DICOM
Digital Imaging and Communications in Medicine

DICOM Educational Conference
Bangkok, Thailand

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DICOM RESULT REPORTING

STRUCTURED REPORTS, JSON, AI

DAVID A. CLUNIE

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Disclosures

- Editor of the DICOM Standard (NEMA Contract)
- Owner of PixelMed Publishing, LLC
- Author of book on DICOM Structured Reporting
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- Supported by NIH U24CA180918 QIICR, NCI Leidos BOA 29XS219 Task Order #05

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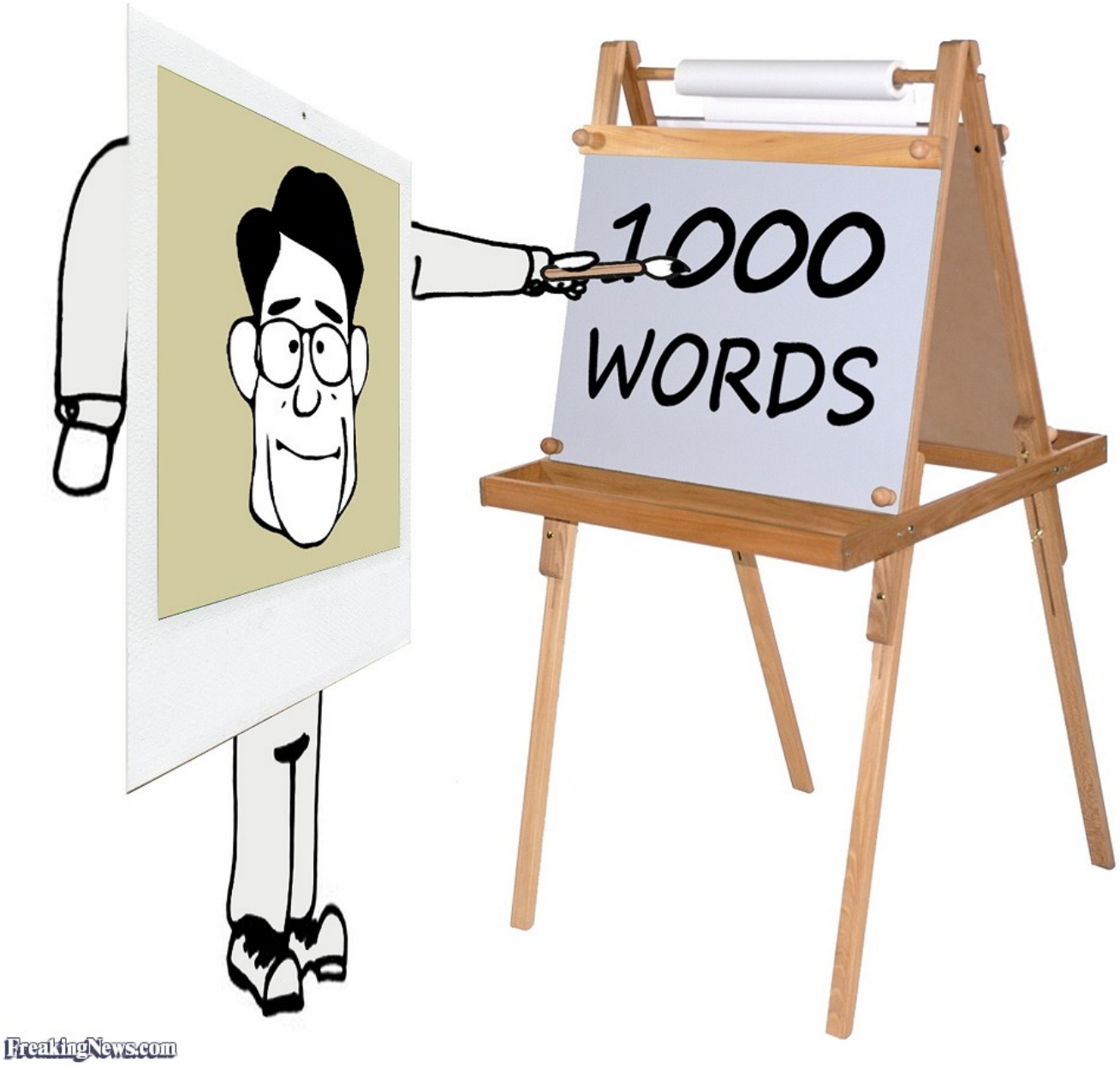

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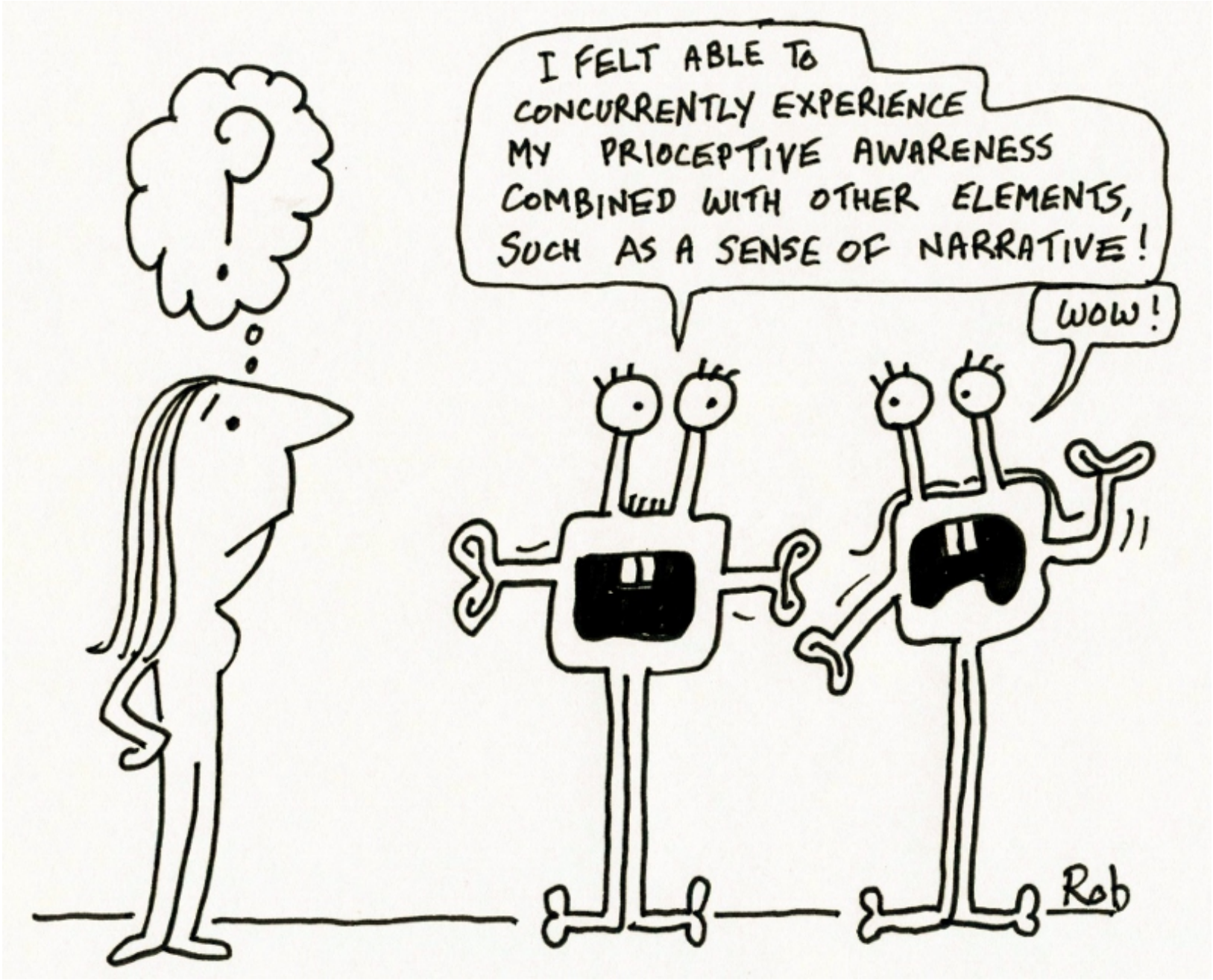

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A Picture Is Worth A Thousand Words:

Needs Assessment for Multimedia Radiology Reports in a Large Tertiary Care Medical Center

Lina Nayak, MD, Christopher F. Beaulieu, MD, PhD, Daniel L. Rubin, MD, MS, Jafi A. Lipson, MD

Rationale and Objectives: Radiology reports are the major, and often only, means of communication between radiologists and their referring clinicians. The purposes of this study are to identify referring physicians' preferences about radiology reports and to quantify their perceived value of multimedia reports (with embedded images) compared with narrative text reports.

Materials and Methods: We contacted 1800 attending physicians from a range of specialties at large tertiary care medical center via e-mail and a hospital newsletter linking to a 24-question electronic survey between July and November 2012. One hundred sixty physicians responded, yielding a response rate of 8.9%. Survey results were analyzed using Statistical Analysis Software (SAS Institute Inc, Cary, NC).

Results: Of the 160 referring physicians respondents, 142 (89%) indicated a general interest in reports with embedded images and completed the remainder of the survey questions. Of 142 respondents, 103 (73%) agreed or strongly agreed that reports with embedded images could improve the quality of interactions with radiologists; 129 respondents (91%) agreed or strongly agreed that having access to significant images enhances understanding of a text-based report; 110 respondents (77%) agreed or strongly agreed that multimedia reports would significantly improve referring physician satisfaction; and 85 respondents (60%) felt strongly or very strongly that multimedia reports would significantly improve patient care and outcomes.

Conclusions: Creating accessible, readable, and automatic multimedia reports should be a high priority to enhance the practice and satisfaction of referring physicians, improve patient care, and emphasize the critical role radiology plays in current medical care.

Key Words: Multimedia reports; radiology reporting; digital images; communication; radiology practice.

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Radiology

Structured Radiology Reporting: Are We There Yet?[1]

Curtis P. Langlotz, MD, PhD

Given the prominent role that information technology will play in the future of health care delivery, the potential benefits of structured reporting systems now seem more relevant than ever. These systems may lead to rapid

cohort design. The same 25 brain magnetic resonance (MR) imaging cases were reviewed in two distinct phases by two separate groups of residents: a control group and an intervention group. The MR imaging cases contained a representative

What is a "Structured Report"?

