Supporting Dynamic Situation Awareness in Online Group Discussion: A Visualization Approach

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Abstract

Situation awareness (SA) has been well recognized as a critical yet often elusive foundation for effective group decision-making. The task of identifying and understanding dynamic, evolving discussion situation can be quite challenging, especially when coping with information overload and time pressure. With the wide adoption of collaborative software in support of group collaboration, there has been exponential growth of online group discussion. As a result, the traditional thread-based hierarchical structure and presentation of group messages become ineffective in support of real-time SA, which may affect the process and outcome of group collaboration. To address this important problem, in this study, we propose a novel visualization-based approach to supporting users’ SA in online group discussion and decision making. We have also developed a set of new variables to measure SA in online group discussion from three key aspects: discussion snapshot, discussion evolution, and people. The proposed approach was empirically evaluated by using a prototype system and discussion data collected from an online group discussion session. The results show that the proposed approach significantly improves user performance and perception of SA in group discussion. The findings of this study provide significant research contributions and practical implications for the design and use of situation-aware collaborative software.

1. Introduction

Collaborative software, which is designed to help a group of people involved in a common task achieve their goals, has been proven effective in producing measurable gains and improving group process and outcome in team work [1]. However, it would be very tedious, time consuming, and practically challenging for users to understand the evolution and different aspects (e.g., individual participation and the extent to which an issue has been agreed or supported) of discussion by manually wading through all the posts organized in threads, especially when group discussion is intensive.

Situation awareness (SA) is referred to as a person’s perception of environmental elements within certain time and space, the comprehension of their meaning, and the projection of their status in the near future. SA is considered as a critical factor for successful group decision making, in which the information volume is often quite high [2]. For example, by identifying the percentage of participants who have contributed at least one comment on a specific alternative (i.e., a solution to the discussion topic), a facilitator or a manager can assess the degree of participation of group members in discussing that alternative, and decide if calling for more participation is necessary. However, achieving SA of online group discussion is not a trivial task due to the dynamics and evolving nature of online discussion (e.g., frequent change of discussed topics, attitude/opinion shift of individuals toward an issue), as well as a large amount of information accumulated that needs to be processed (i.e., information overload).

To achieve SA of online group discussion with a thread-based structure of discussion, a user must identify related messages, read those messages to extract attributes (e.g., keywords, author, and post time) of interest, memorize extracted information (if working memory is not enough, some form of external memory like pencil and paper is necessary), and finally form an understanding of the discussion situation by integrating diverse pieces of information through developing mental models. In that case, the gap between overloaded information and limited cognitive resources of a user will negatively affect the effectiveness and efficiency of SA. According to Cognitive Fit Theory [3], most extant collaborative systems that adopt the thread-based structure and presentation of discussion messages do not provide effective support for SA.
To address the above limitation, we propose an integrative visualization-based approach to SA for collaborative software, aiming to help users understand the discussion situation quickly and precisely through dynamically generated and diverse graphic diagrams. Visualization is any technique for presenting intensive information and communicating both abstract and concrete ideas clearly and effectively through graphical means. Although visualization techniques have been explored for presenting a summary of discussion messages stored in computer-mediated communication (CMC) archives [4-7], there has been little work on visualization in support of dynamic multi-aspect (snapshot, evolution, and people) SA in group discussion context in the literature. In addition, to our best knowledge, there is no existing research that has investigated visualization support for SA at both general (e.g., entire discussion session) and specific (e.g., individual discussion topic or issue) levels, which is critical for gaining a comprehensive view of group discussion. This research aims to fill these knowledge gaps by answering the following research questions:

Q1: How can situation awareness be measured from multiple aspects in the online group discussion context?
Q2: How to dynamically visualize different aspects of SA at different levels in a collaborative system?
Q3: Can visualization improve situation awareness of online group discussion in comparison to the traditional thread-based discussion environment?

The rest of the paper is organized as follows. Section 2 briefly reviews the related work on SA in collaborative software and on visualization in computer-mediated communication. Section 3 presents the research model and hypotheses based on Cognitive Fit theory and Endsley’s SA model. Section 4 introduces research methodology and experimental design, followed by data analysis and results presented in Section 5. In section 6, we will discuss major findings, contributions, practical implications, and limitations of this research. Finally, the paper is concluded with discussion on future research in Section 7.

