Health Informatics at Minnesota
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The First Fifty Years

Dominique A. Tobbell, PhD

University of Minnesota Institute for Health Informatics
Minneapolis

Tasora
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Envisioning a New Field of Science

Envisioning a new scientific field can be seen as an act of prophecy: it relies on accurately seeing into the future where science is going, how its existing bodies of work can be merged and rearranged with novel elements to create a new scientific “species” that will offer previously unattainable results and will eventually dethrone the old paradigms. This is not an easy task. Arthur C. Clark wrote that the “hazards of prophecy” are the “failure of nerve” and the “failure of imagination”: the inability to believe that certain future possibilities may materialize and the inability to foresee future possibilities.

Certainly the innovators of the field of health informatics at the University of Minnesota did not suffer from any of those hazards of prophecy when envisioning informatics as a new discipline on campus, long before most other institutions did. The clarity with which they saw the future, as the reader of this volume will discover, was extraordinary and clearly evidenced by how accurately they anticipated major informatics discoveries and by how fresh their vision still reads today.

At the same time, a nascent field has to be nourished with substantial resources and well-designed organizational and administrative structures and personnel; it has to challenge the existing paradigms but also fit into the complex scientific enterprise; and it has to attract and educate top talent from established competing disciplines. Finally, significant results have to be produced, fast enough and often enough, to ensure that the whole endeavor will be successful and sustained.

In accordance to the vision of the founders of informatics at the University of Minnesota, the field of health informatics since the early 1960s has produced in the United States and internationally many major accomplishments. The best way to understand impact is to consider that if it were not for the field, essential tools, systems and theoretical foundations that span the spectrum from basic science to translational science to clinical science would not have existed and the loss would be deeply significant for all fields of biomedicine and health sciences. Indicatively, informatics has produced electronic health records, computerized provider order entry, diagnostic and therapeutic clinical decision support systems, medical ontologies, literature databases, genomic and other omic databases, biomedical information retrieval methods, sequence alignment tools, phylogenetic analysis tools, a plethora of high throughput assay methods and systems supporting discovery and personalized medicine,
de novo genome assembly, telehealth, many algorithms and methods for predictive and causal modeling in healthcare, and countless other indispensable tools, methods and findings.

Undoubtedly the informatics field has been a huge success and equally clearly the University of Minnesota has been at the forefront of it as one of the oldest academic homes for health informatics in the world (celebrating fifty years in 2015). The University of Minnesota has been a hotbed for methodological innovation in health informatics with excellent impact and a track record of federal funding and with breadth and depth of the health informatics faculty’s collaborations with non-informatics faculty on and off campus. Informatics at the University of Minnesota excelled in the interdisciplinarity and interprofessionalism of its faculty and moreover holds the record for the longest-running NLM-funded Training Program in health informatics (1974–2009), educating many informatics leaders in the United States and abroad. This volume covers all of these aspects about the field of health informatics at the University of Minnesota and does so with meticulous attention to historical exactness and detail.

As impressive, wide, and valuable the accomplishments and contributions of the field have been, it is my firm belief that the future will only be brighter. Due to advances in molecular and precision medicine, and the huge need and emerging capability to understand disease and healthcare delivery both in its small-scale reductionist detail and at a “system” level, health sciences and medicine are in a major “phase transition”. This revolutionary period may be comparable only to such past monumental paradigm shifts as those conferred by the introduction of vaccination, anesthesia, and antibiotics. And because informatics is indispensable for this transition, it is literally interwoven and a major catalyst and enabler for both the drive to personalized and precision medicine and to understand and re-engineer the healthcare system for vastly increased quality, value, and access.

The current generation of informaticists, we are thus very lucky for being active in such a historic time and are even luckier to benefit from the remarkable inheritance of foundational knowledge and technology handed to us by our academic forbearers. Because of standing on these giants’ shoulders we can hope—and expect—to solve the problems ahead for the benefit of science and society. It is thus very fitting that this volume, written with extraordinary skill by Prof. Dominique A. Tobbell, PhD, aims to and succeeds in describing in vivid detail and with great respect to historical accuracy, the efforts and the accomplishments of innovators and academic visionaries that form an essential foundation for the amazing discoveries ahead of us.

Constantin F. Aliferis MD, PhD, FACMI
Director, Institute for Health Informatics
University of Minnesota,
Minnesota, MN, July of 2015
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Health Informatics at Minnesota
Writing in 1978, Eugene Ackerman, PhD, director of the Division of Health Computer Sciences at the University of Minnesota Medical School, reflected that in 1960, “digital computers in the health sciences or biomedical areas were still a rarity. While business concerns were rapidly adopting computer aids, the biomedical community regarded computers as an expensive and rarely used research tool.” In 1965, however, the University of Minnesota College of Medical Sciences’ newly established biomedical computing facility, the Biomedical Data Processing Unit, was working with the Control Data Corporation 3100 computer. By 1967, the staff and faculty working in the Biomedical Data Processing Unit (which was then funded by a National Institutes of Health Research Resource grant) had upgraded to Control Data Corporation’s 3200 computer and 6600 system. They were using these computer systems to research and develop graphical display techniques, statistical classification and medical diagnosis, storage and retrieval programs for large data files, mathematical modeling and simulation, signal processing, and laboratory information systems.

The mid-1960s represent a defining moment in the early history of health informatics nationally. It was a moment when the first professional organization in biomedical computing (an early iteration of health informatics), the Society for Biomedical Computing, was established and led by Octo Barnett, MD, (1966), and the first journal in the field, *Computers and Biomedical Research*, was initiated by the Latter Day Saints (LDS) Hospital and the University of Utah (both in Salt Lake City, Utah) and published by Academic Press, New York, with Homer R. Warner, MD, PhD, as its editor (1967). Both Warner, at LDS Hospital and the University of Utah, and Barnett, at Massachusetts General Hospital in Boston and Harvard University in Cambridge were early pioneers in health informatics. Warner had educational roots at the University of Minnesota. After completing undergraduate and medical degrees at the University of Utah in the 1940s, he completed a residency in internal medicine and a PhD in physiology at the University of Minnesota in 1953. Warner’s dissertation was “on the development of a method for estimating the stroke volume of the heart on a beat-by-beat basis from the shape of the pressure wave from the aorta.” He returned to the University of Utah and LDS Hospital in 1954.

In a 2005 interview, Warner described the atmosphere in the mid-1960s at the LDS Hospital. Recalling when the Cardiovascular Diagnostic Laboratory he directed upgraded to a Control Data Corporation
3200 computer, Warner reflected: “Those were very exciting times. It was a wonderful time. . . . Nobody could have accomplished what we did then, because there was no tool available. It’s hard to imagine these days, that we could have been in that situation. I stayed awake lots of nights trying to think of what to do with that machine, because we had all that computing power, and a few very capable people to work with it . . . it was a real challenge.”

Health informaticians and historians alike place the origins of the field of health informatics in the United States in the 1960s. By the late-1950s, Robert Ledley, DDS, and Lee Lusted, MD, were pioneering the application of digital computing to problems in biology and medicine. The success of Ledley and Lusted’s work contributed to the National Institutes of Health’s decision, beginning in 1960, to support research and development projects using computers in medicine and the establishment of university-based biomedical computing facilities (discussed in chapter one). The federal government’s substantial investment in biomedical computing in the early 1960s established biomedical computing as a viable area of research.

In 2015, fifty years after Ackerman and his colleagues in the Biomedical Data Processing Unit began working with the Control Data Corporation 3100, biomedical health informatics is a global, interdisciplinary, and interprofessional field driving transformations in clinical and translational research, health care, and education, and is central to several health policy initiatives. For example, beginning in the early 2000s, health informaticians have been essential to a series of federal and state initiatives to secure widespread implementation of interoperable electronic health records by 2015, which were intended to improve health care quality, access, and patient experience, and to reduce costs. Not only has the field exploded in terms of research capacity and health care and policy impact since the 1960s, it has grown in size. In the United States, the American Medical Informatics Association, the professional home of leading biomedical and health informaticians, “is the center of action for more than 5,000 health care professionals, informatics researchers, and thought-leaders in biomedicine, health care and science.” The number of university departments, divisions or centers of biomedical and health informatics has also grown tremendously. In 2015, the American Medical Informatics Association listed sixty graduate degree, postdoctoral, and medical fellowship programs in biomedical and health informatics, including professional specialties of nursing, pharmacy, dental, public health, and others.

Globally, the field has also expanded significantly. While the International Medical Informatics Association’s (IMIA) membership of “constituent [national and regional health informatics] organizations and their members” has grown since its predecessor organization was founded in 1967 (discussed below), since 2002 it has also established four international regional sites that promote biomedical and health informatics activities in those regions: the Asia Pacific Association for Medical Informatics (launched in 1993); the European Federation for Medical Informatics (founded in 1976); the Pan African Health Informatics Association (established in 1993); and the Middle East Association for Health Informatics (founded in 2002 and inaugurated as a new IMIA regional site in 2009). The global expansion of the field is also demonstrated by the growth of the lead industry trade organization, Healthcare Information and Management Systems Society, which was founded in 1961. As of 2015, its membership included “more than 52,000 individuals, of which more than two-thirds work in healthcare provider, governmental and not-for-profit organizations across the globe, plus over 600 corporations and 250 partner organizations.” In addition to the United States, where it is headquartered, the Healthcare Information and Management Systems Society has offices in Europe, the Middle East, and Latin America.

The University of Minnesota has been a major
leader in the field of health informatics since the field’s origins in the early 1960s. The University founded its first biomedical computing facility at the end of 1964, offered its first graduate courses in biomedical computing in 1966, and established its first graduate program in health informatics in 1973. From 1974 to 2009, the University of Minnesota received thirty-five years of continuous funding from the National Library of Medicine (NLM) Training Grant programs, making it the longest NLM-funded program in the country (discussed in chapter two). The alumni of the University’s NLM training program and graduate program have gone on to hold national and international leadership positions. By 2015, the University of Minnesota’s biomedical health informatics faculty and alumni were national and international leaders in core specialties in biomedical and health informatics research, including clinical decision support systems; telehealth; the development and implementation of standardized terminologies; the evaluation of electronic health records and health information exchange; data mining; natural language processing; and clinical informatics. The University’s health informatician’s are transforming the clinical research enterprise and health care delivery locally and nationally through collaborations such as the National Institutes of Health Clinical and Translational Awards consortium, the Patient-Care Outcomes Institute–funded Great Plains Collaborative, and the National Center for Advancing Translational Science Accrual to Clinical Trials Project.

This book tells the story of the history of health informatics at the University of Minnesota, situating the University’s history in the broader history of biomedical health informatics and the history of U.S. health policy. Before delving into the University of Minnesota’s history of health informatics it is important to consider the emergence of health informatics in the 1960s and 1970s, what defines the field of health informatics—and its earlier conceptual iterations—and how that definition has changed over time, who some of the early pioneers of the field—and some of their early contributions to the field—have been, and why understanding the history of the field and an institution’s place within this history is a valuable tool as we look to the future.

Establishing a New Discipline

Historians and sociologists of professionalization and discipline-formation have identified a series of basic “events” from which professionalization and discipline-formation typically result: the creation of specialized journals and conferences, the creation of professionally dominated work sites, the formation of professional associations, the development of schools and other knowledge institutions, and the instantiation of licensing laws demarcating entrance to the profession. The development of health informatics is a story of discipline formation. As those working in biomedical computing beginning in the 1960s worked to establish the research, development, and computer systems applied to issues in medicine and health as a distinct field within biomedical science and medicine, they engaged in the process of discipline formation. As they did so they pursued many of the steps that historians and sociologists have identified as crucial to that process. They created specialized journals and conferences, formed professional associations, established departments or divisions of health informatics in universities, and, more recently, launched accreditation and certification initiatives.

The creation of distinctive journals and conferences in an emerging discipline enables the new types of specialized knowledge, concepts, methods, and technologies being produced to be shared among practitioners of the field. In selecting which articles their journal will publish, editors and reviewers designate the types of research questions and topics that are important to—indeed definitive of—the field. As mentioned above, the first peer-reviewed specialized journal in the field, Computers in Biomedical
Research was established in 1967. In Warner’s inaugural editorial he described the type of research the journal would accept: "physiological data acquisition, derivation and testing of mathematical models of biological systems, automated classification of single- and multi-dimensional patterns (diagnosis), computer-based hospital communication, development of and experience with special techniques and devices for interfacing computers to biomedical systems, the use of computers for automated control of a biomedical environment, and any other areas in which computers and biomedicine intersect."12 For Warner, never had there been a time in the history of biomedical research when a tool (in this case the computer) had “been developed that has such potential for exerting a positive effect on the development of biomedicine as a science.”13 A series of specialized journals followed. In 1972, the American Medical Association launched Computers in Medicine. That same year, Gallagher Printing in New York published the Journal of Clinical Computing. In 1977, Plenum Press in New York began publishing the Journal of Medical Systems. In 1983, Springer-Verlag in New York launched MD Computing (initially published as Medcomp).14 And in 1983, the first journal in nursing informatics, Computers in Nursing, was published by J. B. Lippincott in Philadelphia; it was renamed CIN: Computers, Informatics, Nursing in 1986.

The formation of specialized professional associations facilitates the creation of and socialization to a discipline-specific identity. The rules and regulations regarding membership to the organization, the discussions regarding what should define the field (discussed below), who can be a member, and what the theme or structure of the organization’s next annual conference will be all contribute to demarcating the boundaries of the new discipline. According to Morris Collen, MD, the Society for Advanced Medical Systems, established in 1968, was the first professional organization in the United States “with the primary goal of furthering technology systems in medicine, especially computer-based systems.” The earliest professional association in the United States that was “committed entirely to medical informatics,” however, was the Society for Computer Medicine, which was officially chartered in 1971. In the 1970s, Collen noted, each organization had fewer than five hundred members “and it became increasingly evident to members who belonged to the boards of both organizations that there was considerable duplication of effort for many common objectives.”15 As Collen recalled in a 2005 interview,

[In the 1970s] Marion Ball was president of SCM, the Society for Computer Medicine, and Rudi Bickel was president of SAMS, the Society for Advanced Medical Systems. We’d been trying to get those two societies together for years, because they had similar goals and a few hundred members each. So Marion and Rudi brought SCM and SAMS together and held a joint conference in 1981, and then [in 1982] formally joined them to form the American Association for Medical Systems and Informatics (AAMSI).

The annual Symposium for Computer Applications in Medical Care (SCAMC), run by Tom Piemme, was already going well. Then another organization developed as people were beginning to start a college [to recognize those making the most significant contributions to the field]. So [Donald A. B.] Lindberg and three or four of us who had been presidents of societies decided to start a college, the American College of Medical Informatics (ACMI). [M.] Scott Blois became the first president of ACMI; I was the second president. Then we got together and decided to combine all three (SCAMC, AAMSI, and ACMI) into the American Medical Informatics Association (AMIA).16

AMIA was founded in 1988 and remains the professional association for biomedical and health informaticians in the United States. AMIA published the inaugural issue of its official journal, the Journal of
In 1994, the American Medical Informatics Association, in January 1994.

The International Medical Informatics Association (IMIA), the world body for health and biomedical informatics, was established under Swiss law in 1989. However, it was originally established as Technical Committee 4 of the International Federation for Information Processing in 1967. In 1979, IMIA evolved from a Special Interest Group of the International Federation for Information Processing to its current status as a fully independent organization. IMIA launched publication of its official journals, the *Yearbook of Medical Informatics*, in 1992, and the *International Journal of Medical Informatics* in 1997.

In 1982, the first professional association for nursing informaticians, Capital Area Roundtable on Informatics in Nursing (CARING), was founded; it was developed and organized by Susan McDermott, MBA, RN, P. J. Hallberg, RN, BSN, and Susan Newbold, MS, RN-BC, FAAN, FHIMSS, “as a non-profit undertaking to provide a forum for the advancement of automated healthcare information systems.” As Newbold recalled, for nurses working in the early 1980s with the first hospital computer systems,

we really didn’t know what the job was, because there was no one at our organization to model . . . on which to model our role, so that’s why we had to call upon other colleagues that worked in area hospitals that had that system [IBM Patient Care System] or similar systems. And about that time is when I contacted, or perhaps she contacted me, my colleague, P. J. Hallberg, who worked at a local hospital, at a Washington D.C. hospital, contacted me, and we met with several other nurses, Susan McDermott was one of them, helping each other get through this process. (Ellipses in original.)

The Capital Area Roundtable on Informatics in Nursing’s mission was to advance “the delivery of quality healthcare through the integration of informatics in practice, education, administration, and research.” Then in 1992, a group of nursing informaticians based in Southern California led by Melodie Kaltenbaugh founded the American Nursing Informatics Association (ANIA). The goal of ANIA was “to provide networking, education, and information resources that enrich and strengthen the roles of nurses in the field of informatics.” ANIA defined the field of nursing informatics as including the “domains of clinical information, education and administration decision support.” In 2005, the leadership of the Capital Area Roundtable on Informatics in Nursing and ANIA began discussions about merging the two organizations; they held their first joint conference in 2007, and in 2010 the two organizations finally merged, creating ANIA-CARING. In 2012 the name of the organized was changed to ANIA.

Another major nursing informatics organization, the Alliance for Nursing Informatics (ANI) was established in 2004 by “18 national and regional nursing informatics groups. When ANI was founded, the boards of directors of AMIA and the Healthcare Information and Management Systems Society agreed “to provide ongoing support, coordination, and leadership.” In its first year, ANI established three objectives: (1) to foster “the further development of a united voice for nursing informatics and provide a forum for its expression”; (2) to provide “a single point of connection between nursing informatics individuals and groups and the broader nursing and health care community”; and (3) provide a “forum to engage nursing informatics organizations to identify leadership, provide mentorship, and respond to opportunities that support and encourage nursing informatics participation in activities.” In 2006, *CIN: Computers, Informatics, Nursing* became the official journal of ANI.

Like the creation of specialized journals, the establishment of specialized conferences in the new discipline facilitates the circulation of new knowledge among participants. Conferences also enable networking among members of the new discipline,
which facilitates the creation of and socialization to a discipline-identity. Conference organizers and program committees, by selecting the papers and posters that will be included in the conference, also play a significant role in establishing the types of research questions, knowledge, concepts, methods, and technologies that are definitive of the field. In this sense, conferences, like journals, play a critical role in demarcating the boundaries of the field.

The first specialized conferences in health informatics were held in the late 1960s. The Society for Advanced Medical Systems held its first conference in Milwaukee, Wisconsin, in 1968 and the Society for Computer Medicine held its first annual conference in 1973. In 1974, the International Federation for Information Processing hosted the First World Congress on Medical Informatics (MEDINFO 74) in Stockholm, Sweden, and went on to hold a world congress every three years. The proceedings of the MEDINFO conferences were published in the year following the meeting. Also in 1974, the University of Illinois and the Regional Health Resource Center in Urbana, Illinois, initiated the First Illinois Conference on Medical Information Systems. In 1977, the Symposium for Computer Applications in Medical Care hosted its first annual fall conference in Washington D.C. The Proceedings of the Symposium for Computer Applications in Medical Care was published annually. In 1995, AMIA began hosting the annual fall conference and the proceedings were renamed the Proceedings of the AMIA Symposium. In 1985, IMIA held its first Working Conference on the Impact of Computers in Nursing in London, England; it continued to hold a conference every three years.

The establishment of departments or divisions of health informatics or graduate programs in health informatics at universities enables practitioners to train future generations of health informaticians. This is not only critical to the longevity of the profession and the continued production of new knowledge, it also socializes students to the discipline and begins instilling in students the identity of the discipline. Several universities were engaged in biomedical computing research in the 1960s but not all were involved in educating students in the new field. At the same time, many of those engaged in informatics research in the 1960s and 1970s were also training PhD and postdoctoral students in their laboratories. However in some of those institutions no department or division of health informatics existed and many of the students being trained by informaticians were formally affiliated with and awarded degrees by other university departments, including departments of computer science, engineering, biometry, and applied mathematics.

Some of the earliest examples of graduate programs in health informatics in the United States include the University of Utah, Duke University, the University of Minnesota, the University of California, San Francisco, the Georgia Institute of Technology, the University of Missouri, Columbia, and Stanford University. In 1964, the University of Utah established the first department of health informatics in the world, initially called the Department of Biophysics and Bioengineering; it was in the College of Engineering. The department awarded its first PhD (the first in informatics in the United States) in 1965. In 1972, the department was administratively relocated to the School of Medicine and in 1976 renamed the Department of Medical Biophysics and Computing (a new Department of Bioengineering remained in the College of Engineering). In 1985, the department was renamed the Department of Medical Informatics. Warner chaired the University of Utah’s department from 1964 through 1996.

Duke University in Durham, North Carolina, began to informally train PhD students in the late 1960s, with W. Ed Hammond, PhD, supervising his first student in 1968. During the 1970s, Duke University had a “loose group” of eight to ten PhD students in the informatics track of the graduate program in Biomedical Engineering. The University of
Minnesota offered its first graduate courses in biomedical computing in 1966. In 1969, the University established the Division of Health Computer Sciences in the Medical School’s Department of Laboratory Medicine as the academic home of health informatics. In 1973, the Division of Health Computer Sciences established its first graduate program in health informatics, the graduate program in biometry and health information systems, offered jointly with the Division of Biometry through the School of Public Health (discussed in chapter two). In 1971, the University of California, San Francisco established its Medical Information Science program, led by Marsden Scott Blois, MD, PhD. In 1973, the Georgia Institute of Technology’s School of Information Science and Emory University’s School of Medicine, both in Atlanta, Georgia, launched a joint graduate degree program, the Graduate Program in Biomedical Information and Computer Science. Vladimir Slamecka, PhD, director of Georgia Tech’s School of Information Science initiated and directed the program. The program was inaugurated in 1973 and was funded by an NLM training grant (discussed below). The graduate program, however, was discontinued in 1979.

The University of Missouri, Columbia began training students in health informatics in the 1970s, led by Donald A. B. Lindberg, MD, professor of Information Science and of Pathology. In 1982, Edward H. Shortliffe, MD, PhD, was founding director of Stanford University’s graduate program in medical informatics. The training of new health informaticians was further advanced when the NLM established the new NLM Training Grant program in 1974. The goal of the grant program was to provide graduate and postdoctoral training in health science computing “enriched by other technological skills in engineering, management and evaluation.” In 1984, the year that Lindberg became director of the NLM, the focus of the NLM training program changed from training biomedical users of computers to training researchers in and developers of biomedical computing. Among the first universities to receive the NLM training grants were the University of Alabama–Birmingham (1974); the University of California–San Francisco (1974); the University of Minnesota (1974); Case Western Reserve University (1975); Mount Sinai School of Medicine–City University of New York (1976); the Ohio State University (1976); the University of Missouri, Columbia (1976); the University of Illinois–Urbana (1977); and Stanford University (1982). While several of these universities’ NLM training programs were short-lived (for example, Georgia Institute of Technology’s program ended in 1979), several thrived for many years and some continue today. For example, as noted earlier, the University of Minnesota received thirty-five years of continuous funding from the NLM Training Grant programs, from 1974 to 2009 (for more on the training programs, see chapter two).

By the early 1990s, a plethora of leading informaticians were publishing articles on the emerging discipline of medical informatics. In each case, however, the definitions were entirely medical in focus. In 1990, for example, Robert Greenes, MD, PhD, at Massachusetts General Hospital and Harvard University, and Shortliffe at Stanford University surveyed the evolution of medical informatics over the previous three decades in “Medical Informatics: An Emerging Academic Discipline and Institutional Priority.” Noting that medicine as practiced in 1990 required “physicians” to routinely access up-to-date knowledge and advice, necessitating the “distillation of knowledge, proper interpretation of data and application of knowledge,” Greenes and Shortliffe highlighted the critical research and development work medical informaticians had conducted since the 1960s to enable that work. In particular, informaticians had made possible the collection and analysis of patient data and the communication of that data among health care professionals, as well as access to the biomedical literature, which health care professionals
were using to support clinical decision making. As physicians, medical educators, administrators, and policy makers were appreciating the importance of medical informatics to the infrastructure of biomedical research and health care practice, “professionals in medical informatics are increasingly called on to participate in practical issues of determining institutional priorities, dealing with financial management, and reconciling academic and operational concerns.” For example, “In increasing numbers of hospitals, the Chief Information Officer,” a position routinely held by an informatician, “has evolved as a member of the executive committee of the institution.” Greenes and Shortliffe predicted “that academic medical centers will gradually move toward acceptance of this model for their entire institutions.” All of these factors made clear, Greenes and Shortliffe argued, that medical informatics was its own discipline. Specifically, “medical informatics has a unique combination of training requirements because of the need to promote the kind of multidisciplinary thinking required for research in the field. Activities of the medical informatics specialist are generally not viewed as mainstream by existing departments.” And, they continued, “Even when active in the clinical setting, the medical informatics professional is likely to share academic interests more strongly with colleagues in that field than with colleagues in the clinical department.”34

For Thomas L. Lincoln, MD, at the University of Southern California School of Medicine, also writing in 1990, the discipline of medical informatics had formulated “its own concepts, categories and rules” to address fundamental questions related to the interactions of computer systems and medical science and clinical care and developed a “rich and many sided body of knowledge” giving the “field legitimate standing in its own right.”35

By the early 1990s then, health informatics had emerged as a discipline “in its own right.” At this time, the field had several specialized journals and conferences, specialized professional associations (in the United States and internationally), several departments or divisions of health informatics and graduate programs in health informatics had been established, and leading informaticians were asserting that health informatics had emerged as a new discipline.

Only recently has AMIA (American Medical Informatics Association) begun the process of accrediting graduate programs and clinical fellowships in informatics and certifying individuals trained in informatics. As AMIA president and chief executive officer, Douglas B. Frisda, MD, PhD, FACP, FACMI, explained in March 2015, accreditation and certification activities are “part of maturing the field.”36 Where accreditation is “a rigorous evaluation and monitoring peer review process assuring that education programs and institutions meet professional standards of academic and operational integrity and quality,” he continued, certification is a “credentialing process that demonstrates a qualification that an individual can perform a specific position, professional role, or set of tasks.”37 (Emphasis in original.) Both provided “an assurance that a standard of quality is met.” As such, Charles Friedman, PhD, FACMI, chair of the AMIA Academic Forum asserted six months earlier, accreditation and certification activities were “essential” to “support the distinct profession of informatics.”38

Since 2005, AMIA has been working on the issue of certification for individuals who practice clinical and health informatics.39 In 2007, AMIA initiated plans to establish clinical informatics as a medical subspecialty. The first American medical specialty board, the American Board for Ophthalmic Examinations (renamed the American Board in Ophthalmology), was formally created in 1916 and incorporated the following year.40 The first subspecialties were of the American Board of Internal Medicine, which included allergy, cardiovascular diseases, gastroenterology, and tuberculosis, received certification in 1941.41 Given the long history of specialty and subspecialty certification in medicine, AMIA’s leadership had a
well-established path to follow to secure approval by the American Board of Medical Specialties to establish clinical informatics as a subspecialty. In March 2007, with funding from the Robert Wood Johnson Foundation, AMIA launched an eighteen-month process to define the core content of the subspecialty and training requirements for the proposed clinical informatics fellowship. In September 2011, the American Board of Medical Specialties approved the clinical informatics subspecialty that was sponsored by the American Board of Preventive Medicine. In 2014, the Accreditation Council for Graduate Medical Education approved its first group of Clinical Informatics Fellows Programs with Stanford University, the University of Illinois–Chicago, Oregon Health and Science University, and the Regenstrief Institute at Indiana University.

In February 2012, the AMIA Academic Forum created a task force on Advanced Interprofessional Informatics Certification. Stuart Speedie, PhD, FACMI (IHI core faculty, University of Minnesota) chaired the Academic Forum from 2011 to 2012 and has served as a member on it since that time, and Connie Delaney, PhD, RN, FAAN, FACMI (dean, School of Nursing, IHI core faculty and former acting IHI director, University of Minnesota) has served on the committee since 2014. The task force established three basic principles: (1) “a pathway to certification for individuals not eligible for the subspecialty certification is critical,” (2) “such a pathway should focus on the core informatics content that is relevant to all professions,” and (3) “interprofessional informatics certification should be at the graduate level, based on the same core content used for the subspecialty certification, have the same rigor as the subspecialty certification process and convey the same level of assurance of competency as the subspecialty certification.” In December 2014, AMIA convened an interorganizational work group that included the major professional associations representing nutritionists and dietitians and colleges of nursing, pharmacy, dentistry, public health, osteopathic medicine, and radiology to build on the work of the Advanced Interprofessional Informatics Certification task force and recommend the core content and eligibility pathways necessary for certification. The work group will present its recommendations to the AMIA Board of Directors in November 2015. For several years, AMIA has also been working to establish accreditation in health professional schools that also offer training in clinical informatics.

Key to training the new generation of health informaticians, to socializing students and new practitioners to the discipline, and to identifying and defending the boundaries of the field was being able to define exactly what constituted the field’s domain of knowledge and practice. As with any discipline, that definition is liable to change over time, not only as the knowledge, theories, and technologies underpinning the field change, but also as funding priorities, health care needs, and health policy imperatives shift, and leadership of the discipline evolves.

**Naming and Defining Health Informatics**

The first combined reference to *medical* and *informatics* did not appear in English until 1974. During the 1960s and continuing through 1970s, before the term *medical informatics* was widely accepted by informaticians, a variety of names were used to describe the application of digital computers to medicine. Among them were *biomedical computer*, *medical computing*, *medical computer science*, *computer medicine*, *medical electronic data processing*, *medical information processing*, *medical software engineering*, and *medical computer technology*. A new discipline requires a specific and unified name. Thus, until the term *medical informatics* was more widely accepted as an acceptable designator among practitioners working in the area of computing, biomedicine, and health, the discipline was one very much still in formation.
Without a unified name for the study of computers and biomedicine, there was unlikely to be a definition of what the parameters of the work would be. However, Warner’s 1967 inaugural editorial in *Computers and Biomedical Research* (discussed above), does provide some clues as to what leading researchers in this nascent discipline believed the parameters to be. Warner conceptualized the interdisciplinary field (and he was clear that it was interdisciplinary) of biomedical computing as concerned with data acquisition and analysis and the development of computer systems, models, and tools to improve health care.47

By the early 1980s, informaticians from Europe and the United States had accepted *medical informatics* as the designated term for the discipline. At this time, they were engaged in the process of defining the field. Donald A. B. Lindberg, MD, then director of the NLM, for example, defined medical informatics as providing “the theoretical basis for the application of computer and automated information systems to biomedicine and health affairs. . . . Medical informatics studies biomedical information, data, knowledge—their storage, retrieval, and optimal use for problem-solving and decision-making. It touches on all basic and applied fields in biomedical science and is closely tied to modern information technology, notably in the area of computing and communication.”48 Marsden Scott Blois and Shortliffe’s definition was similar: “Medical informatics is the rapidly developing scientific field that deals with the storage, retrieval, and optimal use of biomedical information, data, and knowledge for problem solving and decision making. It accordingly touches on basic and applied fields in biomedical science and is closely tied to modern information technologies, notably in the areas of computing and communication (medical computer science).”49

As leading informatician Morris Collen, MD, summarized in his history of the field in 1995, medical informatics “was thus broadened in its definition to include not only the device (the computer) and what the device processed (information), but also all applications to medical research and development, education, and medical practice, including such functions as clinical decision support.”50

While Lindberg, Blois, Shortliffe, and Collen offered definitions of *medical* informatics, in 1989 Judith R. Graves, PhD, RN, and Sheila Corcoran, PhD, RN, provided the first definition of *nursing informatics*. Both were pioneering nursing informaticians from the University of Minnesota. Graves was in the 1984 cohort of NLM Training Grant fellows at the University of Minnesota and was supervised by Corcoran, associate professor in the University of Minnesota School of Nursing. After completing her fellowship, Graves went on to serve as founding director of the Office of Nursing Informatics at the University of Utah College of Nursing. In their foundational article, Graves and Corcoran defined nursing informatics as “a combination of computer science, information science and nursing science designed to assist in the management and processing of nursing data, information and knowledge to support the practice of nursing and the delivery of nursing care. The framework for nursing informatics relies on a taxonomy and definitions of the central concepts of data, information and knowledge.” The management component of informatics, they continued:

is the functional ability to collect, aggregate, organize, move and represent information in an economical, efficient way that is useful to users of the system. The processing component of informatics is viewed as being analogous processing that is done by nurses (and other clinicians) to make clinical decisions, by researchers to discover and verify knowledge and by theorists to develop nursing theory. In practice, processing is considered as a transformation of data or information, from one form to another, usually at a more complex state of organization or meaning. There is a progression of transfor-
mation of data into information and information into knowledge. Knowledge is used both in making decisions and in making new discoveries. Both processes—decision making and discovery—can be modelled and represented in computer programs.51 (Emphases in original.)

For Graves and Corcoran, by emphasizing its utility by nurses and other clinicians, informatics was by definition interprofessional. This is no surprise given that interprofessionalism had been a defining and distinctive feature of the University of Minnesota’s health informatics program since its launch in 1965. In the years that Graves was an NLM Training Grant fellow at the University of Minnesota (1984–1986), she was joined by four physicians, a biometrist, and a cognitive scientist.

Collen noted in his history of the field that the 1980s also saw the introduction of the terms clinical informatics (1984), dental informatics (1986), and health informatics (1984).52 Indeed, beginning in the mid-1980s, debate emerged among informaticians as to whether medical informatics referred only to the use of information technologies by physicians at the point-of-care or by all health care professionals.53 In a 1984 editorial in Methods of Information in Medicine, J. H. Milsum and C. A. Laszlo suggested it was time to move from medical to health informatics. Several social and economic factors were shaping the health care system “in new directions,” warranting such a renaming. In particular, clients (patient no longer being the appropriate term), as consumers, were demonstrating “a stronger tendency . . . to question and assess the various options available for diagnosis, therapy and prevention, before undertaking formally to decide among them in collaboration with their physicians.” Furthermore, Milsum and Laszlo noted, as the health care system structurally changed to incorporate the prevention of illness and promotion of health it would necessarily increasingly involve the participation of the “client.” “While in traditional medical care the professional obtained, organized, maintained, and had exclusive access to information related to the patient,” they explained, “the new health care modalities require that much information must be available to the client. This requires new and innovative ways of collecting, processing, protecting, displaying, and using information.” This also meant that informaticians would need to find appropriate ways to integrate traditional medical, demographic, and public health databases and systems. “These new systems, operated by both individual professionals and clients,” they noted, “have additional data requirements and novel structures.” Given these changed contexts, Milsum and Laszlo contended, “it may be much more appropriate to use the term ‘Health Informatics’ rather than ‘Medical Informatics.’”54

Yet for the University of Minnesota the question of medical versus health informatics had always been moot. Within the first five years of founding the Biomedical Data Processing Unit, the University’s informaticians had engaged in interprofessional collaborative research projects in epidemiology, environmental health, hospital administration, biometry, and medicine (see chapters one and three). During the 1970s, the University’s informaticians taught graduate students in public health and pharmacy in addition to medical students, and offered specialized courses in each of those health professions. From the very beginning of its NLM training grant program in 1974 (and likewise its graduate program), the University of Minnesota prioritized interprofessional training. The training program had numerous fellows in public health, several more nursing fellows after Graves, got its first dental fellow in 1987, and its first fellow in veterinary medicine in 1994. Most significantly, the name of the academic division, the Division of Health Computer Sciences and later the Division of and then Institute for Health Informatics, and its graduate programs (first the graduate program in Biometry and Health Information Systems in 1973 and then the graduate program in Health Informatics in 1986)
signaled that the research, education, and service missions of the University of Minnesota's informaticians were explicitly interprofessional.

By 2015, the definition of the field of biomedical and health informatics (now the accepted terms for the field) included a separate definition of the science of informatics that was more encompassing. AMIA defines biomedical health informatics as “the interdisciplinary, scientific field that studies and pursues the objective uses of biomedical data, information, and knowledge for scientific inquiry, problem solving, and decision making, motivated by efforts to improve human health.” The interdisciplinary science of informatics, AMIA’s definition continues, drives innovation that is defining future approaches to information and knowledge management in biomedical research, clinical care, and public health. Informatics researchers develop, introduce, and evaluate new biomedically motivated methods in areas as diverse as data mining (deriving new knowledge from large databases), natural language or text processing, cognitive science, human interface design, decision support, databases, and algorithms for analyzing large amounts of data generated in public health, clinical research, or genomics/proteomics. . . . All work in informatics is motivated by the need to create new solutions—often using information technology—that enhance biomedical science, the health of the populace, and the quality and safety of care that is provided to individuals when they are ill.

The term biomedical informatics had emerged in the 1990s “as the Human Genome Project and the expanding issues in data analysis for basic biology led to a greater awareness that the methods and processes of what had been known as ‘medical informatics’ were broadly applicable across all of biomedicine.” Since 2012, when AMIA last updated its definition of the field, the term health informatics, which is part of biomedical informatics, is composed of public health informatics (also referred to by the broader term, population informatics) and clinical informatics, which in turn includes the subfields of medical, nursing, and dental informatics.

You can learn a lot about the history of an emerging discipline—the types of research questions being asked, the types of theories, concepts, methods, and technologies used—by looking at some of the earliest research being conducted by its leading practitioners. It is never easy to single out just a few pioneers within a field for there are always many more individuals who marshaled key institutional, state, or federal support, contributed foundational concepts, major innovations, and significant breakthroughs that could be just as worthy of attention. Still, in this brief excursion into the early history of health informatics, choices must be made. In the few histories of the field that have been written there are three informaticians always featured: Homer Warner, MD, PhD, G. Octo Barnett, MD, and Morris Collen, MD. Both Warner and Collen were alumni of the University of Minnesota. Warner had completed his residency in internal medicine and received his PhD in physiology at the University in 1953, while Collen had completed his undergraduate and medical degrees at the University in the late 1930s and early 1940s. Warner, Barnett, and Collen were all engaged in innovative work in biomedical computing by the mid-1960s and each had, by the 1970s, a transformative effect on the field. It is to these three men—and their early contributions to the field—that we now turn.

### Early Pioneers and Early Innovations in Health Informatics

The results of Ledley and Lusted’s research in the 1950s prompted other researchers to investigate the
possible application of computers to medicine. In 1957, Ledley and Lusted began a decade-long collaborative project to computerize medical diagnosis. In 1959, Warner, then director of the Latter Day Saints (LDS) Hospital’s Cardiovascular Diagnosis Laboratory, was shown by a colleague an article by Ledley and Lusted in which they had described using probabilities and logic to make a medical diagnosis. After reading the 1959 article by Ledley and Lusted, Warner recalled,

We thought, well, that might be a good thing to try, because we've got a lot of patients coming through our laboratory with congenital heart disease. So we began collecting data by asking each of the doctors who referred us cases for catheterization to fill out a checklist of the patient’s manifestations, and also to put down their own estimate of what they thought the patient had. And so we'd then send the patient through our diagnostic procedures. . . . We'd use that data, then, to create a matrix of symptoms and diseases and find sensitivities and specificities and so on. Once we created that program, then we began to study new patients to see if we could actually predict a diagnosis on a given patient before the diagnostic procedure was done.

Partly as a result of Warner's diagnostic study, the LDS Hospital received an NIH Research Resource grant that enabled the Cardiovascular Diagnostic Laboratory to get the hospital's first digital computer.

Warner and his colleagues at the LDS Hospital and the University of Utah went on to develop in 1967 the first hospital information system, the Health Evaluation through Logical Processing (HELP) program, that collected patient data needed for clinical decision making and incorporated a medical knowledge base and inference engine to assist clinicians in making decisions. Warner’s team was motivated after realizing that the nurses working in the LDS Hospital intensive care unit were being overwhelmed with information about their patients’ statuses: “We had all this data, but we didn’t know what it meant.” Describing a particular situation in which an ICU nurse was struggling to evaluate a post-surgical ICU patient who was having “some hemodynamic disturbances,” Warner recounted calling the resident down to see the patient: “We thought the patient probably had a cardiac tamponade. We called the surgeon, and he agreed, so they took the patient back and took care of it.” Following that encounter, Warner continued, “I thought, wouldn’t it be nice if we could store that thought process we’d been through so the next time that set of events occurred, we’d recognize what it was, we could help that nurse, and she wouldn’t just have to try to process the data without any help. That was the beginning of the HELP system.”

In 1975, Intermountain Healthcare absorbed LDS Hospital, and by the end of the 1980s, the HELP system was extended into ten hospitals at Intermountain Healthcare. As of 2015, the HELP system was still in wide use at the twenty-two hospitals at Intermountain Healthcare.

G. Octo Barnett, MD, was another innovative leader in informatics who, like Warner, pioneered one of the first medical information systems. In 1964, Barnett was recruited to Massachusetts General Hospital in Boston to serve as founding director of the Laboratory of Computer Science—a biomedical computing research and development group; to take over leadership of the Hospital Computer Project; and to serve as professor of medicine at Harvard Medical School in Cambridge, Massachusetts. The Hospital Computer Project had been established in 1962 under a contract held by Massachusetts General Hospital and the Cambridge firm, Bolt Beranek and Newman and funded jointly by the NIH and the American Hospital Association. Bolt Beranek and Newman was active in the early development of time-sharing computer systems, and one of its senior
managers, Jordan Baruch, “had a vision of the useful impact that such a system would have on the information processing needs of a hospital.” “From the initial formulation,” Barnett described, the medical information system “was conceived as being interactive and conversational in real time. The dialog was to have error-checking, to have on-line help, and to be branching in response to the particular set of entries given by the user. One of the most radical of the specifications was the plan to include ‘standing-orders’ in the computer so that it could automatically detect and respond to specific data entries or to specific values of the data base.” Between 1964 and 1966, Barnett, Baruch, and colleagues “focused on the development of an admission discharge census system, a laboratory information system, and a medications ordering system.”62

As Collen has described in his account of Barnett’s work, in 1966, “the program had been operational for less than one year as a demonstration system on a group of 10 to 40 beds, in parallel with the traditional hospital operating procedures. This pilot project included an admission-discharge census system, a medications ordering system, and a laboratory reporting system. . . . Computer programs appeared to the user in an interactive mode wherein the computer asked a question and the user entered a response.” If using the medication order program, the physician would order a drug for a patient, the system would automatically check “the patient’s identification data and the spelling and dosage limits for the drug ordered,” list “all active medication orders for the patient,” and provide “important drug information entered by the pharmacists into the hospital formulary. Each hour on each patient care unit the computer” would generate “a list of medications to be administered at that hour.” The computer would also list “laboratory test results, with weekly summaries organized in a format designed by the users to display tests in associated groups, such as serum, electrolytes and hematology.”63

In 1968, Barnett introduced their medical information system, the Computer Stored Ambulatory Record (COSTAR) system. It was first implemented at the Harvard Community Health Plan, which began testing the COSTAR system in 1969.64 As Barnett recalled, “The dean of the [Harvard] medical school was starting up the Harvard Community Health Plan, one of the first HMOs. He was doing computer developments with medical education. . . . He basically wanted the HMO to be concerned not just with care, but also with research about what care was, and how well it worked. And so he said what he really needed to have was some sort of automation of the medical record.”65 Following the successful implementation of COSTAR in the Harvard Community Health Plan, COSTAR was launched in the public domain in 1975 and adopted by industry.66 By 1987, the Harvard Community Health Plan “had installed 10 minicomputers to support clinical computing in their 9 care facilities, which together serve an active membership of more than 225,000 people.” At that time, the COSTAR system contained individual records for nearly 550,000 people generated over its twenty years of operation.67 Like the HELP system, the COSTAR system is still in use today. Barnett’s work also led to the development of the general-purpose computer program language MUMPS (Massachusetts General Hospital Utility Multi-Programming System) and several other innovative computer systems including, DXplain, Primary Care Office Insite, and Pulmonary Artery Catheter Waveform Interpretation Tool (PACath).68

Morris F. Collen, MD, was also an early leader in health informatics. Collen was born and raised in Saint Paul, Minnesota, and received his bachelor’s degree in electrical engineering and his medical degree from the University of Minnesota. In 1942, Collen joined the Kaiser Company (which was reorganized and renamed Kaiser Permanente [KP] in 1951). In 1961, KP’s cofounder and chief of staff, Sidney Garfield, MD, appointed Collen founding director of the Department of Medical Methods Research. The focus
of the department was “to develop better methods by using computers for providing patients’ care.” By the mid-1960s, Collen was directing company resources toward computerizing patient screening. As Collen has described, in 1963, KP’s Oakland medical center had begun using “an IBM 1440 computer to store and process the patient data collected during multiphasic health checkups in both the Oakland and San Francisco medical centers.” Between July 1964 and June 1965, the Oakland medical center had processed 35,000 computer-stored medical records. In Collen’s computerized multiphasic screening system, computers were used to track the thirty-one tests administered by physicians, nurses, and the patients themselves in the screening center. As historian Joseph November has noted, by the late 1960s, “many of KP’s 2 million patients had been screened using Collen’s system.” As Jochen R. Moehr, MD, PhD, recalled, “within a decade, Dr. Collen accumulated several millions of health checkup data sets on more than a million subjects, creating in the process not only a prototype electronic health record, but also a phenomenal basis for research, and this despite the immaturity of the technology available in the fifties and sixties.”

Collen’s efforts went beyond computerized multiphasic screening. In 1965, Collen’s Department of Medical Methods Research established a subsidiary computer center to “develop a prototype MIS [medical information system], with the specific objectives of developing: a central integrated database with a computer medical record for each patient in the hospital and in the office; medical application subsystems for multiphasic testing, clinical laboratory, hospital admissions, and bed census; and retrieval programs to scan the database for health services and epidemiological research.” By 1970, Collen and colleagues had developed an operational “physically integrated, continuing, computer-based medical record” that was “structured to store all classes of patient-related data (identification, administrative, and clinical data) from inpatient, outpatient, and ancillary services.” New data could be continually updated in the system over the lifetime of the patient. The system was also capable of “accepting the variable format of medical data input, and of responding to the need for retrieving data in real time from individual patient records.”

Warner’s HELP system, Barnett’s COSTAR system, and Collen’s prototype medical information system were all innovative systems developed in the same period. However, while HELP and COSTAR thrived and are still in use today, Collen’s system was never fully developed and implemented. Collen’s medical information system project had been financed partly by a National Center Health Services Research and Development grant and partly by KP. Because of the declining economy and President Nixon’s cuts to federal spending, including funding of medical research, the federal government terminated the Health Service Research and Development grant program in 1973. As a result of the costs associated with further developing the medical information system, KP decided to discontinue funding the project. “So,” Collen recalls, “we had to close down all the computer systems development. At that time, we had electronic medical records in our database for more than one million patients, and that legacy database is still used to this day for longitudinal research studies.”

Although health informaticians were working in other domains of research during the 1960s and 1970s (such as mathematical modeling and simulation; database design, development, and implementation; and signal processing), the work by Warner, Barnett, and Collen on the development of medical information systems was central, not only to garnering institutional, federal, and industry support for health informatics, but also to improving health care delivery. Shortly after these medical information systems were implemented it was clear that the systems were improving workflow, saving time, reducing errors, and improving care.
Photo courtesy of the National Library of Medicine

Homer Warner, MD, PhD, c. 1970
Photo courtesy of Special Collections Department, J. Willard Marriott Library, University of Utah
Homer Warner, MD, PhD, (left), with two colleagues, at the University of Utah.
Photo courtesy of Special Collections Department, J. Willard Marriott Library, University of Utah

Octo Barnett, MD, c. 1987
Photo courtesy of the Countway Medical Library, Harvard University
Morris Collen, MD, c. 1975


Morris Collen, MD, explains how blood is analyzed by the equipment in the foreground and results fed to the computer (January 1966). Listening are (l to r): Dr. Cecil D. Cutting, Kaiser Permanente Medical Group, Executive Director; Representative John Fogarty of Rhode Island, Chairman of the House Appropriations Committee; Dr. Eugene Guthrie, Chief of the Chronic Diseases Division of the Bureau of State Services; and Dr. Aaron Christensen, Assistant Surgeon General of the Public Health Service and Chief of the Bureau of State Services. Senior Chemist George Young looks on (far left).

