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# Exploring presentation methods for tomographic medical image viewing

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## Abstract

This paper explores the presentation of tomographic medical images on a computer screen. Limitations of the computer screen are apparent, as even a very large computer monitor cannot display an entire study consisting of dozens of images at once. Our objective is to propose filmless computer presentation methods for these images, in particular for magnetic resonance images. First, we observe the magnetic resonance image analysis task in the traditional light screen environment where presentation of many images has always been possible. We then propose solutions for meeting requirements in the computer environment. After implementation of these solutions we obtain user feedback on alternatives in order to determine feasibility and preference.

Observations reveal three requirement categories: user control of film management, navigation of images and image series, and simultaneous availability of detail and context. We developed a framework of detail-in-context-technique parameters for the purpose of viewing tomographic medical images and presented our solution directions to the radiologists for feedback. Results from the user feedback study support the feasibility of the proposed approaches and clearly indicate the importance of presentation issues in the development of medical imaging viewing systems.
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*Keywords:* User interfaces; User-centered task analysis; Tomographic MRI medical image viewing; Screen real estate problem; Detail-in-context

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## 1. Introduction

Medical image-viewing stations and digital picture archival and communications systems (PACS) are becoming commonplace in larger hospitals and beginning to infiltrate

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into smaller hospitals and private clinics. This move towards computerized image viewing is motivated by several factors. Medical image display systems can assist with image analysis by providing intelligent manipulation and processing of the image data; images are more readily retrieved and displayed when they are electronically stored, and on-line images can be exchanged and shared among hospital departments and between remote locations.

Traditionally, medical images are printed onto film for analysis and viewing. Utilizing the computer for these tasks involves displaying digital image sets on the computer screen instead of displaying films on a traditional light screen (see Fig. 1). Computer image viewing systems can provide a variety of 2D and 3D representations of tomographic image data and can facilitate interpretation by filtering and enhancing image data to highlight information. Many tomographic imaging modalities where sections of an object are imaged, such as magnetic resonance imaging (MRI) and computer assisted tomography (CAT), result in multiple sets of image series, which may vary in contrast, orientation and location. These images and series of images each provide relevant information to the study and must be presented to the radiologist quickly and intuitively. In addition to image rendering, the layout, ordering and prioritization of related images must also be addressed. It is here that the limitations of the computer screen become apparent, as even a very large screen cannot display an entire set of MR image series at once. The analysis of MR image films on the traditional light screen evolved with no such limitations and warrants consideration.

Hence, to understand better the issues involved in presenting tomographic images on a computer screen, and in particular, MR images, we conducted a preliminary study of traditional MRI analysis using films on the traditional light screen. The resulting observations provide insight into MRI viewing criteria and these criteria in turn drive solutions for the presentation of the images on a viewing station. Criteria involving user control of film management, smooth navigation of images and simultaneous availability of detail and context are converted to five design categories meant to deal with various aspects of the computer screen limitations. In particular, *detail-in-context* becomes the focus of our

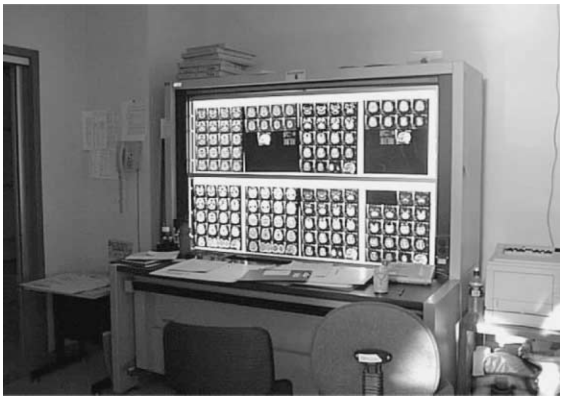


Fig. 1. The traditional light screen used by radiologists to display MR images.

work. We examined existing detail-in-context techniques and provide a framework of parameters in order to identify a detail-in-context technique to suite the MRI viewing situation. Several algorithmic variations are identified and discussed. Finally, in order to examine the viability and usefulness of the work to date, a user feedback study was conducted.

The paper is organized as follows: Section 2 describes related work. Section 3 describes our observations of radiologists in a traditional film environment. Section 4 discusses how these observations have guided the future direction of MRI presentation on the computer screen. Section 5 applies these observations to the development of criteria for MRI detail-in-context viewing. Section 6 briefly outlines the algorithmic variations that we implemented. Section 7 describes the initial user feedback study on design solutions, focusing on those aspects relating to detail-in-context. Section 8 presents our conclusions.

## 2. Related work

### 2.1. The screen real estate problem

The screen real estate problem can be described as the problem of presenting information within the space available on a computer screen. Typically the desired information must be compressed, abstracted, or otherwise distorted to fit into the relatively small area. The problem is common to many different applications and solutions vary depending on the domain requirements. Literature from visualization, graph layout, database, and human–computer interaction domains all offer insight to different aspects of this problem. A common screen real estate problem is the issue of providing contextual information concurrently with essential detailed information. Scaling can be used to enlarge detail and shrink context, while abstraction, especially in the form of filtering and hierarchical clustering, can selectively hide contextual data thus allowing more space for the detailed data. Early detail-in-context techniques provided one item of interest (focal point) with full detail, while the other items were distorted in some manner to fit the remaining space [7,12,18]. While these early techniques allowed only one focal point, most current approaches allow multiple focal points. Other approaches include the use of clustering techniques [1,16,19], radial magnification [4], and continuous zoom [2]. Some approaches [12,17] distort shape and relative size, while others [19] do not. See [10,13,14] for full details of taxonomy, comparison, and discussions of distorted presentation techniques.