- Human perspective (radiologist, cardiologist, pathologist, referring physician …)
  - not a massive blob of prose (narrative)
  - organized
  - hierarchical
  - sections and sub-sections
  - bulleted lists
  - question and answer rather then single sentence
- Machine perspective
  - coded section headings
  - coded questions with answers:
    - coded answer
    - text answer
    - numeric answer (with coded units)
  - links to images, regions of interest, coordinates (spatial & temporal)

Machine Readable Reports

Source: DARPA

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AI CHANGES THE GAME

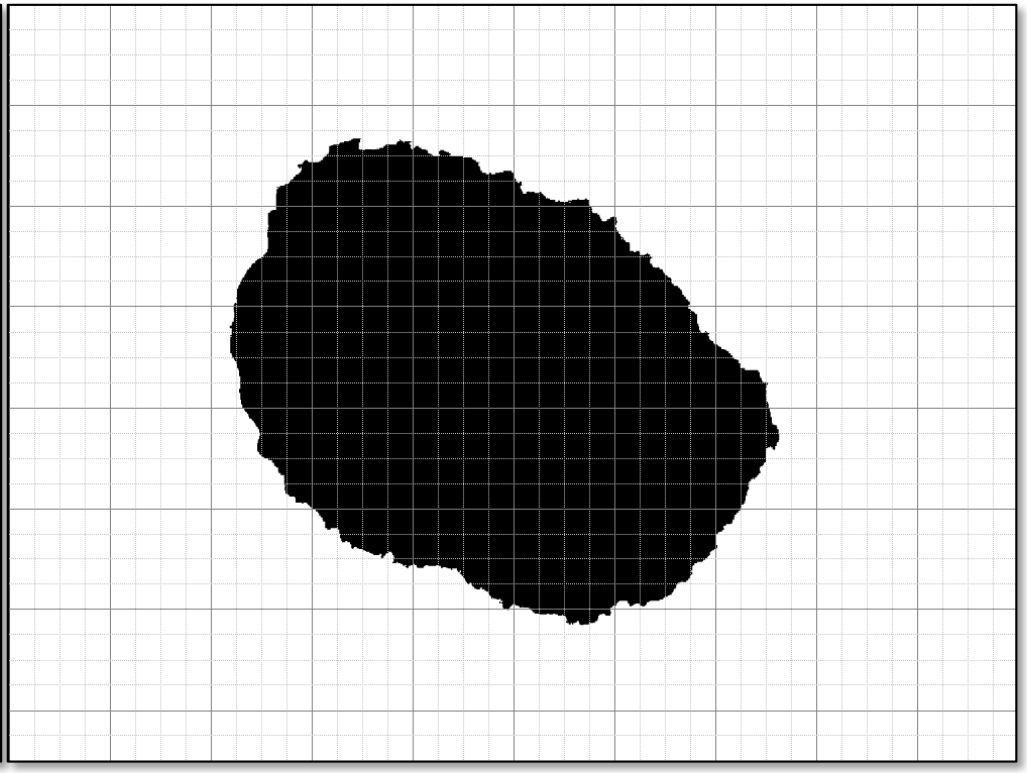
Annotation – Granularity

- Patient/Case
- Imaging Study
- Series/Acquisition
- Image
- Frame (pixel data array at one place in space/time/…)
- Region ("of interest" – ROI)
- Single point (label each/every voxel/pixel)

- All supported DICOM Structured Report (SR) or SEG

Annotation Representation

Contour – 2D Coordinates (SR)



Rasterized Bitmap (SEG)

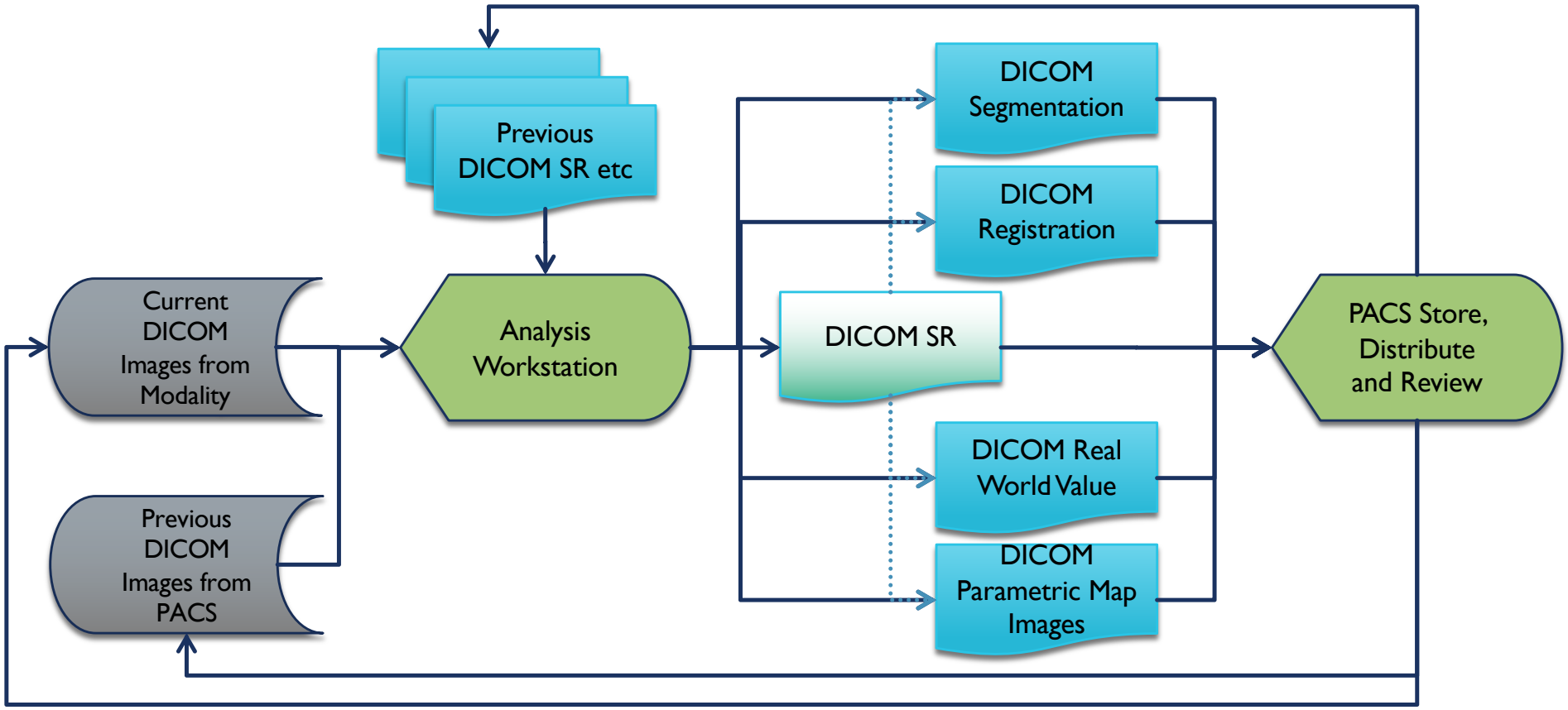
Presentation States relatively useless

- DICOM Presentation States are great for capturing state of rendering to human
  - zoom/pan, window center/width, …
  - but limited text and graphic annotations
  - no semantics
  - not even linkage of graphics and text
  - can be referenced from SR to set appropriate viewing conditions for referenced images
- Unfortunately are very popular with PACS due to their simplicity
  - better than no DICOM capture of annotations at all of course
  - means product managers not motivated to add SR support
- Ideally, all PACS viewers would support displaying any kind of SR
  - not just tabulating/rendering hierarchical content as text
  - not just jumping to reference image
  - but also displaying all coordinates/SEG references overlaid on images
  - preferably with local context from the tree such as finding, measurements and units

