DICOM: Testament of Time

David A. Clunie (PixelMed)

dclunie@dclunie.com

2021/12/14

ESMRMB: MRI Together workshop

MRI Together

A global workshop on Open Science and Reproducibility
December 2021

Speaker name:

Dr David A. Clunie, PixelMed

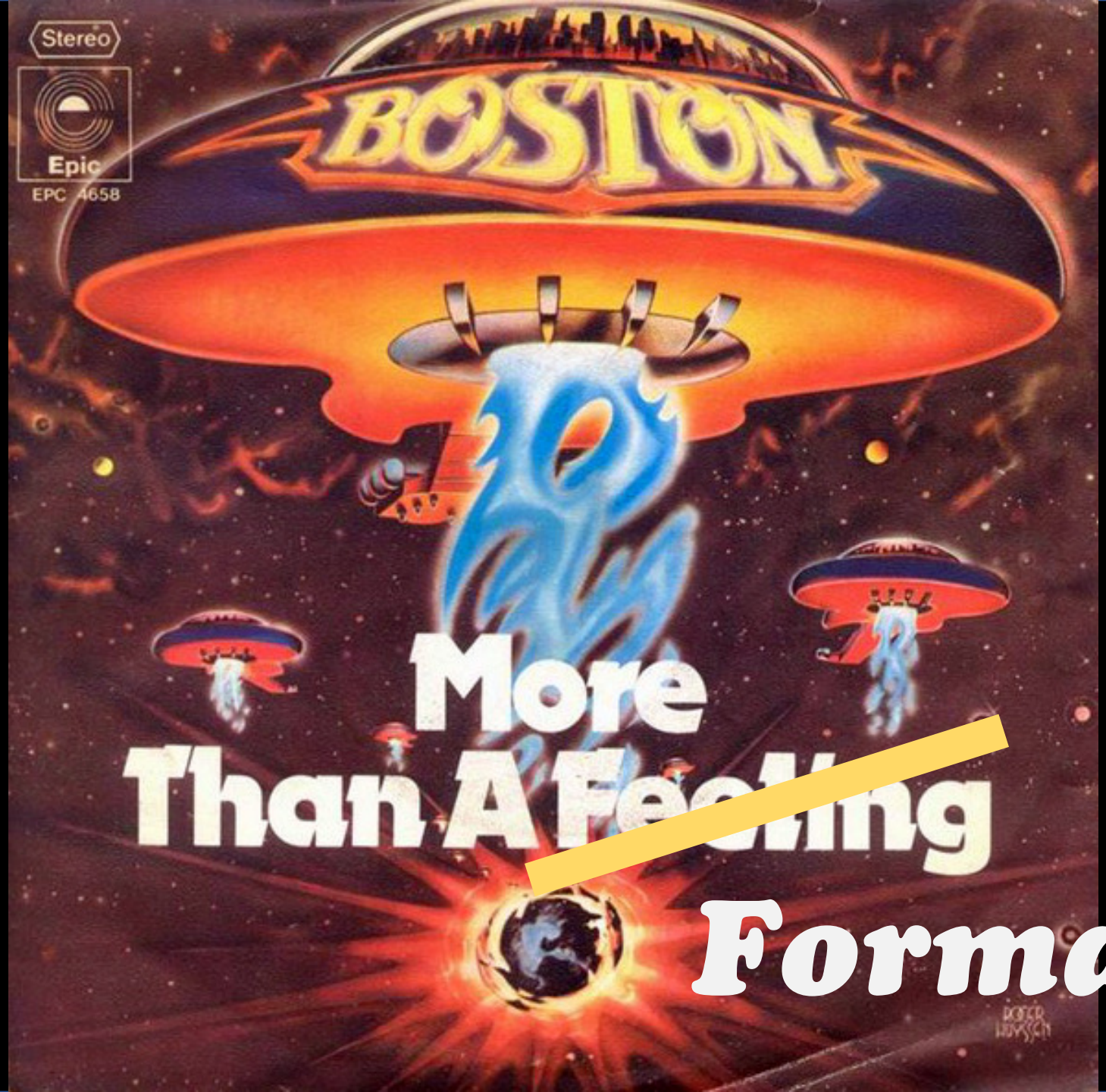
Conflicts of interest regarding this presentation:

Editor, DICOM Standard (NEMA contractor).
Various academic and commercial consulting contracts as DICOM SME.

ESMRMB
European Society for Magnetic Resonance in Medicine and Biology

DICOM

Digital Imaging and Communications in Medicine



Format

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

What is DICOM?

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

Open Science needs Open Standards

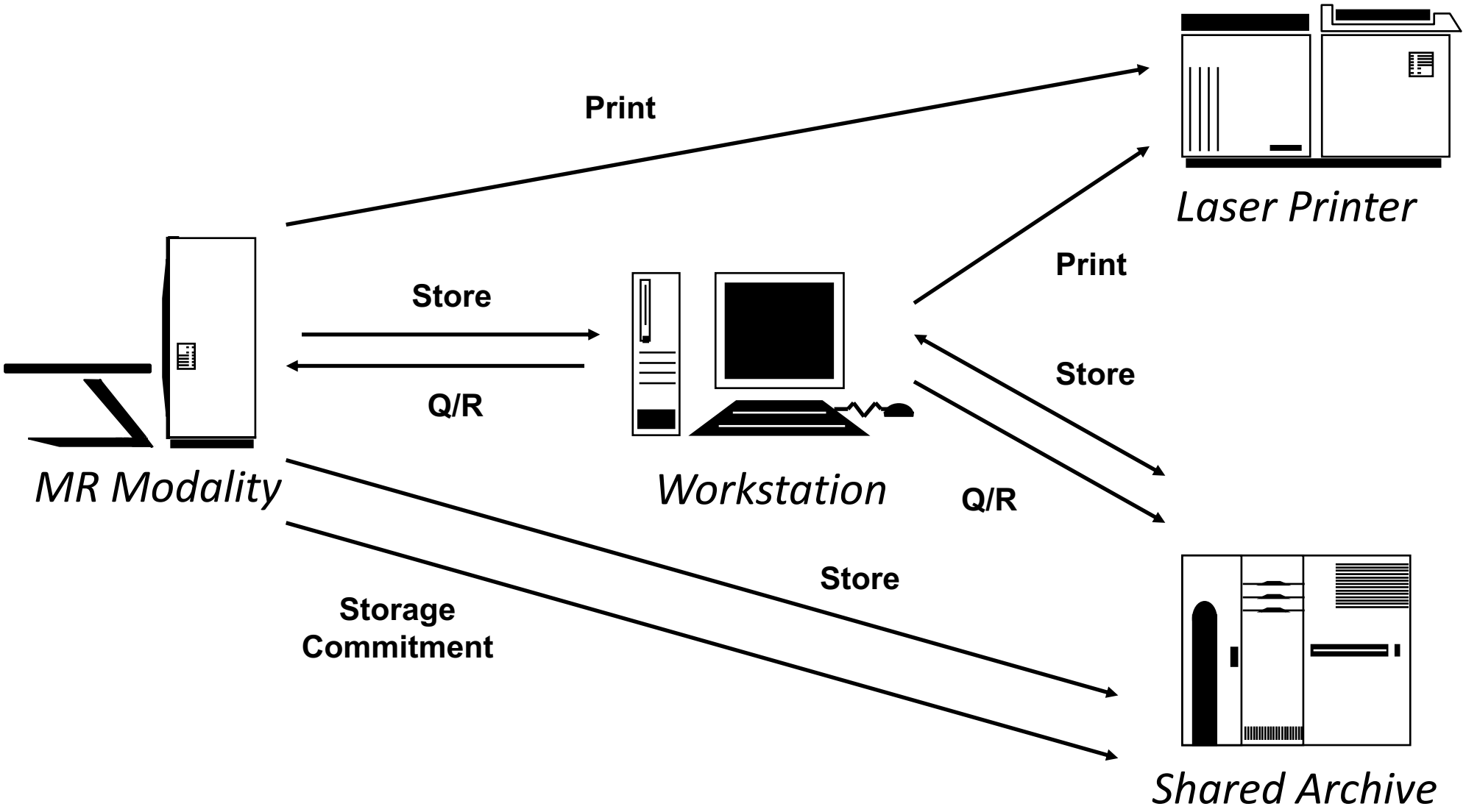
- DICOM is Open:
  - publicly available and freely accessible (no fee to download, unlike ISO standards)
  - freely readable (source written in open format XML DocBook)
  - free to use (no license fees to implement, no commercial restrictions, no agreement)
  - free of (known) external IP restrictions (theoretically procedures allow RAND not FRAND, but so far all no cost)
  - free to extend (private elements, SOP Classes) (non-viral)
  - free to participate and contribute to (though membership fee required to vote)
  - http://en.wikipedia.org/wiki/Open_standard
- High quality open source reference libraries and utilities freely available:
  - dcmtk (C++)
  - dcm4che (Java)
  - pydicom (Python)

