Presentation of MRI on a computer screen

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ABSTRACT

This paper examines the presentation of Magnetic Resonance Images (MRI) on a computer screen. In order to understand the issues involved with the diagnostic-viewing task performed by the radiologist, field observations were obtained in the traditional light screen environment. Requirement issues uncovered included: user control over grouping, size and position of images; navigation of images and image groups; and provision of both presentation detail and presentation context. Existing presentation techniques and variations were explored in order to obtain an initial design direction to address these issues.

In particular, the provision of both presentation detail and presentation context was addressed and suitable emphasis layout algorithms examined. An appropriate variable scaling layout algorithm was chosen to provide magnification of selected images while maintaining the contextual images at a smaller scale on the screen at the same time. MR image tolerance levels to presentation distortions inherent in the layout were identified and alternative approaches suggested for further consideration.

An initial user feedback study was conducted to determine preference and degree of user enthusiasm to design proposals. Response to the scaling layouts pointed to continuing issues with distortion tolerance and provided further insight into the radiologists' needs. Trade-off between visualization enhancements and distortions resulting from detail-in-context layouts were examined, a catalog of distortions and tolerances presented and a new variation of the layout algorithm developed. Future work includes more extensive user studies to further determine desirable and undesirable elements of the proposed solutions.

1. INTRODUCTION

Many radiology departments are changing from traditional film and light screens to computerized viewing stations. Reconstructed digital images are stored in computer memory and displayed via image display consoles or PAC systems. In a typical light screen environment, the imaging technician creates film layouts from the acquired images as per the radiologists' instructions, adjusting contrast and field of view (FOV) as appropriate. From the layouts, films are created and the radiologist views some or all of these on a large light screen. In a computerized environment, the technician may still adjust the images but no films are created and images are stored in computer memory. The radiologist then views images on the computer screen paging through image series one or several images at a time.

This shift to computer image display is motivated by two factors: 1) bringing medical images on-line facilitates exchange of image information among hospital departments and between remote locations; and 2) functionality provided by computerized medical imaging display systems can assist the medical image diagnosis process. However, the presentation of images on a computer in a manner that provides the same advantages as the light screen remains a difficult problem. The light screen is capable of presenting all images in full size and at the same time. This ability to display both *detailed* and *contextual* information at the same time is difficult to obtain on the computer screen, as screen size is limited. Medical image modalities that involve images slices, such as Magnetic Resonance Images (MRI), Computerized Axial Tomography (CAT) and Positron Emission Tomography (PET)) are especially susceptible to this issue as they involve a large number of inter-related images.

We looked at the MRI viewing and diagnostic tasks in order to determine presentation issues and reviewed relevant literature in order to propose solutions. It was found that research in *detail-in-context,* also known as *distortion*, techniques addressed the problem of simultaneous presentation of detail and context.

2. RELATED WORK

Detail-in-context techniques are used to visually display sufficient detail of focal information without losing surrounding contextual information. Typically detail is required when presenting information of focal interest while a less detailed display is sufficient for contextual information which provides peripheral data. It is possible to minimize contextual areas leaving more display space for focal areas. One of the following methods can be used: scaling, where focal areas are enlarged and contextual areas become progressively smaller; filtering, where non-focal areas become progressively hidden; and abstraction, where non-focal areas become progressively abstracted or nested. As these techniques are in essence emphasizing certain aspects of information or data while de-emphasizing others, they are often classified as *emphasis* techniques. As detail-in-context must also invariably distort the data to some degree, the same methods have also been called *distortion* techniques.

An early technique, called *Bifocal Display* [1], consisted of a center display or *focus* where detailed information was presented and two display panels to either side where the remaining items were distorted in order to fit the remaining space. Encoding was used to attach information to the data items in the side panels. This idea was later adapted to become the *Perspective Wall* [2] where the side panels are given perspective much as though they were walls distancing away from the user. Furnas originated the *fisheye view* concept in [3]. Although this term was later used to describe many varieties of detail-in-context views, the original notion was based on a fisheye lens. The fisheye lens referred to techniques, which used variable scaling or other methods to provide full detail within the area of interest (focal point) and progressively less detail (more distortion) as distance grows from the focal point. Distance may be defined in different ways. Furnas used suppression of data points to obtain this affect in his *Fisheye Views*. A *degree of interest* was assigned to each data element or point and a user chosen threshold determined whether the data was displayed or suppressed. The degree of interest was based on a previously determined *a priori importance* value combined with the distance from the user-selected focus. In [4] three *perspective* mappings are described: *fisheye mapping*, *orthogonal fisheye mapping* and *biform mapping*. These all maintain the original fisheye lens paradigm, though orthogonal fisheyes preserve orthogonality and biform mapping divides data into *view areas* instead of *view points*. Early techniques like the Bifocal Display, Perspective Wall and original fisheye were limited to only one focal point. Studies performed by Furnas [3] showed that situations existed where people would want to select more than one focus and most techniques now allow multiple focal points.

