A Peripheralized Digital Image Management System: Prospectus

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The number of diagnostic radiology examinations being performed on digitally formatted imaging equipment is continually increasing. However, most digital data are recorded as analogue images and the films stored in a central file. The dynamic range of raw digital data is lost. Currently, the space and cost requirements for storage of all digital data have discouraged most users from attempting it. This article presents the concepts and describes the requirements and initial fabrication of a system that will capture and retain all digital data using a network of peripheralized image acquisition, display, and storage devices. Any piece of digitally formatted equipment can be interfaced into the system. A real-time computer capability provides that any digital examination can be reviewed at any display station for up to 10 days.

In most radiology departments, radiographic information is used and stored as analogue images on film, manually assembled in individual patient jackets and retained in a central file. If all examinations are in the jacket, the system has the advantages of random access; quick, easy, and inexpensive display; immediate correlation of images from various technologies; and relatively simple storage requirements. Centralized radiographic storage systems also have several disadvantages, the foremost being limitation of the diagnostic information to one user or display site at a time. In addition, very recent examinations, particularly from geographically separated parts of the department, may not yet have been incorporated into the jacket when they are needed by the radiologist or referring clinician.

Digital imaging equipment is being increasingly used in patient care. In 1980, 103,299 examinations were performed in our department. Of these, 17,957 examinations (17.3%) used digitally formatted images. In 1981, of the 113,613 examinations performed, 24,363 (21.4%) were obtained on digital equipment. But the potential advantages of digital formats are lost forever if only an analogue image is recorded on film. If original digital data are not stored, they cannot be reworked, and there is no opportunity to take advantage of the rapid access, integration, and multisite display potential afforded by modern digital systems. Currently, the space and cost requirements of storing all digital data recorded onto magnetic tapes or disks have discouraged most users from attempting it.

As diagnostic imaging instrumentation continues to shift from the standard radiographic analogue film to digital acquisition systems, centralized management strategies will become increasingly stressed and inefficient. At the University of Kansas we are fabricating and testing a system that will capture and retain all digital image data with peripheralized (not centralized) acquisition, display, and storage devices. Simultaneously, at any number of peripheral locations, analogue displays of digitized information from any one of the several digitally formatted imaging technologies will be conveniently available to radiologists and other physicians for individual patient consultation and management.

We present the design concepts of such a peripheralized digital imaging and

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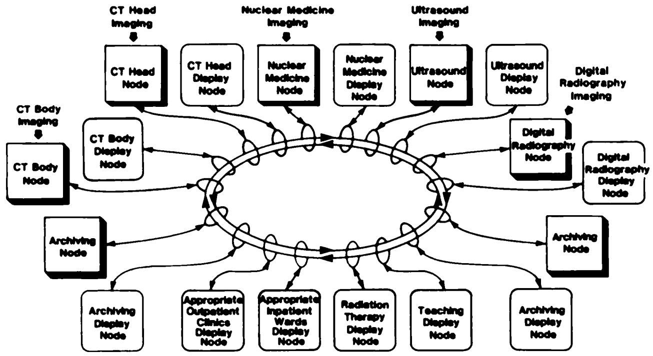

Fig. 1.—Peripheralized digital image management system.

storage network and describe the functions to be satisfied and equipment components required. From quantitative information on current numbers of examinations and demands for their review in our hospital, some specifications for the system capacity and projections for cost have been developed. Optimal response time for users and impact on institutional resources are considered in the light of the forseeable new technical developments.

System Design

The peripheralized image system under development is an area network of computer equipment [1] which interconnects all digitally formatted diagnostic units for image acquisition, multidirectional transfer, display, and/or storage (fig. 1). For maximum effectiveness, the system should: (1) rapidly display analogue and/or digital images from every diagnostic technology; (2) collate and/or integrate digital image information from any and all diagnostic methods; (3) efficiently store diagnostic information; and (4) effectively retrieve digital images and diagnostic data.

Each piece of imaging equipment is interfaced to a node and connected to other nodes through fiber-optic links in a double-ring network structure. A node is a point of entry into or egress from the network and performs one of three functions: image acquisition and formatting, image display and manipulation, or image storage. Each image acquisition and formatting node can be interfaced to more than one and up to four imaging devices of a similar technology. The connective links are two fiber-optic cables. Fiber-optic technology uses pulses of light traveling down hair-thin fibers [2]. They provide many advantages compared to electrical coaxial cables, including a larger band width, lower cost, lighter weight, smaller size, and electrical noise immunity. Commercially available fiber-optic cables operate bidirectionally and are capable of data transfer rates of 20 megabits (Mbit)/sec. Computer communication protocols required for distributed processing and variable-length information packets will impose a software overhead so that the effective information transfer rate will be about 10 Mbit/sec [3].

