A Time-location-Based Itinerary Visualization

Florian Haag[1], Thomas Schlegel[2] and Thomas Ertl[1]
[1]*Institute for Visualization and Interactive Systems, University of Stuttgart, Universitätsstraße 38, 70569 Stuttgart, Germany*
[2]*Junior Professorship Software Engineering of Ubiquitous Systems, Technische Universität Dresden, Nöthnitzer Straße 46, 01178 Dresden, Germany*

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Abstract: With the advent of linked data sources, transportation information systems are no longer limited to indicating how to get from one location to another. They can suggest where to go shopping on the way or plan several synchronized itineraries for groups of travelers. Along with these developments, information about stopovers evolves from mere additional data to a crucial part of the itinerary. However, current time-based visualizations of itineraries cannot adequately convey the stopovers contained in an itinerary. We propose a time-location-based itinerary visualization that can be used when planning trips, which allows for the easy comparison of itineraries with different routes, and for aligning itineraries of several travelers in collaborative scenarios. We describe the visualization concept and report on a user study that confirms the basic ideas and provides a number of insights on how the visualization can be developed further.

1 INTRODUCTION

Automated travel planning systems for public transportation have become commonplace in many countries. Instead of transportation company employees, software searches for the appropriate itineraries based upon the user's wishes. In particular, such travel information systems are increasingly used on mobile devices (Heimonen, 2009), and a multitude of efforts to cater to mobile users of transportation information systems have been undertaken (Arikawa et al., 2007; Ferris et al., 2010).

With the increased integration of linked data into services for general audiences, different kinds of information and data from several sources can be automatically combined (Gahleitner and Wöß, 2004; Walther et al., 2009). This is particularly promising in the field of transportation, where the raw data from travel itineraries can be cross-linked with information about shopping opportunities or points of interest for tourists (Alves et al., 2009; Husain and Dih, 2012).

An additional aspect to consider is that information systems get integrated into and start supporting our social lives (Khalil and Connelly, 2005). Systems that support not only single users, but groups of users in their mutual lives are being developed (Boticki et al., 2011). Travelling is one of these social activities; groups of people join each other for common legs of a journey or meet each other while underway (Garcia et al., 2011).

As a result, trip planning systems of the future will do more than just find an itinerary that brings a traveler from one place to another. They will suggest an itinerary that lets users run errands without making detours, or choose routes so they can meet friends who are underway at roughly the same time. Consequently, the current ways to display itineraries are not sufficient for that kind of trip planning, as they were designed with single trips for single or homogenous groups of travelers in mind. Instead, new visualizations are required to provide an overview of the available itineraries, with information about possible activities at stopovers or about itineraries of other travelers.

2 RELATED WORK

A very widespread approach for displaying itinerary suggestions is a tabular display. This is offered by systems such as the website of the German railroad operator *Deutsche Bahn AG* (DB, 2014) and provides a basic, text-based overview of the available trips.

Other services have enhanced such a table-based view so that the vertical axis indicates time. Sev-

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eral alternative trip suggestions are placed next to one another, similar to Gantt charts (overview by Wilson (2003)) or the LifeLines approach (Plaisant et al., 1996). Sometimes, detailed information can be made available upon request (Batrinca et al., 2013). On the other hand, displaying the relevant information side by side allows for a direct comparison between timelines (Havre et al., 2000; Zhao et al., 2012). This time-based approach has become widespread in practice, in the context of passenger traffic (Daimler, 2014; Schildbach, 2014) as well as transport logistics (NETRONIC, 2013) or work scheduling (Chau et al., 2004). Additional information such as the estimated walking time at stops (if travelers have to bridge a distance to get to the connecting vehicle) can be integrated into this kind of visualization. However, the described timeline approaches do not provide an easy way to get an idea of the different routes used by the trip suggestions.

