DICOM
Digital Imaging and Communications in Medicine

DICOM Educational Conference
Bangkok, Thailand

OCTOBER 3-4, 2019

DICOM ENTERPRISE IMAGING AND WHOLE SLIDE IMAGING

DAVID A. CLUNIE

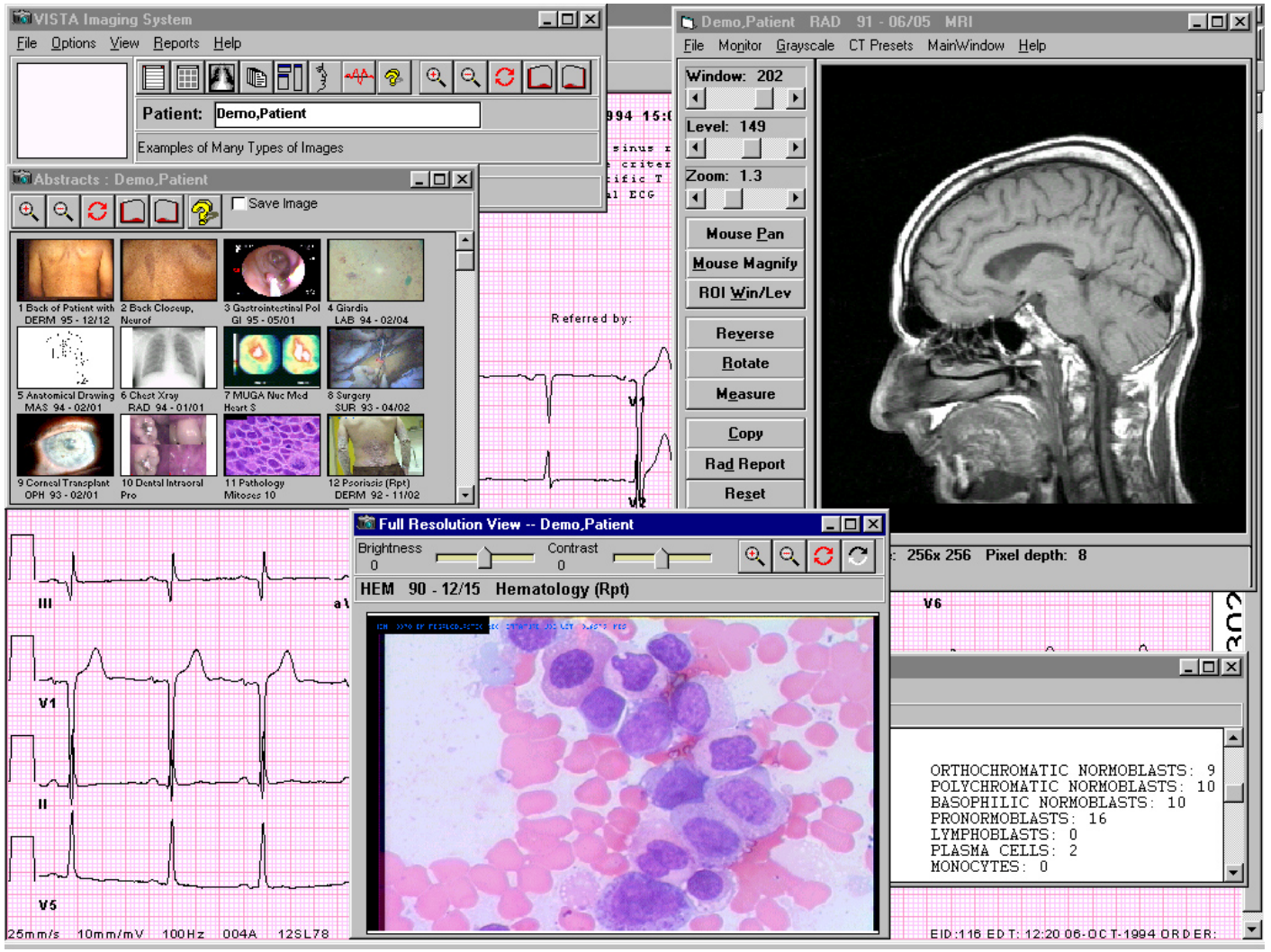
PIXELMED PUBLISHING, LLC

Disclosures

- Editor of the DICOM Standard (NEMA Contract)
- Owner of PixelMed Publishing, LLC
- Consulting for BKMedical, Canfield, Carestream, Imago, MDDX (Bioclinica)
- Supported by NIH U24CA180918 QIICR, NCI Leidos BOA 29XS219 Task Order #05

Wide Variety of Images

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



Slide of VA VISTA 1995-7 from Kuzmak P, Dayhoff R

Visible Light IODs and SOP Classes

- VL Endoscopic Image (IOD and Storage SOP Class)
- VL Microscopic Image
- VL Slide-Coordinates Microscopic Image
- VL Photographic Image

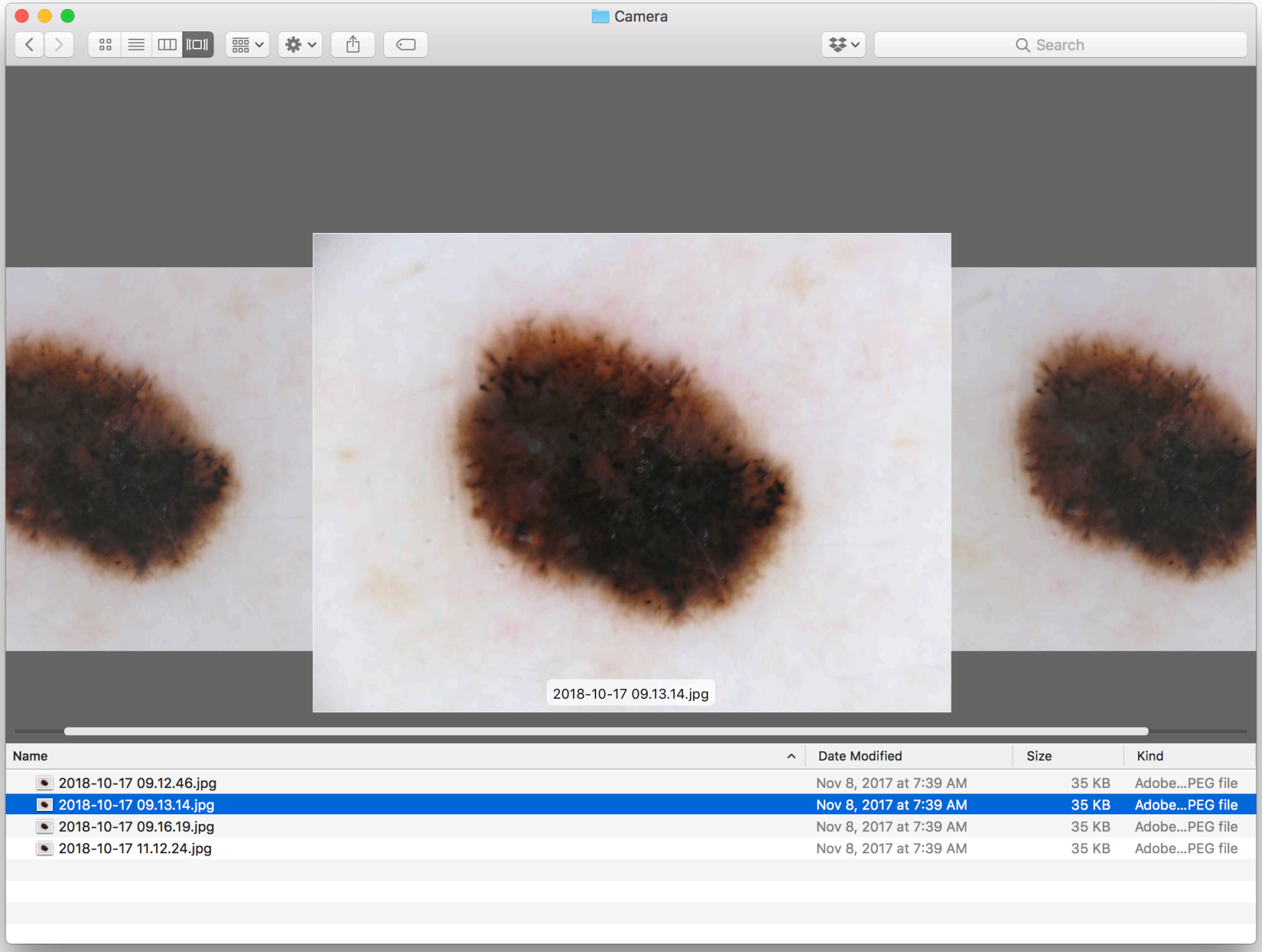
- Video Endoscopic Image
- Video Microscopic Image
- Video Photographic Image

- VL Whole Slide Microscopy Image

Ophthalmic IODs and SOP Classes

- Ophthalmic Photography 8 bit Image
- Ophthalmic Photography 16 bit Image
- Ophthalmic Tomography Image
- Ophthalmic Refractive Measurements (Lensometry, Visual Acuity, …)
- Ophthalmic Visual Field Static Perimetry Measurements
- Ophthalmic Thickness Map
- Wide Field Ophthalmic Photography Stereographic Projection Image
- Wide Field Ophthalmic Photography 3D Coordinates Image
- Ophthalmic Optical Coherence Tomography En Face Image
- Ophthalmic Optical Coherence Tomography B-scan Volume Analysis


Serial number:
100001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Search
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Name
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Adobe...PEG file
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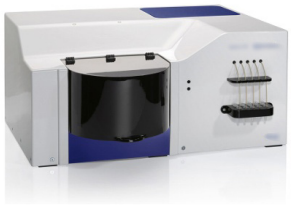
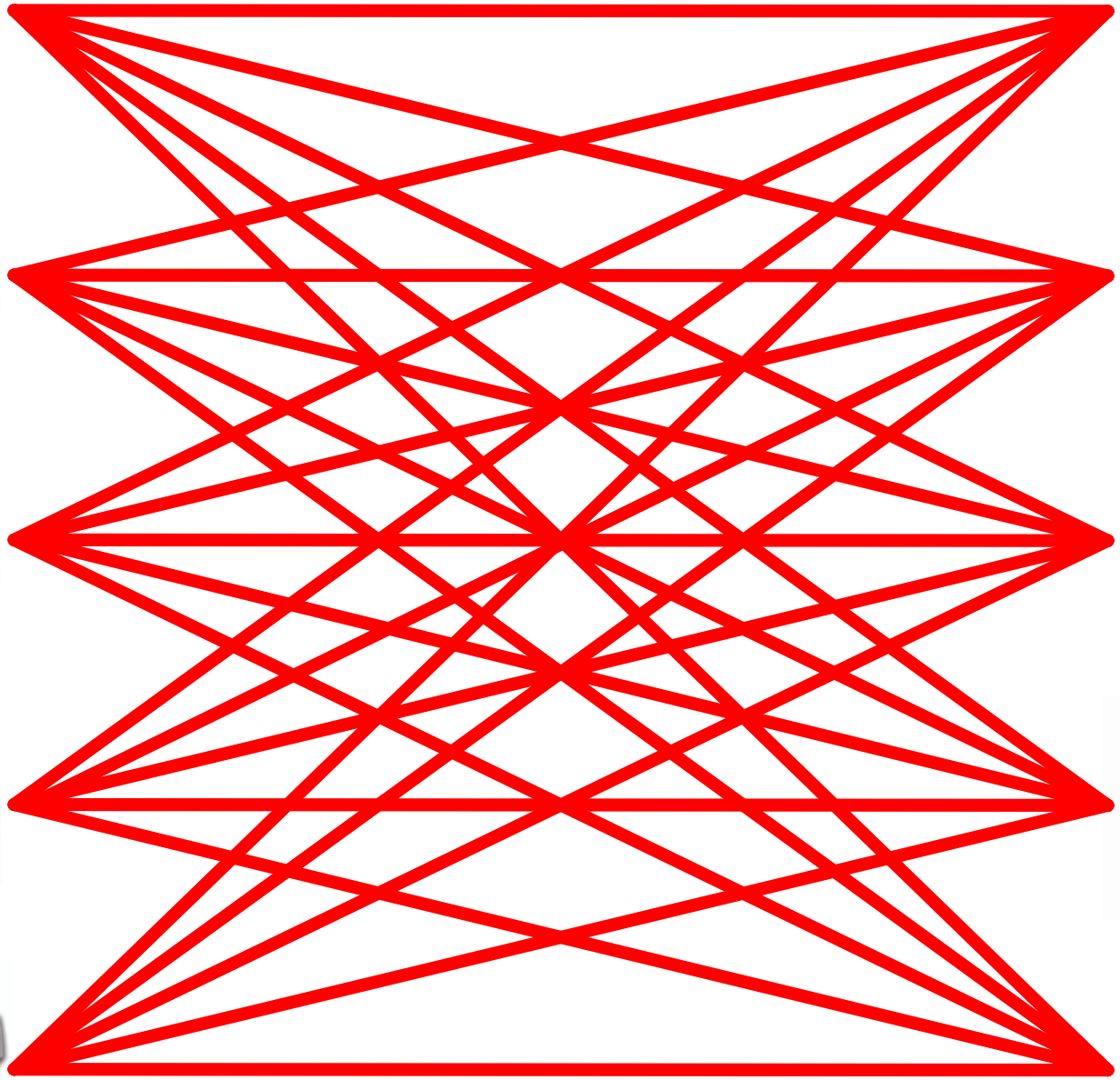
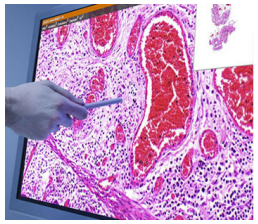
Interoperability

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

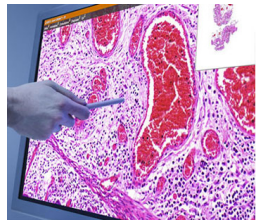
IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. 1990

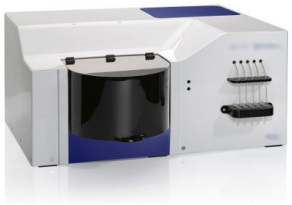




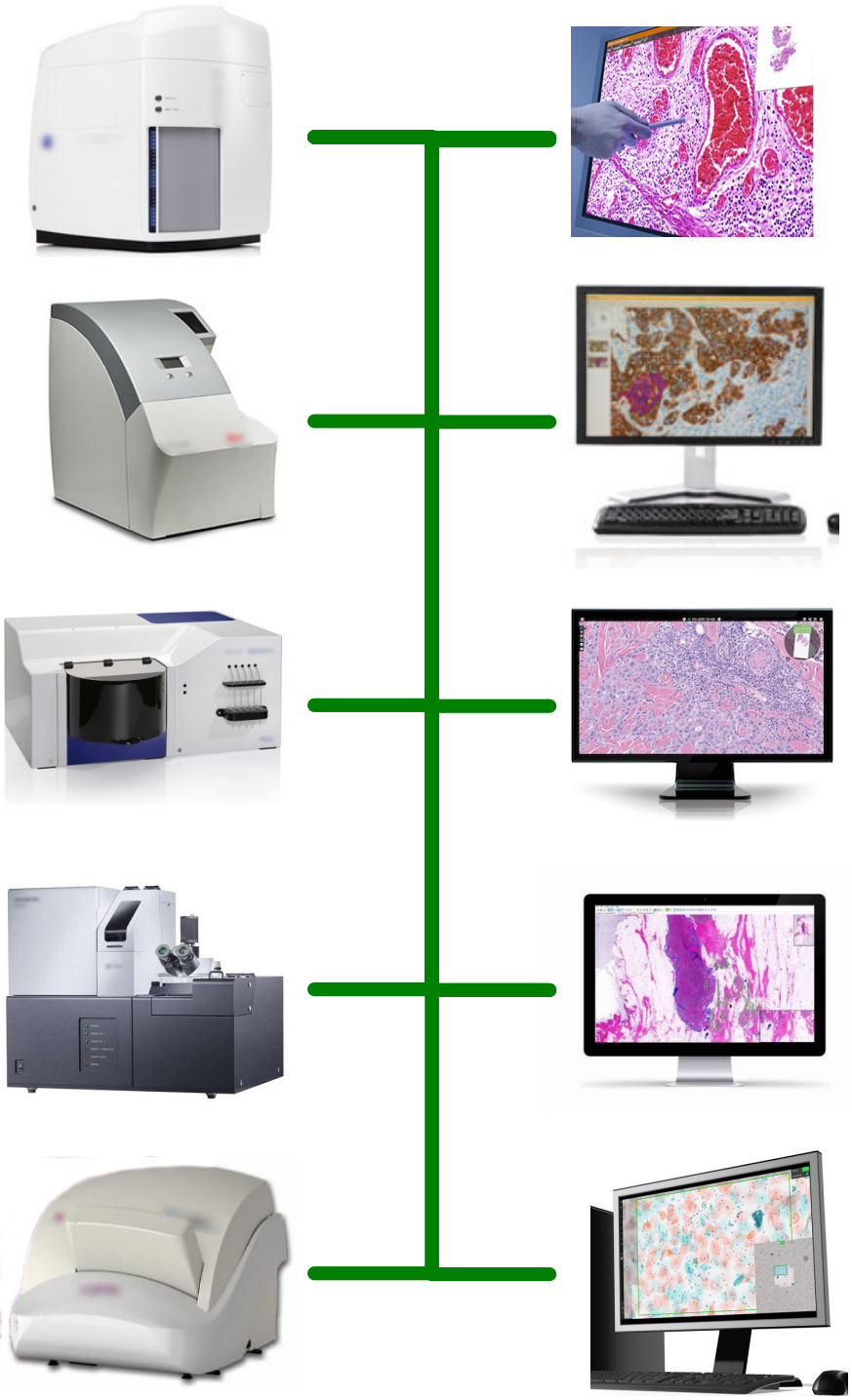




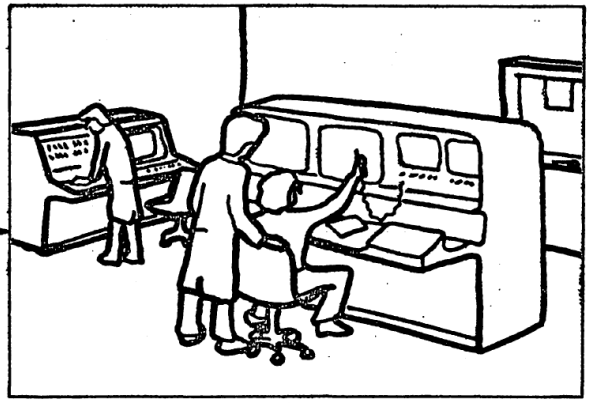


DICOM[SM]

