

Evaluation of Viewing Methods for Magnetic Resonance Images

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ABSTRACT

Medical images are increasingly being examined on computer monitors. In contrast to the traditional film viewbox, the use of computer displays often involves a trade-off between the number and size of images shown and the available screen space. This paper focuses on two solutions to this problem: the "thumbnail" technique and the "detail-in-context" technique. The thumbnail technique, implemented in many current commercial medical imaging systems, presents an overview of the images in a thumbnail bar while selected images are magnified in a separate window. Our earlier work suggested the use of a detail-in-context technique which displays all images in one window utilizing multiple magnification levels. We conducted a controlled experiment to evaluate both techniques. No significant difference was found for performance and preference. However, differences were found in the interaction patterns and comments provided by the participants. The detail-in-context technique accommodated many individual strategies and offered good capabilities for comparing different images whereas the thumbnail technique strongly encouraged sequential examination of the images and allowed for high magnification factors. Given the results of this study, our research suggests new alternatives to the presentation of medical images and provides an increased understanding of the usability of existing medical image viewing methods.

Keywords: Viewing Methods, Detail-in-Context, Thumbnails, MRI, Image Sequences, User Interfaces

1. INTRODUCTION

In a traditional radiology environment, medical images are typically examined by attaching partly transparent photographic films to a large viewbox which is lit from behind. In Magnetic Resonance Imaging (MRI), one such film may show up to 20 successive image slices of the scanned volume. During patient examinations, up to eight such films are viewed side by side. Thus, the radiologist is able to instantly access more than 100 images. It is difficult to implement such a scenario in a digital viewing environment given the trade-off between the available computer screen space and the number of displayed images.

This problem has been addressed in different ways. We describe a image presentation technique that is commonly used in commercial medical imaging systems. We then propose a new technique which we developed based on previous research, field observations, and interviews of radiologists at a local hospital. Although variations of both techniques have been implemented, little is known about the way users interact with the techniques. Towards this end, we conducted a controlled experiment to identify frequent interaction strategies as well as statistically significant differences between the two techniques. The experiment is presented in the third section of this paper. We then conclude with the results of the experiment and the potential impact on radiology.

2. IMAGE PRESENTATION TECHNIQUES

2.1. The Thumbnail Technique

Background

Dayhoff and Kuzmak [3] describe the user interface of an internally developed hospital information system. A typical MR image sequence is displayed in two separate windows. One window contains small versions of the images, allowing the user to select an image for further magnification. The selected image is then displayed in the second window at its full resolution. This technique, which we will refer to as the "thumbnail technique", is also implemented in READS, a software package described by Erickson *et al.* [4]. To obtain an overview of image presentation techniques utilized in current medical image viewing software, we also examined the technical specifications and descriptions of thirty commercial products on the World Wide Web. Despite most descriptions' focus on technical features rather than the user interface, we extrapolated from screenshots and concluded that the thumbnail technique was the most frequently implemented method for image

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presentation. In a study described by Honea *et al.* [8], a small group of radiologists, administrative, and technical personnel evaluated five commercial medical imaging products developed for the PC. The authors state that the lack of crucial functions and the poorly designed user interface “seems to be the result of incomplete requirement definition, inadequate software development, or deliberate decisions to limit product development.”

Description of the Thumbnail Technique

At University of British Columbia (UBC) Hospital in Vancouver, Canada, we examined a medical imaging display system in use by the radiologists. The software, called “Advantage Windows” by General Electric Medical, is an implementation of the thumbnail technique. Based on the main functionality of its user interface, we developed a software prototype which we then evaluated in a user study.

Figure 1 shows a screenshot of our prototype. The image display is divided into two parts. The large display area in the middle shows four successive image slices. Clicking on an image in the thumbnail bar on the right causes it to be displayed in the top left corner of the main display area, followed by the three following sequential images. To select a different magnification factor for the enlarged images, the layout of the main display area is changed by clicking on one of the buttons on the left side.

