The
Medicine
Behind the
Image

Impact of New DICOM Objects on Handling Large Data Sets

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RADPHARM
The Imaging Core Lab

Disclosures

- David Clunie, MB.,BS., FRACR
  - *CTO, RadPharm, Inc. (formerly Princeton Radiology Pharmaceutical Research)*
  - *PixelMed Publishing - contractor for the NEMA Enhanced CT and MR test tools and images*

Acknowledgments

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Large Datasets

- Pose not just challenges due to their sheer bulk (time and cost to transfer and store)
- An interoperability challenge in terms of how the data is organized and how it should be navigated, rendered and analyzed
- A paradigm challenge in terms of new application and visualization concepts

DICOM Challenges

- Expansion of scope
  - From images to workflow, reporting, therapy …
- Evolution of modality technology
  - Speed and resolution of CT
  - Pulse sequences, gradients and field strength in MR
- Evolution of clinical applications
  - Enabled by technology
  - Enabled by contrast agents and radionuclides

DICOM Challenges

- More information
- More slices
- More complex applications on workstation

- Greater expectations of inter-functionality between different vendors modalities and workstations

1993 DICOM Image Objects

- Computed Radiography
- Computed Tomography
- Magnetic Resonance Imaging
- Nuclear Medicine
- Ultrasound
- Secondary Capture

2005 DICOM Image Objects

- Computed Radiography
- Computed Tomography
- Magnetic Resonance Imaging
- Nuclear Medicine
- Ultrasound
- Secondary Capture
- X-Ray Angiography
- X-Ray Fluoroscopy
- Positron Emission Tomography
- Radiotherapy (RT) Image
- Hardcopy Image
- Digital X-Ray
- Digital Mammography
- Intra-oral Radiography
- Visible Light Endoscopy & Video
- VL Photography & Video
- Visible Light Microscopy
- Multi-frame Secondary Capture
- Enhanced MR
- MR Spectroscopy
- Raw Data
- Enhanced CT
- Enhanced XA/XRF
- Ophthalmic Photography

2005 DICOM Non-Images

- Radiotherapy (RT) Structure Set, Plan, Dose, Treatment Record
- Waveforms (ECG, Hemodynamic, Audio)
- Grayscale, Color and Blending Presentation States
- Structured Reports
- Key Object Selection
- Mammography and Chest Computer Assisted Detection (CAD)
- Procedure Log
- Spatial Registration and Fiducials
- Stereometric Relationship

What is *Interoperability* ?

- Analogy of web server/browser:
  - Inter-connectivity - both talk TCP/IP
  - Inter-operability - both talk HTTP and HTML
  - Inter-functionality - not guaranteed:
    - “versions” of HTML poorly controlled
    - layout not constrained by HTML
    - availability of proprietary extensions (plug-ins, applets)
    - e.g., “this page only for IE version 5.0”
- Good, but not good enough for healthcare

DICOM and *Interoperability*

- For example, conformance to DICOM
  - will guarantee network connection
  - will guarantee storage of MR image:
    - from Modality to Workstation
  - will NOT guarantee (but will facilitate):
    - workstation will display image "correctly"
    - workstation can perform the analysis the user wants
  - facilitated by mandatory attributes for:
    - identification, annotation, positioning, etc.
    - *newer DICOM objects increase what is mandatory*

Greater Interfunctionality

- Some clinical scenarios for new DICOM images
  - Cardiac motion - vendor independent applications that handle spatial and temporal (cardiac cycle) CT and MR images
  - Diffusion MR - vendor independent applications that handle diffusion B value and direction
  - Multi-stack spine - vendor independent applications that recognize stacks of parallel slices through inter-vertebral disk spaces
  - Contrast and perfusion - vendor independent applications that recognize timing and phase of enhancement in CT and MR images for display and or quantitative analysis
  - Spectroscopy - vendor independent applications that process and display single-voxel, multi-voxel or multi-slice MR spectra and reference and metabolite map images

Enhanced DICOM Images

- Enhanced MR Image - Supplement 49
- Enhanced CT Image - Supplement 58
- Enhanced XA/XRF - Supplement 83
- Enhanced PET - work in progress

Multi-frame Organization of New CT & MR Images

- Original objects
  - Series organization + single frame + a few attributes + terms
- Enhanced objects
  - Multiple frames in a single object
  - Many more standard mandatory attributes
  - Many more standard terms
- Enables
  - Greater interfunctionality of applications
  - More effective hanging protocols
  - Reduced dependence on private attributes

Technique Attributes & Terms

	CT		MR	
SOP Class	Original	Enhanced	Original	Enhanced
Attributes (Mandatory)	18 (0)	41 (39)	44 (2)	103 (94)
Terms (Enumerated)	4 (2)	86 (18)	38 (9)	228 (47)

CT Image Type Value 3

- Original SOP Classes
  - AXIAL or LOCALIZER
- Enhanced SOP Classes
  - Common to CT and MR
    - ANGIO, FLUOROSCOPY, LOCALIZER, MOTION, PERFUSION, PRE_CONTRAST, POST_CONTRAST, REST, STRESS, VOLUME
  - CT-specific
    - ATTENUATION, CARDIAC, CARDIAC_GATED, REFERENCE

MR Acquisition Contrast

- Original SOP Classes
  - Guess from echo and repetition time, etc.
- Enhanced SOP Classes
  - New mandatory frame level attribute
  - Acquisition Contrast
    - DIFFUSION, FLOW_ENCODED, FLUID_ATTENUATED, PERFUSION, PROTON_DENSITY, STIR, TAGGING, T1, T2, T2_STAR, TOF, UNKNOWN

Geometry unchanged

- Same as original SOP Classes
- Image Position and Orientation (Patient)
- Still need to compute AXIAL, SAGITTAL or CORONAL from orientation vector
- Still need to compute edge labels (A/P etc) from orientation vector
- May still need to compare orientation vectors to determine if slices are parallel - stacks will be discussed later

Enhanced Contrast/Bolus

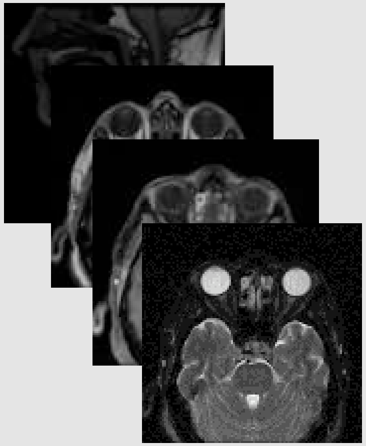
- Original SOP Classes
  - Plain text description
  - Difficult to determine presence/absence
    - E.g., description value of "None"
  - Single agent (did not distinguish oral/iv)
  - Codes optional and never used
- Enhanced SOP Classes
  - Mandatory codes only
  - Multiple items with separate coded routes & timing
  - Presence or absence per-frame can be described

Coded anatomic regions

- Original SOP Classes
  - Incomplete list of optional defined terms
  - Optional laterality
- Enhanced SOP Classes
  - Mandatory coded anatomic region
  - Comprehensive & appropriate list of codes
  - Mandatory laterality
  - Per-frame or for entire object

Hanging protocol rule impact

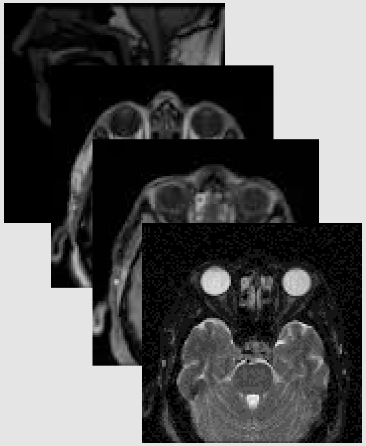
T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD



Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1



Hanging protocol rule impact

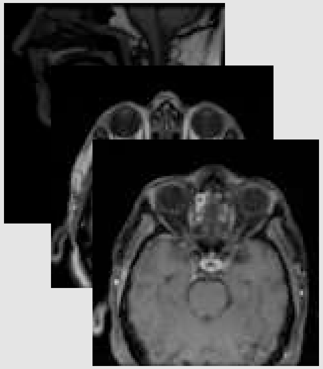
T1 SAG PRE GD

T1 AXIAL PRE GD

T2 AXIAL

T1 AXIAL POST GD

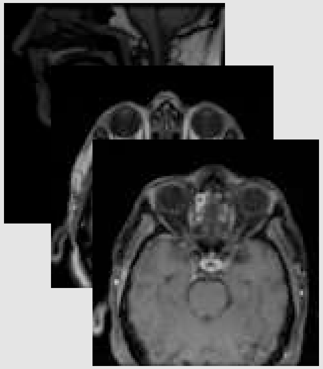
Acquisition Contrast = T1



Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 0\1\0\0\0\-1



Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 0\1\0\0\0\-1

Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 0\1\0\0\0\-1
Contrast Agent #1
Administered = NO
Route = (G-D101,SNM3, “IV”)
Ingredient = (C-17800,SRT, “Gd”)

Hanging protocol rule impact

T1 AXIAL PRE GD

T2 AXIAL

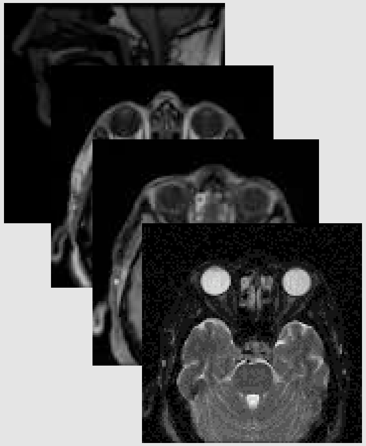
T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 0\1\0\0\0\-1
Contrast Agent #1
Administered = NO
Route = (G-D101,SNM3, “IV”)
Ingredient = (C-17800,SRT, “Gd”)

Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 1\0\0\0\1\0
Contrast Agent #1
    Administered = NO
    Route = (G-D101,SNM3, “IV”)
    Ingredient = (C-17800,SRT, “Gd”)



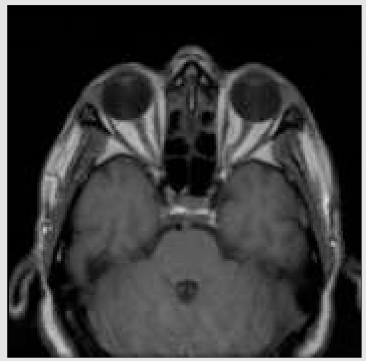
Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 1\0\0\0\1\0
Contrast Agent #1
  Administered = NO
  Route = (G-D101,SNM3, "IV")
  Ingredient = (C-17800,SRT, "Gd")

Hanging protocol rule impact

T1 SAG PRE GD



T2 AXIAL

T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 1\0\0\0\1\0
Contrast Agent #1

Administered = NO
Route = (G-D101,SNM3, “IV”)
Ingredient = (C-17800,SRT, “Gd”)

Hanging protocol rule impact

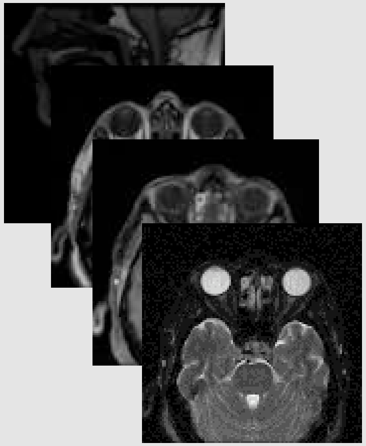
T1 SAG PRE GD

T1 AXIAL PRE GD

T2 AXIAL

T1 AXIAL POST GD

Acquisition Contrast = T2
Image Orientation ≈ 1\0\0\0\1\0



Hanging protocol rule impact

T1 SAG PRE GD

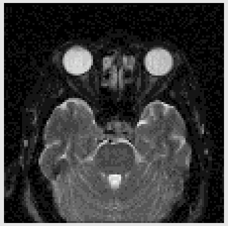
T1 AXIAL PRE GD

T2 AXIAL

T1 AXIAL POST GD

Acquisition Contrast = T2

Image Orientation ≈ 1\0\0\0\1\0



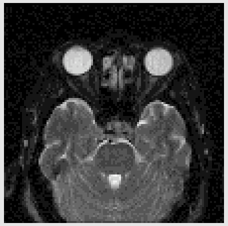
Hanging protocol rule impact

T1 SAG PRE GD

T1 AXIAL PRE GD

T1 AXIAL POST GD

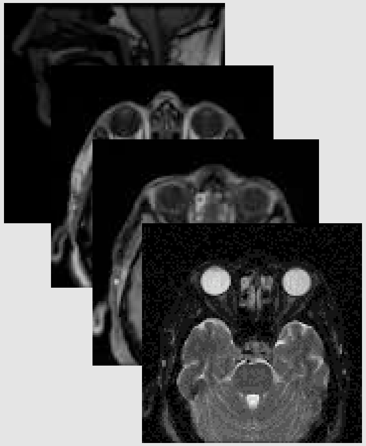
Acquisition Contrast = T2
Image Orientation ≈ 1\0\0\0\1\0



Hanging protocol rule impact

T1 SAG PRE GD	T1 AXIAL PRE GD	T2 AXIAL	T1 AXIAL POST GD

Acquisition Contrast = T1
Image Orientation ≈ 1\0\0\0\1\0
Contrast Agent #1
- Administered = YES
- Route = (G-D101,SNM3, “IV”)
- Ingredient = (C-17800,SRT, “Gd”)

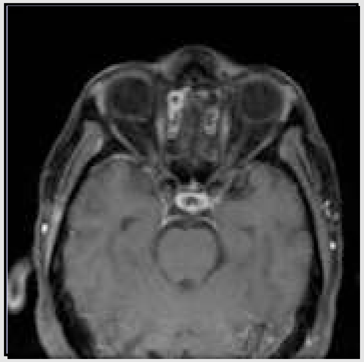


Hanging protocol rule impact

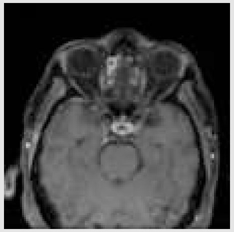
T1 SAG PRE GD

T1 AXIAL PRE GD

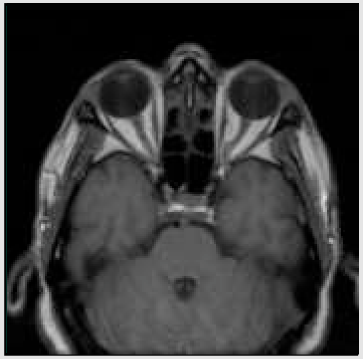
T2 AXIAL

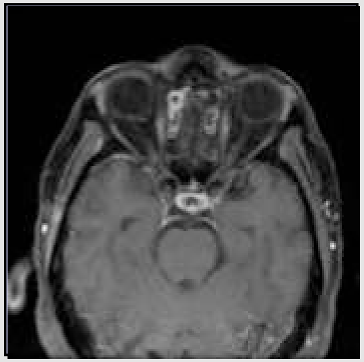
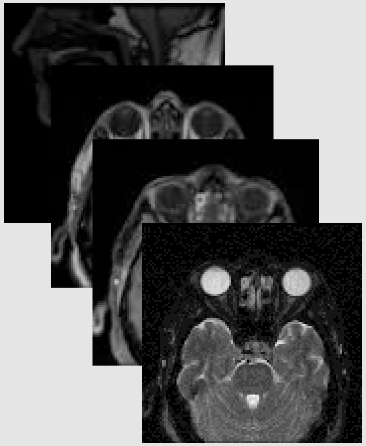


Acquisition Contrast = T1
Image Orientation ≈ 1\0\0\0\1\0
Contrast Agent #1
Administered = YES
Route = (G-D101,SNM3, “IV”)
Ingredient = (C-17800,SRT, “Gd”)

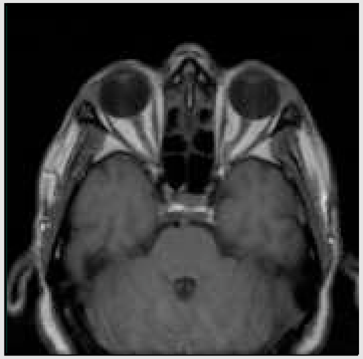


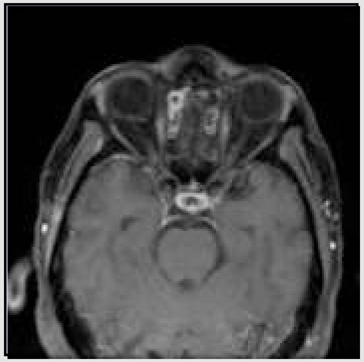
Hanging protocol rule impact

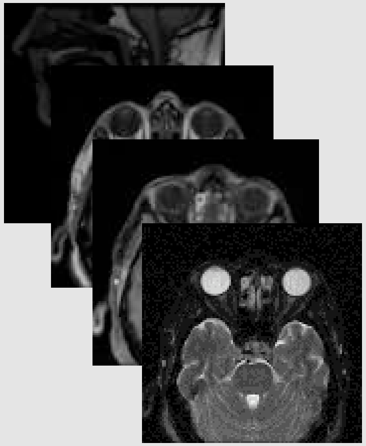



Hanging protocol rule impact



Same rules, independent of whether:
- one single multi-frame image
- one multi-frame image per acquisition
- one slice per single frame image
- one series or multiple



Hanging protocol support

- A productivity advantage of the CT and MR objects
- Should not have to tailor hanging protocol rules to specific vendors or devices or versions
- Reliable and standard information
  - Mandatory and standard places (attributes)
  - Mandatory and standard values
- As technology evolves, yet more standard values will be added to the standard
- Eliminate dependence on site configured Series Number or Series Description, whether from acquisition protocol or entered by operator

Dynamic Contrast

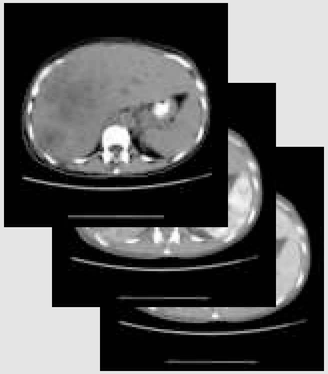
- Conventional hanging protocols are rarely sophisticated enough to recognize multiple phases of contrast enhancement, e.g., during CT of liver
- Old DICOM objects have no standard information about contrast phase
- New objects name phases of contrast administration for each frame
  - PRE_CONTRAST, POST_CONTRAST, IMMEDIATE, DYNAMIC, STEADY_STATE, DELAYED, ARTERIAL, CAPILLARY, VENOUS, PORTAL_VENOUS

Hanging protocol rule impact - dynamic contrast

PRE

ARTERIAL

DELAY

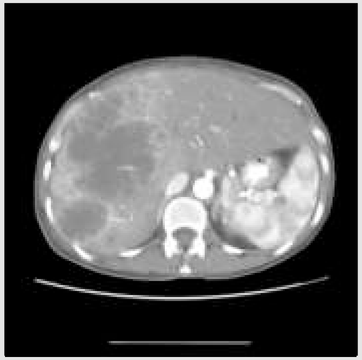


Hanging protocol rule impact - dynamic contrast

ARTERIAL

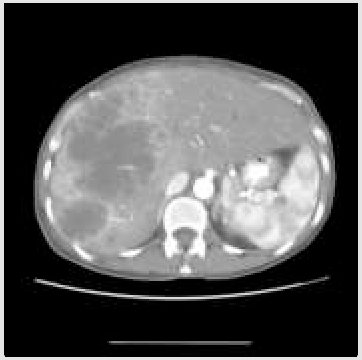
DELAY

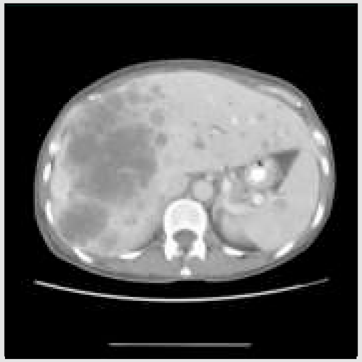
Hanging protocol rule impact - dynamic contrast

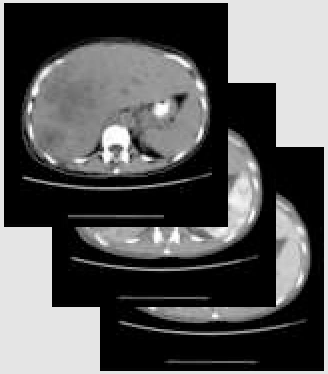


DELAY

Hanging protocol rule impact - dynamic contrast







DICOM Hanging Protocols

- Foregoing describes how to use attributes in Enhanced CT and MR objects to improve any hanging protocol engine, including proprietary software
- DICOM also has recently defined Hanging Protocol SOP Classes
- To store hanging protocol rules centrally and exchange them between different systems
- Not a pre-requisite for making use of the enhanced image objects to improve hanging

Beyond simple image display

- Visualization
- Temporal change
  - Short term
  - Long term
- Quantitation and Analysis

Visualization

- MPR
- 3D surface and volume rendering
- MIP for angiography

Temporal change

- Short term
  - Perfusion
  - Cardiac cycle
- Long term
  - Change between studies

Quantitation and analysis

- Processing of multiple frames
- Measurement of morphology
  - Linear distance
  - Volumetrics
- Measurement of physiology and function
  - Perfusion and diffusion
  - fMRI
- Registration
  - between acquisitions, studies & modalities

Supporting advanced applications

- Original SOP Classes
  - Minimal standard acquisition information
  - Imprecisely defined timing information
  - No organizational structures except Series
  - Quantitation mixed with grayscale pipeline
- Enhanced SOP Classes
  - Detailed descriptions of advanced acquisition protocols
  - Accurate and well-defined timing information
  - Pre-defined organizational structures
  - Quantitative values and color support

Enhanced MR attribute types

- Separate gradient and RF echo train lengths
- Out-of-plane phase encoding steps
- Flow compensation
- Spectrally selective excitation & suppression
- Blood signal nulling
- Tagging
- Diffusion values and direction
- Spatial saturation slabs
- Velocity encoding
- Chemical shift imaging (metabolite maps)

