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Integrating HIS–RIS–PACS: the Freiburg experience

E. Kotter, M. Langer

Department of Radiology, Freiburg University Hospital, D-79106 Freiburg, Germany

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Abstract. With the integration of different formerly isolated information systems, such as Hospital Information System (HIS), Radiology Information System (RIS), Picture Archiving and Communication System (PACS) and modalities, we evolve towards an architecture of distributed information processing in radiology, the data being stored in distributed databases. The frontier between the cooperative information systems becomes more subtle than in the past, and it seems more convenient to distinguish the different computer functionalities or services used in radiology than to detail the functions of RIS and PACS. This paper opens with a description of the different computer services used in radiology and how they relate one to another. It also shows how these functionalities could be integrated within a global Radiology Information and Archiving System. Finally, it shows the degree of systems interconnection that can be achieved presently, using the PACS–RIS installation at the University Hospital of Freiburg as an example.

Key words: Picture archiving and communications systems – Radiology Information Systems – Hospital Information Systems – Radiographic image interpretation, computer assisted – Computer communication networks

Introduction

Historically, different information systems, such as Hospital Information Systems (HIS), Radiology Information Systems (RIS), and Picture Archiving and Communication Systems (PACS), have been introduced into radiology departments to meet specific needs. Hospital Information Systems were introduced to manage patient demographics, insurance information, billing and controlling. Radiology Information Systems usually manages patient scheduling, patient information (demographics and requisition information), imaging technique information, radiological reports, and management function for the radiology department. Picture Archiving and Communication Systems were introduced to meet the demands for a more time- and cost-effective image storage and transmission. Other information systems, such as automatic speech transcription systems [1] or systems for computer-assisted diagnosis, will be introduced in clinical routine in a few years.

The first generation of these information systems was established without an integration strategy. This led to a typical environment in which most data were stored in information systems, but usually on separate systems, with the need to manually reenter data to the different information systems and the use of arrays of computer terminals (HIS, RIS and PACS) to display all available information.

During the past years, many efforts in standardisation (DICOM, HL7) allowed a better approach of the systems integration in the radiology department. Using database-to-database transfer of information [2], information can be transmitted from the HIS to the RIS, from the latter to the PACS and the modalities, and be distributed within the hospital. The database-to-database transfer model makes it necessary to hold data redundantly on the information systems and to be very careful about database synchronisation in order to avoid inconsistencies.

The next generation of information systems will rely on a distributed database model, allowing the access to specific data through a single interface. Together with client-server computing, this will introduce the area of distributed information processing in radiology. Thus, the distinction between the different information systems in radiology will become less important and the integration of different information systems will become the cornerstone of information processing in radiology [3]. For this reason, we first analyse some important elements of PACS technology, then show how they could

Correspondence to: M. Langer

be integrated in the future, and later we describe a highly integrated cluster of information systems in radiology as it can be implemented presently.

PACS-related technology

Image acquisition

Many reasons are pushing radiologists towards increasing the proportion of digitally generated images. Historically, nuclear medicine was the first to introduce digital imaging techniques [4]. Computed tomography and MR images always exist in a digital format since they are computer generated. Digital subtraction angiography has led to digital fluoroscopy images. Ultrasound equipment has been digitised in the past two decades. The last area to convert is conventional projection radiography, mainly because the throughput and the image quality were not suitable for routine until recently. The availability of digital imaging methods for all fields of radiology allows the introduction of digital image archiving and management. The enhanced image management facilities of PACS in turn accelerate the introduction of digital modalities.

Interfacing of digital image generation systems

Any digital imaging equipment has at least two inputs and one output. The image data are generated by the imaging device itself (CT, MR) or introduced via an imaging plate (CR). The patient data are usually entered manually via keyboard. The image data leave the system together with patient and examination data to be printed or stored in a digital archive.

Until recently, the connection of an imaging device to film printers relied on industry standards or proprietary protocols; the connection to an archive was entirely based on proprietary protocols. The adoption of the DICOM Standard [5, 6] presently allows the connection of most recent imaging devices to a DICOM-compatible archive and printers [4]. Older modalities have to be connected to the archive using so-called gateways which translate the proprietary image format into a DICOM-compatible format.

The connection of fluoroscopy and ultrasound systems theoretically introduces the possibility of storing all images of an examination. This would result in a tremendous amount of data to be archived. The choice of most installations is to only archive selected images, as is done presently with hardcopies [7].

The manual entry of patient and examination data to the modality is subject to a high error rate and should be replaced by the automatic transmission of patient and examination data from the RIS to the modalities. The modalities should provide worklists where the patient and examination data can simply be selected by the technician. The DICOM standard has been extended to support the management of worklists [8, 9], but DICOM-compliant worklist management is not implemented on most modalities yet.

Table 1. Typical size of digital images

Procedure	Typical pixel size	Size of single image (Mbyte)	Typical no. of images/ procedure	Total size (Mbyte)
Chest X-ray pa and lateral	1760 × 2140	7.35	2	14.7
CT examination	512 × 512	0.52	40	21
MR examination	256 × 256	0.13	80	10.5

pa, postero-anterior

Storage technology

An efficient archive of radiological images must be able to safely store and retrieve very large data sets in a very short time. A typical CR image (35 × 43-cm imaging plate) holds 1760 by 2140 pixels, i.e. 3766400 pixels. Each pixel is stored in two bytes, so a total storage space of 7.356 Mbytes is needed for a single CR image. Table 1 gives a synopsis of memory requirements of different imaging techniques.

In very large PAC systems, the peak image acquisition rate can be as high as 1.8 Gbytes per hour [10]. This data stream would push the limits of current storage technology if a single image archive were used. Distributed archiving of images on multiple image archives achieves a higher data throughput and seems to be an appropriate technology for the short-term storage of images [10].

