The
Medicine
Behind the
Image

DICOM Implementations for Digital Radiography

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RADPHARM
The Imaging Core Lab

Disclosures

- David Clunie, MB.,BS., FRACR
  - *CTO, RadPharm, Inc. (formerly Princeton Radiology Pharmaceutical Research)*
  - *Proprietor PixelMed Publishing*
  - *Formerly contractor for GE Medical Systems*

Learning Objectives

- Projection radiography and DICOM
- Requirements and design of DX objects
- Implementation strategies
  - Creator of images (modality)
  - Consumers of images (PACS/workstations)
- Status and adoption
- Purchasing strategies

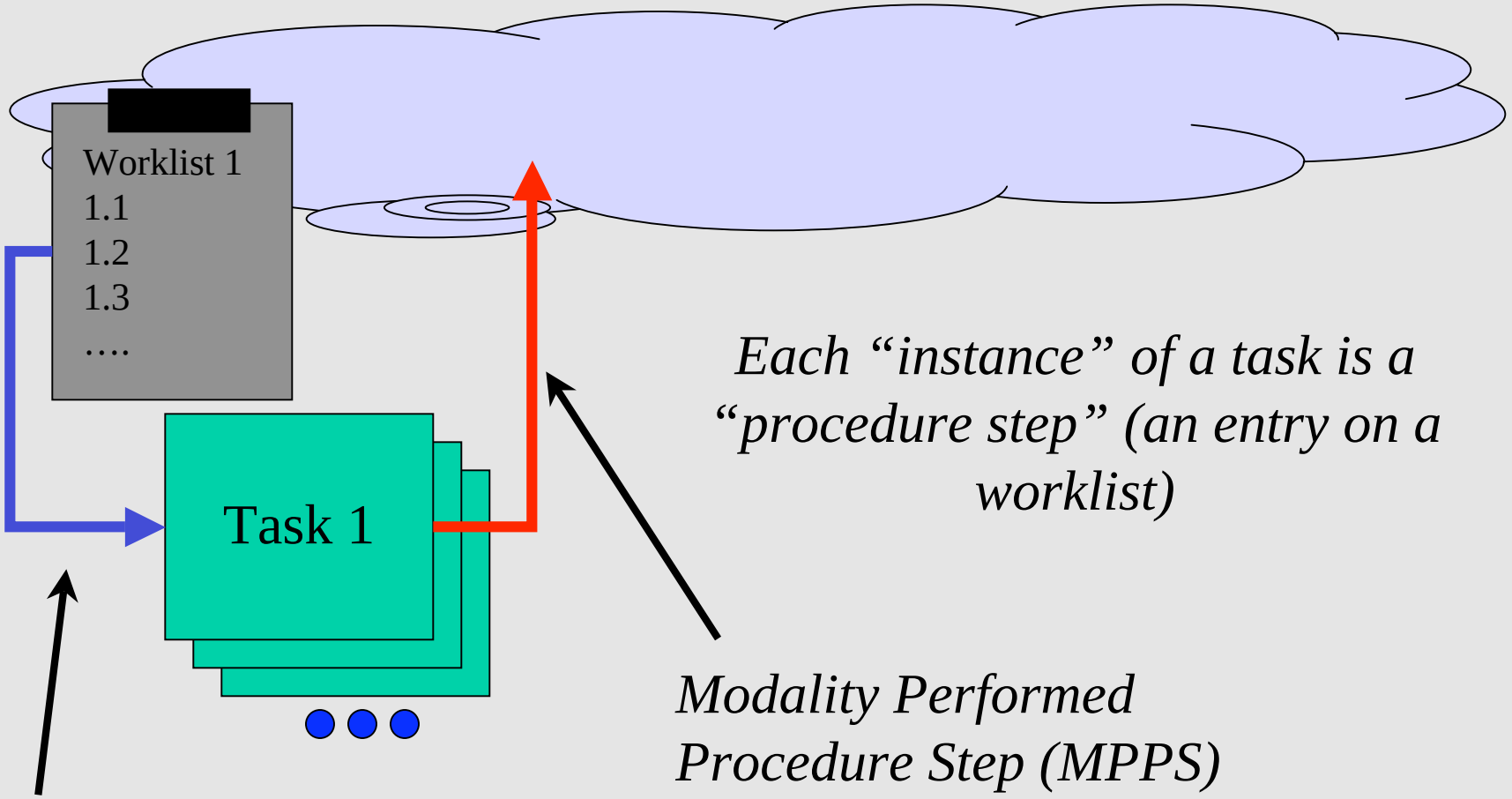
Relevance of DICOM

- DICOM is only an interface/integration tool
- Most benefits of digital detectors unrelated:
  - Quality and characteristics of acquired images
  - Rapid patient turn-around (no processing wait)
- But, DICOM has services to improve …
  - In-room and enterprise-wide workflow
  - Hanging efficiency
  - Distributed consistency of image appearance

DICOM and Workflow

- Bad “old” days:
  - modality operator types in patient and study identification and often makes mistakes
  - such mistakes -> PACS/RIS mismatch with requests, wrong routing, “lost” studies, etc.
- DICOM Modality Worklist
  - choose from pick-list of tasks (+/- bar code)
  - greatly reduces such errors
  - more “header” information pre-populated

DICOM and Workflow



Each "instance" of a task is a "procedure step" (an entry on a worklist)

Modality Performed Procedure Step (MPPS)

Modality Worklist (MWL)

Purchasing Guideline #1

Do not buy a DX or CR or PACS without DICOM Modality Worklist !

Why ?

Single greatest DICOM-related contributor to improved system productivity

Worklist vs. IHE SWF Profile

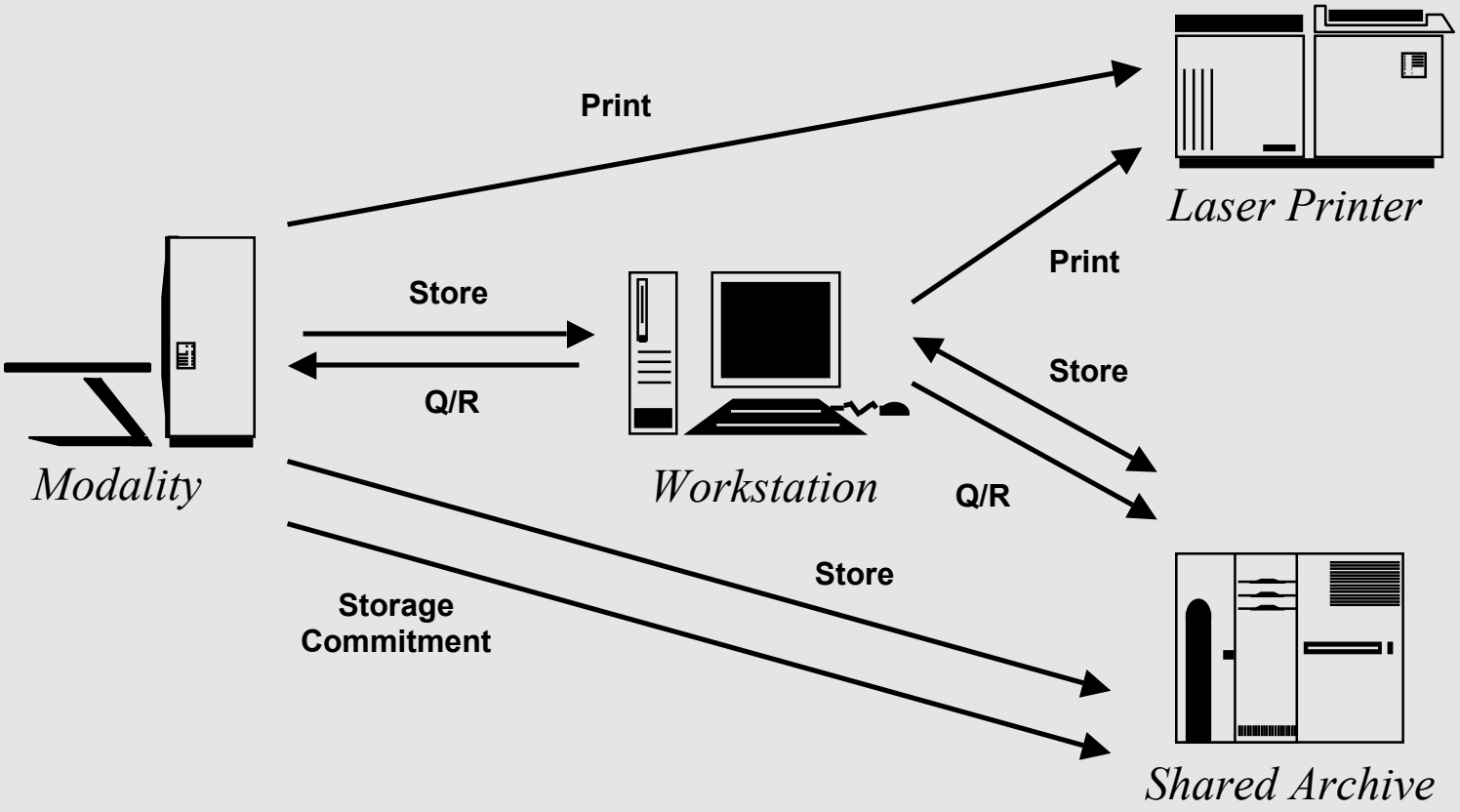
- Integrating the Healthcare Enterprise
- Scheduled Workflow Integration Profile
- Includes DICOM Modality Worklist
  - Additional assumptions and constraints
- Modality Performed Procedure Step
  - Lets RIS/PACS know what was done, completion
- Storage Commitment
  - Makes sure images have been stored, before locally purging

