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# Possibilities for Healthcare Computing

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**Abstract** Advances in computing technology promise to aid in achieving the goals of healthcare. We review how such changes can support each of the goals of healthcare as identified by the U.S. Institute of Medicine: safety, effectiveness, patient-centricity, timeliness, efficiency, and equitability. We also describe current foci of computing technology research aimed at realizing the ambitious goals for health information technology that have been set by the American Recovery and Reinvestment Act of 2009 and the Health Reform Act of 2010. Finally, we mention efforts to build health information technologies to support improved healthcare delivery in developing countries.

**Keywords** healthcare computing, United States national plans, meaningful use criteria, substitutable applications, medical natural language processing, mobile health, telehealth

## 1 Introduction

The U.S. National Academies' Institute of Medicine defines the ideal healthcare system to be safe, effective, patient-centered, timely, efficient, and equitable<sup>[1]</sup>. In this brief paper, we look at specifics of these goals and examine how computing and information technology can support their achievement.

*Safety* is a primary requirement of healthcare. Manual record keeping, especially via hand-written notes and orders, has been identified as a huge impediment to safety. Today, electronic health records (EHRs) are promoted as a potential boon to dramatically improving this situation. Such records can clearly avoid illegibility, make records instantly available in many places — thus supporting communication and collaborations among teams of medical practitioners — and provide the technical underpinnings of many other safety-relevant innovations<sup>[2]</sup>. For example, computerized physician order entry (CPOE) can help to eliminate errors in drug orders by warning the physician at the time the order is made of potential allergies, drug interactions, or grossly inappropriate doses<sup>[3]</sup>. It can also help to reduce pharmacy costs by showing the physician the relative costs of alternative medicines, and allowing him or her to choose the best medication, taking cost as well as effectiveness into consideration<sup>[4]</sup>.

EHRs can also support the development and deployment of standard ways to do standard things. Guidelines and care plans have been advanced as excellent ways to reduce variability in clinical practice, to help assure good outcomes and to reduce costs<sup>[5]</sup>. For example, some hospitals have developed highly effective methods of preventing the spread of methicillin-resistant staphylococcus aureus (MRSA)<sup>[6]</sup>, and such practices need to be incorporated into the behavior of all others as well<sup>[7]</sup>. The computer can help to guide, remind and cajole practitioners to follow such guidelines, and to document actions that deviate from them and the consequences of such deviations.

For less well-established goals, computers can still play an important role in providing decision support. This can include appropriate abstraction and presentation of detailed clinical data to paint a comprehensive picture of the patient's state and trajectory<sup>[8]</sup>, providing advice or critiquing based on built-in expertise or the statistical summarization of past experience, and making available an automatic "second opinion" for all difficult clinical decisions<sup>[9]</sup>. Adoption of a "crash reporting" system, similar to that used by aviation authorities when airplane accidents occur, could also encourage us to learn from every poor clinical outcome.

*Effectiveness* depends on knowing what is best to do in many clinical situations and assuring that it is done.

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Survey

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Perhaps the most critical need to achieve effectiveness is to collect and analyze data on all care, and especially on its outcomes<sup>[10]</sup>. That will allow us to learn efficiently from experience, and to model the effectiveness of medicines, tests and procedures in various conditions. In addition to these technical changes, we must also reform healthcare to perform more diligent follow-up on acute care and to engage patients more effectively. We also need to switch our focus from a myopic attention to individual events and actions instead to a more long-term pursuit of entire medical episodes<sup>[11]</sup>. At least in US healthcare, this requires moving away from “fee for service” reimbursements, which focus on individual encounters.

*Patient-Centered* care treats the patient as an important source of guidance about his or her own goals and preferences, takes advantage of the patient’s own abilities to observe and report, and empowers the patient to collaborate with providers to manage care<sup>[12]</sup>. There are many good reasons to do this. The patient is always present. The patient provides continuity of memory. The patient best understands his or her own preferences and willingness to do what is recommended. The patient has the most “skin in the game” — cares the most about what happens. And not unimportantly, the patient is willing to work for free!