2. Related Work

2.1 Situation Awareness Theories

There are three dominant theoretical approaches to SA, including the information processing approach, the activity approach, and the ecological approach. Among them, Endsley’s model [8] following the information processing approach is one of the mostly accepted. That model includes three levels of SA formation, namely perception, comprehension, and projection [8]. Level-1 and level-2 SA entails understanding of what has happened, while level-3 SA requires understanding of what will happen. In this research, we only concentrate on understanding of level-1 and level-2 SA.

Endsley [9] proposed a framework that specified the mechanisms and processes involved in SA based on information processing theory. In this framework, perception, attention, pattern matching with long term memory (LTM), and synthesis, analysis & metacognitive processes are four critical cognitive processes involved in SA. In this study, Endsley’s framework with four processes is used to explain user’s SA performance across different systems.

2.2 Visualization of Computer-Mediated Communication (CMC)

Existing CMC visualization systems mainly focus on presenting discussion content, participants’ behavior, or social networks among participants [4, 10-12]. The visualization of discussion content is aimed to help users find messages of interest. For example, Chen et al. [10] have created a tool that maps a collection of comments into a two-dimensional grid with a Self Organization Mapping (SOM) algorithm, and assigns a label to each grid (i.e., a cluster of comments) to help sense making. The behavior visualization, such as PeopleGarden [4] and Chat Circles [11], helps users understand the interaction behavior of participants in a CMC community, such as subgroup formation, time duration of individual members in a community, and temporal change of social network visualization describes the characteristics of social networks formed during CMC. One example is ContactMap [12], which visualizes an address book to help users manage their social connections. There are also systems that combine more than one visualization approach [e.g., 16, 17, 48]. For instance, the Loom system [13] integrates content analysis and behavior description to help increase the understanding of a CMC community; the Conversation Map system [5] provides an overview of discussion content and the social network of a CMC archive.

The limitations of existing research on supporting SA in online group discussion can be summarized as follows. First, the existing research on visualization of CMC archives mainly serves for social interaction purposes. The visualization of task oriented discussions (i.e., discussions specific to solving a problem) has been lacking in the literature. Second, existing tools do not allow the visualization of an evolving discussion process, which is extremely important for improving group members’ understanding of a group process [14].
Last but not the least, the effect of visualizing participants’ contribution to task oriented discussion on SA has not been empirically examined.

In this study, we mainly concentrate on visualization of group member behavior in online discussion. Behavior visualization in previous studies was at a macro level (i.e., presenting participants’ overall behavior in a discussion forum). The visualization of participants’ behavior at a micro level (e.g., presenting participants’ behavior related to a specific discussion topic or issue), despite its importance to SA, is still rare. So far, we have not found any system design for and empirical studies on visualizing participants’ creativity and engagement in online group discussion. This study is aimed to fill this void.

3. Theoretical Foundation and Hypotheses development

To address the limitations of existing research, we propose and empirically evaluate a new visualization approach to situation awareness in online group discussion. A major challenge in SA of group discussion is to deal with information overload. Therefore, new tools that enhance SA should be designed by either increasing human cognitive resources or reducing the complexity of information to be explored. The proposed visualization approach aims to improve users’ SA of online group discussion by supporting cognitive processes involved in SA through information visualization. It consists of three visualizers: snapshot visualizer, evolution visualizer, and people visualizer. Each visualizer deploys a different visualization approach to addressing corresponding SA needs. Those three visualizers are designed as plug-ins that can be easily integrated with a traditional thread-based collaborative system to enhance users’ SA.

We assessed the effect of the proposed visualization approach based on user performance and perception of SA, with a traditional thread-based discussion environment being used as the control. The overall research model is shown in Figure 1. User performance has been commonly assessed by task accuracy and task completion time in group support systems research [15, 16]. User perception is measured by perceived ease of use and perceived usefulness, which are commonly used for evaluating information technologies and users’ adoption intention [17]. Specifically, perceived ease of use refers to the degree to which a user believes that a system can be used effortlessly, and perceived usefulness refers to the degree to which a user believes that a system can improve his/her task performance.

