Computational Technology for Effective Health Care: Immediate Steps and Strategic Directions

Willam W. Stead and Herbert S. Lin, editors; Committee on Engaging the Computer Science Research Community in Health Care Informatics; National Research Council

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Summary

BACKGROUND AND INTRODUCTION

Health care is an information- and knowledge-intensive enterprise. In the future, health care providers will need to rely increasingly on information technology (IT) to acquire, manage, analyze, and disseminate health care information and knowledge. Many studies have identified deficiencies in the current health care system, including inadequate care, superfluous or incorrect care, immense inefficiencies and hence high costs, and inequities in access to care. In response, federal policy makers have tended to focus on the creation and interchange of electronic health information and the use of IT as critical infrastructural improvements whose deployments help to address some (but by no means all) of these deficiencies.

Any systematic effort to change the medical and health information management paradigm from one based on paper to one based on IT must address two basic challenges: using the best technology available today to build and deploy systems in the short term and identifying the gaps between the best of today's technology and what is ultimately needed to improve health care. The first provides opportunities for near-term improvement; the second informs basic research and the design of future systems.

The present study was chartered by its sponsors to help elucidate how the computer science research community can help to meet both of these challenges. Members of this community are familiar with the newest ideas in computer science and are thus in a position both to offer insight

into how they might apply to the health care problems of today and to identify opportunities for new advances. However, the study described in this report was conducted by an interdisciplinary committee of experts not only from the computer science community (including members with expertise in fields such as databases, security, networking, human-computer interaction, and large-scale system deployments), but also from health/biomedical informatics and from health care per se (e.g., physicians who have worked with information technologies) to provide a suitable grounding in the realities of and thinking in these disciplines.

By design, the effort of the Committee on Engaging the Computer Science Research Community in Health Care Informatics was both time- and resource-limited. In its work, the committee focused primarily on understanding the nature and impact of the IT investments made by major health care organizations. Thus, this study does not touch except in the most peripheral way on a myriad of complex social, political, and economic issues that complicate the task of health care reform.

The evidentiary basis for this study involves several threads. The primary observational evidence was derived from committee site visits to eight medical centers around the country—for the most part acknowledged leaders in applying IT to health care—on the theory that many of the important innovations and achievements for health care IT would be found in such organizations thought to be leaders in the field. In addition, this study built on previous work of the Institute of Medicine (IOM) and the National Academy of Engineering on health care (specifically, the committee adopted as a point of departure the IOM series "Crossing the Quality Chasm"[1]) and on a selective literature review.

These multiple sources of evidence—viewed from the committee's perspective—suggest that current efforts aimed at the nationwide deployment of health care IT will not be sufficient to achieve the vision of 21st century health care, and may even set back the cause if these efforts continue wholly without change from their present course. Specifically, success in this regard will require greater emphasis on providing cognitive support for health care providers and for patients and family caregivers on the part of computer science and health/biomedical informatics researchers. Vendors, health care organizations, and government will also have to pay attention to cognitive support, which refers to computer-based tools and systems that offer clinicians and patients assistance for thinking about and solving problems related to specific instances of health care. This point is the central conclusion of this report.

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[1]Institute of Medicine, *Crossing the Quality Chasm: A New Health System for the 21st Century*, The National Academies Press, Washington, D.C., 2005, available at http://www.nap.edu/catalog.php?record_id=10027.

HEALTH CARE IN THE UNITED STATES TODAY

It is widely recognized that today's health care fails to deliver the most effective care and suffers substantially as a result of medical errors. In addition, many medical interventions undertaken today are in fact not necessary. These persistent problems do not reflect incompetence on the part of health care professionals—rather, they are a consequence of the inherent intellectual complexity of health care taken as a whole and a medical care environment that has not been adequately structured to help clinicians avoid mistakes or to systematically improve their decision making and practice. Administrative and organizational fragmentation, together with complex, distributed, and unclear authority and responsibility, further complicates the health care environment.

Many of the relevant factors can be classified largely into three distinct areas: the tasks and workflow of health care, the institution and economics of health care, and the nature of health care IT as it is currently implemented.