The need for a very fast image retrieval and the need to store very large amounts of data oppose one another. The price of data storage media is inversely proportional to their speed. For reasons of economy and data safety, it is impossible presently to store all data on fast magnetic disk subsystems [11]. One solution to this dilemma is to store all data with a high probability to be accessed in the near future on a fast and expensive storage subsystem, and to hold the complete set of image data on a slower but less expensive storage medium. This kind of storage management is called hierarchical storage management (HSM).

This term embraces the interconnection of storage media in a cascade and the use of intelligent algorithms to determine where the data have to be stored in order to guarantee short retrieval times. Table 2 resumes the different storage media in use.

The ideal storage medium for PACS purposes should be reliable so that data once stored are guaranteed against alteration, fast for both access and transfer speed, and cheap in medium costs and costs of the infrastructure (jukebox, robot). Frost discusses classical storage technologies [12]. He points out the need of a PACS architecture flexible enough to support the integration of new storage technologies as they appear on the market.

Write-once media

Most PACS installations employ jukeboxes of WORM (Write Once, Read Many) platters as mass storage medium. These optical disks offer the advantage of high-

Table 2. Characteristics of typical storage media. RAM random access memory; WORM write once, read many

Storage medium	Typical capacity	Typical access speed	Typical transfer speed (Mbyte/s)	Average price per MByte (medium only; ECU)
RAM	16 Mbyte (PC) to 1 Gbyte (workstations, servers)	< 100 ns		7.5
Magnetic disk	1 Gbyte (PC) to 200 Gbyte	< 20 ms	8	0.15
Magneto-optical disk	2.6 Gbyte/disk	< 35 ms	3	0.10
Optical tape	1 Tbyte/tape	?	?	?
Optical disks (WORM)	50 Gbyte to 2.4 TByte	< 30 s	1	0.05
Magnetic tape robot	Up to 50 Tbyte and more	< 35 s[a]	15	0.00014

[a] See [14]

density storage with superior data security. Data stored on these disks cannot be erased or modified since it is literally burned into the surface of the disk. Only physical destruction of the disks can destroy the data.

On the other hand, the access to the stored data is relatively slow compared with magnetic disks, and the WORM media are expensive compared with magnetic tapes. As data cannot be erased from the disks, and as data are written to disks in a more or less consecutive manner (it is impossible to reserve an entire disk for every patient), the data of one patient will usually be distributed over several disks, thus increasing the need for time-consuming disk changes [13].

Rewritable media

With rewritable media, such as magneto-optical disk (MOD) or magnetic tapes, the data can be reorganised in such a way that all images belonging to a particular patient are stored on one or more cassettes or disks instead of being distributed on a large number of media, thus reducing robot motions and increasing performance while retrieving images [13].

Recent high-capacity tape technology combines several types of tapes in one single robotic system functioning as a fileserver [13, 14]. Data transfer rates of 19 mm D2 helical scan tape cassettes (digital videotape) exceed those of optical disks (15 Mbytes/s compared with 2 Mbytes/s). Data security is guaranteed by continuous verification of data integrity of the tapes. Whenever error rates exceed 1 bit in 10^{13} on a tape, this tape is copied to a new cassette, and the old tape is discarded. The ability to combine several generations of media in one robot guarantees data integrity over a long period.

One possible problem with rewritable media as compared with WORMs is that data are not protected from manipulation.

Outsourcing

Mass storage of historical data could be outsourced. Several vendors propose the long-time archiving of large amounts of data. To our knowledge, no PACS installation uses this kind of technology. The main advantage of this approach is that the hospital delegates the responsibility for the data security to the provider. In this scenario, the storage provider has to guarantee the integrity and inalterability of the data. He is also responsible for providing a state-of-the-art storage system, including data migration from one storage technology generation to the next. Data security as well as legal aspects of this technology have to be evaluated.

Network technology

The use of a standardised network technology is a prerequisite for digital image communication. Due to the limitation of then-existing network technologies, promising attempts were made in the early 1990s to develop specialised network technologies for medical image communication [15, 16], but the market of medical imaging is too small to set standards in the field of networking.

One can distinguish between two basically different network technologies: shared medium technologies and switching technologies. In shared medium technologies (broadcast networking), the bandwidth of the communication medium is shared between all instances exchanging messages and the bottleneck in terms of throughput is the bandwidth of the communication medium. In switching technologies, a switch establishes a point-to-point communication (channel) between two instances every time it is necessary. Each channel has access to the full bandwidth of the transport medium, the limiting factor being the bandwidth of the switch. The most popular networking technologies are listed in Table 3. Several good introductions to networking in radiology have been published [16–19].

During the past years, asynchronous transfer mode (ATM) has been considered by many authors as the networking technology best adapted to image communication in medicine [20–23]. An ATM network provides an aggregate bandwidth and throughput that seems sufficient to satisfy the needs of image communication in radiology [20]. The use of an ATM network allows the use of up to 90% of the channel bandwidth (usually 155 Mbit/s). The switches in an ATM network establish point-to-point communications. Up to the maximum bandwidth of the switches (aggregate bandwidth), the throughput of an ATM network does not decrease with the number of communicating instances. In contrast to Ethernet LANs, ATM networks also can operate as

Table 3. Characteristics of different network architectures. FDDI fibre-distributed data interface; ATM asynchronous transfer mode; CSMA/CD carrier sense multiple access with collision detection; UTP unshielded twisted pair; STP shielded twisted pair

	Broadcast Networks			Switched channels	
	Ethernet IEEE 802.3	Fast Ethernet	FDDI (Fiber Distributed Data Interface)	Switched Ethernet	ATM (Asynchronous Transfer Mode)
Topology	Bus	Bus	Dual ring	Star	Star
Access method	CSMA/CD	CSMA/CD	Timed token passing	CSMA/CD	Cell switching
Transport medium	Coaxial cable, STP and UTP		STP, UTP, Optical fiber	STP and UTP	Optical fiber
Transmission rate	10 Mbit/s	100 Mbit/s	100 Mbit/s	10 Mbit/s per channel	155 Mbit/s per channel[a]

