Technical Challenges in Enterprise Imaging

David A. Clunie

PixelMed Publishing, LLC

Financial Disclosures

- Grants/Research Support: NCI (Essex, BWH IDC)
- Consulting Fees: Canfield, Imago, MDDX, Lunit, BKMedical
- Editor of DICOM Standard (NEMA/MITA Contractor)
- Other: Owner of PixelMed Publishing

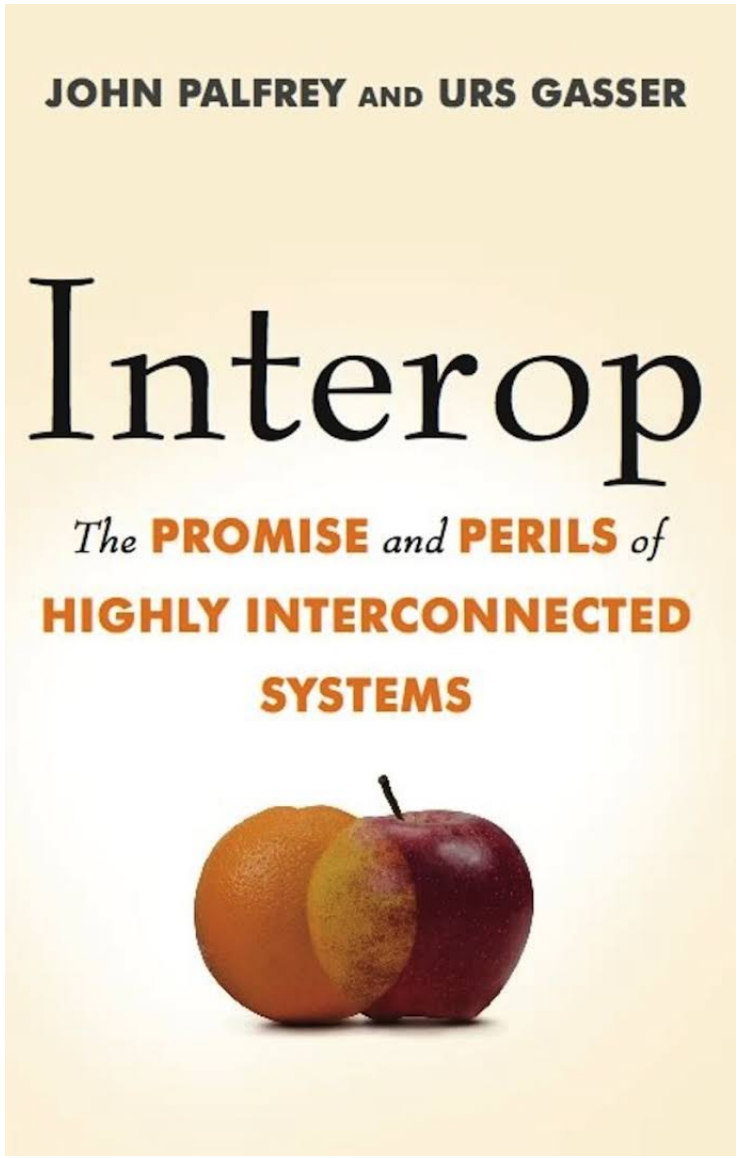
Technical Challenges

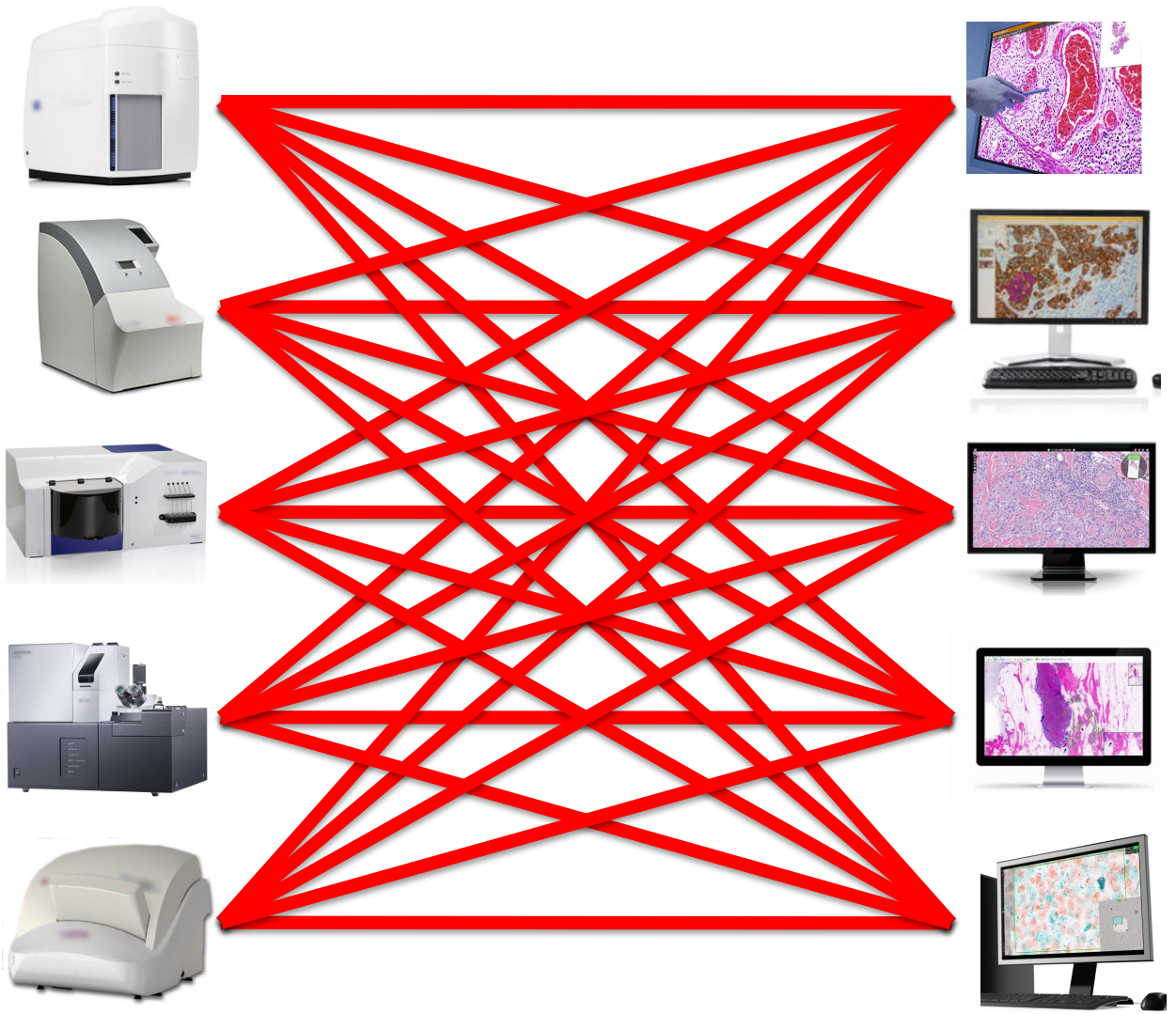
- Interoperability
- Metadata
- Workflow
- Simpler DICOM services (DICOMweb)
- Privacy and Security
- Anatomical pathology (whole slides)
- [Color consistency management]
- [Annotations]

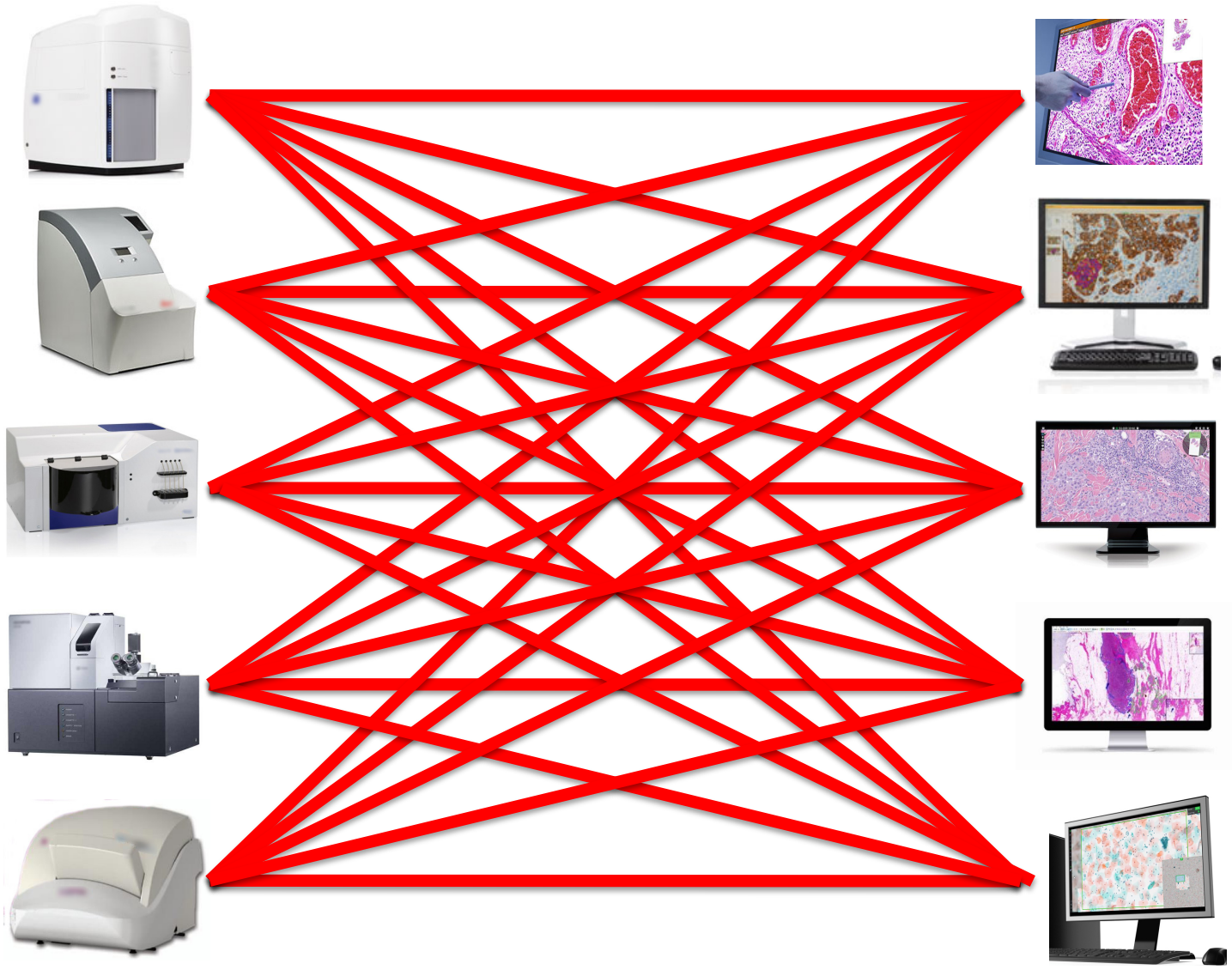
Interoperability

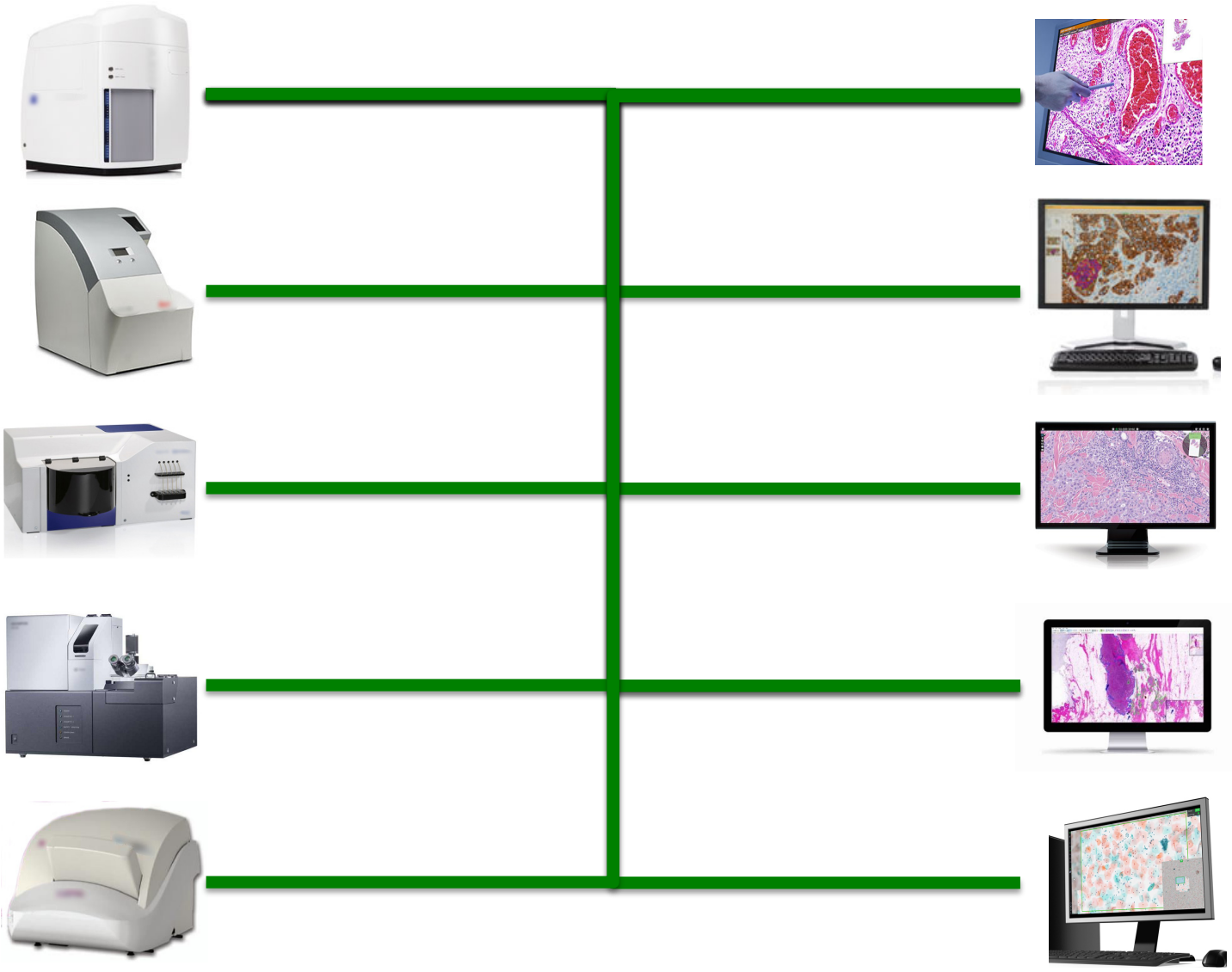
*"the ability of two or more systems or components to **exchange** information and to **use** the information that has been exchanged"*