Figure 1. The research model

Cognitive Fit Theory [3] suggests that the correspondence between a task and the information presentation format lead to superior task performance of individual users. Therefore, information should be presented in a format that helps users effectively utilize the working memory while performing a task. According to Vessey [18], matching presentation to tasks leads to the use of similar problem-solving processes, and hence helps creation of a consistent mental representation. According to Endsley’s SA model, a person has to transform everything perceived, comprehended, and projected into an internal mental representation before he/she can understand the situation as a product. Therefore, the design of this research focuses on facilitating such formation of a mental representation in collaborative software.

The snapshot aspect of SA refers to the static status of basic elements in an online group discussion session. In this research, we propose to use a pre-attentive radial tree to support snapshot SA. A radial tree is a focus and context visualization technique that displays a tree structure of content that expands outwards radially. We select the radial tree visualization to support snapshot SA because it fits well with different pre-attentive features and has been proven to be effective in presenting hierarchical, highly dynamic data [19]. In this study, a radial tree is featured by pre-attentive elements such as color, size and shape, which can be perceived by human eyes very quickly without searching. Typically, visual tasks that can be performed within 200 milliseconds or less are considered pre-attentive [22]. More specifically, we designed a pre-attentive radial tree that uses shape to represent message type, size to indicate the number of comments, and color to indicate the number of participants.

A pre-attentive radial tree can improve human’s perception process of SA by parallel processing and pre-attentive perceptual processing of human eyes.
First, the perception process of SA can be enhanced by a radial tree in support of parallel processing [20]. Visualized information can be processed in two different ways called controlled and automatic processing [21]. Extracting information from a radial tree that follows the mechanism of automatic processing should be faster than extracting information from a text interface that follows the mechanism of controlled processing.

Second, the perception process of SA can be enhanced by radial tree visualization through introducing pre-attentive features [20]. We predict that a pre-attentive radial tree will be perceived by human eyes faster and more accurately than a text interface.

In general, leveraging parallel processing and incorporating pre-attentive features could improve the perception process of SA. According to Endsley’s SA theoretical model, the improvement of perception of elements appearing in an environment will improve SA as a product [9]. From a cognitive fit view, a snapshot SA task requires revealing the relationship among alternatives discussed in the group discussion, so a pre-attentive radial tree should better fit the snapshot SA task than a thread-based text interface. Therefore, we predict that using pre-attentive radial tree visualization will lead to significantly better performance of snapshot SA and user perception than using a traditional thread-based hierarchy. Thus the first hypothesis is proposed as follows:

H1: For snapshot situation awareness of online group discussion, compared to providing a thread-based text interface, providing visualization of discussion through a pre-attentive radial tree in a collaborative software will lead to

(a) reduction of task completion time,
(b) increase of task accuracy,
(c) increase of perceived usefulness and
(d) increase of perceived ease of use.

The evolution aspect of SA refers to dynamic evolution of basic elements in an online group discussion session. In this research, we adopt line graphs to support evolution SA. A line graph is a type of graph that displays information as a series of data points connected by straight line segments [23]. Each line graph may include several lines in different colors that represent different trends of multiple alternatives.

A line graph can improve human’s attention process and pattern matching process of SA. First, the attention process of SA can be enhanced by line graphs through reducing the number of information chunks to a more manageable scale. According to Miller’s theory of information processing [24], a person’s short-term memory can only hold approximately seven (plus or minus two) chunks of information at any time. A user can hold much more information presented in a line graph in his/her memory than that presented in a text interface, which eventually reduces the gap between information overload and limited cognitive resources.

In addition, the pattern matching process of SA can be enhanced by a line graph through abstracting and aggregating data at a high level [20]. A line in a line graph can be considered as an aggregated form of information through abstraction and selective omission, which shows a high-level pattern. Such a pattern could be difficult, if not impossible, to be recognized without such a high level abstraction [20].

