Interoperability, Transfer Between Enterprises, Archival, Compression and Disaster Recovery

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Questions about appearance

- Why do different vendors' images look different on the same workstation ?
- Why do the same images look different on different workstations ?
- Why can't I reprocess the image on my third party workstation ?
- Why don't the images look the same on my workstation as when the technologist exposed them ?

Questions about hanging

- Why are the standard four views not hung in the order and orientation I want ?
- Why do some vendors' images hang properly and not others ?
- Why do different vendors' images display as different sizes ?
- Why are the standard views spaced apart and not back to back ?
- Can I share hanging protocols between systems from different vendors ?
- Can I store hanging protocols centrally so that they don't have to be configured in each workstation ?

Questions about CAD

- Can I share a CAD server between different vendors' acquisition systems ?
- Should I send the CAD For Processing or For Presentation images ?
- If I send the CAD For Processing, how do I view the results since I can't display For Processing images ?
- How can I save the CAD output in the archive ?
- How can I send the CAD output with the patient and to the referring physician ?
- How can I save the CAD output in a form that PACS can display ?
- Why do my CAD marks look different on different systems ?

Questions about workflow

- Why don’t my mammography workstations support reporting work lists from the PACS ?
- Why do I have to manually query for each study rather than have it made instantly available when I hit “next” ?
- Can’t the workstation anticipate my workflow ?
- Can work lists be shared with workstations ?
- Can the PACS store mammography reports from mammography reporting system vendors ?

Questions about transfer

- Why do I need digital images of priors ?
- How can I get digital images of priors ?
- How should I send my images and CAD and reports ?
- What should I give the patient ?
- How can I import external prior images, CAD and reports into my PACS ?
- Should I archive external priors in my own archive ?

Questions about archival

- Do I really have to store all the images I viewed whilst reporting ?
- Why should I store the For Presentation images ?
- Why should I store the For Processing images ?
- How can I store the CAD results ?
- Why should I store images on site ?
- Do I really have to keep an off site backup of what is stored ?
- How much does archival cost ?

Questions about compression

- Can I use compression at all ?
- Can I lossy compress prior to primary reading ?
- Can I lossy compress prior to CAD ?
- Can I lossy compress in the archive after reading ?
- Can I lossy compress when sending images out ?
- Can I lossy compress for tele-mammography ?

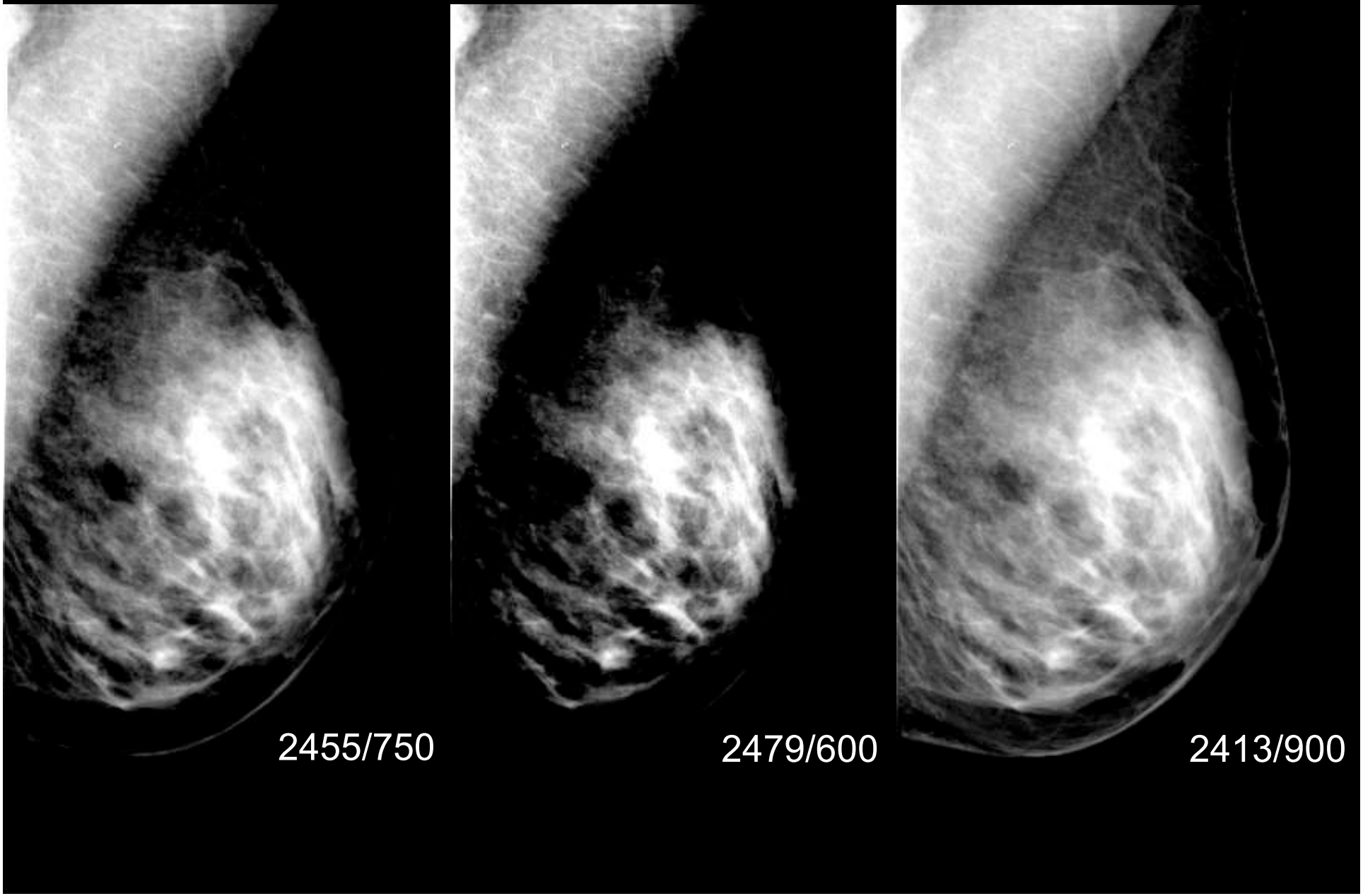
Questions about disaster recovery

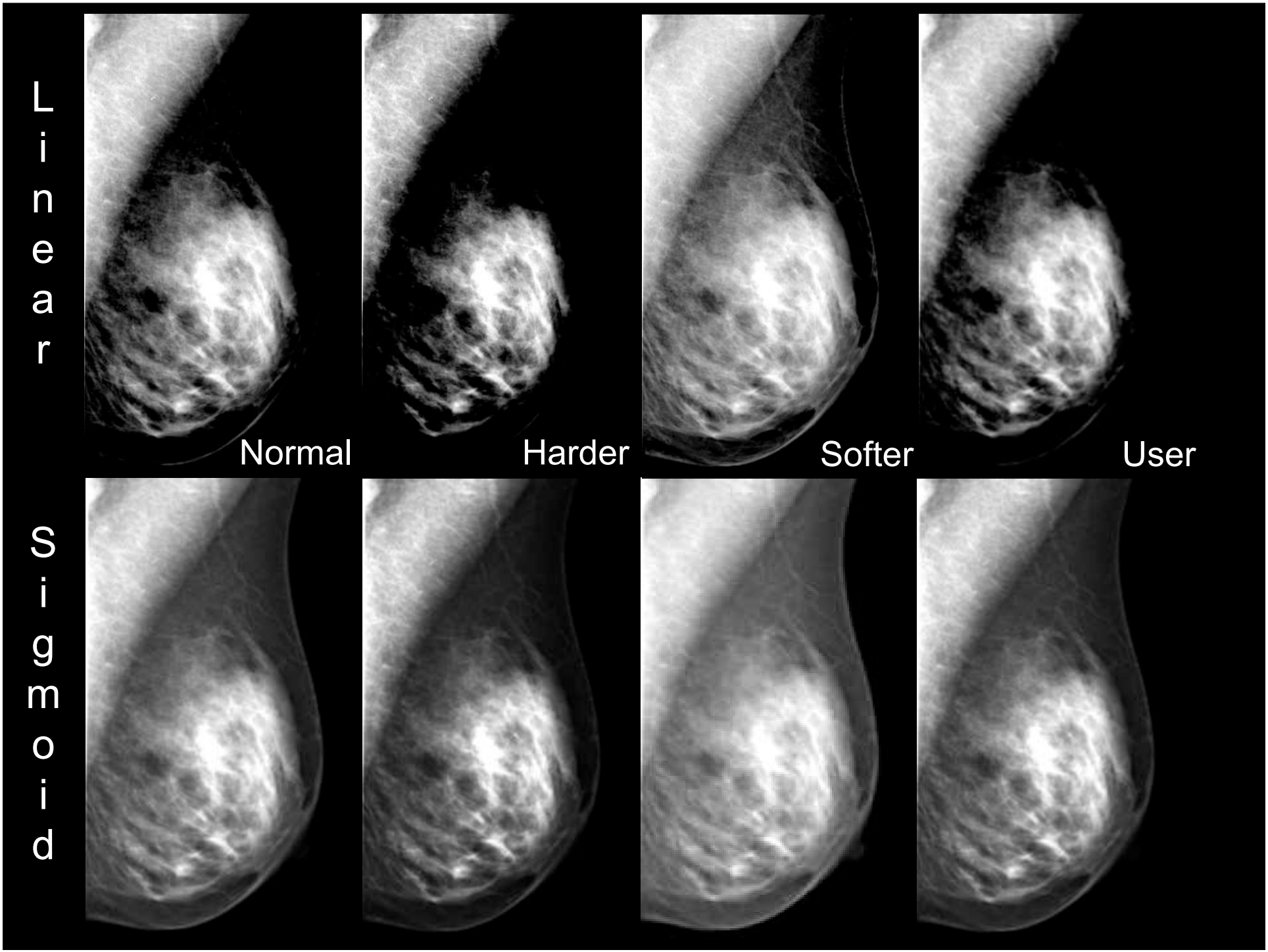
- How long can you afford to be down ?
- How long can you afford to be without priors ?
- How long will it take to replace lost workstation/network/server hardware ?
- How long will it take to restore entire image archive from backup ?
- How long will it take to retrieve a particular prior from backup ?
- How long will it take to restore database from backup ?

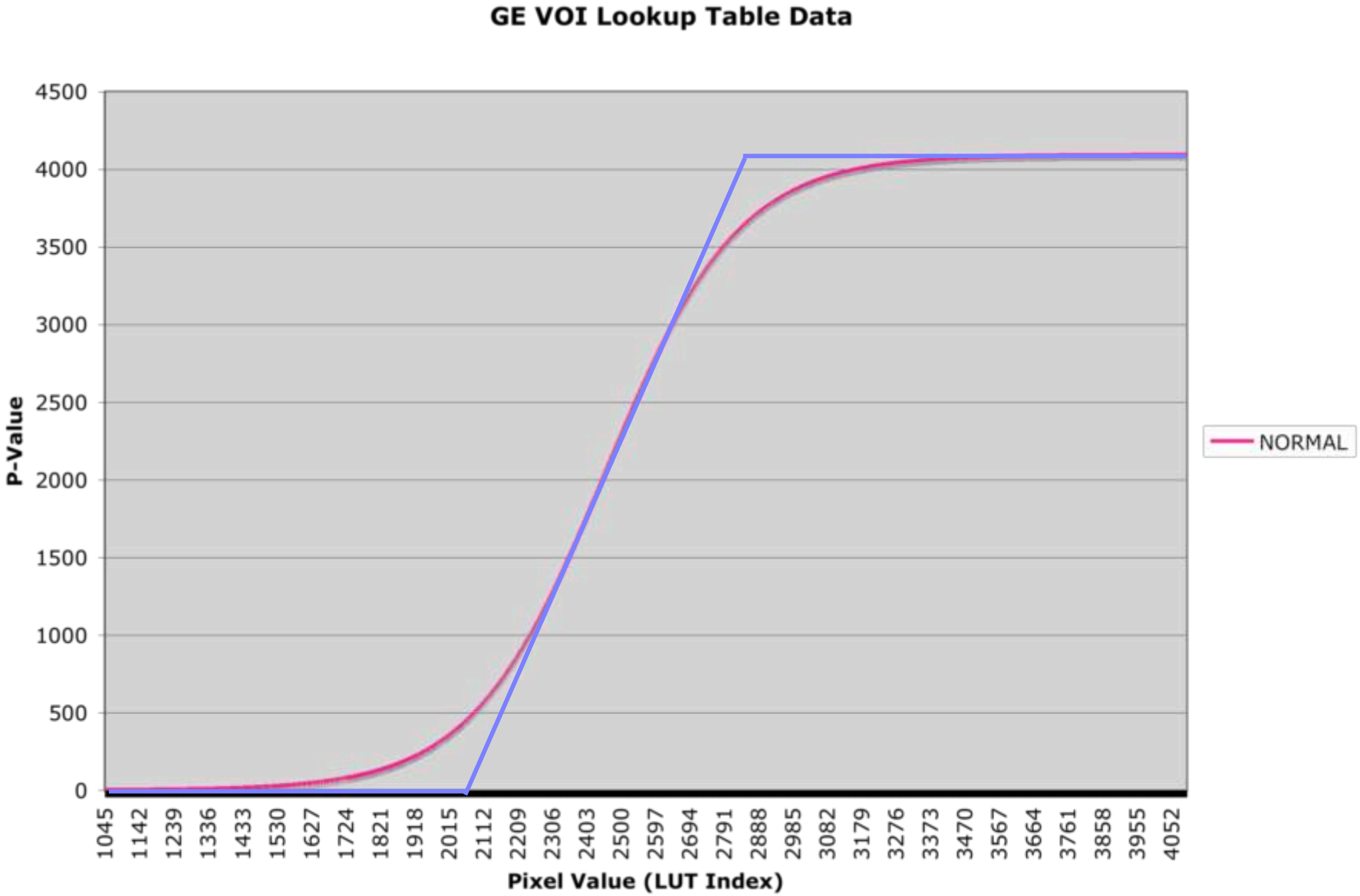
Image contrast adjustment

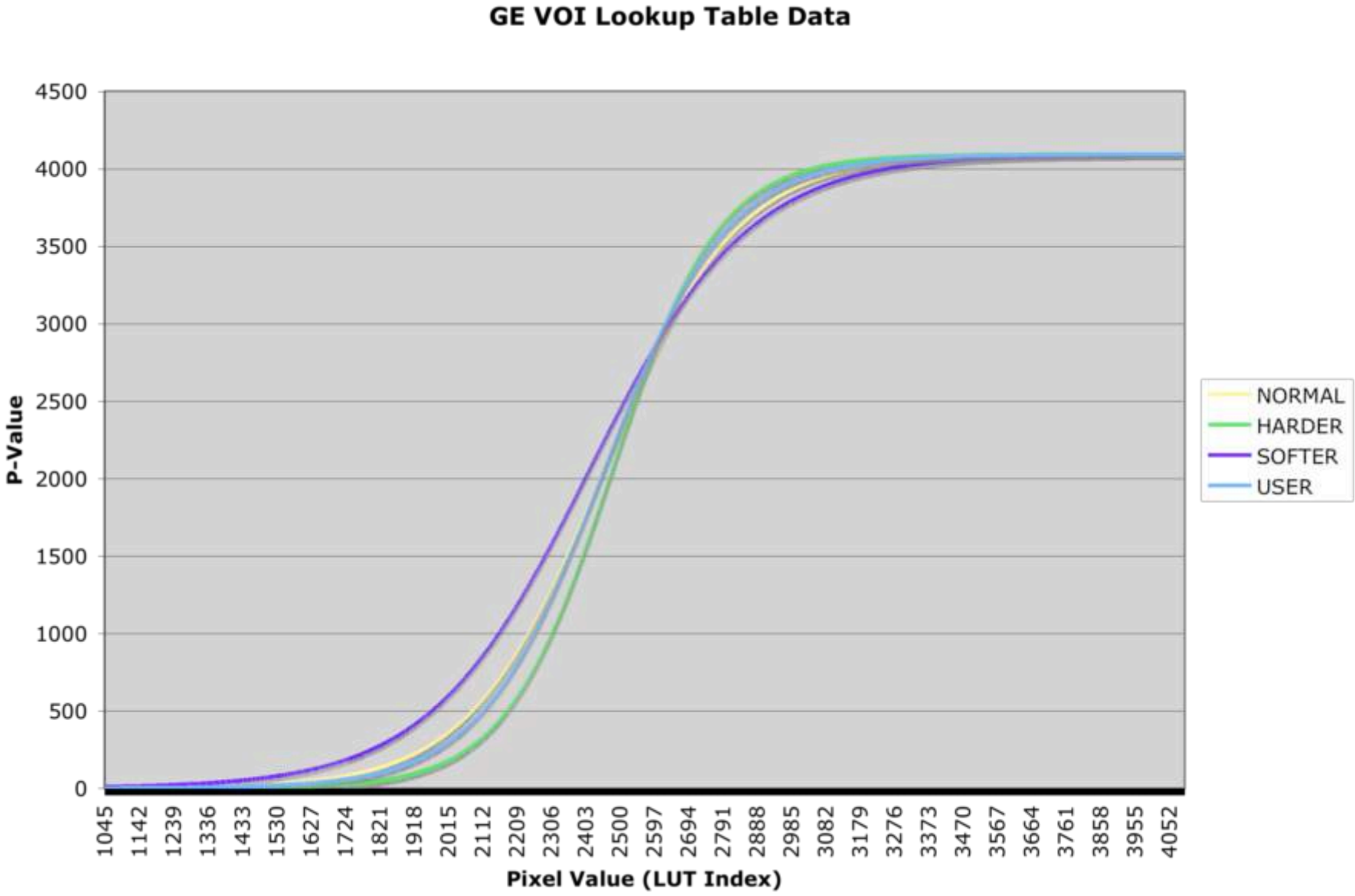
- A single presentation of image contrast is usually not sufficient
- Adjust the image for light and dark areas
- Traditionally
  - Linear window center and width
- Non-linear contrast adjustment
  - Lookup table (LUT)
  - Function
- DICOM supports all three

Linear window - bright and dark areas clipped




Linear
Sigmoid
Normal
Harder
Softer
User


GE VOI Lookup Table Data
P-Value
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1045
1142
1239
1336
1433
1530
1627
1724
1821
1918
2015
2112
2209
2306
2403
2500
2597
2694
2791
2888
2985
3082
3179
3276
3373
3470
3567
3664
3761
3858
3955
4052
Pixel Value (LUT Index)
NORMAL


GE VOI Lookup Table Data
P-Value
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1045
1142
1239
1336
1433
1530
1627
1724
1821
1918
2015
2112
2209
2306
2403
2500
2597
2694
2791
2888
2985
3082
3179
3276
3373
3470
3567
3664
3761
3858
3955
4052
Pixel Value (LUT Index)
NORMAL
HARDER
SOFTER
USER

Non-linear Lookup Tables

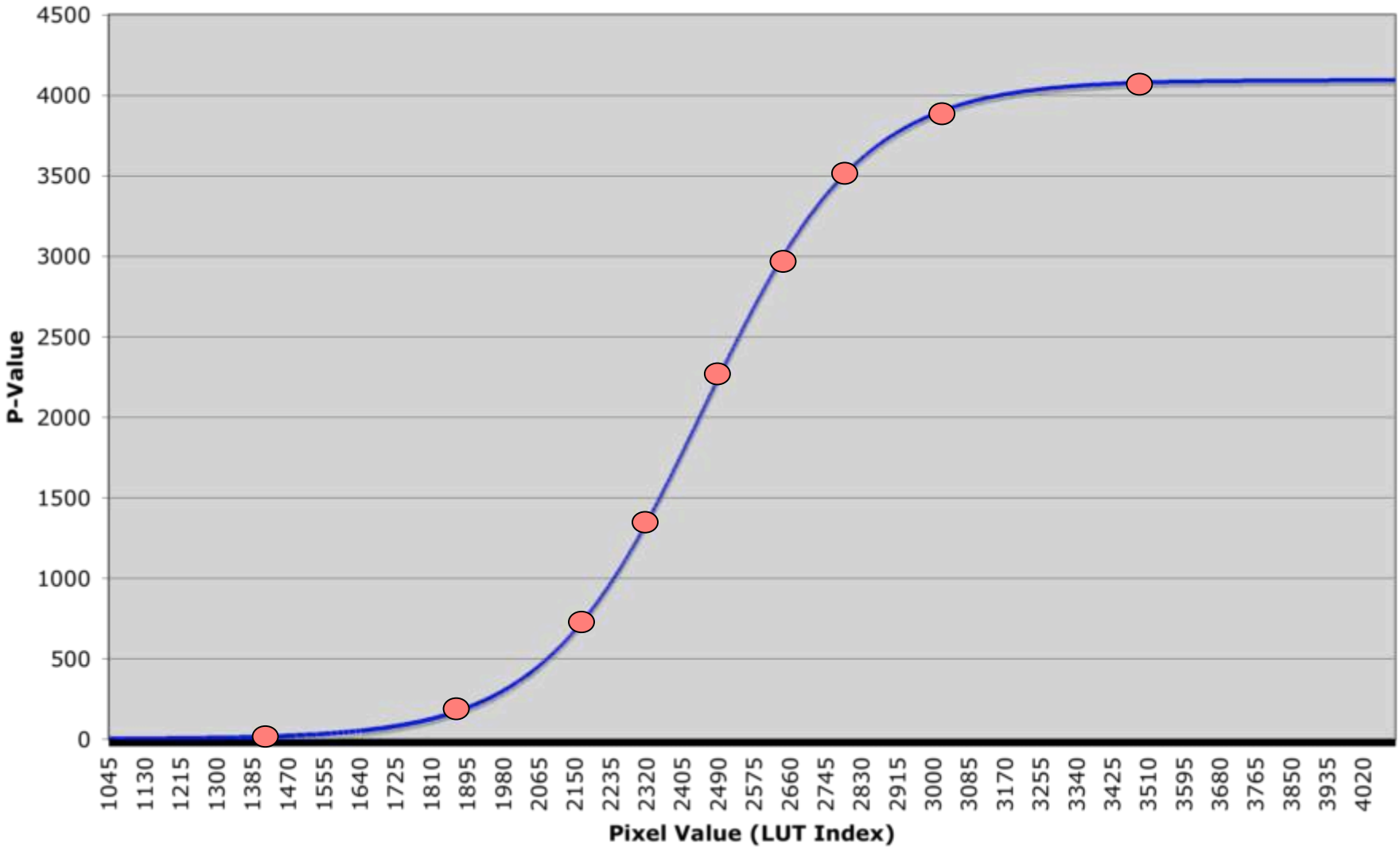
- Encoded in DICOM as VOI LUT
  - A table of output values for each input value
- May be more than one
- May co-exist with window values
- Applied as alternatives, not successively
- DICOM does not mandate particular display behavior
- BUT, all mammography workstations should be able to apply any VOI LUT encoded in the image
- A common reason that images look “different” on another vendor’s workstation is that these LUTs are being ignored

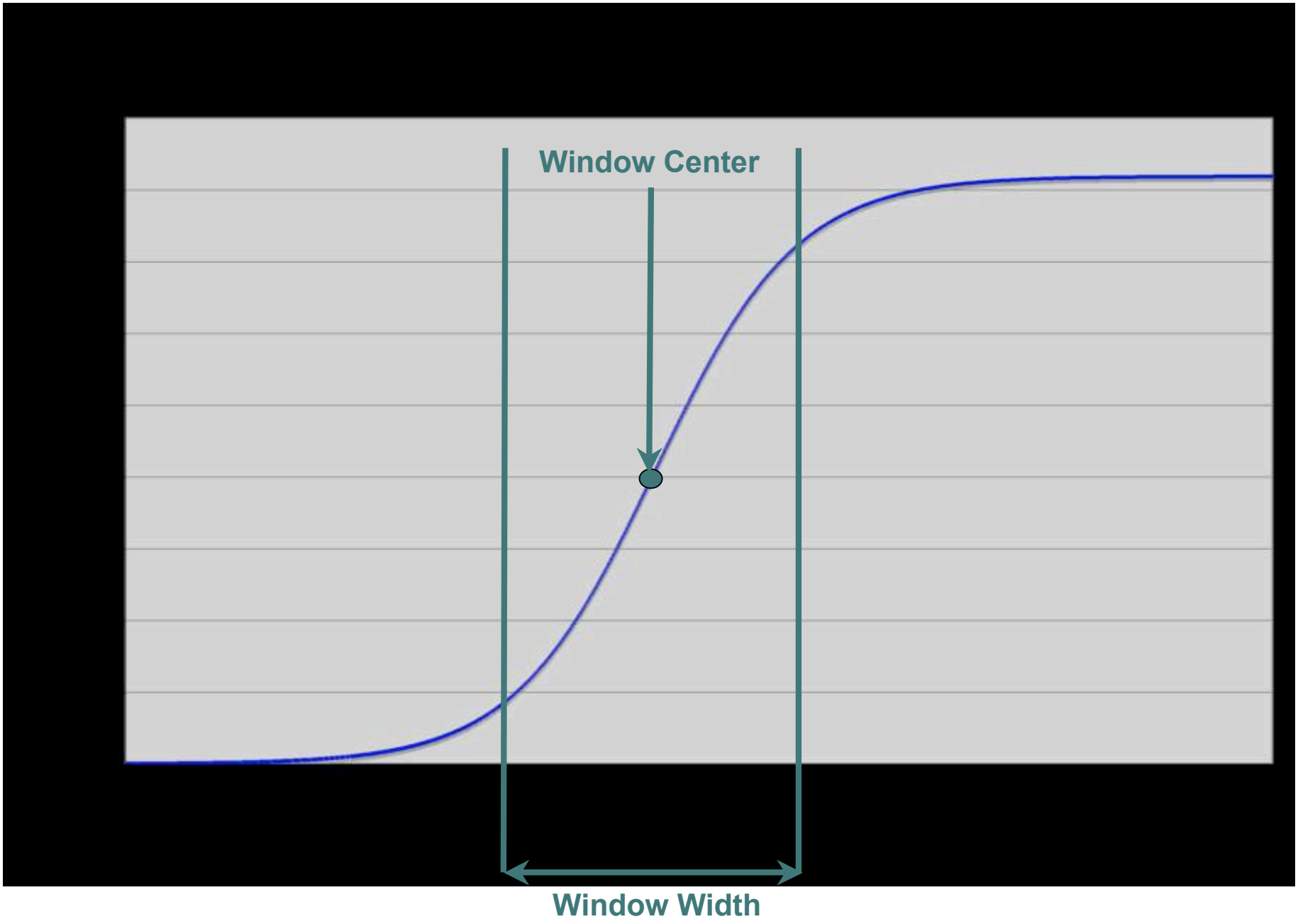
User adjustment with LUTs

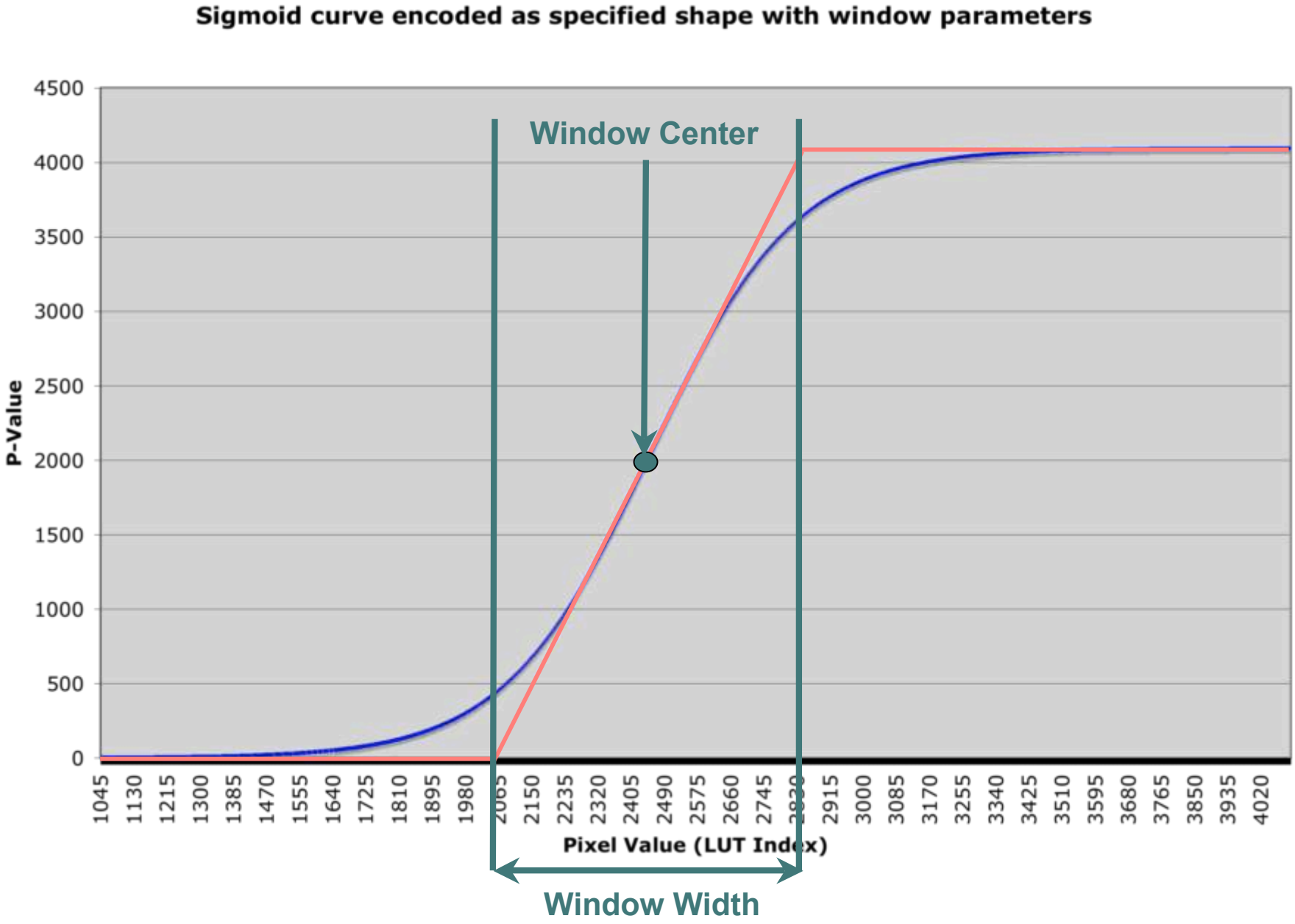
- Suppose the workstation vendor does support and apply the LUTs
- How does the user then adjust the contrast ?
- Workstation can interpret user's window center/width changes as adjustments to the LUT input range
- Workstation can save the user's changes by computing a new LUT
- Would all be much easier if there were parameters to a function, rather than a table