- *The tasks and workflow of health care*. Health care decisions often require reasoning under high degrees of uncertainty about a patient's medical state and the effectiveness of past and future treatments for the particular patient. In addition, medical workflows are often complex and non-transparent and are characterized by many interruptions, inadequately defined roles and responsibilities, poorly kept and managed schedules, and little documentation of steps, expectations, and outcomes. Complex care is increasingly provided to patients in a time- and resource-pressured environment because of the need to contain costs.

- *The institution and economics of health care*. The large number of health care payers and coverage plans, each with its own rules for coverage, complicates administration. In addition, incentives for payment are often distorted or perverse, leading (for example) to more generous compensation for medical procedures than for communication with patients or for diagnosis or preventive care. Patients and providers must also navigate a confusing landscape of tertiary care centers, community hospitals, clinics, primary and specialist doctors and other providers, payers, health plans, and information sources.

- *Current implementations of health care IT*. Many health care organizations do spend considerable money on IT, but the IT is often implemented in systems in a monolithic fashion that makes even small changes hard to introduce. Furthermore, IT applications appear designed largely to automate tasks or business processes. They are often designed in ways that simply mimic existing paper-based forms and provide little support for the cognitive tasks of clinicians or the workflow of the people who must actually use the system. Moreover, these applications do not take advan-

tage of human-computer interaction principles, leading to poor designs that can increase the chance of error, add to rather than reduce work, and compound the frustrations of executing required tasks. As a result, these applications sometimes increase workload, and they can introduce new forms of error that are difficult to detect.

A number of trends will put additional pressure for change on the health care environment. These trends include an aging population and a corresponding increase in the complexity and weight of the disease burden, the emergence of genome-based personalized medicine, a larger role for patients in managing their own health care, and yet greater emphasis on efficiency and cost control in health care. As a result, health care processes will become more complex and more time-constrained, and the demands placed on care providers will become more intense.

A VISION FOR 21st CENTURY HEALTH CARE AND WELLNESS

The IOM defines health care quality as "the degree to which health services for individuals and populations increase the likelihood of desired health outcomes and are consistent with current professional knowledge,"[2] and in recent years, a broad consensus has emerged on the future health care environment. In the words of the IOM, health care should be safe, effective, patient-centered, timely, efficient, and equitable.[3] Achieving this vision entails many different factors (e.g., systemic changes in how to pay for health care, an emphasis on disease prevention rather than disease treatment), but none is more important than the effective use of information.

The committee identified seven information-intensive aspects of the IOM's vision for 21st century health care:

- Comprehensive data on patients' conditions, treatments, and outcomes;
- Cognitive support for health care professionals and patients to help integrate patient-specific data where possible and account for any uncertainties that remain;
- Cognitive support for health care professionals to help integrate evidence-based practice guidelines and research results into daily practice;

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[2]Institute of Medicine, *Medicare: A Strategy for Quality Assurance*, National Academy Press, Washington, D.C., 1990, available at http://www.nap.edu/catalog.php?record_id=1547.

[3]Institute of Medicine, *Crossing the Quality Chasm: A New Health System for the 21st Century*, The National Academies Press, Washington, D.C., 2005, available at http://www.nap.edu/catalog.php?record_id=10027.

- Instruments and tools that allow clinicians to manage a portfolio of patients and to highlight problems as they arise both for an individual patient and within populations;
- Rapid integration of new instrumentation, biological knowledge, treatment modalities, and so on into a "learning" health care system that encourages early adoption of promising methods but also analyzes all patient experience as experimental data;
- Accommodation of growing heterogeneity of locales for provision of care, including home instrumentation for monitoring and treatment, lifestyle integration, and remote assistance; and
- Empowerment of patients and their families in effective management of health care decisions and their implementation, including personal health records, education about the individual's conditions and options, and support of timely and focused communication with professional health care providers.

