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The Computer Meets Medicine and Biology: Emergence of a Discipline

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After reading this chapter, you should know the answers to these questions:

- Why is information management a central issue in biomedical research and clinical practice?
- What are integrated information management environments, and how might we expect them to affect the practice of medicine, the promotion of health, and biomedical research in coming years?
- What do we mean by the terms *medical computer science*, *medical computing*, *biomedical informatics*, *clinical informatics*, *nursing informatics*, *bioinformatics*, and *health informatics*?
- Why should health professionals, life scientists, and students of the health professions learn about biomedical informatics concepts and informatics applications?
- How has the development of modern computing technologies and the Internet changed the nature of biomedical computing?
- How is biomedical informatics related to clinical practice, biomedical engineering, molecular biology, decision science, information science, and computer science?
- How does information in clinical medicine and health differ from information in the basic sciences?
- How can changes in computer technology and the way medical care is financed influence the integration of medical computing into clinical practice?

1.1 Integrated Information Management: Technology's Promise[1]

After scientists had developed the first digital computers in the 1940s, society was told that these new machines would soon be serving routinely as memory devices, assisting with calculations and with information retrieval. Within the next decade, physicians and other health workers had begun to hear about the dramatic effects that such technology would have on medical practice. More than five decades of remarkable progress in computing have followed those early predictions, and many of the original prophesies have

[1] Portions of this section are adapted from a paper presented at Medinfo98 in Seoul, Korea (Shortliffe, 1998a).
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come to pass. Stories regarding the "information revolution" fill our newspapers and popular magazines, and today's children show an uncanny ability to make use of computers as routine tools for study and entertainment. Similarly, clinical workstations are now available on hospital wards and in outpatient offices. Yet many observers cite the health care system as being slow to understand information technology, to exploit it for its unique practical and strategic functionalities, and to incorporate it effectively into the work environment. Nonetheless, the enormous technological advances of the last two decades—personal computers and graphical workstations, new methods for human–computer interactions, innovations in mass storage of data, personal digital assistants, the Internet and the World Wide Web, wireless communications—have all combined to make routine use of computers by all health workers and biomedical scientists inevitable. A new world is already with us, but its greatest influence is yet to come. This book will teach you both about our present resources and accomplishments *and* about what we can expect in the years ahead.

It is remarkable that the first personal computers did not appear until the late 1970s, and the World Wide Web dates only to the early 1990s. This dizzying rate of change, combined with equally pervasive and revolutionary changes in almost all international health care systems during the past decade, makes it difficult for health care planners and institutional managers to try to deal with both issues at once. Yet many observers now believe that the two topics are inextricably related and that planning for the new health care environments of the twenty-first century requires a deep understanding of the role that information technology is likely to play in those environments.

What might that future hold for the typical practicing clinician? As we shall discuss in detail in Chapter 12, no clinical computing topic is gaining more attention currently than is the issue of electronic health records (EHRs). Health care organizations are finding that they do not have systems in place that allow them to answer questions that are crucially important for strategic planning and for their better understanding of how they compare with other provider groups in their local or regional competitive environment. In the past, administrative and financial data were the major elements required for such planning, but comprehensive clinical data are now also important for institutional self-analysis and strategic planning. Furthermore, the inefficiencies and frustrations associated with the use of paper-based medical records have become increasingly clear (Dick and Steen, 1991 [revised 1997]), especially when inadequate access to clinical information is one of the principal barriers that clinicians encounter when trying to increase their efficiency in order to meet productivity goals for their practices.

1.1.1 Electronic Health Records: Anticipating the Future

Many health care institutions are seeking to develop integrated clinical workstations. These are single-entry points into a medical world in which computational tools assist not only clinical matters (reporting results of tests, allowing direct entry of orders by clinicians, facilitating access to transcribed reports, and in some cases supporting telemedicine applications or decision-support functions) but also administrative and financial topics (e.g., tracking of patients within the hospital, managing materials and inventory, supporting personnel functions, and managing the payroll), research (e.g., analyzing the outcomes associated with treatments and procedures, performing quality assurance, supporting clinical trials, and implementing various treatment protocols), scholarly information (e.g., accessing digital libraries, supporting bibliographic search, and providing access to drug information databases), and even office automation (e.g., providing access to spreadsheets, word processors). The key idea, however, is that at the heart of the evolving clinical workstation lies the medical record in a new incarnation: electronic, accessible, confidential, secure, acceptable to clinicians and patients, and integrated with other types of nonpatient-specific information.

Inadequacy of the Traditional Paper Record

The paper-based medical record is woefully inadequate for meeting the needs of modern medicine. It arose in the nineteenth century as a highly personalized "lab notebook" that clinicians could use to record their observations and plans so that they could be reminded of pertinent details when they next saw the same patient. There were no bureaucratic requirements, no assumptions that the record would be used to support communication among varied providers of care, and few data or test results to fill up the record's pages. The record that met the needs of clinicians a century ago has struggled mightily to adjust over the decades and to accommodate to new requirements as health care and medicine have changed.

Difficulty in obtaining information, either about a specific patient or about a general issue related to patient management, is a frustrating but common occurrence for practitioners. With increasing pressures to enhance clinical productivity, practitioners have begun to clamor for more reliable systems that provide facile, intuitive access to the information they need at the time they are seeing their patients. The EHR offers the hope for such improved access to patient-specific information and should provide a major benefit both for the quality of care and for the quality of life for clinicians in practice.

Despite the obvious need for a new record-keeping paradigm, most organizations have found it challenging to try to move to a paperless, computer-based clinical record (see Chapters 12 and 13). This observation forces us to ask the following questions: "What is a health record in the modern world? Are the available products and systems well matched with the modern notions of a comprehensive health record?" Companies offer medical record products, yet the packages are limited in their capabilities and seldom seem to meet the full range of needs defined within our complex health care organizations.

The complexity associated with automating medical records is best appreciated if one analyzes the *processes* associated with the creation and use of such records rather than thinking of the record as an object that can be moved around as needed within the institution. For example, on the input side (Figure 1.1), the medical record requires the integration of processes for data capture and for merging information from diverse sources. The contents of the paper record have traditionally been organized chronologically—often a severe limitation when a clinician seeks to find a specific piece of information that could occur almost anywhere within the chart. To be useful,

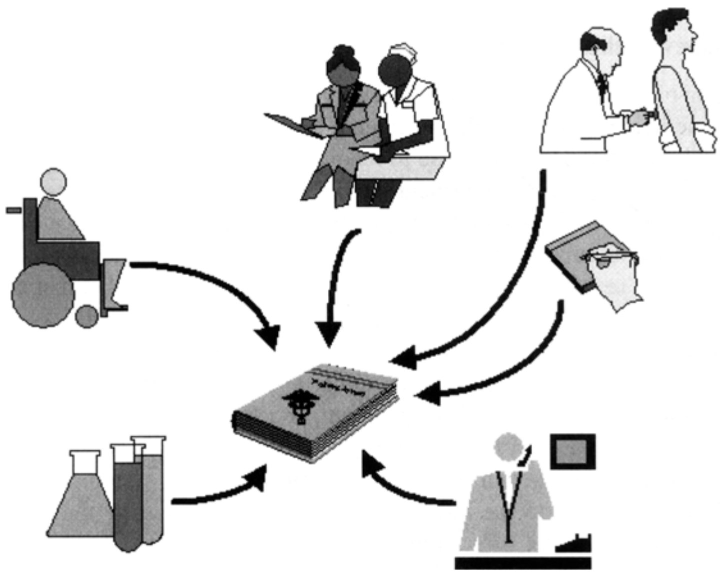

Figure 1.1. Inputs to the medical record. The traditional paper medical record is created by a variety of organizational processes that capture varying types of information (notes regarding direct encounters between health professionals and patients, laboratory or radiologic results, reports of telephone calls or prescriptions, and data obtained directly from patients). The record thus becomes a merged collection of such data, generally organized in chronological order.

the record system must make it easy to access and display needed data, to analyze them, and to share them among colleagues and with secondary users of the record who are not involved in direct patient care (Figure 1.2). Thus, the computer-based medical record is best viewed not as an object, or a product, but rather as a set of processes that an organization must put into place, supported by technology (Figure 1.3). Implementing electronic records is inherently a systems-integration task; it is not possible to buy a medical record system for a complex organization as an off-the-shelf product. Joint development is crucial.

The Medical Record and Clinical Trials

The arguments for automating medical records are summarized in Chapters 2 and 12 and in the Institute of Medicine's report on computer-based patient records (CPRs; Dick and Steen, 1991 [revised 1997]). One argument that warrants emphasis is the importance of the electronic record in supporting **clinical trials**—experiments in which data from specific patient interactions are pooled and analyzed in order to learn about the safety and efficacy of new treatments or tests and to gain insight into disease processes that are not otherwise well understood. Medical researchers are constrained today by clumsy methods for acquiring the data needed for clinical trials, generally relying on manual capture of information onto datasheets that are later transcribed into

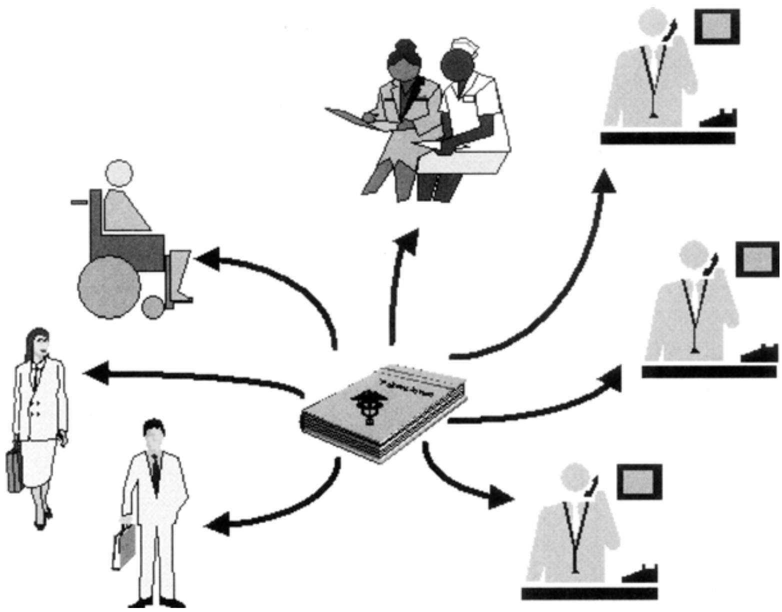

Figure 1.2. Outputs from the medical record. Once information is collected in the traditional paper medical record, it may be provided to a wide variety of potential users of the chart. These users include health professionals and the patients themselves but also a wide variety of "secondary users" (represented here by the individuals in business suits) who have valid reasons for accessing the record but who are not involved with direct patient care. Numerous providers are typically involved in a patient's care, so the chart also serves as a means for communicating among them. The mechanisms for displaying, analyzing, and sharing information from such records results from a set of processes that often vary substantially across several patient care settings and institutions.

computer databases for statistical analysis (Figure 1.4). The approach is labor-intensive, fraught with opportunities for error, and adds to the high costs associated with randomized prospective research protocols.

The use of EHRs offers many advantages to those carrying out clinical research. Most obviously, it helps to eliminate the manual task of extracting data from charts or filling out specialized datasheets. The data needed for a study can be derived directly from the EHR, thus making research data collection a by-product of routine clinical record keeping (Figure 1.5). Other advantages accrue as well. For example, the record environment can help to ensure compliance with a research protocol, pointing out to a clinician when a patient is eligible for a study or when the protocol for a study calls for a specific management plan given the currently available data about that patient. We are also seeing the development of novel authoring environments for clinical trial protocols that can help to ensure that the data elements needed for the trial are compatible with the local EHR's conventions for representing patient descriptors.

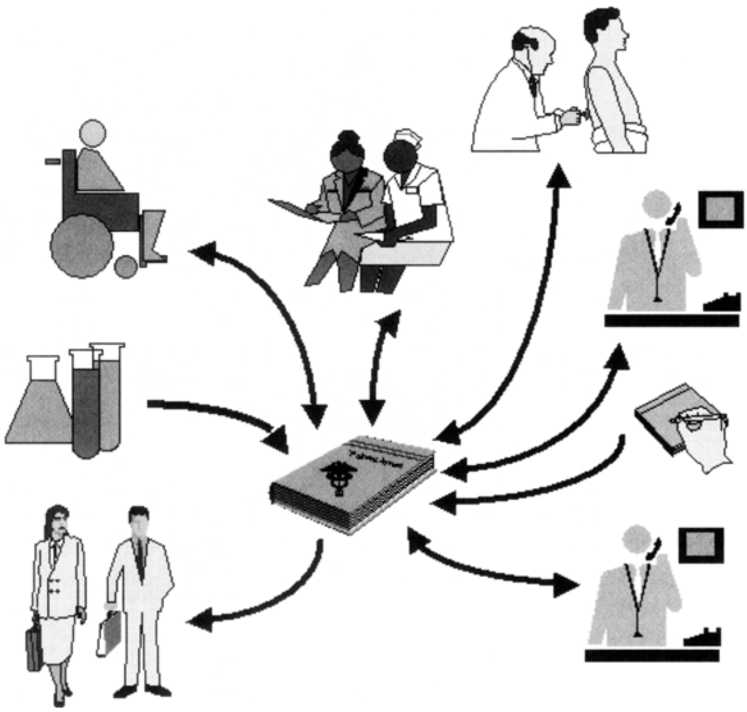

Figure 1.3. Complex processes demanded of the record. As shown in Figures 1.1 and 1.2, the medical record is the incarnation of a complex set of organizational processes, which both gather information to be shared and then distribute that information to those who have valid reasons for accessing it. Paper-based documents are severely limited in meeting the diverse requirements for data collection and information access that are implied by this diagram.

