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The Impact of Image Storage Organization on the Effectiveness of PACS

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Picture archiving communication system (PACS) requires efficient handling of large amounts of data. Mass storage systems are cost effective but slow, while very fast systems, like frame buffers and parallel transfer disks, are expensive. The image traffic can be divided into inbound traffic generated by diagnostic modalities and outbound traffic into workstations. At the contact points with medical professionals, the responses must be fast. Archiving, on the other hand, can employ slower but less expensive storage systems, provided that the primary activities are not impeded. This article illustrates a segmentation architecture meeting these requirements based on a clearly defined PACS concept.

KEY WORDS: image storage, PACS architecture, optical archiving.

IMAGE STORAGE and image access are important aspects of picture archiving communication system (PACS) and deserve much attention by the system designer. The reporting radiologist in front of an alternator has very fast access to a bank of images and has already optimized the process of information transfer: visual input and verbal output. He expects of PACS improvements beyond that offered by such an alternator and he has expressed in various meetings and publications what he would consider an acceptable performance: fast and reliable access to all stored images from a number of locations. Although these expectations are clearly understood, the technical implementations are still unsatisfactory or unaffordable.

In this article, available technologies for storing large amounts of image data will be discussed. It will be shown that segmentation of storage devices is necessary in order to reach an optimum compromise between performance and cost. The competition is mainly between magnetic and optical storage systems. Optical storage technology promised already a decade ago to supply high-density digital image storage of archival quality at low cost.[1] Magnetic data recording technology has made more progress than optical technology and offers fastest data rates at lowest costs for removable media. There are, however, noteworthy trends in optical removable storage media, which will be discussed later.

Isolated storage devices do not determine the effective image access time but the overall system architecture and storage segmentation. In order to better define the task of segmentation design a typical workload of a PACS radiology department will be assumed.

The interrelationship between resolution and storage requirement can be seen in Table 1, which cites American Hospital Association data[2] and lists the number of procedures per bed and per year for larger US hospitals. For plain film radiography, we find that 124 procedures are performed per bed per year. All other diagnostic modalities generate smaller numbers of procedures per bed per year. The next column shows the resulting number of images, and the third column shows the number of square feet of film used. The fourth column shows the number of images per procedure followed by kB (kilobytes or 1000s of bytes) per image. The number "5000" is derived from 2000 pixels horizontally

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Table 1. Yearly Productivity Projections

	Procedures/ bed	Images/ bed	Square ft film/ bed	Images/ procedure	kB/Image	Mbyte/bed	%
Radiography	124	354	394	3	5000	1770	70
Contrast	20	207	198	10	1000	207	8
Special procedure	4	285	94	71	1000	285	11
Ultrasound	10	360	31	36	250	90	4
CT	9	205	33	23	500	103	4
MRI	2	64	7	32	250	16	1
DSA	5	81	18	16	500	41	2
Nuclear medicine	7	98	6	14	33	3	
Total	181	1654	781	9		2514	100

NOTE. Procedures per bed are related to images per bed and Mbytes per bed. Reprinted with permission.[2]

by 2500 lines, each 8 bits deep. If it is assumed that more bits are required per pixel, this number would increase correspondingly.

The column "Mbyte/bed/y" indicates the total amount of megabytes produced by a particular modality per bed per year. The last column shows the percentage of the particular modality to the total production, indicating that radiographic procedures produce by far the largest fraction of image data. This fact permits already the conclusion that a completely "filmless" PACS will be difficult to implement.

SYSTEM ARCHITECTURE

While it is generally assumed that PACS is a distributed system, several implementations are possible and have been described.[3,4] A system architecture that resembles that of a conventional department with a film library and a film archive is shown in Fig 1. It is topologically a "star" configuration with the "Digital Image Library" at the hub and input devices (modalities) as well as output devices (workstations) at the rim. This, incidentally, is the topology of CommView, the PACS developed by AT&T (West Longbranch, NJ) and marketed by Philips (Shelton, CT).

