DICOM and its role in IDC

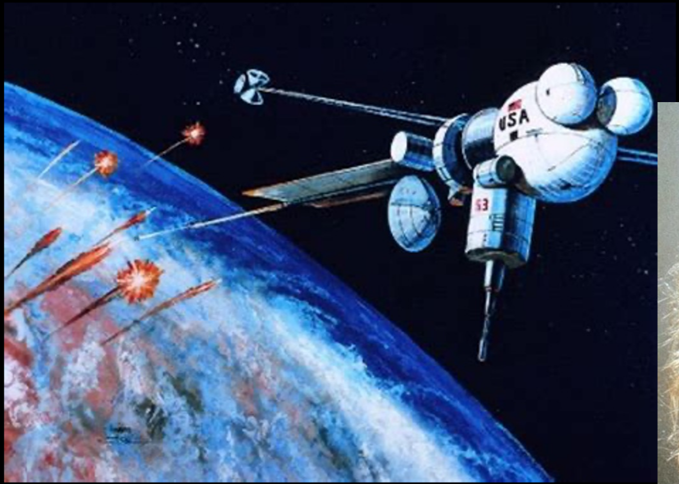
David Clunie, PixelMed

Why DICOM?

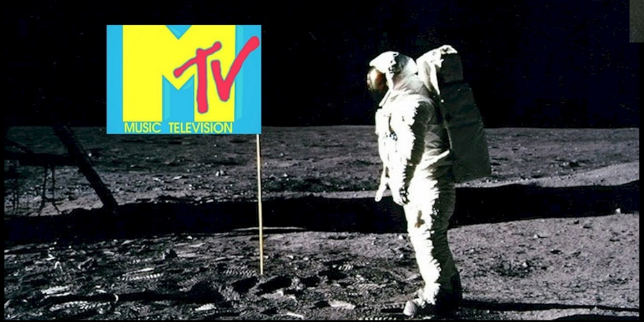
- It's everywhere
  - it's what comes out of the scanners (radiology)
  - it's what is stored in the clinical archives
  - it's what off-the-shelf workstations and viewers support
- It's open to access and use
- It has lots of free open source tools that support it
- It's supported and maintained
- It has all the metadata
  - identifying and descriptive
  - patient (subject, case), study, series, image, acquisition, …
- It supports all sorts of modalities, old and new
  - CT, MR, NM, PET, US, X-Ray, Fluoro, Angio, …
- It supports visible light
  - esp. histopathology Whole Slide microscopy imaging (WSI)
- It supports annotations, ROIs, quantitative result storage, …

Why not DICOM?

- It's *"woefully archaic"* [Merck 2017] - dates back to early 1980's
  - mitigation: updated with modern approaches - DICOMweb, JSON
- It's too complicated
  - mitigation: provide tools, integrate w. libraries, training, support
- It isn't "*insert name of research/proprietary format here*" [Li 2016]
  - e.g., NIfTI, BIDS, NRRD, OME-TIFF, TensorFlow Record, …
  - mitigation: provide converters, integrate w. libraries
- It isn't (usually) one file containing everything
  - historically one slice per file - needs grouping/sorting
  - mitigation: updated standard w. multi-frame - FAILED - to be adopted
  - mitigation: provide tools to sort, organize, convert, …
- …
- Not sufficient to justify using alternative research-specific format in IDC
- DICOM can be extended for research purposes (and we do)

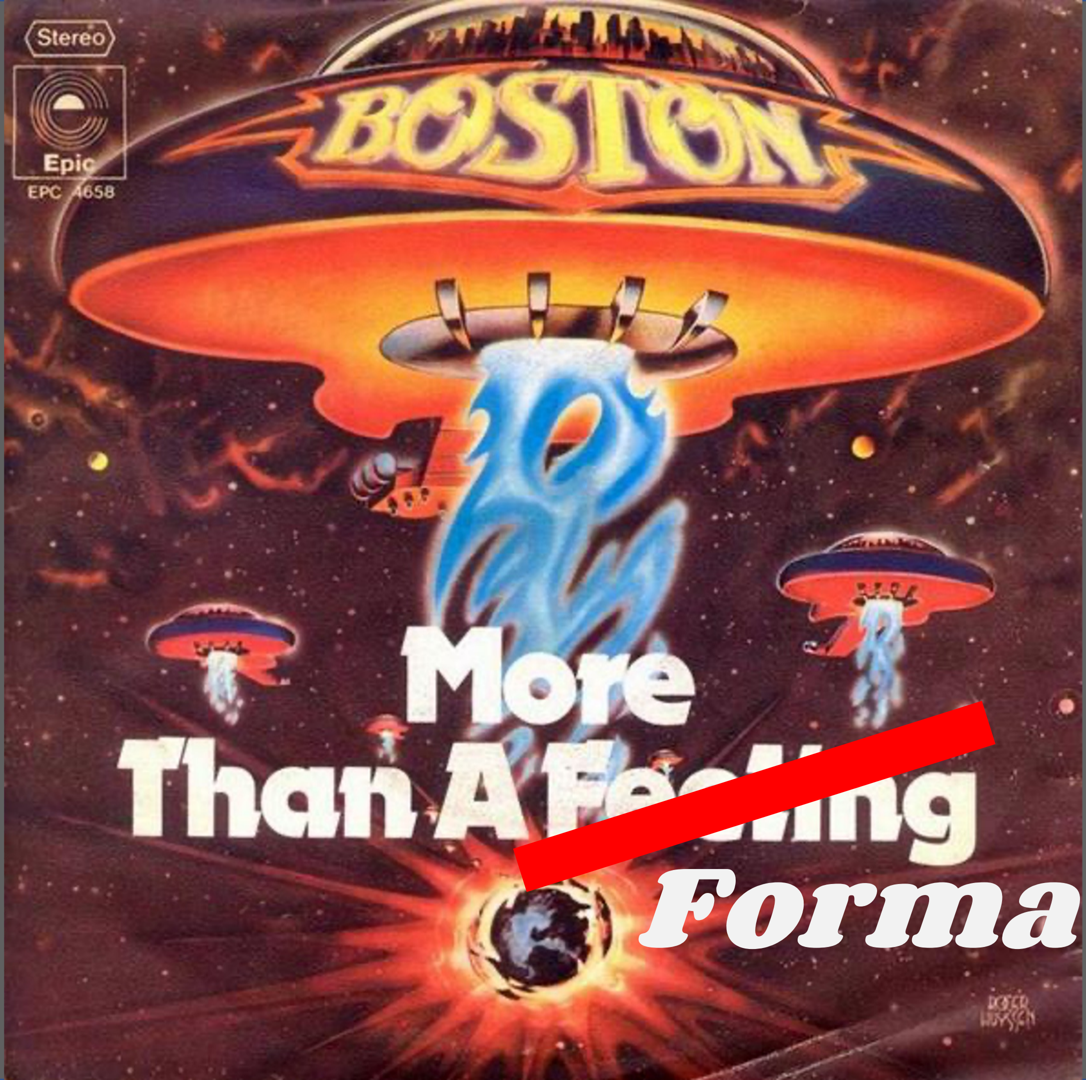


I want my MTV!



DICOM℠

Digital Imaging and Communications in Medicine



http://en.wikipedia.org/wiki/More_Than_a_Feeling

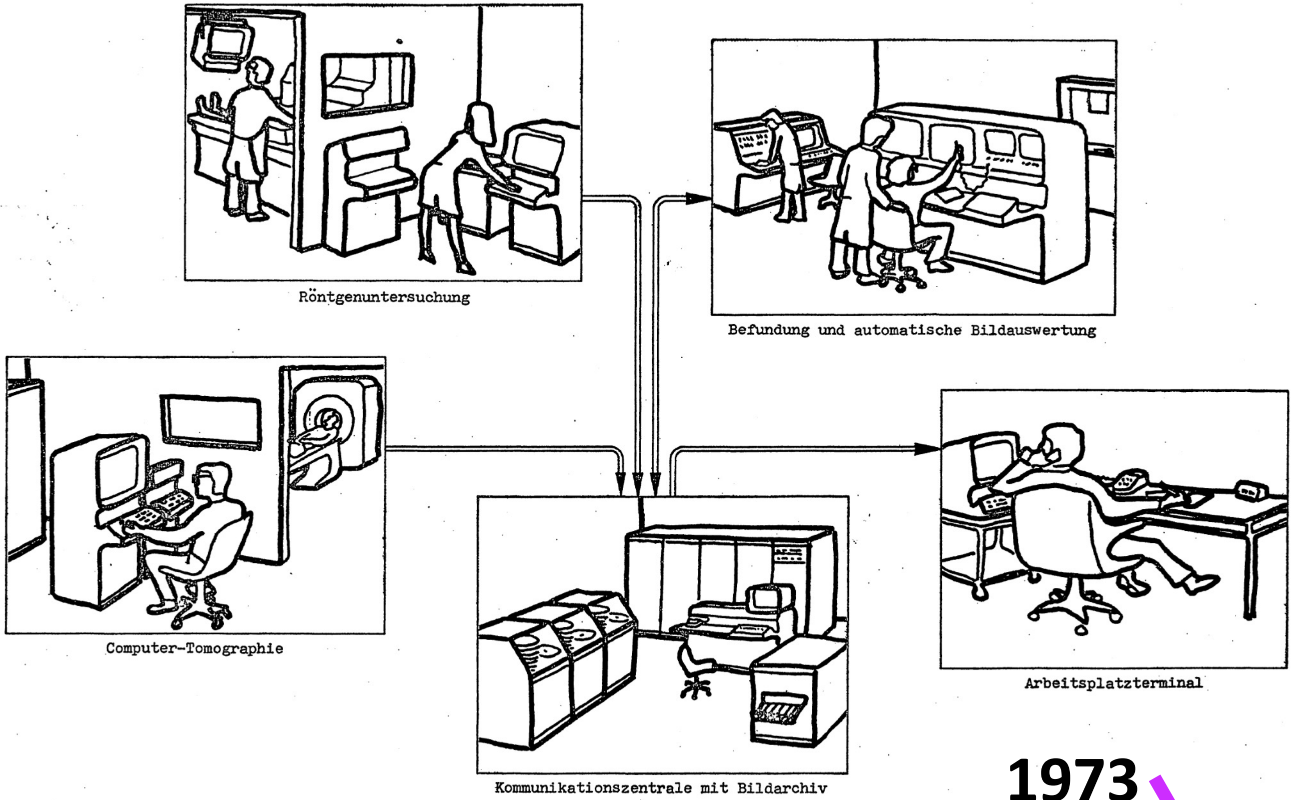
What is DICOM?

