The
Medicine
Behind the
Image

DICOM, PACS and Veterinary Radiology

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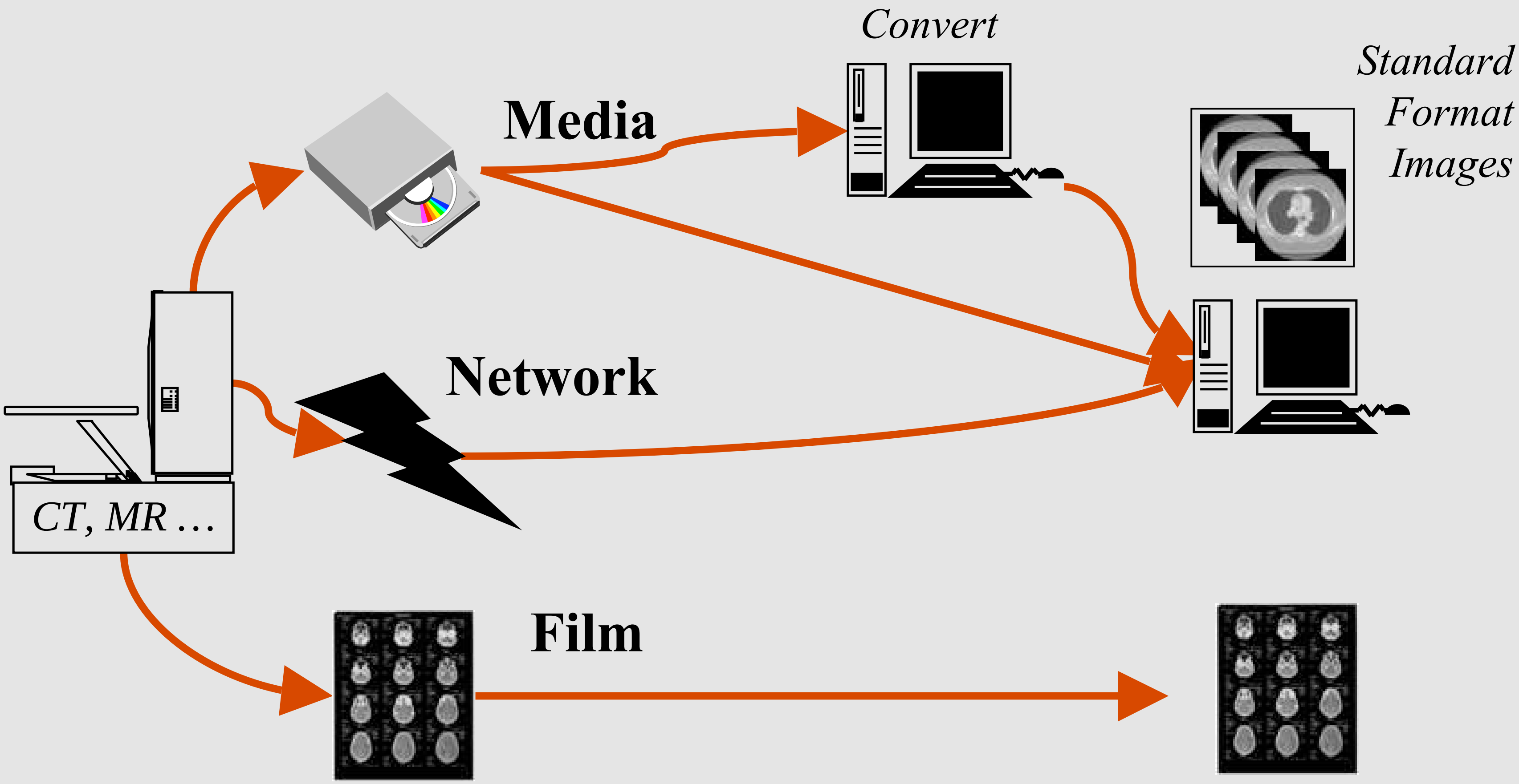
Overview

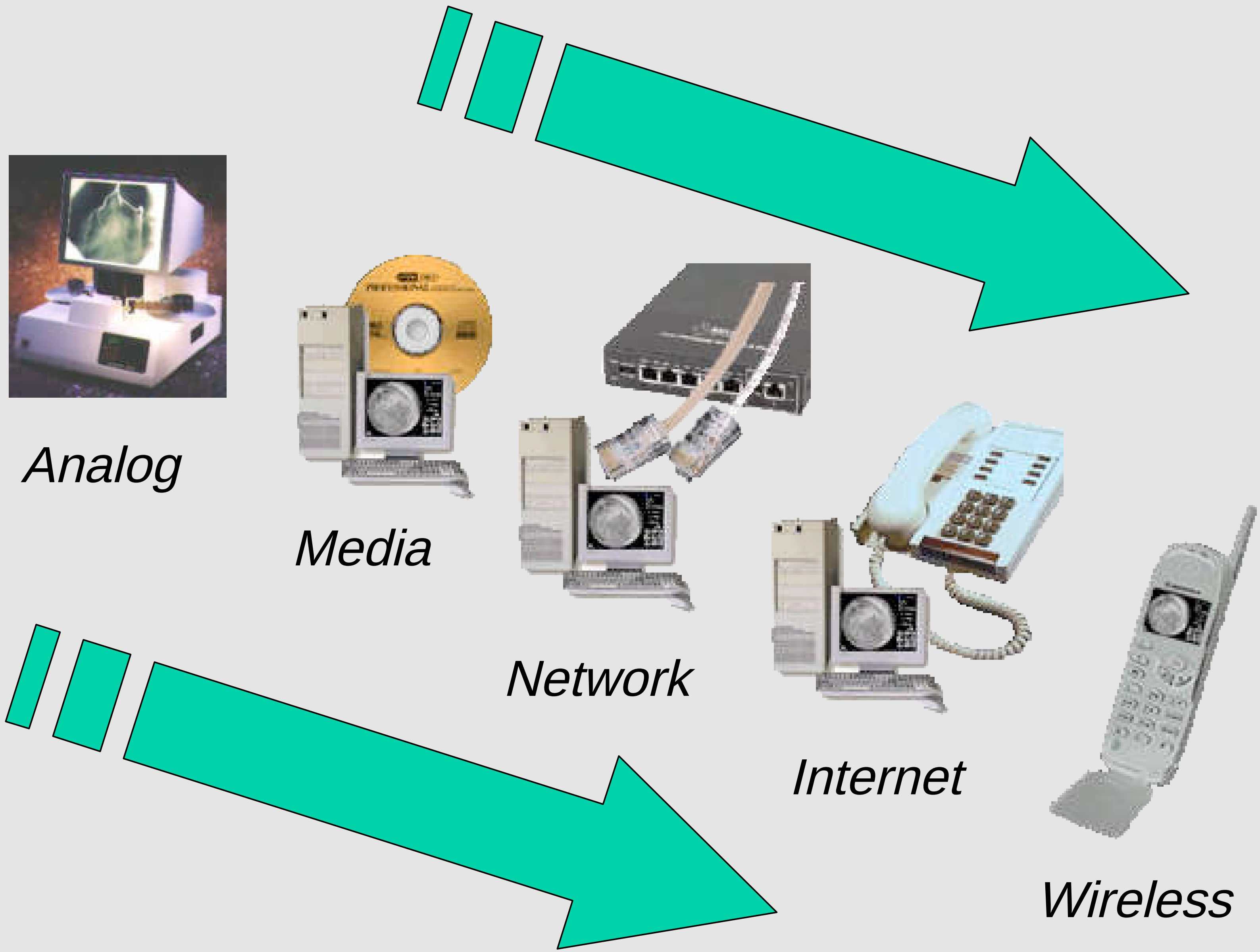
- Why Digital ?
- PACS and the need for DICOM
- What is DICOM ?
- Veterinary-specific gaps and issues
- DICOM and workflow
- DICOM and consistency of appearance

Why Digital ?

- Images: fidelity and flexibility
  - CT, MR, PET, NM and now US are digital to start with
  - CR and Digital X-Ray replacing film also
  - Printing to film involves loss of information and quality
- Efficiency
  - Storage (less bulk, ease of transport)
- Multiple simultaneous access
  - Fewer repeats for lost film
  - Copying film leads to substantial quality loss
- Review, search and analysis
  - More powerful visualization and analysis tools
  - Quantitation of values, segmentation, registration

Image Transfer

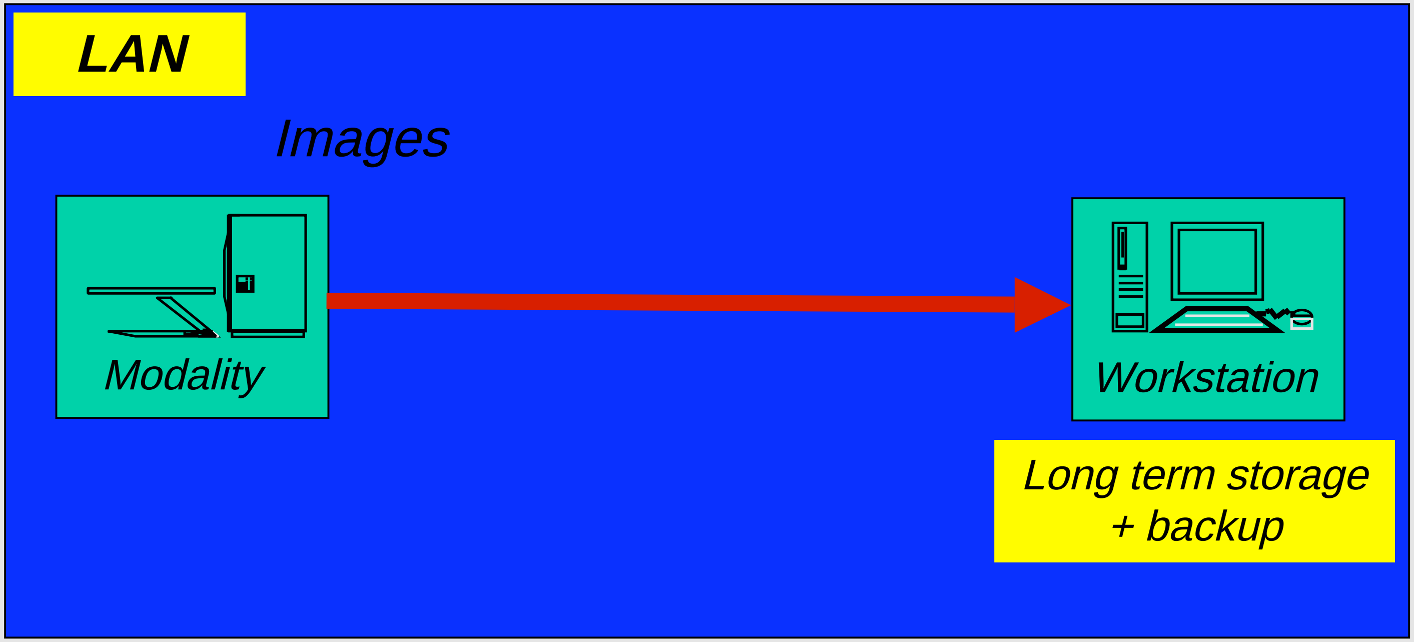



Analog
Media
Network
Internet
Wireless

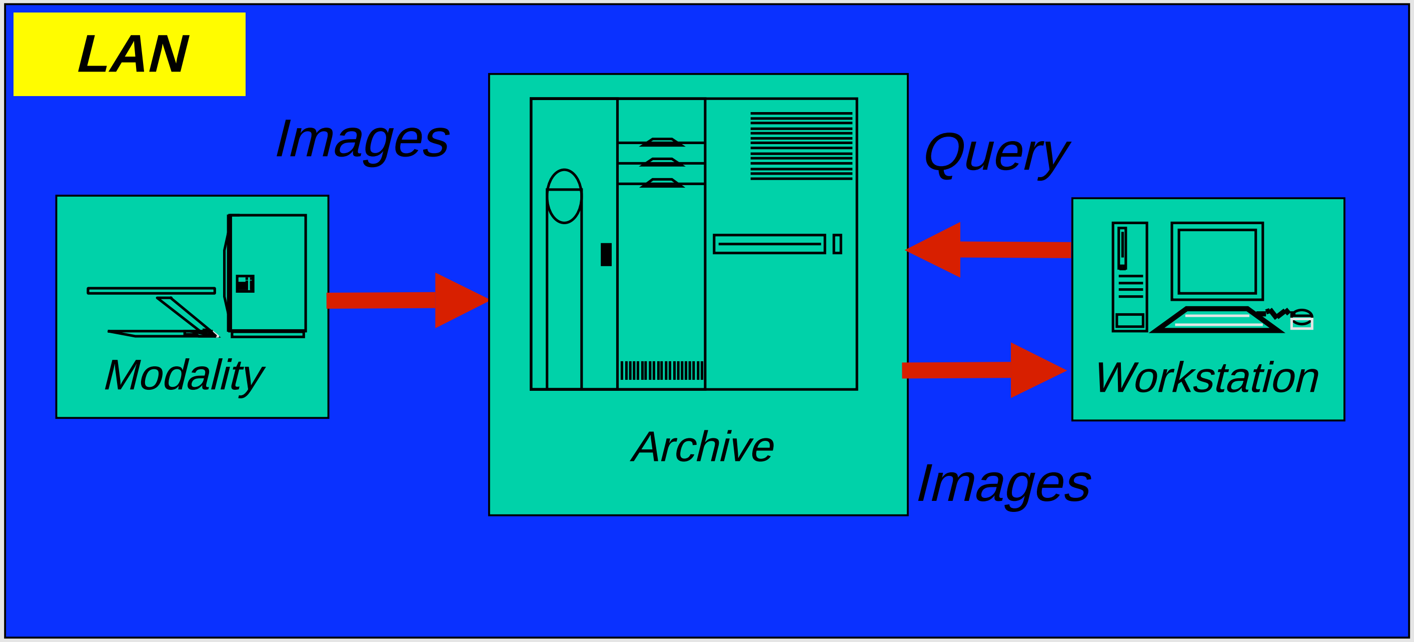
Deployment Scenarios

- Within local office or facility only
  - Take advantage of digital quality
  - Softcopy reading
  - Avoid storing film
  - Storage of priors from previous visits for comparison
  - From small to large facility, even one modality and one workstation
- Between facilities, providers or patients/owners
  - Referrals to specialist facilities
  - Referral to or consultation with other providers (teleconsultation)
  - CD to give to patient/owner (for next time, or just for interest)

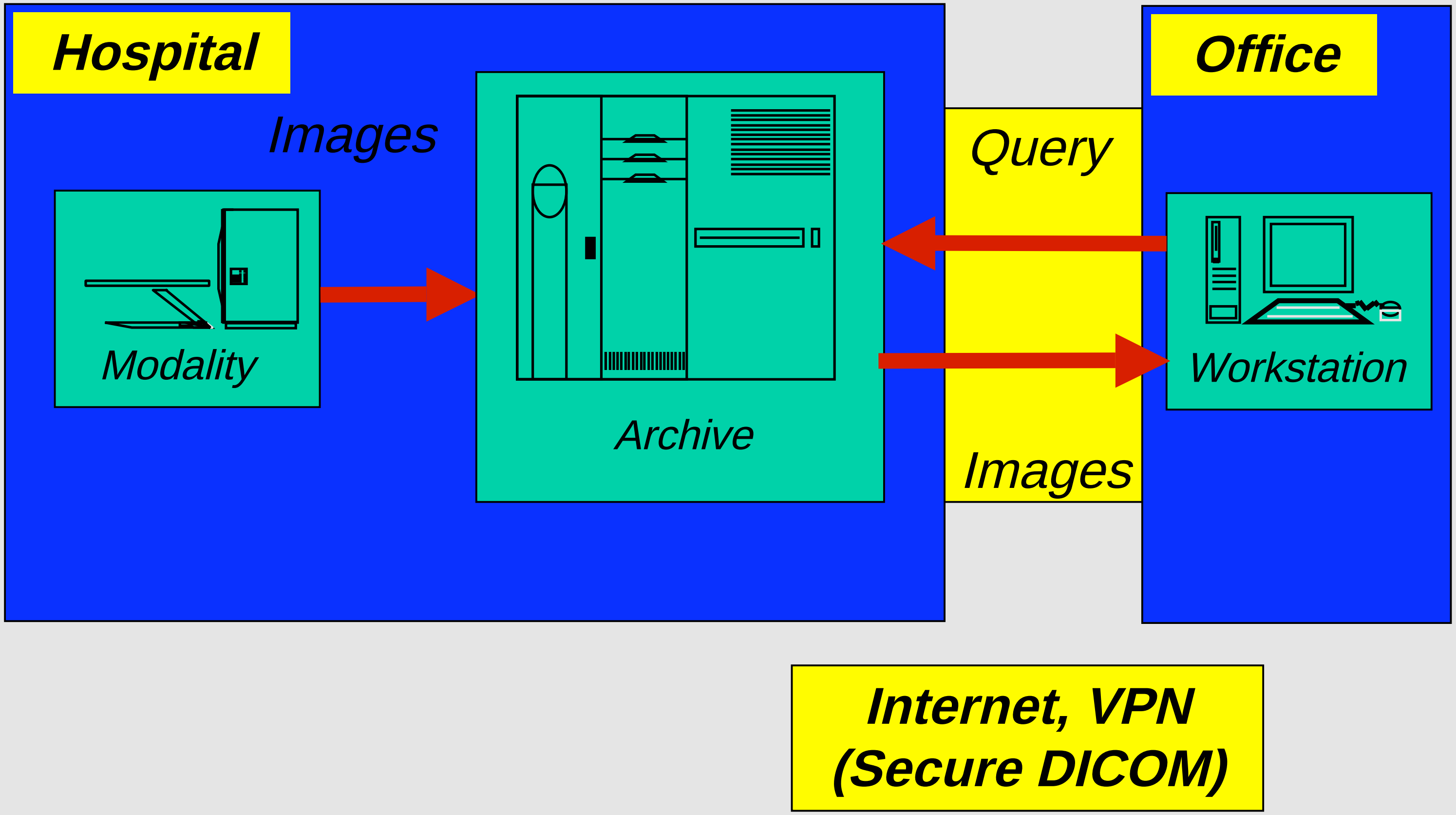
Simplest Case



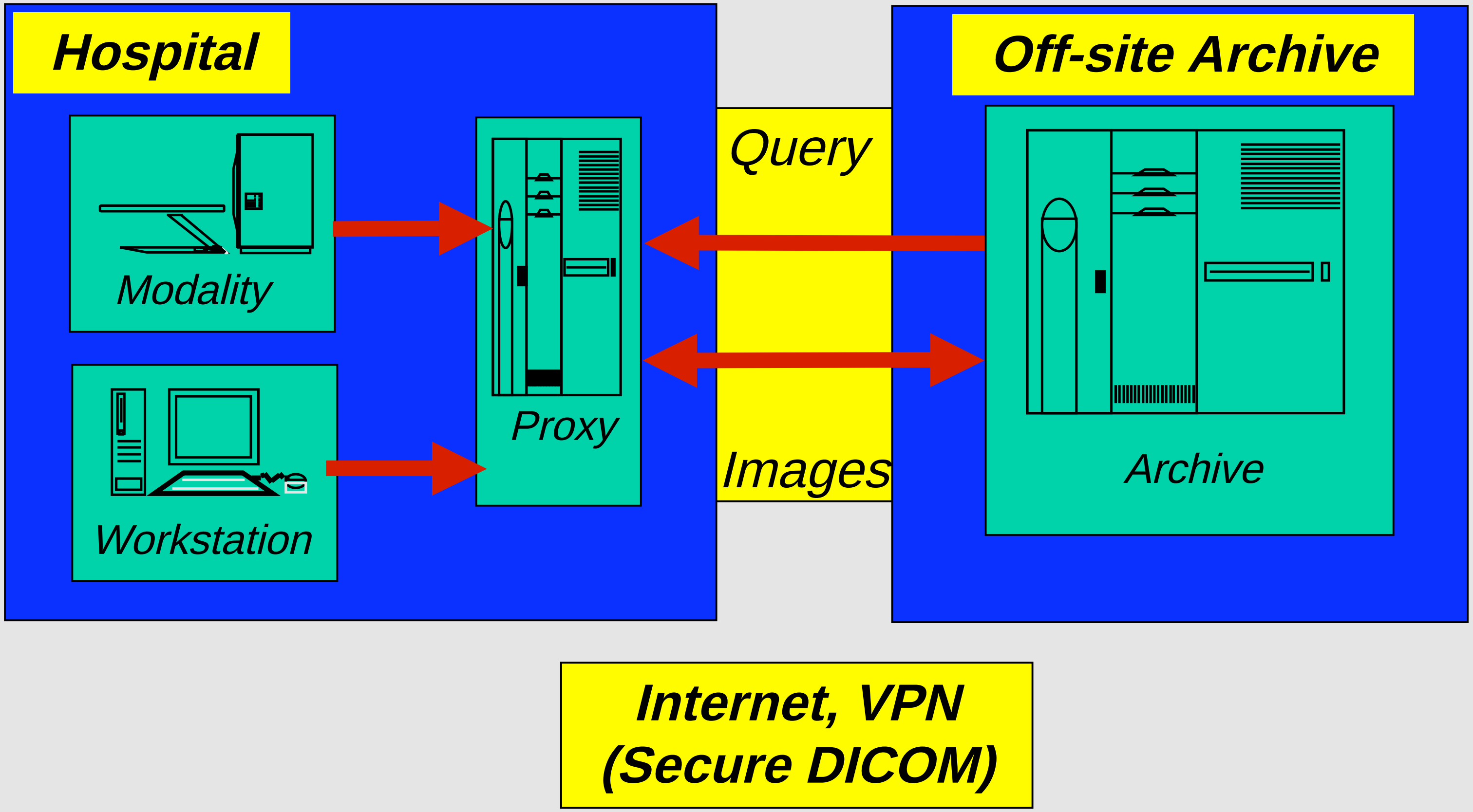
Local Storage



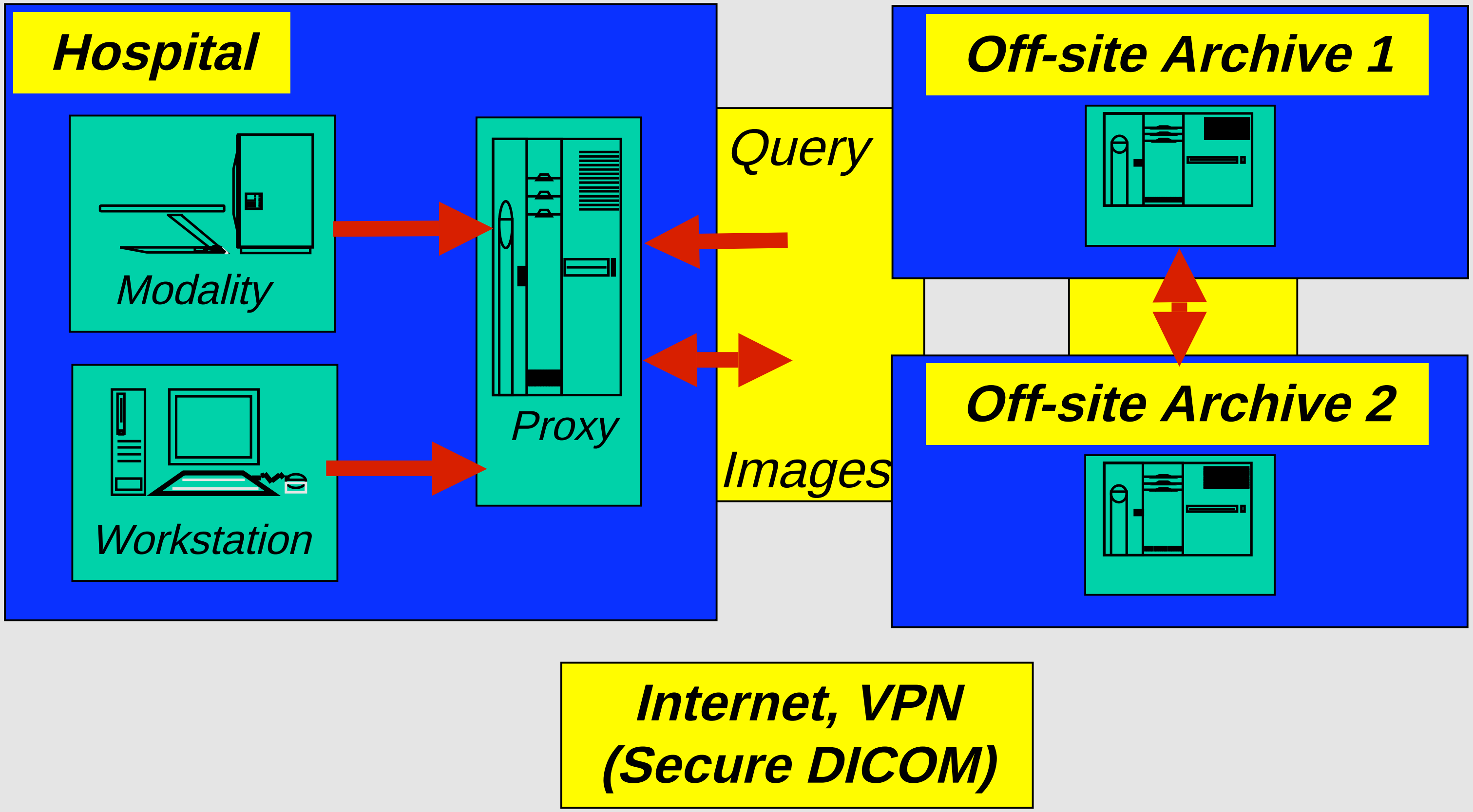
Remote Access



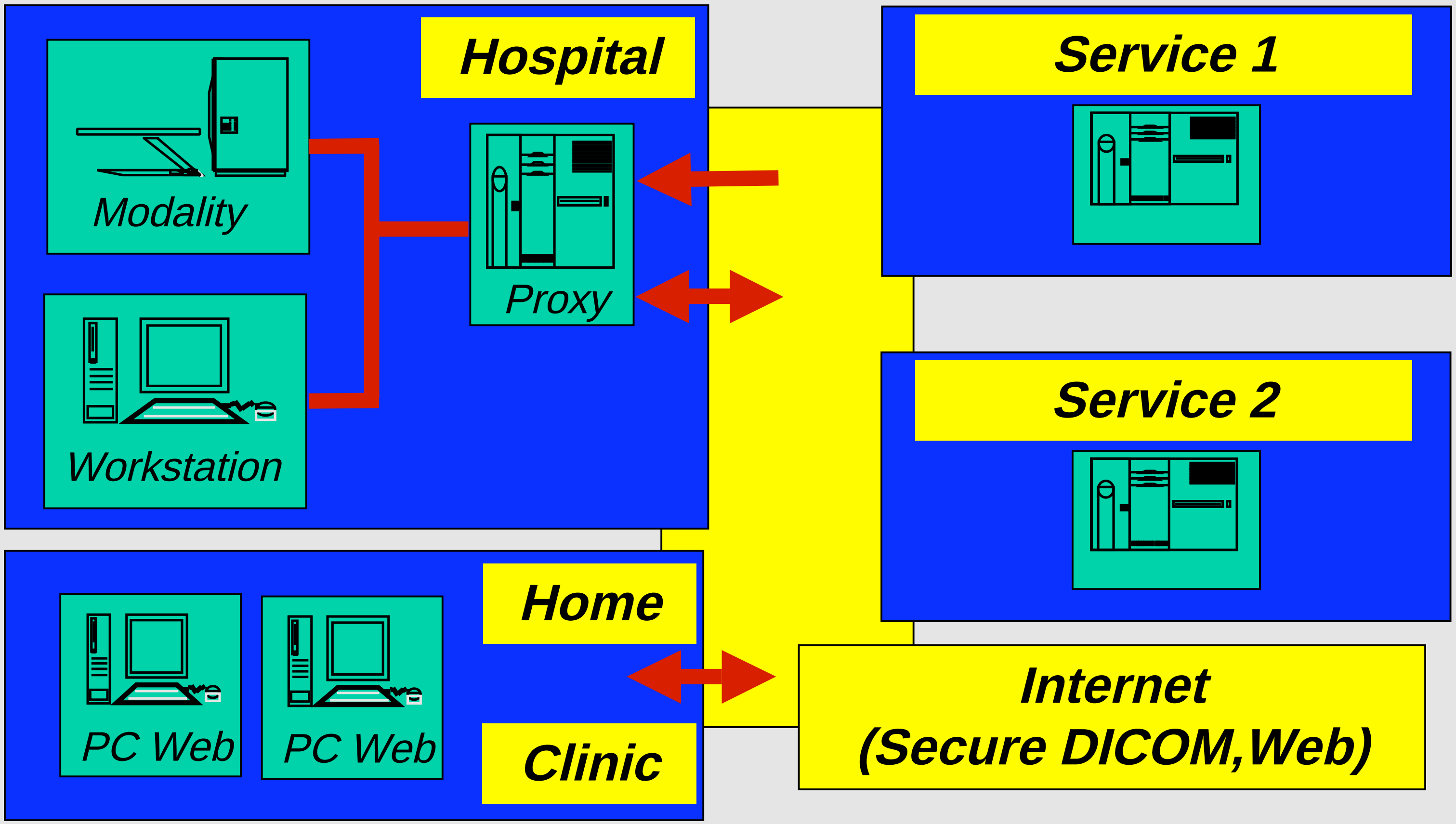
Off-site Archival



Off-site Archival - Replication, Load Sharing



Application Service Provider



PACS

- All these scenarios fall under the general category of PACS - *Picture Archiving and Communication System*
- Smallest - “mini-PACS”
- Large PACS
- Integrated and federated PACS
- Multi-modality PACS
- Multi-specialty PACS (radiology, cardiology)

PACS Beginnings

- Lemke, 1979
  - "A network of Medical Workstations for Integrated Word and Picture Communication in Medicine"
- Capp, 1981
  - "Photoelectronic Radiology Department"

1982 - "The year of PACS"

- First International Conference and Workshop on Picture Archiving and Communications Systems, SPIE, Newport Beach
- First International Symposium on PACS and PHD (Personal Health Data), Japan Association of Medical Imaging Technology

Who named PACS ?

