Spatial Conformity Research of Temporal Order Information Presentation in Visualization Design

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Abstract. The topic of dynamic presentation of temporal order information relates to both the node information flowing with time and the location changing in 2D space. In this paper, psychological research methods were applied to research the feasible representation method of temporal order information on the base of human cognitive characteristics. That was the research on relevance of temporal order presentation and space order presentation. We tried to study on the dynamic information presentation processes of the nodes arranged regular in horizontal linear trace. The eye-tracker recorded the performance of 30 valid subjects in different nodes skip way, horizontal moving direction and moving time. Through the analysis of accuracy and reaction time, the conclusion has been drawn that the possible presentation methods with optimal performance.

Keywords: Visualization design · Temporal order · Space coherence · Data type compatibility

1 Information Visualization

In the complex environment of big data, the information interface with visualization is the only effective way for the user to perceive data regardless of any method to deal with the dataset. The target of information visualization is human—the user; therefore, we should discuss the problem of information visualization representation on the point of visual cognition peculiarity of human beings.

The information needs of human are flexible. That means what they want to know is not only the global understanding of the information system but also the detailed characterization of some specific key points. In visualization design, the information we need to representation is not unusual the homogeneous information on different temporal. Thus, it is essential for the user that perceived the situation of information flowing over time to grasp the characteristics of information overall. So, how to define the rule of change to make the user perceive the flow of information of the visualization interface accurately and quickly?

A grounded model of information Visualization sense making should consist of the five major cognitive activities: encountering visualization, constructing a frame,

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exploring visualization, questioning the frame and floundering on visualization, proposed by Lee et al. (2016). Koerner et al. (2014) tried to make the eye trace regular clearly via observing the eye movement under the transformation of hierarchical graphs. Jigsaw provides automatic extraction of entities and a time line to organize them (Gorg et al. 2014). Timeline (temporal order) visualization is an important tool for sense making. And Nguyen's research (2014, 2016) focus on the dynamic interactive time line visualization for sensemaking.

2 Dynamic Display of Temporal Order Information

The perception of spatio-temporal pattern is a fundamental part of visual cognition (Gibson 1966; Schill et al. 2001; Crowder 2014). The topic of consistency of temporal order and spatial coding has been controversy in the field of psychology. The focal point is whether the adding spatial cue could improve the memory performance of temporal order (De Lillo 2004; Parmentier 2006; Körner 2014). And this issue has a strong practical significance in information visualization design.

As far as designers are concerned, data type compatibility (DTC) should be taken into account. That is to build the consistency over the mental models, visual presentation and information characterization (Garnham 1997). With the generation of stream processing technology dataset and the growth of computer performance, we can present the temporal order information in a dynamic way. The so-called dynamic presentation can be regarded as image sets constantly changing on every unit of time (1 frame). While the retinal variables (location, shape, color, size, proportion, etc.) of design element changing at every frame, we can perceive the dynamic change of the design element. And the dynamic variables attracted users' attention most (Tam and Ho 2006; Opach et al. 2014). Differences in the direction and speed of changes of design elements in spatial position have the different influence on the consequent of building the mental model of temporal order. This is the theoretical basis of this paper.

3 Research Methods

3.1 Purpose

In order to find out the most reasonable dynamic skip way of linear nodes, we designed three experiments to compare different nodes skip way, horizontal moving direction and different nodes skip time respectively. The dependent variable was the subjects' cognitive performance, which evaluated by the recall accuracy, reaction time and the skip magnitude of gaze points. Based on this comparison to discriminant the merits of the materials.

3.2 Equipment and Subjects

The Tobii X2-300 compact non-contact eye tracker has been taken to collect eye-tracking data of subjects. The instrument sampling frequency is 30 Hz, the staring

accuracy is 0.4°–0.5° and the head movement range is 50 × 36 cm. The resolution ratio of experimental animation material is 1280 × 960 px. The materials were presented by a HP 21 inch screen with the brightness of 92 cd/m^2. The laboratory was in the normal lighting conditions (40 W fluorescent). The distance between the subjects and the screen was about 550–600 mm.

