VISUALISATION TECHNIQUES FOR TEMPORAL INFORMATION

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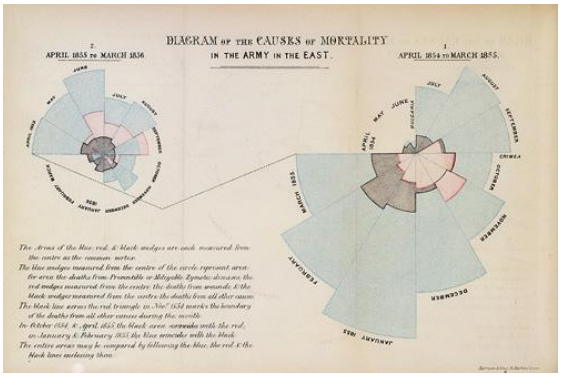
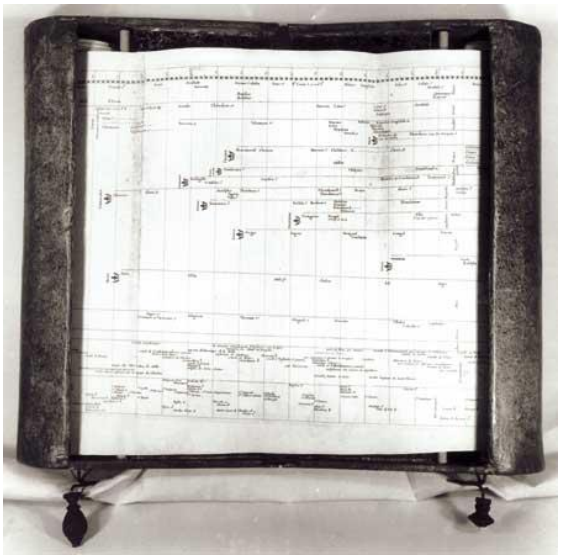
This document is a high level overview of graphical representations of temporal information. It is intended to be a short personal guide to the relevant literature and applications. It is intended to encourage further reading and research, rather than being a definitive review.

GRAPHICAL REPRESENTATIONS OF TEMPORAL INFORMATION

I've trawled through several historical reviews[1], looking for timeline innovations. Most early representations of time were cyclical[2]. Here is a great relatively recent example by Florence Nightingale.



Within the of historic evolution of timelines[3] the first linear axis timelines appeared around the mid 18th century.



The vertical dimension of the main data area is almost always used to group related types of information. Horizontal lines denote duration, or related events. Vertical bands help the eye line up and compare information, as well as

This basic format is still the most commonly used approach to representing temporal information.

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[1] For example, "Milestones in the history of thematic cartography, statistical graphics, and data visualisation", Michael Friendly May 1 2007. http://www.math.yorku.ca/SCS/Gallery/milestone/milestone.pdf

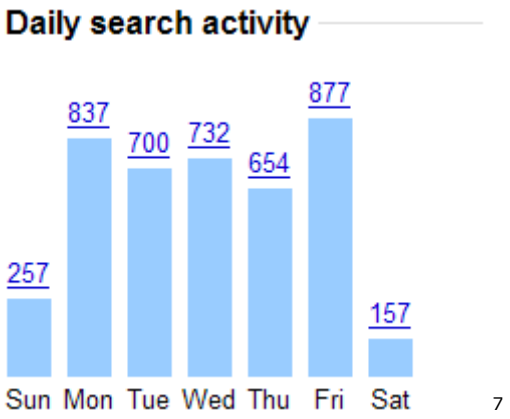
[2] See "A taxonomy of temporal data visualisation techniques", Daassi, Nigay, Fauvet http://iihm.imag.fr/publs/2006/RevI3_DaassiNigayFauvet.pdf for contemporary examples

[3] "A Timeline of Timelines", Sasha Archibald & Daniel Rosenberg. http://www.cabinetmagazine.org/issues/13/timelines.php. This also shows some 'sparklines'  ,  that appeared in Tristram Shandy around the same time!

Non-linear versions appeared much later[4]. Another variant is to orient flow time top to bottom[5] on the page, although left-to-right orientations are much more common.

