DICOM Standard Approach:

Whole Slide Imaging Deployment

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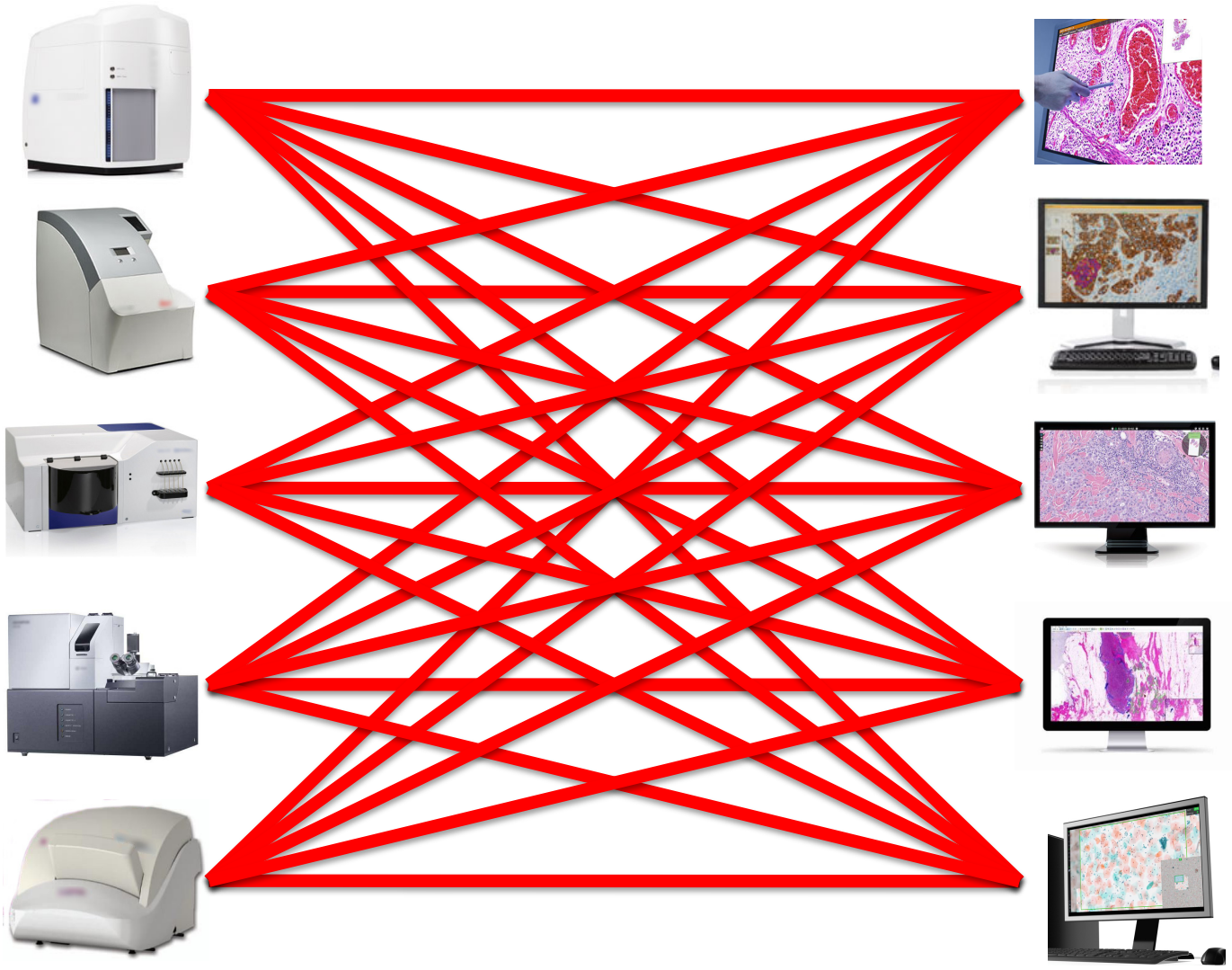
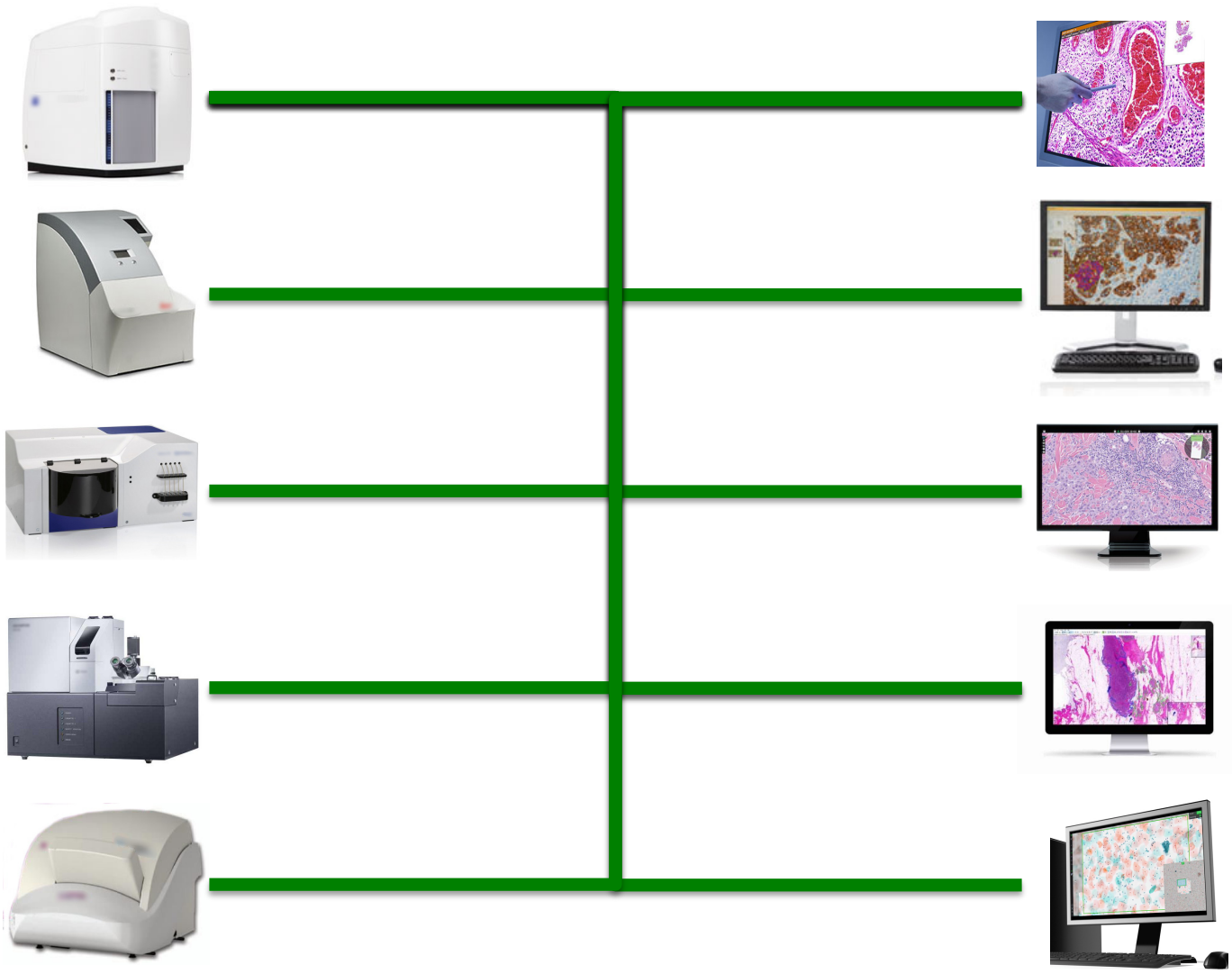
Pixelmed Publishing, LLC.

Interoperability

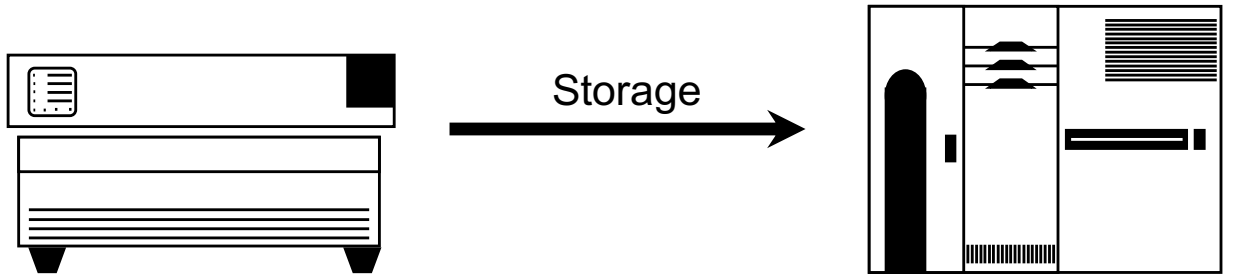
*"the ability of two or more systems or components to **exchange** information and to **use** the information that has been exchanged"*

IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. 1990





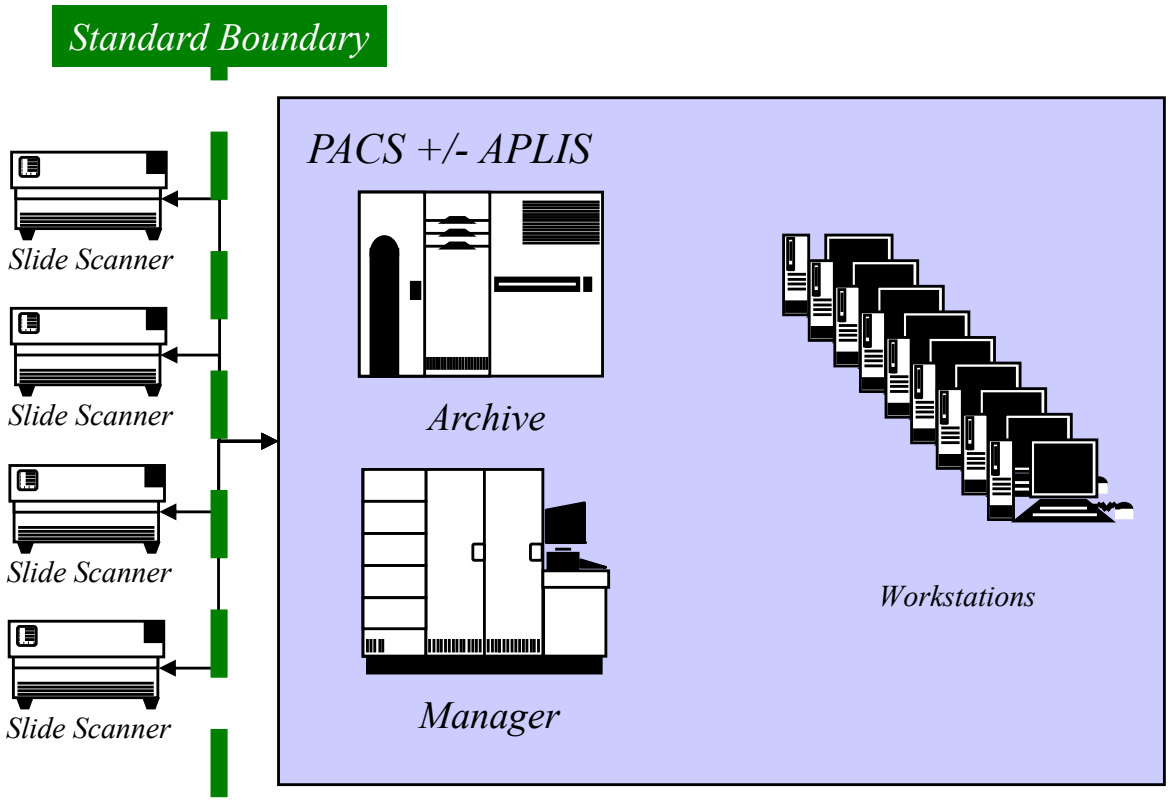
DICOM and Slide Scanner



Slide Scanner

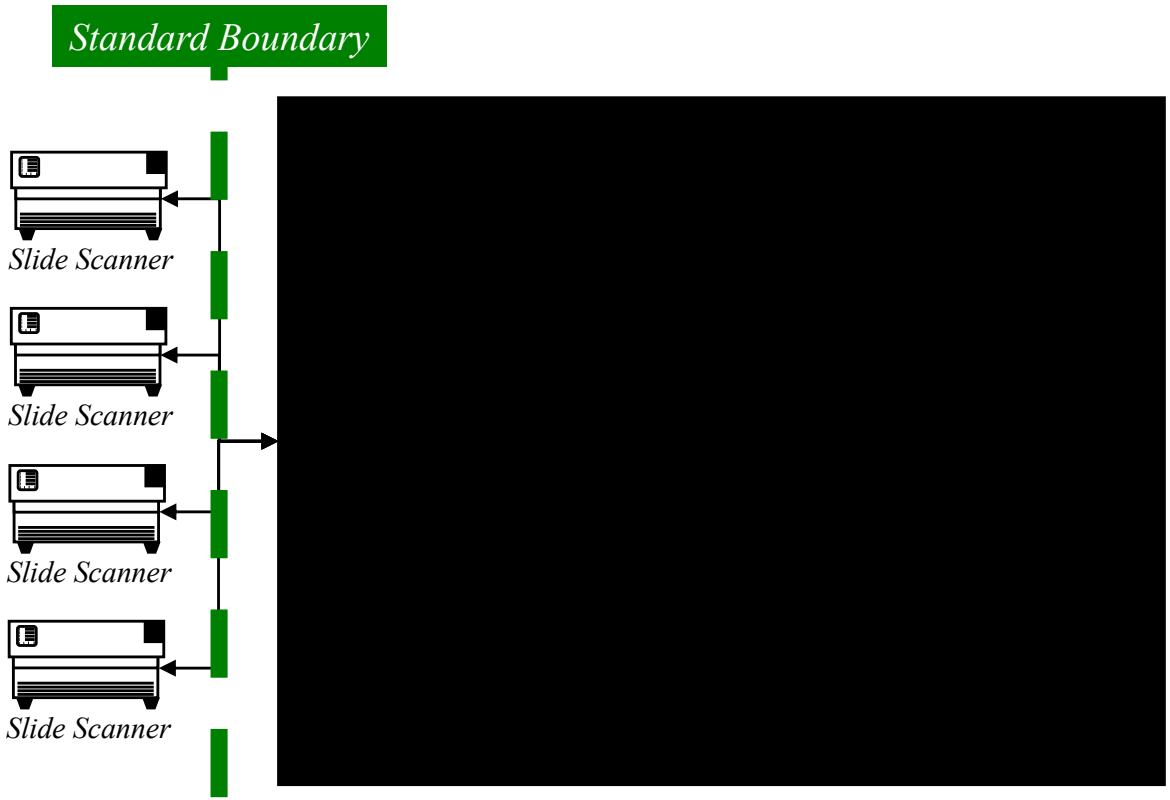
PACS

DICOM WSI to PACS

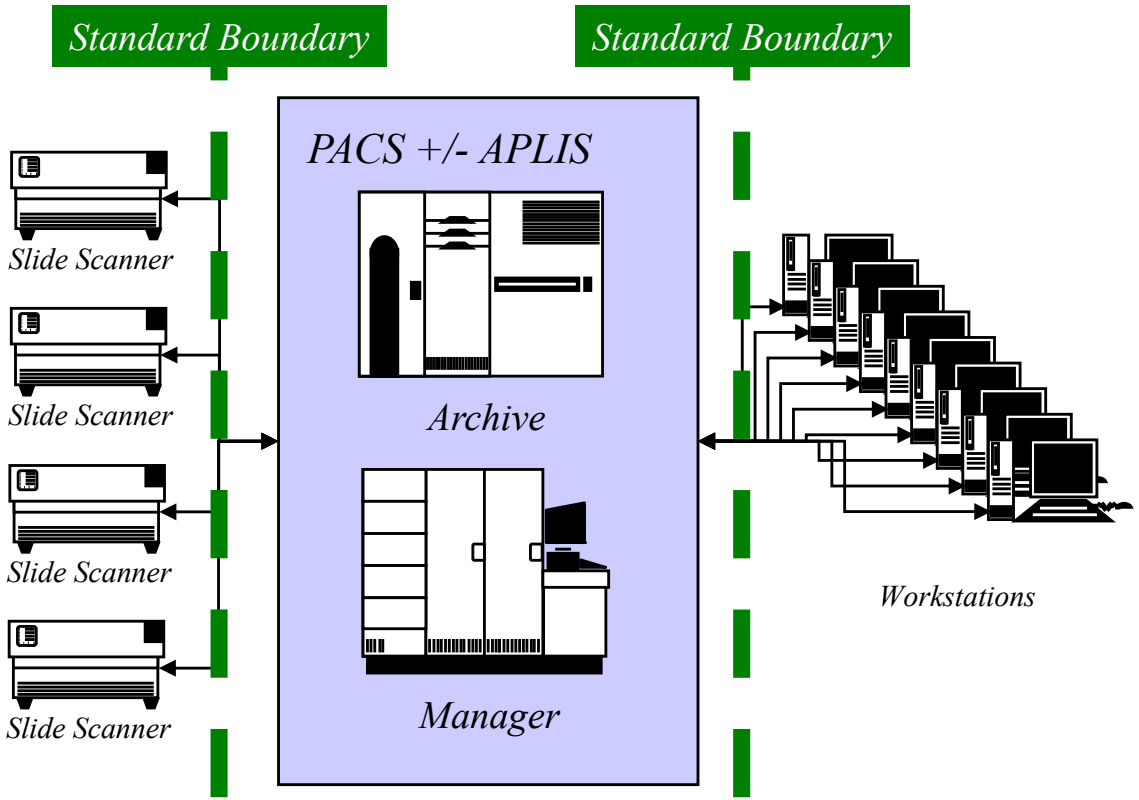


Single Vendor Black Box
FDA “entire pixel pathway”

