The Effect of Motion in Graphical User Interfaces

Paul U. Lee[1], Alexander Klippel[2], and Heike Tappe[3]

[1]San Jose State University
NASA Ames Research Center, Mail Stop 262-4
Moffett Field, CA 94035-1000 USA
plee@mail.arc.nasa.gov
[2]Universität Bremen - Cognitive Systems Group
Department for Informatics and Mathematics, PO box 330
440 Bremen GERMANY
klippel@informatik.uni-bremen.de
[3]Humboldt University at Berlin
Department of English and American Studies
10099 Berlin GERMANY
heike.tappe@rz.hu-berlin.de

Abstract. Motion can be an effective tool to focus user's attention and to support the parsing of complex information in graphical user interfaces. Despite the ubiquitous use of motion in animated displays, its effectiveness has been marginal at best. The ineffectiveness of many animated displays may be due to a mismatch between the attributes of motion and the nature of the task at hand. To test this hypothesis, we examined different modes of route presentation that are commonly used today (e.g. internet maps, GPS maps, etc.) and their effects on the subsequent route memory. Participants learned a route from a map of a fictitious town. The route was presented to them either as a solid line (static) or as a moving dot (dynamic). In a subsequent memory task, participants recalled fewer pertinent landmarks (i.e. landmarks at the turns) in the dynamic condition, likely due to the moving dot that focused equally on critical and less important parts of the route. A second study included a combined (i.e. both static and dynamic) presentation mode, which potentially had a better recall than either presentation mode alone. Additionally, verbalization data confirmed that the static presentation mode allocated the attention to the task relevant information better than the dynamic mode. These findings support the hypothesis that animated tasks are conceived of as sequences of discrete steps, and that the motion in animated displays inhibits the discretization process. The results also suggest that a combined presentation mode can unite the benefits of both static and dynamic modes.

1 Introduction

Animations have become an important design tool in recent graphical user interfaces, as they motivate interactions and draw attention to specific contents. However, the efficacy of animated displays has been questioned by many researchers (e.g. Hegarty, 1992; Palmiter & Elkerton, 1993; Tversky, Morrison, & Betrancourt, 2002). This seems surprising since many graphic representations of physical spaces (e.g. weather

A. Butz et al. (Eds.): Smart Graphics 2003, LNCS 2733, pp. 12–21, 2003.

maps) or devices (e.g. pulley systems) have an intrinsic dynamic component. Hence, the representation of the dynamic aspects through animation should have facilitated information processing.

Tversky and her colleagues (2002) have reviewed animation research and concluded that animated graphics failed to show an advantage over static graphics in facilitating learning and comprehension when the information content and the level of interactivity were equated. They hypothesized that the drawback of animation was due to perceptual and cognitive limitations in the processing of a changing visual situation. They proposed a potential cognitive constraint that people conceive continuous events as composed of discrete steps (Zacks et al., 2001). The discretizations of events occur systematically and the break points of the events (i.e. points where events are segmented) are better remembered than other points within an event. If this is true, then a sequence of static graphics that focuses on the correct set of discrete steps may be more effective than an animated graphics.

Although animation research has failed to show increased learning and comprehension, the property of motion in animated graphics has shown some promise as an effective mechanism for visually organizing complex information by grabbing user's attention and perceptually grouping otherwise dissimilar objects (Bartram & Ware, 2002). The motion can also embed certain temporal components of actions, such as speed, which may be more difficult to infer from a sequence of static graphics. Based on these benefits and costs associated with motion, we hypothesize that the efficacy of static vs. animated graphics depends on the match between the attributes of the presentation mode and the nature of the task. If the motion in an animated display can effectively draw user's attention to the task relevant information, then it may facilitate learning. Otherwise, it can distract the user from attending to the task-relevant information and thereby inhibit the learning process.

2 Dynamic vs. Static Presentation of Route Information

To test this hypothesis, we compared the efficacy of motion in conveying route information by maps. Recently, route maps have become widely available through the Web and through handheld and on-board navigation systems (e.g. Agrawala & Stolte, 2001; Baus et al., 2001). Despite the ubiquitous status of route maps, optimal visual presentation methods are still a matter of research. For example, route maps integrated in on-board navigation systems present routes dynamically with a moving arrow that traverses the map to simulate an imagined navigator. In contrast, internet maps present information statically with lines or arrows representing a route (Fig. 1). Differences in the presentation modes are induced by technical constraints of each medium, rather than by considering cognitive processes.