- Open standard
- Specification for ***<u>interoperability</u>***
- Protocol for messaging and transport (including web services - DICOMweb)
- Services for storage and management
- Metadata encoding mechanism
- Information object definition
- Common information model (reflected in metadata)
- Pixel data encoding mechanism (including lossless/lossy compression)
- Application functionality specification and conformance mechanism
- Annotation, rendering and reporting mechanisms

Interoperability

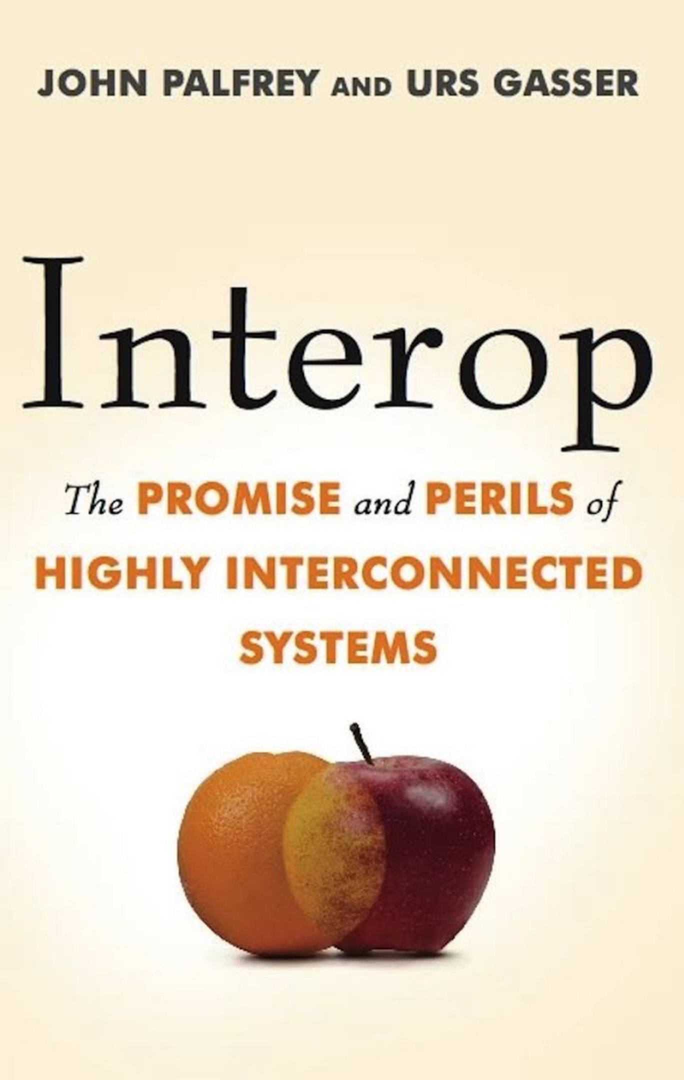
"the ability of two or more systems or components to exchange information and to use the information that has been exchanged"

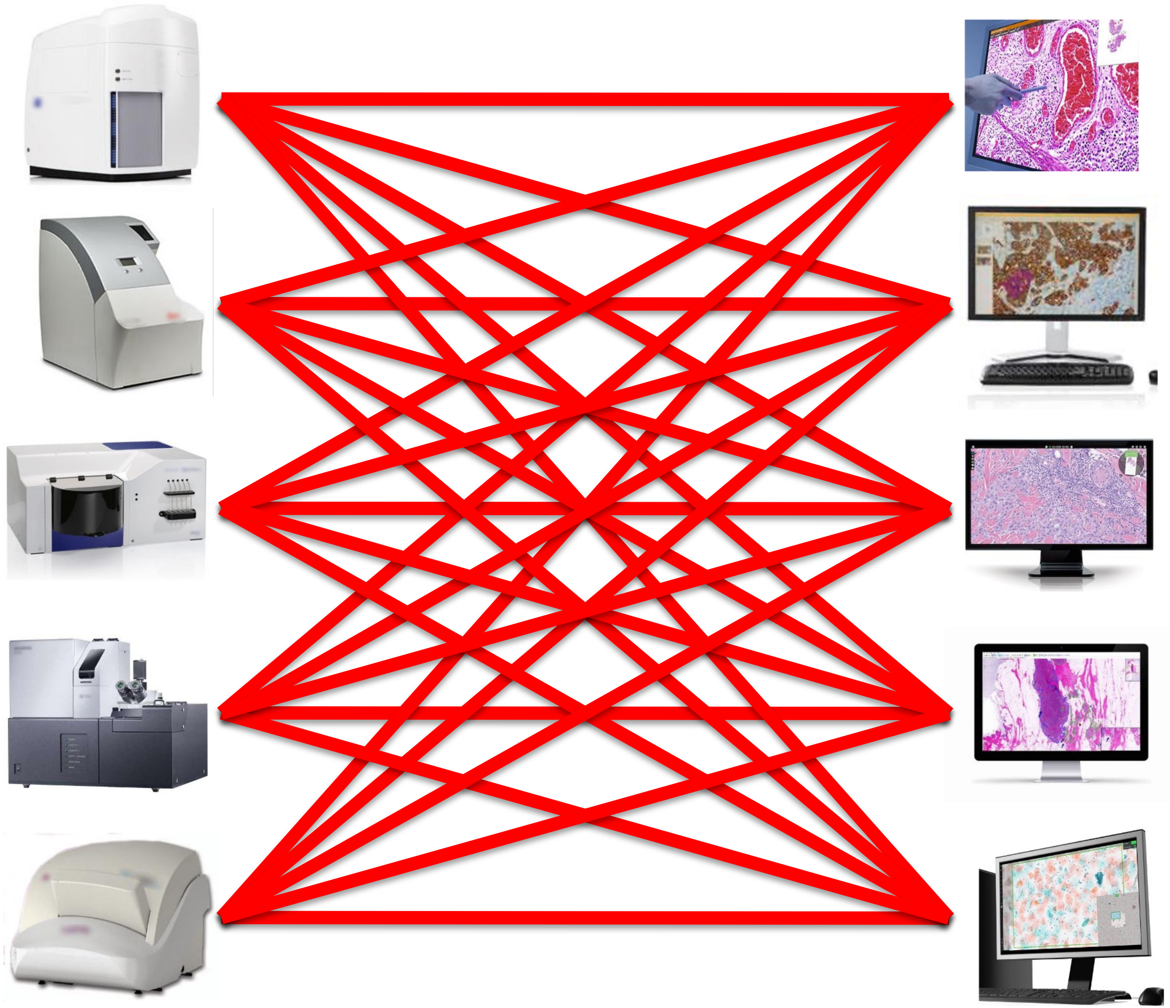
[IEEE Standard Computer Dictionary: A Compilation of IEEE Standard Computer Glossaries. 1990]



