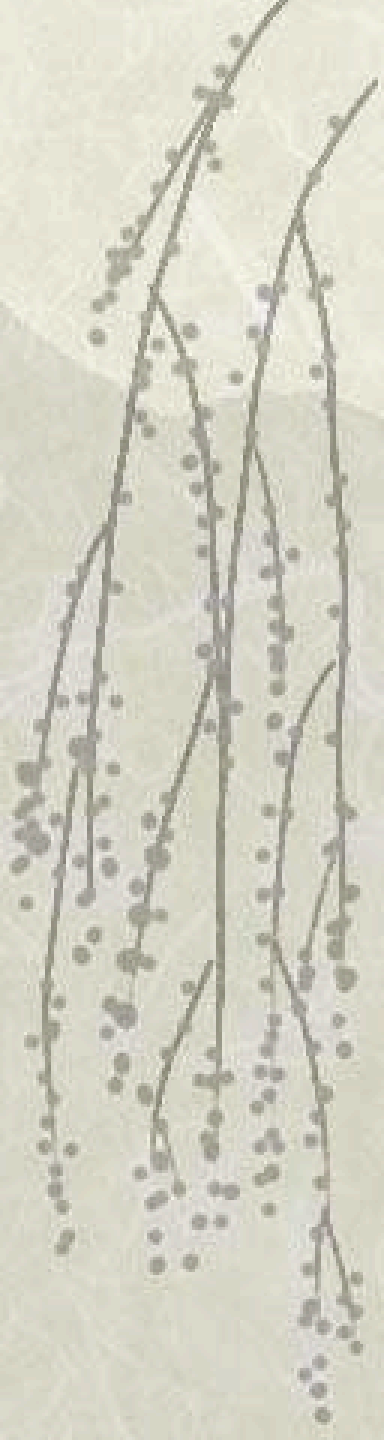
PACS: Then and Now (… and Tomorrow !)

David Clunie, MBBS, FRACR

CTO - RadPharm

(Princeton Radiology Pharmaceutical Research)



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 the 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 does PACS mean to you ?

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

What did PACS mean 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

PACS II, 1983 Table of Contents

- Introduction
  - Impact on organization of radiology departments
  - Analysis of justification for modality integration
  - Computer: friend or foe
- Digital archiving devices and systems
  - Optical storage
  - High density digital tape records
  - Digital light box
- Operational systems being evaluated
  - Medical image distribution, storage and retrieval network
  - PACS workbench at Mallinckrodt Institute of Radiology
  - All digital nuclear medicine department
  - Clinical experience with an operating prototype PACS

PACS II, 1983 Table of Contents

- Prototype systems being developed
  - Working PACS prototype
  - Early experience with fiber optic PACS
  - Introductory systems analysis considerations
- Imaging device interfacing
- Standards for PACS systems
  - What types of standards would be useful ?
  - Local area network upper layer standardization
  - Message protocols for radiologic consultations
  - PACS user level requirements

PACS II, 1983 Table of Contents

- Display systems and requirements
  - Concept of the diagnostic image workstation
  - Design and implementation of multiple digital viewing stations
  - Compression for PACS and CT archival
  - Requirements for display and analysis of 3D medical image data
  - Implementation of a diagnostic display and image manipulation node
  - Determinants of acceptability of radiographic images for archival digital storage
- Available hardware and software
  - Broadband coaxial cable image viewing and processing for radiology
  - Professional acceptance of electronic images in radiologic practice
  - Digital radiology at UCLA: a feasibility study
  - Practical considerations in digital cardiac angiography

PACS II, 1983 Table of Contents

- Image database and management
  - Investigation of structures and operations for medical image databases
  - PACS database design
  - Future directions in image management: medical and practical considerations
  - Approach to an economic model for radiology departments

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

Definition of Large Scale PACS

- Bauman et al
  - In daily clinical operation
  - At least 3 or 4 modalities connected
  - Workstations inside and outside radiology
  - Can handle >= 20,000 procedures per year
- In early 1990's - count on one hand

Surveys of Large Scale PACS

- Bauman et al 1994, 1996, 2000
- Large PACS
  - 1993 - 13
  - 1995 - 23
  - 1998 - 65 (underestimated)
- 1998
  - CT 83%, CR 71%, MR 70%, US 66%

		RIS	HIS	Reads	Vendor
1988	University Hospital Graz	X		-	Siemens
1989	Credit Valley Hospital		X	-	Philips
1989	Hokkaido University Hospital	X	X	-	NEC
1992	Danube Hospital SMZO	X	X	+	Siemens
1992	Free University of Brussels PRIMIS	X	X	-	Own
1992	Madigan Army Medical Center	X		+/-	Loral
1992	UCLA Health Sciences Center	X	X		Own
1992	University Hospital of Geneva	X	X		Own
1992	University of Florida	X	X		Kodak
1992	Wright Patterson AFB Medical Center		X		Loral
1993	Baltimore VA Medical Center		X	+	Loral
1993	Brooke Army Medical Center	X	X	-	Loral
1993	University of Pittsburgh	X	X		Own
1993	Viborg County Hospital	X	X	+/-	Siemens
1994	Brigham & Women's Hospital	X		-	Kodak
1994	Conquest Hospital			-	Simis
1994	Houston VA Medical Center Hospital		X	+/-	Emed
1994	Osaka University Hospital	X	X		NEC
1994	Samsung Medical Center	X	X	-	Loral
1994	Toshiba Hospital	X	X	+/-	Toshiba
1994	University of California San Francisco	X	X		Own
1994	University of Virginia				Emed
1995	Hospital University of Pennsylvania	X		-	Own

Surveys of Large Scale PACS

- Most digital modalities
- Importance of RIS/HIS connectivity
- Spread across Europe, Asia & USA
- Several sites filmless in early 1990's !
  - Danube, Baltimore VA
  - Except for mammography
- Interest by the military stimulating

Implementation Approaches

- Early
  - Home grown
  - Home grown with vendor partnership
  - Vendor supplied custom installation
  - Off-the-shelf vendor supplied
- Today
  - Vast majority off-the-shelf vendor supplied

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

Changes in Regulatory Scenario

- PACS are Medical Devices
  - Class I - general controls
  - Class II - special controls (e.g., 510k substantial equivalence)
  - Class III - pre-market approval (PMA)
- 1991 First PACS classification (updated 1993)
  - Guidance for the Content and Review of 510(k) Notifications for Picture Archiving and Communications Systems (PACS) and Related Devices (8/93)
- 2000
  - Guidance for the Submission Of Premarket Notifications for Medical Image Management Devices (7/00)
- Recognition of off-the-shelf nature of much PACS hardware
- Storage and communication devices are Class 1 if no lossy compression

Some of the challenges

- Integration of modalities beyond radiology into a single infrastructure
  - Visible light
  - Cardiology
  - Nuclear medicine
- Specific application support
  - PACS workstations relatively simple in terms of viewing rather than processing and analysis
- Growing volume of data per study
  - Challenges storage, communication and display technology and design
- Security infra-structure integration
- Electronic medical record integration

What does PACS mean to you ?

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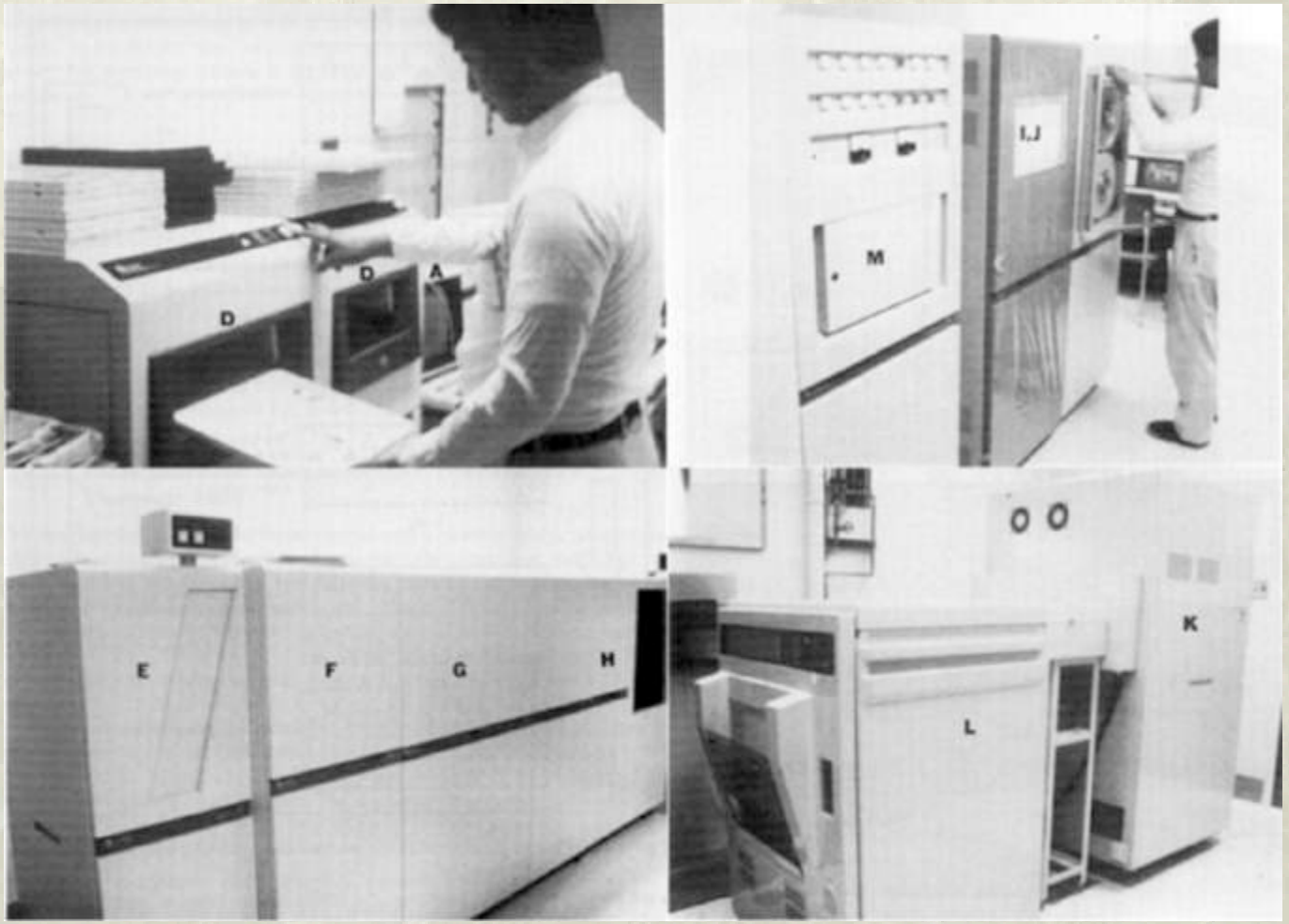
- Storage
- Distribution, locally and remotely
- Display
- Reporting creation, distribution, storage
- Workflow management
- Integration with other information (systems)

Acquisition

- Early PACS required
  - Proprietary connections to digital modalities
  - Video frame-grabbing
  - Film digitization (initially no CR)
- Computed Radiography
  - Introduced by Fujifilm 1983
  - Originally intended to print to film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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 (not networked, no files)
- Tag-value pairs of data elements
  - Describing acquisition and identifying patient

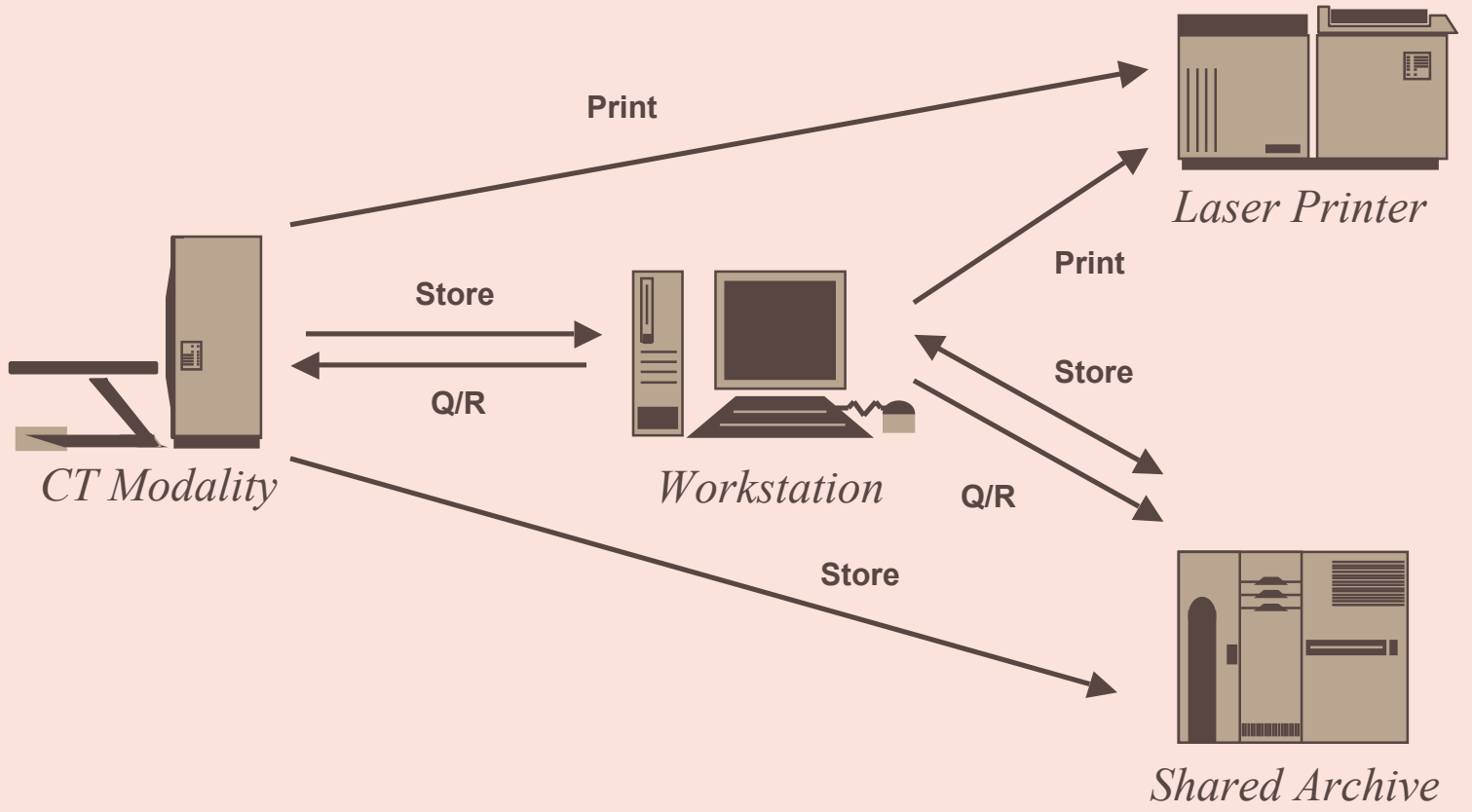
Acquisition - Standards

- Post-ACR-NEMA PACS and Modalities
  - Several systems adopted ACR-NEMA concepts within 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 supporting
  - Specific modality requirements for all modalities
  - Network based transport and services

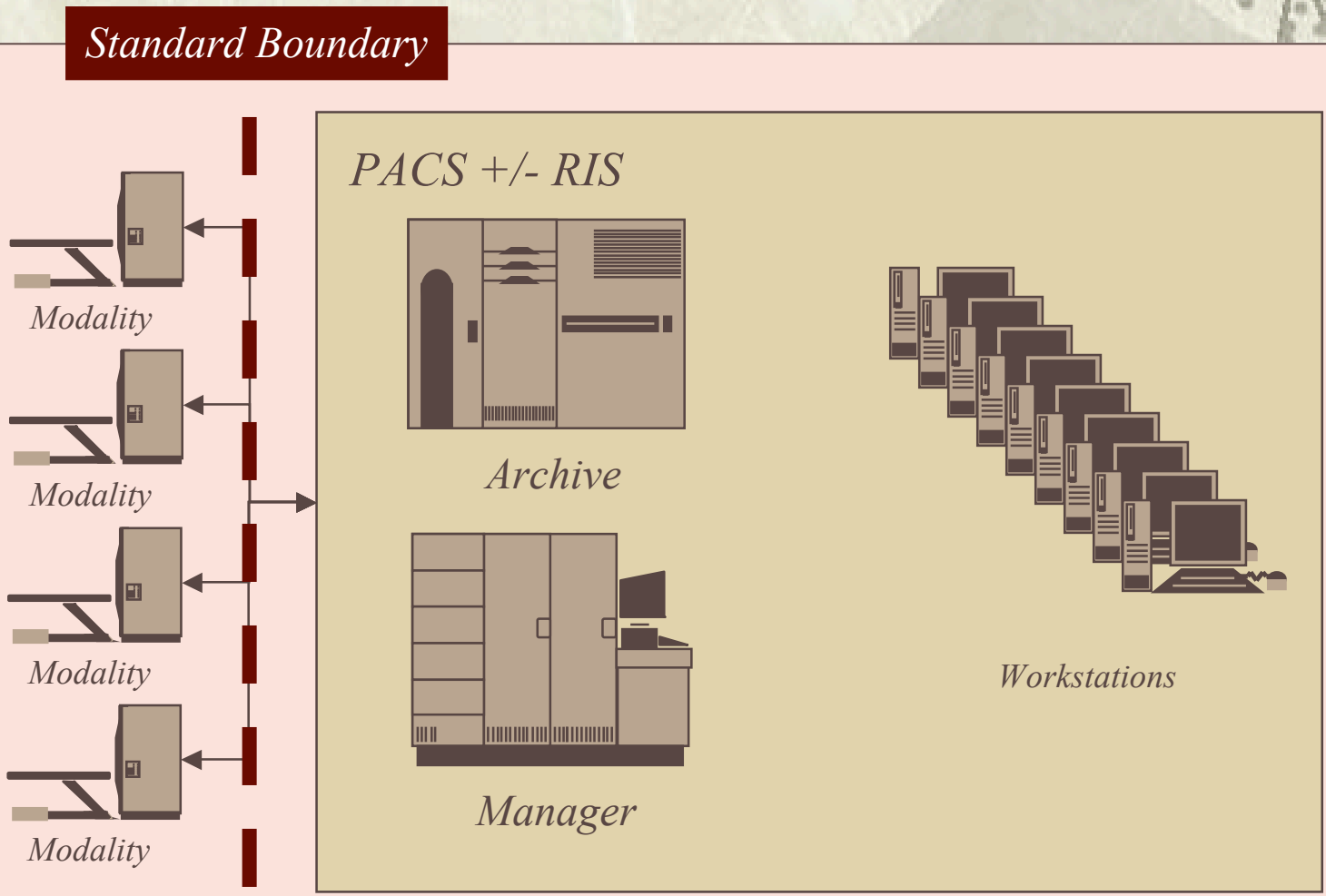
Acquisition - Standards - DICOM

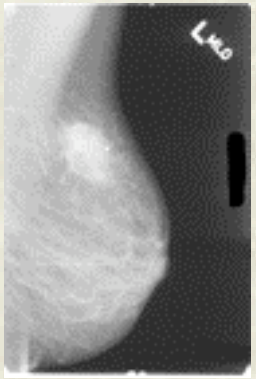
- 1993 DICOM - Digital Imaging and Communications in Medicine
- Network-based (TCP/IP over Ethernet)
- Services for
  - Storage (transfer)
  - Query and retrieval
  - Printing
- Derived from ACR-NEMA
- Added concepts of modality-specific information objects
- Conformance requirements and statement
-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