- Debate in 1982 meeting as to whether to use “image” or “picture”
- Initial conference name was “Distributed Computerized Picture Information Systems (DCPIS)”
- André Duerinckx writes in 1983 SPIE paper that he coined the term in summer of 1981
- Others have attributed it variously; Sam Dwyer allegedly attributes it to Judith M. Prewitt

What does PACS mean ?

- Physics and Astronomy Classification Scheme
- Political Action Committee(s)
- Pan-American Climate Studies
- *Picture Archiving and Communication System*

What PACS means to you ?

- Multi-modality digital acquisition
- Storage
- Distribution, locally and remotely
- Display
- Reporting creation, distribution, storage
- Workflow management
- Integration with other information (systems)
- *Integration of equipment from multiple vendors*

PACS in 1982 ?

- Pretty much the same
- Less ambitious in scope
- Not all modalities (CR not yet available)
- More emphasis on storage, transfer and display than workflow
- *No standards, but recognition of the need for them*
- Relatively impractical given technology of the day
- A grand vision for the future

Major PACS Eras

- 1980's
  - Evolution of concepts, technologies, prototypes and installation of mini-PACS
- 1990's
  - Practical deployment of "Large Scale PACS"
  - Development and adoption of standards
- 2000's
  - Noticeable increase in market penetration
  - Increasing "commoditization" of PACS

So what has changed ?

- Driving forces
  - Less emphasis on cost savings from eliminating films
  - Greater emphasis on productivity and quality of care
  - Organizational benefit, not just radiology department
- Underlying technology infrastructure
  - Faster networks, bigger disks, better displays
  - Cheaper
- Users have created a demand
  - Vendors have responded
- Complexity better understood
  - Exceptional cases better supported
  - Focus on workflow management

Some of the challenges

- Integration of modalities beyond radiology into a single infrastructure
  - Visible light
  - Cardiology
  - Nuclear medicine
- Specific application support
  - PACS workstations "dumb" - viewing not processing & analysis
- Growing volume of data per study
  - Challenges storage, communication and display technology/design
- Security infra-structure integration
- Electronic medical record integration

Acquisition

- Early PACS required
  - Proprietary connections to digital modalities
  - Video frame-grabbing of CT and MR
  - Film digitization (initially no CR)
- Computed Radiography
  - Introduced by Fujifilm 1983
  - Originally intended to print to film


D
D
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Acquisition - Standards

- Proprietary connections
  - Not scalable
  - Too expensive
  - Single vendor for PACS and all modalities implausible
- 1983 ACR-NEMA Committee
  - American College of Radiology
  - National Electrical Manufacturer's Association
- 1985 ACR-NEMA Version 1.0
- 1988 ACR-NEMA Version 2.0
- 50 pin plug point-to-point interface (no network, no files)
- Tag-value pairs of data elements
  - Describing acquisition and identifying patient

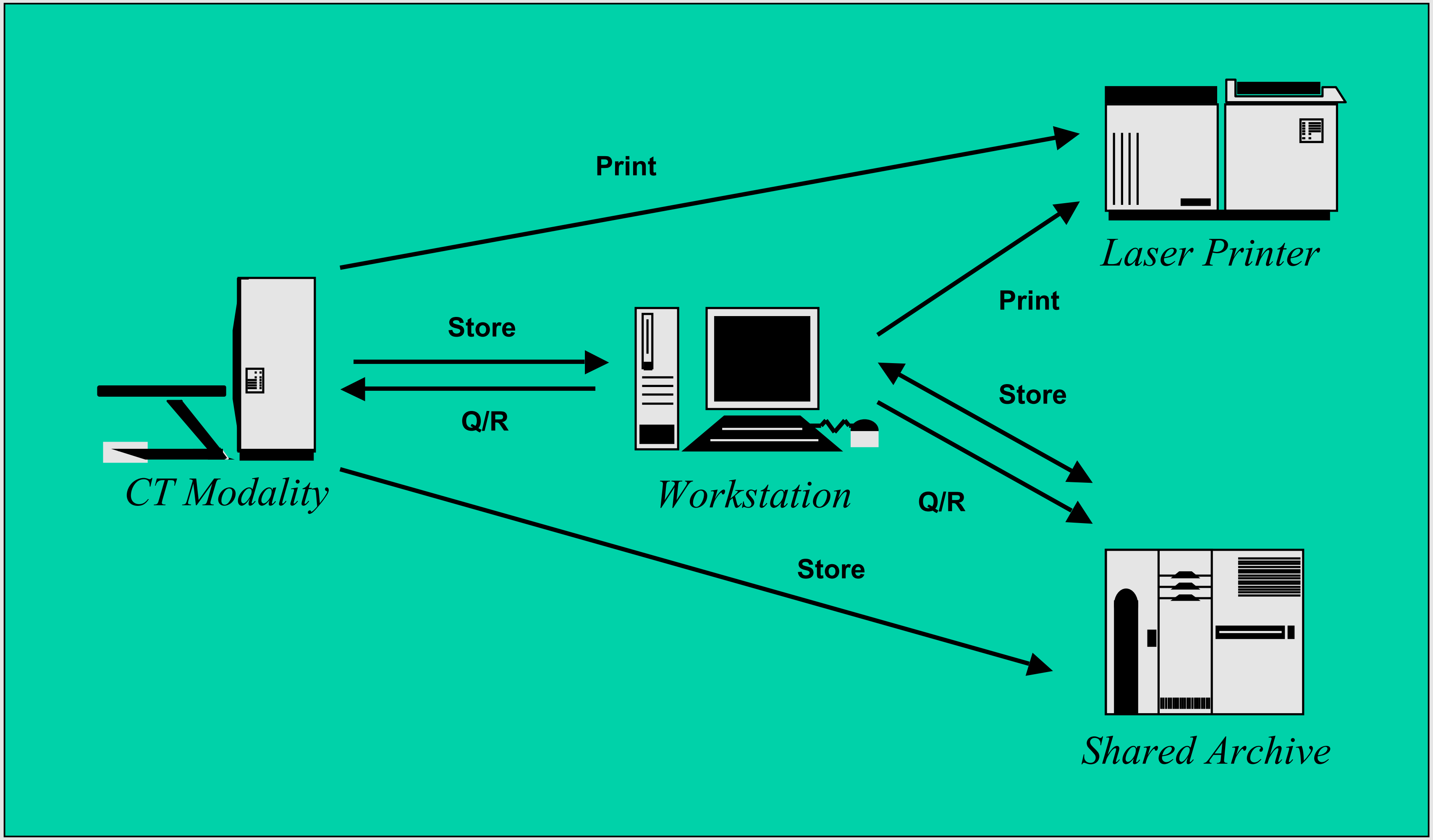
Acquisition - Standards

- Post-ACR-NEMA PACS and Modalities
  - Several vendors used ACR-NEMA ideas in proprietary networks
  - Siemens-Philips SPI
  - ACR-NEMA as a file format
- 1982 Interfile for Nuclear Medicine
  - AAPM
  - European COST-B2 project
- By 1990's still no widely adopted standard for
  - Specific modality requirements for all modalities
  - Network based transport and services

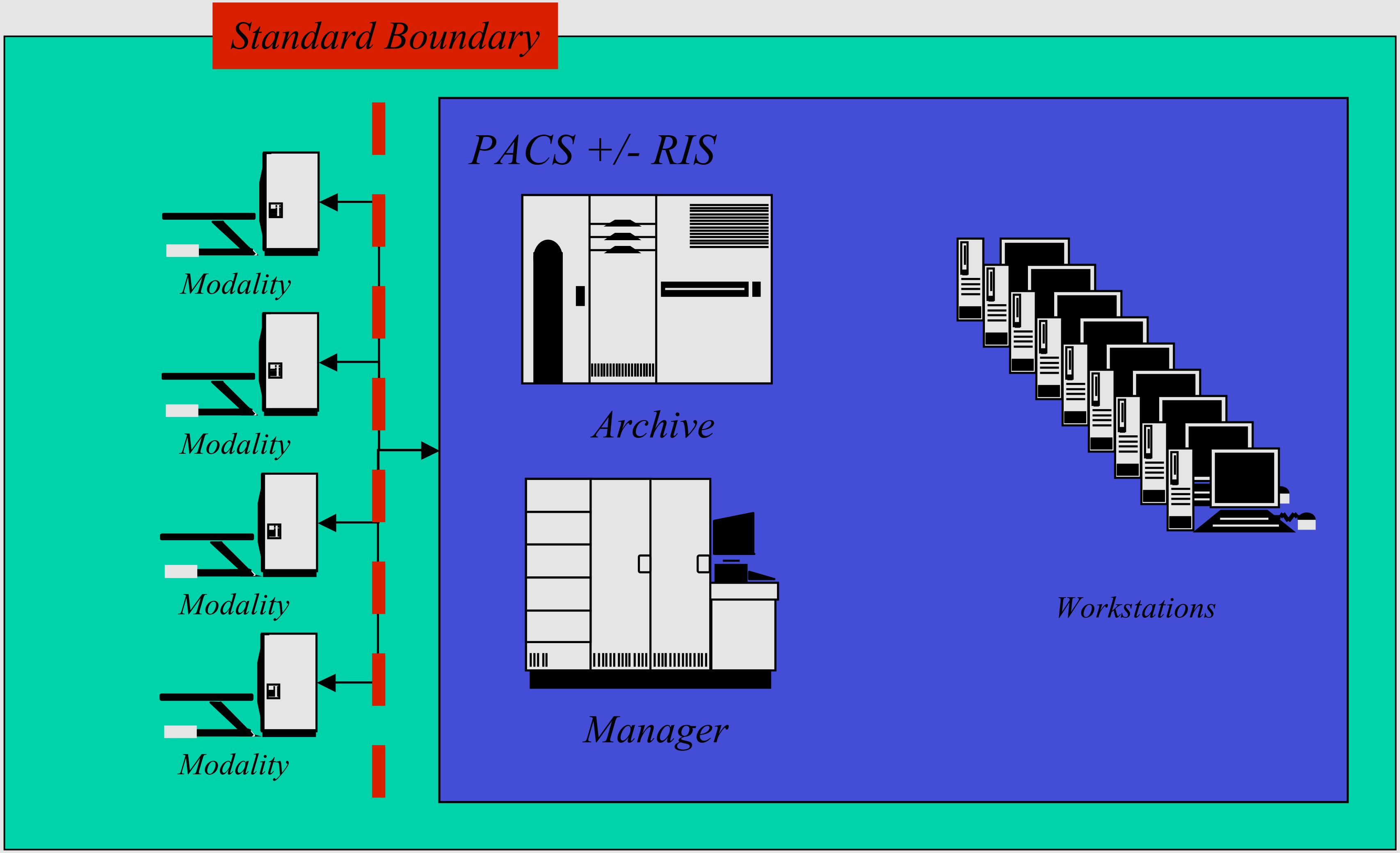
Acquisition - DICOM

- 1993 - Digital Imaging and Communications in Medicine
- Network-based
  - TCP/IP over Ethernet
- Services for
  - Storage (transfer)
  - Query and retrieval
  - Printing
- Derived from ACR-NEMA
- Added concepts of modality-specific information objects
- Conformance requirements and statement
- Interchange file format and media quickly added (1995)

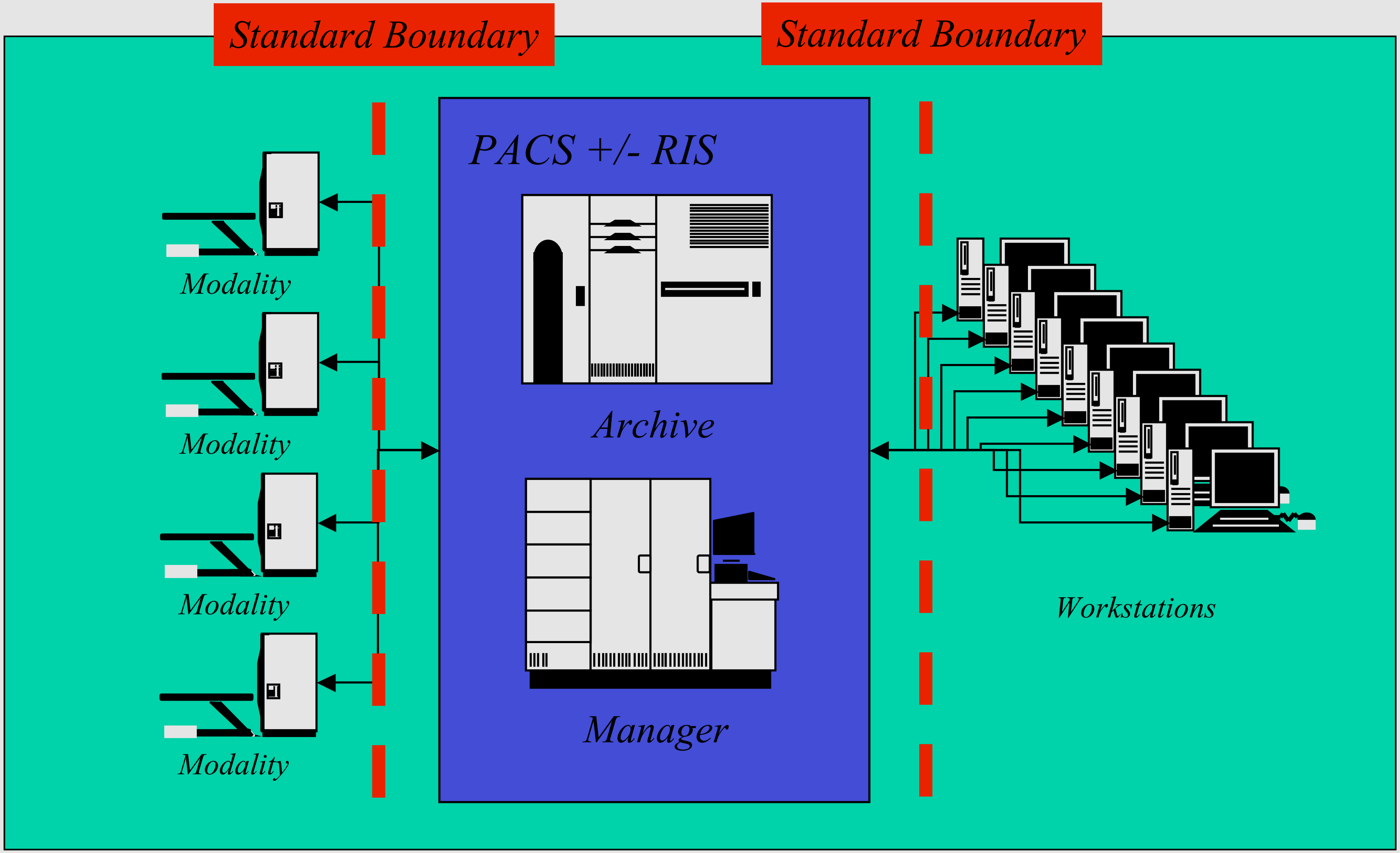
DICOM Mini-PACS

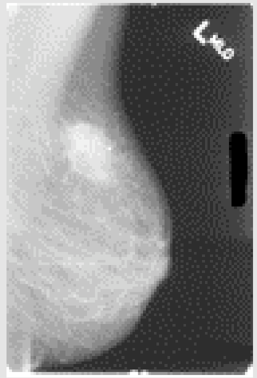
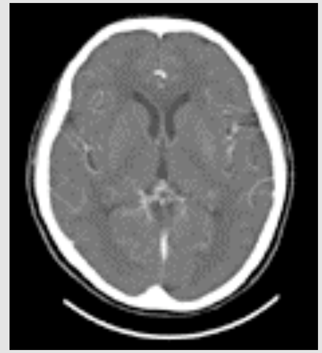


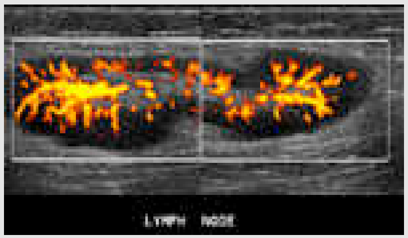
DICOM and the PACS



DICOM and the PACS

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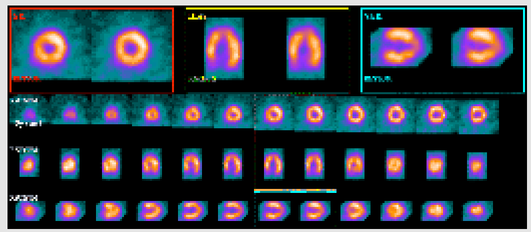
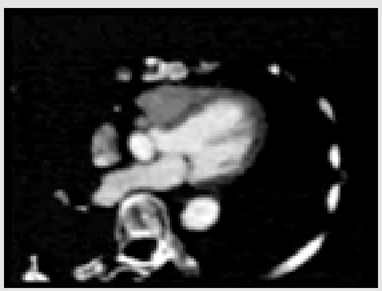
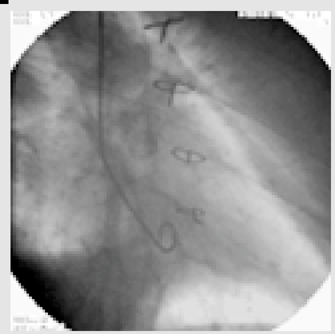
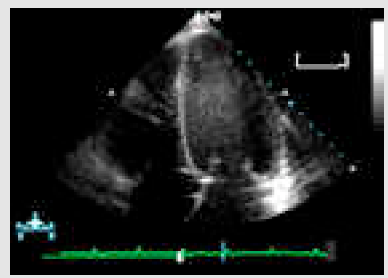
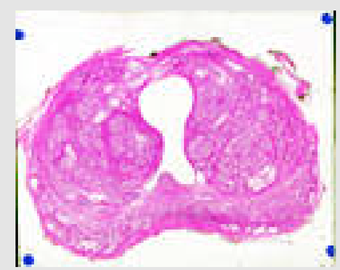




1993 DICOM Image Objects

- 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 about other standards?

- Pure imaging standards (TIFF, JPEG, etc.)
  - limited support for medical image types
  - don’t encode domain specific information
- Other domains inappropriate
  - military, remote sensing, astronomical, etc.
- ISO standards (e.g., IPI) never adopted
- Other medical standards don’t do images
  - HL7, P1073, etc

What kinds of images ?

- Characteristics
  - grayscale, indexed color or true color
  - 8 or 16 bit
  - signed or unsigned
- Domain (modality specific)
  - CT, MR, CR, DR, XA, XRF, US, NM, PET
  - Microscopy, endoscopy, fundoscopy ...

Key goals of DICOM

- Support *interoperability*
  - NOT interfunctionality
  - WITHOUT defining (restricting) architecture
- Define *conformance*
  - specific services and objects
  - documentation (Conformance Statement)
  - negotiation
- Voluntary compliance

DICOM does *NOT* define:

- PACS or Image Management Architecture
- Distributed Object Management
- Radiology/Hospital Information System
- Complete Electronic Medical Record

- These are the realm of IHE - *Integrating the Healthcare Enterprise*

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

DICOM and *Interoperability*

- Object oriented definition
  - data structures, e.g., MR image object
    - ➢ composite model of real world entities
      - patient, study, series
      - general image, specialized to MR image
  - services, e.g., image storage
  - together => service/object pairs (SOP)
- Roles (user or provider) (SCU or SCP)
- Role + SOP Class => Conformance

DICOM SOP Classes/Roles

- MR scanner may say:
  - "I am an MR Image Storage Service Class User (SCU)"
- Workstation may say:
  - "I am an MR Image Storage Service Class Provider (SCP) (amongst other things)"

MR images may be transferred

DICOM SOP Classes/Roles

- Angiography device may say:
  - “I am an XA Image Storage Service Class User (SCU)”
- Workstation may say:
  - “I am not an XA Image Storage Service Class Provider (SCP) (though I do support other kinds of images like CT and MR)”

This pair cannot transfer XA images

Why is DICOM so specific ?

- For example,
  - MR Image
    - single frame, 12-16 bit grayscale image
    - MR acquisition - pulse sequence parameters
    - 3D patient relative co-ordinate/vector position
  - X-Ray Angiography Image
    - multi-frame, 8-10 bit grayscale image
    - XA acquisition - radiation/collimation/motion
    - Dynamic C-arm/table relative positioning

DICOM SOP Classes/Roles

- Workstation may say:
  - "I am a Basic Grayscale Print Management Meta SOP Class SCU"
- Printer may say:
  - "I am a Basic Grayscale Print Management Meta SOP Class SCP"

Images may be printed

DICOM SOP Classes/Roles

- Ultrasound scanner may say:
  - "I am a Basic Color Print Management Meta SOP Class SCU"
- Printer may say:
  - "I am only a Basic Grayscale Print Management Meta SOP Class SCP"

This pair cannot print images

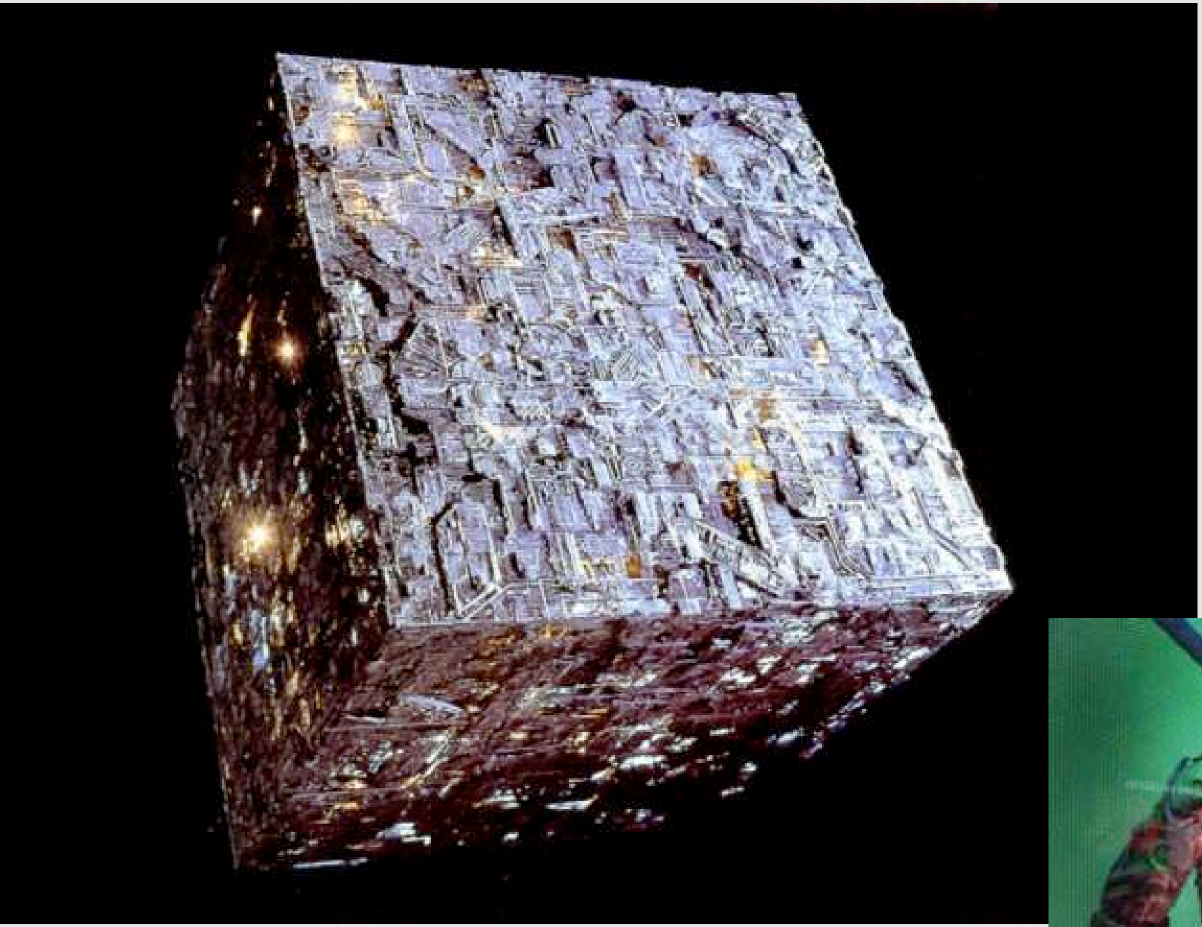
DICOM Conformance

- Capabilities defined *a priori* in the mandatory DICOM Conformance Statement
  - Allows users/other vendors/integrators to plan effectively
- Capabilities negotiated live on the network
  - Association Establishment phase before transfer
  - Allows ad hoc networks to be setup and configured
  - Allows devices to explore capabilities and change behavior dynamically (e.g., SCP doesn’t support DX so fall back to CR image transfer)
  - Allows negotiation of compression transfer syntaxes (mandatory uncompressed default)

DICOM Penetration

- Acquisition modality
  - cannot buy a digital radiology modality that does not at least have DICOM image transfer
  - typically will have DICOM print and workflow services (modality worklist) as well
  - many starting to support DICOM Structured Reports for export of measurements (e.g., cardiac and obstetric ultrasound)
- PACS
  - cannot buy a PACS that will not accept DICOM images
  - vast majority will support DICOM queries
  - many supply worklist services to modalities
- Printers
  - cannot buy a medical printer that does not support DICOM

NEMA, Suite 1847
1300 North 17th Street
Rosslyn, VA
22209
Ph: (703) 841-3285



DICOM and Veterinary

- Re-use of human acquisition modalities
- Veterinary-specific modalities
- General purpose PACS and workstations
- Veterinary PACS and workstations
- Veterinary information systems

DICOM Gaps for Veterinary

- Animal identification
- Animal characteristics
- Positioning and anatomy
- Procedure classification

Identification & Characteristics

- Human
  - Patient name and ID
  - Fixed attributes - sex, DOB
  - At time of study - age, height, weight (rarely ethnicity, etc.)
- Animal
  - Animal name and ID
  - Fixed attributes - sex, DOB, but also species, breed
  - At time of study - owner, neutered, breed registry ID

Identification & Characteristics

- What needs to be stored in the image “header” rather than elsewhere ?
  - Reliable identification
  - Information required for display to allow interpretation
  - Do not try to bury entire medical record in the image
- Strategy
  - Re-use existing DICOM attributes as appropriate, e.g., Patient Name and ID to store animal’s name and ID
  - Add new optional attributes to existing DICOM image definitions, or conditional upon subject being an animal, e.g. Owner
  - Use codes rather than free text wherever possible and practical

Identification & Characteristics

- Current proposal being considered by WG 25 …

- Owner (one person; ? need for multiple, for organization)
- Neutered (yes/no)
- Species Code Sequence (one item allowed)
- Breed Code Sequence (one or more items allowed)
- Breed Description (free text)
- Breed Registry Sequence (one or more items, for multiple registries)
  - Registration Number
  - Breed Registration Authority Code Sequence (1 item allowed)
  - Breed Registration Authority Description (in case no code for naming the registry)

Codes versus Free Text

- Enumerated values:
  – Neutered - values of YES, NO - nothing else permitted
- Free text operator entry, e.g., of species:
  – “dog”, “canine”, “K9”
  – makes searching for all “dog” images difficult
- Coded sequences - pull-down lists in UI
  – Coding scheme - “SRT” (SNOMED)
  – Code value - “L-80700”
  – Code meaning - “Canine species”

Codes

- Re-use work of outside organizations like SNOMED
  - SNOMED already has veterinary content and relationships with professional organizations like AVMA
  - Cost and licensing issues - DICOM has a relationship that allows license and royalty free use of codes used in DICOM - also free in US for now
- Species
  - Relatively short list and relatively complete in existing coding schemes
- Breed
  - Very long list and moderately complete in existing coding schemes
  - Will need work to maintain, e.g. as new “breeds” emerge like “puggle”, “cockapoo”, “speagle”, “labradoodle” …
  - Will always need free text alternative for new and mixed breeds, especially those owners feel strongly about but are not generally accepted, e.g., “Polish warmblood”

Anatomy Issues

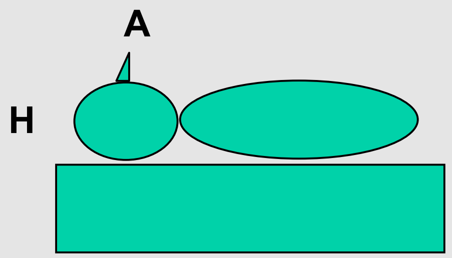
- DICOM anatomy
  - Body Part Examined
    - list of string terms or free text
    - E.g., “CHEST” or “BRAIN” or “WRIST”
  - Anatomic Region Sequence
    - SNOMED codes - broad range of granularity
    - Re-use human codes - add sufficient new veterinary codes
- Vendors and operators often send no such information
  - Typically embedded in free text Study or Series Description
  - E.g., Study Description = “CT Chest/Abdomen and Pelvis”
  - E.g., Series Description = “Left wrist lateral”
  - Inadequate anatomic information compromises ability to position and orient (hang) images properly for display

Positioning Issues

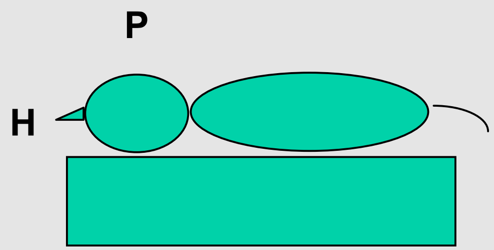
- Standard human anatomic position
- Quadrupeds similar, but different
- Less of an issue for projection radiography
  - Views and labels manually chosen
  - Does affect how images are oriented (hung) for display
- Cross-sectional (CT and MR) positioning
  - Practical positioning of anesthetized animal on table
  - Especially head and limbs