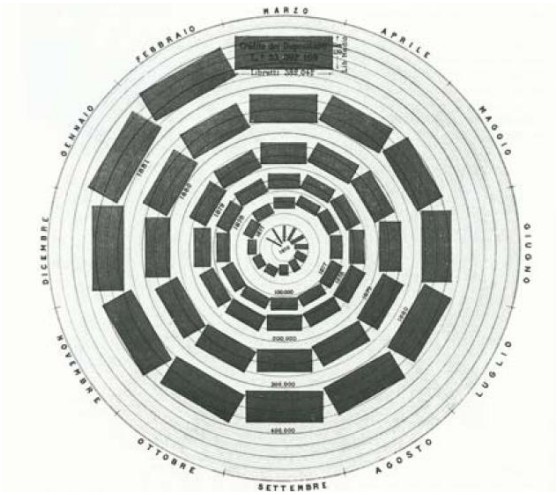
Other notable representations include calendars[6] of course.

Simple graphs (histograms, pie charts) of statistical counts are often used to show overall patterns.



[7]

Spiral representations are often rediscovered.



Spirals are appropriate for some tasks because they have cycles (e.g., months above) as well has a linear progression (generally outwards from the centre). Here is a rectangular variant that has more regularity in terms of space available per time slot.

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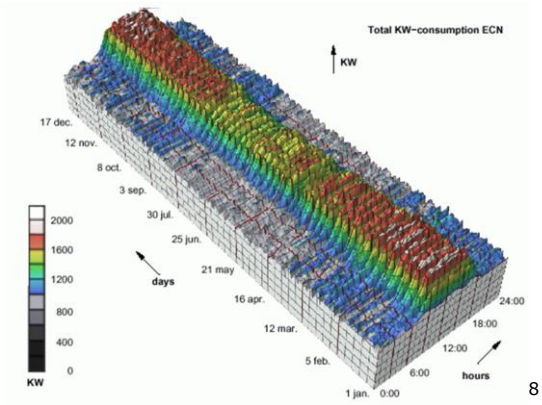
[4] "Timelines and Visual Histories" http://www.math.yorku.ca/SCS/Gallery/timelines.html#non-linear

[5] Many examples include http://www.timelineindex.com/content/select/729/1023,729 http://infodisiac.com/Wikipedia/EasyTimeline/Introduction.htm

[6] This example comes from Google Web History

[7] Google Trends



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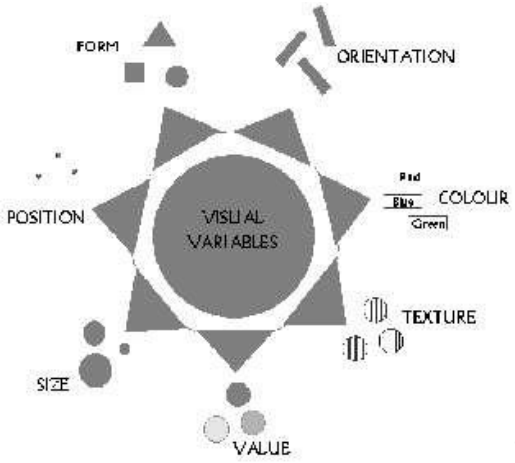
A GRAPHICS CONTEXT

Of the seven 'visual variables' of Bertin,



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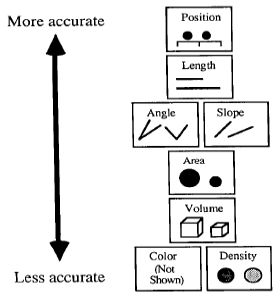
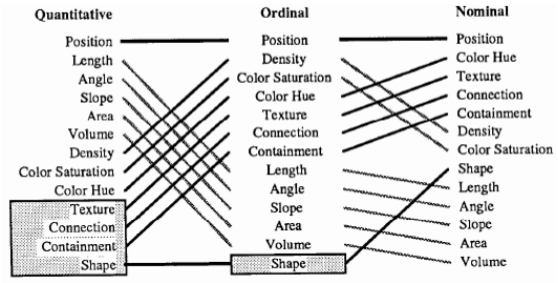
most approaches to time visualisations use position to represent time[10]. Most commonly, colour, value (dark/light), form and size are used to represent the temporal data. Colour and value are frequently used for visualising cyclical patterns (weekends, months, hours of darkness, etc.). Form tends to be used for qualities which do not change over time, such as categories[11].

The basis for these choices may MacKinlay's[12] diagrams below concerning the suitability of visual variables for data types. A general picture:



And now applied to certain data types:



TIME BARS

Where data is represented against a time flow along one axis, representations summarise key information about that flow in a region I'll call a "time bar".