**Why History Matters**

In a 2014 interview reviewing the history of health informatics at the University of Minnesota, Läel Gatewood, PhD, FACMI, director of the University of Minnesota’s Division of Health Computer Sciences from 1979 to 2000, asserted, it’s important to acknowledge that “we’re stepping on the shoulders of others.” Gatewood referred in particular to Eugene Johnson, PhD, the founding director of the University’s Biomedical Data Processing Unit, Eugene Ackerman, PhD, FACMI, the first director of the Division of Health Computer Sciences (1969–1979), and her colleagues and early supporters of health informatics at the University of Minnesota in the 1960s and 1970s. Gatewood referred also to her fellow pioneers in health informatics who worked outside the University of Minnesota, the likes of Warner, Barnett, and Collen, whose foundational research and development—like that of Gatewood and her University of Minnesota colleagues—was helping to transform biomedical research, health care delivery, and education.

Similarly, in his 2014 interview, Donald Connelly, MD, PhD, FACMI, who directed the University of Minnesota’s Division of Health Informatics (the successor to the Division of Health Computer Sciences) from 2001 to 2005, and subsequently the Institute for Health Informatics from 2006 to 2008, expressed the importance of acknowledging the individuals and the work done by those individuals in getting health informatics established at the University: “Thanks to some of the early folks in the informatics scene here, including Gene Ackerman and Läel—Läel has been tireless—ensuring that there are informatics opportunities and academic learning at this institution. I think all of us who’ve followed have a great deal of thankfulness and gratitude for their laying down the original foundation and pathway.”

This is one reason why history matters; to first identify and then acknowledge the critical roles played by individuals in establishing a new discipline, a new academic home for the discipline, a new graduate and training program for training the next generation of researchers, clinicians, and educators in the discipline, and in establishing new research agendas for the discipline. As Gatewood and Connelly’s comments indicate, such developments do not take place because of the actions of a single individual, they occur only through the collaborative efforts of multiple individuals. These efforts, however, inevitably involve setbacks, disagreements, negotiations, unintended consequences, and paths not taken. The efforts of individuals—sometimes working cooperatively and other times at odds—always take place in the social and cultural context of the particular time and the particular place. Politics—institutional, professional, local, state, and national—matter a great deal. For example, the levels of federal funding for health informatics are—and have always been—determined by national spending priorities (as set by Congress), which in turn are influenced by health policy imperatives and thus national politics. The degree of support a department or division of health informatics receives from its university is in turn contingent on institutional funding priorities, university budgets, and, thus institutional politics (at a state-supported school, the state budget and state politics). History then, is never a story of inevitable linear progress.

By examining the history of health informatics at the University of Minnesota, we are not only documenting that history—inevitable in and of itself—we are also giving insight into the influence of institutional, state, national, and professional politics on the making of a new discipline. This is a very timely moment to do so. While the University of Minnesota is celebrating fifty years of health informatics in 2015, the field of health informatics is barely a few years older. Until very recently, only a handful of histories had been written of the field and all but one of those was written in or before the 1990s. All of these histories have focused exclusively on medical informatics.
and none has taken that history beyond the 1980s. Recently, however, the major informatics associations are beginning to document the field’s history. In an innovative project initiated by Delaney in 2000, AMIA established the Nursing Informatics History Project. The project, which was led by Bonnie Westra, PhD, RN, FAAN, FACMI from 2004 to 2010 (associate professor and director, Center for Nursing Informatics, University of Minnesota School of Nursing, IHI core faculty), preserves the materials of nursing informatics pioneers and nursing informatics organizations (this component of the project was started by Virginia Saba, EdD, honorary PhD, DS, RN, FAAN, FACMI, in 1997); preserves the stories of the pioneers through oral history interviews; and conducts historical research on the evolution of informatics as a specialty in nursing. There are currently thirty-three oral history interviews posted on AMIA’s website. In 2009, the IMIA Board approved an IMIA Fiftieth Anniversary History Project to produce a historical volume and other materials to commemorate the anniversary of the foundation of the Technical Committee 4 of IFIP in 1967.

It is time to bring the history of health informatics up to date and to document those institutions like the University of Minnesota that have been leaders in the field since the 1960s. Health Informatics at Minnesota: The First Fifty Years is one of the only histories of biomedical and health informatics in the United States that brings that history up to 2015. As this book shows, for fifty years, the University of Minnesota has been a center of research and educational innovation in health and biomedical informatics; it is one of the oldest graduate programs in health informatics, teaching and graduating students in biomedical computing since 1966. It is the longest continuously funded NLM training grant program. The alumni of its graduate program and NLM training programs have gone on to hold national and international leadership positions. The University of Minnesota has been a model of interprofessional health informatics education and research since its inception. This book documents the pioneering fifty-year history of health informatics at the University of Minnesota.

For more about the history of health informatics at the University of Minnesota visit http://healthinformatics.umn.edu/history
The founding of the Biomedical Data Processing Unit (BDPU) on December 17, 1964, a general purpose computer facility for the health sciences, marked the arrival of biomedical computing at the University of Minnesota. Dr. Arnold Lazarow, MD, PhD, as chairman of the University of Minnesota College of Medical Sciences Computer Facilities Committee, announced the establishment of the BDPU, which would later evolve into health informatics. Eugene Johnson, PhD, associate professor of biometry in the University of Minnesota School of Public Health, was appointed director of the BDPU. When it was launched, the BDPU had only two full-time staff—Johnson and a senior programmer. The designated physical space for the computing facility had yet to be renovated. The BDPU was administratively located within the office of the dean of the University of Minnesota College of Medical Sciences. Five years later, the BDPU was relocated to the University of Minnesota Department of Laboratory Medicine (renamed the Department of Laboratory Medicine and Pathology in 1973) within the University of Minnesota Medical School and also in 1969 it was renamed the Division of Health Computer Sciences. In 2000, the Division of Health Computer Sciences was renamed the Division of Health Informatics. The Institute for Health Informatics was created within the Academic Health Center (AHC) in 2006, thus replacing the Division of Health Informatics. By 2015, the Institute for Health Informatics occupied 4,988 square feet of space in the Biomedical Library and had seventeen core faculty. This chapter tells the story of the transformation of the various institutional iterations of health informatics at the University of Minnesota, focusing on the achievements and challenges encountered during this transformation.

Establishing Biomedical Computing at the University of Minnesota

The BDPU was established as interest was growing among researchers, health care professionals, and the
National Institutes of Health (NIH) in the potential use of computers in medicine and biomedical research. By the late-1950s, Robert Ledley, DDS, and Lee Lusted, MD, were pioneering the application of digital computing to problems in biology and medicine. Since the mid-1950s, Ledley had been researching the use of operational simulation in medicine and the computerization of medical diagnosis while working in the Johns Hopkins University Operations Research Office. In 1957, Ledley and Lusted (at the NIH Airborne Instruments Laboratory) began a decade-long collaborative project to computerize diagnoses. The early work of Ledley and Lusted attracted the attention of NIH director James A. Shannon, MD, PhD, a strong advocate of biomedical computing, and R. Keith Cannan, ScD, director of the National Research Council’s Division of Medical Sciences. In 1957, Cannan established an ad hoc Committee on Medical Uses of Computers within the Division of Medical Sciences and appointed Ledley as head of the committee. In that role, Ledley (then at George Washington University Engineering School) conducted “a survey of computer use in biology and medicine” and led “the effort to persuade the federal government to help computerize those fields.” As historian Joseph November describes, Ledley’s survey work caught the attention of Senator Hubert H. Humphrey (D-MN), a long time advocate of government support of science and technology. Humphrey “commissioned the publication of Ledley’s survey in 1960 as an official Senate report titled Scientific Achievements and Future Possibilities for Computers and Other Electronic Devices in Medicine and Related Biology.” It is perhaps no coincidence that at this time, Minnesota was home to a burgeoning computer industry.2

Ledley’s report garnered significant Senate support, and capitalizing on this, in 1960, Shannon established the Advisory Committee on Computers in Research (ACCR) within the Division of Research Resources “for the express purpose of facilitating computer use among biomedical researchers.”3 Lusted served as its first chair. The establishment of the ACCR signaled the beginning of the federal government’s investment in biomedical computing. As November explains, “Drawing directly from the monies Congress had apportioned to the NIH . . . the ACCR would evaluate and directly fund computer-related research. Effectively, the ACCR had been handed a blank check.”4 The impact of the ACCR’s grant program cannot be understated. By the end of 1963, the ACCR had awarded “$17,873,263 to grantees, and had committed another $23,081,114 to them for the years 1964 and 1965.”5 In 1962, Congress authorized the expenditure of $2 million by the ACCR to establish centers that would “foster the sciences of biomathematics and biomedical electronics, with particular emphasis on the application of computers to biomedical problems.”6 The federal government’s substantial investment in biomedical computing in the early 1960s established the biomedical computer as a viable area of research, framing the University of Minnesota’s early efforts to enter the field.

In 1962, cognizant of these early discussions about the potential applications of computers to medicine, dean Robert Howard of the University of Minnesota College of Medical Sciences appointed a subcommittee of the College’s Computer Facilities Committee “to consider the question of setting up a computer facility in the Medical School for clinical data storage and retrieval for research purposes in various areas, including cancer, heart disease, neurology, psychiatry, and obstetrics.”7 The College of Medical Sciences was composed of the Medical School, School of Public Health, School of Nursing, and University Hospital and Clinics. The dean of the College of Medical Sciences also served as dean of the Medical School, whereas directors were appointed to lead the schools of public health and nursing and a hospital director to lead the University Hospital and Clinics. The dean of the College of Medical Sciences had ultimate authority over all units within the College.
Dean Howard’s decision to appoint a subcommittee of the Computer Facilities Committee reflected his concern that valuable clinical data was being recorded and filed every day in the University hospitals “in such a way as virtually to lose them for future investigative use.”8 The subcommittee “made a preliminary survey of current or prospective computer applications in the Medical School,” supplementing the survey “by personal meetings with representatives of at least 5 private firms and correspondence with over 40 others.” In January 1964, IBM offered to conduct a “no strings attached” survey and submit a report that would include “an evaluation of the need (present and future) of the Medical School for computer facilities and recommendations for best meeting such need as exists, in terms of both hardware and personnel.”9

On the basis of these surveys and conversations, the College’s Computer Facilities Committee—at that time chaired by Nathan Lifson, MD, PhD, of the Department of Physiology—determined that “computers will play an increasing[ly] important role in biomedical research and that this application can be facilitated by a cooperative effort between biomedical scientists, biostatisticians, systems engineers, and programmers.” They also concluded, however, that at that time both the College of Medical Sciences and the University’s central computing facility, the Numerical Analysis Center, lacked “adequately trained, interested personnel . . . who can translate adequately the needs of the biologist into terms that can be programmed into and analyzed by the computer.” Likewise, the committee found that “[m]ost biomedical scientists, because of limitations in their physical sciences training, are not able, without extensive guidance or further training, to define their problems sufficiently in mathematical terms or to write their own computer programs.” Thus, the committee concluded, “more training and encouragement in the use of computers must be available within the College of Medical Sciences.”10

The committee launched plans “to establish a computer-oriented biomathematical group of individuals within the College of Medical Sciences.”11 To this end, the Computer Facilities Committee planned to submit an application in February 1965 for a NIH National Center for Research Resources grant (previously the ACCR grant program) to establish a biomedical computing facility at the University of Minnesota. A prerequisite for obtaining a Research Resources grant, however, was to have in a place “a suitable ‘Director’ of the proposed facility.” In May 1964, the College’s Computer Facilities Committee recommended to dean Howard that the College of Medical Sciences establish a position for a director of biomedical computing. Dean Howard approved and the committee began looking for appropriate candidates.12

The committee also developed a proposal to request permission from the University of Minnesota’s all-University Computer Committee to establish a biomedical data processing facility within the College of Medical Sciences. The Computer Facilities Committee recognized that “support of the all-University committee would be essential for both the establishment of the Medical School facility and its successful operation.” Although the subcommittee had pointed to the inadequacies of the University’s computing facilities as one justification for establishing a biomedical computing facility, the Computer Facilities Committee made clear that their goals were not provincial but rather inclusive: “any arrangement should serve the interests of the University as a whole.”13

In August 1964 the College of Medical Science’s Computer Facilities Committee submitted its first proposal to the all-University Computer Committee. Following a series of informal conversations between members of the Computer Facilities Committee and the University administration, both the administration and the all-University committee recommended that the College’s Computer Facilities Committee revise their proposal to include more precise plans for
the facility, particularly regarding the system’s hardware requirements. The College’s Computer Facilities Committee, now chaired by Arnold Lazarow, MD, PhD, of the Department of Anatomy, submitted their revised proposal on October 9, 1964. Their proposal included the following:

1. Establishment within the College of Medical Sciences of a biomathematical group with personnel knowledgeable in the use of modern electronic data processing systems. This group would be able to interact effectively with biomedical scientists and would formulate their needs in terms that can be programmed for and analyzed by the computer. Biomathematicians, systems analysts, systems engineers, and programmers will be included in this specialized staff.

2. Establishment of one or more small data preparation units within the [College of Medical Sciences], which can be linked as satellites to the Numerical Analysis Center and to other large computing systems [such as Control Data Corporation’s Processing Center in Minneapolis] . . .

3. Provision of instruction and training of biomedical scientists in the use of modern data processing equipment and techniques toward the solution of numerous biological and clinical research problems.

4. Provision of a consulting group and adequate peripheral equipment for analog-digital conversion of biomedical data. Provision must also be made for adequate pre-processing of original data.14

The proposal also included a request of “$50,000 for the initial development of a minimal physical site within the Medical School that would house personnel, satellite link and necessary ancillary equipment.”15 Four days later, on October 13, 1964, the University Computer Committee granted the College of Medical Sciences approval to establish a biomedical data processing facility. The proposed location for the facility was an area of unfinished space in the basement of the Masonic Memorial Hospital.16

That month, the Computer Facilities Committee identified Eugene Johnson, PhD, associate professor of biometry in the School of Public Health, as the ideal candidate for director of the proposed facility. Johnson had earned a BA (1949) and MA (1950) in Mathematics and a PhD (1956) in biostatistics from the University of Minnesota. In addition to holding faculty positions in biometry and industrial engineering at the University, and in mathematics at Gustavus Adolphus College, Johnson had consulted in operations research and experimental computer design for numerous companies, including Scientific Computers, Inc.; Sperry-Rand; Cargill; Green Giant; and International Milling. Johnson also had broad experience with computer applications and, perhaps most significantly, during his tenure in biometry at the University, “nearly one-half of his time was spent in cooperation with investigators in medicine and biology. During this period, extending over sixteen years . . . Dr. Johnson . . . had numerous contacts with nearly every department in the Medical Center . . . A large number of students and staff have thus benefited substantially in their research from Dr. Johnson’s ability 1) to grasp a problem, 2) to design an experimental approach to it, including problems of measurement, and 3) to evaluate the resulting data objectively and critically.” In addition to having demonstrated administrative abilities by coordinating group research efforts, committee member Franz Halberg concluded that “Dr. Johnson’s major forte consists of a background that weds with training in mathematics and biostatistics, an on-the-job familiarity with biology and medicine, that can be acquired only by long-term and across-the-board consulting, in a Center such as that at the University of Minnesota.”17

Lazarow announced the establishment of the Biomedical Data Processing Unit (BDPU) on December 17, 1964, at which time Eugene Johnson resumed responsibilities as director. On January 1, 1965, dean
Howard made Johnson’s appointment as director of the BDPU official. Johnson’s appointment was 50 percent time as director and 50 percent time as associate professor in the School of Public Health’s Division of Biometry; his salary was $17,000 per annum, paid by the College of Medical Sciences (the School of Public Health was located within the College of Medical Sciences). The only other full-time staff appointed to the BPDU was senior programmer, Michael Diffley, whose salary was also paid by the College. The BDPU, however, did not yet exist in physical form. The renovations to the unfinished space in the basement of Masonic Memorial Hospital were estimated to cost between $102,000 and $132,000.

As the Computer Facilities Committee had been planning since May 1964, in February 1965, Johnson submitted an application for an NIH Research Resources grant to support both the cost of these renovations and provide salary support to enable the recruitment of sufficient personnel to staff the BDPU. In that proposal Johnson requested salary support for (in addition to himself and Diffley) a systems analyst, a systems engineer, a biostatistician, a mathematician, four programmers, and several support staff positions. In addition to requesting funds for renovation, Johnson requested funds for the purchase or renting of computer equipment. The grant application was successful. Effective September 1, 1965, the BDPU was awarded a $216,300 Research Resources grant (RR-267). The BDPU—and its successor, the Division of Health Computer Sciences—received continuous NIH Research Resources funding through December 31, 1975.

Johnson had noted in the NIH proposal that the recruitment of a research professor in biomedical computing was “important to the overall plan” of the BDPU. Johnson and the College of Medical Sciences Computer Facilities Committee, however, had decided to approach local funding sources to support the position. During the fall of 1965, Johnson successfully applied to the Hill Family Foundation to support a research professorship in biomedical computing sciences. The foundation provided five years of funding, subsequently renewed for five years but with decreasing amounts each year, to support the Hill Family Foundation Professorship in Biomedical Computing Sciences. In July 1967, Eugene Ackerman, PhD, was appointed Hill Family Foundation Professor of Biomedical Computing and professor of Biometry in the School of Public Health. Ackerman had earned a BA in Physics from Swarthmore College in Swarthmore, Pennsylvania, in 1941; an ScM in Physics from Brown University in Providence, Rhode Island, in 1943; and a PhD in Biophysics from the University of Wisconsin–Madison in 1949. After receiving his doctorate, Ackerman joined the physics and biophysics faculty at Pennsylvania State University and completed several sabbaticals in the biophysics laboratory of Britton Chance, PhD, at the University of Pennsylvania during the 1950s. During this early part of his career, Ackerman’s research focused on mathematical modeling of the ultrasonic behavior of cells and enzyme kinetics.

In 1960, Ackerman moved to the Mayo Clinic in Rochester, Minnesota, where he served as associate professor of biophysics. His research at the Mayo Clinic focused on the development of mathematical models of physiological systems, including the ultrasonic behavior of cells, enzyme kinetics, blood glucose regulation, and patterns of infectious disease epidemics. While at Mayo he held adjunct appointments in biophysics and computer science at the University of Minnesota and developed a Mayo satellite program of the University’s biophysics graduate program, which authorized Mayo’s program to award a MS degree in biophysics. When Ackerman arrived at the University of Minnesota, he had a national reputation in biophysics and an established and well-respected research career in mathematical modeling.

As outlined in the initial grant proposal to the NIH, the goals of the BDPU were four-fold: (i) “to provide staff, equipment and training” to facilitate
the conduct of “computer oriented research projects” in the medical sciences; (2) “to develop sufficient professional competence and local facilities so that the Biomedical Data Processing Unit will have its own research programs in the medical-computing sciences”; (3) “to stimulate investigators in biology and medical areas not now utilizing computers to be aware of the potential and to assist them in considering new developments”; and (4) to serve as “an academic unit for training specialists in medical-computing sciences.”

To fulfill these goals, the BDPU’s activities were organized into four areas: core research, a service bureau, user research, and didactic training and support.

In the first few years, the BDPU’s core research work focused on developing a computer network built around its Control Data Corporation 3300 computer and connected to the University Computer Center’s Control Data 6600 computer to serve the research and educational needs of the College of Medical Sciences. As of late 1968, the BDPU envisioned its network consisting “primarily of smaller peripheral computers, each having stand-alone capability and each capable of communicating with the 3300. . . . Each peripheral computer could serve several adjacent laboratories or one laboratory might have many smaller computers.” The BDPU research staff were in the process of developing hardware and software for the communications network.

The research staff’s second research area focused on problems in simulation and nonlinear optimization. An increasing number of researchers in the School of Public Health’s Division of Biometry, and the Medical School’s departments of physiology, radiology, and biochemistry were using mathematical models to study complex biological systems with the aid of computers. The use of computers, however, required the adjustment of optimal values that matched the model as closely as possible to the experimental data, which depended on biomathematical considerations. The aims of the BDPU researchers were “to optimize the use of the investigators’ time and to allow him [sic] to focus on biological considerations rather than the details of electronic stimulation.” As such, they were investigating schemes and programs for parameter optimization.

A third area of research was the development of new software to improve graphic display techniques. One BDPU staff member developed a user-oriented plotting and display software that allowed a user to obtain “single or multiple X-Y graphs on the incremental plotter, the high speed printer or the CRT unit.” The only information the user needed to supply to use the software package was the coordinates and number of points to be graphed, labels for the axes, and a table. The software also included many optional control features. The staff member was also working on developing a contour display that would use “both the incremental plotter and the high speed printer in order to present digitized images obtained from sources such as films or television pictures produced by x-ray, light microscopy or electron microscopy techniques.”

The BDPU’s fourth research project concerned the use of statistical techniques as an aid in the diagnostic process and as a screening tool in conjunction with automated measuring devices. As of late 1968, the staff had “developed a new method for evaluating the ability of a variable set and classification procedure to classify,” which had been applied successfully in “5 or 6 different clinical research areas.”

The BDPU’s Analysis and Programming Service Bureau provided advice and design in logical systems, electronic systems, and computer programming to students, faculty, and staff in the College of Medical Sciences. Although initially the BDPU had provided this consulting service for free, as of July 1, 1968, the NIH required the BDPU, as a condition of the Research Resources grant, to charge for all computer time. From the NIH’s perspective, “the federal budget available for computer facility support had dwindled” because of the “tremendous increases in demands for computer utilization. . . . The fee-for-
service system shifts an appropriate share of the responsibility over to . . . individual investigator-users of the facilities.” The NIH hoped that requiring the Medical School or University Hospital to contribute substantial support to the facility would prevent the biomedical computing facilities from turning into “a mundane, uninspired, technical service operation.”31

As a result of the new NIH policy, the University established the BDPU’s Service Bureau as a non-profit, fee-for-service entity. Aware that some researchers without their own sources of funding, especially graduate students, would not be able to afford the computer charges, the BDPU established “a local granting agency” that would “receive and evaluate applications for computer usage. Those who are awarded such grants will receive credits for computer hours which they may use to meet the charges which will be billed to them directly.”32 In the first six months of 1968, the Service Bureau had provided consulting services to research projects conducted in the departments of anatomy, medicine, ophthalmology, pediatrics, physical medicine, and medical administration in the Medical School, the divisions of environmental health, hospital administration, and biometry in the School of Public Health, and University Hospitals, the University Health Service, the V.A. Hospital, Hennepin County General Hospital, the Mayo Clinic, and the Minnesota Department of Health.33

A major area of focus for the BDPU, in which staff served as co-investigators or consultants, was that of user research. As the BDPU’s 1968 annual report noted, “Several hundred pages would be insufficient to present in detail the wide variety and range of topics of the research projects of the users of the [BDPU] Control Data 3300 system.” The report highlighted several types of user research. One such type of research involved the development of techniques and software to manage and analyze large data files, either for ongoing data collection or for retrospective studies. For example, in the late 1960s the BDPU staff collaborated on the Minnesota Coronary Survey and the Red Lake Indian Study. In the first, the BDPU’s staff worked with epidemiologists in the School of Public Health to track the relationship of cardiac risk factors to the incidence of coronary disease. Their work involved getting a weekly census of all the participating patients at the seven state hospitals and printing meal labels for every patient; the labels indicated whether the patient would receive the low-saturated-fat treatment or the control diet. In the second, the BDPU’s staff supported the work of physicians in the University of Minnesota’s departments of laboratory medicine and pediatrics on a prospective study of streptococcal and staphylococcal infections in children living on the Red Lake Indian Reservation. The staff were responsible for handling the data produced by the detailed laboratory bacteriology and urinalysis reports collected every two weeks for two years on several hundred children.34

The final aspect of the BDPU’s activities centered on providing training support in computer science to the users and prospective users of the BDPU, and educating graduate students in biomedical computing. By 1968, the BDPU offered didactic courses and seminars in computer programming, computer applications, and mathematical biology through the Division of Biometry in the School of Public Health. Several PhD candidates in biometry conducted research under the supervision of the BDPU staff. Several graduate students in biometry, biophysics, and environmental health were working on dissertation topics that depended on the availability of computer time in the BDPU and were being “assisted with informal instruction in programming, computer operation and mathematical biology as needed.” The BDPU was also developing plans—and looking into potential funding sources—to establish a postdoctoral training program that would enable “senior faculty members in the biomedical sciences as well as medical residents in various specialties . . . to spend about one year studying the use of mathematics and computers in medicine and biology.” The envisioned training program
would consist of existing didactic courses, supervised independent reading and exercises, and an appropriate research project.\textsuperscript{35}

In July 1968, Eugene Johnson suffered a mild heart attack. During his illness and recovery, Eugene Ackerman served as interim director. Although Johnson recovered and resumed some of his former responsibilities, he resigned as director of the BDPU at the end of December 1968.\textsuperscript{36} During that fall, dean Howard of the College of Medical Sciences had asked the College’s Computer Advisory Committee (previously the Computer Facilities Committee) to consider the possibility of administratively relocating the BDPU. On April 1, 1969, the BDPU was reassigned as a division of the Department of Laboratory Medicine (after 1973, the Department of Laboratory Medicine and Pathology) in the Medical School, where Ellis S. Benson, MD, served as chair. The BDPU was also renamed the Division of Health Computer Sciences (DHCS). Ackerman was appointed director of the Division.\textsuperscript{37} The following year, the College of Medical Sciences was dissolved and the University’s previously autonomous College of Pharmacy and School or Dentistry were reorganized, along with the Medical School, schools of nursing and public health, and University Hospital and Clinics, into a centrally organized and administered academic health center referred to as the University of Minnesota Health Sciences Center (the College of Veterinary Medicine was incorporated into the Health Sciences Center in 1985). Each of the health science units was led by a dean, and the University Hospital and Clinics was led by a hospital director; both reported to the vice president for Health Sciences. The DHCS was granted “clearer research service responsibilities and a broader mission to explore the applications of biotechnology [computing] to the health sciences.”\textsuperscript{38} At that time, the DHCS was composed of five faculty, six research fellows, one instructor, nine full-time programmers and programmer trainees, seven administrative and technical support staff, and six graduate student assistants.\textsuperscript{39}

By 1971, Ackerman had organized the DHCS into four new operational units. The first, Health Computer Service, led by Bruce Borass and composed principally of programmers, provided programming support and other computer services to students, researchers, and faculty in the health sciences. One of the goals of the Service was for the applications programming staff “to contribute their accumulated knowledge and experience toward computer utilization in health care analysis, health care delivery, and health science research.” As had the BDPU’s Service Bureau, the Health Computer Service charged fees for their services.

The second unit, the Health Sciences Computer Systems, led by Michael Diffley, developed and maintained DHCS’s hardware and software systems. During the early 1970s, the staff in the Computer Systems section were engaged in “continuing efforts to extend the computer facilities at [DH]CS to a wider range of Health Science investigators through remote access.”\textsuperscript{40}

The DHCS’s third unit, Biotechnology Research, led by Laël Gatewood, included all core research projects in which DHCS faculty members were principal investigators. Such research focused on applications where the computer programs or techniques met “one of the following goals: 1) a new application not previously demonstrated elsewhere; 2) an extended application which is usable by a wide variety of local users; [or] 3) an augmented application which makes the biotechnology resource valuable to a new group of users.” The staff’s main areas of research interest involved “physiological systems described by mathematical models, and simulation and analysis of such models by various computer techniques.” In particular, they were studying various systems that included virus epidemics, blood-glucose regulation, biochemical monitoring, patient monitoring, myocardial revascularization, diagnostic classification, and donor blood distribution.\textsuperscript{41}

The DHCS’s fourth operational unit was Health Care Technology Training, also led by Gatewood.
Because research training was not under the purview of the Research Resources grant, the training offered by the DHCS’s faculty was supported by non-grant funds. That training continued and expanded upon the earlier training initiatives provided by the BDPU: informal seminars, short noncredit courses, and graduate-level courses.\(^{42}\) To stabilize and expand its training program, the DHCS looked for additional funding. In 1974, after a series of false starts (described in chapter two), the DHCS was awarded one of the first grants from the National Library of Medicine’s (NLM) new Training in Health Computer Sciences grant program.

Despite the overwhelming demands for consulting services and research collaboration and support placed on the BDPU and DHCS staff, tensions emerged early on between Johnson and Ackerman and the health sciences administration over the academic status and institutional support afforded the unit. These tensions would continue to plague the BDPU and the DHCS for several decades. In April 1968, Johnson wrote an open letter to the College of Medical Sciences Computer Advisory Committee (previously the Computer Facilities Committee), which Lazarow still chaired. In it, Johnson noted that when he’d been appointed BDPU director it had been a “mutually agreed upon” goal to “develop an academic specialty scientific area and that [the BDPU staff] would have academic appointments.” And further, “The casual way in which this agreement was accomplished has been a source of disappointment to me since we started.”\(^{43}\) Johnson saw part of the problem in the committee’s lack of understanding about what actually constituted medical computing sciences. The “routine calculations on statistical analysis, solving sets of differential equations or sets of linear equations” was, Johnson emphasized, “a very small part of medical computing . . . [and] this glorified desk calculator orientation to the computer is no justification for the existence of our medical computing facilities.” Rather, Johnson argued that the primary justification for the facilities, staff, and equipment of the BDPU centered on the “consideration of systems which will involve the computer as an essential ingredient.” For Johnson this meant “the systems which must be studied (research) and taught to students (education) and implemented (patient service).” The BDPU’s professional staff were best able to lead these efforts, Johnson argued, by integrating recent developments in “systems analysis, operations research, bioengineering, and biometry” into efforts to develop “feed-back control systems, hospital information systems, programmed learning, diagnosis strategies, etc.” At that time, however, the BDPU’s staff had “no academic status[,] which give us no right to comment” and meant they were excluded from any such systems planning in the Health Science Center and University Hospital.\(^{44}\)

Key to raising the academic standing of the BDPU, Johnson argued, was for “the professional aspect of this group to be taken seriously.” As an example, if researchers within the College of Medical Sciences (and later, the Health Science Center) were to undertake a project involving “systems analysis, biomathematics, file management etc. and is going to require hiring of special personnel or obtaining specialist consultants, this group [the BDPU] should be encouraged to take the project.” In this regard, Johnson insisted the professional judgment of the BDPU staff should be respected. Equally important, however, was the College’s commitment to building biomedical computing as an academic discipline. Johnson argued that it would be difficult to recruit competent professionals to the BDPU unless they were shown proof that such discipline-building was already taking place. As part of this, Johnson insisted part of their support needed to come from academic work, including teaching new courses and advising graduate students.\(^{45}\)

A related and persistent tension that confronted Johnson and constrained the BDPU and its institutional successor, the Division of Health Computer Sciences (DHCS), concerned the chronic lack of institutional and state funding and the continual reliance
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on so-called soft federal funding. The lack of institutional support was especially pressing when federal funding was threatened or reduced. Indeed, the NIH biomedical computer Research Resources grant program began to diminish in the late 1960s, reflecting a change in policy at the NIH. As historian Joseph November has documented, in January 1964 the Advisory Committee on Computers in Research (ACCR) was reconstituted as the NIH Computer Research Study Section and in the process the study section was stripped of the ACCR’s earlier autonomy and authority. Where the ACCR had directly funded biomedical computing projects, as a study section, “the CRSS [Computer Research Study Section] could only recommend to NIH institutes how they should allocate their resources to projects that would ostensibly make significant use of computers.”

The work of the Computer Research Study Section and of the proponents of biomedical computing on the NIH campus were, as November explains, hampered by the fact that despite the ACCR’s “glowing 1964 self-assessment,” there was “a growing consensus . . . the group’s work had yielded little in the way of recognizable (that is, published) results.”

The Special Resources Branch of the NIH’s Division of Research and Facilities Resources (established in 1962) provided ongoing support to the biomedical computing projects initiated under the ACCR grants program and provided additional grants to assist institutions in acquiring computer equipment. Bruce D. Waxman, PhD, led the Special Resources Branch until 1968. As November describes, under Waxman’s leadership the Special Resources Branch continued the original mission of the ACCR to foster the development and application of biomedical computing to research and clinical practice. However, when William F. Raub, PhD, replaced Waxman as head of the Special Resources Branch in 1968, the mission of the Division of Research and Facilities Resources changed. “Broadly, the DRFR’s [Division of Research and Facilities Resources’] policy was, in Raub’s words, to ‘create, nurture, withdraw.’” This meant that “the DRFR would provide money for several years to create a computing center, then help that center grow to the point where its use would become ‘routine,’ and finally withdraw support when the center became self-sufficient.”

This change in NIH policy led to the gradual decline in Research Resources grant support to the BDPU beginning in the late 1960s. Reflecting on this period, Raub saw the reduction in funding being due to “1) the overall slowdown in Government research spending and 2) the rather cautious attitude on the part of the mainstream of the biomedical research community as to just how far the community can (and should) penetrate their discipline.” For example, during the grant year 1968–1969, the NIH had reduced the BDPU/DHCS’s budget of approximately $650,000 in direct costs by $140,000 without providing any guidelines or directions on what activities to eliminate.

Amidst declining NIH funding, Ackerman fought to secure increased institutional support for the DHCS. During a site visit in the spring of 1971 by the NIH’s Division of Research Resources, the evaluation team had expressed concern about the University’s “meager financial support” of the DHCS. The Medical School administration responded with assurances of its “continuing strong interest in and deep concern for the ongoing program of teaching, research, and service provided by the Health Computer Sciences Division,” but explained that unfortunately “translation of those interests and concerns into ‘hard’ University and State support is a most difficult problem in the present period of contracted state support to the University of Minnesota, and therefore, in turn, for basic financing in the Medical School.”

Certainly, the 1970s was a period of declining state support for the University. Associate dean of the Medical School, Mead Cavert, explained that the school planned in the 1971–1972 fiscal year to redistribute $15,000 of University funding received from the
State of Minnesota from other activities into DHCS, and planned to allocate an additional $20,000 annually of University funding received from the State to DHCS in the 1972–1973 fiscal year, “to the extent that such funds become available to the Medical School from University redistribution of resources within a University-wide program now being implemented toward 1972–73 budgeting.” Cavert explained that under this University plan, “reallocation of State-allocated funds will be made to programs and units within the University judged to be of relatively high priority in meeting the University and State’s educational objectives. The Medical School will be able to allocate some of those funds to the high priority needs of the [DHCS].”

Although securing institutional support for the DHCS continued to be a struggle, by 1978, support of the core faculty had increased. By then the level of recurring state funding was over $100,000, which supported 25 percent of the DHCS teaching faculty’s time. Most significantly, in 1974, with Ackerman as principal investigator, the DHCS had been awarded a National Library of Medicine training grant. The NLM Training Grant Program, which is discussed in detail in chapter two, prepared pre- and post-doctoral fellows “to serve as scientists in health services computer facilities, as instructors in health services training programs, as coordinators for health delivery facilities, and as independent investigators capable of originating and directing significant programs in biotechnology as applied to health services research and development.” The DHCS went on to receive ten years of continuous funding from the NLM Training in Health Computer Sciences grant program through June 30, 1984, when the focus of the NLM training grant program changed. In those ten years, the DHCS supported thirty-seven pre- and post-doctoral students on the training grant.

In addition to fighting for institutional support, as director of the DHCS, Ackerman also had to continually assert the academic status and place of biomedical computing within the Department of Laboratory Medicine and Pathology. Donald Connelly, laboratory medicine resident, Public Health Service Fellow and doctoral student in the DHCS, and subsequently assistant professor in the DHCS during the 1970s recalled that while Ellis Benson, MD, chair of the Department of Laboratory Medicine and Pathology was very supportive of DHCS, the rest of the department “was led by, if not physicians, then by PhDs that had a classical bioscience type of background in chemistry or something of that nature.” Connelly continued that he “could sense his [Ackerman’s] frustration at times of not being quite in the club, if you will, of departmental players, our players. But I think that was because informatics was different than everything else. I think he did everything he could to be an effective resource gatherer in that situation.”

After ten years Eugene Ackerman stepped down as director of the Division of Health Computer Sciences in 1979. In those ten years Ackerman had transformed biomedical computing on the University of Minnesota campus. The BDPU served primarily a service role within the health sciences, training students and faculty in the use of computers in biomedical research and supporting those research efforts. In contrast, the DHCS’s primary role was an academic one. During his tenure, Ackerman marshaled additional institutional support, and with funding from the NIH Research Resources grant and a NLM Training in Health Computer Sciences grant, he oversaw the establishment of the graduate program in biometry and health information systems (discussed in chapter two), and hired additional faculty, research associates, and programmers to the division. By 1979, DHCS had six faculty members with appointments in the Department of Laboratory Medicine and Pathology: professor Eugene Ackerman, PhD, associate professors Stanley Finkelstein, PhD and Laël Gatewood, PhD, and assistant professors, Myra Chern, PhD, Donald Connelly, MD, PhD, and Lynda Ellis, PhD. Stanley Finkelstein, PhD, hired by Ackerman
in 1977, speculated, “If Gene were not here and were not able to convince people . . . without his vision and his leadership, there would not have been a Division of Health Computer Sciences.”

The Division of Health Computer Sciences, 1979–2000

On July 1, 1979, Laël Gatewood, PhD, was appointed director of DHCS. The appointment was fitting. Gatewood had worked with Ackerman at the Mayo Clinic since 1962. In 1967, when Ackerman joined the faculty of the BDPU, Gatewood moved with him and was hired as a research fellow in the Division of Biometry in the School of Public Health. Gatewood also served as an advisor and technical writer for the BDPU while working on her PhD in biometry (which she earned in 1971). Along with Ackerman, Gatewood thus had the longest tenure at the BDPU and DHCS.

Indeed, Ackerman had for some time been preparing Gatewood to eventually take over from him. As Gatewood reflected, “I think he trained me as his protégé to take over everything that he started . . . He initiated a number of things that he, then, left for me to do, and they were all things that I enjoyed doing.” From the beginning of their working relationship, Ackerman had pushed Gatewood in directions she “had not anticipated. Doing a master’s and doing a PhD was not planned. Writing articles was not planned, nor presenting them at national meetings. Teaching classes, and helping to develop and continue a training program; helping to develop and continue the Simulation Resource; each of these, I thought, well, he’ll just go on planning. So I just took on more and more of the work. . . . He set the vision but, then, I continued working towards that goal during the next years. So tremendous incentive, a tremendous mind that I could not hope to emulate.”

Under Gatewood’s leadership, the DHCS training and research programs grew, supported by major federal grants. As mentioned above, the DHCS received ten years of continuous funding from the NLM training grant program from 1974 until the NLM changed the focus of the grant program in 1984. That year, the DHCS was awarded a new NLM training grant, and would go on to receive 25 years of continuous funding through 2009. The long history of the DHCS’s NLM training programs is discussed in detail in chapter two. The NLM training program is a defining element of the history of health informatics at the University of Minnesota: the University of Minnesota was among the first institutions to be awarded the NLM’s first year of training grants in 1974, and it is the longest funded training program, having received 35 years of continuous NLM training program funding.

As the NLM training program grew so too did the graduate program. Between 1973 and 1985, students wishing to obtain a graduate degree in health computer sciences did so by pursuing the Health Information Systems track of the graduate program in biometry and health information systems. In October 1985, the biometry and health information systems graduate program applied to the Graduate School to change the name of the graduate program to biometry and the DHCS applied to the Graduate School to establish an independent graduate program in health informatics. On December 12, 1986, the University Regents approved both proposals, establishing the graduate program in health informatics, offering both MS and PhD degrees (the biometry and health information systems program was renamed the graduate program in biostatistics). This history is told in detail in chapter two.

Throughout the 1980s and 1990s “the biggest thing within the Division other than the [NLM] training program, was,” as Stanley Finkelstein, PhD, asserted, “the [National] Micropopulation [Simulation] Resource.” During the 1970s, Eugene Ackerman (in collaboration with Lila Elveback, PhD, at the Mayo Clinic and John P. Fox, MD, PhD, at the University of Washington) and Gatewood had worked on population-based models of
epidemic simulation. To continue and expand upon this work, Ackerman, as principal investigator, successfully applied for a NIH Research Pre-Resource grant to establish a “simulation pre-resource for stochastic population models.” The Pre-Resource grant was awarded in September 1983 and ran through June 1987, when the NIH began funding the National Micropopulation Simulation Resource with a Research Resources grant until 1995. The DHCS’s National Micropopulation Simulation Resource was a hub of research innovation in the simulation of genetic disorders, chronic diseases, infectious diseases, neural networks, and social networks.

During the 1980s and 1990s, the DHCS faculty also produced cutting-edge research and developed innovative technologies in the fields of clinical decision-making and laboratory information systems, telehealth and home monitoring, and microbial biotechnology databases. The National Micropopulation Simulation Resource and the faculty’s research programs secured the visibility and reputation of the DHCS nationally and internationally. (The National Micropopulation Simulation Resource and the DHCS’s other research programs are discussed in detail in chapter three).

Beginning in the 1980s, the DHCS developed close ties with the Minnesota Department of Health (MDH). Between the early 1980s and early 1990s, much of the collaboration took place through the National Micropopulation Simulation Resource. Denton Peterson, PhD, at the MDH worked closely with Gatewood and the National Micropopulation Simulation Resource staff to develop simulations of influenza outbreaks and influenza vaccine efficacy in nursing homes, and simulations of HIV transmission, intervention, and prevention (described in chapter three). Another critical area of collaboration between MDH and DHCS was in the establishment of statewide registries for cancer and immunization. On both of these projects Gatewood served as health informatics consultant. In the mid-1980s, Alan P. Bender, DVM, PhD, at MDH directed the establishment of a statewide cancer surveillance registry system, the Minnesota Cancer Surveillance System. With funding from the Bush Foundation and the Minnesota division of the American Cancer Society, Bender, Gatewood, and colleagues developed the registry system by identifying cancers through pathology records. This pathology-based approach differed from traditional cancer surveillance registries that were based on hospital discharge records. The MDH established the cancer registry to “1) monitor the incidence of cancers to help identify potential public health problems; 2) target intervention resources more accurately for communities, patients, and their families; 3) inform health professionals and educate citizens about identified cancer risks, early detection, and treatment; 4) promote high-quality population-based research to provide better information for cancer control; and 5) to answer public concerns and questions about cancer.”

In the early 1990s, the MDH prioritized the establishment of a statewide immunization registry system, the Minnesota Immunization Information Connection, following a series of measles outbreaks in 1988 and 1989. MDH, along with other state health departments, confronted two major problems with childhood immunizations: “incomplete immunization records and an increasingly complex immunization schedule” were making “it difficult for parents and providers to know what shots their children and clients need[ed].” At the MDH, Martin LaVenture, MPH, and colleagues, in consultation with Gatewood, argued that immunization registries would “help make complete and accurate records more easily available to parents and health care providers.” They would also “foster the timely sending of reminder notices for children who are due for immunizations and make it possible for providers to quickly assess immunization rates in their clinic.” Furthermore, public health officials could “use registries to determine immunization rates, to identify pockets of need where immunization rates are low and to target resources.” With support from
the Robert Wood Johnson Foundation, LaVenture explains, “We worked in conjunction with Laël and the immunization program, almost to the end of the decade . . . implementing [the] immunization registry systems across the state.”63 The “Minnesota Model” was a decentralized system of “community-based registries which link together local clinics, hospitals, health plans, public health departments, and schools in each region.” Each community-based registry then links to a “state hub.”64 The establishment of the immunization registry “was a big effort,” LaVenture recalls, “because of a lot of issues that needed to be worked out. Standards kinds of issues. How do you do matching of clients? Privacy types of issues. What do records look like? What are good information models? What should be the information flow? All of that development activity was done in collaboration with [the DHCS]. That was a wonderful beginning of some collaborative efforts.”65

As evidence of the international prominence of the DHCS’s leadership in training health informaticians, in 1999 the University of Minnesota was invited to join the International Partnership in Health Informatics Education. In 1996, the University of Amsterdam established study abroad programs for its students. As part of this, the University of Amsterdam sought to build collaborative relationships between its “relatively young” medical informatics program and “older and more established medical informatics schools” in Europe and the United States. The first collaboration was established in 1998 with the medical informatics joint program at the University of Heidelberg/University of Heilbronn directed by Reinhold Haux, PhD. In 1999, “eminent professors of different universities in both countries were invited to teach” at the first “master class” held in Rolduc, a convent in the southern province of Limburg in the Netherlands. “Following the success of the Rolduc master class, the University of Minnesota and University of Utah informatics training programs were invited—and in 2000 approved—to join the collaboration.”66 As Gatewood recalled the moment, “We felt that this was quite a feather in our cap, because they went around interviewing all of the prominent NLM [training] programs at that time, and decided on the two of us.”67 The University of Minnesota hosted the third master class in 2001 and the eighth in 2006. Today only one other American university is a member of International Partnership in Health Informatics Education—the University of Washington’s Biomedical and Health Informatics Graduate Program, which is directed by George Demiris, PhD, who received his PhD in health informatics from the University of Minnesota in 2000. The other international partners include the University of Health Informatics and Technology in Tyrol, Austria, which joined in 2001, and the Graduate Institute of Biomedical Informatics, College of Medical Science and Technology, Taipei Medical University in Taiwan, which joined in 2012.68

Gatewood’s leadership in health informatics extended beyond Minnesota. In 1984, Gatewood was among the first group of fifty-five health informaticians to be inducted into the newly created American College of Medical Informatics (Eugene Ackerman, PhD, was inducted in 1985). Gatewood was one of only four women to be inducted that year. In part, Gatewood was recognized for the work she had done “bringing together several of the separate physician computing organizations.” These included the American Association for Medical Systems and Informatics and the Symposium for Computer Applications in Medical Care.69 In 1988, the American Association for Medical Systems and Informatics, the Symposium for Computer Applications in Medical Care, and the American College of Medical Informatics merged to form the American Medical Informatics Association (AMIA).70 Gatewood had served on various committees and the executive boards of the Society for Advanced Medical Systems (the first professional organization in the United States with the primary goal of advancing technology systems in medicine)
and the Symposium for Computer Applications in Medical Care, and went on to hold several leadership positions within AMIA over her career. Gatewood was also the first secretary of the American College of Medical Informatics.

As the DHCS’s reputation flourished outside the University, within it, the DHCS faced significant obstacles because of “a lack of knowledge and appreciation of what informatics is or could be.” From the 1980s through early 2000s, the DHCS struggled to secure sufficient institutional support from the University administration and the Department of Laboratory Medicine and Pathology. This coincided with over a decade of retrenchment at the University of Minnesota beginning in the late 1970s. For example, in February 1983, University president Nils Hasselmo, PhD, asked the dean of the Medical School, N. L. Gault, MD, to “to develop a plan to reduce its 0100 [state funds] spending by 9.4 percent or $2,060,000 by the end of the 1983–85 biennium.” Hasselmo outlined to Gault the “specific issues which the Medical School should consider when preparing its plan.” These included “the possible consolidations or eliminations of courses, programs, or departments in the School.” Six years later, in 1989, dean of the Medical School, David Brown, MD, wrote to Hasselmo expressing his “sadness and dismay at the recent financial actions of the University.” Brown spoke in particular of the University administration’s “disinterested, hostile and jealous” response to the Medical School’s efforts to build interdisciplinary programs with the other health science schools. Brown noted, for example, that he had been “expected to establish a first class biomedical engineering program on a shoestring both for the core program and with nothing to develop a graduate program.” For Brown it was clear, “the Medical School faculty has been told more meaningfully than in words that the University’s priorities are elsewhere,” and he was certain that “the message of antagonism and polarization . . . is likely to prevail.”