As illustrated in Fig 1, the data stream flows in two directions: inbound is the data flow generated by the modalities such as computed tomography (CT), magnetic resonance imaging (MRI), digital subtraction angiography, computed radiography, (CR) and others. Outbound is the user-originated stream of images from the central image library to the various workstations. Data quantities as listed in Table 1 are assumed to be supplied by the respective modalities and converge ultimately on the image library. The conversions of the original modality image format into a compatible format will not be discussed here, but it is assumed that such compatibility exists and is performed in the IUs of Fig 1. Throughout this article, the emphasis is on images, while generation, transfer, and storage of patient data is assumed to be implemented in a satisfactory manner by a radiology information system.

It is furthermore assumed that the primary diagnosis is established at the modality in question. This assumption may not be acceptable to some promoters of PACS, but clarifies the underlying PACS concept of this article. For CT, MRI and ultrasound (US) images this assumption poses no challenge. For radiography, however, as well as Radiography/Fluorographs and DSA images, PACS is generally assumed to offer advantages also for the diagnostic process. In particular, teleradiology is only meaningful if it can handle traffic of diagnostic images and not only "review images." Still, this article deals only with the organization, traffic, and storage of images for which the primary diagnosis has already been established. The target of optimization is access to archived images by medical specialties as well as authorized persons outside the hospital, including referring physicians. Images have to be transferred by the interface units (IUs) into the PACS environment with minimal disruption of the revenue generating modalities. This means that the data transfer rates into the PACS environment must match the average acquisition rates and may even have to match the maximum acquisition rates. It is furthermore assumed that image data are not transferred back into the generating modalities after some kind of post-processing. This assumption is increasingly endorsed by experts who recognize