DICOM Cluster or Mini-PACS



DICOM and the PACS

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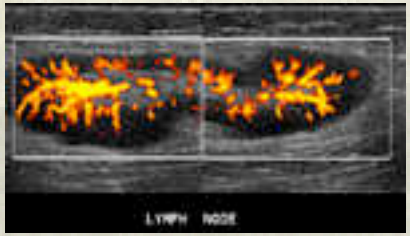
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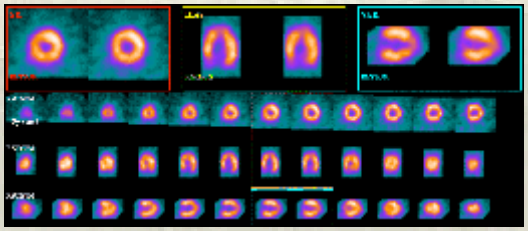
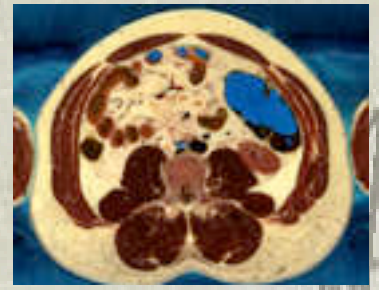
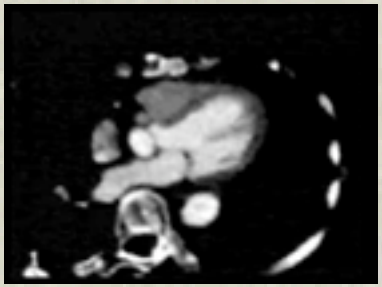
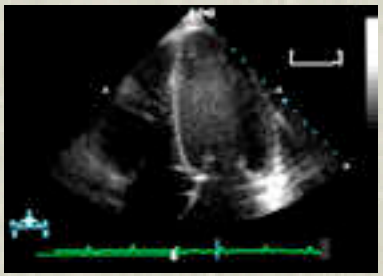
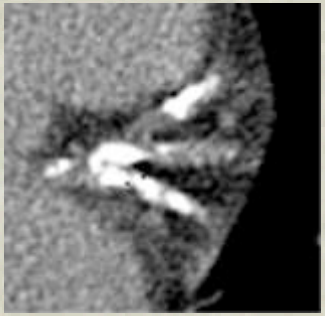
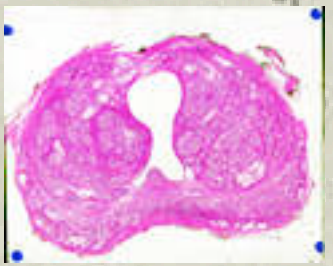












1993 DICOM Image Objects

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

2004 DICOM Image Objects

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

2004 DICOM Non-Images

- RT Structure Set, Plan, Dose, Treatment Record
- Waveforms (ECG, Hemodynamic, Audio)
- Grayscale Presentation State
- Structured Reports
- Key Object Selection
- Mammo and Chest CAD
- Procedure Log
- Spatial Registration and Fiducials
- Stereometric Relationship

New DICOM Image Objects

- Focus on PACS productivity
- More mandatory attributes
- Body part, orientation and position
  - for hanging on PACS workstations
  - requires operator involvement
  - workflow tradeoffs - operator vs. downstream
- Consistency of appearance
  - Pixels in P-Values (Grayscale Standard Display Function)

Management Features of Film

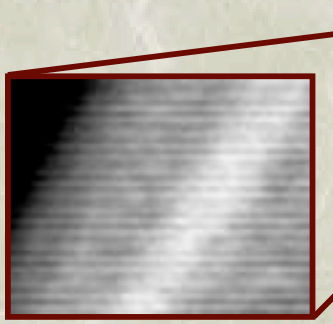
Visual Cues to Human:
Modality = X-ray
Anatomy = Skull
Projection = Lateral

Row Direction = Ant
Col Direction = Feet

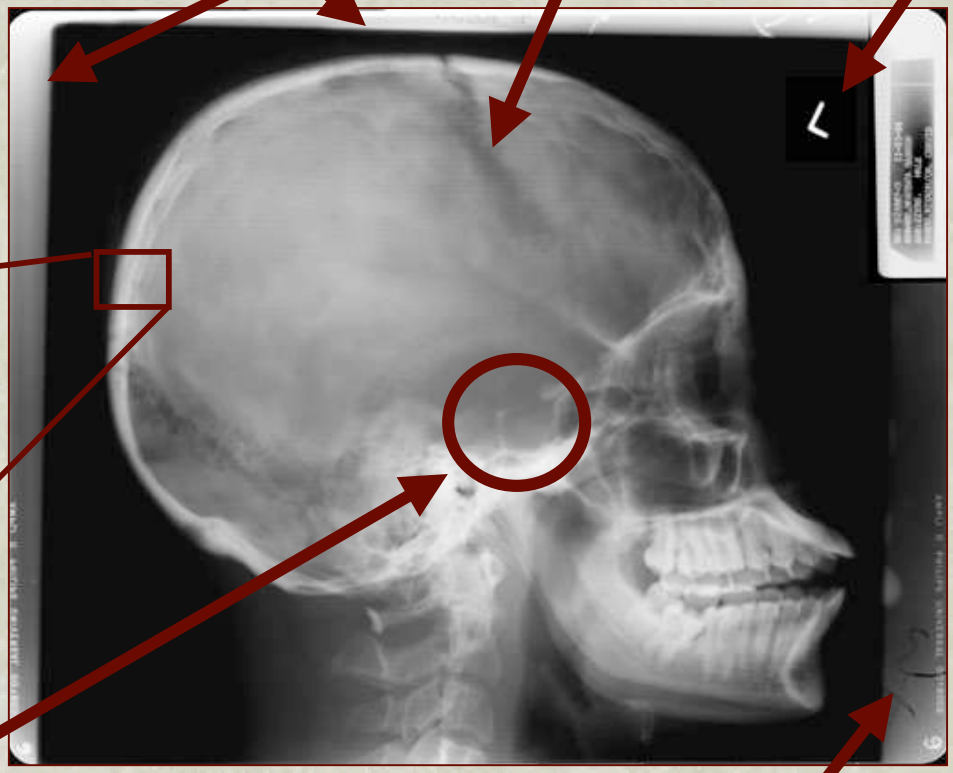
Grayscale: Film type & exposure

Collimator Edges

Lead Marker:
Laterality = L
Projection = L



Grid Used = Yes



Flashed ID:
Patient Name
Patient ID
Patient DOB
Patient Sex
Physician
Institution

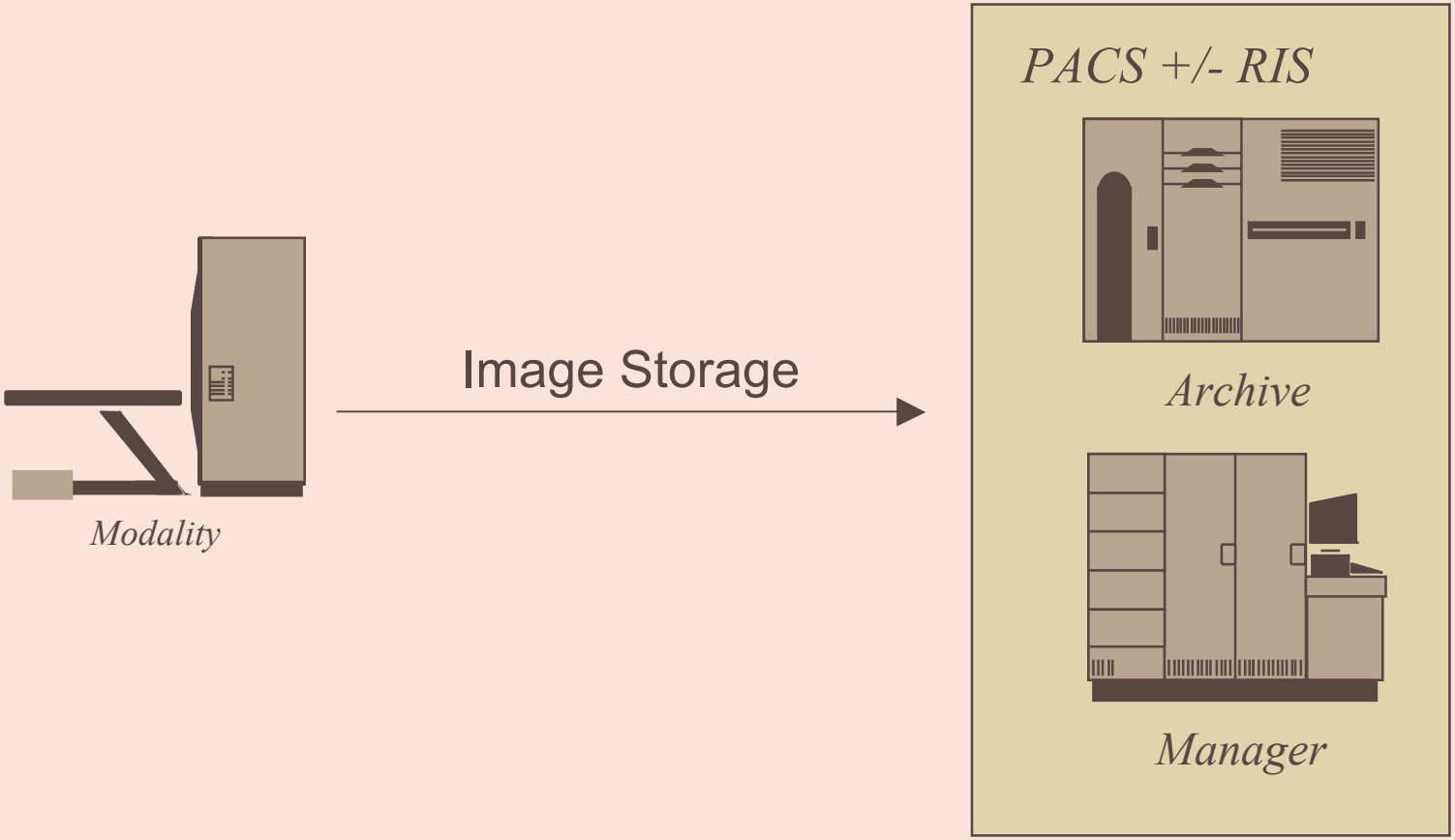
Wax Pencil:
Enlarged Sella

Wax Pencil: Film Number

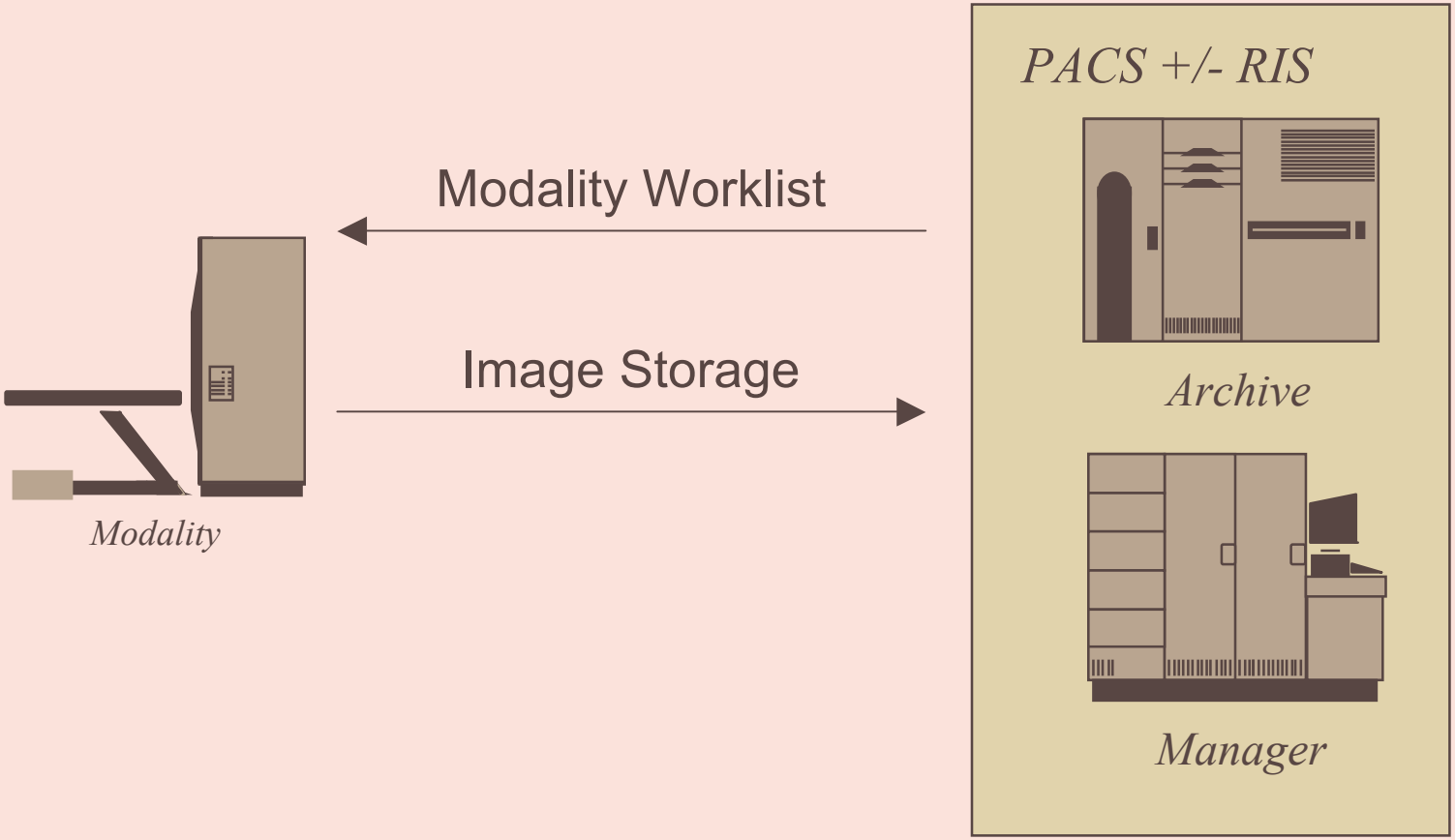
Information for Hanging

Modality: Mammography
Anatomic Region: Breast
Image Laterality: L
View Code: Medio-Lateral Oblique
Patient Orientation: A\FR

DICOM - More than images



DICOM - More than images



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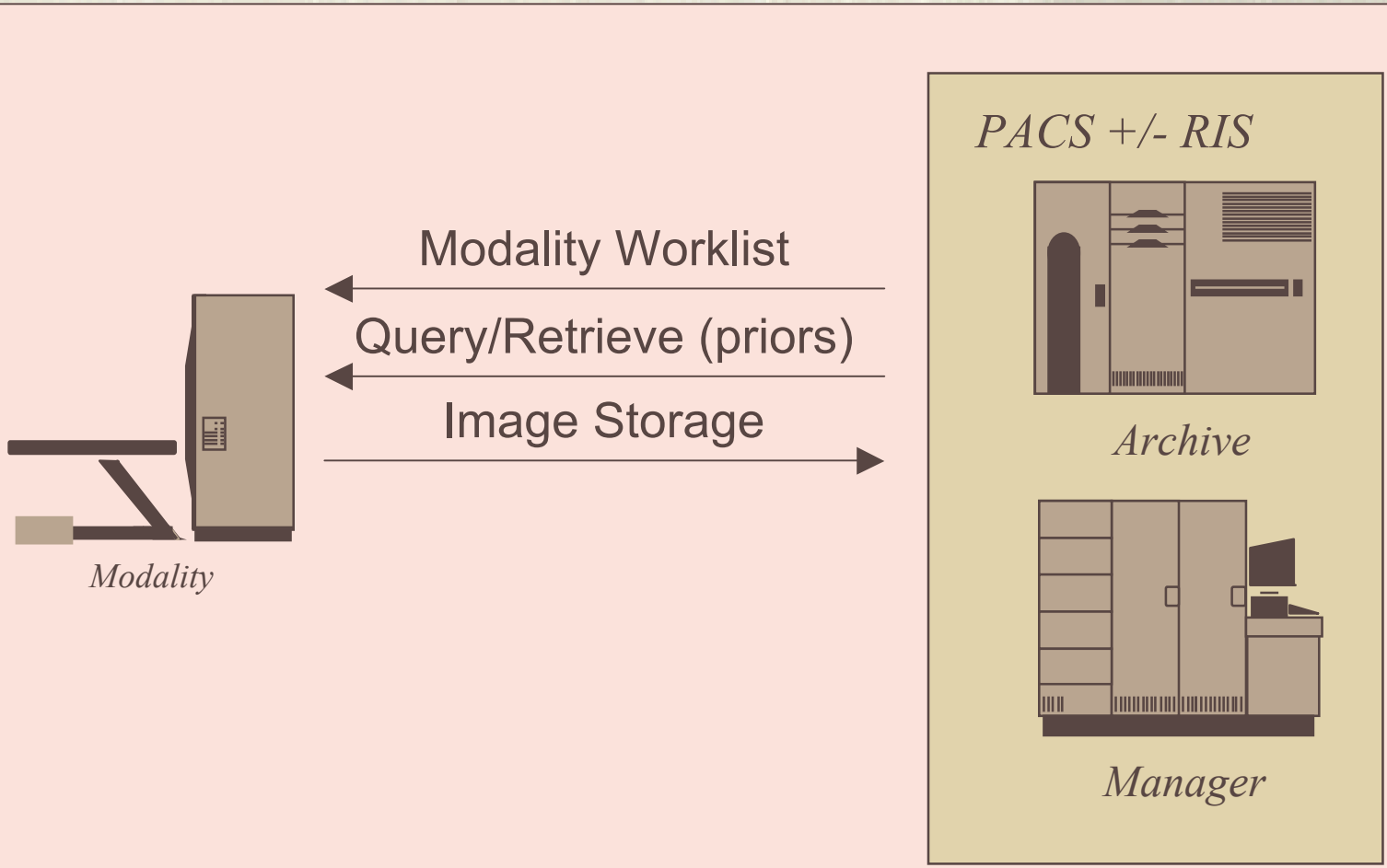