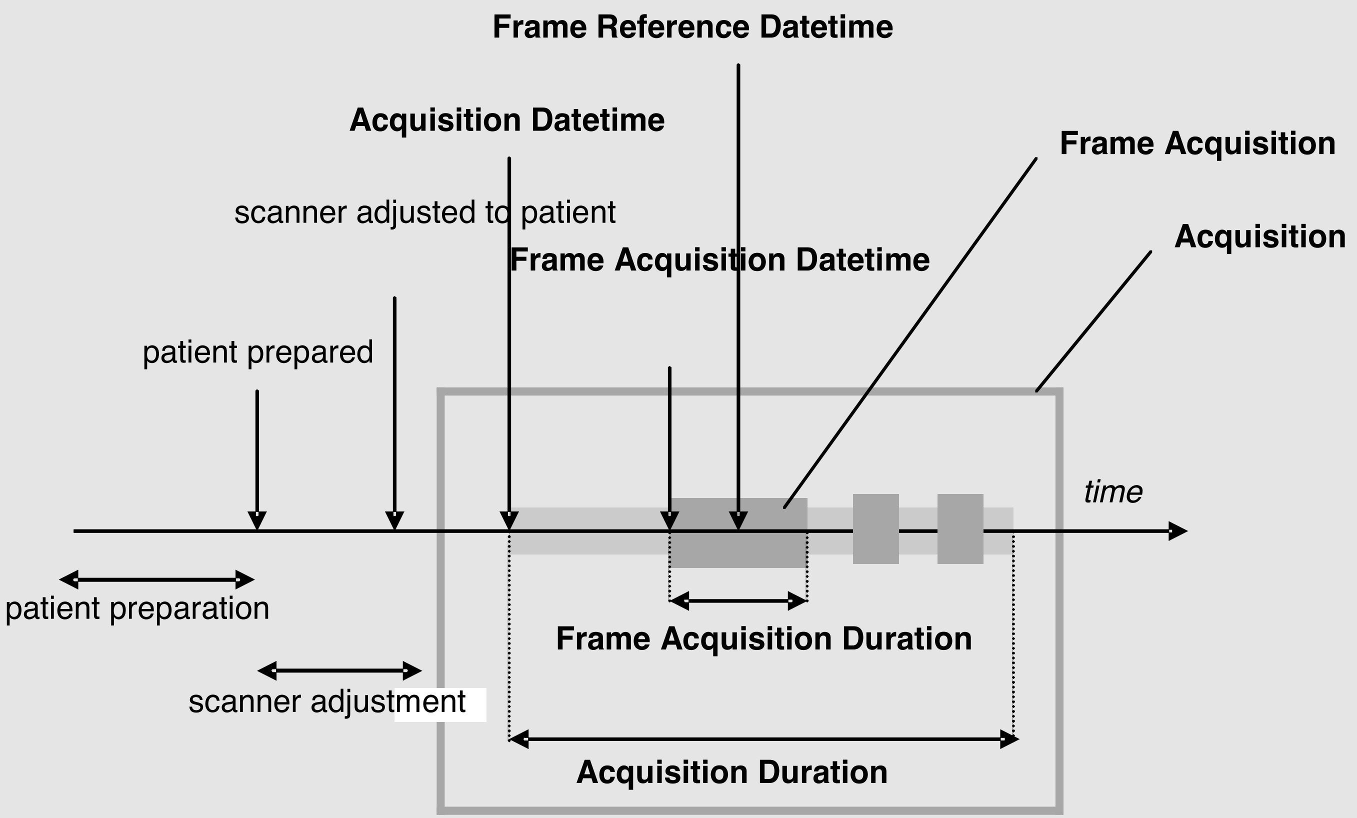
Enhanced CT attribute types

- Acquisition type
- Constant volume and fluoroscopy
- Single and total collimation width (for multiple detectors)
- Table speed, feed and spiral pitch factor
- Reconstruction geometry and convolution kernel
- Exposure information, dose savings and $CTDI_{Vol}$

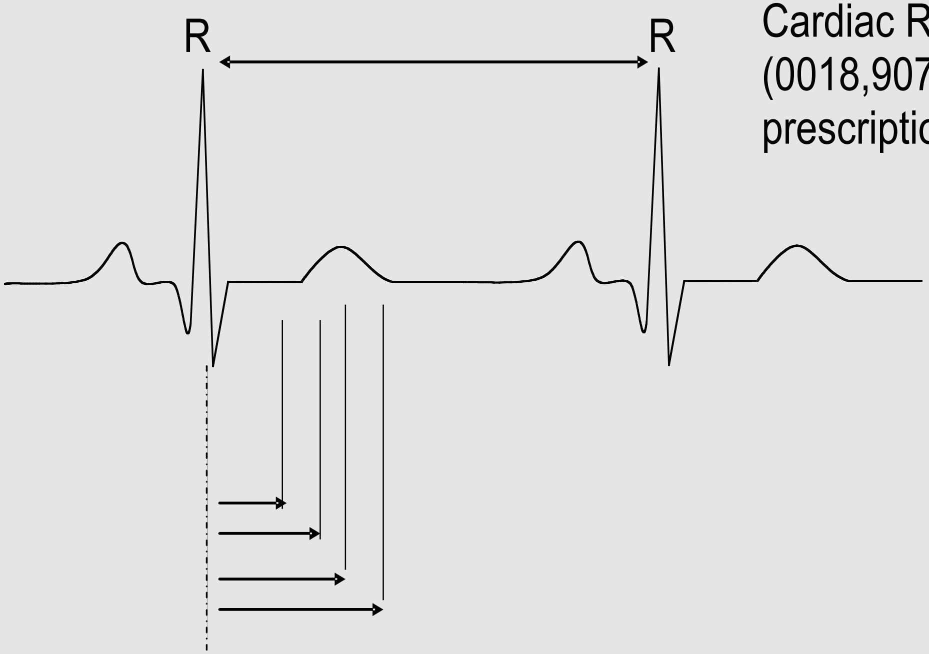
Timing information

- Original SOP Classes
  - Inconsistent use of Content (Image) and Acquisition Time
  - Contrast timing information never used
- Enhanced SOP Classes
  - Unambiguous definition of acquisition timing
  - Explicit relationships with contrast & cardiac timing

Timing information



Timing information



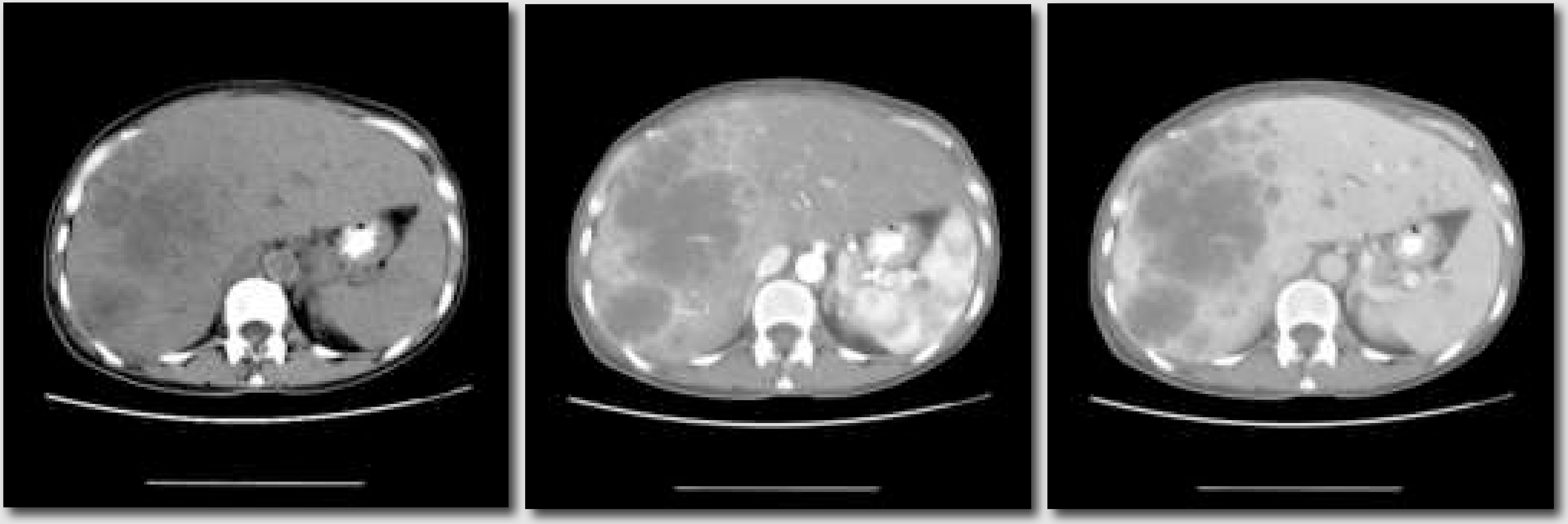
Cardiac R-R Interval Specified (0018,9070): R-R interval in ms at prescription time.

Trigger Delay Time (0020,9153): prescribed delay in ms after latest R-peak.

Contrast timing

- Numeric - Administration Profile
  - Allows for multiple contrast agents and phases
  - Volume, start/stop times, rates and duration
- Categorical
  - Can be specified on a per-frame basis
  - Administered - YES/NO
  - Detected - YES/NO
  - Phase - PRE_CONTRAST, POST_CONTRAST, IMMEDIATE, DYNAMIC, STEADY_STATE, DELAYED, ARTERIAL, CAPILLARY, VENOUS, PORTAL_VENOUS

Contrast timing - phase for hanging protocols



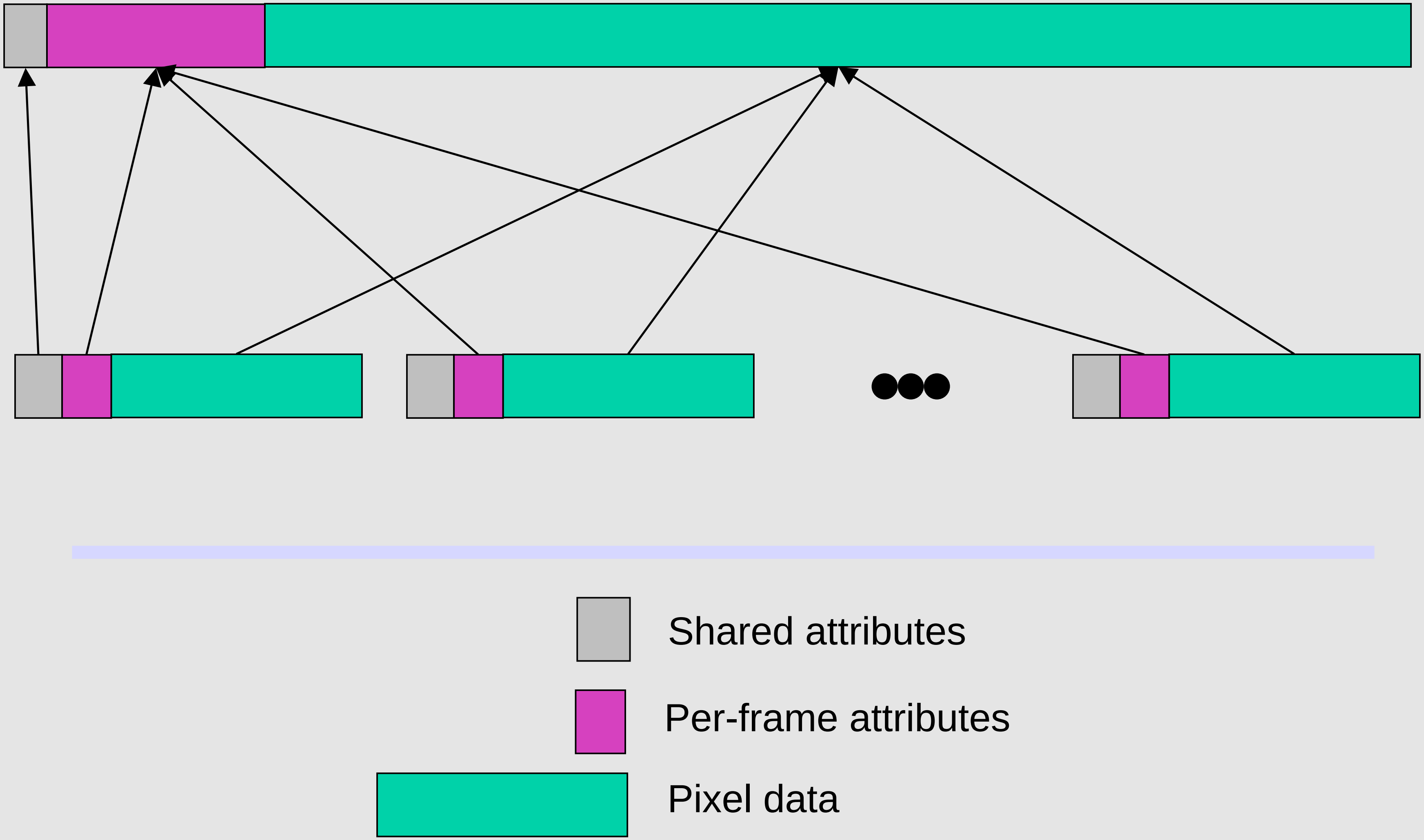
Organizational Features

- Multi-frame pixel data
- Shared and per-frame functional groups
  - Each functional group contains attributes that likely vary as a group, e.g. Pixel Measures, Plane Orientation, Velocity Encoding, etc.
  - Compact & makes explicit what doesn’t change
- Dimensions
  - *a priori* hints as to how the frames are organized
  - Specify intended order of traversal, such as space, then time (e.g., for cardiac cine loops)
- Stacks
  - Groups of spatially-related slices, repeatable
- Temporal positions

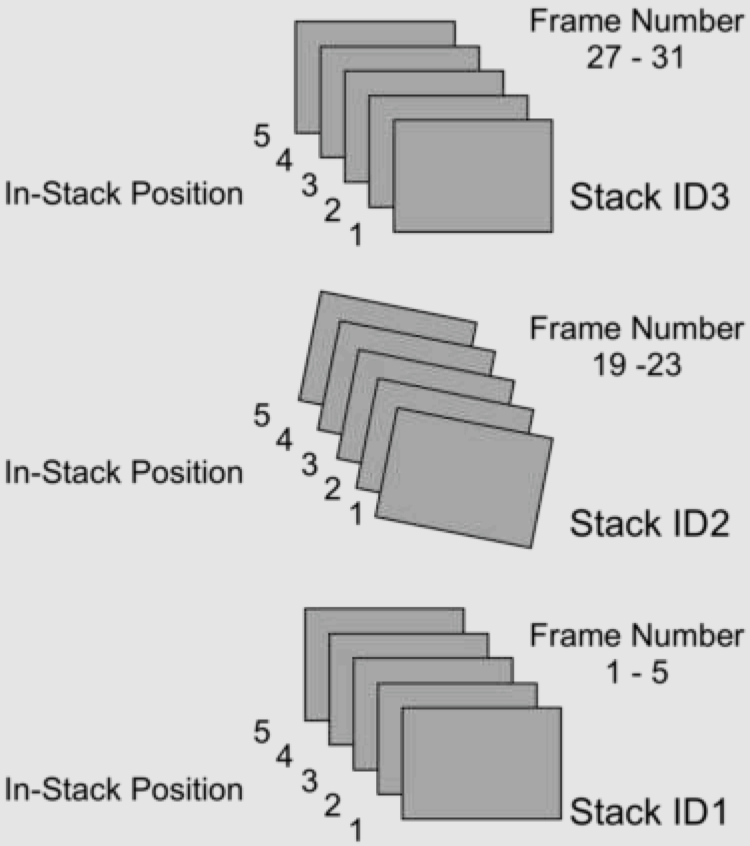
Organization of Data

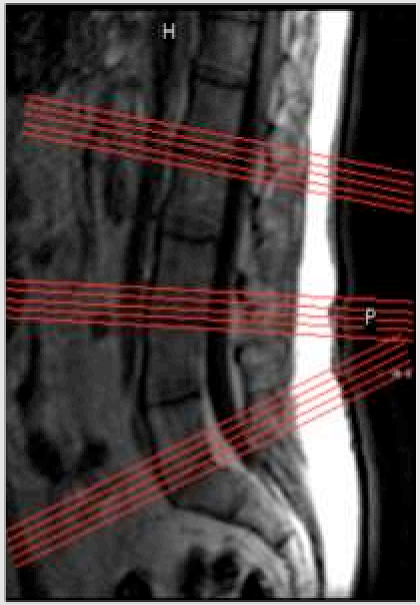
- Goal is to reduce the work that the receiving application has to do to "figure out"
  - How the data is organized
  - Why it is organized that way
- Without preventing use of the data in unanticipated ways
  - E.g. 3D on a dataset not intended as a volume
- Two levels
  - The detailed shared & per-frame attributes
  - The overall dimensions, stacks and temporal positions

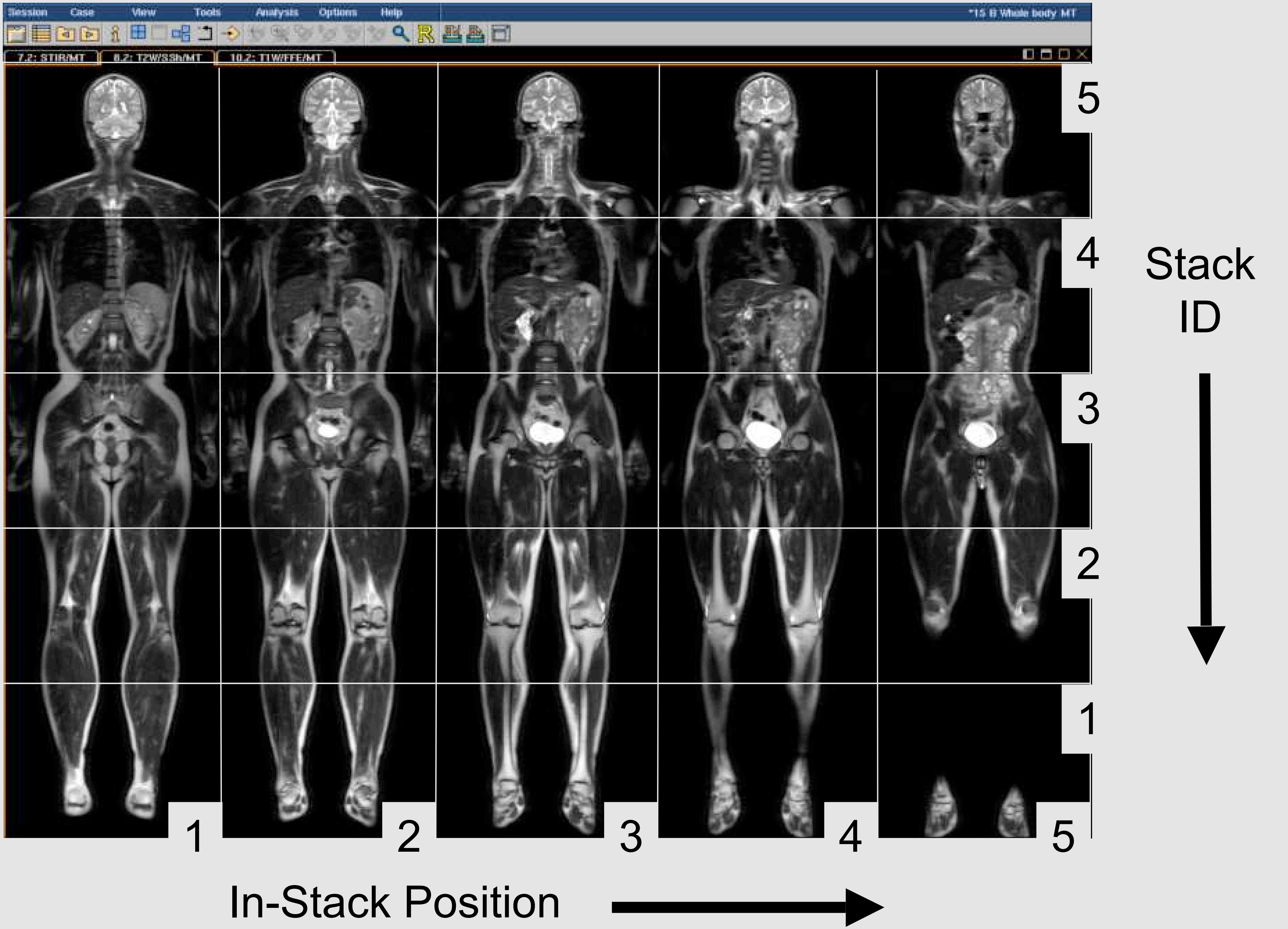
Multi-frame Functional Groups



Stacks


Frame Number
27 - 31
5
4
3
2
1
In-Stack Position
Stack ID3
Frame Number
19 -23
5
4
3
2
1
In-Stack Position
Stack ID2
Frame Number
1 - 5
5
4
3
2
1
In-Stack Position
Stack ID1


H
P

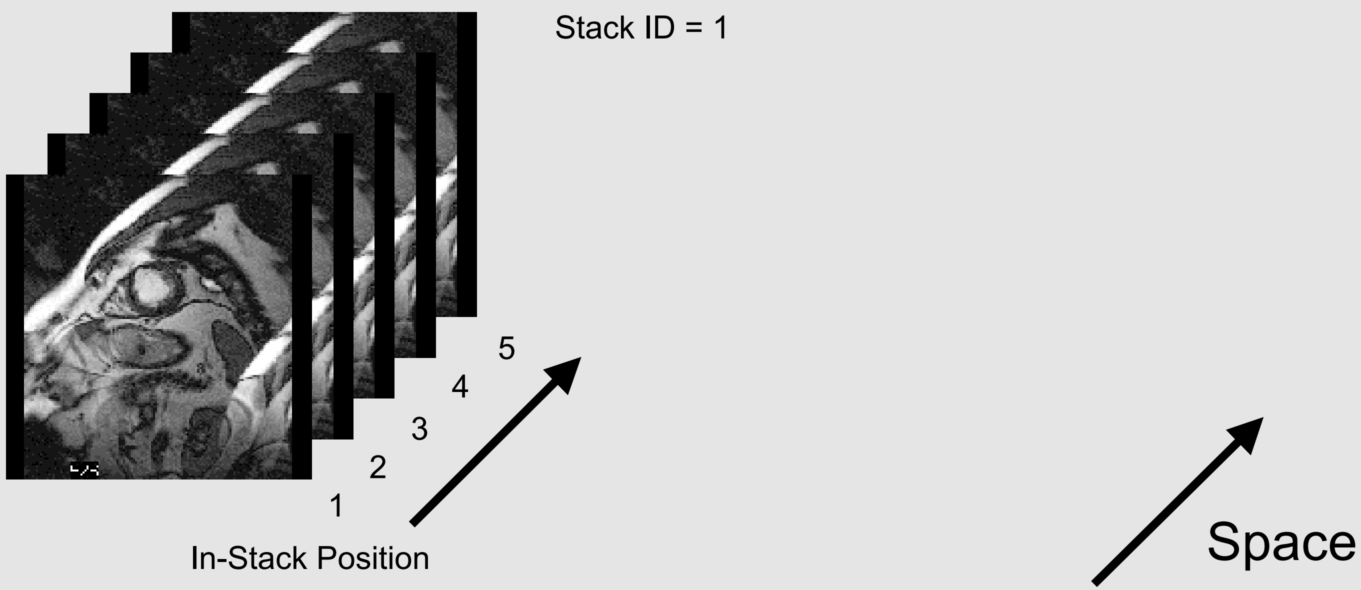


Session
Case
View
Tools
Analysis
Options
Help
*15 B Whole body MT
7.2: STIR/MT
8.2: T2W/SSh/MT
10.2: T1W/FFE/MT
5
4
3
2
1
Stack ID
1
2
3
4
5
In-Stack Position

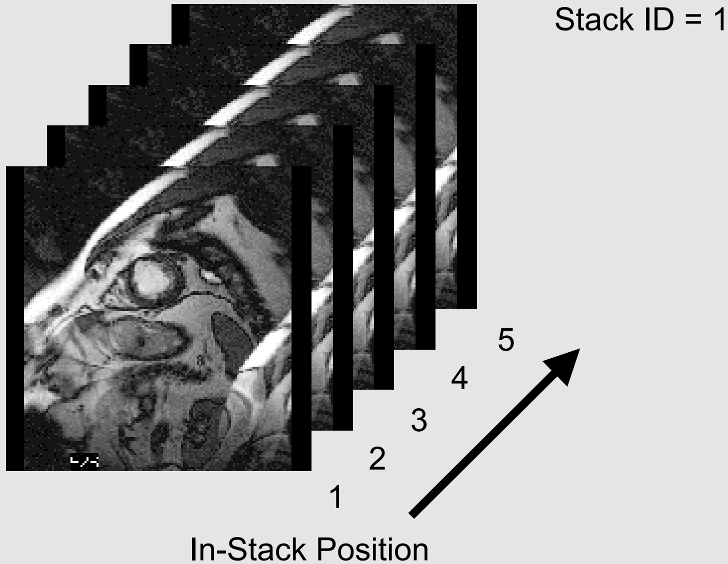
Dimensions

Start with a dimension of space.