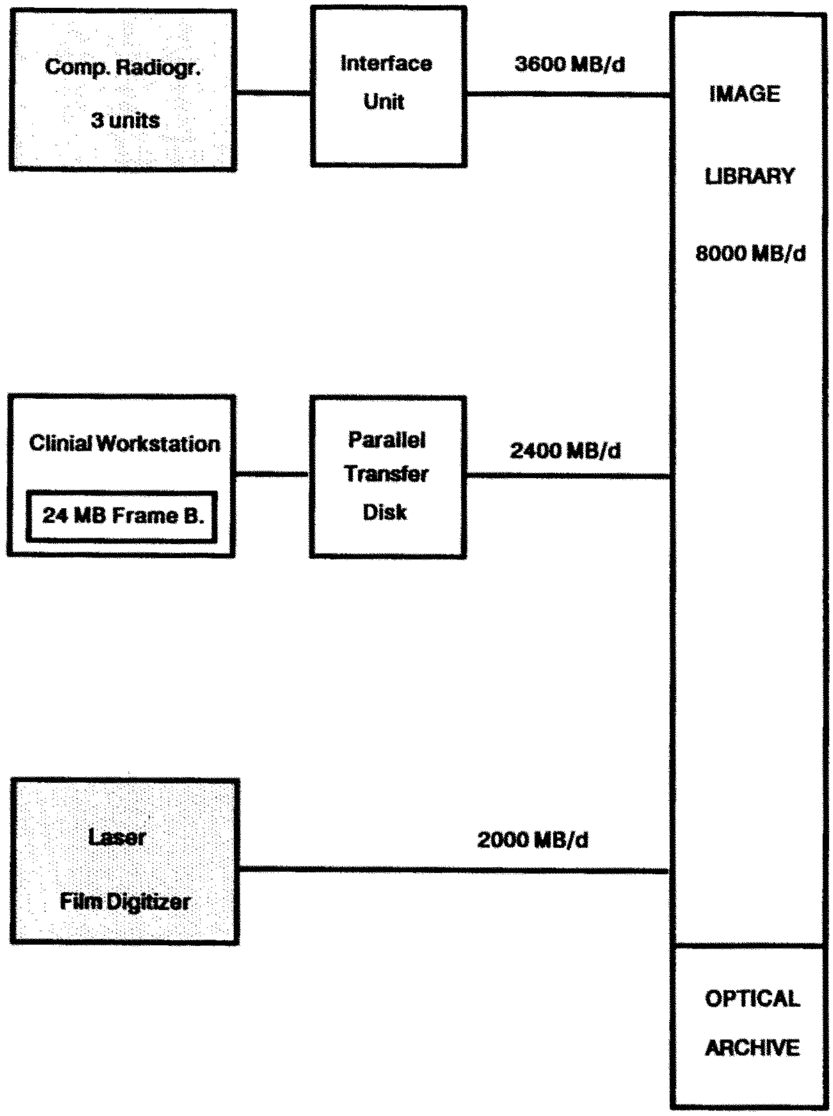

Fig 1. Inbound and outbound image traffic demonstrated for radiographic procedures. Three CR systems are assumed to produce these data. Outbound traffic handles mainly nonradiographic images for review.

that an omnipotent image processing PACS workstation is unrealistic.

The traffic out of the image library into workstations, however, is bidirectional because edited or postprocessed images will also be deposited in the image library. These workstation are information centers for authorized participants in PACS and supply images related to diagnostic cases as an important type of information.

The assumed architecture offers no direct connection between workstations, but only via the central image library. This assumption may again run counter to some desires but is intended to preserve the authority of the reporting modality expert. Only if and when such expert has released images for which he is responsible can others gain access via the image library. This restriction is similar to good practices in a department.

Attached to the image library is, for instance, an optical jukebox as a long-term archive. It will hold image data of nonactive cases on removable media. As mentioned above, the data base controlling search and retrieval is not part of this discussion, but it should be assumed that it exists and performs satisfactorily.

INBOUND TRAFFIC

Both data rate and data quantity vary from modality to modality. Digital cine for cardiac examinations produces the highest data rate of a least 8 Mbytes per s (Fig 2). This rate is equivalent to 30 images of 512 × 512 resolution and 8-bits data depth. Fast parallel disks are

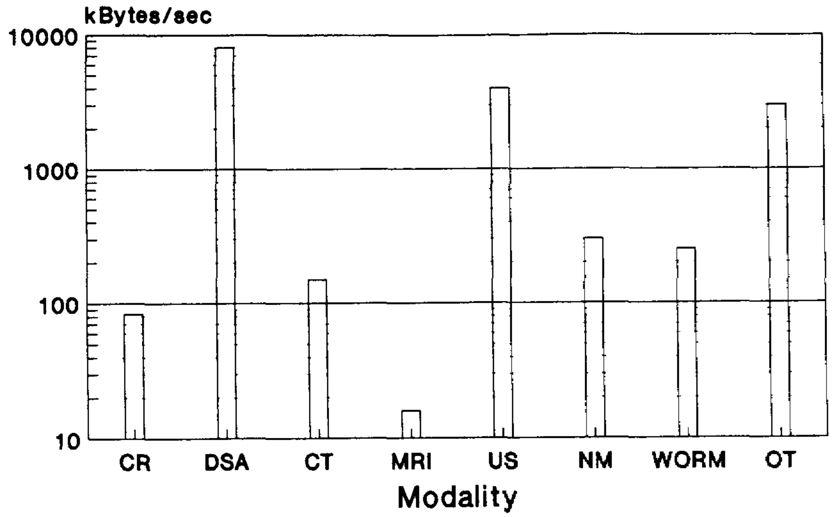

Fig 2. Comparison of various acquisition rates for modalities and for typical optical media and systems.

commonly used, but necessitate periodic transfer into a removable secondary storage and, therefore, interruption of data acquisition. This second storage should ideally offer inexpensive, yet fast archival storage. Although optical technology development was expected to produce equipment that can offer a data rate of 50 Mbits per s (6.3 Mbytes/second)[5] such development has not yet occurred, although a recently announced product[12] could qualify. Magnetic removable storage, providing high data rates at low medium cost, is also available.[6,7]

Other modalities such as CR, CT and MRI produce large amounts of data but at lower rates and are offered with dedicated optical storage. US and nuclear medicine imaging operate generally in cine mode but generate image of lower data quantities and lower resolution.