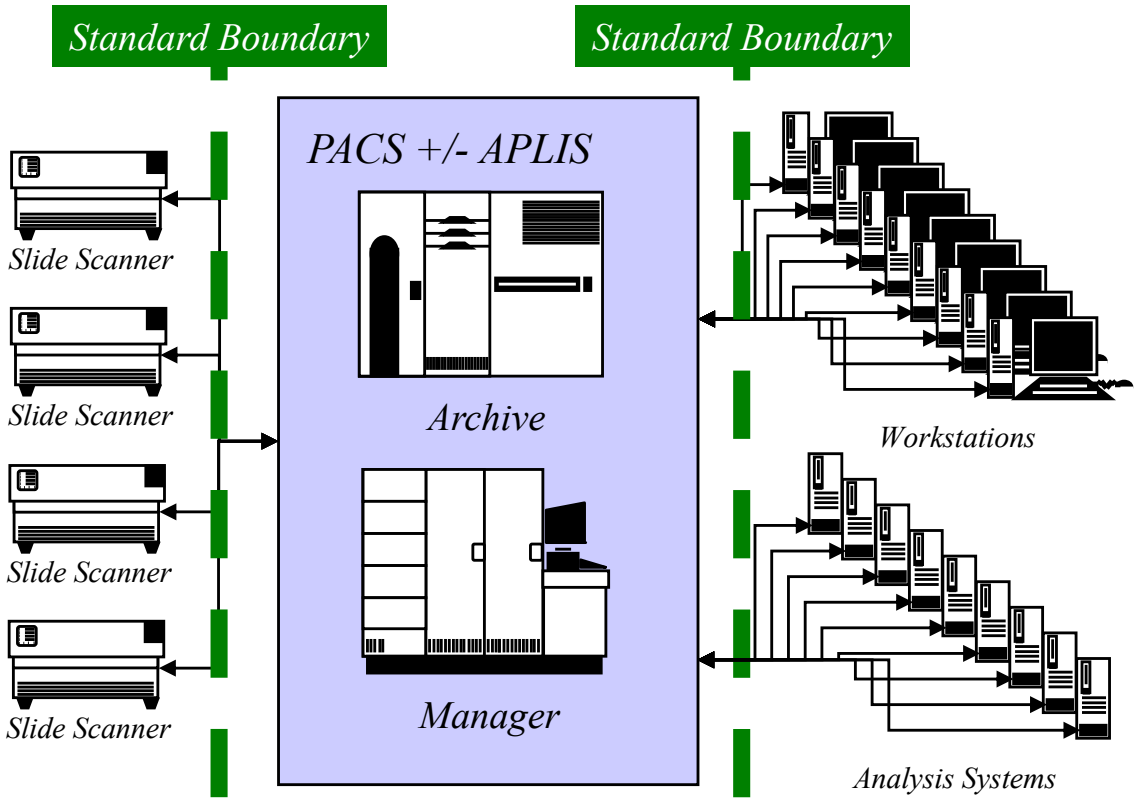
DICOM WSI to Black Box PACS



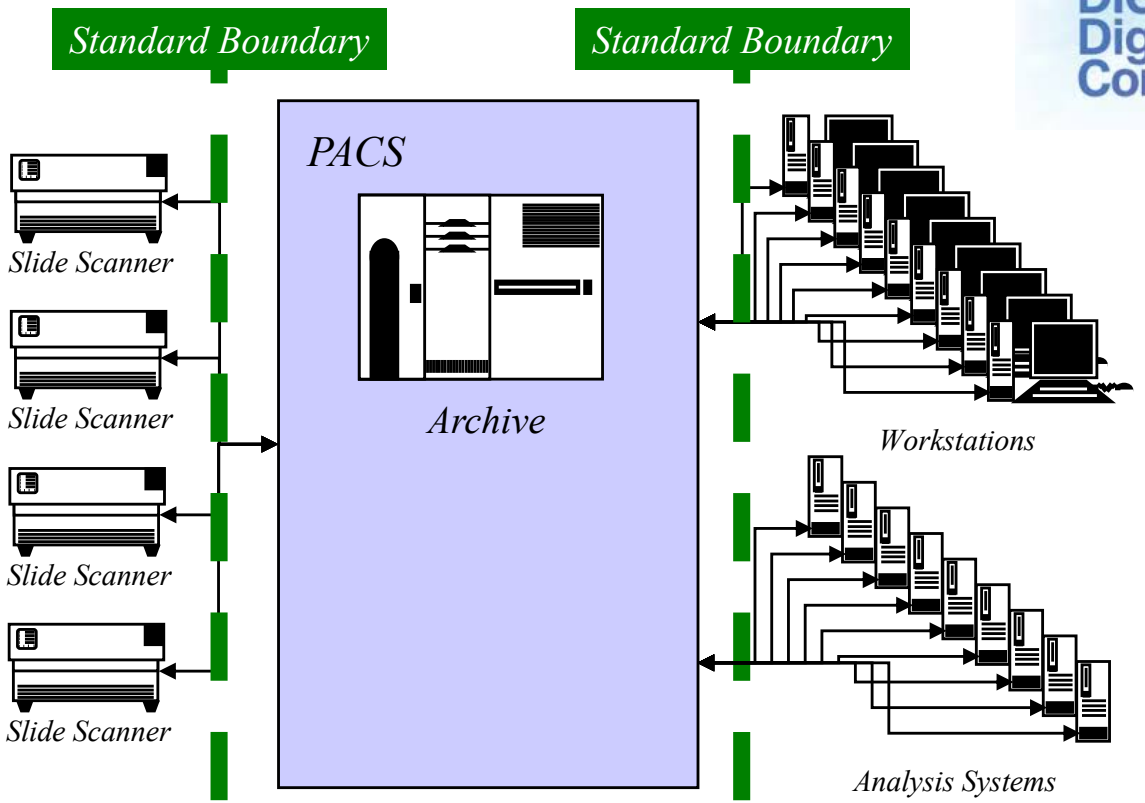
DICOM – Pathology Workstation



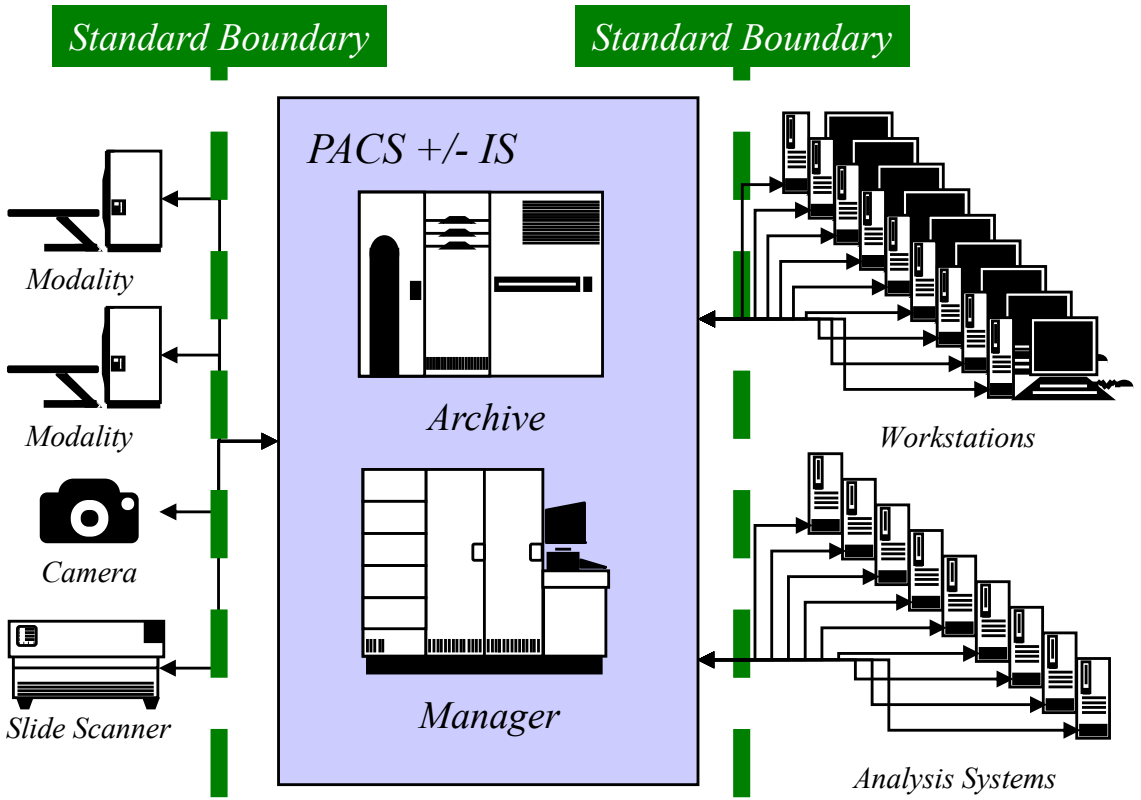
DICOM – Analysis Systems



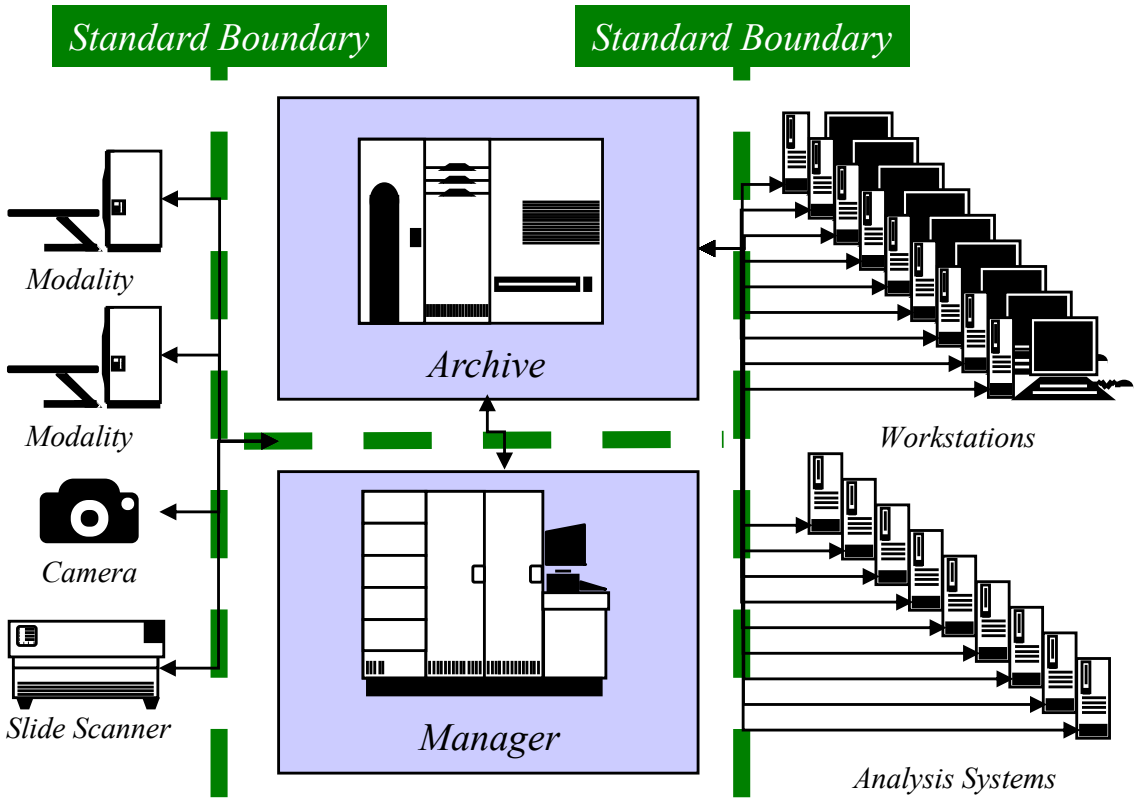
DICOM – Connectathon



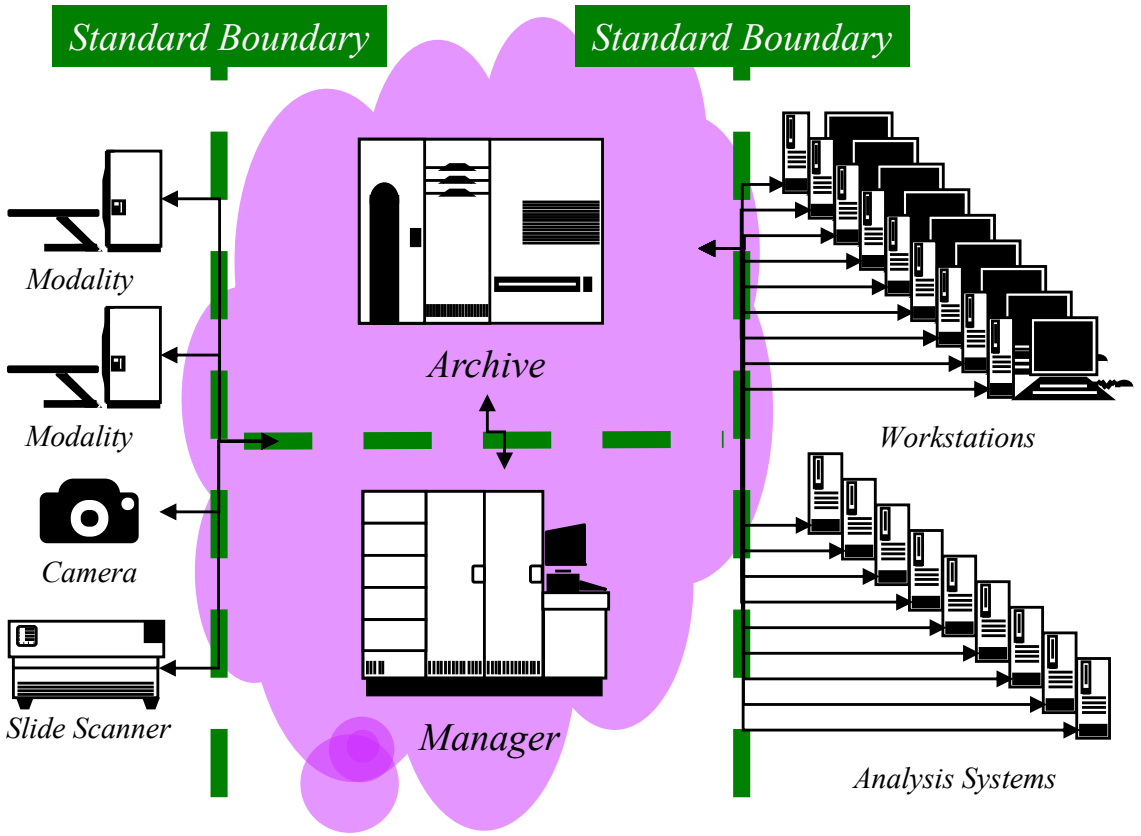
DICOM – Enterprise Imaging



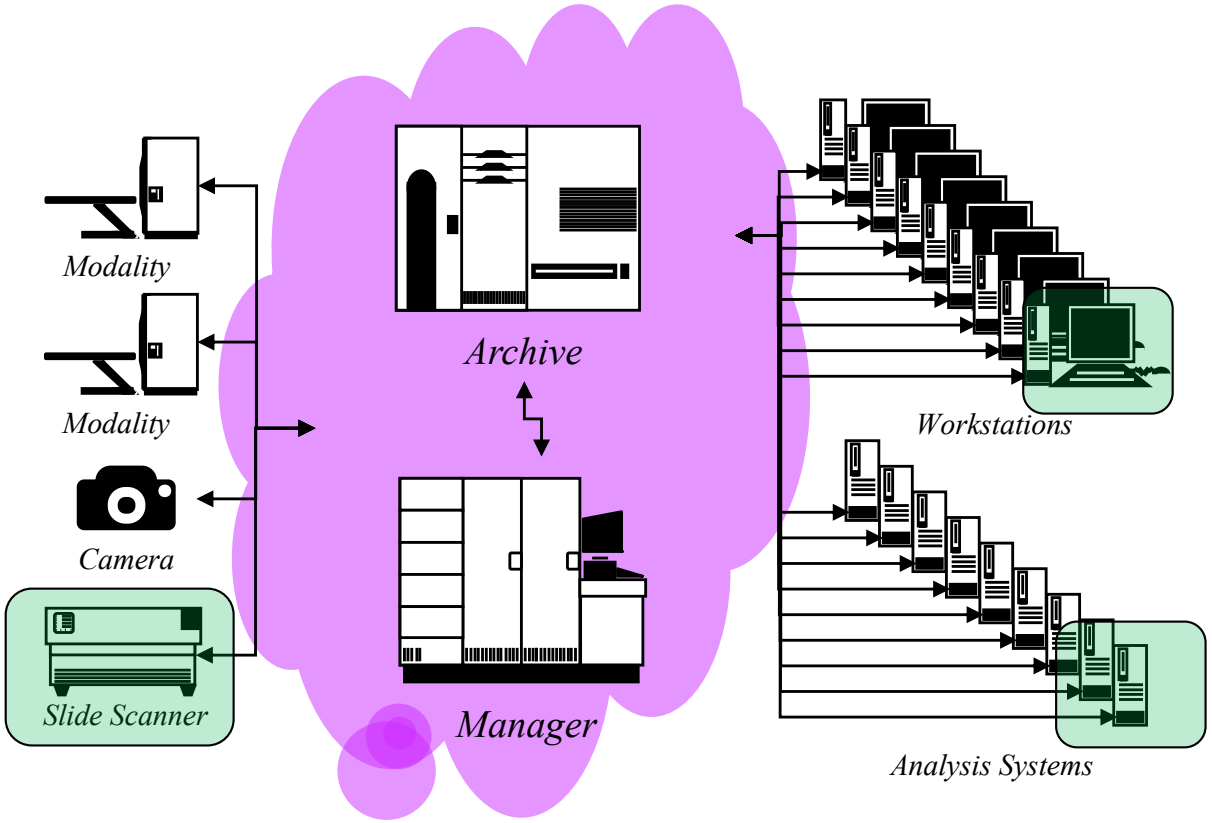
DICOM – Deconstructed PACS



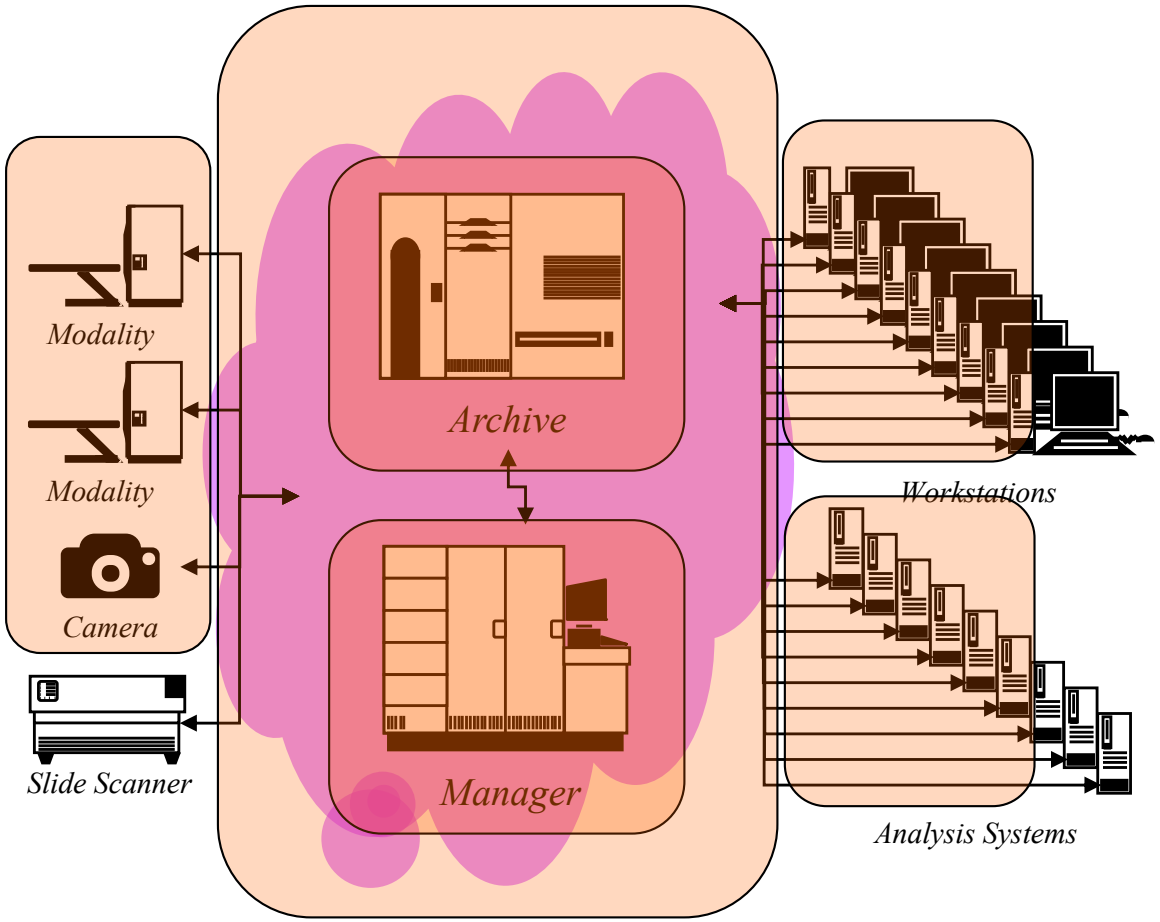
DICOM to the Cloud

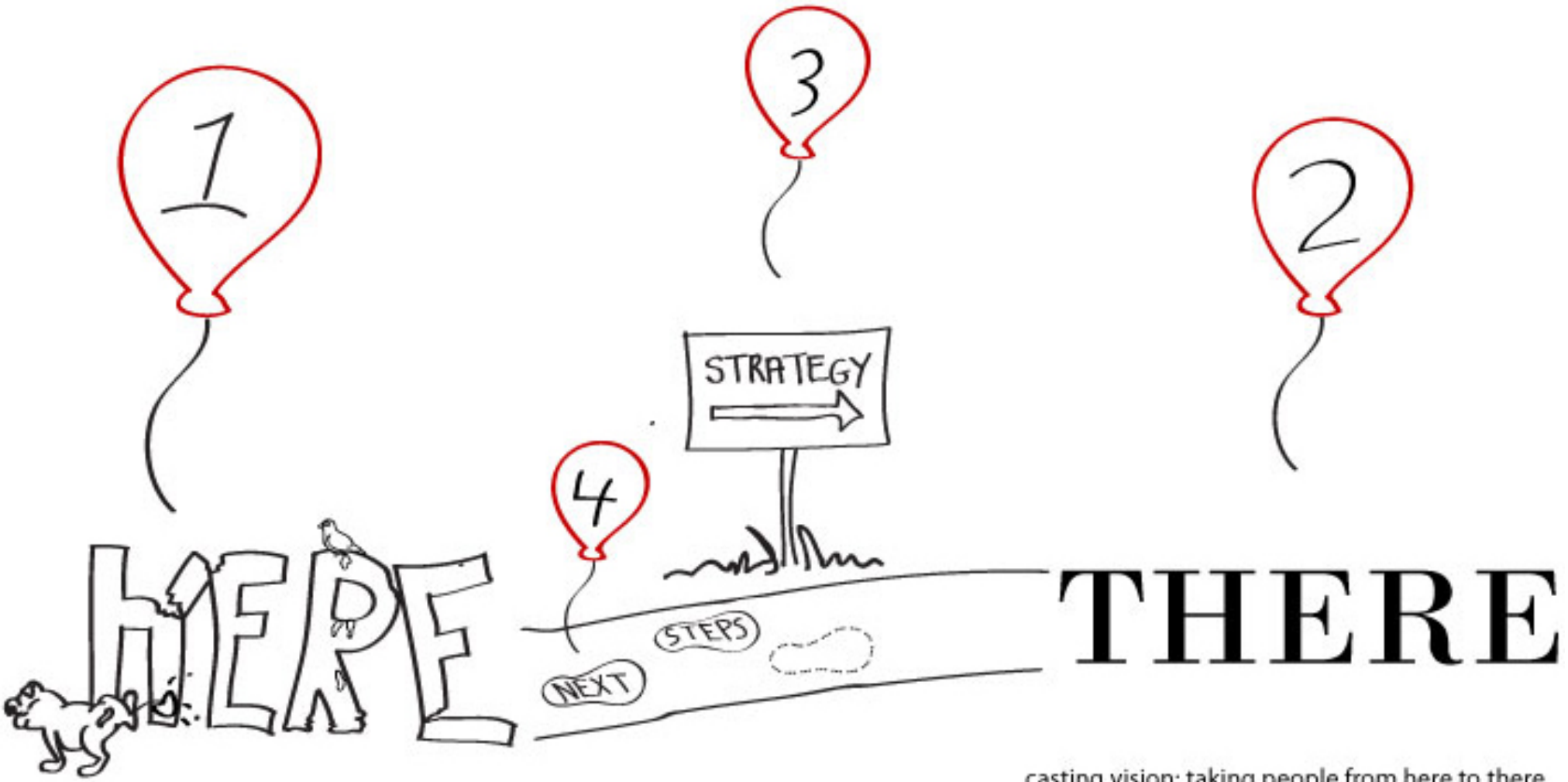


Pathologist/Department



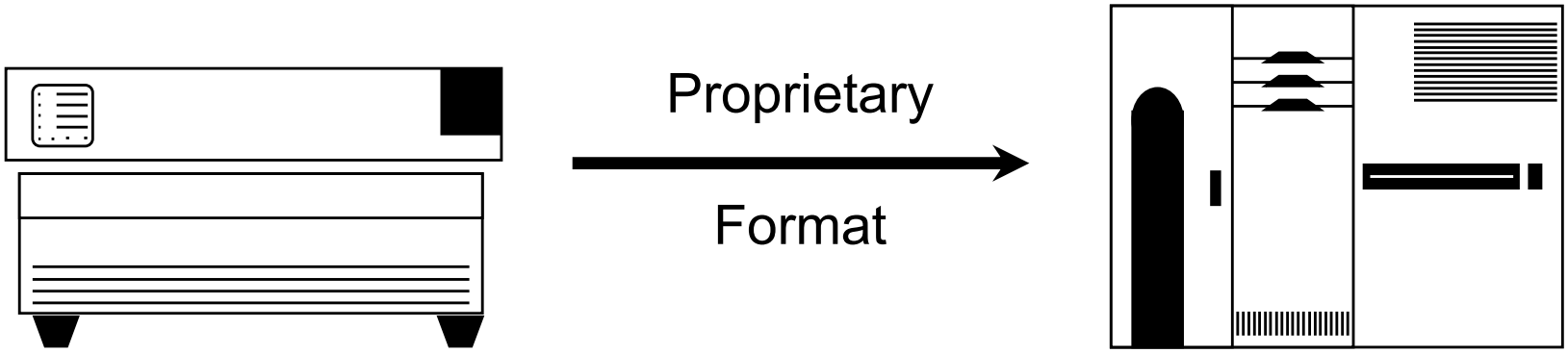
Enterprise IT





