Summit on Color in Medical Imaging 2013

DICOM & IHE Standards for Medical Color Imaging

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Affiliations & Disclosures

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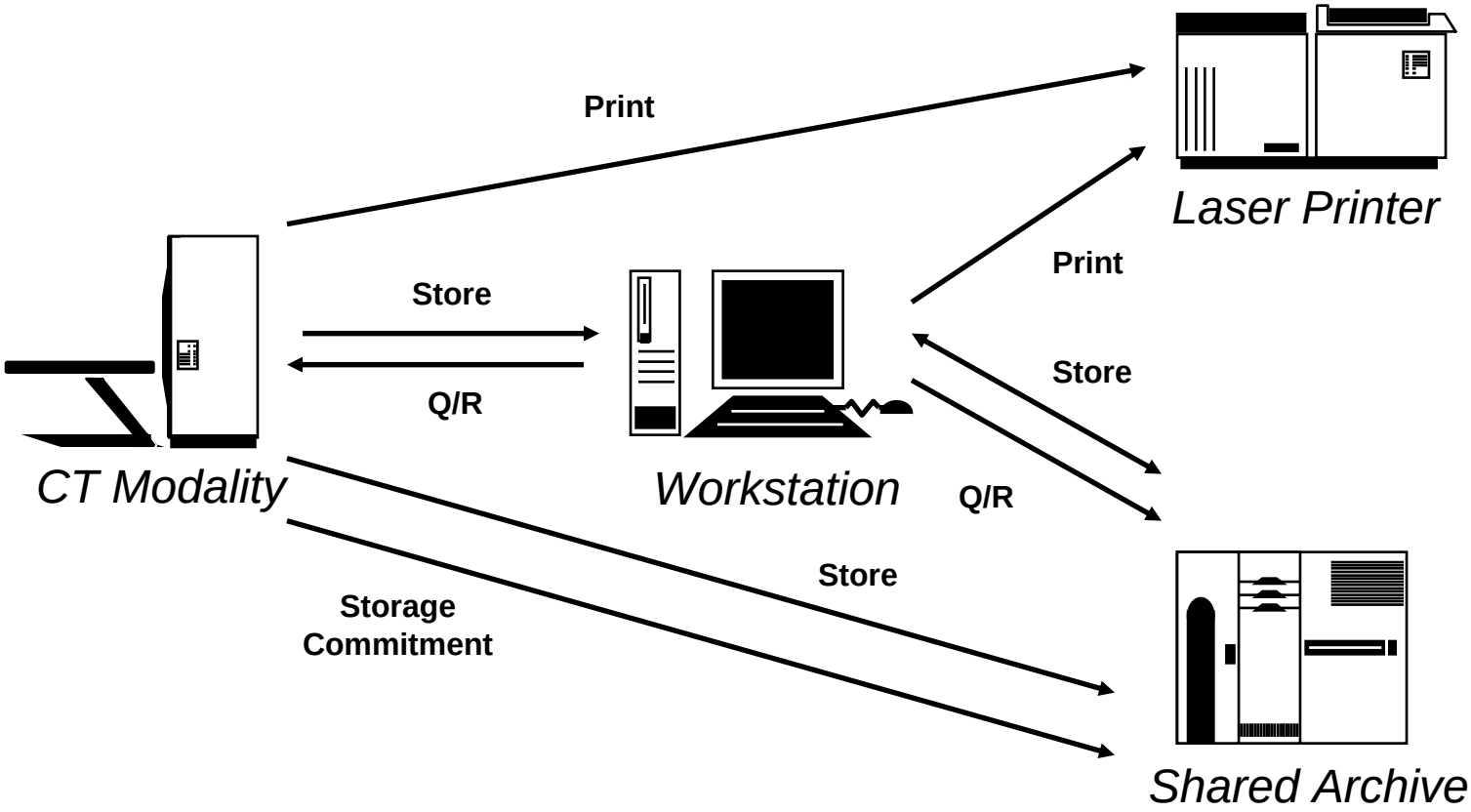
Overview

- What are DICOM and IHE
- History of presentation-related issues
- Grayscale Standard Display Function (GSDF)
- ICC Profiles – images and presentation states
- Color pipeline
- Other color matters
- Issues and gaps
- Sup 124 Communication of Display Parameters

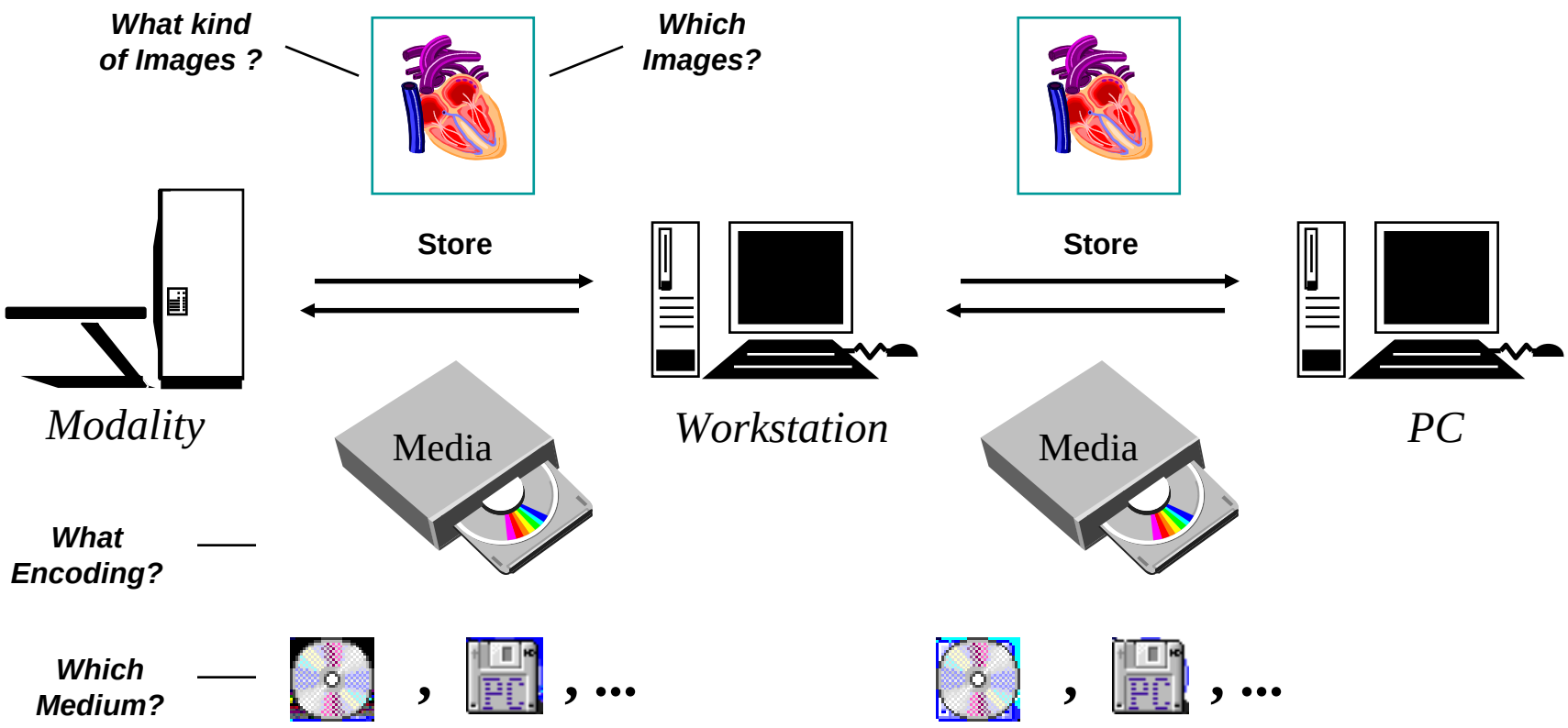
What is DICOM?

- A file format
  - tagged, like TIFF, but with patient, study & technique stuff, managed object identifers
- A network protocol
  - like ftp or http, but object oriented
- Services
  - not just transfer (C-STORE)
  - query (C-FIND), retrieve (C-MOVE, C-GET
  - workflow

