Preface

The need to efficiently deliver and process information in the healthcare and biomedical sectors is a primary concern among practitioners, researchers, and patients alike. Medical informatics—a field that has emerged at the intersection of information technology and medicine—has transformed modern healthcare and created new, more pervasive methods for access to information, records, and even medical advice. As medical informatics continues to evolve and researchers continue to create and implement technologies for use in the study and practice of medicine, we must continue to understand, develop, and utilize the latest in medical research and exploration.

In recent years, the applications and technologies generated through the study of medical informatics have grown in both number and popularity. As a result, researchers, clinicians, practitioners, and educators have devised a variety of techniques and methodologies to develop, deliver, and, at the same time, evaluate the effectiveness of their use. The explosion of methodologies in the field has created an abundance of new, state-of-the-art literature related to all aspects of this expanding discipline. This body of work allows researchers to learn about the fundamental theories, latest discoveries, and forthcoming trends in the field of medical informatics.

Constant technological and theoretical innovation challenges researchers to remain informed of and continue to develop and deliver methodologies and techniques utilizing the discipline's latest advancements. In order to provide the most comprehensive, in-depth, and current coverage of all related topics and their applications, as well as to offer a single reference source on all conceptual, methodological, technical, and managerial issues in medical informatics, Information Science Reference is pleased to offer a four-volume reference collection on this rapidly growing discipline. This collection aims to empower researchers, practitioners, and students by facilitating their comprehensive understanding of the most critical areas within this field of study.

This collection, entitled **Medical Informatics: Concepts, Methodologies, Tools, and Applications**, is organized into eight distinct sections which are as follows: 1) Fundamental Concepts and Theories, 2) Development and Design Methodologies, 3) Tools and Technologies, 4) Utilization and Application, 5) Organizational and Social Implications, 6) Managerial Impact, 7) Critical Issues, and 8) Emerging Trends. The following paragraphs provide a summary of what is covered in each section of this multi-volume reference collection.

Section I, **Fundamental Concepts and Theories**, serves as a foundation for this exhaustive reference tool by addressing crucial theories essential to understanding medical informatics. Opening this elemental section is "Evaluation of Health Information Systems: Challenges and Approaches" by Elske Ammenwerth, Stefan Gräber, Thomas Bürkle, and Carola Iller. This selection addresses some of the primary issues and challenges in evaluating the use of IT in healthcare and suggests methods for improvement. Specific issues in medical informatics, such as the emergence of the Internet as a healthcare tool and knowledge management as it pertains to the healthcare industry, are discussed in selections such as "The Telehealth Divide" by Mary Schmeida and Ramona McNeal and "Knowledge Management in Healthcare" by Sushil K. Sharma, Nilmini Wickramasinghe, and Jatinder N.D. Gupta. Within the contribution "Information Technology (IT) and the Healthcare Industry: A SWOT Analysis," authors Marilyn M. Helms, Rita Moore, and Mohammad Ahmadi utilize the SWOT analysis (strengths, weaknesses, opportunities and threats) to conceptualize and further evaluate the many issues facing IT implementation in healthcare, which include improved patient safety, cost, and user resistance. The selections within this comprehensive, foundational section allow readers to learn from expert research on the elemental theories underscoring medical informatics.

Section II, **Development and Design Methodologies**, contains in-depth coverage of conceptual architectures and frameworks, providing the reader with a comprehensive understanding of emerging theoretical and conceptual developments within the development and utilization of medical technologies. "The Development of a Health Data Quality Programme" by Karolyn Kerr and Tony Norris presents the case of the New Zealand Ministry of Health's construction of a new data quality strategy aligned with the current health information program. Other selections, such as "Building Better E-Health Through a Personal Health Informatics Pedagogy" by E. Vance Wilson and "The PsyGrid Experience: Using Web Services in the Study of Schizophrenia" by John Ainsworth and Robert Harper, offer insight into the design and use of Web services to guide and inform medical decisions. The design and implementation of mobile-based health services is explored at length in selections such as "Enabling Conceptual Framework for Mobile-Based Application in Healthcare" by Matthew W. Guah; "Design of an Enhanced 3G-Based Mobile Healthcare System" by José Ruiz Mas, Eduardo Antonio Viruete Navarro, Carolina Hernández Ramos, Álvaro Alesanco Iglesias, Julián Fernández Navajas, Antonio Valdovinos Bardají, Robert S. H. Istepanian, and José García Moros; and "The M-Health Reference Model: An Organizing Framework for Conceptualizing Mobile Health Systems" by Phillip Olla and Joseph Tan. From basic designs to abstract development, chapters such as "A Cross-Cultural Framework for Evolution" by Pekka Turunenand and "A Distributed Patient Identification Protocol Based on Control Numbers with Semantic Annotation" by Marco Eichelberg, Thomas Aden, and Wilfried Thoben serve to expand the reaches of development and design methodologies within the field of medical informatics.

Section III, **Tools and Technologies**, presents extensive coverage of various tools and technologies and their use in creating and expanding the reaches of health and biomedicine. The emergence of wireless and mobile devices and the opportunities these devices present for revolutionizing traditional patient care is the subject of articles such as "PDA Usability for Telemedicine Support" by Shirley Ann Becker; "A Preliminary Study toward Wireless Integration of Patient Information System" by Abdul-Rahman Al-Ali, Tarik Ozkul, and Taha Landolsi; and "Choosing Technologies for Handheld and Ubiquitous Decision Support" by Darren Woollatt, Paul Koop, Sara Jones, and Jim Warren. Advancements in imaging for medical and biomedical applications are analyzed and assessed in several selections, which include "Imaging the Human Brain with Magnetoencephalography" by Dimitrios Pantazis and Richard M. Leahy and "Imaging Technologies and their Applications in Biomedicine and Bioengineering" by Nikolaos Giannakakis and Efstratios Poravas. The latter of these two chapters discusses biomedical imaging technologies such as MRI and x-ray, offering insight into the research opportunities these technologies have provided as well as the limitations associated with their use. The rigorously researched chapters contained within this section offer readers countless examples of modern tools and technologies that emerge from or can be applied to the medical and healthcare sectors.

Section IV, **Utilization and Application**, investigates the use and implementation of medical technologies and informatics in a variety of contexts. This collection of innovative research begins with "Successful Health Information System Implementation" by Kristiina Häyrinen and Kaija Saranto in which primary success factors for employing health systems, such as system qualities, information quality, usage, user satisfaction, and individual impact, are analyzed. The delivery of health information via telecommunications networks (also known as telehealth) is studied in selections such as "Telehealth Organizational Implementation Guideline Issues: A Canadian Perspective" by researchers Maryann Yeo and Penny A. Jennett and "Tele-Medicine: Building Knowledge-Base Tele-Health Capability in New Zealand" by Nabeel A. Y. Al-Qirim. Further contributions explore other key strategies and factors that relate to the successful use of electronic health records, mobile e-health, ICT, and knowledge management in a medical environment. From established applications to forthcoming innovations, contributions in this section provide excellent coverage of today's global community and demonstrate how medical informatics impacts the social, economic, and political fabric of our present-day global village.

Section V, **Organizational and Social Implications**, includes a wide range of research pertaining to the organizational and cultural implications of medical informatics. "Using Hospital Web Sites to Enhance Communication" by Sherrie D. Cannoy and Lakshmi Iyer investigates patient communication-enhancing features of hospital Web sites, ultimately contending that a hospital's Web presence must both address and cater to users' communication needs in order to be effective. Web portals and their use in fostering social interaction and knowledge enhancement are explored at length in chapters such as "Intelligent Portals for Supporting Medical Information Needs" by Jane Moon and Frada Burstein, "Health Portals and Menu-Driven Identities" by Lynette Kvasny and Jennifer Warren, and "Empowerment and Health Portals" by Mats Edenius. Other issues that are surveyed within this section include the implications of the digital divide in healthcare within Michele Masucci's "Digital Divide and E-Health Implications for E-Collaboration Research" and community-centered IT outreaches within Rosanna Tarsiero's "Community-Based Information Technology Interventions for Persons with Mental Illness." Overall, the discussions presented in this section offer insight into the integration of medical informatics in society and the benefit these innovations have provided.

SectionVI, **Managerial Impact**, presents contemporary coverage of the managerial applications and implications of medical informatics. Core concepts such as information security management, outsourcing, and healthcare technology management are discussed in this collection. "Information Assurance in E-Healthcare" by Sherrie D. Cannoy and A. F. Salam addresses the healthcare industry's limited adoption of IT advancements, which is now being remedied by new advancements in information assurance that guarantee the safety of patients' medical records. Similarly, within their article "Modelling Context-Aware Security for Electronic Health Records," Pravin Shetty and Seng Loke suggest context-based security policies for health organizations, which are able to adapt to new, incoming threats. Later contributions, such as "E-Health Dot-Coms' Critical Success Factors," further investigate the Internet's role in reshaping healthcare. Within this selection, authors Abrams A. O'Buyonge and Leida Chen evaluate the business models utilized by heath-information Web sites (such as WebMD) and present the lessons learned from a managerial perspective. The comprehensive research in this section offers an overview of the major issues that healthcare practitioners, governments, and even consumers must address in order to remain informed about the latest managerial changes in the field of medical informatics.

Section VII, **Critical Issues**, presents readers with an in-depth analysis of the more theoretical and conceptual issues within this growing field of study by addressing topics such as the quality and security of medical information. Specifically, these topics are discussed in selections such as "Medical Ethical and Policy Issues Arising from RIA" by Jimmie L. Joseph and David P. Cook and "E-Health Security and Privacy" by Yingge Wang, Qiang Cheng, and Jie Cheng. The latter of these two selections investigates relevant concepts, technologies, limitations, challenges, and trends in e-health security and privacy, along with standards such as the Health Insurance Portability and Accountability Act (HIPAA). Similarly, in contributions such as "Reliability and Evaluation of Health Information Online" by Elmer V. Bernstam and Funda Meric-Bernstam, the issue of how to effectively evaluate online health information is debated and a how-to guide for obtaining medical information online is suggested. Later selections, which include "Ontology-Based Spelling Correction for Searching Medical Information," review more novel issues, such as the difficulty in retrieving medical information online due to errors in spelling medical terms. In this chapter, researchers Jane Moon and Frada Burstein from Monash University propose an ontology-based architecture that would assist users with medical information retrieval. In all, the theoretical and abstract issues presented and analyzed within this collection form the backbone of revolutionary research in and evaluation of medical informatics.

The concluding section of this authoritative reference tool, **Emerging Trends**, highlights research potential within the field of medical informatics while exploring uncharted areas of study for the advancement of the discipline. The development and deployment of new forms of health information technologies (HITs) are proposed in Avnish Rastogi, Tugrul Daim, and Joseph Tan's "Charting Health Information Technology Futures for Healthcare Services Organizations," while the latest innovations in e-heath systems are analyzed in Pirkko Nykänen's "E-Health Systems: Their Use and Visions for the Future." In the contribution "Outsourcing of Medical Surgery and the Evolution of Medical Telesurgery," Shawna Sando asserts that, due to the rising cost of healthcare in the United States, the best alternative for some low- and middle-class citizens is to seek medical care overseas—to engage in "medical tourism." Other new trends, such as the emergence of evidence-based medicine, the creation of biotechnology portals in medicine, and revolutions in emergency medical services, are discussed in this collection. This final section demonstrates that medical informatics, with its propensity for constant change and evolution, will continue to both shape and define the modern face of healthcare and the ways in which we interact with health-related information.

Although the contents of this multi-volume book are organized within the preceding eight sections which offer a progression of coverage of important concepts, methodologies, technologies, applications, social issues, and emerging trends, the reader can also identify specific contents by utilizing the extensive indexing system listed at the end of each volume. Furthermore, to ensure that the scholar, researcher, and educator have access to the entire contents of this multi-volume set, as well as additional coverage that could not be included in the print version of this publication, the publisher will provide unlimited, multi-user electronic access to the online aggregated database of this collection for the life of the edition free of charge when a library purchases a print copy. In addition to providing content not included within the print version, this aggregated database is also continually updated to ensure that the most current research is available to those interested in medical informatics.

As medical technologies and the methods for evaluating medical data continue to evolve and new ways to store, process and access information are discovered, medical informatics will become an increasingly critical field of study. The nature of personal heath records, diagnosis, and even treatment have changed drastically due to the efforts of researchers, practitioners, and patients to make medical information more easily available, more secure, and of a higher quality than ever before. Innovations in the effective storage, retrieval, and understanding of medical information capitalize on the constant technological changes that seek to streamline and improve modern society.

The diverse and comprehensive coverage of medical informatics in this four-volume, authoritative publication will contribute to a better understanding of all topics, research, and discoveries in this developing, significant field of study. Furthermore, the contributions included in this multi-volume collection series will be instrumental in the expansion of the body of knowledge in this enormous field, resulting in a greater understanding of the fundamentals while also fueling the research initiatives in emerging fields. We at Information Science Reference, along with the editor of this collection, hope that this multi-volume collection will become instrumental in the expansion of the discipline and will promote the continued growth of medical informatics.

Medical Informatics (MI): Major Concepts, Methodologies, Tools & Applications

Joseph Tan
Wayne State University, USA

INTRODUCTION

Medical informatics (MI) is an inherently complex subject. The widening scope of its knowledge may be traced to the cross-disciplinary interactions of specialized knowledge domains – in particular, those of information sciences, computer sciences, and clinical sciences.

Over the last several decades, the field and sub-fields of MI – with its focus on clinical-based data and processes, and that of the even broader health informatics (HI) area (which embraces both clinical-based and health services administrative domain datasets and processes) – have now matured with the aim of achieving notable goals by transforming both complex organizational knowledge-based services as well as data-intensive, information-laden processes. These goals include improving physician-patient communications and relationships, promoting a higher quality of life, and achieving a more efficient and effective healthcare services delivery system.