When people recall route information, they decompose the route into a set of discrete route parts, consisting of only minimal information such as turns and landmarks at the turns, in congruence with effective wayfinding aids (Jackson, 1998). The turns in route directions are key decision points in which the user has to remember to re-orient himself in order to remain on the route. Analogous to event break points, the turning points (decision points with a direction change or DP+) are better remembered than the non-turning points (decision points with no direction change or DP-). Most of the landmarks and intersections along the route are omitted

(Ward et al., 1986; Denis, 1997; Lee & Tversky, in preparation), or parts of the route are chunked to higher order route (direction) elements (Klippel et al., in press).

Fig. 1. Examples of dynamic (left) and static (right) route maps

Based on these findings, we predict that dynamically presented route information would hinder subsequent route memory. Given that the key components of route directions are turns and landmarks at the turns, we predict that a static route would allow users to allocate their attention according to the task goals, resulting in a better memory for the landmarks at the turns. In contrast, dynamically presented route information directs users to pay attention to the motion itself, resulting in more equal allocation of attention and subsequent memory to the landmarks at turning (DP+) and non-turning (DP-) points on the route.

By studying how various presentation modes affect the acquisition of route information, especially landmarks, this study aims to shed light on appropriately designing user interfaces to best support cognitive processes. Since landmarks at decision points (i.e. DP+ and DP-) are critical components of route information, we will focus on participants' recall of these landmarks.

2.1 Method

Participants. Forty-three undergraduates, 21 male and 22 female, from Stanford University participated individually in partial fulfillment of a course requirement. The minimum criterion of 30% recall rate eliminated the data of three men and one woman. The data of the remaining thirty-nine participants were analyzed.

Materials and Procedure. We employed a map of a fictitious town consisting of a street network and various landmarks, such as McDonald's and gas stations. We restricted the design to the following functions and appearances of landmarks:

- We chose only instantly recognizable landmarks, such as McDonalds and Seven Eleven, thereby eliminating the need for a legend.
- The landmarks were placed only at decision points – (DP+) and (DP-).
- There were an equal number of landmarks at the turns (DP+) and at the crossing paths along the route (DP-).
- We restricted ourselves to point-like landmarks and avoided street names.

The route in the map was presented statically or dynamically. The static condition presented the complete route between a start and a destination point as a solid line (Fig. 2). In contrast, the dynamic condition conveyed the route by a moving dot. The participants were assigned randomly to one of the two presentation conditions. They were asked to remember the route as they viewed the map for 3 minutes. Immediately afterwards, they were given a map with only the street network and were asked to draw the route and all of the landmarks that they could remember, both on and off of the route.

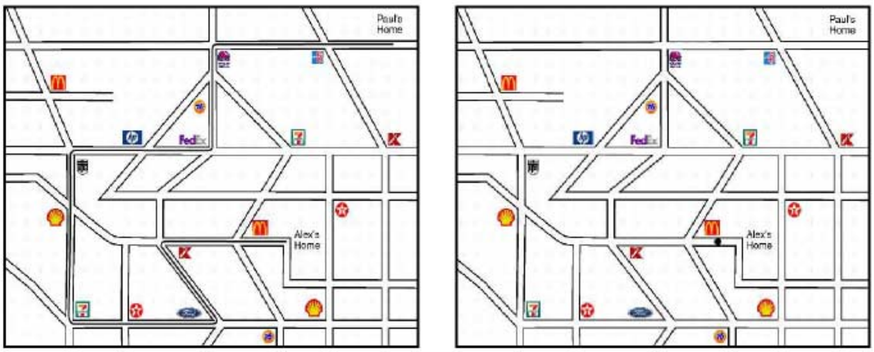

Fig. 2. Route map with a static (left) or a dynamic (right) presentation of the route

2.2 Results

The recalled landmarks were analyzed for static and dynamic route presentation according to the following three categories: landmarks at the turns (DP+), landmarks at the crossing paths (DP-), and landmarks not on the route. The accuracy of the recalled landmarks and the route were coded for each participant. Partial credits were given for partially correct recalls. Whenever a landmark was recalled but placed on a wrong intersection along the route, 0.25 credits were assigned. A quarter credits were also assigned when a wrong landmark was placed on a correct location. When a correct landmark was placed on a correct intersection but was placed on a wrong corner (e.g. on the left side instead of on the right), 0.75 credits were assigned.

