The
Medicine
Behind the
Image

DIGITAL BREAST IMAGING INFORMATICS:

CONSIDERATIONS FOR PACS ADMINISTRATORS

David Clunie, CTO, RadPharm, Inc.

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Digital Breast Imaging

- Digital Mammography +/- CAD
- Digital Breast Tomosynthesis (DBT)
- Breast ultrasound – 2D and 3D
- MRI – Dynamic Contrast +/- “CAD”
- NM, PET, specific tracers
- “Exotic” modalities – optical tomography

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Mammography is DIFFERENT !

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Mammography Differences

- Very highly regulated – MQSA in US
- Relatively poorly reimbursed
- Screening is insensitive & non-specific
- Screening -> mortality reduction
- Frequently litigated
- Short read times (esp. screening 1-2min)
- Relatively large projection images

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Mammography Differences

- Stylized reading process (hanging)
- Pixel matrix exceeds display matrix
- Features may be one pixel in size
- Grayscale rendering is demanding
- CAD is often used
- Both raw and processed images needed
- May need reprocessing

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Mammography Differences

- May need extra views - wet read/recall
- May need additional modality (US,MR)
- May need biopsy
- Priors are vital – film or (outside) digital
- Must give patient CD / interpretable film
- Lossy compression forbidden
- Reporting stylized & letter required

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Regulations - MQSA

- URL for MQSA questions:
  - http://www.fda.gov/CDRH/mammography/robohelp/START.HTM
- E.g., under “Transfer of Records” …

Question 4: With the introduction of Full Field Digital Mammography, what constitutes a mammogram for retention and transfer purposes, the digital data or the hardcopy film?

Question 5: We have an FFDM unit and do not keep hardcopy of our exams (i.e., we retain the images electronically). When patients request the release of their exam, we create a hardcopy for them. May we charge the patient for the cost of creating the hardcopy?

Question 6: Can a facility use lossless compression to transmit images to the patient or other medical institutions for final interpretation?

Question 7: Can a facility use lossy compression to transmit images to the patient or other medical institutions for final interpretation?

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Projection Image Size

- One image
  - 1914x2294 ≈ 4.2 MB
  - 3328x4096 ≈ 13 MB
  - 4095x5625 ≈ 22 MB
- Lossless compressed 5:1
  - From 0.84 to 4.4MB
- Four views, both For Processing and For Presentation (8 images) in one study
  - 33.6 to 176MB uncompressed
  - 6.7 to 35.2MB lossless compressed

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Impact of Image Size

- Affects long term archive, interchange media
- Impact on workstation performance
  - transfer from server to workstation (network)
  - transfer from disk to RAM to frame buffer
- Users alternate between hanging steps
  - tab back and forth between layouts instantly
- Work-list based pre-loading to disk/RAM
  - next case ready and waiting instantly

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Reading Process & Layout

- 4 screening views L/R CC/MLO +/- prior
- Flipped correctly back-to-back
- +/- CAD marks
- Overview (gestalt) on two monitors
- Fit breast to screen – rest same size
- Detailed comparison (1:1 pixels)
- Film comparison (true-size)
- Extra views (mustn't be skipped)

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Workstation Requirements

- Size - current and priors same size, fit to screen, true size
- Orientation - correctly flipped
- Annotation - not on the breast; enough to QC
- Justification - back-to-back with no gap
- Grayscale contrast - as the vendor intended
- Background air suppression - for windowing & inversion

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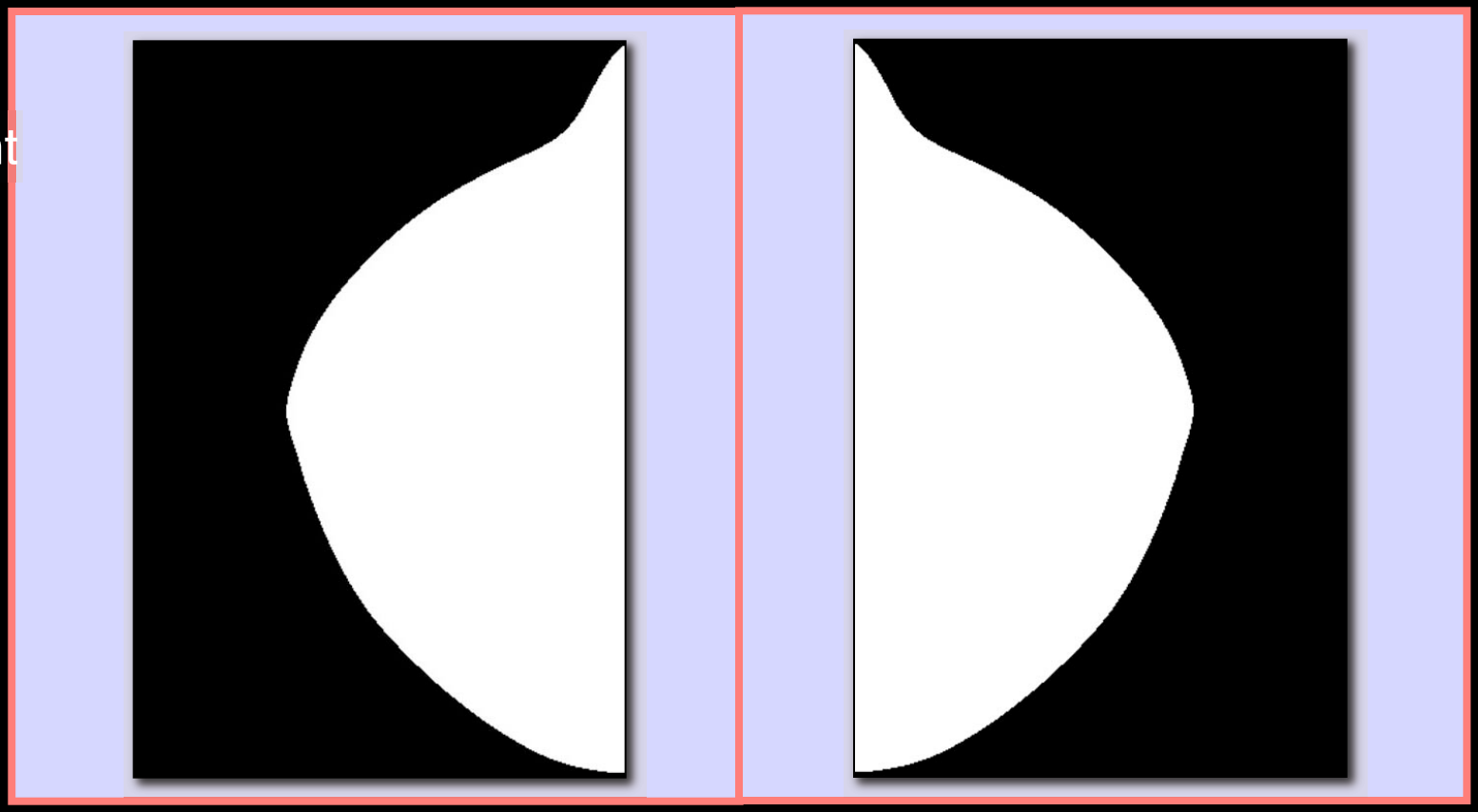
View - CC Laterality - Right