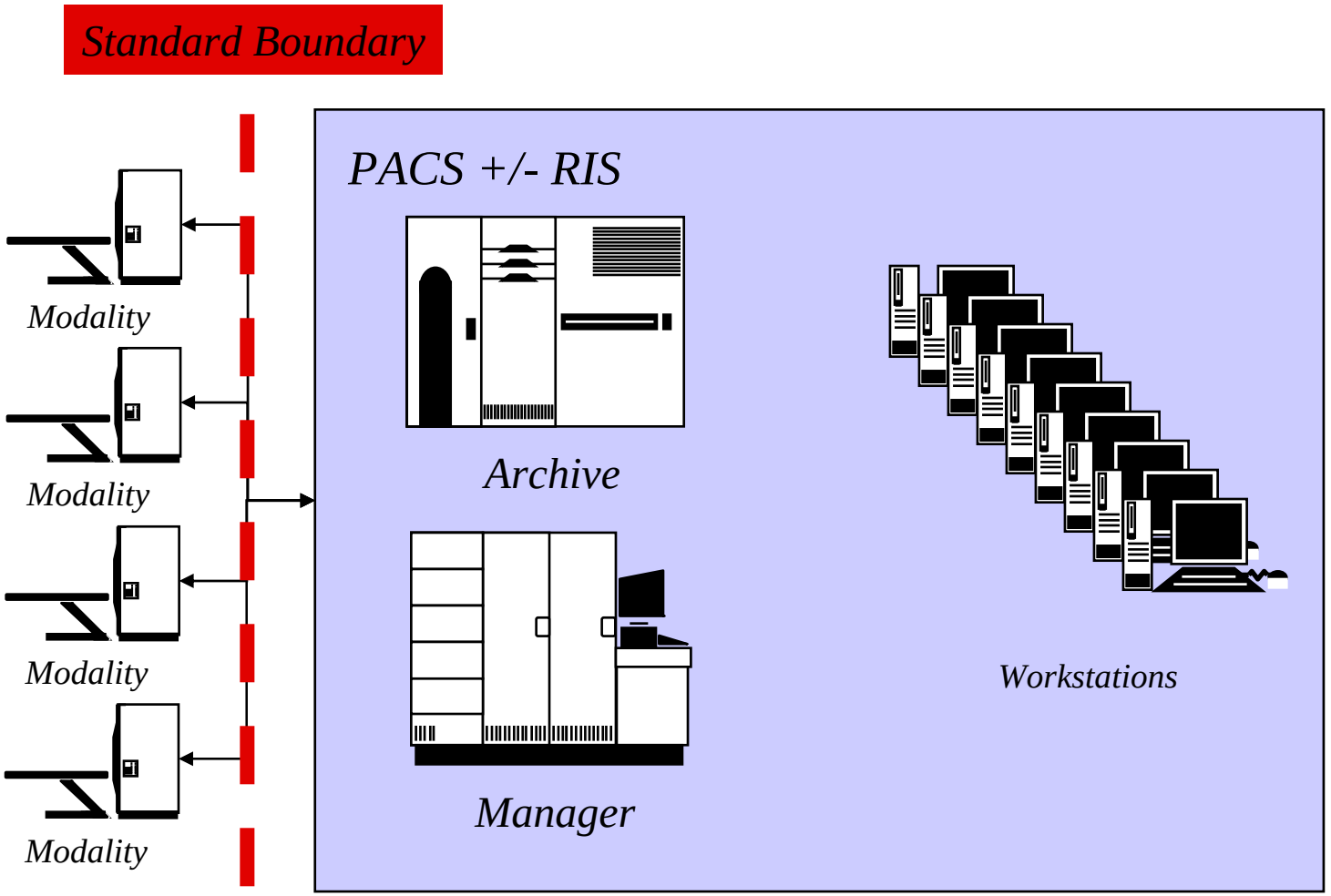
Example of DICOM Services



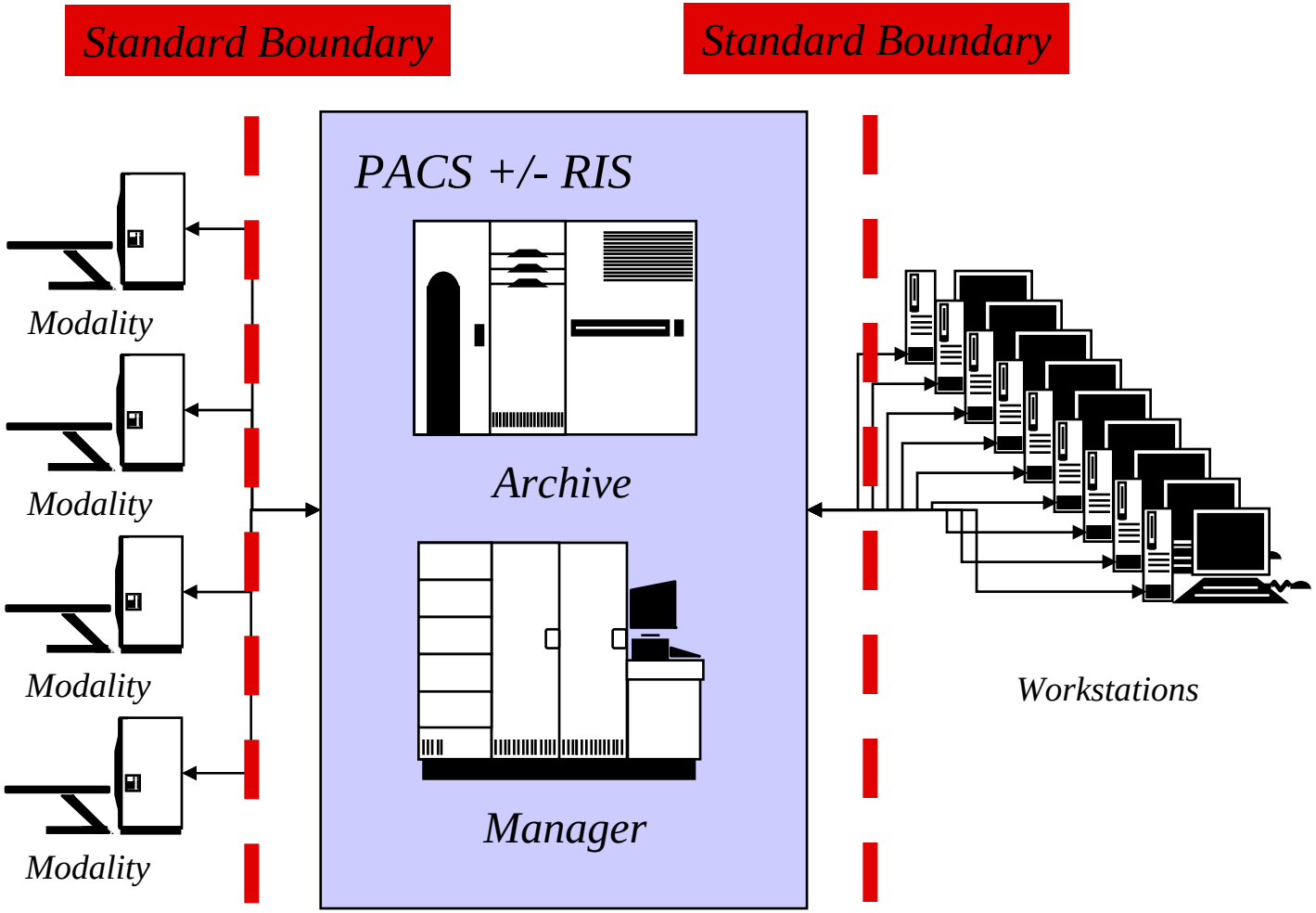
Local Interchange Media



DICOM and the PACS



DICOM and the PACS

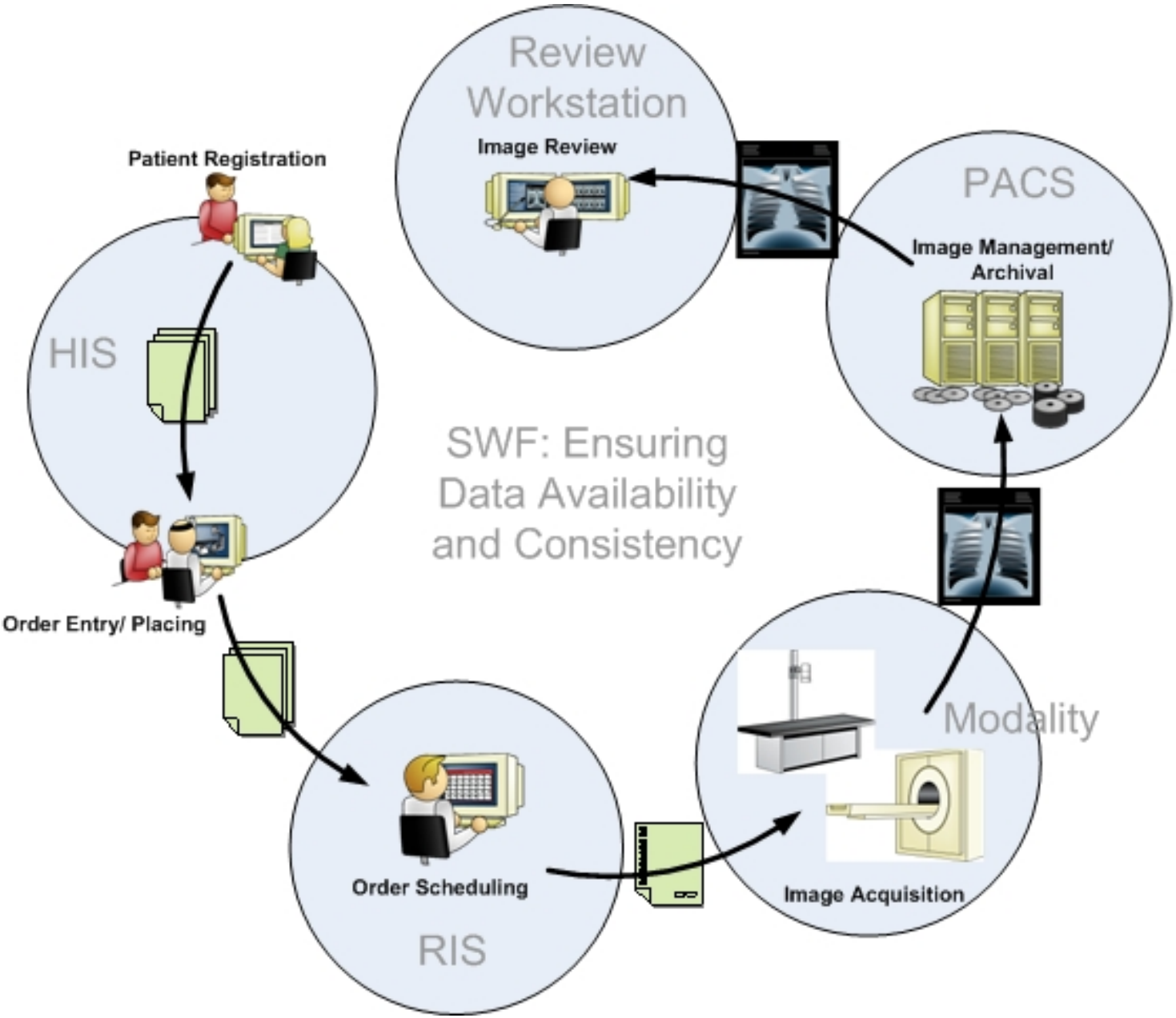


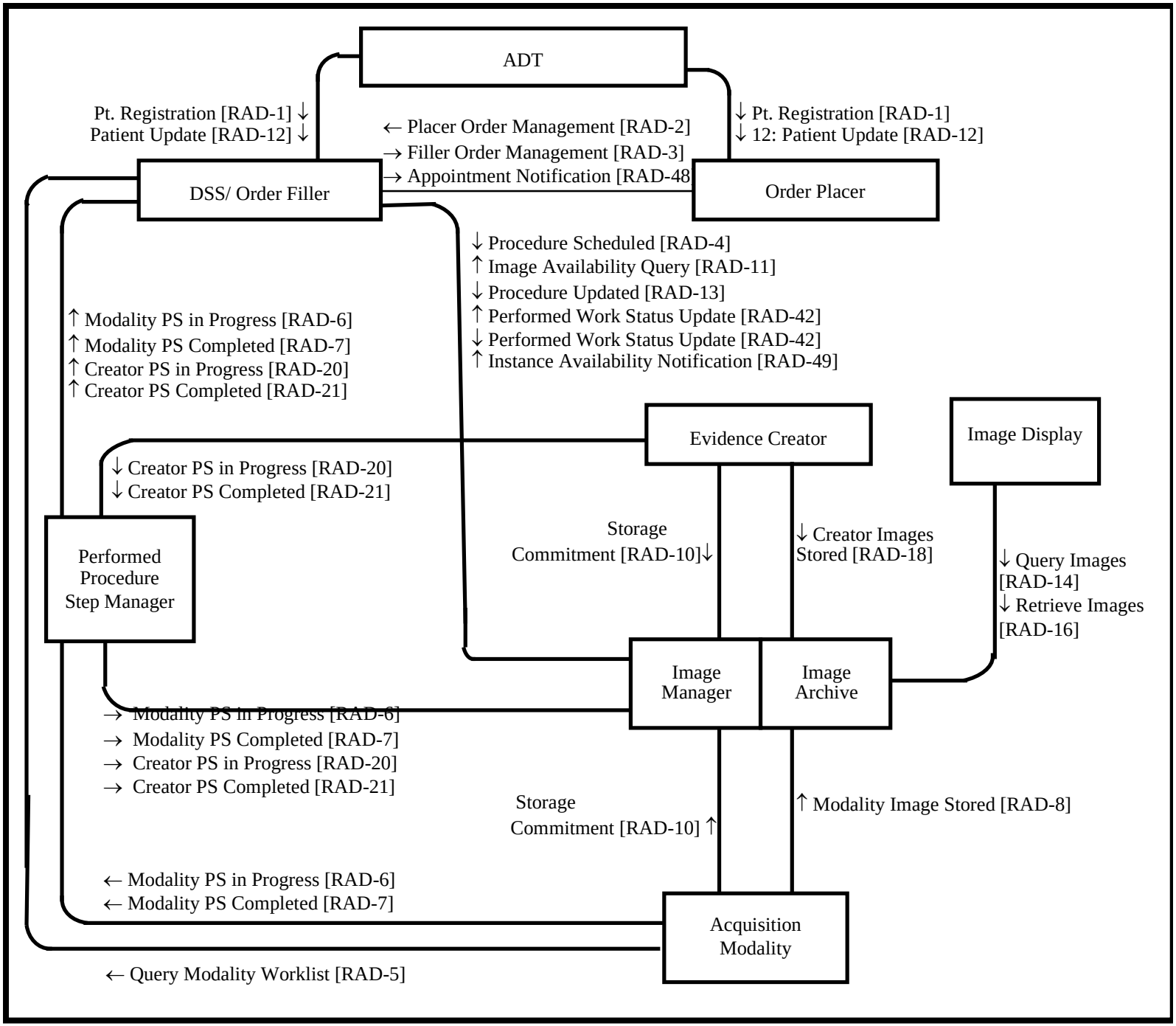
What is DICOM?