Interoperability – Definition

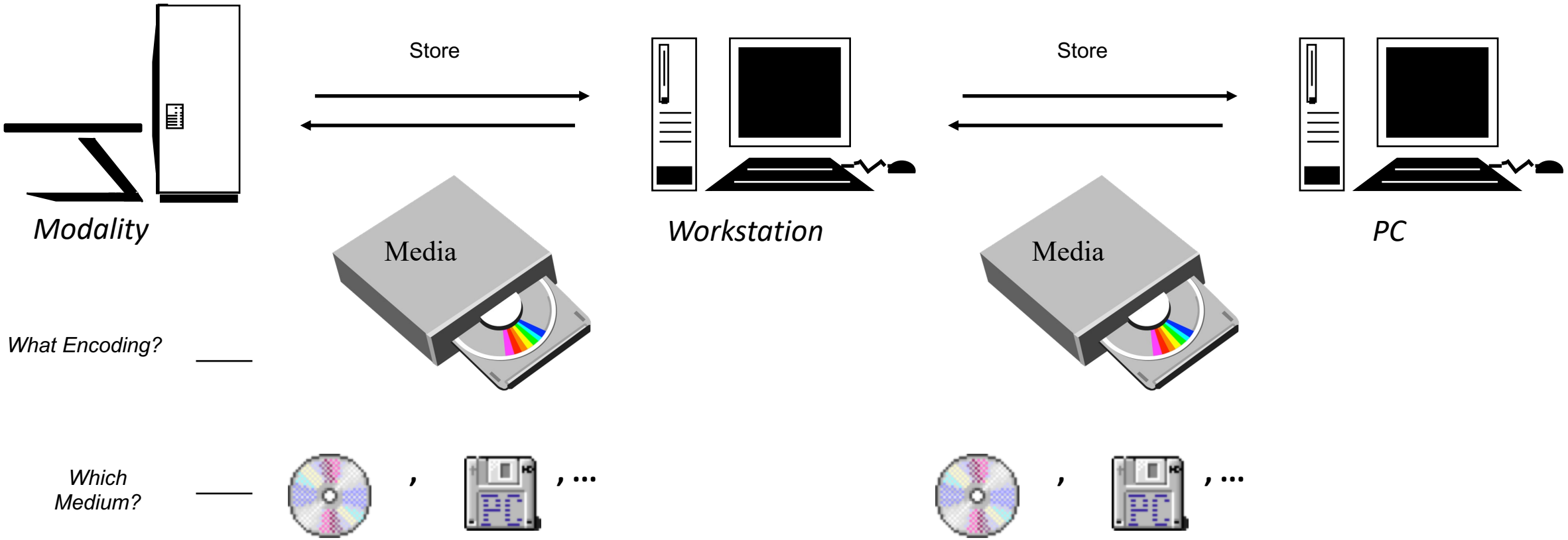
*"the ability of two or more systems or components to **exchange** information and to **use** the information that has been exchanged"*

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

DICOM Services – circa mid-90's



DICOM Network and Media



Why is DICOM the way it is?

- Who was/is the customer?
  - turnkey clinical device purchaser
- Who decides?
  - what goes in medical imaging device products
- When did it start?
  - product of the eighties – consequences

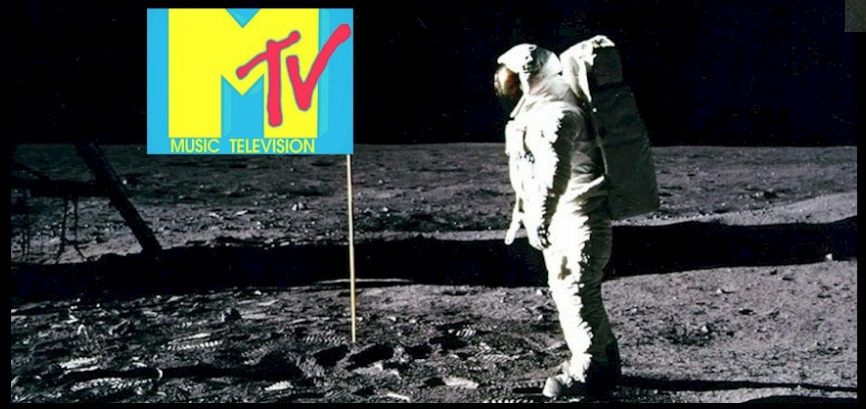
Who?

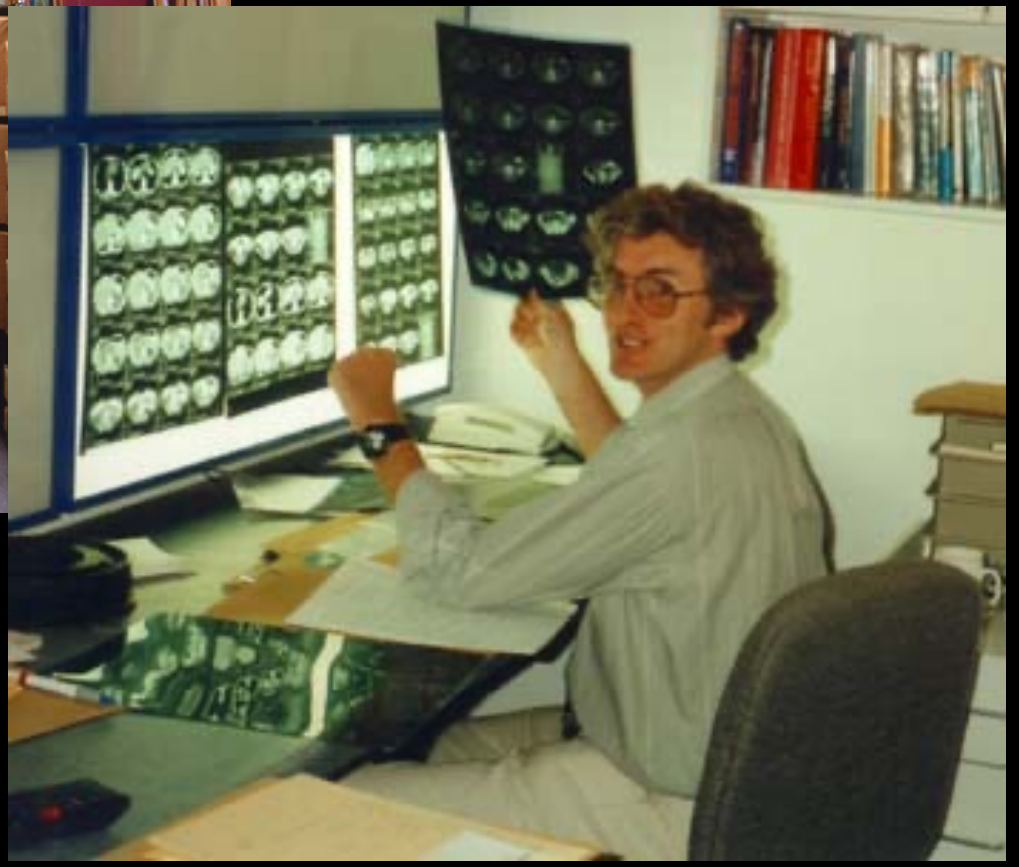
- Who is supported by the standard?
  - clinical radiologist
  - referring clinician
  - research radiologist
  - research scientist, engineer, physicist, etc.
  - clinical trialists
  - vendor engineers
- Different users have different requirements
  - (near) plug and play, high throughput, managed services, patient oriented, safety
  - technically sophisticated, manual effort, file-oriented, research focus, specific needs
  - allowing for innovation -> extensibility -> (transient) reduced interoperability
- Who decides?
  - vendor product managers allocate engineering resources
  - focus is almost exclusively clinical – those who buy scanners, workstations, PACS, …


USA

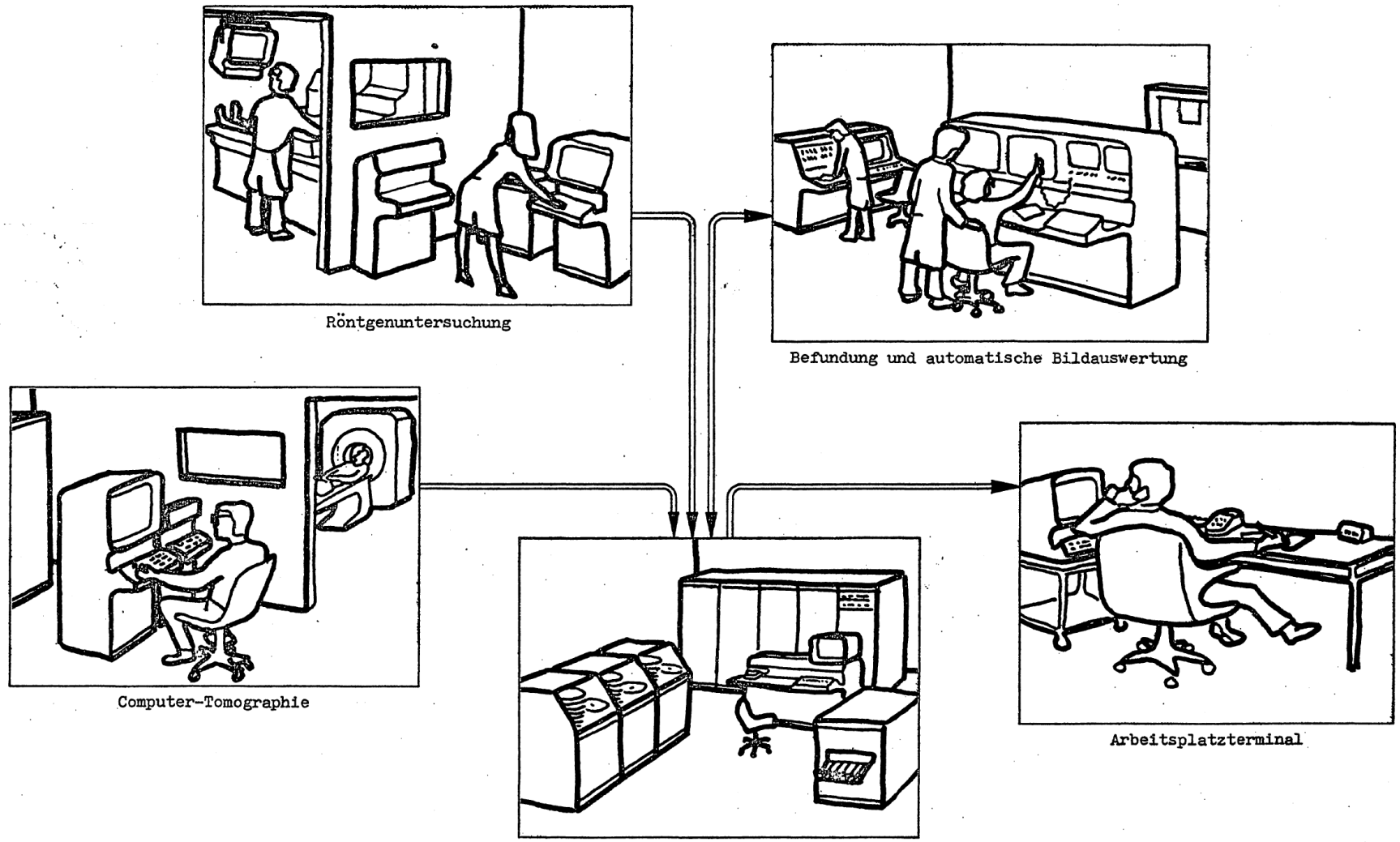

3456788
1 2 3
4 5 6
7 8 9
* 0 #
Rcl Clr Snd
Sto Fcn End
Pwr Lock Vol
British
TELECOM

I want my MTV!