### 2.2. Medical image viewing

Medical picture archiving and communications systems (PACS) are systems that deal, in general, with all aspects of the transmission, storage, processing and display of sets of digital image files. All PACS require some facility for presenting one or more images that may provide insight into image presentation techniques. However, most studies of PACS focus either on the perceptual issues such as described by Krupinski in [9], or on the general usability of the whole system through user-centered studies described by Erickson and Kossack [6].

For applications where generally only one image is examined at a time, sub-windows are often used to display relevant versions or portions of the image [3,8,20]. Sub-windows are also used to display related images or display different planar views and 3D-volume rendering [3]. Sub-windows can be coupled so that user action in one is reflected in the others [20]. Volume sets of tomographic images (as in MRI and CAT) are generally presented in two layouts, tiled and stacked. In tiled mode it may be necessary to use scrolling techniques [11] in order to view all of the images if there are too many. In stacked mode, consecutive 2D slices can be stacked over each other to produce a so-called ‘‘cine’’ mode [15] where a 3D volume of 2D slices is viewed in succession in an animated manner. In cine mode only the current (top) slice is visible at any given time.

All systems reviewed use some form of magnification but many restrict this function to system-defined values and increments [5,24]. Beyond 2D presentations of images, 3D rendering [3,8,15] and 3D reconstruction [3,15] are also used for viewing and browsing. None of the systems investigated maintain the context of the images on the screen while magnifying a specified image or portion. Our earlier work related to visual representations of magnetic resonance images is reported by van der Heyden and coworkers [21,22].

## 3. Initial user observations

A task-centered design approach was taken to observe and understand real representative tasks pertaining to the analysis of tomographic MR images. A series of informal discussions with radiologists and observations of their work with MRI provided insight into the traditional light screen environment as well as the analysis process used by the radiologists.

### *3.1. Background to tomographic images*

Tomographic image sets are large because they are formed in 2D slices that together represent a volume (i.e. third dimension). This is significant because it implies that a key aspect of tomographic image viewing is the visualization of the 3D volume as represented by the slice set. We refer to any complete set of tomographic slices as a volume set. In a traditional film environment, the radiologists mentally recreate the 3D volume by envisioning the transition between each of the slices. Secondly, tomographic image groups can also consist of images of various planar orientations: axial, sagittal or coronal. Furthermore, MR volume sets can also differ by way of contrast, as parameters can be manipulated during acquisition to change the data acquisition parameters and hence the resulting tissue contrast. These contrasts reveal different tissue types and anomalies using different grey scale intensity levels and are an important factor in the identification of healthy and unhealthy tissue.

### *3.2. Field observations*

A field study was conducted at Vancouver General Hospital to understand the MRI analysis process. Informal observations of five radiologists interacting in a traditional filmoriented environment were gathered over an 8-week period using researcher field-notes and videotape data. Observations were gathered during five 1 h diagnostic teaching sessions involving both intern and staff radiologists. Question and answer sessions were also conducted with the radiologists following the diagnostic sessions to better understand the nature of the images and the diagnostic process.

The light screen panel used in this study consisted of two visible screens positioned one above the other to form a 58 in. × 38 in. display area (see Fig. 1). Displaying MR images using this traditional technology allows up to eight MRI films to be placed on the visible screens where each film measures 14 in. × 17 in. and contains 15–20 images depending on image size and shape. Other screens may also be loaded with images but are hidden from the display and must be moved into the lighted area to be viewed. Films are initially arranged on the light screen by the radiologist in training who arrives first and makes an initial interpretation. The staff radiologist arrives later to lead the final analyses. Usually the images related to one MR case study fit on two screens and thus are viewed as one continuous display area but occasionally more than two screens are required to display the images. Films are arranged according to volume sets where appropriate or according to individual preference. Films from different studies are sometimes included in the case, such as historical images for reference. Some films may also be initially excluded as not relevant.

Observations gathered from the research field-notes, video tape data, and interviews identified 13 key aspects of the MRI analysis process. These observations are summarized in Table 1, column 1.

### 3.3. *Discussion of initial field study*

An MRI study contains a large and complex set of images, involving various subsets of images with interrelations, which are important to the diagnostic analysis. Radiologists search for many types of anomalies both within an image and across related images. At the same time, comparisons among slices involve transitions from one slice to the next comparing to the "norm" in order to locate unhealthy anomalies. Sometimes, symmetry is also used in this comparison to the norm. Planar views are used to fill gaps and provide a "whole picture". Often, all of the comparisons are necessary in order to obtain a final diagnosis.

Observations and discussions reveal that all images are scanned at least once and several subgroups of images are highlighted for simultaneous viewing and comparison purposes. Permanently positioning films into subgroup clusters is not feasible since some images are used in multiple subgroups. Radiologists solve this problem by dynamically reorganizing the films when needed or physically moving around the display space to view the disconnected images. 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.

Further examination of the observations and comments from the radiologists resulted in identification of tasks and associated requirements (shown in Table 1, columns 2 and 3). These requirements can be grouped into three main categories: control, navigation, and detail-in-context.