- Behavior
  - rendering pipeline
  - display calibration
  - annotation (region of interest, measurement)
- Modality-specific
  - CT, MR, DX, …
  - ophthalmic photography, endoscopy, WSI
- Generic
  - secondary capture, photography

IHE - Integrating the Healthcare Enterprise

- Standards integrated into profiles
  - sequencing and behavior
  - actors and transactions
  - workflow oriented
- Additional behavior
  - Scheduled Workflow (SWF)
  - Consistent Presentation of Images (CPI)
- Testing
  - Connectathons – NA, Europe, Japan, …


Review
Workstation
Image Review
PACS
Image Management/
Archival
Patient Registration
HIS
SWF: Ensuring
Data Availability
and Consistency
Order Entry/ Placing
Modality
Order Scheduling
RIS
Image Acquisition


ADT
Pt. Registration [RAD-1] ↓
Patient Update [RAD-12] ↓
← Placer Order Management [RAD-2]
→ Filler Order Management [RAD-3]
→ Appointment Notification [RAD-48]
↓ Pt. Registration [RAD-1]
↓ 12: Patient Update [RAD-12]
DSS/ Order Filler
Order Placer
↓ Procedure Scheduled [RAD-4]
↑ Image Availability Query [RAD-11]
↓ Procedure Updated [RAD-13]
↑ Performed Work Status Update [RAD-42]
↓ Performed Work Status Update [RAD-42]
↑ Instance Availability Notification [RAD-49]
↑ Modality PS in Progress [RAD-6]
↑ Modality PS Completed [RAD-7]
↑ Creator PS in Progress [RAD-20]
↑ Creator PS Completed [RAD-21]
Evidence Creator
Image Display
↓ Creator PS in Progress [RAD-20]
↓ Creator PS Completed [RAD-21]
Performed Procedure Step Manager
Storage Commitment [RAD-10]↓
↓ Creator Images Stored [RAD-18]
↓ Query Images [RAD-14]
↓ Retrieve Images [RAD-16]
Image Manager
Image Archive
→ Modality PS in Progress [RAD-6]
→ Modality PS Completed [RAD-7]
→ Creator PS in Progress [RAD-20]
→ Creator PS Completed [RAD-21]
Storage Commitment [RAD-10] ↑
↑ Modality Image Stored [RAD-8]
← Modality PS in Progress [RAD-6]
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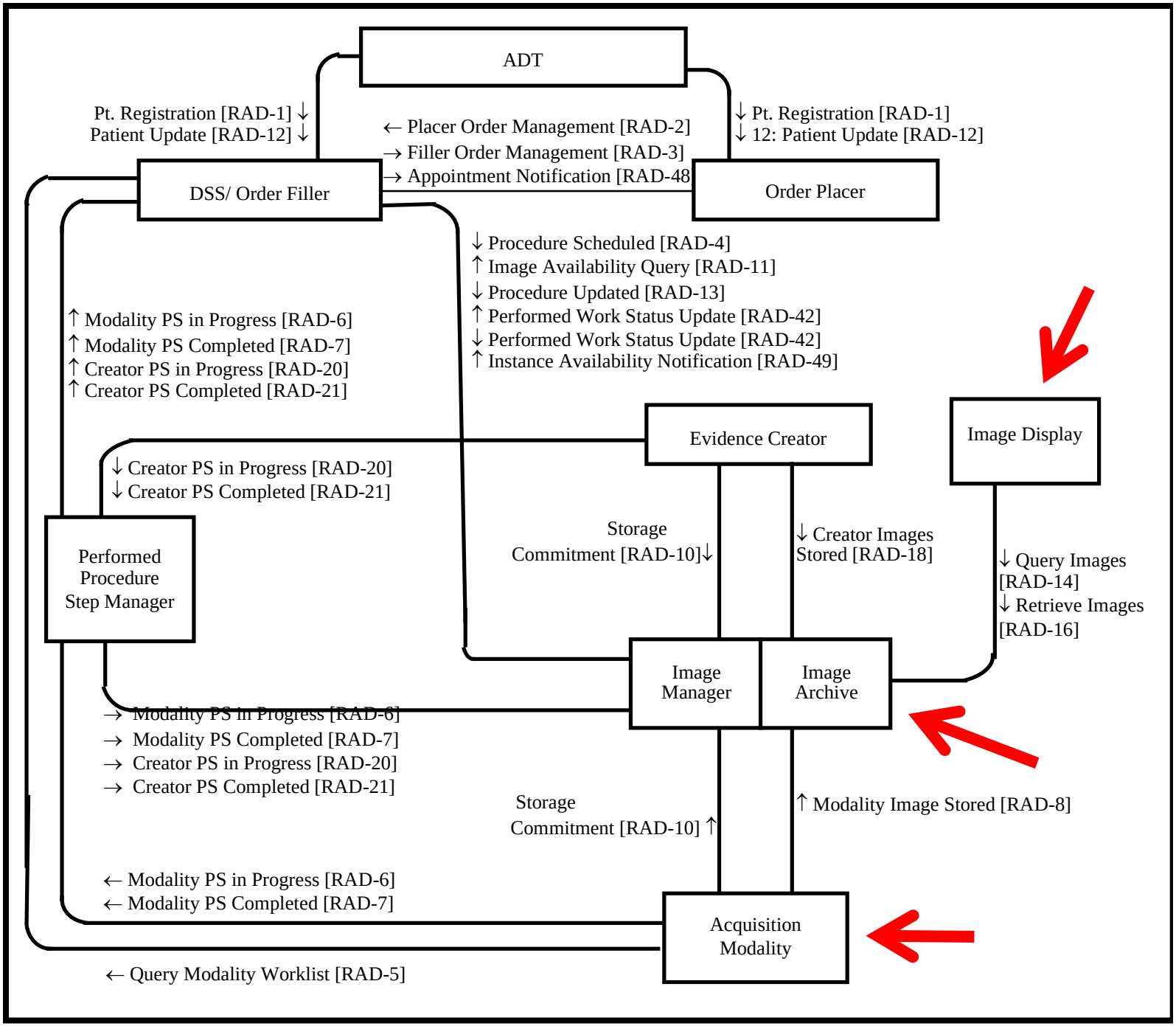
Acquisition Modality
← Query Modality Worklist [RAD-5]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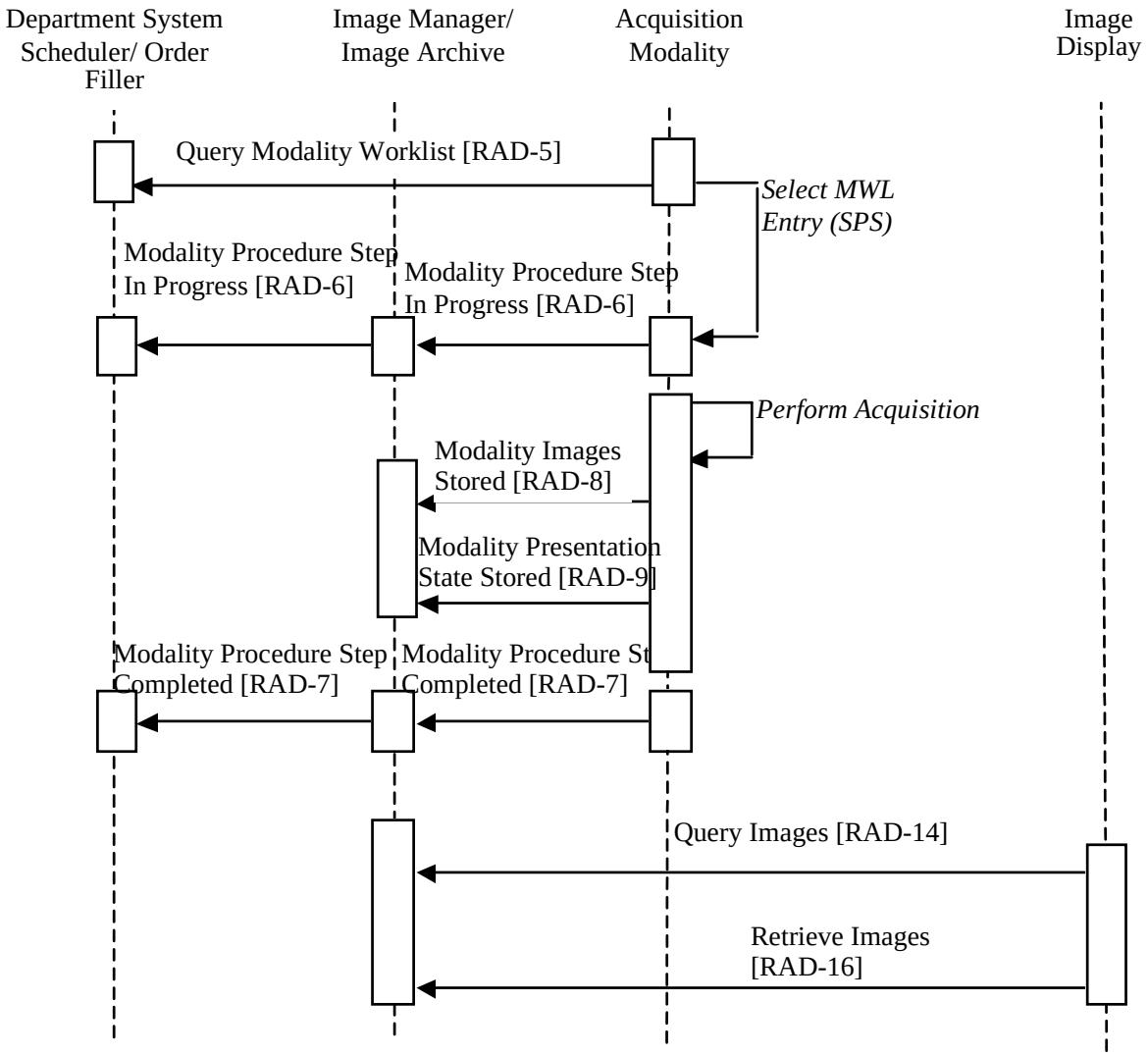
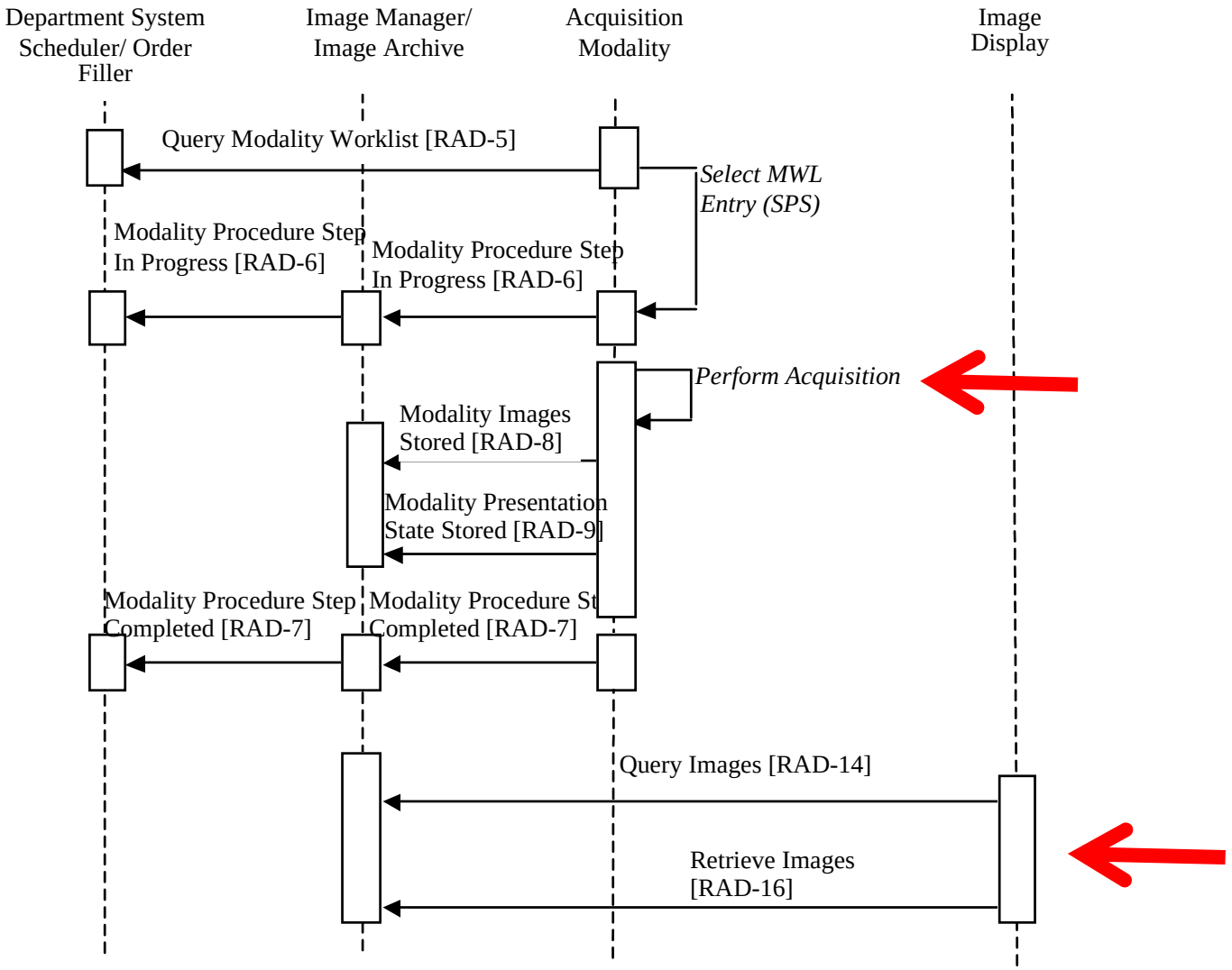