According to Endsley’s SA theoretical model, the improvement of the attention process and pattern matching process of SA will in turn improve SA as a product [9]. A text interface cannot show the discussion trend directly. Based on Cognitive Fit Theory, a line graph should fit an evolution SA task better than a text interface. Therefore, we predict that a line graph provides better cognitive process support to SA and will have more positive impact on evolution SA performance and user perception than a traditional thread-based hierarchy. Thus the second hypothesis is proposed as follows:

H2: For evolution situation awareness of online group discussion, compared to providing a thread-based text interface, providing visualization of discussions through a line graph in a collaborative software will lead to

(a) reduction of task completion time,
(b) increase of task accuracy,
(c) increase of perceived usefulness, and
(d) increase of perceived ease of use.

The people aspect of SA refers to the statistics of individual group member’s contribution to group discussion. In this research, we adopt a floral visualization approach to support people SA. A floral presentation uses a flower to depict an individual user’s involvement in group discussion [6]. A floral presentation can improve human’s pattern matching process and synthesis process of SA by providing an intuitive flower graph and leveraging gestalt perceptual processing.

First, the pattern matching process of SA can be enhanced by floral presentations for judging current situation. Flower presentations of people are intuitive and easy to understand [4]. In addition, different characteristics of an individual’s participation in group discussion, which are represented by the features of a flower, can be distinguished easily [4]. A pattern recognition through such characteristics of a flower can be performed very quickly without much cognitive burden [25].

Second, the synthesis process of SA can be enhanced by the floral presentation from a gestalt perceptual processing perspective. With the floral
presentation, one can form a holistic view of an individual even before knowing the details. Because people SA tasks require grouping different aspects of a person to make a judgment about his/her participation in discussion, such a floral presentation allows users to make a quick and precise judgment even before they get details of each aspect of an individual.

By following the Gestalt Theory, the floral presentation of individual participation in group discussion can improve the pattern matching process and synthesis process of SA. In comparison, a thread-based text interface uses symbolic representation and only shows the detail of one post at a time, causing greater difficulty in understanding a participant’s contribution as a whole. Therefore, we predict that the floral presentation should fit people SA tasks better and will provide a higher level of cognitive process support to SA than a thread-based text interface, resulting in better people SA performance and user perception. Thus, we propose the third hypothesis as follows:

**H3:** For people situation awareness of online group discussion, compared to providing a thread-based text interface, providing visualization of discussion through a floral visualization approach in a collaborative software will lead to

(a) reduction of task completion time,
(b) increase of task accuracy,
(c) increase of perceived usefulness, and
(d) increase of perceived ease of use.

### 4. Research Methodology

We conducted an empirical evaluation of the effectiveness and usability of the proposed visualization approach by using a prototype system. The hypotheses were tested through a controlled laboratory experiment with a 3 × 2 factorial design. SA aspects (snapshot SA, evolution SA and people SA) and cognitive process support for SA (low vs. high) were treated as within-subjects factors. Participants were asked to perform two discussion situation awareness tasks independently using either the visualization system or a traditional, thread-based online group discussion system (i.e., the benchmark).

#### 4.1 Experimental Systems

**4.1.1. The benchmark system.** We used a traditional thread-based group discussion system without any visualization components as the benchmark system. The benchmark system adopted hierarchical and linear organization schemes. The hierarchical structure of discussion messages can show the content relationships among messages and participants (i.e., who responded to whom), and the linear structure reflects the temporal relationships among messages.

We selected this system as the benchmark for a couple of reasons. First, it also provides the information that the proposed visualization system aims to present, but in a traditional thread-based text format, which serves the purpose of the evaluation. Second, this benchmark system has been deployed and used in the department of authors for online group discussion and decision making for several years. It has been proven to be very reliable and easy to use with little training.

**4.1.2. The Visualization System.** We developed a prototype system based on the proposed approach. The system consists of three visualizers, which can be shown in the right panel of the system interface: a snapshot visualizer, an evolution visualizer, and a people visualizer.

