AAPM 2005 1

AAPM 2005 2

=> Network & Storage Design

Network & Storage Design

The archive and communication system requirements depend on acquisition and presentation requirements.

- Acquisition:
  - Where are the modalities located and how much data is generated?
- Retrieval:
  - Who will retrieve images, how often, and where are they located?

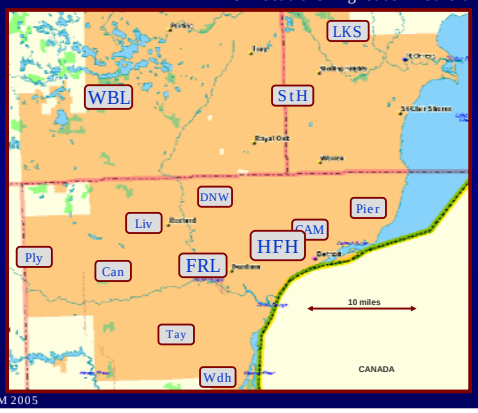
AAPM 2005 3

HFHS Facilities with PACS

13 Locations in greater Detroit

550k exams per year

X-ray
CT
MR
US
NM
PET



AAPM 2005 4

HFHS Procedure/Workgroup Model

For each operational region, the procedure volume done by each modality was considered in relation to the professional radiology workgroup

2003 data

Northwest Region

Northeast Region

Western Wayne Region

Main Campus

	General	Chest	Skeletal	Breast	Nuclear Med.	Body CT-MRI	Neuro	Ultrasound	Angiography
CT	_	_	2167	na	_	19499	21665	_	_
MR	_	_	5744	na		5744	_	_	_
NM	_	_	_	na	12678	_	_	_	_
US	_	_	3547	na	_	_	_	31926	_
Mamm	_	_	_	na	_	_	_	_	_
Radiogr.	12741	100578	70469	na	_	_	_	_	6420

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Data storage per modality/workgroup

	<Mbytes> per Image	Images per Study	Mbytes* per Study
CT - Neuro	0.529	35	7.41
CT - Skel.	0.529	200	42.32
CT - Body	0.529	70	14.81
MR - Neuro	0.135	120	6.48
MR - Skel.	0.135	150	8.10
MR - Body	0.135	200	10.80
Rad - Chest	10	2	8.00
Rad - Skel	10	3	12.00
Rad - Neuro	10	3	12.00
Rad - Gen	10	5	20.00
ER - Neuro	10	3	12.00
ER - Skel	10	3	12.00
ER - Chest	10	1.7	6.80
US	0.6	35	8.40
US - Skel	0.6	35	8.40
NM	0.26	16	1.66
Mamm	10	4	16.00
Fluoro	2	15	12.00
Spec. Pr.	0.529	20	4.23
Mobile	10	1.1	4.40

*Compression Ratio = 2.5

2003 data

The exam data size of was determined in relation to modality and workgroup in order to model network traffic and storage requirements based on procedure volume.

- Determined data size/study based on average acquisition parameters.
- Average number of images acquired/study/workgroup determined by audit.

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Study Acquisition time

For each modality, the time to deliver images to the archive depends on the study size and available bandwidth.

For example;

Study	sec	MB	Mb/sec
Skel. CT	300	42.3	1.4
Gen. Rad.	300	20.0	0.7
Body MR	300	10.8	0.3

Note: 1 MB/sec of data requires ~ 10 Mb/sec channel speed

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Communication channel requirement

For all modalities that share a channel, the required channel speed must be available the majority of the time for all devices.

For example;

Study	devices	studies/hr	<Mb/s>	PeakMb/s
Skel. CT	4	2.0	0.9	2.7
Gen. Rad.	6	4.0	1.3	3.9
Body MR	2	1.5	0.1	0.3

Network Mb/sec = 3 * <Mb/s> MINIMUM

This is the approximate peak to mean ratio

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HFHS network specifications

HFHS 2003 Design specs

	GB/yr	GB/day	daytime GB/hr	<kB/sec>	peak Mb/sec	channel spec.
FRL to Main:	179.3	0.69	0.074	21	0.62	2.06
BLM to Main:	116.0	0.45	0.048	13	0.40	1.33
LKS to Main:	69.4	0.27	0.029	8	0.24	0.80
TAY to FRL:	218.1	0.84	0.090	25	0.75	2.50
LIV to FRL:	123.6	0.48	0.051	14	0.42	1.42
DNW to FRL:	108.9	0.42	0.045	12	0.37	1.25
STH to LKS:	306.9	1.18	0.127	35	1.06	3.52
Main to archive:	3181.5	12.24	1.313	365	10.94	36.47
FRL to archive:	1131.5	4.35	0.467	130	3.89	12.97
BLM to archive:	615.1	2.37	0.254	71	2.12	7.05
LKS to archive:	460.3	1.77	0.190	53	1.58	5.28
Total to Archive:	5388.3	20.7	2.2	618	62	