The valid subjects were 30 graduate students (13 women), aged ranged from 22 to 28. All had normal or corrected- to- normal vision and no color blindness or color weakness. Before the formal experiments, the subjects participated in a practice test to become familiar with the rules of the experiments.

3.3 Materials

At first, we deleted the specific contents of the information nodes for removing the affecting factor of the contents to the subjects. We extracted the most simplified primitive structure of the temporal order information and present it as solid dots. All the nodes were in accordance with the horizontal linear arrangement. The middle node represented the information of the current time at that moment, and the nodes in both ends were arranged with the distance in descending order, to characterized the span of time, as shown in Fig. 1.

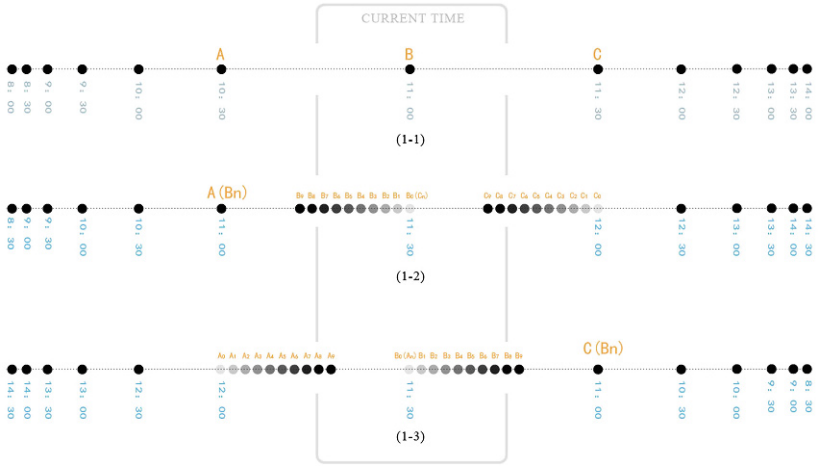

Fig. 1. The dynamic moving skip ways

(1–1) The basic temporal order information presentation structure. (1–2) Dynamic moving skips direction 1: from right to left. (1–3) Dynamic moving skip direction 2: from left to right.

In the experiment, the time information was replaced by the senseless uppercase and lowercase monogrammed (see Fig. 2). A pretest has been done to keep the difficulty of experiment in a reasonable range, in order to avoid the occurrence of “celling phenomenon” and “floor phenomenon”.

Fig. 2. The meaningless representation method used in this experiment

The animations and images involving in this experiment were generated by Adobe Flash and the export format was gif with a sequence to ensure the images within the finite size and clarity. In addition to the portion needed to be compared, others were in the same design, including: (1) all the elements were in the linear arranged way; (2) all the elements were moving along the horizontal linear direction; (3) all in the same primitive presentation method, using the solid dots to represent the information nodes; (4) all the images were in the same figure-ground relationship, with the white color (CMYK = 0, 0, 0, 0) was taken as the background and the blue color (CMYK = 90, 60, 0, 0) as the figure one; (5) the uniform application of meaningless upper-case + lowercase letter pairs as the node information elements, such as Gf and the meaningful letter pairs was excluding as If, Or and AB because these letter pairs prone to associative memory.

The experiment designed in the subjects of 3 × 4. The independent variable I was the moving skip way while the independent II was moving skip direction and the variable III was moving skip time, respectively 500 ms, 1000 ms, 1500 ms and 2000 ms. The dependent variable was the cognitive performance of the user. It was synthesized evaluated on the measure index of correct rate of recall questions, the reactive time and the coincidence rate between the eye movement track and the setting track.