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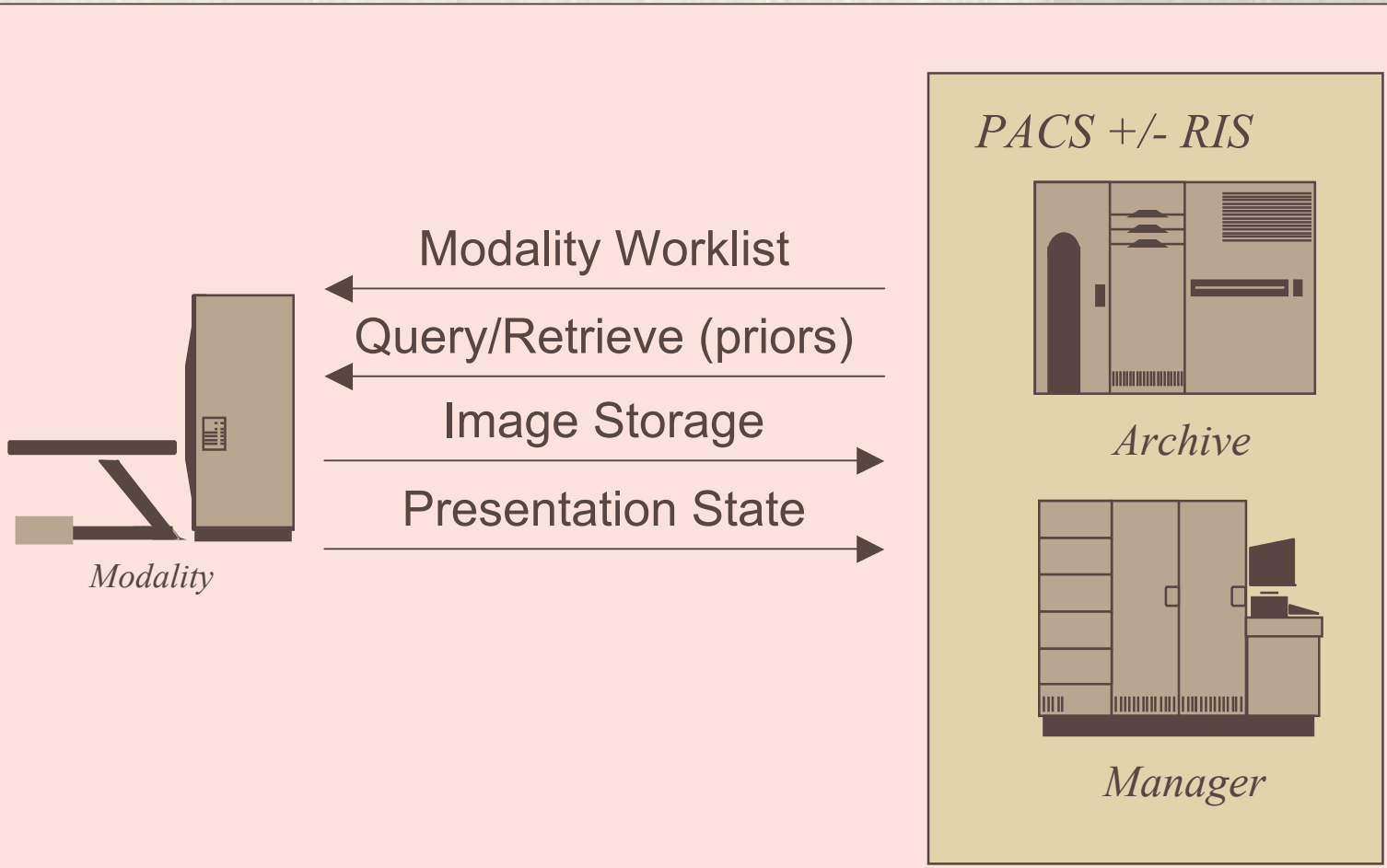

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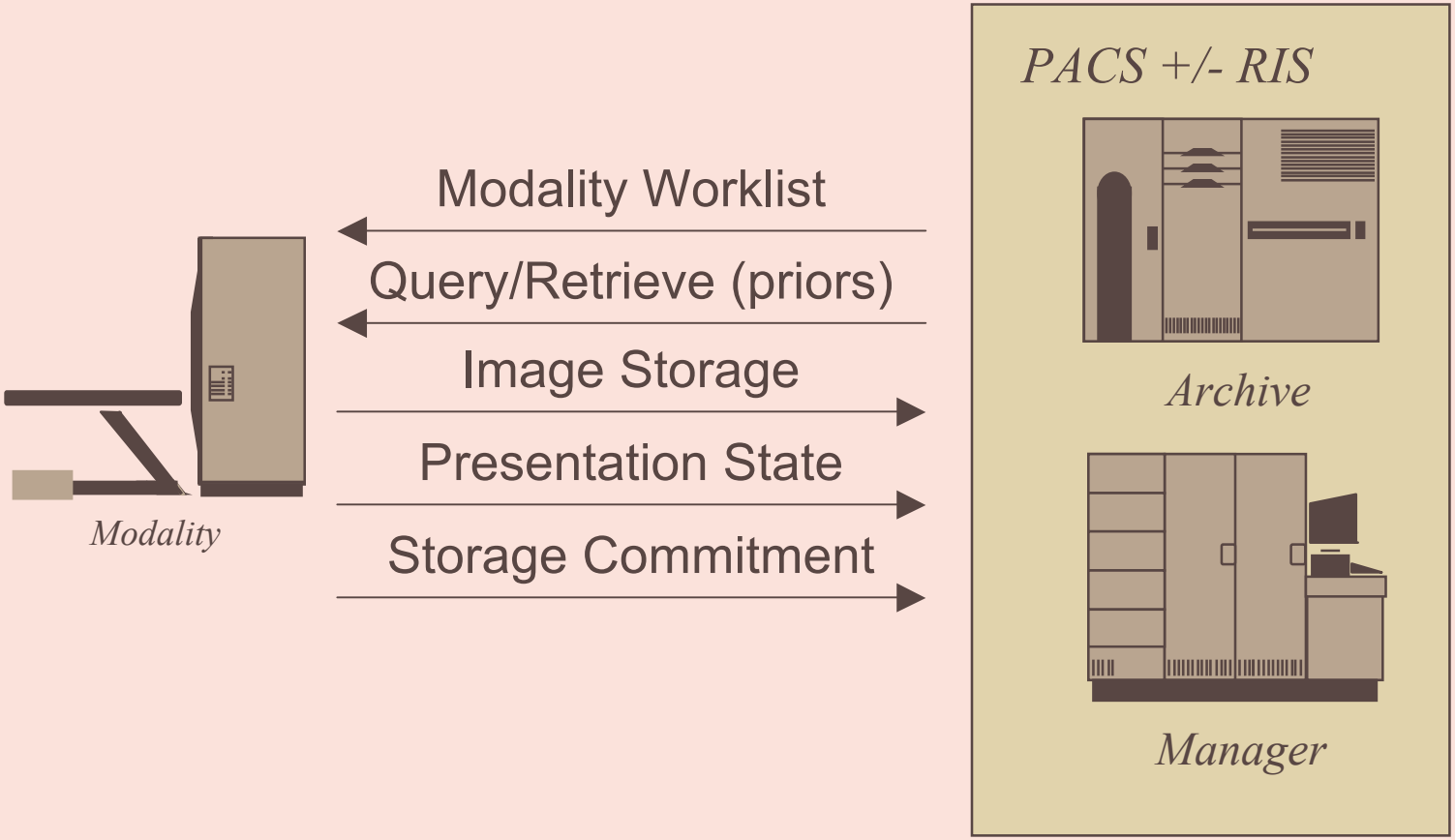
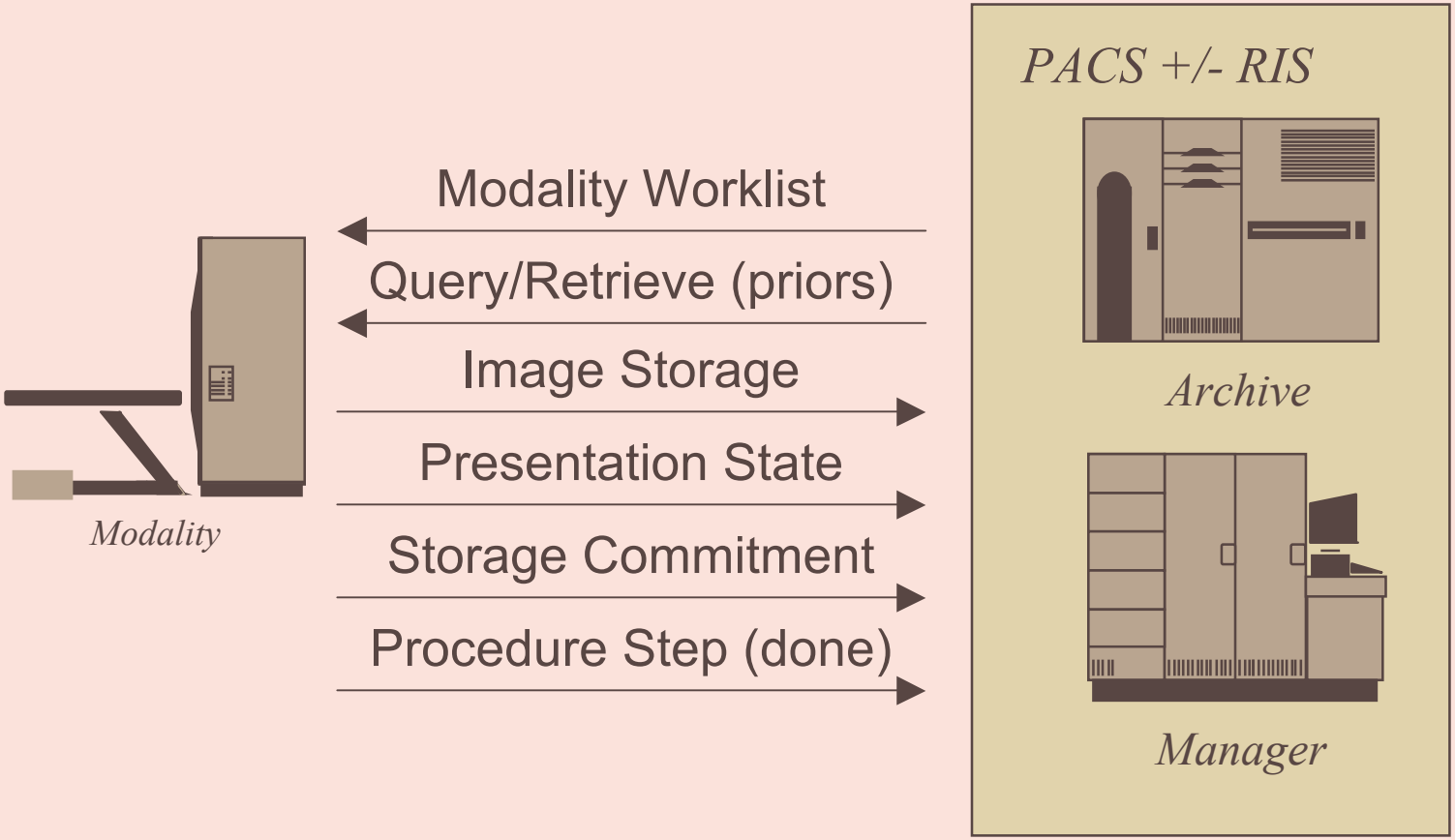


DICOM - More than images



DICOM - More than images

- Storage of images and associated information
  - Presentation states - window, annotation, flip/zoom
  - Measurements (SRs)
  - Procedure logs
- Workflow and reliability
  - Modality Worklist - scheduling and identification
  - Modality Performed Procedure Step - completion
  - Storage Commitment - reliable transfer

Acquisition and IHE

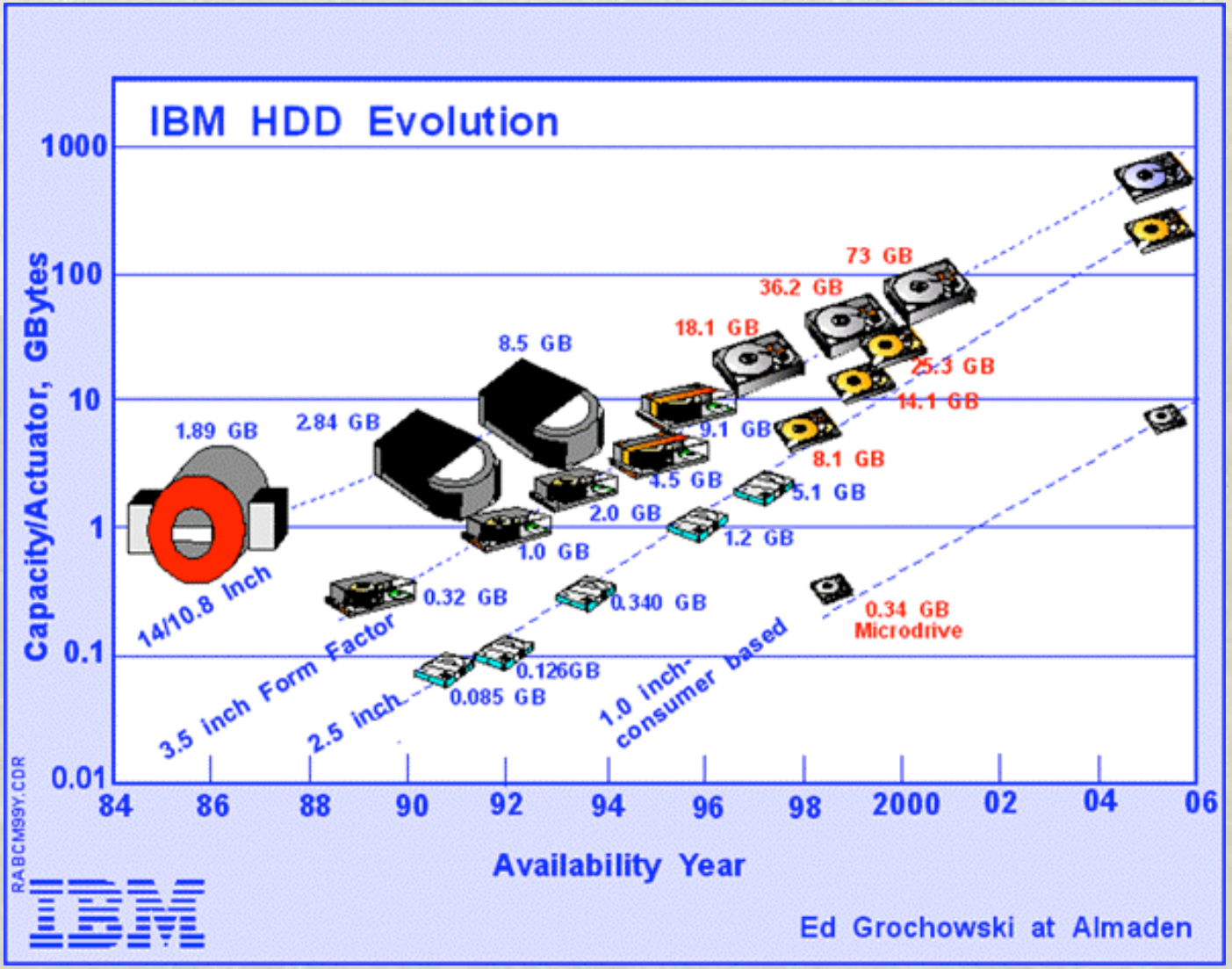
- Many required services
- Need grouping into profiles
- Integrating the Health Care Enterprise
  - RSNA
  - HIMSS
- Scheduled Workflow (SWF) profile
- Consistent Presentation of Images (CPI) profile
- Presentation of Grouped Procedures (PGP) profile
- All modality-related transactions are DICOM
- Other IHE actors and transactions also HL7 V2.3

Storage

- A primary underling technology issue
- Previously hard disk and archive media
  - Slow, bulky, limited capacity, expensive
- Now
  - Fast, compact, enormous capacity, cheap
- Technology advances
- Leverage consumer and business market
- As much storage in this laptop (100GB) as 50 early 2GB 12” optical disk platters !

Storage Capacity Expansion

- Early 12 and 14” optical platters
- 5.25” (130mm) magneto-optical disks
- High speed tape (DLT, AIT, LTO)
- Robot capacity and speed
- Consumer optical - CD-R, DVD-R
- All-spinning - RAID
- Network Attached Storage (NAS)
- Storage Area Networks (SANs)


IBM HDD Evolution
Capacity/Actuator, GBytes
1000
100
10
1
0.1
0.01
84
86
88
90
92
94
96
98
2000
02
04
06
Availability Year
1.89 GB
14/10.8 Inch
2.84 GB
8.5 GB
1.0 GB
0.32 GB
3.5 inch Form Factor
2.0 GB
4.5 GB
0.340 GB
2.5 inch
0.126GB
0.085 GB
18.1 GB
9.1 GB
1.2 GB
1.0 inch-
consumer based
36.2 GB
73 GB
25.3 GB
14.1 GB
8.1 GB
5.1 GB
0.34 GB
Microdrive
RABCM99Y.CDR
IBM
Ed Grochowski at Almaden

RAID

- Redundant Arrays of Inexpensive Disks
  - "Independent"
- UC Berkeley 1987
- Make multiple small cheap disks
- Look like single large/fast/reliable one
- Also usually "hot-swappable"
- Leverage availability of slower lower cost consumer disk with cheaper interfaces

Storage Infrastructure

- Direct attached storage
  - Host directly accesses logical blocks on media
  - Host implements filesystem
- Network attached storage (NAS)
  - File servers
  - Network storage appliances
  - Granularity of interface is the “file”
- Storage area networks (SANs)

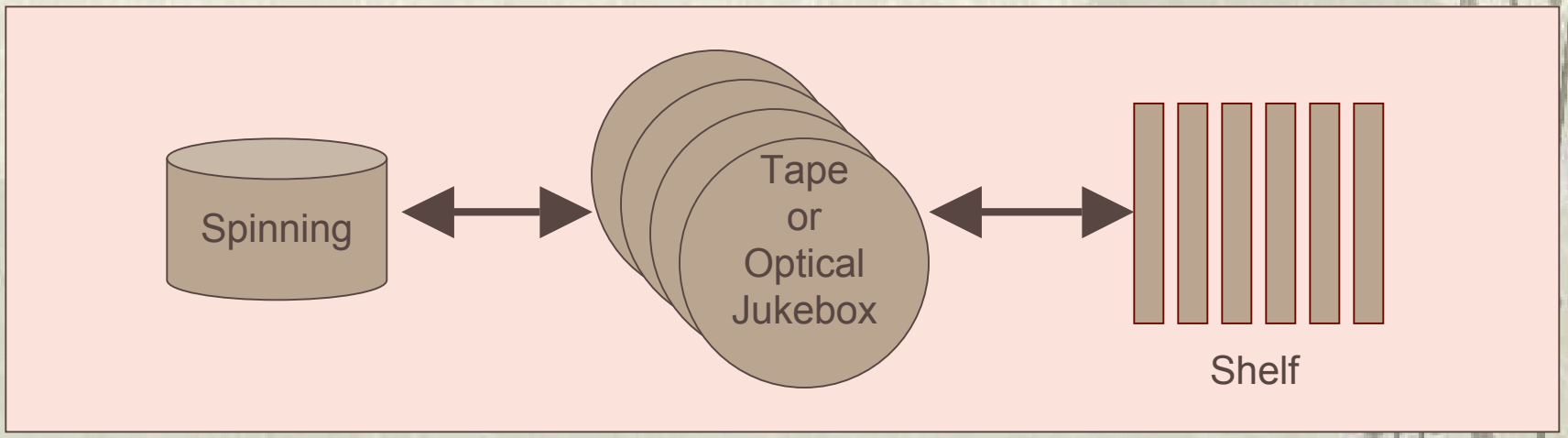
Storage Area Networks

- Term coined by Tandem for ServerNet product
- Treats storage devices as network nodes
  - High performance connections (FibreChannel)
  - High performance switches
- Allows for
  - Aggregation
  - Central or distributed location
  - Expansion of shared pool of storage
  - Shared access by multiple hosts
  - Backup and redundancy
  - Dynamic reconfiguration without being taken offline