Table 1
User observations and associated tasks and requirements

| # | Observations | Tasks | Requirements |
|---|---|---|---|
| 1 | Placing films on the light screen. | Set-up films for viewing. | Ability to choose films and film position for the session from the current case study. |
| 2 | Moving from top to bottom, right to left, of the light screen to view every image. | Scan all images. | Ability to view all films in the presentation simultaneously. |
| 3 | Pointing at images from different areas of the light screen. | Select images from different volume sets. | Ability to find and select images from any volume set. |
| 4 | Pointing at specific areas within an image, examining and sometimes measuring the areas. | Examine images closely. | Ability to view an image up close. |
| 5 | Pointing at an image while examining other images and returning periodically to the reference image. | Mark an image for future reference. | Ability to locate, relocate and mark images. |
| 6 | Pointing at several images one by one repeatedly and examining each individually in sequence. | Compare multiple images. | Ability to group related images from different films.<br>Ability to view some images in user created groups up close without losing sight of the rest of the images in the group. |
| 7 | Sweeping hand motion across an entire film especially in the initial stages of viewing. | Interpret a film as a volume. | Ability to view a volume set as a group with adequate detail. |
| 8 | Moving light panels up and down to bring images closer to the viewer. | View images up close. | Ability to view groups of images up close. |
| 9 | Moving films to a different location for better grouping and context during consultation. | Group films. | Ability to control relative position of films during session. |
| 10 | Holding film up to light panel. | View images up close. | Ability to view one or more images up close without losing sight of other images in the set or losing sight of other volume sets. |
| 11 | Removing films from the light panel. | Clear space in the display area. | Ability to control information hiding. |
| 12 | Adding films for additional information. | Add supplementary information during consultation. | Ability to add films to the session while it is ongoing. |
| 13 | Returning to view previously selected images multiple times. | Revisit image groups for more detailed inspection. | Ability to locate and relocate groups of images. |

- *Control*: Provide flexible user control over the location, size, visibility and membership of groups. This includes the ability to interactively create user-defined image groups from non-sequential images and to control group location, visibility and display size.
- *Navigation*: Ability to locate and relocate images as well as groups of images. This involves the user knowing where to find an image or image group that is of current interest.
- *Detail-in-context*: Ability to view one or more images (image groups) up close while still viewing the remaining images. This 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. Initial design solution

The information gathered from the related work and the initial observations are combined to create an initial design approach that addresses the three requirement categories: *control*, *navigation* and *detail-in-context*. The common approach to computerized image presentation is to provide an anchored display area in which a number of images are displayed. This approach is fairly rigid and does not provide the user with much control over image sequence, position or context. For example, if the user chooses four images per display, the images will appear sequentially in the display area four at a time. The user cannot position, group, hide or enlarge images as desired, and the sequence of the group cannot be changed. The display area also suffers from the detail-in-context problem. This problem is often addressed by scrolling, panning and coupled windows. However, these methods all require a shift of focus on the part of the user and this cognitive chore can be disruptive and especially undesirable when comparison of images is crucial for medical diagnosis.

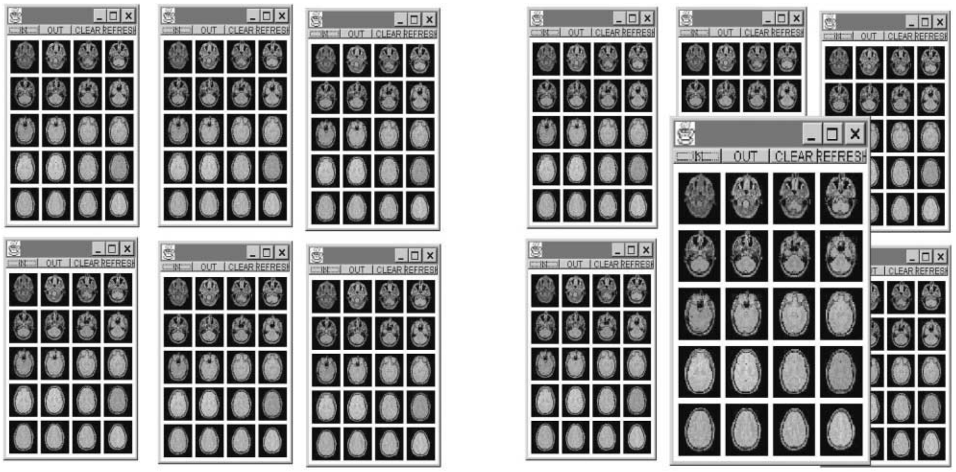
Five design directions are chosen to overcome these shortcomings and satisfy the design requirements identified from the initial user observations: metaphor, structure, windowing, workspace and detail-in-context. The adaptation of the light screen *metaphor* and existing MRI data *structure* do not directly address the requirements identified but provide a familiar theme from which to apply the other three directions.

### *4.1. Windowing*

Use windowing techniques to provide control and flexibility. This addresses the *control requirements* since windows can easily be adapted to incorporate desirable interactive grouping features. Films, which represent volume sets, are placed in windows to achieve user control of location, size and visibility components. Fig. 2(a) shows six films set up and ready for viewing. Each film has been placed in a window and can be moved, resized, closed or iconized. Fig. 2(b) demonstrates a film being enlarged. Users can also create user-defined image groups by placing individual images into an empty window as shown in Fig. 3(a)–(c).