Sigmoid LUT function

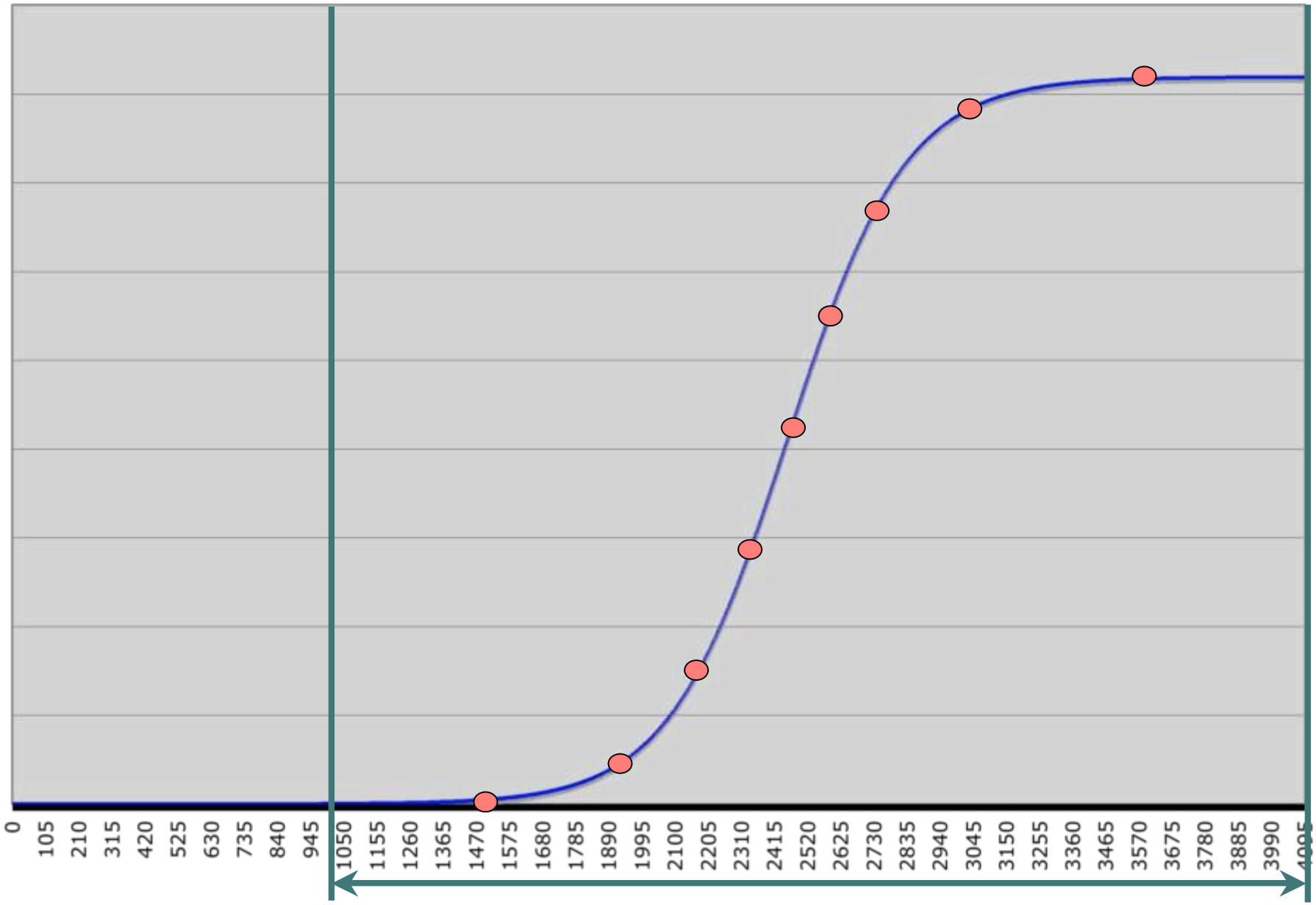
$$OUT = \frac{Output\_range}{1 + \exp\left(-4 \frac{IN - WC}{WW} \right)}$$


Sigmoid curve encoded as VOI Lookup Table Data
P-Value
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1045
1130
1215
1300
1385
1470
1555
1640
1725
1810
1895
1980
2065
2150
2235
2320
2405
2490
2575
2660
2745
2830
2915
3000
3085
3170
3255
3340
3425
3510
3595
3680
3765
3850
3935
4020
Pixel Value (LUT Index)

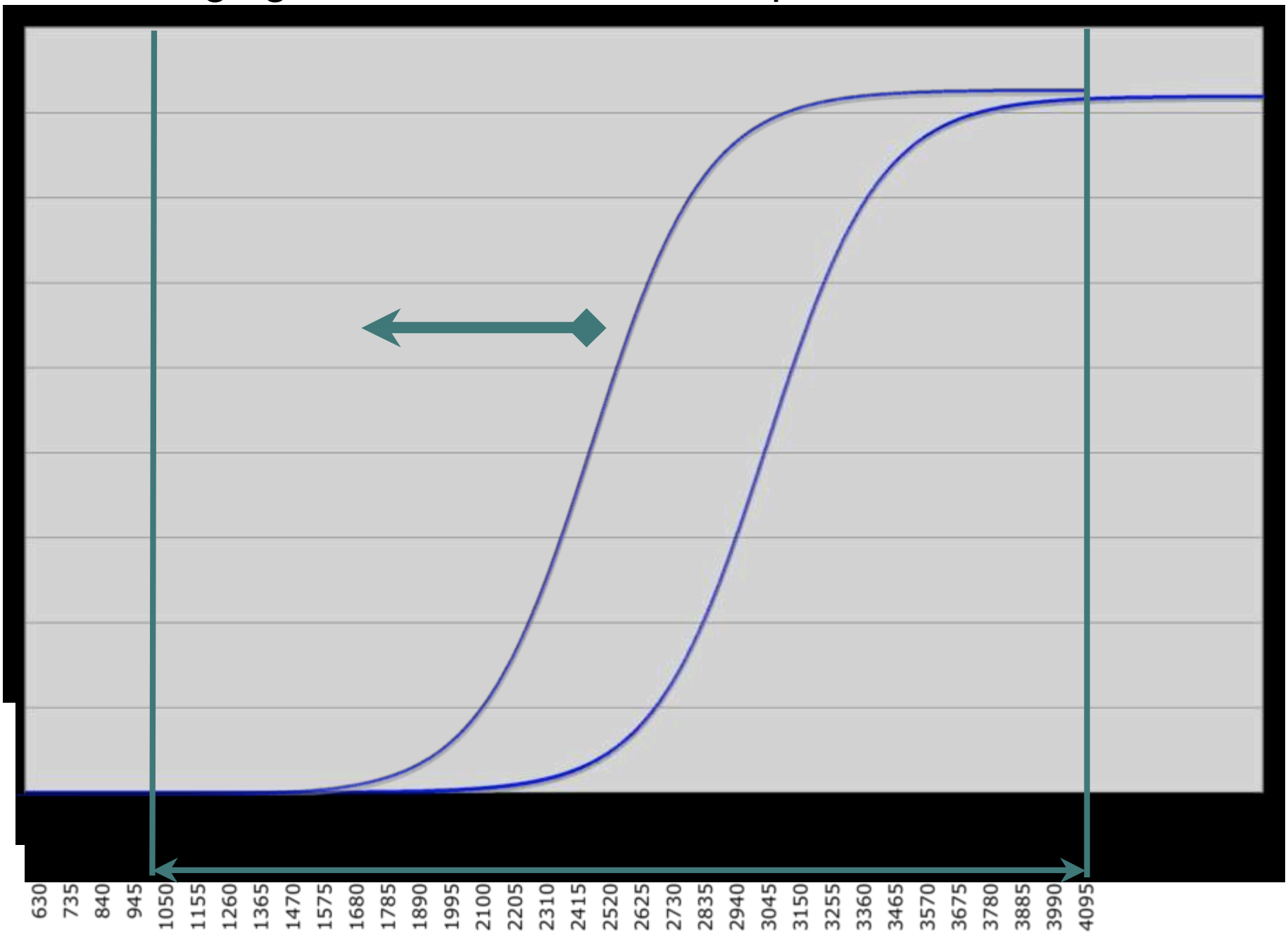

Window Center
Window Width


Sigmoid curve encoded as specified shape with window parameters
Window Center
Window Width
P-Value
Pixel Value (LUT Index)
4500
4000
3500
3000
2500
2000
1500
1000
500
0
1045
1130
1215
1300
1385
1470
1555
1640
1725
1810
1895
1980
2065
2150
2235
2320
2405
2490
2575
2660
2745
2830
2915
3000
3085
3170
3255
3340
3425
3510
3595
3680
3765
3850
3935
4020

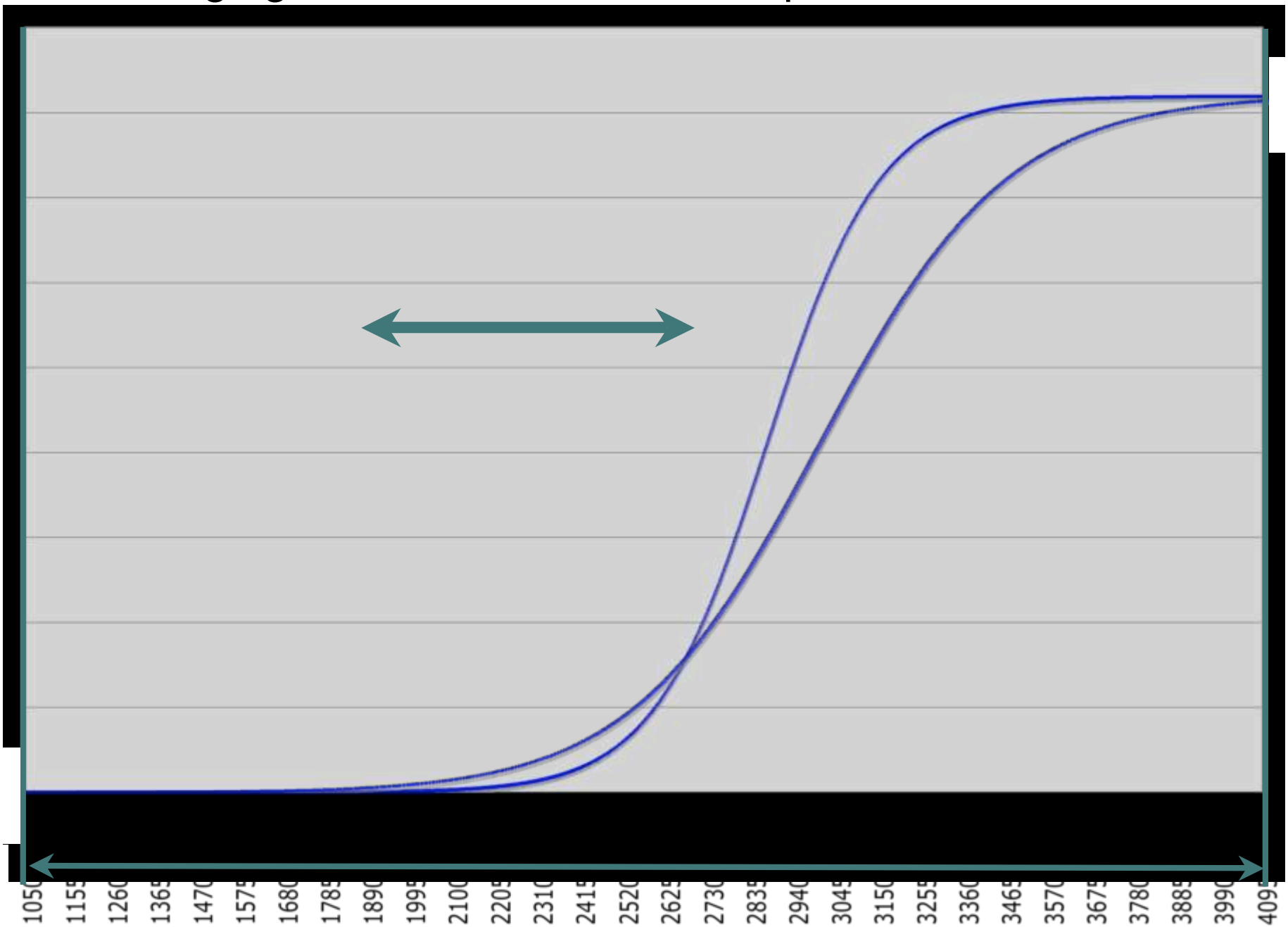
LUT is specified over a defined range of input values



Changing the “level” of the LUT input values

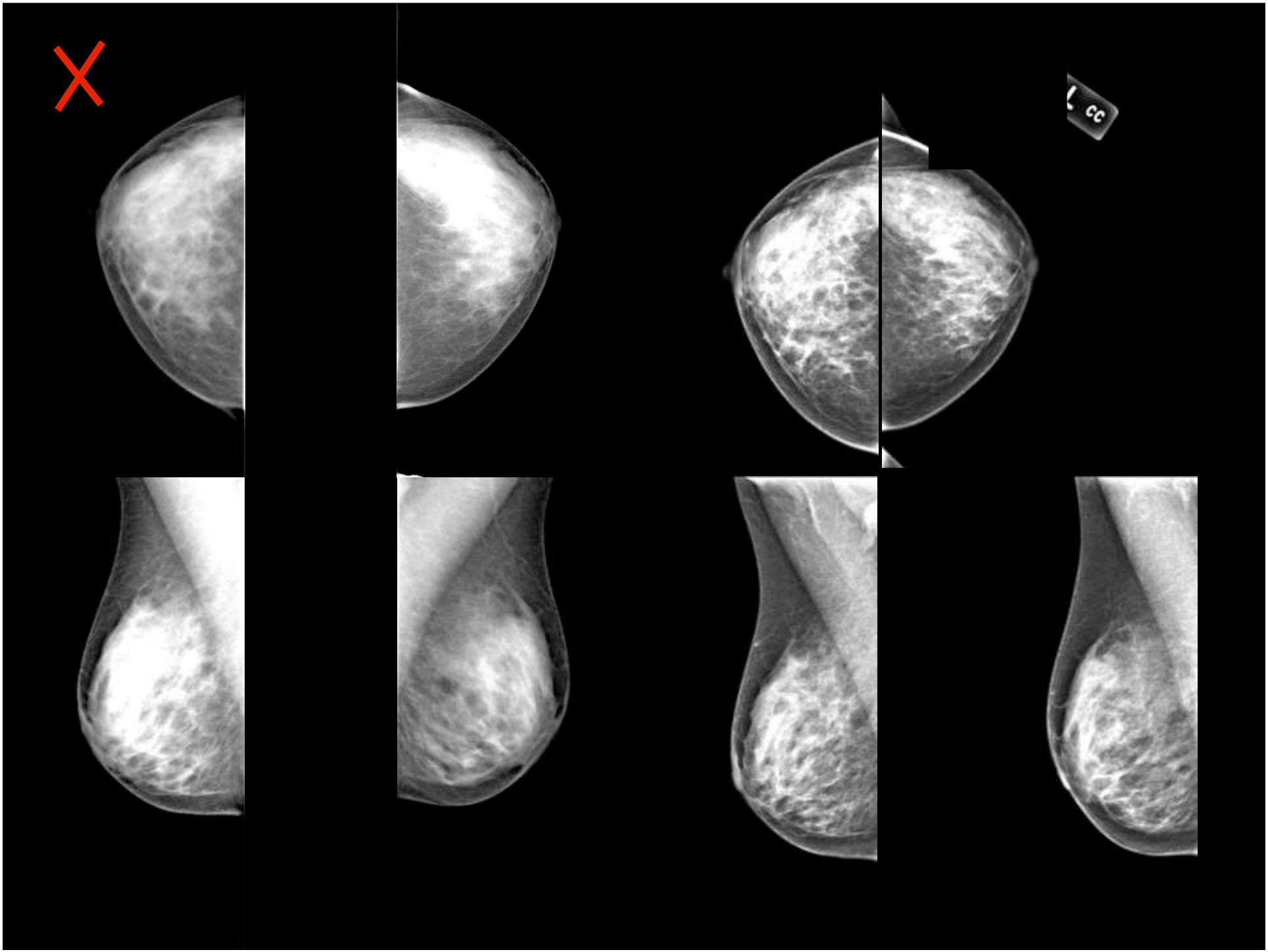


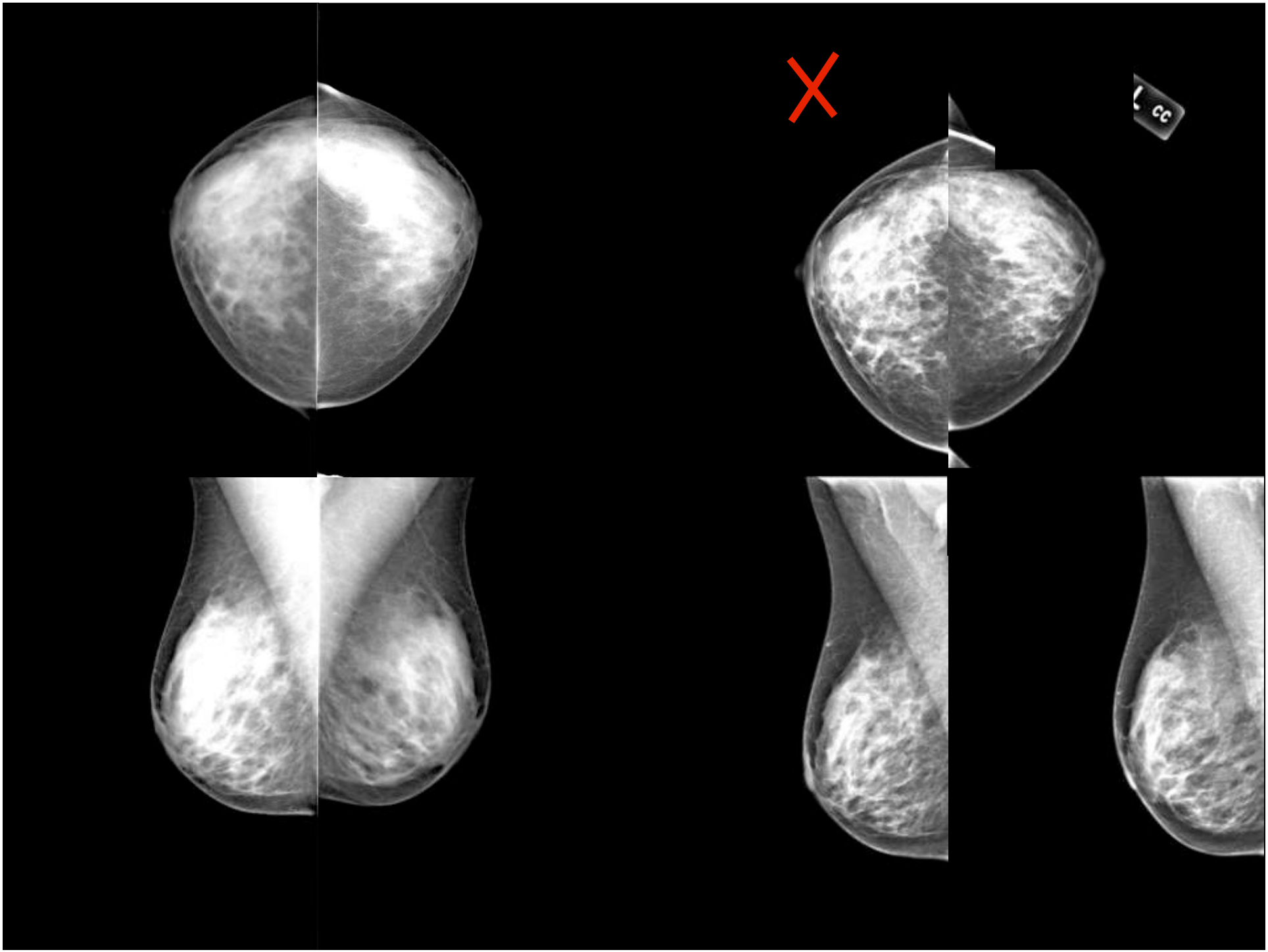
Changing the “width” of the LUT input values

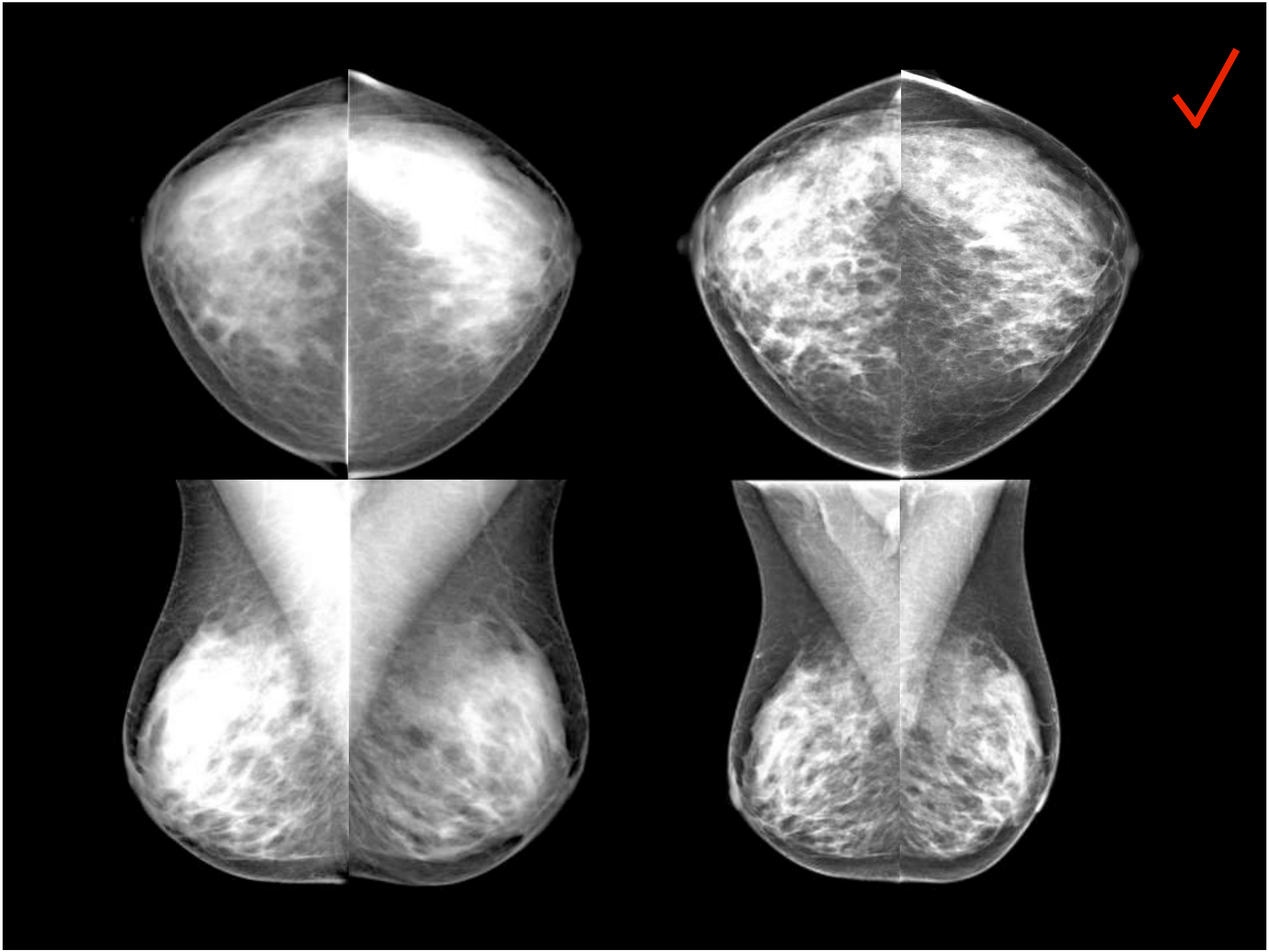


Sigmoid function support

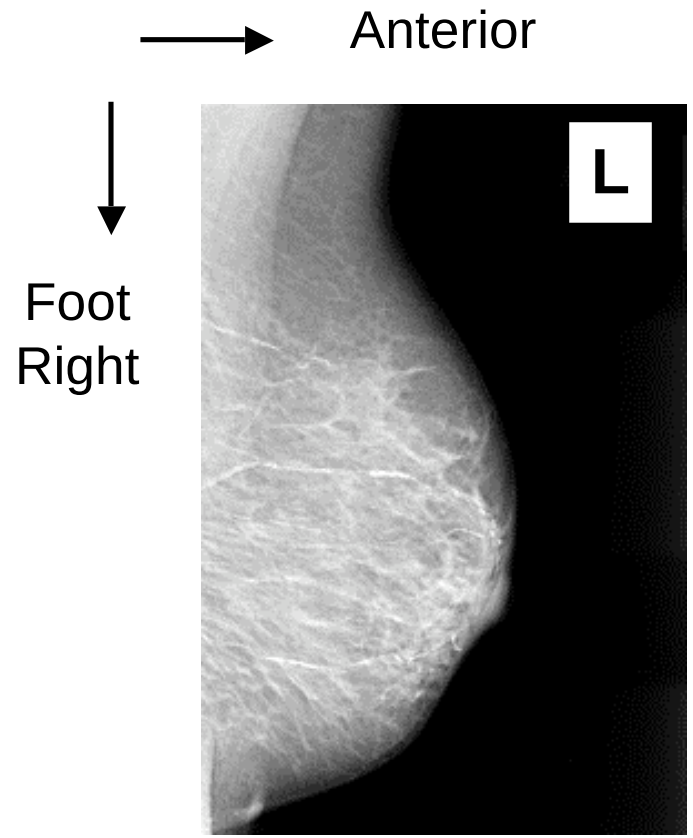
- Curve shape added as optional attribute in CP 467
- If present, workstation should make use of it
- If absent, workstation should apply any LUT that is present instead
- If neither present, use any linear window values present
- This strategy will maximize likelihood of images appearing on third party workstations the same as the acquisition vendor intends
- The sigmoid function provides a convenient means of allowing user adjustments, but adjustment of LUTs must be supported as well