Total Satellite to Main Campus Archive = 25.3
(3 times minimum design rule)

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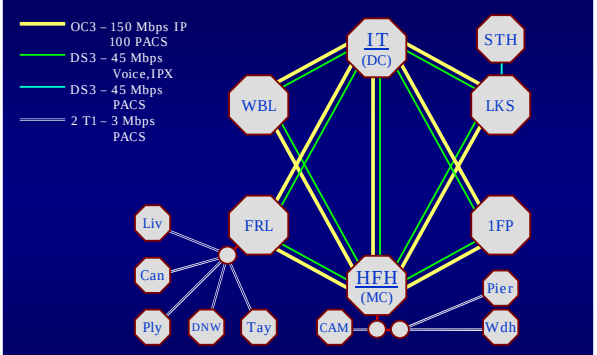
HFHS PACS Network



Data communication between the 15 HFHS Facilities that have PACS operations.

AAPM 2005 10

Network performance

Measured rates

The PACS network at HFHS delivers a single CR image in .5 seconds to Radiology reading stations

Facility	Net	MB/s	Sec/CR
Main Campus	LAN	7 – 9	.5
Fairlane	OC3	7 – 9	.5
W. Bloomfield	OC3	7 – 9	.5
Lakeside	OC3	7 – 9	.5
Sterling Hts.	DS3	2.5 – 3.5	1.3
Taylor*	2 T1	.25 - .35	13
Livonia*	2 T1	.30 - .35	12
Detroit NW*	2 T1	.20 - .24	18

*acquisition only

A well balanced network configuration provides consistent transfer rates.

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Gartner #1

Bandwidth will be more cost effective than computing

- The number 1 technology prediction by Gartner is that network capacity will increase faster than computing, memory and storage capacity to produce a major shift in the relative cost of remote versus local computing.
- This is catalyzing a move toward more centralized network services, using grid computing models and thin clients.

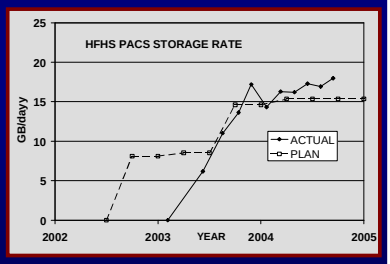
Ten predictions to shake your world
By Dan Farber, Tech Update
October 10, 2002

AAPM 2005 12

Estimation of Storage Requirements

- Knowledge of procedure volume by modality and study type along with the corresponding study data size allows the storage requirements of an archive to be accurately estimated.

Because of the low cost of storage devices, redundant storage is practical for cache and for disaster recovery purposes.



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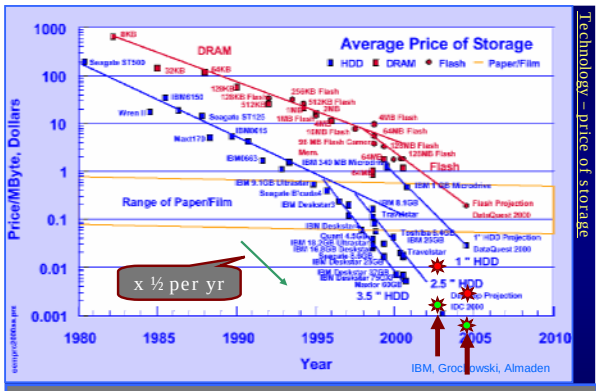
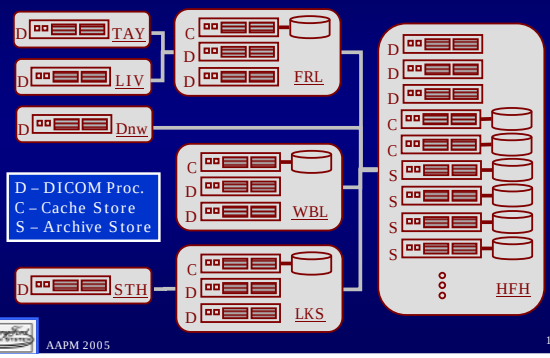


Jul 2004	IDE DRIVEs	$ 650 USD/TB	$.0006 USD/MB
	SCSI RAID5	$6,250 USD/TB	$.0062 USD/MB

Stentor iSyntax

Dicom processors convert modality data to compressed coefficients that are stored in cache units while migrating to the central archive.