The institutional situation became particularly challenging for DHCS after Ellis Benson, MD, retired as chair of the Department of Laboratory Medicine and Pathology in 1989. In 1990, Leo Furcht, MD, was appointed chair of the department. As Stanley Finkelstein, PhD, noted, “as the overall direction of Health Computer Sciences sort of expanded, there was a general feeling—I think it was more greatly expanded when Leo Furcht became the chairman of the Department—that the core of Health Informatics was not necessarily a clinical laboratory. It was in lots of other things.” Furcht remained supportive of the DHCS but the level of support, as it had been under Benson’s leadership of the department, was minimal. “It was a very lean time,” Gatewood explained, “because of the lack of state and Medical School funding on all educational activities of his department . . . and the number of resident training positions continued to be cut because of decreases in Medicare funding, and other changes within the University of Minnesota hospitals and Fairview systems.”

As a result of these “very lean” times, Finkelstein stated, “we were not able to hire anybody to increase the level of activity and the breadth of potential research resources.” And as the faculty aged, the situation became more severe. As Donald Connelly, MD, PhD, noted, “if a faculty [member] retired, that position would be retired as well.” Reflecting this policy, during the early 1980s when the DHCS was at its peak in terms of institutional support, it had had seven or eight FTE faculty; in 1999, there were only 3.5 FTE faculty and they were “expected to continue to do the same amount of work as did the seven or eight.” It was particularly disappointing for the faculty that they had been unable to secure a tenure line for Michael Altman, PhD, who had played an integral role in the work of the National Micro-population Simulation Resource since the mid-1980s. As Gatewood explained, “Michael Altmann was extremely promising if he were to continue a computer science focus to our work and take it into the theoretical basis of social networks. This was not seen as an
area that [Leo] Furcht wanted to encourage, at that point, and he cut back because of the lack of state and Medical School funding on all educational activities of the [Department of Laboratory Medicine and Pathology].”78

There was some good news, however. In February 1995, Stuart Speedie, PhD, joined DHCS when his wife, Marilyn Speedie, PhD, was recruited by the provost for Health Sciences, William Brody, MD, PhD, to serve as dean of the University of Minnesota College of Pharmacy. Stuart Speedie came to DHCS after spending twenty years at the University of Maryland where he had built a national reputation researching the impact of health information technologies on patient outcomes, provider perceptions and attitudes, and organizational outcomes. Upon his arrival at the University of Minnesota, Speedie was appointed 50 percent time in DHCS and 50 percent time in the Office of the Provost for the Health Sciences, where he held the positions of director of Health Science Academic Information Systems until July 1996 and special assistant to the Provost for Information Technology until the end of 1999. Commenting on the status of DHCS when he arrived, Speedie recalled, “It was, in some ways, sort of winding down.” At that time, Donald Connelly had taken a brief leave to co-found Abaton.com, which specialized in the development of Internet-based applications for use by clinicians, including “electronic prescribing, lab ordering, results reporting and office workflow modules.”79 In 1999, McKesson HBOC, Inc., purchased Abaton.com and in 2000 made it a component of its new online unit, iMcKesson.80 “There was the [National Micropopulation] simulation facility,” Speedie continued, “that Gatewood had had funded for a number of years. That was closing down at about that time. . . . But there was Lynda Ellis and Stan [Stanley M.] Finkelstein and Laël C. Gatewood and myself. We were basically running the Division; although I was really the new guy on the block, at that point.” These were the 3.5 FTE faculty remaining in DHCS in 1999.81

To be sure, DHCS was not the only program in the health sciences that was struggling to secure sustained institutional support. In April 1997, senior vice president for Health Sciences (which the position of provost for Health Sciences had recently been renamed), Frank Cerra, MD, formed a task force of the Academic Health Center (AHC) Finance and Planning Committee to review the status of AHC programs in allied health fields. In particular, Cerra wanted the task force to define the contributions of those programs to the University mission, determine their national standing and accreditation, and examine alternative AHC organizational structures to enhance their effectiveness. The DHCS’s graduate program in health informatics was among the allied health programs that the task force was to review (the other programs under consideration were medical technology, physical therapy, occupational therapy, mortuary science, and dental hygiene). A year later, the AHC Finance and Planning Committee called on Cerra to take “prompt action” to improve the institutional and financial situation for these programs. Because of “the national standing of these programs and the demand for the health care professionals trained by these programs,” the committee argued, “these programs should be . . . supported and stabilized.” The committee reflected that “under the current structure, these programs have been financially strapped because of the financial difficulties within their current parent department(s).” The committee urged, “while funding problems are a reality we all face, the scholarly and educational missions of these allied health disciplines must be judged on their own merits.” Failure to do so could lead to the “unnecessary tarnishing of these programs’ reputations and the associated negative impact on their recruiting of the best and the brightest.”82 It is unclear what, if anything, resulted from these meetings; the financial support granted to DHCS did not change as a result.

In spite of Gatewood’s strong and “indefatigable” leadership and “a core faculty that really was good and
energetic and smart, good researchers... able to get their things done,” the institutional hurdles stymied the growth of DHCS. As Finkelstein explained: “If you look around, the places that have really jumped ahead” have had someone who “was able to get the ear of some high-up vice president or whoever it is where some of the decisions are really made. We tended to work, to a large extent, through the department structure and the department head who, sometimes, well I won’t say sometimes, but would have to work through the dean and the whole structure there. I think to a great extent, there was a lack of knowledge and appreciation of what informatics is or could be,” and that undermined the efforts of Gatewood and others to build the program. Of course, Finkelstein points out, health informatics is no longer an obscure discipline, “now when everybody talks about informatics [it’s] as though it’s sort of this discipline that’s going to solve everything.”

From the Division of Health Computer Sciences to the Institute for Health Informatics, 2000–2015

In May 2000, Gatewood stepped down after twenty-one years as director of DHCS. “I felt that there were other things to do than continue administrative hassles,” Gatewood recalled, not least because “it was a very lean time and difficult to see the future.” Donald Connelly, MD, PhD, followed Gatewood as director. After Gatewood, Connelly had the longest tenure in the Division. He had first joined the DHCS as a public health service fellow and doctoral student in 1972 at the same time that he began his residency in laboratory medicine. After completing his residency in 1974, Connelly was appointed to assistant professor in the Department of Laboratory Medicine and Pathology, director of the Laboratory Data Division, and faculty in DHCS. He earned his PhD in biometry and health information systems in 1977. By the mid-1980s, Connelly already had a national and international reputation for his research in laboratory information systems (which will be discussed in chapter three). In 1986 he was inducted into the American College of Medical Informatics.

When Connelly took over from Gatewood as director, the Division of Health Computer Sciences was renamed the Division of Health Informatics (DHI). At the same time, the Division was moved from the basement of Masonic Memorial Hospital to the seventh floor of the Mayo Memorial Building, the so-called hub of the Academic Health Center complex, from which all other Health Science buildings "radiate." The new space included a new computer laboratory/classroom for use in the DHI’s educational programs and access to the AHC’s fiber network and Biological Computational Center.

In spite of the name and location change, little else about the Division’s institutional situation changed. People within the University “still didn’t really, really understand what the importance of informatics was.” As Connelly described it, “There wasn’t a big slab of money with which you could do anything. There was absolutely no capability of building anything. I liken us to being kept just on the survival side of anorexia.” The lack of support to hire new faculty was becoming especially critical as the majority of the DHI’s faculty were "approaching the last decade of their academic life."

Things did start to change for the DHI, however, in the mid-2000s. In 1996, provost for Health Sciences, William Brody, MD, PhD, left the University to assume the presidency of Johns Hopkins University, and Frank Cerra, MD, was appointed the new provost for Health Sciences (the position was renamed senior vice president for Health Sciences the following year). As Gatewood reflected, “Frank Cerra had an enduring love of technology and informatics and always had very good ways of recommending people to be involved and [finding] possible funding avenues for
the unit.”89 Cerra recounted that in the early 2000s he had approached University president Mark Yudof, about the need for the University to build an “information infrastructure” that could support the development of large research databases, the management of financial data and big epidemiological studies in public health, the coordination of global clinical studies, and the vast amounts of data coming from genomics research. As Cerra recalled noting to Yudof, “We have all this information but we have no knowledge about how to really use it. It’s all mom and pop stuff. It’s all based in databases that can’t talk to each other. There’s no commonality of fields. . . . We need a university-wide genomics program.” To this end, in 2000, the Academic Health Center established the Biomedical Genomics Center to promote the effort in genomics, functional genomics, bioinformatics and stem cell development.90 The success of the Biomedical Genomics Center “led to even greater demands for an informatics infrastructure.”91

Then in 2006, the NIH launched the Clinical and Translational Science Award (CTSA) program. The program was “designed to address the development and implementation of national standards and best practices for the full range of translation, from basic discovery to clinical and community-engaged research.” In particular the program was established to (1) “Create academic homes for clinical and translational research”; (2) “Provide investigators and research teams with research cores, tools and a local environment that encourages and facilitates the conduct of clinical and translational research, including with community and research partners”; and (3) “Train the scientific workforce needed for the translational sciences.” The NIH regarded the improvement of “data-sharing and informatics tools” as a core tenet of the CTSA program.92 Connelly recalled the importance of the CTSA program to the DHI: “Whereas those of us who had been inside informatics here for a long time, [and] tried to promulgate the importance of it, it wasn’t until NIH application directives clearly spelled out the importance of informatics” that the significance of health informatics was recognized within the university.93

As part of Cerra’s effort to build the University’s strength in informatics, the previous year, in 2005, he had recruited Connie Delaney, PhD, RN, FAAN, FACMI, as the new dean of the School of Nursing. Delaney joined the University of Minnesota from the University of Iowa where she had previously earned an MA in nursing (1978) and PhD in education administration and computer applications (1986). After completing her doctorate, Delaney completed a post-doctoral fellowship in nursing informatics at the University of Utah under the supervision of Judith Graves, PhD, RN, the first nurse informatician who had trained in the Division of Health Computer Sciences as an NLM training grant fellow between 1984 and 1986. In 2004, Delaney was inducted into the American College of Medical Informatics. By the time she was interviewing for the deanship Delaney was “a world-recognized informatician.” As Cerra recalled, “I said, ‘You’re coming here as dean but your informatics skills we need.’”94

Delaney’s informatics skills were not only critical to Cerra’s vision of informatics, they were of equal importance to the health informatics faculty. For several years Stuart Speedie had been trying to gather support to establish a department of health informatics, “which, ultimately, did not get very far . . . [because] learning about the politics of the University of Minnesota and the difficulties of establishing departments was difficult to do, so we sort of backed off.” When Delaney arrived at the School of Nursing, Speedie continued, “we had been floating this idea of an informatics center, kicking that around for a couple of years, and Connie came along, so we . . . brought her into the fold.” Speedie, Connelly, and Delaney pursued the idea and were able to get “some traction” with the leadership of the Academic Health Center.95 The AHC deans—Deborah Powell, MD, of the Medical School; John Finnegan Jr., PhD, of the School of Public Health; Marilyn Speedie, PhD, dean
of the College of Pharmacy; Jeffrey Klausner, DVM, dean of the College of Veterinary Medicine; Patrick Lloyd, DDS, dean of the Dental School; and Delaney, dean of the School of Nursing—and Linda Watson, director of the Health Sciences Libraries, believed an institute for health informatics would strengthen the University’s bid to secure both a CTSA and another NLM training grant.

Consistent with the efforts of Cerra to build the University’s informatics infrastructure, in 2006, Cerra and the AHC deans established the Institute for Health Informatics (IHI). The IHI was sponsored by the dean of the Graduate School and given oversight by a steering committee composed of all of the AHC deans. Connelly served as inaugural director of the IHI. Finally, after forty-one years of ambivalent University support, the establishment of the IHI demonstrated the unequivocal commitment of the AHC and University administration to the growth and development of the field of health informatics. That recognition came not because of the existing national and international reputations of the University’s health informatics program but, as Connelly reflected, “as kind of a response to sudden external recognition that informatics was important... The Institute was the University of Minnesota’s response to the national recognition that informatics was important in translational science.”

In December 2007, Julie Jacko, PhD, was appointed director of IHI. Jacko joined the University of Minnesota from Georgia Institute of Technology when her husband, Francois Sainfort, PhD, was appointed the Mayo professor and director of the Division of Health Policy and Management in the School of Public Health. In addition to her appointment as director of the Institute, Jacko was also appointed as professor in the School of Public Health and in the School of Nursing. Jacko had earned her PhD in industrial and systems engineering from Purdue University and was a prolific researcher in the design, implementation, and evaluation of interactive computer systems in health care and health care delivery.

For Gatewood, Jacko’s arrive on campus “was fortuitous... it was apparent that this would be a very new association with human–computer interaction. It was needed because this was the way the field was moving.”

The three years of Jacko’s directorship was a time of growth for the IHI; as Cerra reflected, “she came here and did a lot of good work.” As part of Jacko’s hiring package, she negotiated funding to renovate new space for the IHI on the third floor of the Biomedical Library (part of the Health Sciences Libraries) in Diehl Hall. BWBR Architects created plans for the new space in March 2008 and the IHI’s offices were inaugurated with an open house in April 2009. Jacko also secured funding to recruit new faculty to the IHI. To reinforce the interprofessionalism of health informatics and develop strong collaborative relationships across the AHC, new faculty were hired jointly with other schools and colleges in the AHC. New hires were made according to a tiered faculty framework. The IHI engaged faculty at one of three tiers: IHI faculty fellow, IHI (school/college) fellow (e.g., IHI pharmacy fellow), or IHI affiliate. An IHI faculty fellow would be hired at 50 percent or more by the IHI, with the remainder funded by the AHC school/college of interest. An IHI school/college fellow’s total salary and/or salary augmentation would be jointly funded by IHI (at a rate less than 50 percent but greater than zero) and the AHC school/college of interest. The IHI would make no salary contributions to IHI affiliate faculty.

During Jacko’s tenure as director two new IHI faculty fellows were hired: Terrence Adam, RPh, MD, PhD (assistant professor, Department of Pharmaceutical Care and Health Systems, College of Pharmacy) and Genevieve Melton-Meaux, MD, FACS, FASCRS (assistant professor, Department of Surgery, Medical School). Bonnie Westra, PhD, RN (assistant professor, School of Nursing), who was a 100-percent-appointment in the School of Nursing, also joined the IHI during Jacko’s tenure.
Jacko also secured a major grant for IHI during her tenure. The 2009 Health Information Technology for Economic and Clinical Health (HITECH) Act established a training grant program that was administered by the Office of the National Coordinator for Health Information Technology, to support the development of university-based training programs for health information professionals. In 2009, Jacko, with IHI faculty fellows Terrence Adam, MD, PhD, assistant professor in the College of Pharmacy and Bonnie Westra, PhD, RN, assistant professor in the School of Nursing, as co-principal investigators, and in collaboration with the University of Minnesota-Crookston and the College of St. Scholastica, received a $5,145,705 University-Based Training of Health Information Technology Professionals grant from the Office of the National Coordinator for Health Information Technology. The grant supported the University Partnership for Health Informatics—the private-public university partnership between the two University of Minnesota campuses and the College of St. Scholastica (the grant is discussed in detail in chapter two). As Speedie noted, the awarding of the University Partnership for Health Informatics grant “had a huge impact on the growth of the program. We grew up to ninety students from thirty. That was a huge impact.” The grant also included salary support for a teaching position; the IHI hired David Pieczewicz, PhD, clinical assistant professor, who had received his PhD in health informatics from the graduate program in 2007.

The IHI also experienced some significant disappointments during Jacko’s tenure. Between 2006 and 2010, the University submitted four grant proposals for a CTSA, the last two of which were rejected on the grounds that they “didn’t have a well-developed informatics infrastructure.” Jacko was named the head of the biomedical informatics components of the grant on these last two grant applications.

Then on December 14, 2010, Jacko and her husband, Francois Sainfort, PhD, “were disciplined by the university after a review of the facts surrounding their transition from the Georgia Institute of Technology to the University of Minnesota in 2007–2008.” That discipline included letters of reprimand and the requirement “to pay the university approximately $59,000.” Jacko was subsequently removed as director of IHI. The following March, the University was informed that Jacko and Sainfort were each being “indicted on multiple felony counts by a grand jury in the state of Georgia.” A press release was issued by the University News Service on March 9, 2011, stating that the Georgia Attorney General’s indictment alleged that Jacko and Sainfort “conspired to be employed full time and receive salary from Georgia Tech while simultaneously being employed full time and collecting salary from the University of Minnesota. The indictment also charges that the two fraudulently billed Georgia Tech for travel expenses, inappropriately directed payments to a relative, and lied about their dual employment and the purpose of the Georgia Tech–funded travel.” The Georgia criminal case was later concluded with Sainfort taking an Alford plea to a single count of false statements and writings; all other charges against him, and all charges against Jacko, were dismissed. On January 4, 2013, as disciplinary charges by the University were pending, Jacko and Sainfort resigned from the University.

After Jacko left as IHI director, Delaney was appointed acting director while also maintaining her position as dean of the School of Nursing. The impact of Delaney’s assumption of the directorship was felt almost immediately. Delaney was asked by Bruce Blazar, MD, principal investigator of the CTSA grant (since 2008), and Frank Cerra, senior vice president for health sciences, to lead the biomedical informatics component of the fifth CTSA grant application. In 2011, the University’s Clinical and Translational Science Institute (CTSI, which was established in 2009) was awarded a $51 million CTSA. Bruce Blazar, MD, has been director of the CTSI since 2009. Delaney
served as associate director and led the Biomedical Informatics (BMI) core (from December 2010 to May 2015), one of the five cores that constitute the CTSI.

In addition to the CTSA, the University has invested heavily in biomedical and health informatics since 2010. In April that year, Blazar presented to University President Robert Bruininks and his leadership team the need for the University to invest in biomedical informatics. In response, Bruininks committed $5 million that was matched by $5 million from the AHC in addition to $1.1 million recurring AHC funds for the IHI (which would total $6.6 million from 2010–2016, recurring thereafter). The Office of the Vice President for Research further provided $13.4 million support for a University-wide bioinformatics effort. In total, in 2010 the University made a five-year $30 million investment in informatics.

These investments helped make possible two major infrastructure initiatives at the CTSI-BMI. The Academic Health Center Information Exchange, founded in partnership with the CTSI, established and maintains a fully automated, state-of-the-science platform of systems, applications, databases, and analytical tools to support the researchers/users for operations of research and evaluation of clinical outcomes for all of the health sciences. This platform enables secure, timely capture and exchange of information between databases in the Academic Health Center; other schools, colleges, and research centers within the University of Minnesota; Fairview Health Services; University of Minnesota Physicians; and as feasible, entities outside the University. In 2013, CTSI-BMI launched the Informatics Consulting Service as a single point of contact for informatics expertise, clinical data, and tools and resources, which support researchers within the academic and clinical practice.

The CTSI and the growth of health informatics expertise and infrastructure have bolstered the growth of the University of Minnesota’s collaborative research networks across the United States to further support research. For example, in 2014, Biomedical Informatics was awarded a $485,660 grant (Delaney, Site PI) from the Patient-Centered Outcomes Research Institute to be one of the few sites creating the Great Plains Collaborative. The Great Plains Collaborative is a network of ten leading medical centers in Iowa, Kansas, Minnesota, Missouri, Nebraska, Texas, and Wisconsin that is “committed to a shared vision of improving healthcare delivery through ongoing learning, adoption of evidence-based practices, and active research dissemination.” Also in 2014, CTSI-BMI was awarded a $324,455 grant (Delaney, Site PI) from the NIH’s National Center for Advancing Translational Sciences Accrual to Clinical Trials Project. The goal of the project is to create a network made up of sites from the CTSA consortium to accelerate participant accrual to the nation’s highest priority clinical trials. To achieve this goal, the project takes advantage of the “widespread implementation of electronic health records and the extensive informatics and regulatory expertise within the CTSA Consortium.”

Since Delaney became acting director, seven new core faculty members have been hired or appointed: Chih-Lin Chi, PhD, MBA (assistant professor, School of Nursing); Saif Khairat, PhD (clinical assistant professor); Stephen Parente, PhD, MPH (professor and director, Medical Industry Leadership Institute and Minnesota Insurance Industry Chair of Health Finance, University of Minnesota Carlson School of Management); Venkatesh Rudrapatna, MD, MPH (assistant professor, Division of Hematology, Oncology and Transplantation, Medical School); Gyorgy Simon, PhD (clinical assistant professor); and Rui Zhang, PhD (assistant professor, Department of Surgery, Medical School). Also, the IHI’s research programs expanded into new areas. The IHI’s scope of research now includes nationally recognized areas of methodologic development in natural language processing led by Serguei Pakhomov, PhD, associate professor in the College of Pharmacy’s Department of Pharmaceutical
Health Informatics at Minnesota

Care and Health Systems and Melton-Meaux; the design of standard terminologies and ontologies led by Christopher Chute, MD, DrPH, FACMI (professor of medical informatics, Mayo Clinic and IHI core faculty until 2015), Delaney, Westra, and Karen Monsen, PhD, RN, FAAN, associate professor in the School of Nursing; the testing and evaluation of electronic health records systems led by Delaney and Westra; the design and testing of better ways of presenting information to improve decision making and designing and implementing information systems to support clinical research led by Adam; data science led by Chi, Delaney, Westra, Monsen, Parente, and Simon; and telehealth led by Speedie and Finkelstein. Of those core faculty members, several have been inducted into the American College of Medical Informatics: Chute in 1995, Speedie in 2008, and Westra in 2011 (in addition to Gatewood in 1984, Ackerman in 1985, Connelly in 1986, Delaney in 2004, and LaVenture in 2011).

As further indication of the national and international prominence of the University of Minnesota’s health informaticians, several IHI core faculty have held key leadership positions within AMIA, the national professional association for health informatics, and the International Medical Informatics Association, the world body for health and biomedical informatics. Since 1988 Delaney has been a member of AMIA’s Nursing Informatics Work Group, serving as chair from 2003 to 2004. Delaney has also served on AMIA’s Committee on Nursing Informatics Competencies (1998–2000); as co-chair of the Committee for Nursing Informatics Educators Consortium (1998–2006); as member of the Publications Committee (2001–2) and Scientific Program Committee (2002–3, 2011–present); as School of Nursing representative on the Academic Forum (2014–present); and has served on the Board of Directors (2004–11) and on the Executive Committee of the Leadership Council of Deans and Chairs. Delaney also holds several positions within the International Medical Informatics Association. Since 2001, she has chaired the International Nursing Minimum Data Set Task Force (see chapter three), and since 2009 she has served on the leadership of International Medical Informatics Association–Nursing Informatics and as a member of the International Medical Informatics Association–Nursing Informatics Special Interest Group. Also, between 2003 and 2006, Delaney was a member of the Scientific Program Committee, 9th International Congress in Nursing Informatics, which was chaired by University of Minnesota Health Informatics alum, Hyeoun-Ae Park, PhD, RN.

Westra and Speedie have also held leadership positions within AMIA. Westra has served on AMIA’s Nursing Informatics Working Group Executive Committee (2007–12) and its Board of Directors (2008–12). She has served as the AMIA Academic Forum Secretary (2011–12); held membership and leadership positions on the AMIA Symposium Planning Committee (2011–14); and served as a member of AMIA’s Nominating Committee (2013) and Education Committee (2014). Speedie has served as chair (2011–12), past chair (2013), and at large representative (2014–16) on AMIA’s Academic Forum. The Academic Forum took the lead in facilitating AMIA’s joining the Commission on Accreditation for Health Informatics and Information Management Education as an organizational member in 2014. Related to this, Speedie has been a member of the AMIA Commission on Accreditation for Health Informatics and Information Management Education Accreditation Task Force and currently serves as AMIA representative on the Commission on Accreditation for Health Informatics and Information Management Education Board of Directors (2015–18).

In addition to having national and international leadership roles, the IHI also has strong ties with the Minnesota Department of Health (MDH). Since the mid-2000s, the University of Minnesota’s health informaticians have played key roles in the state’s efforts
to build Minnesota’s health informatics capacities and improve the state’s health care system.

**Collaborating with the State: The Minnesota e-Health Initiative**

As mentioned earlier, the health informatics faculty had worked as consultants on several initiatives with the MDH since the early 1980s. However, the relationship between the faculty and the MDH intensified with the launch of the Minnesota e-Health Initiative in 2004. The e-Health Initiative was launched as health policymakers throughout the country, the federal government, and other state governments committed to accelerating the use of health information technology, building a health information infrastructure, and facilitating health information exchange (HIE) to reduce health care costs and improve health care quality.

In June 2000, the Centers for Disease Control and Prevention’s (CDC) National Committee on Vital and Health Statistics issued a report that called for the establishment of a national health information infrastructure. In 2004, President George W. Bush created, through an Executive Order, the Office of the National Coordinator for Health Information Technology. The Office of the National Coordinator for Health Information Technology was “to provide leadership for the development and nationwide implementation of an interoperable health information technology infrastructure to improve the quality and efficiency of health care.” As part of this leadership, the Office of the National Coordinator for Health Information Technology provided $139 million in funding through the Agency for Healthcare Research and Quality for health information technology programs.

Building on previous reports, the Department of Health and Human Services released a report in July 2004, *The Decade of Health Information Technology: Delivering Consumer-Centric and Information-Rich Health Care* that called for both the establishment of a “national health information network” to enable nationwide interoperability” and “regional health information organizations,” which would provide local leadership, oversight, fiduciary responsibility, and governance for the development, implementation, and application of secure health information exchange across health care settings.” In practice, the regional health information organizations bring together local stakeholders (e.g., hospitals, physician practices, radiology centers, and laboratories) with clinical data and establish the infrastructure for health information exchange. Once operational, HIE “allows patients’ clinical data to electronically follow them between care delivery settings.” With the rising costs of health care, policymakers and researchers projected that HIE had the potential to generate substantial cost-savings and improvements in the quality of care. In 2005, for example, Jan Walker and colleagues at the Center for Information Technology Leadership, Partners HealthCare System in Boston, estimated that a fully standardized and interoperable HIE once fully implemented could yield a net value of $77.8 billion per year, or approximately 5 percent of the projected $1,661 trillion spent on U.S. health care in 2003.

By 2005, researchers, health care professionals, and policymakers involved in developing and implementing local and regional HIE had identified at least three significant challenges to establishing a uniform health information infrastructure. First, there was a lack of consistent data standards. As John Halamka of CareGroup Healthcare System and Harvard Medical School and colleagues explained in 2005, “Although a core set of data standards is generally recognized, and most vendors can implement these standards in their system, they are not consistently implemented between every pair of institutions that wish to exchange
data. In addition, most “real-world” problems, such as transferring a prescription electronically, require that several sets of data be bundled together.” This includes standards for the underlying demographic clinical data, standards for packaging the message, and standards for transmission of the message. “These ‘profiles’ of standards” had not, as of 2005, been “identified, documented, or commonly adopted.”

Second, privacy and security were major concerns. Specifically, Halamka et al. continued, “Information exchange rests upon trust—each network user trusts that every other user will handle sensitive information in a predictable way. Other than the minimal requirements of the Health Insurance Portability and Accountability Act (HIPAA) of 1996, there are no uniform agreements about security or privacy of health information across a network.”

Third, because of the variability in information technology networks being used by the different regional health information organizations and national systems like Kaiser Permanente and the Veterans Health Administration, policymakers, researchers, and informaticians identified the need to implement interoperability standards that would ensure that the different systems could “talk with one another.” As Halamka et al. explained, “Any approach to interoperability to support information exchange among these existing systems must accommodate all of these local systems and allow newcomers at every level of sophistication to participate.” Establishing standards for interoperability in HIE became a major policy focus beginning in 2005.

By late 2005, policymakers had begun to realize “that a large ‘national health information network’ was likely not ‘the answer.’” After several years of federally and privately funded local and national HIE initiatives, policymakers had identified “differences in market-level characteristics, the need for ‘social capital’ to enable the sharing of information among diverse, and in some cases—competing organizations, concerns about the privacy and security of a nationwide network, and sheer technical feasibility,” as barriers to a national network. Instead, “policymakers at multiple levels of the system began to recognize that a set of state, regional and local health information exchanges—a ‘network of networks’ was likely the best route forward for digitizing the U.S. healthcare system.” In response, the CDC, the Office of the National Coordinator for Health Information Technology, and the Advisory Committee on Computers in Research initiated grant and contract programs that directed funds to organizations at the state and local levels to facilitate HIE. Private organizations including the eHealth Initiative Foundation, the Markle Foundation, and the Robert Wood Johnson Foundation launched similar funding initiatives.

In 2004, the Minnesota Department of Health launched the Minnesota e-Health Initiative following the directive set forth in the Laws of Minnesota 2004, chapter 288, article 7, section 7. The directive called for Minnesota’s Commissioner of Health to convene an Electronic Health Record Planning and Implementation Work Group that would (1) identify barriers to the adoption and implementation of EHR systems in the state; (2) identify core components of an EHR and standards for interoperability; (3) assess the status of current implementation of EHRs in the state; (4) assess the costs of implementing EHR systems for primary and acute health care providers; (5) identify partnership models and collaboration potential for implementing EHR systems; (6) monitor the development of federal standards, coordinate input to the National Health Information Infrastructure process, and ensure that Minnesota’s recommendations are consistent with emerging federal standards; and (7) identify barriers and develop a plan to develop unified record system among public hospitals and clinics.

Three years later, in 2007, the Minnesota legislature passed a statute mandating that all hospitals and health care providers have an interoperable EHR system in place by January 1, 2015. The statute also man-
dated that the “commissioner of health, in consultation with the e-Health Advisory Committee, shall develop a statewide plan to meet this goal, including uniform standards to be used for the interoperable system for sharing and synchronizing patient data across systems,” by January 1, 2009. These standards, the statute continued, “must be compatible with federal efforts.” Interoperability of EHR systems means “the ability of two or more EHR systems or components of EHR systems to exchange information electronically, securely, accurately and verifiably, when and where needed.”

Directed by MDH’s Martin LaVenture, MPH, PhD, FACMI (an alumnus of the graduate program, member of IHI’s core faculty since 2004, and inducted into ACMI in 2011), the Minnesota e-Health Initiative is “a public-private collaborative whose vision is to accelerate the adoption and use of health information technology in order to improve health care quality, increase patient safety, reduce health care costs, and improve public health.” The e-Health Initiative is, as LaVenture asserts, “a really big deal. This is the first in the country to establish a state-wide initiative to say, ‘We need to advance the use of technology in a coordinated and systematic way, to establish an infrastructure that supports a capability for capturing and using information.’”

The IHI faculty have been involved in the development and implementation of the initiative since 2004. “Right from the beginning,” LaVenture explained, “the University and informatics were part of the e-Health Advisory Committee. . . . All people that are engaged with the Institute were actively involved in the committees and the work groups.” The e-Health Initiative is advised by 24-member steering committee composed of “leaders and experts representing major healthcare organizations, providers, local public health departments, healthcare buyers and payers, consumers, health informatics, and other experts.” Representing the health informatics faculty on the steering committee have been Donald Connelly, MD, PhD (2006–10) Bonnie Westra, RN, PhD (2008– ), Julie Jacko, PhD (2010–11), and Stuart Speedie, PhD (2012– ). Martha Witrak, PhD, RN, a graduate of the University of Minnesota School of Nursing and dean of the College of St. Scholastica School of Nursing, has served on the steering committee since 2010. In particular, LaVenture described, the Standards and “Interoperability Work Group is one of the work groups that Don Connelly and Laël Gatewood have played a big role in supporting. It’s a lot of informatics issues and policy related to that.”

In 2013, Bonnie Westra, PhD, RN, FAAN, FACMI (associate professor, School of Nursing and IHI core faculty) and Karen Monsen, PhD, RN, FAAN (associate professor, School of Nursing and IHI affiliate faculty) joined the Minnesota e-Health Initiative Standards and Interoperability Work Group. Their efforts focused on how to exchange information using the consolidated clinical document architecture. The consolidated clinical document architecture is a “base standard which provides a common architecture, coding, semantic framework, and markup language for the creation of electronic clinical documents.” It includes templates for all possible documents that convey clinical data within the EHR, including the continuity of care document, consultation note, diagnostic imaging report, discharge summary, history and physical, operative note, procedure note, and unstructured document.

At the Standards and Interoperability Work Group, Westra and Monsen, with Lisa Klotzbach from Olmsted county and Diane Thorsen from Otter Tail county’s public health department in New York Mills, Minnesota, presented on the importance of using an American Nurses Association (ANA)-recognized standardized terminology to exchange health information through the consolidated clinical document architecture. In response, the Work Group recommended that an ANA-recognized standardized nursing terminology be incorporated into EHR in all health care settings. On August 6, 2014, the Minnesota Department
of Health adopted the Work Group’s recommendations and encouraged “regional and national organizations to support the national adoption of standard nursing terminologies.”

This achievement was groundbreaking: Minnesota was the first state in the country to adopt standardized nursing terminologies. The work of the University’s health informaticians was vital to this success, as LaVenture recalls: “Working with Bonnie Westra and other University of Minnesota Nursing Informaticians, we have pioneered, just recently, the first nursing standards. Informatics and the influence there and our advice from there and the engagement have been really crucial.” Westra, Monsen, and Connie Delaney, who also contributed to development and implementation of standardized nursing terminologies, are national leaders in the field. Monsen leads the Omaha System Partnership for Knowledge Discovery and Health Care Quality, and Westra and Delaney “lead the development of a National Action Plan to have sharable/comparable nursing data to conduct Big Data science.” In June 2013, Delaney and Westra organized and the University of Minnesota School of Nursing hosted the “Nursing Knowledge: Big Data and Science for Transforming Health Care Conference.” This national invitational conference brought together seventy stakeholders from nursing practice, education, information technology, professional nursing, and informatics and standards organizations “to develop a national action plan and harmonize the efforts of multiple individuals and organizations to implement standardized nursing terminologies and subsequent use of nursing data for research and quality improvement.”

Minnesota’s leadership also reflects the state’s “long history of implementing one of the ANA-recognized terminologies, the Omaha System, in community-based settings.” As Westra and Lynn Choromanski, PhD, RN-BC, chair of Healthcare Information and Management Systems Society Minnesota Chapter Nursing Informatics Committee, reported, “Almost every county in Minnesota has implemented the Omaha System in its public health agency, and many home care agencies also have adopted the Omaha System.” The impact of Minnesota’s recommendation that standardized nursing terminologies be incorporated into all EHRs cannot be overstated. In March 2015, the ANA board of directors approved a position statement that reflected the recommendations of Minnesota’s Department of Health; indeed, in its specifics, the recommendations look almost identical to those from Minnesota. In its statement, the ANA “continues to advocate for the use of the ANA recognized terminologies supporting nursing practice within the Electronic Health Record (EHR) and other health information technology solutions,” and recommends that all health care settings “create a plan for implementing an ANA recognized terminology supporting nursing practice within their EHR.”

In addition to research collaborations and the faculty’s “invaluable” contributions to the e-Health Initiative, LaVenture sees education as a vital and ongoing interaction between MDH and IHI. As LaVenture explained, “Underpinning all of it, we still maintain a core group of people trained at the University. We have several staff here that have received either certificates or take[n] courses. We see informatics as the core science underpinning all of our e-health activities.” This educational collaboration operates on two levels: the MDH sends “students to IHI for classes . . . and we’ve tried to help support development of the curriculum.” For example, LaVenture is involved with developing curriculum in areas related to public health. “We’ve sent I don’t know how many students, at least many dozens of students.” The MDH also operates as a practicum site for students in the health informatics graduate program. LaVenture would like to see the educational interactions between MDH and the university formalized. “We have . . . informal policies, but not an official organizational policy,” he explains. “What I’d like to see with the University here, is to establish more of
an official policy . . . so we can better get some of the students actively engaged” in MDH’s work, “sort of institutionalize the process, [so] that if I’m not here that it will go on, hopefully, smoothly.”

The Institute for Health Informatics had seventeen core faculty with co-appointments in the College of Pharmacy, School of Nursing, Medical School, and the Carlson School of Management as of 2015. The IHI also has affiliated faculty with appointments in the College of Veterinary Medicine; School of Dentistry; School of Public Health; and College of Science and Engineering; as well as positions in the Minnesota Department of Health; Hennepin County Medical Center; Health Partners and Health Partners Research Foundation; Fairview Health Systems; Regional Extension Assistance Center for Health Information Technology; the University of St. Thomas; the Mayo Clinic; Infitgo, LLC; Forward Solutions, Inc.; Allina Health and Hospitals; the College of St. Scholastica; Blue Cross/Blue Shield; and LogicStream Health, Inc.

In July 2015, Vice President for Health Sciences, Brooks Jackson, MD, appointed Constantin Aliferis, MD, PhD, FACMI, as the new director of IHI and chief informatics research officer at the University of Minnesota. Aliferis joined the IHI from New York University (NYU) where he was founding director of NYU’s Center for Health Informatics and Bioinformatics. He also served as director of the biomedical informatics cores of NYU’s Clinical and Translational Science Institute and Cancer Center. Aliferis is a leader in “high dimensional modeling and analysis designed to transform biomedical data into novel actionable scientific knowledge.” His research focuses on three broad areas: (1) the “use of advanced informatics and analytics to accelerate and enhance the sophistication, volume, quality and reproducibility of scientific research”; (2) “quality and cost improvements of healthcare using Big Data approaches”; and (3) precision medicine.” The arrival of Aliferis marks the beginning of an exciting new era in health informatics at the University of Minnesota.
Arnold Lazarow, MD, PhD
source: University of Minnesota

Eugene Ackerman, PhD, FACMI
Photo courtesy of Laël Gatewood, PhD, FACMI

Laël Gatewood, PhD, FACMI
source: University of Minnesota
Donald Connelly, MD, PhD, FACMI
source: University of Minnesota

Frank Cerra, MD
source: University of Minnesota

Bruce Blazar, MD
source: University of Minnesota
Marty LaVenture, MPH, PhD, FACMI
Source: University of Minnesota

Constantin Aliferis, MD, PhD, FACMI
Source: University of Minnesota
Training the Next Generation of Health Informaticians

The University of Minnesota has one of the oldest graduate training programs in health informatics in the United States; its health informatics faculty has been teaching health informatics graduate courses and training masters and doctoral students since 1965. That year, the University of Minnesota Graduate School approved Eugene Ackerman, PhD, at the Mayo Clinic in Rochester, Minnesota, to introduce biomedical computing into the curriculum of the newly created joint Mayo Clinic/University of Minnesota Master’s in Biophysics Program. The following year, in 1966, Eugene Johnson, PhD, introduced the University’s first graduate course in health informatics through the School of Public Health’s Division of Biometry. In 1974, the University was among the first to receive a National Library of Medicine (NLM) Training Grant. In 2015, the graduate program in Health Informatics offered PhD, MS, and Master’s in Health Informatics degrees, had 17 core faculty, and had collaborated to introduce informatics courses and certificate programs in the schools of public health and nursing. This chapter describes the history of the University of Minnesota’s programs to train the next generation of health informaticians. This history is characterized by an emphasis on interprofessional education and the University’s 35-year history of continuous funding by the National Library of Medicine (NLM) training grant programs.

Introducing Graduate Education in Health Informatics

As the faculty and staff of the University of Minnesota Biomedical Data Processing Unit (BDPU) expanded their research and service work, the faculty viewed the training of students and researchers in biomedical computing as a growing priority. While training was part of the mandate of the NIH (National Institutes of Health) National Center for Research Resources grant, it was unfunded. Instead, the grant specified that research training should be the responsibility of the
The BDPU had been able to include training within its grant-supported activities because a certain level of training was necessary in order to equip graduate students, faculty, and researchers to use computers in their biomedical research. To this end, in the fall quarter of 1966, Eugene Johnson introduced the first course in biomedical computing through the University of Minnesota School of Public Health’s Division of Biometry: Biomedical Computing. After Ackerman joined the faculty in the fall of 1967, he introduced a second course, mathematical biology, in the 1968 winter quarter. Ackerman had originally developed this course as part of curriculum of the joint Mayo Clinic/University of Minnesota Master’s in Biophysics Program. The introduction of mathematical biology reflected “the mathematized biology and medicine” the NIH’s Advisory Committee on Computers in Research grant (which had been used to establish the BDPU), “had sought to help develop.” Because Johnson and Ackerman had appointments in the School of Public Health’s Division of Biometry, all courses taught by BDPU faculty were offered through the graduate program in biometry.

Until 1973, biometry at the University of Minnesota consisted of three major components: biostatistics, biomedical computing, and mathematical biology. That year, however, reflecting the greater involvement with computer sciences and information systems, the faculty in the Division of Biometry received University of Minnesota Graduate School and University Regents approval to rename the graduate program as Biometry and Health Information Systems, and created two tracks, each with its associated sets of courses. The first track, Biometry, focused on biostatistics and was taught by the faculty in biometry. The second track, Health Information Systems, included biomedical computing and mathematical biology and was taught by the faculty in the Division of Health Computer Sciences (DHCS). Stanley Finkelstein, PhD, who joined the DHCS as associate professor in 1977, reflected on the two-track graduate program: “The faculty that were responsible for the health computer science track, if you will, were the four or five of us in Lab Medicine and the faculty responsible for the biometry biostatistics piece were in the School of Public Health. That seemed to work well. It was an interesting way of putting things together. Graduate students would come into the program and they would have to decide which one of these tracks they wanted. Some first-year courses, everybody took. So, the biostat people had to learn a little bit about health computer sciences and the health information systems people had a sequence of required biostatistical courses. That went on for a number of years.”

Those shared core courses included introductory courses in biometry and biomedical computing and a course in consulting oriented to the particular track. For those on the health information systems track, the computer consulting course introduced students to several health service clients and enumerated the problems for which the clients were seeking consultation. Students would then work with the clients to specify the objectives, system design, development schedules, and evaluation criteria for each client’s project. Finally, the students would prepare a proposal for institutional or government funding. As Laël Gatewood, PhD, reflected, however, the incorporation of biomedical computing courses in the biometry curriculum was “a balancing act from the very beginning.” It was challenging “to try and model a new developing training program and methodology within a long established, highly structured program, particularly one that, in the case of Biometry, had been based on long-existing fields of mathematics and statistics and had only begun to be colored by computer sciences in the 1970s.”

By 1971, the introductory graduate-level course, biomedical computing, was taught as a nine-credit course over three quarters by Richard Heath and Gatewood and was intended as “the major introduction of research workers in the health sciences to our computer resources and to biomedical com-
puter applications in general." The course provided an introduction to digital computers and FORTRAN programming, with applications in biology and medicine; information capture, storage, retrieval, and display; and usage of statistical analysis packages. Other topics discussed were simulation, analog signal processing, nonlinear models, and hospital information systems. Also by 1971, the faculty had added four additional graduate-level courses related to biomedical computing: Computer Methodology in the Delivery of Health Care, Advanced Topics in Health Computer Science I, II, and III, Analytical Techniques for Health Delivery Systems, and Mathematical Biology I, II, and III. As the faculty further developed these courses, several faculty members also published instructional material that accompanied their courses. For example, in 1979, Ackerman and Gatewood published *Mathematical Models in the Health Sciences: A Computer-Aided Approach* (Minneapolis: University of Minnesota Press, 1979), which accompanied the advanced course, Mathematical Biology, and Ackerman, together with Lynda Ellis, PhD, and Lawrence William, PhD, published the second edition of *Biophysical Science* (Englewood Cliffs, NJ: Prentice-Hall, 1979), which was used in several courses.

In addition to teaching at the graduate level, the DHCS faculty had also introduced an intensive six-week elective, Computers and Medicine, that was available to fourth-year medical students. During the elective, students received individual tutorial supervision in reading about computers and their use in the delivery of health services, and in computer programming, and they visited several of the numerous small computer centers within the University’s Health Science Center and at the Veterans Administration Hospital and Mayo Clinic. The students also attended a series of ongoing lectures and seminars during those weeks and were given opportunities to engage in research in the field of biomedical computing.

To support classroom teaching in health information systems, in 1974, the Health Sciences Center opened the Health Sciences Computer Learning Laboratory in the Malcolm Moos Health Sciences Tower. The laboratory occupied an 857-square-feet L-shaped room and was equipped with several terminals and related equipment for use by health science students taking health information systems courses and other courses offered by health science faculty that required computer-aided instruction. The laboratory was supervised by Lynda Ellis, PhD, and staffed for over forty hours a week by the instructors and teaching assistants of courses that required use of the laboratory. Although no formal classes were held in the laboratory, it had facilities for up to twenty students and was used for small review sessions or demonstration in several courses.

Several of the DHCS faculty members also served on the graduate faculties of other programs, including biometry, computer and information sciences, laboratory medicine, biophysics, social and administrative pharmacy, bioengineering, and operations, enabling them to advise graduate and post-doctoral students in these disciplines. In 1971, of the DHCS faculty, Ackerman had six PhD advisees; Eugene Johnson, PhD, had one post-doctoral, two PhD, and two MS student advisees; John W. Rosevear, MD, PhD, had one post-doctoral, one PhD, and one MD/PhD student advisee; and Richard Moore, PhD, had one MS advisee. The division also supported training through informal seminars (in particular, the Joint Biophysical Sciences Seminar established by Ackerman and Otto Schmitt, PhD, professor of electrical engineering) and short non-credit courses in biomedical computing topics.

The health information systems track of the Biometry and Health Information Systems program grew through the 1970s and by 1979, the DHCS faculty offered twenty-one courses in health computer sciences, including courses specific to pharmacy students and residents in laboratory medicine and pathology. The course, Computers in Pharmacy, was introduced in 1978 and developed by Gatewood and
Norrie Wilkins, a PhD student in social and administrative pharmacy. The course introduced students in the PharmD program to the applications of computer technology “in meeting the demands of the pharmacy profession including information processing, accounting, administrative and health care services.”

For several years, the DHCS faculty had offered a one-week intensive rotation that provided an introduction and overview of the use of computers in laboratory medicine and pathology to residents. In addition to lectures, the residents worked with laboratory computer systems. After completing this elective, several students wanted to engage with the DHCS faculty investigating topics related to the use of computers in laboratory medicine or pathology. Subsequently, the DHCS faculty introduced a month-long elective that expanded upon the one-week elective. During the new elective, residents developed a short research project using laboratory computer systems. In 2015, this one-month rotation was reintroduced as a requirement for clinical pathology/anatomic pathology residents in the laboratory medicine and pathology residency program.

Establishing the Graduate Program in Health Informatics

Between 1973 and 1985, students wishing to obtain a graduate degree in health computer sciences did so by pursuing the health information systems track of the Biometry and Health Information Systems graduate program in the School of Public Health’s Division of Biometry. But as the field of biomedical computing grew, the rationale for a joint graduate program came under pressure. The two faculty groups administering the two-track curriculum were in different schools (the School of Public Health and the Medical School), which introduced administrative challenges; each track entailed different sets of requirements, which created confusion for the students, and the disparate research of the two faculties and interests of the two groups of students made “a single focus” for the graduate program “harder to define.” As Gatewood recalled, “The joint program with Biometry continued under various stresses, because we had separate faculty. We had separate exams, separate theses. There was some dissatisfaction that the faculty on the Biometry side did not know what was going on in the health computing side.”

As a result, in October 1985, the Biometry and Health Information Systems graduate program applied to the Graduate School to change the name of the graduate program to Biometry and eliminate the health information systems track within the program. Simultaneously, the DHCS applied to the Graduate School to establish a graduate program in health informatics. On December 12, 1986, the University Regents approved both proposals, marking the establishment of the graduate program—offering both MS and PhD degrees—in health informatics. At that time, approximately twenty students transferred from the biometry and health information systems program and five new students were admitted for early admission the following spring.

