Maybe… Maybe not: Uncertainty in Time-Oriented Data Visualization

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1 – Uncertainty of Time

There are many ways to model time in information systems and time is modeled differently for different applications depending on the particular problems. A number of major design aspects and features which are particularly important when modeling time can be found in Fig 1. Focusing on the visualization of temporal uncertainty, we will take a closer look on the aspects of *branching time*, *multiple perspectives*, and *indeterminacy*.

If there is no complete or exact information about time specifications or if time primitives are converted from one granularity to another, uncertainties are introduced and have to be dealt with. *Indeterminacy* might be introduced by explicit specification (e.g., earliest beginning and latest beginning of an interval, see Fig. 2) or is implicitly present in the case of multiple granularities. For instance, the statement "Activity A started on June 14, 2009 and ended on June 17, 2009" can be modeled by the beginning instant "June 14, 2009" and the end instant "June 17, 2009" both at the granularity of days. If we look at this interval from a granularity of hours, the interval might begin and end at any point in time between 0 a.m. and 12 p.m. of the specified day [1].

The so-called *branching time* is a complex form of time domain organization. Here, multiple strands of time branch out and allow the description and comparison of alternative scenarios (e.g., in project planning) where only one of the alternatives will actually happen. However, branching is not only useful for future scenarios but can also be applied for investigating the past, e.g., for modeling possible causes of a given decision. In contrast to *branching time* where only one path through time will/did actually happen, *multiple perspectives* facilitate simultaneous (even contrary) views of time, which are necessary, for instance, to structure eyewitness reports. A further example of *multiple perspectives* are stochastic multi-run simulations. For a single experiment, there might be completely different output data progressions depending on the respective initialization [1].

2 – Visualization Techniques

When it comes to a comprehensive categorization of different methods to visually encode uncertainty, most existing work focuses on geospatial data or spatio-temporal data, (e.g., [6, 7]). According to these findings, uncertainty can be mapped to visual attributes, such as color, transparency, line width, texture,

[1] Aigner, W., Miksch, S., Schumann, H., Tominski, C., *Visualization of Time-Oriented Data*, Springer, London, 2011.

[2] Aigner, W., Miksch, S., Thurnher, B., and Biffl, S., *PlanningLines: Novel Glyphs for Representing Temporal Uncertainties and their Evaluation*, Proc. of the International Conference Information Visualisation (IV), p. 457–463, 2005.

[3] Harris, R., *Information Graphics: A Comprehensive Illustrated Reference,* Oxford University Press, New York, 1999.

[4] Kosara, R. and Miksch, S., *Metaphors of Movement - A Visualization and User Interface for Time-Oriented, Skeletal Plans*, Artificial Intelligence in Medicine, Special Issue: Information Visualization in Medicine, 22(2):111–131, 2001.

[5] Kosara, R. and Miksch, S., *Visualization Methods for Data Analysis and Planning*, International Journal of Medical Informatics, 68(1–3):141–153, 2002.

[6] Pang, A., Wittenbrink, C., and Lodha, S., *Approaches to Uncertainty Visualization*, Visual Computer, 13:370 – 390, 1997.

[7] Senaratne, H., Gerharz, L., *An Assessment and Categorisation of Quantitative Uncertainty Visualisation Methods for Geospatial Data*, Poster Abstract in Proc. of the 14th AGILE Conference - Advancing Geoinformation Science for a Changing World, 2011.

Information that is temporally indeterminate can be characterized as 'don't know when information', or more precisely, as 'don't know exactly when information'. Examples of this are inexact knowledge (e.g., "time when the earth was formed"), future planning data (e.g., "it will take 2-3 weeks"), or imprecise event times (e.g., "one or two days ago"). We will take a closer look on possible methods to visually encode temporal uncertainty (partially derived from methods to encode geospatial uncertainty) as well as on existing approaches of visualizing uncertainty of time-oriented data.