1.1.2 Recurring Issues that Must Be Addressed

There are at least four major issues that have consistently constrained our efforts to build effective patient record systems: (1) the need for standards in the area of clinical terminology; (2) concerns regarding data privacy, confidentiality, and security; (3) challenges of data entry by physicians; and (4) difficulties associated with the integration of record systems with other information resources in the health care setting. The first of these issues is discussed in detail in Chapter 7, and privacy is one of the central topics in Chapter 10. Issues of direct data entry by clinicians are discussed in Chapters 2 and 12 and throughout many other chapters as well. In Section 1.1.3 we examine recent trends in networking and ask how communications are changing the way in which the patient care record can be better integrated with other relevant information resources and clinical processes, which are currently fragmented and poorly coordinated.

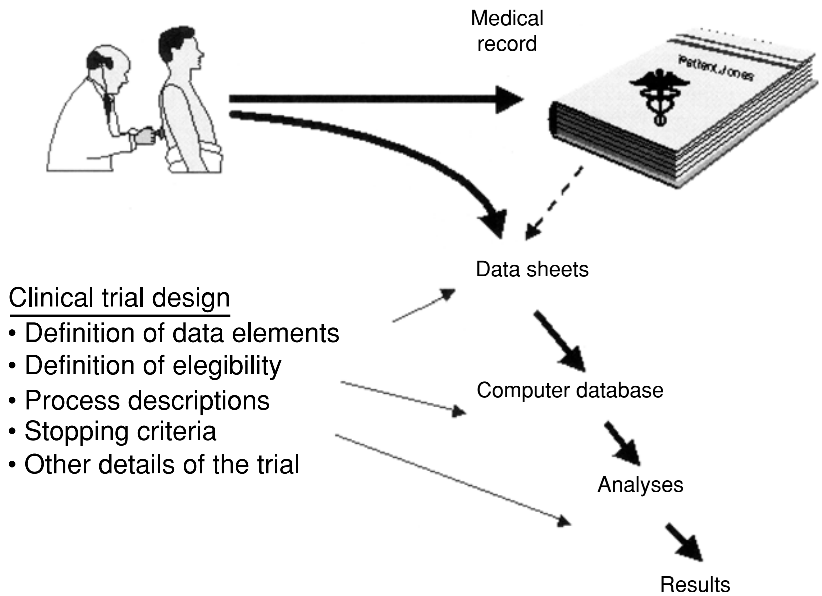

Figure 1.4. Conventional data collection for clinical trials. Although modern clinical trials routinely use computer systems for data storage and analysis, the gathering of research data is often a manual task. Physicians who care for patients enrolled in trials are often asked to fill out special datasheets for later transcription into computer databases. Alternatively, data managers are hired to abstract the relevant data from the traditional paper chart. The trials are generally designed to define data elements that are required and the methods for analysis, but it is common for the process of collecting those data in a structured format to be left to manual processes at the point of patient care.

1.1.3 Integrating the Patient Record with Other Information Resources

Experience has shown that physicians are "horizontal" users of information technology (Greenes and Shortliffe, 1990). Rather than becoming "power users" of a narrowly defined software package, they tend to seek broad functionality across a wide variety of systems and resources. Thus, routine use of computers, and of EHRs, will be most easily achieved if the computing environment offers a critical mass of functionality that makes the system both smoothly integrated and useful for essentially every patient encounter.

With the introduction of networked systems within our health care organizations, there are new opportunities to integrate a wide variety of resources through single clinical workstations (see Chapter 10). The nature of the integration tasks is illustrated in Figure 1.6, in which various workstations are shown at the upper left (machines for use by patients, clinicians, or clerical staff) connected to an enterprise-wide network or **intranet**. In such an environment, diverse clinical, financial, and administrative databases all need to be accessed and integrated, typically by using networks to tie them

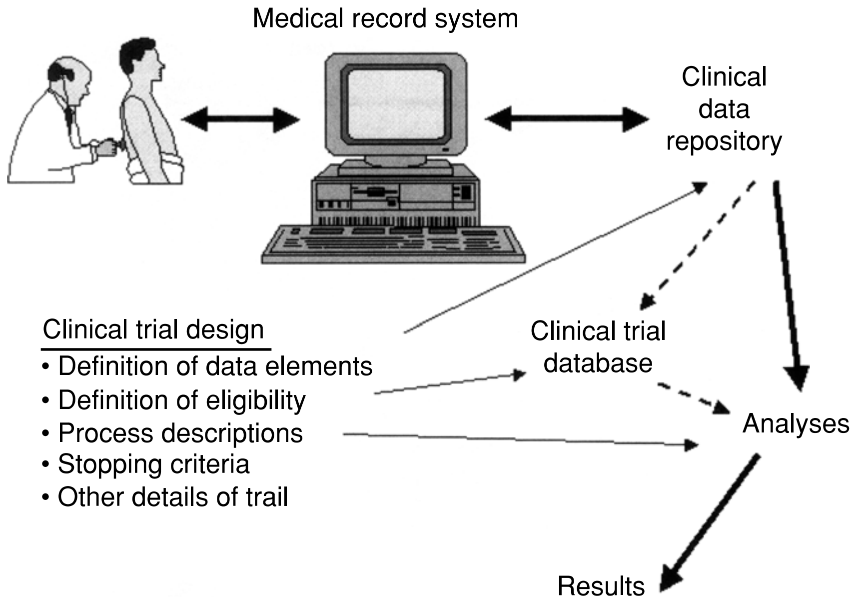

Figure 1.5. Role of electronic health records (EHRs) in supporting clinical trials. With the introduction of computer-based patient record (CPR) systems, the collection of research data for clinical trials can become a by-product of the routine care of the patients. Research data may be analyzed directly from the clinical data repository, or a secondary research database may be created by downloading information from the online patient records. The manual processes in Figure 1.4 are thereby eliminated. In addition, the interaction of the physician with the medical record permits two-way communication, which can greatly improve the quality and efficiency of the clinical trial. Physicians can be reminded when their patients are eligible for an experimental protocol, and the computer system can also remind the clinicians of the rules that are defined by the research protocol, thereby increasing compliance with the experimental plan.

together and a variety of standards for sharing data among them. Thus the clinical data repository has developed as an increasingly common idea. This term refers to a central computer that gathers and integrates clinical data from diverse sources such as the chemistry and microbiology laboratories, the pharmacy, and the radiology department. As is suggested in the diagram, this clinical database can provide the nidus for what will evolve into an EHR as more and more clinical data become available in electronic form and the need for the paper documents shrinks and eventually vanishes.

Another theme in the changing world of health care is the increasing investment in the creation of **clinical guidelines** and **pathways** (see Chapter 20), generally in an effort to reduce practice variability and to develop consensus approaches to recurring management problems. Several government and professional organizations, as well as individual provider groups, have invested heavily in guideline development, often putting an emphasis on using clear evidence from the literature, rather than expert opinion alone,

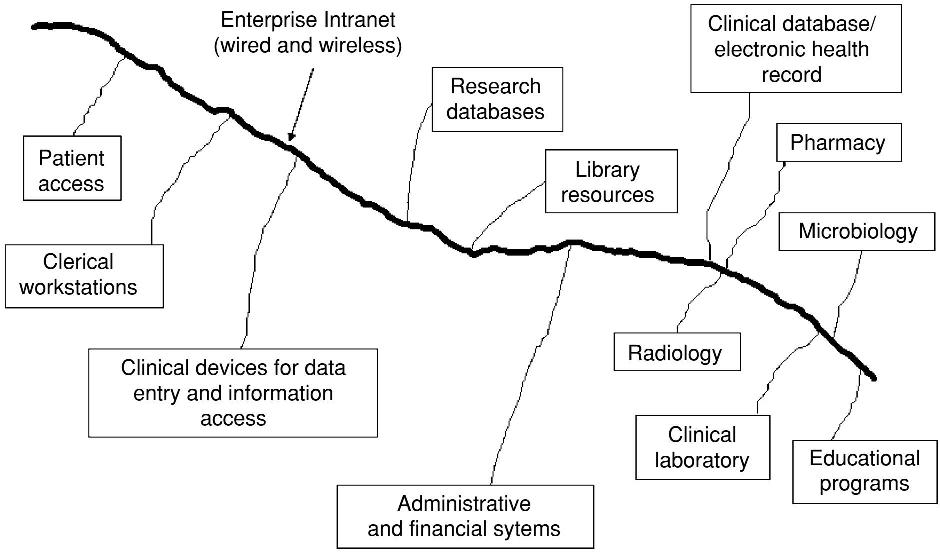

Figure 1.6. Networking the organization. We already live in an era when large hospitals and health care systems have implemented widespread networking technologies that allow diverse systems and users to communicate with one another within their organization. The *enterprise intranet* is a locally controlled network that extends throughout a health care system. It allows specialized workstations to access a wide variety of information sources: educational, clinical, financial, and administrative. An electronic health record (EHR) emerges from such an architecture if a system is implemented that gathers patient-specific data from multiple sources and merges them for ease of access by users such as those illustrated in Figure 1.2. Such systems are often called clinical data repositories, particularly if they do not yet contain the full range of information that would normally occur in a medical record. The enterprise intranet faces challenges of connectivity and integration that are a microcosm of what the larger community experiences in trying to link EHRs and other clinical systems from different organizations.

as the basis for the advice. Despite the success in creating such **evidence-based guidelines**, there is a growing recognition that we need better methods for delivering the decision logic to the point of care. Guidelines that appear in monographs or journal articles tend to sit on shelves, unavailable when the knowledge they contain would be most valuable to practitioners. Computer-based tools for implementing such guidelines, and integrating them with the EHR, present a potential means for making high-quality advice available in the routine clinical setting. Many organizations are accordingly attempting to integrate decision-support tools with their nascent electronic record systems.

Rethinking Common Assumptions

One of the first instincts of software developers is to create an electronic version of an object or process from the physical world. Some familiar notion provides the inspiration for a new software product. Once the software version has been developed, however, human ingenuity and creativity often lead to an evolution that extends the software version far beyond what was initially contemplated. The computer can thus facilitate paradigm shifts in how we think about such familiar concepts.

Consider, for example, the remarkable difference between today's word processors and the typewriter, which was the original inspiration for their development. Although the early word processors were designed largely to allow users to avoid retyping papers each time a minor change was made to a document, the word processors of today bear little resemblance to a typewriter. Consider all the powerful desktop-publishing facilities, integration of figures, spelling correction, grammar aids, etc. Similarly, today's spreadsheet programs bear little resemblance to the tables of numbers that we once created on graph paper. Also consider automatic teller machines (ATMs) and their facilitation of today's worldwide banking in ways that were never contemplated when the industry depended on human bank tellers.

It is accordingly logical to ask what the health record will become after it has been effectively implemented on computer systems and new opportunities for its enhancement become increasingly clear to us. It is unlikely that the computer-based health record a decade from now will bear much resemblance to the antiquated paper folder that still dominates many of our health care environments. One way to anticipate the changes that are likely to occur is to consider the potential role of wide-area networking and the Internet in the record's evolution.

Extending the Record Beyond the Single Institution

In considering ongoing trends in information technology that are likely to make changes inevitable, it would be difficult to start with any topic other than the Internet. The Internet began in 1968 as a U.S. research activity funded by the Advanced Research Projects Agency (ARPA) of the Department of Defense. Initially known as the ARPAnet, the network began as a novel mechanism for allowing a handful of defense-related mainframe computers, located mostly at academic institutions or in the defense industry, to share data files with each other and to provide remote access to computing power at other locations. The notion of electronic mail arose soon thereafter, and machine-to-machine electronic mail exchanges quickly became a major component of the network's traffic. As the technology matured, its value for nonmilitary research activities was recognized, and by 1973 the first medically related research computer had been added to the network (Shortliffe, 1998b, 2000).

During the 1980s, the technology began to be developed in other parts of the world, and the National Science Foundation took over the task of running the principal high-speed **backbone network** in the United States. The first hospitals, mostly academic centers, began to be connected to what had by then become known as the Internet, and in a major policy move it was decided to allow commercial organizations to join the network as well. By April 1995, the Internet in the United States had become a fully commercialized operation, no longer depending on the U.S. government to support even the major backbone connections. Many people point to the Internet as a superb example of the facilitating role of federal investment in promoting innovative technologies. The

Internet is a major societal force that arguably would never have been created if the research and development, plus the coordinating activities, had been left to the private sector.

The explosive growth of the Internet did not occur until the late 1990s, when the World Wide Web (which had been conceived initially by the physics community as a way of using the Internet to share preprints with photographs and diagrams among researchers) was introduced and popularized. The Web is highly intuitive, requires no special training, and provides a mechanism for access to multimedia information that accounts for its remarkable growth as a worldwide phenomenon.

The societal impact of this communications phenomenon cannot be overstated, especially given the international connectivity that has grown phenomenally in the past 15 years. Countries that once were isolated from information that was important to citizens, ranging from consumers to scientists to those interested in political issues, are now finding new options for bringing timely information to the desktop machines of individuals with an Internet connection.

There has accordingly been a major upheaval in the telecommunications industry, with companies that used to be in different businesses now finding that their activities and technologies have merged. In the United States, legislation was passed in 1996 to allow new competition to develop and new industries to emerge. There is ample evidence of the merging of technologies such as cable television, telephone, networking, and satellite communications. High-speed lines into homes and offices are widely available, wireless networking is ubiquitous, and inexpensive mechanisms for connecting to the Internet without using a computer (e.g., using cell phones) have also emerged. The impact on all individuals is likely to be great and hence on our patients and on their access to information and to their health care providers. Medicine cannot afford to ignore these rapidly occurring changes.

1.1.4 A Model of Integrated Disease Surveillance[2]

To emphasize the role that the nation's networking infrastructure could play in integrating clinical data and enhancing care delivery, let us envision one model of how disease surveillance, prevention, and care could be influenced by information and communications technology a decade or so from now. Imagine the day when *all* providers, regardless of practice setting (hospitals, emergency rooms, small offices, community clinics, military bases, multispecialty groups, etc.) use EHRs in their medical practices both to assist in patient care and to provide patients with counsel on illness prevention. The full impact of this use of electronic resources will occur when data from all such records are pooled in regional and national surveillance databases (Figure 1.7), mediated through connectivity with the Internet. The challenge, of course, is to find a way to integrate data from such diverse practice settings, especially since it is inevitable that multiple vendors and system developers will be active in the marketplace, competing to provide value-added capabilities that will excite and attract the practitioners for whom their EHR product is intended.