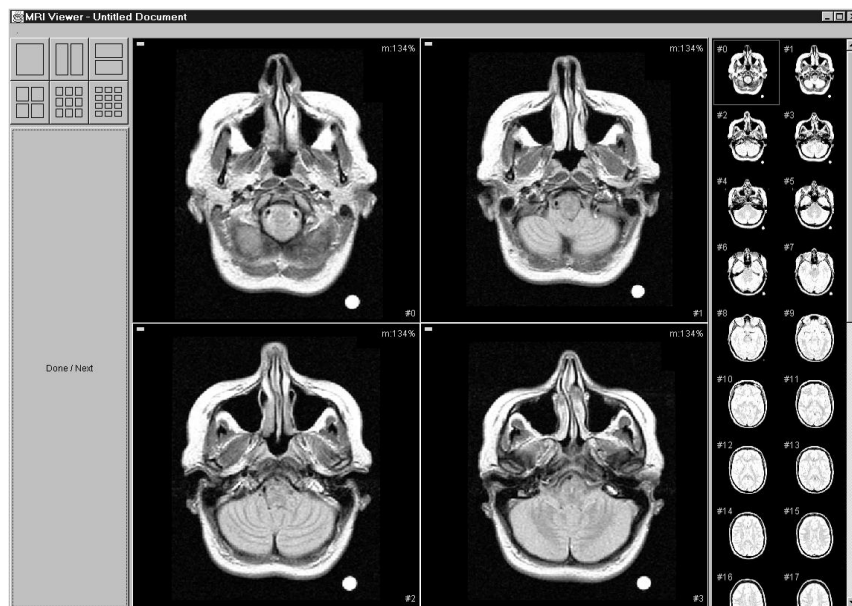


Figure 1. The thumbnail implementation

2.2. The Detail-in-Context Technique

Background

Detail-in-context is a visualization technique which displays detailed information as well as contextual information. Given that screen space is often limited, this is achieved by assigning different magnification levels to different parts of the data. Data around a user-selected focus or lens is displayed at a higher magnification level while the remaining data is compressed and displayed in lesser detail in order to fit the available screen space. Detail-in-context techniques have been applied to a variety of types of information, including early attempts such as Spence and Apperley’s Bifocal Display [16] in 1982 and Furnas’s fish-eye view [6] in 1986.

We distinguish three types of information: discrete information spaces, hierarchical networks, and continuous information spaces. Discrete information spaces (Figure 2a) typically consist of interrelated discrete units such as graphs or tables. In a first step, a degree of interest (DOI) value is typically assigned to each unit. In the second step, the layout is computed by the algorithm, assigning higher magnification factors to higher DOI values. Examples include the Rubber Sheet by Sarkar *et al.* [14], the Table Lens by Rao and Card [13], and SHriMP by Storey and Müller [17]. Hierarchical networks (Figure 2b) allow units to be grouped and be treated as a single unit. As the DOI of a unit exceeds a specified value, it is expanded into its sub-units. This technique has been implemented by Bartram *et al.* [1] in the Continuous Zoom as well as by Fisher *et al.* [5] in CZWeb, an application that visualizes pathways through the Internet. The third type of algorithms deals with continuous information spaces (Figure 2c) which do not consist of separate units but one object with an infinite resolution

such as a picture or a volume. Mackinlay *et al.* [12] present the Perspective Wall which smoothly integrates detailed and contextual data on a bent virtual wall. Carpendale *et al.* [2] visualize geological maps with their Elastic Presentation Space algorithm. Keahy and Robertson [9] present an alternative technique for non-linear magnification of two-dimensional continuous data.