Sagittal Positioning

- Human
  - Likely positioned in gantry supine
  - Nose is anterior (ventral)
  - Vertex is towards head (craniad)



- Dog
  - Likely positioned in gantry prone
  - Nose is towards head (craniad)
  - Vertex is posterior (dorsal)



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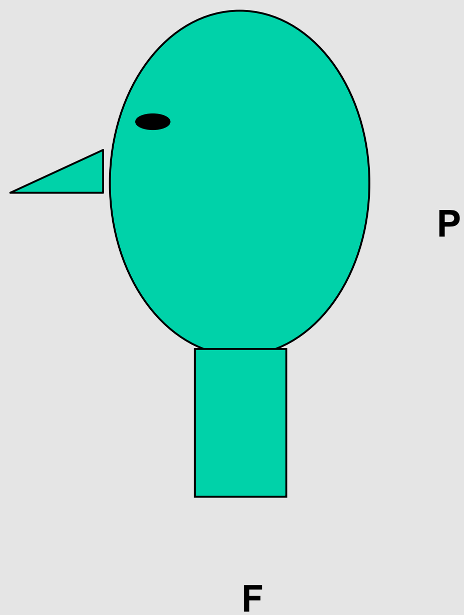

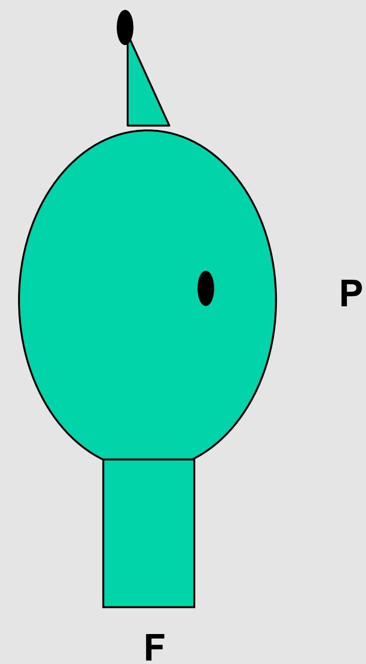

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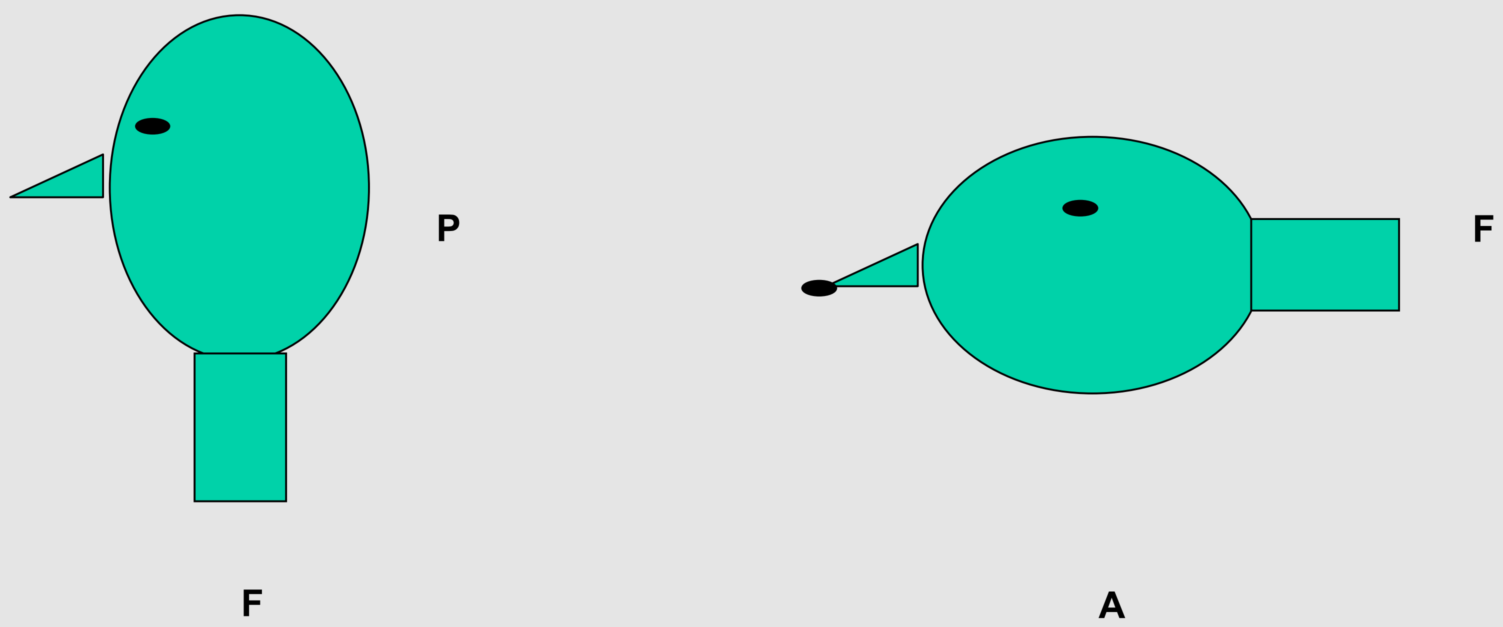
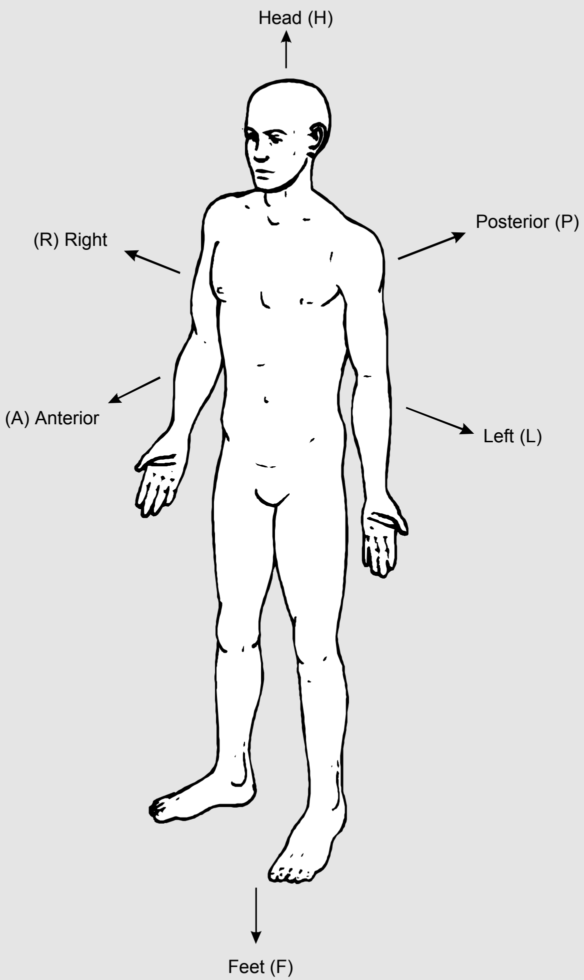


Positioning Issues

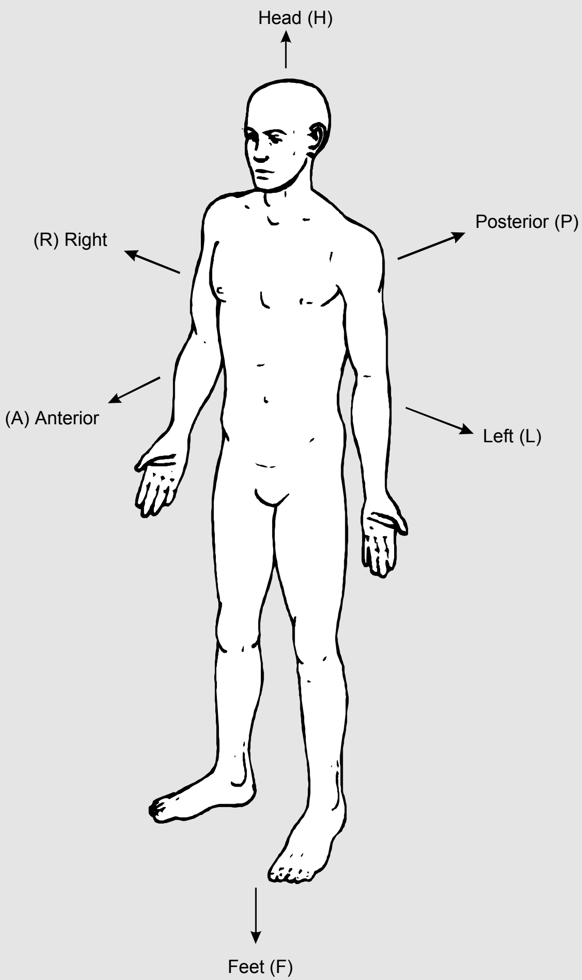
- Who cares ?
- Left versus right side not likely affected
- Default assumptions of display software
  - "human" software - may have to rotate/flip each time
- Consistency of 3D software
  - As long as coordinate system is consistent, not issue
  - 3D navigation tools awkward if human assumptions
- Inconsistency between vendors if not defined in advance by a standard

DICOM Standard Positions

- DICOM PS 3.17 Annex A
- Illustrations of interpretation of orientation
  - L v. R (left or right)
  - A v. P (anterior, ventral or posterior, dorsal)
  - H v. F (towards head, craniad, rostral or foot, caudad)
- Limbs
  - Palmar, plantar = A (anterior, ventral) in humans



The standard anatomic position is standing erect with the palms facing anterior. This position is used to define a label for the direction of the fingers and toes (toward the Feet (F) while the direction of the wrist and ankle is towards the Head (H). This labeling is retained despite changes in the position of the extremities. For bilaterally symmetric body parts, a laterality indicator (R or L) should be used.



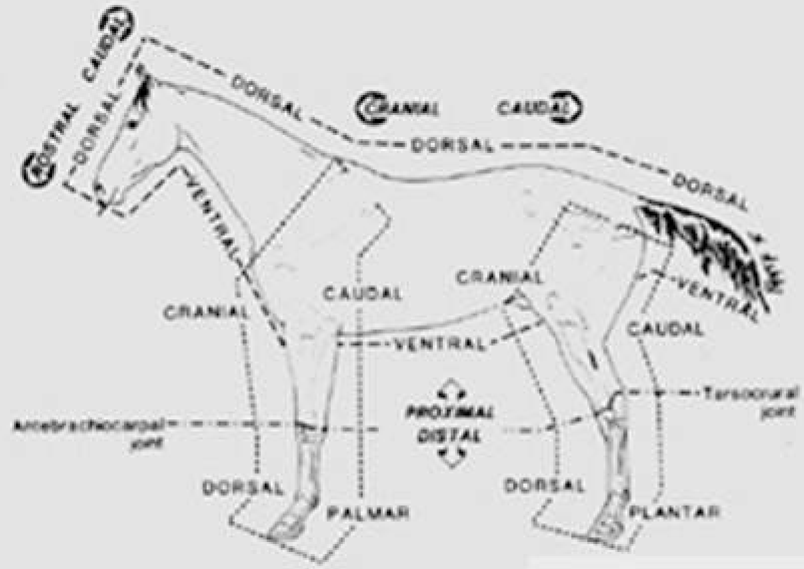


FIG. 1. Proper anatomic directional terms

TABLE 1. Directional Terms and Abbreviations Used to Describe Radiographic Views

Left (Le)	Medial (M)
Right (Rt)	Lateral (L)
Dorsal (D)	Proximal (Pr)
Ventral (V)	Distal (Di)
Cranial (Cr)	Palmar (Pa)
Caudal (Cd)	Plantar (Pl)
Rostral (R)	Oblique (O)

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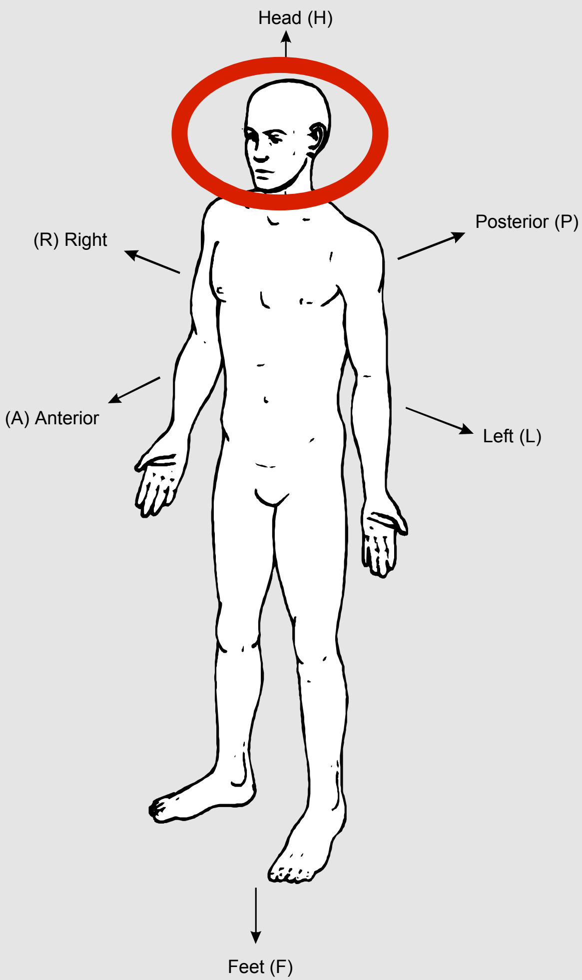
From Dr. Patricia Rose's web site at http://www.upei.ca/~vca341/



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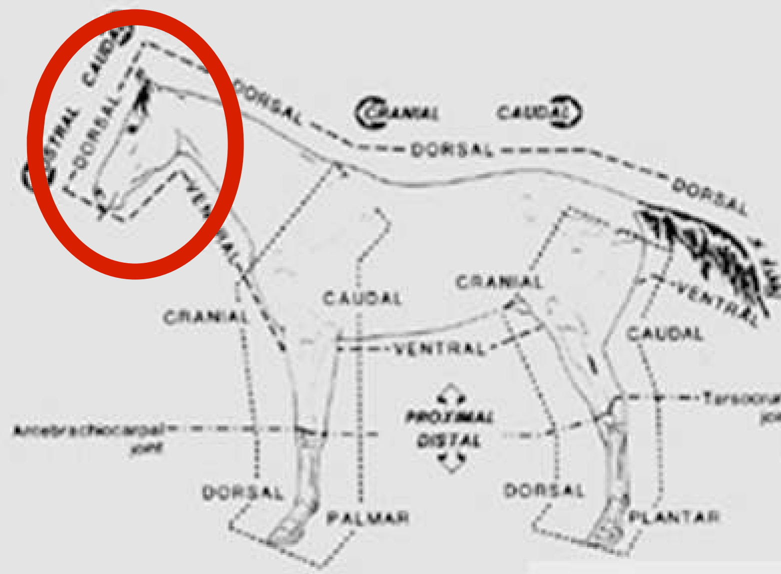
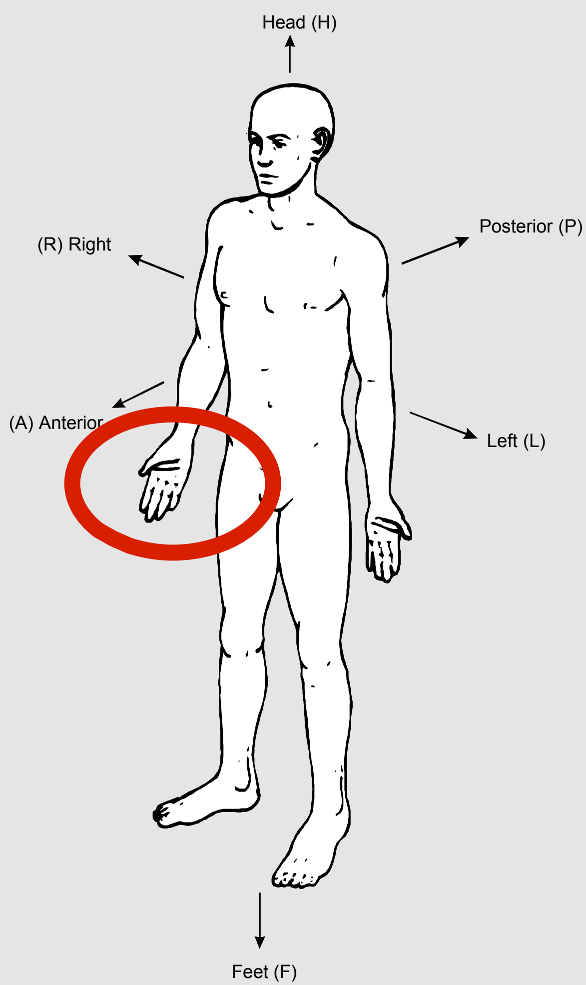


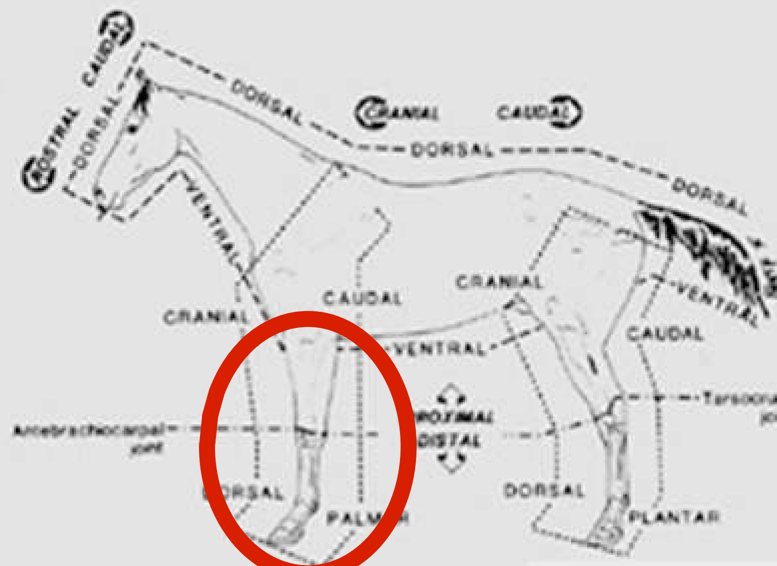
FIG. 1. Proper anatomic directional terms

TABLE 1. Directional Terms and Abbreviations Used to Describe Radiographic Views

Left (Le)	Medial (M)
Right (Rt)	Lateral (L)
Dorsal (D)	Proximal (Pr)
Ventral (V)	Distal (Di)
Cranial (Cr)	Palmar (Pa)
Caudal (Cd)	Plantar (Pl)
Rostral (R)	Oblique (O)

From Dr. Patricia Rose's web site at http://www.upei.ca/~vca341/





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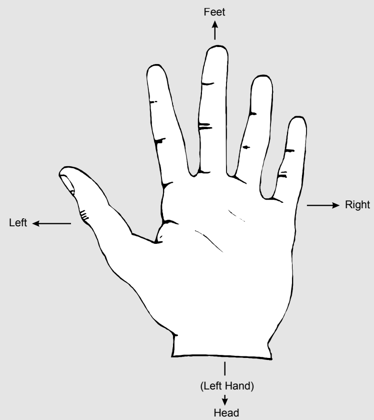
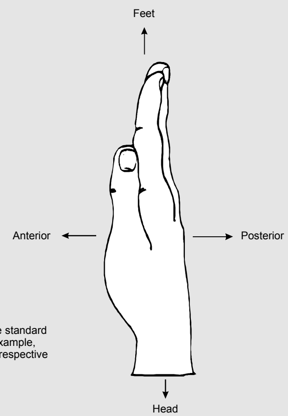
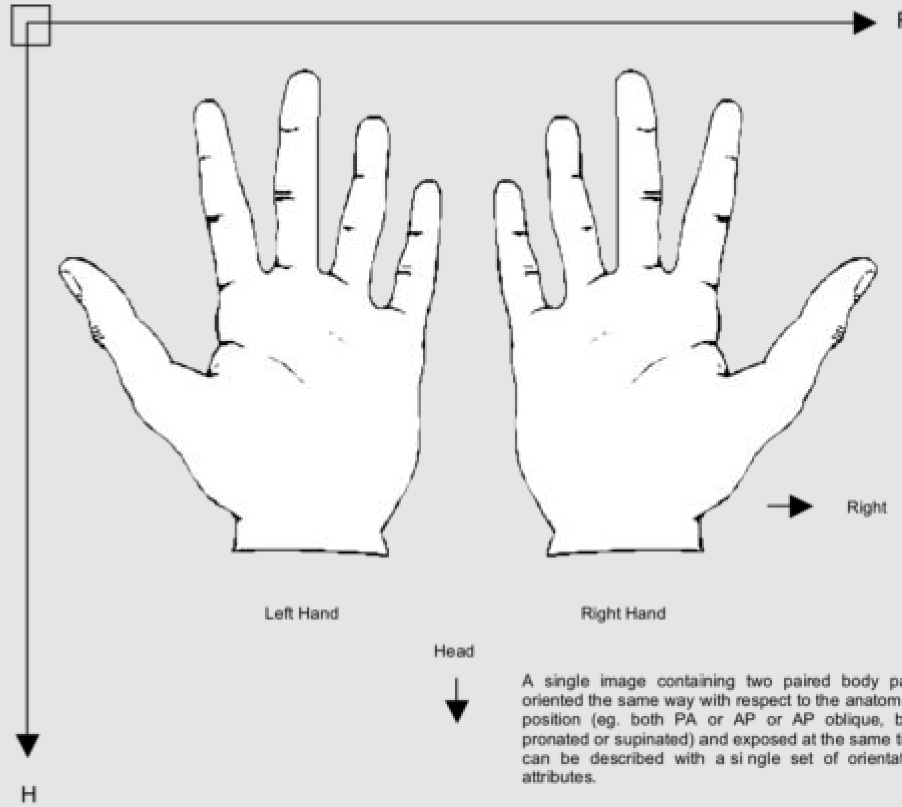
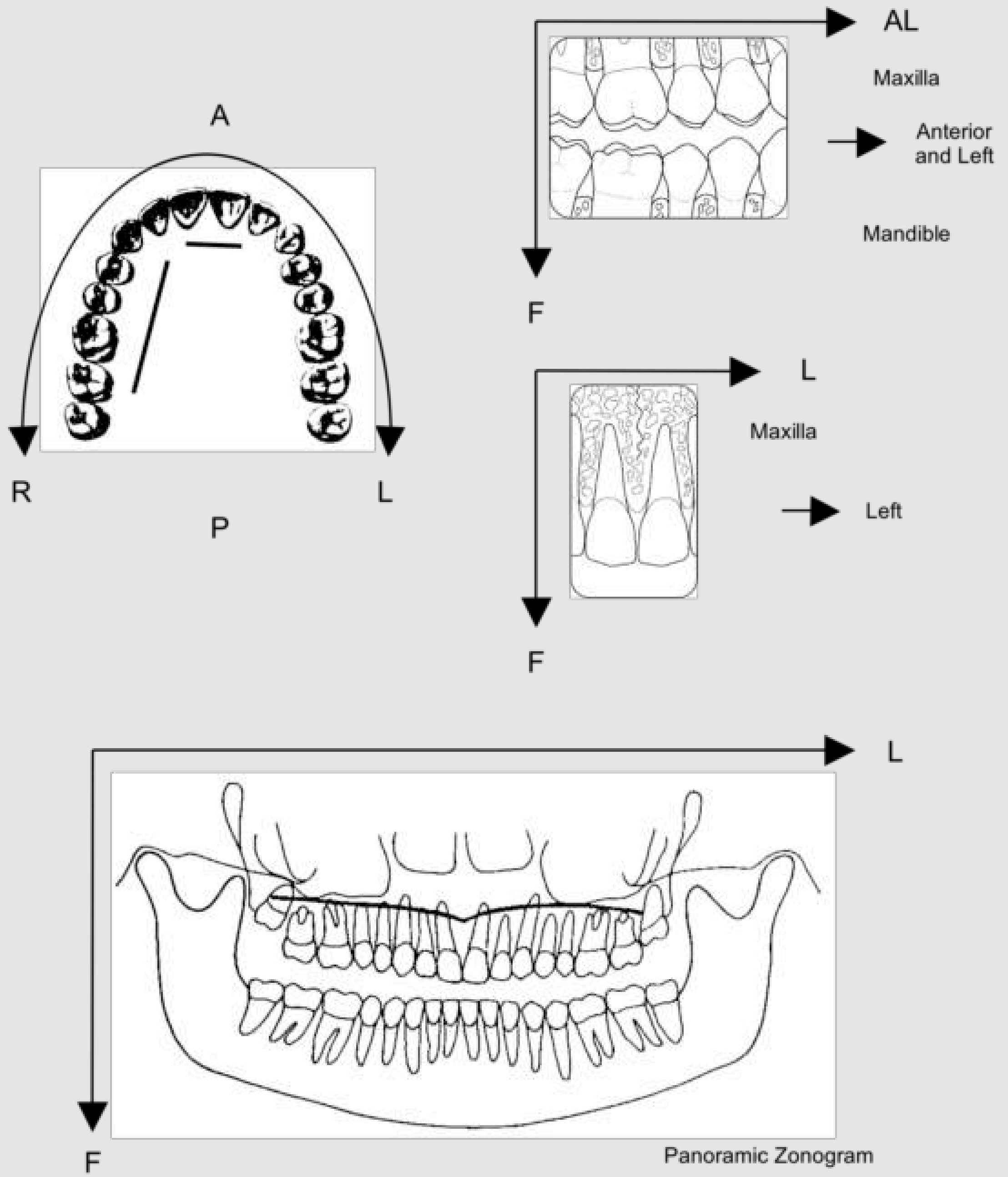




For the hands, the direction labels are based on the standard anatomic position. For the left hand illustrated for example, LEFT will always be in the direction of the thumb, irrespective of position changes.



A single image containing two paired body parts oriented the same way with respect to the anatomical position (eg. both PA or AP or AP oblique, both pronated or supinated) and exposed at the same time can be described with a si ngle set of orientation attributes.


A
R
L
P
AL
Maxilla
Anterior and Left
Mandible
F
L
Maxilla
Left
F
L
F
Panoramic Zonogram

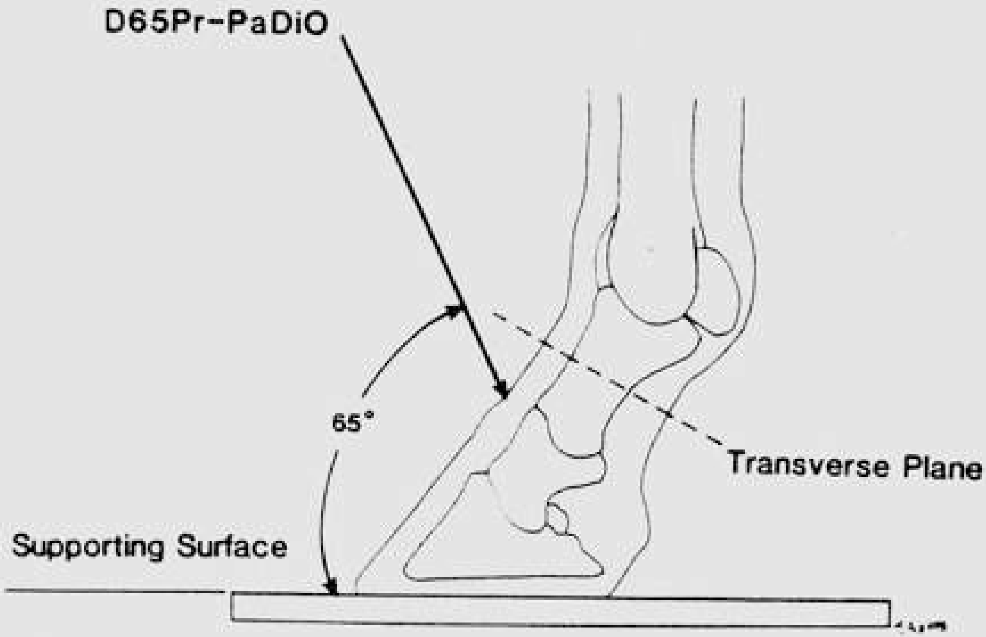
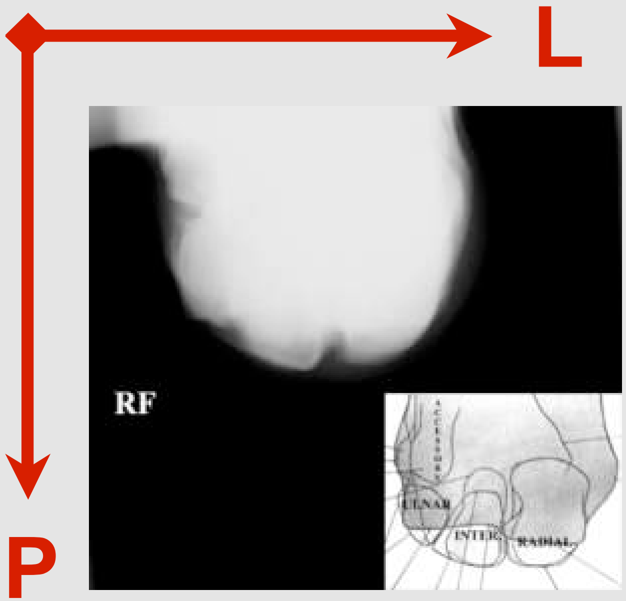


FIG. 5. A dorsoproximal–palmarodistal oblique (DPr–PaDiO) view of the equine distal phalanx and distal sesamoid bone made at 65° proximal to the supporting surface. This projection could be described more accurately as a D65Pr–PaDiO.



From Dr. Patricia Rose's web site at
http://www.upei.ca/~vca341/


F
A
mister aqua (thailand) co., ltd

?

F

A

?

