Sketching Temporal Uncertainty - An Exploratory User Study

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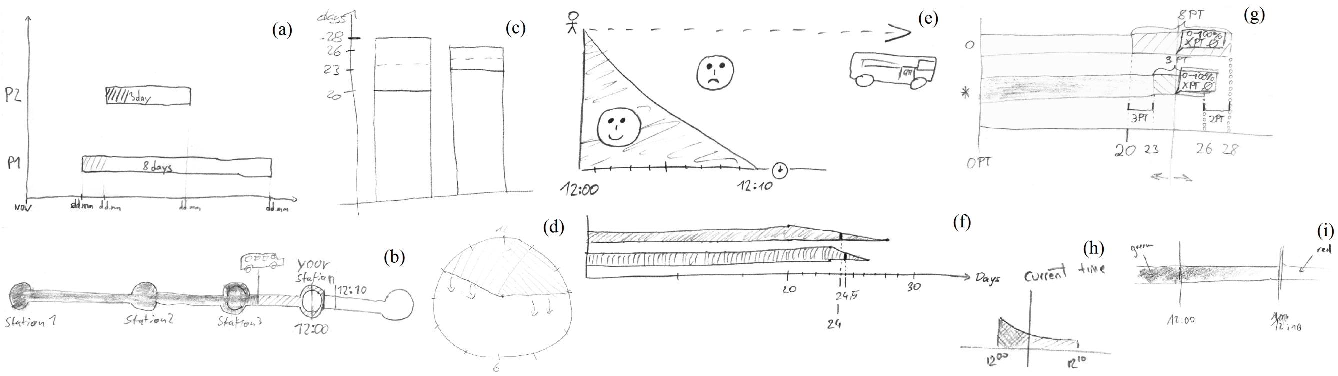

Figure 1: *Example sketches from our study for each identified category of temporal uncertainty visualization. (a) Encodes uncertain start times within the bounds of horizontal bars. (b) Uses bars and and information that supports our specific* bus scenario *(the bus icon is only cosmetic and does not encode any uncertainty information). (c) One of the few examples of a vertical time axis. (d) A clock metaphor is used to convey the notion of time. (e) A temporal line chart with additional smiley icons. (f) Encodes uncertainty values in the width of horizontal bars on a temporal axis. (g) In this bounded visualization the user interacts with a slider to get exact probability values. (h) A temporal line chart with additional use of a color gradient. (i) A typical gradient plot encoding the uncertainty in a color gradient.*

Abstract

Real world datasets frequently contain inherent uncertainty of some kind. Most of the work in the context of visualizing temporal uncertainty, focus on evaluating and comparing different visualization approaches. This effort may yield answers about the chosen techniques, but usually leaves the question open if there are other approaches, which would be more intuitive to the users. To answer this question, we conducted an exploratory user study. 32 participants were asked to draw sketches how they would visualize given scenarios about temporal uncertainty. The collected drawings were analyzed using an open coding approach. These results are presented and four hypotheses, meant to guide future research, are derived.

CCS Concepts

• ***Human-centered computing*** → ***Empirical studies in visualization;***

1. Introduction

Datasets containing information retrieved from the real world may contain some amount of uncertainty. This uncertainty is often inherent to the data for instance, because certain measurements can never be exact or because some kind of aggregation was already applied. This is also true for temporal data. Sometimes the exact time of an event is not known (e.g., 'time of the big bang'), is given in an inexact way (e.g., 'for the past few hours') or is an imprecise prediction of the future (e.g., 'it will take one or two days'). In recent years, there has been an effort to incorporate the aspect of temporal uncertainty into visualizations [GBFM16,KM01,CC01,Mes00,AMTB05,Har00]. When devising such novel visualizations it is important to evaluate the fi-

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nal design, to make sure that it effectively supports the target user group in their tasks. Furthermore, it is important to not only do evaluation after the design and implementation of a solution, but also before [And08]. A thorough characterization of different evaluation methods during the design process of visualizations is given by Tamara Munzner's Nested Model [Mun09].

There are also user studies not directly aimed at evaluating a specific visualization, but are of a more exploratory nature [WHC15, WCR*11, GJZ*12]. The goal of such experiments is to gain general insights regarding visualizations and their usage, as well as the identification of potential directions for future research. The work presented in this paper is a user study of this kind. The goal of this experiment is to identify intuitive visual representations and approaches in regard to temporal uncertainty. Our understanding of the term 'intuitive' in this context stems from the definition of Naumann et al. who state: *'A technical system is, in the context of a certain task, intuitively usable while the particular user is able to interact effectively, not-consciously using previous knowledge.'* [NHI*07, p. 129]

To reach our goal, we posed typical everyday scenarios to our participants and asked them to sketch a visualization, that would support them in a given task within this scenario. The main contributions of this work are:

- The design and results of a qualitative user study about the visualization of temporal uncertainty.
- Insights on how participants would intuitively sketch temporal uncertainty.
- A categorization of the identified types of temporal uncertainty visualization.
- Four hypotheses derived from the study results, giving directions for future research.