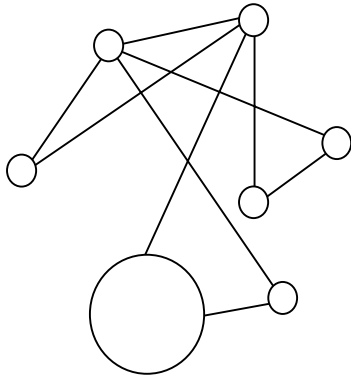


Figure 2a. Discrete information spaces

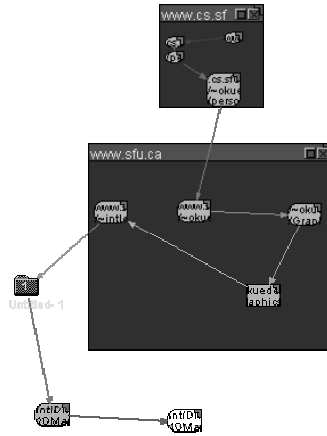


Figure 2b. Hierarchical networks

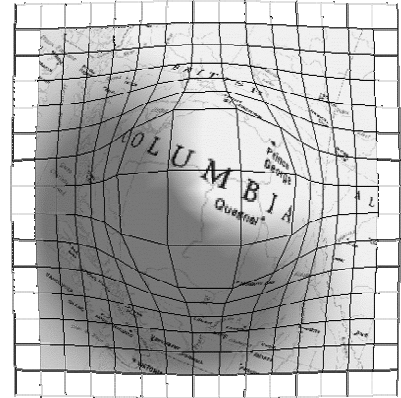


Figure 2c. Continuous information spaces

Detail-in-Context and Medical Imaging

Van der Heyden *et al.* [18,19] conducted extensive field observations of MRI radiologists in a traditional viewbox environment. From these observations, a set of requirements for MRI viewing software was identified. The main requirements were:

1. the ability to view all films in the presentation simultaneously,
2. the ability to view an image up close without losing sight of the remaining images,
3. the ability to group related images from different films, and
4. the ability to control information hiding.

Based on these requirements, van der Heyden *et al.* concluded that, given the lack of sufficient screen space with desktop monitors, detail-in-context was a viable approach to the presentation of MR images. Following the development of a number of detail-in-context layout algorithms, radiologists were presented screenshots and questionnaires in an informal user study. The radiologists' answers suggested that detail-in-context was feasible.

Description of the Detail-in-Context Technique

Given the results of this previous research, we conducted additional field observations at UBC Hospital in order to answer open questions and resolve problems of the early layout algorithms. We identified the following additional constraints:

1. Early layouts aligned images along the vertical axis as well as the horizontal axis, creating large unused spaces. Since the radiologists examined the images from left to right, we suggested aligning the images along the horizontal axis only.
2. Multiple images can be selected for magnification. The radiologists we observed frequently compared two or more images and sometimes used their fingers to compare the size of anomalies in different images. To allow them to do this on the computer screen, all selected images were set to the same magnification factor.
3. In the user study of van der Heyden *et al.*, it was determined that a minimum resolution of 30×30 pixels was required to distinguish the images. In our implementation, images were never displayed at a lower magnification.
4. It was observed that the radiologists tried to turn off any unnecessary light source to reduce distraction. Therefore, space between images always remained black.

Figure 3 shows a screenshot of our second software prototype which is an implementation of a detail-in-context technique. When the user clicks on an image, it is magnified and the remaining images become smaller. Clicking on an image again causes it to return to its previous size. Multiple images can be selected and transitions between different layouts are



Figure 3. The detail-in-context implementation.

animated to let the user keep track of the images' movement and magnification changes. A menu allows the user to change the default magnification factor.

2.3. Previous Evaluations

Few researchers have investigated detail-in-context techniques in user studies. Hollands *et al.* [7] compared a full-zoom technique using scrollbars (scrolling technique) to a detail-in-context technique. Both techniques were applied to a map of a fictional subway. According to the researchers, the inconclusive results were due to the fact that the users were not familiar with distorted views. Schaffer *et al.* [15] evaluated their detail-in-context technique against a scrolling technique which was applied to a hierarchical network. The users' performance was significantly better in the detail-in-context technique. Using a map of the London Underground, Leung *et al.* [11] compared the Perspective Wall to three other display techniques: the Bifocal Display, a scrolling technique, and a scrolling technique with an overview on a separate screen. The results showed that the performance of the detail-in-context techniques was only better when the users were required to locate stations. When they traced routes, the performance was better with the scrolling and the overview techniques.

