DICOM as a format for neuro-imaging with fMRI

David Clunie, MBBS, FRACR

CTO - RadPharm

(Princeton Radiology Pharmaceutical Research)

overview

- background & history
- encoding mechanisms
- existing MR image storage object
- new multi-frame MR object
- spatial registration & fiducials
- time-based waveforms
- services, beyond storage

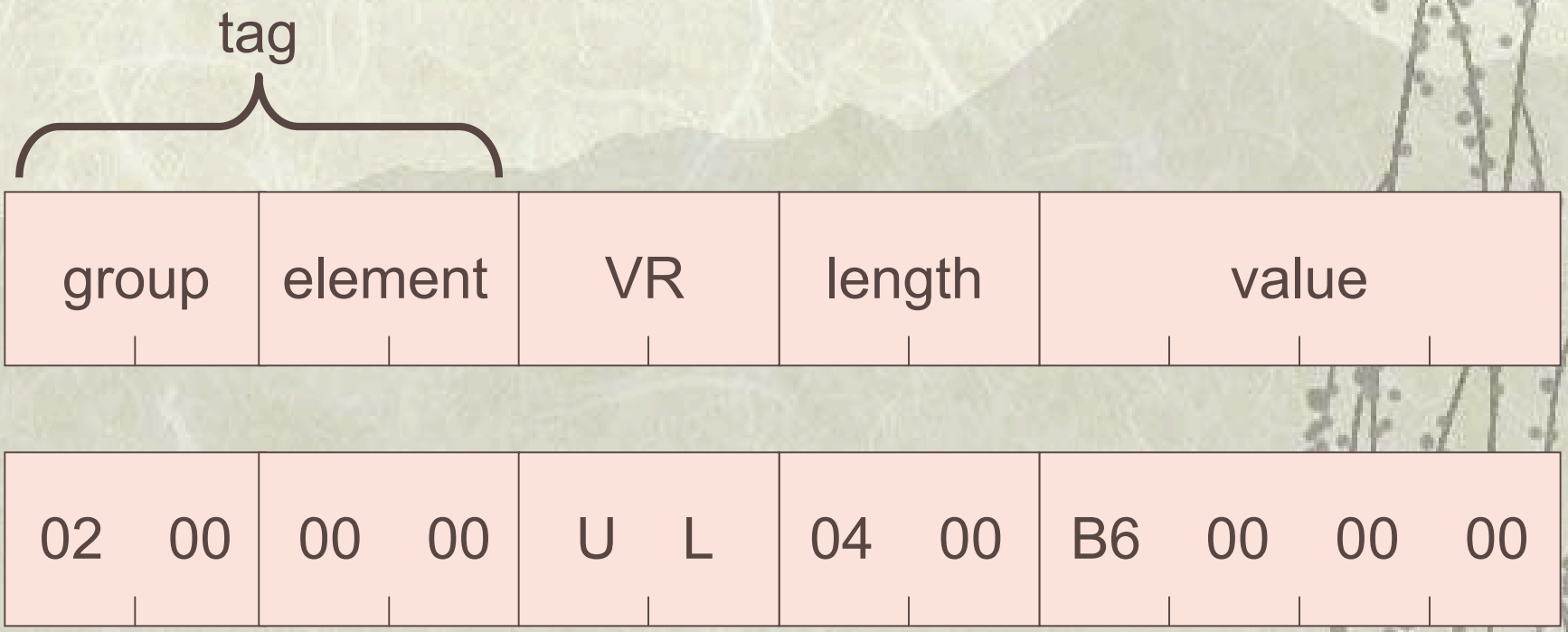
background & history

- 1985 ACR-NEMA
- 1993 DICOM (Digital Imaging and COmmunication in Medicine)
- network services
- modality, workstation, printer, PACS
- 1995 interchange media file format
- ubiquitous in radiology, cardiology

encoding mechanisms

- defined in part 5
- list of tag-value pairs (like TIFF)
  - binary tag
  - binary or string value, depending on VR
- value representation (VR)
  - specifies the data type
  - integers, floats, strings, names, dates
  - individual values or bulk data

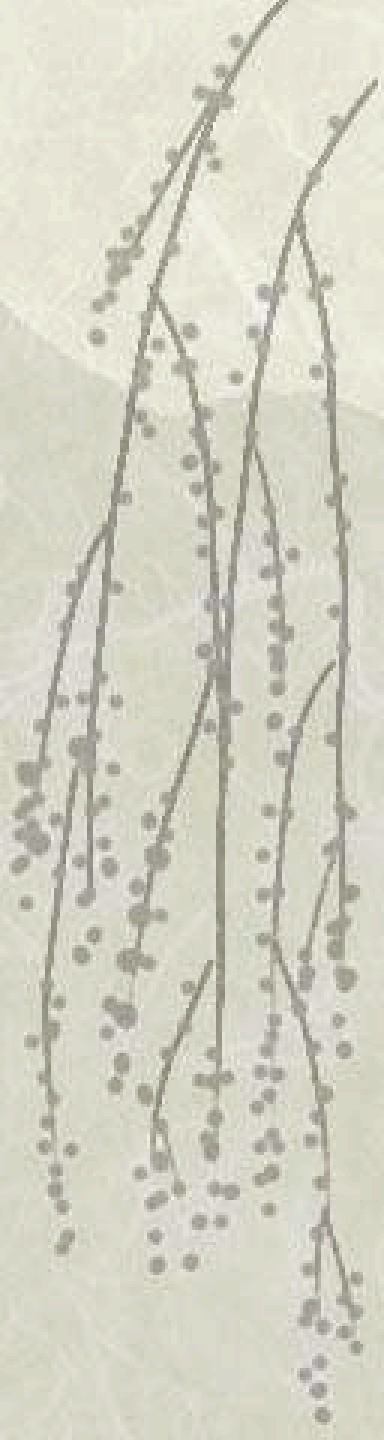
tag-value pair



*Little Endian Explicit Value Representation Transfer Syntax

dataset

- list of concatenated tag-value pairs
- encoded in ascending tag order
- tags cannot repeat
- end of dataset is implicitly defined
  - end of file
  - end of message (on network)
- obsolete: group lengths
- allows for private attributes for extension



data dictionary

- where tags are defined (part 6)
- names of tags
  - e.g., (0008,0020) Study Date
- value representation
  - e.g., (0008,0020) VR = DA
- value multiplicity
  - e.g., (0008,0020) VM = 1

dataset excerpt

```
...
(0028,0002) Samples per Pixel              VR=<US>   VL=<0x0002>  [0x0001]
(0028,0004) Photometric Interpretation     VR=<CS>   VL=<0x000c>  <MONOCHROME2 >
(0028,0008) Number of Frames               VR=<IS>   VL=<0x0004>  <124 >
(0028,0010) Rows                           VR=<US>   VL=<0x0002>  [0x0100]
(0028,0011) Columns                        VR=<US>   VL=<0x0002>  [0x0100]
(0028,0100) Bits Allocated                 VR=<US>   VL=<0x0002>  [0x0010]
(0028,0101) Bits Stored                    VR=<US>   VL=<0x0002>  [0x0010]
(0028,0102) High Bit                       VR=<US>   VL=<0x0002>  [0x000f]
...

...
00000560  .. .. .. .. .. .. 28 00  02 00 55 53 02 00 01 00  |..........US....|
00000570  28 00 04 00 43 53 0c 00  4d 4f 4e 4f 43 48 52 4f  |(...CS..MONOCHRO|
00000580  4d 45 32 20 28 00 08 00  49 53 04 00 31 32 34 20  |ME2 (...IS..124 |
00000590  28 00 10 00 55 53 02 00  00 01 28 00 11 00 55 53  |(...US....(...US|
000005a0  02 00 00 01 28 00 00 01  55 53 02 00 10 00 28 00  |....(...US....(.|
000005b0  01 01 55 53 02 00 10 00  28 00 02 01 55 53 02 00  |..US....(...US..|
...
```

*names are shown for clarity - they are not actually encoded

implementation - toolkit

- impractical to parse/create binary tag-value pair formats by hand
- experience with consumer formats
  - toolkits & libraries for TIFF, JPEG, PNG, ZIP, XML
- DICOM toolkits & libraries
  - free, open-source & commercial
  - widely re-used in many commercial & free applications
  - all common languages & platforms
  - encoding, parsing, network services
  - validation tools

toolkit - object parsing

- Java example

```
AttributeList list = new AttributeList();

list.read(new DicomInputStream(
   new FileInputStream(dicomFileName)));

SourceImage volume = SourceImage(list);
BufferedImage[] frames = volume.getBufferedImages();

double[] spacing =
   list.get(TagFromName.PixelSpacing).getDoubleValues();
```

toolkit - object creation

- Java example

```
AttributeList list = new AttributeList();
{
   Attribute a =
        new UnsignedShortAttribute(TagFromName.Rows);
   a.addValue(256);
   list.put(a);
}
...
list.write(outFile,TransferSyntax.ExplicitVRLittleEndian);
```

toolkit - higher level support

- Java example

```
AttributeList list;

GeometryOfVolume geometry = new GeometryOfVolume(list);

double[] location = new double[3];      // in 3d space

geometry.lookupImageCoordinate(location,col,row,frame);
```

toolkit - validation tool

- vital tool for creators of images
- correctness of encoding
- correctness of object

```
% dciodvfy XH1323D5
Error - Media Storage SOP Instance UID different from SOP
   Instance UID
Error - Value invalid for this VR - (0x0029,0x2920) LO ?
   LO [0] = <$%
$1$> - Character invalid for this VR = '' (0xd)
DXImageForPresentation
Warning - Optional Type 1C Conditional
   Element=<PlanarConfiguration> Module=<ImagePixel>
```

nesting: sequences

- some descriptions require repeating regular structures
- special VR: SQ - Sequence of Items
- each Item is an entire dataset
- allows for unlimited nesting depth
- may be fixed length or delimited

sequence excerpt

```
…
(0028,9110) Pixel Measures Sequence  VR=<SQ>   VL=<0xffffffff>
(fffe,e000) Item                               VL=<0xffffffff>
(0018,0050) Slice Thickness          VR=<DS>   VL=<0x0008>  <1.20000 >
(0028,0030) Pixel Spacing            VR=<DS>   VL=<0x0012>  <0.937500\0.937500 >
(fffe,e00d) Item Delimitation Item
(fffe,e0dd) Sequence Delimitation Item
…
```

*Note that string values are padded to even lengths

*Note the backslash ‘\’ delimiter between string values

*Sequence and Item VL of 0xffffffff means delimited

*Names are shown for clarity - they are not actually encoded

private attributes for extensions

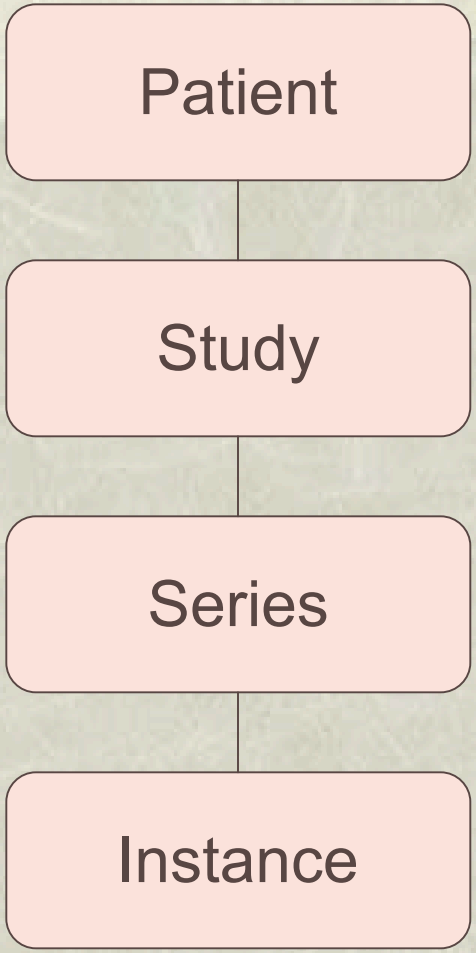
- odd group numbers are all private
- (gggg,00cc) is a private creator string
- (gggg,ccxx) is the block defined for that creator

(0019,0010)	“David’s Stuff”
(0019,0011)	“Harry’s Stuff”
(0019,1001)	1st of david’s private attributes
(0019,1002)	2nd of david’s private attributes
…	
(0019,1101)	1st of harry’s private attributes
(0019,1102)	2nd of harry’s private attributes
…	

