



ARTS1422 Data Visualization

Lecture 11

Temporal Data Visualization

Quan Li
Spring 2024
2024. 04.02

OUTLINE

- Temporal Data Visualization
- Temporal Spatial Data Visualization
- Streaming Data Visualization
- Design Principles





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Temporal Data



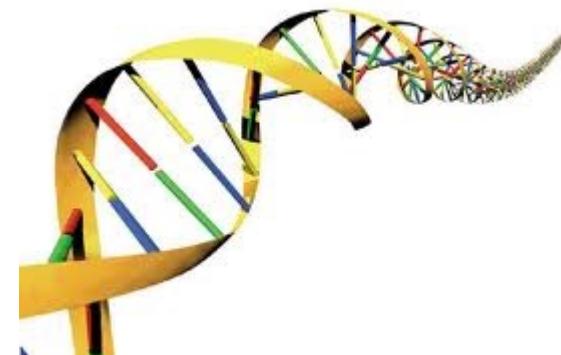
● Time-series data; or time-varying data

- Stock price
- Temperature

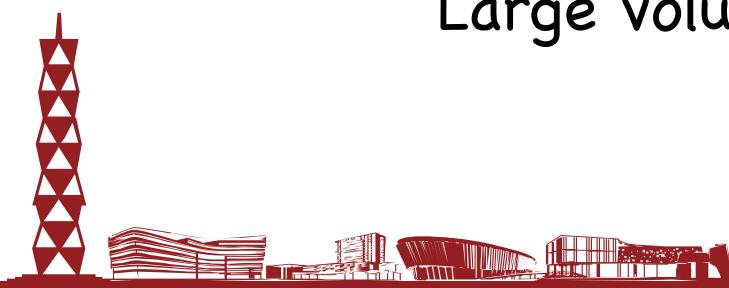


● Sequential data

- Text
- DNA, protein sequence



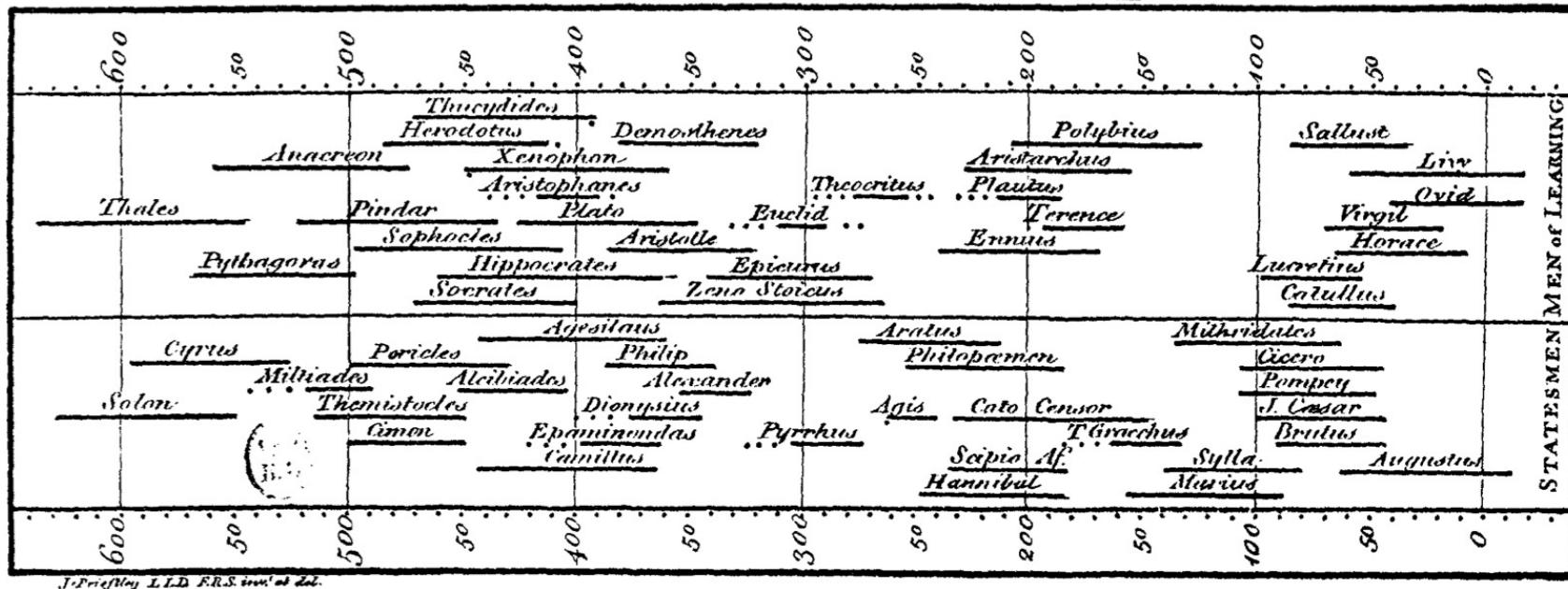
Large volume, high dimensional, multivariate, widely used



Example

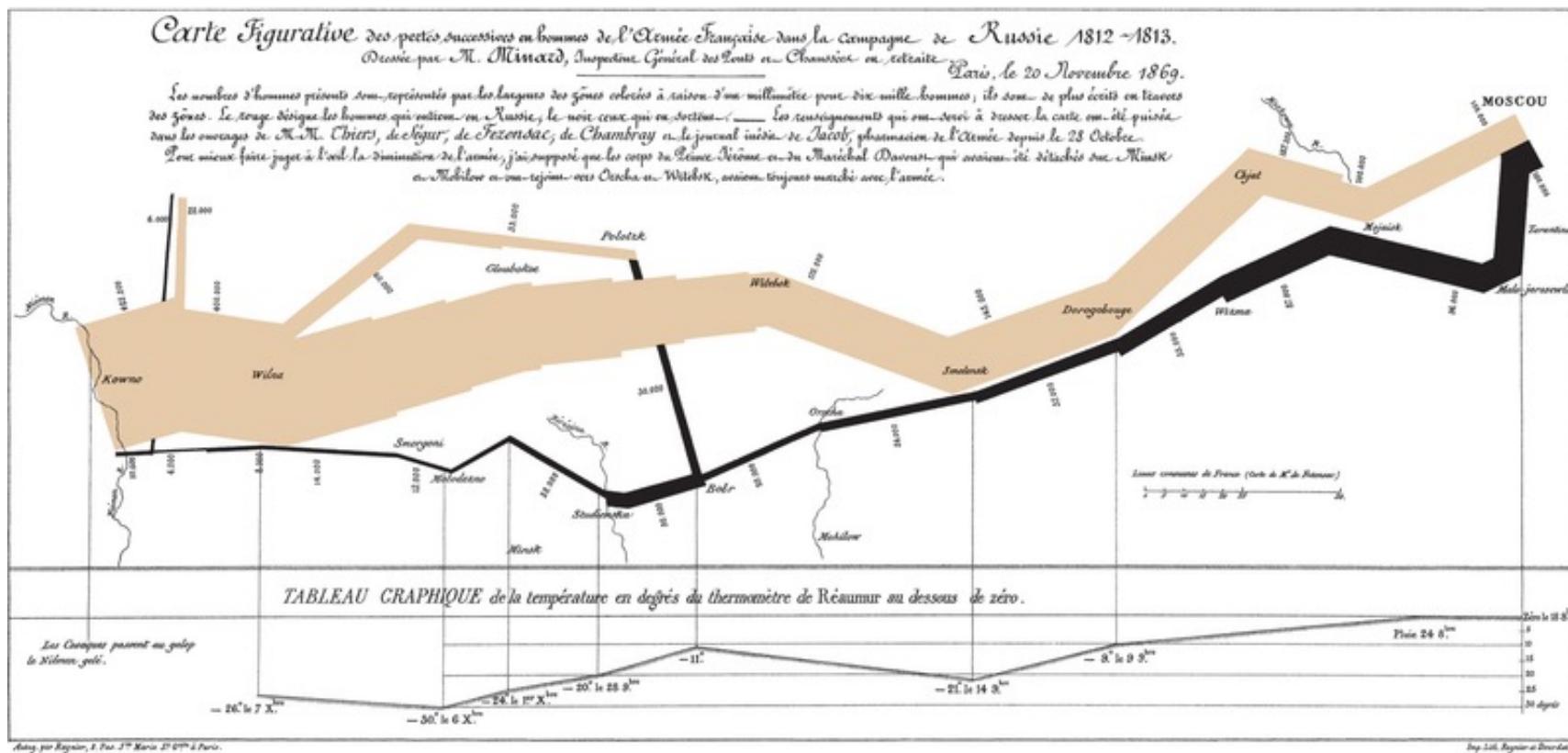
The linear, chronological form of Joseph Priestley's Chart of Biography (1765) dominates the design of contemporary timelines.

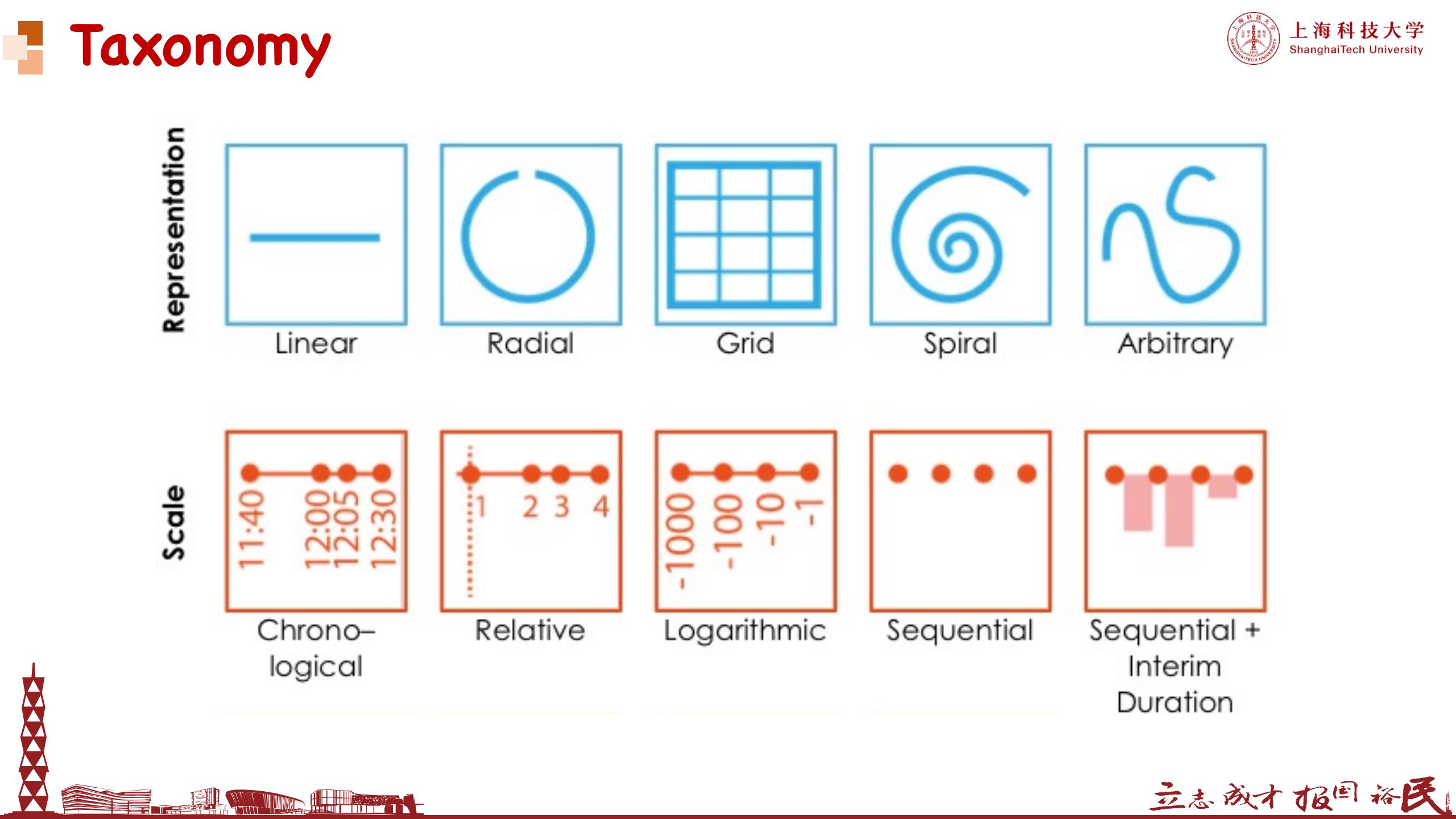
A Specimen of a Chart of Biography.

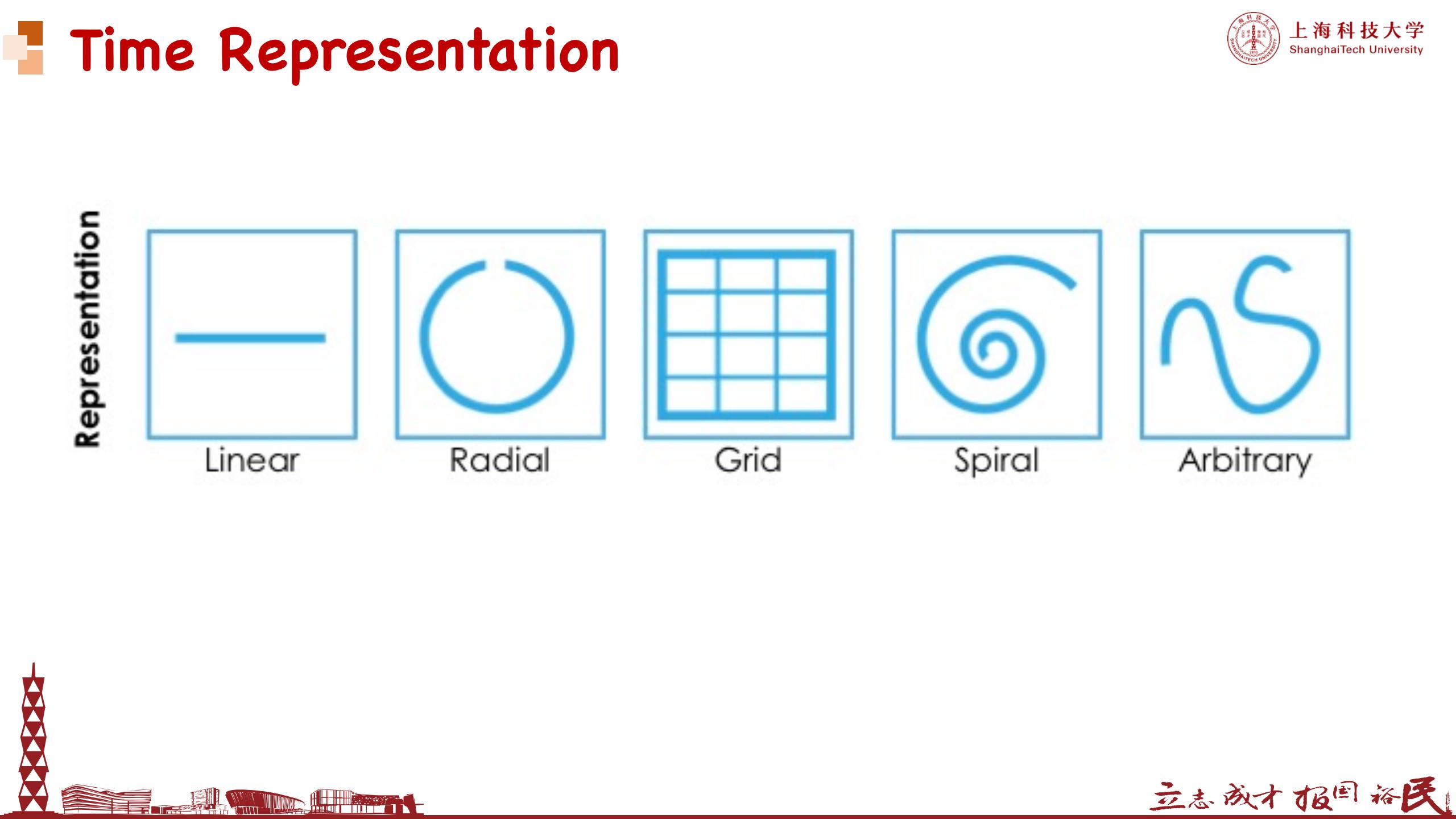


Example

Charles Minard's 1869 chart showing the number of men in Napoleon's 1812 Russian campaign army, their movements, as well as the temperature they encountered on the return path.



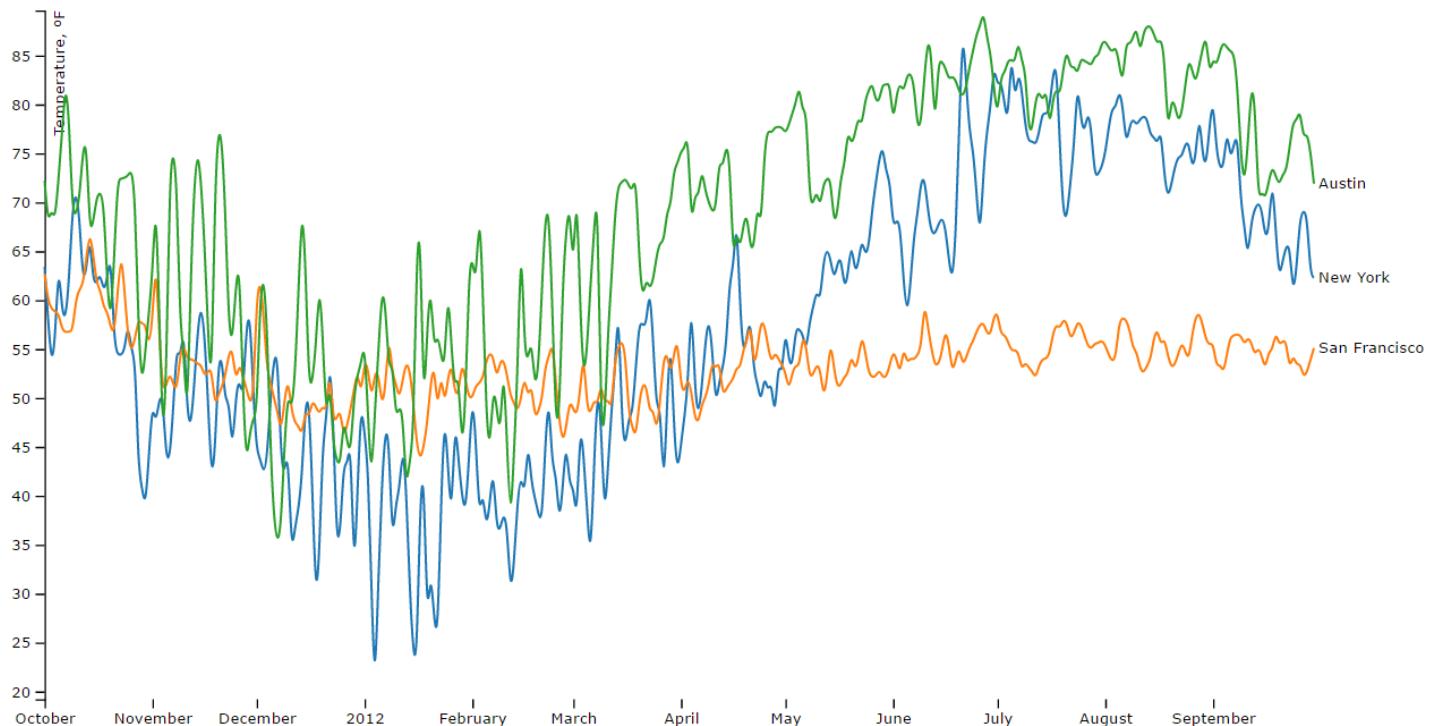


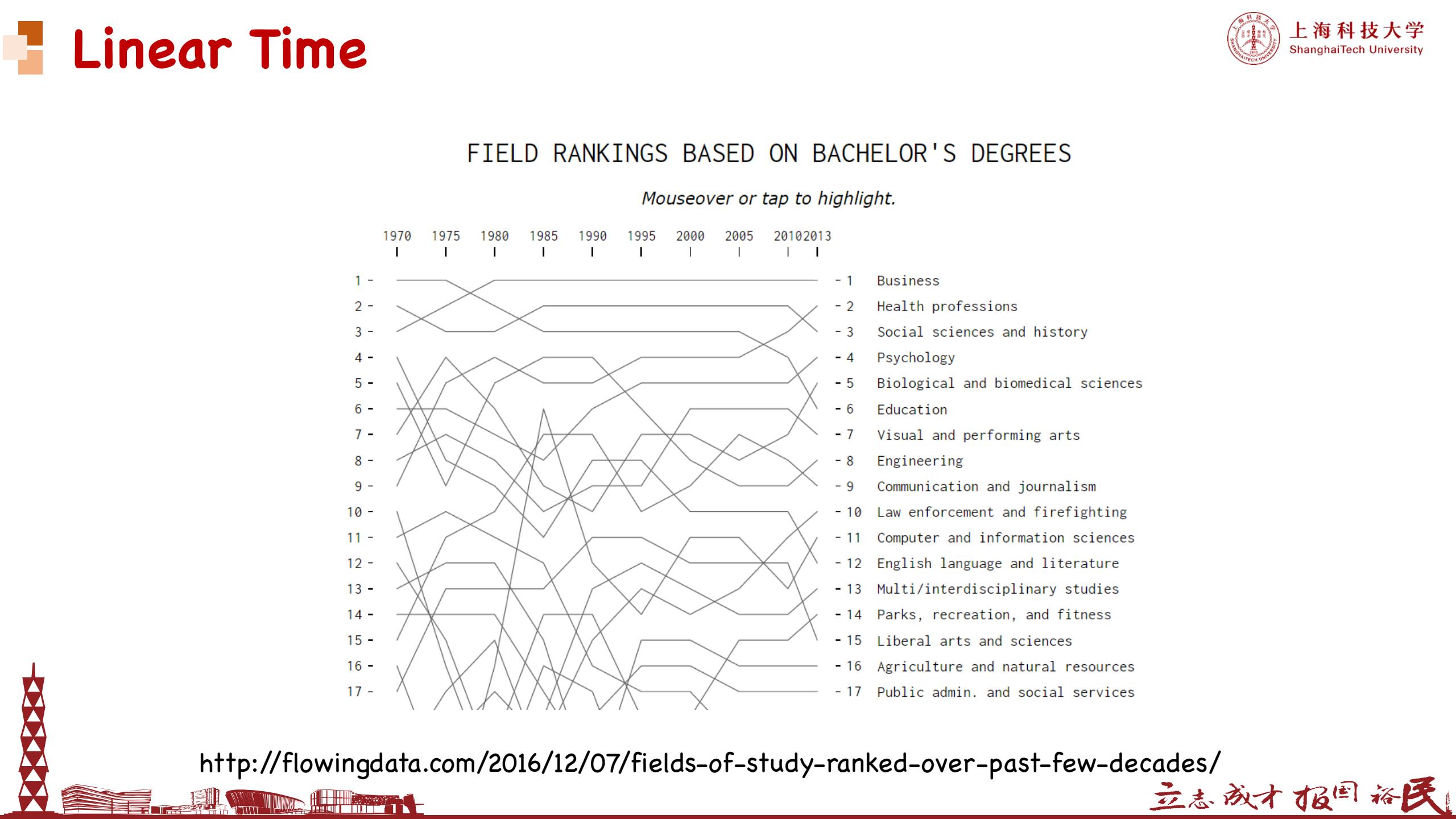


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Linear Time

- Present time data as a 2D line graph and with
 - time on x-axis
 - the other variable on y-axis





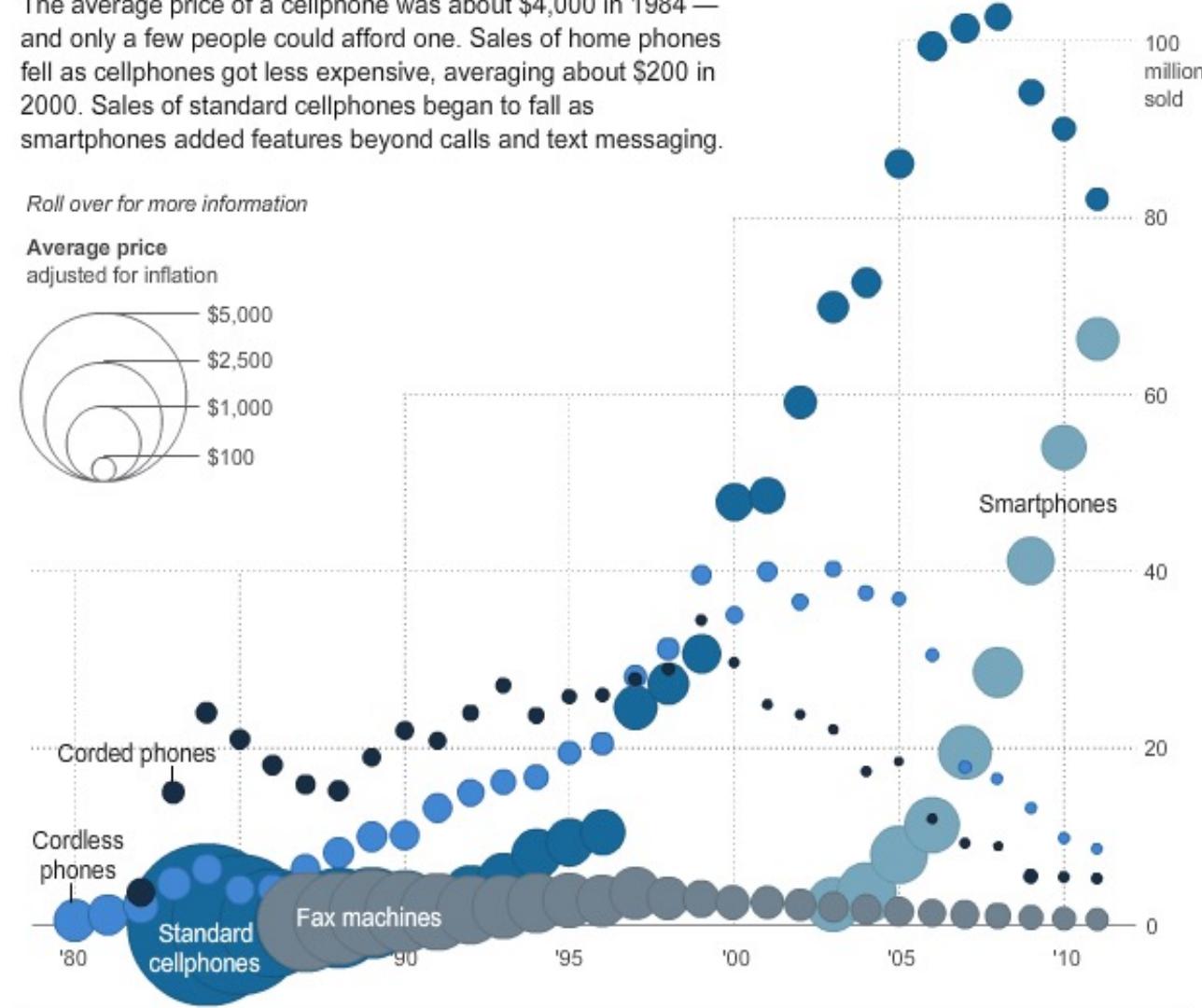
Linear Time

Size of circles : price

The average price of a cellphone was about \$4,000 in 1984 — and only a few people could afford one. Sales of home phones fell as cellphones got less expensive, averaging about \$200 in 2000. Sales of standard cellphones began to fall as smartphones added features beyond calls and text messaging.