### *4.2. Workspace*

Use the workspace concept to provide easy access to film overviews. This addresses the *navigation requirements* by organizing the work area and facilitating navigation of films.



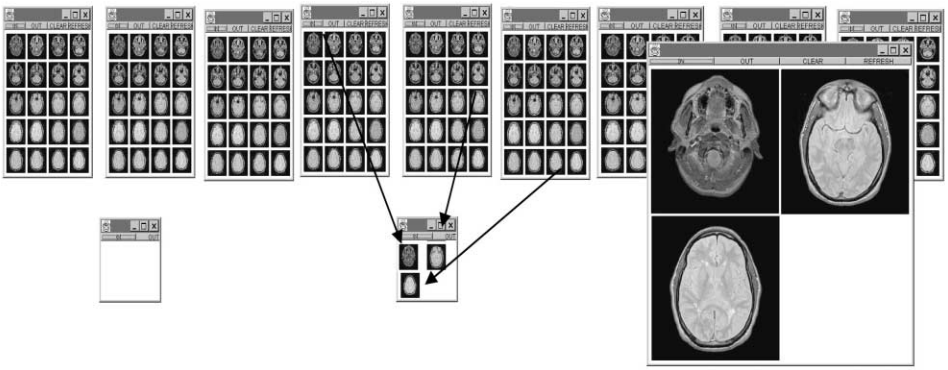
(a) (b)

Fig. 2. Volume films as windows.

Workspaces and overviews are defined to represent either the full case study or a subset of the study used in a working analysis session.

### 4.3. Detail-in-context

Use detail-in-context techniques to provide flexible image layouts that do not sacrifice contextual information. This addresses the *detail-in-context requirements* by supporting the selection of one or more ''focal'' images for enlargement and shrinking the remaining images so they remain visible but fit in the limited space. Detail-in-context requires further examination before adaptation to the problem can be attempted. Sections 5 and 6 discuss



(a) (b) (c)

Fig. 3. Creating and enlarging a user-defined group.

MRI specific criteria for detail-in-context techniques and apply these to an algorithmic solution. The feasibility and usefulness of all design proposals are investigated in the user study in Section 7.

## 5. Detail-in-context for tomographic medical images

In order to address the screen real estate problem, current medical viewing systems rely on standard zooming and panning techniques, in combination with large screens or multiple computer screens. Zooming and panning techniques can only solve part of the problem, as in order to provide space for the magnification of an image, the image context is sacrificed. Meanwhile, large and multiple screens are expensive and often not an option for smaller hospitals or for use in remote consultation. By using a detail-in-context technique, whole images can be enlarged while other images remain visible, though de-emphasized. More images can be displayed on the screen without losing image size or detail in selected images. The rest of this section examines the possibility of applying detail-in-context techniques to tomographic image viewing, particularly to MRI.

### *5.1. Framework for detail-in-context in MRI*

To develop an appropriate detail-in-context technique for MRI viewing we first develop a framework of parameters as they relate to this application. Detail-in-context techniques spatially re-organize data elements, changing the relative emphasis through different transformations. If the full context is to remain to some degree visible, an increase in scale for a selected region of the presentation has to be compensated for by a corresponding decrease in scale elsewhere in the presentation. Therefore, all detail-in-context techniques make use of some type of distortion in order to achieve the detail-in-context presentation. These distortions can vary considerably in approach and in visual effects. As a result, a particular detail-in-context technique may be more or less suited to a particular set of data and tasks. Introducing the use of distortion to viewing of medical images must be done with care. To this end, we examine distortion parameters and develop a framework of distortion effects that relates directly to MRI viewing requirements. The framework does not attempt to deal with graphical or algorithmic aspects of the detail-in-context techniques but rather is developed from an MRI application perspective. At each level of categorization the relative applicability to MRI viewing is noted and only sections relevant to MRI viewing are expanded.

#### *5.1.1. Fundamental parameters for viewing medical tomographic images*

A *normal view* [14] is a view that has not been transformed, that is a view with no enlarged focal elements, and serves as a basis from which our classifications are described. From the perspective of MRI viewing the fundamental parameters are: the basic types of distortion, the types of data elements, and the number of focal elements.

*5.1.1.1. Basic-distortion types*. Detail-in-context techniques achieve data manipulation by: *scaling*, where focal areas are enlarged and contextual areas shrunk; *filtering*, where contextual areas are hidden; or by *abstraction*, where contextual areas are abstracted or nested. In addition, it is possible to have many *levels* of distortion where each level introduces a different degree of scaling, filtering or abstraction. For 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. Furthermore, we do not want to remove images from sequences under examination. For this reason, *scaling* is the only basic distortion type that may be acceptable for our application of MRI viewing.

*5.1.1.2. Data element types*. We define the fundamental data element types: *point*, *region,* and *node*, from a presentation perspective. Point data usually involves an image where pixels relate to each other forming a picture that is recognizable to the user. An example of this is a geographical map. Region data is defined as consisting of non-overlapping areas that are not separated by any space. When regions are used as data elements, variations in distortion are usually applied by region, creating distortions that are uniform across a region. Node data elements are separated spatially and each node represents a complete concept or picture. Nodes are typically used in presentations that involve graph structure layouts. Distortion of nodes is usually performed on the nodes, and distortion within a node is uniform. Since MR images are treated as separate entities and manipulated as such, we identify node data as the fundamental MRI data type. These data elements are typically either *focal*, the elements of interest, or *contextual*, elements having contextual value which do not require detailed representation. A *focal node* refers to a node that is scaled up or magnified, and *contextual nodes* refer to those nodes that are scaled down.