[2] This section is adapted from a discussion that originally appeared in (Shortliffe and Sondik, 2004).

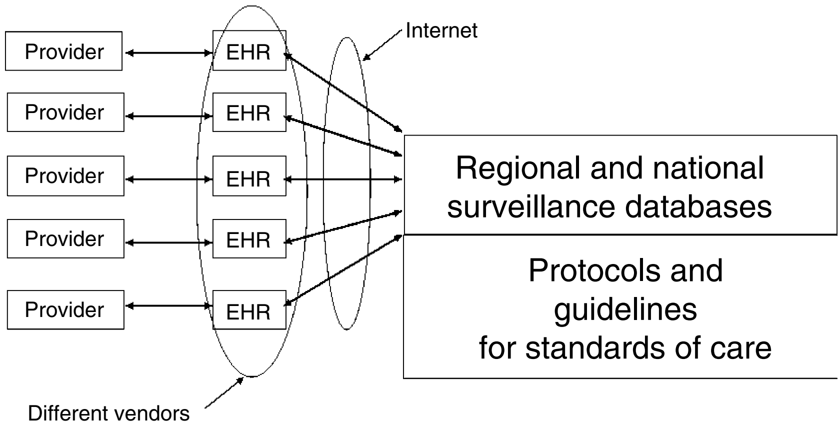

Figure 1.7. A future vision of surveillance databases, in which clinical data are pooled in regional and national repositories through a process of data submission that occurs over the Internet (with attention to privacy and security concerns as discussed in the text). When information is effectively gathered, pooled, and analyzed, there are significant opportunities for feeding back the results of derived insights to practitioners at the point of care.

The practical need to pool and integrate clinical data from such diverse resources and systems emphasizes the practical issues that must be addressed if this vision is to be achieved. Interestingly, most of the potential barriers are logistical, political, and financial rather than technical in nature:

- *Encryption of data*: Concerns regarding privacy and data protection require that Internet transmission of clinical information occur only if those data are **encrypted**, with an established mechanism for identifying and authenticating individuals before they are allowed to decrypt the information for surveillance or research use.
- *HIPAA-compliant policies*: The privacy and security rules that resulted from the 1996 Health Insurance Portability and Accountability Act (HIPAA) do not prohibit the pooling and use of such data (see Chapter 10), but they do lay down policy rules and technical security practices that must be part of the solution in achieving the vision proposed.
- *Standards for data transmission and sharing*: Sharing data over networks requires that all developers of EHRs and clinical databases adopt a single set of standards for communicating and sharing information. The de facto standard for such sharing, **Health Level 7 (HL7),** is widely used but still not uniformly adopted, implemented, or utilized (see Chapter 7).
- *Standards for data definitions*: A uniform "envelope" for digital communication, such as HL7, does not assure that the *contents* of such messages will be understood or standardized. The pooling and integration of data requires the adoption of standards for clinical terminology and for the schemas used to store clinical information in databases (see Chapter 7).

- *Quality control and error checking*: Any system for accumulating, analyzing, and utilizing clinical data from diverse sources must be complemented by a rigorous approach to quality control and error checking. It is crucial that users have faith in the accuracy and comprehensiveness of the data that are collected in such repositories, because policies, guidelines, and a variety of metrics can be derived over time from such information.
- *Regional and national surveillance databases*: Any adoption of the model in Figure 1.7 will require mechanisms for creating, funding, and maintaining the regional and national databases that are involved. The role of state and Federal governments will need to be clarified, and the political issues addressed (including the concerns of some members of the populace that any government role in managing or analyzing their health data may have societal repercussions that threaten individual liberties, employability, etc.).

With the establishment of surveillance databases, and a robust system of Internet integration with EHRs, summary information can flow back to providers to enhance their decision making at the point of care (Figure 1.7). This assumes standards that allow such information to be integrated into the vendor-supplied products that the clinicians use in their practice settings. These may be EHRs or, increasingly, **order-entry systems** that clinicians use to specify the actions that they want to have taken for the treatment or management of their patients. Furthermore, as is shown in Figure 1.7, the databases can help to support the creation of evidence-based guidelines, or clinical research protocols, which can be delivered to practitioners through the feedback process. Thus one should envision a day when clinicians, at the point of care, will receive integrated, nondogmatic, supportive information regarding:

- Recommended steps for health promotion and disease prevention
- Detection of syndromes or problems, either in their community or more widely
- Trends and patterns of public health importance
- Clinical guidelines, adapted for execution and integration into patient-specific decision support rather than simply provided as text documents
- Opportunities for distributed (community-based) clinical research, whereby patients are enrolled in clinical trials and protocol guidelines are in turn integrated with the clinicians' EHR to support protocol-compliant management of enrolled patients

Implementing the National Health Information Infrastructure

As was previously mentioned, large provider organizations, including hospitals and distributed health systems, routinely use networking technology as the infrastructure on which they build their computer-based communications channels (Figure 1.6). With departmental computer systems (e.g., radiology, clinical laboratory, microbiology, and pharmacy) connected to the network, institutions generally collect and store data in a central clinical data repository. Over time, as this repository becomes more and more comprehensive, it effectively becomes an EHR. Clinicians access the patient data in such repositories using a variety of methods, ranging from tethered workstations installed in offices or nursing stations to handheld wireless devices such as personal digital assistants (PDAs) or tablet computers. Clerical staff members use the same network to enter and access information, and sometimes patients are invited to enter their histories, to access educational materials, or even to review their personal clinical data over such networks. Data may be submitted to research databases, and the users of the network typically have access to library resources or to administrative or financial systems. The integration of such resources within an organization depends on a robust enterprise intranet (Figure 1.6). The implementation and maintenance of an advanced network is one of the fiscal and organizational challenges faced by complex provider institutions.

In the outpatient setting, both small and large networks are becoming commonplace (Figure 1.8). Within an ambulatory practice, physicians and other personnel may have several computers networked together and sharing data from an EHR system. The full utility of the system depends on gateways from these local networks into the Internet because that is where the patients and business associates (such as pharmacies and clinical laboratories) increasingly access and provide information. Several EHR products provide specialized Web interfaces so that patients can access their physician's practice for purposes ranging from appointment scheduling to review of laboratory results and drug lists.

The future vision of Figure 1.7 requires that the surveillance databases that need to be built will depend on the submission of data over the Internet from clinical databases that reside in large organizations (Figure 1.6) and outpatient practice settings (Figure 1.8). Furthermore, the delivery of information to these settings depends on an infrastructure that supports the integration of decision-support elements with the records

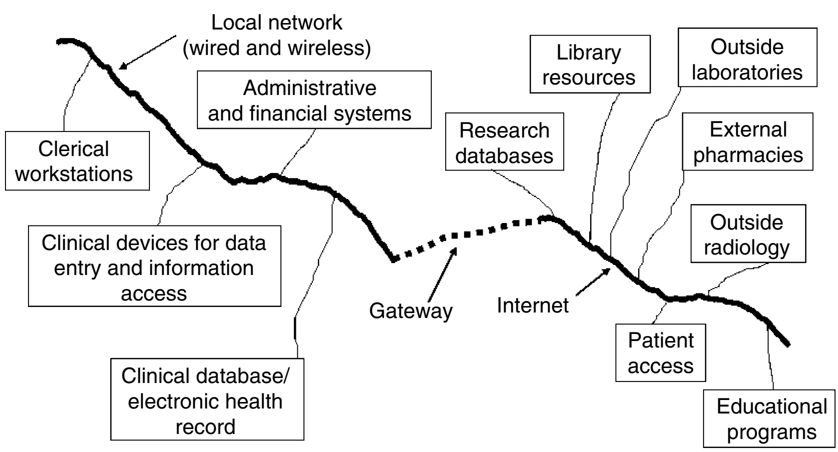

Figure 1.8. Communications networks are increasingly found in outpatient practice settings, including small office practices, but much of their value is enhanced when they are linked through gateways to the Internet and to information resources, organizations, and individuals beyond their own doors.

and order-entry systems used in these same practice environments. *We must tap into these clinical data, as a by-product of routine patient encounters, if we want to create shared research and surveillance databases* (Figure 1.7). If the submission of data for research or surveillance purposes requires an extra step, or special effort by busy clinicians, the process likely will fail, regardless of the good intentions of practitioners. Moreover, this extra step should not be necessary. We can build integrated systems on standards that allow automated data submission and collection via the Internet in a secure, responsible, and confidential manner.

Thus the vision laid out in Figure 1.7 depends on the creation of a **National Health Information Infrastructure (NHII)** (Figure 1.9), which links all practices and practitioners in the country (see Chapter 15 for an extensive discussion), offering them value in terms of access to information, decision support when desired, communication channels with patients and colleagues, and even support for their business operations (e.g., by online submission of invoices to payers that carries the potential for error checking and real-time verification, which will, in turn, greatly shorten the payment cycle for accounts receivable). This idealistic model addresses a large number of the serious problems facing our health care system, ranging from error prevention and reduction in practice variation to reduced administrative costs and enhanced efficiency. The public health system, including disease surveillance, will be only one of the many beneficiaries of such a transition.

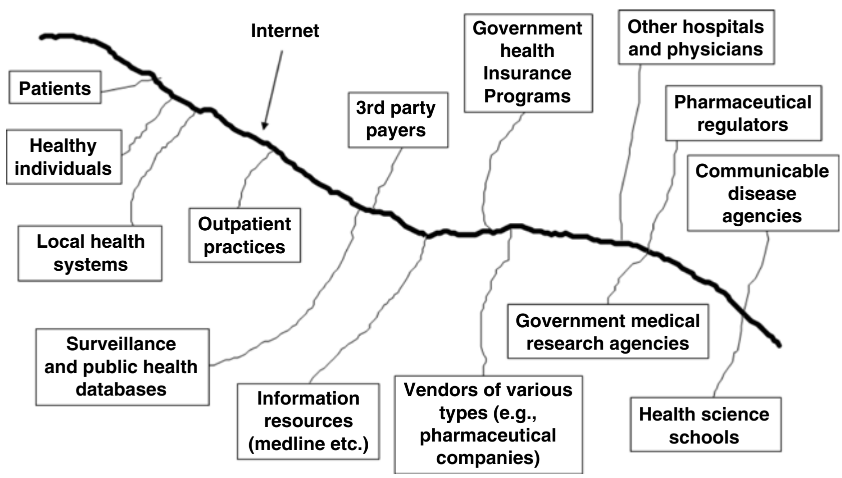

Figure 1.9. Moving beyond the organization. The integrated interconnectivity of all the clinical systems, building on networking technology and standards for data exchange and privacy protection, creates a National Health Information Infrastructure (NHII), which supports clinical care, research, and the public health. The *enterprise Internet* is the integration of an organization's intranet (Figure 1.6, encapsulated in the box here labeled "Local Health System") with the full potential of the worldwide Internet. Both providers and patients increasingly access the Internet for a wide variety of information sources and functions suggested by this diagram (see text).

The Cycle of Information Flow in Clinical Care

The concepts outlined above lead to a composite model of cyclical information flow in the future, as is shown in Figure 1.10. Beginning at the left of the diagram, physicians caring for patients use electronic health records. Information from these records will be forwarded automatically to regional and national registries as well as to research databases (if the patient is enrolled in a community-based clinical trial). The information can be used to develop standards for prevention and treatment, with major guidance from biomedical research. Researchers can draw information either directly from the health records or from the pooled data in registries. The standards for treatment in turn will be translated into protocols, guidelines, and educational materials. This new knowledge and decision-support functionality will be delivered via the NHII back to the clinicians so that the information informs the practice of medicine at the point of care, where it is integrated seamlessly with EHRs and order-entry systems.

Implications for Patients

As the number of Internet users grows, it is not surprising that increasing numbers of patients, as well as healthy individuals, are turning to the Internet for health information (see Figure 1.9). It is a rare North American physician who has not encountered a patient who comes to an appointment armed with a question, or a stack of laser-printed

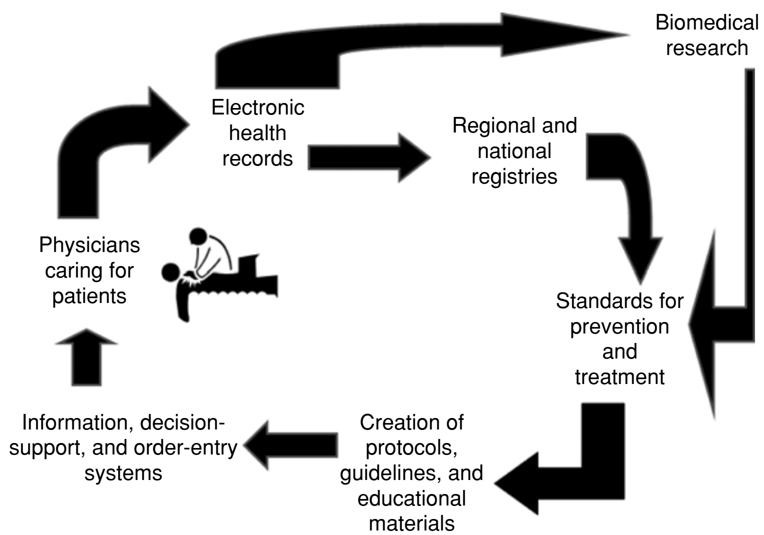

Figure 1.10. The ultimate goal is to create a cycle of information flow, whereby data from distributed electronic health records (EHRs) are automatically submitted to registries and research databases. The resulting new knowledge then can feed back to practitioners at the point of care, using a variety of computer-supported decision support delivery mechanisms.

pages, that arose due to medically related searches on the Web. The companies that provide search engines for the Internet report that medically related sites are among the most popular ones being explored by consumers. As a result, physicians and other care providers must be prepared to deal with information that patients discover on the Web and bring with them when they seek care from clinicians. Some of the information is timely and excellent; in this sense physicians can often learn about innovations from their patients and will need to be increasingly open to the kinds of questions that this enhanced access to information will generate from patients in their practices. On the other hand, much of the health information on the Web lacks peer review or is purely anecdotal. People who lack medical training can be misled by such information, just as they have been in the past by printed information in books and magazines dealing with fad treatments from anecdotal sources. In addition, some sites provide personalized advice, often for a fee, with all the attendant concerns about the quality of the suggestions and the ability to give valid advice based on an electronic mail or Web-based interaction.