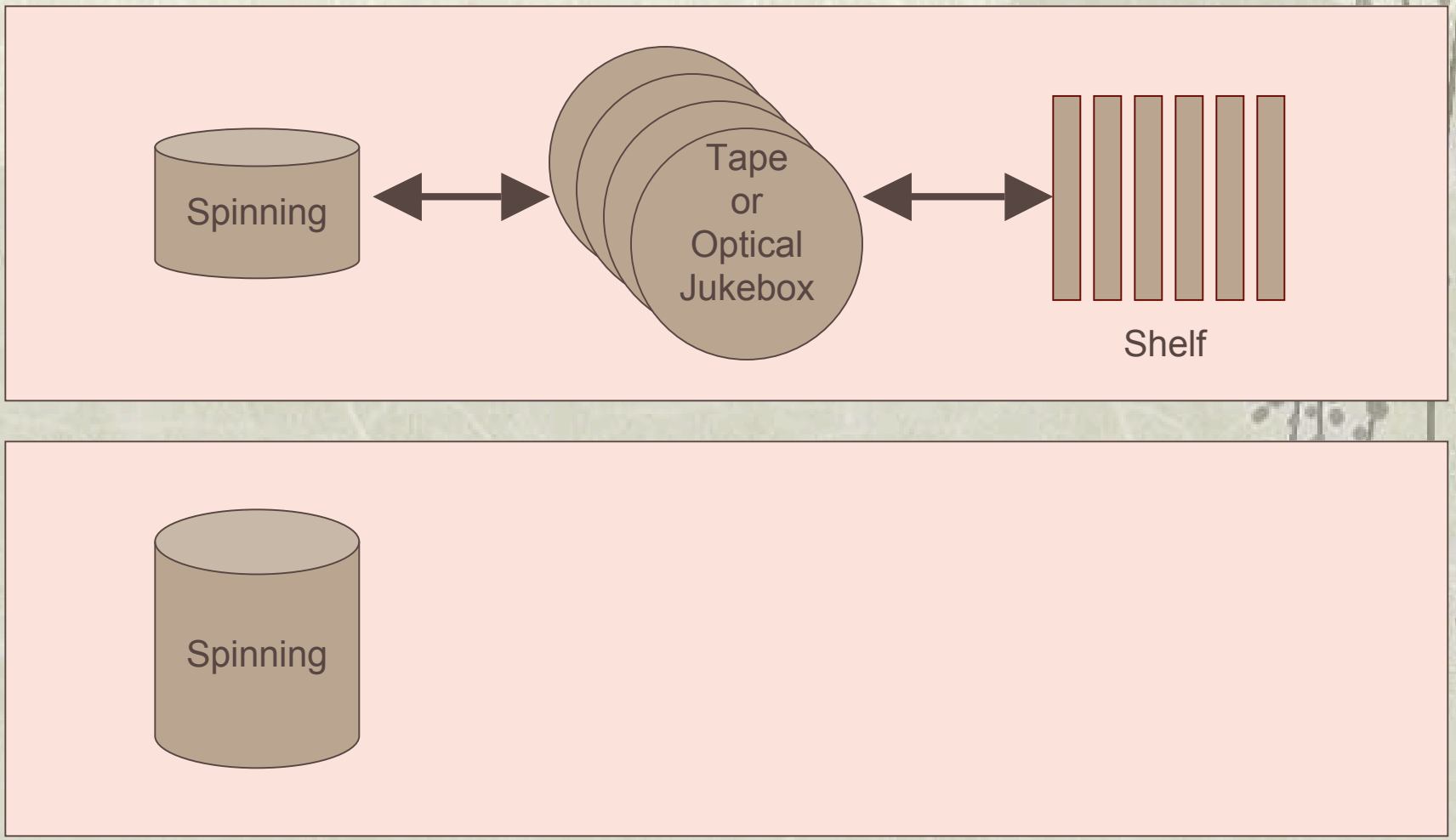
Early Storage Paradigm

- On-line capacity limited - days, weeks, months
- Hierarchical storage management
  - 1st tier fast
  - 2nd tier slow (e.g., optical or tape juke box)
  - 3rd tier offline (e.g., shelf management)
- Jukebox and shelf managed media served archival function
- Fetch on demand from 2nd/3rd tier slow
- Intelligent pre-fetching of priors
- Migration when less likely to be used
- Workstation storage capacity & network limited
  - Distributed (rather than on-demand central) architectures require intelligent routing & caching

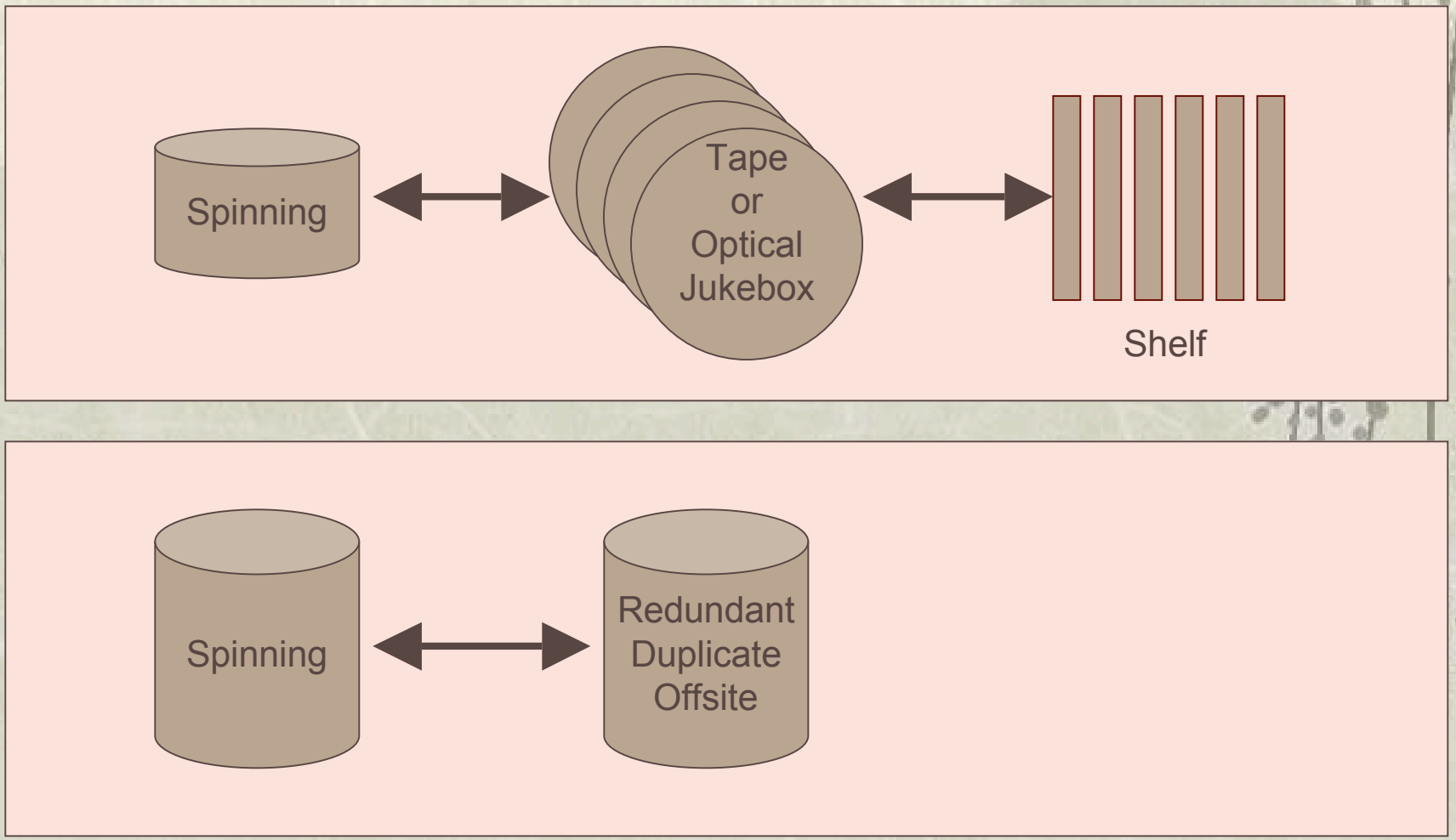
Storage Paradigms



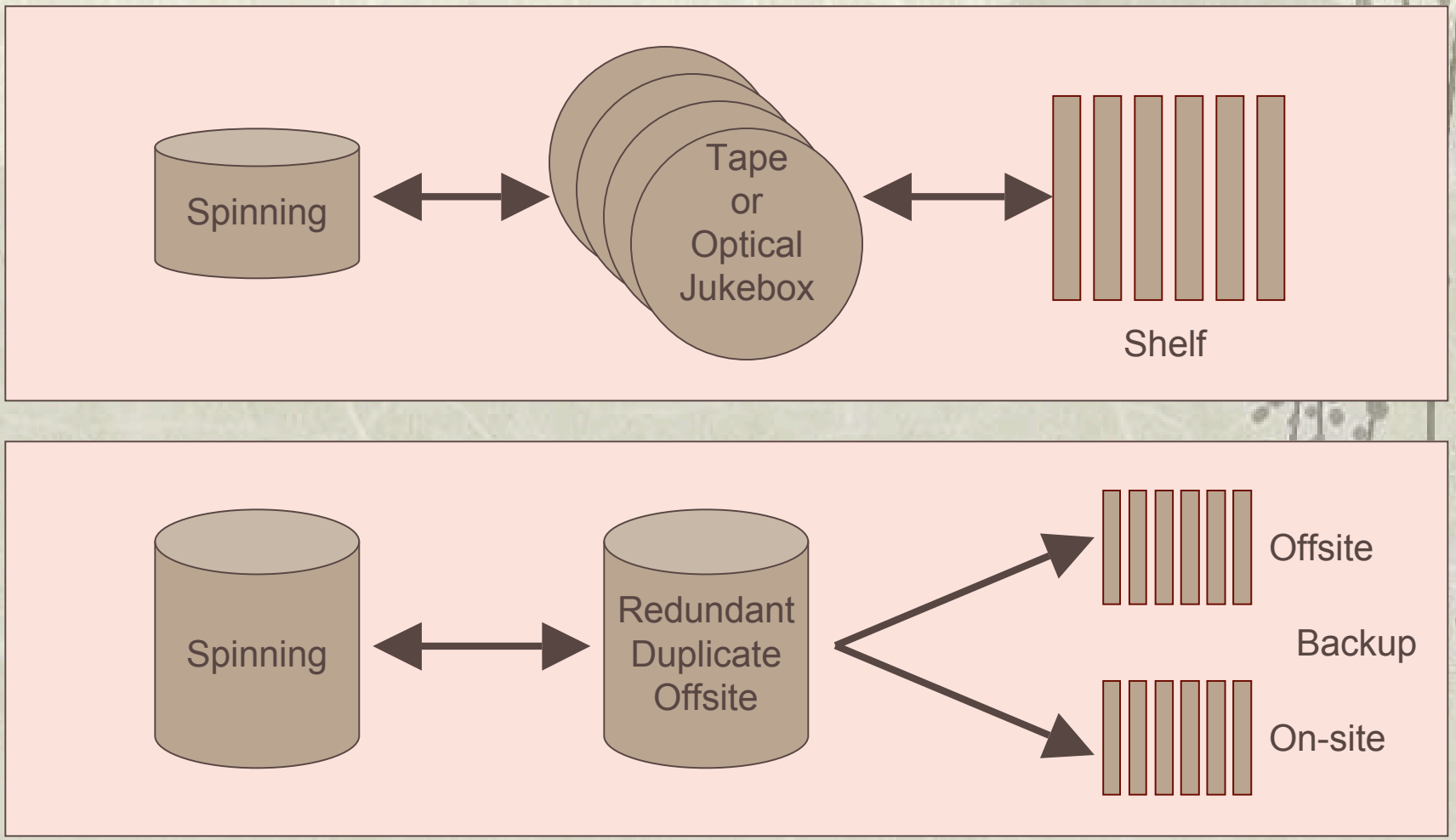
Storage Paradigms



Storage Paradigms



Storage Paradigms



HSM vs. All-Spinning +Backup

- Off-site backup options
- Trade-off
  - Cost of on-site maintenance
  - Cost of communications bandwidth
  - Relative availability of prior studies
- ASP business model
  - Capital vs. operational costs
  - Per-study fees

Legal storage issues

- Feasible to store everything online forever
- Not always acceptable
  - What to store
  - How long
  - When to purge it
- Complexity of purge strategy may not be worth the effort
- Longevity of archival/backup media
  - Degradation of media overtime
  - Ablative media
  - Influence of other industries - Sarbanes-Oxley
  - OD vs. CD-R/DVD-R vs. forms of tape

Disaster Recovery

- "Business Continuity"
- Off-site
  - Backup of image and data alone may be insufficient
  - Replicas of application servers
- Who ?
  - An institution's own sites
  - PACS vendor supplied
  - 3rd party data/application/colocation facility
- Procedures - SOPs
- Regular testing and monitoring
- How long does it take to
  - Restore several terabytes of images from tape ?
  - Reconstruct database ?
  - Failover to offsite server (performance live over communications link)
  - Transport offsite server back onsite

Reliability and Availability

- Early
  - No practical approaches
  - Cost of reducing single points of failure prohibitive
- Today
  - Reliable internal redundancy commonplace
  - Equipment satisfies conventional business requirements
  - Redundant power supplies, hot-swappable drives etc.
  - Off-the-shelf hardware and operating system support
    - Clustering
    - Load-balancing
    - Fail-over
    - Replication of file systems and applications

Legacy Migration

- No PACS lasts forever
- Vendors come and go
- Vendors change their architecture
- Plan for end of life before purchase
- Migration issues
  - Images
  - Database (with patient reconciliation)
- Standard formats and compression schemes inside

Remote Maintenance & Support

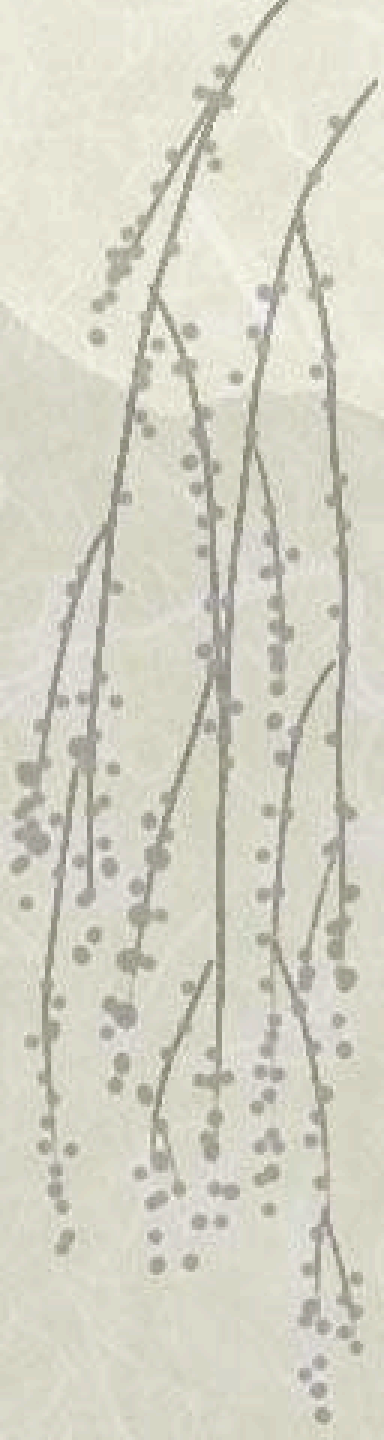
- Early
  - On-site full-time programmers and/or vendor supplied engineer(s)
  - “Replace file-room clerks with PhDs - same # of FTE’s”
- Today
  - Remote logging, diagnostics, repairs and upgrades, just like modalities
  - Complicated by HIPAA Privacy Rule, but not insurmountable
  - Local IT staff and biomedical engineers
    - Basic hardware service
  - Remote vendor
    - Service software and configuration
    - Triage service calls

Involvement of Conventional IT

- Previously
  - radiology centric
  - turn-key
  - single vendor
  - standalone
- Increasing
  - Re-use of infrastructure (shared fast networks, shared fast enterprise storage e.g. SANs)
  - Enterprise policies, procedures & infrastructure for privacy, security and support
  - EMR integration, not just HIS/RIS interface

Distribution

- Locally and remotely
- Evolution of local network technology
  - Ethernet 10Mb/s, 100 Mb/s, 1Gb/s
- Dedicated lines to offsite storage
- Evolution of remote network access
  - Public Internet + VPN
  - Dialup vs. DSL/Cable modem
- Protocols
  - DICOM over TCP/IP
  - HTTP for web browser
- Compression



Network Topology

- Early
  - Separated bulk data (images) from other traffic (command and control, non-PACS traffic)
- Today
  - Ordinary network tools (routers)
  - Logical separation of traffic
  - Allocation of bandwidth and quality of service

Teleradiology

- After hours support (night coverage)
  - If no radiologist on-site
  - As specialist support for junior staff
  - Especially ER, ICU
- Out-sourcing (on-shore or off-shore)
  - Expertise
  - Cost
  - Preliminary reads
  - Time-shifting - especially military

Early Teleradiology

- Frame grabbers and film digitization
- Significant lossy compression
- Dialup connections
- Store and forward paradigm
- Proprietary protocols
- Dedicated software at physician's home
- Limited functionality
- Preliminary reads only

PACS + Teleradiology

- Natural extension of existing PACS
- Often same protocols and services
- Lossless, progressive or lossy compression
- On-demand retrieval possible
- Often same workstation application
- Full datasets and full functionality (e.g. 3D)
- Low cost, self-calibrating, space-saving, cool, quiet flat panel displays
- Extension of organization's security infrastructure

Referring Physician Distribution

- Intranet/Internet access to lower costs
  - Web or thin or thick client
  - Requires security infra-structure
- Sophisticated referring physicians
  - Full functionality workstation
  - High quality calibrated display
- Offsite without network access
  - CDs
  - Print to paper or film
- Also referral to other institutions
  - CDs to import into next PACS

Mini-PACS to Enterprise PACS

- Early efforts used Mini-PACS
  - ICU, ER for projection radiography (with CR)
  - Clusters of CT/MR scanners & 3D workstations sharing printers
  - Ultrasound, Nuclear Medicine, Cardiac angiography only
- Hospital-wide PACS
  - All CR, CT and MR in radiology, selective clinics, wards
- Enterprise PACS
  - All modalities, including US, NM and cardiology
  - Other sources like gastroenterology, ophthalmology, pathology
  - Every location of patient contact
  - Every doctor's office
  - Operating rooms
  - Remote access (home, other offices, other sites)

Enterprise PACS

"All images everywhere"

Subset of seamless EMR integration

"All information everywhere"

Regional or National PACS

- Pre-requisites
  - Common requirements (equipment & standards)
  - Shared patient identification
  - Shared images
  - Shared non-image information
- Currently
  - Several European projects
  - US VA/DOD requirements
- Really desirable or feasible on a large scale ?