**Snapshot visualizer**

In the snapshot visualizer shown in Figure 2, each node represents a discussion message while an arrow-headed edge between two nodes represents a reply-to relationship. We use the shape of a node to indicate its message type (e.g., rectangles for issues, stars for alternatives, circles for support position, and half circles for objection position). The size of a node indicates the intensity of discussion related to that node. The intensity of a node is measured by the number of messages replying to that node directly or indirectly. We normalize the intensity of each node by dividing the maximum intensity of all nodes except for the root node, and then use ten different sizes to represent different normalized intensity values. In addition, the color of a node indicates the level of participation. We use ten gray colors with different levels of intensity to represent different participation levels. The deeper the color is, the more intensive the discussion participation would be. The snapshot visualizer also provides a mouse-over display of descriptive information about a node, showing the title, content, poster, and time stamp of the corresponding message.
Evolution Visualizer

The evolution visualizer utilizes the line graph presentation to display the evolving patterns of discussion over a period of time (shown in Figure 3). Each line in a line graph is in a different color and represents a different alternative in the discussion. In the evolution visualizer, the X axis of a line graph represents time, and the Y axis represents the value of a variable (e.g., participation and intensity). More than one line can be displayed in one graph to help users gain more insights by comparing different evolution patterns of different alternatives.

People visualizer

The people visualizer employs a floral visualization approach (Figure 4) to depict the discussion behavior of any individual participant involved in group discussion with ‘a person flower’. In the visualizer, each flower, which contains petals and leaves, represents an individual person. The number of petals of a flower is equal to the total number of messages that a person has posted in group discussion. The number of leaves indicates the number of alternatives that a person has proposed. The height of a flower corresponds to the number of messages (both comments and alternatives) posted by an individual. There is a number shown next to the petals or leaves to indicate the exact numbers. When a user is asked to compare flowers with similar number of petals and/or leaves, he/she can refer to those numbers.

4.2 Measurements

4.2.1. Dependent and independent variables. In this research, we employed objective situation awareness measures because they are more straightforward, easy to quantify and understand, and fit the goal of the study better than subjective measures.

Dependent variables include SA performance and user perception. We assessed individuals’ SA performance via task accuracy and task completion time. Task accuracy was measured by comparing a user’s judgment of the discussion situation with the correct judgment from experts. If a user’s judgment is identical to the correct judgment, it will be considered correct; otherwise it is incorrect. There is no partially correct. So the accuracy of SA was measured by the percentage of correct answers. Task completion time was measured by the time that a participant took to finish an SA task, which was automatically recorded by the experimental systems.

We also assessed user perception via participants’ perceived ease of use (PEOU) and perceived usefulness (PU) of both systems in support of SA through post-experiment questionnaires. The questionnaire items were adapted from previous studies [17], with five items measuring PEOU and the other six measuring PU. One of the original PEOU items developed by Davis [17] about a system’s interaction flexibility was excluded because it was not applicable to both systems in our study. All questions were framed using a 7-point Likert scale (with 1 representing ‘strongly disagree’ and 7 representing ‘strongly agree’). Both PEOU and PU were measured by the average of the scores that a participant assigned.
to the corresponding items. User were also asked to use a 7-point Likert scale (with 1 representing strongly disagree and 7 representing strongly agree) to indicate their preference between two experimental systems for finishing the corresponding SA tasks.

Finally, it is worth noting that we measured individual situation awareness from three aspects introduced in Section 4.2.2 (i.e., snapshot, evolution, and people SA). Participants were asked to finish several types of SA tasks in the experiment that focused on different aspects of SA.

4.2.2. Measures of SA. We have developed three new categories of variables for measuring SA of group discussion.

(1) Snapshot SA variable: It measures the percentage of all participants who have made at least one comment on a target node or its child nodes. This variable is helpful for facilitator to identify unbalanced discussion and encourage equal participation.

(2) Evolution SA variable: It measures the change of the number of posted comments related to a particular alternative over time. This variable is helpful to detect any premature closure of an alternative search process and decision-making in the early stage of group discussion.

(3) People SA variable: It measures the number of messages (both alternatives and comments) proposed by a group member. This variable is helpful to indicates users’ dedication to discussion. It’s also helpful for facilitators to identify significant contributors who can be considered as group leaders for future similar group tasks.