DICOM Storage (Transfer)

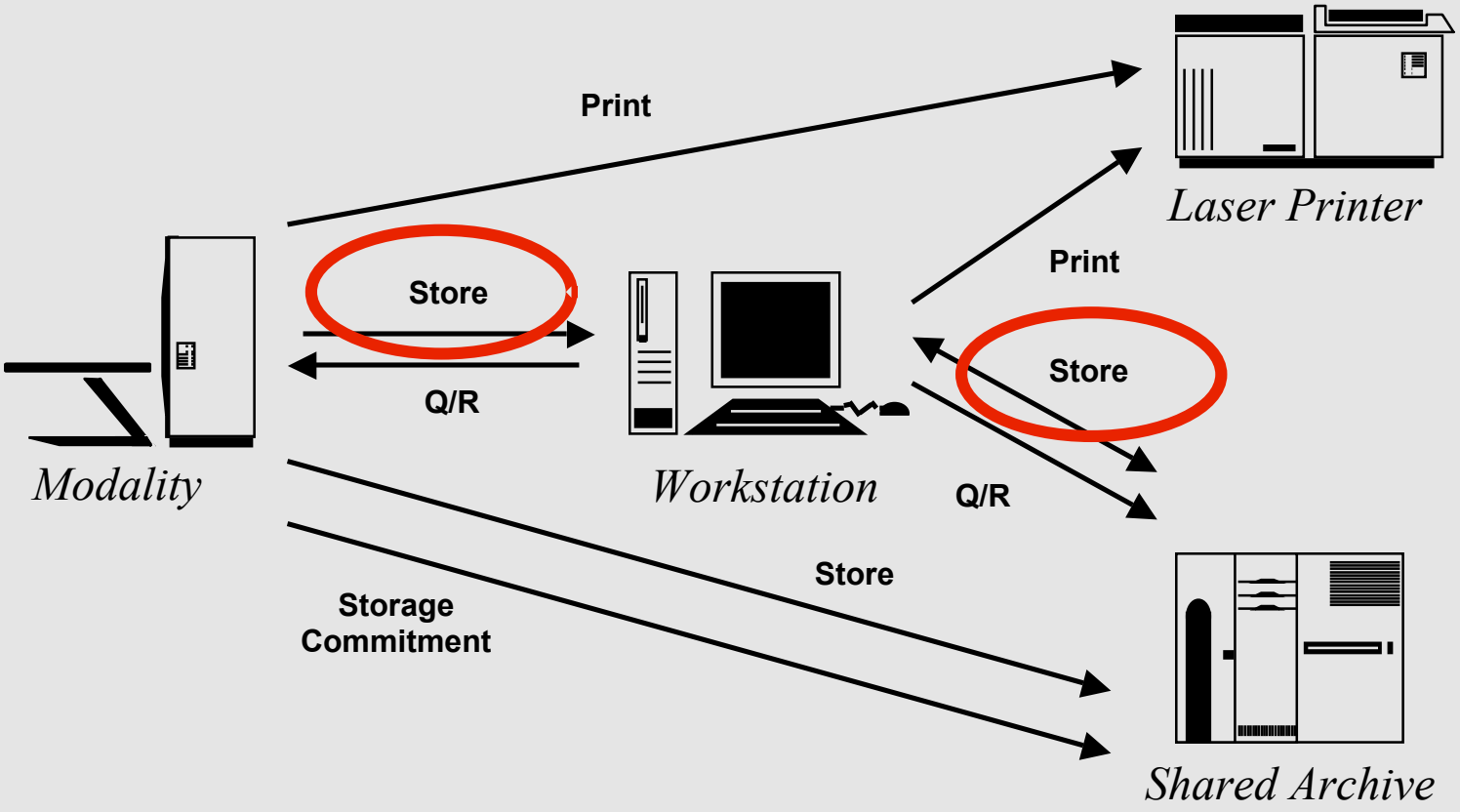
- DICOM consists of services for storage (transfer) of images, presentation states and reports across the network and on media

- Other DICOM services for query and retrieval of objects, workflow management, storage management and printing

DICOM Services



DICOM Services



DICOM Storage Objects

- Projection radiography objects
  - Computed radiography (CR)
  - Secondary capture (SC) - for film/screen
  - X-ray Angio/Radiofluoroscopy (XA/XRF)
  - Digital X-Ray (DX, MG, IO)
- Cross-sectional objects
  - Computed Tomography (CT)
  - Magnetic Resonance (MR)
  - Ultrasound (US), Nuclear Medicine (NM) ...

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DICOM CR Image Object

- CR
  - doesn’t describe new detectors well
  - no useful grouping images by series
  - multiple exposures per image allowed
  - anatomy, view etc. poorly described
  - grayscale not defined
  - relation to x-ray intensity not defined
  - processed vs. unprocessed controversy

DICOM Issues for a PACS

- Services adequate (store, Q/R etc)
- Application (esp. reporting) limitations:
  - routing of images (worklist or station)
  - identification of image/exam type
  - grouping of images
  - layout of images
  - grayscale appearance of images

DX Design Goals - Technologies

- Support established technologies
  - Computed Radiography
  - Thoravision (selenium drum)
  - Optically scanned film
  - CCDs for small area (dental, mammo bx)
- Support more recent technologies
  - large flat panels (+/- scintillator)
  - slit scans, etc.

DX Design Goals - Features

- New technology & new characteristics
- Characteristics of image pixel data
  - Contrast changes & image processing
  - Relationship to X-ray intensity
- Quality control needs description of
  - Acquisition
  - Detector behavior & identification
  - Dose

DX Design Goals - PACS Issues

- Modality and PACS vendors/groups traditionally have separate goals
- Cost effective deployment of digital detector technology may well depend on efficient image management and efficient soft copy reading
- Encourage attractiveness of digital detectors by improving PACS usability & productivity

Digital X-Ray WG Goals

- Support new digital detector technology
- Reuse existing DICOM facilities
- Support for PACS integration
- Enhance workflow/productivity
- Consistent image appearance
- Support advanced applications
- Support regulatory requirements

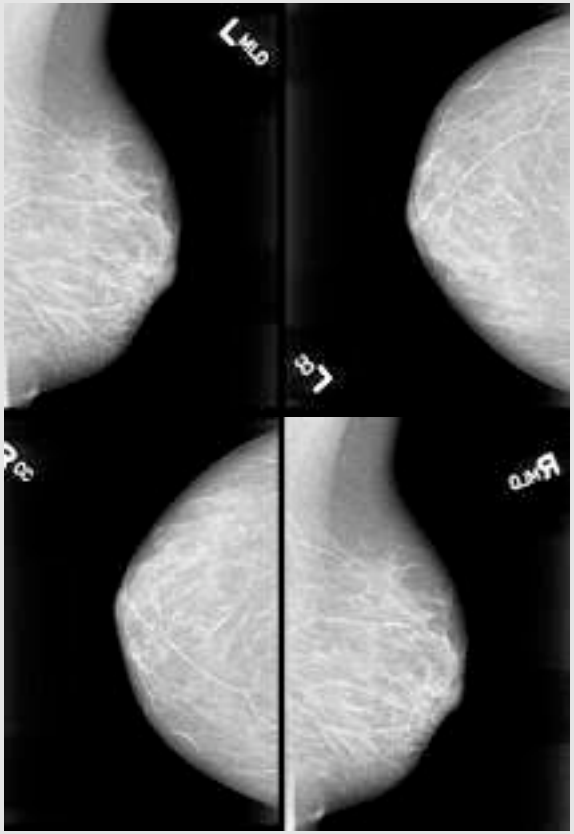
Identifying the PACS Needs

- Image management functions of PACS
  - matching images with request
  - matching images with old studies
  - routing images to reading worklist/station based on request/anatomy/physician
- Softcopy reading functions of PACS
  - images in correct order & orientation
  - images with appropriate grayscale

Failure to Meet PACS Needs

- Radiologists can't read
  - images without request
  - request without images
  - images without old images
  - images not on reading worklist or station
- Radiologists won't read or read slowly
  - images in wrong order or upside down
  - images with wrong contrast

