Effective Presentation of Medical Images

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Effective Presentation of Medical Images

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The presentation of medical images should enable both accurate diagnosis and convenient use. The effective presentation of single images is discussed first, followed by issues related to presenting multiple images.

Single Images

Display Scale Uniformity

Image perception should be as independent as possible of the display medium and the particular console on which the image is displayed. A user at one display station should not perceive different information in the image than a colleague at another station examining the same image. This consistency may not be entirely realistic since the higher quality system might provide improved overall sensitivity to intensity changes. At the very least, the system should not mislead the user by providing lower sensitivity in one range of intensities than another, unless the user has explicitly chosen to sacrifice sensitivity in one range in order to obtain higher sensitivity in another.

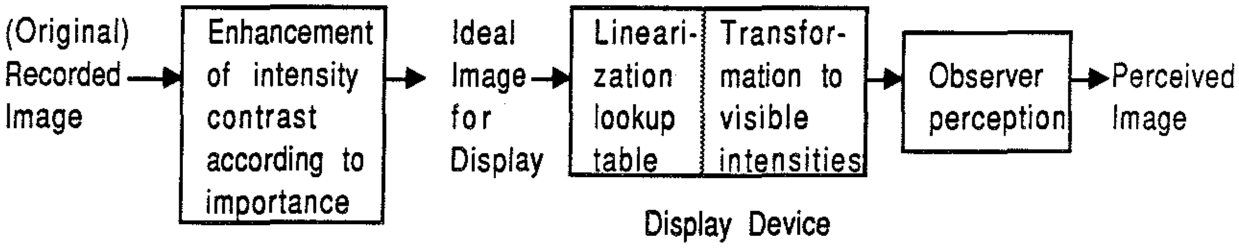

Figure 1. Image display sequence

This objective can be achieved by correcting the displayed intensities to compensate for the peculiarities of the display medium and the observer's perception. On a conventional video display system the compensation is achieved (see Figure 1) using a feature called a lookup table, giving the actual intensity to be displayed for each point on the display scale. The compensation should be chosen so that the sequence of the display and observer faithfully transmit intensity differences input to them. That is, after the digital image is in a form ideal for appreciating image contrast, the perceived image should have proportional contrasts.

We have suggested [Pizer, 1985] that fidelity between the perceived and ideal image exists when the intensity input to the display is made proportional to the perceptibility rank of the corresponding intensity in the perceived image. The perceptibility rank of an intensity is measured in just noticeable differences and gives the number of small intensity increments of equal perceptibility from the bottom of the scale to the intensity in question. A lookup table that transforms each input level to a displayed level so as to achieve this property is said to "linearize" the display/observer sequence. We have developed methods* to construct this lookup table from photometric measurements of displayed monochrome intensities, using previously acquired observer measurements of just noticeable differences (*jnd's*) or a model that predicts them.

Figure 2 shows an image displayed on an unlinearized display device and the same image displayed after linearization. Linearization makes a substantial difference. Whether the difference is an improvement or not can be considered only after image contrast has been ideally enhanced. Contrast enhancement is treated in the following section.

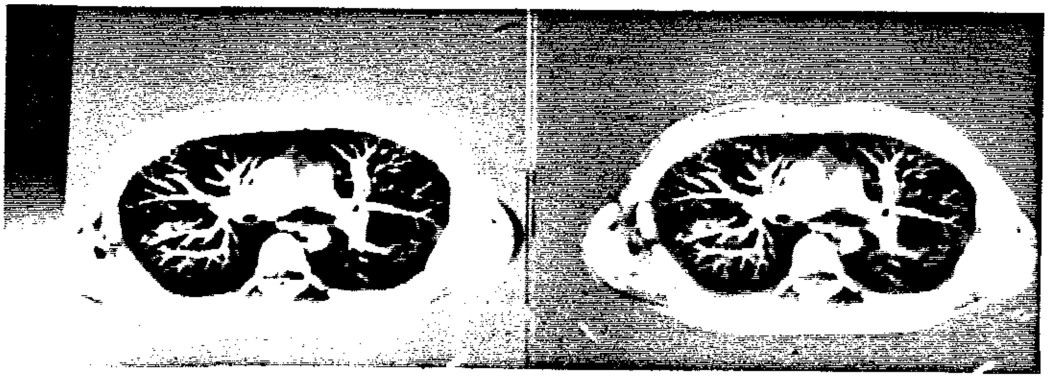

Figure 2. Unlinearized vs. linearized display

We have reported previously that the linearization required is relatively independent of observer [Johnston, 1986]. New results [Rogers, 1987] show that for CRT display, linearization is relatively independent of environmental illumination also, at least over a limited range. To measure

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*Programs in FORTRAN for producing this linearizing lookup table from photometric measurements are available upon request from the authors.

this independence, we compute the validity of using a linearization based on a set of observer jnd data from one situation to linearize in a situation characterized by a another set of observer data. The result is a value which compares the degree to which the first linearization causes the second set of jnd's to become constant, as they are when fully linearized (see Figure 3). The value expresses the average deviation from the ideal constant jnd level as a percentage of that level.