While some statistical results exist for specific detail-in-context techniques, little is known about the way users interact with them. For the design of interactive systems, however, it may be helpful to know users' strategies, difficulties, and preferences in order to maximize performance. Therefore, we have run a controlled experiment that investigated the way users interact with both detail-in-context and thumbnail techniques.

3. EVALUATION OF IMAGE DISPLAY TECHNIQUES

3.1. Overview and Setting

We evaluated the detail-in-context and the thumbnail technique in a controlled experiment which involved two conditions: detail-in-context and thumbnails. The experiment was conducted at Simon Fraser University, Canada, in April 2000. We performed statistical as well as qualitative analyses in order to point out differences in performance, preference, and user strategies, between the two techniques. A complete description of the study and the results are given in Kuederle's M.Sc. thesis [10].

3.2. Participants

It was initially planned to let radiologists participate in the study. However, the sample size required was larger than the number of MRI radiologists working in the Greater Vancouver area. In addition, their heavy workload as well as the logistics of obtaining ethics approval with the use of real patient data made it difficult to run the experiment within a reasonable time frame. Therefore, we recruited 32 university students from various disciplines. This also had the advantage of allowing generalizations to a broader population.

3.3. Experimental Task

To allow the medically untrained participants to complete the task, it was modelled after the radiologists' work without the need for anatomical knowledge or experience with radiology. The basic task remained the same: find and describe an anomaly in a sequence of images. The anomaly (clubs, spades, hearts, or diamonds) was an artificial tag placed on a familiar object (see Figure 4). The object was then photographed from different, equally spaced angles. The greyscale images were shown to the participants using one of the display techniques. The participants then circled the type of anomaly (clubs, spades, hearts, or diamonds) and the number of the image that it appeared in, on a separate answer sheet. To prevent predictions, the anomaly was randomly removed from some images. Of the ten presented image sequences, two did not contain any anomaly.

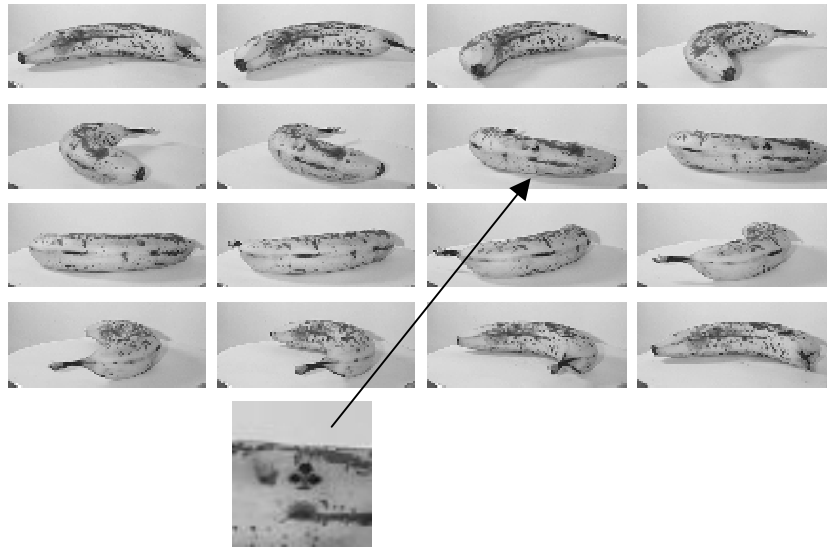


Figure 4. An example image sequence.

3.4. Procedure and Data Collection

A background questionnaire before the start of the experiment assessed the participants' experience with computers and digital images. After a training session on an example image sequence, the participants were asked to work with the first display technique which showed five image sequences. After each sequence, the participants clicked on the "Done/Next" button to bring up the next image sequence. Upon completion, they practiced with the implementation of the second display technique and completed the task on five more image sequences. All events such as mouse clicks, magnification factor changes, start, and end of trial were recorded in a computer log. At the end of the experiment, the participants filled out a questionnaire with the opportunity to indicate their preference for one of the techniques as well as to provide comments.