MTV
MUSIC TELEVISION




Mayo



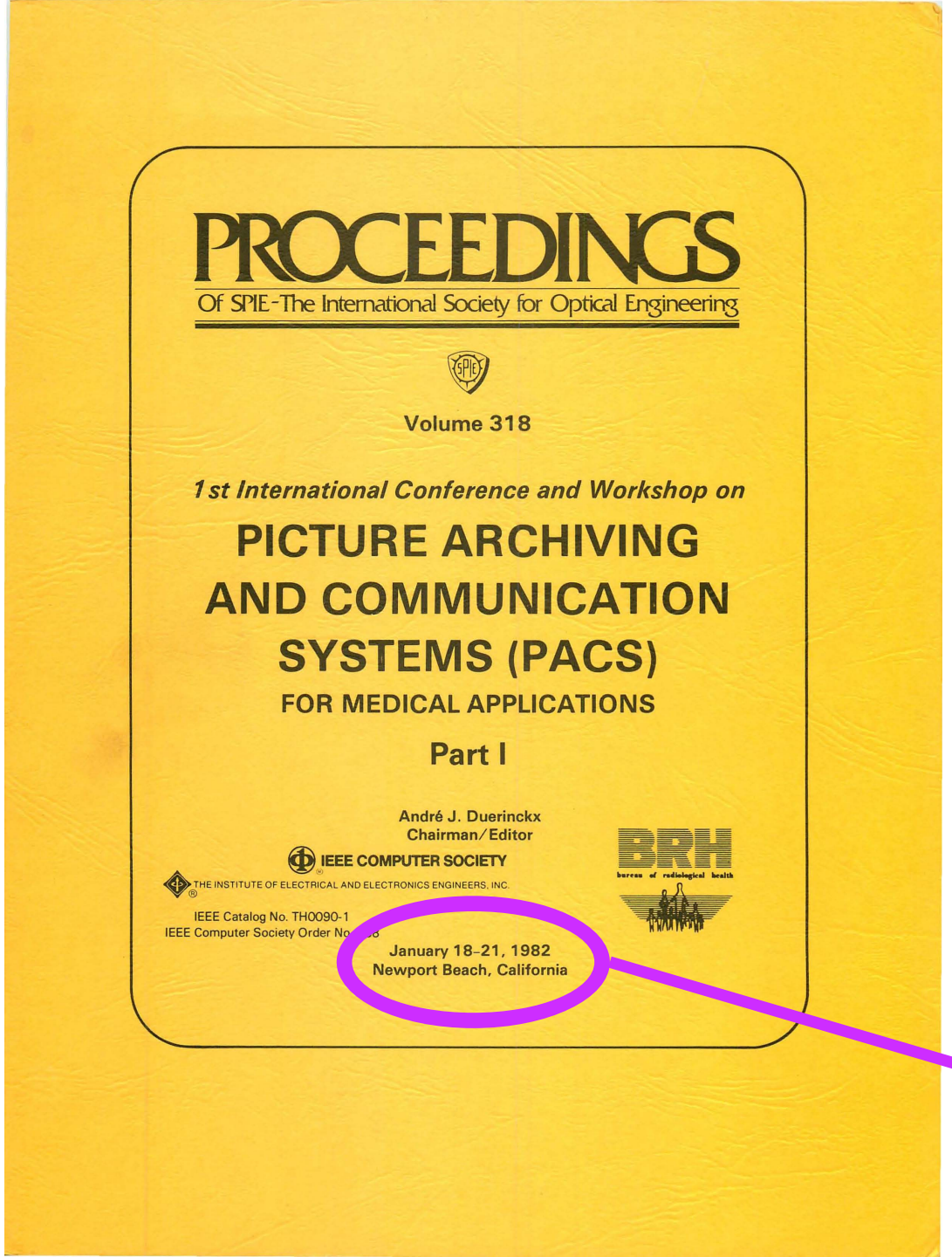
1973

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.


REWRITABLE
Verbatim
1024 Bytes/Sector
Side
Rewritable
6 GB

General Electric Signa Magnetic Tape Format

Revision 2.0.4


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
THE INSTITUTE OF ELECTRICAL AND ELECTRONICS ENGINEERS, INC.
IEEE Catalog No. TH0090-1
IEEE Computer Society Order No.
January 18-21, 1982
Newport Beach, California
BRH
bureau of radiological health

1982

39 years ago – radiology PACS and DICOM ubiquitous 15-20 years later!

DICOM – Brief History

- 1982 – 1st PACS Conference – session on standards
- 1982 – AAPM Report 10 – Standard Format for Image Interchange
- 1983 – ad hoc meeting between FDA, ACR & NEMA
- 1983 – 1st meeting of ACR-NEMA “Digital Imaging and Communications Standards” Cmte
- 1985 – ACR-NEMA 300-1985 (“version 1.0”) issued

- 1988 – ACR-NEMA 300-1988 (“version 2.0”) issued
- 1990 – Inter-vendor testing of version 2.0 at Georgetown
- 1992 – Trial of DICOM (“version 3.0) at RSNA

- 1993 – DICOM 3.0 issued

DICOM – Brief History

- 1982 – 1st PACS Conference – session on standards
- 1982 – AAPM Report 10 – Standard Format for Image Interchange
- 1983 – ad hoc meeting between FDA, ACR & NEMA
- 1983 – 1st meeting of ACR-NEMA "Digital Imaging and Communications Standards" Cmte
- 1985 – ACR-NEMA 300-1985 ("version 1.0") issued
- 1985 – IEEE 802.3 Ethernet (based on 1976 Metcalfe)
- 1986 – Aldus TIFF (version 3; prior versions drafts only)
- 1987 – CompuServe GIF
- 1988 – ACR-NEMA 300-1988 ("version 2.0") issued
- 1990 – Inter-vendor testing of version 2.0 at Georgetown
- 1992 – Trial of DICOM ("version 3.0) at RSNA
- 1992 – JPEG (ITU T.81; ISO 10918-1 1994)
- 1993 – DICOM 3.0 issued

DICOM – Brief History

- ACR-NEMA versions 1 and 2
  - 50-pin 16 bit parallel interface
  - no network (assumed “network interface unit”)
  - layered
  - messages with commands and data
  - tag-value pairs
  - described patients, studies, images
  - described modality, acquisition, 3D position, etc.

