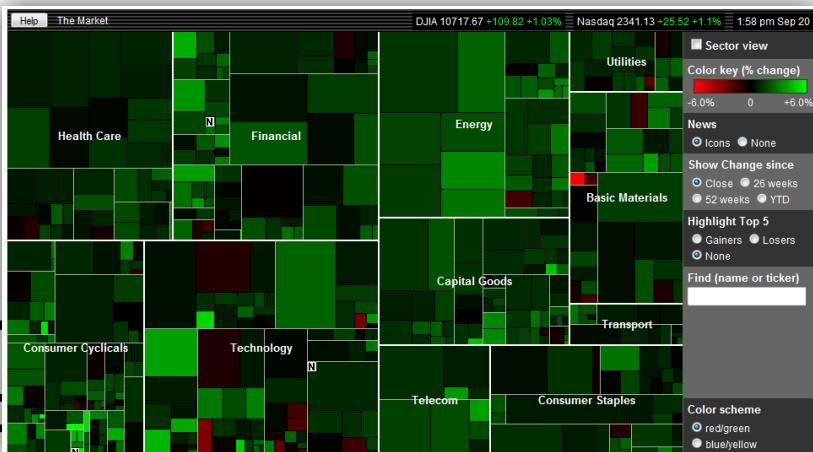
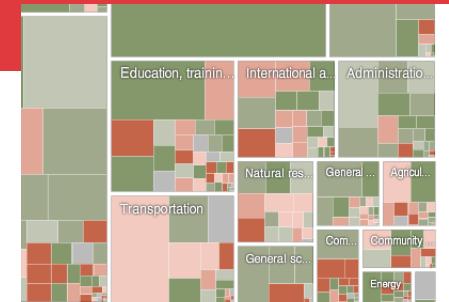
# TREEMAPS

- Space-filling tree visualization from 1991
  - Enclosure: children within parents
  - Slice-and-dice layout: alternate horizontal/vertical
  - Area can encode data (size of nodes)

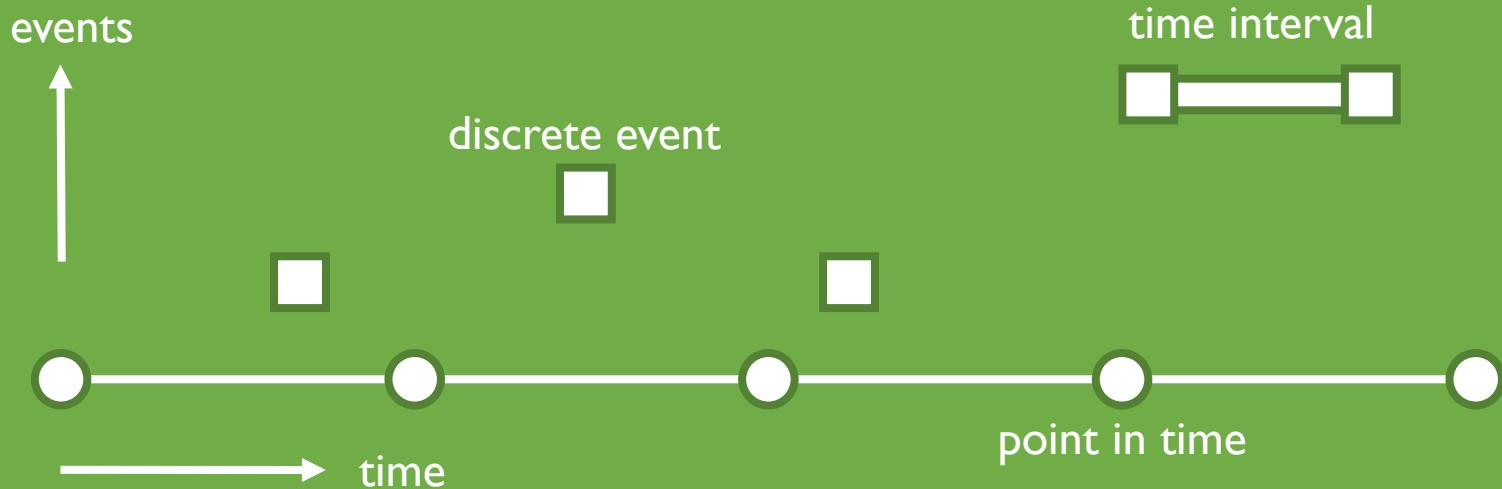


# EXAMPLES OF TREEMAPS

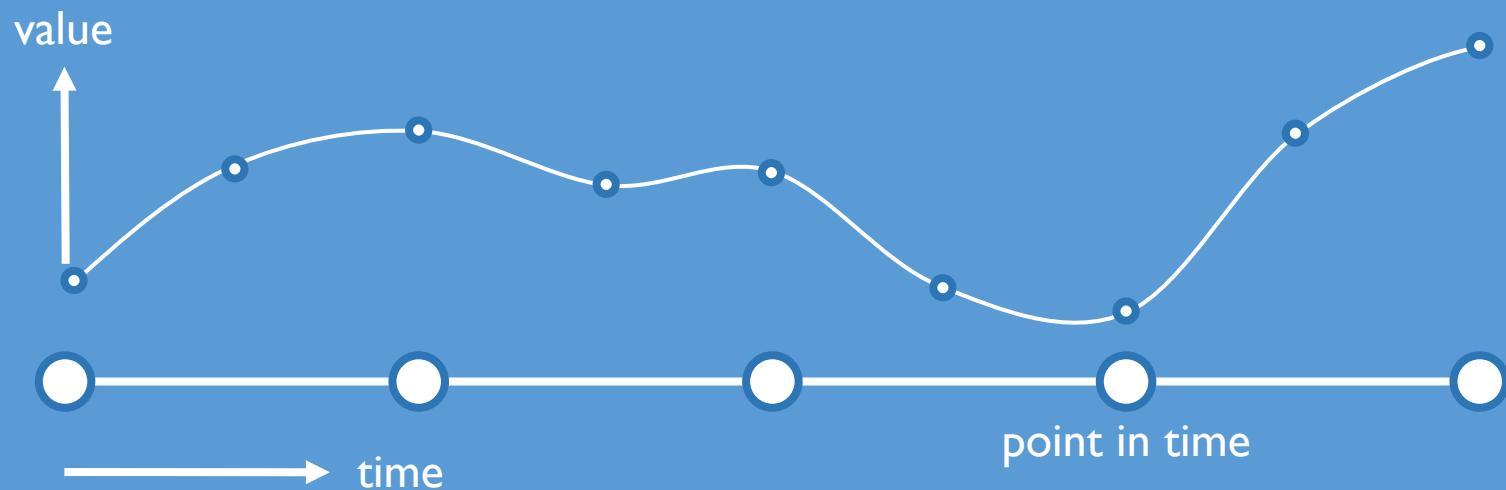
- NY Times: 2010 budget proposal
- American consumer spending
- D3: <http://bl.ocks.org/mbostock/4063582>
- Treemap history:  
<http://www.cs.umd.edu/hcil/treemap-history/>