3.5. Independent Variables

We identified three independent variables:

- *Display Condition:* There were two conditions: detail-in-context and thumbnails.
- *Image Sequence Set:* Two similar sets of five image sequences were presented in each display condition. The order of the image sequences within a set was randomised.
- *Gender:* An equal number of men and women participated in the study.

Each participant worked on both conditions. Thus, the experiment was a $2 \times 2 \times 2$ (condition \times set \times gender) mixed design, with gender as the between subjects factor and condition and set as within subject factors. All independent variables were counterbalanced, resulting in four condition \times set groups with four females and four males in each group.

3.6. Dependent Variables

To understand how users interact with both display techniques, we investigated two aspects:

- *Interaction patterns:* Keeping computer logs of all user interaction with the system allowed us to identify patterns, strategies, and differences for each display technique.

- *Comments:* Feedback collected in the post-session questionnaires was examined to gain insight into the participants' perceptions and problems when working with the software.
- *Performance and preference:* We were also interested in any statistical differences between the two display techniques. Therefore, we measured time to complete the task, accuracy of the participants' answers, and their preference indicated in the questionnaire.

4. RESULTS AND DISCUSSION

4.1. Interaction Patterns

Trial Charts

In order to examine the way the participants interacted with our software, we developed a method that transformed the raw computer logs into a visual representation which clearly showed each event as well as its relationship with other events. This representation, called "trial chart", is shown in Figure 5 for a trial in the detail-in-context condition. A trial chart contains mouse click events and magnification change events of one trial with time in milliseconds on the horizontal axis and image number on the vertical axis. Mouse click events are displayed as black dots. In the detail-in-context condition, the lines between mouse click events denote the time the image was magnified, since a second mouse click returned the image to its previous size. In the thumbnail condition (Figure 6), lines emphasize the order of events and circles indicate a mouse click in the large display area (which did not have an effect on the images). Magnification change events are displayed at the top of the trial chart. The grey areas denote images that contain an anomaly.

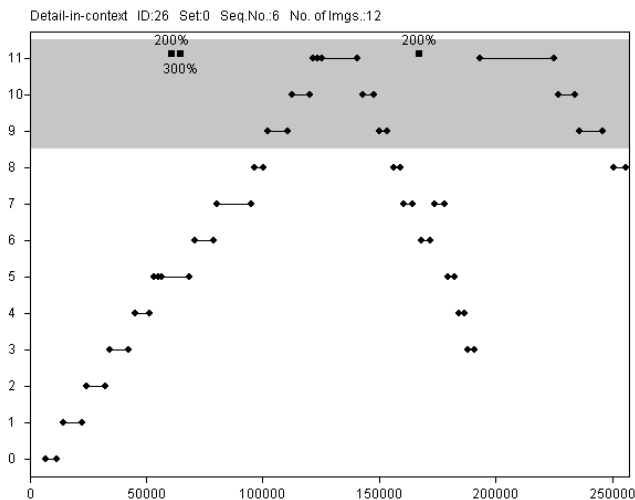


Figure 5. A trial chart in the detail-in-context condition (time in milliseconds on the horizontal axis, image numbers on the vertical axis).

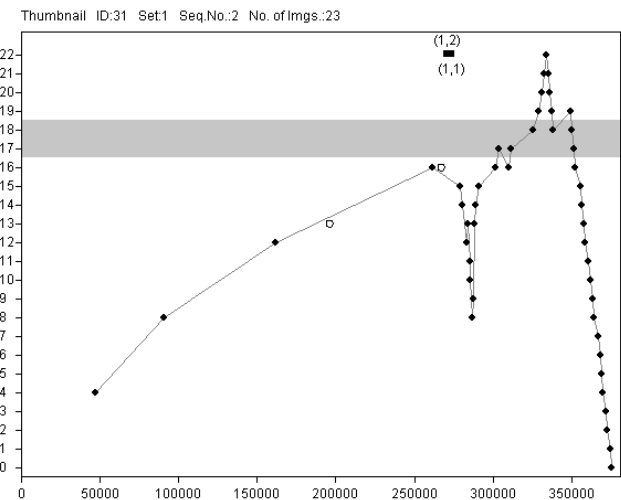


Figure 6. A trial chart in the thumbnail condition (time in milliseconds on the horizontal axis, image numbers on the vertical axis).