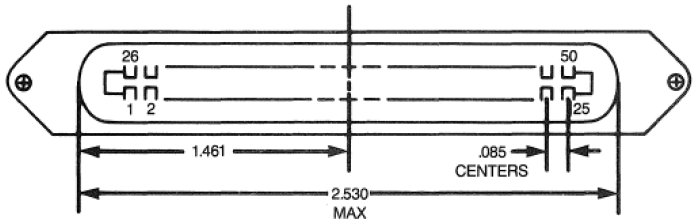


Figure 7-4
CONNECTOR—50 PIN FEMALE RECEPTACLE FRONT VIEW

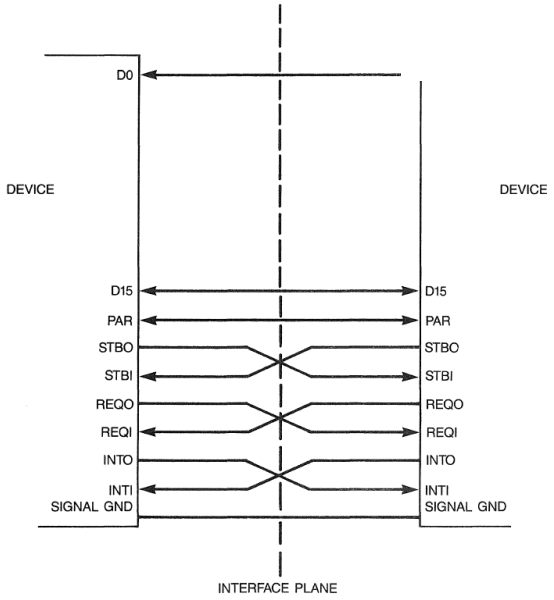


Figure 7-2
PHYSICAL AND LOGICAL INTERFACE

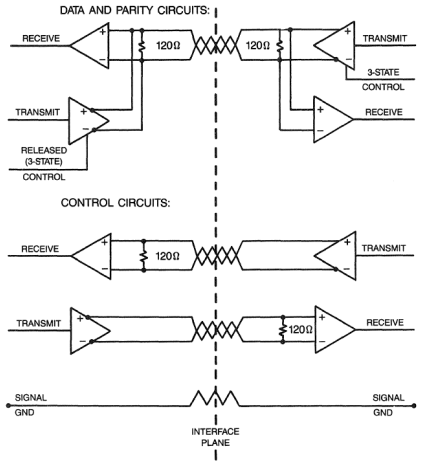


Figure 7-3
TYPICAL INTERFACE CIRCUIT

MESSAGE STRUCTURE
SEND__REQUEST

GROUP	ELEMENT	LENGTH	VALUE	MEANING	DESCRIPTION
0000	0000	0004 0000	0044 0000		Even number of bytes from the end of this field to the beginning of the next group
0000	0001	0004 0000	0190 0010		Even number of bytes from the end of this field to the end of the message
0000	0100	0002 0000	0001	''0001''	Command field = SEND__ REQUEST
0000	0110	0004 0000	3231 4133	''123A''	Device generated message ID
0000	0200	0004 0000	4344 3148	''DCH1''	Logical address of sender
0000	0300	0004 0000	4341 3148	''ACH1''	Logical address of receiver
0000	0800	0002 0000	0000	''0000''	Data type = image
0008	0000	0004 0000	0084 0000		Group length
0008	0001	0004 0000	0140 0010		Message length
0008	0010	000C 0000	4341 2D52 454E 414D 3120 302E	''ACR-NEMA 1.0''	Recognition code
0008	0020	000A 0000	3931 3538 312E 2E31 3532	''1985.11.25''	Study date
0008	0030	0008 0000	3231 303A 3A35 3935	''12:05:59''	Study time
0008	0040	0006 0000	4D49 4741 2045	''Image''	Data set type
0008	0060	0002 0000	5244	''DR''	Modality
0008	0070	0004 0000	4241 4443	''ABCD''	Manufacturer
0008	0080	000E 0000	454D 4352 2059 4F48 5053 5449 4C41	''Mercy Hospital''	Institution ID

MESSAGE STRUCTURE
SEND__REQUEST

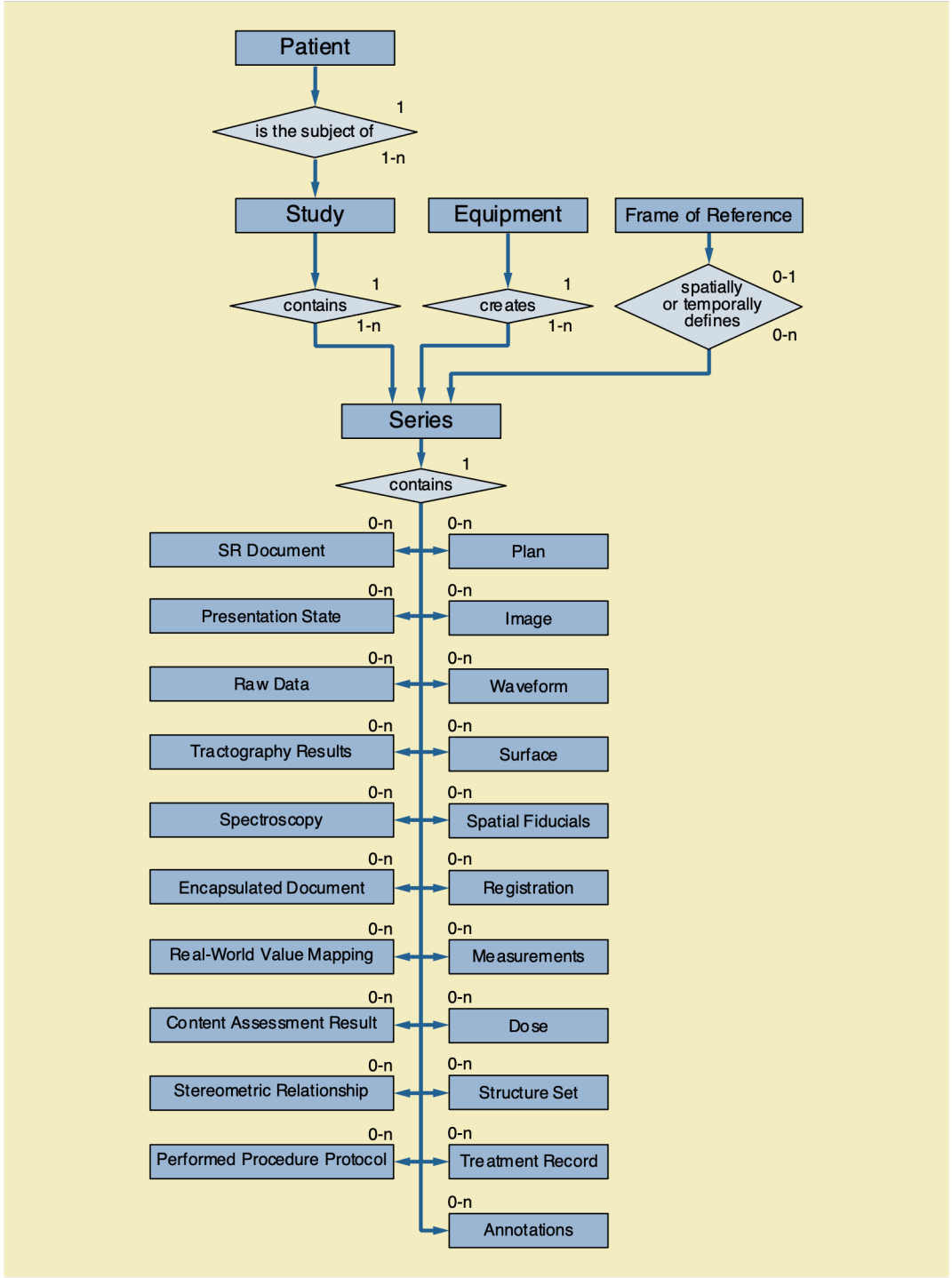
GROUP	ELEMENT	LENGTH	VALUE	MEANING	DESCRIPTION
0000	0000	0004 0000	0044 0000		Even number of bytes from the end of this field to the beginning of the next group
0000	0001	0004 0000	0190 0010		Even number of bytes from the end of this field to the end of the message
0000	0100	0002 0000	0001	''0001''	Command field = SEND__ REQUEST
0000	0110	0004 0000	3231 4133	''123A''	Device generated message ID
0000	0200	0004 0000	4344 3148	''DCH1''	Logical address of sender
0000	0300	0004 0000	4341 3148	''ACH1''	Logical address of receiver
0008	0000	0004 0000	0084 0000		Group length
0008	0001	0004 0000	0140 0010		Message length
0008	0010	000C 0000	4341 2D52 454E 414D 3120 302E	''ACR-NEMA 1.0''	Recognition code
0008	0020	000A 0000	3931 3538 312E 2E31 3532	''1985.11.25''	Study date
0008	0030	0008 0000	3231 303A 3A35 3935	''12:05:59''	Study time
0008	0040	0006 0000	4D49 4741 2045	''Image''	Data set type
0008	0060	0002 0000	5244	''DR''	Modality
0008	0070	0004 0000	4241 4443	''ABCD''	Manufacturer
0008	0080	000E 0000	454D 4352 2059 4F48 5053 5449 4C41	''Mercy Hospital''	Institution ID

DICOM – Brief History

- ACR-NEMA versions 1 and 2
  - 50-pin 16 bit parallel interface
  - no network (assumed “network interface unit”)
  - layered
  - messages with commands and data
  - tag-value pairs
  - described patients, studies, images
  - described modality, acquisition, 3D position, etc.
- DICOM “3.0”
  - TCP/IP network protocol (and OSI semantics)
  - “object-oriented” description & conformance

How DICOM differs (as a file format)

- DICOM dataset (PACS, message) embedded in file wrapper (PS3.10)
- Clinical, acquisition and modality-specific information model
- "Attributes" of "Modules" of "Information Objects" aka. metadata
- Metadata to identify and describe
- Metadata is embedded in each and every file
- E.g., PatientName, PatientID (MRN)
- Each dataset (file, instance) given a globally Unique Identifier (UID)
- Grouping – commonality of higher level entity UIDs (Study, Series)