A set of contiguous slices through the heart.

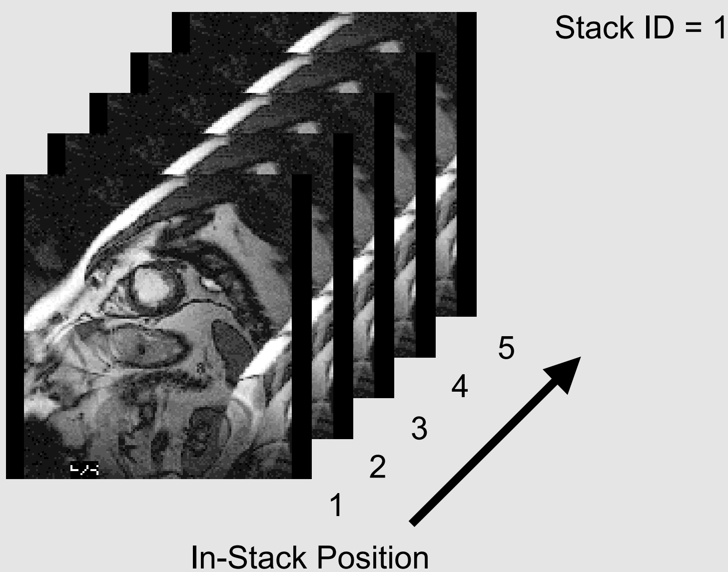


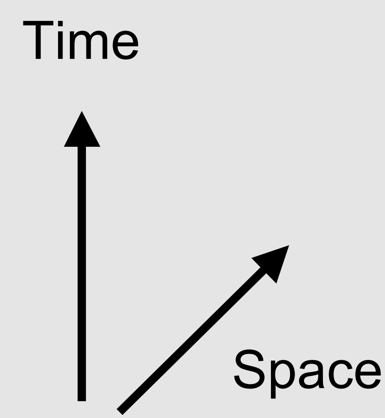
Trigger Delay Time	Temporal Position Index
48 ms	2
0 ms	1

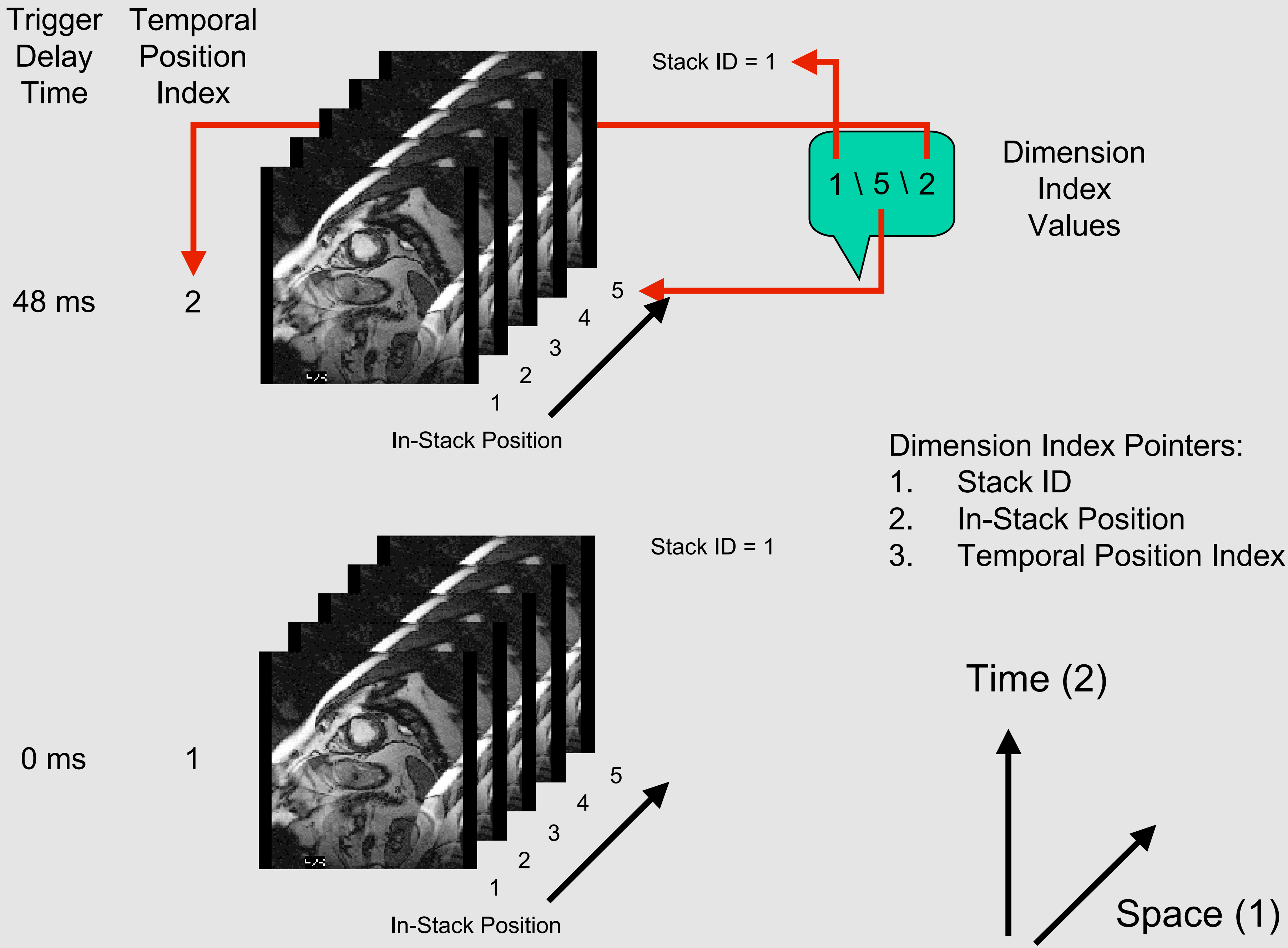


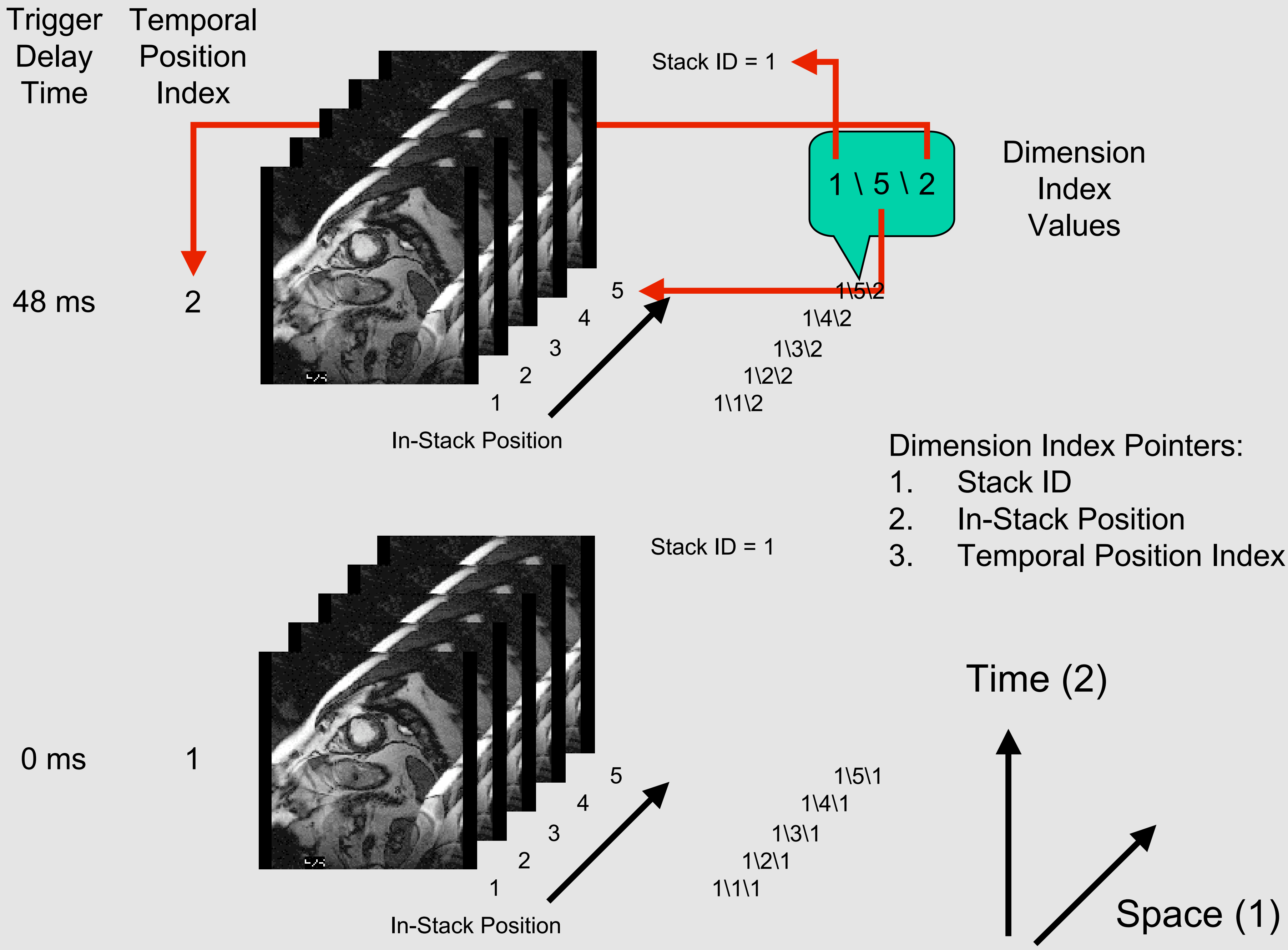
Add dimension of time (delay time from R-wave).

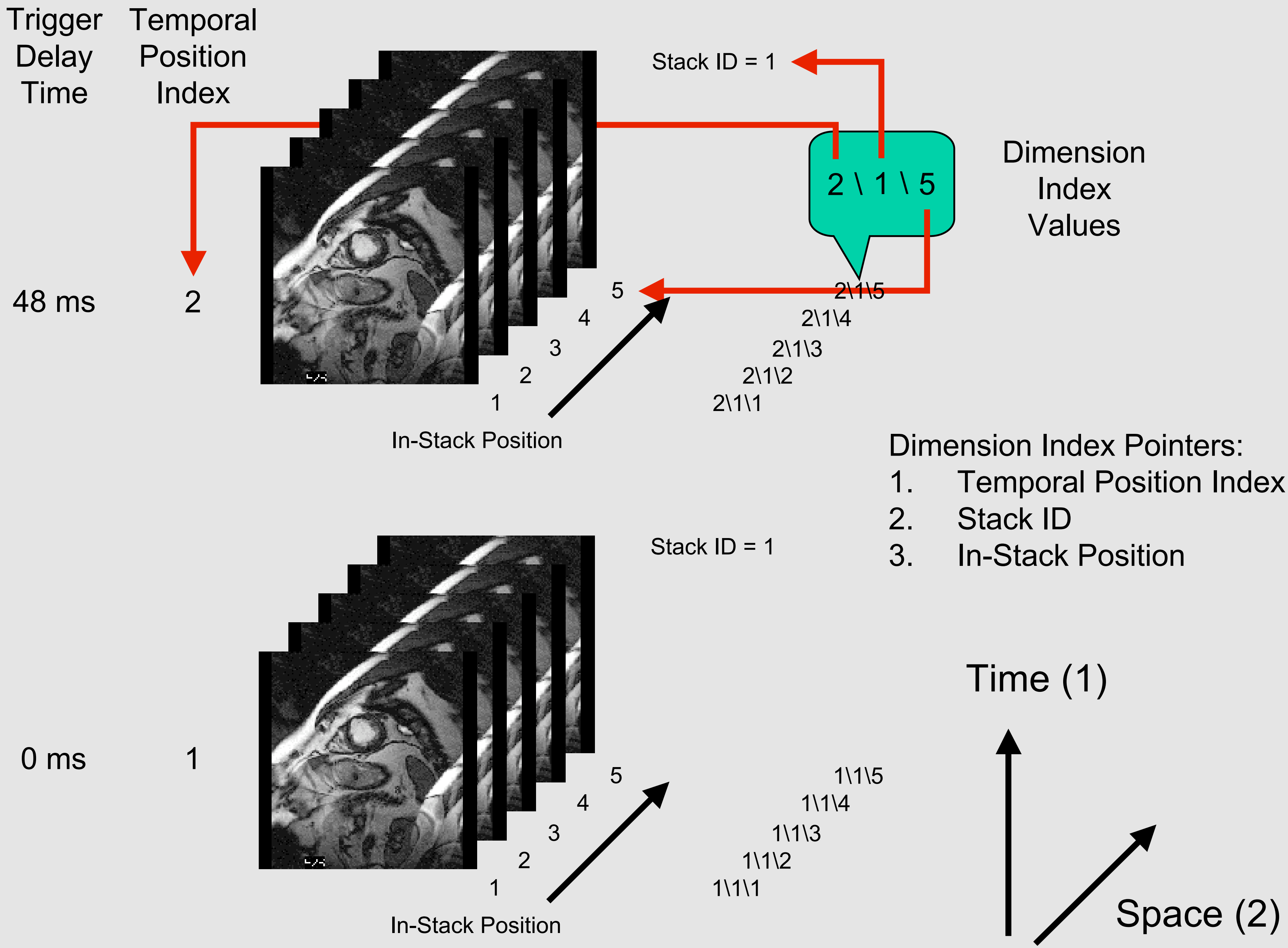
Sets of contiguous slices throughout cardiac cycle.



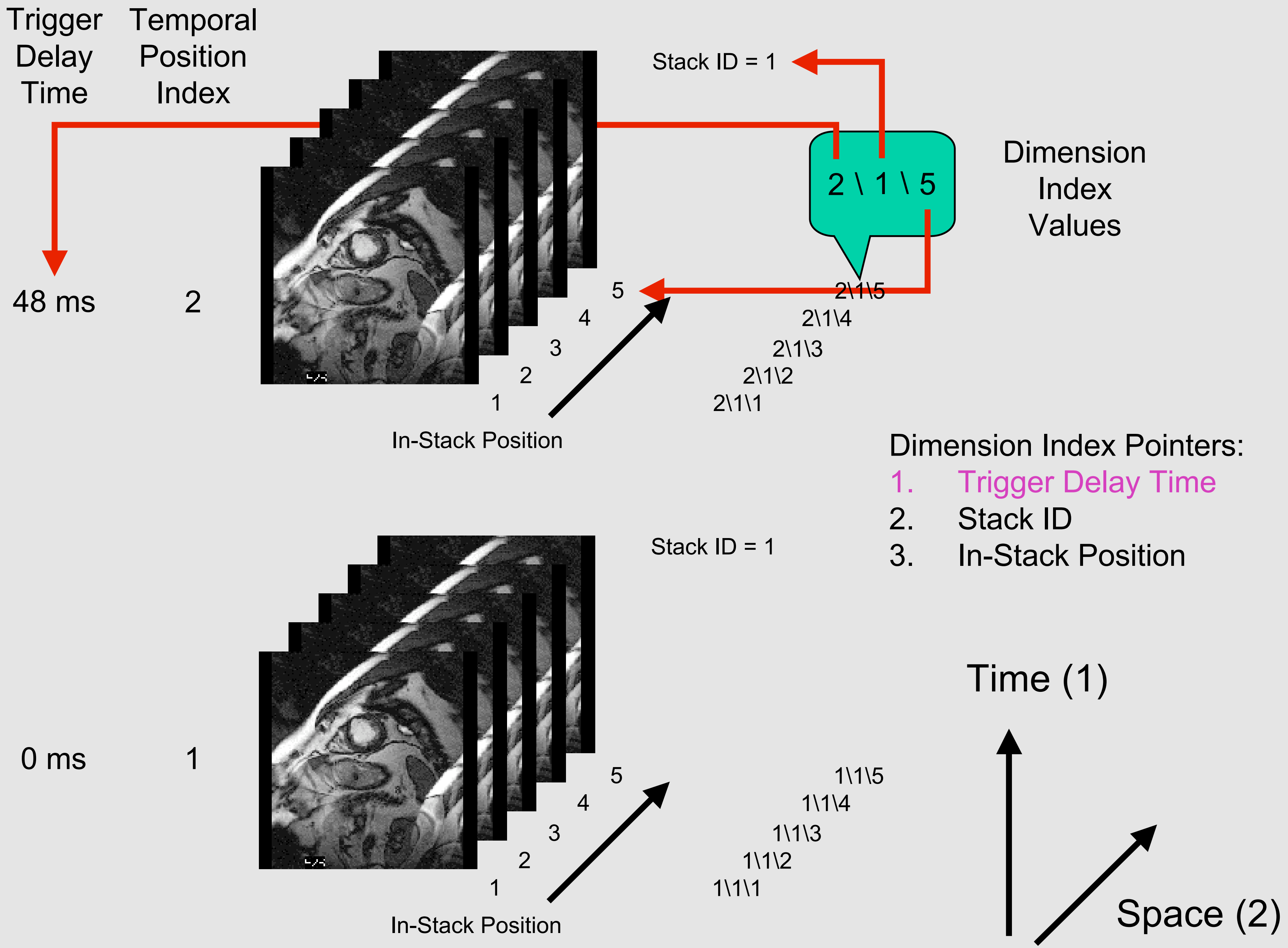



Trigger Delay Time
Temporal Position Index
Stack ID = 1
1 \ 5 \ 2
Dimension Index Values
48 ms
2
5
4
3
2
1
In-Stack Position
Dimension Index Pointers:
1. Stack ID
2. In-Stack Position
3. Temporal Position Index
Stack ID = 1
0 ms
1
5
4
3
2
1
In-Stack Position
Time (2)
Space (1)


Trigger Delay Time
Temporal 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)



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


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

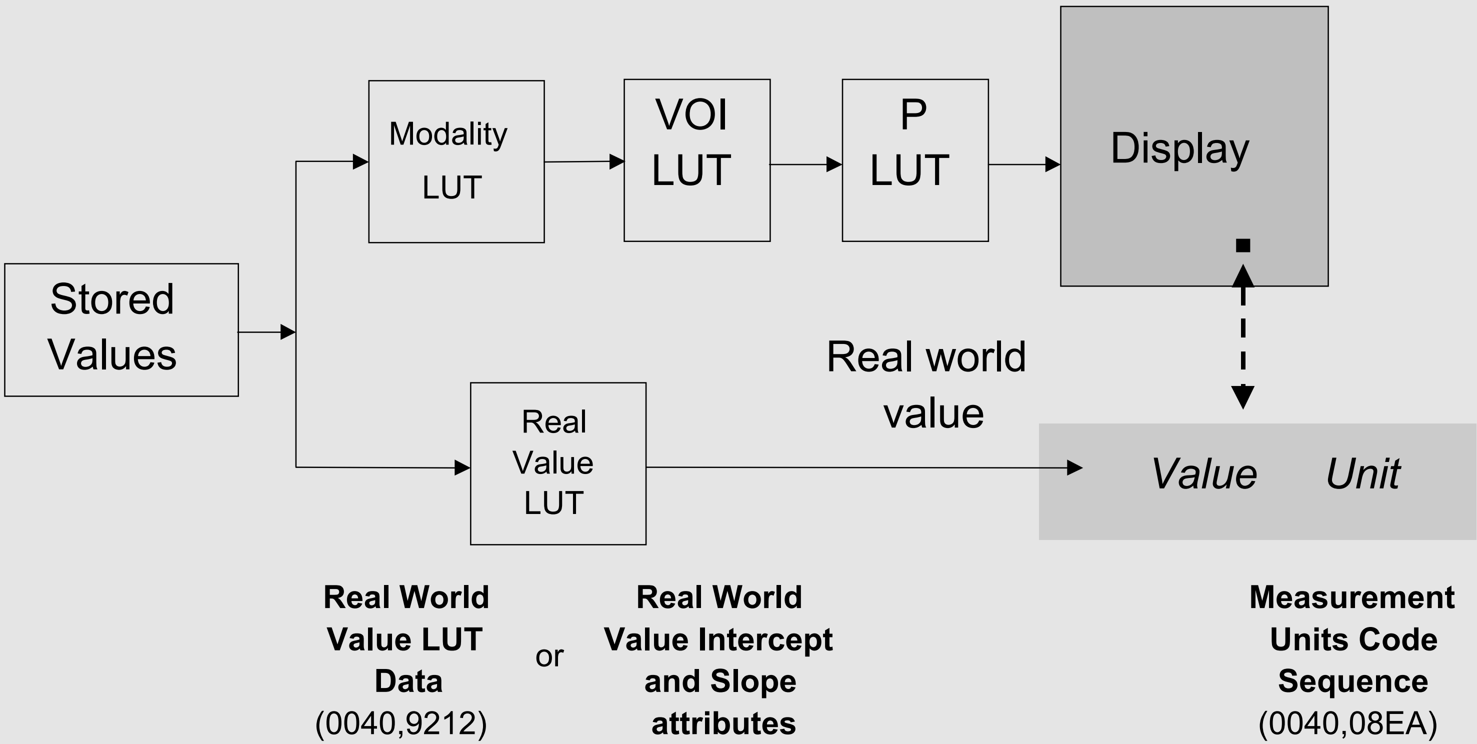
Dimension features

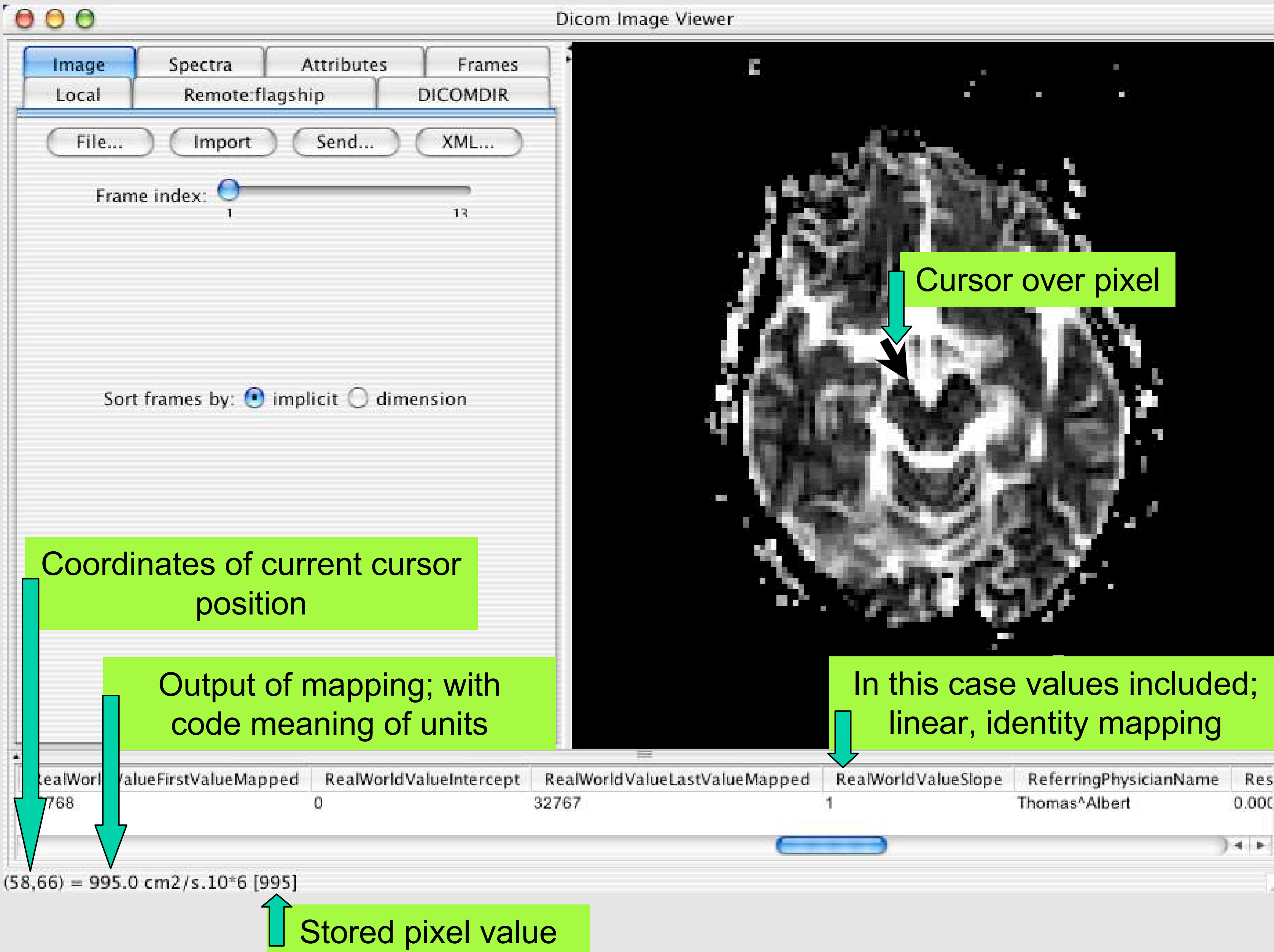
- Description of dimensions separate from their indices
  - Dimensions are described once
  - Indices within dimensions are encoded per-frame
- Receiving application only needs to follow the index values
  - Does NOT need to select or sort by attribute value
  - Dimensions can be entire functional groups
  - Dimensions can be private attributes or functional groups