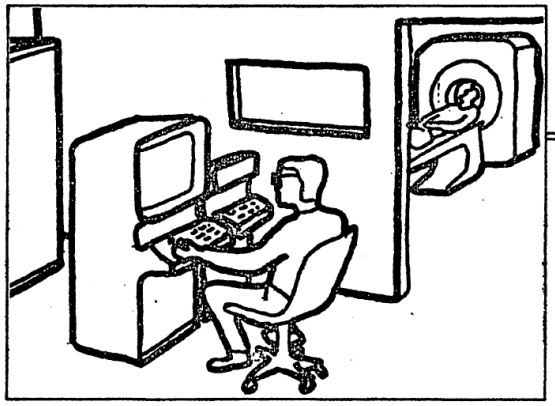
Digital Imaging and Communications in Medicine



Röntgenuntersuchung

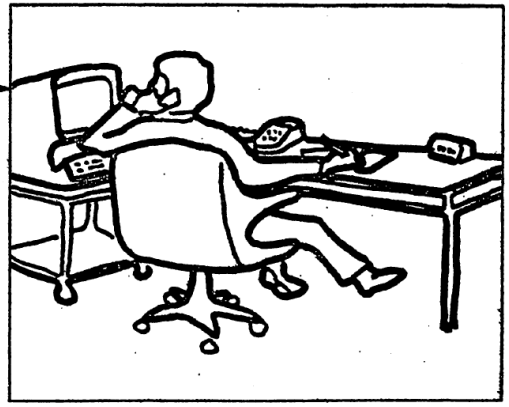


Befundung und automatische Bildauswertung



Computer-Tomographie

Kommunikationszentrale mit Bildarchiv

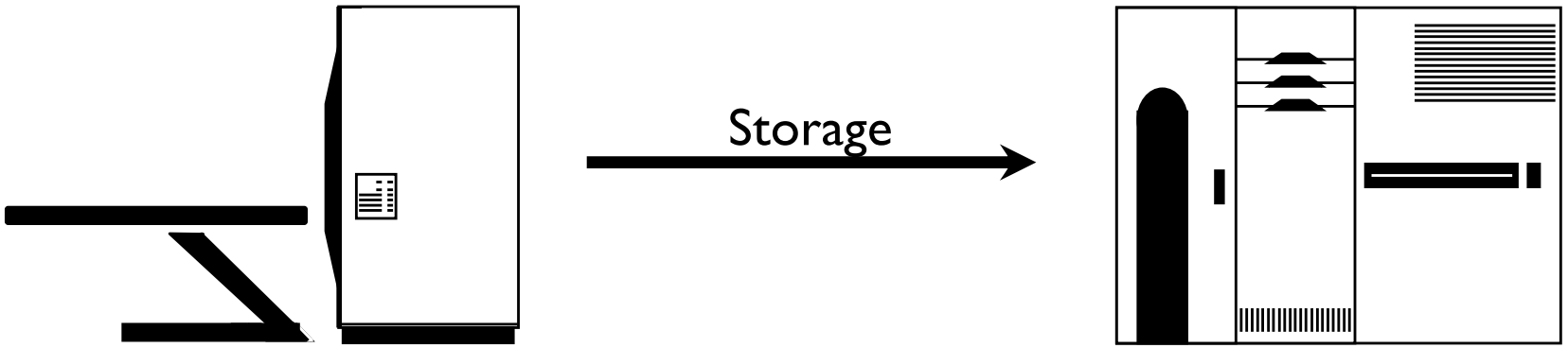


Arbeitsplatzterminal

1973

Meyer-Ebrecht D. [Electronic Archival System for X-Rays Images - Work proposal for a research project in the years 1974 and 1975] Elektronisches Archivierungssystem für Röntgenbilder – Arbeitsvorschlag für ein Forschungsprojekt in den Jahren 1974 und 1975. Hamburg, Germany: Philips Research Labs; 1973 Oct.