Operation of the system under development (fig. 1) is illustrated by considering a patient who had just completed a nuclear medicine examination. The patient's images are

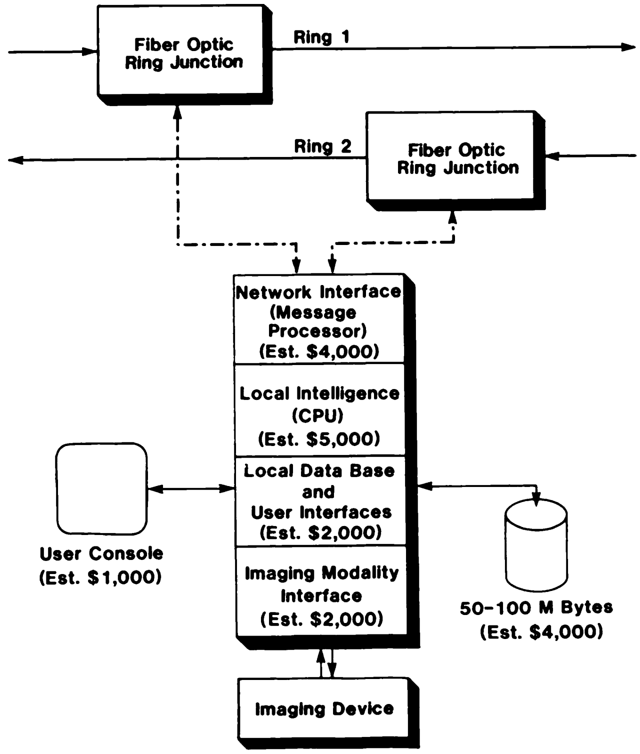

Fig. 2.—Image acquisition and formatting node ($18,000/node).

temporarily stored in the nuclear medicine image acquisition and formatting node (fig. 2). On request from any display node (fig. 3), all image information is transferred to that display node where it can be reviewed. Each display node provides for on-line viewing of all the examinations obtained over a 10 day period. Images from any digital technology can be transferred from one display node to another. Several display nodes can be placed throughout the radiology department and at various sites throughout the hospital complex. Clinics could be interfaced into the system for a distance of up to 5 miles (8 km). Any display node in the system can monitor patient examinations as they are acquired by the image acquisition and formatting node. Diagnostic information is simultaneously stored in on-line archival nodes (fig. 4).

There are at least four design requirements that must be considered in developing such an image management system. First, the technical operation of the system must be simple, convenient, and rapid. The user should be insulated from as many of the operational details as possible. Acceptance of such a system by both radiologists and clinicians will be enhanced by a set of operational instructions that are logical, easily remembered, short, descriptive, and error tolerant. Second, three types of "software information packets" of variable length require transmission throughout the area network: (1) control information packets, which are short records used in controlling and managing the system; (2) text information packets, which are alphanumeric records used for messages, patient data, consultation reports,