# TIMELINES

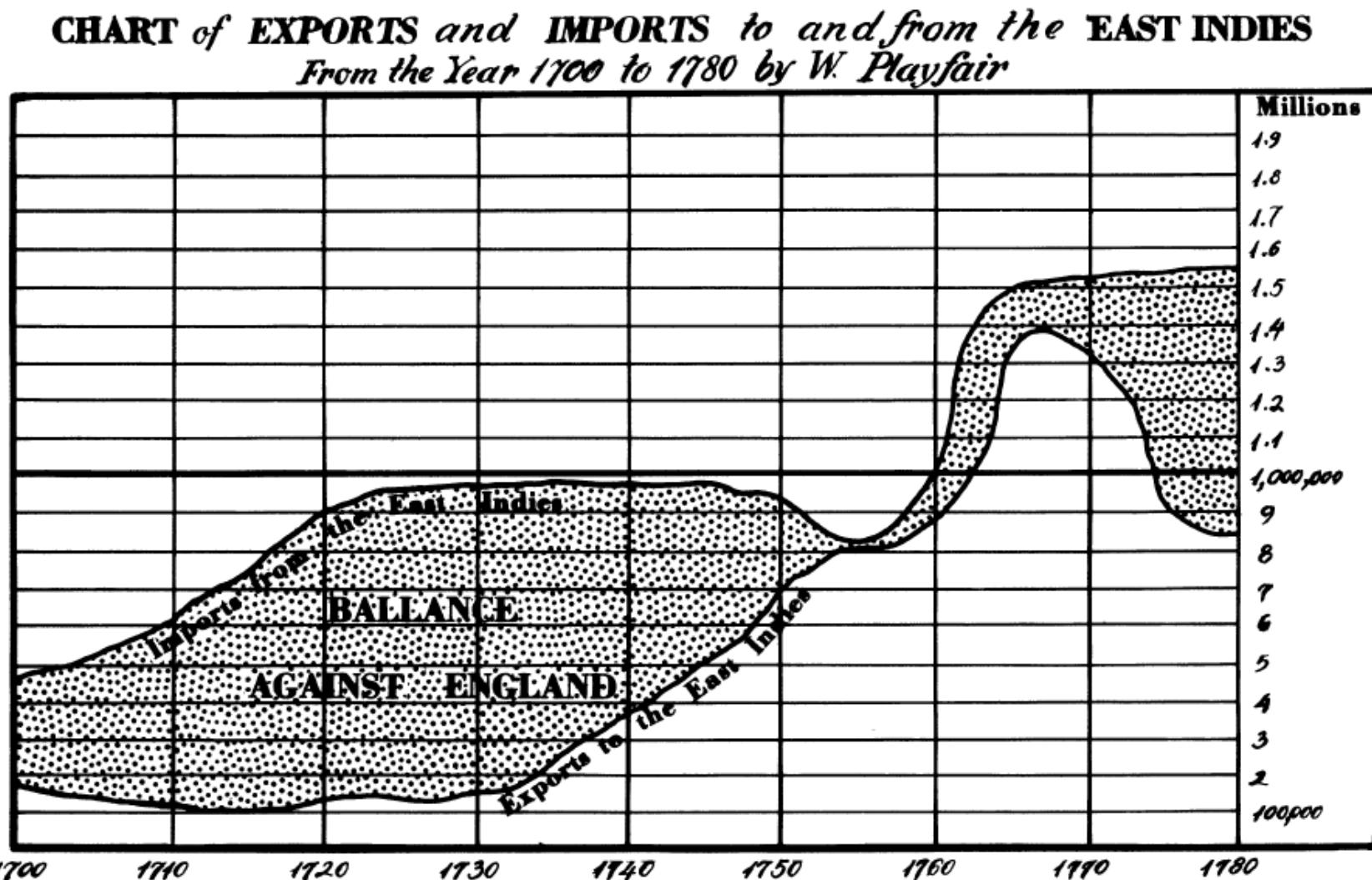


# TIME-SERIES



[Playfair, 1785]

# EXAMPLE: WILLIAM PLAYFAIR (1759-1823)



The Bottom Line is Divided into Years the Right hand Line into HUNDRED THOUSAND POUNDS

*single the right*

*is from Page 31<sup>st</sup>*

*Published in the Act Divine 16<sup>th</sup> Aug. 1785*

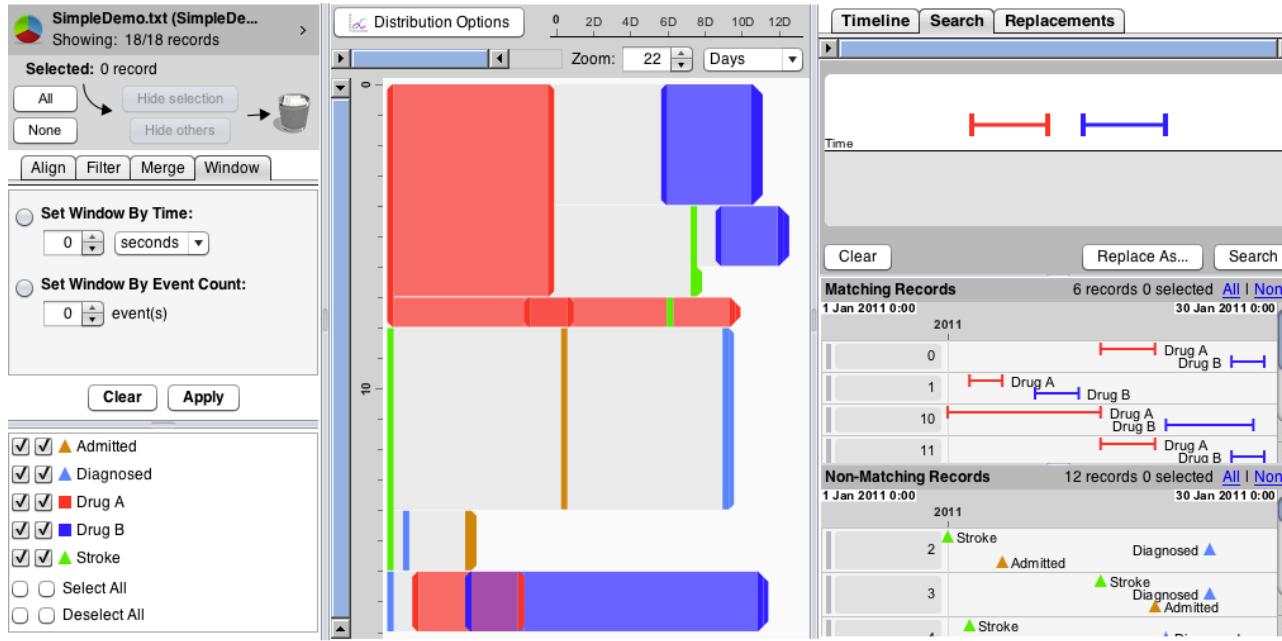
# EXAMPLE: GOOGLE FINANCE



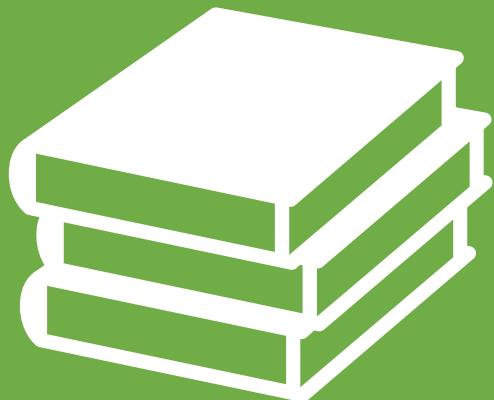
# EVENTFLOW

- Discrete event data
- Free for academic use, licensed for commercial use
  - <http://hcil.umd.edu/eventflow/>