casting vision: taking people from here to there

Evolution to DICOM Integration

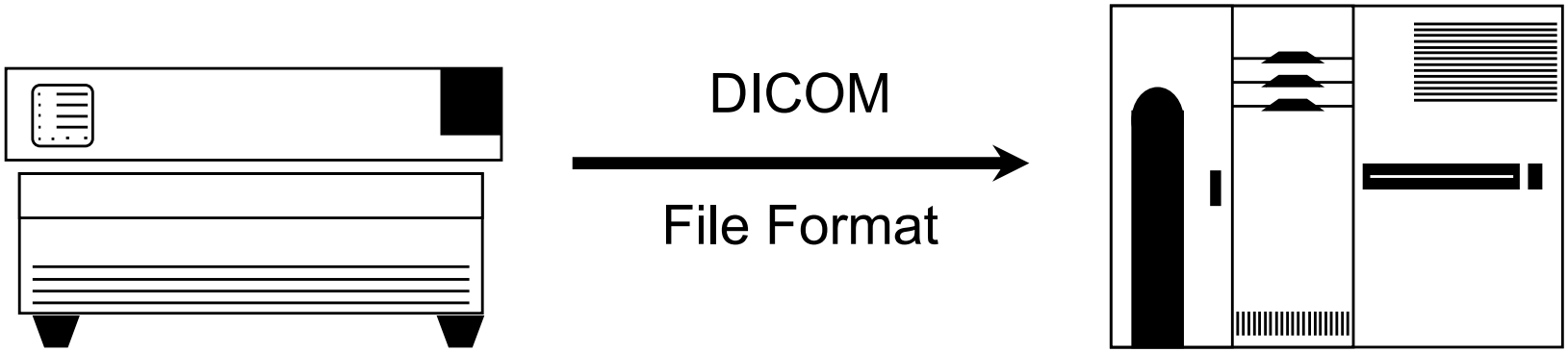


Slide Scanner

PACS

The Legacy Situation

Evolution to DICOM Integration

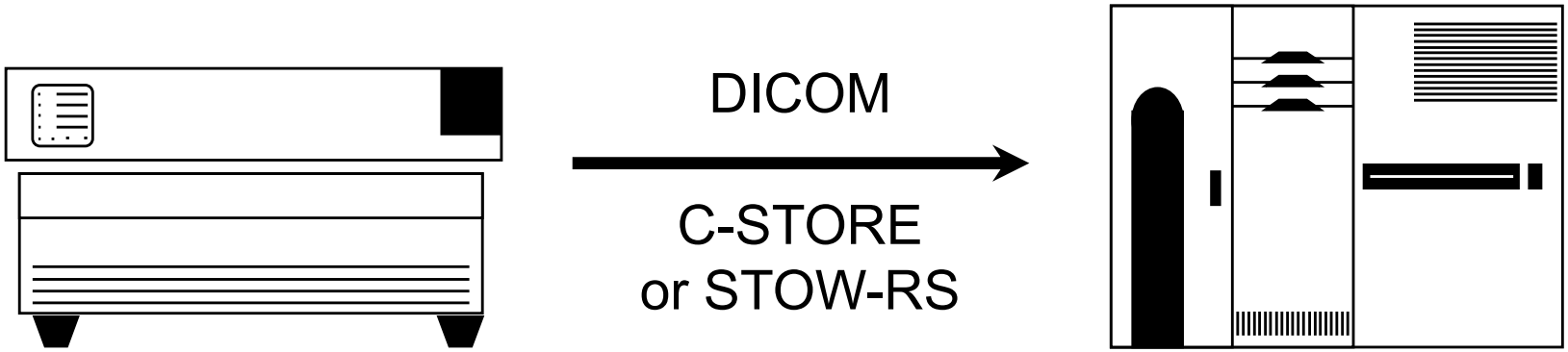


Slide Scanner

PACS

Standard Format but without Automated Transfer

Evolution to DICOM Integration

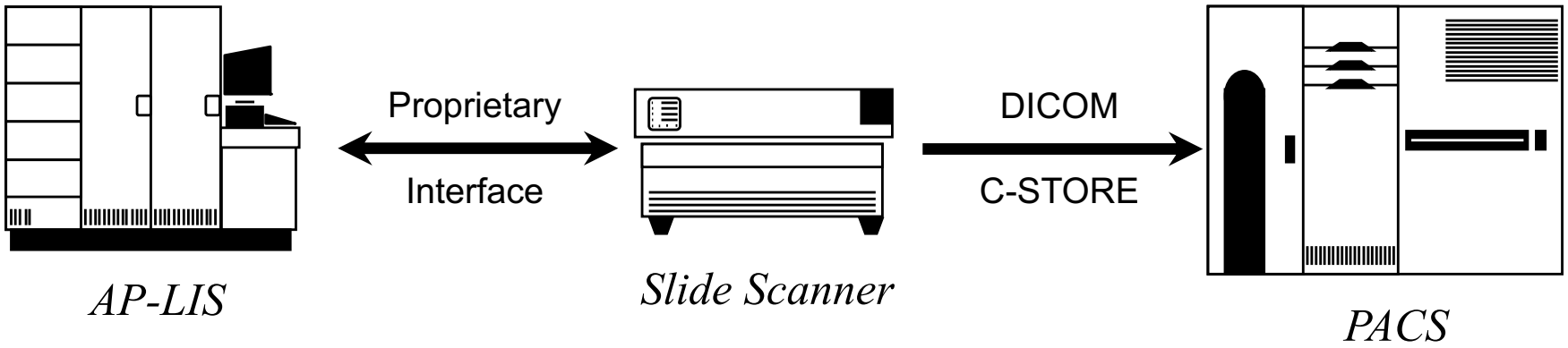


Slide Scanner

PACS

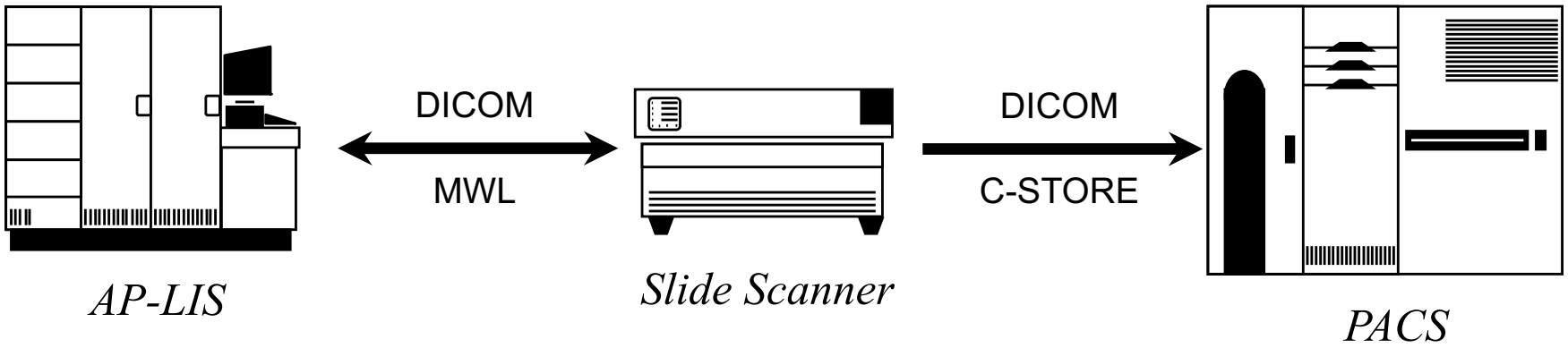
Standard Format with Automated Transfer

Evolution to DICOM Integration



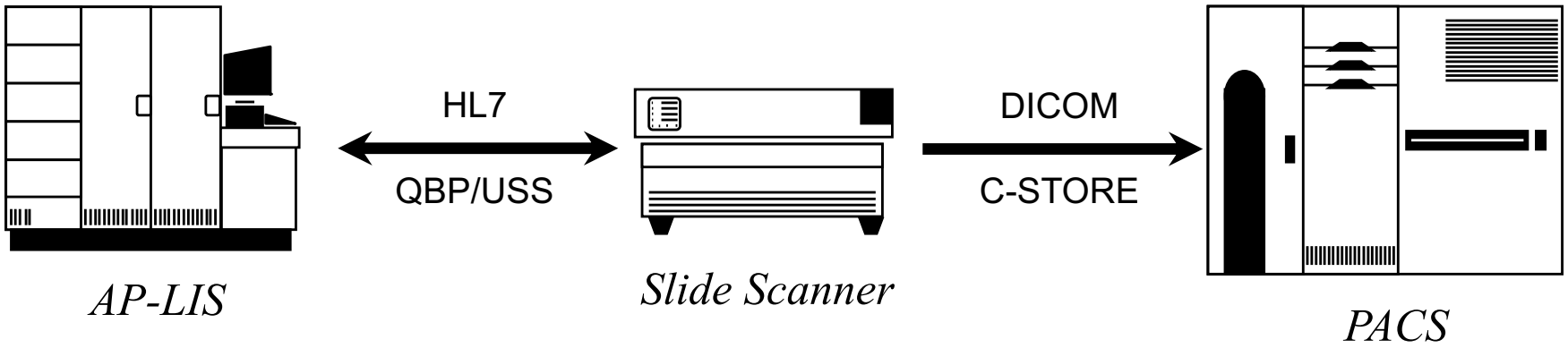
Standard Images but Customized IS Integration