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


JOHN PALFREY AND URS GASSER
Interop
The PROMISE and PERILS of
HIGHLY INTERCONNECTED
SYSTEMS

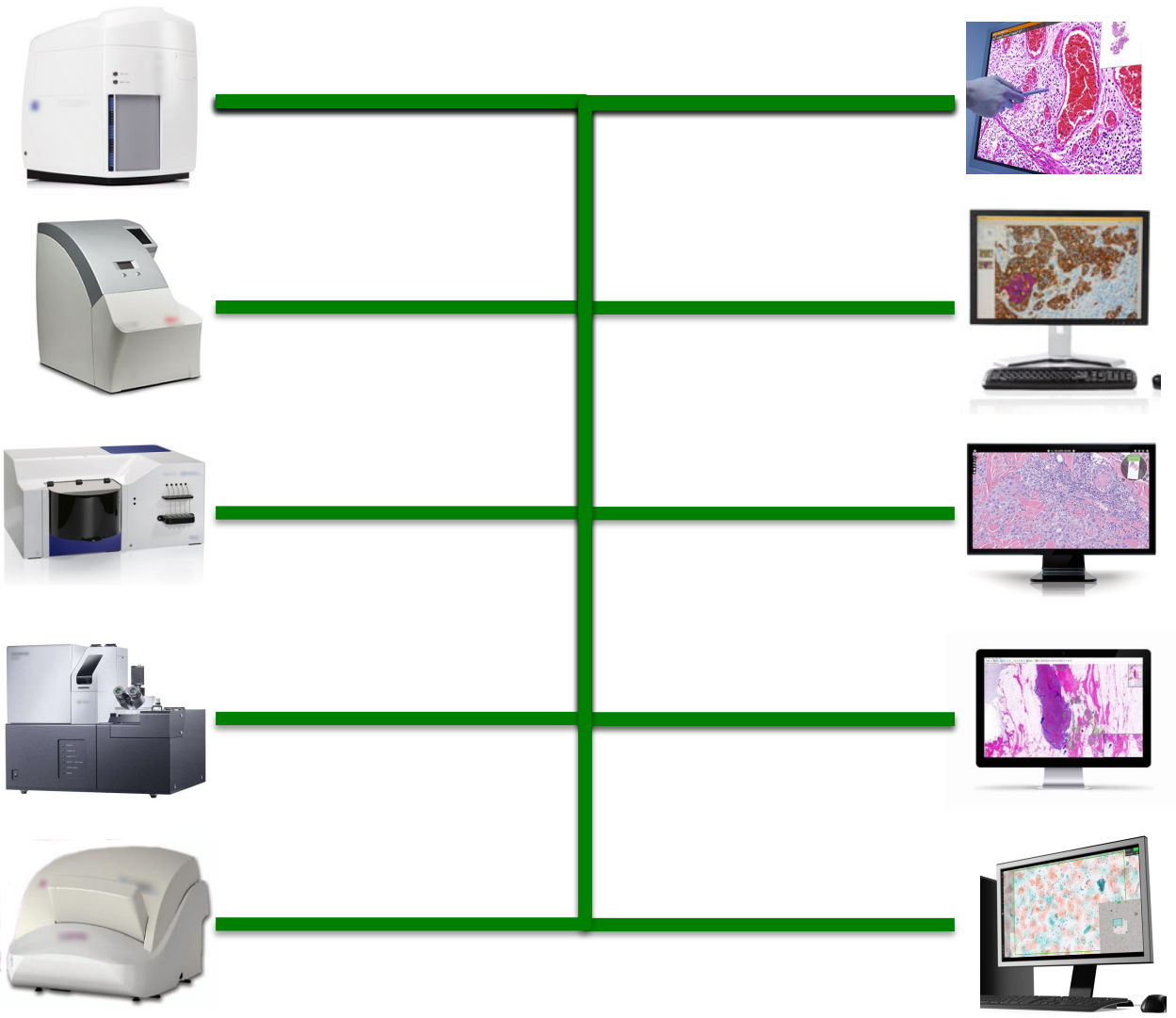


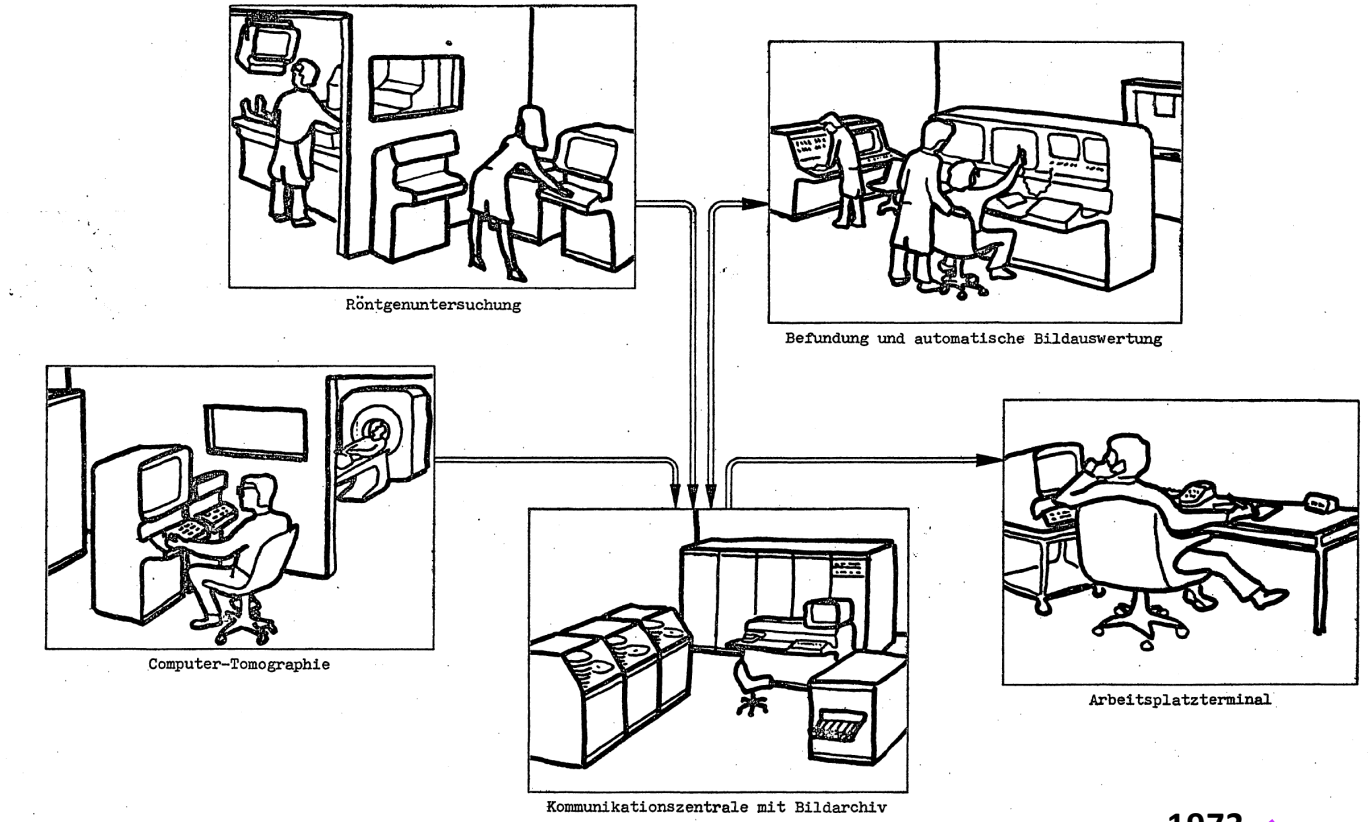




DICOM℠

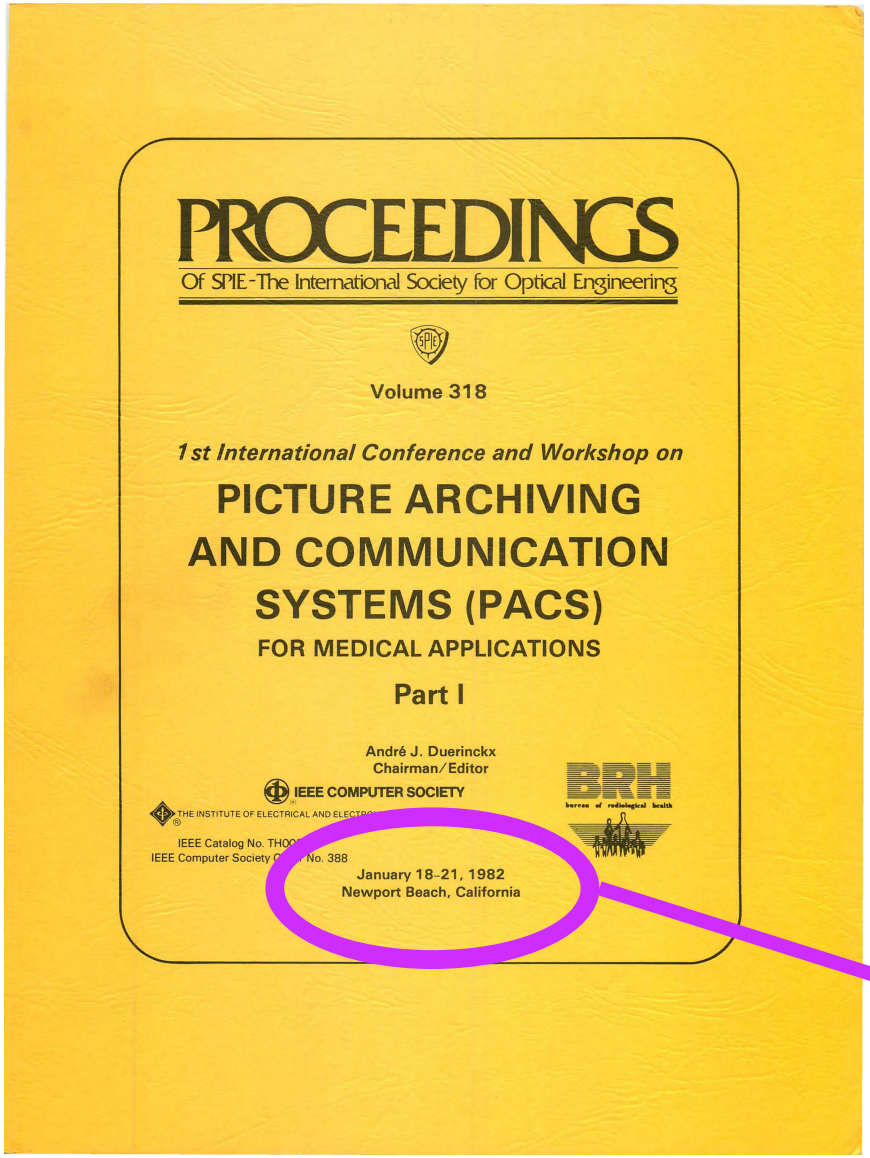
Digital Imaging and Communications in Medicine





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.


PROCEEDINGS
Of SPIE-The International Society for Optical Engineering
Volume 318
1st International Conference and Workshop on
PICTURE ARCHIVING AND COMMUNICATION SYSTEMS (PACS)
FOR MEDICAL APPLICATIONS
Part I
André J. Duerinckx
Chairman/Editor
IEEE COMPUTER SOCIETY
BRH
bureau of radiological health
January 18-21, 1982
Newport Beach, California

1982

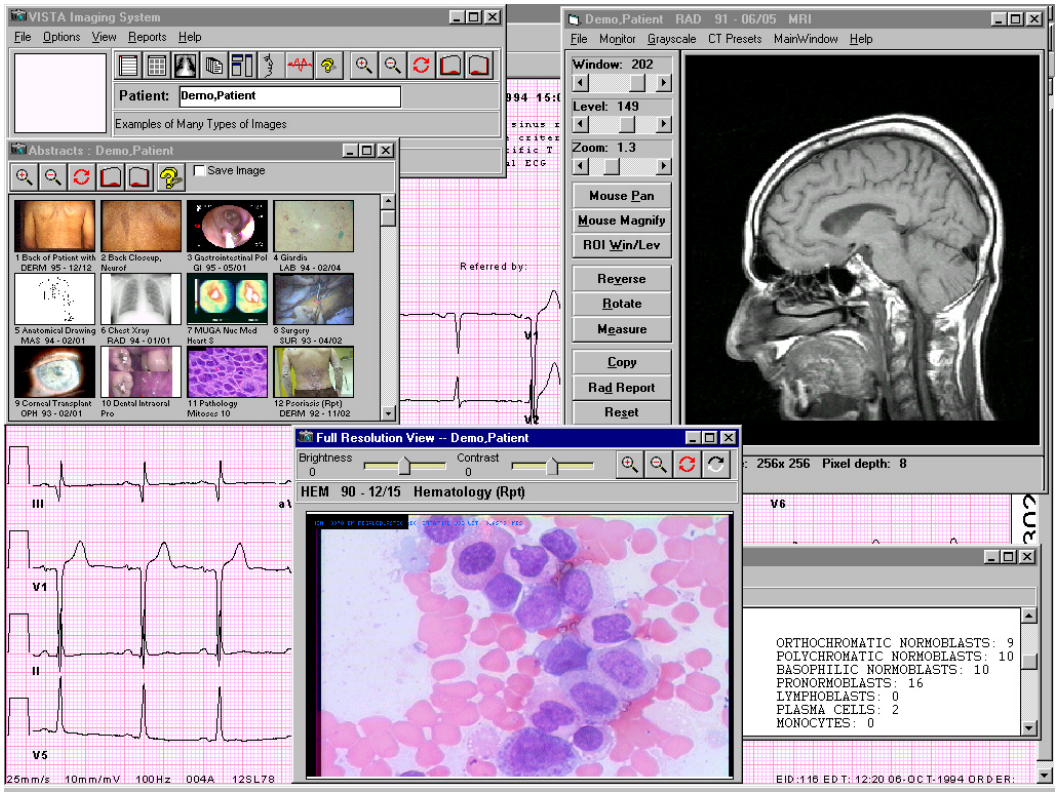
37 years ago – radiology PACS and DICOM usage ubiquitous now!

