Chapter 2
Historical Background

> There is a magic in graphs. The profile of a curve reveals in a flash a whole situation – the life history of an epidemic, a panic, or an era of prosperity. The curve informs the mind, awakens the imagination, convinces.
>
> Henry D. Hubbard in Brinton (1939, Preface)

Long before computers even appeared, visualization was used to represent time-oriented data. Probably the oldest time-series representation to be found in literature is the illustration of planetary orbits created in the 10th or possibly 11th century (see Figure 2.1). The illustration is part of a text from a monastery school and shows inclinations of the planetary orbits as a function of time.

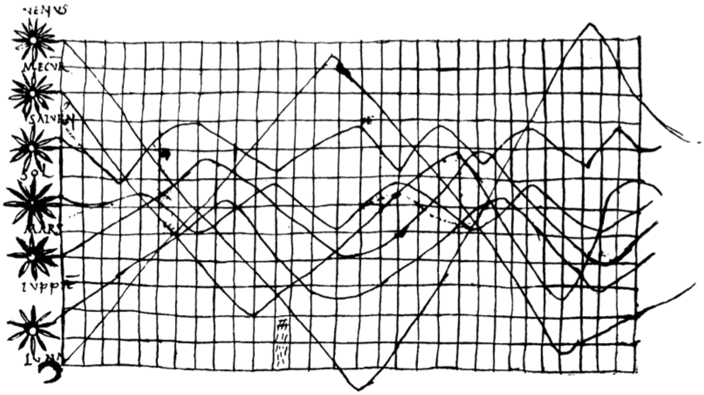

Fig. 2.1: Time-series plot depicting planetary orbits (10th/11th century). The illustration is part of a text from a monastery school and shows the inclinations of the planetary orbits over time. *© 1936 University of Chicago Press. Reprinted, with permission, from Funkhouser (1936, p. 261).*

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In human history, keeping track of the passage of time, the seasons of the year, and planning ahead for them has been one of the most important tasks of even the earliest human civilizations. Being essential for central elements of life, for example, for agriculture or religious acts, a variety of tools such as bone engravings as well as visual representations of calendars can be found throughout history. Figure 2.2 shows an example of a perpetual calendar from 1594 designed by Ortensio Toro that shows the Gregorian calendar for a 400-year cycle. It allowed date calculations far into the future.

An example of a particularly interesting artifact by Native American people is the Time Ball shown in Figure 2.3. Unlike calendars that are valid for larger parts of people, the time ball is a mnemonic device, i.e., a tangible, personal record of developments and life events over the course of its owner's life. It acted as a memory aid usually kept by women where simple knots recorded individual days and meaningful occasions, such as births, deaths, marriages, or days of bounty, hardship, and even conflicts were highlighted using special markers. These included glass beads, shells, cloth fragments, or human hair.

To broaden the view beyond computer-aided visualization and provide background information on the history of visualization methods, we present historical and application-specific representations. They mostly consist of historical techniques of the pre-computer age, such as the works of William Playfair, Étienne-Jules Marey, or Charles Joseph Minard.

Furthermore, we will take the reader on a journey through the arts. Throughout history, artists have been concerned with the question of how to incorporate the dynamics of time and motion in their artworks. We present a few outstanding art movements and art forms that are characterized by a strong focus on representing temporal concepts. We believe that art can be a valuable source of inspiration; concepts or methods developed by artists might even be applicable to information visualization, possibly improving existing techniques or creating entirely new ones.

2.1 Classic Ways of Graphing Time

Representing business data graphically is a broad application field with a long tradition. William Playfair (1759–1823) can be seen as the protagonist and founding father of modern statistical graphs. He published the first known time-series depicting economic data in his *Commercial and Political Atlas* of 1786 (Playfair and Corry, 1786). His works contain basically all of the widely-known standard representation techniques (see Figure 2.4, 2.5, 2.6, and 2.7) such as the pie chart, the silhouette graph (↪ p. 281) , the bar graph (↪ p. 234), and the line plot (↪ p. 233).

Playfair's work widely popularized new graphic forms and many other economists and statisticians built upon this to develop them further. One example from 1874 can be seen in Figure 2.8. It shows a fiscal chart of the United States by Francis Amasa Walker (1840–1897) that uses a symmetric layout to contrast state revenues

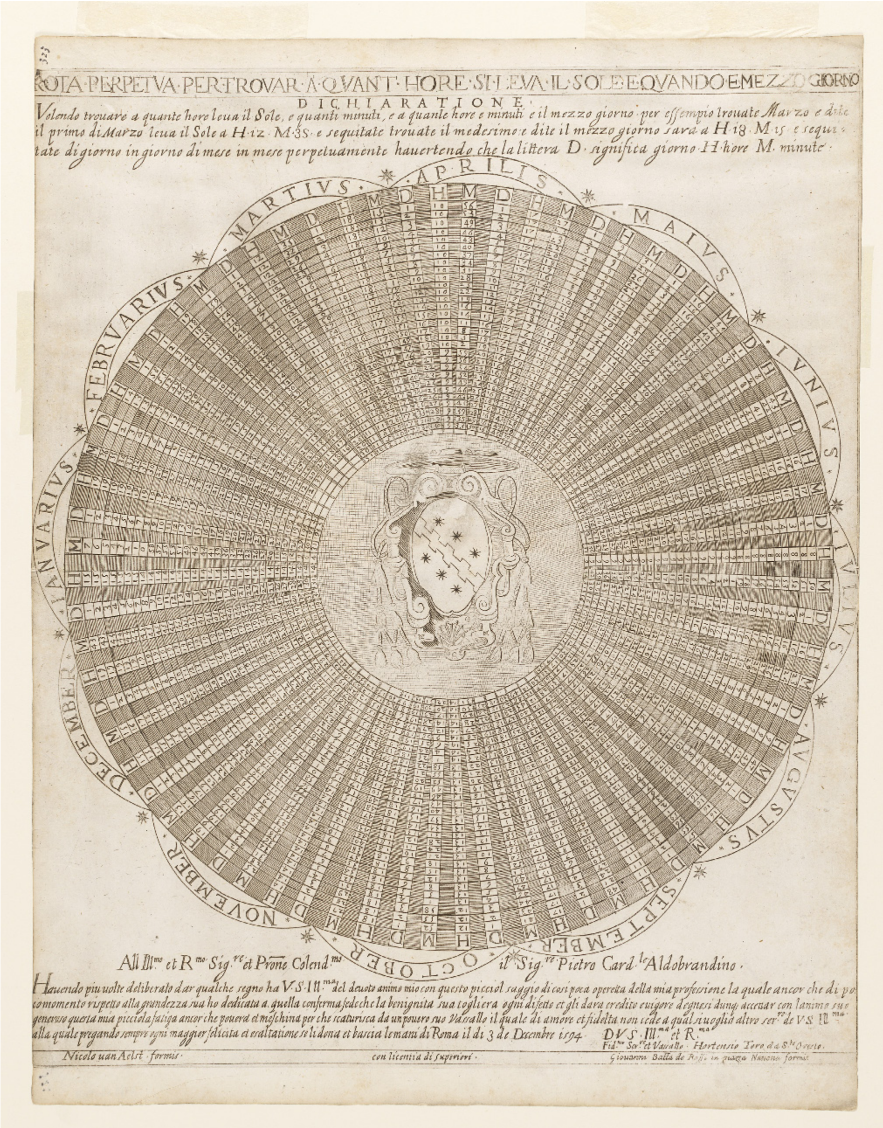


Fig. 2.2: Perpetual calendar (1594). Gregorian calendar designed for a 400-year cycle. 🅮 *Ortensio Toro (Italian, active 16th century). Retrieved from Cooper Hewitt, Smithsonian Design Museum.*

Fig. 2.3 Time Ball (mnemonic device) of the Native American Tribe Yakama by Vivian Harrison (1945). *© Courtesy of the National Museum of the American Indian, Smithsonian Institution (26/9725), from NMAI Photo Services.*

with state expenditures over a period from 1789–1870 in absolute (center) as well as relative terms (stacked bars left and right).

In Figure 2.7 multiple heterogeneous time-oriented variables are integrated within a single view: the weekly wages of a good mechanic as a line plot, the price of a quarter of wheat as a bar graph, as well as historical context utilizing timelines (↪ p. 258). Playfair himself credits the usage of timelines to Joseph Priestley (1733–1804) who created a graphical representation of the life spans of famous historical

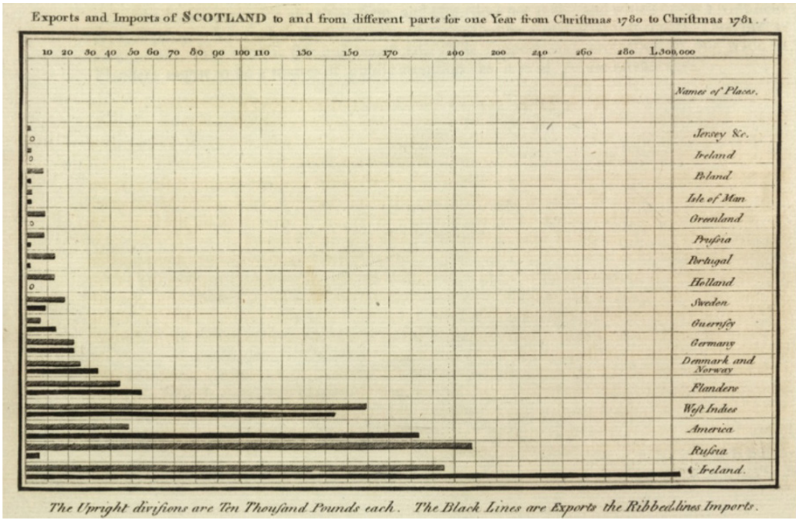


Fig. 2.4: Bar graph from the *Commercial and Political Atlas* by Playfair and Corry (1786) representing exports and imports of Scotland during one year. *🄯 1786 Playfair and Corry. Retrieved from Wikimedia Commons.*

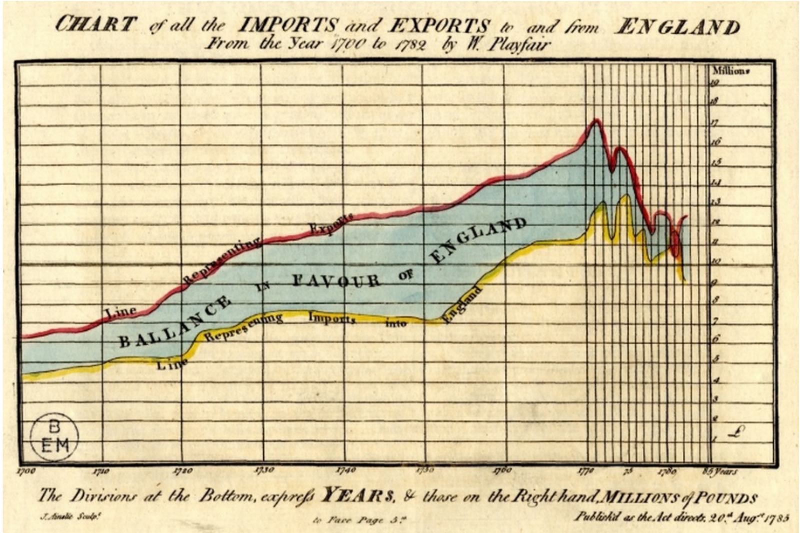


Fig. 2.5: Line plot from the *Commercial and Political Atlas* by Playfair and Corry (1786) representing imports and exports of England from 1700 to 1782. The yellow line on the bottom shows imports into England and the red line at the top exports from England. Color shading is added between the lines to indicate positive (light blue) and negative (red; around 1781) overall balances. *© 1786 Playfair and Corry. Retrieved from Wikimedia Commons.*

