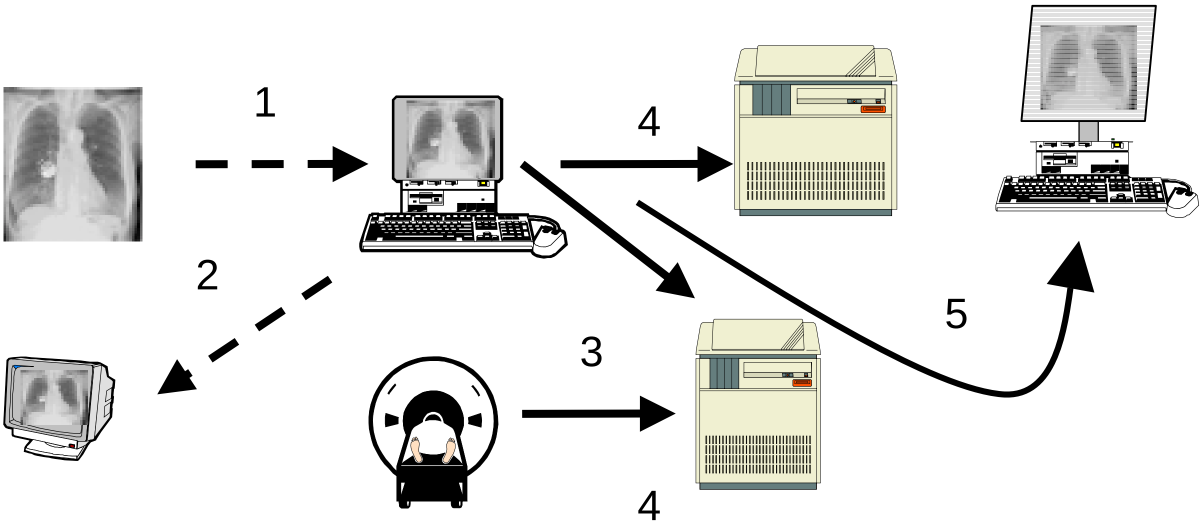
DICOM Softcopy and Hardcopy Consistency Demonstration:

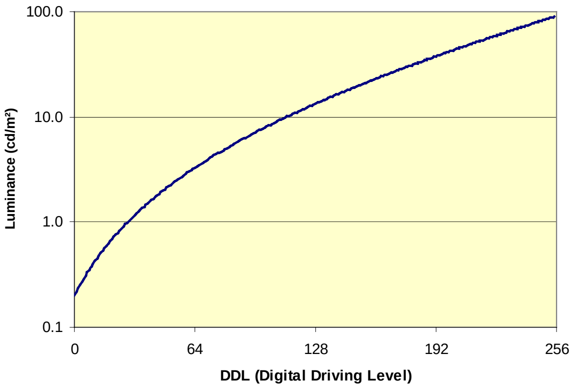


Imagine the following scenarios:

1. A trauma patient is admitted at an outpatient clinic or rural clinic at a remote location. Several X-rays are taken and sent to a hospital for consultation. How can one make sure that what the physician sees at the clinic, matches what is being displayed on the radiologist softcopy workstation at the hospital?
2. The radiologist looks at the image at his high-resolution diagnostic workstation. He or she zooms the image, changes the window center/width, and adds graphics annotation as well as text to the image. He sends it back to the remote site for the physician to look at on his physician workstation. How can this zoom, overlay, annotation and window center/width information be preserved?
3. The radiologist wants to keep this image for his own reference, and sends it to a networked printer for a hardcopy. This printer is also networked to a CT, MR and a computed radiography system. How does one make sure that these films from those different acquisition systems are all printed exactly the same as they were viewed at their modality monitors?
4. The institution has multiple printers from different manufacturers, how can the radiologist be sure that the film looks identical printed from both printers?
5. The image is also sent to another radiologist for a second opinion. This radiologist has a diagnostic viewing station from another vendor, i.e. a different monitor and video display board. As a matter of fact, he has a new flat panel display instead of a conventional CRT. How do we make sure again that the image looks identical?

