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THE VISUAL REPRESENTATION OF TIME IN TIMELINES, GRAPHS, AND CHARTS

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Abstract
A cursory examination of newspapers and magazines shows that much information is conveyed through timelines and time-related graphs and charts. These graphics have a structure that is based upon many factors, including our cognitive representation of time, the direction in which we write, timescales, rhetorical intent, and the restrictions of a two-dimensional surface. This paper examines the theoretical underpinnings of these factors in an effort to assist journalists and informational designers to make clearer and more readable time-related graphics.

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Introduction
An examination of newspapers and magazines shows that much historical, economic, scientific, and other information is conveyed through timelines and time-related graphs and charts. These graphics have a structure that is based upon many factors, including our cognitive representations of time, the development of writing, timescales, rhetorical intent, and the restrictions of a two-dimensional surface. Journalists and information designers may find it useful to understand the theoretical underpinnings of these factors are so that they can make design decisions that maximize the potential for transmitting intended meanings through graphical representations. Font and number systems chosen for a graphic are also important, since all of the marks on the page are part of the design, but these features are not considered in this paper.

Background
While there are several theories and some practical guidebooks on the composition and interpretation of graphics (e.g., Bertin, 1983; Kress & van Leeuwen, 1996; Tufte, 1983, 1999), there is no theory relevant to how time is structured in graphics. This research began with the intention of describing the structuring of time in graphics and the aim of developing practical guidelines that designers could follow to create clearer and more meaningful time-related graphics.

This research began with the hypothesis that humans have an inbuilt cognitive representation of time, that this representation has a structure with rules, and that good graphic designs of time would be constructed following this structure and its rules. One area in which the representation of time is well researched and understood is linguistics. The linguistic representation of time was therefore chosen as a primary theory base for this research. Several other hypotheses were based upon a cursory examination of many examples of graphic representations of time: (1) different graphics have different timescales for different cognitive and practical reasons; (2) the direction in which various cultures write has had an impact on the design of time-related graphics; (3) different graphics have different shapes (e.g., linear, circular) for both cognitive and practical reasons; and (4) the practicalities of fitting a certain amount of information on a two-dimensional page has had an impact on the design of time-related graphics. The remainder of this paper analyses these hypotheses.

Our cognitive representations of time

To understand the construction of time-related graphics, it is important to understand our cognitive representation of time. Our cognitive representation of time can be revealed by analysing the representation of time in language. Time is represented in language primarily through the metaphor *time is space* (Lakoff & Johnson, 1980), in which we think of time as an imaginary place or path along which we walk. In this metaphor, the future lies before us, the past behind, and we stand at *now* (Traugott, 1975). In every sentence we utter, we relate our current place along the path, which is *now*, to the place along the path at which the thing we are speaking of happened, which is *then*. The position of *now* along the path is our primary reference point. This imaginary path, which is present within every sentence, is known as deep semantic or conceptual tense. Figure 1 shows an example of the path of time in language.

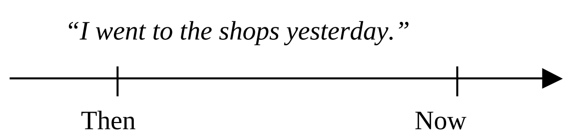

Figure 1. Example of the path of time in language

The imaginary path of time in language has direct corollaries in graphic communication. The path of time that is embedded in language is explicitly shown in graphics such as timelines and clock faces. In addition, just as language has reference points embedded in it to show where *now* and various *thens* are, graphics such as timelines and clock faces have reference points placed on them, too.

Some visual representations of time have actual paths within them and contain figures that literally face the future. Evolutionary timelines, for example, typically run from left to right across the page and show creatures moving along a path in the direction of their future (Figure 2). According to Van Sommers (1984), when most right-handed people draw a face in profile, they draw it facing to the left. This research suggests, therefore, that when people in timelines are portrayed facing to the right, they are deliberately drawn that way so that they can literally appear to be facing towards the future.

There is at least one other writing system in which the facing of images carries meaning, and that is Egyptian hieroglyphic writing in which hieroglyphics based upon living creatures (e.g., birds, people) faced the direction in which the writing began.

Therefore, it is probable that the direction of facing in a timeline carries time-related meaning and mimics the representation of tense in linguistic time.