Sequential Examination

In the trials shown in Figure 5 and 6, the participants examine the images in sequential order. While in the thumbnail condition, all participants showed this behaviour in all trials, it was not the most commonly used strategy in the detail-in-context condition. Figure 7 shows a trial in which images were selected in no obvious order. In some instances, this random exploration phase was followed by a final sequential check to confirm the detected anomalies (see Figure 8).

In the detail-in-context condition, all images were on screen at any time. Hence, the participants were always given an overview of the entire image sequence and could therefore click on images in any arbitrary order. In the thumbnail condition, on the other hand, only a small subset of the images were seen magnified. The size of the images in the thumbnail bar (80×80 pixels) was too small to detect anomalies. Therefore, the participants were encouraged to examine the image sequence in sequential order.

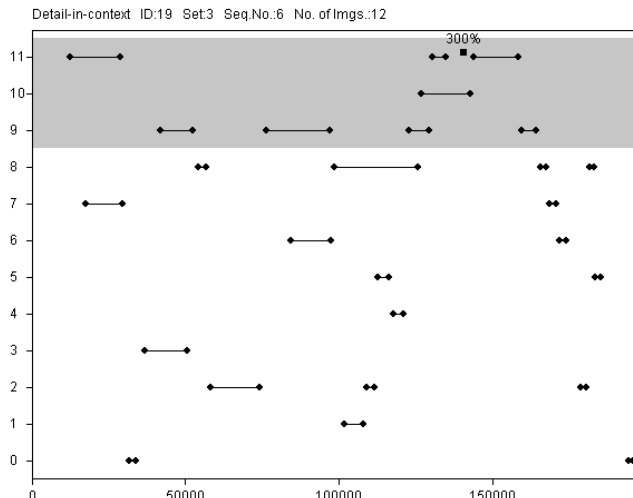


Figure 7. Random selections in the detail-in-context condition.

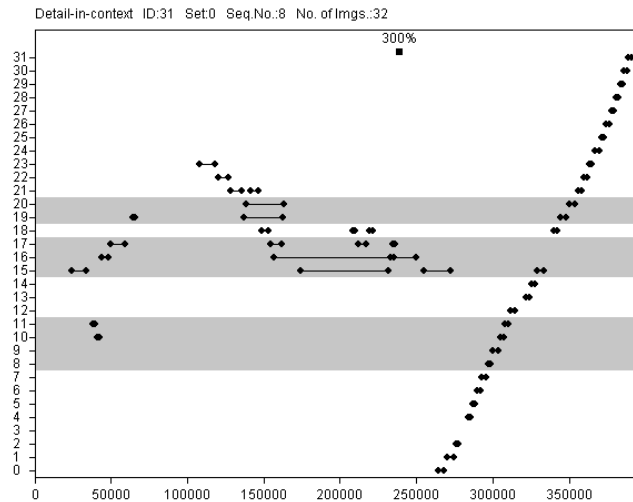


Figure 8. Final checks in the detail-in-context condition

Comparisons

In the trial shown in Figure 5, no two images were magnified at the same time, although the participant was aware of the ability to compare any number of images. Other trial charts such as in Figure 7, 8, and 9, show frequent comparisons between two and more images. The participants can be divided into two groups: participants who made comparisons and participants who did not compare images at all. In addition, the type of comparison also differed for different participants. Figure 9 shows a trial in which one image was magnified during a long period of time as a reference while other images were clicked on in order.

Skipping of Images

In the detail-in-context condition, participants frequently did not magnify certain images at all. Figure 10 shows such a trial in which, for example, images #1 through #7 were not selected. Furthermore, in some image sequences with few images, none of the images were magnified, suggesting that the initial size of the images was sufficiently large to detect anomalies.