AAPM 2005 15

=> Softcopy Image Presentation

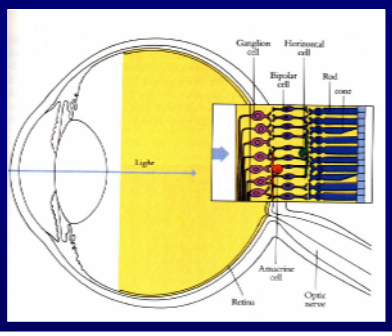
Softcopy Image Presentation

- Display Type:
  What type of display should each user group be using?
  Pixel size and Field of View
- Calibration:
  How can similar grayscales be configured for all devices?
  Enterprise grayscale calibration

AAPM 2005 16

HVS: Retinal anatomy

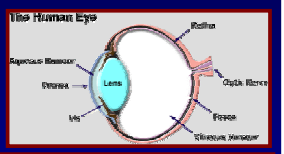
The retina of the human eye contains a network of rods and cones interconnected by neural cells.



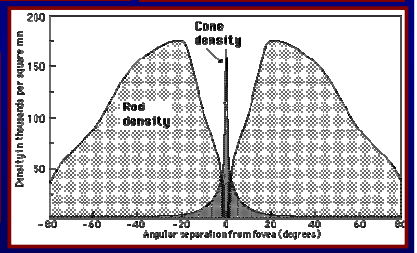
AAPM 2005 17

HVS: Foveal response

Particularly thin cones (2 µm) are densely packed in the central 50 microns of the fovea centralis. They provide high detail color response.



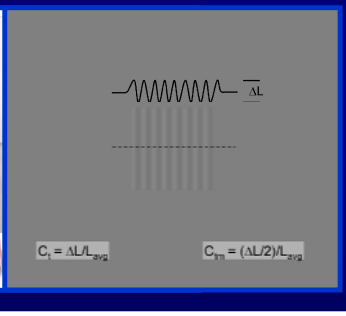
At 60 cm, 1 degree corresponds to a 1 cm field of view. This area is focused on a 288 micron region of the retina, the fovea centralis



AAPM 2005 18

A. Visual Acuity

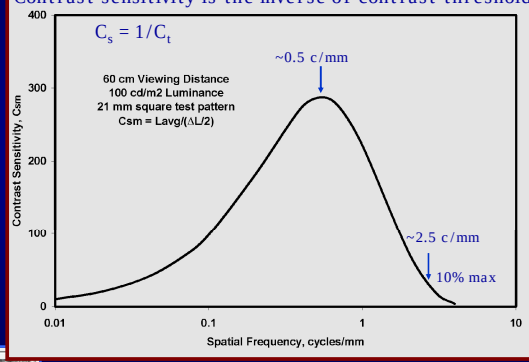
A variety of test patterns are used to assess visual acuity. Clinical measures are done typically with a Snellen eye chart. Much psychovisual research has been done using sinusoidally modulated test targets.



AAPM 2005 19

A. Contrast Sensitivity & spatial acuity

Contrast sensitivity is the inverse of contrast threshold



AAPM 2005 20

A. Pixel Size at Maximum Spatial Acuity

- The pixel size of a display system that matches the resolving power of the human eye depends on the observation distance.
- The visual spatial frequency limit and associated pixel size can be defined as that for which Cs = 10% of maximum.

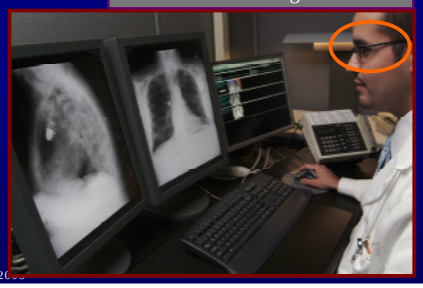
Distance	frequency	pixel size
Close inspection (0.33 m)	5 cycles/mm	0.100 mm/pixel
Normal viewing (0.66 m)	2.5 cycles/mm	0.200 mm/pixel
Consultation view (1.00 m)	1.7 cycles/mm	0.300 mm/pixel

AAPM 2005 21

Field of View

- 21 inch (diagonal) monitors with a field of 32 x 42 cm have provide an effective viewing field for digital radiographs at a normal distance (2/3 m).

