Smart and Connected Health

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Computing plays an increasingly important role in our lives, and not surprisingly, also in all aspects of becoming or staying healthy. Health and well-being are encouraged with the development of many apps, gadgets, and systems focusing on diet and exercise; personalized systems to track and manage diseases; and novel ways for personalized or just-in-time information exchange through connections between patients and their communities. Medication, surgery, and assistive devices rely on computing to analyze data and human responses and guide the implementation and management of therapies and interventions. Large-scale analysis of biomedical data, personal health data, metadata and crowdsourced or social media consumer data are integrated and analyzed to help predict, prevent, or understand ongoing phenomena. Although some technology interventions are mature (for example, providing information via the Internet), others are new and in early, experimental phases (for example, personalized geotagged information in persuasive systems). All these developments, however, have an increasingly broad and significant societal impact.

State of the Field

Today's healthcare has become cost-prohibitive for many and suffers substantially from medical errors and waste.[1] An often-cited reference is the 1998 Institute of Medicine report, which estimated that preventable medical errors lead to as many as 98,000 deaths per year in the United States.[2] Gerard Anderson and Patricia Markovich[3] reported

1541-1672/14/$31.00 © 2014 IEEE
Published by the IEEE Computer Society

that the US spends $1.7 trillion annually (16 percent of its GDP) on healthcare, yet produces significantly lower health outcomes than many other developed countries. Many new government initiatives have been started recently to address these continuing problems and improve healthcare-related outcomes. For example, President Obama's $787 billion federal stimulus package was announced in 2009. The HITECH Act for healthcare information technology (IT) stipulates that healthcare entities in the US need to use IT to fix ingrained problems, with $19 billion in 2011 and a total of $50 billion allocated to this effort over the next 5 years. Internationally, health IT has also become a national priority for many countries that face a large aging population. For example, in January 2009, China's government announced a plan to spend more than $120 billion on the first phase of a 10-year overhaul of its healthcare system.[4]

In academia there has also been significant recent interest in adopting and advancing IT for effective healthcare. The 2009 National Research Council report[1] on "Computational Technology for Effective Health Care" suggests an overarching research grand challenge of developing "patient-centered cognitive support." It also points out several representative research challenges for the IT community, including virtual patient modeling, healthcare automation, healthcare data sharing and collaboration, and healthcare data management at scale. A major research goal of these programs is to develop trusted healthcare systems that offer relevant decision support to clinicians and patients and offer "just in time, just for me" advice at the point of care.

In a research commentary article by Howard Wactlar and his colleagues, entitled "Can Computer Science Save Healthcare?" the authors discuss ways that computer science (or more generally, IT) research could help resolve some of the healthcare crises in America.[5] They propose a program of research and development along four technology thrusts to enable this vision:

- creating an interoperable, digital infrastructure of universal health data and knowledge,
- utilizing diverse data to provide automated and augmented insight, discovery, and evidence-based health and wellness decision support,
- a cyber-based empowering of patients and healthy individuals to play a substantial role in their own health and treatment, and
- monitoring and assisting individuals with intelligent systems—sensors, devices and robotics, to maintain function and independence.

These four suggested health IT thrusts are reflected in the US National Science Foundation (NSF) Smart and Connected Health (SCH) program solicitation (www.nsf.gov/pubs/2013/nsf13543/nsf13543.htm): digital health information infrastructure, from data to knowledge and decisions, empowering individuals, and sensors, devices, and robotics. Initiated in 2011, the SCH program has generated significant interest from the research community. Over the past three years (2011–2013), 75 proposals have been funded from several hundred proposals submitted. The program has been expanded significantly from an intra-directorate solicitation within the NSF Directorate for Computer and Information Science and Engineering (CISE) in 2011 to an inter-agency solicitation involving major NSF directorates and several institutes within the National Institute of Health (NIH) in 2014.