To support effective engagement of the patient in care, we have to provide a minimum set of technical capabilities. First, each patient must have (and, I argue, control) a life-long medical record that brings together in one logical framework all of that person’s medical history<sup>[13]</sup>. Second, we need to develop techniques that can educate the patient about relevant conditions, possible consequences, and the trade-offs in potential actions. Third, a patient-centered healthcare system must provide effective communication between a patient and providers and peers in communities of patients who currently support each other by exchanging experiences through newsgroups and web sites. Finally, if the patient is really empowered to make day-to-day decisions about his or her care, we should support that decision making with advisory systems similar to what we have advocated for providers.

The ultimate goal of patient-centered care is not simply to improve the delivery of healthcare interventions once the patient is ill, but to encourage each individual to engage in behavior that will promote wellness and prevent disease.

*Timely and Efficient* healthcare requires greater sophistication in predicting clinical loads, staffing appropriately, and designing workflows that aggregate needed services at one place and one time. For example, Memorial Sloan-Kettering Cancer Center in New

York recognized in the 1990’s that many of their patients needed to see an oncologist, radiologist, pathologist, surgeon and social worker to plan their course of therapy after initial diagnosis. Instead of having them make individual appointments with each specialist, they created specialized clinics where each needed specialist was immediately available, permitting “one-stop shopping” convenience for their patients<sup>[14]</sup>.

We also hypothesize that good medicine is less expensive medicine. Fewer clinical failures lead to fewer re-hospitalizations, less need to re-do treatments, shorter hospital stays, and the ability to optimize care. In addition, building better trust between provider and patient may permit more rational decision making, leading to faster and more efficient care.

Clayton Christensen, with his co-authors in *The Innovator’s Prescription*<sup>[15]</sup>, also suggest an interesting disaggregation of current medical practice into three major types of activities. In this view, human acumen coupled to increasingly high-precision diagnostic tests will help to determine exactly what is wrong with a sick patient. Then, tested, optimized and highly reproducible treatments can efficiently treat the illness. Finally, networks of care that involve collaboration between the patient, different providers, and other patient groups, can form the basis for care of long-term chronic conditions. Information technology will play a major supportive role in each of these aspects of healthcare.

*Equitable* care means universal equal access to healthcare. The US has just taken a major step toward this goal by adoption of 2010’s health insurance reform law, which should make healthcare affordable to everyone, despite variations in socio-economic status and past medical history. However, there is also growing evidence that healthcare utilization varies widely across different geographic regions of the US, but does not correlate well with outcomes. Researchers at Dartmouth College have found that the rate at which procedures from tonsillectomies to endarterectomies are performed, for example, can vary by a factor of five, without any clear benefit to those communities in which they are done more often<sup>[16]</sup>. Therefore, we need to study healthcare utilization in much the same way as we need to study healthcare itself, to try to find discrepancies that lead to poor care or poor efficiency and to correct them.

Much of modern healthcare research has focused on the treatment of illness, yet historically it is public health interventions — improved sanitation, clean water, sewers, control of disease vectors, immunizations — that have made the most dramatic differences in reducing mortality and morbidity. Information technology can and must support public health tracking

and actions just as much as the care of individuals<sup>[17]</sup>.

Although equity across international borders remains an unrealized wish, those in the developed world are turning more and more attention to the health needs of those in the developing world. Charities and NGOs from the richer countries have created programs to deal with specific medical challenges such as tuberculosis, HIV/AIDS, malaria, and parasite eradication, and have achieved considerable successes with particular patient populations in cooperating countries. With a portfolio of successful programs behind them, a number of these organizations now work together to create and disseminate reusable software platforms that can ease the task of the next group to undertake such projects, and can even empower locally recruited and trained talent to build future applications<sup>[18]</sup>. The widespread dissemination of cell phones, which are embedding more and more powerful computing and communication capabilities every year, also opens up the possibility of easier, more widespread healthcare applications in every part of the world<sup>[19]</sup>.

## 2 The Role of Technology

Information technology can, if appropriately developed and deployed, significantly contribute to achieving the goals described above. The current push by the US government to spur health information technology (HIT) adoption is considered a crucial component of government efforts to make healthcare more equitable and efficient. The health reform legislation that was passed in 2010 has as its main goals providing health insurance coverage for nearly every American, and eliminating the pernicious custom of insurance companies to deny coverage for “pre-existing conditions” — medical problems that a patient had developed before enrolling in a particular insurance plan<sup>[20]</sup>. To make this expansion in insurance coverage financially feasible, the government also hopes to alter the principle of medical payments so that healthcare institutions get paid for achieving quality outcomes for their patients, not simply for providing them more and more treatment. This move is welcome because it emphasizes the true goal of healthcare, and is motivated by numerous studies showing that despite widespread disparities in spending in different parts of the country, there are no corresponding differences in health benefits. Along these same lines, President Obama has recently appointed Prof. Don Berwick of Harvard as the new head of the Medicare system in the US, which pays for close to half of all US healthcare, including most care for the elderly and the very poor. Berwick’s career has focused on healthcare quality and improvement, and he is known as an advocate of prevention over treatment, and of the

use of cost-benefit analysis as a way to rationalize and prioritize healthcare expenditures<sup>[21]</sup>.