Department System Scheduler/ Order Filler
Image Manager/ Image Archive
Acquisition Modality
Image Display
Query Modality Worklist [RAD-5]
Select MWL Entry (SPS)
Modality Procedure Step In Progress [RAD-6]
Modality Procedure Step In Progress [RAD-6]
Perform Acquisition
Modality Images Stored [RAD-8]
Modality Presentation State Stored [RAD-9]
Modality Procedure Step Completed [RAD-7]
Modality Procedure St
Completed [RAD-7]
Query Images [RAD-14]
Retrieve Images [RAD-16]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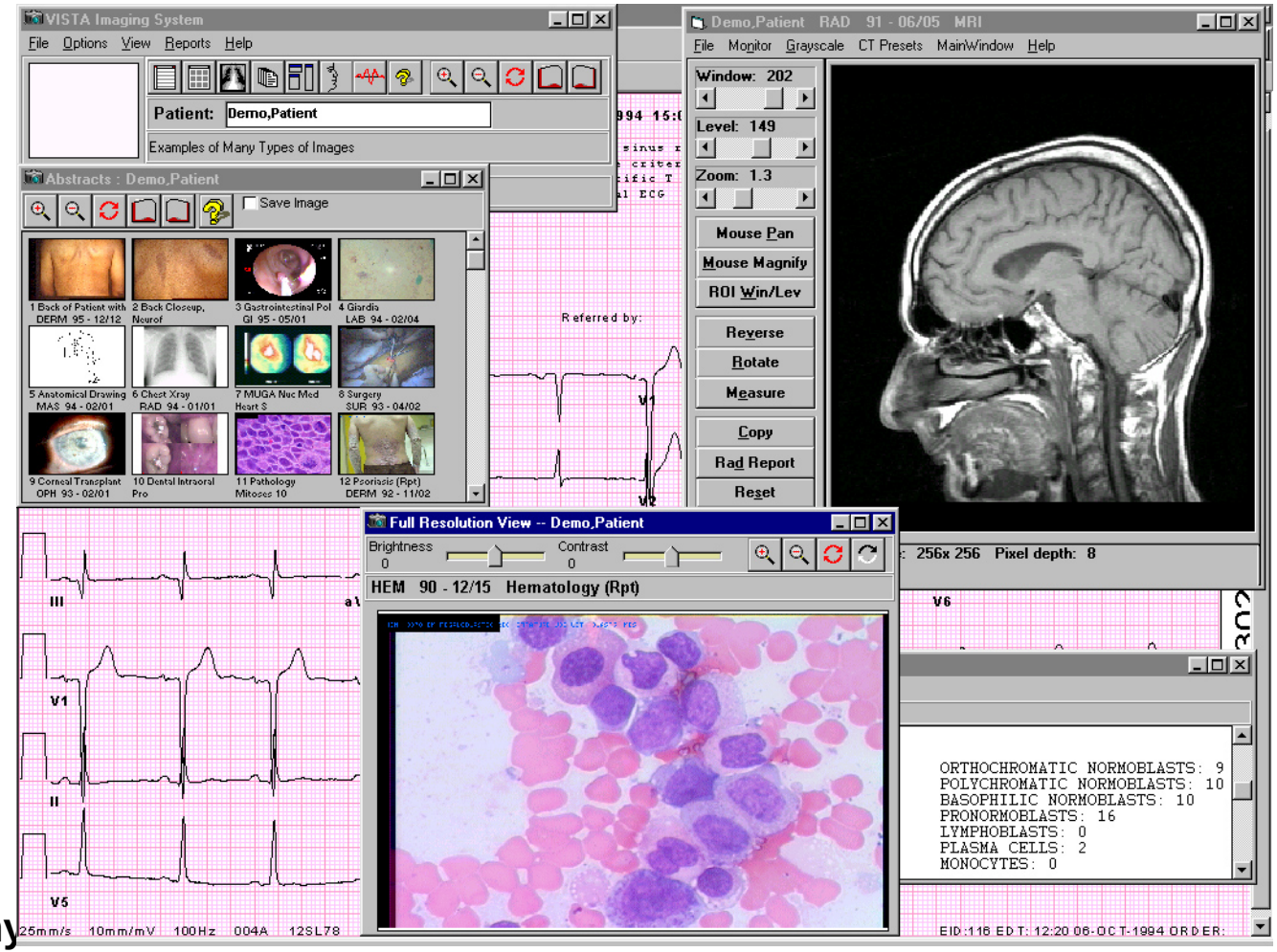
IHE - Connectathons

DICOM & IHE – Not Just Radiology

- Long history of DICOM support
  - Cardiology
  - DICOM “Visible Light” initiative
  - US Veteran’s Affairs (VA) – VISTA Imaging
    - Clinical Capture system
    - “real” DICOM modality workflow (MWL/SWF)
    - standards-based procurement requirements
- IHE
  - started with Radiology “domain”
  - now many others, e.g., Eye Care, Anatomic Pathology, Endoscopy

Wide Variety of Images Integrated with the Online Patient Record

- Cardiology
- Bronchoscopy
- Gastrointestinal Endoscopy
- Hematology
- Pathology
- Surgery
- Nuclear Medicine
- Dental
- Radiology
- Dermatology
- Ophthalmology
- Podiatry
- Vascular
- Urology
- Nursing
- Electrocardiography
- Scanned Documents



Slide of VA VISTA from Dayhoff R, Kuzmak P

DICOM Color Image Objects

- Secondary Capture
  - Original single frame (generic)
  - Multi-frame true color
- Modality-specific pseudo-color
  - US, (NM, PET), MR, OCT
- Modality-specific true color
  - VL & video endoscopy, photography, microscopy
  - Whole slide microscopy (WSI)
  - Ophthalmic photography
- Encapsulated PDF

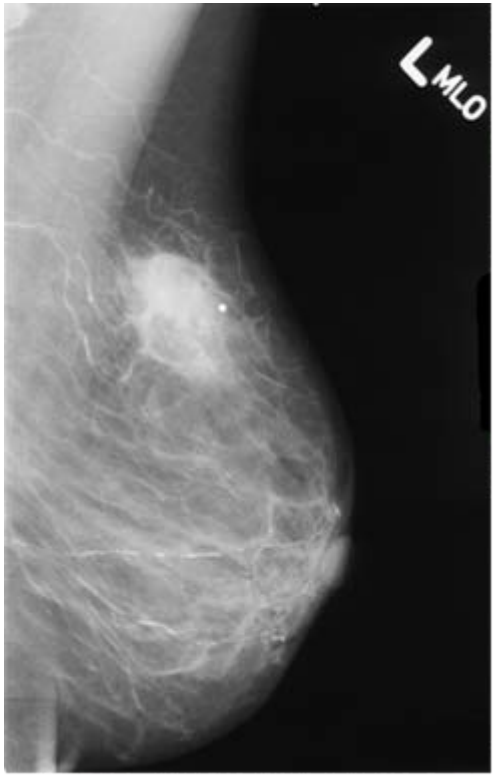
DICOM, IHE & Image Display

- Original standards (1985,1993) silent
- Focused on storage & printing
- Display rendering pipeline grew out of print service pipeline
- A few tags for “windowing” and LUTs
  - window center & width (brightness/contrast)
  - grayscale lookup tables
  - color palette lookup tables

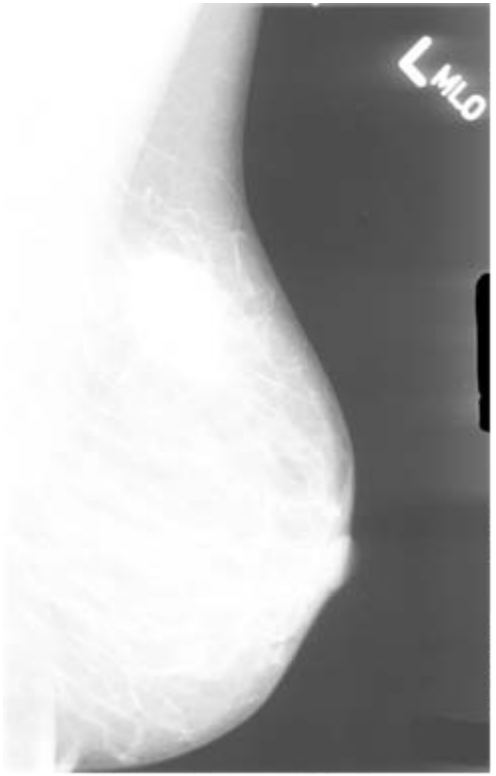
Two Kinds of DICOM Object

- Images
  - tags + Pixel Data like any other format
- Presentation States
  - reference to images to which they apply
  - tags affecting display override those in images
  - point rendering pipeline (grayscale/color)
  - spatial transformation & annotation pipeline
  - e.g., save window/pan/zoom in a few bytes
  - Grayscale Standard Display Function (GSDF)