X
L CC

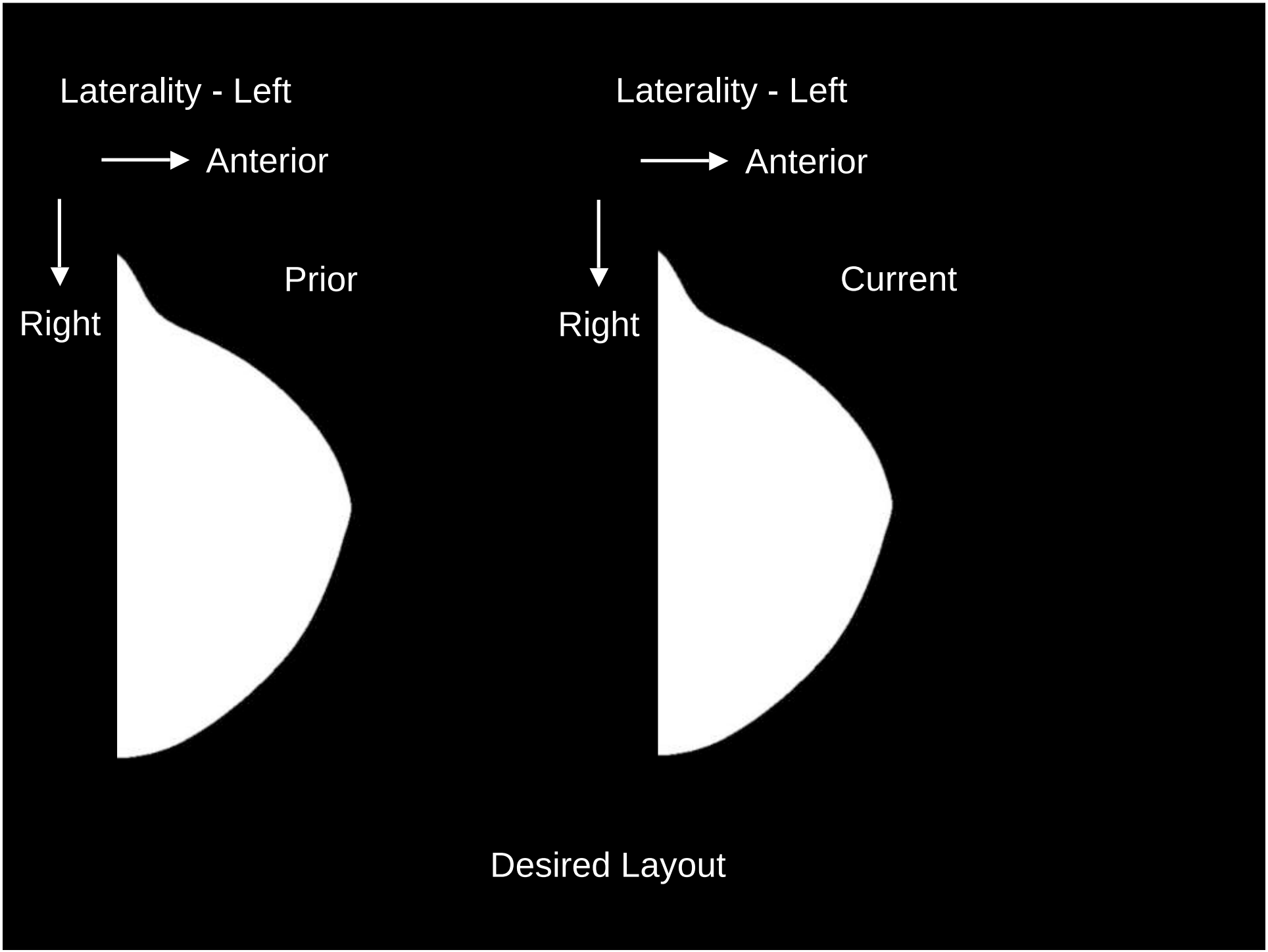

L CC



DICOM Information for Hanging



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

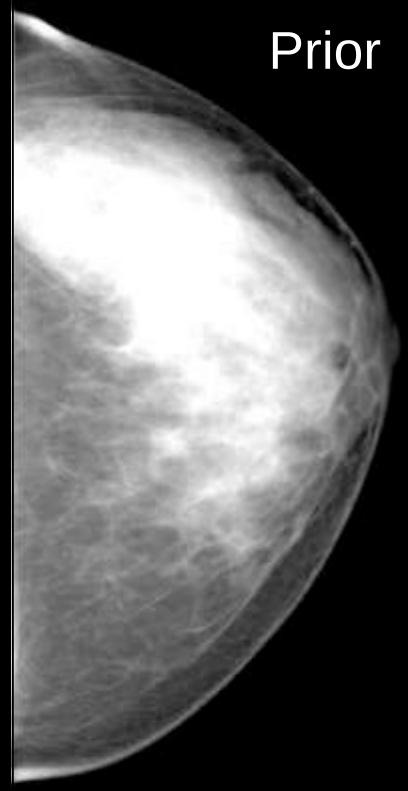

Laterality - Left
Anterior
Right
Prior
Laterality - Left
Anterior
Right
Current
Desired Layout

Laterality - Left

Anterior

Right

Prior

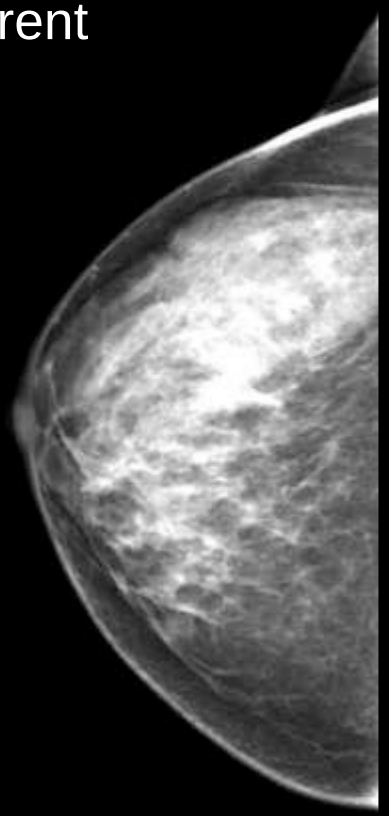


Laterality - Left

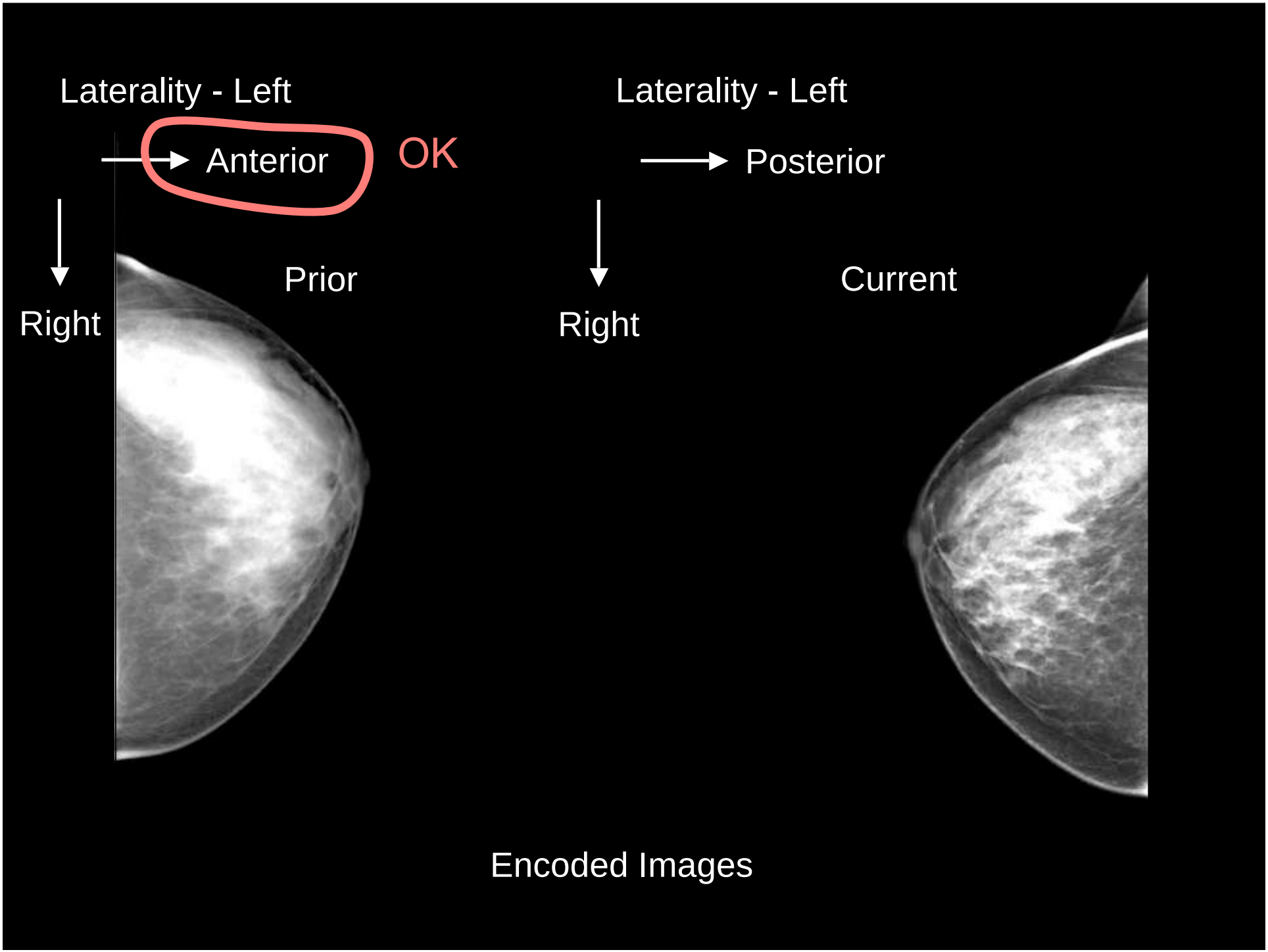
Posterior

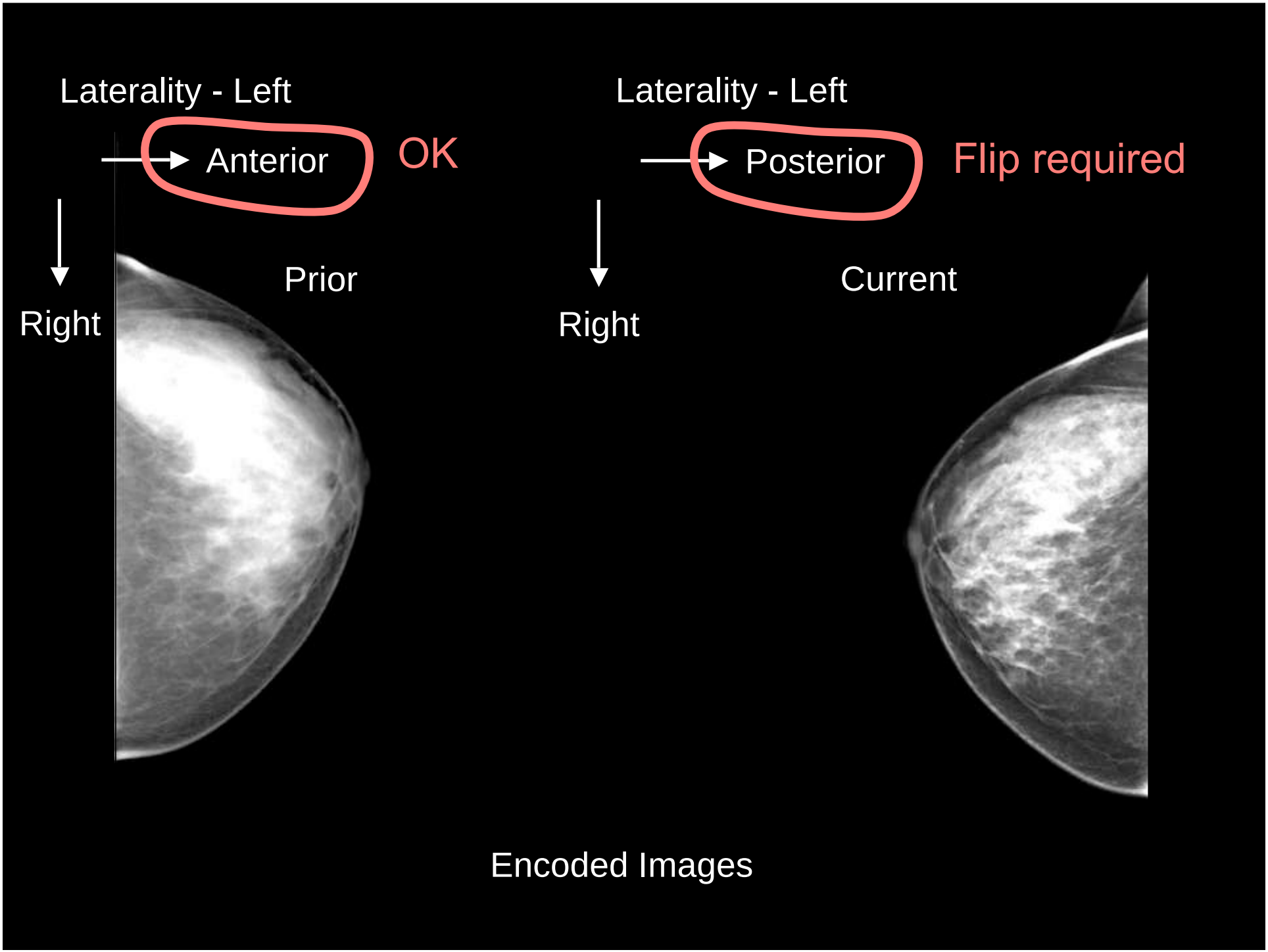
Right

Current



Encoded Images


Laterality - Left
Anterior
OK
Right
Prior
Laterality - Left
Posterior
Right
Current
Encoded Images

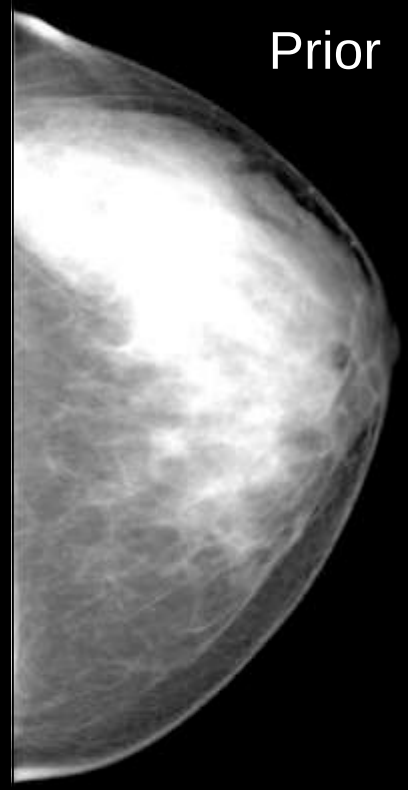

Laterality - Left
Anterior
OK
Right
Prior
Laterality - Left
Posterior
Flip required
Right
Current
Encoded Images

Laterality - Left

Anterior

Right

Prior

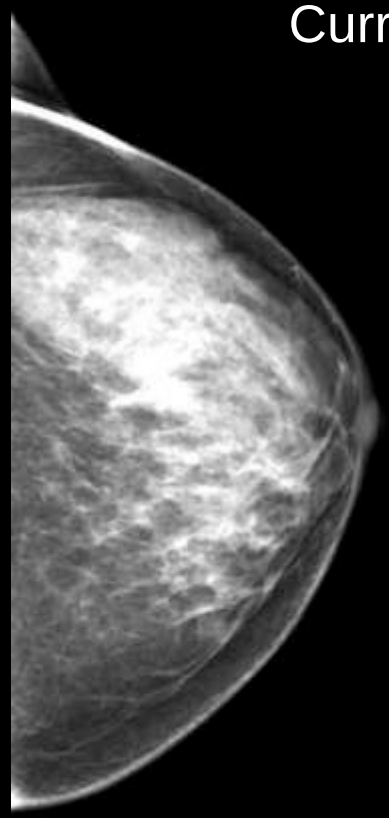


Laterality - Left

Anterior

Right

Current



Images oriented to match desired layout

Orientation of images

- The necessary DICOM attributes are mandatory
  - Always present and correct - safety related issue
  - Dependent on correct user input of laterality (need ability to correct ?)
- So workstations should use them !
- Do not try and force the acquisition vendor to encode the images the way you happen to prefer them
  - Other folks may have different preferences
  - Unusual projections will have correct orientation descriptions but unpredictable pixel data encoding
- Do not try and drive hanging protocols based on manufacturer or model name
  - May change behavior over time or configuration
- General purpose workstations need to support orientation driven hanging for non-mammography applications anyway

Justification of images

- Radiologists like mammograms displayed “back to back”
- Available window view space may be different size than pixel data in image
- Default is usually to center, rather than justify to one side or the other
- Knowledge of desired layout + view + orientation encoded in image allows automatic justification