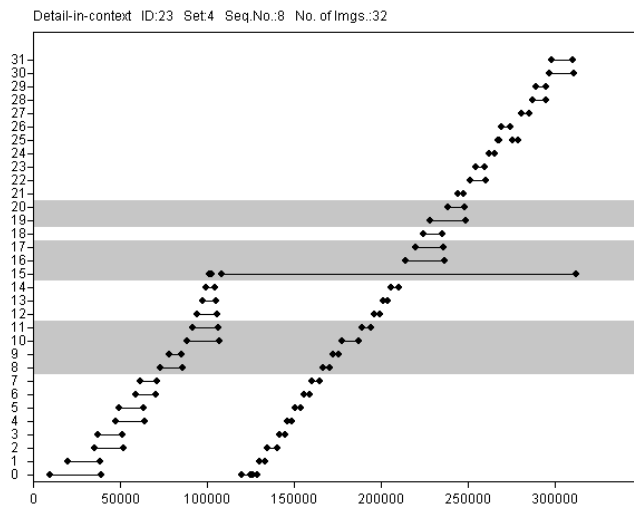


Figure 9. Comparisons in the detail-in-context condition.

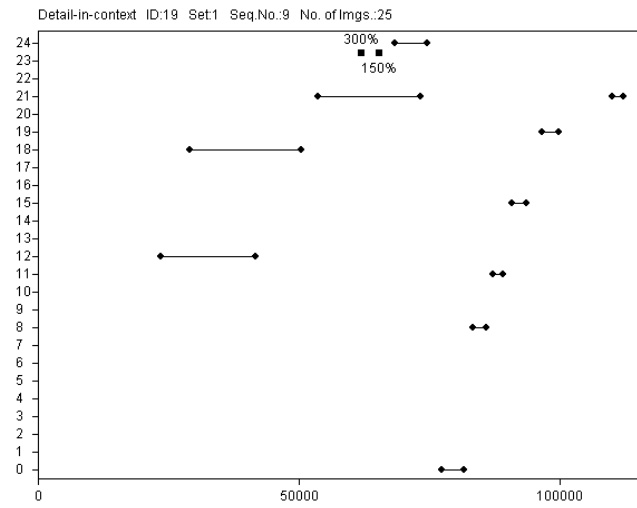


Figure 10. Skipping of images in the detail-in-context condition.

In the thumbnail condition, however, this was not observed in the majority of trials. In only four of all 160 recorded trials, images were skipped. The images in the thumbnail bar were too small to determine the ones which contained the anomaly.

4.2. Comments

The post-session questionnaire provided space for comments on each display technique and for reasons for the participants' preference. Of the large amount of feedback we obtained, we identified a few frequently mentioned points:

- While in the thumbnail condition, only consecutive images could be magnified at the same time, the detail-in-context implementation allowed the selection of any combination of images. Thirteen of the 32 participants rated this as a positive feature.
- Eight participants explicitly mentioned that they liked the fact that the detail-in-context technique provided a global overview of the image sequence. It facilitated the detection of anomalies.
- Six participants reported difficulties with magnification factors in the detail-in-context implementation. As contextual images remained on screen at all times, the selected images often did not attain the desired size. For some participants, this was the reason to indicate thumbnails as their preferred display technique. Selecting a 1×1 layout in the thumbnail implementation allowed much higher magnification factors.
- Eight participants stated that they experienced motion sickness due to the continuous layout changes in the detail-in-context condition. This was the most frequently mentioned reason to prefer the thumbnail technique.
- Nine participants preferred to select an image only once in the thumbnail condition as opposed to the detail-in-context condition, in which images had to be clicked on twice to be magnified as well as minimized.