MULTISCALE TECHNIQUES

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[8] From http://www.cs.ubc.ca/~tmm/courses/cpsc533c-06-fall/slides/design-4x4.pdf

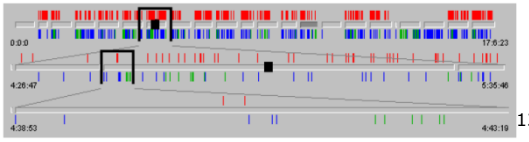
[9] "Semiology of Graphics" Jacques Bertin (1983)

[10] Although see section "Colour coding" for a notable counter example.

[11] MacEachren "How maps work" has further studies of visual variables and their effectiveness for certain tasks.

[12] From a paper by Jock MacKindlay (1986) who has claims to inventing the "information visualisation" field http://www2.parc.com/istl/projects/uir/publications/items/UIR-1986-02-Mackinlay-TOG-Automating.pdf

Time bars often contain several scales. Typically the outer band is at the largest scale – often year ranges - while the inner band(s) are more fine grained.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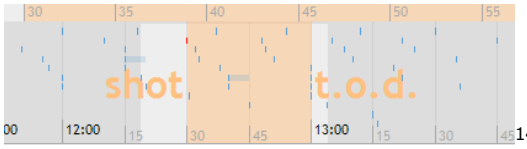

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The finer grained section is normally found nearest the main data window.

OVERVIEW/SPARKLINES

Time bar representations commonly include an element of summarization[15] of the data.

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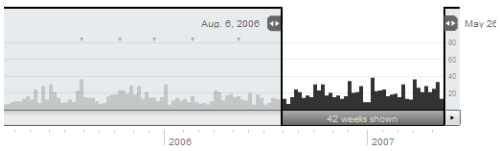

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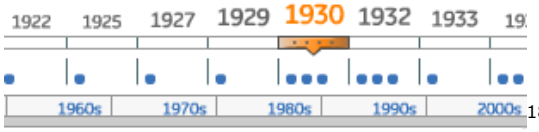

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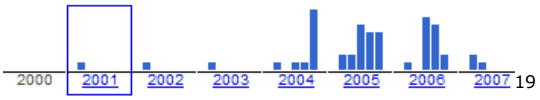

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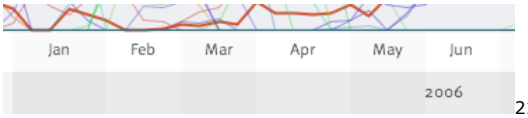
This graphical elements help give context to the currently viewed time slot, as well as providing convenient interaction points for navigation. They follow best practice according to Ben Scheiderman's information visualisation mantra "overview, zoom & filter, details on demand."[20]

BANDING

Banding/shading of adjacent time periods is a common technique. This allows the eye to correlate the time bar against the main data area.



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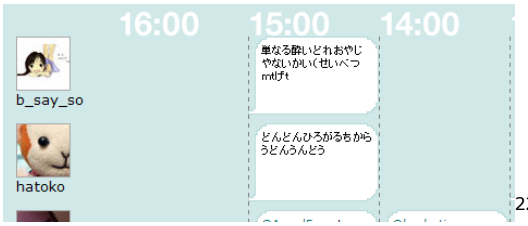
Often bands mean something in context, e.g., weekends. These bands or faint lines are often are drawn on the main data area too.



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[13] http://citeseer.ist.psu.edu/richter99multiscale.html

[14] http://simile.mit.edu/timeline/

[15] Many of these are influenced by Tufte's "sparklines" http://www.edwardtufte.com/bboard/q-and-a-fetch-msg?msg_id=0001OR

[16] Google Finance

[17] New York Times Infographic http://www.nytimes.com/ref/us/20061228_3000FACES_TAB2.html

[18] http://www.ge.com/innovation/FLASH/timeline.html

[19] Timeline views of search results http://www.google.com/experimental/

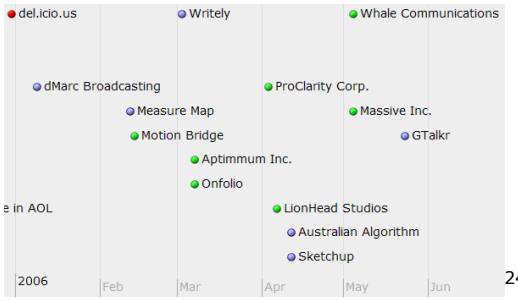
[20] "The eyes have it..", Ben Scheiderman 1996 http://www2.sims.berkeley.edu/courses/is247/f05/readings/Shneiderman_EyesHaveIt_VL96.pdf

[21] http://megamu.com/lastfm/eda/index.html

[22] http://24oclocks.com/

REGULARITY/IRREGULARITY

Almost all visualisations show a regular progression of time, despite the fact that the data distributions are often strongly 'bunched' or stretched out. Often vertical bands within the main data area are used to lay out the information in a 'waterfall' pattern (top left flows to bottom right) to make the best use of space when bunching occurs[23]. Empty regions often are left simply empty.