Grid Computing

- Distributing computational resources over a network
- Need generates availability of standards, infrastructure and middleware
- Allows for possibility of
  - Transparently distributed computationally expensive applications
  - Transparently distributed storage

Security

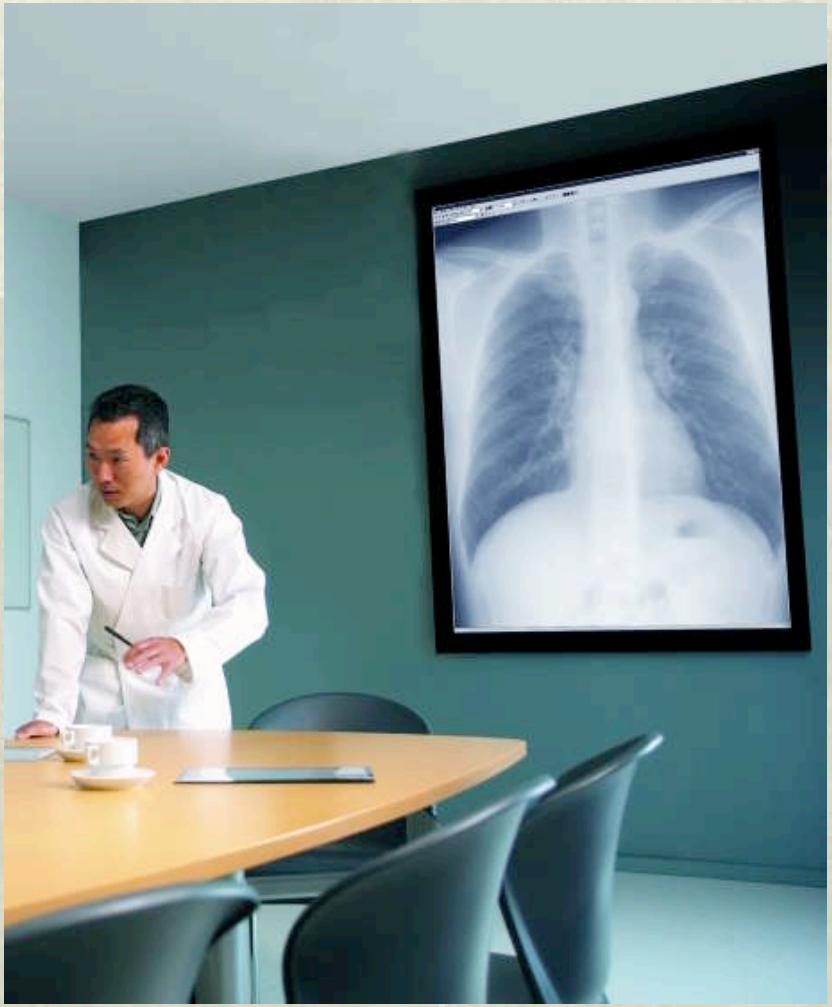
- Technology
  - Ready availability of cryptographic software
  - Sufficient low cost computing power to implement cryptography practically
  - Widely implemented standards to support internet electronic commerce (SSL transport, X509 certificates)
  - Virtual private networks (VPNs) to provide access to and link local area networks (LANs)
- Requirements
  - Availability of bandwidth of public internet
  - Acknowledgement of patient's privacy rights (Japan MHW, European Directive, HIPAA Privacy Rule)

Security Future

- Broader access with granularity of control
- Patient's own access
- National provider access
- Portability of access as patient moves between providers
- Health care cards too small for all images
- National or international infrastructure with delegated access rights to selected information
- No security system is perfect - such a widely accessible infrastructure too vulnerable in the long term ?
- May remain with patient carrying media to replace films
- Security on media ?

Teaching & Consultation

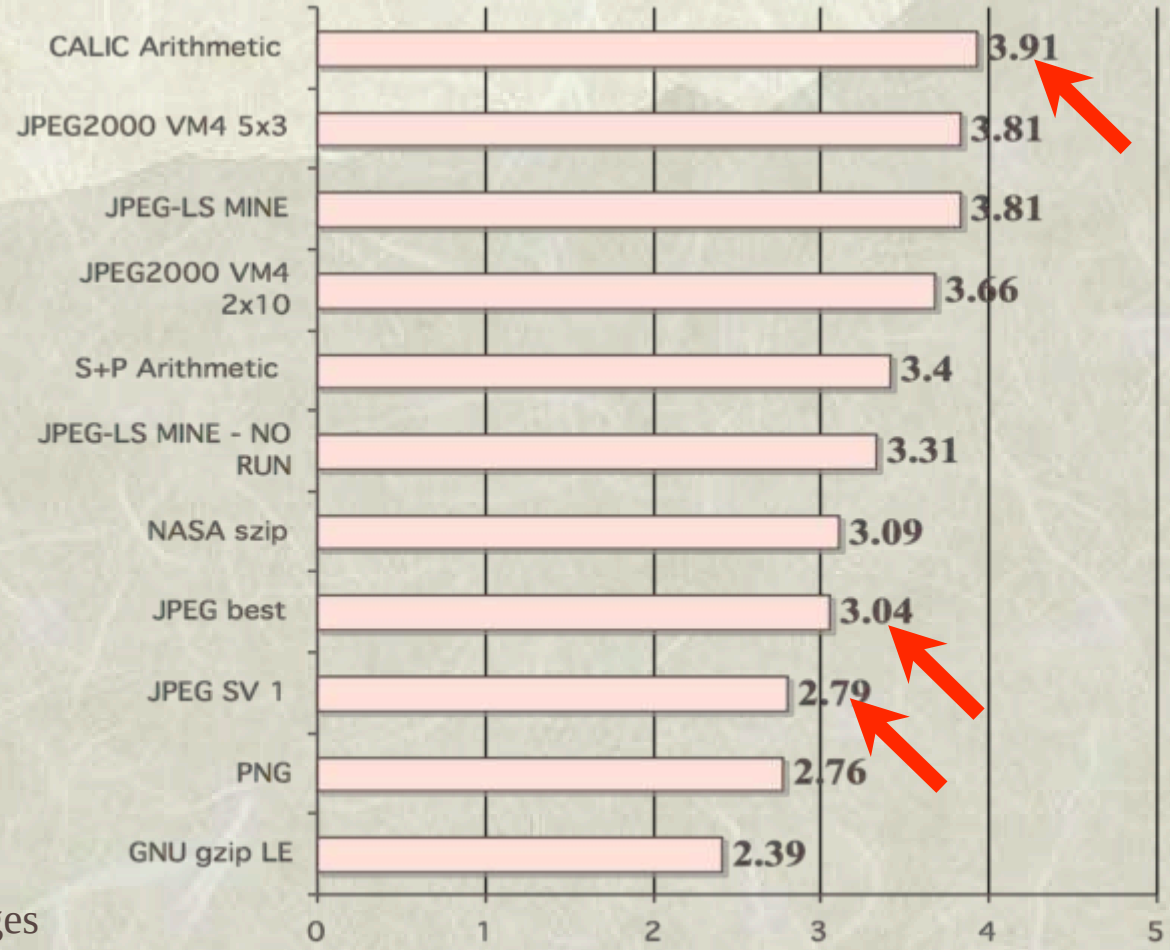
- Teaching files
  - Access and authoring
- Clinical conferences
  - Challenge of authoring/organizing in advance
  - Challenge of presentation
    - Projectors
    - Large flat-panel displays
  - “Workstation” software designed for conferences



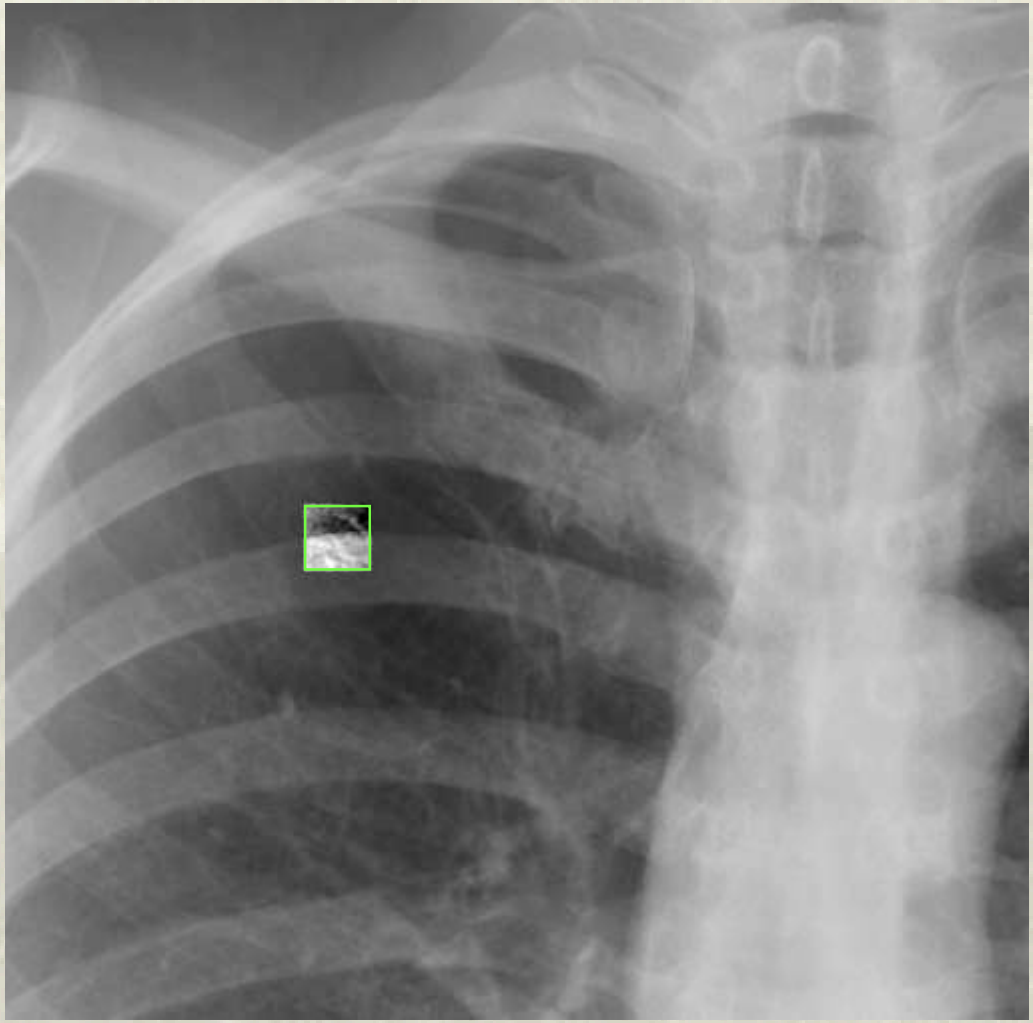
Compression

- For communication & archive
- Greater standardization
- Lossless gains modest
- Lossy gains modest
- Progressive transfer significantly improved
- JPEG 2000 wavelets popular, in DICOM
- Lossy compression for primary reading still unproven
- Lossy compression for long-term archiving has medico-legal implications & impact on CAD

Lossless Compression

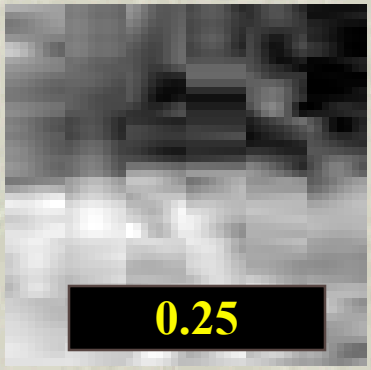


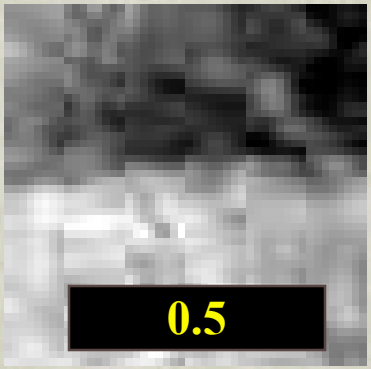
3,679 grayscale
single frame images

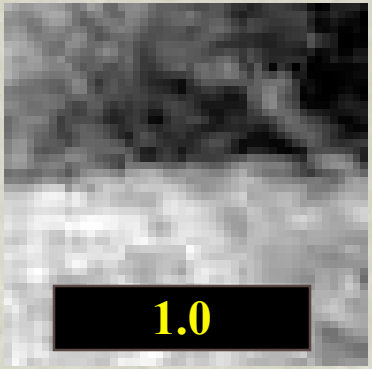


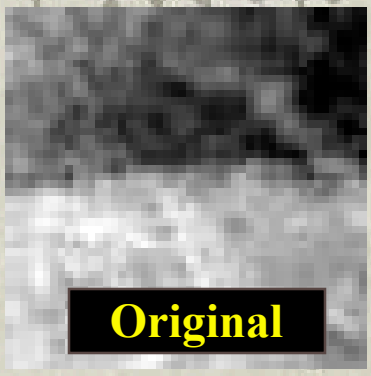
JPEG DCT

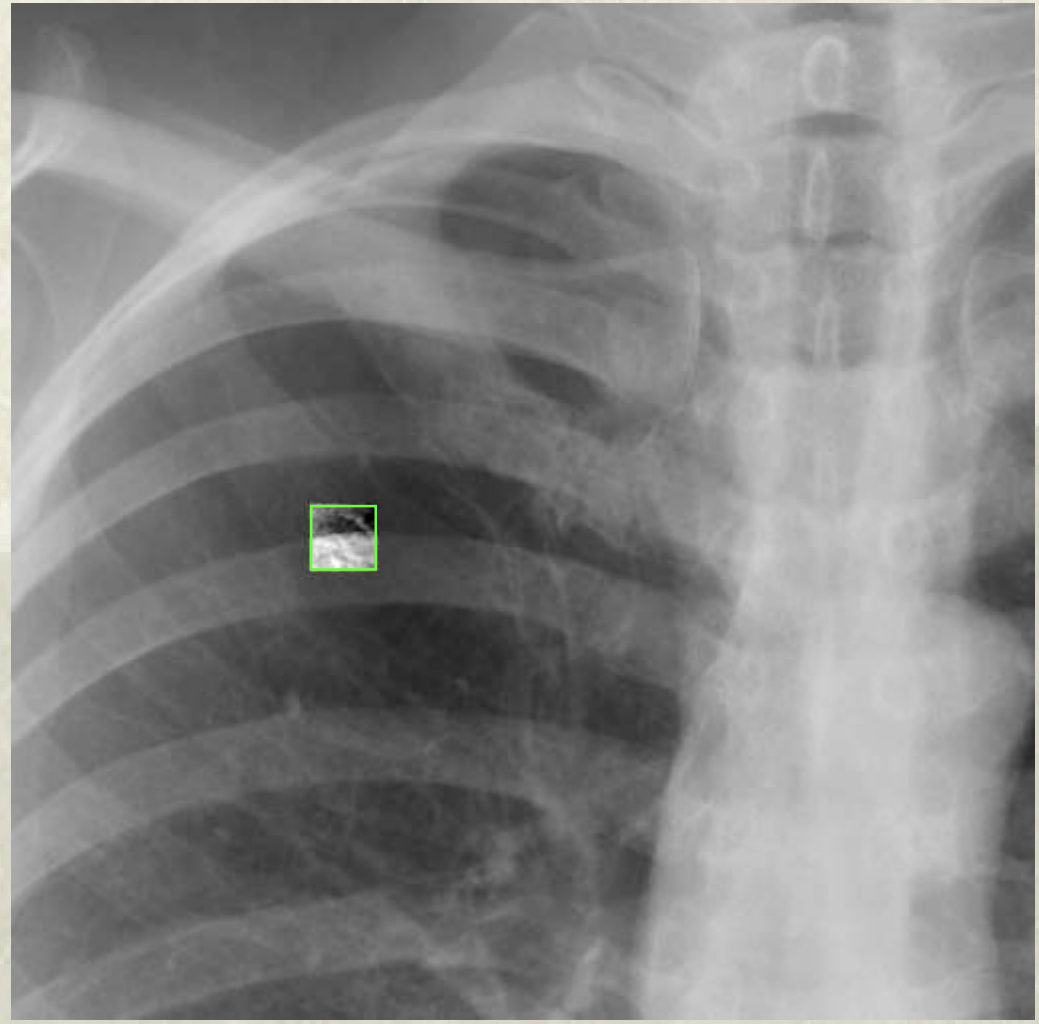
(Foos, Maui, 1999)





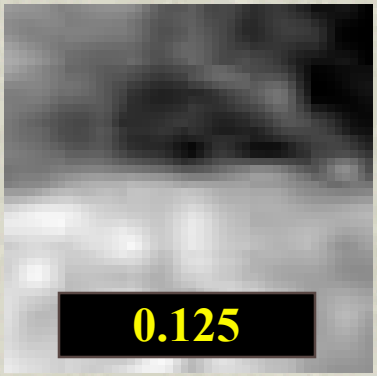


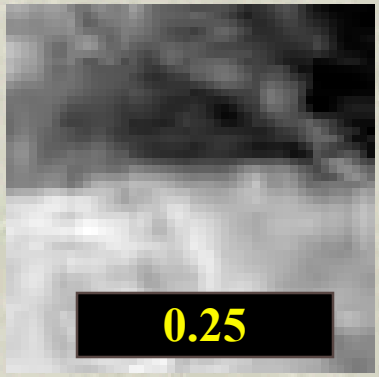


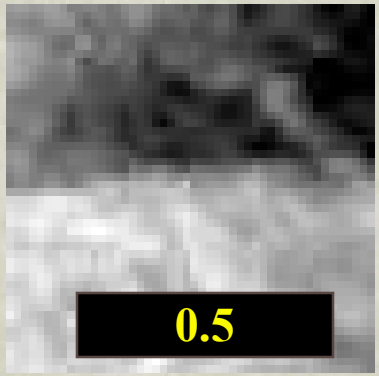


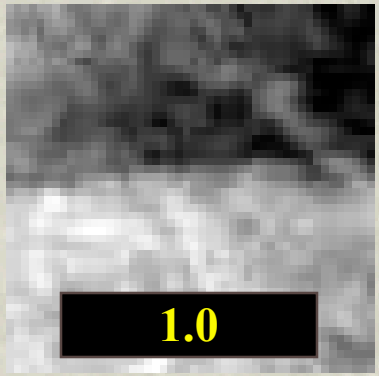
Wavelet

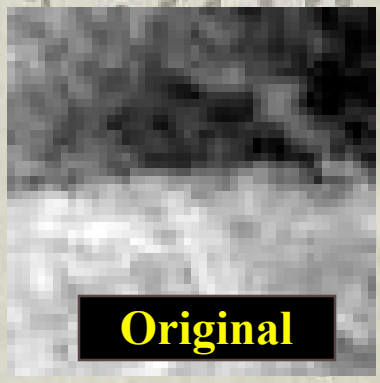
(Foos, Maui, 1999)