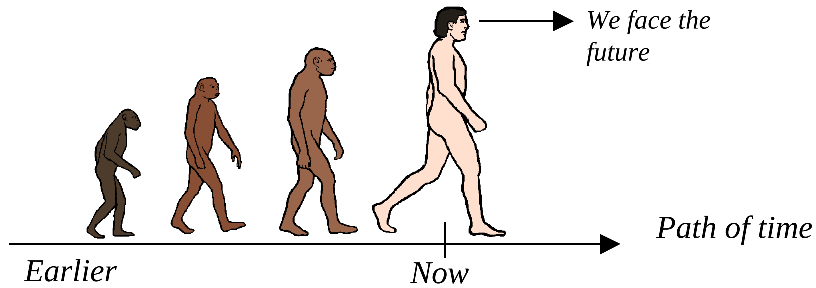

Figure 2. The importance of facing in timelines

The use of right-facing creatures placed along a horizontal line in order from left to right was pioneered by Muybridge (c. 1957) in the 1870’s who developed the first photographs to be viewed as motion pictures. Muybridge placed still cameras at equal-spaced intervals along a line and took photographs of moving people and animals in rapid succession. He displayed these photographs in equal-sized frames along rows following reading order. It is these photographs that helped to form the basis for the design pattern followed in evolutionary timelines.

According to Traugott (1975), the most important subsystems of linguistic time are *tense, temporal sequencing,* and *aspect*. Tense is present in every sentence to denote when something is, has, or will happen. Temporal sequencing refers to when one event occurs in relation to another. Aspect refers to the duration or recurring nature of an event. Traugott said that in language it is difficult to fully separate tense, temporal sequencing, and aspect from one another. This difficulty also applies to visual representations.

To indicate tense, graphic representations of time must include at least four things: (1) an indicator of *now* (the reference point); (2) an indicator of *then* (the time of the event, which could be in the past or in the future); (3) some type of visual differentiation between the past and the future; and (4) for a future event, something that indicates the degree of certainty of that event.

The reference point chosen depends upon the selected timescale. When time is represented with the Gregorian calendar, for example, the date 1 AD is the primary reference point. When time is represented according to the Gregorian calendar year, January 1st is the primary reference point. When time is represented according to the fiscal year, however, July 1st is the primary reference point. When time is represented according to the seven-day week, there is some confusion about the primary reference point because in some representations, Sunday is the start of the week and in others Monday is the start. There can also be some confusion about the primary reference point for the day because, technically, a new day begins at midnight yet many people feel that a new day begins when they awaken.

Figure 3 shows an example of how reference points can be represented in graphics and how the past, present, and future can be differentiated from one another. In this example, the present (now) is represented by the year (which in this case is 1993); the past is to the left of now and is represented with solid lines; and the present is to the right of now and is represented with dotted lines.

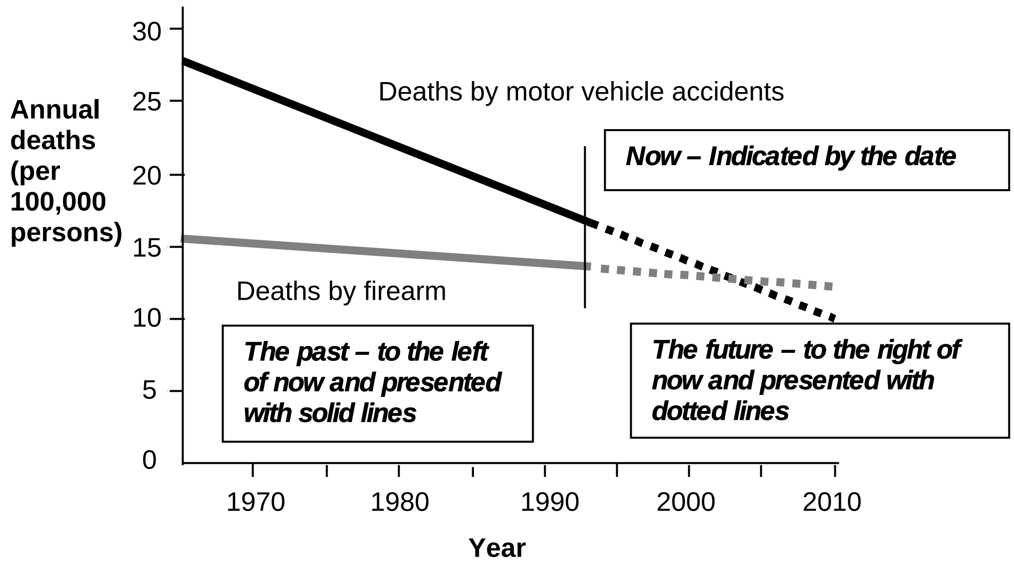

Figure 3. Gun and automobile mortality statistics (data from Wallich, P. (November, 1993) Grim statistics. *Scientific American*, p.7)