Roll over for more information

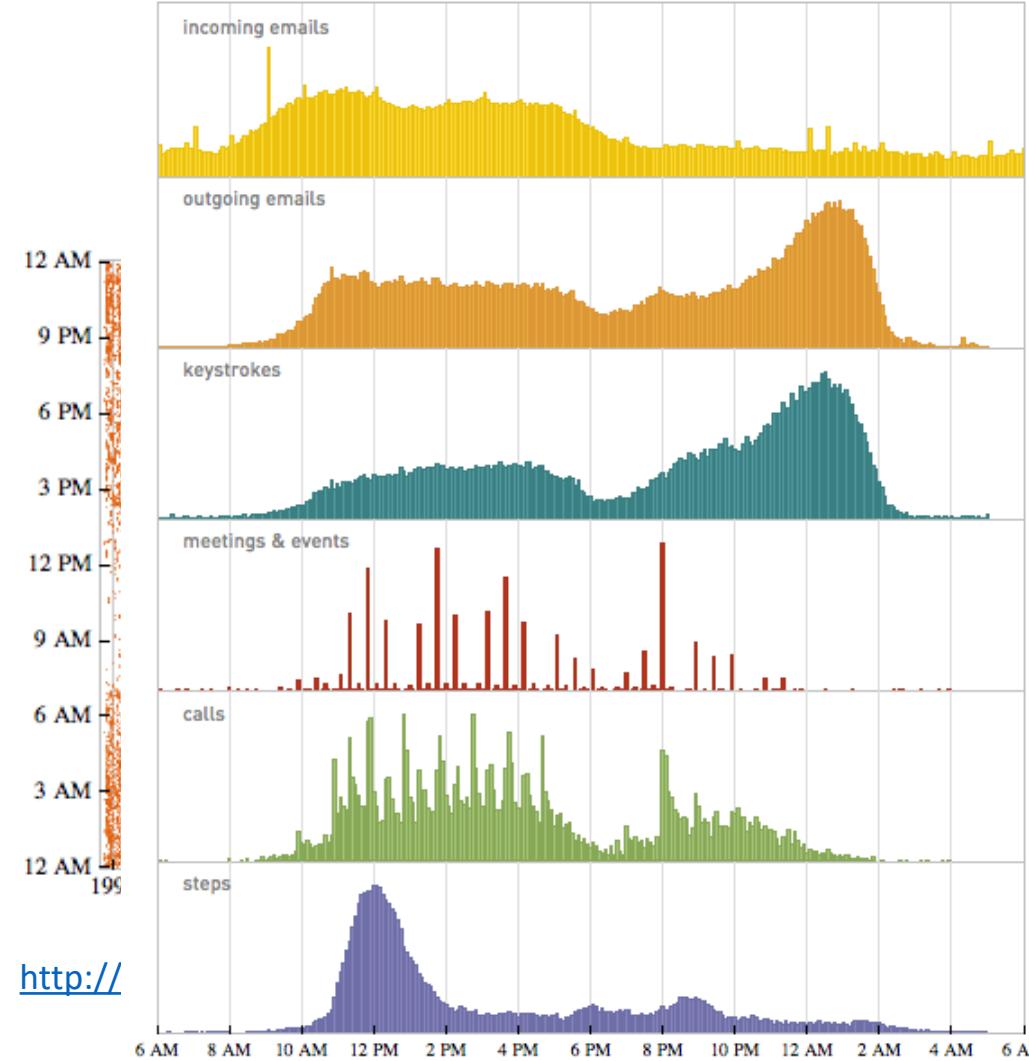
Average price
adjusted for inflation



NOTE: 2010 data are estimates and 2011 data are projections. GRAPHIC: Alicia Parlapiano / The Washington Post - January 10, 2011.

Linear Time

- Stephen Wolfram's *Personal Data Visualization Report*



Linear Time

Records fell like the summer rain that never came

■ 2011 began with an early-February Arctic blast that caused problems statewide, including school closures, rolling blackouts and less-than-ideal conditions for the Super Bowl in Arlington.

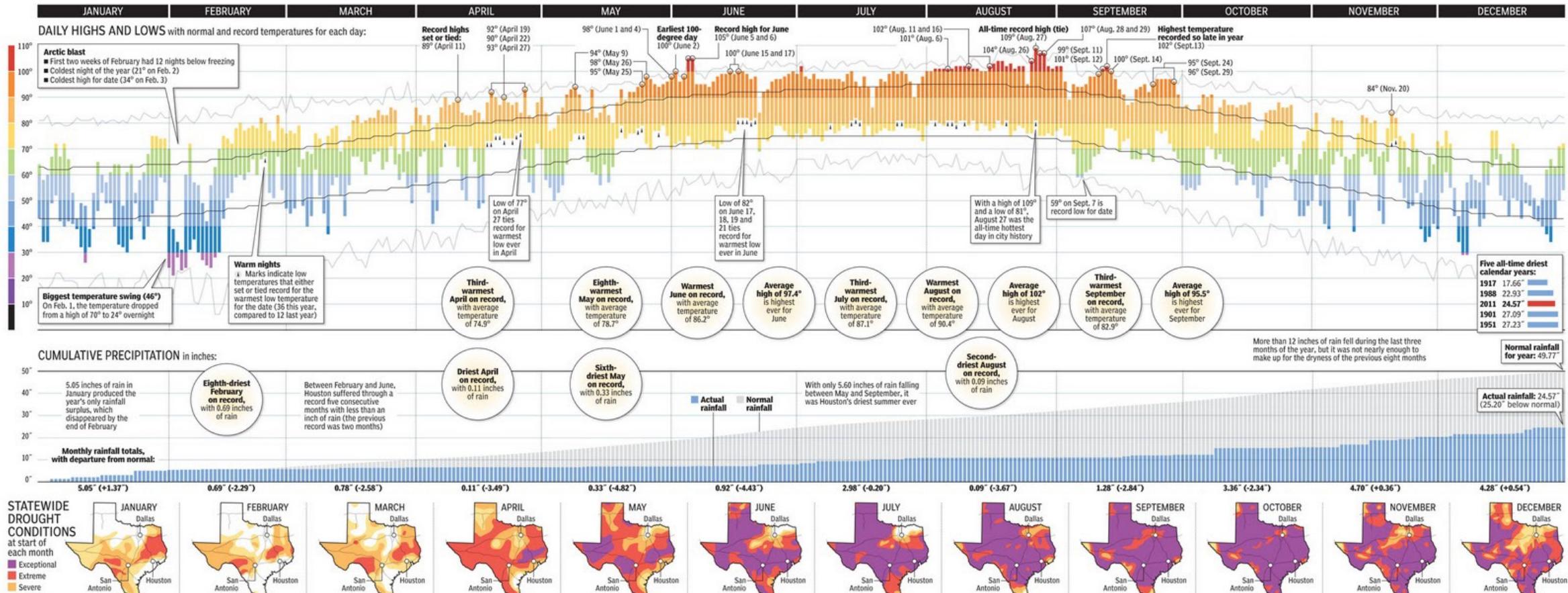
■ The cold didn't last long, however, and soon gave way to month after month of record-high temperatures, devastating drought, and scorching wildfires.

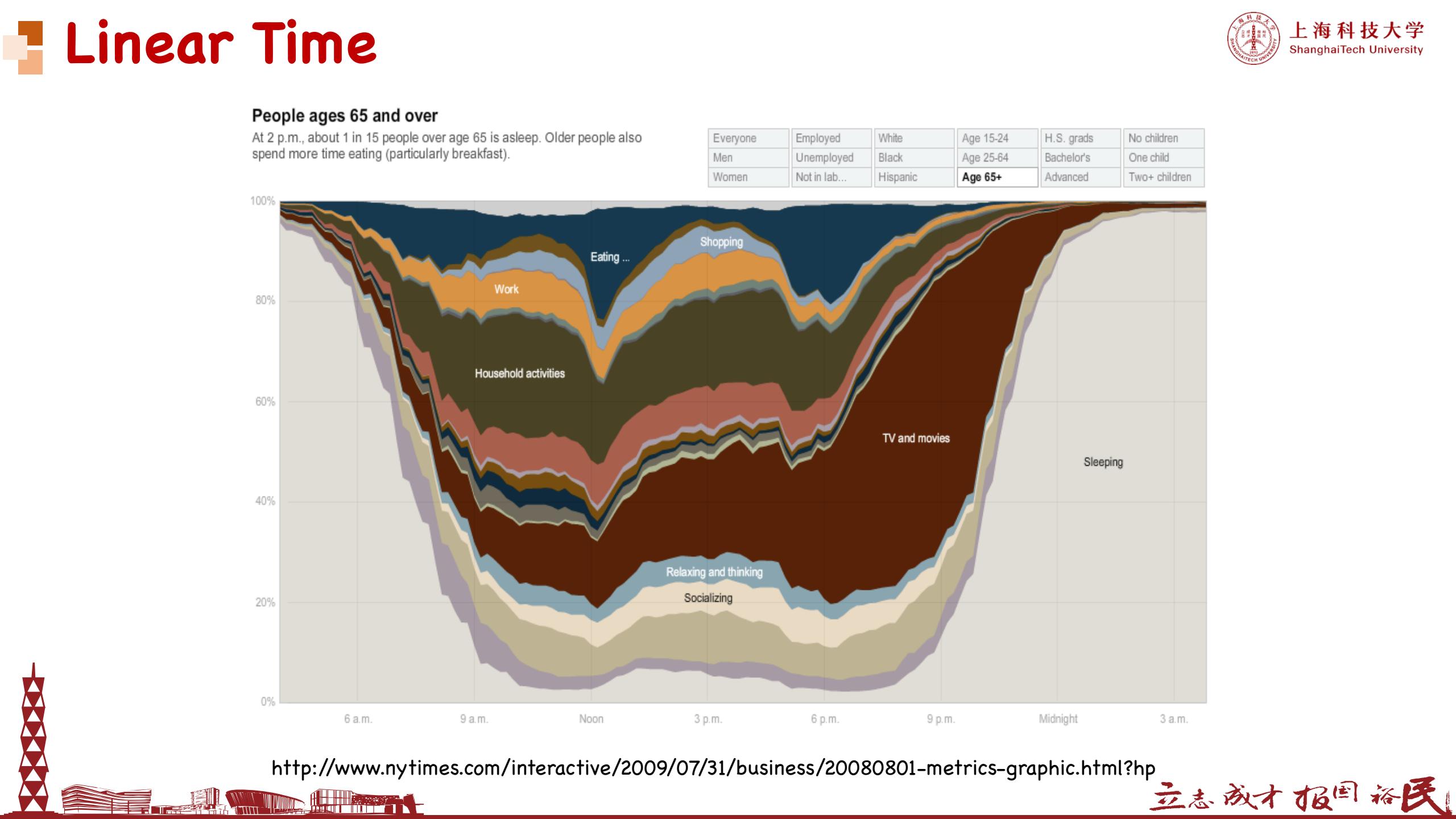
■ In all, Houston had more than 60 daily temperature records tied or broken. After seeing only two 100-degree days in 2010, the city endured 46 days at or above the century mark in 2011, including most of August.

■ The drought, which had been brewing since 2008, peaked in October, with nearly the entire state suffering in the "exceptional" category. Rain returned at the end of the year, but the drought is far from over.

How to read the chart

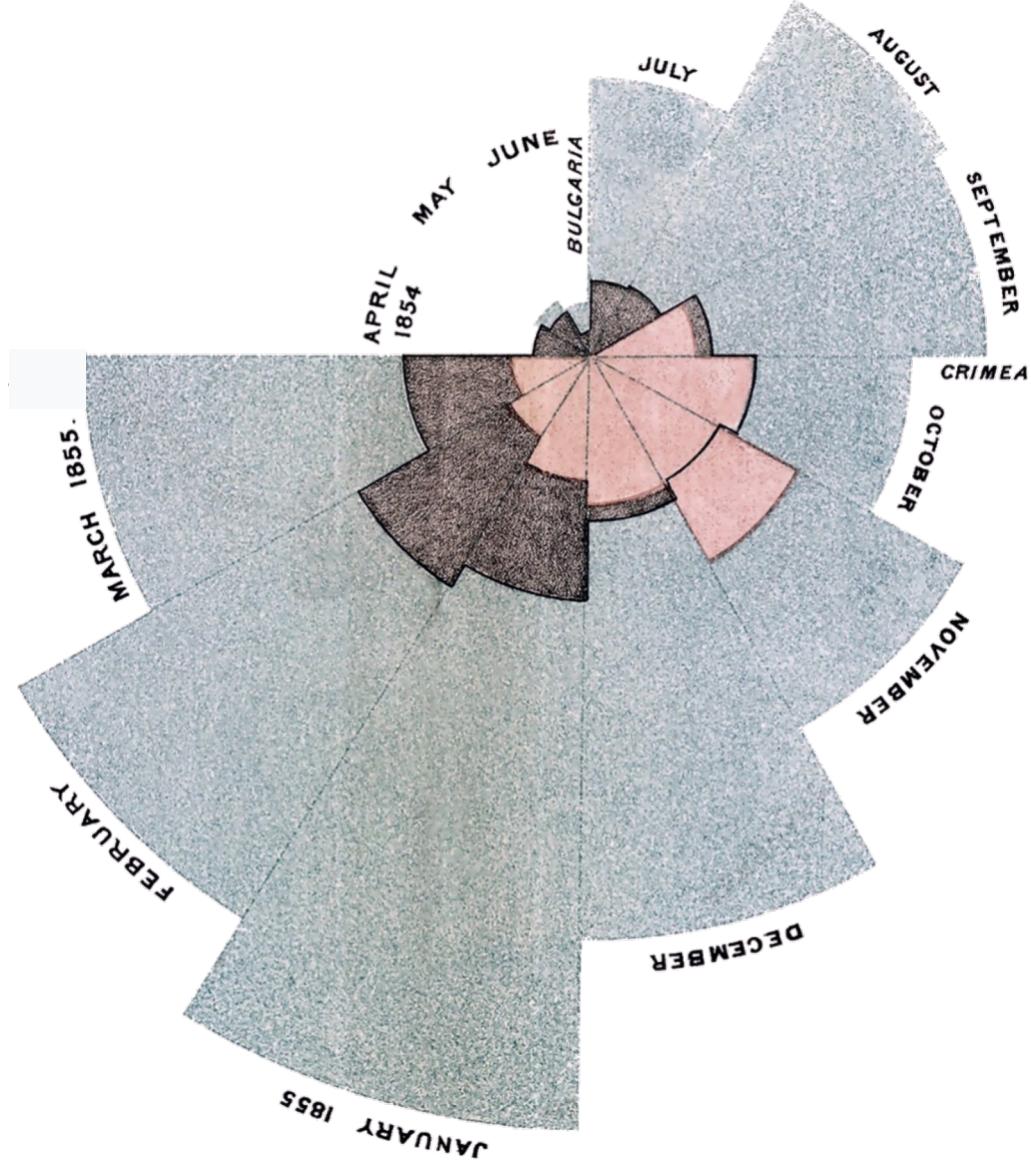
- Record highs (yellow line)
- Normal highs (green line)
- Normal lows (blue line)
- Record lows (grey line)

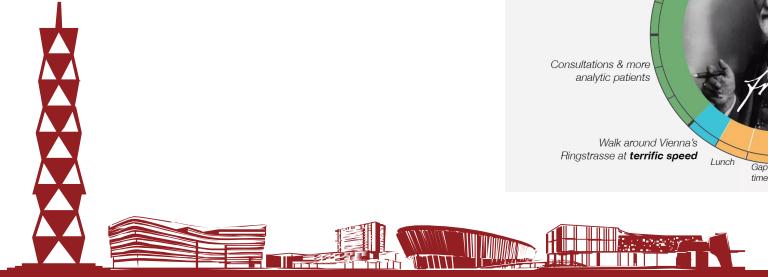
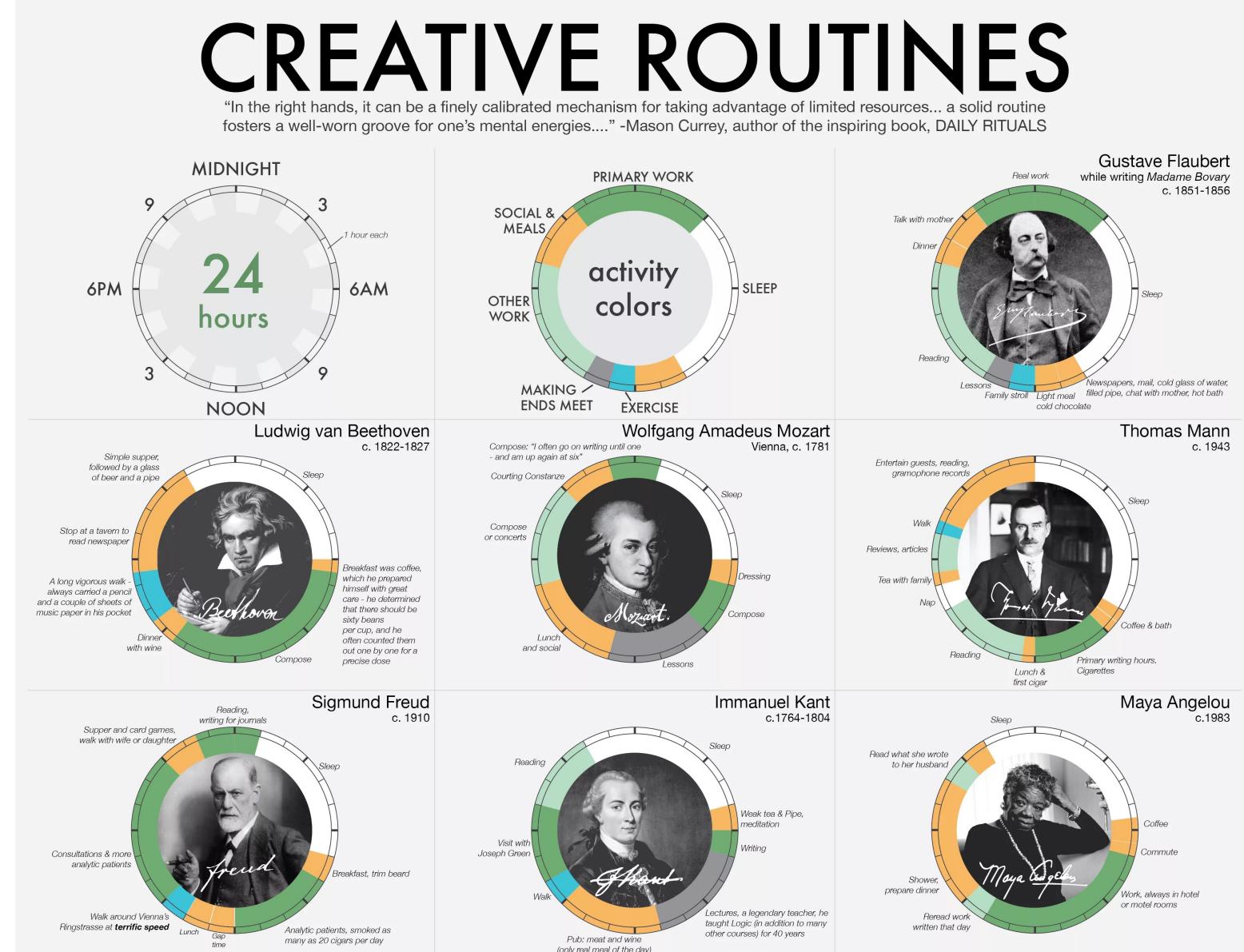




Radial Time

- Data distributed along the spiral
- To reveal cyclic pattern





KronoMiner

Using Multi-Foci Navigation for the
Visual Exploration of Time-Series Data

Jian Zhao¹

Fanny Chevalier²

Ravin Balakrishnan¹

¹University of Toronto

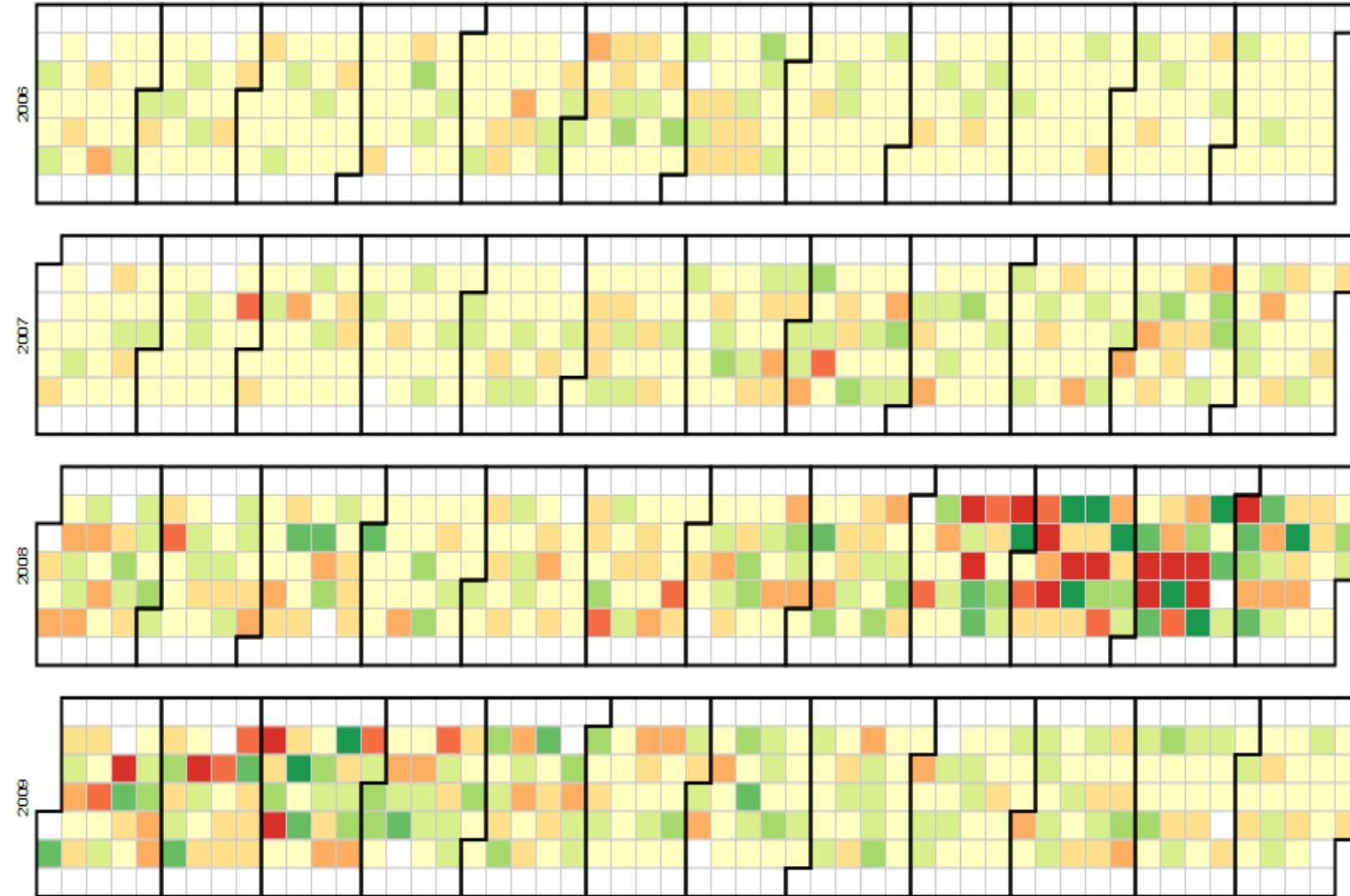
²OCAD University



Grid Time



Dow Jones stock price from 2006 to 2009

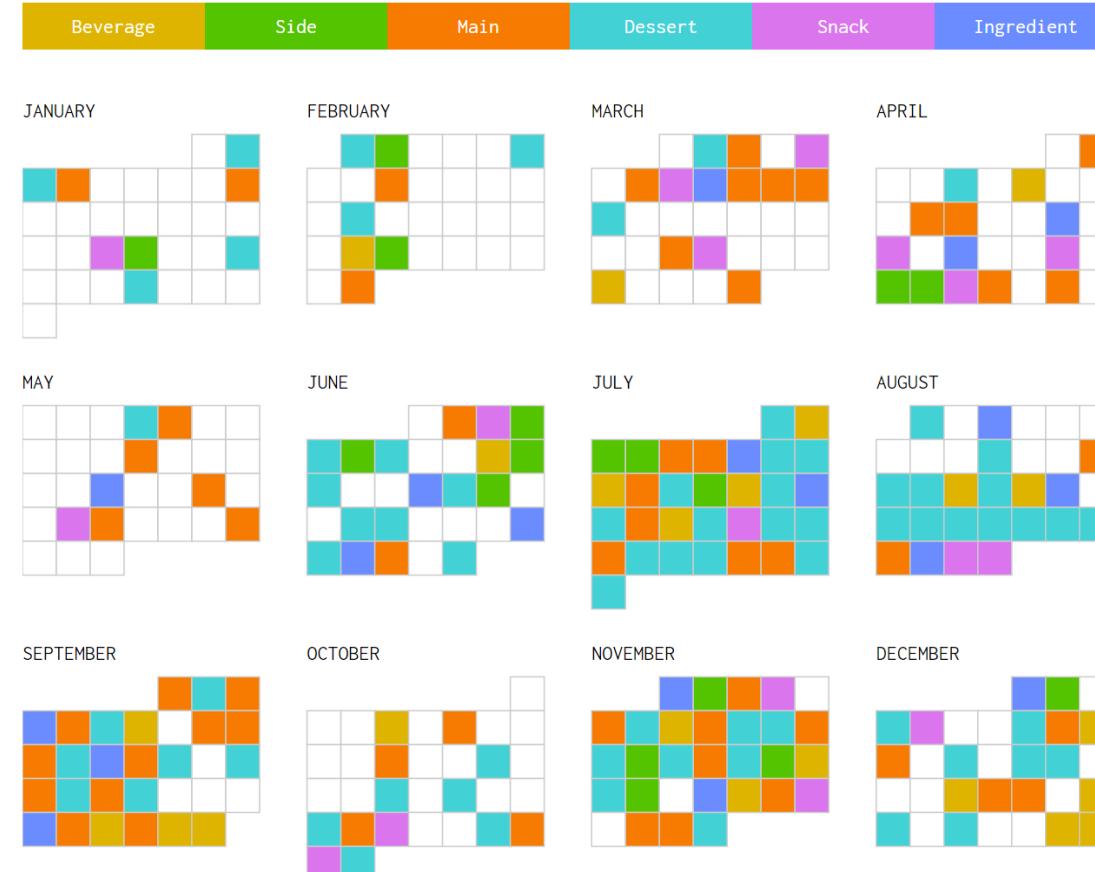


<http://mbostock.github.com/d3/ex/calendar.html>



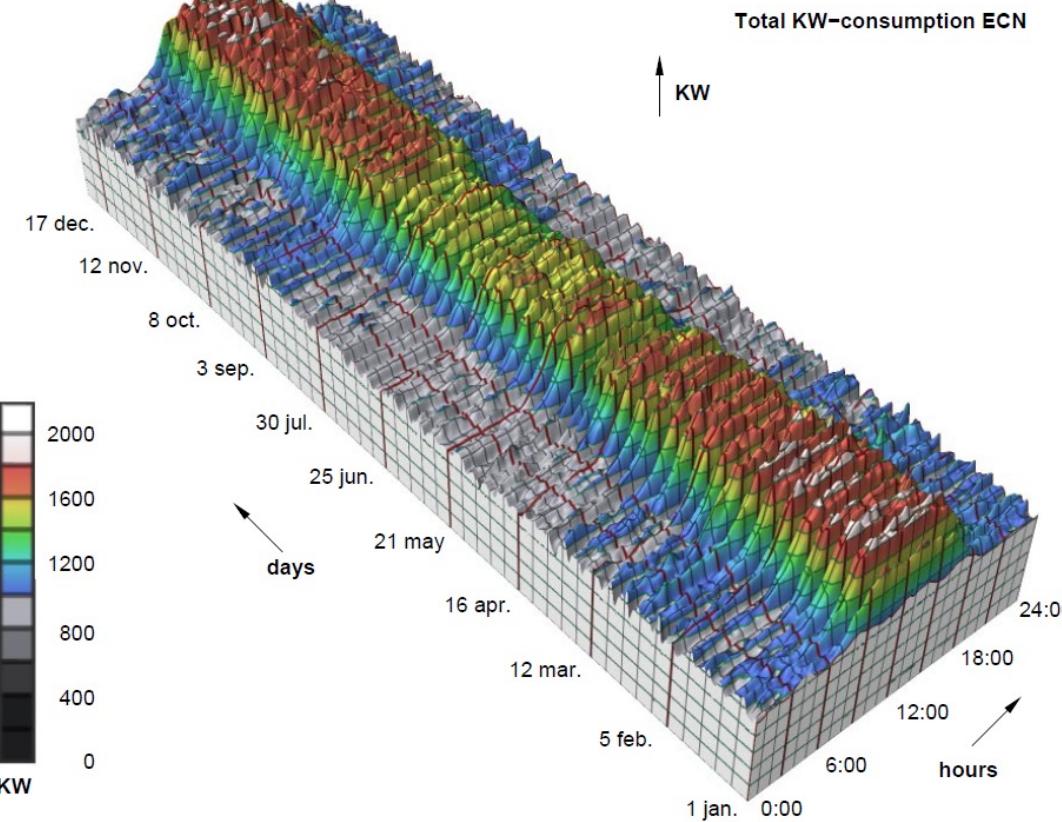
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All the National Food Days