The participants remembered very few landmarks that were not on the route (4% for the static route; 2% for the dynamic route); these were excluded from subsequent analyses. Using repeated measures design, the results showed that the DP+ landmarks were recalled better (72.4%) than the DP- landmarks (27.0%). $F(1,37) = 87.9$, $p < 0.001$. This finding confirmed that the participants overwhelmingly remembered the landmarks at the turns than other landmarks since they were most pertinent to route directions.

More relevant results were whether the presentation mode (i.e. static vs. dynamic) affected the recall memory. If the motion in the dynamic route guided participants' attention equally to the DP+ and DP- landmarks, it would increase the recall of landmarks along the route (DP-) and decrease the recall of landmarks at the turns

(DP+) relative to the static route. Additionally, the dynamic condition revealed the route piecemeal, taking away the "big picture" of the overall route and forcing the participants to attend to the moving dot to gather the route information. Despite the lack of "big picture" in the dynamic condition, the overall recall rate did not vary significantly across conditions (52.3% for static and 47.3% for dynamic). $F(1,37) = 1.53$, $p > 0.2$. The accuracy of the generated route seemed slightly better for the dynamic (85%) than for the static condition (74%) but the results were not significant. $\chi_1 = 0.77$, $p > 0.38$.

The results (Fig. 3) confirmed our hypothesis that the presentation mode would affect the type of landmarks recalled. $F(1,37) = 4.1$, $p < 0.05$. The difference in the recall rate between DP+ (turns) and DP- (non-turns) landmarks were greater for the static condition (80.0% for DP+; 24.6% for DP-) than for the dynamic condition (65.2% for DP+; 29.4% for DP-). As predicted, the dynamic route presentation reduced the recall rate of landmarks at the turns and increased the recall of landmarks along the route, suggesting that it guided the participants to attend less to the route relevant landmarks. However, the dynamic presentation did not completely override the task goals since they recalled the DP+ landmarks more often than the DP- landmarks.

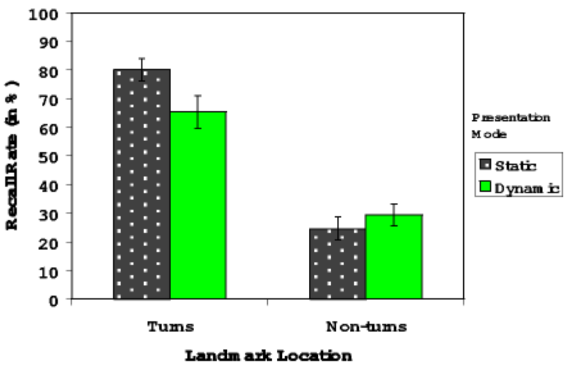

Fig. 3. Effects of presentation modes on the landmark recalls

In summary, the participants had a significantly greater recall of landmarks at the turns in the static condition, which suggests that they could freely allocate their attention to pertinent route information, which happened to be landmarks at turns (DP+). In the dynamic condition, however, the motion of the "imagined navigator" dot and the lack of the complete route information constrained the participants to allocate their attention more evenly along the route, resulting in a relatively even distribution of the recall rate for DP+ and DP- landmarks. As predicted, the mismatch between the attributes of motion in the dynamic route map and the route direction task, which requires selective attention to the turns, resulted in an inferior memory of the relevant route information in the dynamic presentation mode.

3 Combined Presentation Mode with Verbalization

The previous experiment demonstrated that animated objects in a dynamic display can reduce the task efficacy when the motion distracts the user from attending to the task relevant information. However, the experimental design raises further questions. The conclusion that the motion itself was the source of the memory difference between the static and dynamic condition was confounded by the fact that without the knowledge of the complete route in the dynamic condition, the participants did not have a choice of attending to the upcoming turn instead of the current location of the moving dot.

