Medical Physics Imaging Informatics in the Classroom and in Practice

W.F. Sensakovic, PhD, DABR, MRSC

FLORIDA HOSPITAL
The skill to heal. The spirit to care.

UCF

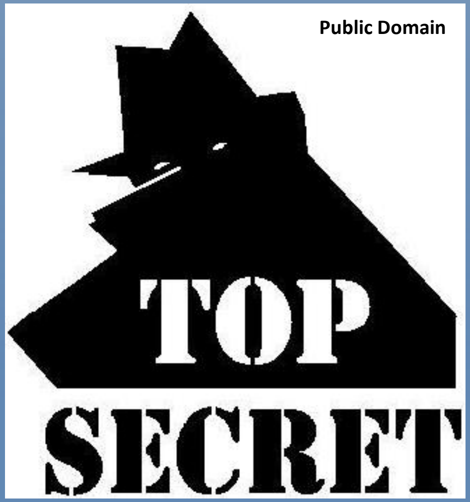
ADVENTIST UNIVERSITY OF HEALTH SCIENCES
Florida Hospital's University

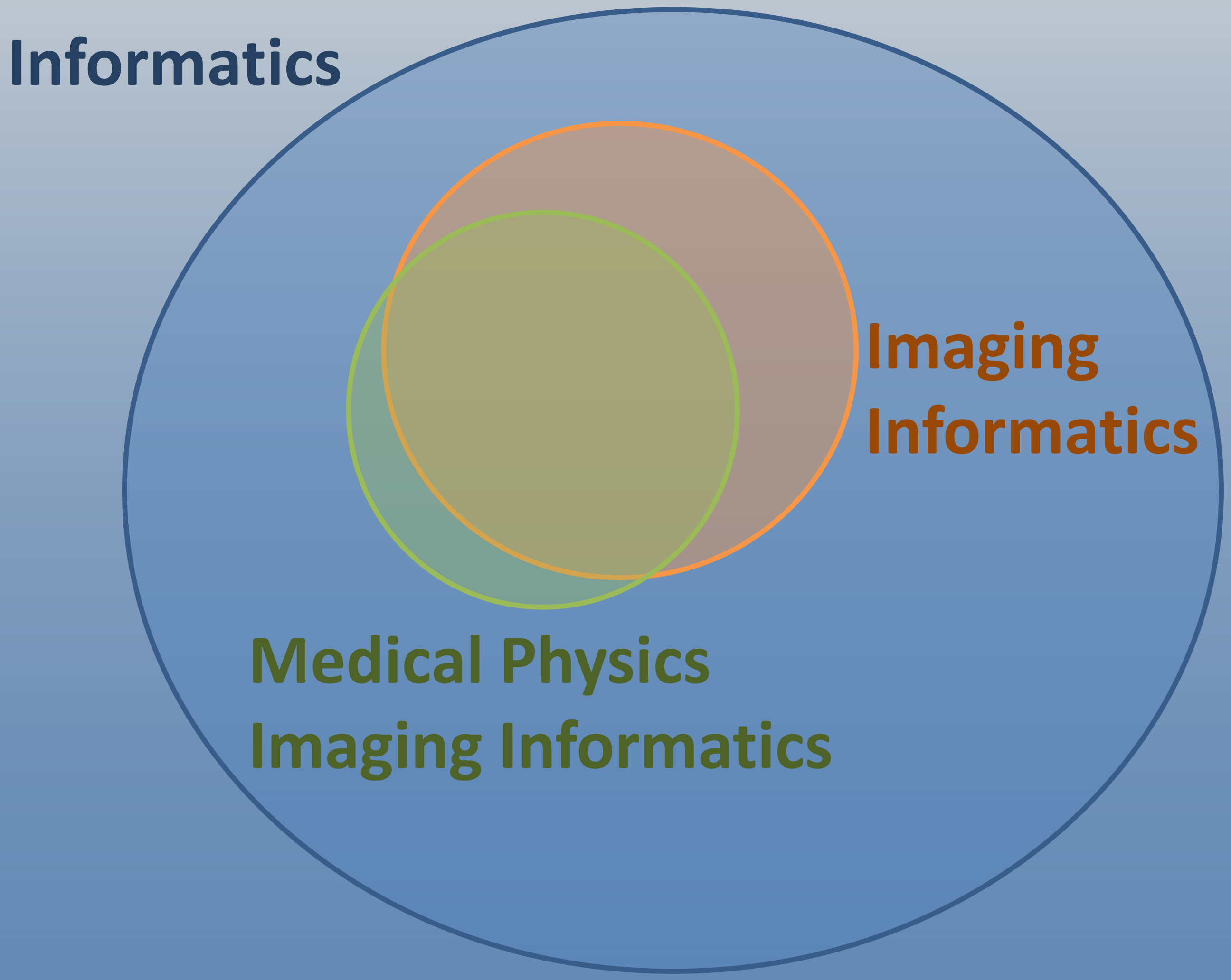
FLORIDA STATE UNIVERSITY

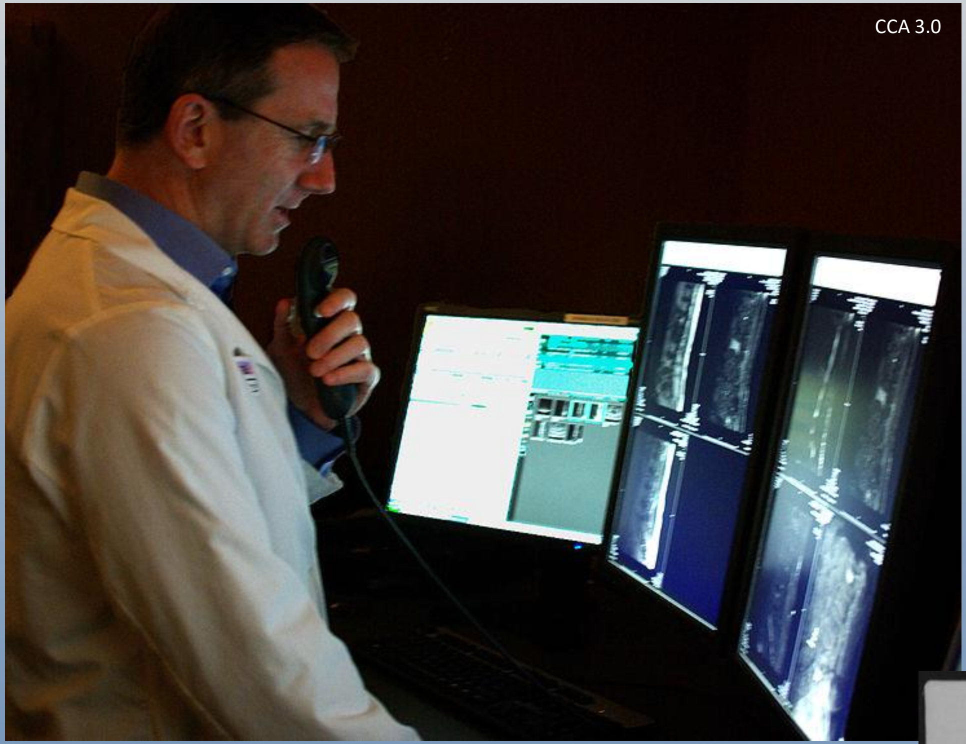
Relevant Conflicts of Interest

Chair of the Imaging Physics Curricula Subcommittee

Attendees/trainees should not construe any of the discussion or content of the session as insider information about the American Board of Radiology or its examinations.




Informatics
Imaging Informatics
Medical Physics Imaging Informatics



Acquisition, storage, retrieval, and use of information

- **AAPM Curriculum for Diagnostic Radiology Residents**
  - **https://www.aapm.org/education/ERG/DIARAD/**
- **RSNA/AAPM Physics Teaching Modules**
  - **https://www.rsna.org/Physics-Modules/**
- **ACR-AAPM-SIIM Practice Parameters and Technical Standards**
  - **http://www.acr.org/Quality-Safety/Standards-Guidelines**
  - **http://siim.org/page/practice_guidelines**
- **JACR Informatics Collection**
  - **http://informatics.jacr.org/Imaging_it_reference_guide**
- **Many others**
  - **Books, task groups, journal reviews, standards, etc.**

Module 5: Basic Imaging

After completing this module, the resident should be able to apply the "Fundamental Knowledge" and "Clinical Applications" learned from the module to example tasks, such as those found in "Clinical Problem-solving."

Fundamental Knowledge:

1. Define common descriptive statistics (e.g., mean, variance, etc.) used in the radiology literature.
2. Define metrics and methods used to measure image quality and assess imaging systems.
3. Define the characteristics of a display and how they interact with the human visual system to impact perceived image quality.
4. Understand basic concepts of image processing and image archiving.

Clinical Application:

1. Assess the validity of the type of statistical analysis used in the radiology literature.
2. Evaluate how display, ambient lighting, and luminance affect reader performance.
3. Develop custom hanging protocols for display of images.
4. Be familiar with display quality control.
5. Be familiar with the DICOM standard.

Clinical Problem-solving:

1. How would you set up a quality improvement study for a digital radiography system?
2. How would one use ROC analysis to compare performance between systems from different modalities or manufacturers?
3. Explain to a physician why reading a chest radiograph on a tablet (e.g., ipad) might give a lower probability of detecting disease than reading the same exam in a reading room.
4. Choose a window and level for detecting a soft-tissue lesion in the mediastinum.
5. Explain why large, high-resolution displays are necessary for mammography.
6. Evaluate the added value of a CAD system for detection of lung nodules.

Curriculum:

5. Basic Imaging
  - 5.1. Basic Statistics
    - 5.1.1. Systematic and Random Error
    - 5.1.2. Precision, Accuracy, and Reproducibility
    - 5.1.3. Statistical Distributions: Poisson and Normal
    - 5.1.4. Central Tendency: Mean, Median, and Mode
    - 5.1.5. Dispersion: Standard Deviation, Variance, Range, and Percentiles
    - 5.1.6. Correlation: Pearson Correlation
    - 5.1.7. Confidence Intervals and Standard Error
    - 5.1.8. Propagation of Error
    - 5.1.9. Statistical Analysis
  - 5.2. Imaging System Properties and Image Quality Metrics
    - 5.2.1. Image Domains
      - 5.2.1.1. Spatial
      - 5.2.1.2. Frequency
      - 5.2.1.3. Temporal
    - 5.2.2. Contrast
    - 5.2.3. Spatial Resolution
      - 5.2.3.1. Point and Line Spread Functions
      - 5.2.3.2. Full Width at Half Maximum (FWHM)
      - 5.2.3.3. Modulation Transfer Function (MTF)
    - 5.2.4. Noise
      - 5.2.4.1. Quantum Mottle
      - 5.2.4.2. Other Sources
      - 5.2.4.3. Noise Frequency
    - 5.2.5. Dynamic Range and Latitude
    - 5.2.6. Contrast-to-noise Ratio (CNR), Signal-to-noise Ratio (SNR), Detective Quantum Efficiency (DQE)
    - 5.2.7. Temporal Resolution
  - 5.3. Image Representations
    - 5.3.1. Pixels, Bytes, Field-of-view, and the Image Matrix
    - 5.3.2. Grayscale and Color Images
    - 5.3.3. Spatial Frequency and Frequency Space
      - 5.3.3.1. Aliasing: Temporal, Spatial, and Bit-depth
      - 5.3.3.2. Nyquist Limit
    - 5.3.4. Axial, Multi-planar, and Curvilinear Reconstructions
    - 5.3.5. Maximum and Minimum Intensity Projections
    - 5.3.6. Surface and Volume Rendering
    - 5.3.7. Multi-modal Imaging
    - 5.3.8. Time-resolved Imaging
    - 5.3.9. Quantitative Imaging and Representation of Physical Data
      - 5.3.9.1. Overlays, Color Maps, and Vectors
  - 5.4. Image Processing
    - 5.4.1. Non-uniformity and Defect Correction
    - 5.4.2. Image Subtraction
    - 5.4.3. Segmentation and the Region-of-interest
      - 5.4.3.1. Automated vs. Semi-automated vs. Manual
    - 5.4.4. Look-up Tables (LUT)
      - 5.4.4.1. Window and Level
      - 5.4.4.2. Nonlinear Tables and Characteristic Curves
      - 5.4.4.3. Histogram and Equalization
        - 5.4.4.3.1. Value of Interest
        - 5.4.4.3.2. Anatomical
    - 5.4.5. Frequency Processing
      - 5.4.5.1. Edge Enhancement
        - 5.4.5.1.1. Un-sharp Masking
      - 5.4.5.2. Smoothing
    - 5.4.6. Digital Magnification (Zoom)
    - 5.4.7. Quantitative Analysis
      - 5.4.7.1. Object Size Measurement
      - 5.4.7.2. Shape and Texture
      - 5.4.7.3. Motion and Flow
    - 5.4.8. Reconstruction
      - 5.4.8.1. Simple Back-projection
      - 5.4.8.2. Filtered Back-projection
      - 5.4.8.3. Iterative Reconstruction Methods
      - 5.4.8.4. Sinogram
    - 5.4.9. Computer-aided Detection and Diagnosis
  - 5.5. Display Characteristics and Viewing Conditions
    - 5.5.1. Technologies
      - 5.5.1.1. Gray Scale and Color
    - 5.5.2. Characteristics
      - 5.5.2.1. Luminance
      - 5.5.2.2. Pixel Pitch and Matrix Size
      - 5.5.2.3. Quality Control
        - 5.5.2.3.1. Grayscale Standard Display Function and Just Noticeable Differences
    - 5.5.3. Viewing Conditions
      - 5.5.3.1. Viewing Distance
      - 5.5.3.2. Viewing Angle
      - 5.5.3.3. Ambient Lighting and Illuminance
  - 5.6. The Human Visual System, Perception, and Observer Studies
    - 5.6.1. Visual Acuity, Contrast Sensitivity, and Conspicuity
    - 5.6.2. Metrics of Observer Performance
      - 5.6.2.1. Predictive Values
      - 5.6.2.2. Sensitivity, Specificity, and Accuracy
      - 5.6.2.3. Contrast-detail
      - 5.6.2.4. Receiver Operating Characteristic (ROC) Analysis
  - 5.7. Informatics
    - 5.7.1. Basic Computer Terminology
    - 5.7.2. Importance of Standards and Conformance
    - 5.7.3. Integrating Healthcare Enterprise (IHE), Health Level 7 (HL7), and DICOM
      - 5.7.3.1. Modality Work list
      - 5.7.3.2. Components and Terminology of DICOM
    - 5.7.4. Picture Archiving and Communication System (PACS), Radiology Information System (RIS), and Hospital Information System (HIS)
    - 5.7.5. Electronic Medical Record (EMR)
    - 5.7.6. Networks
      - 5.7.6.1. Bandwidth and Communication Protocols
    - 5.7.7. Storage
      - 5.7.7.1. Storage Requirements and Disaster Recovery
      - 5.7.7.2. Lossy vs. Lossless Data Compression
    - 5.7.8. Security and Privacy
      - 5.7.8.1. Anonymization, Encryption, and Firewalls
      - 5.7.8.2. Research, Health Insurance Portability and Accountability Act (HIPAA) and Institutional Review Boards (IRB)

Q7. The definition of segmentation in medical image processing is:

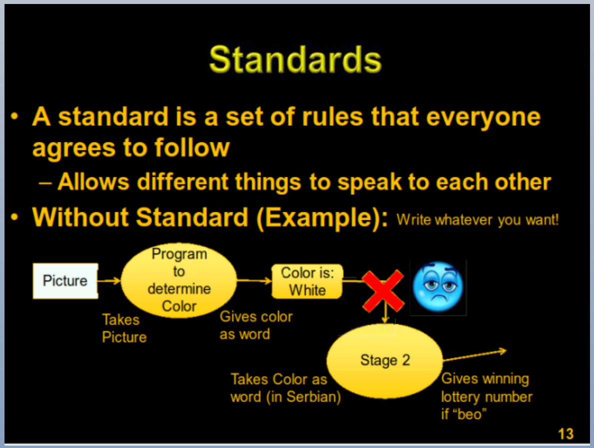
A. Reduction of pixel intensity variations by averaging adjacent pixels
B. Identification of the pixels which compose a structure of interest in an image
C. Eliminating low spatial frequencies from the image
D. Altering the relative intensities of the image pixels