<http://flowingdata.com/2016/08/18/all-the-national-food-days/>





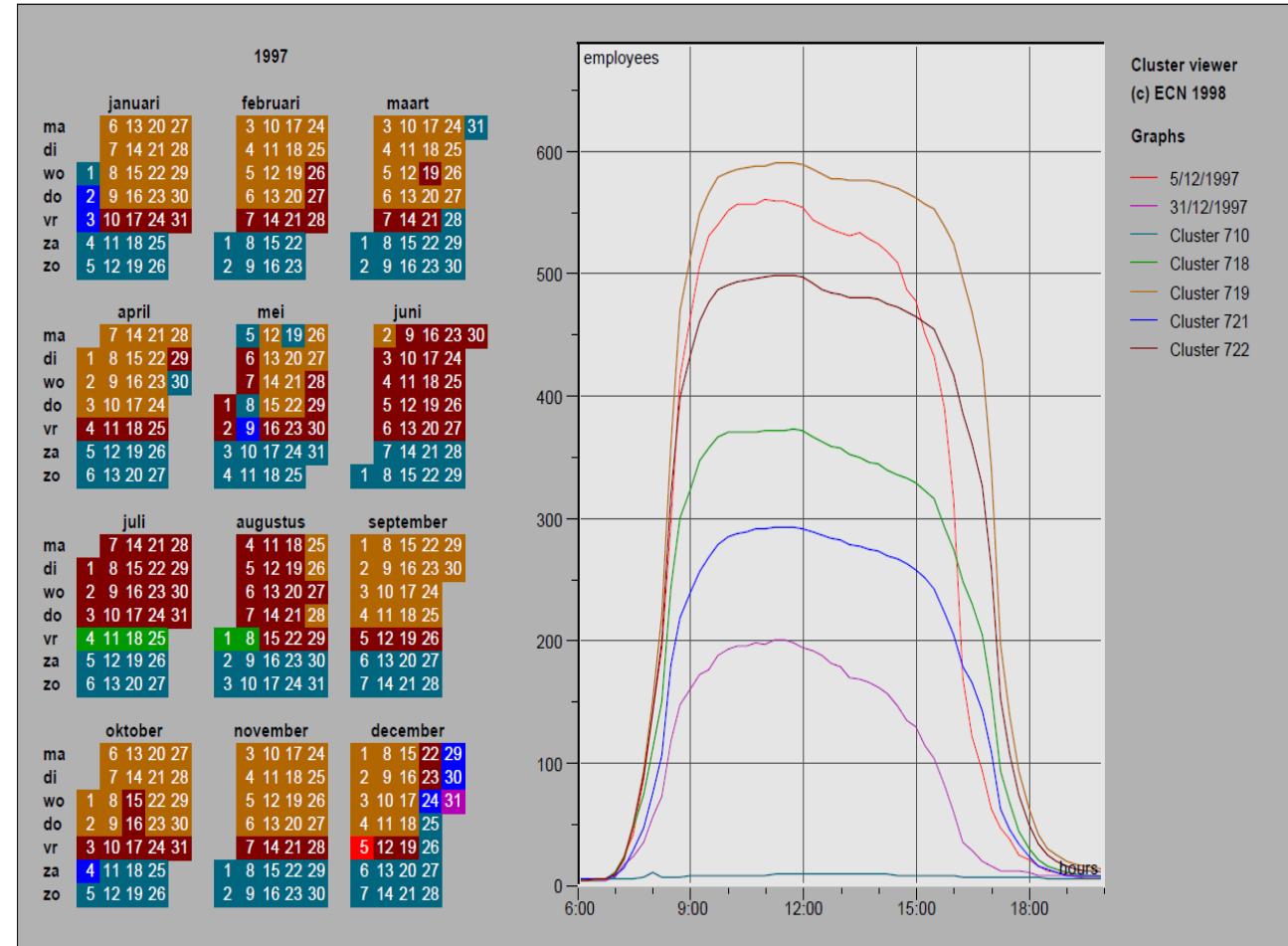
Good
Typical daily pattern
Seasonal trends

Bad
Weekly pattern
Details

Jarke J. van Wijk, Edward R. van Selow: Cluster and Calendar Based Visualization of Time Series Data.



Grid Time

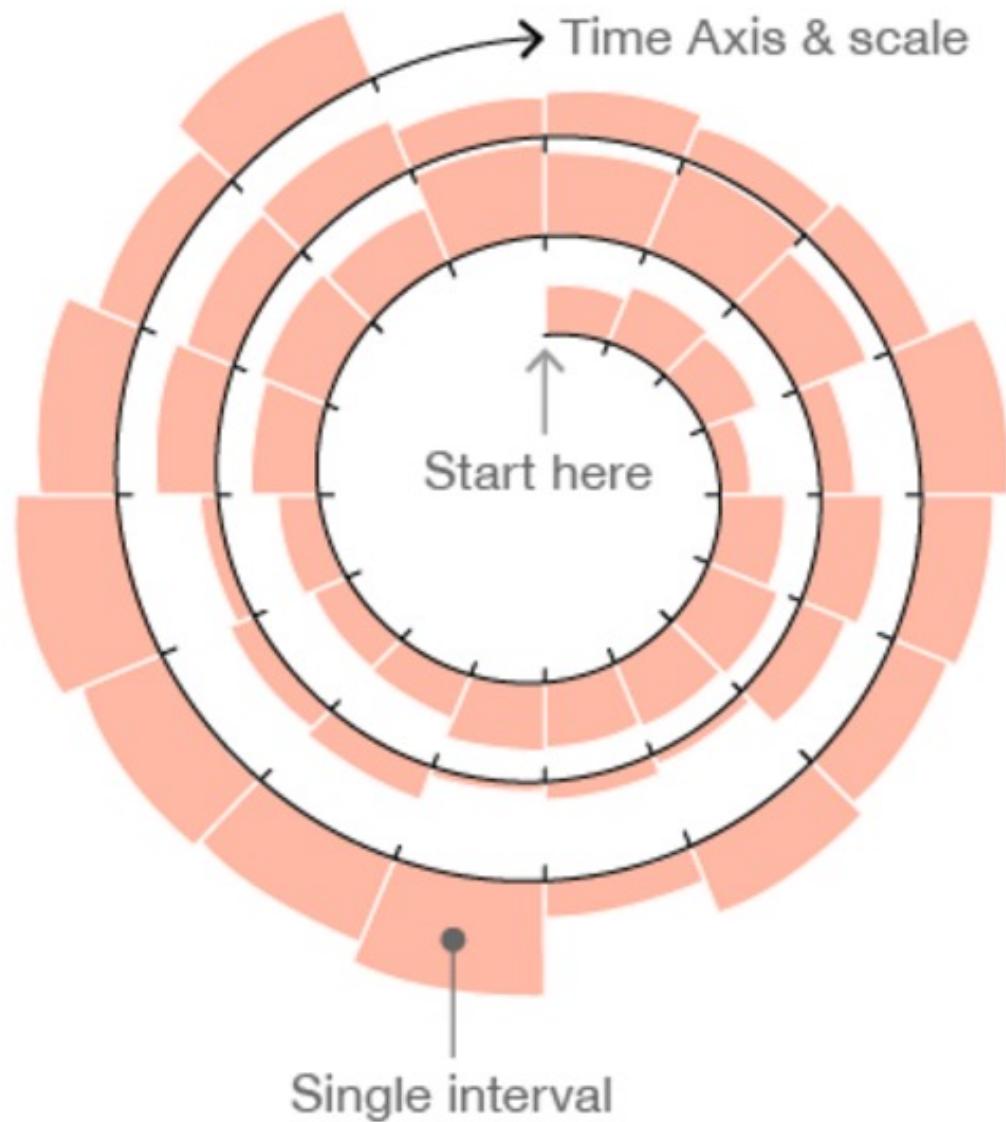


Employee's Attendance

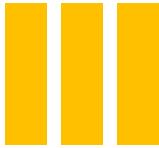
Jarke J. van Wijk, Edward R. van Selow: Cluster and Calendar Based Visualization of Time Series Data.



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Spiral Time



Arbitrary Time

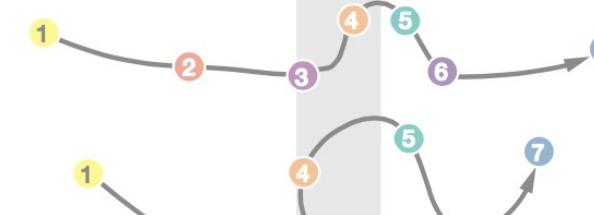


Time Curves: Folding Time to Visualize Patterns of Temporal Evolution in Data



Circles are data cases with a time stamp.
Similar colors indicate similar data cases.

Folding:

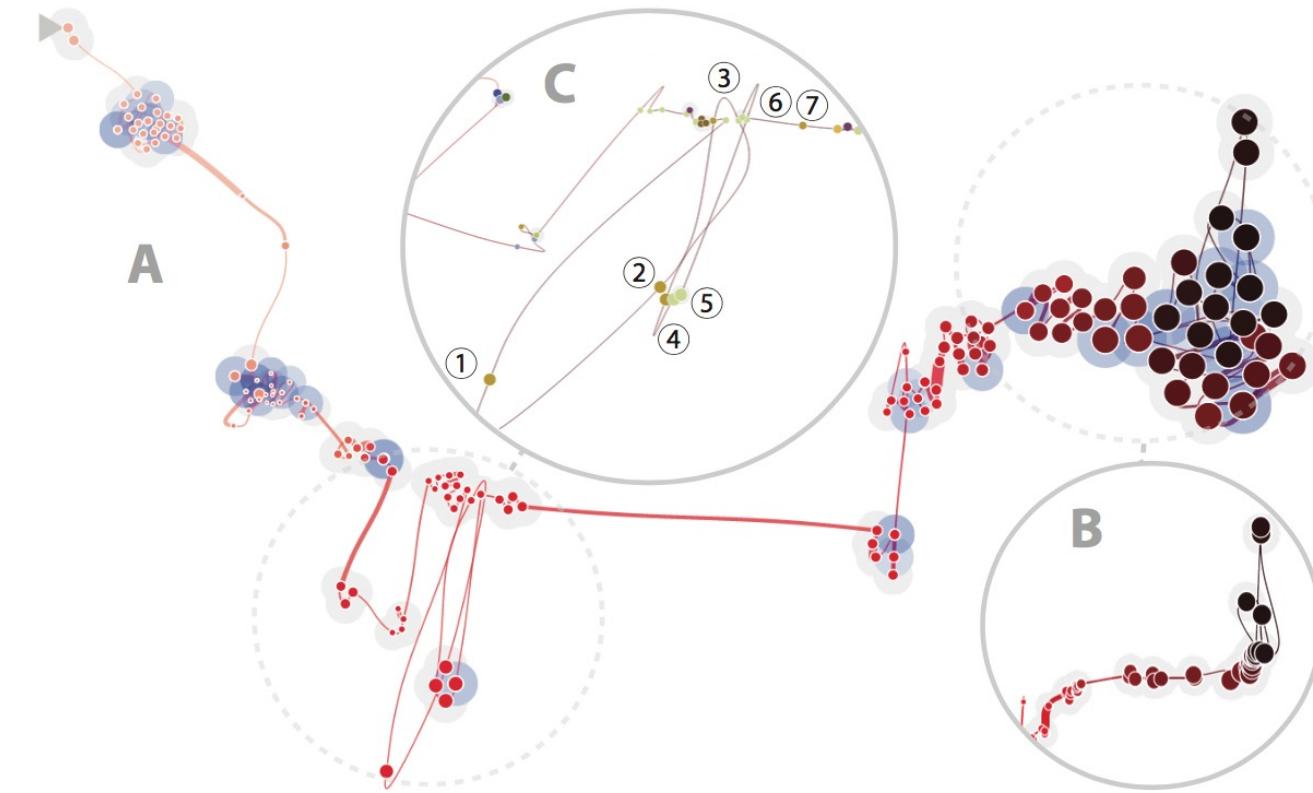


Time curve:



The temporal ordering of data cases is preserved.
Spatial proximity now indicates similarity.

(a) Folding time

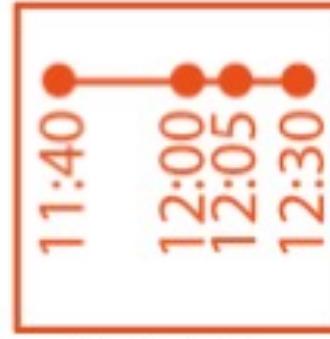
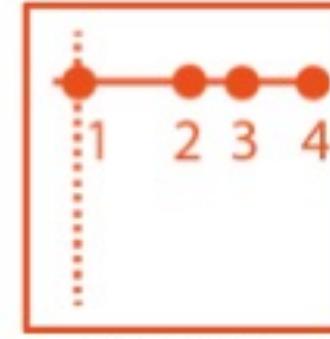


(b) History of the Wikipedia article on Palestine

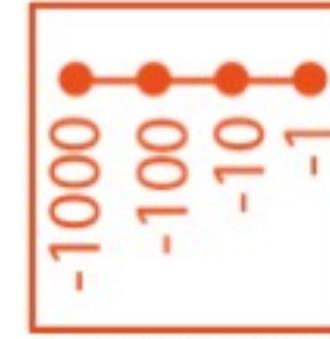
<http://www.aviz.fr/~bbach/timecurves/>



Scale

Chrono-
logical

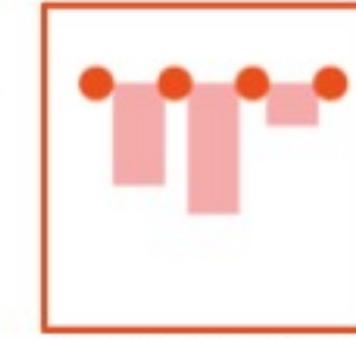
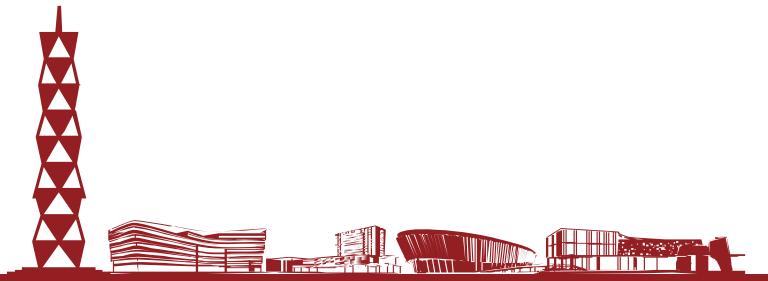
Relative

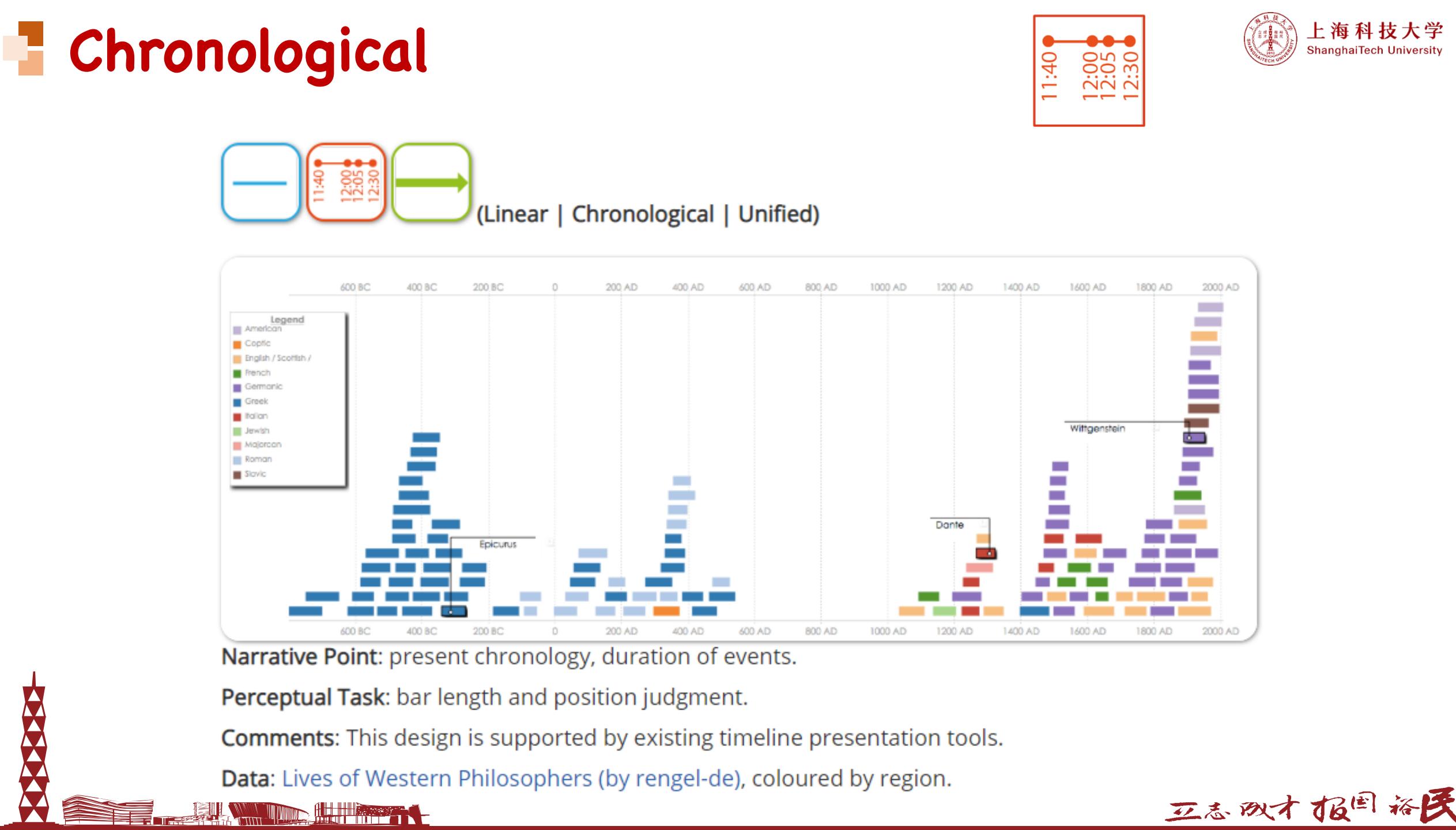


Logarithmic



Sequential

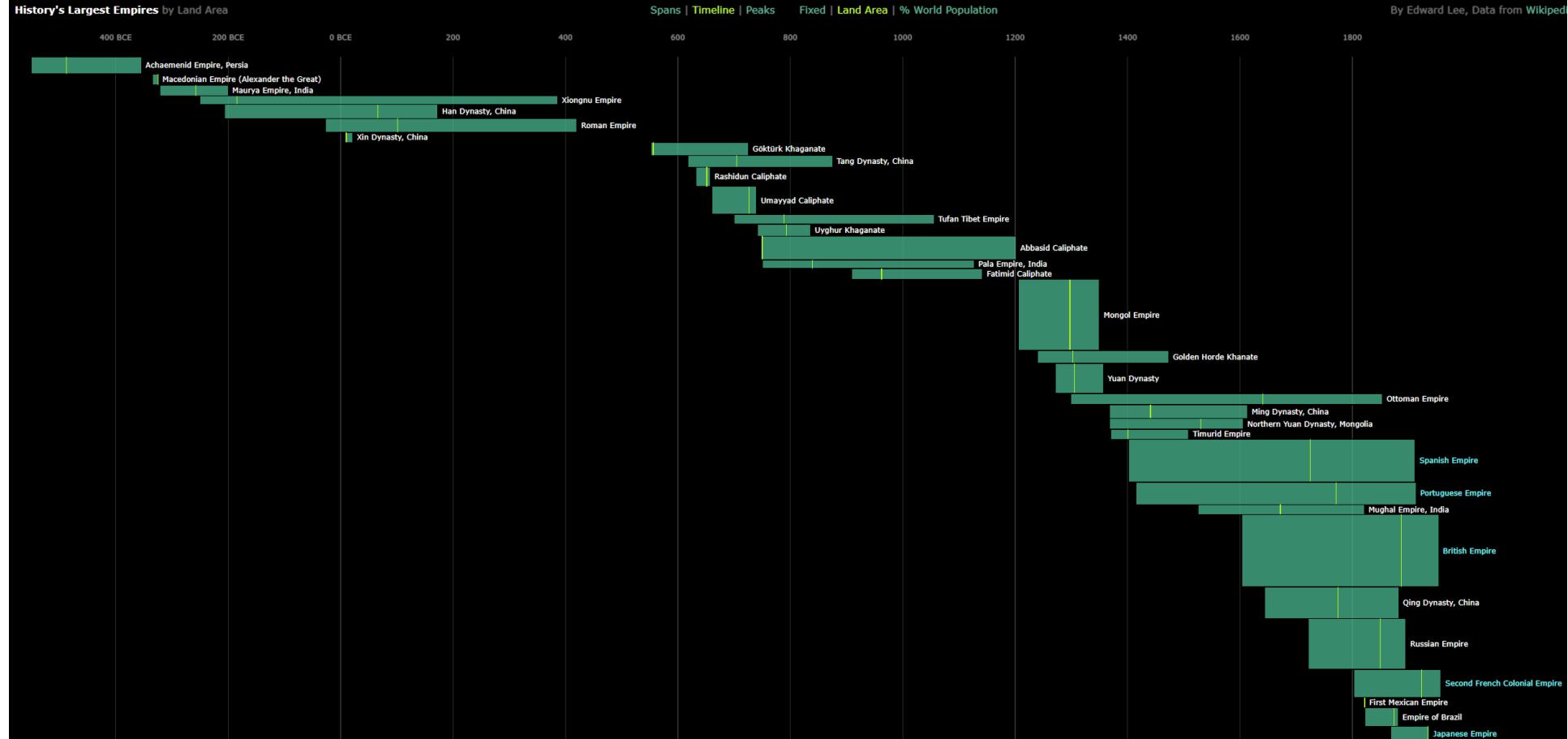
Sequential +
Interim
Duration



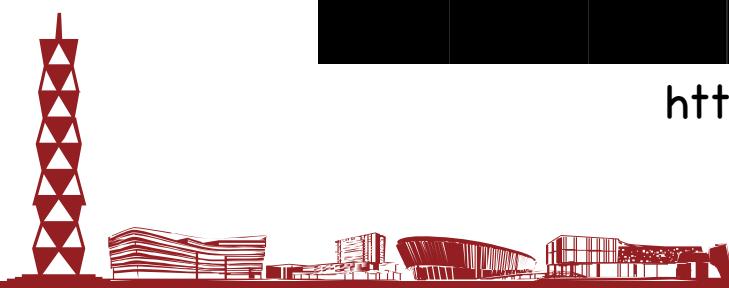
Chronological

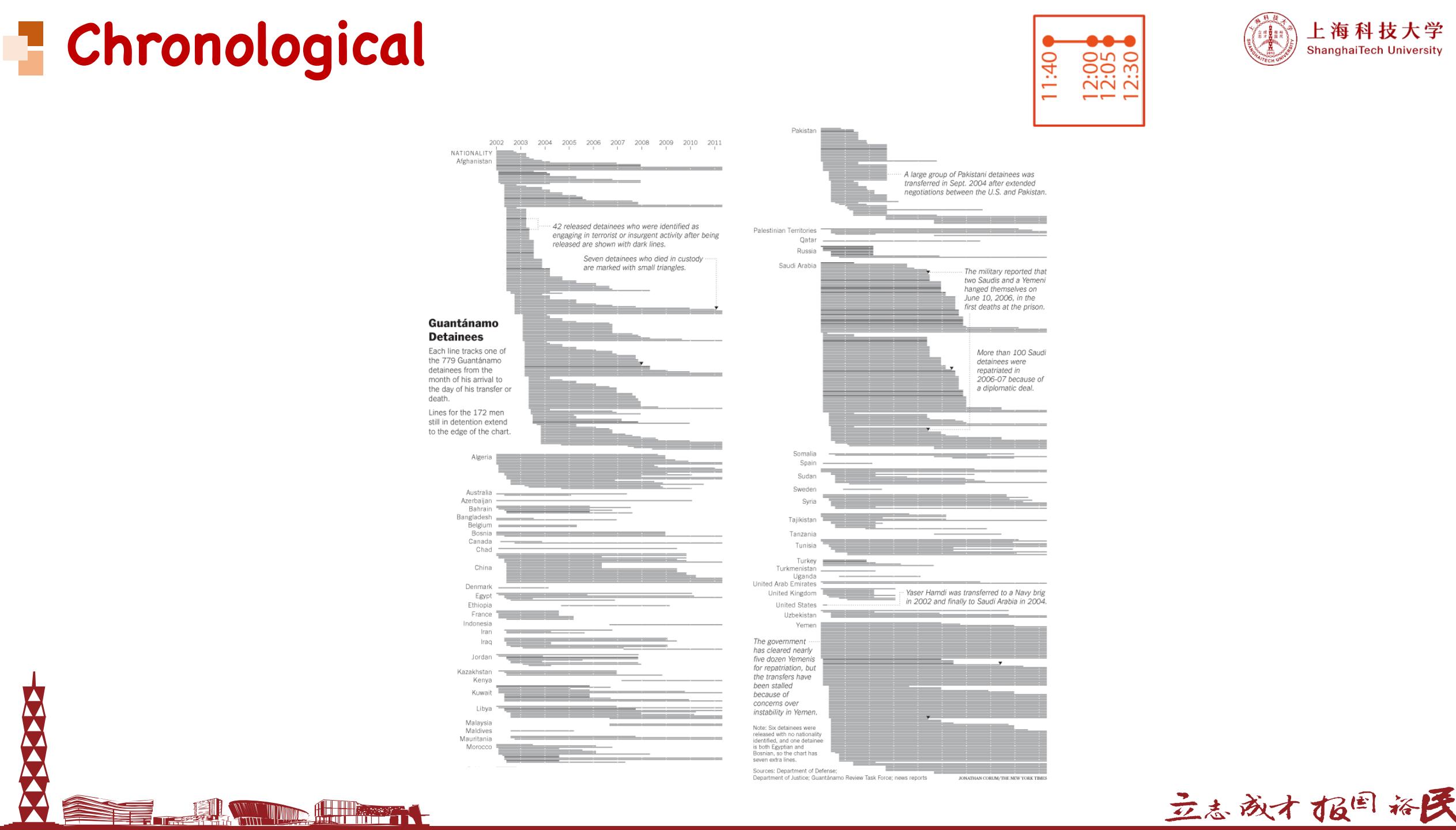


History's Largest Empires



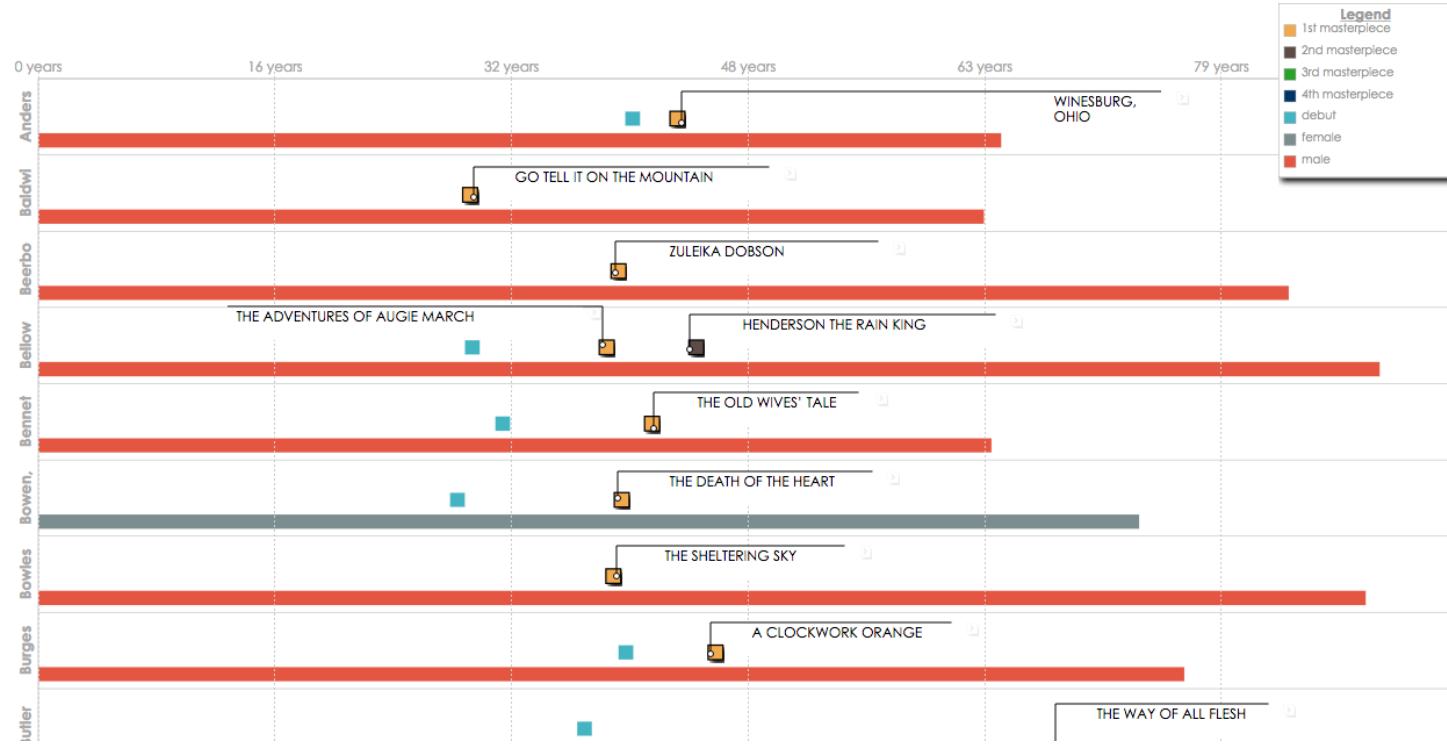
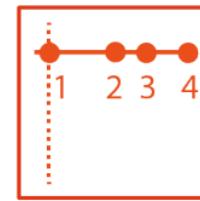
<http://nowherenearithaca.github.io/empires/index.html>







Relative

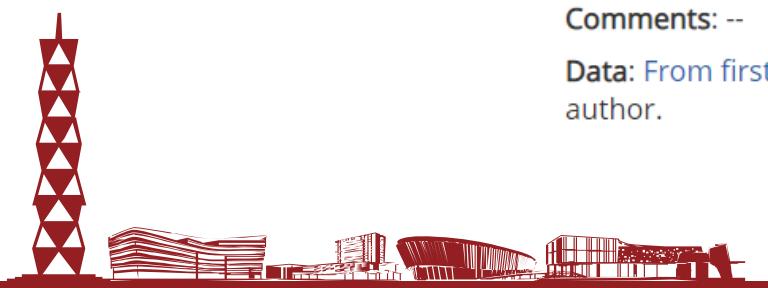


Narrative Point: compare relative chronology, duration of events between facets, present relative synchronicities.

