DICOMWeb 2015 Conference & Hands-on Workshop

Best and Worst Practices and Software Development Tools – DICOM

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Background & Disclosures

- Owner, PixelMed Publishing, LLC
- Radiologist
- Independent Consultant
- Editor of DICOM Standard
- Formerly co-chair DICOM Standards Committee
- Formerly co-chair IHE Radiology Technical Committee

Best and Worst Practices Learning Objectives

- It's still DICOM and they are still Medical Images
- Scope – emphasis on Display
- Robustness Principle
- Conformance Statement for Design
- Variability in Real World Images
- Rendering Pipeline Permutations
- Measurements and Annotations
- Pixel Data Bits, Padding and Shutters
- Samples and Tools

It's still DICOM

- Excitement about Web vs. "traditional"
  - less arcane nomenclature
  - less need for special developer training
  - "generic" tools – HTTP, URL, XML, JSON
- It's still a "DICOM" "file"
  - even if retrieved with an HTTP GET
  - even if translated to JSON or XML
  - still need to "understand" "model" & data
  - still need to cope with Pixel Data vagaries

They are still Medical Images

- Both “utility” and “safety” aspects to consider
- From all:
  - types of “modalities”
  - different vendors
  - different hardware and software versions
  - archives of old and new studies
- Maybe compliant:
  - perfectly so
  - almost so
  - egregiously non-compliant but still usable

Reality Check
Experience versus Theory

- You do not have the luxury of assuming everything you will encounter will work because it is encoded just like:
  - the first image you tested with
  - the subset of images you have to test with
  - the images from your first customer site
  - the images you found with Google
  - the only machine's images you have tested so far
  - the only vendor's images you have tested so far
  - the only modality's images you have tested so far

Read the Standard Web Stuff

- You need to read the standard (blech!):
- Not directly relevant to Web stuff:
  - Service Classes (PS3.4) – 404 pages (mostly skip)
  - Message Exchange (PS3.7) – 128 pages (skip)
  - Network Communication (PS3.8) – 72 pages (skip)
- Directly relevant to Web stuff:
  - Web Services (PS3.18) – 138 pages
  - Application Hosting (PS3.19) – 96 pages (XML bits)

Read the Standard Image Stuff

- To understand “images” you must read these
- Relevant regardless of web or “traditional:
  - Data Structures & Encoding (PS3.5) – 138 pages
  - Information Object Definitions (PS3.3) – 1338 pages
- Need to reference:
  - Data Dictionary (PS3.6) – 204 pages
- For measurements, codes (SR, etc.):
  - Content Mapping Resource (PS3.16) – 1150 pages
- If you need examples:
  - Explanatory Information (PS3.17) – 692 pages

Write Perfect, Read Anything (Postel's Robustness Principle)

"Be conservative in what you do, be liberal in what you accept from others."

RFC 761 TCP

Jon Postel (1943-1998)

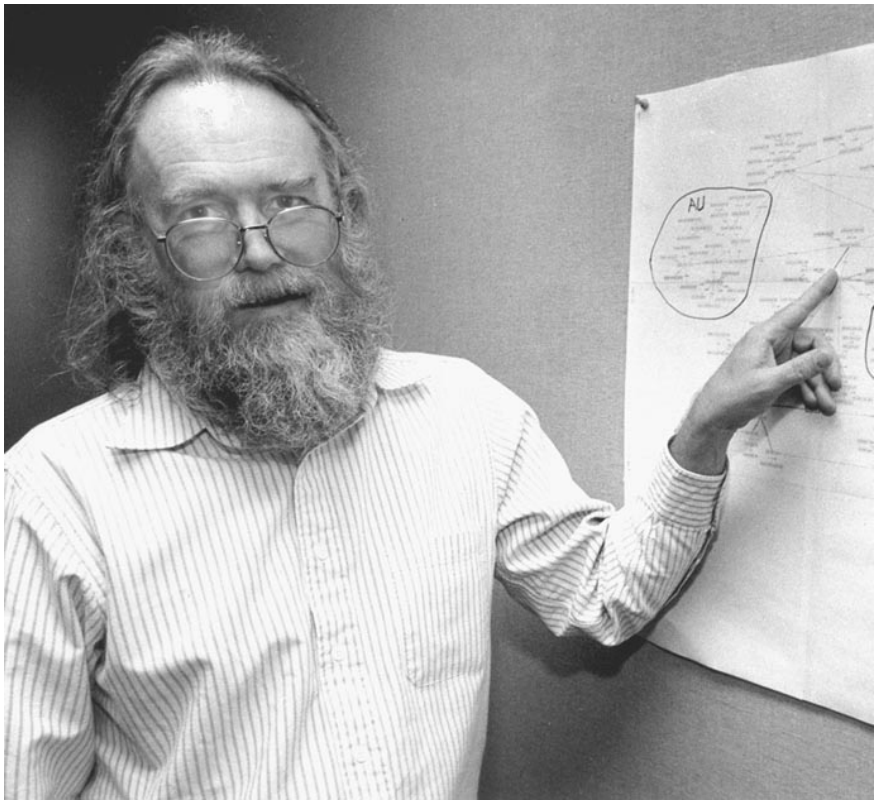

Photo by Irene Fertik, USC News Service. Copyright 1994, USC.