3.4 Processes

During the formal experiment, subjects read the guidance language first and pressed any key on the keyboard to start the experiment. At first, the center of the screen presented fixations "+" for 500 ms, then the animation of characterizing linear nodes flowing pattern began to paly. There was a certain space distance between the "+" and the animation information in order to keep the initial viewpoint away from the area of temporal order information. It was benefit for our extracting the eye trace. As shown in Fig. 3, the animation was composed by a sequence of n images in gif format. The first

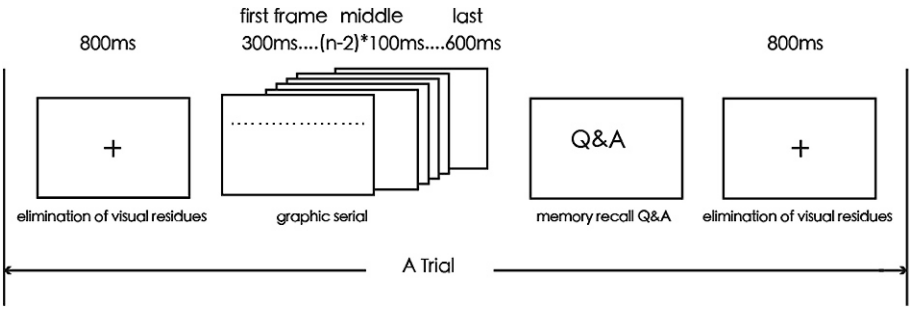

Fig. 3. The experiment process

image presented for 300 ms, the n-2 middle images presented for 100 ms/per page and the last one presented for 600 ms. When the animation finished, the question emerged with 5 options. The subjects could make a judgment by clicking the left mouse button. By this, we could measure the subjects' memories performance of nodes information recall.

In each animation, the nodes were represented by blue dots. The middle node represented the information of current time at that moment, and nodes in both ends were getting close gradually to represent the information with farther distance of time (in the past or in the future), seen in Figs. 1 and 2.

4 Results

4.1 Moving Skip Way

The first section of the experiment was to compare the subjects' behavior in different moving skip way of the nodes. The control group was in the instant moving skip way, that means after displaying a certain period the node information directly changed to the new one. And the experimental group was in the gradually moving skip way, as shown in Fig. 1 (1–2). Both the groups had the same moving skip time of 1000 ms, and the same moving skip direction from right to left (the left node representatives the passing moment). In the instant moving skip condition, we observed an average rate of 43.3 % correct recall responses. In contrast, the average rate of correct node information recall response in the gradually skip condition was 56.7 %. The result shows that both the main effect of accuracy ($t = -1.025$, $df = 58$, $P = 0.310 > 0.05$) and reaction time ($t = -0.9605$, $df = 58$, $P = 0.341 > 0.05$) were not significant.

Subsequently, we improved the experiment by done some adjustments of the moving skip way. The total moving skip time was 1000 ms with 10 frames composing it. In the improved condition, the nodes gradually moved during the first 500 ms(as same as the gradual moving skip way) and then shielded the nodes' information for 500 ms. At last, the last frame presented for 300 ms(as same as the instant and gradual moving skip way). We compared the data of the improved group with the instant group and the gradual group and found that both the main effect of accuracy ($F = 4.602$, $df = 87$ $P = 0.013 < 0.05$) and reaction time ($F = 3.330$, $df = 87$ $P = 0.040 < 0.05$) were significant, seen in Fig. 4. The only different between the gradual moving group and the improved group was the short shield of the old information of the nodes but the data result varied widely. The result can be interpreted as a short blanking allowing the participants to take the initiative to adjust their mental model for preparing a new working memory.

4.2 Moving Skip Direction

The second section of the experiment was to compare the subjects' behavior in different horizontal moving skip direction of the nodes. The control group was in the moving direction from right to left (the left nodes representative the passing moments), while the experimental group was from left to right (the right nodes representative the