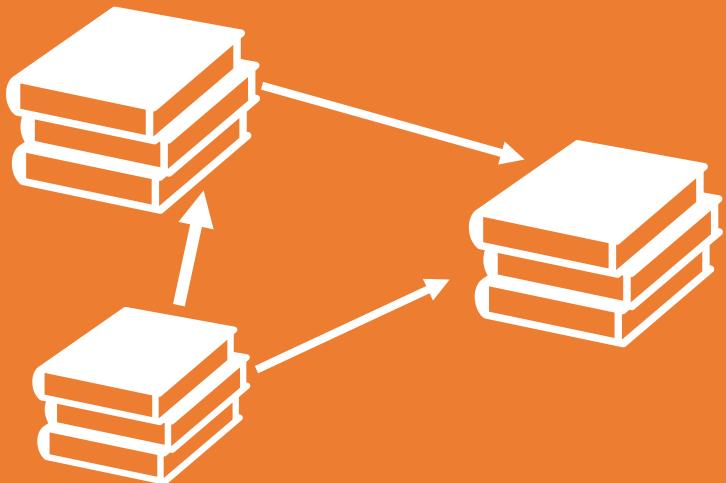
<https://youtu.be/FHgcJDnW8q8>



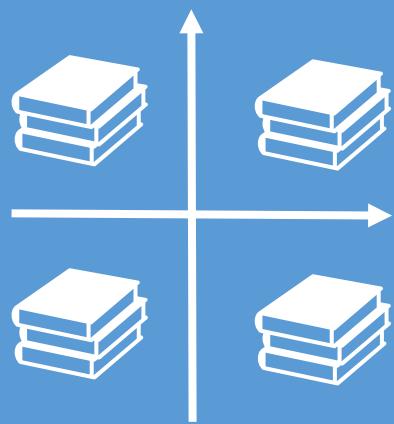
# RAW TEXT



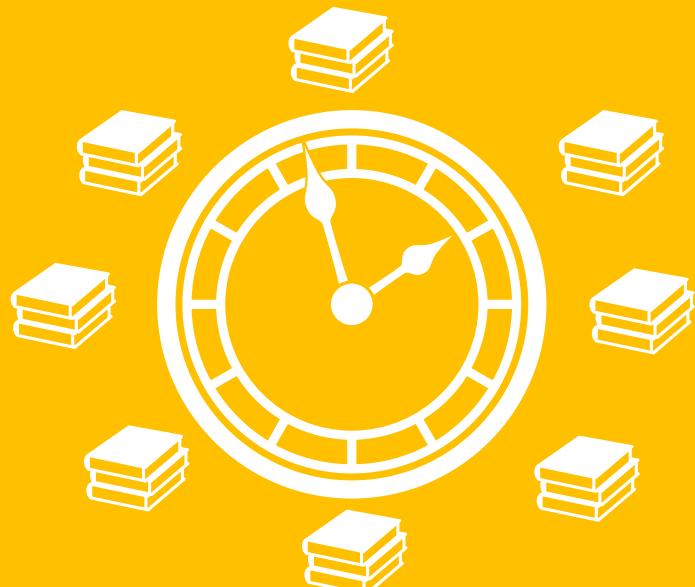
# TEXT + LINKS



# TEXT + SPACE



# TEXT + TIME



# THE PROBLEM WITH TEXT

- Characters is a visual representation of text
- **Challenge:** Is there a way to visualize text that does not show all of the text
  - ...but is still useful?
  - ...that shows both detail and context?
- This is the main premise of **text analytics and visualization**



# WORDCLOUD/TAGCLOUD

- Canonical form of text visualization
  - Everyone has seen them on the Web
    - Originally used to describe content of a website
    - Invented on the photo sharing site Flickr
  - Visualization technique
    - Sort words by frequency
    - Remove stop words
      - Common words
      - Human-generated list
    - Weigh size by frequency
    - Draw most common words on a canvas



# WORDTREE

- Visual search tool for unstructured text
- Visual concordance
  - Alphabetical list of principal words with context
- Pick a phrase, show all of its context

Search **i have a dream** Back Forward Start End Occurrence Order Clicks Will Zoom

8 hits

**i have a dream**

that

one day

today ! i have a dream that one day

this nation will rise up and live out the true meaning of its creed : " we hold these truths to be self - evident ,  
on the red hills of georgia , the sons of former slaves and the sons of former slave owners will be able to sit down together  
even the state of mississippi , a state sweltering with the heat of injustice , sweltering with the heat of oppression , will be transformed into  
, down in alabama , with its vicious racists , with its governor having his lips dripping with the words of " interposition " and "  
every valley shall be exalted , and every hill and mountain shall be made low , the rough places will be made plain , and the  
  
Click to view "with"

, down in alabama , with its vicious racists , with its governor having his lips dripping with the words of " interposition " and "  
every valley shall be exalted , and every hill and mountain shall be made low , the rough places will be made plain , and the

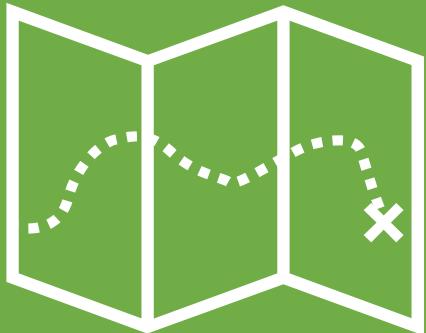
MARYLAND

# TYPOGRAPHIC MAPS

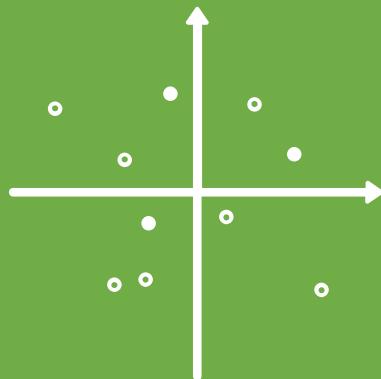
[Afzal 2012]

