Respiratory Sound Analysis
Developing More Fully Integrated Diagnostic and Assessment Systems
While working in the area of pacemakers almost three decades ago, I recall discussing the artificial heart with some fellow biomedical engineers. At first the discussion was strictly devoted to the physiological, mechanoelectrical, and systems levels. Slowly, however, the technical discussion moved into the matter of economics and the cost-effectiveness of the device as it related to the entire process. At a point in that debate, it became clear that there was a chasm between the wonderful opportunities that such devices could offer with respect to saving or prolonging someone’s life and the stark economic realities related to affordability, no matter where in the world a patient lived. Part of this discussion dealt with the fact that for the price of a single artificial heart, 100 people could have a pacemaker implanted or replaced.

Today, as we examine the rising operational costs in the U.S. healthcare industry (i.e., malpractice insurance, administrative costs, pharmaceuticals, managed care, hospitals, changing technologies, etc.), we can easily understand how these runaway costs not only hold a plethora of negative repercussions for our national economy but also impact healthcare at the local level, such as affecting just how well a local hospital’s emergency department (ED) can properly allocate its capacities and capabilities. The same thought must be extended to the prospect of operating effectively during a major crisis. It has come to light, for example, that the 41 million individuals without medical insurance in the United States now look to use these same EDs as the primary providers of their healthcare. Naturally, having to extend care to the uninsured degrades normal ED operational capabilities and capacities—to the point that about once every minute an ambulance is turned away from a hospital and sent to another [1]. Of course, rising costs produce other cascading, unanticipated, and possibly undesirable effects. For instance, they drive consumers to more desirable outlets and venues—in this case, making medical outsourcing [2] a viable choice for the consumer.

Additionally, this now flattened world a la Friedman [3] purports to have opened up unique, worldwide cost-controlling opportunities to many. Friedman describes the role of information technology as a social and economic equalizer for the “have-nots” of the world. Particularly in the United States, the complexity involved in the extension of healthcare to both the “haves” and “have-nots” is ever increasing, from the sheer volume of tests administered to the number of specialists that are likely to be involved in a case to the administration of therapies. At every juncture, information technologies (IT) have become a powerful decisive force in the administration and quality of care. Given this area of immense importance, there is one associated problem area that very few have focused on to date. For the uninitiated, it is important to highlight that this one area throws an imposing shadow not only over the U.S. healthcare system and public health but over national and international security as well. That vastly mysterious area is interoperability. As an example of interoperability, imagine an individual who has had an electronic health record (EHR) in his or her private life for 20 years. This individual proceeds to have a career in the armed forces for a period of 25 years, and after retirement becomes a part of the Veterans Administration (VA)’s health record-keeping system. Today, there is a need for this veteran’s EHR to transition smoothly from one system to the next [civilian, Department of Defense (DoD), and VA], and to do so without suffering any exceptions (missing or inaccurate records) in the process. Yet, there is little that anyone can offer in the way of knowledge or assurance that this expectation can be met!

A Turning of the Tide

Recently, at a seminal IEEE-sponsored June meeting in Cambridge, Massachusetts, titled “Special Session on Integration and Interoperability of National Security Information Systems,” a fundamentally intellectual turning of the tide on the nature of uninteroperability took place. Discussions there served to confirm that de facto adoption of any preexisting definitions of interoperability, such as the one inked by the DoD, amounted to a violation of intellectual due-process when discussing the perennially intractable problem of uninteroperability.

The special session—a veritable gathering of the world’s who’s who in computing, communications, innovations, and policymaking—succeeded immensely in spotlighting the array of misunderstandings and complexities related to interoperability. Gene Amdahl, Simon Ramo, Marcian “Ted” Hoff Jr., James Treybig, Gordon Bell, William J. Harris, Rona Stillman, Jeffrey Hunker, and Brenton Greene were some of the luminaries featured at this event. They stressed a systems approach, which is as yet absent from all efforts thus far to achieve interoperability.

Dr. Robert Mathews, distinguished senior research scholar on national security affairs and U.S. industrial preparedness at the Center for Strategic Advancement of Telematics and Informatics, and perhaps the world’s leading authority on interoperability, has said that the manner in which we...
have been studying the interoperability of information systems for more than half a century is in essence incorrect. He suggests that we are ignoring key multidisciplinary and interdisciplinary aspects of the problem in our considerations in addition to not using a systems approach. Dr. Mathews, who organized this historic IEEE gathering, including its intellectually compelling mix of subjects and themes, added that existing intellectual orientations and the definitions for interoperability are profoundly puzzling and full of equivocations. He says that such orientations have at best served to wage a disinformation campaign against those in the scientific and operational communities, tearing much needed attention and resources away from a holistic (comprehensive) treatment of the problem. IEEE-USA has fundamentally reaffirmed this view, acknowledging the boundless usage of the term interoperability, while noting discernible vagueness of meaning in common use [4]. Moving forward with a systems approach has been difficult at best for the scientific community, for there is an insufficient appreciation of the processes involved.