These issues can be addressed today with the implementation of two new areas of the Digital Imaging and Communications in Medicine (DICOM) standard. This consists of the sections that deal with the grayscale consistency, and the part that handles the appearance such as the rotation, annotation, zoom, and any other manipulations. This allows images to be displayed consistently on different softcopy and hardcopy devices. These devices could be from different manufacturers, employ a different technology (e.g. CRT vs. LCD), have different characteristics (max. Brightness and/or Density) and work under different ambient light environments.
For consistent grayscale, the DICOM working group selected a mathematically defined function derived from the Barten model of human contrast sensitivity. How is this curve

generated? It is based on mapping digital input values onto the light output (luminance) of a monitor or optical density of a film. One can think of this standard being generated by placing a human observer in front of a monitor, changing the luminance output of the monitor in small steps from black to white, and relaying when they observe a Just Noticeable Difference in gray scale display for the specific target as defined in the DICOM display standard. Our eye-brain detection system does not work linearly, i.e., it is much less sensitive in the black than in the white. Therefore, why would one map all those black values into luminance as displayed on the monitor, when no one would be able to notice the difference between those small changes anyway? To accommodate this, in the black area, the input values are mapped into large luminance increments, while in the white area, they are mapped to smaller ones. This curve is standardized as part of the DICOM standard. Adherence to this standard means that a device supports mapping the input values to either standard luminance values in the case of a monitor, or to density values in the case of a printer.

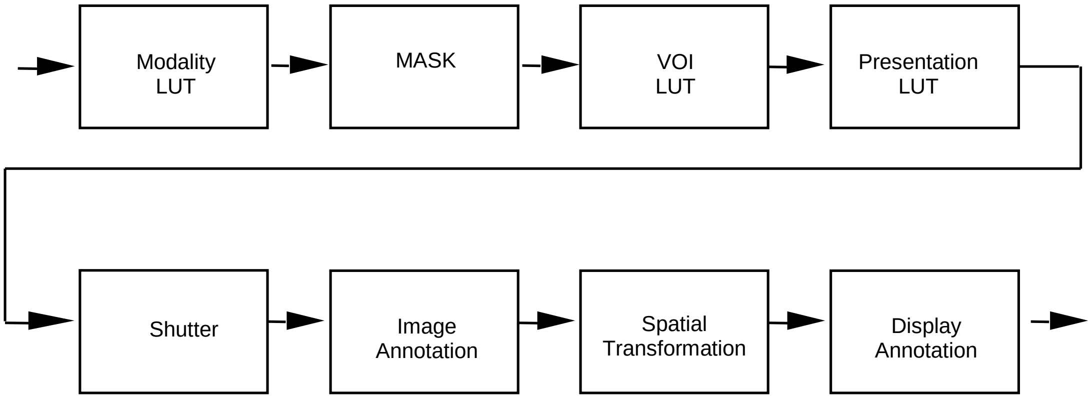


Now we have a standard available, it is a matter of calibrating the monitor and printers according to this curve. That is why we need the availability of calibration tools. Most vendors that sell softcopy display devices provide a tool that includes a luminance meter that can be placed on the monitor and allows the light output (luminance) to be measured. This output can be compared with the actual Grayscale Standard Display Function (GSDF) and any differences can be calculated and be saved. The number of measuring steps needed to make a good approximation of this curve are at least 50, and because most tools automatically vary the input value, this is not such a big deal. One can purchase this as a kit that provides you with a Look Up Table to be downloaded either directly onto the specific video display controller, or that can be saved and used by the display application software to make the necessary corrections. The same applies for hardcopy, i.e. printers will need to be calibrated according to this curve. Vendors that sell hardcopy devices can utilize a densitometer to measure optical density at specific locations on film and then calibrate the printer to adjust laser power output to conform to the GSDF.

There is another part of the image presentation and that is the preservation of the appearance of the image. Until recently, there was no mechanism within DICOM to communicate between workstations what viewing operations took place on the image. Some vendors were using proprietary means of communicating this information, or some just could not accommodate this at all. Fortunately, a new DICOM service handling these issues, the "Softcopy Presentation State", has been specified.

The Presentation State includes the zoom factor, its specific window level and width value, displaying overlays, masks and/or shutters, and preserving the image orientation. For example, when making an X-ray of a chest of a football player, one typically uses the 14” by 17” image plate horizontally in order to get his shoulders on the image. In the film world, it is obvious that the image has to be rotated 90 degrees, or displayed in a landscape vs. a portrait mode. When a technologist QA’s this particular image, he or she typically rotates it to make sure it comes up appropriately at the viewing station. All this presentation information, together with zoom factors, annotations, etc. can now be preserved in a special presentation DICOM object and sent with the image to other workstations resulting in the same appearance. These objects can even be stored on an archive and retrieved later.