Problems of Inconsistency



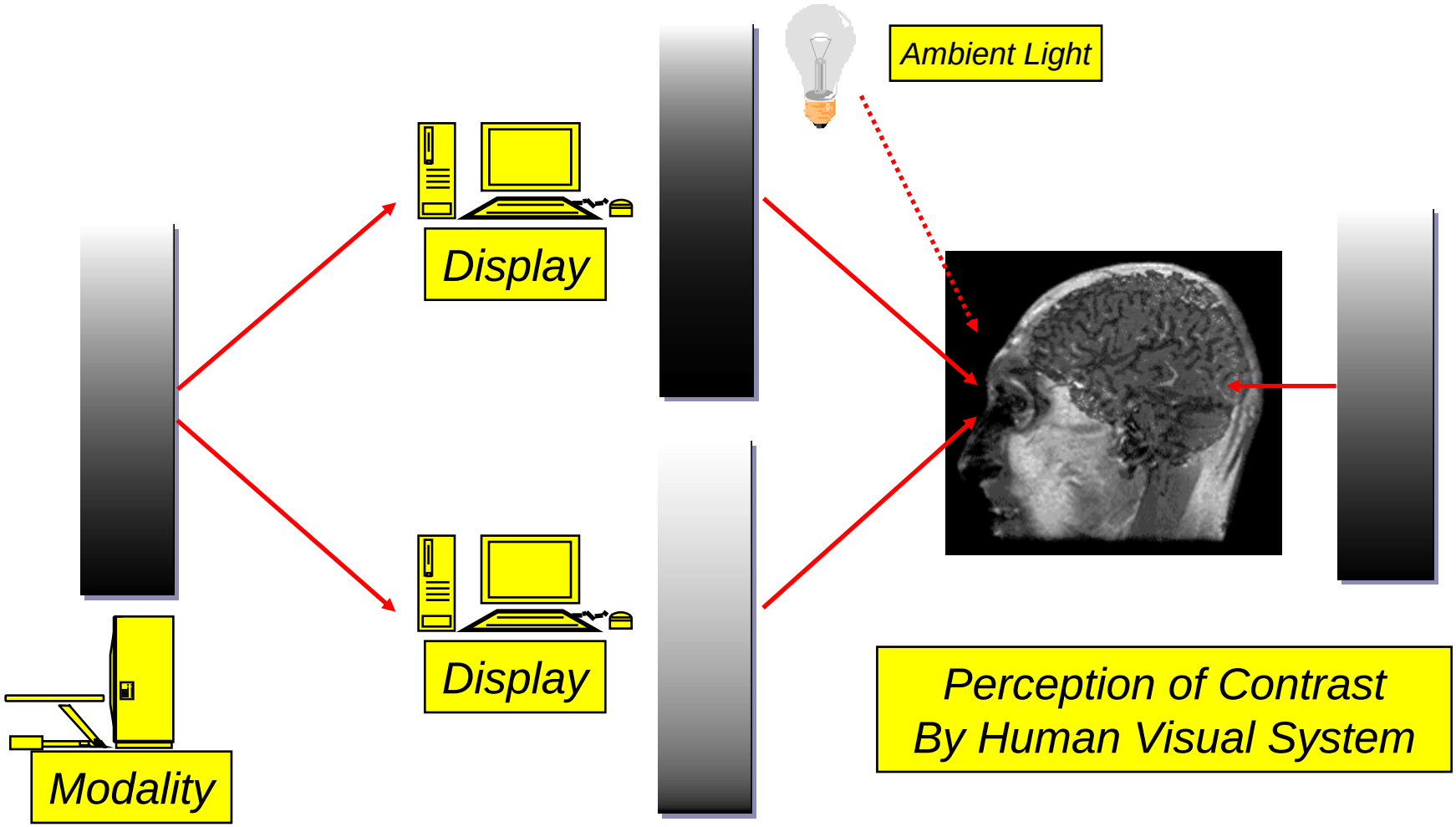
mass visible



mass invisible

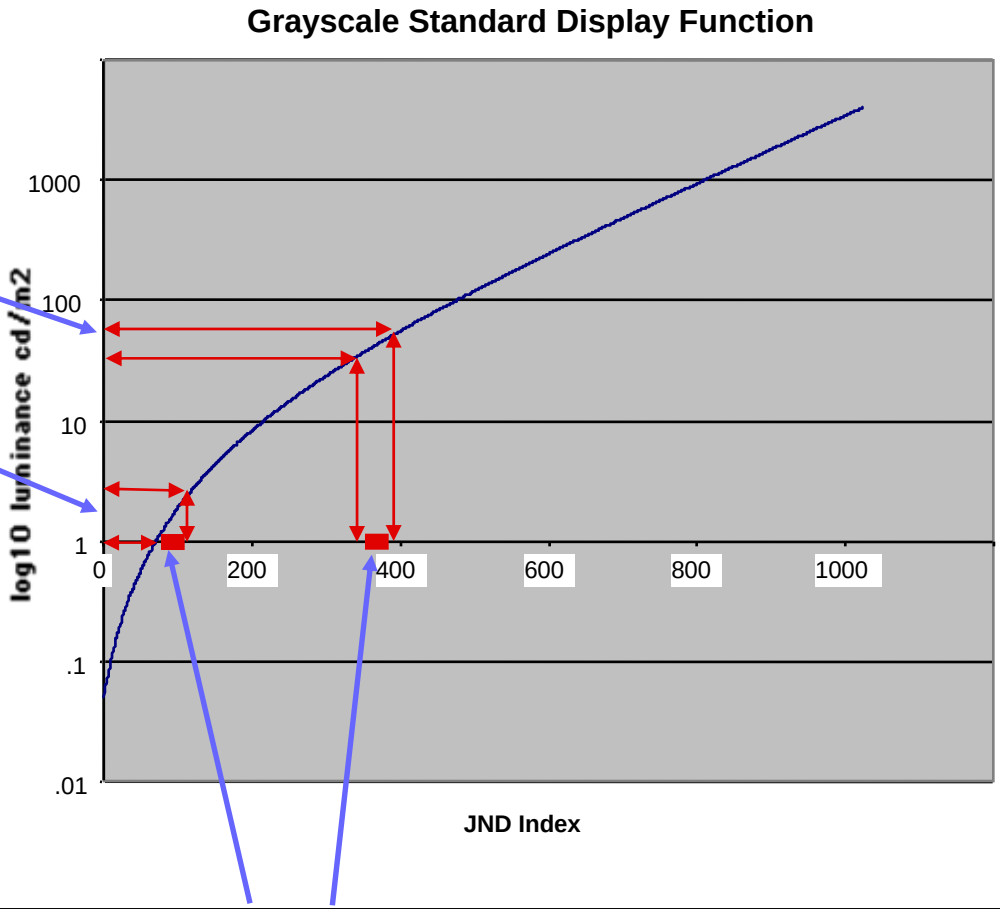
- Windowing chosen on one display device
- Rendered on another with different display
- Mass expected to be seen is no longer seen

Perceptual Linearization



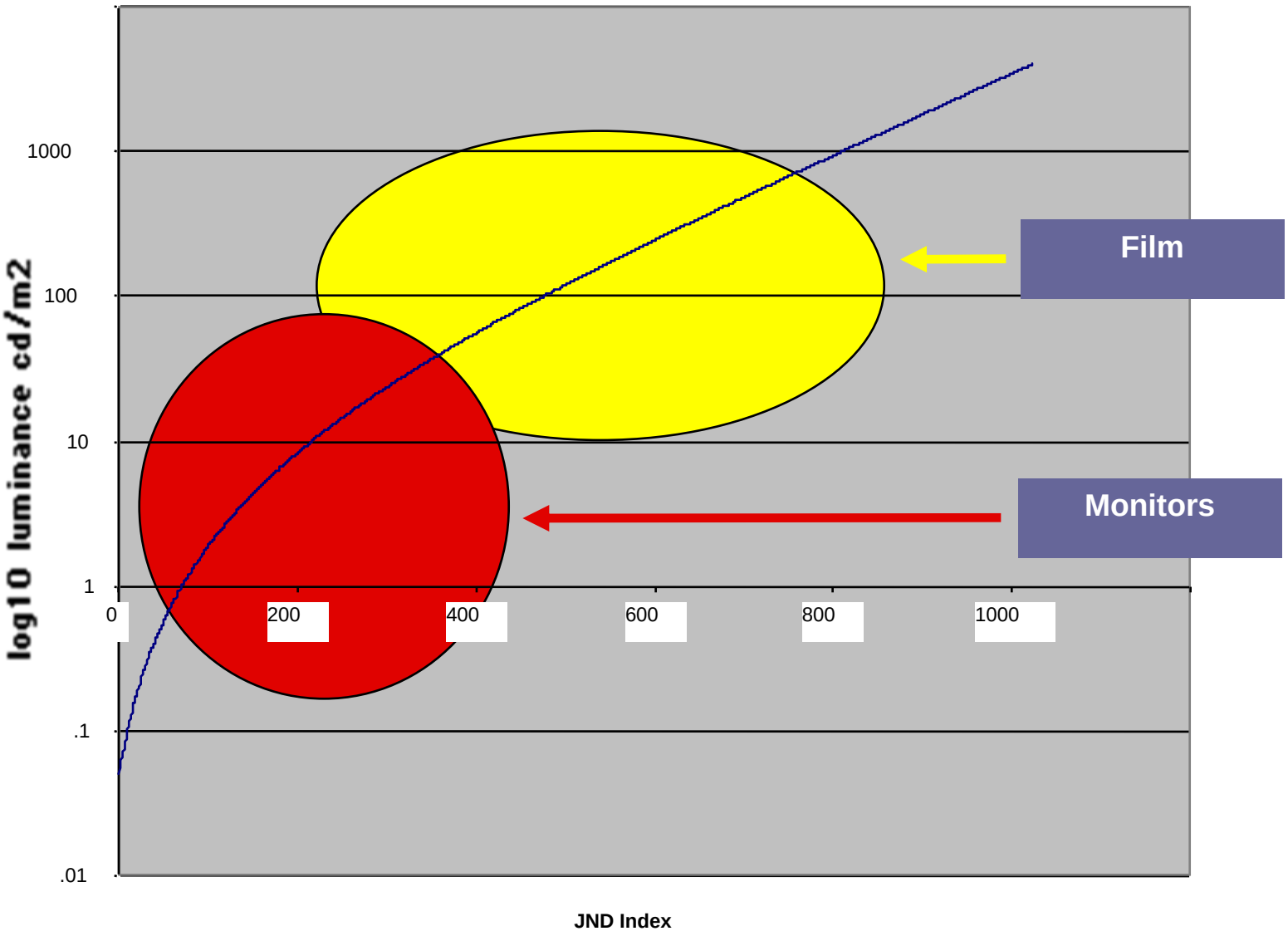
Perceptual Linearization

Despite different change in absolute luminance



Same number of Just Noticeable Difference == Same perceived contrast

Grayscale Standard Display Function



GSDF - Adoption

- Near universal in radiology
- Broad acceptance of the need for calibration
- Dedicated medical displays provide for calibration (manual or automated)
- Ambient light compensation
- Calibration tools for non-medical displays
- Practice standards (ACR) recommend it
- AAPM TG 18 describes methods & tools
- DICOM defines curve, not compliance limits

What about color?

- DICOM's initial priority was radiology
- Radiology color apps all pseudo-color
- But questions arose as to how to
  - annotate color images
  - save pan/zoom/flip/rotation of color images
  - achieve consistent contrast & color
  - handle true color in same system (PACS)
  - display color & grayscale together
- Not color experts – consulted ICC

Already had for color ...

- Image encoding mechanism
  - Photometric Interpretation
  - Adequate bit depth
  - Multiple samples per pixel
- Uncompressed pixel data
- Compressed pixel data support
  - other industry standards, JPEG, J2K, MPEG
- Color independent transformations

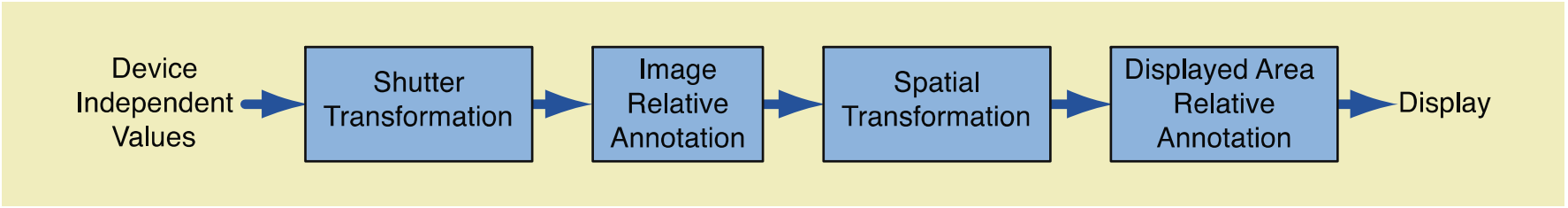
Photometric Interpretation

- Similar to TIFF
- MONOCHROME1,2 … grayscale
- RGB … true or pseudo-color
- PALETTE COLOR … indexed
- YBR_FULL_422, etc., … compressed
- CMYK … not used
- RGBA (alpha) … not used
- Linked to Samples Per Pixel (1,3)

Bits Stored, Bits Allocated

- Uncompressed
  - used versus padded (whole bytes)
  - most grayscale > 8 bit, e.g., 12 in 16
  - color usually 3 samples of 8 bits
  - color can be 16
  - single or multiple frame (e.g., for video)
- Compressed (encapsulated)
  - opaque bit stream of 8 bit bytes
  - e.g., JPEG SOI to EOI segments