4.3 Participants

A total of eighty-seven undergraduate students with a major in Management Information Systems participated in the experiment. Among all participants, forty-two were male, and forty-five were female. The age range of participants was between 19 and 24. All of them had considerable experience with some computer-mediated communication tools like instant messaging, online chat rooms, or Web forums, but none had any prior experience with either experimental system used in this study. Participants were rewarded with extra course credits for their participation. To better motivate them, participants were informed before the experiment that the amount of credits that they would receive may vary depending on their performance in the experiment. In addition, the top performers (i.e., achieving the highest accuracies of SA with the least time) were rewarded with extra cash bonus.

4.4 Experimental Tasks

We adopted two subsets of a digital archive of group discussion supported by a group support system on the classic tea-bag problem [26] collected in a previous study [27]. The two subsets were carefully edited so that they had the same numbers of alternatives, comments, participants, as well as the same duration time. The tea-bag problem is an idea generation task that requires group members to discuss what a tea-bag manufacturer should do with surplus capacity. We incorporated discussion messages of those two selected subsets into experimental systems to create a hypothetical online group discussion session, and asked participants to independently identify the discussion situation and answer situation related questions using both the visualization-based and thread-based systems. To minimize the confounding learning effect, the sequence of the use of two systems, as well as individual SA tasks focusing on different SA aspects, were randomized for each participant.

4.5 Experimental Procedures

Before the formal experiment started, participants had a training session to help them familiarize with both visualization and benchmark systems. They were also given a couple of exercise tasks similar to the formal experimental tasks to ensure that they fully understood how to perform those tasks using two systems. In addition, each subject was asked to finish a pre-experiment test to ensure that they have had sufficient understanding of both systems and different SA variables. The formal experiment would not start until participants were ready.

The formal experiment consisted of two sessions. In the first session, participants performed three SA tasks, each corresponding to a unique SA aspect, using one of the two systems, and then completed a questionnaire related to their perceptions of the system that they just used. In the second session, participants switched to another system (with a different group discussion subset), performed three other SA tasks (each also corresponded to a unique SA aspect), and reported their perception of the system. Every task required users to answer fact-based questions about discussion situation. In each task, participants were given a question related to certain discussion situation. The goal of participants was to find the correct answer as quickly as possible. To avoid any possible learning effect, the sequence of three questions (i.e., those about snapshot SA, evolution SA and people SA) in each session was also randomized for individual participants.
5. Data Analysis and Results

We used repeated measures ANOVA to analyze the effect of cognitive process support on accuracy, task completion time, perceived usefulness, and perceived ease of use in completing SA tasks.

5.1 Task Completion Time

We ran a repeated measure ANOVA on task completion time (seconds) for each SA aspect (shown in Table 1). For snapshot SA, results reveal a significant main effect of cognitive process support for SA (F = 5.94, p < 0.05). Therefore, H1(a) is supported.

For evolution SA, the repeated measure ANOVA reveals a significant main effect of cognitive process support (F = 12.49, p < 0.01). Therefore, H2(a) is supported.

For people SA, the repeated measure ANOVA reveals a significant main effect of cognitive process support (F = 82.43, p < 0.001). Therefore, H3(a) is supported.

Table 1. Comparison of task completion time (seconds)

<table>
<thead>
<tr>
<th>SA Perspective</th>
<th>Thread Mean (Std. Error)</th>
<th>Visualization Mean (Std. Error)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snapshot</td>
<td>99.58 (8.70)</td>
<td>76.31 (5.60)</td>
<td>0.017*</td>
</tr>
<tr>
<td>Evolution</td>
<td>129.22 (6.75)</td>
<td>95.53 (6.66)</td>
<td>0.001**</td>
</tr>
<tr>
<td>People</td>
<td>145.07 (9.63)</td>
<td>45.39 (6.13)</td>
<td>0.000***</td>
</tr>
</tbody>
</table>

Note: *: p<0.05; **: p<0.01; ***: p<.001

5.2 Accuracy

We ran a repeated measure ANOVA on accuracy for each SA aspect (shown in Table 2). For snapshot SA, result reveals no significant effect of cognitive process support (F = 2.42, p > 0.05). It implies that the pre-attentive radial tree visualization did not improve the accuracy of snapshot situation awareness within certain task completion time. Therefore, H1(b) is not supported.