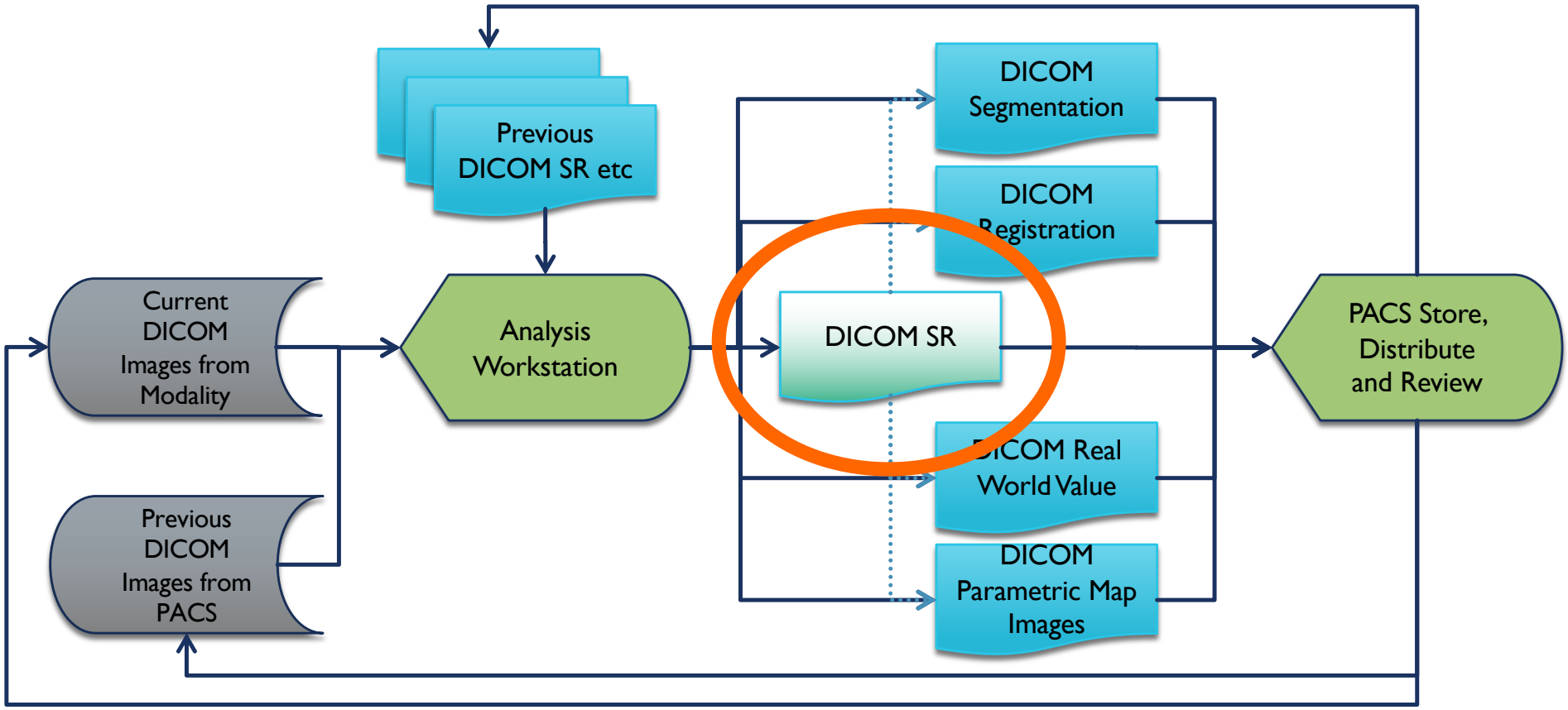
DICOM Structured Reports

- A machine-readable structured report that satisfies humans too
- Added to DICOM circa 2000
- Primary use-cases circa 2018
  - Ultrasound cart output – echocardiography, obstetric measurements
  - Mammography CAD output
  - Radiation Dose from CT and projection X-Ray devices (RDSR)
  - Key Object Selection (KOS)
  - limited use for human-generated narrative reports with section structuring
- Major new use-cases in the quantitative/machine learning era
  - tumor/lesion region of interest encoding
  - quantitative measurements and categorical classification
    - created by humans or machines
    - consumed by humans or machines

DICOM Non-Image Objects



DICOM SR organizes them …



DICOMDIR

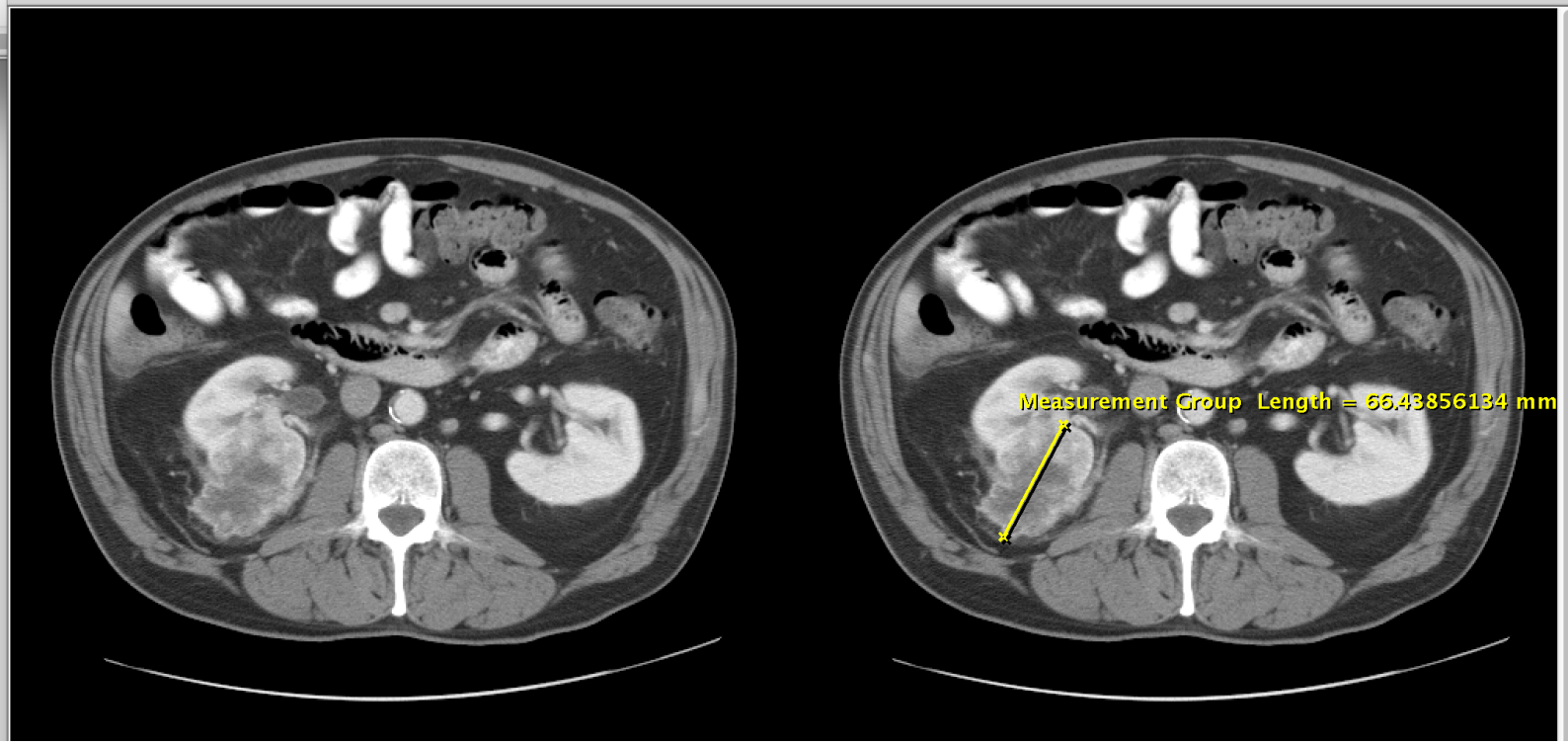
- Top
  - Patient TCGA-BP-4343 TCGA-BP-4343
    - Study 19870620 19870620 Renal
      - Series 3 {CT}
      - Series 105 {CT} 3 MIN DELAY
      - Series 4578 {SR} Crowds Cure Cancer
        - SR Document 1

CompletionFlag	ContentDate	ContentTime	Insta
COMPLETE	20171126	224217	1

TCGA-BP-4343[TCGA-BP-4343]:[19870620:Renal]:4578[SR:Crowds Cure Cancer Annotation as Measuremer

- : CONTAINER: Imaging Measurement Report [SEPARATE] (DCMR,1500)
  - HAS CONCEPT MOD: CODE: Language of Content Item and Descendants = English
    - HAS CONCEPT MOD: CODE: Country of Language = United States
  - HAS OBS CONTEXT: PNAME: Person Observer Name = accomplished_peafowl
  - HAS CONCEPT MOD: CODE: Procedure reported = CT Abdomen
  - CONTAINS: CONTAINER: Image Library [SEPARATE]
    - CONTAINS: CONTAINER: Image Library Group [SEPARATE]
      - CONTAINS: IMAGE: = 1.2.840.10008.5.1.4.1.1.2 : 1.3.6.1.4.1.14519.5.2.1.9203.4004.26801842228881857322651602376
        - HAS ACQ CONTEXT: CODE: Modality = Computed Tomography
        - HAS ACQ CONTEXT: DATE: Study Date = 19870620
        - HAS ACQ CONTEXT: TIME: Study Time = 135823
  - CONTAINS: CONTAINER: Imaging Measurements [SEPARATE]
    - CONTAINS: CONTAINER: Measurement Group [SEPARATE]
      - HAS OBS CONTEXT: TEXT: Tracking Identifier = 5b6eb4301d3175942d29985a3d0fbb00
      - HAS OBS CONTEXT: UIDREF: Tracking Unique Identifier = 1.3.6.1.4.1.5962.1.1.0.0.0.1535644357.22655.1
      - HAS CONCEPT MOD: CODE: Finding Site = Kidney
      - CONTAINS: NUM: Length = 66.43856134 mm
        - INFERRED FROM: SCOORD: = POLYLINE (172.835357666016,270.064086914062,133.798889160156,343.045318
          - SELECTED FROM: IMAGE: = 1.2.840.10008.5.1.4.1.1.2 : 1.3.6.1.4.1.14519.5.2.1.9203.4004.268018422288818573

TCGA-BP-4343[TCGA-BP-4343]:[19870620:CT CH/AB/PEL KIDNEY PROTOCOL]:3[CT:]:57:



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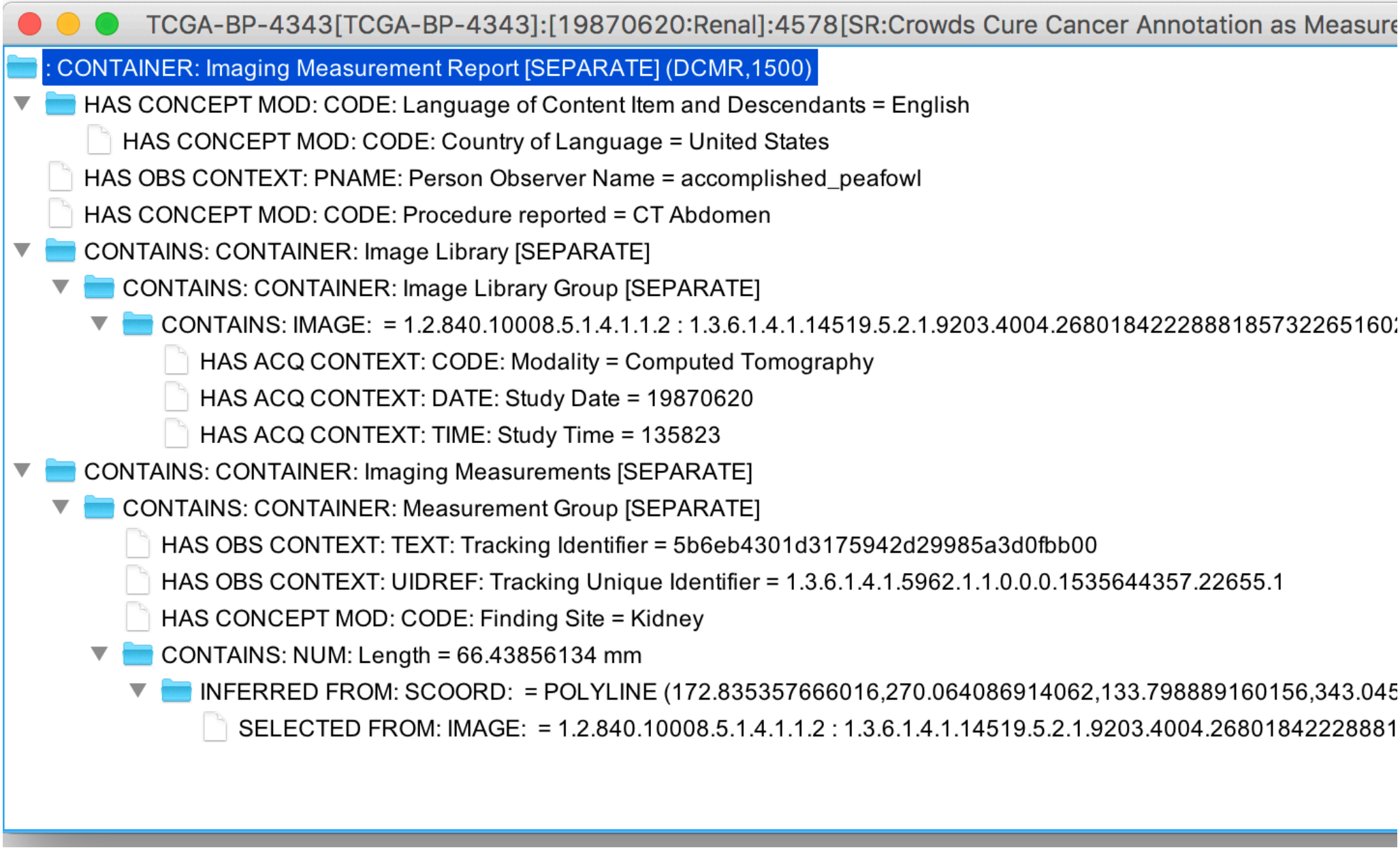

```
Report")  [SEPARATE] (DCMR,1500)
"Language of Content Item and Descendants")  = (eng,RFC5646,"Engl
121046,DCM,"Country of Language")  = (US,ISO3166_1,"United States
,"Person Observer Name")  = "accomplished_peafowl"
"Procedure reported")  = (41806-1,LN,"CT Abdomen")
mage Library")  [SEPARATE]
6200,DCM,"Image Library Group")  [SEPARATE]
GE:  = (1.2.840.10008.5.1.4.1.1.2,1.3.6.1.4.1.14519.5.2.1.9203.40
S ACQ CONTEXT: CODE: (121139,DCM,"Modality")  = (CT,DCM,"Computed
S ACQ CONTEXT: DATE: (111060,DCM,"Study Date")  = "19870620"
S ACQ CONTEXT: TIME: (111061,DCM,"Study Time")  = "135823"
maging Measurements")  [SEPARATE]
5007,DCM,"Measurement Group")  [SEPARATE]
XT: TEXT: (112039,DCM,"Tracking Identifier")  = "5b6eb4301d317594
XT: UIDREF: (112040,DCM,"Tracking Unique Identifier")  = "1.3.6.1
OD: CODE: (G-C0E3,SRT,"Finding Site")  = (T-71000,SRT,"Kidney")
: (G-D7FE,SRT,"Length")  = 66.43856134 (mm,UCUM,"mm")
FERRED FROM: SCOORD:  = POLYLINE {172.835357666016,270.0640869140
1.4.1.1: SELECTED FROM: IMAGE:  = (1.2.840.10008.5.1.4.1.1.2,1.3.
```

```
Report")  [SEPARATE] (DCMR,1500)
"Language of Content Item and Descendants")  = (eng,RFC5646,"Engl
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,"Person Observer Name")  = "accomplished_peafowl"
"Procedure reported")  = (41806-1,LN,"CT Abdomen")
mage Library")  [SEPARATE]
6200,DCM,"Image Library Group")  [SEPARATE]
GE:  = (1.2.840.10008.5.1.4.1.1.2,1.3.6.1.4.1.14519.5.2.1.9203.40
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S ACQ CONTEXT: TIME: (111061,DCM,"Study Time")  = "135823"
maging Measurements")  [SEPARATE]
5007,DCM,"Measurement Group")  [SEPARATE]
XT: TEXT: (112039,DCM,"Tracking Identifier")  = "5b6eb4301d317594
XT: UIDREF: (112040,DCM,"Tracking Unique Identifier")  = "1.3.6.1
OD: CODE: (G-C0E3,SRT,"Finding Site")  = (T-71000,SRT,"Kidney")
: (G-D7FE,SRT,"Length")  = 66.43856134 (mm,UCUM,"mm")
FERRED FROM: SCOORD:  = POLYLINE {172.835357666016,270.0640869140
1.4.1.1: SELECTED FROM: IMAGE:  = (1.2.840.10008.5.1.4.1.1.2,1.3.
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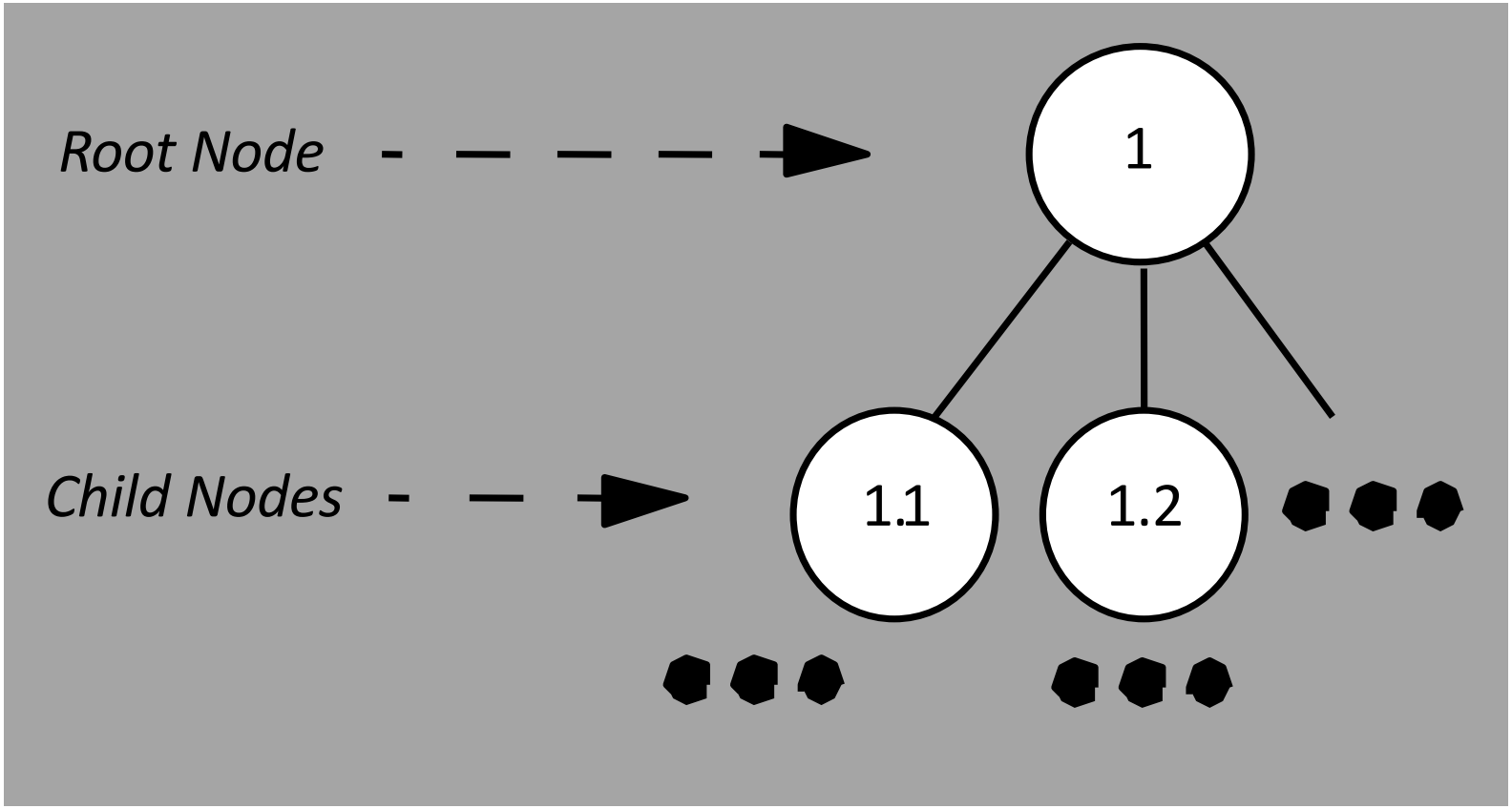
SR Content is a Tree

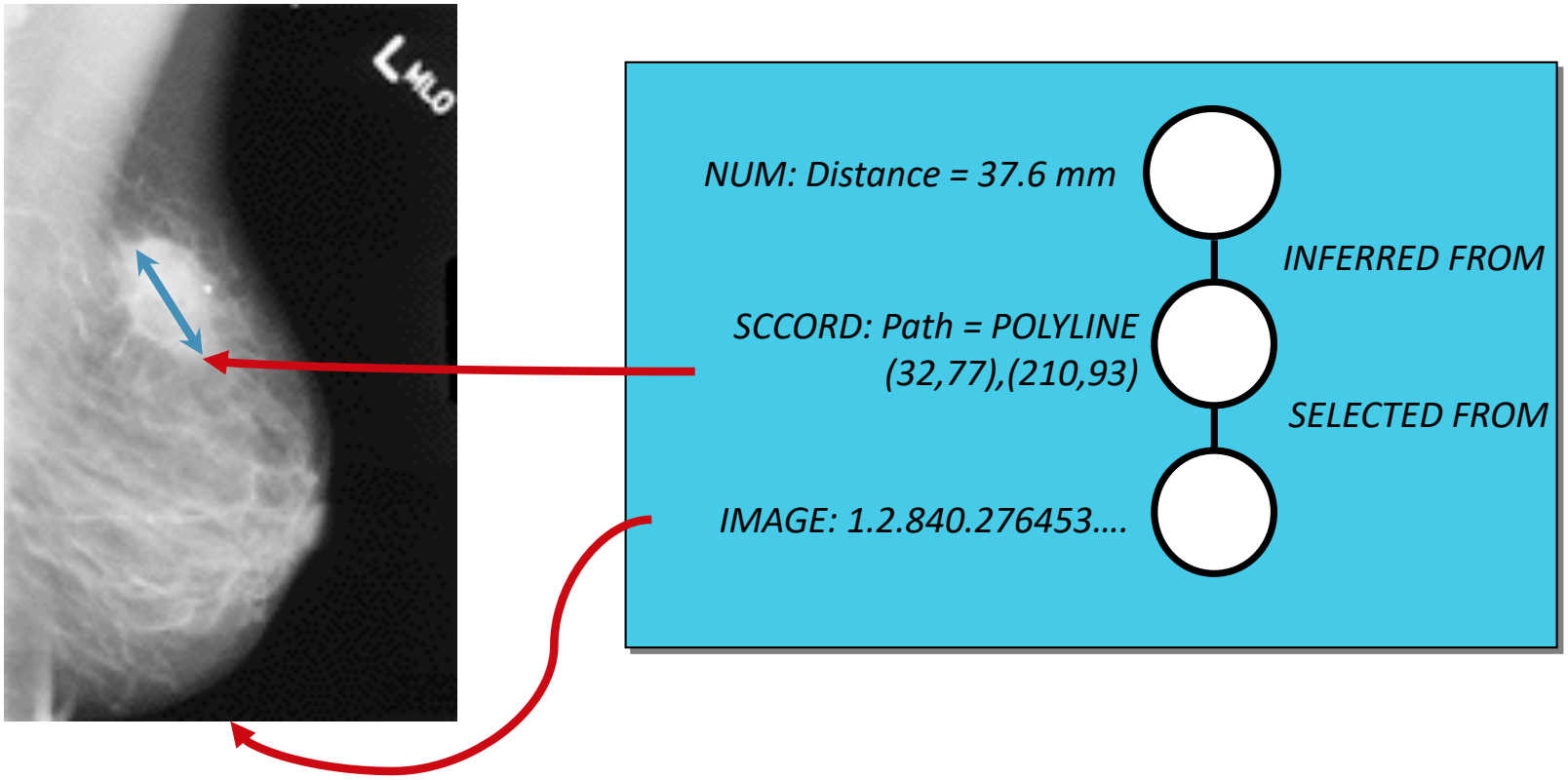


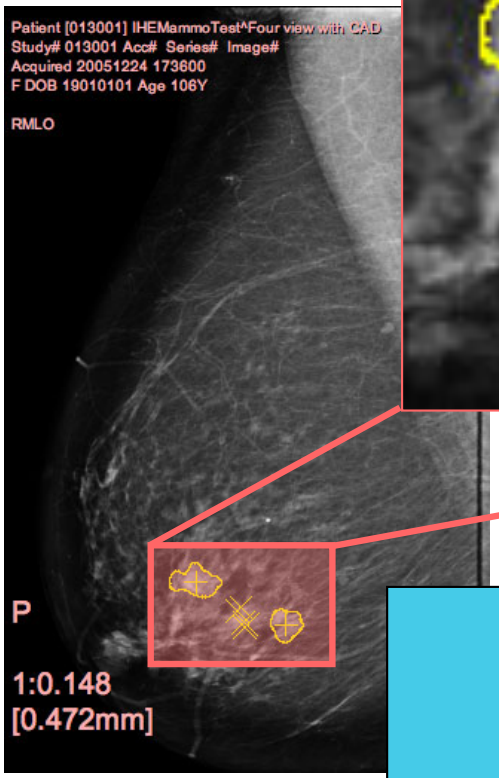
Each Node (Content Item)

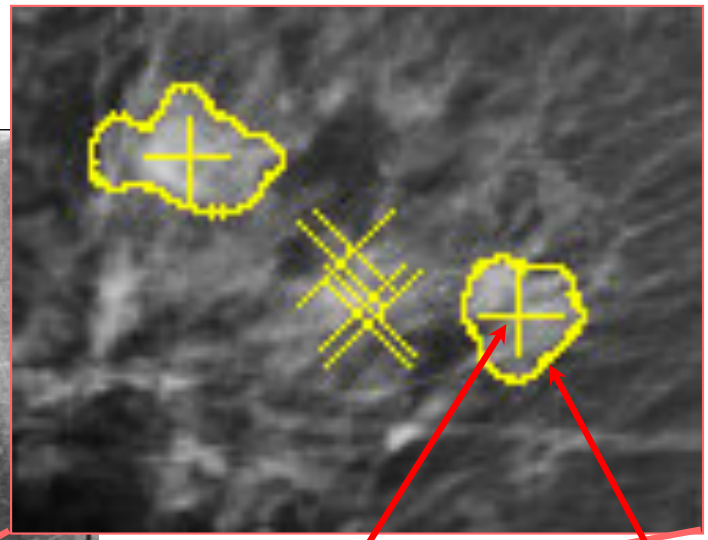
- Is a "name-value" pair
  - e.g. "finding" = "mass"
- Concept "name" is always coded
  - e.g. (121071, DCM, "Finding")
- "Value" may be one of several "value types"
- "Value" may be coded too
  - e.g. (M-37000, SRT, "Hemorrhage")
  - e.g. 37.2 (mm2, UCUM, "square millimeters")

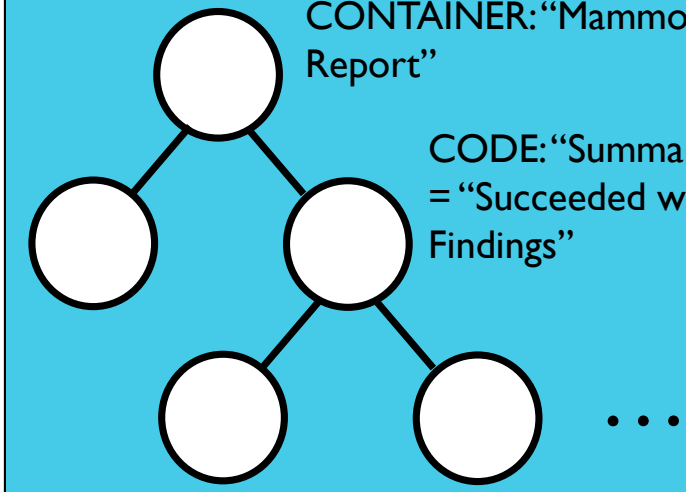
Value Types

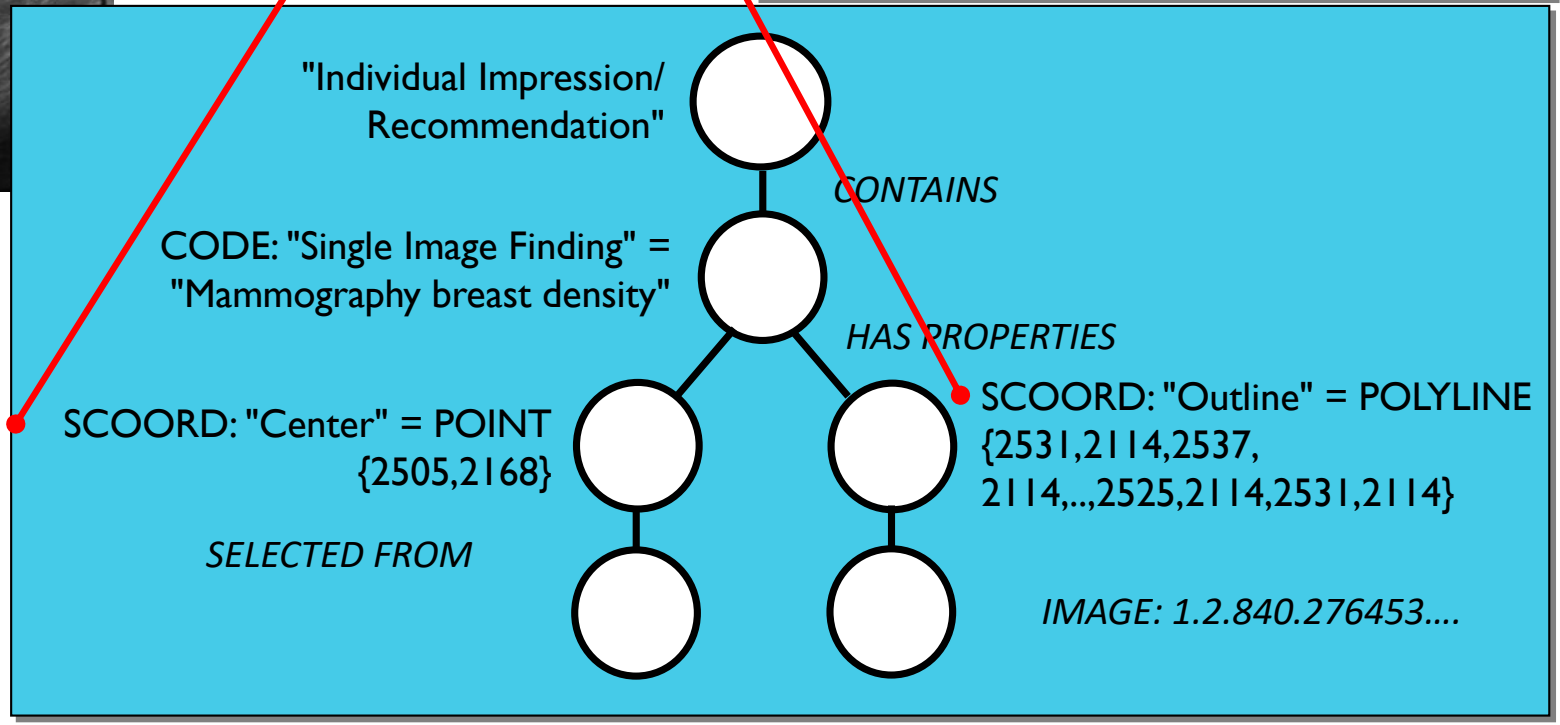
- TEXT
- CODE
- NUM
- PNAME
- DATE
- TIME