Common part of grayscale and color pipeline

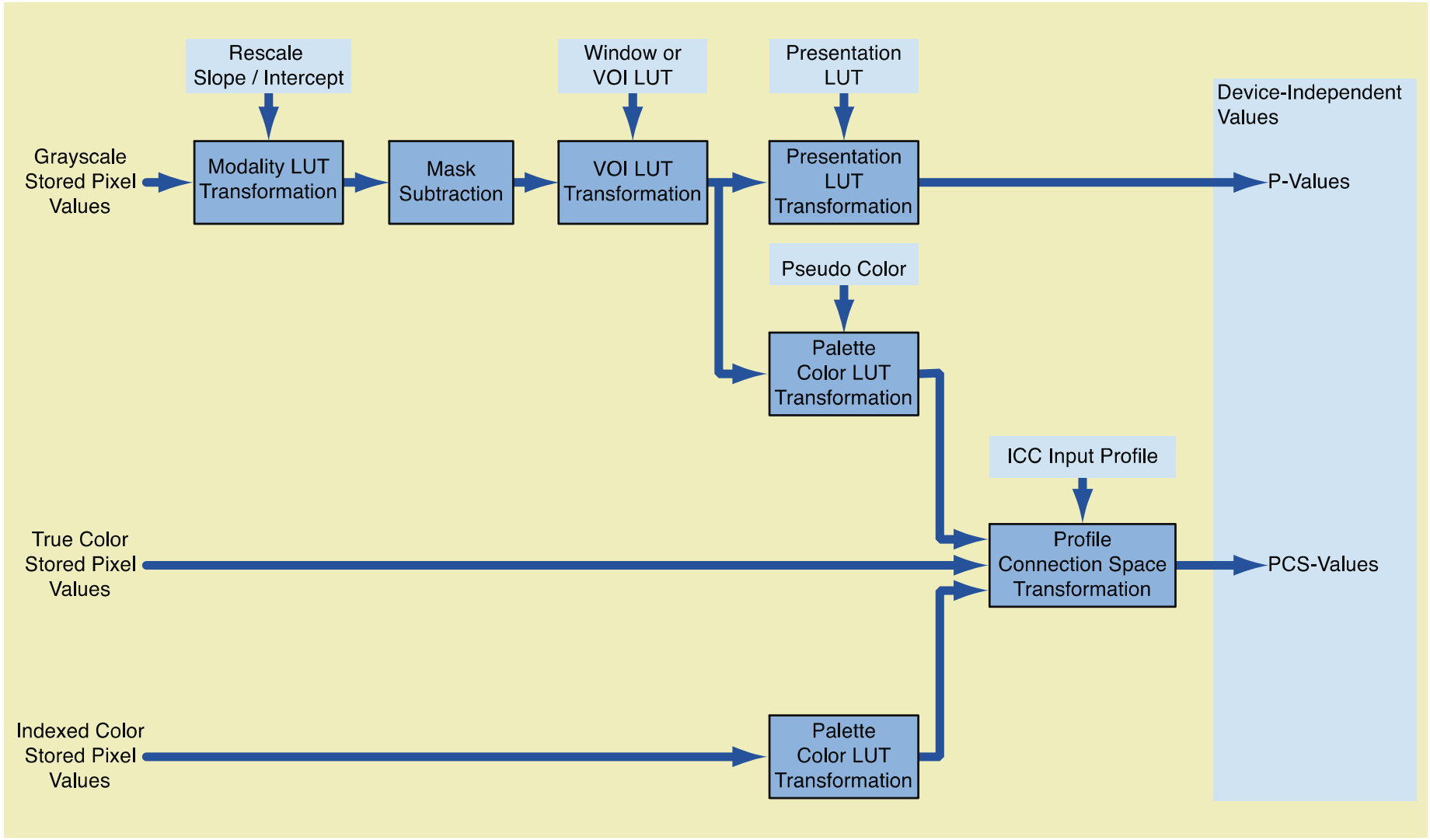


What was missing for color consistency?

- Could encode images
- Could specify spatial transformations
- Could specify graphics & text
- Missing device independent values
  - for color image pixels
  - for colors of annotations
- Committee lacked expertise in color

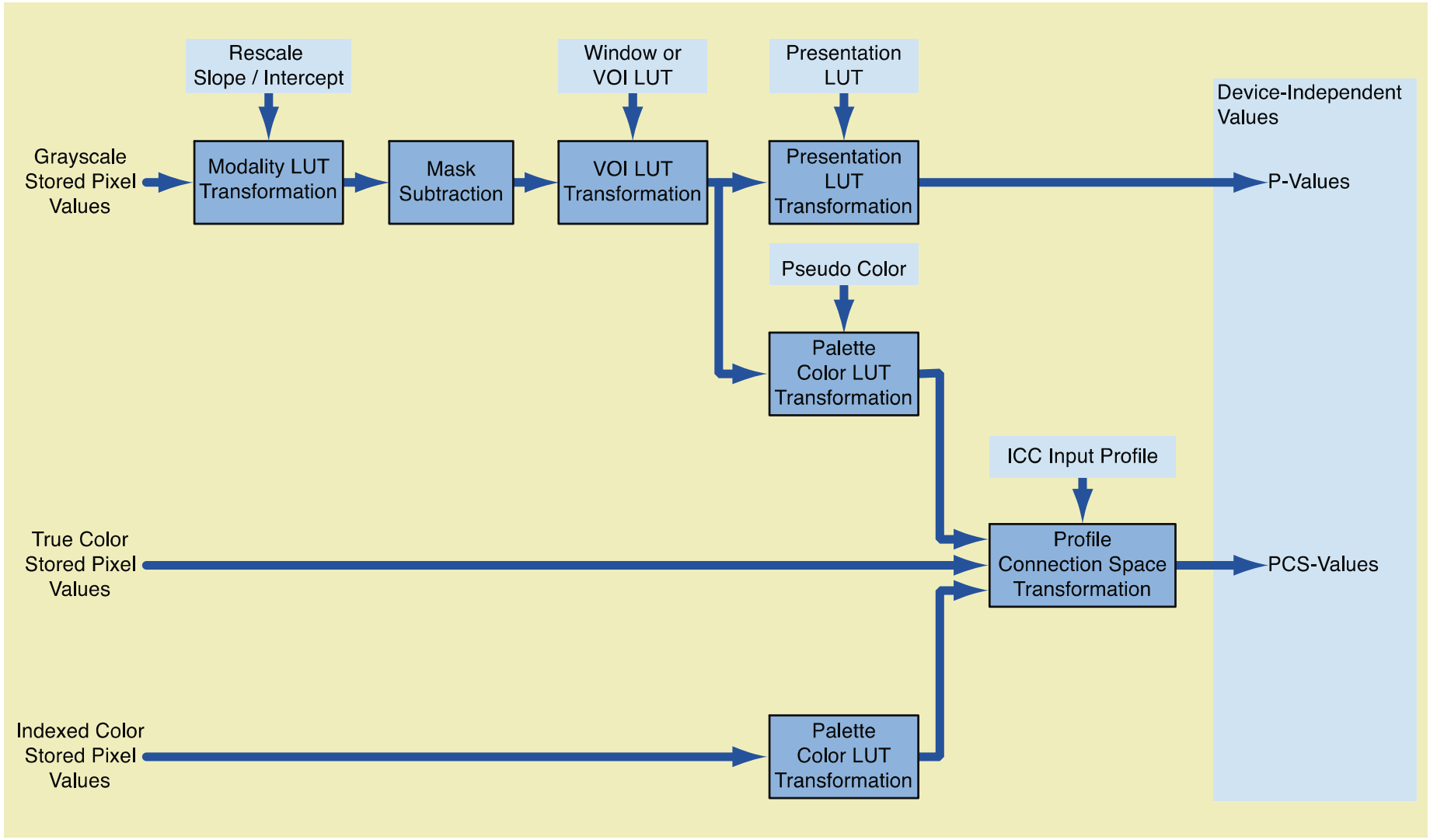
Solution – ICC Profile & CIE

- Color device-independent values
  - to be in ICC Profile Connection Space (PCS)
- Added ICC profile
  - optional all existing & new color image objects
- True & pseudo-color presentation states
  - all with mandatory ICC profile
- Defined non-pixel data color values
  - as CIELab PCS values (e.g., text color, etc.)


Rescale
Slope / Intercept
Window or
VOI LUT
Presentation
LUT
Device-Independent
Values
Grayscale
Stored Pixel
Values
Modality LUT
Transformation
Mask
Subtraction
VOI LUT
Transformation
Presentation
LUT
Transformation
P-Values
Pseudo Color
Palette
Color LUT
Transformation
ICC Input Profile
True Color
Stored Pixel
Values
Profile
Connection Space
Transformation
PCS-Values
Indexed Color
Stored Pixel
Values
Palette
Color LUT
Transformation

What is still missing in the DICOM color pipeline?

- No equivalent of grayscale “windowing”
  - no brightness/contrast adjustment
- No color “corrections”
  - other than burned in to pixels (or ICC profile)
- No “user preference” adjustments
  - other than burned in to pixels (or ICC profile)
- No generalized (non-linear) transformations of multiple channels
  - other than in ICC profile
  - except for new Ultrasound Volume object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ICC Profiles in DICOM objects

- A single ICCProfile tag
- With an even length binary payload
- Shall (required)
  - be an Input Profile (“scnr”)
  - RGB -> CIELab or CIEXYZ
- Should (recommended)
  - have perceptual rendering intent
  - use 16 bit LUTs
  - have chromaticAdaptation tag if not D50

ICC Profile Version

- Original Supplement 100
  - referenced ICC.1:2003-09 (v4.1.0)
- Updated in CP 676
  - references ISO 15076-1:2005 (v4.2.0.0)
- Not yet updated to current
  - ICC.1:2010 (v4.3.0.0)
- But not restricted to v2 or v4 profiles
- No explicit discussion of v2/v4 issues
  - Perceptual Reference Medium Gamut (PRMG)
  - white point & black point

ICC in DICOM - Reality Check

- Color image storage/display routine in PACS
- But no ICC profile use in products or images
- All real-world color presentation states
  - illegally use grayscale PS for color images
  - illegally leave out mandatory ICC Profile tag
  - just stuff in a default sRGB profile (because presence of something is mandatory)
- Finding a default sRGB profile
  - take old HP v2, or v2 or v4 from ICC web site
  - replace “dply” or “spac” with “scnr”

ICC Profiles buried in DICOM JPEG or PDF objects

- DICOM uses JPEG (etc.) for compression
  - conversion (encapsulation) of standalone JPEG (e.g., from camera) to DICOM
  - could leave ICC Profile in JPEG bit stream, if present, rather than extract it to DICOM level
  - surprising effects (profile may be applied during decompression by some codecs)
- DICOM can also encapsulate PDF
  - PDF can also contain ICC Profiles

Beyond color “consistency”

- What about aspects of acquisition?
- Illumination & light path filtration
- Multi-spectral acquisitions
- Specified for
  - Whole Slide microscopy
  - Ophthalmic Photography
- Re-usable in future for
  - GI endoscopy, …

WS Optical Path Module

- One or more paths
  - referenced for each frame of WS tiled image
- Illumination
  - description, codes, wavelength
  - “full spectrum”, “transmission”, “xenon arc”, …
- Light path filtration
- Image path filtration
- For each path
  - may have palette & ICC profile if monochrome

Ophthalmic Photographic Parameters Module

- Shares many tags & codes for light path with the WSI Optical Path Module
  - e.g., LightPathFilterTypeStackCodeSequence
  - e.g., “Red optical filter”
- Specific codes for device & illumination
  - e.g., “Fundus camera”, “Indirect iris transillumination”
- ChannelDescriptionCodeSequence
  - when RGB PhotometricInterpretation is not really RGB