Clustering techniques can be used to provide detail-in-context when information is easily described in hierarchical terms. Tree Maps [5] and Cone trees [6] are examples of such techniques. An example of a system using hierarchical clustering can be found in [7] where network nodes are *clustered* to varying degrees of nesting in order to allow the user to trade off between detail and context as desired. Nodes are expanded when further detail is required and contracted when they are not the focal point of interest. Another example where hierarchical clustering is used to provide control over detail-in-context is SHriMP, an approach for visualizing software structure represented by clustered nodes which was integrated into a reverse engineering system (Rigi) [8]. Both [7] and [8] use magnification as well as clustering.

Detail-in-context methods relating to graph structures (see [9] for survey) are different from techniques that use points or areas as their data elements. Graph structures consider *nodes* to be the elements and arcs are sometimes used to define binary relations. Nodes are considered separate entities that must be laid out in some relation to each other. General layout techniques often originate from graph layout algorithms where nodes need to be laid out on the screen in such a way that the arcs are not entangled or lost [4, 9, 10]. Layout *adjustment* strategies come into play as the layout changes in response to user selected focal nodes. Degree of interest may determine the extent of scaling and distortion of each node but layout adjustment strategies determine the resulting spatial layout. The *mental map* concept, introduced in [4], refers to the adherence of the spatial layout in the original, non-adjusted view. In [4] three key spatial relations: orthogonality, proximity and topology are introduced. Orthogonality preserves up/down, left/right relations, proximity preserves closeness between nodes and topology is preserved if the distorted graph has the same dual graph as the original graph. It is important to maintain these relations so that the user can continue to identify with the layout and its individual items after layout adjustment.

A much more general and non-graph oriented multi-foci system, 3DPS is described in [11]. 3DPS is a radial magnification approach that unlike the graph based approaches extends distortion evenly in all directions. It is possible to define focal data areas by controlling the uniformity and spread of the distortion and magnification. In this way non-distorted (uniformly magnified) areas can be defined. 3DPS also addresses the problem of disorientation which is often experienced by users when viewing distorted presentations, by providing shading and grid line *visual cues* [12] in order to aid users in correct interpretation of the distortions. Another technique to aid the user in establishing a connection with the distorted layout, is the Continuous Zoom [7, 13]. The Continuous Zoom uses animated magnification and shrinking to provide continuous visual feedback to the user. Observance of the mental map also helps to provide users with visual spatial clues after the distortion. The SHriMP method [8] includes variants that preserve either strict orthogonality or proximity. Topology is also maintained as *straightness of lines* between nodes is maintained in the orthogonal version.

Distorted presentation techniques and graph layout/adjustment techniques differ in many aspects and each may be more or less appropriate, depending on the application. In addition to the provision or lack of visual cues and maintenance of more or fewer aspects of the mental map, some approaches [2, 4, 16] distort shape and relative size, while others [7, 8] do not. Shape and relative size are distorted if magnification is not uniform in all directions. Furthermore, we have seen that some of the earlier systems did not allow for multiple foci while most recent ones do. See [4, 9, 14, 17] for full details of taxonomy, comparison and discussions of distorted presentation techniques.

3. INITIAL OBSERVATIONS

A series of informal observations of radiologists working with MRI provided much insight into the traditional light screen environment as well as into the analysis process and image types used by the radiologists. We found the light screen environment possesses many inherent qualities, which are extremely well suited to the radiologists' tasks. Observations and resulting requirements are described below. Initial observations were first published in [15].

