

Techniques

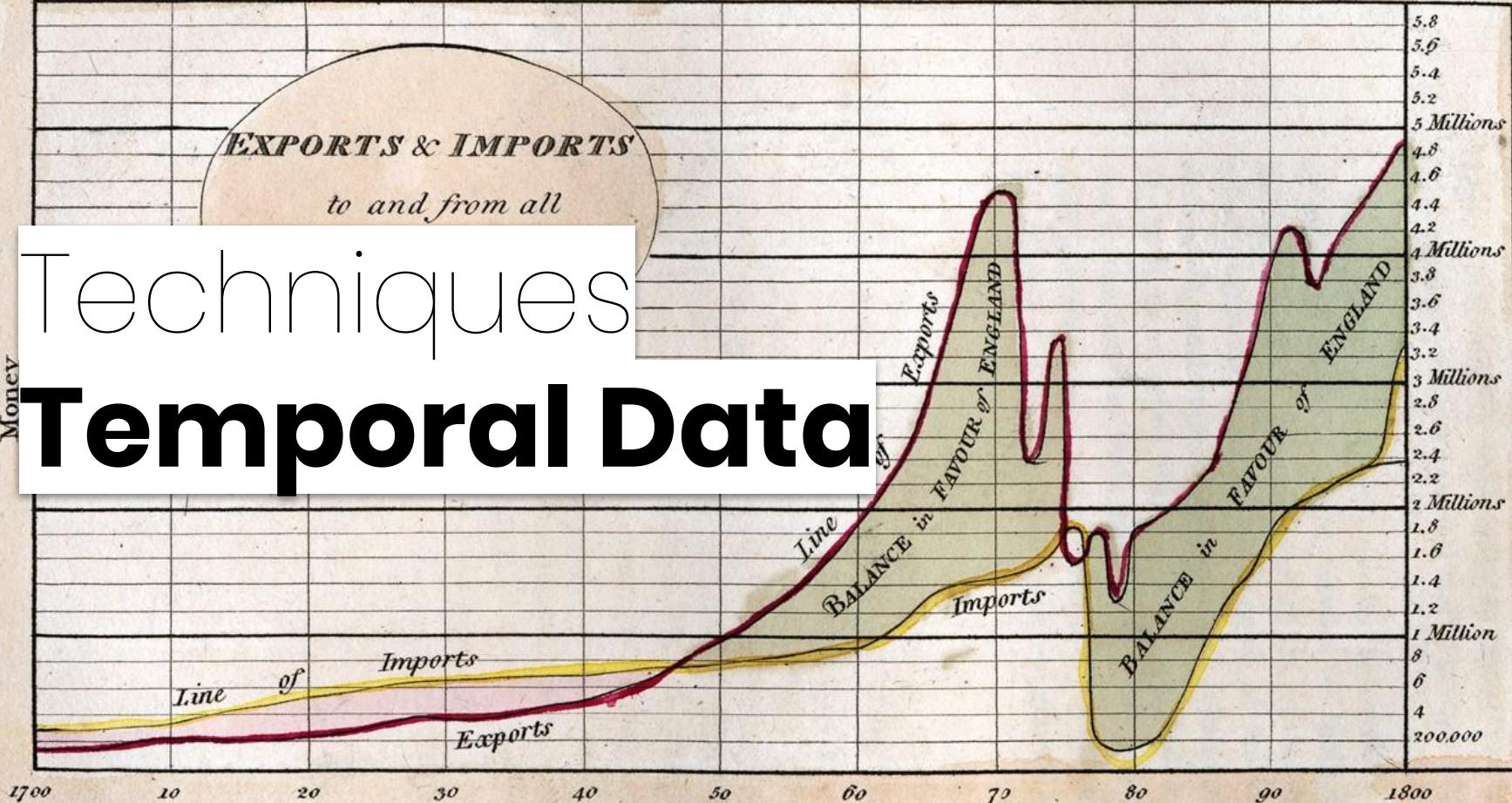
Temporal Data

EXPORTS & IMPORTS

to and from all

Time

Money



Online Course
Data Visualization
for Professionals



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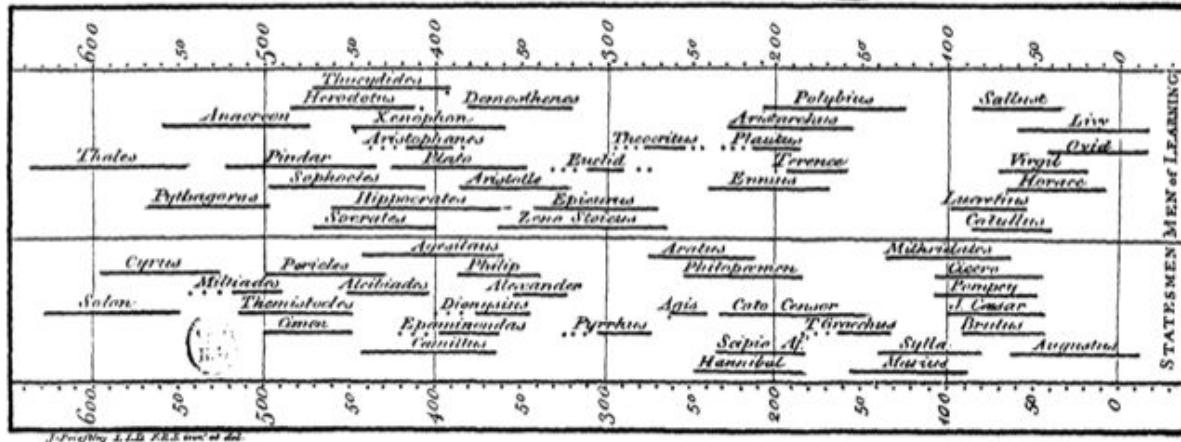
Benjamin Bach

June 2020

<http://benjbach.me>
<https://datavis-online.github.io>

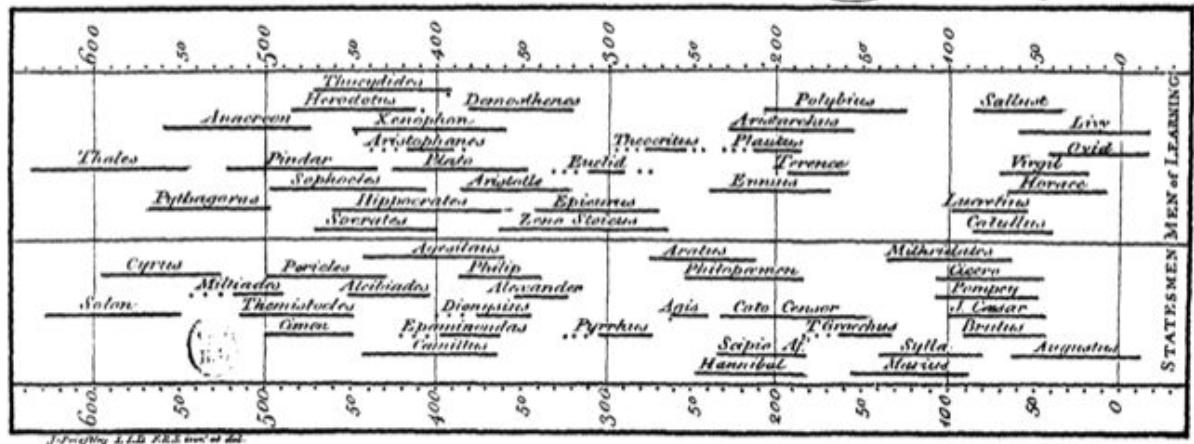
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A Specimen of a Chart of Biography.



Events

A Specimen of a Chart of Biography.

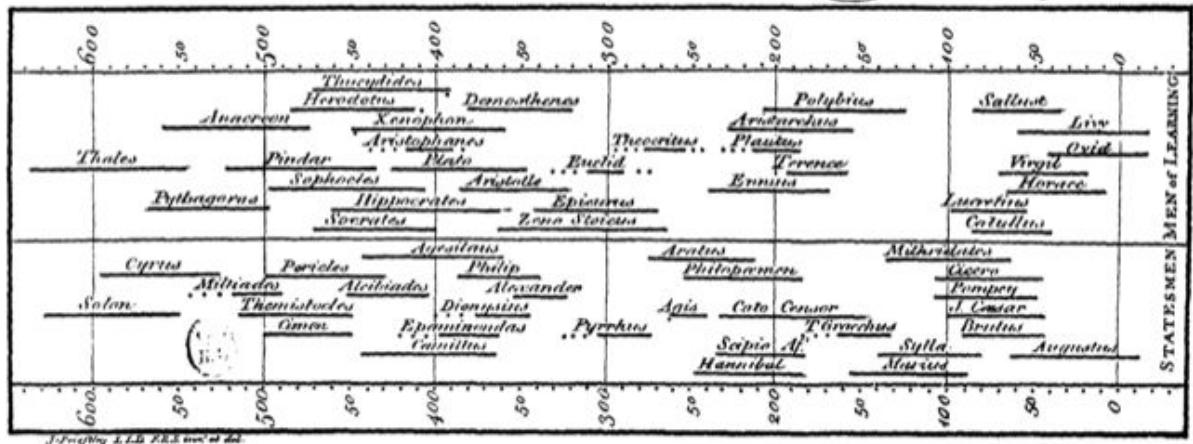


Events



Trajectories

A Specimen of a Chart of Biography.



Events



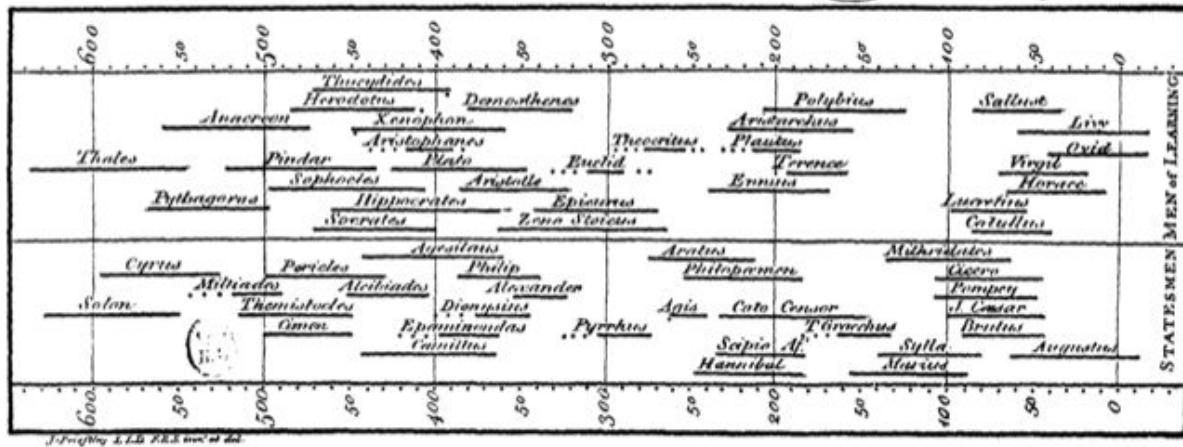
Trajectories

January						
Mo	Tu	We	Th	Fr	Sa	Su
		1	2	3	4	5
6	7	8	9	10	11	12
13	14	15	16	17	18	19
20	21	22	23	24	25	26
27	28	29	30	31		

3:● 10:○ 17:● 24:●

Calendar

A Specimen of a Chart of Biography.



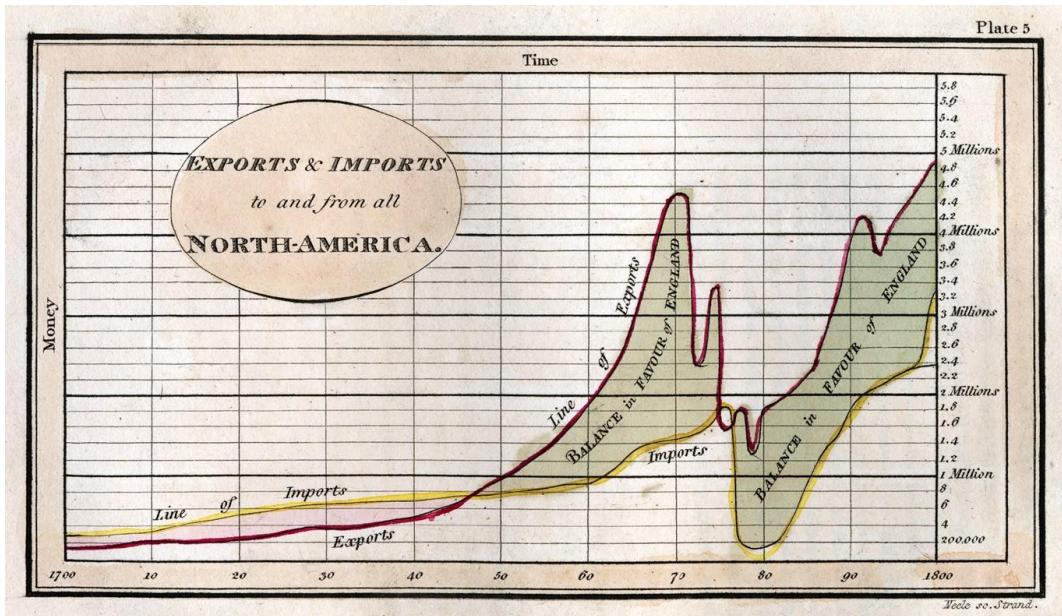
Events



Trajectories



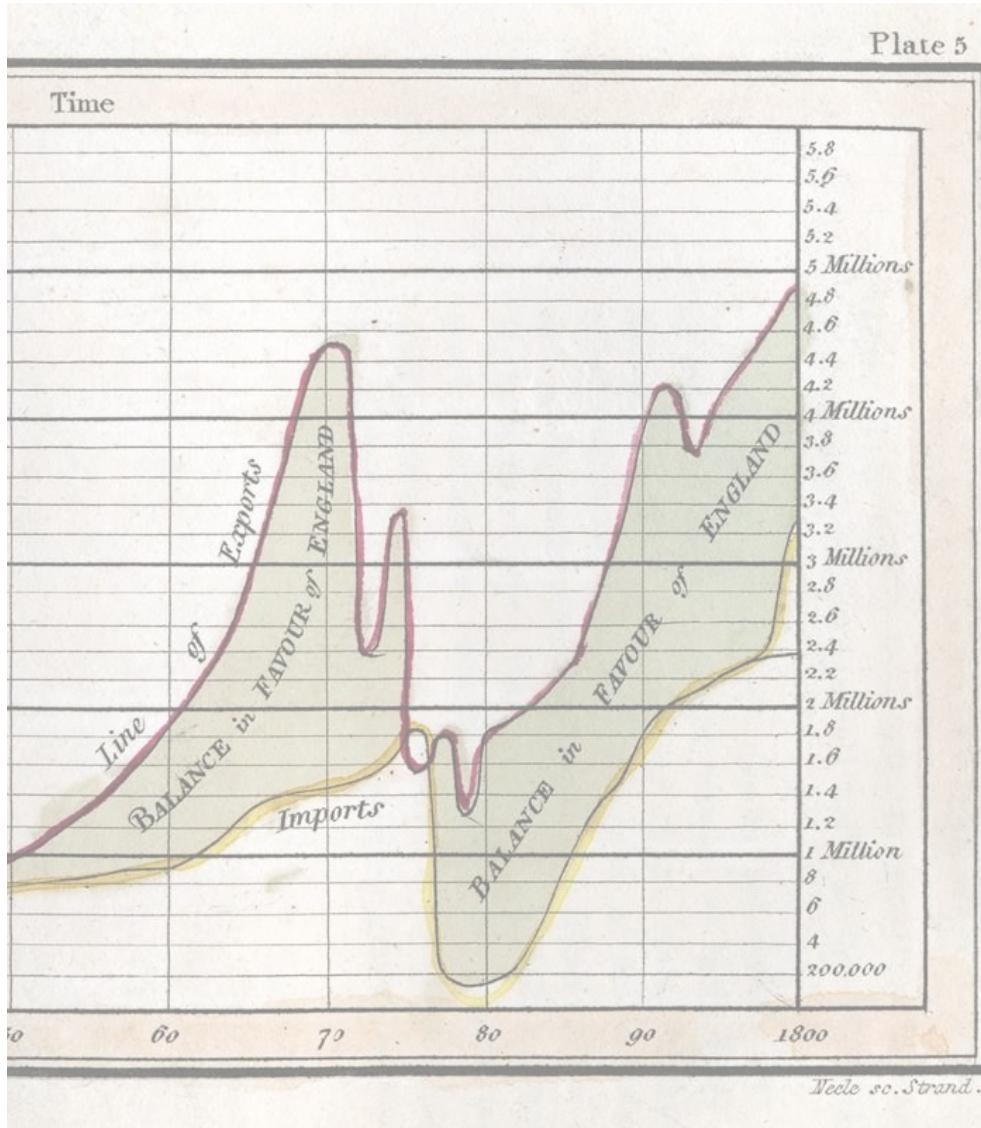
Calendar



Time series

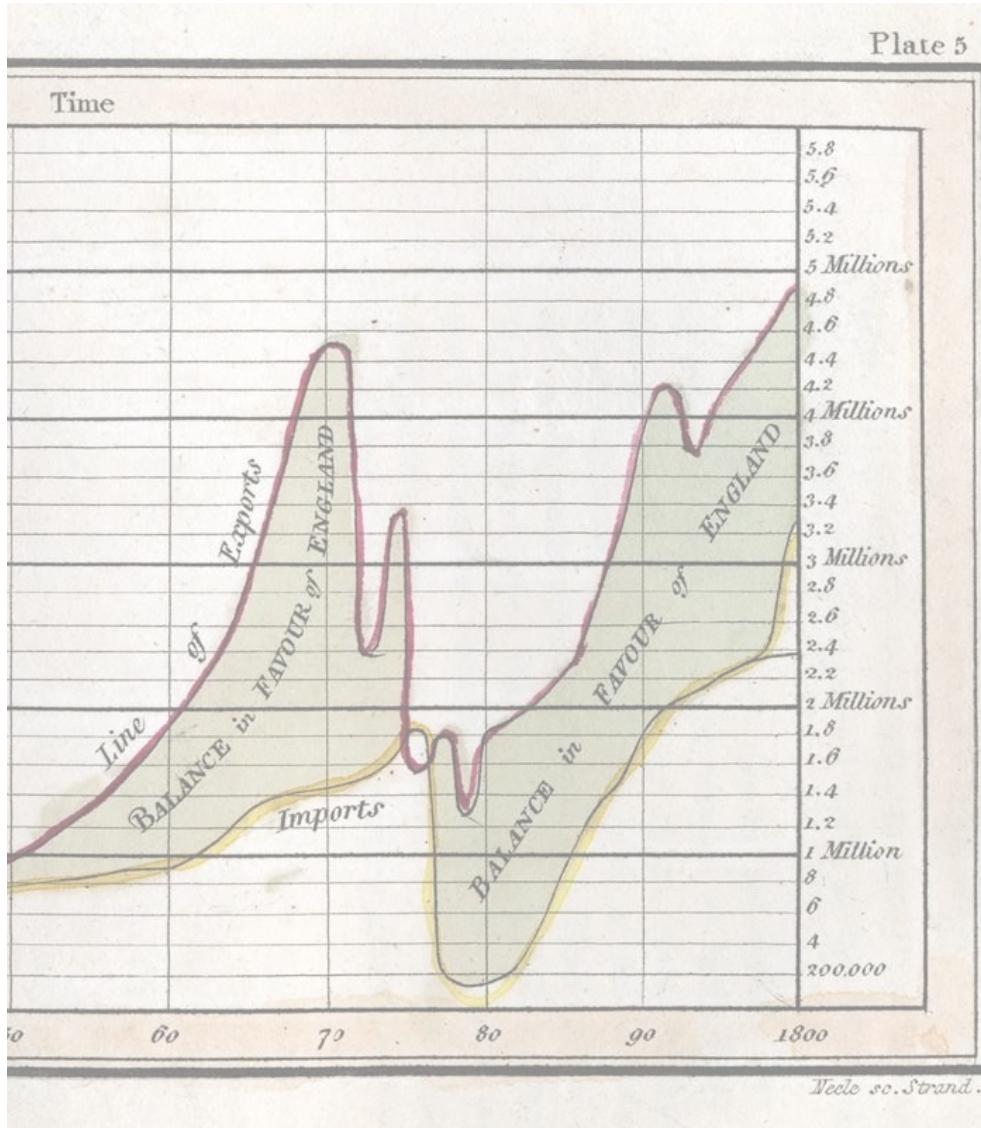
Tasks

- Min, max values, specific values
 - Trends and outliers
 - Change and rate of change
 - Sequence
 - Dynamicity / variation
 - Noise vs. signal
 - Check for specific events that may influence the data
 - Correlate and compare time series
 - Space + time