How would someone know that multiple Presentation States are available? DICOM specifies a hierarchy by which each image belongs to a particular Series to a particular Study to a particular Patient. Each Image has attributes within the header defining to which Series, Study and Patient this Image belongs. The same is true for the Softcopy Presentation State objects, they contain information about the particular Series, Study and Patient that they belong to. Can one create a single Presentation state for multiple Images, for example for all of the Images in a particular Series? Yes, there are pointers within the Presentation State defining for which Images they apply.



The images being printed or displayed consist of individual pixels, that are subject to a series of operations to achieve this consistency, as shown in the Figure. This grayscale transformation can be thought of as two functionally different sequences. The top part is equivalent to the transformation that takes place when applying the parameters to an image to be printed. The Rescale/Slope or Modality LUT takes care of the transformation from pixels into physical values (such as Hounsfield for CT). The MASK is only applicable for certain X-ray images such as Angiography. The VOI LUT or Window Center/Width maps the pixel values into the range that is of interest, and the presentation LUT provides the Presentation or "P-values".

The next (lower) part of the Figure shows how to apply all the parameters that are presentation specific. This includes the shutter transformation, image annotation, spatial transformation such as rotate and/or flip, and annotation which is spatial transformation independent. Note that the information that is stored within the images, such as Window Width/Level, which normally would be used for these transformations, becomes invalid. They are replaced with the information from the presentation state object. As a matter of fact, if one of the parameters from the presentation state storage object is not present, a unity transformation will be applied.

This hardcopy and softcopy consistency demonstration involves the installation of several networked workstations with software that creates, renders and stores Presentation States, applies Presentation States to images, and prints images as rendered by a Presentation State on different printers. This will prove to the user community that image consistency and integrity can be achieved, and that interoperability can be extended from image communication to a consistent presentation and display on both hard- and softcopy.

Acknowledgements:
The NEMA Committee for the Advancement of DICOM and the RSNA host a demonstration of the DICOM Grayscale Softcopy Presentation State Storage and Presentation LUT at the RSNA 1999 annual meeting in Chicago. The goal of Supplements 22 and 33 is to improve the consistency of image appearance for both hardcopy (film) and softcopy (CRT) viewing.

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Agfa-Gevaert N.V. Septestraat 27 B-2640 Mortsel, Belgium. http://medical.agfa.com	Aycan Digitalsysteme GMBH Panoramaweg 12 D-97318 Kitzingen, Germany http://www.aycan.de	BARCO/Methieus 1600 NW Compton Drive Beaverton, OR 97006
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Compaq Computer Corporation 6406 Ivy Lane COP 2-2 Greenbelt, MD 20770 www.compaq.com	DOME Imaging Systems Inc. 400 Fifth Avenue Waltham, MA 02451-8738, USA www.dome.com	GE Medical Systems P. O. Box 414, SN-473 Milwaukee, WI 53201 gemedicalsystems.com.
Gossen Foto und Lichtmesstechnik Lina-Ammon-Str. 22 90471 Nuernberg, Germany www.gossen-photo.de	Institute for Microtherapy Universitaetsstrasse 142 D - 44799 Bochum, Germany www.microtherapy.de/go/cs	IMAGE Smiths, Inc. 19512-D Amaranth Drive Germantown, Md. 20874 www.image-smiths.com
Cedara Software 6509 Airport Road Mississauga, ON, L4V 1S6, Canada www.cedara.com	Eastman Kodak Company 343 State Street Rochester, NY 14650-0519 www.kodak.com/go/health	Merge Technologies Inc 1126 S. 70th Street Milwaukee, WI 53215-3151, USA www.merge.com
Kuratorium OFFIS e.V. Escherweg 2 D - 26121 Oldenburg, Germany http://www.offis.de/	OTech Inc. 2001 East Oakshores Drive Crossroads TX 76227, USA www.otechimg.com	Philips Medical Systems Veenpluis 4-6, PO Box 10,000 5680 DA Best, Netherlands www.medical.philips.com
Quintiles Intelligent Imaging 521 Plymouth Rd #115 Plymouth Meeting, PA 19462, USA www.i2image.com	Siemens, Display Technologies A&D SE DT, Siemensallee 84 Karlsruhe, Germany 76187 www.ad.siemens.de/monitors	Sun Microsystems, Inc. 1 Network Circle Burlington, MA 01803 www.sun.com

The software used to generate the presentation states and print these including the GSDF and presentation LUT will be available in the public domain and can be downloaded from:
http://www.microtherapy.de/go/dicomscope or http://www.offis.de/projekte/dicom