Productivity - Image Hanging



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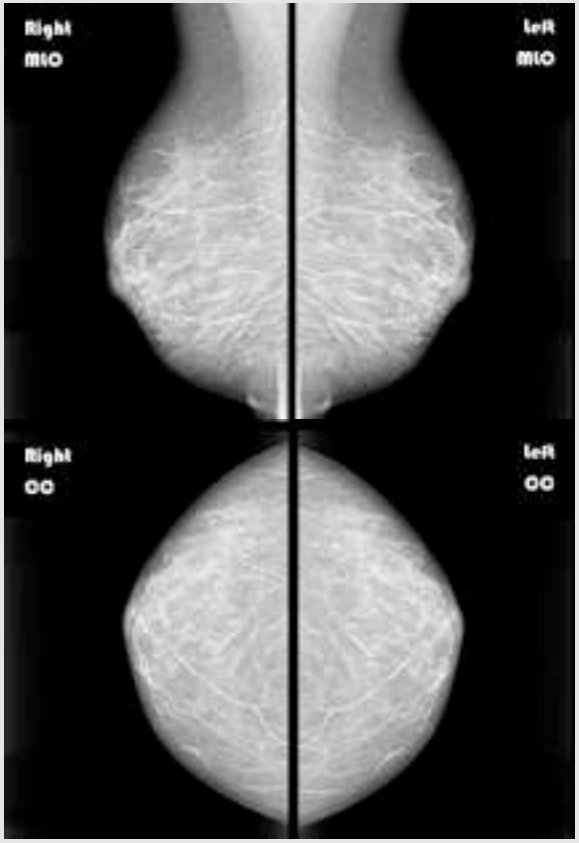


✓

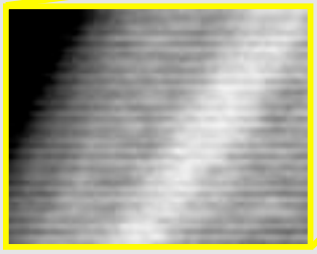
Satisfying the PACS Needs

- Emulate all the functions of film
  - Visual cues
    - for file clerk/technologist/radiologist
  - Flashed identification
  - Lead markers
  - Wax pencil marks
  - Well defined, repeatable grayscale

Management Features of Film

Visual Cues to Human:
Modality = X-ray
Anatomy = Skull
Projection = Lateral

Row Direction = Ant
Col Direction = Feet

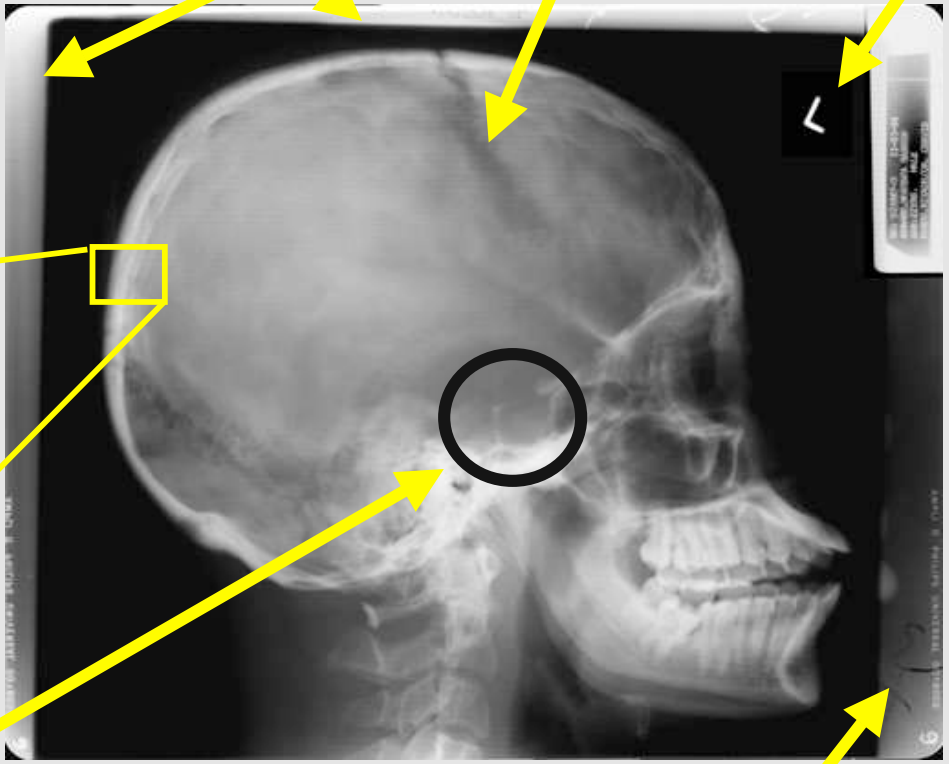


Grid Used = Yes

Wax Pencil:
Enlarged Sella

Grayscale: Film type & exposure

Collimator Edges

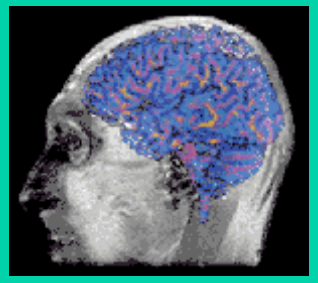


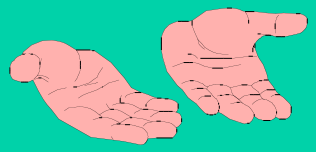
Wax Pencil: Film Number

Lead Marker:
Laterality = L
Projection = L

Flashed ID:
Patient Name
Patient ID
Patient DOB
Patient Sex
Physician
Institution

Hanging a Film

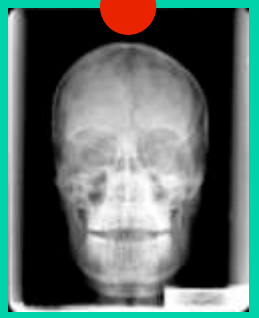


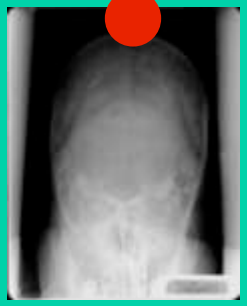


Technology

L	L	L	L
Old Lateral	*New Lateral*	*New Frontal*	*New Townes*
F	F	F	F

Old Study





New Study

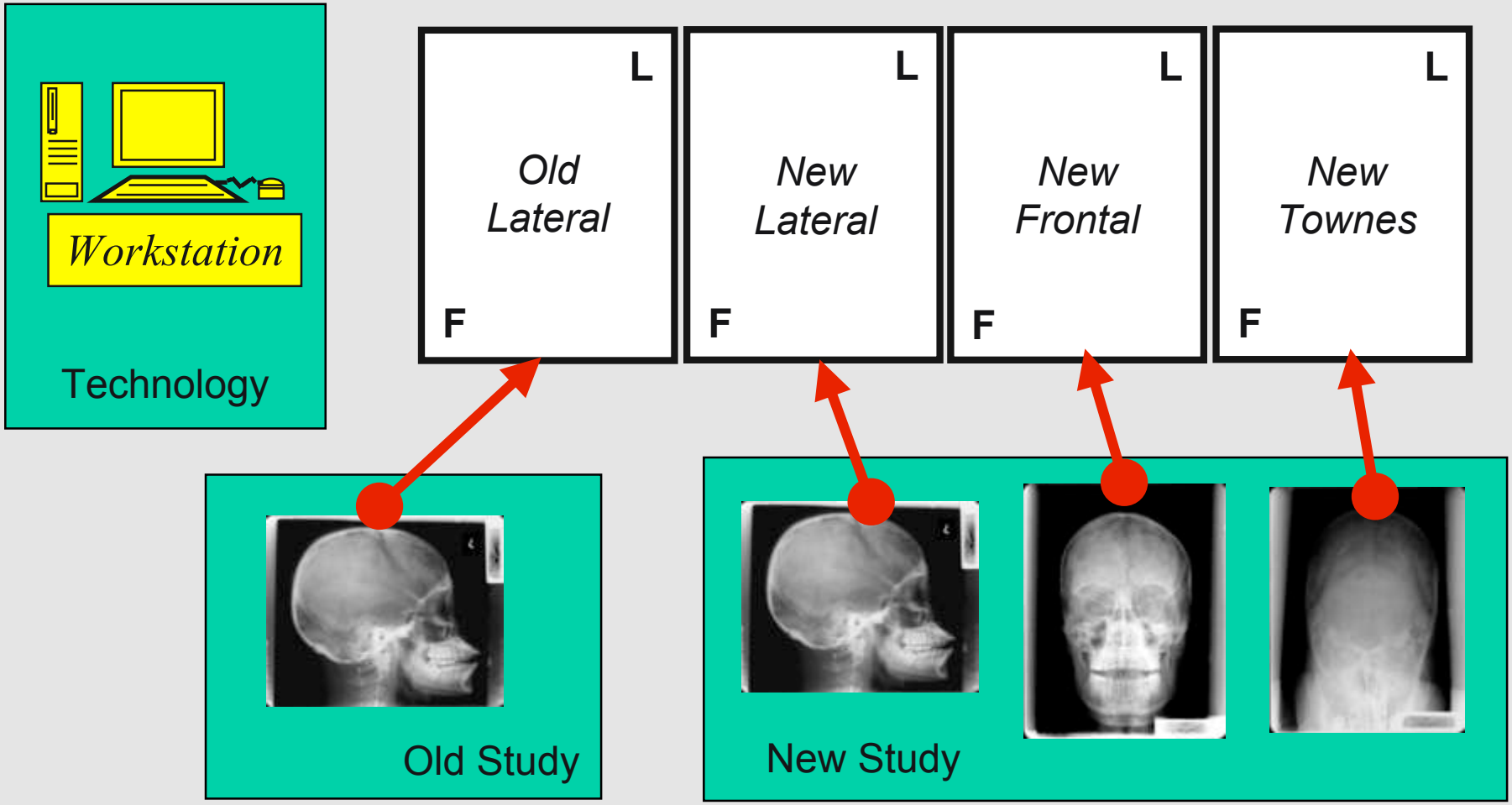
Hanging a Film

- Extract films from patient folder
- Sort into old and new films
- Verify patient name & ID on each film
- Arrange into desired hanging order
  - Match old with new for same anatomy/view
- Turn/flip to correct orientation
  - Left on right of viewbox, feet on bottom
- Turn on lightbox, +/- use bright light