Map-based views are based upon the geographic properties of the transportation network and display the temporal aspect only as an additional factor (Cherry et al., 2006) or in a separate view (Stewart et al., 2013). While they provide a good overview of the available routes and the whereabouts of the respective stopovers, they do not allow for a quick comparison of departure and arrival times or durations of waiting phases at stopovers. Related approaches provide chances for integrating additional information into the maps, but do not propose a complete possible solution that displays the full itineraries (Böttger et al., 2008). When spatial and temporal information are combined, visualizations tend to focus on the exact representation of the spatial aspect without allowing for a direct comparison of times and durations in overlapping itineraries (Thudt et al., 2013; Ventura and McGuffin, 2014). If both aspects are represented, comparing itineraries at the same or at overlapping locations becomes problematic (Hewagamage et al., 1999), or—when using three dimensions—times cannot always be clearly seen at a glance (Kraak, 2003).

Alternatively, place-time-charts have been proposed as a visualization base rather than a geographical map. They are not only used for transportation or logistics planning (VIA, 2013; Goverde and Meng, 2011; Regmi and Hanaoka, 2012), but have also been proposed for passenger information, however without integrating any extended information on the transfers directly in the visualization (Masoodian and Budd, 2004).

A schematic graph-based and a matrix-based view have been presented, as well (Keller et al., 2011). While both provided an overview of the number of routes and the travel time, the graph-based visualization did not allow for an intuitive *comparison* of the travel times, while the matrix-based visualization required memorizing the mapping of colors to various aspects of the itineraries.

Therefore, none of the existing visualizations gives a good idea of where several itineraries coincide or differ in terms of location, while also conveying an adequate comparison of the arrival and departure times at each stop.

3 TIME-LOCATION-BASED ITINERARY VISUALIZATION

We propose a timetable visualization for trip planning that provides an overview of both the time and the location in the course of the journey, and that allows for a side-by-side comparison of several alternative itineraries. Locations are abstracted to logical places, such as named stops in a public transportation network, rather than the physical (geographical) location. The respective information can be retrieved from linked data sources that provide meta-information on businesses and facilities near public transportation stops (Ruta et al., 2012).

3.1 Basic Itinerary Layout

As a basis for our visualization, we chose a grid-based approach, comparable to the small multiple paradigm (Tufte, 1983, p. 48): Rows in the grid represent single stops that appear in any of the displayed itineraries, while each itinerary occupies one column in the grid. Each cell of the grid indicates a stop (origin, destination, or intermediate transfer).

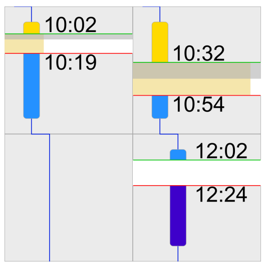

Figure 1: Depiction of four grid cells in the time-location-based visualization. They contain an excerpt of two itineraries (columns) at two stops (rows). Three transfers are shown (the different colors of the wide bars represent different transportation lines). The left itinerary does not require a transfer at the second shown stop.

Figure 1 shows four exemplary cells in the itinerary grid. In keeping with the aforementioned placement, the two columns belong to two distinct itineraries, and the two rows indicate how two different locations are integrated in those two itineraries. The lower left cell only shows a thin connecting line, meaning that there is no transfer required at the given location in that itinerary. The other cells each feature a wide bar indicating—by its height—the time spent at the location, as well as two tall bars symbolizing the means of transportation used to get to and depart from the location. The colors of these tall bars match the line colors from the transit map for a good visual correspondence here, though other color mappings are conceivable.

3.2 Transfer Information

The time spent at each location is represented by the height of the wide white bar. At its upper and lower edge, a thin bar represents the arrival and the departure time, respectively. These times are also written as text above and below the according lines. Thus, the vertical dimension represents time.

The same scaling is used across the whole grid. Each grid row has its own time axis, so arrival and departure times at one location can be compared visually across all itineraries.

Finally, the white area may partially be filled with two semi-transparent rectangles. One rectangle extends from the arrival time downward and indicates the estimated walking time at the location. The other rectangle extends from the left border of the cell to the right as an indicator for the walking distance—the further the cell is filled horizontally, the closer the walking distance gets to the maximum distance displayed in the bottom right corner of the screen (cf. Figure 2).