Eyeglasses should be optimized for a normal viewing distance



AAPM 2005 22

A. Pixel array and Megapixels

- The pixel size needed for visualizing full detail and the field of view dictate the pixel array size and the total number of pixels.

Distance	pixel size	32 x 42 cm array size	MegaPixels
Close (0.33 m)	0.100 mm	3200 x 4200	13.4
Normal (0.66 m)	0.200 mm	1600 x 2100	3.4

- idtech 3 MP panel
  20.8 inch (32 x 42 cm) 3.1 megapixels (.207 mm pixels)

AAPM 2005 23

Field of View

- Use of image zoom features is ergonomically better than leaning forward for close inspection.
- Split deck tables with a broad front deck usefully prohibit close inspection with 3 MP monitors.

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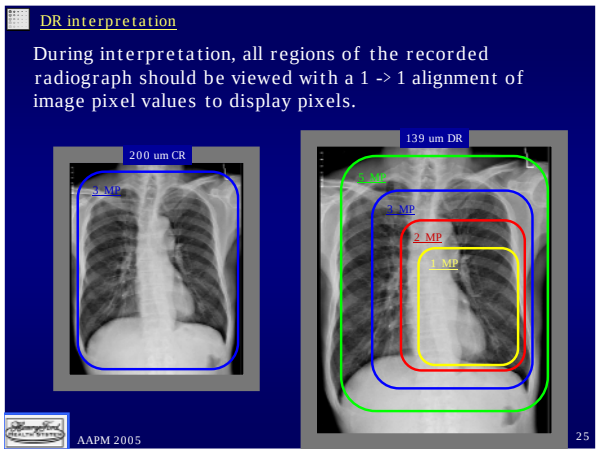
DR interpretation
During interpretation, all regions of the recorded radiograph should be viewed with a 1 -> 1 alignment of image pixel values to display pixels.
200 um CR
3 MP
139 um DR
5 MP
3 MP
2 MP
1 MP
AAPM 2005
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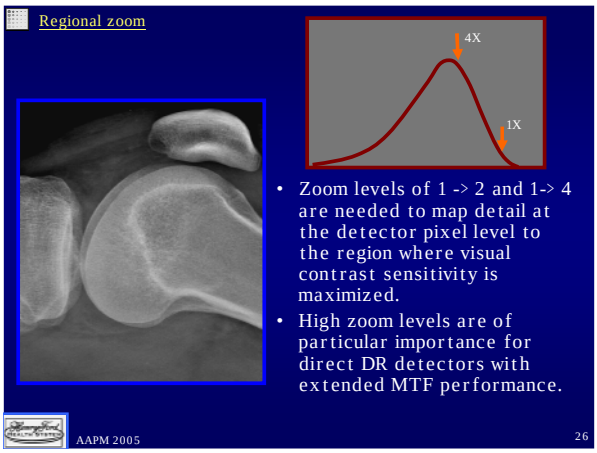
Regional zoom
4X
1X
• Zoom levels of 1 -> 2 and 1-> 4 are needed to map detail at the detector pixel level to the region where visual contrast sensitivity is maximized.
• High zoom levels are of particular importance for direct DR detectors with extended MTF performance.
AAPM 2005
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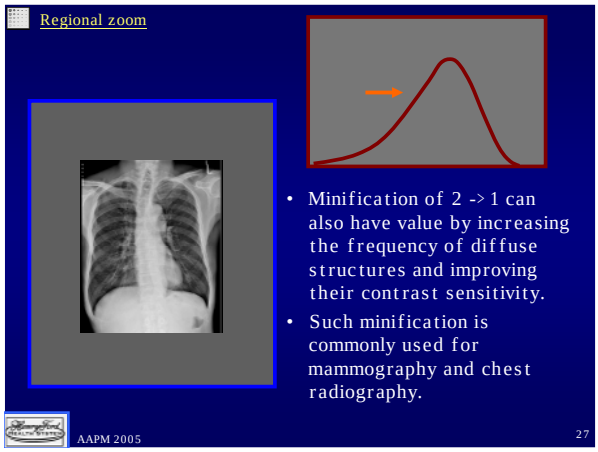
Regional zoom
• Minification of 2 -> 1 can also have value by increasing the frequency of diffuse structures and improving their contrast sensitivity.
• Such minification is commonly used for mammography and chest radiography.
AAPM 2005
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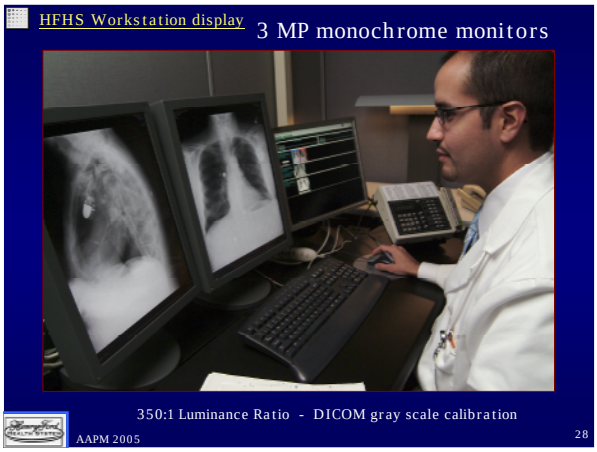
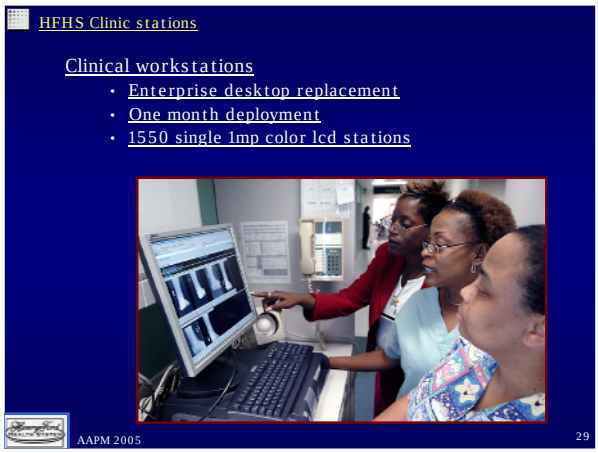