Debate About Applicability of Robustness Principle

- Impact on security
  - Internet protocol vulnerabilities experience
  - alternative: “fail hard and fast” (“Postel wrong”)
- Impact on (medical device) safety?
  - whether display is (nominally) for “primary diagnosis” or “review”, it is still for patient care
  - display “correctly”
  - display “as intended”
  - display “if at all possible”
  - inaccessibility as dangerous as dubious quality?

A Patch for Postel's Robustness Principle

Len Sassaman | Katholieke Universiteit Leuven
Meredith L. Patterson | Red Lambda
Sergey Bratus | Dartmouth College

1 (of 3): Be *definite* about what you accept.

http://www.cs.dartmouth.edu/~sergey/langsec//papers/postel-patch.pdf

DICOM and Robustness
On “Being Definite”

- DICOM’s answer to “being definite” has always been the Conformance Statement
- Summarizes and details what your implementation does and does not do.

- *Recommendation: Write the DICOM Conformance Statement BEFORE YOU START WRITING THE CODE*

Conformance Statement as a Design Document

- Do it regardless of whether
  - you are sending or receiving
  - on the network or using files
  - traditional or WADO-WS or –RS
  - a modality, and archive or a viewer
- ESPECIALLY important for a display
  - what Pixel Data patterns you accept
  - what modalities
  - what attributes to use for sorting and navigation
  - what attributes to use for (corner) annotations

Conformance Statement “like” Design Document

Attribute Name	Tag	Type	Attribute Description	Import Behavior	Export Behavior	Comments
Image Pixel Module (M)						
Samples per Pixel	(0028,0002)	1	Number of samples (planes) in this image.	Check is 1	Always 1	Only single channel images displayed.
Photometric Interpretation	(0028,0004)	1	Specifies the intended interpretation of the pixel data.	Check is "MONOCHROME2"	Always "MONOCHROME2"	No color or MONOCHROME1 support.
Rows	(0028,0010)	1	Number of rows in the image.	USE	As necessary	No theoretical limit (apart from DICOM VR limitation to 16 bit values); will impact performance if too large; consider limiting rather than failing.
Bits Allocated	(0028,0100)	1	Number of bits allocated for each pixel sample. Each sample shall have the same number of bits allocated.	USE	Always 16	Standard allows for 8 or 16, but our data is always > 8 bits. Should we also support 8 bit images that may come from other vendors? Check with marketing.
Pixel Representation	(0028,0103)	1	Data representation of the pixel samples. Enumerated Values: 0000H = unsigned integer. 0001H = 2's complement	Check is 0	Always 0	Our data is always unsigned. Should we also support signed images that may come from other vendors? Check with marketing.
Pixel Aspect Ratio	(0028,0034)	1C	Ratio of the vertical size and horizontal size of the pixels in the image specified by a pair of integer values where the first value is the vertical pixel size, and the second value is the horizontal pixel size.	IGNORE	NEVER	Is not sent because Pixel Spacing is always sent.

How much Variability is there? Really?

- PACS is a 30 year+ industry
- DICOM is a 30 year old standard
- “Evolved” over time, not necessarily consistently across or even within modalities
- Grows by “consensus” of “committees”

Alexey Sergeev 2012

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- PACS is a 30 year+ industry
- DICOM is a 30 year old standard
- “Evolved” over time, not necessarily consistently across or even within modalities
- Grows by “consensus” of “committees”
- Maybe union rather than intersection
- Rendering and value pipeline example

ACR-NEMA 1985

5.2.8 Image Display

If a transformation of pixel values to a gray scale display is specified, it shall be contained in Lookup Table Descriptors—Gray (0028H,1100H) and Lookup Data—Gray (0028H,1200H) and Window Center (0028H,1050H) and Window Width (0028H,1051H), or a Rescale Intercept (0028H,1052H) and Rescale Slope (0028H,1053H). The window transformation shall be applied to the result of the rescale or lookup table transformations. If both the rescale and lookup table transformations are present the lookup table transformation shall be applied to the result of the rescale transformation.

If there are multiple window or rescale transformations, then these shall be stored as multiple values of the elements.

If a transform of pixel values to a red, green or blue display is specified, it shall be contained in the corresponding lookup table elements.