With the first record of medical information came the germination of the MI concept. Its rapid diffusion is evidenced by the support it receives from an eclectic well of traditionally established medical practices, an increasing range of applied health data methodologies, and more efficient and effective clinical research tools and applications. Dissatisfied with the insufficient ways in which early forms of medical data were largely acquired and interpreted, academics and learned practitioners from diverse clinical and informatics disciplines have spurred the development of MI through their contributions.

Today, characteristic of its expanding scope, MI has branched into administrative health informatics, bioinformatics, clinical informatics, consumer health informatics, dental informatics, health management and services informatics, health sciences informatics, telematics, nursing informatics, pharmacy informatics, public health informatics, and veterinary informatics. A variety of names for MI have also arisen, including, but not limited to, computer-based medical information systems (MIS), methods of information in medicine, medical computer science, medical information processing, medical decisional models, medical computer technology, among other, closely related medical information systems/information technology (IS/IT) terminologies.

MI Definitions & Evolving Perspectives

Every MI student should be cognizant of MI's roots and the many attempts, over the years, to differentiate among the diverse perspectives of its developing sub-fields. Accordingly, a survey on early efforts to define the MI field and sub-fields can be extracted from the extant literature including archived, existing, and more recent MI-related journals such as *Angewandte Informatik, BMC Medical Informatics & Decision Making*, *Computer Programs in Biomedicine, Computers and Biomedical Research, International Journal of Bio-Medical Computing, International Journal of Electronic Healthcare, International Journal of Healthcare Information Systems & Informatics, International Journal of Medical Informatics*, *Canadian Medical Informatics, Journal of the American Medical Informatics Association*, *Journal of the American Society for Information Science, Journal of Clinical Computing, Journal of Healthcare Information Management, Journal of Medical Systems, Medical & Biological Engineering & Computing, Medical Decision Making, and Methods of Information in Medicine*. Owing to space limitation, the readers are asked to seek out further readings, as provided in the citations and other parts of this 4-volume work.

Primarily among countries influenced by Western Culture and Civilization, the conceptualization of MI began with a series of academic debates and educational efforts. These debates and efforts sought to provide substantive arguments for the preference of one school of thought over another, so that clinical students might be better educated, and to allow for the many aspects and identities of this germinating field to be differentiated. Indeed, the key definitions of MI found over the decades have provided us with a rich understanding of its different roots and perspectives. Among the earliest definitions, for instance, Collen (1977) conceived MI broadly as the computerization of medicine, including medical services, education, and research. Years later, van Bemmel (1984) defined MI on the basis of the knowledge and experience gained from processing and communicating medical and health care information via a paired theoretical-practical lens on the medical process. The Blois-Shortliffe (1990) description of MI largely evolved the *central hypothesis*, which is presented separately in this overview. Their biomedical perspective rendered MI operational by relating it to the storage, retrieval, and optimal use of clinical data, information, and knowledge for diagnostic, therapeutic, and prognostic problem solving. Stead, in 1998, referred to MI as a "science" on the nature, structure, collection, and use of health information. Most recently, Hersh (2002) defined the MI field as an integrative discipline that interweaves the applications of computational, cognitive, informational, organizational, and other sciences on the processes and use of clinical and biomedical information.

Put together, a cohesive definition of MI for the purpose of this work may be conceived as a *complex science that integrates relevant theories, design methodologies, and knowledge of best practices drawn from various cognitive, computational, informational, organizational, and other expert knowledge domains when applied synergistically to collecting, storing, organizing, manipulating, using, and disseminating clinical-based and health-related information.* Over the last two decades, we have seen the evolution of MI to a broadening diversification of sub-fields and major themes. Some of these sub-disciplines include, for example, health management information systems (HMIS) and/or health information management (HIM), health care information systems (HCIS) and/or health care information technology (HCIT), health decision support systems (HDSS) and/or clinical decision support systems (CDSS), telehealth and/or telemedicine, consumer health informatics, e-health, patient-centered e-health (PCEH), and m-health.

For the convenience of the readers, Table 1 provides a list of the acronyms mentioned in this review with its associated terminology listed for easy reference.

Table 1. Acronyms for MI Readers (©J. Tan, 2008. Used with permission)

Acronym	Associated Term
AHIMA	The American Health Information Management Association
AI	Artificial Intelligence
ATA	American Telemedicine Association
CCHIT	Certification Commission for Healthcare Information Technology
CDSS	Clinical Decision Support Systems
Cio/cto	Chief Information Officer/Chief Technology Officer
COSTAR	Computer Stored Ambulatory Record System
CPR	Computerized Patient Records
CSFs	Critical Success Factors
CTA	Cognitive Task Analysis
DEA	Data Envelopment Analysis
EBM	Evidence-Based Medicine
E-DSS	Expert Diagnostic Support System
EHRs	Electronic Health Records
EKG or ECG	Electrocardiography
ES	Expert Systems
GIS	Geographical Information Systems
GST	General Systems Theory
HCIS/HCIT	Health Care Information Systems/Health Care Information Technology
HCTM	Health Care Technology Management
HDSS	Health Decision Support Systems
HELP	Health Evaluation (through) Logical Processing
HHS	Health and Human Services
HI	Health Informatics
HIM	Health Information Management
HIMSS	Health Information Management & Systems Society
HIPAA	Health Insurance Portability and Accountability Act
HIS	Hospital Information Systems
HMIS	Health Management Information Systems
HMOs	Health Maintenance Organizations
ICT	Information & Communications Technology
IS/IT	Information Systems/Information Technology
JCAHO	Joint Commission on Accreditation of Healthcare Organizations
M-Health	Mobile Health
MI	Medical Informatics
MIS	Medical Information Systems
MS	Multiple Sclerosis
MUMPS	Massachusetts General Hospital Utility Multi-Programming System
NNs	Neural Networks

Table 1. continued

Acronym	Associated Term
ONCHIT	The Office of the National Coordinator for Health Information Technology
OOAD	Object-Oriented Analysis and Design
OSS	Open Source Software
PCEH	Patient-Centered E-Health
POMR/PROMIS	Problem-Oriented Medical Record/ Problem-Oriented Medical Information Systems
RMRS	Regenstrief Medical Record System
SA/SD	Systems Analysis/Systems Design
SDLC	Systems Development Life Cycle
SNOMED	Systematized Nomenclature of Medicine
SSM	Soft System Methodology
TMR	The Medical Record
TPR	True-Positive Rate
TNR	True-Negative Rate
u-health	Ubiquitous Healthcare
v-health	Virtual Healthcare
VR	Virtual Reality
VPR	Virtual Patient Records

MI History

Notwithstanding, "informatics" as a revolution in scientific methodologies may be traced to the 1946 invention of ENIAC, the first truly "electronic" computer used for high-speed mathematical tabulations during WWII. What followed evolved into the era of mainframes, where only the very large and well-funded hospitals of developed countries such as the United Kingdom, France, Sweden, Italy, Japan, Germany, Canada, and the US could afford to house/use these first-generation, large-scale computers that tended to fill entire floors. Processing computerized health data on a massive scale dictated that the dawn of MI thinking be characterized by the use of apparently sophisticated mechanisms, which could only be manned by highly-paid scientists and skilled professionals. During those early years, a key challenge was that of developing reliable and dependable health information and recording systems for hospitals supporting patient care and laboratory services. Eventually, specialized computer languages such as Medlars, Medline, SNOMED (Systematized Nomenclature of Medicine), and MUMPS (Massachusetts General Hospital Utility Multi-Programming System) were developed. These eventually led to the successful design and implementation of major computerized health record systems and databases, such as COSTAR (Computer Stored Ambulatory Record System), RMRS (the Regenstrief Medical Record System), TMR (The Medical Record), HELP (Health Evaluation through Logical Processing) system, and POMR/PROMIS (the Problem-Oriented Medical Record/Information Systems). Historical developments of these various systems play a paramount role in both the broader MI and the more specific hospital information systems (HIS) movements.

Indeed, functional hospital information systems soon became a reality when a growing group of hospitals across the US (including Akron Children's, Baptist, Charlotte Memorial, Desconess, El Camino, Henry Ford, Latter Day Saints, Mary's Help, Monmouth Medical Center, St. Francis, Washington Veteran's Administration, and others) as well as Europe (including Sweden's Danderyd Hospital and Karolinska Hospital, England's London Hospital and Kings Hospital, and Germany's Hanover Hospital) collaborated to advance the development of a prototype for efficient and effective management of health records. Despite the risk of major failures, these "pioneering" hospitals invested large sums of money, time, and effort to accomplish the mission of hospital computerization. With the surging interest expressed by these hospitals, and the potential market opportunities that arose from this movement, large computer vendors such as Burroughs, Control Data, Honeywell, IBM, and NCR began providing generous support for this development. Lockheed Information Systems Division, McDonnell-Douglas, General Electric, Technicon Corporation, and several other companies experienced in applying computers to the management of complex systems also joined in the effort. Ultimately, the Technicon system, which was initiated by Lockheed for the El Camino Hospital in Mountain View, California, and later bought over and improved by the Technicon Corporation under the leadership of Edwin Whitehead, became the "successful" prototype that laid the foundation for the majority of functional hospital information systems we know today – systems that gradually diffused throughout North America and Europe. The major lesson in the El Camino project was the significance of paying attention to users' information needs and of effecting a change in users' attitudes, especially if there is major resistance from key stakeholder user groups, such as physicians and nurses.

As evidence of continuing gains in productivity and efficiency were traced back to computerization, the early and mid-70's saw a growing diffusion of large-scale data-processing applications in medicine and health record systems among major teaching hospitals. As noted, COSTAR, RMRS, TMR, and POMR were among these early and successful prototypes. COSTAR, a patient record system developed at the Massachusetts General Hospital by Octo Barnett, was later extended to record patient data on different types of ailments, such as multiple sclerosis (MS-COSTAR). RMRS is a summary-type patient record system implemented in 1972, and TMR is an evolving medical record system developed in the mid 1970s at the Duke University Medical Center. POMR, developed by Lawrence Weed in the 1970s, is an important health record methodology offering a logical and group-based approach to medical problem solving. All participating members of the patient's healthcare team can easily follow through on the prescribed treatment protocol by linking the problem list (serving as the record's table of contents) in POMR to its database (comprising the history, physical examination, and initial laboratory findings), the initial plan (including tests, procedures, and other treatments), and the documented progress notes.

When minicomputers and microcomputers were introduced into medicine during the late 1970s and early 1980s, physicians and clinical practitioners quickly realized the speed and astounding harnessing power with which computers could process large and massive volumes of medical and other health-related data. This would improve not only clinical decisional efficiencies, but also its effectiveness. During this time, increasing interest in the application of artificial intelligence (AI) to medicine and health decision support systems (HDSS) soon created an explosive growth in the MI field. At the same time, major progress in MI was achieved by various attempts among clinicians to use medical computation for dentistry, radiology, pharmacy, nursing, as well as the incorporation of rule-based and frame-based algorithms into expert systems for the purpose of training resident physicians or less-than-expert clinicians. Notably, MYCIN and INTERNIST-1 are among the most popularly cited and well-documented clinical expert systems (Shortliffe et al. 2001). Altogether, the MI movement contributed heavily to the use of these automated record systems, as well as their applications of expert systems for training physician specialists and guiding decisions of less-than-experts. Eventually, it was only a matter of time before a considerable need for the diffusion of MI concepts into all the different sub-specialty medical areas would arise.

In summary, the MI discipline has continued to expand, with immense diversification and integration of concepts found in the medical sub-fields linking healthcare information management, medicine, computer technology, and information science. In the early years, established areas of MI concerned general medical informatics, clinical medicine decision making, biomedical computing, computing in biomedical engineering, nursing informatics, pharmacy informatics, dentistry informatics, hospital information systems, and education. Today, the extension of the MI concept is recognized by every discipline under the umbrella of health sciences that relates to linking rapidly advancing technologies to health and patient care services delivery.

At this point, it is important for the readers to glance briefly through the remaining sections of this overview chapter. Section II focuses on basic MI concepts, theories, and its central hypothesis. Section III highlights MI development and design methodologies. Section IV concentrates on MI tools and applications. Section V surveys MI major themes, utilization and applications, while Section VI shifts focus to MI organizational and social impacts. Section VII reviews key implementation issues and managerial impact of MI. Section VIII discusses critical issues, and Section IX highlights MI emerging trends. Section X concludes the entire exposition with a concentration on how the different underlying issues, themes, and emerging trends may be joined together to achieve effective medical informatics services, education, and research in the coming years.

BASIC CONCEPTS, THEORIES & CENTRAL HYPOTHESIS

Informatics basically refers to advances in the information sciences, a discipline which has accumulated an impressive array of methods for data, information, and knowledge processing. Informatics, when applied to medicine, combines human and computer elements to generate timely and relevant patient data, organized medical information, and accumulated knowledge, which, together, aids clinicians in retrieving, storing, analyzing, disseminating, and sharing diagnostic, therapeutic and prognostic decisions, treatment planning, and evaluation processes. Other commonly encountered MI terms include health informatics, clinical informatics, health information systems, health information technology, health information management, medical information science, as well as medical (health) informatics and telematics.

Health Data, Clinical Information & Medical Knowledge

In MI conceptualization, health data are subtly differentiated from clinical information and medical knowledge. Whereas the former emphasizes some form of source-gathered raw fact, such as recording a patient's medical history before generating any meaningful information processing, the latter terms entail converting data into organized clinical information-knowledge. Hence, the significance lies in the application of readily available methods or tools to produce accessible, appropriate, accurate, and aggregated information-knowledge from sourced data. At the level of converting information into knowledge, the same rules apply. With more complex methods or cognitive-based techniques, "wisdom," "rules of thumb," "probabilities," and other "likely associations" – all of which aid pattern recognition and future health-related decision situations, under increasingly complex or uncertain situations – are produced from seemingly unrelated information. Medical knowledge, in this sense, refers to the cumulative experience of applying useful clinical information management techniques to yield timely and significant decisions.