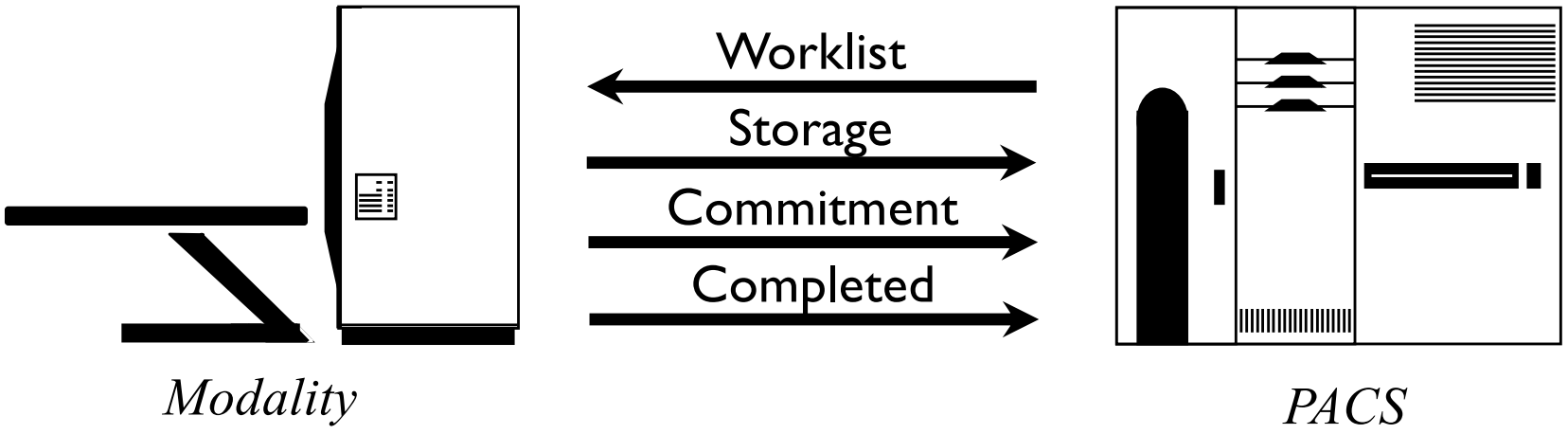
DICOM and Radiology Modality



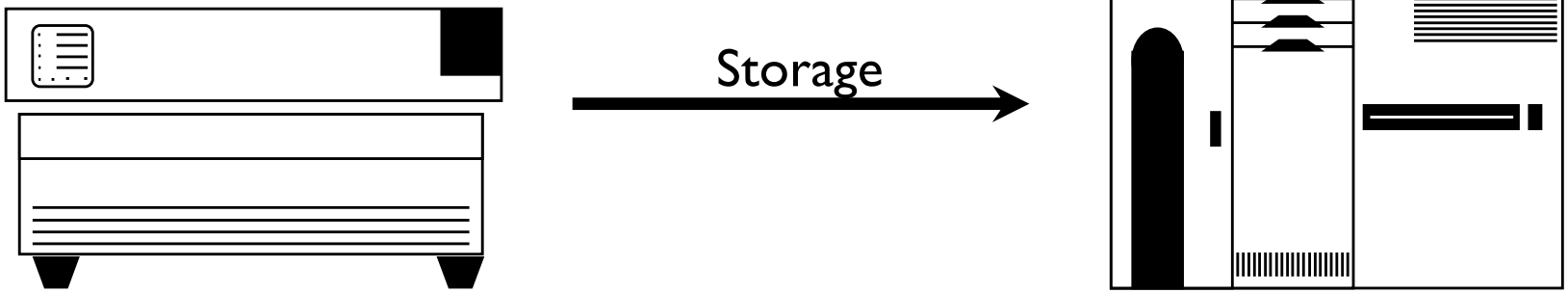
Modality

PACS

DICOM and Radiology Modality



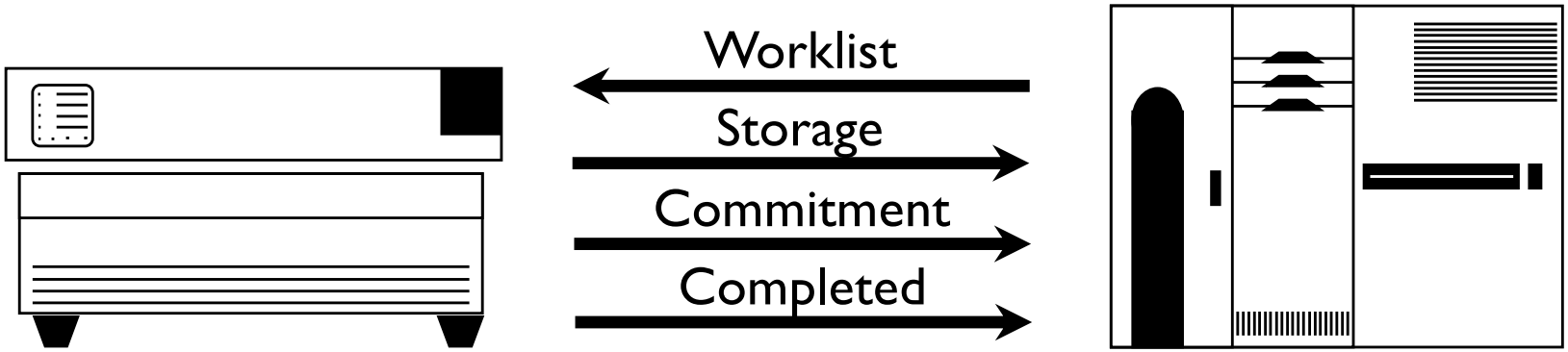
DICOM and Slide Scanner



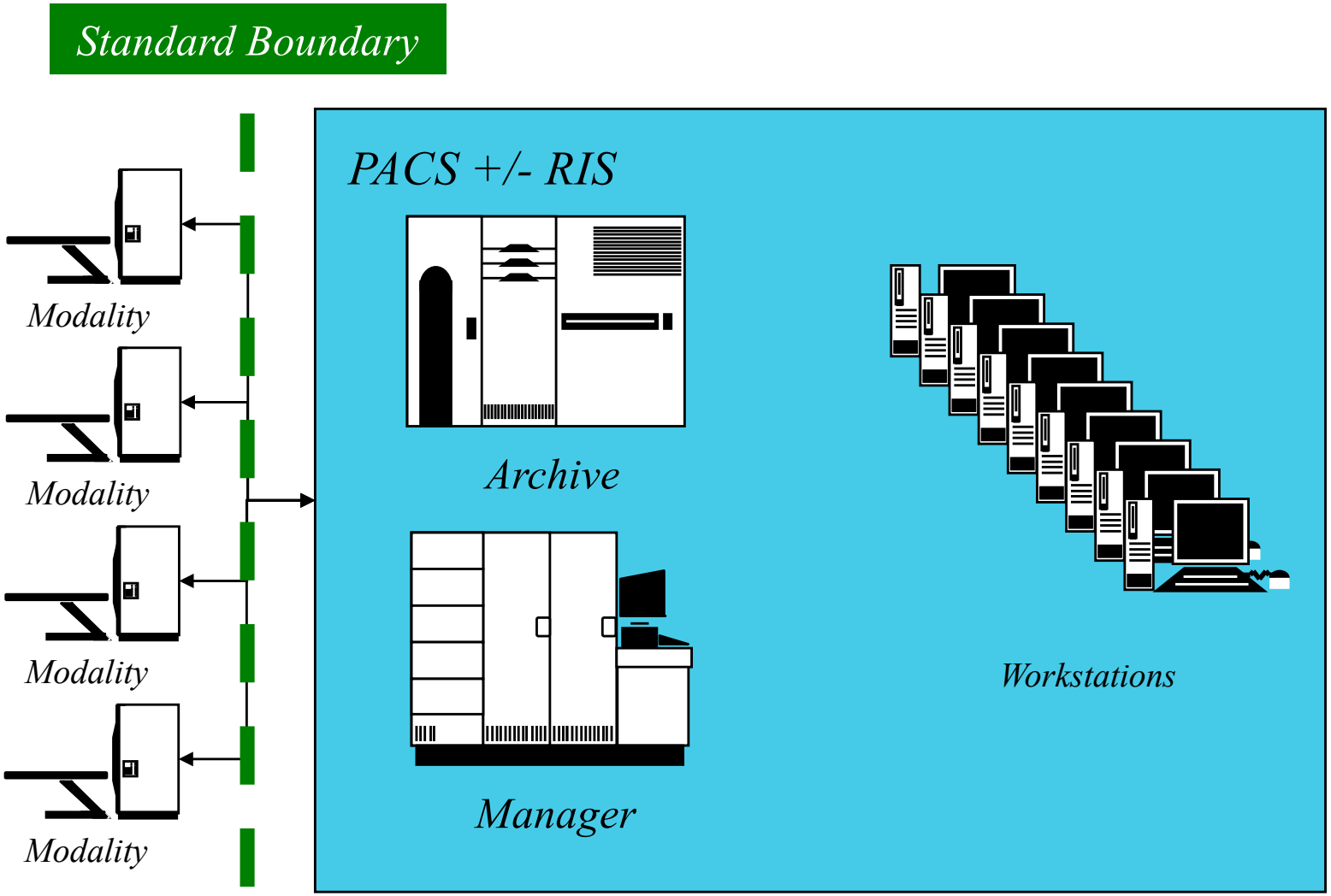
Slide Scanner

PACS

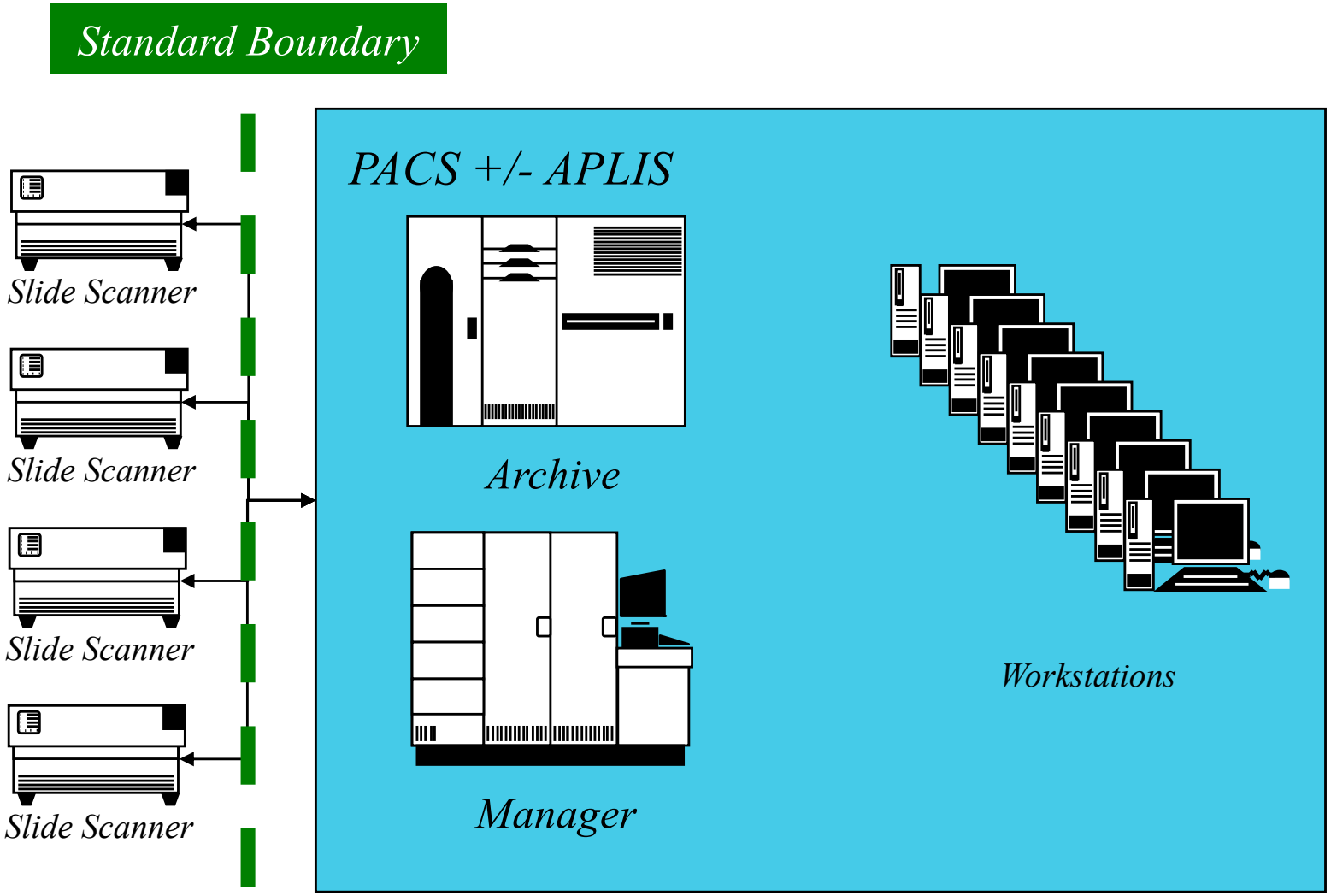
DICOM and Slide Scanner



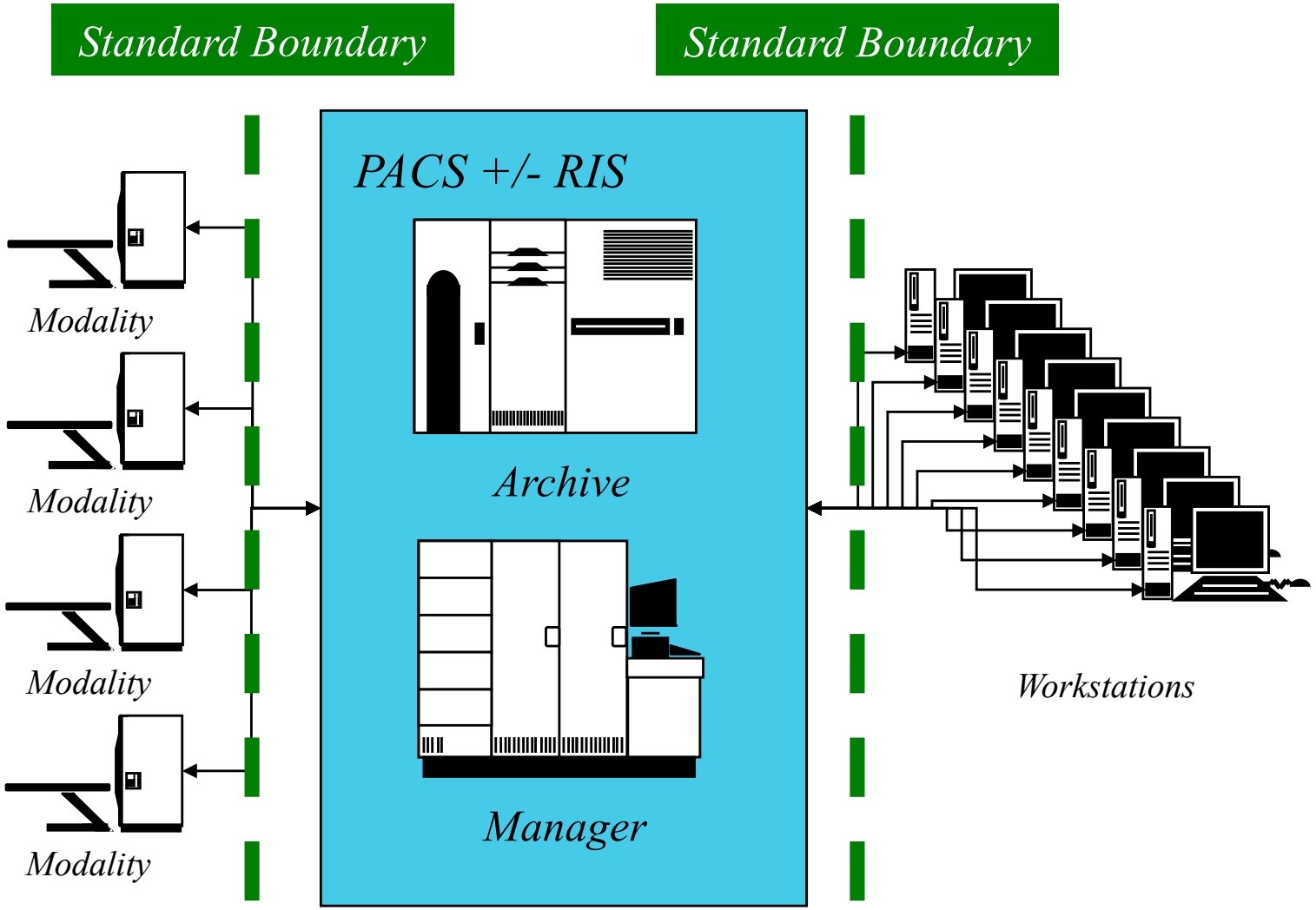
DICOM Modality to PACS



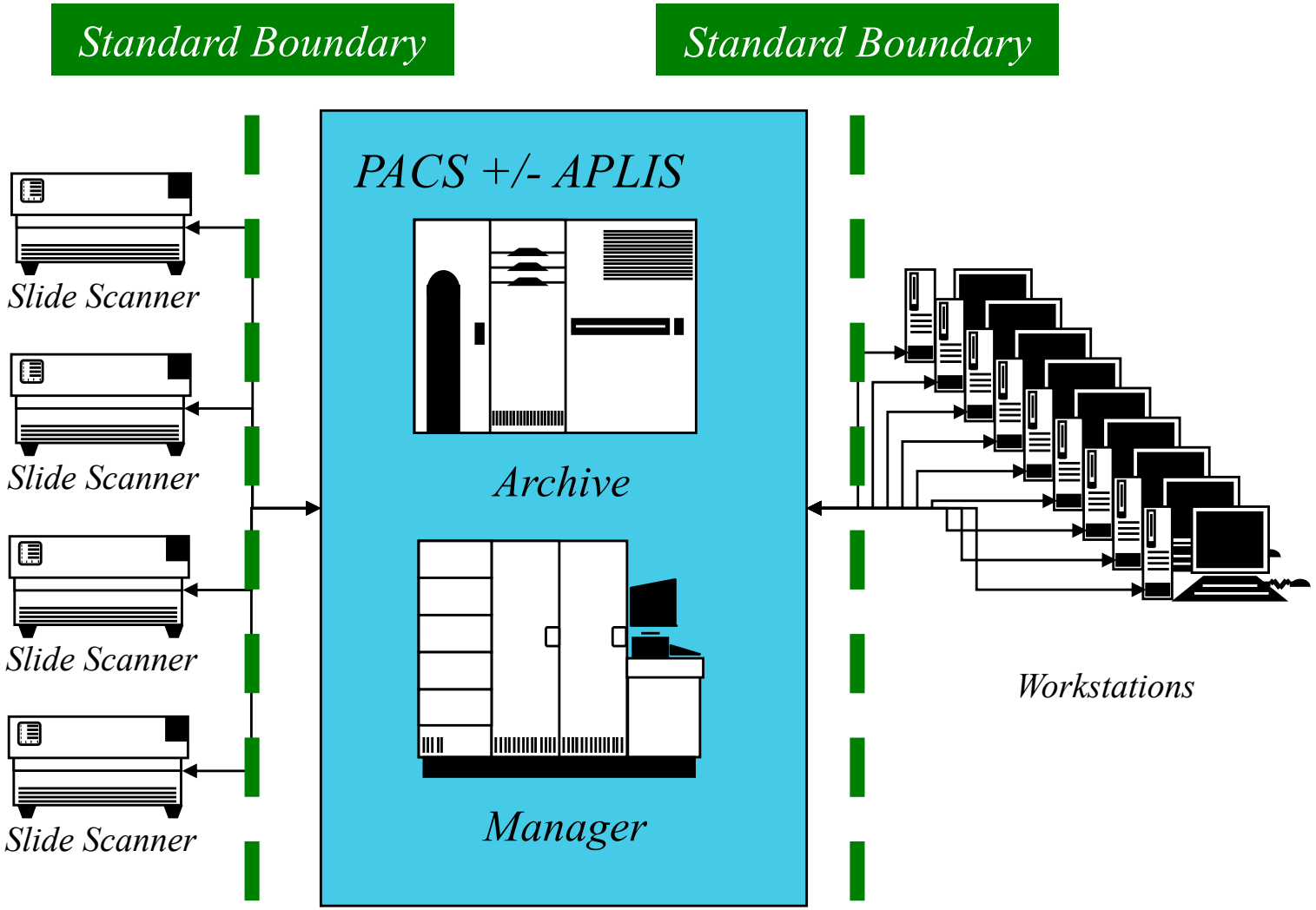
DICOM WSI to PACS



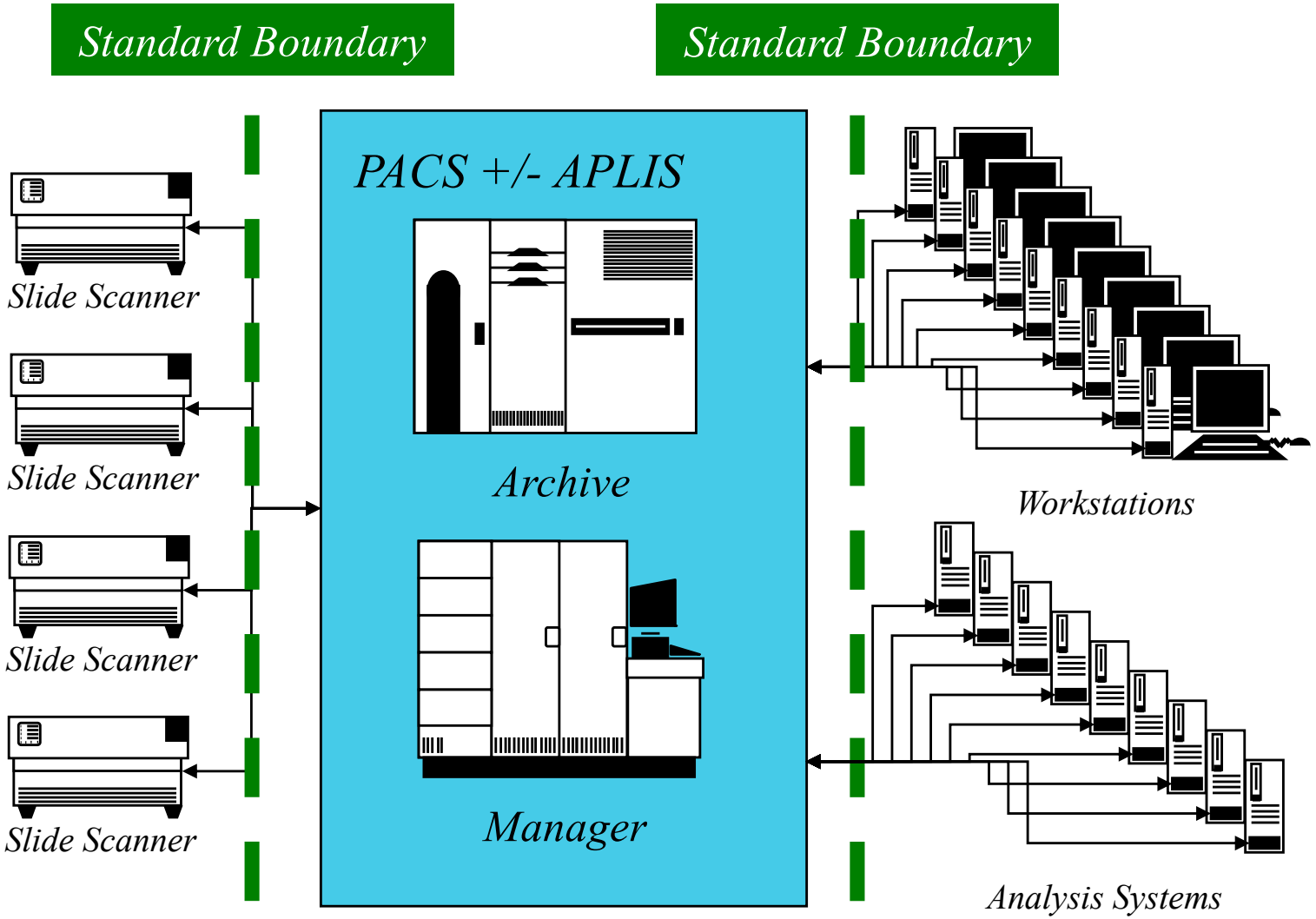
DICOM – Radiology Workstation



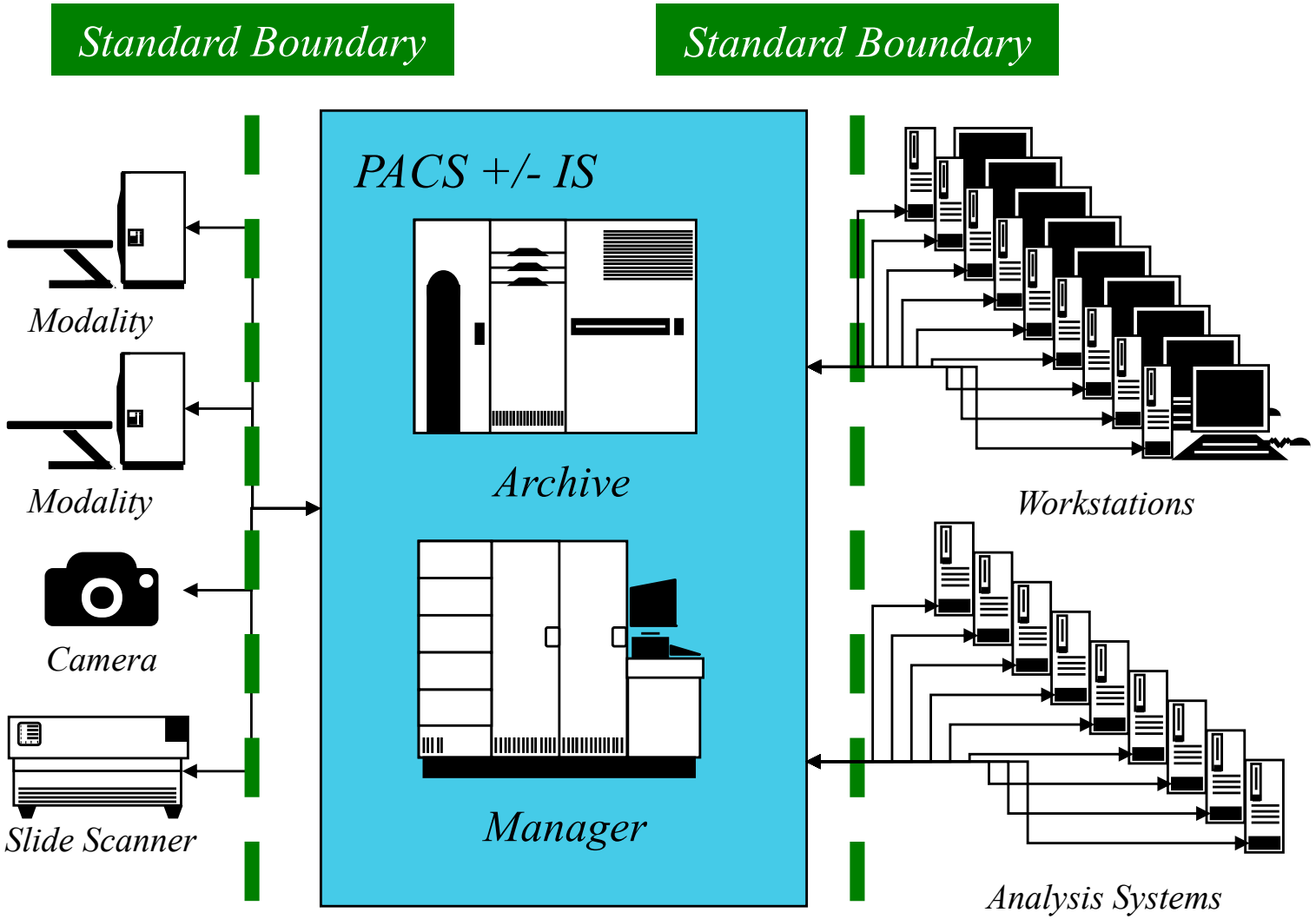
DICOM – Pathology Workstation



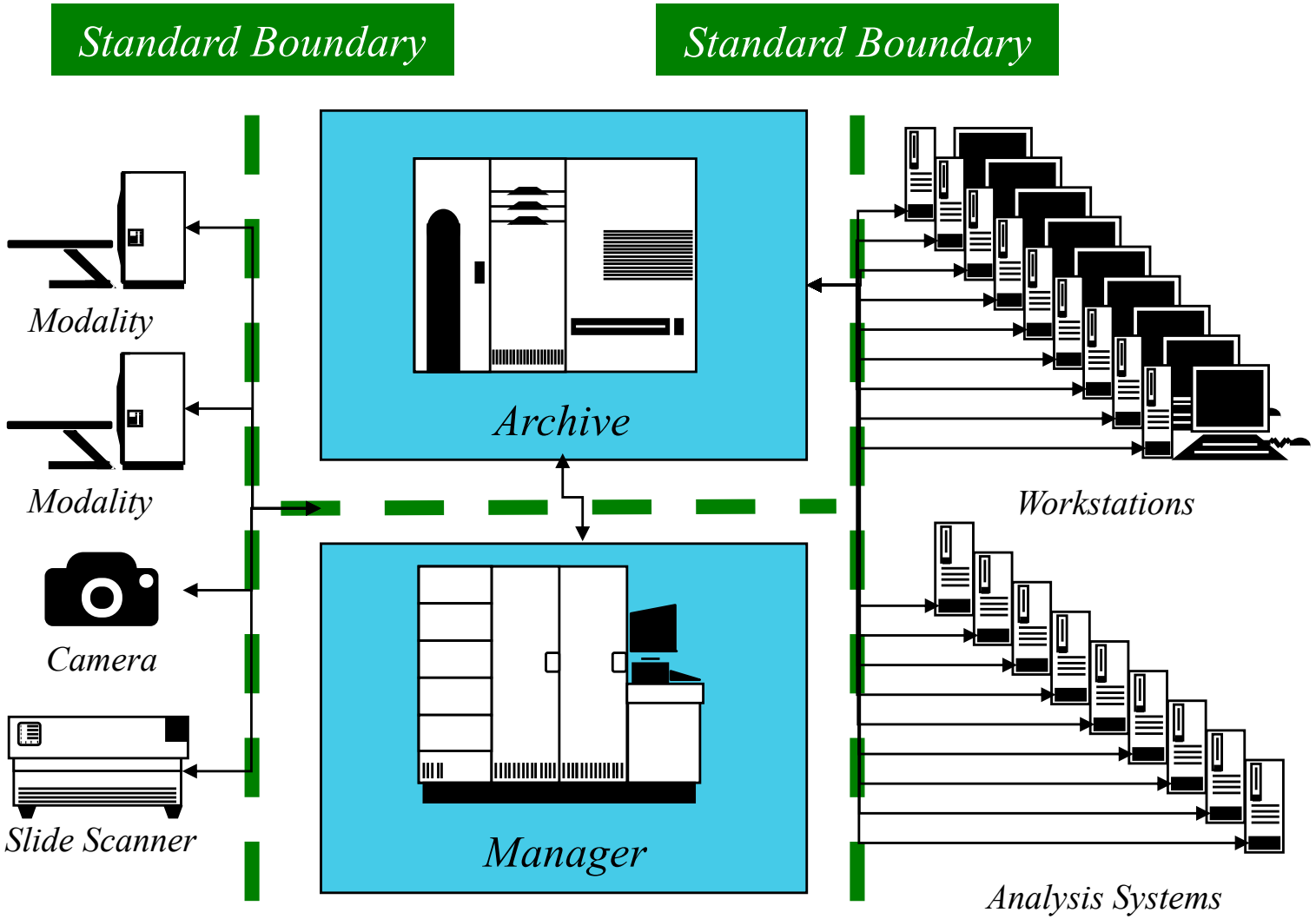
DICOM – Analysis Systems



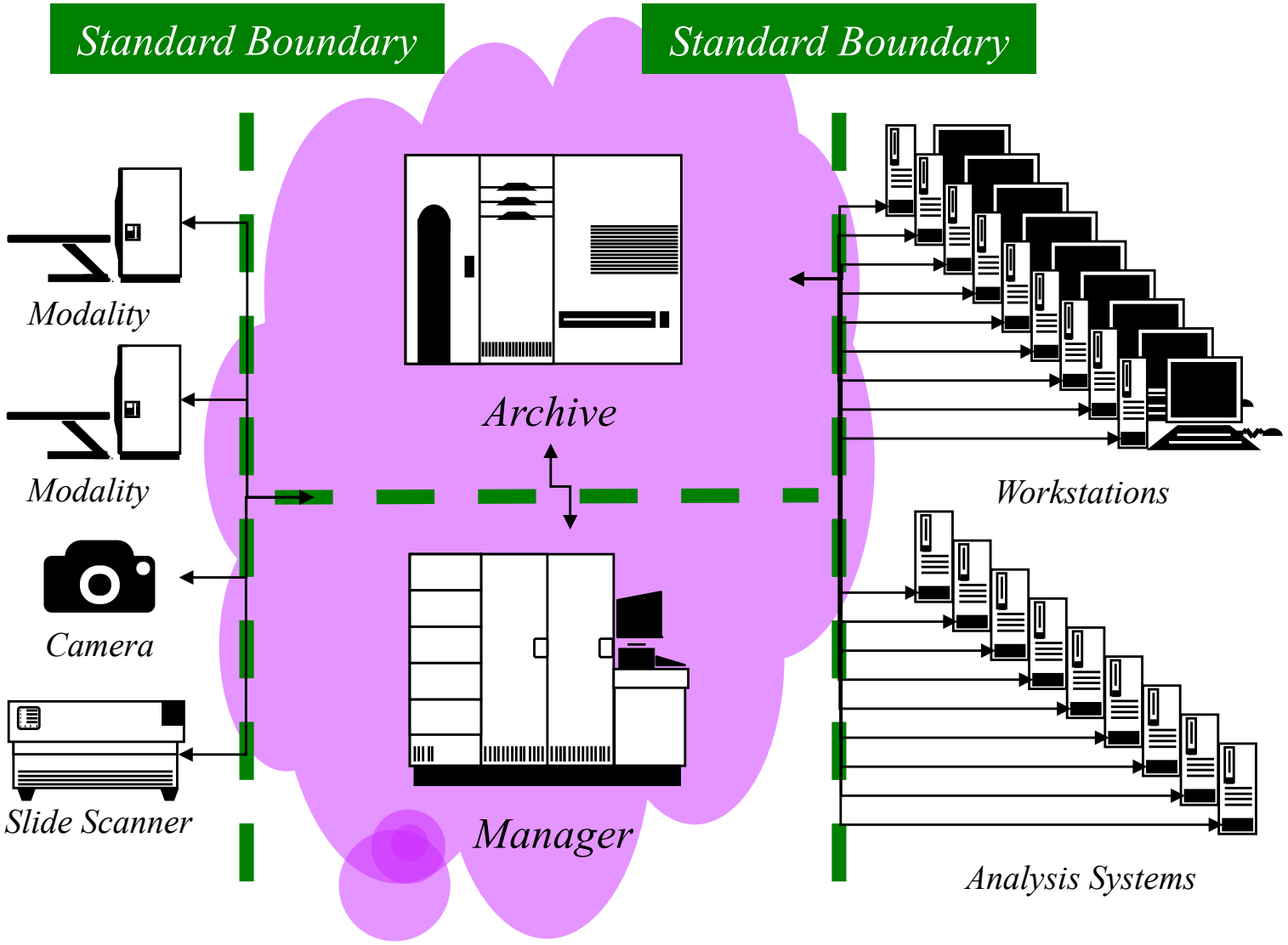
DICOM – Enterprise Imaging



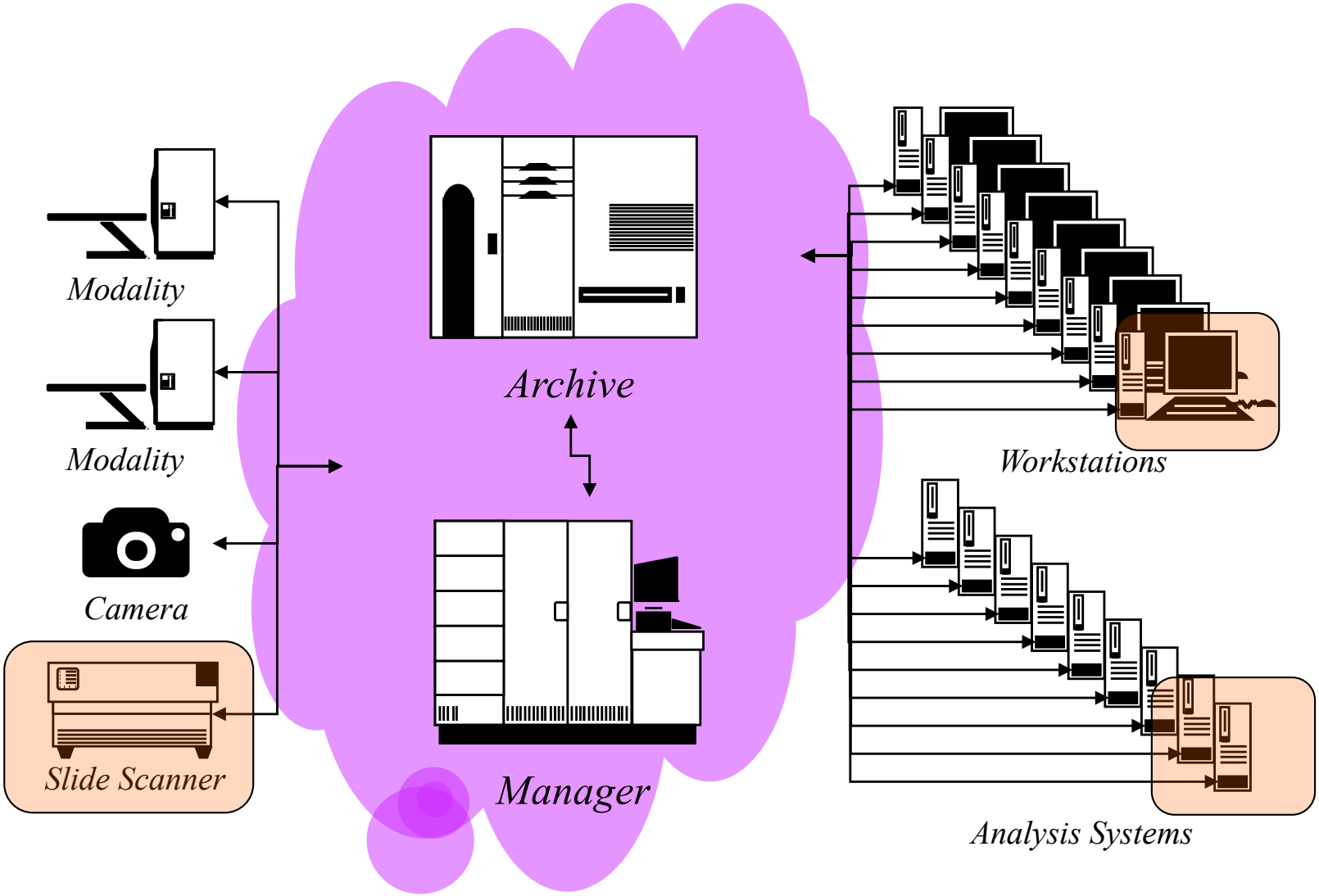
DICOM – Deconstructed PACS



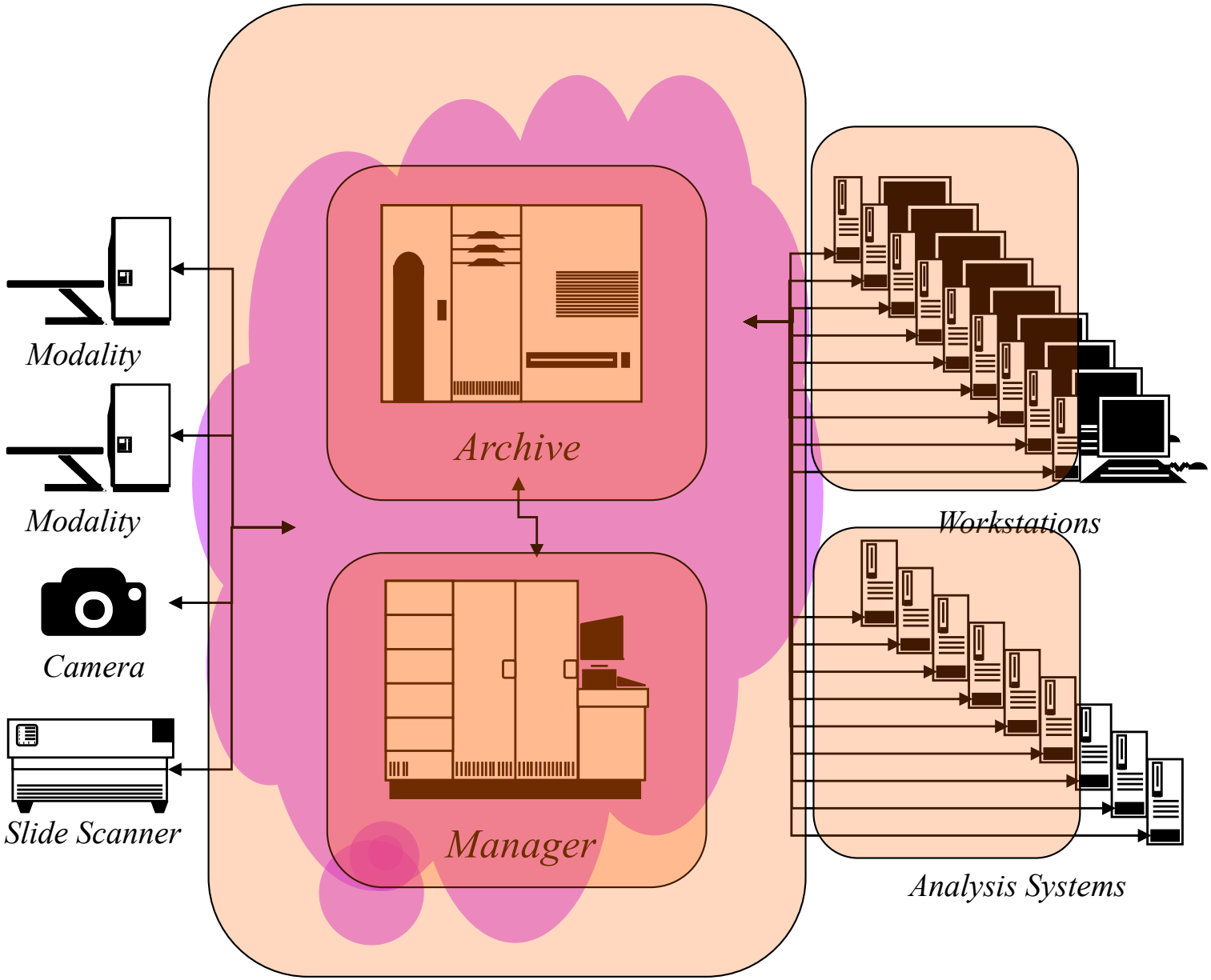
Cloud


Standard Boundary
Standard Boundary
Modality
Modality
Camera
Slide Scanner
Archive
Manager
Workstations
Analysis Systems

Pathologist/Department



Enterprise IT (Security, Reliability)



Why DICOM?

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- Enormous experience in radiology and cardiology
- 34 years since ACR-NEMA PS3 Standard (1985)
- A consensus of user and industry representatives; later adopted by ISO as ISO 12052
- 80 million CT studies per year in US (CBS News, 2015) – all DICOM
- Huge supporting infra-structure – for both DICOM file format, protocol and services
- All manner of products essentially commoditized: scanners, archives, workstations, viewers, PACS, toolkits for products, testing, analysis, research
- Both commercial and free, closed and open source tools
- Conformance and interoperability testing venues (e.g., IHE Connectathons)
- Modality agnostic – e.g., XR, MR, NM also Visible Light, esp. Ophthalmology, Endoscopy
- Application agnostic – human, veterinary, small animal research, non-destructive testing (esp. aerospace and nuclear power), security (esp. baggage scanning)
- Emphasis on reliable, consistent, standard metadata (common data elements, value sets)

Why not DICOM?

- More effort than most trivial file formats – toolkits are generally required