Temporal sequencing is indicated in graphic representations when more than one event is indicated in the representation. Graphic representations of time can indicate whether one event overlaps with another; whether the events occur simultaneously; which event began first; and which event will end first. Aspect designates the duration of an event, whether an event is bounded (e.g., did the event happen once or does it happen all of the time), and whether an event recurs. Figure 4 shows an example of the graphical representation of temporal sequencing and aspect in a series of timelines.

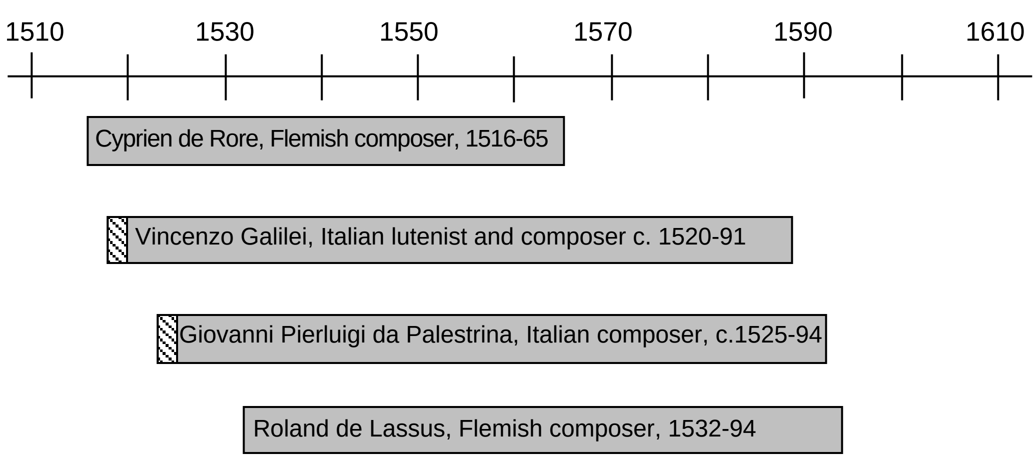

Figure 4. Some composers of the 1500's. This timeline shows an example of how temporal sequencing and aspect can be represented visually.

In Figure 4, temporal sequencing is expressed by a comparison of the starting positions at the left of each timeline. These positions represents the year in which each composer's life began. The line that is furthest to the left started first, the next one towards the right came next, and so on. These lines can be read as follows, "Cyprien de Rore was born first, and then, we believe, Vincenzo Galilei was born, and so on."

Aspect is expressed in Figure 4 by the boundaries of each line and by the relationship of one line to another. For example, looking at these lines we can say that Cyprien de Rore lived from 1516 to 1565, and that from 1532 to 1565, all of these composers were concurrently alive.

In addition to tense, temporal sequencing, and aspect, *mood* is also important in expressing information about time. We use mood to express information about the future, such as whether something *is going to happen* or *might* happen. The future form is created by adding modal auxiliaries before the present tense. Examples of modal auxiliaries include *is going to*, *will*, *shall*, *could*, *would*, *may*, *might*, and *must*. Modal auxiliaries convey that something will happen in the future, and how certain we are that the thing will happen. The degree of certainty we perceive is indicated through the modal we chose to use. The modals *is going to*, *will*, *shall*, and *must* all indicate a greater degree of certainty than the modals *could*, *would*, or *might*. In graphic representations of time, a more certain future event is often represented with a solid line, whereas a less certain event is often represented by a change in colour or texture (e.g., a solid line becomes a dotted line). Refer back to Figure 3 for an example.

Timescales

Different types of events are measured with different types of measuring scales. Stephens (1951) defines a scale as 'a rule for the assignment of numerals (numbers) to aspects of objects or events.' Stephens describes nominal, ordinal, interval, and ratio scales in relation to measurement in general, not specifically in relation to the measurement of time. Only ordinal, interval, and ratio scales apply to the visual representation of time.