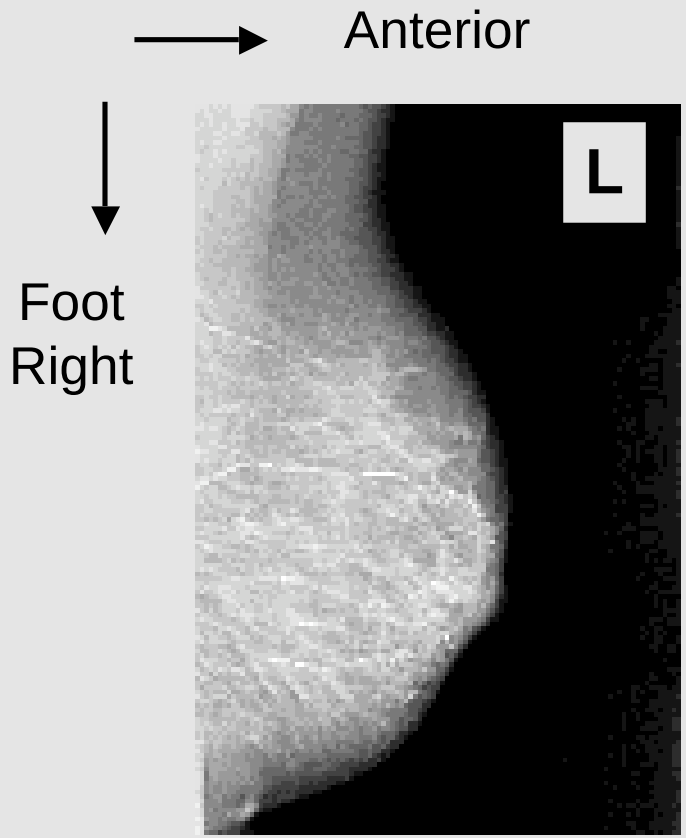
Displaying an Image

- Receive studies from worklist/prefetch
- Match modality/anatomy with protocol
- Per protocol:
  - arrange old and new images
  - arrange by anatomy/laterality view
  - rotate/flip image based on orientation
  - annotate images as desired
  - select from available contrast choices

Display Hanging Protocols



Information for Hanging



Modality: Mammography
Anatomic Region: Breast
Image Laterality: L
View Code: Medio-Lateral Oblique
Patient Orientation: A\FR

DICOM Support for Hanging

	CR Image	DX Image
Modality	Non-specific	More specific
Anatomy	Optional,text	(Required),coded
Laterality	Optional	Required
View	Optional,text	(Required),coded
Orientation	Optional	Required

Key distinguishing feature of DX object family:

- *More critical attributes are required*
- *More critical attributes are coded*

Purchasing Guideline #2

Insist on DX support in both modality (CR and DX) and PACS workstations !

Why ?

Hanging of projection images difficult without mandatory, coded attributes

It takes two (+1/2) to tango …

- DX support in modality
- DX support in PACS image manager/archive
- ***DX support in PACS Workstation***

- Just storing and displaying the images conventionally is not enough to show benefit - need to *USE* the extra information
- Difficult to ascertain from conformance statements

Purchasing Guideline #3

Insist on hanging protocols driven by DX coded attributes in PACS workstations !

Why ?

Mandatory, coded attributes from modality yield no benefit if they are never used

DICOM & Hanging Protocols

- Supplement 60
- Defines a standard format for central storage and interchange of hanging protocols
- Potential for a site or physicians personal hanging protocols to be:
  - Configured centrally
  - Exchanged between workstations and PACS from different vendors
- Start asking your vendors if they plan to support this

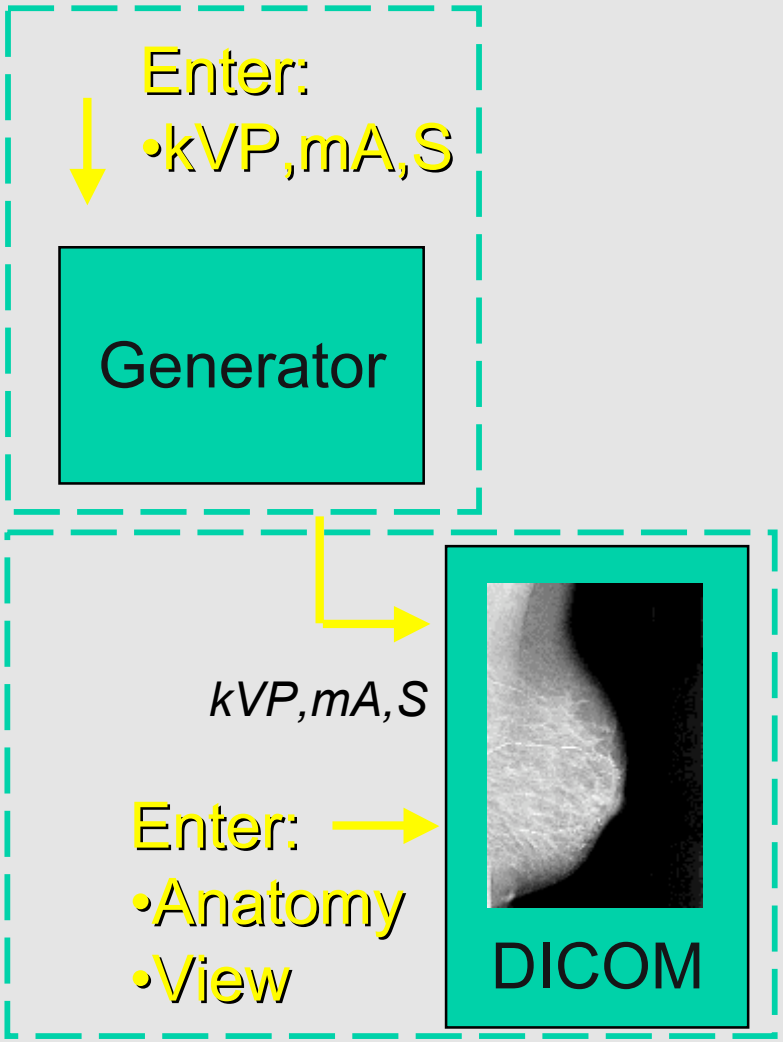
Implementing DX Objects

- SCU (the modality or x-ray system)
  - source of mandatory attributes
  - orientation of the image
  - contrast/processing choice
- SCP (the PACS or workstation)
  - take advantage of new attributes
    - routing/reading worklist improvement
    - hanging or default display protocols
  - *standardization of existing practice*

DX Modality Design

- Distinguish
  - add-on systems
  - integrated systems
- Goal is minimize operator's burden
  - don't re-enter information
  - take advantage of known information
- Is a trade-off when necessary
  - PACS efficiency prioritized over modality

Generator Protocol Data



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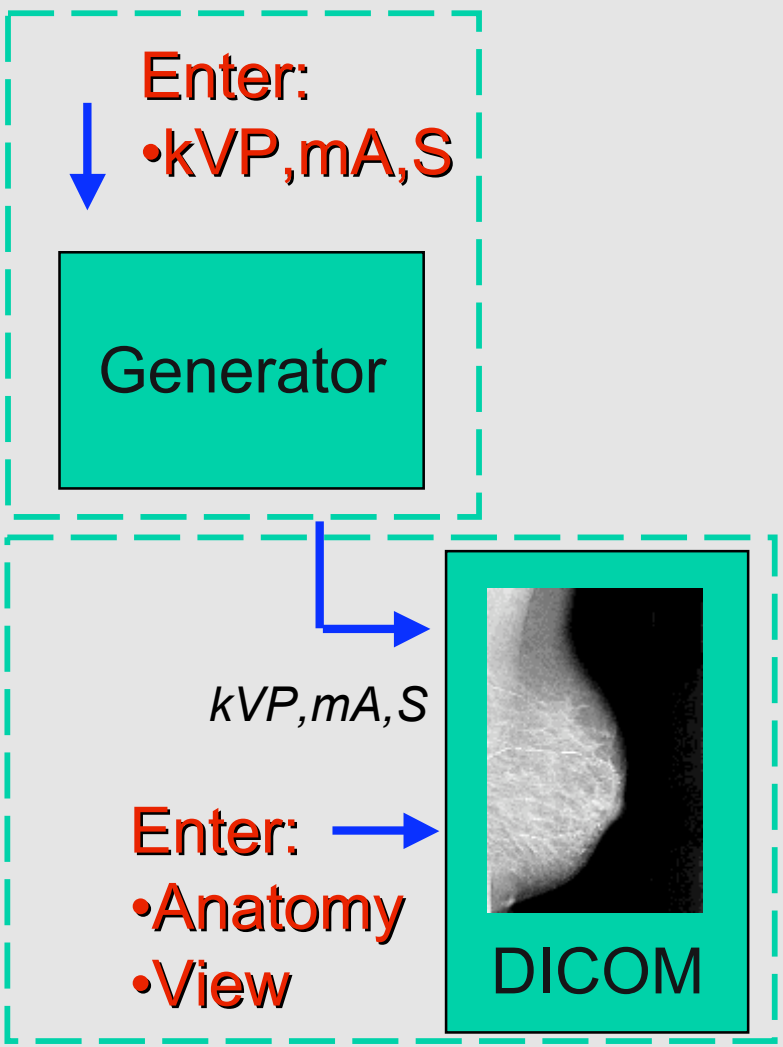