Hence, in this follow up study, we tried to overcome this shortcoming in two ways. First, we added a condition that combined the static and dynamic components of the route presentation by superimposing a moving dot on a solid line. In this presentation mode, the participants could take a divergent strategy to attend to either the static route or the moving dot. This combined mode is also closer to the actual presentation mode used in the current on-board navigations systems which have a “you are here” arrow that moves along a static route (see Fig. 1).

Second, we increased the speed of the presentation and let the participants view it multiple times. The increased speed seemed more “natural” to the users and the multiple presentations meant that the users could minimize the inherent disadvantage of the dynamic presentation since they could gain the knowledge of the overall route after the first presentation. To make sure that the participants attended to the route, we required them to give route directions during the viewing sessions.

3.1 Method

Participants. Sixty-one undergraduates, 26 male and 35 female, from Stanford University participated individually in partial fulfillment of a course requirement. The minimum criterion of 30% recall rate eliminated the data of three men and four women. The data of the remaining fifty-four participants were analyzed.

Materials and Procedure. We used the same map stimuli as in the previous experiment. The route in the map was presented statically, dynamically, or both. The combined condition presented static and dynamic route information by superimposing a moving dot on a solid line. The participants were assigned randomly to one of the three presentation conditions. They were asked to remember the route as they viewed the map. They were also asked to give route directions during the viewing sessions. They viewed it three times, for 1.5 minutes each. After they finished the verbalizations, they were given a map with only the street network and were asked to draw the route and all of the landmarks they could remember.

3.2 Results

The participants recalled landmarks at the turns (DP+) (57.7%) better than the landmarks at the non-turns (DP-) (48.2%). $F(1,51) = 5.33$, $p < 0.025$. However, the recall ratio between the DP+ and DP- landmarks was greatly reduced compared to the previous experiment. As in the first experiment, we had concerns that the dynamic condition was significantly harder than the static condition because participants had to reconstruct the route from a moving dot in dynamic condition. However, the total number of recalled landmarks did not differ significantly between conditions (51.6%, 51.4%, 56.1% for dynamic, static, and combined conditions, respectively; $F(2,51) = 0.56$, $p > 0.5$), suggesting that multiple presentations further minimized the recall difference between conditions. The accuracy of the generated route also did not vary significantly across conditions (78%, 68%, 71% for static, dynamic, and combined conditions, respectively). $\chi_2 = 0.44$, $p > 0.8$.

Fig. 4 illustrates the percentages of recalled landmarks when the route was shown statically, dynamically, or both. Analogous to the previous experiment, the DP+ and DP- landmarks were recalled more equally for the dynamic condition (52.0% for the turns; 50.9% for the non-turns) than the static condition (57.2% for the turns; 46.1% for the non-turns). Interestingly, when a moving dot was superimposed on top of a static route, participants recalled even more landmarks at turns (64.7%) than non-turns (47.5%). However, the interaction between landmark types (i.e. turns vs. non-turns) and presentation mode (i.e. static, dynamic, and combined) was not significant. $F(1,51) = 1.23$, $p > 0.3$. It seemed that the multiple presentations of the route and/or the verbalization of the route shifted the task focus to attend more to landmarks at non-turns across all conditions. Further investigation is needed to determine which factor(s) contributed to this shift.