- DATETIME
- CONTAINER
- UIDREF
- COMPOSITE
- IMAGE
- WAVEFORM
- SCOORD(3D)
- TCOORD


L MLO
NUM: Distance = 37.6 mm
INFERRED FROM
SCCORD: Path = POLYLINE
(32,77),(210,93)
SELECTED FROM
IMAGE: 1.2.840.276453….

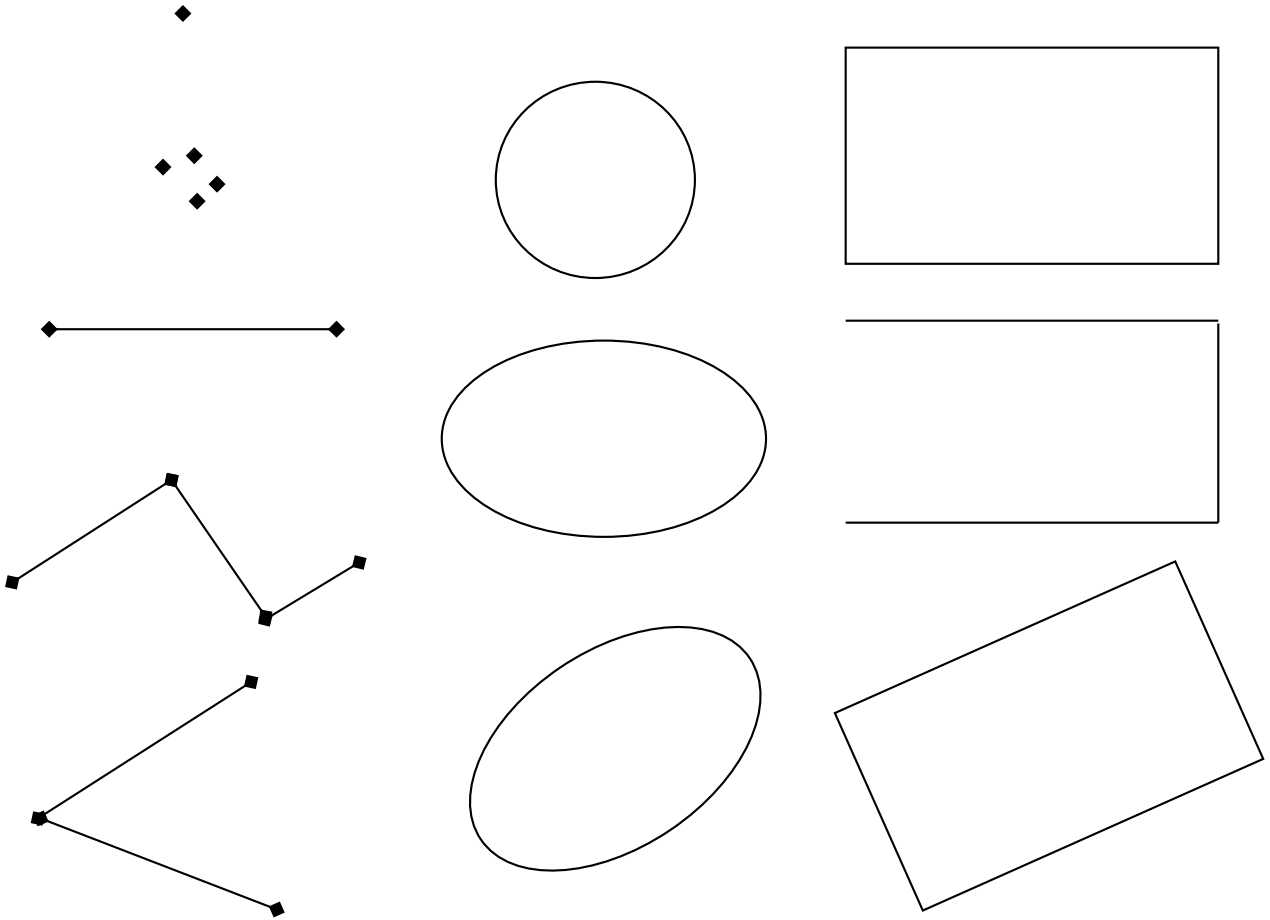

Patient [013001] IHEMammoTest^Four view with CAD
Study# 013001 Acc# Series# Image#
Acquired 20051224 173600
F DOB 19010101 Age 106Y
RMLO
P
1:0.148
[0.472mm]




CONTAINER: "Mammo CAD Report"
CODE: "Summary" = "Succeeded with Findings"
CONTAINER: "Individual Impression/ Recommendation"


"Individual Impression/ Recommendation"
CONTAINS
CODE: "Single Image Finding" = "Mammography breast density"
HAS PROPERTIES
SCOORD: "Center" = POINT {2505,2168}
SCOORD: "Outline" = POLYLINE {2531,2114,2537, 2114,..,2525,2114,2531,2114}
SELECTED FROM
IMAGE: 1.2.840.276453....

Spatial Coordinates



POINT
MULTIPOINT
POLYLINE
CIRCLE
ELLIPSE

Temporal Coordinates

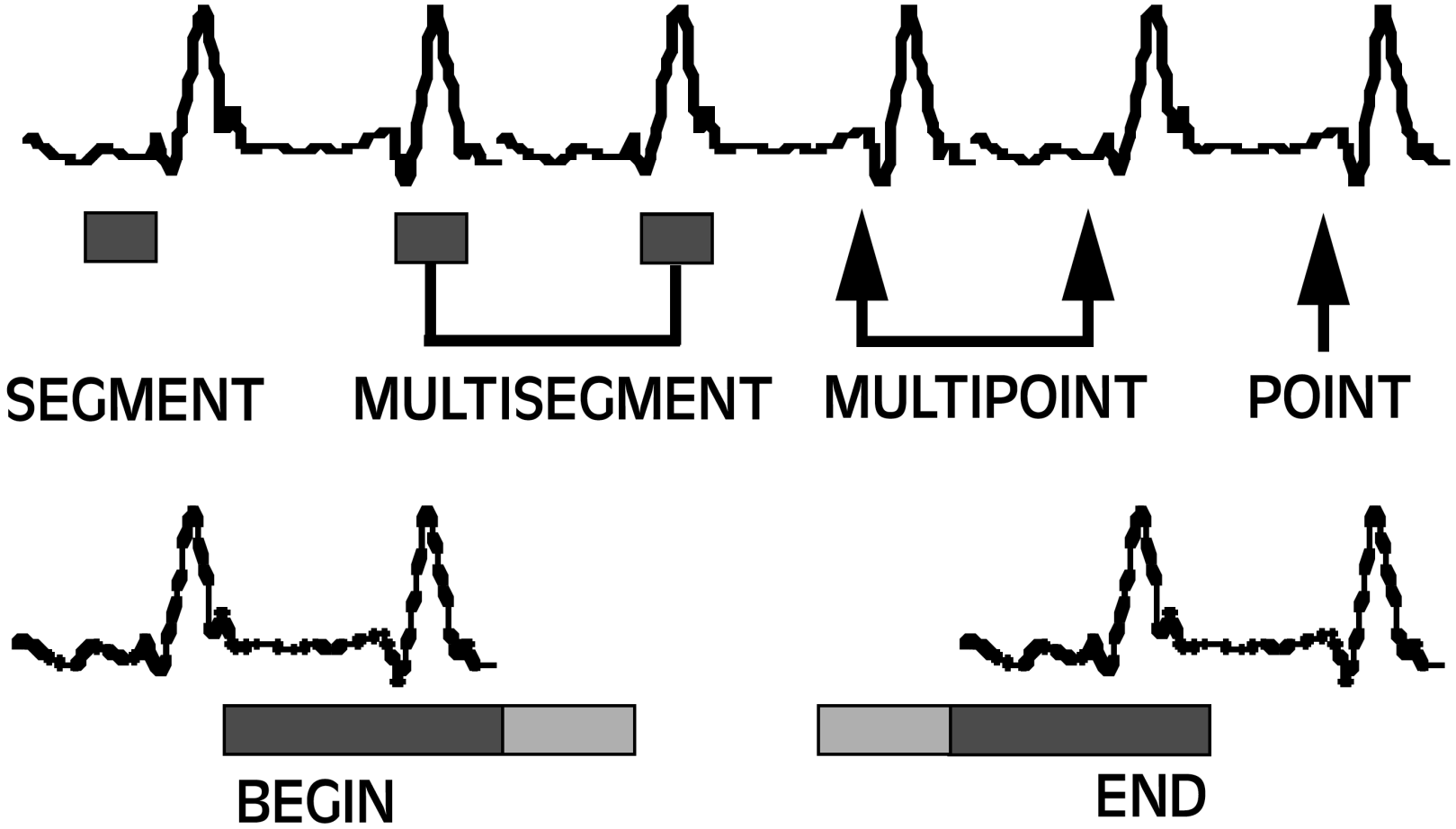
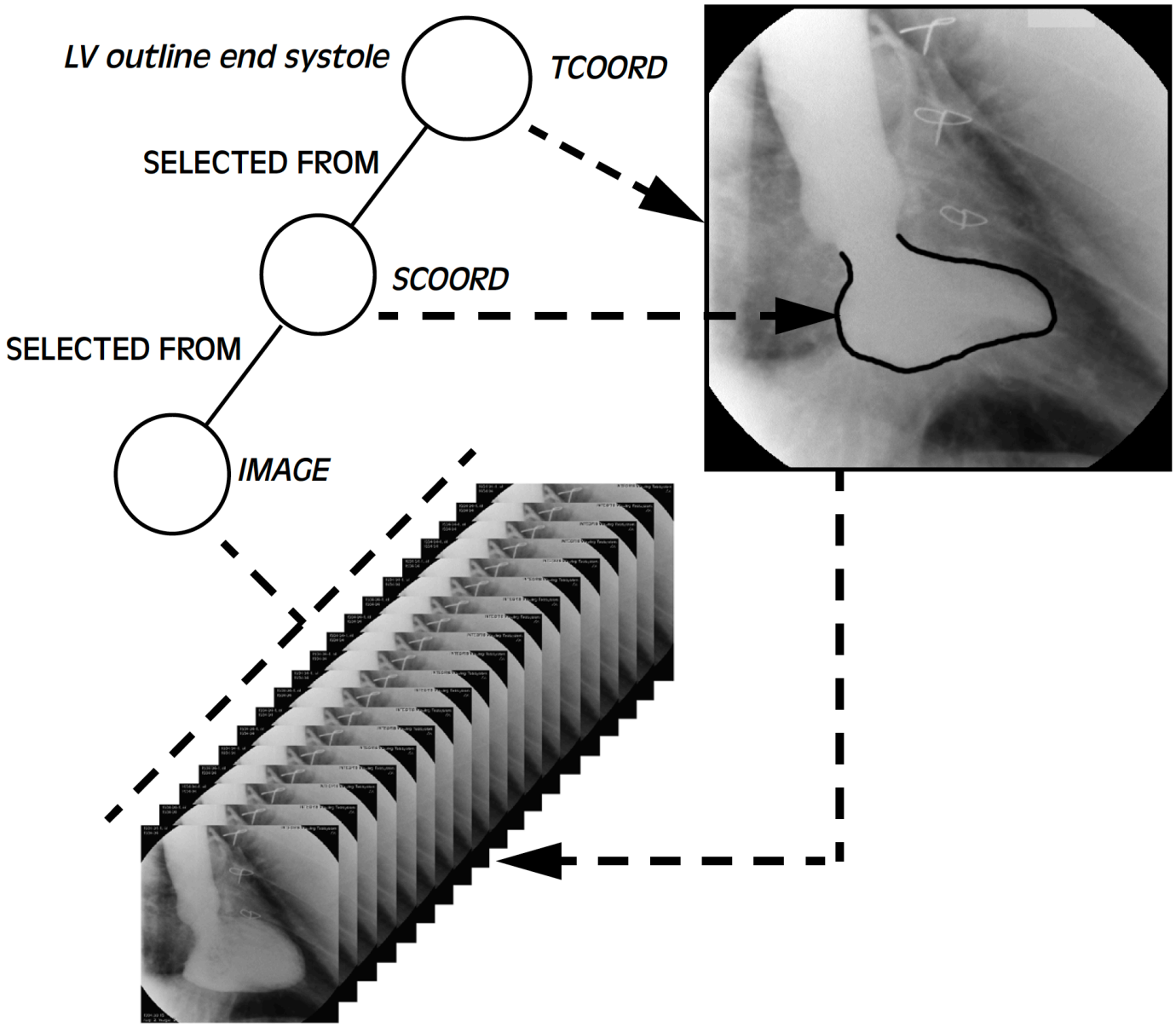
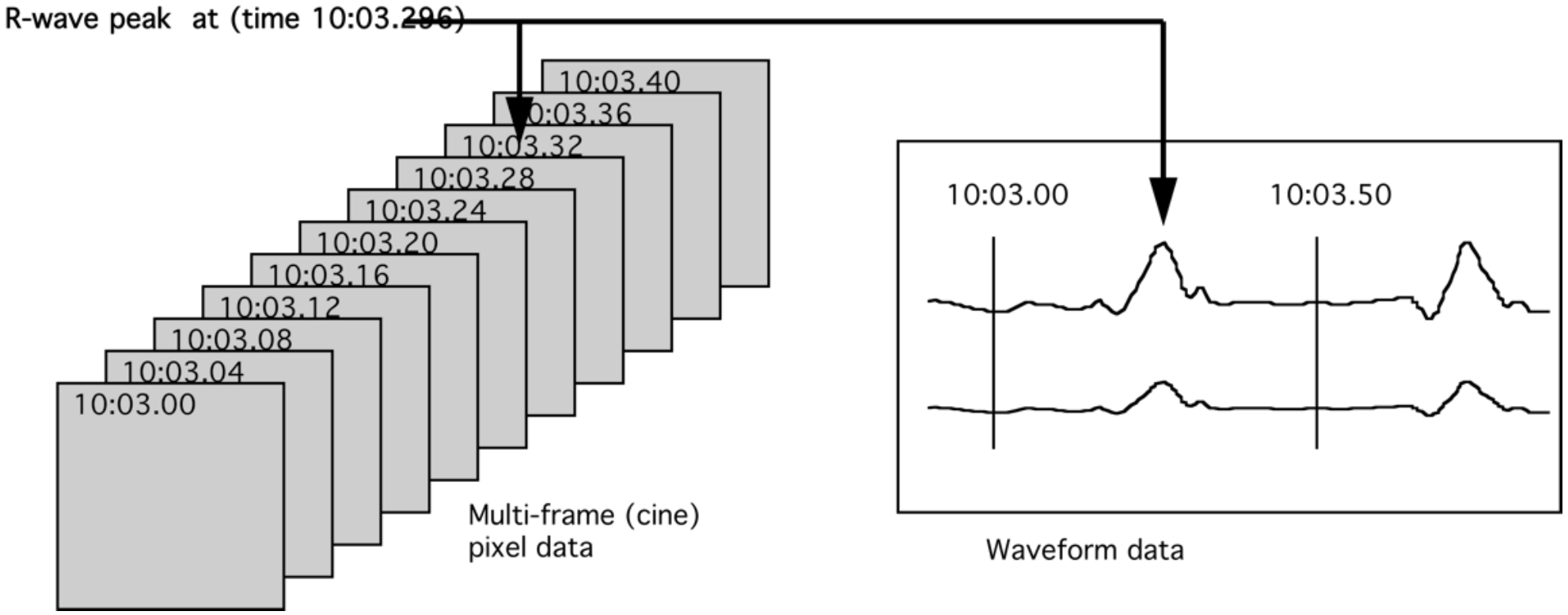


Image Temporal and Spatial Coordinates



Temporal Coordinates applied to both Images and Waveforms



What about Codes?

- DICOM uses external lexicons
  - SNOMED
  - LOINC
  - RADLEX
  - defines DCM codes & definitions if no other good scheme
- EHR push towards more reliable codes
  - e.g., EHR interoperability and common data elements
  - RIS, modalities and PACS implementations could do better
  - institutions need to standardize internal procedure codes
  - harmonize/bridge imaging/EHR codes

Codes for Structured Reports

- Codes needed for
  - entities, e.g., lesions, tumors, tissue types
  - location, e.g., anatomic site
  - characteristics, e.g., edges, enhancement
  - measurements, e.g., volume, sum of areas, mean
  - units, e.g., HU, mm
- Availability
  - many already - SNOMED, LOINC, RADLEX, DCM, NCI, UCUM
  - more being defined every day
  - vendors also use private codes
  - need to anticipate code evolution (configurable producer/consumer)

ROI and Segmentation Codes

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Table CID 7150. Segmentation Property Categories

Coding Scheme Designator	Code Value	Code Meaning	SNOMED-RT ID	UMLS Concept Unique ID	Segmentation Property Type Context Group
SCT	85756007	Tissue	T-D0050	C0040300	CID 7191 “Tissue Segmentation Property Types”
SCT	123037004	Anatomical Structure	T-D000A	C1268086	CID 7192 “Anatomical Structure Segmentation Property Types”
SCT	260787004	Physical object	A-00004	C0085089	CID 7193 “Physical Object Segmentation Property Types”
SCT	49755003	Morphologically Abnormal Structure	M-01000	C0221198	CID 7194 “Morphologically Abnormal Structure Segmentation Property Types”
SCT	246464006	Function	R-42019	C0542341	CID 7195 “Function Segmentation Property Types”