Posterior

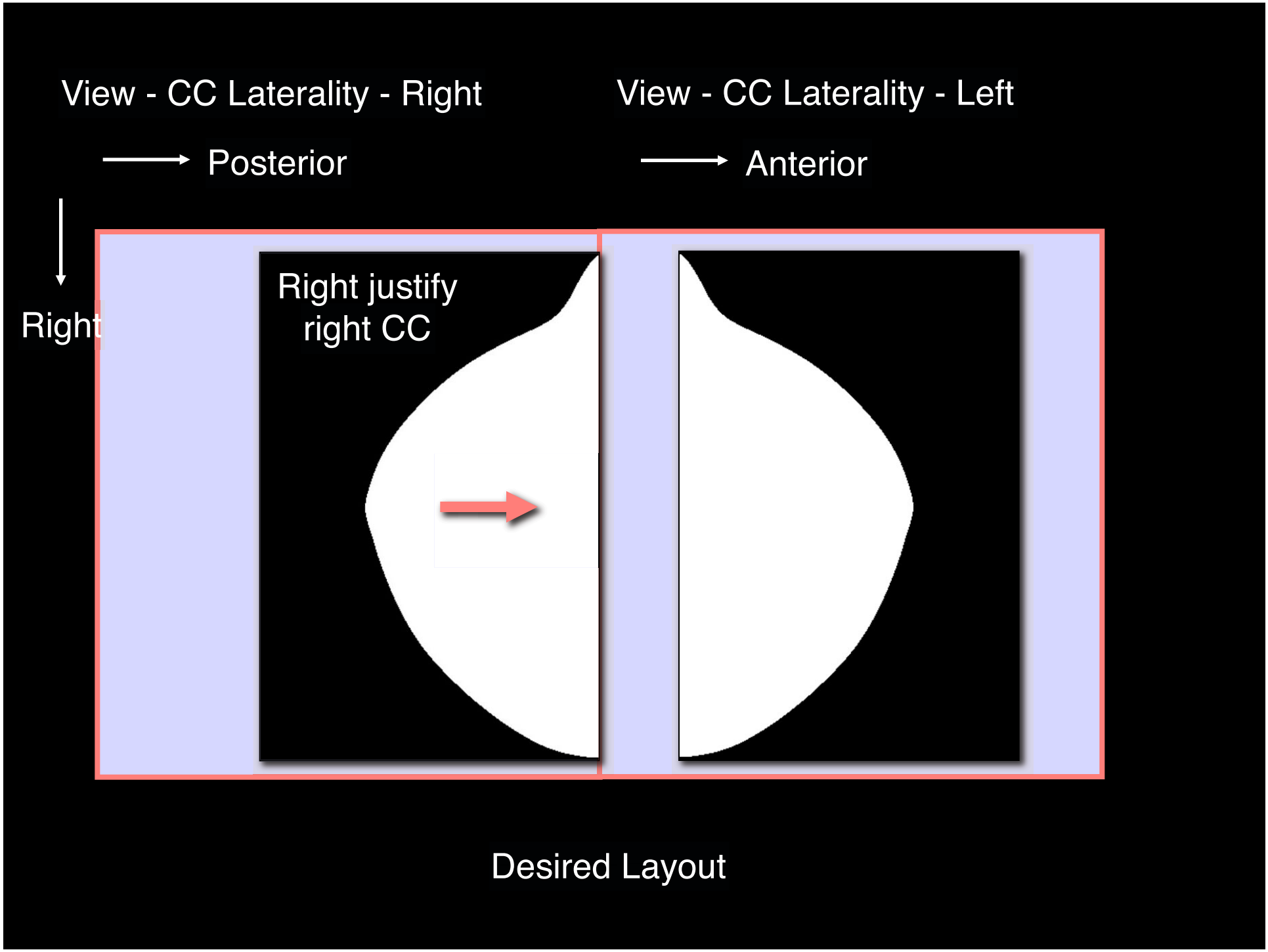
Right

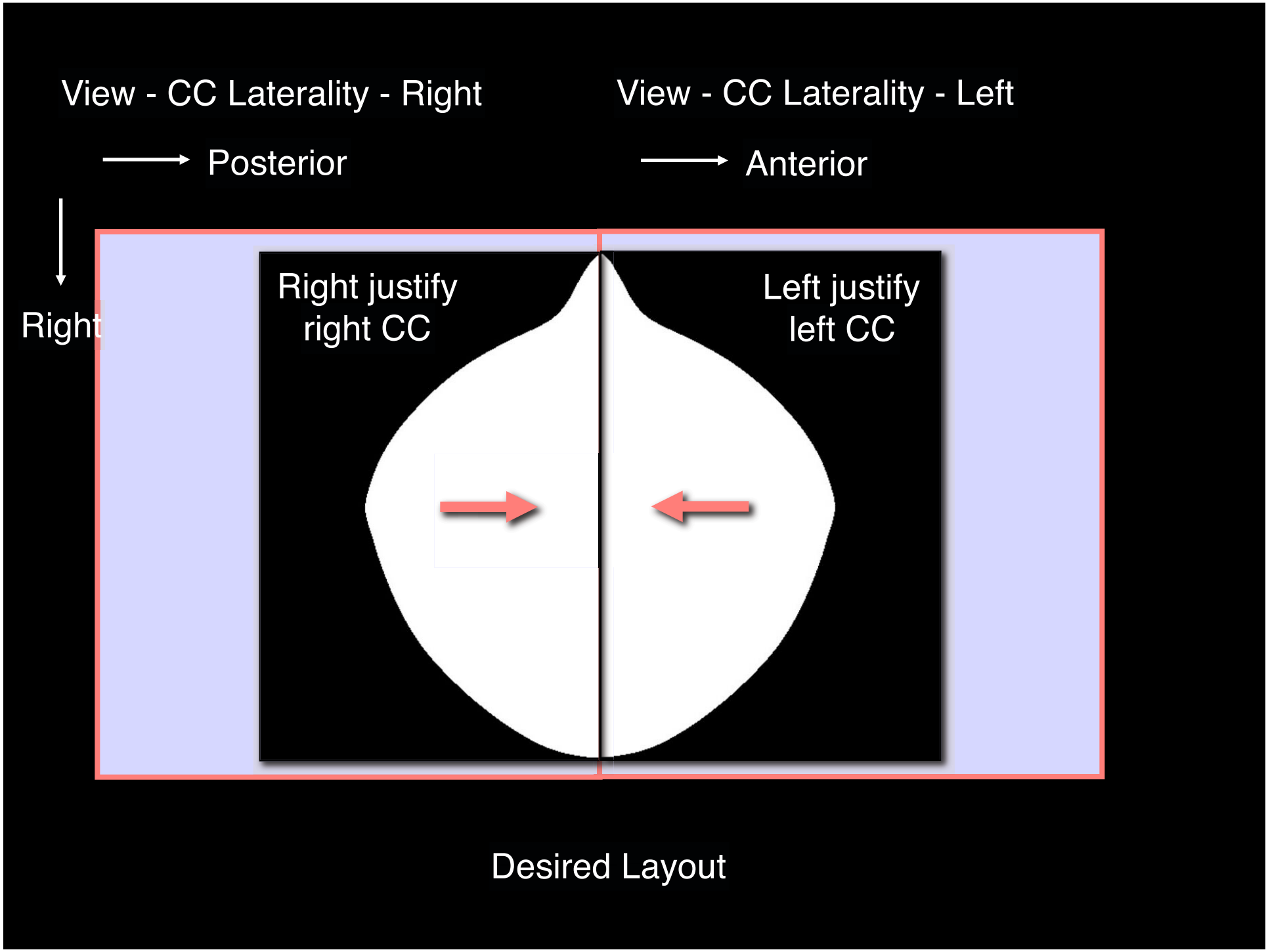
View - CC Laterality - Left

Anterior

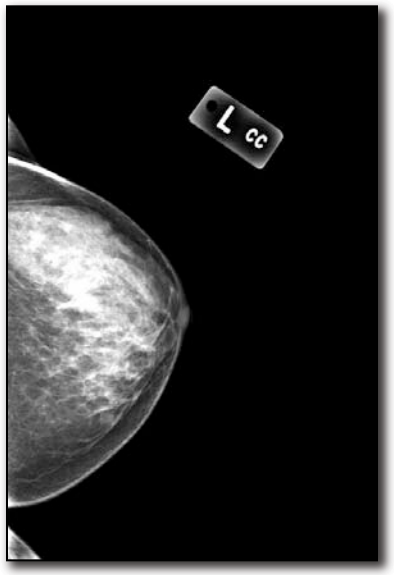


Layout without justification

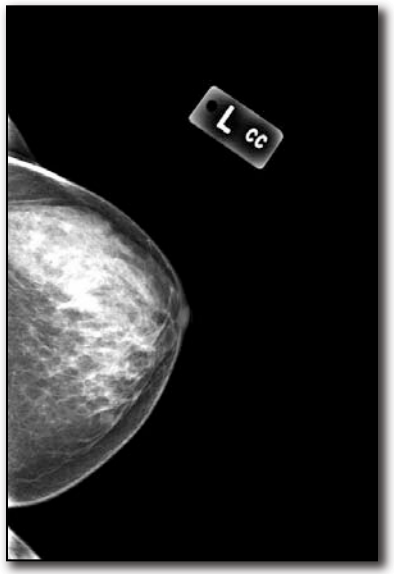

View - CC Laterality - Right
Posterior
View - CC Laterality - Left
Anterior
Right
Right justify
right CC
Desired Layout


View - CC Laterality - Right
Posterior
View - CC Laterality - Left
Anterior
Right
Right justify
right CC
Left justify
left CC
Desired Layout

