COMPUTERS IN HEALTH CARE

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Introduction to Clinical Informatics

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Systems for Managing Medical Information

Introduction

Informatics, the science of information management, employs a variety of techniques to automate the collection, storage, utilization, and transmission of information. Because it relies on the use of computers, informatics requires that information be represented in an encoded, computer-readable format.

The first computer applications were limited to numerical calculations and simple administrative tasks. In the last decade, computers have evolved to manage more and more complex elements such as images and sounds, often referred to as *multimedia objects*. At the same time, the development of communication networks has enabled the interconnection of computer systems, allowing previously independent applications to interact. Today enterprises are able to build their information systems from computers, networks, and communication protocols much like an urban architect plans and builds a new city.

This chapter provides a succinct review of the techniques used in medical information systems. It is organized around the following themes: the hardware and software fundamentals of computing; methods for encoding information so that it can be processed by computers; communications networks; and hardware and software architectures for information systems.

Principles of Computer Operations

Computers process information that has been stored in their central memory according to a predefined sequence of instructions called a *computer program*. Programs are written in a language that the machine can understand called a *programming language*. Figure 1.1 illustrates basic computer architecture.

The *central processing unit* (CPU), or processor, executes the instructions contained in the program according to the logical sequence or algorithm determined by the programmer. Operations are performed on the data provided as input to the program, which then calculates the results, called output. The processor and central memory make up the central processing unit of the computer. They communicate over an internal electronic circuit called the communication bus. The central processor is usually composed of an arithmetic-logic unit (ALU), which performs the calculations, and a control unit, which manages the execution sequence of the program instructions.

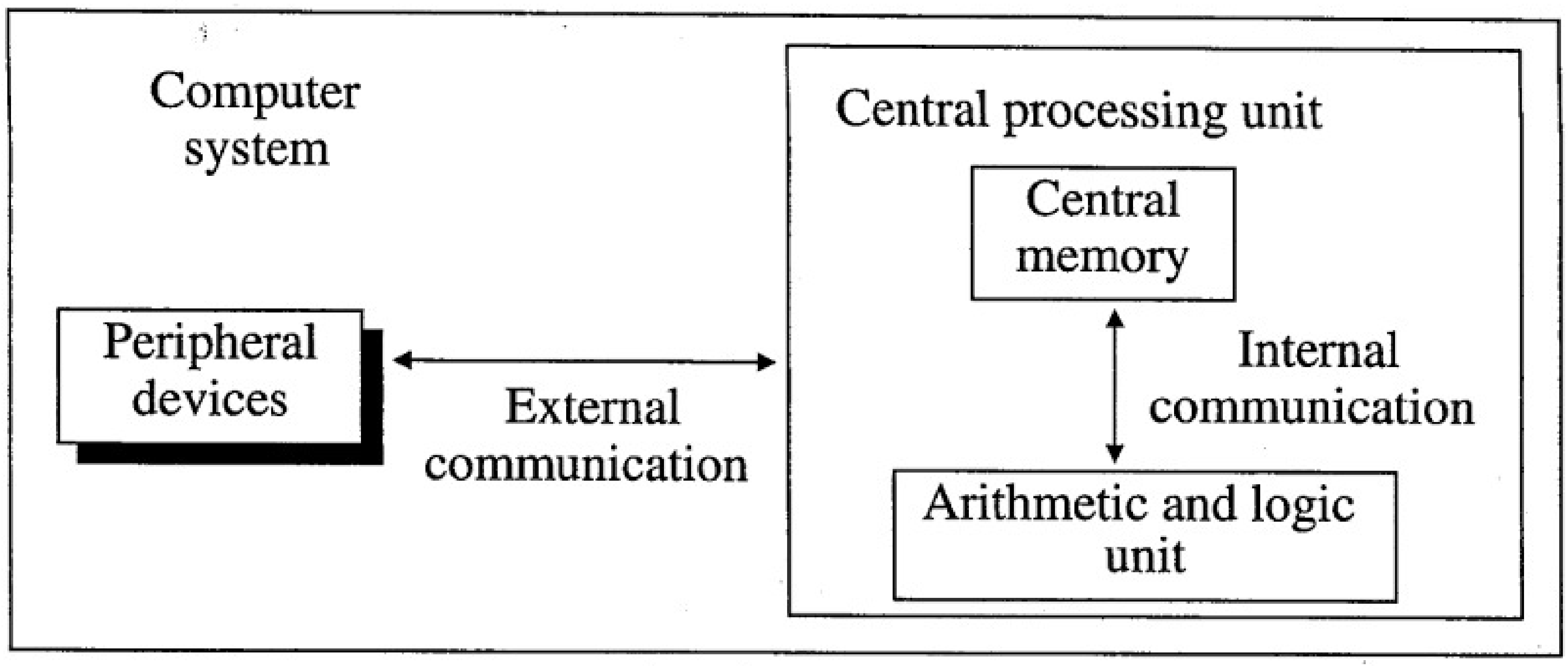

Figure 1.1 : Basic principles of data processing systems

Input and output data coexist with the program in the computer's central memory. Input data and programs are transmitted to the central processing unit via the input peripherals. Results coming from the central processing unit may be stored on output peripherals.

Hardware Architecture

The fundamental architecture of the majority of modern computers is a more- or less-sophisticated version of the Von Neumann architecture presented in figure 1.1. Differences include the modalities of coding information in the machine, memory organization, performance, and the number of processors used (Figure 1.2).

Encoding Information in a Machine

All data are represented by a combination of items called binary digits, or *bits*. Electronics makes possible the construction of elements that are stable in either of two states, conventionally called "0" and "1". Bit sequences are used to represent both the program instructions and the data manipulated by the programs (numbers, alphabetic characters, images, sounds, etc.). Two bits may encode four states (00, 01, 10, and 11), three bits encode eight states, and so on. A group of eight bits is a *byte*, and can represent one of 256 possible combinations. This is sufficient to encode the principal typographical characters of an Indo-European language. Figure 1.3 illustrates the principle of binary representation for an integer in one byte.