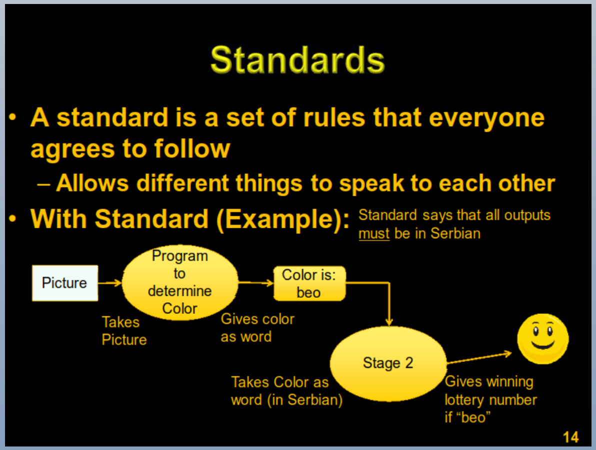
Answer: B – Identification of the pixels which compose a structure of interest in an image

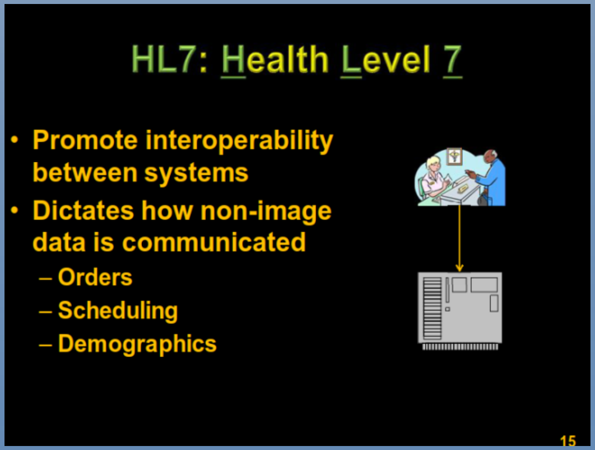
Explanation: A is the definition of blurring or low pass filtering, C is high pass filtering or edge detection, and D is windowing or altering the look-up table. Segmentation is the identification of those pixels in the image which compose a structure or structures of interest to the observer or system.

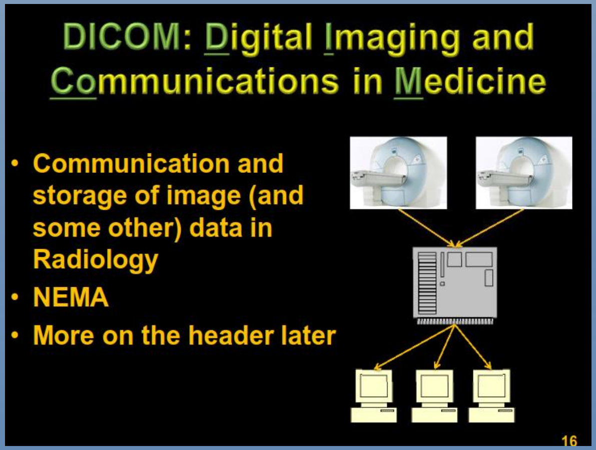
References:

1. Bankman, I., ed. *Handbook of Medical Image Processing and Analysis*, 2nd ed. Burlington, MA: Academic Press, 2009.
2. Bick, U., M.L. Giger, R.A. Schmidt, et al. "Automated segmentation of digitized mammograms." *Acad. Radiol.* 2:1-9, 1995.
3. Bushberg, J.T., et al. *The Essential Physics of Medical Imaging*, 3rd ed. Philadelphia: Lippincott Williams & Wilkins, 2012