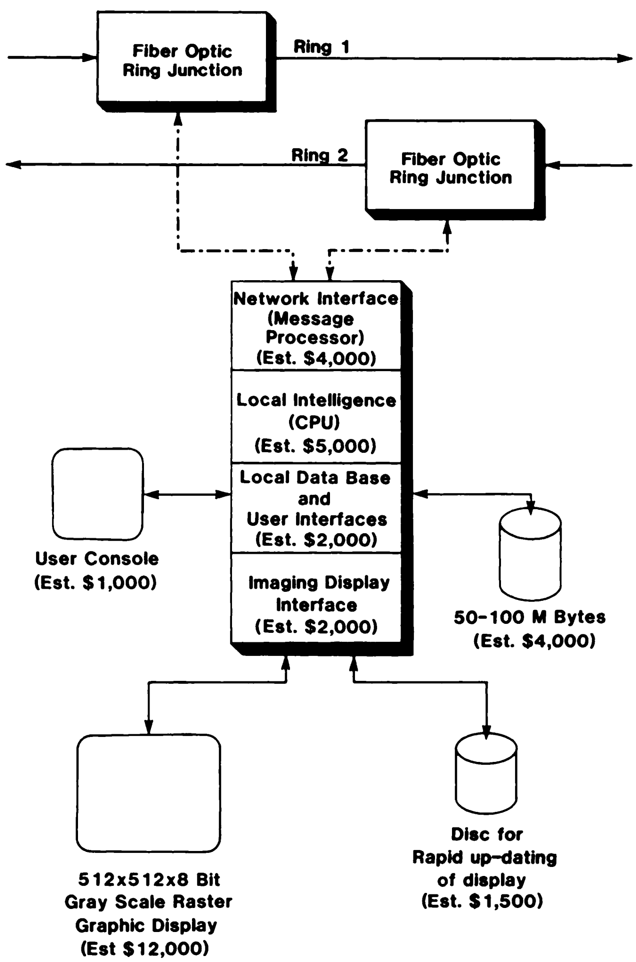

Fig. 3.—Interactive display and image manipulation node ($31,500/node).

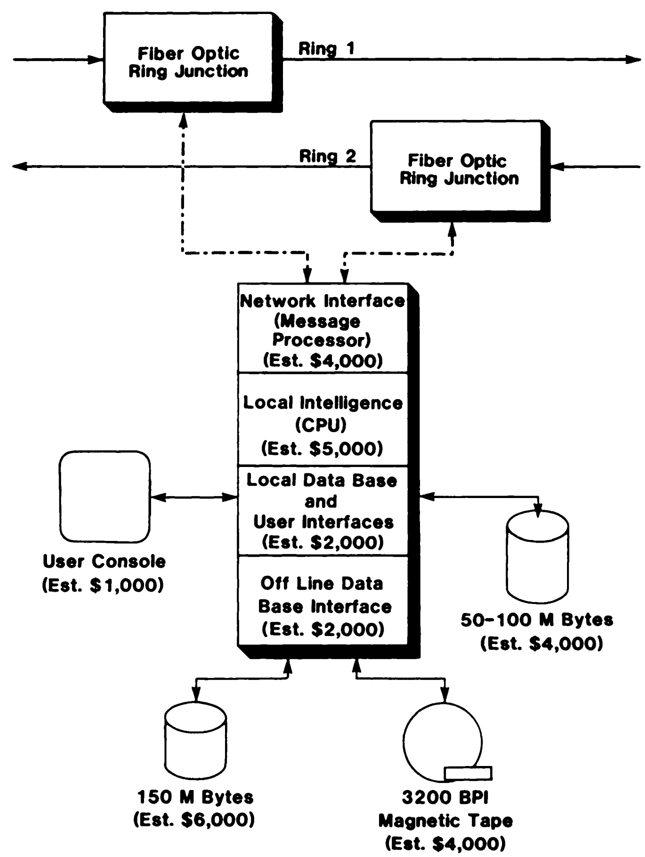

Fig. 4.—10 day on-line and long-term storage node ($28,000/node).

and system status reports; and (3) diagnostic imaging information packets, which are long records containing the image information. These variable-length records require the use of carefully designed system communication protocols.

Third, all diagnostic image data must be stored at two or more distinct locations in the area network. If a patient's diagnostic images are stored at two nodes and if a mishap occurs during image transfer or image manipulation at one node, the user can rapidly recover the data from the back-up node. The requirement of duplicate on-line storage assures some system redundancy and increased storage capability.

The fourth requirement deals with selecting a network topology or connective arrangement of the various nodes in the system. While there are numerous network configurations [4, 5], a double-ring structure offers several advantages [6, 7]. The ring structure suits the point-to-point nature of fiber optics as a transmission medium. At each node, the fiber-optic ring is interfaced to a fiber-optic junction. These junctions represent data path switches controlled by information in the packet being transmitted. If the switch is closed, then the information packet is routed into a node buffer. If the switch is open, the information packet continues down the ring until it arrives at the desired node. This same scheme may be used to establish a bridge or connection to other networks. The double-ring structure (fig. 1) provides for system redundancy and increased reliability. If one of the fiber-optic links becomes inoperative, then the second link may be used as a back-up.

These four system requirements provide the framework on which various functions can be implemented for each node in the system.