Evolution to DICOM Integration



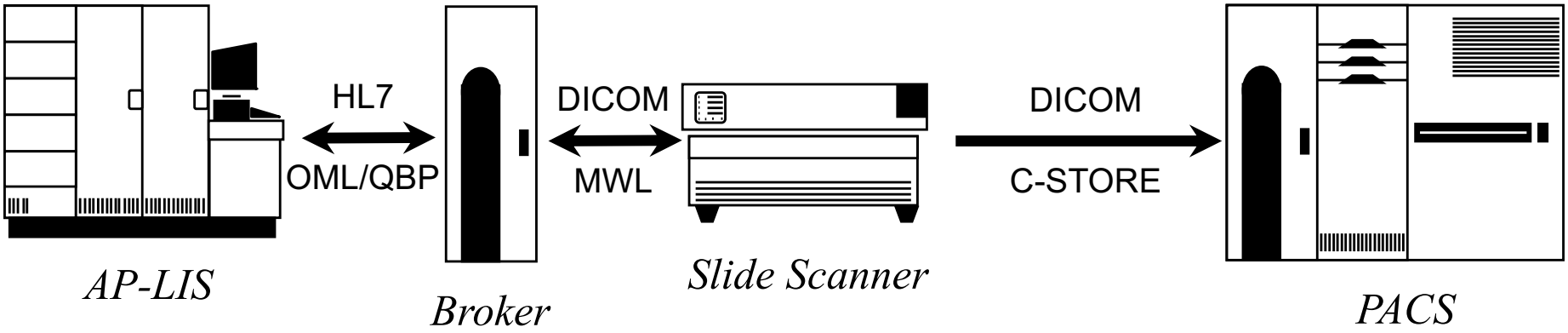
Standard Images and IS Integration using DICOM

Evolution to DICOM Integration



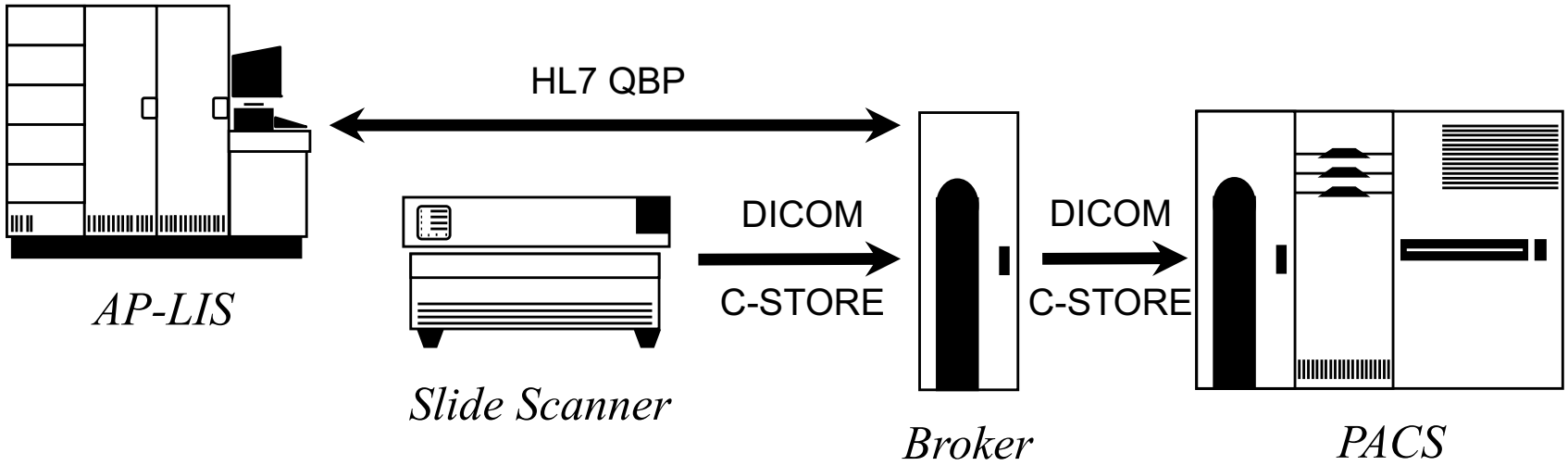
Standard Images and IS Integration using HL7 V2

Evolution to DICOM Integration



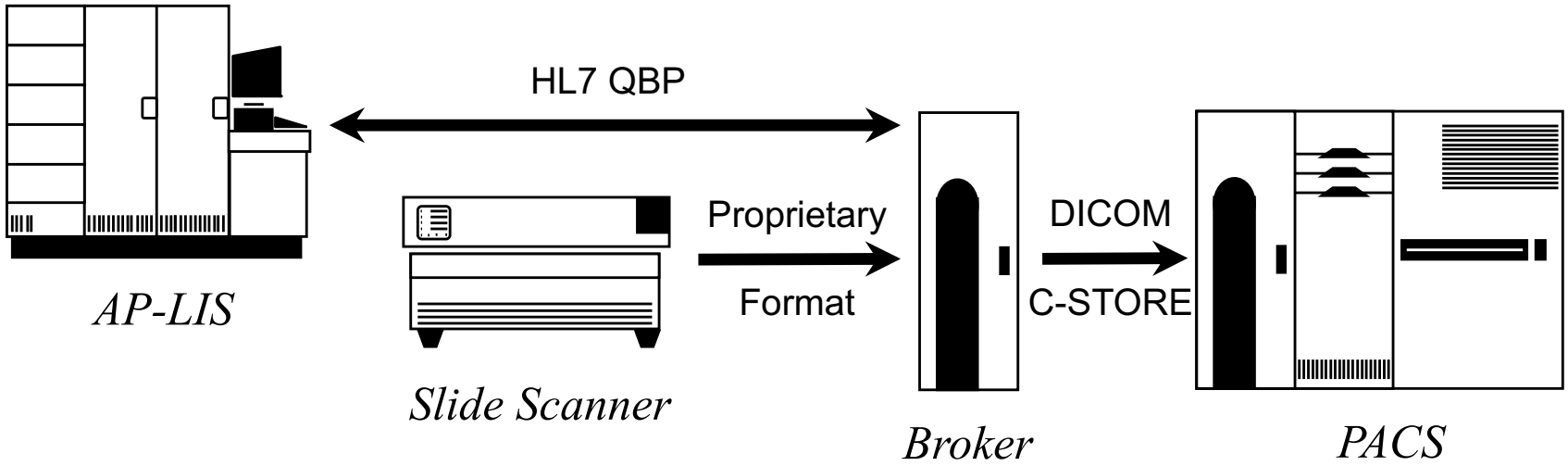
Standard Images and HL7/DICOM IS Integration

Evolution to DICOM Integration



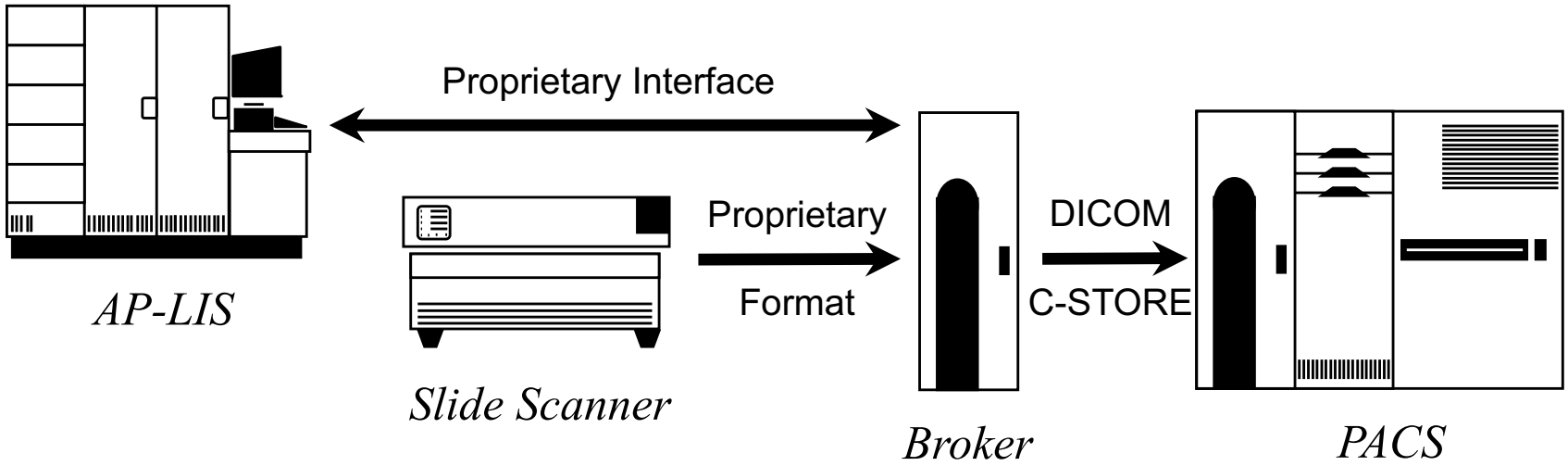
Broker "improves" DICOM with IS Metadata

Evolution to DICOM Integration



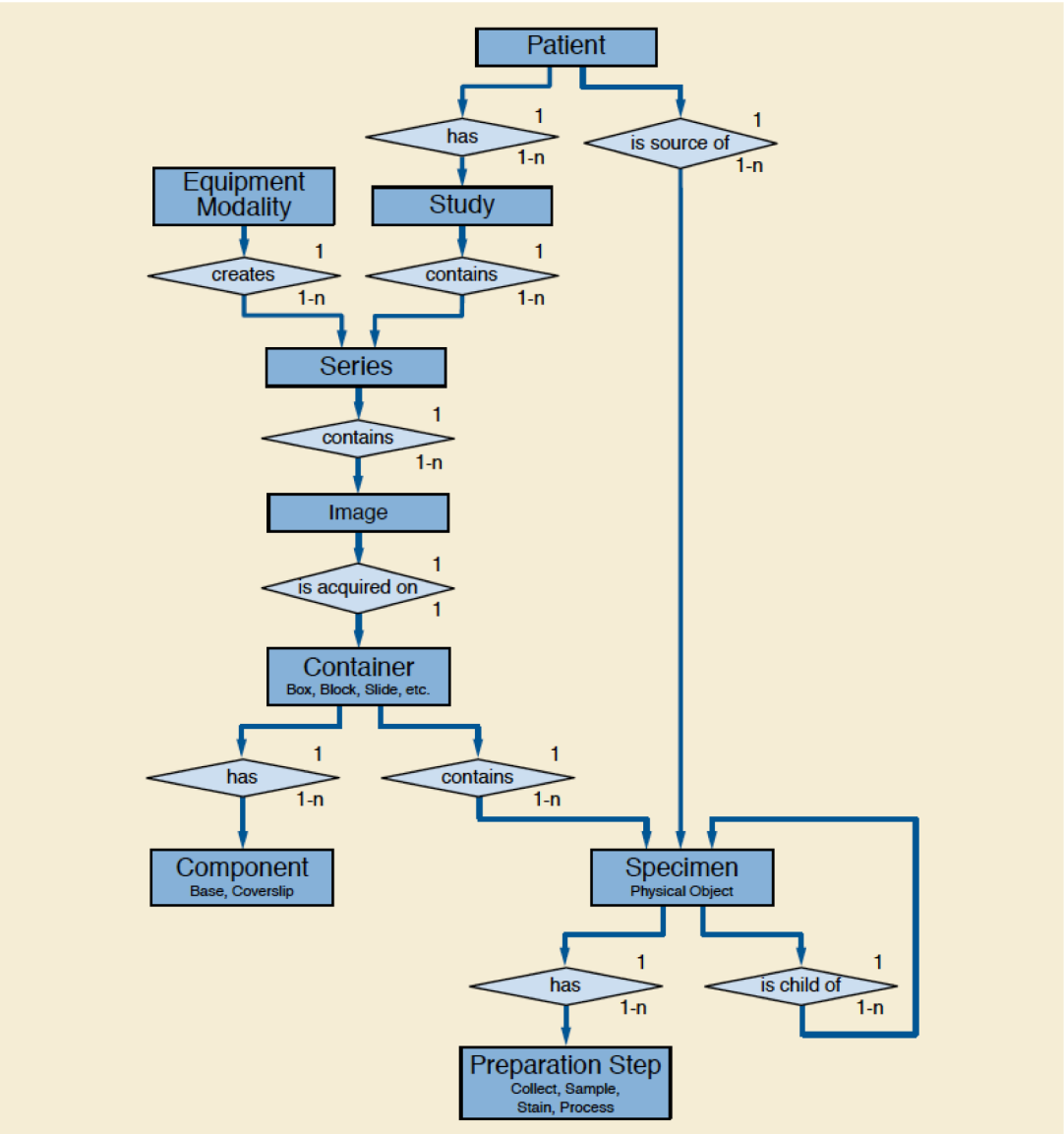
Broker handles everything – HL7 to IS

Evolution to DICOM Integration



Broker handles everything – all proprietary

http://media.propertycasualty360.com/propertycasualty360/article/2015/07/08/complexity-illustration-shutterstock215549044.jpg

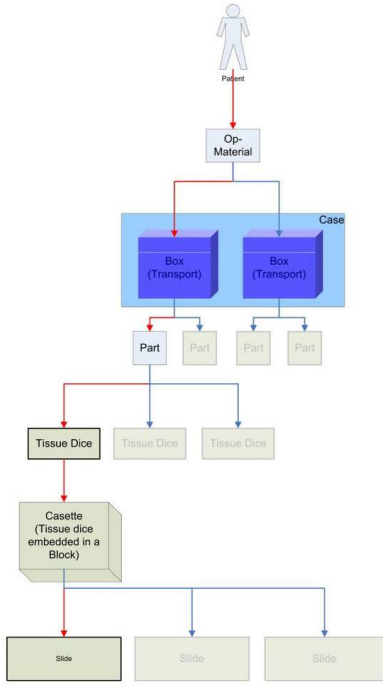

Patient
has
1
1-n
is source of
1
1-n
Equipment Modality
Study
creates
1
1-n
contains
1
1-n
Series
contains
1
1-n
Image
is acquired on
1
1
Container
Box, Block, Slide, etc.
has
1
1-n
contains
1
1-n
Component
Base, Coverslip
Specimen
Physical Object
has
1
1-n
is child of
1
1-n
Preparation Step
Collect, Sample,
Stain, Process