CROSSING THE HEALTH CARE IT CHASM

The committee observed a number of success stories in the implementation of health care IT. But although seeing these successes was encouraging, they fall far short, even in the aggregate, of what is needed to support the IOM's vision of quality health care. IT-related activities of health professionals observed by the committee in these organizations were rarely well integrated into clinical practice. Health care IT was rarely used to provide clinicians with evidence-based decision support and feedback; to support data-driven process improvement; or to link clinical care and research. Health care IT rarely provided an integrative view of patient data. Care providers spent a great deal of time in electronically documenting what they did for patients, but these providers often said that they were entering the information to comply with regulations or to defend against lawsuits, rather than because they expected someone to use it to improve clinical care. Health care IT implementation time lines were often measured in decades, and most systems were poorly or incompletely integrated into practice.

Although the use of health care IT is an integral element of health care in the 21st century, the current focus of the health care IT efforts that the committee observed is not sufficient to drive the kind of change in health care that is truly needed. The nation faces a health care IT chasm that is analogous to the quality chasm highlighted by the IOM over the past decade. So that the nation can cross the health care IT chasm, the committee advocates re-balancing the portfolio of investments in health care IT to place a greater emphasis on providing cognitive support for health care providers, patients, and family caregivers; observing proven principles for success in designing and implementing IT; and accelerating

research related to health care in the computer and social sciences and in health/biomedical informatics.

PRINCIPLES FOR SUCCESS

Change in the health care system can be viewed from two equally important perspectives—those of evolutionary and of radical change. Evolutionary change means continuous, iterative improvement of existing processes sustained over long periods of time. Radical change means qualitatively new ways of conceptualizing and solving health and health care problems and revolutionary ways of addressing those problems. Any approach to health care IT should enable and anticipate both types of change since they work together over time.

The committee identified five principles related to evolutionary change and four related to radical change to guide successful use of health care IT to support a 21st century vision of health care. These principles are elaborated in Chapter 4.

Principles for Evolutionary Change

1. Focus on improvements in care—technology is secondary.
2. Seek incremental gain from incremental effort.
3. Record available data so that today's biomedical knowledge can be used to interpret the data to drive care, process improvement, and research.
4. Design for human and organizational factors so that social and institutional processes will not pose barriers to appropriately taking advantage of technology.
5. Support the cognitive functions of all caregivers, including health professionals, patients, and their families.

Principles for Radical Change

6. Architect information and workflow systems to accommodate disruptive change.
7. Archive data for subsequent re-interpretation, that is, in anticipation of future advances in biomedical knowledge that may change today's interpretation of data and advances in computer science that may provide new ways of extracting meaningful and useful knowledge from existing data stores.
8. Seek and develop technologies that identify and eliminate ineffective work processes.
9. Seek and develop technologies that clarify the context of data.

RESEARCH CHALLENGES

There are deep intellectual research challenges at the nexus of health care and computer science (and health/biomedical informatics as well). The committee found it useful to conceptualize necessary research efforts along two separate dimensions. The first dimension is the extent to which new fundamental, general-purpose research is needed. Some problems in health care can be seen as having solutions on a relatively clear path forward from existing technologies (e.g., aggregation of patient health care information into a common data repository), whereas others are genuinely advanced problems (e.g., aggregation of patient health care information into a trustworthy database with explicit representation of uncertainty). (Also, note that this first dimension aligns to a large degree with the evolutionary/radical change dichotomy described above, where evolutionary change can be associated with straightforward extrapolation of current knowledge and technology, and radical change with problem domains that will require successes in fundamental research.)

A second dimension is the extent to which new research specific to health care and biomedicine is needed. This second dimension is rooted in the observation that some advances needed for improving health care are general problems in computer science (e.g., achieving high availability with low system management overhead), and others are highly specific to health care (e.g., developing high-quality devices for human-computer interaction that do not inadvertently help to spread infection as care providers move from patient to patient). This distinction is helpful because a broad coalition might fund and pursue the former, whereas the latter might be of interest to a narrower set in the health and biomedical informatics communities.

During the committee's discussions, patient-centered cognitive support emerged as an overarching grand research challenge to focus health-related efforts of the computer science research community, which can play an important role in helping to cross the health care IT chasm.