*5.1.1.3. Number of focal elements*. Some detail-in-context techniques support multiple focal elements while earlier techniques recognized only a single focal element. Since the analyses of MRI includes comparison of two or more images we assume the necessity of multiple focal nodes for the rest of the discussion.

### *5.1.2. Expanding the scale basic-distortion parameter*

*5.1.2.1. Relative-distortion types*. Scaling can result in two relative-distortions: *relative-shape-distortion and relative-size-distortion.* Relative-distortions are distortions of properties which rely on the relationship between data elements or between different aspects of any given data element. Relative-shape-distortion occurs when the shape of an element is distorted. For instance, this can happen when one dimension of the element is scaled to a greater degree than the other dimension. Relative-shape-distortions are unacceptable in medical images as the preservation of aspect ratio is very important. Relative-size is a relation between data elements. When some elements are scaled to a different degree than other elements, uniform relative-size is lost and a relative-size-distortion is created. Therefore, in terms of scaling, only relative-size-distortions are acceptable.

*5.1.2.2. Positional-distortion types*. Positional-distortions are changes in the spatial organization of data elements are defined with respect to the normal view. Misue et al. [13] explain how the preservation of positional relations across a distortion transformation may facilitate the preservation of the ‘‘mental map’’ that the user creates. They identify

Table 2
Positional-distortions

| Type of positional-distortion | Description of effect of distortion |
|---|---|
| Orthogonality-distortion | Right/left, up/down relations are not maintained. |
| Proximity-distortion | Near and far relations are not maintained. |
| Topology-distortion | Inside/outside relationships are not maintained. |
| Parallelism-distortion | Data elements that lined up in straight lines in the original view no longer do. This distortion can be considered as part of the orthogonality property. In this case the orthogonality is said to be "strict". |
| White-space-distortion | White space vs. used space ratio has changed. Usually manifests in poor space utilization and redundant white space. |

three such relations: *orthogonality*, *proximity* and *topology*. We add *parallelism*, a term used in [19] with respect to graph layouts, and *white space* to possible positional-distortions. Parallelism refers to the alignment of the images, in particular keeping image centers in a given row or column in a straight line. White space refers to the amount of space that is not utilized by either the focal nodes or the contextual nodes (for radiologists, this is actually black). Positional-distortions are summarized in Table 2.

Sequential positioning of images and maintenance of positioning information are very important for the MRI analysis task. We interpret this as a need to preserve orthogonality and maintain at least some parallelism. Therefore, positional-distortions that affect orthogonality of the layouts are considered unacceptable and while it is possible that small adjustments in parallelism may be acceptable, we will endeavour to minimize these. Further, distortions that affect proximity are only minimally acceptable in that we will allow the distances between nodes to change but not which nodes are adjacent to which. Topological changes such as overlapping are not considered acceptable. 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 thus allowing the images to be as large as possible.

*5.1.2.3. Distortion levels.* We define a distortion level as the degree of occurrence of a fundamental distortion, which, for this discussion is the degree to which a node has been scaled. Table 3 outlines the distortion levels. The difference between *dual-level-distortion*, exactly two levels of distortion, and *multi-level-distortion*, is considerable when judging its suitability. Often multi-level-distortions attach a weight to data elements that is related to the element's distance from the focus. As relative scale is applied according to this weight, this can result in constantly changing the degree of scaling across the contextual elements.

Table 3
Distortion levels

| Type of distortion levels | Description of distortion |
|---|---|
| Dual-level-distortions | Two distortion levels, one for focal nodes and one for contextual nodes. |
| Focal-node-multi-level-distortions | More than one distortion level among focal nodes. |
| Contextual-node-multi-level-distortions | More than one distortion level among contextual nodes. |

Table 4
Distortion acceptability for MRI presentation requirements

| Type of distortion | Acceptable | Minimally acceptable | Not acceptable |
|---|---|---|---|
| Relative-distortion | | Relative-size-distortion, | Relative-shape-distortion |
| Positional-distortion | Proximity | Parallelism, white space | Orthogonality, topology |
| Distortion levels | Dual | Contextual-nodes-multi-level | Focal-nodes-multi-level |

With a dual-level-distortion, all contextual elements are equal. Even three levels of distortion introduces an element of complexity to the resulting display.

### *5.2. Suitable criteria for MRI presentation*

Categorizing the different aspects of distortions in this manner creates a framework that aids in determining suitable criteria for the current application, MRI viewing, and in choosing a detail-in-context technique that most closely fits these criteria. Criteria include the ability to have multiple focal elements and to operate on a node data element type. The acceptability of the basic-distortions for MRI viewing is categorized in Table 4 as, *acceptable*, *minimally acceptable* and *not acceptable*.

## 6. Detail-in-context techniques for MRI viewing

From our observations, we believe that using a detail-in-context technique may address the radiologist's need to examine MR images in detail while still maintaining the contextual information from the sequence. To adhere to stringent constraints outlined in the above criteria, we examine research in computational presentation in order to find an appropriate detail-in-context technique that fulfills our MRI viewing requirements.