To encourage HIT adoption, the American Reinvestment and Recovery Act (the 2009 stimulus bill) also includes between \$19~45 billion (depending on what exactly one counts) to encourage doctors’ offices, clinics and hospitals to adopt and use HIT. Encouragement comes as financial subsidies starting in 2011 to help acquire and put to use electronic health record (EHR) systems, and penalties for failure to adopt them starting about 2015<sup>[22]</sup>. To assure that money invested in such systems is not simply wasted, the payments also require demonstration of *meaningful use*. Namely, subsidy recipients must show that they use EHRs for some clinical functions, they must support the electronic exchange of patient data with other providers to improve the quality of care, and they must use these systems to report clinical quality measures to insurance payers and public health agencies. Furthermore, the data should be accurate, lead to better actions, improve reporting, and make billing more efficient. Table 1 shows the 28 criteria that were proposed as requirements to receive subsidy payments in 2011<sup>[23]</sup>.

The Office of the National Coordinator (ONC) for HIT (within the Department of Health and Human Services) has also funded an ambitious set of four national collaborative projects to address specific needs for the following technical challenges<sup>[24]</sup>:

1) *Security of Health Information Technology* research to address the challenges of developing security and risk mitigation policies and the technologies necessary to build and preserve the public trust as health IT systems become ubiquitous. (*University of Illinois, Urbana-Champaign*)

2) *Patient-Centered Cognitive Support* research to address the need to harness the power of health IT in a patient-focused manner and align the technology with the day-to-day practice of medicine to support clinicians as they care for patients. (*University of Texas Health Sciences Center, Houston*)

3) *Healthcare Application and Network Platform Architectures* research to focus on the development of new and improved architectures that are necessary to achieve electronic exchange and use of health information in a secure, private, and accurate manner. (*Harvard University*)

4) *Secondary Use of Electronic Health Record Data* research to identify strategies to enhance the use of health IT in improving the overall quality of healthcare, population health and clinical research while protecting patient privacy. (*Mayo Clinic*)

The lead institutions are shown in italics, though each project involves many others as well. Here, I want to briefly mention the goals of each of these projects.

**Table 1.** Initially Proposed Meaningful Use Criteria to Earn Incentive Payments for EHR Adoption in 2011

1. CPOE (computerized practitioner order entry)	15. Check insurance eligibility electronically
2. Drug screening	16. Submit claims electronically
3. Maintain problem list in ICD-9-CM or SNOMED-CT	17. Provide patients with an electronic copy of their information upon request
4. Electronic prescribing	18. Provide patients with an electronic copy of discharge instructions and procedures at time of discharge
5. Maintain active medication list	19. Provide patients with timely electronic access to their information
6. Maintain active medication allergy list	20. Provide a clinical summary for each visit
7. Record demographics	21. Exchange clinical information electronically with other providers and patient authorized entities
8. Record vital signs	22. Perform medication reconciliation at relevant encounters and each transition of care
9. Record smoking status for patients age 13 and over	23. Provide summary care record for each transition of care and referral
10. Incorporate clinical lab test results into EHR as structured data	24. Submit data to immunization registries
11. Generate lists of patients by specific conditions to use for quality improvement, reduction of disparities, and outreach	25. Submit reportable lab results to public health agencies
12. Report quality measures to CMS or states	26. Submit syndromic surveillance data to public health agencies
13. Send reminders to patients based on patient preferences and selected by specific criteria for preventive/follow up care	27. Protect health information
14. Implement five clinical decision rules, . . . , based on demographic data, diagnosis, conditions, test results, and/or medication list	28. Transparency of data sharing

Project 1 addresses the need to create HIT systems that are at the same time able to share data for legitimate purposes but prevent improper leakage of those data due to accident, criminal activity, or technical breakdown. Failure to protect such data can lead to a rejection of the whole enterprise, but clumsy methods can interfere with usability<sup>[25]</sup>. We know how to create highly secure systems, but they require cumbersome techniques such as two-factor authentication based on cryptographic tokens, biometric identification and passwords, frequent password changes, and extensive use of encryption. These are all highly inconvenient and costly to implement even for modest sized groups such as healthcare providers. If patients also need to follow such rules, we have no experience creating and maintaining authentication systems at that scale. Banking and commerce have avoided these approaches for clients, but their losses can be made whole with money, whereas many feel that the loss of confidentiality if a health system leaks information cannot be appropriately compensated.