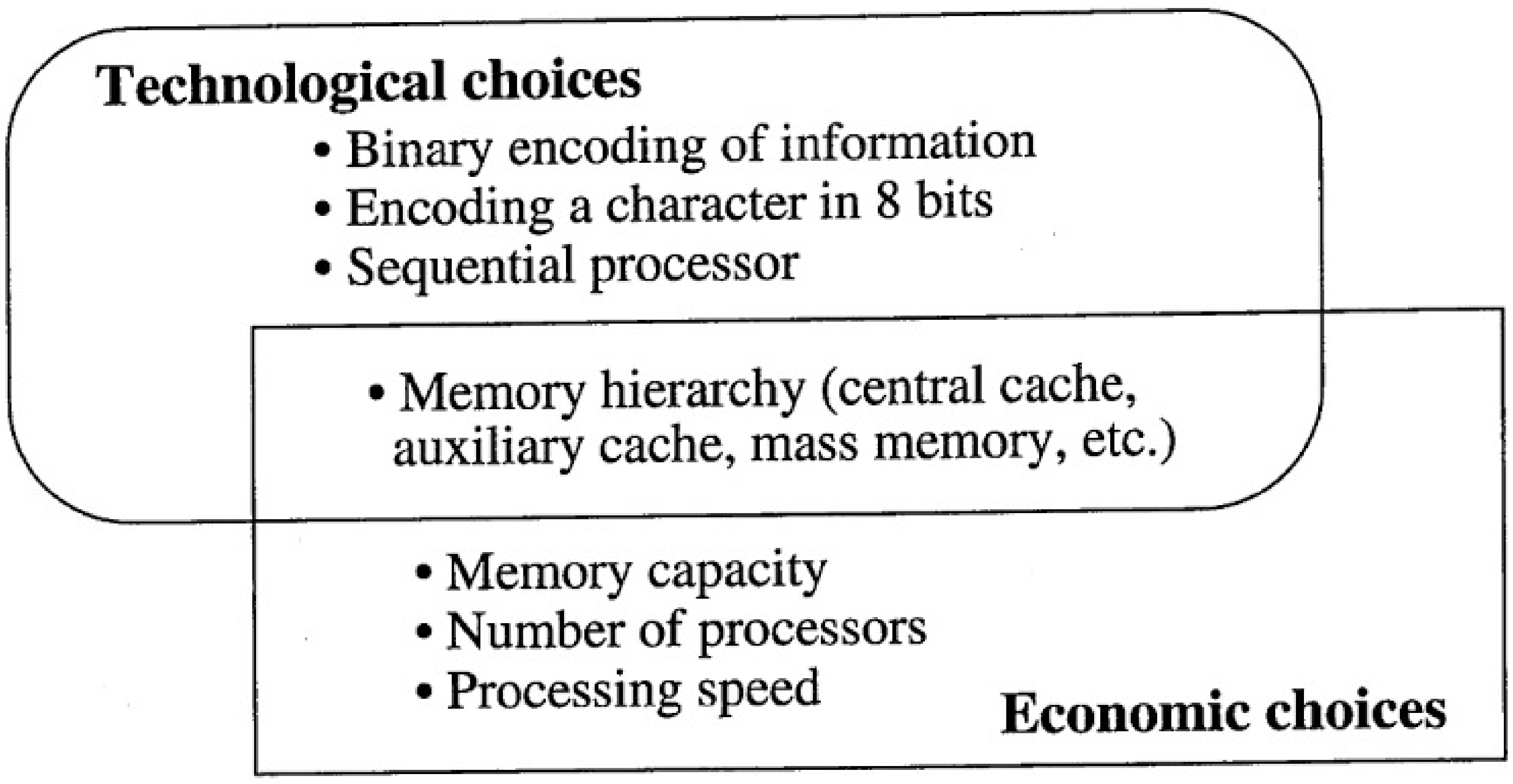

Figure 1.2 : Data processing strategies

The ASCII code (American Standard Code for Information Interchange) is a seven-bit standard code representing 128 characters, while the ISO (International Standards Organization) Latin-1 code is an extension of the ASCII code to eight bits. Text may thus be encoded as of a set of bytes. Other conventions have been established to represent numbers or more complex objects such as images. Unfortunately, these may vary from one computer to another, often requiring special transcoding programs. The characters on a Macintosh computer, for example, are encoded differently from those on an IBM PC.

Decimal	Binary	Power of
0	0	
1	1	
2	10	2
3	11	
4	100	2^2
5	101	
6	110	
7	111	
8	1000	2^3

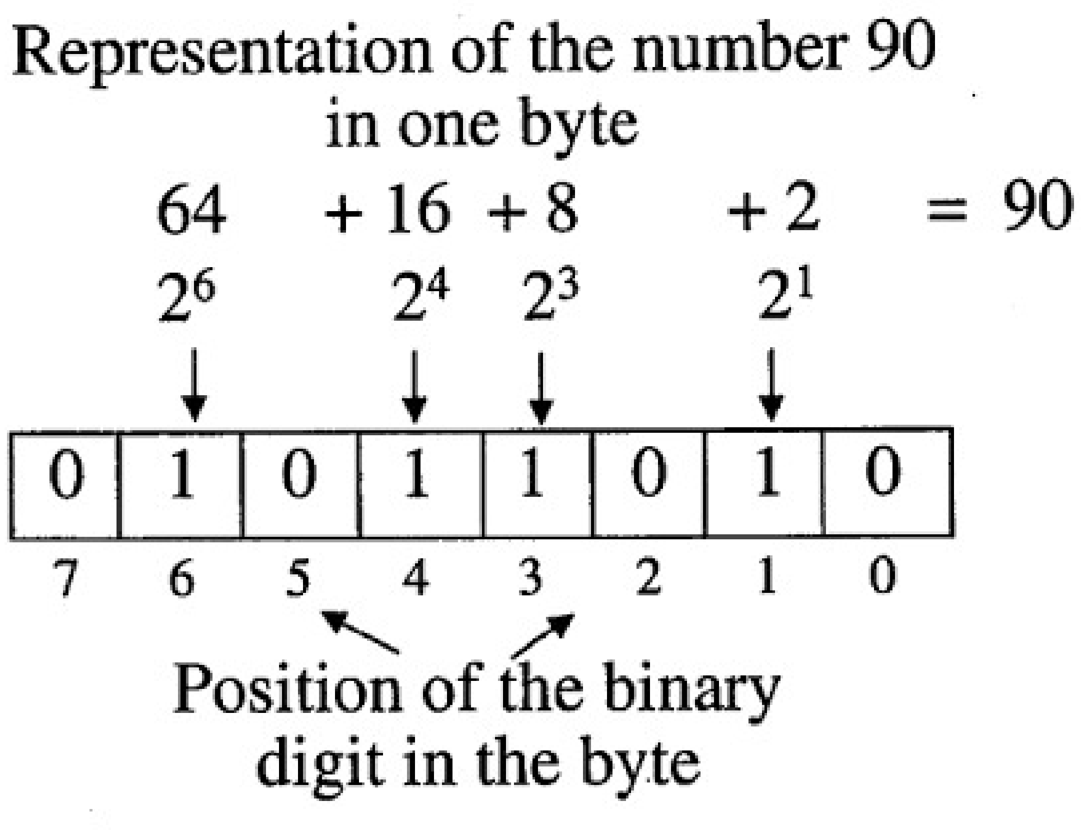

Figure 1.3 : The binary representation of an integer in one byte

Program instructions are normally encoded in memory in a small number of bytes (e.g., 2, 3, 4, or 8), creating "words" of 16, 24, 32, or 64 bits.