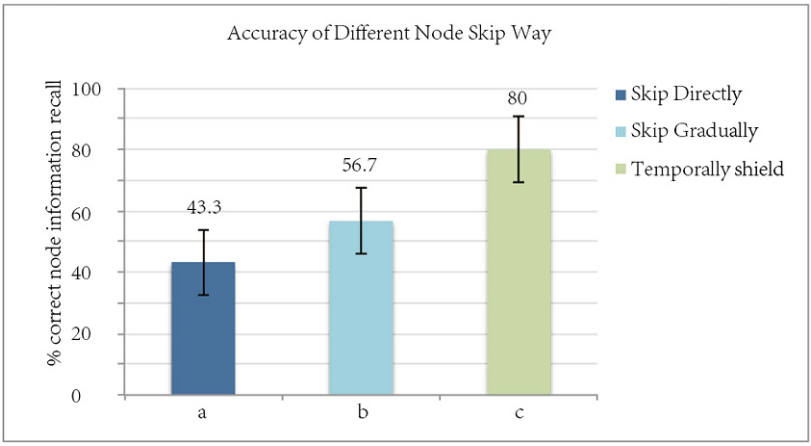

Fig. 4. The accuracy of different nodes moving skip way (The left bar is the condition of instant moving skip way, the middle bar is the condition of gradual moving skip way, the right is the condition of improved moving skip way. In all the conditions, the moving skip is in 1000 ms and the last frame presents for 300 ms)

passing). Both in the two conditions, the total moving skips were in 1000 ms and in the gradual moving skip way.

The result showed that in the same moving skip way and skip time, the different horizontal moving direction influence the subjects' performance very little with the main effect of accuracy ($t = 0.766$, $df = 58$, $P = 0.447 > 0.05$) and of the reaction time ($t = 0.432$, $df = 58$, $P = 0.667 > 0.05$), respectively. That was, the people did not have a clear definition of the positive direction of the horizontal linear direction. And we tend to define the psychological positive direction according to the animation moving direction.

4.3 Moving Skip Time

The third section of the experiment was to compare the subjects' behavior in different moving skip time of the nodes. The subjects observed four kinds of animations with the skip time of 500 ms, 1000 ms, 1500 ms and 2000 ms. Of each group of materials were based on the gradual moving skip way and the horizontal moving direction rom right to left (the left nodes representative the passing moments). The results of this experiment showed that the main effect of accuracy as ($F = 2.818$, $df = 116$ $P = 0.042 < 0.05$), and the main effect of reaction time was ($F = 6.981$, $df = 116$ $P = 0.000 < 0.05$). Both of them were reflected as a significant difference.

This showed that the moving time is one of the key factors for participants' working memory on nodes information. As shown in Figs. 5 and 6, we could get a comprehensive insight of the 30 valid participants' data: the accuracy reached a peak around the moving skip time of 1500 ms between two nodes while the reaction time reached a trough. We could also draw a conclusion that the optimal recall performance is taken place on the moving skip time of 1500 ms.

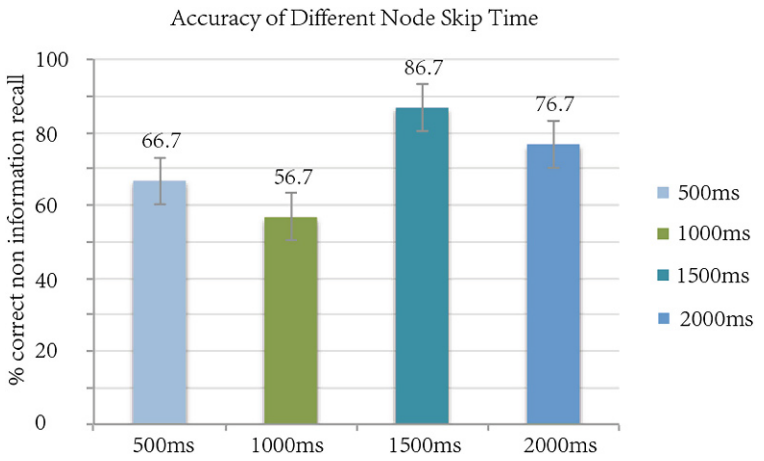

Fig. 5. The reaction time of different node moving skip time between adjacent nodes (from left to right are 500 ms, 1000 ms, 1500 ms, 2000 ms respectively).

