Guidelines for the Effective Design of Spatio-Temporal Maps

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Abstract.

Dynamic spatio-temporal maps are used to show change in feature properties, location, or both. Map readers are more challenged when attempting to comprehend these maps because of the increased complexity that is inherent with dynamic displays. We know that we can help readers by following some map design guidelines for the display of spatio-temporal data. For example, these maps are best used to show 1) data that have "micro time steps" rather than data with temporal gaps, and/or 2) data that have a "forced" neighborhood (e.g., isopleth, not choropleth). Limiting the complexity of the visualization and the length of time that it is displayed will result in better understanding. In addition, map comprehension can often be improved by allowing readers a level of interactivity (e.g., the ability to use playback controls).

It is also possible to help map readers gain better understanding of dynamic spatio-temporal maps using some of the same marginalia as for static maps, such as titles, legends, and graphs, as well as marginalia specific to spatio-temporal maps, such as timelines. This paperoffers guidelines for the use of these map marginaliafor spatio-temporal maps. Appropriate selection, design, and layout of these map elements can improve map readers' ability to better comprehend more complex dynamic displays. Through a variety of examples, I demonstrate that the judicious use of marginalia on dynamic displays can provide greater clarity of the mapped subject and more aesthetically pleasing visualizations. These guidelines provide map makers with a set of best practices for better design and compilation of dynamic maps for visualizing spatio-temporal data.

Keywords: Animation, Best Practice, Design, Dynamic, Graph, Guideline, Legend, Map, Map Element, Marginalia, Spatio-temporal, Timeline

1. Introduction

Spatio-temporal data have both a spatial (geographic) and temporal (time) component. Examples include the movement of airplanes from origins to destinations, the occurrence of traffic accidents over a year, the flow of water within a river system, and the variation in demographics between censuses. Maps that display spatio-temporal data can be either static (the display does not change) or dynamic (the display varies, as with frames in an animation) (Kraak 2001). It is often useful to map spatio-temporal data dynamically because the varying nature of the data is intuitively expressed in the changing display (Moellering 1980, Monmonier 1990, MacEachren 1995, Harrower 2000). However, this intuitive understanding is countered by the increased complexity of the visualization because it changes, and this can lead to lack of understanding or misinterpretation of the mapped data.

To create effective displays of spatio-temporal data, it is helpful to keep in mind some of the things we already know about these types of maps[1].Guidelines for dynamic displays can relate to the data on the map, how the map is displayed, the map marginalia, and use of the map. For this paper, map use will not be considered specifically, although it is understood that it is impossible to completely uncouple the design and compilation of a map from its use.

In general, it is best if the display transitions smoothly (Moellering 1980). This can be promoted though the use of "micro time steps" rather than data with temporal gaps.Data that have a "forced" neighborhood (e.g., an isopleth map) will display more smoothly than data with unconstrained neighborhoods (e.g., a choropleth map) (MacEachren 1991). Increased complexity (i.e., for both the map and the marginalia) can reduce the understanding of dynamic displays—as Morrison et al (2000) note, "Clearly, complexity challenges comprehension." Increased speed and length of the dynamic display can also decrease understanding (Lightner 2010).Partially in response to the desire to reduce speed, people viewing dynamic displays prefer some interactivity,at the least to control the playback of the display (Monmonier & Gluck 1994).

Guidelines for the dynamic display of spatio-temporal data have also been applied to dynamically displayed non-temporal properties of the data.For example, DiBiase et al. (1992) created a dynamic display of world earthquakes, from the least to most catastrophic, to emphasize attribute change

[1]See Thrower (1991) and Campbell & Egbert (1990) for early summaries of cartographic animation research; Opach (2005) provides a more recent account of work in this area; and Slocum et al. (2005) offer a textbook explanation of cartographic concepts and practices relating to animated maps

rather than chronological change. This paper does not specifically consider the dynamic display of non-temporal data, although the guidelines offered herein may also apply to these types of maps.

Along with the recommendations above, I offer guidelines, illustrated with graphic examples, for significant marginalia for dynamic maps, including timelines, legends, titles and text, and graphs.My guidelines are not rules, and they have not been subjected to user testing. Rather, they reflect best practices that I have identified through personal experience and observation of mapping spatio-temporal data in dynamic displays.

2. Definitions

2.1. Dynamic Displays

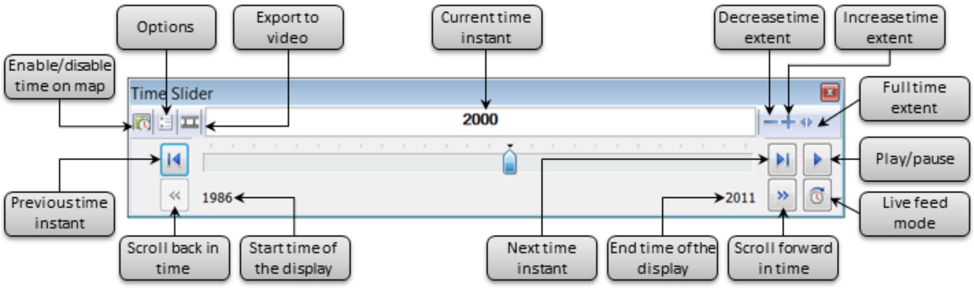
To avoid potential confusion, a number of terms are introduced that related to dynamic displays. These terms define the nature of the data or the properties of the display. For the purposes of this paper, it is assumed that the spatio-temporal data are stored in a GIS format, such as a geodatabase in ArcGIS.It is also assumed that commercial off-the-shelf software, like ArcGIS, is used to create and view the displays. The terms below reflect this assumption.