Specimen: Identify & Describe

- DICOM Supplement 122 (2008) replaced an earlier effort
- Harmonized with HL7 V2 SPM and draft V3 Specimen Domain Information Model – predates FHIR Specimen Resource
- Accession, Specimen, Container (like Clinical Lab)
- Specimen Preparation Description
- Communication: image header, worklist, performed procedure step, image query
- "store specimen information necessary to understand and interpret an image … ***in contexts where the LIS is not available***"

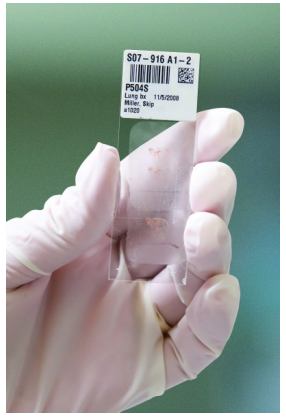
Specimen: Identify

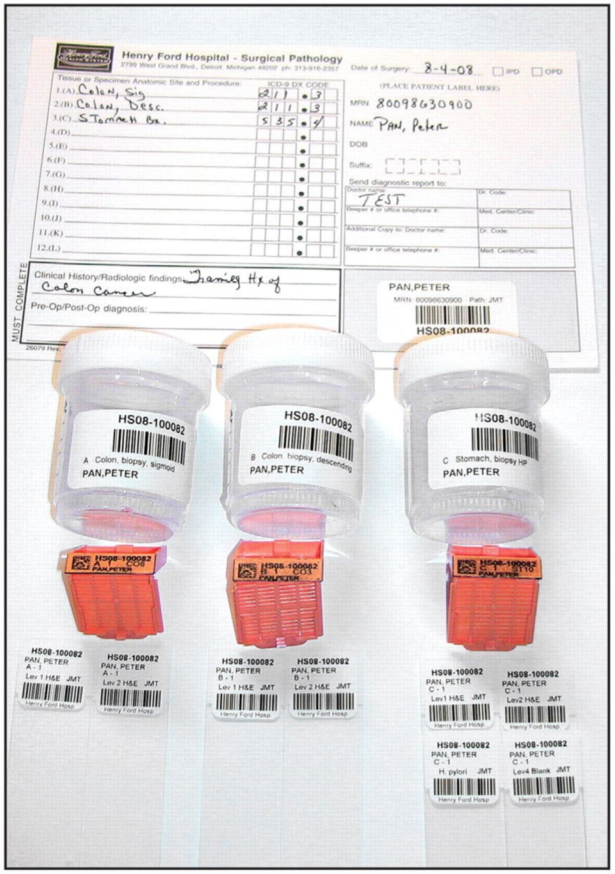
- Accession Number
  - unit of work (case: order- report)
  - same as radiology
- “Specimens in Containers”
- Specimen Identifier
  - single discrete physical object considered a unit in workflow
- Container Identifier
  - part, cassette, block, section, slide, …
  - container components … coverslip, etc.
- No “Slide Identifier”, etc. per se – coded Container Type
- Flexible: more than one specimen per slide (container), etc.



What about the slide barcode?

- Obviously barcodes are the key to automated workflow
- No standardized practice for what goes in the barcode
  - all identifiers and entire description of processing?
  - just one identifier: Accession, Specimen, Container (Slide, Block, …)
  - combination of identifiers?
  - some other identifier with defined scope of uniqueness?
- Does it matter if it is just used for “matching” in a lab defined/configurable manner?
- I.e., can it remain “opaque” yet be interoperable?
- DICOM Slide Label Module: Barcode Value attribute
- IHE Laboratory Barcode Labeling (LBL) profile





Zarbo et al. The Henry Ford Production System: Reduction of Surgical Pathology In-Process Misidentification Defects by Bar Code–Specified Work Process Standardization. Am J Clin Pathol. 2009.

Patient ID / Order ID / Case ID (OF) / Part ID / Block ID / Slide ID

P072345: LUNG Luke
- OR123: Lungectomy
  - DP07110 : Lungectomy
    - DP07110-A: Left upper lobe (gross image)
      - DP07110-A-1: Frozen section, mass
        - DP07110-A-1-1: FS
        - DP07110-A-1-2: H&E
      - DP07110-A-2: Entire stapled
        - DP07110-A-2-1: H&E
      - DP07110-A-3: Entire stapled
        - DP07110-A-3-1: H&E
      - DP07110-A-4: Entire stapled
        - DP07110-A-4-1: H&E
      - DP07110-A-5: Entire mass
        - DP07110-A-5-1: H&E (WSI)
        - DP07110-A-5-2: Elastic
      - DP07110-A-6: Entire mass
        - DP07110-A-6-1: H&E
        - DP07110-A-6-2: Elastic
      - DP07110-A-7: Unvolved lung tissue
        - DP07110-A-7-1: H&E
      - DP07110-A-8: Unvolved lung tissue
        - DP07110-A-8-1: H&E
    - DP07110-B: Upper division left upper apical posterior & anterior segments
      - DP07110-B-1: Vascular margin
        - DP07110-B-1-1: H&E
      - DP07110-B-2: Bronchial margin
        - DP07110-B-2-1: H&E
      - DP07110-B-3: Stapled line margin

IHE Anatomic Pathology (PAT) Technical Framework Volume 1 Revision 2.0 2010. Figure 3.1-1: Use Case 1.1 Sampling process (one specimen per container).

Specimen: Describe

- Can be omitted entirely (and still be valid DICOM object)
  - just rely on identifiers to pull from AP-LIS
  - means all recipients (viewers, analyzers) need to be configured/customized to talk to AP-LIS
  - means when image is disconnected from AP-LIS (e.g., migrated, shared, referred) all context is lost
- DICOM (radiology, etc.) convention is to include ***full description in every image***
  - text/coded description of fixation, staining, anatomy, etc.
  - any recipient can use this embedded information ***without needing to query another system***

Specimen: Describe

- Textual
  - Short and Detailed textual descriptions
- Coded/Structured
  - Specimen Preparation Sequence
  - preparation steps – coded names and coded values
  - anatomical information
- Also description of optical path
  - Illumination color, type, …

Coded Structured Example

- Container Type Code Sequence = (A-0101B, SRT, "Microscope slide”)
- Specimen Type Code Sequence = (G-8439, SRT, "Tissue section”)
- Primary Anatomic Structure Sequence = (T-62000, SRT, "Liver")
- (P3-02000, SRT, "Specimen Collection") = (P1-03100, SRT, "Biopsy ")
- (111704, DCM, "Sampling Method") = (P3-4000D, SRT, "Block sectioning")
- (G-C350, SRT, "Using substance") = (C-22968, SRT, "hematoxylin stain")
- (G-C350, SRT, "Using substance") = (C-22919, SRT, "water soluble eosin stain")
- (F-6221B, SRT, "Tissue Fixative") = (C-2141B, SRT, "Formalin")
- (F-6221A, SRT, "Embedding medium") = (F-616D8, SRT, "Paraffin wax")
- Illumination Color Code Sequence = (R-102C0, SRT, "Full Spectrum”)
- Illumination Type Code Sequence = (111744, DCM, "Brightfield illumination”)

Slide scanner perspective

- Just wants to scan and offload downstream, fast and reliably
- Automated matching of scanned barcode to AP-LIS supplied identifying and descriptive information – DICOM Modality Worklist (MWL) and IHE Anatomical Pathology Workflow (APW); HL7 V2 query (QBP) and IHE Laboratory Device Automation (LDA), Laboratory Analytical Workflow (LAW)
- Quality control – human interaction
- High volume – automated transfer on completion of scan or QC OK
- Native to DICOM WSI Storage conversion – scan order may not match encoded tile order – computational power/memory – latency but no bottleneck (cannot be rate limiting step)
- Reliability of transfer – did it get there and did you store it – DICOM Storage Commitment
- Signaling of completion to other systems – DICOM Modality Performed Procedure Step (MPPS), HL7 V2 specimen status update (SSU)

http://www.nofrackingway.us/wp-content/uploads/2012/10/regurgitate.jpg

IHE AP Workflow (APW)

- Based on Radiology Scheduled Workflow (SWF)
- Developed at same time as DICOM Sup 122
- Query (pull) model – scanner talks DICOM MWL to Order Filler that "brokers" HL7 V2 ADT, ORM, SPM, SAC messages
- Never really finished – some editing incomplete (tag values)
- No query on Barcode Value – Accession/Specimen/Container IDs
- Never tested in Connectathon, never implemented in the field (?)
- IHE Anatomic Pathology (PAT) merged with IHE LAB, now PALM
- Could be made to work – or do scanners want to do HL7 themselves?
- Specimen processing description mapping from HL7 to DICOM MWL?

http://pathcore.com/sedeen/

Viewer perspective

- Finding it
- Organizing it
- Displaying description of it
- Displaying it
- Interactively analyzing it
- Annotating it

“It” being the right image(s) for current workflow context

Viewer: Finding it – Query

- Standard DICOM query keys
  - *** caveat: generic archives (“VNAs”) may or may not be configurable to index pathology-specific keys (metadata) of interest even though present in images
- Identifiers
  - e.g., find images for Accession Number X
  - e.g., find WSI images for Patient ID X from date range Y to Z
- Descriptors
  - e.g., find WSI images with stain code X for Patient ID Y
  - e.g., find breast WSI images with IHC stain X for women aged Y to Z who also have MR and tomosynthesis images

Viewer: Organizing it – Hanging

- Standard DICOM attributes and codes
  - *** caveat: when local codes are used, display software needs to configurable
- Virtual slide tray
  - in what order are slide icons laid out
  - what code-derived labels are displayed to user (“H&E” not “C-22968, C-22919”)
  - what text descriptions to incorporate
  - analogous to radiology “hanging protocol” rules for layout (DICOM can store these)
- Full view layout
  - side-by-side comparisons (different stains, current v. prior), same or multiple screens
- Scripting multi-disciplinary team meetings, tumor boards, review sessions
  - preselect what images to show, what zoom levels, annotations, etc.
  - save and restore “state” of display and sequence of those states
  - analogous to radiology “presentation states”, “structured displays” (DICOM objects)

Viewer: Describing it

- Standard DICOM identifying attributes
  - can display Patient Name/ID, Accession #, Specimen Type and ID, Container Type and ID
- Descriptive attributes – what, what for, and where from?
  - e.g., anatomy, fixation, stain, etc.
  - don't display them at all – assume side-by-side with another application (AP-LIS, EMR, etc.) – manually synchronized, scan barcode, automatically synchronized (CCOW, IHE Invoke Image Display (IID) etc.)
  - query from somewhere (AP-LIS, EMR, etc.) when needed using identifier(s) by standard (HL7 V2 QBP, FHIR Specimen) or custom/proprietary API
  - from DICOM image header, if present (C-STORE, WADO-RS Retrieve Metadata)
- Deployment scenarios
  - inside one AP department
  - between AP departments in same integrated "enterprise" (multi-site)
  - outside AP department (e.g., clinicians, team meetings)
  - outside site/enterprise (telepathology, consultation, referral)