We eliminate a large class of detail-in-context techniques that employ continuous changes in level of distortion since this violates the requirement to minimize the number of levels of distortion. (i.e. [10,12]). Also, the Zoom family [2] is not appropriate as it allows a looser interpretation of orthogonality than would be ideal in this case. Bifocal display [18] comes closer as it has only two levels of distortion and preserves orthogonality; however, it has only a single focus.

Though developed for software engineering, the orthogonal variant of the SHriMP [19] approach provides the closest to fit to the observed requirements, as it complies with most of the layout requirements described above. SHriMP 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 other than scaling in size, ensuring that the images themselves (i.e. their shapes) are not distorted. Furthermore, SHriMP also preserves orthogonal relationships in a manner that preserves parallelism. However, in the SHriMP orthogonal variant, although the 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 are minimally acceptable, we can trade these off against white-space problems.

In order to address the unique aspects and requirements of tomographic MRI viewing, we developed several alternative detail-in-context techniques [23]. Two of these, *space-preserving* and *constrained variants,* seem promising but are also not precise matches to MRI viewing requirements.

### 6.1. SHriMP orthogonal variant

The SHriMP [19] algorithm assigns space to all nodes when one or more of those nodes have been magnified and ensures that all nodes remain within the available space and do not overlap. This algorithm limits distortion to scaling only and each node maintains its shape. This description is of one variant of the algorithm that maintains the orthogonality. All SHriMP variants are based on the principle of pushing nodes into a preliminary position in order to allow room for the focal node(s) and then scaling all nodes around the center point of the grid in order to fit them into the given space (see Fig. 4).

Storey [19] describes the translation vector [*Tx,Ty*] that pushes each node away from the focus. This vector can be found on a coordinate system where the origin is placed in the upper left-hand corner by partitioning the space into nine partitions, regardless of the number of nodes in the grid. The algorithm is based on the scaling equations

$$x' = Cx + S(x - Cx) \tag{1}$$

$$y' = Cy + S(y - Cy) \tag{2}$$

The point $(x, y)$ is scaled around the point $(Cx, Cy)$ according to scaling factor $S$. In this case $(Cx, Cy)$ are the grid center coordinates. Including the translation vector $T$ results in

$$x' = Cx + S(x + Tx - Cx) \tag{3}$$

$$y' = Cy + S(y + Ty - Cy) \tag{4}$$

In order to scale the nodes back to within the confines of the original space, the scale factor $S$ must be set equal to the original grid size (originalSize) divided by the grid size after the nodes have been pushed (requestedSize)

$$S = \frac{\text{originalSize}}{\text{requestedSize}}. \tag{5}$$

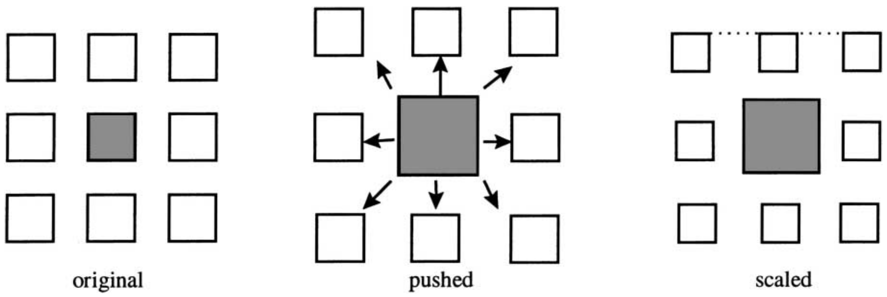


Fig. 4. Focal node is enlarged, non-focal nodes are pushed then scaled.

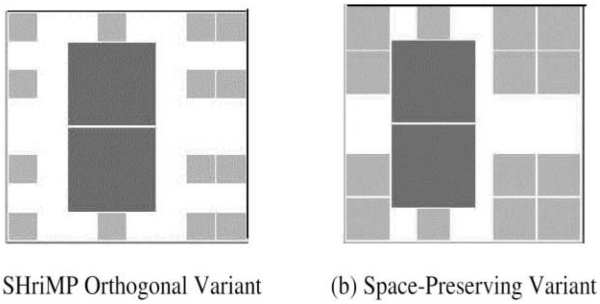


Fig. 5. (a) Shows the original SHriMP orthogonal variant and (b) shows the alternative space-preserving approach.

### 6.2. Space-preserving variant

We look first at an intuitive approach to utilizing white space. Fig. 5(a) shows the layout resulting from the SHriMP orthogonal variant algorithm and a possible alternative space-preserving variant (Fig. 5(b)) 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 Fig. 5(a), nodes directly in line with the expanding focal 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 (Fig. 5(b)). In the SHriMP algorithm (Fig. 5(a)) all contextual nodes conform to the minimum sized node and are thus of equal size. If relative-size is sacrificed we can obtain better space utilization. In the space-preserving variant (Fig. 5(b)) some contextual nodes remain larger though a relative-size-distortion has been introduced for the contextual nodes.

Unfortunately, sacrificing relative-size also leads to deterioration of parallelism. We can see by the figures that parallelism is sacrificed as we maximize use of space and increase number of node sizes. 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 image complexity.