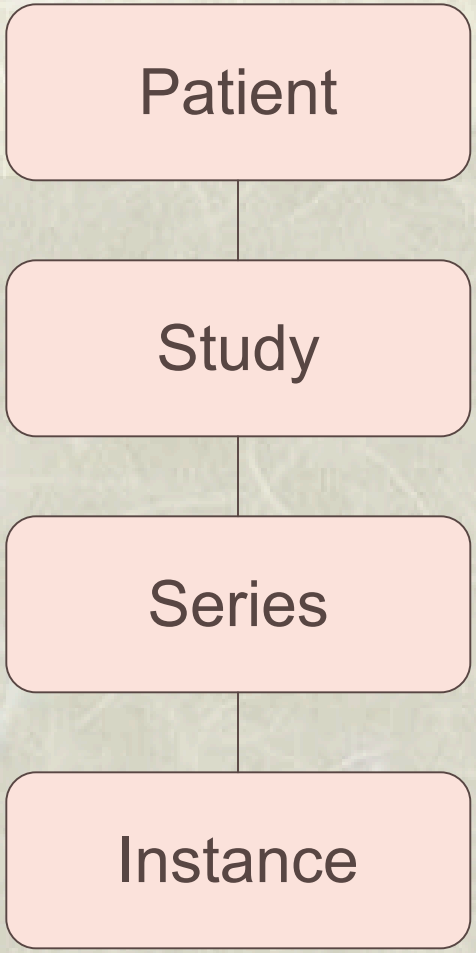
information objects

- unconstrained list of attributes insufficient for interoperability
- modality-specific objects
- information object definition (IOD)
- modules (mandatory/optional)
- attributes (mandatory/optional)
- information model
- defined in Part 3

information model



composite IOD modules



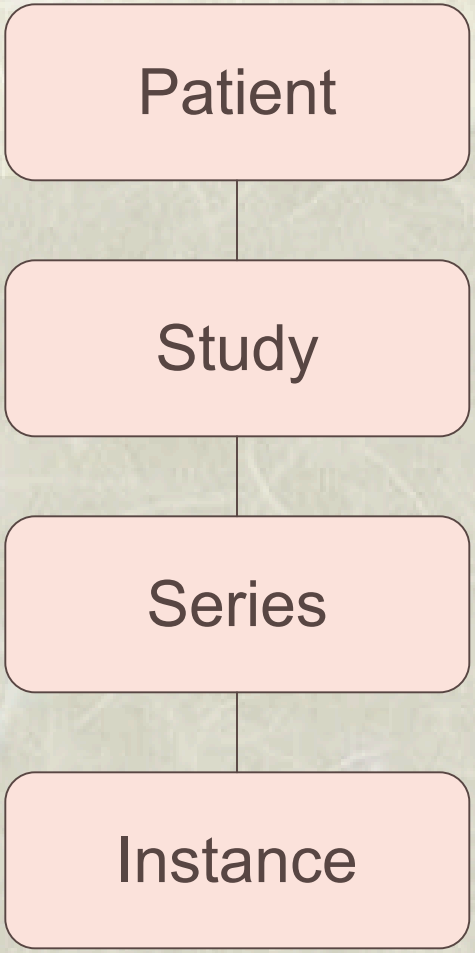
General Patient

General Study
Patient Study

General Series
General Equipment
Frame of Reference

General Image
Image Plane
Image Pixel
SOP Common

MR image IOD



General Patient

General Study
Patient Study

General Series
General Equipment
Frame of Reference

General Image
Image Plane
Image Pixel
SOP Common

MR Image

image IODs

*Computed Radiography (CR) Image

*Computed Tomography (CT) Image

Enhanced Computed Tomography (CT) Image

*Magnetic Resonance (MR) Image

Enhanced MR Image

MR Spectroscopy

Raw Data

*Nuclear Medicine (NM) Image

*Ultrasound (US) Image

Ultrasound (US) Multi-frame image

*Secondary Capture Image

Multi-frame Single Bit Secondary Capture Image

Multi-frame Grayscale Byte Secondary Capture Image

Multi-frame Grayscale Word Secondary Capture Image

Multi-frame True Color Secondary Capture Image

X-Ray Angiographic (XA) Image

X-Ray RF Image

Positron Emission Tomography (PET) Image

Hardcopy Grayscale Image

Hardcopy Color Image

Digital X-Ray (DX) Image

Digital Mammography X-Ray Image

Digital Intra-oral X-Ray Image

Visible Light (VL) Endoscopic Image

Visible Light (VL) Microscopic Image

Visible Light (VL) Slide-Coordinates Microscopic Image

Visible Light (VL) Photographic Image

Video Endoscopic Image

Video Microscopic Image

Video Photographic Image

non-image IODs

- Radio-Therapy (RT) Image
- Radio-Therapy (RT) Dose
- Radio-Therapy (RT) Structure Set
- Radio-Therapy (RT) Plan Information
- Radio-Therapy (RT) Beams Treatment Record
- Radio-Therapy (RT) Brachy Treatment Record
- Radio-Therapy (RT) Treatment Summary Record
- Basic Voice Audio Waveform
- 12-Lead Electrocardiogram Waveform
- General Electrocardiogram Waveform
- Ambulatory Electrocardiogram Waveform
- Hemodynamic Information Waveform
- Basic Cardiac Electrophysiology Waveform
- Spatial Registration
- Spatial Fiducials

- Basic Text Structured Report
- Enhanced Structured Report
- Comprehensive Structured Report
- Key Object Selection Document
- Mammography CAD
- Chest CAD
- Procedure Log
- Grayscale Softcopy Presentation State
- Stored Print
- *Standalone Overlay
- *Standalone Curve
- *Basic Study Descriptor
- *Standalone Modality LUT
- *Standalone VOI LUT
- Standalone PET Curve

composite IODs

- all image and non-image composite IODs share the same basic information model
- can use common architecture to store, exchange and query objects (e.g., in PACS archive)
- as much commonality factored out as possible
- infrastructure is readily extensible to new modalities as well as private extensions

example module

IMAGE PLANE MODULE ATTRIBUTES

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

*Type 1 required, 2 required, may be zero length, 3 optional

persistent objects

- instances of composite IODs are
  - persistent
  - immutable
  - uniquely identified
  - may be referenced
- SOP Instance UID
  - *globally* unique
  - e.g., *1.3.6.1.4.1.5962.1.1.5017.1.2.2791*

unique identifiers

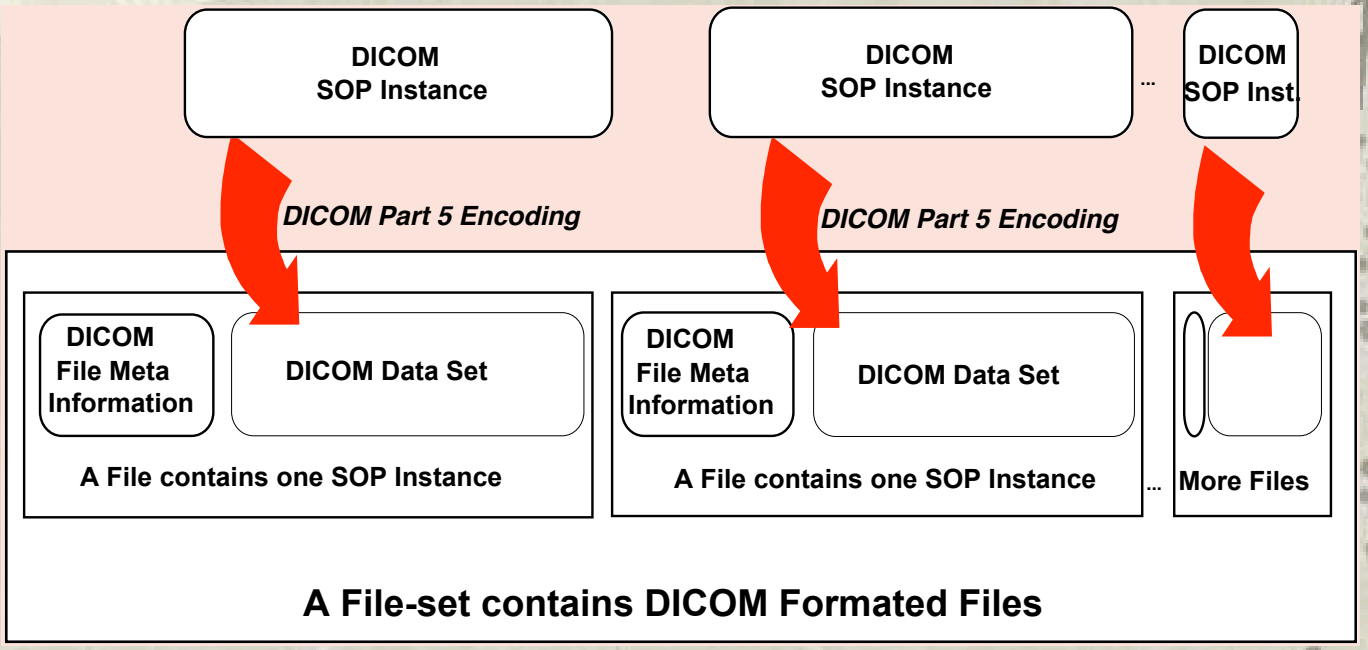
- at each level of information model (other than patient)
- Study Instance UID
- Series Instance UID
- SOP Instance UID

- locates every instance within model
- new object creators MUST create new UIDs

meta-information header

- dataset is defined for network transmission
- network negotiation of:
  - encoding (transfer syntax)
  - type of object (SOP class)
- no negotiation possible on media, so interchange file format defines
  - meta-information header

meta information header



types of content in images

- management & identification
  - e.g., patient names, study date, UIDs
- descriptive
  - e.g., study & series description
- common technique
  - e.g., pixel spacing, slice thickness, 3D position and orientation, timing & gating parameters
- modality-specific technique
  - e.g., echo time, pulse sequence

3D position & orientation

- frame of reference module
  - UID of coordinate system
  - shared between objects (e.g. slices)
- coordinate system
  - patient (not gantry) relative
  - right-handed Cartesian
  - Left Posterior Head +ve
  - arbitrary (but consistent) origin

3D position & orientation

- Image Plane Module
- Image Position (Patient) attribute
  - coordinate (XYZ) mm offset from origin
  - top left hand corner (TLHC)
  - center of voxel
- Image Orientation (Patient) attribute
  - unit vector of row (XYZ)
  - unit vector of column (XYZ)

3D position & orientation

- 300mm FOV axial slice at isocenter
- Image Position (Patient)
  - -150.0\-150.0\0.0
- Image Orientation (Patient)
  - 1.0\0.0\0.0 (i.e., row left)
  - 0.0\1.0\0.0 (i.e., column posterior)
- vector is necessary
  - acquisition may be oblique in 1 or more axes
  - especially if graphically prescribed

describing orientation

- given row and column vectors, for each
  - find largest absolute value
    - e.g., 0.72\0.69\0.00, largest is X (Left-Right)
  - determine sign
    - e.g., 0.72\0.69\0.00, X is +ve, therefore Left
- to further qualify oblique
  - find next largest absolute value
    - e.g., 0.72\0.69\0.00, next is Y (Pos-Ant) describe “LP”
- more complex example
    - 0.9994\-0.0078\-0.0340\0.0000\0.9744\-0.2250
    - L(AF)\PF, i.e., oblique axial (lumbar disk)

use of position & orientation

- arrange slices in same acquisition
  - if parallel, same orientation vectors
  - sort position along normal to orientation
- cross-reference location in slices in different acquisitions but same frame of reference
- spatial registration between frames of reference
  - encode as affine transform in spatial registration IOD
- specify location of fiducials
  - for landmark based registration

extracting volumes

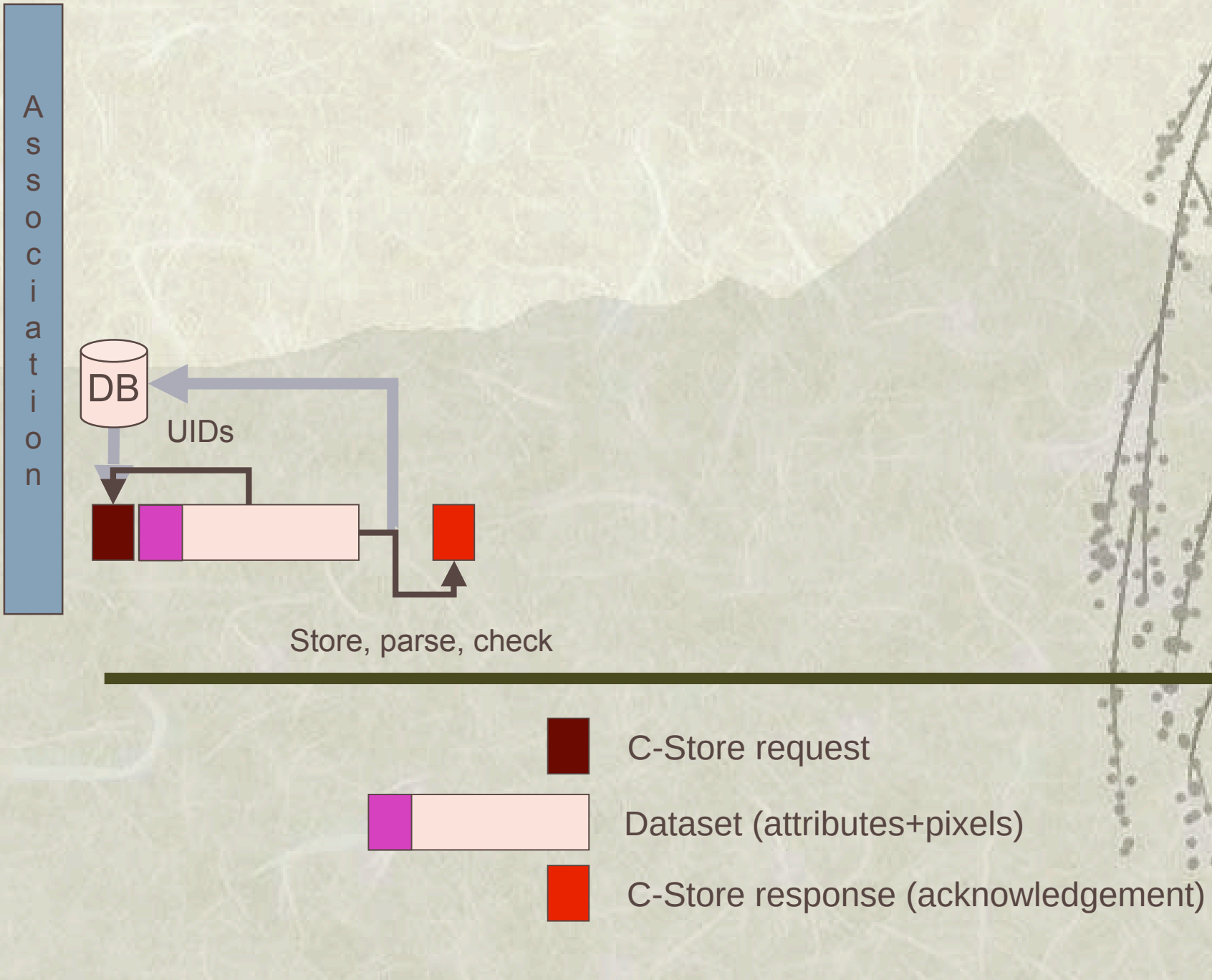
- pre-DICOM
  - vendors stored one slice per image file
- DICOM inherited this legacy
- images within a series
  - are they all the same volume ?
  - are they parallel ?
  - are they contiguous ?
  - are they sorted ?
  - are they acquired at the same time ?
- DICOM requires no specific series semantics