In a more positive light, the new communications technologies offer clinicians creative ways to interact with their patients and to provide higher quality care. Years ago medicine adopted the telephone as a standard vehicle for facilitating patient care, and we now take this kind of interaction with patients for granted. If we extend the audio channel to include our visual sense as well, the notion of **telemedicine** emerges (see Chapter 14). Although there are major challenges, which are largely regulatory and fiscal, to be overcome before telemedicine is likely to be widely adopted for direct patient care (Grigsby and Sanders, 1998), there are specialized settings in which it is already proving to be successful and cost-effective (e.g., international medicine, teleradiology, and video-based care of patients in state and federal prisons).

A potentially more practical concept in the short term is to use computers and the Internet as the basis for communication between patients and providers. For example, there has been rapid growth in the use of electronic mail as a mechanism for avoiding "telephone tag" and allowing simple questions to be answered asynchronously (the telephone requires synchronous communication; electronic mail does not). More exploratory, but extremely promising, are communications methods based on the technology of the Web. For example, there are young companies that work with managed care organizations and health care systems to provide Web-based facilities for disease management. Patients log in to a private Web site, provide information about the status of their chronic disease (e.g., blood glucose readings in diabetes), and later obtain feedback from their physician or from disease managers who seek to keep the patients healthy at home, thereby decreasing the need for emergency room or clinic visits.

1.1.4 Requirements for Achieving the Vision

Many of the concepts proposed above depend on the emergence of an Internet with much higher **bandwidth** and **reliability**, decreased **latency**, and financial models that make the applications cost-effective and practical. Major research efforts are underway to address some of these concerns, including the federal **Large-Scale Networking** activity in the United States.[3] In addition, academic institutions have banded together in a consortium designed to create new test beds for high-bandwidth communications in support of research and education. Their initial effort has built on existing federally funded or experimental networks and is known as **Internet 2**.[4] Exploratory efforts that continue to push the state of the art in Internet technology all have significant implications for the future of health care delivery in general and of the computer-based health record in particular (Shortliffe, 1998c).

Education and Training There is a difference between computer literacy (familiarity with computers and their routine uses in our society) and knowledge of the role that computing and communications technology can and should play in our health care system. We are generally doing a poor job of training future clinicians in the latter area and are thereby leaving them poorly equipped for the challenges and opportunities they will face in the rapidly changing practice environments that surround them (Shortliffe, 1995a).

Furthermore, much of the future vision we have proposed here can be achieved only if educational institutions produce a cadre of talented individuals who not only comprehend computing and communications technology but also have a deep understanding of the biomedical milieu and of the needs of practitioners and other health workers. Computer science training alone is not adequate. Fortunately, we have begun to see the creation of formal training programs in biomedical informatics that provide custom-tailored educational opportunities. Many of the trainees are life science researchers, physicians, nurses, pharmacists, and other health professionals who see the career opportunities and challenges at the intersections of biomedicine, information science, computer science, and communications technologies. The demand for such individuals far outstrips the supply, however, both for academic and industrial career pathways (Greenes and Shortliffe, 1990). We need more training programs, expansion of those that already exist, plus support for junior faculty in health science schools who may wish to seek additional training in this area.[5]

Organizational and Management Change Finally, as implied above, there needs to be a greater understanding among health care leaders regarding the role of process reengineering in successful software implementation. Health care provides some of the most complex organizational structures in society, and it is simplistic to assume that off-the-shelf products will be smoothly introduced into a new institution without major analysis, redesign, and cooperative joint-development efforts. Underinvestment and a failure to understand the requirements for process reengineering as part of software implementation, as well as problems with technical leadership and planning, account for many of the frustrating experiences that health care organizations report in their efforts to use computers more effectively in support of patient care and provider productivity.

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[3] Large-Scale Networking initiative is the successor to the **Next Generation Internet** program, which was active in the 1990s. See http://www.itrd.gov/subcommittee/lsn.html

[4] See www.internet2.org

[5] A directory of some existing training programs is available on the Web at http://www.amia.org/resource/acad&training/f1.html

The vision of the future described here is meant to provide a glimpse of what lies ahead and to suggest the topics that need to be addressed in a book such as this one. Essentially all of the following chapters touch on some aspect of the vision of integrated systems, which extend beyond single institutions. Before embarking on these topics, however, let us emphasize two points. First, the vision presented earlier in this section will become reality only if individual hospitals, academic medical centers, and national coordinating bodies provide the standards, infrastructure, and resources that are necessary. No individual system developer, vendor, or administrator can mandate the standards for connectivity and data sharing implied by an integrated environment such as the one illustrated in Figure 1.9. A national initiative of cooperative planning and implementation for computing and communications resources within single institutions and clinics is required before practitioners will have routine access to information. A uniform environment is required if transitions between resources are to be facile and uncomplicated.

Second, although our vision focused on the clinician's view of integrated information access, other workers in the field have similar needs that can be addressed in similar ways. The academic research community has already made use of much of the technology that needs to be coalesced if the clinical user is to have similar access to data and information.

With this discussion as background, let us now consider the discipline that has led to the development of many of the facilities that need to be brought together in the integrated medical-computing environment of the future. The remainder of this chapter deals with medical computing as a field and with medical information as a subject of study. It provides additional background needed to understand many of the subsequent chapters in this book.

1.2 The Use of Computers in Biomedicine

Biomedical applications of computers is a phrase that evokes different images depending on the nature of one's involvement in the field. To a hospital administrator, it might suggest the maintenance of medical records using computers; to a decision scientist, it might mean the assistance of computers in disease diagnosis; to a basic scientist, it might mean the use of computers for maintaining and retrieving gene-sequencing information. Many physicians immediately think of office-practice tools for tasks such as patient billing or appointment scheduling. The field includes study of all these activities and of a great many others too. More important, it includes the consideration of various external factors that affect the biomedical setting. Unless you keep in mind these surrounding factors, it may be difficult to understand how biomedical computing can help us to tie together the diverse aspects of health care and its delivery.

To achieve a unified perspective, we might consider three related topics: (1) the applications of computers in biomedicine; (2) the concept of medical information (why it is important in medical practice and why we might want to use computers to process it); and (3) the structural features of medicine, including all those subtopics to which computers might be applied. The first of these is the subject of this book. We mention the second and third topics briefly in this and the next chapter, and we provide references in the Suggested Readings section for those students who wish to learn more.

The modern computer is still a relatively young device. Because the computer as a machine is exciting, people may pay a disproportionate amount of attention to it as such—at the expense of considering what the computer can do given the numbers, concepts, ideas, and cognitive underpinnings of a field such as medicine. In recent years, computer scientists, philosophers, psychologists, and other scholars have *collectively* begun to consider such matters as the nature of information and knowledge and how human beings process such concepts. These investigations have been given a sense of timeliness (if not urgency) by the simple existence of the computer. The cognitive activities of clinician begins in practice probably have received more attention over the past two decades than in all previous history (see Chapter 4). Again, the existence of the computer and the possibilities of its extending a clinician's cognitive powers have motivated most of these studies. To develop computer-based tools to assist with decisions, we must understand more clearly such human processes as diagnosis, therapy planning, decision making, and problem solving in medicine.

1.2.1 Terminology

Since the 1960s, by which time almost anyone doing serious biomedical computation had access to some kind of computer system, people have been uncertain what name they should use for the biomedical application of computer science concepts. The name *computer science* was itself new in 1960 and was only vaguely defined. Even today, *computer science* is used more as a matter of convention than as an explanation of the field's scientific content.

We use the phrase **medical computer science** to refer to the subdivision of computer science that applies the methods of the larger field to medical topics. As you will see, however, medicine has provided a rich area for computer science research, and several basic computing insights and methodologies have been derived from applied medical-computing research.

The term **information science**, which is occasionally used in conjunction with *computer science*, originated in the field of library science and is used to refer, somewhat generally, to the broad range of issues related to the management of both paper-based and electronically stored information. Much of what information science originally set out to be is now drawing renewed interest under the name **cognitive science**.

Information theory, in contrast, was first developed by scientists concerned about the physics of communication; it has evolved into what may be viewed as a new branch of mathematics. The results scientists have obtained with information theory have illuminated many processes in communications technology, but they have had little effect on our understanding of *human* information processing.

The terms **biomedical computing** or **biocomputation** have been used for a number of years. They are nondescriptive and neutral, implying only that computers are employed for some purpose in biology or medicine. They are often associated with bioengineering applications of computers, however, in which the devices are viewed more as tools for a bioengineering application than as the primary focus of research.

A term originally introduced in Europe is **medical informatics**, which is broader than **medical computing** (it includes such topics as medical statistics, record keeping, and the study of the nature of medical information itself) and deemphasizes the computer while focusing instead on the nature of the field to which computations are applied. Because the term *informatics* became widely accepted in the United States only during the 1990s, **medical information science** had often been used instead in this country; this term, however, may be confused with library science, and it does not capture the broader implications of the European term. As a result, the name *medical informatics* appeared by 2000 to have become the preferred term, even in the United States, although some people dislike the use of what they consider to be an awkward neologism. Indeed, this is the name of the field that we used in the first two editions of this textbook, and it is still heavily used in professional and academic settings. However, especially since the rise of **bioinformatics**, many observers have expressed concern that the adjective "medical" is too focused on physicians and fails to appreciate the relevance of this discipline to other health and life science professionals, although most people in the field do not intend that the word "medical" be viewed as being specifically physician-oriented or even illness-oriented. Thus, the term *health informatics*, or *health care informatics*, has gained some popularity, even though it has the disadvantage of tending to exclude applications to biology (Chapter 22) and, as we will argue shortly, it tends to focus the field's name on an application domain (public health and prevention) rather than the basic discipline and its broad range of applicability.

In the late 1990s, the director of the National Institutes of Health (NIH), Harold Varmus, appointed an advisory group called the Working Group on Biomedical Computing. In June 1999, the group provided a report[6] recommending that the NIH undertake an initiative called the **Biomedical Information Science and Technology Initiative (BISTI)**. With the subsequent creation of another NIH organization called the Bioinformatics Working Group, the visibility of informatics applications in biology was greatly enhanced. Today bioinformatics is a major area of activity at the NIH[7] and in many universities and biotechnology companies around the world. The explosive growth of this field, however, has added to the confusion regarding the naming conventions we have been discussing. In addition, the relationship between *medical informatics* and *bioinformatics* became unclear. As a result, in an effort to be more inclusive and to embrace the biological applications with which many medical informatics groups had already been involved, the name *medical informatics* has gradually given way to **biomedical informatics**. Several academic groups have already changed their names, and a major medical informatics journal (*Computers and Biomedical Research*) was reborn as *The Journal of Biomedical Informatics*.

Despite these concerns, we believe that the broad range of issues in biomedical information management does require an appropriate name and, beginning with this edition, we use the term *biomedical informatics* for this purpose throughout this book. It is becoming the most widely accepted term and should be viewed as encompassing broadly all areas of application in health, clinical practice, and biomedical research. When we speak specifically about computers and their use within biomedical informatics

[6] Available at http://www.nih.gov/about/director/060399.html
[7] See http://www.bisti.nih.gov/

activities, we use the terms biomedical computer science (for the methodologic issues) or biomedical computing (to describe the activity itself). Note, however, that biomedical informatics has many other component sciences in addition to computer science. These include the decision sciences, statistics, cognitive science, information science, and even management sciences. We return to this point shortly when we discuss the basic versus applied nature of the field when it is viewed as a basic research discipline.

Although labels such as these are arbitrary, they are by no means insignificant. In the case of new fields of endeavor or branches of science, they are important both in designating the field and in defining or restricting its contents. The most distinctive feature of the modern computer is the generality of its application. The nearly unlimited range of computer uses complicates the business of naming the field. As a result, the nature of computer science is perhaps better illustrated by examples than by attempts at formal definition. Much of this book presents examples that do just this.

Definition: In summary, *we define biomedical informatics as the scientific field that deals with biomedical information, data, and knowledge—their storage, retrieval, and optimal use for problem solving and decision making*. It accordingly touches on all basic and applied fields in biomedical science and is closely tied to modern information technologies, notably in the areas of computing and communication (biomedical computer science). The emergence of biomedical informatics as a new discipline is due in large part to rapid advances in computing and communications technology, to an increasing awareness that the knowledge base of biomedicine is essentially unmanageable by traditional paper-based methods, and to a growing conviction that the process of informed decision making is as important to modern biomedicine as is the collection of facts on which clinical decisions or research plans are made.

1.2.2 Historical Perspective

The modern digital computer grew out of developments in the United States and abroad during World War II, and general-purpose computers began to appear in the marketplace by the mid-1950s (Figure 1.11). Speculation about what might be done with such machines (if they should ever become reliable) had, however, begun much earlier. Scholars at least as far back as the Middle Ages often had raised the question of whether human reasoning might be explained in terms of formal or algorithmic processes.[8] Gottfried Wilhelm von Leibnitz, a seventeenth-century German philosopher and mathematician, tried to develop a calculus that could be used to simulate human reasoning. The notion of a "logic engine" was subsequently worked out by Charles Babbage in the mid nineteenth century.