3.1 Background

The traditional technology for displaying MRI images is the use of a large light screen panel. The panel used in the current study consists of two visible screens each measuring 58″ × 19", positioned one above the other to form a 58″ × 38″ display area. This total area is large enough to display eight MRI films where each film measures 14″ × 17″ and contains 15 to 20 images depending on image size and shape. Several more screens exist but are hidden from the display area. These can be pre-loaded with images and moved into the lighted area as desired.

Images are typically grouped into scan sets containing a number of sequential slices making up a volume. These are usually distinguished by planar orientation (i.e. axial, sagittal, coronal) or by contrast weight, though other factors such as field of view and patient contrast injection may differentiate the scan sets. Contrast sets are determined at data acquisition time and differ in grey scale representations. This difference in "contrast" is an important factor in the identification of healthy and unhealthy tissue.

Image data is acquired in volume sets by technicians while the patient remains in the MRI machine, and traditional films are then made from this data. The number and types of images depend on the case at hand and are determined by the technicians with input from the radiologist. The entire set of films resulting from one patient in one session is referred to as a *study*. Note that volume sets belonging to the same study always represent the same area of anatomy but vary in contrast and/or planar orientation. Each film represents a different plane or contrast and provides unique information with respect to the analysis and validation process.

3.2 Field observations

A field study was conducted at Vancouver Hospital to understand the MRI analysis process. Informal observations of radiologists interacting in a traditional film-oriented environment were gathered using researcher field-notes. Observations were gathered during five one-hour diagnostic teaching sessions involving both intern and staff radiologists.

Early in the session, there is little discussion as the staff radiologist scans the entire display area. Later, activities are more focused around a subset of the images which may or may not be scattered around the display area and often belong to multiple films. Arrangement of the films cannot accommodate all aspects of the analyses and in a typical session there is a great deal of physical movement by the radiologists. The radiologists will stand up, sit down, and move to the left or to the right of the screen in order to focus on specific images or image groups. Pointing or sweeping hand motions are also used and can indicate areas of interest. Often radiologists point at one or more images for a prolonged period, marking them for comparison purposes or future reference. The light panels and films themselves may also be moved by the radiologists. The upper panel of the screen is sometimes moved down, closer to the observers, and films are sometimes moved to different locations of the screen for better grouping and context. At times an entire film may be extracted from the light screen and held up to the light by hand for closer viewing. Additional films are occasionally placed on the screens while other films are removed. In this manner, each session appears to progress in a similar fashion, with the frequency of movements varying from one radiologist to the other. The pattern of observations and comparisons made in each session, however, is unique and dependent on both the radiologist and the case at hand.

3.3 Requirements

It is apparent from observations and discussions that all images are briefly viewed at least once and several subgroups of images are singled out for simultaneous viewing or comparison purposes. As sub-groups may involve some of the same images, it is not possible to permanently position the films so that the components of each subgroup are close together. Radiologists typically solve this problem through physical movement or by reorganization of the films, obtaining multiple groupings of images as required. Although this method appears cumbersome, it allows radiologists complete control and flexibility with regard to which images they view up close, which images they view as a group and which image sets they scan as a whole.

The traditional light screen is well suited to the presentation of MRI as it provides flexibility and control over the films, easy navigation of images and is large enough to provide both detail and context of images and image films. These qualities facilitate the overview, comparison and detailed examination tasks of the radiologists and directly relate to the requirements listed above. We formalize these qualities and create overall requirements categories that are described below

Control: Provide flexible user control over the location, size, visibility and membership of groups. This includes the abilities to create user defined image groups and to control group location, visibility and display size.

Navigation: Ability to locate and relocate images as well as groups of images.
The navigation issue involves the user knowing where to find an image or image group that are of current interest. In other words, the dynamic processes of locating and re-locating images and image groups from the current study during the viewing or diagnostic task. This entails knowing where the object is and remembering how to find it again.

Detail-in-context: Ability to view one or more images (image groups) up close without losing the remaining images (image groups). Detail-in-context includes the ability to view images up close as well as to view multiple images or image groups as overviews. It also includes the ability to present individual image detail and related contextual images at the same time without enlarging the space occupied by the specified group.