Veterinary Action Items

- Describe standard anatomic positions
  - for appropriate subset of species
- Describe appropriate interpretation of row and column direction for standard radiographic projections
- Enumerate coded lists of standard projections
  - facilitates correct automatic population of orientation attributes without operator intervention

DICOM 3D Coordinates

- "Frame of Reference" defines origin
  - Fixed but arbitrary, set by operator
- Cartesian space (orthogonal X, Y, Z)
- Units are mm
- Every slice
  - Position relative to origin (3 points)
  - Orientation of row and column directions (unit vectors)

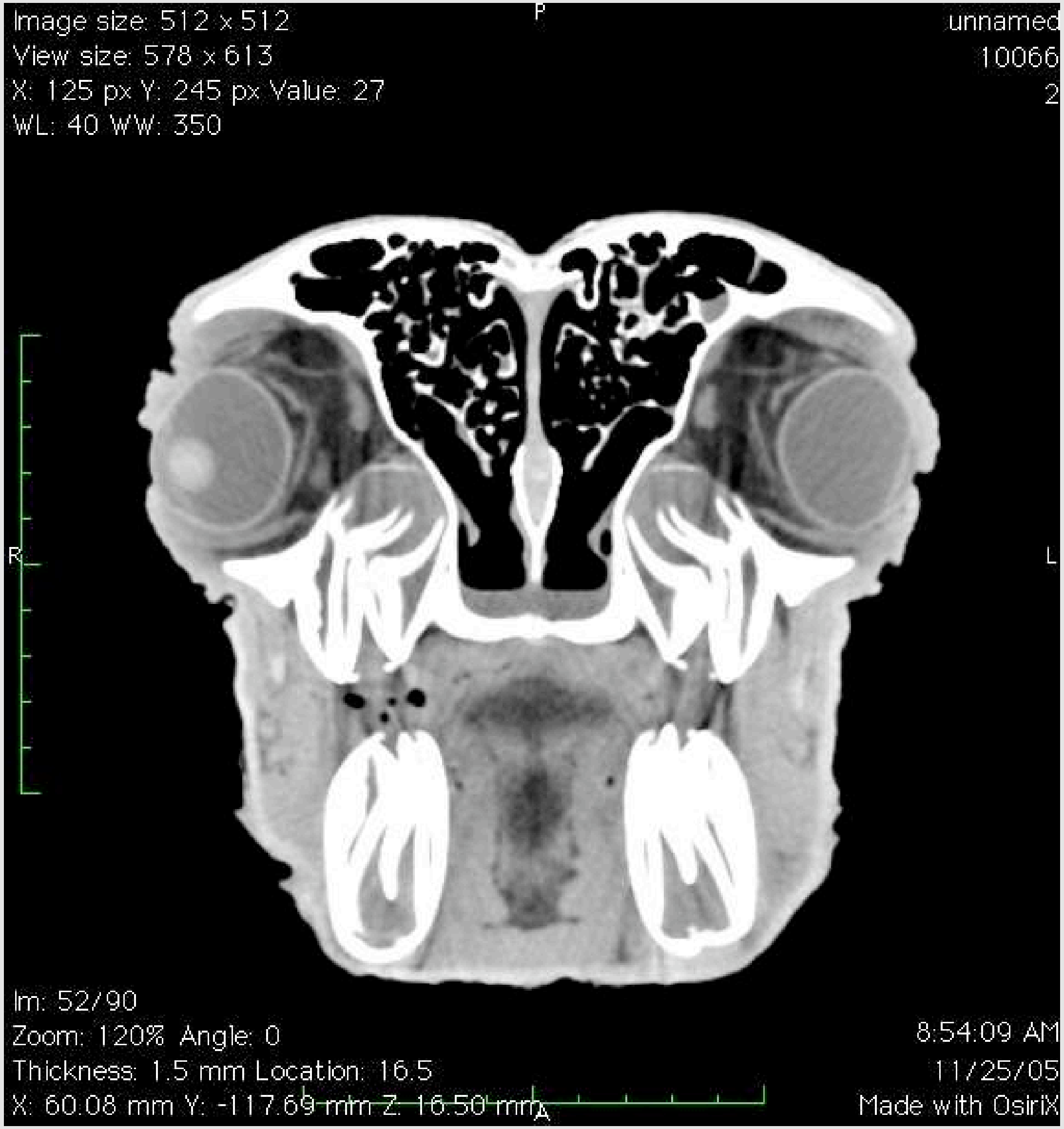
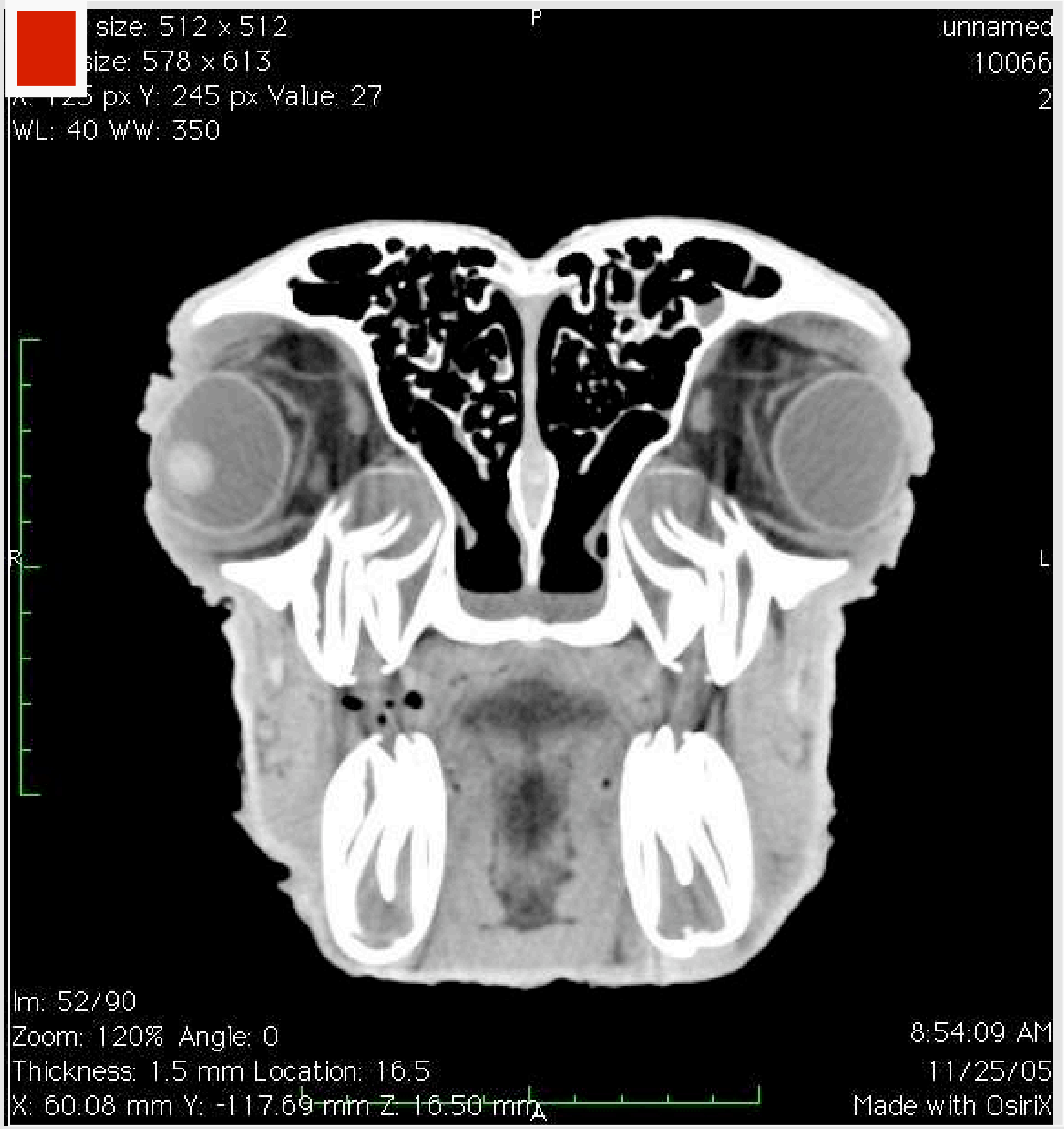
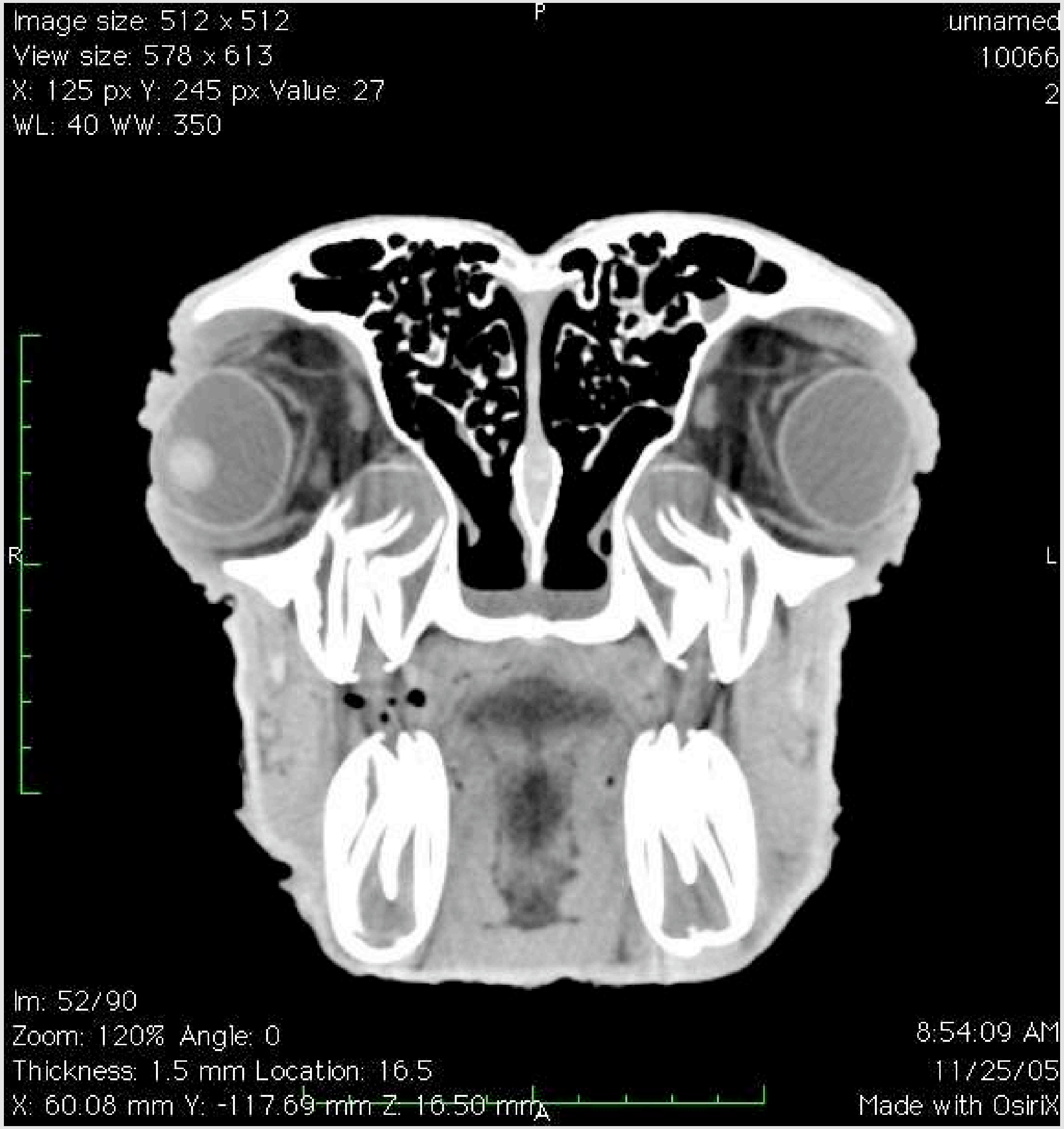


Image size: 512 x 512
View size: 578 x 613
X: 125 px Y: 245 px Value: 27
WL: 40 WW: 350
P
unnamed
10066
2
R
L
Im: 52/90
Zoom: 120% Angle: 0
Thickness: 1.5 mm Location: 16.5
X: 60.08 mm Y: -117.69 mm Z: 16.50 mm
A
8:54:09 AM
11/25/05
Made with OsiriX

TLHC pixel - offset from origin 0\0\16.5



1\0\0



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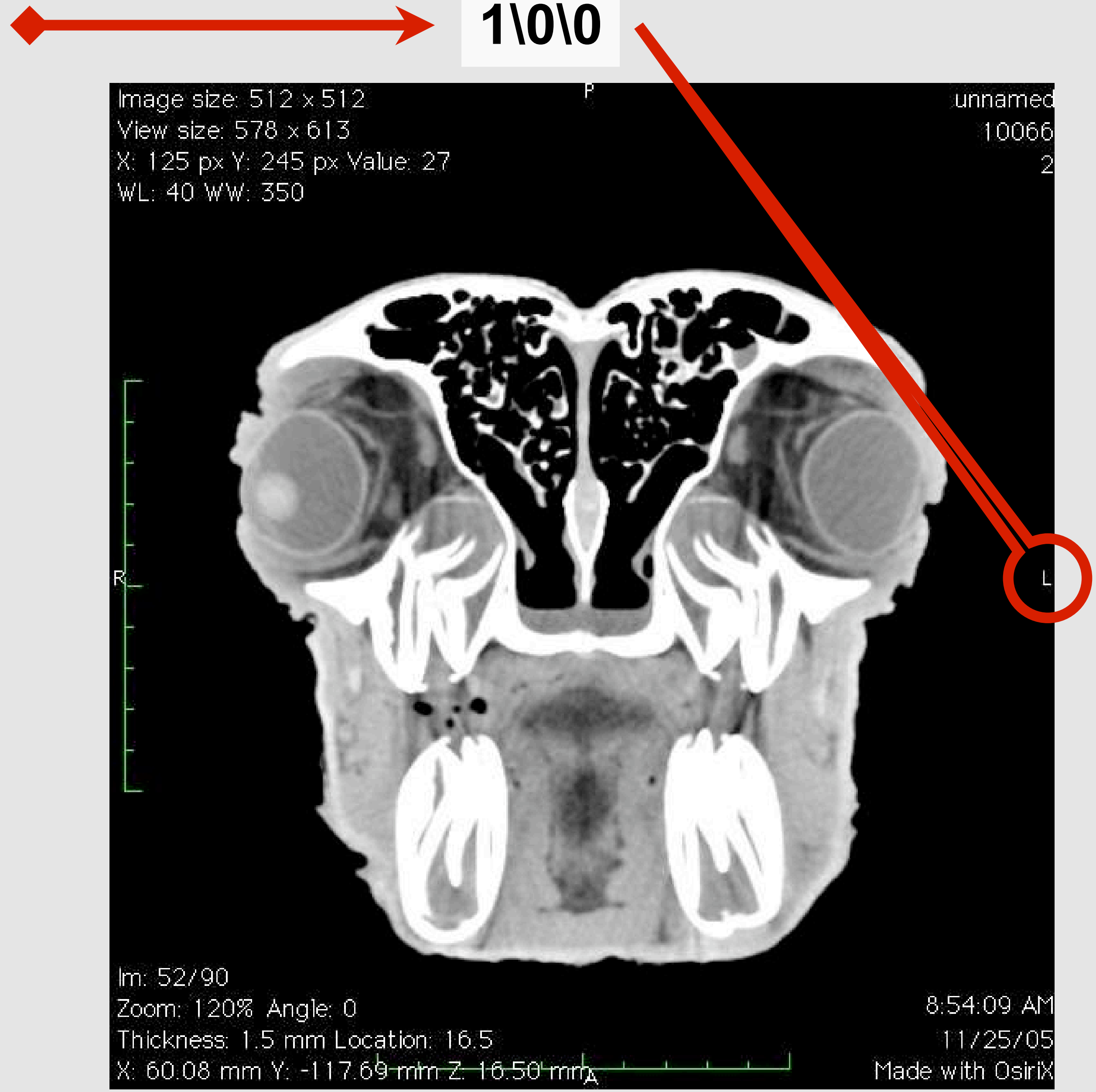
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View size: 578 x 613
X: 125 px Y: 245 px Value: 27
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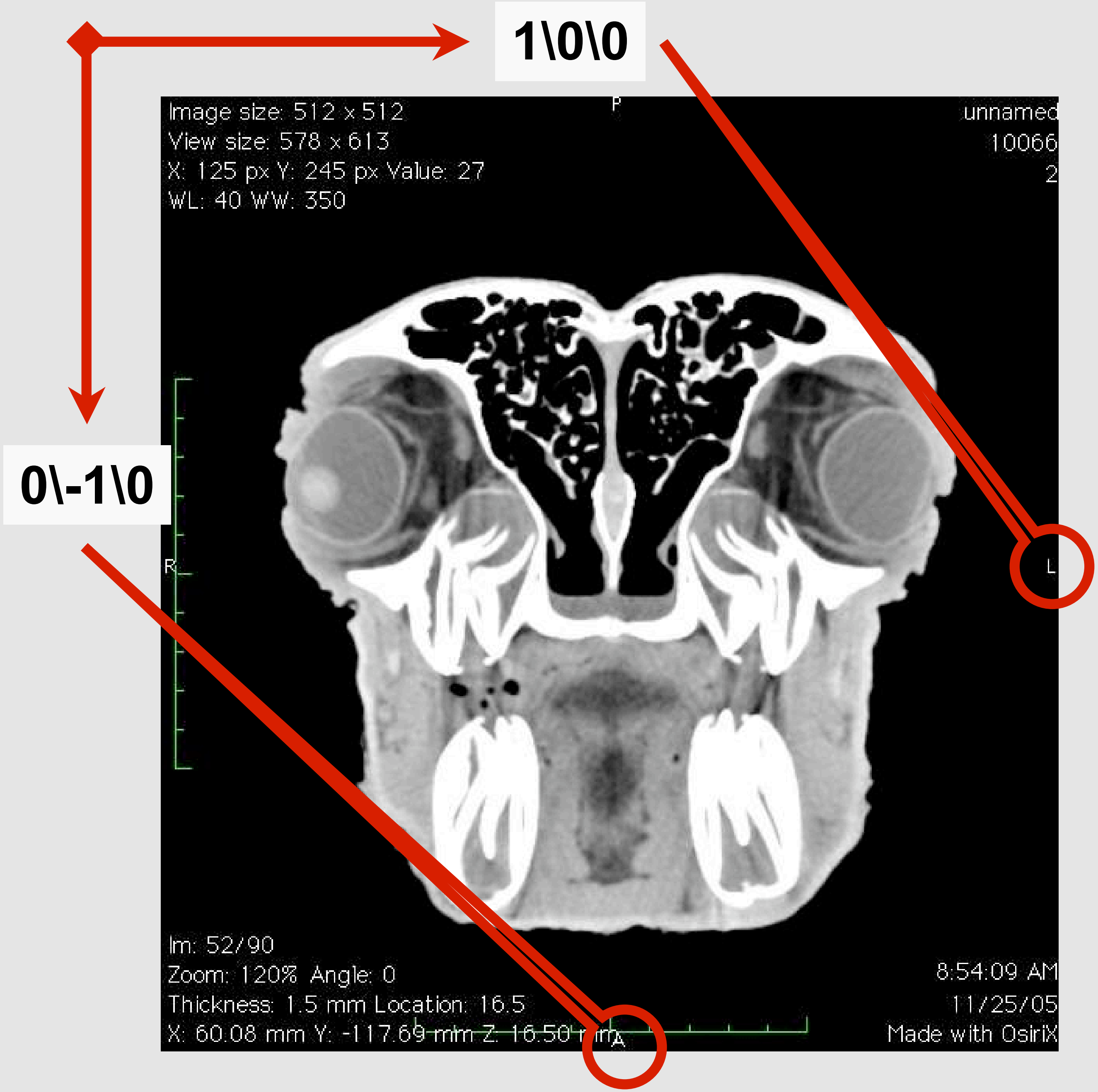

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Image size: 512 x 512
View size: 578 x 613
X: 125 px Y: 245 px Value: 27
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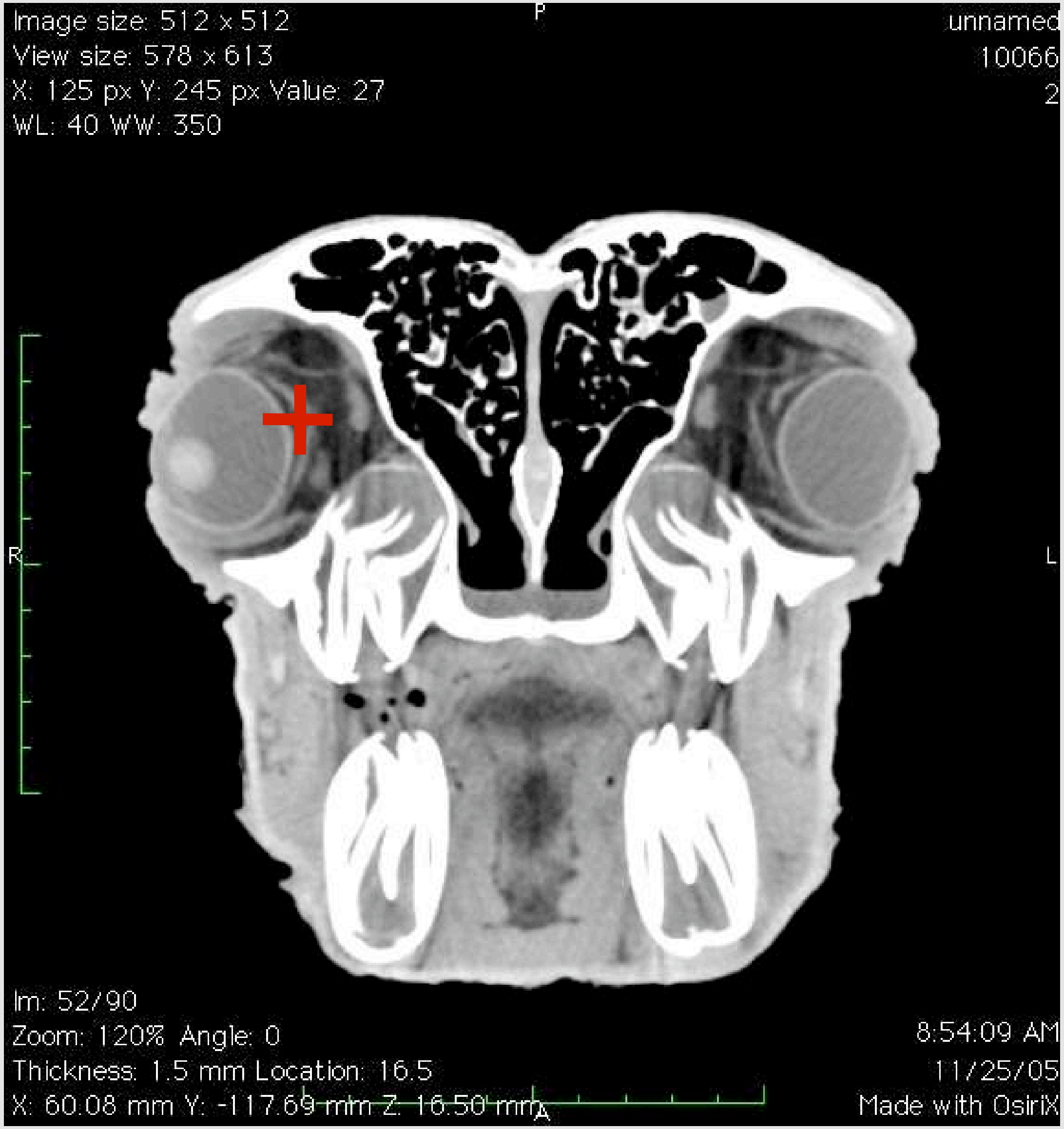
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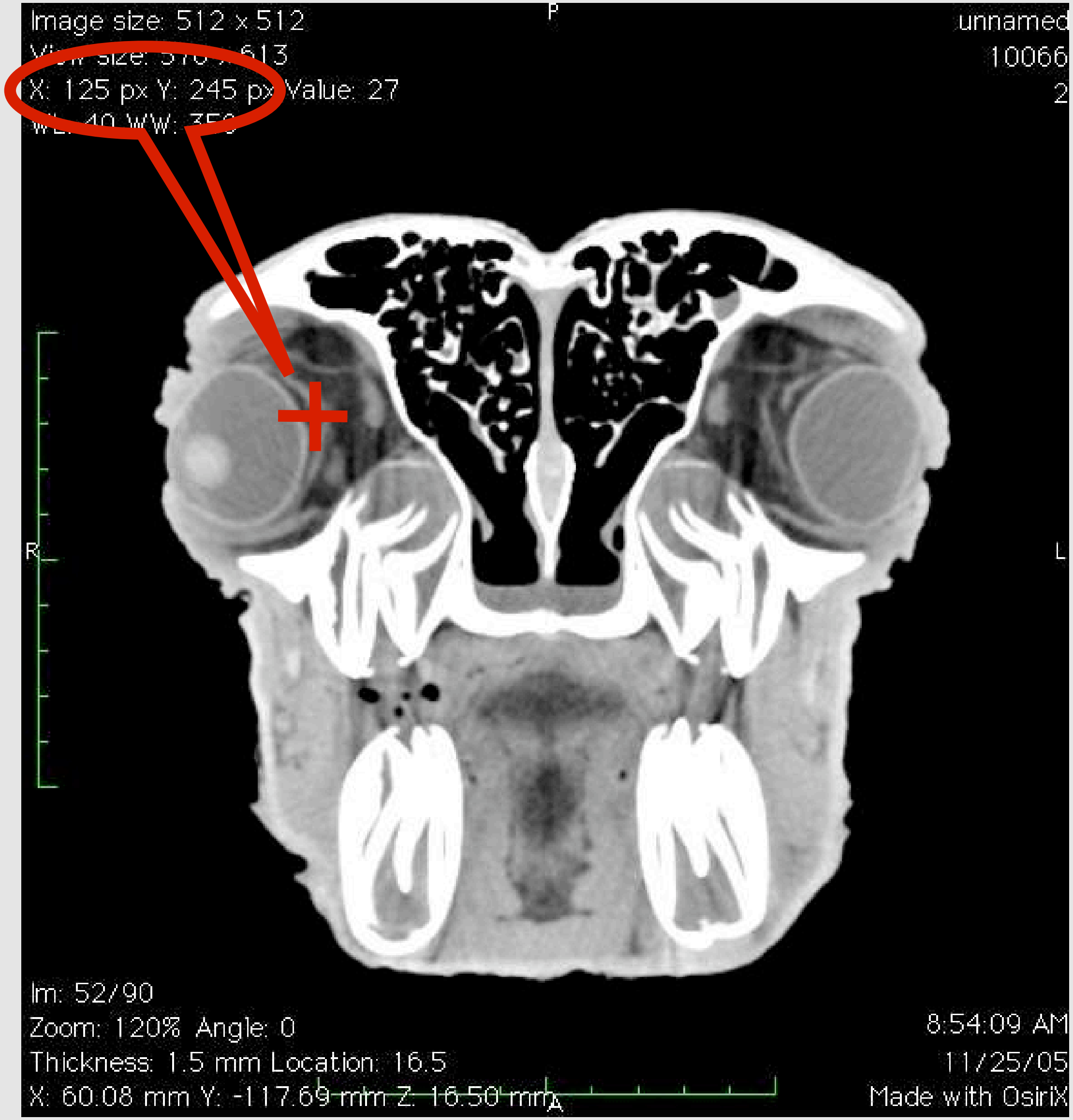
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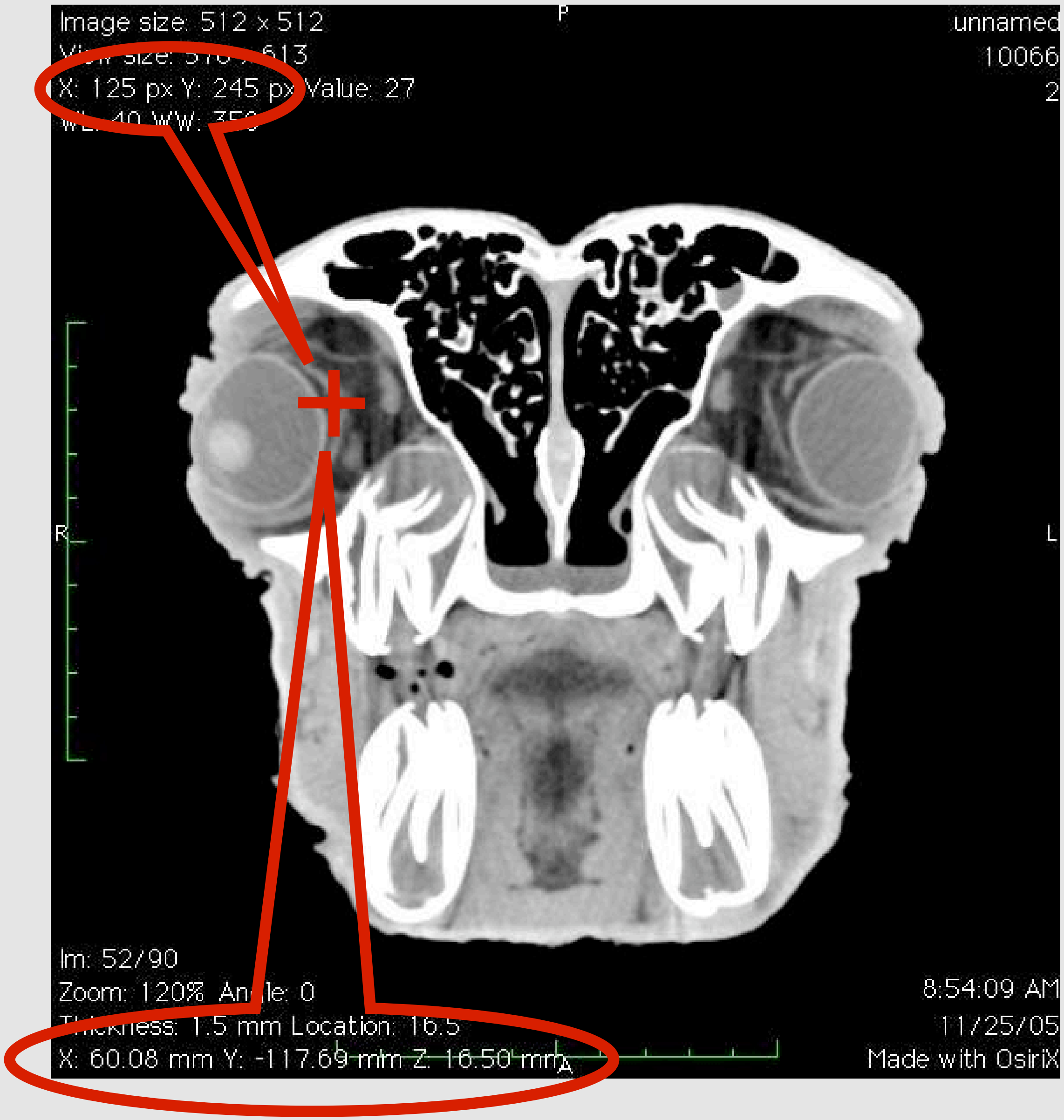