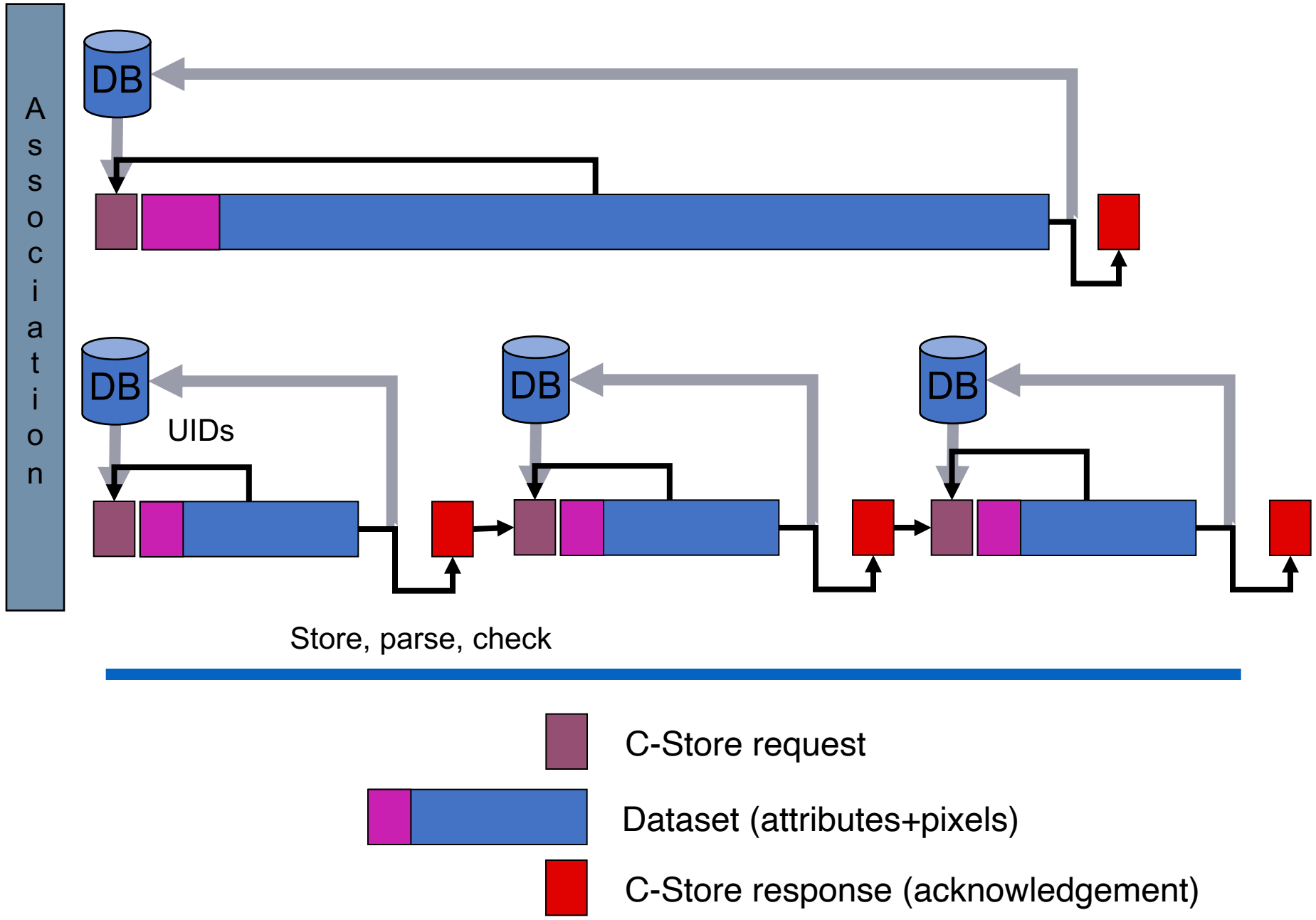

Patient
1
is the subject of
1-n
Study
Equipment
Frame of Reference
1
contains
1-n
1
creates
1-n
0-1
spatially
or temporally
defines
0-n
Series
1
contains
0-n
SR Document
0-n
Plan
0-n
Presentation State
0-n
Image
0-n
Raw Data
0-n
Waveform
0-n
Tractography Results
0-n
Surface
0-n
Spectroscopy
0-n
Spatial Fiducials
0-n
Encapsulated Document
0-n
Registration
0-n
Real-World Value Mapping
0-n
Measurements
0-n
Content Assessment Result
0-n
Dose
0-n
Stereometric Relationship
0-n
Structure Set
0-n
Performed Procedure Protocol
0-n
Treatment Record
0-n
Annotations

What DICOM inherited from legacy formats

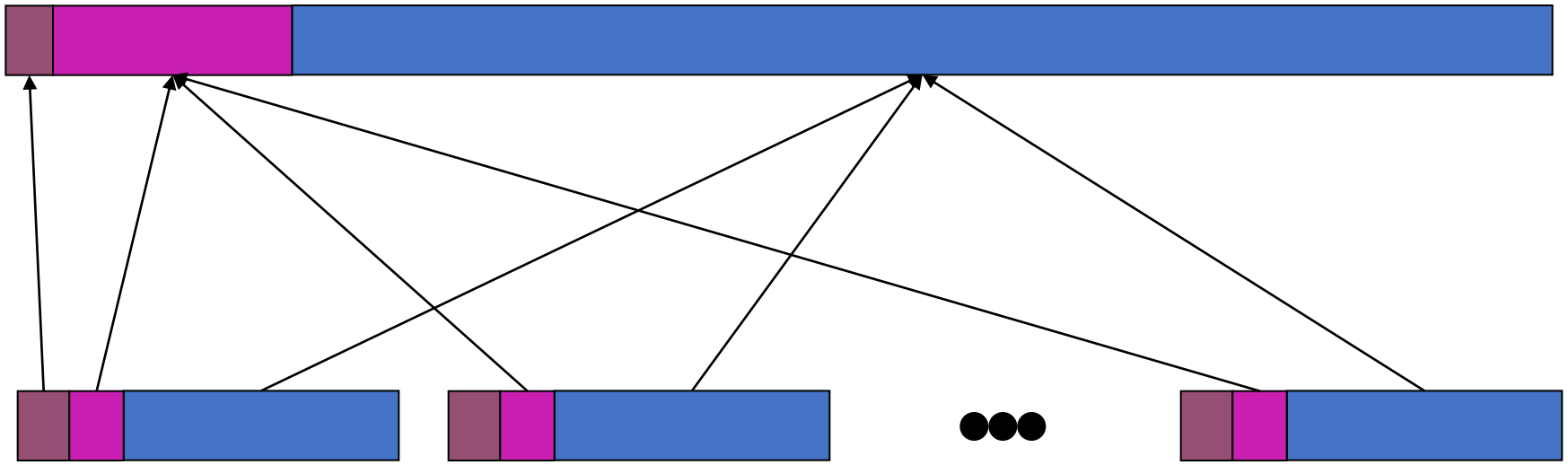
- Major scanner vendors already had proprietary MR & CT formats
  - GE Genesis (and others)
  - Siemens & Philips – Standard Product Interconnect (SPI) – ACR-NEMA based
  - …
- One instance (file) per reconstructed slice
- Binary fixed layout or tag-value pair stream
- Header usually embedded with pixel data
- Composite entities – patient, study, acquisition, series, instance data
- What was available from operator or pulse sequence and parameters
- In general, predated "volume" acquisitions (or use cases for 3D)

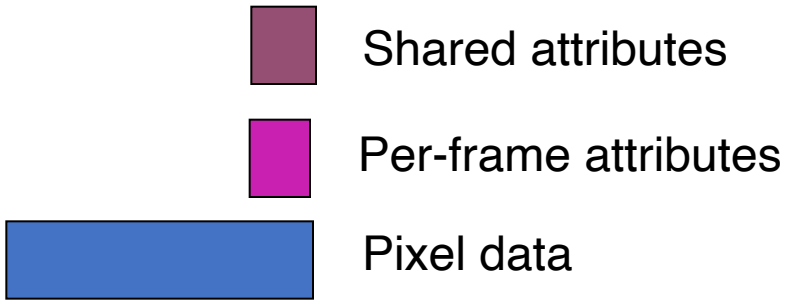
Trying to do better – Enhanced MultiFrame

- DICOM Sup 49 Enhanced MR Image Storage SOP Class (2002)
- Allow multiple slices in one dataset (file)
- Mechanism to factor out commonality of per-slice description
- Make many more acquisition-related attributes mandatory
- Make many more values standard codes (e.g., acquisition contrast)
- More precise definition of timing (e.g., for perfusion)
- Explicit specification of Dimensions (e.g., space, time, B value)
- Separate quantitation from rendering pipeline (RWV from Windowing)
- Miserable failure (MR) – significant adoption by only one vendor
- Core of all new IODs, including segmentation, parametric maps


Association
DB
DB
UIDs
DB
DB
Store, parse, check
C-Store request
Dataset (attributes+pixels)
C-Store response (acknowledgement)

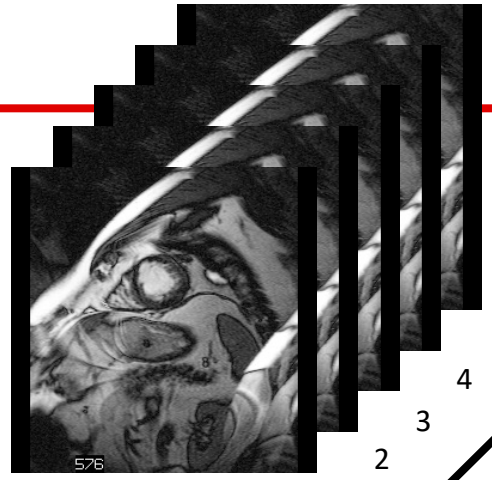
Multi-frame Functional Groups





Trigger Delay Time

Temporal Position Index



Stack ID = 1

2 \ 1 \ 5

Dimension Index Values

48 ms

2

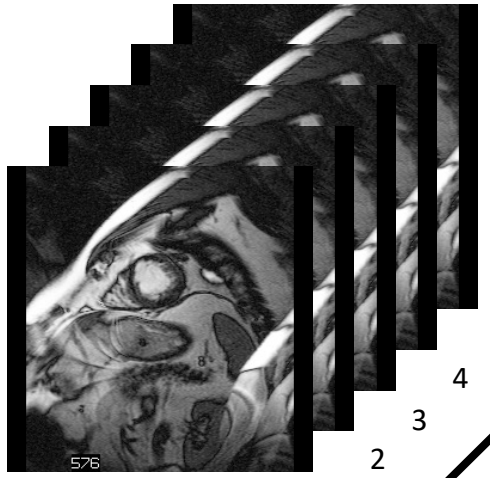
5
4
3
2
1

In-Stack Position

2\1\5
2\1\4
2\1\3
2\1\2
2\1\1

Dimension Index Pointers:

1. Temporal Position Index
2. Stack ID
3. In-Stack Position



Stack ID = 1

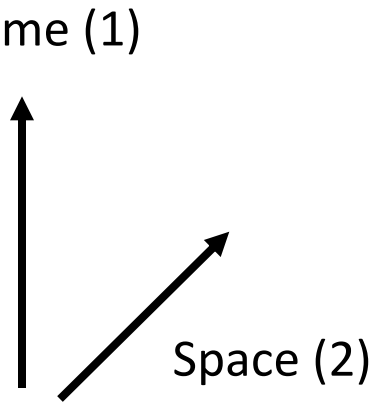
0 ms

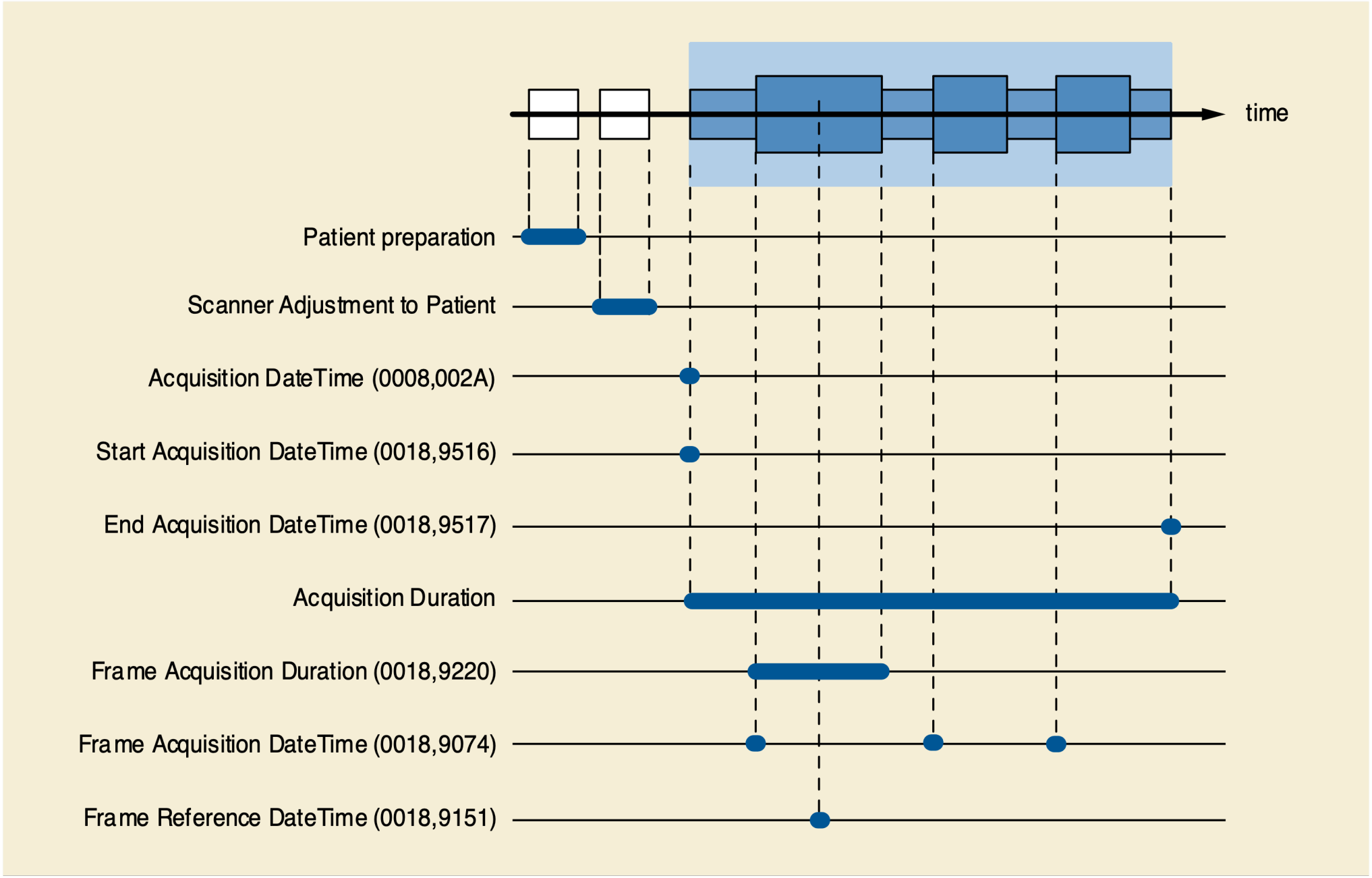
1

5
4
3
2
1

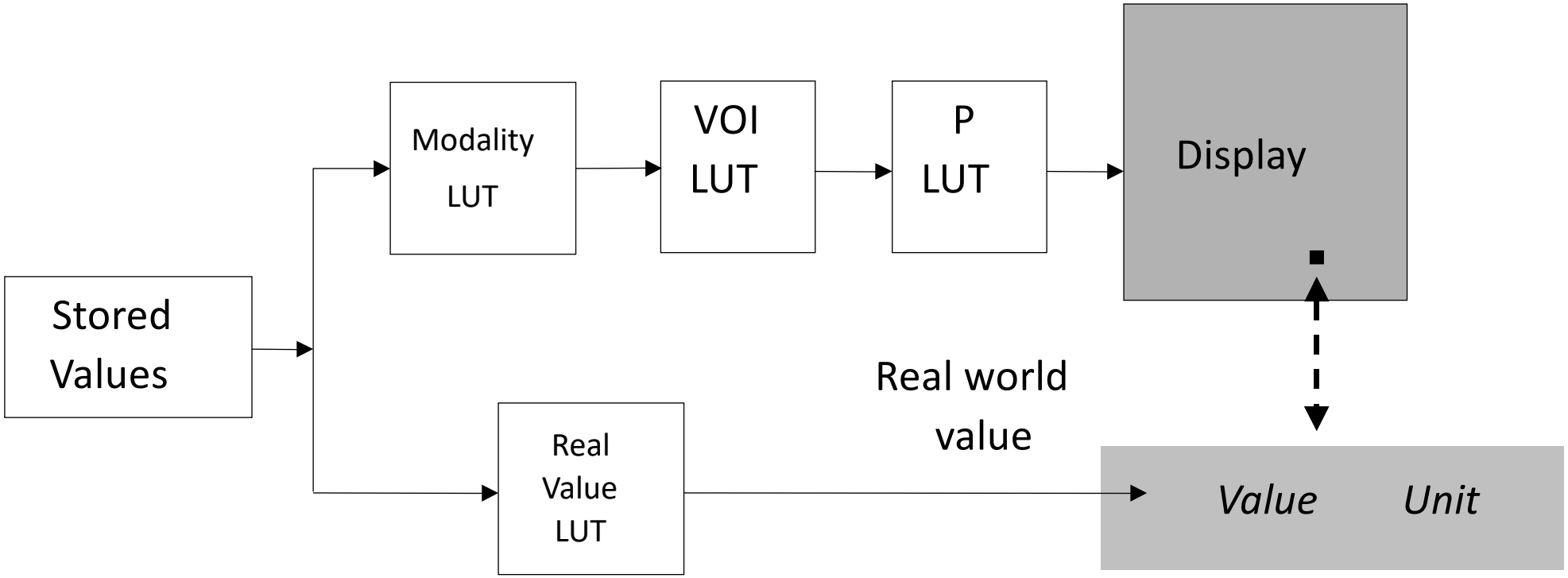
In-Stack Position

1\1\5
1\1\4
1\1\3
1\1\2
1\1\1




time
Patient preparation
Scanner Adjustment to Patient
Acquisition DateTime (0008,002A)
Start Acquisition DateTime (0018,9516)
End Acquisition DateTime (0018,9517)
Acquisition Duration
Frame Acquisition Duration (0018,9220)
Frame Acquisition DateTime (0018,9074)
Frame Reference DateTime (0018,9151)

Real World Value Mapping



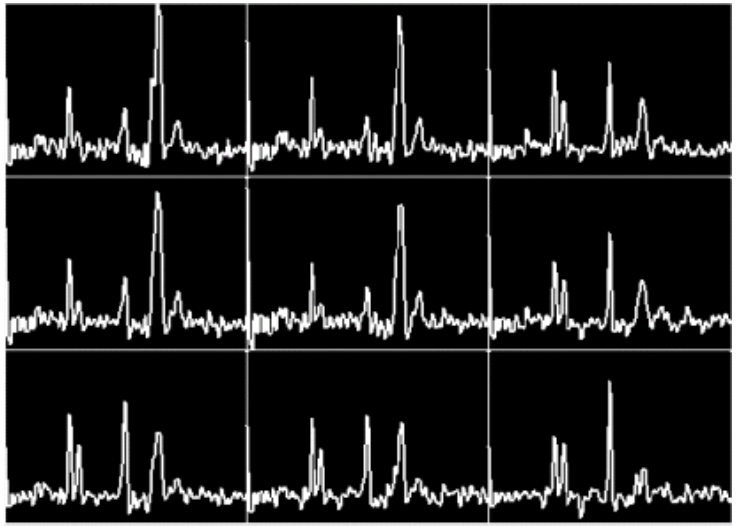
Real World Value LUT Data (0040,9212)

or

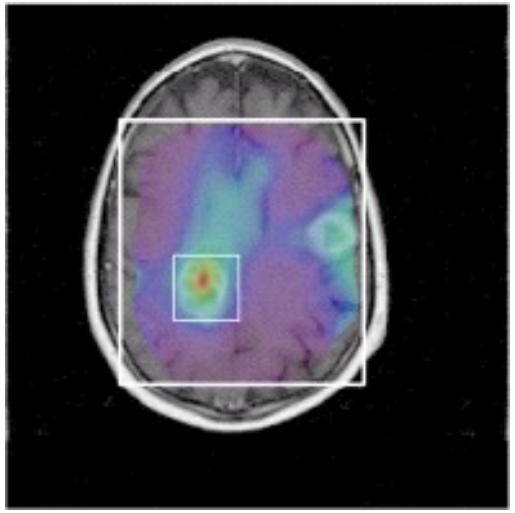
Real World Value Intercept and Slope attributes

Measurement Units Code Sequence (0040,08EA)

MR Spectroscopy



Storage of
Spectroscopy Data



Metabolite Maps

MR Raw Data

- Email from me to NEMA dated 1993/05/16:

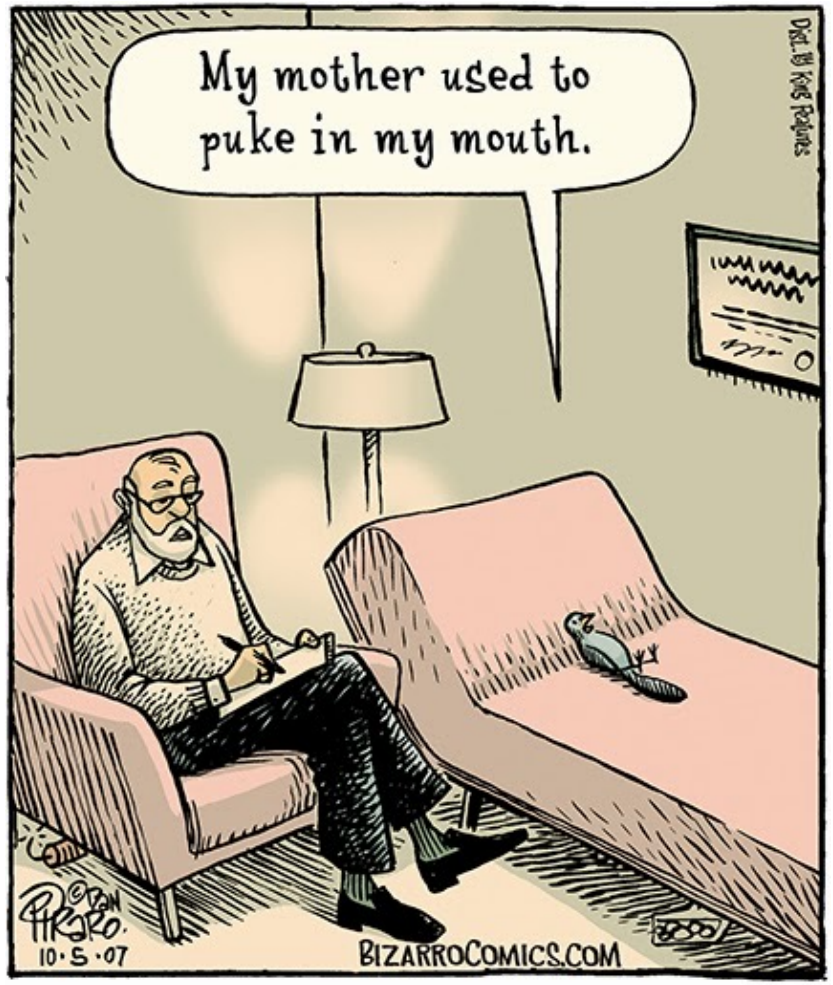
"It just occurred to me that the MR module in proposed DICOM 3 makes no provision for transferring the raw data."

"Now, I know that most manufacturers don't make this quite as easy to get at as the image data, but it is there and many people use it, so DICOM might as well make provision for it. This would in no way oblige manufacturers to provide it along with everything else but would make it easy for those who wanted to (key selling feature to MR physicists here). Also it would be handy for vendors implementing remote diagnostics over a network link to a DICOM compatible machine rather than through a modem hidden in a cabinet)."

MR Raw Data

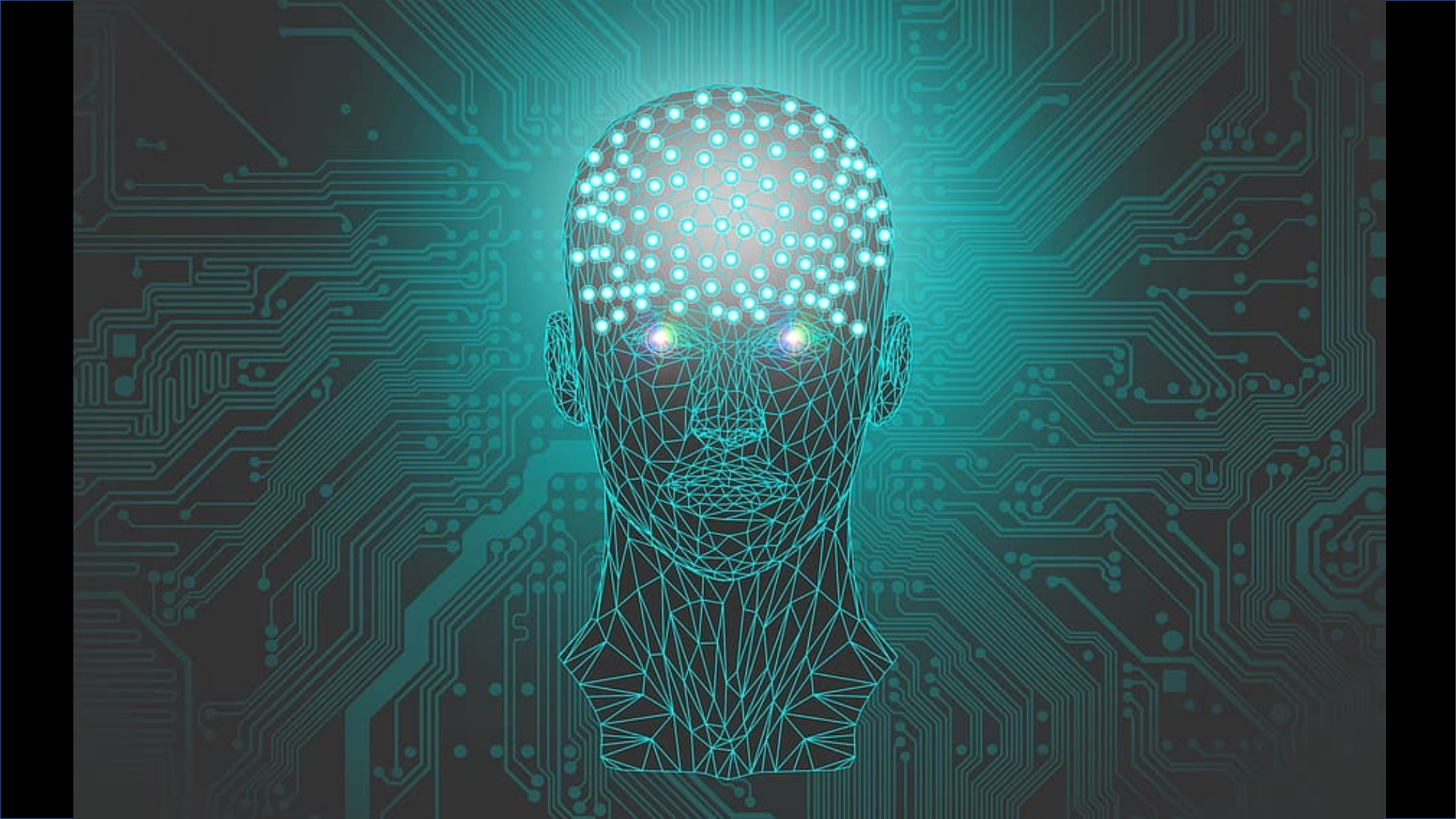
- Not addressed in DICOM 3.0 1993
- Nobody interested when followed up in 1995
- By 2002 (Sup 49), consensus to encapsulate as private data elements
- Raw Data IOD
  - traditional patient/study/series/equipment information model attributes
  - no standard payload – private elements for bulk raw data & its descriptors
  - not modality-specific (i.e., can use for CT, PET, etc.)
- *"The Raw Data stored with the Raw Data Module consists of one or more private attributes that are vendor specific. No rules are specified about the content and format of the raw data."*

Store and Regurgitate



MR Raw Data

- Store and regurgitate has limited utility beyond archival
- Researchers would obviously prefer interoperable raw data
- Vendors (at least in DICOM WG 16) remain uninterested
- ISMRM Raw Data (ISMRMRD) a promising start
- Disappointing that ISMRMRD is not DICOM-based
- Contrast with DICOM-CT-PD (projection data) developed by CT physicists for use of raw data for reconstruction challenges



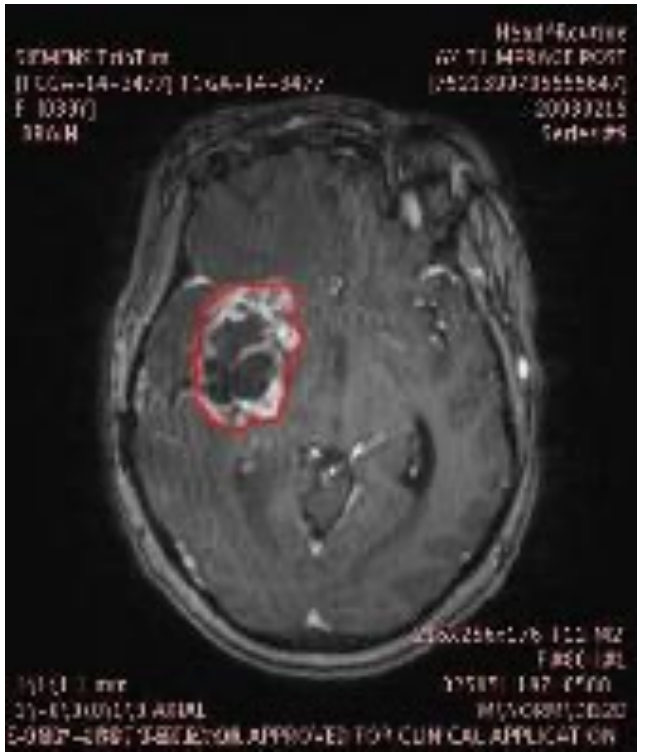
Quantitation and AI

- Historically, many MR applications have been quantitative
- Results have rarely been persisted in DICOM standard form
- Screenshots saved as DICOM for human visualization
- Useless semantically (not machine readable or re-usable)
- Surge of (renewed) interest in AI is a new market force
- Processed +/- annotated data of value for training/testing/reporting
- Revitalized interest in historic and more recent DICOM mechanisms
- Viewer ability to superimpose (beyond PET), e.g., parameter, heatmap
- *Integration with clinical PACS using DICOM format, protocol, services