DICOM – Diversity from early on …

- DICOM has been around a very long time (1985 ACR-NEMA)
- DICOM has been doing more than radiology for a long time too
- Cardiology – 1995
- Radiotherapy – 1996
- Visible Light – 1998 – including Slide Microscopy
- Even before that – Secondary Capture RGB – 1993
- Increasingly specialty specific image types and metadata
- Whole Slide Imaging – 2010
- Ophthalmic Tomography Angiography – 2017

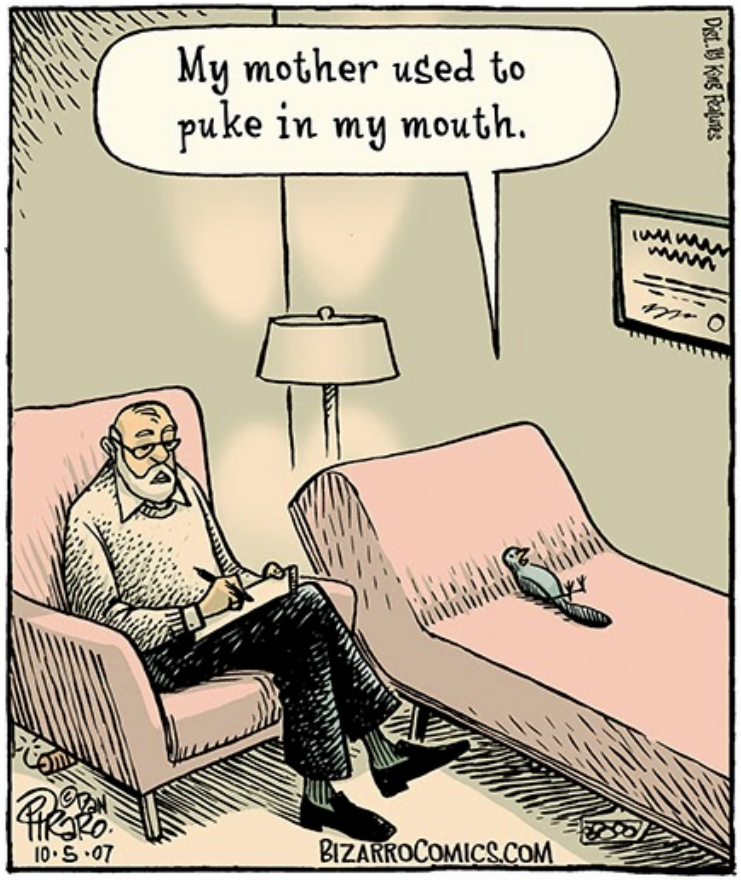
Wide Variety of Images Integrated with the Online Patient Record

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



"Kuzmak P, Dayhoff R. 10 Years of DICOM at the Department of Veterans Affairs. DICOM Workshop; 2003 Oct 1."

Store, Find & Regurgitate +/- View



Storing anything and everything

- … with DICOM …
- Specific SOP Class and IOD – e.g., Ophthalmic Photography
- Generic SOP Class and IOD – e.g., VL Photographic
- Anything at all SOP Class & IOD – e.g., Secondary Capture
- Distinguished by Pixel Data restrictions & metadata
- Pixel Data “payload” – uncompressed or compressed (e.g., JPEG-*, MPEG-*)
- Metadata (“header”) – composite (shared) and modality (clinical application) specific

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

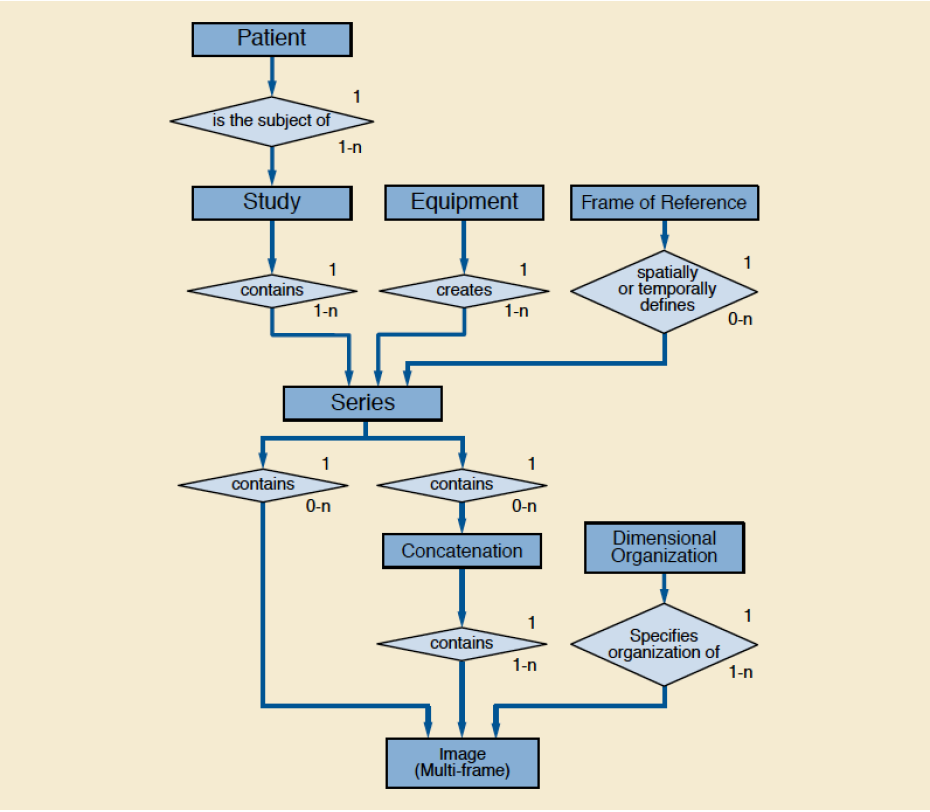
It's the metadata, stupid

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

Composite Context

- All of the stuff that is the same across multiple images (files, instances) … i.e., of the DICOM Composite Information Model:
  - Patient … same for all instances for patient
  - Study … same for all instances for procedure
  - Series … new for each related acquisition or derivation
  - Equipment
  - Multi-Frame Dimensions
  - Frame of Reference … e.g., if same slide coordinates
- Provides the basis for database/browser structure

Composite Information Model



Extreme Metadata – or not

- Every image needs the Pixel Data described (rows, columns, bit depth, etc.), and unique identifiers
- Beyond that lot or a little, whatever is needed
- Bare minimum – some identifier to match some other system – recipient does the matching work
- Everything and the kitchen sink – detailed description of the patient's state, acquisition process, etc., using standard string values or codes – recipient is passive
- The latter is the norm in radiology

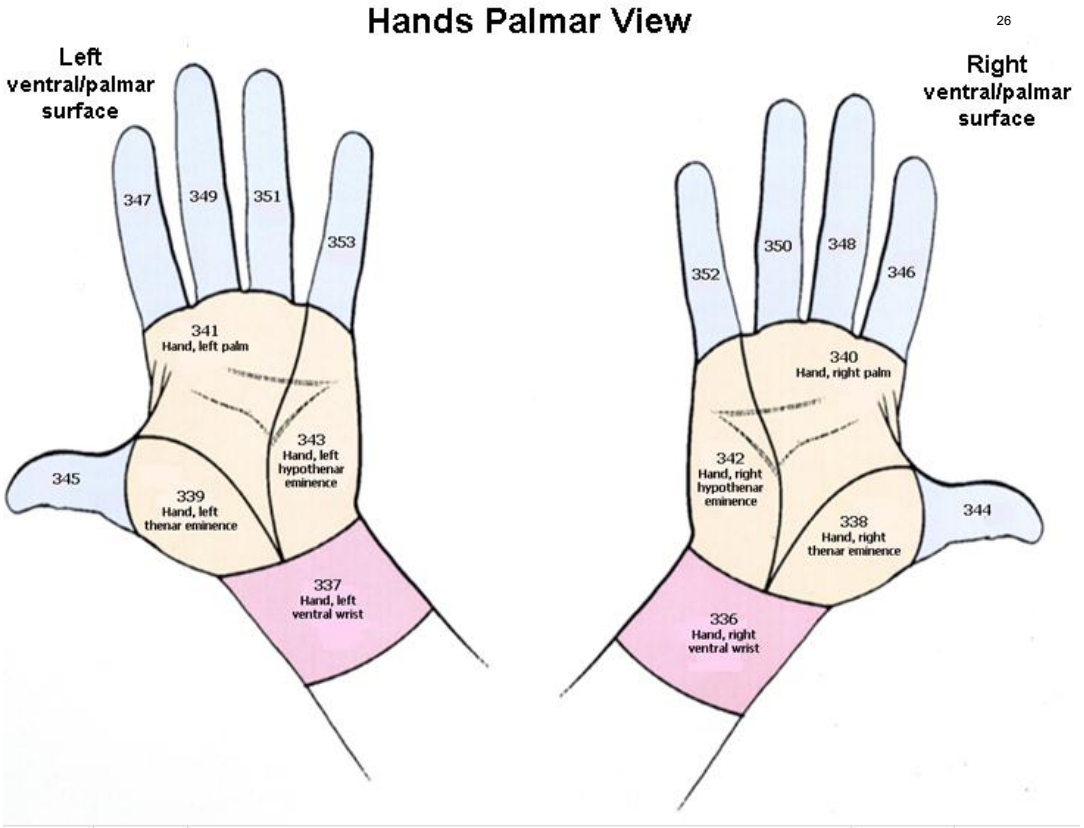
Minimum Chips

- As little as possible in one of the generic SOP Classes
- Very few required Type 1 (required) attributes
- Type 2 required attributes may be “empty” if unknown
- Can omit Type 3 (optional) attributes and entire optional modules
- Only Patient ID (empty name, DOB, age, sex – server will lookup, coerce)
- Send Content (or Acquisition) Date and Time only – server (or user) can match to other records captured contemporaneously
- Absent/empty Accession Number, Admission ID, Service Episode ID
- Make up some (Study, Series, Instance) UIDs
- With STOW-RS, can even omit the Pixel Data description, and let the server figure it out from the JPEG payload

More than the minimum

- Can do better by adding what is relevant to the recipient
- Textual descriptions (e.g., in Study/Series Description, Image Comments)
- Modality – more specific than “other”
- A little anatomy – may be hardwired (e.g., knee arthroscopy, colonoscopy, retinal fundoscopy) or user controlled (e.g., handheld skin lesion photos) – is best coded (e.g., SNOMED, FMA, clinical specialty codes such as NYU Melanoma CCG) rather than just text string
- Guiding principle – what can the recipient benefit from that is not too burdensome to capture?
- Radiology experience – rich metadata drives hanging protocols, prior pre-fetching, finding the right stuff in the study/series browser

Surface Anatomy – NYU, Mayo



Surface Anatomy in DICOM

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	371311000	Skin of upper extremity	T-02008	C0222201		XA4BA8				523b	523	523a
SCT	41310005	Skin of upper eyelid	T-02131	C0222089	24761	XA9K79	105		104	103		104
DCM	130322	Skin of upper eyelid margin				XA53T1	107		106	107		106
FMA	61426	Skin of upper inner quadrant of breast		C2363130	61426	XA3LS6	211		210	211		210
SCT	16251004	Skin of upper lip	T-02151	C0222102	24765	XA0K68	29		30	29		30
FMA	61439	Skin of upper outer quadrant of left breast		C0931805	61439	XA2Q54	209		208	209		208
DCM	130302	Skin of upper paraspinal region					232		232			
SCT	54440003	Skin of upper trunk	T-02401	C0222138		XA4QH7					520	

Extremely rich metadata

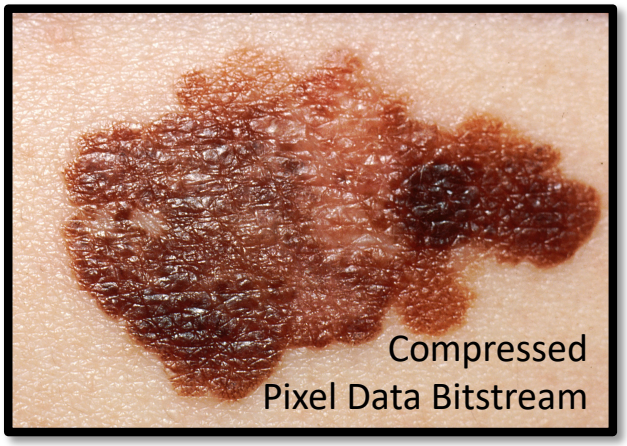
- All sorts of stuff relevant to the interpretation
- Even if another local source, needed when image is exported
- Identification and description of the patient
- Other Patient IDs, age, height, weight
- Patient (or specimen) preparation, positioning
- Acquisition process (e.g., illumination, filtration)
- Special aspects of the technique (e.g., fluorescence)

Why does this matter?

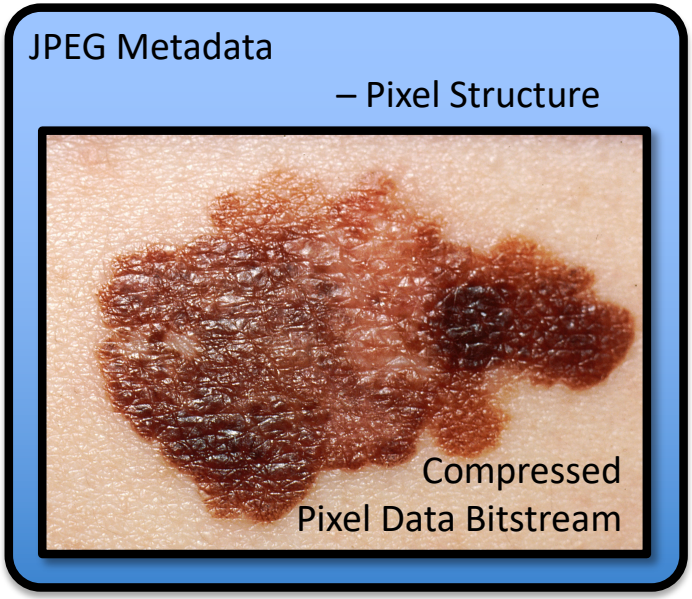
- Why not just save “consumer format” data in a content management system, and let it worry about the metadata?
- Export beyond the system (enterprise) – transfer, referrals
- Import from elsewhere – where does the metadata come from?
- Migrations – VNAs, CMS, EMRs go end-of-life just like PACS do – do you really want to repeat the pain of your last legacy PACS migration with its proprietary database and non-standard internal file format and proprietary compression?
- Mergers and acquisitions – when a company gets swallowed, new owner will want to assimilate products, and standards (DICOM) help