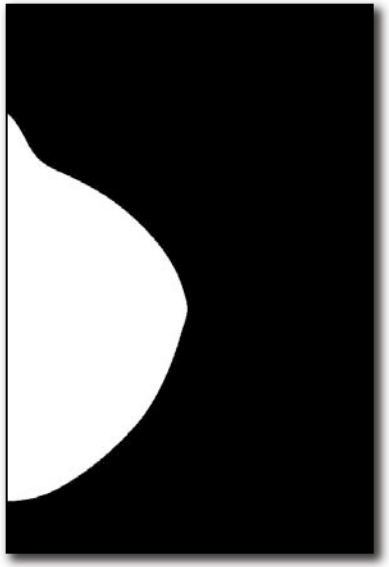
Original



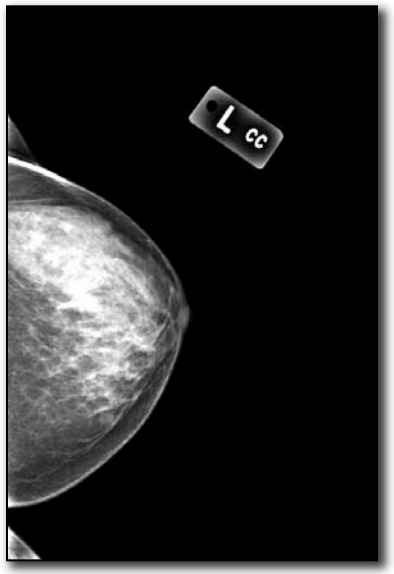
Original



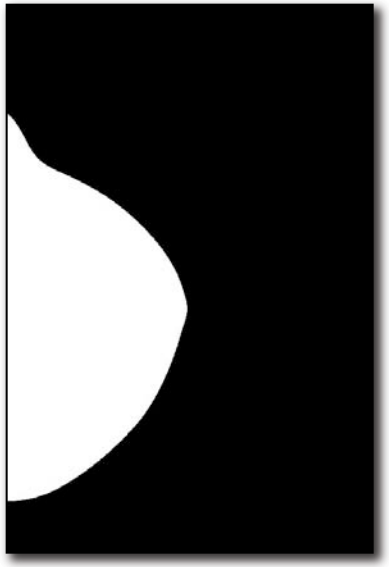
Outline



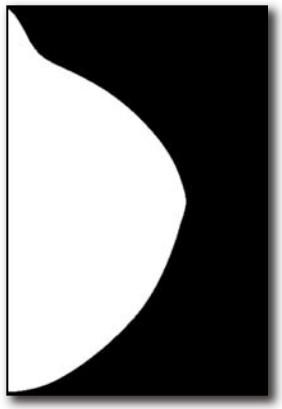
Original



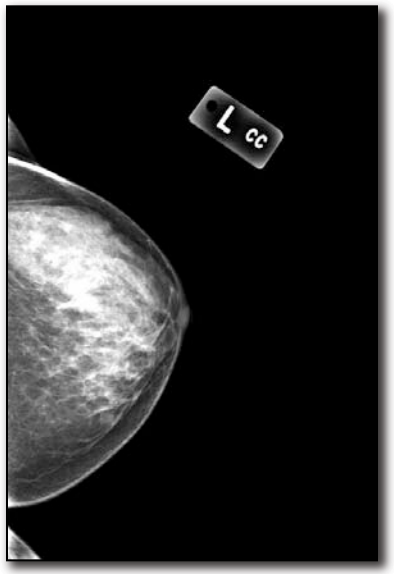
Outline



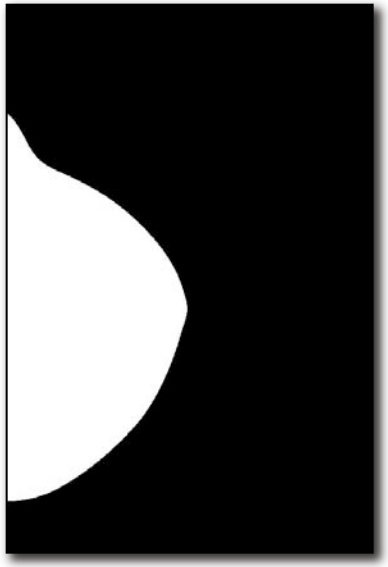
Boundary



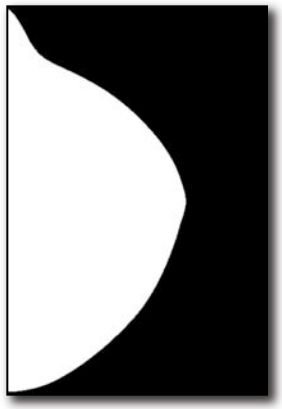
Original



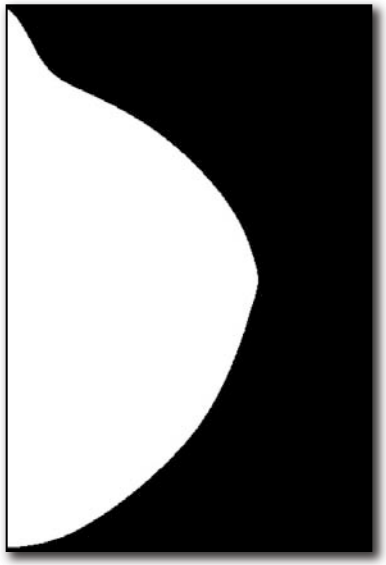
Outline

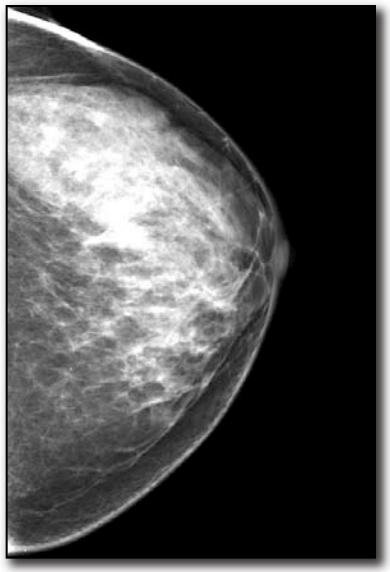


Boundary

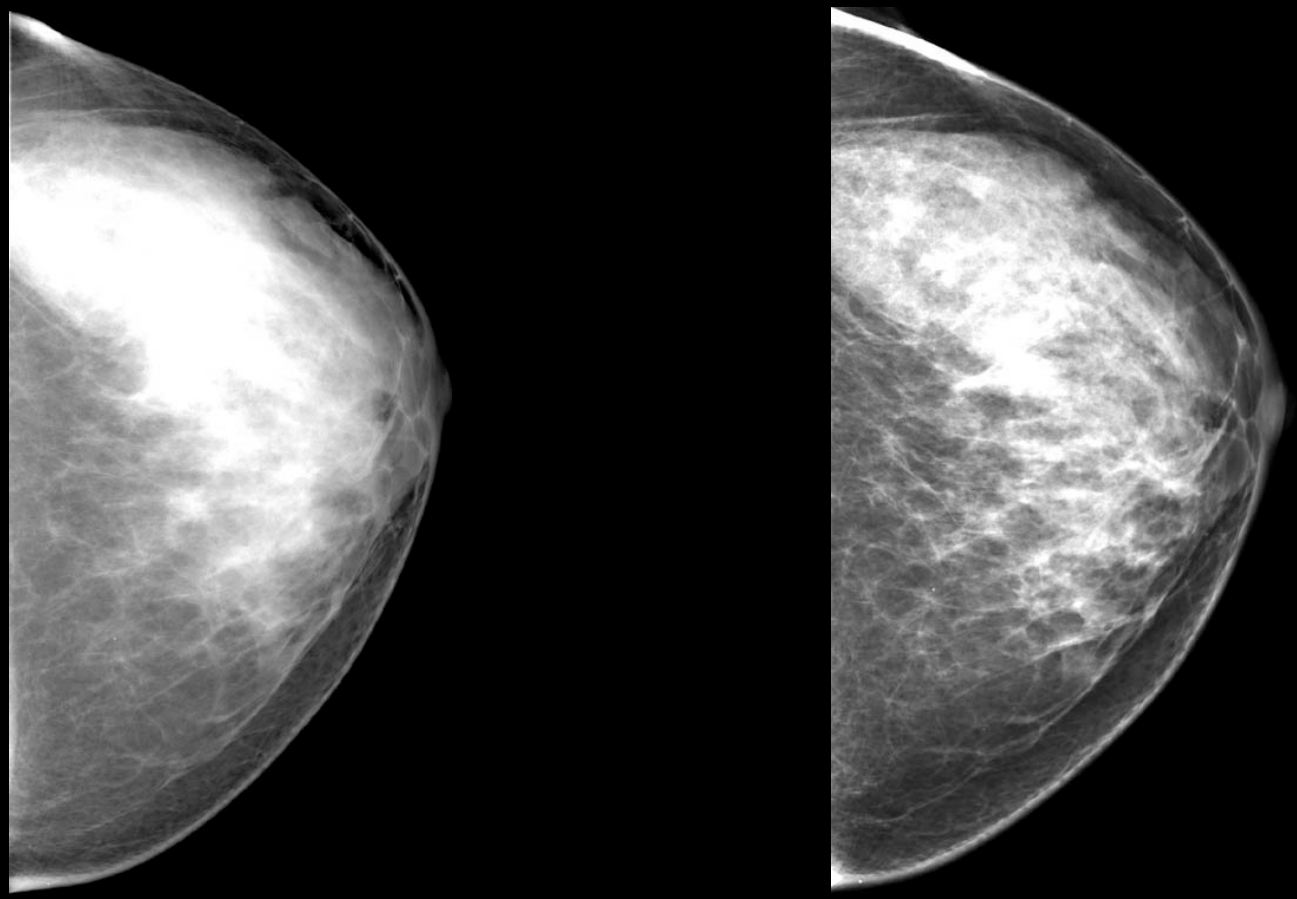


Fit Screen

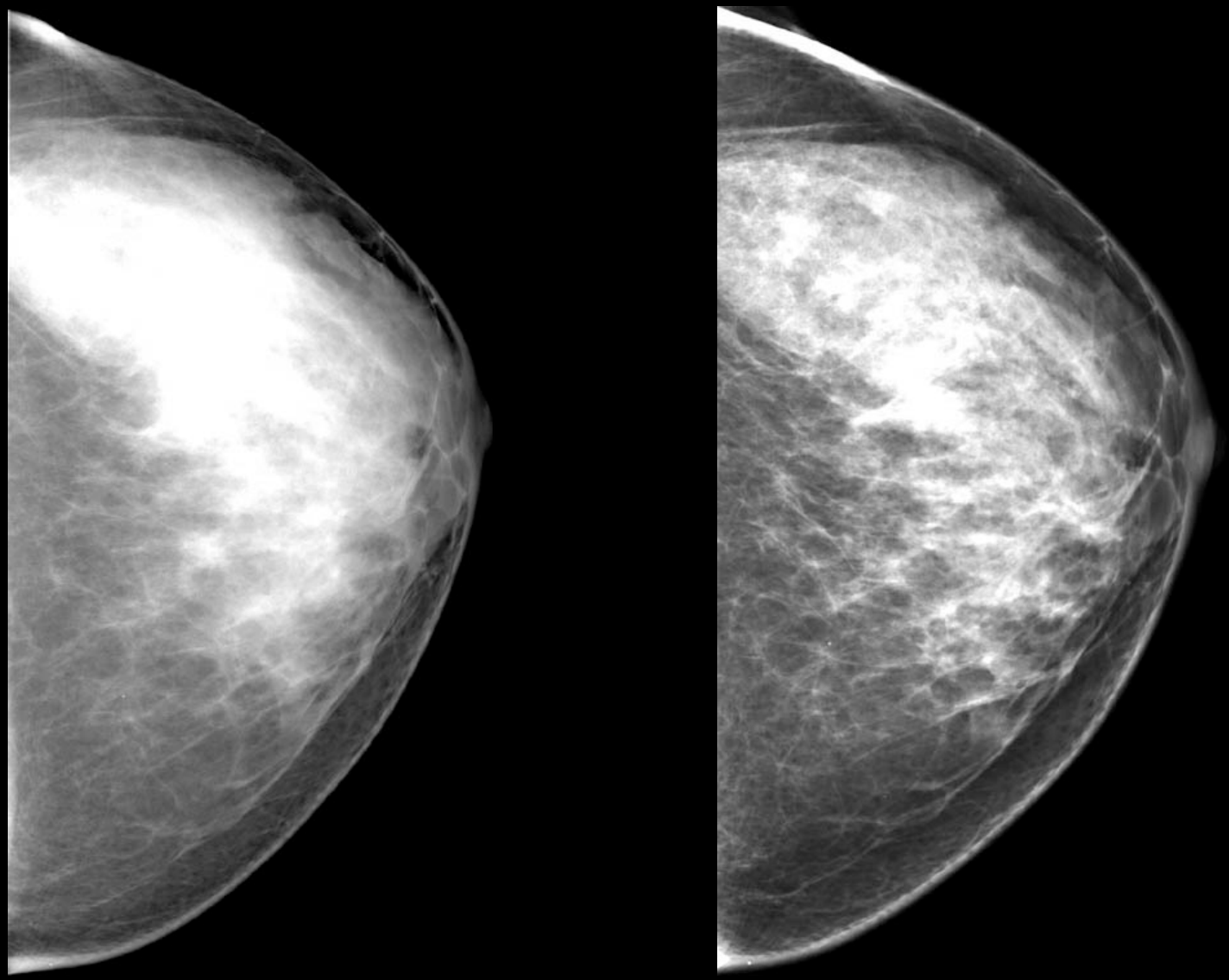




Same size



Same size and fitted to screen



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IHE Mammo Profile

- Defines the minimum display features required in all Image Display actors
- Defines what DICOM attributes shall be used to implement them
- Defines which DICOM Attributes the Acquisition Modality must populate
- Also addresses printing

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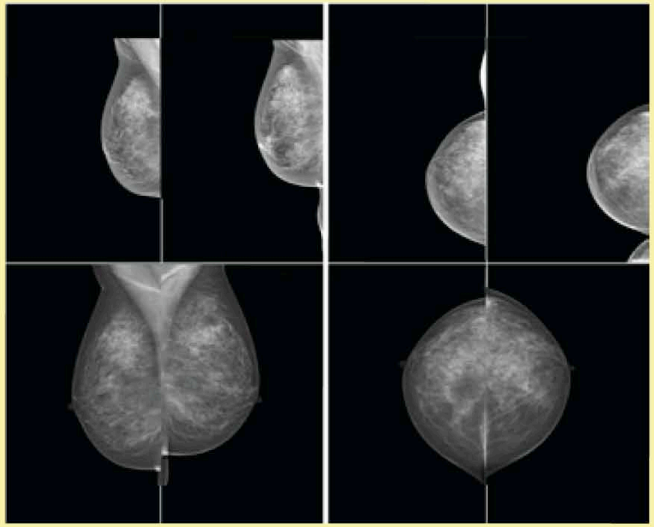
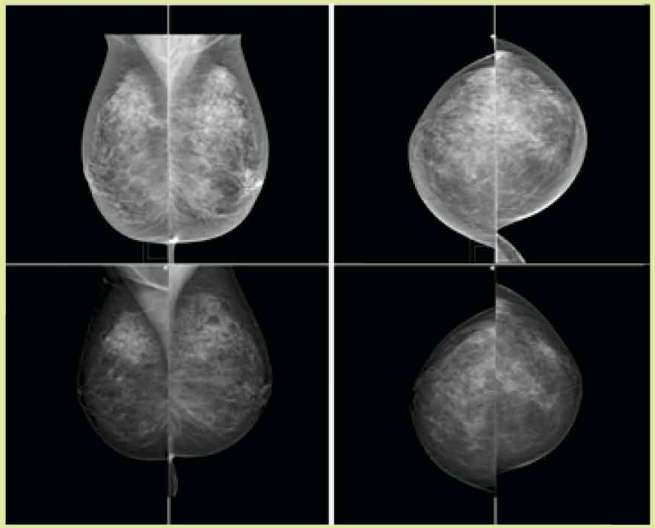
Non-IHE