### 6.3. Constrained variant

This approach relies on constraining the area 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 foci from further active sections, these foci 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. Fig. 6 shows a 4 × 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. However, sequential selection of foci can lead to many levels of distortion.

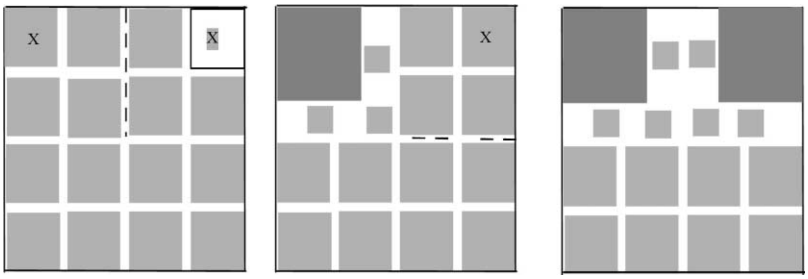


Fig. 6. Shows the constrained approach.

## 7. User feedback study

An exploratory user feedback study comparing these layout variations was conducted to address some of the issues uncovered from the initial user observations, and to guide future design directions of MRI presentation on the computer screen. The study was designed to determine the validity of the proposed design directions as well as obtain specific user feedback on issues concerning the usefulness of film overviews, user control, and presentation of both detail and contextual information.

### *7.1. Method*

The study was conducted at Vancouver General Hospital, where three male radiologists participated. All three participants work with MRI and were available for MRI diagnostic consultation at the hospital, however, it was difficult to find additional expert participants (radiologists) who could afford the time and were willing to participate in the study. 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 min. Participants were given answer sheets which 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. All questions were given in the same order for each participant.

Issues investigated in this study relate to the feasibility of MRI presentation on a computer screen related to the requirements derived from the initial user observations. It was also necessary to determine whether certain design directions (user control, navigation issues and detail-in-context) would be useful to the radiologists and usable in a MRI analysis task. The following section describes how these issues were evaluated along with the results.

Table 5
Minimal size of images to distinguish between criteria

| Distinguishing between volume sets | Distinguishing between slices | Diagnostic |
|---|---|---|
| 25–45 pixels | 35–115 pixels | Full size (256 pixels) |

## 7.2. Discussions

### 7.2.1. Feasibility

Before delving into various presentation strategies to provide both local detail information and global context within a display, it was necessary to determine whether images smaller than normal size would be useful to the radiologists. The task of MRI analysis is extremely sensitive and misleading information cannot be tolerated. Radiologists were asked to specify the minimum image size that was acceptable for three types of analysis tasks: distinguishing between volume sets; distinguishing between slices; and for diagnostic purposes. The participants were given a series of 17 MR brain image sets ranging from 25 to 256 pixels (full size) and instructed to indicate the minimum size that would fulfill the specified requirements. Table 5 summarizes the minimum image sizes selected by the radiologists for each criterion.

As expected, all the radiologists agreed that full size images were necessary for diagnostic tasks. Interestingly though, for other peripheral tasks such as distinguishing between volume sets and distinguishing between slices, the minimum sizes specified were substantially smaller than full size (25–45 pixels squared).

While the image size results indicate the feasibility of placing multiple images on the display, it was also important to address whether the radiologists would find it useful to be able to view an overview of some or all of the volume films simultaneously on the screen, and if so, how many images they would like to view. Table 6 shows the radiologists ranking with respect to the usefulness of volume set overviews and the desired number of volume sets in an overview. The participants were asked to provide a range rather than just a number. The ranking scales ranged from 1 to 4 with 1 corresponding to not useful and 4 to most useful.

The results affirmed that having some or all volume sets on the screen at one time is desirable as long as they are distinguishable from each other. Participants also indicated

Table 6
Overall usefulness of user control features[a]

| Participant | Volume set overview | Number of volume sets desired (films distinguishable from each other) | Number of volume sets desired (films diagnostic (full) size) |
|---|---|---|---|
| #1 | 3 | All | 2 |
| #2 | 2 | 1–2 | 4–8 |
| #3 | 4 | 4–8 | 4–8 |

[a] Rankings from 1 (not useful) to 4 (most useful) and the number of volume sets desired in an overview.

that it would be useful to have more than one volume set of full size images. Combined with the information gathered concerning image sizes, and volume set overviews, these results establish the feasibility and potential usefulness of presenting several volume sets on a single display.

#### *7.2.2. User control*

One of the key requirements identified from the initial user observations was user control. The traditional light screen environment provided some user control since it enabled films to be removed from the display and reorganized. Other control, however, was difficult such as the magnification of individual films or the clustering of images distributed across films. Radiologists' preferences for various control aspects were solicited through numerical rankings. The participants were shown figures to illustrate the concepts being ranked. These concepts included the ability to select, move, and magnify films and the ability to create user-defined groups comprised of images from various volume films. The ranking scales ranged from 1 to 4 with 1 corresponding to not useful and 4 to most useful. Table 7 shows the radiologists' ranking for each criterion.

All three radiologists agreed that user control over films was important for the MRI analysis task. Two of the three also indicated a strong preference for the ability to create user-defined groups of films. These results confirm our hypothesis from the initial user observations that user control would be both desirable and useful.

These results indicate that the user-defined groups might have anywhere from 1 to 8 images. This is encouraging as it verifies that the concept of user-defined groups is a useful one and that the radiologists can foresee choosing a number of images out of their regular sequence.