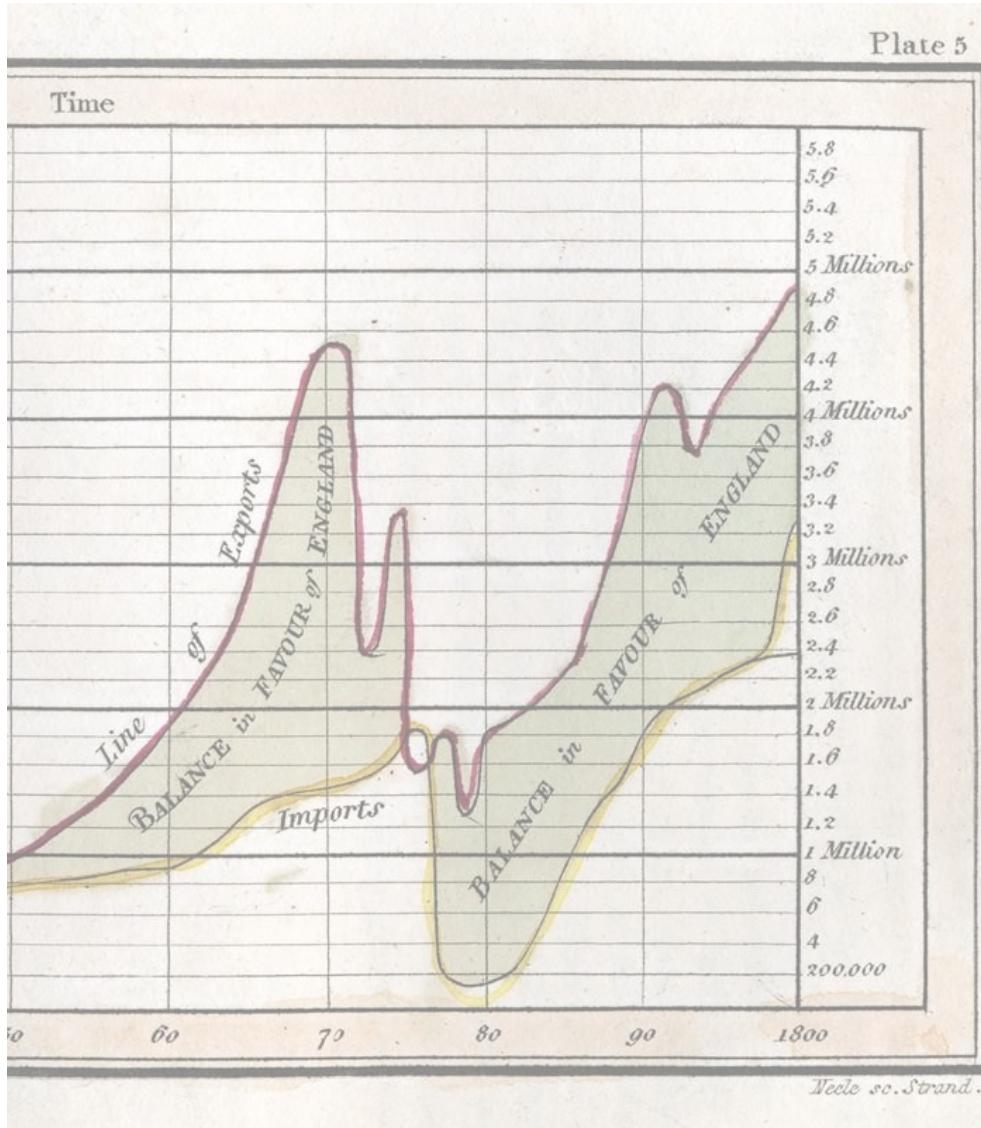
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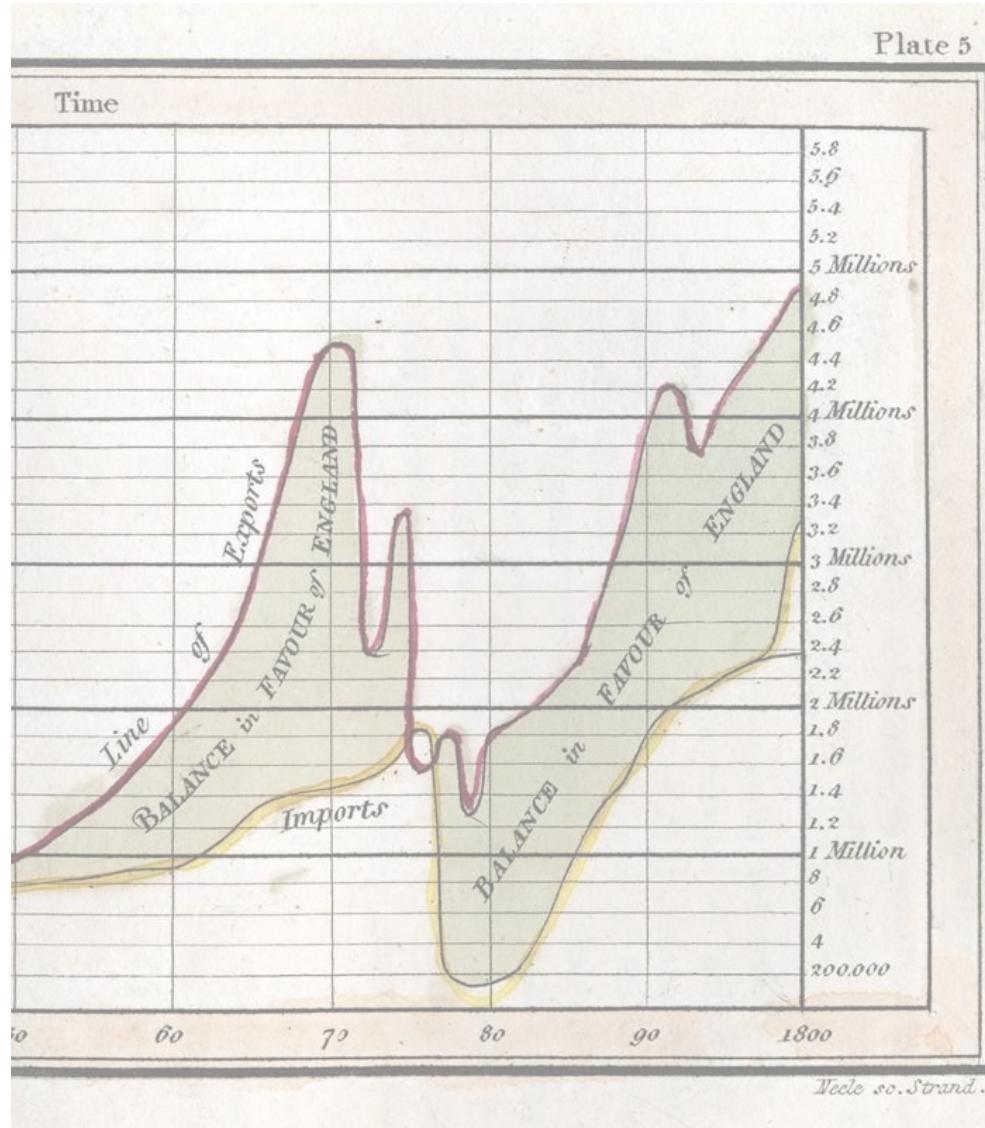
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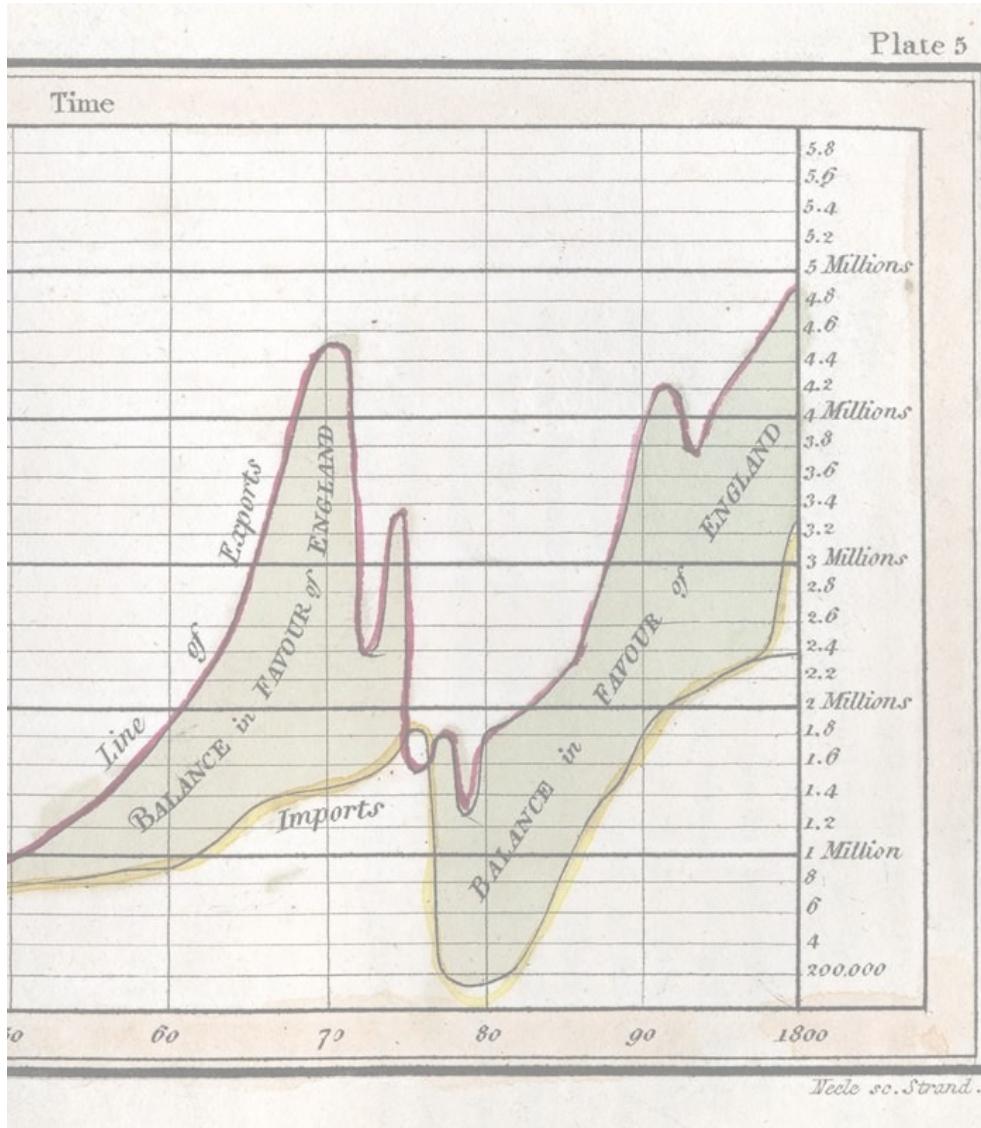
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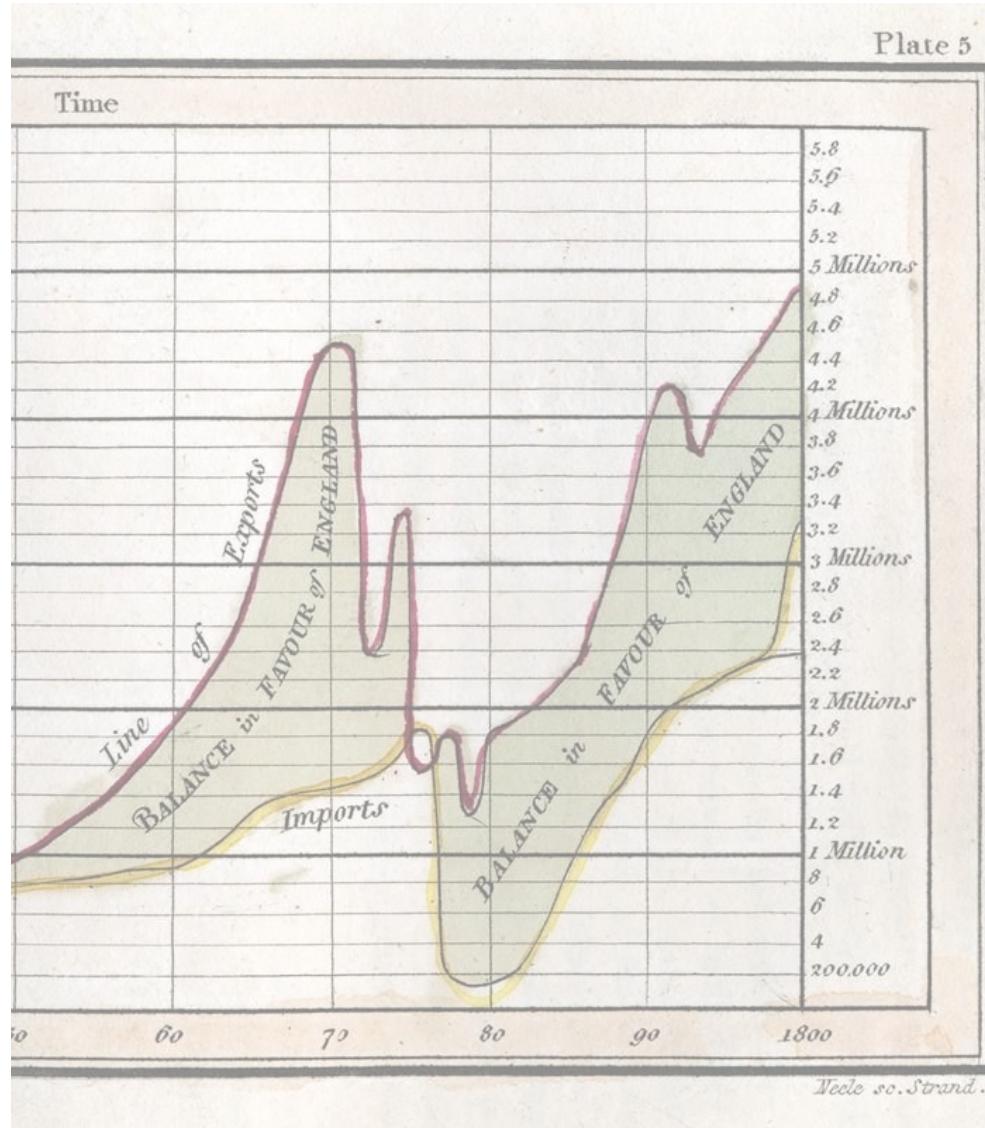
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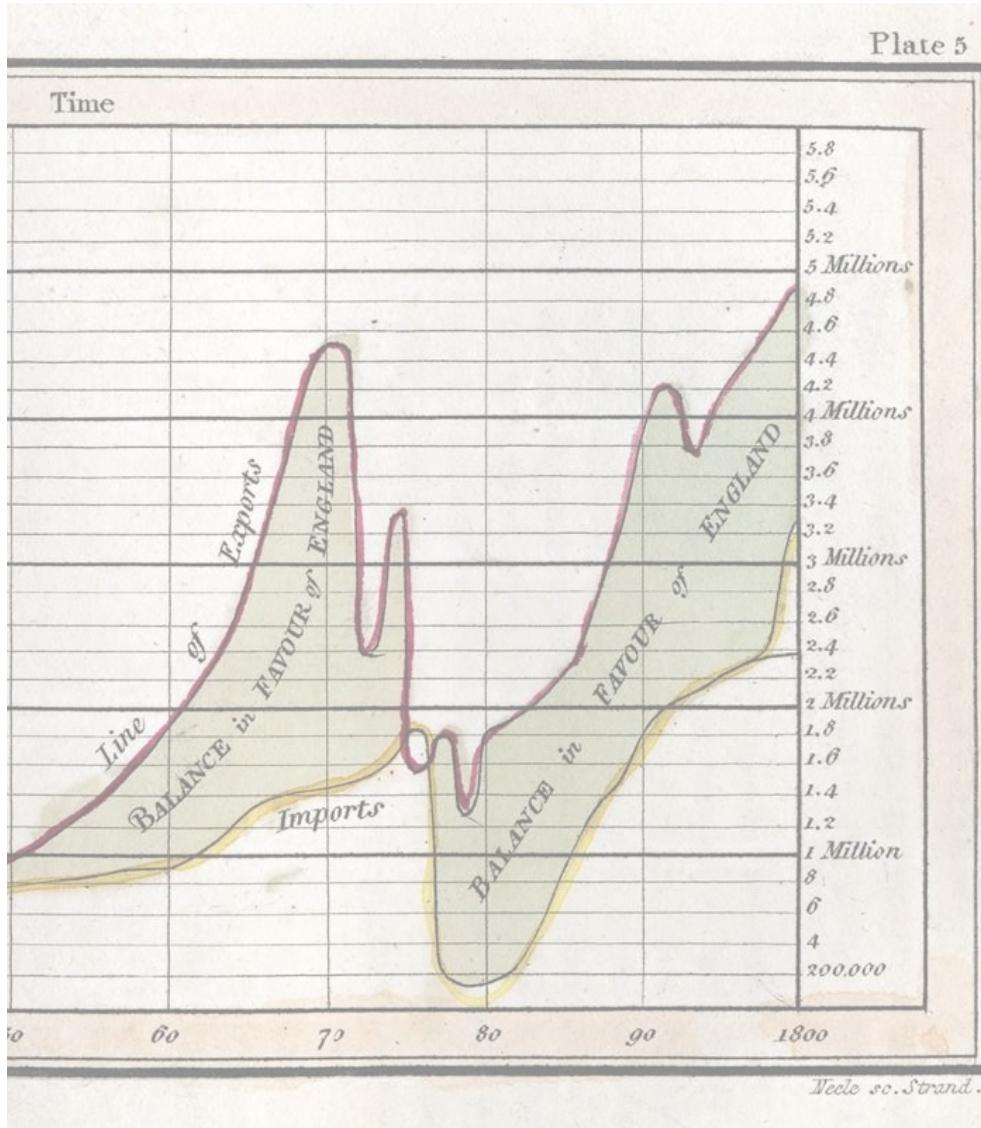
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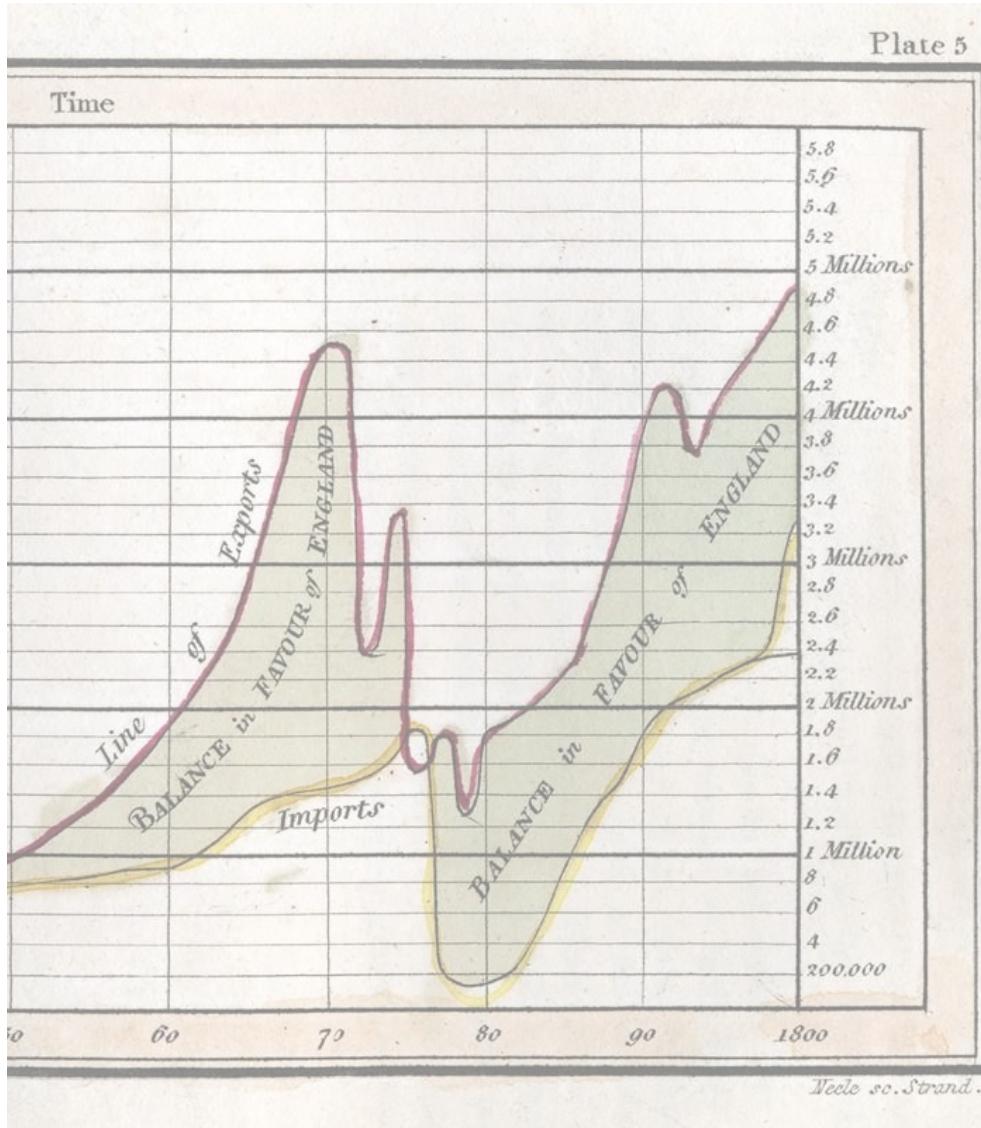
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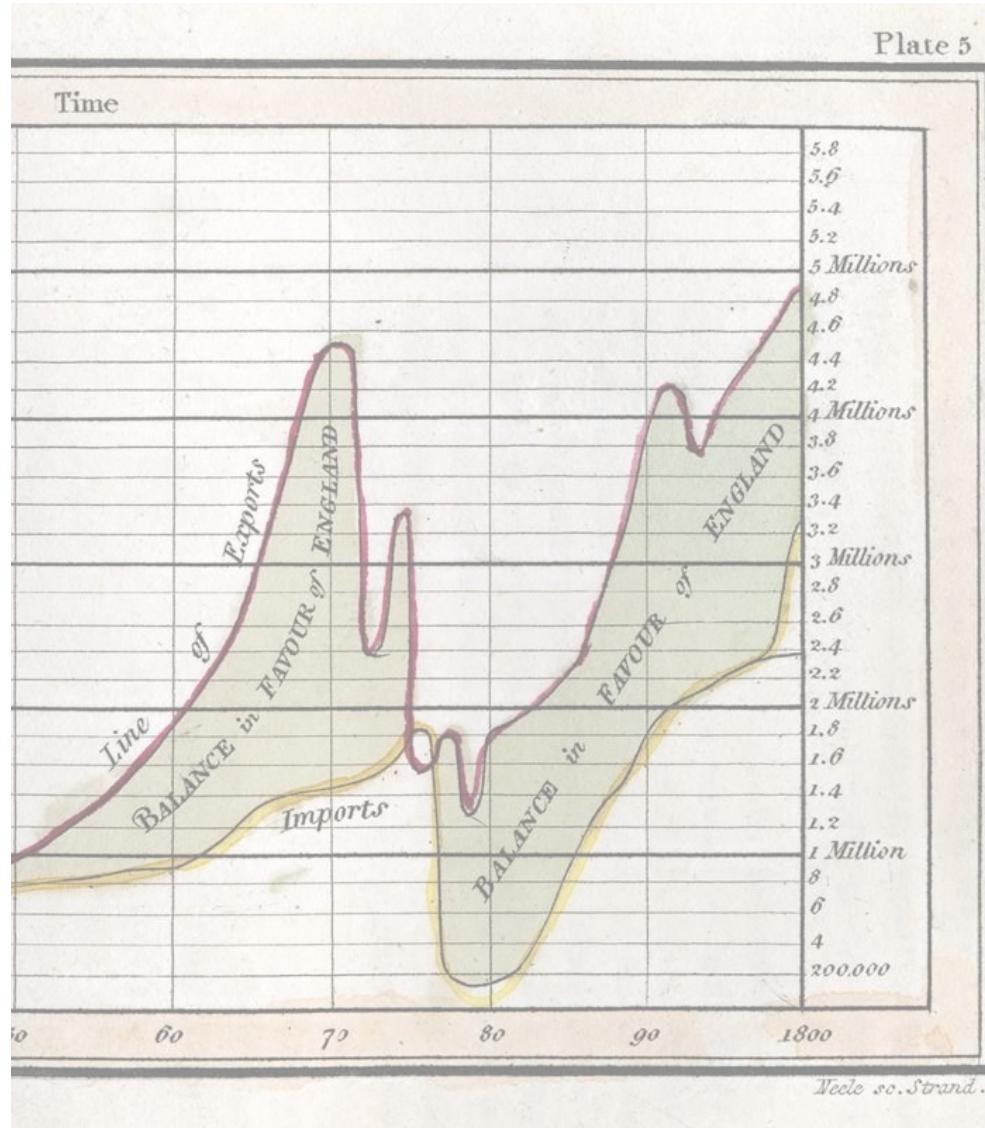
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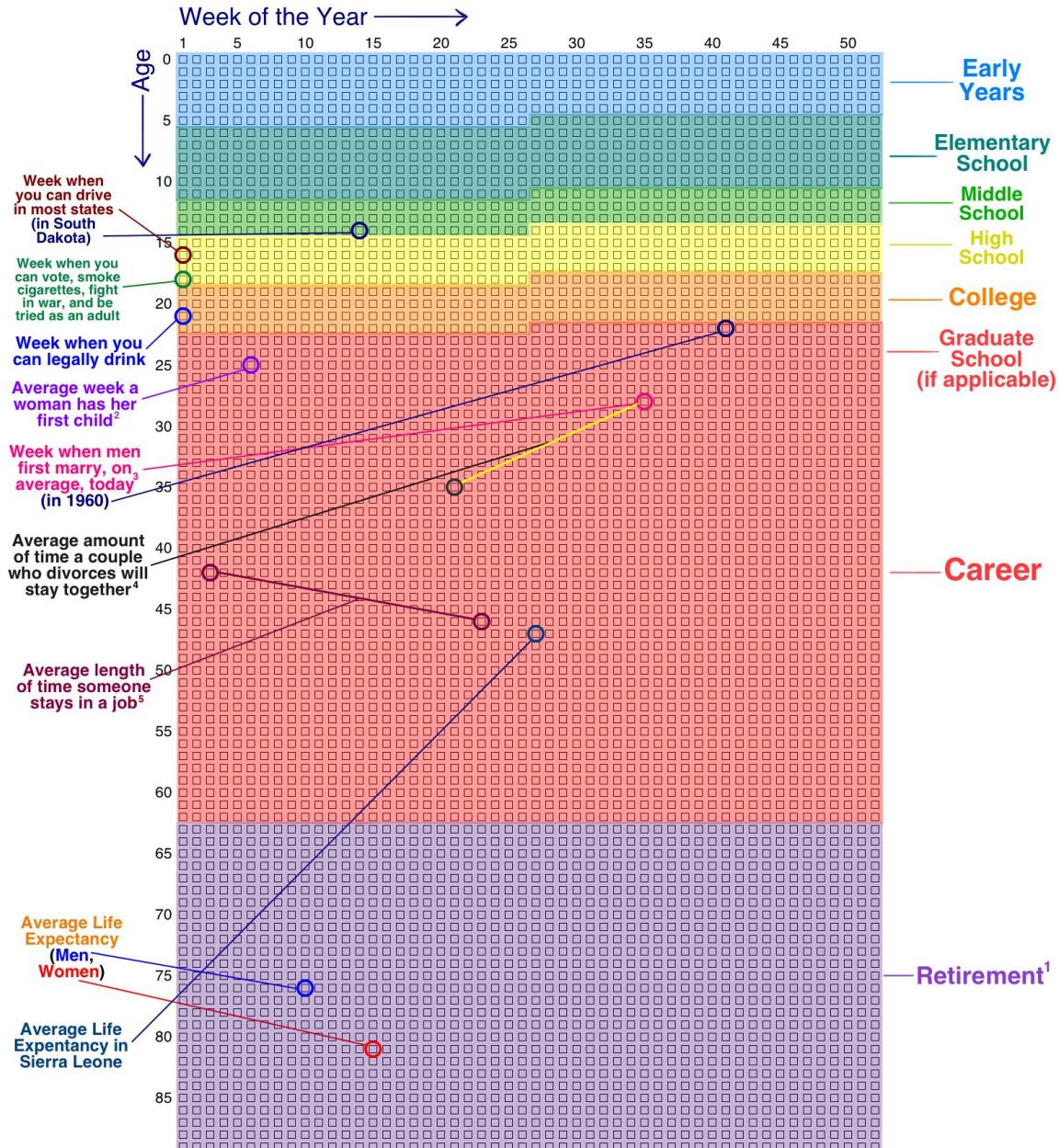
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Time is complex

- Directed
- Cyclic
- Quantities
- Scales
- Parallelity
- Granules: weeks, months

The Life of a Typical American



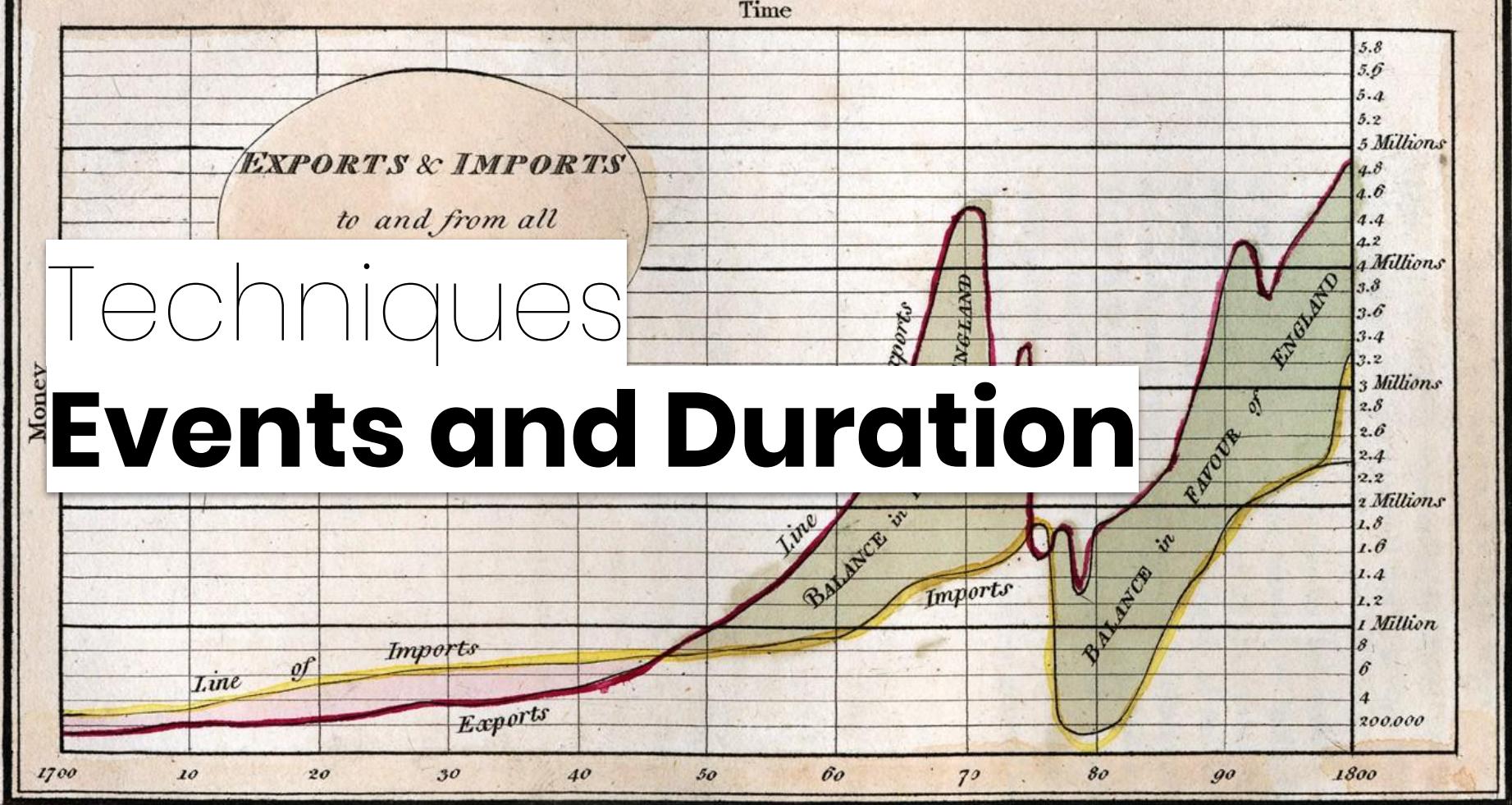
Outline

How to visualize temporal data?

- Event data
- Time series
- Many time series
- Multidimensional temporal data
- Space-time cubes
- Time curves

Techniques

Events and Duration



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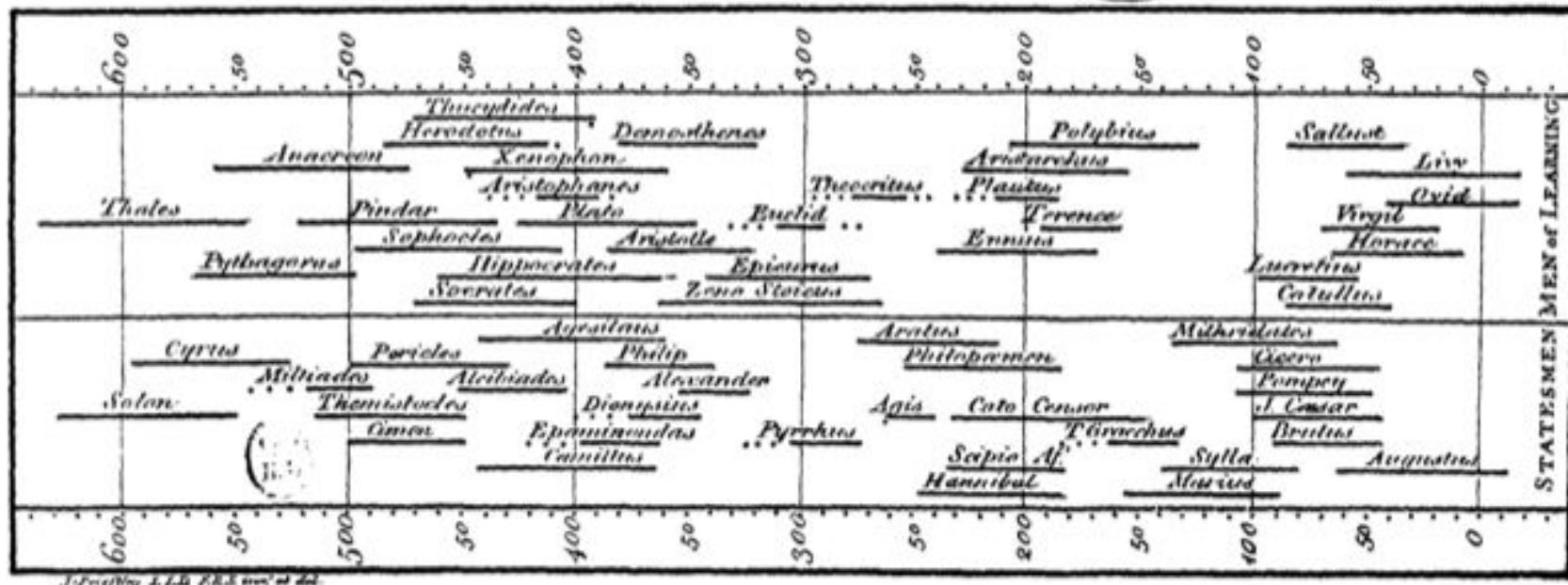
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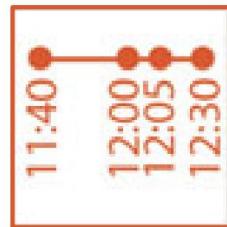
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Events and durations

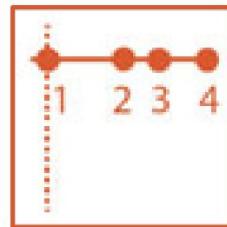
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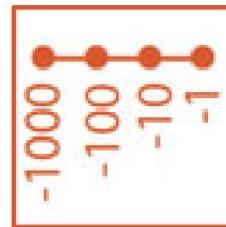
Scale