extracting volumes

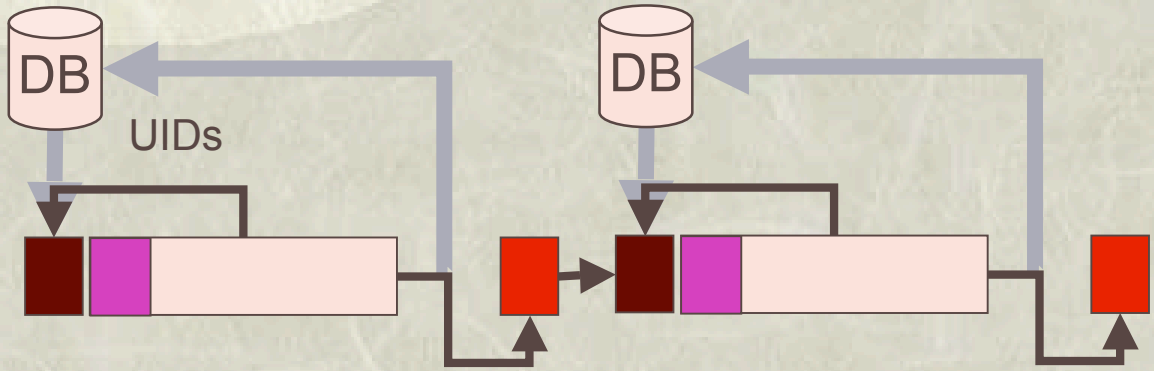
- given a series of images, partition
  - rows, columns same
  - pixel spacing (therefore FOV) same
  - image orientation same (parallel)
  - reconstruction interval same (position along normal to orientation)
  - timing same (can be a challenge)
  - pulse sequence & parameters same

new approach - new IOD

- enhanced multi-frame MR image
- address issues with decade old IOD
  - allow multiple slices in single object
  - potential transfer performance gains
  - communicate dimension navigation information known by creating application, rather than try to derive it retrospectively
  - encode new technique attributes
  - increase consistency: mandatory attributes


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

Association

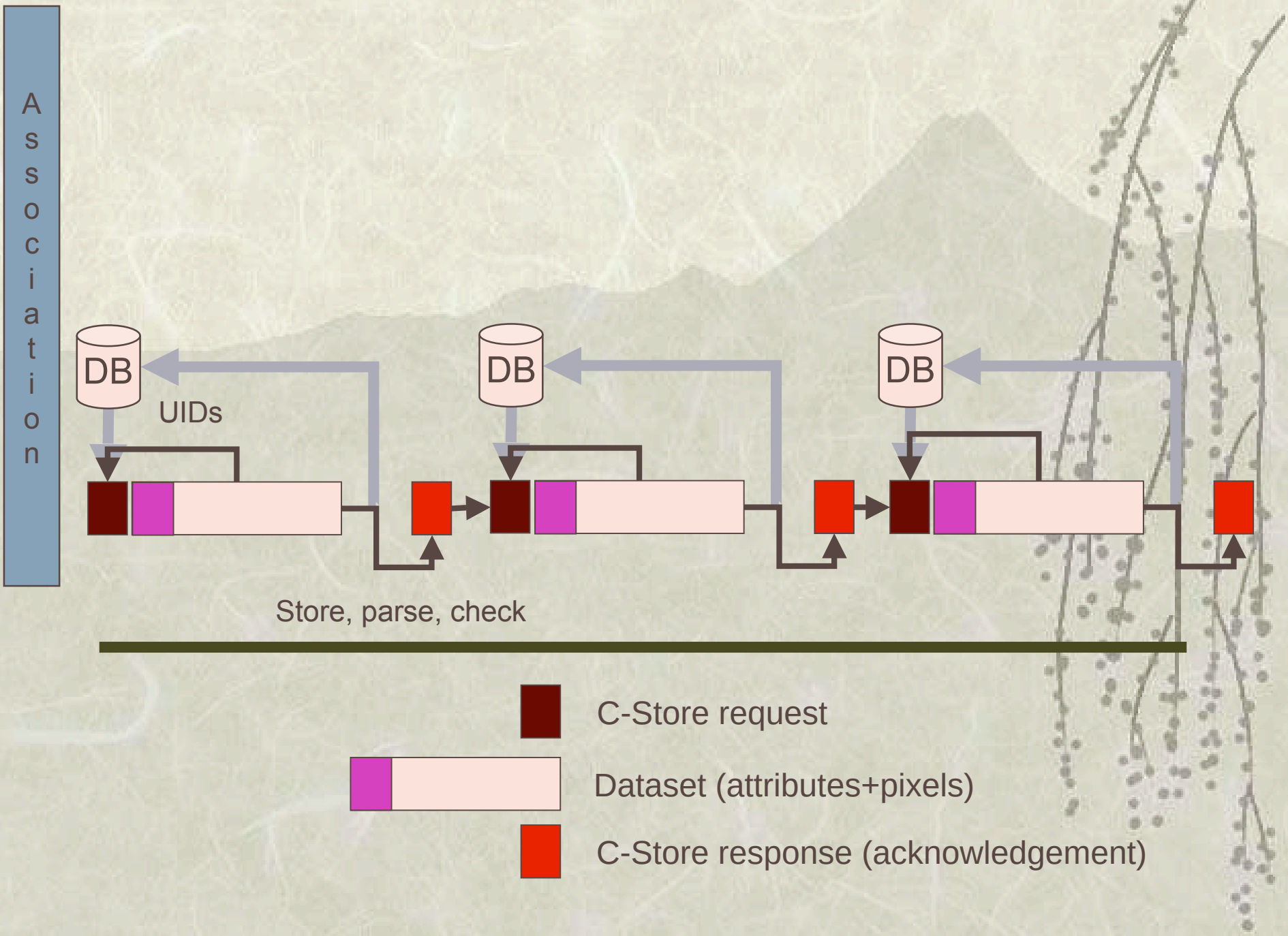


Store, parse, check

C-Store request

Dataset (attributes+pixels)

C-Store response (acknowledgement)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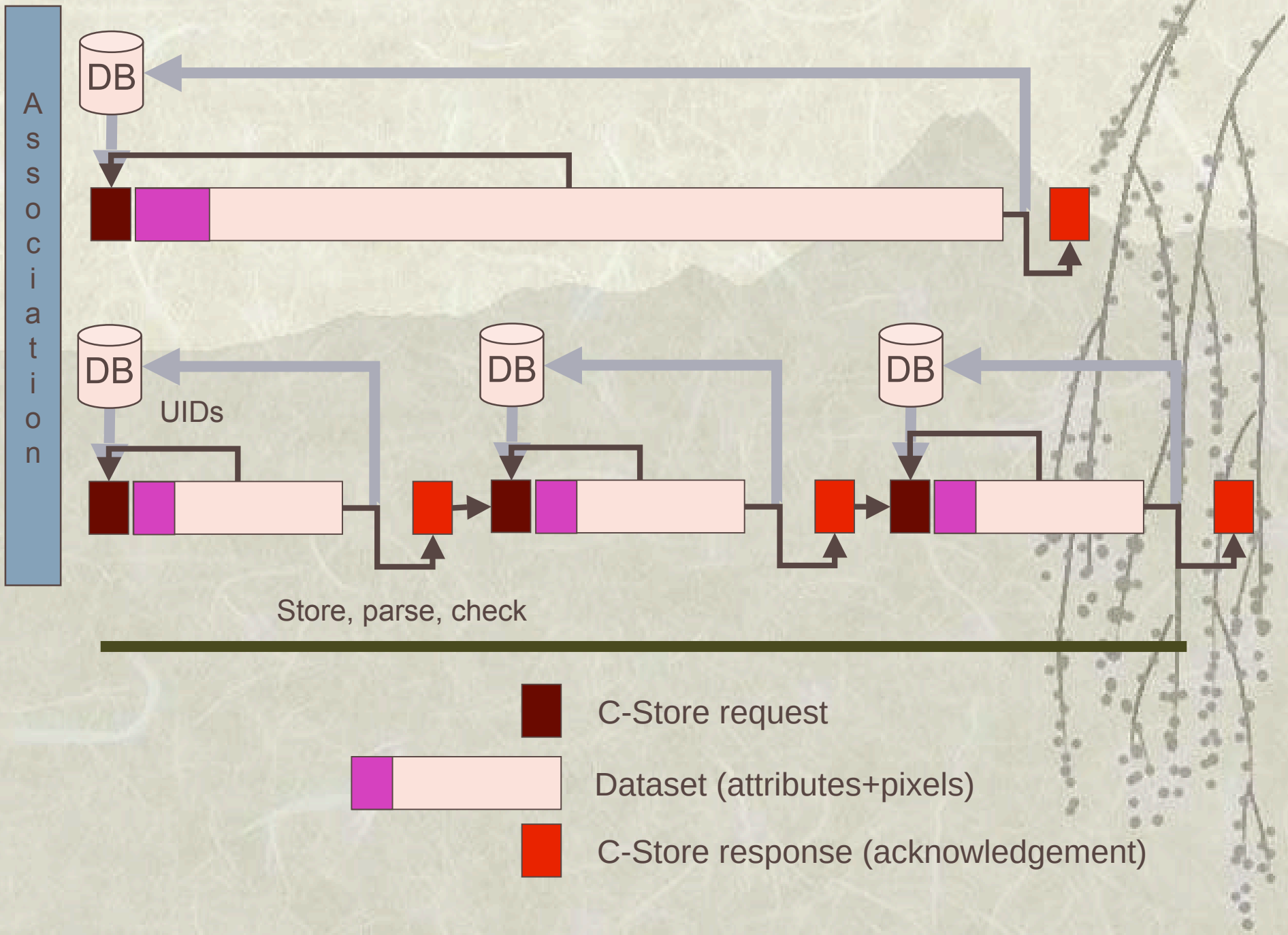
Association
DB
DB
UIDs
DB
DB
Store, parse, check
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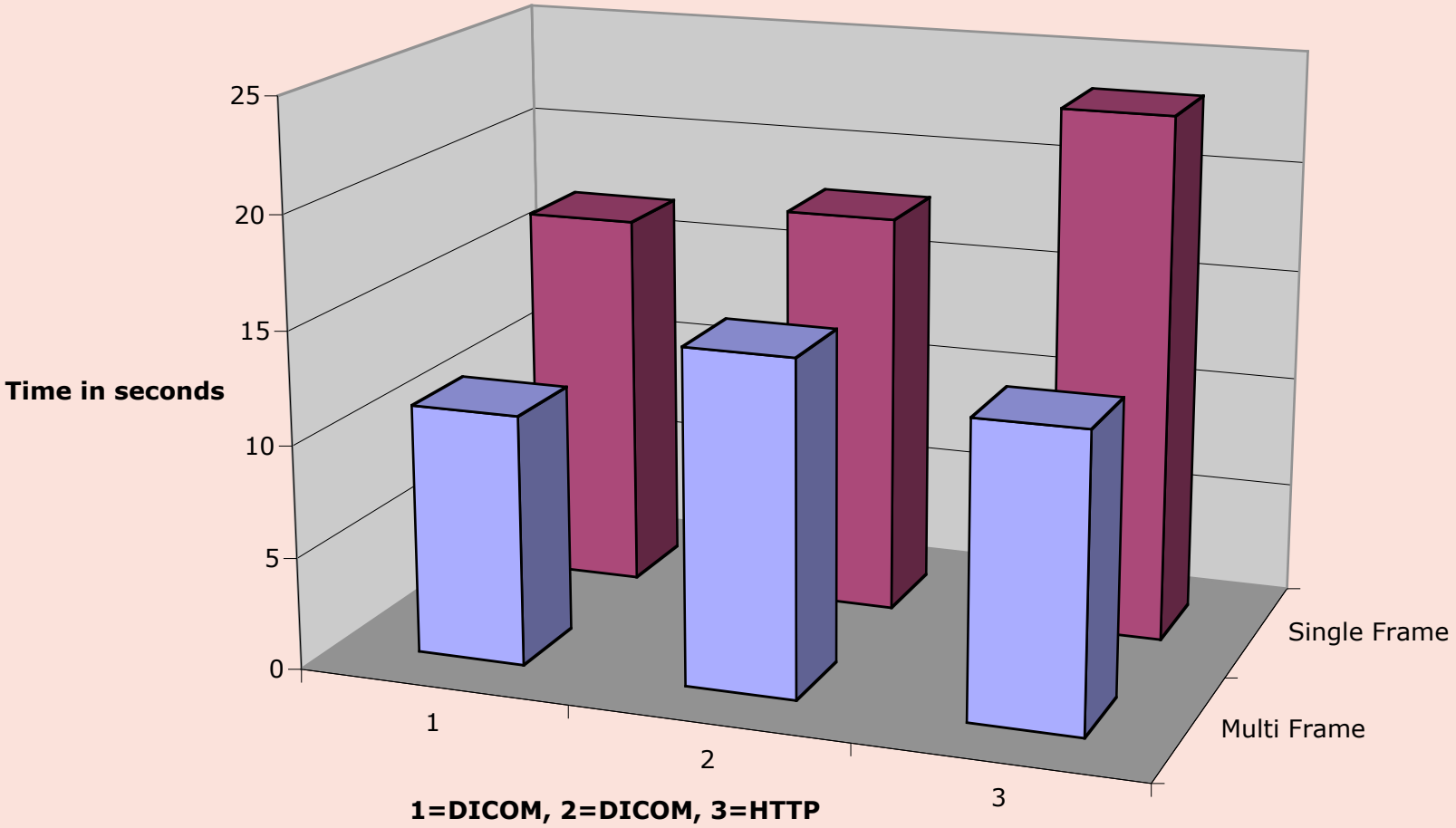
CTA - 548x512x512 (275MB) File read/transfer/save (GB Ethernet)