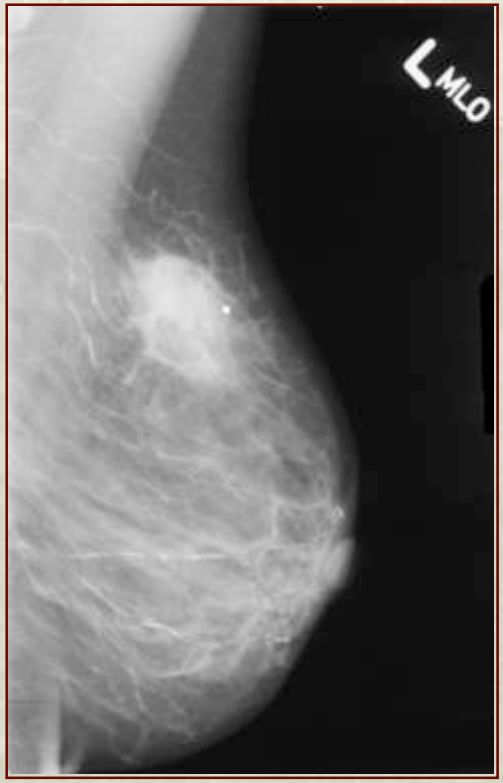
Workstations & Displays

- Original PACS articles optimistically envisaged 1k by 1k monitors
- Goal became film emulation
- Attain 1:1 pixel display - same size as CR
- 5 “megapixel” (MP) 2.5k by 2k portrait CRTs
- High brightness
- Evolution towards flat panels (LCDs)
- Good evidence that 3 MP LCDs are adequate
- Goal is filmless primary reading of all modalities
- Even mammography (5MP LCD approved)

Workstations & Displays

- LCD vs. CRT
- How many monitors ?
- How many pixels, bits ?
- Calibration - DICOM Display Function
- Grayscale vs. color (and NM, advanced processing)
- Ergonomics

Problems of Inconsistency

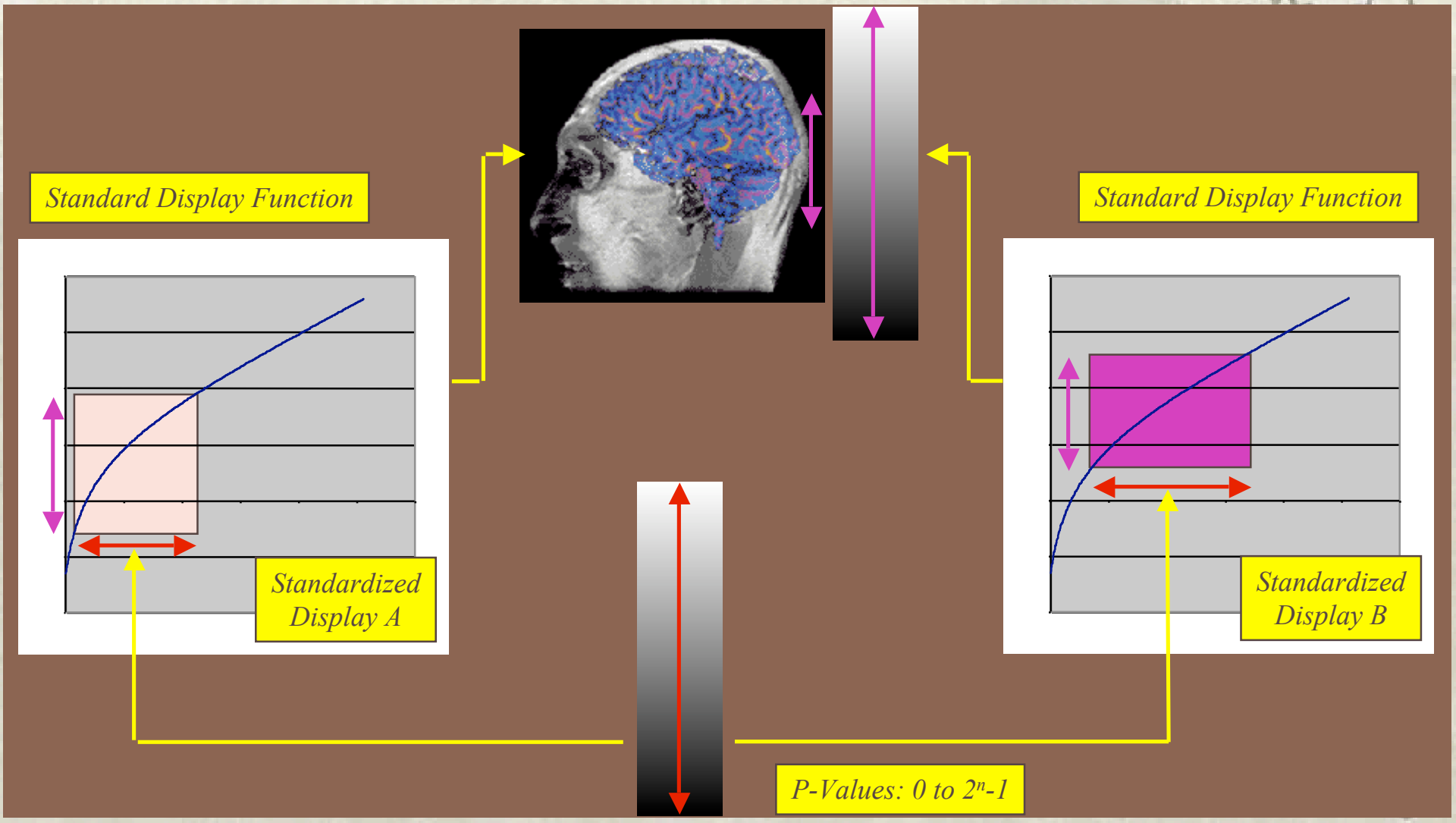


mass visible

mass invisible

- Window chosen on one display device
- Rendered on another with different display
- Mass expected to be seen is no longer seen

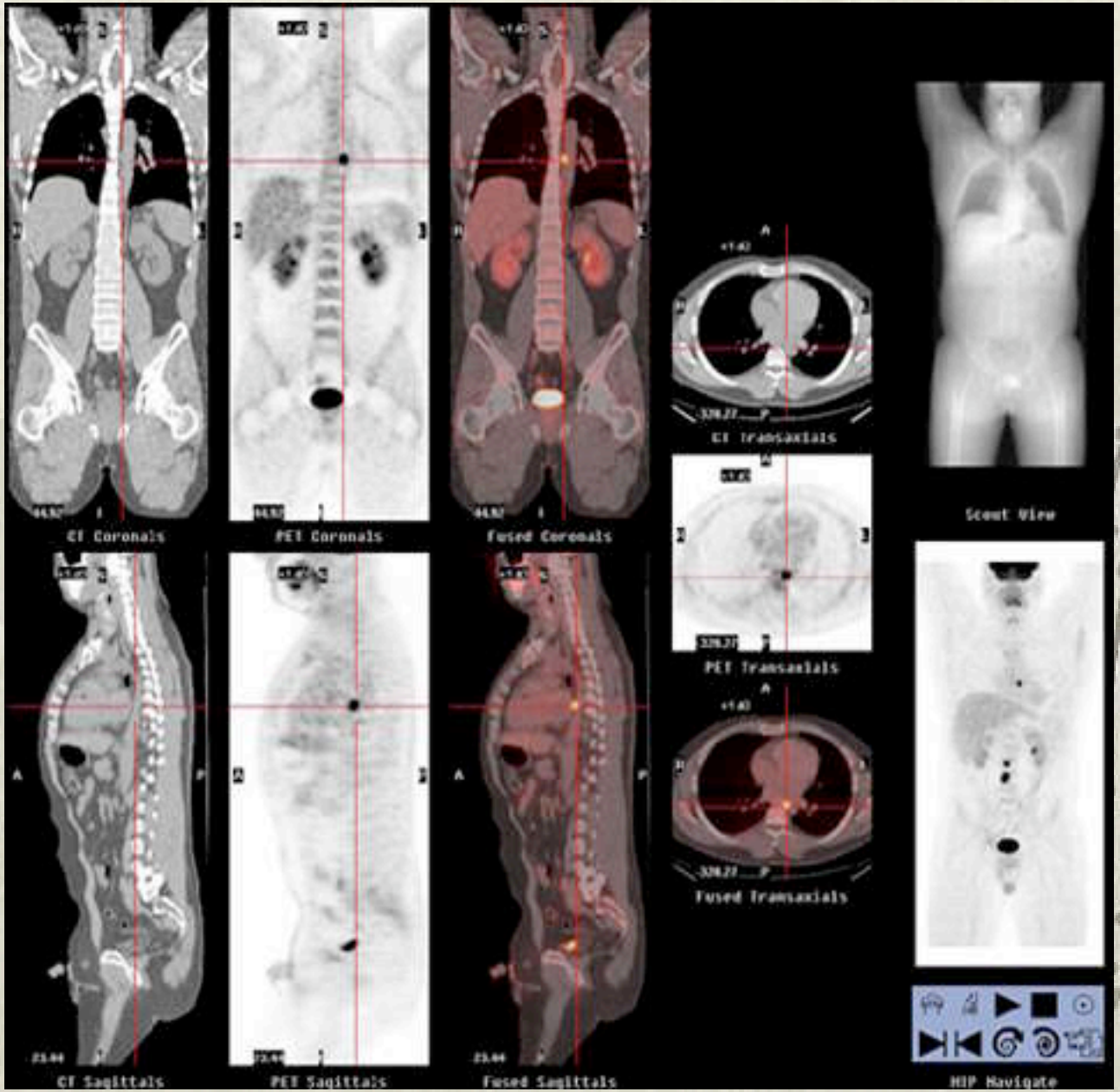
Device Independent Contrast



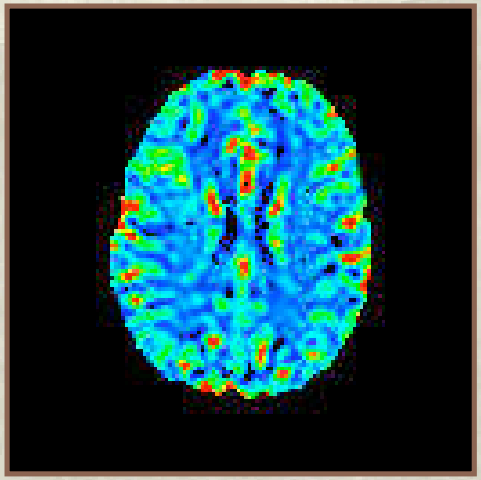

L
MLO
W:750 L:2419
L
MLO
BARCO
BARCO

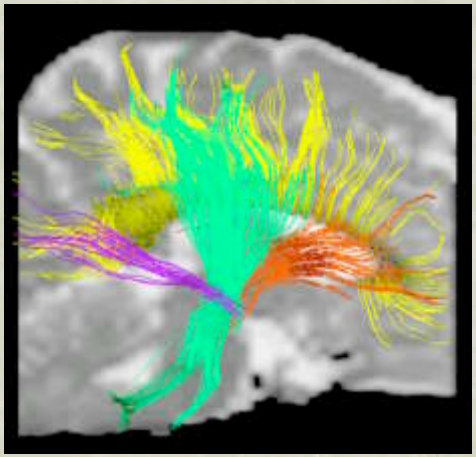
Workstation Functionality

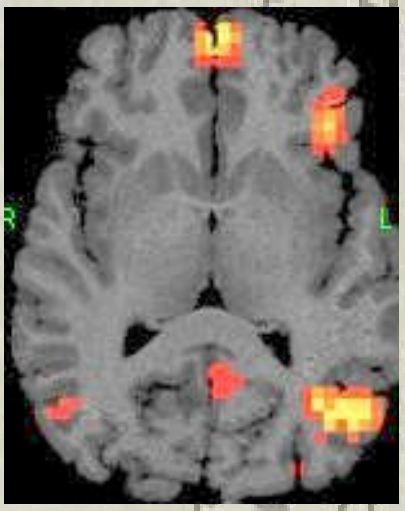
- Tiled vs. stack mode
- Hanging/default display protocols
- 3D/MPR
- Larger data volume
- Modality-specific processing - NM, PET/CT fusion
- Multi-modality - including color, cine
- Quantitative analysis - record measurements, application specific (e.g. quantitative LVA)


CT Coronals
PET Coronals
Fused Coronals
CT Transaxials
Scout View
PET Transaxials
Fused Transaxials
CT Sagittals
PET Sagittals
Fused Sagittals
HIP Navigate

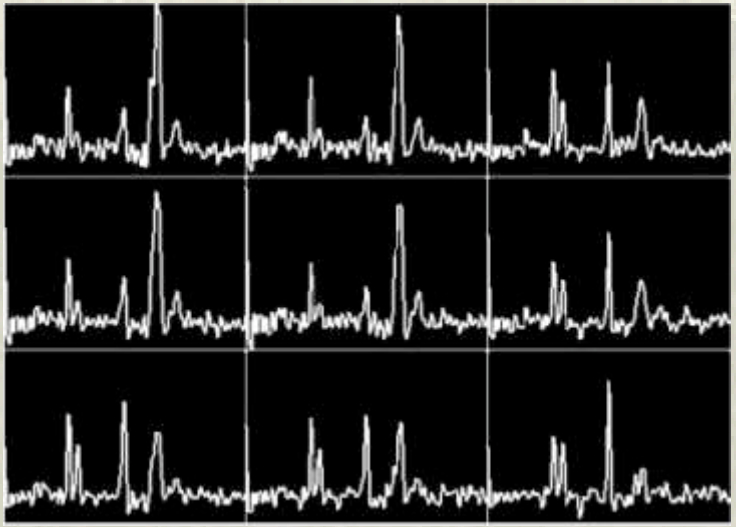
Color Information



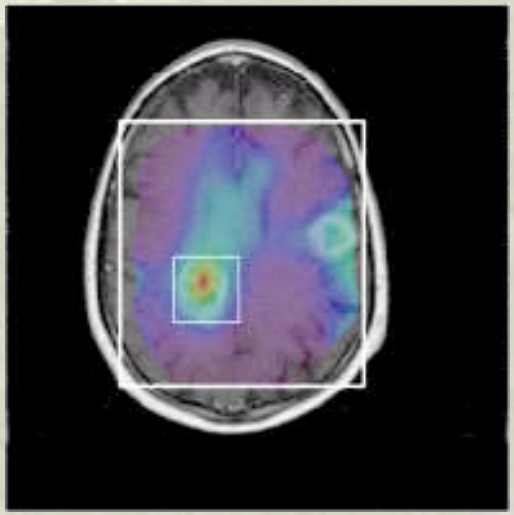




Spectroscopy



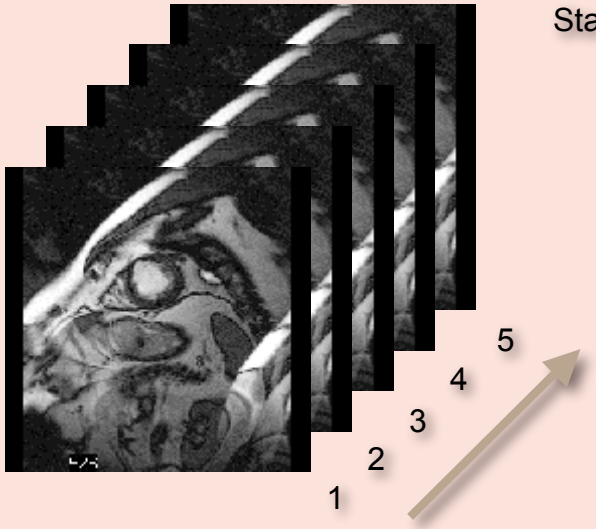
Display of
Spectroscopy Data



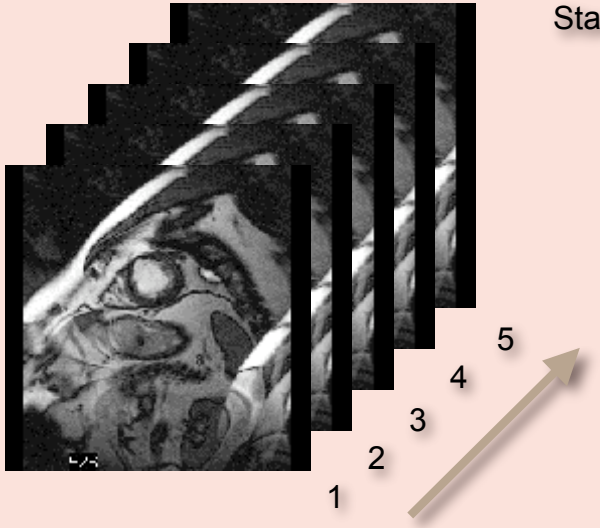
Metabolite Maps

Trigger Delay Time

48 ms



0 ms



New Applications

- PET/CT fusion
- Automated longitudinal comparison with registration
- Rigid and deformable registration
- Molecular imaging - agents targeted to monitoring therapy
- Manual, semi-automated and automated quantitative analysis
- Computer assisted detection and diagnosis (mammography and chest) available on workstation
- Mammography soft-copy reading and review

Exploding Dataset Size

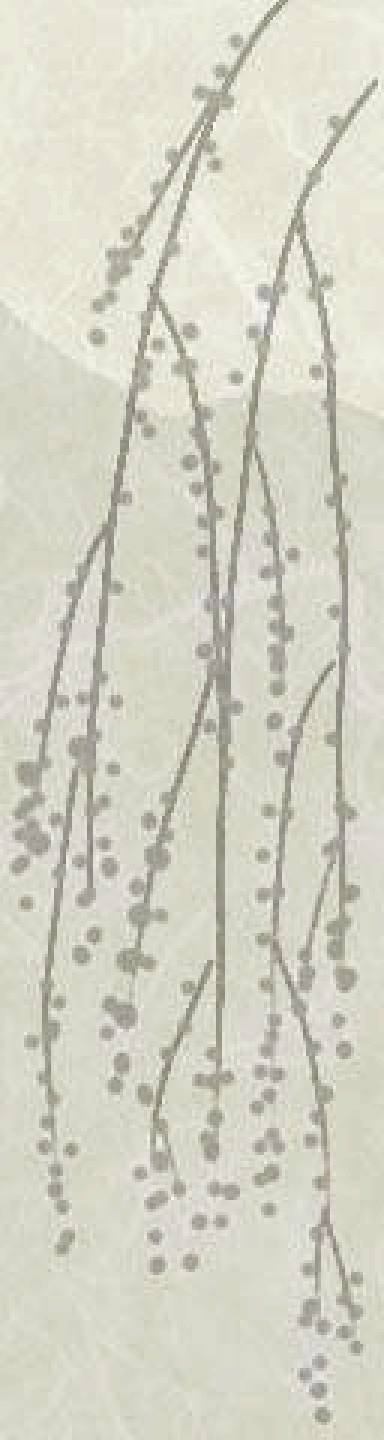
- Multidetector CT: 4,8,16,32,64
- Isotropic voxels
  - Same dimension between slices as within
  - Allows reconstruction in non-axial planes with full fidelity
  - Typical volume CT
    - 64 slices and 4cm per rotation (0.625 mm per slice) in .375 seconds (isotropic 32cm field of view)
    - Chest/abdo/pelvis 24 cm of coverage - 384 0.625 mm slices (192MB uncompressed)
    - Compare with 10mm slices - 24 slices (12MB) - 16 fold increase
- Motion elimination and angiography
  - Dynamic cardiac studies - several gigabytes !
- Even MR is a problem
  - Larger matrix sizes, whole body scans, functional acquisitions