Camera

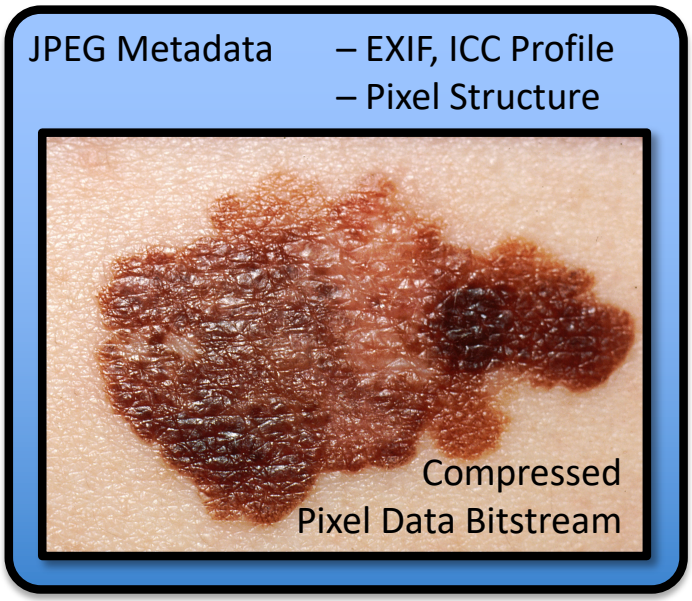
Camera

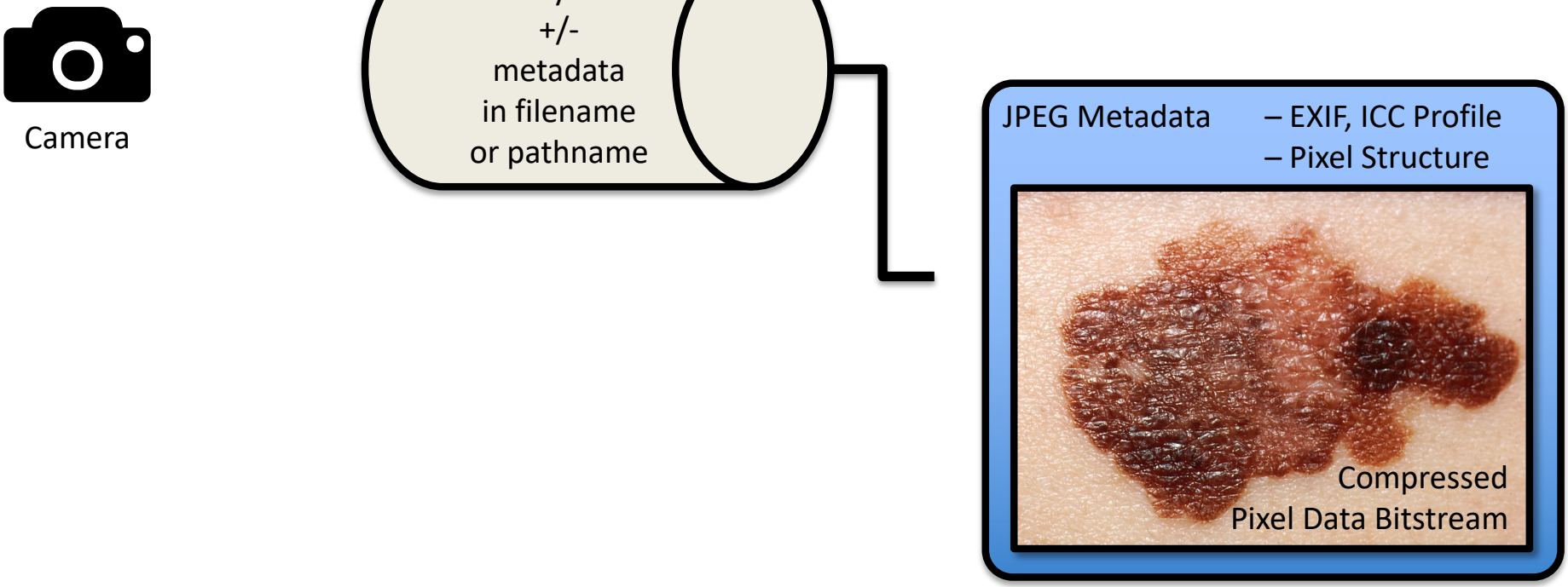


Camera


JPEG Metadata
– Pixel Structure
Compressed
Pixel Data Bitstream

Camera


JPEG Metadata
– EXIF, ICC Profile
– Pixel Structure
Compressed
Pixel Data Bitstream


Camera
File system
+/-
metadata
in filename
or pathname
JPEG Metadata
– EXIF, ICC Profile
– Pixel Structure
Compressed
Pixel Data Bitstream

Metadata – Solution 1

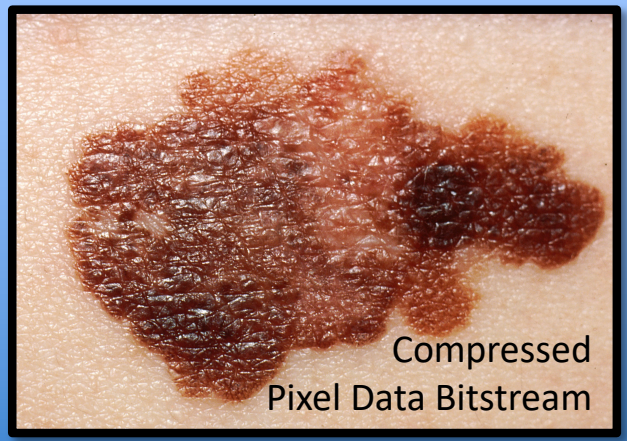
Do it with DICOM

DICOM File

Camera

File system
+/-
metadata
in filename
or pathname

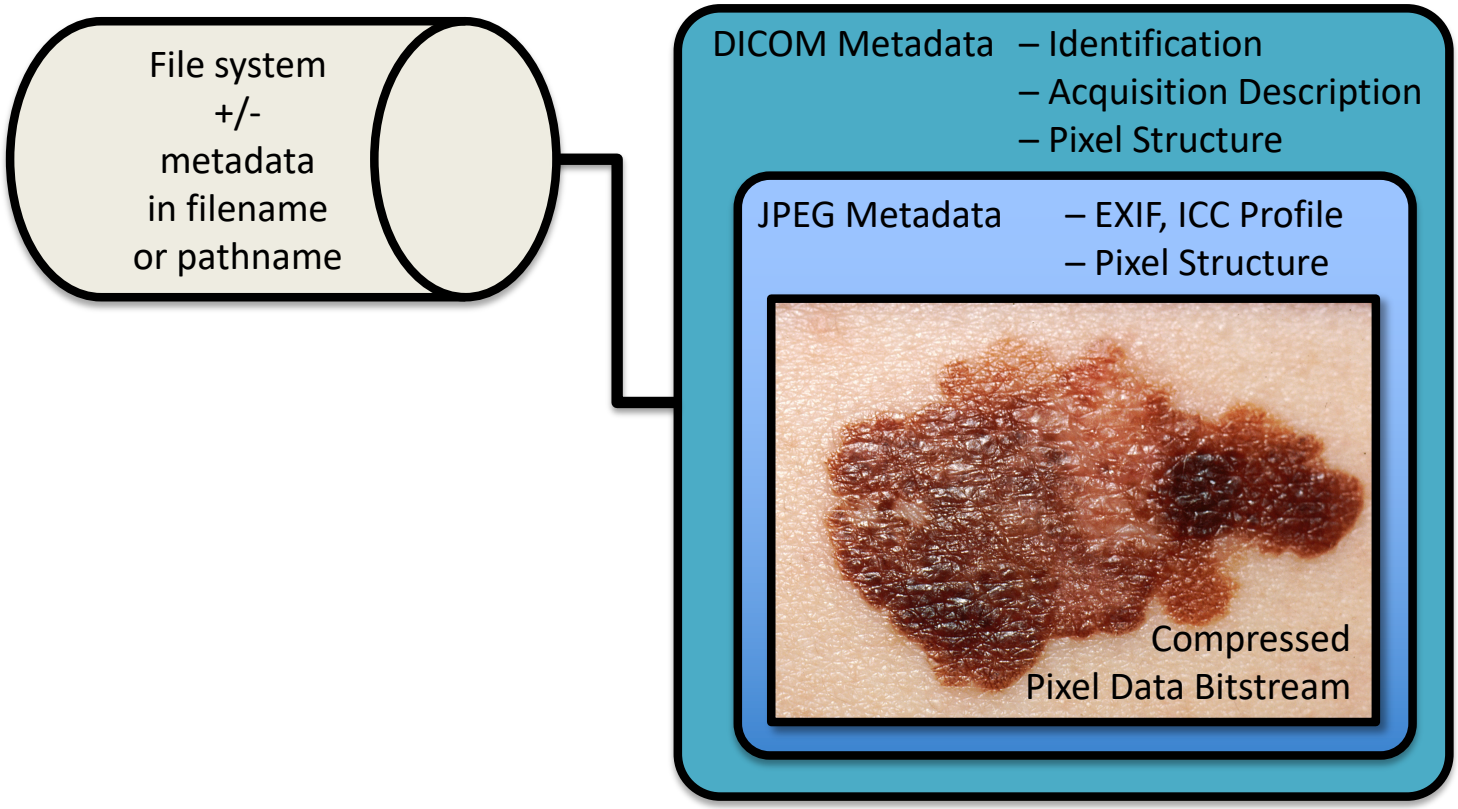
JPEG Metadata – EXIF, ICC Profile
– Pixel Structure