By the mid-1980s, the faculty were increasing their efforts to recruit medical students to the field. In 1987, the graduate program in health informatics established ties to the MD/PhD program. Two years later, it sponsored its first two MD/PhD students, Nathaniel Stewart and John Rydberg. Both had finished their first two years of medical school and were beginning their doctoral studies in biomedical engineering. Both were also fellows in the NLM training program (described later), with Stewart working in the management information systems research cluster directed by Gatewood and Rydberg in the medical imaging research cluster directed by George Wilcox, PhD. In 1988, the DHCS introduced a new elective, “Computer Applications in Medicine and Medical Research,” for third- and fourth-year medical students. During the rotation, which could last three, four, or six weeks, students would work on independent research proj-
ects involving computers in medicine with a DHCS faculty member; attend one or more graduate school courses involving computers in medicine; attend relevant seminars; read books, journal articles, and manuals appropriate to the field and to their project; and write a final report.23

Preparation of Practitioners for the New “Health Information Infrastructure”

By the early 2000s, the importance of health information technologies and practitioners trained in their use for improving health care delivery had assumed national significance. In June 2000, the National Committee on Vital and Health Statistics of the Centers for Disease Control and Prevention’s National Center for Health Statistics issued a report, “Toward a National Health Information Infrastructure.”24 As the title suggests, the report called for the establishment of a national health information infrastructure—“a set of technologies, standards, applications, systems, values, and laws that support all facets of individual health care, and public health.”25 “Through the use of integrated technologies,” the report asserted, “different segments of the medical care system will be able to ‘talk’ to one another better and faster, and, in the process, dramatically increase diagnostic accuracy and spot potential errors before they injure patients.”26 Although much of the technology was already available, the report made clear that before such a system could be put in place, legal, societal, organizational, and cultural barriers had to be overcome. These included the development of “comprehensive privacy protections for personal health information”; the reaching of a social consensus about “how we think about health information and information sharing”; “agreed-upon information guardians that can exchange data with each other”; “standards for online consumer/patient information”; the development and implementation of “security technology . . . to assure that health information can safely travel over the internet”; the establishment of public/private partnerships to create the networks, systems, and applications to support the national health information infrastructure in order to share the costs; the development of consensus among health care professions and their “acceptance of practice guidelines and other knowledge management tools” and “consumers and patients must have confidence the NHII [national health information infrastructure] will deliver real benefits”; and, to guarantee equity, “technology and online information and services must be available in all homes and communities” and “online resources must be culturally and linguistically appropriate for an increasingly diverse population, and presented in clear and useful formats regardless of their education level.”27 The report called on “Congress, government agencies, health care professionals and organizations, technology and communication companies, research institutions, community organizations and the public,” to help move the health information technologies and systems from the current state of development to the fully envisioned national health information infrastructure.28

Professionals trained in the use of health information technologies were recognized as critical to successful implementation of this health information infrastructure. Therefore, at the beginning of the 2000s, the faculty in the Division of Health Informatics (the DHCS had been renamed in May 2000 to match the name of its graduate program) began plans to establish a terminal, one-year master’s in health informatics (MHI). Stuart Speedie, PhD, led that effort. As he explained, “It seemed to us, at the time, that there was a demand from people who were already working to have additional training in the area and that the traditional science research based master’s degree was too much for them. So we needed a more professionally oriented degree.”29 Rather than preparing health informatics researchers, the MHI degree would train practitioners interested in using health information
technologies to solve health care problems. As Donald Connelly, MD, PhD, explained, one of the priorities of the MHI “was to increase the number of people trained in informatics with a focus on implementing electronic medical records. The effort was, well, we need these people out in practice rather than up in the lab researching things so much, so the terminal master’s came out of that.”

After being approved by the Graduate School and regents in 2002, the graduate program in health informatics admitted its first students to the MHI program in the fall of 2003. At the same time, the graduate program established the joint MD/MHI program, which enabled medical students to take a year off after their first two years of medical school to complete the coursework and program project for the MHI, and then return to finish their medical school clinical clerkships. The Division of Health Informatics hoped to establish this “year-off training in informatics” as a joint package for other types of health professional students in the Academic Health Center. As of June 2015, sixty-eight students had graduated from the MHI program.

Four years after the National Committee on Vital and Health Statistics report, President George W. Bush announced in the 2004 State of the Union address, “an ambitious goal of assuring that most Americans have electronic health records within the next 10 years.” He singled out health information technologies such as “electronic medical records, computerized ordering of prescriptions and other medical tests, clinical decision support tools and secure exchange of authorized information,” as key to “improve[ing] quality, reduc[ing] errors, and prevent[ing] deaths.” That year, through an Executive Order, President Bush created the Office of the National Coordinator for Health Information Technology (ONC), which was “to provide leadership for the development and nationwide implementation of an interoperable health information technology infrastructure to improve the quality and efficiency of health care.” The Executive Order was not legislatively mandated at that time. However, on February 17, 2009, President Barack H. Obama signed into law the Health Information Technology for Economic and Clinical Health (HITECH) Act as part of the American Recovery and Reinvestment Act. The Act was administered by the ONC and included the provision of $32 million for a training grant program to support the development of university-based training programs for health information professionals.

In 2009, Connie Delaney, PhD, RN, FAAN, FACMI (acting director of the Institute for Health Informatics from December 2010 to May 2015) was appointed to the ONC’s Health Information Technology Policy Committee by the acting comptroller general of the United States and head of the Government Accounting Office, a committee position she continues to hold.

In 2006, the Institute for Health Informatics, located in the Academic Health Center, had replaced the Division of Health Informatics as the institutional home of health informatics on the University of Minnesota’s campus. At the end of 2007, Connelly, who had directed DHI since 2000, stepped down as director of the Institute and Julie Jacko, PhD, from the Georgia Institute of Technology was appointed director of the Institute for Health Informatics. With Jacko as principal investigator and Institute for Health Informatics faculty members, Terrance Adam, MD, PhD, assistant professor in the College of Pharmacy and a former NLM trainee (2000–3) and Bonnie Westra, PhD, RN, assistant professor in the School of Nursing as co-principal investigators on the grant, the University of Minnesota–Twin Cities, in partnership with the University of Minnesota–Crookston and the College of St. Scholastica, applied for a University-Based Training of Health Information Technology Professionals grant from the ONC.

In the grant proposal, Jacko and colleagues sought funding for the University Partnership for Health Informatics (UP-HI)—a private–public university partnership between the University of Minnesota–
Twin Cities, the University of Minnesota–Crookston, and the College of St. Scholastica—that would build on the strength of their existing health information technology (HIT) programs to “expedite the infusion of qualified graduates into our nation’s workforce.” In particular, they planned to “rapidly train” students to serve in all six ONC-identified HIT professional roles requiring university-level training: 1) Clinical/Public Health Leaders; 2) Health Information Management and Exchange Specialists; 3) Health Information Privacy and Security Specialists; 4) Research and Development Specialists; 5) Programmers and Software Engineers; and 6) HIT specialists. The UP-HI planned to do so by leveraging and enhancing the member institution’s existing certificate and degree programs, including the University of Minnesota–Twin Cities’ MHI and MS in Health Informatics, Certificate in Nursing Informatics, MS in Computer Science, and the School of Public Health’s Certificate in Preparedness, Response, and Recovery and MS in Health Services Research, Policy, and Administration; the University of Minnesota–Crookston’s Health Informatics Minor for Software Engineers and the Health Informatics Specialist Certificate; and the College of St. Scholastica’s Nursing Informatics Certificate, the Health Information Management and Exchange Specialist Certificate, and the MS in Health Information Management.

In April 2010, the UP-HI was awarded a three-year $5,145,705 grant by the ONC. After receiving the grant, Jacko said, “This is the first cross-institutional, Minnesota-based, private–public consortium that has regional reach and impact focused exclusively on the preparation of university graduates for health informatics technology roles. . . . The consortium institutions represent the most mature and highly regarded university undergraduate, graduate and certificate health informatics programs in Minnesota. This also really builds on the University of Minnesota’s history of more than 35 years of training graduate students in health informatics.”

To ensure that their graduates would be able to meet and be responsive to the changing needs of HIT users, UP-HI created a Community Partner Council composed “of a core of 18 key community partners selected on the basis of their experience and expertise gained from strategic organizations who represent a broad spectrum of academic institutions, government agencies, suburban, rural, and underserved urban healthcare providers.” The Community Partner Council would provide ongoing advisory input on the UP-HI training program, assist with recruitment into UP-HI, identify mentors for students within its organizations, and work with UP-HI faculty and students to identify job opportunities and workforce needs. Through these community networks, the students would also be able to participate in work immersion experiences in acute and ambulatory care environments, public health agencies, and other Minnesota e-Health stakeholders and HITECH–funded programs.

The creation of the Community Partner Council represented an innovative approach to workforce education. Before the establishment of UP-HI, “community partners in the region had not been sufficiently engaged to inform health information technology curricula in a bi-directional and sustained fashion.” This had created a gap between HIT theory and practice; what students were learning in the classroom did not always map onto “what they would really need to know to be productive in the HIT workplace.” The workforce education provided by UP-HI had the potential to address this gap by “integrating practitioner expertise into the student learning experience.” Because community partners understood the ways in which workforce needs evolve according to changes in technology and regulation, they could play a critical role in curriculum development to ensure the curriculum remained responsive to workplace needs.

UP-HI’s university-based training grant from the ONC ended on September 30, 2013. By April 1, 2013, 102 students had completed either certificate
programs or graduated with an MHI degree and 13 had graduated with MS degrees. The remaining students enrolled in UP-HI programs continued to be funded through completion of their studies through a no-cost extension to the grant. As part of the grant, UP-HI conducted surveys of its graduates to determine their career progress after completing the UP-HI program. In the 2013 survey, 88 out of 141 students trained in the UP-HI program responded. Before enrolling in UP-HI training, 28 percent of respondents indicated they had held HIT jobs, whereas after UP-HI training 60 percent of respondents held HIT-related jobs. The impact of the UP-HI program was also reflected in some of the respondents’ comments. As one noted, “I have found that I have a better overall understanding of systems and what’s involved, along with things to consider when looking at products or changes within our system.” Another graduate, who had been appointed to a new role after graduating from an UP-HI program, commented, “my new role allows me to be much more involved in HIT in a higher capacity, such as being a team lead for our ICD-10 project and implementing the new features for HIE [Health Information Exchange] in both Epic and CORHIO [Colorado Regional Health Information Organization], rather than just providing input.” Another noted that due to the education received through the UP-HI training program, she had been able to use her “education to drive our EMR [electronic medical record] implementation in our department.”

In keeping with the University of Minnesota’s fifty-year history of health informatics education, the UP-HI program took an innovative approach to training the next generation of health informatics professionals. The initiative not only prioritized new institutional partnerships and community collaboration but also prioritized interprofessionalism. As Gatewood noted, the UP-HI “built on the interprofessional training that we had been establishing through our coursework and the direction of the training program, offering courses, small group projects, and research topics that were of interest to people from other health fields than just medicine alone.”

Continuing its commitment to interprofessionalism, since 2007, the IHI graduate faculty have collaborated to introduce eight courses in nursing informatics offered by the School of Nursing. These include Health Informatics and Information Technology; Interprofessional Health Care Informatics; Consumer Health Informatics; Consumer Health Informatics Practicum; Knowledge Representation and Interoperability; Population Health Informatics; Population Health Informatics Practicum; and Clinical Decisions Support. In 2009, the School of Nursing introduced a certificate program in nursing informatics, the Leadership in Health Information Technology for Health Professionals Certificate, designed for health care and public health professionals. By combining clinical or public health advanced preparation with course work in HIT, the certificate program prepares students to “lead the successful deployment and use of HIT to achieve transformational improvement in the quality, safety, outcomes, and thus in the value of health services.”

The School of Nursing also began offering a nursing informatics specialty within the Doctorate of Nursing Practice program, the first school of nursing in the United States to do so.

In 2008, the Institute for Health Informatics graduate faculty also collaborated to introduce a new course in public health informatics, Managing Public Health Systems, offered by the School of Public Health. Since 2014, they have collaborated to introduce four additional courses: Public Health Systems Analysis and Development Practicum, Managing Electronic Health Information, Data and Information for Public Health Management, and Introduction to Public Health Informatics. The School of Public Health also offers the Master’s of Public Health in Public Health Informatics and the Public Health Informatics Certificate. Students in the Master’s of Public Health in Public Health Informatics program “learn how to design, develop and manage public health information
systems, including vital statistics systems, online analytical processing tools, immunization registries, population health surveillance, [and] community health information networks.” The certificate program is a nine- to twelve-month program that provides students with “the ability to conceive, design, develop, implement, and use IT by applying informatics skills in the public health domain; the systems engineering technical skills necessary to lead the development of public health information systems; and key technical and leadership skills necessary to manage information systems within an organization or organizational networks such as community health information networks and health information exchanges.”

The University of Minnesota’s graduate and training programs in health informatics have been characterized, since their founding, by a core commitment to interprofessionalism. This commitment was further reflected in the thirty-five-year history of the University’s NLM training programs in health informatics.

**National Library of Medicine Training Programs**

As noted in chapter one, Johnson and Ackerman as directors of the BDPU and DHCS, respectively, both viewed training in biomedical computing as a core—albeit unfunded—component of the Research Resources grant. In 1971, in order to secure more sustained support that would enable the expansion of their training program, Ackerman applied for a five-year training grant from the Public Health Service’s National Center for Health Services Research and Development. The DHCS’s proposed training program would build on the Division’s existing course work and system of advising. Trainees would also “complete at least one research project of sufficient magnitude that the trainee can be listed as first author on the resulting publication.” The DHCS sought to train predoctoral students with a background in any natural or social science or mathematics (and preferably with a master’s degree in biometry, biophysics, or biometry), and postdoctoral trainees, principally MDs who had completed at least their internship. The goal of the program was to train personnel “able to function as scientists in health services computer centers, as instructors in health services training programs and as independent investigators capable of originating and directing significant programs in biotechnology as applied to health services research and development.”

Although their application had been encouraged by the Public Health Service’s National Center for Health Services Research and Development’s personnel and approved by the Health Services Training Study Section and the Health Services Section, the DHCS’s application was not funded. As Gatewood recalled, “at the time that we submitted an application that we felt sure would be funded, we had had quite a bit of discussion with the project officer.” The general sense among the faculty was that the proposal had been unsuccessful because the program had “dropped education from its name.” The DHCS did, however, receive a post-doctoral fellowship from the Public Health Service’s National Center for Health Services Research and Development, which was able to support the training of one post-doctoral student, Donald Connelly, who was also completing his residency in laboratory medicine and pathology (he would go on to become a faculty member in DHCS).

Subsequently, the NLM assumed responsibility for training in the health computer sciences and biomedical computing and in 1972, Ackerman and Gatewood applied for the newly created NLM Training Grant, which they titled Training Grant in Health Computer Sciences. The NLM’s priority for awarding the training grants was to develop instructors in health computing for academic health centers.

The educational goals of the DHCS’s training grant were to “1. Instruct students in the basic discipline of computing for the health sciences; 2. Add advanced training in information, engineering and/or computer sciences; 3. Provide graduate courses in
health service informatics for all health professionals; 4. Find student research opportunities combining previous and acquired skills to promote health care; and 5. Integrate coursework, seminars, consulting and research into a comprehensive graduate program.49

The emphasis on training “all health professionals” signaled the NLM’s own commitment to interprofessionalism. In summary, the goal of the training grant was to provide pre- and post-doctoral training in health science computing, “enriched by other technological skills in engineering, management and evaluation.”50 By also taking courses in related graduate programs, trainees “integrated applied, information[,] and health sciences,” and were provided with opportunities to conduct health services research. Ultimately, the DHCS faculty sought to equip trainees “to serve as scientists in health services computer facilities, as instructors in health services training programs, as coordinators for health delivery facilities, and as independent investigators capable of originating and directing significant programs in biotechnology as applied to health services research and development.”51

The DHCS’s grant application was successful and the University of Minnesota was in the first pool of institutions to receive a NLM training grant. The first cohort of NLM training grant fellows arrived in the summer of 1974 and included William Greenberg and Ruby Celeste, both of whom were working towards their MS in biometry and health information systems; Elsa Roe, a board certified pediatrician completing training in computer applications in medicine and respiratory physiology; and James Fine, who was completing his residency in Laboratory Medicine and Pathology and an MS in biometry and health information systems. Upon completion of their respective training, Greenberg completed a PhD in bioengineering at the University of California, Berkeley, and went on to work in developing advanced signal processing algorithms at MIT’s Lincoln Laboratory; Celeste completed a medical degree and surgical residency; Roe resumed clinical practice at La Rabida Children’s Hospital at the University of Chicago; and Fine joined the faculty at the University of Washington, Seattle, as an assistant professor in laboratory medicine and as director of laboratory computer systems.52

**Interdisciplinarity in Education**

A core characteristic of Minnesota’s training program was the interdisciplinarity of both its students and faculty. By 1981, the DHCS’s faculty had been trained in biophysics (Ackerman, PhD, and Gatewood, PhD), biostatistics (Johnson, PhD), biometry (Gatewood, PhD, and Myra Chern, PhD), laboratory medicine and pathology and health information systems (Connelly, MD, PhD), biochemistry (Ellis, PhD), electrical engineering and systems science (Finkelstein, PhD), quantitative genetics (Stephen Rich, PhD), and management information systems (Jay Hamann, PhD). In addition, several faculty from other departments contributed to the interdisciplinarity of the training program. In the late 1970s, for example, Glenn Brudvig (Biomedical Library), Kenneth Keller, PhD (Department of Chemical Engineering), Donald McQuarrie, MD (Department of Surgery), William Munrow, PhD, and Marvin Stein, PhD (Department of Computer Science), Otto Schmitt, PhD (Department of Biophysics, Bioengineering), and Robert Schwanke, MPH (Interdisciplinary Studies, School of Public Health) joined the faculty of the training program.53

Finkelstein noted that in the first years of the training grant, “the trainees were typically former undergraduate engineers or computer science people . . . or they were clinical folks, docs or nurses or, sometimes, pharmacy people.” Finkelstein continued, “One of the important aspects of the training grant was to get these two different cultures to talk to each other and to work with each other and understand what they were doing . . . All of a sudden, they’re together in this graduate program. One
of the functions of some of the early, first year courses was to get these folks to talk to each other and to understand each other’s language.”

Gatewood, who became co-director of the training grant in 1978 and director of the DHCS after Ackerman stepped down in 1979, similarly recalled the faculty’s commitment to fostering interdisciplinarity. In recruiting graduate students and NLM trainees, “We tried to make sure that we had an equal blend of health professionals as well as people interested in a computer science degree or laboratorians who came and were interested in whatever degree would match their research. So we were not just training people that were awarded an HINF [Health Informatics] degree, but they may have received their degree from other programs, as well.”

By emphasizing the training of both computer scientists and health care professionals, the DHCS faculty met the goals set forth by the Association for Computing Machinery Curriculum Committee on Health Computing Education in its 1978 report, Health Computing: Curriculum for an Emerging Profession. The Association for Computing Machinery committee’s report had noted that despite the great potential that computers held for reducing health care costs and improving the health care delivery system, clinicians and administrators had been slow to incorporate them into practice in part because there was a shortage of well-trained health computer professionals. This dearth, the committee noted, was in part “due to the fact that career rewards are lacking because the discipline has not been well defined and there is no concrete professional identity among health computing specialists.” Although the NLM training program was a significant step, the committee observed that “many of these programs and indeed several other health computing programs in the country began by teaching health computer science to medical people.” By contrast, “there have been fewer formal efforts to teach computer scientists how to apply their products to the health care delivery system.” To this end, in 1978, the Association for Computing Machinery Curriculum Committee called on health computing programs to train computer scientists in addition to health professionals in health computing, something that the University of Minnesota’s NLM training program had been doing since 1974.

The DHCS received ten years of continuous funding from the NLM’s training grant program from July 1, 1974 through June 30, 1984, when the focus of the NLM’s training program changed. In those ten years, the DHCS had supported thirty-seven pre- and post-doctoral students on the training grant: thirteen physicians, eight other health professionals, nine students with a health-oriented background, and seven with a technological-oriented background such as mathematics, computer science, or operations research. The majority of NLM fellows went on to careers in the health fields either as scientists or educators in academia or industry, or as analysts or consultants. Among this majority, soon after the end of their training, nine were serving “as directors of health computing systems in laboratories and clinics or patient monitoring units.”

In the early 1980s, the priorities of the NLM shifted away from training biomedical users of computers to training researchers in and developers of biomedical computing. Reflecting this shift in priorities, in 1983, the NLM invited applications for its re-oriented Training Grant program.

In 1983, with Gatewood as principal investigator, the DHCS successfully applied for an NLM training grant, which Gatewood titled, Research Training in Medical Informatics, and in July 1984, the first cohort of trainees arrived on campus. The new training program differed significantly from the earlier training program. Rather than a focus on both pre- and post-doctoral students, the goal of the new training program was “to train postdoctoral students in techniques of information management and provide a suitable environment and guidance for these new investigators to initiate research efforts of their own.” The primary mechanism by which the DHCS would
prepare the trainees for research was through the development of Research Training Clusters in Health Informatics. As Connelly explained, biomedical computing was a very broad area because “you could make computers do just about anything . . . but that’s not necessarily the best way of developing a strong program. It’s better to get some focus, so that’s what these clusters would attempt to do and bring people of similar interests together . . . It often does lead to more synergy because multiple people are not necessarily [on] the same idea but at least working in the same area. That can bring strength in terms of research publications and impact.”

The decision to organize the DHCS’s research program into synergistic clusters not only promoted research productivity among the faculty, it also facilitated the training of health informatics researchers. As Gatewood reflected, “I think that was an innovation . . . it helped to identify the fact that the new trainee was joining an already existing research program, so they had research models. They had people with projects. They had people who were publishing, people with data, and people who were involved in teaching courses and bringing students up to speed. So even though it got a little thin at times in terms of research clusters, it, essentially, I think, worked out very well.” Connelly reiterated the point, recalling that, “The training grants made the University of Minnesota . . . a very fertile place.”

Initially, the DHCS established seven research clusters. Paul Johnson, PhD, professor of educational psychology and management sciences directed cognitive approaches in clinical decision making (later termed cognitive sciences). Johnson and colleagues “developed a theory of diagnosis by tracing expert decision processes using “thinking aloud” protocols in which subjects verbalize[d] their thoughts while making decisions,” and “developed a computer simulation of the model inferred from analysis of these protocols,” and “[investigated] methods of assessing characteristics of expert problem solving knowledge and its relationship to data collection and patient management skills.” Sheila Corcoran, PhD, RN, assistant professor of nursing directed the nursing decision making cluster, where she and her colleagues were “studying the decision making processes used by hospice nurses when developing drug administration plans to control pain, using verbal, ‘thinking aloud,’ protocols and decision analysis of the performance of experts and novices on simulated cases.”

Connelly directed the cluster regarding clinical decision making, which had two ongoing research projects. In the first, Connelly’s team was “investigating the use of referential, patient management and diagnostic displays as a means to overcome limitations of a clinician’s memory, attention and inference” in order to “support the more effective utilization of the increasing mass of lab data available for decision making.” In the second project, Connelly and his colleagues were collaborating with the University of Minnesota Blood Bank to define and construct a platelet transfusion database and use it “to characterize platelet usage patterns and to find patterns that may indicate sub-optimal use of an expensive and vital medical resource.” This research led to the development and implementation of ESPRE (Expert System for Platelet Request System), an automated decision support system for blood bank personnel assessing requests for platelets, which is discussed in chapter three.

Thomas Kottke, MD, assistant professor of medicine and epidemiology directed diagnostic classification of cardiovascular disease cluster. Kottke’s team created criteria and computer software to allow for the automation of diagnostic classification in epidemiological studies. The electronic communications cluster directed by Ackerman was researching “the use of computer and electronic communication technology in the preparation and distribution of journals.” The health information management cluster, directed by Gatewood, involved the development of decision support aids for various “departments, service units and health agencies.” The aids were “asso-
associated either with personal computers used for field data acquisition or CAI [computer aided instruction], or . . . integrated into existing health service information systems.\(^67\)

To be sure, the name and nature of the research clusters changed over time to reflect changes in research interests and personnel among the faculty. For example, by 1987, the electronic communications and the diagnostic classification of cardiovascular disease clusters had been disbanded and replaced by a simulation resource research cluster directed by Ackerman, a clinical trial diffusion research cluster directed by Gatewood, a biomedical library and information management cluster (later termed information analysis) directed by Sherrilynne Fuller, PhD, director of the Biomedical Library, and a biomedical supercomputer applications cluster directed by George Wilcox, PhD, associate professor of pharmacology.\(^67\)

With the launch of the training grant, the DHCS also established a weekly health informatics seminar in which members of each research cluster were responsible for hosting a three-week set of seminars on the current work of the cluster. In November 1985, for example, members of the biomedical library and information management research cluster, including an NLM trainee, Judith Graves, PhD, RN, presented on the research and development of bibliographic databases.\(^69\) Reflecting the faculty’s commitment to modeling a research environment, the faculty encouraged trainees (and also students in the graduate program) to prepare research articles on which they would be first author. This was seen as critical to preparing the NLM trainees for research careers. “We didn’t always succeed,” Gatewood explained, “but we tried to make them practitioners in the field.”\(^70\)

**Interprofessional Training**

A defining feature of Minnesota’s training program—and one that has characterized the fifty-year history of health informatics at the University—is its interprofessionalism. The majority of the medical informatics training programs in the 1970s and 1980s were, indeed, medical; that is, they emphasized the training of physicians in medical informatics. Minnesota’s program was different; from the beginning, it prioritized the training of all health care professionals and thus embodied the representativeness of health informatics. As a reflection of this, the first group of NLM fellows in 1984 included three physicians—Kent Spackman, MD; Joel Stoeckler, MD; and Diane Shoemaker, MD—and a nurse researcher, Judith Graves, PhD, RN. Graves’ informatics research, under the supervision of nursing faculty member Sheila Corcoran, PhD, RN, included the use of computer support in clinical decision-making and the design and development of knowledge bases to support nursing clinical practice.\(^71\) Graves was a foundational leader in the field of nursing informatics, establishing the Office of Nursing Informatics, College of Nursing at the University of Utah.\(^72\) (Graves also went on to serve as the post-doctoral supervisor of Connie Delaney, PhD, RN, FAAN, FACMI, acting director of the Institute for Health Informatics from December 2010 through May 2015 and dean of the University of Minnesota School of Nursing). Because of her work and others, Minnesota was one of the first institutions to be recognized for its work in nursing informatics. In a recent interview, Milton Corn, MD, deputy director for research and education at the NLM and previously director of the NLM’s Extramural Programs Division, reflected that Minnesota’s NLM training program “took more seriously, than any other program I can think of, early . . . interest in nursing informatics rather than the physician-centric point of view that predominated.”\(^73\)

In 1987, the DHCS’s first dental fellow arrived. Under the supervision of Gatewood, Paul Lang, DDS, MPH, investigated the use of computers to gather and analyze information for health- and business-related decision-making in dentistry, the analysis of dental databases, and the quality assessment of dental
practices. The diversity of the 1993 NLM fellows perhaps best showcases what Gatewood sees as one of the distinctive features of Minnesota’s health informatics program: “it illustrated that a program that was set up for training of medical professionals, students, residents, [and] physicians could equally be used with profit by all health professionals.” That year, the NLM fellows included two nurses, an optical scientist, a pharmacy doctoral student (who had also trained as a dental hygienist and held a Master of Public Health), a computer scientist, and five physicians. The following year, in 1994, the program saw the arrival of its first veterinary informatician, Elizabeth Lund, DVM, one of the first such informaticians to combine clinical practice recording with the collection of a database on disease and interventions in companion animals. “So I would say,” Gatewood continued, the University of Minnesota “was one of the first interprofessional examples of truly health computing.”

Evolving the NLM Training Program: The Mayo Clinic Collaboration

The DHCS’s NLM-funded Research Training in Medical Informatics program evolved over the course of its twenty-five years of funding. A major aspect of the University of Minnesota training program’s evolution is the collaboration that developed between the DHCS and the Mayo Clinic’s Division of Biomedical Informatics in the Department of Health Sciences Research. That collaboration began formally in 1990 when Christopher Chute, MD, DrPH, FACMI, founding director of the Division of Biomedical Informatics, was appointed as an associate member of the University of Minnesota’s health informatics graduate faculty. Chute, an internist and clinical epidemiologist, had joined the faculty of the Mayo Clinic in 1988 as assistant professor of epidemiology in the Department of Health Sciences Research, and a year later established the Division of Biomedical Informatics. Chute saw an opportunity at the Mayo Clinic “to build a scientific basis for the infrastructure of epidemiology and the systematic analysis of clinical data.” But having “no formal training whatsoever in informatics,” he “leaned very heavily on Gatewood and faculty members at the University of Minnesota. . . . Lael was among my informatics mentors and helped me shape my early career.”

In January 2015, Chute left the Mayo Clinic and joined the faculty at Johns Hopkins University. At Johns Hopkins University, Chute is the Bloomberg Distinguished Professor of Health Informatics, professor of medicine in the School of Medicine, professor of health policy and management in the Bloomberg School of Public Health, professor of health informatics in the School of Nursing, and chief health informatics research officer for the Johns Hopkins University Health System.

The DHCS—and its predecessor, the BDPU—had a long history of research collaboration with the Mayo Clinic, beginning with Ackerman’s ongoing collaborations with his former colleagues at the Mayo Clinic, such as Lila R. Elveback, PhD. Gatewood had also worked with Ackerman at the Mayo Clinic before joining the University of Minnesota. Informal connections between the Mayo Clinic and the NLM training program began to emerge in the late 1980s when NLM training fellow, John Rydberg, conducted his doctoral research on magnetic resonance imaging in a laboratory at the Mayo Clinic. Chute’s appointment in 1990 as an associate member of the graduate faculty in health informatics, however, formalized that relationship, allowing Chute to advise graduate students, teach graduate courses, and serve on examination committees at the University of Minnesota. Chute also began directing a clinical data representation cluster, reflecting his research expertise in natural language processing. Three years later, Chute’s colleague, George Klee, MD, PhD (a graduate of the Biometry and Health Information
Training the Next Generation of Health Informaticians

The partnership between the University of Minnesota and the Mayo Clinic on the NLM training program worked well during the 1990s and early 2000s. As Chute explained, “I think there was a great deal of synergy between Mayo Clinic and the University of Minnesota in those days, because we [the Mayo Clinic] had a fairly active informatics research program up and going by then, working with patient data, working with national consortia, working with other programs in applying informatics in a large clinical practice. [The University of] Minnesota had, and still has, a far greater didactic depth, larger faculty, a more established curriculum, a deeper bench for teaching and education, more experience in the management of how you actually engage students and graduate them, all those pesky things that come up with formal education. So, we were great partners.”

Evolving the NLM Training Program: Program Challenges

While some of the changes that occurred within the DHCS’s training program over its thirty-five years of NLM funding were internally generated by developments in faculty research and administrative changes within the DHCS, Department of Laboratory Medicine and Pathology, Medical School, and University, much of the training program’s evolution occurred in response to the shifting expectations of the NLM. As the NLM’s Corn explained: “we [the NLM] evolved our training programs a great deal as we saw informatics evolve.” The initial shift in direction—from training users and preparing teachers of biomedical computing to researchers in health informatics—had come in 1984 with the phase out of the University of Minnesota’s NLM-funded Training in Health Computer Sciences program and launch of the NLM-funded Research Training in Medical Informatics program. Initially, the NLM was particularly interested in research in clinical informatics, such as applying computers to clinical care broadly defined, and as Corn reflected, “My impressions, through the haze of memory, of the Minnesota program were that they were spot on when they started with the zeitgeist, which was clinical information. . . . The early Minnesota programs were really superbly well adapted to that and in many ways richer than many of the others for several reasons,” primarily the program’s strong interest and experience in public health and nursing informatics. “But then,” Corn continued, the NLM “evolved, and I think from our point of view, the Minnesota conception of the training program didn’t evolve, perhaps, quite in the direction that we were looking for.”

This failure to adapt contributed to the NLM’s decision not to renew the University’s training grant beyond the 2002–2007 grant (aside from a no-cost extension allowed through 2009). “From our [the NLM’s] point of view,” Corn explained, the University of Minnesota “was less successful than some of the others [NLM training programs at other university medical schools] in making these changes.” Corn pointed, in particular, to the developments in genomics in the 1990s and the development of bioinformatics—the computational analysis and management of biological data. The management of genomic data “loomed as a very large problem,” Corn recalled, “the sheer thousands of man-hours” needed to sequence the data would not have been possible without the use of computers. “So there was no question,” Corn continued, “that here we had a major scientific achievement that required a computer partnership.” The leadership at the NLM “began to wonder who was going to do this kind of computation research. The people trained to do the
biochemistry and the biology had not been trained to deal with vast amounts of information, especially of this sort. We thought that there would have to be bioinformaticians." As a result, in the 1990s the NLM decided to broaden the training programs to include bioinformatics as well as clinical informatics. Corn continued, "We put a great deal of emphasis in the competitions beginning in the 1990s on implying that you’ll get a lot more points during the review of your application if you’re paying attention to the fact that information management for science is just as important as information management for clinical care. Some of the programs reacted very cleverly to that and others more clumsily." Corn’s recollection of the Minnesota’s response to this new focus of the NLM training program was that they “didn’t quite know how they were going to do bioinformatics.”

To be sure, in 1993, as part of the training program the DHCS introduced a new research cluster led by Ellis in computational molecular biology. Ellis was working with Lawrence Wackett, PhD, in the Department of Biochemistry to develop a web-based database of microbial biocatalytic reactions and biodegradation pathways, an example of bioinformatics research. In 1998, the research cluster, still led by Ellis, was renamed bioinformatics. The emphasis of the training program, however, as Corn had surmised, remained with clinical informatics. There were at least three reasons for the DHCS’s reluctance to more fully integrate bioinformatics into the training program. First, as discussed in chapter one, throughout the 1980s, 1990s, and early 2000s, the DHCS struggled to secure sufficient institutional support from the University administration and the Department of Laboratory Medicine and Pathology. The DHCS had no administrative support or funding to hire new faculty and so, as Finkelstein observed, “that became an issue. If the program is not allowed to grow, it’s not going to go anywhere.” The lack of access to a guaranteed source of funding and departmental support to hire new faculty only served to reinforce the fact that the strength of the DHCS’s faculty and training program lay in clinical informatics.

A second reason relates at least in part to problems of organizational inertia. During the early 2000s, the vice provost for research and associate dean of the graduate school and subsequently interim dean of the graduate school, Victor A. Bloomfield, PhD, worked with several faculty members to establish a graduate minor in bioinformatics. Ellis, who was part of the committee to establish the graduate minor, recounted the inertia that plagued the first year of those efforts: “We had one organizational meeting and, then, a year passed, and I asked Vic Bloomfield, ‘When is this going to go? I know how these things should work. This is not working.’ Finally, he said, ‘Well, Lynda, would you like the job?’” Ellis was subsequently made head of the committee: we "met, at least," she said. The graduate minor program in bioinformatics was established through the Department of Laboratory Medicine and Pathology and first offered to graduate students in 2003. Students enrolled in the minor were required to take core coursework in computer and biological sciences, including courses in genomics or sequence analysis and statistical genomics. The graduate minor in bioinformatics, however, was terminated at the end of the 2011/2012 academic year. It was replaced, essentially, by the graduate program in Biomedical Informatics and Computational Biology (BICB). The BICB graduate program was established at the University of Minnesota–Rochester in fall 2008; Claudia Neuhauser, PhD, led the initiative. In the fall of 2012, the first BICB graduate courses were offered on the Twin Cities campus. Ellis explained, “I was as active in” the creation of the BICB graduate program “as I was allowed to be, but the handwriting was on the wall.” As Ellis was considering retirement, “there was nobody that wanted to take it [the graduate minor] over. It seemed like the thing to do was, it was my time to close it. I did talk to Claudia [Neuhauser] about merging the two [Bioinformatics
and BICB graduate programs], but that didn’t work out. So in about a ten-year span, it [the graduate minor] grew, flourished, and, then, died.”

A third factor, reflective of a broader pattern within the fields of bioinformatics and clinical informatics, contributes to the difficulties the DHCS faculty had building bioinformatics into the training program. As Chute described it, “the bioinformatics world and the clinical informatics world have led parallel lives. This has been true in many other academic institutions.” While Chute sees a lot of overlap between the two fields, he speculates that the two fields “probably for the most part, will remain parallel despite efforts to house them in single departments or single groups, because their traditions and their underlying science are not identical.” Chute continues, “I think the genomic community grew, more or less, out of the statistical genetics community, with a lot of emphasis on computational algorithm and a lot of emphasis on statistical association and probability. While informatics has its epidemiologic analog, so to speak, in statistical genetics in terms of comparative effectiveness research or other kinds of patient outcomes research, it is driven by a different set of machinery. We’re not so sequence dependent. We’re not obsessed with four nucleotides. Our world is, I won’t say richer, but more complex. You can do a lot with four nucleotides academically. It’s a different culture. You see that even manifest today with the Minnesota/Mayo relationship where we have the parallel BICB relationship and the continuing collaboration in clinical informatics space.”

The tension between bioinformatics and clinical informatics as distinct fields was reflected more broadly within the NLM’s training program. Corn noted that in some of the NLM-funded university training programs, “As bioinformatics got started... it fused with the clinical informatics. But in many places, perhaps the majority, it split into a different academic unit. They [the university training programs] didn’t hate it, but it just seemed a little hobby that some people were doing. The bioinformatics, that was science. That was real health care computing. So they split it off. In some of our sites the split did not hurt clinical informatics at all, at others, clinical informatics, standing alone, grew weaker.” Corn continued, “There’s no question, though, that the schools in which computational bioinformatics split off had more trouble coming up with a clinical-informatics-only application that was satisfying, but a few did it very well. It may have been harder for Minnesota. Certainly, some of the new programs [that combined bioinformatics and clinical informatics] we took on have been very successful. It’s probably easier for them, because they didn’t have any barnacles, and they didn’t have any people who said, ‘Well, we’ve always done it this way.’”

The inability of the DHCS (renamed the Division of Health Informatics in 2000) to fully integrate bioinformatics into its training program was only one element in the NLM’s decision not to approve the 2006 training grant application. Beginning in the mid-2000s, Chute looked to expand the Mayo Clinic component for the joint University of Minnesota/Mayo Clinic training program. In 2003, the Mayo Clinic and Arizona State University initiated an educational program that resulted in a joint nursing education program, joint faculty appointments, dual degree programs, and various collaborative research projects between the two institutions. Chute sought to utilize this partnership and establish Arizona State University’s Department of Biomedical Informatics and the Scottsdale campus of the Mayo Clinic as training sites for the NLM training program. The resulting tripartite training program, as a collaborative initiative between the University of Minnesota, the Mayo Clinic, and Arizona State University, was proposed in the 2006 NLM training grant application. In addition to research opportunities at each of the sites, the training consortium would use videoconferencing technologies and other telecommunication technologies to “provide a common set of
educational experiences focusing on the basics of medical informatics."

The proposed training consortium, however, was not well received by the NLM reviewers. As Corn recalled, “we never did understand the combination with Arizona [State University]. It’s possible that that might have worked, but our reviewers never liked it. We didn’t think,” Corn continued, “that there ever was much in the way of interchange between the two programs [the University of Minnesota/Mayo Clinic and Arizona State University]. The students never moved much from one to the other. . . . No one could figure out how that was going to work with Arizona. It sounded vaguely like there’d be distance learning and some use of telecommunications, but it really didn’t look like integrated programs, that the students were meeting each other or would be having mentors from the other places.” For Corn and the reviewers, it was also significant that Arizona State University’s biomedical informatics program “was known in the field to be an interesting but shaky work in progress.” It was also unclear what the University of Minnesota’s participation in the initiative with Arizona State University and the Mayo Clinic would be. “It seemed so odd,” Corn noted, “because we had started with [the University of] Minnesota. It had done all that wonderful stuff all those years and, now, was sort of an afterthought.” Ultimately, Corn reflected, “Our feeling at that time was that it wasn’t that Minnesota as a medical center had lost its way, but that the program that was being offered to us for funding had lost its way. I remember thinking, and so did some of the other reviewers, that it had, perhaps, been presented prematurely.”

The NLM did not approve the 2006 University of Minnesota/Mayo Clinic training grant application. In 2008, the NLM awarded the university a no-cost extension to their final five-year grant (which had been awarded in 2002), which would allow the final NLM trainees to complete their training. When that no-cost extension ended in 2009, it marked the end of twenty-five years of continuous NLM-funding of the Research Training in Medical Informatics program and thirty-five years of continuous health informatics training grant support from the NLM. In the twenty-five years of the research training program, the University of Minnesota program had trained fifty-eight fellows including at least eight nurses, two dentists and one dental hygienist, one veterinarian, two pharmacists, and twenty-nine physicians, several of whom focused on public health informatics. The remainder of the NLM trainees had been PhDs in basic or computer sciences or bioengineering. As Gatewood asserted, Minnesota’s training program was an interprofessional example of “truly health computing.”

Alumni

The success of the University of Minnesota’s graduate program in Health Informatics and of its thirty-five-year history of NLM training programs are visible in many ways. One example is in the research achievements of the health informatics faculty, the subject of chapter three. Another clear measure of the success of the University of Minnesota’s health informatics programs is in the accomplishments of its alumni, many of whom have gone on to become national and international leaders in the field of health informatics. Table 2.1 highlights just some of the graduate and NLM training program alumni. In addition to those highlighted in the table, the alumni of the graduate and training program not only represent the interprofessionalism of these programs but also the programs’ commitment to training health informaticians for academia and the health care industry more broadly. These commitments became all the more important following publication of the National Committee on Vital and Health Statistics report in June 2000, and the subsequent prioritization by health policymakers and the federal government to build a national health information infrastructure that would enable health
information exchange among different sectors of the health care system.\textsuperscript{103}

The University’s health informatics alumni have played important roles in developing and upgrading health information technologies, like electronic health record systems, that make a health information infrastructure possible and that facilitate accurate, secure, and verifiable health information exchange. The placement of University health informatics alumni in companies that design health information technologies that “connect people and [health care] systems”\textsuperscript{104} (Cerner); provide health systems with “the ability to optimize their EHR [electronic health records] through strategic clinical decision support management”\textsuperscript{105} (LogicStream); and develop, manage, and license “medical terminology and IT [information technology] software applications” that bridge the “information gap between clinicians, coders, and patients in the U.S. and abroad”\textsuperscript{106} (Intelligent Medical Objects), for example, help move the health information technologies and systems from the current state of development to the fully envisioned national health information infrastructure, as called for by the National Committee on Vital and Health Statistics report.\textsuperscript{107} Through their positions as chief information officers or directors of IT integration at academic medical centers, alumni play a critical role in the strategic and effective management of electronic health records systems (in addition to all other IT systems within the medical center) that are the key medium through which health information exchange occurs. The alumni who have held leadership positions in international not-for-profit organizations, like the International Health Terminology Standards Organization, which produces SNOMED-CT—the most comprehensive, multilingual health care terminology in the world that enables “consistent, processable representation of clinical content in [electronic health records]”\textsuperscript{108}; and the Healthcare Information Management and Systems Society, which leads “endeavors optimizing health engagements and care outcomes through information technology,”\textsuperscript{109} have facilitated the bringing together of governmental agencies and corporations around the world (and health care providers and not-for-profit organizations in the case of the Healthcare Information and Management Systems Society) to achieve innovations in health information technologies. The International Medical Informatics Association, for which alum Hyeoun-Ae Park will become President in 2016, has a similarly global mission: to bring together scientists, researchers, users, vendors, developers, consultants, and suppliers to fulfill its commitment to “promoting best practice in the use of information and communication technologies within biomedical informatics and in health and healthcare.”\textsuperscript{110} Finally, the numerous alumni that hold faculty appointments in health informatics units or departments in universities and academic health centers carry out essential health research in the field that will play a crucial role in the subsequent development and innovation of health information technologies and the capacities of health information exchange.

One final example of the University of Minnesota’s remarkable alumni is the unique story of Kjell Lindgren, MD, MHI, MPH. After receiving his medical degree from the University of Colorado in 2002, Lindgren completed a three-year residency in emergency medicine at Hennepin County Medical Center in Minneapolis in 2005. From 2005 to 2006, Lindgren was an NLM training grant fellow and in 2006 completed an MHI degree at the University of Minnesota. After graduating from the University, Lindgren completed a Master of Public Health (2007) and a two-year residency in aerospace medicine (2008) at the University of Texas Medical Branch in Galveston. In 2009, Lindgren was selected as one of fourteen members of the twentieth NASA (National Aeronautics and Space Administration) astronaut class and underwent two years of training and evaluation.\textsuperscript{111} Lindgren was a member of the flight crew of Expedition 44 to the International Space Station, which launched on July 22, 2015.\textsuperscript{112} During the five months Lindgren would spend at the International
Space Station, he and his fellow crew members would continue experiments already underway in biology, biotechnology, physical science, an Earth science.\textsuperscript{113} In a press interview before his space flight, Lindgren told reporters that the training he had received at the University of Minnesota had helped him apply information theory to the practice of clinical medicine.\textsuperscript{114}

As the University of Minnesota’s health informatics graduate and NLM training programs and the success of its alumni have shown, the future of health informatics graduate education and training will remain committed to interprofessionalism and preparing health informaticians for careers in all sectors of the health care system.

### Table 2.1: Past and Current Leadership Positions of Health Informatics Alumni in Industry, Academia, and Health Informatics Organizations

<table>
<thead>
<tr>
<th>Name</th>
<th>Years of NLM Fellowship/Graduation</th>
<th>Former Leadership Position</th>
<th>Current Leadership Position</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nawanan Theera-Ampornpunt</td>
<td>MS ’09; PhD ’11</td>
<td>Deputy Executive Director for Informatics, Chakri Naruebodindra Medical Institute, Faculty of Medicine Ramathibodi Hospital, Mahidol University, Bangkok, Thailand</td>
<td></td>
</tr>
<tr>
<td>Gregory Critchfield, MD</td>
<td>NLM ’81–84</td>
<td>President, Myriad Genetic Laboratories</td>
<td>CEO, Sera Prognostics</td>
</tr>
<tr>
<td>James Fine, MD</td>
<td>NLM ’74–76; MS ’77</td>
<td>Chair, Laboratory Medicine and Chief Information Officer, University of Washington Medicine</td>
<td></td>
</tr>
<tr>
<td>John Glaser, PhD, FACMI</td>
<td>NLM ’80–84; PhD ’84</td>
<td>President, Healthcare Information and Management Systems Society</td>
<td>Senior Vice President, Cerner</td>
</tr>
<tr>
<td>Judith Graves, PhD, RN, FAAN</td>
<td>NLM ’84–86</td>
<td>Founding Director, Office of Nursing Informatics, University of Utah; Director, Virginia Henderson International Nursing Library, Sigma Theta Tau International Honor Society of Nursing</td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Degree(s)</td>
<td>Position/Role</td>
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<td></td>
</tr>
<tr>
<td>Mark W. Jurkovich, DDS, MBA</td>
<td>MHI '13</td>
<td>Former President, Minnesota Dental Association; Former President, Minnesota Academy of General Dentistry</td>
<td></td>
</tr>
<tr>
<td>Boonchai Kijsanayotin, PhD</td>
<td>MS '04; PhD '08</td>
<td>Medical Informatics Office, Ministry of Public Health, Thailand; Co-chair, Asian eHealth Information Network</td>
<td></td>
</tr>
<tr>
<td>Kjell Lindgren, MD, MHI, MPH</td>
<td>NLM '05–06; MHI '06</td>
<td>Member of 20th NASA astronaut class (2009); NASA flight crew, Expedition 44 to International Space Station, July 2015</td>
<td></td>
</tr>
<tr>
<td>Curtis Parvin, PhD</td>
<td>NLM '75–77; PhD '80</td>
<td>Clinical Research Associate Professor, Internal Medicine and Director of Informatics and Statistics, University of Washington School of Medicine, St. Louis</td>
<td></td>
</tr>
<tr>
<td>Hyeoun-Ae Park, PhD, RN</td>
<td>PhD '87</td>
<td>Dean, Seoul National University College of Nursing, Seoul, Republic of Korea</td>
<td></td>
</tr>
<tr>
<td>Andrea Pitkus, MS, PhD</td>
<td>NLM '06; PhD '10</td>
<td>Product Manager for Laboratory Information Technology, Intelligent Medical Objects</td>
<td></td>
</tr>
<tr>
<td>Daniel Rubin, MD, MHI</td>
<td>NLM '06; MHI '12</td>
<td>Director of Clinical Development, Wolters Kluwer Health</td>
<td></td>
</tr>
<tr>
<td>Edward Schulz, MD</td>
<td>NLM '80–84</td>
<td>Director, Information Technology Integration, Vanderbilt University Medical Center</td>
<td></td>
</tr>
<tr>
<td>Kent Spackman, MD, PhD, FACMI</td>
<td>NLM '84–86</td>
<td>Scientific Director, SNOMED International; Head of Terminology, International Health Terminology Standards Development Organization</td>
<td></td>
</tr>
<tr>
<td>James Turley, PhD, RN</td>
<td>NLM '93</td>
<td>Associate Professor and Associate Dean for Research, University of Texas School of Health Information Sciences at Houston</td>
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</tbody>
</table>
Milton Corn, MD, Deputy Director for Research and Education, National Library of Medicine

Photo courtesy of National Library of Medicine

Christopher Chute, MD, DrPH, FACMI

Source: University of Minnesota

Hyeoun-Ae Park, PhD, RN

Photo provided by Hyeoun-Ae Park
Rui Zhang holding his PhD diploma, with David Pieczkiewicz, PhD, Director of Graduate Studies, and Genevieve Melton-Meaux, MS, MD, c. 2014

source: Institute for Health Informatics, University of Minnesota
Chapter
THREE

Innovations in Health Informatics Research, 1965–2005

For fifty years, the University of Minnesota has been a center of innovation in health informatics research. Since the late 1960s, the University’s health informaticians have produced cutting-edge research and developed innovative technologies in the fields of signal processing, database design and management, clinical decision-making systems, micropopulation simulation modeling, vocabularies and natural language processing, and telehealth and home monitoring. This research has been characterized by interdisciplinarity and interprofessionalism.