- Complexity is implicit in the use case more than the "format" per se – harder problems require more effort and discipline to be interoperable
- Population of metadata takes effort – is it worth that effort?
- Traditional DICOM network transport protocols are unique, though TCP/IP based – mitigated through more recent use of HTTP (WADO) using XML, JSON metadata
- Pixel data encoding not a perfect match for WSI virtual microscopy – questions of size limits and tile access – multi-frame tiles are a hack (like TIFF), but are workable
- Intellectual property (patent) distractions for WSI – now resolved
- Legacy of use of proprietary (albeit mostly TIFF-based) – why change if downstream users/apps are willing to cope?
- DICOM Conformance is not a panacea – claims of support are limited to query, storage and retrieval, worklists, etc., but NOT visualization (but DICOM does enable viewers)

Status quo for WSI

- Hodgepodge of proprietary file formats
- Some (Big-)TIFF-based (good), some not (bad)
- Some with extensions to TIFF (e.g., JPEG 2000 compression)
- Some disclosed publicly, some not
- Usually used with vendor-supplied viewer or proprietary SDK
- Possibly readable by open source or 3rd party
- Limited integration of scanners with Anatomical Laboratory Information Systems (APLIS), if at all, perhaps requiring expensive customization
- No metadata: fragile linkage to contextual data (patient, slide, handling, staining) by filename or scanned slide identifier only
- When decoupled from environment (APLIS, proprietary PACS), lose contextual data

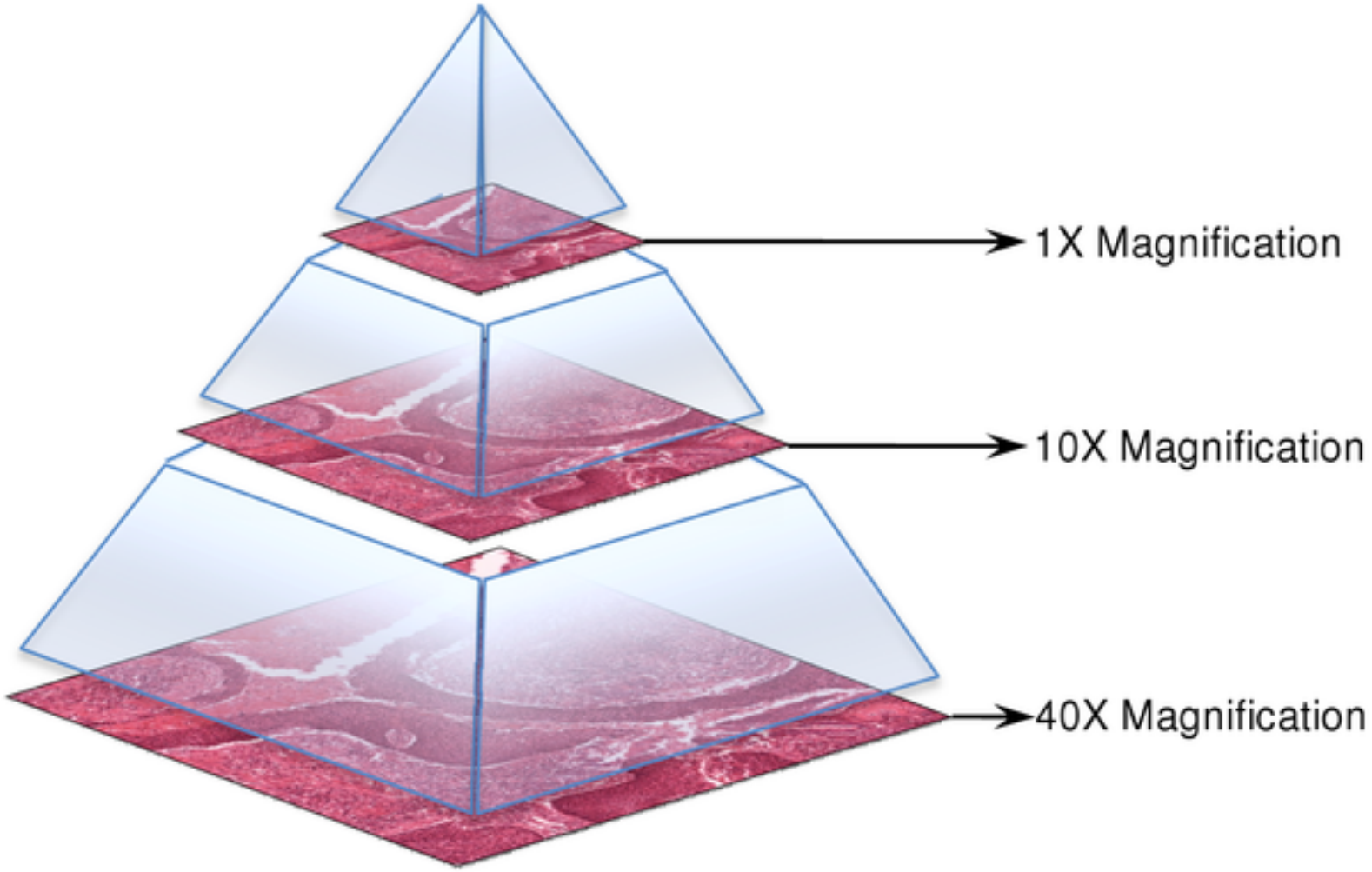
DICOM WSI – 2005 to 2019

- 1999 – Sup 15 – Visible Light including Microscopy
- 2005 – WG 26 got to work on WSI etc.
- 2006 – IHE Anatomic Pathology Domain
- 2008 – Sup 122 – Specimen Module
- 2008 – IHE Anatomic Pathology Workflow
- 2010 – Sup 145 – Whole Slide Microscopic Image IOD
- … *seven years of silence* …
- 2017 – 1st premarket approval for primary diagnostic use
- 2017 – 1st WG 26 Digital Pathology Connectathon (PV)
- 2018 – three Connectathons (PathInfo, ECDP/NDP, PV)
- 2019 – 2nd premarket approval for primary diagnostic use
- 2019 – 6th Connectathon upcoming – 11 vendors registered