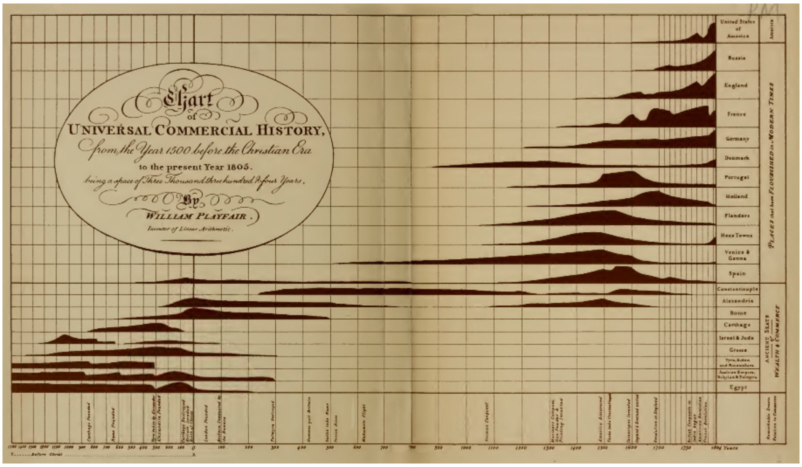


Fig. 2.6: Silhouette graph used by William Playfair (1805) to represent the rise and fall of nations over a period of more than 3000 years. A horizontal time scale is shown at the bottom that uses a compressed scale for the years before Christ on the left. Important events are indicated textually above the time scale. Countries are grouped vertically into Ancient Seats of Wealth & Commerce (bottom), Places that have Flourished in Modern Times (center), and America (top). *© 1805 Playfair. Retrieved from Wikimedia Commons.*

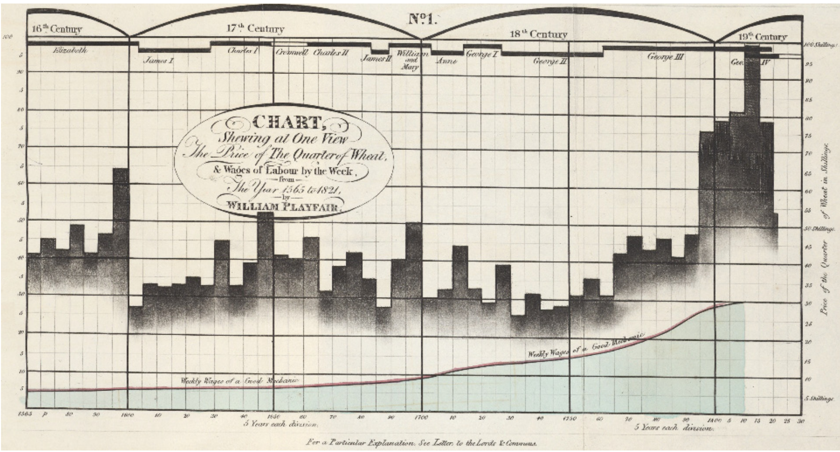


Fig. 2.7: Information rich chart of William Playfair (1821) that depicts the weekly wages of a good mechanic (line plot at the bottom), the price of a quarter of wheat (bar graph in the center), as well as historical context (timeline at the top) over a time period of more than 250 years. *1821 Playfair. Retrieved from Wikimedia Commons.*

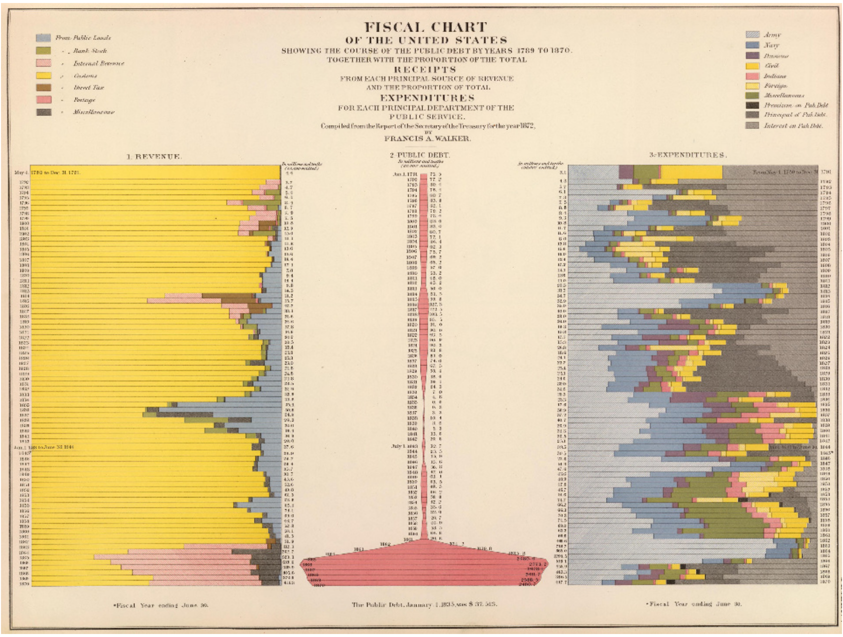


Fig. 2.8: Fiscal chart of the United States showing the the development of public debt for the years 1789 to 1870 together with the proportions of receipts and expenditures. *1874 Walker. Retrieved from David Rumsey Map Collection, David Rumsey Map Center, Stanford Libraries.*

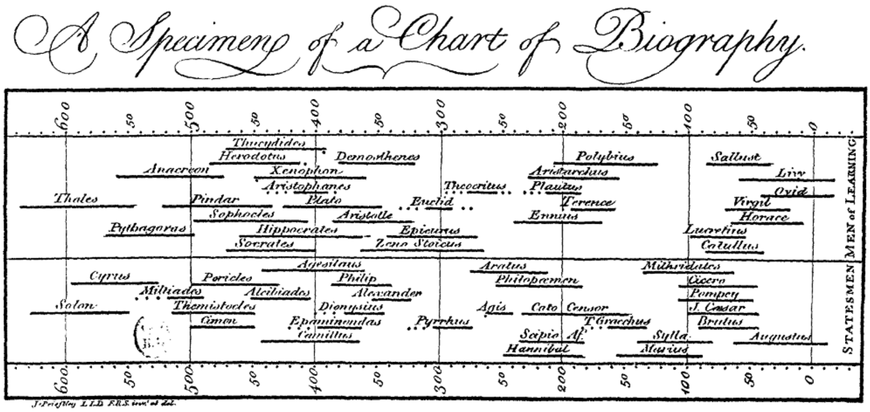


Fig. 2.9: *Chart of biography* by Joseph Priestley (1765) that portrays the life spans of famous historical persons using timelines. 🅮 *1765 Priestley. Retrieved from Wikimedia Commons.*

persons divided into two groups of Statesmen and Men of Learning (see Figure 2.9). The usage of a horizontal line to represent an interval of time might seem obvious to us nowadays, but in Priestley's days this was certainly not the case. This is reflected in the fact that he devoted four pages of text to describe and justify his technique to his readers. A remarkable detail of Priestley's graphical method is that he acknowledged the importance of representing temporal uncertainties and provided a solution to deal with them using dots. Even different levels of uncertainty were taken into account, ranging from dots below lines to lines and dotted lines.

Even earlier than both Priestley and Playfair, Jacques Barbeu-Dubourg (1709–1779) created the earliest known modern timeline. His *carte chronographique* (Barbeu-Dubourg, 1753) consisted of multiple sheets of paper that were glued together and add up to a total length of 16.5 meters (see Figure 2.10). A rare version of the chart is available at Princeton University Library where the paper is mounted on two rollers in a foldable case that can be scrolled via two handles (see Ferguson (1991) for a detailed description).

Another prominent example of a graphical representation of historical information via annotated timelines is *Deacon's synchronological chart of universal history* which was originally published in 1890 and was drawn by Edmund Hull (see Figure 2.11). Various reprints and books extending the original historic facts to the present and adaptations for specialized areas like for example inventions and explorations can be found in the literature (e.g., Third Millennium Press, 2001). A slightly different layout approach for depicting historical data is Willard's Chronographer of American History (see Figure 2.12). In contrast to the example before, Emma Willard uses a botanical tree metaphor to structure historical periods combined with a round time scale on the outside.

Apart from calendars, maps have also been an essential tool in human history for thousands of years. Combining time-oriented data with cartographic maps allows for

Fig. 2.10: *Carte chronographique* by Jacques Barbeu-Dubourg (1753) that shows the known history from the beginning of time up to 1760. Multiple sheets of paper were glued together and mounted in the *chronology machine* which allows to manually scroll back and forth in time using two handles. *© Courtesy of Rare Book Division, Department of Rare Books and Special Collections, Princeton University Library, from Princeton University Library Catalog.*

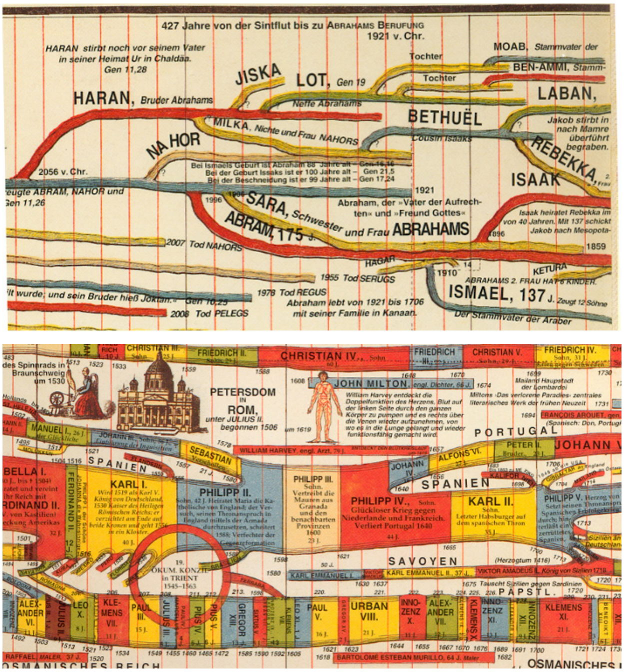


Fig. 2.11: Parts of Deacon's synchronological chart of universal history. © *2001 Third Millennium Press Ltd. Reprinted, with permission, from Third Millennium Press (2001).*

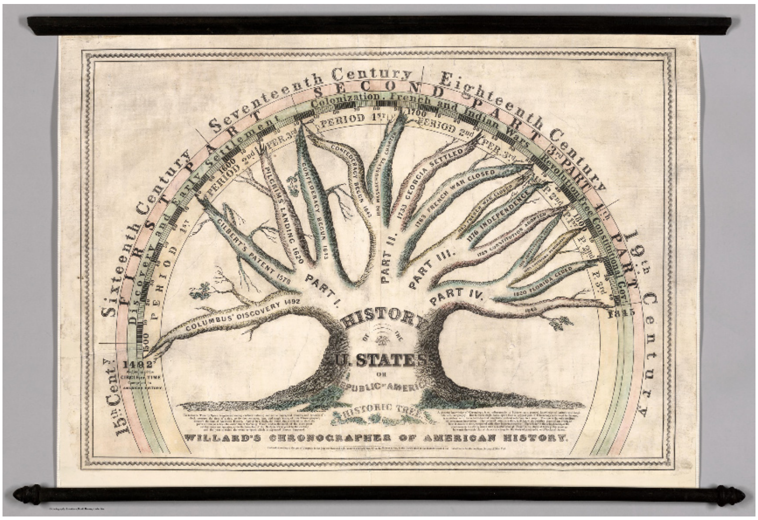


Fig. 2.12: Chronographer of American History by Emma Willard (1845). Wall map for representing important events in American history.