Project 2 focuses on making individual facts about a patient meaningful in the context of taking care of the whole patient. It involves integration of individual patient information across modalities, time and care providers, supporting visualization of anatomical, functional and pathologic conditions, illustration of changes over time, with the ability at all times to “drill down” to find supporting details<sup>[26]</sup>. Success in this will also permit semi-automated application of

evidence-based guidelines, monitoring and alerting on deviations from guidelines, development of standard order sets, and deployment of disease management “dashboards” that can keep track of care for a cohort of patients. Other goals include continuous tracking of patient health state by unobtrusive instruments that can non-invasively measure heart rate and blood pressure, temperature, movement and exercise, respiration, urine composition, food and liquid consumption, and transdermal serum components such as glucose. Such advances will help to empower patients and make possible real-time communication and monitoring of their health state. Part of the challenge of this effort is to identify how users can best make sense of the vast amounts of data we are now starting to be able to collect about individual patients. Cognitive, rather than purely technical models are likely to be paramount.

Project 3 is motivated by the observation that most of today’s HIT systems are monolithic, closed systems that hinder incremental improvements. My colleagues, Isaac Kohane and Ken Mandl at Harvard, who run this project, are working toward a model most like that of the various new cell phone application stores, where applications to support specific HIT needs could compete and lead to natural selection, permit disruptive innovation, and avoid “design by committee” failures in the real world. Their fundamental principles are full liquidity of data, so nothing is locked into specific systems, and open standards that can encourage both free and commercial software, and make substitutability of

applications a paramount goal. They suggest that categories of such applications can create natural competitive markets in areas such as medication management, data acquisition, documentation, patient panel management, quality improvement, communication, public health reporting, support of research, and decision support<sup>[27]</sup>. Creation and adoption of standards poses historically difficult problems. If standards are too loose, interoperability of applications is hindered if they interpret the same data item to mean (somewhat) different things. However, waiting until universal standards are in place virtually guarantees that little progress will occur. The challenge is to find an appropriate middle ground.

Project 4, in which I play a part, focuses on the opportunity of using vast and growing stores of clinical data gathered in the course of patient care for other important purposes. One is to improve the quality and timeliness of public health reporting. The other is to support translational research by matching recent huge advances in our ability to acquire genetic data with a corresponding improvement in acquisition of phenotype and environmental data from clinical records. Achieving this goal requires the ability to share vast stores of clinical data safely, common terminologies and ontologies to make those data meaningful across institutional boundaries, and natural language processing methods to turn preponderantly narrative text into formalized data elements. Consider the following fragment of an actual (de-identified) discharge summary:

“Mr. Blind is a 79-year-old white male with a history of diabetes mellitus, inferior myocardial infarction, who underwent open repair of his increased diverticulum November 13th at Sephsandpot Center.

The patient developed hematemesis November 15th and was intubated for respiratory distress. He was transferred to the Valtawnprinceel Community Memorial Hospital for endoscopy and esophagoscopy on the 16th of November which showed a 2 cm linear tear of the esophagus at 30 to 32 cm. The patient’s hematocrit was stable and he was given no further intervention.

The patient attempted a gastrografin swallow on the 21st, but was unable to cooperate with probable aspiration. The patient also had been receiving generous intravenous hydration during the period for which he was NPO for his esophageal tear and intravenous Lasix for a question of pulmonary congestion.

On the morning of the 22nd the patient developed tachypnea with a chest X-ray showing a question of congestive heart failure. A medical consult was obtained at the Valtawnprinceel Community Memorial Hospital. The patient was given intravenous Lasix.