A**dynamic display** is a visualization in which there is change in the location and/or attributes of the features being mapped. Although these are also sometimes called animations, I make a clear distinction between dynamic and animated displays.**Animations** are visualizations in which there is change in the display, but it does necessarily reflect change in the properties of featuresor their locations. Animated displays include dynamic displays, but they also include visualizationsin which feature locations/attributes do not change, such as fly-throughs which reflect change in the viewing perspective only. These and other visualizations that are not driven by changesin either the location or properties of features are not considered in this paper.

A**time instant** is a single point in time or a single event in a sequence. A **time step** is the range between two sequentially displayed time instants—essentially, the value used to control the dynamic display, such as an hour, day, or year, or the value in a sequence. A **time series** is a chronological or sequential set of time steps. A time series characterized by a certain unique condition or event is a **period**. For example, a period could be characterized by the fact that there is no change in any of the time instants, while the rest of the time instants have some change. A **time extent** is the range between two time instants. The **full timeextent** is the range between the first and last time instants. The**time attribute** is a field in the GIS database that contains the temporal or sequential information.A **time stamp** is a value in the time attribute.

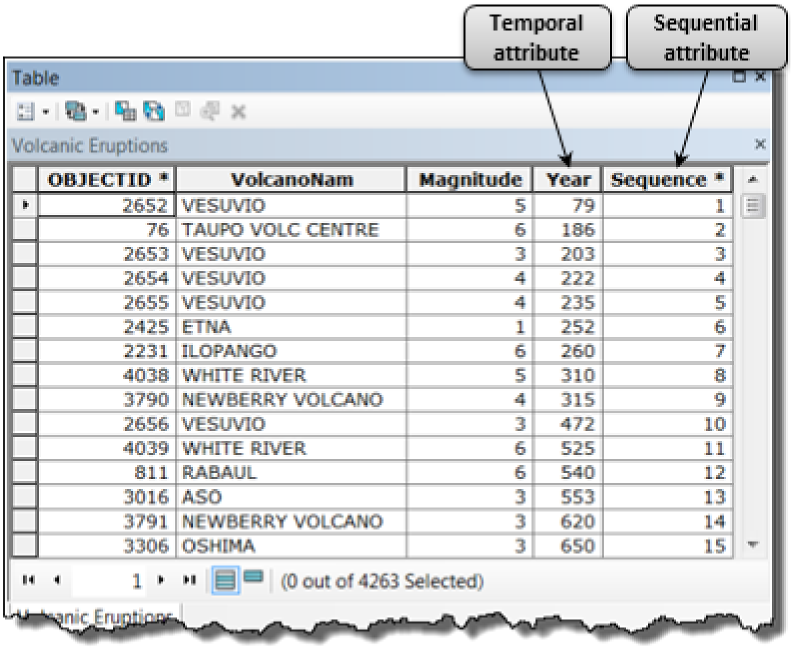
The term **playback** refers to playing or replaying the dynamic display. **Playback controls**, used to manage the playback, commonly include stopping and starting the display, going to the next or previous time instant, going to the first or last time instant, and looping through or reversing the dynamic display at the end of the full time extent (*Figure 1*).Although this is also sometimes called a timeline (Kraak et al. 1997), I define that term differently below.

Figure 1. Example of playback controls (Source: ArcGIS Online Help: http://re-



sources.arcgis.com/en/help/main/10.1/index.html#//005z0000000z000000).

Playbacks can be either chronological or sequential depending on the time attribute used to specify the time steps (*Figure 2*). **Chronological**playbacks are driven by time steps that represent an understandable measure of time. The time steps for **sequential** playbacks are based on an attribute that relates to numbers in a sequence, an effective approach to use when the data have temporal gaps. For example, a world map of major volcanic events could be shown in sequence from earliest to latest to eliminate gaps when no events occur (see the sequential attribute in *Figure 2*). If the playback is sequential, playback controls will reflect the sequence number rather than an understandable measure of time.