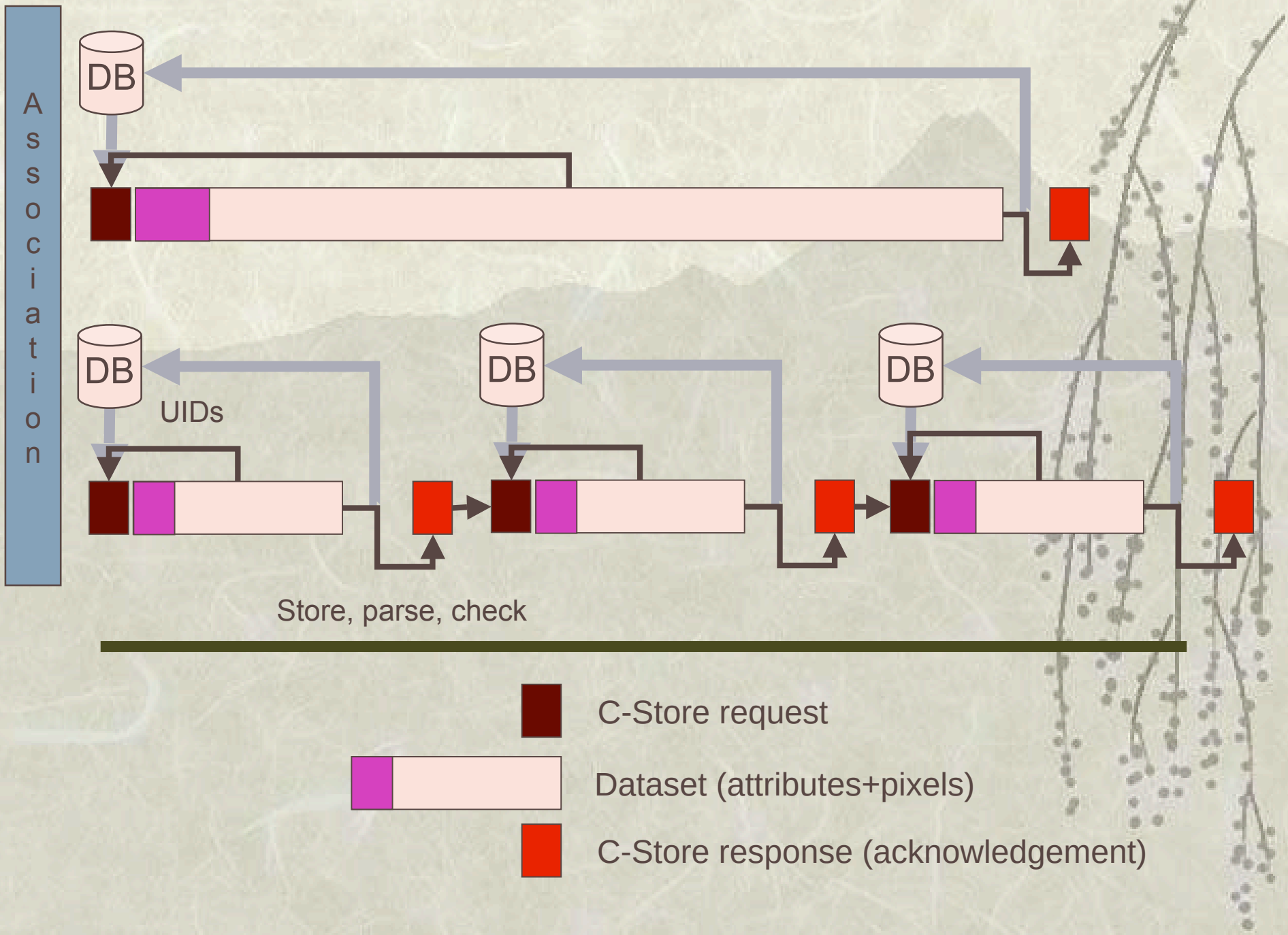
Exploding Dataset Size

- Challenge for technology
  - Storage
  - Transmission
  - Memory - 64 bit architectures ?
  - Rendering - local or server based ?
- Reading paradigm
  - Only practical with stack mode
  - Greater need for MPR & 3D
  - Greater need for hanging protocols tailored to exam type and indication

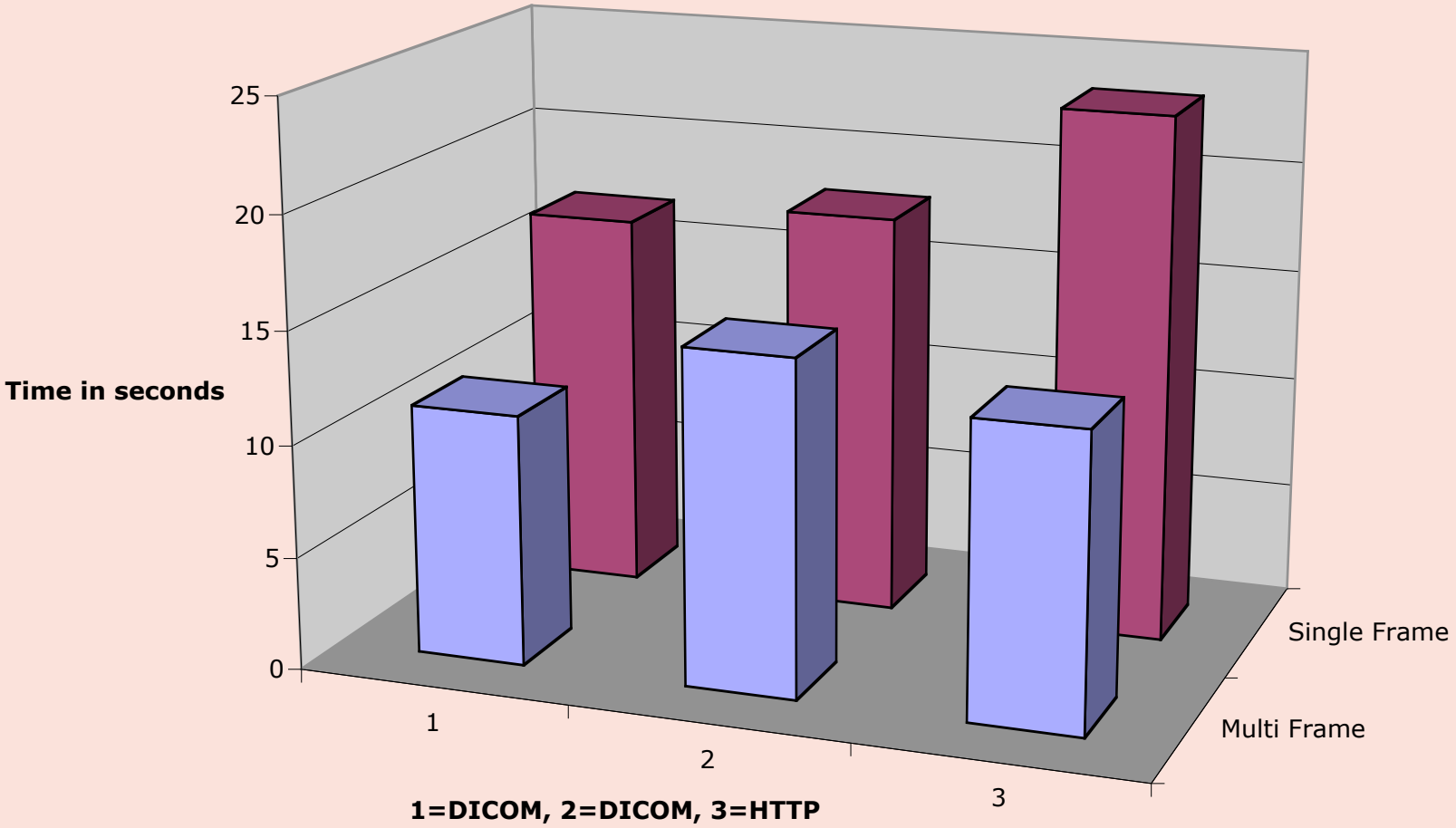
Exploding Dataset Size

- Meeting the challenge
- Standards - DICOM
  - New CT & MR objects
    - Multiframe encoding
    - New dimension organization for easier navigation
  - Spatial registration to support fusion
  - Hanging protocols
  - Color presentation state and blending
- SCAR - TRIP
  - Transforming the Radiology Interpretation Process
- Technology
  - 64-bit hardware, operating system and applications essential




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

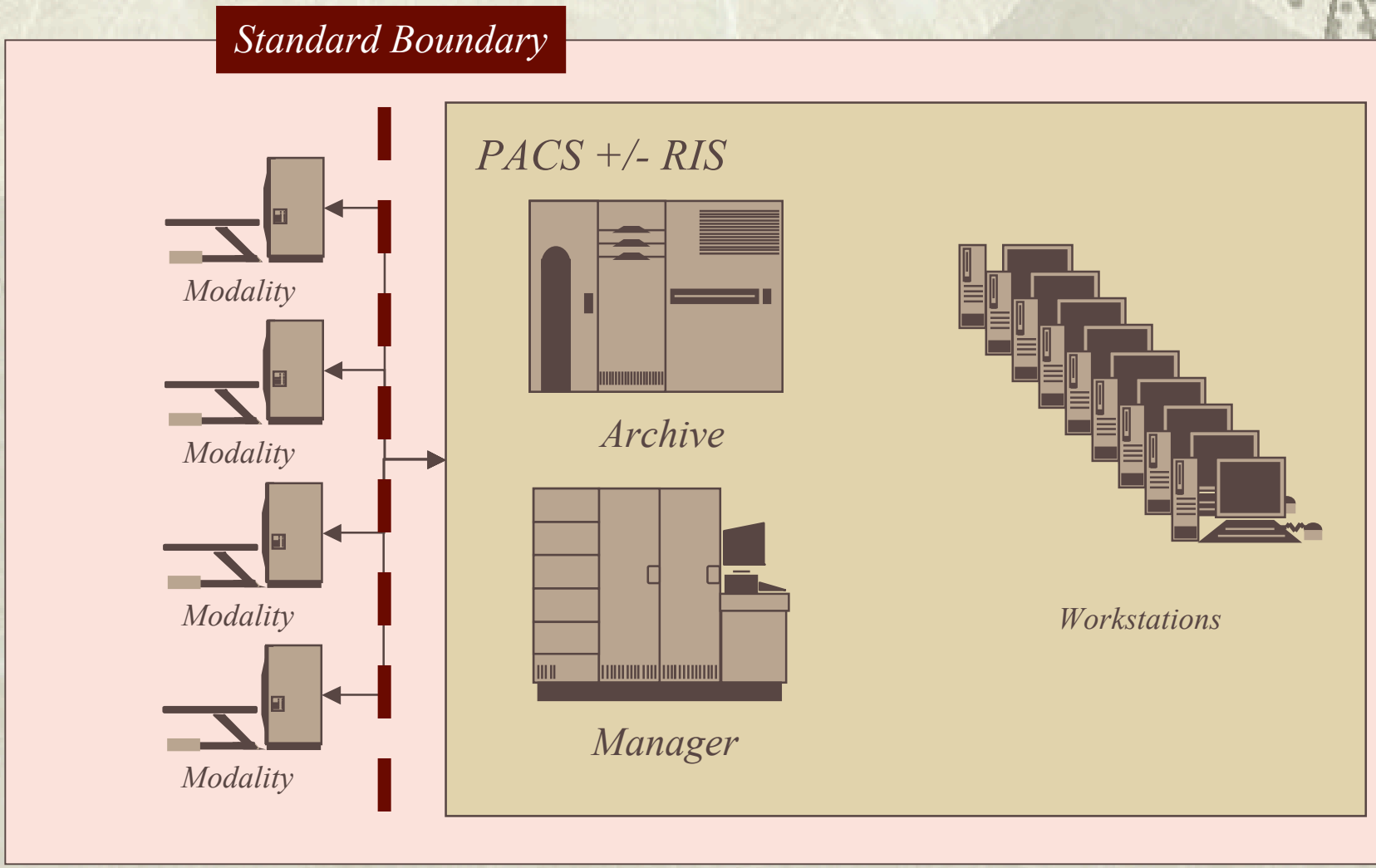
CTA - 548x512x512 (275MB) File read/transfer/save (GB Ethernet)

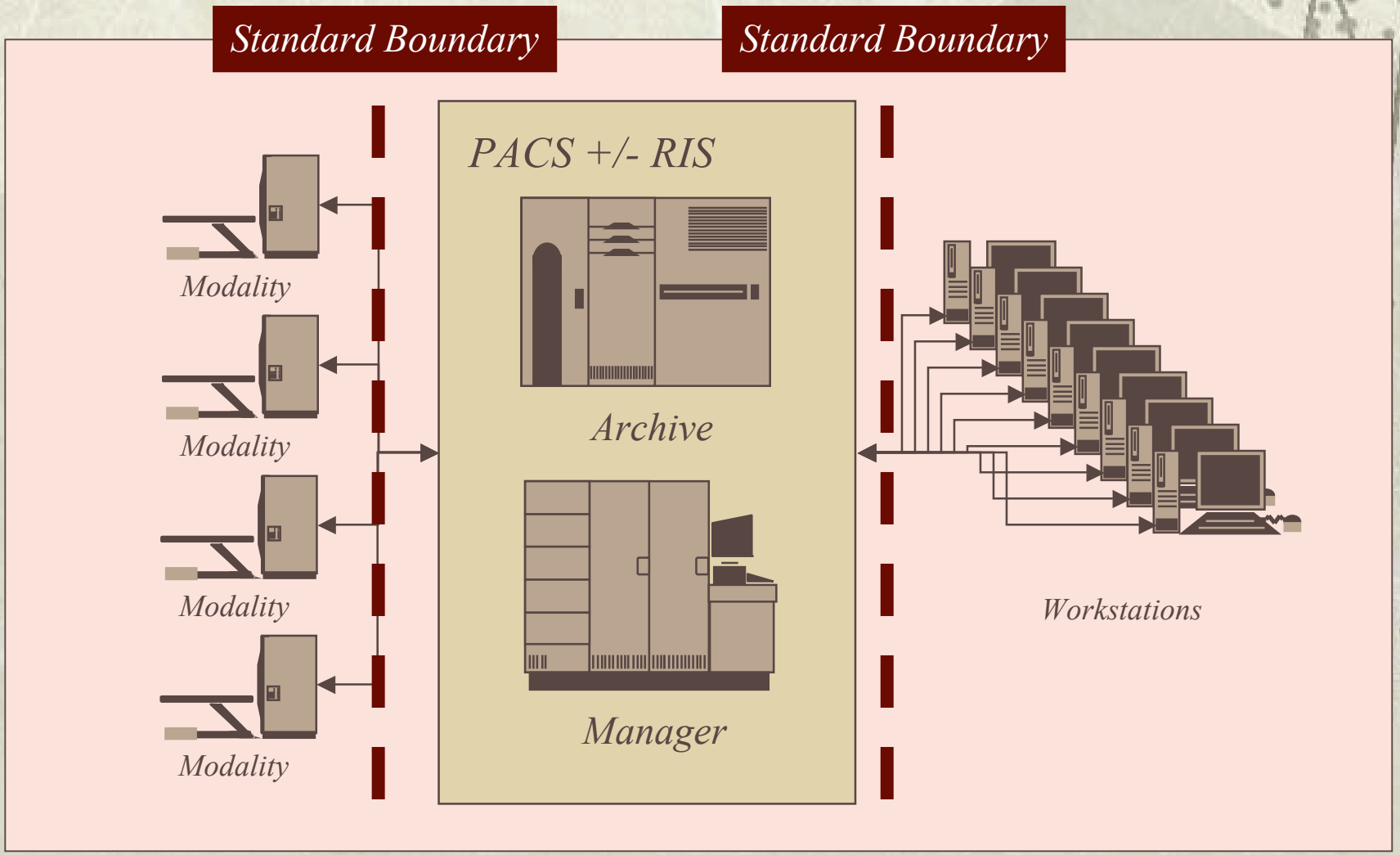


	1	2	3
Multi Frame	11.14111111	14.86703704	13.07333333
Single Frame	16.905	17.97	23.42666667