According to our measurements, the validity value comparing the linearizations required for ambient illumination of 4 lux (very dim light) and 40 lux (low room light) is 27.4%. This value is smaller than 35.0%, an inter-observer validity value, comparing the linearizations for all observers and one observer. In contrast, linearization for an ambient light of 150 lux (light resulting from uncovered light boxes) by data from 4 lux gives a validity value of 66.1%, suggesting that a separate linearization would be required for such a highly lit environment.

Some of our results indicate tentatively that the linearization required is relatively independent of the image being presented.

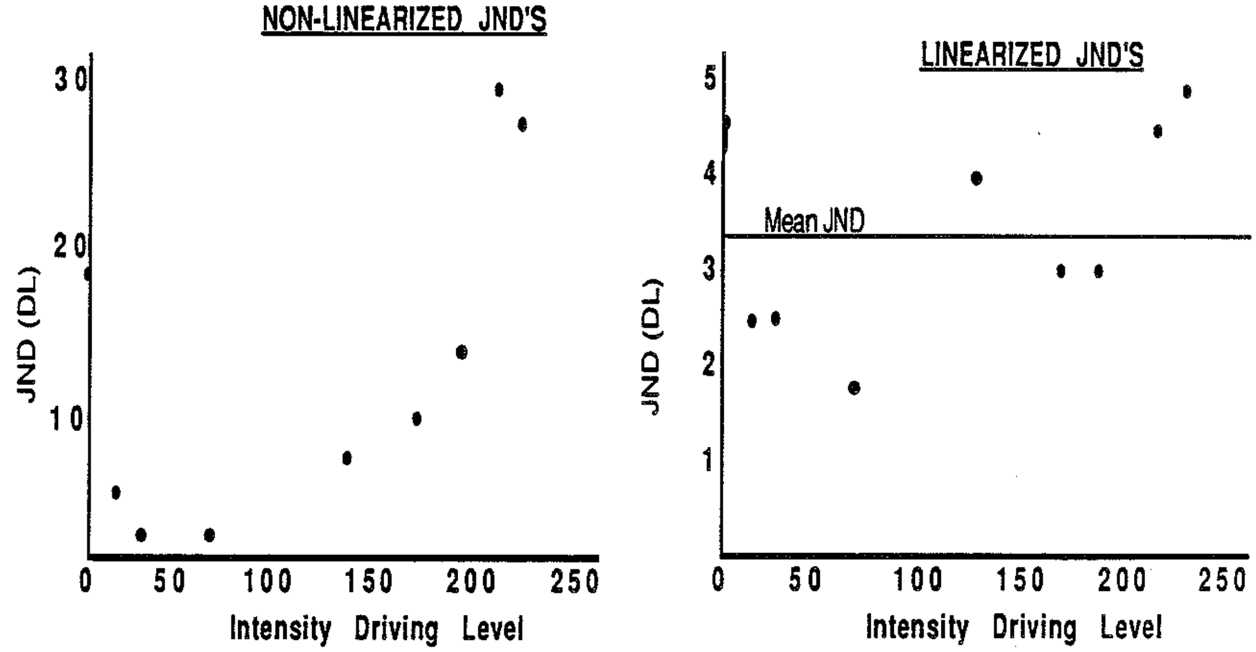

Figure 3. Validity value definition

Contrast Enhancement

Contrast enhancement should have the single goal of transmitting information in the image data most effectively, that is, making intensity differences increase with the importance of the difference. Linearization allows us to focus on this single goal for contrast enhancement, since it ensures that any differences which are input to the linearized display will be faithfully transmitted to the perceived image.

Contrast at any position in an image is perceived in relation to local image context, and not to the whole image. Hence, at each position in an image, displayed intensity should adapt to the local intensity distribution. That is, the foremost property of a contrast enhancement method should be that for each point in the image the resulting intensity should depend on a region centered at that point. We call this the *contextual region* of the point.