Ordinal scales arrange items in rank order from less to more (or vice versa) with no specific interval of measurement between items. In relation to time, ordinal scales are appropriate for placing events that are of no exact (or determinate) duration or that began at no particular (or an indeterminate) time in order of their occurrence. For example, the steps a mother bird follows to feed her chicks do not have specific amounts of time associated with them but do have an order, which in the case of time, runs from earlier to later. Figure 2 showed an example of an ordinal scale. In this example, the males are presented in order, but not along a specific time scale.
Any visual representation of time that does not indicate calendar dates or specific quantities of equal units of time (e.g., seconds, minutes, hours, etc.) is considered to have an ordinal scale. The main purpose of such representations is not to show when the events began or how much time each step in a sequence of events takes, has taken, or will take, but rather what the steps were and in what order they occurred.

Interval scales arrange items from less to more by equal increments of measurement but have no true zero point. According to Stephens (1951), 'The zero point on an interval scale is a matter of convention or convenience…' (p.27). In relation to time, calendar dates (e.g., year, month, day) are examples of interval scales. Any calendar, be it Gregorian, Julian, Islamic, Ancient Egyptian, Chinese, or Mesoamerican, has a conventional date on which the calendar begins (e.g., 1AD in the Gregorian calendar) and by which the dates in one calendar can be converted to another.

Ratio scales have the same features as interval scales except that they have a true zero point. In relation to time, ratio scales are used to measure durations of events in equal units of time (e.g., number of hours in a day; seconds it takes to run a 50 meter race; weeks in a semester; or years in the life of the average Australian woman) and speed of motion over distance (e.g., km/hour) or in number of oscillations or revolutions per equal unit of time.

The timescale by which an event is measured and the scale by which it is visually displayed are frequently two different types of scales. For example, events that are measured with an interval scale may be displayed along an ordinal scale. Therefore, scales need to be described by both the type of physical measurement system used and the visual arrangement of the scale.

There are three possibilities for the visual display of scales: ordinal, interval, and technologically-determined. In a visual ordinal scale, a particular unit of time does not equal a particular unit of space whereas in a visual interval scale, a particular unit of time equals a particular unit of space (e.g., 1cm = 1 second). Some visual scales are neither ordinal nor interval but are, instead, technologically-determined. For example, some early sundials displayed unequal visual intervals between the hours, but the intervals were determined by the orientation of the sundial to the sun, not by the way in which the hours were measured on a given day, which was by a ratio scale.

Designers choose the measurement scale and the visual scale based upon their purpose, the information to be displayed, and the space available. If a designer's intent is to show exact-time relationships between different events or to show how some phenomena changes over time, then it is best to combine an interval or ratio measurement scale with an interval visual display. Most graphs that are set in a Cartesian coordinate system fit this model. If a designer's intent is to show the order and times in which particular events occurred, then the combination of an interval or ratio measurement scale with an ordinal visual display should be effective.

Writing and the visual representation of time

Timelines can take a variety of forms including horizontal lines, vertical lines, lines that move back and forth or up and down a page (a format known as *boustrophedon* from the Greek, meaning 'as the ox plows' (Diringer, 1968)), spirals, or follow a winding path like a road on a map. The majority of timelines, however, run from left to right along the horizontal. Vertical timelines, in contrast, can run from bottom to top or from top to bottom.

Zwaan (1965 as cited in Winn, 1994) has noted that people's perception of the direction of time-movement on the page reflects the direction in which they write. In his research on Dutch and Israeli subjects, Zwaan found that the Dutch, who read from left to right, associate the left side of the page with the ideas of 'proximity,' 'past' and 'self.' Israeli subjects, who read from right to left, associate these ideas with the right side of the page. Therefore, the concepts of past or earlier are located on the side of the page where the writing begins and the concepts of future or later are located where the writing ends (Figure 5).