In essence, health data are specific facts and parameters. A good piece of datum is characterized by its accuracy, completeness, relevance, reliability, security, and timeliness. Accuracy is achieved when health data recorded are true, precise, and valid about the status of a patient's condition; for example, a temperature of 102°F recorded as 101°F is approximate but, nevertheless, inaccurate. Completeness dictates that all required health data should (and must) be recorded; for example, a unique identifier must exist in the patient master index (PMI) for each patient recorded in a database in order to differentiate among individual patients. Relevance ensures that appropriate and necessary data is made available to authorized clinical staff whenever and wherever necessary; for example, cardiologists should be able to view their patients' electrocardiography (EKG or ECG) reports in order to monitor the progress of their patients' heart conditions. Reliability requires that health data recorded are trustworthy and consistent; for example, if the allergy list of a patient exists in a hospital food services system, the same list should also be accessible from, and appear in, its pharmacy system. To ensure that patient data confidentiality is not compromised, and to safeguard against potential data misuse, security and privacy regulations stipulate that only designated persons with valid access rights can view or make authorized changes to recorded data. Last, but not least, timeliness ensures that the available health data are current and accessible for the decisions and tasks at hand, especially when they are of a crucial nature, such as in life and death situations.

Clinical data are unique and somewhat different from the financial and accounting data that are captured in routine business transactions. Clinical data are typically obtained in many different forms, so that the episodes and/or trajectory of care a patient encounters may be generated on a longitudinal basis. Even so, data about a patient may be entered by different clinicians, in different departments, and at different times to show the progress of the patient's wellness recovery: for example, a nurse may jot down the demographics, weight, temperature, and blood pressure measurements of a patient arriving at the clinic; then, through lengthy progress notes, the physician and/or other specialists would record their observations about and diagnosis of the patient's symptoms and complaints. While some of these data are textual in nature, quantitative analysis, in many instances, can also be made by comparing certain measurements taken of the patient to those from a relevant cohort of patients. Moreover, the physician and/or specialists may send the patient for further laboratory tests and other diagnostic scans, which will offer additional measures or markers. Subsequently, these data can be fitted with various biostatistical and/or complex computational models, tabulated and/or presented graphically to check for familiar patterns, and further digitized for convenient sharing among other clinical experts for the purpose of second opinions or referral interpretations. Indeed, it is the accumulated knowledge, embedded in the different biostatistical and mathematical models, that these expert medical consultants rely upon for accurate pattern matching when performing further diagnostic, therapeutic, and prognostic decisions about the patient. Thus, all the while, from admitting to discharging a patient, this cycle of data-information-knowledge processing is repeated continuously to enhance the art and science of MI.

In practice, every clinician is also a health informatician. MI starts with the collection of meaningful, accurate, relevant, complete, and usable datasets. While health databases must be properly organized and rendered accessible and available to health informaticians in a timely fashion, it is also critical to consider and understand, prior to the data gathering process, the requirements that these databases pose. Otherwise, managing and maintaining inappropriate or unnecessary data, especially in large medical databases, may wastefully drain away valuable and critical organizational resources.

Users of medical and health-related data range from patients to care providers, government agencies, health care planners, judicial agents, educators, researchers, and third-party payers. Different types of users may also require different scopes, formats, and presentations of data. To achieve best practices in MI, a full comprehension of the central hypothesis underlying the MI philosophy is critical. However, before discussing this core informatics ideology, we will first survey some of the key MI theories.

For years, MI researchers and academics from across the globe have attempted to etch an identity for the MI field. Yet, the evolution of its many definitions and perspectives, the explosive growth of the field and the continuing diversification of its sub-fields made it a very difficult task to cumulate a tradition for MI theories, methods and practices. Nonetheless, it may still be argued that MI conceptual foundations are rooted in several generally cited theories: the general systems theory, decision analytic theory, various human information processing, problem-solving and cognitive theories, as well as relevant social and organizational theories such as the theory of innovation diffusion, theory on management change, theory of interpersonal behavior and technology acceptance model. Due to space limitation, we will only cover a few of the more popularly cited theories.

GST

General Systems Theory (GST), or "Cybernetics," is a cornerstone of MI development. GST has played a key role in many other contemporary sciences during the emerging information era (Bertalanffy, 1968). The theory begins with the empirical observation that every "system," regardless of its disciplinary domain, shares some common characteristics in its underlying structure such as system synergy and system triad, and exhibits some similar behavioral patterns such as statistical constancy, growth, decay and/or other known (unknown) patterns.

All systems have objects and attributes. Objects constitute the components of a system, whereas attributes are the properties associated with these objects; essentially, an attribute is an abstract descriptor that characterizes and defines the component parts of the system. A person is an object and the attributes may be the person's demographics. A system combines all the objects and their attributes and defines the relationships among these objects, thereby enabling the different parts to add up to some greater whole than all of its individual parts. For example, the emergent property of a university system is more than just its faculty, students, classes and degree programs because of the many interfaces it coordinates among the objects related to the university, the community it serves, and the various donors and funding agencies that support the university's existence.

More generally, a system is a set of interrelated elements. An open system is one that interacts with its environment whereas a closed system does not. The structure of a system may involve a hierarchy of embedded subsystems, each having its own unified purpose that contributes jointly to the functioning of the larger system. The functioning of these subsystems can also vary in complexity. The simplest process involves a triad: an input, a process and an output. More complicated functioning may involve a series of conversion processes, positive and negative feedback mechanisms, and the channels through which the environment can exert its influence. Viewing the health service delivery industry from an open systems perspective will therefore provide valuable insights into the functioning and structure of the contextual system for MI technologies and applications. As such, understanding the application of GST on health services delivery systems can better define the role and function of the MI applications.

In designing an expert system for diagnosing problems of lower back pain (see Lin Lin et al. in Tan, 2005), for example, objects of the system may include the patients, the therapists attending to the patients, and the expert diagnostic system itself. The attributes describing the object "patient" may include the patient's demographics, a brief description of the pain patterns experienced by the patient, the cause of the injuries leading to the pain, the level of pain and an estimated length of time the pain has persisted. Moreover, the treatment plan for the pain to be administered daily may vary depending if the patient is highly motivated to get well, the potential for the patient to move and be tolerant of the pain, the patient-therapist relationship, whether or not there is a job action among the therapists at the time of the treatment administration, or if there has been a sudden snow-storm, making it difficult to transport the patient to the treatment facility. In general, it is expected that those therapists using the expert diagnostic support system will have gained a better judgment over time to guide the patient treatment protocol to reach some level of statistical stability or equilibrium than those not aided by the system, if the expert system is to be considered functioning efficiently and effectively.

A major body of MI knowledge and research is therefore the application of GST in the context of patient treatment planning and the development and use of computerized decision aids to obtain valuable insights into the behavior of complex, real-world systems. As computerized decision models are attempts to imitate systems from a particular viewpoint, and clinicians (or groups of clinicians) who run mostly through rational decision-making mechanisms are sub-systems in the larger context of MI user-computer systems, the close relationship between computerized models and clinicians cannot be overly emphasized. Such computerized aids are primarily supported by the application of decision analytic theory, which is discussed next.

Decision Analytic Theory

Decision analytic theory has also been widely applied in MI to provide logical rationalization on relatively complex judgmental tasks, for example, the application of well-tested decision rules such as Bayesian technique to ease computation and reduce uncertainties about clinical guidance on whether to proceed or not proceed with a certain form of therapy or surgical intervention for a certain patient. Its appeal in MI is, therefore, its ability to provide the clinical decision makers with a model, such as a decision analytic or computerized model, that would yield a more accurate and rational representation of the clinical case reality. In the MI context, the application of decision analytic theory on clinical decision problems has been largely defined by the use of programmable models to reduce complexities, and achieving a decision outcome that lessen its influence from that of mere human emotion and biases.

When incorporating programmable and semi-programmable models for MI applications, a taxonomy of models along a decision complexity continuum, including, but not limited to, decision analysis techniques, mathematical programming, computer simulation models, heuristic programming, and non-quantitative (qualitative data) modeling should be considered. Incidentally, these models are not intended to replace the decision makers, but to serve as aids to the clinicians in rationalizing their decision-making process and justifying their final choices. For example, if a clinician is armed with a set of data that contains information about the probability of the onset of multiple sclerosis (MS) for a particular patient, it may be important for the clinician to consult with a decision aid to guide the prognosis before jumping into conclusion based simply on short-sighted self-evaluation of the complex dataset. Hence, the term "decision support tools" is often used.

Decision analysis is popularly used to aid clinical decisions under uncertainty and risk. Two simple examples are the use of decision tables and decision trees. The computation essentially generates the expected outcome of each alternative among a given set of alternatives on the basis of available (unavailable) information about the environment and converts the information on uncertainty into risk estimates by means of Bayesian technique, Markov chains or other more esoteric mathematical or probabilistic models.

In situations where there can be many more alternatives and it is not possible to generate a manageable set of alternatives, mathematical programming takes the approach that reality can be simplified and represented as a set of mathematical equations or relationships. These relationships represent the constraints and limitations on the number of inputs as well as the relationships between inputs and the outcome variables. The commonly employed linear programming technique used in providing optimal solutions to many well-structured, mostly single goal (criteria) problems is a simple illustration of mathematical programming. Other more sophisticated mathematical programming techniques used to solve complex, semi-structured, multi-criteria problems include non-linear programming, dynamic programming, 0-1 programming, and data envelopment analysis (DEA).

If the complexity of the problem situation increases to the extent that the relationships among the variables cannot be conveniently simplified into a series of mathematical relationships, then computer simulations, certainty factors and stochastic modeling may be used. In "survival analysis" where prognostication is to be predicted by a clinician, for instance, methods such as life tables, Kaplan-Meier analysis, and Cox regression may be used. In a computer simulation, either the real distribution of variables can be used, or a probabilistic distribution may be applied to model the variable distribution to be simulated. In this respect, using simulation to model reality can allow the relationships between variables to be kept either very simple or closer to reality. Moreover, data that have been collected in the past may be used to test and validate the simulation model. When the validity of the simulated model can be demonstrated, further experiments can be constructed to compare various alternatives. These experiments have the advantage that time can be compressed significantly, allowing several months or years to be modeled quickly within a single simulation run that may last only a few minutes. In contrast to mathematical programming, however, only good enough ("satisficing") solutions rather than optimizing solutions can be expected from the use of computer simulation models.

In highly complex situations where the problems are considered somewhat ill-structured and even simulation cannot be applied, heuristics or rules-of-thumbs such as rule-based systems, frame-based systems as well as neural networks (NNs) methodology are often employed by decision makers to aid problem solving. These heuristics may be incorporated into a computer model of the situation; thus, the term, heuristic programming. An example of heuristic programming is the use of expert methods such as neural computing (networks). NNs are experimental computer designs that purport to build intelligent algorithms. NNs operate in a manner modeled after our human brains, in particular our cognitive ability to recognize patterns. Another class of heuristic models is that of genetic algorithms. Genetic algorithms randomly generate initial solutions to specific procedures, which can then be further recombined and mutated at random just as in an evolutionary process to produce offspring solutions that may yield better offspring and parent solutions or new algorithms. For example, a set of generic operators can be used to generate specific procedures for developing routing and scheduling heuristics for solving an ambulance dispatching problem. These generic operators can then be stored for generating new algorithms. In this way, new customers can be added, routes can be merged, and the sequence of customers can be modified using different sets of generic operators. A form of visual interactive modeling can then be used to allow the user to see the results and intervene to change the procedure if the results are not as experienced. Other examples of heuristic programming include the use of fuzzy logic, case-based reasoning and rough-set methods since these techniques often incorporate experts' heuristics in generating problem solutions.

At the farthest end of the decision complexity spectrum lie the non-quantitative (qualitative analysis) models. The field of non-quantitative analysis is very young and there is a need for considerable research to examine the applications of different approaches and use of computerized models for such analysis. The rationale for clinicians to employ MI thinking such as using an ES, AI or even human-controlled robots instead of relying on knowledge and/or experience gained through the traditional case-by-case bedside training is to achieve a high level, combined human-automated intelligent symbiosis in the art of using and interpreting medical evidence.

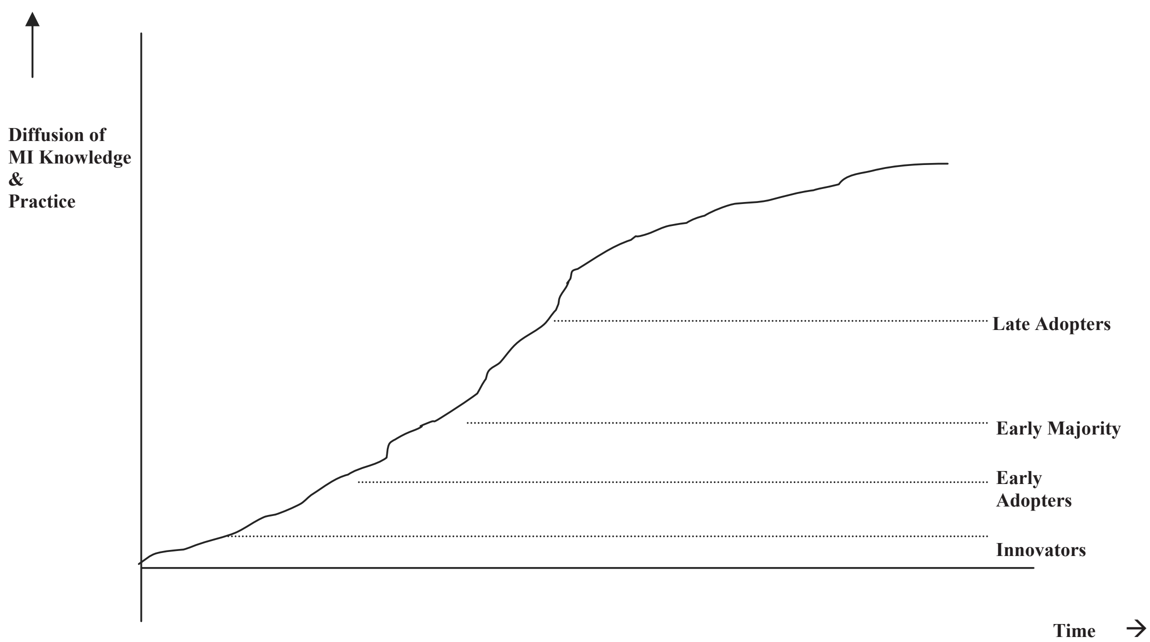
Social & Organizational Theories

As with any emergent discipline, the need for innovation, continuing growth and development encourages MI researchers and practitioners to draw selectively from theories proposed and tested in many related but previously established disciplines. Specific to MI diffusion strategies, the social and organizational theories have provided insightful guidance for MI research and practice.