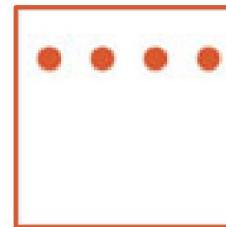
Chrono-
logical



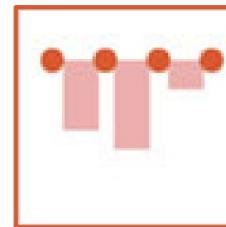
Relative



Logarithmic



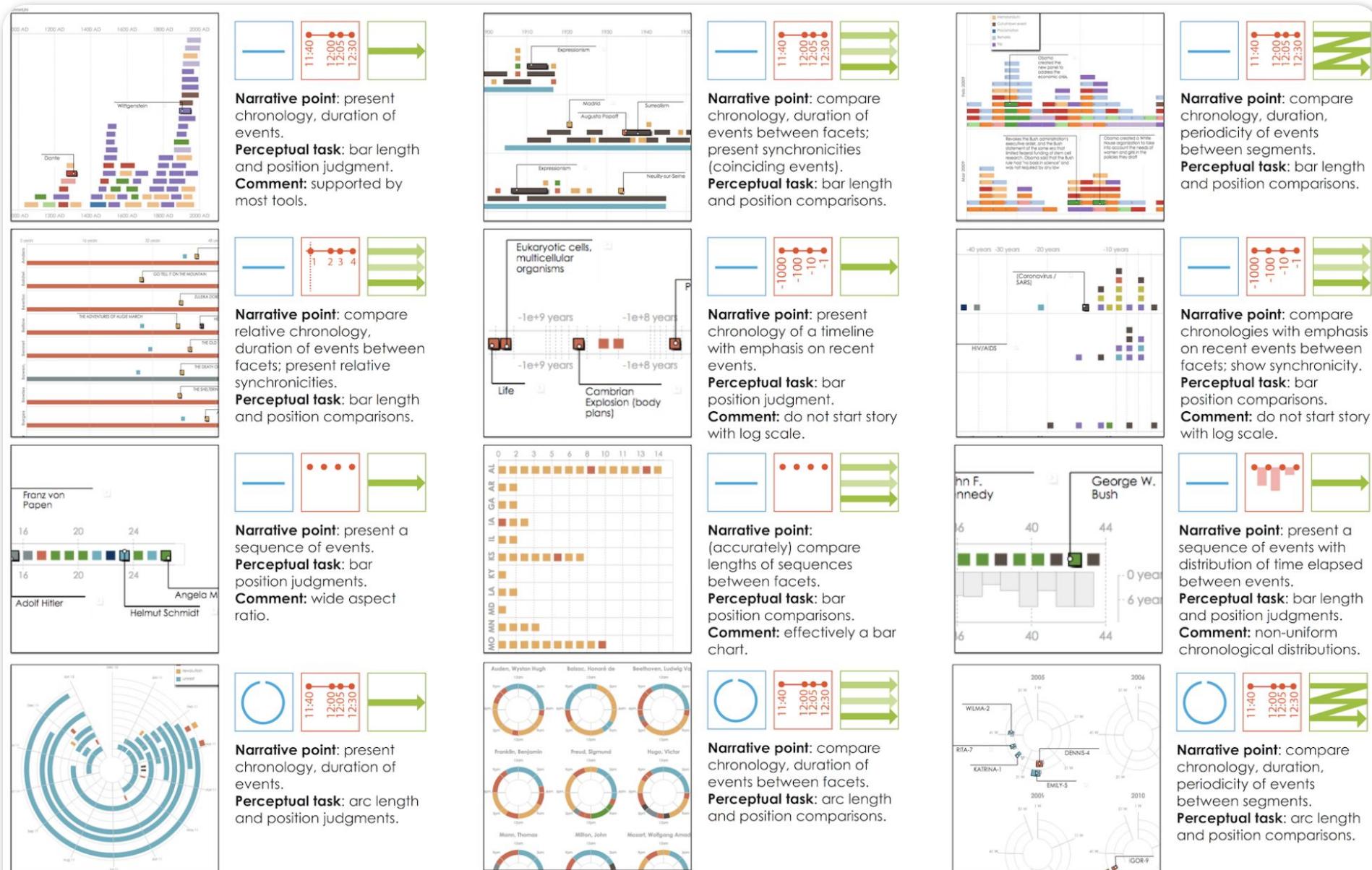
Sequential



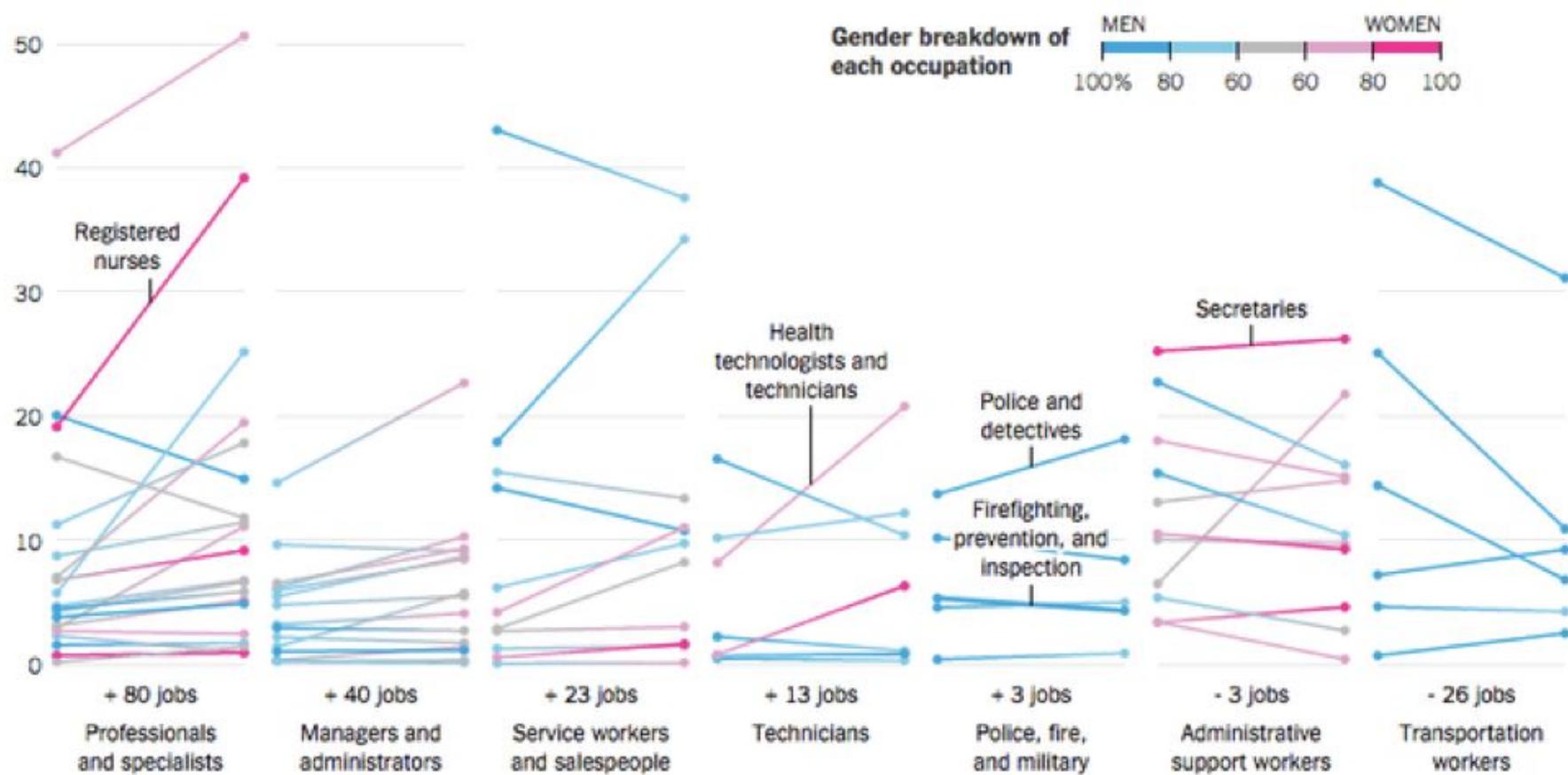
Sequential +
Interim
Duration

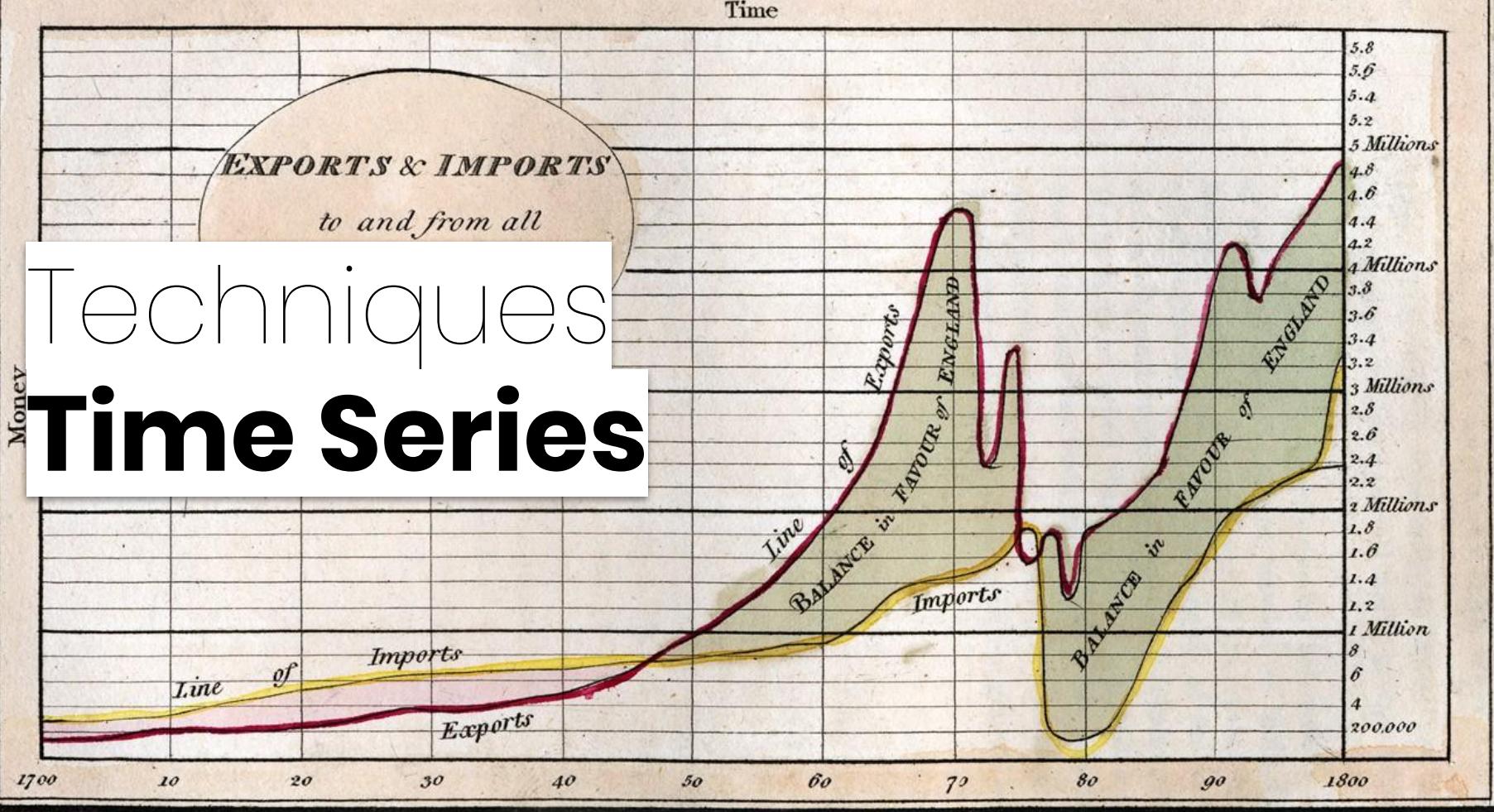
Timeline visualizations

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



Trend chart





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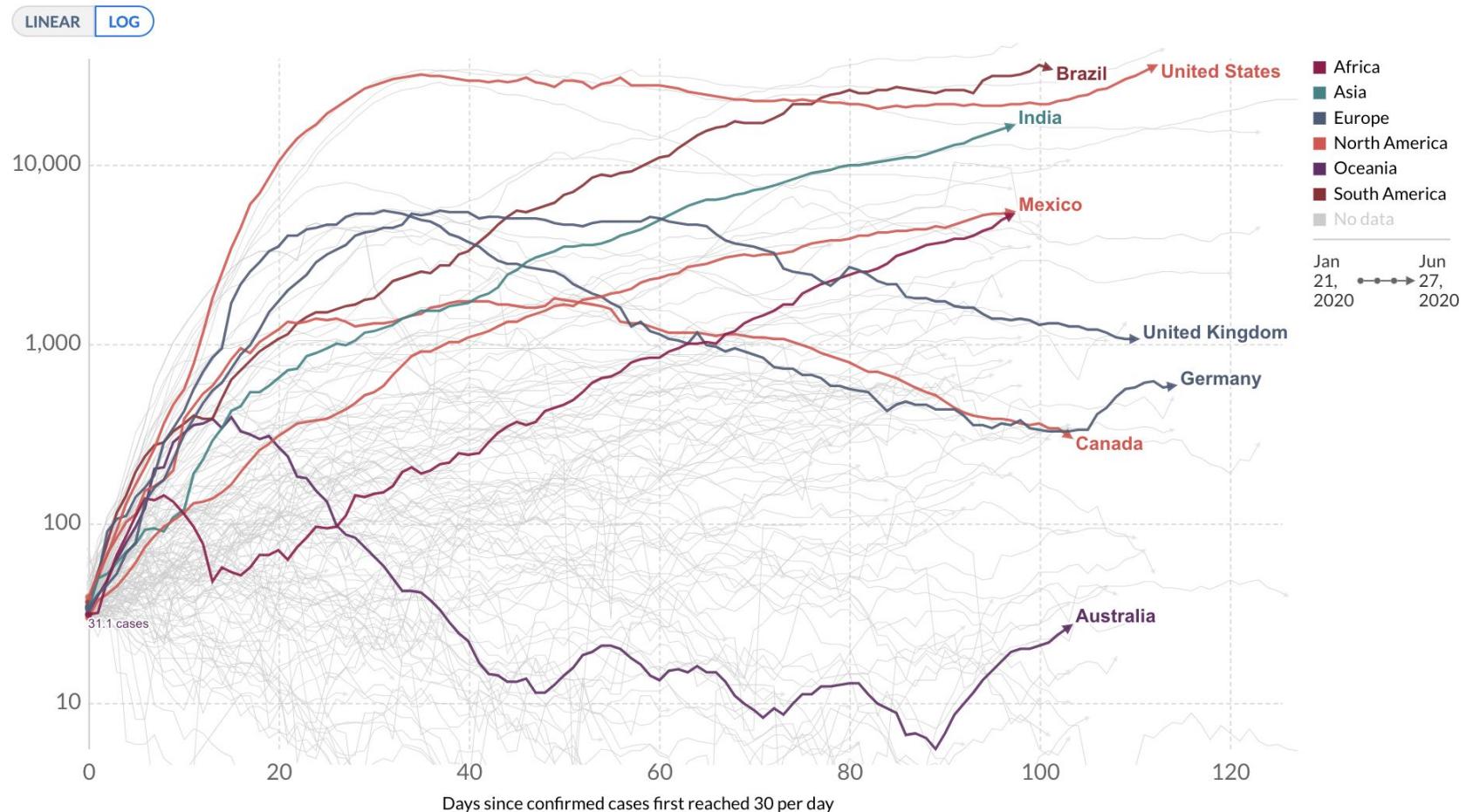
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Time series

Daily new confirmed COVID-19 cases

Shown is the rolling 7-day average. The number of confirmed cases is lower than the number of actual cases; the main reason for that is limited testing.

Our World
in Data



Source: European CDC – Situation Update Worldwide - Data last updated 27th Jun, 10:52 (GMT+01:00), European CDC – Situation Update Worldwide

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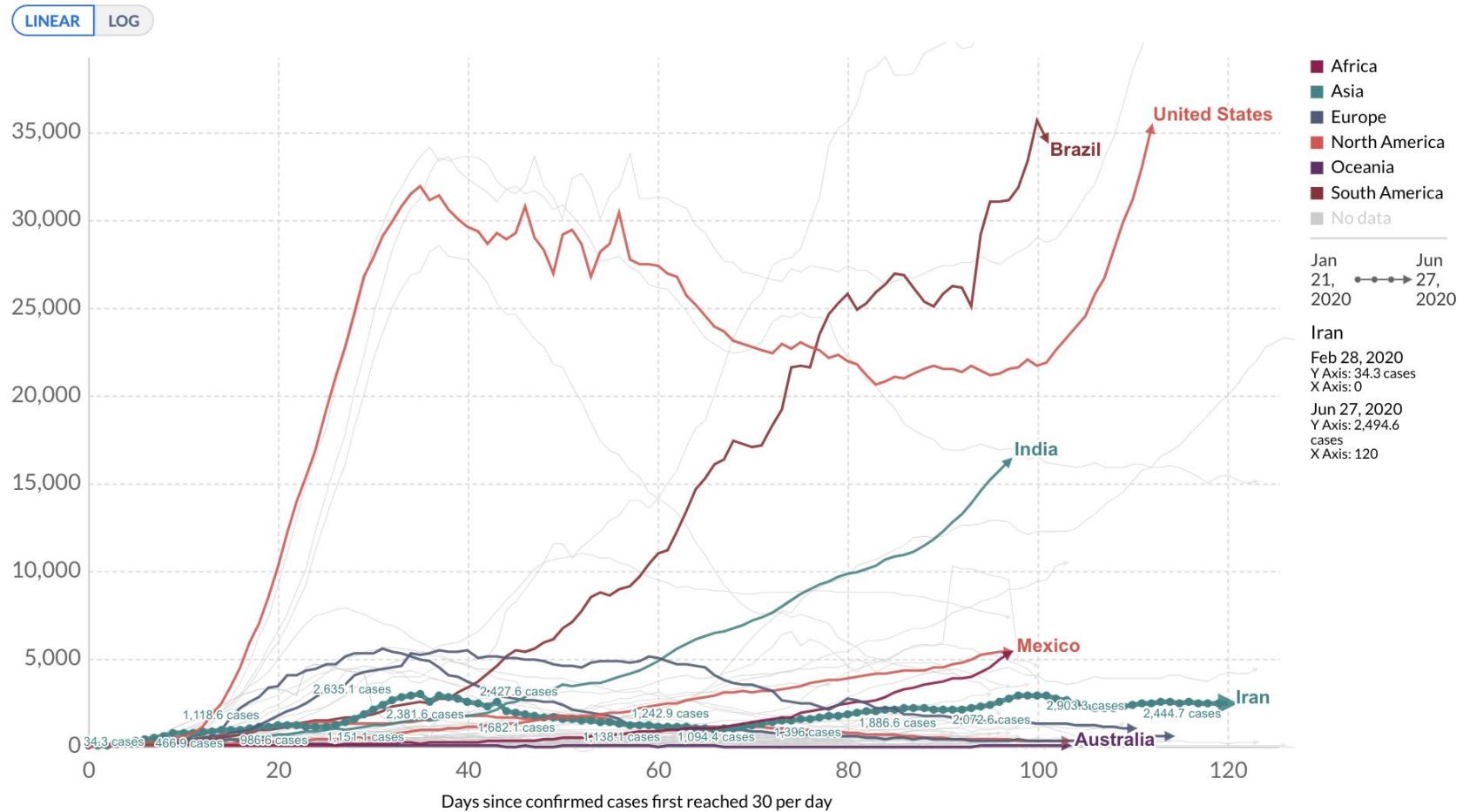
▶ Jan 21, 2020 Jun 27, 2020

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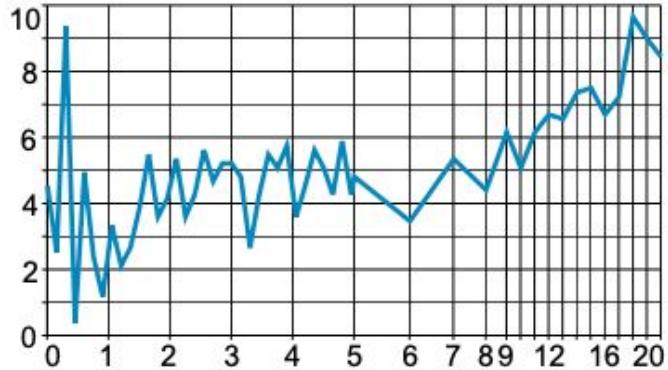


Source: European CDC – Situation Update Worldwide - Data last updated 27th Jun, 10:52 (GMT+01:00), European CDC – Situation Update Worldwide

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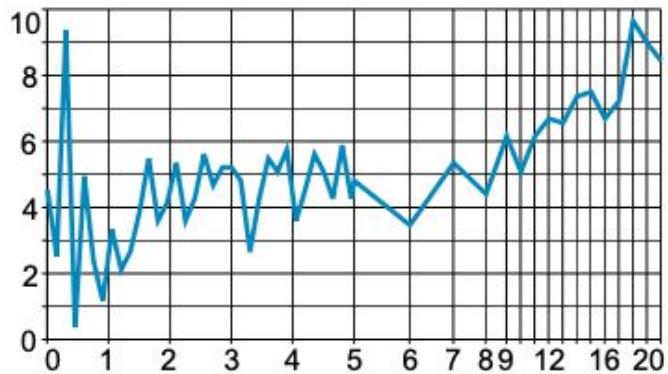
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Dual-Scale Data Charts

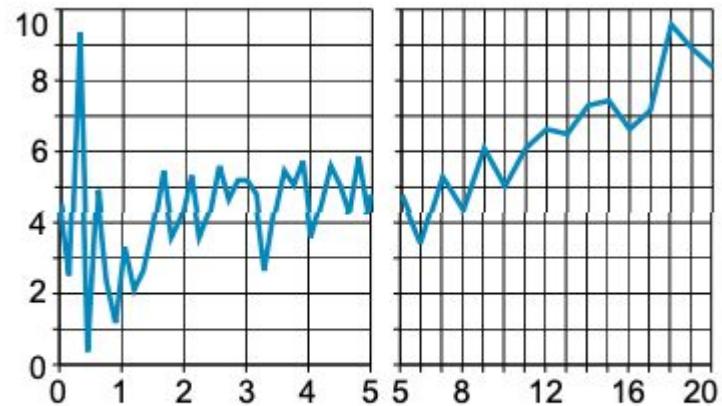


(a) A lens chart.

Dual-Scale Data Charts

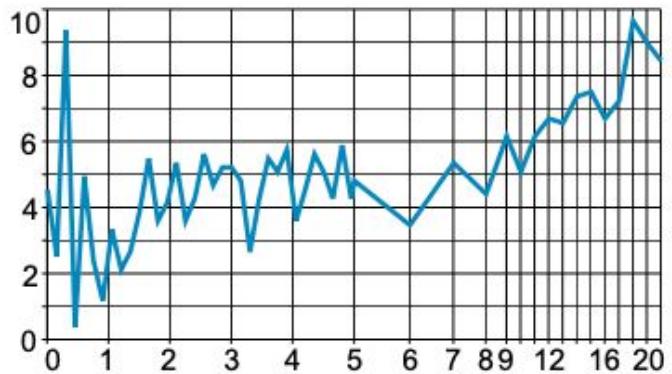


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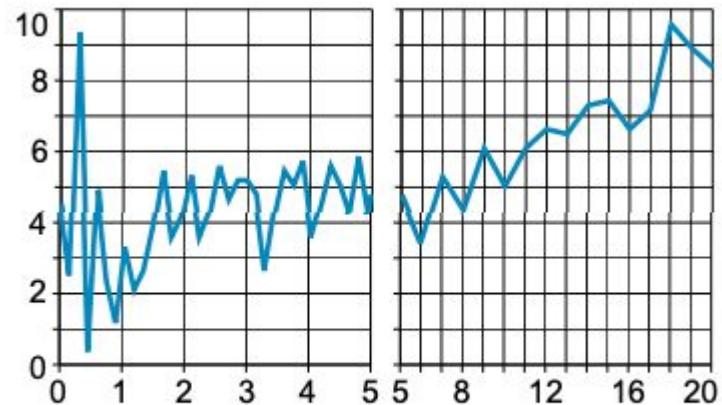


(a) A broken chart.

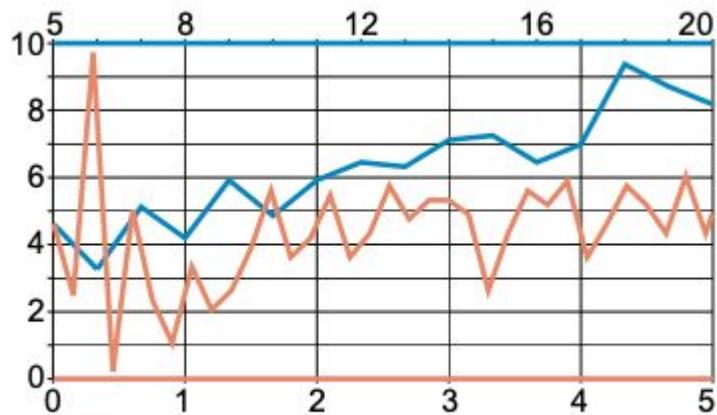
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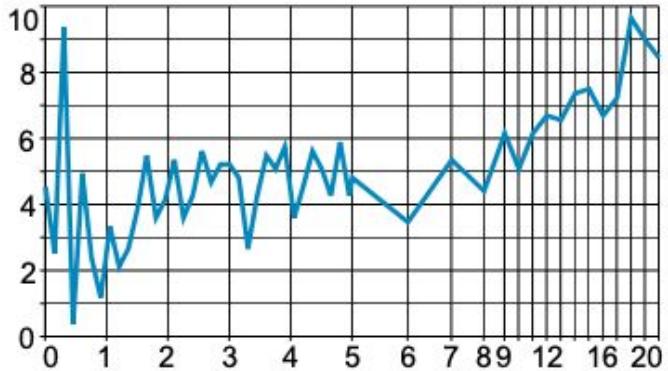


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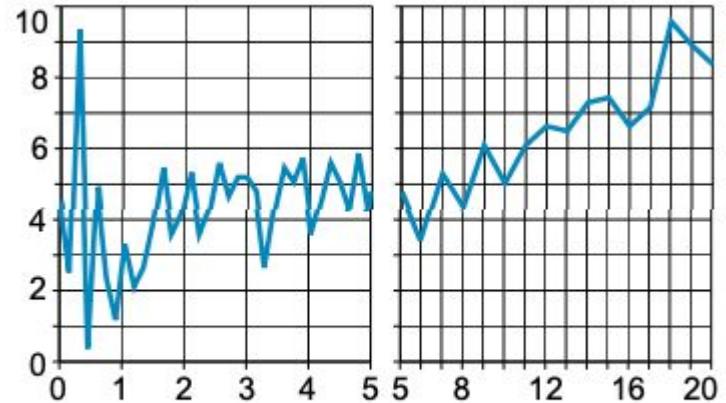


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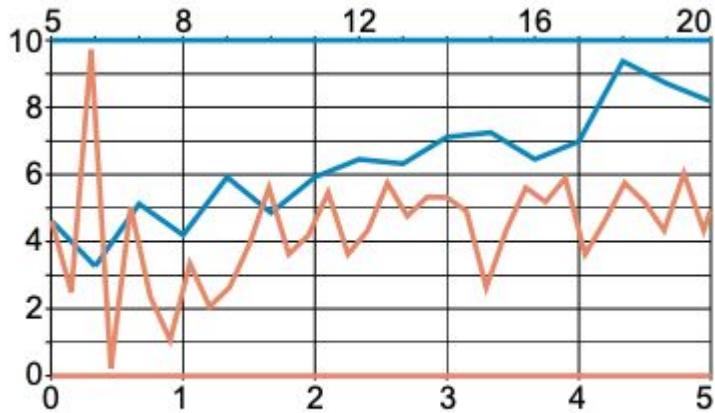
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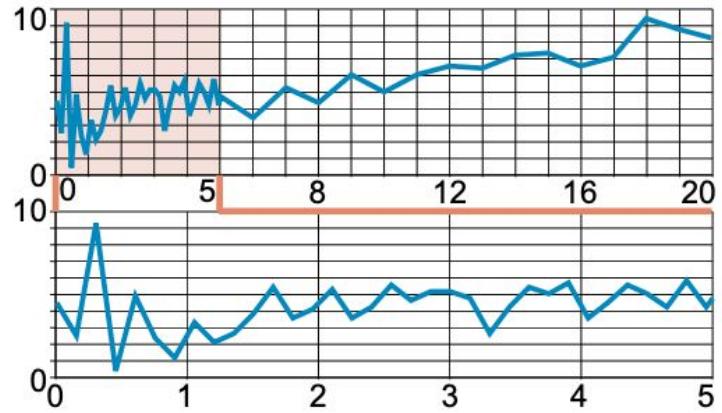
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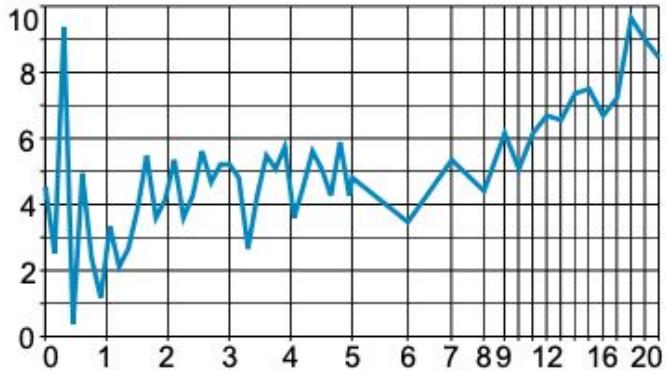


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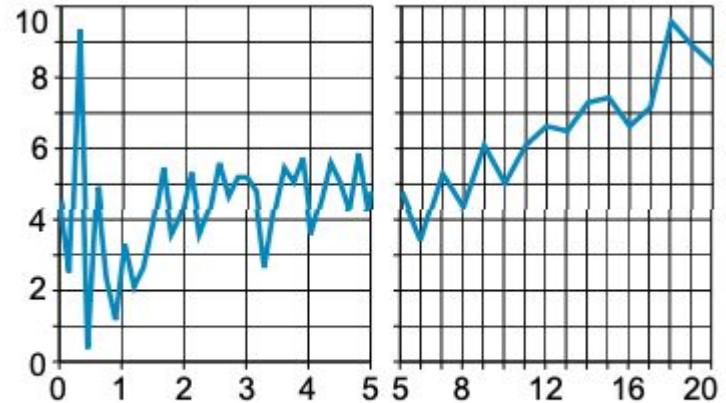


(a) A cut-out chart.

Dual-Scale Data Charts



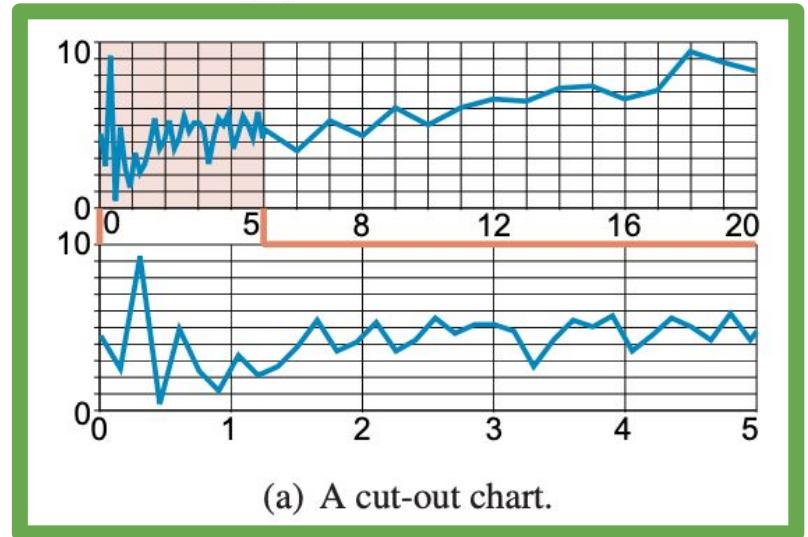
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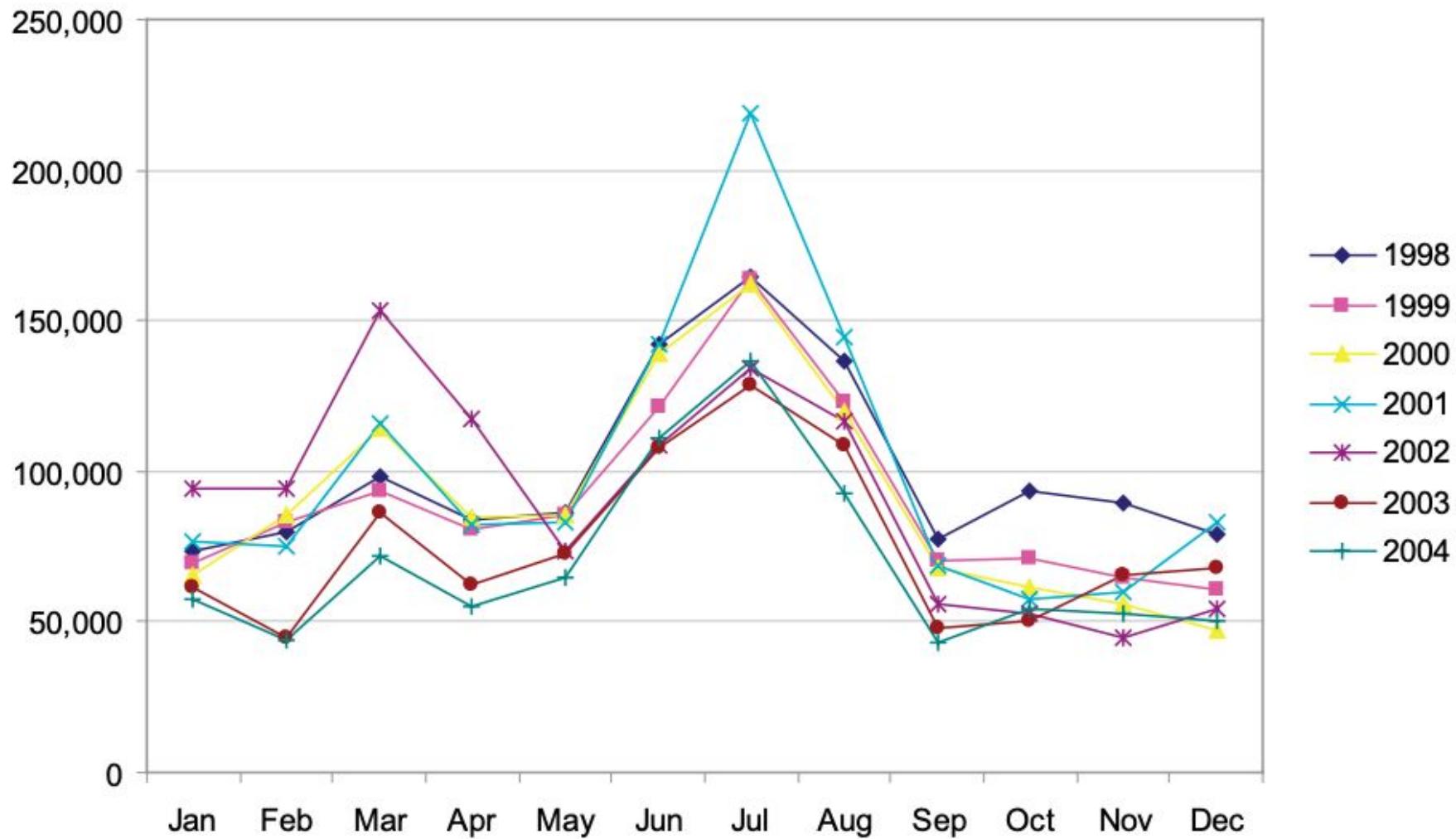