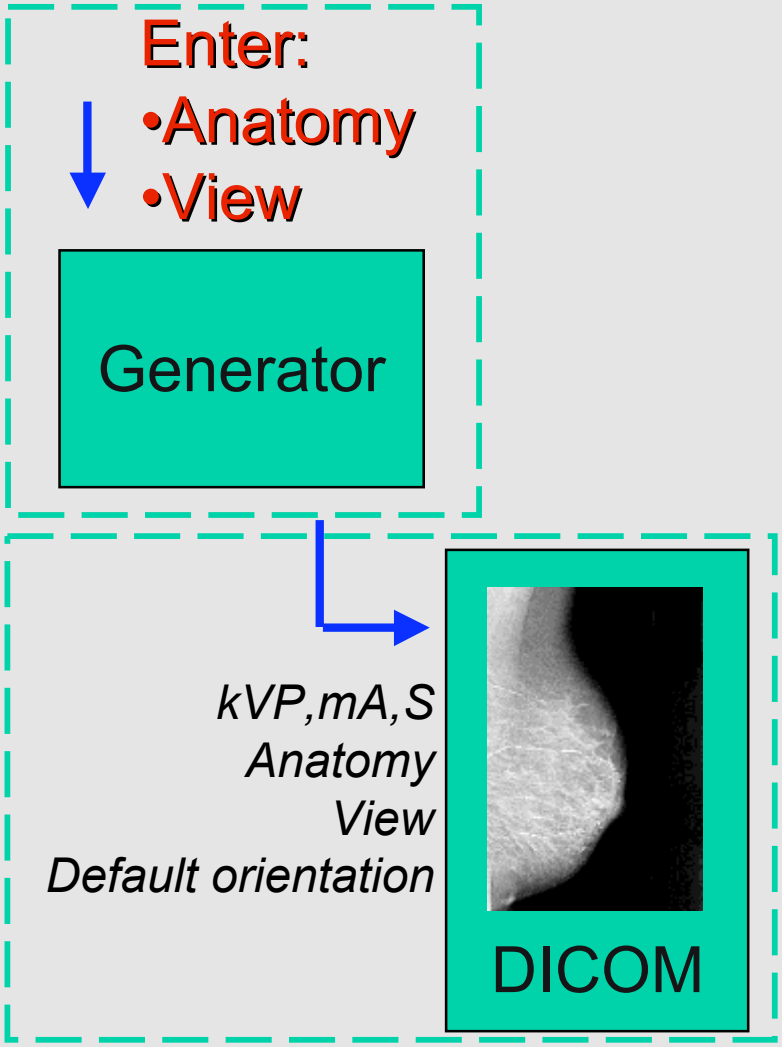

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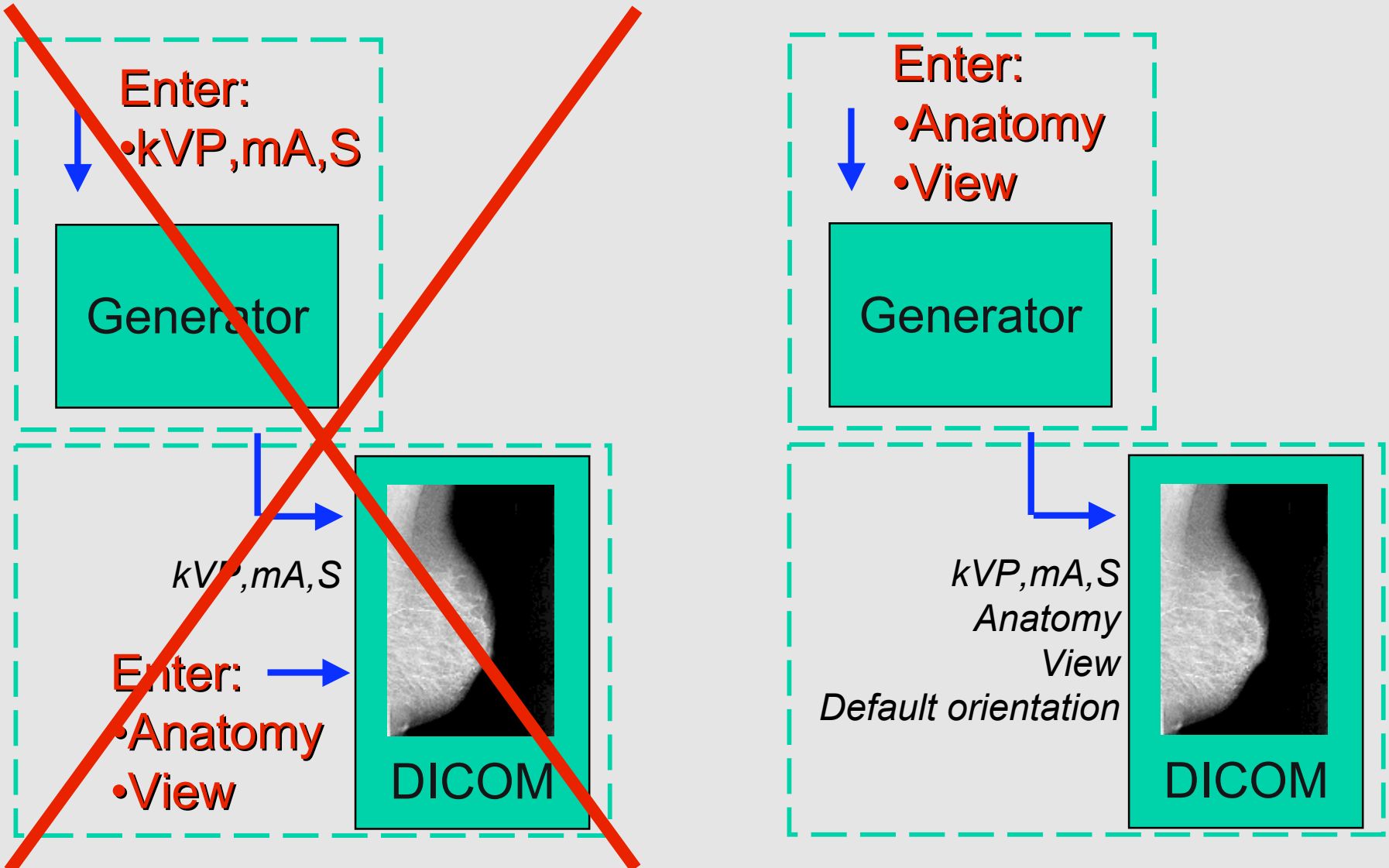


Generator Protocol Data

- Too coarse, e.g. Chest Lat = Oblique
  - make it more granular, including L or R
- Complete attributes in DICOM
  - Technique (kVP,mA,S) and derived dose
  - Anatomy and view
  - Default or preferred orientation
- Select frequency/contrast processing

Sources of Data

- Generator protocol selection
- Detect/select collimation
- Physical gantry (e.g. upright bucky)
- Detect/select filtration on tube
- Detect/select grid
- Detector values and statistics

Determining Orientation

- Use to describe/change orientation:
  - view e.g. PA not AP
  - geometry e.g. upright bucky
  - pixels arranged as viewed from tube side
- Therefore:
  - pixels on right towards patient's right
  - pixels at bottom towards patient's feet
  - either describe or flip to "normal" view

Determining Orientation

Operator selects …

•Image Laterality: L

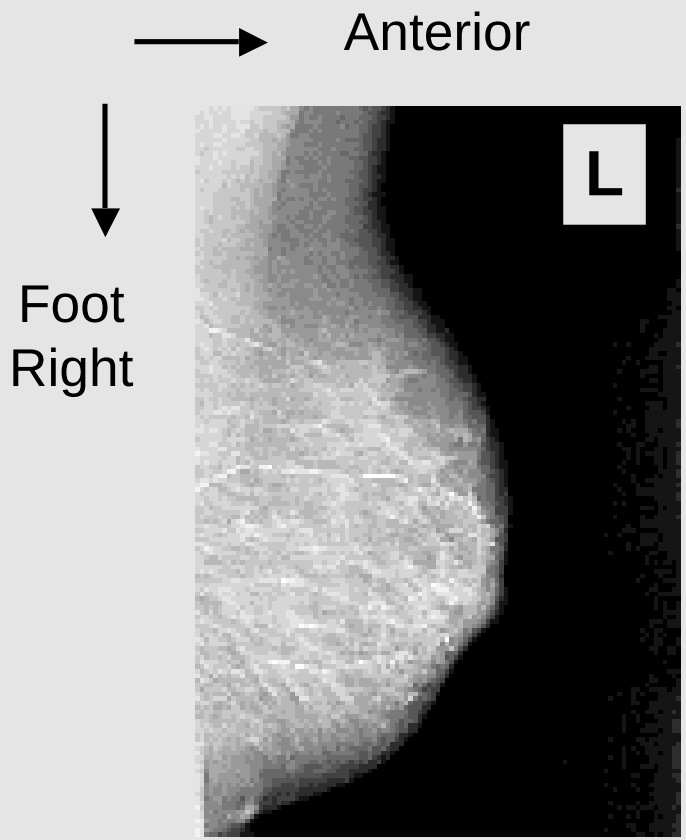
From angle and direction of gantry rotation …

