AIM: Quo Vadis?

Given the critical role medicine plays in our survival and the ubiquity of computing in our lives, it is hardly surprising that practitioners of both medical informatics and Artificial Intelligence in Medicine (AIM) are often encouraged to get on with their business more quickly and effectively. Such is the gist of the viewpoint article by Coiera in this issue of JAMIA. He proposes viewing AIM as a technologic subspecialty of medicine, focusing on challenges presented by current trends toward evidence-based medicine, so that "the final arbiters of success must rest in phrases like 'clinical outcomes' and 'cost-effectiveness' and not in measures like 'computational complexity.'"

From a technologic perspective, such views and impatience are understandable and could encourage AIM researchers to design more clinically effective systems. From the broader perspectives of clinical practice and the sciences of both medicine and computing, it makes sense to pause and consider two related questions: what are the medical problems for which AIM is best suited, and what are the AI problems for which medicine provides a useful domain of study and technologic application?

The most controversial branch of computer science, AI is concerned with the study of human and machine cognition, perception, knowledge, and problem solving, using the computer as its investigative and empirical testing tool. Furthermore, AI research has led to vision, speech, natural language, robotics, game playing, logic, and theorem proving, and knowledge representation and reasoning techniques that have influenced mainstream computational thinking and practice during the past decade, raising (often overly optimistic) expectations that "intelligent systems" are just around the corner. Medical problem solving has historically provided AI researchers (and colleagues in mathematics, statistics, psychology, and engineering) problems of diagnosis, prognosis, and therapy planning to test their theories and models. Progress in knowledge-based AI has come from representing, critiquing, explaining, learning, and reasoning with medical knowledge. Pattern recognition and connectionist models have proven useful for medical classification and data exploration. Therefore, AIM can be proud of its contributions and need not apologize for medicine's justifiable resistance to facile or premature solutions of complex problems.

Developing useful computer formalisms to support medical practitioners involved in making difficult, risky decisions in the face of uncertainty and incompleteness of evidence guarantees an endless supply of significant, though frequently less-than-well-defined, open problems for scientific and technologic research. Researchers must often choose between creating elegant formal models with restricted medical use and plunging into the messy world of practical medical systems, based on computerized medical records, coding and language schemas, graphical user interfaces (GUIs), networking, and distributed databases fed by the sophisticated imaging and sensing systems that increasingly capture the data for medicine today. Some of the work on practical systems will lead to fundamental research in AI and other disciplines. However, most will also involve solving fairly "mundane," though often extremely hard, systems infrastructure design problems.

This tradeoff is in large part responsible for Coiera's strongest critique of AIM—that the work can become inward looking and, at worst, esoteric or irrelevant to medicine. To overcome such tendencies, his challenge to AIM is that it should support the transition to evidence-based medicine by tackling the development of the technology needed to make practice guidelines more accessible, manageable, and updatable. However, this challenge can not be met with technology alone; science and bioethics also are involved.

Medical practice is an art, despite scientific advances over the past 150 years. Applying scientifically derived medical knowledge to patient management has not itself become a science for many reasons, not least the inherent ethical difficulties in designing and executing controlled and reproducible experiments on humans. Decision analysis methods can help in modeling individual preferences and expected clinical outcome tradeoffs for circumscribed medical problems and choices, but utilities are frequently difficult to obtain and validate, and the probabilities needed to capture the tradeoffs are difficult to quantify. Clinical problems are hard to circumscribe. They often unexpectedly connect to other problems the patient has, the environment, or family history. A physician integrates this information intuitively, not formally, in the context of current medical knowledge. Neither formal biostatistical methods nor AI models of clinical cognition have captured more than fragments of the physician's process.

Yet concerns about health costs and hopes of standardizing medical practice to make it more predictable are leading to the development of practice guidelines. Guidelines, however thoughtfully developed by consensus of the best specialty experts, at present resist standardization of format or meaning. They vary from general statements of principle to specific rules about the management of concrete medical condi-
tions. Formalizing this knowledge is needed, and AIM researchers can contribute, but only by closely collaborating with the expert physicians involved. At this point a paradox arises. As noted by Coiera, computer networking and software technology increasingly allow all users, including medical professionals and patients, to rapidly access and manipulate information with great flexibility, if only at a superficial and unstructured level. This encourages lack of uniformity of usage, not standardization. A lack of standardization is acceptable as long as the application of knowledge itself remains an informal matter of practitioner judgment, and responsibility rests, as it always has, with the expert and the patient. But when practitioners are required to use a particular type of semi-formal knowledge, as in guidelines, and their application of it is construed to be rule-like and mechanical, as if the knowledge were indeed completely formal and applicable in a logically deterministic manner, major problems arise.

There is a need to develop much better understanding first, and computational models second, to see how informed, balanced judgment applies knowledge in the assessment of evidence in practice situations. Supporting guidelines by decision-analytic models linked to formal representations of medical semantics and cognitive knowledge (such as influence diagrams and constraint networks that account for ethical and economic constraints on decisions) is a first step. Reliable data from computerized medical records is necessary to validate and implement such models efficiently. Helping to standardize the meaning and representation of medical terms and concepts, as in the Unified Medical Language System (UMLS), is a prerequisite. Helping to develop techniques for recognizing and reducing ambiguity (when possible) in a variety of medical argumentation and reasoning models is equally important, and AIM has much to contribute here. Finding a subset of language that is just adequate for solving a class of problems is a recurring and difficult scientific-philosophical problem. Better linguistic, mathematical, logical, cognitive, and perceptual models, computationally based, are needed. It will also help if these models are complemented by experimental methods that begin to take into account some of the psychophysical changes that are inevitable as we move from purely human to mixed human machine systems. Decision models for multiple “intelligent agents,” whether human or machine-delegated, need to be developed to take into account the goals, responsibilities, and other value-related components of expert judgment. Virtual reality and other “human-in-the-loop” systems should enable the design of controlled medical simulations that can, with appropriate rehearsal and testing regimens, avoid some, though hardly all, ethical constraints that arise when testing human decision-making under risk and uncertainty.

Of course, AI, biostatistics, engineering, cognitive science, and medicine all face challenges here. Sophisticated GUIs, multimedia and image databases, visual programming, and collaborative shared workspace technologies are beginning to provide some technology prerequisites for such investigations. Algorithms with low computational complexity must be developed to handle the incredible throughput of sensory data from biomedical systems and the flexible and expressive reasoning from AI models. Evaluation and validation methods need to be applied appropriately to encourage good experimental design, not to stifle innovation. But for every stage of future technical and scientific progress in solving medical problems and reducing uncertainties, there will always remain difficult resource constraints and tradeoffs that challenge the individual and societal basis of our decision making and actions—including deciding which research to do.

Given the open nature of biologic systems (and of our own conceptions of them), the technological challenge is small compared with the scientific and ethical challenges of understanding the behaviors of active systems that can amplify or constrain our human component in unpredictable ways. These challenges suggest that AIM researchers should pursue their work in the way they know best: driven both by technology and the problems of medicine, but ultimately by their own curiosity and spirit of inquiry. Our children’s outcomes, clinical and otherwise, will in the long term depend on it.

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