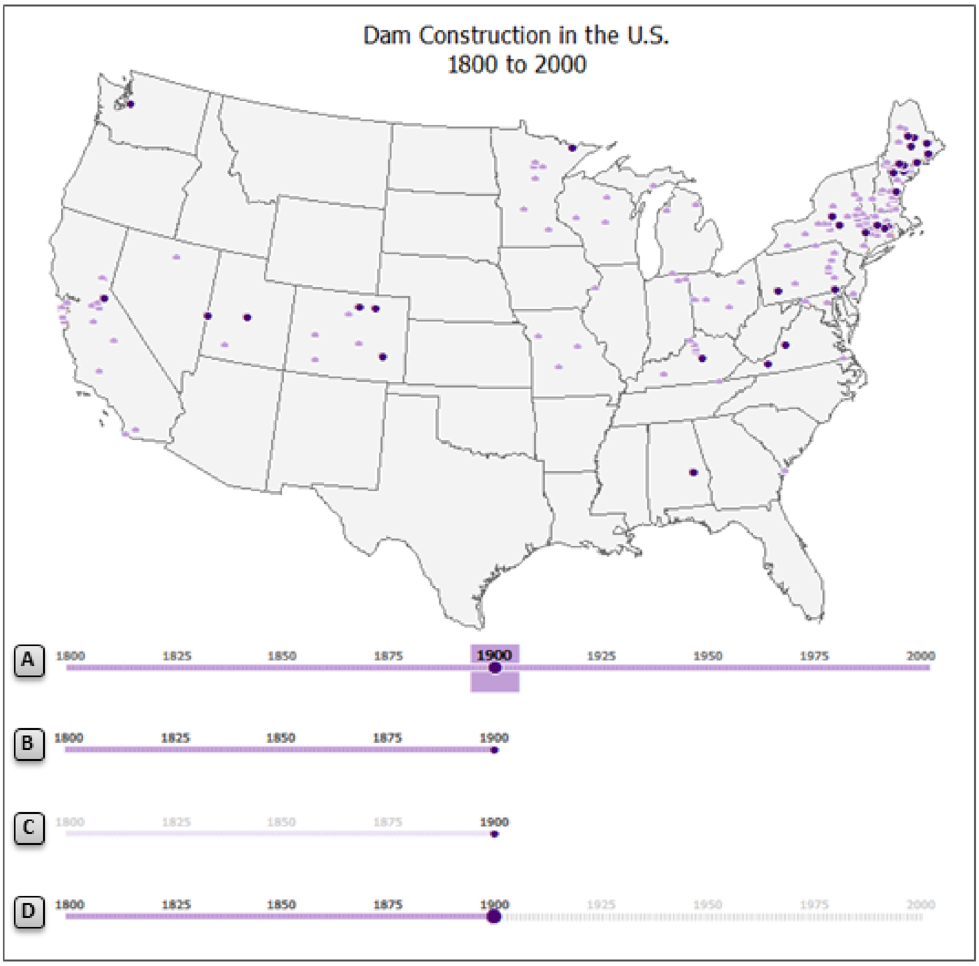


OBJECTID *	VolcanoNam	Magnitude	Year	Sequence *
2652	VESUVIO	5	79	1
76	TAUPO VOLC CENTRE	6	186	2
2653	VESUVIO	3	203	3
2654	VESUVIO	4	222	4
2655	VESUVIO	4	235	5
2425	ETNA	1	252	6
2231	ILOPANGO	6	260	7
4038	WHITE RIVER	5	310	8
3790	NEWBERRY VOLCANO	4	315	9
2656	VESUVIO	3	472	10
4039	WHITE RIVER	6	525	11
811	RABAUL	6	540	12
3016	ASO	3	553	13
3791	NEWBERRY VOLCANO	3	620	14
3306	OSHIMA	3	650	15

Figure 2. The time attribute used to specify the time steps for a chronological display represents a measure of time (A). For sequential displays, the attribute contains numbers in a sequence (B). (Source: A. Buckley, Esri, Inc.)

If the playback is temporal, the time extent between instants cannot vary, and the map display will progress at the same rate temporally from time instant to time instant (e.g., an hour, a day, or a year). For periods when no features change in any time instant, the display will not change, and for periods when there is a lot of change between many adjacent time instants, the display will be very dynamic. If the playback is sequential, the amount of time represented by each time step could vary, and the map display will change with each time step, if change in the attribute value is what the sequencing is based on.

Dynamic display can relate not only to the mapped data but also to the marginalia, such as legends and graphs. There are a number of ways in which dynamic map elements can be displayed during playback. They can be shown in their entirely at the outset with the parts relevant to the current time step highlighted (*Figure 3A*).They can be revealed throughout the display so that parts of the element relevant to each time step are drawn during the time step and retained in future time steps so that by the end of the full time extent the entire element is visible (*Figure 3B*). They can be revealed with **dodging**, in which parts of the element drawn in previous time steps are lightened up so that they creating a lasting impression of the parts of the element that have already have been revealed (*Figure 3C*). Or they can be **overprinted**, or superimposed on a dodged impression of the entire element that is visible throughout the display (*Figure 3D*). These techniques—highlighting, revelation, revelation with dodging, and overprinting—can also be used when mapping the data themselves, if the data do not change position over time (e.g., the location of dams that have been con-



structed rather than the tracked movement of animals).

Figure 3. Methods that can be used to dynamically display map elements, such as the timeline, include highlighting (A), revelation (B), revelation with dodging (C), and overprinting (D). (Source: A. Buckley, Esri, Inc.)