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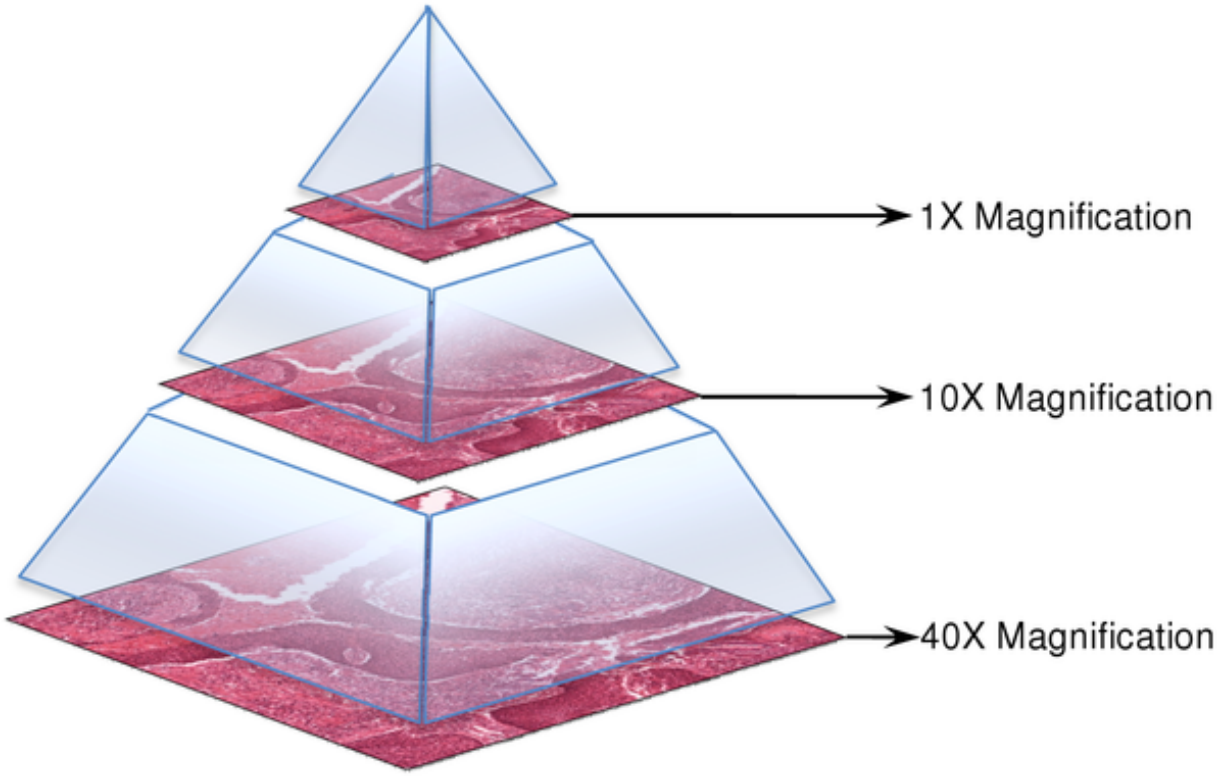
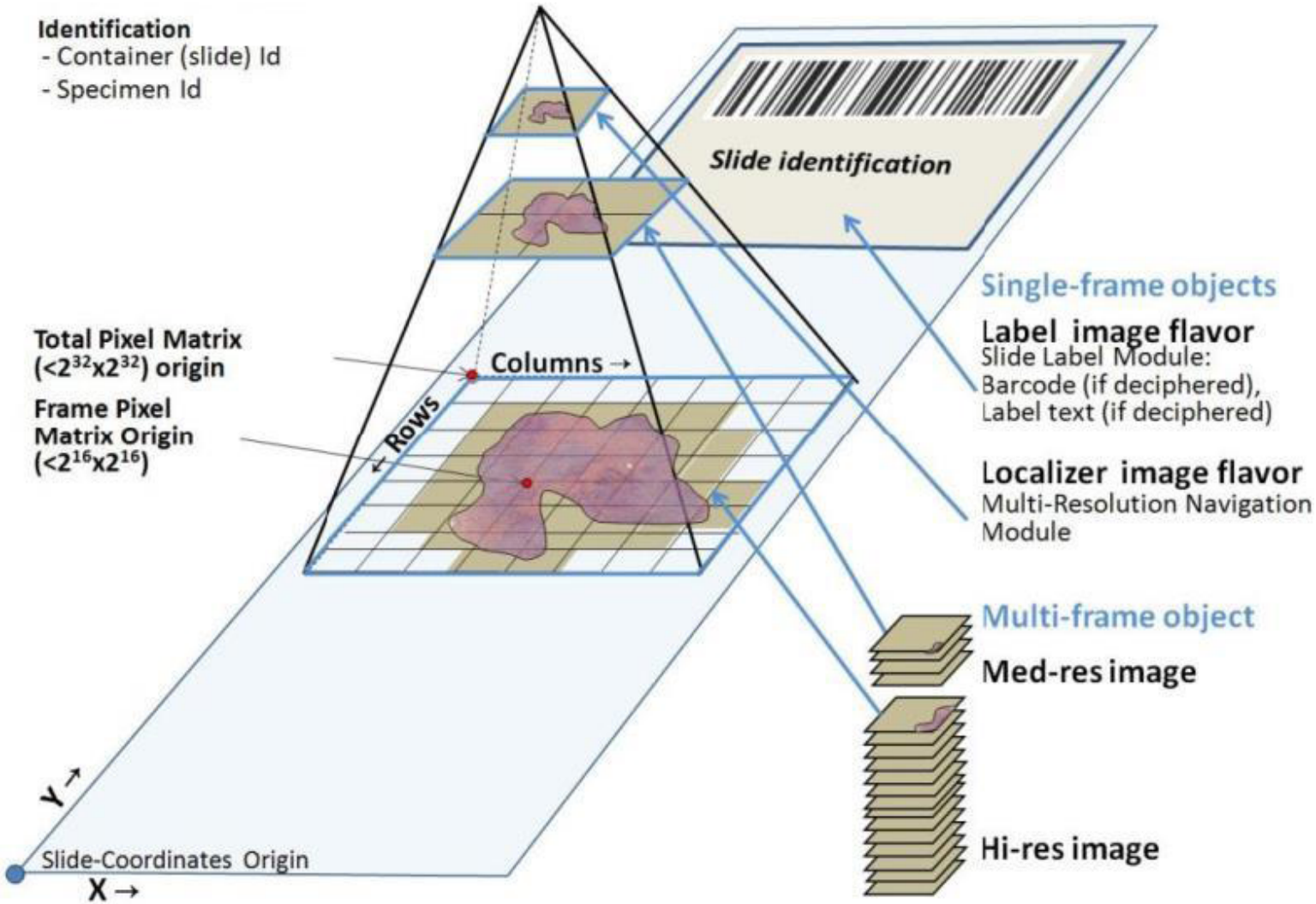
An illustration of how digital slides are stored in a pyramid structure.



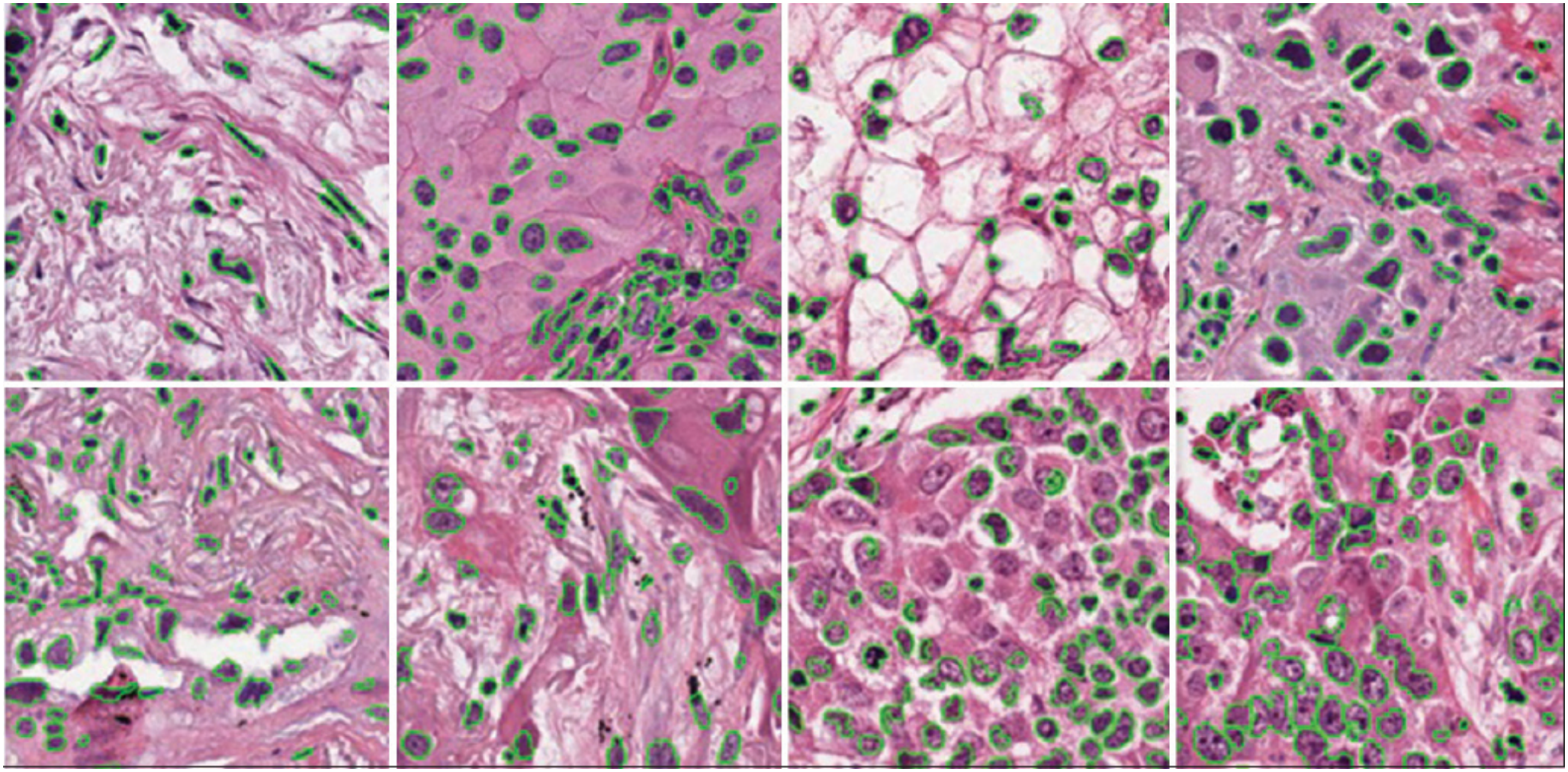
Wang Y, Williamson KE, Kelly PJ, James JA, Hamilton PW (2012) SurfaceSlide: A Multitouch Digital Pathology Platform. PLOS ONE 7(1): e30783. https://doi.org/10.1371/journal.pone.0030783
http://journals.plos.org/plosone/article?id=10.1371/journal.pone.0030783

Garcia-Rojo et al. 2016



Archive perspective

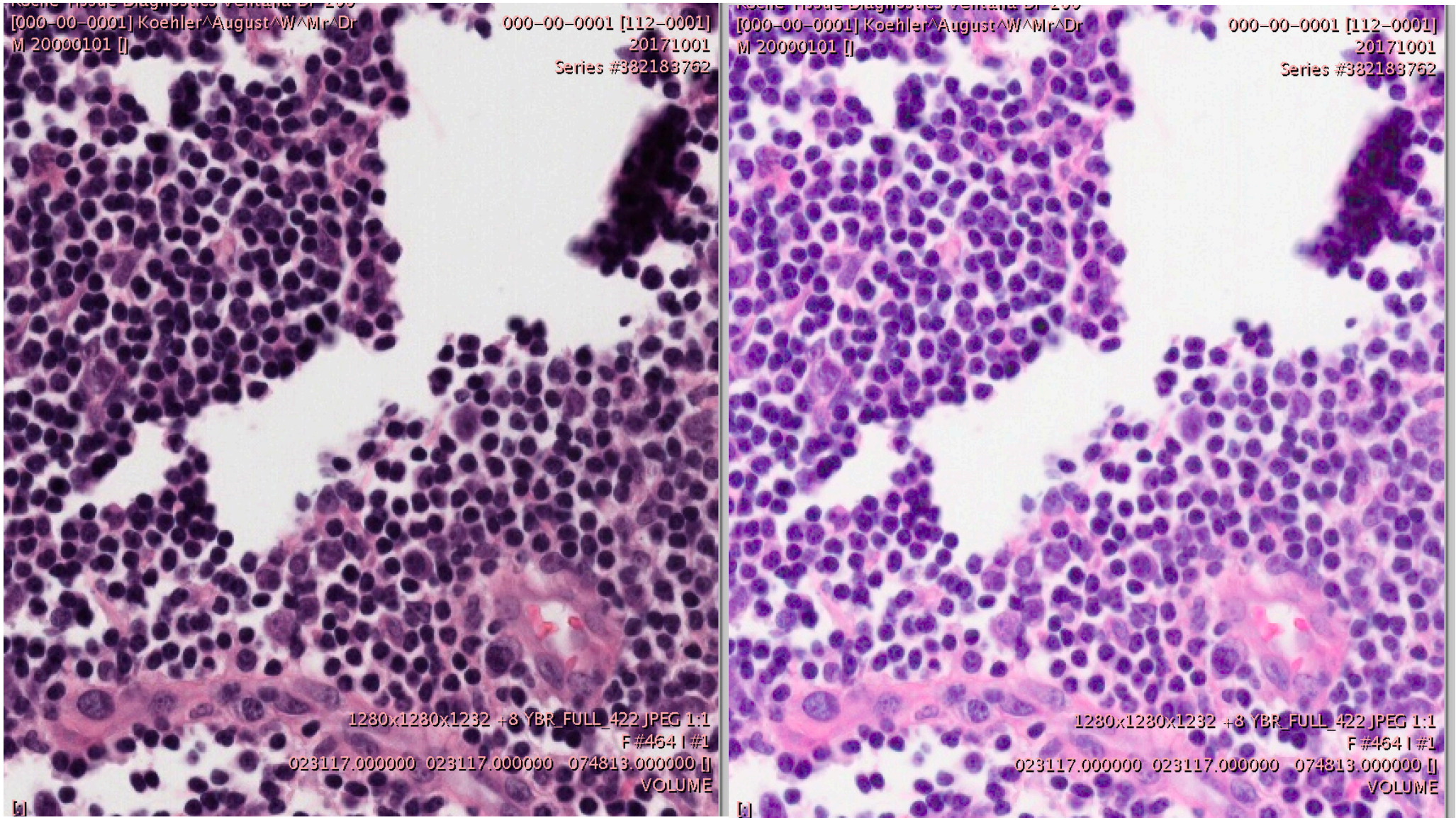
- Really big images
  - no practical size limit if compressed (JPEG, J2K, as WSI always are)
  - theoretically just more frames (e.g., WSI 10x larger than mammo tomo)
  - timeouts while waiting for transfer/storage
  - split into “Concatenations” but archive needs to reassemble for viewer
- What to index as DICOM query keys
  - generic stuff (e.g., patient, accession, anatomy) v. pathology stuff (e.g., specimen, container) v. WSI stuff (e.g., stain) v. visualization stuff
- What interfaces
  - traditional DIMSE C-STORE for reception (could use http STOW-RS)
  - DICOMweb QIDO-RS (query), WADO-RS metadata (JSON) and frames



Wen et al. A methodology for texture feature-based quality assessment in nucleus segmentation of histopathology image. JPI. 2017.

Annotation perspective

- In the viewer
  - user points out things, measures things, identifies stuff to send for analysis
  - wants to save these so they reappear next time and values are reported
  - display analysis results (pre-processed or when returned)
- In the analytic application
  - receive designated Regions of Interest (ROIs), hot spots
  - get entire image or just frames with ROIs
  - produce results: image locations, outlines, segmentations + values, scores
- In the archive
  - store ROIs, locations, outlines, segmentations in DICOM form (SR, SEG)
  - indexed with the rest of the study (i.e., with the images)
  - send to AP-LIS if interested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M 20000101 []
000-00-0001 [112-0001]
20171001
Series #382183762
1280x1280x1232 +8 YBR_FULL_422 JPEG 1:1
F #464 I #1
023117.000000 023117.000000 074813.000000 []
VOLUME
[000-00-0001] Koehler^August^W^Mr^Dr
M 20000101 []
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20171001
Series #382183762
1280x1280x1232 +8 YBR_FULL_422 JPEG 1:1
F #464 I #1
023117.000000 023117.000000 074813.000000 []
VOLUME

Color Variability

- Reality – how specimen is stained
- Scanned – characteristics of scanner
- Encoded – how scanner transforms & tags it
- Rendered – how viewing software transforms it
- Display – how monitor converts to light
- Viewed – environment, ambient light, human

Does it matter? If so, can we control it?