In the context of the innovation diffusion theory, for example, the rate and patterns of MI growth as a discipline, in and of itself, are expected to follow the well-known S curve of innovation diffusion (Rogers, 1983). The innovation diffusion growth pattern typifies the stages of adoption of knowledge and practice in a new field. For instance, the researchers who adopt a new form of analytic method on the basis of their own recognition and awareness of the desirability of this method as applied to similar problems identified in another more establish field will adopt it before others in the MI research and practice community. The first adopters of the new model are known as the innovators. Others who follow will then become early adopters. They will not have access to all of the information that the innovators have about the new model so that they often tend to regard the innovators as experts and will readily adopt the practices advocated by these experts. An additional link to this chain is classified as the early majority, who are then followed by late adopters.

Figure 1 shows the diffusion pattern of MI knowledge and practice over the last few decades. As shown, we are entering an era between the so-called early majority and the late adopters for the diffusion of MI knowledge and practice. This implies that the continuing growth and diffusion of MI knowledge and practice in the coming years is expected to still be relatively high as more and more scholars from various clinical sub-specialties enter the MI discipline. In other words, it appears timely for us to begin consolidating our past knowledge and experience in the MI field and to identify key gaps for future MI research and practice. The release of this particular work is a testament to the rapid growth and expansion of MI field in recent years.

Figure 1. The diffusion of medical informatics (MI) knowledge and practice (© 2008 J. Tan. Used with permission.)



As well, the diffusion theory further implies that successful MI implementation can be achieved through critical support provided by a champion who could act as the innovator or expert, followed by grass-root user groups such as nurses and physician residents (who are willing to become early adopters) to break down the resistance that may be inherent to medical technological innovation and the additional need for attitudinal and behavioral change towards such an innovation. As a critical mass of user support gathers strength, success is eventually achieved due to the proliferation of early majority and late adopters.

More specifically, there have been recurring themes and increasing interests among both the academic and practitioner communities on the potential impact of effective technology management strategies among healthcare organizations and modeling the technology acceptance process. In their contribution on Health Care Technology Management (HCTM), Eisler, Tan and Sheps (in Tan, 2008) took the perspective of technology as the *extension of human and organizational ability*. Based on the results of their study, they found that the major critical dimensions for successful HCTM include the following: (a) Strategic Management factors; (b) Management of Change and Innovation factors; and (c) Organizational Management factors. Among these factors, the functions of a chief technology officer (CTO) were found to be have the largest differences in reported perception based on implementation ratings and gap scores between high performing and low performing teaching hospitals. This result strongly confirmed the message from the literature about the necessity of executive attention and leadership for HCTM. Besides leadership, coordination, and facilitation, the responsibilities of the CTO include such activities as gatekeeping, advocacy, funding, sponsorship, policy and procedure development, promotion, capacity building, and overseeing the technology management system.

Another set of organizational factors that were shown to be critical for successful HCTM include identifying customer needs and priorities; the organizations having effective strategies to respond flexibly and readily to technological change; and the routine evaluation and benchmarking of organization's performance as a function of technology management activities. In summary, organizational theories indicate that there are key differences in HCTM sophistication among healthcare institutions. Major differences occur in areas of strategic technology management, followed by change management, and to a lesser extent, organizational management.

At this point, we would like to steer the readers to a key conceptualization on MI that brought about the informatics revolution in medicine. We called this, the MI "central hypothesis."

The Central Hypothesis

The informatics revolution in medicine during the 1960s and the 70s brought about a surging interest in MI, especially among biostatisticians, public health advocates and epidemiologists, occupational health and environmental scientists, radiologists, general physicians, dentists, pharmacists, nurses and other health professionals. Essentially, many of these clinicians were questioning the use of medical information/knowledge derived merely from the traditional bedside training paradigm. This eventually led to a movement in support of more intelligent applications of effective computerized decision aids that incorporated complex statistical techniques and probabilistic models for improved medical information analysis. In the 1980s, evidence-based medicine emerged to further guide medical decisions and substantially changed the traditional approach to medical reasoning.

Moreover, one should familiarize oneself with a number of commonly used terms in generating diagnostic, therapeutic and prognostic decisions in MI. For instance, public health informaticians describe the impact of diseases on a specific population using terms such as incidence and prevalence rates. "Incidence rates" refers to new occurrences in terms of the number of people newly infected with the disease, usually over a year whereas "prevalence rates" refers to the proportion of people having already been infected with the disease at a particular point in time relative to the size of the population who have already been exposed to the disease.

When testing a particular patient for a specific disease, the sensitivity-specificity dimension of the test is another pair of closely related terms used in MI. A test is said to be as sensitive as it is able to identify those people who truly have the disease (*true positive rate*) among those who have tested positively while a test is said to be as specific as it is able to rule out those people who truly do not have the disease (*true negative rate*) among those who have tested negatively.

Related key concepts used in determining the health status of a patient in diagnosing for the presence of a disease is the positive vs. negative predictive values as derived from the sensitivity-specificity dimension of the test. On the one hand, positive predictive value uses the underlying concepts of incidence-prevalence rates and sensitivity of the test to help a clinician predicts with some assurance the likelihood of the patient having been infected by a disease. On the other hand, negative predictive value uses the same concepts of incidence-prevalence rates and specificity of the test to help a clinician estimates more confidently the increased likelihood of the patient not having been infected by the disease being tested.

When determining the health status of a person with respect to a certain disease, clinicians must therefore recognize that each medical diagnosis is, after all, only an estimation process. What is important is to determine if more tests are truly needed to increase the likelihood estimates and if particular treatments are to be planned and evaluated. In most instances, the patient is subjected to a range of medical tests with the intent that the clinician will arrive at an increasingly comfortable measure of likelihood that the patient will indeed have (or not have) the disease. This, in turn, ensures that the appropriate planning is adopted based on the best treatment protocols available and that the patient will actually benefit from the treatment regiment, considering the fact that the patient indeed do have the disease. In medicine, both false negatives and false positives are costly, not only to the clinicians but even more so to the patients. This is where MI plays a key role and can have a significant impact.

The central hypothesis of the MI philosophy, thus, is that the entire cycle of medical information gathering, storage, analysis, comparison and estimation from one medical test to another can be better managed through the intelligent application of an "informatics" ideology. If this goal is achieved on an ongoing basis, both the clinician and the patient can ultimately contribute to a higher quality of life and an improved wellness to the society. A deep appreciation of this central hypothesis is critical for those yearning to be next generation medical/health informaticians.

MI DEVELOPMENT & DESIGN METHODOLOGIES

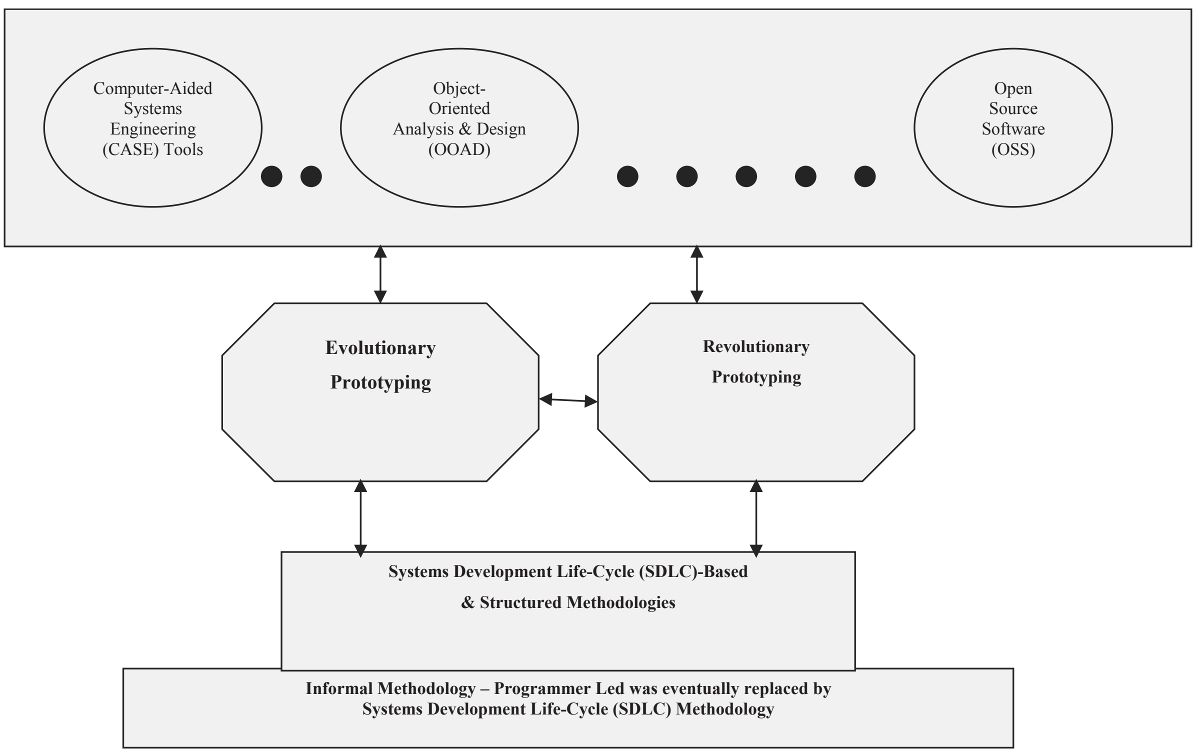
As we have noted previously, a high failure rate of MI deployment has been attributed largely to the lack of attention on the applications of social and organizational theories, in particular, as these theories relate to MI development and design context. It has been estimated that medical systems have an almost fifty percent higher chance of failure than most other information systems deployment due to the specific nature of resistance faced in health care – for example, both physicians and nurses have their own professional cultures and belief systems that may not be aligned with those of managers, systems analysts and informaticians. Hence, new methods for system design and evaluation in this area are badly needed.

Essentially, MI development and design methodologies should bring together the different pieces of the MI puzzle – data, people, hardware and software, network and other resources – towards achieving a vision of an effectively deployed MI systems. Indeed, the challenges of working with physicians who not only have their own professional culture, but may also be considered as much customers as employees of the health care institution in which they practiced is a critical issue for MI technology diffusion. To realize the vision of an accepted MI system throughout the health care institution, the informatics analyst must therefore be able to create a shared vision among key stakeholders with unwavering support from top management. Acceptance of the MI system from key users through active participation in the MI design and development process will be paramount, especially for physician and nurse users.

Once the specification of the system has been fully vetted by the relevant stakeholders, the next step will then be executing a set of related but critical activities including systems analysis, design and evaluation. Systems analysis relates to activities involving the review of current information architecture and the organization needs from the users' perspectives. In contrast, systems design relates to activities involving the specification of new information architecture and systems requirements. Finally, systems evaluation relates to activities involving the continuing testing and endorsing the designed MI system – that the designed MI system is exactly what is needed and will be used once implemented.

The early period of MI development and design has been characterized by the absence of any formalized system development methods. Typically, it was the programmer who bore the major responsibility. Over the years, as user needs became more complex, the need for a formal development process became evident; subsequently, various design methodologies were championed to help minimize the problems of uncoordinated MI development. Each methodology has been based on a philosophical view, which can range from an exclusive focus on the technical aspects to a focus on the user side. Most prominent among the MI development methodologies include the traditional systems development life cycle (SDLC) approach, the structured techniques, prototyping and more contemporary models as shown in Figure 2.

Figure 2. The evolution of medical informatics (MI) design & development methodologies (© 2008 J. Tan. Used with permission)



The SDLC approach involves following a rigid set of procedures beginning with feasibility study. This is followed by systems investigation, analysis, design, and evaluation. The final step entails systems maintenance and review and the entire life cycle is then repeated. While this approach was a significant improvement over the informal leaving-it-to-the-programmer attitude, it nevertheless failed to marshal strong support and acceptance of MI systems among key stakeholders often because of the lack of active user involvement throughout the analysis, design and evaluation phases of the process.

Structured techniques provided an entirely new perspective to systems development with a greater concentration on systems analysis (SA) and systems design (SD) phases – phases where input from end-users are most critical to the eventual success of the implemented system. Use of diagramming techniques, for example, data flow diagrams to depict the data flows between one process and another helps to bring in the views of the users. Other methodology, for example, Structured Systems Analysis and Design Methodology, extends the soft system methodology (SSM) and emphasizes the analysis and design stages of the SDLC model to better capture the views of the end-users.

Nonetheless, both SDLC-based and structured techniques required that users are able to specify in advance the information requirements in the MI system. However, users are often unable to verbalize what they want, and even if they do, their wants may not exactly reflect their real needs. This is evidenced by the many revisions most newly developed MI systems must undergo before these are finally accepted. One philosophical approach that addresses this problem creatively is rapid vs. evolutionary prototyping.

In evolutionary prototyping, the proven “SDLC” and structured methodologies are essentially incorporated into prototyping merely to fine-tune the MI development process, to engage greater user participation, and to enhance user acceptance of the final product. In rapid (revolutionary) prototyping, the designer often uses a creative trial-and-error process to generate an initial prototype quickly. In this instance, fourth generation languages are often applied to produce these rapid initial prototypes. The users as well as programmers are then encouraged to test out, validate and fine-tune these prototypes. Such iterations are then repeated until a final acceptable MI product is achieved.