An Overarching Research Grand Challenge: Patient-Centered Cognitive Support

Much of health care is transactional—admitting a patient, encountering a patient at the bedside or clinic, ordering a drug, interpreting a report, or handing off a patient. Yet transactions are only the operational expression of an understanding of the patient and a set of goals and plans for that patient. Clinicians have in mind a conceptual model of the patient reflecting their understanding of interacting physiological, psychological, societal, and other dimensions. They use new findings—raw data—to refine their understanding of the model they are using. Then, based on

medical knowledge, medical logic, and mostly heuristic decision making, they make orders (transactions) that they hope will improve the condition of or even cure the (real) patient.

Today, clinicians spend a great deal of time and energy searching and sifting through raw data about patients and trying to integrate these data with their general medical knowledge to form relevant mental abstractions and associations relevant to the patient's situation. Such sifting efforts force clinicians to devote precious cognitive resources to the details of data and make it more likely that they will overlook some important higher-order consideration.

The health care IT systems of today tend to squeeze all cognitive support for the clinician through the lens of health care transactions and the related raw data, without an underlying representation of a conceptual model for the patient showing how data fit together and which are important or unimportant. As a result, an understanding of the patient can be lost amidst all the data, all the tests, and all the monitoring equipment.

In the committee's vision of patient-centered cognitive support, the clinician interacts with models and abstractions of the patient that place the raw data into context and synthesize them with medical knowledge in ways that make clinical sense for that patient. Raw data are still available, but they are not the direct focus of the clinician. These virtual patient models are the computational counterparts of the clinician's conceptual model of a patient. They depict and simulate a theory about interactions going on in the patient and enable patient-specific parameterization and multicomponent alerts. They build on submodels of biological and physiological systems and also of epidemiology that take into account, for example, the local prevalence of diseases. The use of these models to establish clinical context would free the clinician from having to make direct sense of raw data, and thus he or she would have a much easier time defining, testing, and exploring his/her own working theory. What links the raw data to the abstract models might be called medical logic—that is, computer-based tools that examine raw data relevant to a specific patient and suggest their clinical implications given the context of the models and abstractions. Computers can then provide decision support—that is, tools that help clinicians decide on a course of action in response to an understanding of the patient's status. At the same time, although clinicians can work with abstractions that keep them from being overwhelmed by data, they must also have the ability to access the raw data as needed if they wish to explore the presented interpretations and abstractions in greater depth.

There are many challenging computer science research problems associated with this vision. Future clinician and patient-facing systems would draw on the data, information, and knowledge obtained in both

patient care and research to provide decision support sensitive to work-flow and human factors. The decision support systems would explicitly incorporate patient utilities, values, and resource constraints (e.g., cost-effectiveness analysis, value of information, and so on). They would support holistic plans, intentions, and multiple decision makers. They would allow users to simulate interventions on the virtual patient before doing them for real. These decision support systems would have transactions built into them to help users carry out orders, in contrast to today's systems in which decision support is commonly an add-on to systems and is designed primarily for transaction processing. Rather than having data entered by clinicians into computer systems, the content of clinical interactions would be captured in self-documenting environments with little or no additional effort on the part of the clinicians. (That is, an intelligent, sensor-rich environment would monitor clinical interactions and reduce sensor input to notes that document the medically significant content of those interactions.)

In addition to the research challenges related to modeling the virtual patient and biomedical knowledge, there are challenges in modeling and supporting multiplayer decision making (e.g., involving family, patient, primary care provider, specialist, payer, and so on). Techniques to interconnect the components are likely to be equally challenging.

Other Representative Research Challenges

• *Modeling*. One aspect of the virtual patient involves modeling various subsystems within a real patient (e.g., different organs, digestive system, and so on) to show how they interact. One approach to modeling physiological subsystems in a specific patient is to appropriately parameterize a generic model of those subsystems. But finding appropriate parameterizations for any given model and coupling the different models and the data to drive them pose significant intellectual challenges. For example, coupling models will require a computational platform that can support multiple interacting components that can be combined into larger and more complex models. Such a platform must not only support parallel operation of the analytical processes but also allow assembly of hierarchical simulation and information structures, dynamically built, exploited, modified when possible on the basis of empirical data, and abandoned when no longer effective.