[a] Up to 622 Mbit/s per channel. Overall data rate limited by the switch (usually > 2 Gbit/s)

Table 4. Viewing stations

Type of viewing station	Main purpose	Required characteristics
Diagnostic viewing station	Primary diagnosis in radiology department	High-resolution, high-luminance monitors. At least two monitors.
Result viewing station	Access to images and reports from outside radiology department	Low-cost system with standard hardware, using graphic hardware of good quality
http viewer	Access images and reports from outside radiology department, possibly from outside hospital	Runs on all computer systems equipped with a WWW browser. Soft- and hardware independent
Presentation viewer	Allows presentation of radiological images to a large audience during case conferences.	Fast and easy-to-use system connected to a video beamer for better visibility to large audiences

wide area networks (WAN), allowing communication over greater distances (for teleradiology purposes) [21]. The speed of ATM networks allows access to images stored on an image server even faster than images stored locally on the hard disk of a standard workstation [22]. This enhanced network speed together with an intelligent and powerful image server architecture may simplify the architecture of future PAC systems because the complex and time-consuming strategies of preloading and auto-routing are no longer necessary. The ATM networks can be combined with switching Ethernet technology, reserving the more expensive ATM links for high-throughput workstations and servers (image and database servers, workstations in the radiology department, intensive care units and the operating theatre) and using cheaper Ethernet links for simple viewing stations on wards.

Viewing stations

A viewing station gives access to all stored images in a PACS environment. Ideally it also integrates access to other information stored in the RIS and the HIS. Many different viewing station designs have been implemented over the past years [24–29], none of them proving to be the ultimate solution. With respect to their main function, different types of viewing stations can be distinguished (Table 4). As they constitute the interface to the system, all of these viewing stations are critical factors for the success of a PACS in the hospital.

Diagnostic viewing station

The diagnostic viewing stations (DVS) will be the routine workplace of the radiologist and great attention must be paid to their architecture and ergonomy. The DVS must be able to display examinations from all modalities (multi-modality viewing station) in a diagnostic image quality. Easy access to historical examinations and reports has to be guaranteed.

In terms of graphic hardware, the minimum configuration required by most authors is a solution with two CRT monitors of 2000 × 2000-pixel resolution and high luminance (> 500 lumen) with a high dynamic range [30]. The CRT units have to guarantee a sufficient image geometry. As individual differences between CRTs are often encountered, the monitors should be selected in pairs with the same image characteristics (same brightness, same phosphor colour). More than two monitors can be useful for comparison to previous examinations but require more space.

Ageing of CRTs with subsequently decreasing luminance is a potential problem and quality monitoring of soft-copy displays should be automated and managed by the PACS [31].

To ensure an ergonomic interface, an operating system based on the windows metaphor should be used for the diagnostic viewing station. Arrangement of images on the different screens in pre-set orders should be automatic [32] and managed by a rule-based system [29]. Basic image manipulation functions must be provided in order to fully exploit the potential of digital images. The two most often used image manipulation functions are centre-window adjustment and image rotation, and these functions should be speed-optimised in order to save time. Centre-window adjustment is used for digital radiographs as well as for CT and MR examinations and allows a dynamic observation of the grey levels of the images. As this function will be performed for virtually each displayed image, it must perform in real-time (it is impossible to do centre-window adjustment without feedback) and should be extremely simple to use. Automatic preset windows, image enlargement (zoom) and translation (pan) should be available.

In addition to conventional viewing of CT and MR examinations, the diagnostic viewing station should provide the possibility to scan through virtual stacks of images (stack or cine-mode). Some viewing stations additionally allow to step parallely through two or more stacks of images (actual and previous examination, examination without and with contrast medium, different MR sequences). In our experience, this feature allows faster interpretation and reporting of CT and MR examinations.

Some calibrated quantification functions are needed: spatial measurements (length, surface, volume) and density measurements (in Hounsfield units for CT). More advanced image processing functions usually are not needed for primary diagnosis and should be reserved to specialised workstations [29].

Result Viewing Station

The Result Viewing Stations (RVS) are mainly intended for the access to radiological images and reports from the clinical wards. For economic reasons, the hardware is less powerful than the DVS hardware. The use of standard PCs running Windows 95 (Microsoft, Seattle, Wash.) allows use of the same hardware for purposes other than PACS purposes. For the acceptance of the PACS by non-radiologists, the RVS should be very simple to use in order to avoid extensive user training. The RVS should be able to present the radiological image together with the radiological report because of the non-diagnostic quality of the graphic hardware. Except image rotation and centre-window adjustment, no image manipulation function is necessary at these workstations; the images should be presented in a way that demonstrates the radiological findings. Specialised RVS may integrate programs for planning of surgical interventions such as the measurements of the dimensions of a total hip prosthesis.

The integrated radiology information system

In many PACS installations there are multiple problems resulting from insufficient integration between different information systems. The redundant entry of patient demographics and examination data results in high rates of data inconsistency in the different databases, this rate may be as high as 33 % [33]. There is no doubt that the integration between HIS, RIS and PACS is absolutely necessary to establish efficient routine PAC systems [3, 34–37].