Today, the evolution of MI design methodologies has moved from the rigid procedural SDLC-based and structured approaches to rapid prototyping to more contemporary models. Prime examples include Computer-Aided Systems (Software) Engineering (CASE) tools, Object-Oriented Analysis and Design (OOAD) and Open Source Software (OSS). CASE tools automate different parts of software or systems development and can assist with any or all aspects of the SA and SD processes. OOAD focuses on the objects that are acted upon in the development process. The methodology is based on the premise that software should be developed out of standard, reusable components wherever possible. Finally, OSS supports the ideology of making certain licensing of the source code for particular working prototypes freely accessible and generally available for other intending users’ adoption and modification within the programming community.

As the number of OSS products in the MI field such as VistA system (a computerized patient records system developed in MUMPS by the US Department of Veteran’s Affairs), OpenEMed (another patient record system), and OSCAR (a family practice office management and medical record system) becomes popularized over time, the OSS model of software development have continued to spread in the MI community. Indeed, recent studies (e.g, Erickson et al. 2005; DeLano, 2005; Scarsbrook, 2007) have shown that the OSS development model can be beneficial in reducing software development costs effectively and allowing for very rapid scientific advancement due to the open sharing of information and software as a way to overcome certain barriers of standardization. A case where OSS adoption is largely responsible for a number of low-cost products implemented successfully throughout the hospital is the Beaumont Hospital in Ireland (Fitzgerald & Kenny, 2004). OSS adoption has also been noted to reduce the need for frequent vendor turnover, lower development costs, and lessen the impact due to the lack of standards affecting electronic patient records in the primary care area (Kantor et al. 2003).

Altogether, the application of social and organizational theories and the adoption of a practical approach to MI design and development that integrates the different user characteristics, technological and organizational components within the larger context of technology change management, evolving user demands and new organizational arrangements will ensure the successful implementation of future increasingly complex MI systems.

MI TOOLS & APPLICATIONS

In this section, our focus on MI tools and applications will encompass the emergence of the evidence-based medicine (EBM) movement in the 1980s, which has significantly changed the way in which medical information is now used in routine healthcare decisions as discussed in Tan (2005), a taxonomy of the decision-aiding strategies or techniques as advocated by Zachary (1986), and the expert knowledge elicitation methods as discussed in Tan with Sheps (1998). Throughout these discussions, the concepts of the electronic medical records (EMR) and the electronic health records (EHR) will be used to illustrate the applicability of these tools.

Evidence-Based Medicine

Evidence-based medicine practice requires the clinician to articulate a clear statement of a patient's medical problem, to screen actively through the extent literature relating to the patient's problem, to evaluate the evidence critically, and from the resulting knowledge, to make the best treatment decisions with regard to the patient's problem.

Markovitz in Tan (2005) described EBM as a five-step process: (1) identify the "clinical question" relevant to the patient by means of asking the following question: "In a given patient population, does a particular intervention, compared to controls or standard therapy, result in an improved outcome?"; (2) use bibliographic databases such as MEDLINE which can be accessed through convenient interfaces like OVID (http://www.ovid.com) and other EBM resources on the Internet to search for problem-related evidence; (3) critically appraise the findings, validity, and applicability of the evidence; (4) incorporate the appraised evidence into the values, preferences and beliefs uphold by the patient; and (5) self-evaluate the process on a continuing basis to further enhance its efficiency and effectiveness. With a wave of advances in biostatistical and clinical research methods, EBM can be achieved typically from sourcing multiple information such as relevant clinical practice guidelines, clinical trials, systematic reviews, and meta-analysis of past studies found in high quality, peer-reviewed journals that focus on the patient's problem.

To illustrate, a trained clinician who is asked to check on the EHR or EMR of a patient (with all the annotated progress notes) should also be expected to be familiar with the terminologies of clinical epidemiology, biostatistics, clinical trial methodology and clinical research designs in order to confidently perform a critical appraisal and rating of the published literature as pertaining to the health status of the examined patient. In many instances, in order to develop acceptable and trusted treatment guidelines for best practices in MI for the patient, the trained physician may consult with a committee of scientists and expert clinicians who may have collectively rated the strength of recommendations for a particular treatment based on the evidence for efficacy or for adverse outcome supporting a recommendation vis-à-vis the quality of evidence supporting the recommendation. The National Guideline Clearinghouse (NGC: http://www.guideline.gov/), sponsored by the US Agency for Healthcare Research and Quality, offers a trusted/authoritative source for such guidelines. In addition, the trained physician may also consult with an increasing number of full-text or summary form guidelines drawn from various professional societies and/or organizations that have used a documented EBM approach have been included and made available through this unique site.

In the realms of medical research, the following is a sampling of key terms that should be clearly understood as these form the building blocks of many research designs and are the basis for a proper evaluation of the MI research literature: informed consent, the internal review board (IRB), debriefing, bench vs. clinical research, prospective vs. retrospective research, control group vs. treatment group, focus groups, blinding vs. double-blinding, randomized control trials, cohort or longitudinal studies vs. case-control studies, attrition, sampling frame, sampling size, power, effect size, statistical vs. clinical significance, qualitative vs. quantitative research, and many other terms (e.g., relative risk, relative risk reduction vs. absolute risk reduction), all of which can be easily found in a standard text on health informatics (see Jordan, 2002) or research methodology (see Kerlinger, 1973;1986). Table 2 provides a glossary of key terms in MI research.

A more detailed explanation of these terms is outside the scope of this review. At this point, we turn to the Zachary (1986) taxonomy of cognitively based decision-aiding strategies.

A Taxonomy of Decision-Aiding Techniques

Several decision-aiding tools and techniques in MI and other healthcare informatics domains have become popular among MI analysts and researchers. A taxonomy of these ranges from information control techniques to process models and/or choice models to representational aids to analysis and reasoning methods to judgment refinement and amplification. Outside of the scope of this discussion would be more complex MI tools and new methodologies such as rough-set analysis, neural networks, and fuzzy-set theory, all of which have been presented in great detail in Tan with Sheps (1998).

Information control techniques involve the storage, retrieval, and organization of data, information and knowledge. Common examples include clinical databases such as an EMR or an EHR or even a comprehensive pharmaceutical database that will permit a physician to look up on comparable prescriptions for use in treating a diagnosed illness. A model-based management system which incorporates the application of a data envelopment analysis (DEA) methodology, for example, to profile the relative efficiency and effectiveness of best practices among a group of selected physicians awaiting the renewal of certain hospital privileges or a knowledge base management system such as an expert system programmed to provide online medical consultation to a physician resident on a specific clinical intervention procedures when faced with a complex MI decision may well be added as enhancement to the basic functioning EMR, EHR or other health database management system.

Process and choice models are computational models that may be applied respectively to help predict the behavior of real-world processes such as through the use of “what-if” capabilities or to solve multi-criteria problems with such techniques as those involving the integration of individual criteria across different aspects and/or alternative choices, for example, the application of multiattribute and multialternative utility models. In other words, these models could be programmed as simply as a single Excel function with “what-if” analysis or could be enriched with a series of increasingly complex computational models. Use of these models can be enriching for physicians who need to make complex decisions beyond just abstracting information from an EMR or EHR.

Representational aids refer to expressions of manipulation of specific representations of decision problems. For example, a visual representational aid could be graphics-based where the clinician reading a set of EMR and EHR progress notes is supplemented with supporting evidence from digital radiological images and reports to help interpret the captured information on the patient wellness recovery. At the

Table 2. Glossary of Key Terms for MI Research Literature (©J. Tan, 2008. Used with permission)

Term	Definition
Attrition	The number of participating subjects dropping out of a study
Bench Research	Laboratory research performed on chemical or biological elements such as cells, genes, and other cultures rather than living human subjects
Blinding	Participants are ignorant of their group treatment assignments during a study
Case-control Studies	The use of naturally occurring vs. control groups to classify study participants
Clinical Research	Research conducted with living human participants
Clinical Significance	The applicability and importance of a study's findings in real-world situations
Cohort Studies	Group (cohort) assignments are not randomized but based on known exposure
Control Group	A group that does not receive the test stimulus but is observed for comparison
Debriefing	A process to correct subjects' wrong/unethical perceptions at end of a study
Double Blinding	Both participants and investigators are ignorant of study group assignments
Effect Size	The degree for which a study variable impacts on the study outcome(s)
Focus Groups	Recruited subjects to draw opinions/observations on various research artifacts
Informed consent	Let subjects know of the study's purpose, risks and credentials of researchers
Internal Review Board (IRB)	An institutional ethics committee to evaluate the potential benefits vis-à-vis the risks of a proposed research
Power Analysis	Method to guide study design/sampling so as to achieve a desired effect size
Prospective Research	A study where subjects' data are followed through "looking forward" in time
Qualitative Research	Research methodology that reflects an objective and positivist legacy
Quantitative Research	Research methodology that reflects a subjective, interpretative approach
Randomized Control Trials (RCT)	Relatively short (prospective) clinical experiments that use randomization as a means of group assignments and controls, requiring lengthy IRB approvals
Retrospective Research	A study where data on subjects are examined by "looking backward" in time
Sampling Frame	The population or list of objects (sampling units such as persons) in a sample
Sampling Size	The number of subjects needed in a study to attain valid scientific evidence
Statistical Significance	Level to which study sample results mimics results expected in a population
Treatment Group	Participants assigned into a group who will be given the intervention studied

community level, a geographical information system (GIS) to depict specific population health hazard distribution or an epidemic among neighboring communities of a county would be a spatial representation of the captured environmental and population health data. Other representational tools could include matrix data and model representational methods.

Analysis and reasoning methods are means of performing problem-specific reasoning on the basis of a representation of a decision problem. For instance, in abstracting information from an EMR or EHR on a patient diagnosed with multiple sclerosis, the clinician may use the symbolic reasoning embedded in an expert system to aid him or her to make a prognosis for this patient. Another example would be the application of mathematical programming techniques for clustering various cases from different cohorts of patients exhibiting similar symptoms and requiring comparable treatments.

Finally, judgment refinement and amplification techniques are formalization and quantification of heuristic judgment processes, for example, bootstrapping and Bayesian theorem application. As discussed throughout Tan with Sheps (1988), medical informaticians have typically employed these analytic tools and techniques as well as automated intelligence applications to enhance decisions rather than simply make a judgment based on EMR or EHR data. Furthermore, these applications can be useful for various clinical areas such as cancer, emergency medicine, utilization review, population health monitoring, and nursing. This brings us to knowledge elicitation methods, a key MI tool and application in building and designing expert systems.

Knowledge Elicitation Methods

Expertise in MI and other healthcare informatics domains (e.g., health information management, nursing informatics, and pharmacy informatics) can generally be grouped along a continuum ranging from laypersons to experts. On the one hand, a layperson may be considered simply as someone who has only common sense or everyday knowledge of the domain. An expert, on the other hand, is someone who has gained specialized knowledge of the domain after many years of training. In between these extremes are beginners (novices), intermediates, and sub-experts. Beginners/novices are those with pre-requisite knowledge assumed by the domain; intermediates are, by default, those whose domain knowledge are just above the beginner level but just below that of the sub-expert level while sub-experts are those with generic but not substantive, in-depth knowledge of the domain. In this section, we discuss approaches to the knowledge extraction problem encountered in designing and developing ES, intelligent DSS and other equally intelligent forms of integrated and emerging MI technologies and applications.

A wide range of techniques has evolved from studies in diverse fields and disciplines (e.g., medical cognition, cognitive psychology, artificial intelligence, organizational science, computer science and linguistic) in terms of eliciting knowledge from humans for the purpose of incorporating such expertise into specialized computer software. Among the more established techniques discussed in the literature are interviews, computer-based interactive techniques, methods involving rating and sorting tasks, protocol analysis, and cognitive task analysis (CTA). Owing to limited space, we will only highlight briefly each of these techniques and their implications for MI development and applications.

Apparently, interviews are direct means of acquiring knowledge from experts; they can be structured or unstructured. In structured interviews, the expert or non-expert may be probed, based on a structured protocol, to describe in sequence how specific cases are normally dealt with when they are performing a certain task, particularly under uncertain or complex situations. In unstructured interviews, the same expert (non-expert) may be asked similar type and related questions in no particular order, depending on answers previously provided. It is also possible for the interviewer to probe for further clarification or to lead the study subject to talk on particular aspects of the problems if the interviewer feels that previous answers provided are inadequate. The disadvantage of using interviews is that it is difficult to expect anyone to be able to articulate precisely the hidden knowledge that is to be extracted because most people will tell us what they think they would be expected to do in performing a certain task then to state what they actually do.

Reading the data abstracted from an EMR or EHR, an expert will anchor on certain important information that a novice may well miss out. Novices also tend to have difficulty differentiating what may be considered the most important pieces of information recorded and this is where eliciting knowledge from a novice vs. an expert in real-world case management helps to generate a high quality consultative expert system such as MYCIN.

Computer-based interactive approaches to knowledge extraction involve having the study subjects use interactive tools or computer programs known as knowledge-based editors to assist them in directly generating computer-assisted knowledge acquisition. OPAL is an example of a graphical knowledge acquisition system for a cancer therapy management program whereas INTERMED is a collaborative project which uses experimental tools for extracting knowledge of medical practice guidelines based on experts' interpretations of written guidelines. Another application of computer-based interactive approach is the use of software designed to analyze case data, thereby automatically inducing the inference rules. In this case, the interactive approach used is essentially an indirect means of knowledge acquisition, that is, a method for which inferences are made about the nature of the expert knowledge from computer analysis of case data. These case data may be abstracted from an EMR or EHR.