• *Automation*. When automated systems are deployed in an operational environment, they must work harmoniously with each other. But in practice, because they have been developed in isolation, they do not, with the result that they provide contradictory signaling and have different monitoring requirements and raise different safety concerns. Most

importantly, they raise issues of trust in these systems—excessive trust leads personnel to believe erroneous indicators and operations, while inadequate trust forces them to check up on these systems, wasting valuable time. Overcoming these operational integration problems for automated systems remains a major challenge.

• *Data sharing and collaboration*. The data relevant to health care are highly heterogeneous. To exploit such data effectively, users need to be able to ask queries that span multiple data sources without requiring the data to be standardized or requiring the user to query each single database in isolation. Today, data integration usually entails a major and costly effort. Research challenges in this area involve data integration systems that are fundamentally easier to use, data integration methodologies that can proceed incrementally while remaining compatible with previous versions, and more flexible architectures for data sharing and integration.

• *Data management at scale*. Presuming the existence of large integrated corpora of data, another major challenge is in managing those data. Some of the important dimensions of medical information management include annotation and metadata, linkage, and privacy.

• *Automated full capture of physician-patient interactions*. Such capture would release clinician time for more productive uses and help to ensure more complete and timely patient records. Some of the important dimensions in this problem domain include real-time transcription and interpretation of the dialog between patient and provider, summarization of physical interactions between patient and provider based on the interpretation of images recorded by various cameras in the patient care room (subject to appropriate privacy safeguards), and correlation of the information contained in the audio and visual transcripts.

RECOMMENDATIONS

Government

Federal and state governments play important roles as supporters of research, payers for health care, and stimulators for education. The committee believes that government organizations—especially the federal government—should explicitly embrace measurable health care quality improvement as the driving rationale for its health care IT adoption efforts, and should shun programs that focus on promoting the adoption of specific clinical applications. Although this principle should not be taken to discourage incentives to invest in infrastructure (networks, workstations, administrative transaction processing systems, platforms for data mining, data repositories, and so on) that provides a foundation on which other specific clinical applications can be built, a top-down focus

on specific clinical applications is likely to result in a premature "freezing" of inefficient workflows and processes and to impede iterative change.

In focusing on the goal to be achieved, namely better and/or less expensive health care, clinicians and other providers will appropriately be drawn to IT only if, where, and when it can be shown to enable them to do their jobs more effectively. Blanket promotion of IT adoption where benefits are not clear or are oversold—especially in a non-infrastructure context—will only waste resources and sour clinicians on the true potential of health care IT.

IT can be a fundamental enabler for both large-scale and small-scale improvement efforts. Because many health care groups have capacities for only a few large-scale improvement methods at a time, small-scale optimization is an important complement. An example of a small-scale optimization would be the use of a guideline alert system that enables individual physicians and/or their clinical teams to continually target areas of practice for self-improvement on guideline-concordant care. But for the most part, the health care IT available in today's market is not well suited to support small-scale optimization, which requires applications that are rapidly customizable in the field by end users. Federally inspired or supported initiatives that incentivize health care organizations to achieve iterative small-scale optimization and subsequent translation of successes to a larger scale are likely to help stimulate the creation of a new market for these customizable applications.

This analysis leads to six important recommendations for the federal government:

- Incentivize clinical performance gains rather than acquisition of IT per se.
- Encourage initiatives to empower iterative process improvement and small-scale optimization.
- Encourage development of standards and measures of health care IT performance related to cognitive support for health professionals and patients, adaptability to support iterative process improvement, and effective use to improve quality.
- Encourage interdisciplinary research in three critical areas: (a) organizational systems-level research into the design of health care systems, processes, and workflow; (b) computable knowledge structures and models for medicine needed to make sense of available patient data including preferences, health behaviors, and so on; and (c) human-computer interaction in a clinical context.
- Encourage (or at least do not impede) efforts by health care organizations and communities to aggregate data about health care people,

processes, and outcomes from all sources subject to appropriate protection of privacy and confidentiality.

• Support additional education and training efforts at the intersection of health care, computer science, and health/biomedical informatics. Current programs of the National Library of Medicine and other institutes of the National Institutes of Health are exemplars of such support.