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X: 60.08 mm Y: -117.69 mm Z: 16.50 mm
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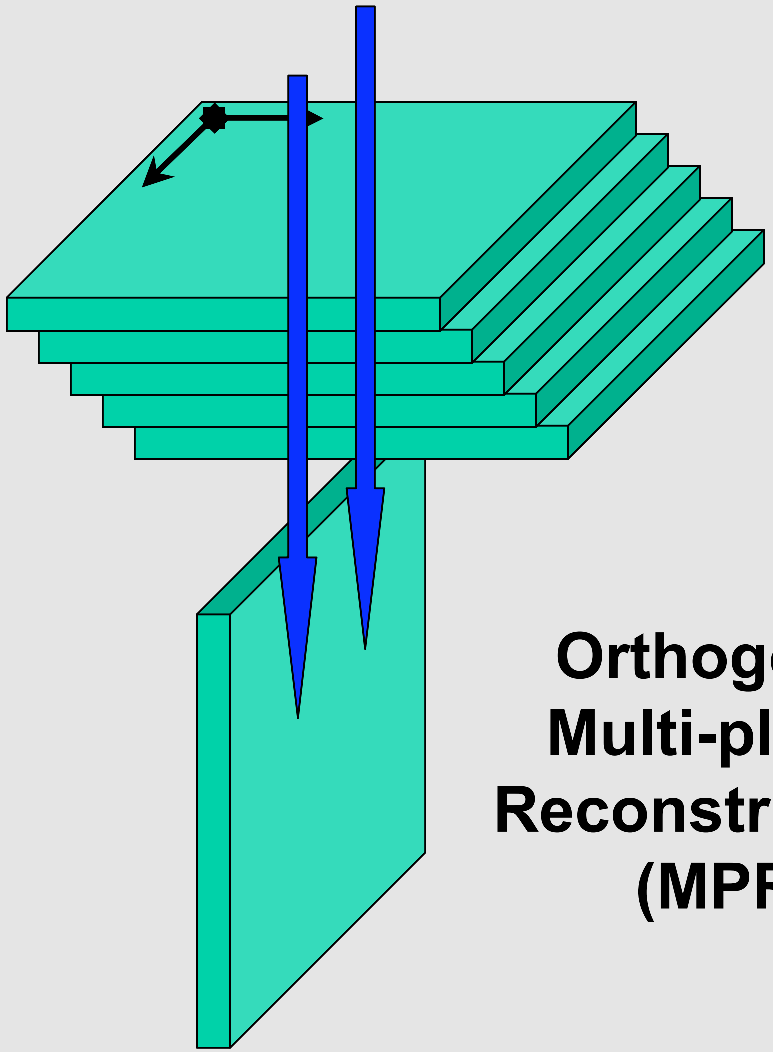
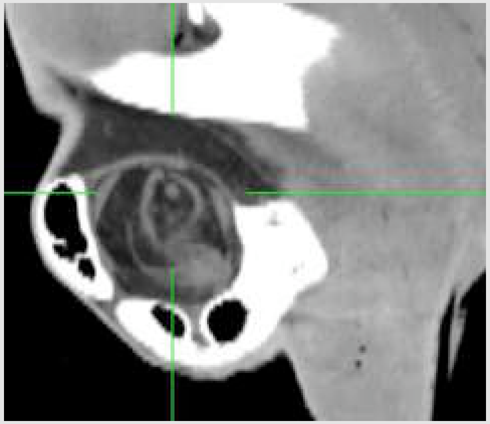
8:54:09 AM
11/25/05
Made with OsiriX

3D Relationships

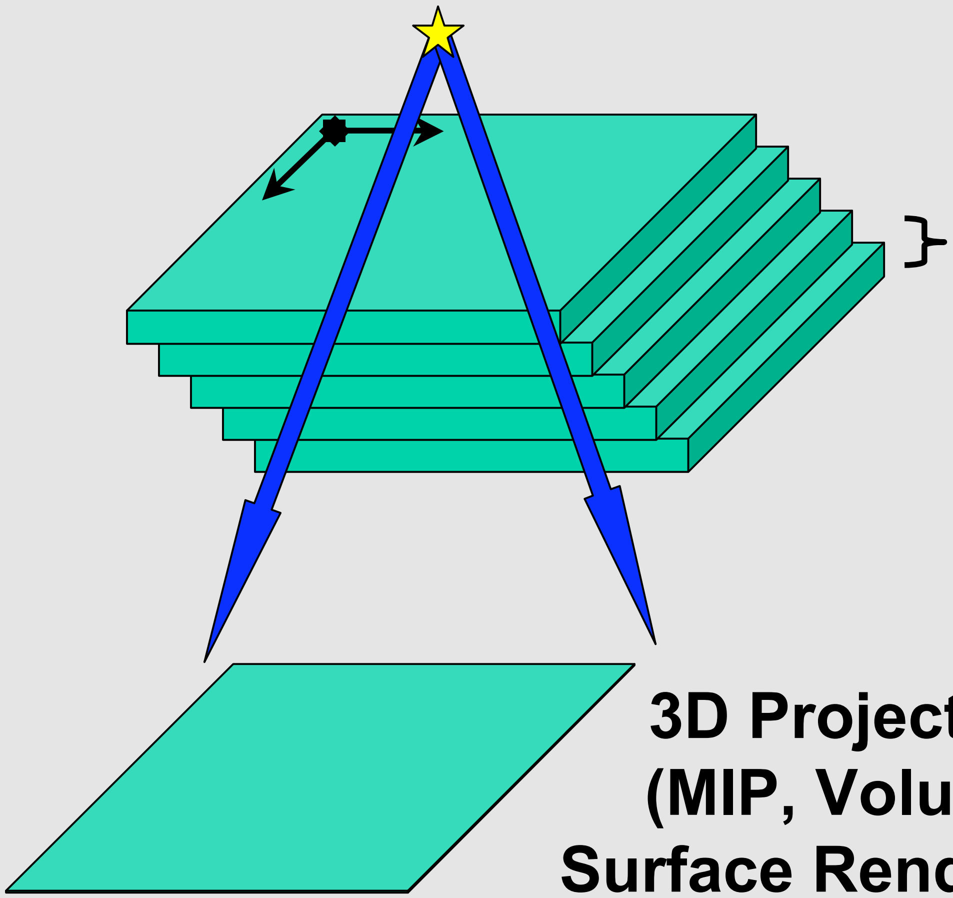


Reconstruction Interval

Orthogonal Multi-planar Reconstruction (MPR)



3D Relationships

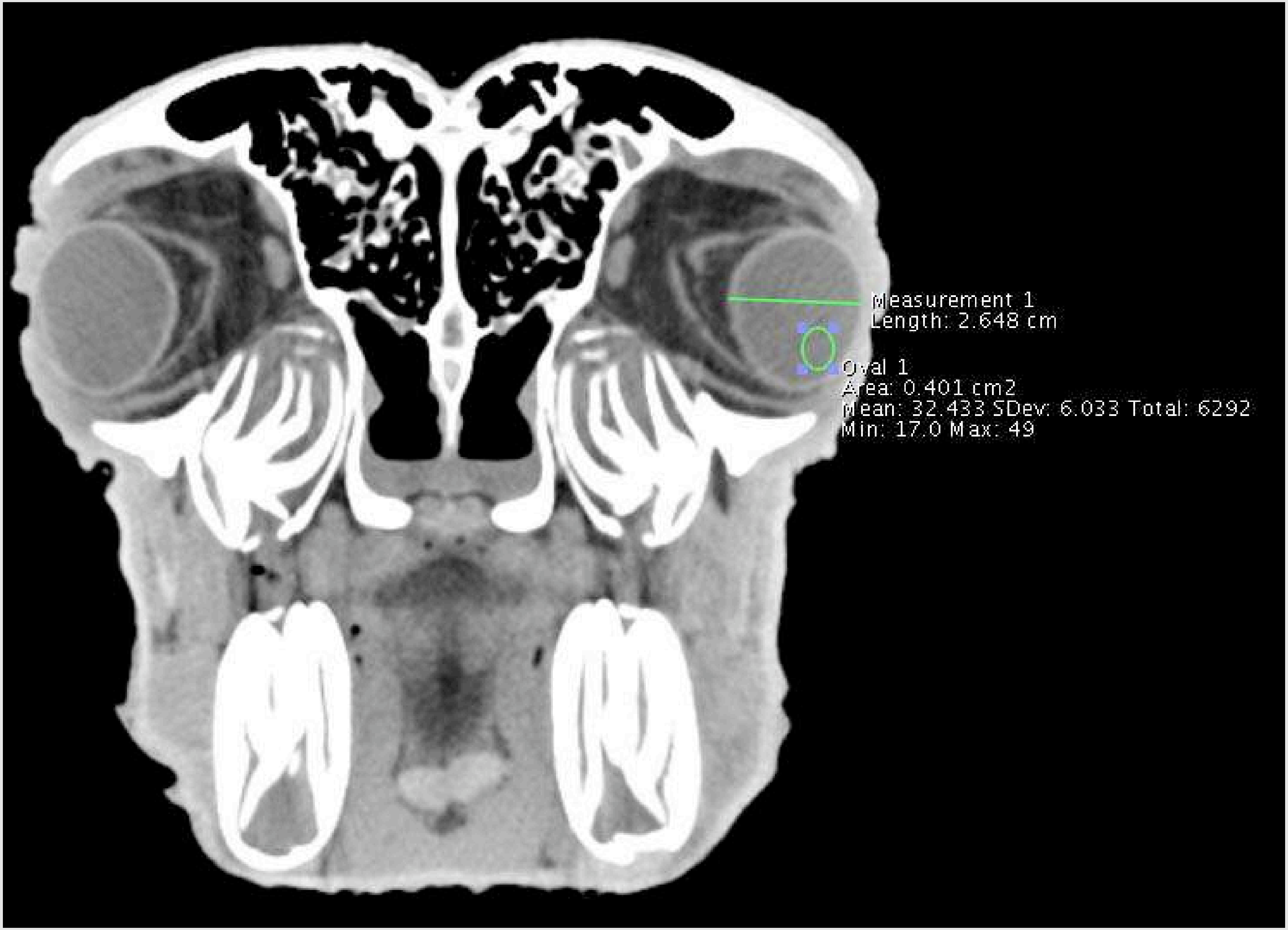


Reconstruction Interval

3D Projection
(MIP, Volume,
Surface Rendering)

Measurements

- Distance
  - Pixel Spacing - in cross-sectional modalities
  - Imager Pixel Spacing - in projection modalities
- Pixel values
  - Hounsfield Units in CT
  - Velocity, etc, in MR
  - Region Calibration in Ultrasound



Measurement 1
Length: 2.648 cm
Oval 1
Area: 0.401 cm2
Mean: 32.433 SDev: 6.033 Total: 6292
Min: 17.0 Max: 49

DICOM Positioning

- Robust interoperable model
- Agreed to and implemented by all vendors
- Allows applications to function properly regardless of source of images
- Mandatory 3D and spacing information for cross-sectional modalities
- Rendering, measurement and analysis

Veterinary Action Items

- Reuse human attributes as far as possible
- Redefine directions for quadrupeds
- Must re-use 3D co-ordinate system since already mandatory (and sufficient)
- Will allow maximum reuse of human software and hardware, including research and open source applications

Beyond Images … Workflow

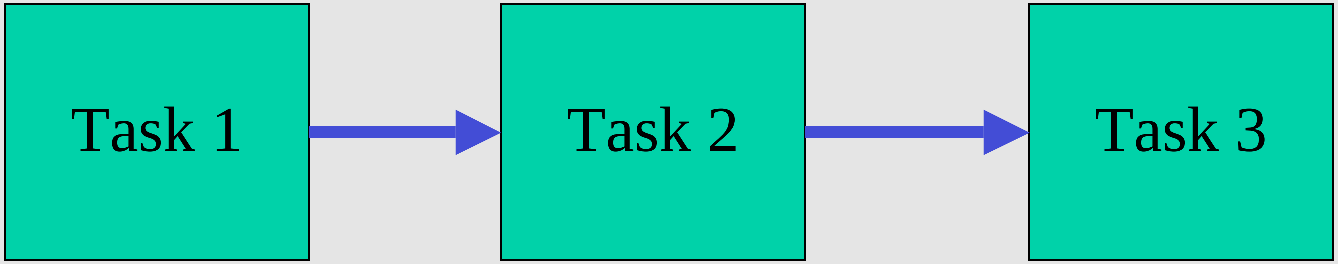
- What is “workflow” ?
- Why is workflow important ?
- Opportunities for workflow management
- DICOM support for workflow management
- RIS/PACS integration and workflow
- IHE profiles related to workflow

What is “workflow” ?

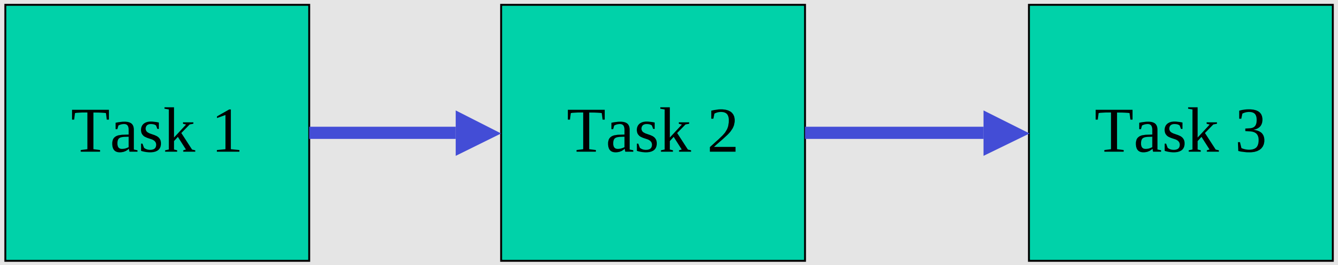
“documents, information or tasks … passed from one participant to another in a way that is governed by rules or procedures”

Workflow Management Coalition
http://www.wfmc.org/

What is "workflow" ?

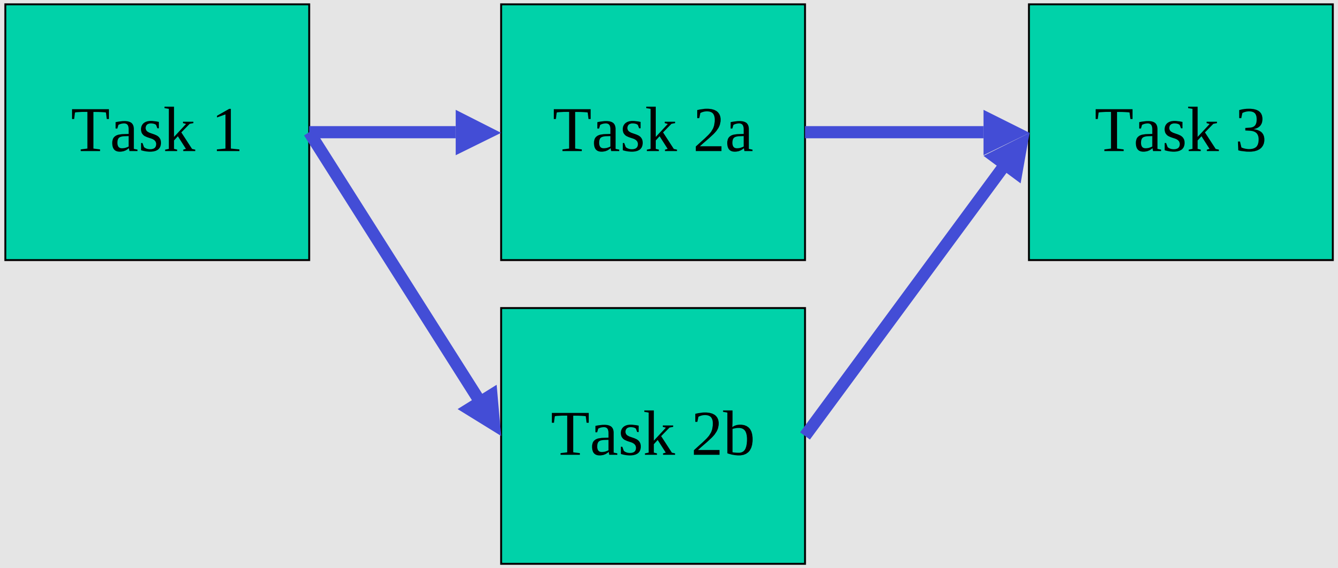


Dependencies

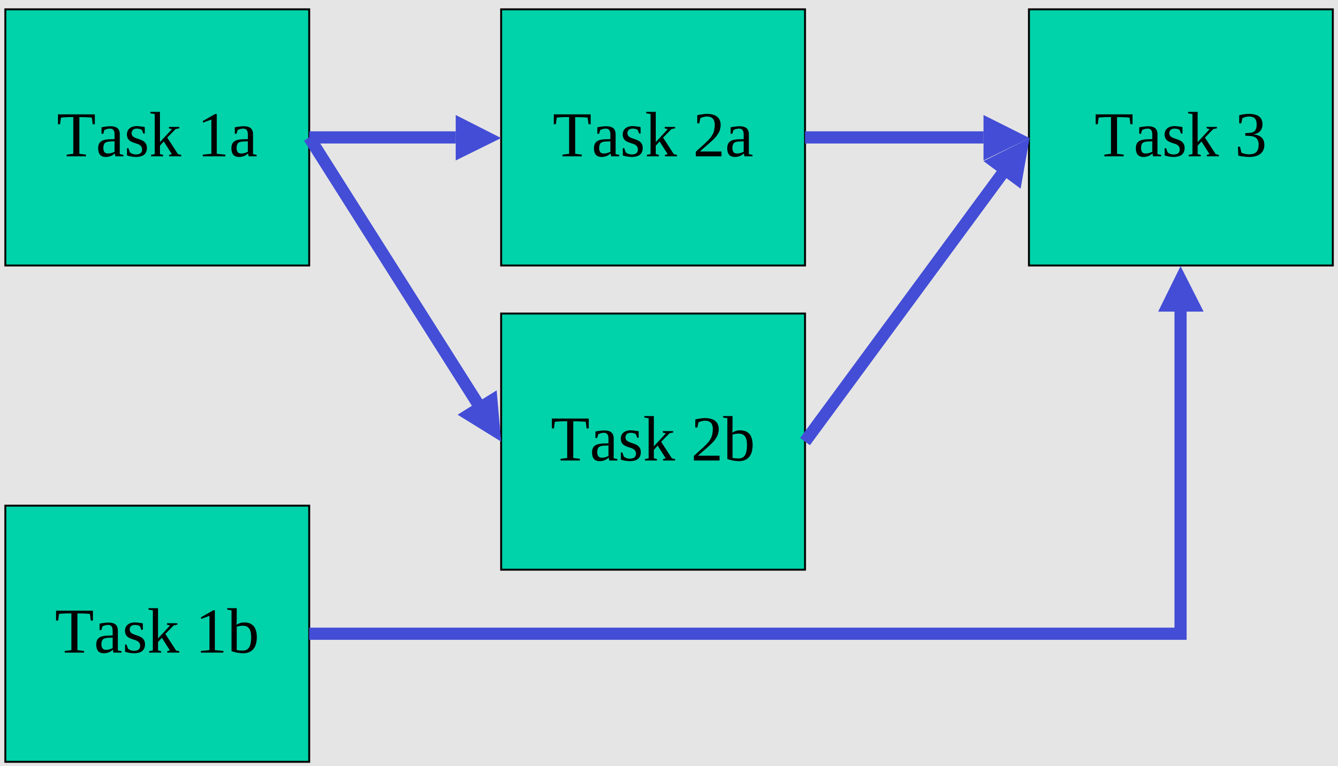


Task 3 commencement is dependent on task 2 completion, whose commencement is in turn dependent on task 1 completion.

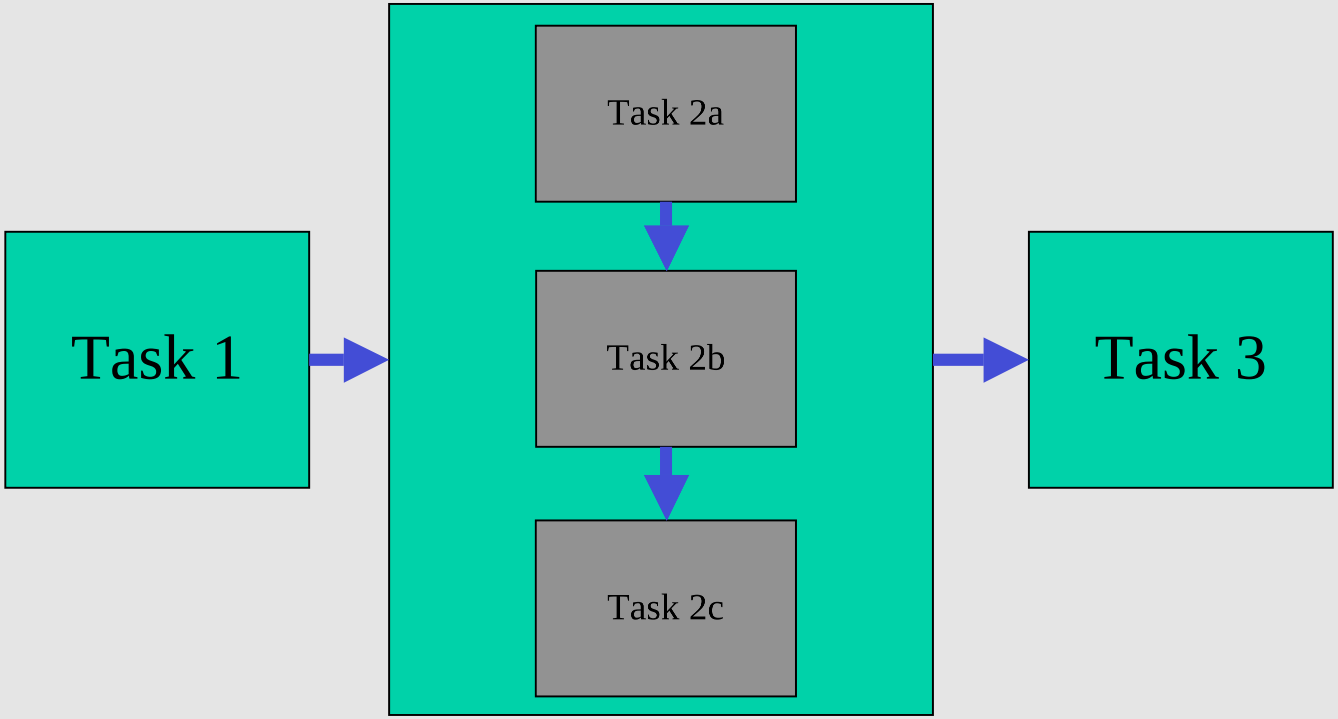
Multiple tasks



Multiple tasks



Sub-tasks



Workflow tasks in PACS

- Image acquisition
  - patient on modality
  - optical film scanning (outside referrals)
- Image quality control (QC)
  - contrast selection (window center/width)
  - film printing
- Image processing
  - 3D (surface rendering, volume rendering, angio MIP)
  - Computer Assisted Diagnosis/Detection (Chest/Mammo CAD)
- Reporting
  - single step (voice recognition or structured application)
  - dictate/transcribe/correct/verify (sub-tasks)

Managing Tasks

- Inputs
  - what is needed before task can begin ?
- Outputs
  - what are the products delivered on completion ?
- Resources allocated
  - what personnel and equipment and consumables ?
- State
  - have we started or finished or given up ?

Interpretation Task

- Inputs
  - current images
  - previous studies' images and reports
- Outputs
  - report (with references to images)
- Resources allocated
  - individual or category of interpreting radiologist
  - specific workstation or category of workstation
- State
  - scheduled/in progress/discontinued/completed

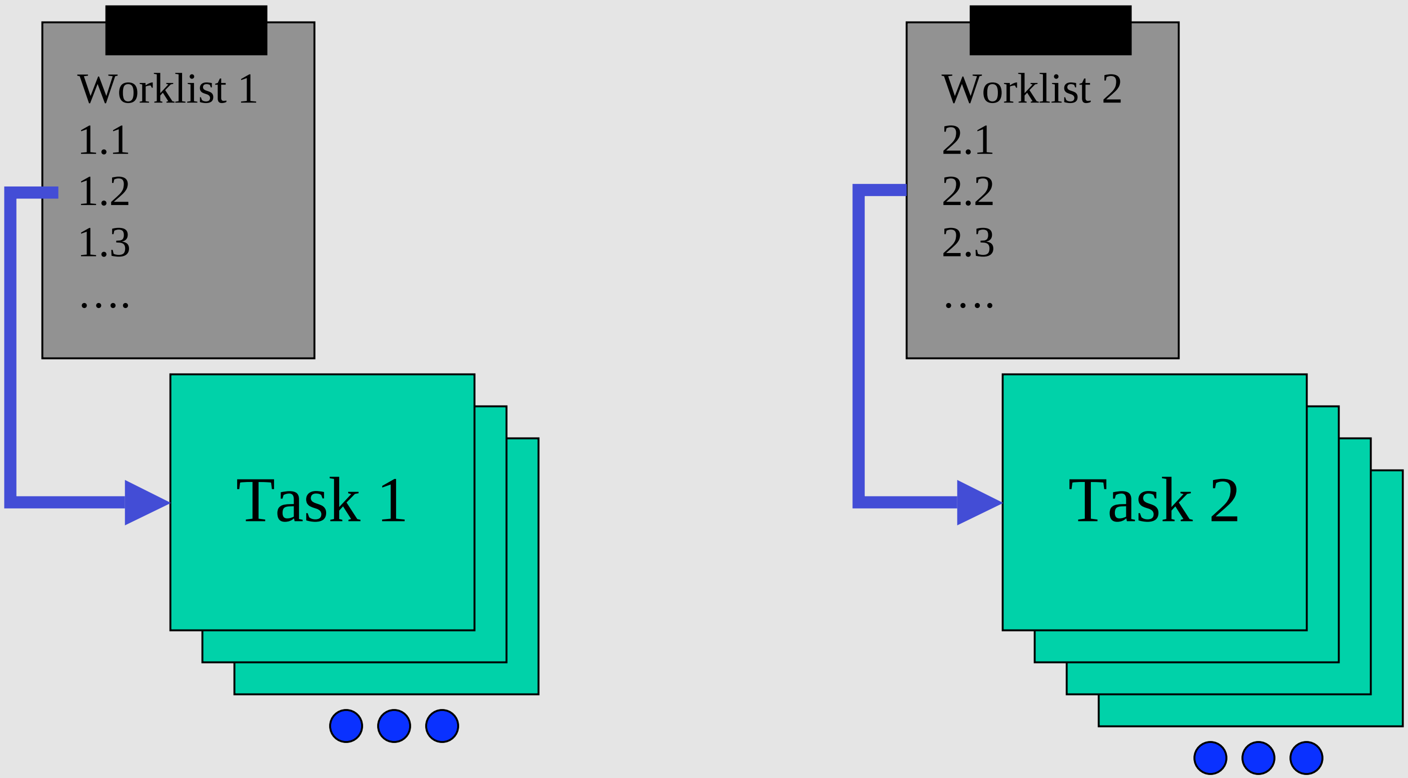
Acquisition Task

- Inputs
  - patient identification and location
  - study identifiers
  - request information
  - [previous studies' images and reports]
- Outputs
  - images and presentation states (+/- measurements in structured reports)
- Resources allocated
  - individual or category of performing radiologist
  - specific scanner or category of scanner
- State
  - scheduled/in progress/discontinued/completed