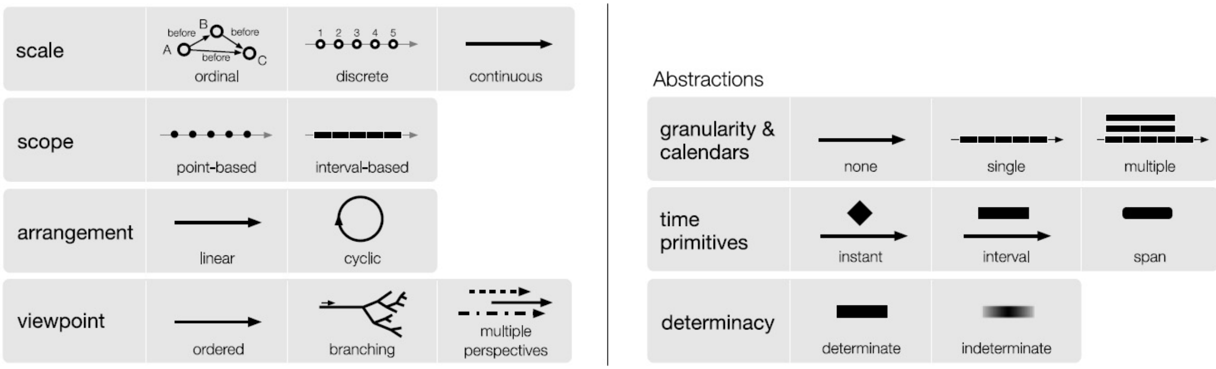

Fig. 1. Design aspects and abstractions of time. *Scale*: *ordinal*: only relative order relations (e.g., before, after), *discrete*: also temporal distances, *continuous*: between any two points in time, another point in time exists. *Scope*: *point-based*: no information about the region between two points in time, *interval-based*: subsections of time having a temporal extent greater than zero. *Arrangement*: *linear*: each element of time has a unique predecessor and a unique successor, *cyclic:* summer is before winter, but winter is also before summer. *Viewpoints*: *ordered*, *branching*, and *multiple perspectives*. Abstractions: *Granularities*: mappings from time values to larger or smaller conceptual units. *Time primitives*: relate data to time. *Instant* and *interval* are anchored (absolute), *span* is unanchored (relative). *Indeterminacy*: incomplete knowledge of temporal attributes [1].

and sharpness or focus; other visualization methods include for instance, side-by-side displays of competing results, side-by-side displays of data values and uncertainty values (adjacent maps), animation, additional transparent layers, additional symbols, glyphs (most commonly error bars), contouring, confidence intervals, but also other methods, like mapping uncertainty to sound. However, the representation of *temporal* uncertainties is quite often accomplished by glyphs (see Fig. 2).

The time annotation glyph [4] (see Fig. 2 (a)) was designed to represent the temporal constraints of future planning of medical treatment plans. It contains a notion for temporal granularity and for missing values / incomplete specifications. PlanningLines [2] allow the depiction of temporal indeterminacies via a glyph consisting of two encapsulated bars representing minimum and maximum duration, that are bounded by two caps that represent the start and end intervals (see Fig. 2 (b)). Decision charts [3] are a graphical representation for depicting future decisions and potential alternative outcomes along with their probabilities over time. In contrast to the other two approaches which use the *ordered* time domain, decision charts use the *branching* time model (see Fig. 3 (c)).

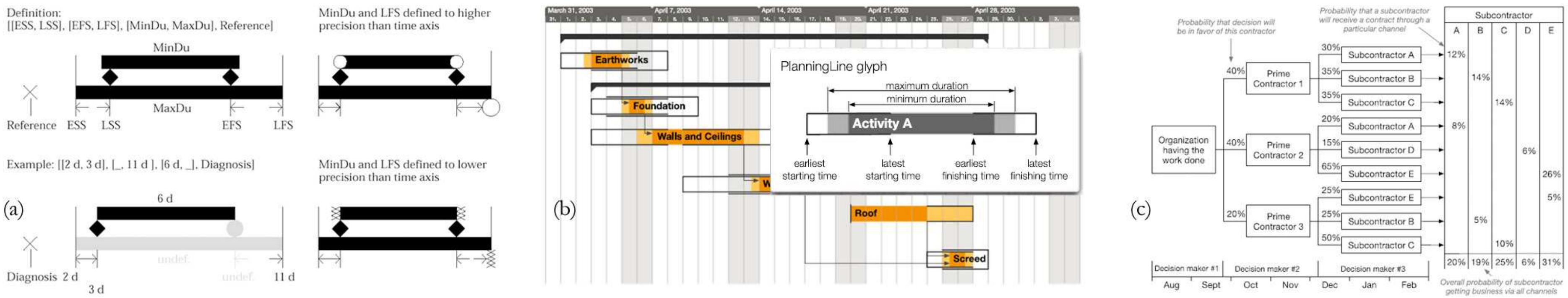

Fig. 2. Approaches of visualizing temporal uncertainty.
(a) Time Annotation Glyph [4]: lower bar of the time-glyph: maximum duration (MaxDur); upper bar: minimum duration (MinDur) of the plan. The two diamonds on top of the MaxDur bar: latest starting shift (LSS) and earliest finishing shift (EFS). The earliest starting shift (ESS), the latest starting shift (LSS), the earliest finishing shift (EFS), and the latest finishing shift (LFS) are indicated by vertical lines below the MaxDur bar.,
(b) PlanningLines [2]: MinDur and MaxDur: two overlaid bars, ESS + LSS / EFS + LFS: the beginning and end of the start and end intervals caps,
(c) Decision charts [3]: Future decisions and corresponding alternative outcomes are depicted over time along with their probabilities.