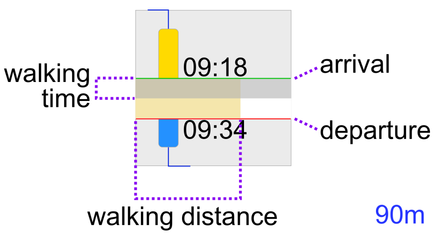

Figure 2: A single grid cell displays some information on a transfer. On the vertical time axis, the times of arrival and departure at the location are shown. About half of the area between the arrival and departure is filled with a grey bar, implying that about half of the stopover time will be required for walking. A yellow bar fills the area horizontally by about $\frac{2}{3}$, which, with respect to the total distance of 90m shown in the lower right corner, points to a walking distance of approximately 60m.

3.3 Static Example

Figure 3 shows an exemplary timetable that displays five itineraries to travel from the stop *Hedelfingen* to the stop *Ellental*. It is evident at a single glance that only itineraries 2 and 4 require a transfer in *Bietigheim-Bissingen*. By comparing the relative vertical placement of arrival and departure lines, users can also recognize that all itineraries in this case take about the same time, and that no two stopovers at any of the stops overlap even by a short amount of time. The stop at Central Station inevitably requires bridging a distance of about 100 meters, as the horizontal walking distance indicator almost completely fills up the stopover area at that location and the reference is indicated as 110 meters in the lower right corner of the screen.

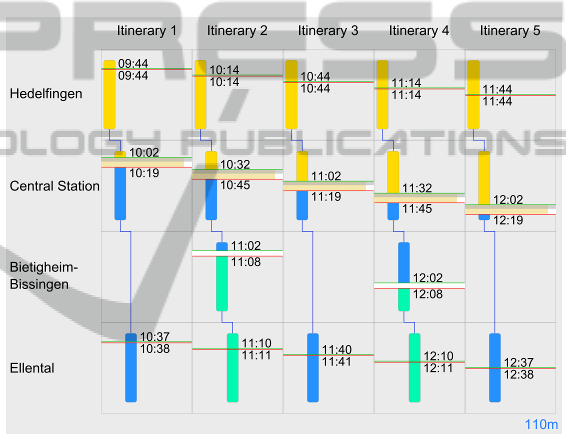

Figure 3: A complete screen showing five itineraries with the time-location-based approach. Two of the itineraries require two intermediate transfers, the other three do not require a transfer at stop *Bietigheim-Bissingen*. Three different colors are used for the vertical bars, which means that three different transportation lines are used in these itineraries (cf. Section 3.1).

3.4 Order of Locations

The order of the locations in the time-location-based approach is not fixed. As different itineraries might include the same locations, but in opposite orders, there is no single optimal ordering for all displayed locations. Instead, the order of rows can be changed.

Figure 4 shows two itineraries, where locations have been ordered based on *Itinerary 1*. For *Itinerary 2*, the order of stopovers is still recognizeable: A thin connection line links the colored tall bars in the order the transfers happen, and moreover, that order is reflected by the horizontal displacement of the tall bars.

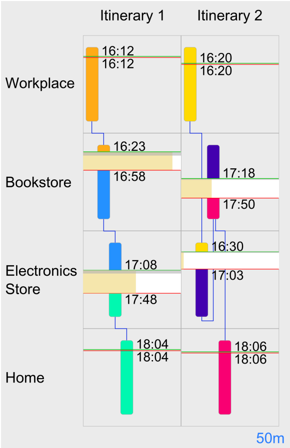

Figure 4: Two itineraries in the time-location-based visualization that visit a bookstore and an electronics store in different orders. The stops are sorted to match the order found in *Itinerary 1*. The order of stops in *Itinerary 2* is still recognizeable both by the horizontal displacement of the thick bars and by the thin blue connection lines.

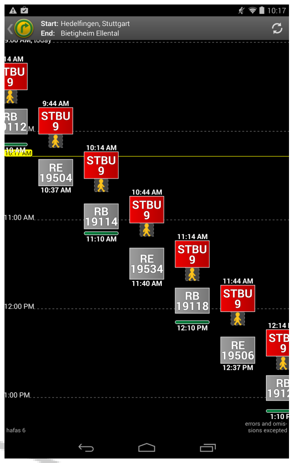

Figure 5: A screenshot of Öffi's (Schildbach, 2014) time-based visualization as shown in the user study.