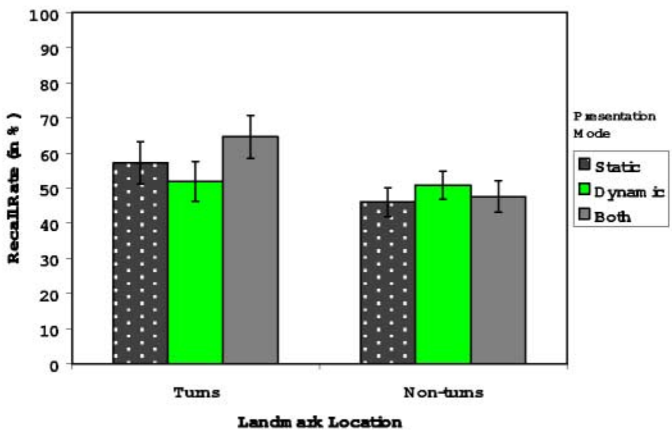

Fig. 4. Recall of landmarks for different presentation modes

Although the presentation mode did not significantly affect the recall memory, verbalization data supported the hypothesis that the static condition would allow more efficient allocation of attention to the pertinent landmarks than the dynamic condition. As expected, most of the landmarks at the turns (DP+) were verbalized in all conditions (80.6%, 90.7%, 91.2% for static, dynamic, and combined condition, respectively), confirming that the important landmarks in route directions were the ones at the turns. Interestingly, the static condition had fewer verbalizations of DP+ landmarks than the other two conditions. $\chi_2 = 7.01$, $p < 0.03$. A closer look at the data revealed that the reduction occurred because participants did not pace themselves properly during the session such that the time ran out before they could complete the verbalization of the route. The preset pace of the dynamic and combined presentations seemed to be an advantage over the static presentation mode.

Similarly, the landmarks at the non-turns (DP-) were verbalized at a lower rate in the static condition (30.6%) than in the dynamic (56.5%) or the combined condition (69.6%). $\chi_2 = 33.4$, $p < 0.001$. Low verbalization rate of DP- landmarks in the static condition was expected since route directions in general omitted these landmarks. Higher verbalization rate of DP- landmarks in the dynamic condition suggested that the verbalization of the route traced by the moving dot prompted the participants to mention more of the DP- landmarks. Interestingly, the combined condition resulted in the most verbalizations of DP- landmarks. The verbalization data suggest that the combination of static route and motion may have drawn more attention to all aspects of the route, including both DP+ and DP- landmarks, although this finding was not reflected in the recall data.

Although the verbalization rate for the DP- landmarks was the lowest for the static condition, the verbalized DP- landmarks were recalled better in the static condition (84.8%) than the dynamic (63.9%) or the combined condition (54.2) (see Table 1). $\chi_2 = 9.22$, $p < 0.01$. The participants in the static condition seemed to verbalize fewer DP- landmarks because these landmarks were less pertinent to route memory. The DP- landmarks that were verbalized may have been deemed important by the participants since they were recalled at a fairly high rate. In contrast, the dynamic and the combined conditions had higher verbalization rate of DP- landmarks, likely due to the motion. However, since the DP- landmarks were less important for the route, they were recalled less despite the higher rate of verbalizations. We failed to see a similar pattern for the DP+ landmarks, as the verbalized landmarks at the turns were not recalled differently across conditions (54.0%, 53.1%, and 62.4% for static, dynamic, and combined condition, respectively. $\chi_2 = 1.99$, $p > 0.39$.

Table 1. Verbalization and recall of verbalized DP- landmarks (non-turns)

	Verbalized DP- Landmarks	Recall of Verbalized DP- Landmarks
Static	**30.6**	**84.8**
Dynamic	**56.5**	**63.9**
Combined	**69.6**	**54.2**

The verbalization data suggest that the static condition was most efficient for the route memory task since participants verbalized (and presumably attended to) mostly the landmarks that they recalled later. Given this finding, we would have expected that the static condition would have the best recall of landmarks at turns, but the data suggest that the combined presentation mode showed potentially the highest recall of the landmarks at the turns, perhaps due to greater attention to all aspects of the route in this mode. We originally predicted that the combined condition would yield results that were somewhere between those of dynamic and static condition, since the availability of both the complete route and the moving dot would give participants a choice to segment either by following the moving dot or by using the static route. This potential benefit of combined presentation mode is noteworthy because the combined condition did not provide any additional information over the static or dynamic condition. Instead, the benefit resulted from directing attention to the route and providing a preset pace of learning as in the dynamic mode but also providing overall route structure like the static route.

4 Conclusions

We varied the presentation mode of routes in maps (i.e. dynamic vs. static) to examine how it affected the memory for landmarks at intersections. We predicted and found that landmarks at the key decision points (DP+) were remembered better after the static presentation of routes than the dynamic presentation, which constrained users to remember all landmarks more equally. Therefore, we concluded that static display of route information was preferable over dynamic display.