Compressed
Pixel Data Bitstream

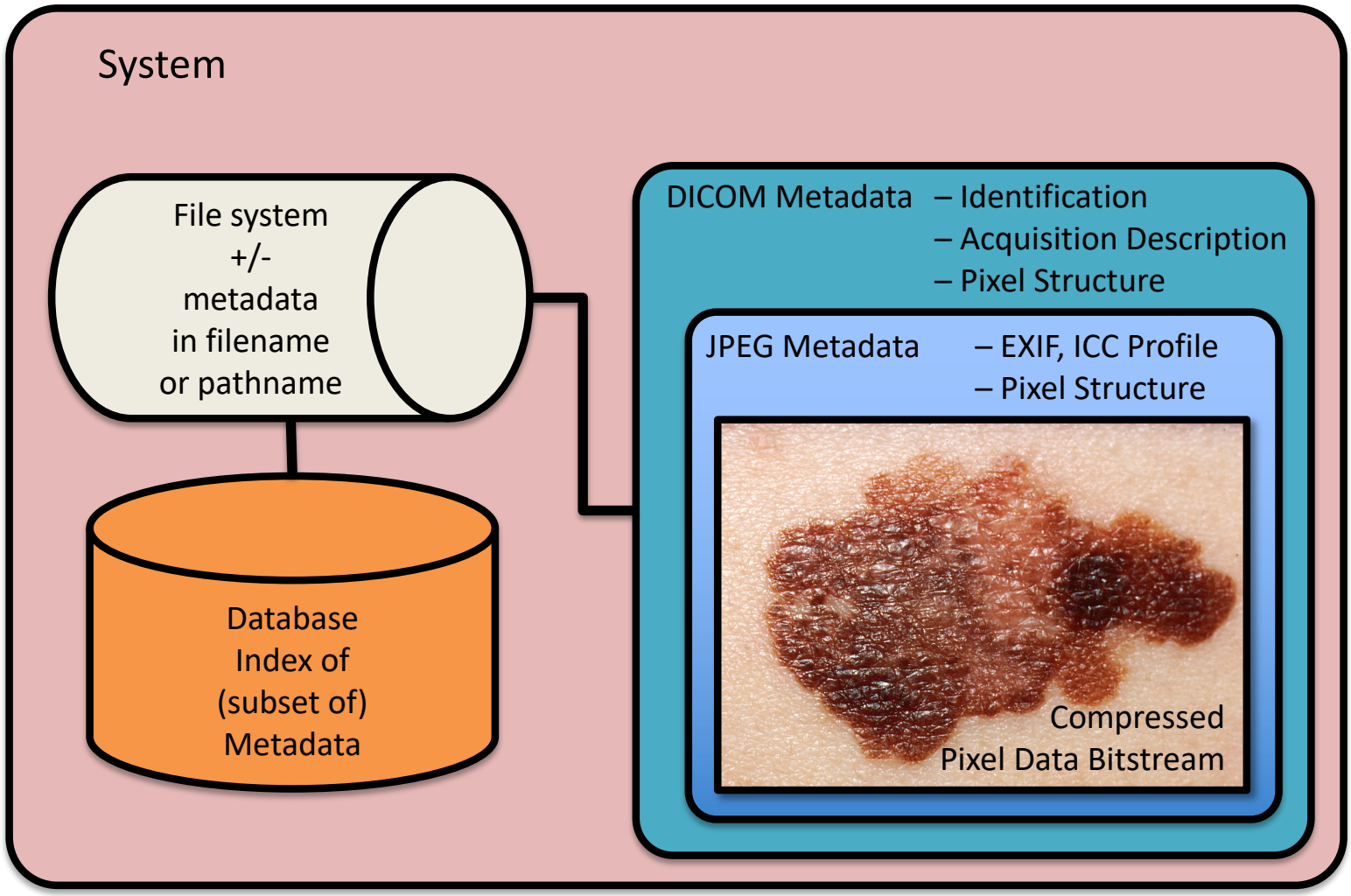
DICOM File

Camera

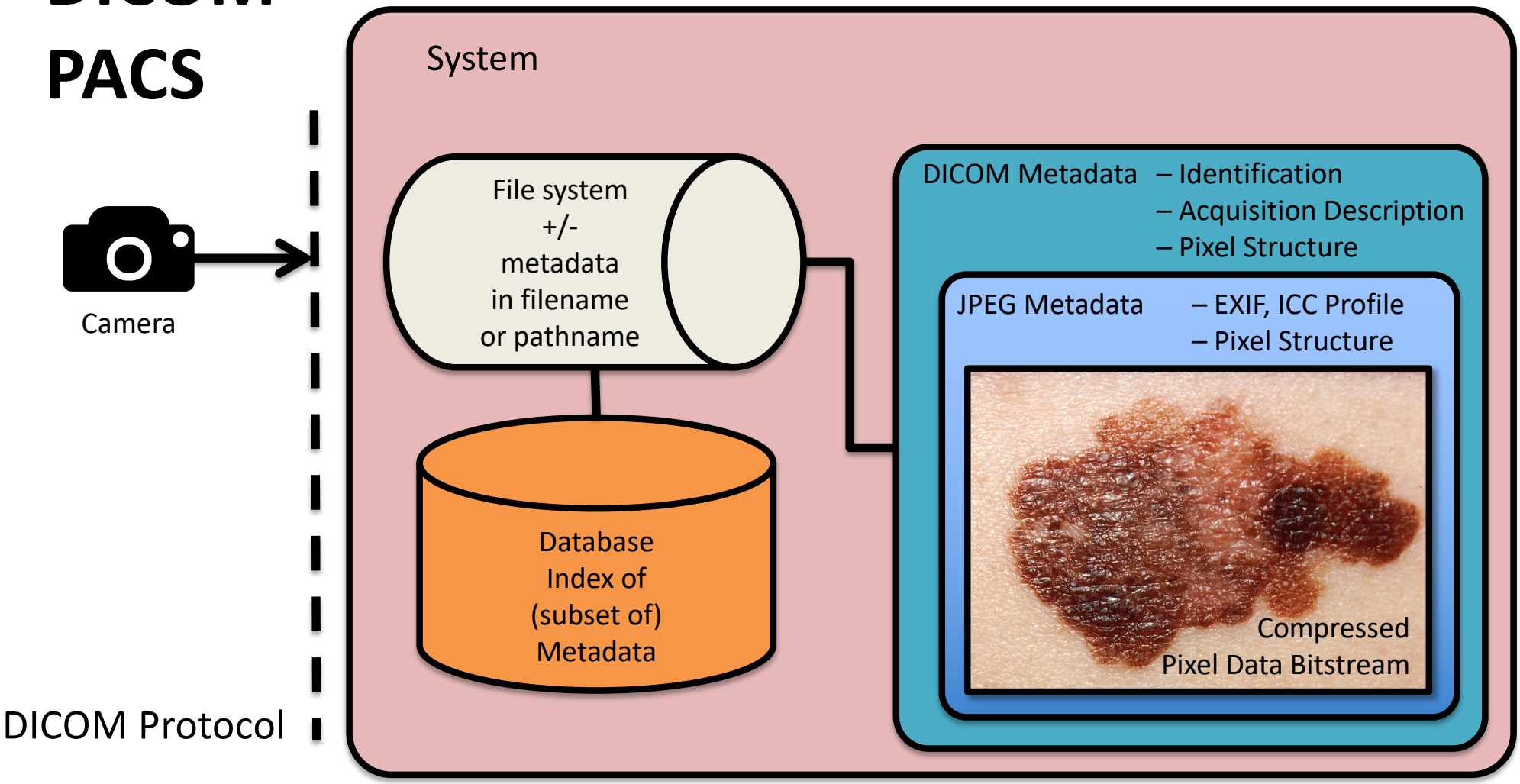


DICOM Fileset

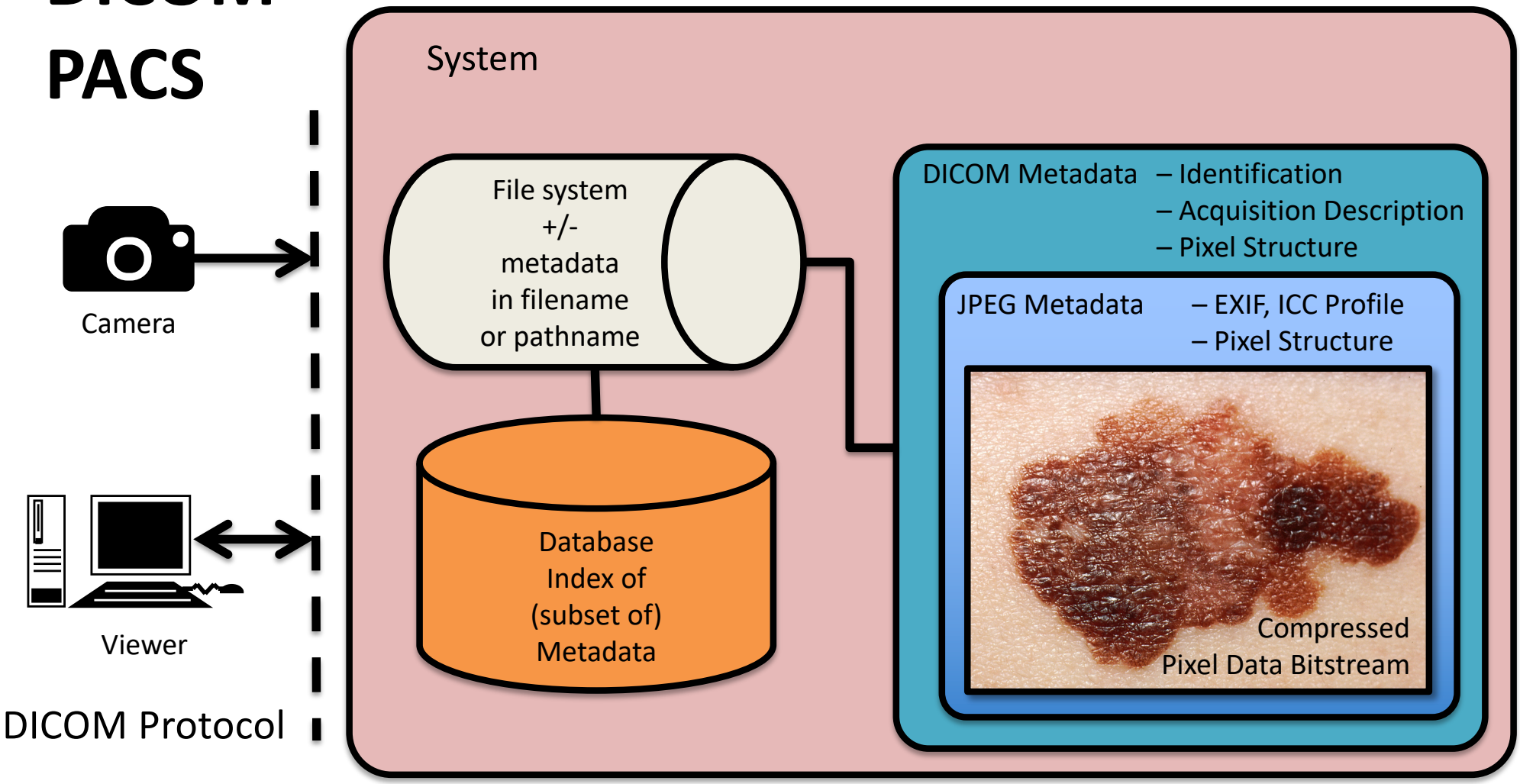
Camera



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
DICOM Protocol

DICOM PACS

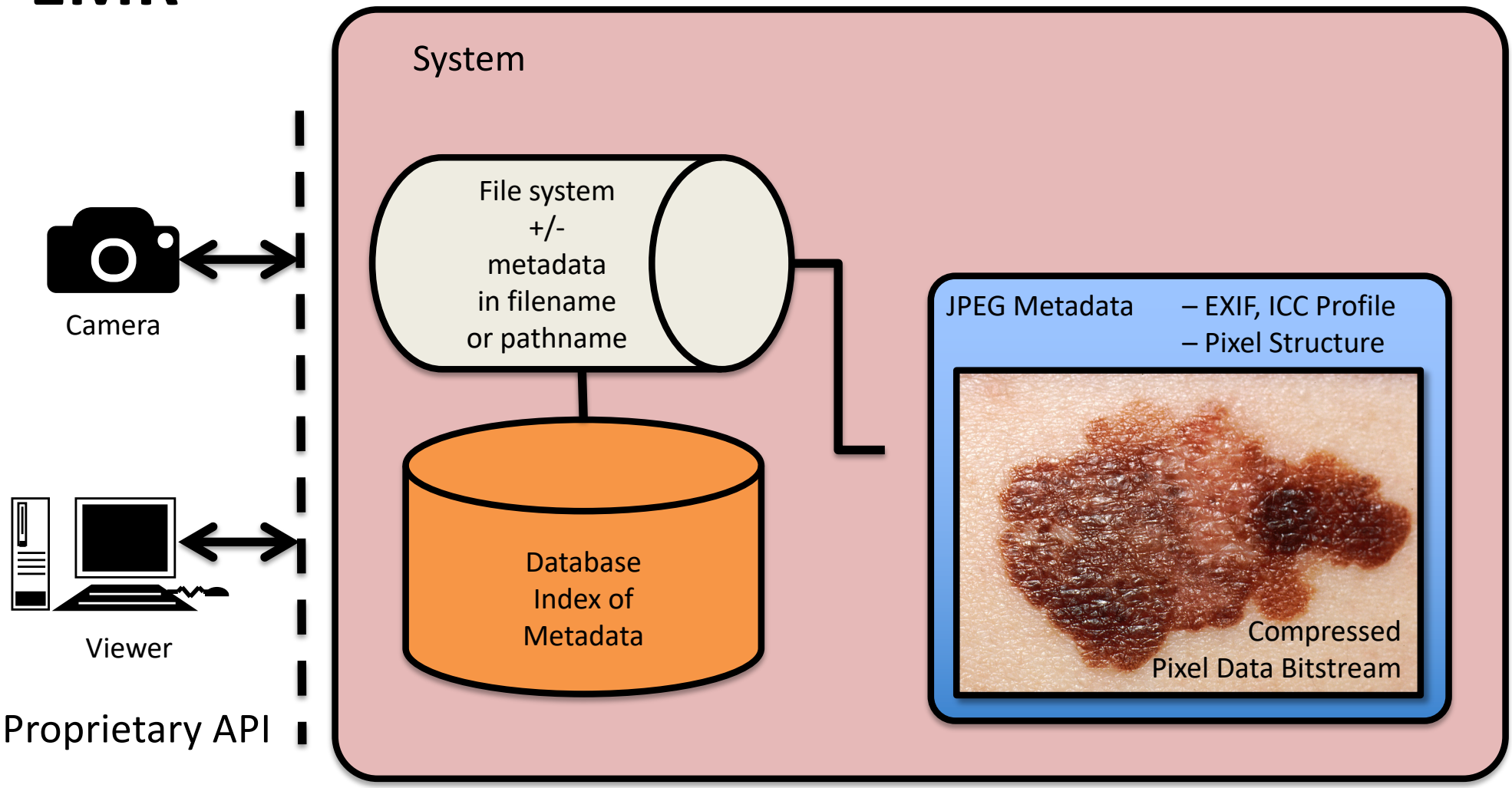

System
File system
+/-
metadata
in filename
or pathname
Database
Index of
(subset of)
Metadata
DICOM Metadata – Identification
– Acquisition Description
– Pixel Structure
JPEG Metadata – EXIF, ICC Profile
– Pixel Structure
Compressed
Pixel Data Bitstream
Camera
Viewer
DICOM Protocol

Metadata – Solution 2

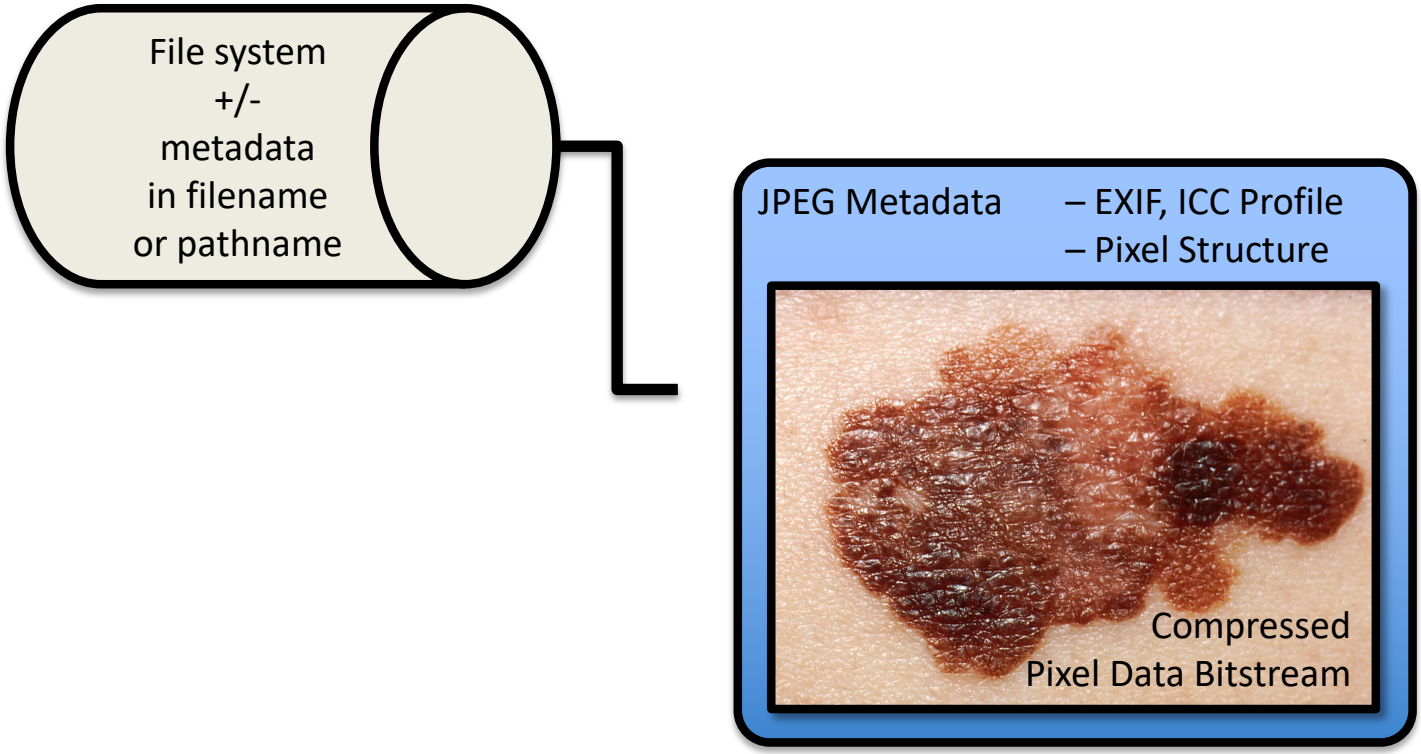
Do it with EMR

“non-DICOM images”

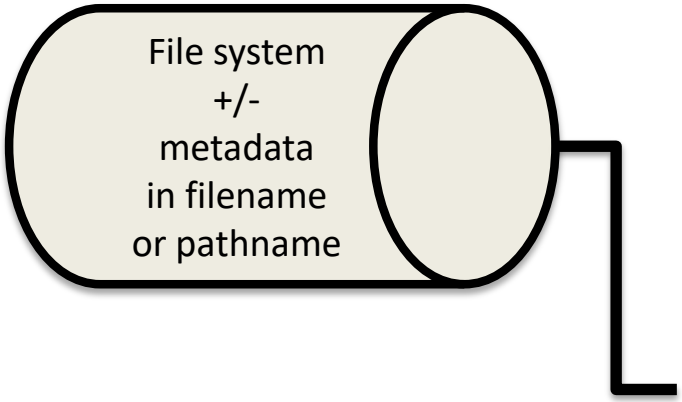
EMR

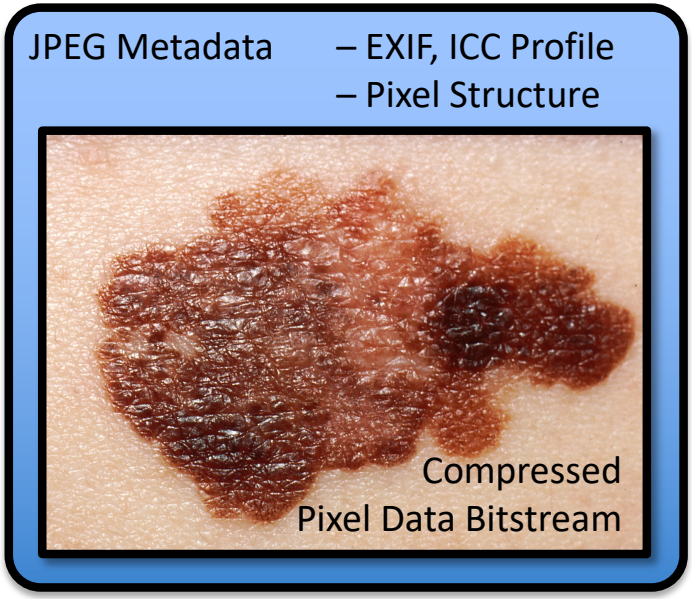

System
File system
+/-
metadata
in filename
or pathname
Database
Index of
Metadata
JPEG Metadata
– EXIF, ICC Profile
– Pixel Structure
Compressed
Pixel Data Bitstream
Camera
Viewer
Proprietary API