Summary : Standardization

Scanning

Color Standardization Algorithm

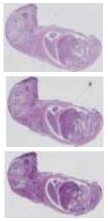
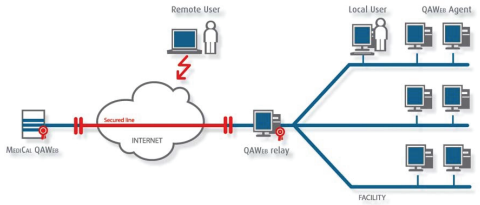


Image Quality Evaluation Algorithm

Display

Online Management System is available



Staining

Digital Staining Standardization is available

MASSACHUSETTS GENERAL HOSPITAL PATHOLOGY

HARVARD MEDICAL SCHOOL

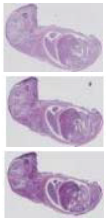
Yukako Yagi, Color aspects and Color Standardization in Digital Microscopy, ICC Summit on Color in Medical Imaging, 2013

Summary : Standardization

Scanning

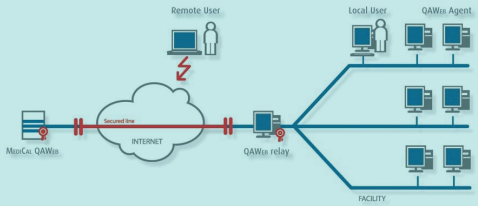
Color Standardization Algorithm

Image Quality Evaluation Algorithm



Display

Online Management System is available



DICOM ICC

Staining

Digital Staining Standardization is available

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Color Variability – DICOM

- Reality – how specimen is stained
- Scanned – characteristics of scanner
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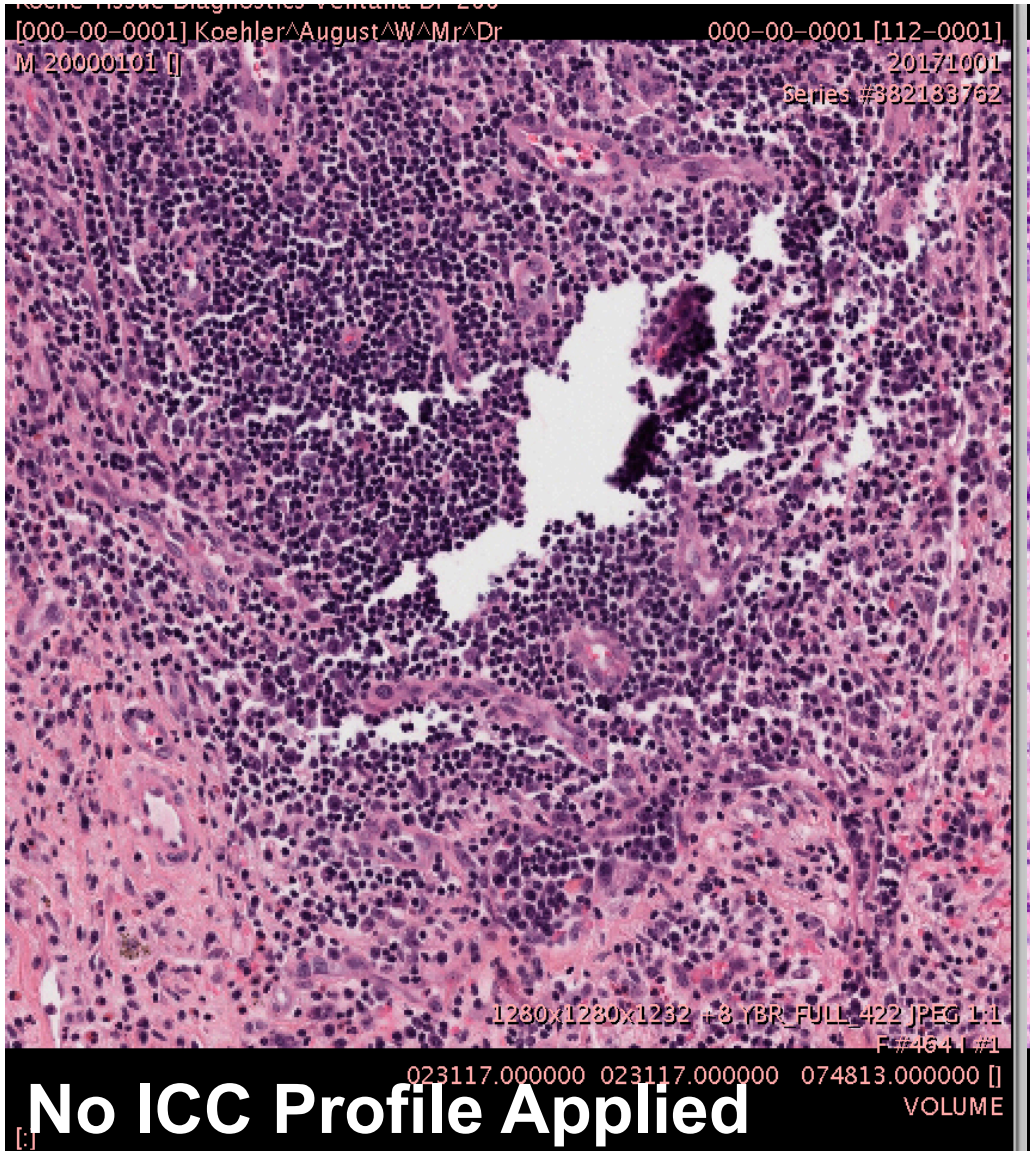
ICC Profiles

DICOM and ICC Profiles

- Characterize the scanning device
  - actually measure or specify nominal profile
- Encode and store the device profile
  - with the image in the DICOM “header”
- Characterize the display device
  - actually measure
  - keep it calibrated (back light degrades)
- Viewing “system” applies color management
  - Transforms pixel values based on input & display profiles

Goal is to achieve “Consistency” – appear similar on every device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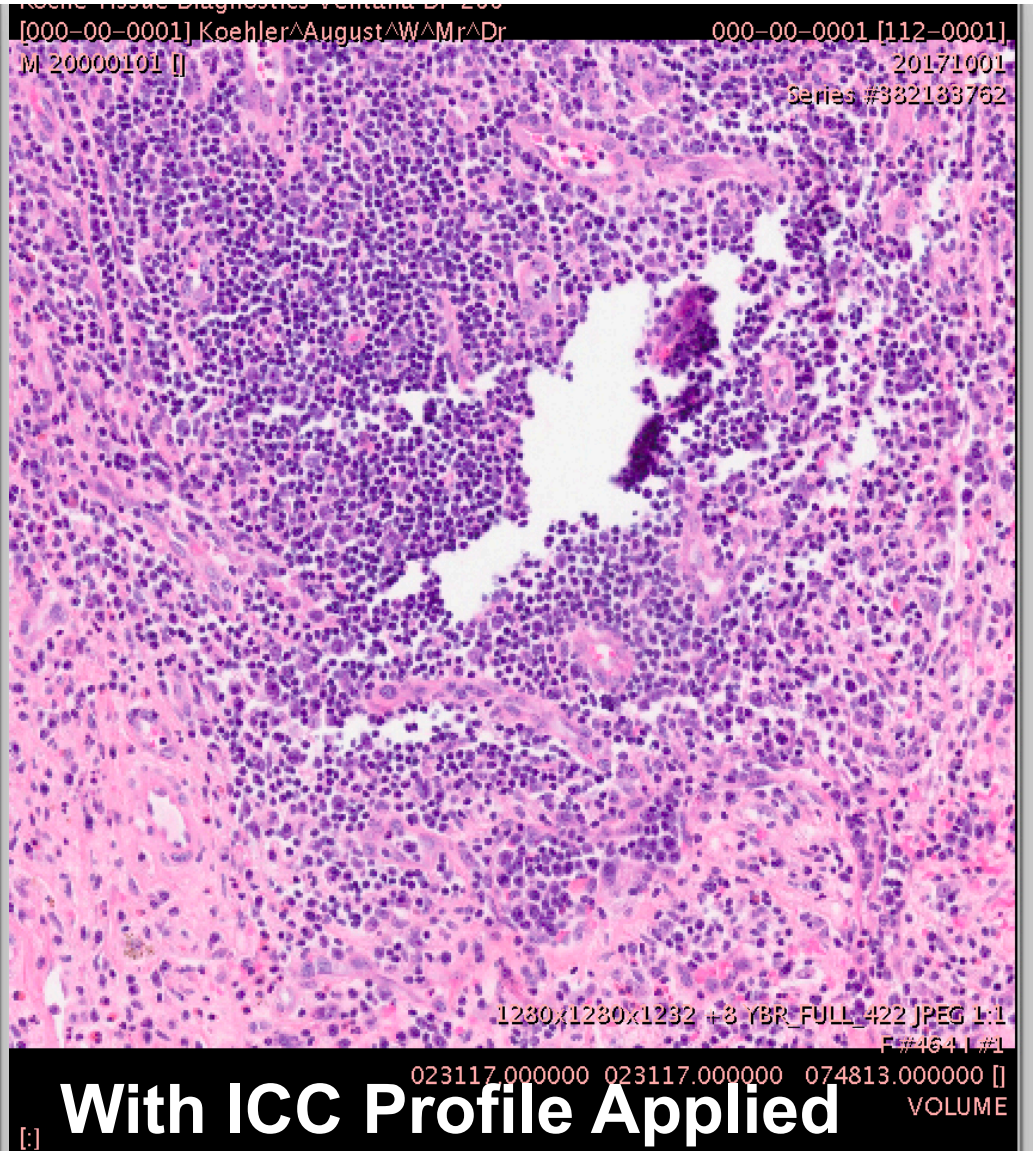
20171001
Series #382188762
1280x1280x1232 +8 YBR_FULL_422 JPEG 1:1
F#464 I #1
023117.000000 023117.000000 074813.000000 []
VOLUME
[:]
No ICC Profile Applied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000-00-0001 [112-0001]
M 20000101 []
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023117.000000 023117.000000 074813.000000 []
VOLUME
[:]
With ICC Profile Applied

Color Management – Where

- On the server
  - viewer specifies target profile (e.g., by name: sRGB, AdobeRGB, …)
  - server does color management to specified target profile
  - client does color management from specified profile to display profile
- On the client using ICC profile in the DICOM “header”
  - retrieve the ICC profile from the metadata
  - retrieve the JPEG frames (tiles) (without embedded ICC profile)
  - client performs rendering by combining them
- On the client using ICC profile in the JPEG frames
  - ask server to copy DICOM ICC profile into JPEG marker segment

Some ICC profiles are (much) larger than frame pixel data!

Dire Straits' Money for Nothing music video (1985)

"I want my ~~MTV~~ DICOM"

Boundaries vs. Architectures

- DICOM standardizes interactions across boundaries between different devices
- What IHE calls “transactions”
- Defines an “information model” but not a functional “architecture”
- I.e., can be mixed and matched in many ways
- Defining/choosing an architecture is the customer’s problem (or their integration contractor’s or single solution vendor’s)
- IHE “profiles” may define deployment patterns for use cases

DICOM – Constraining Flexibility

- DICOM defines the tools
  - IODs, Modules, Attributes, Templates, Codes
  - services – traditional DIMSE services and DICOMweb (http)
- For a specific use case
  - may be too flexible – recipients have to implement all (gratuitous) variants
- E.g., viewer connecting to server
  - pyramid or just base layer
  - dyadic (factor of 2) or unconstrained/variable decimation factor or number of layers
  - sparse or non-sparse frames in predictable or unconstrained raster order
  - Compressed Transfer Syntax: JPEG or JPEG 2000, both or others
  - DICOMDIR on media, DIMSE, DICOMweb on media, DICOMweb: JSON or XML
- Solution: use-case specific “profiles”
  - e.g., Media Application Profiles, ? future “Network Application Profiles” (à la IHE)

DICOM and your RFP/Contract

- "DICOM" now
  - or later (contractually, with penalties)
- Define actors, boundaries and transactions for your architecture & workflow:
  - AP-LIS | scanner, scanner | archive, AP-LIS | archive, …
  - archive | viewer, viewer | AP-LIS, archive | analysis, viewer | analysis, …
- Be specific:
  - DICOM Whole Slide Image Storage SOP Class
  - Compression: Baseline JPEG Transfer Syntax +/- J2K
  - +/- Concatentations (and SCP/server archive assembly if so)
  - C-STORE or DICOMweb STOW-RS (scanner to archive)
  - DICOMweb QIDO-RS, QADO-RS (archive to viewer)
  - Modality Worklist (AP-LIS to scanner) IHE APW and codes
  - Security: authentication, access control, encryption (in transit, at rest) …


Serial number:
100001

DICOM Security

- Secure in transit – network over TLS for both traditional DIMSE and DICOMweb protocols
- Secure in transit – interchange media (DVD, Memory sticks, external hard drives) – Secure DICOM Files are defined (using standard IETF CMS) but rarely used
- Secure at rest – in local or cloud archive or viewer server – Secure DICOM Files theoretically – in practice usually whole disk encryption at operating system level, etc.

- Authentication – usual measures for Web protocols (large variety, even OAUTH2), theoretically have User Identity Extended Negotiation, including Kerberos, SAML, JWT – at device/application level by TLS Client Certificates (IHE ATNA)
- Access control – largely beyond the scope of the standard (server policy based on reliably authenticated identity, which can be communicated *vide supra*)
- Audit trail – IHE ATNA and related profiles for events in DICOM PS3.15

- Standards are all very well, but no use if not implemented in tools, products, sites

No reason not to use DICOM

- Same pixels
- Same quality
- Same size
- Same speed
- Same functionality
- Better interoperability

You will be assimilated!