Dimension applications

- Selection of sort order for simple viewing
- Partitioning of frames for hanging
- Selection of frames that constitute a
  - volume in space
  - temporal sequence
  - contrast administration phase
  - physiological parameter, e.g. diffusion b value

Quantitation of pixel values - Real World Values

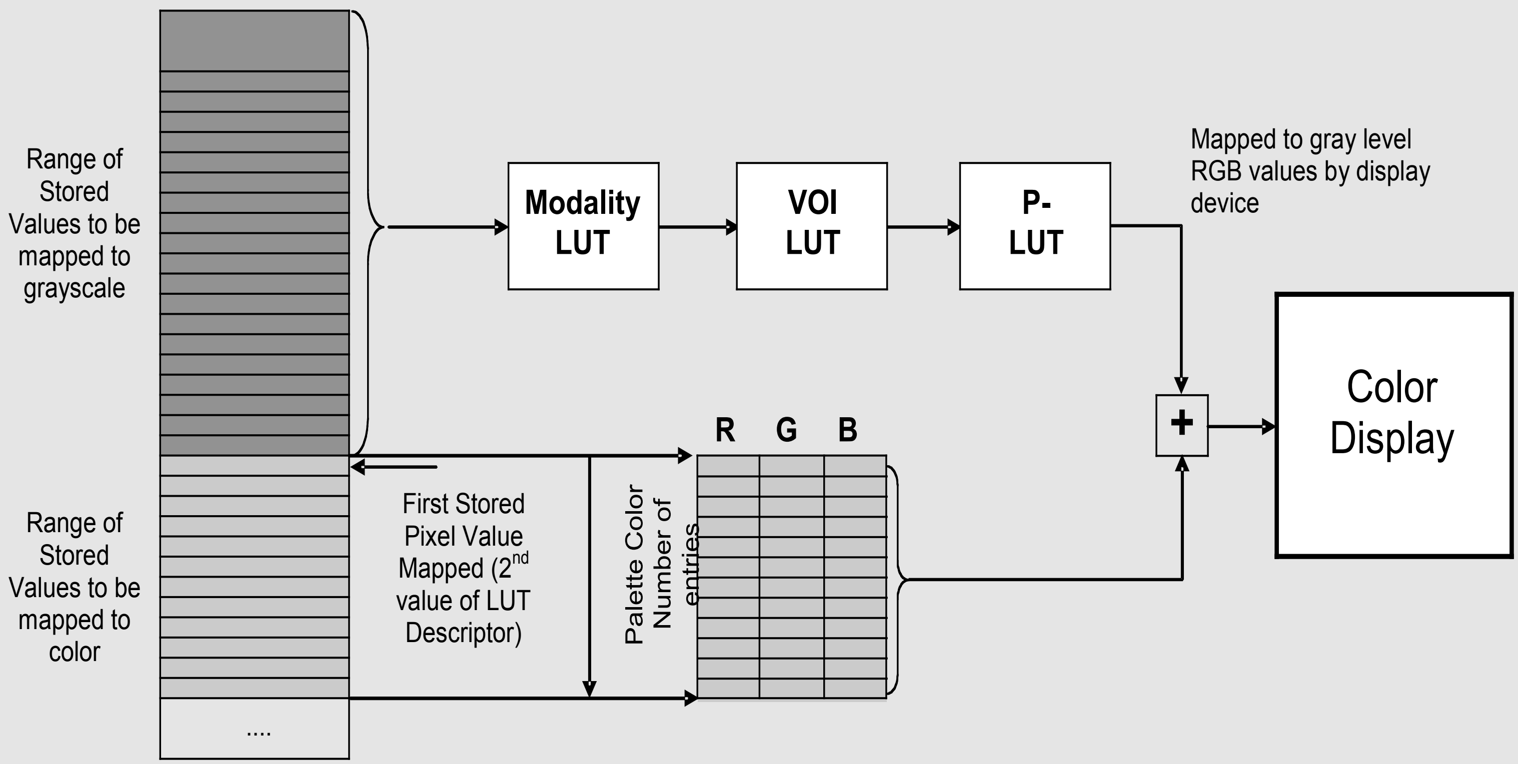



Dicom Image Viewer
Image
Spectra
Attributes
Frames
Local
Remote:flagship
DICOMDIR
File...
Import
Send...
XML...
Frame index:
1
13
Sort frames by:
implicit
dimension
Cursor over pixel
Coordinates of current cursor position
Output of mapping; with code meaning of units
In this case values included; linear, identity mapping
ValueFirstValueMapped
RealWorldValueIntercept
RealWorldValueLastValueMapped
RealWorldValueSlope
ReferringPhysicianName
768
0
32767
1
Thomas^Albert
(58,66) = 995.0 cm2/s.10*6 [995]
Stored pixel value

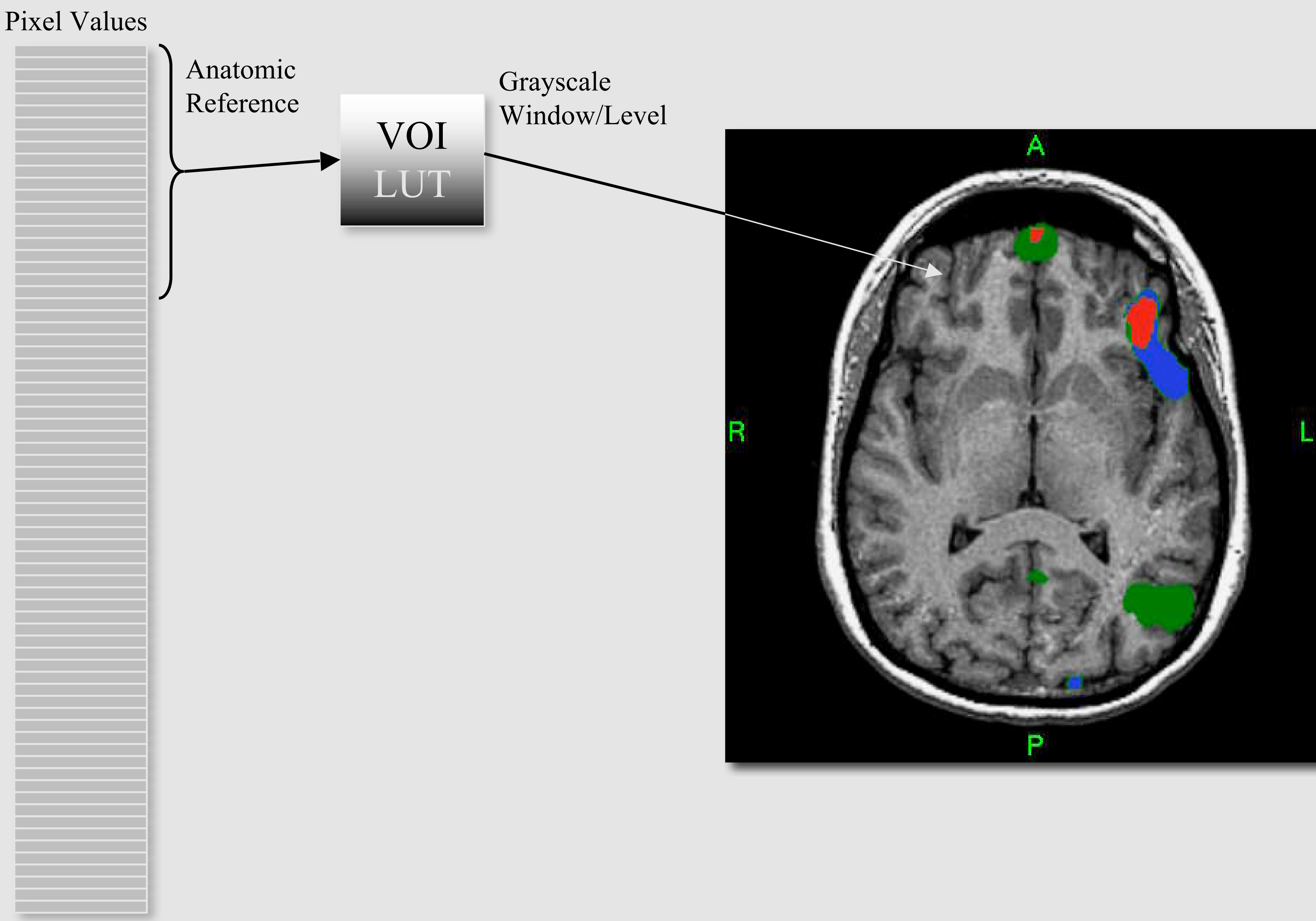
Real World Values

- Separate from grayscale pipeline
- May be non-linear
- May be multiple mappings into different units

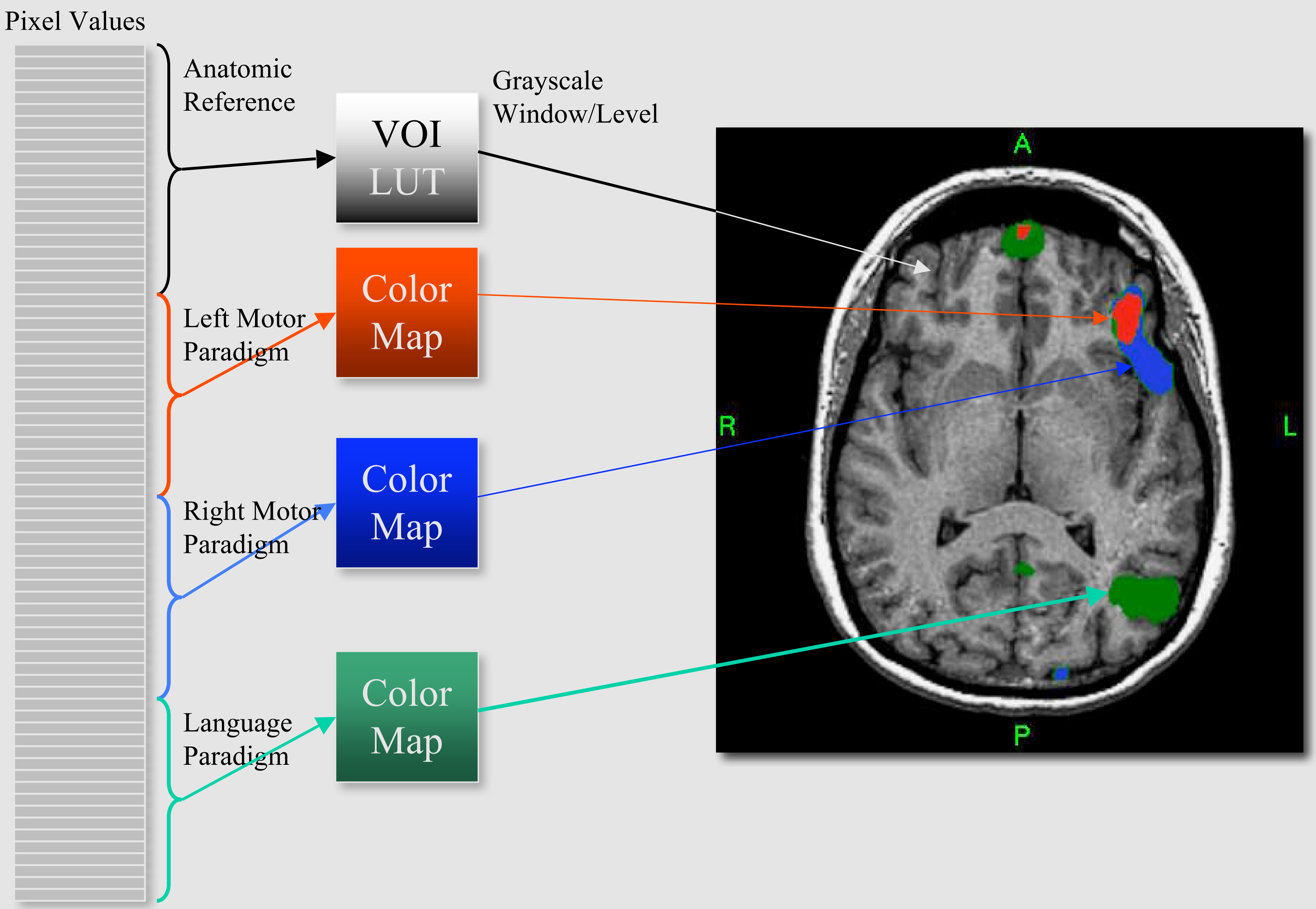
Color display of functional data



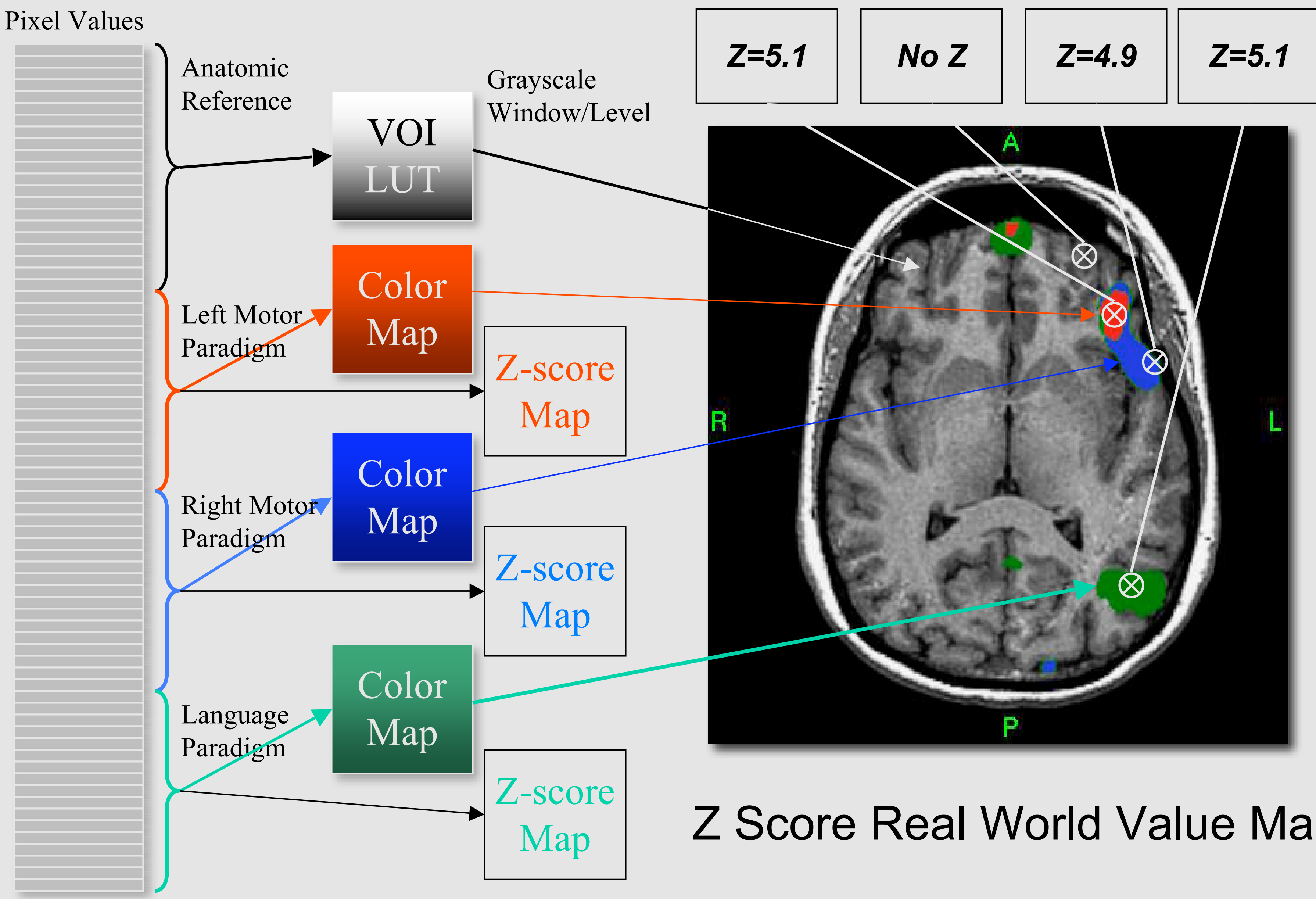
Color by functional paradigm



Color by functional paradigm

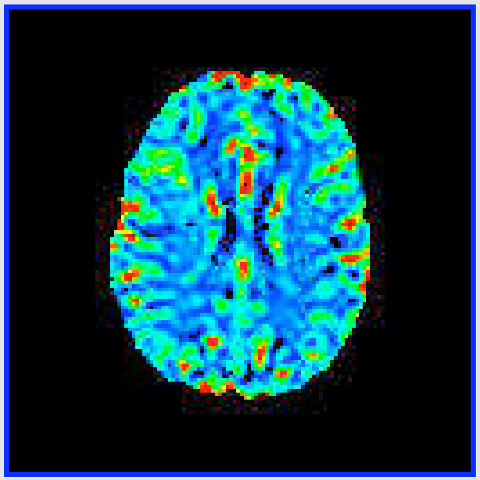


Color by functional paradigm

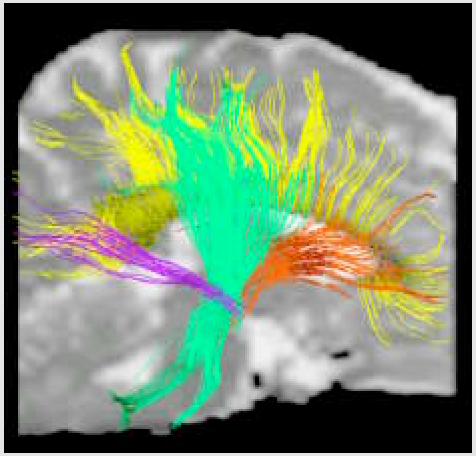


Z Score Real World Value Map

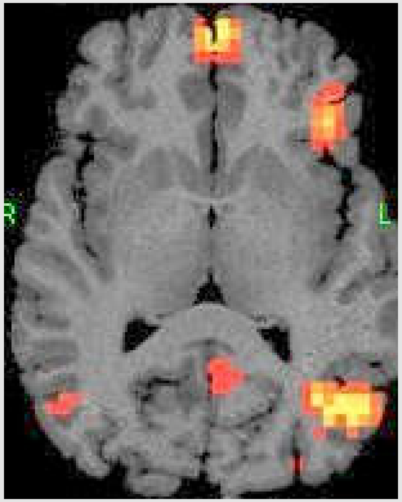
Color information applications



Perfusion



Diffusion

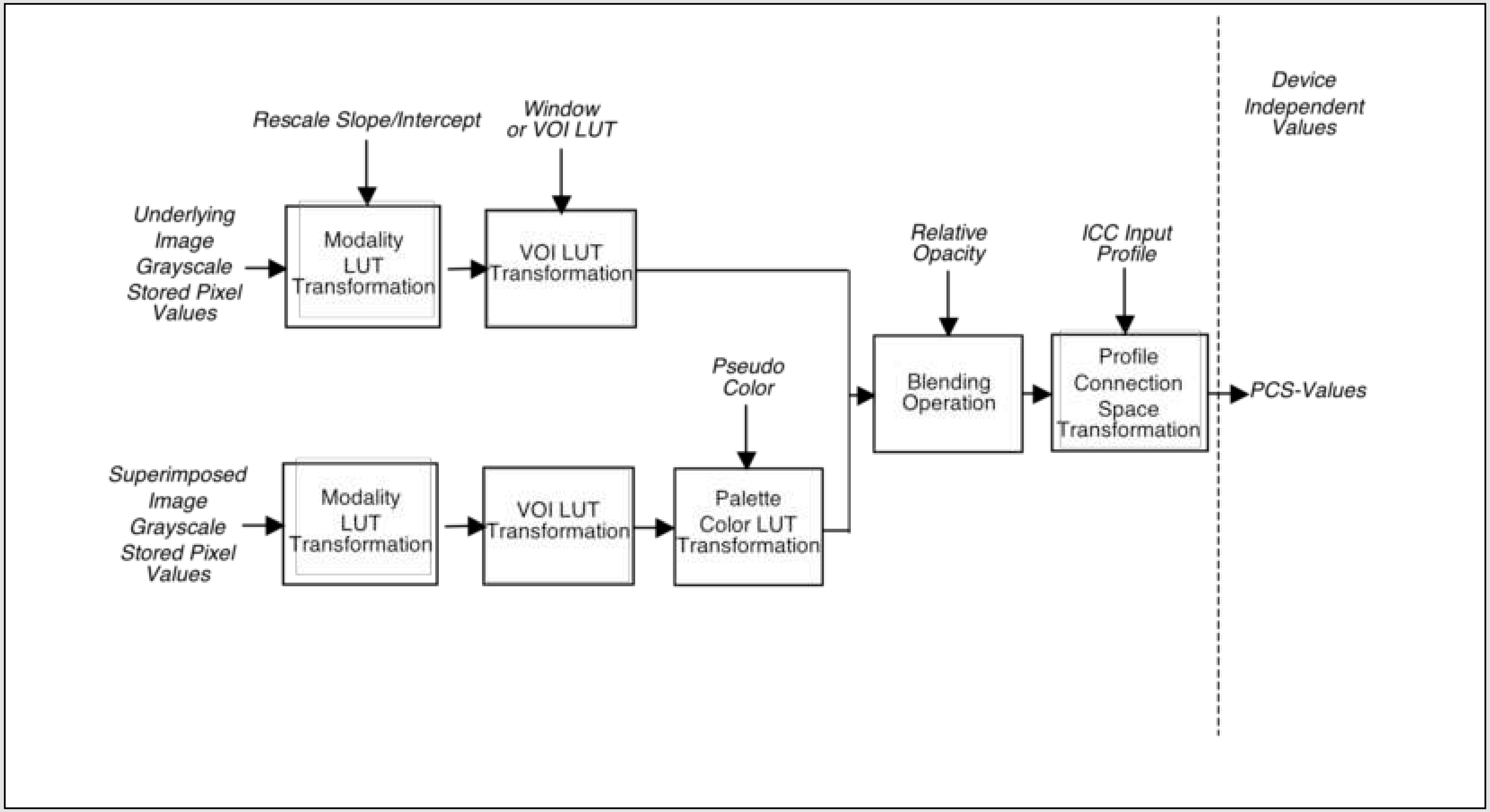


Functional

Color is *not* used for Multi-modality fusion

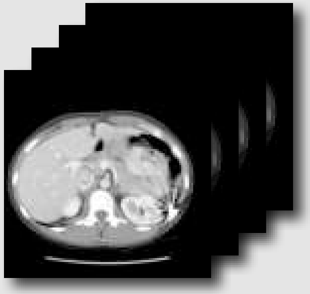
- Intention is to limit color use *in image* to where
  - Information is known added at acquisition
  - Involves pixel value replacement
  - Needs windowing of underlying grayscale
- Does not support transparency
- Separate new DICOM objects for
  - Spatial registration and fiducials
  - Blending presentation state for fusion
  - New enhanced multi-frame PET in development