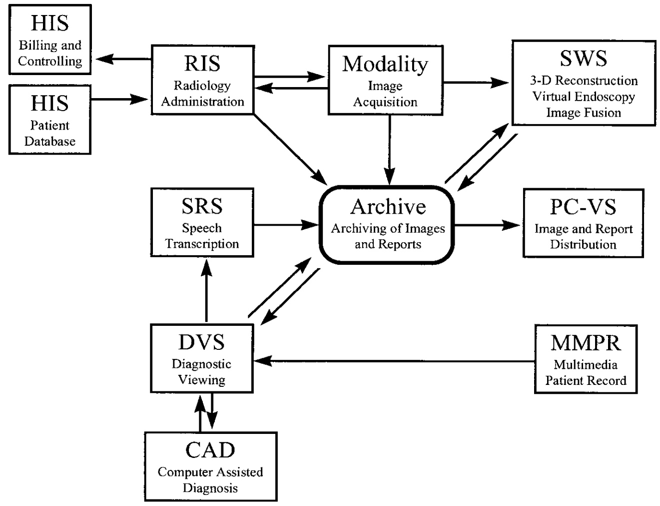

Fig. 1. A totally integrated radiology information and archiving system. *SWS* specialised workstation; *SRS* speech recognition system; *PC-VS* PC viewing station

Another reason for systems integration is that most of the information needed for an efficient PACS image management is stored in the RIS or the HIS. The arrival of a patient to the hospital calls for the retrieval of images from the long-term storage medium to the (faster) short-term storage medium. Most authors agree that the RIS has to be the master of the PACS because the RIS has a broader knowledge about what is going to happen in the radiology department [2, 38]. Figure 1 shows the architecture of a hypothetical integrated RIS.

The HIS patient database sends actualised patient demographics to the RIS either when the patient presents himself to hospital admission (push mechanism) or when he presents himself to the radiology department (pull mechanism). When examinations have been performed, the RIS sends billing data back to the HIS. Communication between HIS and RIS usually uses the HL7 standard or is proprietary.

When an examination has been scheduled, the RIS transmits the corresponding patient demographics and examination data to both, the modality where the examination is to be performed, and the archive. The communication protocol used here is DICOM (HL7 may be used for communication with the archive). When the archive receives scheduling data for a patient who has not been in the radiology department for several months, it automatically retrieves all previous examinations for this patient from the long-term storage module (optical disk or magnetic tape) to the faster RAID system.

The modality provides a worklist allowing to choose the patient and examination to be performed. When the examination is completed and eventually post-processed on the modality or a specialised workstation (SWS), the images are sent to the archive. The archive stores images on the RAID system and indexes them in its database. The modality sends back to the RIS all necessary billing and radiation exposure data.

Interpretation of examinations is done by the radiologists on diagnostic workstations. On every diagnostic

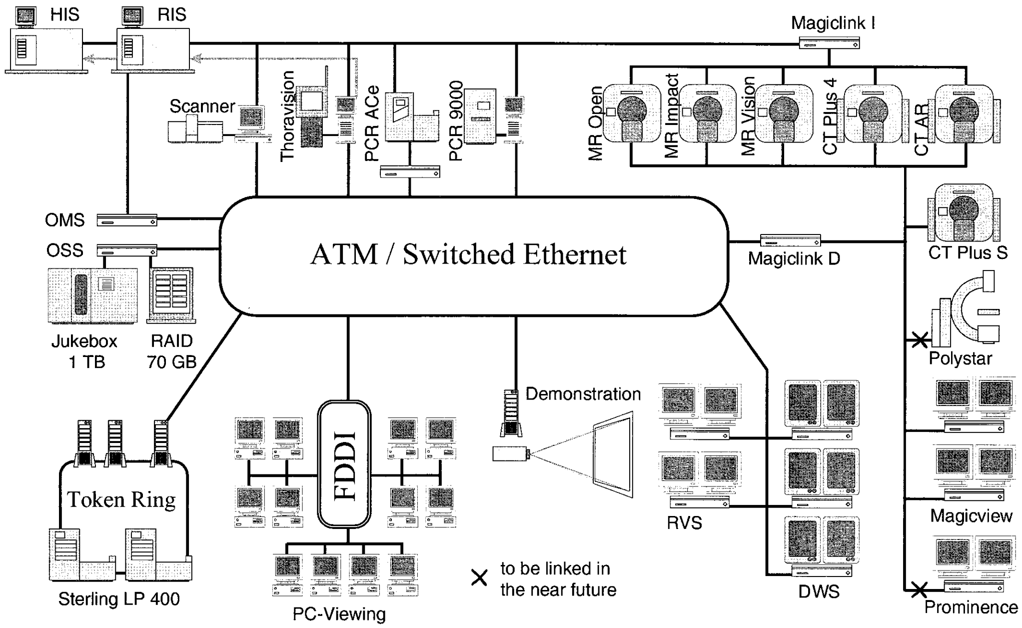

Fig. 2. PACS project status at Freiburg University Hospital

workstation in the department the radiologist can display his personal worklist, containing folders of all patients with examinations he has to report. Every patient folder contains not only the examination to be reported, but also all previous examinations of this patient. On request, the images of the actual examination are transferred from the RAID to the diagnostic workstation and displayed on the CRT. A rule-based expert system will determine in the future if any of the previous examinations may be helpful for the interpretation and triggers the loading and display of these examinations.

From the viewing station, the radiologists will have access to databases of normal and pathological image examples stored in the archive and to expert systems in different fields and to some tools for computer-assisted diagnosis. The access to the hospital-wide multimedia patient record allows the integration of clinical information in the image interpretation process.

In a few years, speech recognition systems, either integrated in or near the diagnostic workstation, will allow real-time transcription of the radiologists' report [1]. Once the report has been transcribed, it is electronically signed off by the radiologist and stored in the archive. The radiologist selects the diagnosis-relevant images of the examination and marks them with a flag.

All signed-off images and reports are accessible throughout the hospital from multifunctional and inexpensive PC viewing stations. These PC–VS always display the diagnosis-relevant images of an examination together with the radiological report. Upon request to the archive, the PC–VS can receive all the images of an examination.