ACR-NEMA 1985

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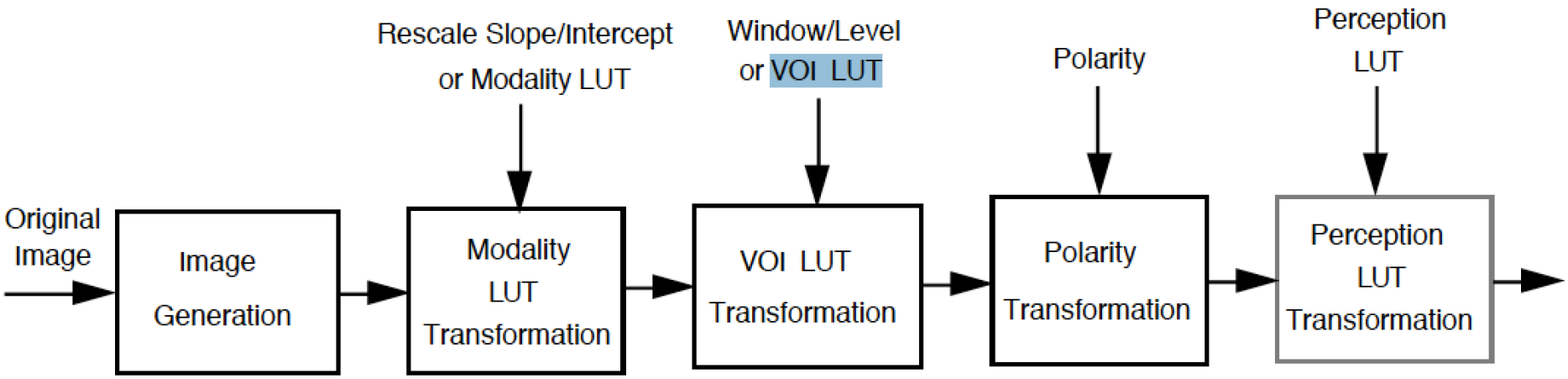
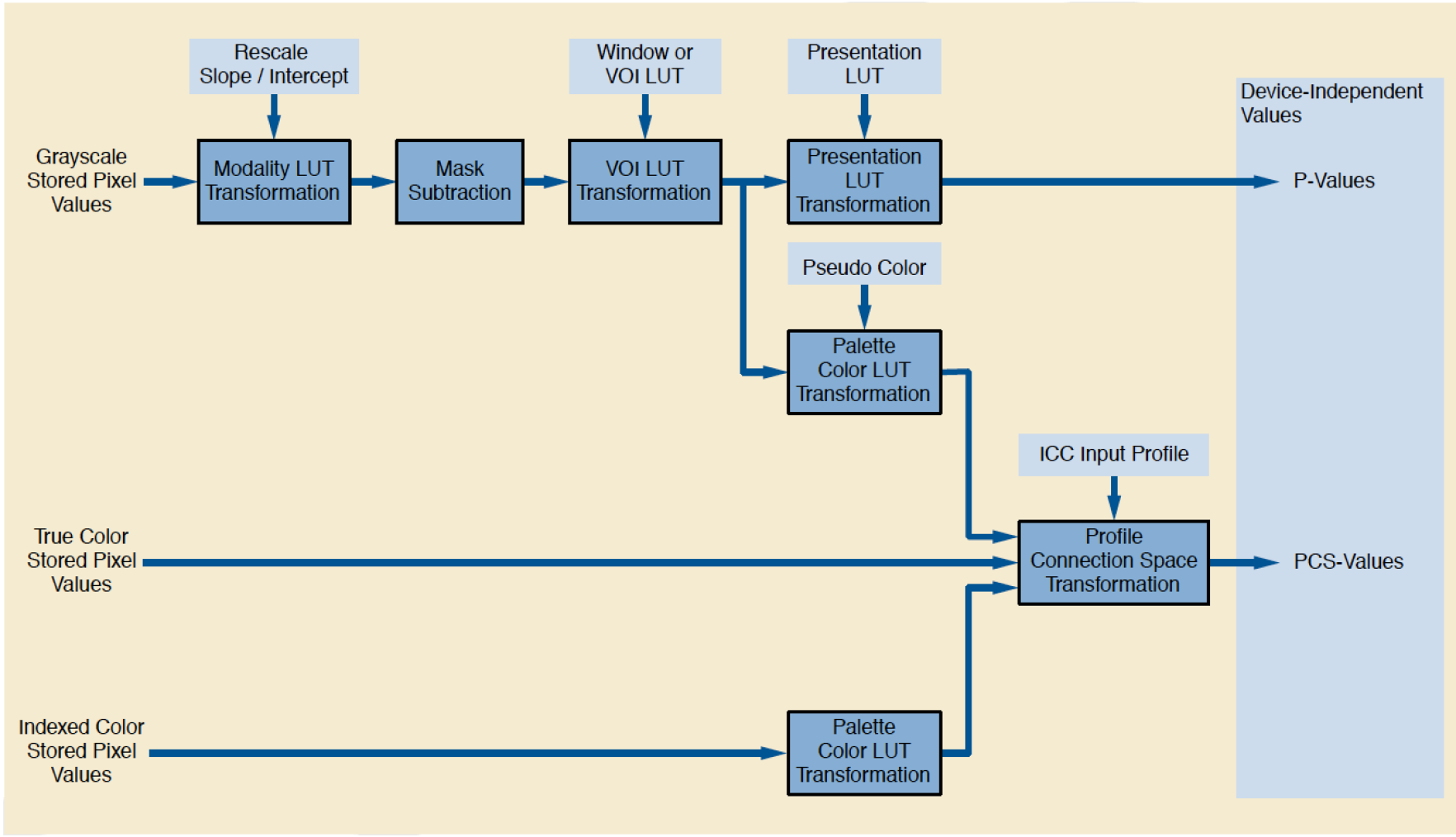
DICOM 1993