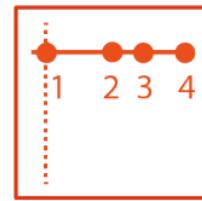
Perceptual Task: bar length and position comparisons.

Comments: --

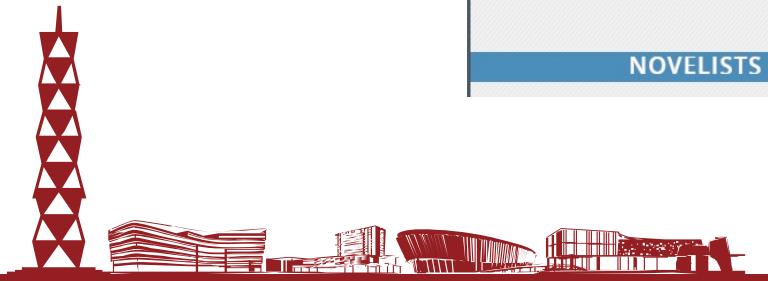
Data: From first published to masterpieces (by Accurat), coloured by event category, faceted by author.



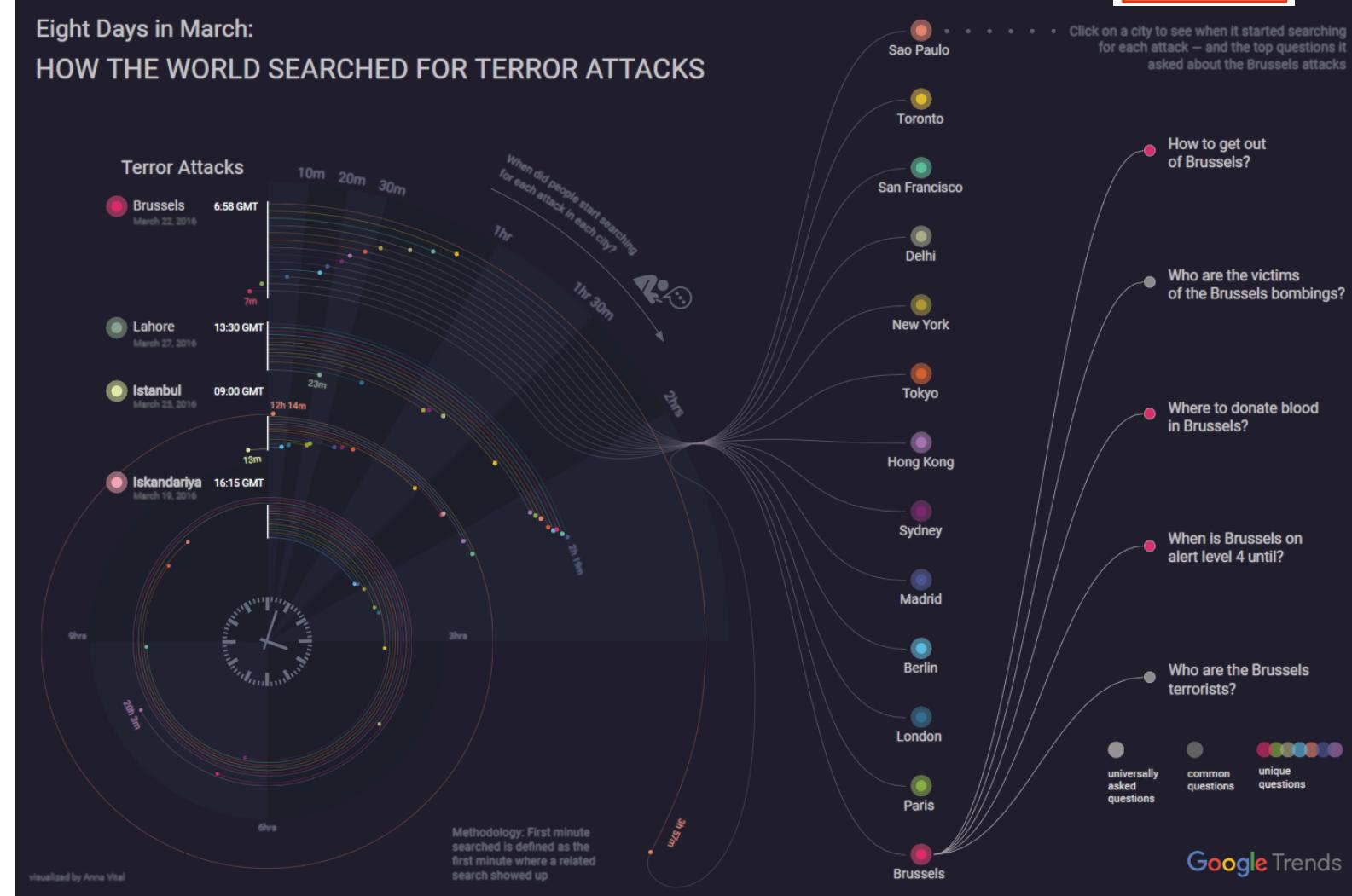
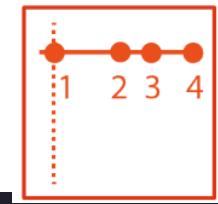
Relative



<http://howold.periscopic.com/>



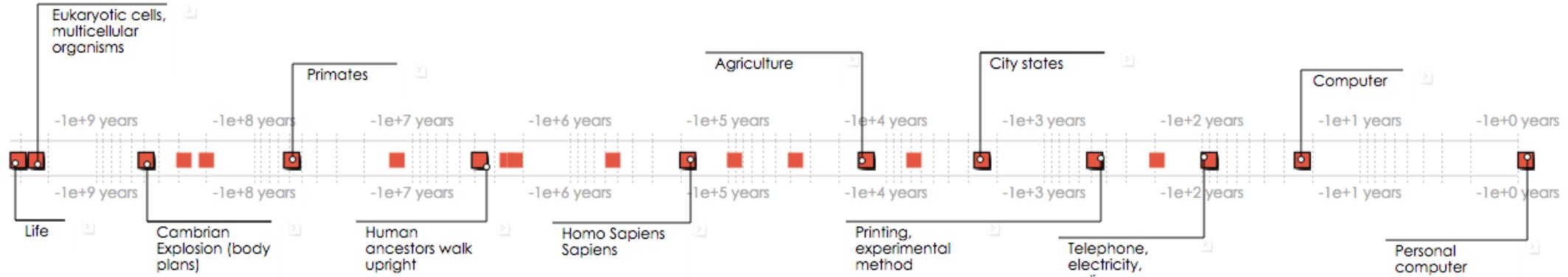
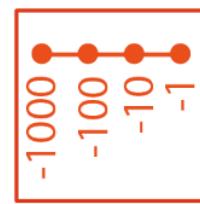
Relative



<http://googletrends.github.io/brussels-attacks/>

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Logarithmic



Narrative Point: present chronology of a timeline with emphasis on recent events.

Perceptual Task: bar position judgment.

Comments: do not start story with log scale.

Data: Countdown to Singularity (by R. Kurzweil).

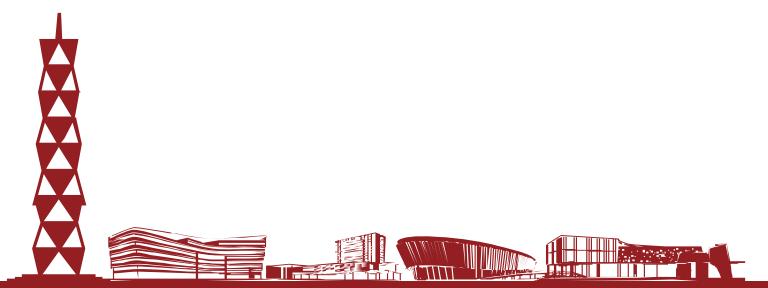
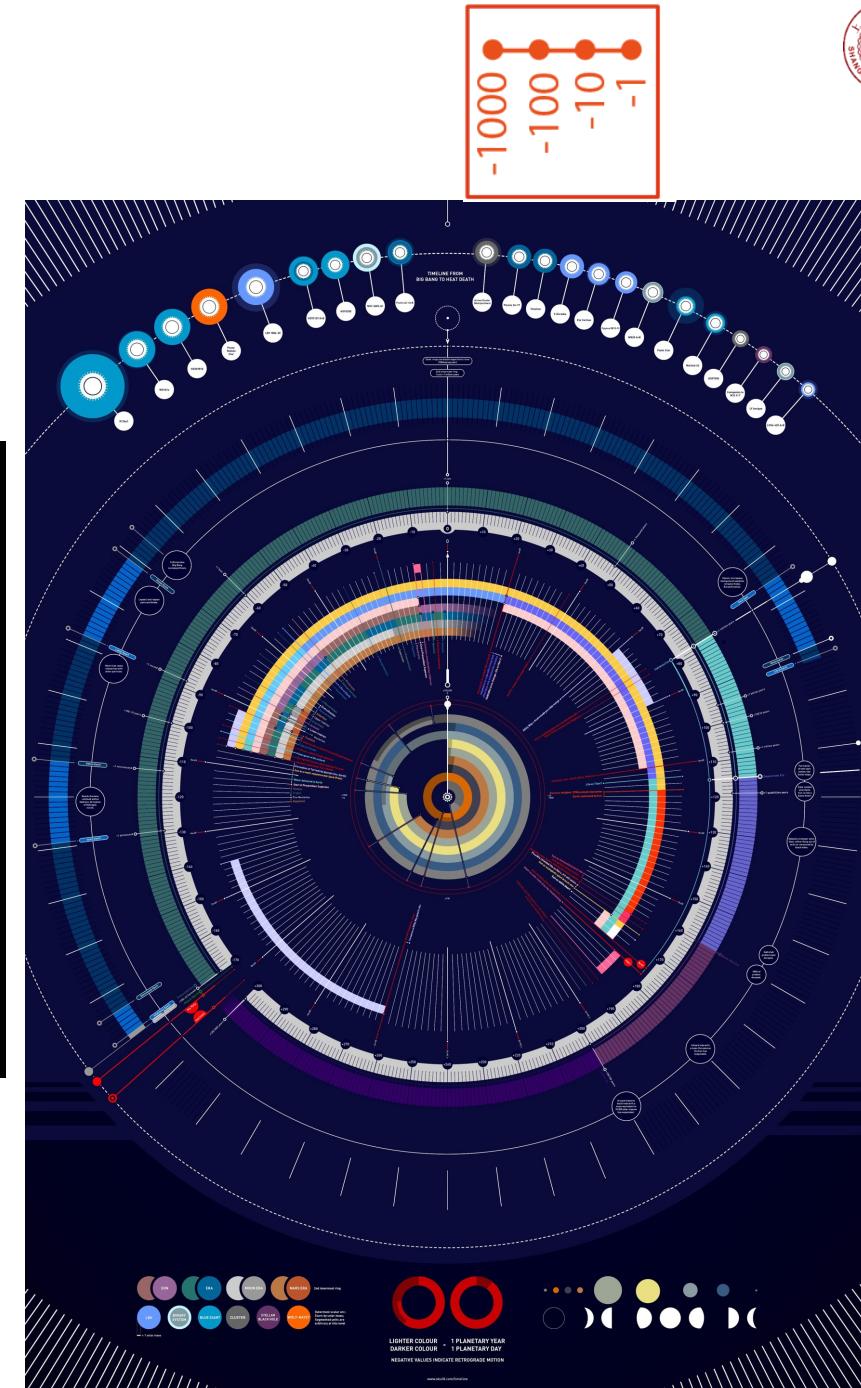
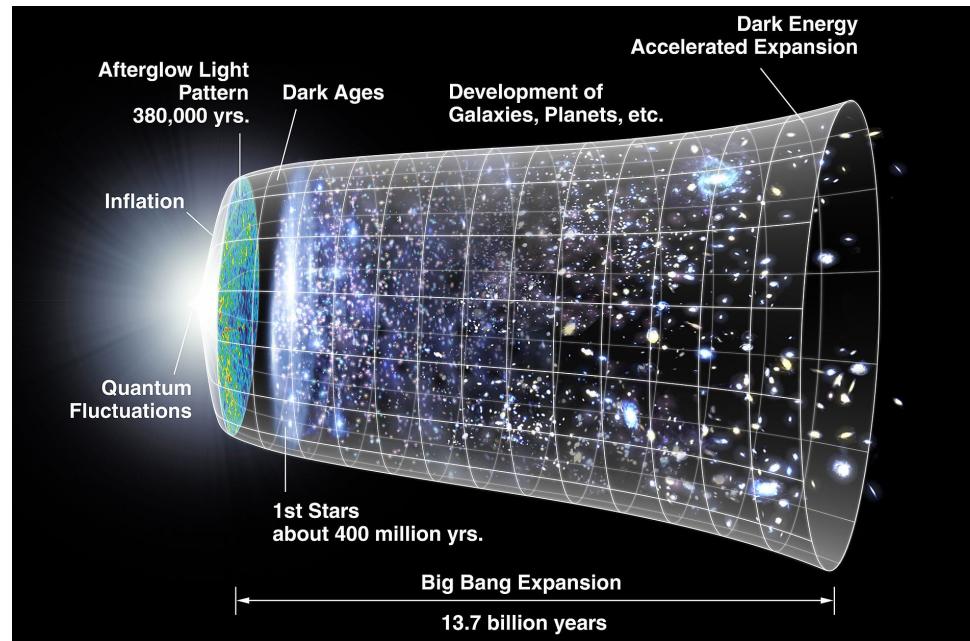


Logarithmic



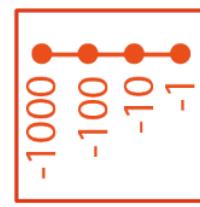
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ShanghaiTech University

Timeline of the Universe



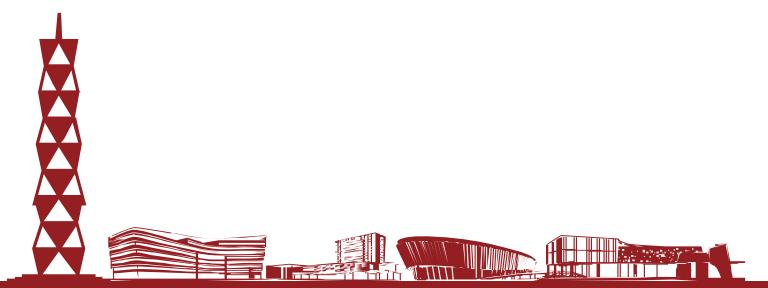
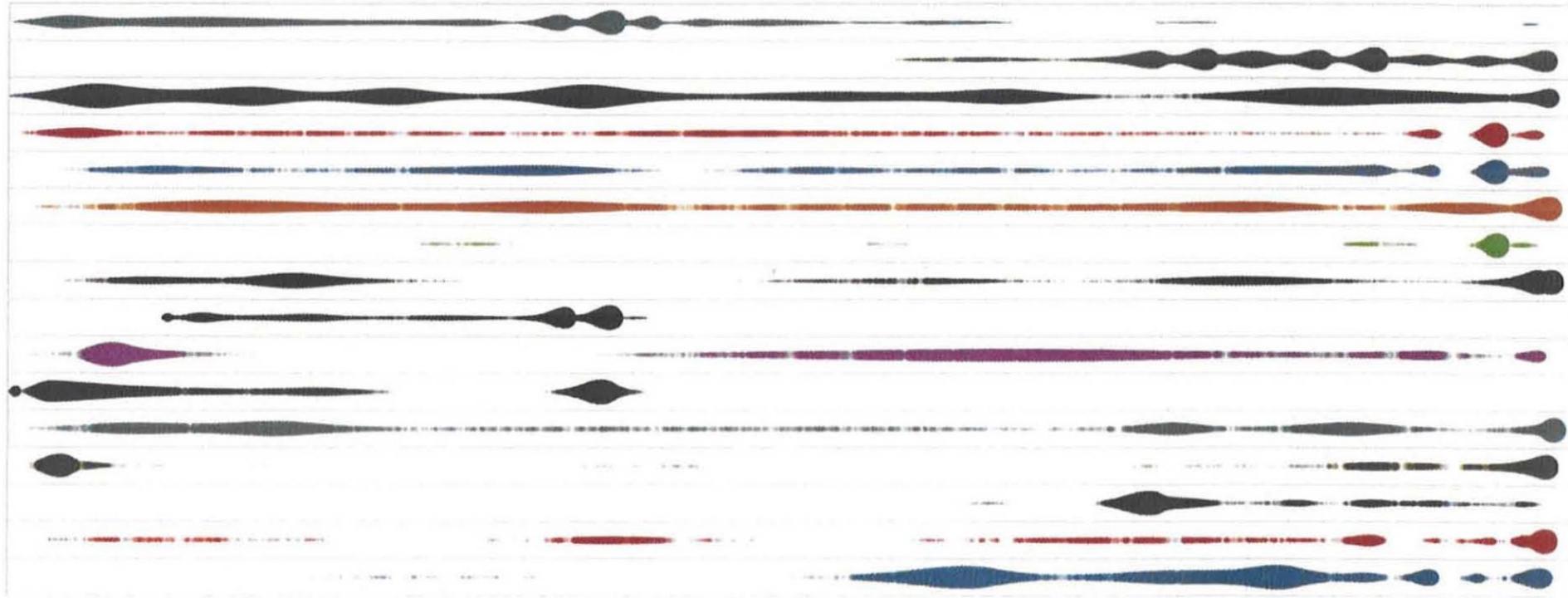
国裕才报

Logarithmic



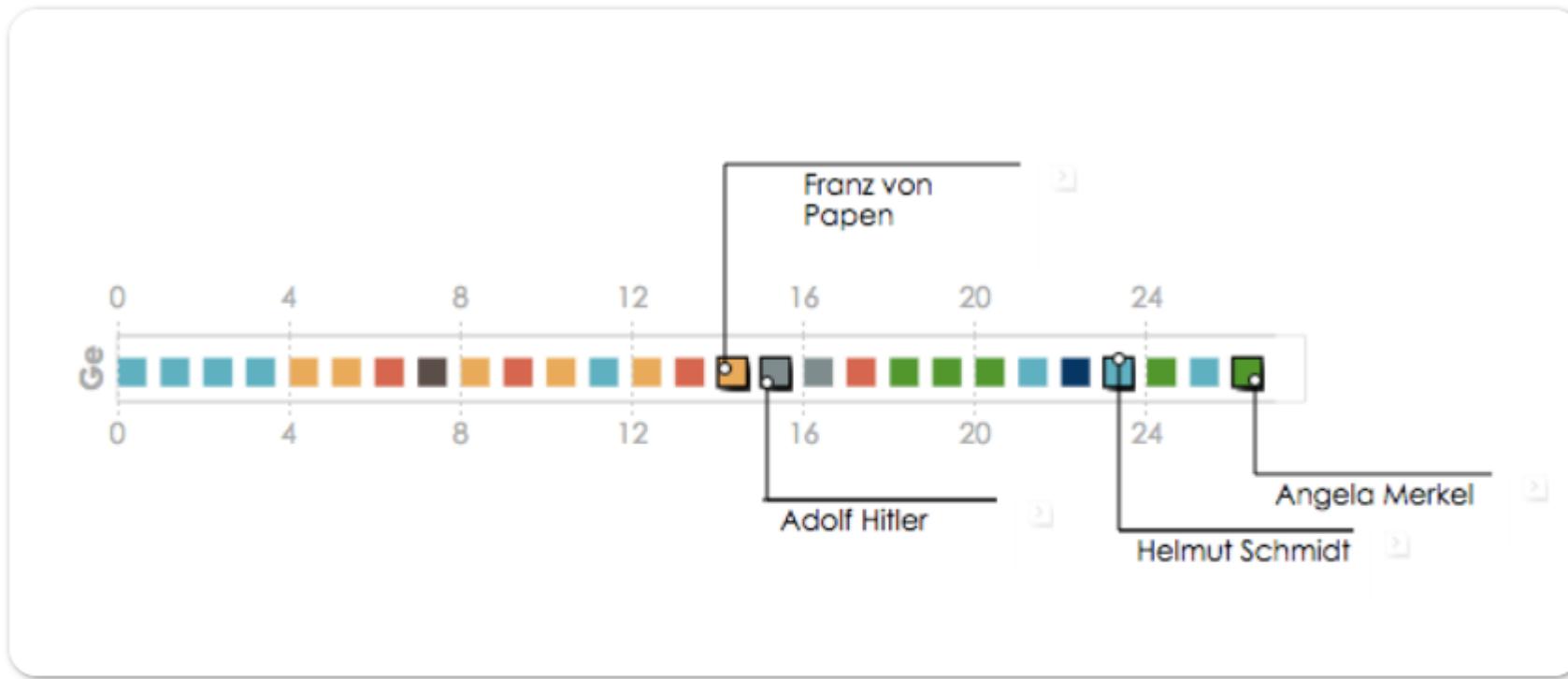
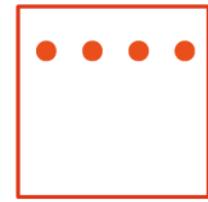
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CloudLines: Compact Display of Event Episodes in Multiple Time-Series



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Sequential



Narrative Point: present a sequence of events.

Perceptual Task: bar position judgments.

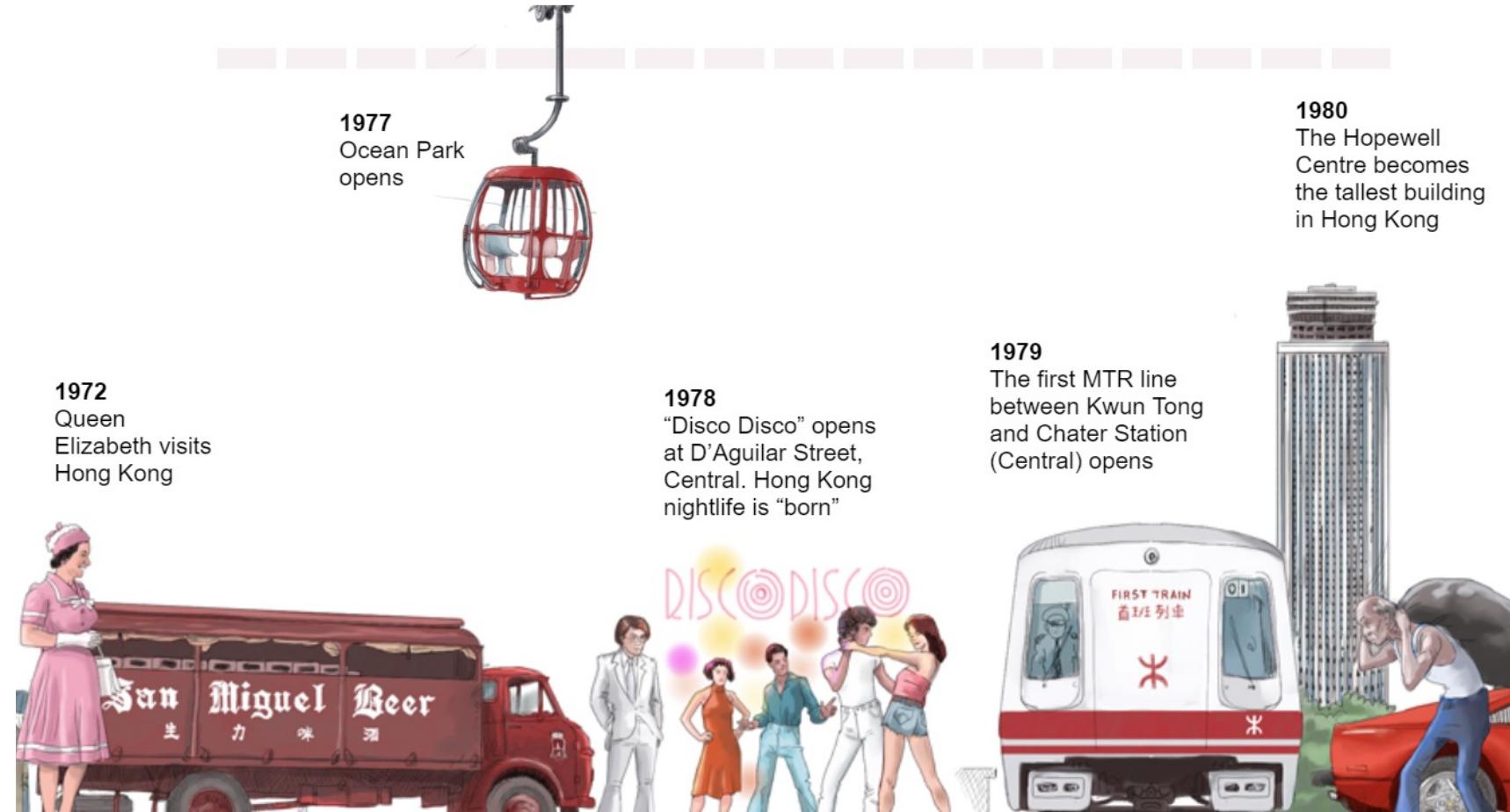
Comments: wide aspect ratio.

Data: German Chancellors ([Wikipedia](#)), coloured by political party.