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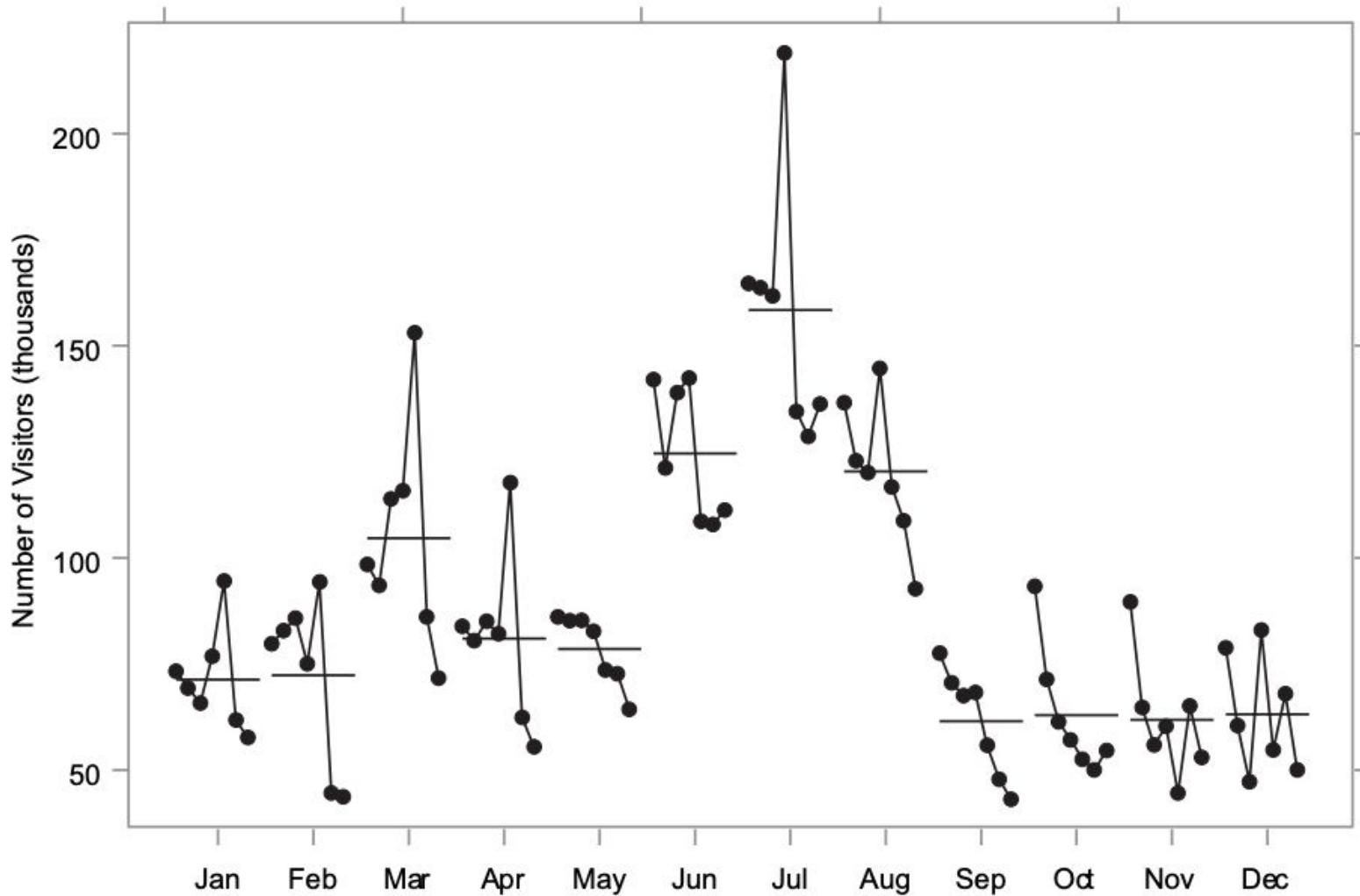


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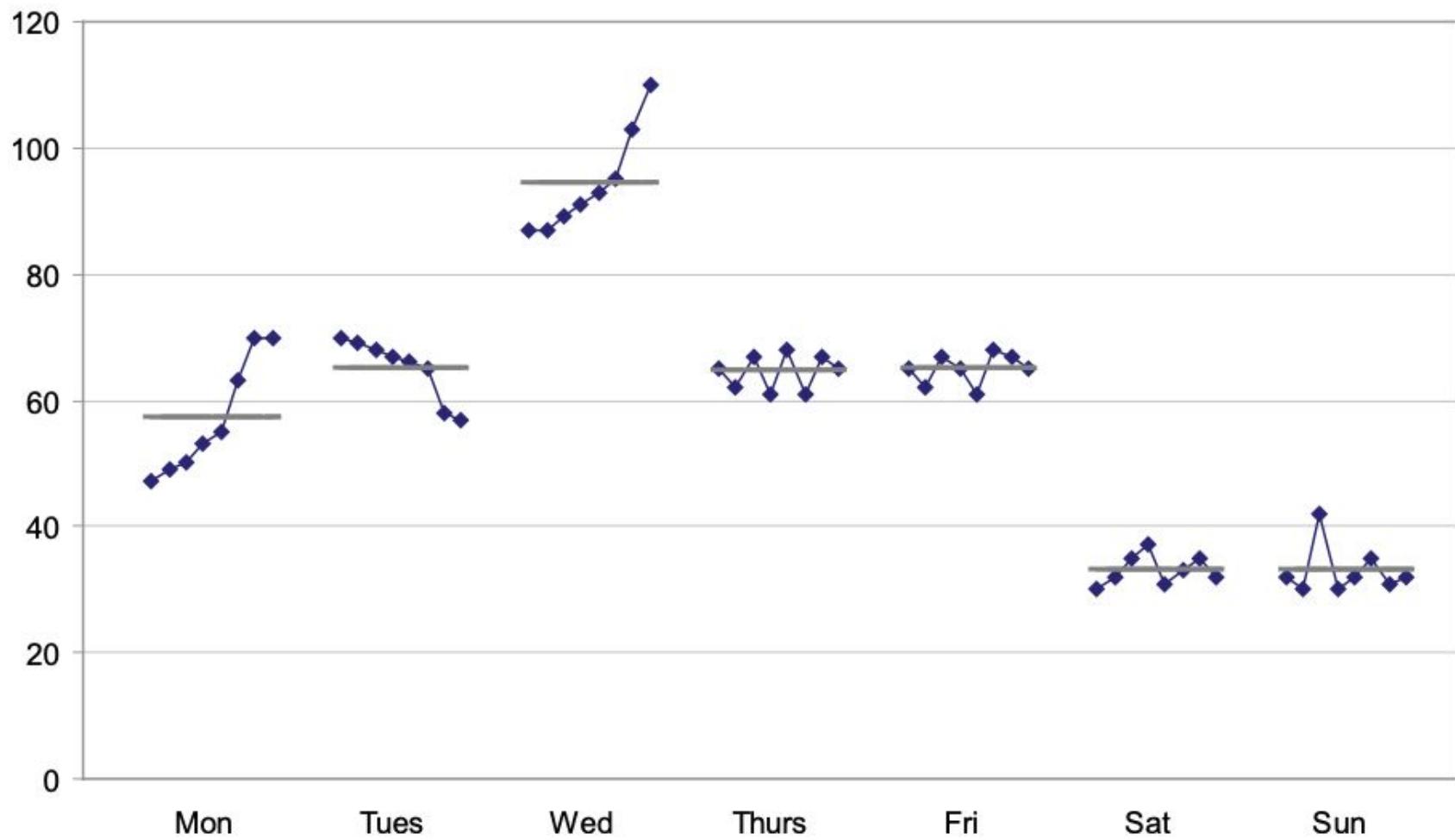
Calendar data



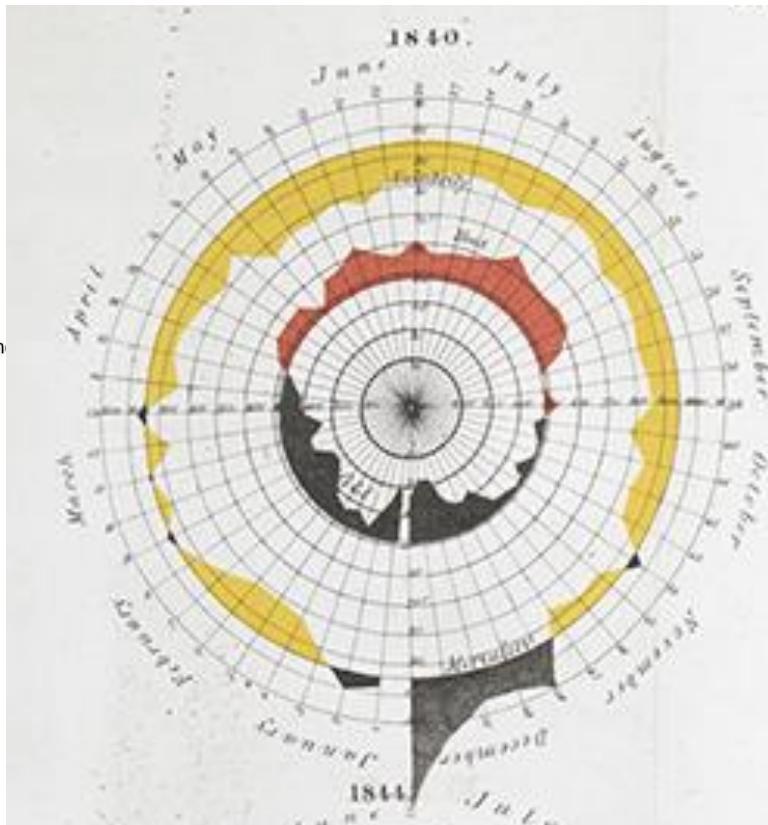
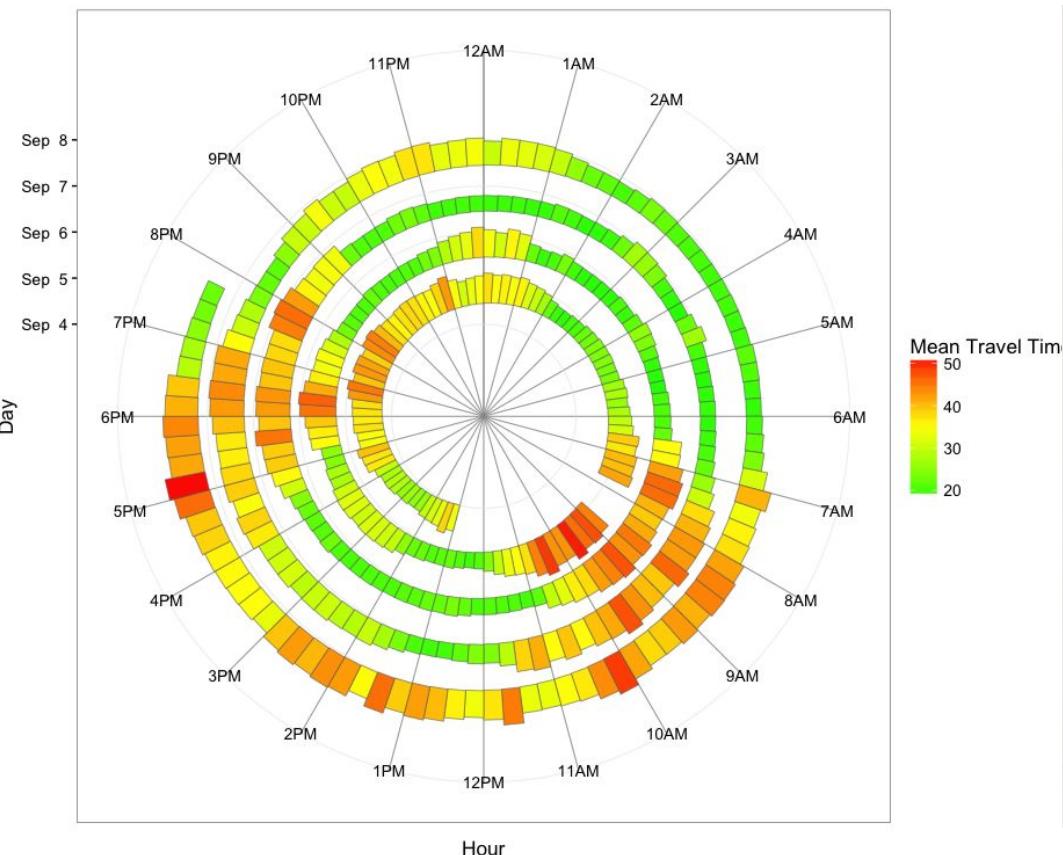
Cycle plots: by month



Cycle plots: by week day



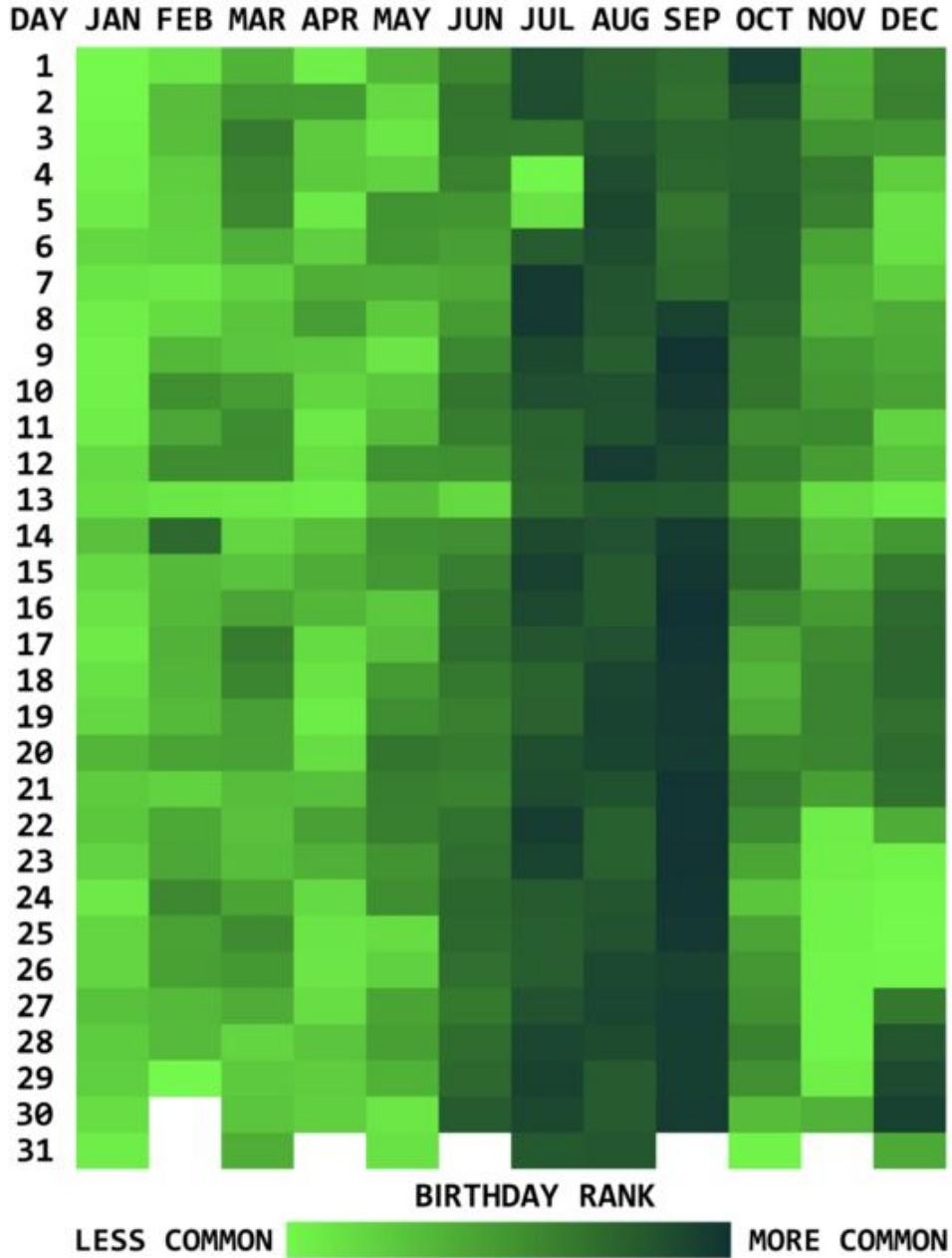
Radial time visualizations



- Show cyclical data / values
- Values in outer layers getting stretched!

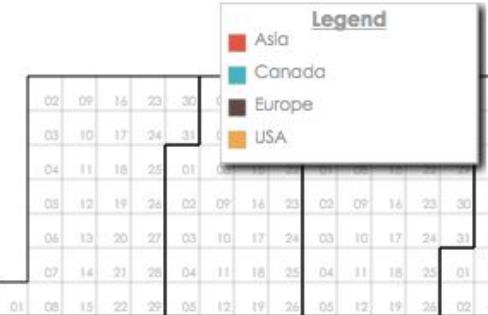
Heatmap

- Calendar data + numerical values
 - + Row and column effects
 - + Easy look up
 - + Space efficient
 - Precise value comparison hard

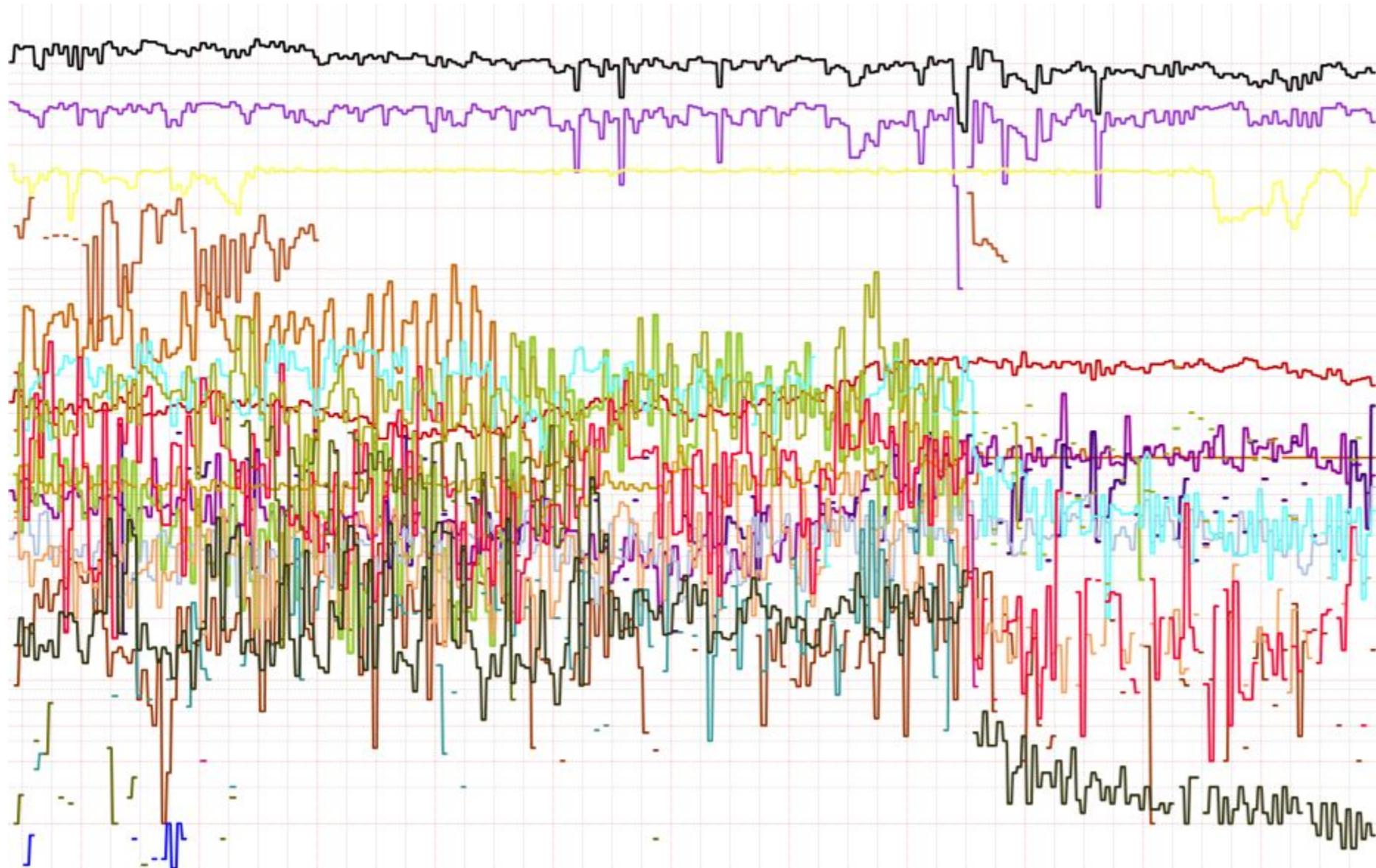


Calendars

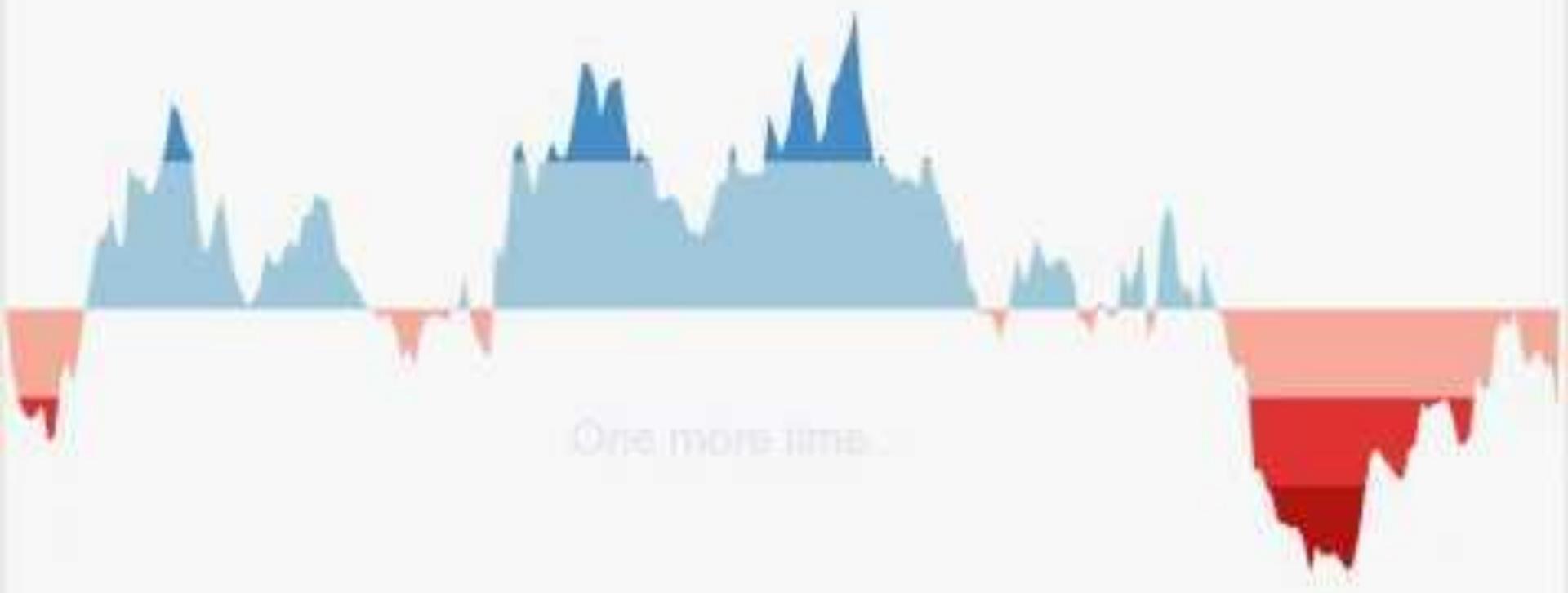
2011



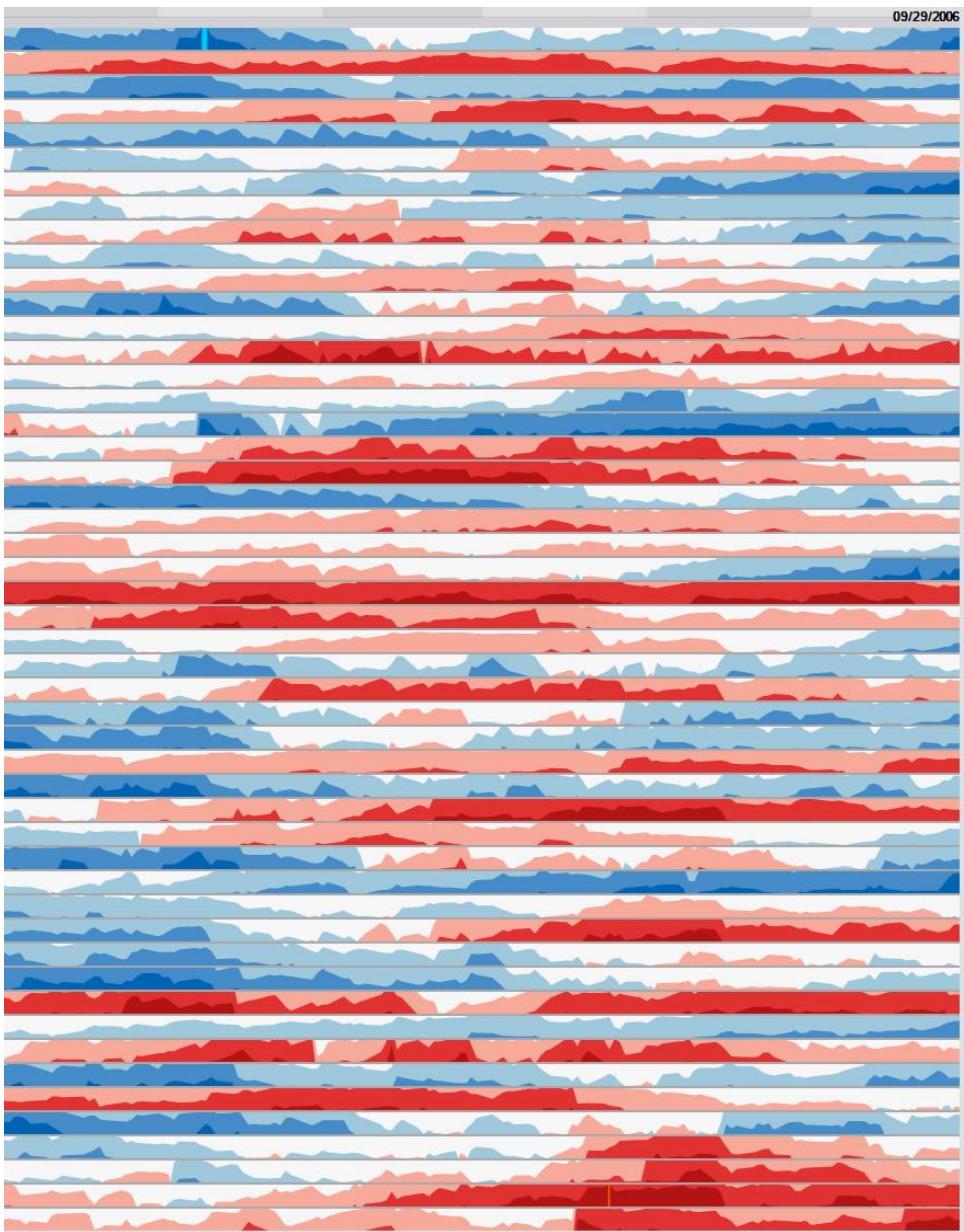
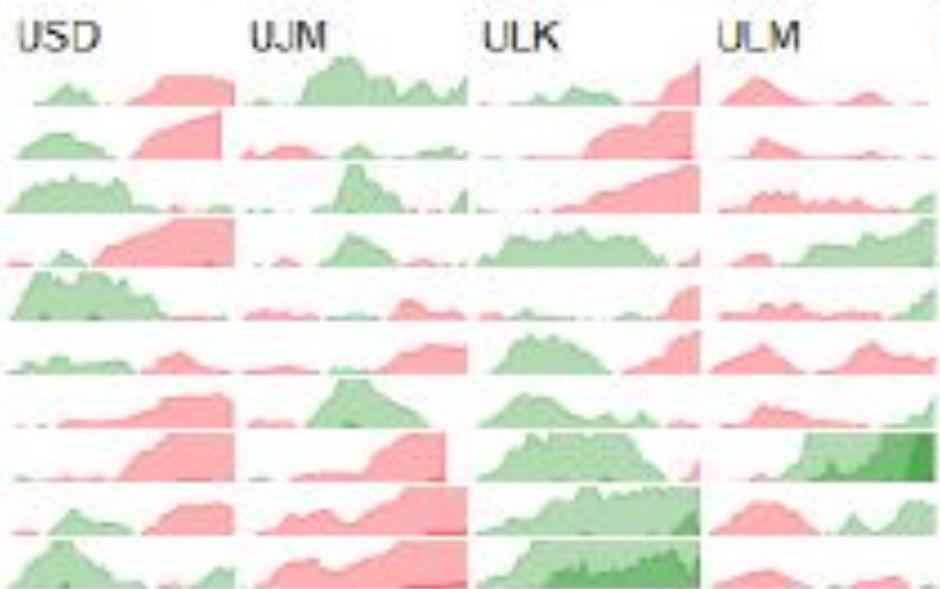
Comparing multiple timelines?



Horizon graphs



Horizon Graphs



Money

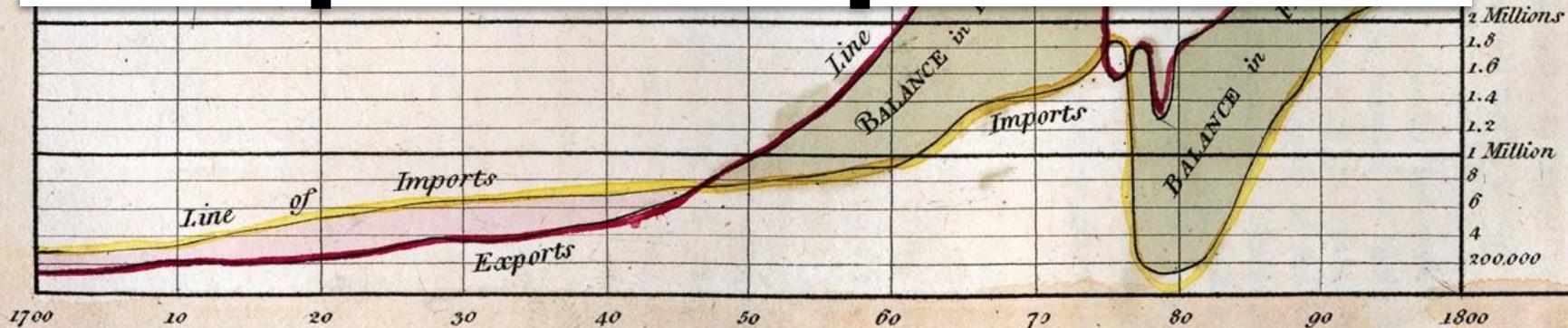
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Connected Scatterplot

METRICS

HANNAH FAIRFIELD

Driving Shifts Into Reverse

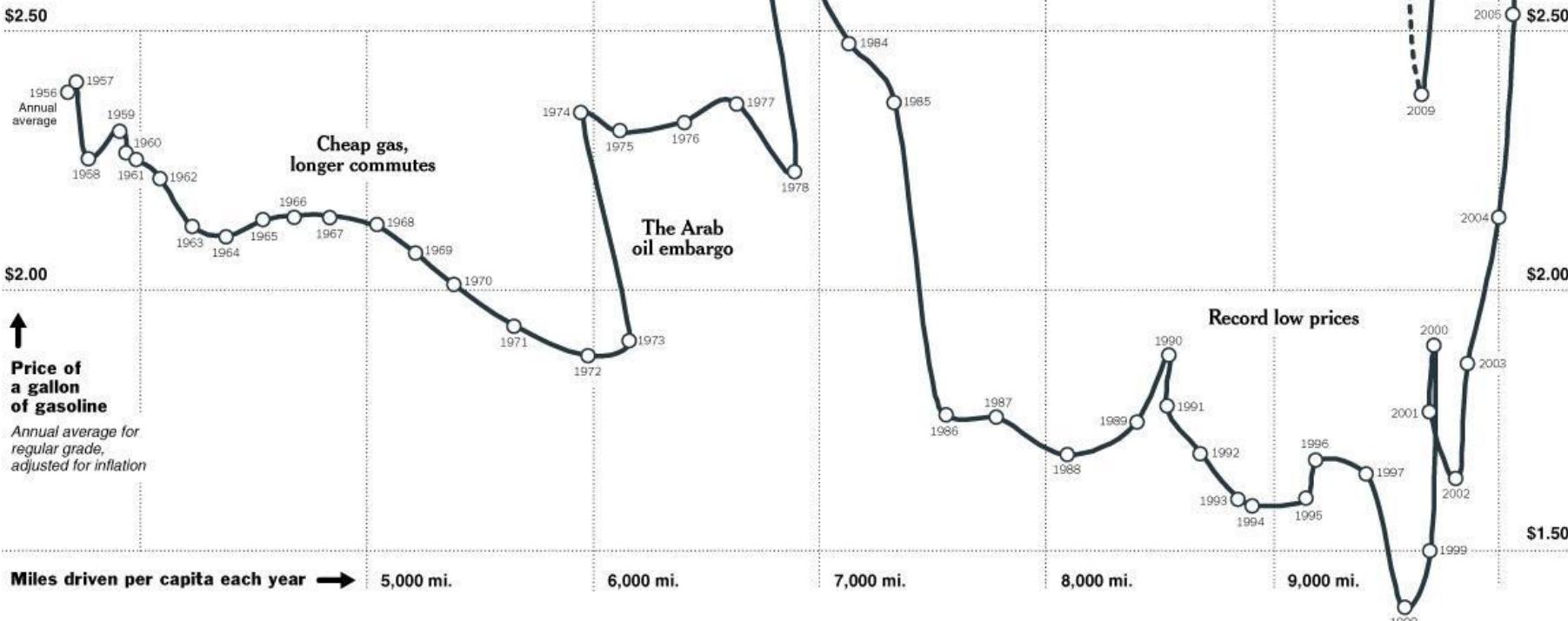
ECONOMISTS have long studied the relationship between driving habits and gasoline prices. Low gas prices can bring periods of profligate driving, and a quick jump in prices can cause many vehicles to languish in garages.