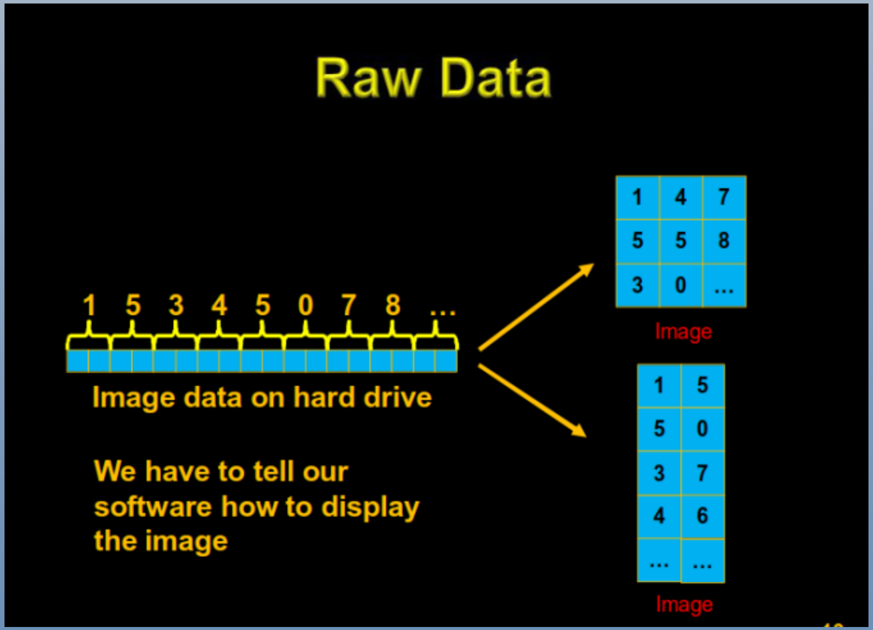

Standards
A standard is a set of rules that everyone agrees to follow
– Allows different things to speak to each other
Without Standard (Example): Write whatever you want!
Picture
Program to determine Color
Takes Picture
Color is: White
Gives color as word
Stage 2
Takes Color as word (in Serbian)
Gives winning lottery number if "beo"
13

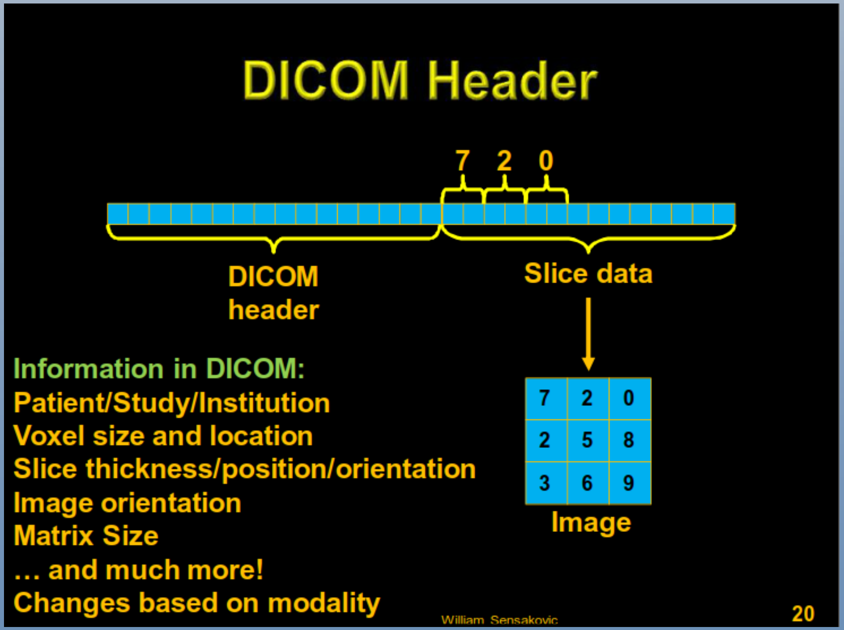

Standards
A standard is a set of rules that everyone agrees to follow
– Allows different things to speak to each other
With Standard (Example): Standard says that all outputs must be in Serbian
Picture
Program to determine Color
Takes Picture
Color is: beo
Gives color as word
Stage 2
Takes Color as word (in Serbian)
Gives winning lottery number if "beo"
14


HL7: Health Level 7
Promote interoperability between systems
Dictates how non-image data is communicated
– Orders
– Scheduling
– Demographics
15


DICOM: Digital Imaging and Communications in Medicine
Communication and storage of image (and some other) data in Radiology
NEMA
More on the header later
16


IHE: Integrating Healthcare Enterprise
Standard agreed upon between DICOM and HL7 for when they conflict with each other
Established by RSNA


Raw Data
1 5 3 4 5 0 7 8 …
Image data on hard drive
We have to tell our software how to display the image
1 4 7
5 5 8
3 0 …
Image
1 5
5 0
3 7
4 6
… …
Image


DICOM Header
7 2 0
DICOM header
Slice data
Information in DICOM:
Patient/Study/Institution
Voxel size and location
Slice thickness/position/orientation
Image orientation
Matrix Size
… and much more!
Changes based on modality
7 2 0
2 5 8
3 6 9
Image
William Sensakovic
20

Tag	VR	Description	Value
0010, 0010	PN	PatientName	jaszczak test 2^small
0010, 0020	LO	PatientID	2.16.840.114379.1000.1.20130308.102058.1780
0010, 0030	DA	PatientBirthDate	
0010, 0040	CS	PatientSex	
0010, 1000	LO	OtherPatientIDs	
0010, 1001	PN	OtherPatientNames	
0010, 1020	DS	PatientSize	0
0010, 1030	DS	PatientWeight	0
0010, 2160	SH	EthnicGroup	
0010, 2180	SH	Occupation	
0018, 0015	CS	BodyPartExamined	
0018, 0050	DS	SliceThickness	3.125
0018, 0070	IS	CountsAccumulated	2
0018, 0071	CS	AcquisitionTerminationCondition	MANU
0018, 0088	DS	SpacingBetweenSlices	-3.125
0018, 1000	LO	DeviceSerialNumber	
0018, 1020	LO	SoftwareVersions	UNKNOWN
0018, 1030	LO	ProtocolName	ACR SMALL PHANTOM
0018, 1061	LO	TriggerSourceOrType	EKG