Throughout its history, the leadership of the University of Minnesota’s Biomedical Data Processing Unit (BDPU), Division of Health Computer Sciences (DHCS), Division of Health Informatics, and Institute for Health Informatics (IHI) has exemplified leading informatics research and fostered a culture of innovation. When Eugene Ackerman, PhD (director, DHCS, 1969–1979), joined the faculty of the University of Minnesota in 1967, he brought with him a tradition of pioneering research in biophysics and the modeling of physiological systems and infectious disease epidemics. Lael Gatewood, PhD (director of DHCS from 1979–2000), had worked with Ackerman at the Mayo Clinic before joining the University in 1967. When she arrived at the University, in addition to continuing her collaborative relationship with Ackerman, she developed her own research projects in mathematical modeling and cardiac epidemiology simulation. By the time Donald Connelly, MD, PhD (director of the Division of Health Informatics, 2000–2006, and IHI, 2006–2007), Julie Jacko, PhD (director of IHI, 2007–2010), Connie Delaney, PhD, RN, FAAN, FACMI (Dean and professor, School of Nursing; acting director of IHI, December 2010–May 2015), and Constantin Aliferis, MD, PhD (director of IHI from June 2015), assumed leadership of health informatics at the University, they had each established themselves as preeminent researchers. Reflecting the prominence of the University’s health informatics leadership, all but Jacko were inducted into the prestigious American College of Medical Informatics: Gatewood as a founding
fellow in 1984, Ackerman in 1985, Connelly in 1986, Delaney in 2004, and Aliferis in 2007. As nationally and internationally recognized researchers, these directors of the health informatics units laid the foundations for their faculty to have productive and innovative research careers.

Ellis Benson, MD, who chaired the Department of Laboratory Medicine and Pathology from 1966 to 1989, also reinforced a culture of experimentation in clinical decision-making among the DHCS faculty. Connelly joined the Department of Laboratory Medicine and Pathology as a resident and the DHCS as a Public Health Service research fellow in 1972. In 1974, he joined the faculty of the Department of Laboratory Medicine and Pathology and DHCS, and in 1977 earned his PhD in biometry and health information systems. As Connelly recalled, “The culture in Laboratory Medicine and Pathology was very conducive to doing strange things. In that day, computing in medicine was probably considered by most as a kind of strange thing.” Connelly’s colleagues would say, “Do what you’re interested in and Dr. Benson will call it laboratory medicine.” For Connelly, “It was a heady time . . . because we were really doing new and interesting things. Just about everything you did was publish-worthy, because not many people were doing it yet.”

In 1995, pioneering health informatician Homer Warner, MD, PhD, of the University of Utah (Warner earned his PhD in physiology at the University of Minnesota in 1953) surveyed the field of health informatics. He broke the field into five different categories: 1) signal processing, 2) database design, 3) decision making, 4) modeling and simulation, and 5) optimizing the interface between the human and the machine.” Warner highlighted informaticians’ success using computer-based signal processing to assist physicians’ analysis of electrocardiogram data, and the application of signal processing to computerized tomography and magnetic resonance imaging. “Under the heading of database,” (emphasis in original), Warner described informaticians’ “design and build systems that allow one person to store information so that someone else can retrieve it without having to know the technical details about how the data are presented.”

The development of clinical decision support systems was another area highlighted by Warner. He noted the important work of informaticians “directed toward facilitating the decision-making process, which may be performed by an expert or by a computer-based model of that expert.” Models and simulation were another key component of the field. For Warner, “The purpose of building a model is to gain insight that often comes from failure of the model to describe quantitatively a relationship that seemed apparent based on intuition. If the model does not fit the data, a new model must be sought. If it does fit the data, it can provide a basis for planning, extrapolation beyond current experience, and sensitivity analysis.” Warner asserted that modeling was “the optimal tool for knowledge management” of complex systems. In the final domain of health informatics research, Warner saw research on natural language processing as critical: “in medical informatics we deal with the human-machine interface, for both the acquisition and the presentation of data [emphasis in original]. Transfer of information to the machine often involves natural language recognition. At this point in time, however, this requires a dialog to accomplish communication and translation without loss of meaning. This continues to be a challenging problem,” which, Warner hoped, health informaticians would soon find a solution to.

The University of Minnesota’s health informatics research had, since the 1970s, focused on all five of these areas: signal processing; modeling and simulation; clinical decision-making; databases; and the interface between humans and computers. The University also developed expertise in a sixth area: home monitoring and telehealth. With the founding of the Institute for Health Informatics in 2006 and the addi-
In the absence of several new faculty members, the University’s expertise in health informatics research expanded into new domains. These included evaluating the impact of electronic health records and health information exchange on health care delivery; applying data mining techniques to electronic health records; the design, development, and implementation of standardized nursing terminologies in electronic health records; the development of new methods in natural language processing; and innovations in clinical decision-support systems. This chapter and chapter four tell the story of the history of health informatics research at the University of Minnesota, focusing on the work of its faculty and the contributions of graduate students and post-doctoral fellows. This chapter reviews the research conducted by the University of Minnesota’s health informaticians in the five research domains highlighted by Warner, and in the field of home monitoring and telehealth. Chapter four focuses on the research innovations of the University’s health informaticians after the establishment of the IHI in 2006.

**Signal Processing**

In 1995, Warner identified signal processing as one of five major research fields in health informatics. The signals being processed could be derived from patients or from analysis equipment. Electrocardiographs measure signals generated directly by patients. The heart muscle generates electrical signals that are detected by electrodes placed appropriately on the patient. The signals, derived from twelve leads, are analyzed with a computer. An electrocardiogram (ECG) is a record of these signals. As A. Hasman explained in 1987, “QRS complexes,” a series of deflections in the ECG that represent electrical activity generated by ventricular depolarization, “may be averaged to obtain an averaged [heart] beat with reduced noise content. Then the beginning and end of the P, Q, R, S, and T waves in the averaged complex are determined. On the basis of calculated intervals and amplitudes the diagnostic part of the analysis program can make suggestions about possibly existing heart disease.”

One of the goals, then, of conducting signal processing in medicine was to generate clinically useful information.

In 1972, Claus Liedtke, PhD, joined DHCS as assistant professor in the Department of Laboratory Medicine and Pathology. He had received his PhD in electrical engineering the previous year at Technische Universität in Berlin, Germany. Liedtke’s research expertise was in the field of signal processing and within a year of joining the DHCS, he had begun a collaborative project with cardiologist Naip Tuna, MD, in the Medical School’s Department of Medicine. In that project, Liedtke and Tuna analyzed ECGs and vectorcardiograms (graphic representation of the magnitude and direction of the electrical forces generated by the heart) to identify possible correlations between ECG and vectorcardiogram measurements and cardiac dysfunction. The project was underwritten by a grant from the National Health and Lung Institute and by the National Institutes of Health (NIH) Research Resources Grant (RR-267) (see chapter one).

In 1976, for example, Tuna, Liedtke, and colleagues published the results of a study evaluating the “value of the atrial electrocardiogram (the P wave) in assessing the severity of ventricular diseases.” They found “the correlation between the right ventricular overload and the ECG changes” of right atrial overload “stronger than the similar correlation for the left side of the heart.” The difference, they suggested, might be explained if “the influence of right ventricular overload on right atrial function is determined early in this course of the disease, whereas the aortic valve disease group represents a relatively more chronic situation starting comparatively at an older age,” with different mechanisms being “involved at various stages of the disease.”

Liedtke also collaborated with Fernando Torres, MD, in the Medical School’s Department of Neurology,
analyzing research subjects’ recorded responses (from several scalp electrodes) to light flashes “at rest (baseline) and during alternate compression of the carotid arteries in the neck.” In the early-1960s, Torres had conducted a pilot study of patients with cerebrovascular disease and asymptomatic patients of comparable age finding that “visual evoked responses (VER) recorded from homologous areas of the scalp showed significant differences in asymmetries between the patients and the controls.” Based on these findings, Torres had suggested that “this difference was due to anoxic changes affecting the VER in the patients.” If this was the case, he continued, it “could constitute a non-invasive method for the detection of anoxia, possibly even before permanent symptoms develop.”

To determine whether the changes measured in the patients were caused by ischemia, Liedtke and Torres undertook a study aimed at demonstrating a “correlation between controlled ischemia and localized changes in VER.” To do this they recorded VER in “normal subjects before, during and after compression of the common carotid artery.” The results of the study, which were published in 1975, showed the technique held clinical promise. Liedtke and Torres anticipated that the main clinical situation in which it could be used would be “when subjects present to the clinic with a history of transient symptoms and signs, not lasting more than 24 hr and most of the time less than 4 to 6 hr. This picture suggests the presence of transient ischemic attacks (TIA), but it could be confused with epileptic phenomena, among other possibilities. The TIA’s tend to repeat. If VER were recorded and analysed” using their method, “after the first episode, while the patient is asymptomatic, this could be made to repeat the procedure during a subsequent attack.” Because their method detected even subtle changes, Liedtke and Torres were confident that TIA would be detected, enabling the patient to be treated accordingly. Liedtke’s collaborations with Tuna and Torres showed the potential clinical applications of signal processing research.

In 1977, Liedtke left the University of Minnesota to return to his native Germany, where he was appointed professor of digital signal processing in the Department of Electrical Engineering at the Universität Hannover. There he continued his research in signal processing. Although Tuna and Torres continued their research programs, research on signal processing by the University’s health informaticians came to end with Liedtke’s departure. The University’s health informaticians, however, developed thriving research programs in the remaining four research domains highlighted by Warner in 1995: database design, decision-making, modeling and simulation, and optimizing the interface between humans and computers. We turn now to the University’s research innovations in database design and management.

**Database Design**

Databases are computerized systems that store and organize data and information so that it can be easily accessed and searched. Health informaticians played key roles in designing and building databases for the storage, organization, and retrieval of health-related and biotechnological data. Health informaticians use database management systems (a set of software programs), to define, manipulate, retrieve, and manage data in a database. At the University of Minnesota, Gatewood and Lynda Ellis, PhD, have been leaders in database design and management.

Gatewood’s work in database design dates back to her time at the Mayo Clinic in the early 1960s. As part of a NIH Research Resources grant-funded biomedical computer facility directed by Ackerman, Gatewood and Ackerman wrote a general purpose FORTRAN-based assembly language file management program that allowed programmers to read and write tapes on the Mayo Clinic’s IBM 1620 computer system. When the tape drives had been added to their IBM 1620
system, and before the availability of the Ackerman/Gatewood program, there was no way for programmers to use the tape drives to read or write data from a FORTRAN program. Gatewood also worked on a file-handling project that used the programming language COBOL to read doubly punched Hollerith cards of the Mayo diagnostic and surgical indices from the 1930s and transfer the results to tape for archival research.

Once at the University of Minnesota, Gatewood’s experience and reputation in database design and management grew as she was recruited to work on several prominent epidemiological and clinical studies. Since the 1960s, Gatewood has worked on database development and management for several major projects. In the late 1960s, she worked with Minnesota state demographer Robert Hiller, projecting Minnesota population statistics for the state’s eighty-seven counties based on previous censuses. Gatewood also worked with oncologist B. J. Kennedy, MD, professor of medicine in the Medical School, to calculate survival statistics for two hundred of his stomach cancer surgery patients. During her work on that project, Gatewood “discovered erroneous chronological data,” and developed “data editing routines and plotting programs for others to use.”

Beginning in the late 1960s and continuing through the late 1970s, Gatewood worked for Alan Treloar, PhD, professor of biometry in the School of Public Health, first as programmer and then as project director of the longitudinal history database that was part of the Menstrual and Reproductive Health Program, led by Treloar. The Menstrual and Reproductive Health Program studied women’s menstruation and related reproductive and other health issues. Additionally, beginning in the early 1970s and continuing through the early 1980s, Gatewood again worked first as programmer and then as project director on the Minnesota Coronary Survey, led by cardiologist Ivan Frantz, MD, professor of medicine in the Medical School. The Minnesota Coronary Survey was a four-and-a-half year, double-blind, randomized clinical trial, conducted in six Minnesota state hospitals and one nursing home, to compare the effects of a control diet with a fat treatment diet on serum cholesterol levels and the incidence of myocardial infarction. In both the Menstrual and Reproductive Health Program and the Minnesota Coronary Survey, Gatewood used the file management software she had developed while at the Mayo Clinic and added a “rudimentary data dictionary for the flat files.” She also “began to investigate the use of commercial database management systems already in use for business applications.”

From 1973 to 1982, the National Heart and Lung Institute funded the Multiple Risk Factor Intervention Trial, a randomized, primary prevention trial conducted at twenty-two clinical centers throughout the United States “to test whether lowering elevated serum cholesterol and diastolic blood pressure and ceasing cigarette smoking would reduce coronary heart disease mortality.” The University of Minnesota was named the coordinating center, which was directed by Marcus Kjelsberg, PhD, professor of biometry in the School of Public Health. Because of Gatewood’s expertise handling clinical data files and experience teaching others, she was recruited by Kjelsberg to serve with Glenn Bartsch, ScD, professor of biometry in the School of Public Health, as co-deputy directors of the Multiple Risk Factor Intervention Trial coordinating center. This introduction into clinical trial coordination led the leaders of the Division of Biometry to expand the division’s capabilities for clinical data management systems and service over the next several decades. This ultimately culminated in the establishment of the University of Minnesota’s Biostatistical Design and Analysis Center, which is part the Clinical and Translation Science Institute and provides statistical and data management support to researchers.

As a result of Gatewood’s work on the Multiple Risk Factor Intervention Trial and the professional connections that grew out of it, she was asked to consult both inside and outside the University of
Minnesota on multicenter and community trials in cardiovascular epidemiology. At the University of Minnesota, Gatewood engaged with the School of Public Health’s Division of Epidemiology (renamed the Division of Epidemiology and Community Health in 1983) to enlarge their in-house computer and programming capabilities to manage their own clinical research studies, and assisted with data management and quality control for the Minnesota and Midwest Community Heart programs directed by Henry Blackburn, MD, professor and director of epidemiology (and later, epidemiology and community health), School of Public Health. Since the early 1980s, the School of Public Health’s divisions of biometry, epidemiology, and community health have achieved national and international prominence for their expert work coordinating more cardiovascular studies and new global HIV/AIDS studies.

Gatewood’s database work took on international significance when she was recruited in 1994 to help design the data management system for the Public Health Coordinating Center of the World Health Organization’s MONICA (Multinational MONItoring of Trends and Determinants in CArdiovascular Disease) Project in Helsinki, Finland. MONICA was established in the early 1980s to monitor trends in cardiovascular disease and relate them to risk factor changes in the population over a ten-year period. The project included thirty-two Collaborating Centers in twenty-one countries.14

Gatewood was involved in data management consulting work at the request of Frederick Goetz, MD, professor of medicine in the University of Minnesota Medical School and director of the University of Minnesota General Clinical Research Center (the predecessor to the Clinical and Translational Science Institute). Gatewood was asked to write an ancillary grant to obtain a CLINFO system, a clinical research database management system designed by the NIH National Center for Research Resources. As Gatewood explained, “this was a rudimentary system to help clinical investigators manage their own clinical research studies with abilities for data entry and edit, data dictionary, file management, descriptive statistics, and publishable computer plots and graphs.”15 After the local CLINFO system was set up, Gatewood directed the system management and staff for the next ten years. Eventually CLINFO was upgraded and merged into PROPHET (funded by the National Center for Research Resources). PROPHET added capabilities in bioinformatics for searching, merging, analyzing, and visualizing clinical data with the early genomic databases such as GenBank (see below). Gatewood served on advisory panels for these nationally funded clinical and research data management systems.

Gatewood also worked with Alan P. Bender, DVM, PhD, at the Minnesota Department of Health in the mid-1980s to develop a clinical registry for the Minnesota Cancer Surveillance System (see chapter one). In the early 1990s, Gatewood worked with Martin LaVenture, MPH, PhD, at the Minnesota Department of Health to help design the Minnesota Immunization Information Connection, a statewide immunization registry system (see chapter one). The cancer and immunization registry systems “paved the way for today’s state-wide registries throughout the United States,” and are still in use in Minnesota in 2015.16

While Gatewood’s expertise was in the area of clinical and epidemiological database design and management, Lynda Ellis, PhD, developed a national reputation in bioinformatics database development. Beginning in the 1980s, computers came to play an increasingly important role in biology, particularly in the collection, storage, organization, and analysis of sequence data (e.g., DNA, RNA, and protein sequence data). This was embodied in the establishment of GenBank at the Los Alamos National Laboratory in New Mexico in 1982, a publicly funded sequence database supported by a $2 million, five-year contract from the NIH (in 1992, GenBank moved to the National Library of Medicine’s National Center for
Biotechnology Information). As Hallam Stevens has described in his history of bioinformatics, by the mid-1980s, “the amounts of data,” particularly molecular biological data, “seemed to be constantly overwhelming biologists’ abilities to analyze and understand them. However, computers seemed to present a ready-made solution: they were designed to handle exactly the kinds of data management problems that biology now presented.” Computers, in particular, were tools that biologists used to build databases of information. These databases, Stevens asserts, cannot be thought of as just collections. Instead, biological databases are orderings of biological materials. They provide ways of dividing up the biological worlds; they are tools that biologists use and interact with. Computer databases store information within carefully crafted digital structures. … Databases construct orderings of scientific knowledge: they are powerful classification schemes that make some information accessible and some relationships obvious, while making other orderings and relationships less natural and familiar. … Databases do not aim to be a straightforward representation of a biological system; rather, they aim to capture some of its important features. The database becomes a digital idealization of a living system, emphasizing particular relationships between particular objects.

As the amount of molecular biological data being generated grew, so too did the number of databases available to collect, organize, and analyze that data. By the early 1990s, molecular biologists, in particular, were concerned that much of that data “flowed in an ad hoc fashion—into isolated databases, in non-standard formats.” The situation was such that “finding all the available information about a particular gene or sequence was becoming nearly impossible.”

Ellis entered this milieu as she began a sabbatical year of research in 1993. Ellis earned her PhD in biochemistry at Brandeis University in 1971 and in 1973 completed a post-doctoral fellowship with Clare Woodward, PhD, in the departments of biochemistry and laboratory medicine and pathology at the University of Minnesota. From 1973, she served as a faculty member in DHCS in the Department of Laboratory Medicine and Pathology. When Ellis was on sabbatical during the academic year 1993–1994, she worked in the laboratory of Lawrence P. Wackett, PhD, in the Department of Biochemistry on the University of Minnesota St. Paul Campus. “I moved over to his lab to help him with some computational-based things,” Ellis recalled.

Wackett’s research focused on investigating enzyme transformations for biotechnological applications, particularly the use of “biodegradation for environmental purposes and biocatalysis for producing specialty chemicals or detection kits.” Because microbial enzymes were well known to represent an invaluable resource for biosynthesizing desirable molecules, and microbial metabolism had long been used to treat agricultural and industrial wastes, researchers interested in biodegradation and biocatalysis were particularly focused on microbial enzyme transformations.

By the mid-1990s, Ellis and Wackett were asserting that biologists and biotechnologists would need “better access to information on microbial biocatalysis” if they were going to produce “innovations in biosynthesis and environmental biotechnology.” “As microbial recombinant techniques become easier,” they continued, “more microbial degradation pathways are discovered, and recycling of wastes to usable chemicals becomes increasingly important, the rational design of organisms for [biodegradation] is not only desirable, but essential.” Such rational design meant that researchers would need to know about (1) “the pollutant’s physical properties, toxicology, EPA regulations and other compound-specific data”; (2) “what metabolic pathways are known both for the biodegradation of the pollutant and the [biocatalysis] of one or more possible marketable compounds”; (3) how “the
In 1995, Ellis and Wackett launched the web-based University of Minnesota Biocatalysis/Biodegradation Database (UM-BBD). The database contains information on microbial biocatalytic reactions and biodegradation pathways for primarily xenobiotic, chemical compounds. The UM-BBD linked users to other databases, such as the Enzyme Metabolic Pathway Database at Argonne National Laboratories in Lemont, Illinois, the Kyoto University Ligand Chemical Database in Japan, MEDLINE (the National Library of Medicine’s online database of published biomedical literature from around the world), Material Safety Data Sheets at the University of Utah, and Extension Toxicology Network at Oregon State University, providing users with centralized access to information on chemical properties, toxicology, enzymes, genes, and intermediary metabolism. In this way, UM-BBD fit the model of bioinformatics in the early- and mid-1990s: it promised to solve the problem of a deluge of microbial data being lost in “isolated databases” in “nonstandard format” by consolidating that data in one large database that would be more easily accessible to users wishing to apply that knowledge to commercial applications.26

By 2000, Ellis, Wackett, and colleagues reported that the UM-BBD was attracting users from over ninety countries on six continents. To improve access to users in Europe and Asia and reduce the load on the U.S. server, in 1999 they arranged for the European Bioinformatics Institute located in Hinxton, England, to mirror the UM-BBD data, and in 2001, they established a second mirror site in the Kyoto Encyclopedia of Genes and Genomes in Kyoto, Japan.27 They later established another mirror site, hosted by the Swiss Federal Institute of Aquatic Science and Technology (Eawag), after Eawag faculty member, Kathrin Fenner, PhD, had completed a post-doctoral fellowship in Wackett’s laboratory. When the UM-BBD’s grant funding concluded, Ellis explained, “I was already looking at retirement. Larry and I had worked closely as a team.” Because no one else at the University was
available to take over the leadership of the UM-BBD, Ellis and Wackett decided to move the database over to Eawag. As a condition of the transfer to Eawag, Ellis continued, Eawag “would continue the name [UM-BBD] for two years with a different URL . . . Then, all rights would [transfer] to Eawag.”28

At launch, the UM-BBD contained information on just four catabolic pathways. In February 2015, the database contained information on 219 pathways, 1,503 reactions, 993 enzymes, 543 microorganism entries, and 249 biotransformation rules.29 The term pathway refers to a “sequence of related reactions that start with a given compound and terminate in intermediary metabolism, metabolic cycles, or when no further microbial metabolism is known,” while biotransformation rules refers to the codification of a chemical reaction.30 The UM-BBD (now named Eawag-BBD) has been a remarkable success, receiving funding from the NIH, National Science Foundation, and Department of Energy.32 As a 2008 review in Current Opinion in Biotechnology extolled, the UM-BBD is “the main—if not the only—public resource for qualitative studies on microbial biotransformations. . . . [It] represents a colossal effort to collect primary data from literature on such processes.”33

Through their work, Gatewood and Ellis established the University of Minnesota as a center of innovation in database development and management in the areas of clinical and epidemiological data (Gatewood) and microbial biotechnology data (Ellis). The databases developed by Gatewood provided critical infrastructural support to clinical and epidemiological researchers as they sought to translate the large amounts of data accumulated during trials into actionable clinical knowledge that could guide clinical or public health practice. Similarly, the UM-BBD developed by Ellis and Wackett enabled scientists in industry, government, and academia to translate microbial knowledge generated at the laboratory bench into biotechnological innovations with practical utility. In each case, Gatewood and Ellis’s research made critical contributions to what we now call translational science.

The development of clinical decision support systems is another area of health informatics focused on the storage and retrieval of health information, and translating that information (what is often “big data”) into improved clinical practice. Led by Connelly, the University of Minnesota’s health informaticians have been leaders in the research and development of clinical decision support systems since the 1970s.

**Laboratory Information Systems and Clinical Decision Making**

In the 1960s, medical informaticians began investigating the possibility of computerizing medical information to increase the accuracy and efficiency of information storage, retrieval, and communication to improve patient care. In 1979, Donald Lindberg, MD, then at the University of Missouri—Columbia and now the recently retired director of the National Library of Medicine, defined Medical Information Systems (MIS) as “a set of formal arrangements by which factors concerning the health or health care of individual patients are stored and processed in computers.”34 An MIS entailed more than just computerized documentation of patients. MIS pioneer Morris F. Collen, MD, described in 1995: “an MIS was a complex integration of multiple subsystems, which could include an administrative information system (AIS), a clinical information system (CIS), and several clinical support systems (CSSs).” In turn, Collen continued, “an AIS included its own subsystems for accounting and business functions,” including patient registration, scheduling, admission and discharge, and for other patient-processing activities. A CIS was used “for those systems of an MIS that were related to direct patient care,” and “CSSs included clinical laboratory, pathology, radiology, electrocardiography, pharmacy,
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and other systems.” By the 1980s, the development of MIS had become a core element of health informatics. A key focus of MIS development concerned the development of clinical decision-support systems. In 1987, health informatics pioneer Edward Shortliffe, MD, PhD, defined a clinical decision–support system as “any computer program designed to help health professionals make clinical decisions.” Clinical decision–support systems, he continued, “deal with medical data about patients (similar to what would be found in a medical record) or with the knowledge of medicine necessary to interpret such data. They generally help in determining the nature of a patient’s disease state or in formulating a plan for reaching a diagnosis or administering therapy.”

Throughout his career, Donald Connelly, MD, PhD, FACMI, has been a leading researcher in the development of laboratory information systems (part of clinical support systems and thus a key constituent of MIS) and clinical decision–support systems. During his residency in laboratory medicine and pathology in the early 1970s, Connelly said that in every laboratory he rotated through he “would often leave a little computer program” that he had developed. In the microbiology laboratory, Connelly described, “They had a mandated requirement to annually report the pattern of antibiotic sensitivity of all organisms cultured in all patients. This was a real big hassle for them because it involved a lot of data. So I wrote a program that they used to key punch in the results of each sensitivity report, and then compile them all. In those days, they probably had a couple thousand of those a year. They would key them in, load them in with my program, and out would come a consolidated report that 23% of the E. coli organisms were sensitive to Antibiotic A but 87% were sensitive to Antibiotic B. I remember putting an edit check in the date field to catch keying errors. In each culture, you had to enter the date of that culture. I put in an edit check—this, I think, I wrote in 1973 or so—‘Don’t allow anything beyond 1989.’ I got a call on January 2 or 3 of 1990, ‘Your program doesn’t work any more.’ First of all, I was surprised they were still using it almost twenty years later. Also, it was pleasing that it was easy enough to fix.”

After Connelly completed his residency in 1974, Ellis Benson, MD, chair of the Department of Laboratory Medicine and Pathology hired Connelly as assistant professor and appointed him director of the department’s Laboratory Data Division. In that position, Connelly was responsible for developing, implementing, and managing the department’s laboratory information system. Ackerman, Connelly noted, “saw me as kind of the protégé to be able to manage that laboratory computer information system when we finally got it installed.” Although the department had tried to develop two of its own information systems, “it always turned out to be a lot bigger project than they thought it would be and, for various reasons, they were not real successful.” Subsequently, Ackerman decided to use the commercial MedLab system.

The MedLab system was based on the HELP (Health Evaluation through Logical Processing) program developed by Warner at the University of Utah and associates at the Latter Day Saints Hospital in Salt Lake City (see Introduction). Warner had previously worked at the Mayo Clinic and earned a PhD in physiology from the University of Minnesota (1953). When physicians entered patient data into the system, the HELP program worked by searching its “knowledge bases to see whether there was any relevant information on the data of which the physician should be made aware.” At the Latter Day Saints Hospital, the patient data included within the system came from “multiphasic screening, computer-based electrocardiogram analysis, computer-based pulmonary function testing, surgical and intensive care unit monitoring, computer-based blood gas determination, computer-based catheterization laboratory, and manual entry of diagnosis data at video terminals.” Physicians could also add additional data as needed. Connelly and “the key manager in the Lab Data Division, Phil Saint Louis, and I basically, lived
with that computer for the first three months,” until they were able to stabilize the laboratory information system “because the mean time between failures was about twenty minutes.”

Early on, Connelly became interested in developing ways to graphically display laboratory data to clinicians. “Even back then,” Connelly recalled, people working in the clinical laboratory “were really generating tons and tons of data [what we would now refer to as “Big Data”]. People ordered tests like crazy. When I was an internal medicine intern, I ordered tests like crazy, too.” The resulting “data deluge” often led to physicians overlooking important laboratory results “because they are hidden in a mass of data competing for the physician’s attention.”

In 1978, Connelly and his colleagues began developing a way to present “this data so that . . . [the] hidden signs would become easier to see.” To do this, they used Control Data Corporation’s interactive terminal, PLATO (Program Logic for Automatic Teaching Operation). The PLATO system included a touch-sensitive plasma display screen that allowed for interactive data entry as well as “high resolution graphic capabilities.” The computer-based laboratory information system “supported approximately 70 terminals and on-line instruments in the clinical laboratory, serology, and outpatient laboratories at the University of Minnesota Hospital.” Using any one of the seventy display terminals, physicians could query “the laboratory computer by invoking one of three modified FORTRAN programs to acquire patient identification information, to select a patient, or to acquire the selected patient’s laboratory data from the laboratory computer’s database.” The laboratory computer system contained two databases. The primary database contained “all laboratory results for current inpatients and those discharged for no more than eight days, and for all outpatients with laboratory work done within the most recent 35 days. Approximately 7,000 patients are represented in the database at any one time.” The secondary database was of a similar size and contained “patient records recently purged from the primary database.” As Connelly described, the features of PLATO enabled them to “present a roster of patients in a particular clinic.” Using the touch-screen feature of the PLATO system, the physician “could touch a patient’s name and, then, touch the tests” of interest, “like maybe I want to see all of the electrolytes for that patient since they’ve been in the hospital. Then . . . [the computer would] present those graphically.”

Because physicians often make “patient management decisions” based on “time-related laboratory tests,” Connelly and his colleagues proposed that graphical displays of laboratory data offered physicians an effective tool for making clinical decisions, by “improve[ing] clinical productivity, enhance[ing] quality of care and control[ling] costs.” However, finding broad physician acceptance of this—and convincing physicians to incorporate computers into their clinical decision-making—was more elusive. As Connelly recalled, “We had a few anecdotes. Some of the physicians using this actually said, ‘Oh, yes, it did reveal a value we had missed.’ So we had anecdotes but we didn’t really, in those early days, collect data that would show that this was actually improving patient care. We had pretty good use, so we figured it wasn’t disservicing patient care.” In an effort to secure more widespread use of this new technology, Connelly and his colleagues “worked on the area of making it more and more user friendly and usable.”

During the 1980s and early 1990s, Connelly centered his research on using computers to support clinical decision-making in two particular areas: (1) the development of clinical workstations (which incorporated a touch screen laboratory reporting system) to improve clinical decision-making in the Neonatal Intensive Care Unit (NICU) at the University of Minnesota Hospital, and (2) the development of an expert system—as part of a clinical workstation—to provide blood bank personnel with decision-making support when evaluating platelet transfusion requests.
In the early 1980s, Connelly approached Theodore Thompson, MD, director of the University of Minnesota Hospital’s NICU about improving the collection and reporting of laboratory data on the unit. In the NICU “there’s tremendous amounts of data flowing. . . . I asked him [Thompson], ‘What would be the best thing we could do for you in the Neonatal Intensive Care Unit in terms of getting lab results back?’ That ended up with a touch screen with graphical display.”

Supported in part by an NLM (National Library of Medicine) Research Training in Medical Informatics grant (described in chapter two), Connelly and his team in the laboratory data division in the Department of Laboratory Medicine and Pathology worked with two people from the clinical laboratories, two from the laboratories’ information services group, the NICU medical director, and two NICU nurses to design the system. The resulting clinical workstation detected results on a new patient and automatically sent a request to the laboratory computer for demographic information. The workstation then provided the clinical staff notice of newly reported laboratory results, which could be viewed by a single touch of the patient’s name displayed on the patient roster screen. The primary results, summarizing recent trends of the 20 most commonly used monitoring tests presented in physiologically-relevant groups with multiple variations of data views and reports, were then displayed. After more than six years of use, Connelly, Thompson, and colleagues evaluated the effectiveness and physician acceptance of the clinical workstation, finding that the overall evaluation of laboratory reporting system “was very positive.” “By most accounts,” their published report concluded, “this workstation would qualify as a successful implementation of a narrow set of medical information services.” Though, they went on to note, they had initially faced “logistical, financial and political” barriers when implementing the workstation. As Connelly recalled, the NICU clinical workstation “really was used intensely” and “lasted for thirteen years,” when the workstation was finally retired and the system was subsequently upgraded.

Also in the 1980s, Connelly and his team were interested in improving the use of platelet transfusions. “At our [University of Minnesota] Hospital, we had a very active bone marrow transplant program,” Connelly explained, “We were one of the biggest users of platelets in the nation. The director of blood banks was interested in not necessarily curtailing platelet use, but making more effective use of the platelets we had, because they were a vital but finite resource.” Indeed, the University of Minnesota Hospital, with its active programs in the treatment of blood disorders and bone marrow transplant program, transfused “well over 50,000 units of platelets” annually, and between 1980 and 1989, the University of Minnesota’s use of platelets had increased 69 percent, while the estimated annual rate at which national platelet use was increasing was 10–20 percent. In the mid- and late-1980s, the clinical indications for platelet transfusions were not well defined because the “appropriateness of platelet transfusion rests on many complex and interrelated issues[,] some of which are well understood, many of which are not.” In spite of this limited knowledge, Connelly recalls, “There were some clinical—they didn’t call them guidelines in those days but they were—guidelines for appropriate platelet use.”

Connelly and his colleagues, Bruce Sielaff, PhD (Sielaff had earned his PhD in biometry and health information systems in 1975), in the Department of Laboratory Medicine and Pathology, and Edward P. Scott from Life Blood, Mid-South Regional Blood Center in Memphis, Tennessee, predicted, however, that once physicians understood more about the ways in which platelets functioned in the treatment of specific diseases and situations, the guidelines for appropriate use of platelets would “become increasingly extensive.” To preemptively deal with this complexity,
they developed an “expert system”—integrated into a clinical workstation—that would assist blood bank personnel in determining “appropriate use of platelet transfusions.” As Connelly, Sielaff, and Scott explained, the advantages of an expert system are that: (1) it can deal with “the complexity, uncertainty, and diversity of clinical medicine . . . more appropriately” than guidelines or other sets of fixed criteria; (2) it can take account of “contingencies related to specific diseases and therapies”; (3) “in contrast to human experts, expert systems are consistent”; (4) it minimizes “human effort related to data acquisition and review,” while enhancing the timeliness of review and feedback”; and (5) it can “document and explain the basis of its conclusions in a clear and understandable manner.”57

Early in 1985, Connelly and his colleagues introduced ESPRE (Expert System for Platelet Request System) at the University of Minnesota Hospital and Clinics with the objective of providing automated decision support for blood bank personnel assessing requests for platelets. Connelly, Sielaff, and Scott made clear that ESPRE was “designed as a decision support tool, not as the final decision maker. . . . In all cases, it is intended that ESPRE’s conclusions be reviewed for reasonableness by the blood bank technologist.”58

In 1991, Connelly, Sielaff, and Scott published the results of a two-month study evaluating the effectiveness of ESPRE. During the two-month period, Connelly and his colleagues selected a random sample of seventy-five requests for platelet transfusions at the University of Minnesota Hospital and Clinics Blood Bank. A blood bank physician reviewed each request and recorded his or her specific reasons for approving or disapproving the request. Using the same clinical data available to the blood bank physician, “these data and the transfusion requests were submitted retrospectively to ESPRE, and the resulting recommendations were compared with the decisions of the initial reviewer.” In the study, seventy-one (97.3 percent) of seventy-three staff-approved requests would have been approved by ESPRE. As Connelly and his colleagues noted, “Although there was very good agreement on the final decision, there was less agreement on the reason(s) for approval or disapproval.” While ESPRE would “list all the indications found to support a request for transfusion,” blood bank reviewers were “unlikely to continue to search for indications after identifying an acceptable one.” Overall, they found that ESPRE “would have approved 44 percent (32/73) of the requests submitted for the same reasons as the staff approved them.” While ESPRE would not “totally eliminate the need for consultation with clinicians to clarify indications for transfusion,” Connelly and colleagues cautioned, the results of the evaluation had shown that it would “however, allow more efficient use of the diminishing amount of time available to physicians and laboratory staff.”59

Throughout the 1990s, Connelly and his colleagues, now joined by Keith Willard, MD, worked to optimize clinical workstations, adapt them to changes in new networking technologies, and broaden their use throughout the University of Minnesota Hospital and Clinics. By November 1992, they were operating ten clinical workstations in four clinical units: adult and pediatric bone marrow transplant units and adult and pediatric hematology/oncology units. Within two years of their introduction, the clinical workstations had helped reduce the costs of laboratory tests associated with bone marrow transplantation cases by 32 percent by helping physicians make more informed choices about when to use laboratory resources.60 In terms of enhancing the workstations, in the early 1990s, Connelly and colleagues drew upon recent developments in data processing and incorporated “the client-server network” model into the architecture of clinical workstations and the broader laboratory information system.61 And in December 1994, Connelly and his team implemented a web-based clinical information system, which enabled clinicians to display the results of clinical laboratory tests on, or order laboratory tests from, the clinical workstation. The new
web-based clinical information system also included “an embedded expert system protocol laboratory ordering system.” They introduced the first system into the solid organ post-transplantation unit at the University of Minnesota Hospital and Clinics, and after informally reviewing the system, Connelly and his team found the web-based system was “extremely well received by our clinical users.”62

In summary, Connelly and his colleagues’ work developing and implementing clinical workstations during the 1980s and early 1990s was innovative. As Collen noted in his history of medical informatics, although “powerful minicomputers called workstations” (his emphasis) had been designed in the 1970s “to take advantage of network file-sharing and multitasking capabilities,” and a few university hospitals were experimenting with clinical workstations in the mid-1980s, widespread adoption of clinical workstations didn’t come until later.63 That Connelly and his colleagues were developing workstations, implementing, and evaluating them from the early 1980s put them at the leading edge of this work. And, as Connelly reflected of ESPRE, it was “one of the forerunners of the modern electronic health record, which can now challenge docs every little step of the way.”64

While Connelly’s research centered on using computer systems to support clinical decision making, the University of Minnesota’s health informaticians also developed national and international reputations as experts in modeling and simulation studies. As Warner had noted in his 1995 review of the health informatics field, modeling was “the optimal tool for knowledge management” of complex systems.65

Mathematical Modeling and Simulation Studies
By the 1960s, mathematical techniques, particularly in the form of biostatistics, had for several decades been used in the biological, medical, and health sciences. The earliest users of mathematical modeling techniques were molecular biologists, particularly the x-ray crystallographers who worked on elucidating the structure of large, complex molecules like hemoglobin and myoglobin beginning in the late 1940s.66 Mathematical modeling techniques had also been employed in the health sciences, although to a lesser degree. The growing availability of computers in the 1960s, however, increased the potential for biomedical researchers to apply mathematical modeling to resolving research problems in the biomedical sciences. As Gatewood and colleagues explained in 1971, “Simulation techniques enable investigation of questions concerning dynamic systems when it is impracticable or impossible to experiment with the actual system. Such techniques have been shown to be particularly useful in the field of mathematical biology, where various aspects of the behavior of living organisms can be expressed in terms of equations. These equations can be solved directly or iteratively using electronic computers.”67

During Ackerman’s tenure at the Mayo Clinic from 1960 to 1967, his research had focused on the development of mathematical models of physiological systems, including the ultrasonic behavior of cells, enzyme kinetics, blood glucose regulation, and patterns of infectious disease epidemics. However, during the 1960s, the computer simulations of biochemical systems, such as efforts to model blood glucose regulation, were not considered too favorably among biochemists. As David Garfinkel, the editor of Computers and Biomedical Research opined in 1968, “biochemical simulation is trapped in a self-perpetuating circle of unfamiliarity.” Most biochemical journals would not consider publishing articles on the subject and many biochemists were unfamiliar with the techniques of simulation. Garfinkel went on to explain, “Many biochemical systems are too complicated for any reasonable model to include all the factors that might be important, leading to complaints of incorrectness and incompleteness, and thus far it has not been possible to explore all possibilities existing in complex sys-
tems. . . . A model which does include most of the relevant factors may also be too complex to optimize the existing texts (so it does not meet the criterion of ‘best fit’), or even to describe in detail within the format of a scientific paper.” It seemed to Garfinkel that if simulation was “to be recognized as a biochemical technique, it must produce results of value in that field.”

Beginning in the early 1960s, Ackerman and Gatewood, together with their Mayo Clinic colleagues, John W. Rosevear, MD, PhD, and George D. Molnar, MD, developed a simplified model of the blood-glucose regulatory system that emphasized “the aspects of the system which are most important for regulation during an oral glucose-tolerance test.” By simplifying the model in this way, the team was able to lump many of the model’s “parameters into a relatively small number of empirically determinable ones.” The group’s initial interest in developing the model was “to combine the blood-glucose levels during the oral glucose-tolerance test in a kinetic model which would lead to a criterion for separating normal from mild diabetics.”

As Gatewood described, Rosevear and Molnar “were inserting a tube into a normal volunteer as well as into brittle diabetics, analyzing a very small amount of blood almost continuously to allow bolus experiments of meals, and insulin, and glucose infusions to see what happened to blood glucose and blood insulin during those experiments. This was an attempt to get at what is still not available today, a continuous monitoring system for diabetics.” The data produced in the clinical studies were “very close” to the data produced in “our modeling experiments.”

In providing researchers and clinicians with what was not then available, Ackerman’s team was producing what Garfinkel had called for: “results of value to the field.” This research, “which is still referred to today as one of the simplest representations of blood glucose regulation by insulin,” subsequently formed the basis of Gatewood’s master’s thesis.

Also during his time at the Mayo Clinic, Ackerman worked with his Mayo colleague, biostatistician Lila R. Elveback, PhD, and epidemiologist John P. Fox, PhD, at the University of Washington to develop population-based models of epidemic disease simulations. Since the late nineteenth century, when physicians, researchers, and public health officials in Europe and the United States accepted the germ theory of disease (that some diseases are caused by specific microorganisms), researchers have sought to understand the behavior of pathogens on their human hosts in order to prevent or limit the development of infectious disease epidemics.

Through the 1970s, biomedical researchers relied on two types of experimental studies for this research. The first type, animal studies, used animal models of infectious diseases. For example, researchers successfully introduced yellow fever and poliomyelitis into rhesus monkeys and were then able to study the pathogenesis of those diseases. Animal models were most useful when the mechanism of infection was similar to the mechanism of human infection. The second experimental study was, in limited cases, to infect human volunteers “with agents causing relatively benign disease, for example the rhinovirus [that] causes the common cold.” In both of these experimental models, the introduction of the infectious agent and the population were well controlled. Such controlled conditions, however, did not account for the complex interactions between the microorganisms, host, and environmental factors, such as population distribution and climate. While “the identity and relative importance of many factors influencing the occurrence of infection and disease can be inferred from well-designed observational studies,” Ackerman, Elveback, and Fox noted, “the validity of such inferences cannot ordinarily be tested experimentally . . . because of the impossibility of controlled prearrangement of exposures of population members under appropriately varying conditions.” Limited to observational studies of human volunteers and experimental studies of animal models, researchers were not able to
experimentally study “the behavior of naturally occurring pathogens in real-life human populations.”

The innovations in biomedical computing in the 1960s and 1970s, however, offered biomedical researchers a new experimental approach for studying the behavior of infectious disease epidemics. Researchers such as Ackerman, Elveback, and Fox developed mathematical models to study the complex behavior of infectious agents in human populations. Researchers could run simulations of these epidemic models on digital computers to calculate “the expected outcome, or distribution of expected outcomes,” of an infectious disease epidemic “given a set of initial conditions.” To build disease-specific models, researchers incorporated data related to the interaction between the pathogen and the susceptible host and to the host population under study derived from laboratory studies of the disease-causing microorganism and observed outbreaks of the specific disease. In addition to demographic information, this data typically included “latent period, incubation period, period of infectiousness, an index of infectivity of the infected host, . . . the ratio of overt to subclinical infection overall and as related to host age,” and “information about the number and distribution of susceptibles in the population and their usual activities and behavior that could affect the occurrence of effective contact.” Such data was essential to building these mathematical models as they provided researchers “with guides to assignment of values to critical parameters” in the model and, “ultimately, as the critical tests of validity of the fully developed model.”

Ackerman, Elveback, and Fox were pioneers in the field of epidemic disease simulations and their collaboration continued after Ackerman moved to the University of Minnesota in 1967. Their published work documented simulations of enteric viral infections, influenza, and influenza immunizations. Gatewood, first at Mayo and then at the University of Minnesota, served as a programmer on these early modeling projects. She developed a new computer program for general purpose modeling of infectious disease epidemics, which became the subject of her doctoral thesis.

In 1984, as a culmination of these research efforts, Ackerman, Elveback, and Fox published the groundbreaking book, *Simulation of Infectious Disease Epidemics*. This early research in epidemic disease modeling laid the foundation for Ackerman and Gatewood to secure an NIH Research Resources Grant and establish a “Simulation Pre-Resource for Stochastic Population Models” in 1983. The goal of the Simulation Pre-Resource was to use the VESPERS-11 simulation software system that Ackerman, Gatewood, and colleagues had developed and genetics software packages “obtained from elsewhere, i.e. LIPED, PAP, and POINTER” to “accommodate models” of infectious, chronic, and genetic diseases. Once developed, the “simulation programs” were “tested for functionality by core research studies of models of: 1) epidemics of infectious diseases, 2) chronic diseases, and 3) diseases with a genetic component.” The expectation, Ackerman stated, was for the “results of these simulations” to prove useful “in exploring mechanisms of disease incidence and spread as well as examining strategies for primary and secondary prevention.”

The Simulation Pre-Resource was also available to non-University of Minnesota researchers to conduct collaborative studies that would “help to test the user friendliness and applicability of the Pre-Resource offerings.” The staff also trained graduate students, medical residents, post-doctoral students, and visiting scientists in simulation work.