2. Related Work

There are a number of studies evaluating different aspects of uncertainty visualization [CG14, PKRJ10, MRO*12], however, there are only a few that focus on the visualization of temporal uncertainty.

Gschwandtner et al. [GBFM16] compare six different visual encodings of temporal uncertainty and the results are several suggestions for which visualization works best for which kind of task. Kay et al. [KKHM16] focused on visualizing realtime predictions of public transport data on mobile devices. They present a novel technique to display probability density on a time axis. The results of the evaluation show that conventional probability density plots can be discretized into dots to reduce the estimation variance of users.

These two previously presented works relate to ours in their focus on temporal uncertainty visualization. On the other hand, a study by Walny et al. [WCR*11] closely relates to ours in its methodology. The focus of their work was to observe researchers as they create spontaneous visualizations on whiteboards. To analyze the observations, an open coding approach was used. Their analysis yields a continuum of observed data representations, reaching from numeric representations to abstract ones. Furthermore, several implications for research and design are deduced and presented.

Most of the empirical work done in the domain of uncertainty visualization aims to evaluate and compare existing and newly devised designs [LBI*12]. This often leaves the question open if the evaluated designs were the user's first choice, or if there is another more intuitive solution. To answer this question we take a more exploratory approach and ask users for their opinion, how they would like uncertainties to be visualized. This leads us to important insights about user preferences in regard to intuitive information visualization.

3. Study Design

Our target user group is the general public, which is why we decided for a heterogeneous group of participants. We recruited 32 participants. 20 of our participants are male, while 12 of them are female. 24 participants were under the age of 30, while 8 were older. We chose our participants in a way that they had varying degrees of experience with visualizations but were no experts in visualization[†].

Since we wanted to understand which representations people intuitively think of in the context of temporal uncertainty, we did not present any visualizations to our participants. Instead, we provided a scenario and a corresponding goal and let the users think of an appropriate representation. This way the results are not merely a comparison of existing techniques, but explore the imaginations and expectations of users in the context of temporal uncertainty. The four scenarios were chosen to be representative for specific tasks that might benefit from the visualization of uncertainties:

1. *Bus scenario* - The first assignment is to create a visualization that supports the user in gauging the probability that an event will happen before/after a given point in time. The concrete scenario described to the participants is as follows: 'A bus should arrive at 12:00, but may be running late for up to 10 minutes. How would you visualize this scenario, so that you can estimate the probability of still catching the bus if you arrive at the bus station at a given point in time?'
2. *Project scenario* - The second scenario is about the comparison of two events with uncertain end times. The assignment is to create a representation that makes it possible to see which of the two events will end earlier on average. The concrete scenario is formulated like this: 'There are two possible approaches to a given project. The first approach will take 20 to 28 days, while the second one will take 23 to 26 days. How would you visualize the scenario, so you can effectively judge which of the two approaches will on average lead to an earlier completion of the project?'
3. *Project scenario* - The third assignment works with the same scenario as the second one, but a different user task should be supported by the visualization. Instead of judging the average completion time, the user should be able to distinguish which of the two events has a higher probability of having ended at a given point in time. The concrete scenario is formulated like this: 'Consider the same two project approaches as before and

[†] Details are given in the supplementary material at: https://aceanddreed.github.io/Sketching-Temporal-Uncertainty/

an additional given point in time. How would you visualize the scenario, so you can effectively gauge which approach is more likely to have finished until the given point in time?' This scenario and the previous one are collectively referred to as the *project scenario*.

4. *Lecture scenario* - The fourth and last scenario is about judging the probability of two events overlapping in time (i.e. taking place at the same time). The concrete scenario is formulated like this: 'Two lectures are taking place after each other. The first lecture will end between 11:50 and 12:05, while the second lecture will start between 12:00 and 12:15. How would you visualize this scenario to be able to judge the probability of an overlap of the two lectures? Furthermore, it should be possible to accurately judge the interval in which an overlap can take place.'

The evaluation was conducted separately with every participant. Every session started with a brief introduction of the purpose of this study and that uncertainty can simply be assumed to be uniform. Afterwards every participant was posed with these same four scenarios in the same order. We made sure everyone understood the scenarios and their tasks in detail. The answers we collected consisted of paper and pencil sketches (with one exception, as one participant preferred to draw on a computer) as well as oral explanations about details and possible interactive means.