1973

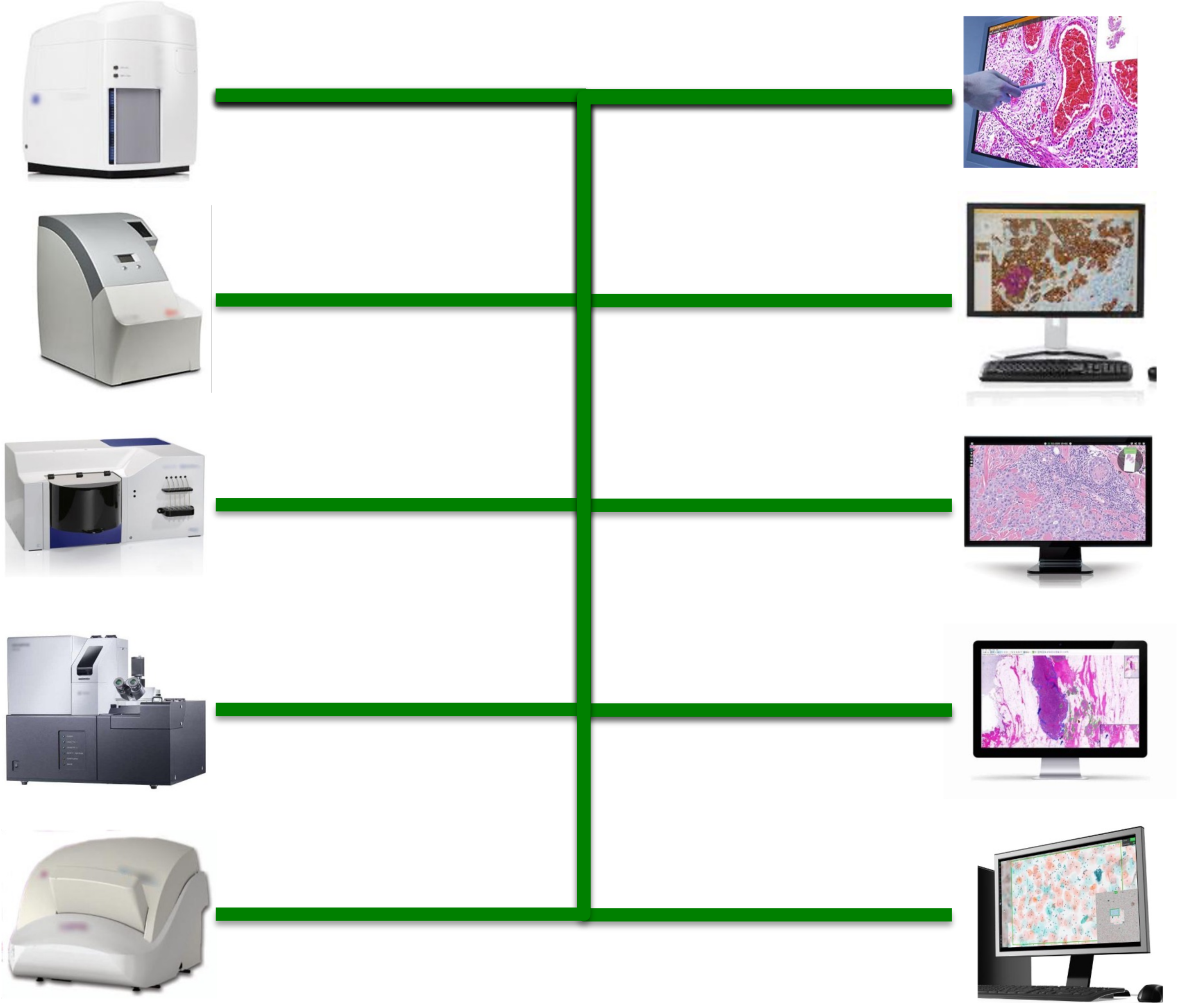
Meyer-Ebrecht D. [Electronic Archival System for X-Rays Images - Work proposal for a research project in the years 1974 and 1975] Elektronisches Archivierungssystem für Röntgenbilder – Arbeitsvorschlag für ein Forschungsprojekt in den Jahren 1974 und 1975. Hamburg, Germany: Philips Research Labs; 1973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

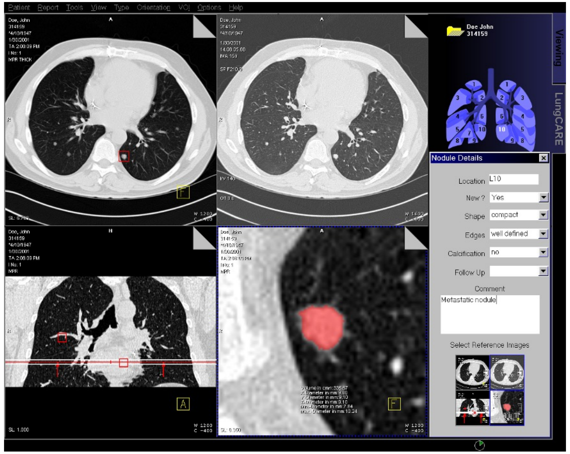

JOHN PALFREY AND URS GASSER
Interop
The PROMISE and PERILS of
HIGHLY INTERCONNECTED
SYSTEMS

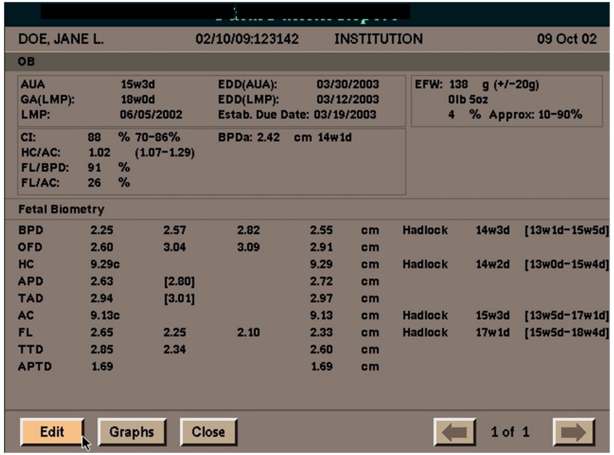


DICOM℠

Digital Imaging and Communications in Medicine




Patient Report Tools View Type Orientation VOI Options Help
Doe John
314159
Nodule Details
Location L10
New ? Yes
Shape compact
Edges well defined
Calcification no
Follow Up
Comment
Metastatic nodule
Select Reference Images
Viewing
LungCARE


DOE, JANE L. 02/10/09:123142 INSTITUTION 09 Oct 02
OB
AUA 15w3d EDD(AUA): 03/30/2003
GA(LMP): 18w0d EDD(LMP): 03/12/2003
LMP: 06/05/2002 Estab. Due Date: 03/19/2003
EFW: 138 g (+/-20g)
0lb 5oz
4 % Approx: 10-90%
CI: 88 % 70-86%
HC/AC: 1.02 (1.07-1.29)
FL/BPD: 91 %
FL/AC: 26 %
BPDa: 2.42 cm 14w1d
Fetal Biometry
BPD 2.25 2.57 2.82 2.55 cm Hadlock 14w3d [13w1d-15w5d]
OFD 2.60 3.04 3.09 2.91 cm
HC 9.29c 9.29 cm Hadlock 14w2d [13w0d-15w4d]
APD 2.63 [2.80] 2.72 cm
TAD 2.94 [3.01] 2.97 cm
AC 9.13c 9.13 cm Hadlock 15w3d [13w5d-17w1d]
FL 2.65 2.25 2.10 2.33 cm Hadlock 17w1d [15w5d-18w4d]
TTD 2.85 2.34 2.60 cm
APTD 1.69 1.69 cm
Edit
Graphs
Close
1 of 1


Patient Applications Argus VF Options Argus Analysis Argus VF Tools Options Help
Doe Jane
Movie
Slow
Fast
Display
Contours
Direction
Patient Information
Output Results
Display Volume Results
Save Data
Reload Data
Viewing
Argus

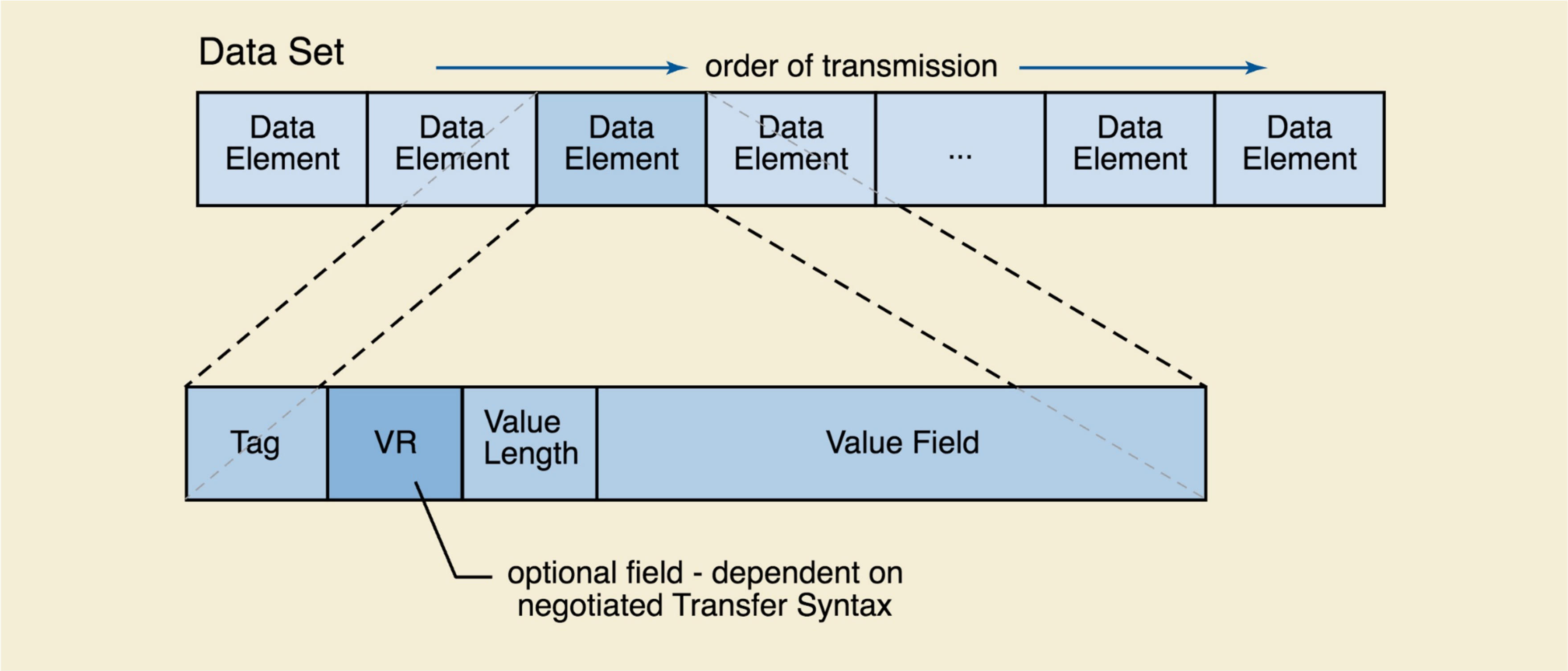
DICOM Files – What's in them?