HFHS Workstation display
3 MP monochrome monitors
350:1 Luminance Ratio - DICOM gray scale calibration
AAPM 2005
28


HFHS Clinic stations
Clinical workstations
• Enterprise desktop replacement
• One month deployment
• 1550 single 1mp color lcd stations
AAPM 2005
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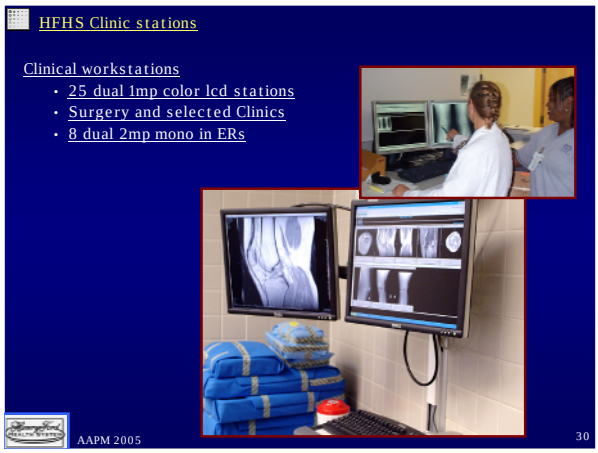
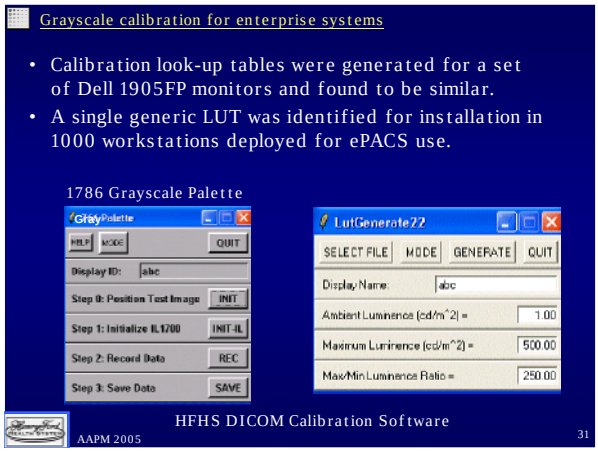