2.2. Time Indicators

Many maps include scale and orientation indicators, often in the form of scale bars and north arrows, respectively.For maps with dynamic displays, time indicators are also useful.In general, these time indicators are more effective when they are graphic rather than textual. With a dynamic text string, it is difficult to track which time instant is currently being displayed and to identify where in the full time extent that time instant falls. Additionally, this time text will likely be redundant with playback controls that also show the current time instant. Designed properly, graphic time indicators can be seen “out of the corner of your eye”, and map readers can get an adequate impression of the general position of the currently displayed time instant within the full time extent without diverting their attention from the main map.

Graphic time indicators can take a variety of forms, and the form can be used to give an indication of the dynamic nature of the displaywhich in turn should reflect the nature of the phenomena being mapped (Kraak et al. 2002, Harrower & Fabrikant 1999). For example, if the display is cyclic and shows variation over the course of a day (e.g., traffic accidents), a clock with dynamically moving hands may be an appropriate time indicator.For displays that are cyclic over the course of a month (e.g., lunar cycles or tides), pages being pulled from a calendar may be a useful time indicator.For displays of linear time, a timeline is often appropriate to use.

A **timeline** is a linear representation of the full time extent that also provides an indication of the currently displayed time instant. The timeline generally expresses a measure of time understandable to the reader, such as the Gregorian calendar or clock time. The timeline need not be created as a line *perse*—text and other graphics (e.g., circles, squares) can be used to give the impression of the time extent. For example, the map in *Figure 4*was constructed using text and a sphere symbol.

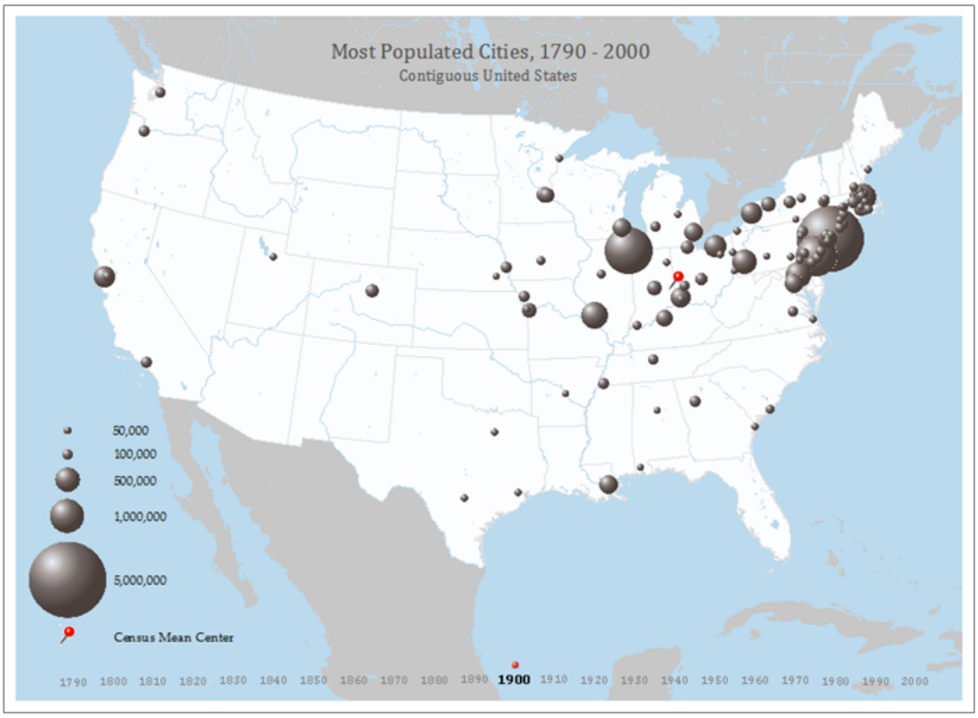


Figure 4. Timelines represent the full time extent and highlight the currently displayed time instant. (Source: A. Buckley, Esri, Inc.)

Timelines need not be straight, as long as they represent the continuous progression of the display.**Ticks** along the timeline indicating time steps need not be regularly spaced. For example, the text for the timeline in *Figure 5* relates to the dates of major occurrences rather than a regular increment.

The same timeline can be used for either chronological or sequential playbacks if the time stamps in the time attribute relate to sequencing for the dynamic display (e.g., when things should appear on the map). For example, for a dynamic display of the changing political boundaries of counties in the world, the timeline could reflect the Gregorian calendar (*Figure 6*). The dynamic display could be shown either by date or by sequence, with the sequential values being incremented for time stamps during which a boundary changes. The same timeline would be appropriate for either a chronological or sequential display.