IEEE Intelligent Systems

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In addition to the NSF SCH program, the NIH has also developed the Big Data to Knowledge (BD2K) initiative in 2013 to enable biomedical scientists to capitalize more fully on the Big Data being generated by those research communities (http://bd2k.nih.gov). NIH has committed $24 million annually for Big Data Centers of Excellence since 2013. Other significant areas of development within BD2K include enabling data utilization, analysis methods and software, and enhancing training. The highly synergistic NSF SCH and NIH BD2K programs promise to help foster a new generation of innovative, transformative, and high-impact smart health research.

The health informatics community has responded positively to the pressing demand for smart health research.[6] The American Medical Informatics Association (AMIA) annual symposium continues to be the most prominent forum for biomedical informatics research, drawing more than 1,500 participants annually. It focuses on the development and use of information to improve biomedical research, translational research, and individual and public health. Several new ACM and IEEE conferences have also drawn attention from the broad computer science and electrical engineering community, including: ACM SIGHIT Health Informatics Symposium (IHI), ACM SIGKDD Workshop on Data Mining for Healthcare (DMH), and IEEE International Conference on Healthcare Informatics (ICHI). Unlike the strong health application focus within AMIA, the ACM/IEEE meetings offer a complementary technical orientation in advanced machine learning, robotics, and sensor research for healthcare.

In This Issue

This special issue brings a selection of articles that showcase the variety of research being conducted, in which computing augments medicine. The work ranges from ontologies and prediction suitable for healthcare providers to technology brought into the clinic or people's homes.

The first two articles focus on information for healthcare providers. In their work on "Humanitarian Assistance Ontology for Emergency Disaster Response," Satria Hutomo Jihan and Aviv Segev describe their creation of a Humanitarian Assistance Ontology containing crisis response concepts, inference logic, and knowledge representation. Their work aims to allow better use of the unstructured information that becomes available in emergency cases, such as the social media data with the 2011 tsunami in Japan. They combine two ontologies, one for crisis identification and one for crisis response, and map terms from blogs, emails, and other texts on the Internet to populate the ontologies. These terms are then, via inference rules, mapped to needs and priorities. The authors tested their approach using blogs on Hurricane Wilma and found that their system scored high on recall for identifying human needs, with an overall F-score better than two baseline approaches.

The second article applies a classic approach in a novel way to expand current data mining technology to predict the timeframe of events that will occur for patients with chronic diseases. In "Time-to-Event Predictive Modeling for Chronic Conditions Using Electronic Health Records," Yu-Kai Lin and his colleagues describe how to leverage information in electronic health records to predict the time to hospitalization for people with diabetes. Comparing a basic and an extended Cox model (the latter includes time-dependent covariates), they achieved 0.87 and 0.90 AUC scores for predicting hospitalization of patients over a time period of 85 months.

The third and fourth papers bring patients and computing together. In "Intelligent Frozen Shoulder Rehabilitation," Ming-Chun Huang and his colleagues focus on frozen shoulder, a common shoulder condition that requires sustained and proper exercise. They developed and evaluated virtual reality training games that provide the patients real-time feedback on their progress. Their system combines Microsoft Kinect and wearable sensors in virtual reality games of different levels. An evaluation with 40 patients, randomly assigned to the control or study group, showed after a four-week training program that the study group significantly outperformed the control group on the four standard evaluation exercises.

Finally, in "Determining Wellness through an Ambient Assisted Living Environment," Nagender Suryadevara and Subhas Mukhopadhyay bring computing into the realm of ambient assisted living. The team developed and evaluated an intelligent system for monitoring daily activities. However, they monitor through observation of usage of everyday objects and comparing an improved wellness function to its previous version. Their system was able to label 94 percent of daily activities and then effectively assess wellness using an integrated wellness function.

We believe the articles presented here offer a sample of the work occurring in this field, both in terms of innovation and the broad range represented. Certainly computing will continue to play a vital role in healthcare, with many breakthroughs in "smart health" on the horizon.

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