Tag	VR	Description	Value
0008, 0008	CS	ImageType	ORIGINAL\PRIMARY\RECON TOMO\EMISSION
0008, 0012	DA	InstanceCreationDate	20130308
0008, 0013	TM	InstanceCreationTime	141903.0000
0008, 0014	UI	InstanceCreatorUID	1.2.840.113619.6.184
0008, 0016	UI	SOPClassUID	1.2.840.10008.5.1.4.1.1.20
0008, 0018	UI	SOPInstanceUID	1.3.6.1.4.1.9590.100.1.2.180392208913665937404438936421097407025
0008, 0020	DA	StudyDate	20130308
0008, 0021	DA	SeriesDate	20130308
0008, 0022	DA	AcquisitionDate	20130308
0008, 0023	DA	ContentDate	20130308
0008, 0030	TM	StudyTime	102058.00
0008, 0031	TM	SeriesTime	103346.00
0008, 0032	TM	AcquisitionTime	134517.00
0008, 0033	TM	ContentTime	140654.00
0008, 0050	SH	AccessionNumber	
0008, 0060	CS	Modality	NM
0008, 0070	LO	Manufacturer	NeuroLogica
0008, 0080	LO	InstitutionName	Florida Hospital Orlando
0008, 0090	PN	ReferringPhysicianName	
0008, 1010	SH	StationName	OHN4ENT

0018, 0060	DS	KVP	120
0018, 0088	DS	SpacingBetweenSlices	5.0
0018, 0090	DS	DataCollectionDiameter	500
0018, 1020	LO	SoftwareVersions	3.5.4
0018, 1030	LO	ProtocolName	ABD/PEL WO/Abdomen
0018, 1100	DS	ReconstructionDiameter	210
0018, 1120	DS	GantryDetectorTilt	0
0018, 1130	DS	TableHeight	111.000000
0018, 1140	CS	RotationDirection	CW
0018, 1150	IS	ExposureTime	842
0018, 1151	IS	XRayTubeCurrent	208
0018, 1152	IS	Exposure	175
0018, 1160	SH	FilterType	B
0018, 1210	SH	ConvolutionKernel	B
0018, 5100	CS	PatientPosition	HFS
▸ 0018, 9321	SQ	CTExposureSequence	<sequence of items>
0018, 9323	CS	ExposureModulationType	NONE
0018, 9345	FD	CTDIvol	11.4

"Why is this image so noisy"

DICOM Header vs. Protocol

3yrs old ✓

Brain Axial 3-6yrs

CTDIvol ✓

kVp & mAs ✓

Kernel ✗

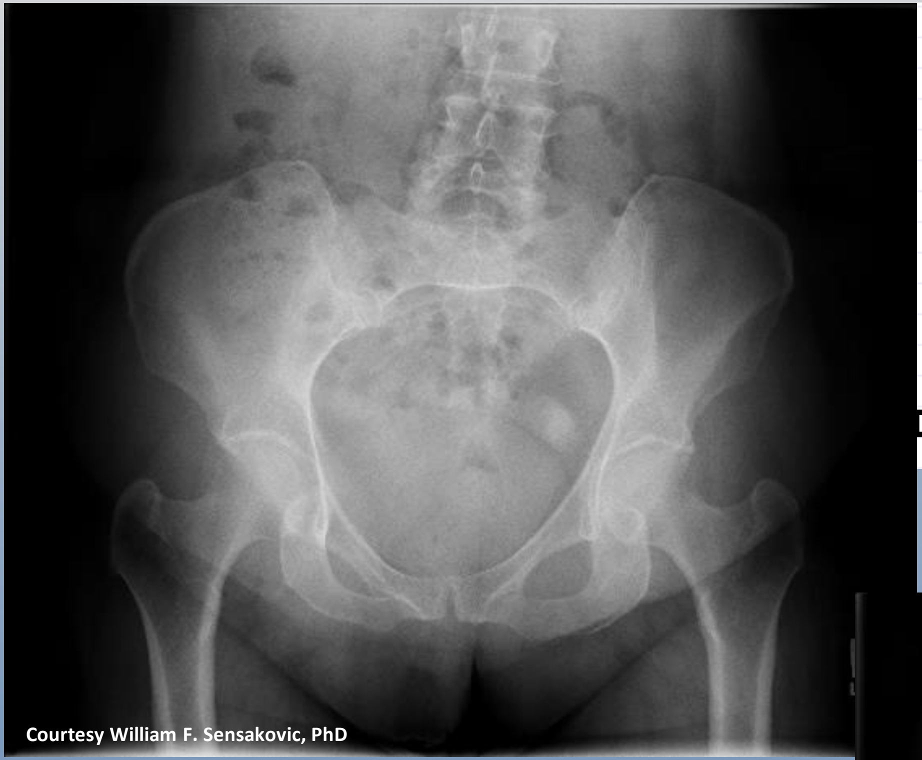
0018, 1160	SH	FilterType	B
0018, 1210	SH	ConvolutionKernel	B