Ultimately, the goal of Ackerman, Gatewood, and their colleagues was to develop the Simulation Pre-Resource into “a fully operational National Research Resource dedicated to the simulation of stochastic micropopulation models.” This they achieved in 1988. With Ackerman as director through June 1990 and Gatewood through June 1995, the National Micropopulation Simulation Resource (NMSR) received continuous NIH funding until June 30, 1995. Throughout its history, an external advisory commit-
committee composed of prominent researchers in simulation, mathematical modeling, and epidemiology supported the work of the NMSR by annually reviewing the status of the resource, reviewing requests from collaborators and users of the resource, assessing project resource allocation, and evaluating future plans for core research and development and dissemination of information about the resource.80

During the twelve-year history of the NMSR (including the four years of Simulation Pre-Resource funding), Ackerman and Gatewood, together with DHCS faculty, Resource staff, and a team of National Library of Medicine (NLM) Training Grant Fellows and doctoral students developed and optimized modeling software for running simulations of genetic disorders, chronic diseases, infectious diseases, neural networks, and social networks. To this end, the Resource included six components. The central component, SUMMERS (Simulation Utilities for Monte Carlo Modeling of Event-driven Research Studies), was a simulation shell. Susan Seaholm, PhD, originally developed the SUMMERS conceptual model as part of her doctoral dissertation in the Biometry and Health Information Systems program at the University of Minnesota (1982).81 The remaining five components were specialized models of SUMMERS, which could be used for performing simulation studies of various biomedical domains. These domains included epidemiology of HIV infection and AIDS (ADDERS),82 epidemics of infectious disease (VESPERS),83 chronic disease intervention studies (CRISPERS);84 genetic ascertainment and underlying models (LINKERS and GRASPERS);85 and studies of artificial neural networks (COGNET).86

In addition to this core research, the Resource staff also engaged in collaborative research projects with researchers from the University of Minnesota and at institutions throughout the country who wanted to use the Resource’s modeling programs. The importance of the NMSR’s work is most clearly seen through the extent of these external research collaborations. For example, for twelve years (1983–1995), Ackerman, Michael Altmann, PhD, and other Resource staff collaborated with Ira M. Longini, PhD, and Michael J. Haber, MD, from the Department of Epidemiology and Biostatistics at Emory University on various aspects of simulating infectious disease epidemics. Stephen Rich, PhD, currently director of the Center for Public Health Genomics at the University of Virginia, directed the genetics component of the NMSR and worked, over the years, with researchers at Columbia University, Harvard University, Massachusetts General Hospital, Duke University, and Louisiana State University Medical School studying inheritance models of various genetic diseases including type 1 diabetes, epilepsy, and schizophrenia.

Gatewood’s work in the NMSR focused on the area of simulating cardiovascular disease epidemiology. Locally, Gatewood worked with cardiologist Thomas E. Kottke, MD, at the Mayo Clinic, using the CRISPERS simulation program to assess the potential impact of various intensive cardiac therapies on the incidence and prevalence of coronary heart disease (CHD), and resulting life expectancy of patients with CHD. She also worked with the University of Minnesota cardiovascular disease epidemiologists, led by Henry Blackburn, MD, using the CRISPERS program to “investigate the relationship between risk factors and morbidity-mortality in the Minnesota [Coronary] Survey data, as well as the relative contributions to the observed decline in the U.S. CHD death rate during the last twenty years of primary prevention, secondary prevention, emergency medical services, hospital care following MI [myocardial infarction], and post-hospitalization medical care.”87

The NMSR served as an important resource for the Minnesota Department of Health. Indeed, from the NMSR’s launch in 1983 through its closure in 1995, Ackerman, Gatewood, and other Resource staff worked closely with Denton Peterson, PhD, from the Department of Health on the simulation of influenza outbreaks and influenza vaccine efficacy in nursing
homes, and on simulation studies of HIV transmission, intervention, and prevention. During the 1980s and 1990s, there was little interest in simulation studies within the field of public health. Peterson “was a pioneer in this area,” Martin (Marty) LaVenture, MPH, PhD, of the Minnesota Department of Health recalled, “which would not have happened,” he continued, “without the work of the Micropopulation Simulation Resource.” The NMSR provided researchers like Peterson with “lots of different models” that “started to take it from an academic micro[population] simulation view, which was a fairly complex tool for many people, to an applied tool.” Peterson, LaVenture noted, “was one of the early bridgers” who took these previously academic simulation tools and showed how valuable they were in an applied setting.88

In the simulation studies of influenza outbreaks and vaccine efficacy in nursing homes, Peterson worked with Gatewood to determine how influenza outbreaks in nursing homes were distributed, what the differences were between influenza outbreaks in years of different levels of influenza activity, how influenza immunization affected outbreak distributions, and how the distribution of vaccine efficacy in nursing home outbreaks were affected by the underlying efficacy of the vaccine. One of the HIV simulation studies conducted during the late 1980s included a collaborative project between Peterson and the DHCS’s Gatewood, Willard, and Altmann, which examined HIV transmission among intravenous drug users. In particular, the team modeled “a dynamic population of injecting drug users” to determine how important “shooting galleries and other random needle-sharing behaviors” were in spreading HIV; what impact the underlying prevalence of HIV had on the success of interventions designed to prevent needle sharing; and what role the social network of injection drug users plays in the spread of HIV.89

In the early 1990s, LaVenture began working with the NMSR to develop a “model of immunization coverage for preschoolers in the state of Minnesota.”90 At the end of the 1980s, the city of St. Paul had experienced a measles outbreak during which several children had died. LaVenture described the simulation project as a look at an outbreak of measles to see “what type of spread can we expect if we have different size populations. We knew there were some where the vaccine was not fully effective, so there were pockets of children at risk for a variety of reasons, for those who don’t get their shots and those who do that are immune. If we try to do some simulation, what might that look like?” The goal of the project was to “take from what was largely an academic piece and try to use it for policy making . . . [and] program decisions.”91 This is an early example of what is today called translational science—of moving discoveries made at the laboratory bench into clinical practice or dissemination to population-based community interventions.92

Ackerman’s early and ongoing work in mathematical modeling had laid the groundwork for Gatewood, Rich, Altmann, and the NMSR’s other staff; graduate students; and post-doctoral fellows to establish the NMSR as a center of innovation. As Gatewood recalled, while there were other simulation resources in the country, “there were none that were discrete event simulation. All of them were continuous modeling stochastic systems, primarily physiological systems . . . we were the only one that was discrete modeling.”93 In contrast, continuous simulation is used to model systems in which the events being simulated are continuous, such as a weather system. As a result, the simulation continuously tracks the system dynamics over time rather than by specific, discrete events.94 Gatewood continued, the NMSR “[kept] us on the map, as far as mathematical modeling was concerned.”95

Another aspect of the University of Minnesota’s health informatics research program, led by Christopher Chute, MD, DrPH, at the Mayo Clinic, focused
on natural language processing (NLP). This is a field concerned with “making computers ‘understand’ statements previously written in human languages,” which in turn facilitates the exchange of data written in clinical documents between providers and electronic health record systems, and enables researchers to extract data from those documents to use in clinical research or health quality assessment.  

**Optimizing the Human–Computer Interface**

Since the 1960s, health informaticians have been concerned with health-related languages. Within clinical documents the majority of content is captured as narrative text; however, as Huibert J. Tange and colleagues explained in 1997, there is no guarantee “that the reader will understand this information exactly as it was meant by the author. The only way to reach unambiguous understandability of medical [and health] narratives is to store them as controlled expressions, with the help of controlled vocabulary.” The availability of controlled vocabularies or systematized nomenclatures, they continued, “would facilitate the exchange of medical data between health-care providers, enable context-dependent decision support, make the medical record accessible for statistical analyses, etc.”

The history of efforts by the international medical community to standardize the classification of diseases dates back to the nineteenth century and culminated in the *International Classification of Diseases*, now in its tenth revision. By the 1990s several more systematized nomenclatures were available to researchers. In 1965, the College of American Pathologists published the *Systematized Nomenclature of Pathology* describing morphology and anatomy. In 1975, the College of American Pathologists expanded the *Systematized Nomenclature of Pathology* to create a *Systematized Nomenclature of Medicine (SNOMED)* and *SNOMED II* in 1979. In 1993, an expanded and revised version was published as *SNOMED International*. The current version, *SNOMED Clinical Terms*, is the result of a merging, in 2002, of *SNOMED RT* (published in 2000) and the United Kingdom National Health Service’s *Clinical Terms Version 3*. The International Health Terminology Standards Development Organization publishes and revises *SNOMED Clinical Terms*. The NLM had also developed the Unified Medical Language System in 1986, under the leadership of Donald Lindberg, MD. The Unified Medical Language System facilitates “the development of computer systems that behave as if they ‘understand’ the meaning of the language of biomedicine and health.”

Despite the availability of *SNOMED International* and the Unified Medical Language System by the early 1990s, health informaticians still confronted a major challenge: how to represent clinical data documented in medical records (increasingly electronic health records) that describe facts about the patients and the care given to them?

The University of Minnesota’s history of research in the standardization of health-related vocabularies and NLP began with Chute’s work at the Mayo Clinic in the early 1990s. Throughout his career, Chute’s research has focused on the vocabularies, semantics, and ontologies for managing patient data. One example of his vocabulary research, published in 1997, was a collaborative project with his Mayo Clinic colleague, Peter L. Elkin, MD. The Mayo Clinic had indexed patient problems, medical diagnoses, and procedures since the early twentieth century. Beginning in the 1990s, the Mayo Clinic had begun computerizing the process with the goal of integrating structured text entry—using controlled health-related terminology—into the new technology of electronic health records. Chute and Elkin, as members of the Mayo Clinic’s Clinical Terminology Committee, played lead roles in the development of the controlled (standardized) terminology.

In their 1997 article, Chute and Elkin reported on their preliminary work to empirically create a clinical terminology. They merged terms in the Mayo Master
Sheet, which captured summary diagnoses, problems, and dismissal impressions, and the Clinical Notes application. They drew two conclusions: (1) “Logistic and operational terms were embedded in these lists, which have little clinical relevance; and (2) “Many terms were combinations of diagnoses and operational qualifiers.” Next, Chute and Elkin “carefully pruned the list of logistical elements, and recorded the reason for reductions” and identified “a preliminary pattern of embedded qualifiers” based on their appearance in the clinical sources. They established the utility and feasibility of distinguishing operational qualifiers (“words or phrases that operationally or administratively qualify the meaning of a diagnosis or problem) from clinical modifiers (“words or terms which modify the severity, location, acuity, or other intrinsic clinical detail or a diagnosis or condition”). Having distinguished “the role of Qualifiers, and establishing an empirical starting point for a Qualifier ontology,” Chute and Elkin then completed “a preliminary thesaurus and ordering for Qualifiers.” This enabled concepts and their synonyms to be identified within the merged clinical corpus, and removed. The “underlying Mayo Terminology” was also “reinforced by the re-addition of terms that had been present only in combination with a Qualifier. Similarly, some phrases had Qualifiers intrinsically embedded in them, where the meaning would be distorted by the excision of the Qualifier; these were retained in the terminology.” Having distinguished “the role of Qualifiers, and establishing an empirical starting point for a Qualifier ontology,” Chute and Elkin then completed “a preliminary thesaurus and ordering for Qualifiers.” This enabled concepts and their synonyms to be identified within the merged clinical corpus, and removed. The “underlying Mayo Terminology” was also “reinforced by the re-addition of terms that had been present only in combination with a Qualifier. Similarly, some phrases had Qualifiers intrinsically embedded in them, where the meaning would be distorted by the excision of the Qualifier; these were retained in the terminology.” Having distinguished “the role of Qualifiers, and establishing an empirical starting point for a Qualifier ontology,” Chute and Elkin then completed “a preliminary thesaurus and ordering for Qualifiers.” This enabled concepts and their synonyms to be identified within the merged clinical corpus, and removed. The “underlying Mayo Terminology” was also “reinforced by the re-addition of terms that had been present only in combination with a Qualifier. Similarly, some phrases had Qualifiers intrinsically embedded in them, where the meaning would be distorted by the excision of the Qualifier; these were retained in the terminology.” This empirical modality, Chute and Elkin concluded, had led to a series of studies evaluating the protocol, which focused “on the practical ability of clinicians to navigate or use our terminology in prototypes of electronic health records. “The ability to qualify existing terms to fit the clinical scenario” was “warmly received” in these studies. Because of this and other related research, Chute recalled, “we developed a reputation here at Mayo as being the vocabulary kids with a scientific emphasis on ontology, but it was shamelessly focused on clinical characterization of patients.”

When Chute joined the University of Minnesota’s graduate faculty in health informatics in 1990, formalizing the relationship between the NLM-funded training program and the Division of Biomedical Informatics, the Mayo Clinic became a practicum site for NLM trainees. Building on his research on terminologies and vocabularies, Chute established the clinical data representation research cluster (by 2000, a second research cluster, clinical compositional semantics, directed by Elkin, had been added). “The people that did their practicums here at the Mayo Clinic,” Chute explained, were “exposed to principles of terminology and data representation in a clinical context with . . . the overarching goal that if we can’t represent clinical information comparably and consistently, then any inferencing we try to do on it is going to be much more difficult if not impossible. Non-comparable data by definition can’t be compared. Thus, we had a major focus on that.”

One of Chute’s long-running projects was the Multi-Institutional Testbed for Clinical Vocabulary, which was a jointly funded initiative (from September 1994 through September 1998) by the NLM and the Agency for Health Care Policy and Research (now the Agency for Healthcare Research and Quality). The project was a collaboration between the Mayo Clinic and Kaiser Permanente, based in Oakland, California, that “examined whether clinical descriptions of patients could be compared among different care environments.” The goal of the project was to increase the efficiency and effectiveness of the retrieval and analysis of clinical data from electronic medical records. At that time, “a major difficulty in realizing the full potential of electronic records rested with the absence of robust clinical terminologies.” Chute’s research group demonstrated “that existing vocabulary standards have large content coverage deficiencies and that their use in policy models can greatly distort measures of quality and outcome predictions . . . The combined clinical environments of the largest HMO and primary care provider [Kaiser-Permanente] and the largest vertically integrated tertiary care provider
[the Mayo Clinic], provides an unparalleled natural laboratory for the development, evaluation, maintenance, and implementation of standard medical terminologies.”

Chute also built a national reputation for his research in NLP. “A lot of our early work,” Chute recalled, “was based on leveraging associations in patient data that could be derived from a semantic characterization that is vocabulary.” For example, in 1992, Chute and colleagues published the results of a study in which they had applied NLP techniques to represent medical concept data. Specifically, they used the technique of Latent Semantic Indexing to generate information matrices based on the “semantic associations to main concepts” located in the Unified Medical Language System Metathesaurus. The team made evaluations “on the complete set and subsets of Metathesaurus main concepts with the semantic type ‘Disease or Syndrome.’” They created main real-number matrices with “main concepts, lexical variants, synonyms, and associated expressions.” For example, using input phrase carcinoma of the lung and applying it to 2,580 main concepts in the Unified Medical Language System with semantic type “Disease or Syndrome,” Chute and colleagues’ five top matches are carcinoma of lung; carcinoma, non-small, cell lung; lung neoplasms; pleural neoplasms; bronchial neoplasms. Based on these and other results, the team concluded that “LSI [latent semantic indexing] may function remarkably well as a mechanism for classifying and retrieving patient record text data.”

A second of Chute’s major research projects was an NLM-funded research project that investigated semantic structures for patient data retrieval. The project was funded from September 30, 1992 through October 31, 2004. The “semantics of patient description,” however, turned out to be “challenging.” As Chute related, “Human language being what it is, trying to have a computer manage the sophistication and subtlety of human language as clinical characteristics and described into what a statistician would characterize as binning or classification or more specific and precise and, ideally, consistent typing of underlying disease concepts, outcomes, and the like, is an enormous challenge and really became the core of our initial work.”

Both the Multi-Institutional Testbed for Clinical Vocabulary and the Semantic Structures for Patient Data Retrieval projects served as research opportunities for University of Minnesota NLM training grant fellows. In 1992, for example, Yiming Yang, PhD, joined the NLM training program. Yang had earned her doctorate in computer science from Kyoto University in Japan. As a fellow she “spent all of her time in Rochester, basically, as a post doc in our group.” Yang was formally incorporated in the NLM-supported research grant, building “on work of mutual interest on large matrix computations, which [was] the focus of Dr. Yang’s clinical data retrieval work.” She also conducted research on latent semantic indexing methodology. After completing her fellowship, Yang joined the faculty in the Language Technology Institute and Computer Science Department at Carnegie Mellon University.

Chute supervised several other NLM fellows in the field of terminology research. In 1998, Marcelline Harris, RN, PhD, joined the NLM training program and worked with Chute evaluating nursing terminologies in electronic health records. After completing her fellowship she joined the faculty as assistant professor of medical informatics at the Mayo Graduate School. Harris later joined the University of Michigan where she is currently associate professor in the Department of Systems, Populations and Leadership in the School of Nursing. In 2000, NLM training fellow Alex Ruggieri, MD, worked with Chute and Elkin on the representation of standard terminologies of health status concepts in health status assessment instruments. Ruggieri is currently managing medical director at Anthem Care Management. Chute also supervised NLM fellows in NLP. In 2002, for example, Serguei Pakhomov, PhD,
joined the NLM training program, “using natural language processing and machine learning techniques for clinical document retrieval and classification, automated thesaurus generation, abbreviation detection and disambiguation as well as term extraction.” Pakhomov is currently associate professor in the Department of Pharmaceutical Care and Health System in the College of Pharmacy at the University of Minnesota and an affiliate faculty member in the Institute for Health Informatics.

During the 1990s there were several other research projects being conducted in Mayo’s Division of Biomedical Informatics that spanned “the spectrum from basic investigation of medical concept architectures and representation, terminology modeling, terminology content evaluation, user interfaces for computer assisted coding, [and] the operational indexing of patient information including diagnostic and surgical procedures, to the retrieval of patient data for applied epidemiologic research or outcome analysis.” The 1998 NLM training grant annual report highlighted two areas that were currently dominating the research-funded activities of Chute’s research group. The first involved “aggressively developing and applying content evaluation tools which measure how much clinical information is captured by a target terminology.” The second related “to the combination of terms to create a clinical phrase,” which “requires the specification of terminology components, optimizations of terminology models, and the integration of such models into user-interface prototypes.”

Since the early 1990s, Chute has been a national and international leader in major health language standards-setting organizations. For example, from 1996 to 1997 Chute chaired the ASTM (formerly, the American Society for Testing and Materials) Committee E31.01 on Healthcare Terminology; from 1997 to 1998 chaired the International Organization for Standardization Member Bodies Planning Task Force on Clinical Terminologies; from 2000 to 2001 and 2004 to 2005 served as vice chair of the American National Standards Institute Health Informatics Standards Board; and from 2001 to 2007 co-chaired the HL7 Vocabulary Committee. Since 2007 Chute has chaired the World Health Organization’s ICD-11 (International Classification of Disease) Revision Steering Committee, and since 2011 has served on the Extramural Standards Advisory Group of the Office of the National Coordinator.

The University of Minnesota’s expertise in the field of standardized health care terminologies grew in the mid-2000s when Connie Delaney, PhD, RN, FAAN, FACMI, was recruited to the University to serve as dean of the School of Nursing and Bonnie Westra, PhD, RN, FAAN, FACMI, was appointed assistant professor in the School of Nursing in 2005, and Karen Monsen, PhD, RN, FAAN, was appointed assistant professor in the School of Nursing in 2007. Delaney served as acting director of IHI from December 2010 to May 2015, and Westra and Monsen hold core and affiliate faculty appointments in IHI, respectively. When Delaney joined the University of Minnesota she was already an international leader in standardized nursing terminologies, and Westra and Monsen were well-established researchers in the field (discussed in chapter four). The University’s health informaticians, led by Chute (until he moved to Johns Hopkins University in 2015), Pakhomov, and Genevieve Melton-Meaux, MA, MD, FACS, FASCRS (associate professor, Department of Surgery; IHI core faculty; chief health information officer, Fairview Health Services and University of Minnesota Physicians), established strong research programs in NLP (also discussed in chapter four).

With the University’s early research program in signal processing, and its on-going programs in database design and management, clinical decision-making, modeling and simulation, and optimizing the human–computer interface, the University’s health informaticians had established the University of Minnesota as a leader in the five major areas of health informatics identified by Warner in 1995. Beginning in the late 1970s, the University’s health informaticians also
became innovators in a sixth field, that of telehome monitoring and telehealth.

**Home Monitoring and Telehealth**

Home monitoring enables patients to be connected, remotely, with "clinics, physician offices, disease management programs, and home care agencies for the purpose of streamlining care delivery, maintaining a close patient connection, and promoting early identification of patient status changes." While telehome monitoring is focused on remote communications between patients and providers, telemedicine in its earlier iterations was concentrated on interactions between providers and clinical institutions.

Although it has its origins in the 1970s, telemedicine emerged in the 1990s as an innovative solution to the persistent problems of (1) shortages of rural health care providers and (2) rural patients' inadequate access to specialized health care services. In 1996 the Institute of Medicine defined it as "the use of electronic information and communications technologies to provide and support health care when distance separates the participants," often specialists and non-specialist clinicians. Characteristically, telemedicine programs "consist of a central facility, such as an urban or academic hospital (known as the 'hub' of the system), and one or more remote sites such as rural or community hospitals or clinics (known as 'spokes')." If a patient living in a rural area needed to see a specialist but there were no appropriate specialists located within driving distance of his or her home, the patient could see his or her primary care provider at the local clinic or community hospital (the spoke). Using the telemedicine system, the local clinician could then connect virtually with a specialist provider at the hub who would provide a consult with the patient and primary care provider. Telehealth is a more comprehensive term than telemedicine and refers to the "electronic transfer of medical information for the purpose of patient care," which includes "clinical, educational and administrative uses and applications." Telehealth incorporates both home monitoring and telemedicine. Since the mid-1980s, the University of Minnesota has been a site of innovative research in home monitoring led by Stanley Finkelstein, PhD, and since the late 1990s in telehealth led by Finkelstein and Stuart Speedie, PhD.

When Finkelstein joined the faculty of the DHCS in the Department of Laboratory Medicine and Pathology in 1977 he brought with him an extensive background in electrical engineering, systems science, and bioengineering, having received a PhD in those fields from the Polytechnic Institute of Brooklyn in 1969. Since his days as an undergraduate student in electrical engineering at the Polytechnic Institute of Brooklyn, Finkelstein had worked on projects that connected engineering principles with physical or biological systems—what would eventually be considered biomedical engineering. In addition to being appointed to the graduate faculty in health informatics when he arrived at the University of Minnesota, he was also appointed to the graduate faculty in biomedical engineering. As Finkelstein reflected, "I was never, actually, what has now come to be known as an informaticist." Instead, Finkelstein continued, "My informatics stuff was based on the engineering kinds of work that I was doing and it always had an informatics flavor to it because we were always collecting and using physiological and clinical data. The work I did in terms of biomedical engineering was always involving direct patient application." From the early 1980s, Finkelstein’s research focused on remote home monitoring of patients.

In the early 1980s, Finkelstein worked with University of Minnesota pediatrician and director of the Cystic Fibrosis Center, Warren J. Warwick, MD, to develop the first home monitoring system for cystic fibrosis (CF) patients in the world. As Finkelstein recalled, when Warwick’s “CF patients would come to see him—and they were coming on a regular
schedule—they thought they were doing really well, but when they went through a full examination, he found that they really weren’t. Was there some way of getting a handle on their condition without them coming in?” The answer, they determined, was to establish a home monitoring program. As Finkelstein continued, “What we were interested in was how could we monitor the patient with a pulmonary function? There weren’t any really good ways. So we ended up using what they use in hospitals after surgery, an incentive spirometer. . . . The advantage of that was it was real cheap and it was very easy to use.” Finkelstein then developed a system by which the patients could record and monitor their pulmonary function and provide regular updates to the hospital treatment team. Patients would record, in a paper diary, a set of measurements that they could make at home. They would then send the diary to Finkelstein’s team by mail every week and a member of the team would input the data. “The idea,” Finkelstein described, was to use these “weekly sets of data to develop some sort of a predictor or decision rule so that when we got the data and ran it through the decision rule, we could identify those kids that might be more at risk [of developing complications and call them into the clinic to be evaluated].”124 The program, which was supported by an NIH Specialized Center for Research (SCOR) grant, ran successfully for several years.

In the early 1990s, with funding from the NIH, Finkelstein collaborated with University of Minnesota pulmonologist Marshall Hertz, MD, to develop a home monitoring system for lung transplant patients (modeled on the one he had developed with Warren Warwick for CF patients). By 1993, more than 2,200 lung and heart-lung transplants had been performed worldwide. Patients’ long-term survival, however, was compromised by opportunistic infections and chronic rejection. There was therefore a clear need for “prompt intervention before the development of severe structural derangement” so as to “maximize the positive effects of therapy.” Early intervention, however, depended on clinicians being able to detect the earliest signs of rejection or infection; home monitoring of pulmonary function provided clinicians with an effective mechanism for doing so.125 At that time, Finkelstein recalled, “the instrumentation that was used for monitoring pulmonary function was typically an electro-mechanical kind of a system that was used in the pulmonary function lab, not at all practical for patients to use at home.” Finkelstein, Hertz, and colleagues put together “what we thought would be a reasonable way of doing home monitoring,” and approached the Minneapolis-based medical device company, Advanced Medical Systems, Inc., that was currently making electronic spirometers (though not for the home). “We got in touch with those folks,” Finkelstein continued, “and sat down and said, ‘Your device looks like it’s probably what we would use, but we need it to do these particular things.’ They said, ‘Oh, sure. That’s easy.’ A month later, the team at Advanced Medical Systems, Inc., delivered to Finkelstein and Hertz “a prototype pretty much doing everything we wanted it to do. We ended up incorporating it in our study and that became the basic instrumentation of the home monitoring program.”126 The collaboration between Hertz, Finkelstein, and Advanced Medical Systems, Inc., is an example of the productive partnerships that could be forged between the University of Minnesota and the companies that constituted Medical (and later, Life Science) Alley.

The device produced by Advanced Medical Systems, Inc., Finkelstein described, “monitored respiratory function and it, also, had the capability of . . . a diary component. So after they [the patient] did the spirometry, it would come up with a series of questions, and they would answer the questions. The answers were typically numeric answers so we would be able to do some coding. It was set up so that they would be able to connect it to their telephone system and just dial the data center and download the data. We asked them to do that, basically, once a week, download it every Saturday.”127
In implementing the home monitoring system, Finkelstein and Hertz faced several challenges: (1) convincing clinicians to rely on patients’ ability to monitor their own lung function; (2) determining whether patients were willing and able to do the monitoring; and (3) determining whether the data collected had any clinical use. To assess the reliability, validity, and thus feasibility of their home monitoring system, Finkelstein, Hertz, and colleagues conducted a two-year pilot study of lung transplant patients at the University of Minnesota Hospital and Clinics, beginning in December 1991. The study evaluated the experiences of eighteen post-transplant patients between the ages of twenty-four and sixty-three using the “electronic diary/spirometer system while outpatient living within the transplant center vicinity and then after returning to their home community.”

We were able to look at the home data that was sent in and, also, look at the data from these patients when they came to clinic. . . . If you plotted the two of them, they weren’t exactly the same, because their particular conditions in a lab that followed and is directed by a trained respiratory person whereas the others are sent from the patient’s home. So one of the issues was how do you replicate that at home without sending a therapist home with it. So we compared the two. We had home data for every day. We only had clinic data four or five times a year. At the points in time when we had clinic data, the home data was pretty close to it. If you followed the pattern of the clinic data, the home data followed the exact same pattern. It was just off by a little bit. Since we weren’t using it particularly for diagnostic purposes, the actual number was not all that important. We were interested in how things changed.

If Finkelstein and Hertz could identify changes in the transplant patient’s condition “early enough before it became a more serious thing,” they could bring the patient into the clinic “for a more thorough workup and try to alleviate the problem or . . . at least to slow it down.”

The data produced by the home monitoring system “were actually good enough to use for making some decisions.” In other words, the pilot study had demonstrated that home measurements were “both reliable (i.e., repeatable) and valid when compared with the ‘gold standard’ of the pulmonary function laboratory. The home monitoring program has been well accepted by patients, is easy to use, and provides data comparable to that collected during clinic visits.”

Due to the success of their home monitoring system, Finkelstein and Hertz were also able to demonstrate that the program was more cost-effective for lung transplant patients. The patients who did home monitoring on a regular basis, Finkelstein continued, “typically had more clinic visits than those that either didn’t do it at all or did it only sporadically. One would say that’s an added expense. But that same group had fewer hospitalizations, which is what we had predicted would happen, because if you can successfully identify a problem before it becomes more serious, you’d call them in to come to clinic and try to work on it and you might be able to prevent hospitalization. Hospitalization is really expensive and a clinic visit was not cheap, but it was a lot less expensive.”

With continuous NIH funding, approximately 280 lung transplant recipients participated in the Lung Transplant Home Monitoring Program at the University of Minnesota between 1992 and 2002. Following the success of the program, “Marshall [Hertz] was able to convince [the University of Minnesota Medical Center] Fairview to implement” the Home Spirometry Program “as part of regular clinical practice.”

Finkelstein and Hertz’s work has had a national impact on health care policy. As of 2012, the Centers for Medicare and Medicaid Services consider the use of “home spirometry devices as medically necessary for monitoring pulmonary function following lung or
heart-lung transplantations.” In providing the “scientific rationale” for establishing this national policy, the Centers for Medicare and Medicaid Services cited two articles by Finkelstein and colleagues.\textsuperscript{135}

Throughout its successful implementation, Finkelstein and Hertz continued to innovate the lung transplant home monitoring system. As the number of home-monitored patients grew, so too did the time transplant clinic nurses spent screening the large amounts of data produced by those patients. As it became “a part of regular clinical practice,” patients send the data in, but, asked Finkelstein, “Who’s going to look at it? Somebody’s got to review it and decide if there’s a potential problem or not.” By the early 2000s, the supply of specialist nurses had become an issue.

“When we first started [the lung transplant home monitoring program back] in the very early 1990s, there were, I think four nurses in the lung transplant program, and it had just started then. When we ended several years ago, the University probably had 600 or somewhere closer to 1,000 lung transplants, but there were still I think six nurses. So . . . people power didn’t coincide with the increased clinical load.” In response, Finkelstein and his colleagues developed “an automated decision system that would look at the data as it came in and decide whether or not a particular patient looked like they were in trouble. If they were identified, for a warning, for example, that information would be sent to the clinical team and they would decide what they could do.”\textsuperscript{136} Between October 2006 and April 2009, the team conducted a randomized controlled trial using sixty-five lung transplant recipients from the University’s lung transplant program. The trial was “designed to determine the relative performance of a computer-based” triage system “compared with a manual nurse-based triage system in terms of patient health and health quality of life.”\textsuperscript{137} During the clinical trial, “half of them [the patients] had their data reviewed by a nurse in the traditional way and half was reviewed by our decision system. It turned out at the end of the study that it didn’t make any difference”; the computer-based decision system produced comparable results to the nurse-based triage system.\textsuperscript{138} As Finkelstein’s team concluded in their 2013 published report of the study, this finding was “especially important given the likely economic constraints on the growth in the nurse workforce capable of providing these early detection triage services.”\textsuperscript{139}

Finkelstein also did highly innovative work in other areas of physiological monitoring. Beginning in the late 1980s, Finkelstein worked with Jay N. Cohn, MD, of the University of Minnesota’s Department of Medicine who was also head of the Cardiovascular Division. “[Cohn] was always interested in hypertension and congestive heart failure. We were looking,” Finkelstein explained, “at some different ways of monitoring things and ended up looking at something very simple, which was the blood pressure waveform, not the blood pressure itself.” “[W]e were able,” Finkelstein continued, “from an engineering perspective to identify what we thought were important characteristics. We actually ended up developing a process to measure, almost non-invasively, what we called arteriovascular compliance, which cardiovascular people talked about but never really measured directly.” In February 1990, Finkelstein and Cohn were awarded patent 4,899,758 by the United States Patent and Trademark Office for their innovation, a method and apparatus for monitoring and diagnosing congestive heart failure and hypertension.\textsuperscript{140} Through their continued collaboration, Finkelstein, Cohn, and colleagues developed a non-invasive monitoring instrument that allowed researchers and clinicians to determine arterial vascular compliance using pulse contour analysis. Finkelstein, Cohn, and two others established the company Hypertension Diagnostics, Inc., to commercialize the instrument, the CV Profiler, and between 1990 and 2004, they received twelve patents for their work.\textsuperscript{141} By obtaining patents on their innovations, Finkelstein, Cohn, and colleagues increased their prospects for secur-
ing industry partners who—guaranteed of exclusive marketing rights—might be willing to commercialize those innovations. Once commercialized, those innovations would then be widely available to clinicians and researchers.

Finkelstein’s collaborative research with Warwick and Hertz had shown that patients could and would provide useful monitoring data in support of clinical decision making. In 1998, this success led Finkelstein, and Stuart Speedie, PhD, as co-principal investigator to establish the TeleHomeCare project (Speedie had joined the DHCS faculty in 1995). That year, Finkelstein and Speedie successfully applied for a Telecommunications and Information Infrastructure Assistant Program grant from the National Telecommunications and Information Administration to fund the project. The Telecommunications and Information Infrastructure Assistant Program was established by the Department of Commerce in 1994 to “provide seed money for innovative, practical projects that extend the benefits of advanced telecommunications and information technology to rural and urban underserved Americans.” Finkelstein and Speedie also secured matching funds from the project’s clinical and industrial partners.

The TeleHomeCare project, which ran from 1998 to 2002, was a collaboration between the University of Minnesota and four clinical partners, the urban Fairview Health System and three partners in rural Minnesota (Tri-County Hospital in Wadena, Lakewood Health Systems in Staples, and Cuyuna Regional Medical System in Crosby). It was developed to improve health care access both in underserved rural areas and underserved urban communities. The program combined “videoconferencing, Internet access, and physiological home monitoring” to provide “virtual visits between homebound patients and home health care providers,” with the goal of improving home care, reducing costs, increasing access, and improving patient satisfaction. Specifically, through videoconferencing, the patient was able to interact “face-to-face” at home with the home health care nurse located at a central site (clinical center or home health care agency); the Internet provided another means of patient-provider communication as well offering the patient access to educational resources; and the home monitoring enabled the patient to record vital signs, symptoms, and clinical measurements that they then transmitted to the clinical site. The project focused on the provision of home healthcare in the treatment of heart failure, chronic obstructive pulmonary disease (COPD), and chronic wound healing, chronic health problems that utilize significant home health care resources.

The TeleHomeCare project had been developed not only to improve health care access in underserved communities but also in response to the rapidly increasing costs of home health care and the growing strain on home health care providers to provide adequate care to homebound patients. Between 1994 and 1999, for example, the costs of home health care increased by over 400 percent, and in 2002, the National Association of Home Care estimated that in the United States $41.3 billion would be spent serving 7.6 million individuals.

To assess both its cost-effectiveness and efficacy, the TeleHomeCare project was organized as a randomized controlled trial. Fifty-three patients were randomly assigned to three groups: the first, the control group, received standard home health visits from nurses; the second group received standard visits from home health nurses plus two supplemental virtual visits per week; and the third group also received home monitoring specific to their underlying health problem, which included monitoring their symptoms, diet, exercise, and medication and reporting them daily using an electronic diary. The virtual visits “consisted of two-way audio and video interactions between a home health nurse at the central site and the [patient] at home.” As Speedie recalled, “We found that there were certainly efficiencies in terms of nursing time. Nurses spent less time...
with those patients [receiving virtual visits] as a result in responding to problems. There were positive outcomes in terms of reduced emergency department visits or hospital admissions." As Finkelstein and colleague Edward Ratner, MD, reported in 2006, patient satisfaction ratings increased among those who received virtual visits. Fewer patients in the intervention group required transfer to a higher level of care (hospital, nursing home) than did control subjects during and within 6 months of participating in TeleHomeCare. Costs per visit were greatest for actual home care visits ($48) and least for video-only virtual visits ($22), with costs for the video-plus-monitoring group in between." Thus, as Speedie explained, "what we were demonstrating was not so much a technology impact but that technology was enabling a higher intensity of care for those patients, because, basically, you were having more frequent contact with them, more frequent exchange of information. That intensity led to better outcomes."

Finkelstein and Speedie’s work in telehealth focuses on using telecommunication technologies to increase health care access, improve the quality of patient care, and reduce health care costs in underserved (primarily rural) communities. Their work has far-reaching national health care delivery and health care policy significance. Since 2013, Speedie has directed the Great Plains Telehealth Resource and Assistance Center, which is one of several regional telehealth resource centers funded through a federal grant from the Office for the Advancement of Telehealth—part of the Health Resources and Services Administration. The Great Plains Telehealth Resource and Assistance Center, which serves Iowa, Minnesota, Nebraska, North Dakota, South Dakota, and Wisconsin, assists health care organizations, networks, and providers in implementing telehealth programs to serve rural and other medically underserved areas. Despite the federal government’s investment in telehealth through the Health Resources and Services Administration’s telehealth initiatives, Medicare and private health insurance companies do not reimburse for telehealth services. As such, research that demonstrates both the clinical effectiveness and cost-savings of telehealth, such as Finkelstein and Speedie’s TeleHomeCare Project, is of national import.

By 2005, the University of Minnesota’s health informaticians had established the University as a center of cutting-edge health informatics research. During the 1970s, Claus Liedtke, in collaboration with his colleagues in the Medical School, had developed a research program in signal processing. From the 1960s, Gatewood and Ellis had built strong programs in database development and management, as had Connelly in the development of clinical decision support systems. During the 1980s and early 1990s, the National Micropopulation Simulation Resource, directed by Ackerman and Gatewood, had put the University of Minnesota on the map for modeling and simulation studies. Beginning in the early 1990s, the University of Minnesota developed robust research programs in standardized vocabularies and terminologies and natural language processing, led by Chute at the Mayo Clinic. And, Finkelstein and Speedie established the University of Minnesota as a major site of research in telehome monitoring and telehealth.
Lynda Ellis, PhD
source: University of Minnesota

Serguei Pakhomov, PhD
source: University of Minnesota
Beginning in the mid-2000s, the University of Minnesota’s health informaticians expanded upon existing research and pursued new initiatives that engaged significant issues of national health care policy. In part, the University’s health informaticians were responding to challenges in the health care system for which innovations in health information technologies offered potential solutions and the significant evolution of the discipline of health informatics. The establishment of new and the expansion of existing research domains by the University’s health informaticians were also the result of new faculty hires made following the founding of the University of Minnesota Institute for Health Informatics (IHI) in 2006.

Between 2006 and 2015, the University of Minnesota’s health informaticians established the University as a center of research excellence in several cutting-edge areas of health informatics research; these included (1) the design, development, and implementation of standardized nursing terminologies in electronic health records, led by Connie Delaney, PhD, RN (dean and professor, School of Nursing; acting director of IHI, December 2010–May 2015), Bonnie Westra, PhD, RN, FAAN, FACMI (associate professor and director, Center of Nursing Informatics, School of Nursing; IHI core faculty), and Karen Monsen, PhD, RN, FAAN (associate professor and codirector, Center of Nursing Informatics, School of Nursing; IHI affiliate faculty), which had links to the earlier work of Christopher Chute, MD, DrPH in standardized terminologies; (2) a research program evaluating the impact of electronic health records and health information exchange on health care delivery led by Donald Connelly, MD, PhD, and Stuart Speedie, PhD; (3) a research program applying data mining techniques to electronic health records to improve health outcomes led by Delaney, Westra, and Monsen; (4) the development of new methods in natural language processing led by Chute, together with Genevieve Melton-Meaux, MA, MD, FACS, FASCRS (associate professor, Department of Surgery; IHI core faculty; chief health information officer, Fairview Health...
Services and University of Minnesota Physicians), and Serguei Pakhomov, PhD (associate professor, Department of Pharmaceutical Care and Health Systems, College of Pharmacy, IHI affiliate faculty); and (5) initiatives to discover new innovations in clinical informatics that expanded upon Connelly’s earlier research in clinical decision support systems led by Terrence Adam, RPh, MD, PhD (associate professor, Department of Pharmaceutical Care and Health Systems, College of Pharmacy; IHI core faculty).

Electronic Health Records and Health Information Exchange

In the first decade of the twenty-first century, health policymakers committed financially, politically, and socially to developing and implementing an information system that would enable the exchange of health data among patients and providers in different health care delivery settings. As described in chapter one, in June 2000, the Centers for Disease Control and Prevention’s National Committee on Vital and Health Statistics issued a report that called for the establishment of a national health information infrastructure. 1 In 1999, the Institute of Medicine Committee on the Quality of Health Care in America had released its first report, To Err Is Human, which addressed issues related to patient safety and laid out a national agenda for reducing errors in health care and improving patient safety. 2 Two years later, in 2001, the Institute of Medicine committee released its report, Crossing the Quality Chasm, calling for “a nationwide commitment of all stakeholders to building an information infrastructure to support health care delivery, consumer health, quality measurement and improvement, public accountability, [and] clinical and health services research.” The Institute of Medicine regarded “the automation of patient-specific clinical information” as central to this initiative, and “should lead to the elimination of most handwritten clinical data by the end of the decade.” 3 Electronic health records (EHRs) were to be the medium through which patients’ health data would be exchanged among different health delivery settings. The Institute of Medicine’s report indicated that the use of EHRs would improve the accuracy and accessibility of patient safety, and the effectiveness and efficiency of health care. 4

Three years after the Institute of Medicine’s Crossing the Quality Chasm report, President George W. Bush announced in the 2004 State of the Union address, “an ambitious goal of assuring that most Americans have electronic health records within the next 10 years.” This, the president promised, “will ensure that complete health care information is available for most Americans at the time and place of care, no matter where it originates.” 5 That year Bush created, through an executive order, the Office of the National Coordinator for Health Information Technology, which provides “leadership for the development and nationwide implementation of an interoperable health information technology infrastructure to improve the quality and efficiency of health care.” 6

Exemplifying the importance of new discoveries and assuring their impact on individual and population health, in July 2006, the Institute of Medicine Roundtable on Evidence-Based Medicine convened a two-day workshop “to consider a broad range of issues important to reengineering clinical research and healthcare delivery so that evidence is available when it is needed, and applied in health care that is both more effective and more efficient than it is today.” A summary of the workshop, The Learning Healthcare System: Workshop Summary, was published the following year in 2007. 7 The workshop was premised on the understanding that information technology—“by expanding the capability to collect and manage data”—will provide “valuable tools to confront” the challenge of generating and applying clinical evidence to improve health care delivery. What was needed, the authors of The Learning Healthcare System asserted, was a “reevaluation of how health care is structured
to develop and apply evidence—from health professions training, to infrastructure development, patient engagement, payments, and measurement”—in order to “orient and direct” the information technology “tools toward the creation of a sustainable system that gets the right care to people when they need it and then captures the results for improvement. The nation needs a healthcare system that learns.”

The Learning Healthcare System singled out three key health information technologies—and health informatics research fields—that were in “most pressing need” for development: (1) clinical decision support systems, “to accommodate the reality that although professional judgment will always be vital to shaping care, the amount of information required for any given decision is moving beyond human capacity,” (2) universal electronic health records, “comprehensive deployment and effective application of the full capabilities in EHRs as an essential prerequisite for the evolution of the learning healthcare system,” and (3) tools for database linkage, mining, and use, “advancing the potential for structured, large databases as new sources of evidence, including issues in fostering interoperable platforms and in developing new means of ongoing searching of those databases for patterns and clinical insights.”

The building of a robust nationwide research discovery infrastructure that would accelerate the translation of scientific knowledge developed at the bench into new clinical discoveries applied at the point of care, training clinical and translational researchers to enable those research efforts, and the engagement of communities across the health care spectrum, including patients, in clinical research efforts was key to the development of a learning healthcare system. This was the foundation of the National Institutes of Health’s Clinical and Translational Award program, which was established in 2006.

Further impetus for urgent change occurred on February 17, 2009, when President Barak H. Obama signed the Health Information Technology for Economic and Clinical Health (HITECH) Act, as part of the American Recovery and Reinvestment Act, which is administered by the Office of the National Coordinator for Health Information Technology (see chapter two). Under the HITECH Act, the Centers for Medicare and Medicaid Services EHR incentive programs provide incentive payments to eligible health care professionals and hospitals “as they adopt, implement, upgrade, or demonstrate meaningful use of certified EHR technology.” Because of the high cost of adopting and implementing EHR systems, these incentive programs have been a significant stimulus to increasing EHR use among “[l]arge private hospitals and multispecialty groups, university-based hospitals and integrated health care delivery systems.” Yet, as Brian Rothman from Vanderbilt University School of Medicine and colleagues noted in 2012, even with these incentive programs in place, “small groups, solo practitioners, and rural and small hospitals are less likely to make the transition to computerized systems, let alone an integrated EHR, due predominantly to the high costs associated with their installation and implementation.” Beginning in 2015, the Centers for Medicare and Medicaid Services imposed penalties for noncompliance. Eligible health care professionals who had not implemented EHR systems and demonstrated their meaningful use by the 2015 deadline had their Medicare reimbursements reduced by 1 percent. For every subsequent year they fail to comply, the rates of reduction increase annually.

To realize the full potential of EHRs as both clinical and research tools depends on their interoperability, which in turn relies on the use of multiple standards to support health information exchange (HIE). Standardized clinical terminologies, like those that Chute helped to develop beginning in the 1990s (see chapter three), are an example of standards that are essential to achieving interoperable HIE. With nurses constituting the largest group of health care professionals in the United States, it is essential that
standardized nursing terminologies are used to “support the development, exchange, and communication of nursing data.” The University of Minnesota’s nurse informaticians—Delaney, Westra, and Monsen—have been at the forefront of efforts to design, develop, and integrate standardized nursing terminologies into EHRs (see also chapter one).

**Interoperable Electronic Health Records and Standard Terminologies**

Standards “are agreed-upon ways to record and exchange data within and across information systems.” They are “one mechanism to ensure validity of data.” Health care standards are “essential to represent, communicate, exchange, manage, and report data, information, and knowledge to support” clinical, including nursing, practice. There are “three types of standards that are most important for nursing” and health care. First are content standards, which are standardized terminologies related to Chute’s early research (see chapter three). These include “the terms that represent a focus of health concerns (diagnoses), interventions, and outcomes consistent with the scope of nursing and health care practice. Second are messaging standards, which enable the exchange of data between information systems; this includes eHealth, which focuses on data exchange.Messaging standards ensure that “data entered into one system are consistent with the meaning when the same data are subsequently displayed in another system.” Third are confidentiality and security standards, which are addressed in part by the Health Insurance Portability and Accountability Act of 1996 (HIPAA).16

Delaney, Westra, and Monsen have been at the forefront of efforts to design, develop, and implement standardized nursing terminologies to support nursing practice. They have played key roles in the development of several American Nursing Association–recognized classification data sets. As a faculty member at the University of Iowa College of Nursing from 1987 through 2005, Delaney was a member of the research team that produced the Nursing Interventions Classification. Located at the University of Iowa College of Nursing, the Nursing Interventions Classification “is a comprehensive, research-based, standardized classification of interventions that nurses perform.”17 It was first published in 1992. Delaney and Westra were both members of the Nursing Outcomes Classification research team. The Nursing Outcomes Classification, also located at the University of Iowa College of Nursing, “is a comprehensive, standardized classification of patient/client outcomes developed to evaluate the effects of interventions provided by nurses or other health care professions.”18 It was first published in 1997. Also since her tenure at the University of Iowa College of Nursing, Delaney has led research teams that coordinated the updates of the Nursing Minimum Data Set; created, developed, and implemented the Nursing Management Minimum Data Set; and founded and developed the International Nursing Minimum Data Set (all discussed below).