4. DESIGN.

While the computer offers many processing and communication benefits to the medical imaging field, image presentation on the computer screen still poses a problem. We chose five design directions in order to address the presentation issues: Metaphor, Structure, Windowing, Workspace and detail-in-context. The first two provide the framework of the design and comply with guidelines determined by work in the field of Human Computer Interaction [18, 19, 20, 21, 22] while the later three address requirement categories in general. Windowing techniques are used to address the control aspects of the requirements and provide control and flexibility of material displayed on the screen. Windowing techniques have already solved many user control issues for the presentation of information on the computer screen and can easily be adapted to incorporate desirable interactive grouping features. Windows containing the set of images pertaining to one scan (scan-image-set) and windows containing images selected by the user from multiple sets (user-defined-image-set) are defined. The workspace concept is used to provide access to image set overviews and addresses the navigation aspect of the requirements. Workspaces or *views* help organize the work area and facilitate navigation of images and image-sets. Examples of research in this area can be found in [1, 23, 24, 25]. Finally, detail-in-context (distortion) techniques are explored to address the detail-in-context requirement category and provide layouts without sacrificing content. We would like to apply detail-in-context techniques to the scan-image-set and the user-defined-image-set as well as to the entire screen. This direction and is further examined and is the focus of this paper. For a more complete discussion of design directions see [26].

4.1 Detail-in-context

The traditional light screen provides a large and flexible display space, while the computer screen limits the number of images that can be displayed effectively. Depending on the computer screen size, once the number of displayed images exceeds some maximum, the image size must be decreased and detail is lost. Current systems rely on standard zooming and panning techniques in combination with large screens or multiple computer screens. Magnifying one image using standard zoom can recapture detail but sacrifices context. Increasing the available computer display space postpones the inevitable conflict between presenting detail and maintaining context but does not resolve it. Furthermore, large or multiple screens are expensive and often not an option for smaller hospitals or for use in remote consultation. We examine existing detail-in-context techniques (DCTs) in order to address this problem. By using such a technique, selected images can be emphasized while other images remain visible but are de-emphasized.

DCTs are complex, vary somewhat in functionality and produce widely different presentation results (See Section 2). These techniques emphasis some data elements and de-emphasis others, using different transformations. Since each emphasis transformation must visually manipulate the data, all DCTs distort the original view in some way. In order to determine the technique best suited to our application, DCT attributes are examined in light of current criteria. We limit the discussion by first constraining three fundamental parameters to suit our application, then discussing the remaining distortion parameters only as applicable. See [26] for the complete analyses of DCT parameters.

4.2 Fundamental parameters

The following three fundamental parameters are constrained by the nature of the MRI data and are discussed initially: emphasis transformation and resulting fundamental distortion; data element best handled by the technique; and capability to emphasize more than one data element at a time. Other presentation distortions are based on these fundamental parameters.

4.2.1 Fundamental-distortion types

The emphasis transformation used by a DCT determines the *fundamental-distortion* of the presentation. From Section 2 we know that data manipulation is achieved by: scaling, where focal areas are enlarged and contextual areas shrunk; by filtering, where contextual areas are hidden; or by abstraction, where contextual areas are abstracted or nested. Each of these results in a distortion and we use these to define fundamental-distortion types. Table 1 summarizes the fundamental distortion types.

Table 1: Emphasis transformation and resulting fundamental distortions

Scaling	Size of focal area is increased while size of contextual areas are decreased
Hierarchical-clustering	Focal area is presented more concretely and contextual areas are further nested and abstracted.
Filtering / thresh-holding	Focal area is entirely visible while parts of contextual data are hidden.

Due to the sensitive nature of medical image data, we cannot abstract the data in any way that will render it unrecognizable or which will obscure the image segmentation used by the radiologists in the analysis. For this reason scaling is the only the fundamental-distortion type that is acceptable. The rest of this discussion is relevant to scaling distortions only.

4.2.2 Data-element types

We define fundamental data elements, *point*, *region* and *node*, from a presentation perspective. These elements are typically either *focal*, the elements of interest, or *contextual*, elements having contextual value and which do not require detailed representation. Point data is usually involves an image where pixels relate to each other by forming a picture that is recognizable to the user. An example of this is a geographical map. Region data can be defined as areas which do not overlap and which are not separated by any space. When regions are used as data elements, variation of distortion can only be applied by region. In other words distortion is uniform across the region. An example of this type of system is the bifocal display [1]. Finally a node is a separate entity in itself. Node data are separated by some space and represent a complete concept or picture. Nodes are typically used in presentations that involve graph structure layouts. As with regions, distortion of nodes can only be performed on nodes and distortion within a node is uniform.