The Computer Science Community

The computer science community can find deep, meaningful, and fundamental intellectual challenges in the health care problem domain (as indicated above). Accordingly, the committee believes that the computer science community should:

• Engage as co-equal intellectual partners and collaborators with health care practitioners and experts in health/biomedical informatics and other relevant disciplines, such as industrial and process engineering and design, in an ongoing relationship to understand and solve problems of importance to health care.

• Develop institutional mechanisms within academia for rewarding work at the health care/computer science interface.

• Support educational and retraining efforts for computer science researchers who want to explore research opportunities in health care.

Health Care Organizations

The senior management in health care organizations and health care payers have often taken the lead in the deployment of IT for health care. They should:

• Organize incentives, roles, workflow, processes, and supporting infrastructure to encourage, support, and respond to opportunities for clinical performance gains.

• Balance the institution's IT portfolio among automation, connectivity, decision support, and data-mining capabilities.

• Develop the necessary data infrastructure for health care improvement by aggregating data regarding people, processes, and outcomes from all sources.

• Insist that vendors supply IT that permits the separation of data from applications and facilitates data transfers to and from other non-vendor applications in shareble and generally useful formats.

• Seek IT solutions that yield incremental gains from incremental efforts.

COMPUTATIONAL TECHNOLOGY FOR EFFECTIVE HEALTH CARE

IMMEDIATE STEPS AND STRATEGIC DIRECTIONS

William W. Stead and Herbert S. Lin, *Editors*

Committee on Engaging the Computer Science Research Community in
Health Care Informatics

Computer Science and Telecommunications Board

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Preface

It is essentially axiomatic that modern health care is an information- and knowledge-intensive enterprise.[1] The information collected in health care includes—among other things—medical records of individual patients (both paper and electronic, spread across many different health care organizations), laboratory test results, information about treatment protocols and drug interactions, and a variety of financial and administrative information. Knowledge resides in the published medical literature, in the higher-order cognitive processes of individual clinicians and care providers, and in the processes of health care organizations that facilitate the provision of care.

Whereas the practices of 20th century health care were based largely on paper, there is now a broad consensus that realizing an improved 21st century vision of health care will require intensive use of information technology to acquire, manage, analyze, and disseminate health care information and knowledge. Accordingly, the Administration and Congress have been moving to encourage the adoption, connectivity, and interoperability of health care information technology. President George W. Bush called for nationwide use of electronic medical records by 2014,[2]

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[1]Institute of Medicine and National Academy of Engineering, *Building a Better Delivery System: A New Engineering/Health Care Partnership*, The National Academies Press, Washington, D.C., 2005, available at http://www.nap.edu/catalog.php?record_id=11378.

[2]Commission on Systemic Interoperability, *Ending the Document Game*, U.S. Government Printing Office, Washington, D.C., 2005, available at http://endingthedocumentgame.gov/.

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and the Department of Health and Human Services (HHS) is involved in various aspects of achieving this goal.[3]

The National Library of Medicine launched this study to support the engagement of individuals from the computer science research community in meeting two challenges posed by health care information technology: identifying how today's computer science-based methodologies and approaches might be applied more effectively to health care, and explicating how the limitations in these methodologies and approaches might be overcome through additional research and development.

The study described in this report was conducted by an interdisciplinary committee of experts in biomedical informatics, computer science and information technology (including databases, security, networking, human-computer interaction, and large-scale system deployments), and health care providers (e.g., physicians who have worked with information technologies). Appendix A provides brief biographical information on the members and the staff of the Committee on Engaging the Computer Science Research Community in Health Care Informatics.

The committee's work focused primarily on understanding the nature and impact of the information technology investments made by major health care organizations. By design, the committee's effort was both time- and resource-limited, and thus the primary function of this report is to lay the groundwork for future efforts that can explore in a second phase some of the identified questions and issues in greater detail. Perhaps most importantly, this study does not touch, except in the most peripheral way, on a myriad of complex social, political, and economic issues that complicate the task of health care reform.