Delaney’s research has focused primarily on validating and extending NANDA International (formerly the North American Nursing Diagnosis Association)—a standardized nursing diagnosis terminology first developed in the United States in 1982 that became an international data set in 2002;19 designing and validating clinical nursing content of EHRs; designing data extraction methods; describing and comparing nursing practice across sites and settings; and discovering knowledge with NANDA, the Nursing Interventions Classification, and the Nursing Outcomes Classification. Westra and Monsen’s research focuses, in particular, on the Omaha System (OS), also one of the American Nurses Association–recognized standardized terminologies that describes and measures the impact of health care services. The OS was developed in the early 1970s by the Voluntary Nurses Association of Omaha and was subsequently...
developed and expanded by a variety of health care researchers, educators, and managers between the 1970s and the late 1990s. Today, the OS “is a comprehensive standardized terminology designed to generate comprehensive data for the description and evaluation of client care.”

As described by Maxim Topaz and colleagues, the OS model is composed of three basic steps: problem, intervention, and outcome. In the first step, Problem Classification Scheme (PCS), “healthcare practitioners collect assessment data, such as signs and symptoms, to identify patients’ problems and to formulate diagnoses. The PCS consists of four domains: environmental, psychosocial, physiological, and health-related behaviors.” In the second step, the Intervention Scheme, the provider implements the actual intervention. There are “four intervention categories: health teaching, guidance, and counseling; treatments and procedures; case management; and surveillance. Specific nursing interventions are further delineated through the use of 75 targets (e.g., ‘cardiac care’ or ‘dietary management’).” In the final step, Problem Rating Scale for Outcomes, “the provider evaluates the care process by measuring its outcomes on a Likert scale in the area of knowledge, behavior, and status of each problem.”

In 2010, Westra and colleagues published the results of a study that tested the “feasibility of abstracting, integrating, and comparing the effective use of a standardized terminology, the Omaha System, across software vendors and 15 home care agencies.” The results of the study demonstrated “the usefulness of the Omaha System for describing practice in home care.” It found that, based on the PCS, patients had an average of four problems, with “most associated with the physiological domain.” The study also found that the most frequent provider intervention was surveillance, followed by teaching, treatments, and case management. Finally, the study found that the problem rating scale of outcomes “demonstrated improvements in knowledge, behavior, and status for most patients.” Where problems existed with using the problem rating scale, Westra and colleagues suggested the problem “reflects the way nurses document rather than validate outcomes.” Based on these results, Westra and colleagues concluded that for nursing data within EHRs to be interoperable, “a standardized nursing terminology must be included in the requirements for an EHR.”

Westra and Monsen, in collaboration with Genevieve Melton-Meaux, MA, MD, FACS, FASCRS (associate professor, Department of Surgery; IHI core faculty; chief health information officer, Fairview Health Services and University of Minnesota Physicians), developed methods for incorporating practical improvements in future OS revisions. Standardized terminologies, including standardized nursing terminologies, used in EHRs need to be regularly re-evaluated and revised to reflect current health care practice and knowledge. The OS, for example, was revised in 2005. A key “threat to the validity of a structured interface [standardized] terminology” is concept duplication. As described above, the OS model is composed of problem–intervention–outcome. Within the intervention scheme there are intervention categories and intervention targets, each of which are necessarily linked to the specific problem. As Westra, Monsen, Melton-Meaux and colleagues described, “In an early edition of the Omaha System, 2 concepts (nutrition, substance use) were exactly duplicated as terms at the problem and target levels.” In the 2005 OS revision, “this conception duplication was addressed by altering target terms (dietary management, substance use cessation); eliminating the exact duplication while maintaining congruence with the original Omaha System targets.” The potential for concept duplication between problem and target terms necessitated the need for further development of the OS.

In 2011, Westra, Monsen, Melton-Meaux and colleagues reported on the results of a study using clinical EHR data from “a public health agency and a skilled homecare, skilled hospital, and palliative care
agency” in which they had identified “a formal semantic structure underlying Omaha System target terms”; assessed the validity of those structures identified; and examined “problem and target terms for concept duplication.” Using linguistic principles and qualitative analysis, the team identified five themes (type of care, type of practitioner, client skills, client needs, and client environment) that “are the basis of a proposed multi-dimensional semantic structure to be used for future revisions of the Intervention Scheme” in the OS. Using concept duplication analysis, they also identified “16 matches of problem and target terms with similar or overlapping names and definitions,” which were “validated empirically using large intervention data sets from community care settings.” The team concluded that their findings demonstrated that the formal semantic structure and study’s recommendations “provide a meaningful method for incorporating practical improvements in future Omaha System Revisions.”

In a follow-up study, also published in 2011, Westra, Monsen, Melton-Meaux and Olamdimeji Farri (health informatics PhD candidate) evaluated clinicians’ use of free text entry in the OS “to inform issues with electronic health record system use and future Omaha System standard development.” They did so by looking at the use of free text associated with OS interventions in a maternal child health home visiting program and in a skilled homecare, hospice, and palliative care program. One of the target terms in the OS is other, which is not defined and instead enables the clinician to enter his or her own text at the target level of the intervention statement. The OS also includes a care description, which “is a detailed, customizable portion of a plan or intervention statement that can be developed and documented by the clinician.” Thus, “in addition to structured entry with the Omaha System (problem–category–target), clinicians also have the option to enter free-text during clinical documentation at the target and care description levels to fill information gaps and provide clinical reasoning.”

In their study, Westra, Monsen, Melton-Meaux, and Farri found that while free-text associated with “other” targets “carried some valuable information, these entries very commonly contained duplicate ‘carry forward entries,’ multiple concepts, [or] mismatched problem focus, or the user failed to identify an existing appropriate target.” For example, clinicians at the homecare, hospice, and palliative care site frequently used target other “to document a complex care plan containing multiple concepts (instead of creating several unique interventions).” In one case, a clinician added free-text for one intervention that addressed the health care supervision problem “add phone follow-up between home visits to review emergent care plan,” continue client/caregiver education regarding disease process, and assess status. However, the clinician had available to her several existing unique interventions that would have appropriately documented the multi-task care plan. As an example of clinicians having a mismatched problem focus or not identifying an existing OS target and instead entering text, “clinicians had a hard time differentiating the scope of similar problems such as digestion-hydration, nutrition, and bowel function.”

In light of their findings, the team concluded that OS user training “is critical to successful documentation,” and in future revisions to the OS, new targets should be added for “activities of daily living, disease pathophysiology, and pain management.”

As noted earlier, a core initiative for reforming the health care system is to collect, exchange, and analyze “accurate, representative, and relevant data regarding information pertaining to patient needs, care provided, outcomes realized, and information about the appropriate use of resources influencing care.” The exchange and analysis of, and knowledge discovery from, EHR data is just one element of this. Data extracted “from computerized systems such as billing
and claims data” are another element. Management and administrative data, including nursing management data, which describe the context of care and care delivery, are equally important. As of 2010, however, while nursing management data were collected in every health care setting, they were not being “captured in data warehouses and/or lack[ed] consistency in definitions and coding,” making it impossible to “reuse these management data to compare patient outcomes and nursing workforce issues within and across settings.” To meet the criteria for meaningful use of EHRs, Westra, Delaney, and colleagues argued, nursing management data “need to be standardized and included in data warehouses along with EHR clinical data.” The Nursing Management Minimum Data Set (NMMDS), they continued, “can fill the void in data warehouses to describe the management of nursing care.”

The NMMDS is a “minimum collection of core variables needed by nurse managers to make decisions and compare nursing practice across institutions and geographical areas. . . . It identifies common elements to represent nursing care delivery or the context of nursing care at the unit level or service line in any setting.” It provides nurse managers and administrators “standardized data that [can] be compared within and across settings to understand how the context of care can influence patient and staff outcomes.”

The NMMDS built upon the National Minimum Data Set (NMDS), which had been developed by a research team led initially by Harriet Werley, PhD, RN, at the University of Wisconsin–Milwaukee. In 1992, Werley and Jane Leske, PhD, described the NMDS as representing “nursing’s initial attempt to standardize the collection, storage, and retrieval of essential, comparable, core nursing data . . . such as, nursing diagnoses, interventions, outcomes, and intensity of nursing care.” These are “items that are used on a regular basis by the majority of nurses in any setting where nursing care is provided.” In 1992, NMDS included sixteen elements categorized into three broad groups: nursing care, client demographics, and service. The information provided by the NMDS data would enable the nursing and other health care researchers to “assess the effectiveness of the nursing interventions, to contribute to clinical and health policy decision making, as well as to demonstrate nursing’s contributions to patient care.” The creation of the NMDS drove the development of standardized nursing terminology as well as the subsequent development of the NMMDS and the International NMDS (iNMDS, discussed below).

The development of the NMMDS was initiated in 1989 and led by Delaney and Diane Huber at the University of Iowa College of Nursing. From 1987 to 1999, Delaney held professor appointments at the University of Iowa College of Nursing as well as a clinical appointment as a staff associate in nursing informatics at the University of Iowa Hospitals and Clinics from 2000 to 2004. From 1997 to 2005, she was coordinator of the University of Iowa’s Health Informatics Program and founding director of the University of Iowa College of Nursing’s Center for Knowledge Discovery. From its founding in 1997, the Center for Knowledge Discovery created the focus of the NMDS and from 2002 it coordinated, in partnership with the American Nursing Association, the ongoing update of the NMDS. Delaney led three research teams at the University of Iowa College of Nursing: NMDS, NMMDS, and iNMDS. When Delaney joined the University of Minnesota as dean of the School of Nursing in 2005, she brought all three projects to the University of Minnesota.

As Delaney, Huber, and colleagues explained in 1992, there was an urgent need for an NMMDS because there “is a pressing need for nursing as a profession to identify its core, essential data, and then to systematically collect that data in an easily retrievable and comparable format that can be incorporated into national databases.” Under pressure from health care
organizations that were in turn responding to pressure from the Joint Commission on the Accreditation of Healthcare Organizations, “Nursing administrators are being challenged to develop language for nursing management databases. These databases are viewed as furthering the development of the [health care] organization’s infrastructure through the collection of data about the linkages among management outcomes and patient outcomes.”

In 1996, following an invitational conference that brought together national nursing experts and the research team to refine the data set using expert consensus methodology, the first NMMDS was published in partnership with the American Organization of Nurse Executives. The NMMDS included a “list of 17 basic NMMDS elements, with standardized definitions and measures for each element,” grouped into three categories: environment, nurse resources, and financial resources. The NMMDS remained “a work in progress” with subsequent updates to the data set expected. Two years later, in 1998, the American Nurses Association recognized the NMMDS as one of two data sets (NMDS and NMMDS) and ten terminologies in nursing.

By 2010, the NMMDS was composed of eighteen data elements organized into three categories: environment, nursing care, and financial resources. As Westra, Delaney, and colleagues described that year, each data element “is operationalized by more specific subconcepts and measures that can be linked with nursing management data already collected.” The value of the NMMDS, they continued, “is that it identifies nursing management variables that can be combined with billing and clinical data to build a better understanding of how nursing resources and the context of care influence patient safety and other outcomes.” It also fosters “an increased understanding of the nursing workforce needs in terms of quantity and level of expertise specific to specialties and settings of care.”

As of 2010, however, the NMMDS was only available as a paper-based survey upon request from the developers. For the full potential of the NMMDS to be realized, the “standardized NMMDS data elements, definitions, measures, and codes” needed to be updated and publicly distributed. Distribution would be “best accomplished by linking it to a federally accepted national terminology [standard] that is publicly available,” such as the Logical Observation Identifier Names and Codes (LOINC) system. LOINC is a publicly available and internationally recognized data set containing universal names and codes that was initially intended for clinical measures and laboratory results that was developed and maintained by the Regenstrief Institute, Inc.

In their 2010 article, Westra, Delaney, and colleagues published the “methods and outcomes of the initial steps to update the definitions and measures for three of the eighteen data elements, normalize these measures to current national standards, and disseminate the data set by linking the NMMDS to LOINC.” The three data elements were then made publicly available on the University of Minnesota School of Nursing Minimum Data Set Knowledge Discovery website. Westra, Delaney, and colleagues updated, measured, and disseminated the first three data elements in the NMMDS: unit/service unique identifier; nursing delivery unit or service; and patient or client population. Once updated and publicly available, the data elements were available to nurse managers to “support multilevel and multiagency analyses of the context of nursing care on patient safety, outcomes, and the nursing workforce information requirements.” Westra, Delaney, and colleagues called on nurse managers, administrators, and researchers to advocate for the inclusion and use of the NMMDS data definitions and coding in health information systems. By 2012, the definitions of six NMMDS data elements had been updated and mapped to LOINC.

In June 2015, all NMMDS data elements had been defined, updated, and incorporated into LOINC, making available a “new standardized data set of more
than 100 coded and measurable terms...that enables health care systems to objectively evaluate and compare the effectiveness of their nursing care, staffing and facilities—unit-by-unit and shift-by-shift.” This meant that if two hospitals using two different EHRs, scheduling, and human resource systems wanted “to compare the incidence of catheter-associated urinary tract infections with their staffing complement,” they could do so because “inside those systems they both use the international LOINC vocabulary standard for reporting the following for their staff: staff mix, education, turnover, satisfaction, years of experience, and certifications. Because they used the same standard for these variables in the NMMDS, they are now able to compare care and outcomes.” The incorporation of NMMDS into LOINC marks the transformation of a grassroots research initiative, created and led initially by Delaney and Huber and subsequently Delaney, into a national standard.

Delaney, Westra, and Monsen have continued to be leaders in the development and implementation of standardized nursing terminologies. Delaney, codveloper of the NMMDS, was also founder of the international Nursing Minimum Data Set (iNMDS). The International Council of Nurses and the International Medical Informatics Association Nursing Informatics Special Interest Group sponsor the iNMDS project, which builds on efforts already underway in individual countries. Delaney has chaired the International Medical Informatics Association’s iNMDS Task Force since 2001. The iNMDS includes three categories of data elements: setting, patient demographics, and nursing care. The iNMDS extended the implementation of the International Council of Nurses’ International Classification for Nursing Practice (ICNP). This is a formal terminology that “provides a dictionary of terms and expressive relationships that nurses can use to describe and report their practice in a systematic way. The resulting information is used reliably to support care and effective decision-making, and inform nursing education, research, and health policy.”

The University of Minnesota School of Nursing’s Center for Nursing Minimum Data Set Knowledge Discovery, directed by Delaney, is one of twelve—and the only center in the United States—international research and development centers for the ICNP. The School of Nursing Center provides “synergy among inter-related essential data set projects, including the iNMDS, NMDS, and NMMDS.” These projects “will continue the development, dissemination and use of ICNP through its use as the clinical portion of the minimum data sets.” Delaney also served as a member of the ICNP’s Strategic Advisory Group from 2005 through 2011.

As mentioned in chapter one, Westra and Monsen led the efforts of the Minnesota e-Health Initiative Standards and Interoperability Work Group that culminated in the Minnesota Department of Health being the first state department of health in the nation to recommend that American Nurses Association–recognized standardized nursing terminology be incorporated into EHR in all health care settings. The strong contributions of the University of Minnesota’s nursing informaticians to the design, development, and implementation of several nursing terminologies with major focus on Omaha System, Nursing Minimum Data Set, Nursing Management Minimum Data Set, international Nursing Minimal Data Set, and International Classification for Nursing Practice, coupled with Chute’s expertise in the field, has created a cadre of expertise that has made the University of Minnesota a national and international center of research and development in standardized terminologies.

As EHRs and HIE took on increasing national significance in the mid-2000s, health policymakers and health care administrators looked to researchers for evidence that these new health information technologies were having an impact on health care delivery. At the University of Minnesota, health informaticians Donald Connelly, MD, PhD, FACMI, and Stuart
Speedie, PhD, led a research program to evaluate just that—the impact of EHR and HIE on health care.

**Evaluating the Impact of Electronic Health Records and Health Information Exchange**

In light of the growing importance of EHRs and HIE to high quality and cost-effective health care, Connelly and Speedie began plans in the early 2000s to research the impact of EHRs and HIE on clinical outcomes and clinical processes in local health care delivery settings. In 2005 they were awarded a five-year, $1.5 million grant by the Agency for Healthcare Research and Quality for the project, “A Community-Shared Clinical Abstract to Improve Care.” Connelly served as project director and Speedie as research director. The goal of the project was to evaluate “the impact of HIE on patients and hospital emergency departments.” As Speedie recalls, “This was the era when there was all this hype about how exchanging data was going to improve outcomes for patients.”

Specifically, Connelly and Speedie investigated the impact of transferring patients’ electronic health records between providers in the emergency department (ED) and other health care settings where the patients’ received care.

As Connelly and Speedie described in their grant proposal, in the absence of HIE, when a patient arrived in an ED of a hospital system in which he or she had no medical record and when the patient was unable to provide the names and doses of his or her current medications, he or she was at risk for adverse drug interactions as the ED providers would write medication orders without full knowledge of the patient’s recent medication use. In addition, the patient would have to undergo redundant testing to clarify his or her underlying problems and current status. Similarly, when a patient was discharged from a hospital in one system and discharge notes were supposed to be sent to the patient’s primary care clinic in a different system, sometimes the discharge notes did not arrive in time for the patient’s follow-up appointment, or the notes “may lack sufficient detail for the primary care provider to continue or formulate an optimal care plan.” The “future pursued” in Connelly and Speedie’s project, by contrast, “was one where providers who are treating a patient for whom they typically would have incomplete or dated information, now have easy and immediate access to an electronic clinical record abstract. The abstract has key information regarding the patient’s recent health status and treatments which contribute to well-informed clinical decisions. The result is fewer errors that would otherwise compromise patient safety, better quality of care, reduction in redundant and inappropriate use of clinical resources, and more efficient work and use of resources.”

Two hypotheses guided this research: (1) “patients who have information accessible in the organization’s information system will receive better care and experience better outcomes than those who do not; and (2) “when such information is made available through health information exchange, that difference will no longer be evident.”

To carry out the project, the University of Minnesota partnered with the Twin Cities’ three major health care systems: Allina Hospitals and Clinics, Fairview Health Services, and HealthPartners. Representatives from each of the three systems were involved in the planning, implementation, and evaluation phases of the project. Initially, Connelly and Speedie focused on patients admitted to the EDs of each health system with congestive heart failure (CHF). At that time, CHF was “the single most common cause of inpatient admission among Medicare patients,” and in 1999, the total cost for heart failure management in the United States was $56 billion. In 2006, Speedie was awarded a three-year, $230,000 University of Minnesota Academic Health Center faculty research development grant to assess the impact of HIE. This project—which was conducted in parallel with the Agency for Healthcare Research and Quality–funded project—extended the initial focus of the Agency for Healthcare Research and Quality grant to patients
with at least one of two chronic conditions—diabetes and asthma. Delaney and Westra were investigators on the Academic Health Center grant.\textsuperscript{55} For the Agency for Healthcare Research and Quality–funded project, Connelly and Speedie proposed HIE interventions in which the EDs of three healthcare systems under study—Allina, Fairview, and HealthPartners—had access to EHR information for patients in each other’s systems. They proposed two levels of intervention. Each of the EDs under study (one each from the Allina, Fairview, and HealthPartners systems) used the same electronic health record system, MyChart, supplied by Epic Systems Corporation. MyChart allows patients to access selected health information from their patient record, enabling them to share the data with the ED physician. Because it is an Internet-based product, it enables each system the capability to access MyChart patient data from each other’s systems. At the Level 1 intervention, ED personnel in all three systems would have electronic access to MyChart data. Connelly and Speedie hypothesized that once MyChart data became available across all three healthcare systems, “the quality of care for CHF patients presenting to the ED from each other’s systems” would “improve across all three systems.” The Level 2 intervention would entail “a standard set of patient information that will be readily accessible across the three systems. Emergency department personnel in all three systems will have electronic access to the other systems’ hospitals and from the clinics owned by Allina and HealthPartners.” Connelly and Speedie expected “the trends in Level 1 to continue but [to] be more pronounced.” The level 2 intervention, however, depended on the development and implementation of Epic Systems Corporation’s HL7 CDA (clinical document architecture) Release 2 with Care Record Summary (CRS).\textsuperscript{56}

Unfortunately, Connelly and Speedie were never able to implement and evaluate either the Level 1 or Level 2 interventions and as such were unable to directly measure the impact of HIE. As Speedie recalls, “we ran into the realities of business, etcetera, what things were supposed to happen and didn’t happen.”\textsuperscript{57} The project was initially delayed when Epic Systems Corporation failed to deliver the necessary technology to implement the HIE process on schedule.\textsuperscript{58} Several other factors contributed to the failed efforts to implement the Level 2 intervention. First, “[p]rivacy and security concerns about the vendor’s [Epic Systems Corporation] approach limited [the] health systems’ acceptance of it” until late in 2009. Second, updates to Minnesota’s privacy regulations related to HIE “led to uncertainty among the legal counsel of [the] health systems that stymied decisions to implement HIE. Third, late in 2007, policymakers and other stakeholders recognized the need for HIE and initiated plans to develop a regional health information organization (see chapter one) in Minnesota. While the project’s ‘executive board committed the project to use the nascent HIE once its communication services became available so as to avoid development of redundant and temporary communication changes . . . the HIE developed at a pace too slow to accommodate [the] project during its funding period.”\textsuperscript{59}

Faced with these realities, Connelly and Speedie modified their research plan. The new plan focused on evaluating the impact of information available from an EHR within each site. They did this by focusing on two ED patient groups at each of the three EDs: internal patients, those who already had an electronic clinical record in that health system at the time of their first ED visit during the period of study, and external patients, those from a different system and thus with no available electronic record.\textsuperscript{60} This new research plan was “based on the notion that health information exchange would supply similar information for external patients were it available.”\textsuperscript{61} Between 2009 and 2014, Connelly, Speedie, and colleagues published several articles based on the results of these studies. As Speedie summarized, “we got initial data that did demonstrate that there was some impact of electronic health records on various outcomes for patients, but it was not as obvious as you would expect.
It was not a huge effect, nor a uniform effect. It varied by disease, and it varied by location.”

In 2009, for example, University of Minnesota health informatics PhD candidate, Nawanan Theera-Ampornpunt, MD, Connelly, Speedie, and colleagues reported on the results of a study that used “secondary data to investigate its impact on surrogate measures of care quality and efficiency among 6,143 congestive heart failure, diabetic, and asthmatic patients” in the three EDs. As surrogates for quality of care, the researchers used the hospitalization rate, ED length of stay, inpatient length of stay, and inpatient mortality rate. The researchers used the numbers of laboratory orders and diagnostic procedures orders during the ED visit as surrogates for resource utilization and costs. While the researchers found “some evidence that prior clinical information accessible in an EHR may be associated with better patient outcomes and more efficient care . . . [a]t one site it was associated with significantly poorer outcomes and less efficient care.”

Three years later, in 2012, Connelly, Speedie, Theera-Ampornpunt, and colleagues reported on the results of a retrospective study of 5,166 adults with heart failure admitted to the three EDs. At two of the EDs, the internal CHF patient “who had some clinical information available within a healthcare system’s EHR when they presented to these two ED sites, had fewer laboratory tests ordered [4.6 percent at site A and 14 percent at site C] . . . fewer medications ordered [33.6 percent at site A and 21.3 percent at site C], and greater odds of surviving if hospitalized.” Patients at the third ED “appeared to be different from the other two with only one significant finding—ED LOS [length of stay] was longer on average” for internal patients who had clinical information available within the healthcare system’s EHR. The authors’ concluded that because “the odds for hospitalization and in-hospital mortality were reduced and some reductions in resource use for patients with CHF were seen” when prior clinical information in the EHR was available to providers in the ED, “the potential economic impact may be substantial for a nation that expended nearly $40 billion on CHF healthcare in 2007.”

Other researchers evaluating the impact of HIE during this period saw similarly mixed results. In 2009, for example, Joshua R. Vest of Texas A&M Health Science Center, College Station, published the results of a study that “tested the hypotheses that HIE information access reduced emergency room visits and inpatient hospitalizations for ambulatory care sensitive conditions [illnesses that if managed properly on an outpatient basis, generally do not result in hospitalization] among medically indigent patients.” The results showed, however, that “accessed HIE information . . . was associated with increased health service utilization.” While Vest pointed to several possible explanations for this unexpected result, he cautioned that expectations that HIE would lead to health care “utilization reductions, however logical, may have to be reevaluated or postponed.”

EHRs also presented researchers with “new opportunities and challenges for research that aims to effectively use” the health data contained within them “to discover new knowledge to improve healthcare.” This research includes, for example, abstracting EHR data “to report quality measures,” reusing EHR data “to discover new knowledge for predicting outcomes and testing new methods to improve outcomes.”

The University of Minnesota’s health informaticians, particularly its nursing informaticians, led by Delaney, Westra, Monsen, and Chih-Lin Chi, PhD, MBA (assistant professor, School of Nursing; IHI core faculty), have become leaders in this area of health informatics research known as data mining.

**Electronic Health Records and Data Mining**

The phrase data mining has its origins in the field of statistics and has been around for forty to fifty years. Computer scientists first adopted the term in the early
1990s “to describe algorithmic and database-oriented methods that search for previously unsuspected structure and patterns in data.” Data mining combines methods from statistics, machine learning, and pattern recognition. In 1996, model developers Usama Fayyad, PhD, Gregory Piatetsky-Shapiro, PhD, and Padhraic Smyth, PhD, described data mining as just one step in the knowledge discovery in databases process. The additional steps in the knowledge discovery process, such as “data preparation, data selection, data cleaning, incorporation of prior knowledge, and proper interpretation of the results of mining, are essential to ensure that useful knowledge is derived from the data.”

As Westra and colleagues noted in 2011, the application of data mining to “analyzing health information is relatively new.” In the early 2000s, some of the first clinical data mining work focused on its application to the analysis of gene expression profiles to molecularly classify different cancers; the analysis of electroencephalogram data and brain imaging data; the detection of adverse drug events; and the discovery of “important linkages between clinical data, nursing interventions, and patient outcomes.” However, both the capacities for and the importance of data mining grew significantly from the mid-2000s after the federal government pushed for the complete implementation of EHRs in all health care delivery settings by the end of 2014, and following the significant growth of data storage capacity. As of 2011, this had generated “terabytes or even petabytes of health data” available in EHRs, which could be analyzed using data mining techniques. Passage of the HITECH Act in 2009 led to the Centers for Medicare and Medicaid Services EHR Incentive Programs, which have provided incentive payments to providers and hospitals for meaningful use of EHRs that include new knowledge discovery.

Since the late-2000s, Westra, Delaney, and Monsen have used data mining in their research at the University of Minnesota to improve patient outcomes and health care quality. In 2014, they were joined by new faculty member, Chi, who had just completed a postdoctoral fellowship at Harvard Medical School’s Center for Biomedical Informatics. Chi’s postdoctoral work built on his PhD research in health informatics and data mining, which he completed in 2009 at the University of Iowa.

Westra’s research has focused on mining EHR data for predicting outcomes for older adults receiving homecare services. In a study published in 2006, for example, Westra, Debra Solomon, MS, RN (clinical coordinator, Fairview Lakes HomeCaring and Hospice), and Donna M. Ashley (systems application specialist, Fairview Lakes HomeCaring and Hospice) integrated the Omaha System (described earlier), which is a research-based standardized method to organize and collect clinical data, and the OASIS (Outcome and Assessment Information Set) data set, which is an outcome assessment tool for home care agencies, in an EHR to document care and mine the data to conduct an outcome-based quality improvement process in home care. Agency staff at the Fairview Lakes HomeCaring and Hospice in Wyoming, Minnesota, “abstracted the Omaha system data from their EHR and compared outcomes between the Omaha System problem of pain and the OASIS pain outcome for 133 patients. Based on chart reviews, the Omaha System pain outcome was identified by the nurse managers as more accurately reflecting the patients’ pain status compared with documentation of the OASIS data.” Westra and colleagues concluded that the case study demonstrated the value of data mining EHR data using the Omaha System data to “validate the accuracy of information” and improve patient outcomes.

In general, the work of Westra, Delaney, and Monsen focuses on demonstrating the value of mining EHR data to improve patient outcomes and nursing practice. In a 2009 study, Monsen, Westra, and colleagues compared four methods for managing standardized nursing classification data in preparation
for performing nursing intervention effectiveness research. The purpose of the study “was to create intervention groups (Phase I) and compare intervention grouping approaches (Phase II) using four approaches applied to home care Omaha System intervention data.” They used three deductive approaches: action category, theoretical, and clinical expert consensus; and one inductive approach: a data-driven method that used “data mining to generate intervention groups.” Each of the four approaches generated unique groups, which meant that each approach had the potential to “differentially predict patient outcomes.” The findings from the study, however, challenged the researchers’ “assumptions about managing nursing classification data.” While the three deductive approaches “were similar” in a few ways (for example “the action was the primary descriptor for the intervention groups”), “the inductive data-driven approach generated novel and overlapping groups that were not based on intervention actions.” Data mining had “revealed new information that we could not have imagined from a theoretical perspective.” Indeed, the results demonstrated “how home care nursing holistically and simultaneously addresses multiple complex health problems.” While further research was certainly needed, Monsen, Westra, and colleagues concluded that data mining “offers a unique way to manage complex intervention data from EHRs for investigating the effectiveness of nurses and other clinicians on patient outcomes.”

In 2011, Westra led an interprofessional team that included University of Minnesota computer scientists, Sanjoy Dey and Michael Steinbach, PhD, that “compared methods of developing predictive rules that are parsimonious and clinically interpretable from EHR home visit data.” The four methods compared were logistic regression and three data mining classification models: rules (Ripper), decision trees (DT), and support vector machines (SVM). Each method was “applied to a case study for one outcome of improvement in oral medication management.” Classification in this study, as described by Westra and colleagues, “is the discovery and validation of models, such as a set of rules, which uses the patient-specific value of selected variables to predict classes of patients (for example, those patients who are likely to improve or not improve with respect to their oral medication management).” At the conclusion of the study, Westra and colleagues found that “Ripper and DT models performed better compared with the SVM model . . . as well as with the logistic regression.” While there were many differences, they also found similarities in the predictors for improvement in oral medication management across all three data mining models. For example, patients “who were more dependent at admission for oral medication management and those who received instruction on medication management were more likely to improve compared with patients needing little or no help.” Though more studies were needed “comparing the clustering of interventions on prediction of home care outcomes,” and providers would need to decide what degree of accuracy was sufficient before implementing a prediction rule in an EHR that would provide clinical decision support, the study was promising for both those working in data mining and those developing clinician decision-support systems.

The longstanding research relationship of the University of Minnesota School of Nursing with UnitedHealth and the expertise in data mining methods developed by the University of Minnesota’s nursing informaticians was critical to the University of Minnesota School of Nursing being invited to join the Optum Labs Research Collaborative in February 2014. Optum Labs is a collaborative research center founded by Optum and the Mayo Clinic in 2013 to improve health care delivery and patient outcomes. Along with the University of Minnesota School of Nursing, Optum Labs’ other partners include the AARP and universities, life sciences, care delivery, and other health care organizations—“stakeholders committed to improving patient care by sharing in-
formation assets, technologies, tools and scientific expertise.” The research produced by Optum Lab partners “is linked to the clinical environment through prototyping and testing in Optum and partners’ care settings, with a goal of achieving knowledge that improves health care delivery and patient outcomes.”

Coordinated by clinical professor Tom Clancy, PhD, RN, the University of Minnesota’s health informaticians have proposed four major research projects that build on their expertise in data mining and highlight the breadth of interprofessionalism in the University’s health informatics research. The first project, led by Westra, builds on Westra, Delaney, and Monsen’s work using OASIS data and Omaha System intervention data to predict hospitalization rates and other health outcomes. This project, “The Relationship Between High Risk Medication Regimes and Rehospitalization of Older Adults,” will evaluate the relationship between polypharmacy, potentially inappropriate medications, and the Medication Regimen Complexity Index, and the cause of thirty-day hospital re-admissions.

The second project, “Identification of a Personalized Statin Treatment Plan to Maximize Treatment Benefits,” led by Chi, builds on his expertise utilizing data mining methods to investigate how a person’s individual characteristics influence the outcome of medical treatments and developing models of complicated medical events and converting them to decision support rules. In this project, Chi proposed to identify personalized treatment plans to minimize adverse events of patients prescribed statins. To optimize clinical value and the usability of personalized statin treatment plans, Chi proposed to customize the personalized statin treatment plan model to patients with a specific clinical problem to improve accuracy of adverse event prevention. To accommodate personalized statin treatment plan usage in different clinical settings, Chi proposed to produce different knowledge forms to personalized statin treatment plans.

The third proposed project, led by Clancy, plans to identify nonphysician primary care providers and determine the impact of new and emerging models of care and the contribution of individual roles, for example, advanced practice nurses and collective interprofessional teams on clinical and administrative outcomes. The fourth project, led by Pinar Karaca-Mandic, associate professor, Division of Health Policy and Management in the School of Public Health, will investigate how clinical evidence diffuses into clinical practice with a focus on the role of health care delivery organizations, physician networks, and markets. Karaca-Mandic’s research team proposes to study new clinical evidence from large randomized clinical trials that had breakthrough findings. Investigators will study randomized clinical trials that provided evidence for efficacy of new therapies as well as trials that provided evidence that previously used treatments are not efficacious. The invaluable contributions of the University of Minnesota’s health informaticians to the Optum Lab partnership is further evidence of the national significance of the University’s data mining research.

The ability of researchers to mine the growing amounts of health data available in EHRs provides them with unique opportunities to discover new knowledge that could lead to improved patient safety, improved health care, and reduced health care costs. Natural language processing (NLP) techniques are foundational to the ability of researchers to extract and use EHR data in clinical and translational research. As described earlier, practitioners of NLP study “problems inherent to the processing, manipulation and understanding of natural language,” with the aim of “making computers ‘understand’ statements previously written in human languages.”

The University of Minnesota’s history of research in NLP dates back to Christopher Chute’s work at the Mayo Clinic in the early 1990s and his key role in the NLM research training in the Medical Informatics Program. Genevieve B. Melton-Meaux, MS, MD, FACS, FASCRS (associate professor, Department of
Surgery; IHI core faculty; chief health information officer, Fairview Health Services and University of Minnesota Physicians), and Serguei Pakhomov, PhD (associate professor, Department of Pharmaceutical Care and Health Systems, College of Pharmacy, IHI affiliate faculty), who was an NLM fellow supervised by Chute from 2002 to 2003, both with national reputations in NLP, currently lead the University’s NLP research initiatives. They codirect IHI’s NLP/Information Extraction Program, which includes a team of investigators, postdoctoral researchers, programmers, and students who use NLP/information extraction to process, extract, and encode information from unstructured biomedical and clinical texts, including clinical texts from the EHR.\(^9\)

**Natural Language Processing and Clinical Data Extraction**

A major challenge confronting researchers using EHR data for clinical and translational research is that much of the detailed patient information is embedded in narrative text. This narrative text is composed of unstructured, nonstandardized terminology, which makes manual information extraction “a very time-consuming and costly process.”\(^9\) For several decades, researchers have developed techniques, including NLP, for processing free-text patient records; and since the late 1990s, several institutions have developed different NLP systems “to convert clinical narrative text into structured data that may then be used for other clinical applications and studies.”\(^9\) The process is far from simple. In 2011, Prakash Madkarni at Yale University, and colleagues enumerated the main “high-level” problems in NLP. First are spelling and grammatical errors, including incorrectly used homophones (words that sound identical but are spelled differently). Second is named entity recognition, or the location and classification of single elements of the text into predefined concepts in a vocabulary. Issues of word/phrase order variation, derivation, inflection, synonyms, and homographs (words that are spelled the same but have different meanings) make named entity recognition challenging. Third is word sense disambiguation (WSD), which involves determining the correct meaning of a homograph, acronym, abbreviation, symbols, or the appropriate sense or concept of an otherwise ambiguous word. Fourth is “inferring whether a named entity is present or absent, and quantifying that inference’s uncertainty.” Fifth is “determining relationships between entities or events, such as ‘treat,’ ‘causes,’ and ‘occurs with.’” And sixth is “making inferences from temporal expressions and temporal relations” to determine whether “something has occurred in the past or may occur in the future.”\(^9\) At the University of Minnesota, Chute, Pakhomov, and Melton-Meaux’s research using NLP has centered on at least four main areas: (1) identifying semantically similar and related terms in biomedical and clinical domains; (2) developing effective techniques for WSD of acronyms, abbreviations, and symbols in clinical documents; (3) information extraction from clinical documents such as operative reports; and (4) discovery of drug–drug interactions from the biomedical literature.\(^9\) For example, in 2010, Pakhomov, Melton-Meaux, along with Terrence Adam, RPh, MD, PhD (associate professor, Department of Pharmaceutical Care and Health Systems, College of Pharmacy; IHI core faculty), and other colleagues from the University of Minnesota published the results of a study that demonstrated that “the relationship between semantic similarity and relatedness” in biomedical terms “is that of unidirectional entailment—pairs of terms that are similar are also likely to be related but not vice versa.” The team also found “a tendency for higher relatedness relative to similarity scores for any given pair of terms.” Their results also suggested that “the semantic associations between clinical terms are largely independent of possible context.”\(^9\) Two years later, in 2012, Pakhomov, Melton-Meaux, and colleagues published the results of a study in
which they examined the relationship between semantic relatedness among medical concepts found in clinical reports and biomedical literature. As the team described, using the SemRep program, researchers can identify explicit and implicit semantic relations between various medical concepts within biomedical articles. Clinical documents such as clinical notes, however, “do not typically contain language that encodes the nature of the semantic relation.” Yet, they serve as “a rich source of empirical information on patient conditions and their treatment[,] including information on potential medication allergies, side effects and adverse effects.” As such, clinicians and researchers can “use clinical notes to find concepts that are strongly related to each other,” but may be unable to “determine the exact nature of the association from clinical documents.” In contrast, the biomedical literature does provide information on “relationships between concepts that have been ‘distilled’ through research.” Pakhomov, Melton-Meaux, and colleagues proposed that a “potential way to leverage the strengths of both clinical text and biomedical literature is by mining the strength of associations between medical concepts from clinical reports and using biomedical literature to determine if the association found in clinical data has been studied and, if so, what is the most likely type of relationship for the association.” This approach, they continued, could also “potentially help in targeting interesting clinically important associations . . . that have not been extensively examined before and may prove to have” clinical significance. Their exploratory study offered an initial test of this proposal by “investigating the relationship between unlabeled semantic relations extracted from clinical reports and labeled relations extracted from biomedical literature.” Their results, while preliminary, showed the “strong potential” of their method for determining the semantic relatedness between medical concepts in clinical reports.

Examples of Melton-Meaux and Pakhomov’s work developing techniques for WSD include a study published with Health Informatics PhD candidate, Sungrim Moon, MS, in 2012. Acronyms and abbreviations are widely used in electronic clinical notes, as they were historically in paper medical records, because they are time-savers. As Melton-Meaux, Pakhomov, and Moon described, “The process of understanding the precise meaning of a given acronym or abbreviation in texts is one of several key functions of automated medical [NLP] systems and is a special case of [WSD].” By improving acronym and abbreviation WSD methods, health informaticians can “enhance automated utilization of clinical texts to support diverse applications that rely on NLP.” In their study, they investigated a large group of clinical acronyms and abbreviations (500 examples each of 50 acronyms and 50 abbreviations) from their clinical notes corpus to understand issues related to practical clinical acronym and abbreviation WSD. They found that when “looking at window orientation and size, a symmetric window of ~40 words was found to have good performance with the left side of the window providing more valuable information compared to the right side.” Their study also demonstrated that “an SVM [support vector machine] classifier with a minimum 125 training samples were needed to achieve at least 90% accuracy for clinical WSD tasks.” The large dataset of acronyms and abbreviations studied, the examination of both window orientation and size, and “looking at the question about minimum training sample numbers with a systematic approach” distinguished Melton-Meaux, Pakhomov, and Moon’s investigation from earlier studies of clinical acronym and abbreviation WSD.

Like acronyms and abbreviations, symbols, which mostly consist of nonalphanumeric characters, often have ambiguous senses. Pakhomov, Melton-Meaux, Moon, and colleagues describe symbol disambiguation as an analogous problem to automatic WSD. As of 2011, “Neither the medical NLP nor computational linguistics literature had focused on symbol resolution to any large extent.” One exception in the
biomedical domain was that researchers had investigated the disambiguation of gene symbols from biomedical texts. In a pilot study published in 2011, Pakhomov, Melton-Meaux, Moon, and colleagues “selected four symbols (‘+’, ‘−’, ‘?’ , and ‘#’) and conducted a set of experiments for automated symbol sense disambiguation using clinical notes.” They investigated symbol senses “using the literature and annotations of a moderate-sized corpus [1,000 randomly selected instances within the corpus for each symbol], and then performed automated symbol disambiguation using three supervised machine-learning classification algorithms: Naïve Bayes, SVM, and Decision Tree classifiers.” Their research demonstrated that “non-alphanumeric symbol disambiguation is feasible, with good performance using standard form-based rules.” They noted though that the rules would “require some calibration for each symbol type with respect to window size for individual symbols.”

Another major area of focus of Pakhomov, Melton-Meaux, and Chute’s research has been information extraction from clinical documents. In 2008, for example, Chute and Pakhomov published the results of a study in which they and colleagues from the Mayo Clinic in Rochester, Minnesota, and Kaiser Permanente in Pasadena, California, investigated whether there was “agreement between patient-reported symptoms of chest pain, dyspnea and cough and the documentation of these symptoms by physicians in the electronic medical record.” The researchers compared the symptoms reported by 1,119 patients on provided information forms “to those identified with [NLP] of the text of clinical notes from care providers. Terms that represent the three symptoms were used to search clinical notes electronically with subsequent manual identification of the context (e.g., affirmative, negated, family history) in which they occur.” The team found “substantial discordance between patient reporting and care provider documentation of the symptoms.” As such, “the symptoms may complement each other and have implications for clinical studies and quality measurements that rely on the medical record for identification of symptoms.” For example, when recruiting participants with specific symptoms for clinical studies, “it may be necessary to use the information reported by patients on self-entry forms in addition to other sources such as clinical notes.”

More recently, Melton-Meaux, Pakhomov, and colleagues’ work extracting information from clinical documents has focused specifically on operative notes, where other researchers have paid less attention. Within an operative report, “the ‘procedure description’ section describes the details of what was observed and performed during the conduct of the procedure.” As opposed to other clinical notes, this section contains “a significant amount of description of actions performed during an operation.” To develop effective computerized NLP systems for operative reports that would enable accurate and effective information extraction from operative notes, researchers need to understand this text and address “the sublanguage domain-specific features of operative notes.” In a study published in 2012, Melton-Meaux, Pakhomov, and colleagues studied and characterized “actions contained in the ‘procedure description’ text of 362,310 operative notes”; utilized “knowledge sources in the linguistic and biomedical NLP fields for mapping actions,” and provided “a resource of procedure-specific actions for other NLP researchers.” The results of their study provided insights into the “language used by surgeons to communicate action events in the operating room” and an “understanding of the relative variability of action expressions.” This work laid the groundwork for the team’s subsequent work developing methodologies for information extraction from operative notes.

The following year, in 2013, Pakhomov, Melton-Meaux, and research developer, Yan Wang, MS, published on their development of “a set of Predicate Argument Structure (PAS) frames for surgical action
verbs to assist in the creation of an [information extraction] system to automatically extract details about the techniques, equipment, and operative steps from operative notes.” Based on an examination of randomly selected sample sentences from 3,000 laparoscopic cholecystectomy notes, they created PropBank-style PAS frames for the thirty top surgical action verbs. Pakhomov, Melton-Meaux, and Wang then evaluated the PAS frames on “sample sentences from operative notes of 6 other gastrointestinal surgical procedures.” The team’s results showed that “the PAS frames created with one type of surgery can successfully denote the usage of the same verbs in operative notes of broader surgical categories.” These findings suggested their tool could be used for “facilitating extraction of structured information from operative notes enabling surgical clinical research and surgical decision support.”

In addition to developing NLP techniques to support clinical research and clinical decision support, Melton-Meaux, Pakhomov, and Rui Zhang, PhD (assistant professor, Department of Surgery, clinical assistant professor and core faculty, IHI), also work in the relatively new field of translational informatics, which bridges the gap between biomedical research and clinical practice. Melton-Meaux, Pakhomov, and Zhang are leading a research program at the cutting edge of translational informatics that uses an NLP system to identify potential drug–drug interactions (DDIs) in a patient’s clinical EHR data based on knowledge transferred from the biomedical literature. DDIs are typically identified through three approaches that focus on identifying the target proteins involved in the metabolism of the interacting drugs: in vitro pharmacology experiments, in vivo clinical pharmacology studies, and pharmacoepidemiology studies. However, “these methods are limited by the need to focus on a small set of target proteins and drugs and are therefore, slow to elucidate an exhaustive set of DDIs while new drugs are continually added to the pharmacopeia. Because they depend on these methods of DDI discovery and anecdotal clinical report, current DDI databases do not include all the potential DDIs.” Pakhomov, Melton-Meaux, Zhang, and colleagues at the National Library of Medicine argued, however, that “some of these interactions may be indirectly derived from the scientific literature or drug-related documents through informatics methods.” The development of “a powerful literature-based discovery (LBD) tool that extract DDI information from biomedical literature,” they continued, “has the potential to significantly enhance patient care.”

In 2014, the team published the results of a study in which they used MetaMap—an NLP tool developed by the NLM that maps biomedical text to concepts in the Unified Medical Language System Metathesaurus—to map medication lists extracted from clinical data to Unified Medical Language System concepts for further extraction. They also used the NLM-developed SemRep, which is used to extract semantic relationships from the biomedical literature in the form of semantic predication. In their study they (1) extracted the personal medication list from clinical data and mapped to the United Medical Language System using MetaMap; (2) extracted “all semantic predications relevant to these medications and the genes and biological functions that they affect”; (3) normalized “gene names to approved gene symbols”; (4) discovered “all possible DDIs based on combinations of semantic predications according to pathway schemas”; (5) provided “potential unknown DDIs after human review and exclusion of known DDIs”; and (6) evaluated “semantic predications.” After checking drug pairs from the medication lists of each of twenty-two patients, the team found nineteen known and sixty-two unknown DDIs, demonstrating that “the use of structured knowledge in the form of relationships from the biomedical literature can support the discovery of potential [DDIs] occurring in patient clinical data.” As DDIs are a serious concern in clinical practice, Melton-Meaux, Pakhomov,
and Zhang’s work in this field has great potential to significantly improve the quality of patient care.

In addition to its strong history of research in natural language processing, the University of Minnesota has a long tradition of leading research in clinical informatics that begins with Donald Connelly’s work developing clinical information systems, Stanley Finkelstein’s collaborative work developing telehome monitoring systems, and Finkelstein and Stuart Speedie’s telehealth projects. Since joining the University of Minnesota in 2007, Terrence Adam, RPh, MD, PhD, has continued this tradition. Adam, in particular, is a leader in the development of clinical decision support systems.

**Clinical Decision Support Systems in Perioperative Medicine**

Clinical decision support (CDS) systems link patient data with an electronic knowledge base to generate information and suggestions that help health care providers make clinical decisions that will improve the care they deliver. Or as health informatics pioneer, Edward Shortliffe, MD, PhD, defined it in 1987 (see earlier), a “medical decision-support system is any computer program designed to help health professionals make clinical decisions.” That year, Shortliffe reflected that “After 25 years of research on medical-decision support systems, investigators have learned a great deal about the difficulties inherent in the task and the complex barriers to successful implementation of programs.” As Shortliffe’s reflection suggests, the research and development of CDS systems dates back to the 1960s.105 There are several types of CDS systems. For example, medication dosing support systems “support drug order decisions such as choosing a dose while adjusting it to the patient’s renal and hepatic functions.” Point-of-care alerts/reminders may show a DDI “or alert health staff of critical laboratory values.” Also, relevant information display systems, which are also referred to as dashboards, “may show patient specific information such as showing potassium levels [that doctors can consider] when ordering digoxin.” Donald Connelly developed clinical workstations for neonatal intensive care units in the 1980s and 1990s, which are another example of this type of CDS system. Expert systems “support physicians by offering complex decision support combining patient characteristics with other electronically available data.” Connelly’s development of an expert system for a platelet request system in the 1980s is an example of an expert system for clinical decision support; also, workflow support systems “encompass tools such as process templates such as for patients being transferred to the intensive care unit or medication reconciliation functions”;106 and finally, order entry systems, which include provider order entry (which offers templates with order sets, such as for the diagnosis and treatment of myocardial infarction) and electronic prescribing.107 Adam’s work in clinical decision support systems focuses, in particular, on the field of perioperative medicine.