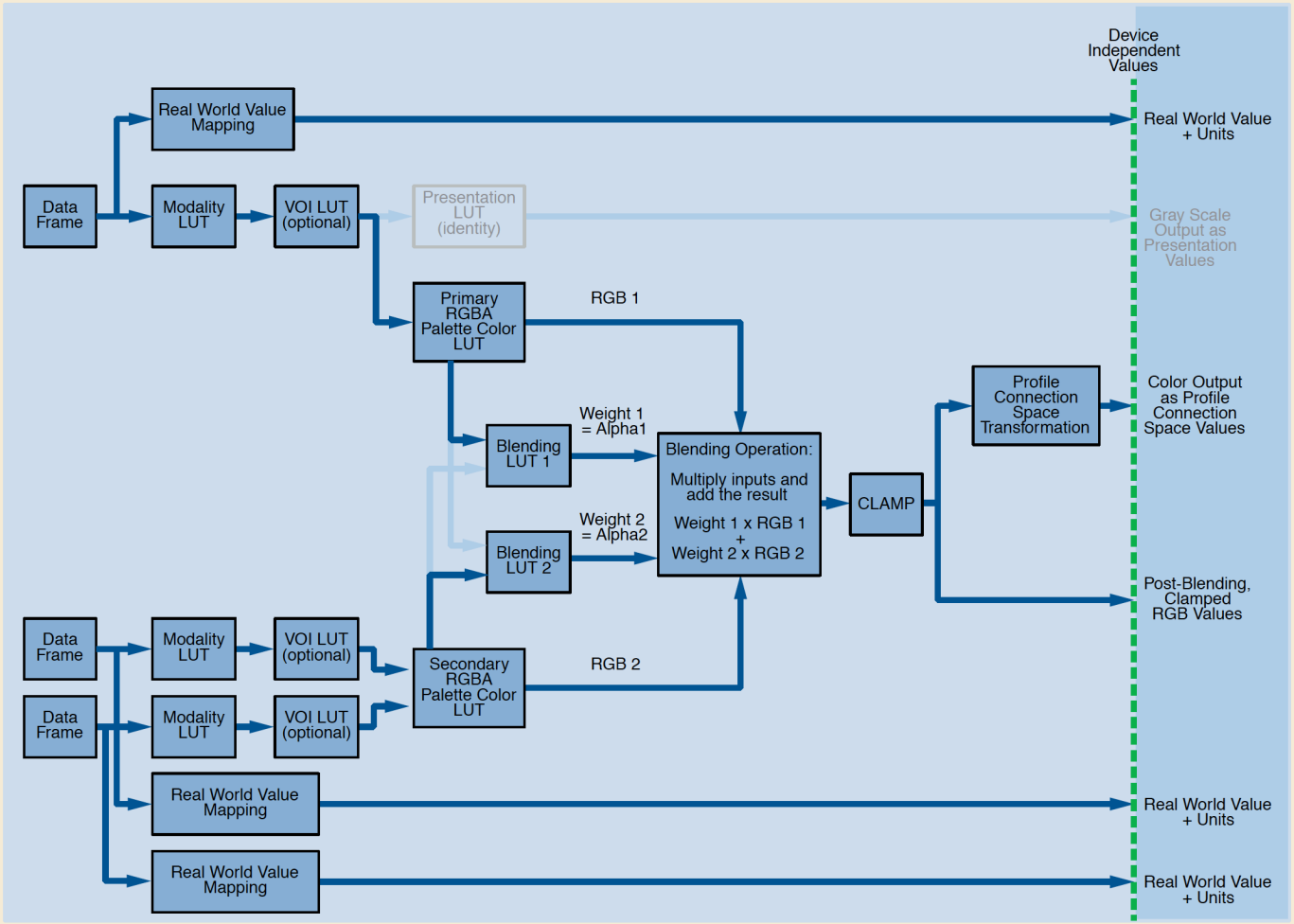
Figure H.2.1.2-1 : Print Management Data Flow Model



