

## Why Do We Keep Turning Time Into Space?

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Most visualization of geospatial data is done via the production of static images; although, occasionally, *animations* are produced to illustrate a temporal sequence, such as the growth in population, or some change in vegetation over time. The advent of commodity high performance computer graphics makes it possible to produce animations at a low cost and high quality for almost any time-varying data set. But should we do it?

In this brief paper, I consider the problem of reasoning about dynamic geospatial data from the perspective of human visual cognition and argue that turning time into space is almost always the right thing to do. I illustrate my argument with some recent work analyzing the underwater behavior of humpback whales.

The most important reason for visually displaying data, as opposed to using words or tables, is to allow for a form of *visual thinking* to occur. As a number of theorists have noted, the key advantages of visual thinking are twofold: *memory support* and *problem solving through pattern finding*.

***Memory Support.*** Graphical entities such as images, symbols and patterns on a display provide *proxies* for concepts. When these entities are fixated, the corresponding concepts become activated in the brain. This kind of visually triggered activation can often be much faster than the retrieval of that same concept from long term memory in the absence of graphical aids (for example, with the eyes shut). When an external concept proxy is available, access is made by means of eye movements which typically take approximately one tenth of a second. Once the proxy is fixated, a corresponding concept is activated within less than two-tenths of a second – hence the advantage. It is possible to place upwards of 30 concept proxies (in the form of images, symbols or patterns) on a screen providing a very rapidly accessible concept buffer. Compare this to the fact that we can hold only approximately three concept “chunks” in verbal working memory at a time. But there is a major limitation – for visual proxies to trigger concept activation, there must be previously learned associations between the visual symbols, images or patterns and certain concepts.

Now consider the problem of an *animated* replay of time varying geospatial data. Concept proxies will disappear and re-appear only when the relevant time window is current on the display. To get the advantage of memory support, it is necessary to either watch a replay, or use some fast forwarding device to get to a point where the symbol appears. Concept proxies can no longer function in the same way, by providing memory access through rapid eye movements.

***Problem solving through pattern finding.*** When we are using a visual display for analysis, the goal is generally to find patterns in the data. These may be patterns having an already known characteristic form. For example, the spatial signature of deep rock formations that signal the likely presence of trapped gas or oil to geologist. Or they may be previously unknown patterns. Finding a novel pattern can be an important act of discovery.

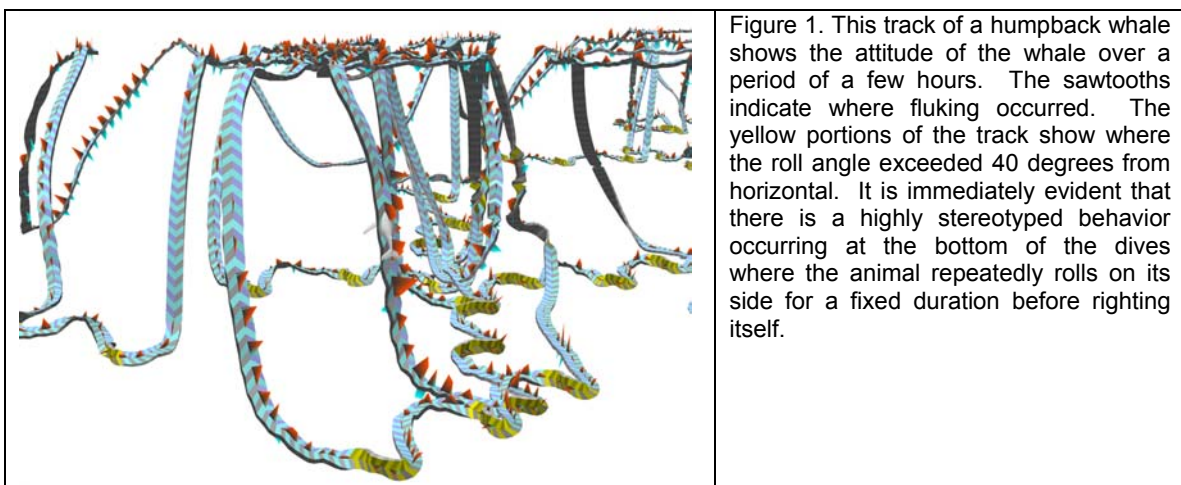
It is certainly the case that we can perceive temporal patterns as well as spatial patterns. For example, non-verbal communication through hand gestures has much more to do with the temporal sequence of hand positions than with the actual shape of the hand. The problem is that for temporal patterns to be perceived clearly they must occur in a short interval. We perceive the movements of the second hand, but not the minute or hour hands. Studies of human *visual working memory* suggest that for a motion pattern to be readily perceived, it should occur within an interval of two seconds or less. Temporal patterns will be clearest if they can be perceived within a single fixation of perhaps half a second.

This obviously poses a problem for those seeking to find novel spatio-temporal patterns that occur *infrequently* in time-varying geospatial data. The analyst watching an animated replay of such data must resort to formally encoding candidate patterns in long term memory. When a pattern re-occurs it can then be compared to the mentally stored pattern. Not only is this cognitively effortful but our capacity to encode novel patterns is very limited. We may only be able to encode a half dozen temporal patterns in an hour of video, and these may not be the right ones.

As an alternative, if the spatio-temporal pattern can be somehow turned into a spatial pattern, then visual comparisons between sections of a time sequence can be made by means of eye movements. Because eye movements are so fast this enables several patterns a second to be compared.

A recent project that applied visualization to analyzing the underwater behavior of humpback whales illustrates these points. We (Ware, et al. 2005) were faced with the problem of visualizing data coming from a tag, attached to a whale with suction cups, that could provide several hours of data on the position and orientation of the whale as it foraged for food at various depths in the ocean. Our first attempt to provide visualization support involve a tool that allowed ethologists to replay the motion of the whale at any desired rate. Hours of study using this tool resulted in the identification of some interesting behavioral patterns. But, although there was some obvious utility, analysis was very time consuming and the analyst was only left with the vaguest idea of how frequent these behaviors actually occurred.

Our second attempt involved creating a pseudo-track of the whale that encoded the attitude of the whale, as well as, its path using a flattened ribbon (see Figure 1).



Using this tool, it often took less than a minute with each new set of whale data to find new patterns in the data, and to recognize where the whale was exhibiting behaviors we had already observed with other animals.

If we abstract and simplify the analytic process that occurred with the ribbon plotting package, the process of visual search for novel patterns can be characterized as consisting of two steps.

*Step 1. Conduct a visual search for an interesting (e.g. unusual) visual pattern. Once an example is found store it in visual working memory.*

*Step 2. Conduct a visual search for similar visual patterns in the display.*

Each of these steps might require ten fixations and take a few seconds to cover the entire display. This means the entire two step process can be repeated as many as a dozen times within a minute.

In this example, finding a way of transforming a temporal pattern into a spatial pattern resulted in an enormous gain in cognitive efficiency. The rate at which new whale behaviors could be discovered was increased by at least two orders of magnitude. More generally, our analysis suggests that except in the case of very rapid, compact temporal patterns, the best way of presenting spatio-temporal data will not be in the form of a playback of events. Instead, the data should, wherever possible, be transformed into spatial patterns in a way that supports rapid visual search.

Ware, C., Arsenault, R., Plumlee, M. 2006, Visualizing the Underwater Behavior of Humpback Whales. IEEE Computer Graphics and Applications, July/August issue. 14-18.