SCT	309825002	Spatial and Relational Concept	R-42018	C0587374	CID 7196 “Spatial and Relational Concept Segmentation Property Types”
SCT	91720002	Body Substance	T-D0080	C0504082	CID 7197 “Body Substance Segmentation Property Types”
SCT	105590001	Substance	F-61002	C0439861	CID 7198 “Substance Segmentation Property Types”

ROI and Segmentation Codes

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Table CID 7153. CNS Segmentation Types

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	80447000	Cerebral aqueduct	T-A1800	C0007769
SCT	40146001	Cerebral cortex	T-A2020	C0007776
SCT	87463005	Cerebral fornix	T-A2970	C0152334
SCT	40146001	Cerebral Gray Matter	T-A2020	C0007776
SCT	68523003	Cerebral White Matter	T-A2030	C0152295
SCT	65216001	Cerebrospinal Fluid	T-A1000	C0007806
SCT	37035000	Cingulum	T-A2840	C0228272

Constrained by Templates

- Generic tree of content items has unbounded complexity, so need constraints
- Templates for interoperability for specific use cases
  - e.g., Mammography CAD
- Templates for entire structure
  - "root level"
- Templates for parts of structure – re-usable
  - e.g., Volumetric ROI Measurements
- Defined in PS3.16, follow pattern similar to Module tables in PS3.3
  - (coded) name of content item
  - requirement type
  - multiplicity
  - conditions
  - value set for coded values
  - coded units for numeric values

Table TID 1411. Volumetric ROI Measurements

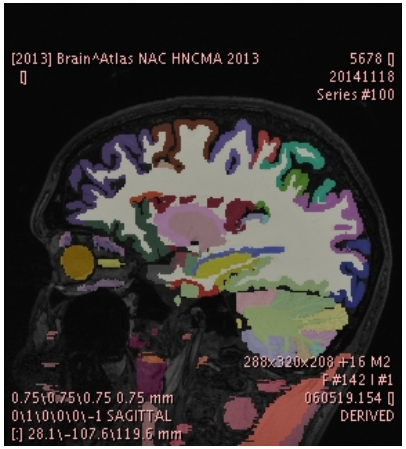
	NL	Rel with Parent	VT	Concept Name	VM	Req Type	Condition	Value Set Constraint
1			CONTAINER	EV (125007, DCM, "Measurement Group")	1	M		
1b	>	HAS OBS CONTEXT	TEXT	EV (C67447, NCIt, "Activity Session")	1	U		
2	>	HAS OBS CONTEXT	TEXT	DT (112039, DCM, "Tracking Identifier")	1	M		
3	>	HAS OBS CONTEXT	UIDREF	EV (112040, DCM, "Tracking Unique Identifier")	1	M		
3b	>	CONTAINS	CODE	EV (121071, DCM, "Finding")	1	U		$FindingType
4	>	CONTAINS	INCLUDE	DTID 1502 “Time Point Context”	1	U		
5	>	CONTAINS	SCOORD	EV (111030, DCM, "Image Region")	1-n	MC	XOR Rows 7, 10	GRAPHIC TYPE = not {MULTIPOINT}
6	>>	SELECTED FROM	IMAGE		1	M		
7	>	CONTAINS	IMAGE	EV (121191, DCM, "Referenced Segment")	1	MC	XOR Rows 5, 10	Reference shall be to a Segmentation Image or Surface Segmentation object, with a single value specified in Referenced Segment Number
8	>	CONTAINS	IMAGE	EV (121233, DCM, "Source image for segmentation")	1-n	MC	XOR Row 9 and IFF Row 7	

Key Object Selection Document

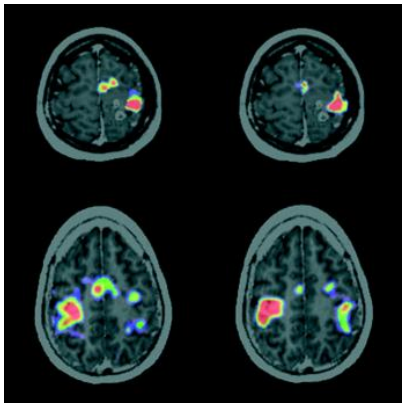
- Specialized form of DICOM Structured Report
  - SOP Class constrains to specific template
- Essentially
  - list of images and other DICOM objects ("manifest")
  - coded Document Title, e.g., "For Clinical Trial Export"
  - text description
- Used in IHE as
  - Key Image Note profile
  - manifest for XDS-I profile

Segmentations and 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