DICOM WSI – What and How

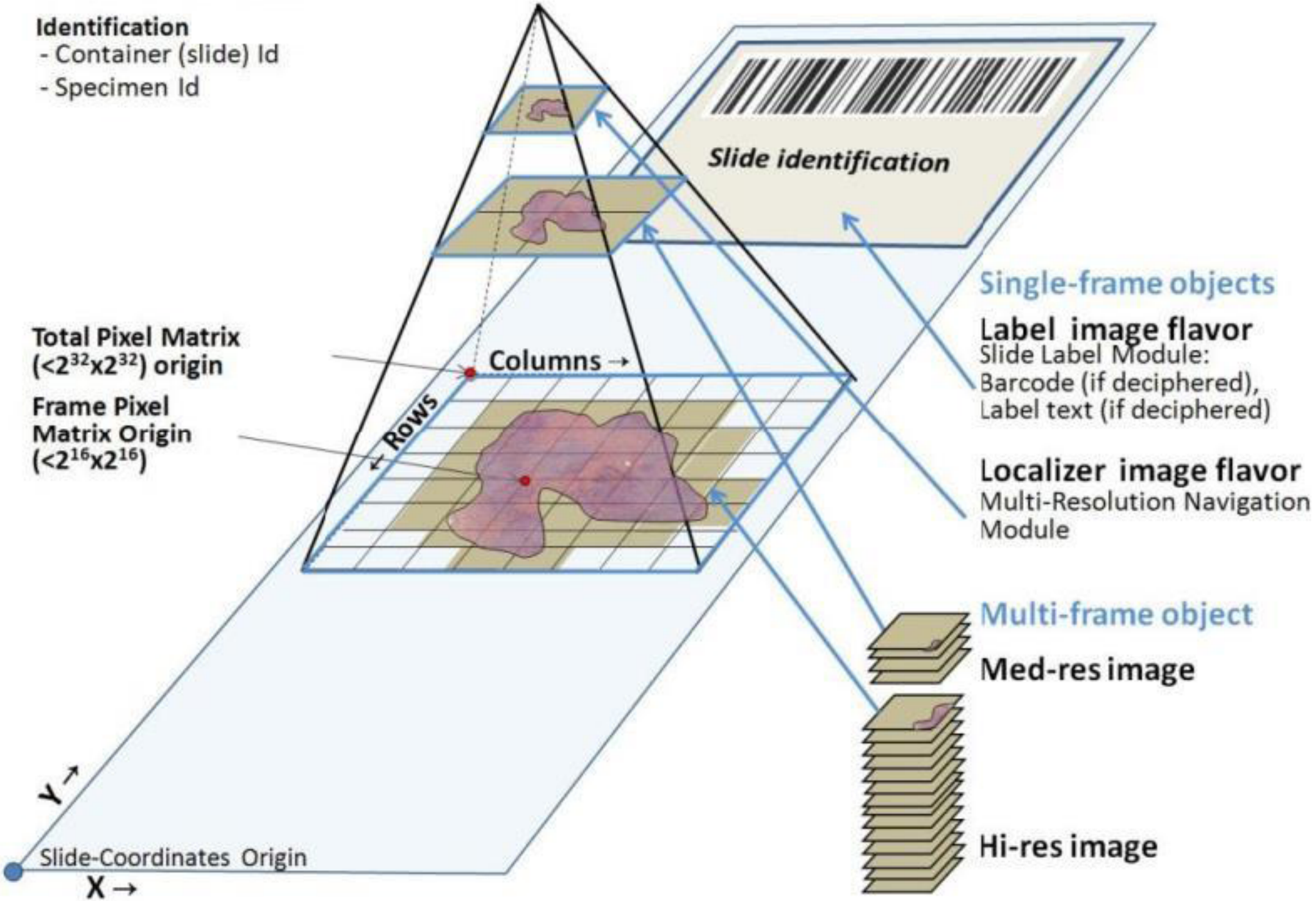
- File format for:
  - whole slide images (tiled pyramid)
  - single fields – slide microscopy
  - gross microscopy
- File contains:
  - compressed pixels (JPEG or JPEG 2000)
  - metadata – identifying and descriptive
- Protocol for sending and receiving, etc.
- Other stuff like workflow, annotation, segmentation, structured reports, …

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



DICOM WSI: Why tiled pyramids?

- Goal is simplicity of access simulating a microscope
- Zoom and pan
- Tiles (frames): allow access to rectangular sub-regions of each resolution layer (without loading entire huge object)
- Pyramid: entire highest resolution layer is very large, so storing lower magnification layers (for faster zooming) takes little extra space (about 30%)
- Works around DICOM single frame size limitations (64k x 64k): no change to underlying DICOM encoding, no change to existing DICOM toolkits and archives
- Do need services for metadata (index: which tile is which frame) and frame-level retrieval – WADO-RS

Why reinvent TIFF?

- TIFF (or BigTIFF) is the basis of many proprietary formats

- Open Microscopy Environment (OME) TIFF is a good format
- Data model and XML metadata
- Microscopy-specific
- Strong in the research community (esp. non-WSI microscopy)
- Open source library support

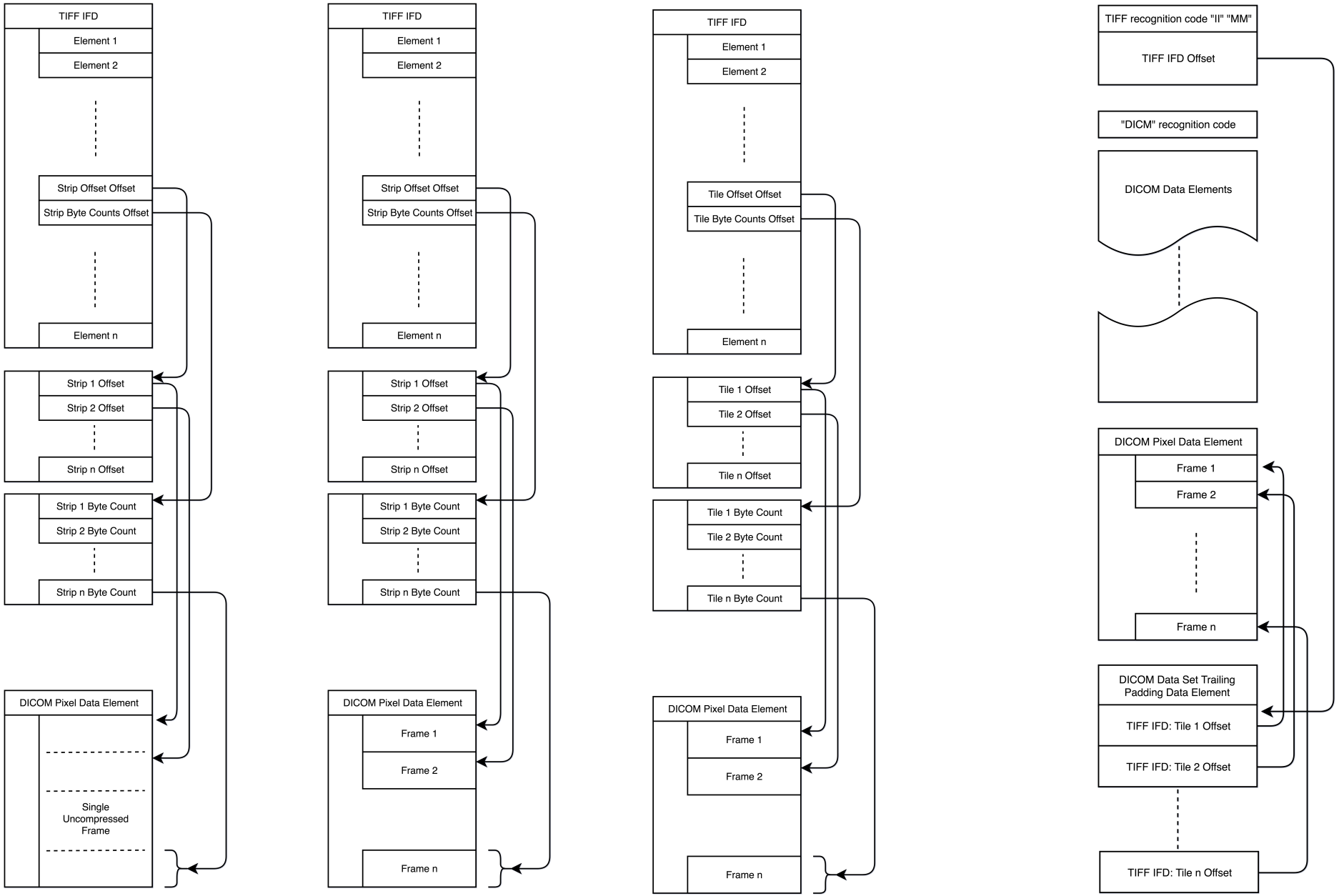
- Real question is: why reinvent DICOM when DICOM is used for all other images in the hospital?
- TIFF usage -> just another silo (pathology), even if it is "open"

https://www.teeturtle.com/products/have-your-cake-and-eat-it-too

Dual Personality DICOM-TIFF

- DICOM file format was designed to coexist with a second format
- Bulk data (compressed pixels) shared between both formats
- E.g., a single stored file can be both DICOM and OME-TIFF
- Ideally would harmonize DICOM and OME metadata so that not only are pixels shared but identification and descriptions consistent

- Mechanism: use 128 byte preamble to contain TIFF Image File Directory (IFD) to points to Dataset Trailing Padding after DICOM content, points back to payload of DICOM Pixel Data element
- Both DICOM and TIFF use sufficiently similar JPEG encoding of pyramidal tiles to make this work for WSI


TIFF IFD
Element 1
Element 2
Strip Offset Offset
Strip Byte Counts Offset
Element n
Strip 1 Offset
Strip 2 Offset
Strip n Offset
Strip 1 Byte Count
Strip 2 Byte Count
Strip n Byte Count
DICOM Pixel Data Element
Single Uncompressed Frame
TIFF IFD
Element 1
Element 2
Strip Offset Offset
Strip Byte Counts Offset
Element n
Strip 1 Offset
Strip 2 Offset
Strip n Offset
Strip 1 Byte Count
Strip 2 Byte Count
Strip n Byte Count
DICOM Pixel Data Element
Frame 1
Frame 2
Frame n
TIFF IFD
Element 1
Element 2
Tile Offset Offset
Tile Byte Counts Offset
Element n
Tile 1 Offset
Tile 2 Offset
Tile n Offset
Tile 1 Byte Count
Tile 2 Byte Count
Tile n Byte Count
DICOM Pixel Data Element
Frame 1
Frame 2
Frame n
TIFF recognition code "II" "MM"
TIFF IFD Offset
"DICM" recognition code
DICOM Data Elements
DICOM Pixel Data Element
Frame 1
Frame 2
Frame n
DICOM Data Set Trailing Padding Data Element
TIFF IFD: Tile 1 Offset
TIFF IFD: Tile 2 Offset
TIFF IFD: Tile n Offset

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Technical Note

Dual-Personality DICOM-TIFF for Whole Slide Images: A Migration Technique for Legacy Software

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Pixelmed Publishing, LLC, Bangor, Pennsylvania, USA

Received: 02 December 2018 Accepted: 06 March 2019 Published: 03 April 2019

Abstract

Despite recently organized Digital Imaging and Communications in Medicine (DICOM) testing and demonstration events involving numerous participating vendors, it is still the case that scanner manufacturers, software developers, and users continue to depend on proprietary file formats rather than adopting the standard DICOM whole slide microscopic image object. Many proprietary formats are Tagged Image File Format (TIFF) based, and existing applications and libraries can read tiled TIFF files. The sluggish adoption of DICOM for whole slide image encoding can be temporarily mitigated by the use of dual-personality DICOM-TIFF files. These are compatible with the installed base of TIFF-based software, as well as newer DICOM-based software. The DICOM file format was deliberately designed to support this dual-personality capability for such transitional situations, although it is rarely used. Furthermore, existing TIFF files can be converted into dual-personality DICOM-TIFF without changing the pixel data. This paper demonstrates the feasibility of extending the dual-personality concept to multiframe-tiled pyramidal whole slide images and explores the issues encountered. Open source code and sample converted images are provided for testing.

Keywords: Digital Imaging and Communications in Medicine, Tagged Image File Format, whole slide imaging

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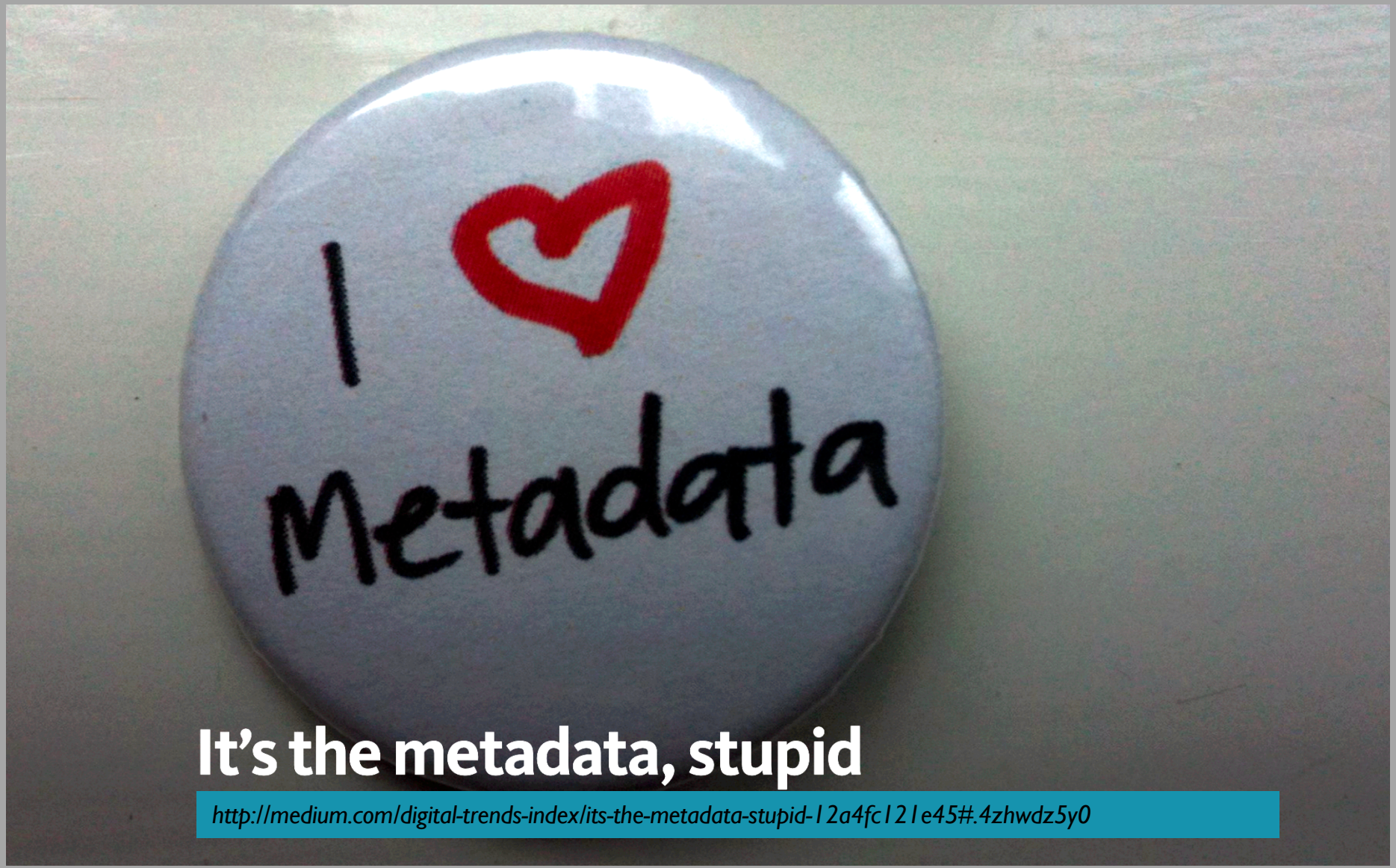

It's the metadata, stupid

http://medium.com/digital-trends-index/its-the-metadata-stupid-12a4fc121e45#.4zhwdz5y0

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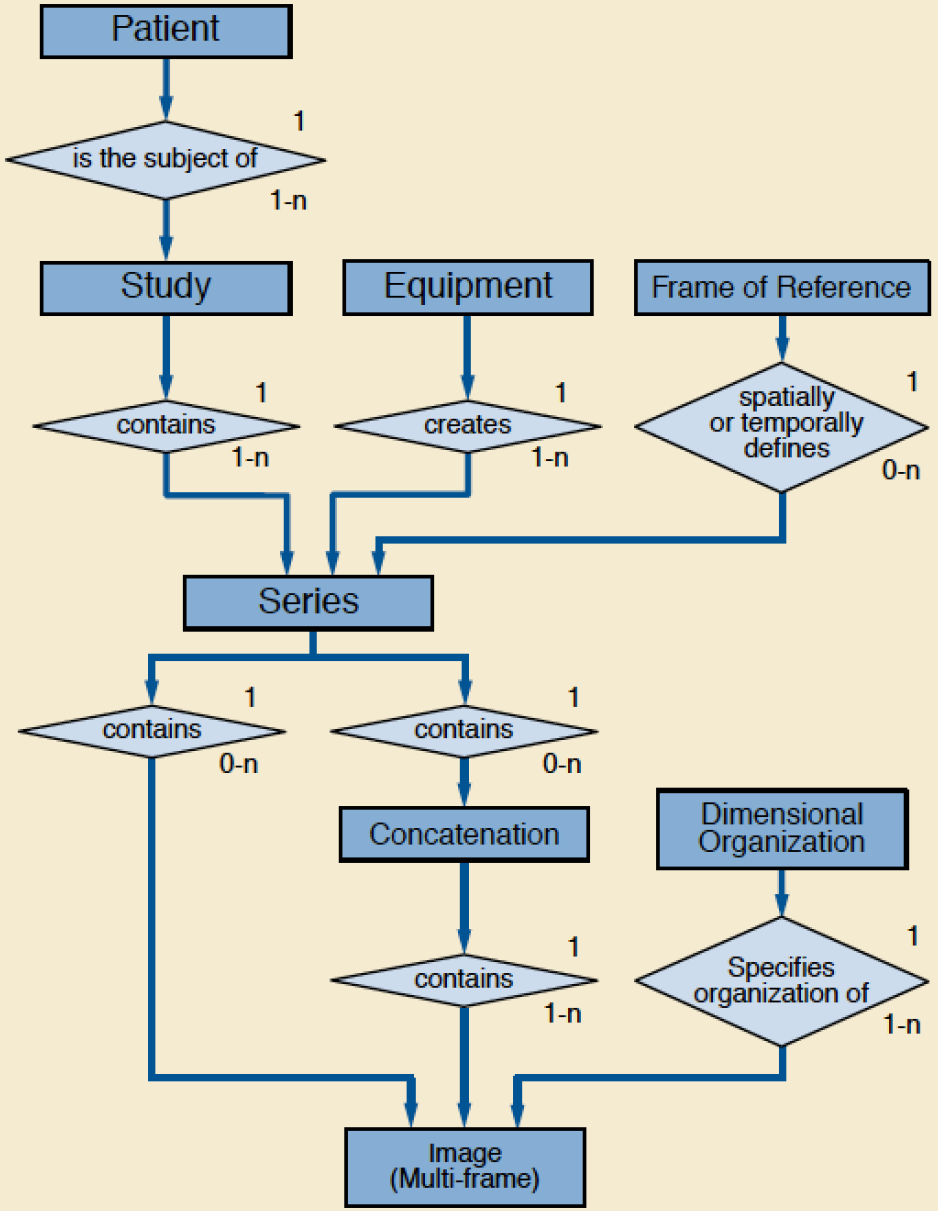