The Memory Hierarchy

Computers utilize many types of memory differentiated by their access time, capacity, and unit cost. Memory size is expressed in kilobytes (K), megabytes (MB) and gigabytes (GB). In order to optimize the price/performance characteristics of a given system, memory is usually organized in hierarchical levels (Figure 1.4).

Central Processing Unit Memory

CPU memory is characterized by high cost per byte and short access times (under one microsecond). This is *direct access* memory, meaning the contents of a single byte or word may be addressed at a given time. This memory is usually volatile: the contents are lost when the computer is turned off.

Three main types of memory may be distinguished:

- *Registers* are regions of memory in the arithmetic-logic unit in which elementary operations (e.g., addition, subtraction, or multiplication) may be performed very rapidly. The number of registers is limited.
- *Cache memory* is used to accelerate transfers between processors and central memory.
- *Central memory* is the base memory of the CPU, containing both data and instructions. Each byte or word in central memory may be addressed directly, in any order. It is often called *random access memory* (RAM). Central memory may be accessed in a set time, on the order of a few nanoseconds.

Type of Memory	Access time	Size
CPU memory		
- Register	0.1 – 10 ns	8 –32 registers
- Cache memory	10 – 50 ns	32 K– 1 MB
- Central memory	10 – 500 ns	32 MB – 16 GB
Peripheral memory		
- Magnetic disks	5 – 100 ms	100 MB – 20 GB
- Optical disks	100 – 300 ms	650 MB – 18 GB
- Magnetic tapes	100 – 2000 s	100 MB – 24 GB
- Microprocessor-based cards	1 – 5 ms	16 K– 256 K

Figure 1.4 : Memory hierarchy

Peripheral Memory

Peripheral memory is characterized by low cost per byte, high capacity (hence the name *mass memory*), and longer access times, from a few microseconds to a few seconds. Some peripheral memory is removable and may be used for backup copies of data. This memory is not addressed by byte or by word but by groups of bytes of a given length called *blocks*. Capacity ranges from several kilobytes up to several gigabytes, which are required for the storage of some multimedia documents. For example, a high-definition color image may occupy a few hundred kilobytes. A 6-minute video sequence, once digitized, requires approximately 2 MB in normal definition and up to ten times more in high definition.

Peripheral memory comes in many categories:

- *Removable magnetic diskettes* store from 1 to 2 MB on a diskette 3.5 in. (9 cm) in diameter. For example, a single high-density diskette of 1.4 MB contains the equivalent of 300 typewritten pages.
- *Magnetic hard disks*, either fixed or removable, have capacities that range from a few dozen megabytes to a few gigabytes. Swapping zones may be reserved on certain hard disks to accelerate the exchange of data from central memory to peripheral memory and to save all or some of the data contained in central memory.
- *Removable optical numerical disks* are available as CD-ROM (compact disc - read-only memory), WORM (write once-read many) or WMRM (write many-read many). The most common size for the first generation of CD-ROMs, WORMs, and WMRM is 5.25 in.(13 cm) for a capacity of approximately 650 MB (or the equivalent of 250,000 pages of text). The most frequently used storage protocol is ISO 9660. Audio compact discs (CD-audio) and interactive compact discs (CD-I) use a different storage format. The second generation is a high-density 5.25 in. format (DVD, for *Digital Versatile Disk*) that is able to store from 4.7 GB to 18 GB of data (the equivalent of 2 to 6 hours of compressed video) and will unify the storage format for these different data types.
- *Memory cards* quickly became popular following the development of banking cards. They are a plastic medium in a standard size (8.5 x 5.4 cm), and one or several magnetic strips are affixed to the back. A relatively small amount of information is stored on the card: approximately 200 characters for a bank card. The addition of a microprocessor transforms the card into a more intelligent device for storing information (an actual peripheral memory) and also a system for access control and processing (a real computer). The capacity of a microprocessor-based card (*smart card*) ranges from 16 to 256 K. It is possible to define parts of the memory that cannot be overwritten (EPROM technology, for electrically programmable read-only memory) and parts that can be erased (EEPROM, for electrically erasable programmable read-only memory). The intelligence feature of the card is particularly interesting for security functions, such as the identification and authentication of the user, the first step to controlling access to an information system.

Computer Categories

Most computers are based on high-performance, integrated microprocessors, such as the Motorola 68xxx, the Intel 80x86, the SUN Sparc, or the Compaq/ Digital Equipment Corporation Alpha. Improvements in computer performance, memory and communication components allows a 30% to 50% annual improvement in the price/performance ratio of computer systems, while their physical size decreases.

Selecting Objects

Pointing tools such as the mouse, light pen, trackball, or a digitizing pad let the user indicate points or draw outlines, and represent a useful complement to the keyboard. Fingers can also be used on touch screens to indicate menu selections.

Voice Recognition

Human voice recognition should develop rapidly over the next few years. This development is related to the power of computers, which, according to experts, must execute a billion instructions per second in order to enable the recognition of spoken sentences.

Display Screens

The visual display unit is the most common man–machine interface. Graphic screens offer high resolution, ranging from 600×400 up to 2500×2000 points or pixels (*picture elements*). They usually include microprocessors with RAM for storing pixels (*bitmap screens*) and ROM for graphics software.

Voice Output

Voice output offers a useful complement to the visual display or printout of results, especially in work environments where a written record is not necessary.

Printers

Two types of printers dominate the market: dot matrix printers (employing either impact or ink-jet technology) and laser printers, which provide very high print quality. These offer the use of numerous character sets or *fonts*. Each font can be described as a matrix of points (bitmapped fonts) or mathematical figures (outline fonts).

Software Architecture

Different software layers enable the system to manage the interaction between the user and the computer. Figure 1.7 divides this software in three major categories.

Operating Systems

The *Operating System* (OS) is the set of low-level programs that make the computer run (managing central memory and peripherals, executing programs, scheduling tasks, and handling communications between the com-

Application programs Productivity software: word processing, spreadsheets, graphics tools, groupware tools, etc. Specialized programs: medical record management, image processing, computer-based training, etc.
Development environments Language libraries, interface managers, database management systems, communication tools, etc.
Operating systems Task management, virtual memory management, peripheral management, etc.

Figure 1.7 : Major software categories

puter's components and the outside world). Some of the most widely distributed operating systems on mini- and mainframe computers include IBM/VM-CMS, Digital-VMS, UNIX and Windows NT; for microcomputers they include Microsoft DOS/Windows, IBM-OS2, Mac OS, and Linux. The operating system maintains the directory of files that are stored in memory (i.e., programs and data). Some operating systems provide virtual memory management, which can split working memory for a process between fast central memory and slower peripheral memory.