The multimedia patient record is a database collecting all relevant medical information (or the links on this information) on patients. It also contains the diagnosis-relevant images in a reduced format (smaller image matrix, grey levels reduced to 8-bit depth) and an extract of the radiological report. When a user asks for the full report or the full-size image, these are dynamically requested and retrieved from the archive to be displayed.

PACS and other information systems at Freiburg University Hospital

Freiburg University Hospital is one of the largest teaching hospitals in Germany. It has more than 1900 beds. Approximately 50,000 inpatients are treated every year and 300,000 outpatient visits per year are performed. The department of diagnostic radiology at Freiburg University Hospital is located in different buildings through the hospital. It is composed of the following main areas: surgical diagnostic radiology, medical diagnostic radiology, paediatric radiology, neuroradiology and gynaecological radiology.

Starting in 1988, the introduction of a picture archiving and communication system was proposed [39]. Due to changes on the vendor's side, technological changes, such as the appearance of ATM, and the introduction of the DICOM 3.0 communication standard, the project was delayed until 1993, when the final project was approved [40, 41]. Development started in 1994, and installation was started in July 1996 and is still ongoing. The system has been in routine use since April 1997. The following describes the actual status of the project (Fig. 2) and some of the modifications due in the near future. Results of our first experiences with the system are given in the appropriate sections.

Systems integration

Identification criteria

Figure 3 shows the identification criteria used in our information system. The HIS (proprietary system)-generated personal identification number (PIN) is transmitted to the RIS when an examination is booked. During booking, the RIS (RADOS-M, Philips Medical Systems, Hamburg, Germany) generates a Study Instance Unique ID (SI-UID, as defined in the DICOM standard) for every examination. Together with patient demographics, these IDs are transmitted to both the archive and the modality where the patient is to be examined. When the images are sent to the archive, they contain these IDs in their header. In the archive, the SI-UID allows association of the images to the correct examination.

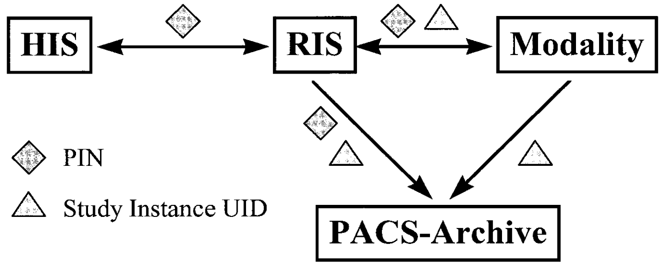

Fig. 3. Identification criteria used in the Freiburg PACS. *PIN* personal identification number

Transmission of data from HIS to RIS

When a patient presents himself to the hospital admission office, after entry or update of his personal data, the HIS generates an eight-digit PIN. This number is unique and remains unchanged for the life of the patient.

Upon scheduling an examination in the RIS, all relevant patient data together with the PIN are transmitted from the HIS to the RIS (Fig. 4). Based on the PIN, the RIS identifies patients already existent in its database. Manual input of patient data to the RIS is reduced to a minimum; only the examination-relevant data have to be entered.

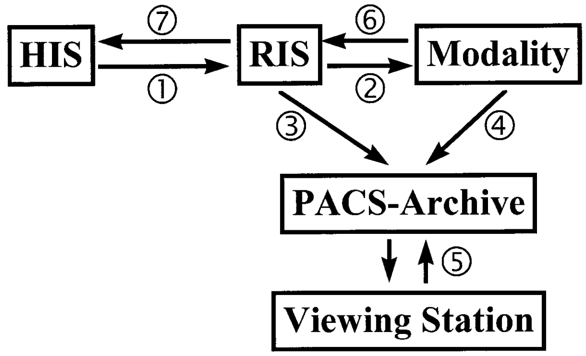

Fig. 4. Dataflow in the Freiburg PACS. *1* Transmission of patient data from HIS to RIS (proprietary); *2* patient and examination data from RIS to modality (proprietary); *3* patient and examination data from RIS to PACS archive (ACR/NEMA 2.0); *4* image data from modality to PACS archive (DICOM); *5* image data between PACS archive and viewing stations (DICOM); *6* data about the performed examination from modality (only Thoravision) to PACS (proprietary); *7* controlling data from RIS to HIS (proprietary)

Transmission of data to the modalities

During the process of booking an examination, the RIS generates an SI-UID. Together with the PIN and the type of examination, this SI-UID is transmitted to the modality where the examination is to be performed.

Most of the modalities were not prepared to receive patient data. The DICOM standard definition for worklist management now provides a well-defined interface for such purposes. For the modalities in our department we had to convince the manufacturers to adapt their systems to be able to receive a simple form of worklist from the RIS. This resulted in all cases in a proprietary interface, usually by transmitting a simple ASCII file containing the booked examinations to the modality.

We now discuss the two main pathways used for transmission.

Direct transmission of ASCII data to the modality. This is in use for the Thoravision system (Philips Medical Systems, Hamburg, Germany, the PCR 9000 System, the PCR Ace System (both Philips Medical Systems, Best, The Netherlands), and the Film Scanner. All of these modalities provide a worklist displaying patient names together with scheduled examinations in several ways:

1. The Thoravision worklist is displayed on the EasyVision controlling the Thoravision and is easy to use. The worklist sets a flag for completed examinations and does not display them in the worklist.
2. The PCR 9000 worklist is displayed on a special liquid crystal display (LCD) and is also easy to use. Patient names are erased from the worklist when the film cassettes for the planned projections have been read. In the case when fewer than the planned projections are read for a patient, the system asks if the examination is finished and removes the patient from the worklist in that case.
3. The PCR ACE worklist is also displayed on an LCD, but two major inconveniences surfaced: (a) patient names are only erased from the worklist after a fixed period of at least 24 h, resulting in very long worklists; and (b) the user has to operate the worklist on a touchscreen, which proved to be to delicate to manipulate, especially when the technicians are in a hurry and when the worklist is very long.
4. The film scanner worklist is displayed on the workstation controlling the film scanner. After the scanning process, when choosing another patient in the worklist the user can decide if he wants to maintain the examination in the worklist.