Until recently, Americans have driven more each year than the previous one, with a few brief exceptions. In 1956, Americans of driving age drove about 4,000 miles a year, on average. Fifty years later, that figure had climbed above 10,000.

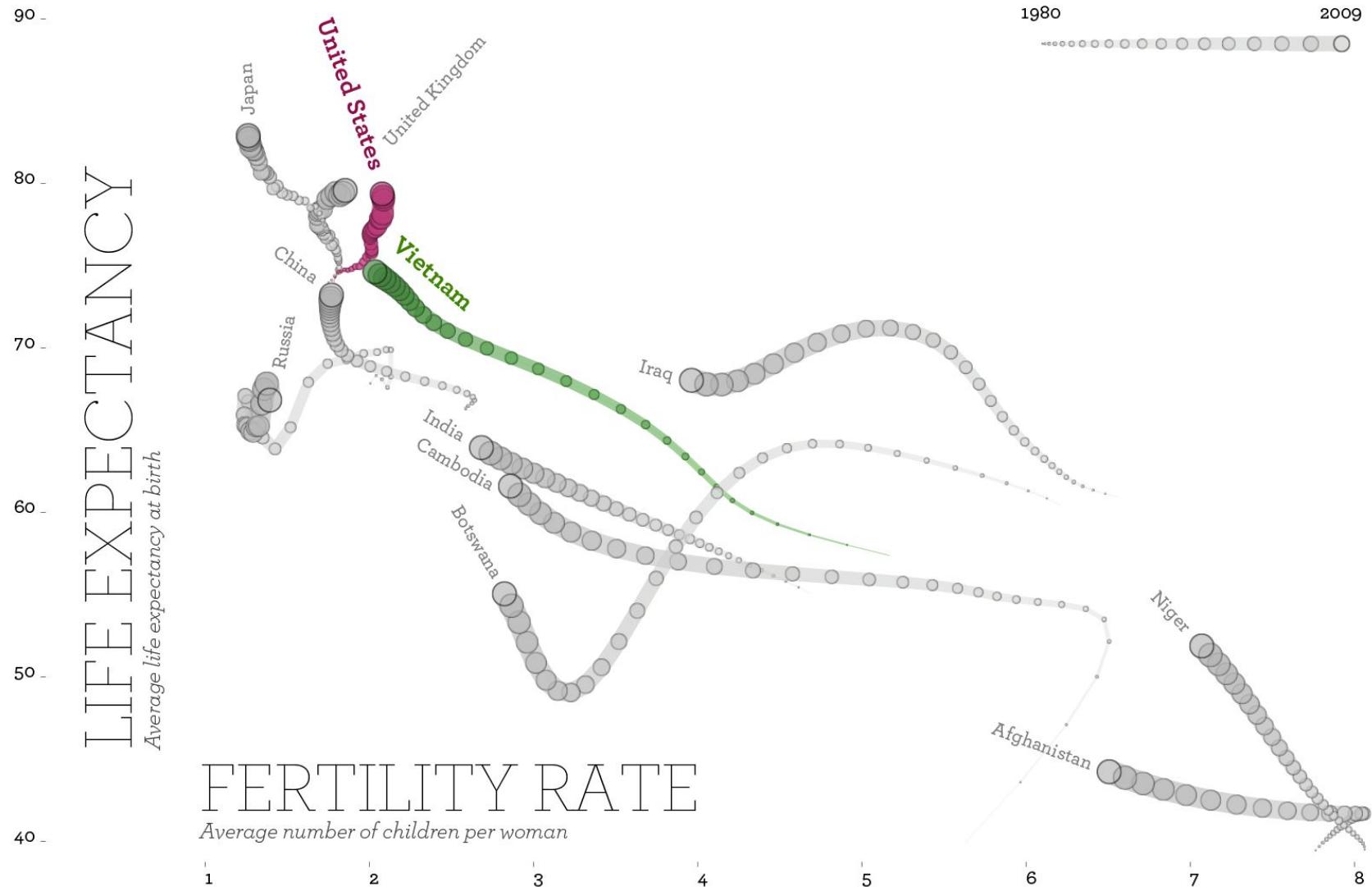
But the latest recession has caused some big changes. High unemployment meant that fewer people were driving to work, and a slump in consumer spending

meant that less freight needed to be moved around the country. As gas prices soared in 2005, the number of miles driven — including commercial and personal — began to fall, and continued to drop after 2008 even as gasoline became cheaper.

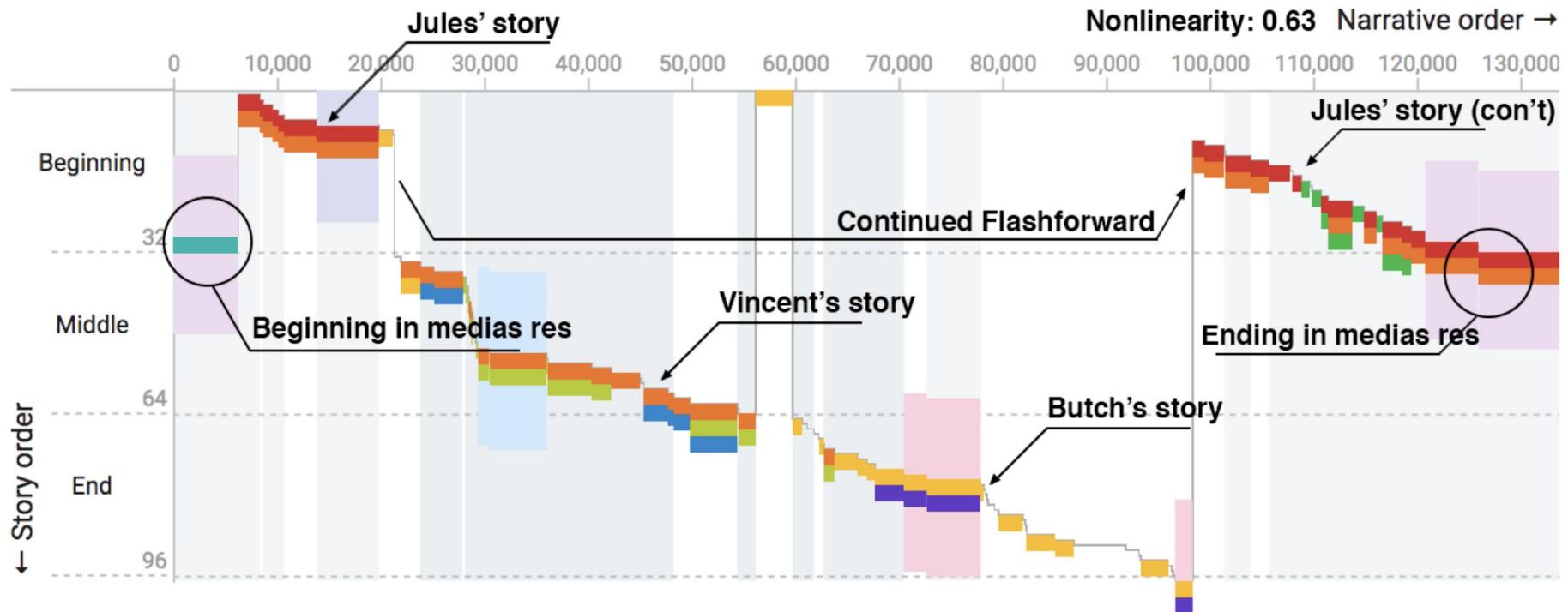
"People were surprised by the very rapid rise in gas prices, and they changed their driving behavior," said Kenneth A. Small, a transportation economist at the University of California, Irvine. "But my suspicion is that it is temporary. As soon as unemployment gets back to pre-recession levels, we will see Americans doing a lot more driving again."



Connected Scatterplots: encoding time

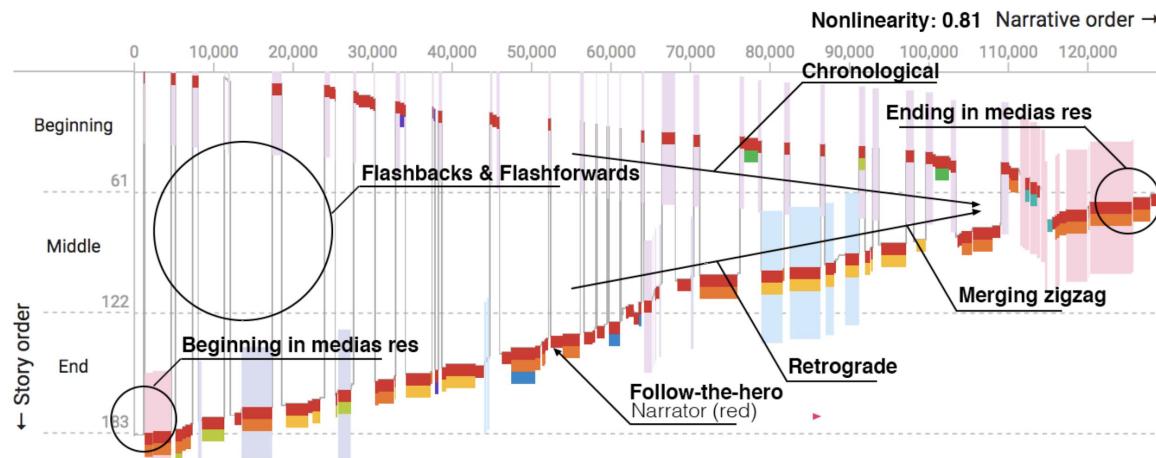
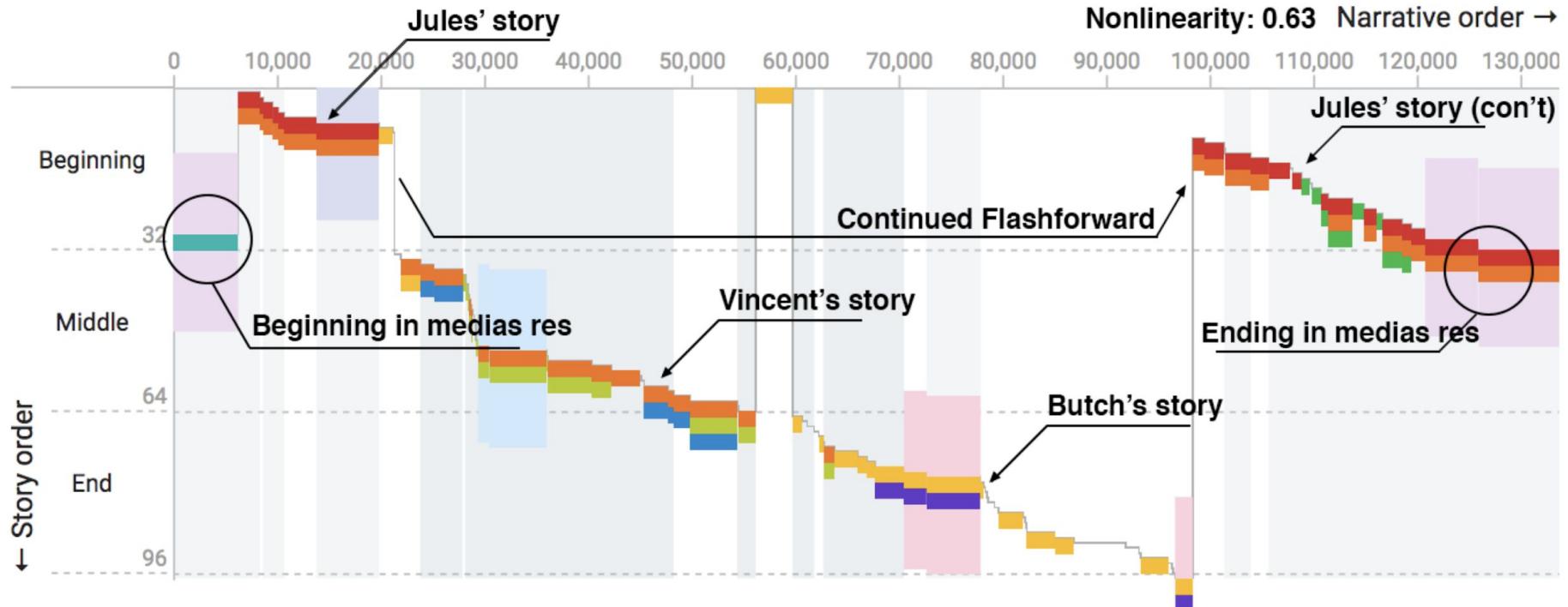


Time vs. Time: Story Curves



Kim, Nam Wook, et al. "Visualizing nonlinear narratives with story curves." *IEEE transactions on visualization and computer graphics* 24.1 (2017): 595-604.

Time vs. Time: Story Curves



Kim, Nam Wook, et al. "Visualizing nonlinear narratives with story curves." *IEEE transactions on visualization and computer graphics* 24.1 (2017): 595-604.

Time Curves

Creation

Timeline:



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

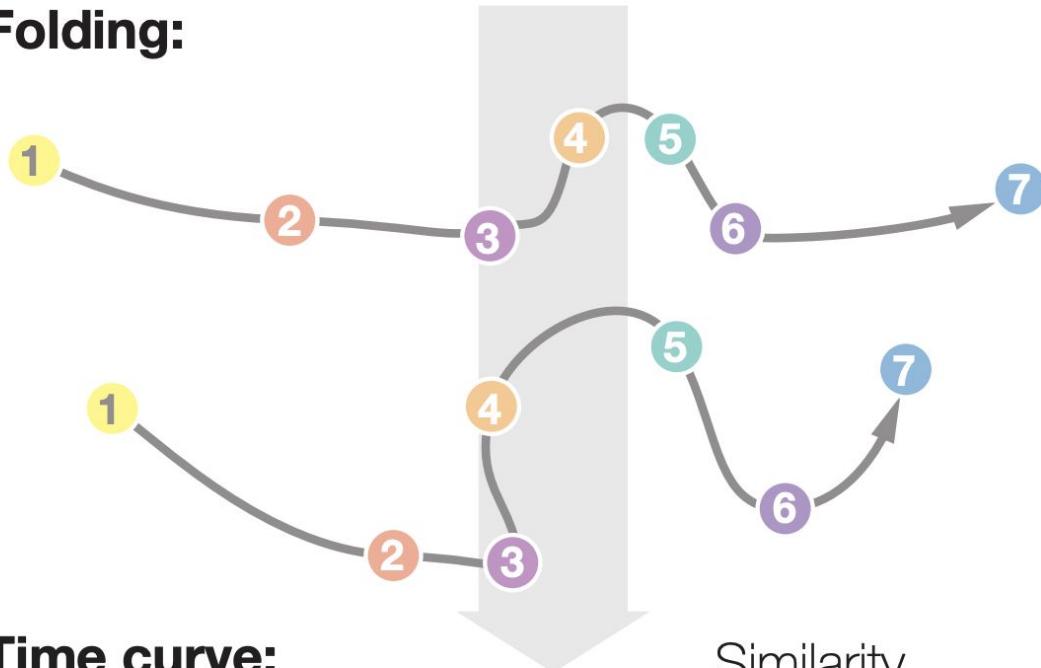
Time Curves Creation

Timeline:

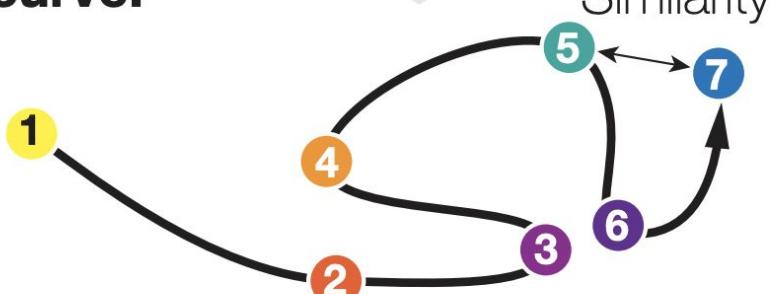


Circles are data cases with a time stamp.
Similar colors indicate similar data cases.

Folding:

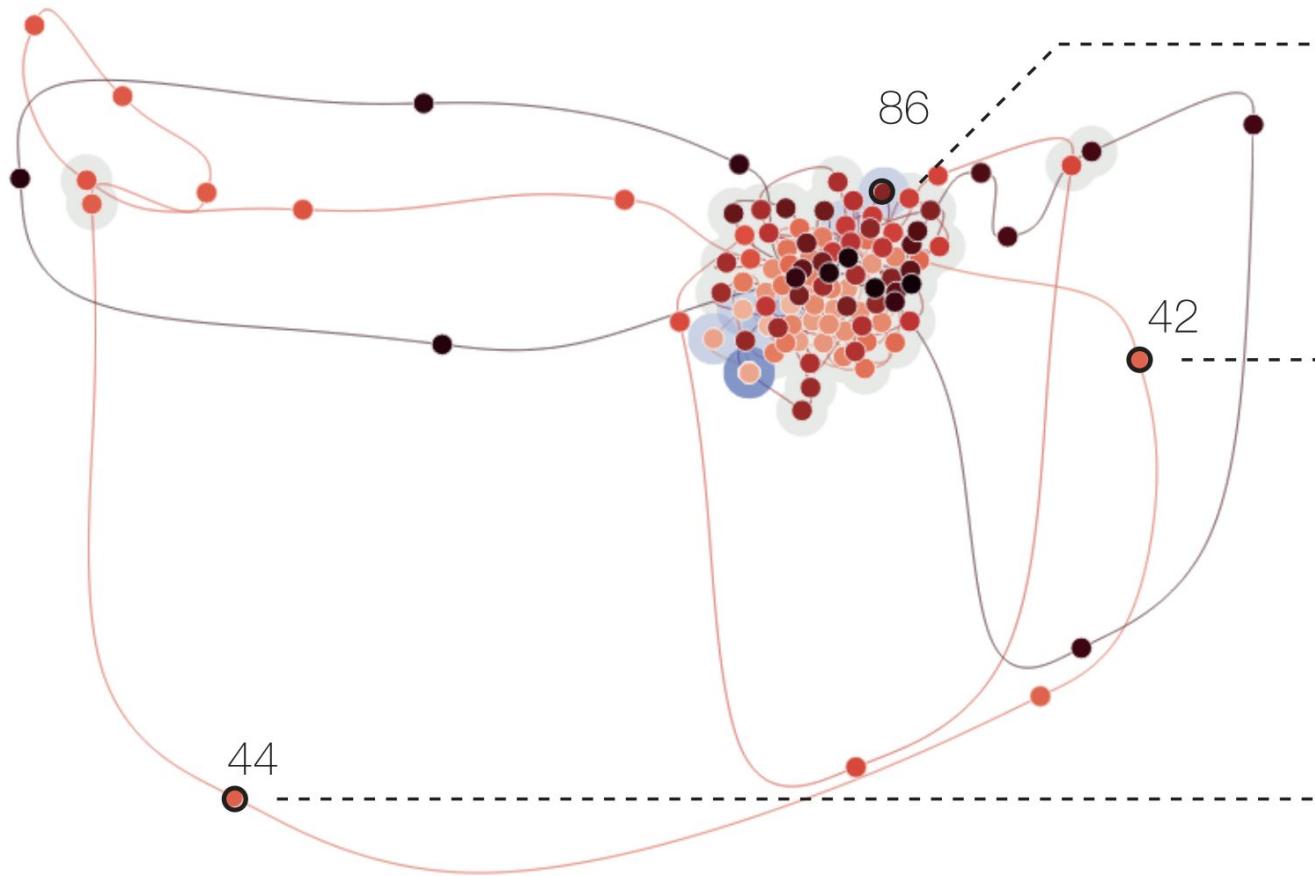


Time curve:



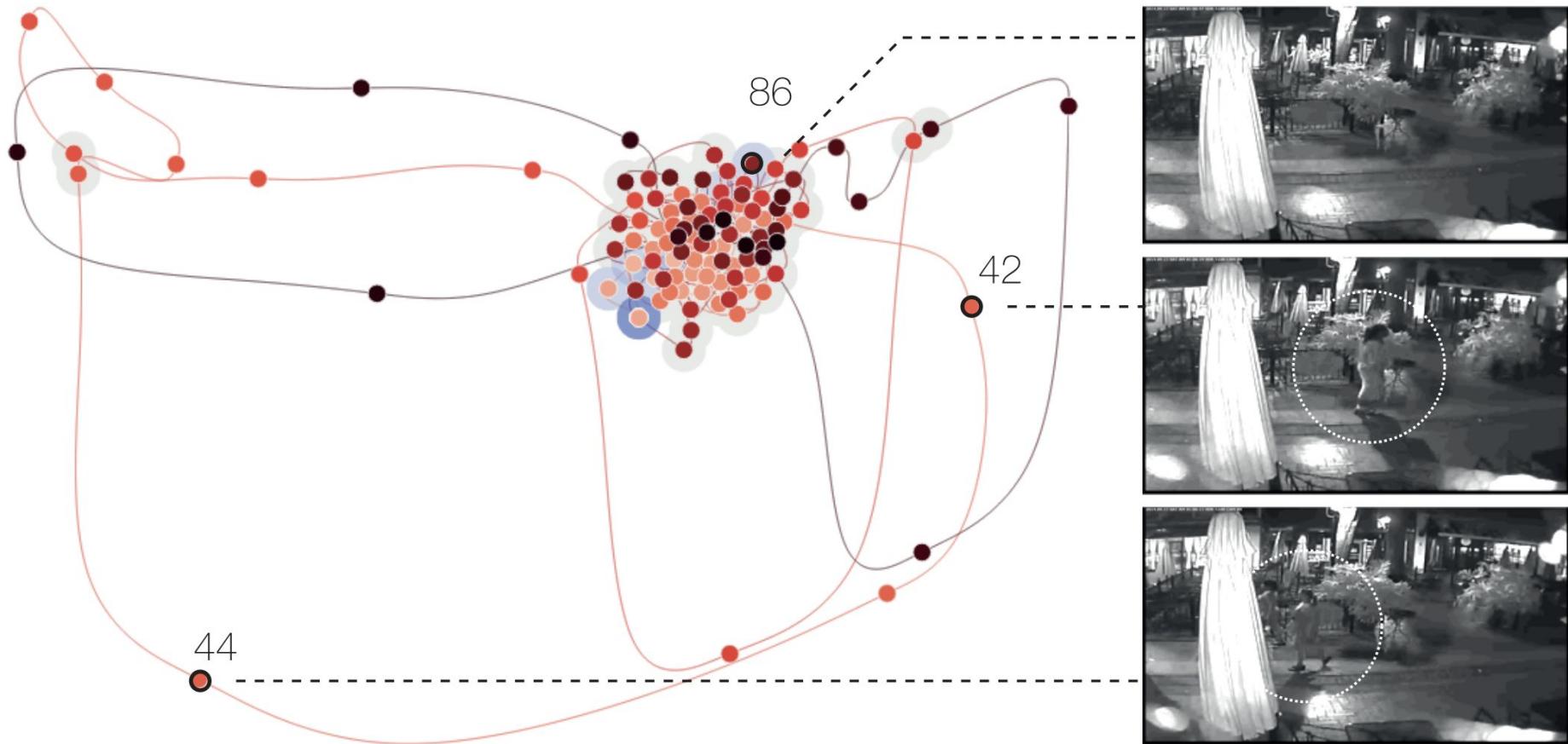
The temporal ordering of data cases is preserved.
Spatial proximity now indicates similarity.

Time Curves



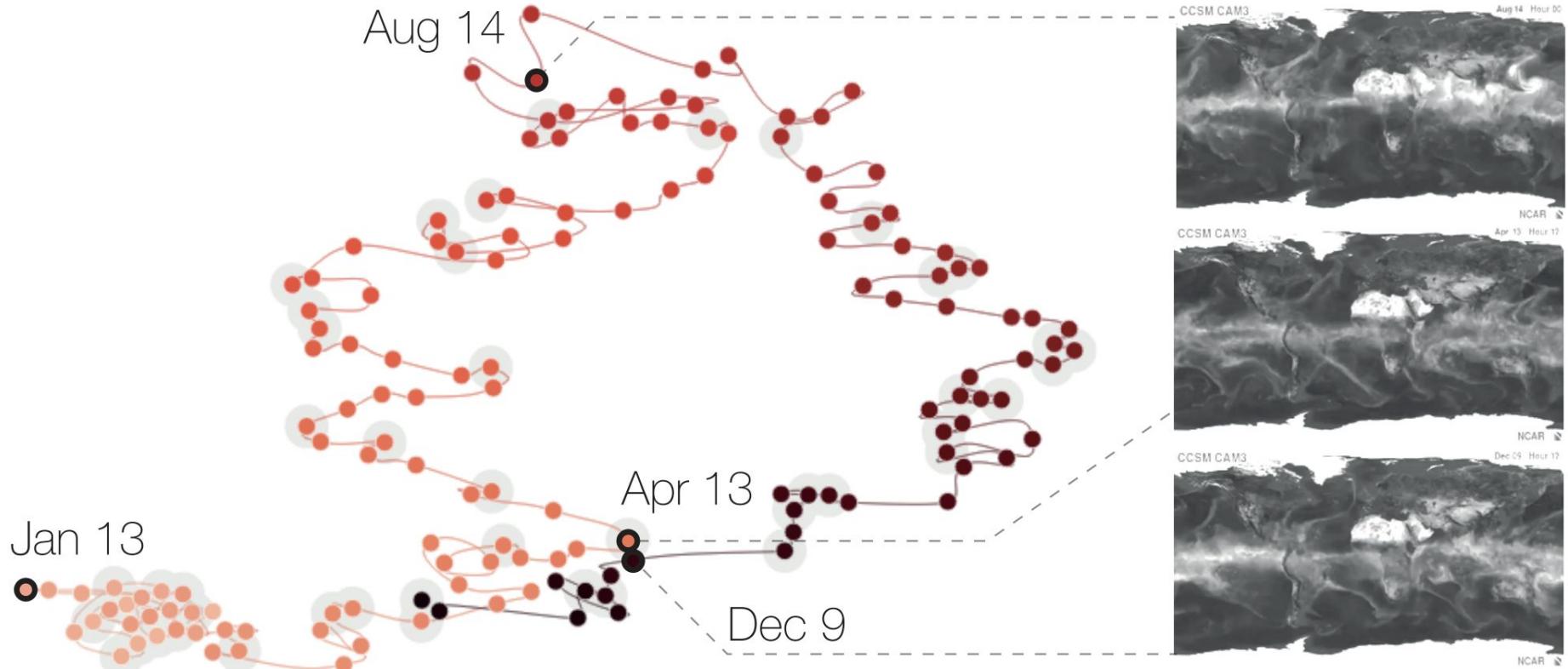
Bach, Benjamin, et al. "Time curves: Folding time to visualize patterns of temporal evolution in data." *IEEE transactions on visualization and computer graphics* 22.1 (2016).

Time Curves

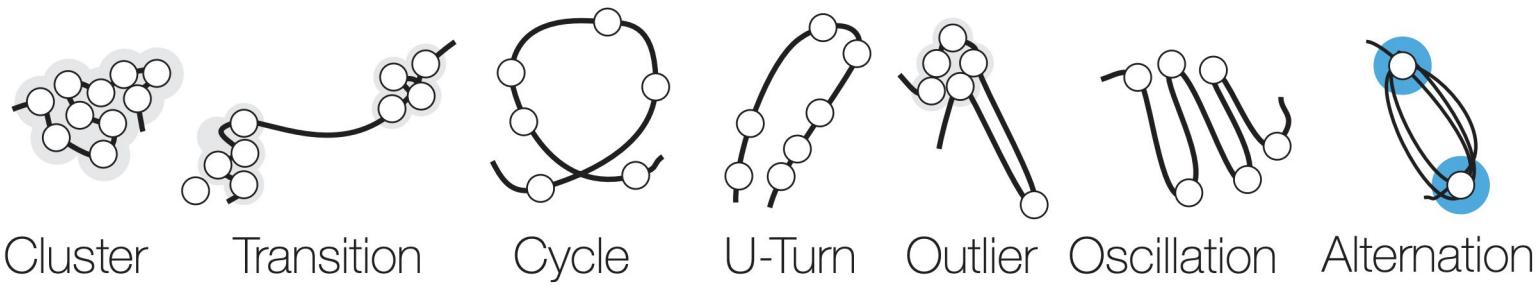


Bach, Benjamin, et al. "Time curves: Folding time to visualize patterns of temporal evolution in data." *IEEE transactions on visualization and computer graphics* 22.1 (2016).