Prior (above) and Current (below) images are of different sizes and inconsistent orientation

IHE Mammo



Prior (above) and Current (below) images are of same size and consistent orientation

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Grayscale Contrast

- Transform stored pixels to display values
- Acquisition vendors use:
  - linear windowing
  - sigmoid function windowing
  - lookup table to encode function
- Unsatisfactory appearance if ignored
- IHE profile requires support for all three
- IHE also requires these be user adjustable
- DICOM GSDF-calibrated display is required
- Not burdensome for addition to typical PACS

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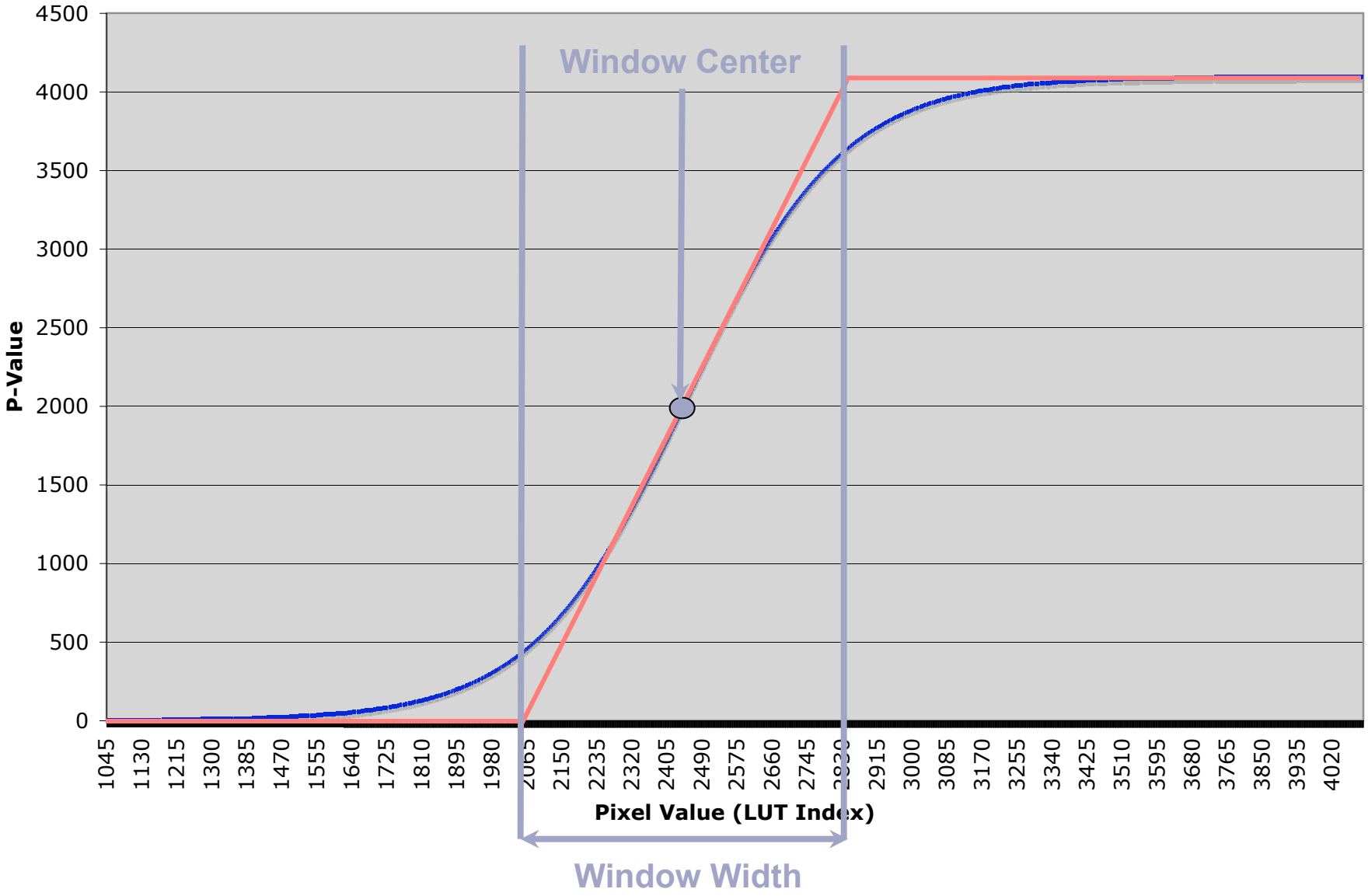
Sigmoid curve encoded as specified shape with window parameters



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Layout and Annotation

- DICOM Mammo object uses codes
  - for View and Modifier
  - needed for flipping to A\F orientation
  - needed for required standard label (“LMLOID”)
  - e.g. Left MLO Implant displaced:

    (“R-10226”,SRT,“MLO”) (“R-102D5”,SRT,“ID”)
- General purpose viewers tend to hang based on plain text (like series description)
- Need mammography-specific programming or scripting to support required functions

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Annotation

- MQSA
- ACR Quality Manual Requirements
- Interpretation, QC and problem solving
- Dose awareness
- Must not overlay/obscure breast tissue
- Gestalt impression during overview
- Must not hide features under annotation

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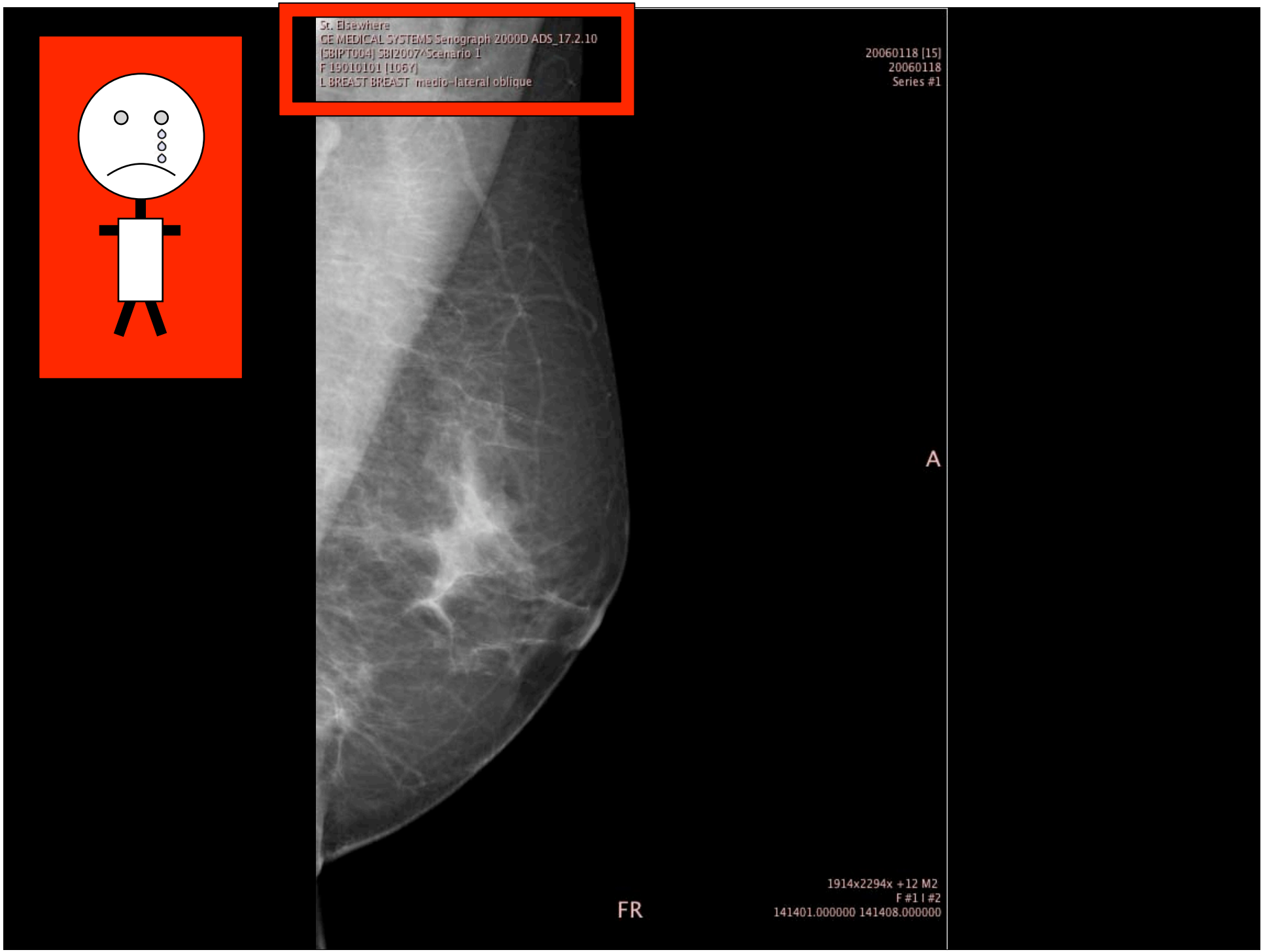
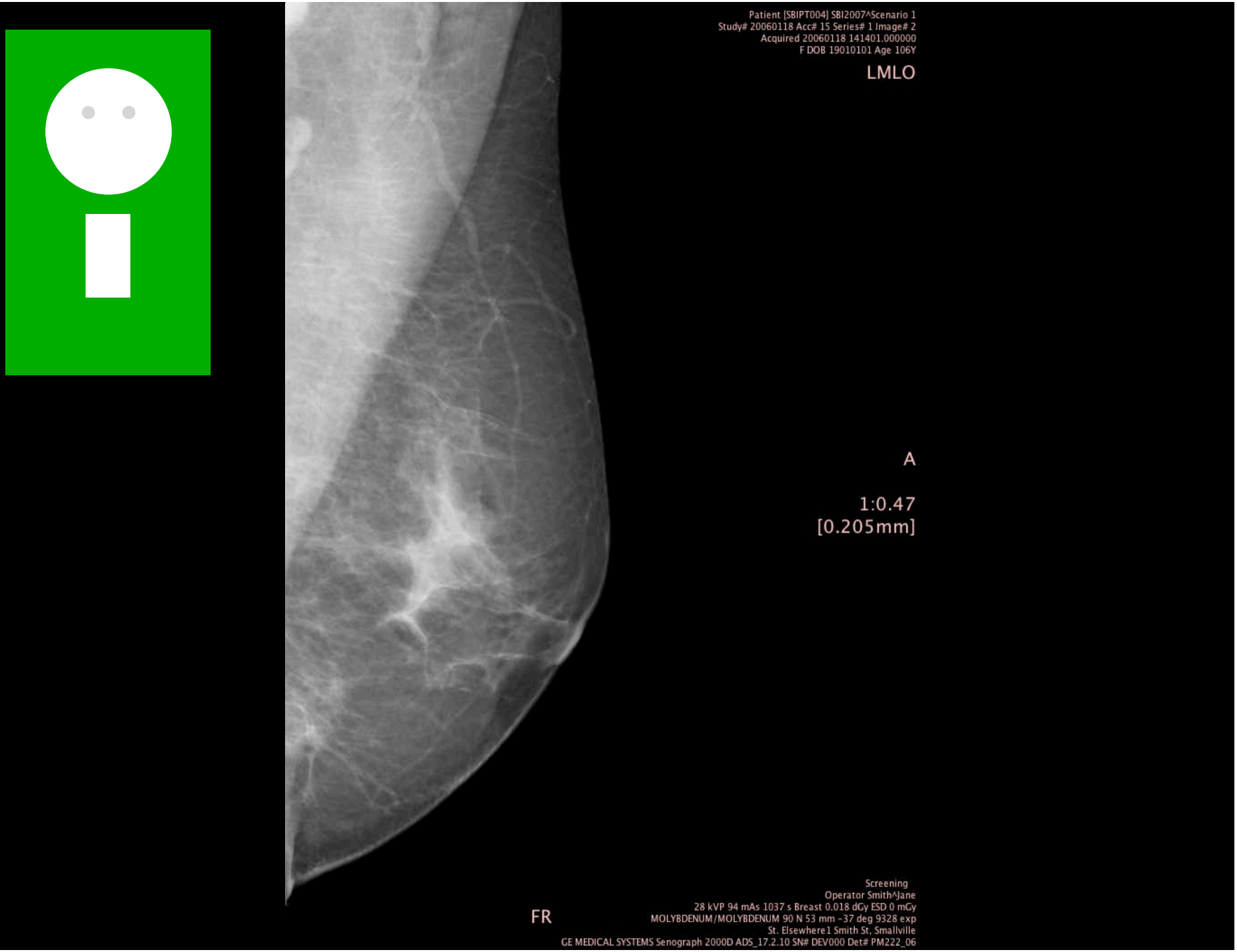