At each image point the objective is to maximize information transmission relative to the contextual region, subject to non-overenhancement of noise [Cormack, 1981]. If the noise properties do not vary across the image, information transmission is maximized by an approach in which each pixel is displayed at an intensity proportional to the rank of its intensity in its contextual region* [Zimmerman, 1985].

Noise overenhancement in nearly homogeneous regions is avoided by modifying the histogram before computing the rank of the center pixel in this histogram (see Figure 4). The modification involves restricting the number of pixels at any intensity to a level proportional to a specified maximum contrast enhancement [Pizer, 1987]. The final method, for which each pixel is displayed at an intensity proportional to its rank in this modified intensity histogram for a contextual region centered at that pixel, is called Contrast Limited Adaptive Histogram Equalization, or CLAHE.

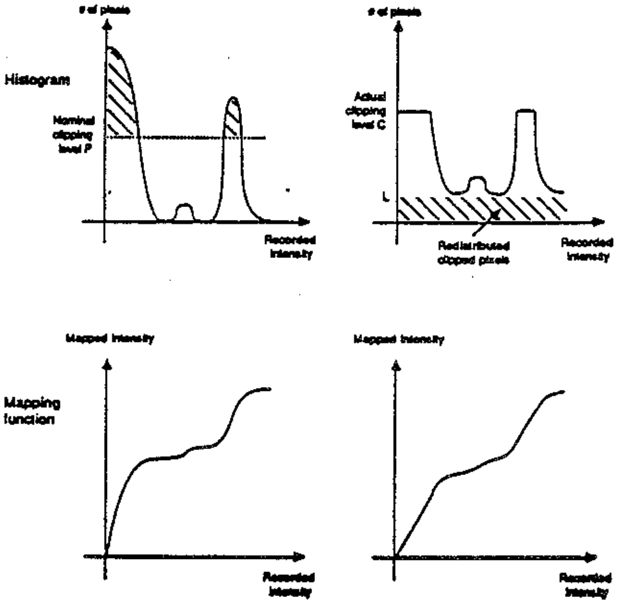

Figure 4. Clipping the histogram to achieve contrast limitation

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*This criterion is sometimes called histogram equalization, but this approach has normally been applied with the whole image as the context.

By a combination of controlled studies [Zimmerman, 1987; ter Haar Romeny, 1985] and selected trials on clinical images, CLAHE has been shown to be very effective for a wide range of medical images (see Figure 5). Included are CT images, where the effect is especially striking in studies in which it is important to appreciate contrast simultaneously in different tissue types; MRI images, in which the effect is especially useful for surface coil images because of the correction for nonhomogeneity of sensitivity with depth; portal film images from radiotherapy, in which the low contrast can be strikingly improved; and a wide range of radiographs, especially angiograms. Even for noisy images such as scintigrams and sonograms, the method provides assurance that every image shows all its useful contrast if a low contrast limitation level is used.

The wide range of images for which CLAHE is useful suggests that it can become a standard display method, available for all images produced by an imaging device or those displayed from a PACS (Picture Archiving and Communication System). Images should be stored in unprocessed form for quantitative analysis or application of another contrast enhancement method such as intensity windowing, but the first presentation should usually be by CLAHE. Since this approach allows diagnosis from a single displayed image for each set of recorded image data, it also economizes in the amount of film or CRT display area needed for any class of images for which the use of more than one intensity window is common.

For a routine application of the method, fast calculation of CLAHE is required, on the order of 1 second per 512 x 512 image or 1/2 minute per 2000 x 2000 image. A parallel computing engine, called MAHEM -- Multiprocessor Adaptive Histogram Equalization Machine -- is now under development [Austin, 1987]. For a parts cost well under $10,000, a machine can be constructed that will produce a close approximation to the final CLAHE result for a 512 x 512 image in under 0.25 sec. and will give the final result in 4 sec. Furthermore, the engine will be applicable to larger images in acceptable times.

Such a machine would allow not only storage of unenhanced images, with enhancement applied between the archive and the display, but also interactive selection of the contrast enhancement limit or the contextual region size, in the strictly limited number of cases where such control might be desired.