HFHS Clinic stations
Clinical workstations
• 25 dual 1mp color lcd stations
• Surgery and selected Clinics
• 8 dual 2mp mono in ERs
AAPM 2005
30


Grayscale calibration for enterprise systems
• Calibration look-up tables were generated for a set of Dell 1905FP monitors and found to be similar.
• A single generic LUT was identified for installation in 1000 workstations deployed for ePACS use.
1786 Grayscale Palette
GrayPalette
HELP
MODE
QUIT
Display ID:
abc
Step 0: Position Test Image
INIT
Step 1: Initialize IL1700
INIT-IL
Step 2: Record Data
REC
Step 3: Save Data
SAVE
LutGenerate22
SELECT FILE
MODE
GENERATE
QUIT
Display Name:
abc
Ambient Luminence (cd/m^2) =
1.00
Maximum Luminence (cd/m^2) =
500.00
Max/Min Luminence Ratio =
250.00
HFHS DICOM Calibration Software
AAPM 2005
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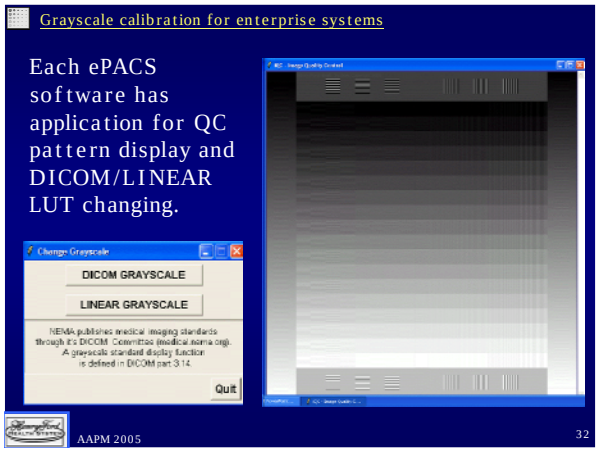
Grayscale calibration for enterprise systems
Each ePACS software has application for QC pattern display and DICOM/LINEAR LUT changing.
Change Grayscale
DICOM GRAYSCALE
LINEAR GRAYSCALE
Quit
AAPM 2005
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=> Performance/QA Monitoring

- Image Quality:
  - Are all images being acquired properly?
  - Are all images being displayed properly?
- Network:
  - Are all devices connected?
  - Are all images transmitted quickly?
- RIS:
  - Are HIS data packets being received?
  - Are all new studies reconciled?
  - Are all studies interpreted quickly?

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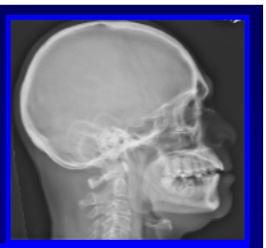
Image Quality

Incorrect Processing

- The image processing parameters configured on CR/DR devices should be periodically audited to insure that they conform with departmental standard values.



⇒ Grayscale Rendition:	Convert signal values to display values
⇒ Exposure Recognition:	Adjust for high/low average exposure.
⇒ Edge Restoration:	Sharpen edges while limiting noise.
⇒ Noise Reduction:	Reduce noise and maintain sharpness
⇒ Contrast Enhancement:	Increase contrast for local detail

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Network Performance - #1

1. Document all RIS-PACS Devices:
   - Effective operations require that key network and device information be known for all systems. (i.e. you can't monitor what you don't know).
   - Use of a simple device database allows easy access to parameters of interest.
   - The HFHS pacStats web site illustrates how devices can be listed by location, modality type, or manufacturer.

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pacStats – modality summary

HFHS pacStats - summary table of all modalities

HFHS ePACS Image Acquisition Devices

Device Totals:
SCUs = 67
DEVs = 147

Table Links:
Configuration Data
Reachability (ping)

Type	SCUs	DEVs
CR	25	95
CT	7	10
DR	3	4
IA	4	4
MG	5	6
MR	8	21
RF	6	6
XA	9	11

Manf	SCUs	DEVs
Agfa	16	50
DeJam	1	1
EKC	16	45
GE	21	37
Lorad	5	6
SIMS	8	8

Facility	SCUs	DEVs
CAM	1	3
Canton	1	3
DNW	1	4
FRL	8	18
HFH	39	71
LKS	2	9
Livonia	1	3
Pierson	1	3
Plymouth	1	3
STH	3	7
Taylor	1	4
WBL	7	16
Woodhaven	1	3

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pacStats – modality table

HFHS pacStats – CT modality table
- Identification information
- Location information
- Network assignments.