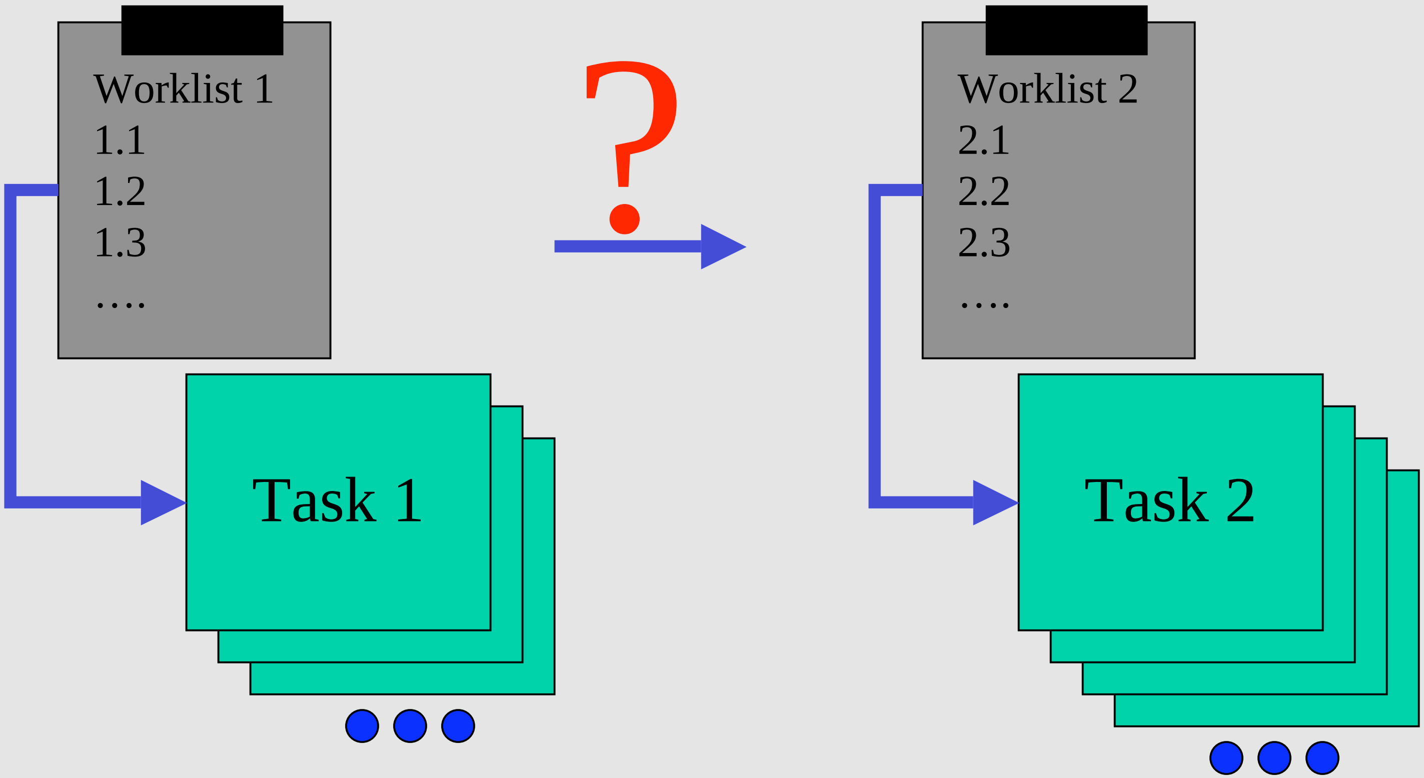
Worklists

- Tasks are listed in a "worklist"
- Each worklist entry contains:
  - input information
  - resource information
  - implicit or explicit "scheduled" state

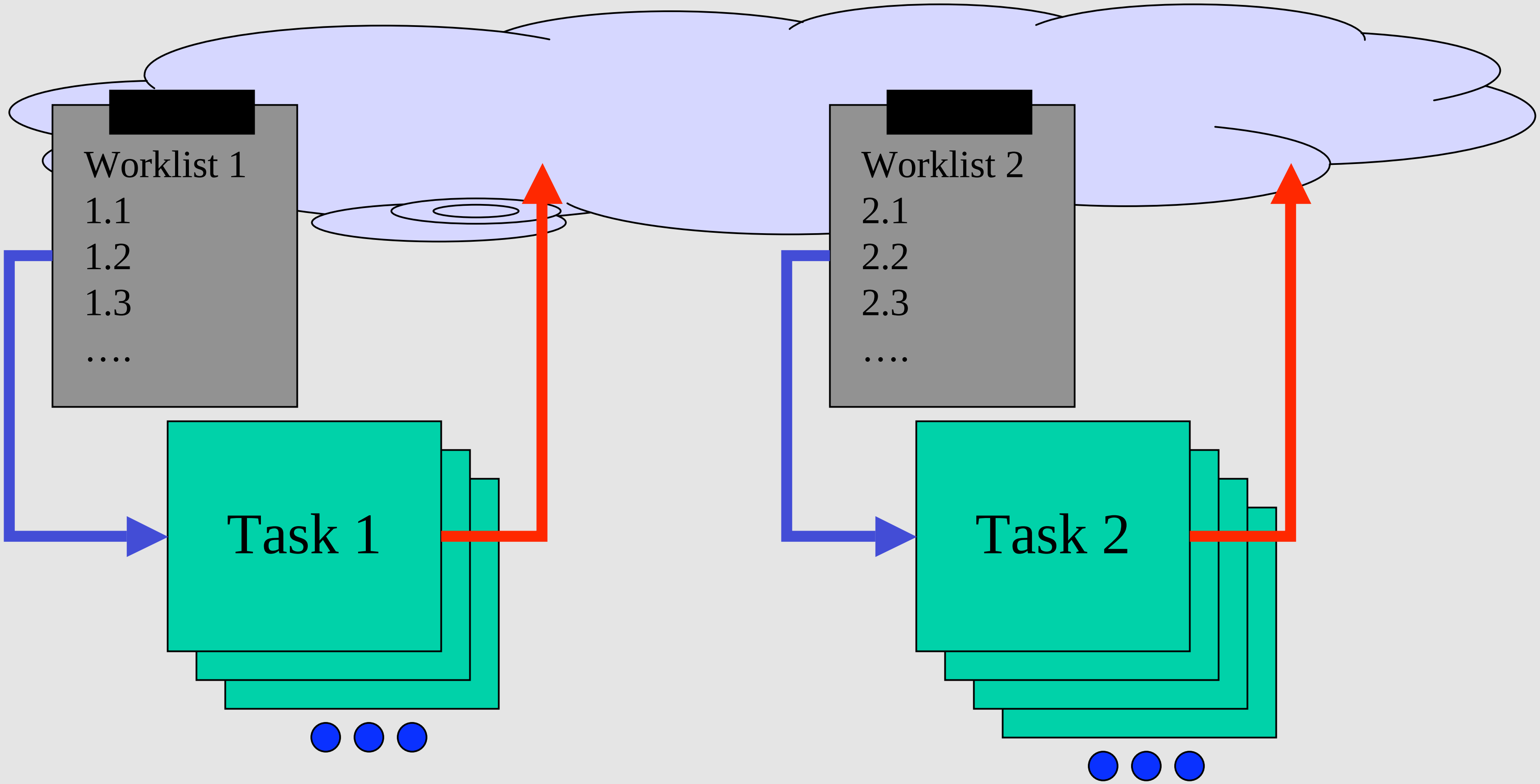
Worklists



"Closing the loop"

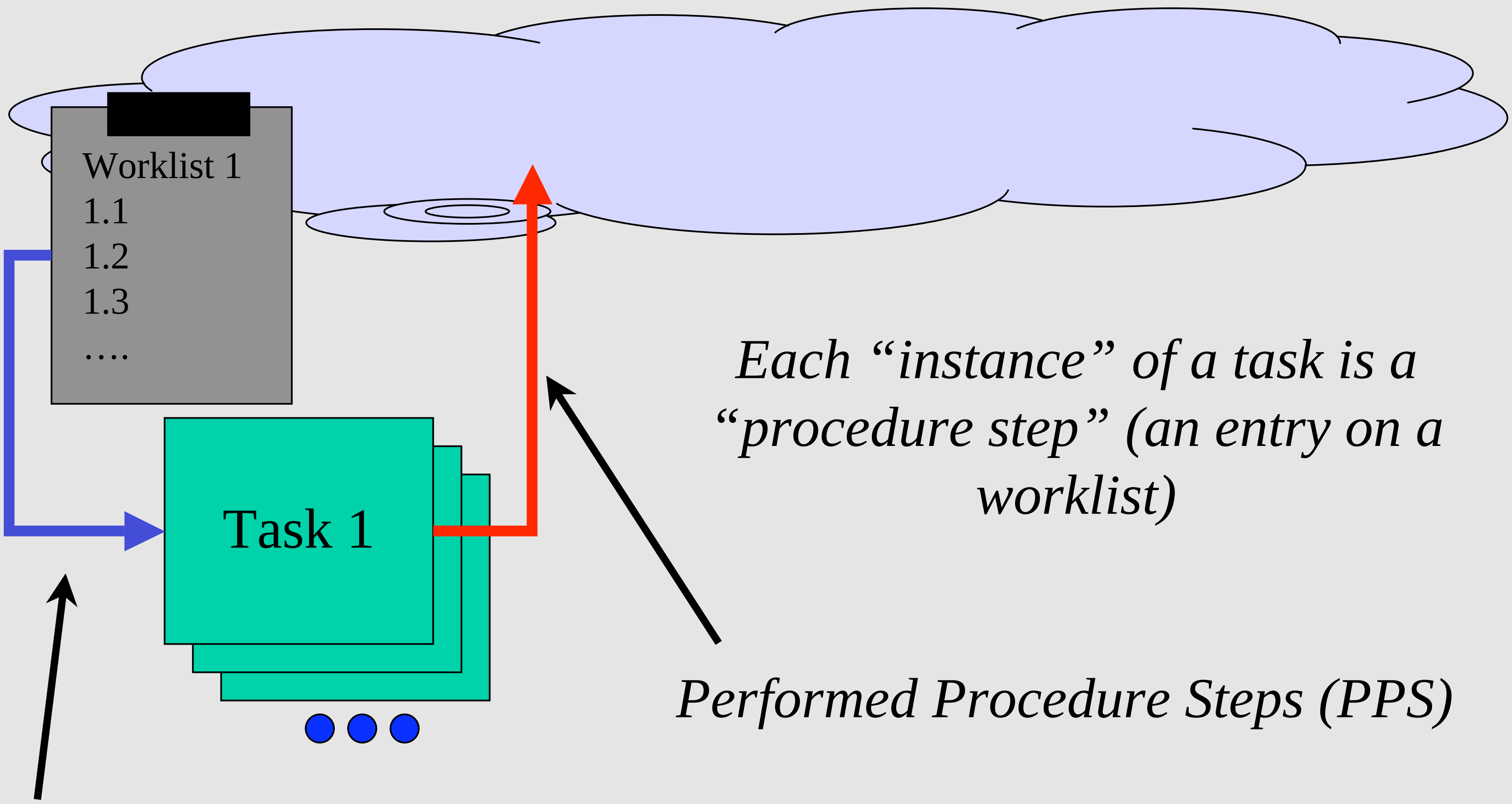


Workflow Manager



"the cloud" - RIS ? PACS ? Workflow System ?

Workflow and DICOM



Each "instance" of a task is a "procedure step" (an entry on a worklist)

Performed Procedure Steps (PPS)

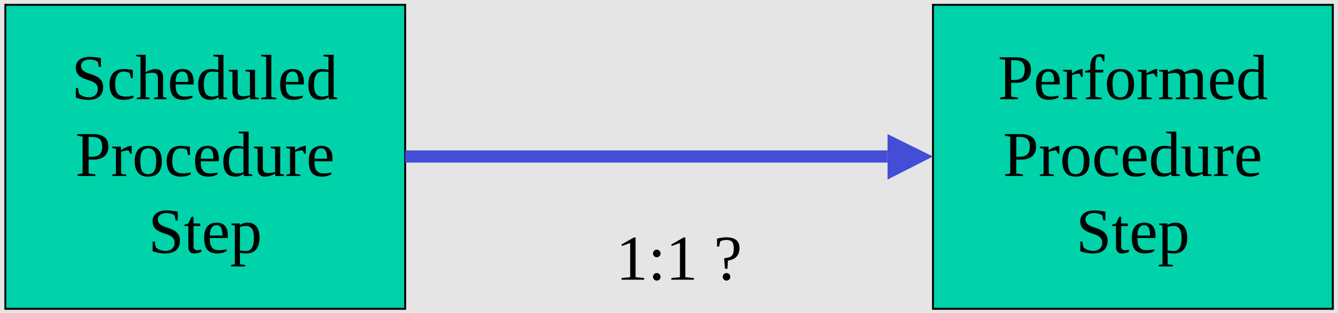
Scheduled Procedure Steps (SPS)

Relationship of Steps

- Inputs
- Resources
- State: scheduled

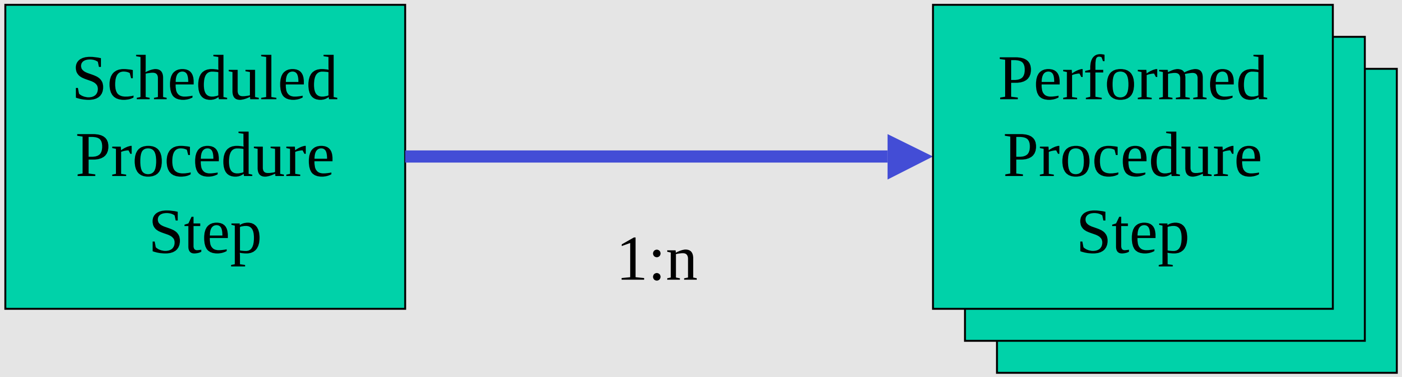
- Outputs
- Consumables
- State

Relationship of Steps



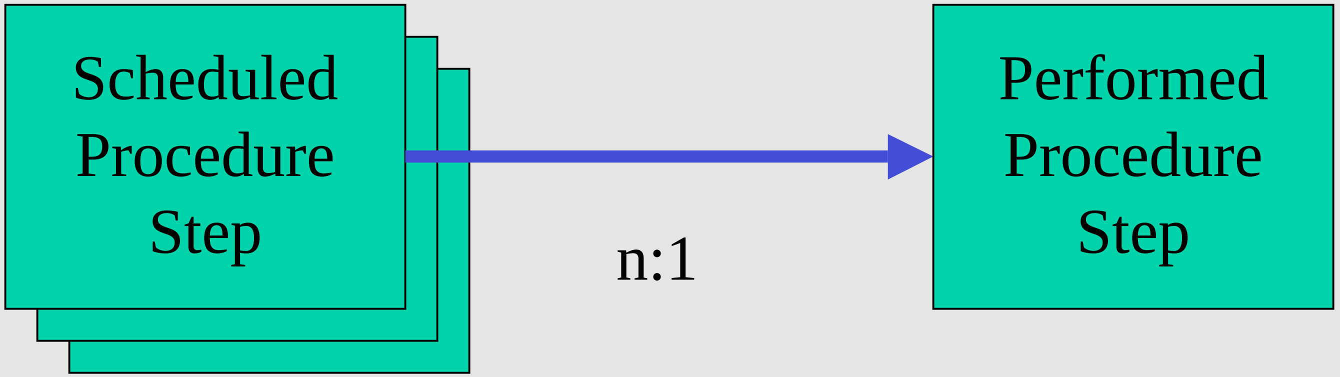
Scheduled procedure step: scan chest/abdomen/pelvis
Performed procedure step: scanned chest/abdomen/pelvis

Relationship of Steps



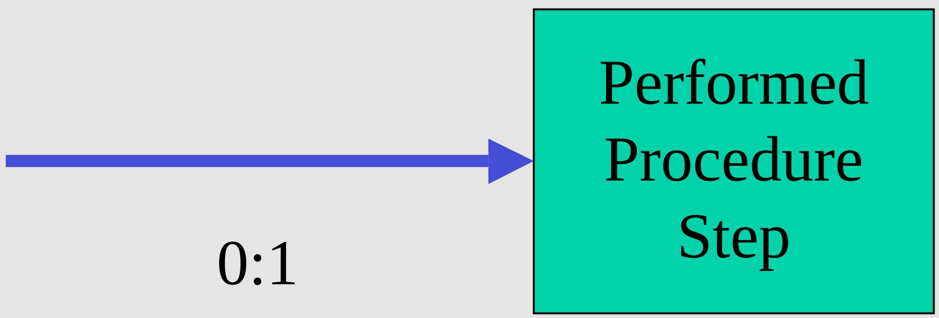
Scheduled procedure step: scan chest/abdomen/pelvis
Performed procedure step: scanned chest
Performed procedure step: scanned abdomen/pelvis

Relationship of Steps



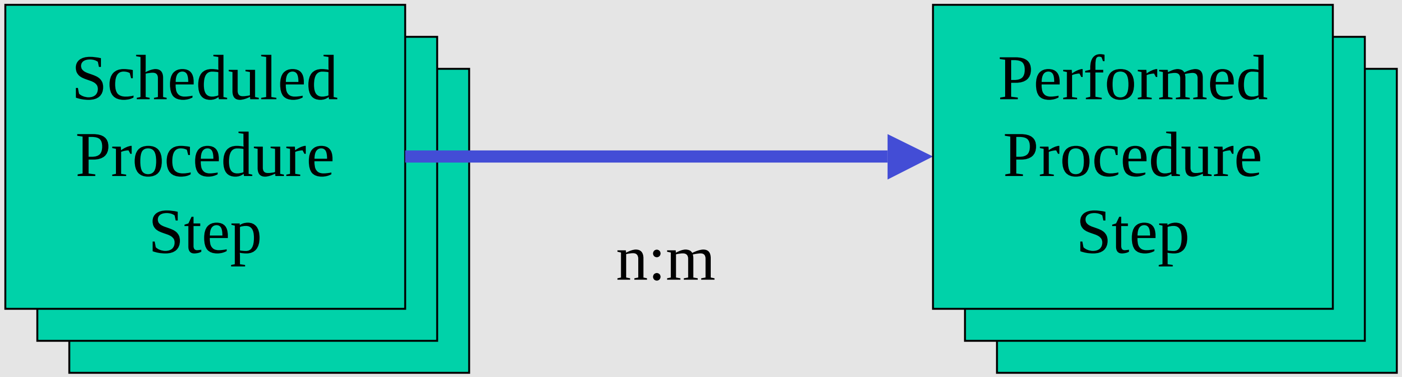
Scheduled procedure step: scan chest
Scheduled procedure step: scan abdomen/pelvis
Performed procedure step: scanned chest/ abdomen/pelvis

Relationship of Steps



unscheduled examination

Relationship of Steps



General case is n:m, where n and m may both be zero

DICOM and Workflow

- Modality Worklist
  - schedule of activity on modality
  - supply RIS/PACS assigned identifiers to modality
  - reduce errors inherent in operator re-entry
  - improve matching of images/requests on PACS

DICOM and Workflow

- Modality Worklist
- Modality Performed Procedure Step
  - provide status to RIS/PACS ("close the loop")
  - summary of results: how many and which images
  - allows RIS/PACS to check that all were received prior to assigning for read

DICOM and Workflow

- Modality Worklist
- Modality Performed Procedure Step
- General Purpose Worklist/Procedure Step
  - initiated to address need for interpretation worklists
  - generic nature of tasks recognized
  - need to support other applications, e.g. CAD

General Purpose Worklist

- List of inputs
  - images and other composite objects (reports)
- Scheduled steps have status
  - scheduled vs. in progress
- Tasks are coded
  - “interpretation”
  - “image processing”
  - …

Deployment

- Which system manages the workflow ?
- Where does the information come from ?
- Which standards are appropriate ?
- Can there be interoperability ?

Modality Worklist

- HIS/RIS sent HL7 ADT +/- OE messages
- Interface box (broker) maintains a database
- Modality implements DICOM MWL SCU
- Interface box acts as MWL SCP

- When to remove worklist entries ?
- What about MPPS ?

Modality Worklist

- Benefits beyond managing workflow
- Worklist provides inputs to modality
  - reliable patient identifiers - don't need to be typed in
  - reliable study identifiers - match to the request
- Identifiers are then used in images
- Images can then be matched later in PACS
  - with the request
  - with prior images
  - with prior reports
  - with the rest of the electronic medical record

Modality Performed PS

- Interface box or other MWL SCP wants to know when to remove MWL entries
- Who else cares ?
- Is PACS/RIS ready to receive MPPS to begin report scheduling ?
- Does MPPS have to be sent to more than one device by modality ?

Worklist for Interpretation

- Until now either:
  - proprietary worklist within RIS/PACS
  - normal query for “available” studies
  - “pushed” in advance to where radiologist is expected
- Use DICOM General Purpose Worklist
- Workstations must implement SCU
- PACS/RIS must implement SCP

Integrating the Healthcare Entreprise (IHE)

- “Acquisition Modality”: MWL/MPPS SCU
- MWL provided by “Order Filler” actor
- MPPS distributed by “PPS Manager” actor
  - to “Order Filler” actor
  - to “Image Manager” actor

“Scheduled Workflow Integration Profile”

IHE and Reporting

- Reports are currently standalone
- Encoded in DICOM Structured Reports
- Actors: creator/manager/repository/reader
- No workflow integration of reporting as yet
- Maybe next year using GP WL/PPS?

Deployment

- Which system manages the workflow ?
  - RIS or PACS or combination of the two
- Where does the information come from ?
  - acquisition task needs order/scheduling information
- Which standards are appropriate ?
  - combination of DICOM and HL7
- Can there be interoperability ?
  - IHE has shown the way for MWL/MPPS
  - remains to be seen if interpretation can be included

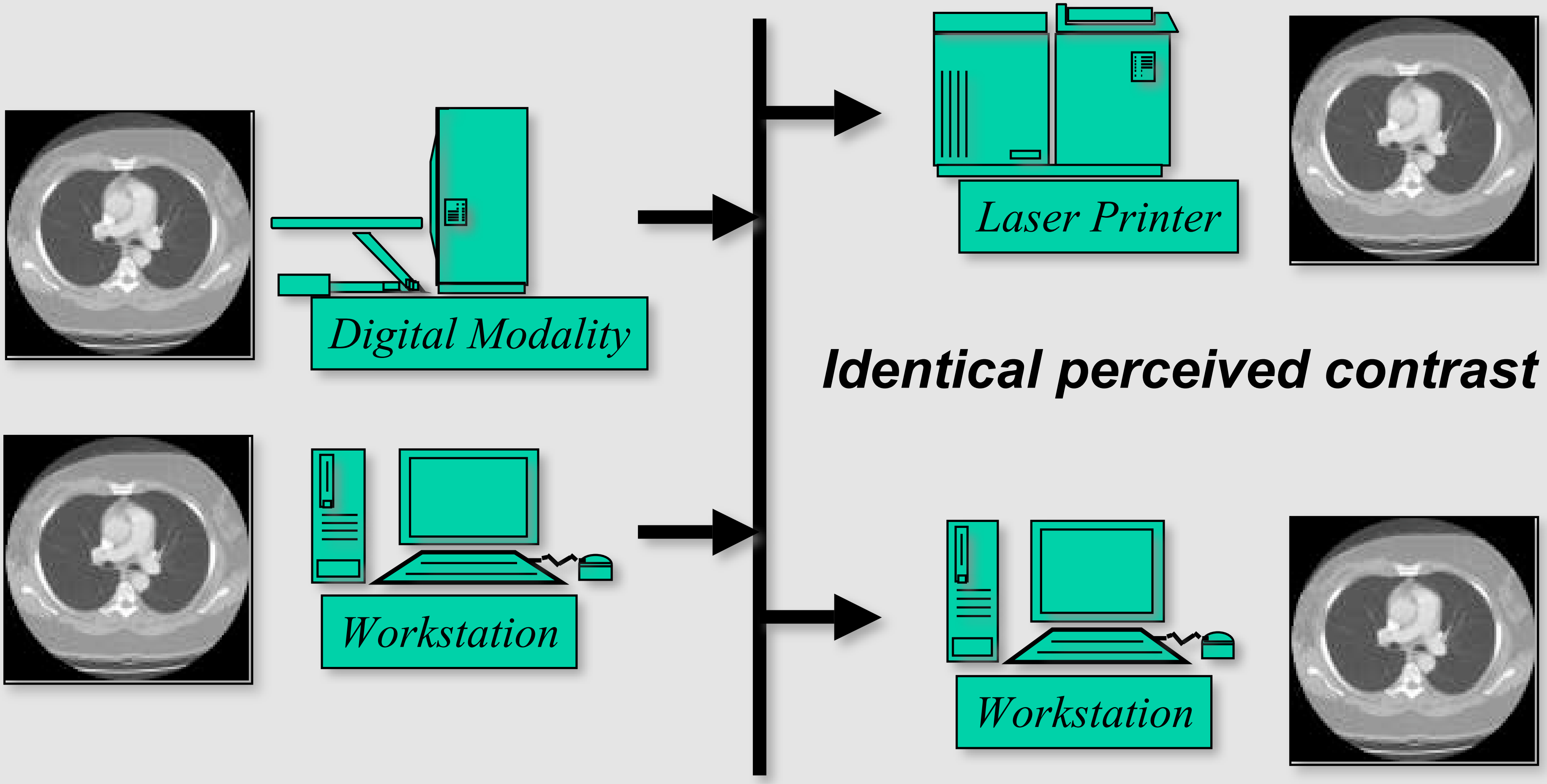
Veterinary Actions Items

- Extend DICOM Modality Worklist to include veterinary identifiers and attributes
  - Owner, Neutered, Species, Breed, etc.
- Extend IHE rules for copying identifiers from worklist into images to include veterinary attributes
- Start IHE Veterinary domain
- Evaluate needs for veterinary reporting content and workflow

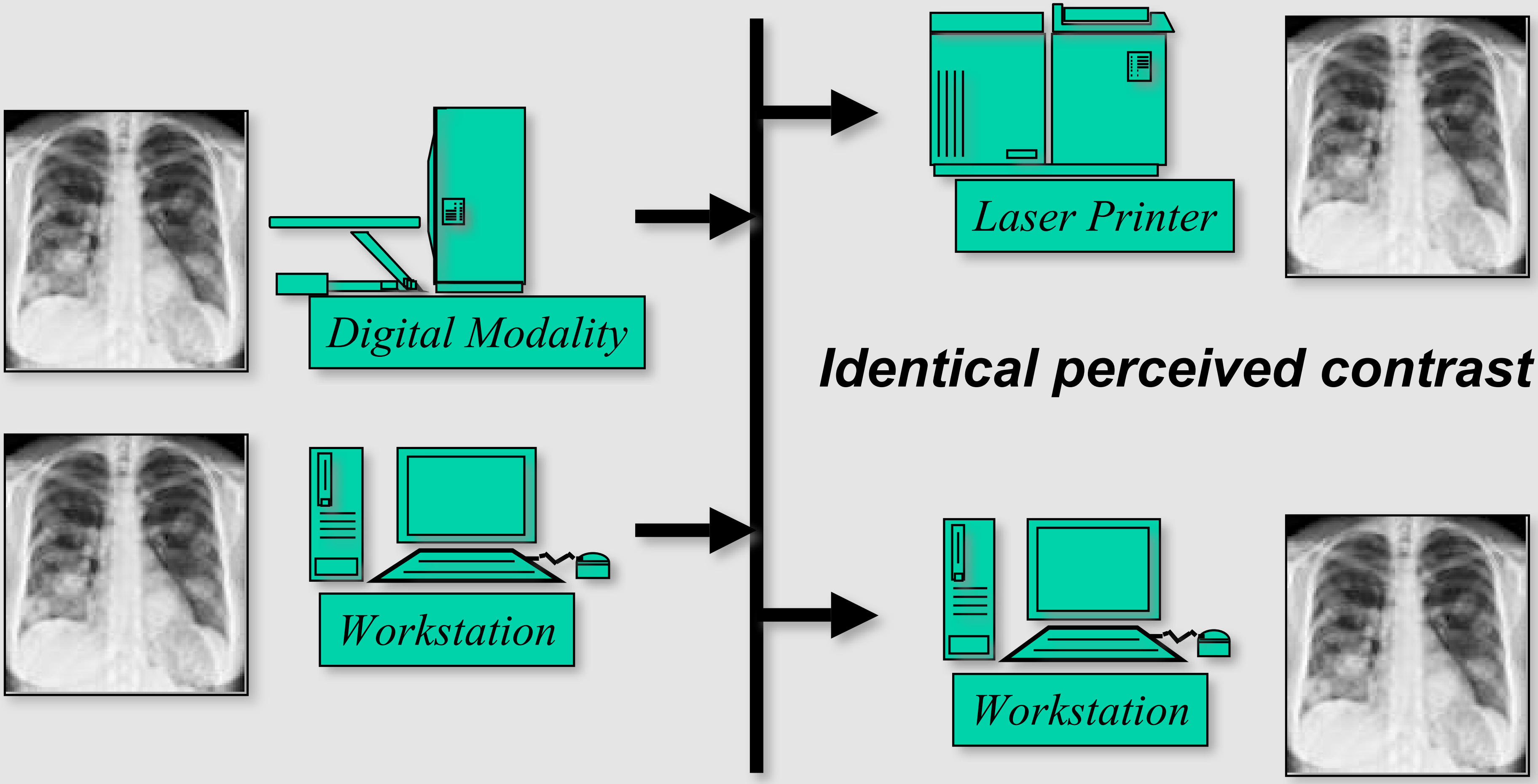
Distributed Image Consistency

- Inconsistent appearance of images
  - Why is it a problem ?
  - What are the causes ?
- Grayscale Standard Display Function
  - The DICOM solution to the problem
  - How it works
  - How to implement it