Psychological research in judgment and personality studies has contributed to the elicitation of knowledge via use of rating and sorting tasks. Here, the attempt is to create a classification scheme, thereby identifying the domain elements along certain meaningful taxonomies. For instance, experts can be asked to sort concepts printed on cards into meaningful clusters. Similarly, these experts may be asked to rate concepts along a certain continuum or among different categories. As an illustration, experts may be asked to rate different whiplash cases involving rear-ended motor vehicle accidents into "mild", "intermediate" and "severe" categories based on varying reports and injuries. In this way, the hidden knowledge based on the experts' general opinions as well as interpretations of these cases can be elicited. A standardization of these terms to describe the different clusters for which the cases may be discriminated can then be captured into the EMR or EHR for the respective patient.

Protocol analysis or thinking aloud may be considered a critical direct approach for knowledge elicitation. This technique has received considerable attention in cognitive psychology. The question has been whether experts are better able to articulate the knowledge they possess in thinking aloud when asked to solve a problem than less-than-experts and what are the notable differences between the thinking strategies of experts versus less-than-experts with regards to solving the same problem in specialized domains. One application of this method in the field of medical cognition is to record down the interactions of experienced physicians (or residents) with patients in terms of diagnosing the patients' problem. The analysis of these differing interactions would provide researchers with insights into the different thinking strategies of residents versus expert physicians when faced with similar diagnostic problem cases. The intent is to use the extracted knowledge for programming intelligent computer software that can serve as useful decision support tools for training residents in real-world settings. Just as interviews, a major problem with protocol analysis is the ability of the experts (or non-experts) to accurately verbalize what may be hidden in their respective thinking/reasoning processes. In many cases, protocol analysis need not be taken under real-life physician-patient interactions, these could also be generated from expert or less-than-expert abstraction of EMR or EHR data on particular patients.

Finally, CTA extends most, if not all, of the above traditional task analysis approaches to include ways of capturing higher-level cognitive processes in task performance as well as physical behaviors (see Kushniruk and Patel in Tan with Sheps, 1998). CTA refers to a set of methodologies, including the use of structured interviews, video analysis of work situations, and protocol analysis or other approaches, that can be applied separately or jointly to capture the knowledge, skills, and processing strategies of experts versus less-than-experts when given complex tasks to solve. CTA generally involves six steps: (1) identify decision problems to be studied in the analysis; (2) generate decision tasks or cases; (3) obtain a record of expert problem solving for the task(s); (4) obtain a record of the problem solving of novices and intermediates for the same task(s) that was (were) presented to the experts in step 3; (5) analyze the performance of experts versus less-than-experts; and (6) recommend the systems requirements, design specifications, and knowledge base contents for the MI development. After repeated and careful investigations as well as rigorous analyses of the data derived from the application of these several steps can we only expect to gain proper and valuable insights towards achieving the right mix of information-knowledge elements by the less-than-experts needed to support their decision making and complex problem solving. In fact, even experts will find an intelligent ES developed from CTA approach useful as the system can serve as a sounding board to situations involving critical life-death decisions. Again, these complex problem situations can be abstracted as typical EMR or EHR cases.

Our review of MI tools and applications has focused on how experts vs. less-than-experts can be aided in making complex medical decision. With patient data captured in EMR and EHR, it is possible to generate powerful tools by capturing and creating expert systems to aid these decisions in complex situations. This, in turn, leads us to the need for recognizing major themes, utilization and applications of the rapidly expanding MI field, which we will now explore.

MI MAJOR THEMES, UTILIZATION & APPLICATIONS

The increasing complexities of the MI "identity" as a result of its explosive growth in inter-disciplinary and multi-disciplinary directions call for an analysis of its major themes, utilization and applications. Over the years, a number of sub-fields, major themes, utilization and applications within the broader MI movement have emerged.

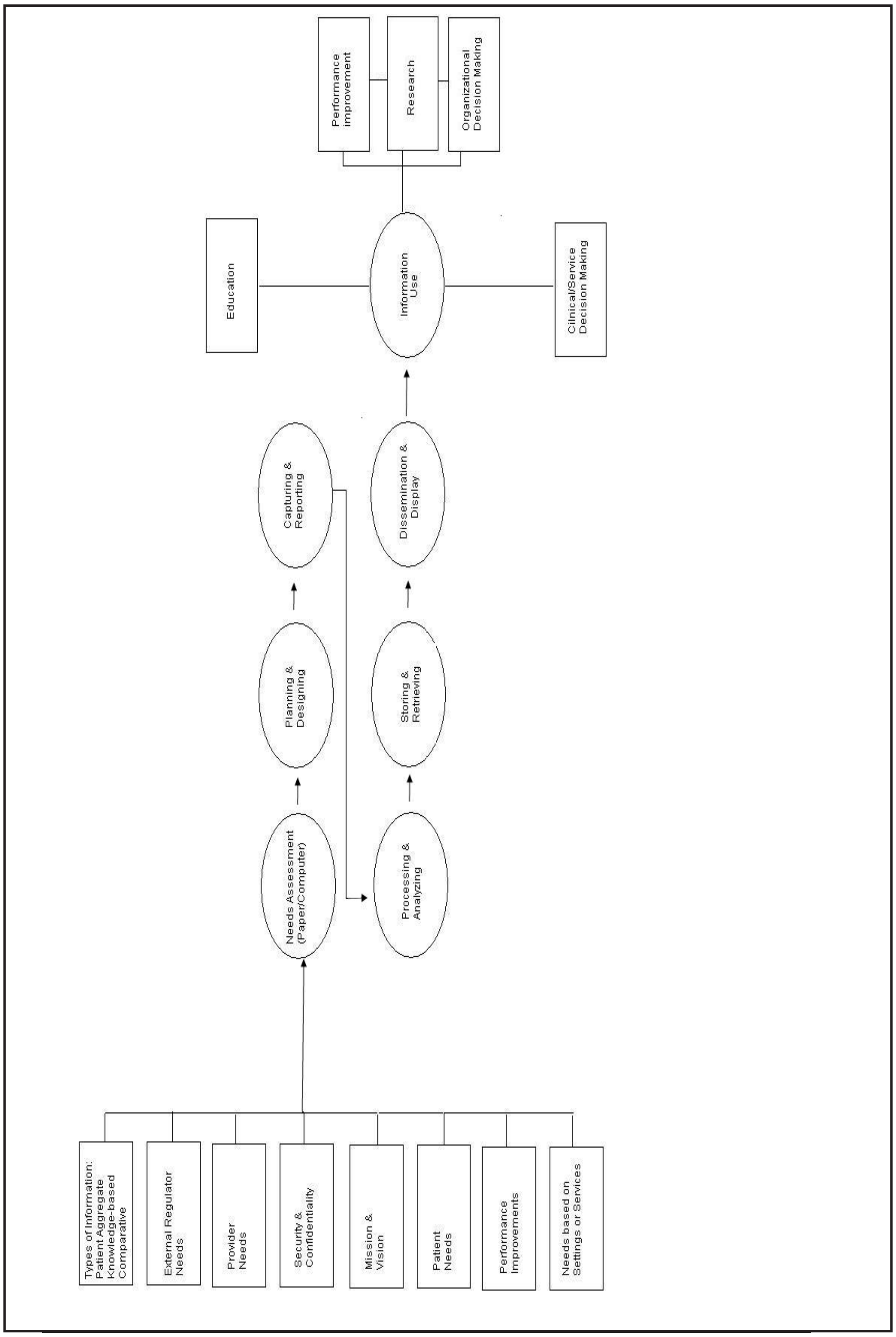
With the limitation on space for this overview, we will briefly cover three key themes encompassing various current utilization and applications that cut popularly across many of the MI sub-fields:

1. Healthcare Information Management (HIM)
2. Health Decision Support Systems (HDSS)
3. Telemedicine

Healthcare Information Management (HIM)

Encompassing a major branch of applied healthcare informatics, HIM professionals are trained to safeguard the accessibility, timeliness, integrity and security of high quality patient records for use by various health professionals. As such, these professionals are expected to be competent in many aspects of applied healthcare informatics, including best practices in health data recording, clinical coding standards and methodologies, Health Insurance Portability and Accountability Act (HIPAA) rules, health laws and regulations pertaining to the preservation of high quality healthcare datasets, healthcare data computing and analytic methods, critical issues on health information systems design and development, and the need to maintain an organizational view of HIM in an evolving and modernized healthcare environment. The American Health Information Management Association (AHIMA) and Health Information Management and Systems Society (HMISS) are the key professional organizations offering certification to HIM professionals and most textbooks written for these certification examinations rely heavily on the 2005 JCAHO (Joint Commission on Accreditation of Healthcare Organizations) model for managing information, as shown in Figure 3.

Figure 3. JCAHO Management of Information Model, 2005 adapted from http://www.jointcommission.org/NR/rdonlyres/656F7F4B-2ECA-4847-8811-B7B54DDA1584/0/LAB2008IMChapter.pdf p.3 of 18



Parallel to the HIS curriculum advocated in Tan (1995; 2001), the JCAHO model depicts a data-information-knowledge processing strategy with collected patient-specific data being aggregated to produce useful and comparable information to accumulate knowledge for supporting the HIM professional activities.

One cornerstone HIM technology that is now being seriously touted to improve patient care delivery is Electronic Health Records (EHRs). Like most HIM applications, EHRs contain both hardware and software components interacting with the human component as a catalyst to bring about customized, efficient and effective sought-after solutions to problem tasks (i.e., generate information-knowledge for patient care decisions) in the different areas of health services delivery. In the US, initial efforts to standardize health information infrastructure were made by ONCHIT, the Office of the National Coordinator for Health Information Technology formed under the US Department of Health and Human Services (HHS) in 2004. Headed by Dr. David Brailer, ONCHIT's mission was to achieve a US-wide adoption and diffusion of interoperable EHRs by 2014. When Dr. Brailer subsequently resigned, the HHS separately funded a nonprofit, private group, the Certification Commission for Healthcare Information Technology (CCHIT), to complete the work on setting standards for EHRs and supporting networks. Vendors meeting these standards were to be certified by CCHIT. By 2006, for example, CCHIT had certified a list of 22 ambulatory EHR products.

Beyond HIM, strong interests in MI among health researchers, educators and practitioners during the late 1980s and early 1990s quickly diversified into areas of expert method applications, clinical decision support systems, nursing decision support systems and other forms of health decision support systems.

Health Decision Support Systems (HDSS)

Researchers have always wanted to add intelligence to computer systems, and its extension to medical IS/IT quickly became noted as a most valuable and noteworthy MI application domain. Intelligent medical IS, it is thought, should be able to mimic the thinking processes of expert clinicians. How such thinking processes may be engineered and expert knowledge programmed into automated systems are issues related to ES development process, an issue we have discussed earlier in the review.

Cognitive scientists believe that the human brain may often be conceived as a "living super-computer." Experiments conducted on the human stimuli-response system inform us of the familiar stories of how human perception, pattern recognition, biases and judgments are formed when exposed to various forms of external stimuli (information) in structured vs. less-than-structured task situations. Findings from many of these studies have stimulated the design of various forms of DSS. Tan (1998) differentiated among data-based DSS, model-based DSS, knowledge-based DSS and graphics-based DSS. The application of a database management approach in which access to various organizational data sources can be achieved via a single, multidimensional data depository is basic to all forms of DSS. A model-based DSS, then, provides the decision maker with the added capability of drawing from a variety of models to fit the problem task situation via the use of a model-base management component. In contrast, the knowledge-based DSS, or more simply, an ES, makes use of embedded rule-based algorithms, frames, neural networks and fuzzy logic to augment human decisions. Finally, the graphics-based DSS, such as a geographical information system (GIS), capitalizes on the power of human visualization through the use of a flexible, graphics-driven interface component. A GIS application in healthcare services may be the digital mapping of a certain epidemic such as the HIV infection among a subpopulation group across various Sub-Sahara African countries to study the spread of the prevailing ailment. This knowledge can then be used to target regional interventions effectively for specific population groups rather than focusing treatments on isolated individuals.

A group HDSS combines analytic modeling, network communications, and decision technology to support group thinking, problem formulation, and goal seeking solutions. It aims essentially at easing the group decision-making processes, and among other things, its use will not only reduce the cognitive burden, but also the mental effort associated with groups of decision makers. A major benefit of group HDSS is its potential for increasing efficiency, effectiveness and productivity of group interactions through the application of asynchronous board meetings, online forums or special group chat facilities. Put together, in conceptualizing and designing any health group/organizational DSS, an important strategy is to achieve a good mix and match of the many different forms of DSS that will best support the combined decision needs of the group or organization.

At this point, we turn to another major theme of MI, telemedicine.

Telemedicine

Telemedicine, telematics or telehealth, according to the American Telemedicine Association (ATA), has a history of moving from the linking of two geographically separate points to achieve a medical service with the potential to administer invasive telesurgical procedures at a distance (first wave), to the use of digital networks to perform virtual consultations, including diagnoses of disease and disorders (second wave), to the empowerment of patients with medical expertise to achieve a higher level of wellness (third wave). In other words, telehealth has continued its mission to expand the boundaries and capabilities of medical services delivery to the underserved populations regardless of their geographical locations as it has the advantage of quickly transferring the medical expertise and capability concentrated in an area to another with low accessibility. The focus of telemedicine has been on medical services, not the changing technologies although changing technologies have accelerated the telehealth movement.

As the cost of such expertise transfer continue to reduce substantially with advancing low-cost telecommunications technology and increased competition, the demands for all forms of telemedical services are growing rapidly and efforts have been underway to seek Federal and third party approval for reimbursing telemedical services. Teleradiology and telephathology are among the first successful applications of telemedicine services as far as gaining third party approval for payment reimbursements. In teleradiology, x-rays or scanned images of patients are digitized and stored electronically for sharing among multiple health providers at geographically distant sites without the need for physician-patient or physician-physician interactions. Like teleradiology, no patient interaction is also needed in telephathology as the phathologists are able to provide diagnosis and consultation remotely via exchange of digitized microscopic or routine surgical images. So far, studies have documented the relative accuracy of telephathological diagnosis, which has spurred its approval for Medicare and Medicaid reimbursements, besides teleradiological services. We expect that with greater interactions among subspecialty consultants and the referring pathologist, telepathology readings would continue to improve.