DICOM since Presentation States



DICOM since
Enhanced US Volume



Grayscale Rendering Pipeline Modality Variation

- ACR-NEMA unambiguous:
  - “window transformation shall be applied to the result of the rescale … operations”
- DICOM 1993
  - defined same/similar attributes in Modules
  - never really specified (beyond print) order of application
- DICOM Sup 33 Presentation States
  - window after rescale, for Presentation State

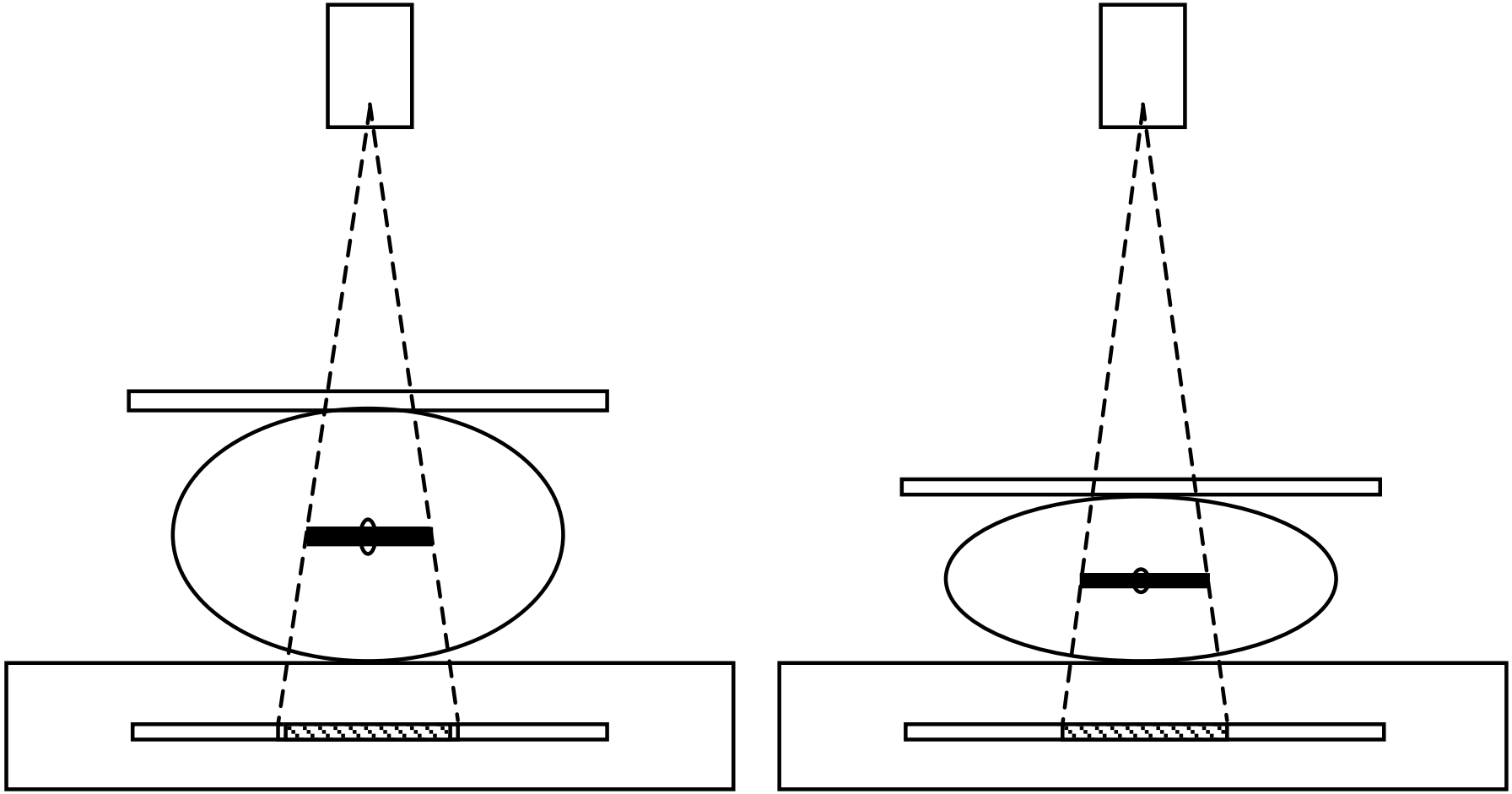
Grayscale Rendering Pipeline Modality Variation

- CT
  - rescale output in Hounsfield Units (HU)
  - radiologists used to HU window numbers
  - no-brainer – window after rescale
- MR
  - no rescale in IOD
  - no-brainer – window stored pixel values (SPV) or identity rescale
  - but what if vendor adds rescale values – legal – use or ignore ?
  - vendor did not intend rescale to be applied before window values
- PET
  - rescale output in defined Units, e.g., SUV (0.0-10.0 or so)
  - small floating point window values not anticipated
  - modality vendors intend to ignore rescale values and window SPV
  - (unless in a Presentation State !)