4. Results

Almost every participant provided a sketch for Scenario 1, 2 and 4. Exceptions were one participant who was not able to provide any sketches and two participants who did not provide a drawing for the *bus scenario* or the *project scenario* respectively. Almost every participant (all but two participants) that provided a sketch for Scenario 2, argued that this sketch also supports the user task of Scenario 3 and hence, did not provide a separate sketch for this scenario. For this reason we assigned a collective name to the two scenarios and evaluated them as one. In total 93 sketches[‡]. and corresponding descriptions were collected which we analyzed with an open coding approach. In the first step appropriate categories need to be defined, by which every sketch can be classified. In our case these categories were defined by cooperatively going through the collected material to look for distinctive features, which led to the following categories (Figure 1 shows example drawings for each category):

C1 – Explicit. Explicit representations somehow encode the uncertainty of an event at a given point in time explicitly, instead of representing the uncertainty by relative position of an element to the bounds of an uncertainty interval. This category is further split up into different types of explicit representations, which are not mutually exclusive.

- **Icons.** Some kind of icon, such as a smiley, encodes the uncertainty (Figure 1 (e)).
- **Color Value.** A color or gray-scale value encodes the uncertainty (Figure 1 (i), and (h)).
- **Length/Height.** The uncertainty is encoded in the length or height of an element (Figure 1 (e), (f), and (h)).
- **Interaction.** The exact uncertainty value is given interactively, for instance, by clicking an element or hovering it (Figure 1 (g)).

C2 – Temporal Line Chart. A form of a conventional line chart on a temporal axis is used to encode the uncertainty (Figure 1 (e), (f), and (h)). Sketches that fall into this category always also count for the category **Explicit–Length/Height**.
C3 – Clock. A clock metaphor was used (Figure 1 (d)).
C4 – Bounded. The uncertainty is given as bounds of an uncertainty interval (Figure 1 (a), (b), (c), and (g)).
C5 – Horizontal Time. Time is represented on a horizontal axis (Figure 1 (a), (b), (i), (e), (f), (g), and (h)).
C6 – Vertical Time. The time is represented on the vertical axis (Figure 1 (c)).

Furthermore, the sketches of the *project scenario* and the *lecture scenario* were divided into **juxtaposed** and **superimposed** representations. The results of the *lecture scenario* are further split up by counting how many superimposed views are using color value to distinguish the two visualized lectures. The collected results for each scenario are presented in Figure 2, 3 and 4 respectively. By looking at the overall results it can be seen that uncertainty is most often explicitly represented through length or height. Icon representations on the other hand were only used in the *bus scenario*. The reason for this could be that this is the only scenario that has a 'good' and a 'bad' outcome (catching or missing the bus), which lends itself to a visualization using smileys or thumbs-up/down representations. Interaction is particularly popular in the *project scenario*. This might be due to the comparison task which requires exact probability values. In the *lecture scenario* the share of bounded representations is higher than in the other scenarios. We believe that this is due to the complexity of the task. It is hard to come up with a good visualization that actually conveys the overlap of two lectures well. This leads many participants to resort to a simple representation of two overlapping intervals. In the *project scenario* juxtaposed representations are more popular than superimposed views, while in the *lecture scenario* it is the other way around. A reason for this could be the nature and focus of the respective tasks. The *project scenario* focuses on the difference of the two intervals, while the *lecture scenario* specifically asks for the overlap of two intervals.

We believe that the true value of our results becomes evident when combining them with other studies on this topic. For instance, Gschwandtner et al. [GBFM16] identified gradient plots to be well suited for judging specific probability values at specified points in time. However, it is not known, for instance, how long it took study participants to understand this kind of visual encoding. As our results indicate that gradient plots are intuitive, we can conclude that gradient plots are recommendable for this task. Moreover, Gschwandtner et al. recommended ambiguation, i.e. using a lighter color to convey uncertain parts of an interval (similar to our *bounded* category). Our results suggest that they are also intuitive. Another interesting connection can be observed between Corell and Gleicher's [CG14] work, which identifies multiple problems of error bars. We believe it is noteworthy that not a single drawing we collected featured a representation that can be considered an error

[‡] all sketches can be found in the supplementary material at: https://aceanddreed.github.io/Sketching-Temporal-Uncertainty/

bar. We derived four hypotheses from these results which are meant to guide future research:

H1 – Line charts and gradient plots are suited for judging specific probability values of points in time. Almost two thirds of the collected sketches for the *bus scenario* featured an explicit representation of uncertainty. The most common types are line charts. We also encountered gradient plots, which are very effective for this kind of task [GBFM16].

H2 – Icons, such as smiley faces, are suited to convey rough probability values, which do not have to be judged precisely. The 31 sketches of the *bus scenario* feature four icon representations. We believe that these are quick to decipher, but lack precision.