St. Elsewhere
GE MEDICAL SYSTEMS Senograph 2000D ADS_17.2.10
(SBIPT004) SBI2007^Scenario 1
F 19010101 [106Y]
L BREAST BREAST medio-lateral oblique
20060118 [15]
20060118
Series #1
A
FR
1914x2294x +12 M2
F #1 I #2
141401.000000 141408.000000


Patient [SBIPT004] SBI2007^Scenario 1
Study# 20060118 Acc# 15 Series# 1 Image# 2
Acquired 20060118 141401.000000
F DOB 19010101 Age 106Y
LMLO
A
1:0.47
[0.205mm]
FR
Screening
Operator Smith^Jane
28 kVP 94 mAs 1037 s Breast 0.018 dGy ESD 0 mGy
MOLYBDENUM/MOLYBDENUM 90 N 53 mm -37 deg 9328 exp
St. Elsewhere1 Smith St, Smallville
GE MEDICAL SYSTEMS Senograph 2000D ADS_17.2.10 SN# DEV000 Det# PM222_06

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Series Organization

- Neither DICOM nor IHE defines Series
  - each image may be separate series
  - one series for set of four screening For Presentation views
  - four series with For Presentation and For Processing pairs in one series for each view
- Robust viewer must not make assumptions about series organization
- IHE profile requires series independence

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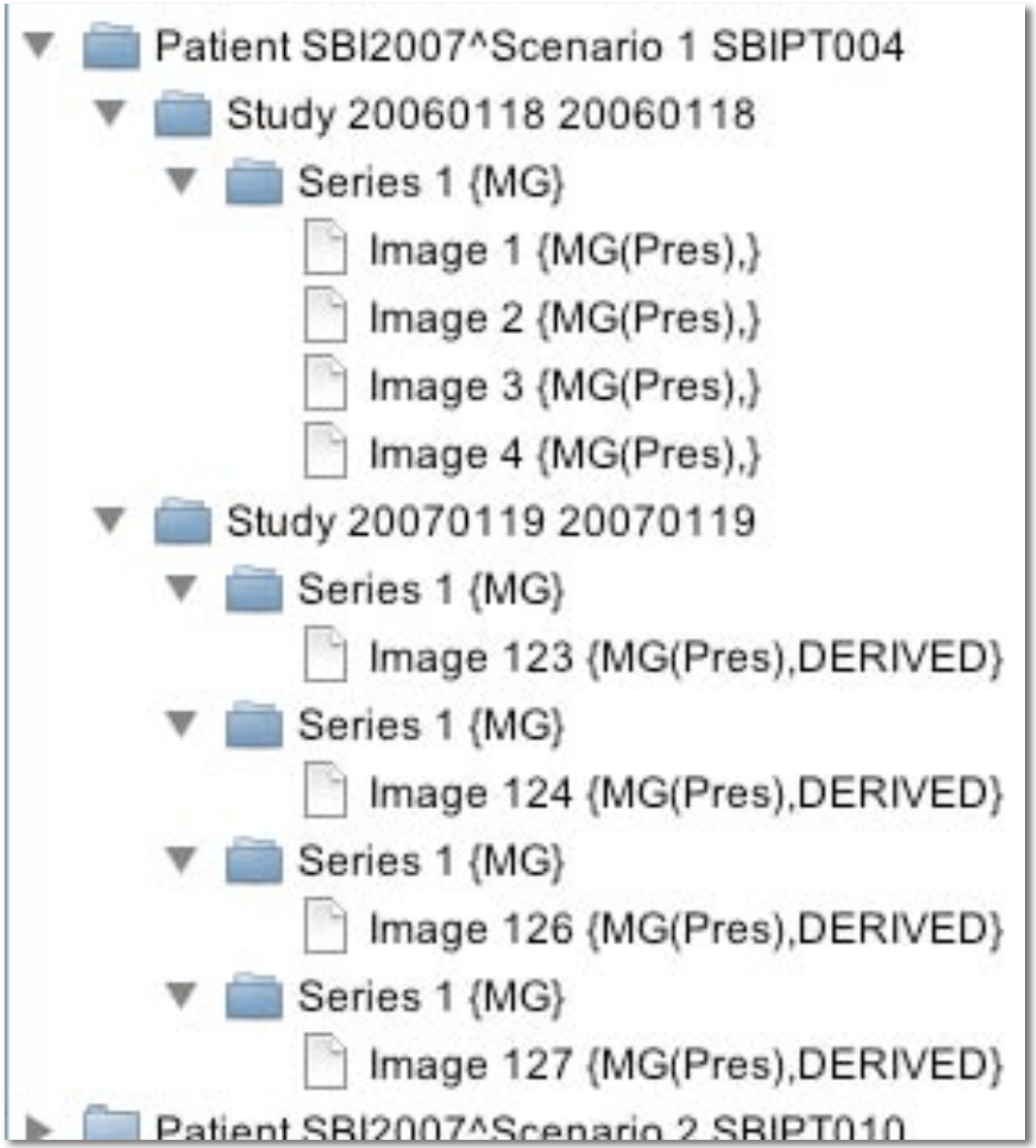
Patient SBI2007^Scenario 1 SBIPT004
Study 20060118 20060118
Series 1 {MG}
Image 1 {MG(Pres),}
Image 2 {MG(Pres),}
Image 3 {MG(Pres),}
Image 4 {MG(Pres),}
Study 20070119 20070119
Series 1 {MG}
Image 123 {MG(Pres),DERIVED}
Series 1 {MG}
Image 124 {MG(Pres),DERIVED}
Series 1 {MG}
Image 126 {MG(Pres),DERIVED}
Series 1 {MG}
Image 127 {MG(Pres),DERIVED}
Patient SBI2007^Scenario 2 SBIPT010

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Workflow

- Scheduled workflow for modality
  - IHE SWF +/- mammography specifics (new in 2008)
- CAD workflow
  - de facto standard “push” workflow
- Reporting workflow
  - no accepted standards
- Image distribution workflow
  - IHE PDI
- Result distribution workflow
  - no accepted standards
- Importation of priors workflow
  - IHE IRWF

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CAD

- Objective – improve sensitivity
- Find and mark suspicious locations
- Two primary informatics problems
  - workflow – movement of images & results
  - result encoding & display

- *Results need to be visible during read*

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CAD "Push" Workflow

- Acquisition modality produces
  - For Processing images -> CAD
  - For Presentation images -> human reader
- CAD server
  - passively receives images
  - when to start CAD ?
  - when to send CAD results ?
- Workstation (+/- PACS) displays
  - For Presentation images
  - with & without CAD marks
  - when is exam "ready to read" (all images/CAD available) ?