Teledermatology, teleneurology and telepsychiatry are other examples of telemedicine applications where teleconsultation plays a key and active role. Beyond teleconsultations, more dynamic interactions may also be achieved in telemedicine, for example, telecare as in telehomecare and telenursing healthcare, telelearning as in videoconferencing and online medical education, and telesurgery. Telesurgery is apparently much more interactive in nature. Telegastroscopy, for instance, involves both remote consultations and surgical procedures. Indeed, the rapid development of robotics, sensor networks and sensor-based remote-activated and monitoring devices to support telesurgical and virtual reality (VR) interventions all promise a brighter future for telemedicine.

Next, we shift focus to social and organizational implications on MI diffusion.

MI ORGANIZATIONAL & SOCIAL IMPLICATIONS

A major aspect to successful MI diffusion and implementation has to do with overcoming the barriers that are related to social and organizational factors. In terms of organizational and social implications for MI diffusion, not only is it critical to underscore its impacts on individual users, groups and organizations, but also it is important to relay how the MI technology may ultimately affect the larger context of our health services delivery system and on society.

As we enter the next era of the MI field, knowledge of MI impacts will pave new directions for MI technology development and innovation. Still, impediments on the future growth and development in MI will surface such as the growing complexity of legal and security issues in MI.

Impacts on Individuals, Groups and Organizations

MI impacts significantly on the individual user, especially the clinician with respect to work habits, information processing efficiency and decision-making capability, as well as reliance on automated intelligence; on a group level, it impacts on the quality of teleconsultations among clinical experts, volume of information exchanges and effectiveness of group decisions; and on the organization level, it impacts on the quality of organizational patient care delivery and global competitiveness.

More specifically, at the individual level, it is critical to know if use of MI applications will result in speed, accuracy, greater clinical significance and decision-making effectiveness for the clinical user. For example, it may be argued that physicians who are equipped with a Blackberry or an iPhone that will serve both as a cellular phone with an automated reference drug directory, and a Net appliance with the capability to access a built-in e-prescription system will be able to better perform an intelligent online prescription request order for their patients anytime, anywhere than physicians who do not adopt such a technological innovation. At the group level, MI will impact on the ability of expert consultants to share and exchange data, to coordinate teamwork and progress group diagnostic and therapeutic activities. A virtual patient record (VPR) system for use by multiple care providers, for example, is one that will integrate all of the information provided by the different clinicians regarding the patient at anyone time.

At the organizational level, MI diffusion will impact on changes such as organizational reporting structure, work habits and culture. Not only will MI be expected to improve clinical productivity and enhance intra-organizational communications, but also it will redefine clinician-patient relationship, improve organizational image, alter organizational culture, increase market competitiveness and open up new avenues for new collaborations, organizational arrangements and partnership services. Health organizations will adopt a more sensitive attitude and mindset towards information sharing and an evolving culture with the experience of having gone through a major MI diffusion; for example, an organization may completely change the way it performs patient care because of automated intelligence, online training, telework habits and virtual network capabilities. When MI implementation fails, the resulting consequences can also be devastating for an organization not only in terms of costs but also personnel turnover, changes in technical leadership and reporting structure and the potential for future MI resistance from users.

Impacts on Health Services Delivery System and Society

The same impacts discussed previously may now be extended to the entire health services delivery system as well as society. For example, the use of the Internet to transfer massive amount of media-rich patient data and the availability of knowledge systems such as robots and automated intelligent systems may induce many legal and ethical questions about privacy, security, as well as individual and institutional intellectual property rights issues. One contention, for example, is: Who owns all the different pieces of the stored medical information about a particular patient? Another question may be: What information should (should not) be kept online about an individual and who has the right to alter the information stored on a MI database? In the past, many of these and other similar questions have prevented desired progress in the MI field. With the enactment of HIPAA rules, answers to many of these questions are becoming clearer but not definite until test cases move forward and authoritative court decisions have been pronounced.

Critical societal impacts of MI advances include changes in how work may be performed (e.g., telecommuting, virtual patient visits, self-diagnosis), changes in the availability, accessibility and affordability of medical expertise to the underserved patient population, new opportunities for cyber-crime and new ways of purchasing telehealth services for consumers, new gadgets and automated devices for helping seniors and the disabled, the construction of healthy "smart" houses and new methods in self-care, wellness promotion and lifestyle changes, and in redefining the quality of one's life. Imagine how MI applications can not only improve the efficient and effective functioning of a group of doctors and nurses, but patients who have access to specialized MI equipment and devices may also be aided to perform self-care and reduce the burden on hospital emergency services.

One sensitive question, for example, has to do with the determination of technological resource allocation to decide who among the "surviving" patients should be saved in the aftermath of an epidemic or major health hazards? Take the September 11 scenario and the fact that there just are not enough first responders and facilities around to save all of the victims who were immediately affected. How does society go about deciding where to allocate the limited MI and other resources to achieve the most justifiable results? These and other aspects of social impacts such as digital divide, cost effectiveness and the productivity paradox relating to ethical, security, legal and political concerns still need to be worked out and answers to these questions are never easy. They will be further explored in the section on critical issues.

MI MANAGERIAL IMPACT & KEY IMPLEMENTATION ISSUES

Any innovation, including MI, will become obsolete if not diffused. In practice, MI diffusion issues relate to MI strategy and vision as well as many other critical issues, which have been discussed partly in the theoretical section of this review such as MI technology management, leadership and acceptance-resistance experiences in MI implementation and will be further explored in the next section.

Here, our focus is on activities dealing with the need for management to create an MI strategy and vision for diffusing competitive, cost-effective MI applications in key areas throughout a healthcare organization. These issues summarize the MI managerial impact.

MI Strategy

While there may be good reasons to support MI innovation such as enhanced patient care, more intelligent clinician decision outcomes, and greater efficiencies in the clinical evaluation process, new efforts may fail for lack of a successful MI strategy.

In essence, MI strategy entails aligning the business or organizational mission (the goals) with the information needs of the users (particularly those of the clinicians and nurses for health care organizations) in the delivery of patient care (the tasks). In other words, three key questions should be asked when structuring an MI innovation diffusion strategy: First, “Is the MI strategy targeted to fulfill the core mission of the organization?” For example, in the case of a center for cancer treatment and research, plan should be in place to position this particular center to become one of the best places in the world to seek cancer treatment owing to its MI innovation diffusion strategy. Second, “What is the clinical significance of the MI innovation?” Here, the center clinicians should actually be benefiting significantly in their practices due to employing MI innovation – the effects should be evidenced in more medical breakthroughs and error prevention due to improved treatment decision outcomes. Finally, “Is the MI innovation serving its ultimate purpose of augmenting patient care delivery?” Herein lies the significance of the MI diffusion equation – are these systems functioning appropriately to save lives, improve the treatment center’s image, and strengthen the provider-patient relationships so cherished by the organization.

A major trend in MI strategic planning is the shifting of responsibilities and power from traditional IS/IT professionals to end users, and more appropriately, to top management. This trend is justified because of the growing acceptance of the notion that IT is a corporate and strategic resource and should be properly managed just like any other organizational assets including land, labor and capital. More recent approaches call for a shortening of the time span among MI strategic planning sessions and more attention paid to the changing marketplace. Regardless of the time span in-between strategic planning sessions, there is always the need to conduct environmental assessment before moving onto the formulation of a MI strategy.

One approach to MI strategic planning is scenario planning. Here, competing multiple futures may be first envisioned and strategies are then developed and tested against these possible futures. The MI vision is then set within these possible futures and further reconciled with current reality. For example, if the MI vision is one in which intelligent, sensor-based medical devices are to be used to monitor cancer patient round-the-clock while the current reality involves only regular treatment visits and emergency monitoring, then the transition to the new MI-intensive environment will not only call for changes in work practices and habits, but new ways of connecting patients to the cancer center electronically. Indeed, no single approach to MI strategy formulation is considered superior; instead, a blending of approaches is often recommended as the various approaches deal with different aspects of creating a feasible MI strategy.

MI Implementation

The challenges of MI implementation are often interwoven with many other social and organizational challenges, including the integration of quality planning, quality control and quality improvement processes to evolve a secure, well-managed, and quality-focused MI environment, the integration of information management technology, organization management technology, and user-interface technology for building an efficient, organization-wide infrastructure to support MI innovation and expansion, and the integration of data, model, and knowledge elements for designing effective MI applications.

Any MI implementation will bring about some form of organizational change, for example, changes in the organizational reporting structure, changes in the level of computing competence required of current and future clinical users, and changes in the information flow processes and decision-making functions of the organization. To ensure that clinicians will have the appropriate knowledge, skills and attitudes that are critical for addressing concerns arising from these MI related changes, it is important that health organizations also address staffing and training issues such as having an aggressive recruitment program for attracting valuable MI professionals from among competitors, creating opportunities for training and development, and employing winning strategies for the retention of knowledgeable and well-trained MI experts.

At the core of MI implementation is overcoming user resistance and cultivating user acceptance through a continuous process of buy-in, quality improvement, participatory decision making such as efforts to involve the users in identifying their information needs, involving them in systems specification, system analysis, systems design, vendor selection, system testing and providing them with flexible and extensive user training opportunities. Remember that physicians and most other clinicians have complex schedule and will not work around their schedule just to attend a training meeting. Moreover, opportunities for input from all end-users of the MI systems will only ensure that the designed system meet the expectation and needs of the users. Most importantly, the users will only be willing to most likely use the system on an increasing basis if they find that there are ways to tell them that the systems benefited them in lightening their workload and in improving their productivity, giving them more time to do patient care. As well, availability, accessibility, efficiency, effectiveness and ease of use of the systems all play a part towards getting the users hooked on the systems.

Together, these key challenges typically point towards the need for an integration of environmental, technological, and organizational components for driving and directing the implementation of various MI technologies and applications successfully within the larger intra-organizational or inter-organizational systems context. Other MI administrative issues may include policies dealing with privacy, security and confidentiality of patient records, legal and ethical considerations in clinical data collection, analysis, and distribution, and organizational policies regarding authorized use of MI.

CRITICAL ISSUES

As noted, the primary objectives of most, if not all, MI implementation are reduced operational costs, greater patient satisfaction, and better quality clinical decisions. As MI systems promise to make information and decision handling more efficient and effective in reducing costly errors and unnecessary delays, as well as projecting an improved professional image, it is important to implement MI applications that are accepted by its users (clinicians).

Critical Success Factors

What factors determine the success of an MI innovation diffusion effort? Critical Success Factors (CSFs) for MI diffusion are those factors that will drive the success of MI diffusion. Based on past studies, commonly held managerial factors for success include effective technology management (TM) and executive leadership, as well as infrastructural factors whereas organizational and social factors include implementation factors and culture-specific factors. The focus of this section will be on the managerial factors as the organizational and social factors are elaborated in Section VII on organizational and social impacts.

Briefly, technology leadership and the management of the MI capacity within the health organization are key success factors for MI innovation and implementation. Top management must work to ensure that appropriate infrastructural support is in place to develop the MI expertise needed to support current and future managerial and organizational functions and activities. In many cases, executive leadership is expected, including directives and policy setting by the chief information officer (CIO) in order to guide necessary organizational restructuring for efficient information processing and effective decision making, the revamping of decision processes, the bridging of MI innovation with changing environment, and the rapid adaptation of new MI capabilities to support increasingly sophisticated clinical information services in this age of information and knowledge explosion.

As we have noted, it is important for an effective MI strategy to impact on the business of the organization. The resistance to MI implementation experienced within an organization is largely due to poor alignment between MI strategy and organizational strategic plan, inadequate communications, lack of user training, and support from top management. A champion for MI to forming a task force that would marshal the needed support and user-analyst relationship and/or user participation throughout the development of MI strategy is an important ingredient to achieve MI diffusion, utilization and acceptance. Without a champion at the senior management level, it is likely that MI resources will not be well allocated and its needs for efficient and effective transformation of the organizational work habits will not be supported. This is especially true for health care organizations, with its established tradition of intensive paper-based information processing, professionally oriented physicians and nurses, and traditional management habits.

Other Issues

Other issues concern computer literacy among clinicians and all health organizational workers catering to patient care functions, the digital divide, the productivity paradox, ethical, legal and security issues. Again, an in-depth treatment of any of these issues is more properly the devotion of another chapter. Here, we will only brief touch on some of them.

Computer literacy, which can often translate into resistance, can be a threat even for highly trained professionals, as they do not want to be embarrassed for showing ignorance about their lag in technological expertise in front of their colleagues. Thus, it may be wise to conduct separate training sessions for executives, physicians, nurses, middle managers and staff.

A broader impact of computer literacy is the digital divide, where it is apparent that we need to pay special attention to the underserved population who may find accessibility to information technology and use of Internet a real challenge. Especially vulnerable are some special groups such as seniors who are also classified as minority and those living in impoverished parts of many of the inner cities. In this instance, the emerging field of e-health is making an impact. Tan and colleagues, for example, are working on educating a group of these seniors in selected urban Detroit areas on healthy aging and lifestyle changes through the use of Internet-based educational software known as the eHealthSmart program. A major aim of this program is to provide Internet-based tutorials on smoking cessation and weight management to the elderly and seniors who are eager to use computers to help themselves in changing their unhealthy lifestyle behaviors.

Another critical issue is the productivity paradox, which refers to the phenomenon that, to date, we have yet to witness the same level of productivity improvements achieved with the automation of processes in the service industry since the advent of computers in the way we have witnessed the effects of automation on productivity experienced in the manufacturing industry. In other words, information technologies, with its increasing applications across all service sector industries, have not been widely productive as anticipated. Apparently, it is argued that, on the one hand, we are not out of the woods yet in terms of maturing from old aged manufacturing productivity and efficiency while, on the other hand, we have yet to reach the stage of being fully immersed in the digital economy to leverage on technological productivity and efficiencies on a massive scale. Time can only tell when this generation will reach the threshold of a critical mass of technology usage to achieve the productivity and efficiency that we have already experienced in manufacturing, albeit the gradual slowdown. What this implies literary is the need for greater and higher MI diffusion in the current century, especially with health care taking a lead role. After all, which industry would thrive with automation in this economy when we are faced with an aging population, an accelerating health care expenditure of approximately 16% to17% of our

GNP? Hopefully, many of us will live to see the promise land of technological productivity that MI diffusion and automation will usher us in.