Once upon a time in Hong Kong: 110 years of South China Morning Post



<http://www.scmp.com/infographics/article/1348896/once-upon-time-hong-kong-110-years-south-china-morning-post>



Sequential



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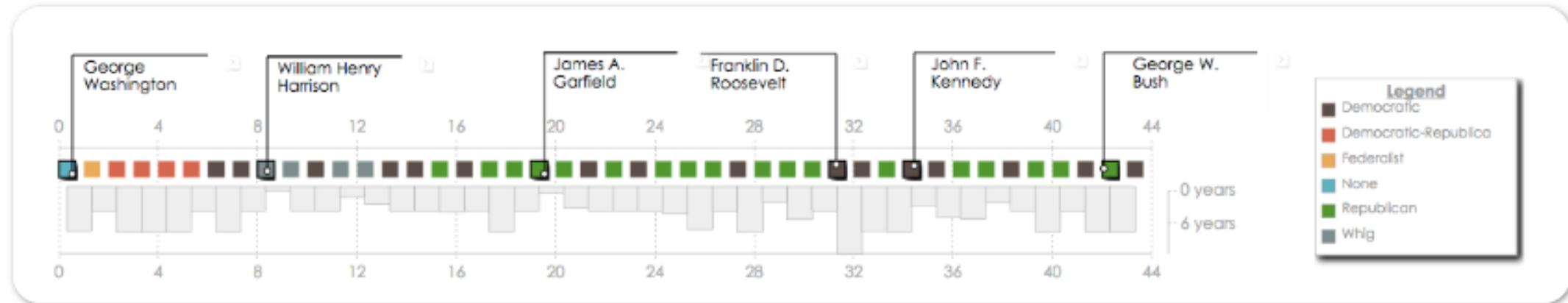
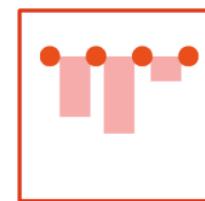


<https://visual.ly/community/infographic/other/evolution-coins-throughout-history>

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Sequential + Interim Duration



Narrative Point: present a sequence of events with distribution of time elapsed between events.

Perceptual Task: bar position judgments (sequence), bar length judgments (interim durations).

Comments: appropriate for non-uniform chronological distributions.

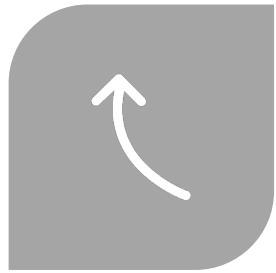
Data: US Presidents ([Wikipedia](#)), coloured by political party, segmented by century.



The Organization of Time



Linear



Flow



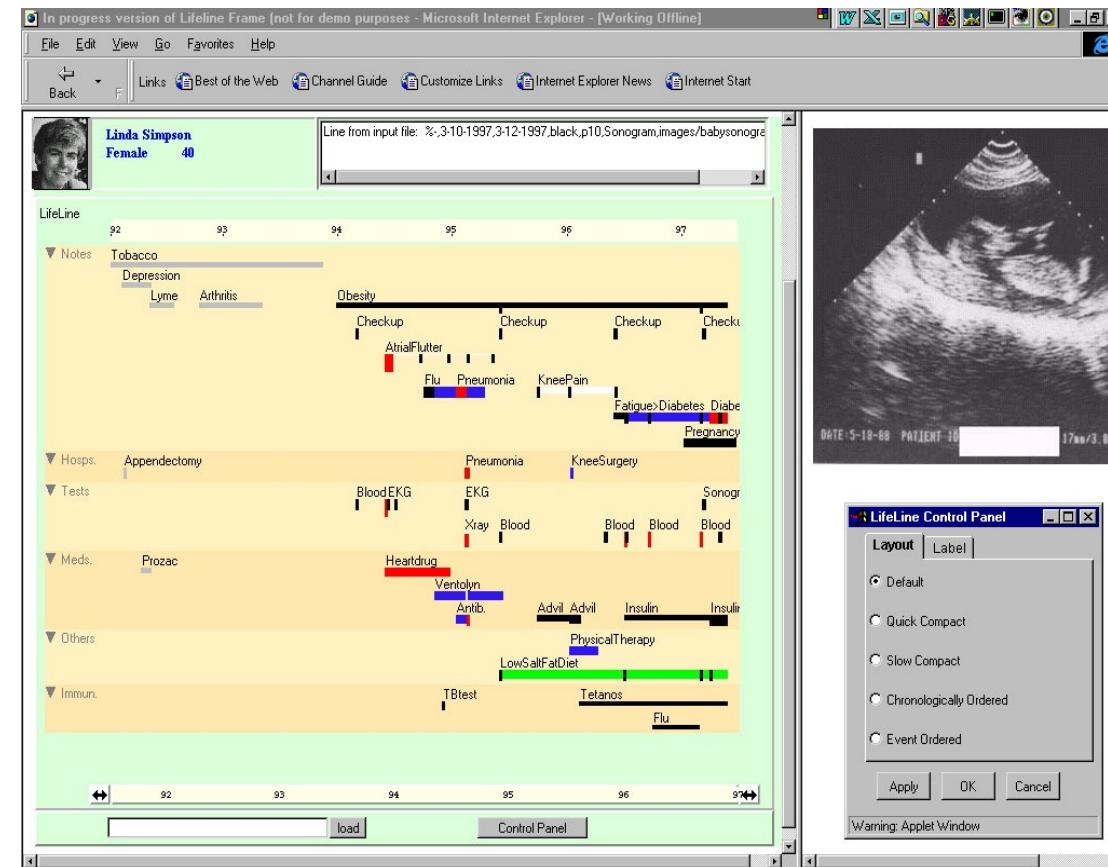
Tree



Graph

Linear & Multi-Perspective

- Multi-perspective Gantt Chart to visualize life lines



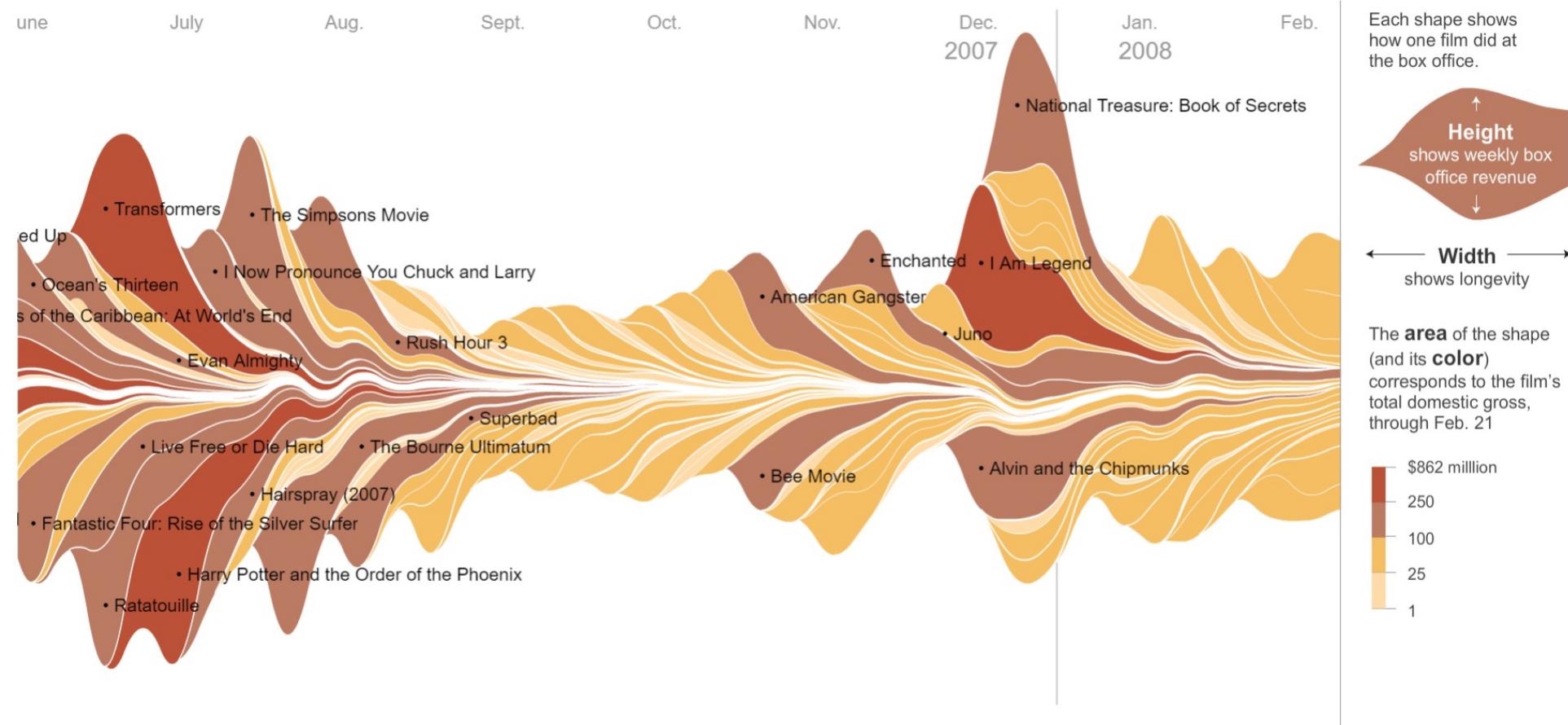
C. Plaisant, B. Milash, A. Rose, S. Widoff, B. Schneiderman. Life Lines: Visualizing personal histories



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StreamGraph

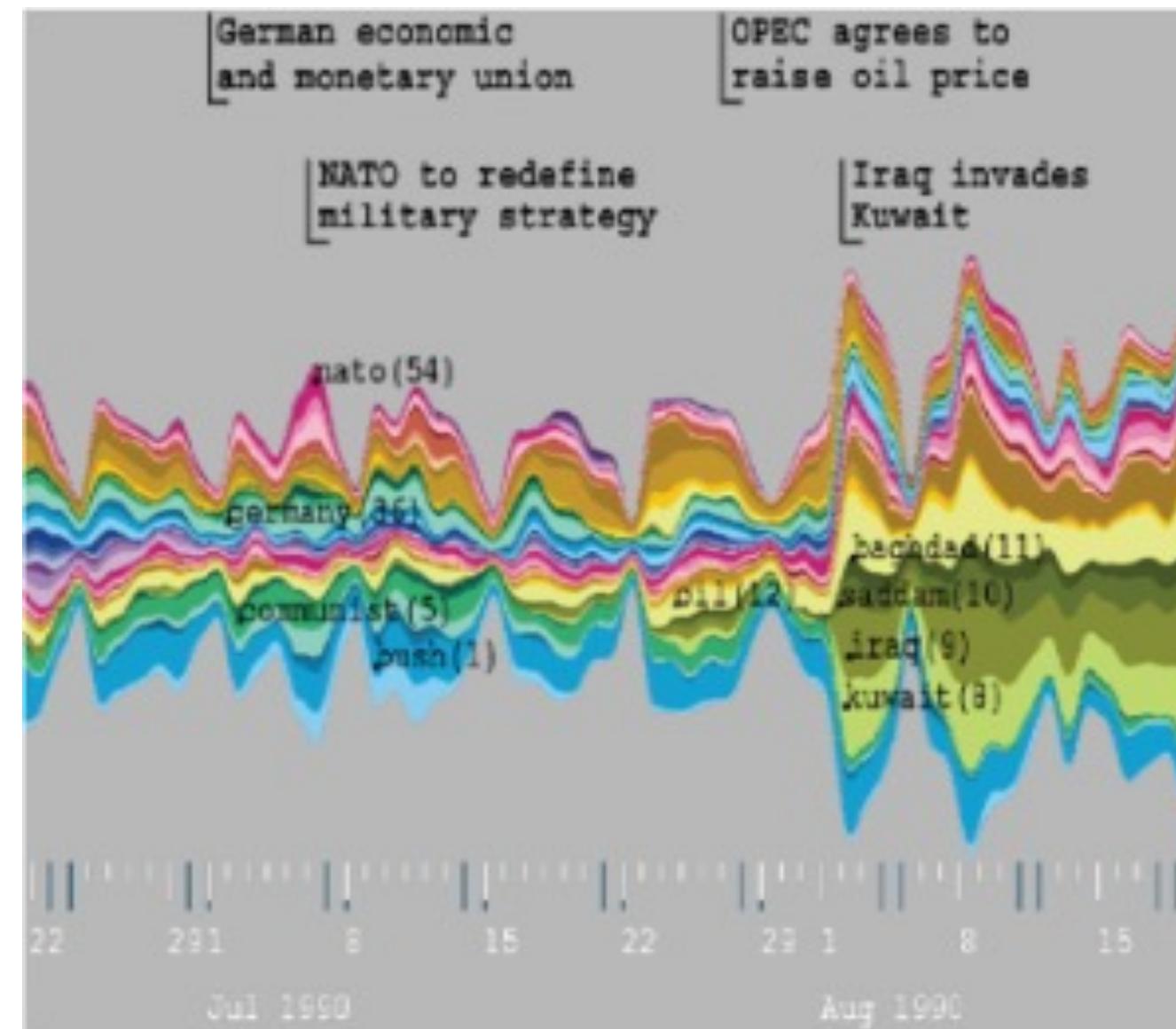


http://www.nytimes.com/interactive/2008/02/23/movies/20080223_REVENUE_GRAPHIC.html



StreamGraph

Multi-perspective
Semantic flow



S. Havre, E. Hetzler, P. Whitney, and L. Nowell. ThemeRiver: Visualizing Thematic Changes in Large Document Collections.



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OpinionFlow: Visualization of User Opinions

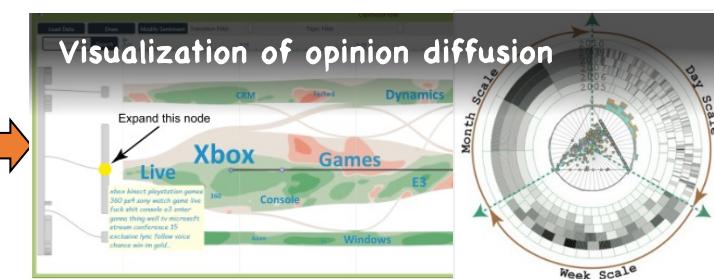
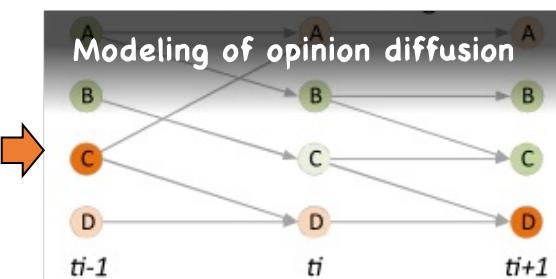
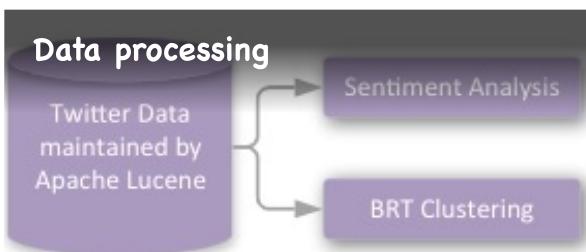


Inhomogeneous data

Ambiguous languages

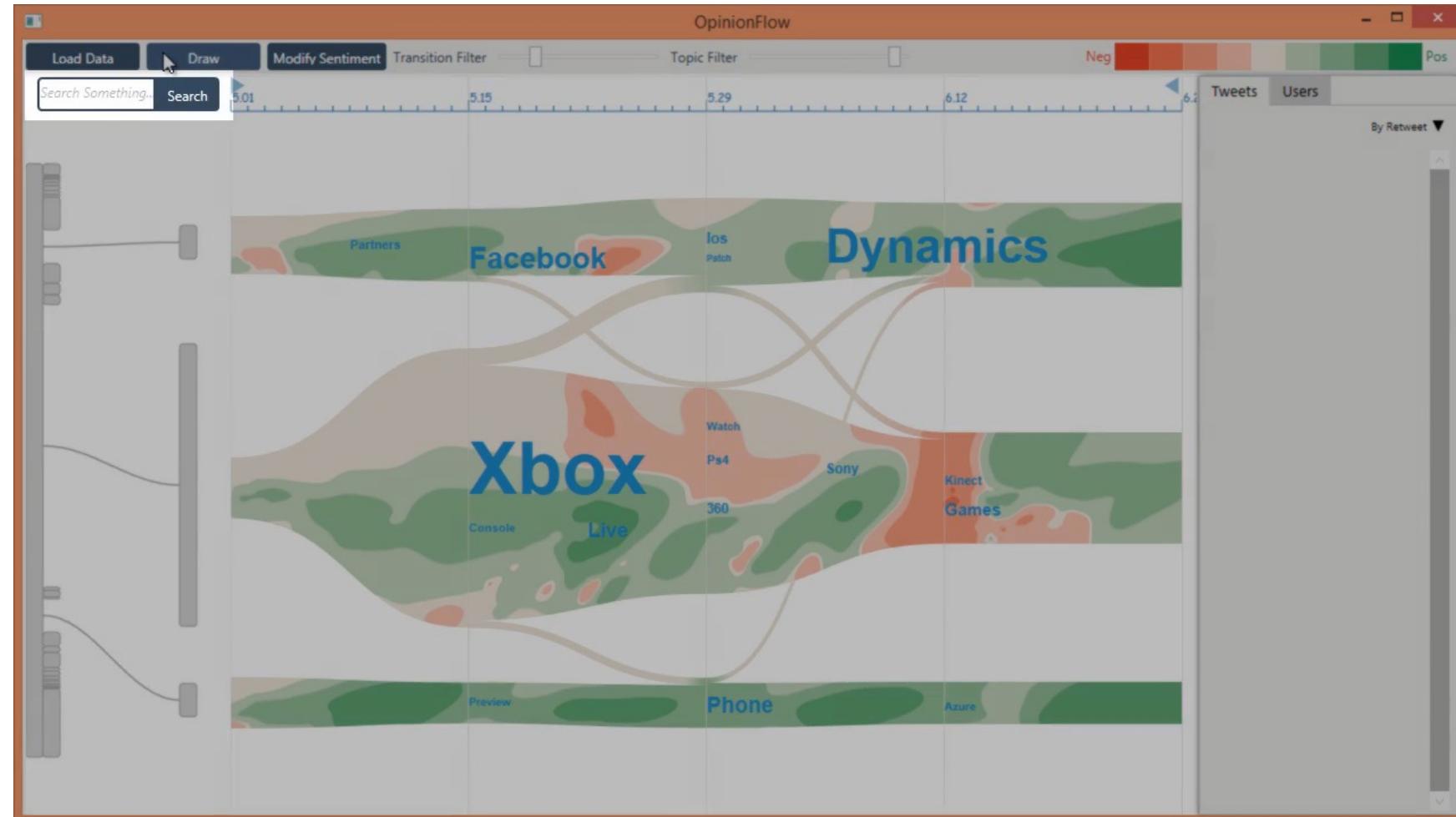
Spreading opinions

Combine opinion mining, topic modeling, subjective logics, and interactive visualization to analyze and explore user opinions.



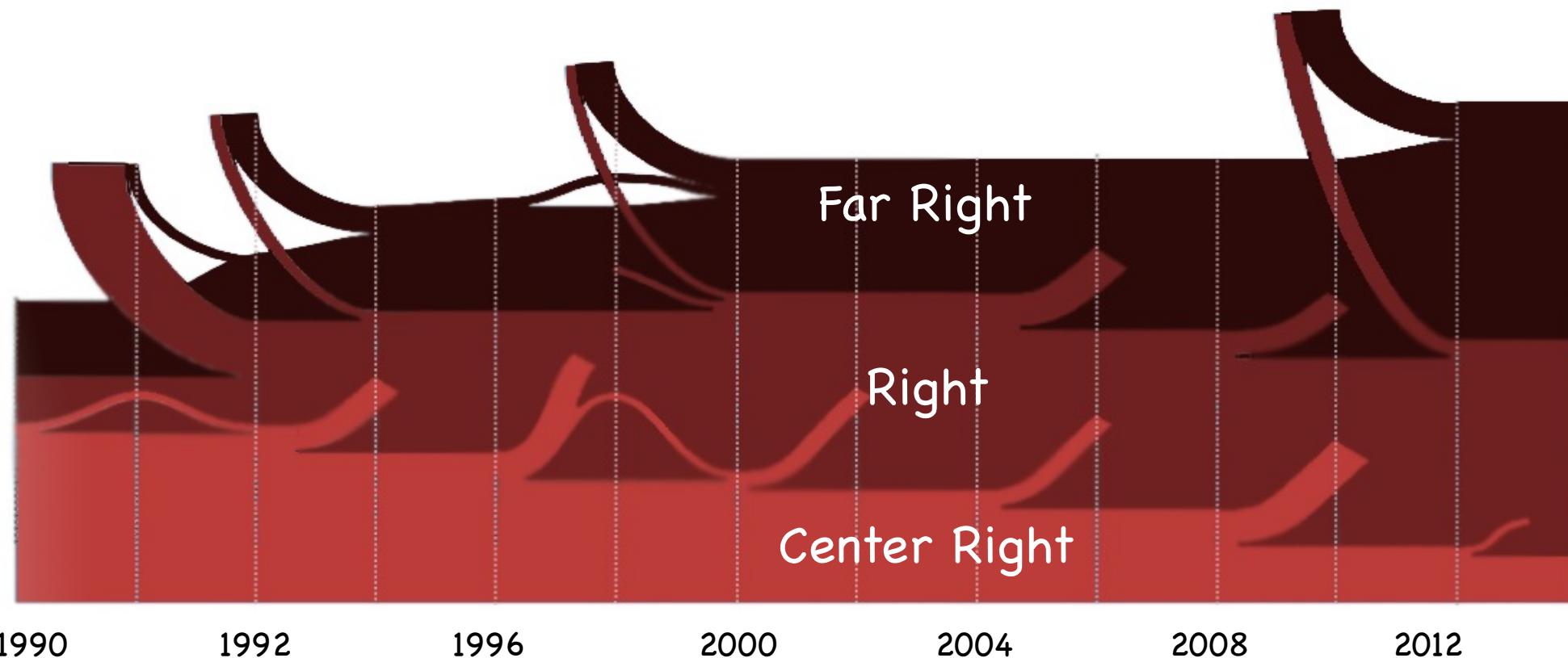
OpinionFlow: Visualization of User Opinions

Use a large data set (1 billion tweets): strong opinions spread more easily and opinion leaders have significant impact



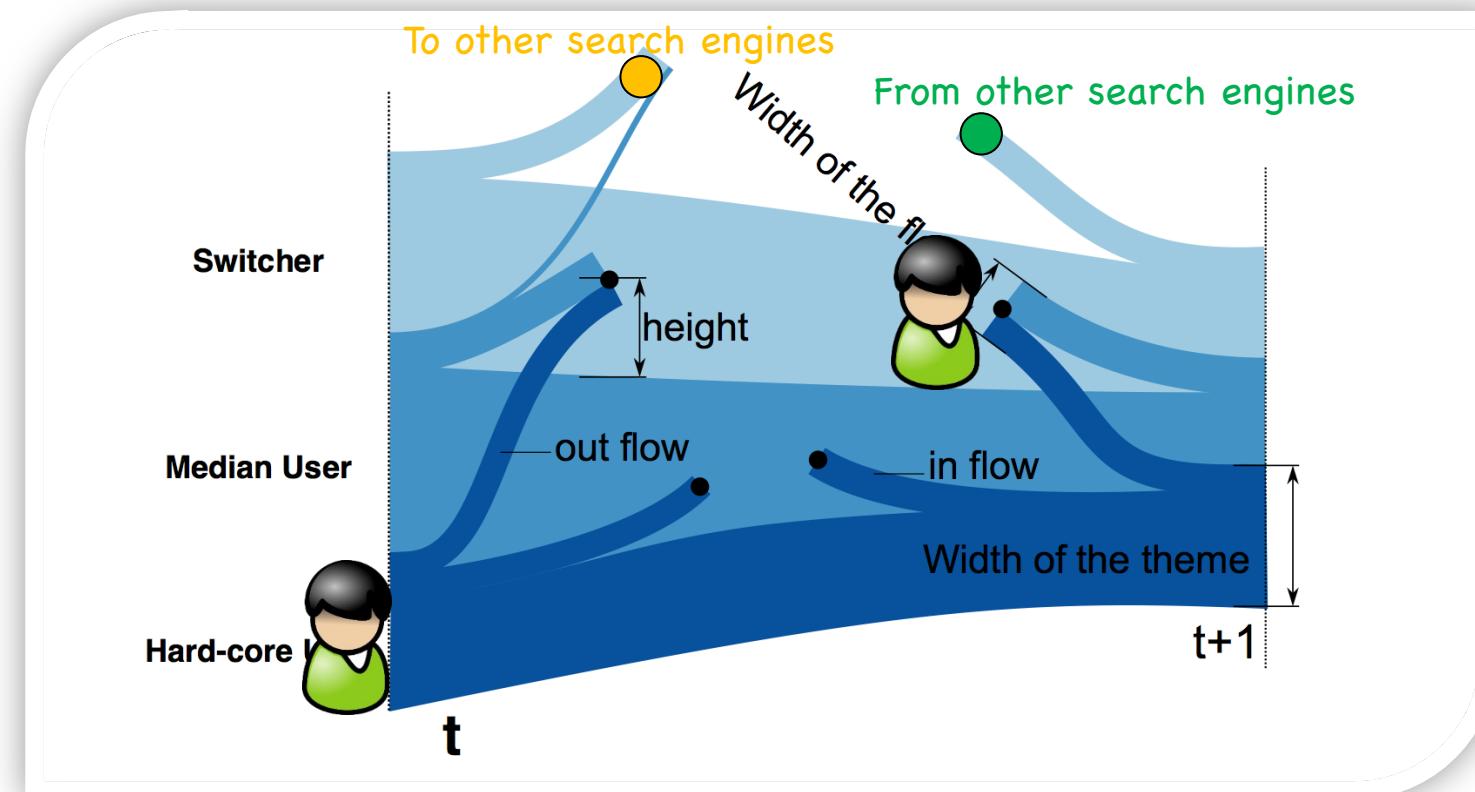
An Example

A History of The United States Congress



LoyalTracker: Visualizing Loyalty Dynamics

- Massive and dynamic data: Intuitive visualization to show dynamic user flow among different loyalty categories
 - Intuitive visual representation
 - Real-time interactions



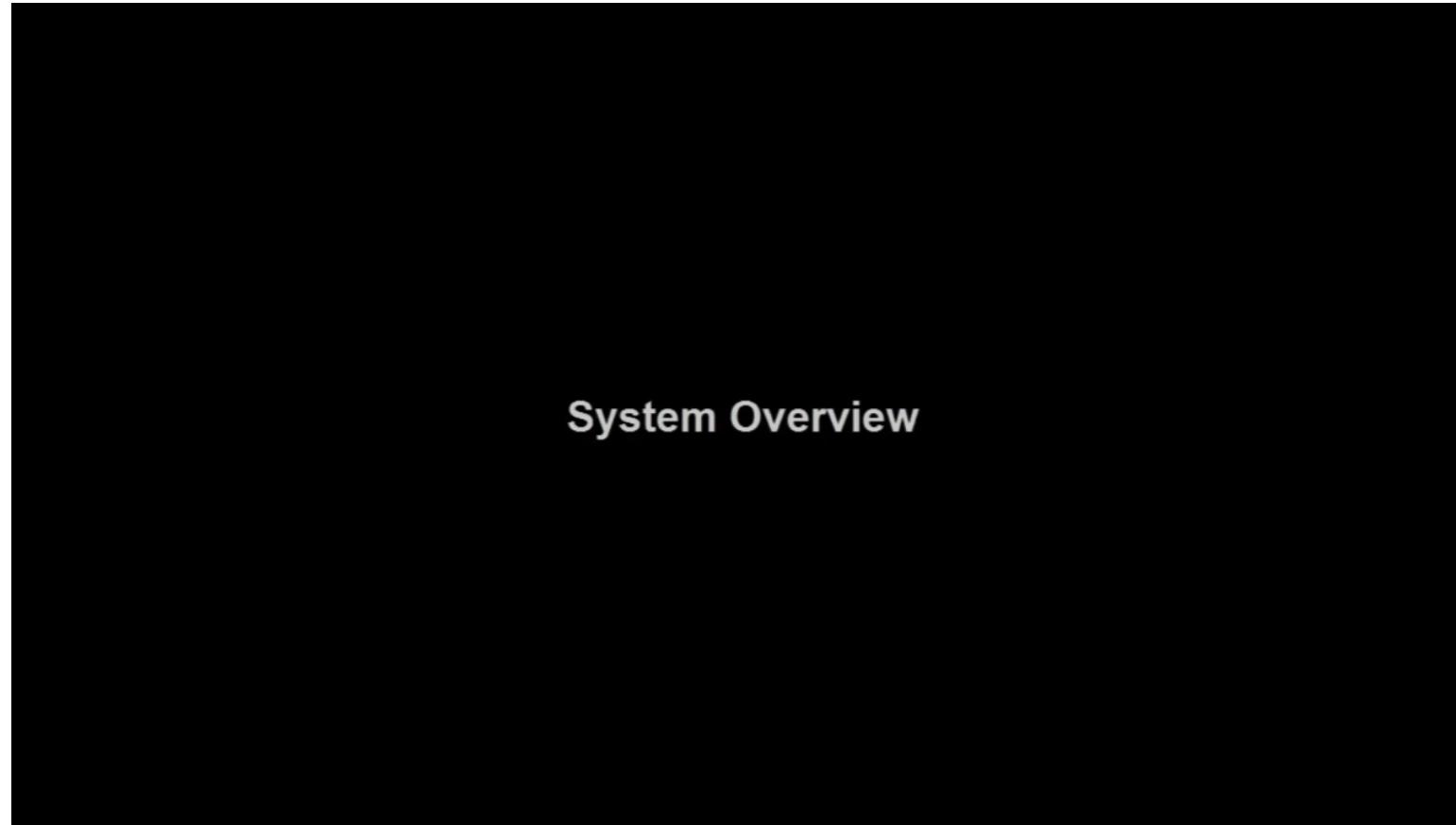
VAST'14 (TVCG)