Development Environments and Utilities

Utilities and development tools are designed for programmers responsible for developing applications. These tools include compilers and interpreters for programming languages, interface management systems, database management systems, and various communication tools. The principles of software development and the tools used are described in detail in the next chapter.

Programming Languages

The computer's central processor executes instructions encoded in *machine language,* or binary language, and stored in the computer's memory. Each computer processor is able to execute a limited number of binary instructions (e.g., addition, subtraction, complements) that are specific to the given processor. RISC-based computers (reduced instruction set computer), which make up the new generation of systems, use a very limited set of elementary instructions that may be executed at very high speeds, in contrast with the previous generation called CISC (complex instruction set computer).

The difficulty of programming in binary language led programmers to develop several generations of *artificial languages* for programming, characterized by a precisely defined syntax and semantics, with a high level of abstraction:

- *Assembly languages*, developed at the same time as the first computers, let programmers use alphabetical operation codes and represent operands in the form of symbols. They are specific to a given processor.
- Third-generation languages (3GL) were developed during the 1960s. They use natural-language words and a processor-independent syntax. The program instructions in a third-generation language are transformed into a machine-executable language. This translation can be carried out either for the entire program, using a *compiler* that transforms the original instructions into an executable object, or on a step-by-step basis by an *interpreter* that can execute the instructions as they are translated. COBOL, C, C++, FORTRAN, and Pascal are examples of compiled languages. BASIC, Java, LISP, MUMPS, and SmallTalk are interpreted. A program written with a 3GL may be compiled or interpreted on computers made by different manufacturers (portability).
- *Fourth-generation languages* (4GL) are higher-level languages designed to facilitate data management and generate reports. They are usually associated with database management systems (DBMS) (see Chapter 2).

Interface Management

The man–machine interface largely determines the success of an information system. In theory, an interface must be natural, efficient, reliable, and easy to understand and to use; in other words, as close as possible to the various human methods of perception and communication such as speech and writing. The Macintosh presented a significant advance in this area. It helped to define a set of conventions for presentation and actions (e.g., how to select, open, or save a file).

Interfaces manage three types of interaction that may be combined: command languages, menu systems, and the direct manipulation of objects.

- A *command language* typically takes the form of a verb followed by the name of an object and optional qualifiers or arguments of the verb. Many computer operating systems and database management systems use command languages. For example, the `dir *.doc` command of the DOS operating system displays the list of files whose names end with `.doc`.
- *Menu systems* present the possible choices on the screen, eliminating or reducing the learning phase.
- *Direct manipulation* was made popular by the Apple Macintosh desk metaphor (Figure 1.8). Interaction takes place using the mouse. The user carries out operations on one or several objects that may be represented as text, graphics, or symbols (e.g., an icon).

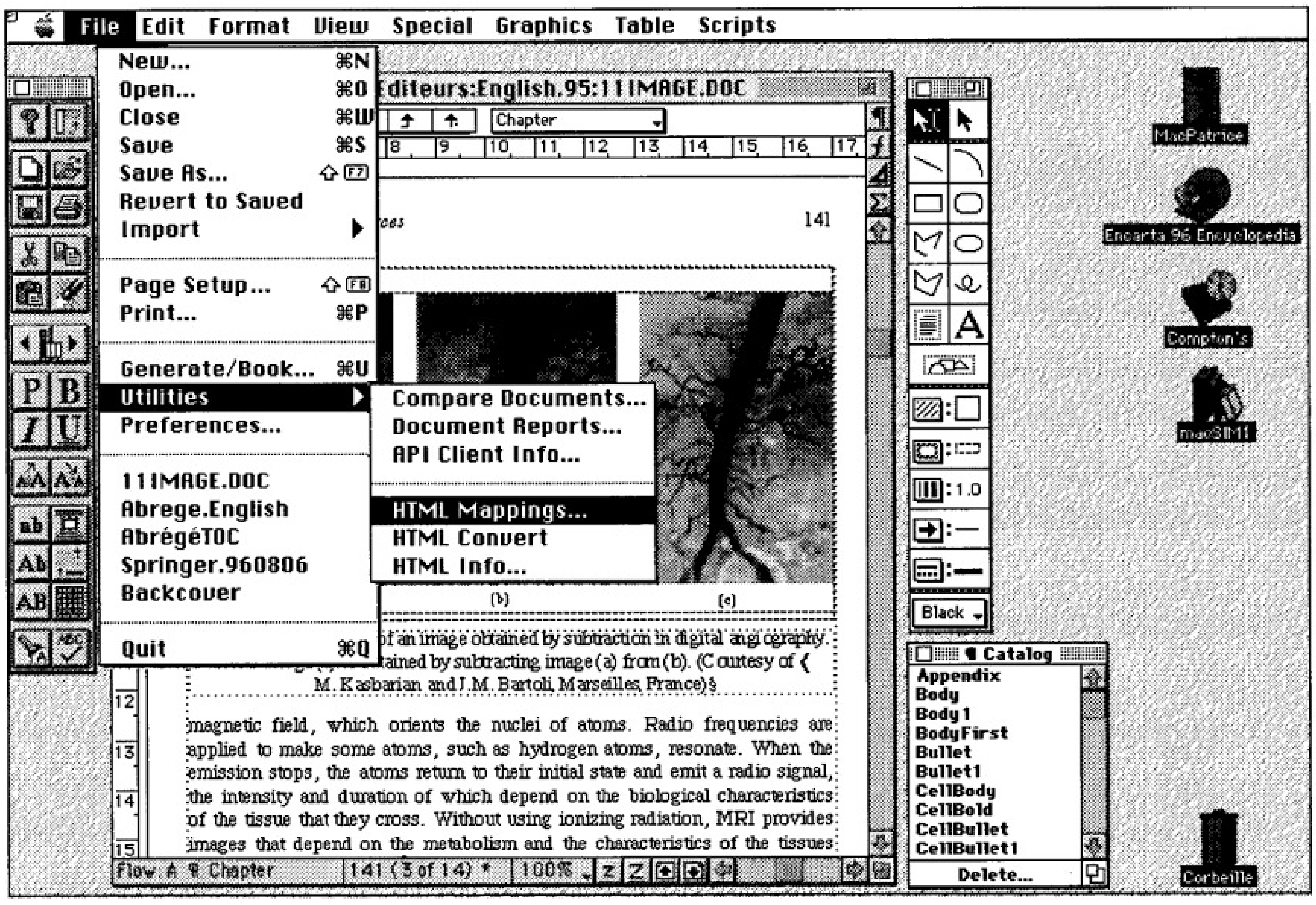

Figure 1.8 : The Apple Macintosh desk metaphor

Application Programs

Application programs are designed for users who are not programmers. Productivity software (e.g., word processing, spreadsheets, drawing tools, or presentation tools), groupware tools (e.g., electronic mail or E-mail), and statistical software are not specific to a given domain. The principal application areas in medicine, such as management of medical records, decision support systems, or computer-based training, are illustrated in Figure 1.9. They are discussed further in later chapters.