MR images must be treated as separate entities and manipulated as such. Therefore the data element type for the current application is a Node. We further use the term *focal nodes* when referring to images that are scaled up or magnified, and the term *contextual nodes* when referring to those nodes that are scaled down.

4.2.3 Number of focal elements

Some DCTs allow for multiple focal elements while earlier techniques recognized only a single focal element. From Section 3 we know that the analyses of MRI includes comparison of two or more images and we assume the necessity of multiple focal nodes for the rest of the discussion.

4.3 Distortion parameters

Two distortion types which result from the three fundamental parameters are the following: relative distortions based on the relations between data and positional distortions based on the position of the data.

4.3.1 Relative distortion types

The Scaling fundamental-distortion can result in two *relative-distortions,* Relative-size-distortion and Shape-distortion. Relative-distortions are distortions of properties which rely on the relationship between data elements or between different aspects of any given data element. When some elements are scaled to a different degree than other elements, relative size is lost and a Relative-size-distortion created. For example, all contextual nodes are the same size in the original view but are of different sizes in the scaled view. Meanwhile, shape of an element can be distorted when one dimension of the element is scaled to a greater degree than the other dimension (e.g. if a square is doubled in the horizontal direction and tripled in the vertical direction the resulting rectangle is no longer square).

We define Size-distortion within focal nodes and within contextual nodes but not among focal-nodes and contextual-nodes, which by definition are scaled to different degrees. Table 2 summarizes relative distortions.

Table 2: Relative distortions

Relative-size-distortion	Relative size between nodes has changed. For example, nodes that were originally the same size are now different sizes.
Shape-distortion	Relative dimensions of a node have changed changing the shape of the node.

4.3.2 Positional distortions

Misue [4] explains how the preservation of the positional relations, *orthogonality* and *proximity* (See Section 2), facilitate the preservation of the "mental map" that the user creates. We add *parallelism,* a term used in [8] with respect to graph layouts, and *white-space* to possible positional distortions. Parallelism refers to the lining up of nodes in straight lines through their centers and white-space refers to space which is not utilized. Positional distortions are summarized in Table 3.

Table 3: Positional distortions

Orthogonality-distortion	Right/left, up/down relations not maintained.
Proximity-distortion	Near and far relations are not maintained.
Parallelism-distortion	Data elements whose centers lined up in straight lines in the original view, no longer do. This distortion is sometimes considered as part of the orthogonality property. In this case the orthogonality is said to be "strict".
White-space-distortion	White space versus used space ratio has changed. It is not possible to eliminate this distortion as DCTs by nature utilize space in a different manner from the original view. Usually manifests in poor space utilization and redundant white space.

4.3.3 Suitability variables

From the above classifications we have the following list of suitability variables for use in matching a DCT to a specific application.

<u>Fundamental distortion types:</u> {magnification, hierarchical clustering, filtering}
<u>Data element types:</u> {point, region, node}
<u>Number of focal elements:</u> {single, multiple}
<u>Relative distortion types:</u> {relative-size-distortion, shape-distortion}
<u>Positional distortions:</u> {orthogonality, proximity, topology, parallelism, space utilization}

4.4 Suitable criteria for MRI presentation

Table 4 shows the fundamental parameters that were chosen to suit our specific data requirements. From Section 3 we also know that sequential positioning of images and maintenance of positioning information are very important to the MRI analysis task. We interpret this as a need to preserve orthogonality and maintain at least some parallelism of the layout. Due to the sensitive nature of this task, we believe that layouts should furthermore be as simple as possible and avoid the complexity created relative size distortions. In particular, focal nodes do not tolerate this type of distortion as images of interest are by nature those which are compared to each other. Similarly, in order to not distort aspects of the medical data, MR image shape cannot be distorted. Finally we would like to reduce white space in an effort to both maintain simplicity of layout and also to utilize as much space as possible thereby allowing the images to be as large as possible. In Table 5 specific distortions are rated as: Not acceptable, Minimally acceptable or as Acceptable.