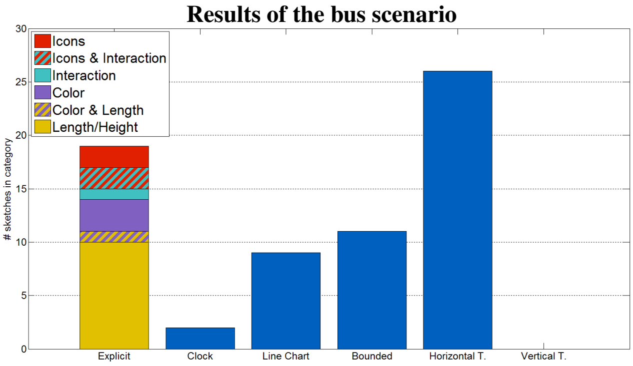

Figure 2: *The bars show how many of the 30 collected sketches fall into each category. Explicit representations may use multiple types of encodings. In this case they are represented by the corresponding hatched areas.*

H3 – Multiple juxtaposed views are better suited to support the comparison of two or more events than superimposed views. The results of the *project scenario* feature almost four times as many sketches with juxtaposed views than superimposed ones.

H4 – Most people prefer an explicit representation of the underlying uncertainty, even if it is not directly relevant for the task at hand. In the first task of the *project scenario* only the average values of the two compared projects are of relevance. Still, the underlying uncertainty was often explicitly represented.

5. Discussion and Conclusion

We conducted an exploratory study of 32 participants sketching temporal uncertainty based on scenarios featuring low-level tasks, which might occur in real world applications. Our results yielded the identification of nine frequent categories, and led us to the formulation of four hypotheses. These hypotheses, however, are not evaluated yet. They merely present interesting observations, which are supposed to give direction to future work. Moreover, the presented list of hypotheses is not exhaustive. Further assumptions, which can be subject of future work, can be made by interpreting patterns and outliers of the presented study results. One could, for instance, investigate why time is almost never depicted on the vertical axis, or why juxtaposition is used more often for comparison

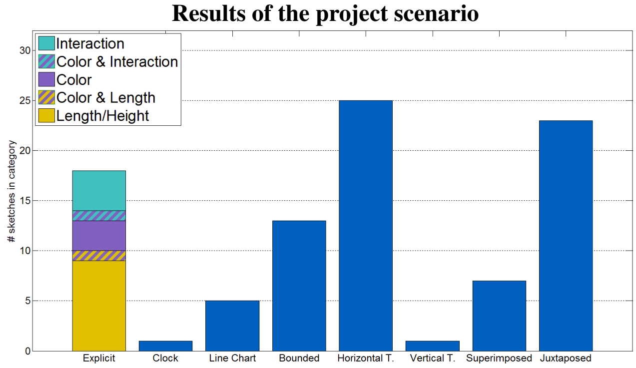

Figure 3: *These are the results of the project scenario, which yielded 32 drawings. In contrast to the results of the bus scenario presented in Figure 2, there are additional categories for superimposed and juxtaposed representations.*

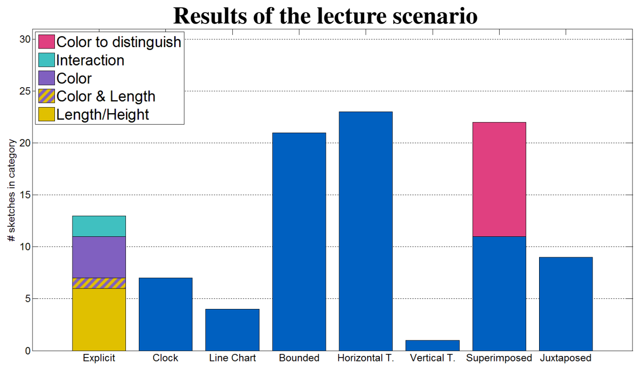

Figure 4: *The results of the 31 lecture scenario sketches also feature categories for superimposed and juxtaposed views. Furthermore, the chart shows that half of the superimposed views use color value to visually distinguish the visualized lectures.*

tasks, while superposition is more frequent in the scenario about temporarily overlapping events. To find more concrete answers toward the intuitiveness of temporal uncertainty visualizations much future work needs to be done. Quantifying this property is inherently hard, since intuitiveness is subjective and probably also affected by the environment a visualization is situated in.

Our results shed light on the user's perspective when it comes to the visualization of temporal uncertainty. They show which types of visualizations are chosen by users, and thus, are intuitively understood. Considering these insights in addition to the effectiveness of a visualization type, allows us to give better recommendations how to visualize temporal uncertainty.

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