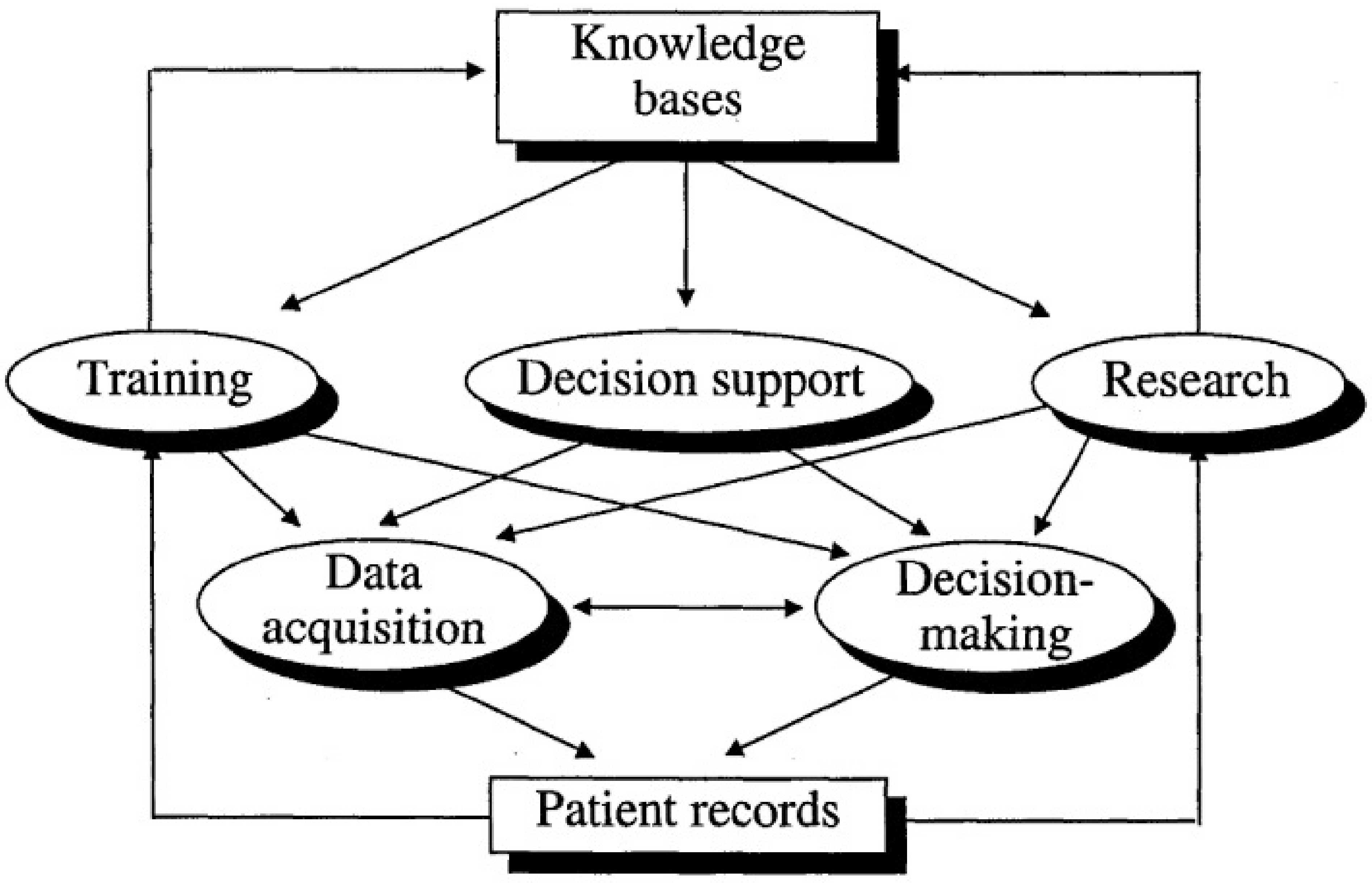

Figure 1.9 : The principal application areas of medical informatics

Communications and Networks

Network Architecture

The development of telecommunications has progressively enabled the creation of computer networks. Connections can be made through electrical cabling, optical fibers, or over the Hertzian waves. Each resource connected to the network is available to all the users who are connected to that network. This access requires knowledge of the location of each application on computers in a *decentralized system*, or may become transparent on a *distributed system.*

Two types of networks may be distinguished by the topology of their connections:

- Computers in a *point-to-point network* are linked together two-by-two to create a star, lattice, or hierarchical structure (Figure 1.10). When low throughputs are sufficient (a few kilobytes per second) a point-to-point link between two remote computers may use modems and the telephone network.