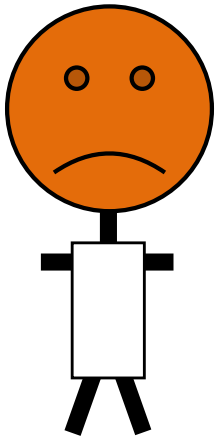
EMR
Export, Migration, Analysis, …



EMR
Export, Migration, Analysis, …







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

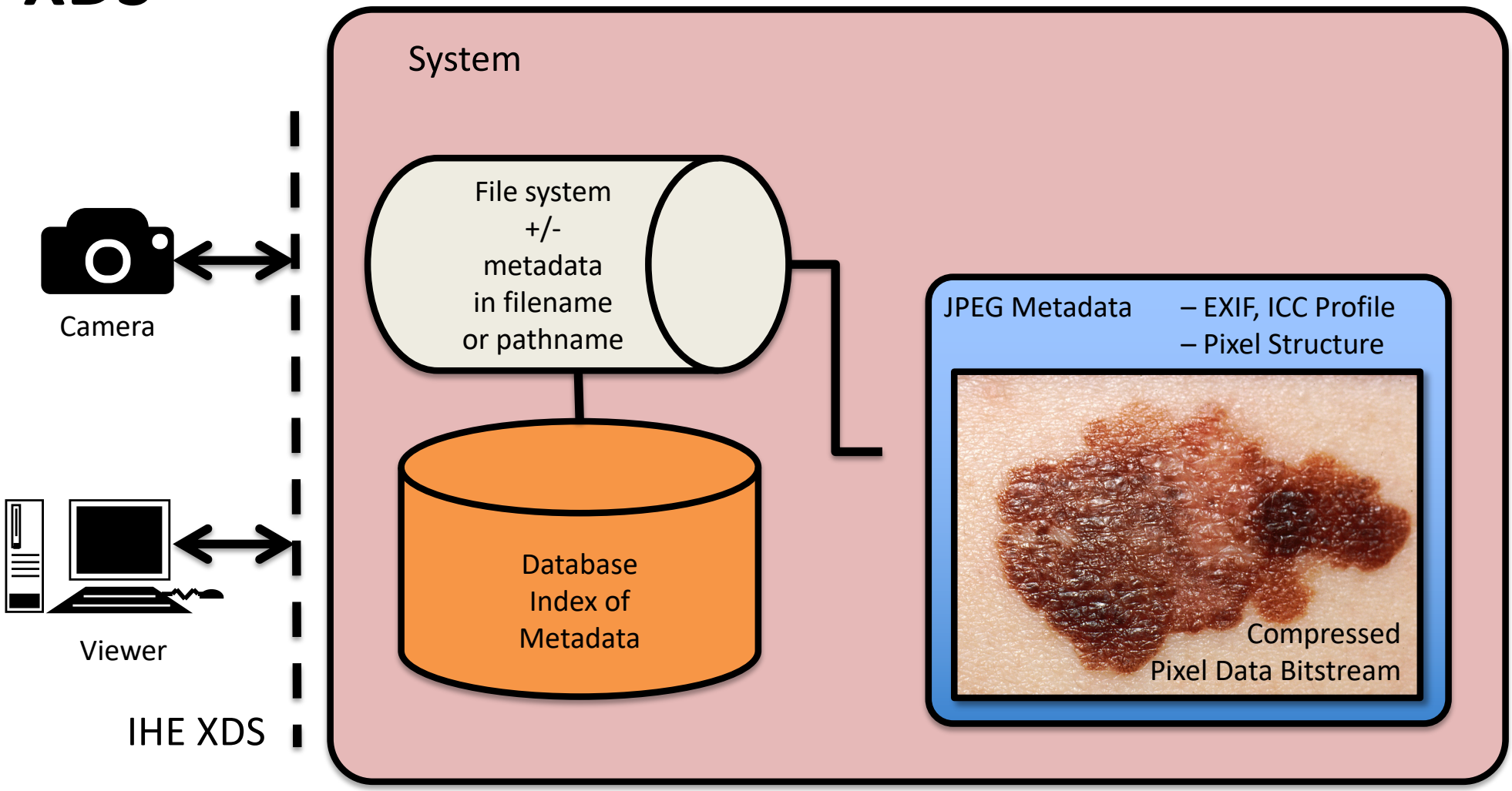

Do it with EMR

Metadata – Solution 3

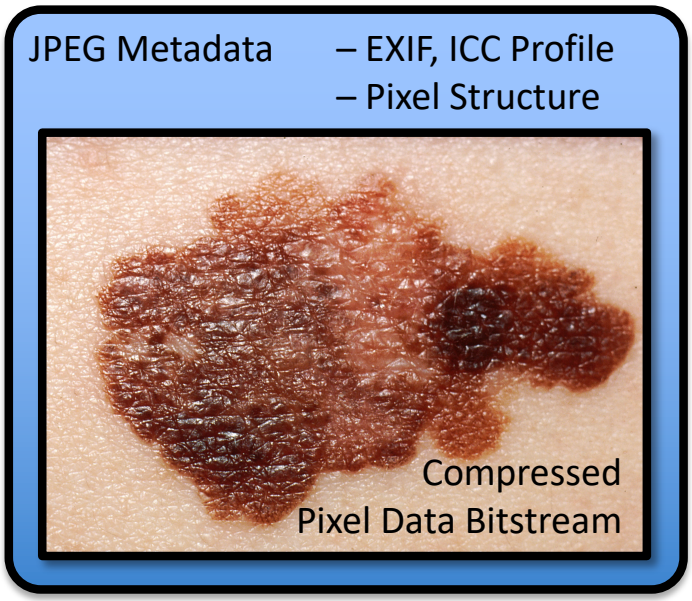
Do it with XDS

“non-DICOM images”

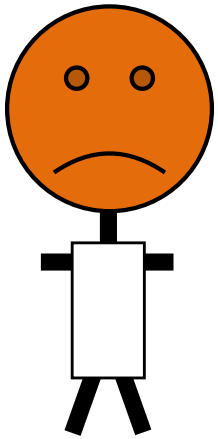
XDS


System
File system
+/-
metadata
in filename
or pathname
Database
Index of
Metadata
JPEG Metadata
– EXIF, ICC Profile
– Pixel Structure
Compressed
Pixel Data Bitstream
Camera
Viewer
IHE XDS

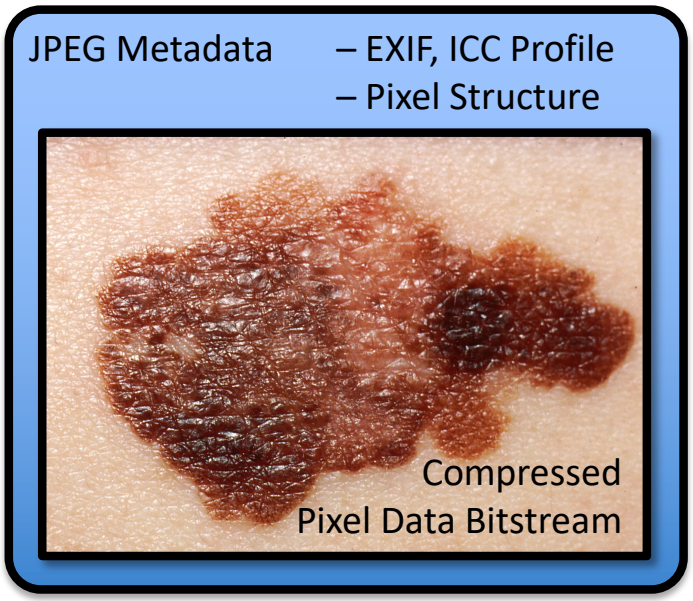
XDS
Export, Migration, Analysis, …



XDS
Export, Migration, Analysis, …



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




Meta ata – Se tion 3
Do it ith XDS
“n n-DICOM im es”

Detachment Sucks!

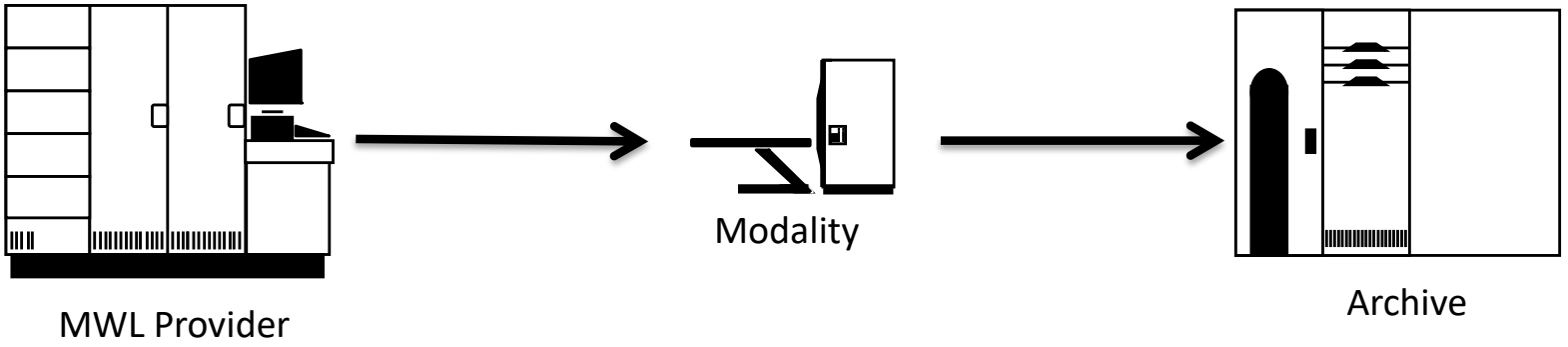
without embedded metadata, that is

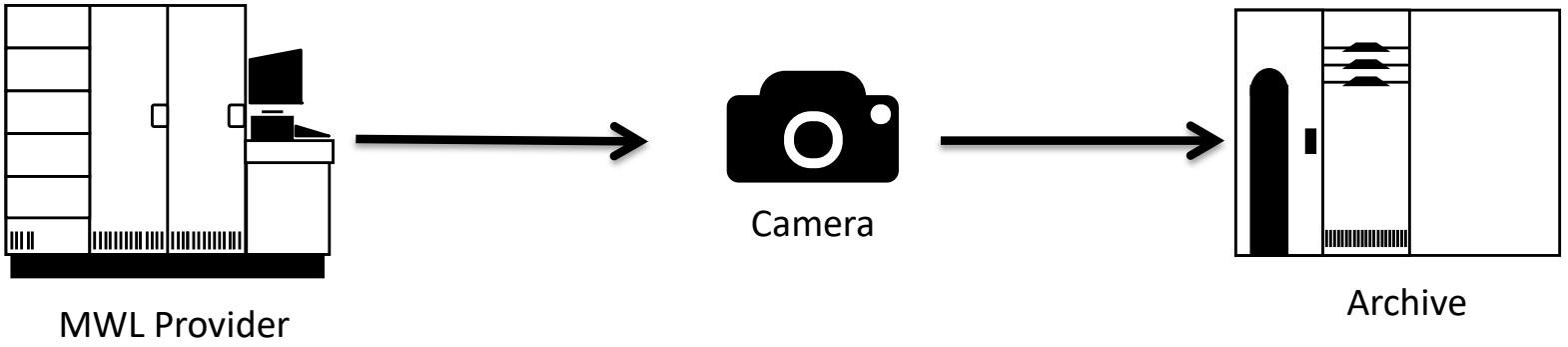
From whence cometh metadata

- Manual data entry sucks (and is error prone)
- It lives naturally in HIS, departmental IS, EMR
- Broadcast/multicast HL7 V2 messages when various “trigger events” occur
- Asynchronous stuff sucks (since it may come when the acquisition device is least/not expecting it) – devices may be “intermittently connected”
- A 3rd party can cache it and respond to queries for it – hence DICOM Modality Worklist (MWL) "broker" was born
- Today one might reinvent MWL with queries on FHIR resources
- HL7 V2 queries have never been popular, but do work

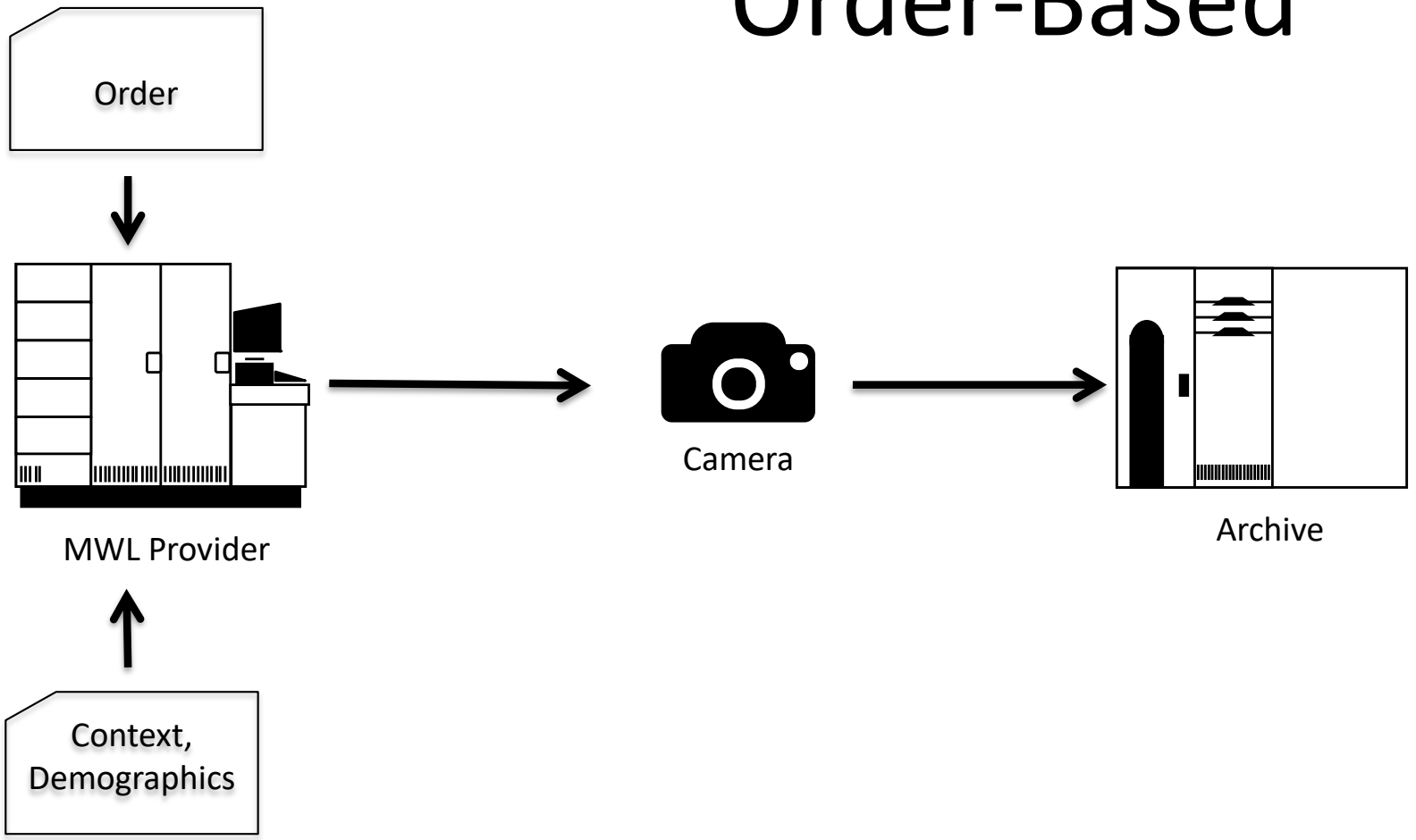
MWL beyond Radiology

- DICOM MWL does NOT depend on their being an order (despite myth)
- E.g., a scheduled clinic visit can trigger creation of a worklist entry
- Admission, Service Episode IDs sent in work lists to match to “encounters”
- E.g., Cardiac Cath. – typically not “ordered” and even if ordered, morph during the procedure (e.g., from diagnostic cath to interventional)
- Extensive use by VA of MWL for ophthalmology, endoscopy, dentistry
- Joint VA/DoD DICOM Modality Conformance Requirements – http://www.va.gov/health/IMAGING/docs/Joint_DICOM_Req_Doc_V_3_0_upd.pdf