Equipment Requirements and Cost Projections

Our department contains the following digitally formatted equipment: two computed tomography (CT) body scanners, five nuclear medicine gamma camera systems, five ultrasound scanners, and two digital fluorography systems. The amount of digital imaging data produced each working day by each technology is provided in table 1 (far right column). Between 254.8 megabytes [Mbyte] (254.8×10^6 bytes) and 502.7 Mbyte of digitally formatted data are generated each day [8]. Combining information from tables 1 and 2 indicates that 41,750–70,250 sheets of x-ray film containing video-recorded analogue images are exposed and will be added

TABLE 1: **Amount of Digital Diagnostic Imaging Data Generated by a Radiology Department Serving a 540-Bed Hospital**

Imaging Method	No. Patients/Day	No. Images/Patient	Size of Each Digital Image	No. Bytes Generated/Working Day
Body CT	10–13	20–40	90,000 pixels, 2 bytes/pixel, patient i.d. block of 1,024 bytes, 512 bytes of technical data required for each image	36.1×10^6 to 93.9×10^6
Head CT	12–15	16–20	Same as body CT	34.6×10^6 to 54.1×10^6
Nuclear medicine	28–42	7–10	128 × 128 pixel array, 2 bytes/pixel, patient i.d. block of 1,024 bytes	6.45×10^6 to 13.8×10^6
Ultrasound	15–20	30–42	512 × 512 pixel array, 1 byte/pixel, patient i.d. block of 1,024 bytes	117.9×10^6 to 220.3×10^6
Digital radiography	10–15	12–16	512 × 512 pixel array, 2 bytes/pixel, patient i.d. block of 1,024 bytes	62.9×10^6 to 125.8×10^6

Note.—Total amount of digital diagnostic imaging data generated/working day is 254.8–502.7 megabytes.

TABLE 2: **Archiving Digital Diagnostic Images**

Imaging Method	No. Film Sheets Recorded/Patient by Multiformat Video Recorders	No. Magnetic Tapes Required/Working Day*
Body CT	2–3 (14 × 17 inch film)	2–5
Head CT	2 (14 × 17 inch film)	2–3
Nuclear medicine	1 (8 × 10 inch film)	1
Ultrasound	5–7 (8 × 10 inch film)	6–11
Digital radiography	2 (14 × 17 inch film)	3–6

* Each magnetic tape is 2,400 feet long and records at 800 bytes/inch; 250 working days/year.

TABLE 3: **Yearly Cost of Managing Digitally Formatted Image Data Using the Present Centralized System***

Imaging Method	Yearly Cost†
Body CT	\$92,750–\$132,535
Head CT	\$97,500–\$120,562
Nuclear medicine	\$191,800–\$272,790
Ultrasound	\$115,200–\$133,600
Digital angiography	\$74,425–\$105,638
Total	\$571,675–\$765,125

* The current management system consists of the following: All CT digital data are stored on 800 bytes/inch magnetic tape, and analogue images are recorded on multiformat video film. Nuclear medicine, ultrasound, and subtraction digital angiographic examinations are recorded as analogue images on film. No digital data are kept.
† The cost is calculated from tables 1–3 in reference [8].

to our central film file this year. If all the digital data generated were retained, 3,750–6,750 magnetic tapes would be stored this year alone. We have documented that the cost of managing this amount and kind of data approximates \$500,000–\$800,000 each year (table 3) [8].

Not only the amount but the demand for digital data significantly influences the requirements of a peripheral management system. On the basis of our experience, the demands for a film jacket during a hospitalization average: (1) a peak demand of 10 requests during the initial 3–4 days from a central, fast-access storage file, with retrieval and refiling times averaging less than 5 min each; (2) a demand of four requests during the rest of the hospitalization, retrieval and refiling times average 8–10 min each; and (3) a demand of three requests during the first year after hospitalization (table 4).

Image acquisition and formatting nodes (fig. 2) have the following common properties: (1) each node is interfaced into the display files of all digital equipment of a similar technology to acquire completed examinations or to reload previous examinations; (2) each node is capable of transferring images to and from any other node in the system; and (3) each node is capable of providing for electronic mail. Electronic mail refers to the generation, sending, and receiving of alphanumeric messages and can include the patient management status, scheduling, equipment status, and perhaps the actual patient report. Every image acquisition and formatting node will contain a universal interface module capable of accessing the raw digital image data from nearly all digitally formatted imaging equipment. This will provide direct memory-access capabilities between a particular piece of equipment and the image management system.