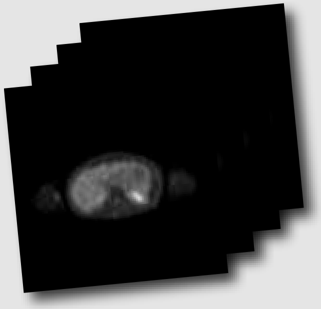
Multi-modality fusion - Blending Presentation State



Blending for multi-modality fusion

select underlying



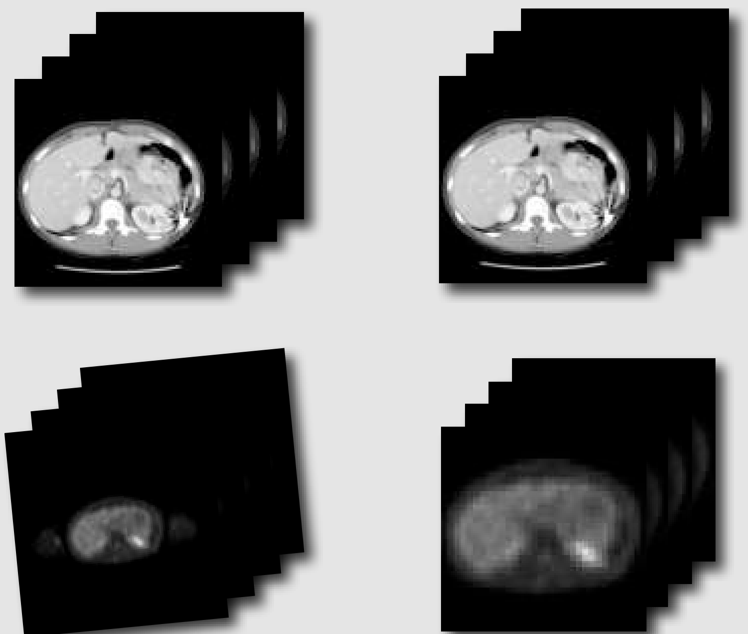


select superimposed

Blending for multi-modality fusion

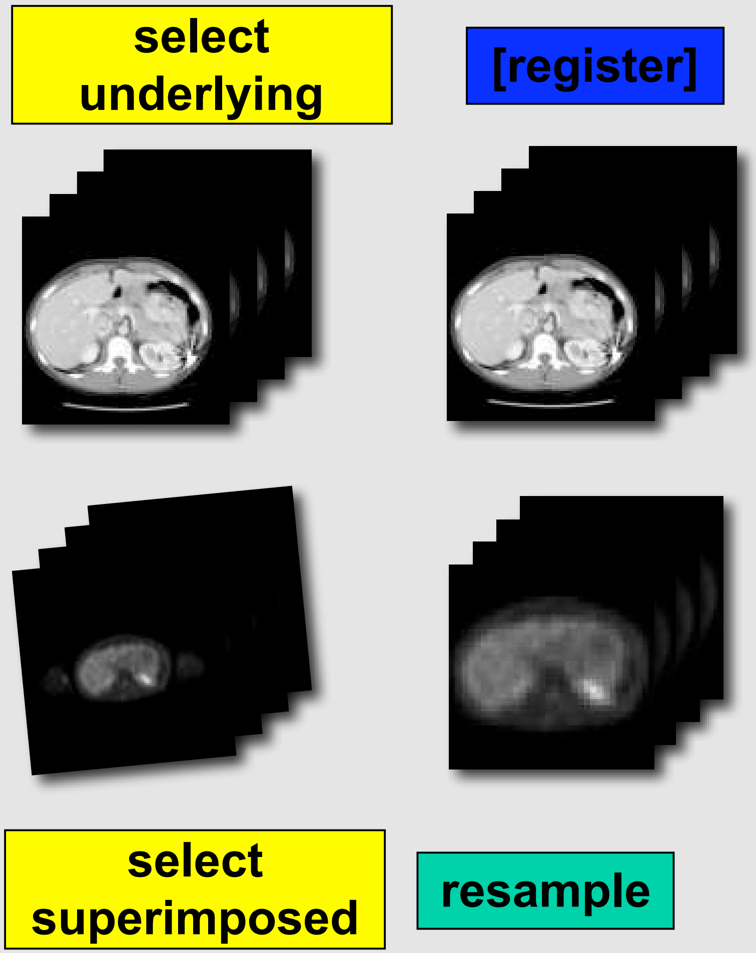
select underlying

[register]

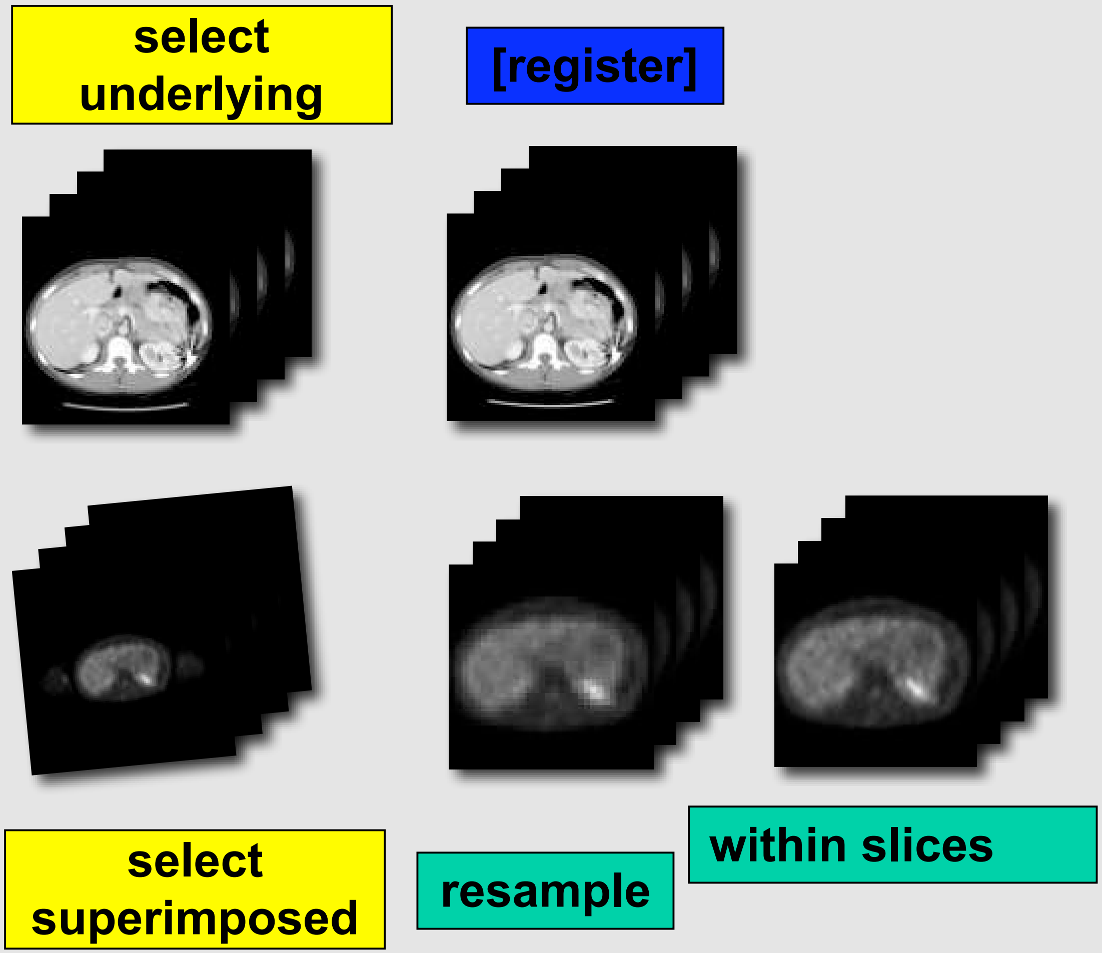


select superimposed

Blending for multi-modality fusion



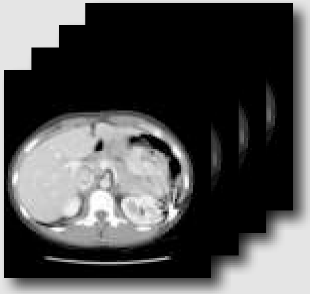
Blending for multi-modality fusion

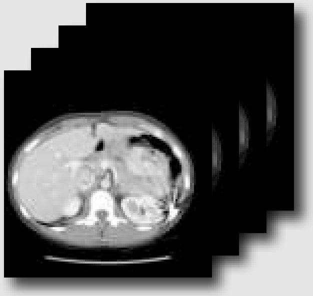


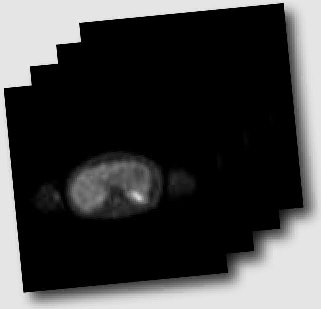
Blending for multi-modality fusion

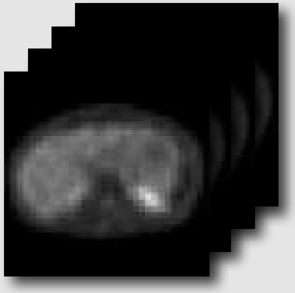
select underlying

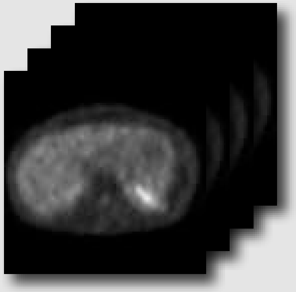
[register]











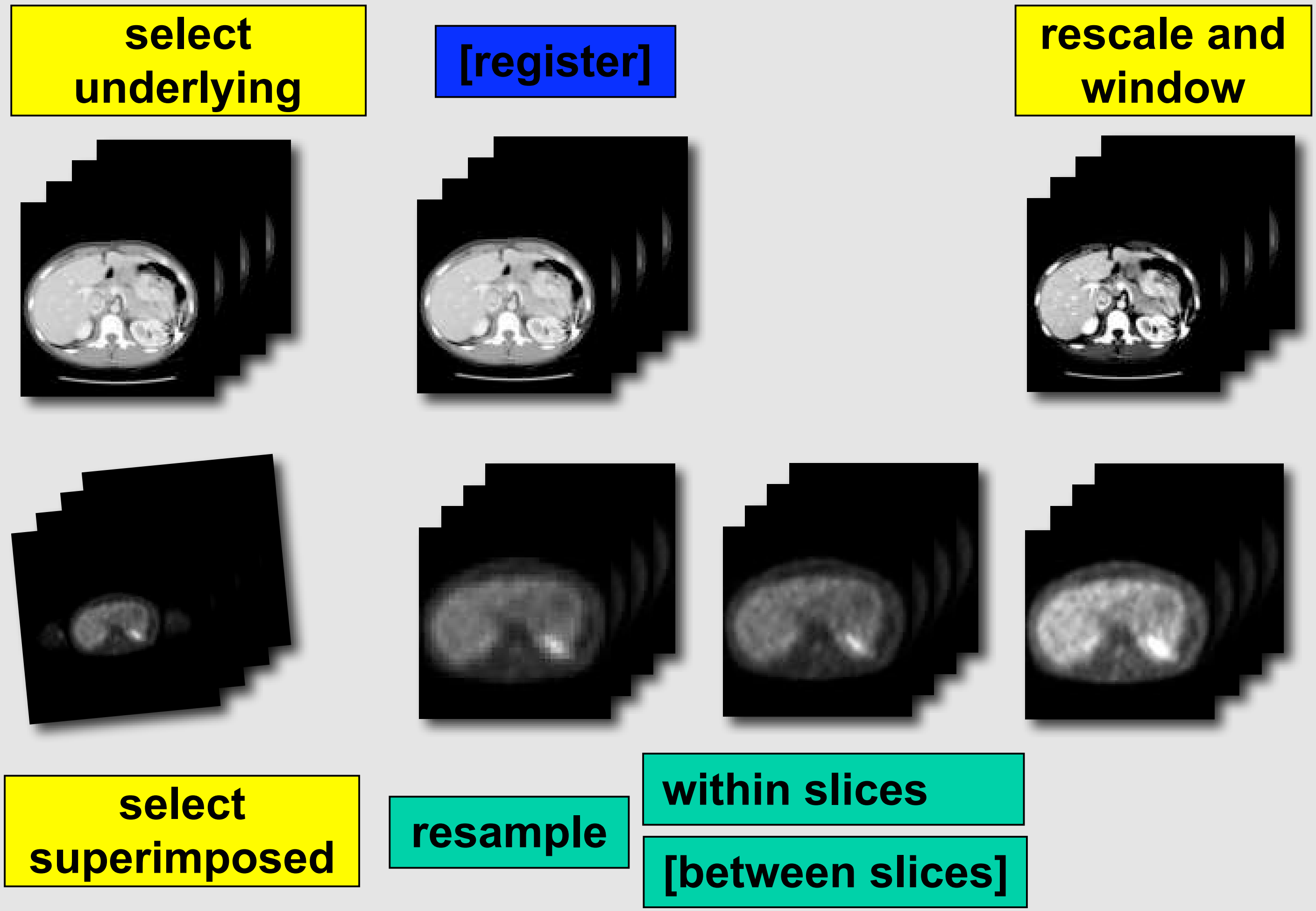
select superimposed

resample

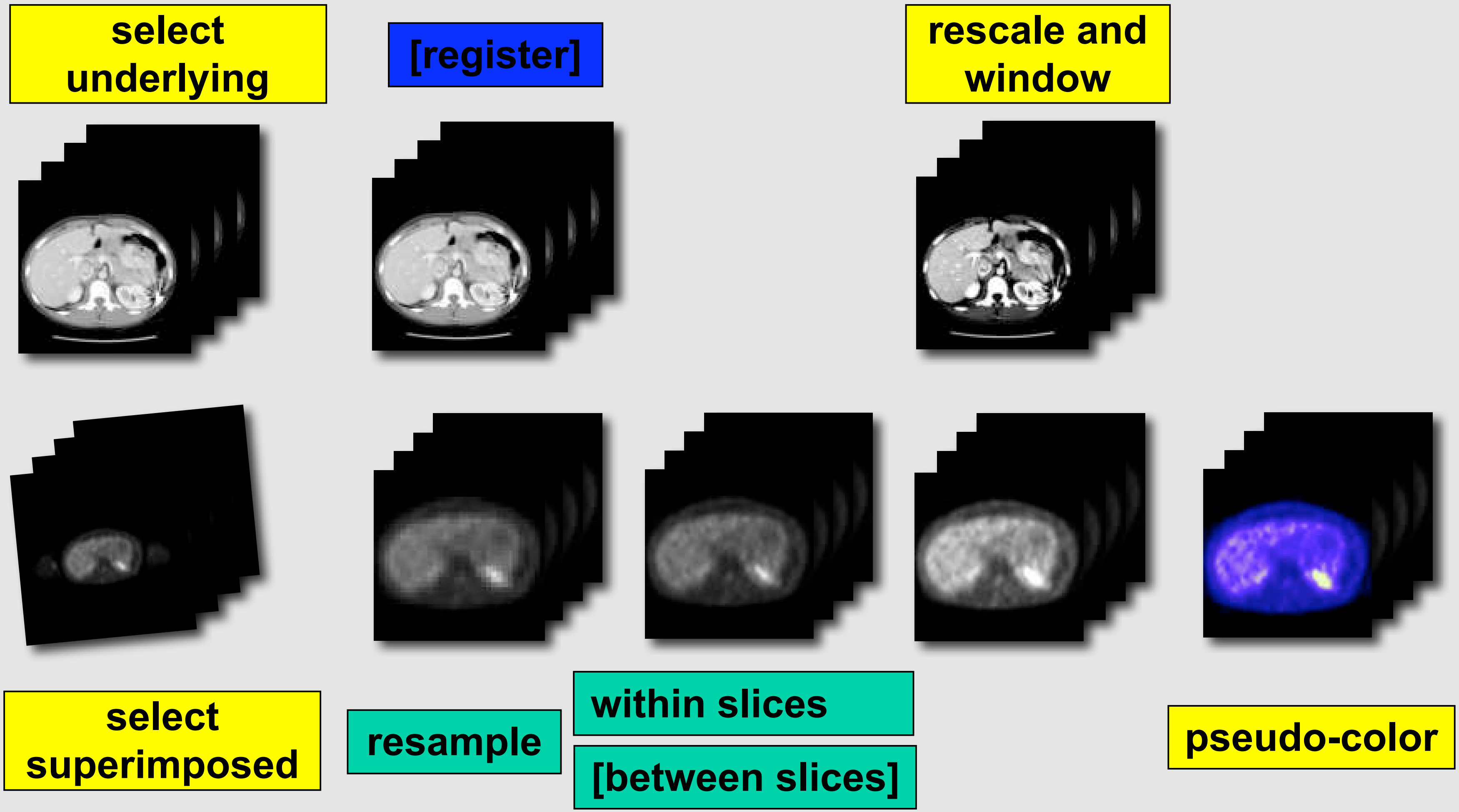
within slices

[between slices]