- Images
  - one slice per data set (file) *or* a bunch of slices (enhanced multi-frame, e.g., a 3D volume, or 4D volume + time or other dimension)
  - from scanner
  - created by analysis
  - that are intermediate work product shared between tools
  - that are parametric maps (physical quantities)
  - that are integers (scaled) or floating point
  - that are pretty pictures (e.g., rendered fusions, screen shots)

DICOM Files – What's in them?

- Non-images
  - registration transformation – rigid or deformation field
  - display instruction – presentation state
  - classification – Segmentation (rasterized, surface), Structure Sets – iso-contours (used in radiotherapy planning)
  - surface meshes and point clouds
  - structured data – Structured Report (SR) (e.g., measurements, categorical statements, annotations, contours)
  - pretty things – scanned documents, encapsulated PDF, STL, …

How are DICOM files encoded?



MR Image Composite IOD

IE	Module	Reference	Usage
Patient	Patient	C.7.1.1	M
Study	General Study	C.7.2.1	M
	Patient Study	C.7.2.2	U
Series	General Series	C.7.3.1	M
Frame of Reference	Frame of Reference	C.7.4.1	M
Equipment	General Equipment	C.7.5.1	M
Image	General Image	C.7.6.1	M
	Image Plane	C.7.6.2	M
	Image Pixel	C.7.6.3	M
	Contrast/bolus	C.7.6.4	C - Required if contrast media was used in this image
	MR Image	C.8.3.1	M
	Overlay Plane	C.9.2	U
	VOI LUT	C.11.2	U
	SOP Common	C.12.1	M

Image Plane Module

Attribute Name	Tag	Type	Attribute Description
Pixel Spacing	(0028,0030)	1	Physical distance in the patient between the center of each pixel, specified by a numeric pair - adjacent row spacing (delimiter) adjacent column spacing in mm.
Image Orientation (Patient)	(0020,0037)	1	The direction cosines of the first row and the first column with respect to the patient. See C.7.6.2.1.1 for further explanation.
Image Position (Patient)	(0020,0032)	1	The x, y, and z coordinates of the upper left hand corner (first pixel transmitted) of the image, in mm. See C.7.6.2.1.1 for further explanation.
Slice Thickness	(0018,0050)	2	Nominal slice thickness, in mm.
Slice Location	(0020,1041)	3	Relative position of exposure expressed in mm. C.7.6.2.1.2 for further explanation.

Example MR Image Dataset

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(0x0008,0x0008) CS Image Type VR=<CS> VL=<0x0010> <ORIGINAL\PRIMARY>
(0x0008,0x0016) UI SOP Class UID VR=<UI> VL=<0x001a> <1.2.840.10008.5.1.4.1.1.4>
(0x0008,0x0018) UI SOP Instance UID VR=<UI> VL=<0x002e>
<1.2.840.113619.2.1.2.1909421756.1.1.602501582>
(0x0008,0x0020) DA Study Date VR=<DA> VL=<0x0008> <19890203>
(0x0008,0x0021) DA Series Date VR=<DA> VL=<0x0008> <19890203>
(0x0008,0x0022) DA Acquisition Date VR=<DA> VL=<0x0008> <19890203>
(0x0008,0x0023) DA Image Date VR=<DA> VL=<0x0008> <19890203>
(0x0008,0x0030) TM Study Time VR=<TM> VL=<0x0006> <092618>
(0x0008,0x0031) TM Series Time VR=<TM> VL=<0x0006> <093221>
(0x0008,0x0032) TM Acquisition Time VR=<TM> VL=<0x0006> <093302>
(0x0008,0x0033) TM Image Time VR=<TM> VL=<0x0006> <093302>
(0x0008,0x0050) SH Accession Number VR=<SH> VL=<0x0000> []
(0x0008,0x0060) CS Modality VR=<CS> VL=<0x0002> <MR>
(0x0008,0x0070) LO Manufacturer VR=<LO> VL=<0x0012> <GE MEDICAL SYSTEMS>
(0x0008,0x0080) LO Institution Name VR=<LO> VL=<0x001c> <THOMAS JEFF UNIVHOSPITAL MRI>
(0x0008,0x0090) PN Referring Physician's Name VR=<PN> VL=<0x0004> <HUME>
(0x0008,0x1010) SH Station Name VR=<SH> VL=<0x0008> <FOR.IC0 >
(0x0008,0x1030) LO Study Description VR=<LO> VL=<0x0004> <KNEE>
(0x0008,0x103e) LO Series Description VR=<LO> VL=<0x0006> <COR T2>
(0x0008,0x1060) PN Name of Physician(s) Reading Study VR=<PN> VL=<0x0004> <BODY>
(0x0008,0x1070) PN Operator's Name VR=<PN> VL=<0x0002> <RB>
(0x0008,0x1090) LO Manufacturer's Model Name VR=<LO> VL=<0x000e> <GENESIS_SIGNA >
(0x0010,0x0010) PN Patient's Name VR=<PN> VL=<0x000c> <* GRX KNEE *>
(0x0010,0x0020) LO Patient's ID VR=<LO> VL=<0x0006> <RSNA2 >
(0x0010,0x0030) DA Patient's Birth Date VR=<DA> VL=<0x0000> []
(0x0010,0x0040) CS Patient's Sex VR=<CS> VL=<0x0002> <M >
(0x0010,0x1010) AS Patient's Age VR=<AS> VL=<0x0004> <034Y>
(0x0010,0x1030) DS Patient's Weight VR=<DS> VL=<0x000a> < 90.718000>
(0x0010,0x21b0) LT Additional Patient History VR=<LT> VL=<0x0008> <R/O TEAR>
(0x0018,0x0020) CS Scanning Sequence VR=<CS> VL=<0x0002> <SE>
(0x0018,0x0021) CS Sequence Variant VR=<CS> VL=<0x0004> <OSP >
(0x0018,0x0022) CS Scan Options VR=<CS> VL=<0x0004> <NPW >
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(0x0018,0x0050) DS Slice Thickness VR=<DS> VL=<0x0008> <5.000000>
(0x0018,0x0080) DS Repetition Time VR=<DS> VL=<0x000c> < 2000.000000>
(0x0018,0x0081) DS Echo Time VR=<DS> VL=<0x000a> < 20.000000>
(0x0018,0x0082) DS Inversion Time VR=<DS> VL=<0x0008> <0.000000>
(0x0018,0x0083) DS Number of Averages VR=<DS> VL=<0x0008> <0.500000>
(0x0018,0x0084) DS Imaging Frequency VR=<DS> VL=<0x0010> < 638746840.00000>
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(0x0018,0x0086) IS Echo Number(s) VR=<IS> VL=<0x0002> < 1>
(0x0018,0x0087) DS Magnetic Field Strength VR=<DS> VL=<0x0006> <15000 >
(0x0018,0x0088) DS Spacing Between Slices VR=<DS> VL=<0x0008> <6.000000>
(0x0018,0x0091) IS Echo Train Length VR=<IS> VL=<0x0002> <0 >
(0x0018,0x0093) DS Percent Sampling VR=<DS> VL=<0x000a> < 53.125000>
(0x0018,0x0094) DS Percent Phase Field of View VR=<DS> VL=<0x000a> <100.000000>
(0x0018,0x1088) IS Heart Rate VR=<IS> VL=<0x0002> <0 >
(0x0018,0x1090) IS Cardiac Number of Images VR=<IS> VL=<0x0002> <0 >
(0x0018,0x1094) IS Trigger Window VR=<IS> VL=<0x0002> <10>
(0x0018,0x1100) DS Reconstruction Diameter VR=<DS> VL=<0x000a> <140.000000>
(0x0018,0x1314) DS Flip Angle VR=<DS> VL=<0x0002> <0 >
(0x0018,0x1315) CS Variable Flip Angle Flag VR=<CS> VL=<0x0002> <N >
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(0x0020,0x0010) SH Study ID VR=<SH> VL=<0x0002> <2 >
(0x0020,0x0011) IS Series Number VR=<IS> VL=<0x0002> < 1>
(0x0020,0x0012) IS Acquisition Number VR=<IS> VL=<0x0002> < 0>
(0x0020,0x0013) IS Image Number VR=<IS> VL=<0x0002> < 1>
(0x0020,0x0032) DS Image Position (Patient) VR=<DS> VL=<0x0020>
<-70.000000\ 18.000000\ 75.000000>
(0x0020,0x0037) DS Image Orientation (Patient) VR=<DS> VL=<0x0038>
< 1.000000\0.000000\0.000000\0.000000\0.000000\ -1.000000>
(0x0020,0x0052) UI Frame of Reference UID VR=<UI> VL=<0x002c>
<1.2.840.113619.2.1.2.596272627.1.602501541.0>
(0x0020,0x0060) CS Laterality VR=<CS> VL=<0x0000> []
(0x0020,0x0110) DS Temporal Resolution VR=<DS> VL=<0x000a> <1120403456>
(0x0020,0x1040) LO Position Reference Indicator VR=<LO> VL=<0x0002> <KN>
(0x0020,0x1041) DS Slice Location VR=<DS> VL=<0x000e> <-18.0000000000>
(0x0028,0x0002) US Samples per Pixel VR=<US> VL=<0x0002> [0x01]
(0x0028,0x0004) CS Photometric Interpretation VR=<CS> VL=<0x000c> <MONOCHROME2 >
(0x0028,0x0010) US Rows VR=<US> VL=<0x0002> [0x100]
(0x0028,0x0011) US Columns VR=<US> VL=<0x0002> [0x100]
(0x0028,0x0030) DS Pixel Spacing VR=<DS> VL=<0x0012> < 0.546875\0.546875>
(0x0028,0x0100) US Bits Allocated VR=<US> VL=<0x0002> [0x10]
(0x0028,0x0101) US Bits Stored VR=<US> VL=<0x0002> [0x10]
(0x0028,0x0102) US High Bit VR=<US> VL=<0x0002> [0x0f]
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DICOM as XML