•View Code: Medio-Lateral Oblique

Therefore …

•Patient Orientation: A\FR

Already in natural view sense so don!t need to flip top/bottom



Laterality/Orientation Problems

- May require a user interface to enter
- May require an operator action enter/confirm
- Mandatory, but operator/vendor may lie !
- Multiple parts on same exposure/detector
- Badly implemented
  - flip left/right AP/PA chest
- Safety related issue

DICOM Support for Routing

- Coded and mandatory attributes help
  - Modality+anatomy+view
- Still critical need for Modality Worklist
  - To supply identifiers that match IS/PACS
  - Patient ID/Name/Study ID
  - *Study Instance UID*

Don't buy a modality or PACS without (a good) modality worklist !!!

Purchasing Guideline #4

Choose a DX Modality that populates attributes with minimal impact on operator productivity !

Why ?

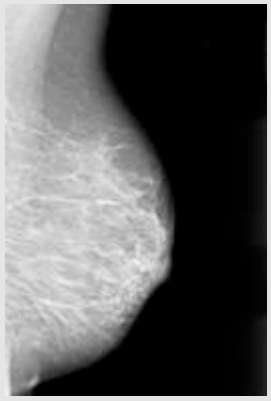
Many sources of information are automatically obtainable or re-usable, and in-room productivity gains are too valuable to sacrifice unnecessarily

And now for something completely different ...

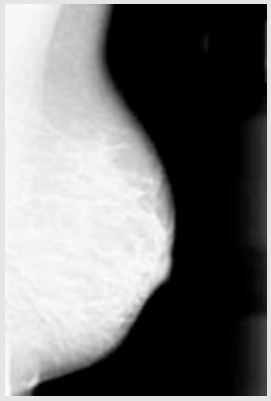
Consistency of Appearance

- Correct grayscale transformations
  - crucial to create “film-like” appearance
  - crucial for distributed consistency of appearance
- Display (& print) devices vary greatly
- Incorrect contrast is a source of
  - inefficiency
  - dissatisfaction
  - fatigue
  - errors in diagnosis

Image Presentation

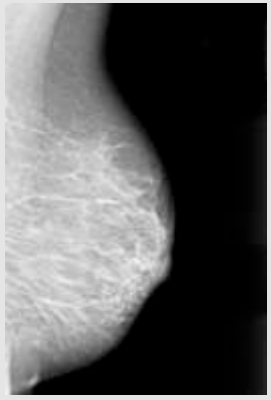


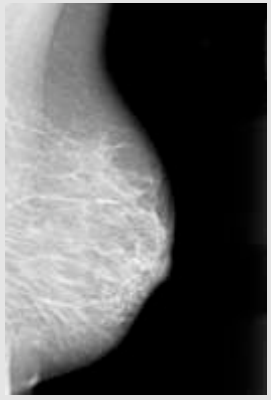
Acquire

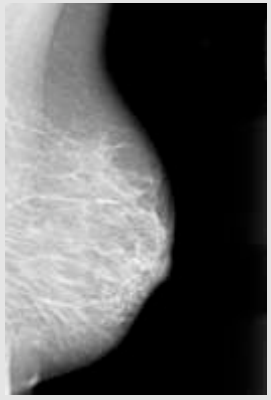


Display

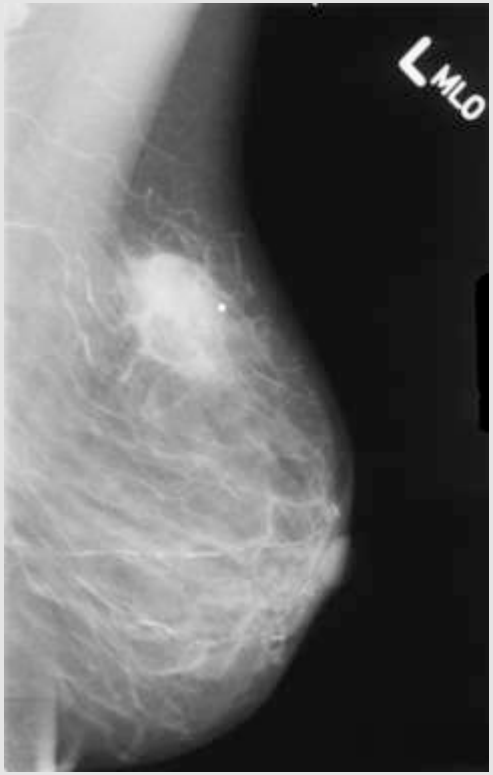
Print



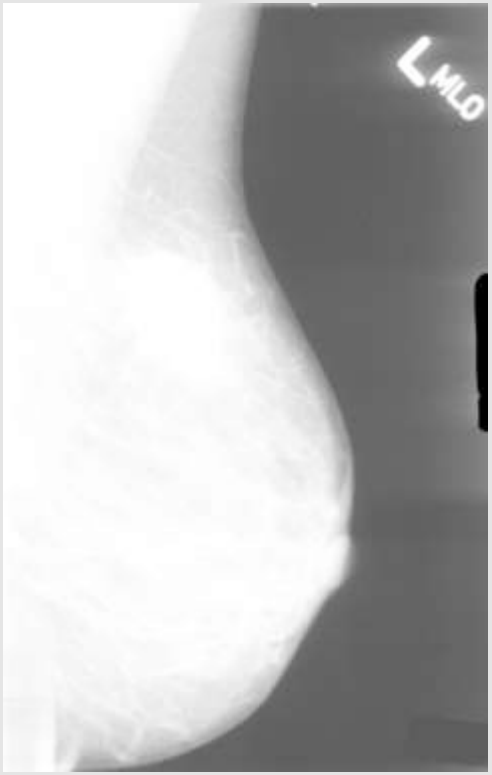




Problems of Inconsistency



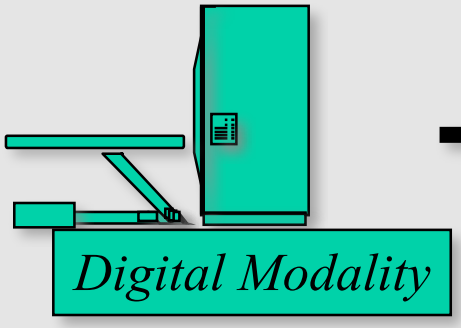
mass visible

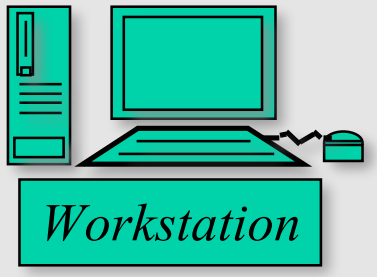


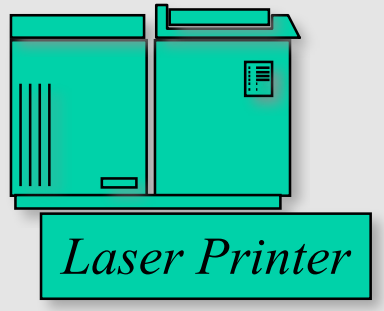
mass invisible

- Appearance chosen on one display device
- Rendered on another with different display
- Mass expected to be seen is no longer seen