A arterial blood gases on 100 percent face mask

showed an oxygen of 205, CO2 57 and PH 7.3. An electrocardiogram showed ST depressions in V2 through V4 which improved with sublingual and intravenous nitroglycerin. The patient was transferred to the Coronary Care Unit for management of his congestive heart failure, ischemia and probable aspiration pneumonia.”

This fragment contains a vast amount of meaningful data, if we can extract it. I have color-coded segments of the text: blue refers to patient conditions and diseases, brown to tests and procedures, magenta to measurement results, and purple to time. Our approach to such extraction problems is to use statistical natural language processing methods. For example, to classify the above phrases with their appropriate categories (colors), we could compute a large number of features from the text and then learn rules or probabilistic models that most accurately predict the categories we have identified by human annotation in the training data. These features include the words themselves, their parts of speech, mappings to dictionary meanings, medical concepts such as terminology from ICD-9, SNOMED, MeSH, etc.,  $n$ -tuples of such features based on textual proximity, further  $n$ -tuples derived from a syntactic analysis of each sentence, the position in the document, section or subsection. We have successfully used such methods to find privacy-threatening identifiers (names, addresses, phone number, institutions, etc.), to identify signs, symptoms, diagnoses, allergies, tests, results, treatments, outcomes, medications, and dosages. The ultimate goal of such work is to turn free-form narratives into a formalized representation of the clinically meaningful content of the entire note. This work is in the tradition of contemporary statistical natural language processing, but deals with a richer, more complex set of data than other typical applications. Further development of machine learning models is also needed once the data have been extracted to combine these data with more conventional numeric and structured data from laboratories, pharmacies, bedside measurements, monitoring equipment, etc. Such combined models may be helpful in automated diagnosis, classification of cases for selection in research studies, or creation of aggregate statistics used in surveillance for public health, drug safety, or learning better clinical methods.

Two other technology contributions will, I believe, have a major positive benefit for improvements in healthcare, though I have no space to explore them here fully. One is the evolution and spread of personally controlled health records, for which I have advocated since the mid-1990’s<sup>[28]</sup>. Such records, under the control of the individual patient or a delegate, would support a life-long continuous record of

clinical conditions, provide patient and family decision support, help in educating the patient to manage his or her chronic diseases and to make informed decisions, and help connect patients through portals to like-minded communities. We proposed such a vision, called *Guardian Angel*, in 1994, and various groups today, including Google Health, Microsoft Healthvault, and Indivo Health/Dossia are trying to turn it into a reality. Sharing insights with ONC's architecture project, the Indivo team is building a highly flexible and substitutable platform that can gradually retire its own features to be replaced by better third-party apps, as has happened for example with Facebook. The core of the platform, however, will support high privacy standards, provide a unified user experience, and ease development.

The other technology developments I consider notable both bring HIT to the developing world. Several research groups, including my colleagues at Partners in Health, have successfully implemented software tools that help clinics and public health authorities in numerous developing countries manage patients who require ongoing and supervised treatment for multi-drug-resistant tuberculosis (MDR-TB), human immunodeficiency virus infections (HIV/AIDS) and other serious diseases. They have pooled their experience to create an open-source electronic record system called OpenMRS<sup>[29]</sup> whose modules support a broad variety of functions: recording clinical status of individual patients, tracking laboratory orders and results, offering decision support to healthcare workers, providing aggregate reporting functions to allow tracking of caseloads, management and forecasting of pharmacy requirements, and support of community health workers to keep track of patients and record ongoing health data from them<sup>[30]</sup>.

Focusing on the growing capabilities and widespread deployment of smartphones, the Sana Mobile<sup>[31]</sup> team is building an infrastructure that supports telemedicine for broader access to health information, consultation with specialists without the need to travel from a rural area, and data gathering for telehealth, including images, sounds, data from other phone-coupled devices, and typed and spoken text. These projects have harnessed the excitement of the volunteerism of dedicated young people, adopted free software philosophies, and reached out actively to draw developers and implementers not only from their root U.S. university communities but from people in the countries where the technologies are meant to be deployed. This approach provides, we expect, a level of sustainable support that will have a profound influence on improving healthcare

delivery across the world.

Healthcare is one of the fundamental needs of humanity, and one of the most strongly motivated desires of people everywhere. Advances in computer and communication technology promise to make current standards of care available to increasingly comprehensive portions of the globe. Further advances foreshadow the development of new methods and approaches that can provide new functionality, new ways to deliver care, and thus to improve health universally.

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