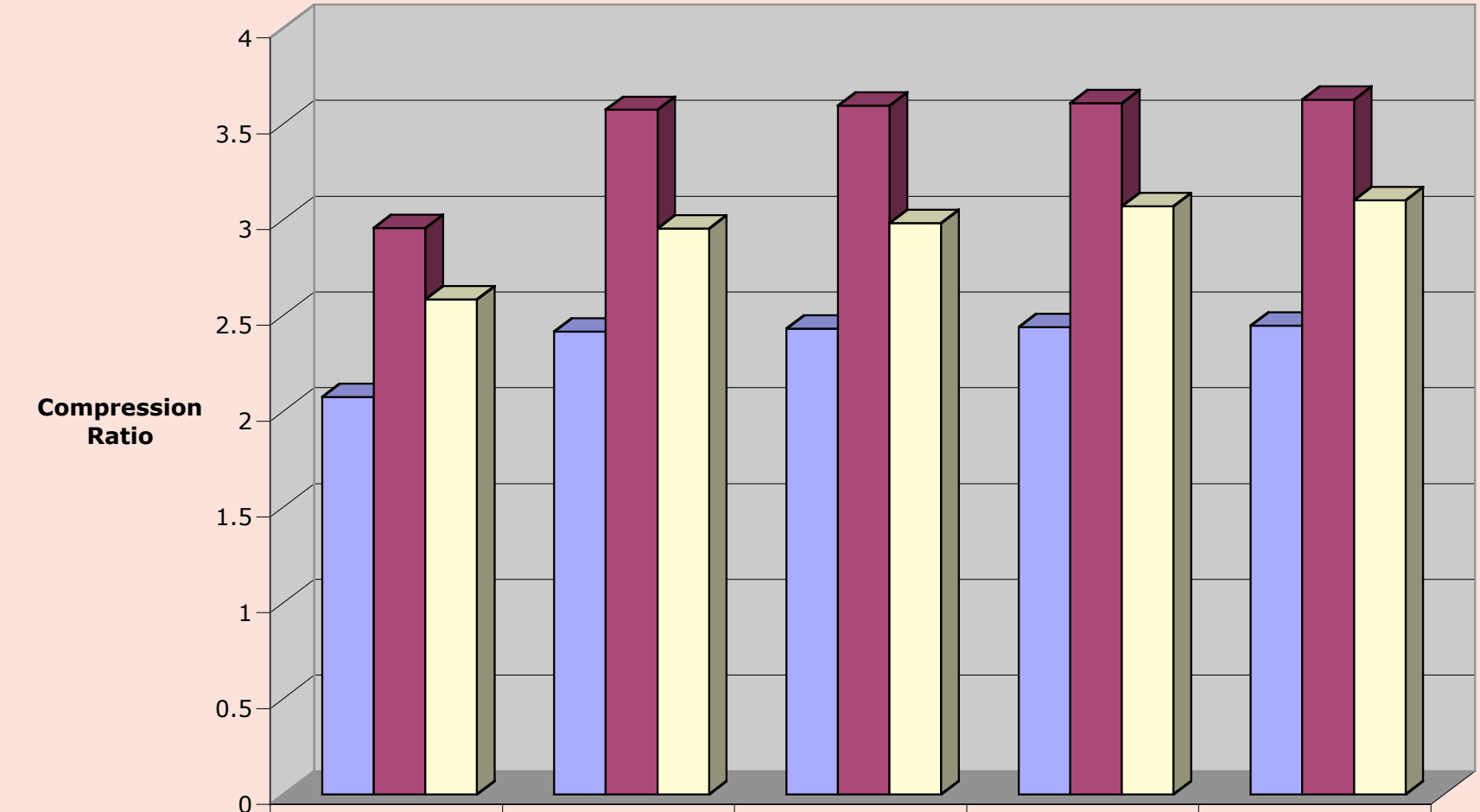


	1	2	3
Multi Frame	11.14111111	14.86703704	13.07333333
Single Frame	16.905	17.97	23.42666667

compression

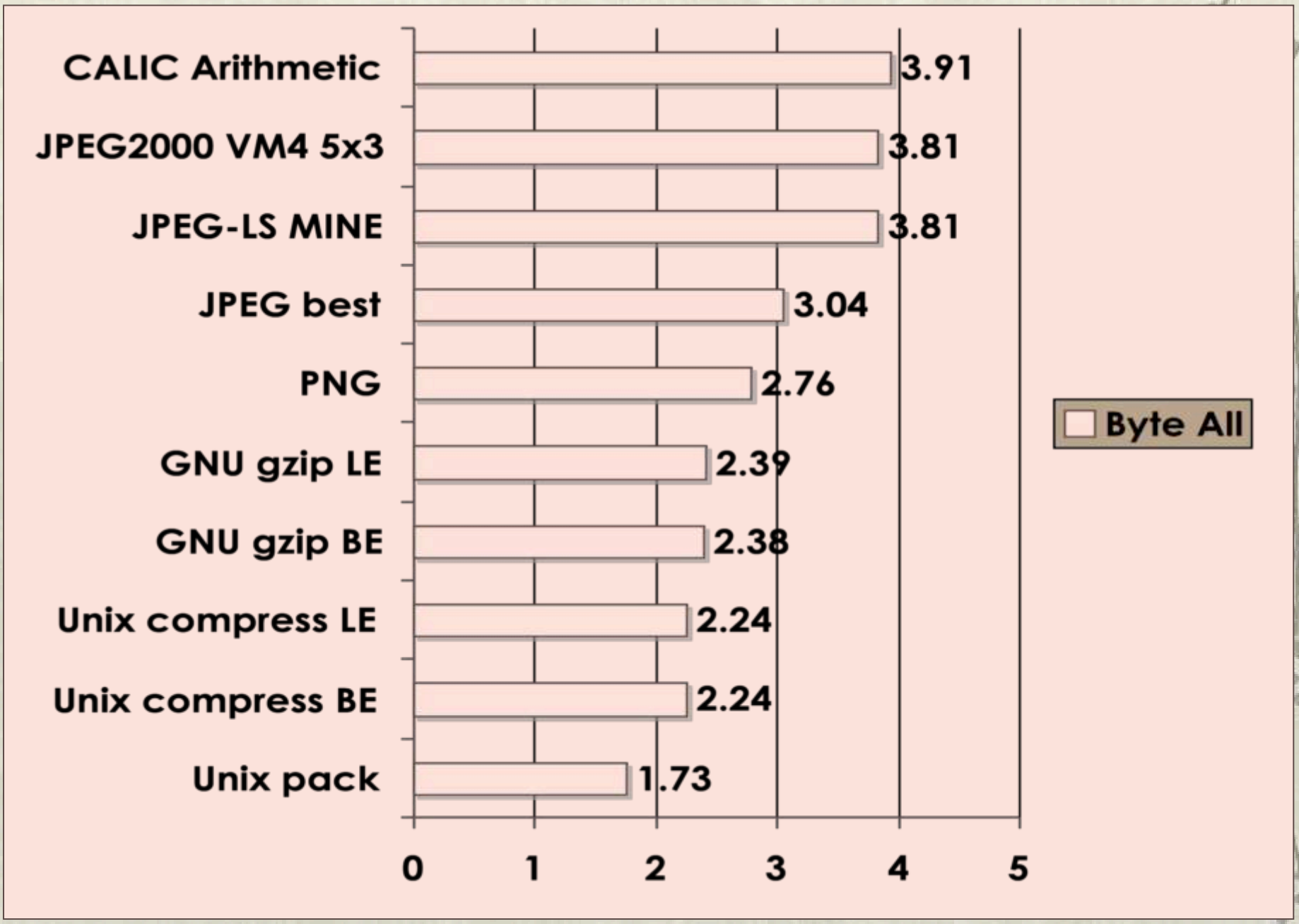
- lossless for fMRI applications
- DICOM offers range of ISO schemes
  - JPEG lossless
  - JPEG-LS
  - JPEG 2000 (2D and multidimensional)
- all such image-aware coders significantly outperform naïve dictionary coders like zip

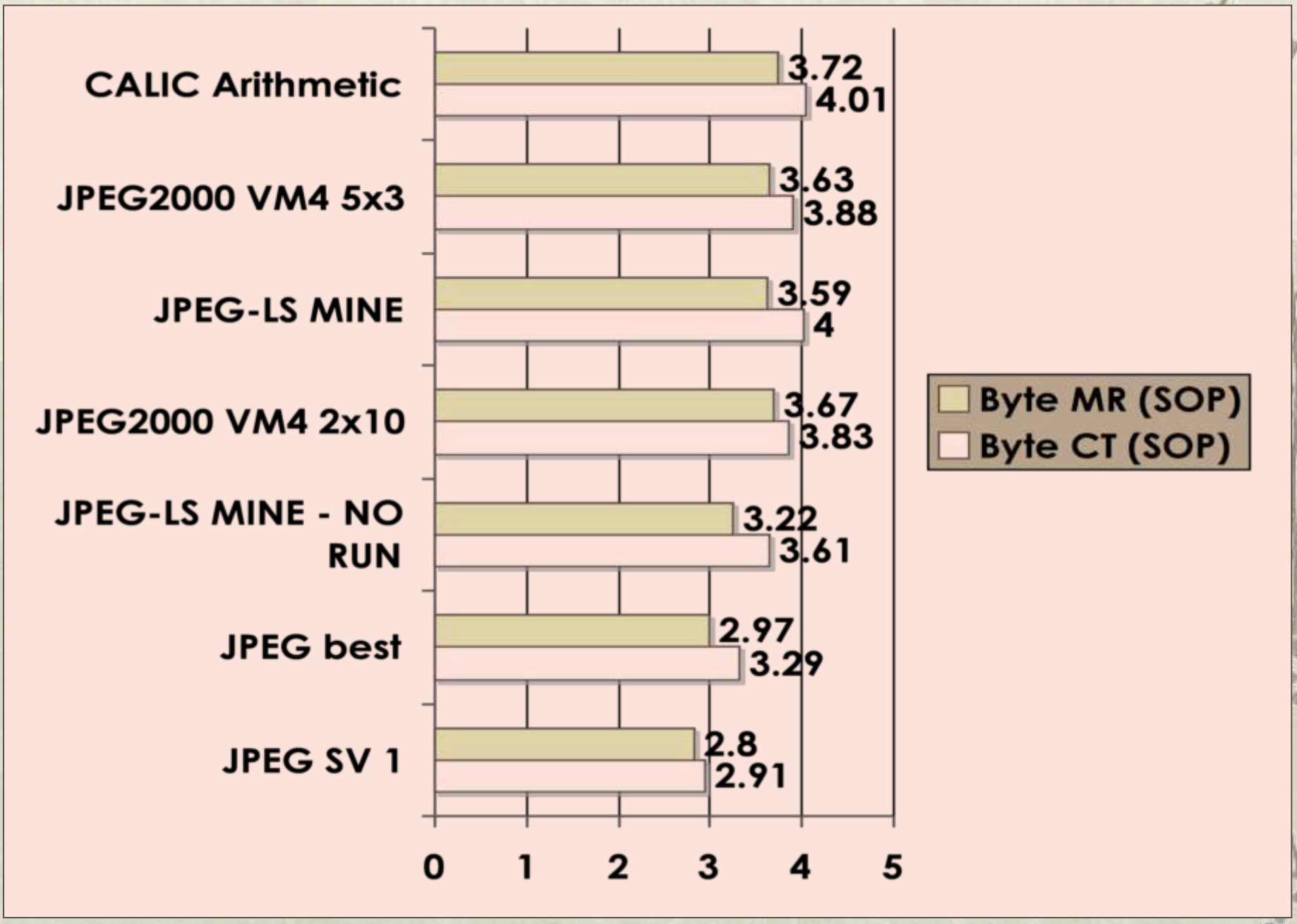
Lossless JPEG 2000 Compression (Alexis Tzannes, Aware, 2003)