For modalities with a high throughput, such as the PCR systems and the Thoravision system, the mechanism of deletion of examinations from the worklist proved to be very important because worklists otherwise become too long.

Transmission to the SIENET world via Magiclink I. In this case data are transmitted to the Magiclink-I interface (Siemens, Erlangen, Germany) via an NFS-mounted directory. One field in every data set contains the information where the examination has to be performed. The Magiclink I routes the information only to the specified modality using the Sienet protocol:

1. For a Somatom Plus S (Siemens, Erlangen, Germany) CT scanner, no interface could be built. This modality is not able to receive the desired information from the Magiclink I.
2. The Magnetom Open, Magnetom Expert and Magnetom Vision (all from Siemens, Erlangen, Germany) have to receive the desired information from a single dummy image, containing the data in its ACR/NEMA 2.0 header. In the database of the modality, the patient is displayed as if an examination has been performed on this modality. The user interface of these modalities allows performance of a so-called renewal of examinations. Unfortunately, there is no possibility to distinguish between patients who already had an examination and those who did not. On modalities with a relatively low throughput, such as MR systems, this is tolerable, but a true worklist mechanism would be preferable.
3. The Somatom Plus (Siemens, Erlangen, Germany) 4 CT scanner provides such a worklist. In this case, the data are sent directly from the Magiclink I as ASCII data to the modality. The modality provides a so-called RIS list, containing all data received from the Magiclink I, and acting like a worklist: the data of the patient can be copied with a click of the mouse into the registration mask of the modality.

Both solutions (for MR and CT systems) perform well in routine operation and were readily accepted by the technicians.

Unfortunately, none of the Siemens modalities provided a data field for the SI-UID, and there was no reserve field that could be used. In all cases, including the Somatom CT Plus 4, we had to misuse an existing field, e. g. “admitting diagnosis”.

For all modalities, the worklist is usually updated in less than 1 min. We experienced some loss of data which had not been tracked down at the time of writing: up to eight data sets per day are not transmitted to the modalities despite a correct process of booking.

Transmission of images from the modalities to the Picture Archive

Some of our modalities provide image communication with the archive compatible with the DICOM standard. The PCR 9000, the Thoravision system, and the Filmscanner Workstation are DICOM compatible. These modalities communicate directly with the archive.

Our Siemens modalities are not directly DICOM compatible. They send their images to the Siemens Magiclink D gateway, which translates the ACR/NEMA 2.0 based SIENET format into a DICOM format and communicates with the archive in the DICOM protocol. Initial problems with the transferred DICOM images showed that these images contained many so-called retired attributes. This is a consequence of the translation process and cannot be resolved until the modalities themselves become DICOM compatible.

For the oldest modalities (e. g. PCR ACE) an interface is used to translate proprietary image format into DICOM format.

For all modalities, one has to choose if all images will be sent to the archive immediately after generation of the image, or if they will be sent once the examination has been completed, reviewed and the images are possibly adjusted by the technician. For tomographic examinations (CT and MR), one clearly has to first complete the examination before sending it to the archive. In this case, the images are sent to the archive either manually (MR modalities) or automatically (CT Somatom Plus 4) once the examination is completed.

This process is different for projection radiography. These modalities often have a high throughput and the technicians usually do not have the time to do time-consuming image post-processing on the associated consoles. Our Thoravision system sends the images automatically once the examination is marked as completed by the technician; image adjustments can be done before this step. The PCR ACE does not offer any post-processing workstation; every image is automatically sent to the archive “as is”. The PCR 9000 system was set up to send all images automatically to the archive once they are generated because of the high throughput of this machine. In this case, eventual post-processing has to be done by the radiologist on the viewing station.

All images transmitted to the archive (except for the Somatom Plus S which has no RIS interface) contain the RIS-generated SI-UID in their DICOM header.

RIS–PACS interface

At the same time data are transmitted to the modalities, data about the patient and the examination are transmitted to the PACS archive. These data always include the PIN and the SI-UID. The Archive database is updated and “knows” of the examination from the time of transmission forward. When the image files are transmitted to the archive, the SI-UID allows immediate association between images and the study.

In our system, the SI-UID is the only criterion used to associate images to an examination. Images sent to the archive without SI-UID (in case of malfunction of the RIS modality transmission, or incorrect use of the worklist of the modality, or timing problems – the image arriving to the archive before the data from the RIS) are accepted by the archive but stored in a special collection of unknown objects. These unknown objects can be associated with the correct examination with a special tool available only to authorized persons.

RIS–PACS transmission is done on an ACR/NEMA 2.0 basis by simple file transmission via NFS.

Modality–RIS interface

This interface exists for only one of the modalities in our department. The Thoravision system sends back to the RIS all data about performed examinations which normally have to be entered into the RIS by the technician. This interface works on a proprietary basis.

RIS–HIS interface

The RIS sends all billing information back to the HIS. This is done by an ASCII file transfer in a proprietary format.

Archive architecture and storage technology

The archive used in Freiburg (Archimedis, Philips Medical Systems, Hamburg, Germany) stores both radiological images and reports. Images and reports are stored in a Patient-Request-Study-Series-Image/Report hierarchy. Every patient is identified by his PIN (generated by the HIS), every request is identified by a request identification number (RIN), and studies and series are identified by the DICOM-compliant SI-UID and SI-UID.

The communication between the archive and the modalities, and between the archive and the PC viewing stations, uses the DICOM protocol. For better performance, the communication between the archive and the diagnostic workstations uses a proprietary protocol, allowing the workstations to have direct access to the archives database and to realise advanced functions such as the automatic update of worklists.