<http://store.axismaps.com/>

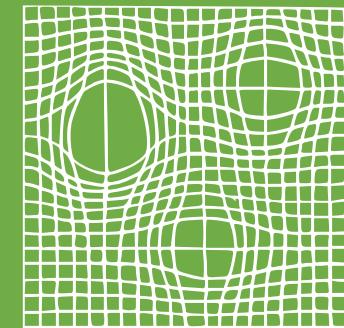
# SPACE



MAPS



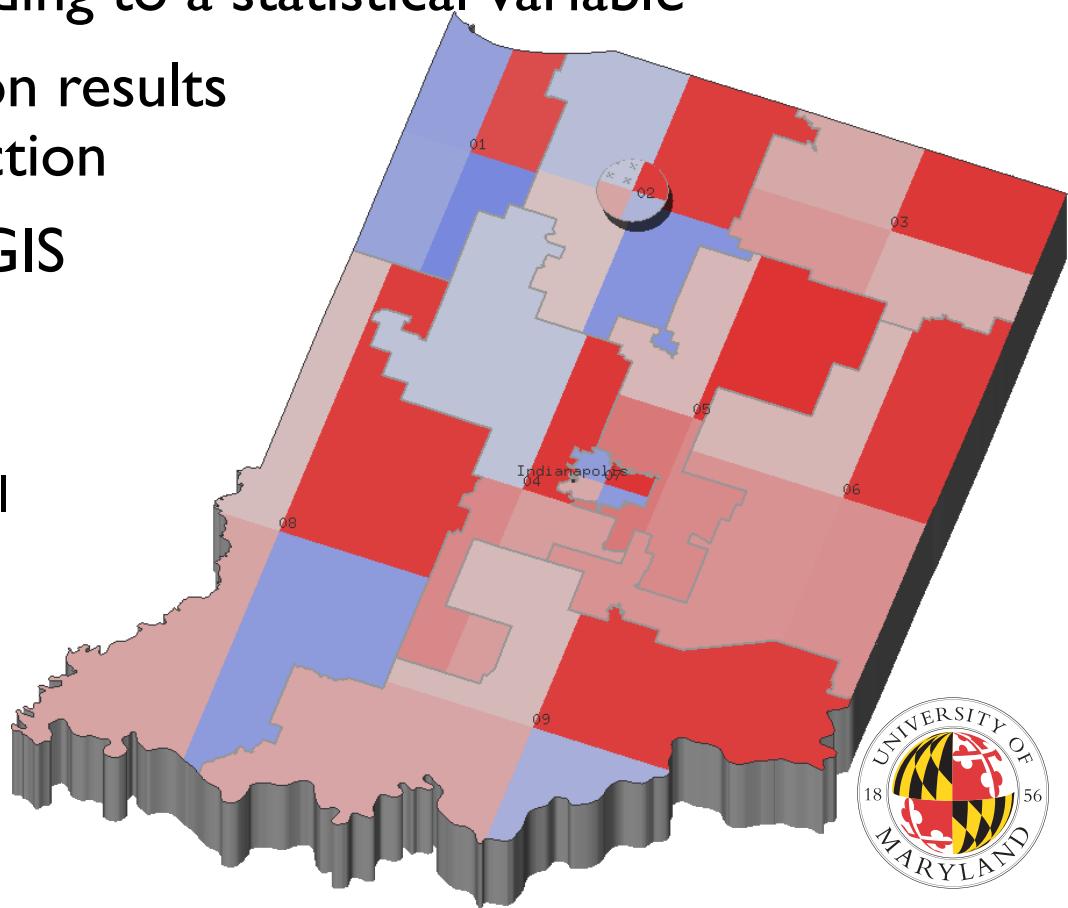
SUBSTRATE



NAVIGATION

# CHOROPLETH MAPS

- Thematic map
- Areas color-coded according to a statistical variable
- **Example:** Indiana election results for 2008 presidential election
- Very commonly used in GIS
- Problems?
  - Is it using space?
  - What about large vs. small geographical areas?
  - How can we improve this?

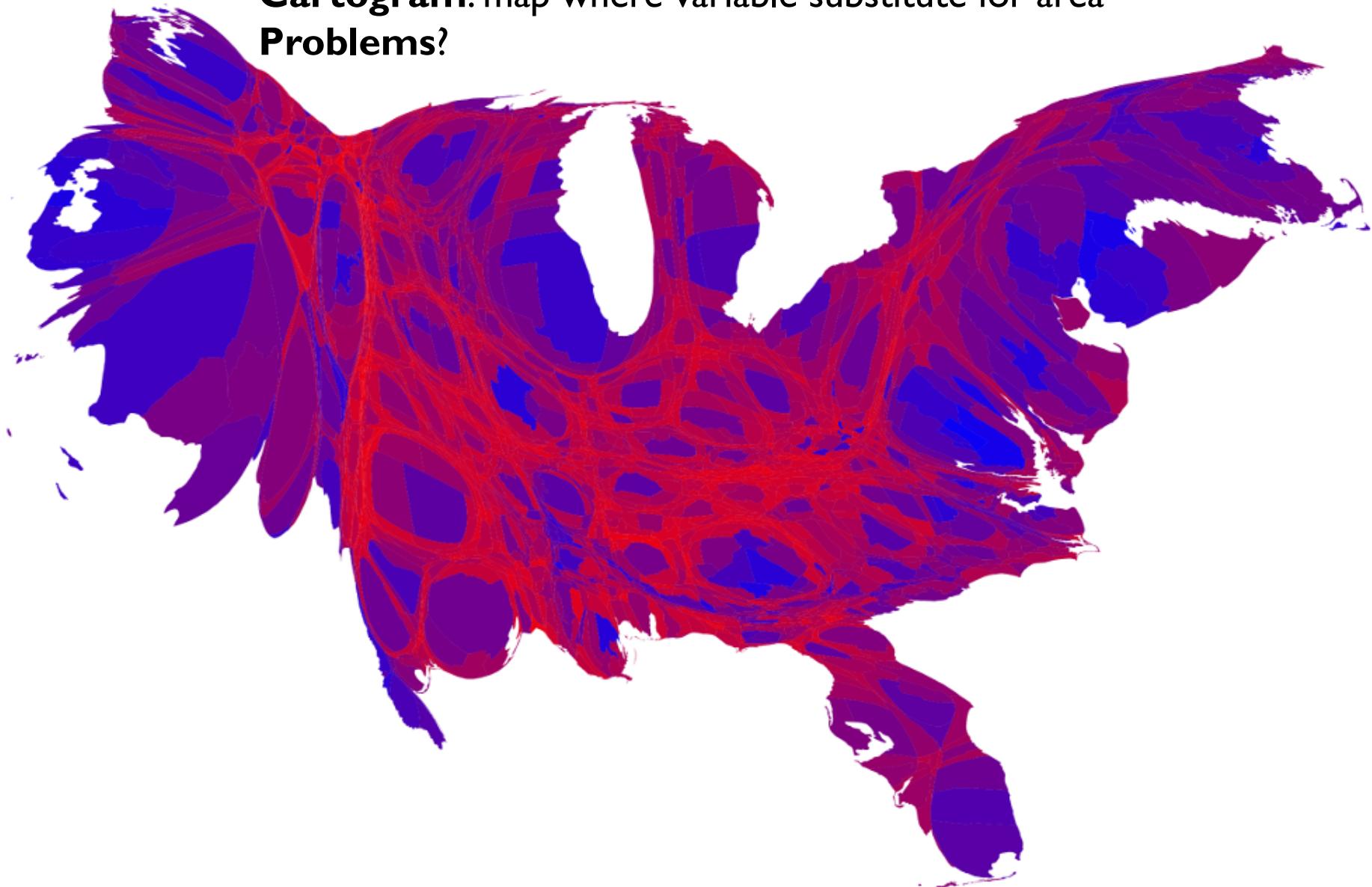


## CARTOGRAMS

Space is fixed in a geographic map! ...or is it?