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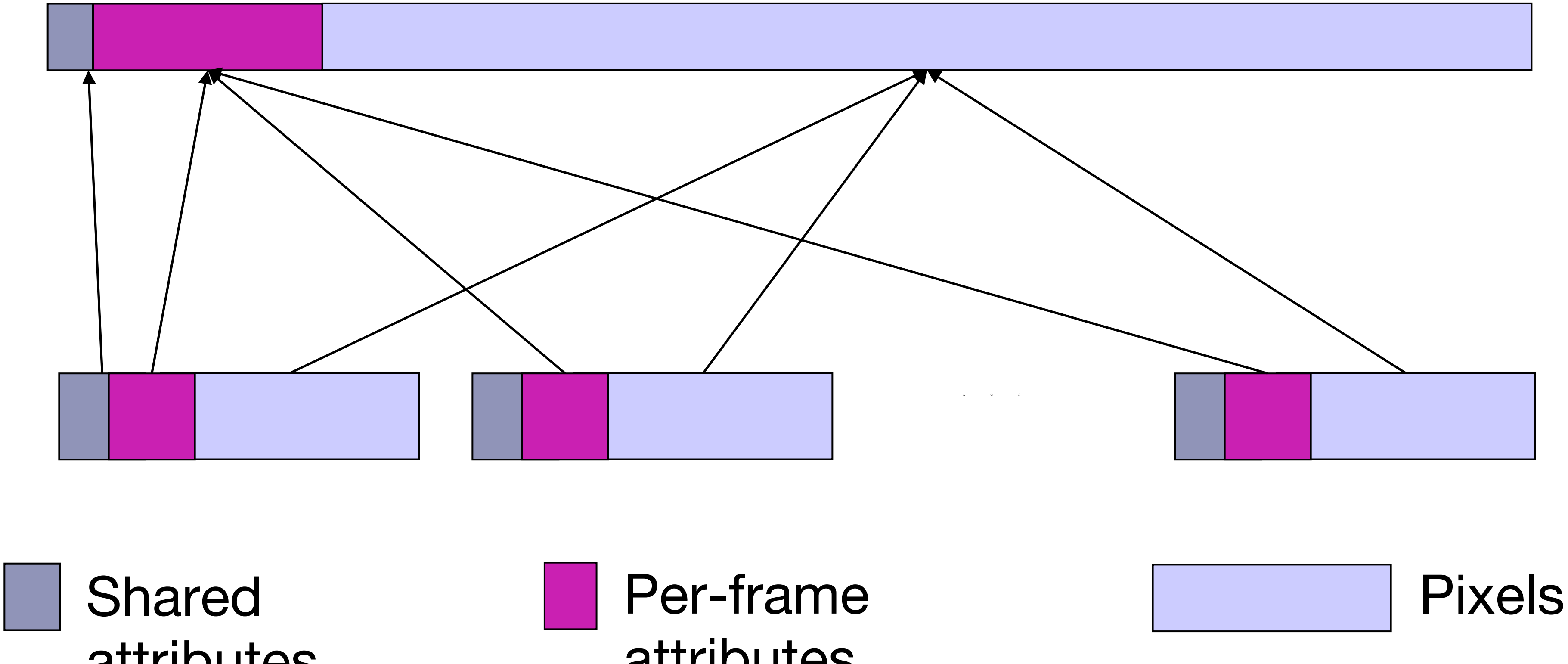
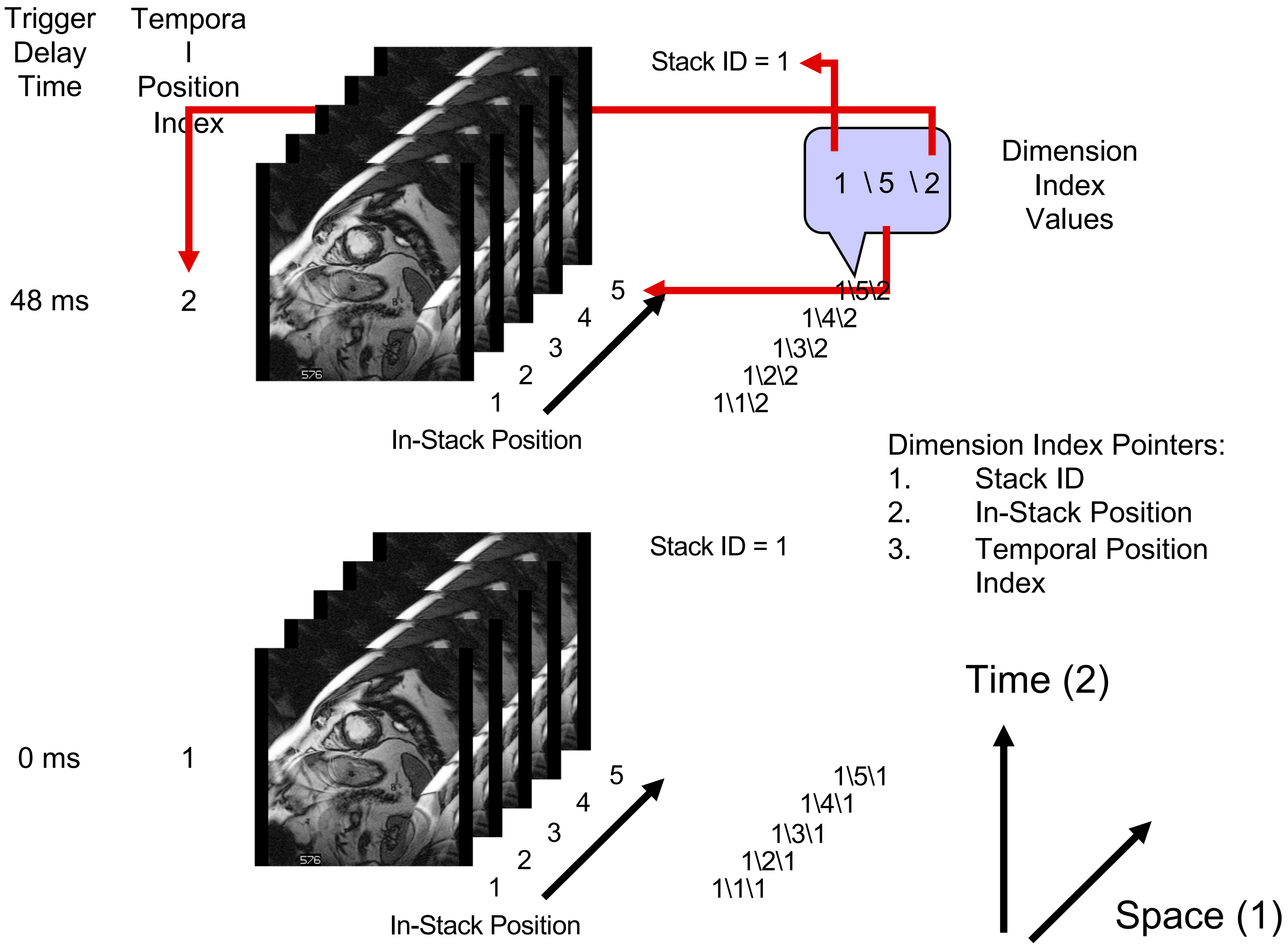
<?xml version="1.0" encoding="UTF-8" xml:space="preserve" ?>
<NativeDicomModel>
  <DicomAttribute tag="0020000D" vr="UI" keyword="StudyInstanceUID”>
    <Value number="1”>1.2.392.200036.9116.2.2.2.1762893313.1029997326.945873</Value>
  </DicomAttribute>
  …
</NativeDicomModel>
```

DICOM as JSON