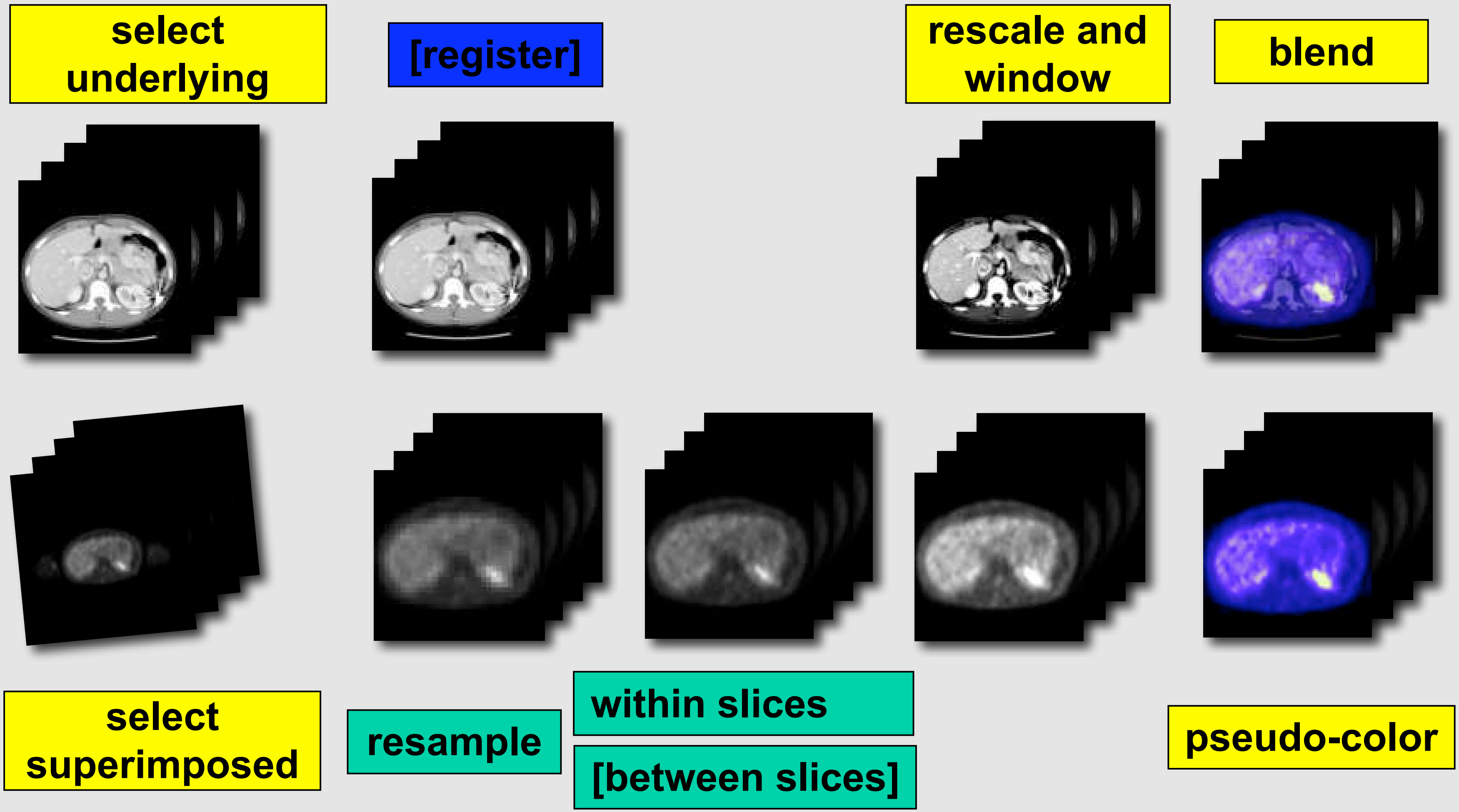
Blending for multi-modality fusion



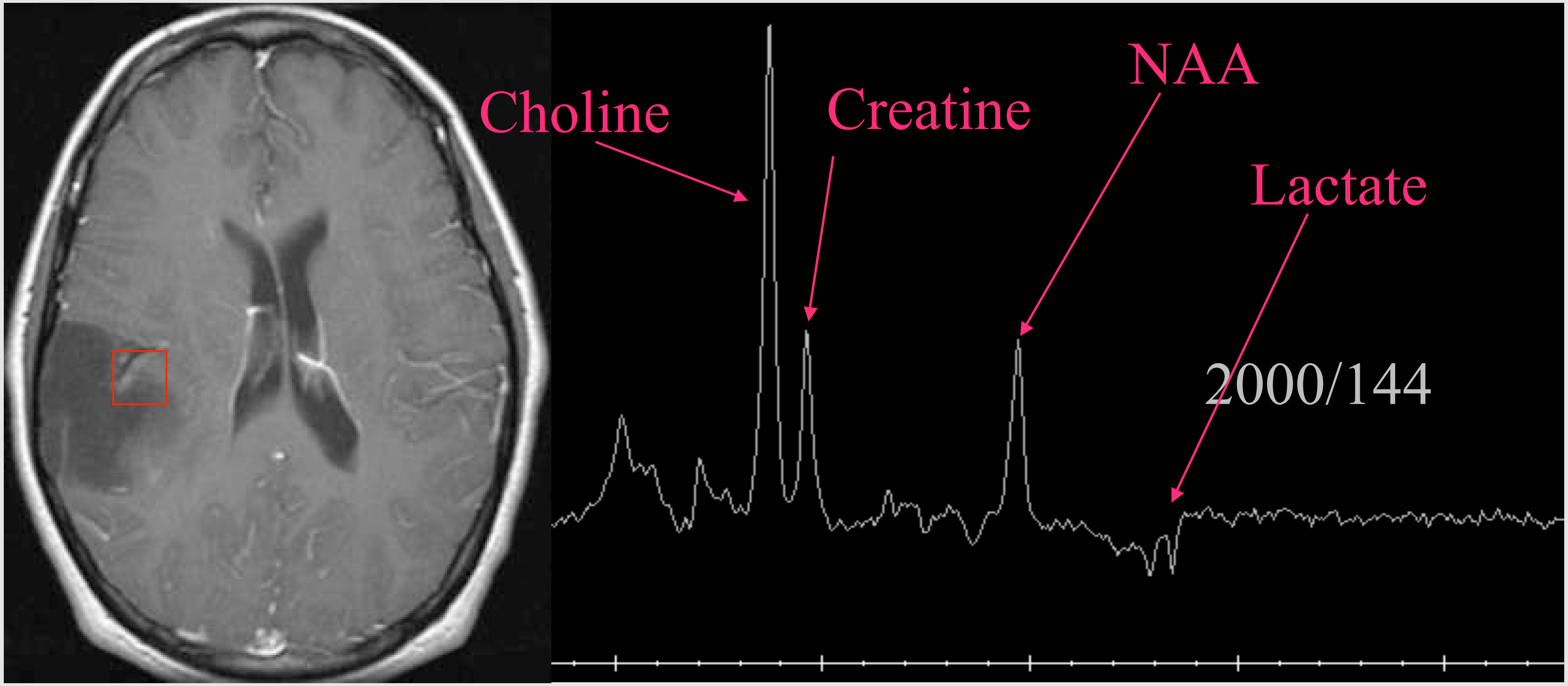
Blending for multi-modality fusion



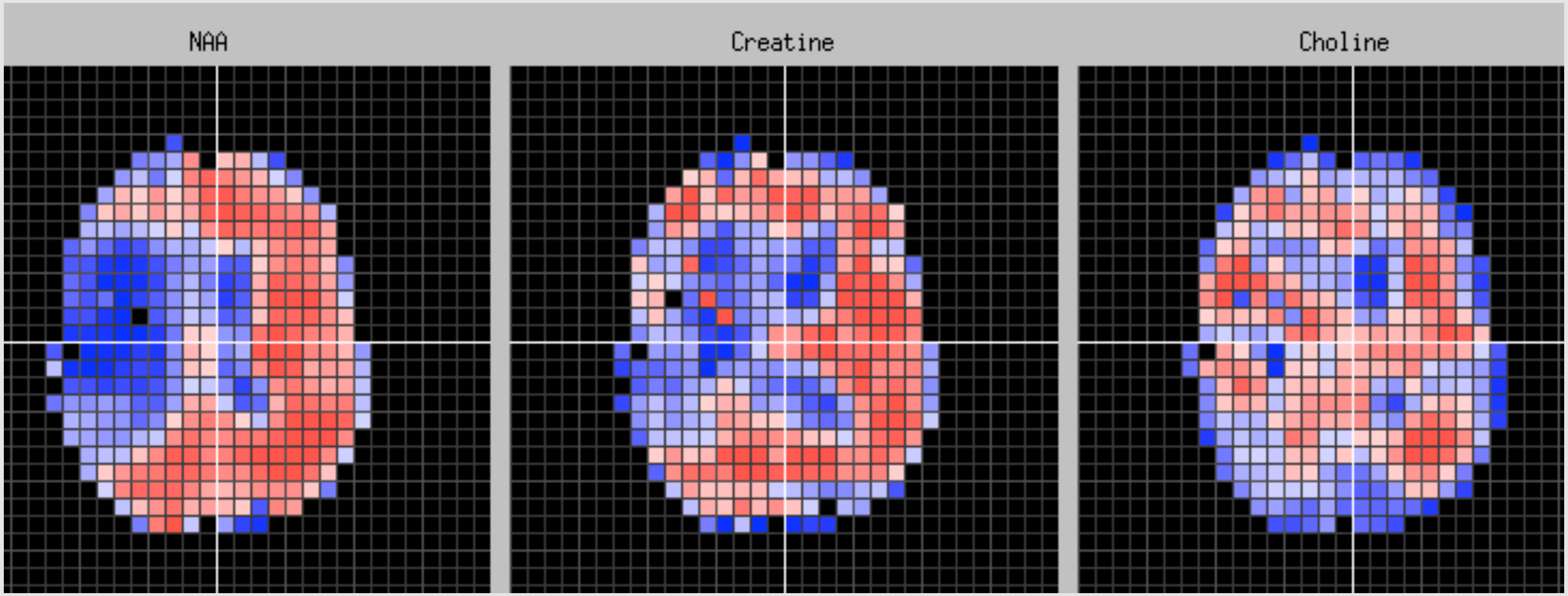
Blending for multi-modality fusion



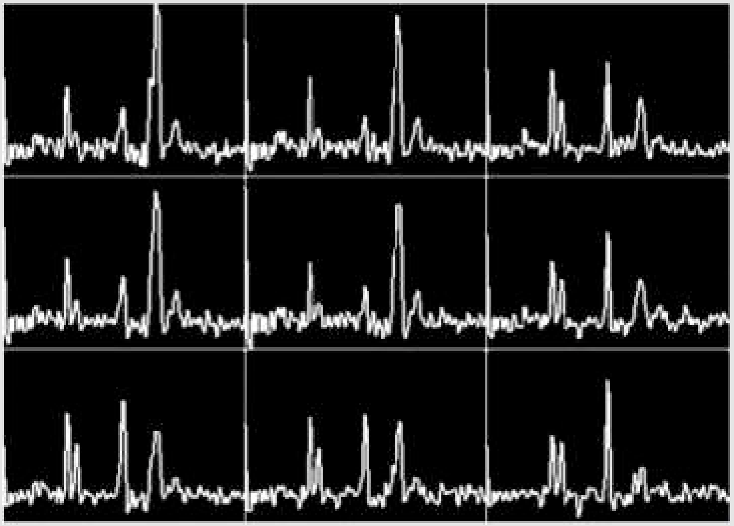
Spectroscopy



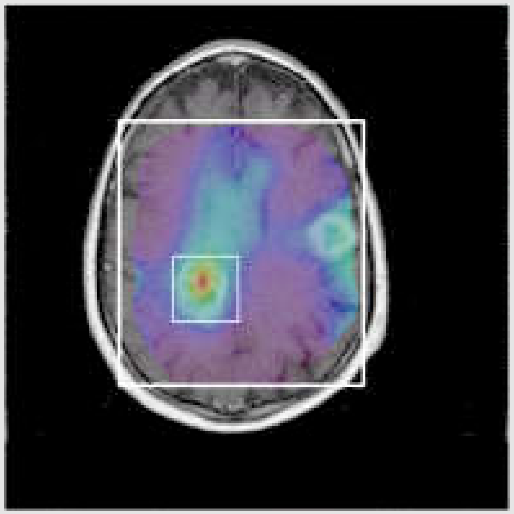
Metabolite Maps



MR Spectroscopy



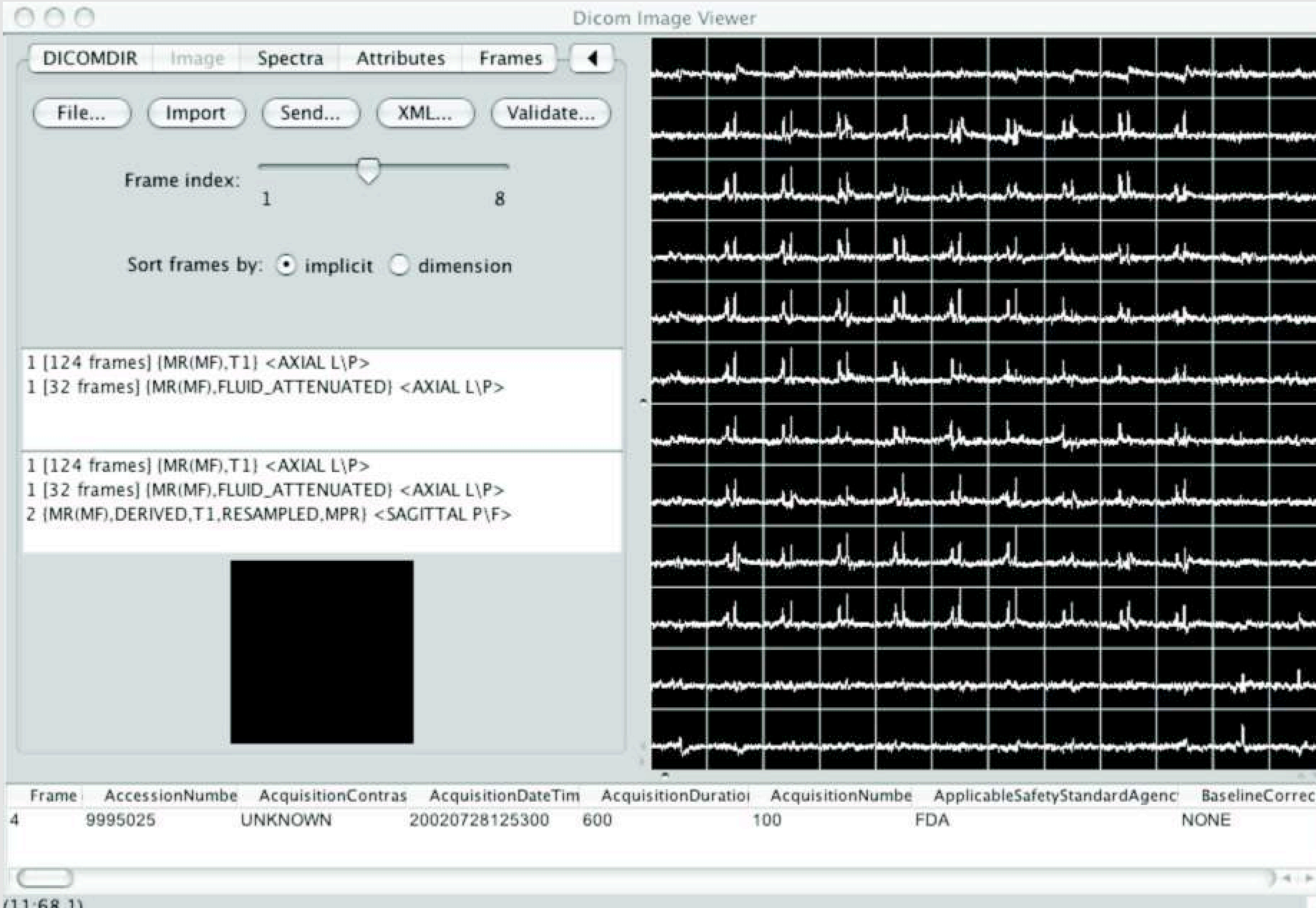
Storage of
Spectroscopy Data

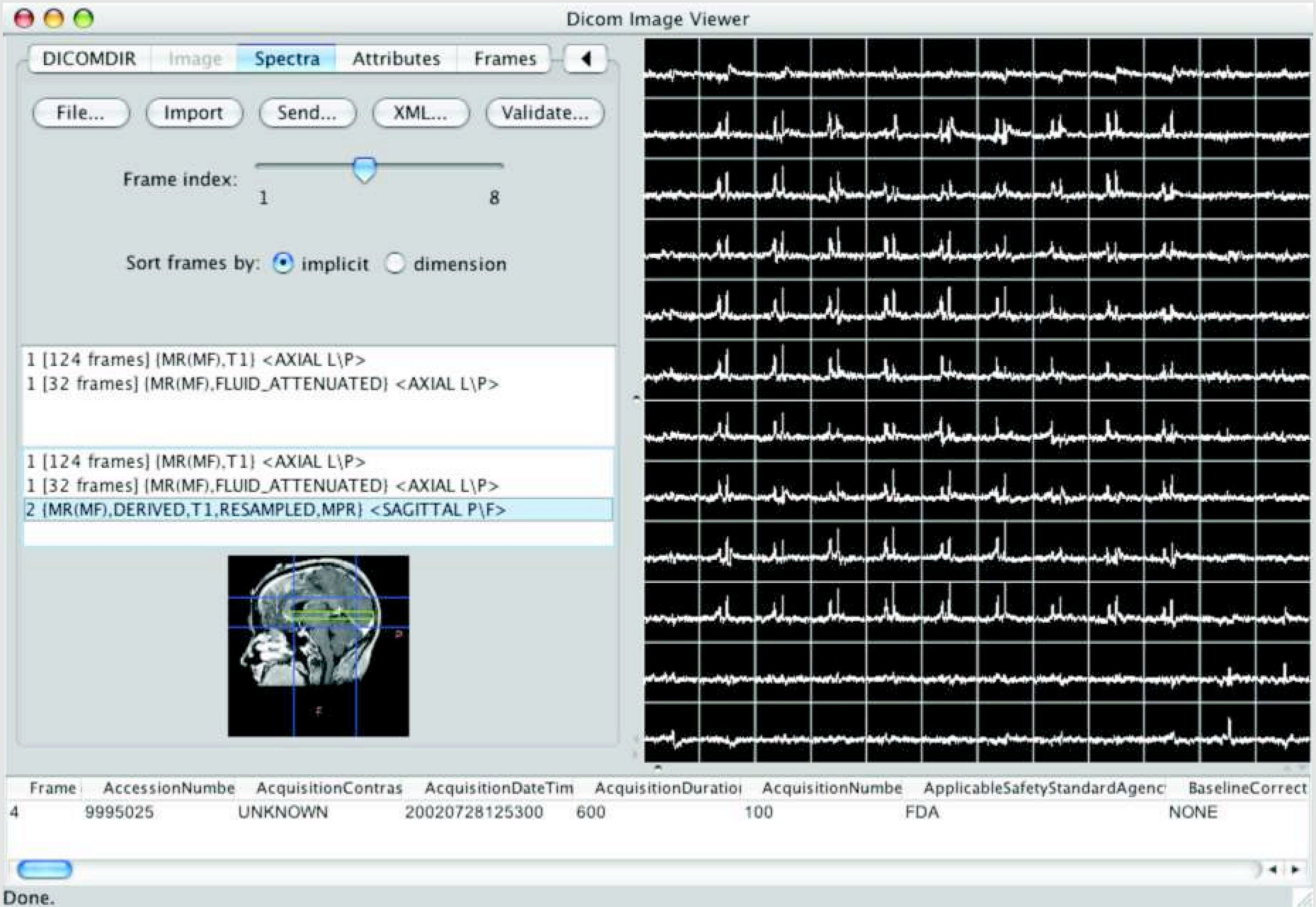


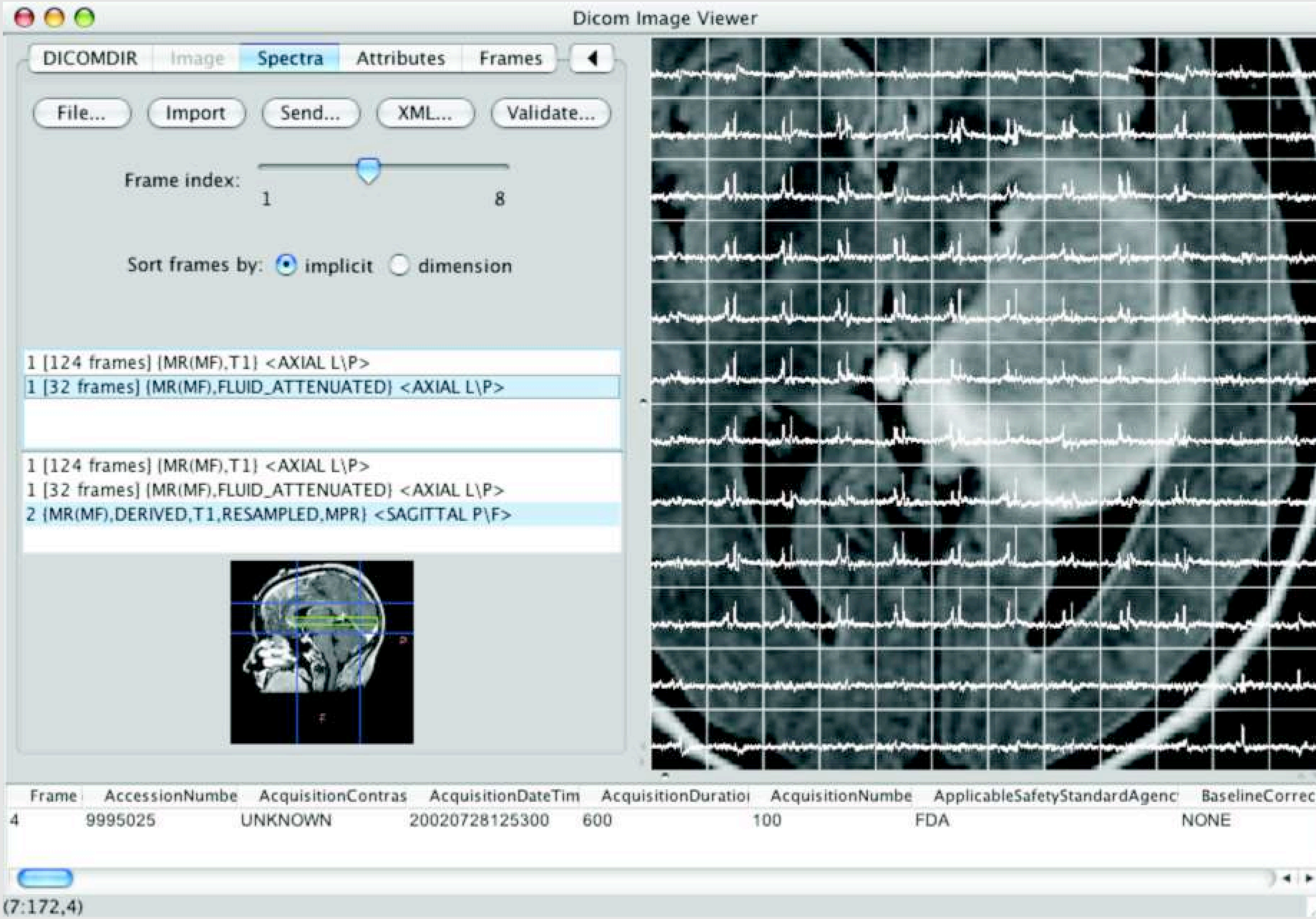
Metabolite Maps

MR Spectroscopy

- Two types of data
  - Spatially localized spectra (signal intensity versus frequency or time)
  - Images of one particular part of the spectrum (chemical shift image or metabolite map)
- Metabolite maps are stored as images
- Spectra cannot be not stored as pixel data
- In the past - stored as screen saves of curves
- Now - MR Spectroscopy SOP Class
  - Arrays of floating point and/or complex values
  - 1D or 2D data for single or multiple voxels and frames
  - Allows for interaction, analysis and quantitation


Dicom Image Viewer
DICOMDIR
Image
Spectra
Attributes
Frames
File...
Import
Send...
XML...
Validate...
Frame index:
1
8
Sort frames by:
implicit
dimension
1 [124 frames] (MR(MF),T1) <AXIAL L\P>
1 [32 frames] (MR(MF),FLUID_ATTENUATED) <AXIAL L\P>
1 [124 frames] (MR(MF),T1) <AXIAL L\P>
1 [32 frames] (MR(MF),FLUID_ATTENUATED) <AXIAL L\P>
2 (MR(MF),DERIVED,T1,RESAMPLED,MPR) <SAGITTAL P\F>
Frame
AccessionNumbe
AcquisitionContras
AcquisitionDateTim
AcquisitionDuratio
AcquisitionNumbe
ApplicableSafetyStandardAgenc
BaselineCorrect
4
9995025
UNKNOWN
20020728125300
600
100
FDA
NONE
(11:68,1)


Dicom Image Viewer
DICOMDIR
Image
Spectra
Attributes
Frames
File...
Import
Send...
XML...
Validate...
Frame index:
1
8
Sort frames by:
implicit
dimension
1 [124 frames] {MR(MF),T1} <AXIAL L\P>
1 [32 frames] {MR(MF),FLUID_ATTENUATED} <AXIAL L\P>
1 [124 frames] {MR(MF),T1} <AXIAL L\P>
1 [32 frames] {MR(MF),FLUID_ATTENUATED} <AXIAL L\P>
2 {MR(MF),DERIVED,T1,RESAMPLED,MPR} <SAGITTAL P\F>
Frame
AccessionNumbe
AcquisitionContras
AcquisitionDateTim
AcquisitionDuratio
AcquisitionNumbe
ApplicableSafetyStandardAgenc
BaselineCorrect
4
9995025
UNKNOWN
20020728125300
600
100
FDA
NONE
Done.