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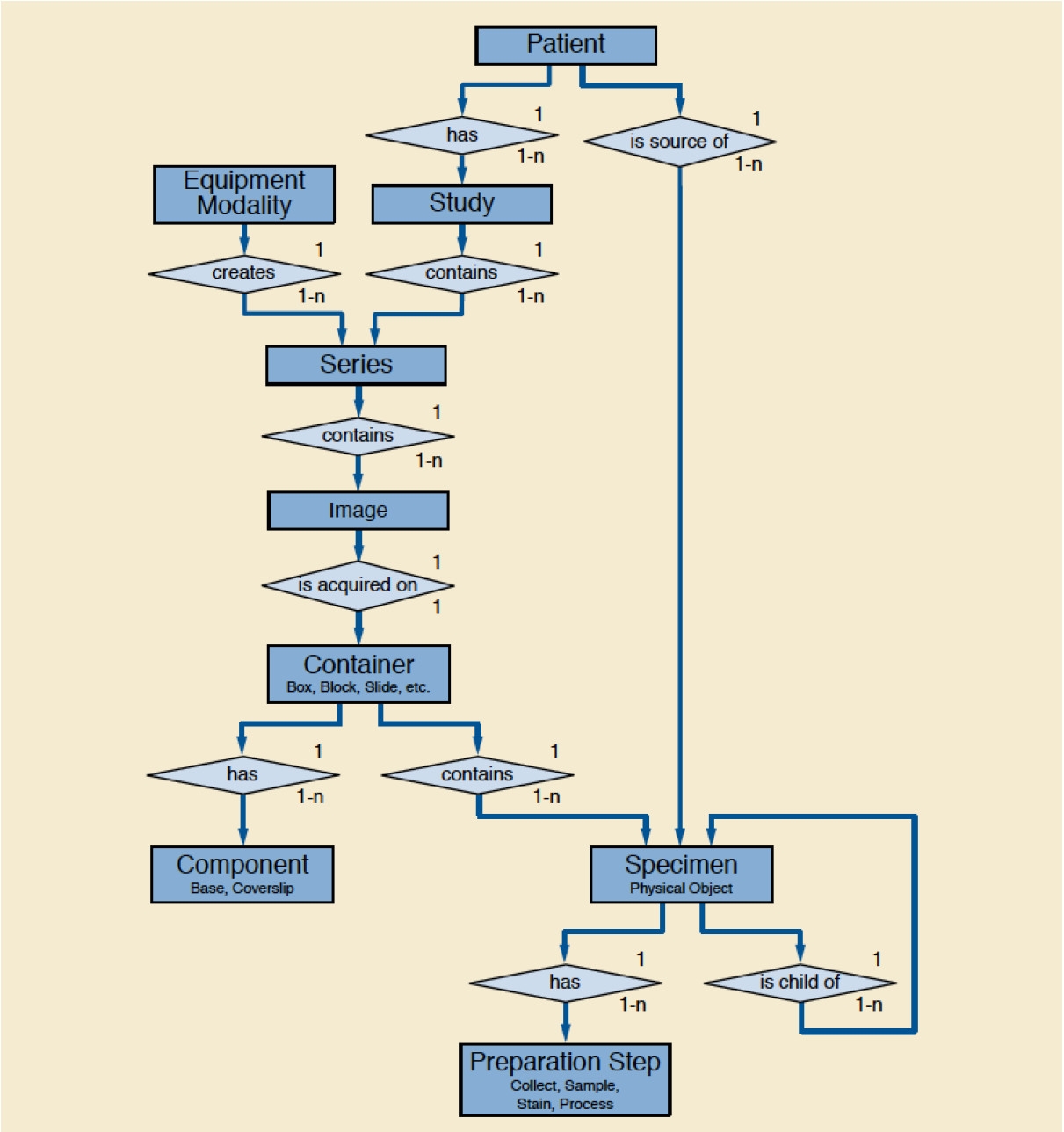
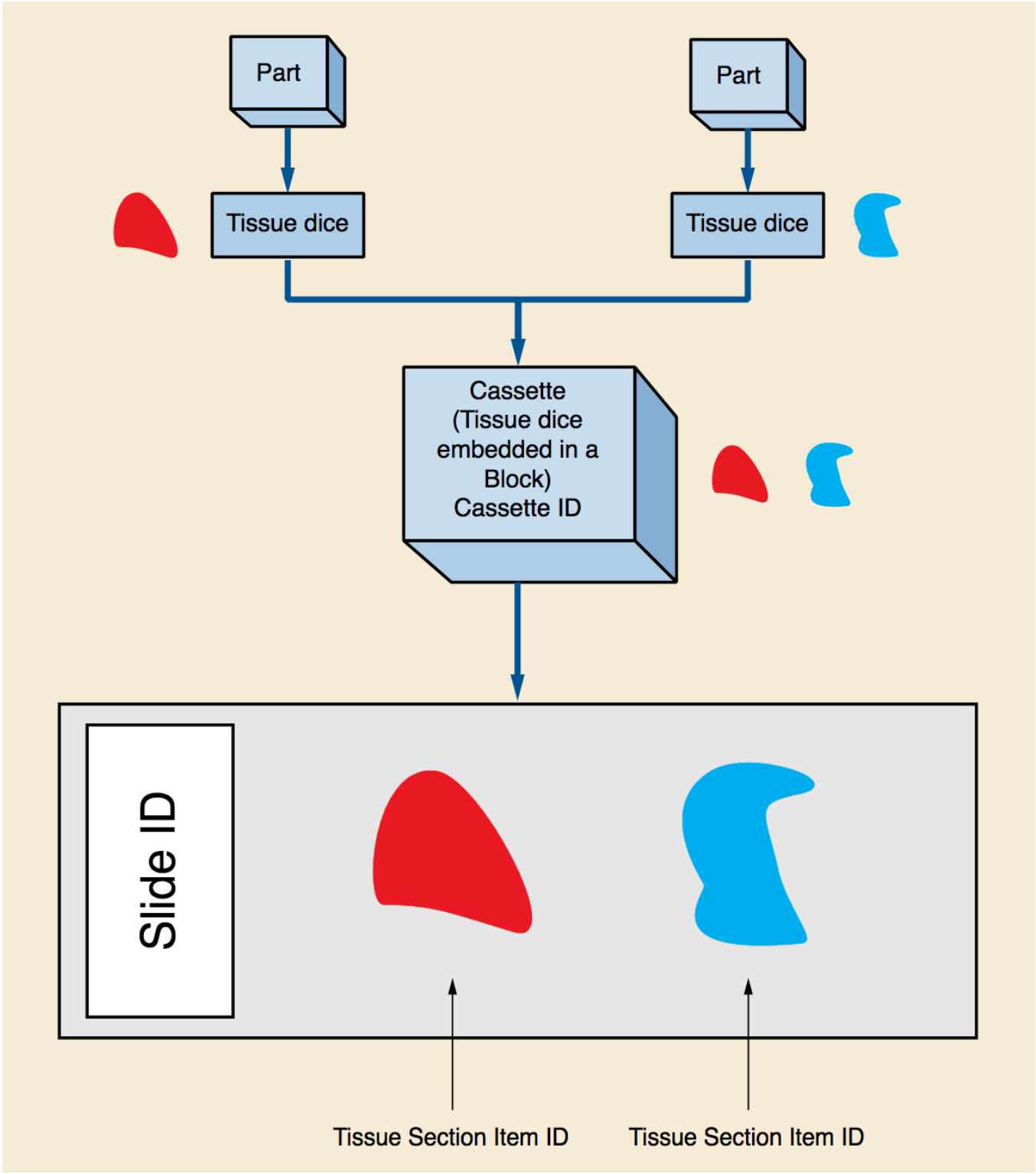



Part
Part
Tissue dice
Tissue dice
Cassette
(Tissue dice
embedded in a
Block)
Cassette ID
Slide ID
Tissue Section Item ID
Tissue Section Item ID

Specimen: Identification

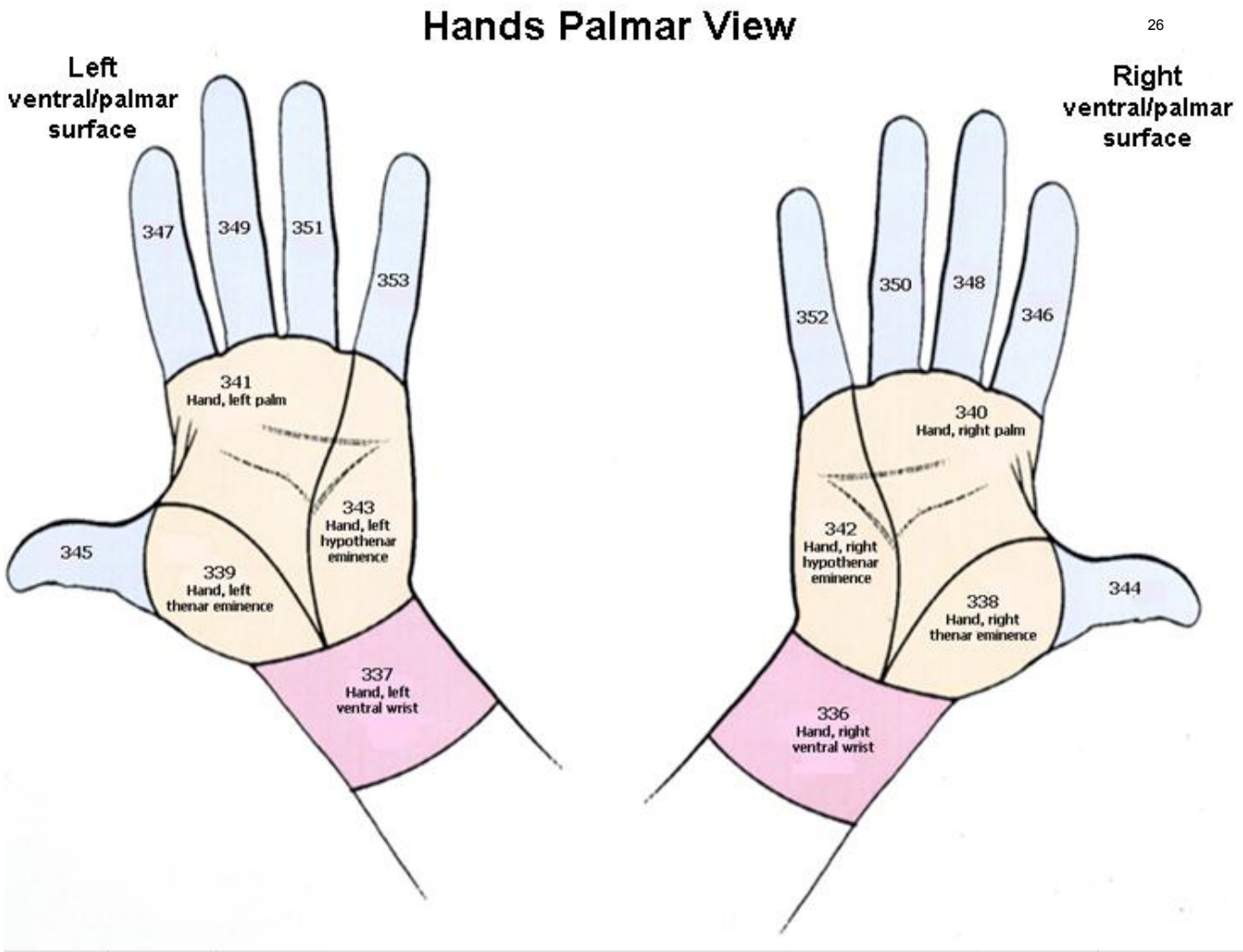
- Accession Number
  - unit of work (case: order- report)
  - same as radiology
- "Specimens in Containers"
- Specimen Identifier
  - single discrete physical object considered a unit in workflow
- Container Identifier
  - part, cassette, block, section, slide, …
  - container components … coverslip,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

Specimen: Description

- Everything is coded with standard codes (mostly SNOMED CT)

- Container Type Code Sequence = (433466003, SCT, "Microscope slide")
- Specimen Type Code Sequence = (430856003, SCT, "Tissue section")
- Primary Anatomic Structure Sequence = (10200004, SCT, "Liver")
- (17636008, SCT, "Specimen Collection") = (86273004, SCT, "Biopsy ")
- (111704, DCM, "Sampling Method") = (434472006, SCT, "Block sectioning")
- (424361007, SCT, "Using substance") = (12710003, SCT, "Hematoxylin stain")
- (424361007, SCT, "Using substance") = (36879007, SCT, "Water soluble eosin stain")
- (430864009, SCT, "Tissue Fixative") = (431510009, SCT, "Formalin")
- (430863003, SCT, "Embedding medium") = (311731000, SCT, "Paraffin wax")
- Illumination Color Code Sequence = (414298005, SCT, "Full Spectrum")
- Illumination Type Code Sequence = (111744, DCM, "Brightfield illumination")

Anatomic Metadata



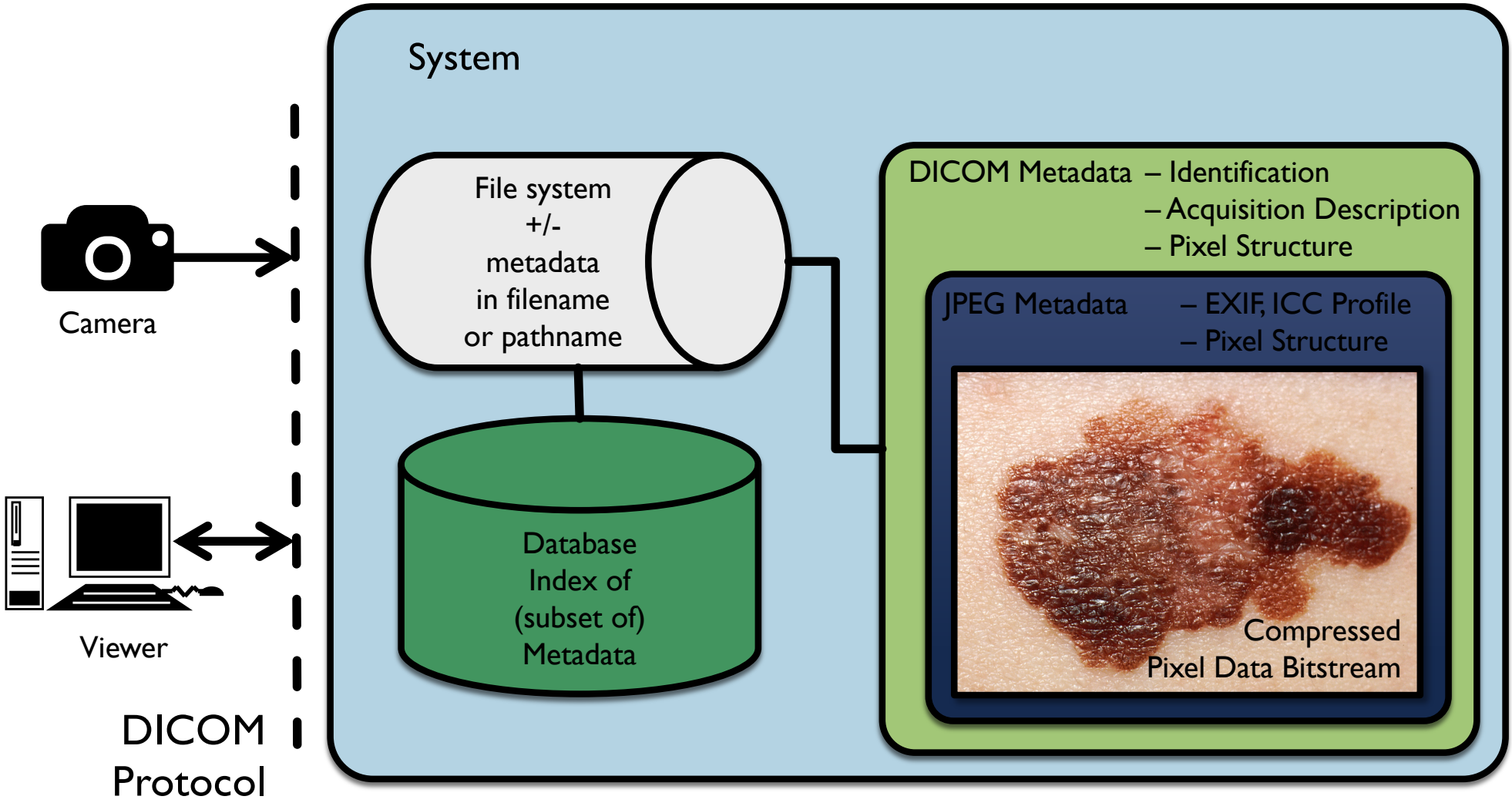
Anatomic Metadata

DICOM
Digital Imaging and Communications in Medicine

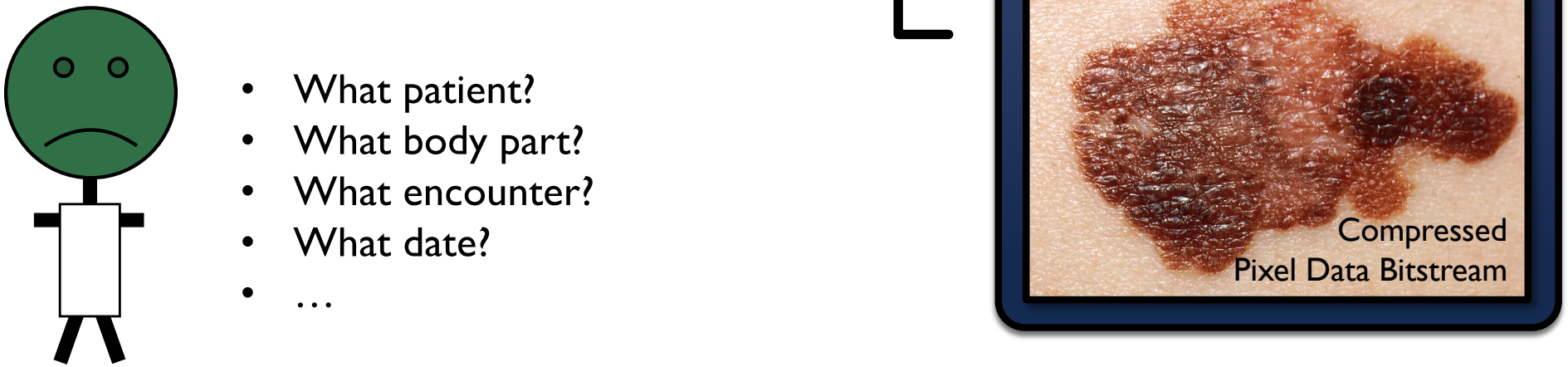
Table CID 4029. Dermatology Anatomic Sites