In the second study, the route was presented multiple times so that an inherent disadvantage of the dynamic route presentation was minimized. A combined static and dynamic presentation mode was also added to test if the users could take advantage of each mode. Verbalization data supported the claims in the first experiment. In the static presentation mode, the user attended mostly to the pertinent landmarks and the landmarks at the non-turning points were attended selectively for subsequent recall. In contrast, participants in the dynamic and combined presentation modes verbalized more often and indiscriminately, suggesting that the verbalization were driven partly by the motion in the display rather than the underlying task. The recall data failed to show significant interaction between presentation modes and landmark types, likely due to multiple presentations of the stimuli, but the data were consistent with the first experiment. The recall of DP+ landmarks also suggested that the combined presentation mode was more effective in directing users' attention to important cues.

The combined presentation mode can unite benefits of both types of displays. The static display allows users to organize the spatial information at hand more freely, applying principles acquired by everyday interaction with the environment, and it encourages a planning component. On the other hand, dynamically displayed information guides users along their way, reducing the stress to self–organize the amount of time available. The combination of different presentation modes and the resulting memory improvement for vital information add to findings regarding the benefits of redundant information display (Hirtle, 1999). In summary, the findings in this paper demonstrate the need for selectively choosing the appropriate presentation mode for the task at hand and encourage further research on the interaction of various information sources, especially their display by different modalities.

Acknowledgements. This research was supported by DAAD PKZ A-01-49336 to the first author and by the Deutsche Forschungsgemeinschaft (DFG) HA 1237-10, (Conceptualization processes in language production), and FR, 806-8 (Aspect maps) to the second and the third author.

References

Agrawala, M. & Stolte, C. (2001). Rending effective route maps: improving usability through generalization. *Proceedings of SIGGRAPH 2001*.

Baus, J., Ding, Y, Kray, C., & Walther, U. (2001). Towards adaptive location-aware mobile assistants. Workshop notes on the IJCAI 2001 workshop on Artificial Intelligence in Mobile Systems.

Bartram, L. & Ware, C. (2002). Filtering and brushing with motion. *Information Visualization.*1(1), 66–79.

Denis, M. (1997). The description of routes: A cognitive approach to the production of spatial discourse. *Cahiers de Psychologie Cognitive,* 16, 409–458.

Hegarty, M., Quilici, J., Narayanan, N. H., Holmquist, S., & Moreno, R. (1999). Multimedia instruction: Lesson from evaluation of a theory-based design. *Journal of Educational Multimedia and Hypermedia,* 8, 119–150.

Hirtle, S. C. (1999). The use of maps, images, and "gestures" for navigation (pp. 31–40). In C. Freksa, W. Brauer, C. Habel, K.F. Wender (eds.). *Spatial cognition II, integrating abstract theories, empirical studies, formal methods, and practical applications*. Springer: Berlin.

Jackson, P. G. (1998). In search for better route guidance instructions. *Ergonomics,* 41(7), 1000–1013.

Klippel, A., Tappe, H., & Habel, C. (in press). Pictorial representations of routes: Chunking route segments during comprehension. In C. Freksa, W. Brauer, C. Habel & K. Wender (eds.), *Spatial Cognition III*. Berlin: Springer.

Palmiter, S., & Elkerton, J. (1993). Animated demonstrations for learning procedural computer-based tasks. *Human-Computer Interaction,* 8(3), 193–216.

Tappe, H., & Habel, C. (1998). Verbalization of dynamic sketch maps: Layers of representation in the conceptualization of Drawing Events. *Poster at Cognitive Science Conference*. Madison WI.

Lee, P. U. & Tversky, B. (in preparation). Keeping the "goodness" in good directions and maps.

Tversky, B., Morrison, J. B., & Betrancourt, M. (2002). Animation: can it facilitate? *International Journal of Human-Computer Studies,* 57, 247–262.

Ward, S.L., Newcombe, N., & Overton, W.F. (1986). Turn left at the church or three miles north: A study of direction giving and sex differences. *Environment and Behavior,* 18, 192–213.

Zacks, J., Tversky, B., & Iyer, G. (2001). Perceiving, remembering, and communicating structure in events. *Journal of Experimental Psychology: General,* 130, 29–58.