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

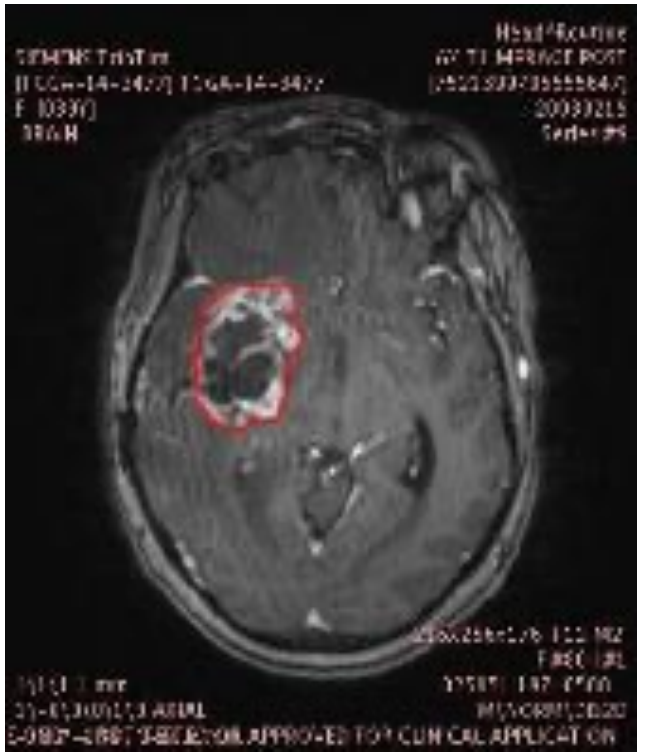
Date	Volume	Auto LD	Auto SD
20021207	27080	49	27
…	…	…	…



DICOM encoding of ROI Annotations

- 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
20021207	27080	49	27
…	…	…	…



DICOM and Annotations

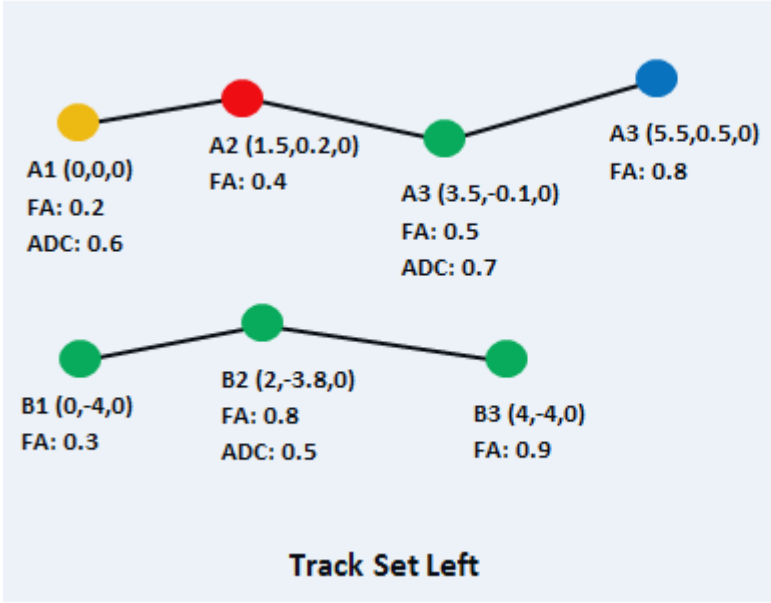
- Relatively new things in DICOM
  - Real World Value Maps
    - coded way to describe voxel values (beyond Rescale Type)
    - retrofitted to all existing DICOM images
    - form of “annotation” that makes pixel values semantically meaningful
  - Parametric Maps
    - RWVM combined with floating point or scaled integer pixels
  - Second-generation Radiotherapy annotations
    - Conceptual Volumes – “grammar” for combining contours, segmentations

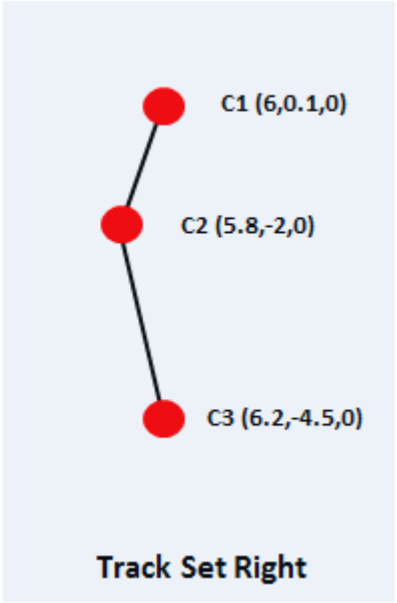
DICOM and Annotations

- Related DICOM IODs
  - Fiducials
    - markers with shape and location
  - Registration
    - rigid
    - deformable
    - well-known frames of reference (e.g., atlases)

DICOM Tractography

- Encoding of tracks by 3D coordinates
- Coded description of what they are (anatomy)
- Measurements at (subset of) points

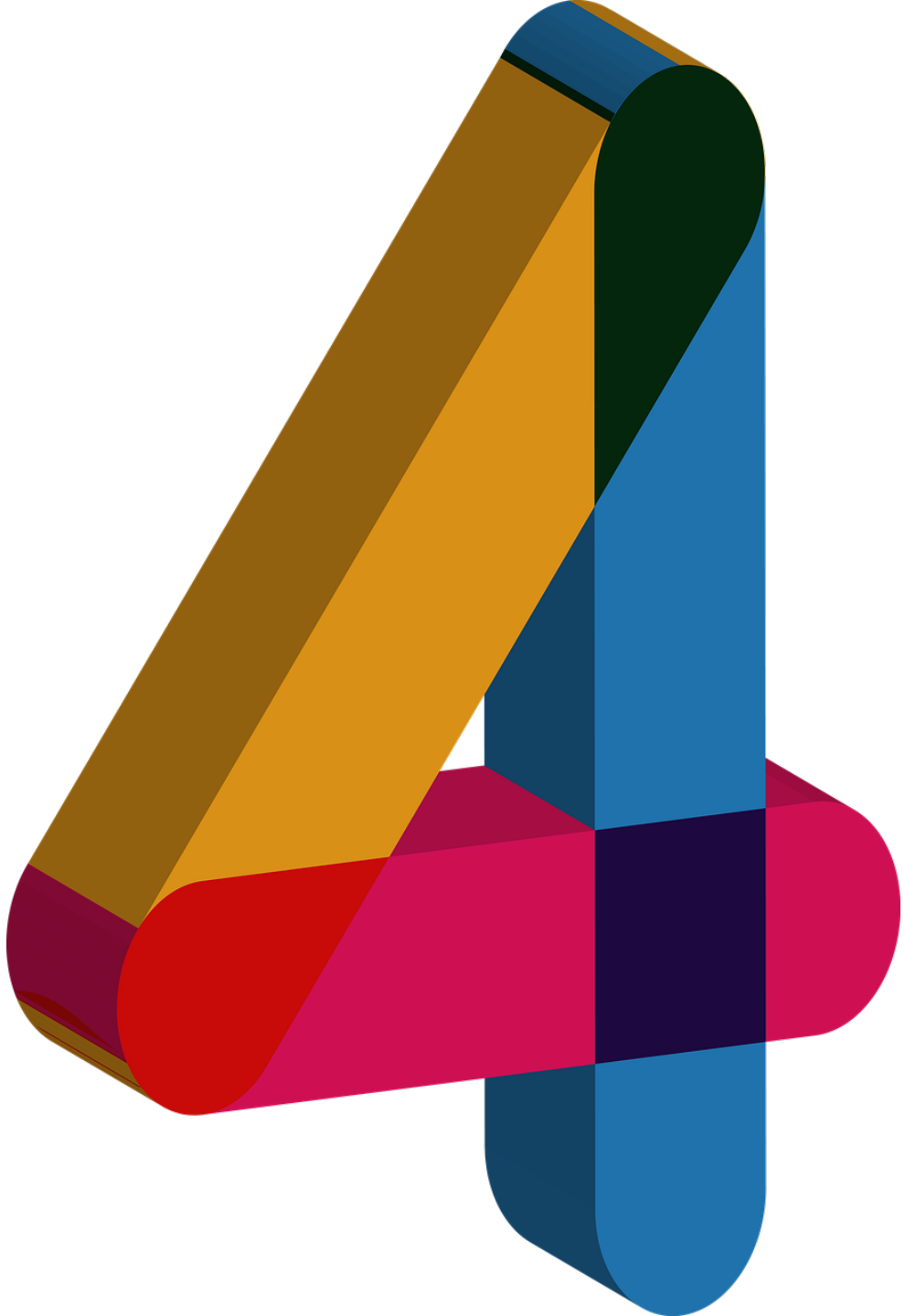





Plus ça change, plus c'est la même chose .
POTDECITATIONS.COM

DICOM Evolves

- New and updated IODs and Attributes for new technology
- *"Woefully archaic"* (Merck 2017)
- New protocols – DICOMweb (http RESTful)
- New representations – XML and JSON metadata
- New compression schemes (still frame and video)
- New data types for bulk data – floating point pixels
- New object types – parametric maps, tractography, EEG
- New security mechanisms – JWT, BCP 195 (TLS)



Future Direction of DICOM

- DICOM could continue to be extended indefinitely
  - incrementally, as historically
  - backward compatibility has long been #1 priority
- DICOM could be completely reconceived
  - new information model
  - new protocols and API
  - new representations
- Does being completely different but solving the same problems add value?
- Do solutions for any "new" problems actually ***require*** new standard?
- E.g., high speed parallel read/write of bulk (pixel) data in cloud?
  - N5/Zarr style fragmentation of bulk data and separation from metadata