**Cartogram:** map where variable substitute for area

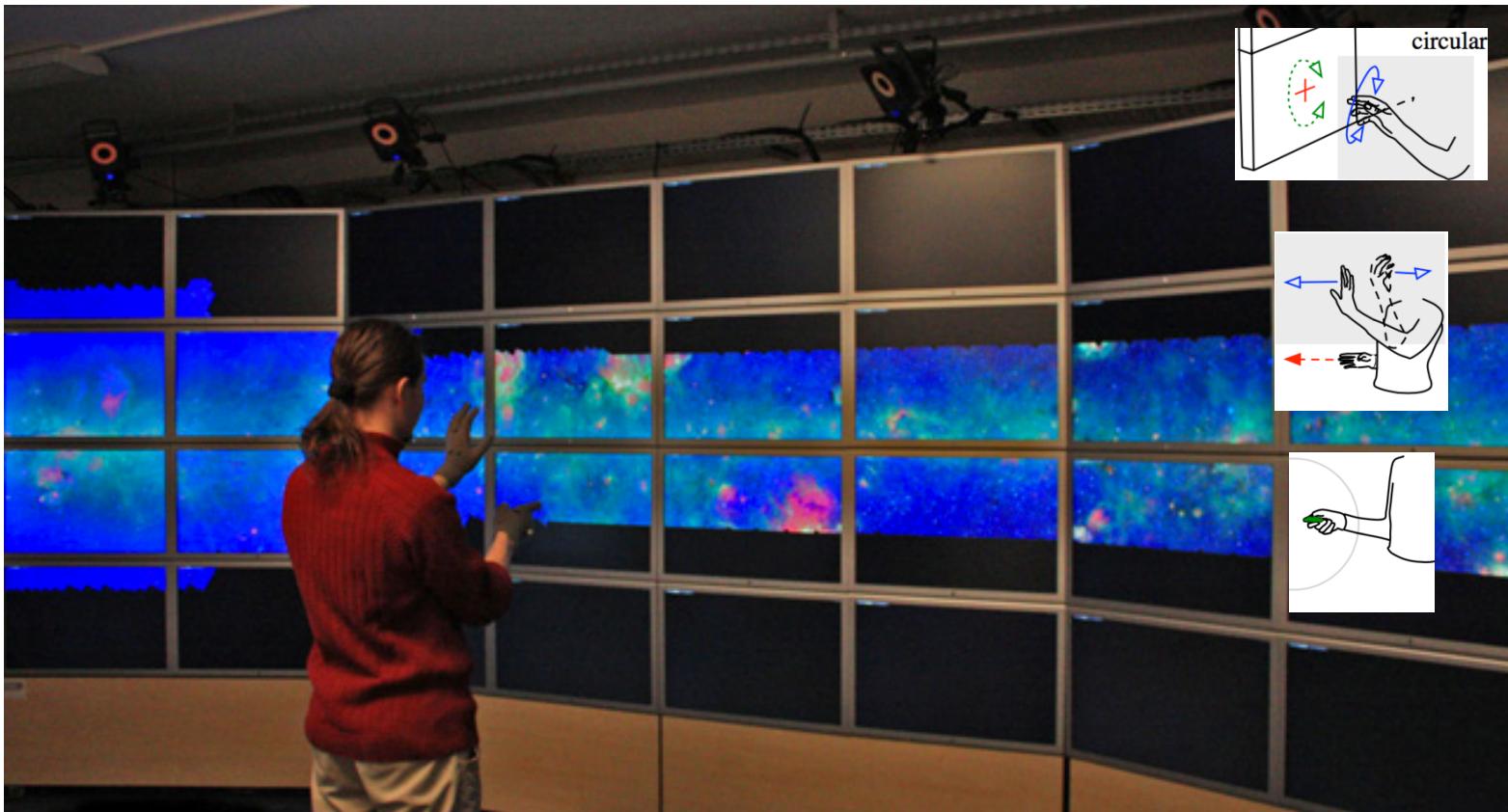
Problems?



# DEVICES



# GESTURES



# PROXEMICS



*The interrelated observations and theories of man's use of space as a specialized elaboration of culture.*

- Edward T. Hall

## Study of proxemics

*The Hidden Dimension, 1966*

- Interpersonal interaction
- Organization of space
- Cultural factors

## F-formation

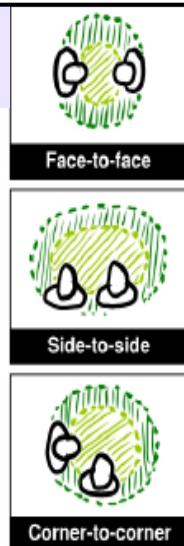
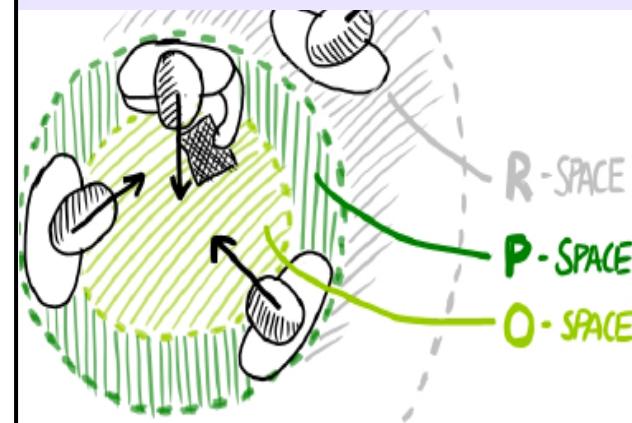