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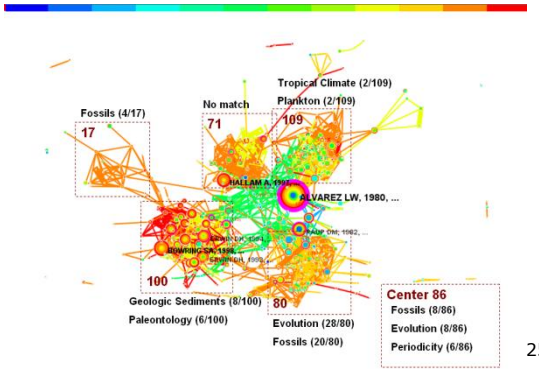
In these representations colour is commonly used to indicate categories of event.

COLOUR CODING

This timeline of papers and citations uses time bar colour within the main data area to good effect.



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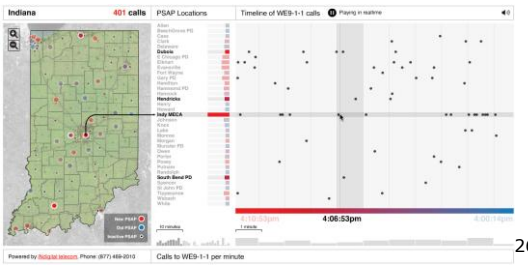
One can clearly see the later citations (red). Size is used for the number of citations.

An emergency response visualisation by the influential Stamen design team also uses colour to good effect.



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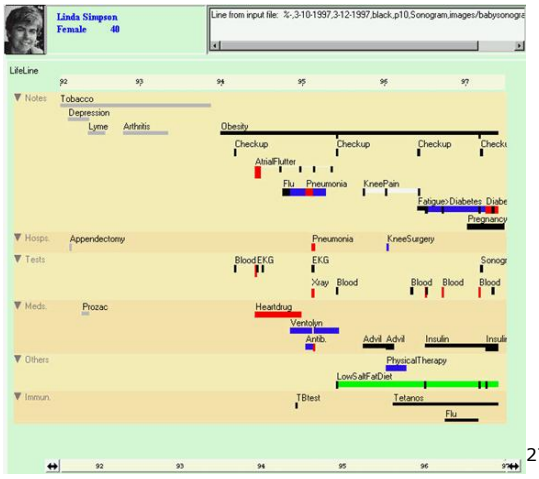
Newer calls to 911 shown in red, and fade to blue as they age. This is one of the few applications where time flows right to left.

MAIN DATA AREA

The main data area typically consists of horizontally stratified information groups. Lifelines from the medical record domain is a good example



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[23] See also http://en.wikipedia.org/wiki/List_of_English_monarchs

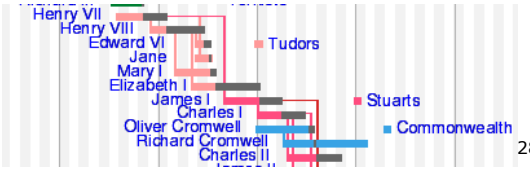
[24] http://www.shmula.com/blog/timelines/google-microsoft-yahoo/g-y-m.htm

[25] CiteSpace: Visualizing Patterns and Trends in Scientific Literature, Chaomei Chen http://cluster.cis.drexel.edu/~cchen/citespace/

[26] http://stamen.com/clients/indigital

[27] http://www.cs.umd.edu/hcil/lifelines/

Annotations cross the horizontal bands when necessary. In the following picture vertical lines indicate descendants.