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LoyalTracker: Visualizing Loyalty Dynamics

- Interactive system for analysis of massive, dynamic data
 - Visualize the changes in loyalty of **3,000,000** users
 - Discover an interesting behavior of loyal searchers who frequently perform navigational searches but with low satisfaction rates



Queries in navigational searches

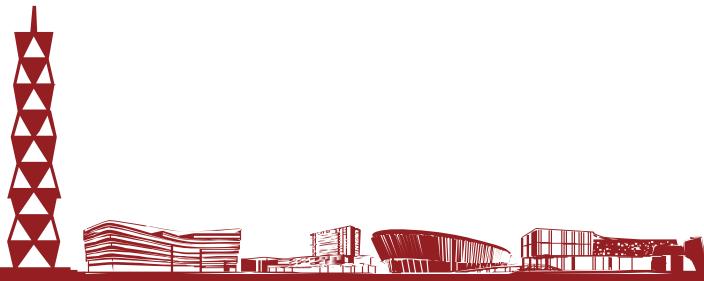
Yahoo
Twitter
Facebook
Google





Methods for Temporal Data

- Statistics methods
- Numerical computation methods
- Data mining
 - Signal decomposition
 - Pattern mining
 - Feature forecasting

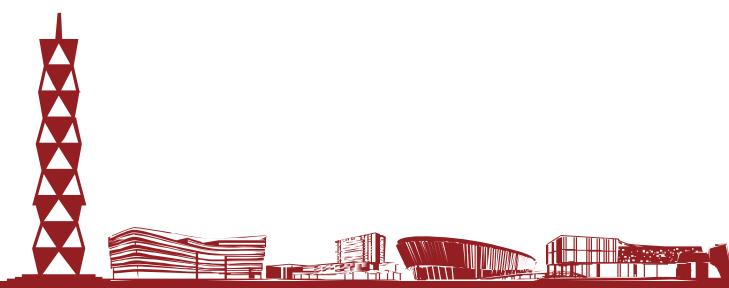




Multivariate Temporal Data Visualization

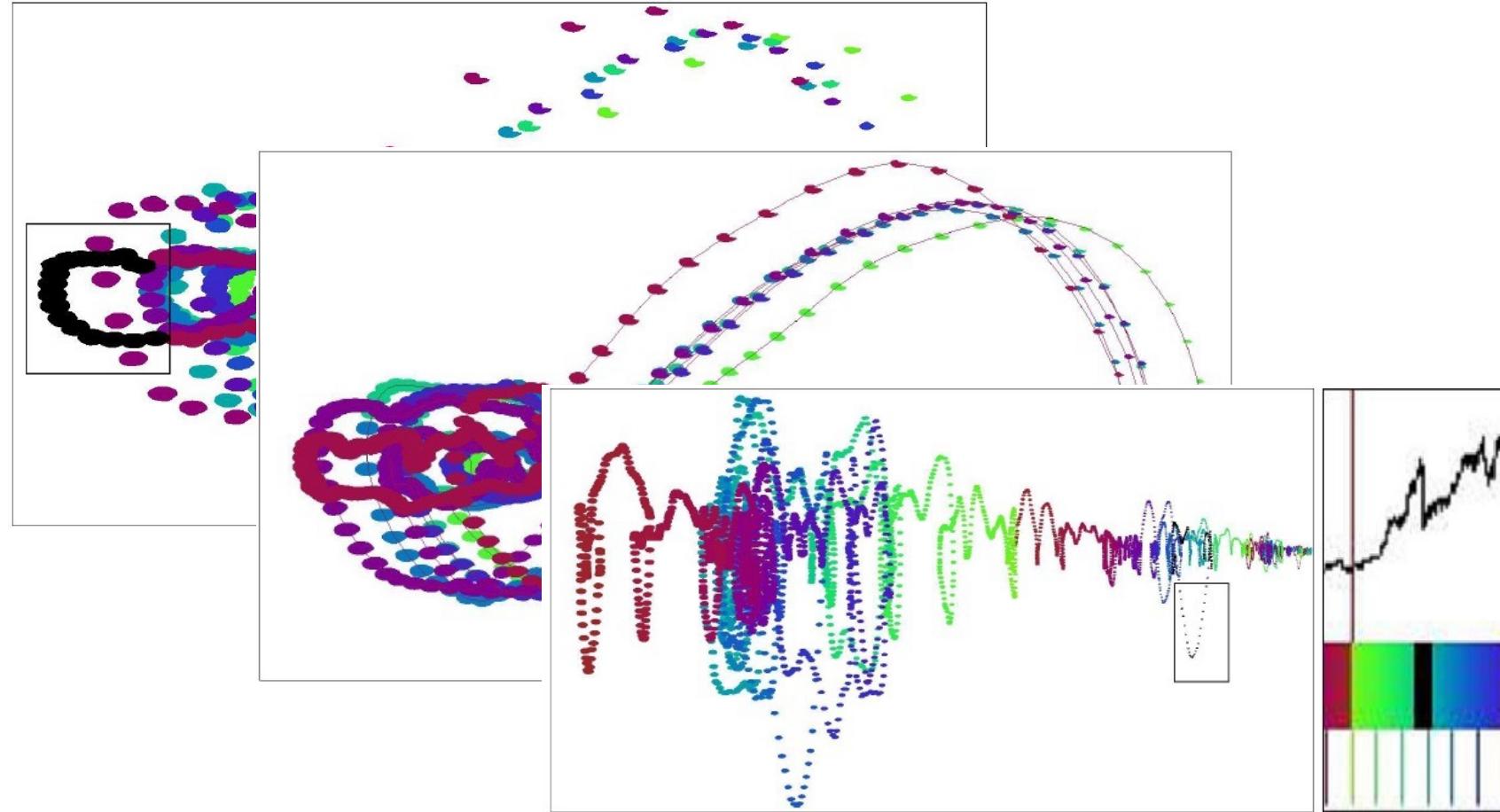


- Data Abstraction
 - Dimension reduction, feature selection
- Data Clustering
 - the kernel is to define the distance by similarity or other metrics
- Feature Analysis
 - Feature extraction, semantic analysis
 - Event: event definition, event extraction, semantic analysis based on events



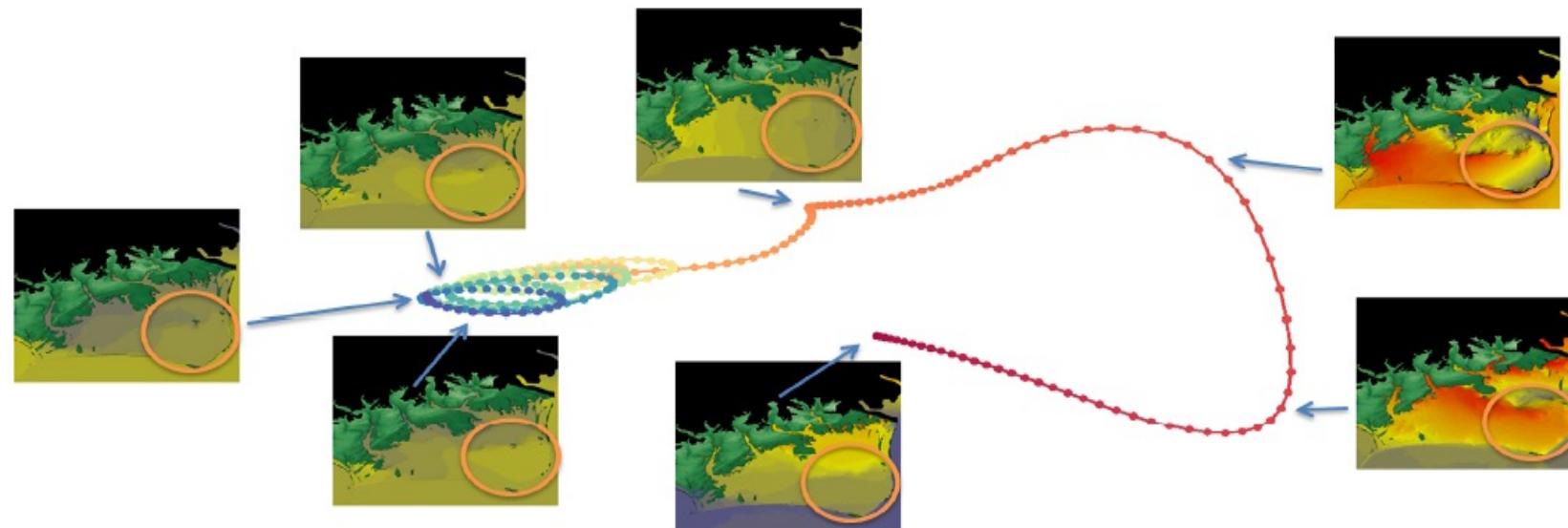
Line-based Representation

Line-based high dimensional projection of electrocardiogram



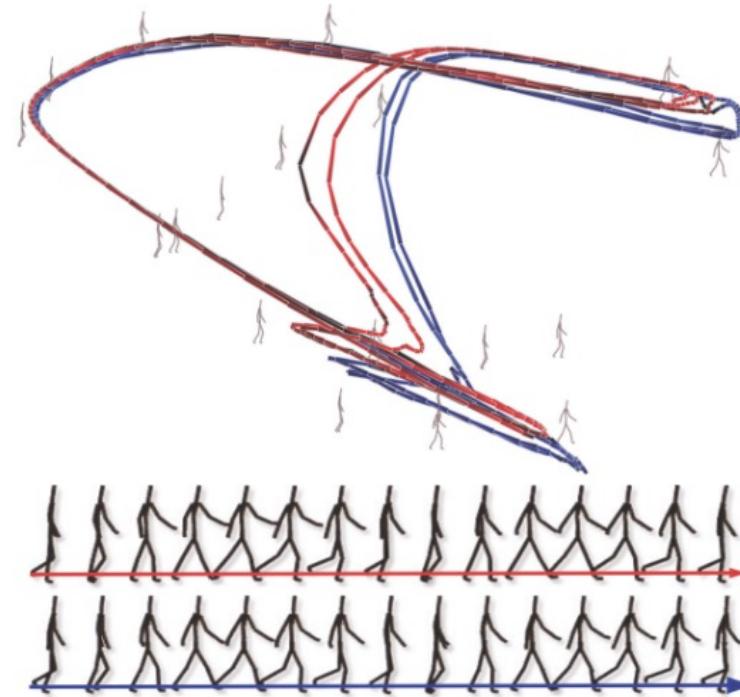
Line-based Representation

- Simulated 3D temporal hurricane volume data visualization

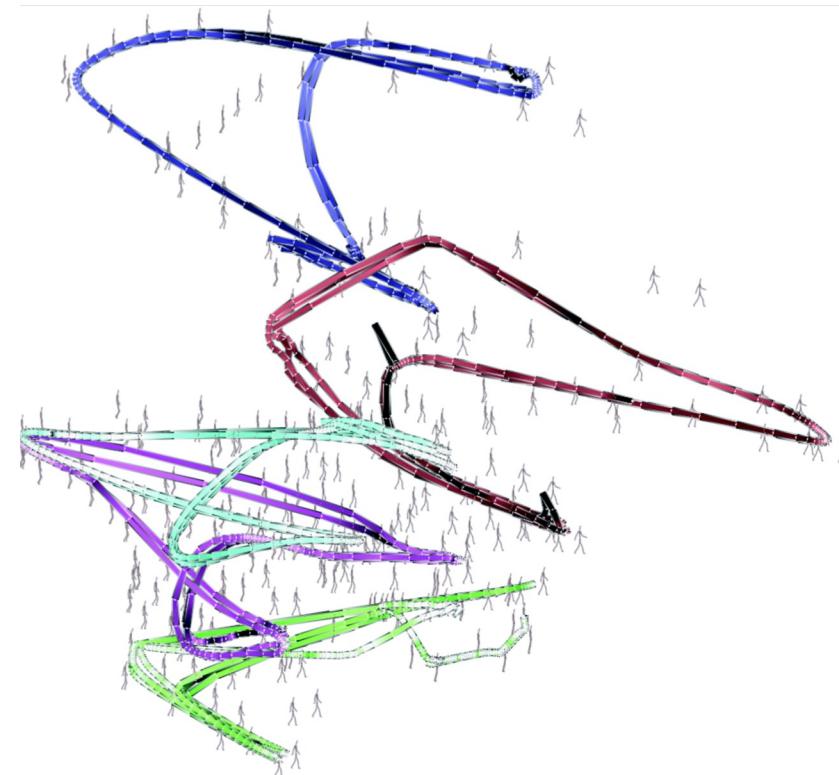


Line-based Representation

- Temporal motion capture data visualization based on high dimension projection



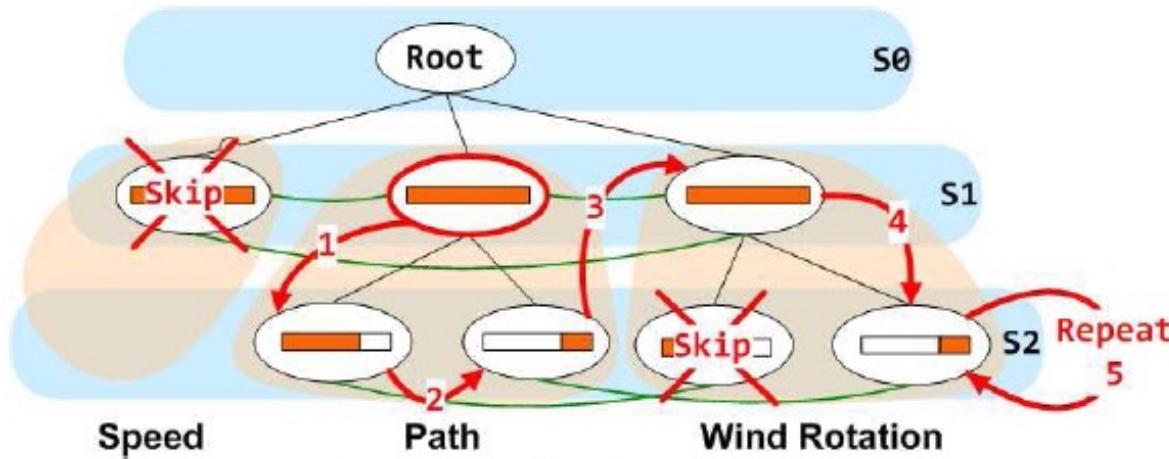
Two walking sequences of the same person



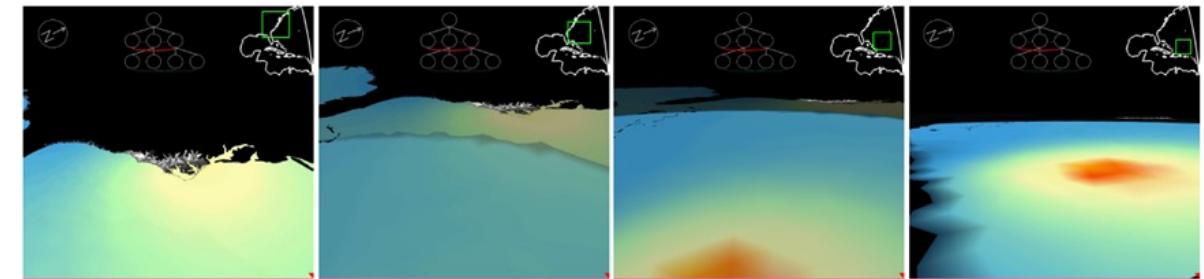
5 people walking



Tree-based Representation



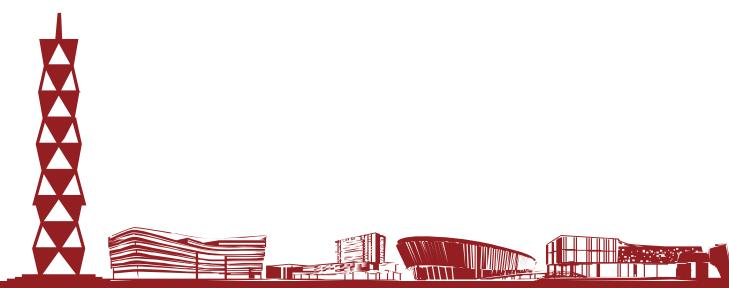
Interactive depth-first search





Line-based Representation

- Static
 - Shows history, multiple perspectives, allows comparison
- Dynamic (animation)
 - Gives feel for process & changes over time, has more space to work with



- Code visualization tool—Code Swarm



http://www.michaelogawa.com/code_swarm/



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American Unemployment from 2007 to 2009



上海科技大学
ShanghaiTech University

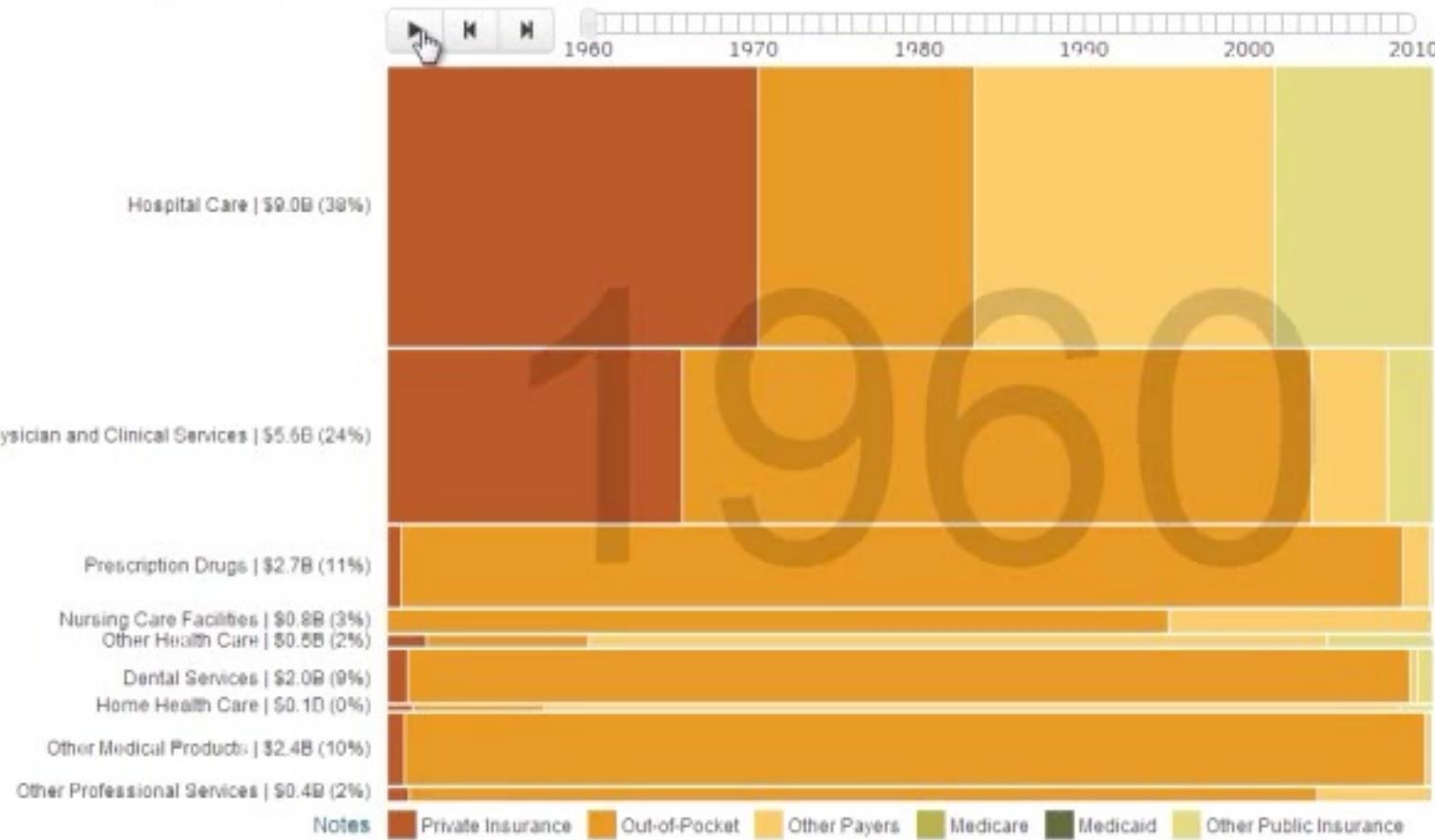


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US Health Care Spending

US Health Care Spending 1960-2010: Who Pays?

Total 1960 Spending: \$23.4B

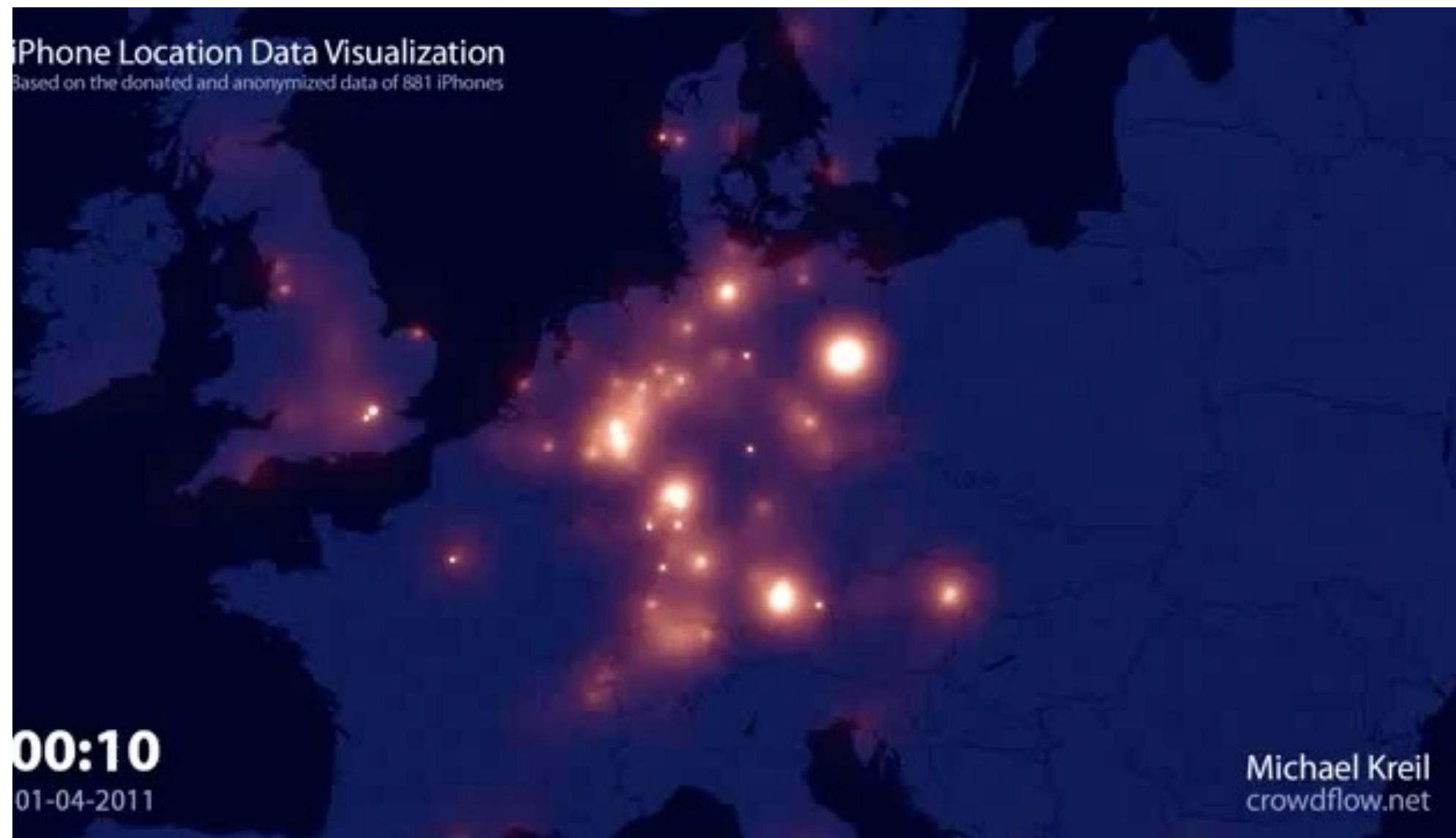


<http://www.chcf.org/publications/2012/08/data-viz-hcc-national>

Fireflies – Visualization of iPhone GPS data



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Trace the Thief



上海科技大学
ShanghaiTech University



<http://vimeo.com/26600798>



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OUTLINE

- Temporal Data Visualization
- Temporal Spatial Data Visualization
- Streaming Data Visualization
- Design Principles



Temporal Spatial Data

- Temporal spatial data contains both time variable and location variable
- Usually represent with animation or 3D display





Nike+ Runs New York City



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1

AM

1,000 Nike+ Runs
New York City
Sep 7th - Dec 21st, 2010



天

LA Traffic Radio



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<http://www.youtube.com/watch?v=72-blGAuh6s>