	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

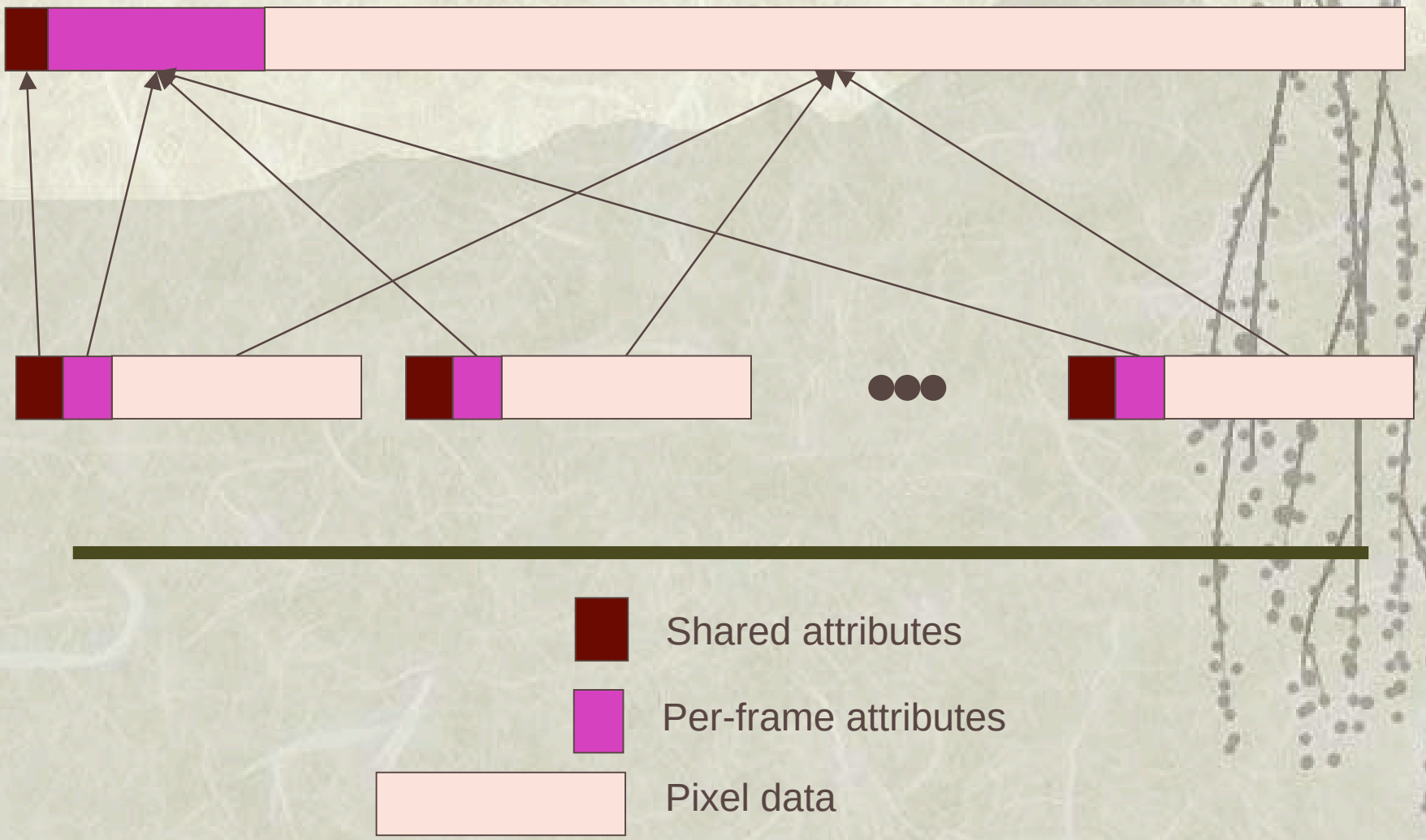

CALIC Arithmetic
3.91
JPEG2000 VM4 5x3
3.81
JPEG-LS MINE
3.81
JPEG best
3.04
PNG
2.76
GNU gzip LE
2.39
GNU gzip BE
2.38
Unix compress LE
2.24
Unix compress BE
2.24
Unix pack
1.73
0
1
2
3
4
5
Byte All


CALIC Arithmetic
3.72
4.01
JPEG2000 VM4 5x3
3.63
3.88
JPEG-LS MINE
3.59
4
JPEG2000 VM4 2x10
3.67
3.83
JPEG-LS MINE - NO RUN
3.22
3.61
JPEG best
2.97
3.29
JPEG SV 1
2.8
2.91
0
1
2
3
4
5
Byte MR (SOP)
Byte CT (SOP)

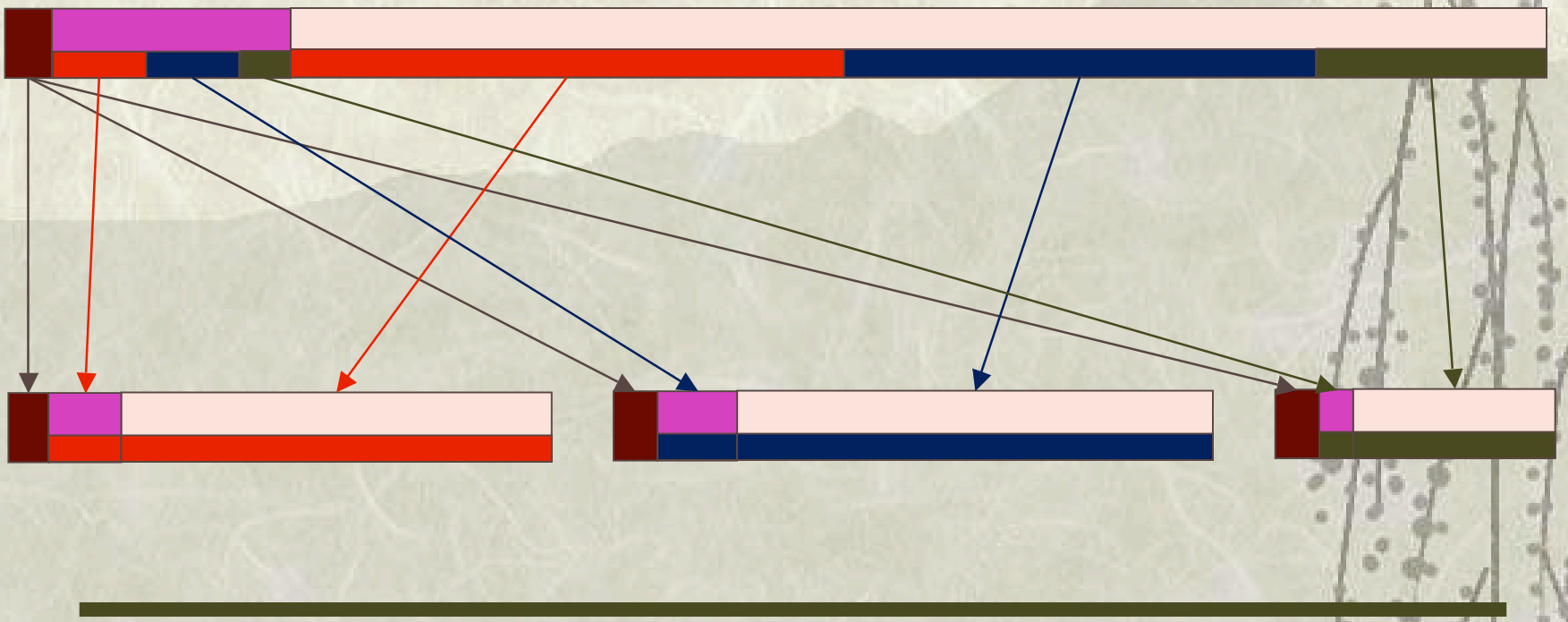
enhanced MR IOD features

- multi-frame pixel data
- comprehensive, mandatory, coded attributes
- shared and per-frame functional groups
  - compact & makes explicit what doesn't change
- dimensions
  - *a priori* hints as to how the frames are organized
- stacks
- temporal positions
- concatenations
  - reasonable size chunks, view in batches as acquired
  - address single file pixel data size limits (2^32-2 or 4GB)

multi-frame functional groups



concatenations



Shared attributes

Per-frame attributes

Pixel data

application support

- more technique-specific attributes
  - majority of them mandatory
- more technique-specific terms
  - categorizing acquisition types
  - describing acquisition parameters
- less dependence on private attributes
- better organization of data

mandatory attributes

	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)

MR Image Type Value 3

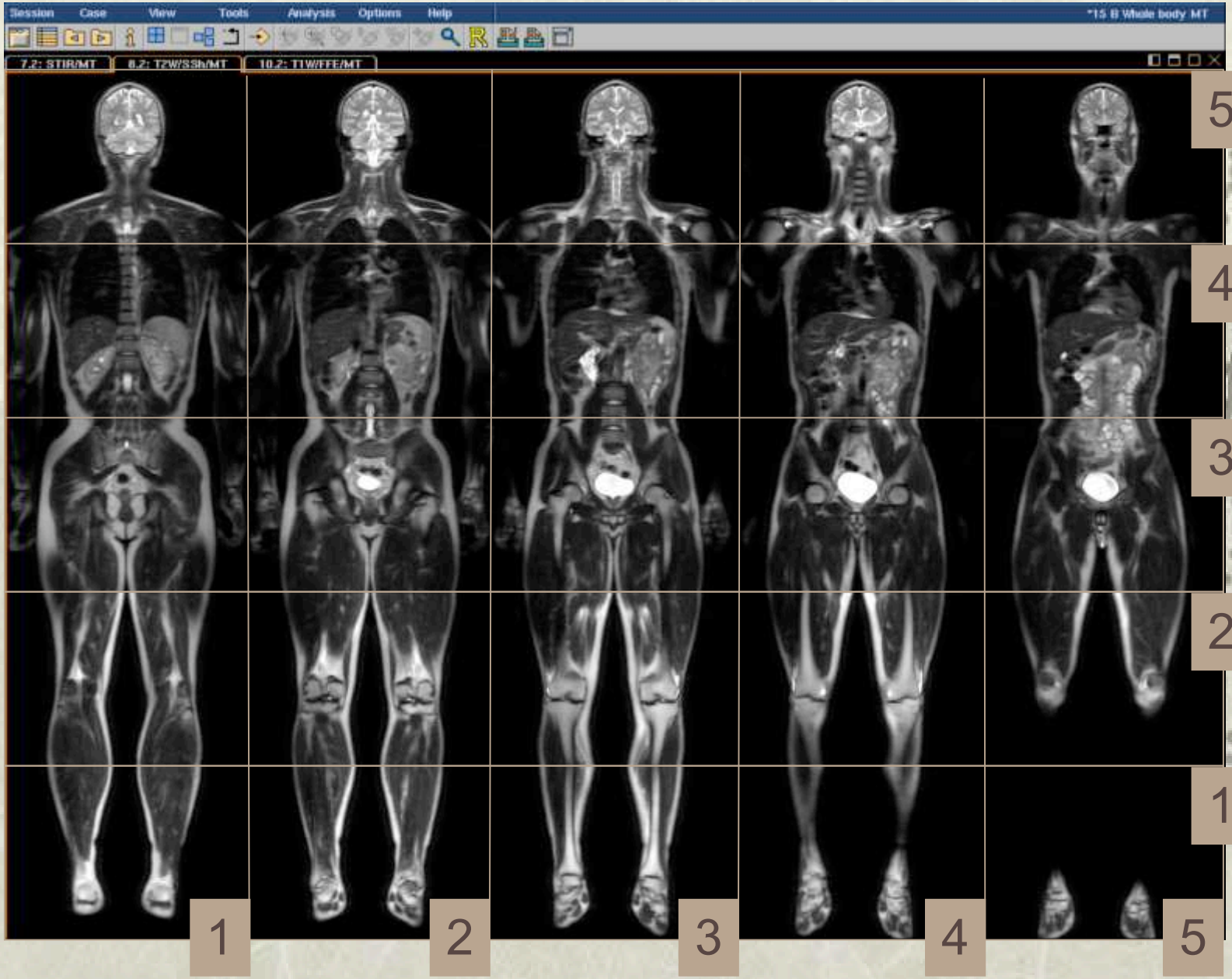
- original MR IOD
  - MPR, PROJECTION IMAGE, T1 MAP, T2 MAP, DIFFUSION MAP, DENSITY MAP, PHASE MAP, VELOCITY MAP, IMAGE ADDITION, PHASE SUBTRACT, MODULUS SUBTRACT, OTHER
- enhanced MR IOD (image "flavor")
  - common to CT and MR
    - ANGIO, FLUOROSCOPY, LOCALIZER, MOTION, PERFUSION, PRE_CONTRAST, POST_CONTRAST, REST, STRESS, VOLUME
  - MR-specific
    - ANGIO_TIME, METABOLITE_MAP, CINE, DIFFUSION, FLOW_ENCODED, FLUID_ATTENUATED, FMRI, MAX_IP, MIN_IP, M_MODE, METABOLITE_MAP, MULTIECHO, PROTON_DENSITY, REALTIME, STIR, TAGGING, TEMPERATURE, T1, T2, T2_STAR, TOF, VELOCITY

MR Image Type Value 4

- original MR IOD
  - none
- enhanced MR IOD (derived pixel contrast)
  - common to CT and MR
    - ADDITION, DIVISION, MASKED, MAXIMUM, MEAN, MINIMUM, MTT, MULTIPLICATION, RCBF, RCBV, RESAMPLED, STD_DEVIATION, SUBTRACTION, T_TEST, TTP, Z_SCORE
  - MR-specific
    - ADC, DIFFUSION, DIFFUSION_ANISO, DIFFUSION_ATTNTD, METABOLITE_MAP, NEI, R_COEFFICIENT, RHO, SCM, SNR_MAP, T1_MAP, T2_STAR_MAP, T2_MAP, TCS, TEMPERATURE, VELOCITY

organization of 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.
- dimensions
  - specify intended order of traversal, such as space, then time (e.g., for cardiac cine loops)
- stacks
  - groups of spatially-related slices, repeatable
- temporal position index



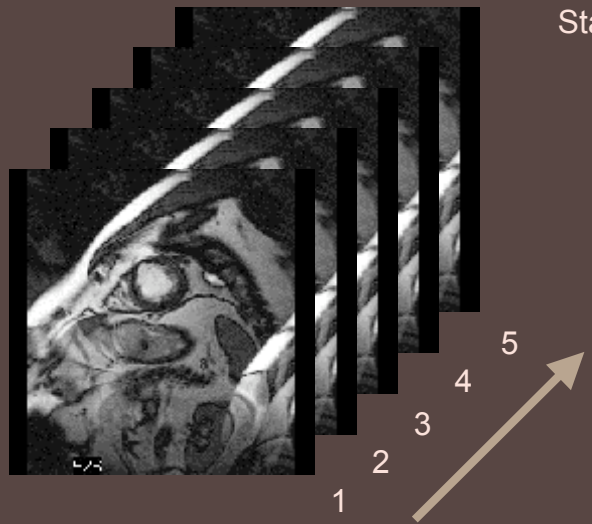
Stack ID

In-Stack Position

Dimensions

Start with a dimension of space.