The first practical application of automatic computing relevant to medicine was Herman Hollerith's development of a punched-card data-processing system for the 1890 U.S. census (Figure 1.12). His methods were soon adapted to **epidemiologic** and public health surveys, initiating the era of electromechanical punched-card data-processing technology, which matured and was widely adopted during the 1920s and

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[8] An algorithm is a well-defined procedure or sequence of steps for solving a problem.

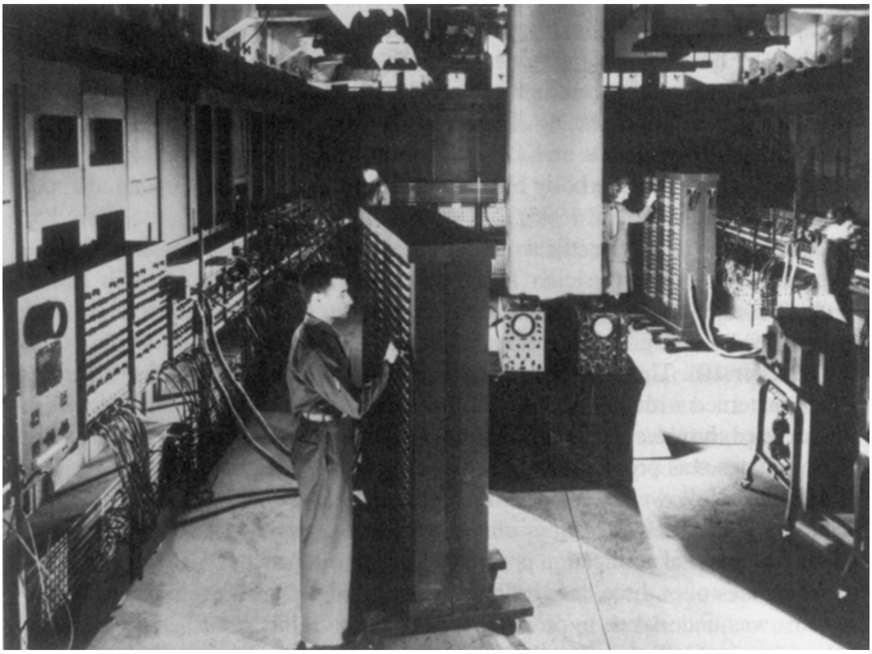

Figure 1.11. The ENIAC. Early computers, such as the ENIAC, were the precursors of today's personal computers (PCs) and handheld calculators. (Photograph courtesy of Unisys Corporation.)

1930s. These techniques were the precursors of the stored program and wholly electronic digital computers, which began to appear in the late 1940s (Collen, 1995).

One early activity in biomedical computing was the attempt to construct systems that would assist a physician in decision making (see Chapter 20). Not all biomedical-

Figure 1.12. Tabulating machines. The Hollerith Tabulating Machine was an early data-processing system that performed automatic computation using punched cards. (Photograph courtesy of the Library of Congress.)

computing programs pursued this course, however. Many of the early ones instead investigated the notion of a total hospital information system (HIS; see Chapter 13). These projects were perhaps less ambitious in that they were more concerned with practical applications in the short term; the difficulties they encountered, however, were still formidable. The earliest work on HISs in the United States was probably that associated with the MEDINET project at General Electric, followed by work at Bolt, Beranek, Newman in Cambridge, Massachusetts, and then at the Massachusetts General Hospital (MGH) in Boston. A number of hospital application programs were developed at MGH by Barnett and his associates over three decades beginning in the early 1960s. Work on similar systems was undertaken by Warner at Latter Day Saints (LDS) Hospital in Salt Lake City, Utah, by Collen at Kaiser Permanente in Oakland, California, by Wiederhold at Stanford University in Stanford, California, and by scientists at Lockheed in Sunnyvale, California.[9]

The course of HIS applications bifurcated in the 1970s. One approach was based on the concept of an integrated or monolithic design in which a single, large, *time-shared computer* would be used to support an entire collection of applications. An alternative was a distributed design that favored the separate implementation of specific applications on smaller individual computers—minicomputers—thereby permitting the independent evolution of systems in the respective application areas. A common assumption was the existence of a single shared database of patient information. The multimachine model was not practical, however, until network technologies permitted rapid and reliable communication among distributed and (sometimes) heterogeneous types of machines. Such distributed HISs began to appear in the 1980s (Simborg et al., 1983).

Biomedical-computing activity broadened in scope and accelerated with the appearance of the *minicomputer* in the early 1970s. These machines made it possible for individual departments or small organizational units to acquire their own dedicated computers and to develop their own application systems (Figure 1.13). In tandem with the introduction of general-purpose software tools that provided standardized facilities to individuals with limited computer training (such as the UNIX operating system and programming environment), the minicomputer put more computing power in the hands of more biomedical investigators than did any other single development until the introduction of the *microprocessor*, a central processing unit (CPU) contained on one or a few chips (Figure 1.14).

Everything changed radically in the late 1970s and early 1980s, when the microprocessor and the *personal computer* (PC) or *microcomputer* became available. Not only could hospital departments afford minicomputers but now individuals also could afford microcomputers. This change enormously broadened the base of computing in our society and gave rise to a new software industry. The first articles on computers in medicine had appeared in clinical journals in the late 1950s, but it was not until the late 1970s that the first advertisements dealing with computers and aimed at physicians began to appear (Figure 1.15). Within a few years, a wide range of computer-based information

[9] The latter system was subsequently taken over and further developed by the Technicon Corporation (subsequently TDS Healthcare Systems Corporation). Until recently, the system continued to be part of the suite of products available from Eclipsys, Inc.

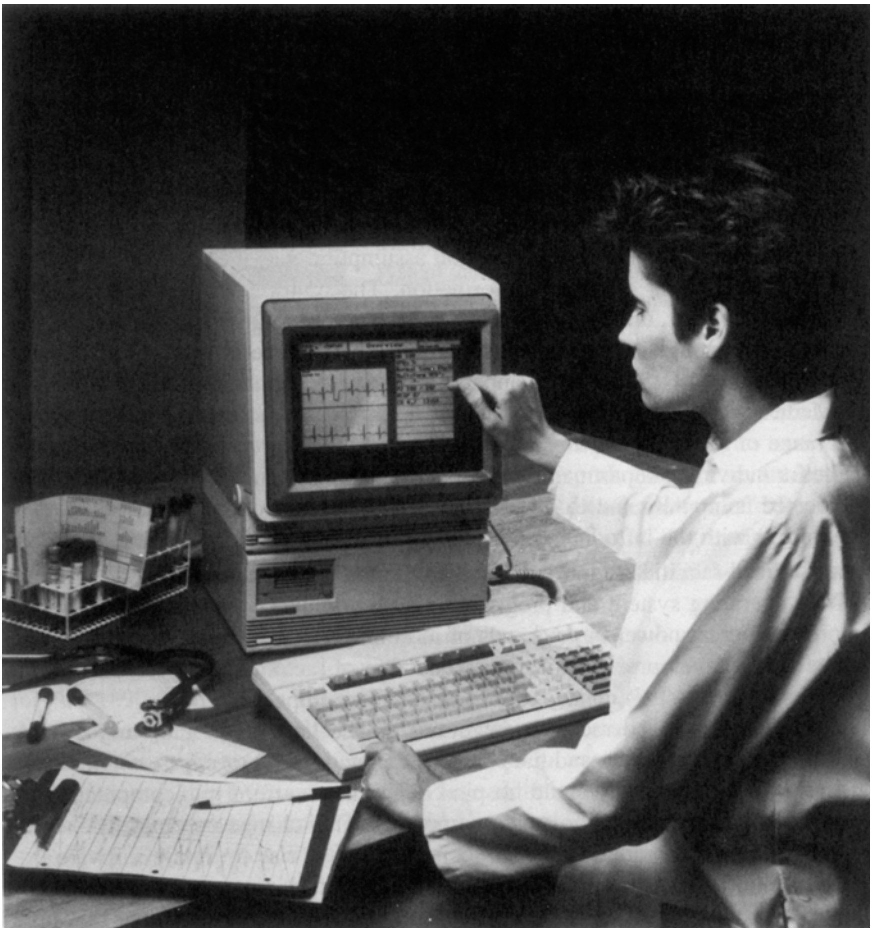

Figure 1.13. Departmental system. Hospital departments, such as the clinical laboratory, were able to implement their own custom-tailored systems when affordable minicomputers became available. Today, these departments often use microcomputers to support administrative and clinical functions. (Photograph courtesy of Hewlett-Packard Company.)

management tools were available as commercial products; their descriptions began to appear in journals alongside the traditional advertisements for drugs and other medical products. Today individual physicians find it practical to employ PCs in a variety of settings, including for applications in patient care or clinical investigation.

The stage is now set with a wide range of hardware of various sizes, types, prices, and capabilities, all of which will continue to evolve in the decades ahead. The trend—reductions in size and cost of computers with simultaneous increases in power (Figure 1.16)—shows no sign of slowing, although scientists are beginning to foresee the ultimate physical limitations to the miniaturization of computer circuits.

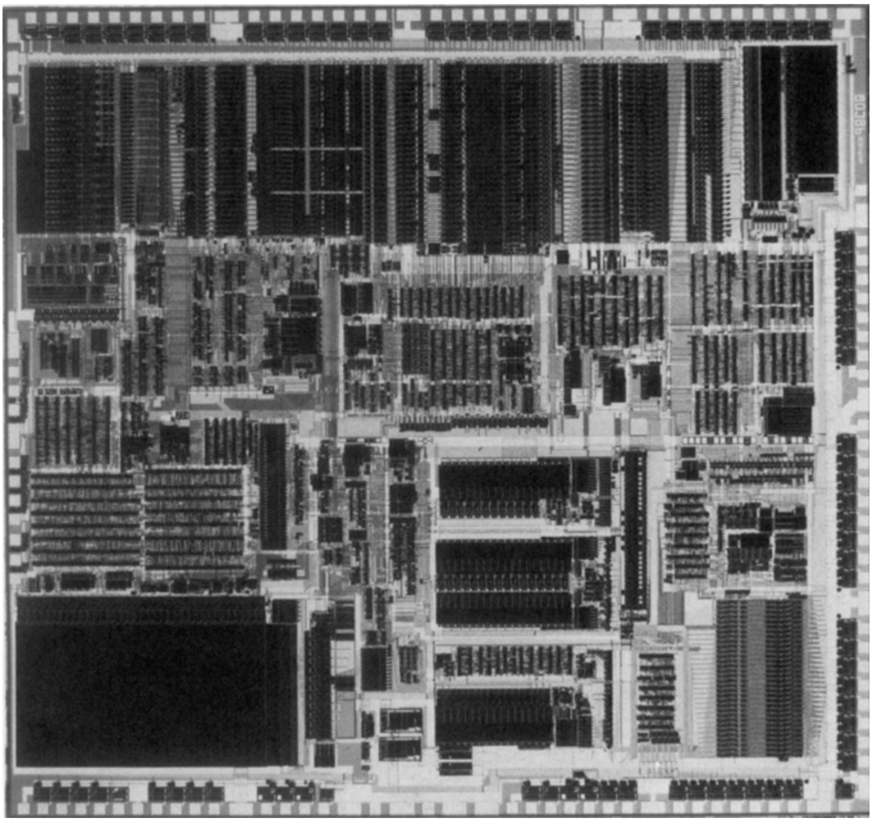

Figure 1.14. Miniature computer. The microprocessor, or "computer on a chip," revolutionized the computer industry in the 1970s. By installing chips in small boxes and connecting them to a computer terminal, engineers produced the personal computer (PC)—an innovation that made it possible for individual users to purchase their own systems.

Progress in biomedical-computing research will continue to be tied to the availability of funding from either government or commercial sources. Because most biomedical-computing research is exploratory and is far from ready for commercial application, the federal government has played a key role in funding the work of the last four decades, mainly through the NIH and the Agency for Health Care Research and Quality (AHRQ). The National Library of Medicine (NLM) has assumed a primary role for biomedical informatics, especially with support for basic research in the field (Figure 1.17). As increasing numbers of applications prove to be cost-effective (see Chapters 6 and 23), it is likely that more development work will shift to industrial settings and that university programs will focus increasingly on fundamental research problems viewed as too speculative for short-term commercialization.

Figure 1.15. Medical advertising. An early advertisement for a portable computer terminal that appeared in general medical journals in the late 1970s. The development of compact, inexpensive peripheral devices and personal computers (PCs) inspired future experiments in marketing directly to clinicians. (Reprinted by permission of copyright holder Texas Instruments Incorporated © 1985.)

1.2.3 Relationship to Biomedical Science and Medical Practice

The exciting accomplishments of biomedical informatics, and the implied potential for future benefits to medicine, must be viewed in the context of our society and of the existing health care system. As early as 1970, an eminent clinician suggested that computers might in time have a revolutionary influence on medical care, on medical education, and even on the selection criteria for health science trainees (Schwartz, 1970). The subsequent enormous growth in computing activity has been met with some trepidation by health professionals. They ask where it will all end. Will health workers gradually be replaced by computers? Will nurses and physicians need to be highly trained in

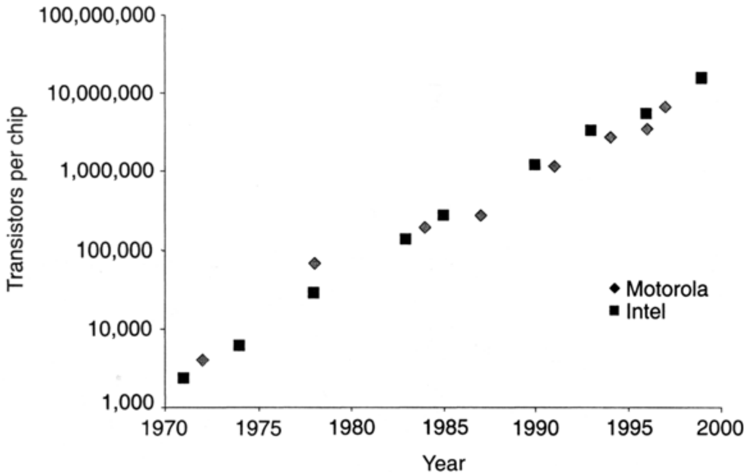

Figure 1.16. Moore's Law. Former Intel chairman Gordon Moore is credited with popularizing the "law" that the size and cost of microprocessor chips will half every 18 months while they double in computing power. This graph shows the exponential growth in the number of transistors that can be integrated on a single microprocessor by two of the major chip manufacturers. (*Source*: San Jose Mercury News, December 1997.)