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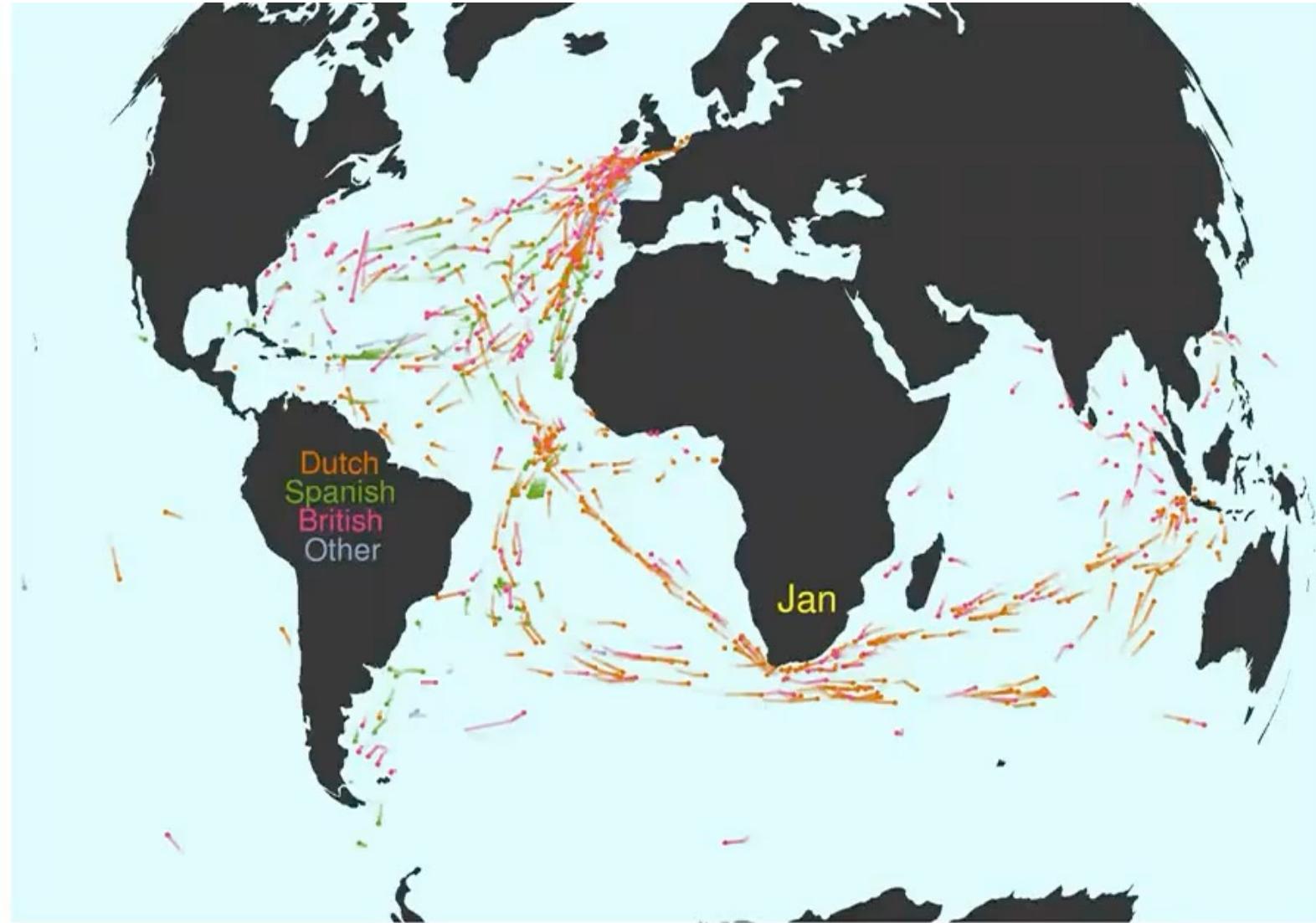
Growth of Walmart



<http://projects.flowingdata.com/walmart/>



Global Ocean Shipping History



<http://sappingattention.blogspot.com/2012/04/visualizing-ocean-shipping.html>

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OUTLINE

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Streaming Data

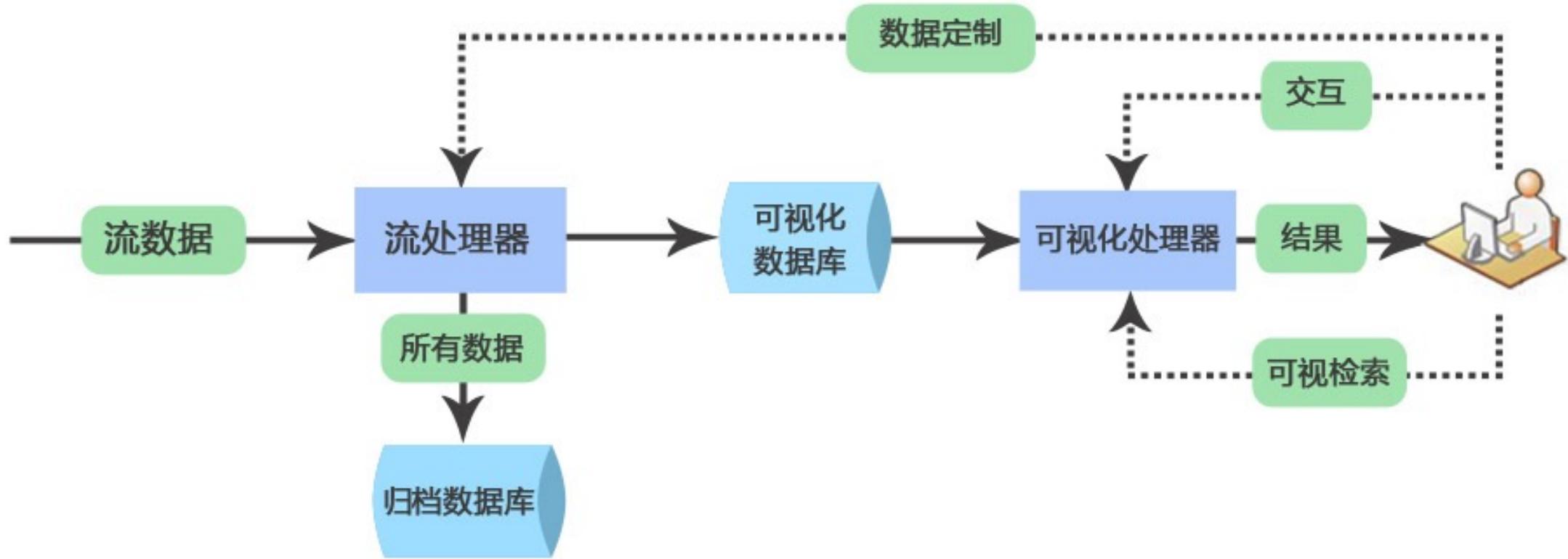
- Streaming data do not arrive together, but instead they are transmitted successively
 - Mobile log
 - Network data package
 - High performance cluster log
 - Sensor log
 - Financial market data(stock data)
 - Social network data



Properties of Streaming Data

- Unlimited in data volume
- Uncontrollable with volume or order of the coming data
- Online analytical processing (OLAP) is needed
- There exists data error and data loss



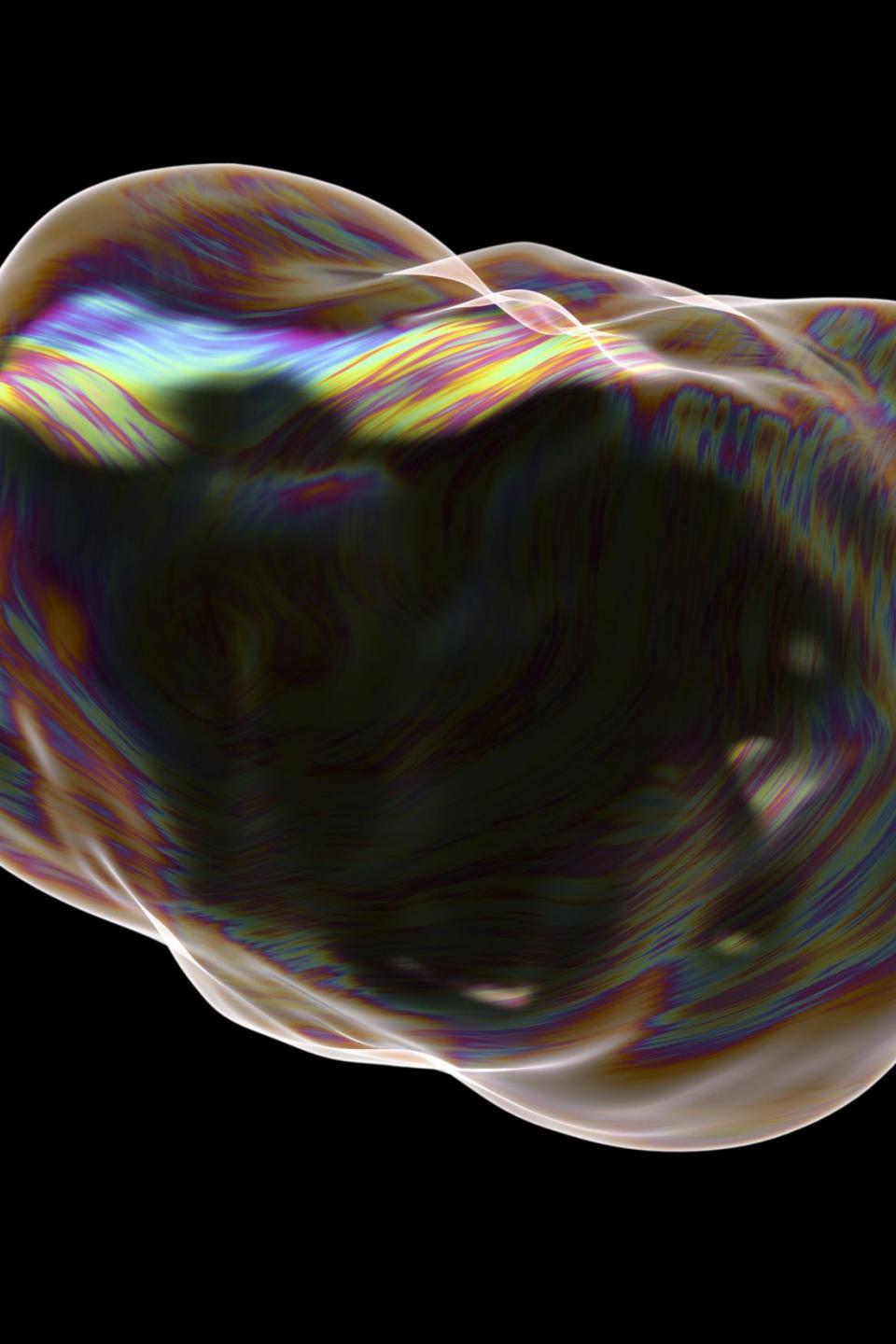


Visualization Process of Streaming Data

Streaming Data Mining

Similarity of temporal data

Symbolic representation



Similarity of Temporal Data

- Basis of temporal data clustering, classification, query, projection or anomaly detection...
 - Shape-based similarity
 - Feature-based similarity
 - Model-based similarity
 - Compression-based similarity

Why Dynamic Time Warping (DTW)?

- Similarity of
 - Sequence A: 1,1,1,10,2,3
 - Sequence B: 1,1,1,2,10,3
- Their Euclidean distance = 16
- But they look almost the same...
- We need a better metric method!

The image shows a chalkboard with several mathematical derivations and a graph.

Derivatives:

- $f'(x) = \lim_{h \rightarrow 0} \frac{f(x+h) - f(x)}{h}$
- $f'(x) = \lim_{h \rightarrow 0} \frac{(x+h)^2 - x^2}{h}$
- $= \lim_{h \rightarrow 0} \frac{x^2 + 2xh + h^2 - x^2}{h}$
- $= \lim_{h \rightarrow 0} \frac{2xh + h^2}{h}$
- $= \lim_{h \rightarrow 0} h(2x + h)$

Graph:

A graph of a function $y = g(x)$ is shown. The graph features a tangent line at point x and a secant line passing through points x and $x+h$. The vertical axis is labeled y and the horizontal axis is labeled x .

Dynamic Time Warping

- Main Idea
- The optimal path is the shortest path from $(1,1)$ to (m, n)
- m, n is the length of sequence A and B

Dynamic Programming Procedures

- 1. Define $D(i, j)$ as the DTW distance between $t(1:i)$ and $r(1:j)$, with the mapping path from $(1, 1)$ to (i, j) .
- 2. Recursion
 - $D(i, j) = |t(i) - r(j)| + \min\{D(i-1, j), D(i-1, j-1), D(i, j-1)\}$
 - with the initial condition $D(1, 1) = |t(1) - r(1)|$
- 3. $D(m, n) = 12$

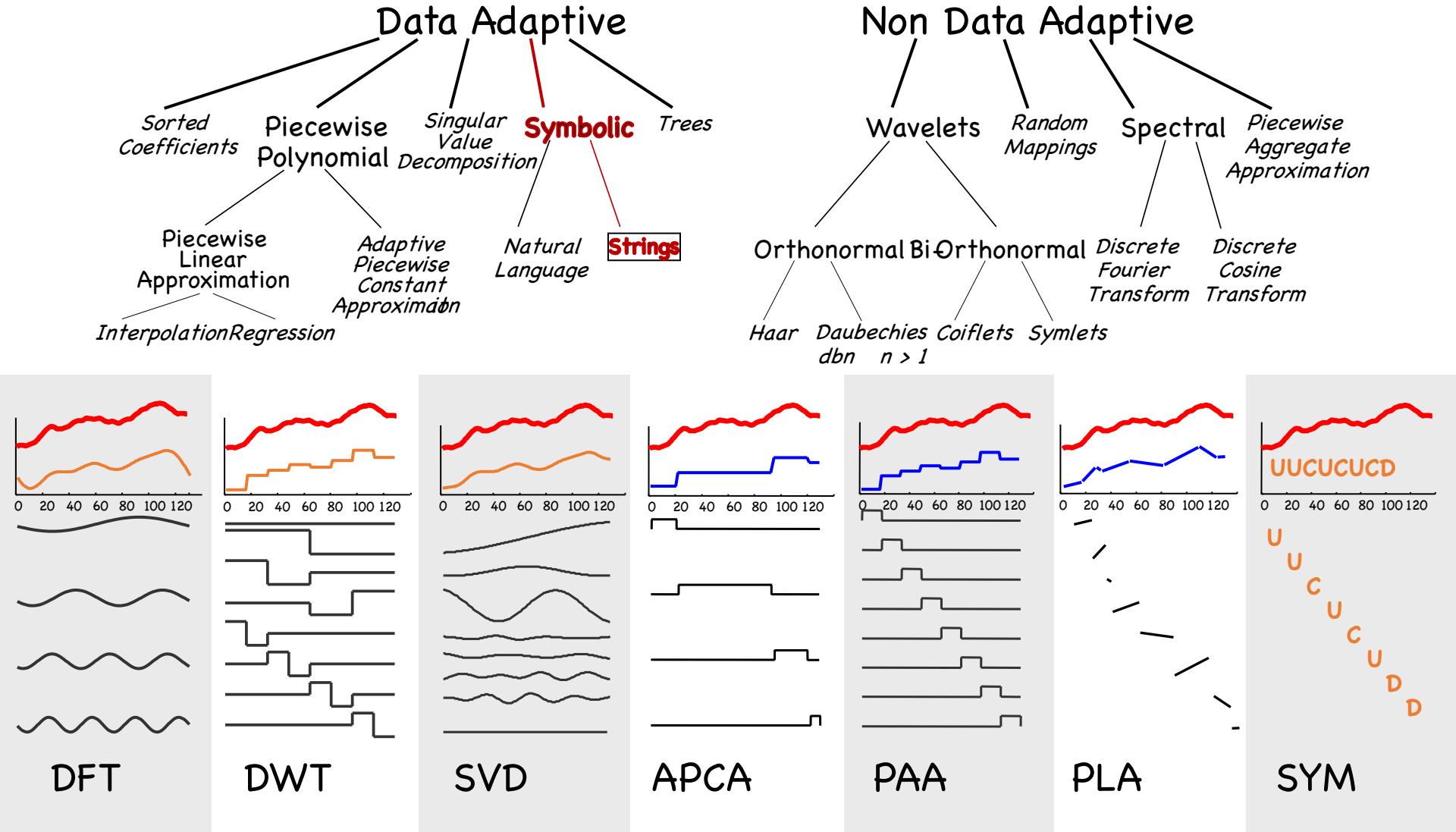
3	12	12	12	11	11	12
2	10	10	10	10	11	12
10	9	9	9	9	9	16
1	0	0	0	1	10	12
1	0	0	0	1	10	12
1	0	0	0	1	10	12
A/B	1	1	1	2	10	3

Symbolic Representation of Time Series

- Symbolic Aggregate Approximation (SAX) allows
 - Lower bounding of Euclidean distance
 - Dimensionality Reduction
 - Numerosity Reduction

From Jessica Lin and Eamonn Keogh's SAX PPT

Time Series Representations



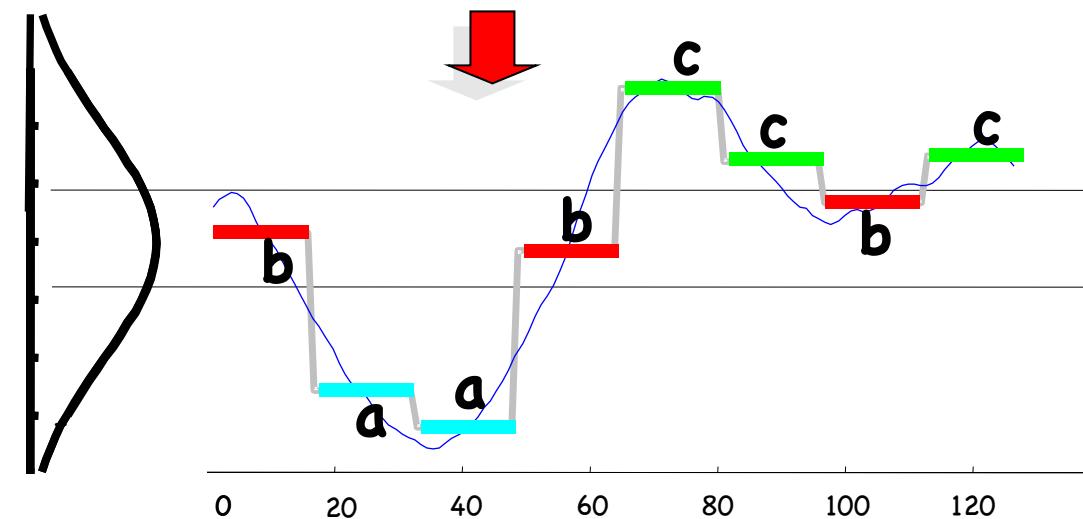
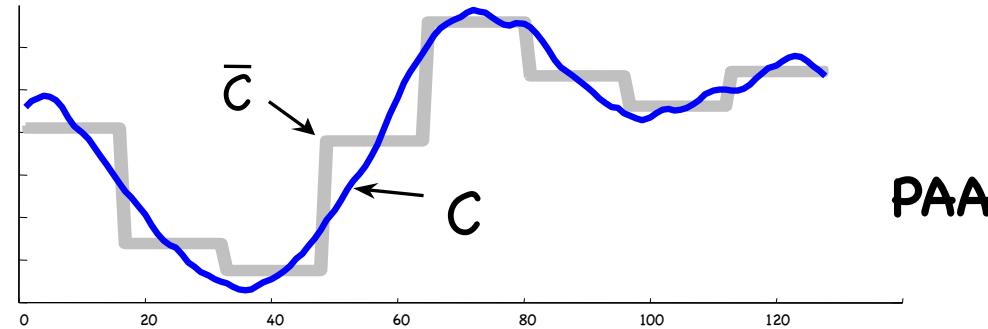
From Jessica Lin and Eamonn Keogh's SAX PPT

How do we obtain SAX?

First convert the time series to PAA representation, then convert the PAA to symbols

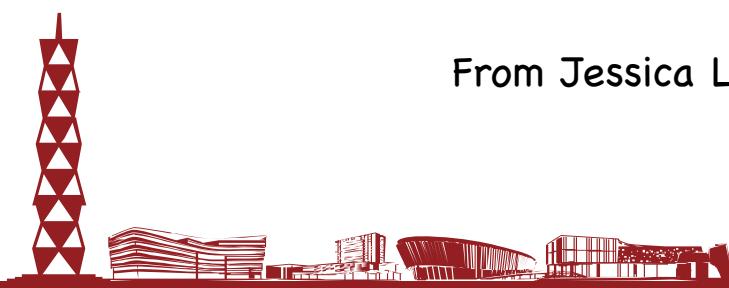
It takes linear time

Once we have done this, we can use Markov models to calculate the probability of any pattern



From Jessica Lin and Eamonn Keogh's SAX PPT

baabccbc





If $x = \text{principalskinner}$
 Σ is $\{\text{a,c,e,i,k,l,n,p,r,s}\}$
 $|x|$ is 16

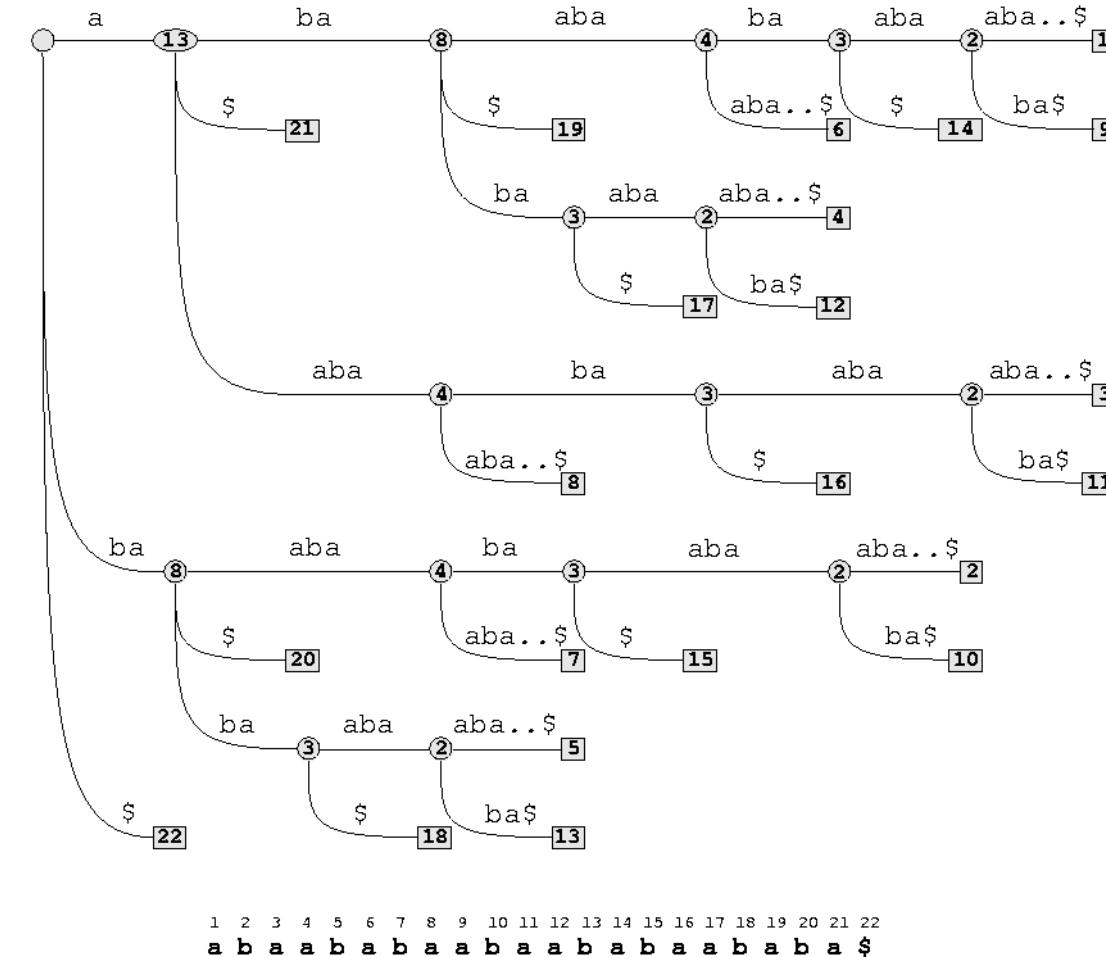
skin is a substring of x
prin is a prefix of x
ner is a suffix of x

If $y = \text{in}$, then $f_x(y) = 2$
If $y = \text{pal}$, then $f_x(y) = 1$

principalskinner

Modifications of Suffix Trees

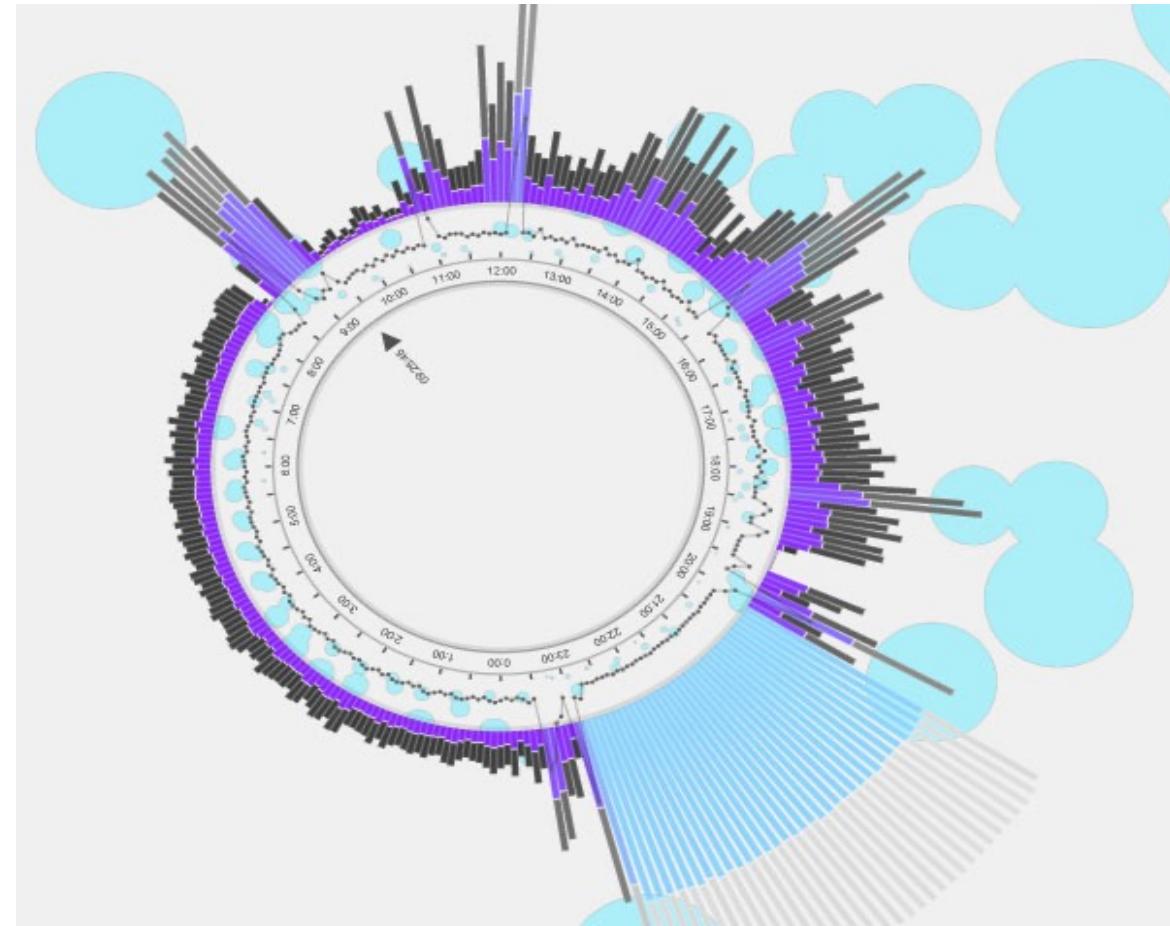
- modifications of suffix trees let us construct a tree of time series in linear space.
- An individual pattern can be tested in constant time!