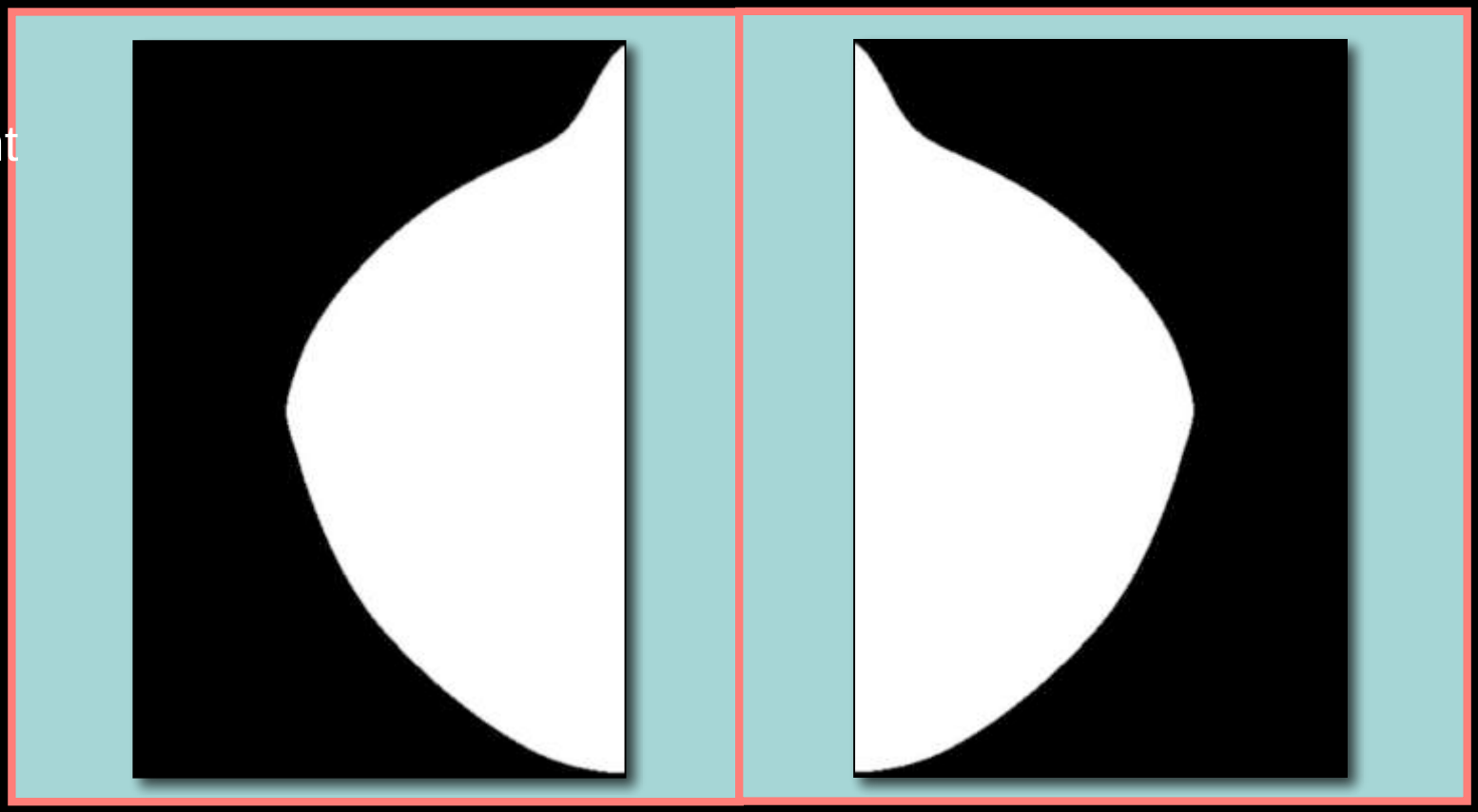
View - CC Laterality - Right

View - CC Laterality - Left

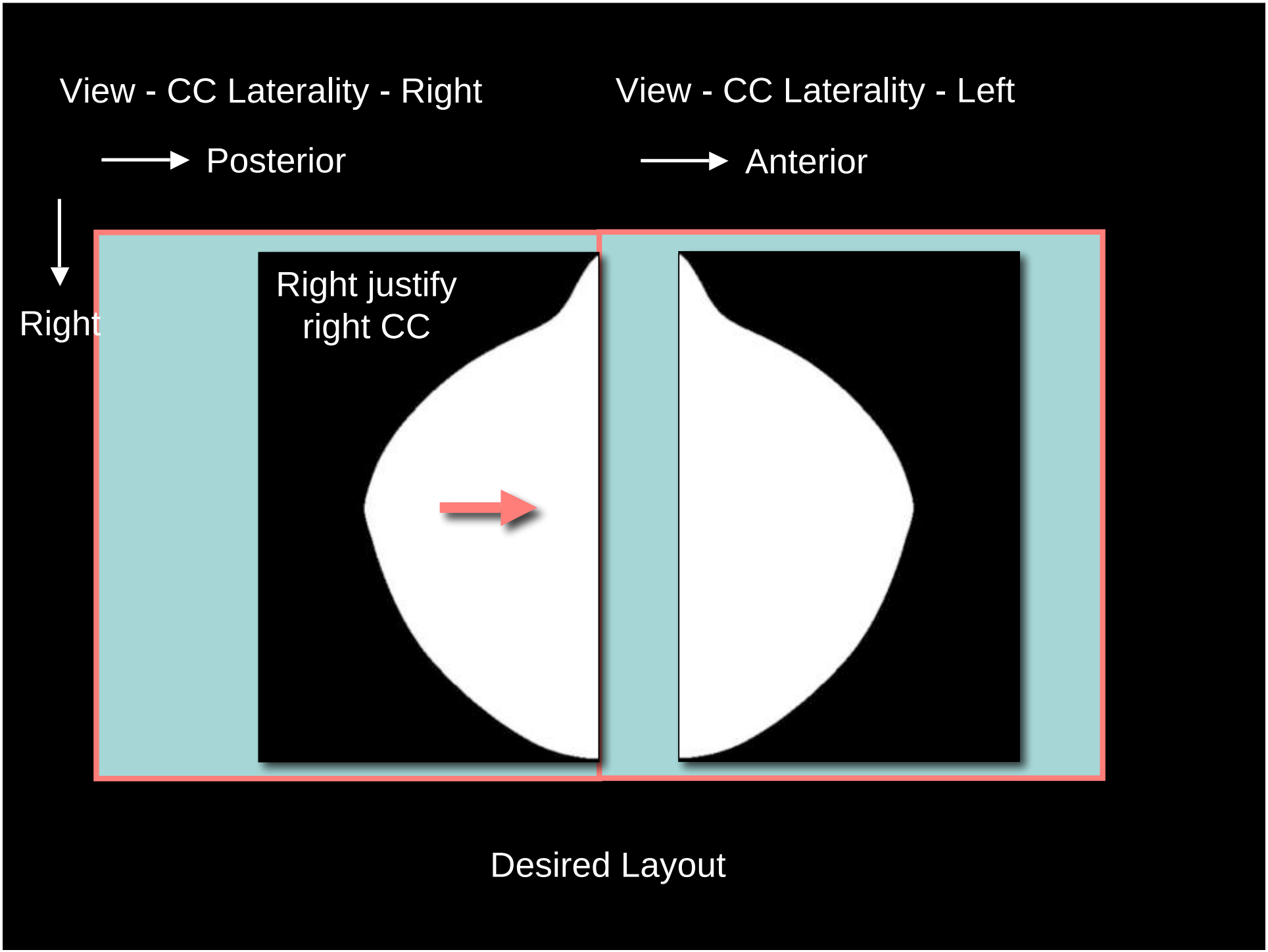
Posterior

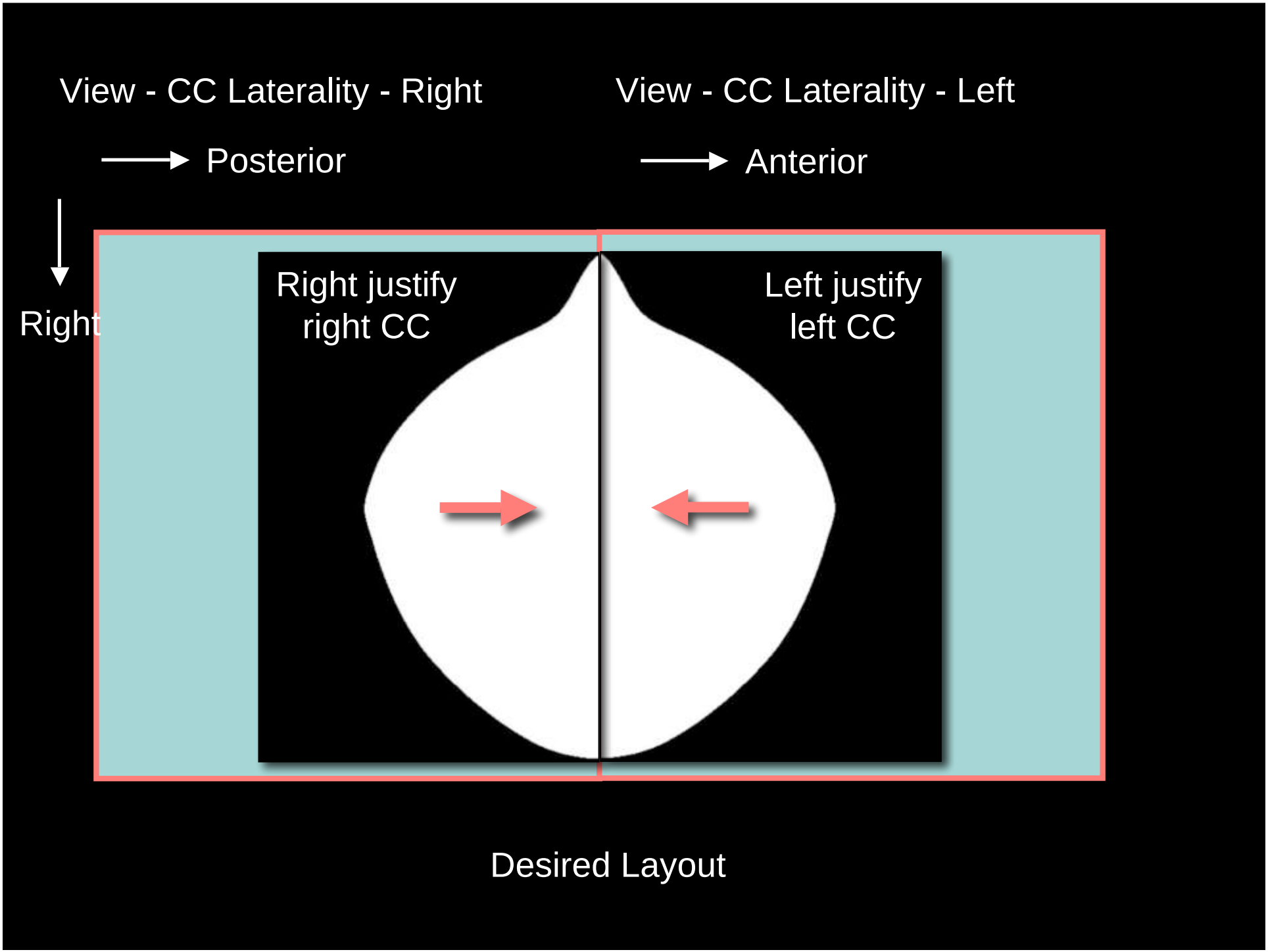
Anterior

Right



Layout without justification

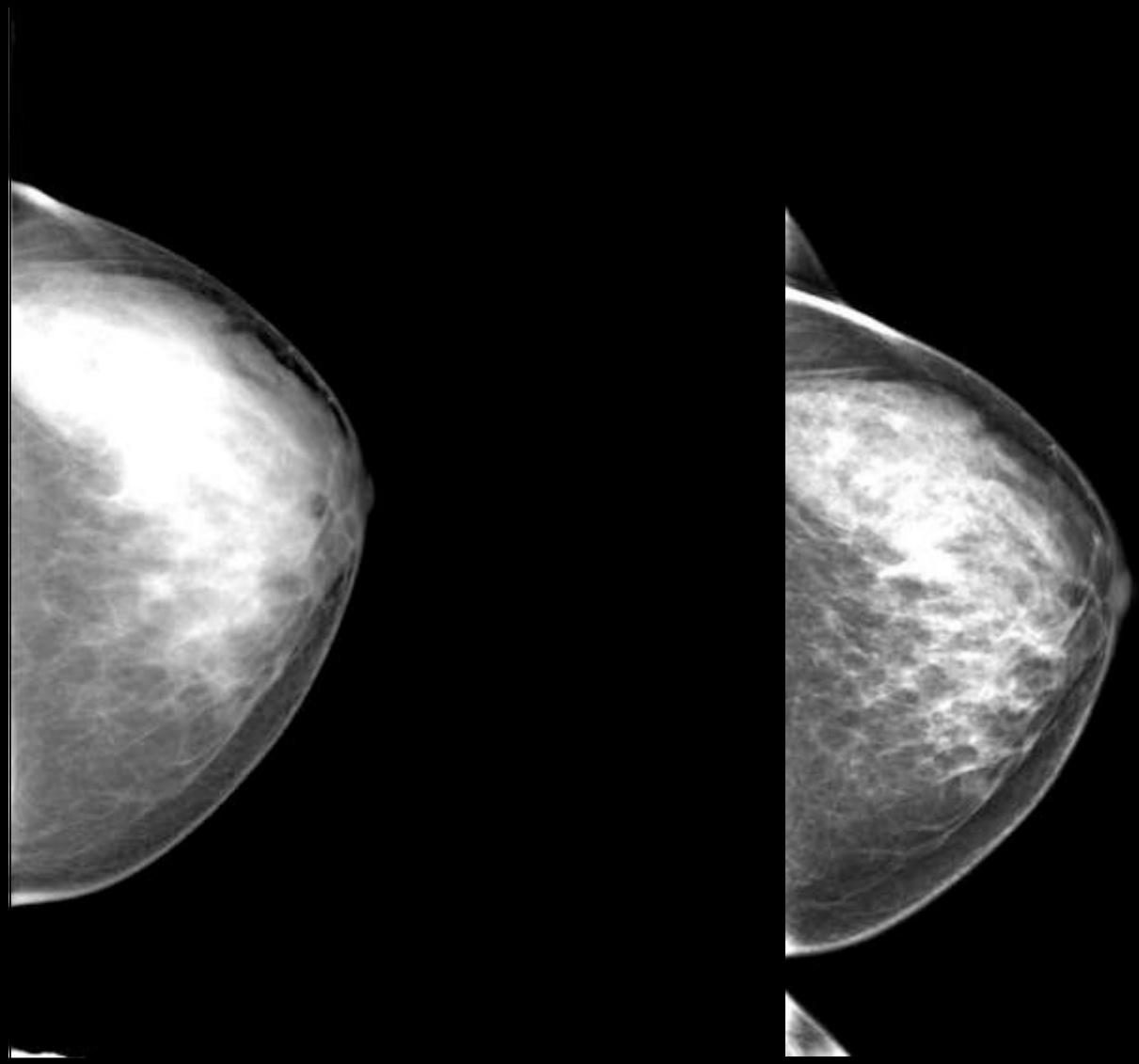

View - CC Laterality - Right
Posterior
View - CC Laterality - Left
Anterior
Right
Right justify
right CC
Desired Layout


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

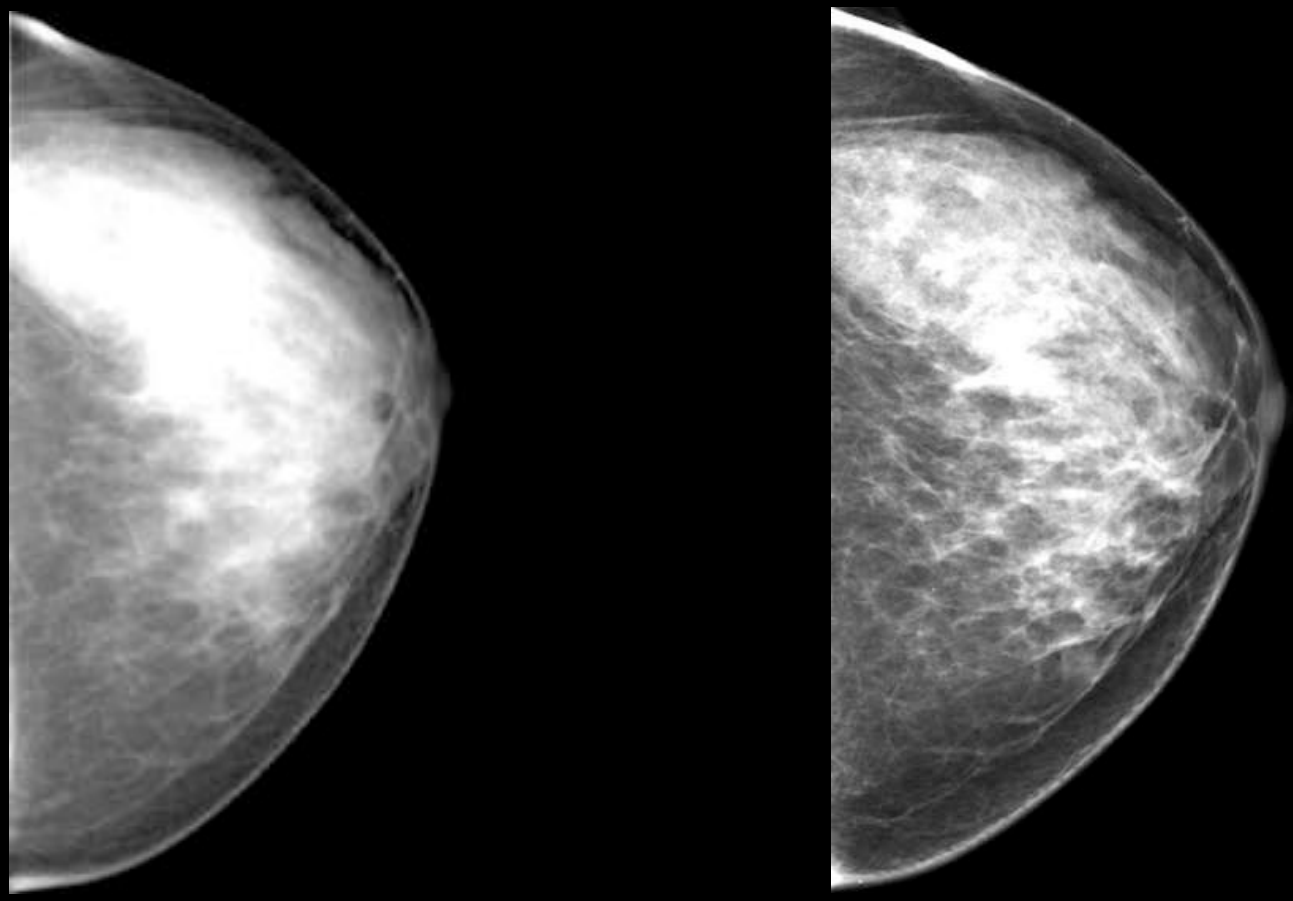
Auto-sizing

- DICOM Imager Pixel Spacing attribute
  - specifies size of pixels in image
- Images from different vendors or modes
  - different pixel size
- For comparison with priors
  - want displayed with the same size
- Use Imager Pixel Spacing
  - to determine magnification factor to same displayed pixel size for all images

Full extent of image fitted to screen



Same size, based on Imager Pixel Spacing

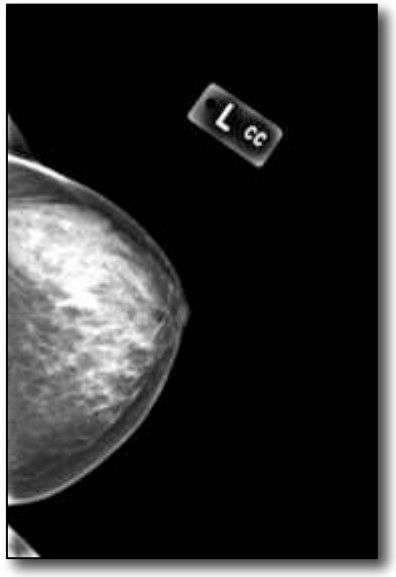


Auto-fit and auto-center

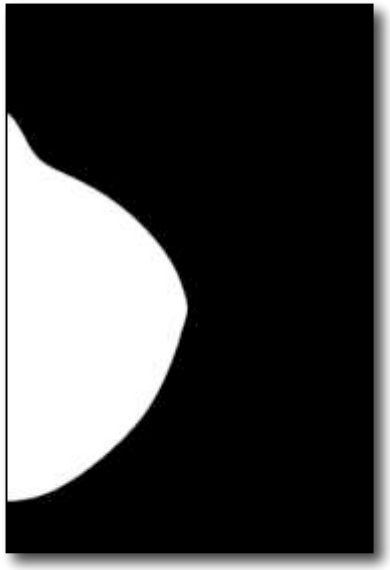
- DICOM Imager Pixel Spacing gets size the same
- What about fitting to screen and centering ?
- Detection of breast outline
  - Acquisition device ?
  - Workstation ?
  - CAD device to workstation ?
- DICOM CAD object contains place for it
  - Not being sent in current CAD objects from vendors
  - Versus bitmap or polygonal display shutter in image or presentation state
- Idealized workflow - set magnification factor to fit “biggest” breast (outline), then scale all others to that size based on Imager Pixel Spacing