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-RT ID	UMLS Concept Unique ID	FMA ID	ICD-11	NYU Code L	NYU Code M	NYU Code R	Mayo Code L	Mayo Code M	Mayo Code R
SCT	182329002	Anterior triangle of neck	T-D03C9	C0446459	57777	XA1NS6	41		42	41		42
SCT	28726007	Cornea	T-AA200	C0229124	58238	XA4C02	109		108			
SCT	85803001	Eyelash	T-01530	C0015422	53669		105		104	105		104
SCT	279479008	Female external urethral orifice	T-81001	C0458493	85266			504				
SCT	279867004	Frenulum of labia minora	T-81206	C0458840	20404	XA0565		508				
SCT	280387007	Groin skin crease	T-01041	C0459399	326449	XA2XG2	519		518			
SCT	386045008	Hair	T-0130A	C0018494	53667						503	
SCT	41296002	Iris	T-AA500	C0022077	58235		109		108	109		108
SCT	279478000	Male external urethral orifice	T-75181	C0458492	85265			513				
FMA	281534	Mucosa of dorsum of oral part of tongue		C4244787	281534	XA8YB9	157		154			

DICOM PACS


System
File system
+/-
metadata
in filename
or pathname
Database
Index of
(subset of)
Metadata
DICOM Metadata – Identification
– Acquisition Description
– Pixel Structure
JPEG Metadata – EXIF, ICC Profile
– Pixel Structure
Compressed
Pixel Data Bitstream
Camera
Viewer
DICOM
Protocol

EMR
Export, Migration, Analysis, …



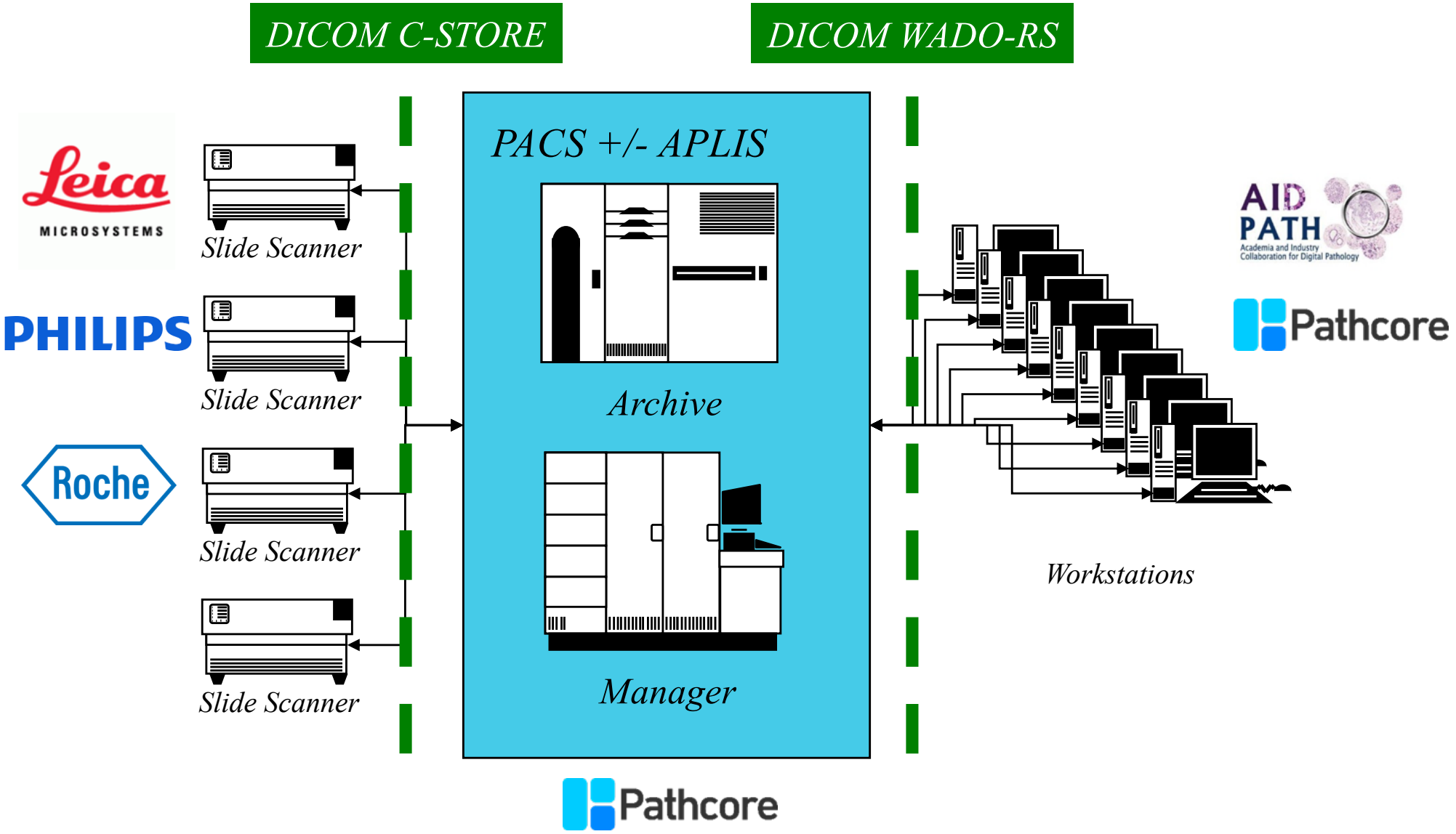
- What patient?
- What body part?
- What encounter?
- What date?
- …

Detachment Sucks!

without embedded metadata, that is

https://imgur.com/gallery/AuD7M

PV 2017 Connectathon



DICOM WG 26 WSI Connectathons
Participation to date

	PV'17	PI'18	ECDP'18	PV'18	ECDP'19
AidPath	View		Archive, View		
Corista		Analyze			
Gestalt				Archive, View	
Neagen				Archive, View	Archive, View
PathCore	Archive, View	Archive, View		Archive, View	
Sectra		View	View	View	
3DHistech					Scan
Hamamatsu		Scan	Scan		Scan
Leica	Scan	Scan		Scan	
Motic				Scan	
Philips	Scan		Scan	Scan	Scan
Roche	Scan	Scan	Scan	Scan	Scan

PV 2017 Connectathon Lessons

- which compression schemes (JPEG, or J2K as well?)
- one layer or entire pyramid from source (viewers expect latter, who makes it?)
- how to recognize which pyramid layer is which (PixelSpacing)
- recognizing a pyramid, in one series, multiple series, multiple per series
- natural order of encoded frames versus their index
- sparseness: entire tile array or selected sub-regions
- tile frame size: same for each resolution layer (e.g., localizer non-square?)
- dimensions described or not?
- localizer with index, or not? in same or separate series?
- concatenations: splitting huge files for transfer, requires reassembly on receipt
- is a label image needed, does it need a barcode? shared between pyramids?
- what optional metadata in image, in query (esp. specimen preparation)?
- specific server services/sequencing for viewing (find vs. metadata retrieve)
- WADO-RS – retrieve or retrieve rendered (multipart MIME burden)
- color consistency – importance of viewer applying embedded ICC profile

PV 2017 Connectathon Lessons

- Need more Connectathons! Need more testing!
- More specific profiling of requirements
  - DICOM CPs to fix details, clarify ambiguities, optimize for common use-cases
  - WG26 or IHE "profile"?
  - clarify patterns of use for specific use cases
  - make choices where alternatives exist, require currently optional features
- Just works, or works for the right reasons?
  - importance of validation against the formal standard requirements
  - currently assisted by mechanical tools (dciodvfy) – could check more
  - avoid using extensions, options, even if agreed upon
  - check with proxy between devices (as used by IHE)
  - create synthetic objects (good & bad) to stress recipients

DICOM
Digital Imaging and Communications in Medicine

Editorial

Digital Imaging and Communications in Medicine Whole Slide Imaging Connectathon at Digital Pathology Association Pathology Visions 2017

David Clunie[1], Dan Hosseinzadeh[2], Mikael Wintell[3], David De Mena[4], Nieves Lajara[5], Marcial Garcia-Rojo[4], Gloria Bueno[5], Kiran Saligrama[6], Aaron Stearrett[6], David Toomey[6], Esther Abels[7], Frank Van Apeldoorn[7], Stephane Langevin[2], Sean Nichols[2], Joachim Schmid[8], Uwe Horchner[8], Bruce Beckwith[9], Anil Parwani[10], Liron Pantanowitz[11]

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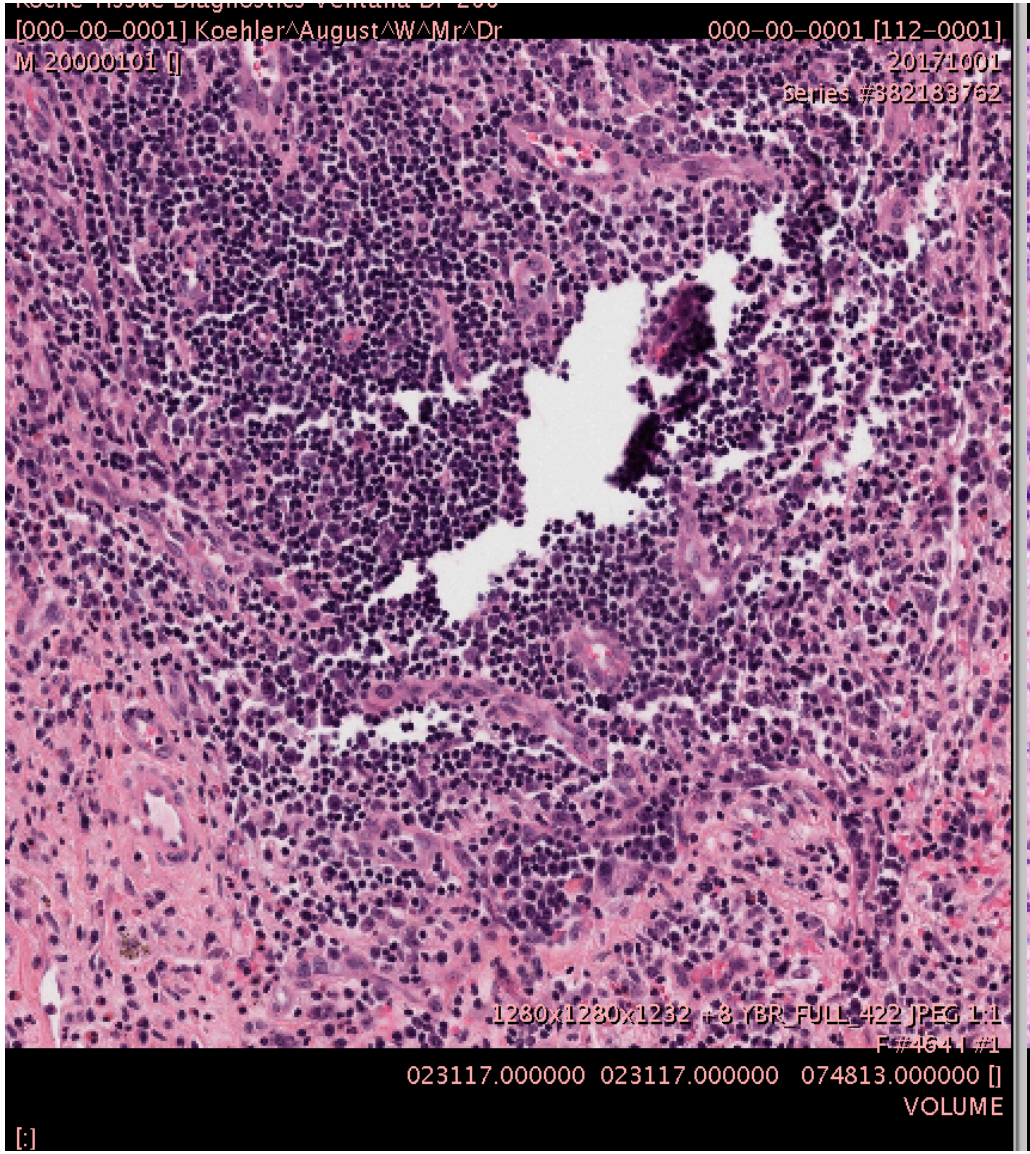
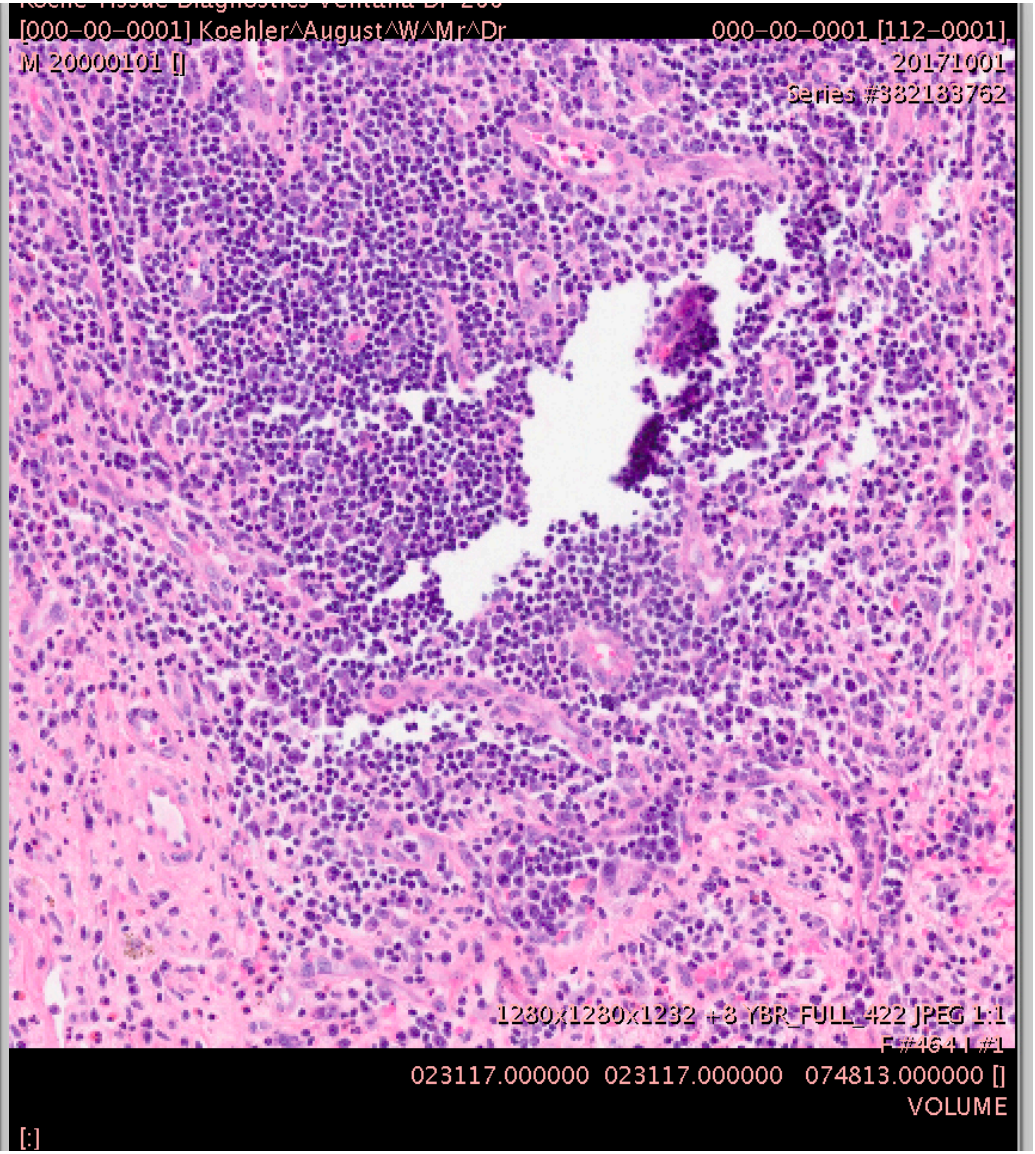
Beyond storage/retrieval …

- Color management
  - color normalization
  - color consistency - ICC profiles
  - services for application of ICC profiles to simplify (Internet browser based) viewers
- Workflow management
  - provision of identification and specimen preparation
- Annotations
  - input ("hot spots") and output from analysis algorithms
  - DICOM Segmentations
  - DICOM Structured Reports
  - ? something new in DICOM that scales to millions of nuclei, membranes, etc.