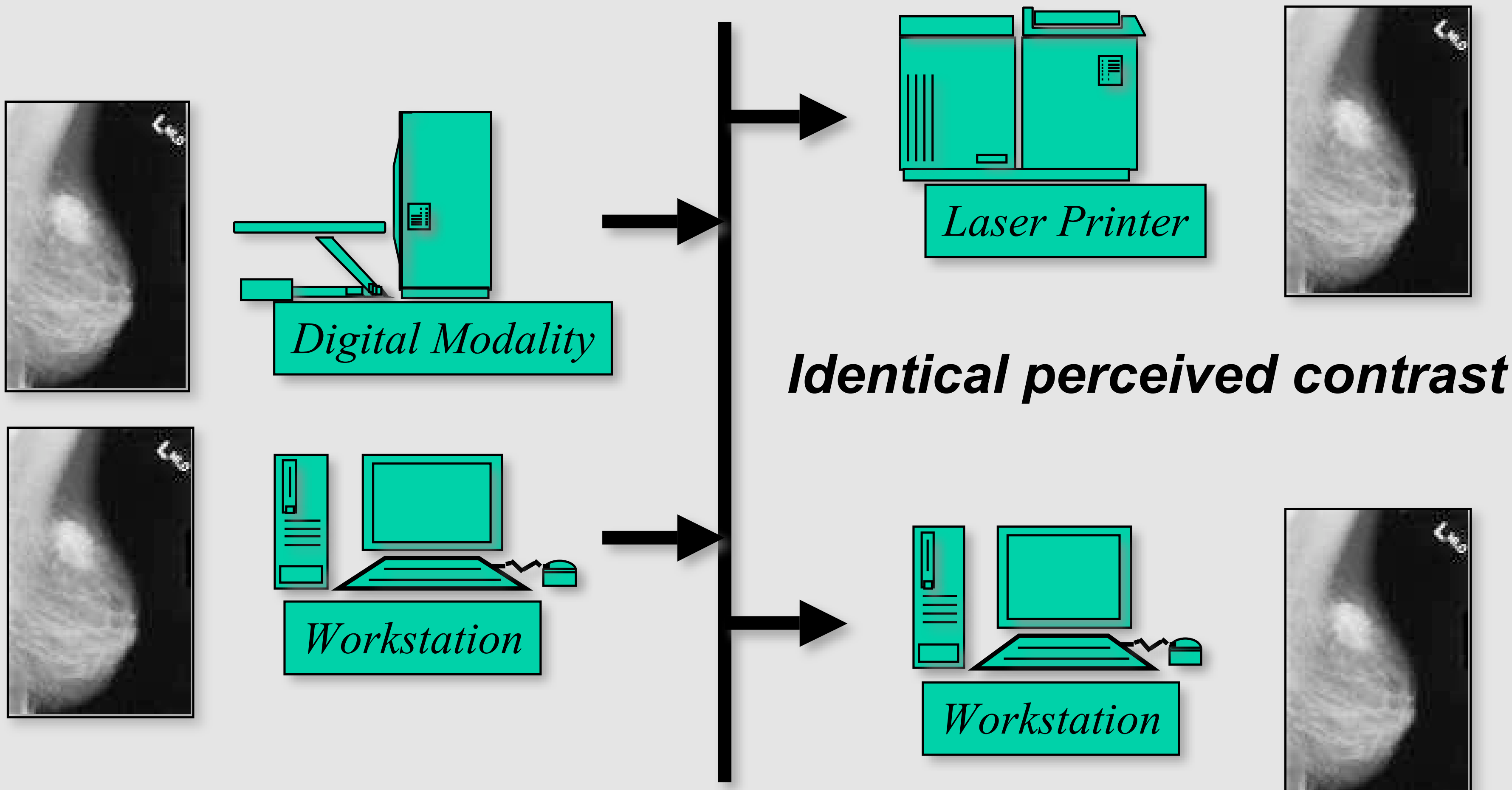
Distributed Image Consistency



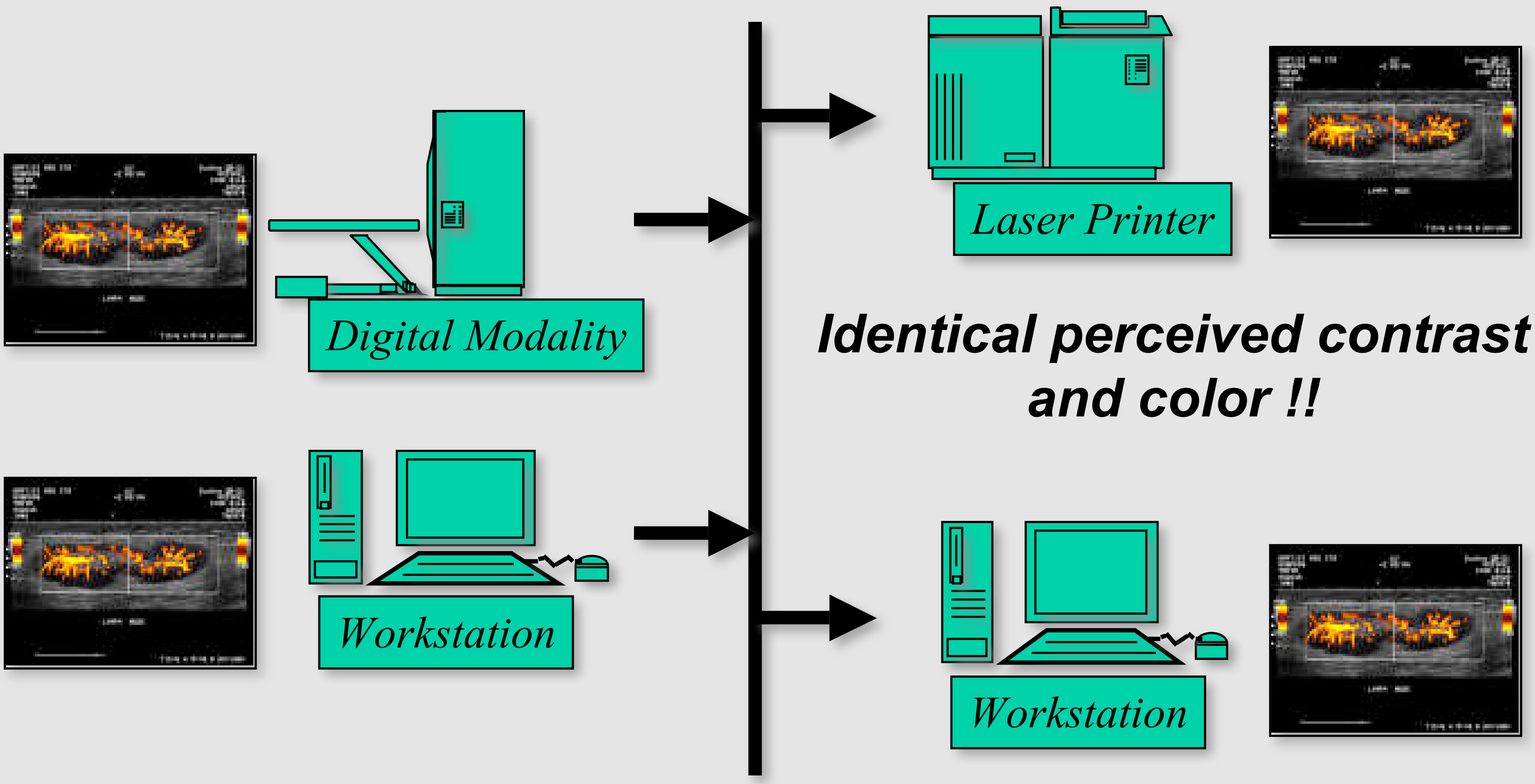
Distributed Image Consistency



Distributed Image Consistency



Distributed Image Consistency



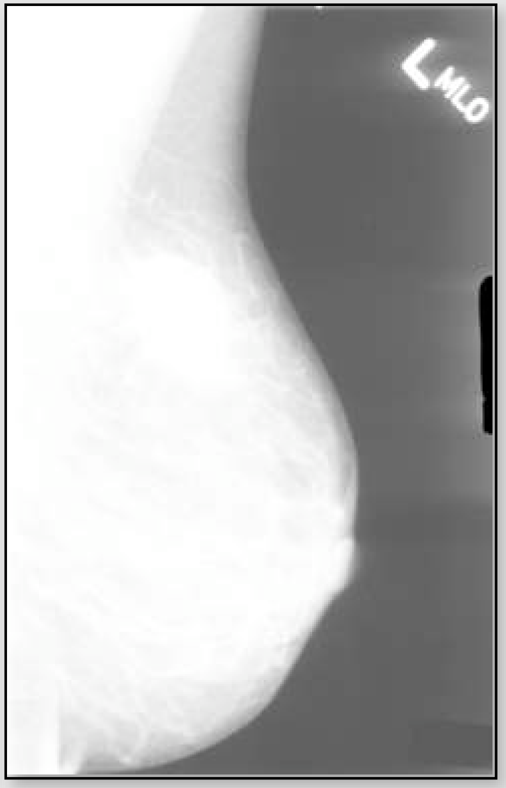
What about color ?

- Consistency is less of an issue:
  - US/NM/PET pseudo-color; VL true color ??
- Consistency is harder to achieve
  - Not just colorimetry (i.e. not just CIELAB)
  - Scene color vs. input color vs. output color
  - Gamut of devices much more variable
  - Greater influence of psychovisual effects
- Extensive standards efforts e.g., ICC
- All color DICOM images now include optional ICC profile, and there is a Color Presentation State

Problems of Inconsistency

- VOI (window center/width) chosen on one device but appears different on another device
- Not all gray levels are rendered or are perceivable
- Displayed images look different from printed images

Problems of Inconsistency



- VOI (window) chosen on one display device
- Rendered on another with different display
- Mass expected to be seen is no longer seen

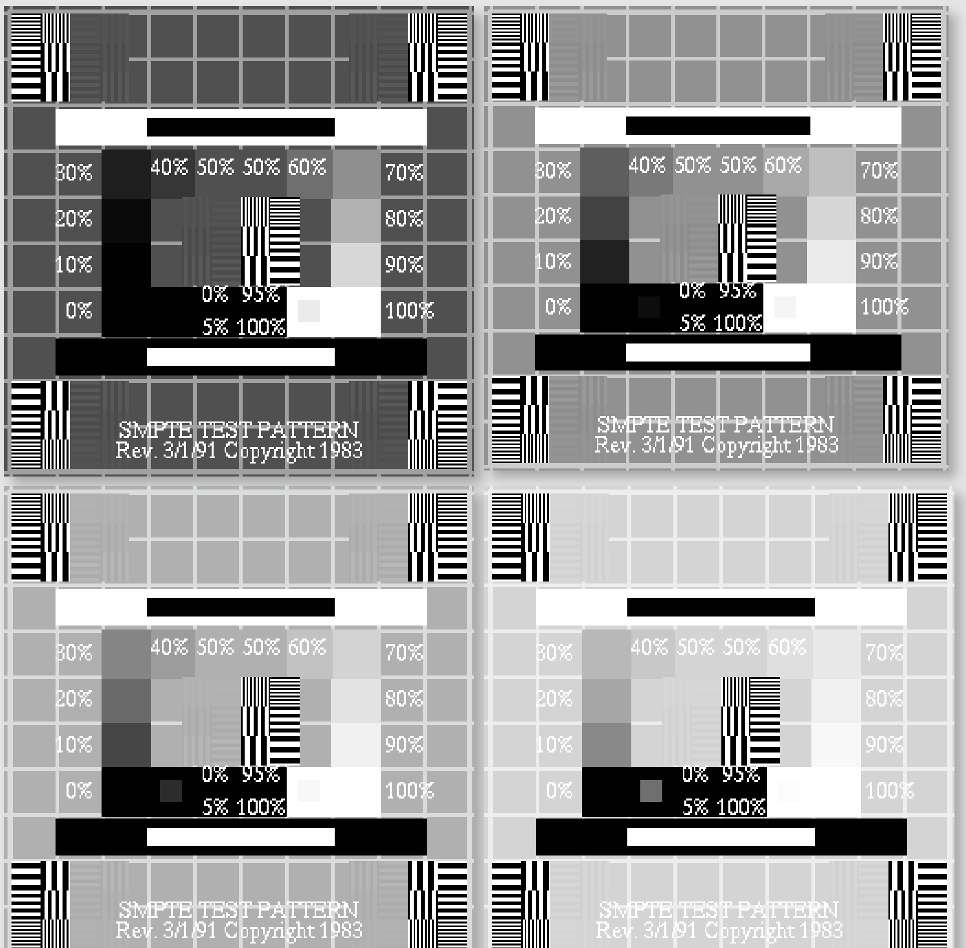
mass visible

mass invisible

Problems of Inconsistency

0.5

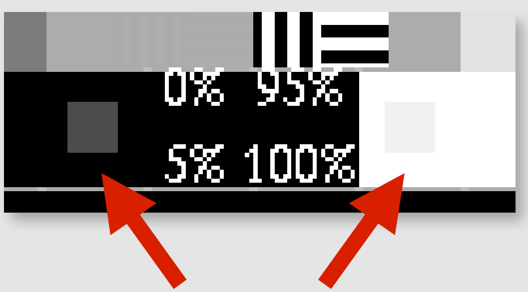
1.0



1.5

3.0

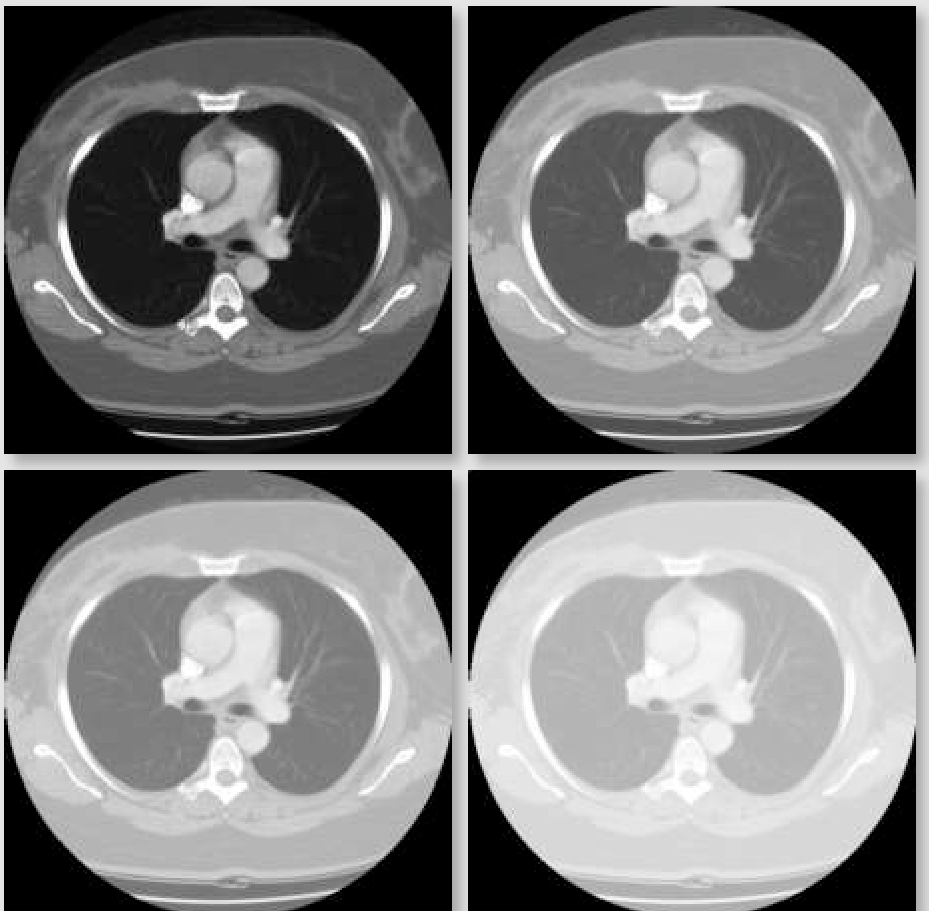
•Not all display levels are perceivable on all devices



Problems of Inconsistency

0.5

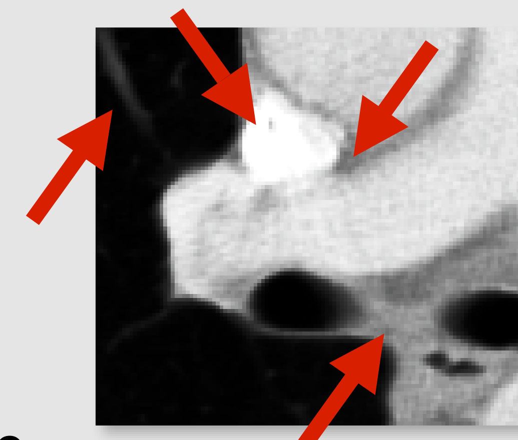
1.0



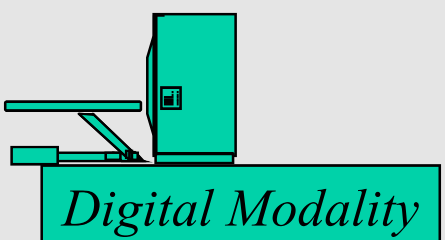
1.5

3.0

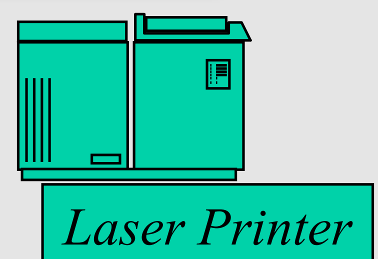
•Not all display levels are perceivable on all devices



Problems of Inconsistency



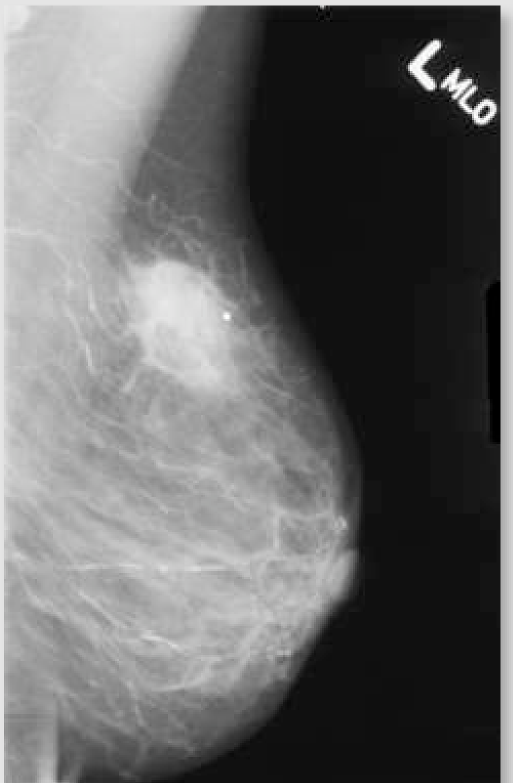
- Printed images don't look like displayed images

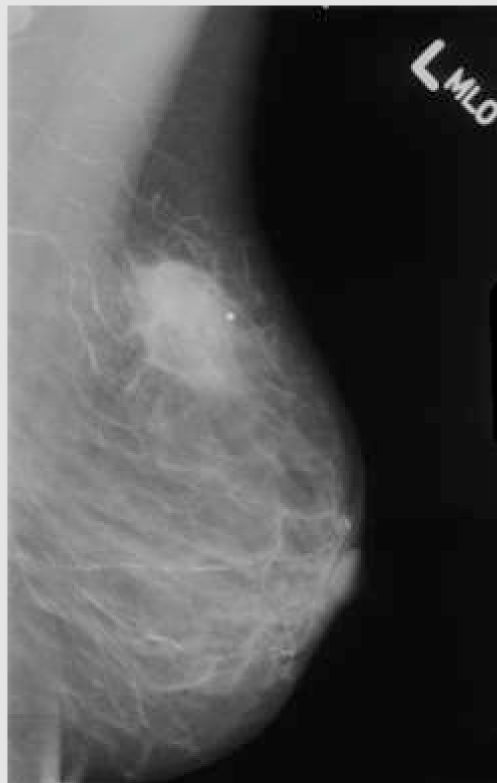


Causes of Inconsistency

- Gamut of device
  - Minimum/maximum luminance/density
- Characteristic curve
  - Mapping digital input to luminance/density
  - Shape
  - Linearity
- Ambient light or illumination

Causes of Inconsistency



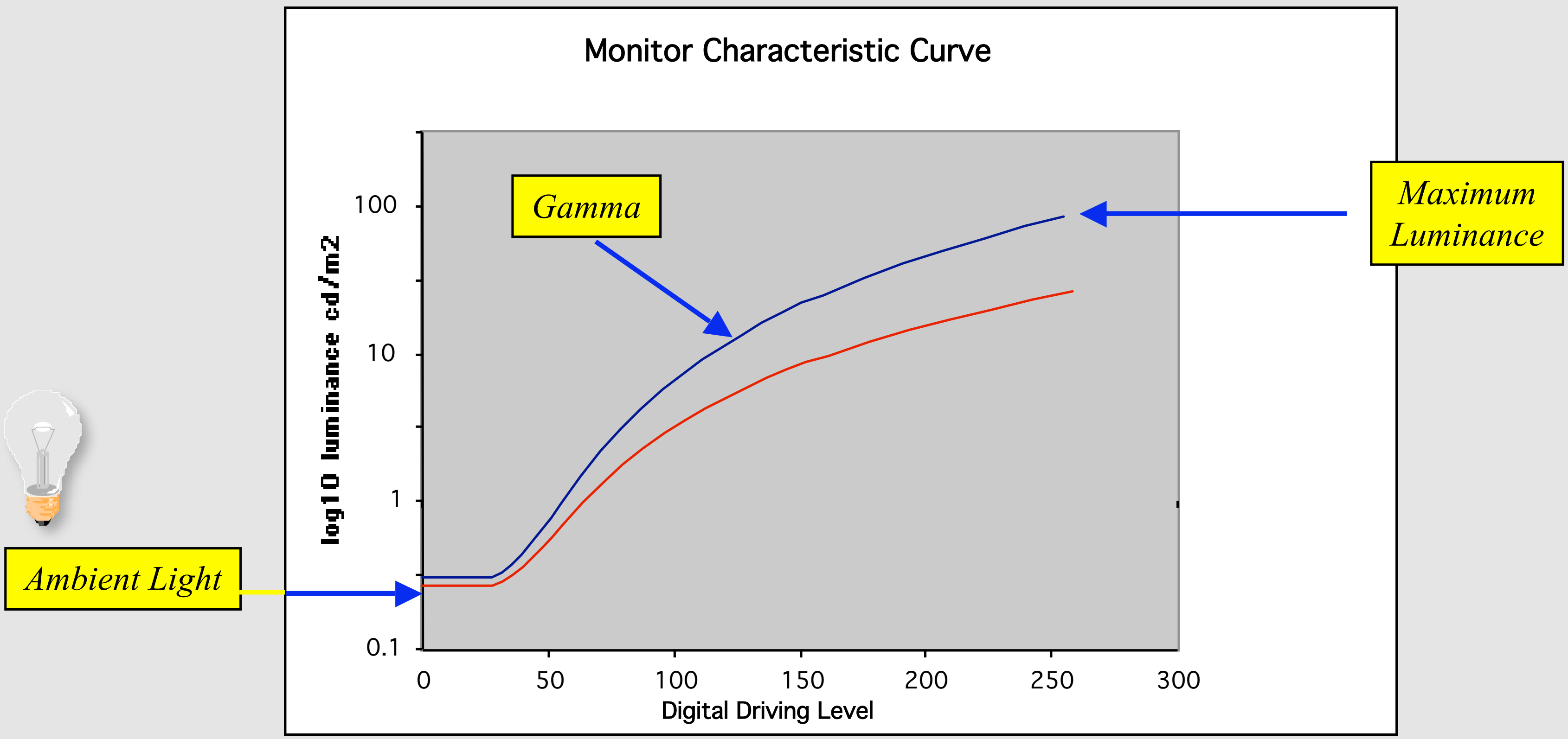


- Display devices vary in the maximum luminance they can produce
- Display CRT vs. film on a light box is an extreme example

1.0

.66

Monitor Characteristic Curves



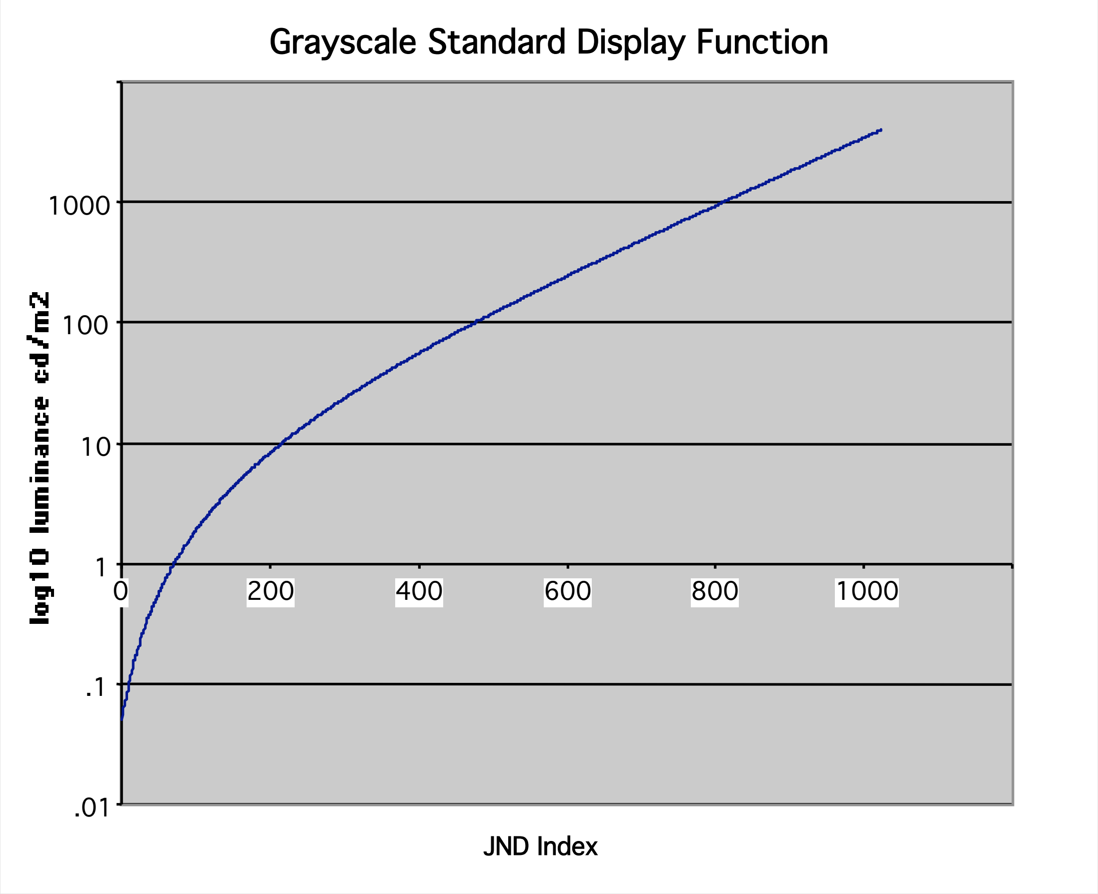
Towards a Standard Display

- Can’t use absolute luminance since display capabilities different
- Can’t use relative luminance since shape of characteristic curves vary
- Solution: exploit known characteristics of the contrast sensitivity of human visual system - contrast perception is different at different levels of luminance

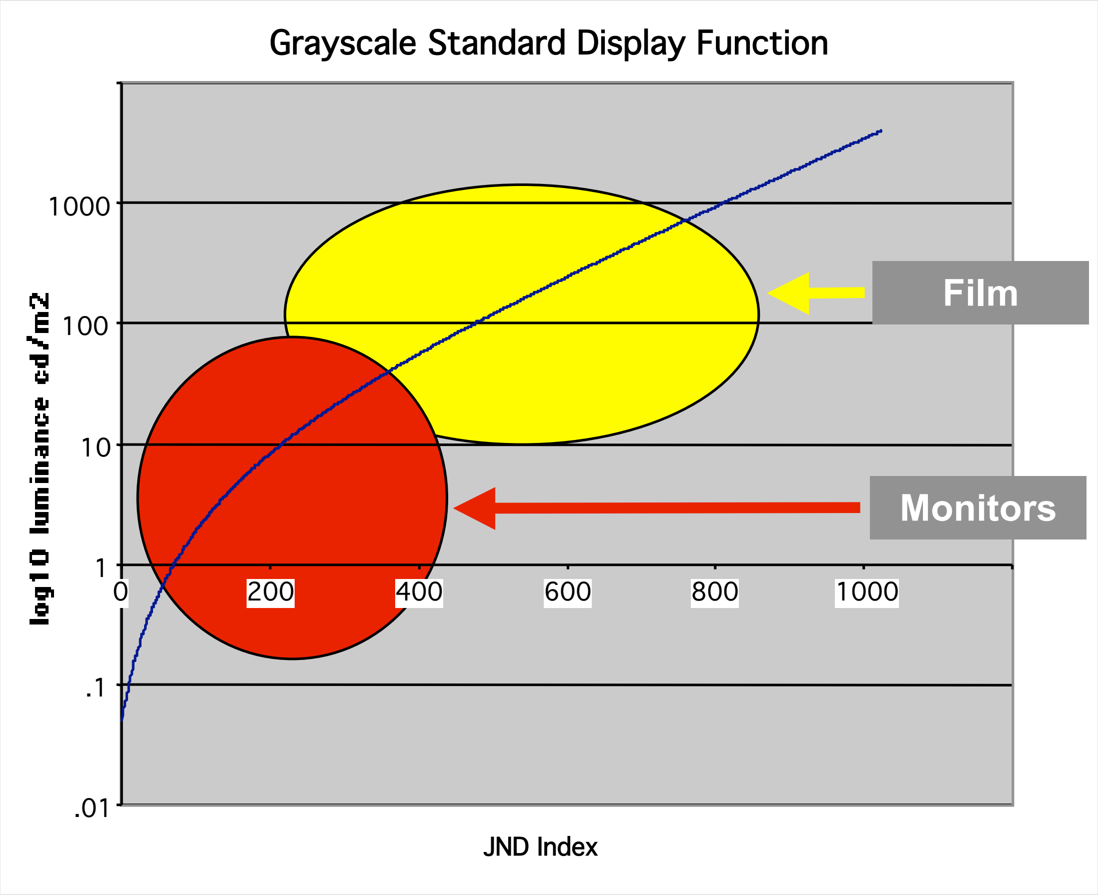
Human Visual System

- Model contrast sensitivity
  - assume a target similar to image features
  - confirm model with measurements
  - Barten's model
- Grayscale Standard Display Function:
  - Input: Just Noticeable Differences (JNDs)
  - Output: absolute luminance