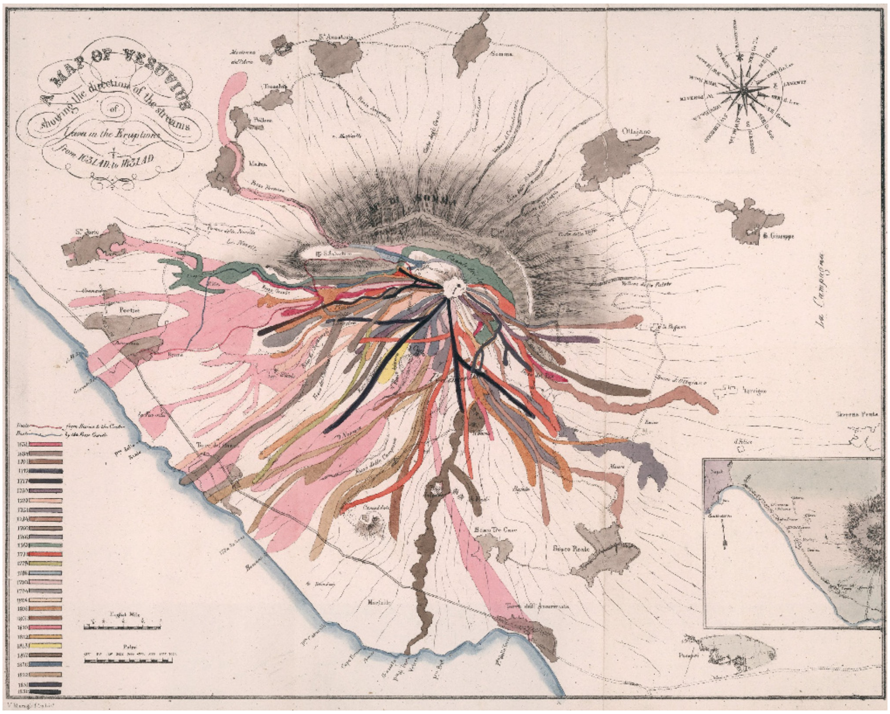


Fig. 2.13: Map of Vesuvius by John Auldjo (1833). It shows the direction of the streams of lava in the eruptions from 1631 to 1831.

depicting both, spatial relationships as well as temporal developments. A remarkable approach for depicting time-orented data on maps is the map of Vesuvius created by John Auldjo (1805–1886) in 1833 (see Figure 2.13). In his map, he uses different color hues to represent time, i.e., the years of eruptions over a period of 200 years, resulting in an ordinal time scale.

Charles Joseph Minard (1781–1870) created a masterpiece of the visualization of historical information in 1869. His graphical representation of *Napoleon's Russian campaign* of 1812 is extraordinarily rich in information, conveying no less than six different variables in two dimensions (see Figure 2.14). Tufte (1983) comments on this representation as follows:

> It may well be the best statistical graphic ever drawn.
>
> Tufte (1983, p. 40)

The basis of the representation is a 2-dimensional map on which a band symbolizing Napoleon's army is drawn. The width of the band is proportional to the army's size; the direction of movement (advance or retreat) is encoded by color.

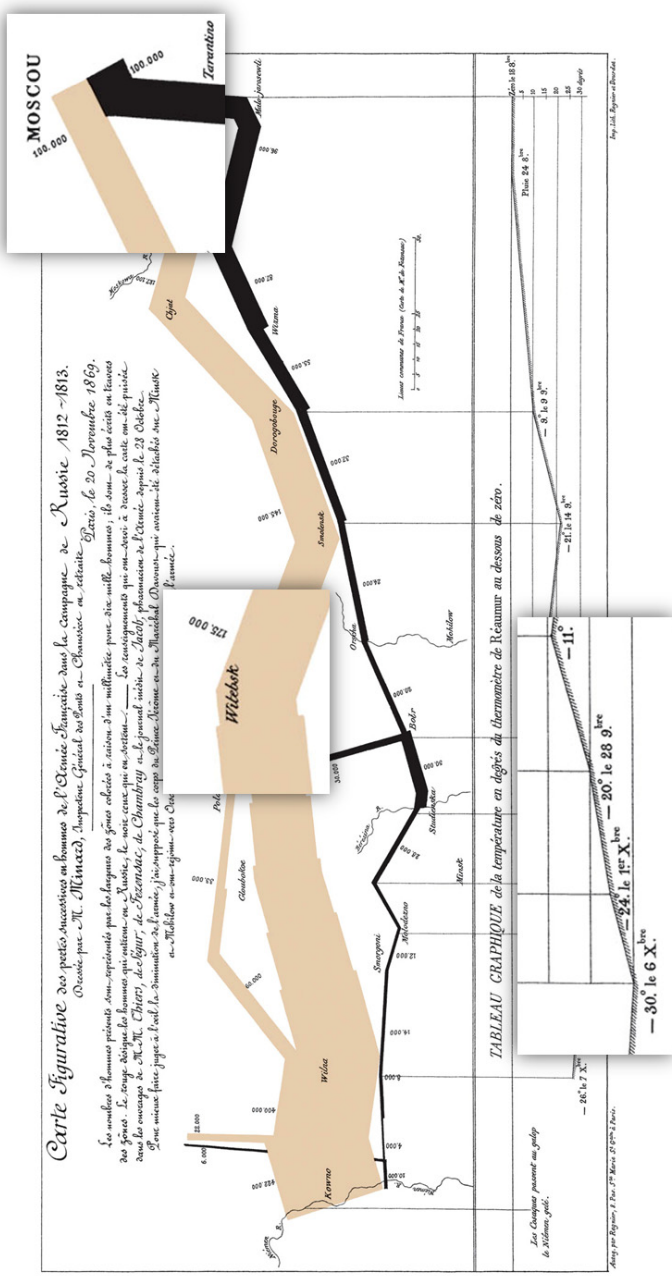


Fig. 2.14: Napoleon's Russian campaign of 1812 by Charles Joseph Minard (1869). A band visually traces the army's location during the campaign, whereby the width of the band indicates the size of the army and the color encodes advance and retreat. Labels and a parallel temperature chart provide additional information.

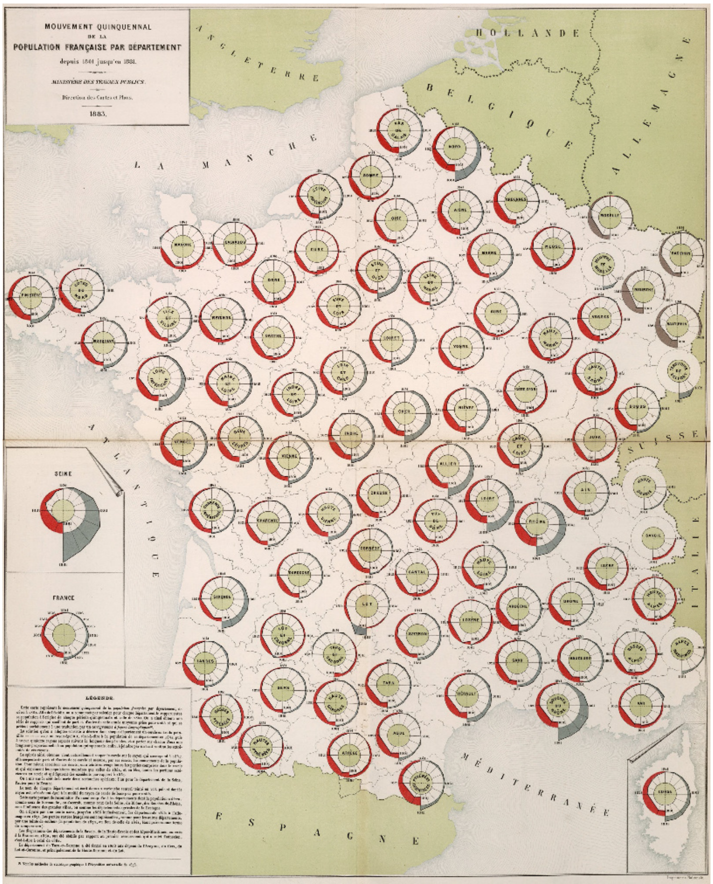


Fig. 2.15: Movement of the population of France between 1801 and 1881 by Émile Cheysson (1883).

Furthermore, various important dates are plotted and a parallel line graph shows the temperature over the course of time.

An early example of combining statistical graphics that use a cyclic time axis with maps is shown in Figure 2.15. The representation of Émile Cheysson created in 1883 shows the movement of the population for each department of France between 1801 and 1881. To make different absolute population values better comparable, the data shown is indexed at the time midpoint 1841 and shown relative to that. Different color hues are used to fill the circular silhouette graph (↪ p. 281) depending on whether the population is below (red) or above (gray) the value of the indexing point. This map is part of a series of graphs created for the French Ministry of Public Works and was inspired by the earlier work of Charles Joseph Minard.

Also in the 19th century, the prominent historic figure Florence Nightingale used a statistical graph to show numbers and causes of deaths over time during the Crimean War. When Nightingale was sent to run a hospital near the Crimean battlefields to care for British casualties of war, she made a devastating discovery: many more men were dying from infectious diseases they had caught in the filthy hospitals of the military than from wounds. By introducing new standards of hygiene and diet, and most importantly, by ensuring proper water treatment, deaths due to infectious diseases fell by 99% within a year. Florence Nightingale tediously recorded mortality data for two years and created a novel diagram to communicate her findings. Figure 2.16 shows two of these *rose charts*. This representation is also called *polar area graph* and consists of circularly arranged wedges that convey quantitative data. Unlike pie charts, all the segments of rose charts have the same angle. Bringing the data in this form clearly revealed the horrible fact that many more soldiers were dying because of preventable diseases they had caught in the hospitals than from wounds sustained in battle. Not only this fact was communicated, but also how this situation could be improved by the right measures; these can be seen from the left rose chart in Figure 2.16. Through this diagram, which was more a call to action than merely a presentation of data, she persuaded the government and the Queen to introduce wide-reaching reforms, thus bringing about a revolution in nursing, health care, and hygiene in hospitals worldwide.