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INTERACTIVE REPRESENTATIONS

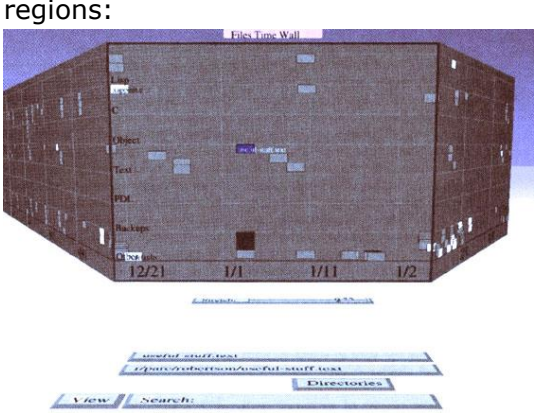
Interactive representations bring new techniques:

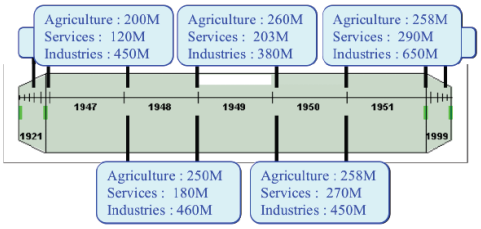
- Showing and hiding data (details on demand) using filters or zooming
- Animation
- "Brushing and linking" – i.e., typically a mouse driven selection of data together with multiple coordinated views[29].

This section shows how some interaction techniques have been applied to temporal visualisations.

FISH-EYE CONCEPTS

The "perspective wall"[30] is a rather old fashioned technique that allows one to visualise a time region in the context of neighbouring time regions:





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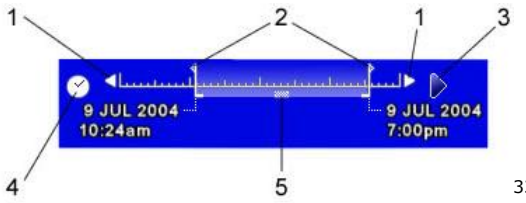
The "Fish-eye" lens metaphor offers a smoother variant, by using a hyperbolic distortion in one dimension[32].

FILTERING

The use of a small time bar for visualizing and interacting with the current time range filter is fairly common. Here is a control for viewing GPS data in Google Earth that contains the basic features.



33

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[28] http://en.wikipedia.org/wiki/List_of_English_monarchs

[29] See e.g., "A Taxonomy of Multiple Window Coordinations" North & Schneiderman

[30] http://www.infovis-wiki.net/index.php/Perspective_Wall

[31] TimeVis from http://iihm.imag.fr/publs/2006/RevI3_DaassiNigayFauvet.pdf

[32] I've seen this somewhere but have lost the reference

[33] http://earth.google.com/userguide/v4/ug_gps.html#timeline

Users set the size of the range of the currently displayed data via (2) and can drag that range via (5). Note the range is displayed textually too.

STRETCHING

In addition to the filtering mechanism described above, some interactions allow a degree of stretching and compressing of the main data area.

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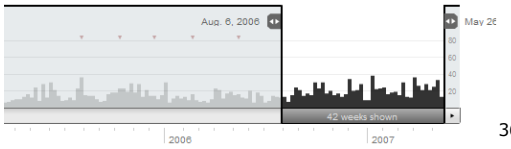

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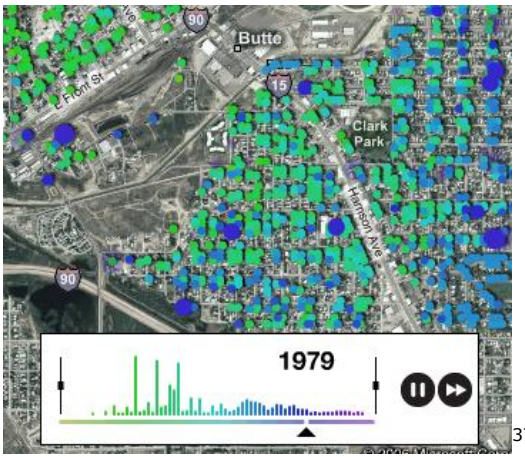
In each of these cases the time flow of the main data area can be controlled via the widgets in the time bar. This interaction helps with Scheiderman's 'zoom and filter' principle.

In each of these both the time bar and the main data area have a constant rate of time flow: whether the same technique would work well on non-linear flows is an interesting question.

ANIMATION

Animation in temporal visualisations typically involves animating data filtered through a 'time window'.



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See also Google Earth's time slider[38]

SPATIO-TEMPORAL REPRESENTATIONS

A recent review[39] makes it clear that this is currently an active research area. This section shows a few notable techniques and examples.

BASIC APPROACH

The basic approach is to have a time bar filter control data plotted over a standard map surface. Time-sliced data for the current filter is drawn on the map.

3D METAPHOR

GeoTime™ visualisations[40][41] use a 3D metaphor, putting time on the z-axis with a map in the x/y plane.