Figure borrowed from Marquardt et al., 2012

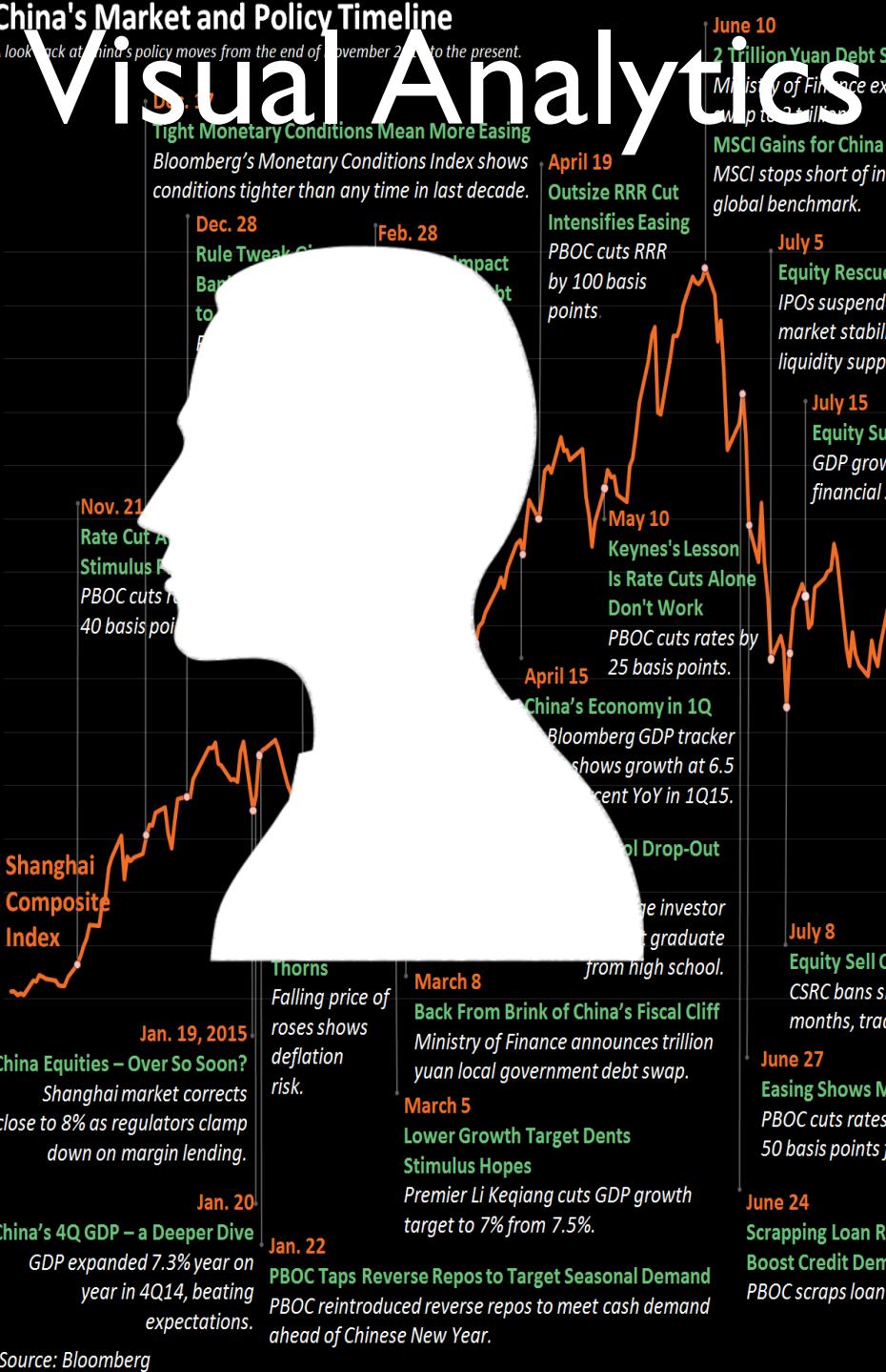
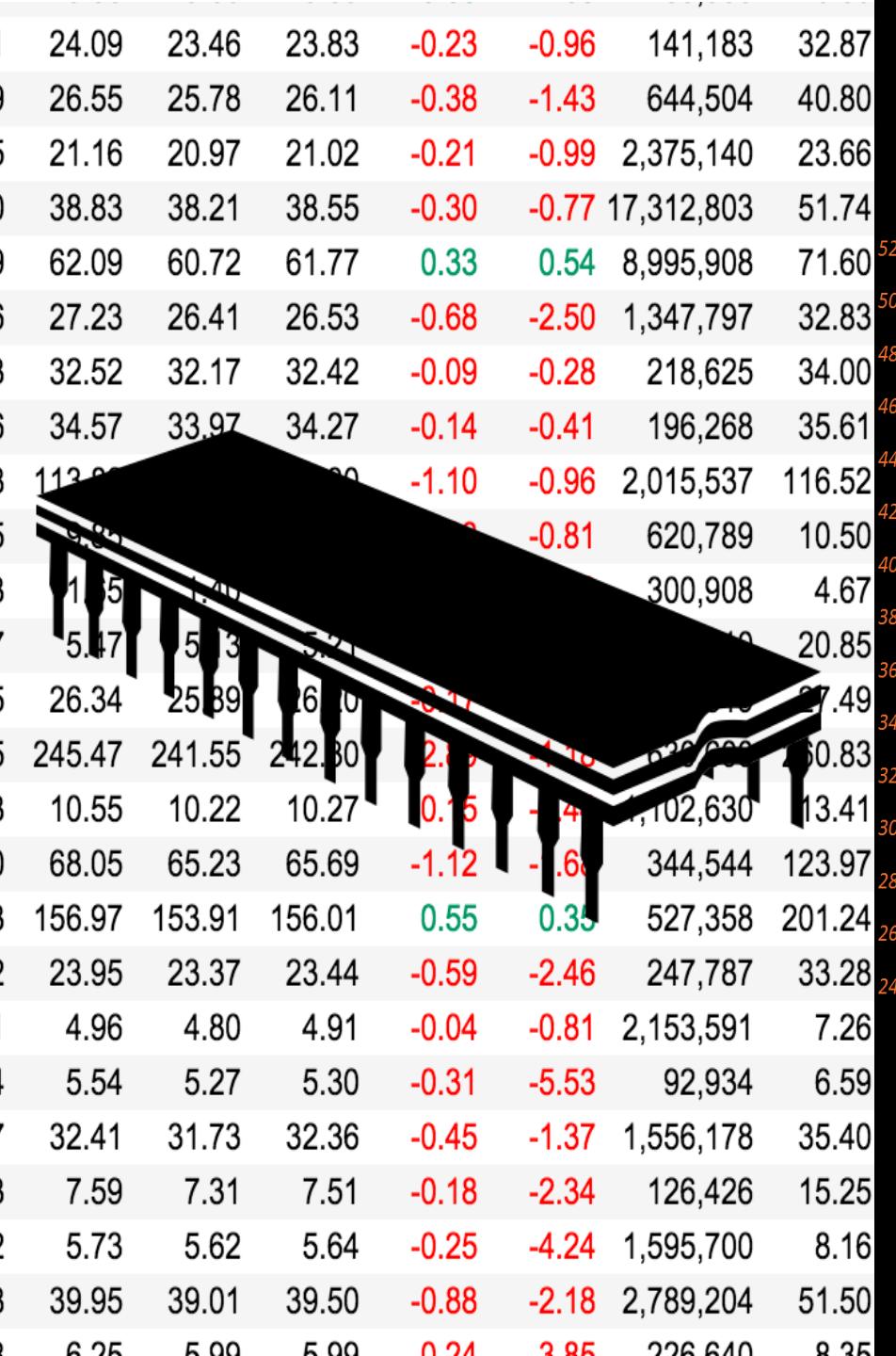


# PROXEMICS + GESTURES FOR VISUALIZATION



# VISUAL ANALYTICS





# TIME-SERIES DATA

Tesla (TSLA)



Apple (AAPL)



Alphabet (GOOGL)



# How can human judgment help in prediction?

## China's Market and Policy Timeline

A look back at China's policy moves from the end of November 2014 to the present.