  - 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
  - recently added floating point voxels and SOP Class (Sup 172)
- Leave "fusion" (superimposition) to application
  - e.g., PET SUV on top of CT
  - can use Blending Presentation State to specify what to fuse



Harvard Brain Atlas NRRD Label Map converted to DICOM Segmentation



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

Traditional Binary DICOM SR

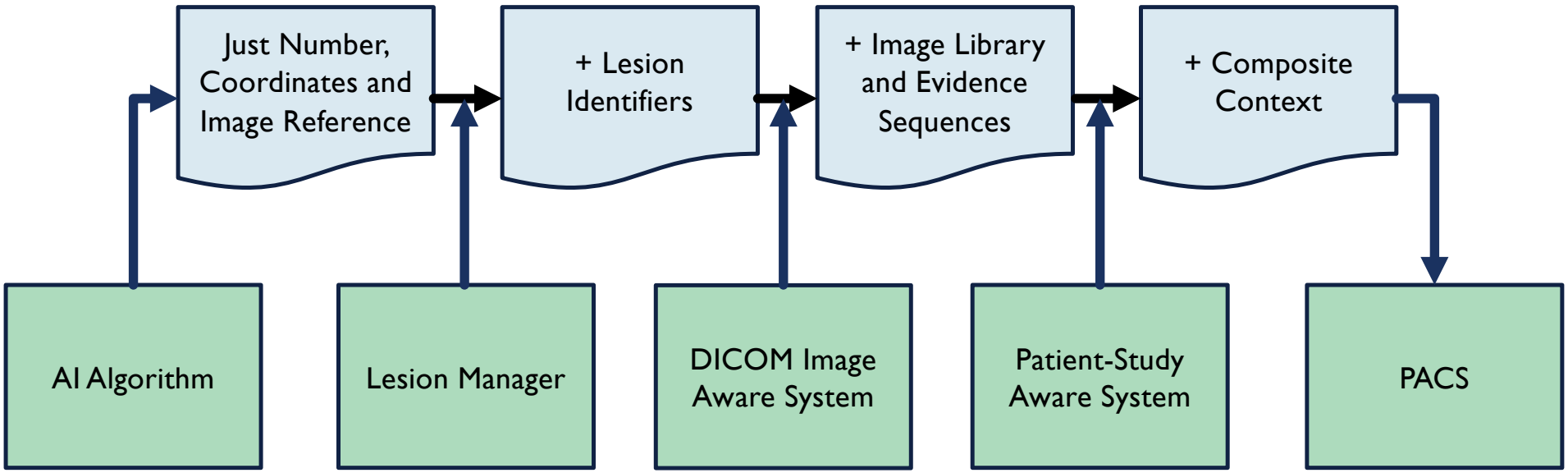
```
00000390  20 00 11 00 49 53 04 00  34 35 37 38 20 00 13 00  | ...IS..4578 ...|
000003a0  49 53 02 00 31 20 40 00  40 a0 43 53 0a 00 43 4f  |IS..1 @.@.CS..CO|
000003b0  4e 54 41 49 4e 45 52 20  40 00 43 a0 53 51 00 00  |NTAINER @.C.SQ..|
000003c0  ff ff ff ff fe ff 00 e0  ff ff ff ff 08 00 00 01  |................|
000003d0  53 48 06 00 31 32 36 30  30 30 08 00 02 01 53 48  |SH..126000....SH|
000003e0  04 00 44 43 4d 20 08 00  04 01 4c 4f 1a 00 49 6d  |..DCM ....LO..Im|
000003f0  61 67 69 6e 67 20 4d 65  61 73 75 72 65 6d 65 6e  |aging Measuremen|
00000400  74 20 52 65 70 6f 72 74  fe ff 0d e0 00 00 00 00  |t Report........|
00000410  fe ff dd e0 00 00 00 00  40 00 50 a0 43 53 08 00  |........@.P.CS..|
00000420  53 45 50 41 52 41 54 45  40 00 78 a0 53 51 00 00  |SEPARATE@.x.SQ..|
00000430  ff ff ff ff fe ff 00 e0  ff ff ff ff 08 00 80 00  |................|
00000440  4c 4f 00 00 08 00 82 00  53 51 00 00 ff ff ff ff  |LO......SQ......|
00000450  fe ff dd e0 00 00 00 00  40 00 01 11 53 51 00 00  |........@...SQ..|
00000460  ff ff ff ff fe ff dd e0  00 00 00 00 40 00 84 a0  |............@...|
00000470  43 53 04 00 50 53 4e 20  40 00 23 a1 50 4e 14 00  |CS..PSN @.#.PN..|
00000480  61 63 63 6f 6d 70 6c 69  73 68 65 64 5f 70 65 61  |accomplished_pea|
00000490  66 6f 77 6c fe ff 0d e0  00 00 00 00 fe ff dd e0  |fowl............|
000004a0  00 00 00 00 40 00 72 a3  53 51 00 00 ff ff ff ff  |....@.r.SQ......|
000004b0  fe ff dd e0 00 00 00 00  40 00 75 a3 53 51 00 00  |........@.u.SQ..|
000004c0  ff ff ff ff fe ff 00 e0  ff ff ff ff 08 00 15 11  |................|
000004d0  53 51 00 00 ff ff ff ff  fe ff 00 e0 ff ff ff ff  |SQ..............|
000004e0  08 00 99 11 53 51 00 00  ff ff ff ff fe ff 00 e0  |....SQ..........|
000004f0  ff ff ff ff 08 00 50 11  55 49 1a 00 31 2e 32 2e  |......P.UI..1.2.|
00000500  38 34 30 2e 31 30 30 30  38 2e 35 2e 31 2e 34 2e  |840.10008.5.1.4.|
00000510  31 2e 31 2e 32 00 08 00  55 11 55 49 40 00 31 2e  |1.1.2...U.UI@.1.|
00000520  33 2e 36 2e 31 2e 34 2e  31 2e 31 34 35 31 39 2e  |3.6.1.4.1.14519.|
00000530  35 2e 32 2e 31 2e 39 32  30 33 2e 34 30 30 34 2e  |5.2.1.9203.4004.|
00000540  32 36 38 30 31 38 34 32  32 32 38 38 38 31 38 35  |2680184222888185|
00000550  37 33 32 32 36 35 31 36  30 32 33 37 36 32 fe ff  |73226516023762..|
```