```
[
  { "0020000D”:
    { "vr": "UI", "Value": [ "1.2.392.200036.9116.2.2.2.1762893313.1029997326.945873" ] }
  },
  …
]
```

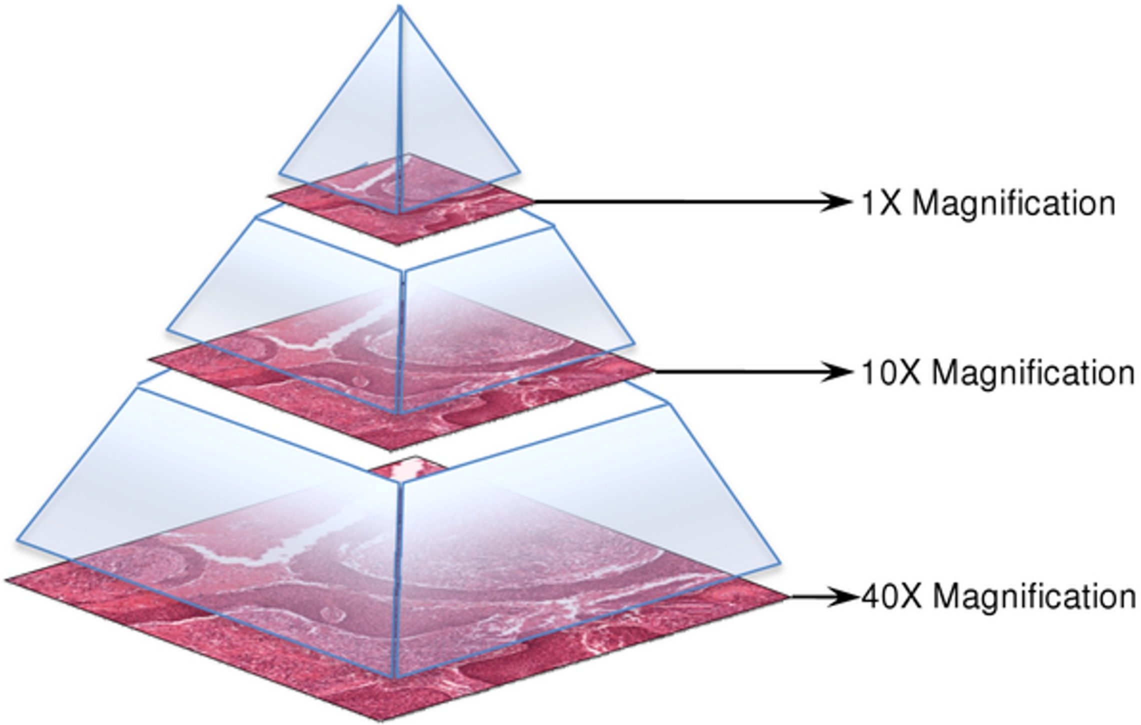
Single vs. Multi-frame Encoding



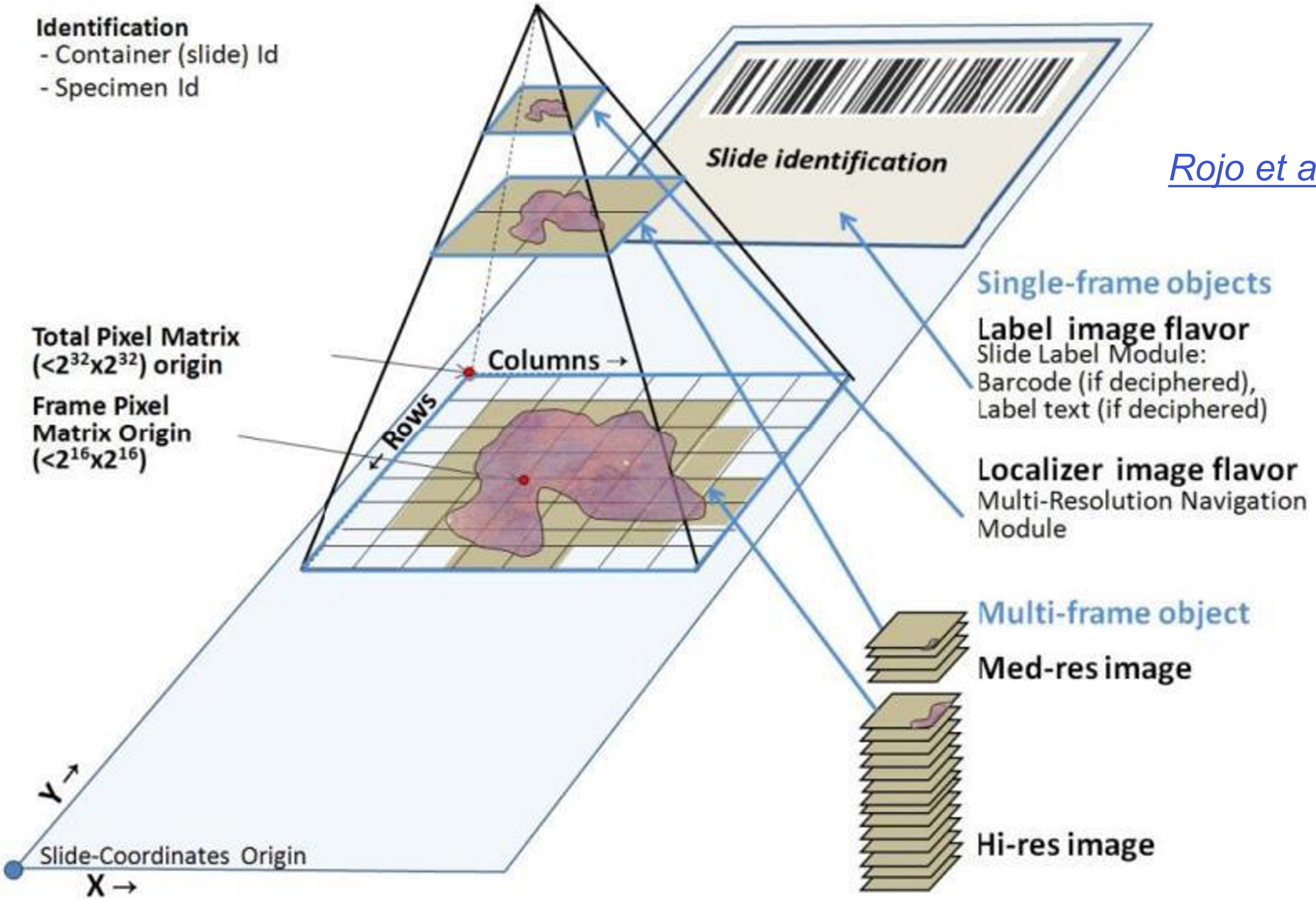


Trigger Delay Time
Tempora l Position Index
Stack ID = 1
1 \5 \2
Dimension Index Values
48 ms
2
5
4
3
2
1
1\5\2
1\4\2
1\3\2
1\2\2
1\1\2
In-Stack Position
Dimension Index Pointers:
1. Stack ID
2. In-Stack Position
3. Temporal Position Index
Stack ID = 1
0 ms
1
5
4
3
2
1
1\5\1
1\4\1
1\3\1
1\2\1
1\1\1
In-Stack Position
Time (2)
Space (1)

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



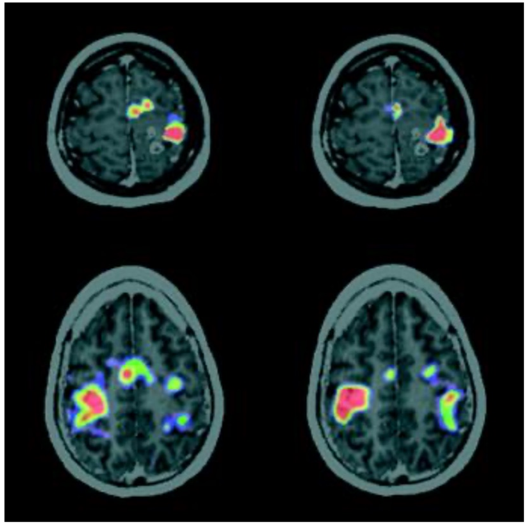
Wang Y, Williamson KE, Kelly PJ, James JA, Hamilton PW (2012) SurfaceSlide: A Multitouch Digital Pathology Platform. PLOS ONE 7(1): e30783. http://doi.org/10.1371/journal.pone.0030783



Rojo et al. 2016

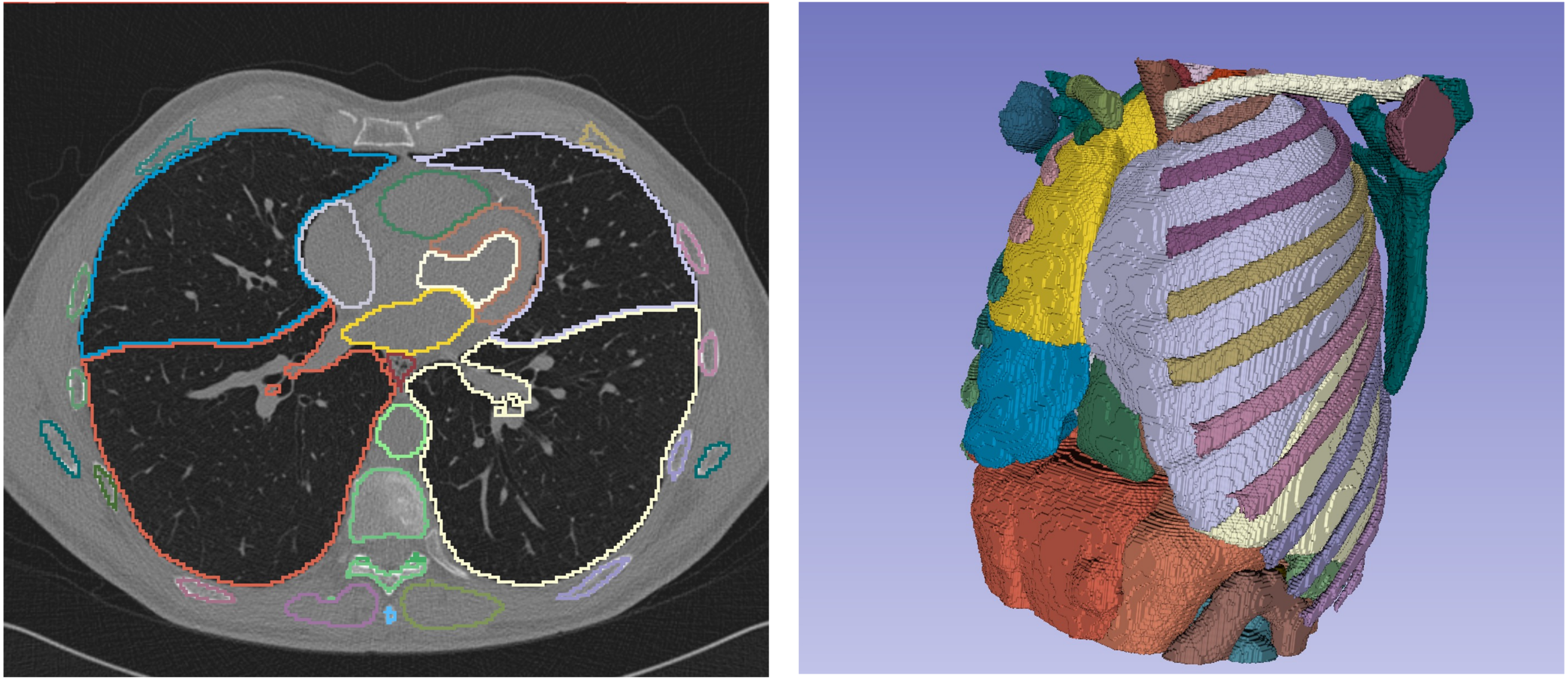
Segmentations & Parametric Maps

- Per-voxel encoding of numeric or label values
- “Images”, but not just “pretty pictures”
  - modality-specific or secondary capture; single or multi-frame
- Segmentations (alternative to label maps)
  - binary, probability, fractional occupancy
  - multiple segments (multiple labels)
- Parametric maps
  - pixel value “means something” – real world value map (RWVM)
  - integers +/- (linear) rescaling to floats (usable by any viewer)
  - “derived” images of modality-specific SOP Class
  - floating point voxels
- Leave “fusion” (superimposition) to application
  - e.g., PET SUV on top of CT
  - can use Blending Presentation State to specify what to fuse



Meyer P T et al. J Neurol Neurosurg Psychiatry 2003;74:471-478

DICOM Segmentation Example



IDC NLST TotalSegmentator example (work in progress)

Segmentation Codes

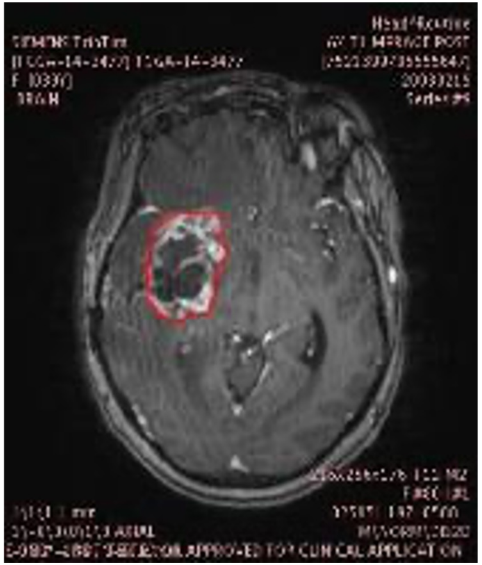
Table CID 7153. CNS Segmentation Type

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-RT ID	UMLS Concept Unique ID
SCT	62818001	Adenohypophysis	T-B1100	C0032008
SCT	4958002	Amygdala	T-A3230	C0002708