4 USER STUDY

We have conducted a small user study to gather some comments by possible users and gain some insight into how they react to and use our visualization. Our study had two goals: On the one hand, we wanted to compare the performance of users in traditional time-based timetable visualizations with that in our time-location-based approach. On the other hand, we wanted to test whether the additional information contained in our timetable visualization approach would be correctly recognized by users.

For the comparative goal, we chose to present screenshots of the free mobile app Öffi (Schildbach, 2014), shown in Figure 5, which is widely used in Germany and provides public transit data for many European cities. It serves as a typical example for the class of transportation information services that display itineraries with a standard time-based visualization (Victor, 2012; Upbin, 2012; Voyages-sncf.com, 2014; Daimler, 2014).

4.1 Participants

Eleven participants between 20 and 30 years of age took part in our user study. All participants thought of themselves as frequent users of public transportation, though only four of them had used mobile applications to retrieve related information. Participants were recruited with a public ad and were not affiliated with the authors.

4.2 Materials

Written descriptions of the featured visualizations were prepared to warrant providing each participant with the same initial information. Trial descriptions, along with a brief presentation of the scenario, were prepared on paper, as well.

The prototypical application, which was installed and configured before the user study on a Samsung Galaxy S4 Android smartphone (cf. Figure 6), includes two major features:

- It displays static screenshots of itineraries output by the comparison application that were retrieved from actual requests to the transportation information system.
- It displays itineraries based upon our time-location-based approach. The displayed itineraries were hard-coded based on the task definitions for the study. Column headers could be tapped to reorder stops based on the respective itinerary (cf. Section 3.4).

Only actual itineraries from the public transit system of the city and region of Stuttgart were used. This use of real data ensured that the itineraries were realistic. Moreover, none of the participants could rely on extensive prior knowledge about Stuttgart's transit system as the study was conducted with inhabitants of Dresden, about 400 kilometers away.

4.3 Design

The study was broken up into four tasks, each of which consisted of three to six trials. Trials were always conducted in the same order to warrant compa-

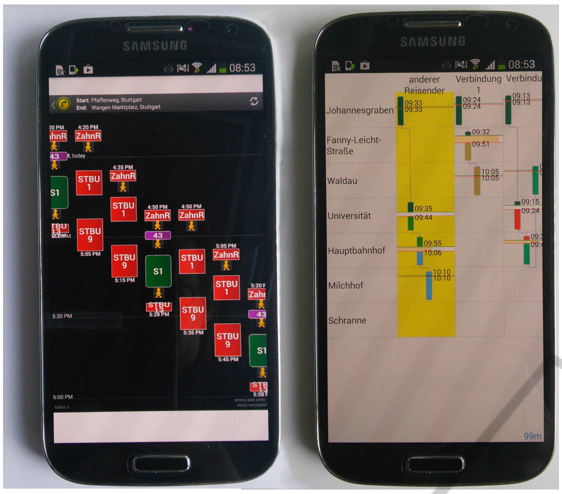

Figure 6: The application used in the study, showing the time-based (left) (Schildbach, 2014) and the time-location-based (right) visualization on devices of the type used in the study. Various itineraries with different stopovers can be seen well on the right-hand device here.

rable results, and because tasks and trials would gradually increase in difficulty.

4.3.1 General Information (Departure and Arrival Times, Number of Routes ...)

The first task aimed at a comparison of our visualization with the traditional time-based approach. Each participant was shown three sets of itineraries with the time-based visualization and three sets of itineraries with the time-location-based visualization. Stop names were shown as locations. Based upon that on-screen output, some general information about the itineraries had to be determined—in detail, the origin and destination of the itineraries, the earliest shown departure time and the latest shown arrival time after and before a given time, respectively, the minimum and maximum number of vehicle changes, as well as the displayed number of distinct routes.