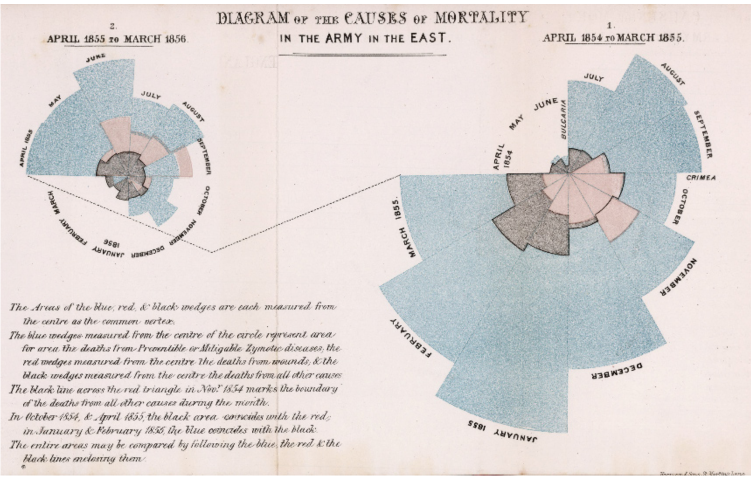


Fig. 2.16: Rose charts showing number of casualties and causes of death in the Crimean War by Florence Nightingale (1858). Red shows deaths from wounds, black represents deaths from accidents and other causes, and blue shows deaths from preventable infectious diseases soldiers caught in hospitals. The chart on the right shows the first year of the war and the chart on the left shows the second year after measures of increased hygiene, diet, and water treatment had been introduced. *1858 Nightingale. Retrieved from Wikimedia Commons.*

A quite different approach to representing historical information is the illustration of the *Cuban missile crisis* during the Cold War by Bertin (1983). The diagram shows decisions, possible decisions, and the outcomes thereof over time (see Figure 2.17). This representation is similar to the *decision chart* (↪ p. 237). Chapple and Garofalo (1977) provided an illustration of *Rock'n'Roll history* shown in Figure 2.18 that depicts protagonists and developments in the area as curved lines that are stacked according to the artists' percentage of annual record sales. The *ThemeRiver™* technique (↪ p. 293) can be seen as a further more formal development of this idea.

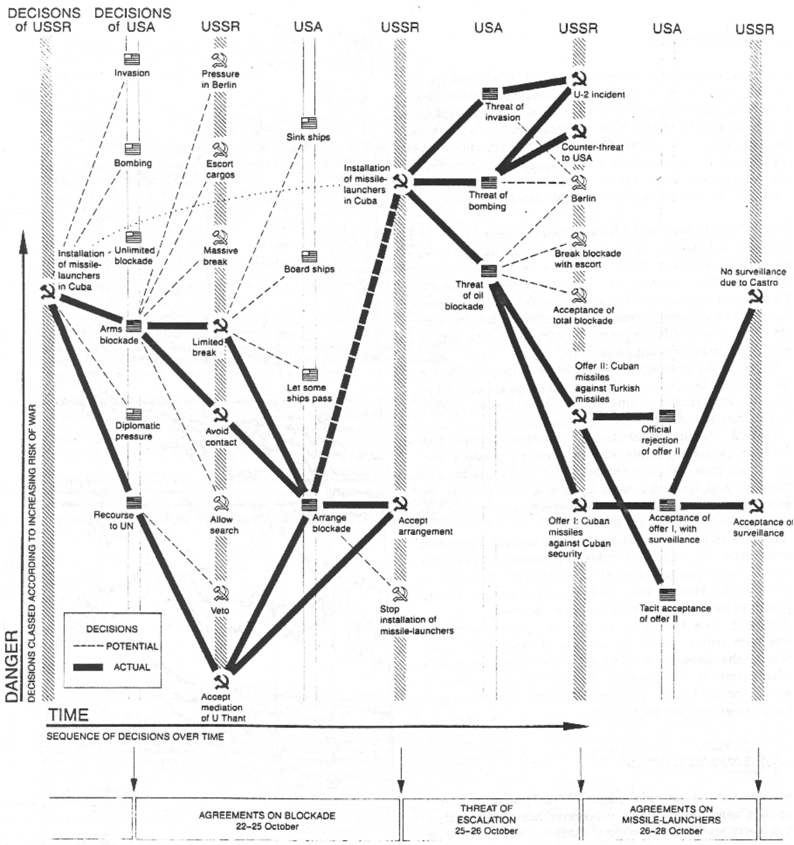


Fig. 2.17: Cuban missile crisis (threat level and decisions over time). The diagram shows decisions, possible decisions, and the outcomes thereof over time. *© 1983 The University of Wisconsin Press. Reprinted, with permission, from Bertin (1983, p. 264).*

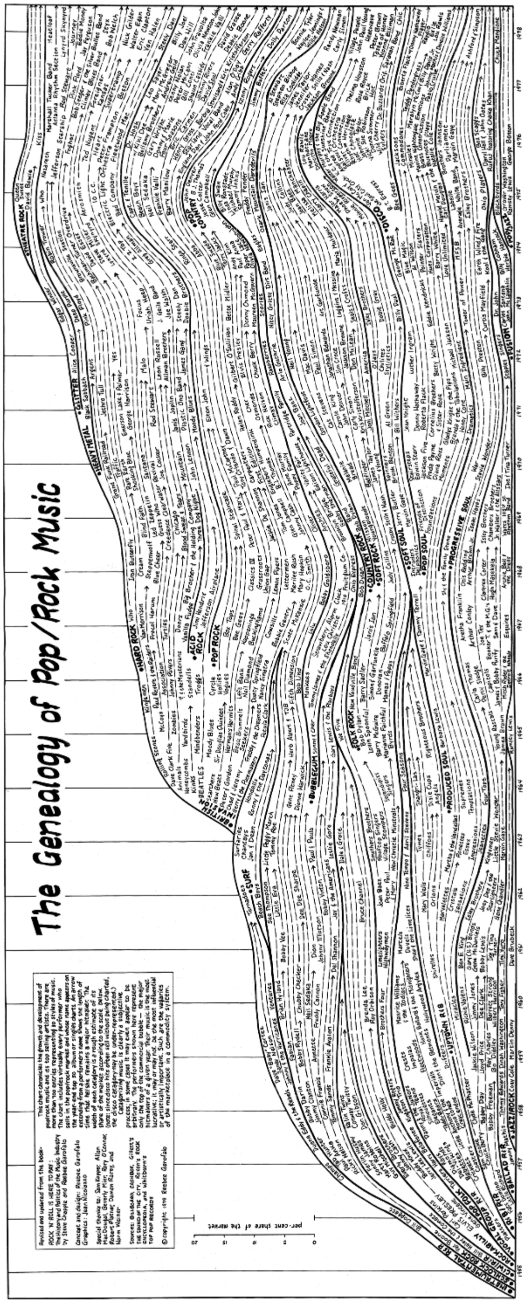


Fig. 2.18: Rock'n'Roll history by Chapple and Garofalo (1977) that depicts protagonists and developments in the area as curved lines that are stacked according to the artists' percentage of annual record sales. © *Courtesy of Reebee Garofalo.*

With the advance of industrialization in the late 19th and early 20th century, optimizing resources and preparing time schedules became essential requirements for improving productivity. One of the main protagonists of the study and optimization of work processes was Frederick Winslow Taylor (1856–1915). His associate Henry Laurence Gantt (1861–1919) studied the order of steps in work processes and developed a family of timeline-based charts as an intuitive visual representation to illustrate and record time-oriented processes (see Figures 2.19 and 2.20). Widely known as *Gantt charts* (↪ p. 253), these representations are such powerful analytical instruments that they are used nearly unchanged in modern project management.

Other interesting representations of work-related data can be seen in Figures 2.21 and 2.22. A record of hours worked per day by an employee is shown in Figure 2.21. It is interesting to note that both axes are used for representing different granularities

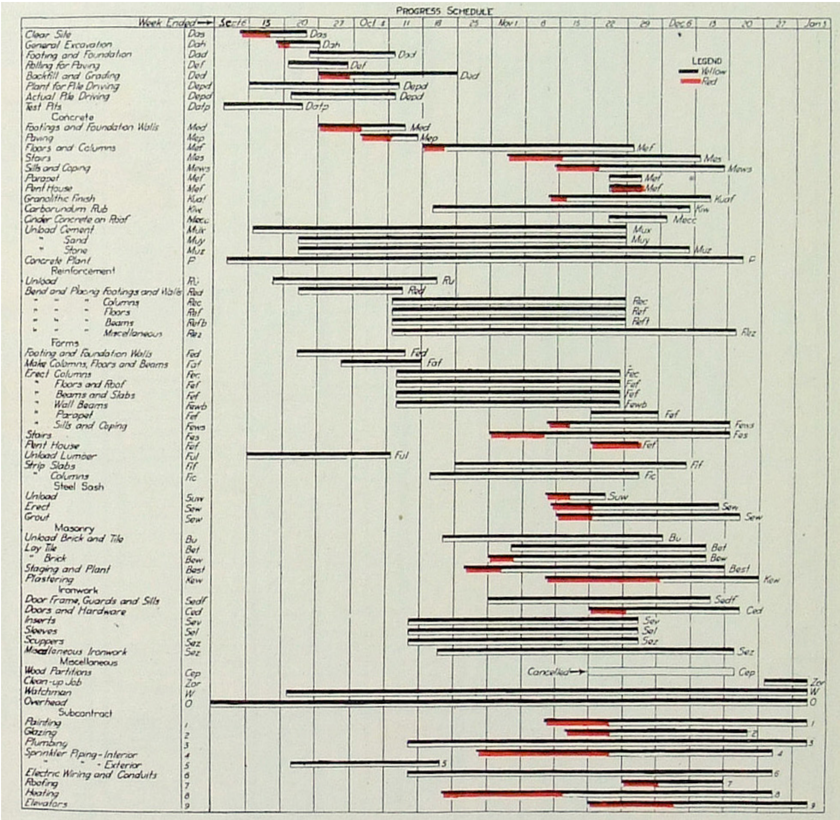


Fig. 2.19: Progress schedule based on the graphical method of Henry L. Gantt (see Brinton, 1939, p. 259). Different work packages are depicted as horizontal lines. Black lines indicate the planned timings; the actual quantity of work done is shown below in red.