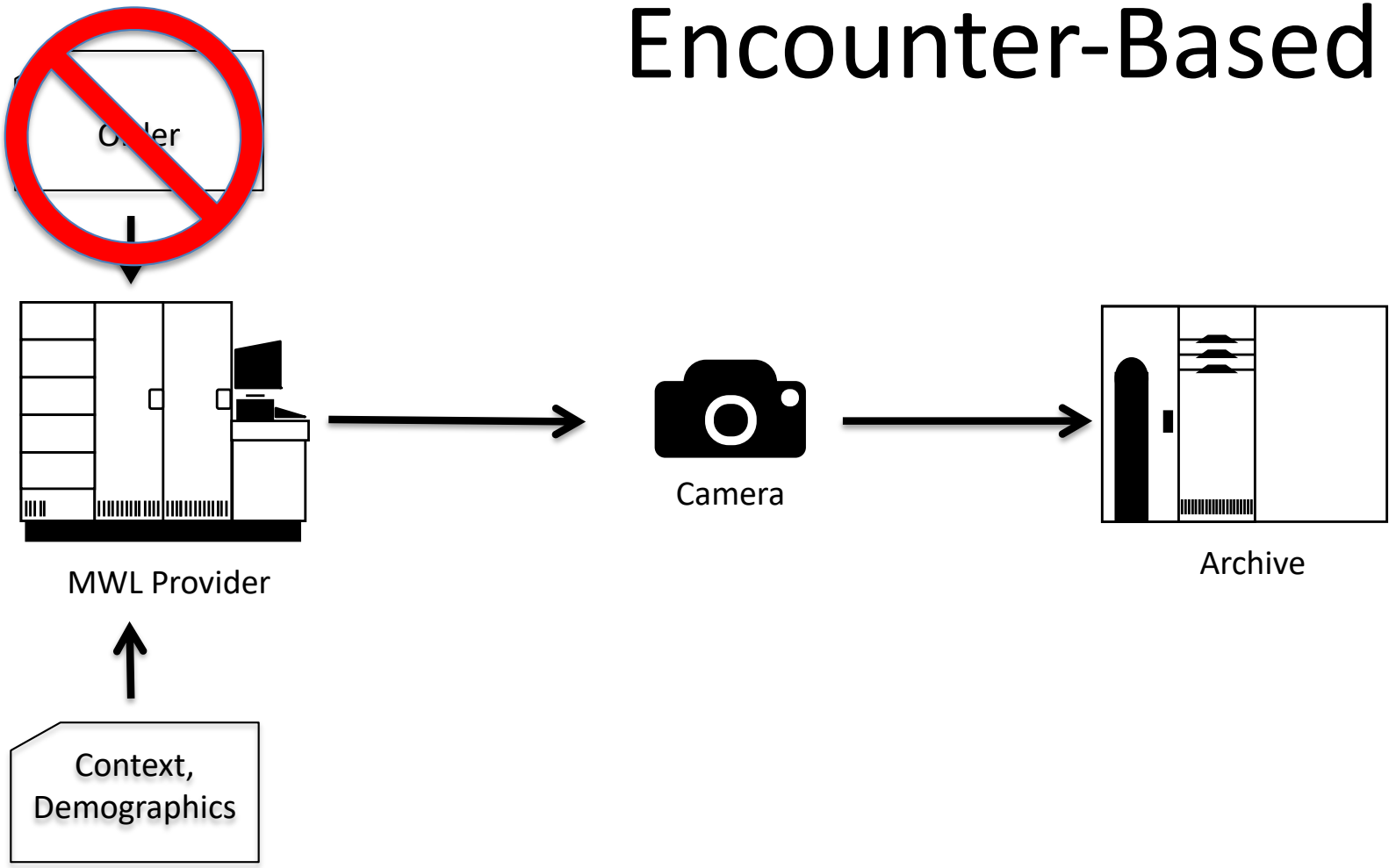

MWL Provider
Modality
Archive


MWL Provider
Camera
Archive

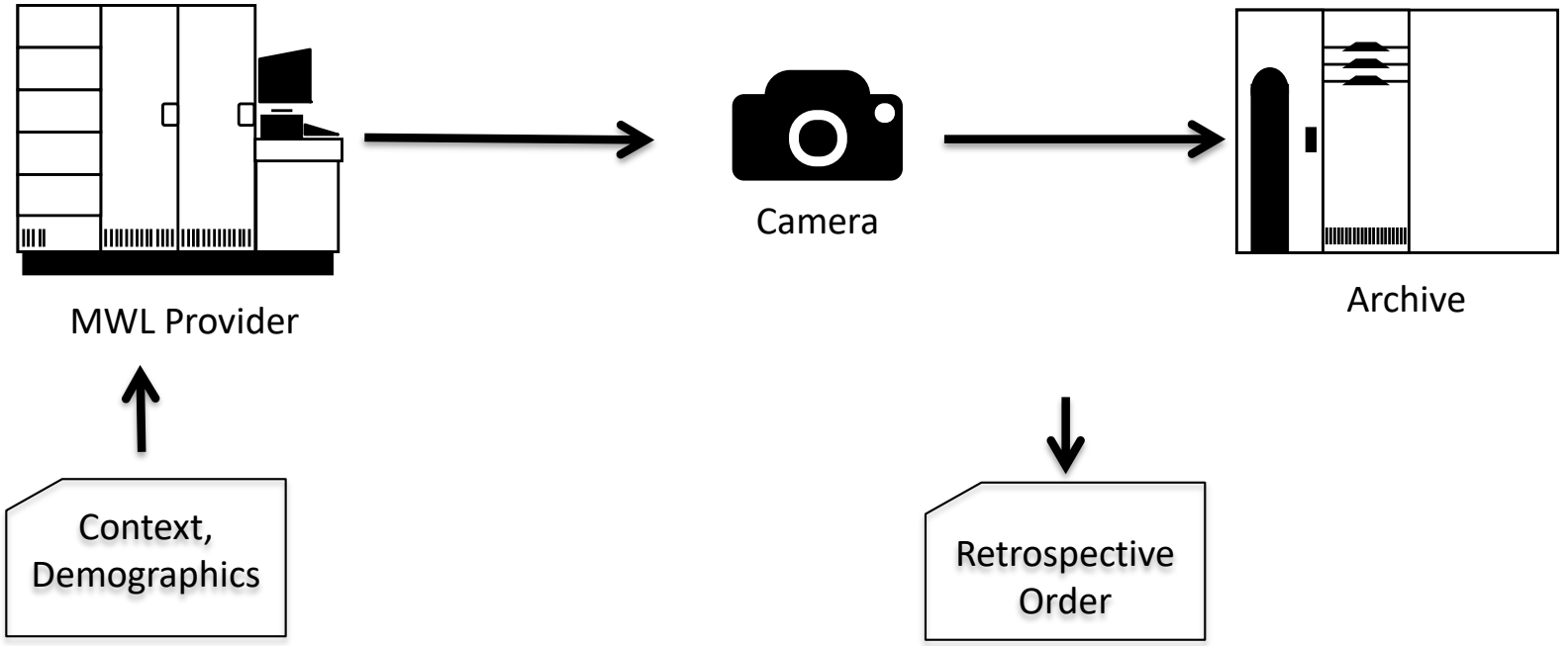
Order-Based



Encounter-Based



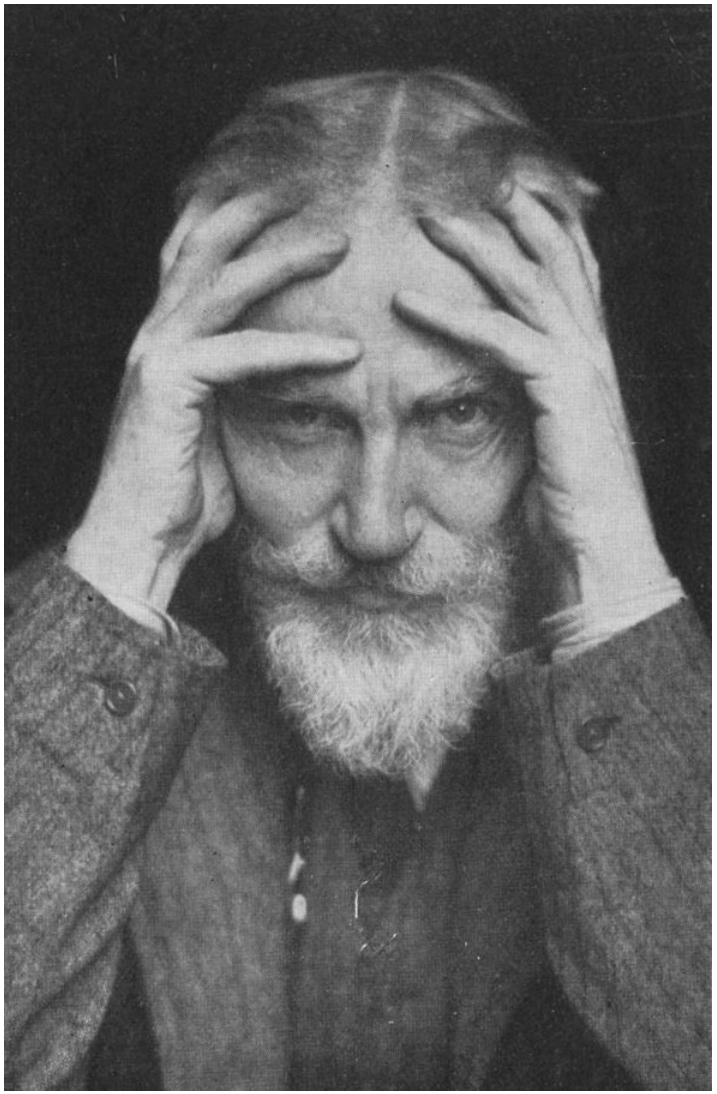
+/- Automatically Generated Order




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

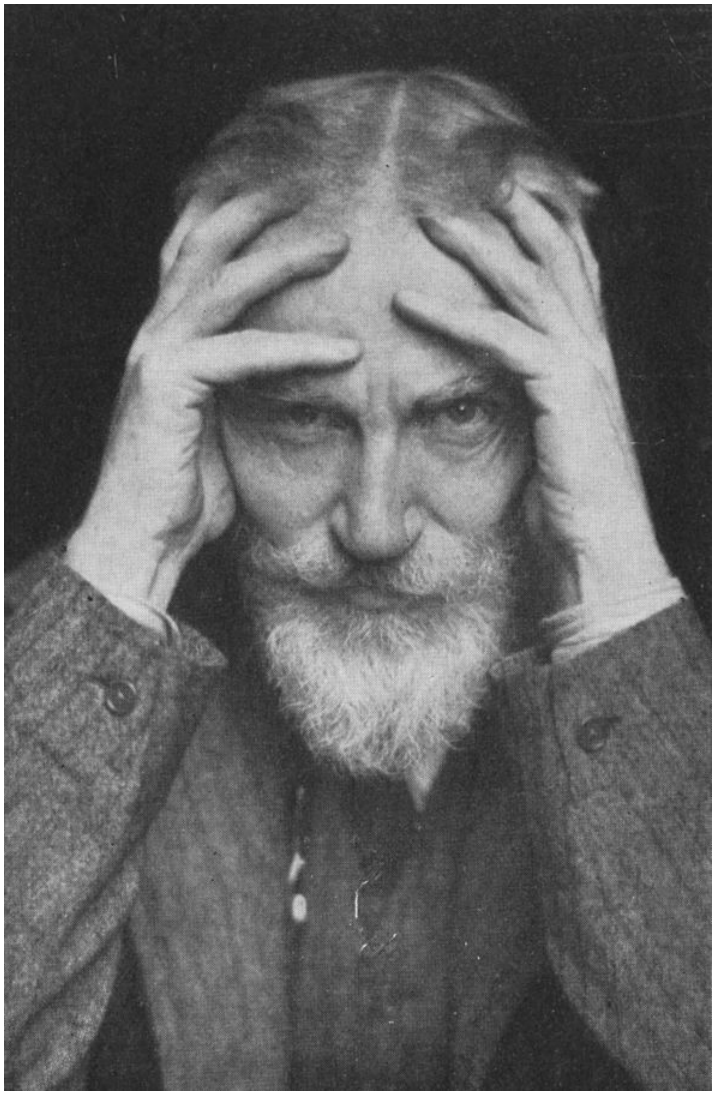
IHE EBIW for Lightweight Devices

- Encounter-Based Imaging Workflow (EBIW)
- Updated trial implementation, but still WIP
- Source of metadata
  - decided DICOM MWL (used for radiology, POC ultrasound) too burdensome
  - HL7 v2 queries not popular
  - so added DICOMweb UPS-RS in addition to C-FIND MWL
  - still fantasizing about FHIR
- Sending images
  - still only C-STORE for now, but plan to add STOW-RS in future revision
- What does it add over a demographics query (e.g., mPDQ in WIC) ?
  - information about the encounter



“Life is not meant to be easy, my child but take courage: it can be delightful.”

Back to Methuselah (1921)



DICOM℠

Digital Imaging and Communications in Medicine

"~~Life~~ is not meant to be easy, my child but take courage: it can be delightful."

Back to Methuselah (1921)

DICOM Made Easy

- Absolute minimum metadata in JSON + JPEG pixel data payload

- DICOMweb
- WADO-RS
- STOW-RS
- IHE Web-based Image Capture (WIC)

DICOMweb Cheatsheet

Study Resources and Actions

Verb	Path	Type	Description
POST	{s}/studies	Store PS3.18 6.6.1	Store instances
GET	{s}/studies?...	Query PS3.18 6.7.1	Query for matching studies
GET	{s}/studies/{studyUID}	Retrieve PS3.18 6.5.1	Retrieve entire study
POST	{s}/studies/{studyUID}	Store PS3.18 6.6.1	Store instances
GET	{s}/studies/{studyUID}/metadata	Retrieve PS3.18 6.5.6	Retrieve metadata
GET	{s}/studies/{studyUID}/series?...	Query PS3.18 6.7.1	Query for matching series in a study
GET	{s}/studies/{studyUID}/series/{seriesUID}	Retrieve PS3.18 6.5.2	Retrieve entire series
GET	{s}/studies/{studyUID}/series/{seriesUID}/metadata	Retrieve PS3.18 6.5.6	Retrieve series metadata
GET	{s}/studies/{studyUID}/series/{seriesUID}/instances?...	Query PS3.18 6.7.1	Query for matching instances in a series
GET	{s}/studies/{studyUID}/series/{seriesUID}/instances/{instanceUID}	Retrieve PS3.18 6.5.3	Retrieve instance
GET	{s}/studies/{studyUID}/series/{seriesUID}/instances/{instanceUID}/metadata	Retrieve PS3.18 6.5.6	Retrieve instance metadata
GET	{s}/studies/{studyUID}/series/{seriesUID}/instances/{instanceUID}/frames/{frames}	Retrieve PS3.18 6.5.4	Retrieve frames in an instance
GET	/{bulkdataReference}	Retrieve PS3.18 6.5.5	Retrieve bulk data

More Information

See http://dicomweb.org and Part 18 of the DICOM Standard, http://dicom.nema.org/standard.html.