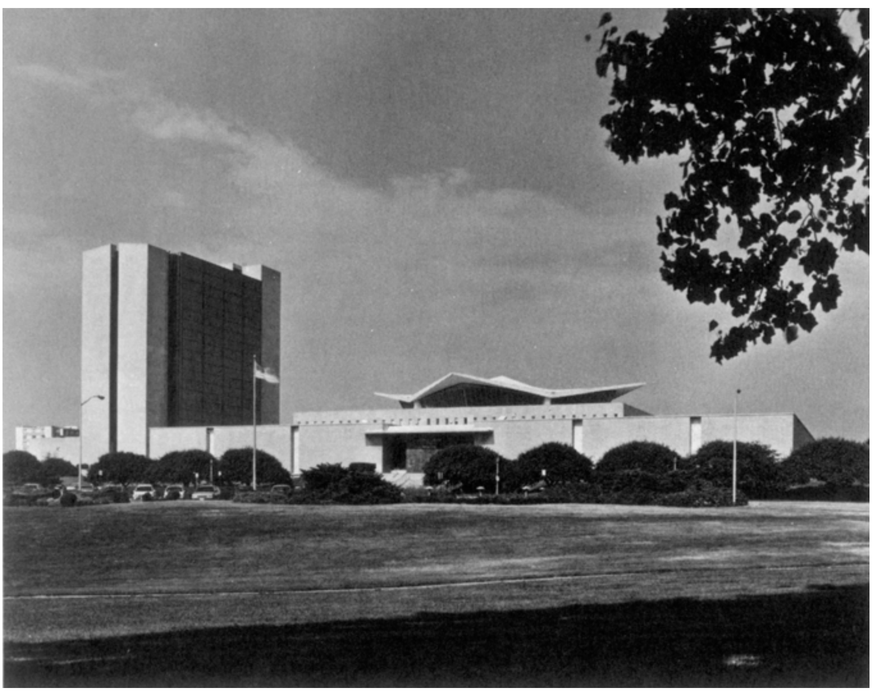

Figure 1.17. The National Library of Medicine (NLM). The NLM, on the campus of the National Institutes of Health (NIH) in Bethesda, Maryland, is the principal biomedical library for the nation (see Chapter 15). It is also a major source of support for research in biomedical informatics. (Photograph courtesy of the National Library of Medicine.)

computer science before they can practice their professions effectively? Will both patients and health workers eventually revolt rather than accept a trend toward automation that they believe may threaten the traditional humanistic values in health care delivery (see Chapter 10) (Shortliffe, 1993)? Will clinicians be viewed as outmoded and backward if they do not turn to computational tools for assistance with information management and decision making (Figure 1.18)?

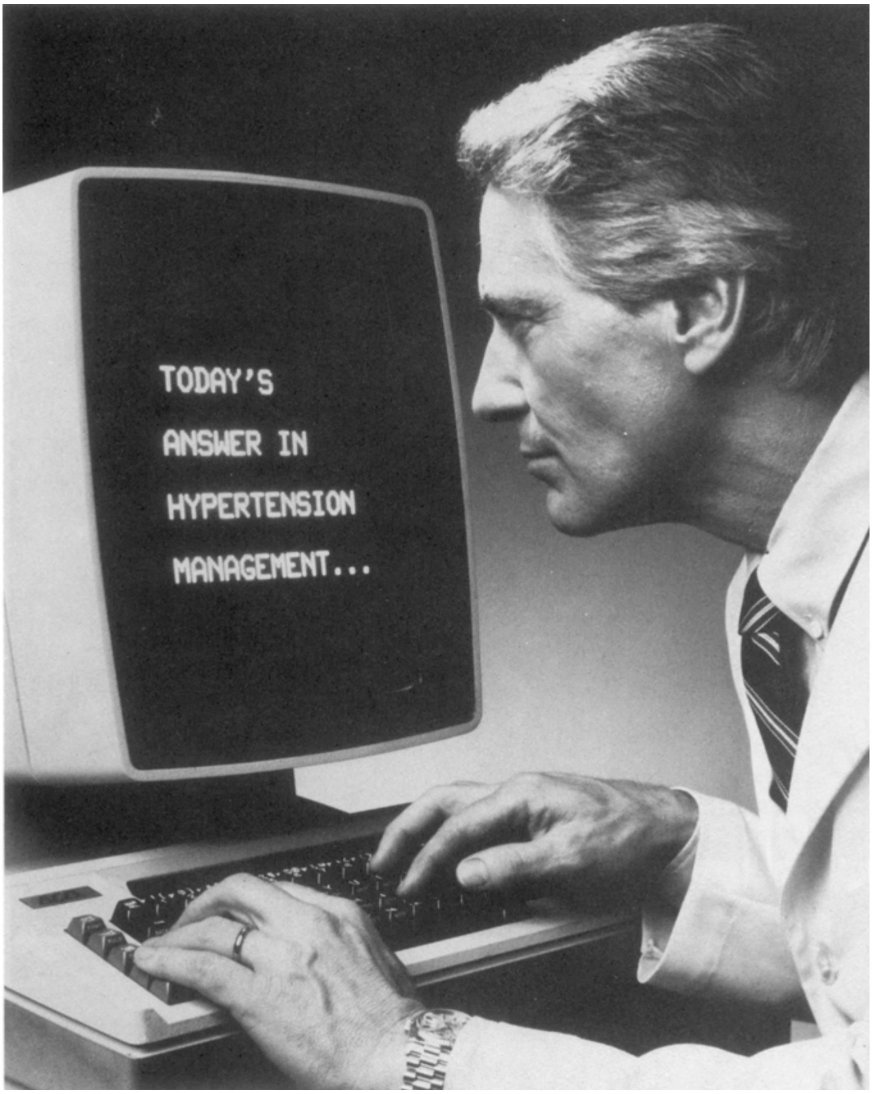

Figure 1.18. Doctor of the future. By the early 1980s, advertisements in medical journals began to use computer equipment as props. The suggestion in this photograph seems to be that an up-to-date physician feels comfortable using computer-based tools in his practice. (Photograph courtesy of ICI Pharma, Division of ICI Americas, Inc.)

Biomedical informatics is intrinsically entwined with the substance of biomedical science. It determines and analyzes the structure of biomedical information and knowledge, whereas biomedical science is constrained by that structure. Biomedical informatics melds the study of biomedical computer science with analyses of biomedical information and knowledge, thereby addressing specifically the interface between computer science and biomedical science. To illustrate what we mean by the "structural" features of medical information and knowledge, we can contrast the properties of the information and knowledge typical of such fields as physics or engineering with the properties of those typical of biomedicine (see Section 1.3).

Biomedical informatics is perhaps best viewed as a basic biomedical science, with a wide variety of potential areas of application (Figure 1.19). The analogy with other **basic sciences** is that biomedical informatics uses the results of past experience to understand, structure, and encode objective and subjective biomedical findings and thus to make them suitable for processing. This approach supports the integration of the findings and their analyses. In turn, the selective distribution of newly created knowledge can aid patient care, health planning, and basic biomedical research.

Biomedical computing is, by its nature, an experimental science. An **experimental science** is characterized by posing questions, designing experiments, performing analyses, and using the information gained to design new experiments. One goal is simply to search for new knowledge, called **basic research**. A second goal is to use this knowledge

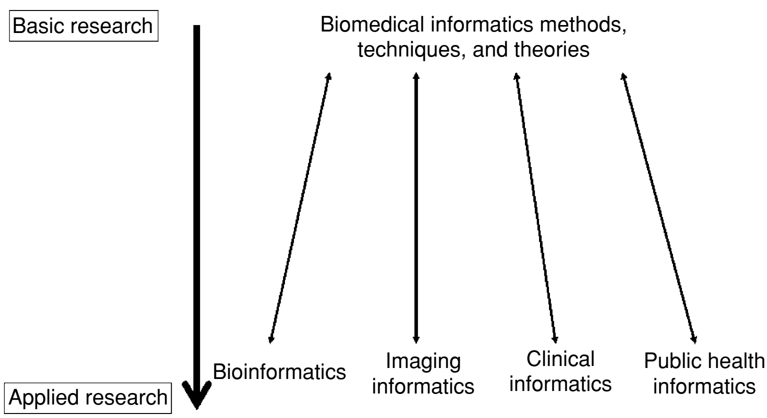

Figure 1.19. Biomedical informatics as basic science. We view the term biomedical informatics as referring to the basic science discipline in which the development and evaluation of new methods and theories are a primary focus of activity. These core concepts and methods in turn have broad applicability in the health and biomedical sciences. The informatics subfields indicated by the names across the bottom of this figure are accordingly best viewed as application domains for a common set of concepts and techniques from the field of biomedical informatics. Note that work in biomedical informatics is motivated totally by the application domains that the field is intended to serve (thus the two-headed arrows in the diagram). Therefore the basic research activities in the field generally result from the identification of a problem in the real world of health or biomedicine for which an informatics solution is sought (see text).

for practical ends, called **applications research**. There is a continuity between these two endeavors (see Figure 1.19). In biomedical informatics, there is an especially tight coupling between the application areas, broad categories of which are indicated at the bottom of Figure 1.19, and the identification of basic research tasks that characterize the scientific underpinnings of the field. Research, however, has shown that there can be a very long period of time between the development of new concepts and methods in basic research and their eventual application in the biomedical world (Balas and Boren, 2000). Furthermore (see Figure 1.20), many discoveries are discarded along the way, leaving only a small percentage of basic research discoveries that have a practical influence on the health and care of patients.

Work in biomedical informatics is inherently motivated by problems encountered in a set of applied domains in biomedicine. The first of these historically has been clinical care (including medicine, nursing, dentistry, and veterinary care), an area of activity that demands patient-oriented informatics applications. We refer to this area as **clinical informatics.**

Closely tied to clinical informatics is **public health informatics** (Figure 1.19), where similar methods are generalized for application to populations of patients rather than to single individuals (see Chapter 15). Thus clinical informatics and public health

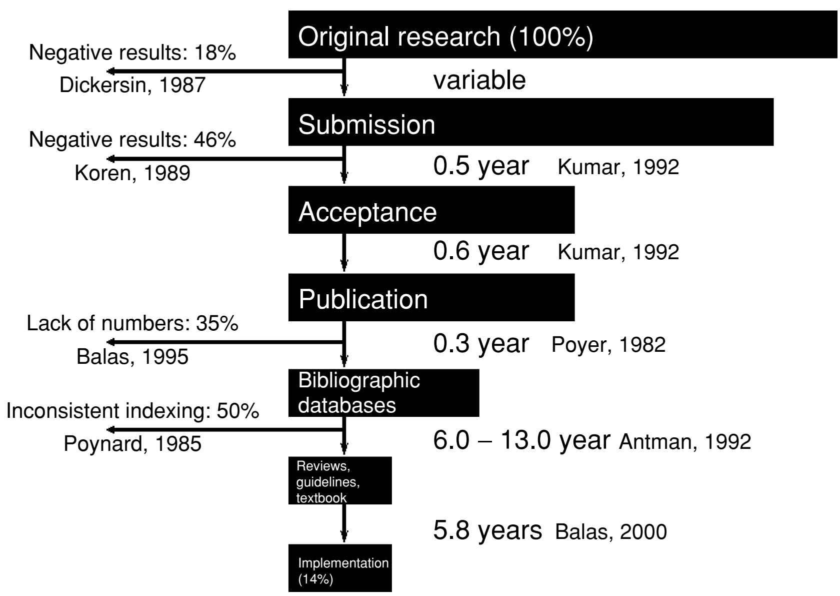

Figure 1.20. Phases in the transfer of research into clinical practice. A synthesis of studies focusing on various phases of this transfer has indicated that it takes an average of 17 years to make innovation part of routine care (Balas and Boren, 2000). Pioneering institutions often apply innovations much sooner, sometimes within a few weeks, but nationwide introduction is usually slow. National utilization rates of specific, well-substantiated procedures also suggests a delay of two decades in reaching the majority of eligible patients. (Courtesy of Dr. Andrew Balas).

informatics share many of the same methods and techniques. Two other large areas of application overlap in some ways with clinical informatics and public health informatics. These include **imaging informatics** (and the set of issues developed around both radiology and other image management and image analysis domains such as pathology, dermatology, and molecular visualization—see Chapters 9 and 18). Finally, there is the burgeoning area of bioinformatics, which at the molecular and cellular levels is offering challenges that draw on many of the same informatics methods as well (see Chapter 22).

As shown in Figure 1.21, there is a spectrum as one moves from left to right across these application domains. In bioinformatics, workers deal with molecular and cellular processes in the application of informatics methods. At the next level, workers focus on tissues and organs, which tend to be the emphasis of imaging informatics work (also called **structural informatics** at some institutions). Progressing to clinical informatics, the focus is on individual patients, and finally to public health, where researchers address problems of populations and of society. Biomedical informatics has important contributions to make across that entire spectrum.