**A Confounding Evolutionary Path**

The dawn of the information age has brought with it profound societal changes, to which we humans have not adjusted well. Vast populations of computational hardware, communication systems, applications, and subordinated support systems make up an intricate, ultracomplex, and highly distributed interdependent super-infrastructure behind every decision-making path. While, metaphorically, the oceans of the world have been reduced to mere ponds, and transcontinental fiber optic bridges have brought the world’s landmasses and their respective populations closer together and economically more interdependent, the curse of the information age is that the aforementioned super-infrastructures must now not only synchronously cohabit with humans everywhere but also must support the way human beings tend to make decisions.

This complicated “arrangement for coexistence,” and the process of satisfying the “man, machine, and the enterprise/support systems” equation, where elaborate processes are involved in the extension of support toward decision making by human beings, “have never really been fully understood,” according to Mathews. He submits that the “man, machine, and the enterprise/support systems” must be better represented in a more fundamental, more holistic (comprehensive) manner.

**Course Correction**

Aside from the fanciful yet bleary definitions carved up by many, and those that exist in popular lore, Mathews attempts to orient us toward interoperability, defining it as “that ability for people to interact with each other, between organizations, across domains of influence and geographical boundaries—supported by the proper decisioning tools and services—to achieve a goal/objective/decision, within set/accepted limits of performance.” He suggests that interoperability cannot be hurriedly consigned to the realm of any technology or any of the system components alone. Rather interoperability must factor in all aspects of the equation that concerning the establishment, maintenance, and improvement of synchrony among all parties that are required to interact to achieve a common goal, objective, or decision. Therefore, Mathews says “every aspect of the man, machine, and enterprise/support system must be properly accounted for, considered, and treated to solve the interoperability problem.”

**Role of Interoperability in U.S. Healthcare Reform**

On 17 July 2003, a one-year-old baby, Jeanella Aranda, received a transplanted liver from her father at the Children’s Medical Center in Dallas, following a surgical procedure to remove a hamartoma. Damage to blood vessels sustained during the removal of the hamartoma required the surgeons to remove Jeanella’s liver. Jeanella’s parents were immediately solicited as potential donors for a partial liver for their daughter; a blood test was quickly administered to each parent to determine who was to be the likely transplant donor. The laboratory first reported that Mrs. Aranda was a match and then subsequently issued a revised report stating that Mr. Aranda was the appropriate donor. In truth, the lab’s first determination was correct.

Following a partial liver transplant from Mr. Aranda, baby Jeanella’s condition quickly began to deteriorate as she developed a postoperative blood disorder, fever, kidney problems, lung hemorrhages, and severe jaundice. On 5 August, 19 days after the transplant, Mrs. Aranda noticed that baby Jeanella was receiving type O blood transfusions, which seemed to be inconsistent with her husband’s blood type (A), and enquired whether there was a transplant-related mismatch. Officials then determined that Mrs. Aranda was correct in her observations. By then, it was already too late. Baby Jeanella died the next day, 20 August [5]. This case surfaced on the heels of another terrible, nationally prominent case of blood type mismatch. Less than six months earlier, 17-year-old Jesica Santillán died after undergoing a heart-lung transplant at Duke University Hospital in North Carolina [6].

In a report titled “To Err Is Human: Building a Safer Health System” [7], the Institute of Medicine of the National Academies reported that medical errors claim more lives in the United States than motor vehicle accidents, breast cancer, or AIDS and that “adverse events” directly related to medical errors cost the nation on the order of
US$37.6 billion a year, of which US$17 billion are completely preventable (These figures represent the lowest estimate as presented by the Institute.). In a more recent report [8], also by the Institute of Medicine, a study conducted at the Brigham and Women’s Hospital in Massachusetts revealed 70 separate incidents of adverse drug events (ADEs) and 194 potential ADEs. The report also notes that, upon further analysis of the data, a system analysis group found 334 errors associated with the documented 264 events in total.