In terms of security and privacy issues, the health care organization is held responsible as the gatekeeper for securing private and critical information on hundreds and thousands of individual patients. Imagine someone finding a jump drive or disks containing private hospitalization records of certain patients who may also be important political figures, legendary athletes, famous entertainers or key legislative and policy makers. Imagine also that intruders are able to hack into the various MI systems and access key information on patient and hospital personnel identification, laboratory test results and digitized radiological images of different patients, or information on storage facilities for key pharmaceutical products and controlled substances. The ramification for losing any such information can be devastating for both the individuals whose information has been stolen as well as for the institution serving as the gatekeeper of our most private and confidential information.

EMERGING TRENDS

Moving on to emerging trends of MI thinking and sub-specialties that have surfaced in recent years, we observe that there are basically two streams of innovation. One group of paradigm shift includes consumer health informatics, electronic healthcare (e-health) and all its sub-fields such as electronic medicine (e-medicine), e-homecare, and patient-centered e-health (PCEH). Another group of paradigm shift concerns mobile healthcare (m-health) technologies, ubiquitous healthcare (u-health), and virtual healthcare (v-health). Here, it is possible only to provide readers with brief glimpses of these sometimes overlapping but emerging MI trends. Readers who are interested in pursuing further details can refer to the readings provided in the bibliography and the rest of this 4-volume work.

Consumer health informatics is bringing about a consumer-driven health care model in that consumers will play a more active and decisive role regarding managing their own health and well being. For the educated consumer, greater access to quality health information is, in and of itself, a form of therapy. E-health is a paradigm shift to re-channel clinical expertise into the hands of the less-than-experts through the applications of e-technology. E-technologies encompass complex MI network design and consumer-oriented informatics, the Internet, wireless communications and emerging technological applications such as web services and remote clinical monitoring devices and management systems. E-medicine, another MI sub-fields, refers to affordable and acceptable use of MI to support health-related services, surveillance, information, education, knowledge, and research dissemination. It is the use of advanced information and communications technology (ICT) to bridge geographic gaps and improve care delivery and education. Patient-centered e-health (PCEH), in a nutshell, represents one of the paradigm shifts that is part of the larger e-health movement where not only is the role of healthcare providers being redefined, but where the expectation bar for consumers to participate actively in decisions leading to their own health as well as the overall quality and acceptability of e-healthcare informatics and services are being raised. Moreover, we see that the various disciplines of e-clinical care, e-public health care, e-nursing and e-homecare overlap to a considerable extent. Apparently, it has not become easier, but more fuzzy, to distinctively separate the different knowledge domains of "e-health," which is the umbrella concept to encompass most, if not all, of these emerging MI sub-disciplines and sub-fields.

M-health, an extension of the e-health concept, refers to mobile-health or use of remote, satellite-based networks, cellular-based networks, and other wireless networks (e.g., sensor-based networks) to effect health data exchange services as well as clinical information and decision support services. Ubiquitous healthcare (u-health), and virtual healthcare (v-health) are the next evolution of MI where concepts such as virtual community networks, ES/HDSS embedded in walls, table-tops, refrigerators, and other objects in the surrounding environment, as well as VR such as use of head mounted displays, smart houses and wearable computing are becoming commonplace. Examples include a doctor checking the status of a patient's wellness in real time by connecting to a nano-sensor device installed in a patient's home or attached physically in some shape, form or manner to the patient or a monitoring system, which automatically contacts the designated health agency to initiate treatment procedure while alerting on an impending heart attack for a patient. Such an evolution can be expected to provide an ubiquitous MI resource for delivering patient care services.

The trending of the MI movement towards achieving u-health and v-health may soon become a reality when personalized information exchanges, integrative knowledge sharing, and decisional support and communications can happen in real time between an institutional care provider and the patient. Electronic health records will be available, accessible, affordable and adaptable to our needs. Nano-science and gene-based therapies will be possible because of intelligent mining of these personal records not only to serve us in terms of our wellness recovery whenever we are injured, but also brings about a sense of equity among the community, serving even those who are unable to insure themselves. Notwithstanding these changes, we have seen how a young discipline such as the MI field can grow and expand quickly to affect every aspects of our daily living, in particular, our health care system, our community and our health.

CONCLUSION

In bringing this discussion to a close, we will use the example of designing a expert diagnostic support system (E-DSS) useful for both physicians and patients to show how the different major facets of MI themes, its theories, central hypothesis, tools/methods, diffusion and impacts can all be combined to achieve effective health care. First, this E-DSS may have to be divided into two components, one to support experts (i.e., physicians, nurses and clinical therapists) and the other for layperson (i.e., consumer, patient) support. This MI tool will, say, be focused on wellness promotion areas such as smoking cessation, weight management, and nutrition advice. On the one hand, the expert component of this E-DSS will mimic the hypothetico-deductive approach used by most clinicians in deriving diagnostic decisions, which is, essentially, an iterative process of data collection, interpretation and hypothesis generation and refinement until a satisfied level of certainty is reached. On the other hand, the layperson component of the E-DSS will mimic an online tutorial for layperson to be educated with the expertise programmed into the different health promoting educational modules. Thus, this E-DSS concept illustrates the central hypothesis of MI philosophy, which is simply to enhance decision making, based on the GST that underlies also many of the evolving MI themes that we have reviewed so far, where synergy effects can be achieved with the combination of individual components in the design of MI applications.

Second, for most of the clinical decisions associated with the E-DSS such as knowing if a female patient is at risk for diabetes due to unhealthy lifestyles, the sensitivity-specificity methodology forms the basis for hypothesis generation. For the E-DSS to "think" like an expert clinician, the system must therefore be taught the different likelihood of specific symptoms to a health challenge, such as the likelihood of having diabetes as a result of being obese, unchanged smoking habits or poor lifestyle behaviors. Such likelihood, better expressed in terms of probability, is a measurement derived from health statistics. The cutoff point in which a patient is diagnosed with a particular challenge is the result of continuous data collection and analysis, for example, a female patient 50 years old is diagnosed with diabetes when her blood glucose reading reaches 5.5. If this cutoff point is reduced, then the sensitivity of the blood glucose test increases while the specificity decreases. Thus, if the cutoff point for diagnosing diabetes for the above clinical group is reduced to 5.4, then more patients will be diagnosed with diabetes. The cutoff point is then a guideline to diagnosing diabetes. However, a patient with a blood glucose reading of 5.6 does not necessarily have diabetes. This is because every clinical test has false positives as every clinical test result is made up true positives, true negatives, false positives, and false negatives. As we noted previously, the true-positive rate (TPR) is the sensitivity probability of a test result and measures the likelihood that the patient being suspected of having the disease does have a positive test result. Conversely, the true-negative rate (TNR) is the specificity probability of a test result and measures the likelihood of a non-diseased patient having a negative test result.

The initial hypothesis of a patient having a certain disease or condition is the pretest probability (i.e., prevalence). This judgment may be based on prior experience or on knowledge of the medical literature. When tests and examinations are conducted, the initial hypothesis is verified, thereby yielding the predictive value, or resulting in the posttest probability. Predictive value is the probability that a disease is present based on a test result. The posttest probability then becomes the pretest probability of the next hypothesis. This leads to the Bayes' theorem to calculate the posttest probability using the pretest probability and the sensitivity and specificity of the test. Herein lies the foundation of MI theory and methodology on which our clinical reasoning model is built upon and programmed into the expert component of the E-DSS to support clinical and diagnostic decisions. It is possible, of course, to apply other methodologies such as neural networks, heuristic programming and case-based reasoning, but our intent here is merely to illustrate a common and specific MI methodology based on a well-known decision theory, the Bayes' theorem. On the layperson component, the E-DSS may be supported with a knowledge base where expert knowledge on weight management, smoking cessation or healthy nutrition can be made available for online consultation.

In terms of MI diffusion and impacts, the E-DSS as we have illustrated must be supported by healthcare organizations that would promote wellness such as third-party payers and accepted by the intending clinical and layperson users in order to be effective and have a positive impact on the individual, group, organization and society. Specifically, the clinician will have a better control of predicting the risk for particular patient to have, say, obese-related diseases, the patient will have a better management of their own lifestyles with access to expert knowledge, the health maintenance organizations (HMOs) or the government will be able to reduce payments on treatment costs due to healthier subscribers, our society will have less burden to bear as people age more gracefully and the list goes on. Further, most HMOs and governmental agencies have numerous other patient record systems with varying computer platforms and data storage structures. How this E-DSS can be integrated or embedded into the larger organizational computing infrastructure is a key challenge. In other words, rather than having patient data stored redundantly in the E-DSS as well as other separate systems such as computerized patient records (CPR), it may be possible to network these different systems so that the same data are stored only once and can be shared virtually among the different sub-systems such as in the HMO's EHRs that was discussed previously. Other related challenges include the need to align the goals of the organization (the business) with the goals of the different sub-systems, for example, the clinician's aim to treat his or her patients speedily, and the aims of the IS/IT support departmental staff to coordinate data collection and standardization, to improve computer-user interfaces, to train users and to encourage their active participation in managing and harnessing the technology. Until a seamless alignment is achieved, the diffusion of MI such as the E-DSS technology will be limited due to lack of acceptance among its supporters.

Finally, the greatest impact of a system like the E-DSS we discussed here will be felt when it can be made available to any clinician as well as any layperson worldwide and not just those living in a certain area or country. In this sense, the development of sensor networks and ubiquitous computing is an ideal platform for MI development. When software applications are run through these wireless networks, the limitations on geographical location and time disappeared. In other words, the necessary health expertise can be made accessible, available and affordable 24/7 anywhere in the world to less-than-expert physicians and underserved patients. When the access interface becomes ubiquitous, the dynamic interactions between the clinician and the patient may not only be limited to diagnostic decision making and treatment planning, but it will be 24/7 monitoring even for disease prevention, lifestyle changes and wellness promotion. As people live longer, such new demands on the next generation MI innovation will certainly be on the rise. Nonetheless, security is always the major issue when MI applications are to be accessed ubiquitously. The integrity, privacy and confidentiality of clinical data must not be compromised when MI development moves in this direction.

REFERENCES

Bertalanffy, L. V. (1968). *General Systems Theory*, New York: Braziller.

Blois M, Shortliffe E. (1990). The computer meets medicine: emergence of a discipline. In: E. Shortliffe, L. Perreault (eds). *Medical Informatics: Computer Applications in Health Care*. v. 20. Reading, MA: Addison-Wesley.

Collen M. (1977). Preliminary announcement for the Third World Conference on Medical Informatics. *Medinfo* 80.

DeLano, W. L. (2005). The case for open-source software in drug discovery. *Drug Discovery Today, 10*(3).

Erickson, B. J., Langer, S., & Nagy, P. (2005). The Role of Open-Source Software in Innovation and Standardization in Radiology. *Journal of the American College of Radiology, 2*(11), 927-931.

Fitzgerald, & Kenny. (2004). Developing an information systems infrastructure with open source software. *Software, IEEE, 21*(1), 50-55.

Hersh, W. (2002). Medical informatics: Improving health care through information. *Journal of the American Medical Association*, 288:1955-1958.

Joint Commission on Accreditation of Healthcare Organizations. (2005). *Comprehensive Accreditation Manual for Hospitals*. Oakbrook Terrace, IL:JCAHO.

Jordan, Theresa J. (2002). *Understanding medical information: A user's guide to informatics & decision making*, New York: McGraw-Hill.

Kantor, G. S., Wilson, W. D., & Midgley, A. (2003). Open-source Software and the Primary Care EMR. *Journal of the American Medical Informatics Association, 10*(6), 616-

Kerlinger, F.N. (1986). *Foundations of Behavioral Research*, 3rd Ed., New York: Holt, Rinehart & Winston.

Newell, A., & Simon, H. A. (1971). *Human Problem Solving*, Englewood Cliffs, NJ: Prentice-Hall.

ACM. (1987, November 5-6). *Proceedings of ACM Conference on History of Medical Informatics*, Bethesda, MD, USA.

Rogers, E. M. (1983). *Diffusion of Innovations, 3rd Edition.* New York: Free Press.

Scarsbrook, A. F. (2007). Open-source software for radiologists: A primer. *Clinical Radiology, 62*(2), 120-130.

Shortliffe, E.H., Perreault, L.E. et al. (Eds.) (2001). *Medical Informatics: Computer Applications in Health Care.* New York: Springer-Verlag.

Stead, W.W. (1998). Medical informatics: On the path toward universal truths. *Journal of the American Medical Informatics Association*, *5*(6), 583-584.

Tan, J. (Ed.) (2005). *E-Health information systems: Introduction to students and professionals*. San Francisco: Jossey-Bass Inc.

Tan, J. (2003). Information Systems (IS) in Health Care. In H. Bidgoli et al. (eds.) *Encyclopedia of Information Systems* (Vol 2, pp. 519-536). Academic Press.

Tan, J. (2001). *Health Management Information Systems: Methods and Practical Applications* Second Edition. Gaithersburg, MD: Aspen Publishing Inc.

Tan, J., & S. Sheps (eds.) (1998). *Health Decision Support Systems*. Gaithersburg, Maryland: Aspen Publishing Inc.

van Bemmel J.H. (1984). The structure of medical informatics. *Medical Informatics*, *3*(4), 175-180.

van Bemmel, J.H. and Musen, M.A. (Eds.) *Handbook of Medical Informatics*. Heidelberg, Germany: Springer, 1997.

Zachary, W. A Cognitively Based Functional Taxonomy of Decision Support Techniques. Human-Computer Interaction 2 (1986):25-63.