#### *7.2.3. Navigation and detail-in-context*

*7.2.3.1. Usefulness of contextual information*. The usefulness of retaining contextual information along with viewing full-sized focal nodes was ranked by radiologists. Table 8, column 1 shows the overall preference for having the ability to view one or more images (or image groups) up close without losing the remaining images. Columns 2, 3, and 4 show the usefulness of contextual nodes with respect to various degrees of visibility: visible as points only; visible and distinguishable from each other; and visible and features distinguishable. The ranking scale ranged from 1 to 4 with 1 corresponding to not useful and 4 to most useful.

Table 7
Overall usefulness of user control features[a]

| Participant | Ability to select move, and magnify films | Ability to create user-defined groups |
|---|---|---|
| #1 | 3 | 4 |
| #2 | 4 | 2 |
| #2 | 4 | 4 |
| Average | 3.66 | 3.33 |

[a] Rankings from 1 (not useful) to 4 (most useful).

Table 8
Usefulness of contextual nodes and overall usefulness of detail-in-context[a]

| Participant | Detail-in-context | Visible as points | Distinguishable from each other | Features distinguishable |
|---|---|---|---|---|
| #1 | 4 | 3 | 4 | 4 |
| #2 | 3 | 2 | 2 | 3 |
| #3 | 4 | 4 | 4 | 4 |
| Average | 3.66 | 3 | 3.33 | 3.66 |

[a] Rankings from 1 (not useful) to 4 (most useful).

All three radiologists agreed that detail-in-context would be a useful feature for the MRI analysis task. Even for the lowest level of visibility, nodes as points, contextual information was ranked 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.

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

*7.2.3.3. Focal selection.* Users were asked to rank the 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. Random selection refers to the selection of images that are not in sequence. The ranking scale ranged from 1 to 4 with 1 corresponding to not useful and 4 to most useful. Table 9, columns 1 and 2 show the results, which indicate that both sequential and random focal node selection would be useful.

The radiologists were also questioned on how many focal nodes they would like to select from an image-set. The results are presented in Table 9, column 3, and indicate that on average, about three focal nodes would likely be selected.

*7.2.3.4. Layout approach preference.* The three layout approaches described in Section 6 — SHriMP orthogonal, space-preserving, and constrained areas — were compared for

Table 9
Rankings for sequential and random selection of focal images[a]

| Participant | Sequential selection | Random selection | Number of magnified images in a scan-image-set |
|---|---|---|---|
| #1 | 4 | 4 | 3–4 |
| #2 | 4 | 2 | 4 |
| #3 | 3 | 3 | 1–4 |
| Average | 3.66 | 3 | |

[a] From 1 (not useful) to 4 (most useful) and number of images the radiologists would like to magnify.

Table 10
Layout comparisons: total number of each layout chosen

| A: SHriMP | B: space-preserving | C: constrained area |
|---|---|---|
| 4 | 3 | 12 |

preference by the radiologists. Six different configurations of MR images using each of the three layout approaches were presented to the radiologists for comparison and comments. Table 10 shows which layout approaches were chosen by the radiologists.

In general, the participants objected to excess white space surrounding the images and as a result chose layout C more often than layouts A and B. Layout C had better space utilization, and therefore minimal white space. However, for some configuration sets despite layout C's minimization of white space, its complexity became unacceptable. The inevitable deterioration of parallelism and relative-size of context nodes in layout C resulted in the choice of layouts A and B, in these cases. This indicates that when some threshold of complexity is exceeded, it may be preferable to sacrifice white space in favour of preservation of parallelism and relative-size.

## 8. Summary and future work

### *8.1. Summary*

This research identifies key aspects related to the presentation of magnetic resonance images (MRI) on a computer screen, focusing on the requirements dictated by the current state of MRI analysis and the feasibility and usefulness of such approaches in a computerized environment. Our observations of the MRI analysis task in the traditional light screen environment provide a good understanding of image presentation issues and requirements. These requirements highlight the importance of user control of films, easy navigation of images and simultaneous availability of detail and context. The general design directions also emphasized the use of metaphor and structure, adopted from the traditional light screen environment.

In addition to an overall understanding of the MRI analysis process, an algorithm was developed that provides both detail and context for viewing MR images, taking the nature of MRI analysis into account. The user feedback study, albeit preliminary, provided positive indications that the suggested design directions are both feasible in a standard computerized environment and useful for the MRI analysis task.

The results of this research provide a significant contribution with respect to MRI analysis on computer screens, and in general for the field of information visualization. The task-centered focus of this research, in both the design and evaluation portions of this work, provides a design direction that is closely tied to MRI analysis tasks. This methodology is essential for the development of systems that are both usable and useful. In addition, our preliminary results indicate this is a viable and prosperous direction for magnetic resonance imaging on the computer screen.

### *8.2. Future work*

Future work in this area includes controlled evaluations of the proposed design suggestions. A prototype image presentation system has been developed to gather more accurate assessments of the design directions proposed and allow radiologists to become more comfortable with the concepts. This system will be used to compare the proposed design to a typical PACS-style presentation, and to the traditional light screen display. Based on the results of this work, as well as iterative design and feedback of the prototype, we will continue to explore detail-in-context layout algorithms and new presentation requirements for medical tomographic images and MRI in particular.

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