HFHS ePACS Device Table

ping	devID	Type	sysID	Manf	function	install	section	Facility	floor	room	ptSCU	ip	netmask	gateway	endNode
1	H2_CT1_RS	CT	HC_C01	GE	Acquisition	-	CT	HFH	H2	1	1	11.64	255.255.252.000	11.127	0.211
4	H2_CT2_LS	CT	HC_C02	GE	Acquisition	10.01.03	CT	HFH	H2	2	1	11.67	255.255.252.000	11.127	0.214
4	H2_CT3_CTI	CT	HC_C03	GE	Acquisition	05.28.05	CT	HFH	H2	3	1	11.68	255.255.252.000	11.127	0.215
1	ER_CT4_LSP	CT	HC_C04	GE	Acquisition	05.23.05	CT	HFH	WCER	-	1	11.69	255.255.252.000	11.127	0.214
1	FRL_CT5_LSF	CT	FL_C01	GE	Acquisition	11.01.02	CT	FRL	1	-	1	53.29	255.255.255.000	53.127	0.126
1	WBL_CT1_LSP	CT	WB_C01	GE	Acquisition	05.01.04	CT	WBL	1	-	1	21.83	255.255.255.000	21.127	0.110
1	STH_CTw1_LSP	CT	HB_C01	GE	Acquisition	03.01.03	CT	STH	1	-	1	150.47	255.255.255.000	150.127	0.142

PING - echo time in milliSec, time limit = 1 sec
PING 1 - no response within 1 sec limit
PING 2 - using echo-error (possible bad address)
PING - - waiting for first ping echo

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Network Performance - #2

2. Check that all devices can be reached:
   - It is important to know that communication packets can be sent and received from all devices.
   - Network management terminology refers to a device as being 'reachable'
   - The pacStats application polls each device at timed intervals and posts the status (see the button icon on the left of the final device lists)

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pacStats – modality table

HFHS pacStats – network trace route

HFHS ePACS Network Response : [redacted] 21.83

Route Trace

Hop	mSec	Address
1	1	[redacted] 78.127
2	1	[redacted] 0.133
3	1	[redacted] 0.110
4	1	[redacted] 21.83

West Bloomfield Medical Ctr.

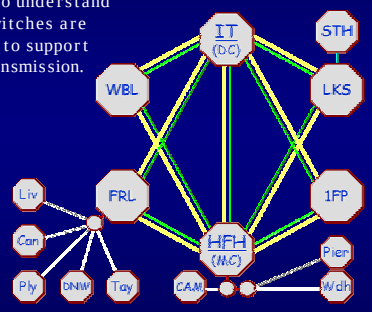
For debugging, a trace route can identify the switches used when communicating with a device.

Network Performance - #3

3. Know your network Topolgy:

- It is essential to understand how network switches are interconnected to support PACS image transmission.

However, when services are provided by communication contractors, network topology information may be difficult to obtain.



pacStats – network discovery

The pacStats application supports a network discovery process that documents topology. Using this as a basis, abnormal network routing, which indicates problems in the network mesh, can be identified and an alert message sent.

Network Topology:
Ctr. Nodes = 10
End Nodes = 17
-MAP-

Network End Nodes

Node IP	Location	Devices
[redacted] 110	WBL_MC.OC3	17
[redacted] 118	LKS_MC.OC3	9
[redacted] 126	FRL_MC.OC3	15
[redacted] 133	BC_OFP.OC3	1
[redacted] 142	STH_LKS-DS3	7
[redacted] 190	Plymon	3
[redacted] 198	Livonia	3
[redacted] 206	Canton	3
[redacted] 210	Plymouth	3
[redacted] 218	Taylor	4
[redacted] 238	DNW	4
[redacted] 254	Woodhaven	3
[redacted] 209	HFH_MC.BCN	3
[redacted] 214	RAD-Sw1	37
[redacted] 218	RAD-Sw2	35
[redacted] 53.65	--	1
[redacted] 53.66	--	1