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[34] Wieden & Kennedy http://www.wk.com/#/

[35] Google Finance

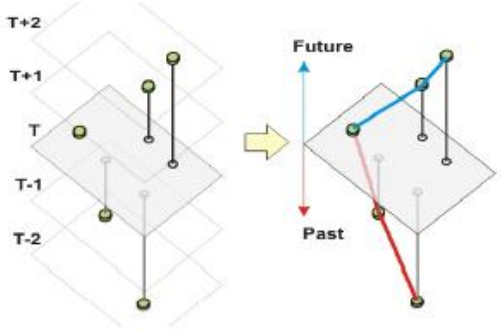
[36] New York Times Infographic http://www.nytimes.com/ref/us/20061228_3000FACES_TAB2.html

[37] http://hindsight.trulia.com/

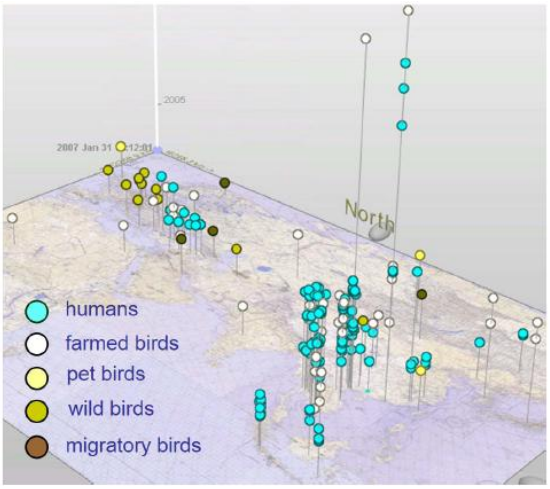
[38] http://earth.google.com/userguide/v4/ug_gps.html#timeline

[39] Andrienko et al http://www.gpa.uq.edu.au/courses/geom/3005/restrict/Andrienko_Visualisation.pdf

[40] "GeoTime Information Visualisation", Kapler & Wright

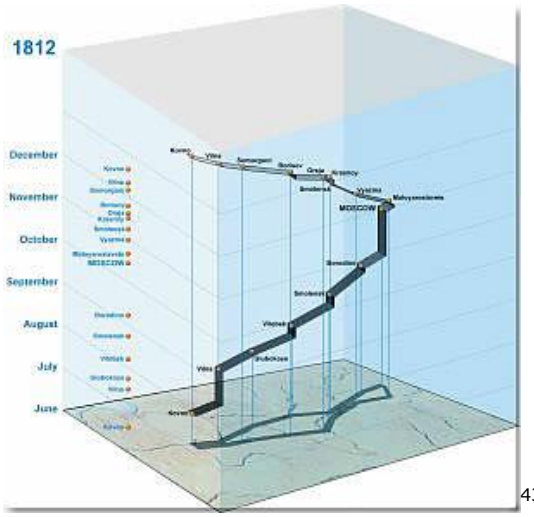


This example[42] plots the spread of avian 'flu.



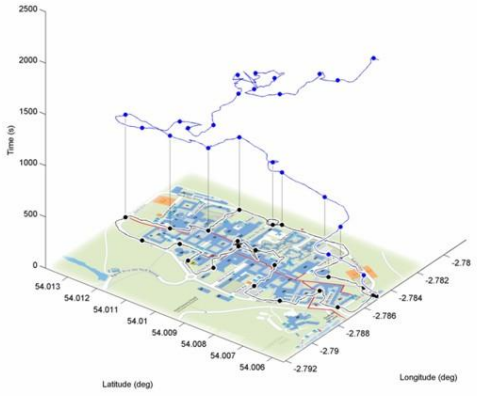
This approach suffers from the standard problems associated with 3D representations. Data points tend to obscure each other (occlusion), there are axes of ambiguity and events' time order and spatial locations can be difficult to determine from a static diagram.

Here's the same idea applied to a classic data visualisation by Minard of Napoleon's Russian campaign.



[43]

Finally, another example from Nokia:



[44]

ONE SPATIAL DIMENSION

I include the next example because it shows that if only one spatial dimension is important, spatio-temporal visualisations can be quite straightforward.