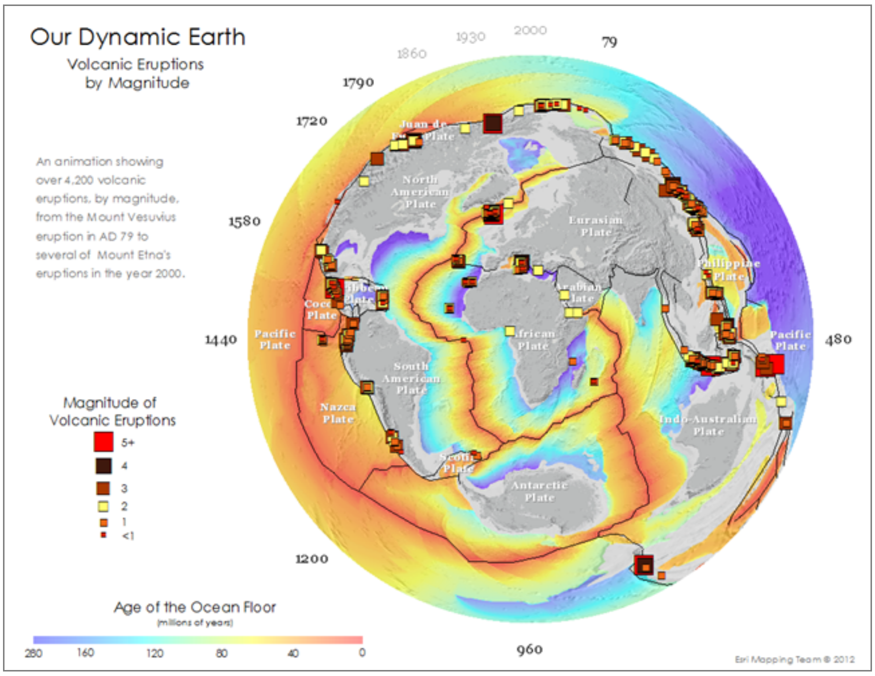


Figure 5. The timeline circles the main map in this example. (Source: A. Buckley, Esri, Inc.)

Figure 6. The Gregorian calendar timeline for this map would work for either chronological or sequential playback if the sequencing reflects the year that features and their labels should be shown on the map. (Source: A. Buckley, Esri, Inc.)

3. Guidelines

3.1. Timelines

It is useful to use a constant scale within the timeline rather than a variable scale (i.e., the range between time instants varies so that some time steps are longer and others are shorter).This helps the map reader to know where the current instant falls within the full time extent, and it allows him or her to predict time instants that have or will be shown. This is especially important if the playback speed is variable. For example, it is sometimes useful to slow down the playback when there is a lot of change and speed up the playback when there is little or no change. A constant timeline will allow the map reader to understand the speed of the playback and whether there are gaps in the temporality of the data, especially if sequencing is used.

Whether the display is chronological or sequential, the map reader should be able to discern which time instant is currently being displayed and where that time instant falls within the full time extent. A constant-interval time-

line will allow this, as well as accommodate variable playback.

Timelines are always dynamic in the sense that the current time instant will always be highlighted dynamically, for example, using text or a symbol.

Other parts of the timeline can be static or dynamic because, as mentioned earlier, map elements such as a timeline can be drawn using highlighting, revelation, revelation with dodging, or overprinting on a dodged timeline (see *Figure 3*).

The timeline can be oriented and situated to reflect the data distribution on the map (*Figure 7*).For example, if the phenomenon being mapped is dispersive, the timeline could be situated near the point of initiation and aligned to the flow of the phenomena over time. For vertically-oriented timelines, the time extent can increase from top to bottom or vice versa. For horizontally-oriented timelines, the first time instantis usually at the left, particularly for maps whose users normally read left to right. For these map readers, reversing the timeline can cause confusion which will be further exacerbated if the playback controls show the progression of the display from left to right.