Optical tape[8] as used in the CREO system[9] (CREO Products, Inc, Burnaby, British Columbia) offers a sustained data rate of 3 Mbytes per second, but even this is too slow for on-line digital cine recording. CR is producing a large amount of image data but at a rate of only 83 kB per second. The limitation is the readout of the storage phosphor that is determined by a physical time constant. It is unlikely that the readout time can be significantly shortened.

COMPARISON OF REMOVABLE RECORDING MEDIA

Table 2 lists some of the most significant removable media for medical diagnostic recording.[10] The floppy diskette is still used but has limited capacity, although new developments will increase both capacity and data rate. Remov-

Table 2. Comparison of Removable Image Storage Systems

Storage Method	Capacity GB	$/Mbyte	System $k	Rate Mbyte/s	Access (sec)
Diskette	0.001	0.5	0.2	0.14	5
Removable-Magnetic disk	0.016	3.75	6	1.2	0.06
Magnetic tape	0.175	0.29	20	1.25	60
Helical tape (Honeywell)	5	0.002	40	2.0	45
Helical tape (Sony)	770	0.001	250	32.0	30
Cartilage tape (IBM 3850)	500	5	2400	0.875	16
12 in. OD	2	0.2	20	0.25	0.2
5.25 in. OD	0.2	0.325	3	0.1	0.2
CREO OT	1000	0.01	220	3.0	28
LTS OT	500	0.005	60	6.0	12
Outbound jukebox	128	0.2	135	0.25	15

NOTE. Media cost is in column two, system cost in column three. Optical jukebox is only one example, jukeboxes are now available up to a terabyte of capacity. Reprinted with permission.[10]

Abbreviations: OD, optical disk; OT, optical tape; LTS, laser tape system.

able magnetic disks are relatively expensive and of limited capacity and data rate. Magnetic tape is listed as reliable medium, certified for archiving of important information. Helical tape, capable of recording at high data rates, is offered by two companies: Honeywell has some time ago announced the VLDS[7] (Very Large Digital Storage) and Sony[6] has recently shown a digital instrument recorder with a recording rate of up to 32 Mbytes per second. This rate would suffice for recording 1000 × 1000 pixel images at video rates.

Optical disks of the WORM (Write Once Read Many) type are still slow,[11] but the optical tape system manufactured by CREO offers a sustained data rate of 3Mbytes per second. A new entry is the Digital Optical Tape System (Laser Tape Systems, Campbell, CA) that also uses the ICI optical tape in a standard IBM 3480 cartridge. Sustained data rates of up to 6 Mbytes per second are possible at low medium and system cost.[12]

ARCHIVING OPTIONS

Short-term archiving of images of active cases is performed by the image library. The average length of stay in US acute care hospitals is 6 days, which means that the image library should be large enough to hold 30 Gbytes of image data. Routine access to old images will further increase this number and increase the cost of such a massive image library. Two options are available. One is reduction of the data quantity by restricting use of CR to certain applications. A CR system can realistically handle 240 films per day (60 000 per year) and requires 8 to 12 Gbytes in the image library, depending on the quantity of old images. Even this magnitude is very large and will require the second option: improving the traffic between image library and archive.

Optical jukeboxes offer storage capacity up to a Terabyte (1000 Gbytes) and access time of the order of magnitude of 6 to 10 seconds. The optical tape system by CREO has slower access time but offers higher data rate and reduced cost. There is renewed interest in distributing image archiving over many disks whereby every patient would have an optical disk assigned.[13] Such an "Image Store and Carry System" would be the first of three options for a "filmless" 500-bed hospital. The daily procedure load of 363 is represented on the average by 121 patients. For a full year this amounts to 30 250 disks that have to be stored, accessed, and updated.

Option 2 would perform long-term archiving with a jukebox holding 100 disks of 2 Gbytes capacity each. Six hundred twenty-five disk would be needed per year or 2.5 disks average per day.

Option 3 uses the Terabyte optical tape system that can store a yearly workload of 1250 Gbytes on 1.25 reels of tape. The daily data quantity would only take up 5 meters of tape.