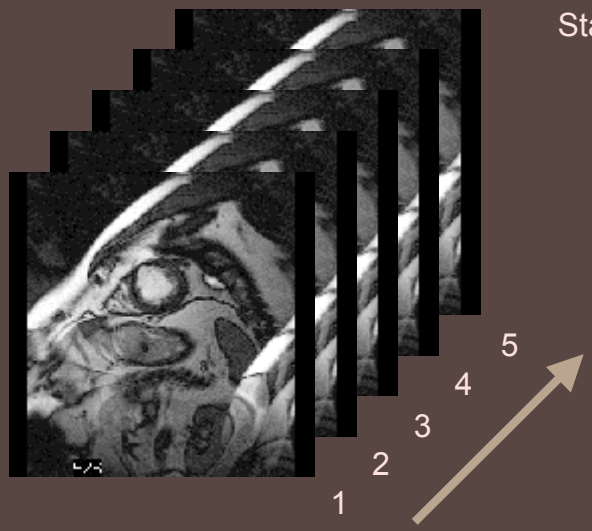
A set of contiguous slices through the heart.



Space

Trigger Delay Time

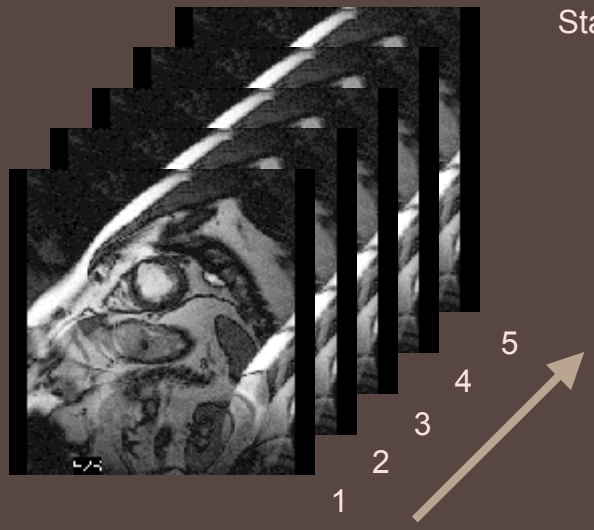
Temporal Position Index



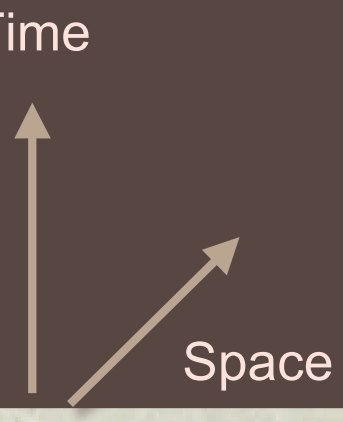
48 ms 2

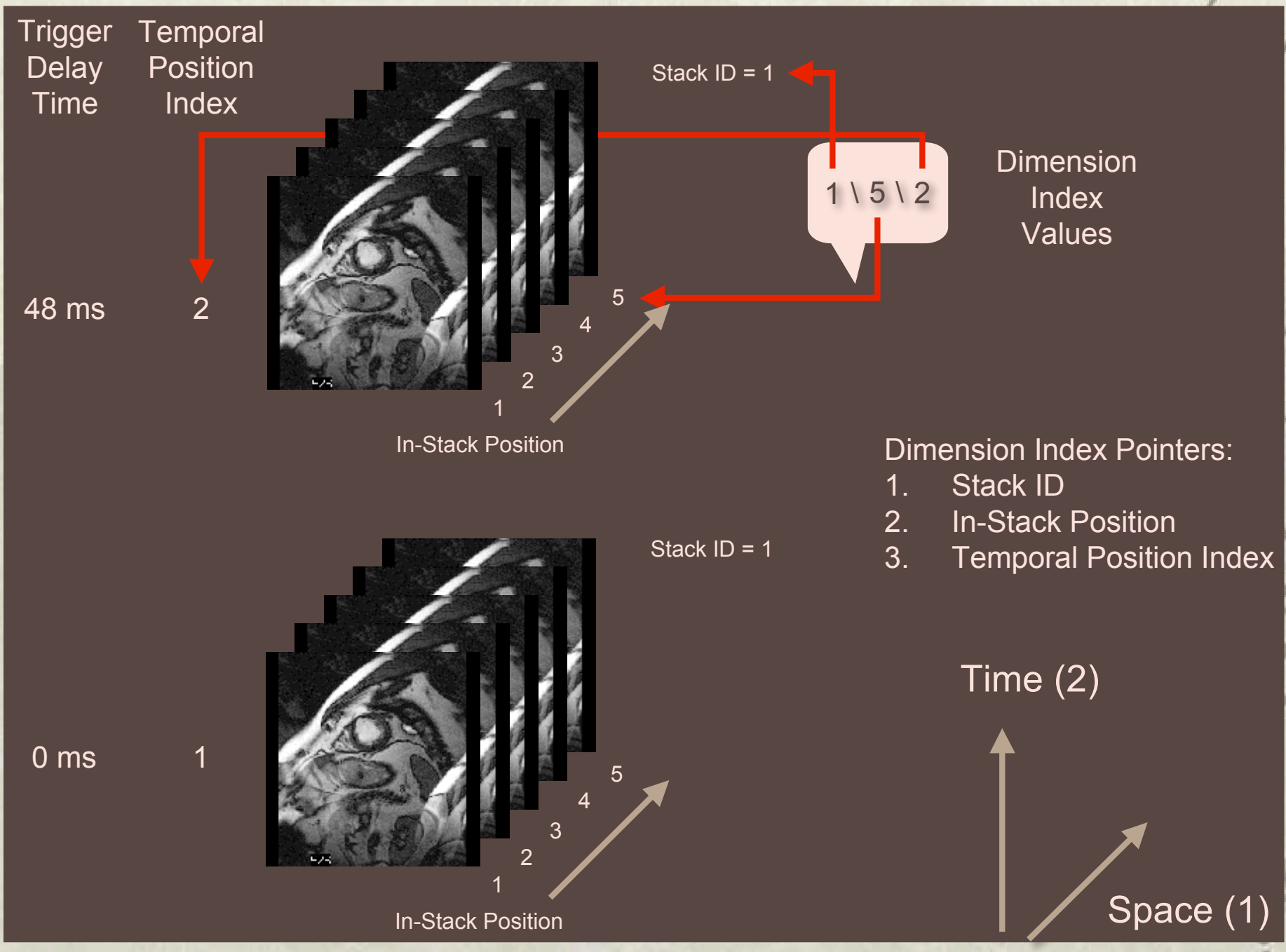
Add dimension of time (delay time from R-wave).

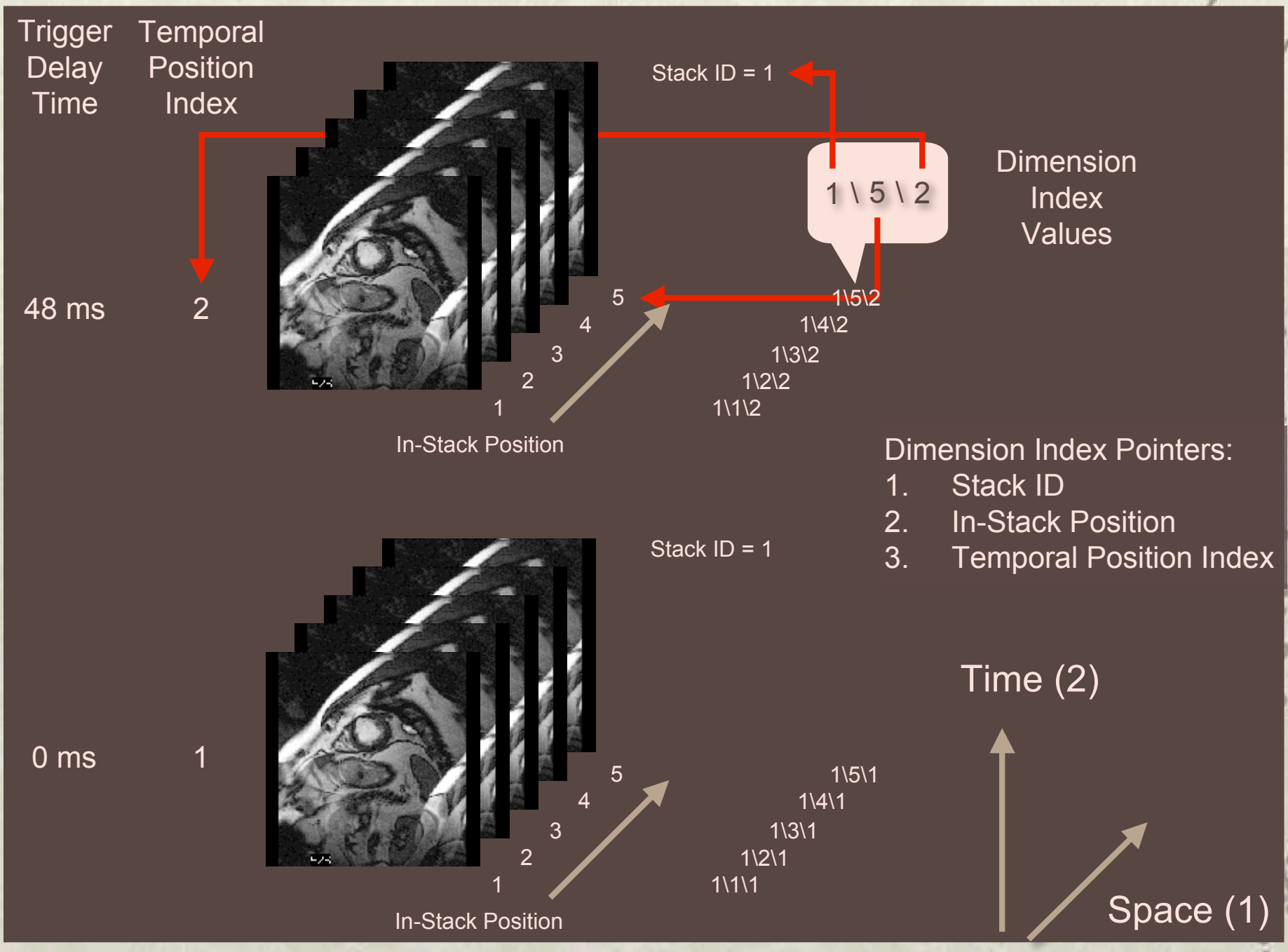
Sets of contiguous slices throughout cardiac cycle.