Image display and manipulation nodes have three requirements (fig. 3). First, this node must enable transfer of imaging data to or from any node in the system, and each display node must be capable of displaying studies from any diagnostic imaging method. Second, this node must be capable of generating or receiving electronic mail from any other node. Third, each image display and manipulation node should be capable of producing the interactive display functions outlined in table 5. High-quality gray-scale display monitors are essential, because a digitally formatted image can only be displayed on an analogue gray-scale monitor. Interactive computer graphics allow image parameters to be rapidly adjusted and the resultant images displayed.

The on-line archiving nodes (fig. 4) contain the digital storage devices which, at present, are magnetic tapes or disks. The factors that determine the number and kind of archiving nodes and strategy for their management depend on the clinical demands for diagnostic image data. These

TABLE 4: **Time Intervals for Archived Digital Diagnostic Imaging Data**

Successive Intervals	Function	Characteristics
Initial (3–4 days)	Clinical examinations, consultation reports	Clinical workup and production of images from a single method; single method diagnosis; integration of image information from more than one imaging method
Second (4–8 days)	Patient's stay in hospital or other care facility	Access to the archived images for consultation, treatment planning, and teaching
Third (first year after hospitalization)	Long-term archiving	Access to the archived images for outpatient clinics, monitoring long-term treatments, or disease progression

TABLE 5: **Interactive Image-Processing Functions for Display and Image Manipulation Nodes**

Function	Description
Presentation	Random patient selection, flexible selection from image data base, selection of sequence and format of images to be displayed, and zoom mode.
Manipulation	Contrast enhancement, background subtraction, gray-scale compression, selection of irregular regions of interest, automatic edge detection, window and level selection, oblique view reconstructions, and three-dimensional displays.
Quantification	Histogram analysis, pixel-value identification, region of interest comparison, distance measurements, line plotting functions, annotate functions, and functional imaging.

demands are characterized by the three successive time intervals cited in table 4. An adequate system will probably consist of a 10 day on-line magnetic-disk (Winchester disk) storage group of archiving nodes placed throughout the system supplemented by conventional long-term shelf storage of disks and tapes. Several technologies now under development could significantly increase archiving capacity as compared to magnetic tapes or disks. Optical disks [9] are a write-once mass storage device capable of archiving 10 billion bits of data. The projected storage cost is about 1 μ¢/bit or one-tenth the cost of magnetic tapes. Another promising device is a laser film recorder which records digital data in encoded form by exposing a strip of film to a sequence of dot patterns [10]. Further, it is estimated that a density of 1 Mbit/in^2 could be successfully archived on standard x-ray film. Such a device would enable the full, dynamic range of the digital data and the desired analogue images to be recorded side-by-side on a single film [11]. The original digital data could be retrieved and remanipulated by the use of the specialized read-write modules placed throughout the department, the hospital complex, and at remote sites.

To equip our department with the described peripheral management system will require six image acquisition and formatting nodes (one for the two CT units, two for the five nuclear medicine gamma camera systems, two for the five ultrasound scanners, and one for the two digital subtraction angiography systems). The cost will be 6 × \$18,000 = \$108,000 (fig. 2). Five interactive image-display and manipulation nodes (fig. 3) are required at a cost of 5 × \$31,500 = \$157,500. These display nodes will be placed in each reading and consultation room in CT, nuclear medicine, ultrasound, and subtraction digital angiography sections of the department. The central film library will have the fifth display node. Additional image-display and manipulation nodes for various hospital office areas or remote clinics can be added as desired. Two on-line and long-term storage nodes at a cost of 2 × \$28,000 = \$56,000 (fig. 4) will be needed. The total equipment cost for these nodes is \$321,500. If prorated over a 5 year period, this is \$64,300/year. The required fiber-optic transmitter-receivers, connectors, and links for our department are estimated to cost \$15,800. Since each piece of hardware in the described system has been purchased individually, and because digital hardware costs are declining, the above dollar figures are estimated to be 12%–15% too high. The system would be maintained with a maintenance contract similar to those used for nuclear medicine and digital fluorography systems or CT scanners. Maintenance contracts are usually estimated at 10%/year of the initial equipment costs. These hardware expenses do not include the prorated software costs required to operate the system.

Discussion

Our clinical colleagues expect and deserve rapid access to any and all patient image information. But at times centralized filing does not serve them well. X-ray film jackets can only be used by one user at a time, and competition may develop for their availability.