For example, although this report emphasizes the role of the clinician, there are other important decision makers in the health care system, including patients, family caregivers, and other health care professionals, whose health care information technology needs the report addresses only peripherally. Similarly, although the data-gathering efforts of the committee were focused primarily on major health care organizations, the majority of health care is delivered in small-practice settings (of two to five physicians) that lack significant organizational support. These omissions do not diminish the significance of the committee's efforts and recommendations, although they do point to the need for more work to understand health care information technology (IT) needs more thoroughly in the areas that the committee did not examine carefully.

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[3]Institute of Medicine, *Opportunities for Coordination and Clarity to Advance the National Health Information Agenda*, The National Academies Press, Washington, D.C., 2007, available at http://www.nap.edu/catalog.php?record_id=12048.

Other important issues omitted in this report that are worthy of serious attention in follow-on reports include the explicit inclusion of instruction in health/biomedical informatics and health care IT in various forms of health care education (e.g., medical and nursing school curricula); legal and cultural barriers to sharing information among various care providers; the development of a strategic plan or roadmap that articulates the strengths, weaknesses, opportunities, and threats to the development of health care IT; standards-development processes in the health care IT industry that might facilitate interoperability; and issues related to personal health records for use by patients, the relationship of education in computer science to health care and biomedical informatics (and vice versa), and organizational support for health care providers that operate on a small scale.

The evidentiary basis for this study involved several threads. The primary observational evidence was derived from committee site visits to eight medical centers around the country (Appendix B provides the agendas for the site visits that the committee conducted). Obviously, a comprehensive view of the current state of the art in the nation's health care information technology cannot be derived from eight site visits—thus, the organizations visited must be regarded as a sampling of the state of practice throughout the country. Care was taken to ensure that the site visits were to medical centers that varied along important dimensions: governance and ownership (government-operated, non-profit, for-profit), academic and community, and in-house technology development and vendor-supplied technology. The centers visited shared one characteristic—for the most part, they were widely acknowledged to be leaders in the use of IT for health care. This choice was made because the committee felt that many of the important innovations and achievements for health care IT would be found in organizations thought to be leaders in the field.

The findings from the site visits are presented in Appendix C as a table of observations, consequences, and opportunities for action. The observations are de-identified generalizations of detail from multiple sites. The consequences and opportunities for action reflect the committee's judgment. In the main text of the committee's report, observations from site visits are cross-referenced where appropriate with the notation $CxOy$. Cx refers to Category x of the committee's observations as grouped in Table C.1 (which lists six categories of observations), and Oy refers to a particular observation as numbered in Table C.1 (which includes a total of 25 observations).

The findings from the site visits were combined with other evidentiary threads:

- *Previous work of the Institute of Medicine (IOM) and the National Academy of Engineering*. Rather than starting from scratch, the committee adopted as a point of departure for its work the IOM series "Crossing the Quality Chasm"—a vision of 21st century health care that is safe, effective, patient-centered, timely, efficient, and equitable.
- *Selective literature review*. In many instances in this report, a claim is made that is based not on direct observation but rather on one or more papers in the scientific literature.
- *Committee expertise*. The committee included a number of individuals with substantial clinical and business expertise in medical centers similar to those visited by the committee and other similar settings. Experiences from these individuals were added to this report as needed.

Eight site visits cannot support development of a statistically significant set of examples and illustrations—nevertheless, the committee believes that its observations and conclusions meet the more important test of substantive significance, especially since they arose as a result of visits to organizations regarded as among the best in the country in applying IT to solve health care problems.

Finally, although the committee's charge (Box P.1) calls attention to the computer science research community, the health/biomedical informatics research community is also a key player for doing the necessary research. The field of health/biomedical informatics emerged from medical informatics, which was described in 1990 by Greenes and Shortliffe as "the field that concerns itself with the cognitive, information processing, and communication tasks of medical practice, education, and research, including the information science and the technology to support these tasks."[4] "Health informatics" and "biomedical informatics" are more recent terms that acknowledge the increasing importance of informatics for aspects of health beyond medicine and for the basic biological sciences in medicine.

Computer science as a discipline does not subsume health/biomedical informatics, although computer scientists can and do make major contributions to that field. Health/biomedical informatics is more than medical computer science, drawing also on the decision, cognitive, and information sciences as well as engineering, organizational theory, and sociology

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[4]Robert Greenes and Edward H. Shortliffe, "Medical Informatics: An Emerging Academic Discipline and Institutional Priority," *Journal of the American Medical Association* 263(8):1114-1120, 1990.