For evolution SA, repeated measure ANOVA on accuracy reveals no significant main effect of cognitive process support (F = 2.71, p > 0.05). It suggests that providing the line graph visualization did not further improve accuracy of evolution situation awareness. Therefore, H2(b) is not supported.

For people SA, repeated measure ANOVA on accuracy reveals a significant main effect of cognitive process support (F = 5.10, p < 0.05). That means floral visualization improves the accuracy of people situation awareness tasks, so H3(b) is supported.

Table 2. Comparison of task accuracy

<table>
<thead>
<tr>
<th>SA Perspective</th>
<th>Thread Mean (Std. Error)</th>
<th>Visualization Mean (Std. Error)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snapshot</td>
<td>81.4% (3.7)</td>
<td>88.9% (3.2)</td>
<td>0.124</td>
</tr>
<tr>
<td>Evolution</td>
<td>93.1% (2.8)</td>
<td>97.7% (1.6)</td>
<td>0.104</td>
</tr>
<tr>
<td>People</td>
<td>91.4% (2.9)</td>
<td>97.5% (1.6)</td>
<td>0.017*</td>
</tr>
</tbody>
</table>

5.3 Perceived Usefulness

Cronbach’s alphas of perceived usefulness (PU) of visualization and thread-based systems were between 0.941 and 0.959, and those of perceived ease of use (PEOU) were between 0.908 and 0.941, all showing high reliability. Factor analysis shows that all six questions PU1-PU6 loaded on the first factor, while the five questions PEOU1-PEOU5 loaded on the second factor.

We ran a repeated measure ANOVA on perceived usefulness for each SA aspect (shown in Table 3). For snapshot SA, result reveals a significant main effect of cognitive process support (F = 89.84, p < 0.001). So H1(c) is supported.

For evolution SA, a repeated measure ANOVA on perceived usefulness reveals a significant main effect of cognitive process support (F = 71.68, p < 0.001). So H2(c) is supported.

For people SA, the repeated measure ANOVA on perceived usefulness reveals a significant main effect of cognitive process support (F = 100.21, p < 0.001). So H3(c) is supported.

Table 3. Comparison of perceived usefulness

<table>
<thead>
<tr>
<th>SA Perspective</th>
<th>Thread Mean (Std. Error)</th>
<th>Visualization Mean (Std. Error)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snapshot</td>
<td>4.67 (0.13)</td>
<td>5.98 (0.10)</td>
<td>0.000***</td>
</tr>
<tr>
<td>Evolution</td>
<td>4.56 (0.14)</td>
<td>5.94 (0.10)</td>
<td>0.000***</td>
</tr>
<tr>
<td>People</td>
<td>4.34 (0.15)</td>
<td>6.06 (0.10)</td>
<td>0.000***</td>
</tr>
</tbody>
</table>

5.4 Perceived Ease of Use

We ran a repeated measure ANOVA on perceived ease of use for each SA aspect (shown in Table 4). For snapshot SA, it reveals a significant main effect of cognitive process support (F = 28.60, p < 0.001). So H1(d) is supported.

For evolution SA, it reveals a significant main effect of cognitive process support (F = 18.12, p < 0.001). So H2(d) is supported.

For people SA, it reveals a significant main effect of cognitive process support (F = 32.00, p < 0.001). So H3(d) is supported.