The technology for developing and implementing an integrated, multiuser, multidirectional, decentralized digital image-management system now exists. Hardware costs for such a system are decreasing. Largely through the introduction of microelectronic fabrication techniques [12], combinations of microcomputer systems and digital communication networks can provide a cost-effective means for interconnecting any number of different diagnostic imaging methods in any part of the hospital complex. Software exists for implementing a digital data communication network using information packets such as used in the Ethernet protocols [13, 14]. Digital networks with high-speed data transfer rates are now possible and particularly suited to network configurations. New imaging systems or technologies [15] (e.g., nuclear magnetic resonance) could be added at any time.

The image-display and manipulation nodes present some problems that must be resolved to achieve maximal use and image format standardization. First, the resolution and dynamic range of digital diagnostic imaging methods vary. The ability to select and simultaneously display a particular CT or nuclear medicine or ultrasound image on a single display device requires the efficient handling of different display formats. Second, each diagnostic imaging method is provided with varying levels of interactive display technology. CT scanner systems are equipped with high-resolution gray-scale interactive computer display systems with dynamic ranges of 10-12 bits/pixel. Ultrasound imaging systems provide for just 5-6 bits/pixel. Third, a number of software packages are being developed for specific imaging methods. For example, nuclear medicine programs are available for cardiac or renal clearance analysis. Ultrasound programs include fetal age calculations by volume or surface area estimators. The display and image manipulation nodes should allow such specialized programs to be used.

There are a number of significant issues to be investigated regarding the configuration and operation of a peripherally oriented diagnostic image-management system before such a system could become generally accepted. Our department is constructing the system described here to determine the necessary components such as the number and types of nodes, software packages, transmission speeds, etc. and requirements for multiformat film, dynamic range display stations, and magnetic disk on-line storage.

We anticipate the image-management system for all digitally formatted data will provide for improved patient care at a reasonable cost. Geographically separated radiographic patient examining areas will be united into a single, bidirectional, on-line data management system. All digital data contained in the system will be immediately retrievable by radiologists or referring clinicians at any image-display and manipulation node. In addition, digitally formatted image data can be reworked throughout their full dynamic range at any display and manipulation node. Remote interactive display nodes can be added as desired. Patient workups should therefore be expedited. Image format standardization will allow the simultaneous display and comparison of diagnostic data from the different digital technologies. The number of analogue images and the amount of x-ray film currently used may be reduced. Examinations can be viewed and reviewed by several users simultaneously. Sequential access (one at a time) constraints imposed by single-film-jacket central-storage schemes would be removed.

REFERENCES

1. Martin J. *Computer networks and distributed processing: software, techniques, and architecture.* Englewood Cliffs: Prentice-Hall, **1981**
2. Midwinter JE. *Optical fibers for transmission.* New York: Wiley, **1979**
3. Kuo FF, ed. *Protocols and techniques for data communication networks.* Englewood Cliffs: Prentice-Hall, **1981**
4. Tanenbaum AS. *Computer networks.* Englewood Cliffs: Prentice-Hall, **1981**
5. Liebowitz BH, Carson JH. *Distributed processing,* 3d ed. Los Alamitos: IEEE Computer Society Press, **1981** (EHO 176-8)
6. Rawson EG, Metcalfe RM. *Fibernet: multimode optical fibers for local computer networks, Second Edition.* Thurber KJ, Freeman HA, eds. Los Alamitos: IEEE Computer Society Press, **1981**:61-68
7. Tsay DP, Liu MT. Mike: a network operating system for the distributed double-loop computer network (DDLCN). *Proceedings IEEE Compsac 81,* IEEE Computer Society **1981**;379:61-68
8. Dwyer III SJ, Templeton AW, Martin NL, et al. The cost of managing diagnostic images. *Radiology* **1982**;144:313-318
9. Bulthuis K, Carasso MG, Heemsherk PJ, Kivits PJ, Kleuters WJ, Zalm P. Ten billion bits on a disk. *IEEE Spectrum* **1979**;16:26-33
10. Kenville RF. Fifteen years of laser recording—where we've been and where we are going. *Optic Engin* **1981**;20:330-334
11. Lee KR, Dwyer III SJ, Anderson WH, et al. Continuous image recording using gray-tone, dry process silver paper. *Radiology* **1981**;139:493-496
12. Clark WA. From electron mobility to logical structure: a view of integrated circuits. *ACM Computing Surveys* **1980**;12:325-356
13. *The Ethernet, a local area network.* Santa Clara: INTEL, **1980**
14. Tropper C. *Local computer network technologies.* New York: Academic, **1981**
15. Capp MP. Radiological imaging—2000 A.D. *Radiology* **1981**;138:541-550