In general, biomedical informatics researchers derive their inspiration from one of the application areas, identifying fundamental methodologic issues that need to be addressed and testing them in system prototypes or, for more mature methods, in actual systems that are used in clinical or biomedical research settings. One important implication of this viewpoint is that the core discipline is identical, regardless of the area of application that a given individual is motivated to address. This argues for unified biomedical informatics educational programs, ones that bring together students with a wide variety of applications interests. Elective courses and internships in areas of specific interest are of course important complements to the core exposures that students

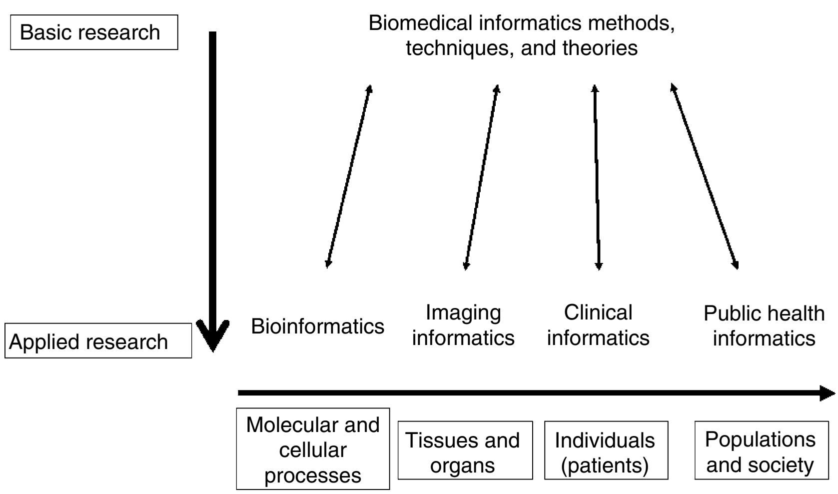

Figure 1.21. Breadth of the biomedical informatics field. The relationship between biomedical informatics as a core scientific discipline and its diverse array of application domains that span biological science, imaging, clinical practice, public health, and others not illustrated (see text).

should receive, but, given the need for teamwork and understanding in the field, it would be counterproductive and wasteful to separate trainees based on the application areas that may interest them.[10]

The scientific contributions of biomedical informatics also can be appreciated through its potential for benefiting the education of health professionals. For example, in the education of medical students, the various cognitive activities of physicians traditionally have tended to be considered separately and in isolation—they have been largely treated as though they are independent and distinct modules of performance. One activity attracting increasing interest is that of formal medical decision making (see Chapter 3). The specific content of this area remains to be defined completely, but the discipline's dependence on formal methods and its use of knowledge and information reveal that it is one aspect of biomedical informatics.

A particular topic in the study of medical decision making is **diagnosis**, which is often conceived and taught as though it were a free-standing and independent activity. Medical students may thus be led to view diagnosis as a process that physicians carry out in isolation before choosing therapy for a patient or proceeding to other modular tasks. A number of studies have shown that this model is oversimplified and that such a decomposition of cognitive tasks may be quite misleading (Elstein et al., 1978; Patel and Groen, 1986). Physicians seem to deal with several tasks at the same time. Although a diagnosis may be one of the first things physicians think about when they see a new patient, patient assessment (diagnosis, management, analysis of treatment results, monitoring of disease progression, etc.) is a process that never really terminates. A physician must be flexible and open-minded. It is generally appropriate to alter the original diagnosis if it turns out that treatment based on it is unsuccessful or if new information weakens the evidence supporting the diagnosis or suggests a second and concurrent disorder. Chapter 4 discusses these issues in greater detail.

When we speak of making a diagnosis, choosing a treatment, managing therapy, making decisions, monitoring a patient, or preventing disease, we are using labels for different aspects of medical care, an entity that has overall unity. The fabric of medical care is a continuum in which these elements are tightly interwoven. Regardless of whether we view computer and information science as a profession, a technology, or a science, there is no doubt about its importance to biomedicine. We can assume computers will be used increasingly in clinical practice, biomedical research, and health science education.

1.2.4 Relationship to Computer Science

During its evolution as an academic entity in universities, computer science followed an unsettled course as involved faculty attempted to identify key topics in the field and to

[10] The biomedical informatics training program at Columbia University, for example, was designed with this perspective in mind. Students with interests in clinical, imaging, public health, and biologic applications are trained together and are required to learn something about each of the other application areas. Details of the curriculum can be found at http://www.dbmi.columbia.edu/educ/curriculum/curriculum.html (see also Shortliffe and Johnson, 2002).

find the discipline's organizational place. Many computer science programs were located in departments of electrical engineering, because major concerns of their researchers were computer architecture and design and the development of practical hardware components. At the same time, computer scientists were interested in programming languages and software, undertakings not particularly characteristic of engineering. Furthermore, their work with algorithm design, computability theory,[11] and other theoretical topics seemed more related to mathematics.

Biomedical informatics draws from all of these activities—development of hardware, software, and computer science theory. Biomedical computing generally has not had a large enough market to influence the course of major hardware developments; i.e., computers have not been developed specifically for biomedical applications. Not till the early 1960s (when health-computing experts occasionally talked about and, in a few instances, developed special medical terminals) have people assumed that biomedical-computing applications would use hardware other than that designed for general use.

The question of whether biomedical applications would require specialized programming languages might have been answered affirmatively in the 1970s by anyone examining the MGH Utility Multi-Programming System, known as the **MUMPS** language (Greenes et al., 1970, Bowie and Barnett, 1976), which was specially developed for use in medical applications. For several years, MUMPS was the most widely used language for medical record processing. Under its new name, **M**, it is still in widespread use. New implementations have been developed for each generation of computers. M, however, like any programming language, is not equally useful for all computing tasks. In addition, the software requirements of medicine are better understood and no longer appear to be unique; rather, they are specific to the kind of task. A program for scientific computation looks pretty much the same whether it is designed for chemical engineering or for pharmacokinetic calculations.

How, then, does biomedical informatics differ from biomedical computer science? Is the new discipline simply the study of computer science with a "biomedical flavor"? If you return to the definition of biomedical informatics that we provided in Section 1.2.1, and then refer to Figure 1.19, we believe you will begin to see why biomedical informatics is more than simply the biomedical application of computer science. The issues that it addresses not only have broad relevance to health, medicine, and biology, but the underlying sciences on which biomedical informatics professionals draw are inherently interdisciplinary as well. Thus, for example, successful biomedical informatics research will often draw on, and contribute to, computer science, but it may also be closely related to the decision sciences (probability theory, decision analysis, or the psychology of human problem solving), cognitive science, information sciences, or the management sciences (Figure 1.22). Furthermore, a biomedical informatics researcher will be tightly linked to some underlying problem from the real world of health or biomedicine. As

[11] Many interesting problems cannot be computed in a finite time and require heuristics. Computability theory is the foundation for assessing the feasibility and cost of computation to provide the complete and correct results to a formally stated problem.

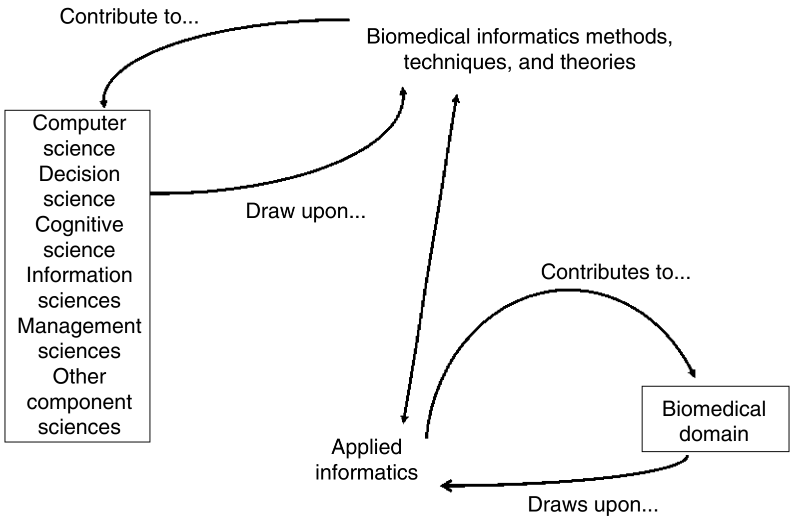

Figure 1.22. Component sciences in biomedical informatics. An informatics application area is motivated by the needs of its associated biomedical domain, to which it attempts to contribute solutions to problems. Thus any applied informatics work draws upon a biomedical domain for its inspiration, and in turn often leads to the delineation of basic research challenges in biomedical informatics that must be tackled if the applied biomedical domain is ultimately to benefit. At the methodologic level, biomedical informatics draws on, and contributes to, a wide variety of component disciplines, of which computer science is only one. As Figures 1.19 and 1.21 show explicitly, biomedical informatics is inherently multidisciplinary, both in its areas of application and in the component sciences on which it draws.

Figure 1.22 illustrates, for example, a biomedical informatics basic researcher or doctoral student will accordingly be motivated by one of the application areas, such as those shown at the bottom of Figures 1.19 and 1.21, but a dissertation worthy of a Ph.D. in the field will usually be identified by a generalizable scientific result that also contributes to one of the component disciplines (Figure 1.22) and on which other scientists can build in the future.

1.2.5 Relationship to Biomedical Engineering

If biomedical informatics is a young discipline, by contrast biomedical engineering is a well-established one. Many engineering and medical schools have formal academic programs in the latter subject, often with departmental status and full-time faculty. How does biomedical informatics relate to biomedical engineering, especially in an era when engineering and computer science are increasingly intertwined?

Biomedical engineering departments emerged 35 to 45 years ago, when technology began to play an increasingly prominent role in medical practice. The emphasis in such departments has tended to be research on, and development of, instrumentation (e.g., as discussed in Chapters 17 and 18, advanced monitoring systems, specialized transducers for clinical or laboratory use, and image-enhancement techniques for use in radiology), with an orientation toward the development of medical devices, prostheses,[12] and specialized research tools (Figure 1.23). In recent years, computing techniques have been used both in the design and building of medical devices and in the medical devices themselves. For example, the "smart" devices increasingly found in most specialties are all dependent on microprocessor technology. Intensive care monitors that generate blood pressure records while calculating mean values and hourly summaries are examples of such "intelligent" devices.

The overlap between biomedical engineering and biomedical informatics suggests that it would be unwise for us to draw compulsively strict boundaries between the two fields. There are ample opportunities for interaction, and there are chapters in this book that clearly overlap with biomedical engineering topics—e.g., Chapter 17 on patient-monitoring systems and Chapter 18 on radiology systems. Even where they meet, however, the fields have differences in emphasis that can help you to understand their different evolutionary histories. In biomedical engineering, the emphasis is on medical devices; in biomedical informatics, the emphasis is on biomedical information and

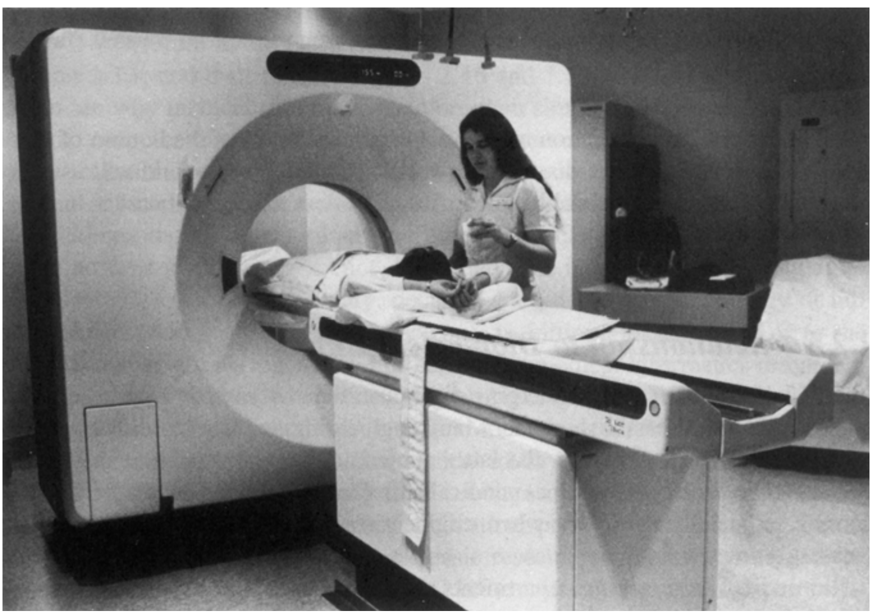

Figure 1.23. Advanced imaging device. Computed tomography (CT) scanners and other imaging devices used in radiology are of interest to both medical computer scientists and biomedical engineers. (Photograph courtesy of Janice Anne Rohn.)

[12] Devices that replace body parts—e.g., artificial hips or hearts.

knowledge and on their management with the use of computers. In both fields, the computer is secondary, although both use computing technology. The emphasis in this book is on the informatics end of the spectrum of biomedical computer science, so we shall not spend much time examining biomedical engineering topics.

1.3 The Nature of Medical Information

From the previous discussion, you might conclude that biomedical applications do not raise any unique problems or concerns. On the contrary, the biomedical environment raises several issues that, in interesting ways, are quite distinct from those encountered in most other domains of computer application. Clinical information seems to be systematically different from the information used in physics, engineering, or even clinical chemistry (which more closely resembles chemical applications generally than it does medical ones). Aspects of biomedical information include an essence of uncertainty—we can never know all about a physiological process, and this results in inevitable variability among individuals. These differences raise special problems. It is partly for this reason that some investigators suggest that biomedical computer science differs from conventional computer science in fundamental ways. We shall explore these differences only briefly here; for details, you can consult Blois' book on this subject (see Suggested Readings).

Let us examine an instance of what we will call a *low-level* (or readily formalized) science. Physics is a natural starting point; in any discussion of the hierarchical relationships among the sciences (from the fourth-century BC Greek philosopher Aristotle to the twentieth-century U.S. librarian Melvil Dewey), physics will be placed near the bottom. Physics characteristically has a certain kind of simplicity, or generality. The concepts and descriptions of the objects and processes of physics, however, are necessarily used in all applied fields, including medicine. The laws of physics and the descriptions of certain kinds of physical processes are essential in representing or explaining functions that we regard as medical in nature. We need to know something about molecular physics, for example, to understand why water is such a good solvent; to explain how nutrient molecules are metabolized, we talk about the role of electron-transfer reactions.