Table 4. Comparison of perceived ease of use

<table>
<thead>
<tr>
<th>SA Perspective</th>
<th>Thread Mean (Std. Error)</th>
<th>Visualization Mean (Std. Error)</th>
<th>Sig.</th>
</tr>
</thead>
<tbody>
<tr>
<td>Snapshot</td>
<td>5.35 (0.12)</td>
<td>5.91 (0.09)</td>
<td>0.000***</td>
</tr>
<tr>
<td>Evolution</td>
<td>5.38 (0.12)</td>
<td>5.85 (0.10)</td>
<td>0.000***</td>
</tr>
<tr>
<td>People</td>
<td>5.25 (0.13)</td>
<td>5.97 (0.09)</td>
<td>0.000***</td>
</tr>
</tbody>
</table>
6. Discussion

6.1 Major Findings

There are several major findings of this study. First, the results strongly indicate that providing pre-attentive radial tree visualization, which allows users to leverage parallel processing and pre-attentive perception of human eyes to improve the perception process of SA, is effective for supporting snapshot SA of online group discussion.

Second, providing a line graph visualization can significantly reduce the completion time of evolution SA tasks, as well as increase perceived ease of use and usefulness of online group discussion systems. The results indicate that providing line graph visualization, which improves the attention process and pattern matching process of SA by reducing the number of information chunks in the search space to a manageable scale in the working memory and abstracting and aggregating data at a high level, is effective for supporting evolution SA of online group discussion.

Third, providing floral visualization can significantly reduce the completion time of people SA tasks, as well as increase perceived ease of use and usefulness of online group discussion systems. The results strongly indicate that providing floral visualization, which improves the pattern matching process and synthesis process of SA by presenting intuitive graphs and leveraging the Gestalt perceptual processing of the human visual system, is effective for supporting people SA of online group discussion. Therefore, in general, those individual visualization techniques can be integrated into online group discussion software to support real-time SA much better than the traditional thread-based hierarchical presentation.

6.2 Theoretical contributions

This research investigates the effect of visualization of group discussion on user performance and perception of SA. This research provides several novel research contributions.

First, prior studies on SA in collaborative software had been lack of theoretical support. This research utilizes Cognitive Fit Theory and Endsley’s SA model as theoretical foundations when proposing visualization methods in support of SA in group discussion. Our study extends and validates the Cognitive Fit Theory in the context of situation awareness in collaborative software. It suggests that visualization approaches that fit the characteristics of SA tasks would help improve user’s performance in those tasks.

Second, this research examines the effect of visualization on user performance and perception in support of SA in online group discussion from three diverse perspectives (i.e., snapshot, evolution and people), which have not been systematically and empirically studied altogether in one empirical study before. This research provides various insights and empirical evidence on how to reduce the time required for SA of group discussion through real-time visualization of discussion.

Third, so far, there have been no existing measures of SA of online group discussion in the literature. This research proposes a set of new variables to measure SA of online group discussion. Progress in scientific fields is highly correlated with the invention of instrumentation to detect prior unseen properties.

Fourth, the proposed visualization approach integrates an evolutionary view of discussion over a time period, which is impossible in traditional thread-based text systems and has never been examined before.

Fifty, this study, for the first time, visualizes participants’ behavior at a micro level (e.g., presenting participants’ behavior related to a specific discussion topic or issue). Behavior visualization in previous studies was at a macro level (i.e., presenting participants’ general behavior covering all areas and boards in a discussion forum).

7. Future Research

The proposed approach has a couple of limitations, which open a few directions for future research. First, in this research, participants were required to assess their SA using archived messages generated from previous studies, instead of using a real-time discussion session. Second, we only tested the effect of a pre-attentive radial tree for snapshot SA, a line graph for evolution SA and a floral presentation for people SA. It would be interesting to evaluate the effectiveness of other visualization approaches (e.g., hyperbolic trees, animation, and people networks) in the future.

With the rapid growth of business globalization and collaboration, collaborative software in support of group tasks has been increasingly adopted and deployed. Previous research has shown that the use of computer-mediated communication and collaboration may lead to both pros and cons [1]. One of the recognized disadvantages is information overloading problem. Another is the timely awareness and understanding of discussion situation. The proposed visualization approach shows promising potentials in

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addressing those problems. With the help from the proposed approach, achieving a precise and up-to-minute discussion SA in a timely manner becomes possible. As tools support discussion SA become increasingly available, it is possible that both facilitators and users can easily judge the discussion status, which in turn benefits group discussion in our daily life.

References