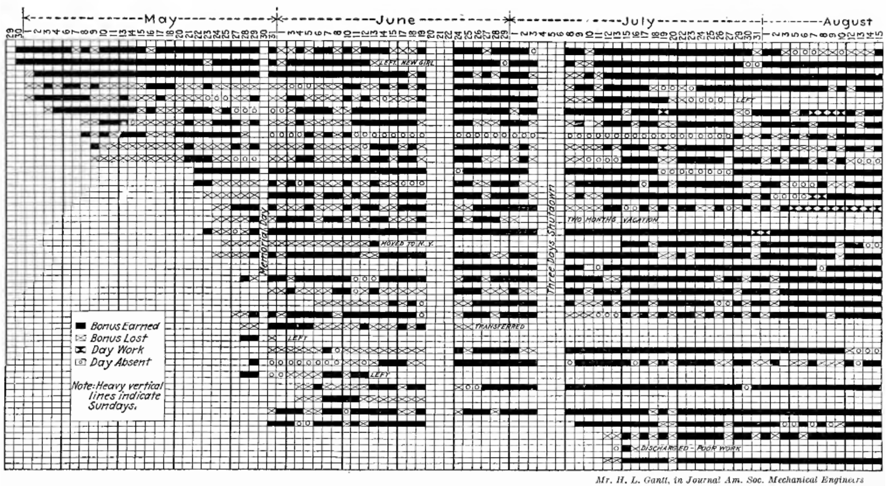


Fig. 2.20: Record of work carried out in one room of a Worsted Mill by Henry L. Gantt (see Brinton, 1914, p. 52). Each row represents one worker and gives information about whether a bonus was earned and if the worker was present. 🄯 *1914 Gantt. Retrieved from Internet Archive.*

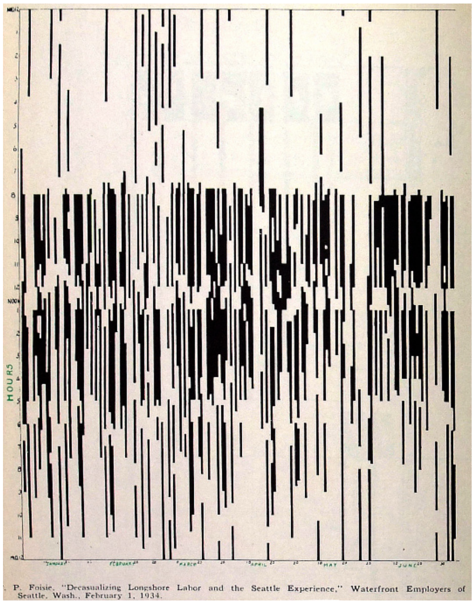


Fig. 2.21 Exact hours and days worked in 1929 by an employee at the Oregon ports (see Brinton, 1939, p. 250). Days are mapped on the horizontal axis and hours per day worked are represented as bars on the vertical axis. The representation shows extreme irregularities in working hours. 🄯 *1934 Foisie. Retrieved from Internet Archive.*

of time, i.e., days on the horizontal axis and hours per day on the vertical axis. Figure 2.22 employs a radial layout of the time and allows a reading on multiple levels: the outer ring shows days without work and the inner rings show hours worked during the day, whereas the green areas indicate night hours.

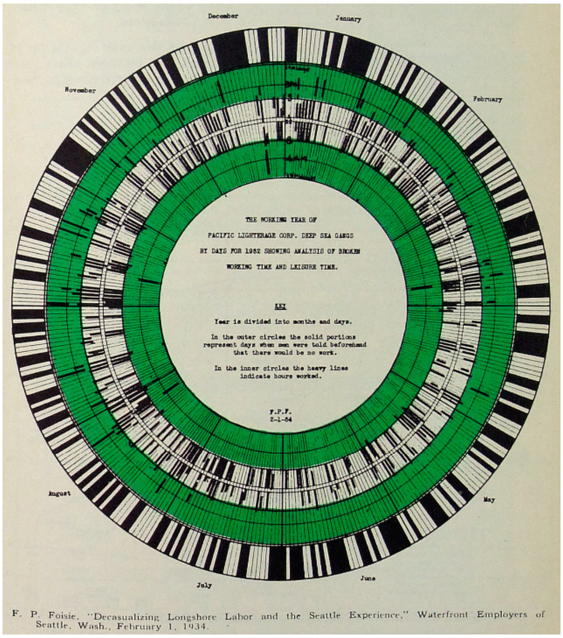


Fig. 2.22 An analysis of working time and leisure time in 1932 (see Brinton, 1939, p. 251). Uses a radial layout of time and allows a reading on multiple levels: the outer ring shows days without work and the inner rings show hours worked during the day, whereas the green areas indicate night hours.

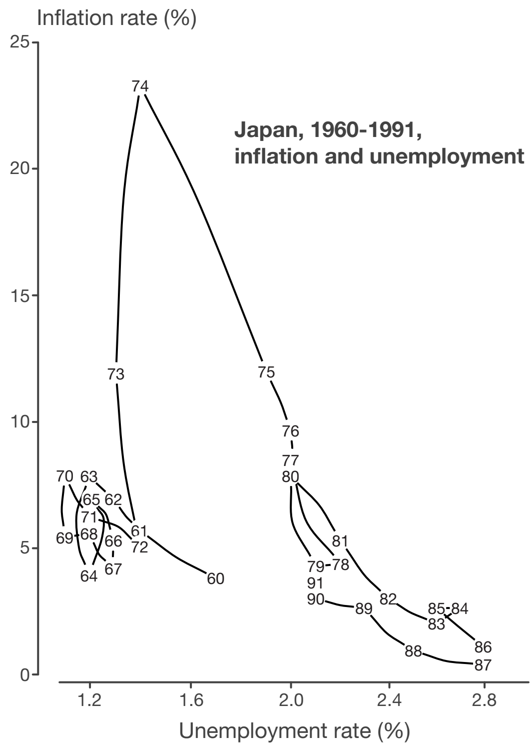


Fig. 2.23 Phillips curve. Unemployment rate (horizontal axis) is plotted against inflation rate (vertical axis). Each point in the plot corresponds to one year and is labeled accordingly. The markers of subsequent years are linked to create a visual trace of time.

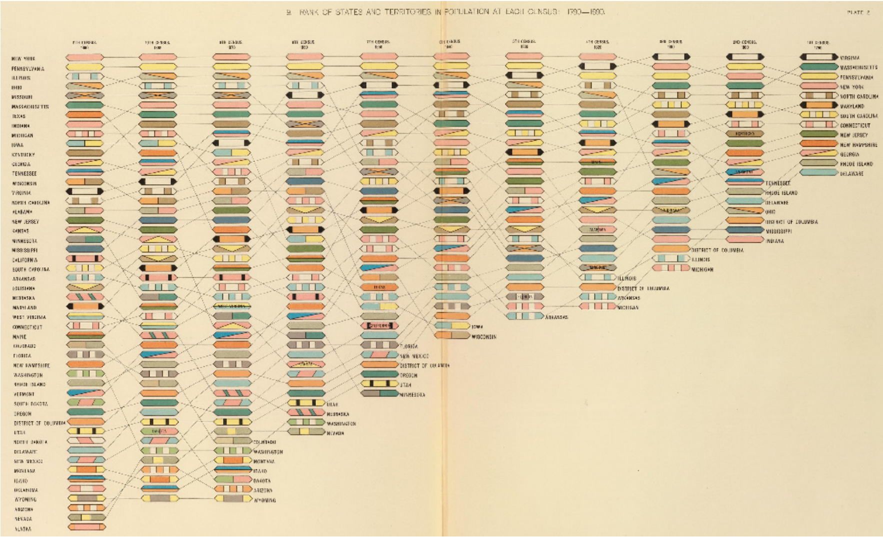


Fig. 2.24: Rank of states and territories in population at each census from 1790 to 1890 by Henry Gannett (1898).

A quite unique representation of economic data is the so-called *Phillips curve* – a 2D plot based on an economic theory that shows unemployment vs. inflation in a Cartesian coordinate system. In this representation, time is neither mapped to the horizontal nor the vertical axis, but is rather shown textually as labeled data points on the curve. This way, the dimension of time is slightly de-emphasized in favor of showing the relationship of two time-dependent variables (see Figure 2.23). Each year's combination of the two variables unemployment rate and inflation rate leads to a data point in 2D space that is marked by the digits of the corresponding year. The markers of subsequent years are connected by a line resulting in a path over the course of time.

For representing positional changes within a set of elements, *rank charts* were already introduced in early statistical publications, for example, by Henry Gannett (1846–1914) or Willard Brinton (1880–1957) (see Figures 2.24 and 2.25). Elements are ordered according to their ranking and displayed next to each other in columns for different points in time. The positional change of individual elements is emphasized by connecting lines. This way, the degree of rank change is represented by the angles of the connecting lines, thus making big changes in rank stand out visually by the use of very steep lines. Note that the two examples differ in the direction of their time axes. While the chart of Henry Gannett (Figure 2.24) uses a time axis from right to left, the example of Willard Brinton (Figures 2.25) employs the more frequently used order from left to right.

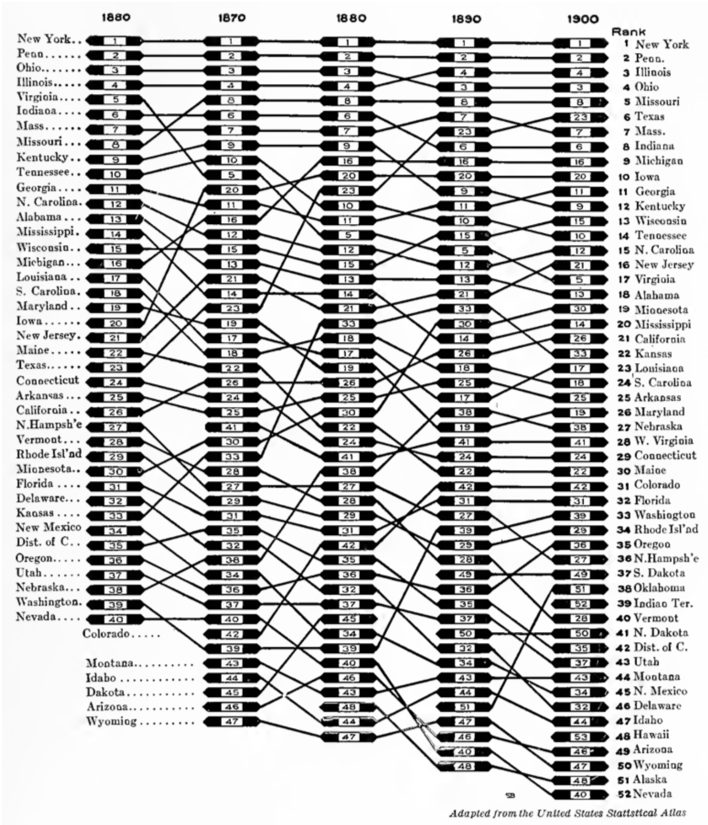


Fig. 2.25: Rank of states and territories in population at different census years from 1860 to 1900 by Willard Brinton (1914, p. 65). *1914 Brinton. Retrieved from Internet Archive.*

A remarkable representation of time-oriented information was created by Étienne-Jules Marey (1830–1904) in the 1880s (see Figure 2.26). It shows the train schedule for the track Paris to Lyon graphically. Basically, a 2D diagram is used which places the individual train stops according to their distance in a list on the vertical axis, while time is represented on the horizontal axis. Thus, horizontal lines are used to identify the individual stops and a vertical raster is used for timing information. The individual trains are represented by diagonal lines running from top-left to bottom-right (Paris–Lyon) and bottom-left to top-right (Lyon–Paris), respectively. The slope of the line gives information about the speed of the train – the steeper the line, the faster the respective train is traveling. Moreover, horizontal sections of the trains' lines indicate if the train stops at the station at all and how long the train stops. On top of that, the density of the lines provides information about the frequency of trains over time. This leads to a clear and powerful representation showing complex information at a glance while allowing for in-depth analysis of