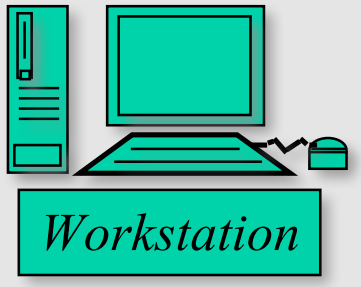
Distributed Image Consistency







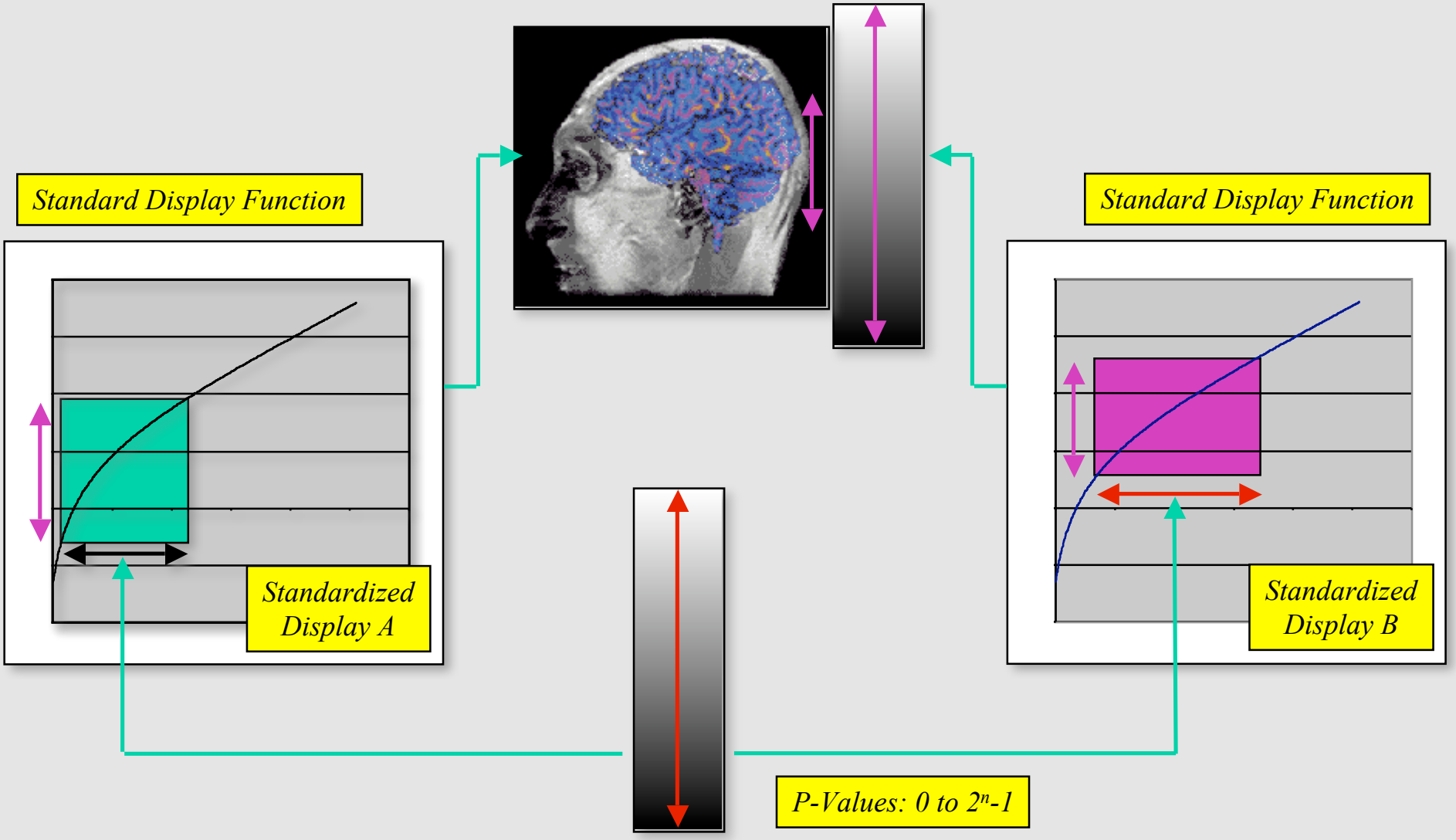
Identical perceived contrast



Grayscale Transformations

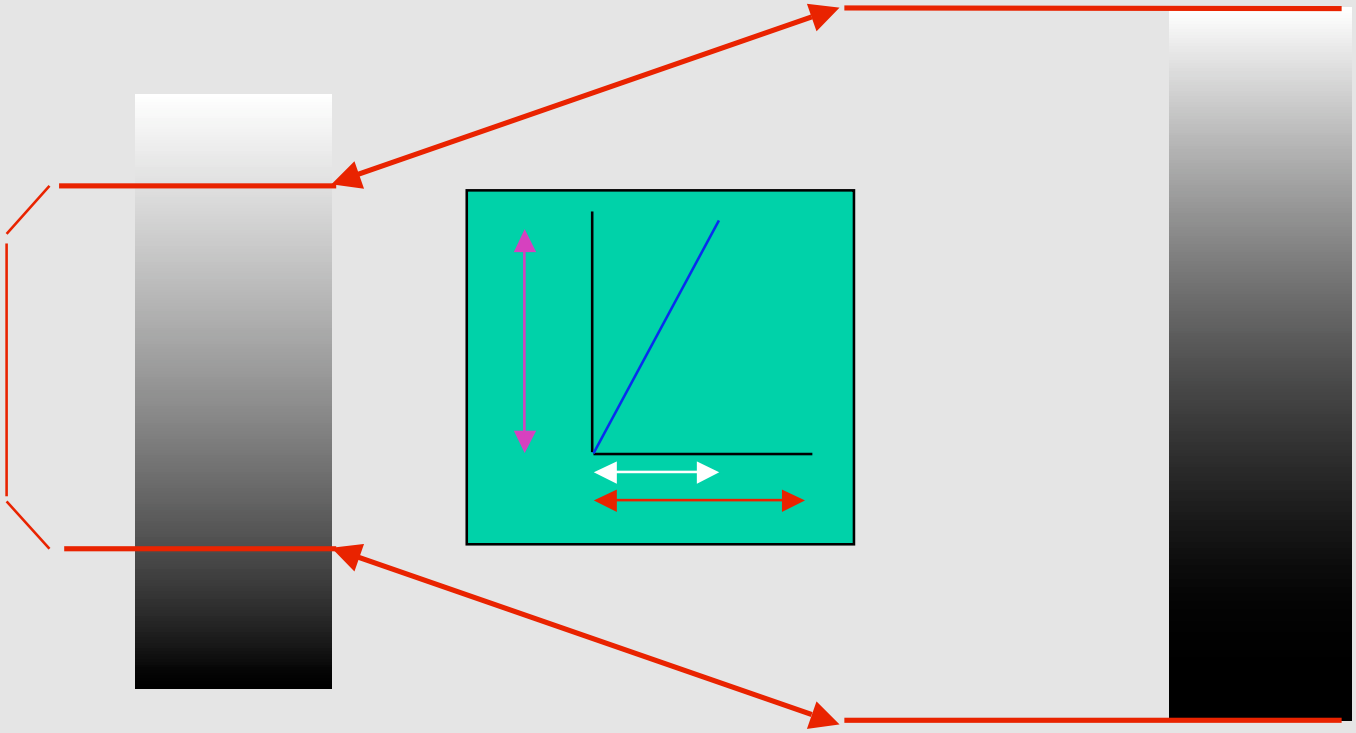
- Pre-DX (CR) DICOM - optional & arbitrary
- DX family - mandatory & standard
- Two key elements
  - appropriate choice of contrast function
    - linear (window center/width) or non-linear LUT
    - automated choice(s) based on anatomy/view
  - standard device independent output space
    - DICOM Grayscale Standard Display Function
    - perceptually linear P-Values

Device Independent Contrast



Implementing Consistency

- Modality implementation
  - operator or machine chooses contrast (window or VOI LUT) targeted to standard display function rather than specific film/camera/monitor
  - must support DX image as an SCU
    - may or may not send window values, non-linear LUT
- PACS workstation implementation
  - must support DX image as an SCP
    - ***must support application of non-linear LUT***
  - display must be standardized
  - display must be calibrated
  - quality control process in place
  - open question - how does user then adjust the image ?