Dicom Image Viewer
DICOMDIR
Image
Spectra
Attributes
Frames
File...
Import
Send...
XML...
Validate...
Frame index:
1
8
Sort frames by:
implicit
dimension
1 [124 frames] (MR(MF),T1) <AXIAL L\P>
1 [32 frames] (MR(MF),FLUID_ATTENUATED) <AXIAL L\P>
1 [124 frames] (MR(MF),T1) <AXIAL L\P>
1 [32 frames] (MR(MF),FLUID_ATTENUATED) <AXIAL L\P>
2 (MR(MF),DERIVED,T1,RESAMPLED,MPR) <SAGITTAL P\F>
Frame
AccessionNumbe
AcquisitionContras
AcquisitionDateTim
AcquisitionDuratio
AcquisitionNumbe
ApplicableSafetyStandardAgenc
BaselineCorrect
4
9995025
UNKNOWN
20020728125300
600
100
FDA
NONE
(7:172,4)

Raw Data

- MR and CT have "raw data" prior to reconstruction into spatial domain images (k-space data, raw views)
- Need for different reconstructions
  - Slice thickness and reconstruction interval
  - Different convolution kernel (bone, lung)
  - Different field of view
  - For CAD versus human viewing
- Raw data is bulky and proprietary
- Local long term archival on modality possible but unusual and inconvenient, therefore time window for retrospective reconstruction is limited

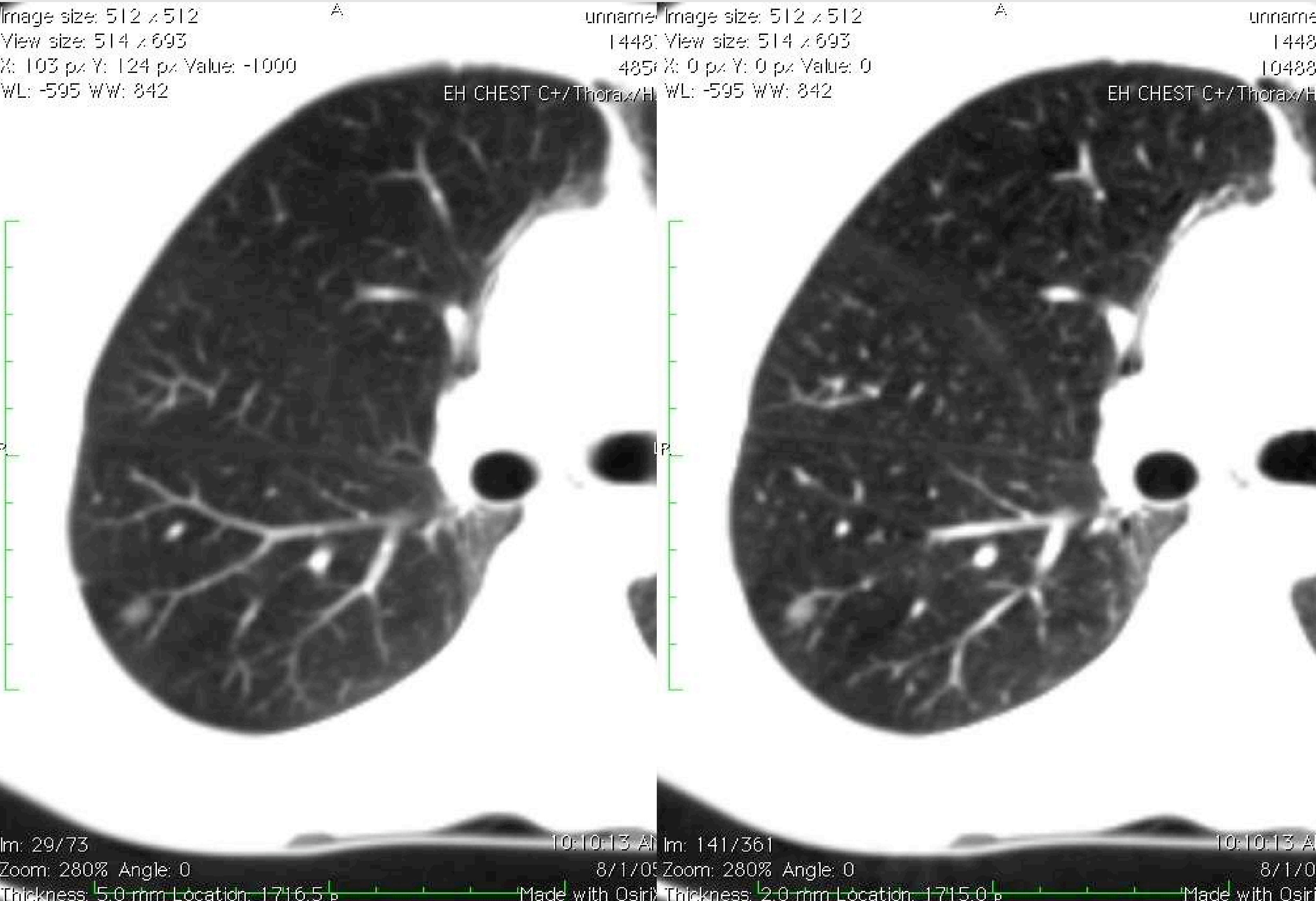


Image size: 512 x 512
View size: 514 x 693
X: 103 px Y: 124 px Value: -1000
WL: -595 WW: 842
A
EH CHEST C+/Thorax/H
Im: 29/73
Zoom: 280% Angle: 0
Thickness: 5.0 mm Location: 1716.5
Image size: 512 x 512
View size: 514 x 693
X: 0 px Y: 0 px Value: 0
WL: -595 WW: 842
A
EH CHEST C+/Thorax/Hx
Im: 141/361
10:10:13 AM
Zoom: 280% Angle: 0
8/1/05
Thickness: 2.0 mm Location: 1715.0
Made with OsiriX

Raw Data SOP Class

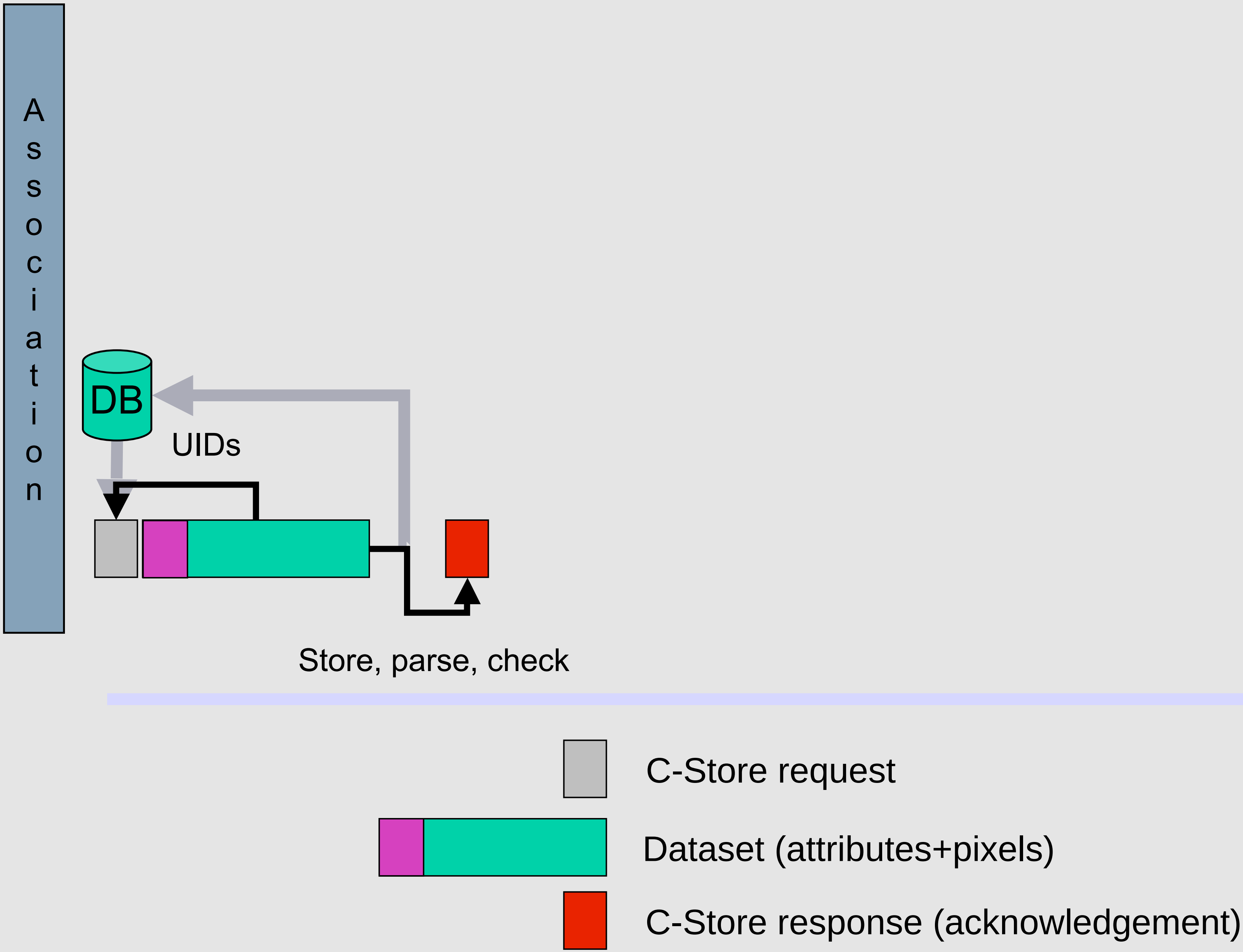
- Goal is storage of encapsulated raw data in the PACS or other central archive
- Without standardizing raw data format
- Defines usual patient, study, series, instance attributes
- No standard payload - raw data assumed to be in private attributes
- Allows for storage and retrieval without understanding
- No expectation that different vendors will be able to use the data
- SOP Instance UID of raw data can be referenced from images and spectra

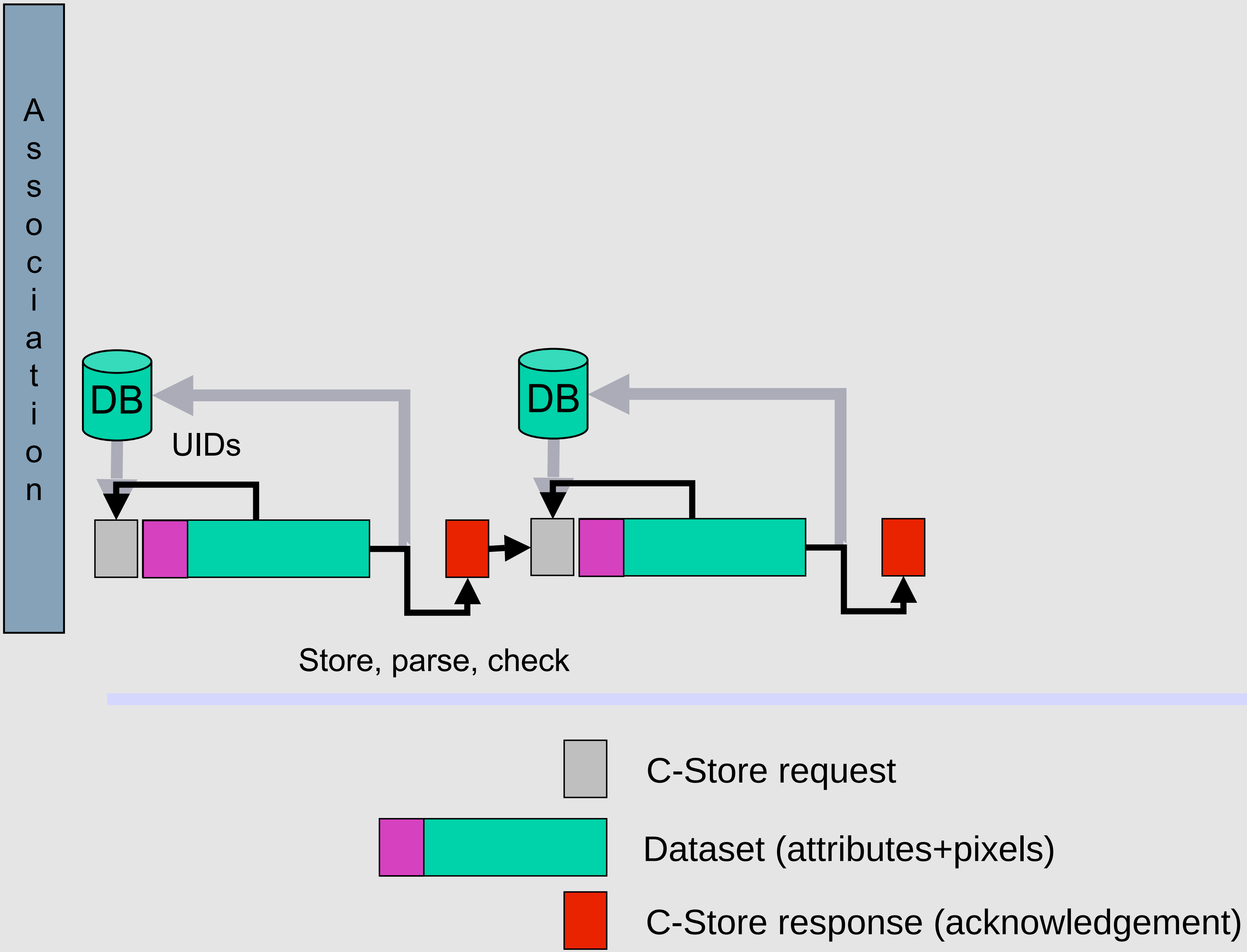
Performance Opportunities

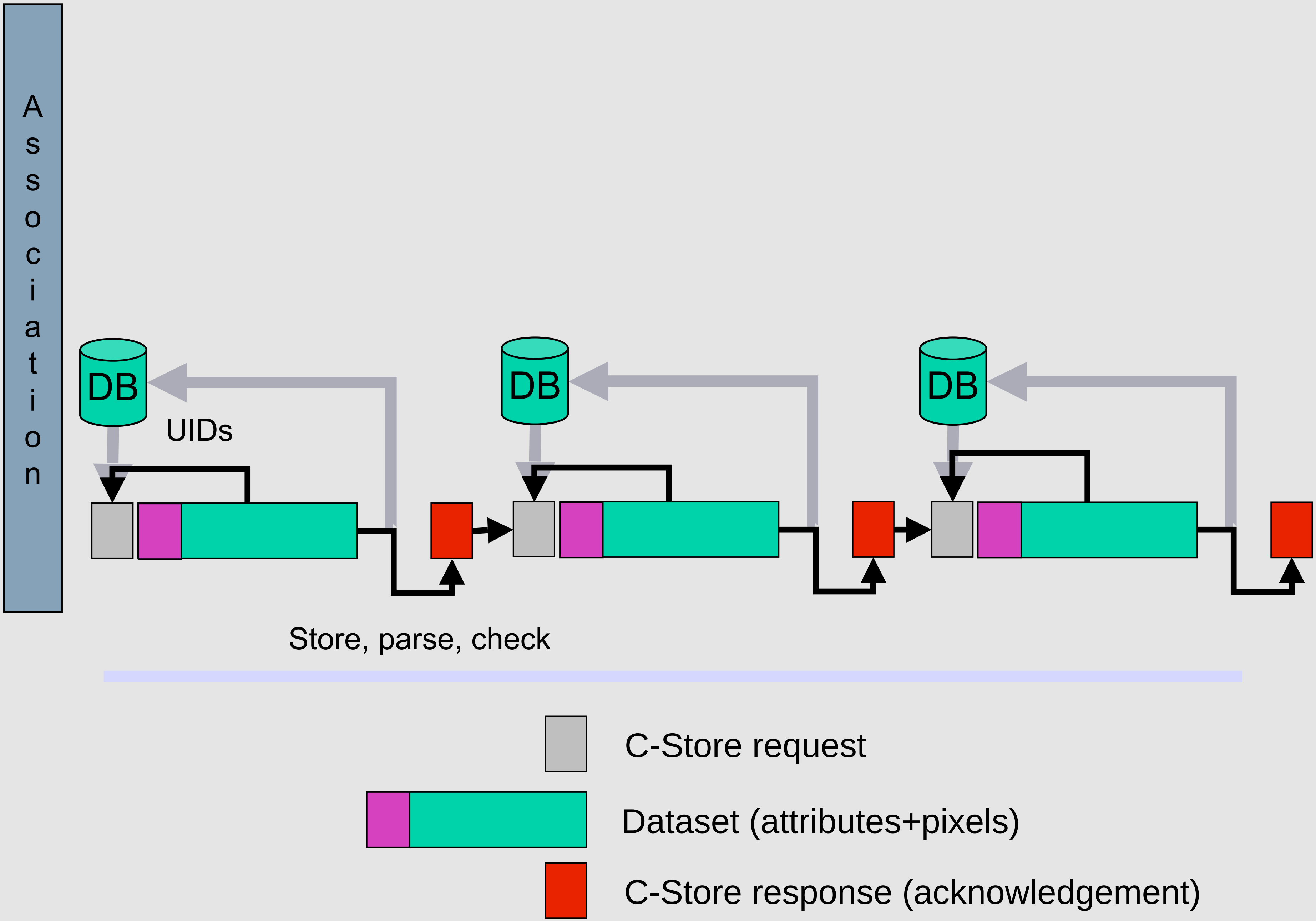
- New multi-frame object does not change
  - TCP connection establishment
  - Association establishment
- Common header information is not repeated
  - But reduction is negligible compared to pixel data size
- Reduced latency (delay) between storage requests
- Creates opportunity for inter-slice (3D) compression

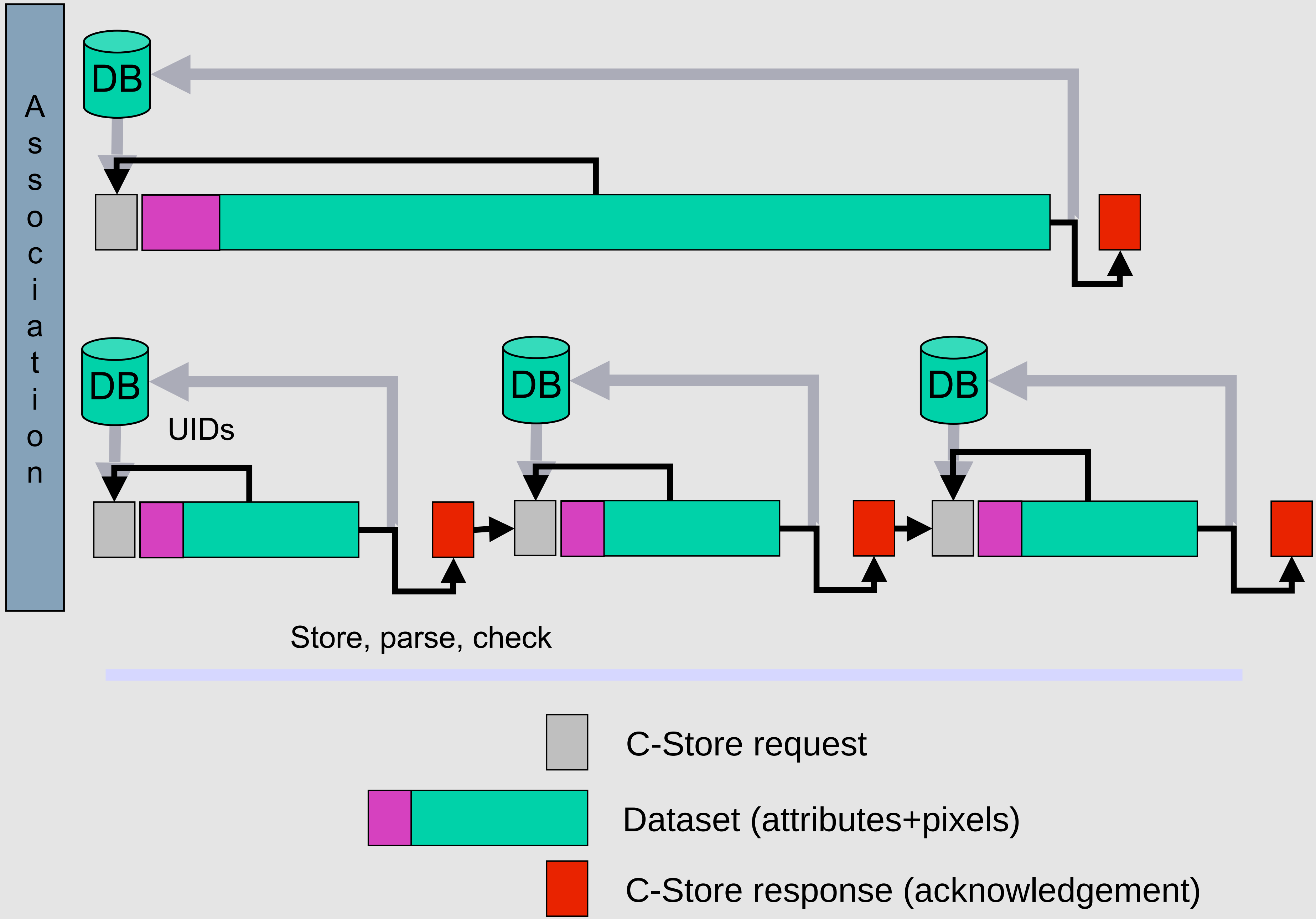
- Extremely implementation-dependent


Association
C-Store request
Dataset (attributes+pixels)
C-Store response (acknowledgement)