4.3.2 Available Time at Stopovers, Walking Distance

In the second task, three sets of itineraries were shown in connection with a scenario where a user needs to run several errands on their way to a destination. Locations were mapped to stop names; some stops were marked to contain special facilities (such as particular stores). Users were asked to identify the itinerary from each set that leaves a maximum amount of time for the errands, and the itinerary that requires the least amount of walking, based on the distance.

4.3.3 Order of Stopovers

For the third task, instead of concrete stops, the locations were labeled *bank*, *supermarket*, etc., and did not necessarily refer to the physically same place across all itineraries. Each itinerary would visit the locations in a different order, and users were asked to identify the itinerary in each set that visits the facilities in a specific order (e.g. fetching money from the bank before buying something in the supermarket).

4.3.4 Aligning with other Itinerary

The fourth task dealt with a short encounter between two acquaintances at a stopover. Therefore, each of three sets of itineraries was combined with an additional highlighted itinerary that had a different origin and destination than the others (cf. Figure 6, right). Users were asked to identify the itinerary that provided the best opportunity to meet the other person (using the highlighted itinerary) underway.

4.4 Procedure

Participants took part in the study one at a time in a closed room, with one supervisor of the study present. The printed information was handed out to them.

Participants were provided with the mobile device on which the application was running. They had some time to get acquainted with both visualizations based on two sample sets of itineraries before starting the tasks. While it was made clear to them that the whole study would be recorded on video, the time measurement in task 1 was not mentioned in order to avoid any feeling of time pressure.

After completing the tasks, participants were asked to provide some comments on the two visualizations, which were noted down by the study supervisor. Each participant concluded the study within 30 to 40 minutes and received a small financial reward.

4.5 Results

While we were primarily interested in user comments on the time-location-based itinerary visualization, we did check the correctness of the responses. This was done in order to determine whether the study participants had correctly understood how to read the visualizations in question. Overall, participants could answer most questions on both visualizations correctly, though error rates—and the distribution of errors among participants—varied considerably. Most answers were given in a timespan between 3 and 20 seconds for both visualizations. Table 1 provides an overview of the correctness of answers.

Table 1: Correctness of responses in the user study: For each task (*T*), the questions, the visualization (time-based (*t*) or time-location-based (*tl*)) and the total number of responses is shown, along with the number of incorrect responses and the number of subjects who responded incorrectly to at least one question.

T	Question	Vis.	Total Resp.	Incorrect Resp.	Incorrect Subj.
1	origin/destination	t	33	0	0
		tl	33	13	6
	earliest departure	t	33	1	1
		tl	33	0	0
	latest arrival	t	33	2	2
		tl	33	6	3
	no. of changes	t	33	3	3
		tl	33	12	5
	number of routes	t	33	12	10
		tl	33	9	4
2	av. time	tl	33	18	10
	min. dist.	tl	33	5	4
3	order	tl	33	6	3
4	meeting	tl	33	1	1

4.5.1 Task 1: General Information

Most of the questions about the general information were correctly solved. Several users, however, had some difficulties recognizing the destination depending on the order of locations in the time-location-based visualization. Determining the number of vehicle changes sometimes proved difficult for a few users especially in the time-location-based approach, whereas this posed no problem to the other six participants. Likewise, seven of the users could correctly distinguish the numbers of routes among the displayed itineraries in the time-location-based model. Using the time-based visualization, in contrast, ten out of the eleven participants failed to determine the number of different routes in one of the trials.

A few participants were discontented with aspects of the time-location-based visualization such as the reordering of locations, the coloring of the tall bars (though there were also positive remarks about these colors matching different lines in the transit system) and the lack of any directly visible information on the concrete lines to use (for instance, a bus number).

4.5.2 Task 2: Available Time at Stopovers, Walking Distance

Exactly recognizing the available time at stopovers proved difficult for most participants, even though eleven of the incorrect answers were still partially correct. In the question about walking distances, seven of the participants did not commit any mistakes.

Several of the participants raised concerns about the time necessary to get used to the time-location-based visualization. Also, they found the time required for walking to be irrelevant. Other participants commented, however, that the displayed information was overall important; that the time available at stopovers was easily recognizable by the vertical time scales and that the indication of the walking distance was useful. Two participants explicitly remarked that they liked the large amount of information shown at a time.