Original

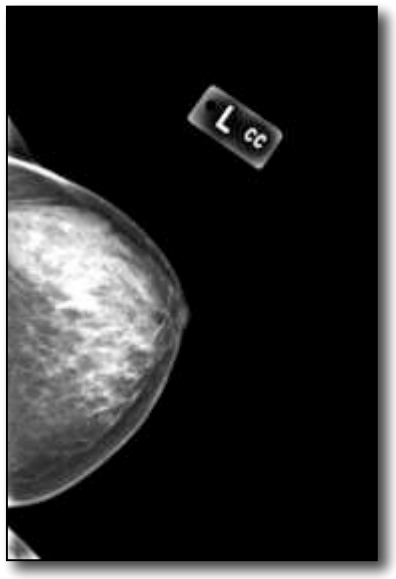
Original



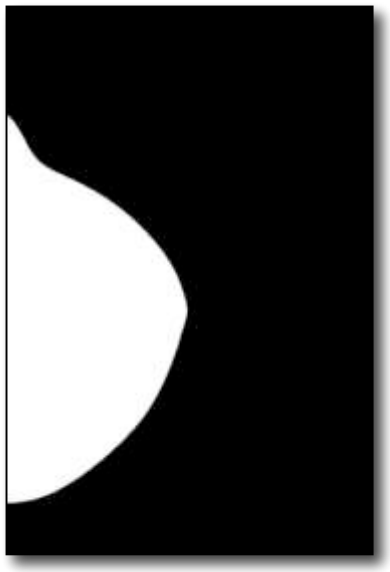
Outline



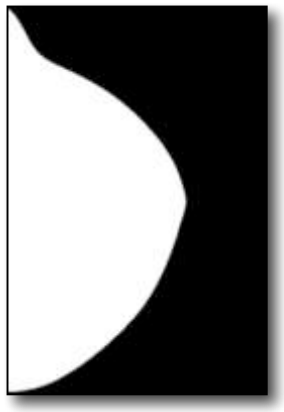
Original



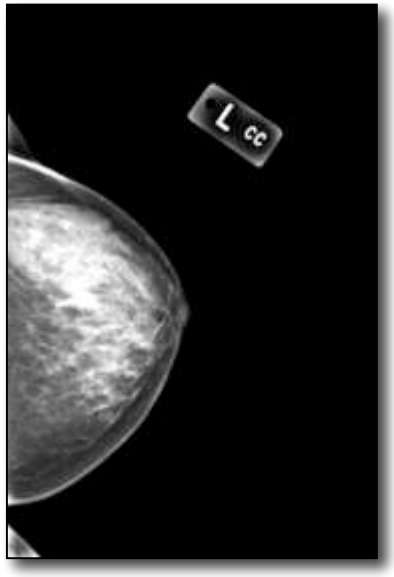
Outline



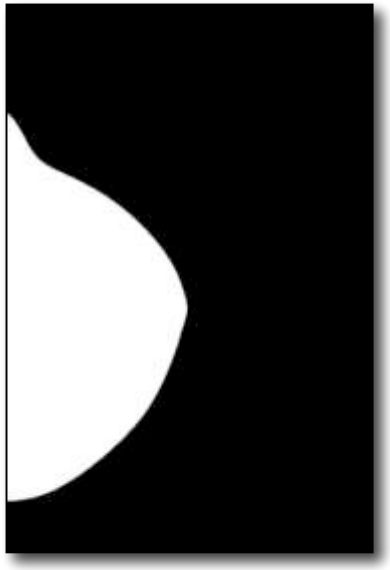
Boundary



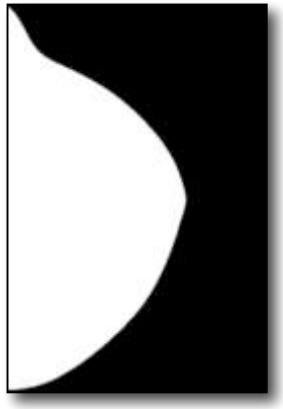
Original



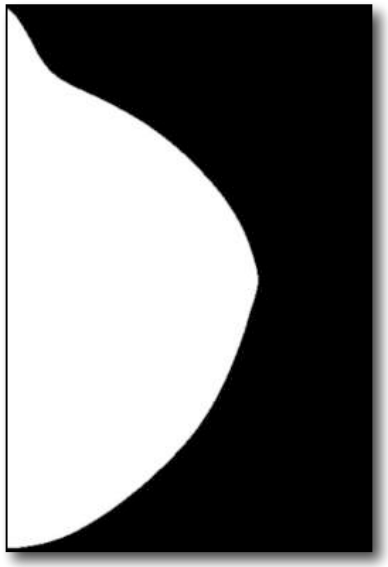
Outline

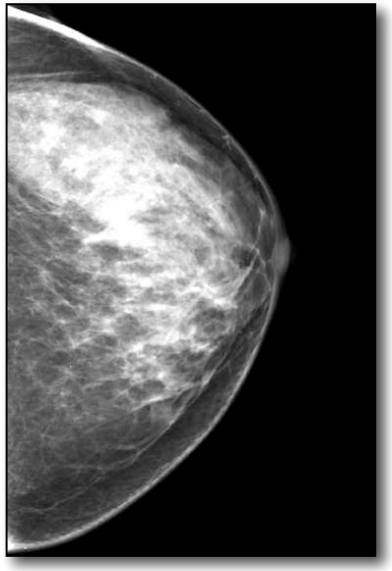


Boundary



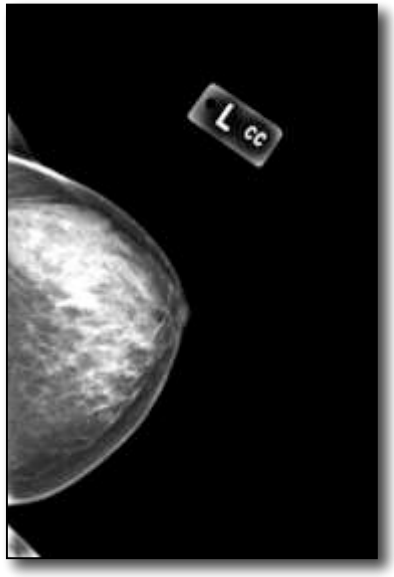
Fit Screen

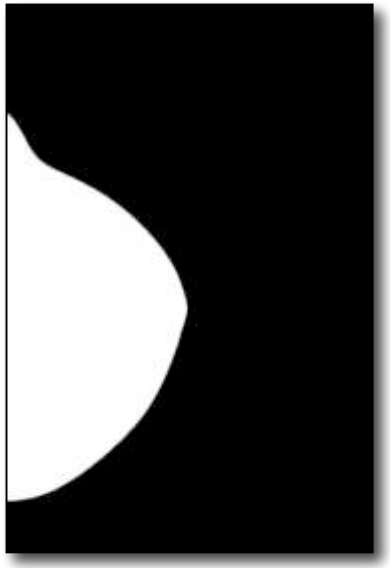


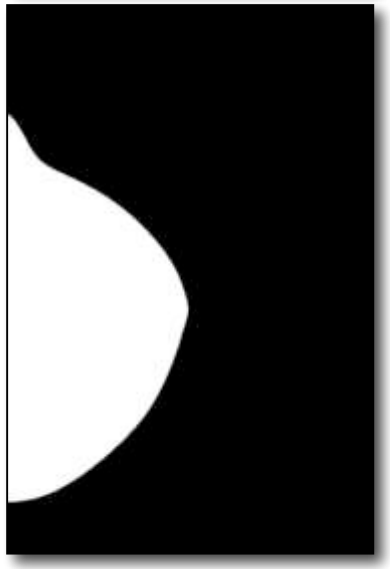


Original

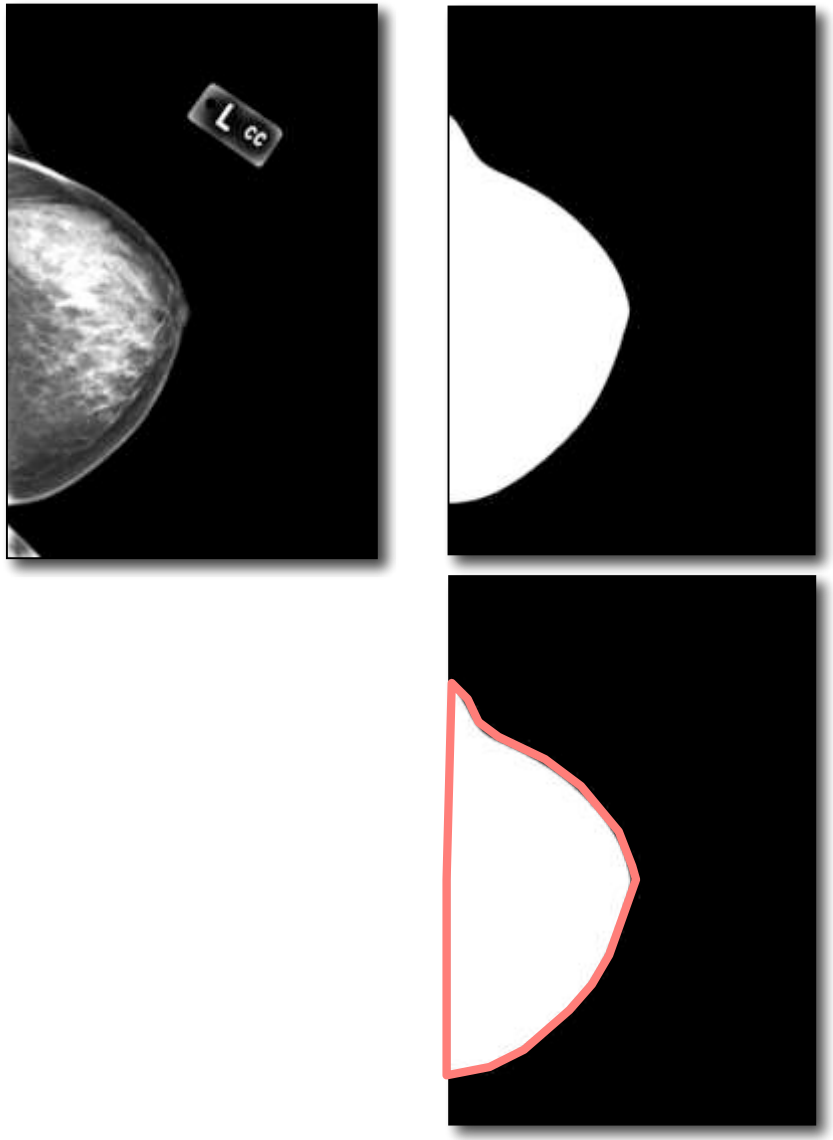
Outline



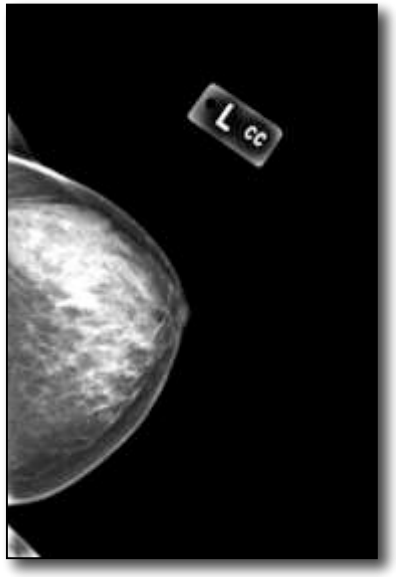


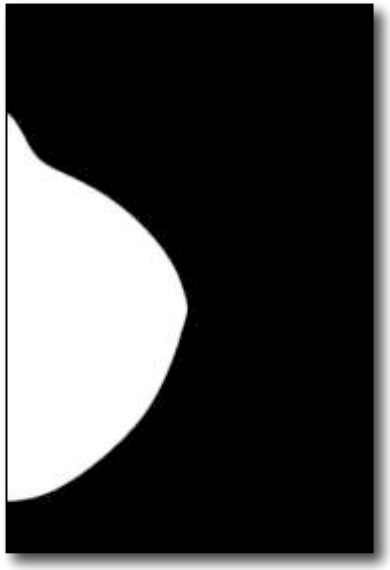


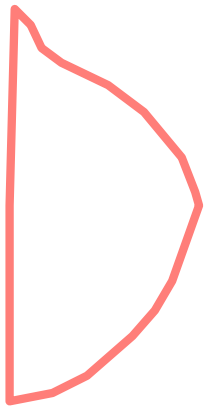
Store as bitmap



Extract as polygon

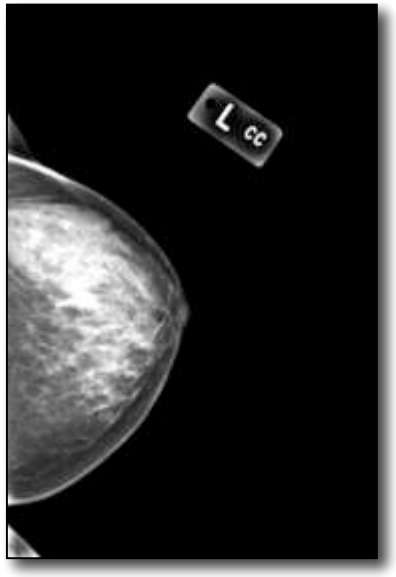


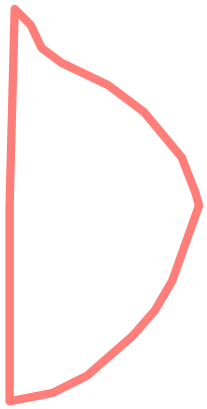




Store as polygonal shutter or in CAD

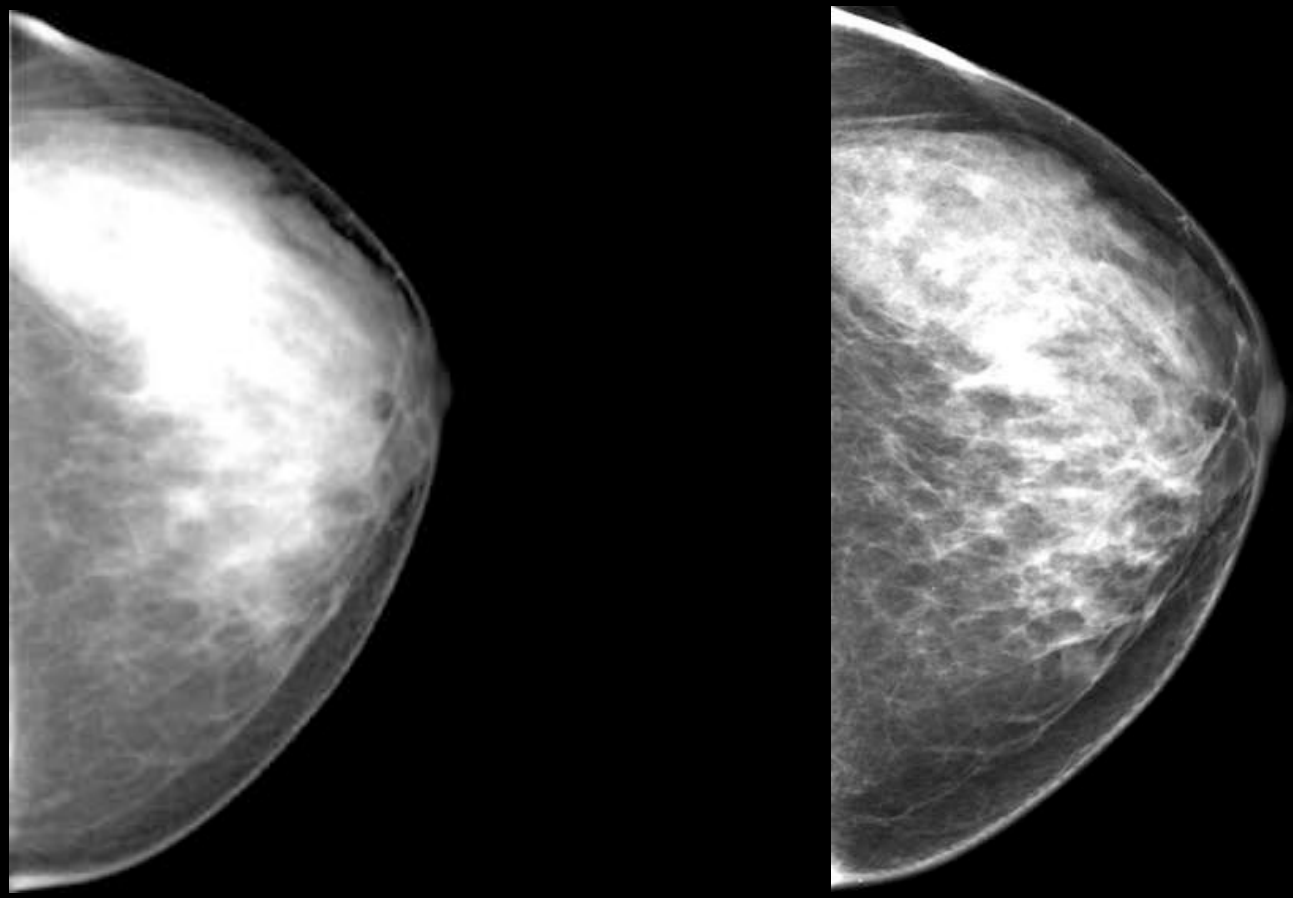
To fit to screen next time



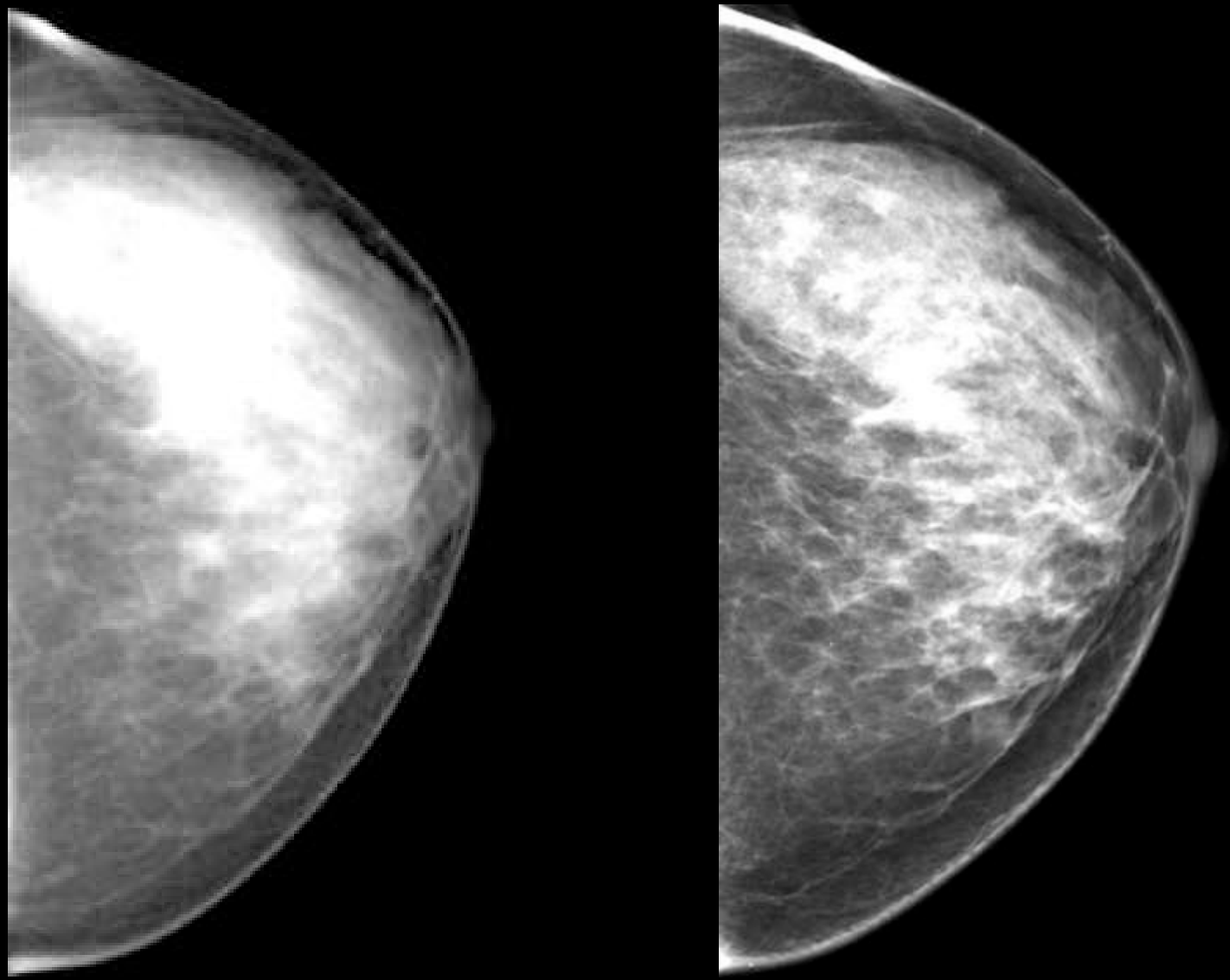


Use stored outline

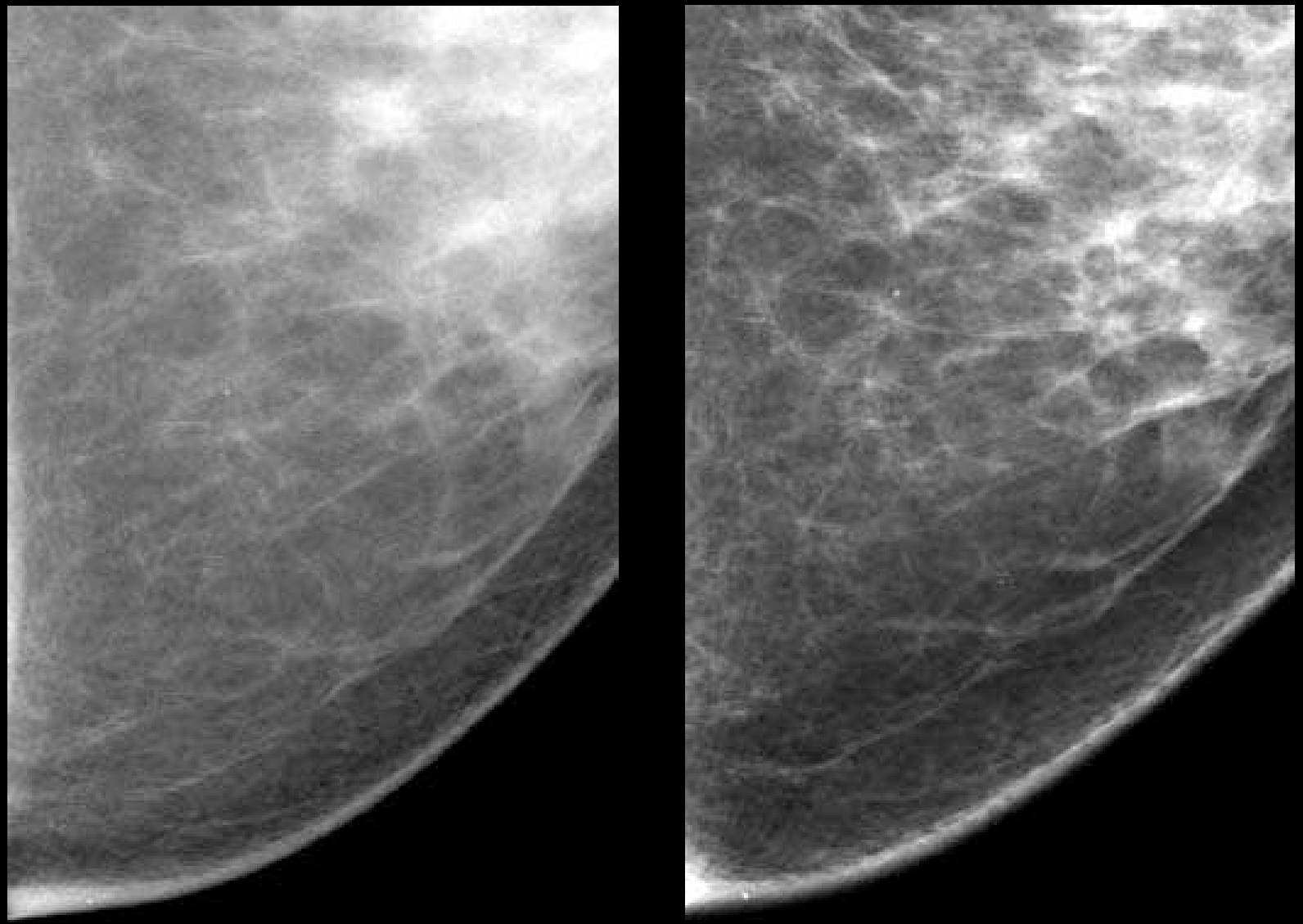
Same size



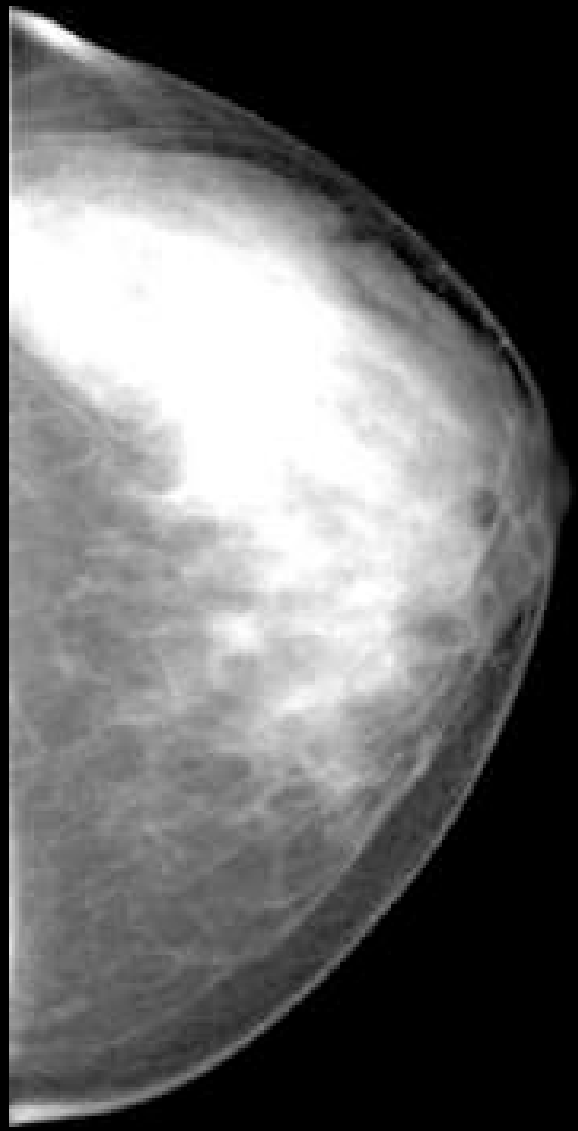
Same size and fitted to screen



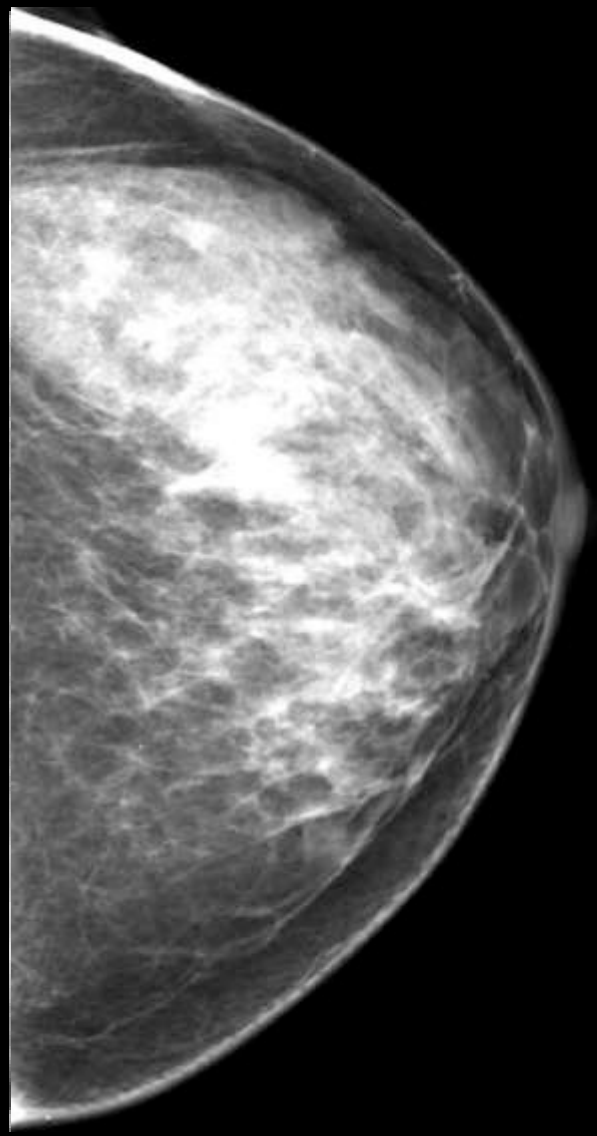
Synchronized size whilst zooming and panning



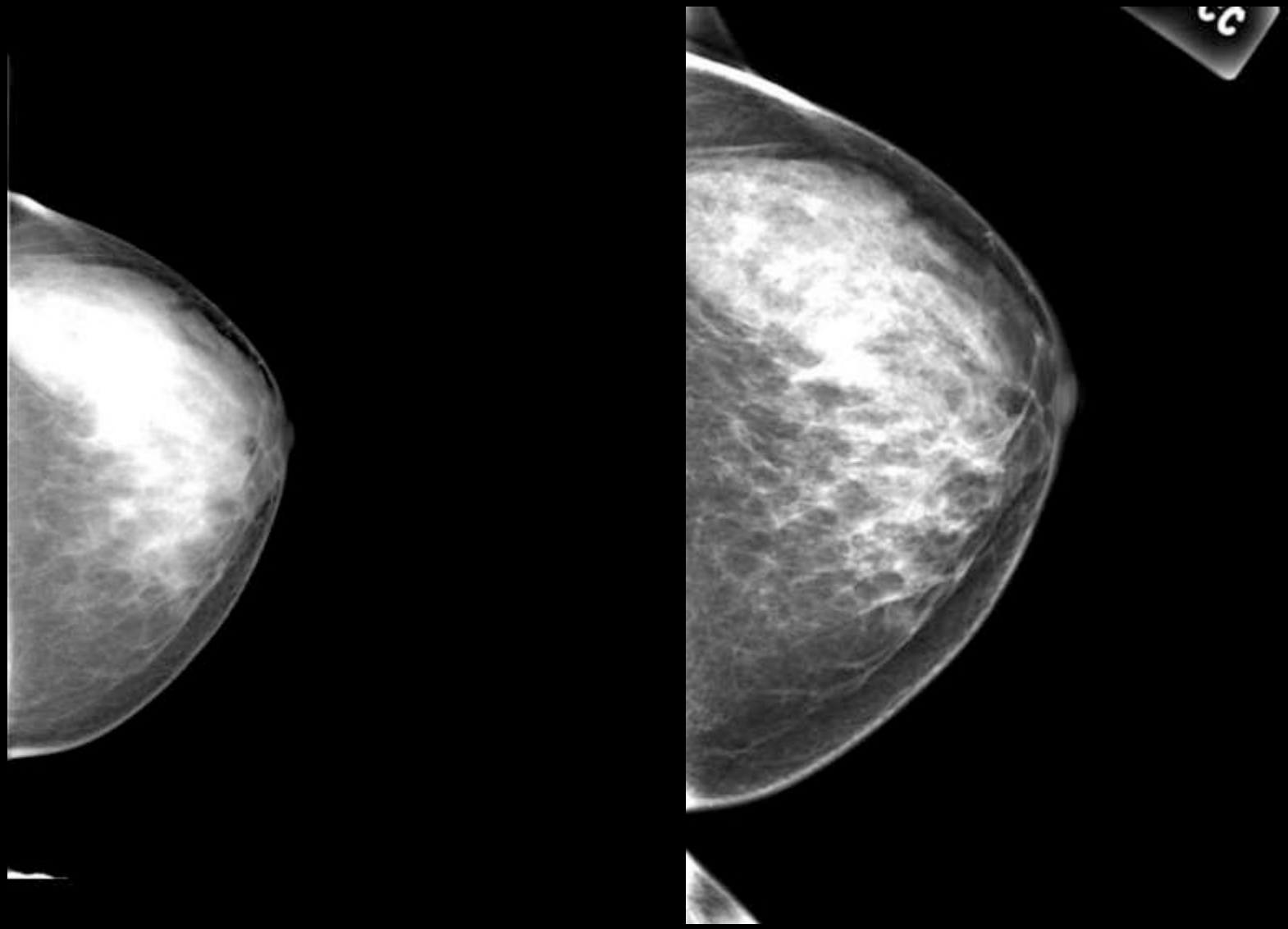
Scroll through time to detect changes using motion