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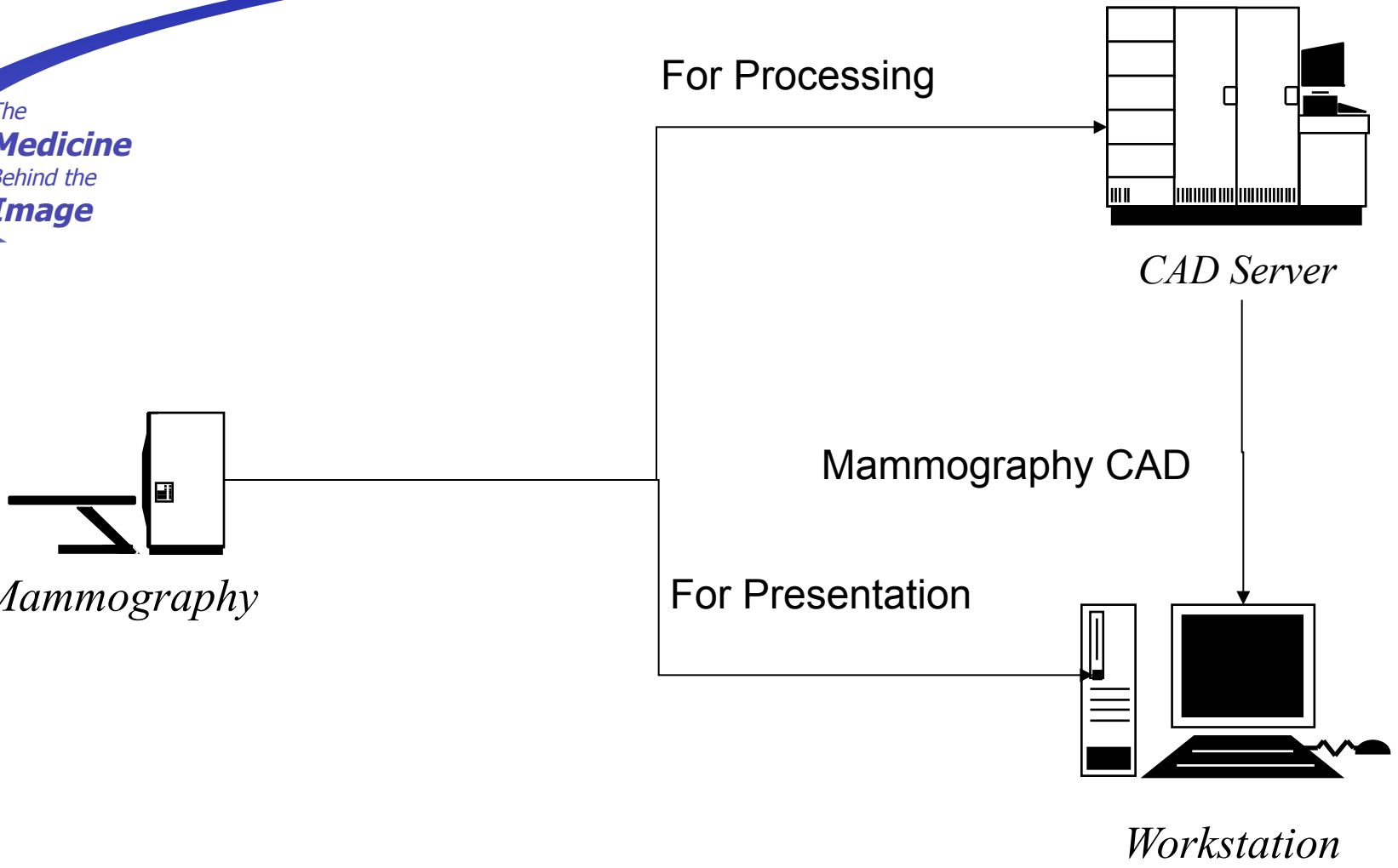

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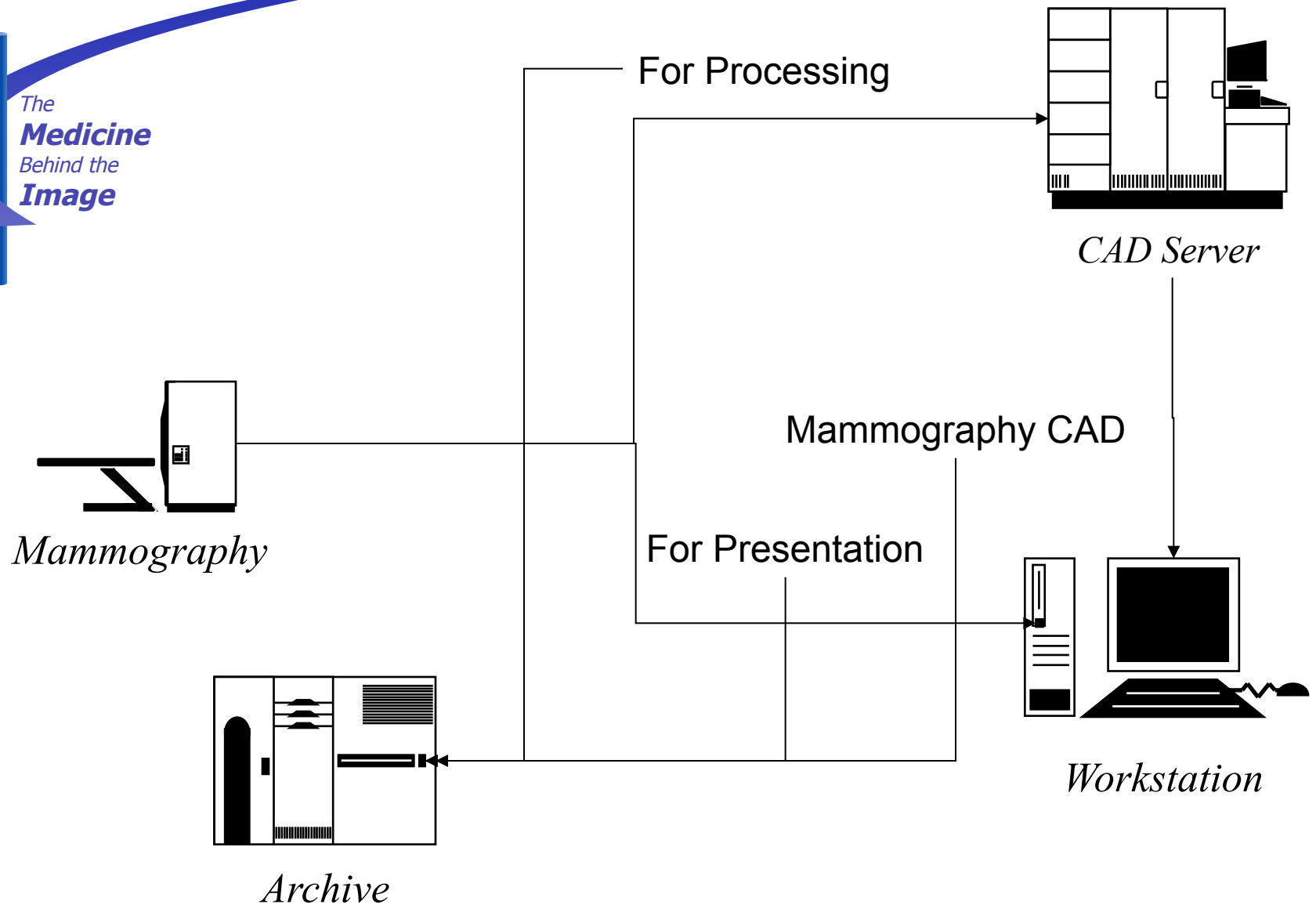

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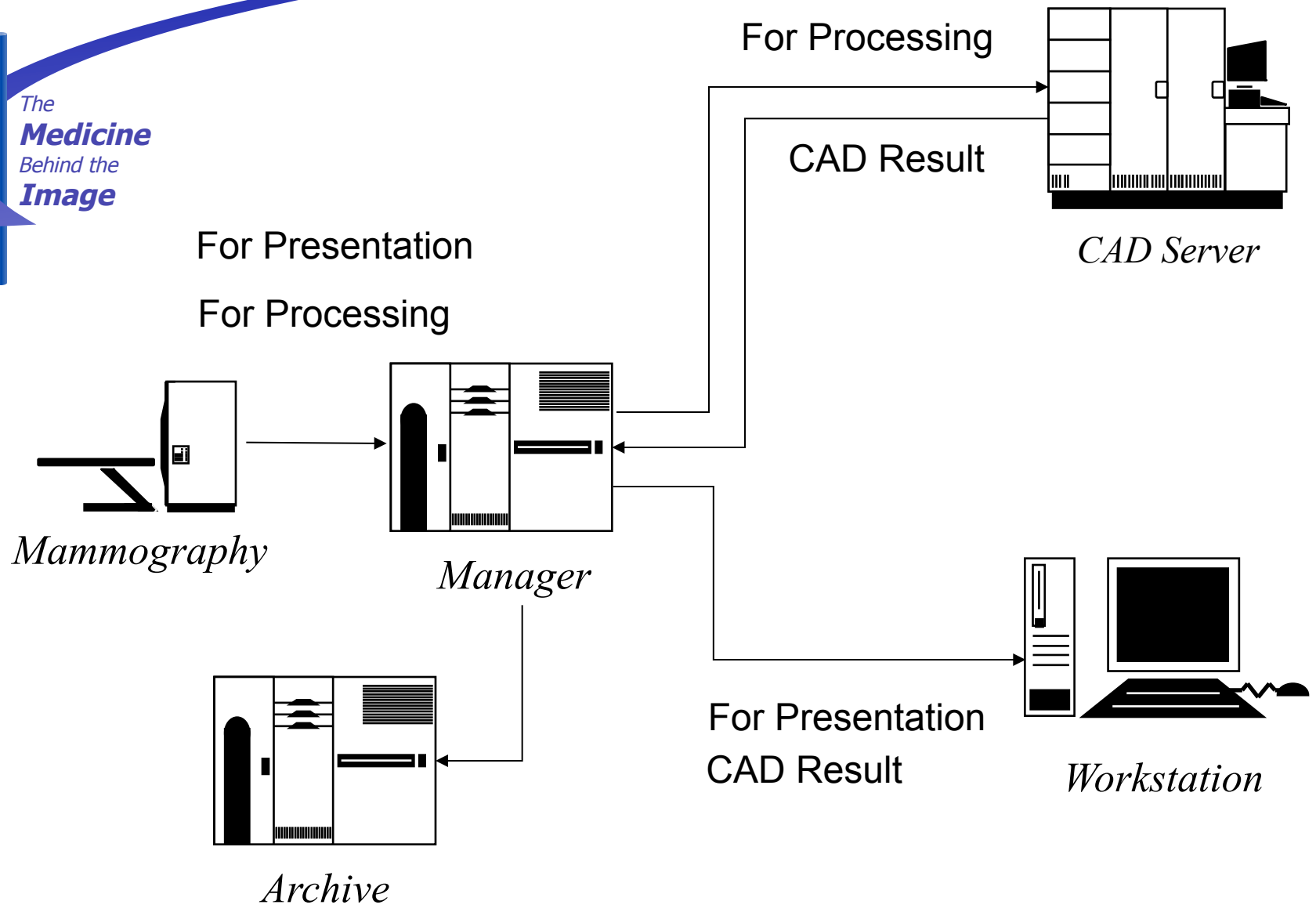

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CAD Encoding

- DICOM Structured Report
  - Mammography CAD SR SOP Class
  - co-ordinates on For Processing image
  - coded classification (mass, micro-calcification)
  - required in all Image Displays by IHE
  - format of displayed marks is not defined/encoded
- Support issues in non-IHE Image Display
  - no support in “ordinary” viewers/PACS
  - poor support – crash if SR too complicated
  - poor filtering of complex content
  - resolving UID reference to For Processing image