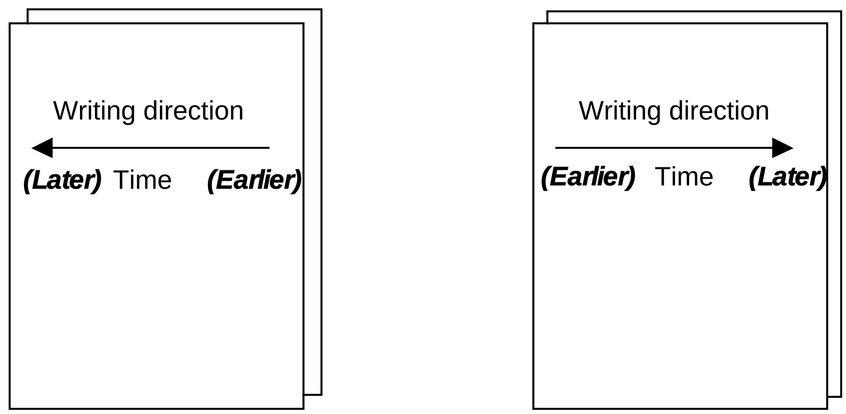

Figure 5. Time and the page in cultures that read along the horizontal. Just as reading progresses in one direction across the page, so does time

Since in left-to-right reading cultures, horizontal timelines only move from left to right, we can say that this format is now a design convention just as starting a sentence with a capital letter is a writing convention. The convention of drawing horizontal timelines with *earlier* on the left and *later* on the right has come from our direction for writing. I have seen timelines that move from right to left only in the literature of cultures that read from right to left. For example, in a Taiwanese home accident-care manual, there are several diagrams that proceed in a zig-zag pattern from right to left across the page. Although many other visual arrangements were also present in this particular manual, a right to left arrangement such as presented in this manual would not typically appear in a left-to-right reading culture.

Arrangements of timelines

As discussed in the previous section, horizontal timelines in left-to-right reading cultures nearly always proceed from left to right. In a study conducted by Van Sommers (1984) in which subjects were asked how they would draw a visual representation of time, most drew a horizontal timeline which proceeded from *earlier* on the left of the page to *later* on the right. None of Van Sommers' subjects drew a horizontal timeline that proceeded from right to left. The second most common answer provided by subjects in this study was a vertical list that was drawn from *earlier* at the top of the page to *later* at the bottom. The third most common answer was a matrix such as found in a diary, timetable, or calendar. The fourth most common answer was a clock face. Descriptions of and reasons for selecting vertical, boustrophedon, circular, winding, matrix, and piral arrangements of time are discussed in this section.

Van Sommers (1984) reported that when recent time spans of months and years are represented in a vertical timeline, time always runs down the page. However, when larger geological or cosmological time spans are represented, time may run up or down the page. Van Sommers explained this inconsistency by saying that geologists are dealing with two primary reference points, the beginning of time and the present, neither of which is tied to an up or down orientation.

Designers may deliberately select a vertical orientation for at least two reasons. First, there is more room available along the vertical than the horizontal on an A4 page' so if the information doesn't fit horizontally, it may fit vertically. Second, the information may be designed to match a physical reality. For example, some geological timelines run from an earlier time at the bottom to a later time at the top to match the way in which sedimentary geological layers are formed.

Figure 6 shows a boustrophedon timeline. Although used and then abandoned by the Greeks for their writing, the boustrophedon arrangement is still used for designing some timelines because of its particular design strength: the boustrophedon arrangement creates continuity from one event to the next. In a boustrophedon design, neither the hand nor the eye has to be raised back to one side of the page to continue writing or reading. Unlike a horizontal timeline, boustrophedon timelines always show an arrow (or arrows) showing how to read the line.