Time Curves: Climate

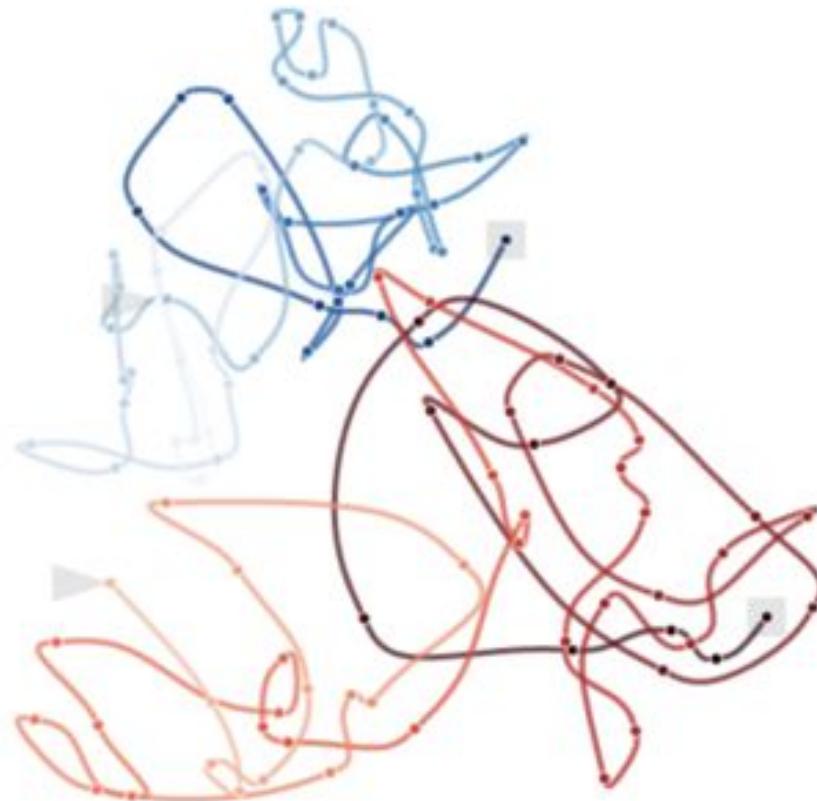


Time Curves: Visual Patterns



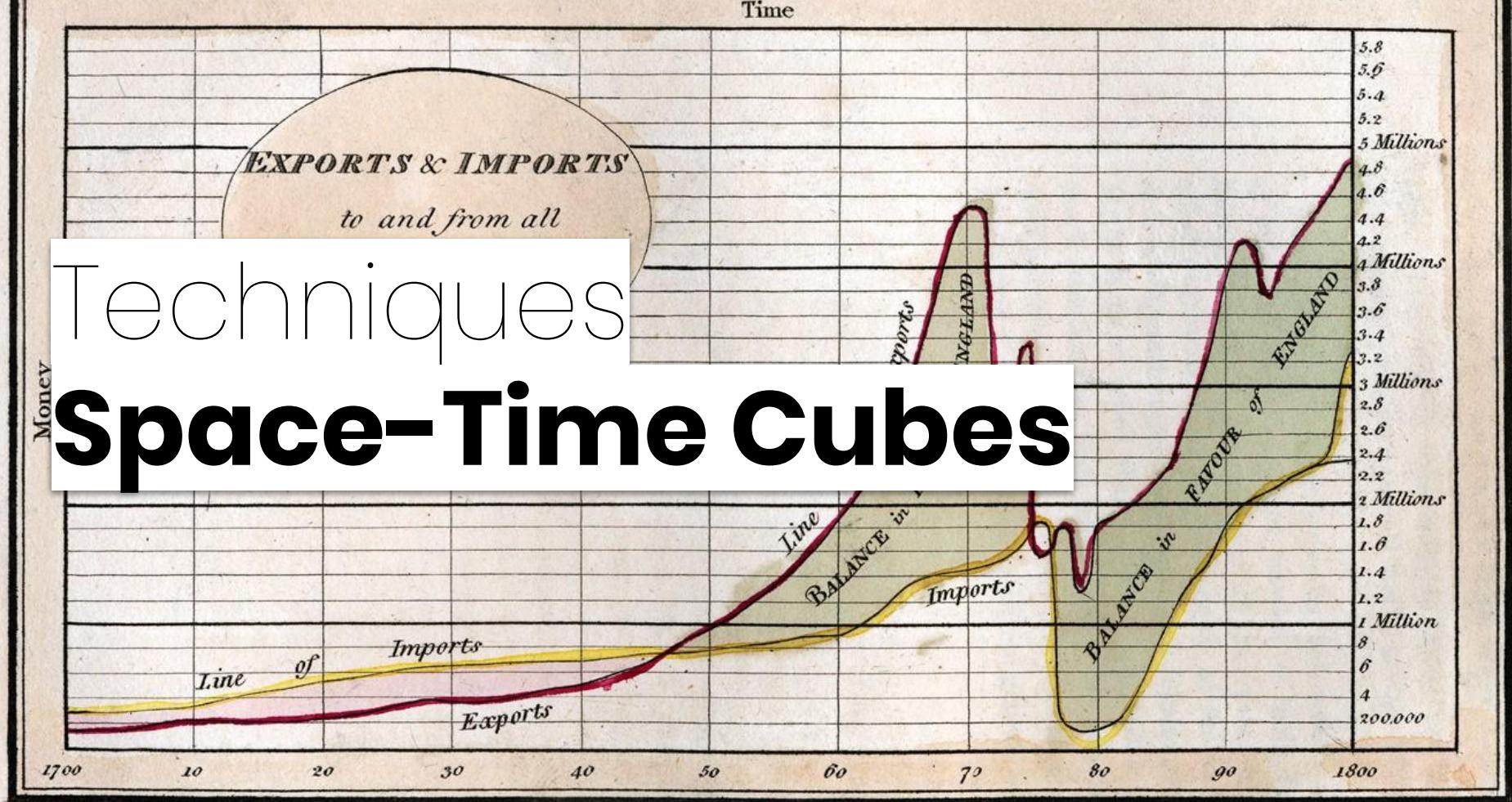
Time Curves

- + Amount of change
- + Signatures
- + Comparison
- Details
- Artifacts due to projection
- Non-trivial



Techniques

Space-Time Cubes



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Benjamin Bach

June 2020

<http://benjbach.me>
<https://datavis-online.github.io>

-- Not for external use --

Trajectories

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 et extrait

Paris, le 20 Novembre 1869

Les nombres d'hommes perdus sont représentés par les largesses des zones colorées à raison d'un millimètre pour dix mille hommes; ils sont de plus écrits en lettres sur ces 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 pris dans les ouvrages de M. Chiat, de Liger, de Tocordat, de Chambray et le journal intime 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 de l'Armée l'entraient du Maréchal Davout qui avaient été détachés sur Moscou au Nihilov et qui rejoignirent Orelle au Wilek, auquel bûjouje marcha avec l'armée.

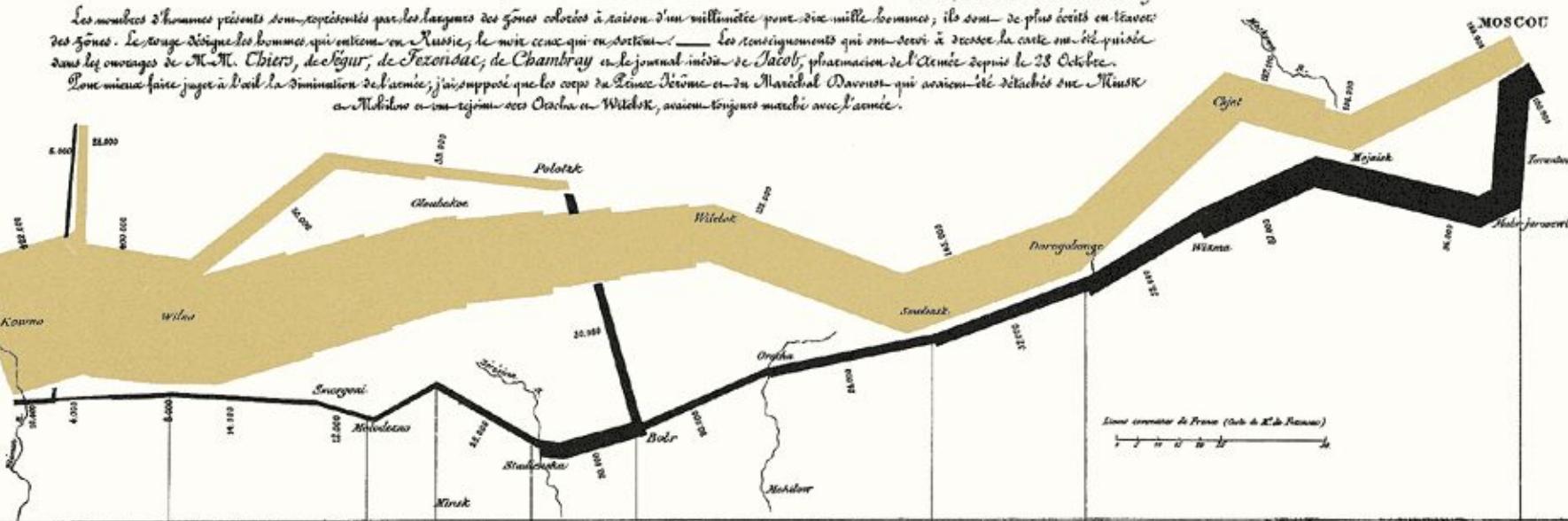


TABLEAU GRAPHIQUE de la température en degrés du thermomètre de Réaumur au dessous de zéro.

Les Cosaques passent au galop le Nilman, gelé.

- 16° le 2 X.^{me}

- 30° le 6 X.^{me}

- 24° le 1^{er} X.^{me}

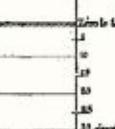
- 20° le 28 9.^{me}

- 11°

- 21° le 14 0.^{me}

- 8° le 9 9.^{me}

Fin le 11 1.^{me}



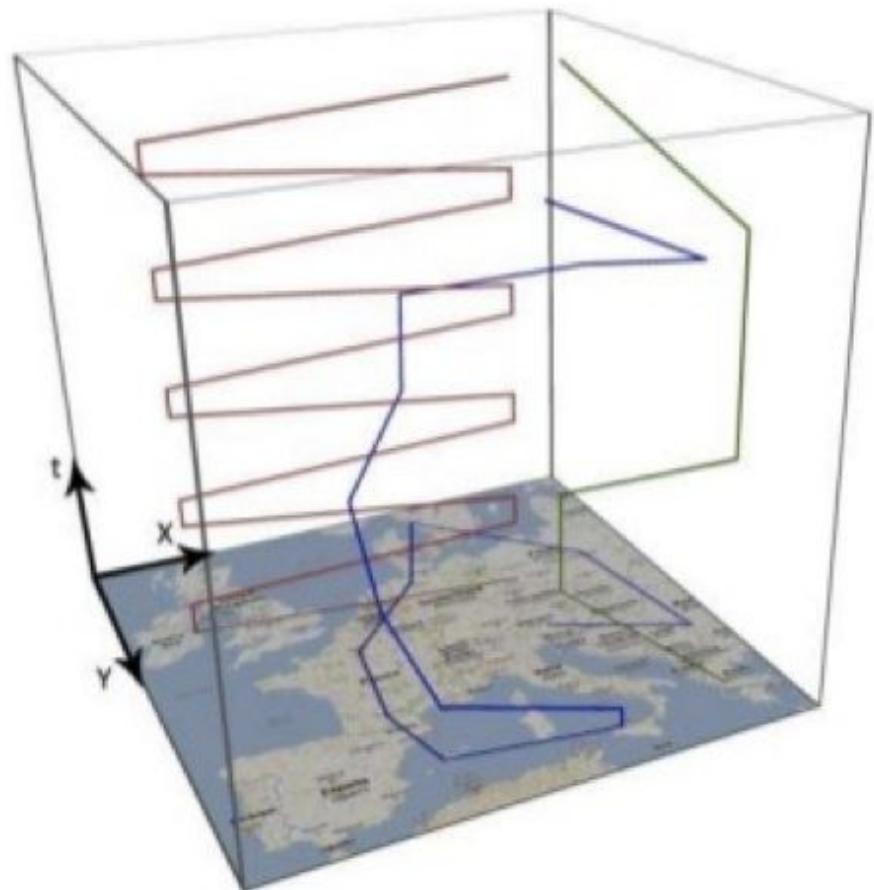
Imp. de Regnier et Courcier.

Charles Joseph Minard (1781-1870)

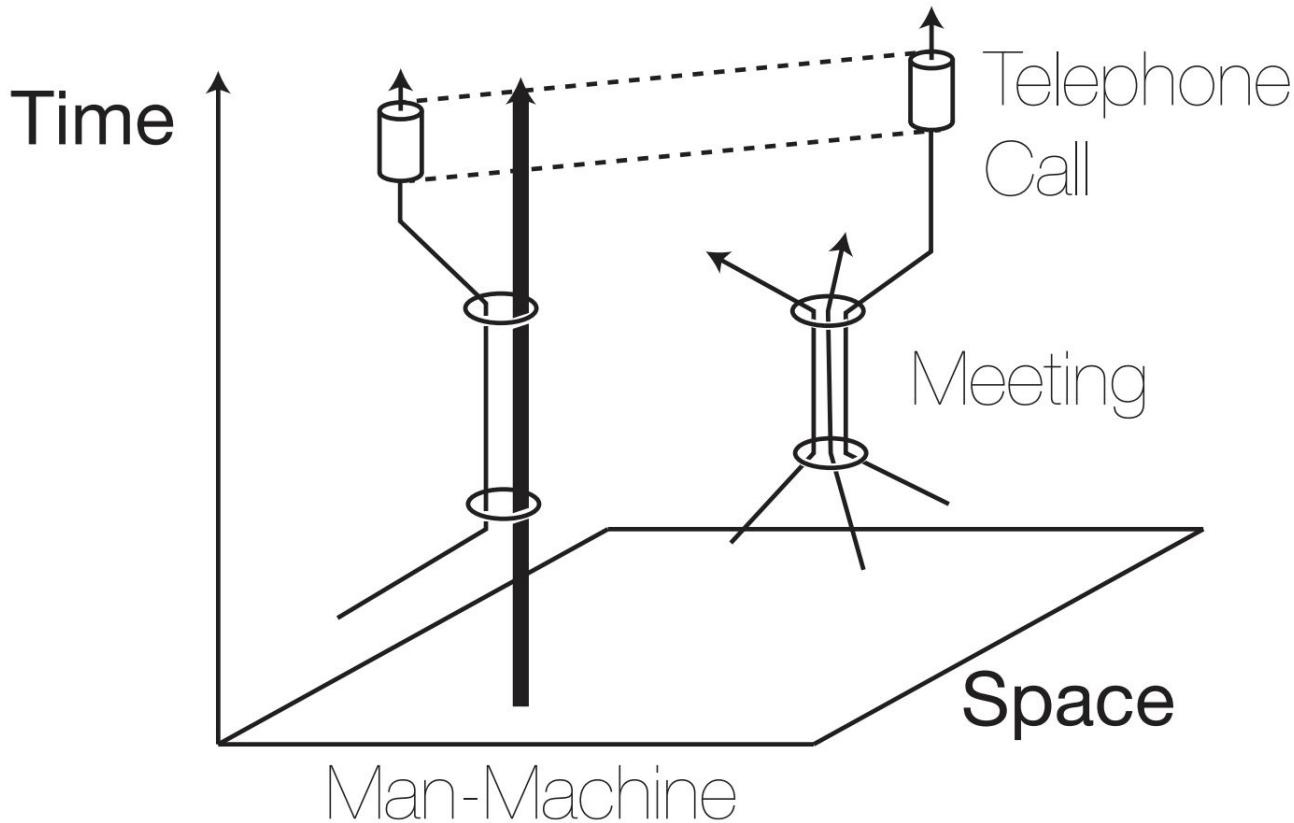
Space-Time Cubes



Space-Time Cubes



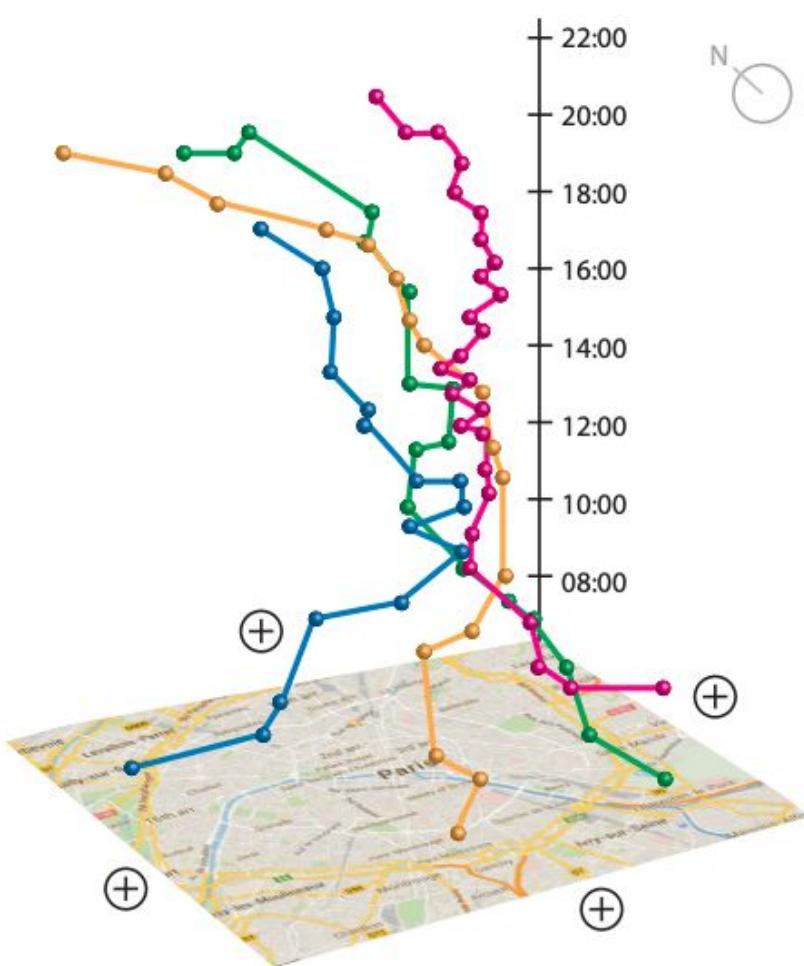
Space-Time Cubes



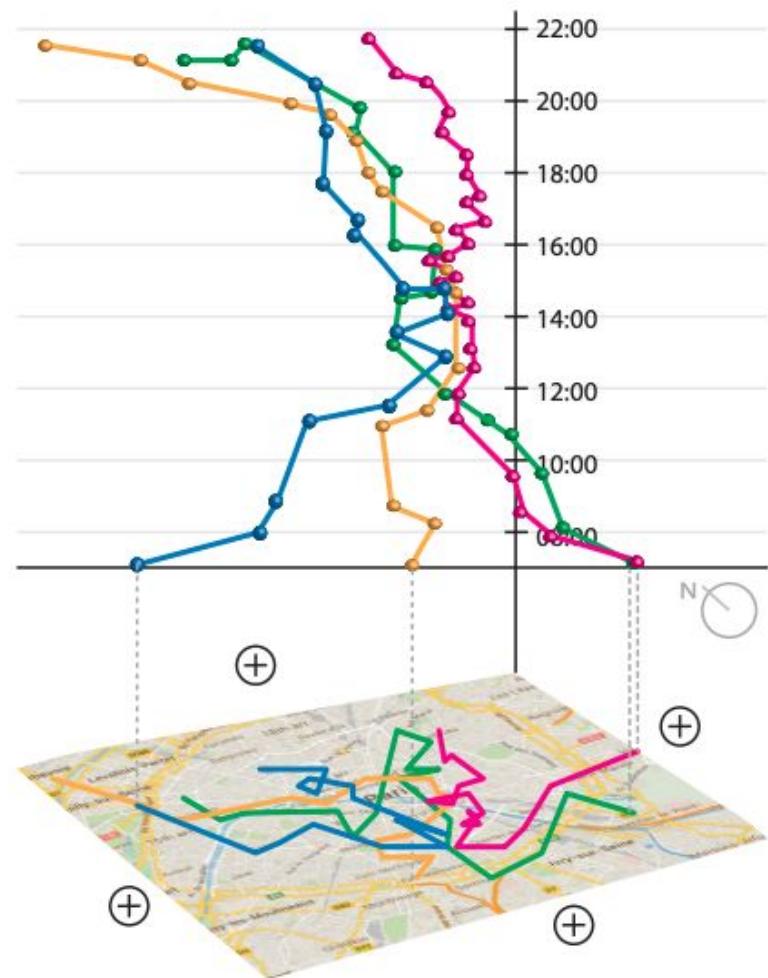
Ilägrstrand, Torsten. "What about people in regional science?." *Papers of the Regional Science Association*. Vol. 24. 1970.

Kraak, Menno-Jan. "The space-time cube revisited from a geovisualization perspective." *Proc. 21st International Cartographic Conference*. Citeseer, 2003.

Space-Time Cubes

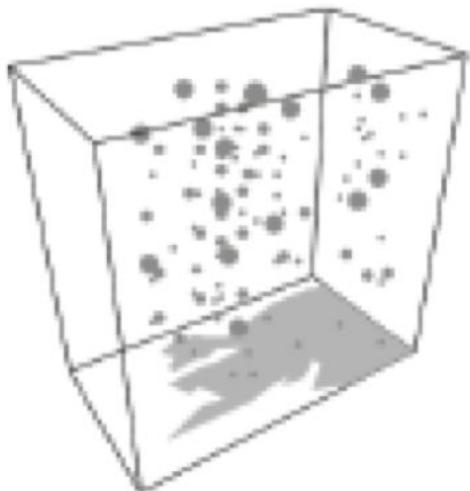


(a) 3D rendering

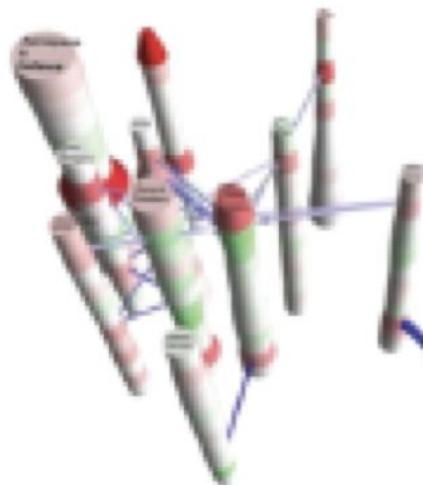


(b) Space flattening (on top)

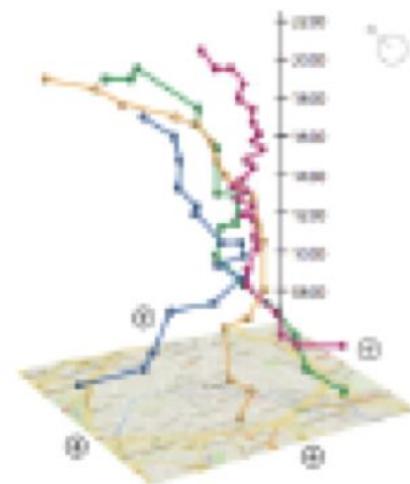
Space time cubes everywhere!



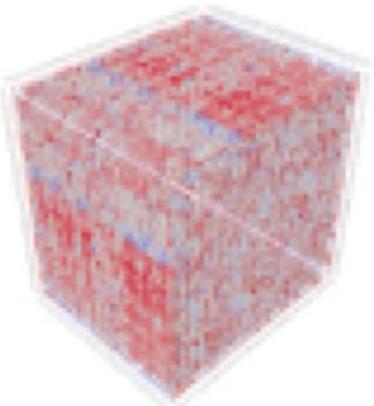
Earthquakes



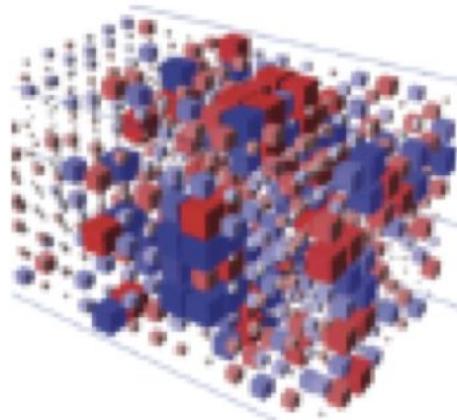
Finance network



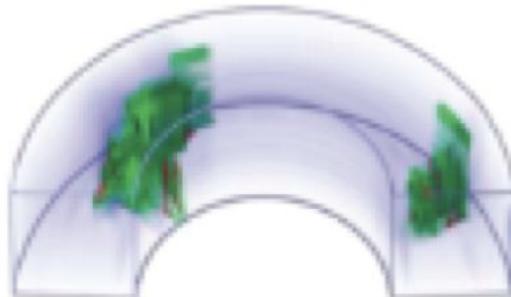
Person movement



Antenna
communication



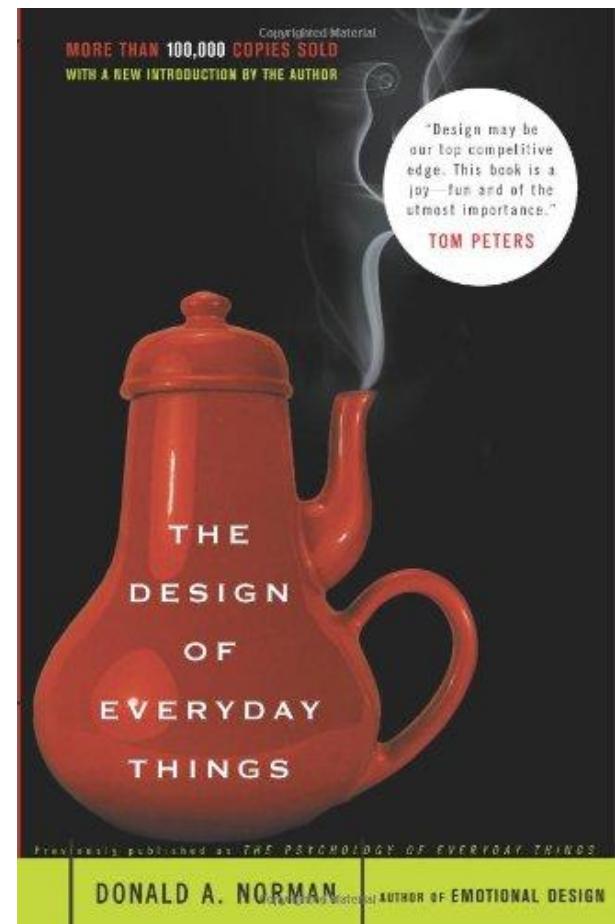
Brain connectivity



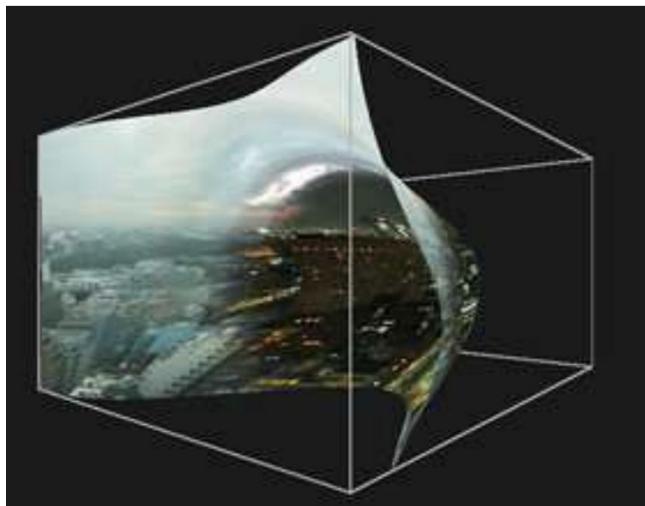
Surveillance video

A word on 3D visualization

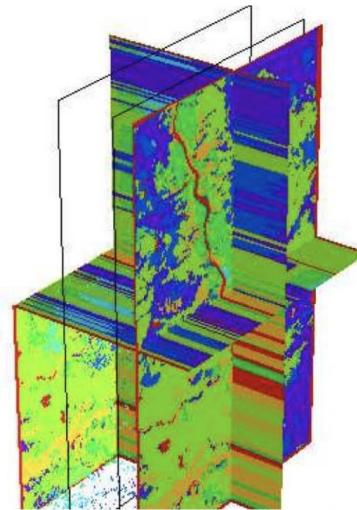
- Causes occlusion
 - Perspective distortion
 - Interaction required
 - Orientation might be tricky
-
- Use 3D as *interaction affordances*
 - Use 3D as *thinking tools and metaphors*



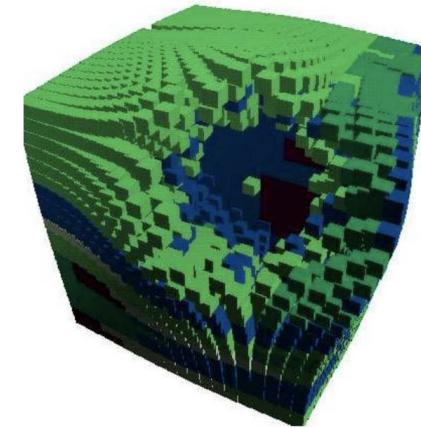
Interactive Exploration



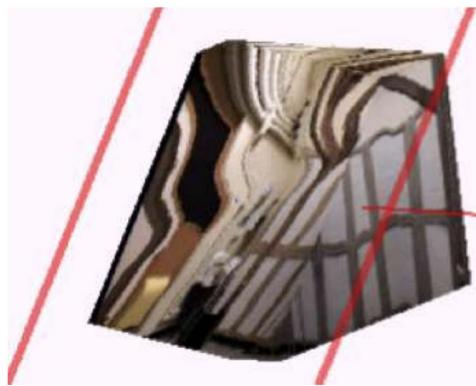
"Poke"-access



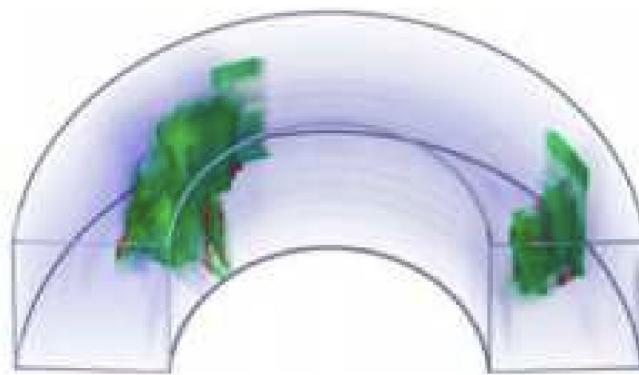
Cutting plane



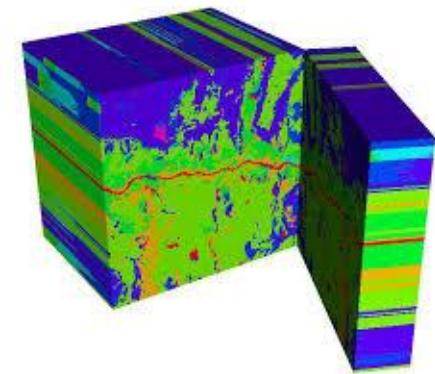
Mouse access



Cutting plane



Transparency
+ bending



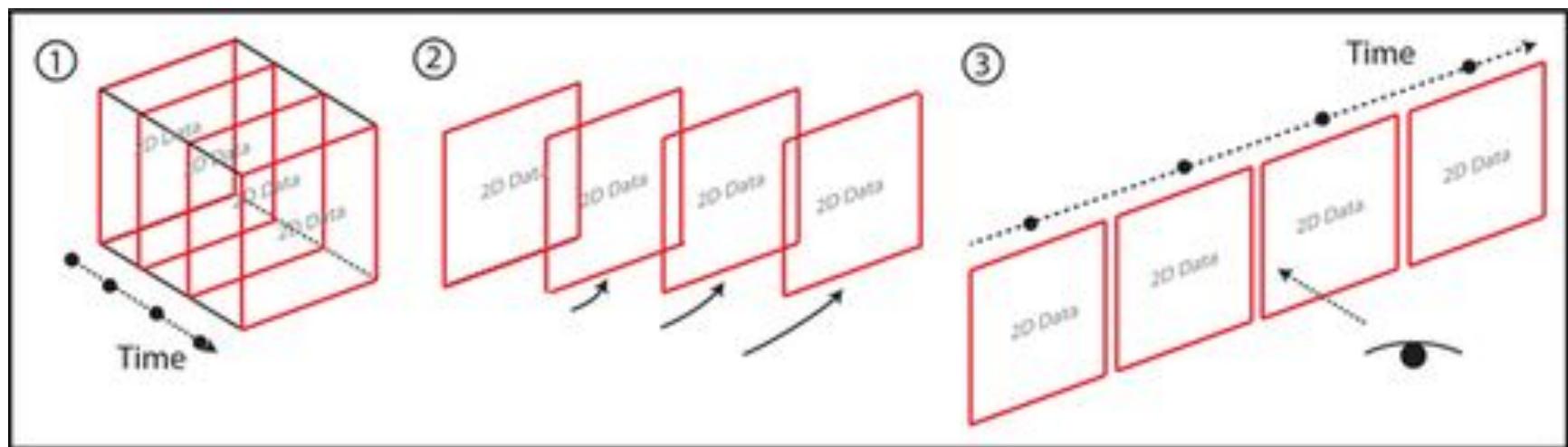
Opening

Interactive Exploration

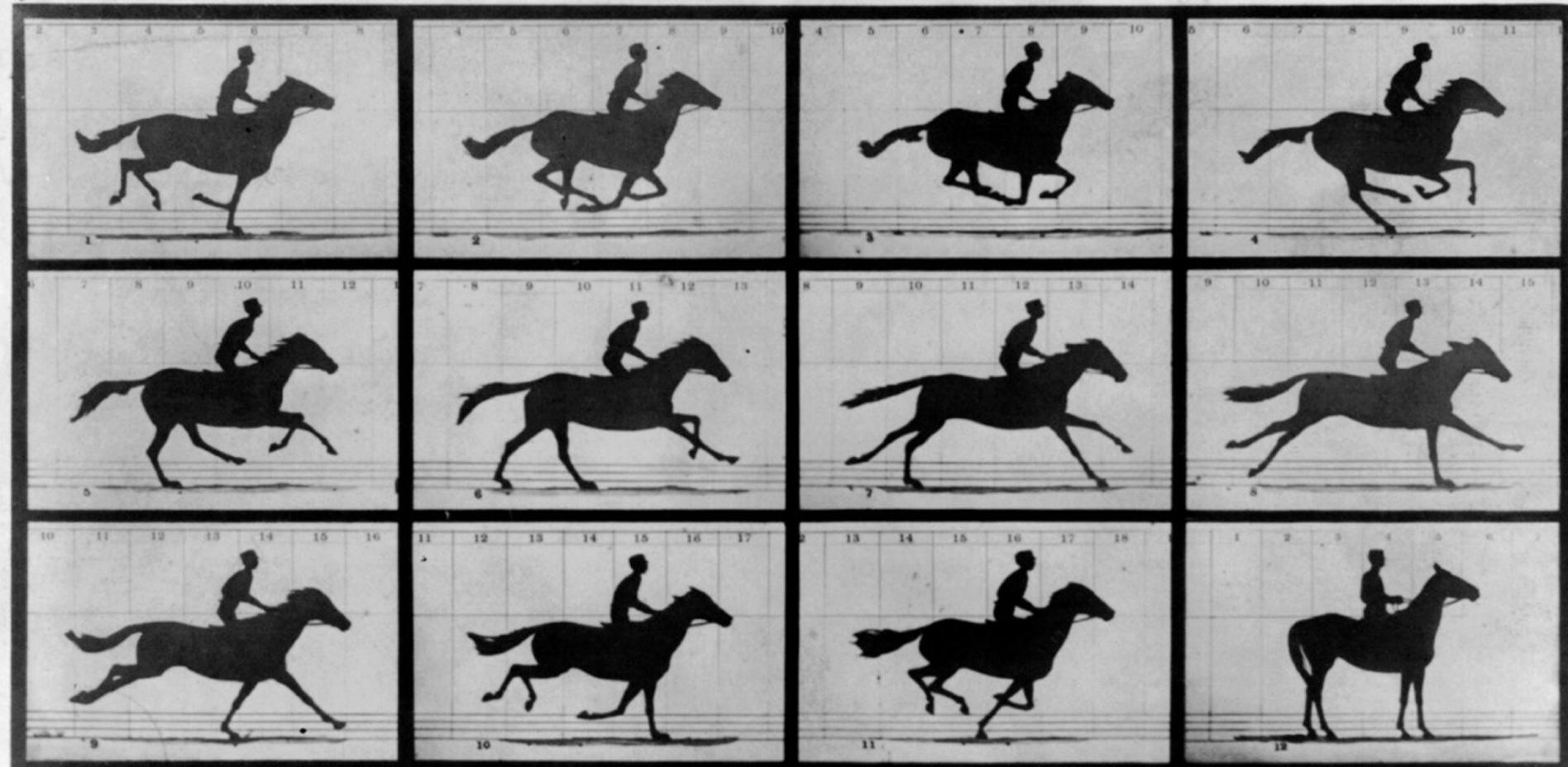


Small Time Multiples

Operations



Eadward Muybridge: Chrono photography



Copyright, 1878, by MUYBRIDGE.