The system analysis group discovered that defects in drug knowledge distribution, dose and identity checking, availability of patient information, order transcription, allergy defense systems, medication order tracking, and interservice communications presented key problem areas, accounting for over 75% of the errors identified. They concluded that there were pervasive systems of systems problems that led to the many errors.

In mulling over this information, Dr. Mathews reminded us that “whenever a system-of-system problem has been identified as such, what people are really referring to is an interoperability problem. We must remember that the very notion of interoperability presupposes a synchronic interworking of all components in constituting systems to achieve the desired goal. When the many steps in the interoperability processes aren’t properly qualified, quantified, associated, monitored, assessed, and improved, things are bound to go wrong. All relationships—however subtle in composing systems—must be properly accounted for.” He continued to state that he wasn’t surprised by these statistics, and alarmingly questioned whether the actual numbers may indeed be much higher than those declared by the Institute of Medicine. According to Matthews, “since most aren’t able to properly define the processes as (it) pertains to interoperability, let alone qualify and quantify the many aspects of any domain of concern well—in this particular case of Brigham and Women’s Hospital—there may very well be many dimensions that go either unreported or underreported as a result.”

After reviewing the prepublication copy of the Institute’s latest report, Dr. Mathew’s observations seem to have been proven accurate. A second study conducted at the Brigham and Women’s Hospital in fact uncovered ADEs at a higher rate than certain other studies involving computerized surveillance. This was due to the fact that the computerized surveillance system used in the new study was adjusted to be more sensitive and was undeniably able to detect milder ADEs, as the surveillance system was governed by a newly minted set of rules for identifying a wider range of ADEs. As Dr. Mathews said, in this case, improving qualification and quantification of the domain and translating that knowledge to improve the computerized surveillance system then permitted the discovery of additional ADEs that would otherwise have gone unnoticed or unreported.

The Future of Interoperability

Dr. Noah Porter, president of Yale, once said “few persons are so familiar with each of the several lines of argument in which lies its strength if it be true, and its weakness if it is false, as to be able to judge of any considerable number. Fewer still are competent to pronounce upon the relation of each part to every other, and the cumulative force of all as they bear upon the grand conclusion.” [10] If I had to account for just one extraordinarily brilliant message that the IEEE Special Session on Integration and Interoperability of National Security Information Systems uncovered, it was that thus far interoperability has been studied and approached quite incorrectly, and that it must be viewed with an interdisciplinary and multidisciplinary perspective (holistic) using a systems approach. With the cerebral assistance of geneticists, seismic engineers, electrical engineers, bridge builders, computer scientists, biologists, structural engineers, metallurgists, economists, physicists, management scientists, policy makers, and analysts, Dr. Mathews both

THE MILITARY AND INTEROPERABILITY

Computers were born of war, and they are still at war. The American military has had the longest tenure and the most diversified experience with computers and electronic communications technology in the United States federal government, and indeed the world. Therefore, it would appear logical that a definition for information systems’ interoperability per a U.S. DoD dictate should become ubiquitously acceptable as an intellectual point of departure for discussions relating to uninteroperability, and indeed it has. Government wide, the DoD definition for interoperability has given rise to similar definitions, with a hint of familiar DoD phraseology. The DoD defines interoperability as that “ability of systems, units, or forces to provide data, information, material, and services to and accept the same from other systems, units, or forces and to use the data, information, material, and services so exchanged to enable them to operate effectively together. According to the DoD, “interoperability is more than just information exchange. It includes systems, processes, procedures, organizations, and missions over the life cycle and must be balanced with information assurance.” (9) And according to the IEEE Standards Computer Dictionary, interoperability is defined as that “ability of two or more systems or components to exchange information and to use the information that has been exchanged.”
cleverly and uniquely proved that if human beings and information technologies are to have an arrangement of coexistence to be interoperable—for the purpose of successfully attaining common goals in a timely, efficient, and effective manner—then going forward we must have a very intimate understanding of any such arrangement for coexistence.

Let’s go back to the example used earlier—an individual with an electronic health record in the civilian, military, and VA sectors—and imagine the consequences of having an interoperable and longitudinal “unique” record throughout the individual’s lifetime. This individual’s life may be saved a few times by having the right information in the right place at the right time. The quality of life may improve, and the number of potential medication or allergy errors may be eliminated. The knowledge stored could also provide information related to environmental factors (e.g., quality of the water and air), as well as short- and long-term effects of diet, exercise, and vaccines. In my view, all these factors, when combined with personal genetic information (while, of course, protecting the rights of privacy), will allow us to move into true disease prevention. True interoperability will help improve the quality of our healthcare and public health systems while significantly reducing expenses.

References

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