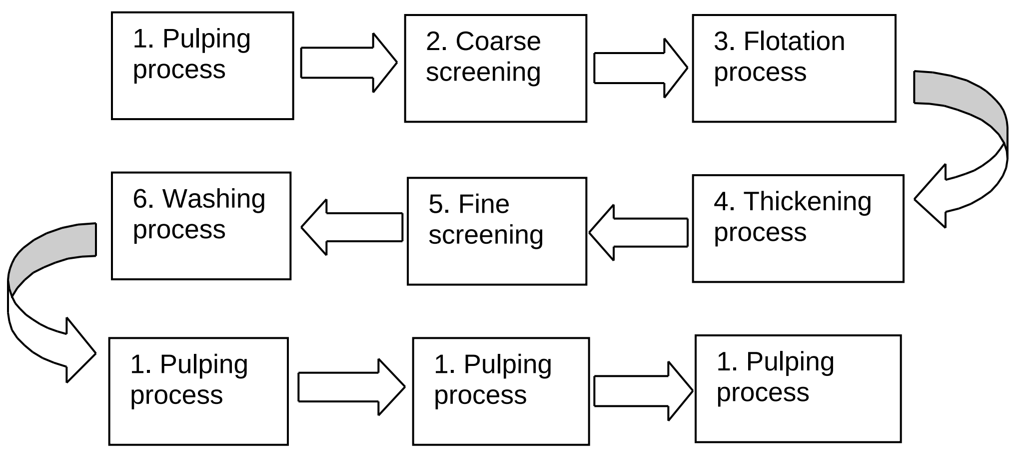

Figure 6. Process for deinking paper. An example of a boustrophedon timeline

Boustrophedon arrangements typically have an ordinal scale and begin in the upper left corner of the page where reading begins. Some arrangements zigzag vertically up and down the page, whereas others zigzag back and forth across the page.

The clock is the most common example of a circular timeline, but this arrangement is also sometimes used to represent other cyclical measures of time, such as the months of a year. The primary advantages of a circular representation of time are that it shows continuity (there is never a break in time) and it emphasizes the cyclical motion of time.

A circular timeline, such as a clock, is cognitively a spiral since the movement always goes in the same direction, and the hours (and minutes and seconds) repeat themselves every day. Visually, this design is an economical use of space since the one circle can be used to represent all days.

The primary reference point on the clock is the 12:00 position at the top of the circle, although before this choice became standardized, other positions had this role. In some early designs from the 1300's, the clockface itself moved, and time was read from a pointer at the top of the dial. (See de'Dondi's astrium in Bedini & Maddison (1966).) In Italy, from the late 1300's, there were clocks that measured the day from sunset and placed this hour (hour 1) at the base of the clock (our 6:00 position). (See a photograph of a clockface in the Duomo, Florence, Italy in McCready (2001).) In the 1700's, there is evidence of a clock in which the day began at sunset (hour 1), and this hour was placed at our 3:00 position. (See a painting of the View of the Piazza of San Giacometto di Rialto in Lippincott (1999).) These various designs show that the choices for the primary reference point were taken from the cardinal positions on the circle, which are the most visually salient points. The 12:00 position we use today was based upon the position of the sun at noon, which is the only constant position of the sun each day over the course of the year, and the only time at which most early mechanical clocks could be accurately reset.

Another valid position for the primary reference point along a circle is the 9:00 position because this position is the leftmost position on the dial, and therefore corresponds with the place where reading begins. In looking at the arrangement of pictures and photographs in magazines and newspapers, the images are often placed in clockwise order, but some arrangements begin at the 9:00 position and others at 12:00. The choice of the 9:00 position has the advantage of corresponding to the position at which reading begins, whereas the choice of the 12:00 position corresponds with where the clock begins.

Timelines arranged as winding paths have a map-like look and are often used to represent a personal timeline (Figure 7). Perceived metaphorically, this type of timeline can show the unforeseen twists, turns, lows, and exciting peaks that come along in a person's life. Marvin Minsky (1985, 1986) used a winding timeline of key times of his life on the cover of his *The Society of Mind* software.