From Jessica Lin and Eamonn Keogh's SAX PPT

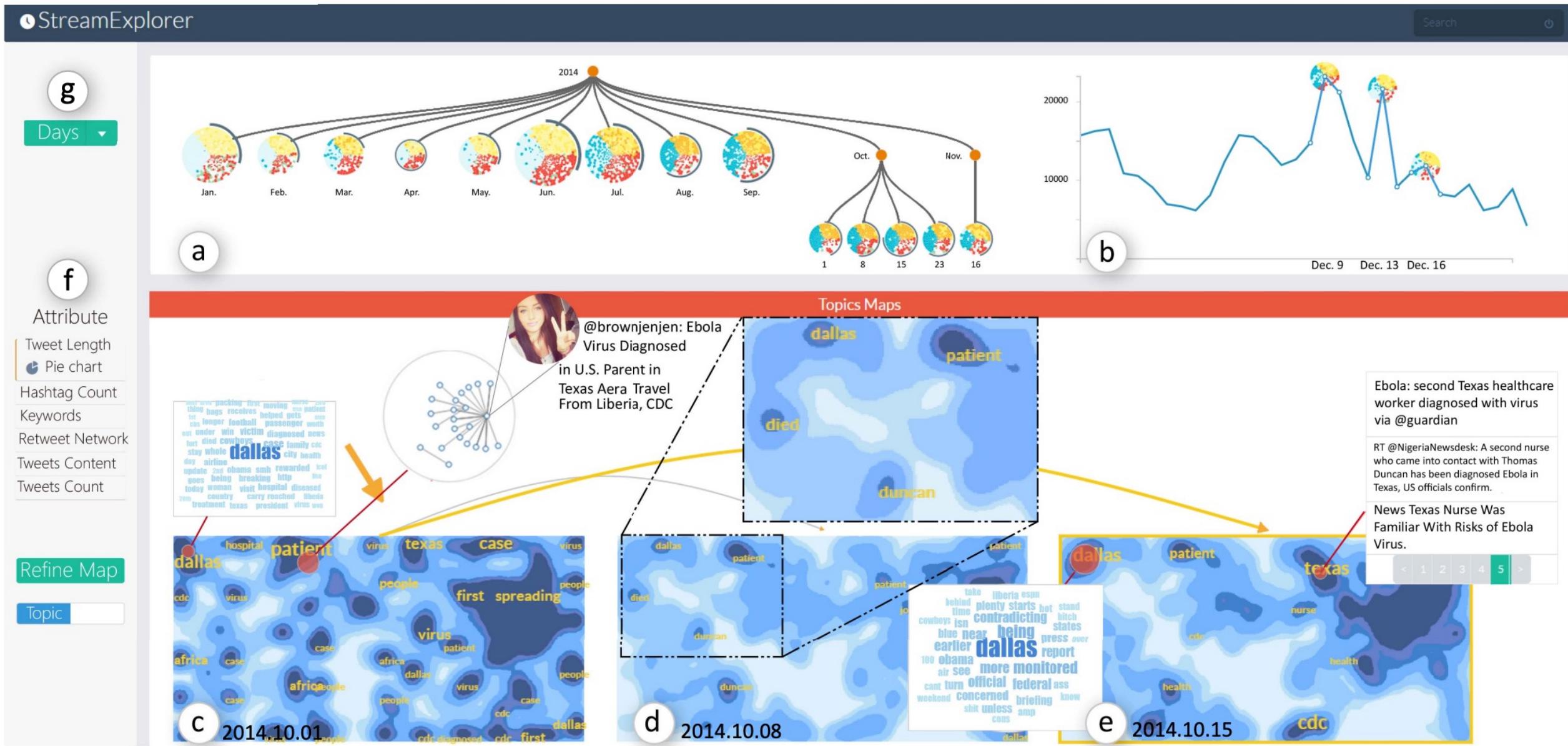
Streaming Data Visualization

- LogTool
- Online user behavior visualization tool



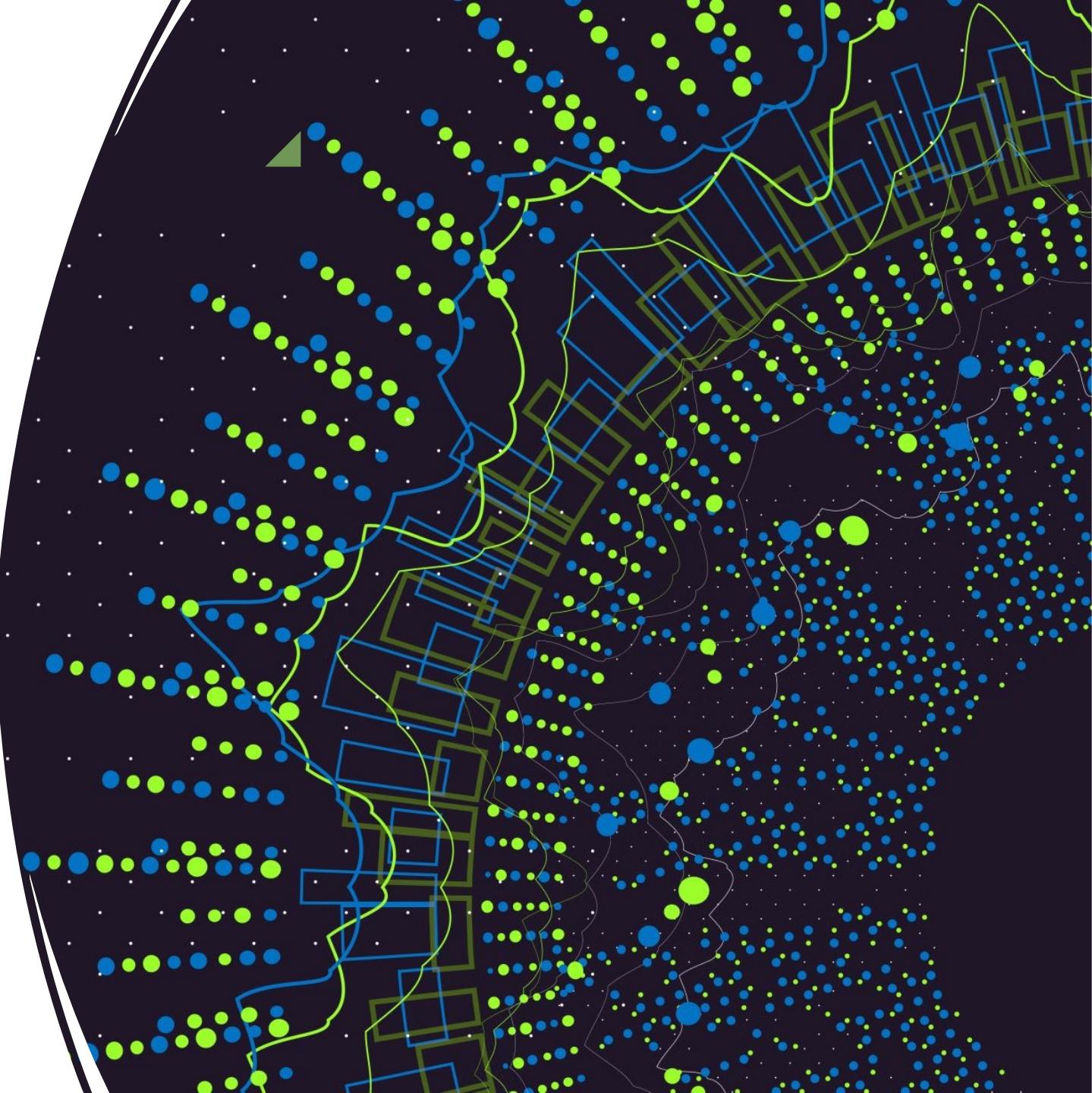
<http://onformative.com>

StreamExplorer: A Multi-Stage System for Visually Exploring Events in Social Streams



OUTLINE

- Temporal Data Visualization
- Temporal Spatial Data Visualization
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- Design Principles



Design Principles

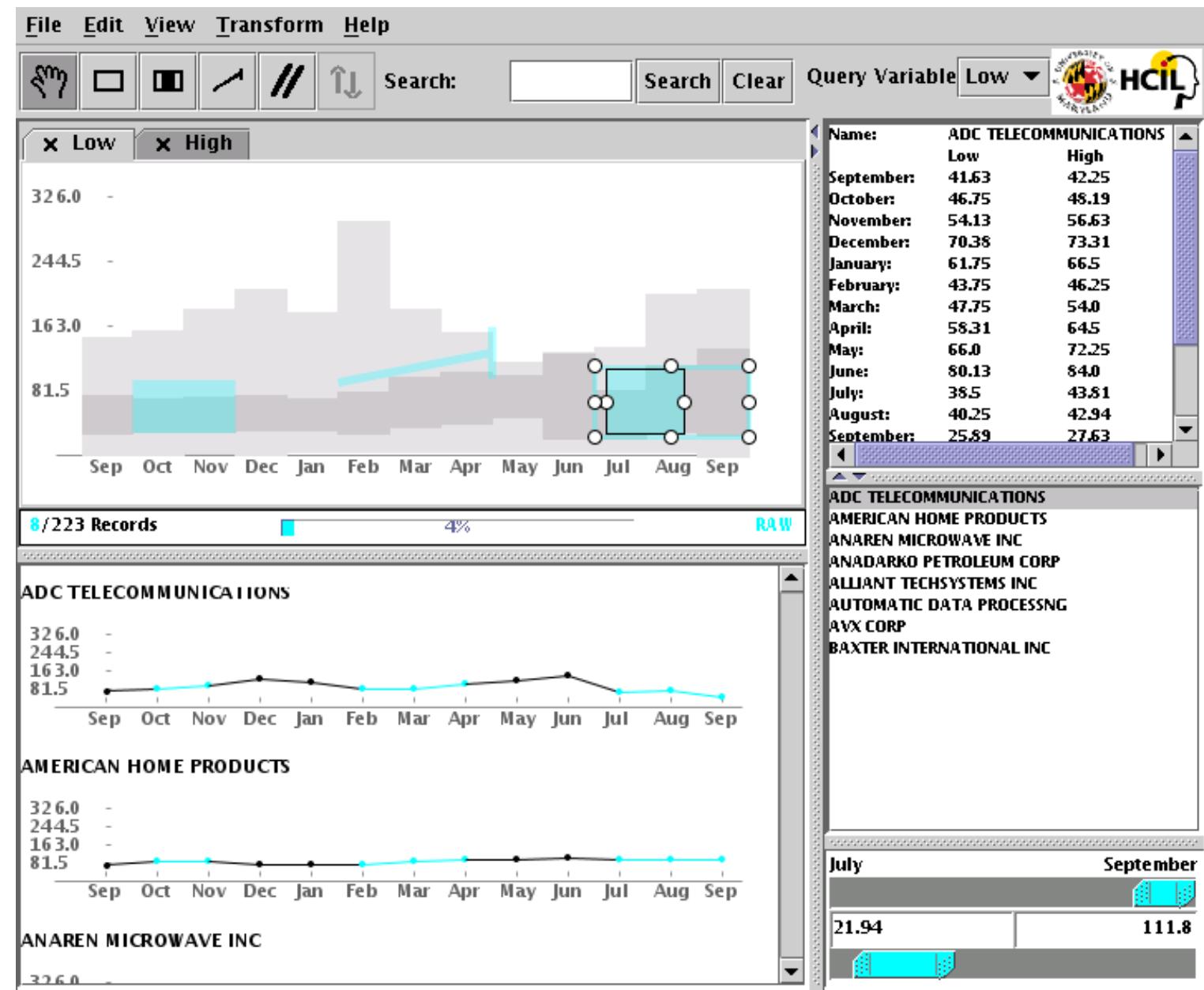
- Show familiar visual representations whenever possible
- Provide side-by-side comparisons of small multiple views
- Spatial position is the strongest visual cue
- Multiple views are more effective when coordinated through explicit linking

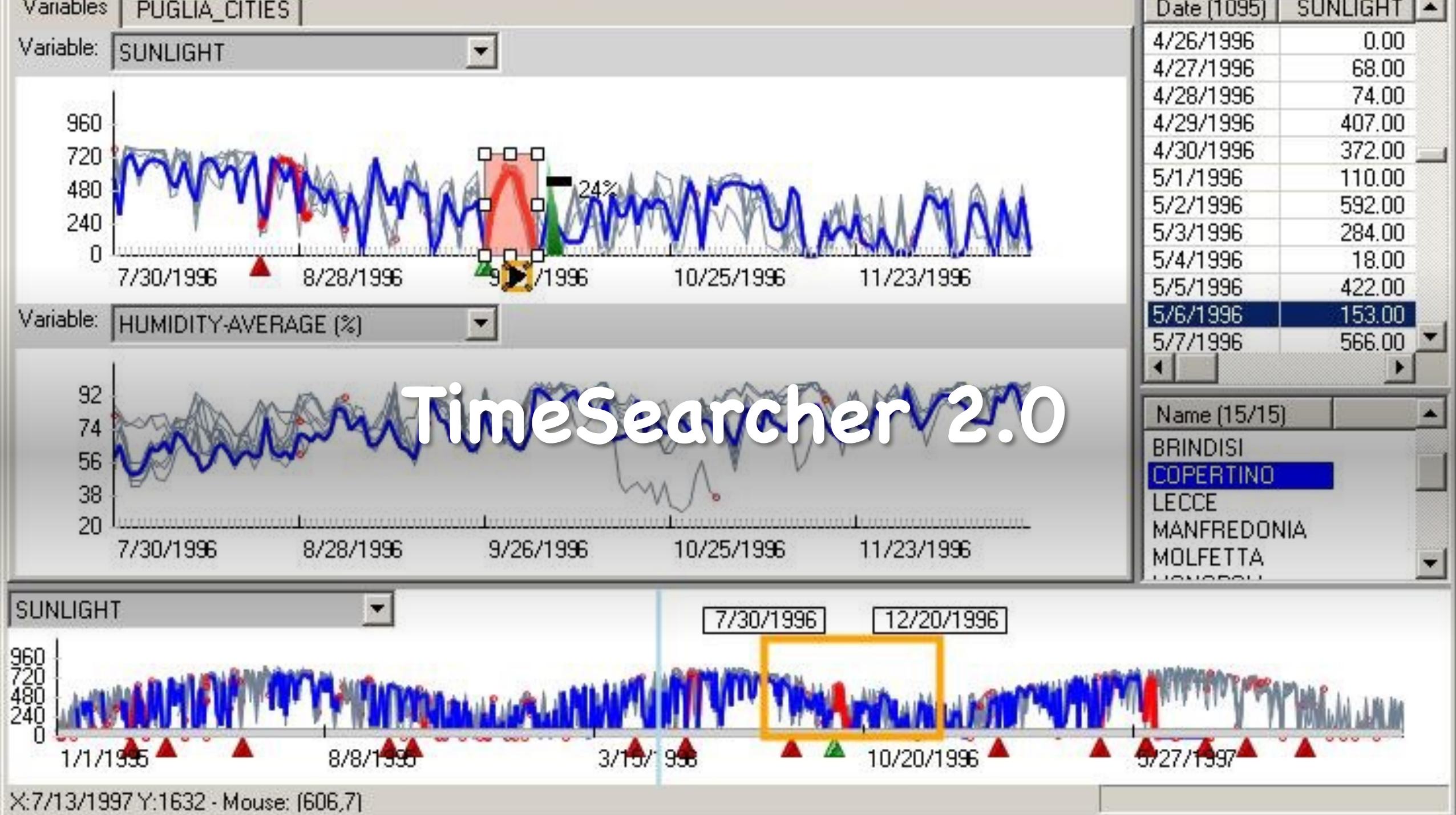


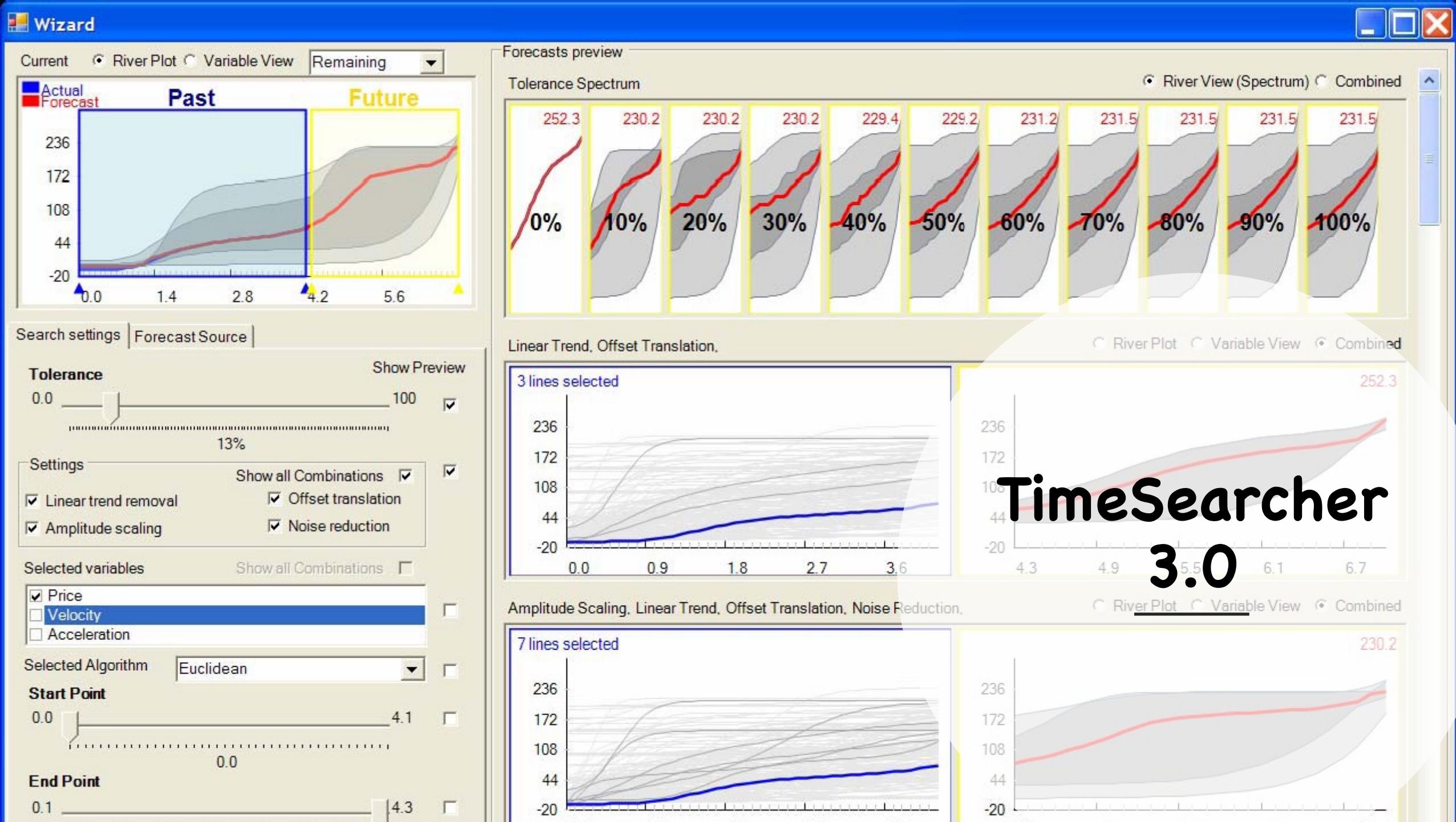
Design Principles

- Follow Shneiderman's mantra
 - Overview first, zoom and filter, detail on demand
- Avoid abrupt visual change
- User actions should receive immediate visual feedback
- Assertion: Showing several levels of detail simultaneously provides useful high information density in context

TimeSearcher 1.0









Wolfgang Aigner
Silvia Miksch
Heidrun Schumann
Christian Tominski

Visualization of Time-Oriented Data

 Springer

Recommended Book

Visualization of Time-Oriented Data

Aigner, W., Miksch, S., Schumann, H., Tominski,
C.Springer



The TimeViz Browser



上海科技大学
ShanghaiTech University

The TimeViz Browser
A Visual Survey of Visualization Techniques for Time-Oriented Data
by Christian Tominski and Wolfgang Aigner

of Techniques: 115

Search:

How to use:
Want - I want to see.
? - I'm neutral.
Hide - Don't show me.

Data

Frame of Reference

- Abstract Want Hide
- Spatial Want Hide

Number of Variables

- Univariate Want Hide
- Multivariate Want Hide

Time

Arrangement

- Linear Want Hide
- Cyclic Want Hide

Time Primitives

- Instant Want Hide
- Interval Want Hide

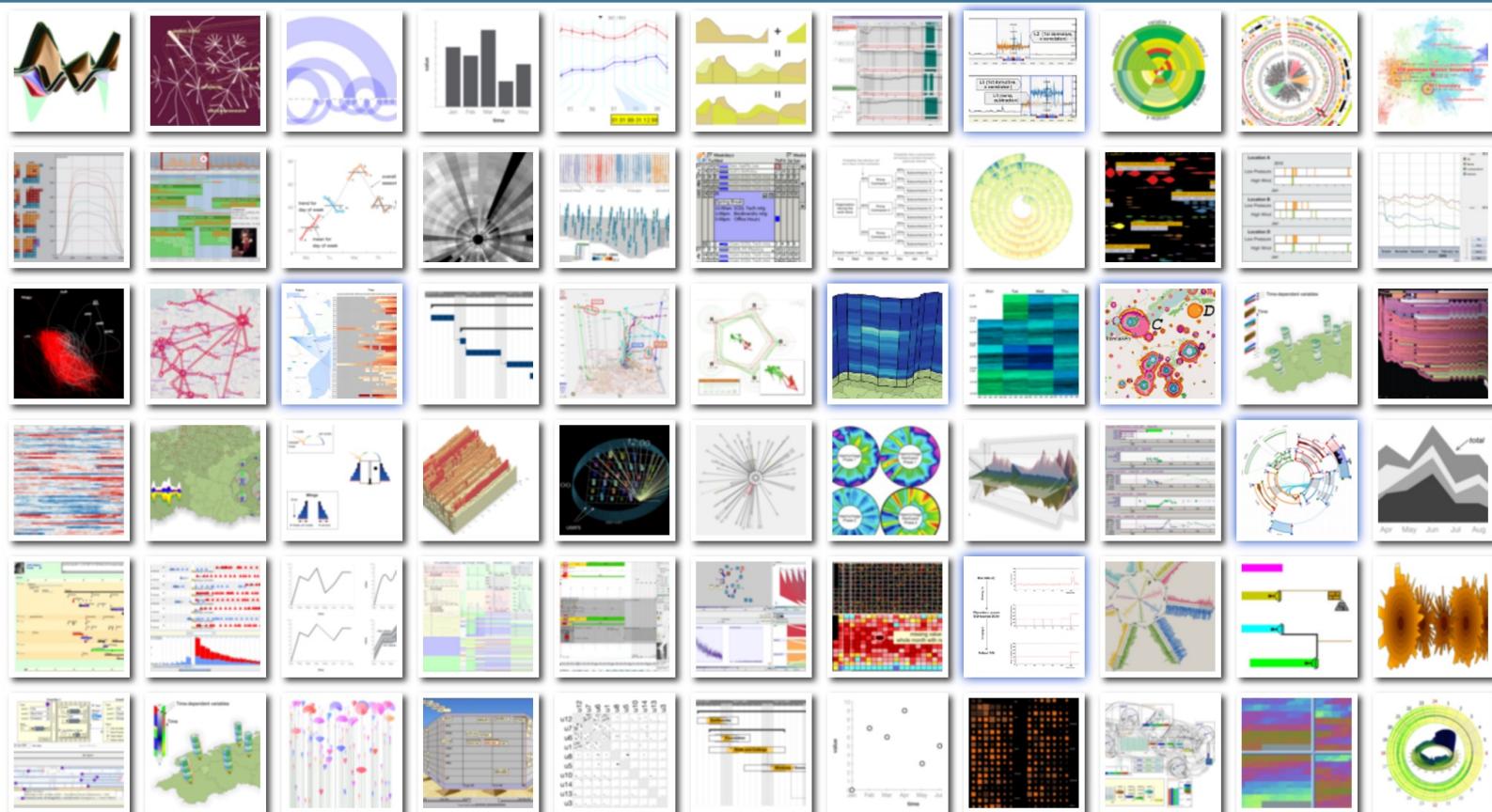
Visualization

Mapping

- Static Want Hide
- Dynamic Want Hide

Dimensionality

- 2D Want Hide



<http://survey.timeviz.net/>

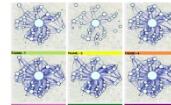


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A Review of Temporal Visualizations

Results:

1



MobilityGraphs: Visual Analysis of Mass Mobility Dynamics via Spatio-Temporal Graphs and Clustering

Tatiana von Landesberger, Felix Brodkorb, Philipp Roskosch, Natalia Andrienko, Gennady Andrienko, Andreas Kerren (2016) contributed by: spacetimecubevis.



2

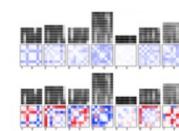


Are there networks in maps? An experimental visualization of personal movement data

Heike Otten, Lennart Hildebrandt, Till Nagel, Marian Dörk, Boris Müller (2015)



3

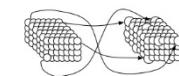


Small MultiPiles: Piling Time to Explore Temporal Patterns in Dynamic Networks

Bach, Henry Riche, Dwyer, Madhyastha, Fekete, Grabowski (2015)



4



Video Granular Synthesis

Angus Graeme Forbes, Javier Villegas (2015)



Filter:

Show all (89)

Networks (48)
Geospatial (24)
Multidimensional (4)
Video (8)
Other (4)



Point-extraction (1)



Time-drilling (10)



Space-drilling (2)



Oblique-drilling (1)



Planar-curvilinear-drilling (0)



Non-planar-drilling (3)



Time-cutting (33)



Space-cutting (9)



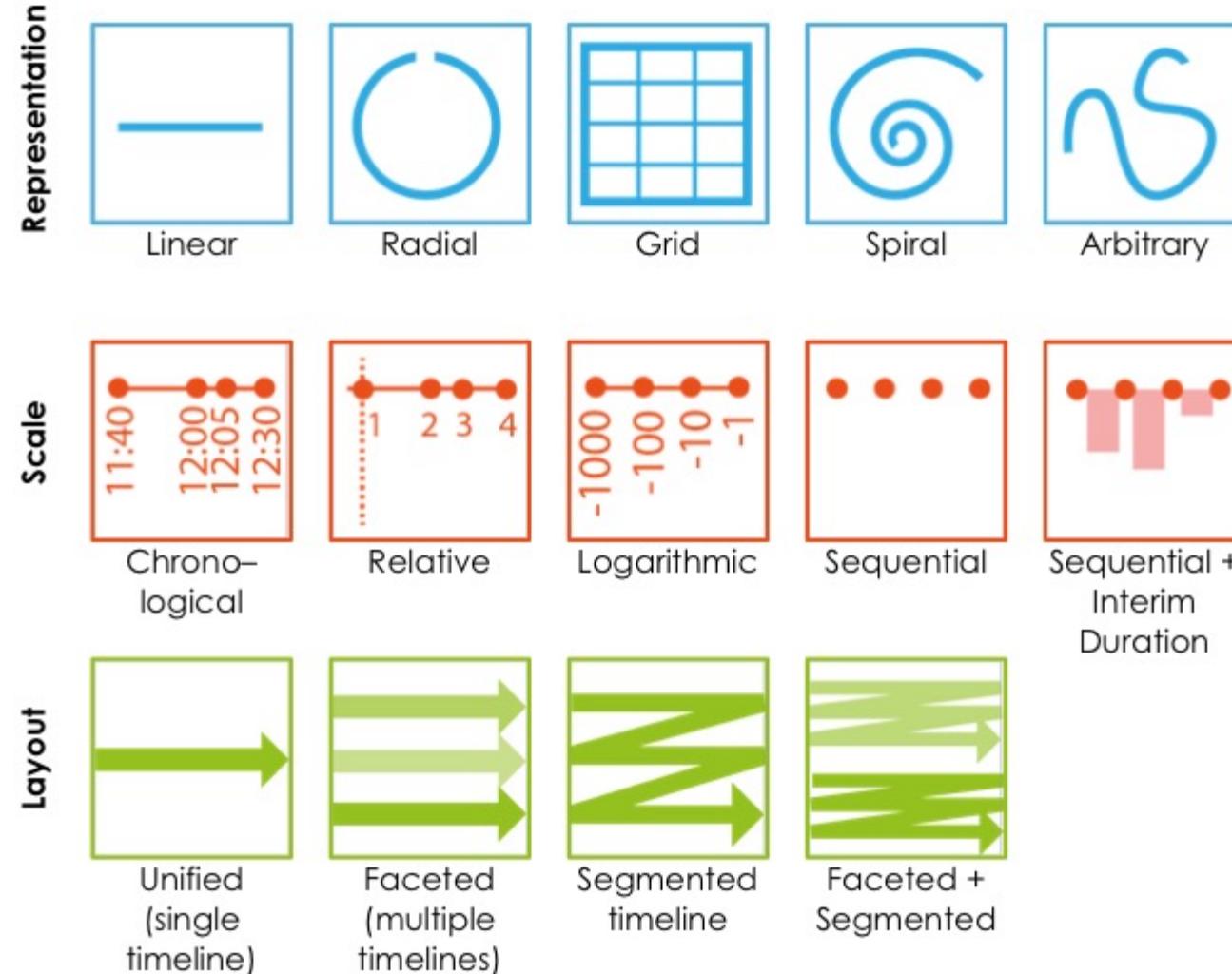
Oblique-cutting (0)



Cuvilinear-space-cutting (4)

<http://spacetimecubevis.com/>

Timelines Revisited

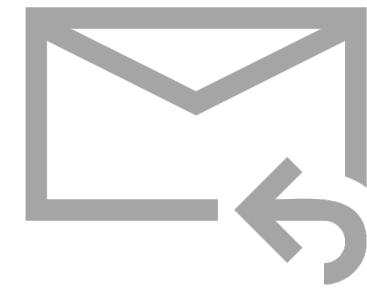


<https://timelinesrevisited.github.io/>



Quan Li

Questions?
Thank you 😊



liquan@shanghaitech.edu.cn