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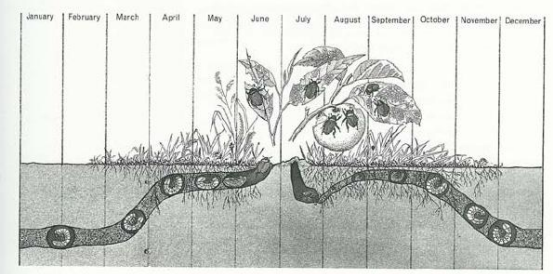
http://www.cs.umd.edu/hcil/VASTcontest06/SUBMITTED/Oculus-nSpace&GeoTime/Oculus-nSpace&GeoTime/ref%20papers/KaplerWright_GeoTime_InfoViz_Final_Conf.pdf

[41] Putting time on the vertical axis was suggested in 1995 by MacEachran in "How Maps Work"

[42] "Avian Flu Case Study with nSpace and GeoTime", Proulx, Tandon, Bodnar, Schroh, Harper & Wright

[43] http://www.itc.nl/personal/kraak/1812/index.htm

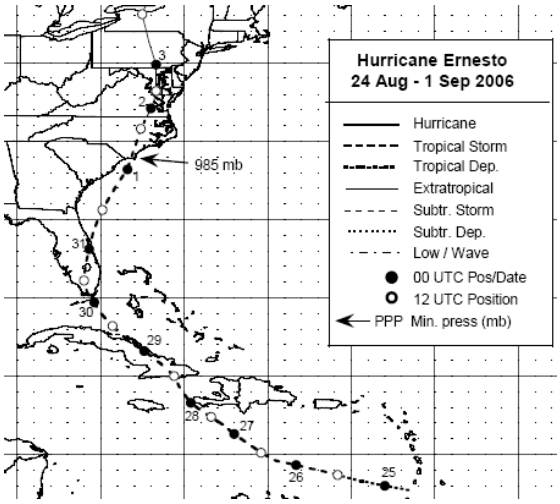
[44] http://blogs.forum.nokia.com/view_entry.html?id=53



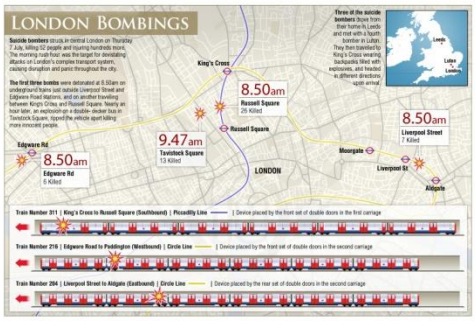
Life circle of Japanese Beetles L. Newman. Man and Insects. 1965

MAP LABELLING

A more straightforward approach is to label events or paths with time information. For example, see this hurricane path map.



Colour, size and texture of the lines are commonly used to represent additional information.



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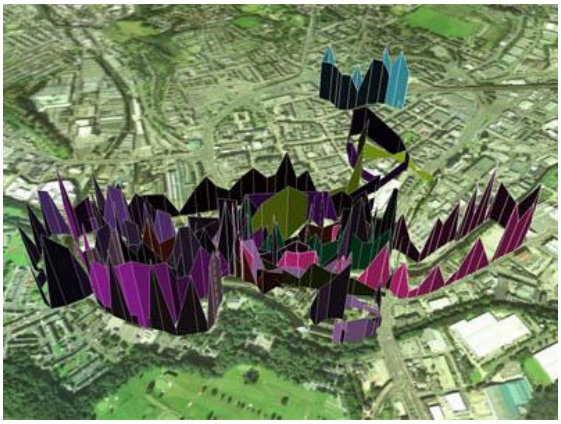
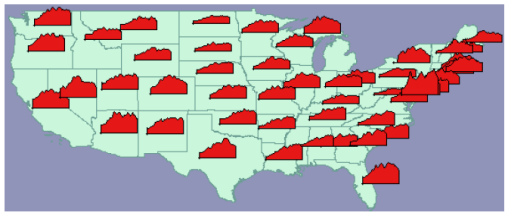
[45] http://www.10create.com/infographics.html

In the biomapping[46] project, emotional state was mapped along a journey:



This is an unusual combination of sparklines with spatial data suffers from



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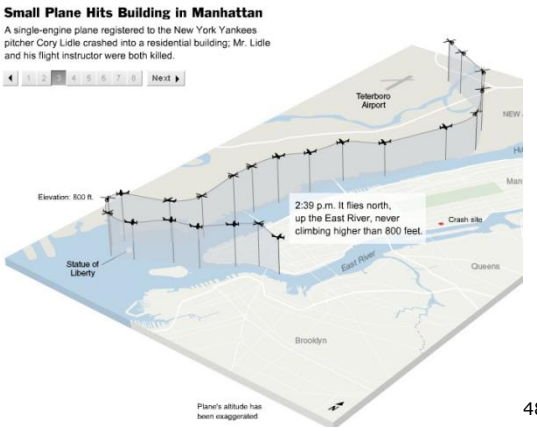
occlusion issues, but is interesting nonetheless.