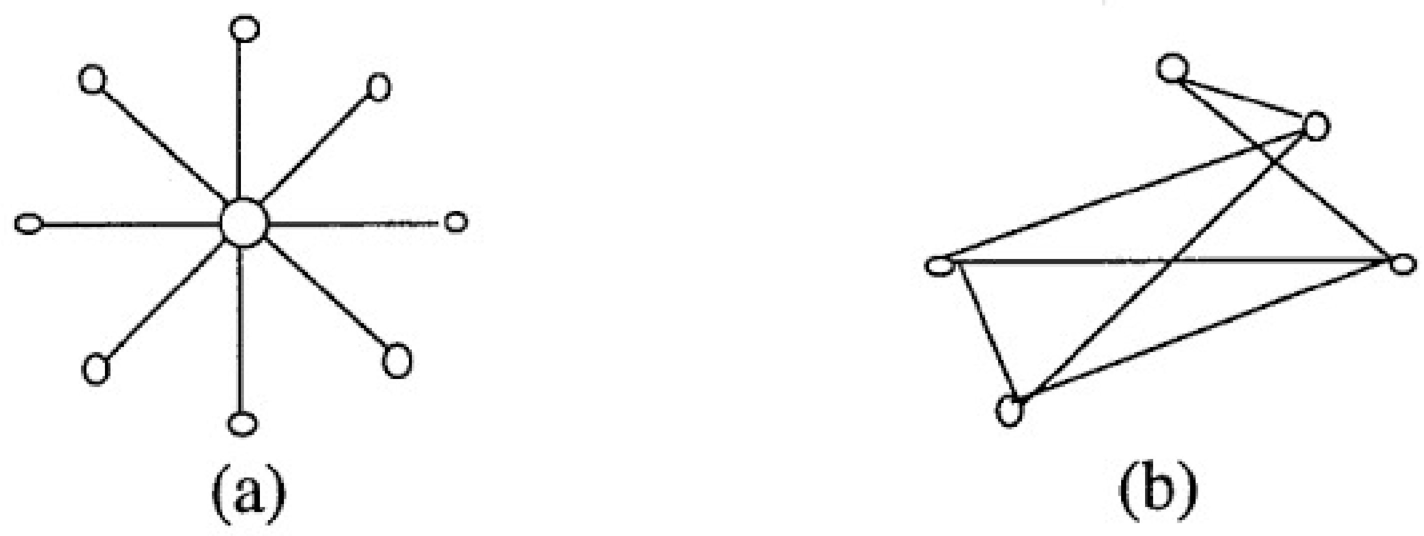

Figure 1.10 : Point-to-point networks, (a) star, (b) lattice

- In *broadcast networks*, messages emitted by one computer are sent to all computers in the network. The network topology may be a bus (e.g., Ethernet allows a rate of 10 Mbits and, more recently, 100 Mbits and 1 Gbits per second); a token ring (e.g., IBM Token Ring at 16 Mbits per second); or may use a communication system based on radio waves or satellite distribution. Several local area networks and wide-area networks use this type of architecture (Figure 1.11).

Two types of networks may be distinguished according to the area covered by the network:

- *Local area networks* (LAN) link several computing resources located from a few meters to a few kilometers apart, with transmission speeds ranging from a few megabits to several gigabits per second.
- *Wide area networks* (WAN) link resources or sets of resources located from a few kilometers to tens of thousands of kilometers apart for satellite transmissions. The ARPANET network, created in 1969 on an initiative of the U.S. Department of Defense Research Projects Agency

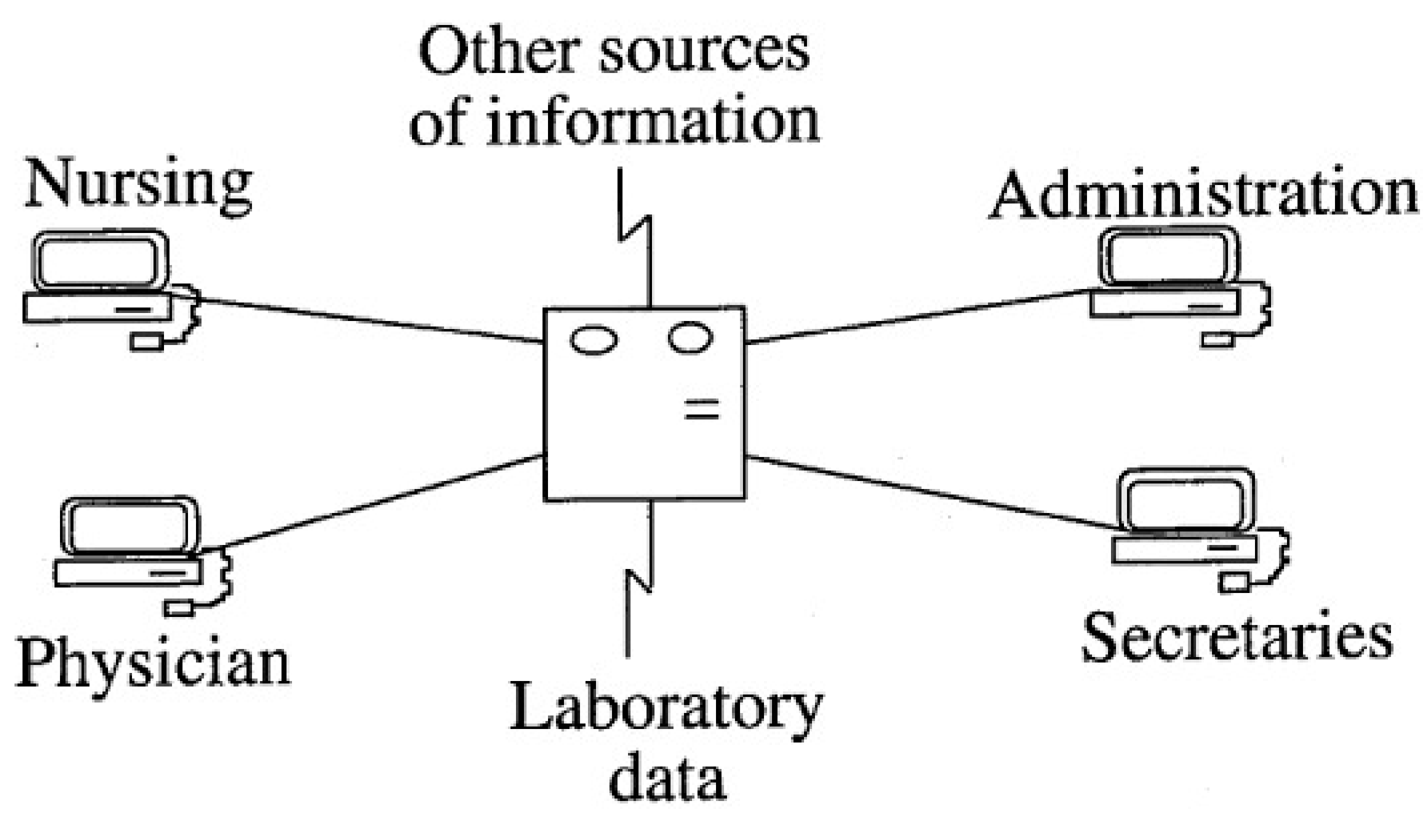

Figure 1.12 : Centralized architecture

tecture's lack of flexibility, which does not allow simple evolution and makes the institution dependent on a single computer manufacturer.

Distributed Systems

Figure 1.13 presents a distributed architecture using specialized local servers to store certain types of information (e.g., patient identities, medical data, laboratory results, images) and manage communications or calculations. This approach builds a computing system in successive stages of hardware and/or software components, which may use equipment from different manufacturers. It increases the complexity of the information system, however, and may cause compatibility problems between various hardware and software components as well as security problems. Each computer becomes a potential Trojan horse for entry into the network (e.g., computer virus introduction).