Dec. 17

Tight Monetary Conditions Mean More Easing

China's central bank eases monetary conditions more than expected, despite inflation above target.

Dec. 28

Rule Tweak Cuts Impact

Bank of China's rule changes will have less impact on lending.

Feb. 28

Intensifies Easing

PBOC cuts RRR by 100 basis points.

July 5

Equity Rescue

IPOs suspended to stabilize market.

liquidity support

July 15

Equity Surge

GDP growth financial

Nov. 21

Rate Cut Alone

Stimulus Fails

PBOC cuts rates by 40 basis points.

April 15

China's Economy in 1Q

Bloomberg GDP tracker shows growth at 6.5

percent YoY in 1Q15.

May 10

Keynes's Lesson

Is Rate Cuts Alone

Don't Work

PBOC cuts rates by 25 basis points.

June 8

Equity Sell Off

CSRC bans shorting for months, trade

June 27

Easing Shows Mixed

PBOC cuts rates by 50 basis points.

July 8

Equity Sell Off

CSRC bans shorting for months, trade

Jan. 19, 2015

China Equities – Over So Soon?

Shanghai market corrects close to 8% as regulators clamp down on margin lending.

Jan. 20

China's 4Q GDP – a Deeper Dive

GDP expanded 7.3% year on year in 4Q14, beating expectations.

Source: Bloomberg

Thorns

Falling price of roses shows deflation risk.

March 8

Back From Brink of China's Fiscal Cliff

Ministry of Finance announces trillion yuan local government debt swap.

March 5

Lower Growth Target Dents Stimulus Hopes

Premier Li Keqiang cuts GDP growth target to 7% from 7.5%.

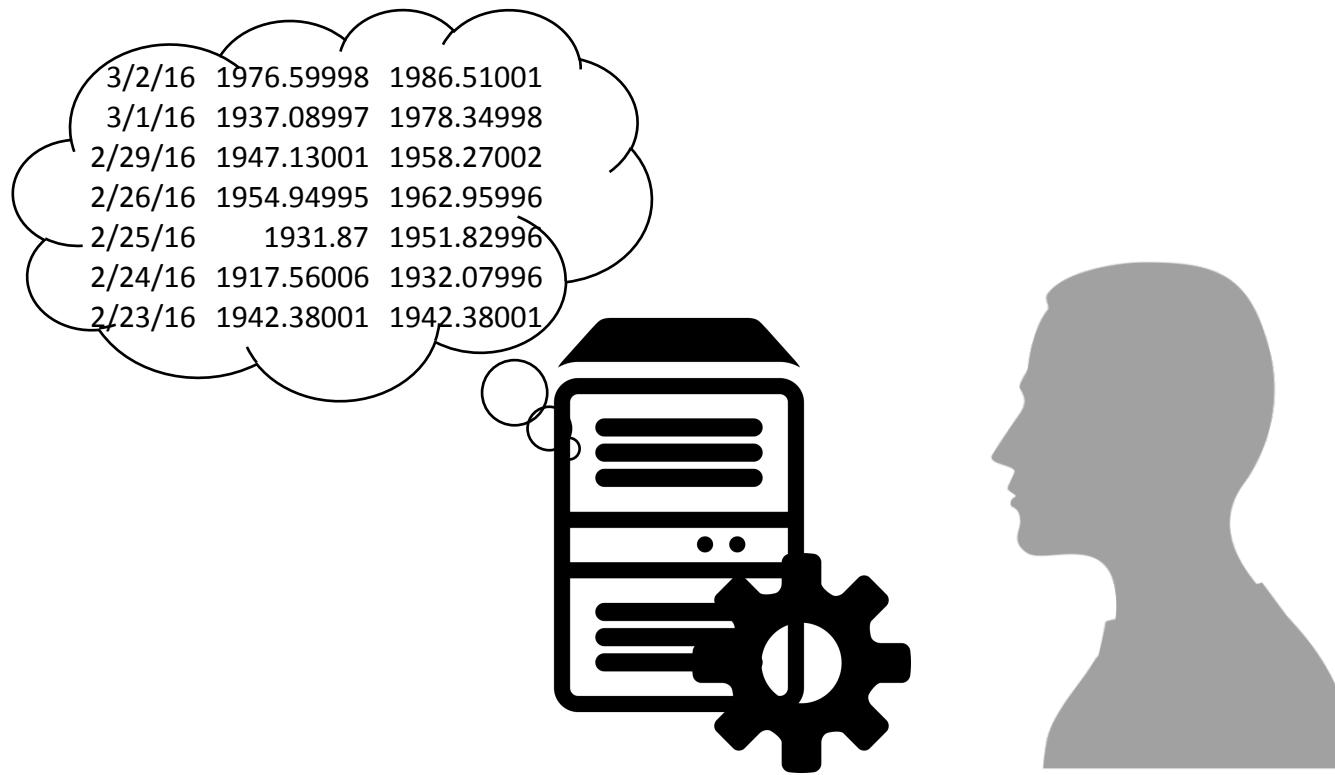
June 24

Scraping Loan Rules

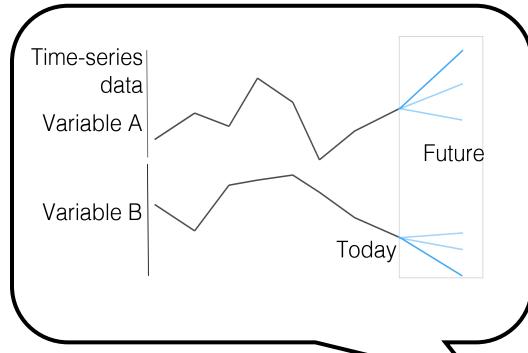
Boost Credit Demand

PBOC scraps loan

# TIMEFORK: INTERACTIVE PREDICTION



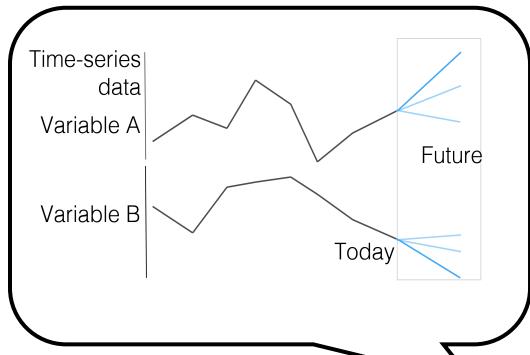
# TIMEFORK: INTERACTIVE PREDICTION



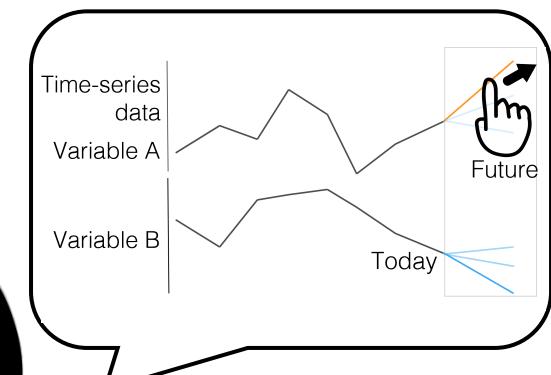
**Time-series visualization  
with predictions**