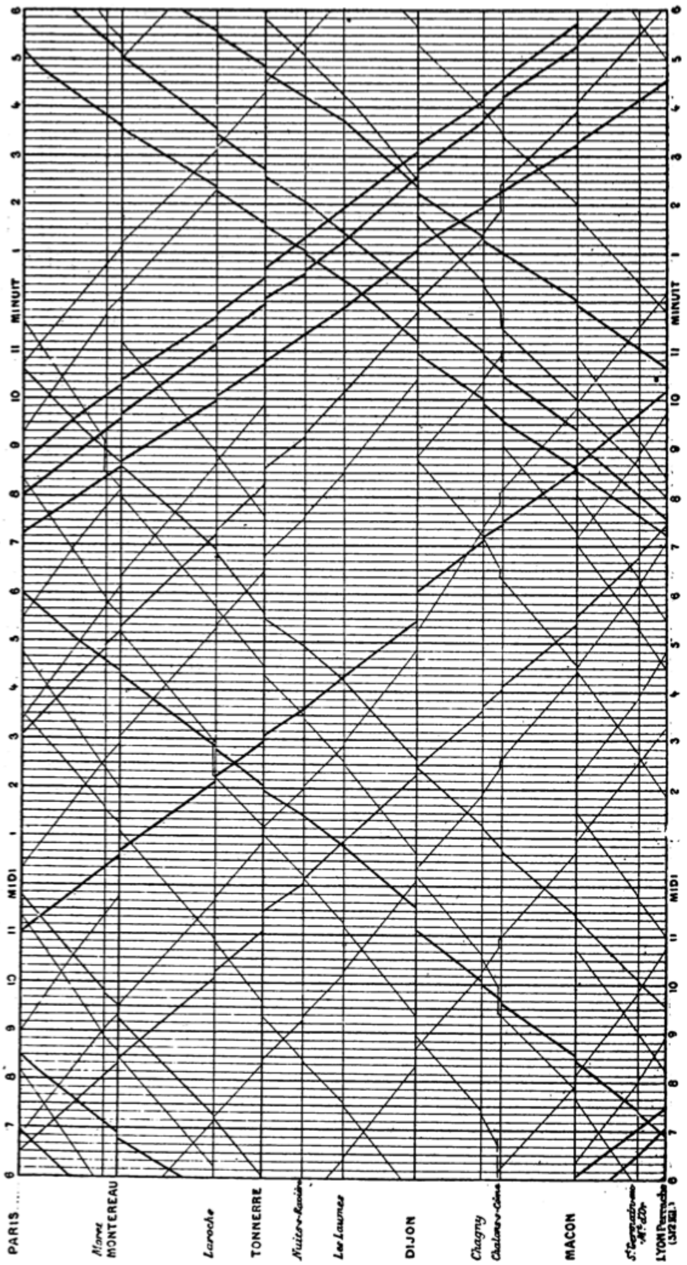


Fig. 2.26: Train schedule by Étienne-Jules Marey (1875, p. 260). Individual train stops are placed according to their distance in a list on the vertical axis, while time is represented on the horizontal axis (figure above is rotated by 90°). The individual trains are represented by diagonal lines running from top-left to bottom-right (Paris–Lyon) and bottom-left to top-right (Lyon–Paris) respectively. *1875 Marey. Retrieved from Internet Archive.*

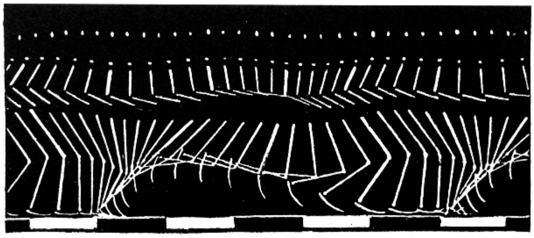


Fig. 2.27 A person walking. Studies of movement by Étienne-Jules Marey (1894, p. 61). 🅭 *1894 Marey. Retrieved from Internet Archive.*

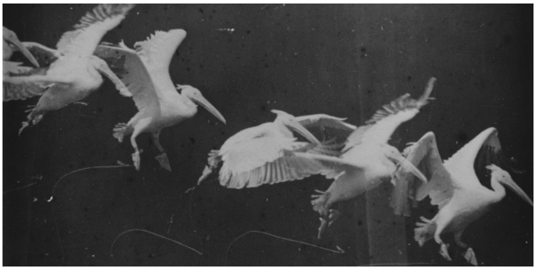


Fig. 2.28 Chronophotography. A photo of flying pelican taken by Étienne-Jules Marey around 1882. 🅭 *1882 Marey. Retrieved from Wikimedia Commons.*

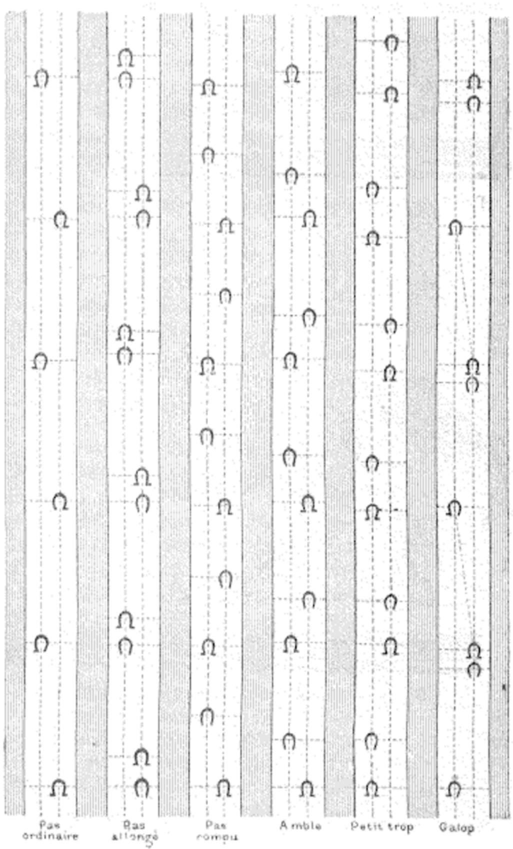


Fig. 2.29 Horse gaits. Studies of movement by Étienne-Jules Marey (1875, p. 147). 🅭 *1875 Marey. Retrieved from Wikimedia Commons.*

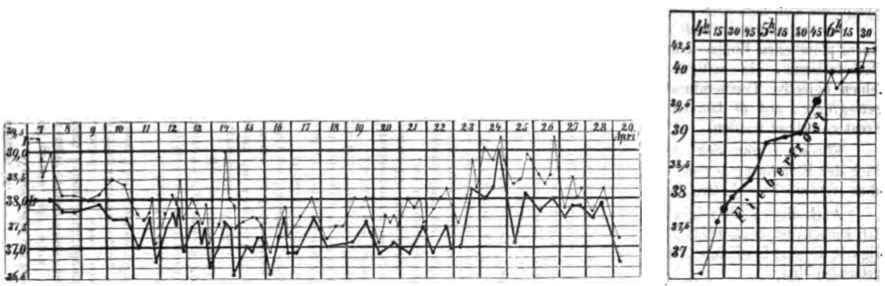
the data. Similar representations have also been used for the Japanese Shinkansen train line and the Javanese Soerabaja-Djokjakarta train line where the track's terrain profile is additionally shown. The basic idea of this representation even stood the test of time and interactive versions are still used today in modern software systems of railway companies to support train scheduling or in ViDX (↪ p. 364) to visualize automated assembly lines.

Étienne-Jules Marey not only created the fabulous train schedule, but was also very interested in exploring all kinds of movement. Born in 1830 in France, he was a trained physician and physiologist. His interest in internal and external movements in humans and animals, such as blood circulation, human walking, horse gaits, or dragonfly flight, led to the decomposition of these movements via novel photography and representation methods (see Figures 2.27, 2.28, and 2.29). This photography method, which is called *chronophotography*, paved the way for the birth of modern film-making at the end of the nineteenth century.

Today, Marey is still a valuable source of inspiration. Reason enough to speak highly of him and his work:

> Tirelessly, this brilliant visionary stopped the passage of time, accelerated it, slowed it down to "see the invisible," and recreated life through images and machines.
>
> La maison du cinema and Cinematheque Francaise (2000)

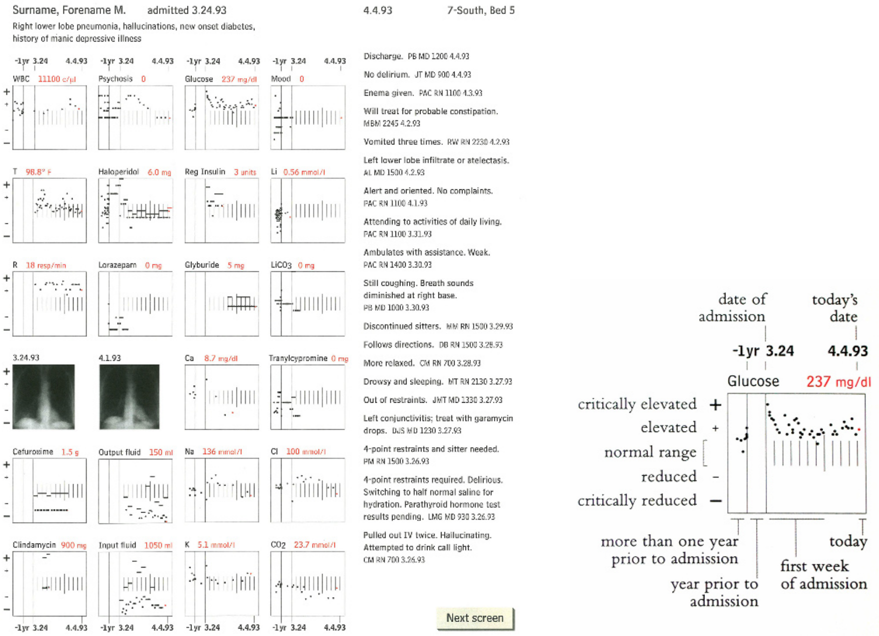
In medicine, large amounts of information are generated which mostly have to be processed by humans. Graphical representations which help to make this myriad of information comprehensible play a crucial role in the workflow of healthcare personnel. These representations range from the *fever curves* of the nineteenth century (see Figure 2.30) and EEG time-series plots (see Figure 2.31) to information-rich patient status overviews (see Figure 2.32). Especially the graphical summary of patient status by Powsner and Tufte (1994) makes use of concepts such as *small multiples* (↪ p. 359), *focus+context* (see p. 137), or the integration of textual and graphical information. It manages to display information on a single page that would otherwise fill up entire file folders and would require serious effort to summarize.



(a) Fever chart. **(b)** Details of Fieberfrost.

Fig. 2.30: Fever charts created by Carl August Wunderlich (1870, p. 161, 167). *1870 Wunderlich. Retrieved from Internet Archive.*

Fig. 2.31 EEG time-series plot. (cc)(by)(sa) *2005 Der Lange. Retrieved from Wikimedia Commons.*



(a) Overview. **(b)** Details.