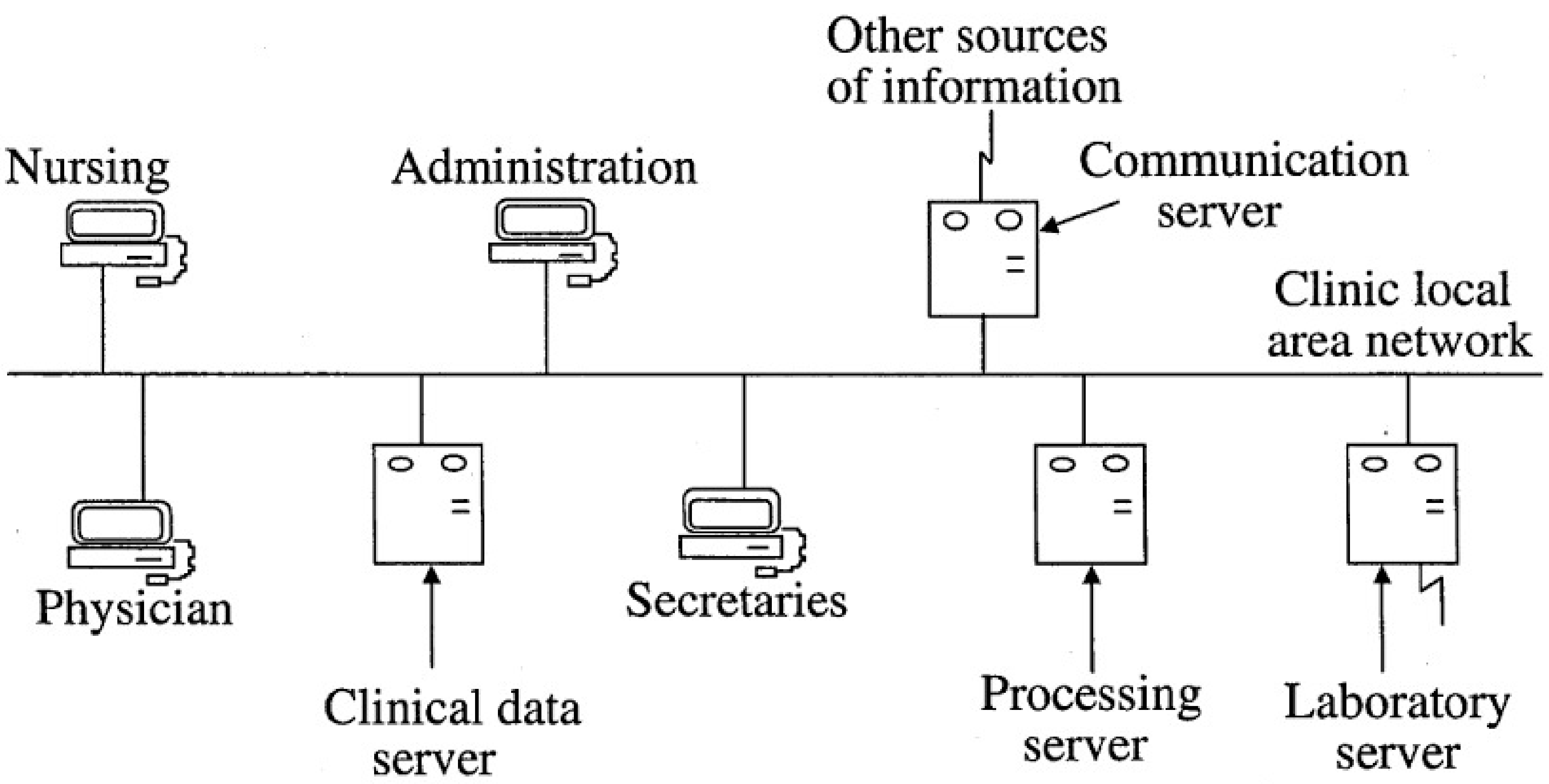

Figure 1.13 : Distributed architecture

Multimedia Workstations

The development of multimedia workstations has become a key element in computer architectures (Figure 1.14). It allows traditional applications to include rich data types (e.g., sound, still images, and animated video sequences) along with the data used in traditional information management. The possibilities for local processing and display facilitate the development of interfaces that hide the complexity of the underlying computer system from the enduser. Finally, access methods such as the smart card may be integrated into the workstation to improve global security for the computing environment.