MORSE'S Gallery, 417 Montgomery St., San Francisco.

THE HORSE IN MOTION.

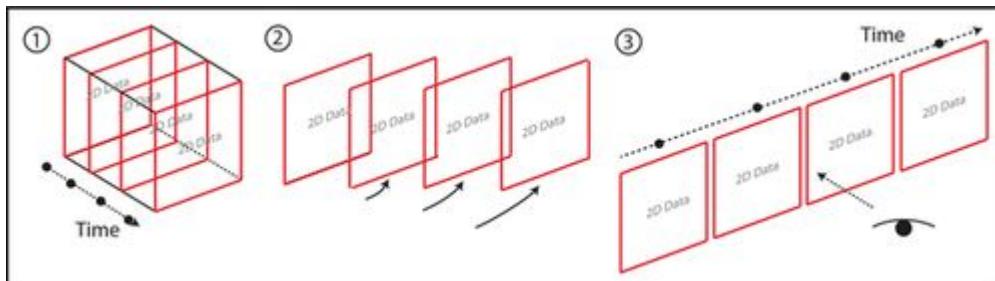
Illustrated by
MUYBRIDGE.

"SALLIE GARDNER," owned by LELAND STANFORD; running at a 1.40 gait over the Palo Alto track, 19th June, 1878.

The negatives of these photographs were made at intervals of twenty-seven inches of distance, and about the twenty-fifth part of a second of time; they illustrate consecutive positions assumed in each twenty-seven inches of progress during a single stride of the mare. The vertical lines were twenty-seven inches apart; the horizontal lines represent elevations of four inches each. The exposure of each negative was less than the two-thousandth part of a second.

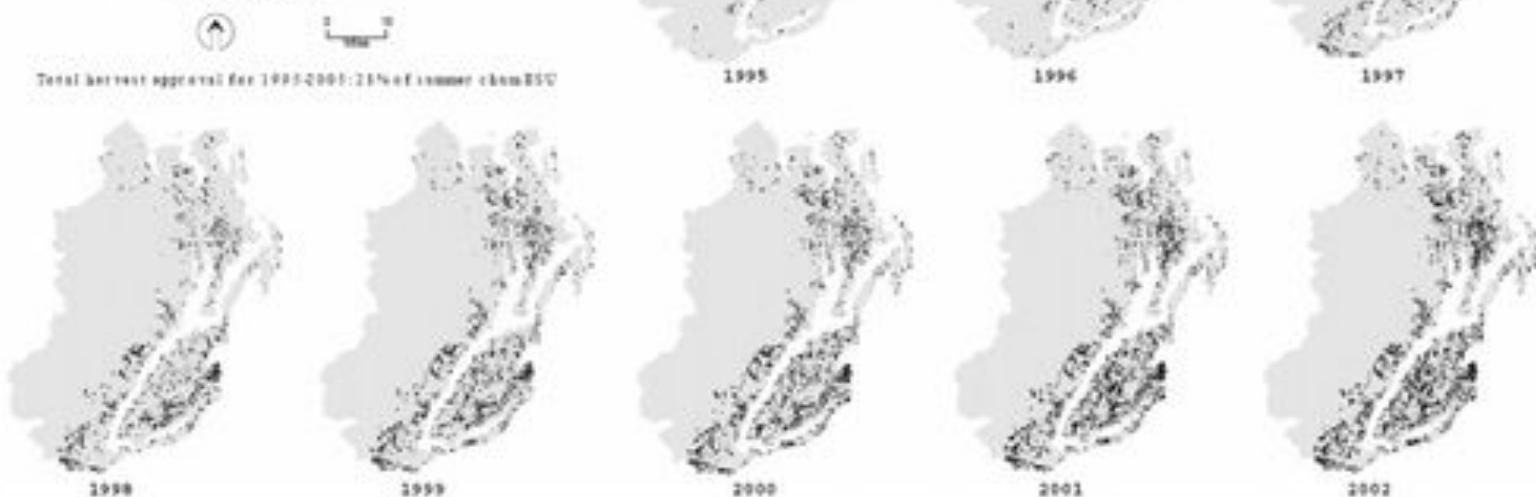
AUTOMATIC ELECTRO-PHOTOGRAPHIC

Small Multiples



Approved Harvest Applications By Year

Location: Head Coast timber claim EUC
Shows: Approved forest practice applications (FPA)
of type cutting or removing timber
and
Harvests in Olympic National Forest
Sources: Washington Dept. Natural Resources
U.S. Forest Service, Quill Creek
Dates: FPA approvals as renewal date
ONF harvest date



Flow Diagram Small Multiples

LÉGENDE — Quantités et couleurs pour chaque Pays de provenance.

	Etats-Unis	Inde (Indochine)	Océan	Egypte	Séné.	Total Amériques ou Asie/Afrique importées
Importations des années...	322.000 ^t	76.200 ^t	41.200 ^t	8.400 ^t	150.000 ^t	453.000 ^t
1858	348.000 ^t	108.000 ^t	27.000 ^t	8.400 ^t	150.000 ^t	423.000 ^t
1864	28.000 ^t	109.000 ^t	27.000 ^t	10.000 ^t	150.000 ^t	165.000 ^t
1865	34.000 ^t	109.000 ^t	27.000 ^t	12.000 ^t	150.000 ^t	163.000 ^t
1866	35.000 ^t	109.000 ^t	26.000 ^t	12.000 ^t	150.000 ^t	163.000 ^t
1867	34.000 ^t	109.000 ^t	26.000 ^t	12.000 ^t	150.000 ^t	163.000 ^t
1868	34.000 ^t	109.000 ^t	26.000 ^t	12.000 ^t	150.000 ^t	163.000 ^t
1869	34.000 ^t	109.000 ^t	26.000 ^t	12.000 ^t	150.000 ^t	163.000 ^t

Importations plus forte que celle de 1858, malgré les énormes réductions de la guerre civile, à cause de la mort de trois des flots.
 2. — Autre diminution due à la guerre civile, le chiffre est encore plus fort en quelques années récentes dépassant même l'Asie.
 3. — Importations des Etats-Unis dans les deux dernières années étant plus forte que les deux autres importations.
 4. — Importations des Etats-Unis dans les deux dernières années étant plus forte que celles d'Asie.
 5. — Diminution considérable par les deux dernières années d'importations de l'Asie.
 6. — Importations des Etats-Unis dans les deux dernières années dépassant plus fortement que celles d'Asie.
 7. — Importations des Etats-Unis dans les deux dernières années dépassant très fortement que celles d'Asie.
 8. — Importations des Etats-Unis dans les deux dernières années dépassant très fortement que celles d'Asie.
 9. — Importations des Etats-Unis dans les deux dernières années dépassant très fortement que celles d'Asie.

CARTE figurative et approximative des quantités de COTON BRUT importées en Europe en 1858 et 1864 et en 1865.

Dressée par M^e MINARD, Inspecteur Général des Ponts et Chaussées en retraite.
 Paris, le 14 Mai 1866.

Les tonnages de coton transportable sont représentés par les longueurs des voies éclusées à raison d'un millième pour cinq milles
 horaires, ce sont de plus exprimés par les nombres écrits au tracé de la voie et dont l'unité est visible toutes.

Les Cartes ont été dressées sur les Documents du Bureau Français, Anglais, Belges, Hollandais, Autrichiens,
 Le Dictionnaire du Commerce, le Trade of cotton de M.L.A. Munn, la revue commerciale et la publication Bradford de Liverpool,
 le Merchant's Almanac de New-York, l'annuaire de Londres, la curiosité Cope d'Alexandria etc.

Observation: Les importations sont un peu plus fortes que celles de la Carte previous je ne saurais offrir d'evidences toutes et que les Etats-Unis donnent en bleu les très petites importations de toute provenance, je n'en ai pas jusqu'à ce rapport.

De l'importation du Coton en 1865.

Les quantités commerciales de cette autre fois des plantes nécessaires depuis que la guerre civile des Etats-Unis d'Amérique a commencé à être déclarée, sont dans le présent.
 Toutes les portées de l'Océan par navigation des routes en Europe ont été calculées
 plus en 1865 qu'en 1858. L'expansion de l'Asie et de la Chine, ainsi que nombre
 considérables de l'Afrique ont rendu plus de voies et de routes nécessaires et ont
 amélioré les moyens de transport. Il y a donc une augmentation de
 importations de toutes sortes, mais à mesure que l'Asie devient une
 puissance commerciale plus grande pour les producteurs de cette plante tropicale.

Toute l'importation de 1865 est enroulée d'un cercle aux dimensions de ce
 qui a été dessiné au point.

En réalité, deux importations diverses, une forte correspondant au bleu. On voit
 une importante importation de Bruxelles et Anvers par le fil de l'Asie. De
 l'autre, de l'Asie à destination de l'Europe, il y a deux voies, une
 directe des marchands vers le royaume d'Irlande et une autre, qui passe
 par l'intermédiaire de routes de la Compagnie Portugaise Orientale et de la
 compagnie des Messageries Impériales.

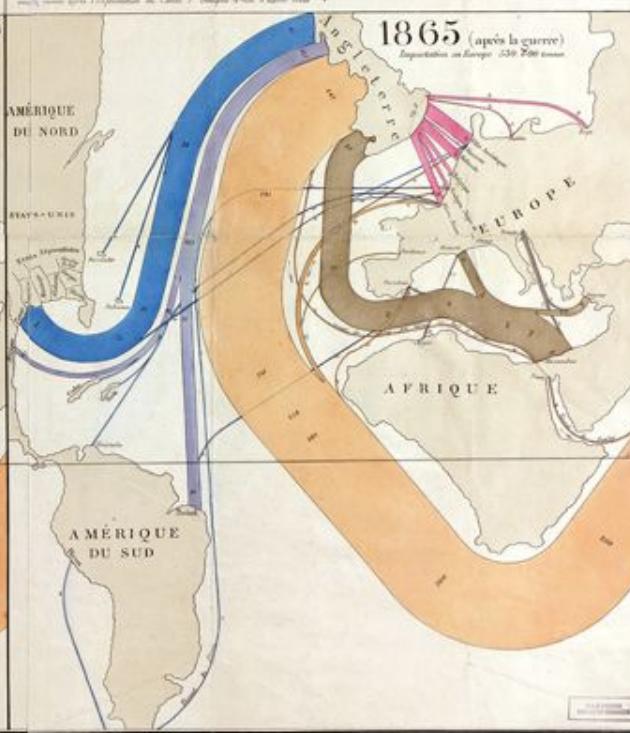
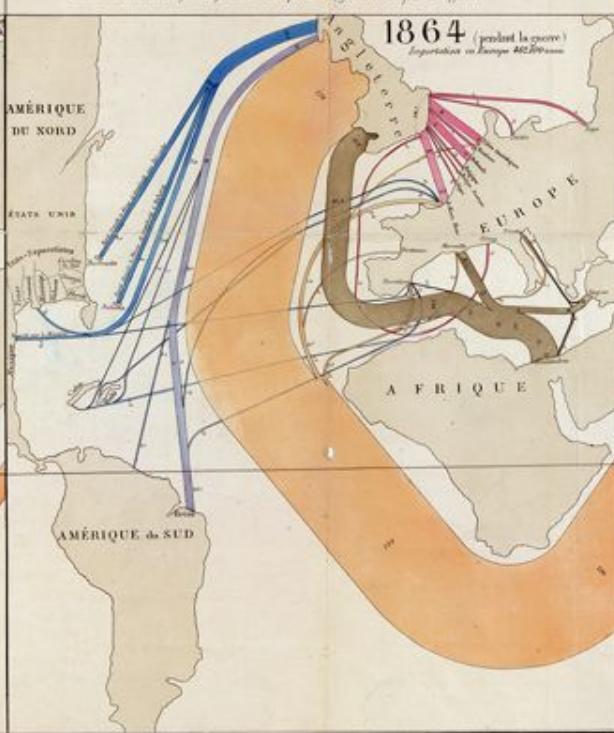
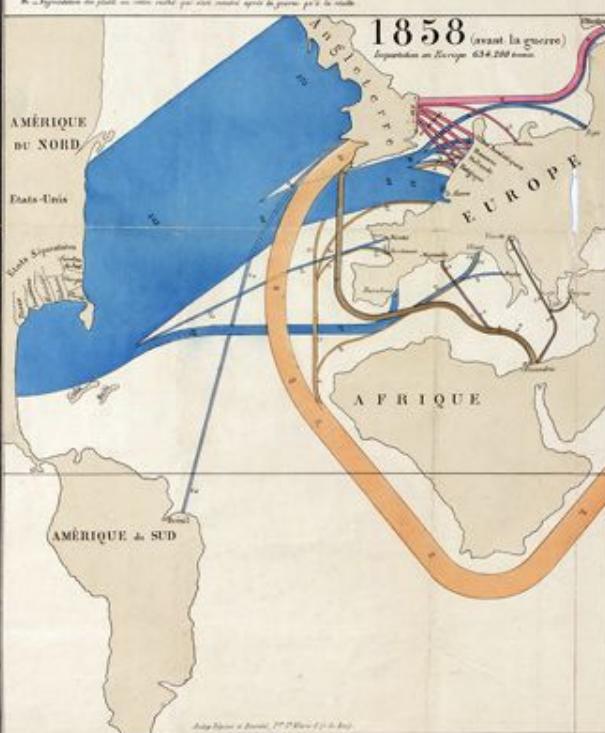
Cette carte a été dressée par l'ordre du Génie de l'École de Saint-Cyr, avec une
 carte moins ancienne après l'exploitation du Canal de Suez, mais celle
 qui a été dressée par l'ordre de l'École de Saint-Cyr.

possible pour le sens d'aller versant intéressant le Maroc et la Mer
 Caspienne. C'est ce qui est au point dans

Un autre sens consiste à la faire suivre des très longs producteurs
 de coton. L'Asie offre par conséquent le meilleur, mais dans le présent,
 tout ce qui est nécessaire est d'expliquer comment l'Asie, alors que
 l'Europe, est devenue plus de voies et de routes et que l'Asie a
 pris un nombre de marchands assez nombreux à travers l'Europe. Il y a donc une augmentation
 importante des importations de toutes sortes, surtout dans les temps commerciaux,
 rendant à toute force un peu des importations compliquées qu'il y a dans un certain
 sens de la sorte. L'une et l'autre sont en effet connexes avec une autre
 qui est la guerre civile.

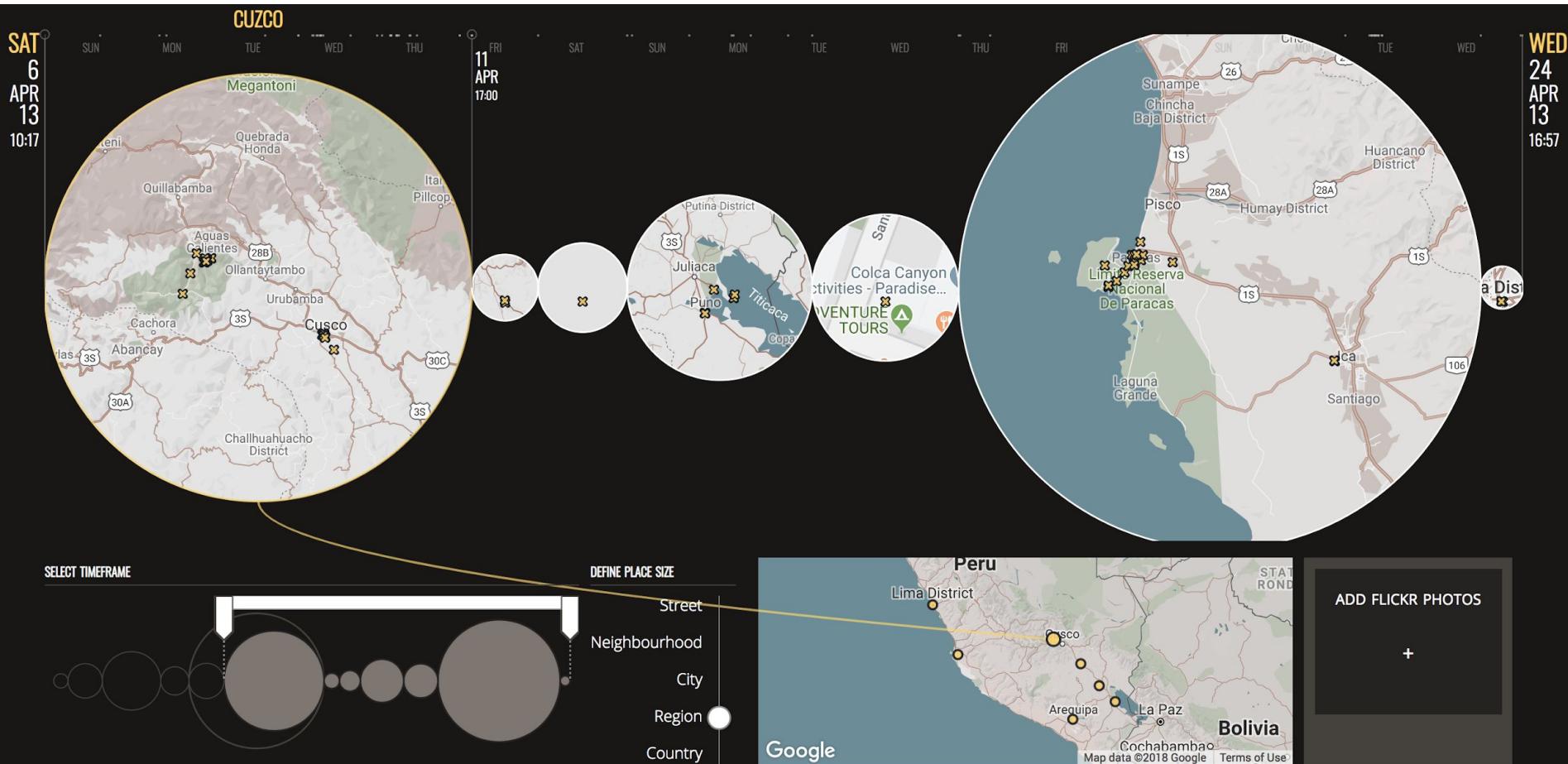
Voilà les grandes forces productrices, quant aux détails, nécessairement
 qui se rattachent presque à l'Asie. Il n'y a pas probable que ce pays entende
 dans la nature. Mais l'Asie est d'une sorte envoi la nature pourra également
 à la vie de quatre millions de ses habitants. Mais dans l'ensemble entre
 les producteurs russes, ces personnes sont utilisées pour le pays d'Europe.
 et pour servir l'Europe, une personne capable de faire un certain
 travail pour l'Europe.

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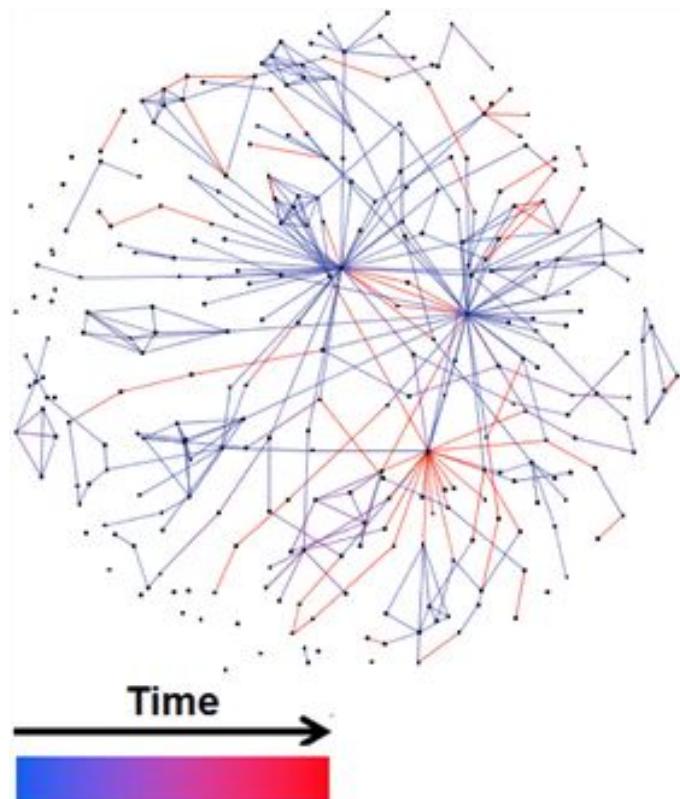
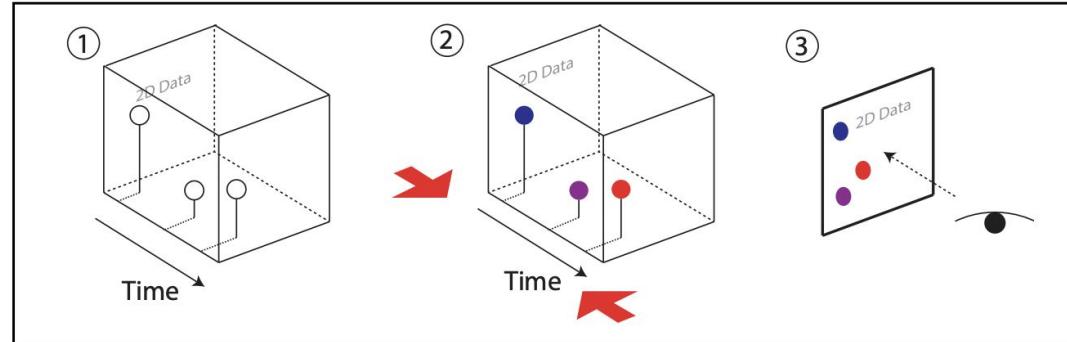
Joseph Minard

Small Multiples



Thudt, Alice, Dominikus Baur, and Sheelagh Carpendale. "Visits: A Spatiotemporal Visualization of Location Histories." *EuroVis (Short Papers)*. 2013.

Coloring+ Flattening

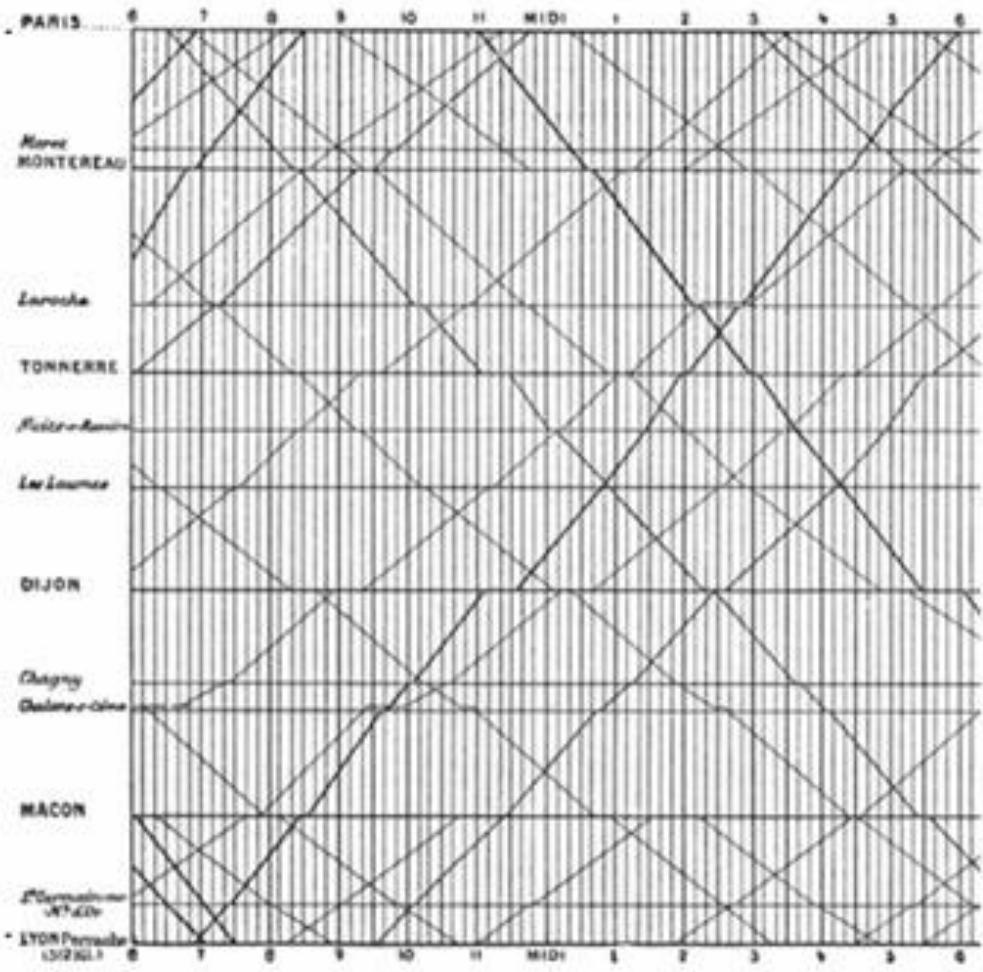
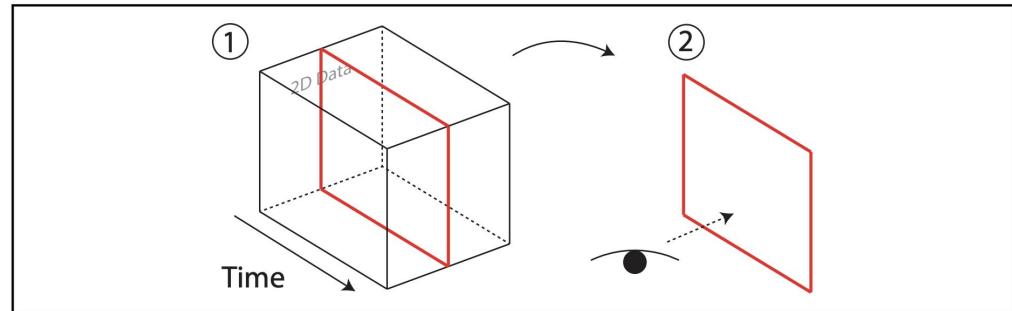


(a)