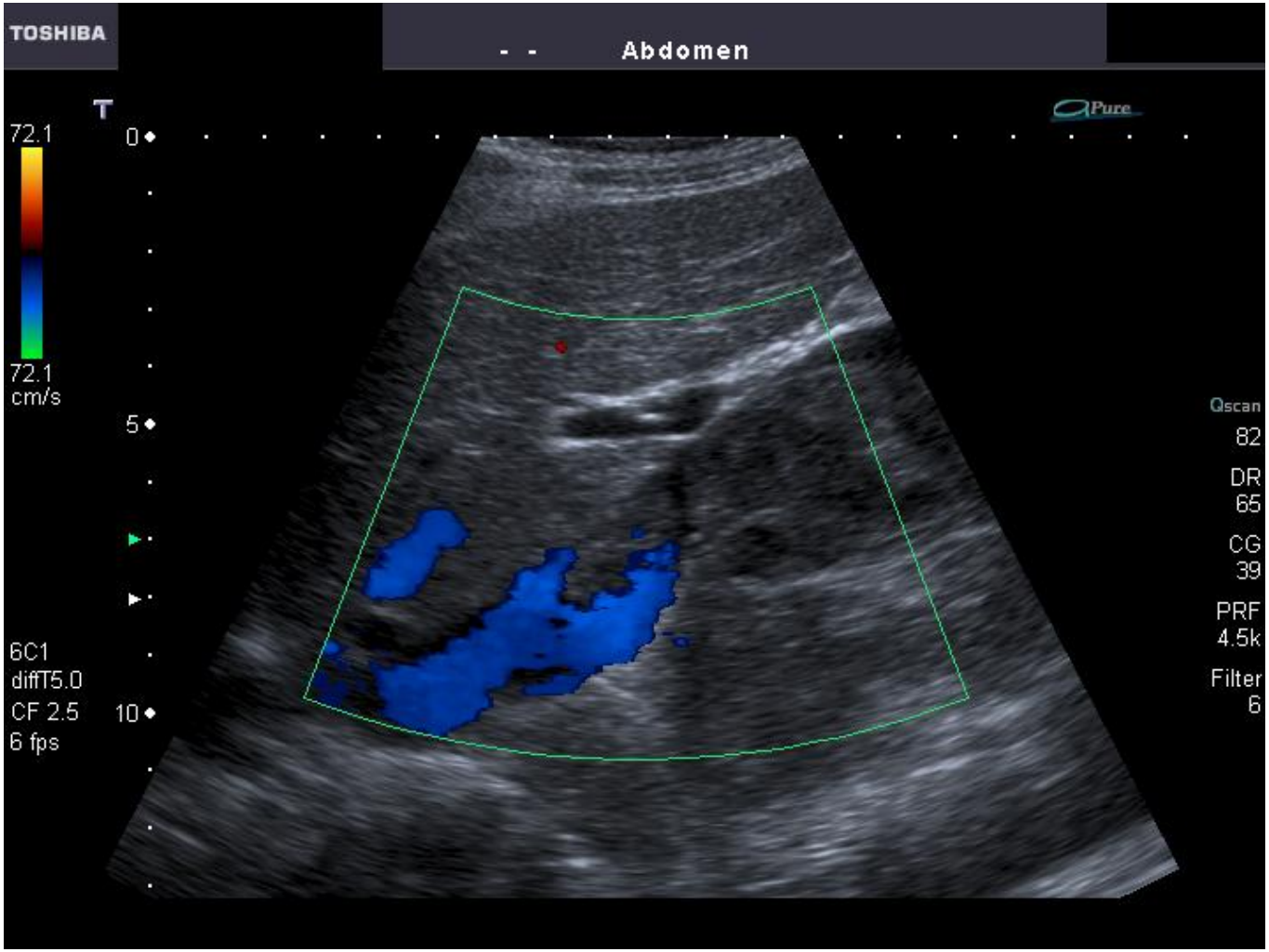
“Size Matters” Modality Variation

- Pixel Spacing ?
- Imager Pixel Spacing ?
- Ultrasound Region Calibration ?
- More than one present (calibrated ?)
- Estimated Radiographic Magnification Factor?
- What does a measurement “mean” in a projection radiograph anyway, with a thick body part and a diverging ray?

Diverging Beam
Object Depth



Sequence of Ultrasound Regions



More Measurements
More than Size

- “Regions of Interest”
- Intensity of pixel/voxel values
- Rescale Slope and Intercept and Type
- Units (PET)
- Derived values: mean, DS, max, etc.
- Real World Value Map
- Do not report non-CT in HU (amateur!)
- Save/restore/share – SR or RTSS

Annotations

- Save/restore/share
- Regions of Interest
- Marks (e.g., arrows pointing to things)
- Text
- Meaning – Codes

- Too many DICOM mechanisms ☹
- Display needs to support all of them!