Table 4: Fundamental parameters of MRI presentation requirements.

Suitability Variable	Chosen Value
Fundamental-distortion	Scaling
Data	Node
Number of Focal Nodes	Multiple

Table 5: Distortion acceptability for MRI presentation requirements.

	Acceptable	Minimally acceptable	Not acceptable
Relative-distortion		Relative-size-distortion,	shape
Positional-distortion	proximity	parallelism, white space	orthogonality
Distortion levels	dual	contextual-nodes-multi-distortion-level	focal-nodes-multi-distortion-level

4.5 Computational choice

The SHriMP [8] approach was chosen as most suitable to our application. SHriMP focuses almost exclusively on criteria that are relevant to MRI. The Orthogonal Variant of SHriMP complies with most of the layout requirements described in the above section. It uses scaling for emphasis, operates on discrete objects (or nodes) and can easily be implemented to provide multiple focal nodes. The individual objects are manipulated without distortion, ensuring that the image shape is not changed. SHriMP also preserves orthogonal relationships in a manner that preserves parallelism completely and maintains relative size among nodes. See Figure 1 (a) for example of SHriMP layout.

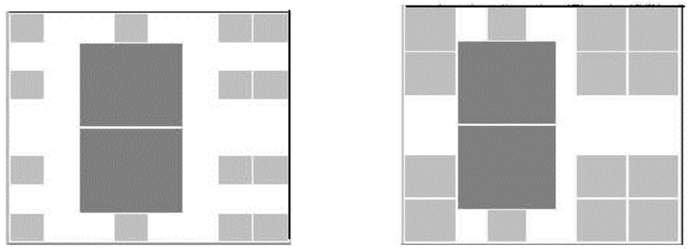
4.5.1 Alternative Approaches

In order to address the unique aspects and requirements of the current application the following alternative approaches are proposed and discussed. Although in the SHriMP Orthogonal Variant shape of both focal and contextual nodes, relative size, orthogonality and parallelism are maintained, space utilization is poor leading to white-space distortion. As relative-size and parallelism distortions were classified as minimally acceptable, we can work to trade these off against white-space problems. The following describes the SHriMP Orthogonal approach and two alternative approaches which address the white space issue. These were first presented in [15].

4.5.1.1 Space preserving approach

We look first at an intuitive approach to utilizing white space. shows first the layout resulting from the SHriMP algorithm and second a possible alternative in which contextual nodes are larger. The SHriMP variant results in redundant white space that could be utilized by some, though not all, of the contextual nodes. For example, in Figure 1 nodes which are compressed towards the top (or bottom) of the grid must shrink as focal nodes expand. However, the remaining contextual nodes do not suffer from the same restrictions and can remain larger (Figure 1(b)). In the original algorithm (a) all contextual nodes conform to the minimum sized nodes and are of equal size while in the alternative approach (b), contextual nodes are of two sizes. We have sacrificed some relative size in order to gain space utilization and increase in size of some contextual nodes.

Unfortunately, sacrificing relative size also leads to deterioration of parallelism. We can see by the figures that as we maximize use of space and increase number of node sizes, the centers of the nodes no longer line up. This can quickly lead to an unacceptable complexity in the resulting layout and it is necessary to be careful about the tradeoff between space usage and layout complexity.



(a) SHriMP Variant 1 (b) Alternative

Figure 1: (a) shows the original SHriMP Variant and (b) shows the alternative space preserving approach.

4.5.1.2 Constrained areas

This approach relies on constraining the area which is affected by the algorithm. Subsections of the grid are isolated to act independently of each other. Magnification and scaling may occur in one section but not in others. By eliminating existing focal nodes from further active sections, these focal nodes are not resized when a new focal node is magnified. In this way the focal nodes can be set to equal size even when selected sequentially. Figure 2 shows a 4 X 4 grid with first one section and focal node selected and then a second section and focal node selected. Note that nodes outside of each section are not affected and that the focal nodes are the same size. It is possible using this variation, to maximize space preservation as many of the nodes need not scale down at all.