Conceptually, the archives' functions can be grouped into the object storage systems (OSS), the object management system (OMS), and the workflow manager (WFM). The OMS is the central database of the PACS. It contains all information about the objects (images and reports) stored in one or several OSS, and thus allows the distributed storage of all objects (images and reports). The OMS associates the images and reports stored with the patients and examinations and knows where and how to retrieve them. The OSS can exist in one or several instances. It stores the images on mass storage media and constitutes an abstraction layer between the OMS and the mass storage device. Several OSSs with different mass storage media can coexist in one PACS, the access to all information being transparent for the OMS, thus allowing the distributed archiving of images and facilitating data migration from one storage technology to another in the future. The WFM allows rule-based retrieval and preloading/auto-routing of images and reports and continuously updates the worklists on the diagnostic workstation (DWS). In the future, a supplementary module will control the access rights to the system in a way adapted to a large hospital [41].

The entire archive runs on two single-processor 167-MHz UltraSPARC workstations with a good performance. The mean data volumes are indicated in Table 5.

Table 5. Mean data volumes

Modality	Images/day (archiving)	Data volume/day (archiving; GByte)	Data volume/day (retrieving; GByte)
CR	240	1.8	2.5
CT	2400	1.2	0.8
MR	1300	0.4	None

We have in use one OSS using a 1-TByte DSM 12″ WORM jukebox with two drives. The jukebox can be upgraded stepwise to a 3-TByte jukebox. Incoming images are first stored on a RAID subsystem with a capacity of 90 GByte. A simple high- and low-watermark algorithm determines when images are transferred from the RAID system to the jukebox. The images to be transferred to the jukebox are chosen according to the first-in first-out principle, but more efficient algorithms, such as last-recently-used, will be introduced in the future.

Network

In order to avoid the throughput problems associated with shared media network technology, we chose the use of a switching network concept. We opted for a high-capacity ATM/switched Ethernet solution allowing us to preserve elements of the preexisting network infrastructure, using the ATM Forum's LAN emulation (LANE) specification [42].

We have chosen a CELLplex 7000 ATM switch (3Com) with a 16×16 switching engine and a 2.48 Gbit/s switching capacity. This switch supports both ATM (155 MBps) and Ethernet (10 MBps) ports and LANE 1.0 services and clients.

The imaging modalities are linked to switched Ethernet ports with a dedicated bandwith of 10 Mbps per port. The servers (OMS and OSS) are linked over ATM lines with 155 Mbps. The interconnection to the existing FDDI hospital backbone is foreseen to be done by an ATM downlink to a router with an ATM interface card (it still uses an Ethernet link). The DWSs are still connected over switched Ethernet but will be connected over ATM in the future.

Viewing

Two types of workstations were developed for our PACS. The diagnostic workstation (DWS, Philips Medical Systems, Hamburg, Germany) is primarily intended for use within the radiology department, whereas the more economic PC viewing station (PC-VS, Philips Medical Systems, Hamburg, Germany) is intended for use on the wards. Five DWS and eight PC-VS are currently in use. Other DICOM compliant viewing stations can be connected to the system for special purposes.

The DWS hardware consists of an UltraSPARC workstation with 256 MByte RAM and a 3 GByte hard disk. It uses specialised graphic boards (DOME) and two or more high-resolution (2300 × 1700 pixel), high-luminance (500 lumen) portrait monitors (Image Systems). The user interface is entirely based on X11/Motif and is mouse/keyboard driven. The software allows the display of images of all modalities in specialised viewers, each of which is equipped with the functions needed for the type of images it displays. The DWS displays a worklist composed of the folders of all patients with new examinations to report. For a faster display, the images of the actual examination are preloaded on the workstations' hard disk. In the future a rule-based system will allow the selective preloading of images of previous examinations to the DWS. Although the DWS allows the routine reporting of CR images in an ergonomic way, our radiologists still prefer to report MR and CT examinations from hardcopies or the MagicViews (Siemens Medical Systems, Erlangen, Germany) because of the ergonomically insufficient stack-view feature of the DWS.

The PC-VS consists of standard PC hardware running under Windows 95 or Windows NT (Microsoft, Seattle, Wash.). The software was designed to allow easy access to the images and reports stored in the archive. For use on the wards, the PC-VS can be configured to always retrieve and display the radiological report together with the images.

Demonstration of radiological images

During interdisciplinary clinical conferences, radiological images have to be presented to large audiences. We developed a specialised viewing station for the presentation of radiological images [43]. The system functions much like a conventional auto-alternator. During the preparation of the demonstration, the images to be presented are retrieved from the archive and arranged side by side on tables. During the conference, the different tables can be displayed even faster than with an auto-alternator and are displayed on a large screen by a video projector.

Conclusion

We achieved a high integration of different, formerly isolated operating information systems in a large radiology department. The interfacing of different information systems allows the correct identification of all data in the system. Loss of data due to errors in data entry was virtually eliminated and all image and report data are correctly associated with the patients. The use of a hospital-wide identification for all patients paves the way for the future introduction of a hypermedia patient record integrating information from different departmental information systems.

The consequent use of internationally recognised standards, especially the DICOM standard for image communication, allowed the integration of systems from different vendors. Our experience shows that different flavours of the DICOM standard exists, and that it cannot be considered as a plug-and-play standard: adaptation is sometimes necessary. When planning for a PACS or integrating new modalities to an existent PACS, the comparison of the DICOM conformance statements is an important step [6]. A comprehensive DICOM test suite would greatly simplify future use of DICOM-compatible equipment [44].

The use of gateways translating proprietary image formats to a DICOM-compatible format is a realistic way to integrate modalities that are not DICOM compliant.