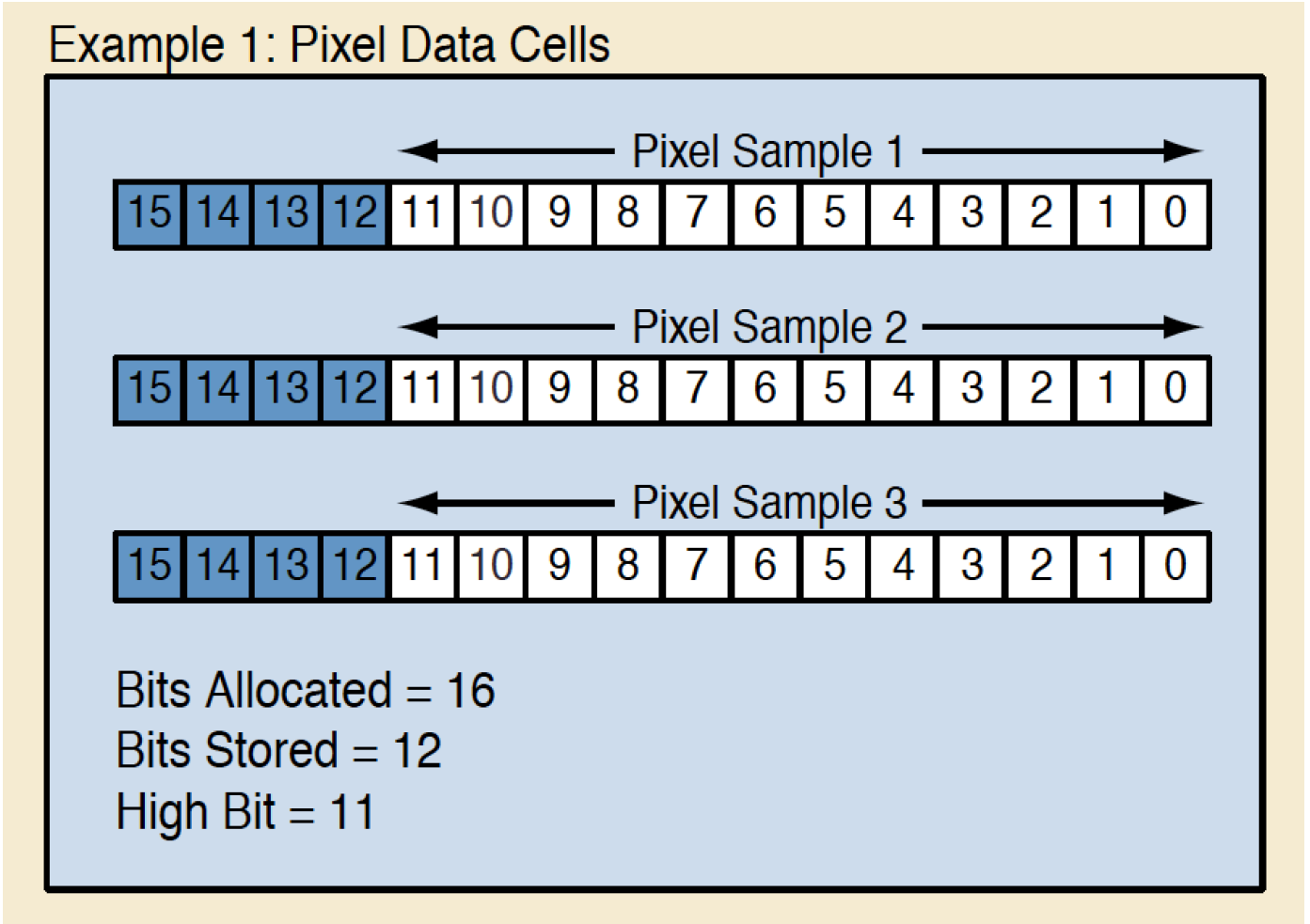
DICOM Annotations
Too Many Mechanisms

- Structured Reports
  - codes, 2D/3D contours, text +/- references to other objects
- Segmentations
  - rasterized and surface (rare)
- Presentation States
  - 2D graphics, text, bitmaps
- RT Structure Sets
  - 3D contours
- Fiducials
- Overlays (in Image)
  - 60xx,3000 Overlay Data
  - in high bits of Pixel Data (retired)
- …

On the Subject of Bits Twiddling is Necessary

- DICOM Pixel Data
  - may be signed or unsigned
  - use fewer bits than byte aligned boundary
- Do NOT assume
  - always unsigned
  - high bits are zero
  - negative values are sign extended
- Always
  - mask and sign extend before using
- Not everything is 8 or 16 bits; unusual, but consider
  - 32 bit RT Dose
  - 32 and 64 bit float Parametric Maps