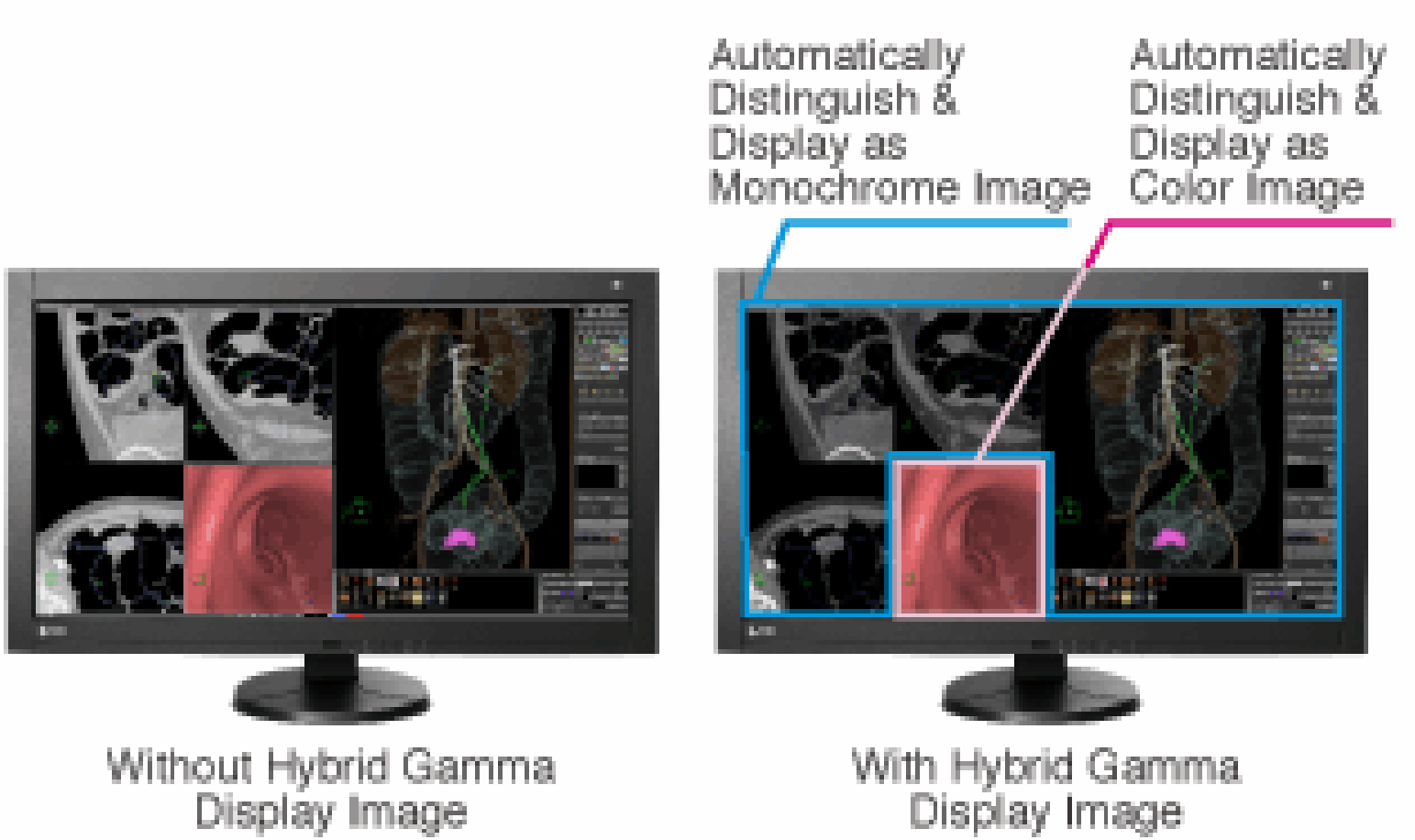
Color Palettes

- Pseudo-color images may contain color palette LUTs
- Pseudo-color presentation state
- Color Palette object
  - has UID and may be referenced & shared
  - standard “well-known” color palettes
- LUTs are RGB
  - use ICC profile for consistency

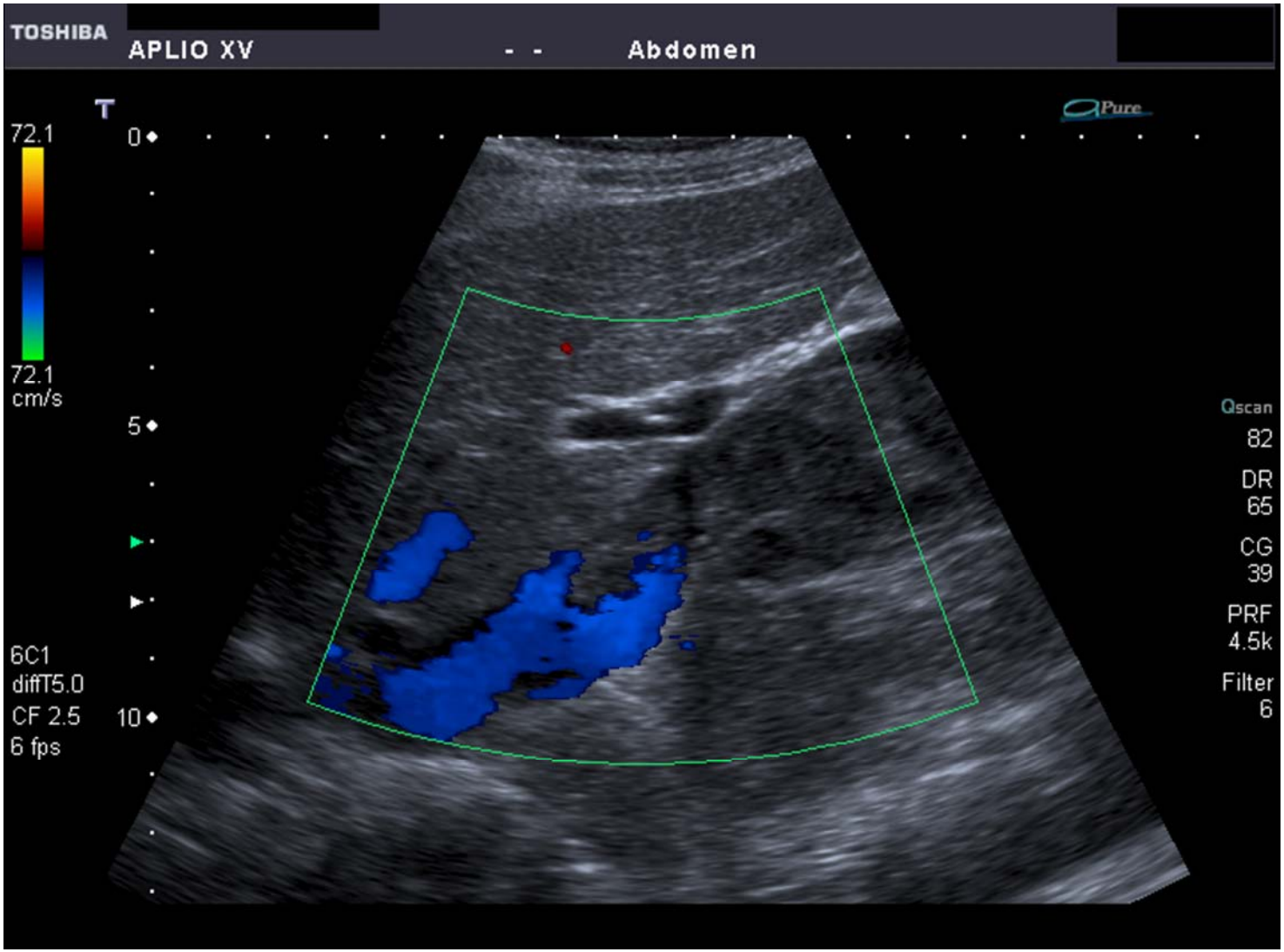
Color and Grayscale Together

- Multi-modality workstations
  - same (large) display
  - mixture of grayscale and color displays
- Grayscale on color monitor
  - which curve to calibrate/convert to
  - multiple screen regions with differing behavior
- Color and grayscale in same image
  - Doppler ultrasound (structure + velocity)
  - CT/PET fusion (structure + function)