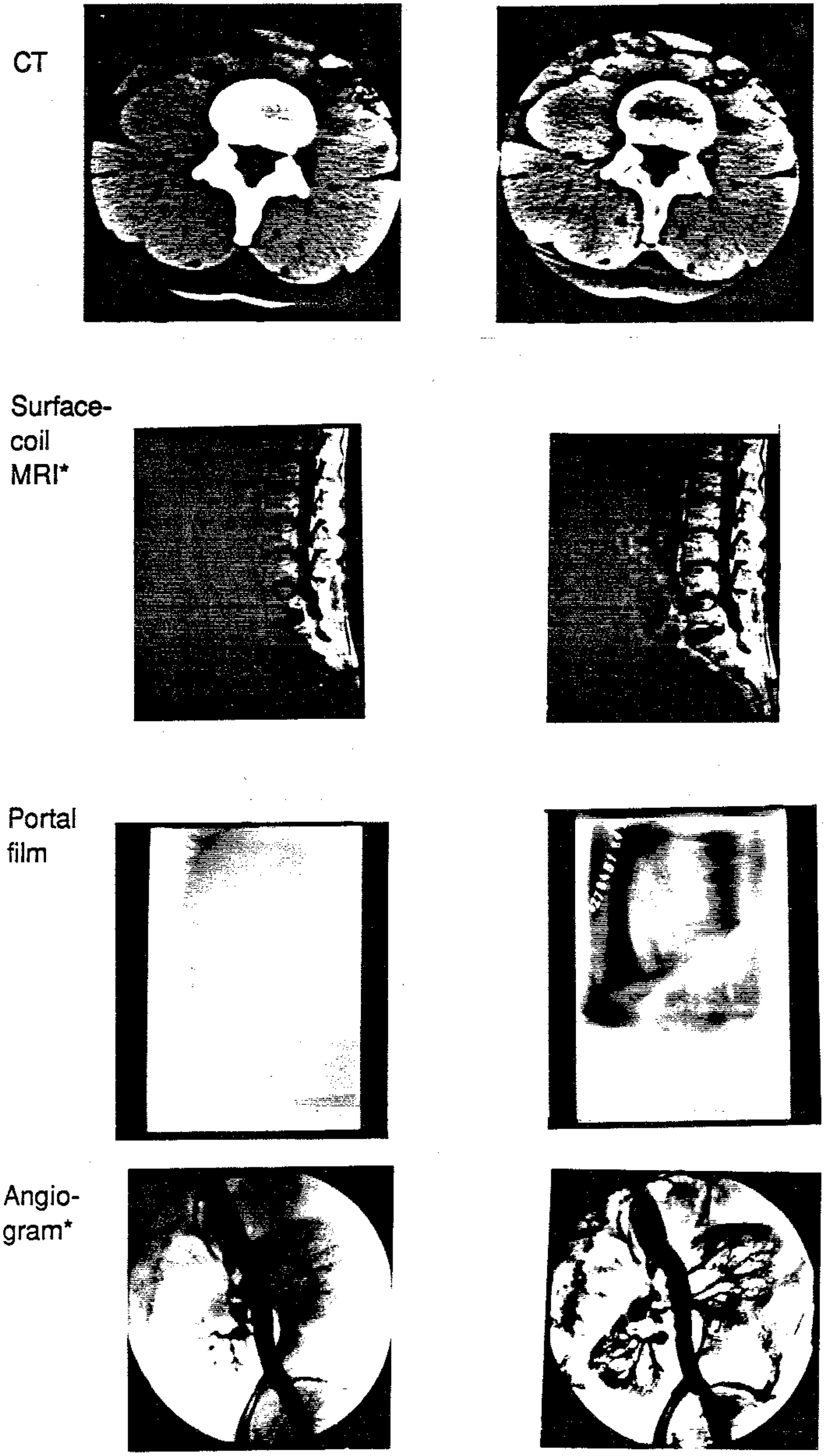

Figure 5. Examples of intensity-windowed vs. CLAHE images

*Compliments of Dept. of Radiology, State University of Utrecht

Multiple Images

With the routine use of CLAHE it is sufficient to display only a single image for each recorded image slice -- there is no need for multiple intensity windows. Nevertheless, it is necessary to provide for the simultaneous display of the multiple slices that make up a single study and the multiple studies that need comparison, e.g., from different examination times or different imaging modalities. An adequate electronic display station must have the same property as the film-based display station now in common use, of providing a convenient means of moving among image slices involved in a diagnostic or treatment planning session.

We [Rogers, 1985; Rogers, 1986] have interviewed radiologists about the needs that a display must satisfy, watched them in action, and had them report orally and point at the image they presently have under examination. These studies show that

1) Clinical evaluation often requires simultaneous use of one or more radiographs, recent multi-slice studies (say 30-slices) from perhaps two imaging methods, plus a previous multi-slice study from one of these methods. Thus many tens of images are simultaneously involved.