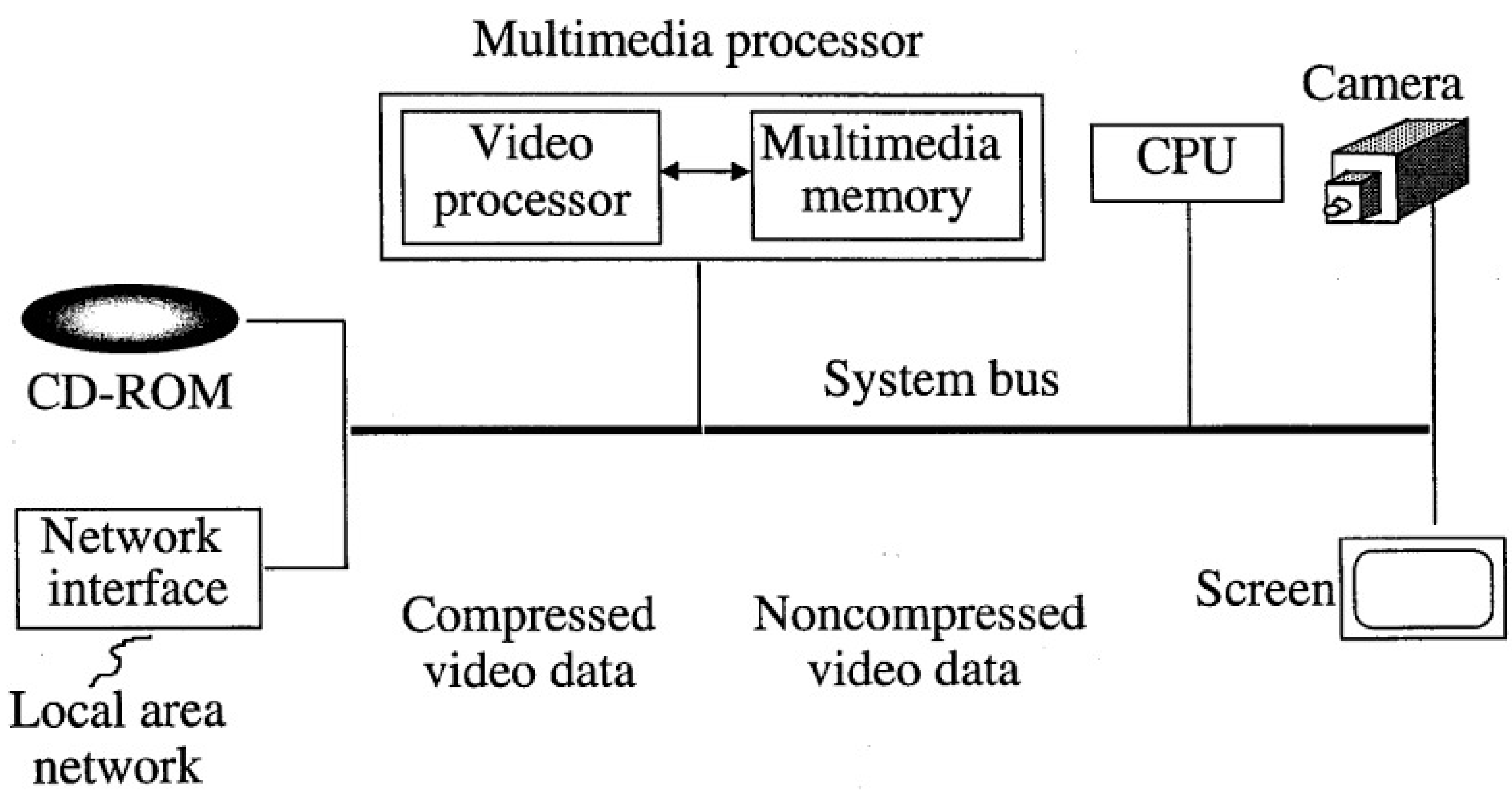

Figure 1.14 : Multimedia architecture (adapted from [Sprague 1992])

The multimedia workstation may progressively fill the role of a camera for image capture, a display or television screen, and a telephone or a videophone, combining these previously disassociated technologies in a single environment [Davis 1991]. The functions of a scanner, printer, copier, and fax may also be grouped together.

Network of Networks

Establishing a network of networks, which ties together the local area networks of the company, changes the concept of the company itself [Tapscott 1993]. Access to the data on the network becomes ubiquitous: at the office via the workstation, at home via personal microcomputers or network computers (teleconsulting and/or teleworking), or via the Hertzian network using a personal assistant equipped with the necessary communications tools. Working in groups (using *groupware*) is enhanced by exchanging messages (e.g., electronic mail or E-mail, group discussions), remote connections, and videoconferencing. Several companies can share resources around a common objective, creating a *virtual company*, as illustrated in Figure 1.15.

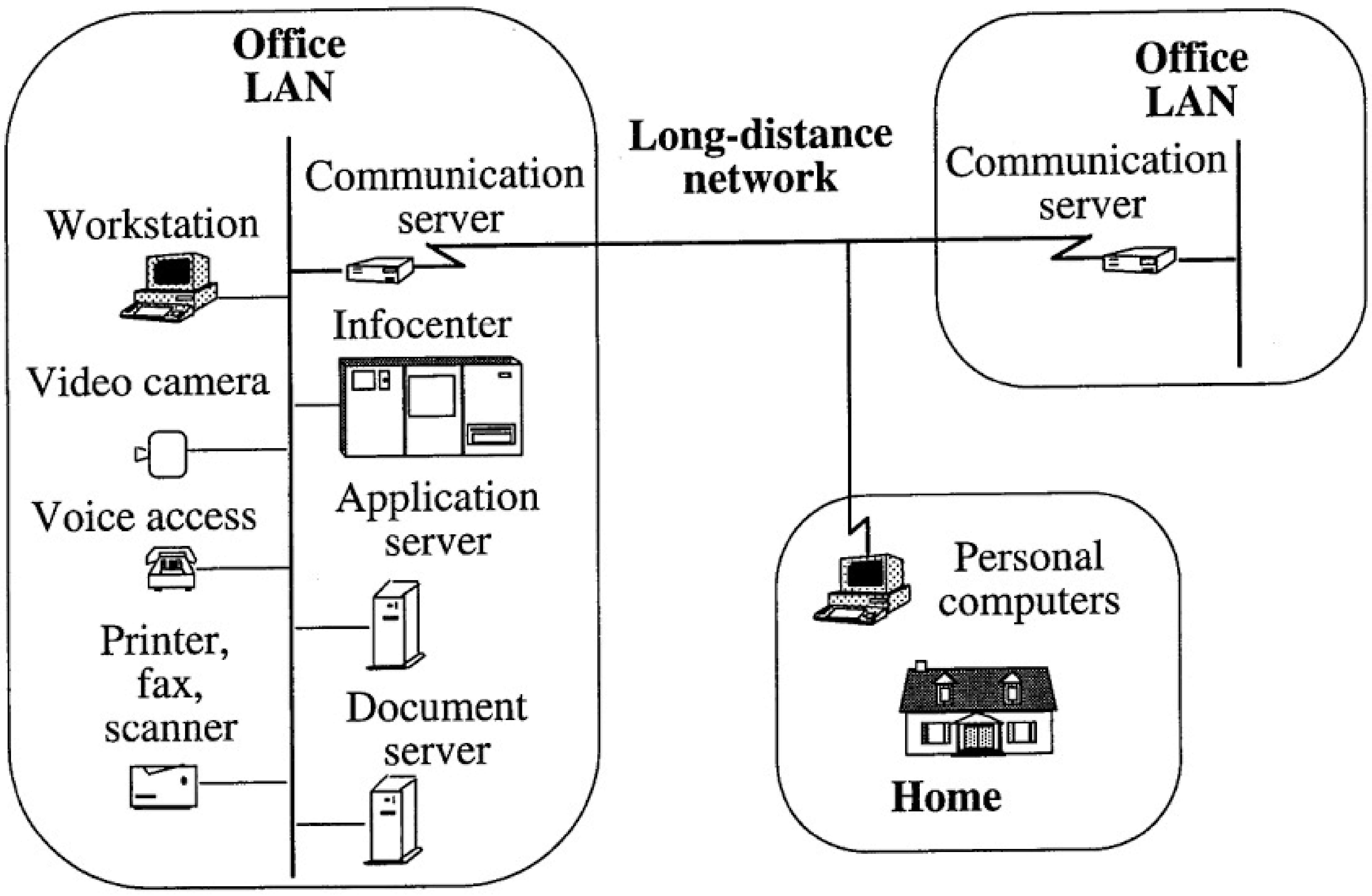

Figure 1.15 : A virtual company

The Internet, initially used by universities and research centers, can virtually connect all world private and public networks. Relying on the TCP/IP protocol, it offers multiple services such as the access to multimedia servers through navigation tools or *browsers*, electronic mail, and distant connection or transfer of data or program files. At the end of 1994, nearly 25,000 networks and 2.5 million computers were connected to the Internet, while traffic increased nearly 10% per month [Laquey 1995]. At the end of 1998, it is estimated that approximately 150 million endusers all over the world are connected. This success and the wide availability and low cost of Internet tools have incited institutions to use the same approach and build local Internet-based networks now called Intranet.

Exercises

- *Explain the differences between informatics and information.*
- *Cite the principal elements of all computers, and describe their respective roles in information processing.*
- *Define the principle of machine coding of information.*
- *Define the concepts of computer programs and programming languages.*
- *Cite the principal software categories.*
- *Discuss some of the difficulties related to managing multimedia information.*