Fig. 2.32: Graphical summary of patient status by Powsner and Tufte (1994). Concise summary of patient information. Uses *small multiples*, *focus+context*, and integrates textual as well as graphical information. © *1997 Graphics Press. Reprinted, with permission, from Tufte (1997, pp. 110–111).*

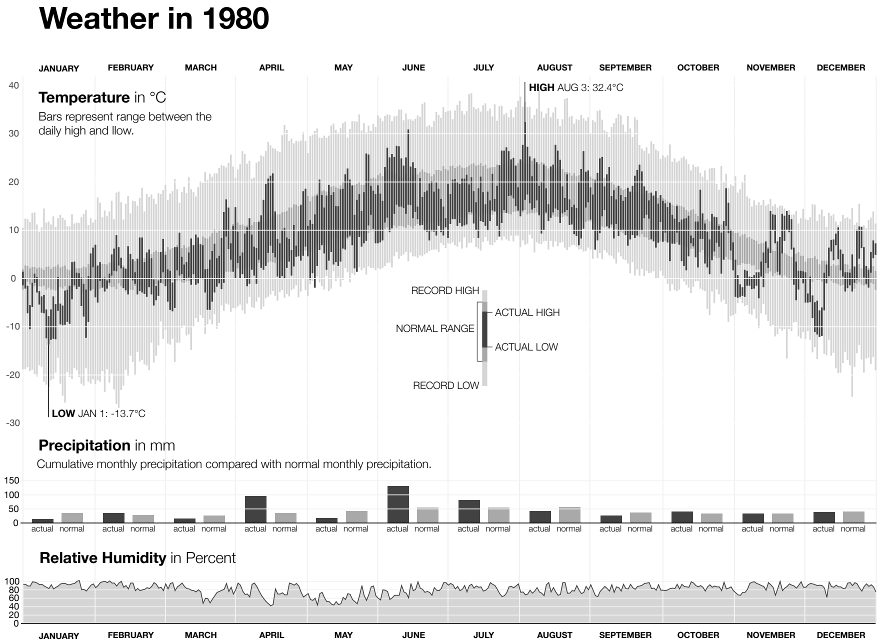


Fig. 2.33: Weather statistics for 1980. Aggregated values are displayed along with detailed information on temperature, humidity, and precipitation. Similar illustrations have been printed annually by the New York Times for more than 30 years. *Generated with Protovis.*

Weather and climate are further well-known application areas dealing with time-oriented data. Here, developments over time are of greater interest than single snapshots. Figure 2.33 shows the adaptation of an extremely information-rich illustration provided by the New York Times for more than 30 years to show New York City's weather developments for a whole year. Monthly and yearly aggregates are displayed along with more detailed information on temperature, humidity, and precipitation. All in all, more than 2500 numbers are shown in this representation in a very compact and readable form. An even earlier example of a visual representation of the weather data of New York City is shown in Figure 2.34. Here, temperatures, wind velocity, relative humidity, wind direction, and the weather conditions of a single month (December, 1912) are displayed.

Considering the long history of visualizing time-oriented data, two main metaphors for representing time can be identified: *arrow/line* and *river*. First, a vast majority of visualization techniques uses lines or arrows to depict time (see Davis, 2012). Commonly, a left-to-right direction is applied where later points in time are shown toward the right. Second, the metaphor of a river was frequently used already in historic depictions (see Rendgen, 2019). This metaphor is also used in contemporary visualization techniques, less often though, for example in ThemeRiver (↪ p. 293) and stream graphs (↪ p. 286).

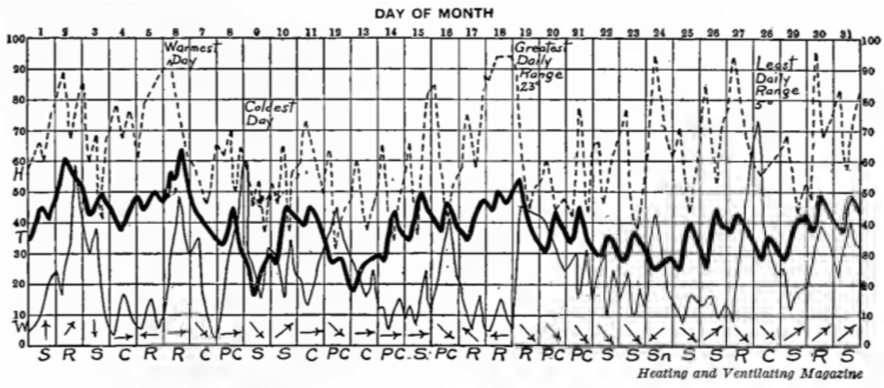


Fig. 2.34: Record of the Weather in New York City for December, 1912 (see Brinton, 1914, p. 93). The bold line indicates temperature in degrees Fahrenheit. The light solid line shows wind velocity in miles per hour. The dotted line depicts relative humidity in percentage from readings taken at 8 a.m. and 8 p.m. Arrows portray the prevailing direction of the wind. Initials at the base of the chart show the weather conditions as follows: S, clear; PC, partly cloudy; C, cloudy; R, rain; Sn, snow. *🅮 1914 Brinton. Retrieved from Internet Archive.*

2.2 Time in Visual Storytelling & Arts

Two disciplines that are seldomly connected to time-oriented information are *visual explanations* and *visual storytelling*. Although ubiquitously used in various forms in daily life, they are rarely considered for visualizing abstract information. Visual explanations are often used in manuals for home electronics, furniture assembly, car repair, and many more (see Figures 2.36 and 2.37). Often, they are used to illustrate

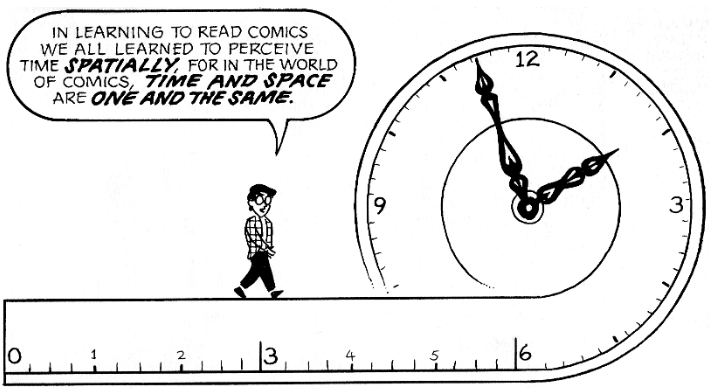


Fig. 2.35: In comics, time and space are one and the same. *© 1993, 1994 HarperCollins Publishers. Reprinted, with permission, from McCloud (1994, p. 100).*

Fig. 2.36: Visual explanation to illustrate a stepwise process as used in Tomitsch et al. (2007). *The authors.*

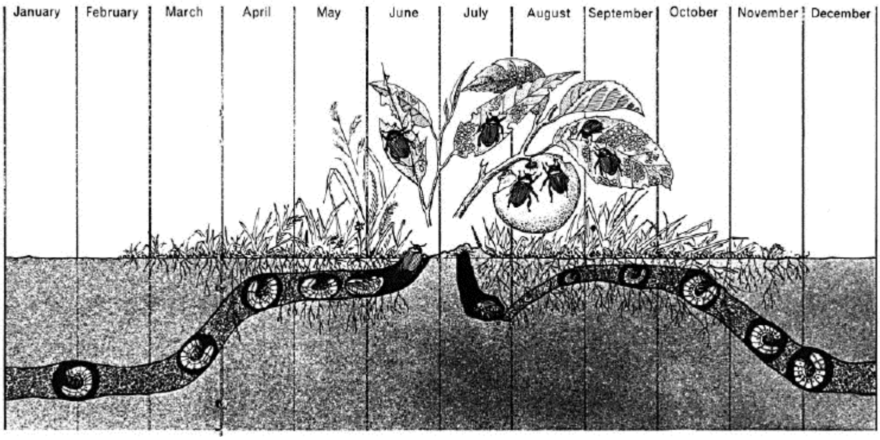
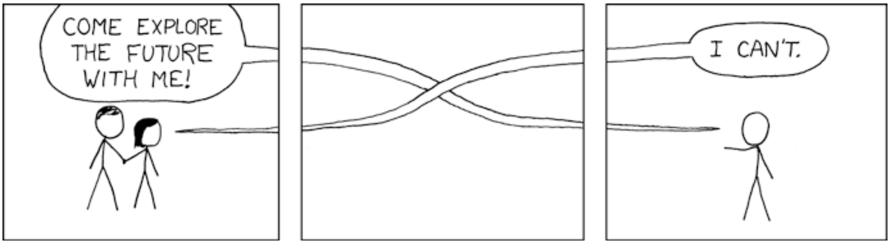


Fig. 2.37: Life Cycle of the Japanese Beetle (Newman, 1965, p. 104–105). © *1990 Graphics Press. Reprinted, with permission, from Tufte (1990, p. 43).*

stepwise processes visually to an international audience to support the often poorly translated textual instructions. The stepwise nature conveys a temporal aspect and might also be applied to represent abstract information. Even older than everything we presented previously is the craft of *storytelling*, especially visual storytelling, starting from caveman paintings and Egyptian hieroglyphs to picture books and comic strips (see Figure 2.35). Time is the central thread that ties everything together in visual storytelling. Many interesting techniques and paradigms exist that might be applicable to visualization in general (see for example Gershon and Page, 2001) as well as to the representation of time-oriented information in particular.

Comics The art of *comics* is often dubbed as *visual storytelling over time* or *sequential art* (a term used by Will Eisner) because temporal flows are represented in

(a) *Classical comic layout representing an ordered sequence of scenes in juxtaposed panels. © Courtesy of Greg Dean, from RealLife Comics.*



(b) *Exploration of the duality of space and time in comic panels. 🅭🅯🄏 "Future" by Randall Munroe. Retrieved from xkcd.com.*

Fig. 2.38: Comics where temporal flows are represented in juxtaposed canvases on a page.

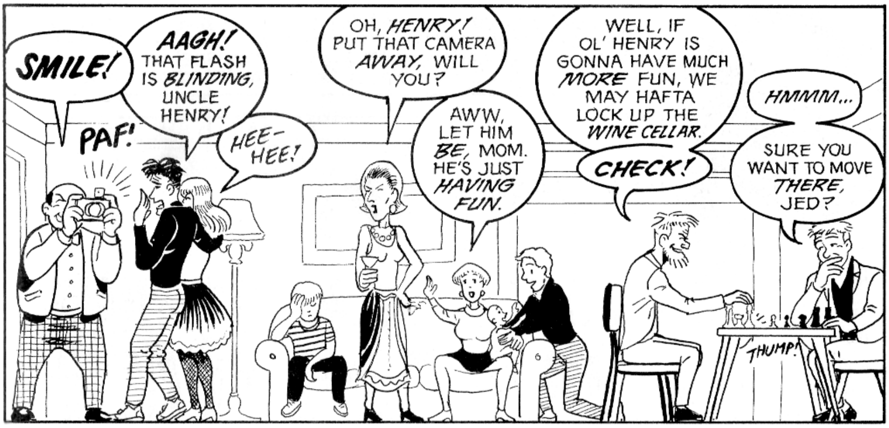


Fig. 2.39: A single comic panel contains more than a frozen moment in time. © *1993, 1994 HarperCollins Publishers. Reprinted, with permission, from McCloud (1994, p. 95).*

juxtaposed canvases on a page (see Figure 2.38). These descriptions already suggest that comics incorporate many concepts of time, while still retaining a static, 2-dimensional form. McCloud (1994) analyzed many of the methods and paradigms of comics, concluding that powerful means of representing time, dynamics, and movement are applied which differ from those applied in painting or photography. Comics allow for the seamless representation of many temporal concepts that may be also applicable to visualization. Basically, the course of time is represented in comics via juxtaposition of panels. But the individual panels portray more than single frozen moments in time and are more than photos placed side by side. Rather, single panels contain whole scenes whose temporal extent may span from milliseconds to arbitrary lengths (see Figure 2.39). Not only the content of a panel sheds light on the length of its duration but also the shape of the panel itself can affect our perception of time. Even more freedom in a temporal sense is given by the transition from one panel to the next or by the space between panels, respectively (see Figure 2.40). Here, time might be compressed, expanded, and rewound; deja vu's might be incorporated and much more. This also implies that comics are not just simply linearly told stories. Comics are very versatile and much more powerful in incorporating time in comparison to paintings, photographs, and even film. Besides the purely temporal aspect, motion is another important topic in comics. Several visual techniques, such as motion lines or action lines with additional effects like multiple images, streaking effects, or blurring are applied (see Figure 2.41). In part, these techniques are borrowed from photography. Research work on generating these comic-like effects from motion pictures has been conducted, for example, in Markovic and Gelautz (2006).