The realisation of interfaces from the RIS to the modalities is one of the cornerstones in our PACS, as it allows the transmission of data needed for the correct identification of image data in the archive. Because the manufacturers have not yet implemented the DICOM standard for this purpose, proprietary solutions were established. The RIS–modality interfaces in use perform well, lead to a near 100 % correct association of images with patient and report data. Moreover, these interfaces greatly facilitated the acceptance of the complex and new system by the radiology technicians as they simplify their work by eliminating the manual entry of patient data to the modalities.

Different kinds of viewing stations were developed for use in the radiology department, on ward and for presentation of radiological images to a large audience. The viewing stations for the wards are still in a test phase.

The presentation of images to a large audience from the PACS is in routine since October 1996 and constitutes progress in comparison with conventional film presentation on an alternator because the image visibility was greatly enhanced. The image quality of the diagnostic workstations is sufficient for the routine work in radiology, but the software ergonomy is still to be enhanced to allow better reporting of CT and MR examinations.

Within the radiology department, the system automatically manages the workflow by establishing worklists and preloading the corresponding images to the workstations. This feature allows a better throughput for radiologists.

The PACS at the University Hospital at Freiburg has been in operation since April 1997. It is intended to provide filmless operation in the future, but this goal can only be achieved with more ergonomic CT and MR viewing and the deployment of PC-VS on the wards. Other future developments include the connection of several digital modalities to the system within the next year and the replacement of proprietary interfaces between the RIS and the modalities as soon as the manufacturers ship DICOM-Worklist-Management for their modalities.

The assessment of PACS is very complex and data from different studies disagree about the costs and benefits of PACSs [45]. No standardised model for cost-benefit studies exists, and well-defined criteria of the costs and benefits of PACS are missing. We probably need more experience with PACSs before these criteria can be defined [46]. Only large multicentre groups with extensive experience with PACS can define these standardised criteria [47].

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Book review

European Radiology

ESNR CD-ROM educational series, Lasion Europe N. V., Aartselaar, Belgium.
Balériaux D. et al: MRI of Spinal Cord Diseases, vol. 1, **US $ 195.00, Edition '95–'96.**
Patay Z. et al: Applied MR Neuro-Angiography, vol. 2, **US $ 195.00, 1997.**
Wilms G. et al: Imaging of Cerebral Tumors, vol. 3, **US $ 195.00, Edition '97–'98.**

In the Western world one may assume that every physician has access to a computer and that many use PCs for running their business and writing letters, that they access the Internet, communicate by e-mail and use Medline, Embase and other medical sources to obtain up-to-date information about a variety of medical issues.

Apart from the many opportunities to access existing knowledge via the Internet, a sophisticated computer system offers the possibility of using CD-ROMs for entertainment, information and learning.

In a combined effort of the European Society of Neuroradiology, Nycomed and Lasion Europe NV and with the driving force of D. Balériaux, 3 CD-ROMs on neuroradiological subjects are now available: on spinal tumours, MR angiography and cerebral tumours.

In this review we will address three questions:

1. What is the required computer configuration?
2. What are the advantages and disadvantages of the CD-ROM learning system?
3. Will electronic learning and information eventually replace books and journals, even conferences, courses and congresses?

Finally we will review the three CD-ROMs in more detail.

1. *Installation and configuration requirements.*
The system requirements as given in the manual of the CDs are: IBM compatible PC, 486 or higher, 8 MB RAM, 256 super colours VGA monitor, ISO 9660 CD-ROM drive, Microsoft compatible mouse, Microsoft Windows 3.1 or higher. Note that these are minimum requirements. It is especially important that the PC is equipped with an appropriate video adaptor (graphic card) and that the corresponding driver is properly installed to run at least 256 colours.

2. *Advantages and disadvantages.*
If your PC satisfies the requirements listed under point 1, you start the machine, put the CD-ROM in the driver and follow the instructions. Immediately after that you can open the CD-ROM from Medical Applications. From the index you can choose the item you want to study. Text and images are shown. You can browse through the text, click on the images and, surprisingly, you may be watching a video presentation of the neurosurgical intervention and looking at the histology of the lesion at the next double click. This is the most fascinating aspect of this modality. For those who want to study specific subjects of, in this case, neuroradiological disorders, the index makes it simple to find your way in the information. If you want, you can add your own notes, enter via keywords or first letters of keywords.

The main disadvantage of the CD-ROM modality is the necessity of having a computer available. This pins the seeker of information to one place. Books, copies of articles, syllabus and such can be taken everywhere and studied in all possible (and sometimes impossible) places. This already partially answers question 3.

3. It is highly improbable that this modality will take over the teaching process and make other sources of information, books and articles (journals), superfluous. In the long run, in an entirely digitized radiological department, one can imagine that CD-ROM information could be integrated in the workstation from which reporting is done. This is still years ahead in the future. Reading books and articles in trains, planes, sitting in a comfortable chair, behind a desk or while studying a case on a light panel, will remain for a long time to come the favourite way to study or look for references. It is obvious, however, that learning by CD-ROM will become an important addition to the arsenal of teaching tools. CD-ROM will also provide a useful source of references, and, because you are already at the computer, you can use your Internet connection to provide any necessary extra information.

The three CD-ROMs:

1. *MRI of spinal tumours.*
By D. Balériaux et al.
This was the first of the series reviewed here and for me still the favourite example of how to use the medium to capture the attention of the novice and the trained neuroradiologist. The student is given a detailed excursion in the field and learns which methods to use for which purpose and how to interpret the images obtained in this way. There is emphasis on clinically relevant differential diagnostic aspects. In this CD-ROM one is taken literally through the MR image into the operating room to follow "live" the neurosurgeon exploring the tumour. The next double click shows, behind the MR image, the histological finding. This adds more value to this unique teaching instrument.

(to be contd. p. 1721)