Workflow Resources and Actions

Verb	Path	Type	Description
POST	{s}/workitems{?AffectedSOPInstanceUID}	PS3.18 6.9.1	CreateUPS
POST	{s}/workitems/{UPSInstanceUID}{?transaction}	PS3.18 6.9.2	UpdateUPS
GET	{s}/workitems{?query*}	PS3.18 6.9.3	SearchForUPS
GET	{s}/workitems/{UPSInstanceUID}	PS3.18 6.9.4	RetrieveUPS
PUT	{s}/workitems/{UPSInstanceUID}/state	PS3.18 6.9.5	ChangeUPSState
POST	{s}/workitems/{UPSInstanceUID}/cancelrequest	PS3.18 6.9.6	RequestUPS Cancellation
POST	{s}/workitems/{UPSInstanceUID}/subscribers/{AETitle}{?deletionlock}	PS3.18 6.9.7	CreateSubscription
POST	{s}/workitems/1.2.840.10008.5.1.4.34.5/	PS3.18 6.9.8	SuspendGlobal Subscription
DELETE	{s}/workitems/{UPSInstanceUID}/subscribers/{AETitle}	PS3.18 6.9.9	DeleteSubscription
GET	{s}/subscribers/{AETitle}	PS3.18 6.9.10	OpenEventChannel
N/A	N/A	PS3.18 6.9.11	SendEventReport

Payloads

XML

```
<NativeDicomModel>
  <DicomAttribute Tag="00080020"
VR="DT" Keyword="StudyDate">
    <Value
number="1">20130409</value>
  </DicomAttribute>
  <DicomAttribute Tag="00080030"
VR="TM" Keyword="StudyTime">
    <Value
number="1">131600.0000</value>
  </DicomAttribute>
  …
</NativeDicomModel>
```

JSON

```
{
    "00080020": {
        "vr": "DT",
        "Value":
["20130409"]
    },
    "00080030": {
        "vr": "TM",
        "Value":
["131600.0000"]
    },
    …
}
```

(these payloads are excerpts to show payload structure; these are not complete)


Serial number:
100001

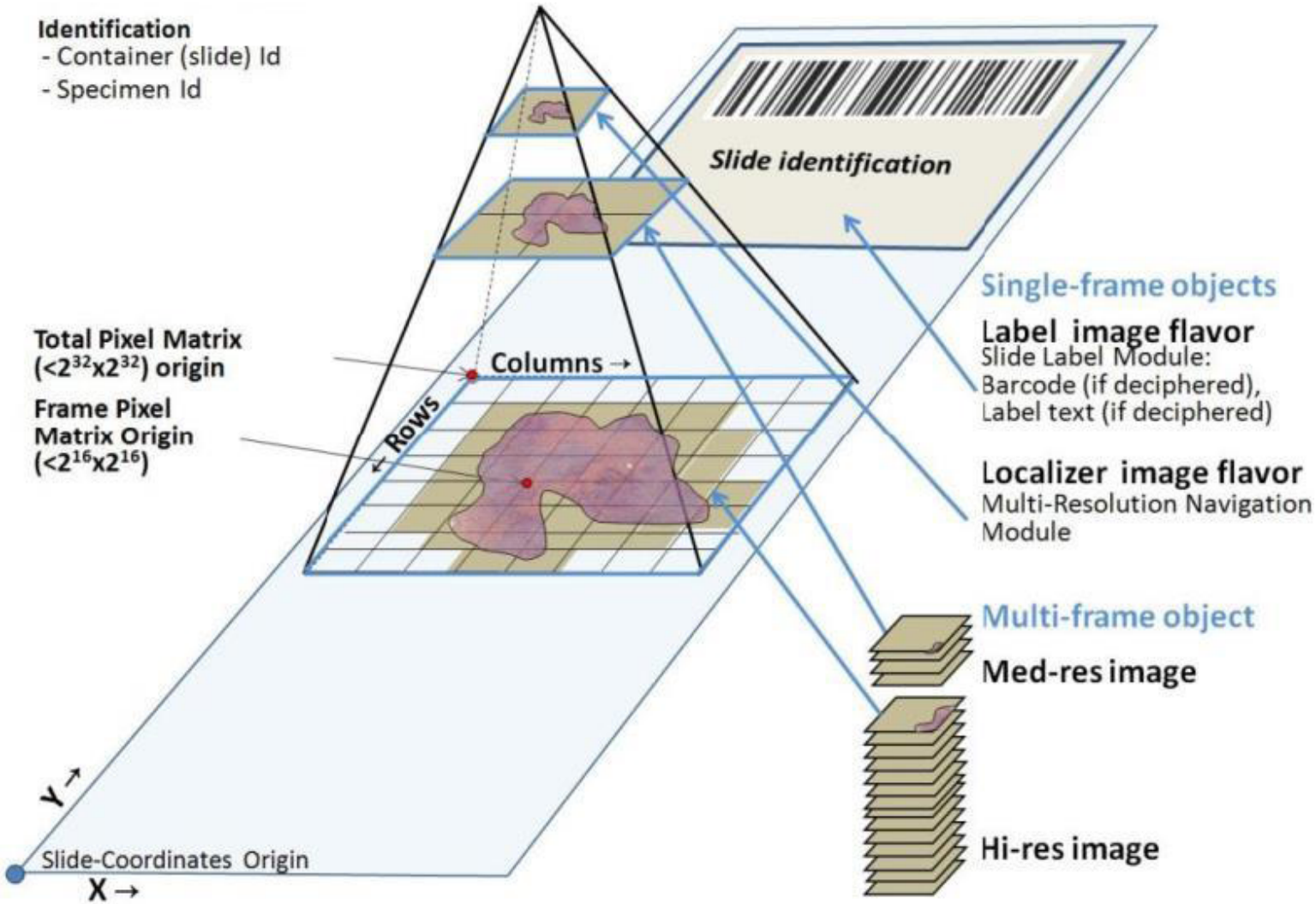
Security concerns

- You will be breached
- There is no such thing as a “secure internal” network – trend to "zero trust" paradigm
- All transactions should be secured (encrypted: DICOM, HTTP over TLS)
- This includes scanner to PACS, camera to PACS, viewer to PACS, …
- Mobile devices – lack of physical control, BYOD, need to purge cached content, …
- Encryption at rest (on disk) as well as in transit (on wire, in air)
- Think beyond regulatory (HIPAA, GDPR) compliance: availability – ransomware
- DICOM defines access control, integrity and encryption mechanisms – but hardly anybody implements or activates them
- DICOMweb inherits multitude of standard web approaches for RESTful APIs
- Access control standards – IHE Internet User Authentication (IUA) – OAuth, JWT
- Confidentiality, integrity and availability (CIA triad)
- A primary motivation for “enterprise” imaging is enterprise level security/reliability

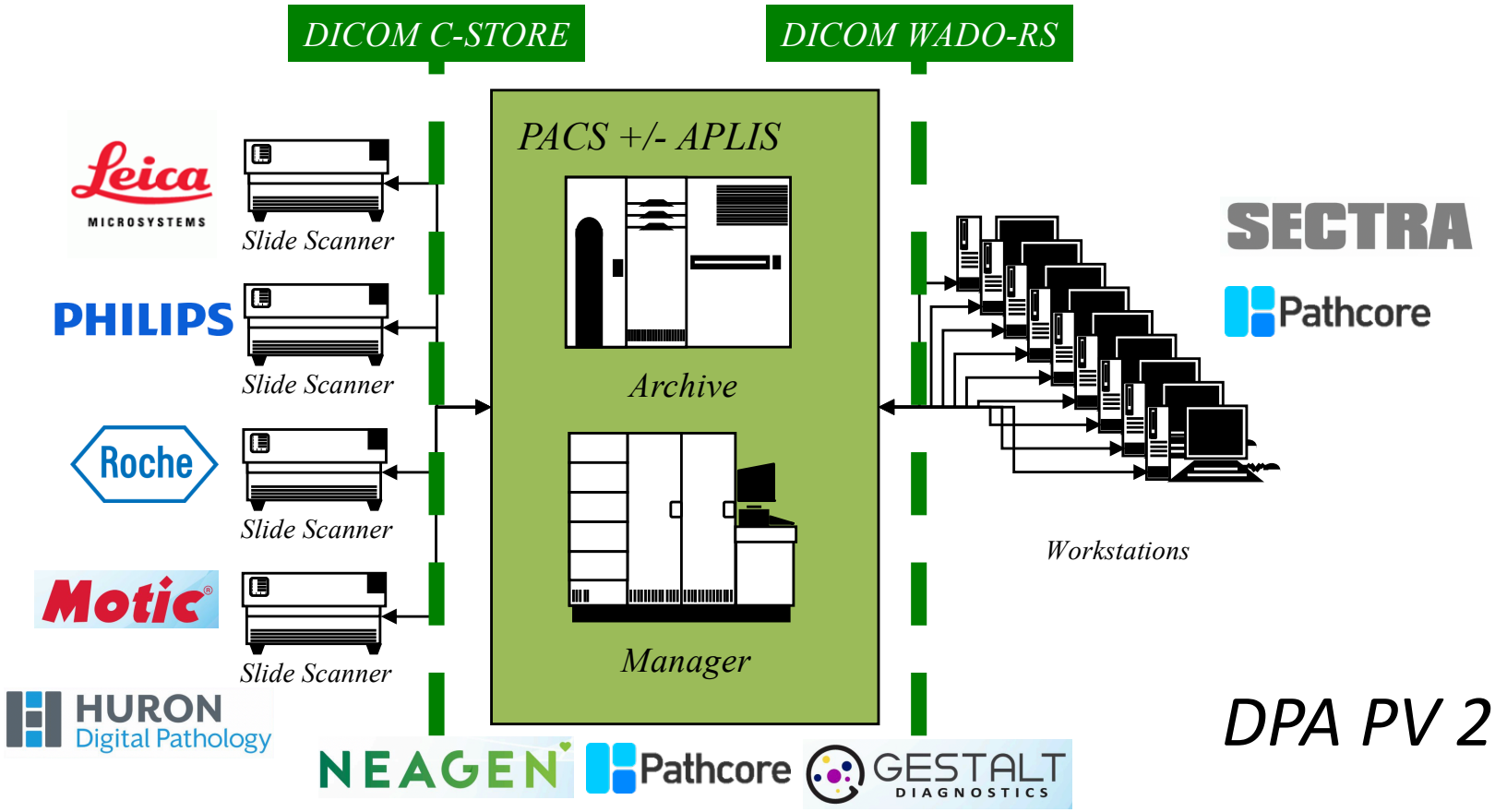
Privacy concerns

- Largely ignored for radiology in the past
- Especially challenging for some types of enterprise imaging
- E.g., nude whole body/genitalia, pediatric, distressing (burn/trauma) photography
- Balance risk against utility, user acceptance and safety
- Genuine patient/worker concern v. obsessive political correctness
- Sensitivity classification model/attributes/flags (different policy for different images)
- Patient consent or restriction model/attributes/flags
- Role-based access control (RBAC), Attribute-based access control (ABAC), …
- Patient-specific care team + role in care + off-hours coverage
- Genuine restriction of access versus policy + retrospective audit
- Beyond state of the art in current EMRs, PACS, VNAs ? Separate "pools"?
- Leverage enterprise-wide identity management solutions across EMR & PACS

Garcia-Rojo et al. 2016

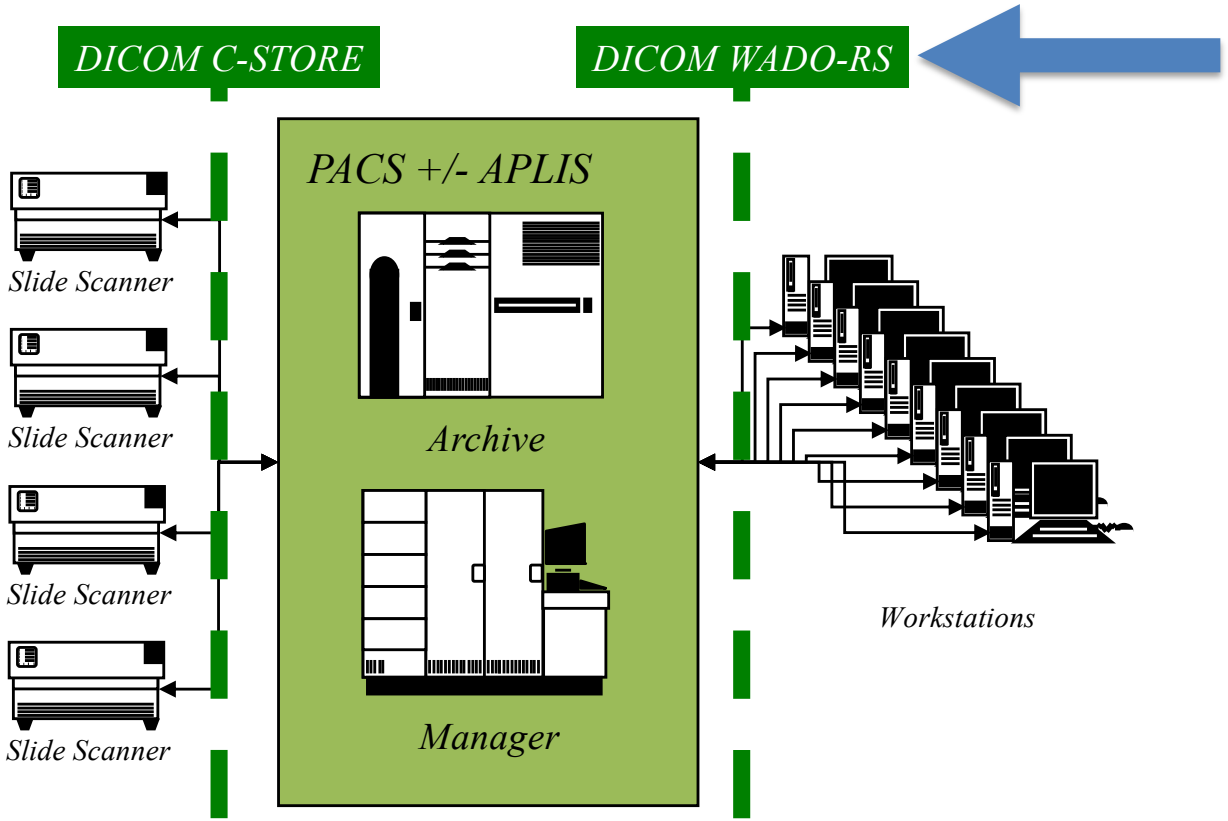


DICOM and Whole Slide Imaging



DPA PV 2018

DICOM and Whole Slide Imaging



We are from Enterprise IT
and are here to help you!