Box P.1 Study Statement of Task

The Computer Science and Telecommunications Board will conduct a 2-phase study to examine information technology (IT) problems faced by the health care system in realizing the emerging vision of patient-centered, evidence-based, efficient health care using electronic health records and other IT. The study will focus on the foundation issue of the electronic health record.

In phase 1, the committee will conduct a series of site visits to a variety of health care delivery sites. A short (roughly 5000 word) phase 1 report, based largely on the site visits, will assess the match between today's health information systems and current plans for using electronic health records nationwide, identify important information management problems that could be solved relatively easily and inexpensively (i.e., where short payback periods and quick improvements would be possible) by today's technologies, provide (non-comprehensive) illustrations of how today's knowledge about computer science and IT could be used to provide immediate short-term benefits to the health care system, and lay out important questions that future reports (from this or other studies) should address.

In phase 2, the committee will prepare a phase 2 report identifying technical areas where additional computer science and IT research is needed to further advance the state of the art of health care IT; priorities for research that will yield significantly increased medical effectiveness or reduced costs; information management problems whose solutions require new practices and policies; and public policy questions that need to be resolved to allow such research to proceed.

Both reports are intended to identify technical solutions to advance health care IT, to expose the information technology and computer science research communities to important technical problems, and to provide a foundation for other studies related to health care informatics.

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with a health and biomedical emphasis that is largely lacking in the world of computer science research. In the context of this report, specialists in health/biomedical informatics can serve a bridging function between the computer science community and the world of biomedicine with which computer science researchers are largely unfamiliar.

For providing information and hosting site visits for the committee, the committee expresses its appreciation to a number of organizations: Partners HealthCare (David Bates, Henry Chueh, Anuj Dalal, John Glaser, and Jeff Schnipper), the University of Pittsburgh Medical Center (Jocelyn Benes, Jody Cervenak, Jacque Dailey, Steven Docimo, Tom

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A number of individuals also briefed the committee during open sessions: B. Alton Brantley (principal, the CCI Group), Kenneth D. Mandl (Harvard Medical School and Harvard-MIT Division of Health Sciences and Technology), Greg Walton (HIMSS Analytics), Denis Cortese (Mayo Clinic), Peter Neupert (Microsoft), Scott Wallace (National Coalition for Health Care IT), Janet Corrigan (National Quality Forum), Alicia A. Bradford (Office of the National Coordinator for Health Information Technology), Peter J. Fabri (University of South Florida and Northwestern University), and Gina Grumke and Monique Lambert (Intel). Betsy Humphreys and Donald A.B. Lindberg from the National Library of Medicine provided the charge to the committee at its first meeting.

The committee also appreciates the efforts of David Padgham, associate program officer, who left the National Research Council in May 2008, in organizing these site visits and other information-gathering sessions of the committee. Finally, the committee thanks Herbert Lin, study director and chief scientist of the Computer Science and Telecommunications Board, for his counsel throughout the project and his effort in developing the report.

Acknowledgment of Reviewers

This report has been reviewed in draft form by individuals chosen for their diverse perspectives and technical expertise, in accordance with procedures approved by the National Research Council's Report Review Committee. The purpose of this independent review is to provide candid and critical comments that will assist the institution in making its published report as sound as possible and to ensure that the report meets institutional standards for objectivity, evidence, and responsiveness to the study charge. The review comments and draft manuscript remain confidential to protect the integrity of the deliberative process. We wish to thank the following individuals for their review of this report:

Gregory D. Abowd, Georgia Institute of Technology,
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Although the reviewers listed above have provided many constructive comments and suggestions, they were not asked to endorse the conclusions or recommendations, nor did they see the final draft of the report before its release. The review of this report was overseen by David G. Hoel of the Medical University of South Carolina and Victor Vyssotsky. Appointed by the National Research Council, they were responsible for making certain that an independent examination of this report was carried out in accordance with institutional procedures and that all review comments were carefully considered. Responsibility for the final content of this report rests entirely with the authoring committee and the institution.

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