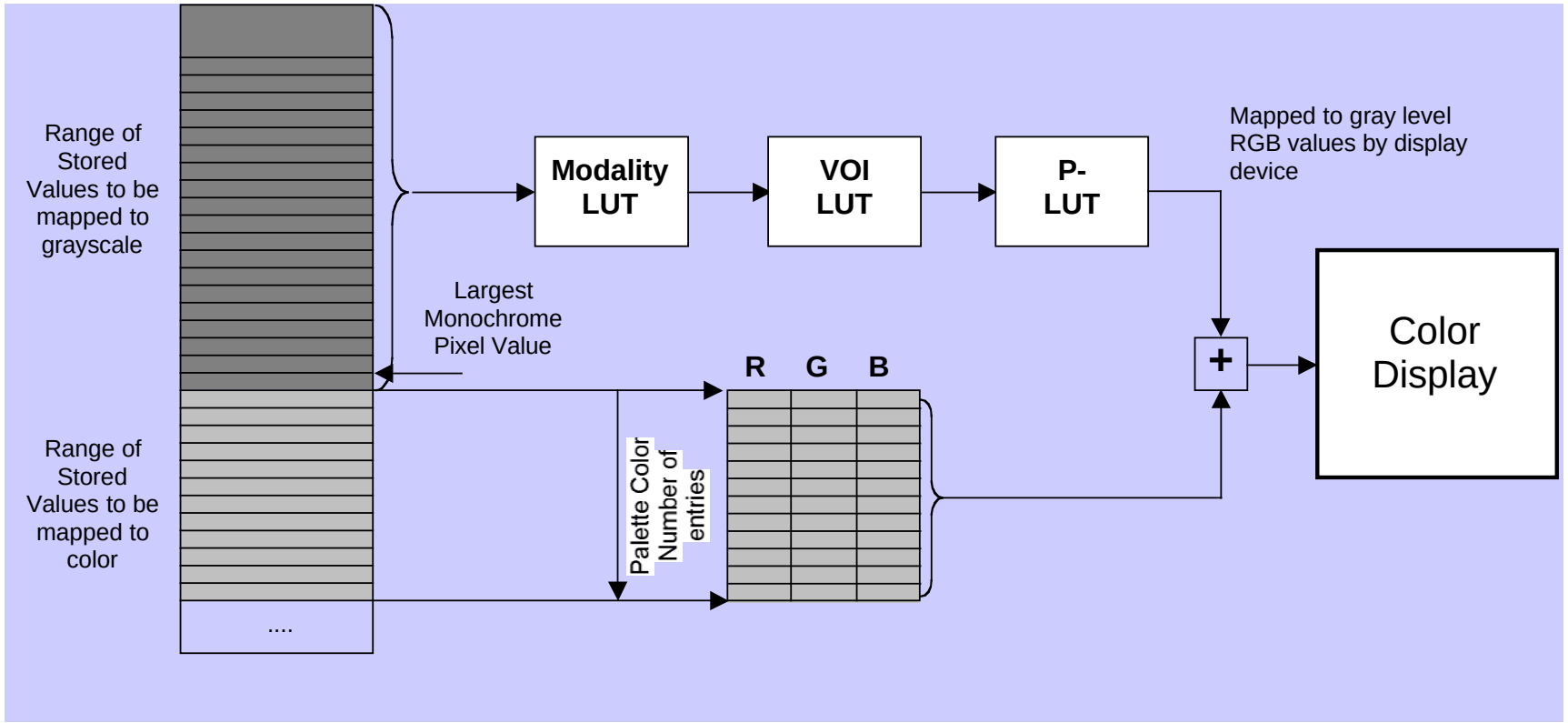
Eizo Hybrid Gamma



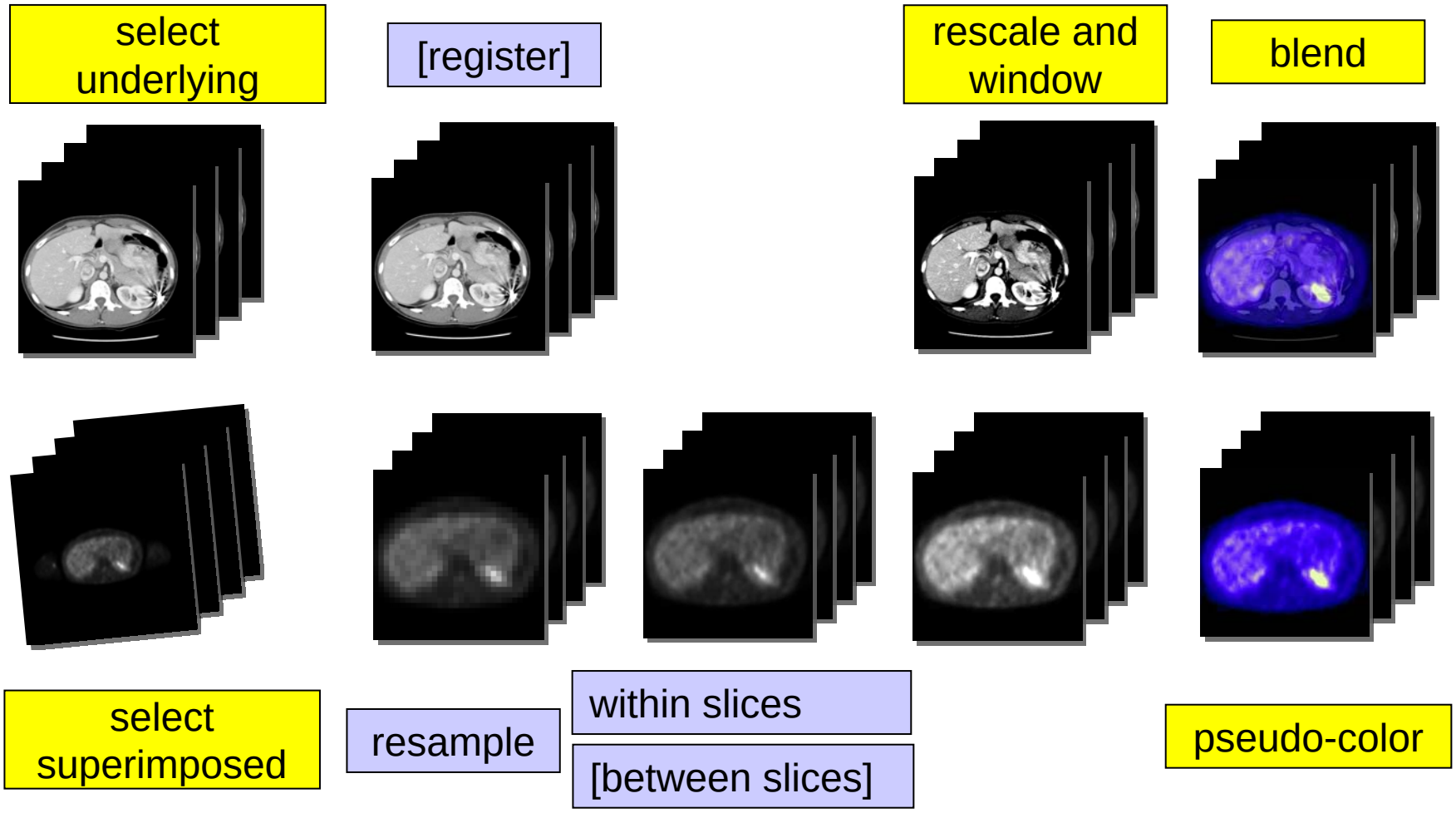
DICOM Color Doppler US



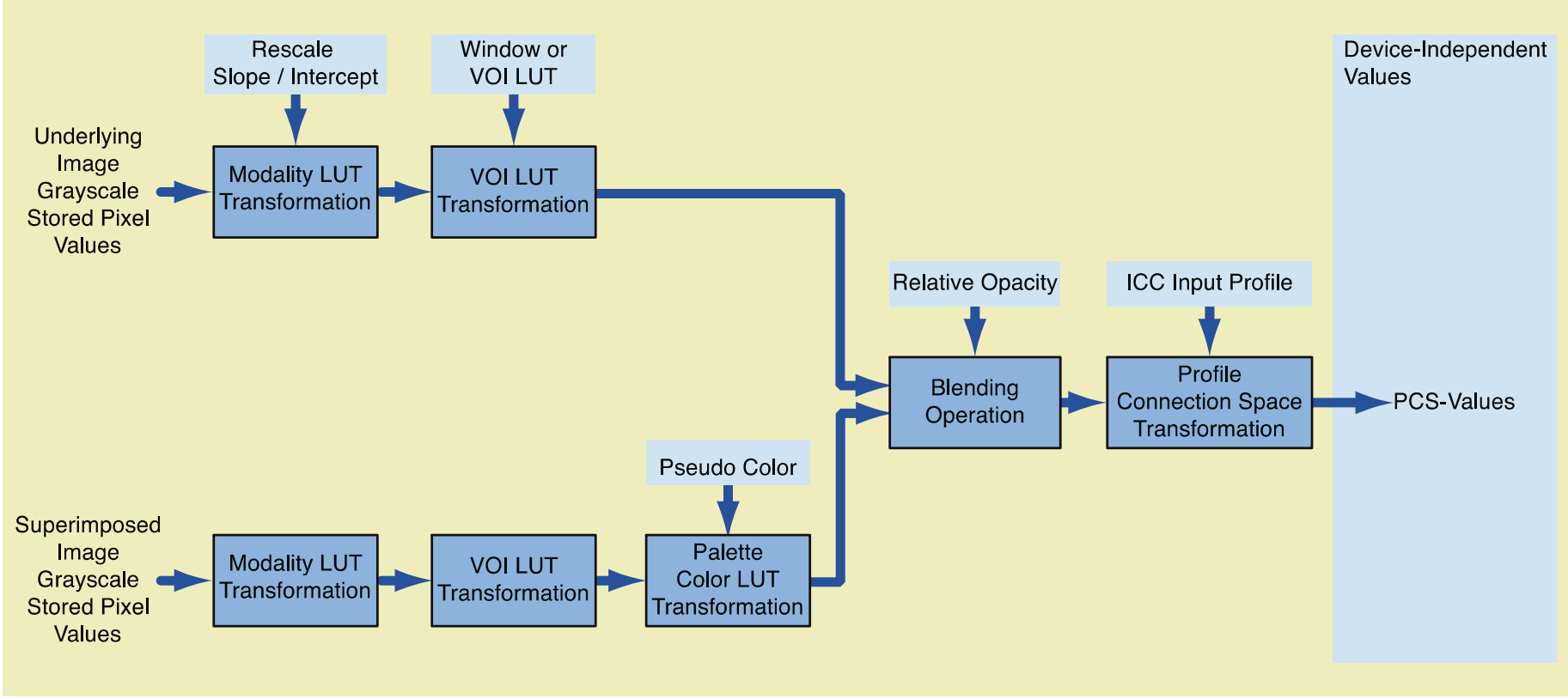
DICOM Supplemental Palette Color LUT



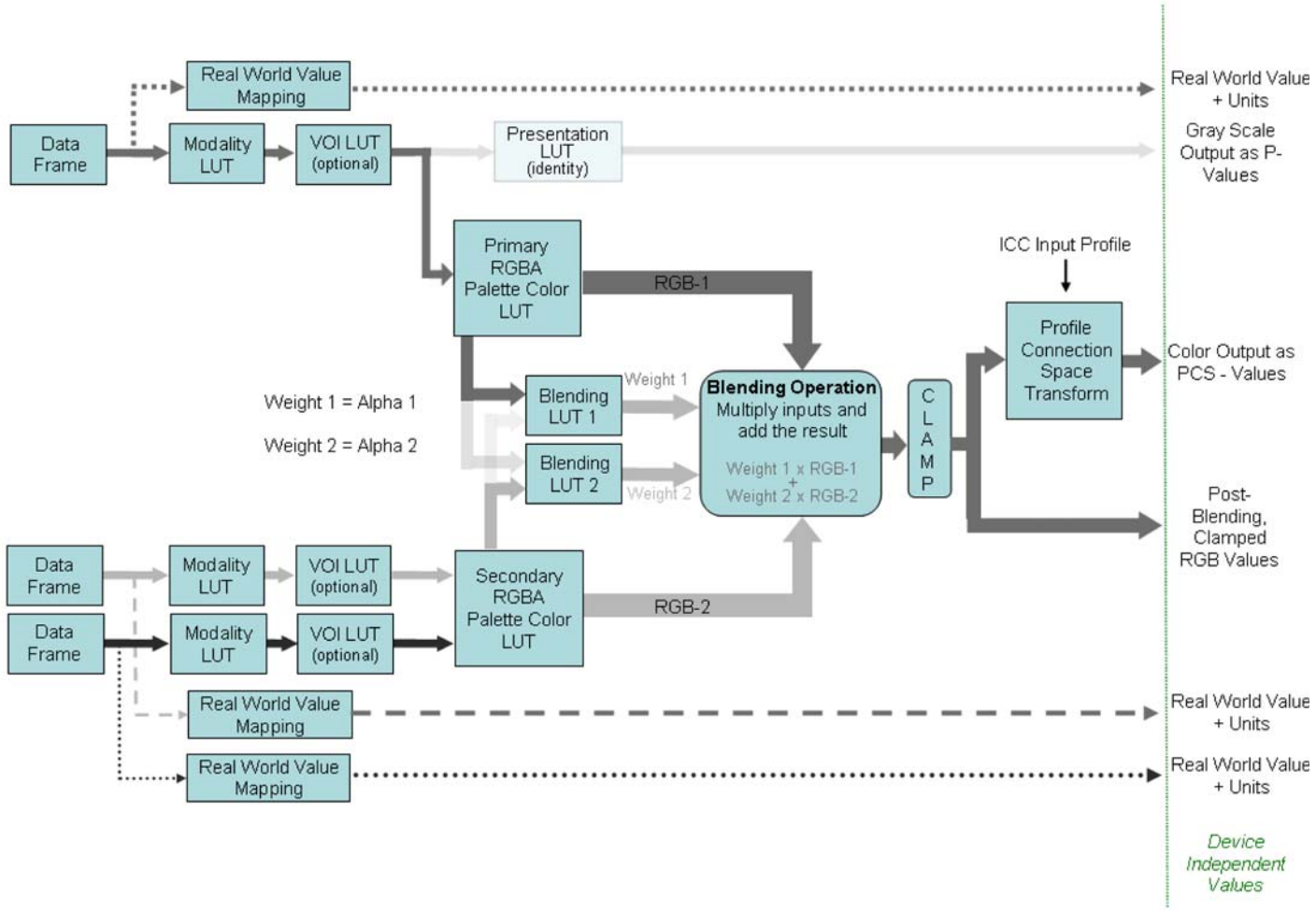
Blending ... e.g., for CT-PET



Blending Presentation State



Ultrasound Volume Blending e.g., Tissue/Velocity/Variance



Raw Format Needed in DICOM?

- Add support for “camera raw” encapsulation?
  - vendor-specific raw?
  - encapsulate Adobe DNG (Digital Negative) format?
  - DNG is TIFF-based – transcode DNG tags to DICOM??
  - DNG not “raw enough”? adopted? still need vendor raw?
- Benefits
  - store in PACS with patient & study identifiers
  - advanced processing possible on raw format
- DICOM does have generic “Raw Data” object
  - standard meta-data + private payload
- DICOM “For Processing” DX, MG (used in CAD)

Sup 124 - Communication of Display Parameters

- Started in Japan by JIRA
- Work in progress for some time
- Display System Management Service
- Retrieval of display system characteristics and performance information
- Calibration management & retrieval (may be deferred)
- Grayscale (not just GSDF) & color support (not just ICC Profiles)

Conclusions

- Despite its grayscale origins, DICOM supports color images
- Support for color consistency via ICC Profiles available but unimplemented
- Other aspects of color such as description of parameters available for specific modalities
- DICOM WS microscopy now standard