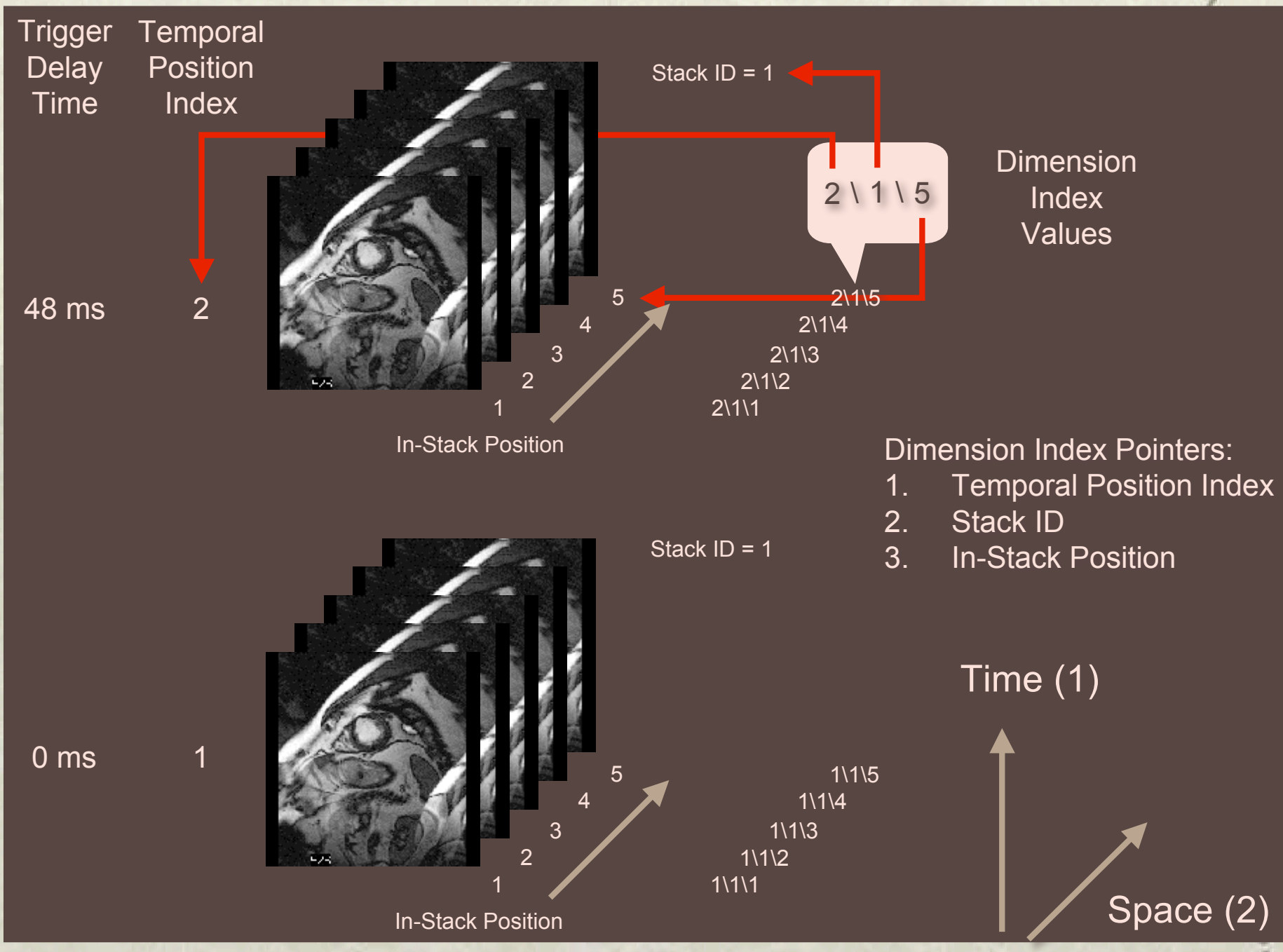


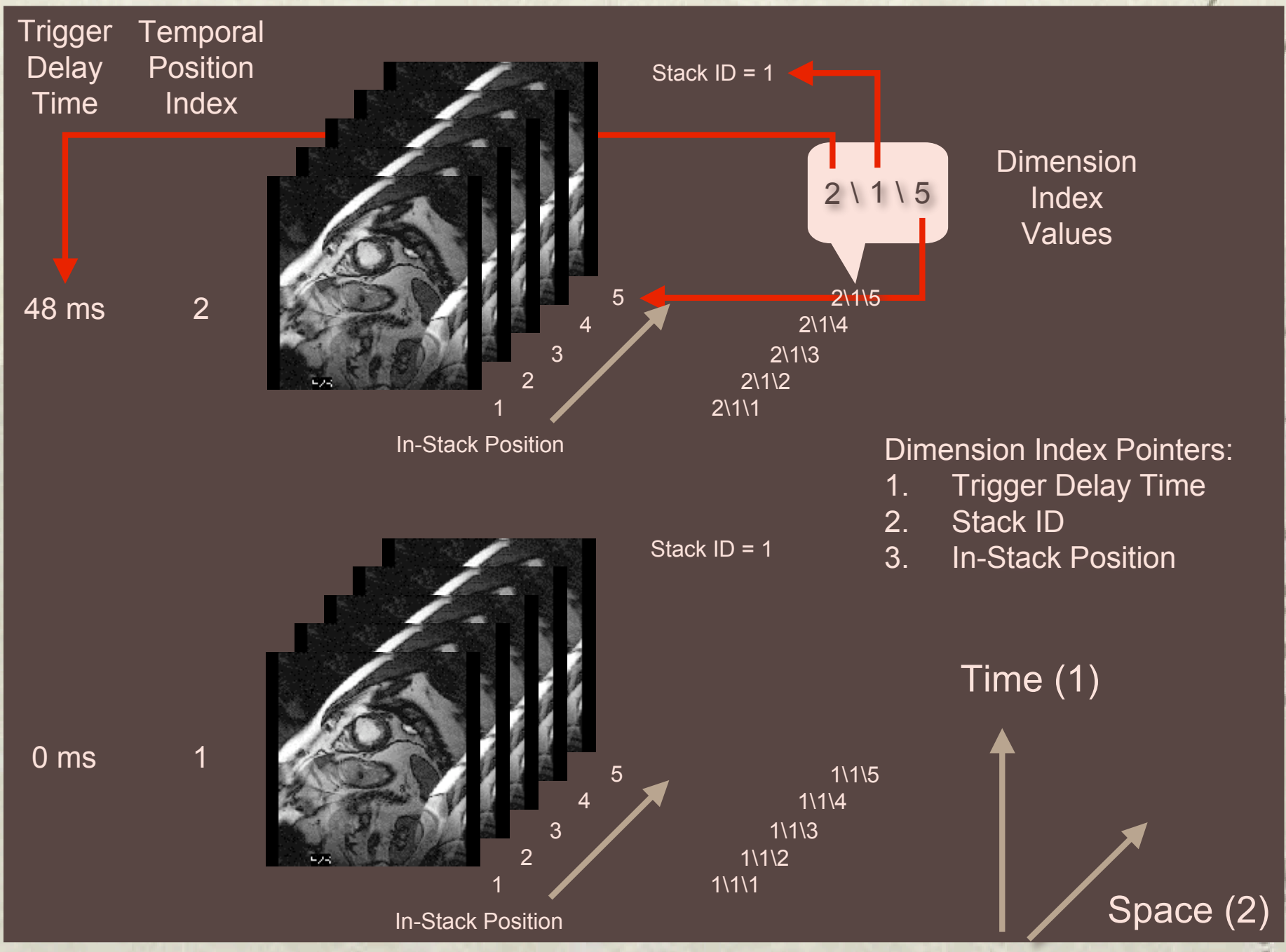
0 ms 1




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
In-Stack Position
1\5\2
1\4\2
1\3\2
1\2\2
1\1\2
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
1\5\1
1\4\1
1\3\1
1\2\1
1\1\1
Time (2)
Space (1)

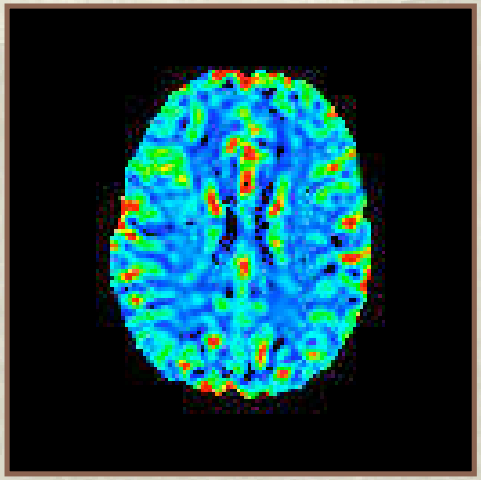

Trigger Delay Time
Temporal Position Index
Stack ID = 1
2 \ 1 \ 5
Dimension Index Values
48 ms
2
5
4
3
2
1
2\1\5
2\1\4
2\1\3
2\1\2
2\1\1
In-Stack Position
Dimension Index Pointers:
1. Temporal Position Index
2. Stack ID
3. In-Stack Position
Stack ID = 1
0 ms
1
5
4
3
2
1
1\1\5
1\1\4
1\1\3
1\1\2
1\1\1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

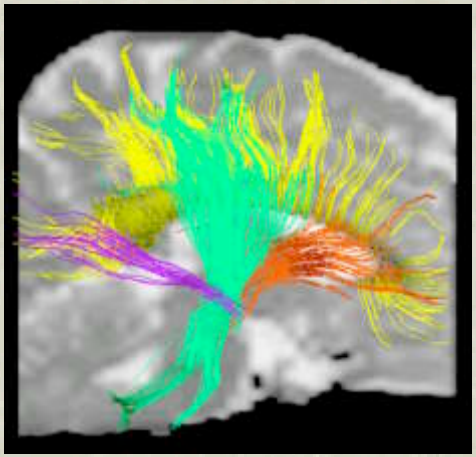

Trigger Delay Time
Temporal Position Index
Stack ID = 1
2 \ 1 \ 5
Dimension Index Values
48 ms
2
5
4
3
2
1
2\1\5
2\1\4
2\1\3
2\1\2
2\1\1
In-Stack Position
Dimension Index Pointers:
1. Trigger Delay Time
2. Stack ID
3. In-Stack Position
Stack ID = 1
0 ms
1
5
4
3
2
1
1\1\5
1\1\4
1\1\3
1\1\2
1\1\1
In-Stack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

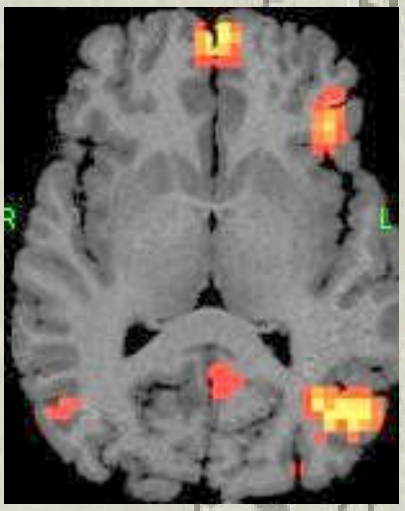
organization of data

- 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 recon on a dataset not intended as a volume
- two levels
  - the detailed shared & per-frame attributes
  - the overall dimensions, stacks and temporal positions