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

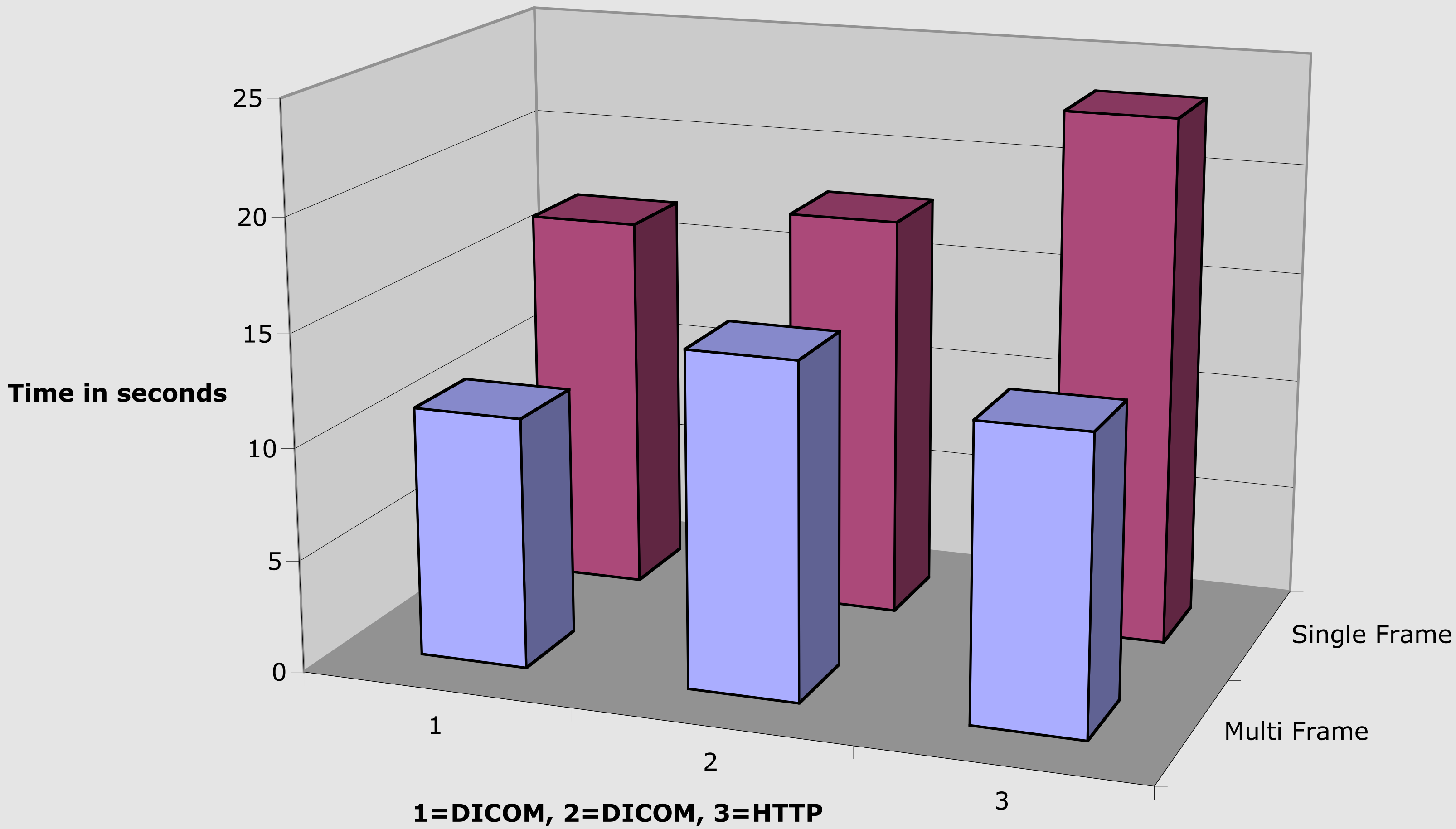

Association
DB
UIDs
DB
Store, parse, check
C-Store request
Dataset (attributes+pixels)
C-Store response (acknowledgement)


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



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

CTA - 548x512x512 (275MB) File read/transfer/save (GB Ethernet)

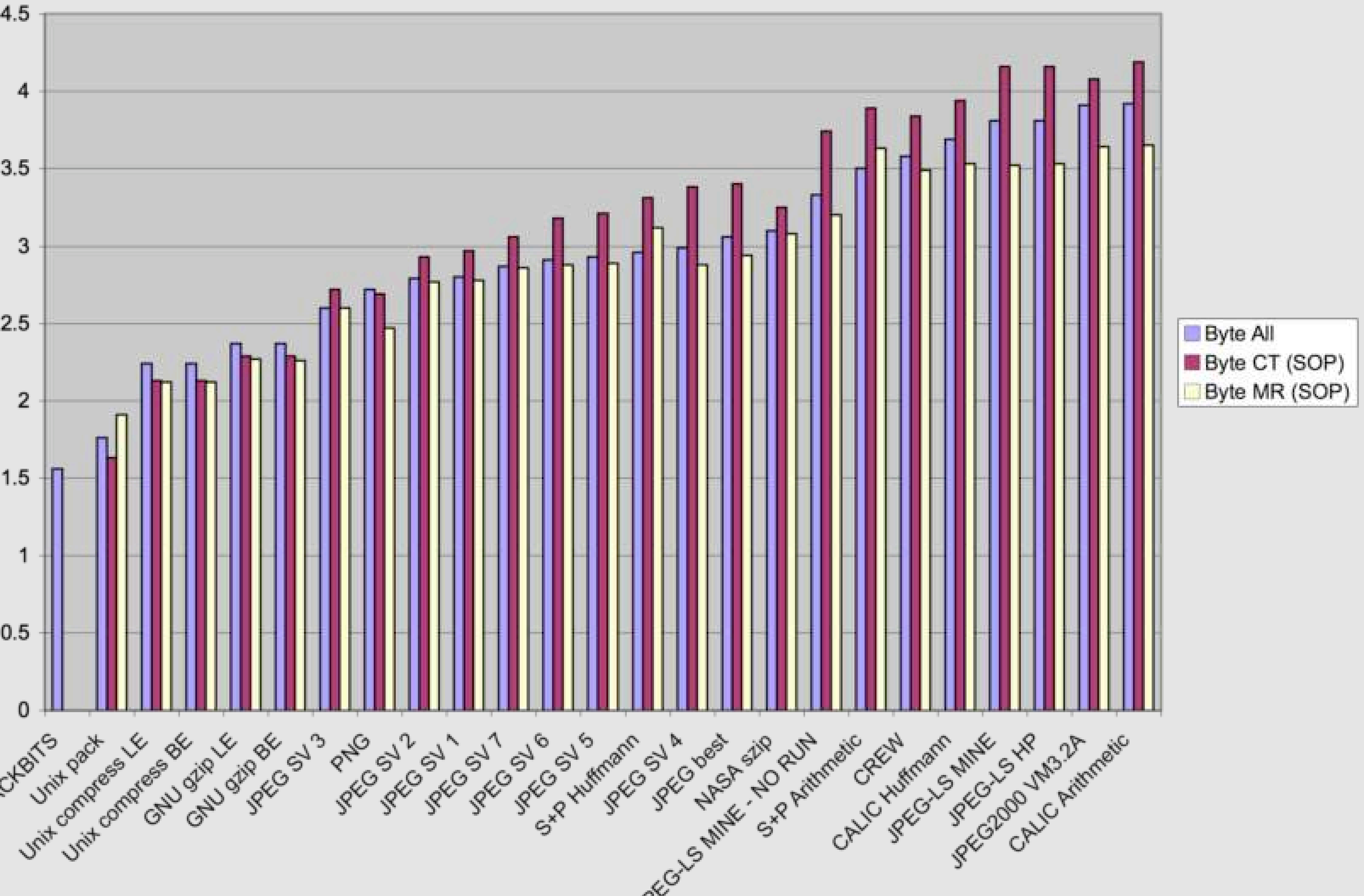


	1	2	3
Multi Frame	11.14111111	14.86703704	13.07333333
Single Frame	16.905	17.97	23.42666667

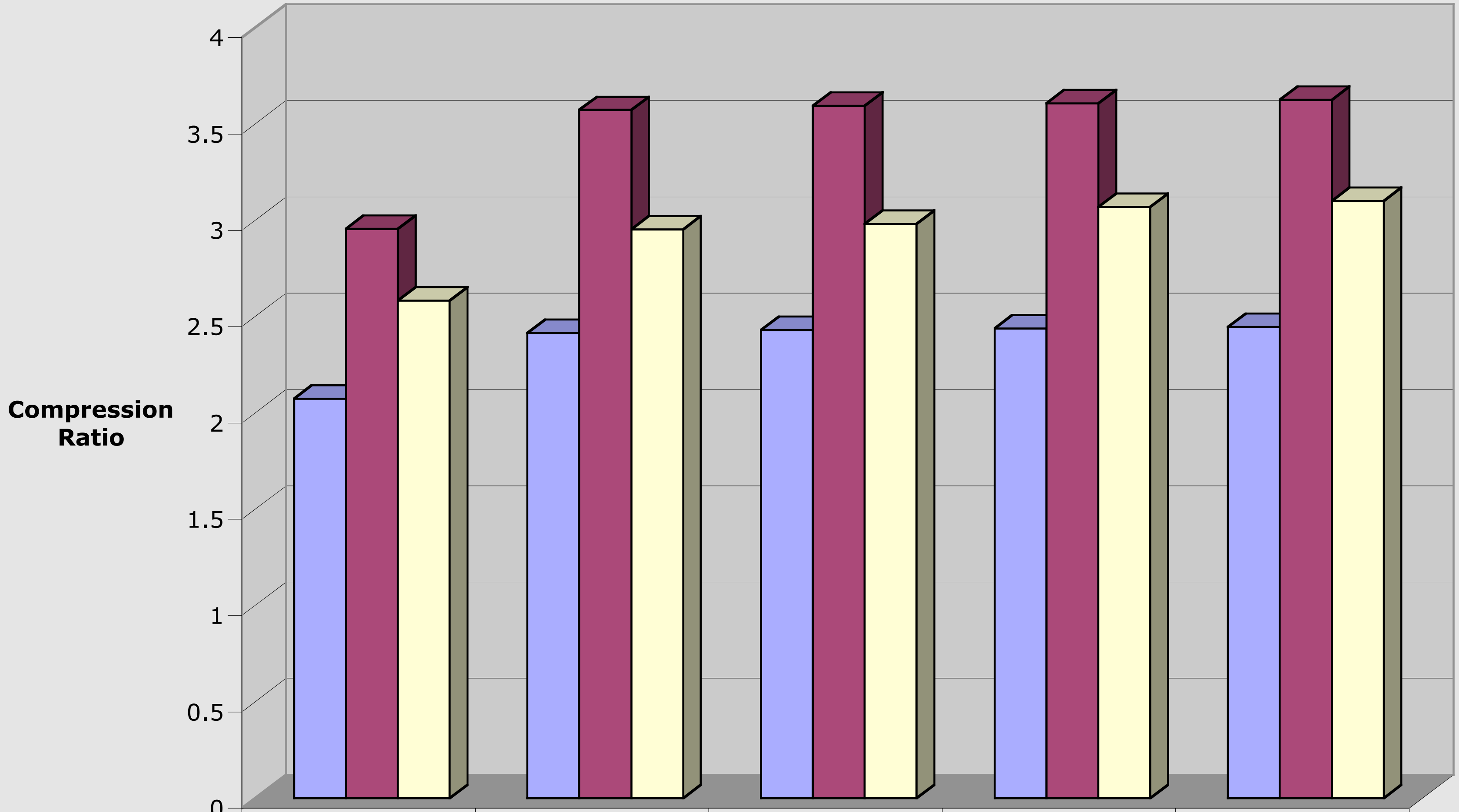
Multi-frame compression

- Original CT and MR SOP Classes are single frame
  - Compression only possible within a single frame
  - Lossless - typically 3:1 or 4:1 for CT and MR
- Multi-frame objects
  - Opportunity to take advantage of redundancy between frames
  - Spatial redundancy - JPEG 2000 Part 2
    - Lossless gain modest, lossy gain more substantial
  - Motion prediction - MPEG-2 and others
  - New schemes - H.264/MPEG-4 Part 10
  - Entire dataset (e.g., 3D volume) or adjacent slabs

Single frame lossless compression

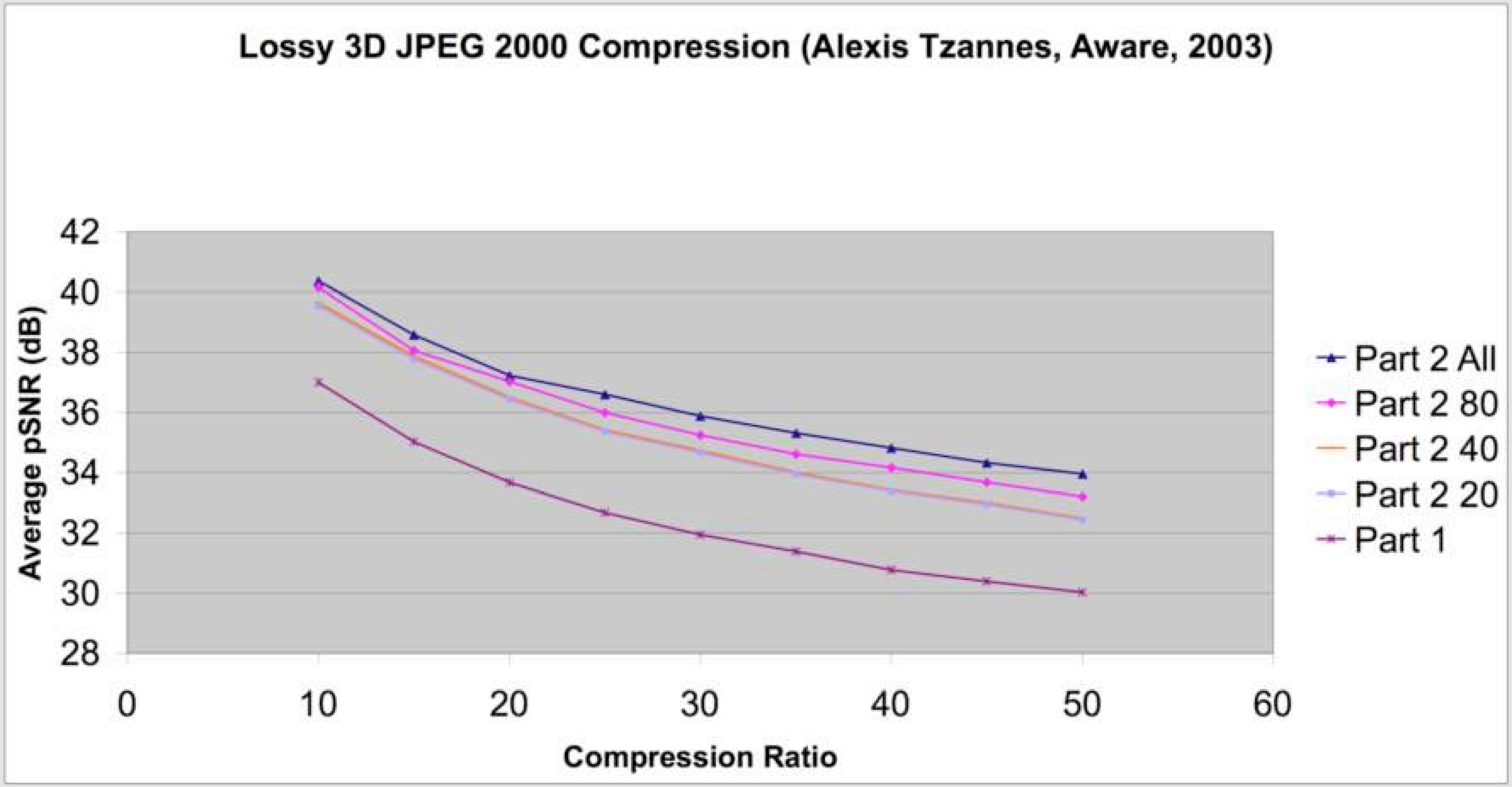


Lossless JPEG 2000 Compression (Alexis Tzannes, Aware, 2003)

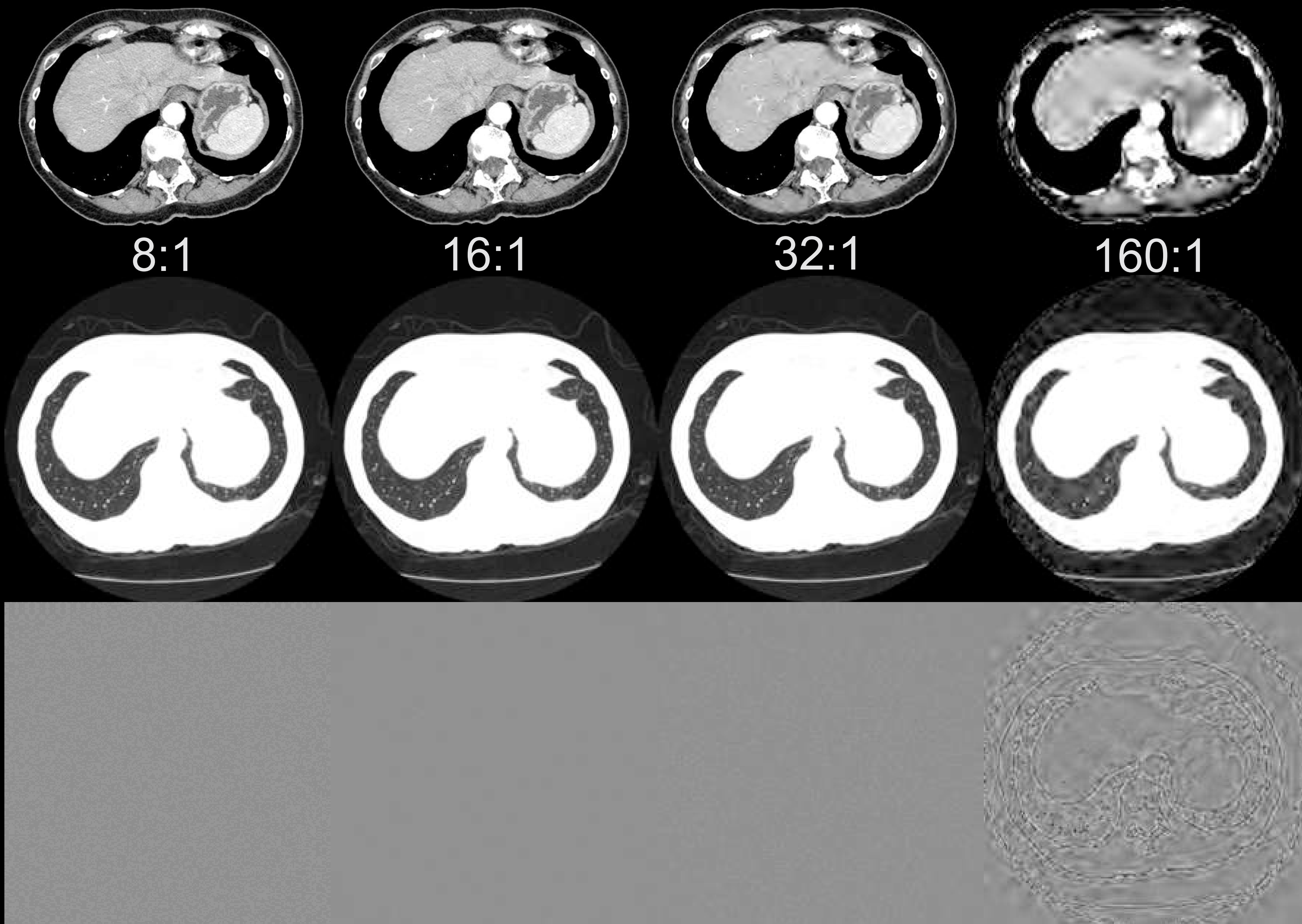


	single	20	40	80	all
127x256x8 7.9MB	2.073490814	2.415902141	2.430769231	2.438271605	2.445820433
449x512x16 224MB	2.955145119	3.572567783	3.595505618	3.607085346	3.624595469
620x512x16 310MB	2.583333333	2.952380952	2.980769231	3.069306931	3.1

Slices in 3rd dimension


Lossy 3D JPEG 2000 Compression (Alexis Tzannes, Aware, 2003)
Average pSNR (dB)
42
40
38
36
34
32
30
28
0
10
20
30
40
50
60
Compression Ratio
Part 2 All
Part 2 80
Part 2 40
Part 2 20
Part 1

2D JPEG 2000 0.625mm slices




1:1

8:1

16:1


16:1 3D

1:1

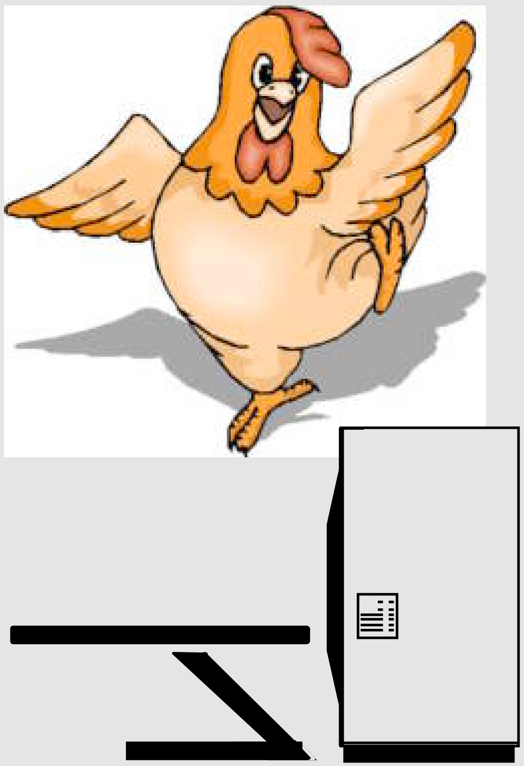
32:1


160:1

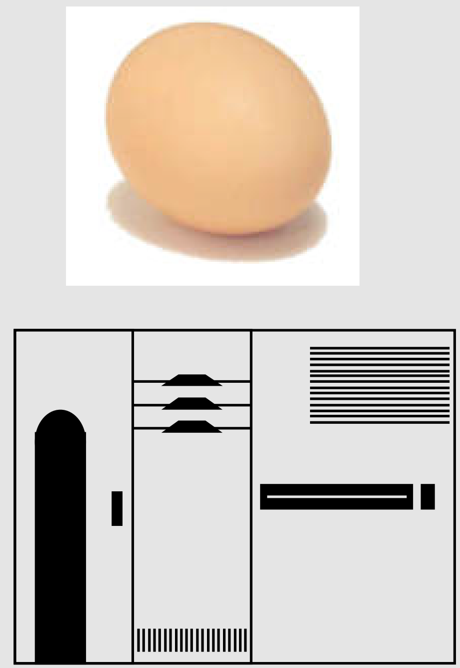
Multi-frame compression performance reality check

- Lossless compression in 3D
  - Slight gain - 15 to 20% smaller than 2D
- Lossy compression in 3D
  - Modest gain - possibly 50% smaller than 2D
  - But - only relatively modest loss before noticeable
  - Perhaps (?) 16:1
- Siddiqui et al, SCAR 2004
  - Thinner slices compress poorly due to noise
  - 3D JPEG 2000 compression may be used to compensate
  - Suggest using JND rather than PSNR as a metric
- Need more experiments
  - Effect on observer performance unknown

But when ?



Modality



PACS

NEMA Initiatives

- MR test tools, images and spectra available
- CT test tools and images developed
- Implementation testing & demonstration
  - June 2005 - SCAR demonstration
  - November 2005 - RSNA InfoRAD demonstration
- After SCAR, CT test tools and images released

NEMA & SCAR
Test & Demonstration

Purpose of the Test & Demonstration

- Participants
  - Test that it works
  - Identify problems and solutions
- Other vendors
  - Show what work needs to be done
- Users
  - Show that at works
  - Begin to show some of the benefits
    - Performance
    - Interoperability of new attributes, dimensions, applications, spectroscopy … testing of clinical scenarios

Not just MR & CT …

- Need for new multi-frame PET object
  - Currently single slice
  - Much renewed interest in PET-CT fusion
  - First draft during SNM June 2005 meeting
- X-ray angiography now part of the standard
  - Support for digital detectors
  - New acquisition types
- Tomosynthesis/cone beam CT - new work

Conclusion

- New DICOM image and other objects to address new applications
- Greater interfunctionality for more complex clinical scenarios and applications
- Performance opportunities for large data volumes
- Compression opportunities