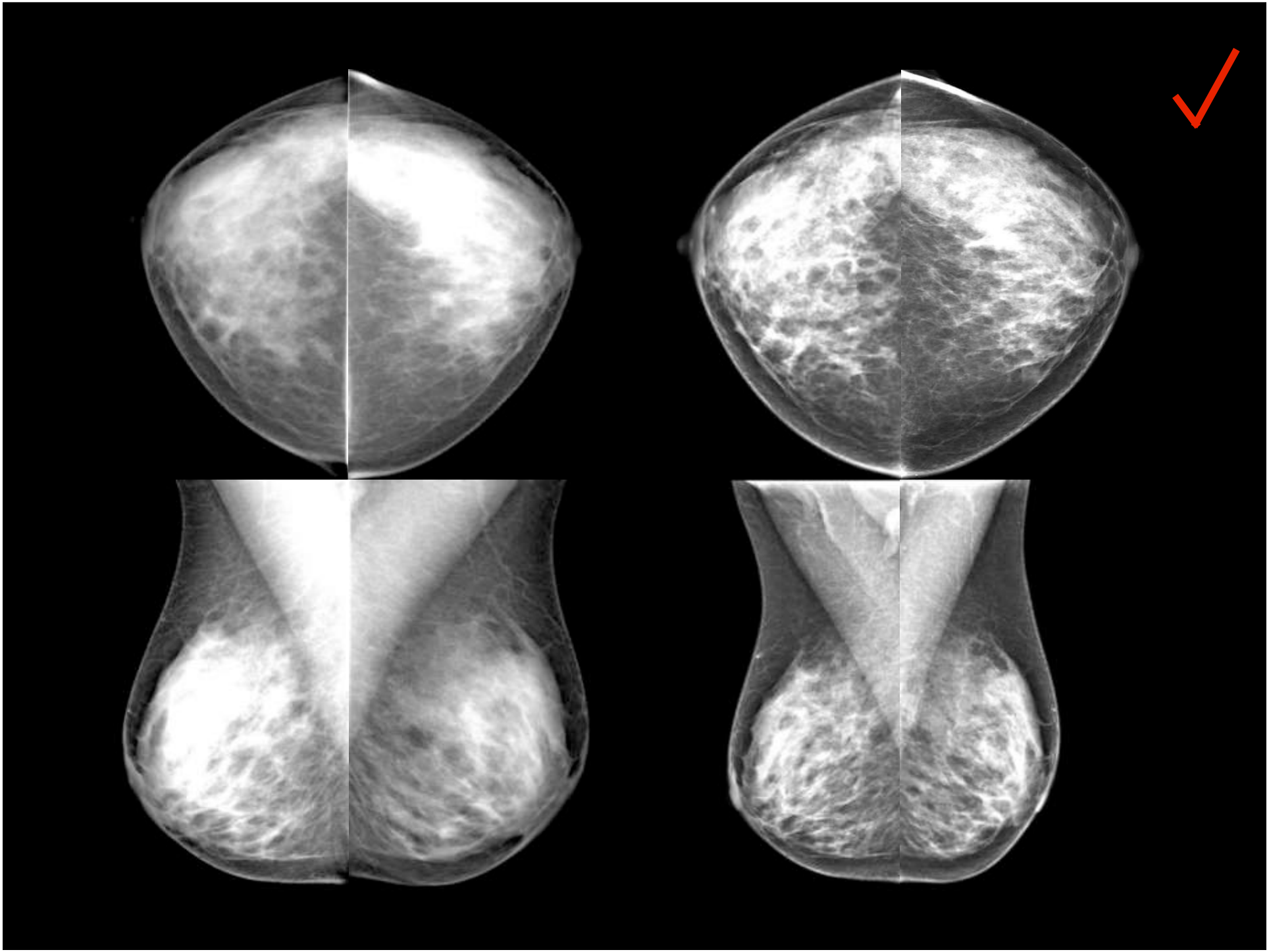


Scroll through time to detect changes using motion



1:1 acquired to display pixel 5MP different sensors



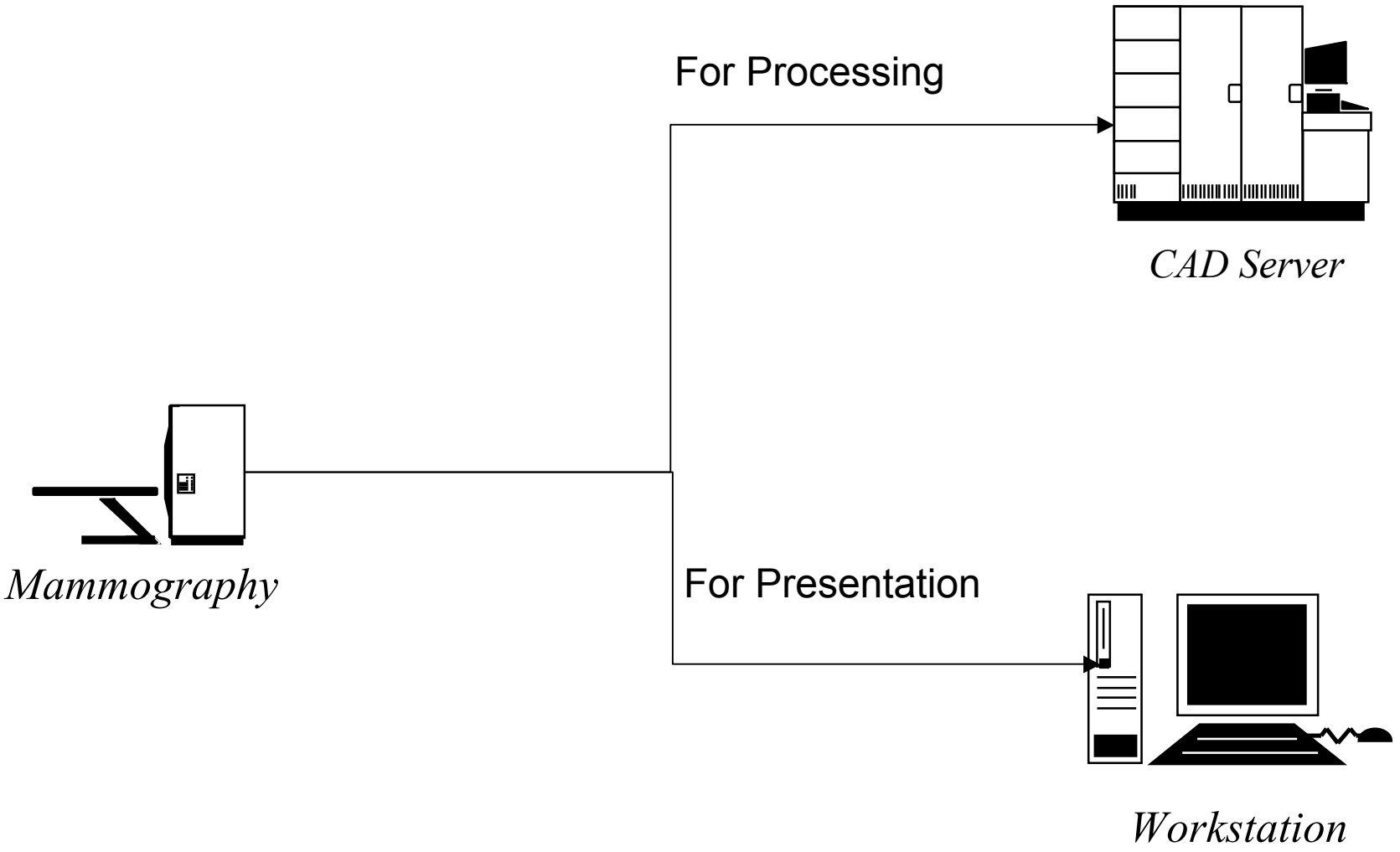


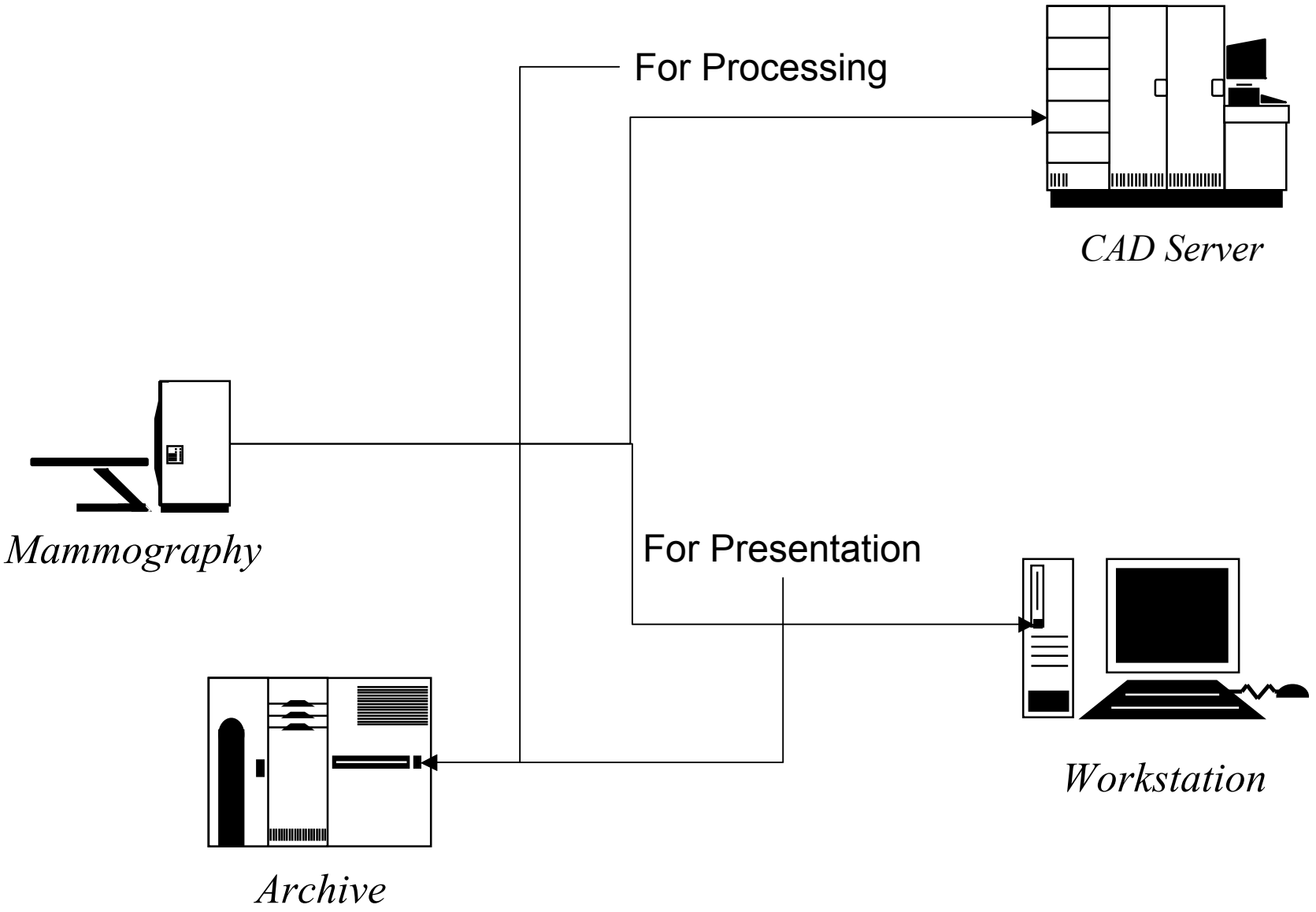
CAD workflow

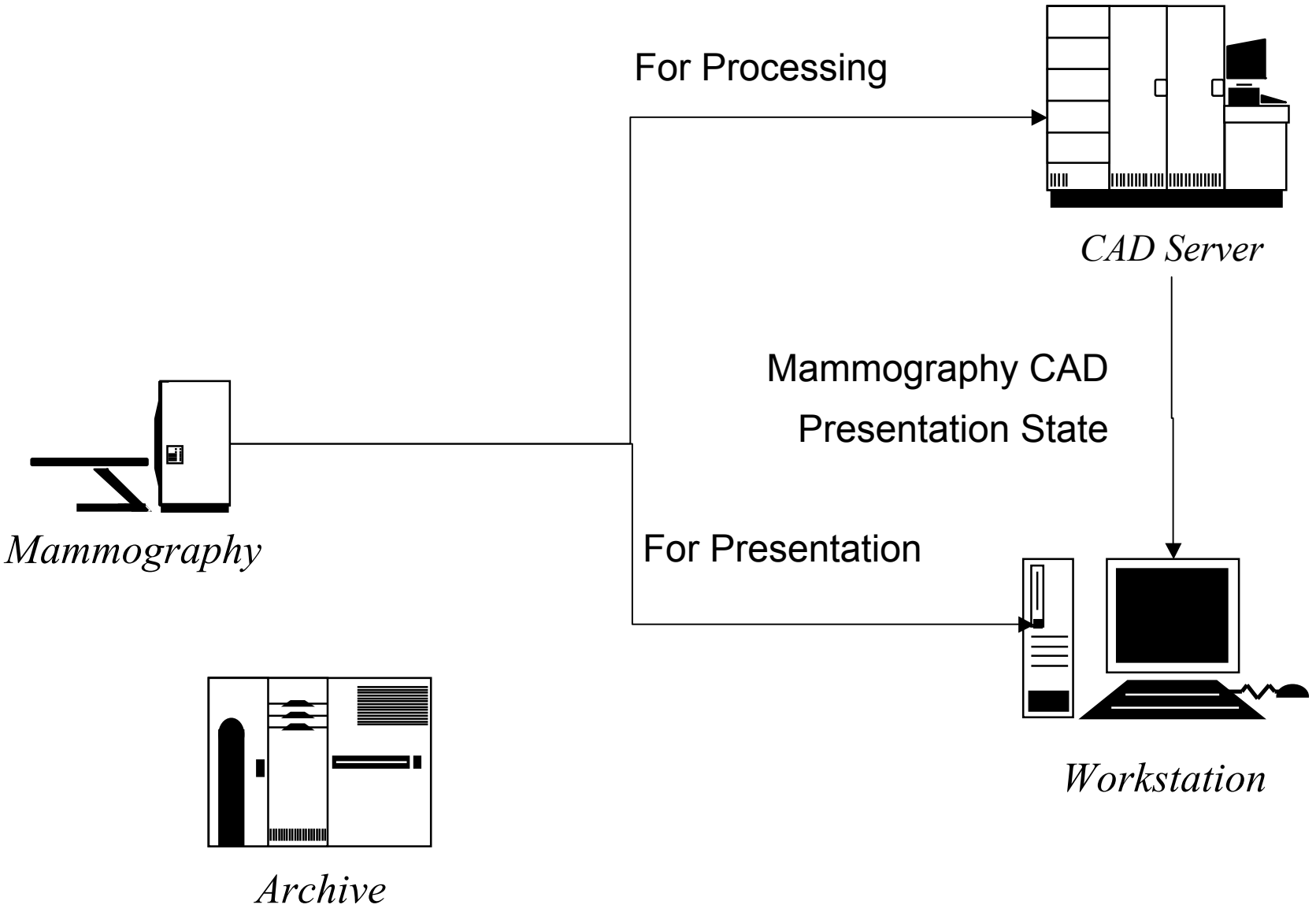
- CAD prefers For Processing images
- Interoperable display requires For Presentation images
- Therefore CAD marks must be created on For Processing images and applied to For Presentation - requires that
  - appropriate references exist
  - spatial concordance between For Processing and For Presentation pixel data (e.g., if flipped or scaled or deformed, marks would be applied in wrong location)

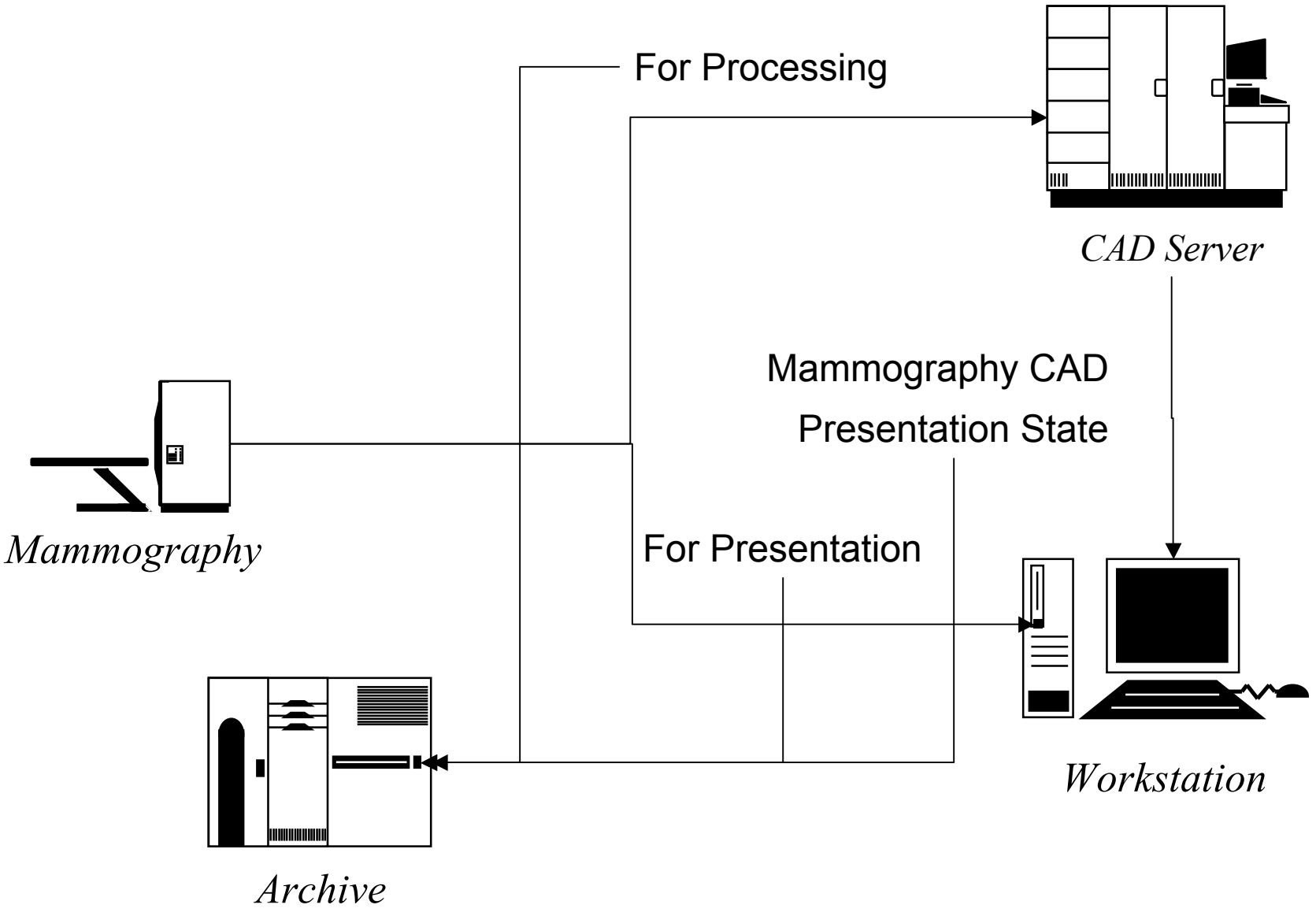
CAD result encoding

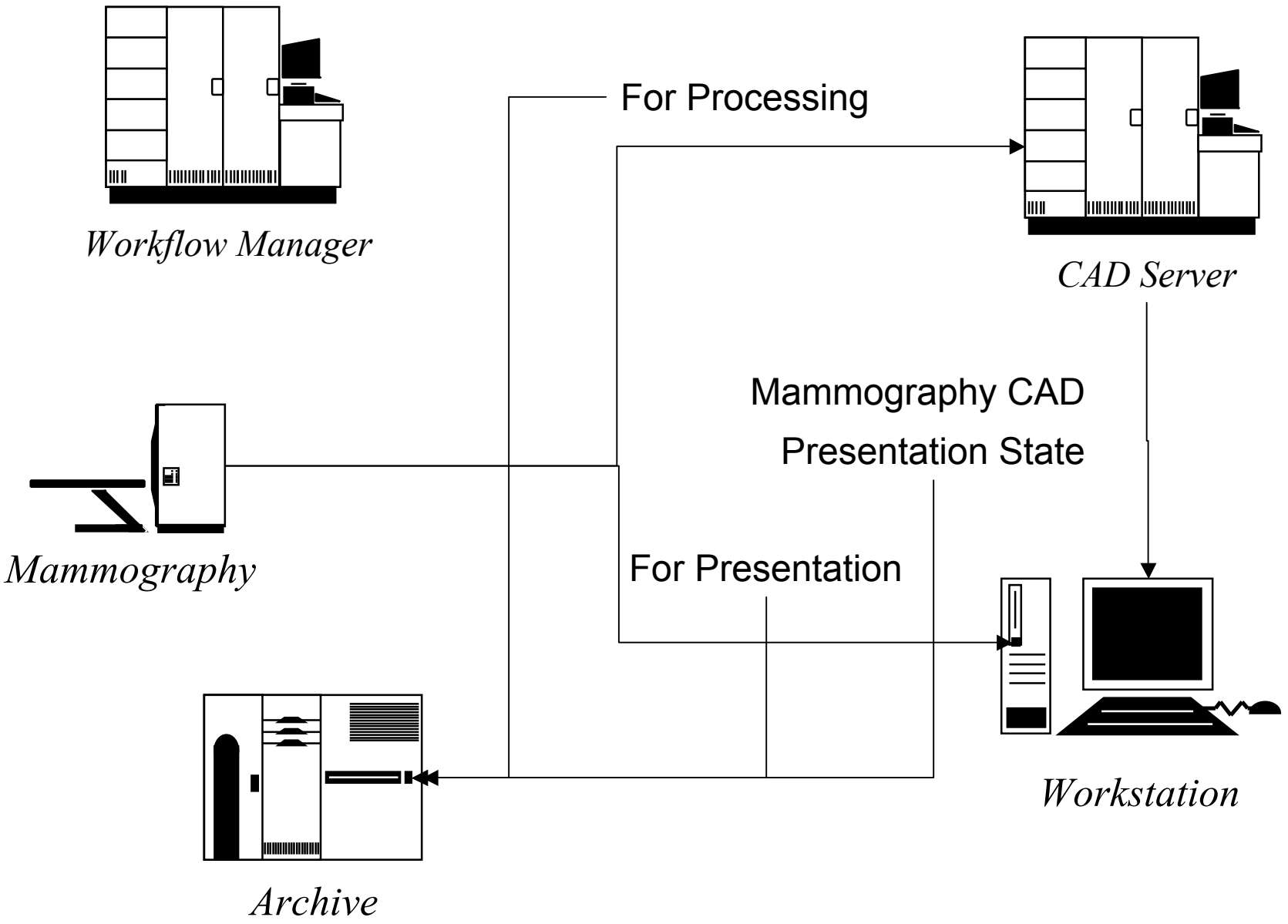
- DICOM Mammography CAD
  - contains the location information
  - but not what the marks should look like
- DICOM Presentation State (GSPS)
  - can be created from the CAD object
  - use an approved appearance for the marks (appearance may affect performance of user)
  - be displayed by any workstation that supports GSPS, even if CAD “illiterate”


For Processing
CAD Server
Mammography
For Presentation
Workstation


For Processing
CAD Server
Mammography
For Presentation
Workstation
Archive


For Processing
CAD Server
Mammography CAD
Presentation State
Mammography
For Presentation
Workstation
Archive


For Processing
CAD Server
Mammography CAD
Presentation State
Mammography
For Presentation
Workstation
Archive


Workflow Manager
For Processing
CAD Server
Mammography CAD
Presentation State
Mammography
For Presentation
Workstation
Archive

For Processing v Presentation

- Pixels from sensor need to be processed in some way before display
  - at acquisition system (send/save “raw”)
  - at workstation (send/save “processed”)
- DICOM design based on previous experience with CR images
  - CR object did not make the distinction
  - Different choices by different vendors resulted in poor interoperability (inconsistent of appearance)
  - Configurable choices -> mixture of types in the archive
  - “Raw” form precluded use of other workstations without proprietary algorithm licensing or reverse engineering

For Processing v Presentation

- For Presentation
  - Ready to be displayed to the user
  - As long as the grayscale information is applied
    - Window center/width(s)
    - Lookup Table(s)
  - As long as the display is calibrated to the Grayscale Display Function (GSDF)
  - Mandatory for all systems (acquire & display)
  - Intended as the “baseline” for all (dumb) workstations
- For Processing
  - Not ready to be displayed to the user
  - Intent is to allows storage & retrieval for “re-processing”

Processing types

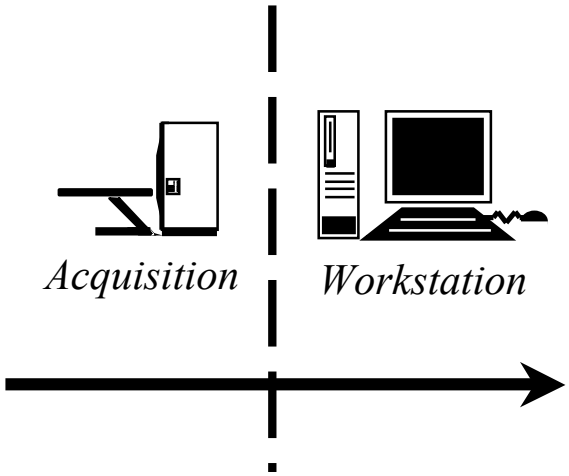
- Sensor-specific processing
  - Exposure compensation
  - Tile stitching
  - Defect correction
- Sensor-independent processing
  - Point operations
    - linear to log (to x-ray intensity)
    - contrast transformation
  - Image operations
    - noise reduction
    - sharpening
    - frequency selective filtering (e.g. in wavelet domain)
    - thickness compensation

Factored out and encoded in DICOM

Could factor out and encode in DICOM ?

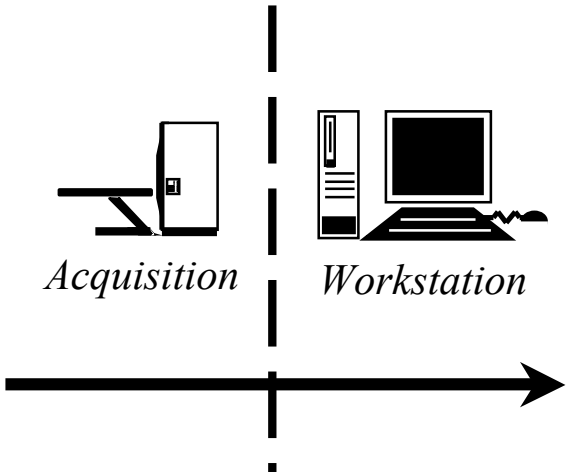
For Processing

For Presentation



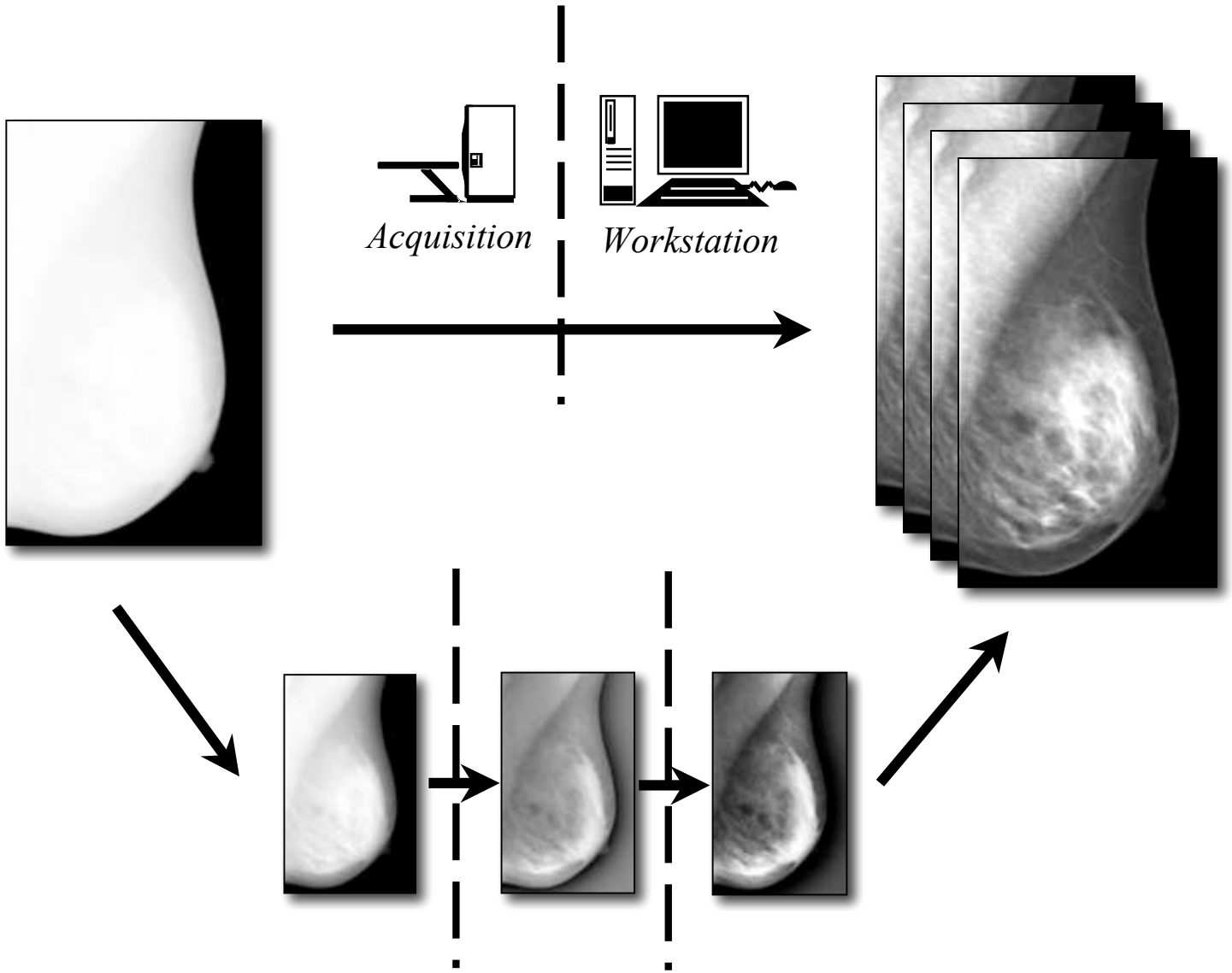
For Processing

For Presentation



For Processing

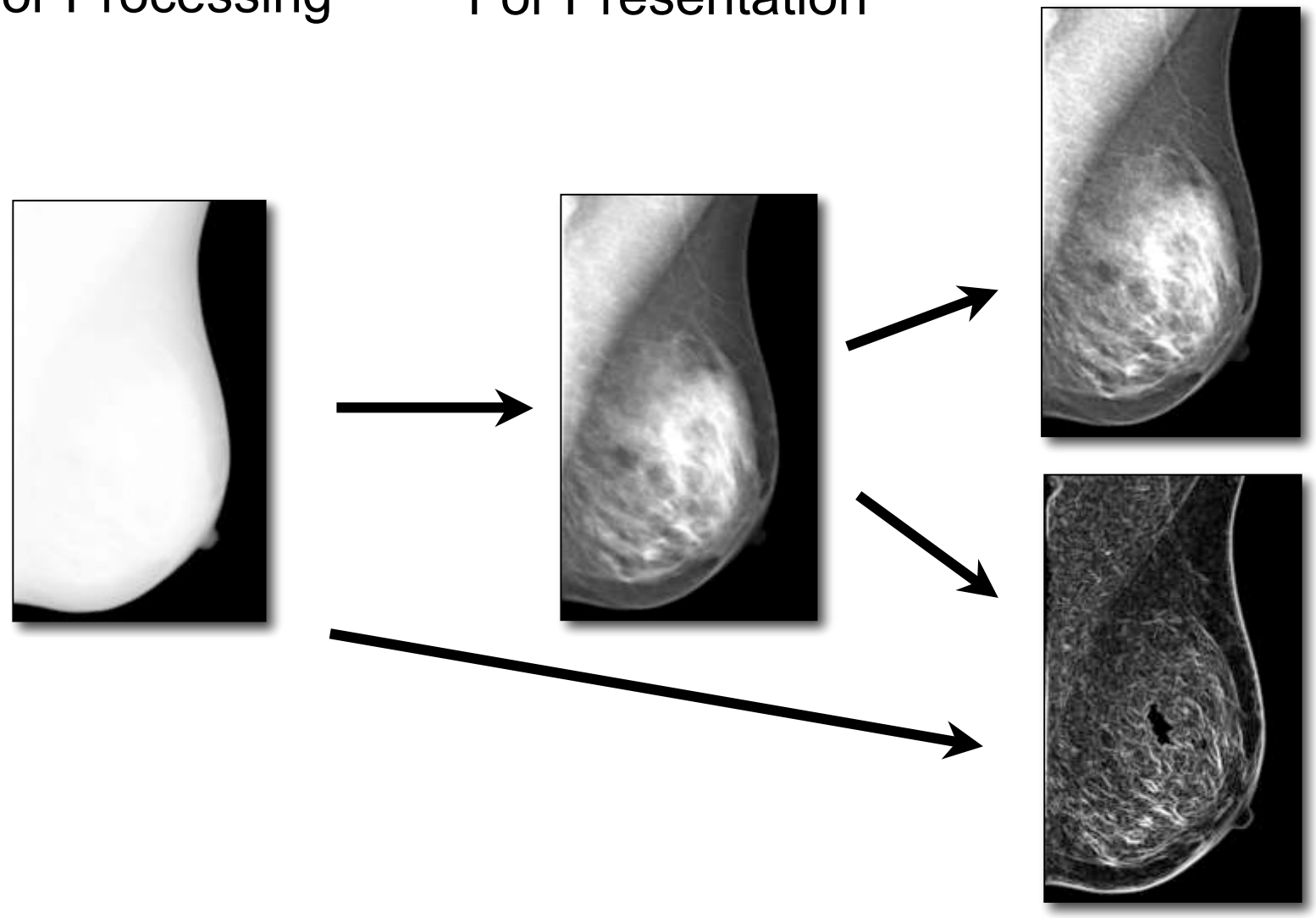
For Presentation



For Processing

For Presentation

For Presentation



Derived

Perhaps a fundamental conflict between requirements

- Users want all images from all vendors to look the same on all workstations (outside priors)
- Vendors want to distinguish themselves by making their images look “better” than their competitors
- Need to separate added value of the sensor as opposed to the processing that is not sensor specific ?