Music & dance Music notes are a notation almost everybody is aware of, but it is one which is rarely seen in conjunction with time-oriented information (see Figure 2.42). Nevertheless, music notes are clearly a visual representation of temporal information

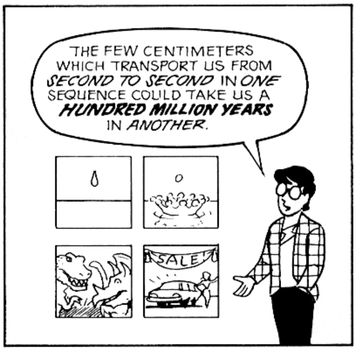


Fig. 2.40: Transitions between panels might span intervals of arbitrary length. © *1993, 1994 HarperCollins Publishers. Reprinted, with permission, from McCloud (1994, p. 100).*

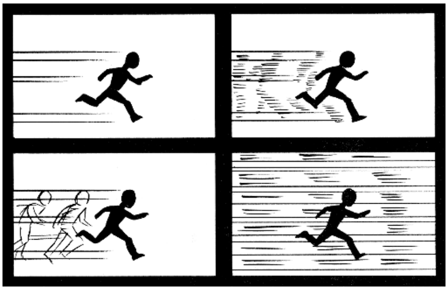


Fig. 2.41: Techniques to represent movement in comics (motion lines, streaking, multiple images, background streaking). © *1993, 1994 HarperCollins Publishers. Reprinted, with permission, from McCloud (1994, p. 114).*

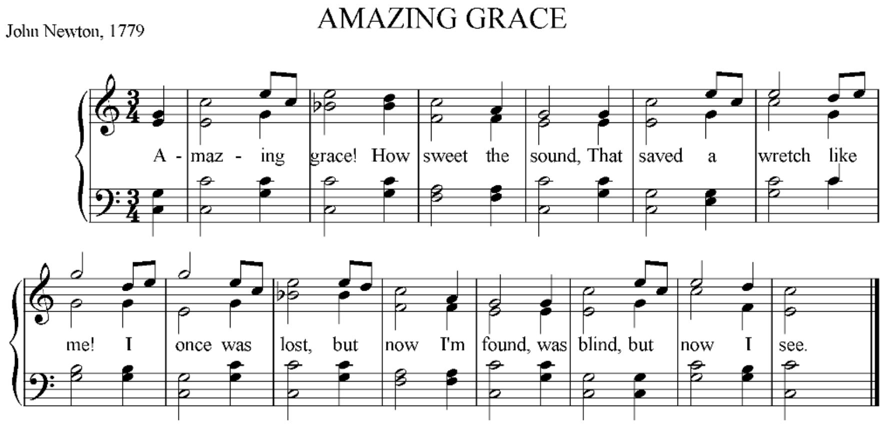


Fig. 2.42: Music notation of "Amazing Grace". A rich set of symbols, lines, and text visualizes beat, rhythm, pitch, note length, pausing, instrument tuning, and parallelism. *2007 HenryLi. Retrieved from Wikimedia Commons.*

– even more than that. A rich set of different symbols, lines, and text constitute a very powerful visual language. Beat, rhythm, pitch, note length, pausing, instrument tuning, and parallelism are the most important visualized parameters. In fact, it is hard to imagine any other way of representing musical compositions than via music notes. Related to that, special notations are used for recording dance performances statically on paper (see Figure 2.43).

Movies One art form that is only touched upon briefly here, but which might also offer interesting ideas for visualization, is *film*. We will present movies that exemplify

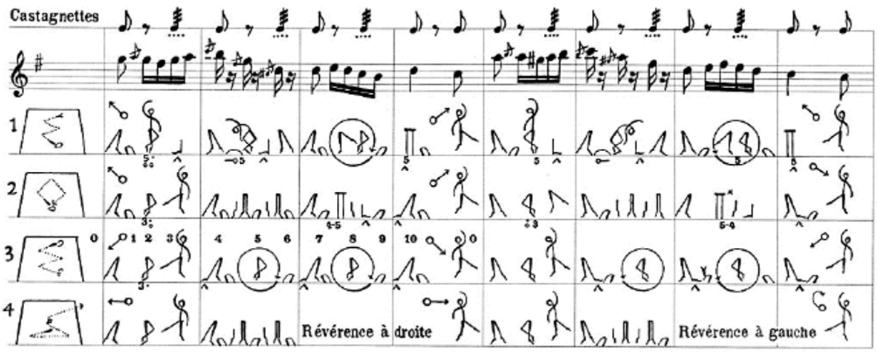


Fig. 2.43: Dance notation. Used for recording dance performances statically on paper. *© 1990 Graphics Press. Reprinted, with permission, from Tufte (1990, p. 117).*

how moviemakers are able to transport highly non-linear stories in the temporally linear medium of film. These examples pertain to the plot of a film, and not to filming or cutting techniques.

Run Lola Run[1] is a movie that presents several possible successions of events sequentially throughout the film (compare *branching time* in Section 3.1.1). The individual episodes begin at the same point in time and show different possible strands of events.

The movie *Pulp Fiction*[2] comprises an even more complicated and challenging plot. It is a collection of different episodes that are semantically as well as temporally linked. Moreover, the movie ends by continuing the very first scene in the movie, thus closing the loop.

A further example of the use of interesting temporal constellations in film is the movie *Memento*.[3] The main character of the movie is a man who suffers from short-term memory loss, and who uses notes and tattoos to hunt for his wife's killer. What makes the storytelling so challenging is the fact that time flows backward from scene to scene (i.e., the end is shown at the beginning and the story progresses to the beginning from there).

Music videos are also often used as an innovation playground where directors can experiment with unconventional temporal flows such as the *reverse narrative* as used in Coldplay's *The Scientist*.[4]

Paintings A very interesting approach to overcoming the limitations of time can be found in *Renaissance* paintings. Here, sequences of different temporal episodes are shown in a single composition. Figure 2.44 for example shows a painting by

[1] Run Lola Run (Lola rennt), written and directed by Tom Twyker, 1998.

[2] Pulp Fiction, written by Quentin Tarantino et al., directed by Quentin Tarantino, 1994.

[3] Memento, written by J. and C. Nolan, directed by Christopher Nolan, 2000.

[4] The Scientist, recorded by Coldplay, music video directed by Jamie Thraves, 2001.

Fig. 2.44: Masolino da Panicale, Curing the Crippled and the Resurrection of Tabitha (Brancacci Chapel, S. Maria del Carmine, Florence, Italy), 1420s. Different stages or episodes of a single person are shown within a unifying scenery. *1424 Masolino da Panicale. Retrieved from Wikimedia Commons.*

Masolino da Panicale that presents two scenes in the life of St. Peter within a single scenery. While this method of showing different stages or episodes within a unifying scenery was well understood by the people at that time (the Middle Ages), it might not be as easily understood by a modern viewer. In his article, Jones (2020) provides an overview of how paintings depict time and mentions that:

> Paint is usually thought to be a static medium, capable of depicting only frozen instants of time. Yet with a little inventiveness, it's possible for paint to represent the passage of time too.
>
> Jones (2020)

The beginning of the 20th century was characterized by new findings and breakthroughs in the natural sciences, especially in mathematics and physics, such as Einstein's theory of relativity. But not only the world of science was shaken by these developments; artists also addressed these topics in their own way. Foremost among these were the protagonists of the art movement of *Cubism*, who focused on incorporating time in their artworks. They coined the term *Four-dimensional Art*. In his book, Miller (2001) gives an overview of the history of this movement.

As already mentioned, the concept of the n-dimensional space in mathematics and physics inspired artists to think about 4D space. Figure 2.45 shows Marcel Duchamp's painting *Nude Descending a Staircase* which incorporates the dimension of time in a very interesting way by overlaying different stages of a person's movement. Another example is Pablo Picasso's *Portrait of Ambroise Vollard* (see Figure 2.46), where many different observations are composed and partly overlaid to form a single picture. The artists wanted to put emphasis on the *process* of looking and recording over time (in contrast to taking a photo). These new ways of bringing the fourth dimension into the static domain of pictures are still a challenge to viewers today.

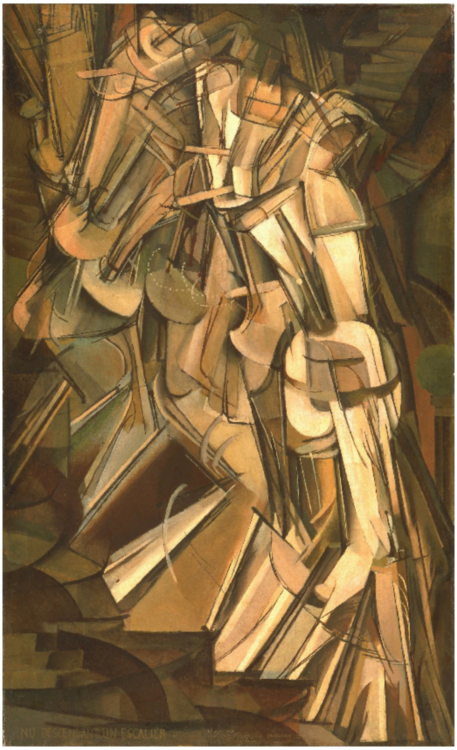


Fig. 2.45 Marcel Duchamp, Nude Descending a Staircase (No. 2), 1912. The dimension time is incorporated by overlaying different stages of a person's movement. © *2010 VBK, Vienna.*

Fig. 2.46 Pablo Picasso, Portrait of Ambroise Vollard, 1910. Many different observations are composed and partly overlaid to form a single picture. © *2010 Succession Picasso/VBK, Vienna.*

2.3 Summary

We have provided a brief review of relevant historical and application-specific visualization techniques and representations of time in the visual arts. Our aim was to provide historical context for developments in this area and to present some ideas from related fields that might act as a further source of inspiration for designing visualizations. Furthermore, this chapter has demonstrated the enormous breadth of the topic which we are only able to cover in part.

Readers interested in more information about historical representations of time-oriented data and historical representations in general are referred to the wonderful books of Tufte (1983), Tufte (1990), Tufte (1997), Tufte (2006), Wainer (2005), Rosenberg and Grafton (2010), Davis (2017), Rendgen (2019), and Dick (2020). Michael Friendly's great work on the history of data visualization can be studied in numerous articles such as (Friendly, 2008) as well as online in his Data Visualization Gallery[5] and the Milestones Project.[6] Additionally, interesting historic facts related to time representations are discussed on the Chronographics Weblog[7] of Stephen Boyd Davis.

Now, after setting the stage and considering various concepts and ideas from related disciplines, we will narrow our focus and present a systematic view of the visualization of time-oriented data. In this sense, we will first discuss important aspects that make the handling of time and time-oriented data possible. Following that, the visualization problem itself will be systematically explained and discussed.

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[5] https://www.datavis.ca/gallery

[6] https://www.datavis.ca/milestones

[7] https://chronographics.blogspot.com

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