# TIMEFORK: INTERACTIVE PREDICTION

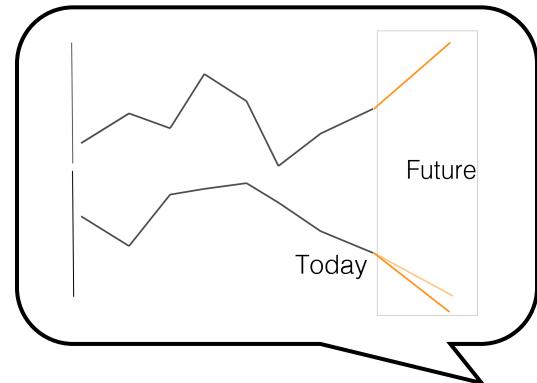


**Time-series visualization  
with predictions**



**Users specify their  
understanding of the future**

# TIMEFORK: INTERACTIVE PREDICTION

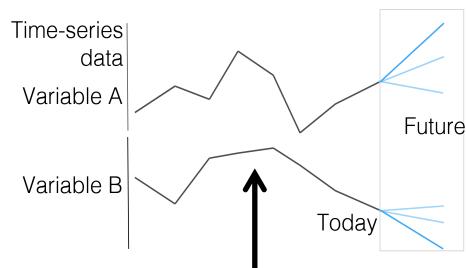


**Predictions updated to reflect user understanding**

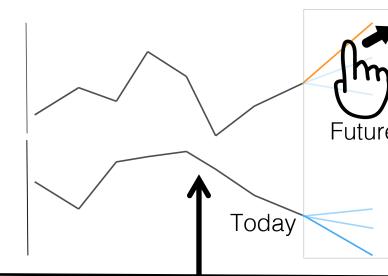


# TIMEFORK: INTERACTIVE PREDICTION

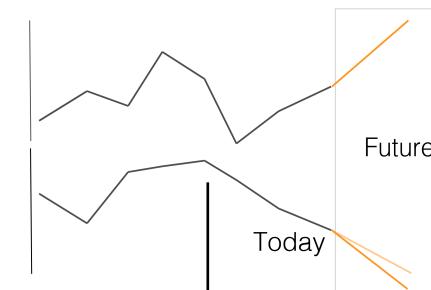
**(1) Forecast**



**(2) Interact**



**(3) Revise**



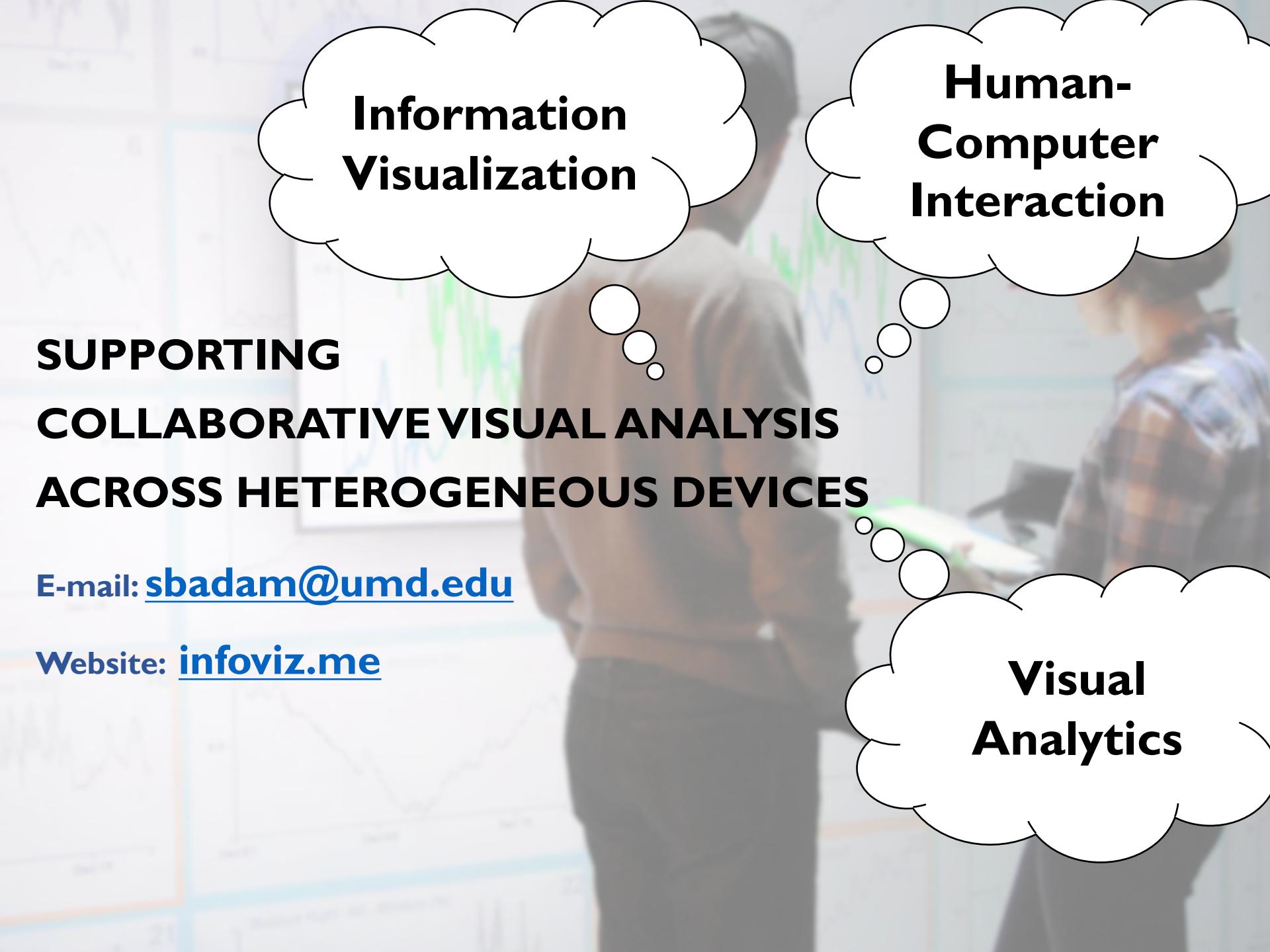
# CLOSING REMARKS



# CONCLUSION

- Data visualization has a long history  
*People have been using images to convey data for a long time...*
- Visualization pipeline  
*From raw data to interactive images*
- No unified theory of visualization (yet)  
*Still very much example-based*
- Techniques based on data type  
*Examples from multidimensional, time, space, and relational data*
- Visual Analytics





**Information  
Visualization**

**Human-  
Computer  
Interaction**

**SUPPORTING  
COLLABORATIVE VISUAL ANALYSIS  
ACROSS HETEROGENEOUS DEVICES**

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Website: [infoviz.me](http://infoviz.me)

**Visual  
Analytics**

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- Images from Flickr (all Creative Commons)



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<http://infoviz.me>

These slides were originally created by **Niklas Elmqvist** ([elm@umd.edu](mailto:elm@umd.edu))

UNIVERSITY OF  
MARYLAND



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