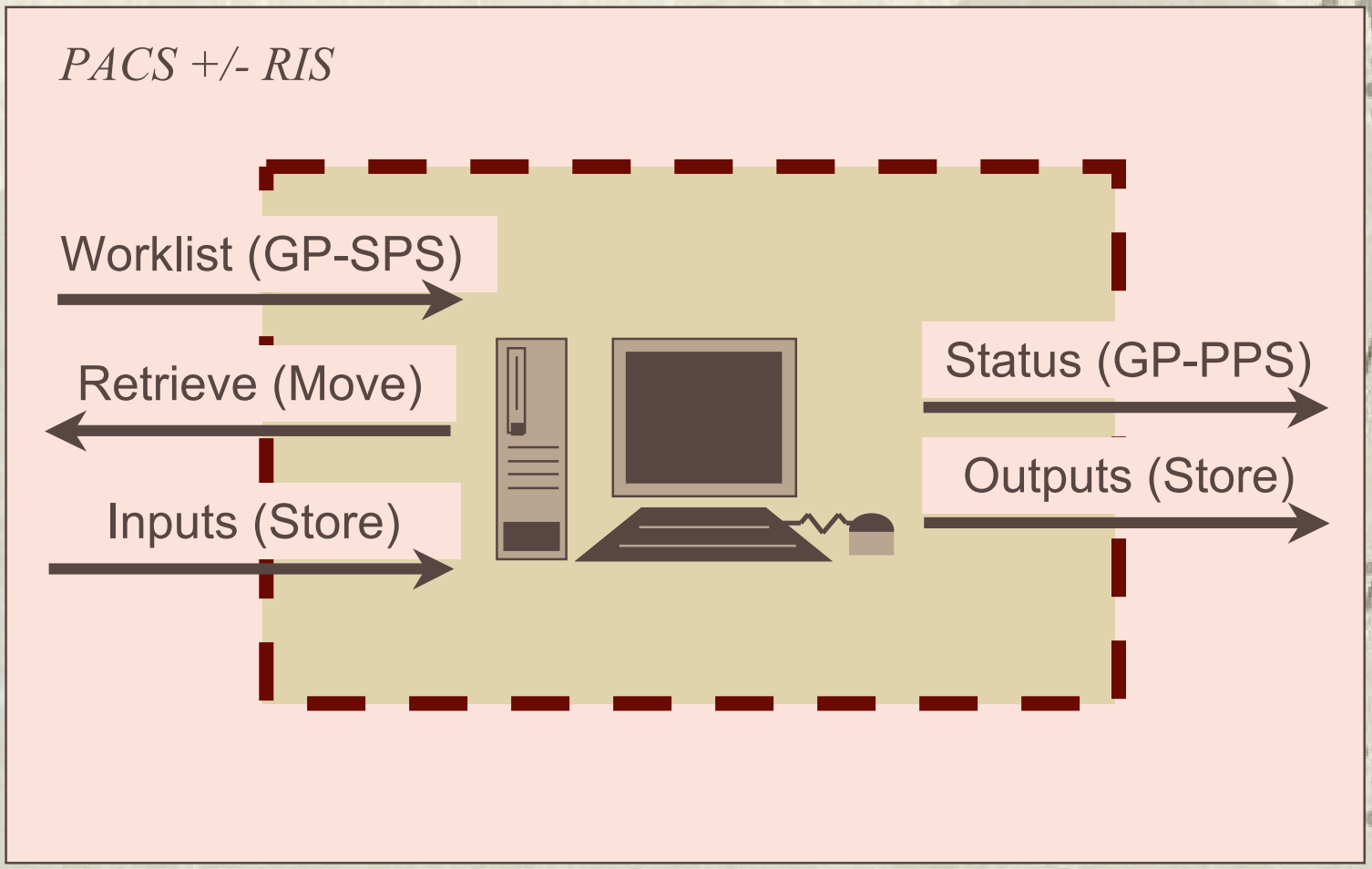
The Workstation Challenge

- Difficult for a PACS vendor to be expert in all modalities and applications
- Approaches
  - In-house development
  - Outsourcing & partnerships
  - Standard DICOM interface to external application
  - Shared context between applications (CCOW)
  - Standard plug-in architecture

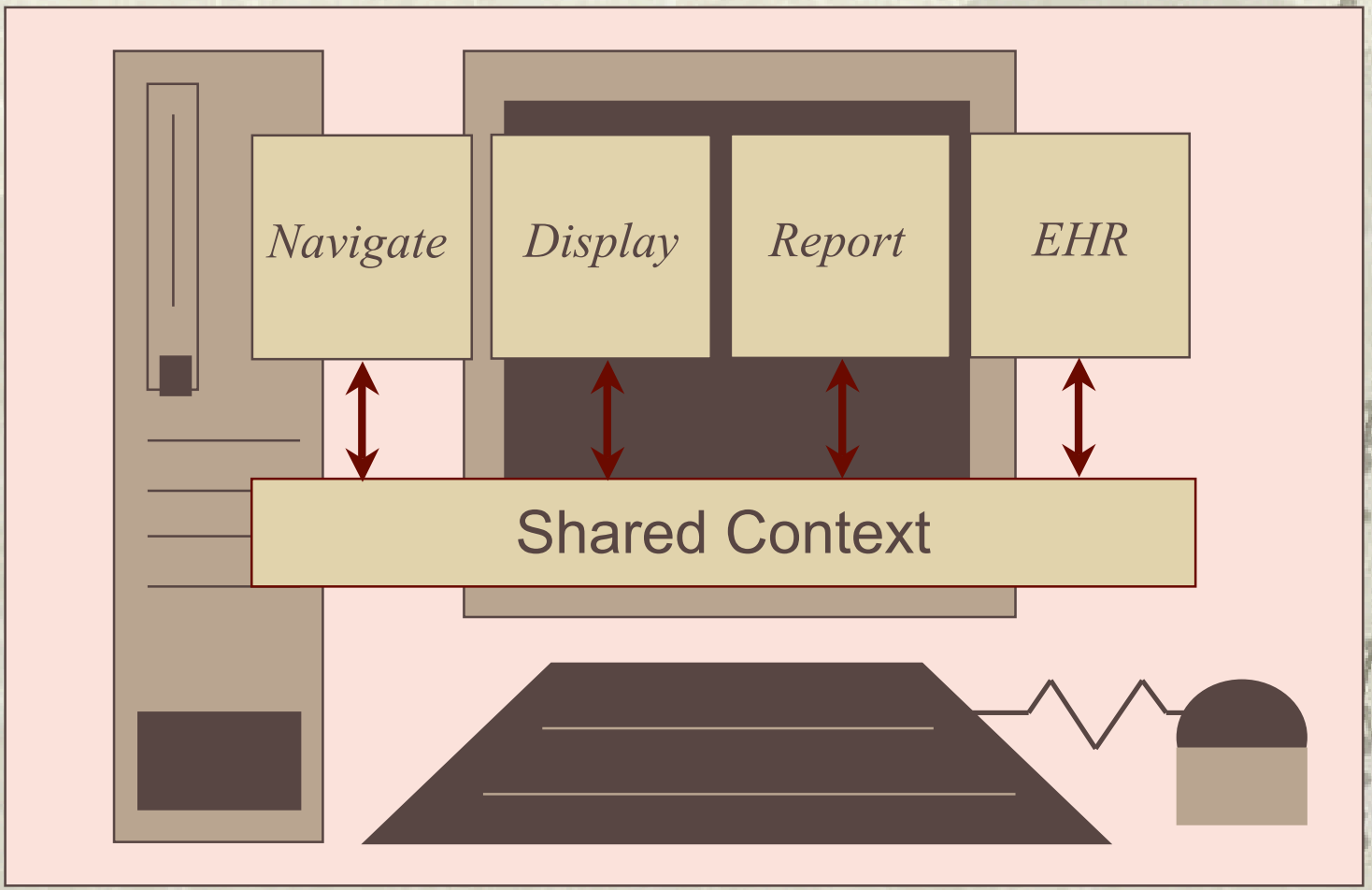

Standard Boundary
PACS +/- RIS
Modality
Modality
Modality
Modality
Archive
Manager
Workstations


Standard Boundary
Standard Boundary
PACS +/- RIS
Modality
Modality
Modality
Modality
Archive
Manager
Workstations

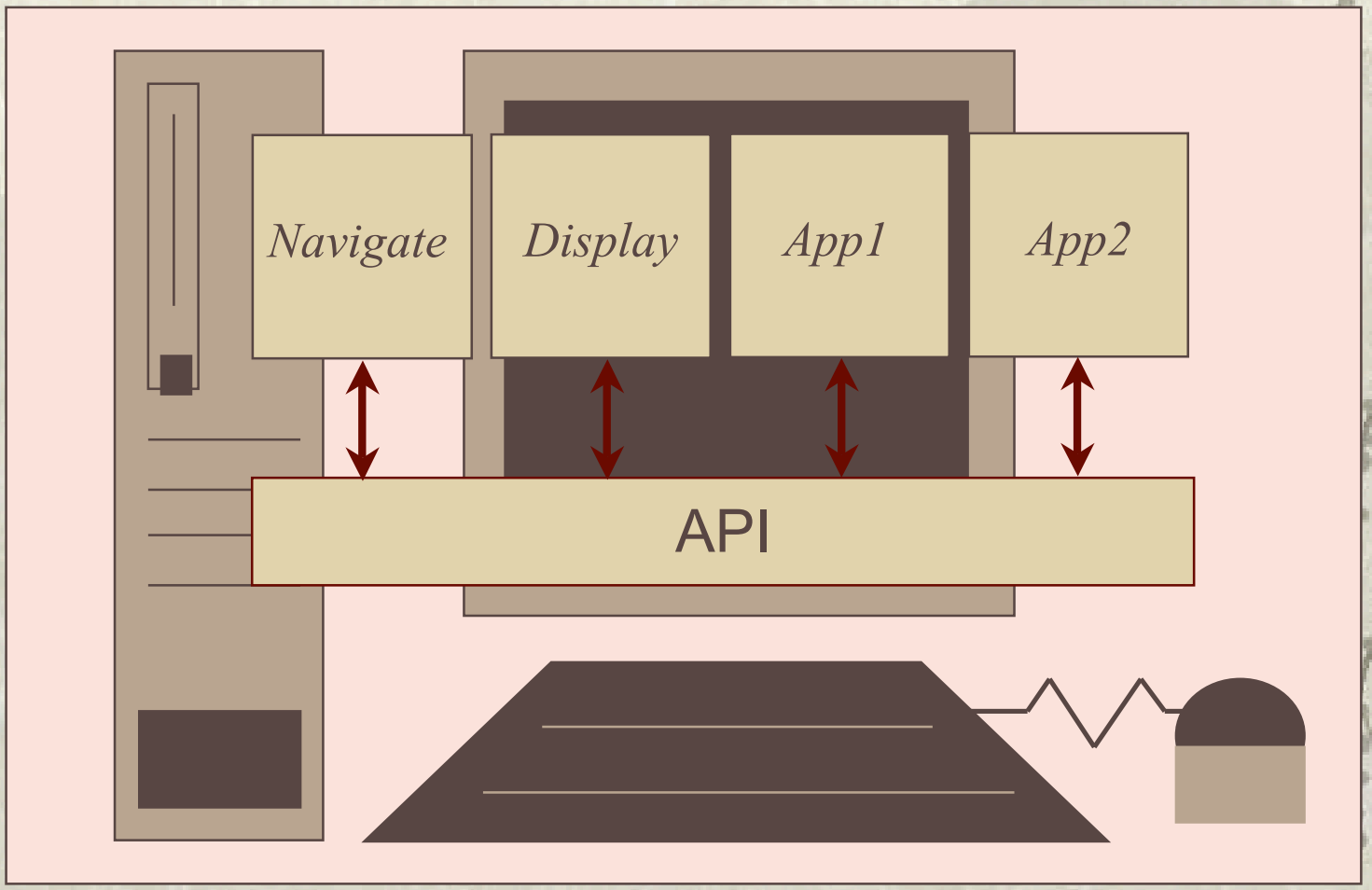
Standard Workstation Services



Standards within Workstation



Standard API within Workstation



Workflow with a PACS

- Acquisition
- Image quality control
- Reading/reporting
  - authoring
  - transcription/recognition
  - distribution
- Post-processing (CAD, Radiotherapy)
- RT Planning

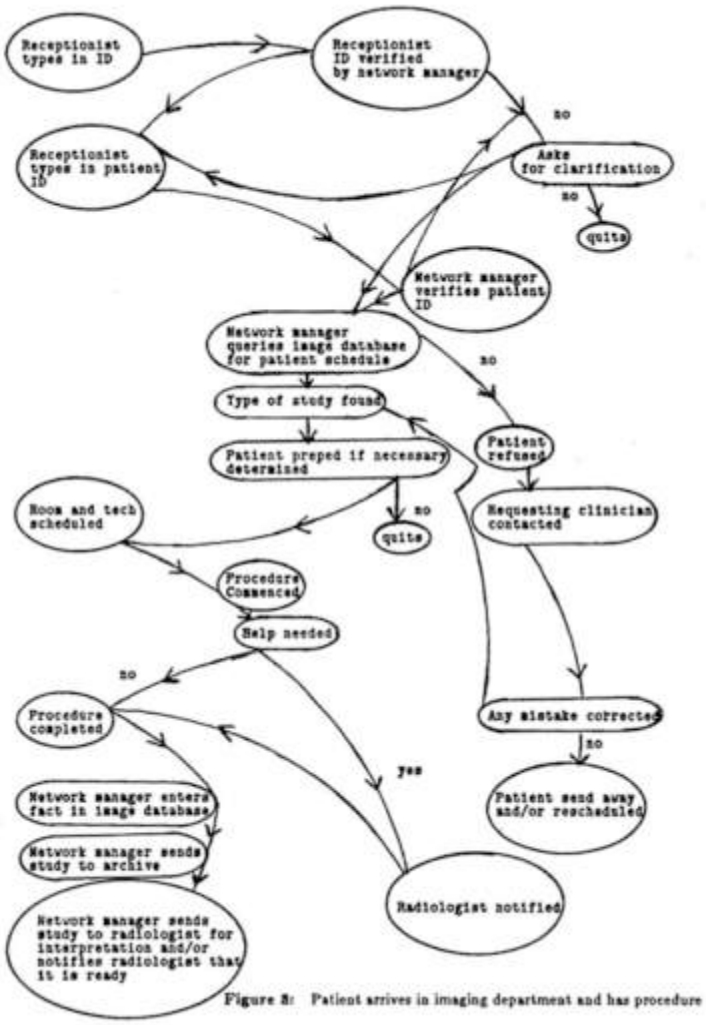
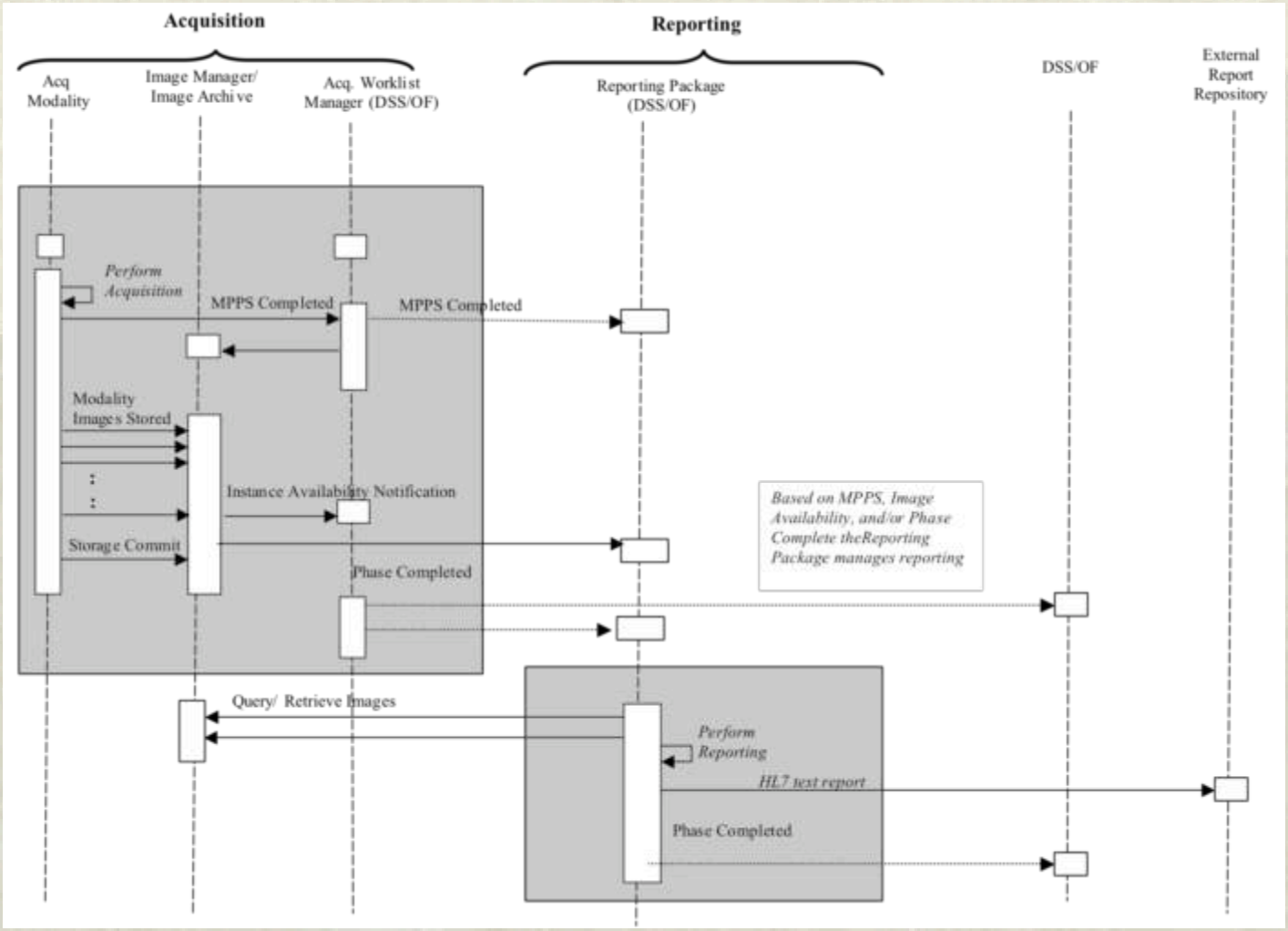


Figure 8: Patient arrives in imaging department and has procedure


Acquisition
Reporting
Acq Modality
Image Manager/ Image Archive
Acq. Worklist Manager (DSS/OF)
Reporting Package (DSS/OF)
DSS/OF
External Report Repository
Perform Acquisition
MPPS Completed
MPPS Completed
Modality Images Stored
Instance Availability Notification
Storage Commit
Phase Completed
Based on MPPS, Image Availability, and/or Phase Complete theReporting Package manages reporting
Query/ Retrieve Images
Perform Reporting
HL7 text report
Phase Completed

Acquisition Workflow

- Modality Worklist
  - Scheduling
  - Eliminate demographics entry
  - Better request matching, identification
  - Assisted protocol setting from procedure codes (IHE)
- Modality Performed Procedure Step
  - Completion status
  - What images and work products constitute step
  - Consumables used reported for billing
  - Radiation dose information
- Storage Commitment
  - Prior to local purging of images from modality
- Use of QC workstations separate from console
  - Traditional operator tasks previously during filming
  - Creation of pre-windowed images for reading
  - Presentation states

Reporting workflow

- Early PACS
  - Simple query mechanism
  - No concept of read status of study
- Browse view of database filtered by
  - User
  - Read status
- True work lists, not filtered views
  - Implies some system is “in charge”
  - Reads are scheduled
  - Driven by rule based triggers, e.g. relevant priors available

Reporting workflow

- Automated pre-fetching of relevant priors
  - Type of exam, indication for exam,historical information
- Hanging (default display) protocols
  - Increasingly sophisticated rules
  - Stored centrally rather than on workstation
  - User editable
  - Portable between vendors, sites, institutions (DICOM)

Reporting workflow

- Voice recognition
- Structure
  - Forms, headings, encoding
- Registry and national database support
- Teaching files
  - Flagging
  - Authoring
  - Consultation during reading
- Standard codes
  - Drive rule based workstation and other workflow
  - Data mining and outcomes analysis

Reporting Workflow

- Report turn-around time
  - A key primary PACS deliverable
- Linkage with relevant images
- Distribution
- Legal attestation of which form ?
  - Content
  - Rendered appearance
- Too many standards
  - HL7 2.x plain text, DICOM SR, HL7 CDA, PDF, etc.

What does PACS mean to you ?

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

PACS Evolution Conclusions

- Feasible now, when once it was not
- Widespread and accepted
- Challenges are those of
  - Scale
  - Complexity
  - Efficiency
  - Heterogeneity supported by standards
  - Re-use of off-the-shelf technology from other industries
  - Better modality-specific application support

“No modality left behind !”