4.3. Performance and Preference

To detect performance differences between the two display techniques, we identified four measures: time to complete all trials in a condition, number of false negatives in a condition, number of false positives in a condition, and number of wrong symbols in a condition.¹ We performed repeated measures analyses of variance on all four measures ($\alpha=.05$). Given the observed differences in the participants' behaviour, it came as a surprise that the only significant effect we found was a Time × First Condition interaction ($F(1,24)=9.004$, $p=.006$). Further analysis revealed that participants starting with the detail-in-context condition improved significantly in trial completion time ($F(1,12)=6.846$, $p=.023$). This effect was not found for participants starting with the thumbnail condition ($F(1,12)=3.162$, ns). This suggests that more time was needed to adjust to the detail-in-context technique which was a new concept for most participants. Thumbnails, on the other hand, are a common image selection technique on the World Wide Web and may have been more familiar to the participants. We also performed a χ^2 -analysis to determine if the participants' preference for one of the two display techniques was significantly higher. No such difference was detected.

4.4. Summary of Results

Given that the only significant effect we found was a learning effect in the detail-in-context condition, we suggest that the users' overall performance is similar in both implementations. However, differences were found in the way users interacted with each technique. The results for the detail-in-context technique can be summarized as follows:

- It accommodates a wide variety of individual strategies.
- A global overview is provided, facilitating the search for anomalies.
- Comparisons can be made between any combination of images.
- Contextual images occupy space needed for images with high magnification factors.
- Constant layout changes may cause motion sickness.

The main results for the thumbnail technique were:

- Examination of the images in sequential order is strongly encouraged.
- Skipping of images is discouraged.
- It allows for high magnification factors for selected images.
- Comparisons can only be made between adjacent images.

¹ False negatives were anomalies that were not reported. False positives were anomalies that were reported although they did not exist. Wrong symbols were shapes of anomalies that were misinterpreted, e.g. reporting clubs instead of spades.

5. IMPACT ON RADIOLOGY

After the analysis of the experimental data, we presented our results to a radiologist at UBC Hospital. The radiologist identified parallels between film reading practice and some of the strategies shown in the trial charts. It was noted that random viewing patterns (see Figure 7) are common among inexperienced radiologists. While radiologists with more training often show a behaviour such as the one in Figure 8 where an initial exploration phase is followed by sequential examination of the images, senior radiologists typically examine the sequence step by step, proceeding from one image to the next. Radiologists are taught to apply this method despite the fact that the overview provided by the photographic films encourages them to skip images and focus directly on the anomaly. As seen in the trial charts, the detail-in-context technique which also provides an overview at any time, allows the application of any strategy. Therefore, the radiologist noted that the thumbnail technique may be more appropriate for a radiological examination since it encourages the user to apply the preferred strategy. Specialized physicians, on the other hand, are not required to examine all images and may want to focus directly on a specific subset of the images. We were told by the radiologist that “specialists would love the detail-in-context technique” because it would save them time to find the region of interest.

6. CONCLUSION

We have presented two techniques for the presentation of Magnetic Resonance Images: thumbnails and detail-in-context. While the thumbnail technique is based on the techniques implemented in many commercial medical imaging systems, the newly developed detail-in-context technique is an application of a visualization technique to the presentation of magnetic resonance images, based on previous research and on our field observations. Implementations of both techniques were evaluated in a controlled user study to investigate the way users interact with each technique. The results showed that the thumbnail technique strongly encourages sequential examination of the images and allows for high magnification factors. The detail-in-context technique accommodates a wide variety of individual strategies and provides good comparison capabilities. The thumbnail technique may be preferred by radiologists while specialized clinicians may prefer the detail-in-context technique.

This research serves to improve our understanding of the way users interact with both the detail-in-context and the thumbnail technique. Our results may allow software designers to make more informed decisions when designing image presentation systems such as in medical imaging.

7. FUTURE WORK

The Ciné technique is another technique that is used by some commercial medical imaging systems. Images are displayed one at a time with no contextual information. Using a trackball or the keyboard, the user can select the previous or the next image of the sequence. In a future study, we may investigate the way users interact with this kind of technique and compare it to the results of the experiment presented in this paper.

The application of our results to radiology is known only to a preliminary degree since only university students participated in our study. We are interested in the way the results of our study apply to a study which involves trained specialists.

Furthermore, we believe that the detail-in-context technique can also be applied to other areas such as meteorology and video editing. Future projects may involve the adaptation of the detail-in-context to different contexts.

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