Obviously, there are advantages and disadvantages with any one of these three options, but technology has progressed to the point that such options are available and can be considered for a realistic implementation of PACS.

OUTBOUND TRAFFIC

Inbound traffic and storage are preconditions for the outbound traffic that supplies images to PACS workstations. The first portion of this traffic is transfer into the workfile of the display stations. Prescheduling during the off-hours greatly improves the performance, ie, the ready accessibility of images. The workstations should be equipped with sufficient storage space to hold at least one case, but preferably one session's worth of images. Three hundred sixty-Mbyte disk drives are generally available at such workstations. A critical performance is the speed with which images can be fetched onto the monitor. Experience with an electronic alternator installed at the University of Washington as deliverable of the Digital Image Network project[14] has shown that image change and image buildup within less than 1 second is acceptable while slower response is objectionable. This means that interim image storage at a workstation should be on parallel transfer disk with a transfer rate of 5 to 10 Mbyte per second. But even such a device may not supply the required performance if used in a conventional manner. Implementations are reported[15,16] using innovative approaches to fast image buildup and use of massive VRAM memories. Digital TV technology offers new possibilities of very fast image transfer while retaining digital data integrity. Such an approach has not yet received sufficient attention.

CONCLUSION

If a primary requirement of a useful PAC system is fast access to a large number of images, organization of image storage has to be optimized. This will require assessment of the various magnetic and optical storage systems but may also require a novel approach to storage space allocation. Parallel transfer magnetic disks offer already fast access to large data blocks and new developments in optical tape technology promise high data rates at very low medium cost. A review of the storage requirements of a filmless radiology department leads to the conclusion that short-term archiving would become complex and very expensive. The suggested solution is design of the long-term archive for fast access and reduction of the digital radiographic workload. Fast image access at the workstation could be accomplished by means of digital TV technology.

REFERENCES

1. Kenney G: Special purpose applications of the optical video disk system: IEEE Transaction on Consumer Electronics 1978, pp 327-334
2. Drew PG: Picture archiving and communication systems. AHA Hospital Technology Series 4, 1985
3. Elms D, Gorkic E, Gudaitis D, et al: Evaluation of several architectures for PAC systems. Proceedings SPIE 536:26-31, 1985
4. Sherman AB: Storage models for PACS: Proceedings SPIE 914:1425-1432, 1988
5. Kenney GC, Lou YK, McFarlane R, et al: An optical disk replaces 25 magnetic tapes: IEEE Spectrum 1979, pp 33-37
6. Sasanuma T: Sony Product Specifications (personal communication)
7. Honeywell: VLDS System specifications. Test Instrument Division, Denver, CO
8. ICI Electronics: Digital Paper specifications. Wilmington DE
9. CREO: Optical Tape Storage System: Product Brochure. CREO Products, Inc. Burnaby, British Columbia
10. Hindel R: Archiving radiological images on WORM optical storage, in Roth JP (ed): Converting Information for WORM Optical Storage. Westport, CT, Meckler Corp, 1990 pp 141-167
11. Hindel R: Review of optical storage technology for archiving digital images. Radiology 161:257-262, 1986
12. Conover A: DOTS: A digital optical taperecorder. Proceedings Optical Drive and Media Technology. Rothchild Consultants San Francisco, CA July 24-26, 1990
13. Ohyama A: Transportable image recording medium. Proceedings IMAC '89, June 4-8, 1989 pp 250-255
14. Loop WJ, Haynor DR, Ramey JA et al: DIN/PACS Evaluation Project: DIN Report. Univ of Washington, Dec 1989
15. Taaffe JL, Kaldis M, Gahm J, et al: Q-RSTAR Digital Image Management and Transmission: Proceedings SCAR '90, June 13-16, 1990 pp 432-438
16. Fasel B: Imagenet—Ein neues Datennetz fuer Bildinformationssysteme in der Medizin: VDI Verlag, Duesseldorf: Series 10, 1990, Duesseldorf, Germany