Bit Level Encoding
PS3.5 Annex D is your friend



Not Done With Bits Yet
Pixel Padding Value

- A signal not to change
  - black “background”
  - while windowing or inverting
  - legacy of “perimeter” encoding of circular reconstructions
- Bottom line is always check
  - each Pixel Data value is or is not equal to Pixel Padding Value
  - or in range of Pixel Padding Range Limit

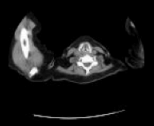
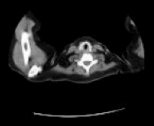
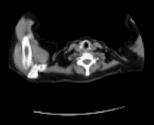
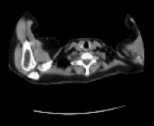
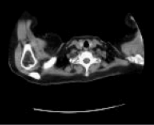
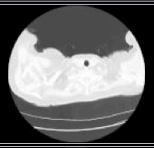
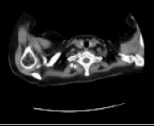
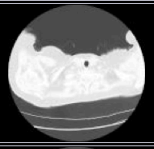
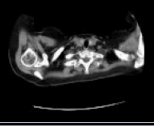
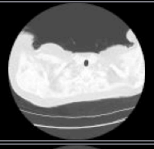
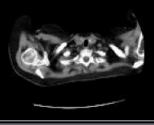
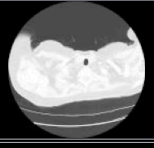
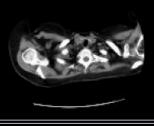
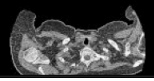
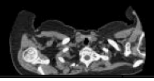
More Pixels and Bits
Display Shutters

- Another way to establish “background”
- Shutters with geometric shapes
  - may be more than one – apply them all
- Bitmap shutters in presentation states

- Like padding, make sure they stay black
- Don’t forget to annotate on top of them not behind them ☺

Beyond One Image
Volumes, Time Series

- Is it a volume?
  - do you care? – sort order vs. 3D MPR, VR
  - Image Orientation/Position (Patient) + normal (dot product)
  - floating point jitter (in Decimal String)
  - same Rows, Columns, Pixel Spacing, Slice Thickness …
- Is it a time series?
  - do you care? – sort order, interleaved, +3D
  - Acquisition or Content Time (or private)
  - cardiac phase timing (absolute/relative)
- Both (4D)?
- More/different “Dimensions”?
- Reconstruction interval vs. Slice Thickness

Position	101645 LUNG 5.000000	101645 STANDARD 5.000000	101734 STANDARD 5.000000	101942 LUNG 1.250000	101942 STANDARD 1.250000	102011 LUNG 1.250000	102011 STANDARD 1.250000	102156 LUNG 1.250000	102208 LUNG 1.250000	102219 LUNG 1.250000
0										
-5										
-10										
-15										
-20										
-25										
-30										
-35										
-40										
-40.97										

Position vs. time+recon+thickness

Visualize “dimensions”: dcacqmap in dicom3tools

```
sh-3.2$ dctable -k InstanceNumber -k ContentTime -k AcquisitionTime -k SliceThickness -k ConvolutionKernel -describe `find . -name '*.dcm'`
Filename        "Acquisition Time"      "Content Time"  "Slice Thickness"       "Convolution Kernel"    "Instance Number"
"./Series002/1.2.840.113619 [redacted] 757.dcm"  "101645"        "101655"        "5.000000"      "STANDARD"      "1 "
"./Series002/1.2.840.113619 [redacted] 758.dcm"  "101645"        "101656"        "5.000000"      "STANDARD"      "2 "
"./Series002/1.2.840.113619 [redacted] 759.dcm"  "101645"        "101658"        "5.000000"      "STANDARD"      "3 "
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```

“Holistic” View of the Study More than just images

- Many other composite instances
  - Structure Reports (measurements)
  - Presentation States
  - Structure Sets
  - Registration
  - Real-World Value Maps
  - Encapsulated PDF, CDA
- The entire Study content is important
- Showing only a subset may be unsafe

Aargh! Overwhelmed! Where are the tools?

- Sample images
  - web site, FAQ, Google searches
  - e.g., signed range, shutter, size test sets
  - NEMA ftp site datasets
  - clinical trial archives (e.g., TCIA)
  - IHE MESA test data
  - synthesize your own (*vide infra*)
- Are images (etc.) good or bad?
  - dciodvfy – validate header against standard
  - “ordinary” DICOM toolkits to inspect/make/change stuff
  - make sure to test bad images too – they are in the wild

Conclusion

- It is not sufficient that your code works
- It must work “for the right reasons”
- That way, it might survive the next DICOM image variant it encounters!