Applying a computer (or any formal computation) to a physical problem in a medical context is no different from doing so in a physics laboratory or for an engineering application. The use of computers in various **low-level processes** (such as those of physics or chemistry) is similar and is independent of the application. If we are talking about the solvent properties of water, it makes no difference whether we happen to be working in geology, engineering, or medicine. Such low-level processes of physics are particularly receptive to mathematical treatment, so using computers for these applications requires only conventional numerical programming.

In biomedicine, however, there are other **higher-level processes** carried out in more complex objects such as organisms (one type of which is patients). Many of the important informational processes are of this kind. When we discuss, describe, or record the properties or behavior of human beings, we are using the descriptions of very high-level objects, the behavior of whom has no counterpart in physics or in engineering. The person using computers to analyze the descriptions of these high-level objects and processes encounters serious difficulties (Blois, 1984).

One might object to this line of argument by remarking that, after all, computers are used routinely in commercial applications in which human beings and situations concerning them are involved and that relevant computations are carried out successfully. The explanation is that, in these commercial applications, the descriptions of human beings and their activities have been so highly abstracted that the events or processes have been reduced to low-level objects. In biomedicine, abstractions carried to this degree would be worthless from either a clinical or research perspective.

For example, one instance of a human being in the banking business is the customer, who may deposit, borrow, withdraw, or invest money. To describe commercial activities such as these, we need only a few properties; the customer can remain an abstract entity. In clinical medicine, however, we could not begin to deal with a patient represented with such skimpy abstractions. We must be prepared to analyze most of the complex behaviors that human beings display and to describe patients as completely as possible. We must deal with the rich descriptions occurring at high levels in the hierarchy, and we may be hard pressed to encode and process this information using the tools of mathematics and computer science that work so well at low levels. In light of these remarks, the general enterprise known as **artificial intelligence (AI)** can be aptly described as the application of computer science to high-level, real-world problems.

Biomedical informatics thus includes computer applications that range from processing of very low-level descriptions, which are little different from their counterparts in physics, chemistry, or engineering, to processing of extremely high-level ones, which are completely and systematically different. When we study human beings in their entirety (including such aspects as human cognition, self-consciousness, intentionality, and behavior), we must use these high-level descriptions. We will find that they raise complex issues to which conventional logic and mathematics are less readily applicable. In general, the attributes of low-level objects appear sharp, crisp, and unambiguous (e.g., "length," "mass"), whereas those of high-level ones tend to be soft, fuzzy, and inexact (e.g., "unpleasant scent," "good").

Just as we need to develop different methods to describe high-level objects, the inference methods we use with such objects may differ from those we use with low-level ones. In formal logic, we begin with the assumption that a given proposition must be either true or false. This feature is essential because logic is concerned with the preservation of truth value under various formal transformations. It is difficult or impossible, however, to assume that all propositions have truth values when we deal with the many high-level descriptions in medicine or, indeed, in everyday situations. Such questions as "Was Woodrow Wilson a good president?" cannot be answered with a "yes" or "no" (unless we limit the question to specific criteria for determining the goodness of presidents). Many common questions in biomedicine have the same property.

1.4 Integrating Biomedical Computing and Medical Practice

It should be clear from the previous discussion that biomedical informatics is a remarkably broad and complex topic. We have argued that information management is intrinsic to medical practice and that interest in using computers to aid in information management has grown over the last four decades. In this chapter and throughout the book, we emphasize the myriad ways in which computers are used in biomedicine to ease the burdens of information processing and the means by which new technology promises to change the delivery of health care. The rate at, and degree to, which such changes are realized will be determined in part by external forces that influence the costs of developing and implementing biomedical applications and the ability of clinicians, patients, and the health care system to accrue the potential benefits.

We can summarize several global forces that are affecting biomedical computing and that will determine the extent to which computers are assimilated into medical practice: (1) new developments in computer hardware and software; (2) a gradual increase in the number of professionals who have been trained in both clinical medicine and biomedical informatics; and (3) ongoing changes in health care financing designed to control the rate of growth of medical expenditures (Chapter 23). We touched on the first of these factors in Section 1.2.2, when we described the historical development of biomedical computing and the trend from mainframe computers to microcomputers and PCs. The future view outlined in Section 1.1 similarly builds on the influence that the Internet has provided throughout society during the last decade. The new hardware technologies have made powerful computers inexpensive and thus available to hospitals, to departments within hospitals, and even to individual physicians. The broad selection of computers of all sizes, prices, and capabilities makes computer applications both attractive and accessible. Technological advances in information storage devices are facilitating the inexpensive storage of large amounts of data, thus improving the feasibility of data-intensive applications, such as the all-digital radiology department discussed in Chapter 18. Standardization of hardware and advances in network technology are making it easier to share data and to integrate related information management functions within a hospital or other health care organization.

Computers are increasingly prevalent in all aspects of our lives, whether as an ATM, as the microprocessor in a microwave oven, or as a word processor. Physicians trained in recent years may have used computer programs to learn diagnostic techniques or to manage the therapy of simulated patients. They may have learned to use a computer to search the medical literature, either directly or with the assistance of a specially trained librarian. Simple exposure to computers does not, however, guarantee an eagerness to embrace the machine. Medical personnel will be unwilling to use computer-based systems that are poorly designed, confusing, unduly time-consuming, or lacking in clear benefit (see Chapters 4 and 6).

The second factor is the increase in the number of professionals who are being trained to understand the biomedical issues as well as the technical and engineering ones. Computer scientists who understand biomedicine are better able to design systems responsive to actual needs. Health professionals who receive formal training in biomedical informatics are likely to build systems using well-established techniques while avoiding the past mistakes of other developers. As more professionals are trained in the special aspects of both fields, and as the programs they develop are introduced, health care professionals are more likely to have useful and usable systems available when they turn to the computer for help with information management tasks.

The third factor affecting the integration of computing technologies into health care settings is managed care and the increasing pressure to control medical spending

(Chapter 23). The escalating tendency to apply technology to all patient care tasks is a frequently cited phenomenon in modern medical practice. Mere physical findings no longer are considered adequate for making diagnoses and planning treatments. In fact, medical students who are taught by more experienced physicians to find subtle diagnostic signs by examining various parts of the body nonetheless often choose to bypass or deemphasize physical examinations in favor of ordering one test after another. Sometimes, they do so without paying sufficient attention to the ensuing cost. Some new technologies replace less expensive, but technologically inferior, tests. In such cases, the use of the more expensive approach is generally justified. Occasionally, computer-related technologies have allowed us to perform tasks that previously were not possible. For example, the scans produced with computed tomography or magnetic resonance imaging (see Chapter 18) have allowed physicians to visualize cross-sectional slices of the body for the first time, and medical instruments in intensive care units perform continuous monitoring of patients' body functions that previously could be checked only episodically (see Chapter 17).

Yet the development of expensive new technologies, and the belief that more technology is better, helped to fuel the rapidly escalating health care costs of the 1970s and 1980s, leading to the introduction of managed care and capitation in recent years. Chapter 23 discusses the mechanisms that opened the door to rapid growth in health expenses and the changes in financing and delivery that were designed to curb spending in the new era of cost consciousness. Integrated computer systems potentially provide the means to capture data for detailed cost accounting, to analyze the relationship of costs of care to the benefits of that care, to evaluate the quality of care provided, and to identify areas of inefficiency. Systems that improve the quality of care while reducing the cost of providing that care clearly will be favored. The effect of cost containment pressures on technologies that increase the cost of care while improving the quality are less clear. Medical technologies, including computers, will need to improve the delivery of medical care while either reducing costs or providing benefits that clearly exceed their costs.

Improvements in hardware and software make computers more suitable for biomedical applications. Designers of medical systems must, however, address satisfactorily many logistical and engineering questions before computers can be fully integrated into medical practice. For example, are computer terminals conveniently located? Could handheld devices effectively replace the tethered terminals and workstations of the past? Can users complete their tasks without excessive delays? Is the system reliable enough to avoid loss of data? Can users interact easily and intuitively with the computer? Are patient data secure and appropriately protected from prying eyes? In addition, cost control pressures produce a growing reluctance to embrace expensive technologies that add to the high cost of health care. The net effect of these opposing trends will in large part determine the degree to which computers are integrated into the health care environment.

In summary, rapid advances in computer hardware and software, coupled with an increasing computer literacy of health care professionals and researchers, favor the implementation of effective computer applications in medical practice and life sciences research. Furthermore, in the increasingly competitive health care industry, providers have a greater need for the information management capabilities supplied by computer systems. The challenge is to demonstrate the financial and clinical advantages of these systems.

Suggested Readings

Altman R.B. (1997). Informatics in the care of patients: Ten notable challenges. *Western Journal of Medicine*, 166(6):118–122.

This thoughtful article was written to introduce the concepts of medical informatics to clinicians while explaining a major set of challenges that help to define the goals and research programs for the field.

Blois M.S. (1984). *Information and Medicine: The Nature of Medical Descriptions*. Berkeley, CA: University of California Press.

The author analyzes the structure of medical knowledge in terms of a hierarchical model of information. He explores the ideas of high- and low-level sciences and suggests that the nature of medical descriptions accounts for difficulties in applying computing technology to medicine.

Collen M.F. (1995). *A History of Medical Informatics in the United States: 1950 to 1990*. Bethesda, MD: American Medical Informatics Association, Hartman Publishing.

This comprehensive book traces the history of the field of medical informatics and identifies the origins of the discipline's name (which first appeared in the English-language literature in 1974).

Degoulet P., Phister B., Fieschi, M. (1997). *Introduction to Clinical Informatics*. New York: Springer-Verlag.

This introductory volume provides a broad view of medical informatics and carries the concepts forward with an emphasis on clinical applications.

Elstein A.S., Shulman L.S., Sprafka S.A. (1978). *Medical Problem Solving: An Analysis of Clinical Reasoning*. Cambridge, MA: Harvard University Press.

This classic collection of papers describes detailed studies that have illuminated several aspects of the ways in which expert and novice physicians solve medical problems.

Friedman CP, Altman RB, Kohane IS, McCormick KA, Miller PL, Ozbolt JG, Shortliffe EH, Stormo GD, Szczepaniak MC, Tuck D, Williamson J (2004). Training the next generation of informaticians: The impact of BISTI and bioinformatics. *Journal of American Medical Informatics Association*, 11:167–172.

This important analysis addresses the changing nature of biomedical informatics due to the revolution in bioinformatics and computational biology. Implications for training, as well as organization of academic groups and curriculum development, are discussed.

Institute of Medicine (1991 [revised 1997]). *The Computer-Based Patient Record: An Essential Technology for Health Care,* Washington, DC: National Academy Press.

Institute of Medicine (2002). *Fostering Rapid Advances in Health Care: Learning from System Demonstrations,* Washington, DC: National Academy Press.

National Research Council (1997). *For The Record: Protecting Electronic Health Information,* Washington, DC: National Academy Press.

National Research Council (2000). *Networking Health: Prescriptions for the Internet*, (Washington, DC: National Academy Press.

This set of four reports from branches of the National Academies of Science have had a major influence on health information technology education and policy over the last 15 years.

Institute of Medicine 2000). *To Err is Human: Building a Safer Health System,* Washington, DC: National Academy Press.

Institute of Medicine (2001). *Crossing the Quality Chasm: A New Health Systems for the 21st Century,* Washington, DC: National Academy Press.

Institute of Medicine (2004). *Patient Safety: Achieving a New Standard for Care,* Washington, DC: National Academy Press.

This series of three reports from the Institute of Medicine have outlined the crucial link between heightened use of information technology and the enhancement of quality and reduction in errors in practice. Major programs in patient safety have resulted from these reports, and they have provided motivation for a heightened interest in health care information technology among policy makers, provider organizations, and even patients.

Panel on Transforming Health Care (2001). *Transforming Health Care Through Information Technology* (President's Information Technology Advisory Committee (PITAC), Report to the President), Washington, DC: National Coordinating Office for IT Research and Development, http://www.nitrd.gov/pubs/pitac/pitac-hc-9feb01.pdf

Panel on Transforming Health Care (2004). *Revolutionizing Health Care Through Information Technology* (PITAC, Report to the President), Washington, DC: National Coordinating Office for IT Research and Development, http://www.nitrd.gov/pitac/reports/20040721_hit_report.pdf

These two reports from a Presidential advisory committee provide a provocative view of the future of information technology in health care, making policy recommendations that have guided the White House and Congress in their recent legislative and program announcements.

Shortliffe E. (1993). Doctors, patients, and computers: Will information technology dehumanize health care delivery? *Proceedings of the American Philosophical Society*, 137(3):390–398.

In this paper, the author examines the frequently expressed concern that the introduction of computing technology into health care settings will disrupt the development of rapport between clinicians and patients and thereby dehumanize the therapeutic process. He argues, rather, that computers may have precisely the opposite effect on the relationship between clinicians and their patients.

van Bemmel J.H., Musen, M.A. (1997). *Handbook of Medical Informatics*. Heidelberg, Germany: Springer-Verlag.

This volume provides a comprehensive overview of the field of medical informatics and is an excellent starting reference point for many of the topics in the field.

Questions for Discussion

1. How do you interpret the phrase "logical behavior"? Do computers behave logically? Do people behave logically? Explain your answers.
2. What do you think it means to say that a computer program is "effective"? Make a list of a dozen computer applications with which you are familiar. List the applications in decreasing order of effectiveness, as you have explained this concept. Then, for each application, indicate your estimate of how well human beings perform the same tasks (this will require that you determine what it means for a human being to be effective). Do you discern any pattern? If so, how do you interpret it?
3. Discuss three society-wide factors that will determine the extent to which computers are assimilated into medical practice.

4. Reread the future vision presented in Section 1.1. Describe the characteristics of an integrated environment for managing medical information. Discuss two ways in which such a system could change medical practice.
5. Do you believe that improving the technical quality of health care entails the risk of dehumanization? If so, is it worth the risk? Explain your reasoning.