SCT	75042008	Arachnoid	T-A1220	C0003707
FMA	276650	Arcuate Fasciculus		C2329633
SCT	12738006	Brain	T-A0100	C0006104
SCT	280371009	Brain cerebrospinal fluid pathway	T-A0109	C0459387
SCT	119238007	Brain stem	T-D0558	C1268144
SCT	35764002	Brain ventricle	T-A1600	C0007799
SCT	11000004	Caudate nucleus	T-A3200	C0007461
SCT	21483005	Central nervous system	T-A0090	C0927232
SCT	33060004	Cerebellar white matter	T-A6080	C0152381
SCT	113305005	Cerebellum	T-A6000	C0007765
SCT	80447000	Cerebral aqueduct	T-A1800	C0007769
SCT	40146001	Cerebral cortex	T-A2020	C0007776

DICOM encoding of ROIs

- Private elements
  - evil & must be stopped
- Curves in image
  - weak semantics, old, retired
- Overlays in image
  - weak semantics
- Presentation States
  - weak semantics, PACS favorite
- Structured Reports
  - best choice, but more work
- RT Structure Sets
  - coordinates only
- Segmentations
  - per-voxel ROIs; use with SR

Date	Volume	Auto LD	Auto SD
2002120 7	27080	49	27
…	…	…	…



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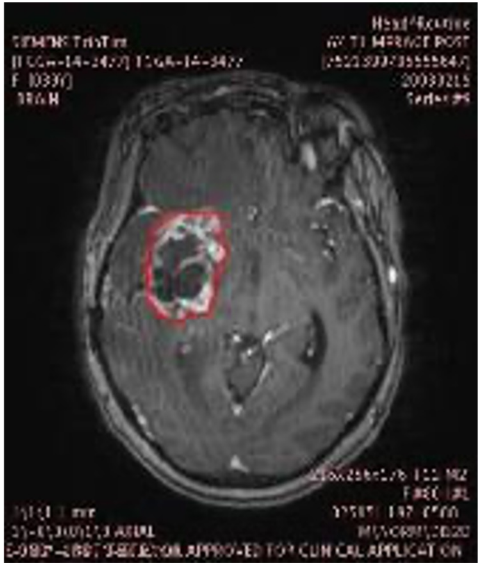
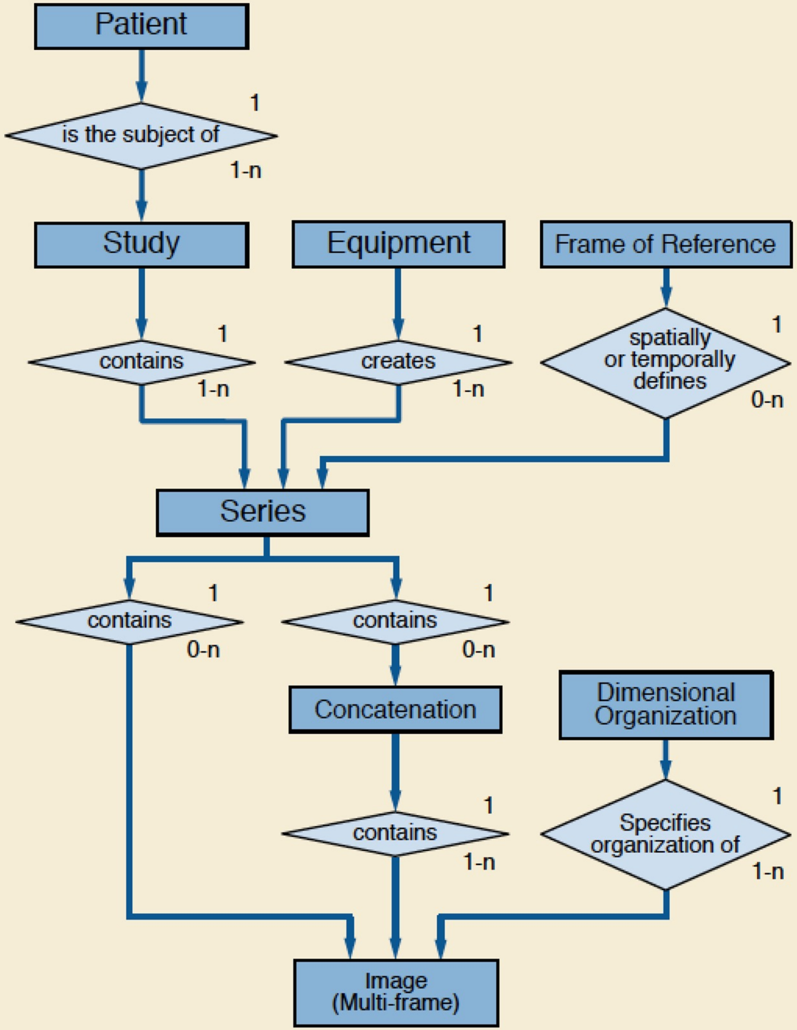
Date	Volume	Auto LD	Auto SD
2002120 7	27080	49	27
…	…	…	…



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



Patient
1
is the subject of
1-n
Study
Equipment
Frame of Reference
1
contains
1-n
1
creates
1-n
1
spatially
or temporally
defines
0-n
Series
1
contains
0-n
1
contains
0-n
Concatenation
Dimensional
Organization
1
contains
1-n
1
Specifies
organization of
1-n
Image
(Multi-frame)

DICOM De-identification – PS3.15

Table E.1-1. Application Level Confidentiality Profile Attributes

Attribute Name	Tag	Retd. (from PS3.6)	In Std. Comp. IOD (from PS3.3)	Basic Prof.	Rtn. Safe Priv. Opt.	Rtn. UIDs Opt.	Rtn. Dev. Id. Opt.	Rtn. Inst. Id. Opt.	Rtn. Pat. Chars. Opt.	Rtn. Long. Full Dates Opt.	Rtn. Long. Modif. Dates Opt.	Clean Desc. Opt.	Clean Struct. Cont. Opt.	Clean Graph. Opt.
Accession Number	(0008,0050)	N	Y	Z										
Acquisition Comments	(0018,4000)	Y	N	X								C		