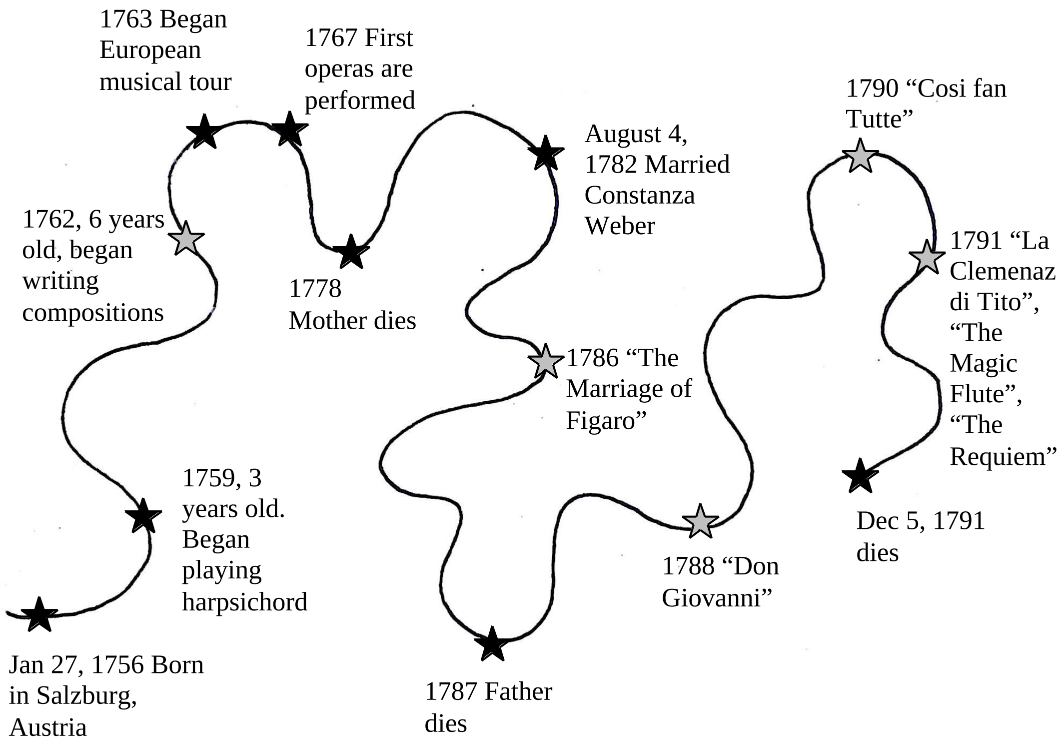

Figure 7. Example of a winding timeline. Key events in the life of Mozart

A winding timeline contains two-visual perspectives. Since it is a map, it can be viewed from a top-down perspective just as roads across a landscape are viewed. However, since the map is not real but designed, the designer has a choice in where the timeline begins. To assist in reading, these timelines typically begin at the left side of the page. Therefore, these timelines also have a side-on perspective.

The most common example of a matrix-style timeline is a calendar. The typical calendar matrix has the smaller unit of measurement (days of the week) running left to right along the top, and the larger unit (week of the month) running top to bottom along the left side.

A matrix is actually a flattened spiral (Figure 8). The advantages of this design are that larger positions of time (months) are broken into cognitively manageable chunks (7-day weeks), patterns of events can be easily visually discerned from week to week, and the design follows reading order. There is some non-standardisation in the design of the calendar, however, in that the primary reference point (the day on which the week begins) varies among calendars. On some calendars, the week begins on Sunday, which is the Christian start of the week, and in others it begins on Monday, which is the typical business start of the week.

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M	T	W	T	F	S	S
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				

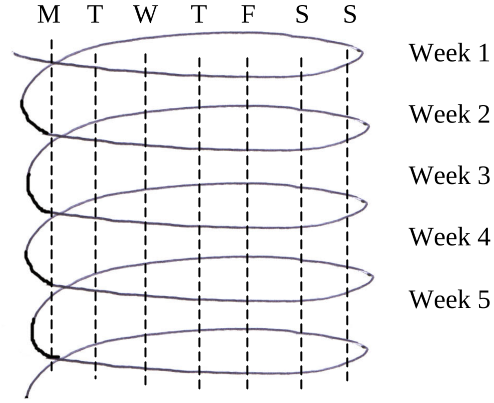

Figure 8. The matrix is a flattened spiral

Like boustrophedon arrangements, the spiral arrangement of time shows continuity of events. Like a clock, it shows time moving in one direction from earlier to later. The spiral also has the advantage of allowing a designer to fit more information onto a page than could be fit with other arrangements. The visual scale on a boustrophedon timeline is typically ordinal, but these timelines often contain dates or other counts of time.

Restrictions of a two-dimensional surface

While particular arrangements of time and particular timescales assist designers in fitting more information onto a two-dimensional surface, there are also other techniques that designers use. Three of these techniques are to fold the timeline, to cut and leave out a portion of time, and, along an interval or ratio timeline, to change the spatial unit by which time is measured.

Conclusions

Some techniques for placing time-related information on the page are now conventions (e.g., the direction in which horizontal timelines go and the positions of the time markers on the clock dial) but there are many choices that can be made over other aspects. Further, some optional areas (the day of the week on which the calendar begins and the starting point for placing graphics in a clockwise arrangement) may eventually become standardised. The primary variables in the design of time-related information are among the reference point, the measurable and visual time scales, and the visual arrangement (e.g., linear, circular).

The design choices depend upon the data itself, the meaning we wish to create with it, and the limitations of the design media. It is important for journalists and information designers to understand both the design conventions and choices so they can develop clearer, more consistent, and easier-to-read graphics.

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