B	Smooth, recommended for CTA, routine abdomen and pelvis

Same scanner and CTDIvol

B	Smooth, recommended for CTA, routine abdomen and pelvis

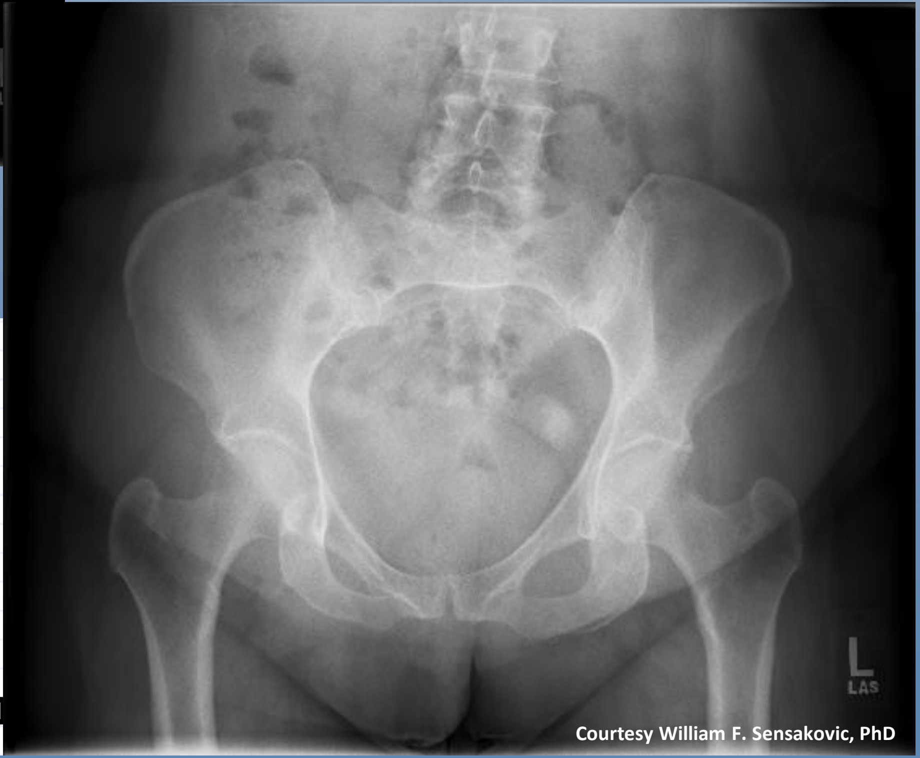
UA	Very smooth, improves bone/brain interface, head scans only