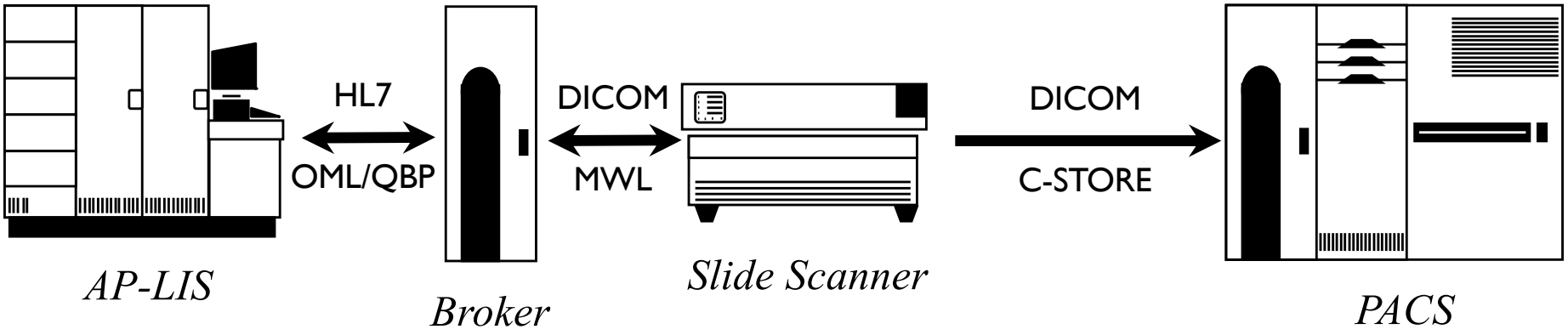


No ICC Profile Applied



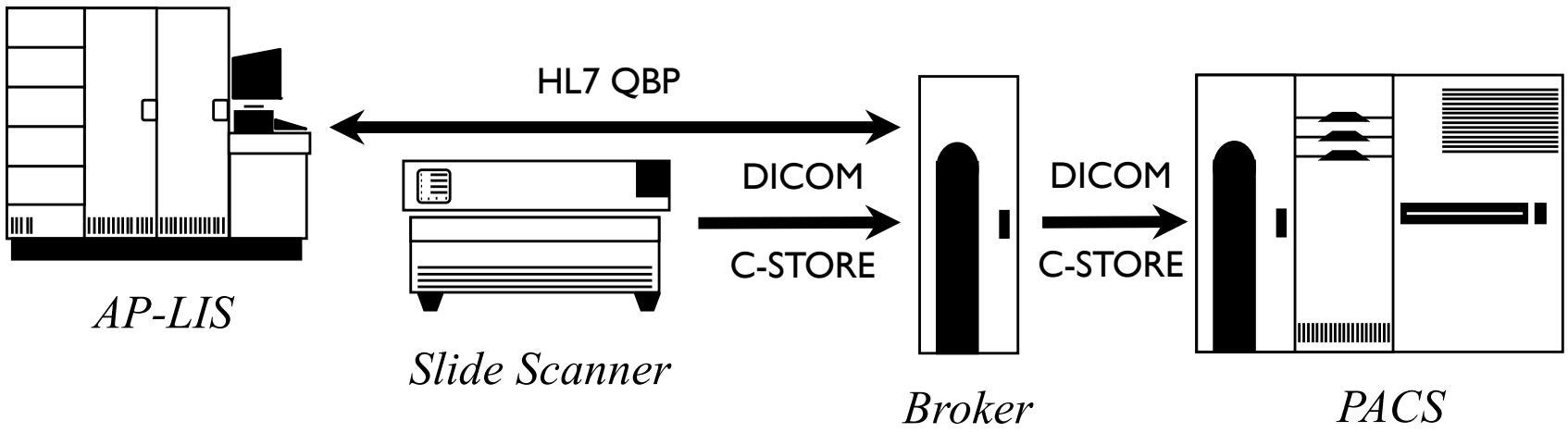
With ICC Profile Applied

Standard Workflow Integration



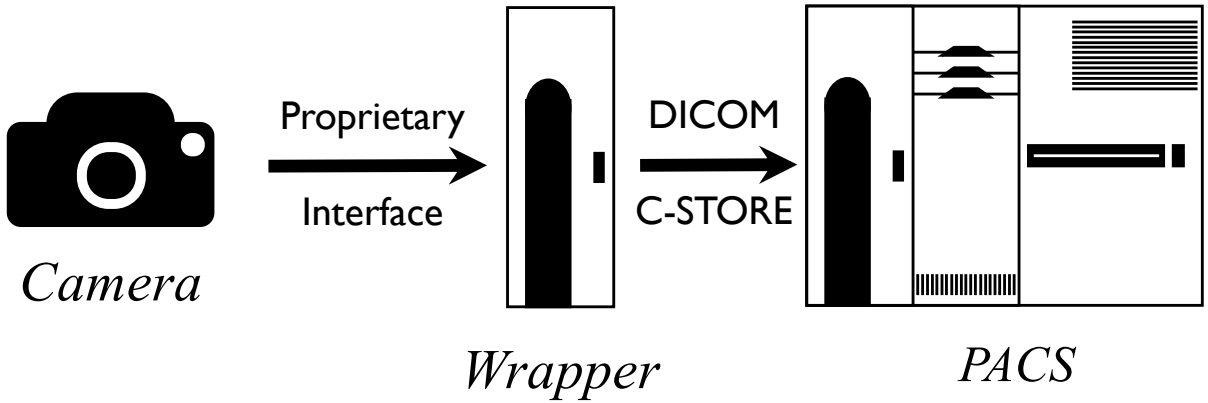
Standard Images and HL7/DICOM IS Integration

Standard Workflow Integration



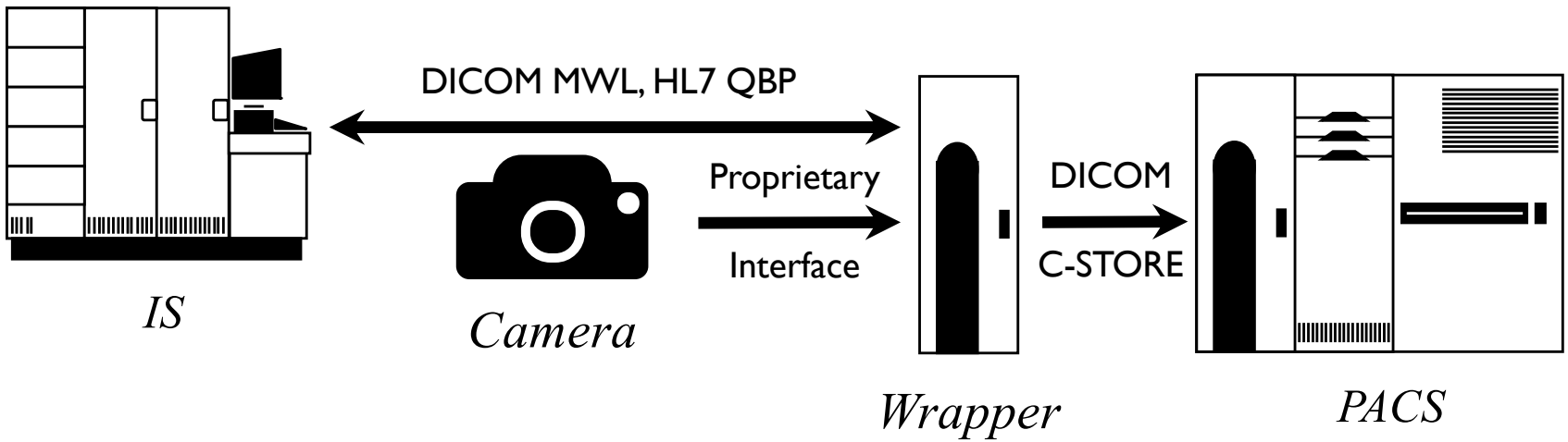
Broker "improves" DICOM with IS Metadata

Camera wrapper application



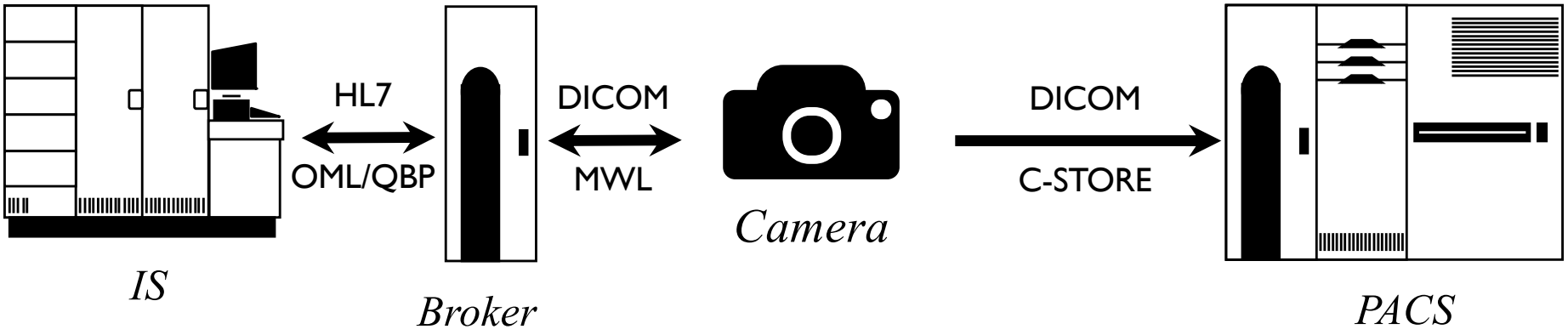
Wrapper provides user interface to populate metadata

IS Integration for Metadata



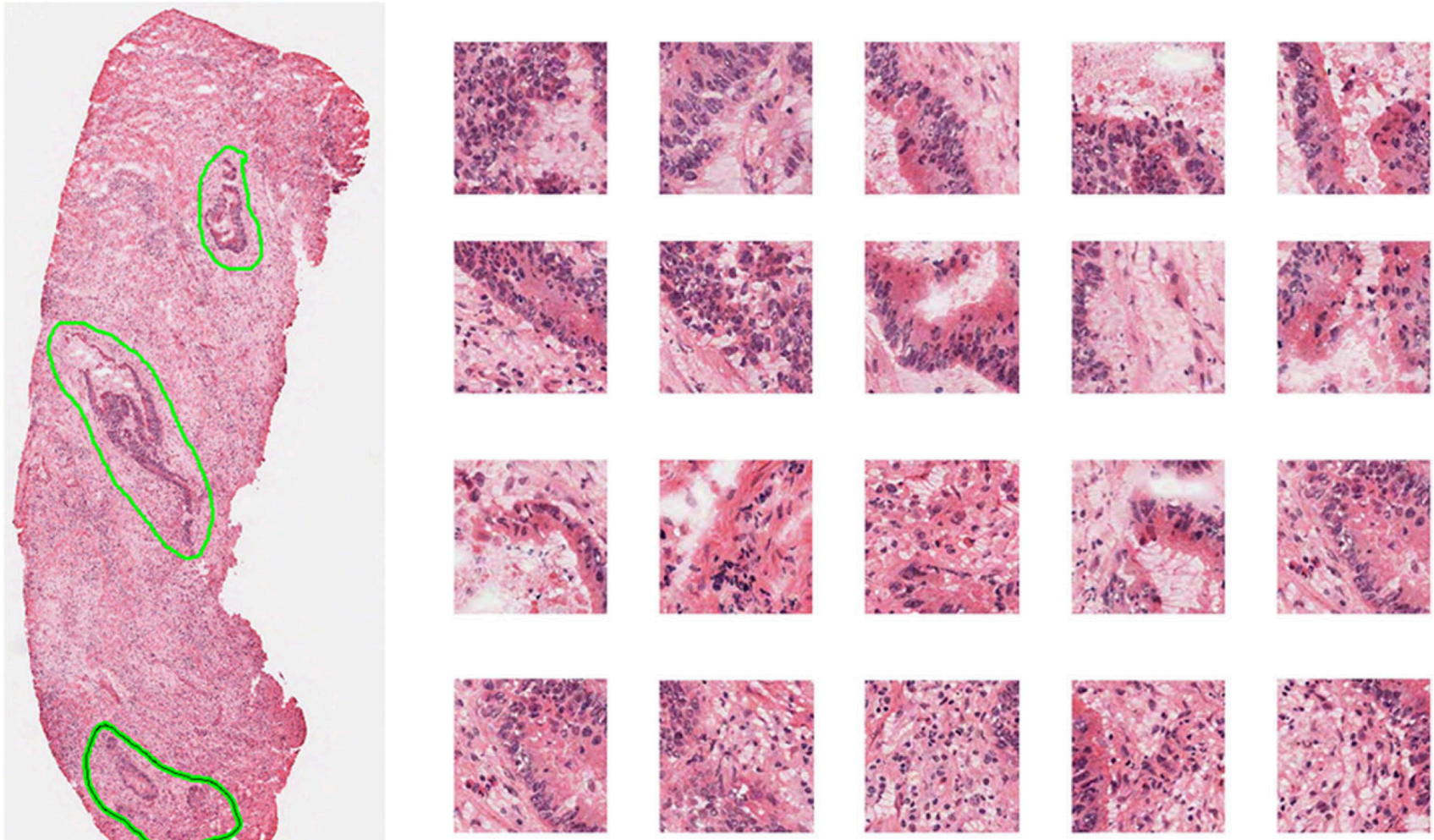
Wrapper re-uses IS-supplied metadata

DICOM Camera with MWL

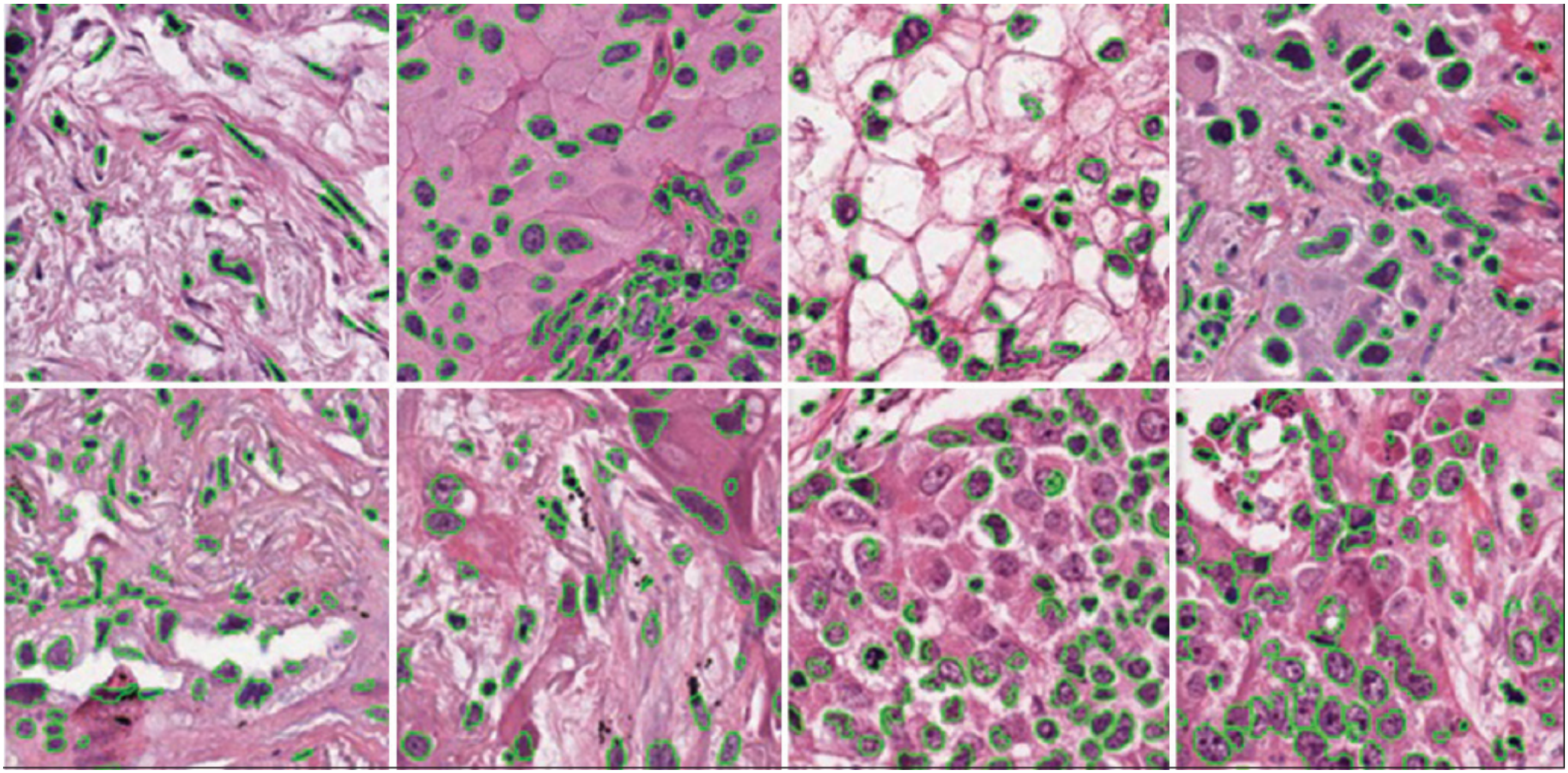


Standard Images and HL7/DICOM IS Integration


HIS/RIS/
Praxis-
programm
PACS/
Bildarchiv
Patientenliste
Aufnahmen
IHE-Workflow mit der DICOM Camera
Setzen Sie einen integrierten Workflow um,
der Ihrer Arbeitsweise entspricht.
WiFi
Wählen Sie einen Patient
Fallnummer scannen
393223-005
19.05.15
Schneider
SÜD
Maria
23.02.1978
54 / 56TRE
19.05.2015
Schneider, Maria
23.02.1978 DERM
Patient auswählen
oder
Fallnummer scannen
Fotografieren



Yoon et al.Tumor Identification in Colorectal Histology Images Using a Convolutional Neural Network. J Digit Imaging. 2018 Jul 31;1–10.



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

Conclusions

- DICOM has had greatest success in radiology and cardiology
- But there is a long tradition of supporting all forms of visible light imaging (esp. ,VA), now branded as "enterprise imaging"
- DICOM provides not only image encoding, but robust, portable and interoperable, common and application-specific identifying and descriptive metadata, unlike any other format
- DICOM provides protocols and services to support storage, query, retrieval and workflow
- Challenging applications like Whole Slide Imaging are supported in DICOM by creative re-use of existing mechanisms (multi-frame images for tiled pyramids), which in turn allows re-use of existing archives and access protocols
- Re-use of DICOM for other 'ologies leverages other DICOM features, like ICC-based color management and annotation