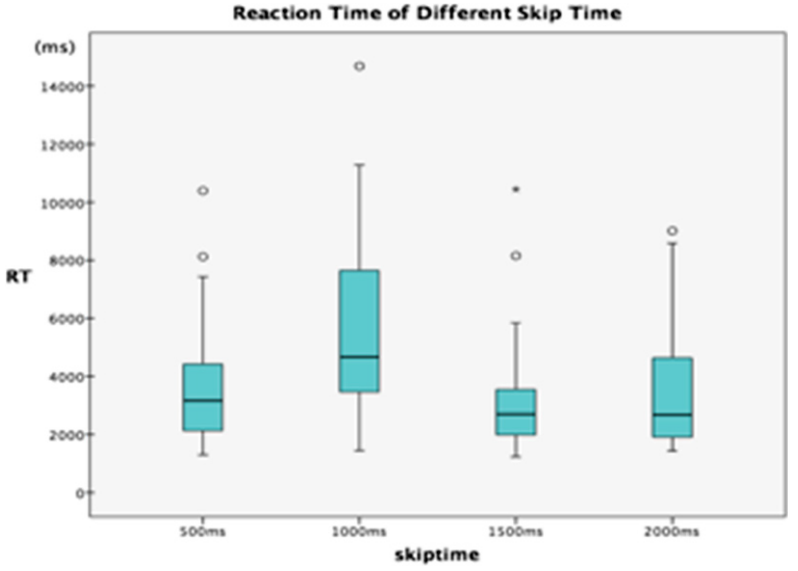

Fig. 6. The accuracy of different node moving skip time between adjacent nodes (from left to right are 500 ms, 1000 ms, 1500 ms, 2000 ms respectively).

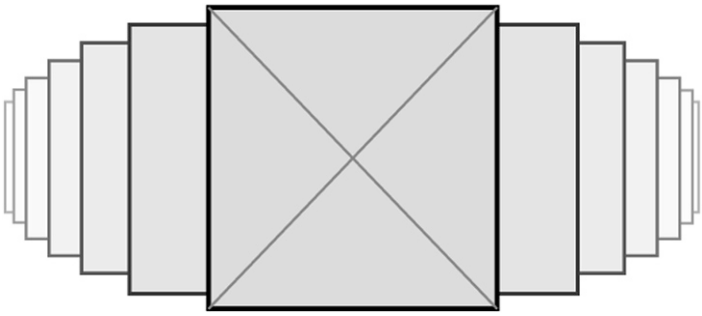

Fig. 7. One of the generalization representation style of the temporal order visualization

5 Conclusions and Generalization

(1) During the dynamic moving process of temporal order nodes arranged in horizontal line, different moving skips way influence significantly on subjects' working memory performance. In the case of controlling other factors and the moving skip time between two nodes equivalently, the performance in the condition of nodes gradually moving in space with the flow of time is better than the condition of nodes instant moving to the next location after presenting a certain time. Before presenting the new node information, a short shield of the old node information is contribution to the people' working memory performance.
(2) During the dynamic moving process of temporal order nodes arranged in horizontal line, we can deduce from the working memory performance of the subjects that they did not show fixed mental positive direction. They always define the psychology positive direction of temporal order information by observing the moving direction of the nodes.
(3) During the dynamic moving process of temporal order nodes arranged in horizontal line, the moving time between the two adjacent nodes has a significant effect on subjects' working memory performance. The experiment proved that when the moving time between two adjacent nodes at around 1500 ms, the subjects' working memory performance reaches the peak.

With the data analysis of the experimental results, we found the relative better performances of the combination of the moving skip way and the moving skip time. As we abandoned the specific content and time information of the temporal order information and used the most simplified coding of meaningless (the solid dots and the meaningless letter pairs), the experience results can be generalized. And it can provide the effective guidance for realization the DTC of the temporal order information visualization design. As shown in Fig. 7, this temporal order information in the form of general representation can be generalized to many visualization cases. So we can directly apply the conclusions to guide the visualization design of the temporal order information.

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