Standard Display Function



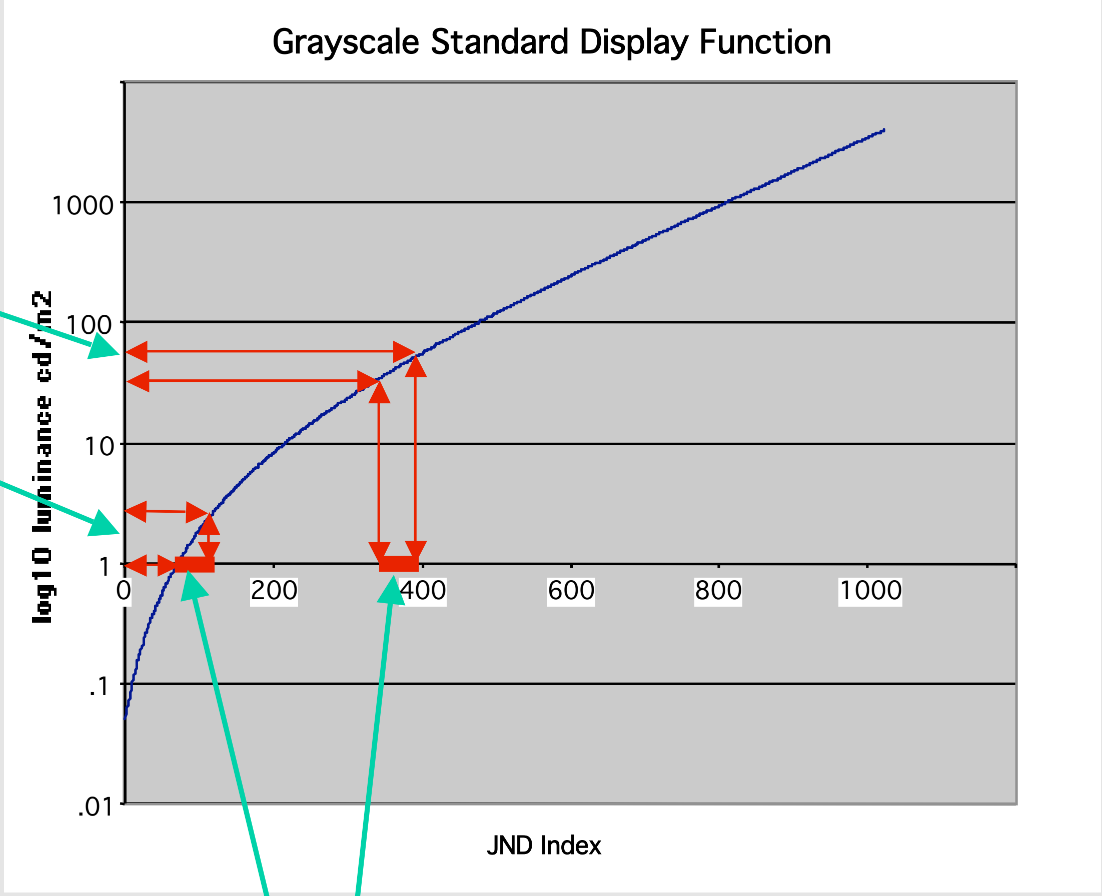
Standard Display Function



Perceptual Linearization

- JND index is “perceptually linearized”:
  - same change in input is perceived by the human observer as the same change in contrast
- Is only a means to achieve device independence
- Does not magically produce a “better” image

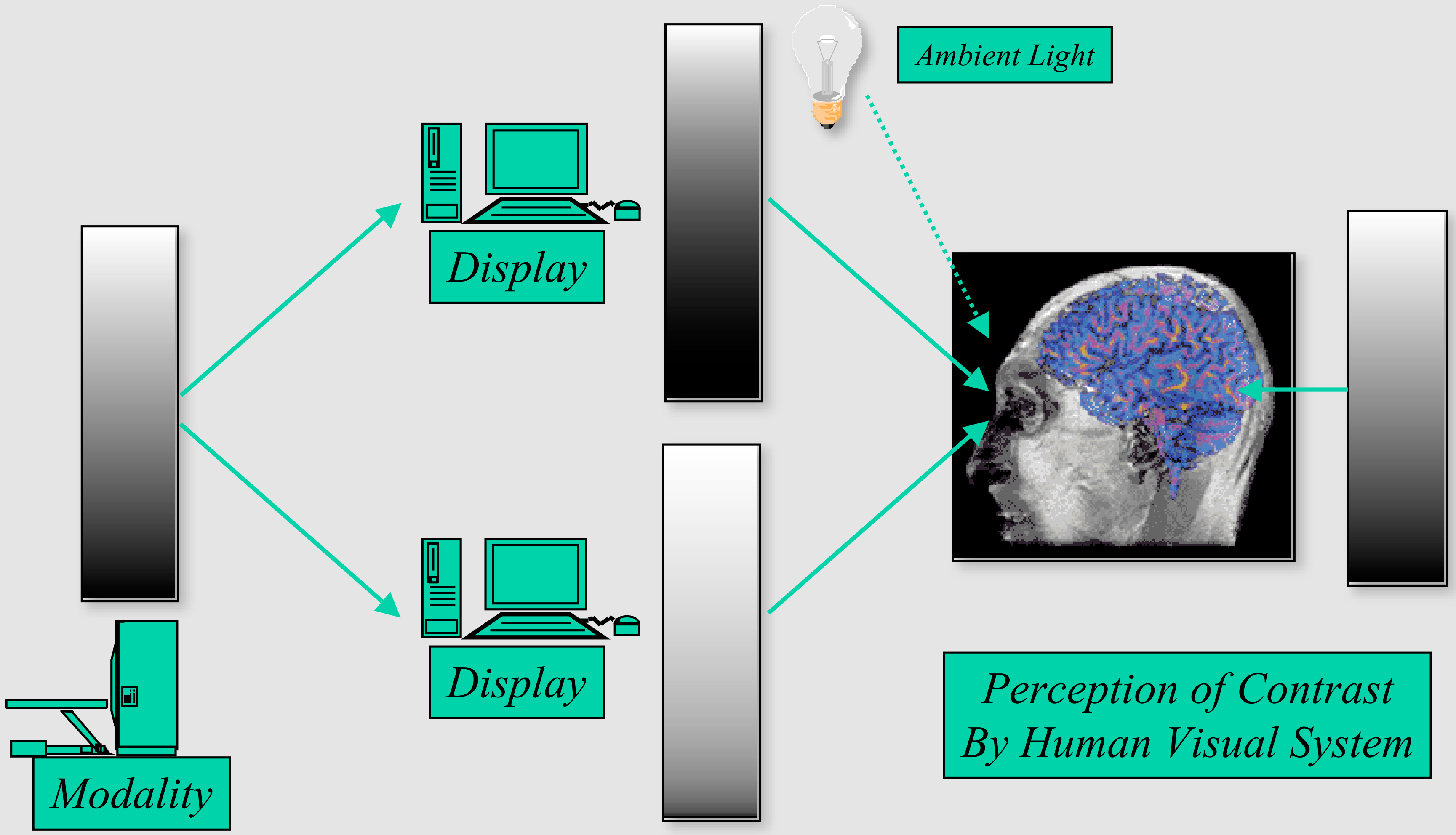
Perceptual Linearization



Despite different change in absolute luminance

Same number of Just Noticeable Difference == Same perceived contrast

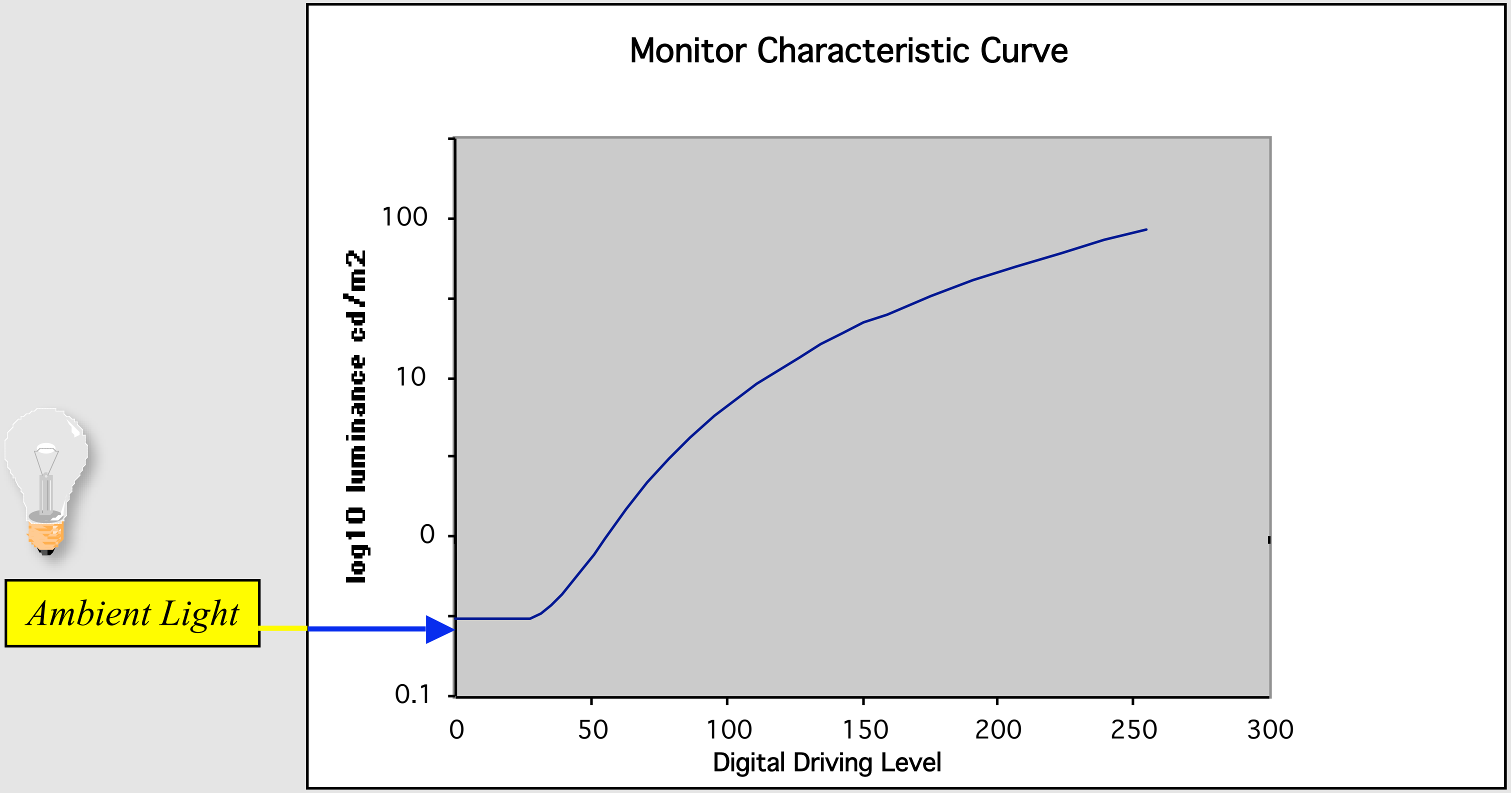
Perceptual Linearization



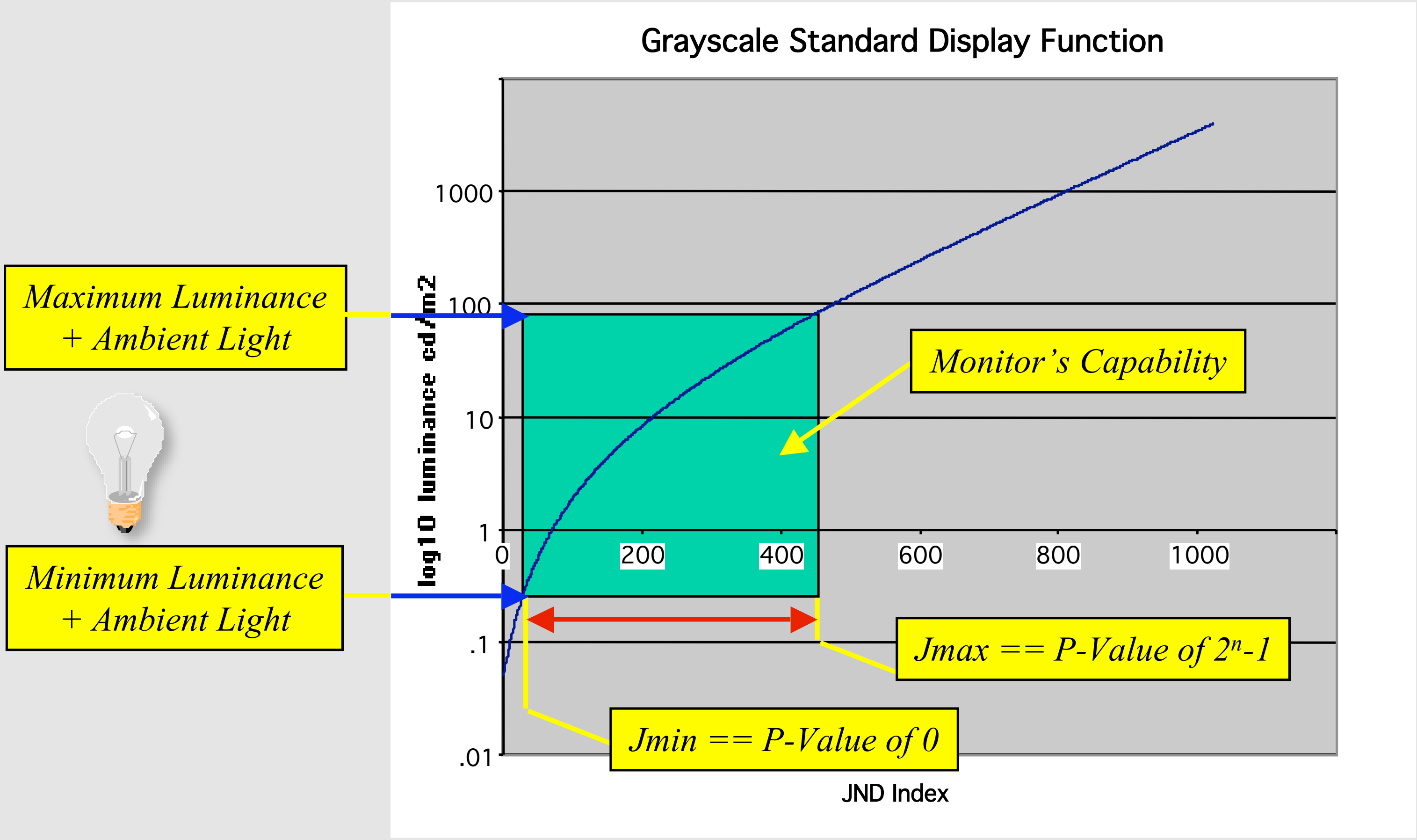
Using the Standard Function

- Maps JNDs to absolute luminance
- Determine range of display
  - minimum to maximum luminance
  - minimum to maximum JND
- Linearly map:
  - minimum input value to minimum JND
  - maximum input value to maximum JND
  - input values are then called “P-Values”

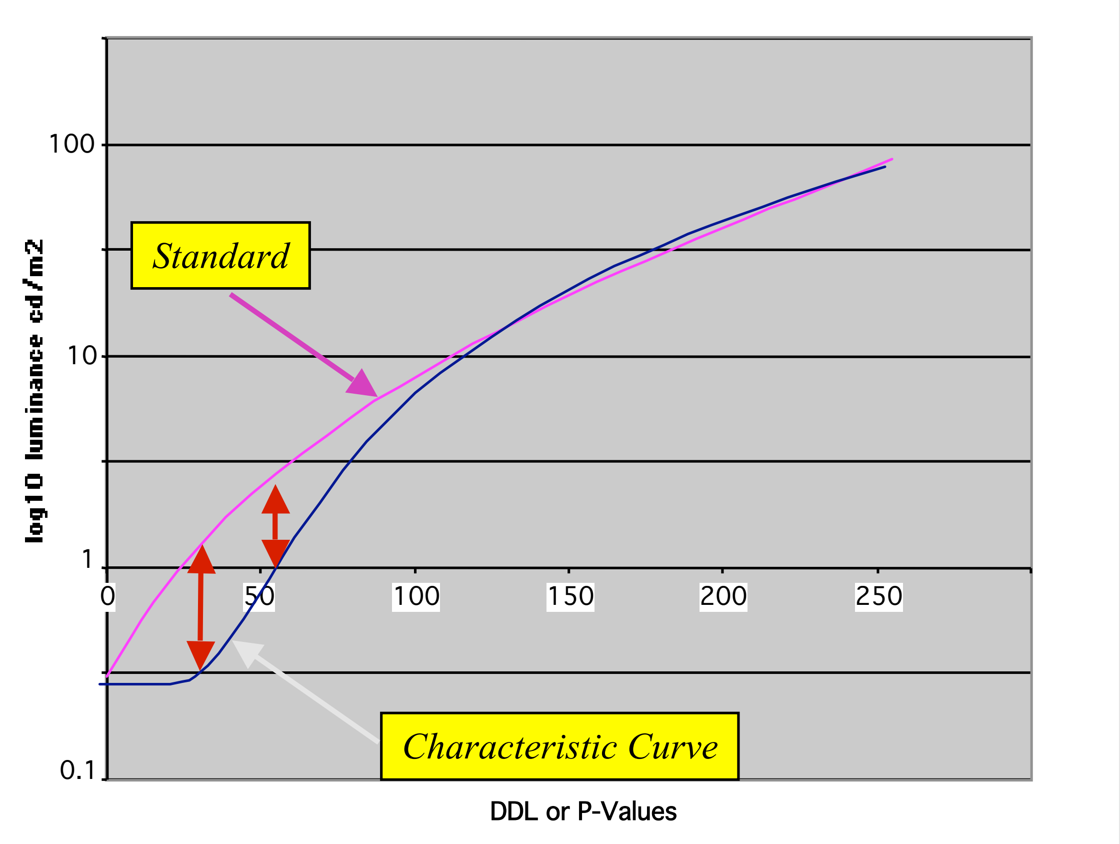
Monitor Characteristic Curve



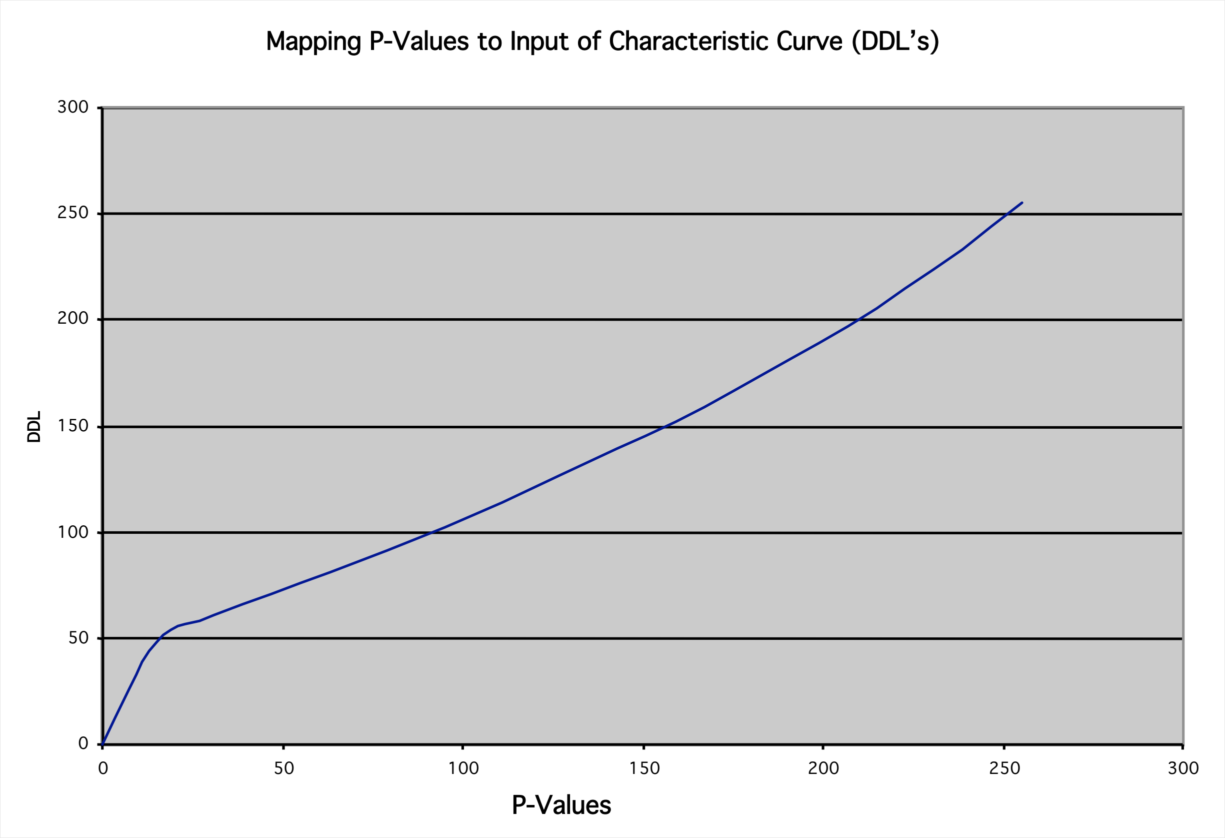
Standard Display Function



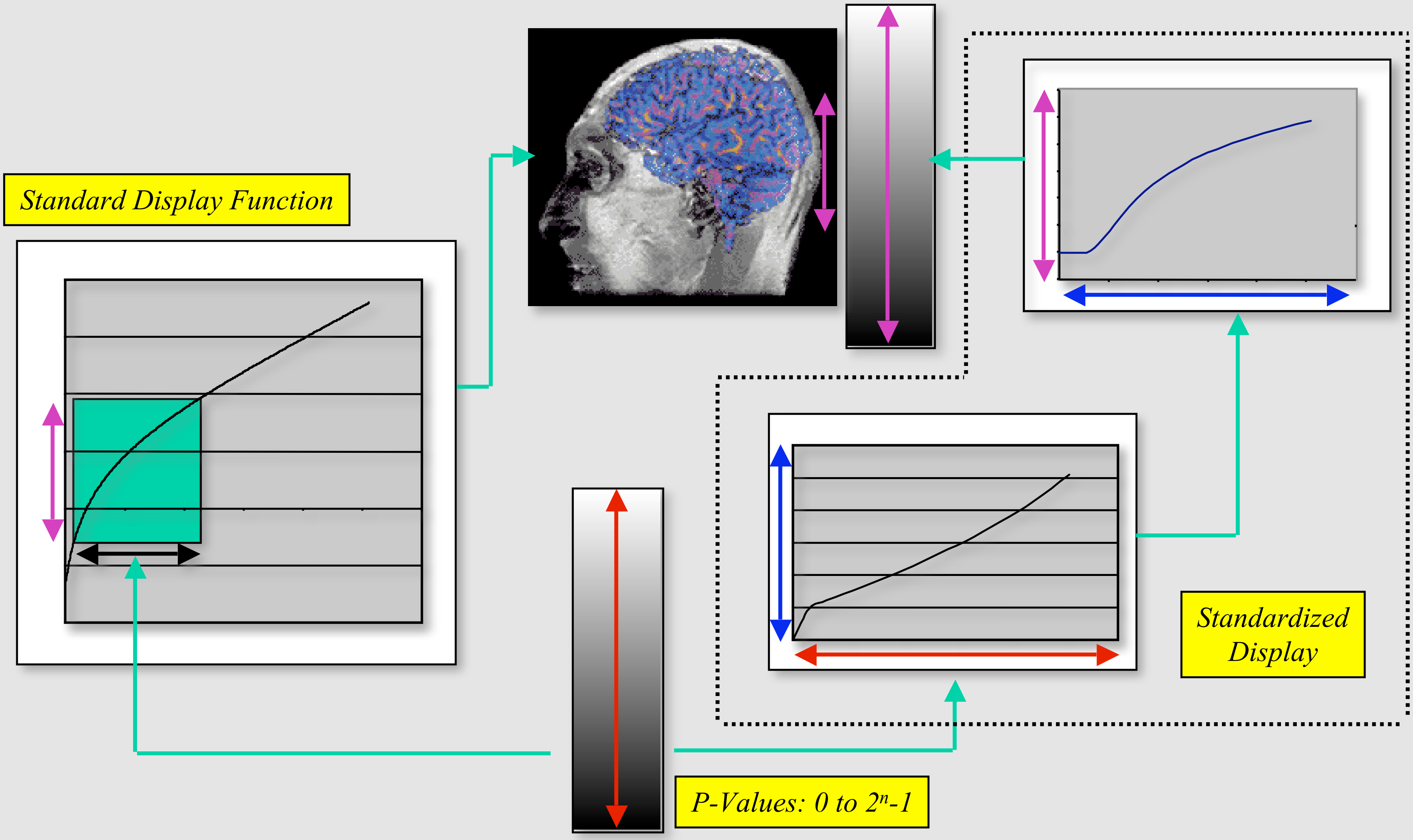
Standardizing a Display



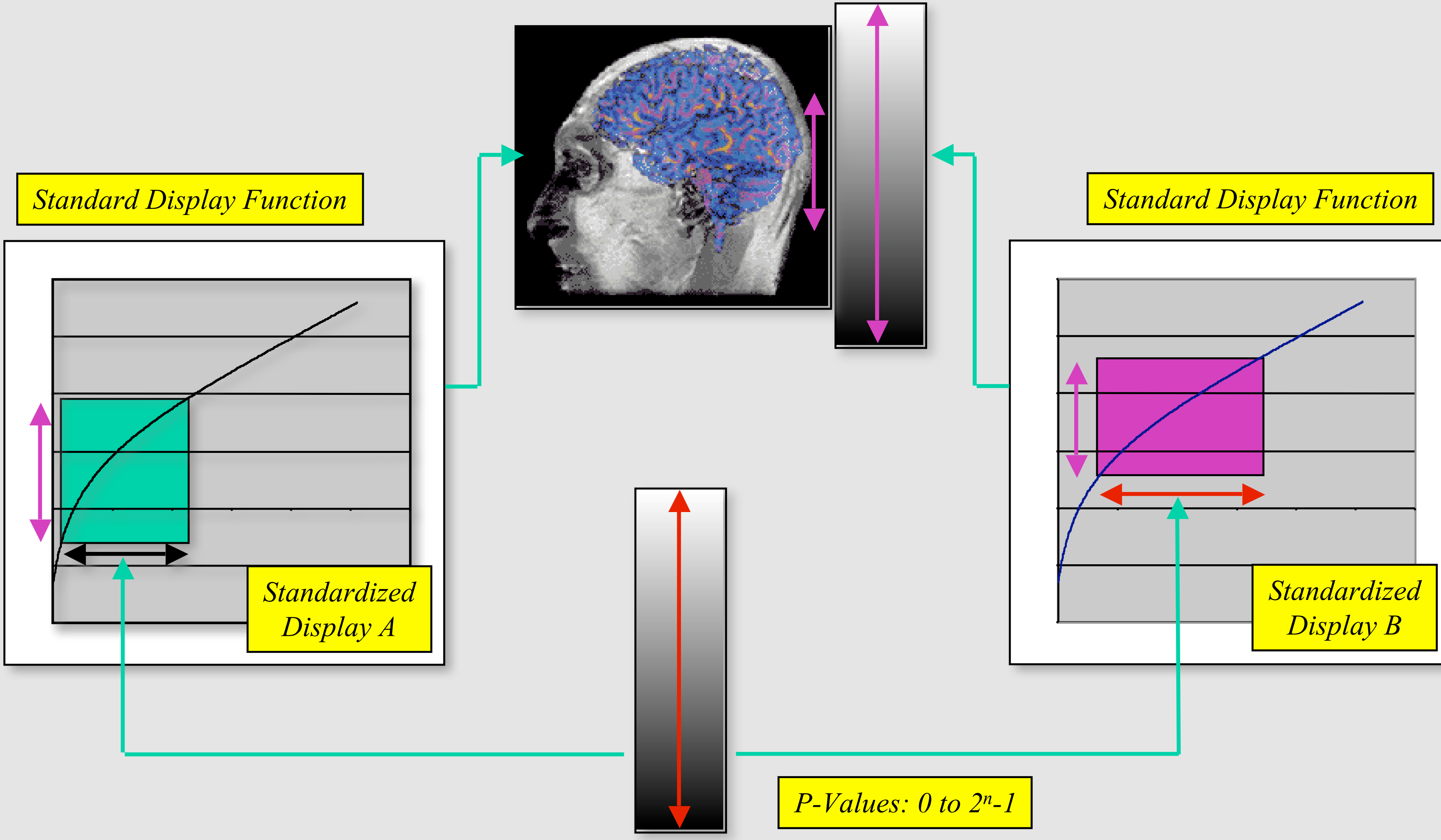
Standardizing a Display



Standardizing a Display



Device Independent Contrast



So what ?

- Device independent presentation of contrast can be achieved using the DICOM Grayscale Standard Display Function to standardize display and print systems

- Therefore images can be made to appear the same (or very similar) on different devices

So what ?

- Images can be made to appear not only similar, but *the way they were intended to appear*, if images and VOI are targeted to a P-value output space
- New DICOM objects defined in P-values
- Old DICOM objects and print use new services (Presentation State and LUT)

Not so hard …

- If you calibrate displays / printers at all, you can include the standard function
- If you use any LUT at all, you can make it model the display function
- If you ignore calibration & LUTs totally (use window system defaults) results will be inconsistent, mediocre and won’t use the full display range