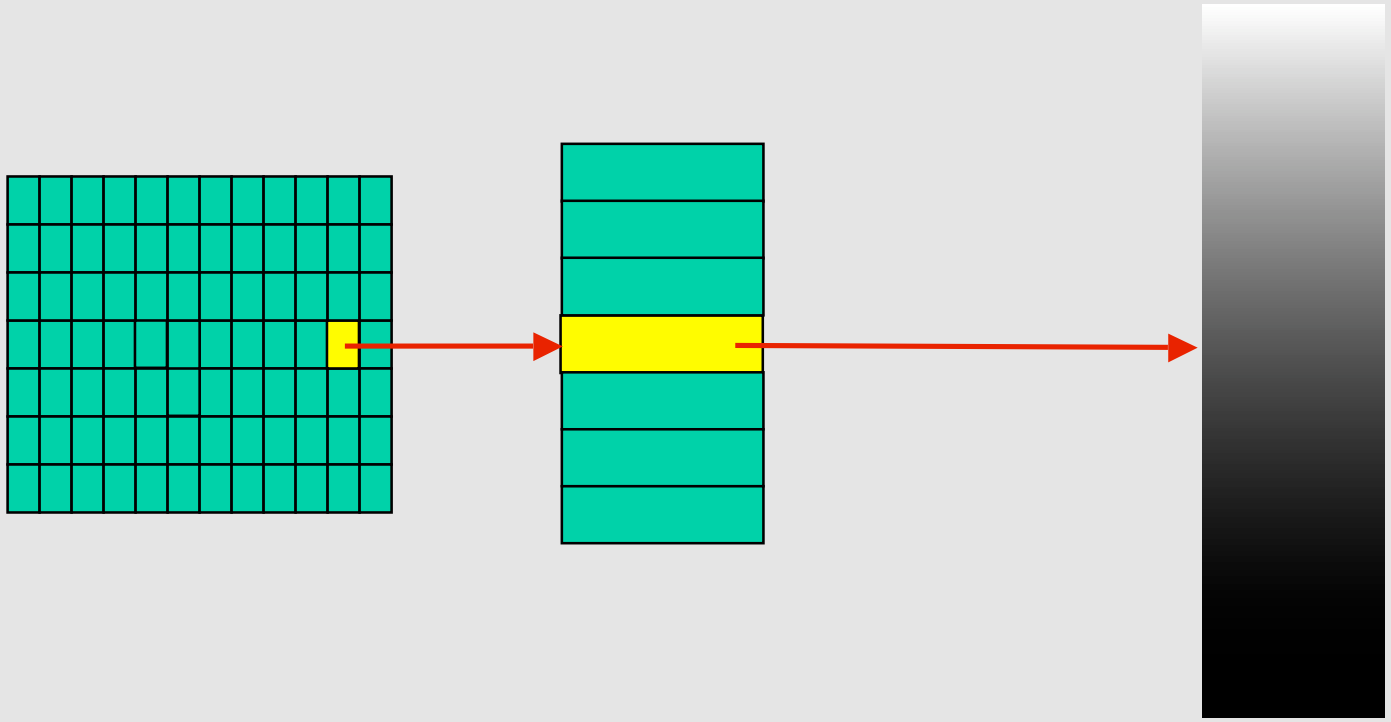


Pixels

Display

Window
Center/Width

Selects range of values to map



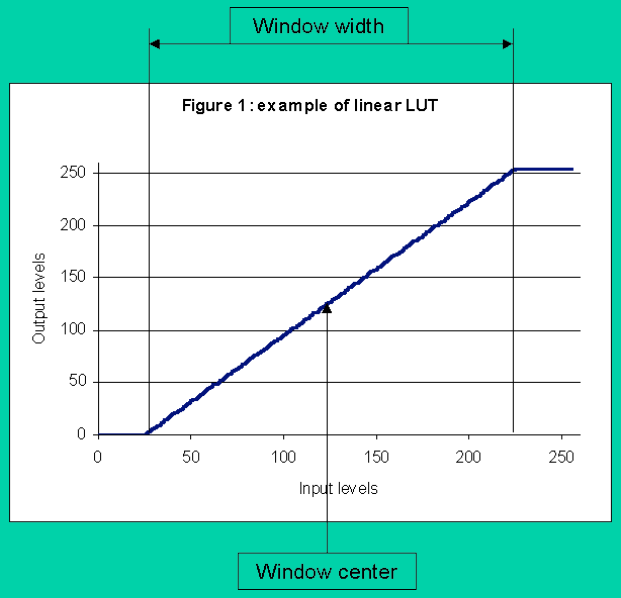
Pixels *Display*

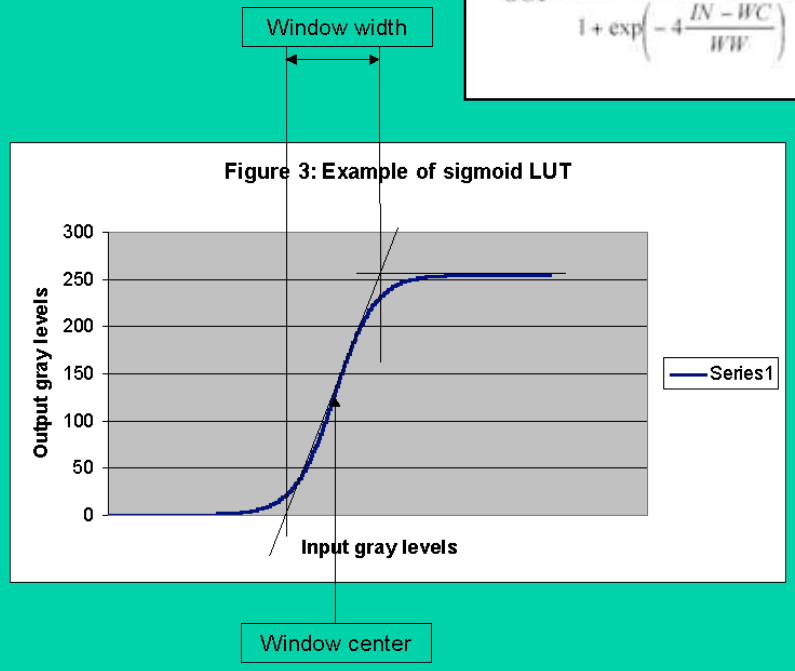
Lookup Table (LUT)

Encodes any shape of function

Sigmoid (Logistic) Curve

$$OUT = \frac{Output\_range}{1 + \exp\left(-4\frac{IN - WC}{WW}\right)}$$





Figures courtesy of Guy Hersemeule, GEMS

Purchasing Guideline #5

Insist on GSDF calibration and full DX image (including VOI LUT) support in modality, QC and PACS workstations !

Why ?

Consistency of appearance needs both ends to be calibrated to similar expectations - the DICOM DX, VOI LUT support and GSDF calibration are the standard solution

Capturing Presentation Changes After Acquisition

- Operator or modality encode presentation information in original image object
  - Processed image “for presentation”
  - Default or selected window or LUT
- Capturing subsequent adjustments
  - By operator or radiologist
  - Excessive to save new (large) image objects
  - Grayscale Presentation State Storage (GSPS)
  - One or more “snapshots” of state separate from images

Purchasing Guideline #6

Insist on Grayscale Presentation State Storage support for DX in QC and PACS workstations !

Why ?

Consistency of appearance resulting from operator or radiologist adjustments needs to be captured and propagated.

What about "processing" ?

- Detector-specific proprietary processing
- "Post-processing" of presentable images

- Achieving interoperability requires that processing be performed at acquisition

- Proprietary processing must not be required in review and diagnostic workstations

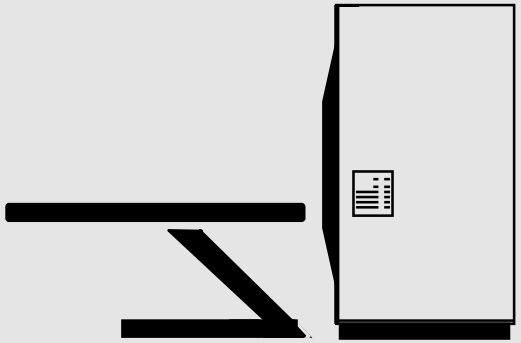
Purchasing Guideline #7

Insist that processing be performed during acquisition, not at workstations !

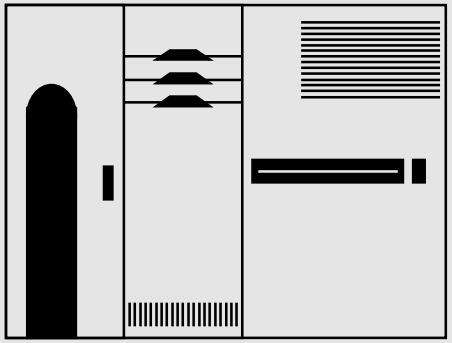
Why ?

Interoperability cannot be achieved if proprietary processing required on PACS workstations for acceptable image appearance.

But when ?



Modality



PACS

Status of Adoption

- Modality - DX (not mammography or CR plates)
  - 7 do (Anexa, Canon, CMT, GE, Hologic, Konica, Lodox, SwissRay)
  - 4 do not (Kodak, IDC, Philips, Siemens)
- PACS - support DX object for storage
  - 32 that do, 2 that do not, 4 unknown (38)
  - 3 more that do compared with 2004 (another 2 dead)
- PACS workstation support for DX/VOI LUT/GSDF
  - unknown - a level of detail not in conformance statements
  - especially with respect to
    - driving hanging protocols and orienting images for display
    - support of calibrated displays
    - VOI lookup tables, not just linear windowing
- In summary - universal on PACS, modalities disappointing

Delays in Adoption - Why ?

- Modality vendors worry PACS won't take DX images
  - mitigate with "fallback" to CR if DX not supported
- PACS vendors see too few DX systems
  - to justify adding DX support
  - to risk depending on extra DX attributes
  - to justify taking advantage of DX-specific features
  - to justify supporting VOI LUTs properly
- Users (customers) aren't very demanding
  - with respect to hanging protocols in workstations
  - with respect to distributed, inter-vendor, image consistency
  - tolerate extensive site-specific tweaking and workarounds

Strategies going forward

- Educate users about what is possible
- Educate vendors about what users need
- Encourage IHE to consider “payload” (content of and which DICOM image objects), not just workflow
- Improve weaknesses identified in standard
- New standard services
  - e.g. DICOM Hanging Protocols

IHE and DX Images

- IHE does not address the “payload” of what is stored in images
- Does not require the Acquisition Modality actors to use the DX IOD
- Does not require any particular behavior of Image Display actors with regard to hanging images
- Does require that the VOI LUT and GSDF be supported for DX IOD

Summary of Guidelines

- Do not buy a DX or CR or PACS without DICOM Modality Worklist (and IHE SWF profile)
- Insist on DX support in both modality (CR and DX) and PACS workstations
- Insist on hanging protocols driven by DX coded attributes in PACS workstations
- Choose a DX modality that populates attributes with minimal impact on operator productivity
- Insist on GSDF calibration and full DX image support (including VOI LUT) in modality, QC and PACS workstations
- Insist on Grayscale Presentation State Storage support for DX in QC and PACS workstations
- Insist that processing be performed during acquisition, not at workstations