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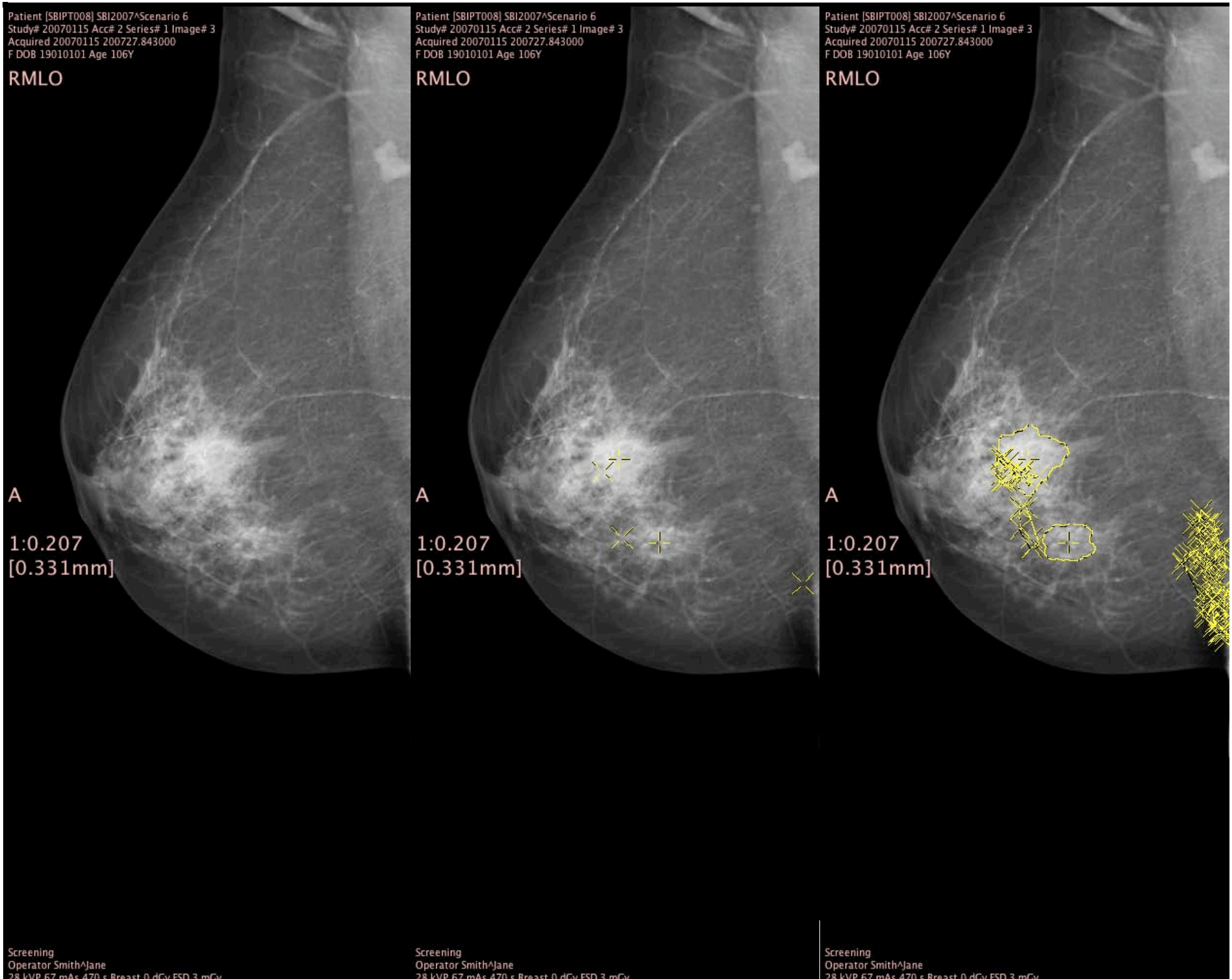
Patient [SBIPT008] SBI2007^Scenario 6
Study# 20070115 Acc# 2 Series# 1 Image# 3
Acquired 20070115 200727.843000
F DOB 19010101 Age 106Y
RMLO
A
1:0.207
[0.331mm]
Screening
Operator Smith^Jane
28 kVP 67 mAs 470 s Breast 0 dGy ESD 3 mGy
Patient [SBIPT008] SBI2007^Scenario 6
Study# 20070115 Acc# 2 Series# 1 Image# 3
Acquired 20070115 200727.843000
F DOB 19010101 Age 106Y
RMLO
A
1:0.207
[0.331mm]
Screening
Operator Smith^Jane
28 kVP 67 mAs 470 s Breast 0 dGy ESD 3 mGy
Patient [SBIPT008] SBI2007^Scenario 6
Study# 20070115 Acc# 2 Series# 1 Image# 3
Acquired 20070115 200727.843000
F DOB 19010101 Age 106Y
RMLO
A
1:0.207
[0.331mm]
Screening
Operator Smith^Jane
28 kVP 67 mAs 470 s Breast 0 dGy ESD 3 mGy

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Non-IHE CAD Workarounds

- Deployment
  - CAD server creates something else than SR CAD
  - convertor box can change SR to something else
- Alternative encodings
  - separate Presentation State object
  - add 6000 overlay to new For Presentation image
  - burned into pixels of another For Presentation image
  - proprietary internal PACS annotation
- Issues with workarounds
  - reader still needs to be able to turn marks on/off
  - size/shape/behavior of marks may affect interpretation

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CAD Archival

- Additional issue of what to archive ?
  - input data (For Processing Images)
  - CAD result itself
- Why archive ?
  - reprocess next year -> better change detection
  - “audit trail” to support decision making
  - retrospective CAD supports interpretation (legal case)
  - clinical trials
- Why not archive ?
  - space (may matter for images, CAD size trivial)
  - “audit trail” of decision with unfortunate outcome

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For Processing/Presentation

- DX family of objects, including mammo
  - For Presentation – processed, ready to view
  - For Processing – raw, not viewable
- All modalities & displays
  - shall support For Presentation
  - may also support For Processing
- CAD requires For Processing
- If user wants different (proprietary) processing
  - reprocess at modality
  - send For Processing to (proprietary) workstation
- Interchange (media) requires >= For Presentation

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Computed Radiography (CR)

- Later to market in USA than fixed detectors
- USA release supports DICOM MG
- Separate devices expose and read cassettes
- Makes it challenging to populate DICOM header
  - demographics, dates, IDs
  - view and orientation
  - technique and dose
- Vendor approaches
  - bar coding
  - retrofitting generator to acquire data
- User should still insist on IHE Mammo compliance

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Compression

- Lossless compression only
- No lossy compression for interpretation
- No studies yet on lossy compression
  - very encouraging results from digitized film
  - still no ROC study on FFDM data
  - confounded by different vendor characteristics, detector size, processing
  - DMIST data set still sequestered and by now probably obsolete

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Lossless compression

- 20 pairs (40 images)
  - of For Processing and For Presentation
- Three vendors
  - 4 pairs Lorad (1 patient, 4 views)
  - 4 pairs Fischer (1 patient, 4 views)
  - 12 pairs GE (3 patients, 4 views each)