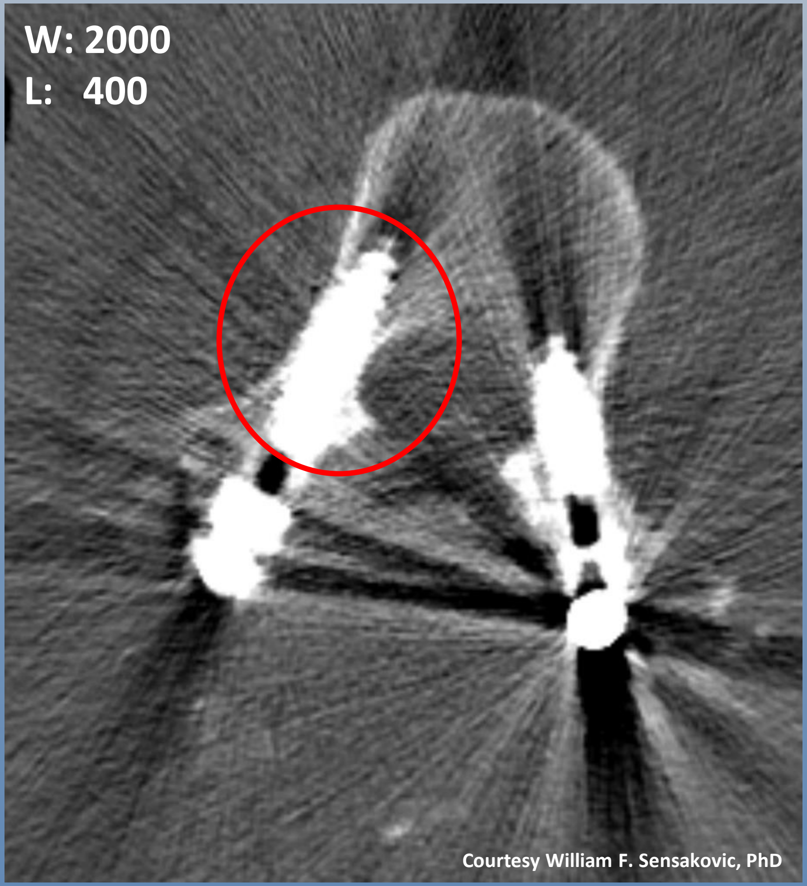
Courtesy William F. Sensakovic, PhD

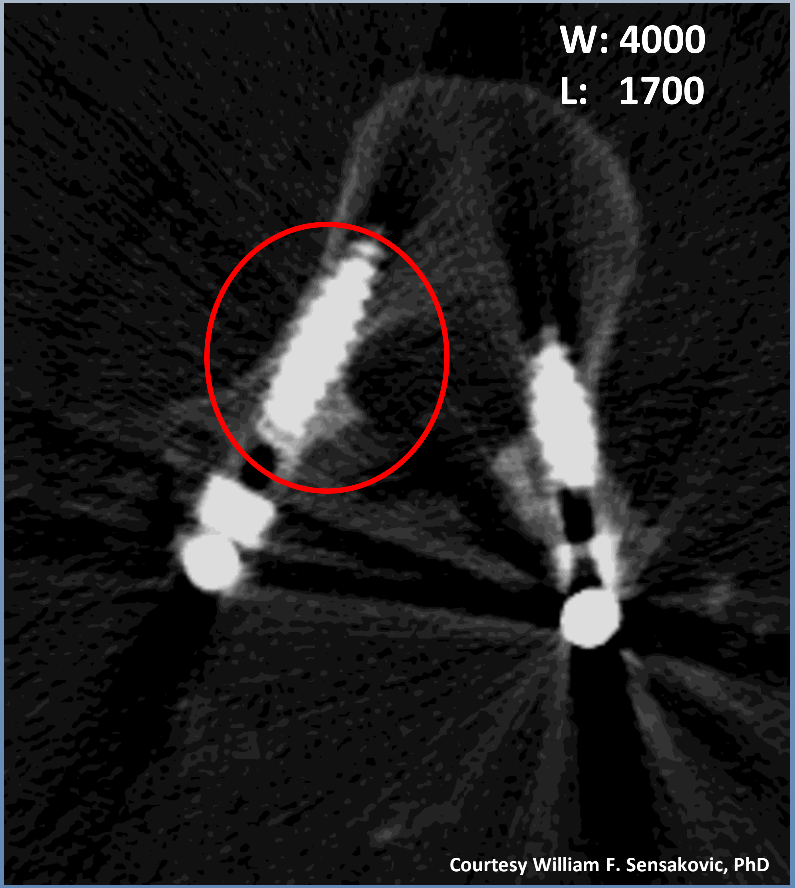
KVP	80.0
DeviceSerialNumber	963335497464
SoftwareVersions	3.0.4\PMS81.101.1.1 GXR GXRIM9.0
ProtocolName	Hip
SpatialResolution	0.143
DistanceSourceToDetector	1016.0
DistanceSourceToPatient	962.0
ExposureTime	18
Exposure	10
ExposureInuAs	10000
ImageAndFluoroscopyAreaDoseProduct	8.842
ImagerPixelSpacing	0.143\0.143
Grid	IN
AcquisitionDeviceProcessingDescription	UNIQUE: S:200 L:4.0 FB d:1.1 g:3.5 sb:2.5 eq:0 nr:0 dc:3.6
RelativeXRayExposure	201

KVP	80.0
DeviceSerialNumber	963335497464
SoftwareVersions	3.0.4\PMS81.101.1.1 GXR GXRIM9.0
ProtocolName	Hip
SpatialResolution	0.143
DistanceSourceToDetector	1016.0
DistanceSourceToPatient	962.0
ExposureTime	18
Exposure	10
ExposureInuAs	10000
ImageAndFluoroscopyAreaDoseProduct	8.842
ImagerPixelSpacing	0.143\0.143
Grid	IN
AcquisitionDeviceProcessingDescription	UNIQUE: S:200 L:4.0 SCL d:1 g:3 sb:3.3 eq:-0.4 nr:0 dc:3.3
RelativeXRayExposure	201



Courtesy William F. Sensakovic, PhD


W: 2000
L: 400
Courtesy William F. Sensakovic, PhD


W: 4000
L: 1700
Courtesy William F. Sensakovic, PhD

- **"Radiologists who <u>over read</u> have more false positives"**
  - **PACS facilitated attending feedback on the resident reads (when attending is not able to be physically present)**
    - **Second read by a radiologist**
  - **Over scrutinize (High Sensitivity; High FPs)**

- “Protocoling is something all diagnostic physicists should be active in ”
  - Attaching a specific protocol to a specific case based on the patient history and referring physician conversation
  - Develop protocols

Some Useful DICOM Parts

- Part 6 – the dictionary
  - All the elements
- Part 3 – define several elements

CTDIvol	(0018,9345)	3	Computed Tomography Dose Index ($CTDI_{vol}$), in mGy according to IEC 60601-2-44, Ed.2.1 (Clause 29.1.103.4), The Volume $CTDI_{vol}$. It describes the average dose for this image for the selected CT conditions of operation.
CTDI Phantom Type Code Sequence	(0018,9346)	3	The type of phantom used for CTDI measurement according to IEC 60601-2-44. Only a single Item is permitted in this Sequence.

- Part 14 – GSDF

01f1, 1026	DS	Unknown Tag & Data	0.798
01f1, 1027	DS	Unknown Tag & Data	0.5
01f1, 1032	CS	Unknown Tag & Data	RIGHT_ON_LEFT
01f1, 1042	SH	Unknown Tag & Data	No
01f1, 1044	OW	Unknown Tag & Data	Large data block not shown!
01f1, 1046	FL	Unknown Tag & Data	0.625
01f1, 1047	SH	Unknown Tag & Data	3D
01f1, 1049	DS	Unknown Tag & Data	40
01f1, 104a	SH	Unknown Tag & Data	NONE
01f1, 104b	SH	Unknown Tag & Data	64x0.625
01f1, 104d	SH	Unknown Tag & Data	YES
01f1, 104e	LO	Unknown Tag & Data	Spine

01f7, 1074	OW	Unknown Tag & Data	Large data block not shown!
01f7, 1075	OW	Unknown Tag & Data	Large data block not shown!
01f7, 107f	OW	Unknown Tag & Data	Large data block not shown!
01f7, 1095	OW	Unknown Tag & Data	0080\0000\0064\0000\0002\0
01f7, 1097	OW	Unknown Tag & Data	Large data block not shown!
01f7, 1099	OW	Unknown Tag & Data	0040\0000\0064\0000\cccd\3
01f7, 109a	OW	Unknown Tag & Data	0080\0000\0064\0000\0014\0
01f7, 109b	IS	Unknown Tag & Data	5

Conclusion

- Our radiologists will know some informatics
- We should know more
- We already use it and have a chance to drive and define its use
- Clinically relevant value added by a physicist
  - Didn’t even talk about dose tracking