Network Central Nodes

Node IP	Location	Links in		Links Out	
[redacted] 118	LKS_MC.OC3	MC_OF.	[redacted] 133	STH_1	[redacted] 142
[redacted] 126	FRL_MC.OC3	MC_OF.	[redacted] 133	N = 3	
[redacted] 133	MC_OFP.OC3	RAD-0.	[redacted] 78.127	N = 6	
[redacted] 210	HFH_WYN-BCN	HFH_IL	[redacted] 209	Woodh	[redacted] 194
[redacted] 250	HFH_OFP.BCN	HFH_IL	[redacted] 209	Pies.	[redacted] 30
[redacted] 122	FRL_FRL	FRL_M.	[redacted] 126	N = 5	
[redacted] 209	HFH_MC.BCN	MC_OF.	[redacted] 133	N = 2	
[redacted] 8.127	RAD-OFP	--		MC_OF	[redacted] 133
[redacted] 1.5	HFH_BC	MC_OF.	[redacted] 133	RAD-S.	[redacted] 214
[redacted] 1.6	HFH_BC	MC_OF.	[redacted] 133	RAD-S.	[redacted] 218

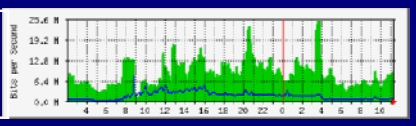
Network Performance - #4

4. Track network speed:
   - For sending images to the archive, or for delivering images to workstations, the point to point transfer speed is important.
   - Standard utility programs (ping) can measure the round trip speed with optional specification for a large packet.
   - One way speed (modality -> archive or archive -> workstation) is more accurate. This requires specialized send/receive applications. DICOM services to support transfer speed monitoring would be of value

Network management using SNMP

- SNMP is the Internet standard protocol developed to manage nodes on an IP network.
- SNMP enables network administrators to manage network performance, find and solve network problems, and plan for network growth.

MSU Radiology switch traffic graphed updated every 5 minutes using MRTG



- However, SNMP does NOT provide point to point data transfer speed information.

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Basic #5 – Reading Stations

5. Monitor Display Workstation performance:
   - Workstations should be monitored to insure proper operation of the computer, the display devices, and the RIS-PACS applications for viewing and reporting.
   - SNMP provides a tool to periodically check memory utilization, cpu utilization, motherboard temperature, and medical LCD display parameters.
   - Application specific data is often written to a log by the PACS display program. Extraction of data from logs can provide information regarding utilization.
   - Migration of PACS utilization data directly to IHE defined SNMP agents is suggested.

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Network Management Software

- Numerous commercial and open source software packages are available for network monitoring. A Web site at Stanford (SLAC) contains an extensive list of tools with links to resource material.

  www.slac.stanford.edu/xorg/nmtf/nmtf-tools.html#public
- The available tools provide excellent methods for generic network monitoring, but do not address the specific needs involved with the monitoring and management of an enterprise system. This requires a more intimate knowledge of the system devices (actors) and the roles they play (transactions).

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Commercial PACS tools

Two commercial PACS monitoring tools are now being used at some medial centers:

- MagicWatch: A PACS/radiology information system (RIS) monitoring station from Siemens that uses HP Openview tools. It's use at the Cleveland Clinic was reported by Lannum (J. Digit Imaging. 2001 Jun;14(2 Suppl 1):17-21)
- PACSwatch: A PACS performance monitor developed originally at Mass. General Hospital and previously sold by Agfa Medical Co. Agfa now considers this an end of life product and has introduced SMART for both monitoring and software maintenance.

These products function only with PACS components provided by the same manufacturer and do not provide the ability to monitor other core components and modalities of an electronic imaging operation.

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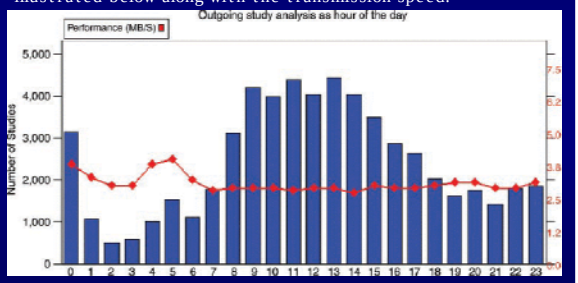
Open Source PACS tools

Nagy previously reported on the use of open source tools for PACS monitoring (Radiographics 2003; 23:795-801).

The studies retrieved per hour from a central archive is illustrated below along with the transmission speed.



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Service contract tools

- Tools available to service providers often provide extensive information regarding the devices for which service support has been contracted.
- However, this information is generally not made available for use with PACS monitoring applications used by operations and management staff of the medical center.
- For new installations, access to performance monitoring tools should be negotiated with the service or purchase contract.

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