ANIMATION

Animation is commonly used:



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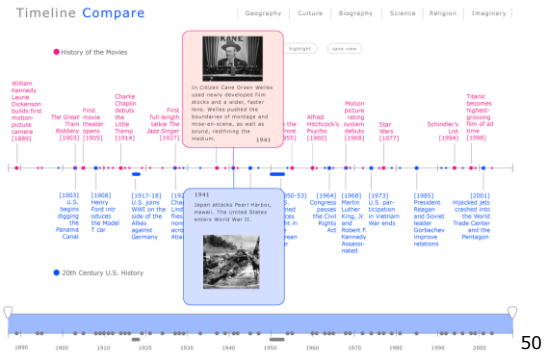
[46] www.biomapping.com see also www.emotionmap.net

[47] Andrienko & Andrienko http://www.ais.fraunhofer.de/and/slides/2005-07-15-filling_gaps.pdf

Animation can be used for narative. It can also be used to draw attention to changes over time. If done well it can enhance the user experience and aesthetics of the tool[49].

EVALUATION

Academic visualisation papers often include a small evaluation element towards the end. Evaluations are rarely comparative and are performed by visualisation experts rather than HCI professionals. Generally this results in huge biases towards authors' own "cool" visualisations.



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An example is the 'timeline compare' project above – although well intentioned and designed well, the evaluation consisted a very small sample size with no working prototype to play with.

Evaluating interactive visualisations is a subject in it's own right[51]: it is a branch of human computer interaction research. It has inherent problems - tools have biases towards the data sets and tasks they were designed for, hence can be hard to compare. Similarly, users have a broad range of expertise and domain knowledge. So a firm methodology is necessary.

Experimental valuations consist of experiments to prove or disprove hypotheses. Typically these revolve around the ability of users to perform tasks: this is measured in terms of time taken and accuracy. Aesthetics and general usability are dealt with using questionnaires. Videos are recorded of activities. A good experimental evaluation is therefore very labour intensive. Furthermore there is a danger that reporting focuses on results of the form "X is better than Y for task Z" but the underlying reasons **why** also need examination[52].

Papers on evaluations can be restricted to very specific visualisations[53], so can be difficult to derive general principles from such studies.

Ideally I'd like to summarise lessons learnt, but due to a lack of depth in the literature on evaluation aspects of temporal visualisations, I'm unable to offer this. Instead it seems a task focused 'fit for purpose' study should be made for each domain.

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[48] New York Times Graphic http://www.nytimes.com/packages/khtml/2006/10/11/nyregion/20061011_CRASH_GRAPHIC.html

[49] Hearst http://vadl.cc.gatech.edu/getDocument.php?doc=89

[50] http://www2.sims.berkeley.edu/courses/is247/f05/projects/timelinecompare/

[51] "Evaluation of Information Visualisation" John Stasko http://vadl.cc.gatech.edu/documents/35_Stasko_eval.pdf

[52] "The What, Where, When and How of Evaluating Visualisations" Jim Foley http://vadl.cc.gatech.edu/taxonomy/cat.php?cat=69

[53] http://hcilab.uniud.it/publications/2001-03/TemporalIntervals_TIME01.pdf

OTHER WORK

Here are a few other recent reviews in the field:

- "Visualizing Time Oriented Data – A Systematic View" – Aigner, Miksch, et al.[54]
- "Visualising Time" - Juan C. Dürsteler [55]
- "Timelines and Visual Histories"[56]

DISCLAIMER

As is probably evident I am not an information visualisation academic, so I apologise if I've not given due reference to prior art. This work has not been formally reviewed. Email me with references and I'll make corrections.

Similarly, if I have breached copyright or made any other legal infringements, please contact me and I'll rectify the problem.

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3rd July 2007

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[54] http://www.donau-uni.ac.at/imperia/md/content/department/ike/ike_publications/2007/refereedjournalarticles/aigner_2007_cg_visualizing-time-oriented-data.pdf

[55] http://www.infovis.net/printMag.php?num=180&lang=2 and see also Google cache: http://64.233.183.104/search?q=cache:b6wFUXy49gEJ:www.infovis.net/printMag.php%3Fnum%3D180%26lang%3D2+%22visualising+time%22+infovis&hl=en&ct=clnk&cd=1&gl=uk

[56] http://www.math.yorku.ca/SCS/Gallery/timelines.html