```
[
  {
    "TrackingIdentifier": [
      "5b6eb4301d3175942d29985a3d0fbb00"
    ]
  },
  {
    "TrackingUniqueIdentifier": [
      "1.3.6.1.4.1.5962.1.1.0.0.0.1535644357.22655.1"
    ]
  },
  {
    "Length": [
      "66.43856134",
      "mm",
      [
        {
          "": [
            "POLYLINE",
            [
              172.83535766601562,
              270.0640869140625,
              133.79888916015625,
              343.0453186035156
            ],
            [
              {
                "": [
                  "1.2.840.10008.5.1.4.1.1.2",
                  "1.3.6.1.4.1.14519.5.2.1.9203.4004.268018422288818573226516023762"
                ]
              }
            ]
          ]
        }
      ]
    ]
  }
]
```

Goals for Simplified DICOM SR in JSON

- Full-fidelity round trip with actual DICOM SR for all constructs (any template)
- Simple (enough to hand write or copy from examples)
- Compact (even terse)
- Understandable (relatively)
- Unambiguous (easily parsable)
- Leverage any existing actual or de facto JSON or evolving AI standards
- Platform independent
- Capable of encoding extracts separated from composite context (such as without "header" rather than content tree, image library, etc., which could be added by separate tool/pass)

Pipeline to add missing stuff to JSON



Conclusions

- DICOM has extensive result reporting encoding capability
- Getting human's to use it is challenging, beyond well established applications like ultrasound measurements
- Machines can produce and consume DICOM results; e.g., mammography CAD results are always encoded as DICOM SR
- Scope of ML/AI use cases for results are adequately covered
- All results can be encoded as DICOM SRs, segmentations or parametric map images
- Templates and codes are already defined for many applications (e.g., TID 1500 for measurements and categorical assessments)
- Modern developer-friendly approaches (JSON representation of SR) are being addressed
- Novel annotation mechanisms (e.g., vast numbers of nuclei in WSI) may require extensions to DICOM (à la MR tractography)