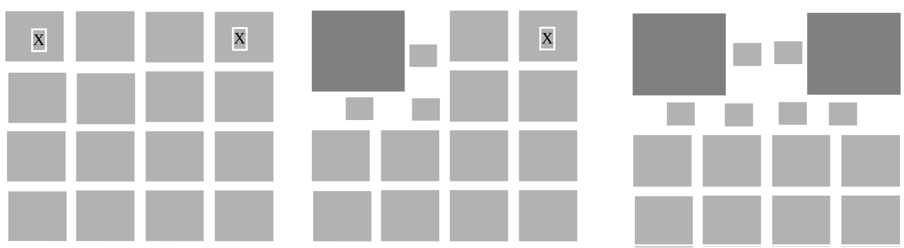


Figure 2: Two focal nodes selected and expanded in turn within constrained areas

5. USER STUDY

A user feedback study was conducted in order to gather preliminary information to guide the future direction of MRI presentation on the computer screen. For the purpose of this paper we are mostly interested in the results relating to the detail-in-context aspect of the proposed design. For complete study results see [26].

5.1 Method

The study took place at the Vancouver General Hospital, University of British Columbia (UBC) site in the spring of 1998. Three radiologists participated in the study. All three participants work with MRI and were available for MRI diagnostic consultation at the hospital. Due to the small number of participants the information is considered informally, serving only to indicate possible acceptance of current concepts and directions for further work.

The researcher met separately on different days with each radiologist. Sessions lasted from 30 to 60 minutes. Participants were given answer sheets that listed question numbers but not questions, and provided additional space for comments. Questions were given verbally by the researcher from a written questionnaire. By asking the questions verbally, it was possible to provide further explanation and assess whether the questions had been understood. This was necessary because radiologists were unfamiliar with computer concepts such as windowing and detail-in-context layouts especially within the context of MRI. Additional clarification was also provided if requested by the participant. Figures were used also used to provide illustration of the concepts.

5.2 Results

5.2.1 General usefulness

General design directions including windowing, User Defined Films, Overviews and Detail-in-context techniques appeared well accepted. Comments during this phase of the study indicated enthusiasm for this overall MRI presentation approach.

5.2.2 Feasibility of visual overview

This portion of the study was implemented to judge the feasibility of displaying small versions of image-sets as study or partial study overviews. The participants were asked to specify the minimum image size, which would suffice for the following three criteria: distinguishing between contrast weight; distinguishing features of individual images; and diagnostic purpose. As expected, full size images were necessary for diagnostic purposes but distinguishing contrast and features required less than full size. Radiologists were able to distinguish some types of contrast with images as small 25 pixels squared and different features with images as small as 35 pixels squared. Radiologists were then asked to determine how many distinguishable image-sets they would like to see on the screen at the same time. Table 6 shows these numbers. Although one of the participants (#2) showed limited interest in the simultaneous presentation of multiple image-sets, the other two (#1 and #3) indicated that a number of sets on the screen would be desirable. Together, these results suggest that overview of image-sets are both feasible and useful.

Table 6: Number of distinguishable scan-image-sets radiologists would like to see in an overview

Participant	Number of distinguishable image-scan-sets
#1	All
#2	1 - 2
#3	4 -8

5.2.3 Usefulness of contextual information

Visibility requirements of contextual nodes were rated by the radiologists in order to determine the usefulness of retaining small contextual nodes along with the full sized focal nodes. Table 7shows radiologists' rankings of contextual node usefulness with respect to various degrees of visibility: visible as points only; visible and distinguishable from each other; and visible and features distinguishable. The rating scale ranged from 1 to 4 with 1 corresponding to *not useful* and 4 to *most useful*.

In general, contextual information was ranked as useful. Even the lowest level of visibility, nodes as points, was ranked as quite useful with an average ranking of 3. This indicates that node position contains information that is useful to the radiologist and that points could be useful as references to particular images. Numbers increase slightly as contextual visibility criterion tightens. The fact that all categories were considered useful indicates that contextual information can indeed be beneficial to the radiologists.

The radiologists were also asked to rank the usefulness of maintaining relative positions (orthogonality and parallelism) of nodes. This was ranked quit high with an average rating of 3. This result supports the validity of positional information and explains why images visible only as points contain useful information.

Table 7: Contextual nodes visibility usefulness rankings from 1 (not useful) to 4 (most useful).