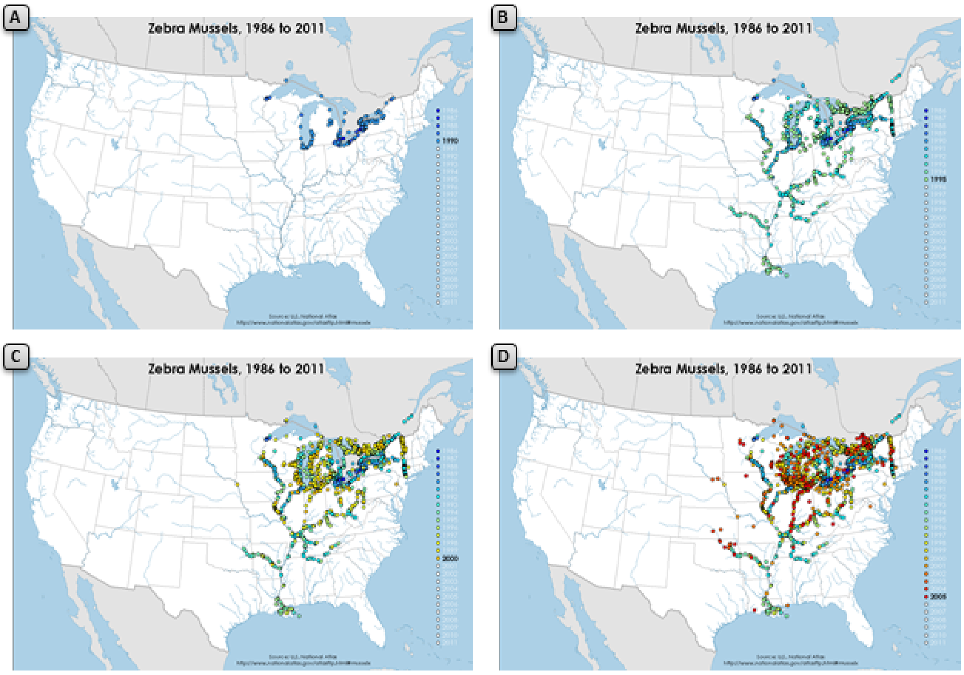


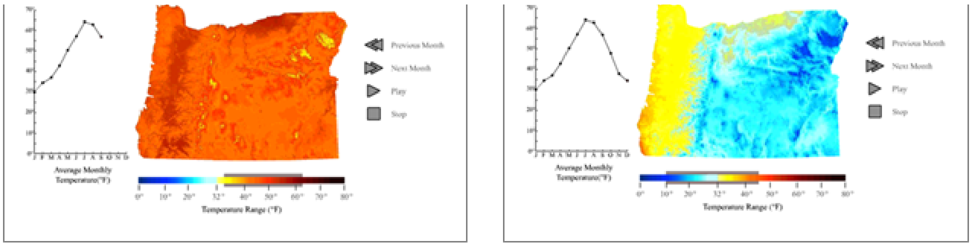
Figure 7. Example of a timeline that is vertically-oriented. Note that the timeline reflectsdispersion from initiation in the north (A) to areas farther south (D). (Source: A. Buckley, Esri, Inc.)

3.2. Legends

A legend explains symbology on the map.Because a dynamic display already has a higher level of complexity due to variation in the display, the legend, and indeed all other map elements in the display, should be kept as uncomplicated and unambiguous as possible.

It is possible to combine the functions of the map's legend with those of the timelines (Kraak et al. 1997, Edsall et al.1997). (Note that timelines can also be combined with graphs, which is explained in *Section 3.4*).Legends can be combined with the playback controls, (Harrower et al. 2000), although this is not easily done with commercial off-the-shelf GIS software. Although Peterson (1999) also demonstrates that "active legends" can also be used to control interactivity, his example of the interactive selection of the maps displayedusing the legend does not necessarily relate to dynamic displays as defined herein because the maps chosenneed not be dynamic.

Legends can be dynamic in the sense that they show or highlight only the symbology for the features that are displayed in the current time step, as well as previously displayed time steps.As with timelines, dynamic legends can be displayed using highlighting(*Figure 8*), revelation, revelation with



dodging, or overprinting. A challenge is to assure that the legend symbology remains exactly the same as on the map even when highlighted.

Figure 8. The legend for this map uses highlighting to identify the set of attribute values shown in the current time step. (Source: G. Carpentier, Oregon State University)

Legends can also be animated to match any animation of symbols on the map. If a map symbol is animated, for example, to flash, slicker, stream, or swoop, then the symbol in the legend could be animated in the same way, thus retaining the desirable visual relationship between symbol properties on the map and in the legend. An example is the legend for the wind map created by Hint.FM (http://hint.fm/wind/), described in Kanalley (2012), in which the legend patches contain animated versions of the symbols on the map (*Figure 9*).

Figure 9. The Wind Map by Hint.FM includes an example of an animated legend.The legend patches at the left are animated to reflect the movement of symbols on the ap. (Source: Hint.FM (http://hint.fm/wind/).

If the dynamic display of the legend becomes too complicated (e.g., there are a lot of symbols in the legend or there is a lot of change during the time steps), the complexity of the legend may make it difficult to comprehend and thus have a negative impact on comprehension of the main map. In addition, if there appears to be more change in the legend than on the main map, attention may be diverted to the legend and away from the map (Peterson 1999).

3.3. Titles and Text

Text should be used extremely judiciously on dynamicallydisplayed maps.-Text is normally used on maps for such marginalia as map/legend titles and subtitles, map/legend explanations, map details (e.g., data sources, map projection, author, date of publication), and for explanation about the content on the map or guidance for using the map. Text is also used in legends for item descriptions and on the map as feature labels.On dynamically displayed maps, text may also be used in time indicators and playback controls.

Title text and map details will likely not change so they should not change dynamically with each time step as they will addunnecessary complexity to the map. Dynamically displayed legend text and map labels will have to be understood within the display of a time step so these text elements should be unambiguous and uncomplicated, and they should be displayed dynamically only if absolutely necessary.Short text strings are preferable and predictable revelation of text will also help map readers (e.g., time labels that are sequential).

Larger blocks of text can be used to provide explanation or guidance to focus the attention of the map reader on significantareas of the map or periods in the display.The details in larger blocks of text may not be retained as well as shorter text strings (e.g., titles, labels, legend text).If map readers pay full attention to the text blocks they may miss crucial images in the dynamic display, and if they focus on the dynamic map display, they will likely miss some of the textual content (Moreno and Mayer 2000).Thus, it might be better to substitute a visual with an audio cue when providing explanation or guidance during the dynamic display.

3.4. Graphs

Graphs are sometimes used to provide further explanation on a map. For spatio-temporal data, the map, which shows the location and type or magnitude of the properties of features over time, can be enhanced using a graph that shows change in quantitative attribute values over time. This not only obviates the need to show the magnitude of values on the map, which can result in a more complex display, it also allows global (i.e., map-wide) variation to be graphically summarized. For example, a map showing the location of dams built within a time extent can be coupled with a graph that shows the number of dams or the cumulative number of dams built in any one time period, or both (*Figure10*). The graph can inform or confirm the map readers' comprehension about what they think they are seeing on the map as it changes over time.