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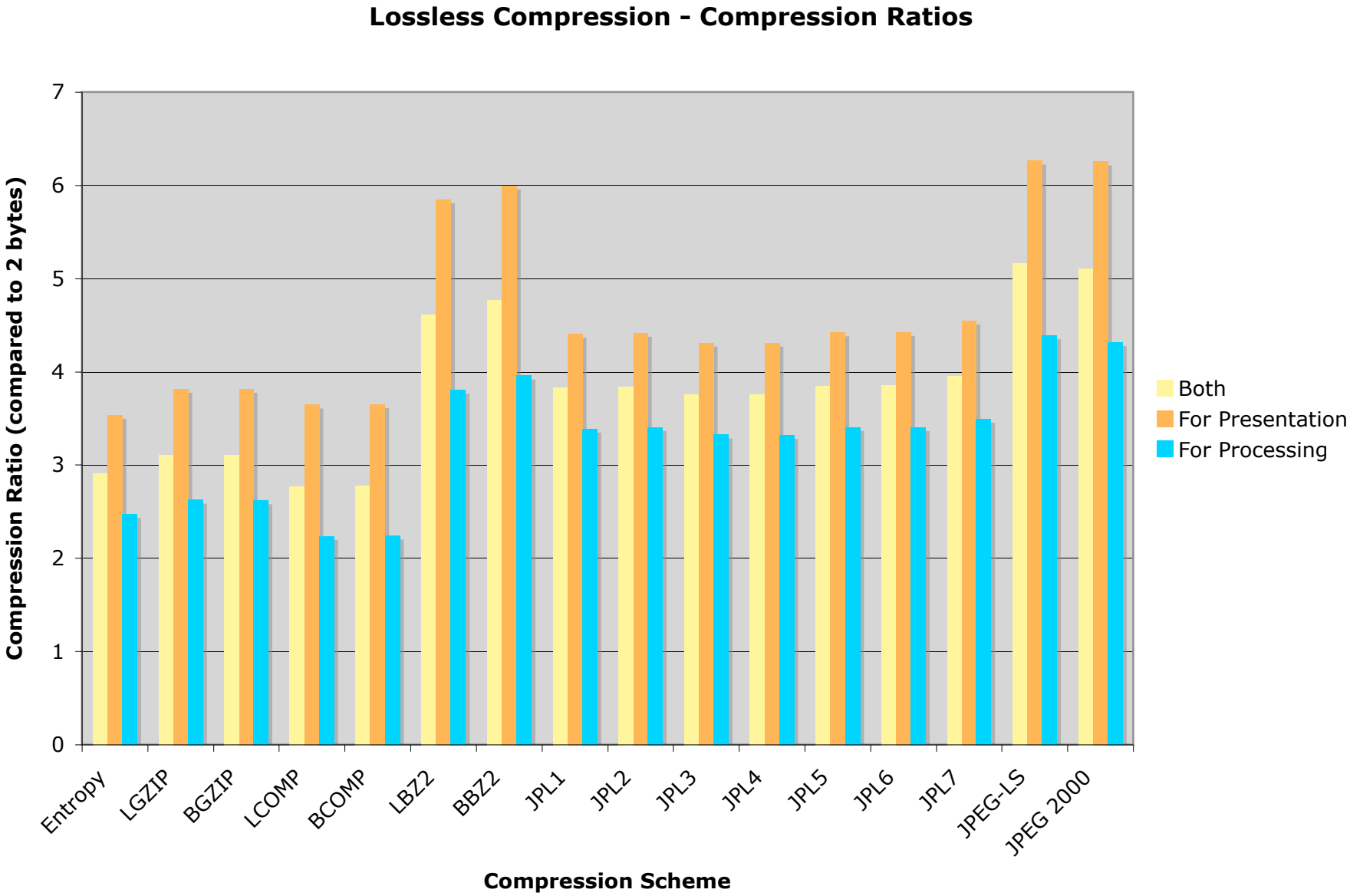
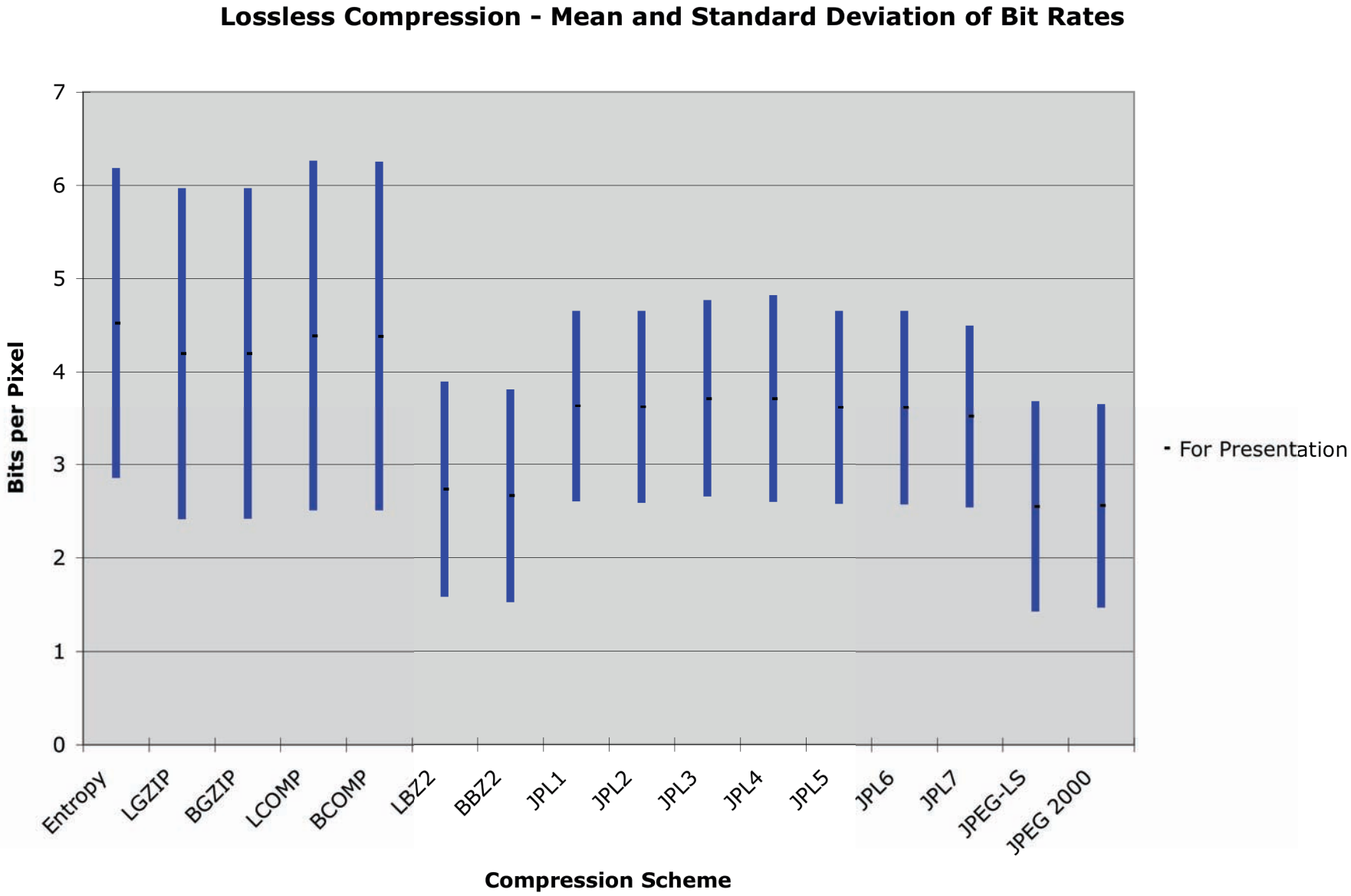

Lossless Compression - Compression Ratios
Compression Ratio (compared to 2 bytes)
0
1
2
3
4
5
6
7
Entropy
LGZIP
BGZIP
LCOMP
BCOMP
LBZ2
BBZ2
JPL1
JPL2
JPL3
JPL4
JPL5
JPL6
JPL7
JPEG-LS
JPEG 2000
Compression Scheme
Both
For Presentation
For Processing


Lossless Compression - Mean and Standard Deviation of Bit Rates
Bits per Pixel
0
1
2
3
4
5
6
7
Entropy
LGZIP
BGZIP
LCOMP
BCOMP
LBZ2
BBZ2
JPL1
JPL2
JPL3
JPL4
JPL5
JPL6
JPL7
JPEG-LS
JPEG 2000
Compression Scheme
- For Presentation

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Lossless compression

- For Presentation > For Processing
  - less noisy
- All compress extremely well
  - mostly air
- Considerable variation
  - size of breast
- JPEG-LS and JPEG 2000 best
  - mean CR 6.27 and 6.25 For Presentation
- Lossless JPEG (SV1) poor
  - mean CR 4.41 For Presentation
  - no run length compression, so poor for large areas of air

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Variation in compressibility

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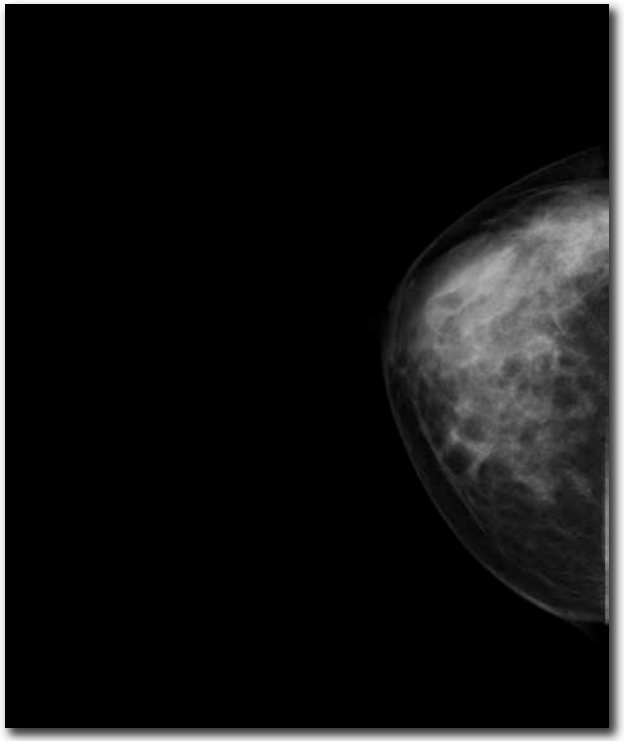
JPEG-LS Lossless



Best - CR 12.9

Worst - CR 3.19

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Transfer between facilities

- Special mammography requirements
- Priors are essential
- Combined film/softcopy undesirable
- Women move (job, insurance, referrer)

- Therefore need standard, portable digital transport mechanism
- Nationwide/regional imaging network is long term
- Portable digital media is currently the only answer

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Media for mammography

- Standard image format - DICOM Mammo Image
  - For Presentation only, or For Processing as well ?
- Standard media - CD or DVD
  - How many images (visits) will fit ? Enough.
- Compression
  - None, lossless (not lossy) ? Which scheme ? PDI - None
- CAD
  - As DICOM Mammography CAD SR ?
  - As DICOM Presentation State ? Both ?
- Radiologist's reports and annotations
  - DICOM Mammography SR ?
  - Other - plain text, HTML, HL7 CDA ?

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Media Viewers

- Many CD viewers not mammo aware
- Suitability for referring doctor
  - e.g., surgeon for biopsy/lumpectomy
- Support for localization of abnormality
  - Presentation States
- Importation expectation avoids issue
  - surgeon's own viewing system
  - next year's radiologist's own workstation
- No proprietary formats & viewers !@#$

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Printing

"For purposes of transferring films, the facility must be able to provide the medical institution, physician, healthcare provider, patient or patient's representative, with hardcopy films of final interpretation quality or, *when it is acceptable to the recipient* (e.g., a transfer between two FFDM facilities), with original or lossless compressed full field digital images electronically."

Questions about MQSA 900.12(c)(4)(ii),(iii)

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Printing

- Must be able to print interpretation quality film
- Physical size for hanging
- True size, for biopsy, comparison as priors
- Annotation, per MQSA and quality manual
- Grayscale 12 bits and as per DICOM GSDF
- Dmax sufficient for mammo (IHE > 3.5)
- Insist on IHE Mammo profile for printing
- Likely requires a dedicated mammo printer with the appropriate film size(s)

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Other modalities

- "Multi-modality" workstation
- Isn't that what a PACS workstation is ?
- Breast ultrasound, same as any other
- Breast MRI more difficult
  - dynamic contrast acquisition
  - requires analysis of time-intensity curve
  - so-called DCE-MR "CAD" application
  - yet another non-integrated 3rd party device ?
  - "plug-in" architecture – DICOM WG 23

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Tomosynthesis

- Multiple projection images
- Reconstructed to make “slices”
- And you thought FFDM images were big !
- Impact of large size
  - archive and interchange media
  - network retrieval on demand to disk and RAM (pre-fetch)
  - speed of scrolling though slices
  - 20MB per slice, not 0.5MB CT, and 5MP display
- DICOM standard format ballot finished
- Vendors may go to market with proprietary format ☹
- Demand DICOM in your contract in reasonable time

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Conclusion

- Mammography is different
- 3rd party workstations are capable, but not integrated without reading worklist
- PACS workstations are getting there
- Insist on IHE Mammo profile, now or in reasonable time per contract with penalties
- Deploy CAD “properly”, with SR CAD
- Archive everything, and do it losslessly
- Produce DICOM/IHE PDI compliant media
- Print interpretation quality films, true size, annotated
- Prepare for tomo, and be afraid !

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IHE Resources

- IHE Mammography web site
  - http://www.ihe.net/Mammo/
- IHE Mammography Profile in Radiology TF
  - http://www.ihe.net/Technical_Framework/index.cfm#radiology
- Going Digital: An IHE Guide for Mammography
  - http://www.ihe.net/Mammo/going_digital_mammography.cfm
- IHE Mammography User's Handbook
  - http://www.ihe.net/Resources/handbook.cfm

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