What to include on media and save in archive

- Who is it for ?
  - Referring physician
  - Radiologist next time (as priors)
- For Presentation images
  - So any one can view it (on their own station)
- For Processing images
  - So as a prior it can be reprocessed (if workstation is capable) to look the same as the current study

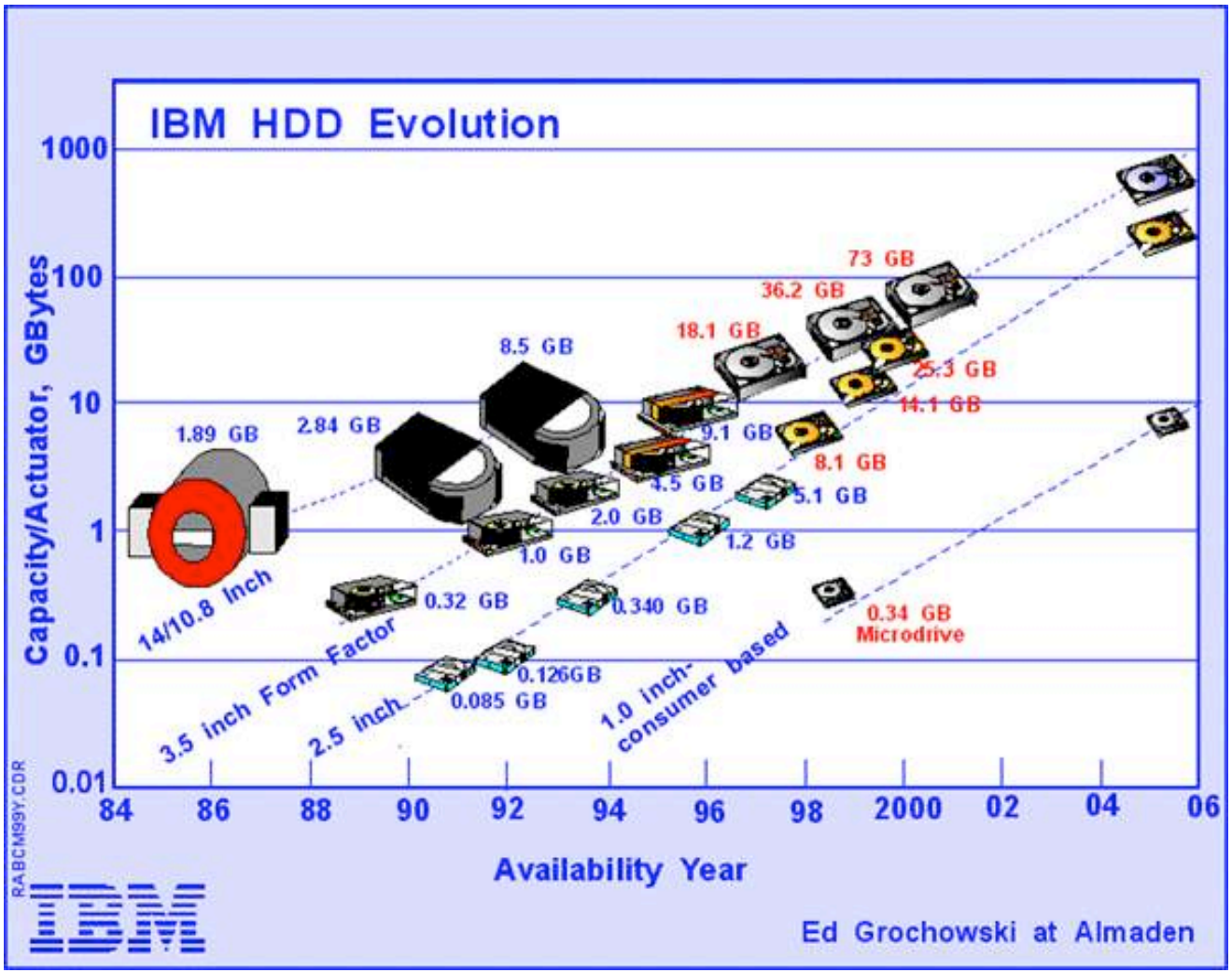
What to include on media and save in archive

- CAD result
  - So suspicious areas reviewed and dismissed can be considered, this time and next
  - As CAD SR, to preserve locations
  - As Presentation States, to be displayable on non-CAD literate workstations
- Mammography report
  - As DICOM Breast Imaging Report, to be of standard form and encoding for review and analysis
  - As DICOM encapsulated PDF, so as to be easily rendered to the display as approved, yet manageable in the PACS

Storage policy issues

- How long must you keep images ?
  - Federal, state, civil litigation requirements
- How long do you want to keep images ?
  - Research, teaching, algorithm testing
- Is the complexity of selective purging worth it ?
  - As disk gets cheaper, keep everything forever
- Longevity of archival media
  - Degradation over time - optical versus tape media
  - Migration to new media
  - Readability with new software - uses standard format and compression
  - Plan ahead for archive and PACS end of life
- Is lossy compression acceptable for long term archive ?

Cost of spinning disk



Cost of spinning disk

- Depends on speed, reliability, redundancy
- Host interface - SAN, NAS, DAS
- Drives - SCSI or (S)ATA
- SATA bare drives - < $1,000/TB ($0.001/MB)
- DAS SATA RAID - $2,000/TB
- SCSI U320 bare drives - $3,500/TB
- F/C SAN/DAS SCSI RAID - $10,000/TB ($0.01/MB)

- LTO 3 400GB Tape - $250/TB ($0.00025/MB)

How much space is needed ?

- 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 exam
  - 33.6 to 176MB uncompressed
  - 6.7 to 35.2MB lossless compressed

How much will fit on media ?

- One exam
  - 33.6 to 176MB uncompressed
  - 6.7 to 35.2MB lossless compressed
- CD-R
  - 600MB
  - Uncompressed from 18 to 3.5 exams
  - Lossless 5:1 from 90 to 17 exams
- DVD-R
  - 4.5GB
  - Uncompressed from 137 to 26 exams
  - Lossless 5:1 from 688 to 131 exams

How much will fit on archive ?

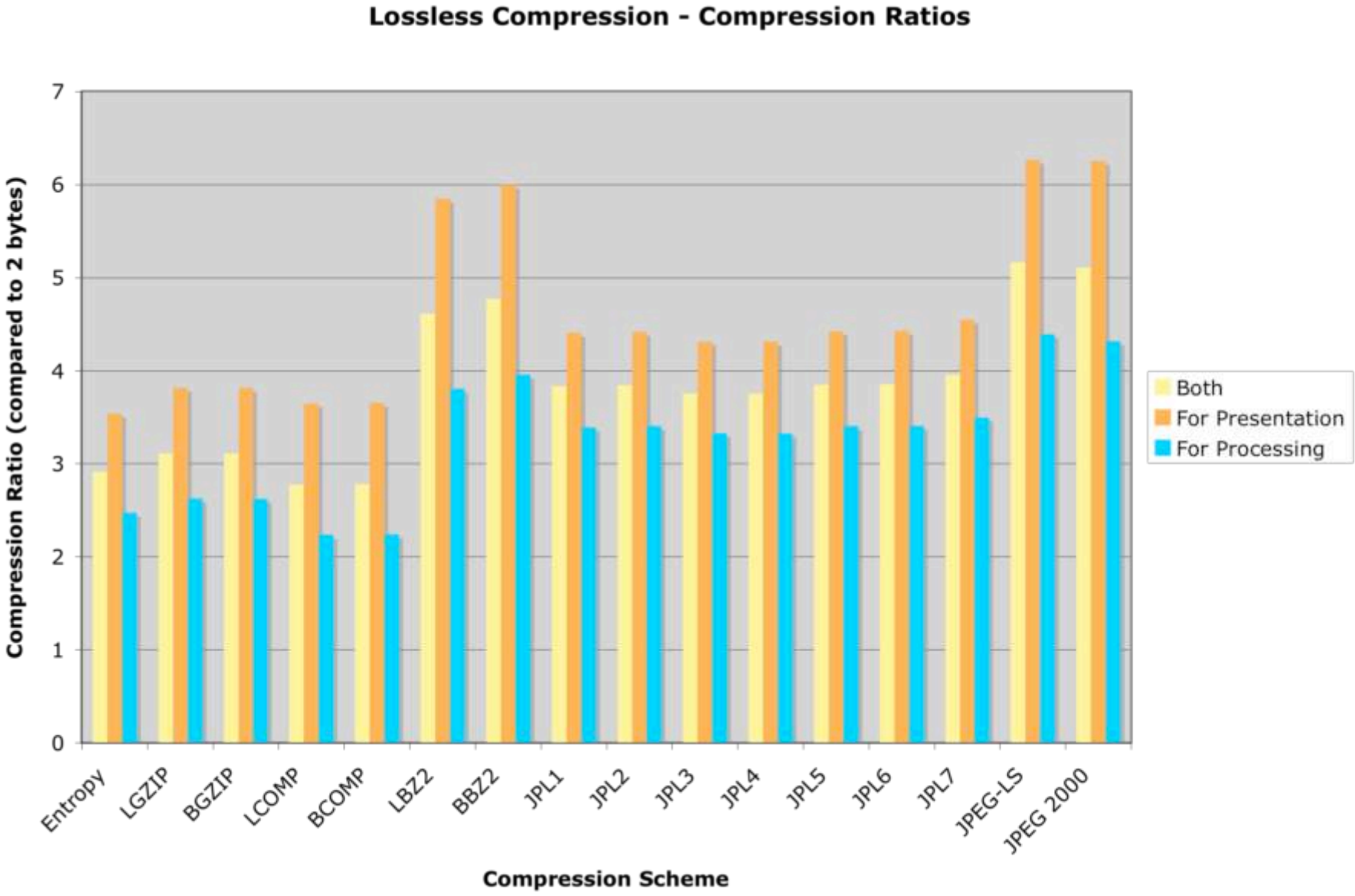
- One exam
  - 33.6 to 176MB uncompressed
  - 6.7 to 35.2MB lossless compressed
- 1 TB RAID
  - Uncompressed from 31,000 to 6,000 exams
  - Lossless 5:1 from 156,500 to 29,800 exams

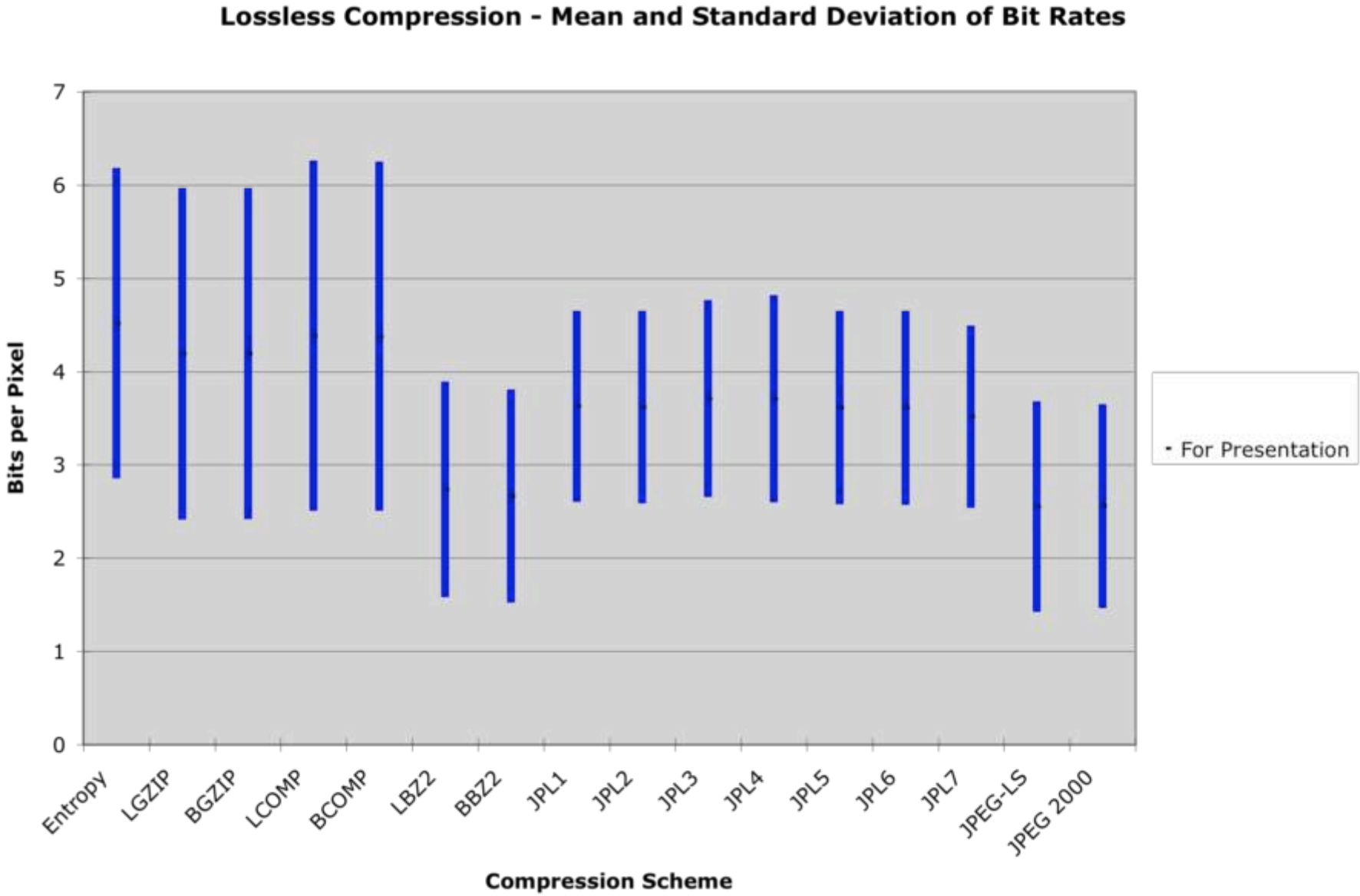
How much does archival cost ?

- One exam
  - 33.6 to 176MB uncompressed
  - 6.7 to 35.2MB lossless compressed
- Archival of lossless compressed
  - Fast disk ($0.01/MB) - $0.067 to $0.35 per exam
  - Slow disk ($0.001/MB) - $0.007 to $0.035 per exam
  - Tape ($0.00025/MB) - $0.002 to $0.009 per exam
- Bottom line
  - So cheap that avoiding storing for processing, or lossy compressing, is almost absurd.

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)


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

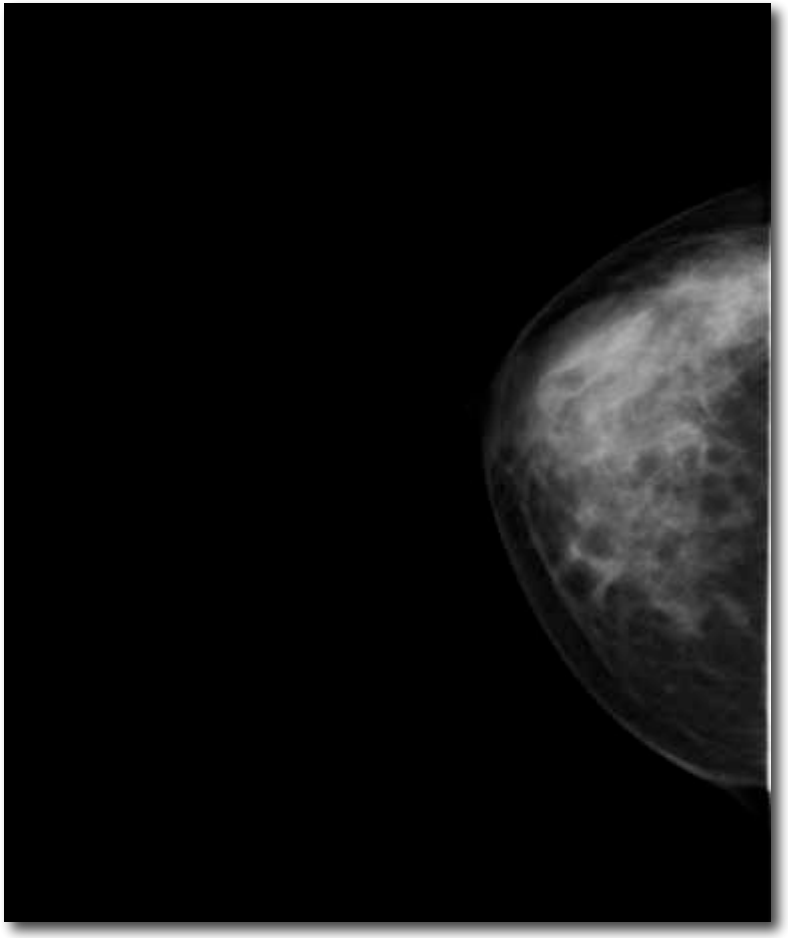

Lossless Compression - Mean and Standard Deviation of Bit Rates
Bits per Pixel
0
1
2
3
4
5
6
7
Entropy
LGZIP
BGZIP
LCOMP
BCOMP
LBZ2
BBZ2
JPL1
JPL2
JPL3
JPL4
JPL5
JPL6
JPL7
JPEG-LS
JPEG 2000
Compression Scheme
For Presentation

Lossless compression

- For Presentation compress better than For Processing - less information
- 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 - poor for large areas of air
- Bzip2 does surprisingly well
  - Mean CR 6.00 For Presentation
  - Large block based scheme - knows nothing about images

Variation in compressibility

JPEG-LS Lossless



Best - CR 12.9

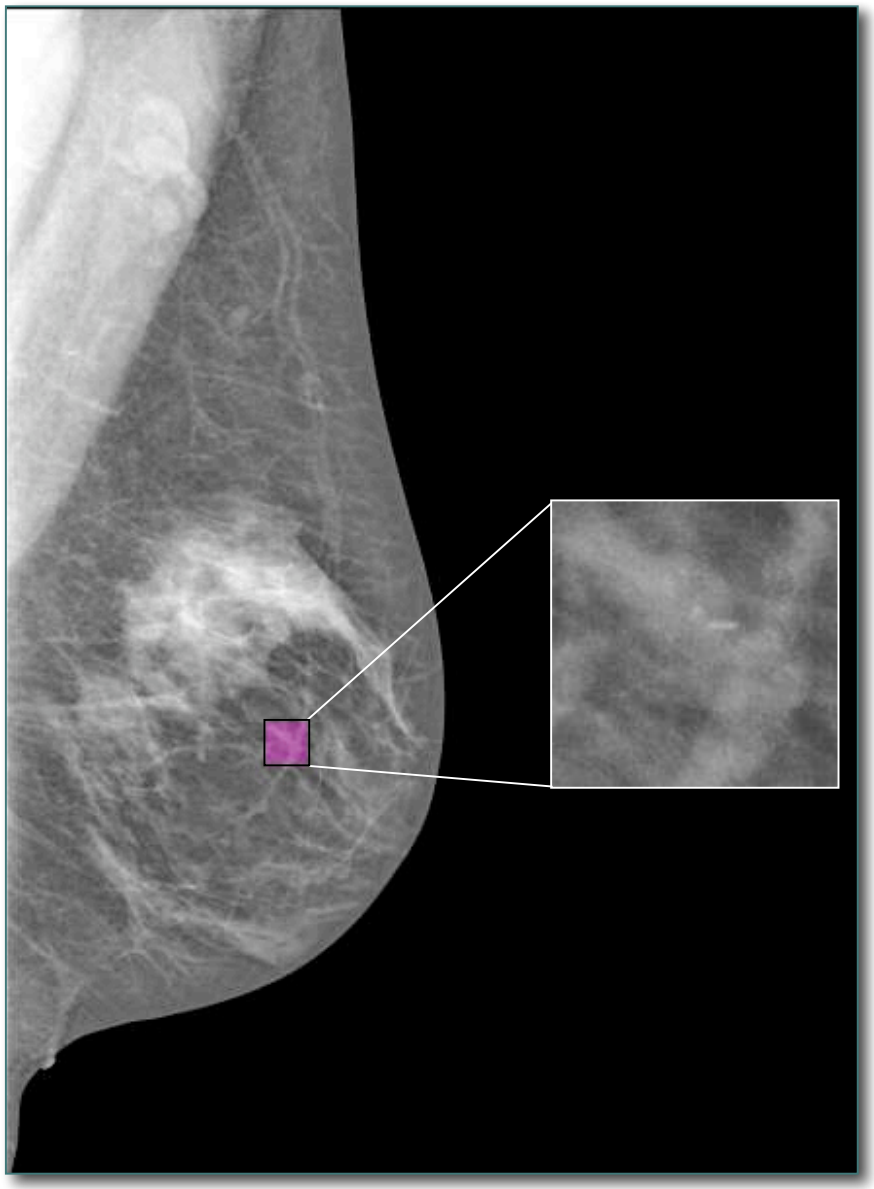
Worst - CR 3.19

Telemammography

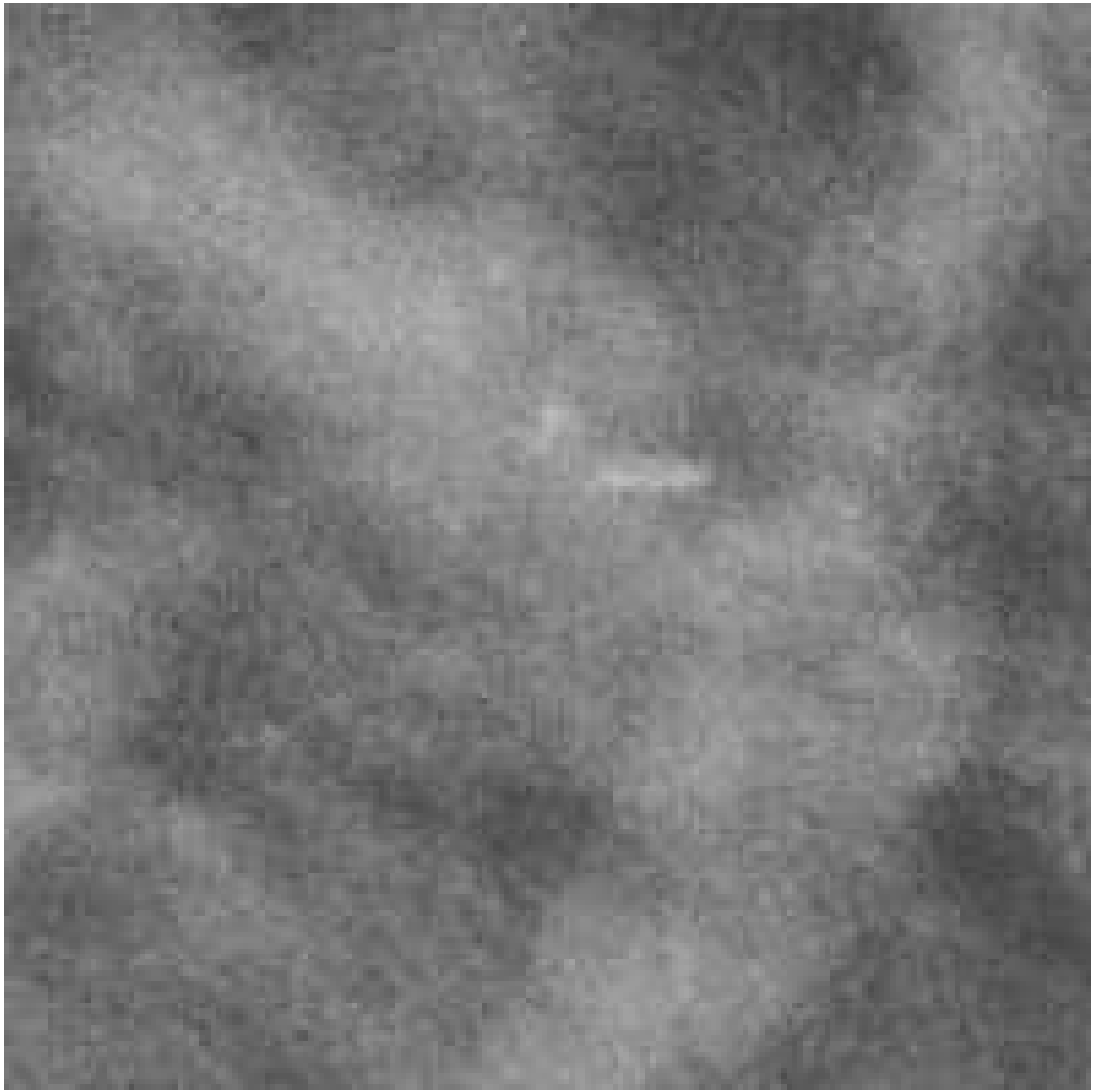
- Feasibility
- Broadband - DSL and Cable
- Performance
  - Speed
  - Throughput
  - Delay
- Compression
  - Lossless - primary reading
  - Lossy - referrers, priors, ??? primary reading

Lossy compression

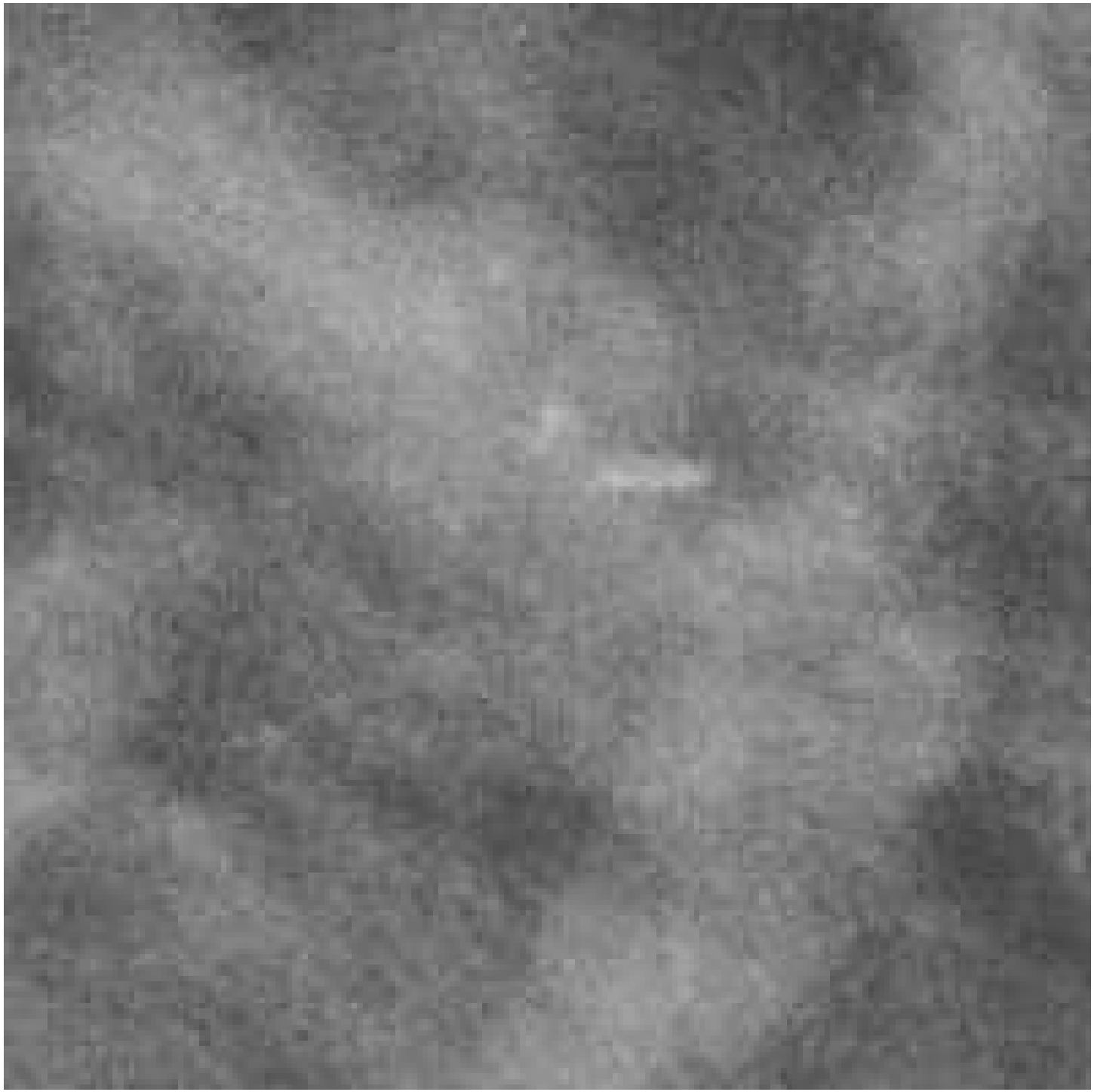
- Is it OK for any purpose ?
- Are wavelets better than JPEG ?
  - Several experiments suggest not, at compression ratios that are practical
- What compression ratio (bit rate) is OK ?
  - Depends on how much information is in image
  - How much air versus breast
- Region of interest compression
  - Compress background more than breast
  - A feature of many schemes, including J2K