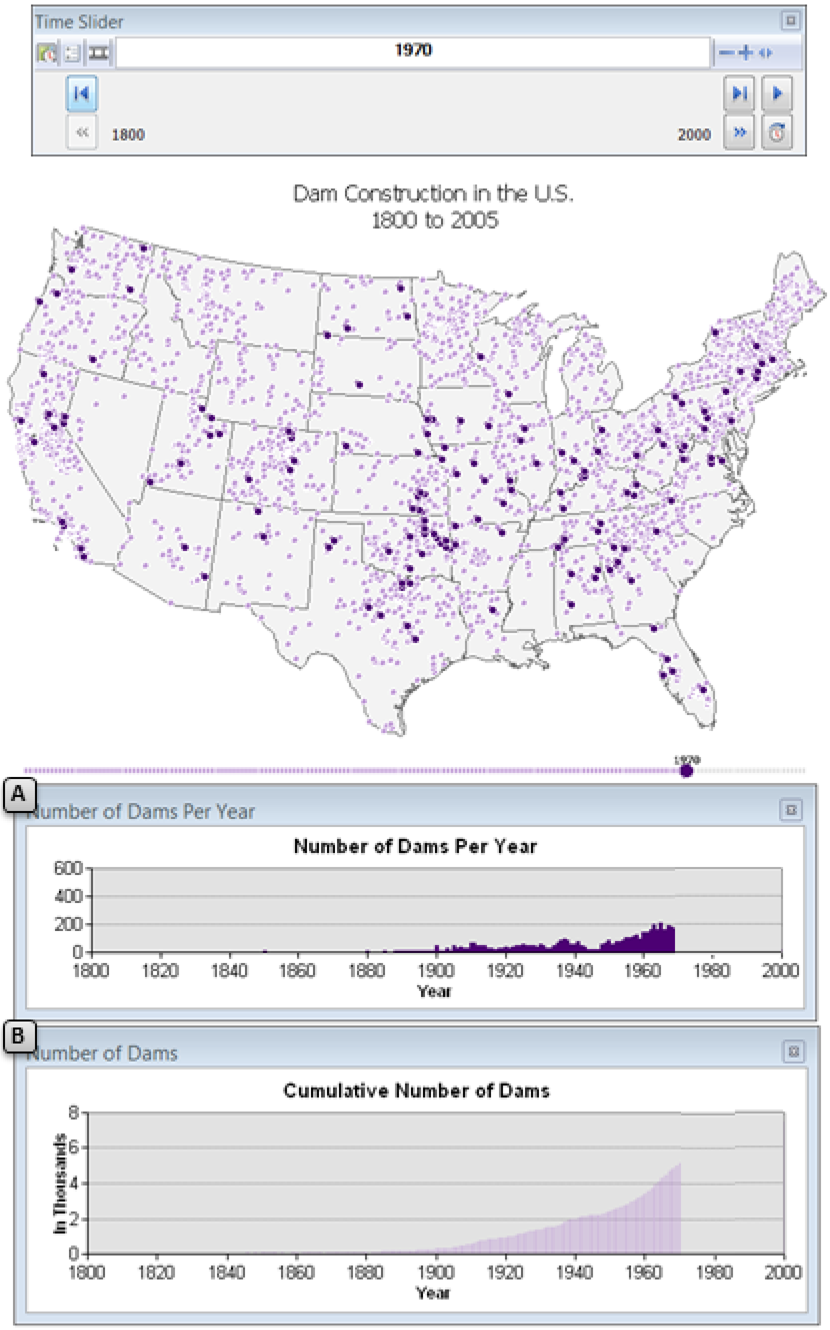


Figure 10. A graph can be used to show the magnitude of change over time, such as the number of dams (A), the cumulative number or dams (B), or both. Mimicking the symbology used on the map visually links the map and the graph. (Source: A. Buckley, Esri, Inc.)

Graphs are generally more complex graphics than timelines or legends because they include axes that relate multiple things. Therefore, they should be used judiciously and kept uncomplicated and unambiguous, as with other map elements (e.g., text should be short and clear). Mimicking the map symbology in the graph may lead to better understanding of the relationship between the mapped and graphed data (see *Figure 10*). Visually linking the map and graph using the same symbology is not always necessary and additional complexity may lead to confusion, especially for more complex graphs or when more than one graph is used (*Figure 11*).The relationship between the map and graph may be clear simply because of how they are displayed synchronously, thus the addition of visual cues, such as color, is redundant and adds unnecessary complexity.

Graphs, like timelines and legends, can also be displayed dynamically, with options for display to include highlighting, revelation, revelation with dodging, or overprinting. For example, the graph in *Figure 11* is displayed using revelation with dodging, while the timeline is displayed using overprinting, and the features on the map are displayed using revelation.