Acquisition Context Sequence	(0040,0555)	N	Y	X/Z									C	
Acquisition Date	(0008,0022)	N	Y	X/Z						K	C			
Acquisition DateTime	(0008,002A)	N	Y	X/Z/D						K	C			
Acquisition Device Processing Description	(0018,1400)	N	Y	X/D								C		
Acquisition Protocol Description	(0018,9424)	N	Y	X								C		
Acquisition Time	(0008,0032)	N	Y	X/Z						K	C			
Actual Human Performers Sequence	(0040,4035)	N	N	X										

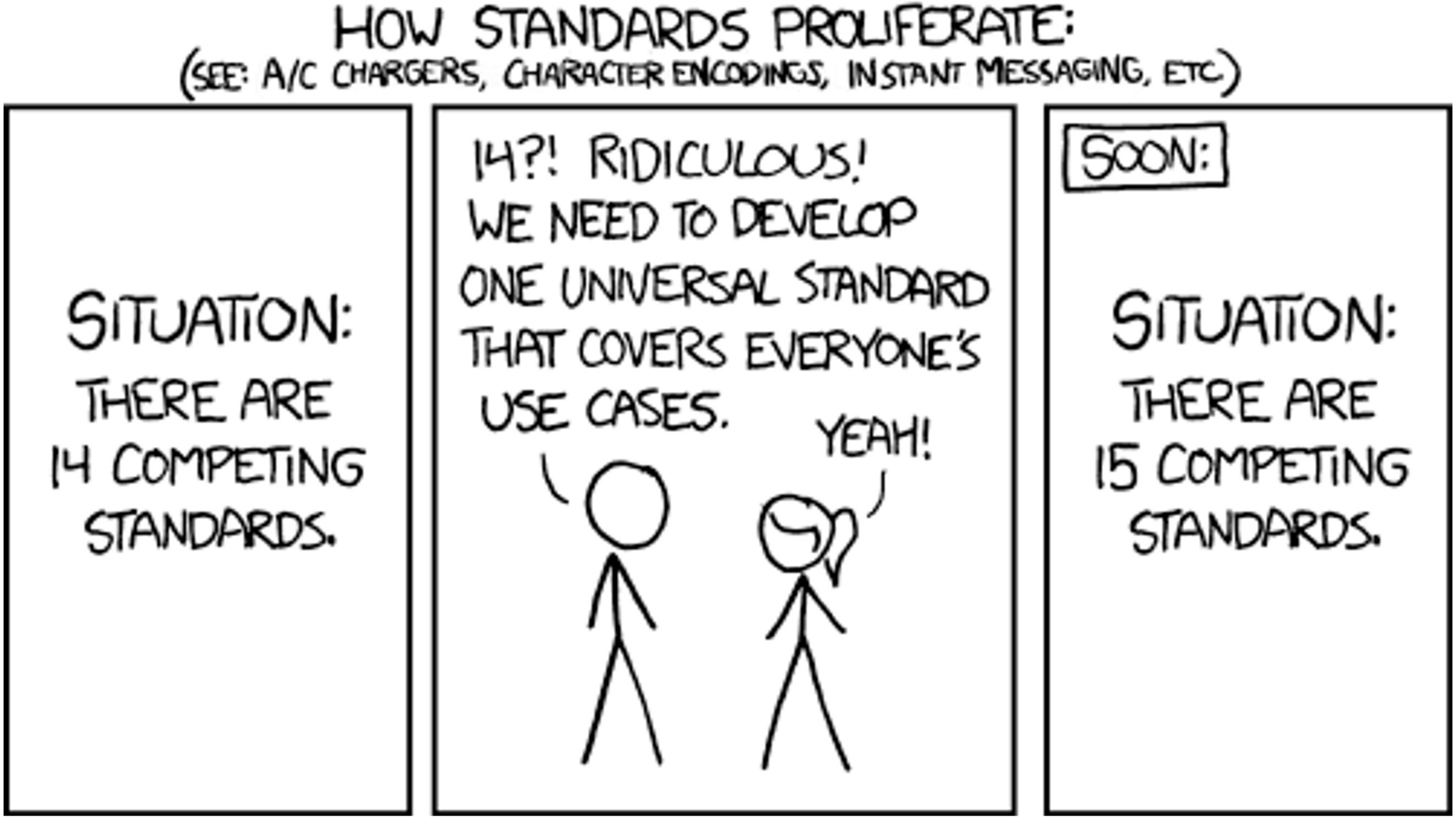
DICOM in IDC - Summary

- It’s the only format we use:
  - in storage buckets (Google, AWS)
  - in DICOMweb server (to support OHIF and Slim viewers)
  - automatically extracted DICOM metadata tabulated in SQL
  - displayed in viewers accessible through portal
- Ingest only already de-identified:
  - radiology images in DICOM
  - selected subset of proprietary (esp. TIFF) WSI that we convert to DICOM
  - annotations and ROIs in DICOM SEG, SR, RTSS
  - some derived datasets that we convert to DICOM SEG, SR, etc.
- Provide:
  - guidance, esp. notebooks
  - tools and pipelines
  - support
  - work on extensions to the standard (corrections, features, new modalities)

Extending the DICOM standard

- There will always be unanticipated use cases (esp. in research)
  - there are means for encoding generic stuff
  - re-using existing standard patterns, modules, attributes, codes
  - adding private attributes and codes as interim last resort
- Add correction proposals (CPs) or supplements to the standard
  - minor additions, clarifications and corrections
  - major new features, modalities, applications
- Fundamental architectural and representational changes
  - DICOMweb
  - JSON and XML
- In future
  - very large dataset handling (esp. parallel writes)
  - ? need to handle N5/zarr-like access patterns and tools
  - some use cases handled by re-indexing (e.g., for range requests)
  - re-use as much infrastructure and code as possible

http://www.phrases.org.uk/images/throw-out-the-baby-with-the-bathwater.jpg



http://xkcd.com/927/


DICOM
Digital Imaging and Communications in Medicine