2) Only a few (around 4) slices from a given imaging method may be under scrutiny at a given time. They are frequently adjacent slices from the same study.

3) The entire study is needed to navigate among all the available slices. These index images need not be at full spatial sampling, however: 128 x 128 is certainly satisfactory, and in fact 64 x 64 seems satisfactory.

4) Fast access to a specified image or group of successive images is required. No more than 1 second should be needed to obtain any slice at full spatial sampling. This requirement implies that all of the images should be stored in main display memory or a very fast disk.

5) The ability to create a new set of slices from an old set to allow quick perusal or examination by a referring physician appears useful.

We are now conducting research with a number of implementations with an index screen and fast access to individual images. Some of these implementations (see Figure 6a) involve 2-3 screens with one dedicated to the index [Johnston, 1986] . Others (see Figure 6b) involve the use of a single screen with either overlaid screen windows or a pop-up index [Beard, 1988].

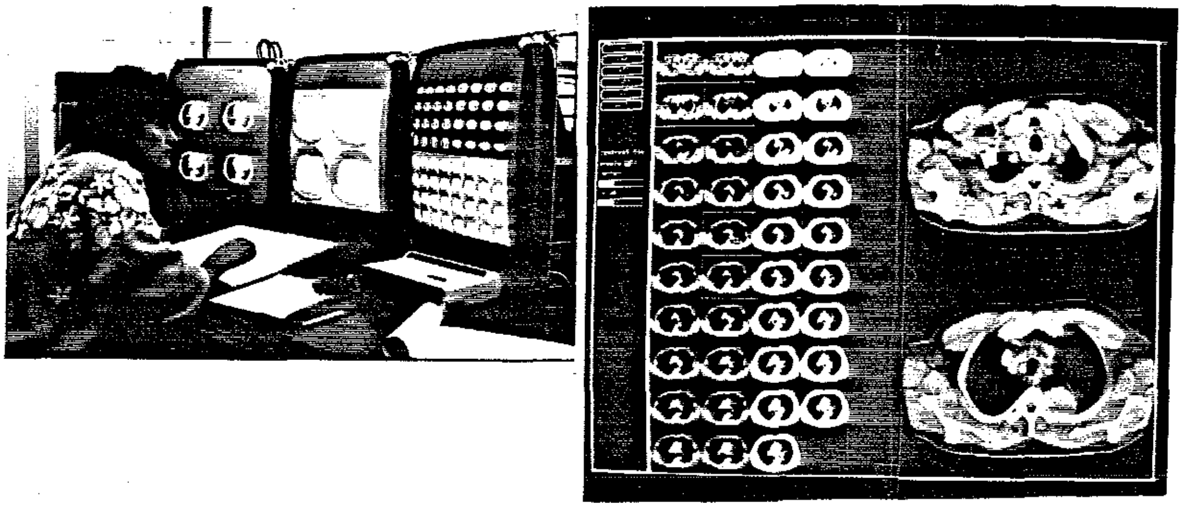

Figure 6. Multiscreen (a) and single-screen (b) display stations

The final display feature to be considered is roaming and zooming. The literature [e.g., MacMahon, 1986; Foley, 1987; Seeley, 1987] suggests that at least 2000 x 2000 spatial sampling is necessary to capture all the diagnostically important information in radiographs. However, it is currently uneconomic for all display stations to be able to display an image at 2000 x 2000 pixels. Zooming into an image to display a part at full sampling and roaming within the whole image to select the desired part for zooming can solve the problem. Roaming and zooming also permit viewing the image information at a larger size for consultation and selecting slices from a navigation index.

While roaming and zooming seem important, studies [e.g., Carmody, 1980] have shown that they can result in a loss of context. It can, for example, lead to the inability to compare symmetric parts of the body. Therefore, it appears important [Beard, 1987] to couple roaming and zooming to a feature where an outline of the presently zoomed region appears on a smaller version of the full image (see Figure 7). Whether this contextual information can be satisfactorily provided on the small navigation index slice, or whether a more highly sampled display of the slice may be necessary for this purpose, is yet to be determined.

Figure 7. A zoomed image with an outline of the zoomed region on a coarsely sampled version of the full image

Summary

In summary, the following should be parts of a useful system for electronic medical image display:

1. All display scales should be linearized.
2. CLAHE should be applied to all slices as they arrive at display.
3. A screen or portion thereof should be dedicated to a low-sampled index of all slices, and navigation among the slices should be accomplished by reference to this index.
4. 1 second access to any slice or group of slices from the index should be provided.

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