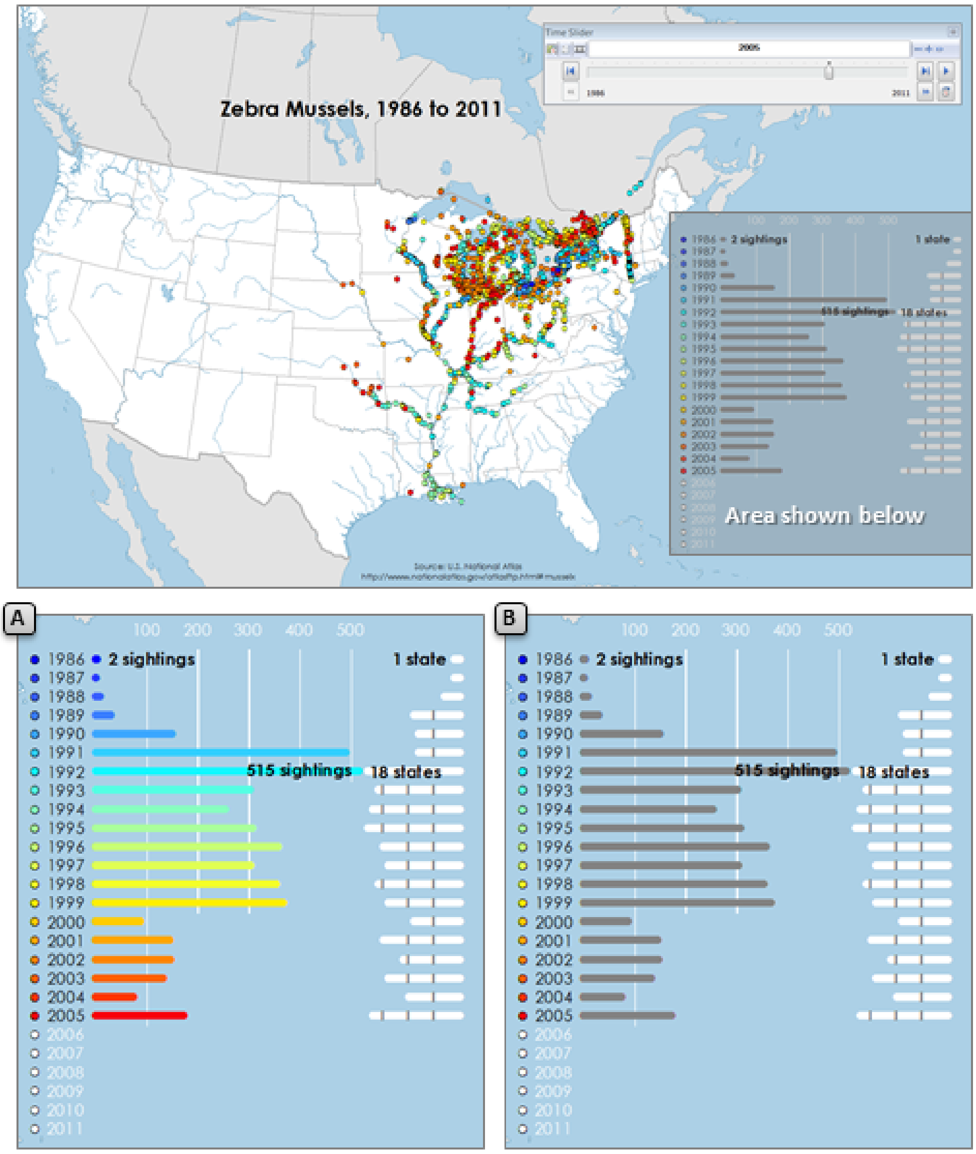


Figure 11. For complex graphs or when more than one graph is used, mimicking symbology on the map, such as color (A) may actually lead to confusion rather than comprehension.The graph can be made simpler (B) using monotone symbology and reserving color for the timeline only. The synchronicity of the map and the marginalia in the display is sufficient to create the visual relationship between the map and its marginalia.(Source: A. Buckley, Esri, Inc.)

4. Other Marginalia

Although maps may contain other marginalia, such as inset maps to show overviews or areas in greater detail, images, and tables, those map elements are not addressed specifically here. Nonetheless, it may be that some of the guidelines offered for the marginalia discussed in this paper—timelines, legends, titles and text, and graphs—may also be useful when thinking about how to design other map elements for dynamic displays. In all cases, the complexity of the display must be balanced against the ease and speed and speed of comprehension.

5. Conclusion

This paper offers guidelines for the effective design spatio-temporal maps, focusing on the use of map marginalia. Initially, guidelines from the work of other were summarized. Terminology related to the nature and display of spatio-temporal data wasprovided.Concepts for the dynamic display of map elements, including highlighting, revelation, revelation with dodging, and overprinting, were introduced and illustrated.Guidelines for specific map elements—timelines, legends, titles and text, and graphs—were also presented and shown in graphic examples. Together, these resourcesprovide map makers with a basis for thinking about the compilation of dynamic maps that show spatio-temporal data. The guidelines provide a set of starting points for the appropriate selection, design, and layout of map elements for spatio-temporal maps with the goal of improving map readers' ability to better comprehend more complex dynamic spatio-temporal displays through greater clarity of the mapped subject and more aesthetically pleasing visualizations.

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