Participant	Visible as points	Distinguishable from each other	Features distinguishable
#1	3	4	4
#2	2	2	3
#3	4	4	4
Average	3	3.33	3.66

5.2.4 Detail-in-context Norms

In order to determine future direction of this work it was important to understand possible norms in the usage of a detail-in-context image presentation system. The following results were gathered to this end.

5.2.4.1 Focal selection

Users were asked to rate usefulness of sequential versus random focal selection. Sequential selection refers to the selection of focal nodes in sequence as they are placed in the image set. For example, in a window where image 0 is in the top left hand corner and image n-1 is in the bottom right hand corner, images 11 to 14 would be in sequence. Random selection refers to the selection of images that are not in sequence. For example, images 3, 6 and 18 in the above example would not be in sequence. Usefulness of sequential and random selection of focal nodes was expected to differ between scan-image-sets, which have an inherent order and user-defined-image-sets, which do not have an inherent order and therefore these categories were assessed separately. Table 8 shows the radiologists' ranking for sequential and random focal selection for both scan-image-sets and user-defined-image-sets. The rating scale ranged from 1 to 4 with 1 corresponding to *not useful* and 4 to *most useful*. Both sequential and random focal node selection was rated as useful.

Table 8: Rankings for sequential and random selection of focal images: from 1 (not useful) to 4 (most useful)

	Scan-image-sets		User-defined-image-sets	
Participant	**Sequential**	**Random**	**Sequential**	**Random**
#1	4	4	4	4
#2	4	2	4	3
#3	3	3	3	3
Average	3.66	3	3.66	3.33

5.2.4.2 Number of focal nodes

This section deals with the number of focal nodes that the radiologists would like to select from an image-set. Radiologists were questioned both with regard to scan-image-sets and user-defined-image-sets. Table 9 shows that on average about three focal nodes would likely be selected.

Table 9: Number of images the radiologists would like to magnify.

Participant	Number of magnified images in a scan-image-set.	Number of magnified images in a user-defined-image-set.
#1	3 - 4	2 - 4
#2	4	2 - 4
#3	1 - 4	2 - 4

5.2.5 Layout approach preference

The three layout approaches described in Section 4.5 were compared for preference by the radiologists. Nine different configurations of MR images using each of the three layout approaches, SHriMP , Space Preserving and Constrained Areas, were presented to the radiologists for comparison and comments. Table 10 shows how many of each layout approach were chosen by the radiologists. Layout approaches are described in Section 4.5.1.

Table 10: Layout comparisons: Total number of each layout chosen.

A: SHriMP	B: Space Preserving	C: Constrained Area
4	3	12

In general, the participants objected to white space and layout C, which has better space utilization, was chosen more often than layouts A and B. However, for some configuration sets, layouts A and B were able to improve white space minimization as well as obtain minimal complexity by preserving orthogonality, parallelism and relative size. Even though layout C still displayed better minimization of white space for these configuration sets, it was more complex having sacrificed parallelism and relative size of context nodes to an unacceptable extent. In these cases, layout C was not chosen. Although white space minimization was a prime concern, a certain amount of white space was better tolerated than complexity of parallelism and relative size. It was further commented by the participants that by simply making the "white space" black, acceptability of unutilized space would improve.

6. DISCUSSION AND FUTURE WORK

In general we found that the presentation of MR images could be accomplished in a manner that provides control and flexibility by using windowing and workspace concepts. Maintaining contextual information along with detailed information was also examined and found generally useful although the manner of displaying both detail and context remains a challenge. In particular, it was found that MRI presentation was suited only to DCT techniques which apply scaling transformations, manipulate node data and provide multiple focal nodes. Study results also indicated that the detail-in-context algorithm should support up to four focal nodes and both random and sequential selection of focal nodes.

It was further hypothesized that orthogonality and multiple levels of scaling among the focal nodes were not acceptable to MR image display and that relative size and parallelism could be traded off in return for a more suitable utilization of space. The algorithm SHriMP was chosen as most suitable and the elimination of white space an objective for alternative approaches based on this algorithm. The initial user study indicated that white space was indeed an important issue and of much concern to the radiologists. However, other layout complexities such as parallelism and relative size could not be traded off indefinitely.

An algorithm based on the space-conserving alternative and on study results was developed. Future work includes feedback to the current algorithm, further refinement of layout algorithms and screen presentations, and more extensive user studies to further determine desirable and undesirable elements of proposed solutions.

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