4.5.3 Tasks 3 & 4: Order of Stopovers, Aligning with other Itinerary

As comments on the tasks focusing on the correct order of stopovers and on aligning one's itinerary with that of an acquaintance were very similar, the results will be presented together.

Tasks 3 and 4 were correctly answered by almost all participants. Only three participants made any mistakes at all in the order-related task. An additional participant corrected their initial erroneous answers for one of the trials in each task 3 and task 4.

Several participants stated that they liked the scenarios presented in these tasks. Two participants spoke favorably of the option to sort the time-location-based view based upon each itinerary. Three participants remarked that they considered the thin connection line across cells unclear especially when locations were not sorted in the order of the examined itinerary, with one of the participants explicitly describing the line as "necessary, but confusing".

Further comments dealt with issues in our prototypical implementation that were not inherent to the visualization concept, such as a lack of feedback about the current location sort order, the fact that the highlighted reference itinerary in task 4 was not fixed to the viewport and would thus sometimes become invisible, and the missing support for zooming.

5 DISCUSSION

We have gathered a number of insights on what could be considered successful and what still needs to be changed for our time-location-based approach to become useful. In general, the study participants were able to solve the tasks by using the time-location-based visualization. In tasks with high error rates for the time-location-based visualization, all mistakes were committed by about half of the participants, while the others solved the respective task correctly. Still, in the comparative task, users mostly performed better in the time-based visualization. One exception is the question about the number of different routes, which reflects that routes cannot be compared in the time-based visualization.

The basic grid layout appeared to be welcomed by users. The side-by-side comparison of the itineraries with different routes and the uniform time-scale across the whole view were pointed out to be good ideas. The same applies to the general amount of information, though differing statements by users imply that some details—such as the estimated walking time—should be made optional. The possibility to align one's itinerary with that of another traveler was positively noted, but it also evoked the question whether the system could automatically determine the best opportunity for a meeting. Travelers may, however, possess some additional knowledge about a particular stop, which is not available to the system and thus could not be factored into such a decision.

The capability to reorder the locations was partly praised, partly criticized. Much of the critique was related to users being unsure about the current sorting, which points to a lack of visible feedback in our implementation. The observed difficulties in recognizing the point of origin and the destination of the trips could be mitigated by giving the respective cells more visual distinctiveness compared to the stopover cells. Moreover, using diagonal lines for the connection lines across cells could further enhance the visibility of the current sorting order and make the connection lines more dissimilar to the grid lines.

Some of the users made remarks about a lack of information, such as the concrete bus or tram lines to use, and expressed that they are used to time-based visualizations. Therefore, a combination of the time-location-based and the time-based visualizations appears to be promising, where the time-location-based view is used during the planning phase and users are free to switch to the time-based view when starting their journey. This, along with explanatory interactive clues displayed upon request, could also help solve the perceived effort to learn how to use the time-location-based visualization.

6 CONCLUSION AND FUTURE WORK

We have discussed the state of the art for visually comparing itineraries. Based upon related work and the requirements resulting from multi-user scenarios, we have defined a novel way to visualize itineraries that can be easily compared both based on temporal and local aspects, and that is suited for the synchronization of trips across travelers. We have implemented a prototypical mock-up of our visualization and have conducted a small user study. Users could solve most tasks correctly and various aspects of the visualization were praised as useful ideas. However, some users also committed a high number of mistakes in some tasks, which have helped identify flaws in some aspects of our initial time-location-based visualization concept. In the discussion of the study results, we have assembled a list of suggestions for the further development of the time-location-based visualization and some open issues that need to be solved.

We are confident that the time-location-based itinerary visualization is a promising approach that should receive further attention. The optimizations hinted at in the study results discussion, zooming features for the time axis, cosmetic changes such as the user suggestion to express certain locations with icons rather than texts, and the integration of real-time information for the displayed itineraries will require some further user experiments. Ultimately, the results may be applicable to other fields as the time-location-based visualization can be generalized for other types of event-related information—event logs of software systems that communicate and exchange data among each other, as well as the planning of shared resources that can be reserved and used by the staff of an enterprise come to mind.

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