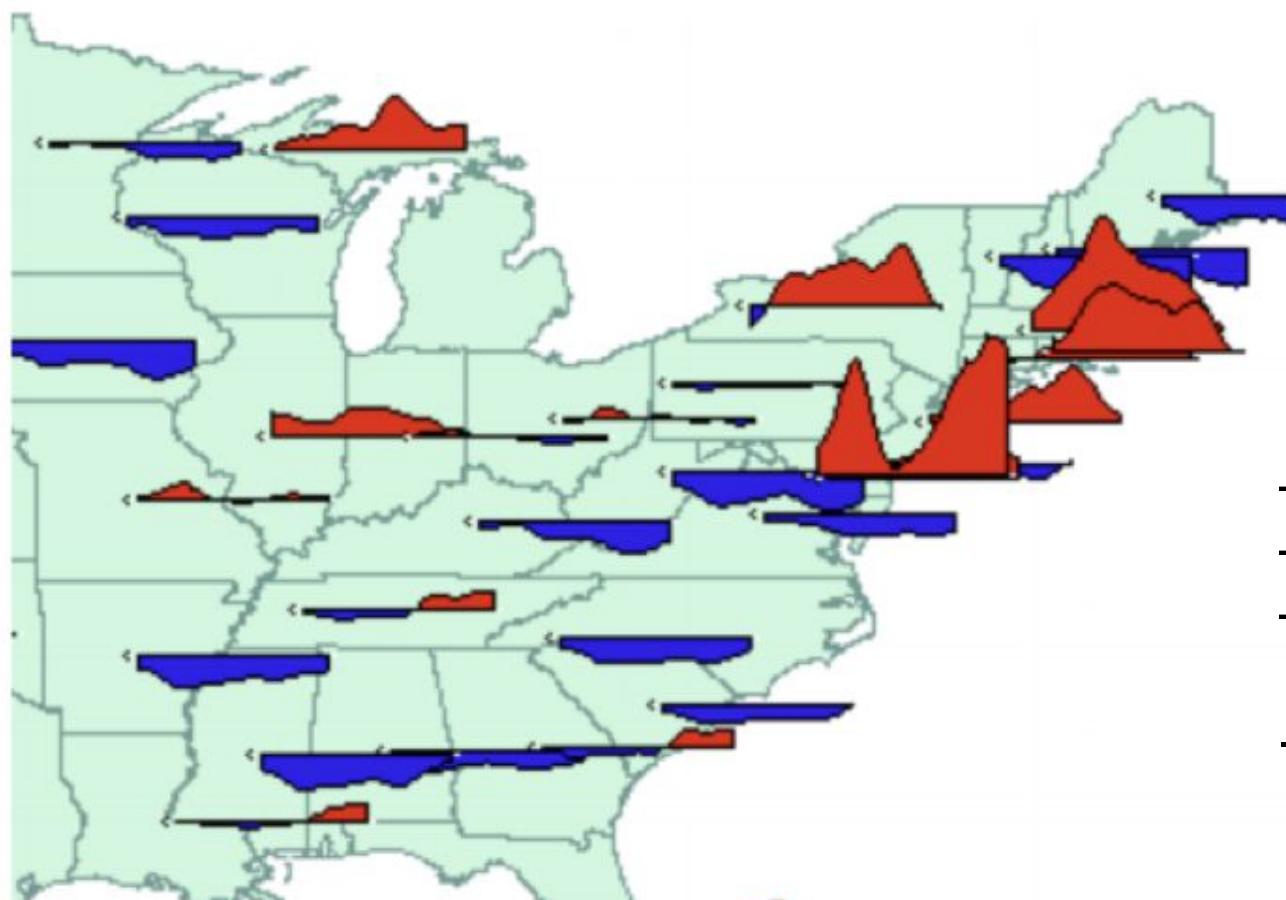
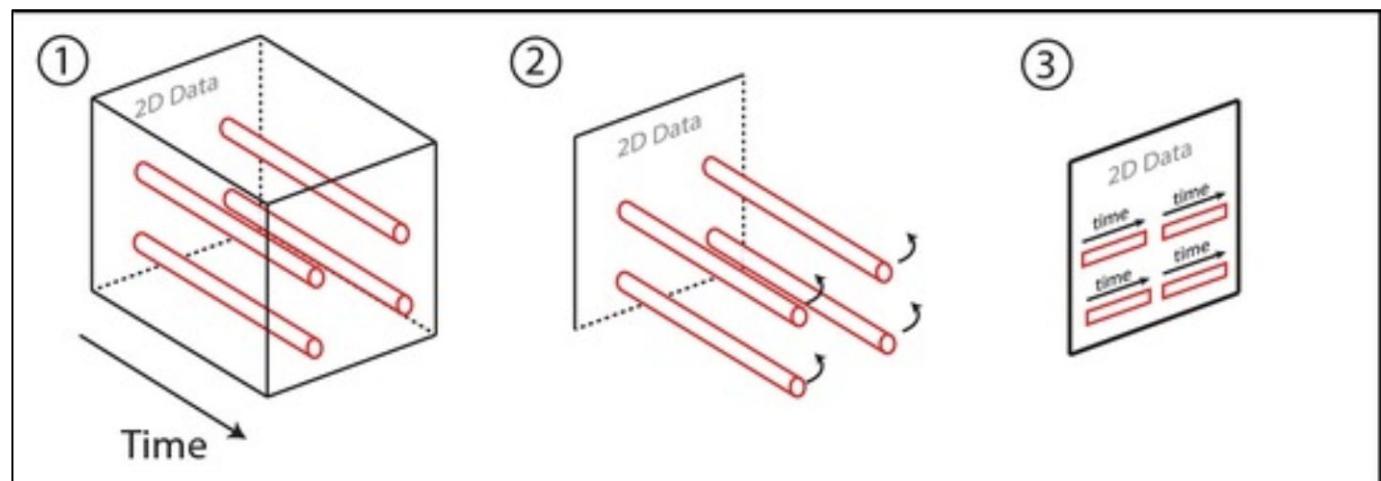


(b)

Cross-cutting

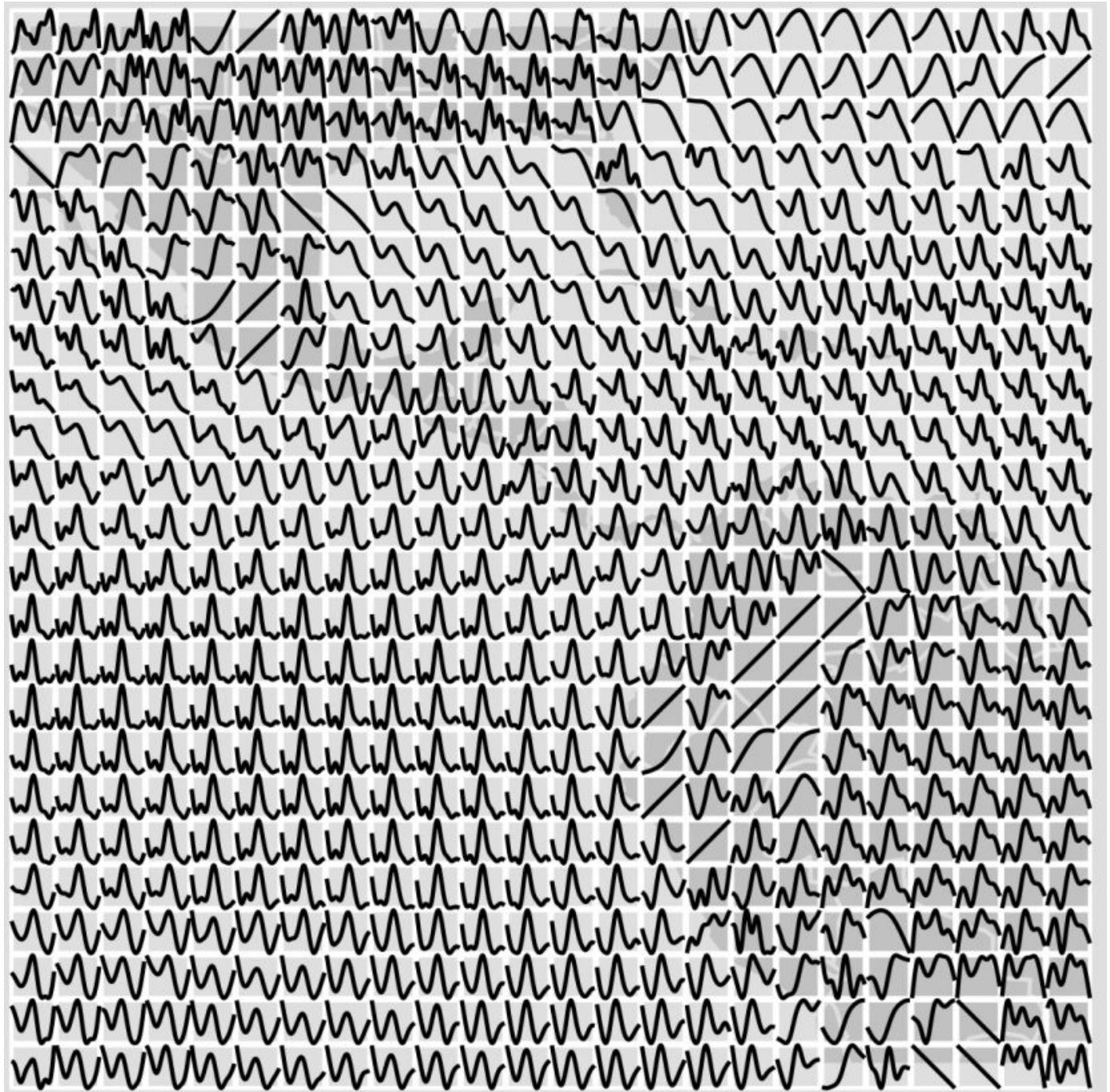


"Drilling"



- + Compare regions
- + Look-up regions
- + Details on regions
- Occlusion

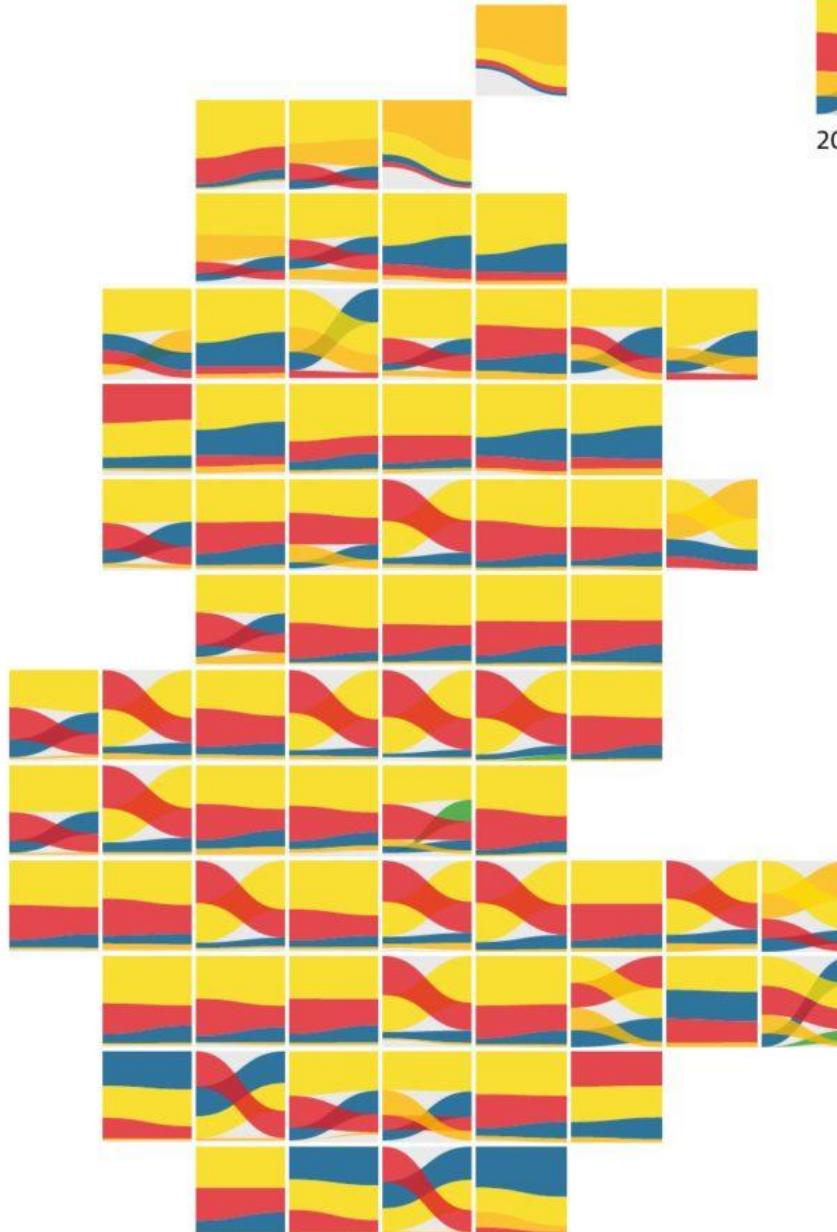
Drilling: Glyph Maps



<https://vita.had.co.nz/papers/glyph-maps.pdf>

How Scotland's political geography changed, seat by seat

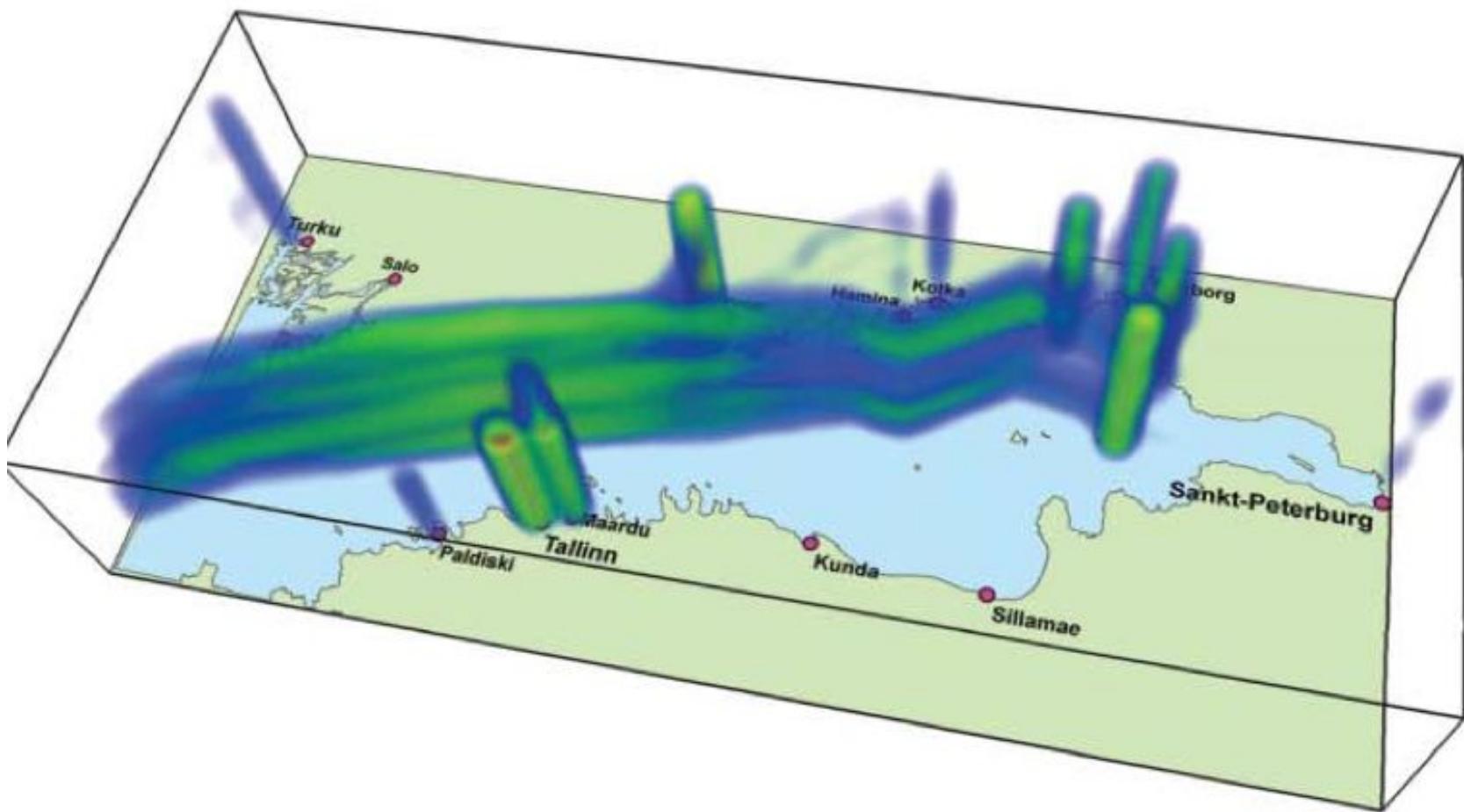
Drilling: Geo-flow



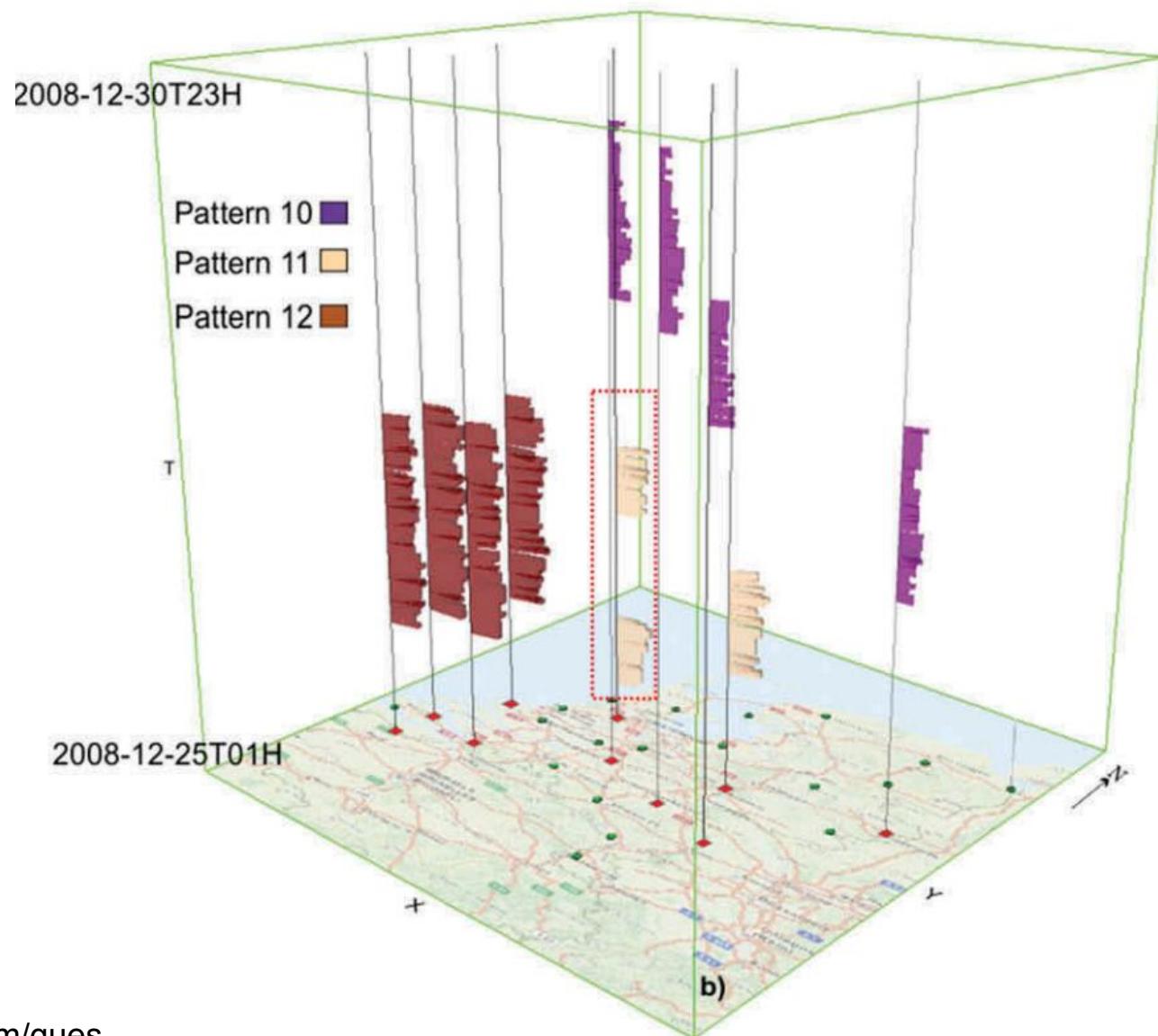
- + Compare regions
- + Look-up regions
- + Details on regions

- Compare far away glyphs
- Glyphs can become small

3D Renderings: density maps

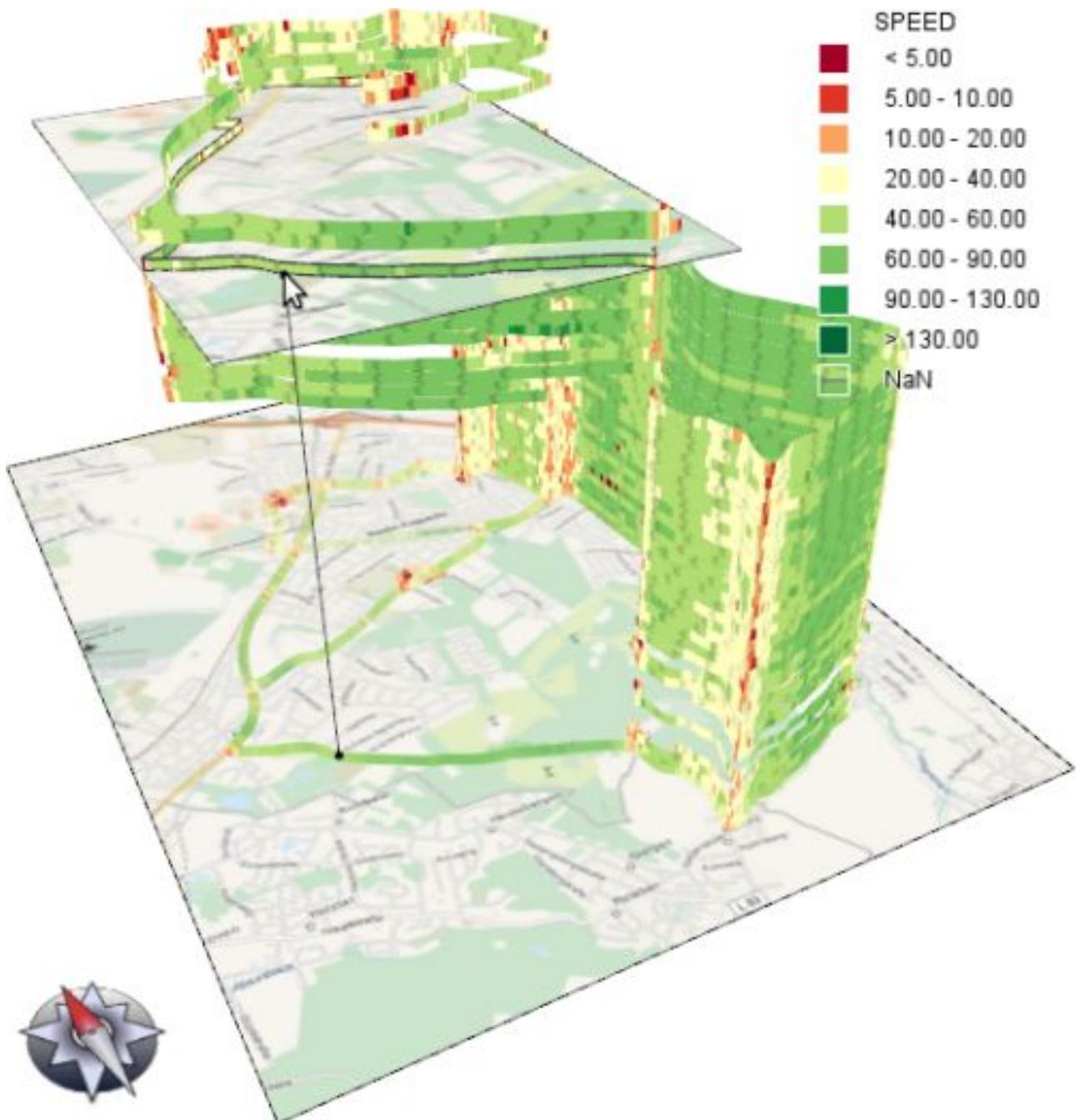


3D + drilling



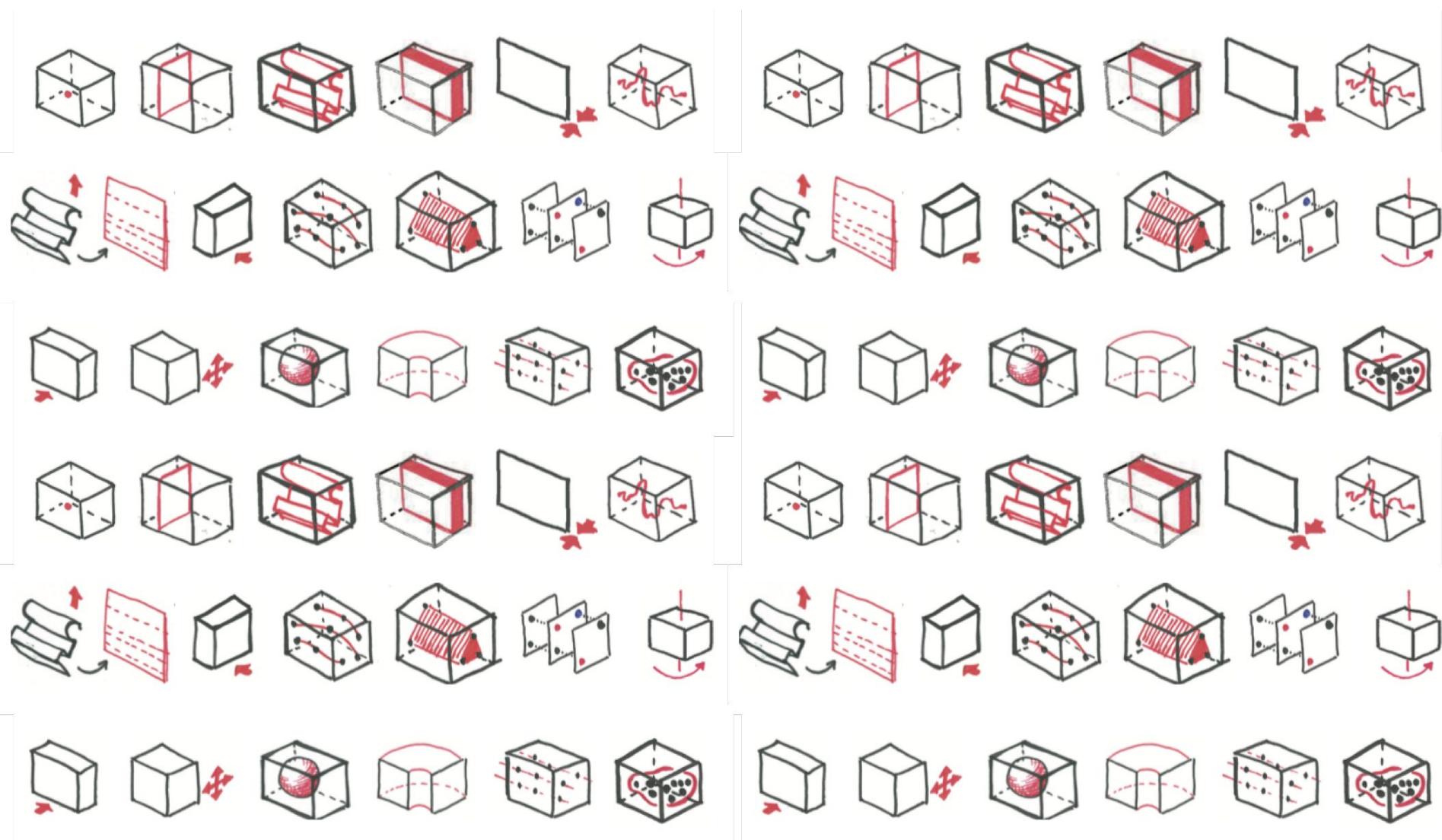
<https://gis.stackexchange.com/questions/202882/create-space-time-cube-in-arcgis-for-desktop>

Trajectory Wall



Andrienko, G., Andrienko, N., Schumann, H., & Tominski, C. (2014). Visualization of trajectory attributes in space–time cube and trajectory wall. In *Cartography from Pole to Pole* (pp. 157-163). Springer, Berlin, Heidelberg.

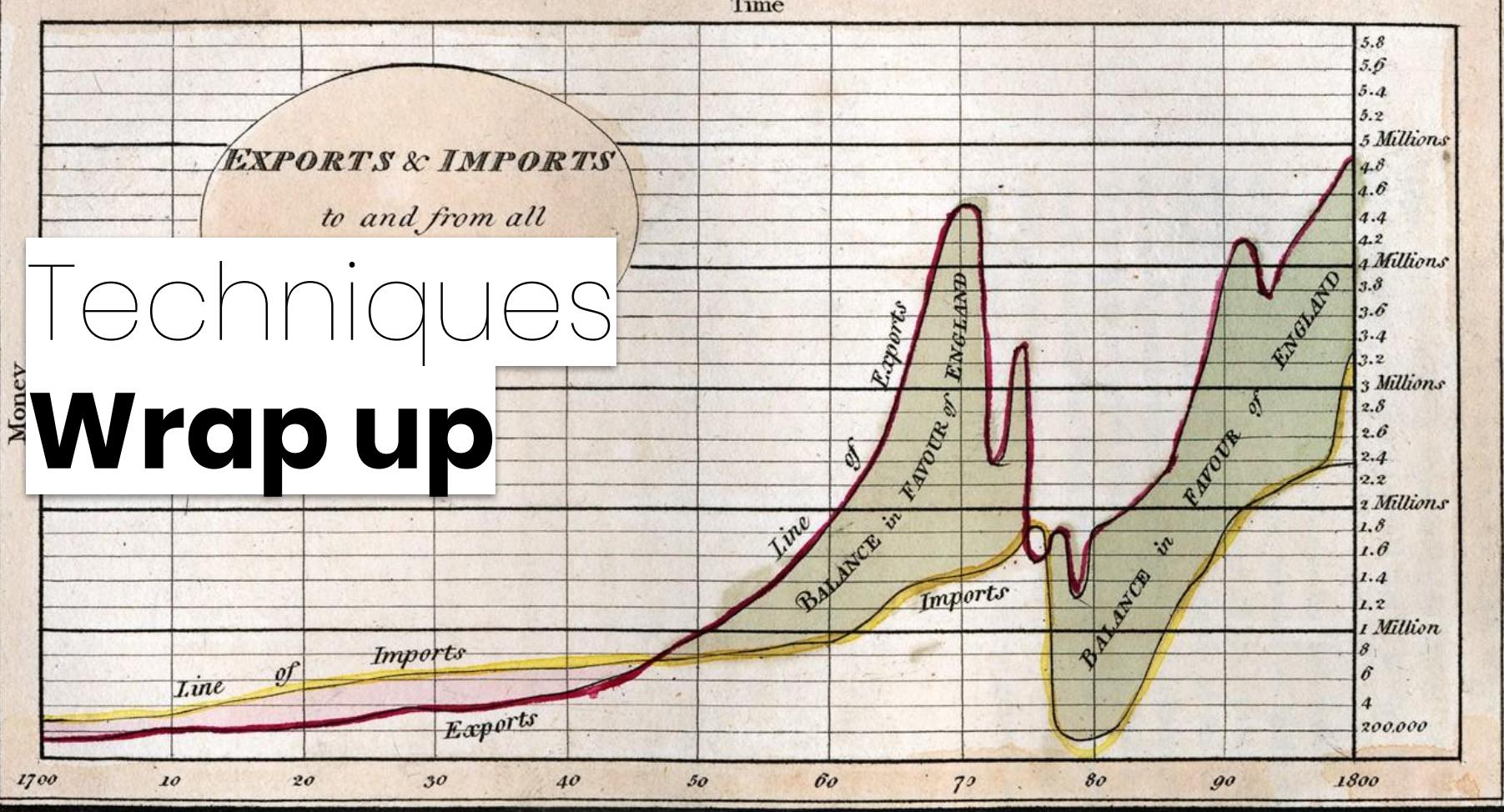
More operations



Khronos Projector



<https://www.youtube.com/watch?v=dZN2ICTRWBU>



Online Course
Data Visualization
for Professionals



THE UNIVERSITY
of EDINBURGH

Benjamin Bach

June 2020

<http://benjbach.me>
<https://datavis-online.github.io>

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Outline

How to visualize temporal data?

- Time is a complex medium
- Time in combination with other data types
- Event data: time lines
- Time series: dual-scales, cycle plots, heatmap
- Many time series: horizon graphs
- Multidimensional temporal data: connected scatterplots
- Geospatial data: space-time cubes
- Similarity data: time curves

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Further Reading

- Alberto Cairo: **The Truthful Art: Chapter 8: Revealing Change**
- Aigner, Wolfgang, et al. **Visualization of time-oriented data.** Springer Science & Business Media, 2011.
- Bach, Benjamin, et al. "**A descriptive framework for temporal data visualizations based on generalized space-time cubes.**" *Computer Graphics Forum.* Vol. 36. No. 6. 2017.
- Rosenberg, Daniel, and Anthony Grafton. **Cartographies of time: A history of the timeline.** Princeton Architectural Press, 2013.
- Brehmer, Matthew, et al. "Timelines revisited: **A design space and considerations for expressive storytelling.**" *IEEE transactions on visualization and computer graphics* 23.9 (2016): 2151-2164.