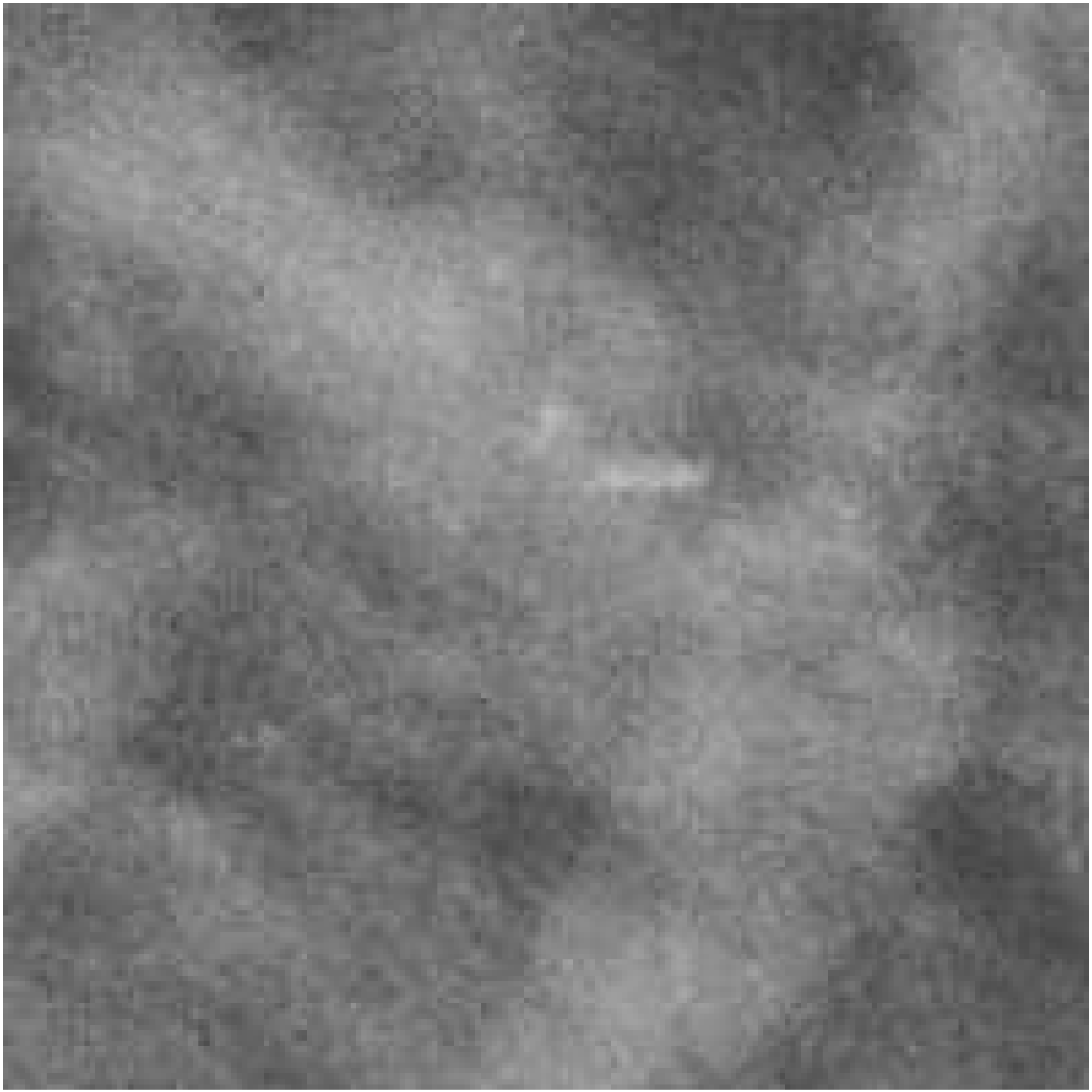
Original
CR 1:1
47MB



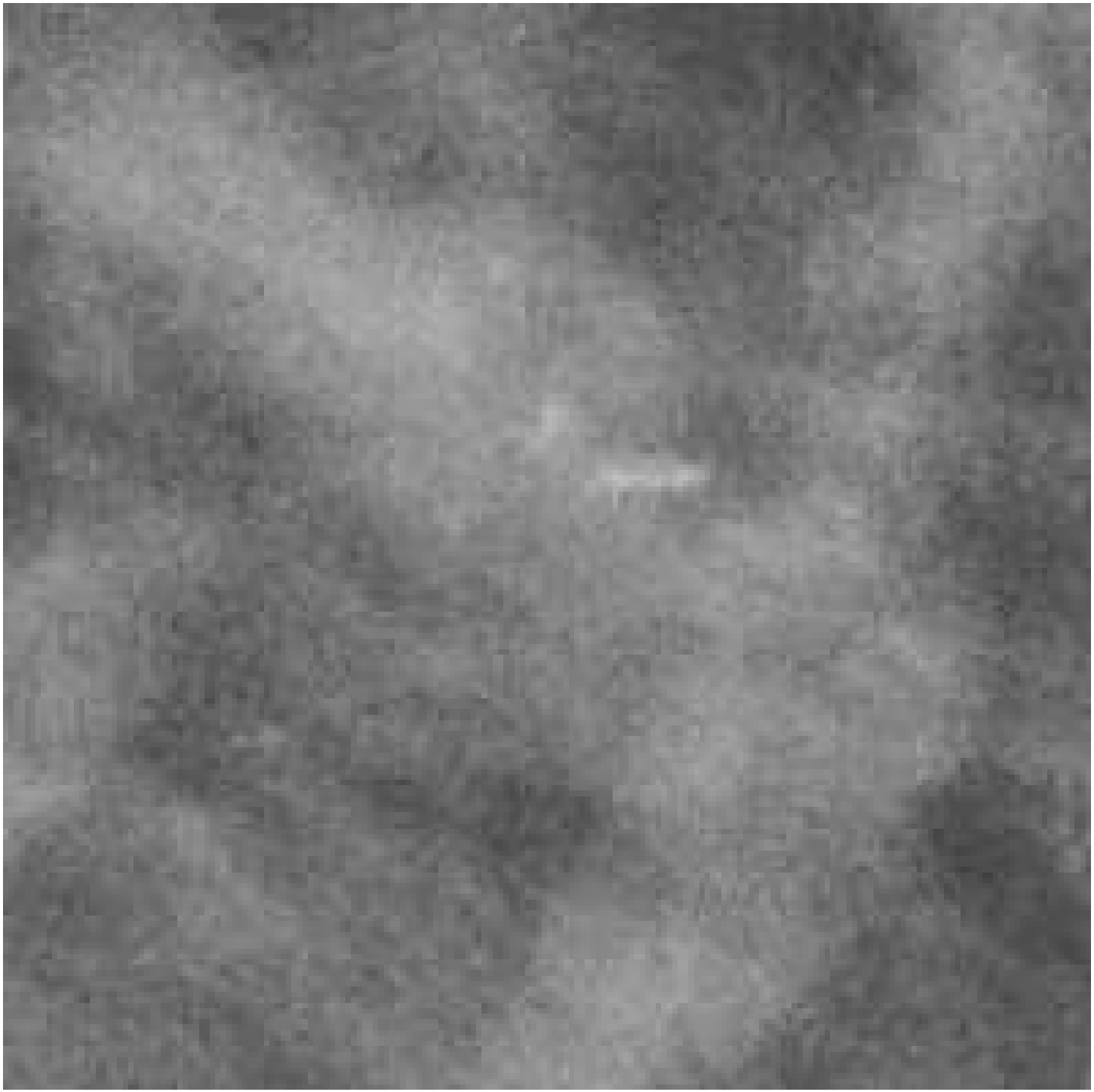
2.0 bpp
CR 8:1
5.7MB



1.0 bpp
CR 16:1
2.9MB



0.5 bpp
CR 32:1
1.4MB



0.325 bpp
CR 44:1
1MB

0.25 bpp
CR 65:1
710kB

0.125 bpp
CR 128:1
710kB

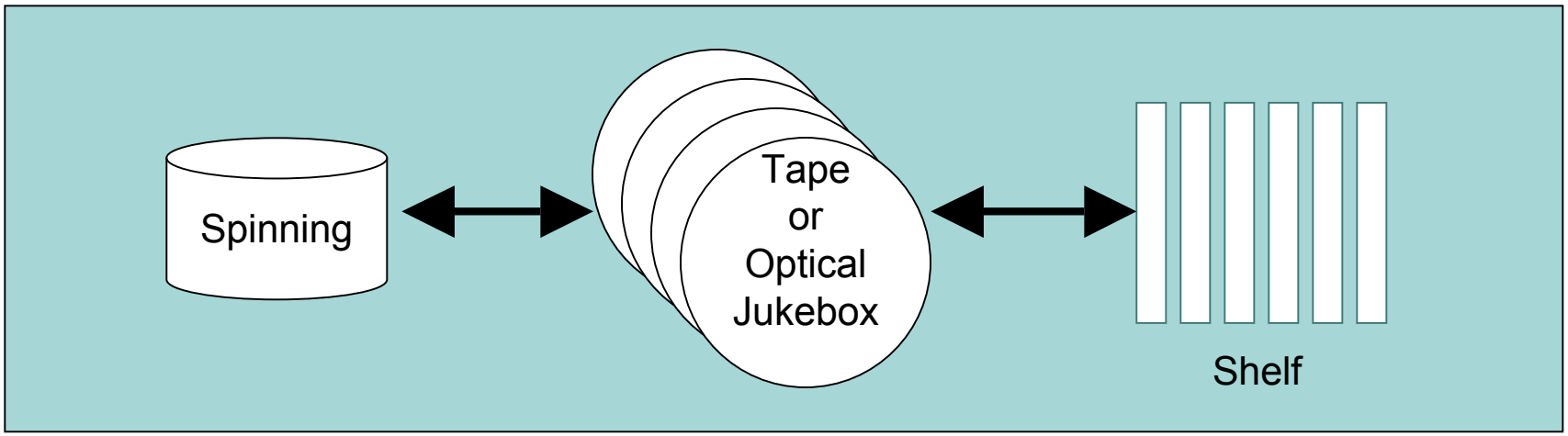
Business Continuity

- More than just ‘disaster recovery’
- Encompasses non-IT related issues
  - Human resources
  - Communications
  - Procurement
  - Environment (space, power)
- However - focus here on images
- HIPAA Security Rule - Contingency Plan

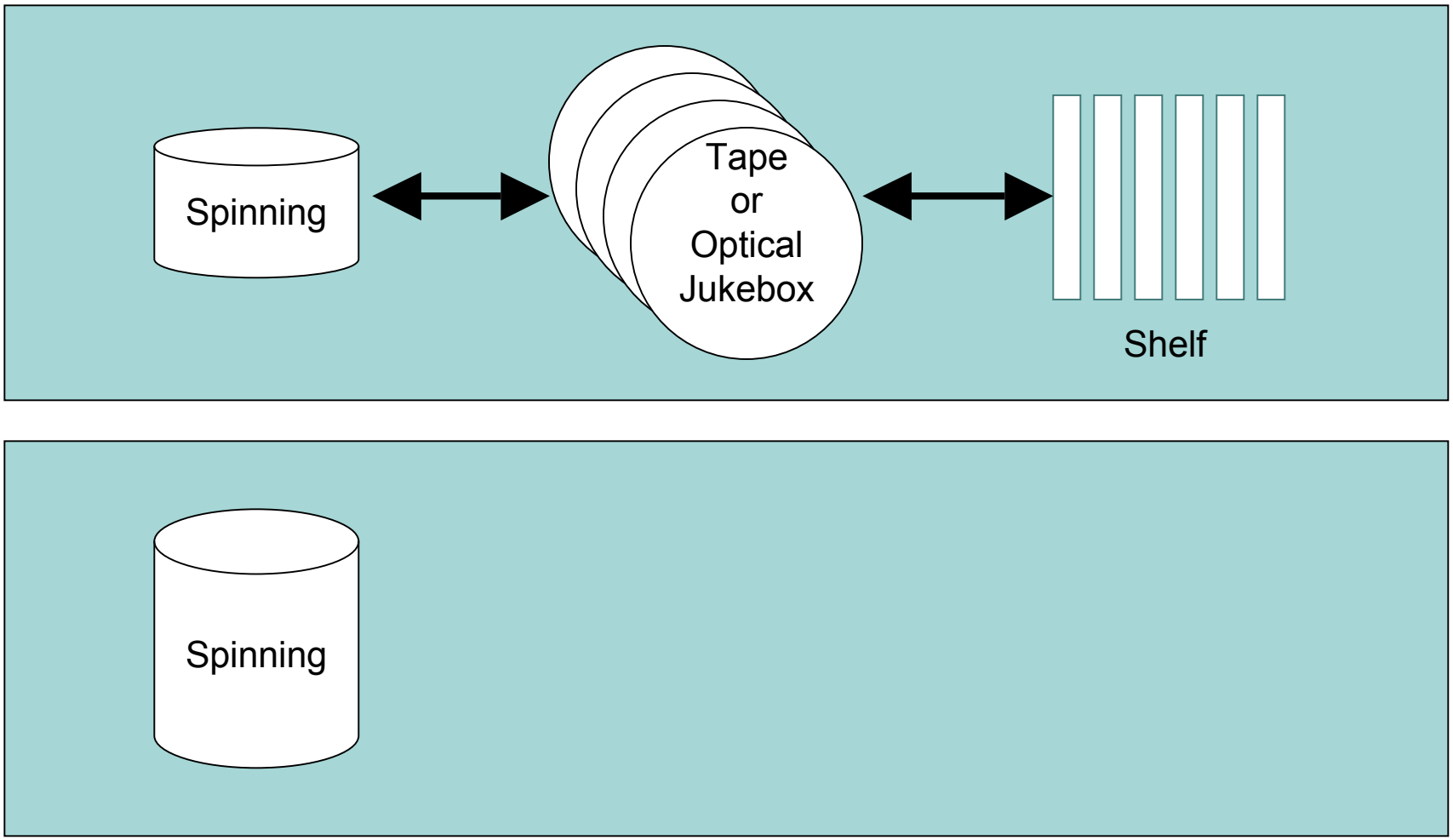
Business Continuity - Images

- Distinguish “backup” from “availability”
- Backup
  - Images can (eventually) be recovered
  - E.g. tape, DVD, CD (on shelf or in robot)
- Availability
  - Image are available (almost) immediately
  - Usually spinning disk offsite
  - Physically transport - takes time
  - Remote access - immediate, expensive bandwidth

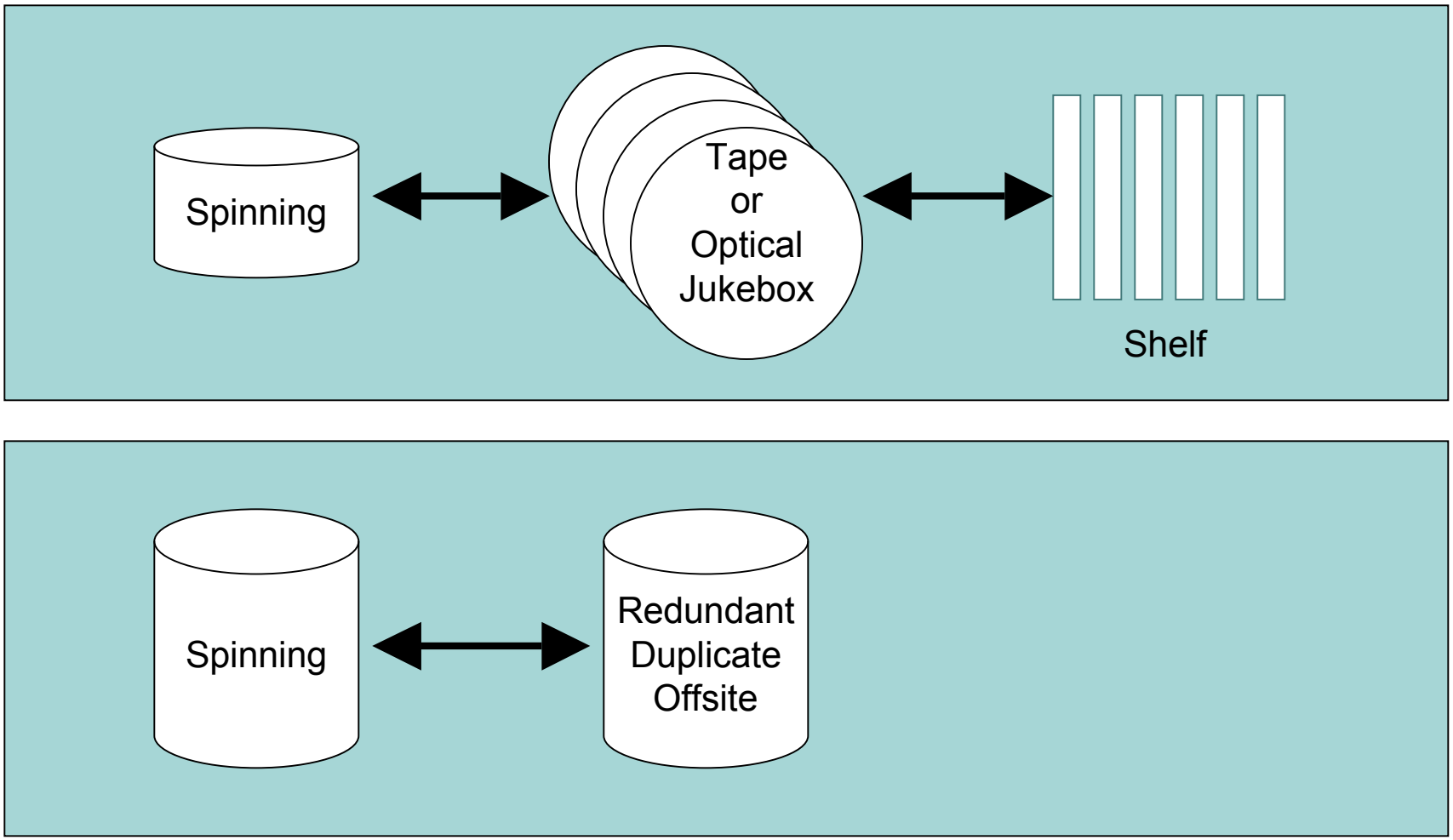
Storage Paradigms



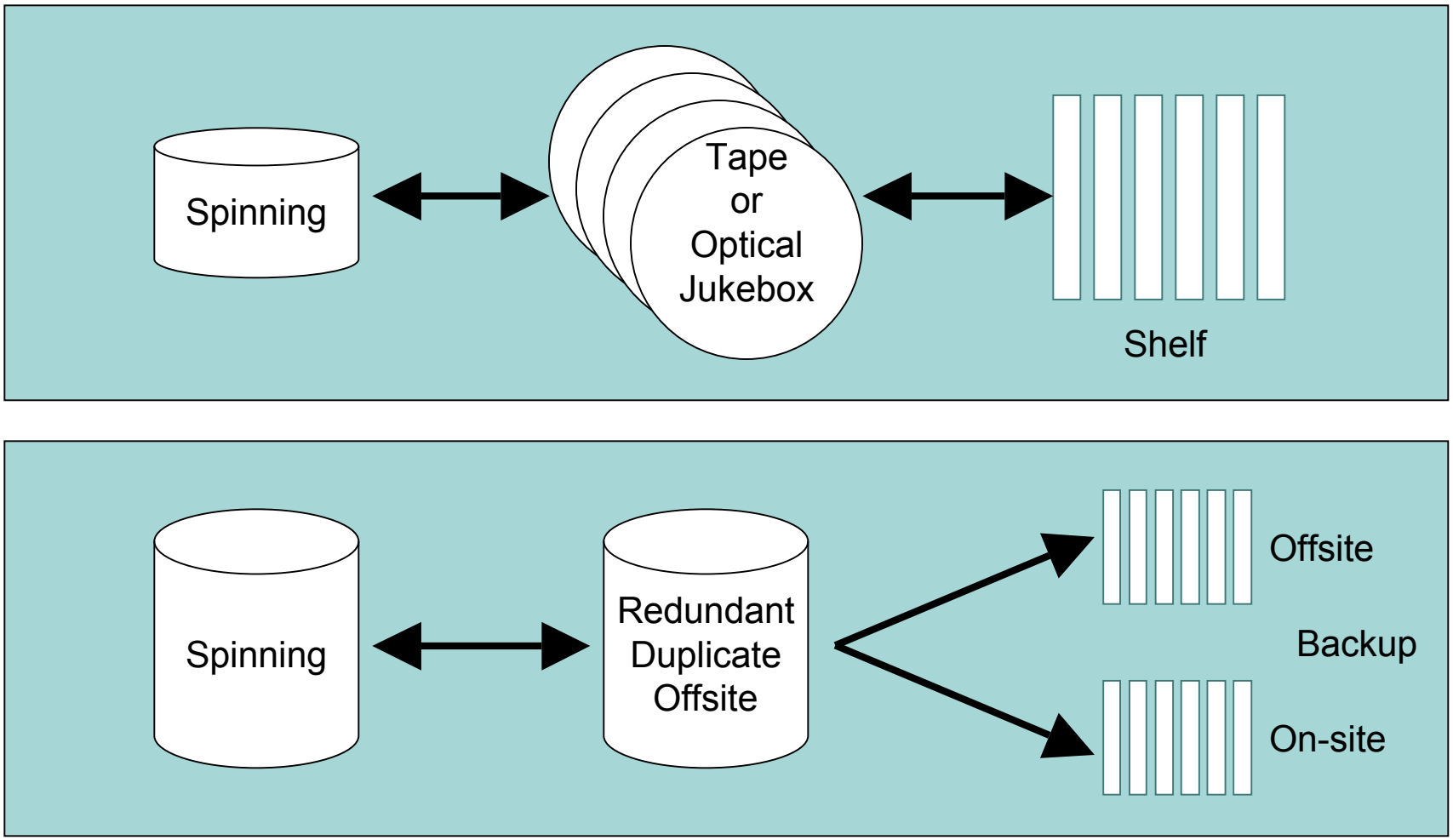
Storage Paradigms



Storage Paradigms



Storage Paradigms



Business Continuity - Images

- Backup choices
  - Offsite copies versus onsite copies (both)
  - Weekly/monthly full plus/or daily incremental
  - Incremental only (constantly growing data set)
  - Recycling offsite tapes - eventually backing up corrupt data
  - Testing them - periodically test retrieval
- Offsite spinning storage for high availability
  - Just disks ? Cheaper, slower disks ?
  - Entire application or just images ? Database ?
  - Still need backups - synchronizing corrupt data

Transfer between enterprises

- 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 a fantasy
- Portable digital media is the only answer

Portable digital media for mammography

- Standard image format - DICOM Mammo Image
  - For processing, for presentation or both ?
- Standard media - CD or DVD
  - How many images (visits) will fit ?
- Compression
  - None, lossless, or lossy ? Which scheme ?
- CAD
  - As DICOM Mammography CAD SR ?
  - As DICOM Presentation State ?
- Human report(s)
  - DICOM Mammography SR ?
  - Other - plain text, HTML, HL7 CDA ?

Transfer between enterprises

- Export for others
- Import as priors for your own review
- In everyone’s interest to standardize
- Nobody wants hybrid films + digital

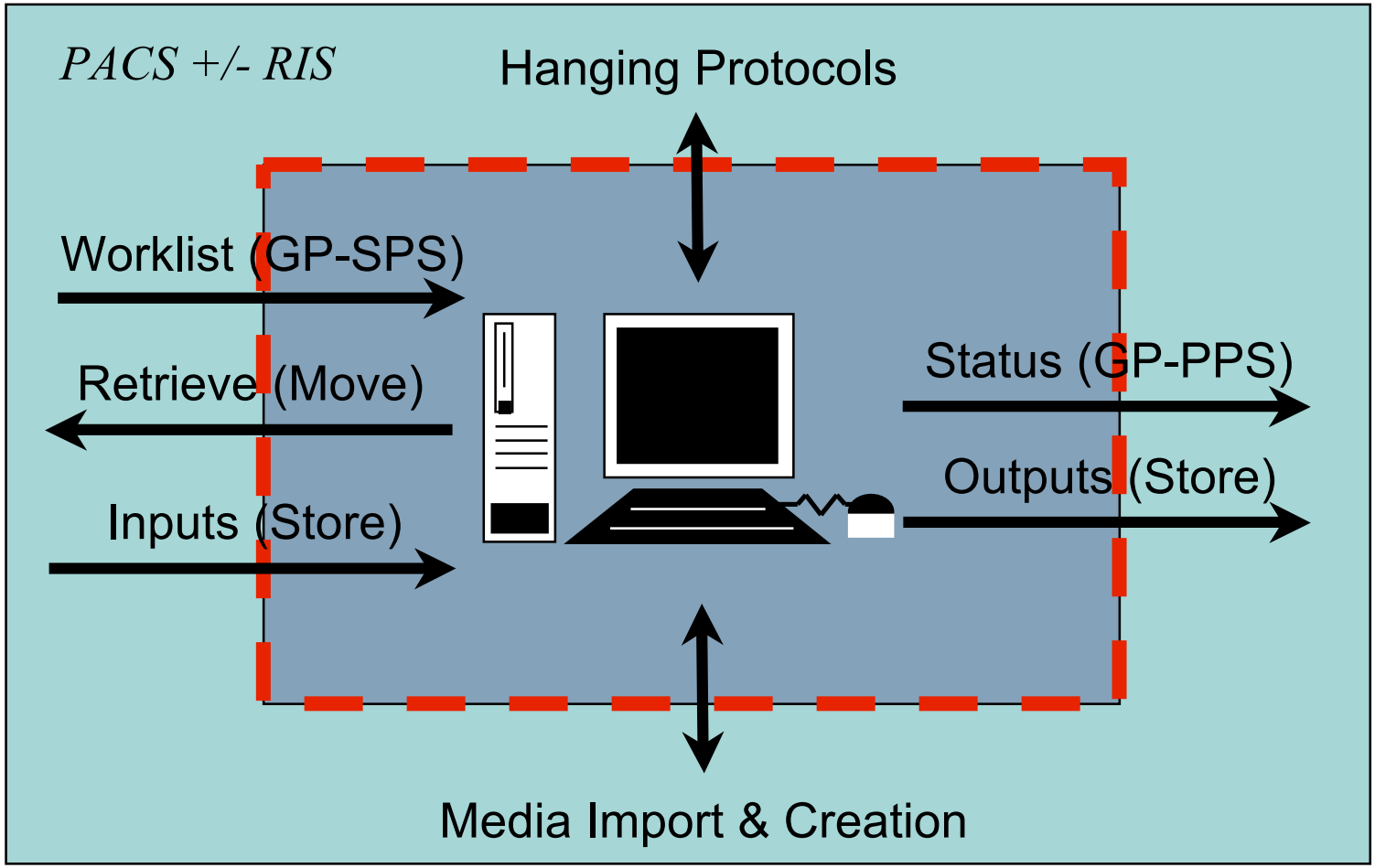
Mammography Workflow

- Acquire + CAD + read + export
  - Include import of priors from outside
  - Include work list control of read (IHE RW)
  - Include display consistency (IHE CPI)
    - Calibration of display
    - LUT and function support
    - Presentation State support
  - Include media creation

Reporting worklist is vital

- Key element is a worklist
- Provided by reporting worklist manager
- Queried for by reporting station
- Allows user to go to “next” task
- Allows pre-fetching for anticipated tasks to maximize workstation performance
- Can be completely standardized using the DICOM GP Worklist
- No need for any proprietary protocol
- Extremely dissatisfying if mammography workstation cannot access PACS reporting worklists

Carving out the Workstation



Key standard services for reporting station

- DICOM Grayscale Standard Display Function
- DICOM Mammography Image (For Presentation)
- DICOM Mammography CAD
- DICOM Grayscale Presentation State
- DICOM Breast Imaging Report
- DICOM General Purpose Worklist
- DICOM Hanging Protocols
- DICOM General Purpose CD/DVD Media Profiles

Completely sufficient to replace all services of any proprietary PACS integrated mammography reading workstation

Beyond DICOM - standards for workflow

- DICOM
  - Defines only boundaries between devices
  - Not how different devices operate together and in sequence to achieve a workflow
- IHE
  - Describes workflows composed from appropriate standards, including DICOM
  - Adds restrictions to standards for specific scenarios
  - Does not (typically) address “payload” of objects
  - Does not (typically) address application “features”
  - Nuclear Medicine workstation requirements set a new precedent for defining payload and features

Potential next steps

- Establish IHE Mammography
- Involve key stakeholders
  - Vendors
    - Acquisition, CAD, Workstation, PACS
  - Users
- Define use cases
- Specify profiles
  - Leverage other IHE profiles from other domains
- Deploy
  - Connectathon
  - Product