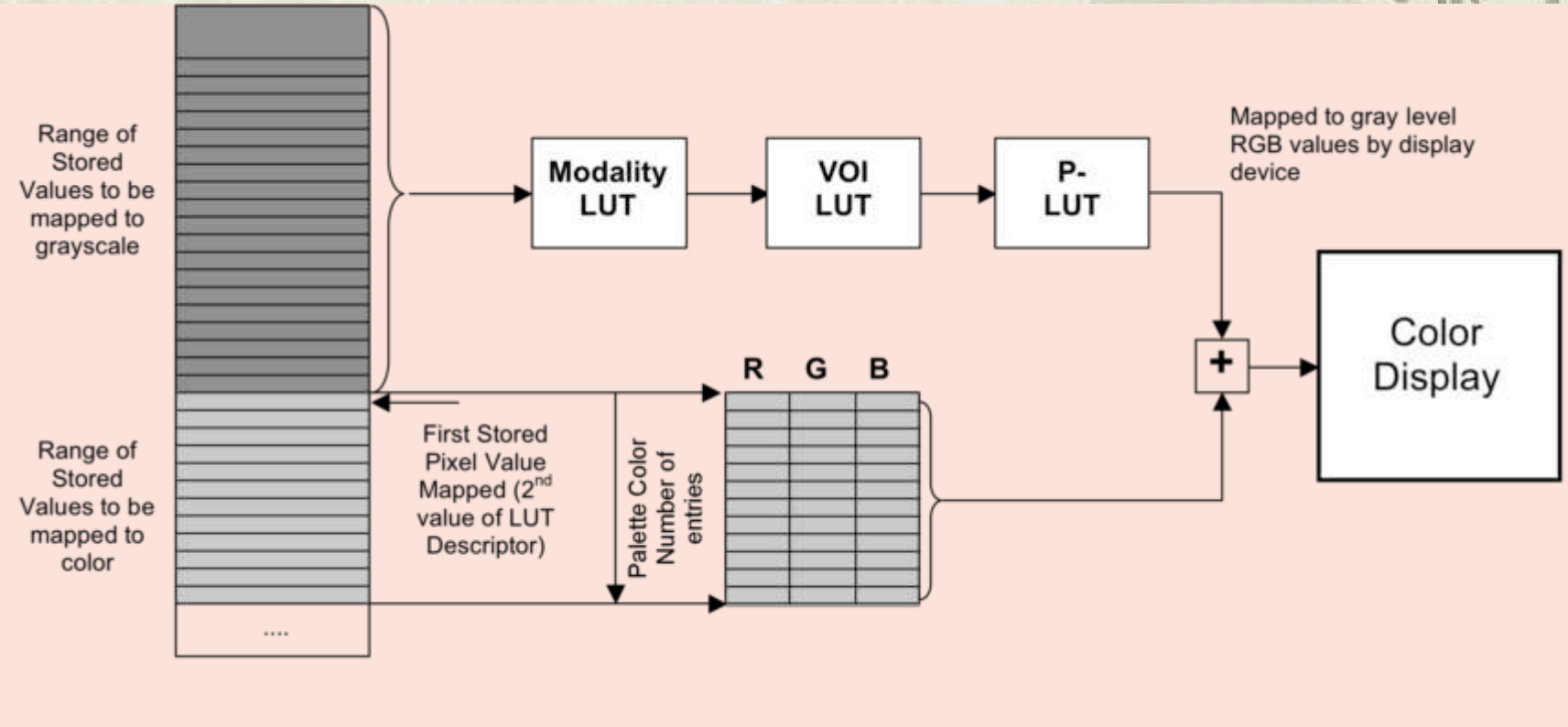
color information





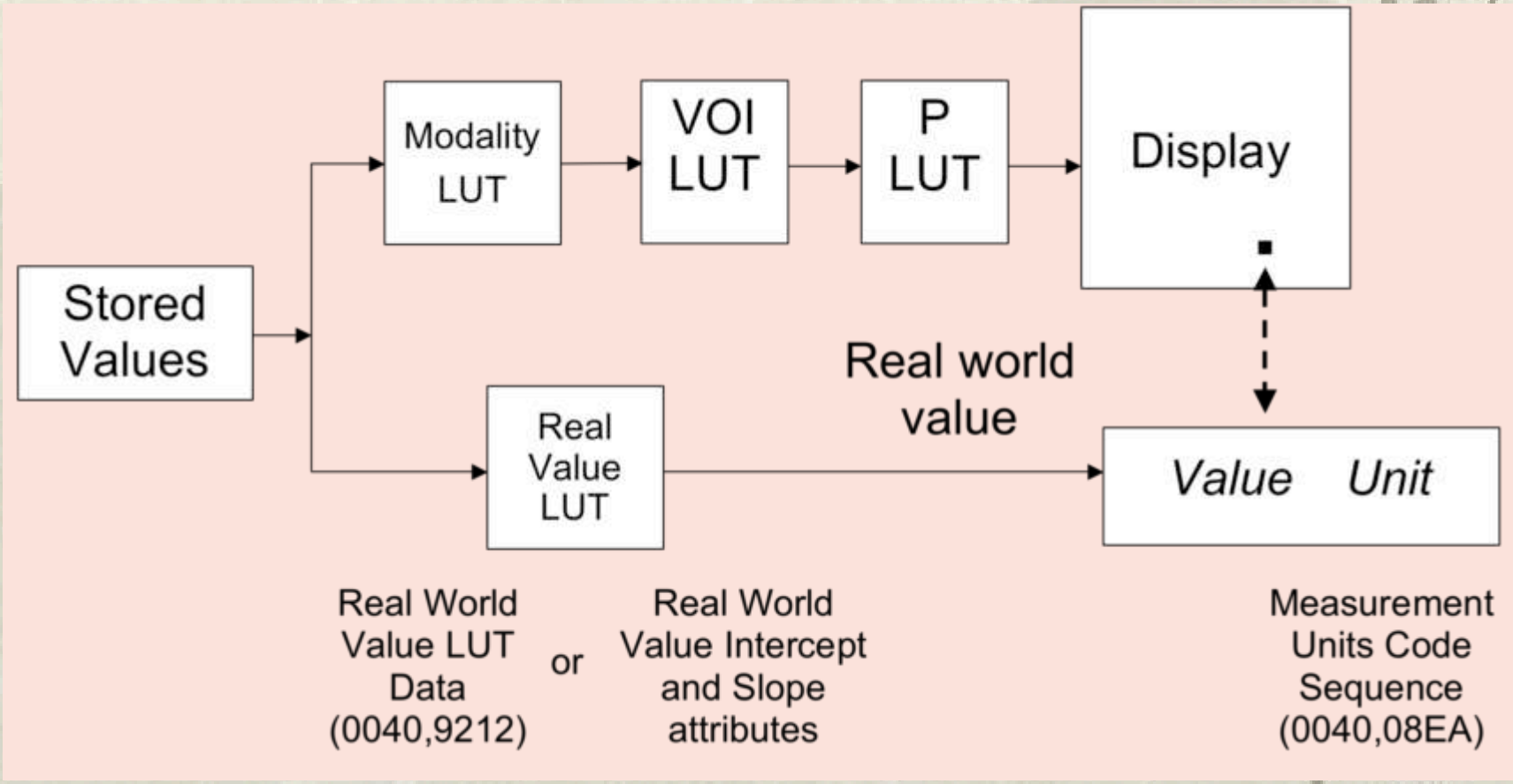


color information



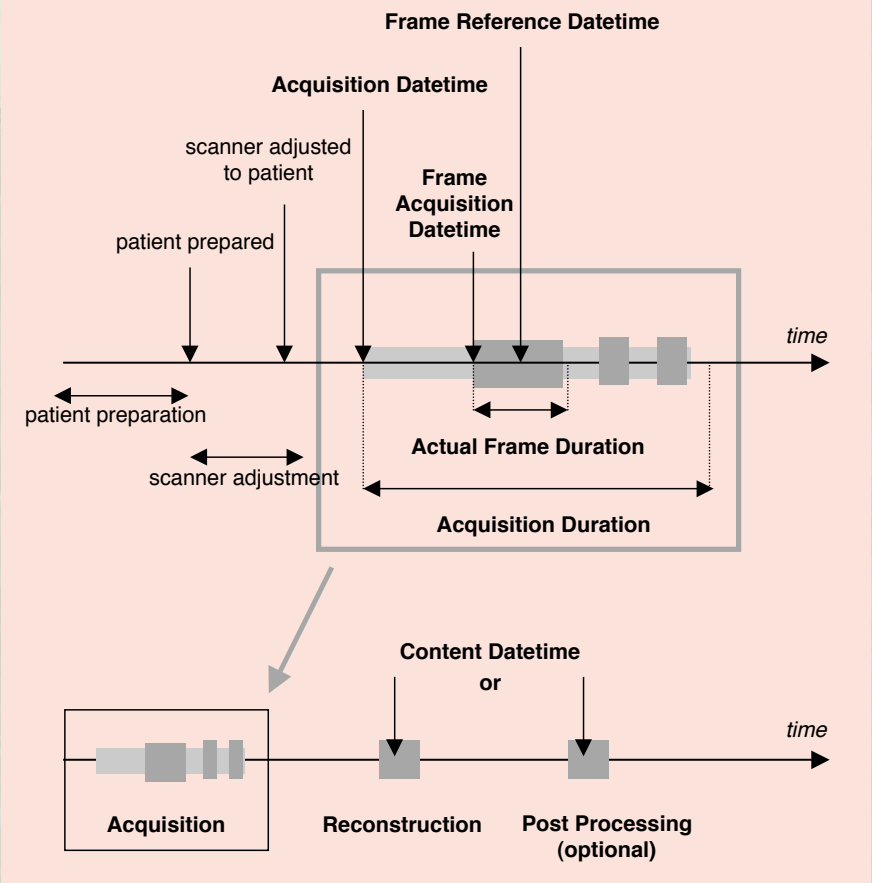
*the “underlying” grayscale data can still be windowed
*there is no transparency, color “replaces” grayscale
*blending (fusion) is defined by a separate presentation object

real world value mapping

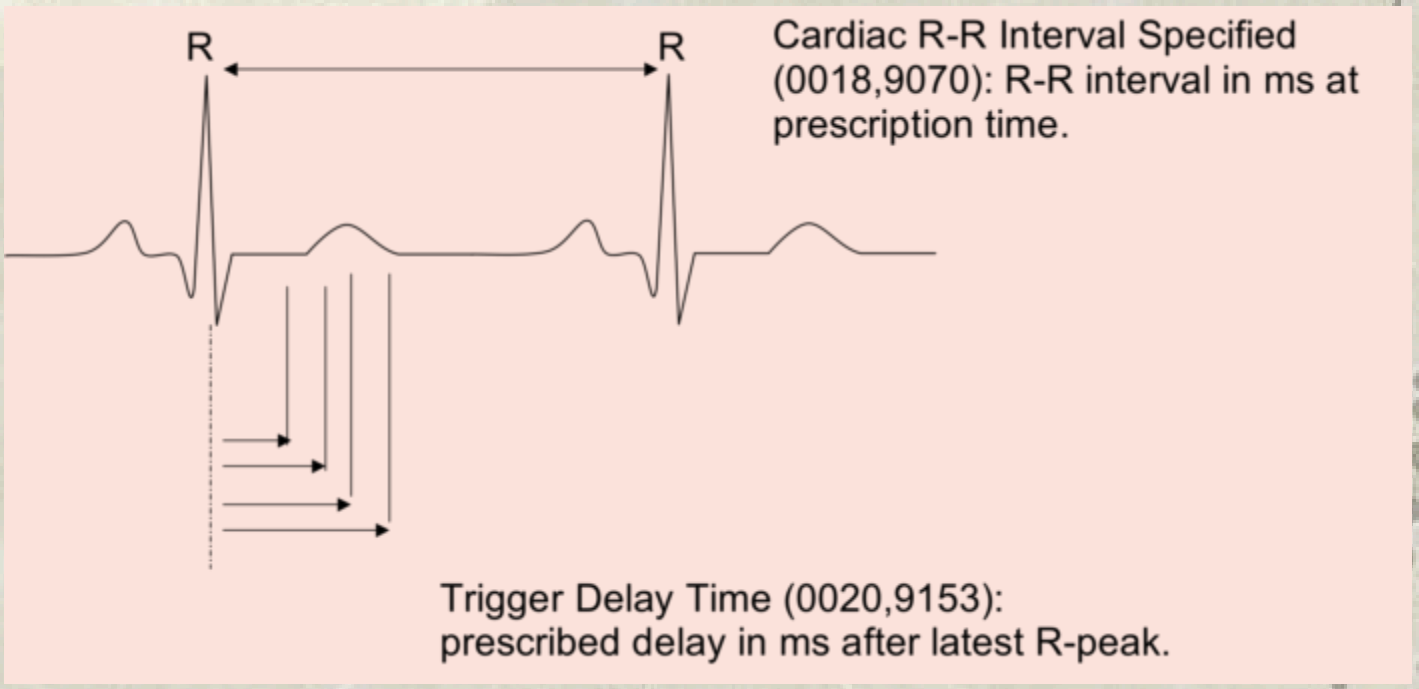


E.g., mapping stored pixel values to velocity (cm/s)

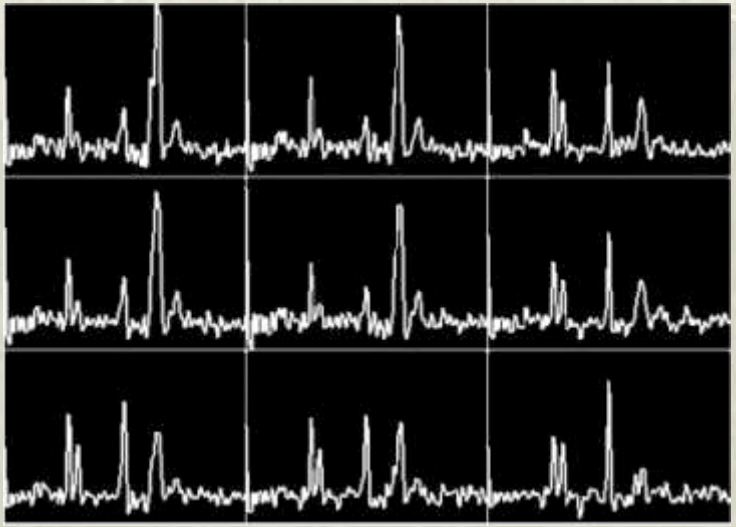
timing information



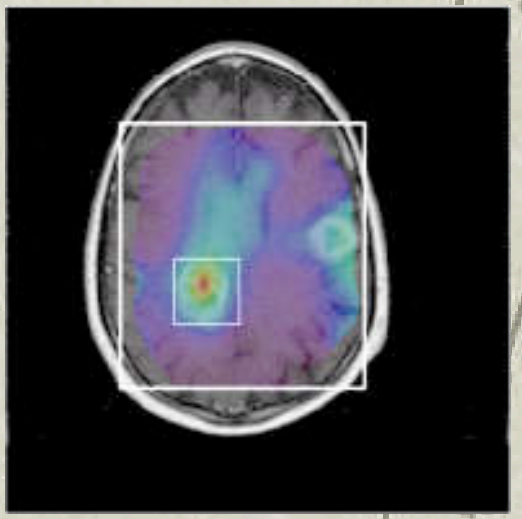
cardiac timing information



spectroscopy

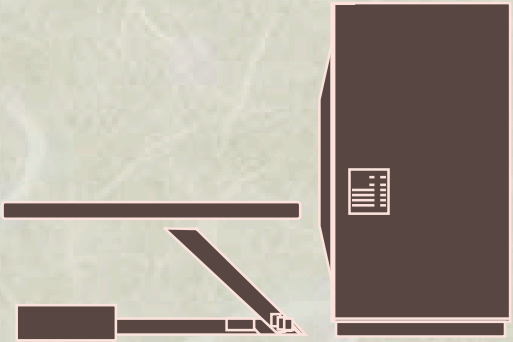


storage of
spectroscopy data

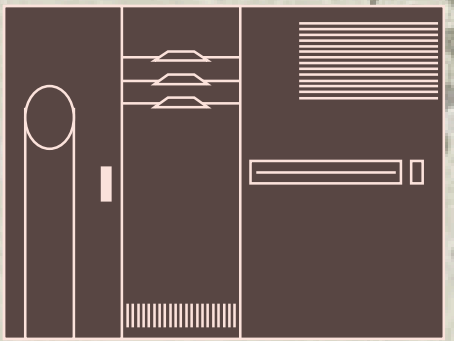


metabolite maps

but when (new MR IOD) ?



Modality



PACS

time-based waveforms

- introduced for cardiac imaging
- ECG, hemodynamic waveforms
- synchronization with images
  - relative to temporal frame of reference
- same as images in terms of
  - model (patient/study/series)
  - encoding (IOD/module/attributes)
- different bulk data payload
  - samples instead of pixels
  - channels and multiplex groups

spatial registration

- growing need to store/interchange
  - multi-modality registration and fusion
- spatial registration object
  - same information model/encoding
  - payload is affine transform between frames of reference
  - well-known frames of reference for common atlases
- separate fiducials object
  - for landmark based registration, etc.
- separate color blending object
  - to specify superimposition of one (registered) volume on another, with color transparency

structured reports

- storage of information with reference to images
  - human-readable reports
  - quantitative analysis and measurements
- structured report object(s)
  - same information model/encoding
  - payload is tree of tag-value pairs
- specialized objects for
  - key instance selection (key image note)
  - mammography and chest CAD
  - procedure log
- templates for general objects for
  - quantitative cardiac and ultrasound analysis, etc.

DICOM services

- not primarily a “file format”
- goal is integration of devices
- “behind the scenes” to everyday user
- network services
  - storage
  - query and retrieval
  - workflow management
    - storage commitment
    - worklist and procedure step
    - instance availability notification
  - print & media creation management

application integration

- crude
  - ability to read/write DICOM “files”
  - folder/file storage hierarchy exposed
  - no use of management capabilities
- elegant
  - ability to query & retrieve & send studies from/to a PACS (clinical or research)
  - details of organization are hidden
  - user sees patients & studies, not files
  - management is reliable, not error prone

processing integration

- processing workflow as a series of transformations
- intermediate forms as image objects
  - encoded as conventional modality IODs
  - secondary capture IODs with extended attributes
  - private IODs
  - new standard IODs
- addition of coded descriptions of type of image
  - e.g., temporally & spatially re-sampled & registered
- can be managed using worklist & procedure step

conclusions about DICOM

- ubiquitous in the clinical environment
- the only standard modality vendors will support
- well-defined, robust and extensible
- new objects regularly added to address state of the art requirements (e.g. enhanced MR IOD)
- no more or less complex than any other standard necessary to encode the information
- simplicity through the use of readily available free & commercial libraries, toolkits & platforms for most operating systems & languages

conclusions about DICOM

- broad base of experienced developers
- readily available support groups and training (e.g. news:comp.protocols.dicom)
- offers integration opportunities well beyond a mere file format
- open development process in which all may participate
- the ND object being developed by the DICOM 3D working group may be of particular interest

potential gaps in DICOM

- encode/describe intermediate forms ?
- floating point pixel data ? vector data ?
- temporal transformation/resampling ?
- waveforms for stimuli/responses ?
- waveforms for EEG & MEG ?
- fMRI technique-specific attributes ?

- others ?