Before a patient undergoes surgery, clinical guidelines require that practitioners perform a patient-specific risk assessment, which includes a patient pre-operative clinical assessment (within one month of the surgery) and review of the clinical literature. The perioperative risk assessment is intended to reduce the risk of surgical complications and to identify patients with risk factors associated with higher post-operative morbidity and mortality, thereby improving health outcomes and potentially reducing inpatient care costs. Risk assessments also help reduce delays to surgery and potential surgical cancellations due to the emergence of new medical problems during the month before surgery, which can have significant economic impacts on the hospital where the surgery is to be performed. The perioperative assessment, however, is challenging because “it is a multispecialty assessment with general practitioners, anesthesia, surgery, nursing, and pharmacy providing input into the sur-
gical planning process. In many cases the primary care provider completes the preoperative evaluation and communicates management recommendations to the surgical team for management in addressing or optimizing pre-existing or new medical problems.” Because of the “challenge of understanding and utilizing clinical preoperative needs,” Adam, Melton-Meaux, and Ahmad M. AbuSalah, MSc (Health Informatics PhD candidate), in 2012 called for the development of new clinical risk identification tools that could “better represent patient risk and facilitate procedural planning.” To this end, Adam, Melton-Meaux, and AbuSalah performed population-based analysis using discharge data from health care providers “to identify data elements affecting inpatient mortality, length of stay and disposition status for patients receiving spinal fusion surgery.” By constructing outcome predictive models they were able to identify “clinically significant variables” that affect patient outcomes, thereby indicating the feasibility of their “analytic framework and model.”

The following year, in 2013, Adam and colleagues introduced a different clinical decision support system for perioperative patient risk management, one that was patient-driven rather than clinician-driven. As Adam and his colleagues noted, an “important partner for the surgical team is the patient, who ultimately has the most at stake from the surgical benefits and potential complications.” While few tools existed for patients to self-identify surgical risks, such tools “could help patients become better informed of their surgical risk and address an important knowledge gap since patients have limited recall of the risks and benefits of surgical interventions after completing the pre-operative clinical workup.”

The team developed a cardiac risk tool—a twenty-five-question patient assessment tool—“to accurately assess and capture patient medical and surgical history, exercise tolerance, and cardiovascular risk perceptions.” They developed the instrument by “mapping the American Heart Association Guidelines for Pre-Operative Risk Assessment of Cardiac Complications of Non-Cardiac Surgery.” The team developed specific questions to “identify each of the six revised cardiac risk index factors” and established “a mapping algorithm . . . to generate a RCRI [Revised Cardiac Risk Index] score with expert provider review.” In addition to the objective cardiac risk factor assessment, the team also developed questions to “identify patient cardiac risk perception on a graded scale. These results were scored with a mapping algorithm to identify relative levels of risk perceived by the patients that reflected current clinical guidelines.” The team then evaluated the risk assessment tools on 309 patients who visited the preoperative medicine clinic in the Department of General Medicine at the Veterans Administration Medical Center in Minneapolis, Minnesota, from December 1, 2011, to February 28, 2013. At the conclusion of the study, Adam and his colleagues found that the “patient’s self-assessment of their perceived pre-operative cardiac risk had poor agreement with expert clinical providers. In contrast, the patient self-report of their primary cardiac risk factors showed substantial inter-rater reliability with the provider assessment. In addition, the patient self-reported risk data mapped well to the existed clinical standards of preoperative cardiac risk [RCRI].” As such, Adam and his colleagues concluded that because patients could adequately provide self-report data that could accurately estimate cardiac risk of surgical interventions, “the development of decision support tools with patient driven interfaces” had the potential to be used for preoperative cardiac assessment.

Adam’s research, like that of his health informatics colleagues, is transforming health care. In 2015, the University of Minnesota’s health informaticians are playing critical roles in developing the state of Minnesota’s health informatics infrastructure by designing, developing, and implementing new health information technologies that are facilitating health information exchange, better clinical decision making, and new knowledge discovery, and through the
ongoing telehealth programs, they are improving health care access and health care delivery in underserved communities.

**Transforming Research Through Health Informatics Expertise**

The expertise of the University of Minnesota’s health informaticians has both been enhanced by and leveraged by the University’s Clinical and Translational Science Institute (CTSI). The CTSI was established in 2009 and awarded a $51 million National Institutes of Health Clinical and Translational Science Award (CTSA) in 2011 (see chapter one). The CTSI, directed by Bruce Blazar, MD, creates “an adaptive, sustainable infrastructure to support clinical translational science at the University of Minnesota; foster[s] meaningful relationships and transparent interactions among” the University and its communities; and “train[s] and reward[s] interdisciplinary clinical translational science teams” at the University and its communities.111

From December 2010 through May 2015, Delaney served as associate director and led the biomedical informatics (BMI) core, one of the five cores that constitute the CTSI. In June 2015, Constantin Aliferis, MD, PhD, FACMI, was recruited to serve as director of the Institute for Health Informatics, as the first University of Minnesota chief research informatics officer, and as associate director of the CTSI’s BMI core.

Several of the CTSI’s core strategies integrate the research of the University of Minnesota’s health informaticians described in this chapter. One strategy is the “[i]nclusion of novel clinical data sources into the UMN-CDR [clinical data repository] to support home health and nursing research.” This builds upon Westra and Monsen’s research using the Omaha System and OASIS data sets, in particular Westra’s use of de-identified OASIS data from one million patients “to study the influence of wound, ostomy, and continence nurses on [patient] outcomes,” and Monsen’s leadership of the Omaha System Partnership for Knowledge Discovery and Health Care Quality. This partnership for knowledge discovery is a “team skilled in outcomes research methods and includes affiliate members from five countries who contribute de-identified clinical data to an international Omaha System data warehouse housed” at the School of Nursing. The partnership also focuses on the “dissemination and translation of evidence to practice settings through the development of standardized workflows that can be adopted within any EHR.”112

A third CTSI strategy that builds on the University’s health informatics expertise is improving tools for biomedical informatics research. This includes NLP tools, led by Pakhomov and Melton-Meaux, and knowledge discovery in databases involving data mining analytic techniques, which includes the work of Delaney, Westra, and Monsen.113

A major infrastructure initiative, which builds on the expertise of the University’s health informaticians to enable the “secure, timely capture and exchange of [biomedical and health] information,” includes the Academic Health Center Information Exchange (AHC IE). Led by Delaney, and with well over sixty engaged interprofessional researchers including Connelly, Melton-Meaux, Westra, and Speedie, who contribute their expertise in ontology, terminology, and NLP; clinical data repository; databases and data mining; data privacy and linkage; and biomedical informatics, the AHC IE is a fully automated platform of systems, applications, databases, and analytical tools to support the researchers and users in operations of research and evaluation of clinical outcomes for all of the health sciences, which enables information exchange among databases in the University of Minnesota, Academic Health Center, Fairview Health Services, University of Minnesota Physicians, and as feasible, outside the University.

The expanded informatics support for researchers is evident through the AHC IE’s core tools and other related additional core tools, which include
(1) Enterprise OnCore, a comprehensive web-based clinical trial management system “that offers clinical-trial lifecycle management, study participant and safety management, and electronic data capture and reporting through its core module”; 114 (2) Experts@Minnesota, the University of Minnesota’s research networking and expertise system, which “allows anyone to browse or search for a researcher’s distinctive expertise, based on publication history, and increases the capacity to identify collaborators and make connections between scholars within and external to the University of Minnesota”; 115 (3) ResearchMatch, which is “a recruitment tool that helps connect researchers and willing volunteers through a free, secure, web-based registry”; 116 (4) REDCap (Research Electronic Data Capture), which is a “secure web application designed to support data capture for research”; 117 and (5) analytical and knowledge discovery tools, among others. 118

The AHC IE represents a large and ongoing organizational investment by the CTSI, the AHC, and the University and its core clinical partners Fairview Health Services and University of Minnesota Physicians. The investment in the AHC IE coupled with other commitments for informatics leadership, faculty, and professionals represents the largest commitment to health informatics in the history of the University of Minnesota. The AHC IE is governed by the AHC, with Brooks Jackson, MD, MBA (vice president for health sciences and dean of the Medical School), and Delaney co-chairing the AHC IE Executive Leadership and Governance Committee in partnership with the CTSI-BMI leadership. It is a model of interprofessional engagement across the AHC and Fairview Health Services, connecting researchers in areas such as cancer, cardiovascular disease, diabetes, infectious disease, pediatrics, and the brain sciences.

The AHC IE relies on a deep partnership with AHC Information Systems, directed by Edward Deegan, particularly its research data management team led by Justin Dale. Dale initially chaired the AHC IE Architecture and Solutions Committee, which is responsible for “designing, planning, and establishing innovations to the AHC IE architecture to achieve the ongoing and successful development of the AHC IE.” Dale’s research data management team members Supreet Kathpalia and Tim Meyer also serve on the Architecture and Solutions Committee. Dale has been instrumental in all aspects of the AHC IE, serving also on the AHC IE’s Informatics Committee, Researcher and User Committee, and Governance and Security Committee. Moreover he has supported the evolution of the Architecture and Solutions Committee to merge with the Informatics Committee, now cochaired by Dale, Westra, and Speedie. The Governance and Security Committee, led in 2015 by Lori Ketola, University of Minnesota chief health information compliance officer and director of health information privacy and compliance, has established exemplary governance principles supporting data security and data sharing. The Minnesota Supercomputing Institute has also been a critical partner facilitated by Jorge Vinals, director of the Minnesota Supercomputing Institute, with initial engagement by Anne-Françoise Lamblin, program director of research informatics support systems at the Minnesota Supercomputing Institute. 119

The infrastructure, resources, and governance provided by the AHC IE was key to the CTSI-BMI core being awarded a $324,455 grant (Delaney, site principal investigator) from the National Institutes of Health’s National Center for Advancing Translational Sciences Accrual to Clinical Trials Project in 2014. The project, which was launched in September 2014 to overcome clinical trial roadblocks, creates a network of up to thirteen sites from the CTSA consortium to accelerate participant accrual to the nation’s highest priority clinical trials. To achieve this goal, the project takes advantage of the “widespread implementation of electronic health records and the extensive informatics and regulatory expertise within the CTSA consortium.” 120 In particular, the initiative “builds
on existing platforms (i2b2/SHRINE) and operating models to create a ‘federated’ network with common standards, data terminology and shared sources.”

In February 2015, Steven Reis, MD, director of the University of Pittsburgh’s CTSA-funded Clinical and Translational Science Institute—also a site of the National Center for Advancing Translational Sciences Accrual to Clinical Trials Project—provided an update on the project. For the previous several months, project investigators had focused on “data harmonization (using the same term for the same type of data) across EHR platforms, technical needs assessment and implementation, regulatory approaches to ensure compliance with protocols with data access and participant contact, and governance development to establish proper agreements among institutions.” As of February 2015, all thirteen of the CTSA “hubs” in the first phase of the accrual to clinical trials project had “implemented the technical platform,” all thirteen sites had “received institutional review board approval,” and eight more “hubs” had been selected for the second phase of the project. Project investigators planned “to include more hubs and coordinate with PCORNet [the National Patient-Centered Clinical Research Network] to synergize the two national efforts.”

PCORNet is an initiative of the Patient-Centered Outcomes Research Initiative (PCORI), an independent, nonprofit, nongovernmental organization located in Washington D.C., with a mandate “to improve the quality and relevance of evidence available to help patients, caregivers, clinicians, employers, insurers, and policymakers make informed health decisions.” PCORI achieves this by funding comparative clinical effectiveness research and by supporting “work that will improve the methods used to conduct such studies.”

PCORI established PCORNet late in 2013 “to improve the nation’s capacity to conduct comparative effectiveness research by creating a large, highly representative network for conducting clinical outcomes research.”

The CTSI and the growth of health informatics expertise and infrastructure bolstered the growth of the University of Minnesota’s collaborative research networks across the United States to further support research. In 2014, Biomedical Informatics was awarded a $485,660 grant (Delaney, site principal investigator) from PCORI to be one of the sites creating the Great Plains Collaborative. The Great Plains Collaborative is a PCORNet clinical research data network of ten leading medical centers in Iowa, Kansas, Minnesota, Missouri, Nebraska, Texas, and Wisconsin that is “committed to a shared vision of improving healthcare delivery through ongoing learning, adoption of evidence-based practices, and active research dissemination.” The Great Plains Collaborative builds on: (1) strong research programs at its sites; (2) “existing community engagement, informatics infrastructures and data warehouses” developed through the CTSA initiative; (3) “extensive expertise with commercial EHR systems and terminology standardization; and (4) “strong working relationships between investigators and healthcare system information technology departments.”

At the University of Minnesota site, prominent researchers have partnered with health informaticians to create innovative methods and expand research capacities in key clinical areas, including childhood obesity (Jayne Fulkerson, PhD, associate professor, School of Nursing, and Aaron Kelly, PhD, associate professor of pediatrics and medicine, Medical School); amyotrophic lateral sclerosis (David Walk, MD, associate professor of neurology, Medical School); and breast cancer (Douglas Yee, MD, professor of medicine and pharmacology, Medical School and Director of the Masonic Cancer Center, and Ann Blaes, MD, assistant professor of medicine, Medical School).

Across the Great Plains Collaborative’s ten sites, its “informatics team has expertise in commercial EHR development and project management, clinical decision support, and standard terminology development.” The Great Plains Collaborative thus capitalizes on the University of Minnesota’s information exchange infrastructure provided by the AHC IE and Delaney, Westra, Speedie, and Chute’s extensive...
background and expertise in the development of stand-
dardized terminologies and data exchange.

The AHC IE has transformed health informatics
at the University of Minnesota. The University of
Minnesota’s health informaticians serve as “bridge
builders” constructing and maintaining the infra-
structure that supports scientists and clinicians using
informatics tools to improve patient care. They develop
the informatics tools that are essential for clinical
translational science. And the University’s health in-
formaticians are “build[ing] bridges to healthy com-
munities” by applying research to improve health in
communities.\textsuperscript{127}

From the founding of health informatics at the Uni-
versity of Minnesota in 1965 through its fifty-year
anniversary in 2015, the University’s health infor-
maticians have been leaders in health informatics
research. Since 2006, building on the cutting-edge
research of the previous forty years, they have es-
lished national and international reputations
developing the health informatics infrastructure
and producing tools to facilitate health information
exchange, better clinical decision making, and new
knowledge discovery. The University of Minnesota’s
health informaticians have responded to the Institute
of Medicine’s 2006 call for a learning health care
system built, in part, on clinical decision support
systems, interoperable EHRs, and tools for data-
base linkage, mining, and use.\textsuperscript{128} In the process the
University’s health informaticians have addressed
major issues in national health care policy and con-
tributed to the improvement of health care for the
state of Minnesota and the nation.
Bonnie Westra, PhD, RN, FAAN, FACMI
source: University of Minnesota

Karen Monsen, PhD, RN, FAAN
source: University of Minnesota

Chih-Lin Chi, PhD, MBA
source: University of Minnesota
Natural Language Processing/Information Extraction Program c. 2014
From L-R: Yan Wang, Genevieve Melton-Meaux, Lindsay Bork, Rui Zhang, Elizabeth Lindemann, Serguei Pakhomov, Reed McEwan, Robert Bill, and Benjamin Knoll

source: University of Minnesota

Genevieve Melton-Meaux, MS, MD, FACS, FASCRS

source: University of Minnesota
For fifty years, the University of Minnesota has been a center of research and educational innovation in biomedical and health informatics. As the previous four chapters have shown, the University of Minnesota’s programs in biomedical computing, health computer sciences, and health informatics have served as the academic home for professional, graduate, and postgraduate education in biomedical health informatics. Those who have been trained in biomedical health informatics have come from and gone on to practice in diverse fields including dentistry, medicine, nursing, pharmacy, public health, veterinary medicine, computer science, library science, and management sciences as well as in roles as health system and policy leaders. Throughout its fifty-year history, the health informatics program at the University of Minnesota has developed strong interprofessional research teams that engage biomedical health informatics for strengthening the future of health and health care and it has fostered engagement with the community and international partners in applying biomedical informatics to improve health and health care. In doing so, the health informatics program has led the interprofessional discovery, application, and teaching of health information sciences to improve the health of individuals and communities.

The fiftieth anniversary of health informatics at the University of Minnesota is not only a time for reflection on the past, it is also a time to look to what the future will hold for health informatics at the University. This is an exciting time for biomedical health informatics at the University of Minnesota. In June 2015, Constantin Aliferis, MD, PhD, FACMI, was recruited to serve as director of the Institute for Health Informatics (IHI), and the first University of Minnesota chief research informatics officer, heading the Clinical and Translational Institute (CTSI) Biomedical Informatics (BMI) program. At the University of Minnesota, Aliferis will also build and lead a Big Data analytics unit for MHealth (collectively the University of Minnesota Academic Health Center [AHC], Fairview Health Systems, and University of...
Minnesota Physicians) and carry the title of chief analytics officer.

This is also an exciting time for the field of biomedical health informatics. For example, the federal and Minnesota state mandated date for implementation of electronic health records was January 1, 2015, which guarantees continuing massive infusions of clinical data available for storage, analysis, and research, and the vast amounts of data being generated from the “-omics” (e.g., genomics, proteomics, microbiomics) that will need to be analyzed and assessed for clinical utility, will provide informaticians with an array of research opportunities that are of national policy significance. Recent national policy initiatives have included the 2008 President’s Council of Advisors on Science and Technology report, Priorities for Personalized Medicine and the Obama administration’s “Big Data Research and Development Initiative,” launched in 2012 (discussed below). This chapter considers the future of biomedical health informatics at the University of Minnesota and how that future is positioned to drive key innovation within the evolving field of biomedical health informatics.

Aliferis’ arrival at the University of Minnesota reflected the substantial commitment made by the University and the AHC to expand health informatics and utilize health informatics expertise to further transform the clinical research enterprise at the University of Minnesota and clinical delivery through MHealth along with national expansion through collaborations such as the Patient-Care Outcomes Institute–funded Great Plains Collaborative and the National Center for Advancing Translational Sciences Accrual to Clinical Trials Project (see chapter four). Aliferis brings to the University of Minnesota extensive experience in pioneering health informatics research and technology development, health informatics education, and national leadership.

Aliferis joined the University of Minnesota from New York University (NYU) where from 2008 to 2015 he was the founding director of the NYU Center for Health Informatics and Bioinformatics, and served as director of the biomedical informatics cores of NYU Clinical and Translational Science Institute and the NYU Cancer Center. He also had a number of other academic and leadership roles at NYU: scientific director of the Best Practices Integrative Informatics Consultation Service; scientific director of the NYU Langone Medical Center High Performance Computing Facility; founding director of the NYU PhD Training Program in Biomedical Informatics and of the terminal MS program in biomedical informatics; and director of the Molecular Signatures Laboratory. Aliferis also held appointments as associate professor in NYU’s departments of pathology and computational biology and data science. Prior to joining NYU, Aliferis had been recruited to Vanderbilt University in Nashville, Tennessee, in 2000 by Randy Miller, MD, and William W. Stead, MD, to serve as founding director of Vanderbilt University’s MS/PhD program in biomedical informatics. From 2001 to 2008, Aliferis served as founding director of Vanderbilt University’s Discovery Systems Laboratory, and was faculty in biomedical informatics, computer science, biostatistics, and cancer biology.

Aliferis brings to the University of Minnesota expertise in informatics methodologies—machine learning and Big Data analytics (data science), and applied informatics. On the methodological level, Aliferis’ research has “focused quite a bit on what’s known as Markov Blanket induction, which is a particular family of techniques for dealing with very, very large and high-dimensional datasets to figure out what’s the smallest set of information that one can extract and be able to do diagnosis and prognosis and, also, to learn about the causal structure of the process that generates the data.”14 In 2001, while at Vanderbilt University, Aliferis had launched the Discovery Systems Laboratory, “which was like a small division . . . because it had also a few faculty
in it and a number of students and staff.” The goal of the laboratory “was to develop next generation algorithms for Big Data analytics, both on the causal side of things and the predictive modeling side of things.” Predictive modeling is an invaluable tool for diagnosis, forecasting, classification, and anticipation of the behavior of a system of change; causal modeling is important for understanding what interventions can be made to change the behavior of the system. As Aliferis recalled, “We were very, very lucky because we were able to do some breakthrough discoveries that were considered very important and at the same time very hard to achieve at the time.”

In 2003, for example, Aliferis’ team introduced a “novel, sound, sample-efficient, and highly-scalable algorithm for variable selection for classification, regression and prediction called HITON.” The algorithm worked “by inducing the Markov Blanket of a variable to be classified or predicted.” To empirically evaluate HITON, Aliferis’ team applied HITON to a wide variety of biomedical tasks with different characteristics that generated large data sets. The first task was drug discovery, “specifically classification of biomolecules as binding to thrombin (hence having potential or not as anticlotting agents) on the basis of molecular structural properties.” The second task was “clinical diagnosis of arrhythmia into 8 possible disease categories on the basis of clinical and EKG [electrocardiogram] data.” The third task was “categorization of text (Medline documents) from the OHSUMED corpus (Joachims version) as relevant to neonatal diseases or not.” The fourth task was “diagnosis of squamus [sic] vs. adenocarcinoma in patients with lung cancer using oligonucleotide gene expression array data.” The fifth task was “diagnosis of prostate cancer from analysis of mass spectrometry signal peaks obtained from human sera.” The results of this early study demonstrated that (i) HITON reduced “the number of variables in the prediction models by three orders of magnitude relative to the original variable set while improving or maintaining accuracy”; and (2) HITON outperformed “the baseline algorithm by selecting more than two orders-of-magnitude smaller variable sets than the baselines, in the selected tasks and datasets.” Before Aliferis’ team introduced the HITON algorithm, the best algorithms available were either heuristic and therefore not accurate or exact but not scalable. The HITON algorithm was the first Markov Boundary discovery algorithm that was scalable, accurate, and sample-efficient. Between 2003 and 2014, Aliferis and colleagues introduced subsequent generations of the algorithms that had additional capabilities that included learning local causal neighborhoods (direct causes and direct effects) in a highly scalable and sample-efficient manner; learning very large causal networks accurately and efficiently; modeling all models in the equivalence class optimally accurate and nonreducible predictor models; handling hidden variables in observational discovery settings; and minimizing the number of experiments in experimental discovery settings. In 2010, Aliferis and colleagues introduced the algorithmic framework Generalized Local Learning that could be used for “learning local causal structure around target variables of interest in the form of direct causes/effects and Markov blankets applicable to very large data sets with relatively small samples.” The framework described how one could develop an infinity of algorithms for these goals and guaranteed their correctness as long as a few simple rules were followed by algorithm designers. Utilizing the Generalized Local Learning framework, researchers could use the selected feature sets for causal discovery and classification.

Aliferis’ methodological work has also included the development of “automated analysis systems known as auto modelers or intelligent front ends to analytics, also work in support vector machines, and Bayesian network methods for causal structure discovery, and for classification or regression.” These auto modelers and intelligent analysis systems address the problem of the limited reproducibility of modern complex
biomedical research due in part to the numerous errors that can occur during the analysis of modern high throughput molecular assay data and other high dimensional Big Data. In 2005, for example, Aliferis and colleagues introduced “a computer system for [a] powerful and reliable cancer diagnostic model creation based on microarray data.” In order to “equip the system with the optimum combination of classifier, gene selection and cross-validation methods,” Aliferis’ team had “performed a systematic and comprehensive evaluation of several major algorithms for multicategory classification, several gene selection methods, multiple ensemble classifier methods and two-cross validation designs using 11 datasets spanning 74 diagnosis categories and 41 cancer types and 12 normal tissue groups.” Their analysis identified multicategory support vector machines as “the most effective classifiers in performing accurate cancer diagnosis from gene expression data.” Furthermore, they determined that gene selection techniques could “significantly improve the classification performance” of both multicategory support vector machines and nonmulticategory support vector machines, and that ensemble classifiers “do not generally improve performance of the best non-ensemble models.” Based on these results, the team had developed a software system, GEMS (Gene Expression Model Selector), “that automates high-quality model construction and enforces sound optimization and performance estimation procedures.” It was the “first such system to be informed by a rigorous comparative analysis of the available algorithms and datasets.” Many large scale evaluations of predictive and causal algorithms and complex analysis protocols followed over the years and informed the best ways to perform complex Big Data analytics in several key types of analysis and with all types of clinical, molecular, and unstructured data (text, bibliographies, network, and digital content).

On the application level, Aliferis has collaborated with colleagues from a variety of disciplines “to build models and do analysis and discovery in many disease domains including various cancers, pneumonia, osteoarthritis, rheumatoid arthritis, infant sepsis, acute respiratory distress syndrome, psoriasis, respiratory infections, and also in a variety of application domains such as microbiomics, cancer therapeutics, [and] risk modeling for patients.” While a PhD student in biomedical informatics at the University of Pittsburgh in Pennsylvania, Aliferis was involved in a project that was a collaboration between two laboratories at the University of Pittsburgh and two laboratories at Carnegie Mellon University in Pittsburgh. The goal of the project “was to contribute to the Pneumonia PORT [Patient Outcomes Research Team] project, which was a set of studies around creating risk models for community-wide pneumonia, dire outcomes, specifically to predict the risk for dying within one year of discharge [from the hospital].” Working with a team that included leading researchers in biomedical informatics, computational biology, and machine learning, such as Gregory F. Cooper, MD, PhD; Tom M. Mitchell, PhD; and Bruce Buchanan, PhD; Aliferis contributed to the development of computer models—based on statistical and machine learning methods—for predicting mortality of hospital patients with pneumonia from their initial presentation. The researchers concluded that clinicians might be able to use the accurate prediction models to make decisions about where to treat patients with pneumonia—in the hospital or at home.

The Pneumonia PORT models, Aliferis noted, “are being used very widely today in the United States and they’re improving the quality of care for patients and the reduced cost [of care] is just dramatic.” In another example of Aliferis’ work applying informatics, he has developed methods in scientometrics, information retrieval, and Internet filtering. This has involved constructing “computer systems that can scan the [biomedical] literature to find the highest quality papers, to extract their contents, [and] to predict their future citations.” In 2003, for example,
Aliferis and Yindalon Aphinyanaphongs, a medical and PhD student at Vanderbilt University (and subsequently faculty at NYU), published on research that demonstrated the effectiveness of using machine learning methods—Naïve Bayes, and linear and polynomial support vector machines—to identify content-specific and high quality PubMed articles. The models they built based on the machine learning methods outperformed (with the polynomial support vector machine model performing the best) “the Boolean based PubMed clinical query filters” currently used for finding high quality information in PubMed. The research, which was further developed and evaluated, showed that machine learning methods could be used to “automatically build models for retrieving high-quality, content-specific articles using inclusion or citation by the ACP [American College of Physicians] Journal Club as a gold standard in a given time period in internal medicine that perform better than the 1994 PubMed clinical query filters.”

Aliferis’ team pioneered innovative machine learning models that could also predict citation counts and correct for biased scientometric measures such as impact factors. In 2008, for example, Aliferis and Lawrence D. Fu, a PhD student at Vanderbilt University (and subsequently faculty at NYU and director of predictive analytics at Everyday Health Inc.), introduced models based on machine learning methods that could “accurately predict citation counts of biomedical publications within a deep horizon of ten years using only predictive information [content-based and bibliometric features] available at publication time.” These models are important for information retrieval, library science, and for enabling researchers to evaluate the academic enterprise using objective and quantitative approaches.

Aliferis and Aphinyanaphongs have also used machine learning methods to develop models “to scan the health web to find what pages are providing validated and up to date medical advice to patients and their proxies as compared to websites that are pure quackery or out of date and dangerous basically for public health.” As Aphinyanaphongs, MD, PhD, and Aliferis (both then at NYU) and colleagues described in 2013, research studies had documented that 65 percent of cancer patients searched the Internet for unproven treatments, 12 percent purchased unconventional therapies online, and 83 percent had used at least one unproven treatment. Published analysis using “a specially formulated search query for non-mainstream cancer treatments” of the top websites identified by search engines “revealed that 10% of the samples contain potentially harmful or definitely harmful material.” Past efforts to identify web page quality consisted of manual approaches and automated approaches. Manual approaches included “(1) patient-applied checklists for identifying characteristics of webpages such as author attribution, (2) organizational certification by quality organizations that provide a seal of approval to high quality webpages, (3) manual review by trained searchers, and (4) public vigilance where patients submit potential fraudulent sites.” However, “none of these checklists or certifications was widely adopted.” A few researchers, including those on Aliferis’ team, had developed automated approaches that “applied machine learning to [assign] reliability scores to web health documents.” But this work had “focused exclusively on the effectiveness of text categorization for judging the reliability of health web pages.”

In their 2013 study, Aliferis’ team used the machine learning models they had previously developed to effectively identify unproven cancer treatments and deployed them on the Internet. Through this study they identified “the practical requirements and corresponding steps toward applying machine learning models to the web.” In doing so, they demonstrated that their “model showed excellent performance in identifying web pages that make unproven claims for other treatments not used to train the model. In practice, this result suggests that a very small subset of un-proven cancer treatments is sufficient to build a
model to identify unproven treatments on the web.” (Emphasis in original.) Their study also showed that “Even though there are distinct differences between types of unproven treatments and the web sites that promote them, there is a commonality in the word content of unproven treatments that are learnable.” As such, “unproven treatments use distinct language to market their claims and this language is learnable.” (Emphasis in original.) Finally, their study showed that “through distributed parallelization and state of the art feature selection, it is possible to prepare the corpora and build and apply models with large scalability.” (Emphasis in original.)

Aliferis’ other work on the application level has included a study published in 2010 that used acute respiratory viral challenge microarray data to develop a molecular signature that for the first time could accurately differentiate between uninfected subjects before viral exposure and the asymptomatic subjects after exposure. This research had both clinical and public health implications. For many years, clinicians did not “have practical means to make a timely and accurate diagnosis of acute viral respiratory infections,” the cause of significant morbidity and mortality in the United States and globally, which led clinicians to “resort to unnecessary antibiotic treatment, which increases healthcare costs and facilitates development of antibiotic resistance.” Although a recent study had proposed a “novel approach . . . for the diagnosis of acute respiratory infections based on microarray gene expression profiles from peripheral blood samples of human subjects,” that approach had failed to distinguish between the gene expression profiles of subjects before viral inoculation from the “profiles of subjects who received viral challenge but remained asymptomatic and uninfected.” The implications of Aliferis and his colleagues’ work was that it would lead to better understanding of host immune response to viral infection, and that with a “more detailed understanding of molecular factors that enable some exposed subjects to avoid infection or remain asymptomatic after the exposure while others demonstrate clinical illness could provide targets for development of more effective vaccines for antiviral treatments.”

Aliferis’ work in the domain of microbiomics has included developing molecular signatures or profiles of the chronic inflammatory skin disease psoriasis using microbiomic data from the skin. The research of Aliferis’ team was part of the National Institutes of Health Common Fund Human Microbiome Project. Established in 2008, the Human Microbiome Project is a collection of all the microorganisms living in association with the human body “with the mission of generating resources that would enable the comprehensive characterization of the human microbiome and analysis of its role in human health and disease.” The results of Aliferis’ team, which were published in 2013, contributed to this mission by demonstrating the feasibility of developing “accurate molecular signatures for the diagnosis of psoriasis from microbiomic data.” This so-called molecular profiling is a technique “for doing advanced diagnosis or prognostication about the outcome of the disease without treatment and post treatment”; it is one way of doing personalized medicine.

Another recent example of Aliferis’ research in the field of applied clinical informatics centers on the development of predictive models—using machine learning algorithms—for late-onset neonatal sepsis using “off-the-shelf medical data and electronic medical records (EMRs).” Specifically, Aliferis and colleagues used all laboratory, clinical, and microbiology data available in the EMR of 299 infants admitted to the neonatal intensive care unit of the Monroe Carell Jr. Children’s Hospital at Vanderbilt University and evaluated for late-onset neonatal sepsis from January 2006 through June 2007. After merging into a single data set the information in the records from the antibiotics, microbiology, laboratory, and neonatal intensive care unit nursing documentation, the team applied machine learning methods to predict the sepsis diagnosis. They then compared the “sensitiv-
ity, specificity, positive predictive value and negative predictive value of sepsis treatment of physicians with the prediction models generated by the machine learning algorithms.” Aliferis and colleagues found that the treatment sensitivity of all nine machine learning algorithms and the specificity of eight of the nine “exceeded that of the physician when [blood] culture-negative sepsis was included. When [blood] culture-positive sepsis was excluded both sensitivity and specificity exceeded that of the physician for all the ML [machine learning] algorithms.” These results were clinically significant: neonatal sepsis represented a significant cause of mortality in neonatal intensive care units (20 percent), and current methods for diagnosing neonatal sepsis were problematic, including an 18 percent false-negative rate of positive blood cultures. As such, whenever clinicians suspected infants admitted to the neonatal intensive care units might have neonatal sepsis, the infants would have their blood drawn and they would be started on antibiotics. On average, Aliferis and colleagues noted, “for every culture-positive sepsis result an additional 11–23 infants receive antibiotic treatments contributing to antibiotic resistance in the community and increased healthcare costs.” The predictive models developed by Aliferis and colleagues would enable early prediction of a sepsis diagnosis with targeted antibiotic therapy, which “could be effective in reducing neonatal mortality, bringing down healthcare costs and . . . likely . . . lower rates of bacterial resistance to antibiotics in the community.”

To date, Aliferis’ research has spanned cancer genomics, microbiomics, and proteomics, and contributed to discoveries in the treatment and prevention of diverse diseases that include pneumonia, infectious diseases, psoriasis, and sepsis, as well as lung cancer, melanoma, osteoarthritis, rheumatoid arthritis, and stroke. With his colleagues he has invented algorithmic methods for causal and predictive discoveries (for which they have been awarded five U.S. patents and have an additional sixteen patents pending or pending provisional), such as for determining how and why humans develop health problems, and for predicting when and to whom such problems will occur in the future. His algorithms have the capacity to analyze Big Data—very large or complex data sets—to identify genetic biomarkers and drug targets and to construct molecular profiles crucial for the development of precision and personalized medicine. Aliferis thus exemplifies the interdisciplinarity, interprofessionalism, and innovativeness of cutting-edge biomedical health informatics research, and brings leadership, a national and international reputation, and expertise in research domains at the forefront of a new era in biomedical and health informatics.

Since Connie Delaney PhD, RN, FAAN, FACMI (dean, School of Nursing, former acting director, IHI, and former director, CTSI-Biomedical Informatics), was appointed acting director of the IHI in late December 2010, a position she held while also serving as dean of the University’s School of Nursing, it had been a priority of Delaney, Bruce Blazar, MD (director of the CTSI), and the AHC leadership to recruit a new IHI director able to focus solely on the work of the IHI and the University’s biomedical and health informatics needs. As Blazar reflected on Aliferis’ recruitment to the University of Minnesota: “It’s really important to have somebody full time who is going to devote their attention to the widespread importance and requirements for the Institute for Health Informatics, for being a chief research informatics officer, for engaging with MHealth, Fairview, the University at large, the Academic Health Center, investigators, and for recruiting new faculty.”

As Aliferis plans for the future of health informatics at the University of Minnesota, he sees two major areas in health care where biomedical health informatics will be playing a lead role. Informatics is “absolutely essential and critical” to (1) the field of personalized medicine, what he sees as “the new human genome project, the new ‘race to the moon’”; and (2) Big Data and healthcare analytics—the use
of “Big Data approaches and, in general, data decision making and the reorganization of healthcare to achieve the goals of reduced costs, increased quality, improved access, and population wellness and health. As amazing as the past contributions in informatics have been,” Aliferis asserted, “the new ones are going to be even bigger.”

Personalized medicine and Big Data and health care analytics are the focus of national health policy. In 2008, for example, the President’s Council of Advisors on Science and Technology issued a report, Priorities for Personalized Medicine, which called for significant “public and private sector action to facilitate the development and introduction of [personalized medicine] into clinical medicine.” In 2012, the Obama administration announced a Big Data research and development initiative that promised “to help solve some of the Nation’s most pressing challenges” by “improving our ability to extract knowledge and insights from large and complex collections of digital data.” As part of the initiative, six federal departments and agencies, including the National Science Foundation and the National Institutes of Health, “announced more than $200 million in new commitments that, together, promise to greatly improve the tools and techniques needed to access, organize, and glean discoveries from huge volumes of digital data.”

This led the National Institutes of Health to launch the Big Data to Knowledge program in 2013. The Big Data to Knowledge program funds research and training activities that support the use of Big Data to enhance biomedical research and discovery. In particular, the goals of the program are to enhance the utility of biomedical Big Data to (1) “facilitate broad use of biomedical digital assets by making them discoverable, accessible, and citable”; (2) “conduct research and develop the methods, software, and tools needed to analyze biomedical Big Data”; (3) “enhance training in the development and use of methods and tools necessary for biomedical Big Data science”; and (4) “support a data ecosystem that accelerates discovery as part of a digital enterprise.”

Two years later, in 2014, President Barack H. Obama asked his secretary of commerce, Penny Pritzker, secretary of energy, Ernest J. Moniz, director of science and technology policy, John Holdren, and director of the national economic council and counselor to the president, John Podesta, to conduct a ninety-day study examining “how Big Data will transform the way we live and work and alter relationships between government, citizens, businesses, and consumers,” including the potential for Big Data to improve health care. In this regard, the reviewers identified three main areas in which Big Data and Big Data analytics could improve both the quality and cost of health care: (1) identifying “disease, exercise, preventive care, and other lifestyle factors that can help keep people from having to seek care from a doctor”; (2) helping to identify “clinical treatments, prescriptions drugs, and public health interventions that may not appear to be effective in smaller samples, across broad populations, or using traditional research methods”; and (3) ensuring “professionals who treat patients have strong performance records and are reimbursed on the quality of patient outcomes rather than the quantity of care delivered.” In order to secure these benefits, the reviewers concluded, the health care data privacy framework would need to be updated to ensure that all health information, regardless of its source, is granted an appropriate level of privacy protection, and “the nation” would need “to adopt universal standards and an architecture that will facilitate controlled access to information across many different types of records.”

The domains of personalized medicine and Big Data analytics intersect in the field of genomic medicine. As Naiem Issa and colleagues observed in 2014, “We are in the era of the ‘-omics’, wherein an individual’s genomic, transcriptome, proteome and metabolome can be scrutinized to the finest resolution to paint a personalized biochemical fingerprint that
enables tailored treatments, prognoses, risk factors, etc.\textsuperscript{30} Research in these and other "omics sciences" is, as Ivan Merelli, PhD, and colleagues reflected that same year, generating vast amounts of Big Data that biomedical informaticians are being tasked with analyzing and interpreting with the goal of better understanding diseases and the "development of better and personalized diagnostics and therapeutics."\textsuperscript{31} This data-driven medicine, as opposed to hypothesis-driven medicine, as described by Fabricio F. Costa, PhD, in 2014, "will facilitate the discovery of new treatment based on multimodel molecular measurements on patients and on learning from the trends in differential diagnosis, prognosis and prescription adverse effects from available clinical databases"; the mining of data from patients' EHRs from which "personalized therapies will enable the application of targeted treatments for specific diseases" and potentially establish "new patient-stratification principles for revealing unknown disease correlations"; and the integration of EHRs with "genetic profiles" will provide "a finer understanding of genotype-phenotype relations."\textsuperscript{32}

National leaders in health policy recognize that informatics, as Aliferis asserts, "is enabling the vision of personalized medicine."\textsuperscript{33} Continuing its series of reports on the learning health care system, in 2015 the Institute of Medicine published Genomics-Enabled Learning Health Care Systems: Gathering and Using Genomic Information to Improve Patient Care and Research: Workshop Summary. The workshop on which the report was based reviewed recent developments in genomic science and medicine, including "the rapidly growing number of new technologies, the associated increase in genomes sequenced, and the resulting massive amounts of new data," Big Data, that were "enabling the ongoing transformation of the traditional, symptom-based approach to health care and treating disease into a condition-based, personalized-medicine approach." Christopher Chute, MD, DrPH, FACMI, an invited speaker at the workshop who at the time was professor of medical informatics at the Mayo Clinic in Rochester, Minnesota, and IHI core faculty (since January 2015, Chute has been Bloomberg distinguished professor of health informatics, professor of medicine, public health, and nursing, and chief health information research officer at Johns Hopkins Bloomberg School of Public Health). The workshop examined "pragmatic approaches" to integrating genomic information into the health care system in order to deliver improved clinical diagnosis and treatment through personalized medicine, thereby transforming health care. The report recommended that (1) in order to "share information seamlessly, EHRs [electronic health records] need to be fully interoperable for genomic information and other clinical information"; researchers needed to (2) develop standardized nomenclature and clinical decision support tools to enable implementation of personalized medicine at the point of care; and (3) develop the platforms, standardized data, and interoperable health care systems to enable data sharing.\textsuperscript{34} Each of these components is dependent on the infrastructure, science, technologies, and expertise of biomedical and health informatics.

Given the national policy significance of personalized medicine and Big Data analytics and their importance to improving health care quality and access and reducing health care costs, ensuring the University of Minnesota is a leader in personalized medicine and Big Data analytics is a core priority for Aliferis. The University of Minnesota is well positioned for this. Aliferis' expertise in Big Data analytics combined with the University of Minnesota's existing expertise in data science and data-driven approaches to personalized medicine (Chih-Lin Chi, MBA, PhD, assistant professor, School of Nursing and IHI core faculty, and Terrence J. Adam, RPh, PhD, MD, associate professor, College of Pharmacy and IHI core faculty); developing and implementing standardized nomenclature and terminologies (Delaney, Bonnie Westra, PhD, RN, FAAN, FACMI, associate professor, School of Nursing and IHI core faculty, and
Karen Monsen, PhD, RN, FAAN, associate professor, School of Nursing and IHI affiliate faculty; clinical decision support systems and clinical informatics (Stuart Speedie, PhD, FACMI, professor, Medical School and IHI core faculty, Stanley Finklestein, PhD, professor, Medical School and IHI core faculty, and Adam); and advanced informatics methods such as machine learning (Aliferis, Rui Zhang, PhD, assistant professor, Medical School, IHI core faculty) and natural language processing (Genevieve Melton-Meaux, MD, MS, associate professor, Medical School, IHI core faculty; Serguei Pakhomov, PhD, associate professor, College of Pharmacy, IHI affiliate faculty, and Zhang) guarantees the University of Minnesota will be key players in this arena.

To ensure the University of Minnesota remains responsive to these national health policy needs and at the center of efforts to transform health care, the University, by recruiting Aliferis, has committed to the continuing growth of biomedical health informatics and to the continued development and strengthening of the informatics infrastructure, principally the Academic Health Center Information Exchange provided in partnership with the University, the Academic Health Center, and the Clinical and Translational Science Institute (CTSI). As Aliferis reflected, “the vision of the [AHC and University] leadership . . . is precisely precision [personalized] medicine” and “the needs of the research community,” which relies on informaticians “to really enable them to do all the amazing projects that they want to do.”35 “People are the most important asset,” and the AHC and University “leadership understands the importance of this.” As a result, the University of Minnesota and AHC leadership has committed resources to the recruitment of new health informatics faculty. Some of these faculty recruitments, Aliferis points out, need to be driven “according to the needs of the community.” In addition to looking “into the future and be[ing] prepared for the future . . . [we] also have to drive some of [our] recruitments in the current strategy around existing needs and making sure that these needs are going to be fulfilled and met.”36

Engagement with the community is a core priority of the IHI, CTSI, and AHC, which is enabled by the Academic Health Center Information Exchange and demonstrated by the University of Minnesota’s participation in the Clinical and Translational Science Award Consortium, the Patient-Centered Outcomes Research Initiative-funded Great Plains Collaborative, and the National Center for Advancing Translational Science Accrual to Clinical Trials Project. Both the Great Plains Collaborative and the Accrual to Clinical Trials Project capitalize on the robust informatics infrastructure provided by the Academic Health Center Information Exchange, the University of Minnesota’s health informatics expertise, and the University’s existing engagement and collaborative research initiatives with the biomedical and health care community (see chapter four).

Aliferis and the leadership of the AHC and University are committed to expanding the University of Minnesota’s health informatics expertise, securing the University’s position as a leading center of health informatics research and education, and ensuring that the University is at the forefront of personalized medicine of all types, which includes merging the molecular with traditional clinical modalities. To achieve this, Aliferis’ vision for growing health informatics at the University is three-pronged: (1) to contribute to excellence in the science of informatics and all science enabled by informatics—within the University and in the broader community; (2) to educate tomorrow’s leaders of informatics; and (3) to educate all within the biomedical and health care communities in core informatics skills and knowledge regardless of their background. The key to contributing to excellence in science is to build upon existing initiatives and to pursue new research initiatives. “Once you achieve excellence in the science of informatics” and in the “science that’s enabled by informatics” (emphasis in original), Aliferis reflected, “everything else follows.
So the grants follow. . . . The growth follows. The good career trajectories for the people involved follow. . . . Excellence is very, very important.”37 Following the fifty years of health informatics research that preceded his arrival at the University of Minnesota, Aliferis’ vision of informatics research is interdisciplinary, interprofessional, and collaborative, incorporating researchers and clinicians from outside of the University:

We want to make informatics into an engine for expanding the scope, the volume, the sophistication, and the impact of science across the [Academic] Health Center and the University. There are specific ways to do it. One major priority is to recruit a number of high-caliber, high-yield, and very collaboratively oriented informatics stars to come aboard and engage with the broader research community, providing for the research community the highest level of informatics, collaborative science, and expert consulting so that they can really push the frontier of what’s possible in terms of research. We are working to create a one-stop shop integrative best practice–oriented informatics consulting and collaborative science core that will provide informatics expert consulting and collaborative science across the spectrum of informatics to all engaged researchers.38

By prioritizing the education of the next generation of health informaticians and the training of nonprofessional health informaticians in core informatics skills, Aliferis is building on the University of Minnesota’s fifty-year history of both graduate education in health informatics and of offering seminars, short courses, and workshops in informatics to interested students, faculty, and researchers in the community (see chapters one and two). Aliferis sees several potential strategies for teaching core informatics skills to nonprofessionals in informatics. One is to hold seminars and workshops on topics that would be broadly useful. A second is to provide mentorship, for example, to “postdocs in specific labs” to help them “come to terms with what are the tools and what are the core techniques that are relevant to that particular lab’s long term research.” A third strategy is “to develop customized training programs and career development programs for faculty, early career faculty, junior faculty, who are interesting in getting a K [Career Development] award . . . or more generally for pursuing a career that is to a large extent depend[ent] on having a solid understanding of informatics, not being an informaticist but requiring informatics.”39

Fundamental to growing health informatics at the University of Minnesota, to expanding the University’s robust informatics infrastructure to continue to transform the clinical and translational research enterprise, to securing the University’s leadership in personalized medicine and Big Data analytics, to training the next generation of health informatics leaders, and to engaging with both the University and the broader biomedical and health care community is the “synergistic and symbiotic” relationship between the IHI and the CTSI, and the role of biomedical informatics within the CTSI. As Aliferis explained, “The CTSI is a great ally in building informatics for the institution and informatics is a great ally for CTSI.”40 As CTSI director Blazar described, the IHI is “the academic epicenter” of health informatics at the University of Minnesota and is critical for building the health informatics workforce; the biomedical informatics core within CTSI is “fundamentally important in all clinical trial activities.”41 As Blazar continued, CTSI-Biomedical Informatics “provides consultative services for investigators [inside the University and in the community] and grant planning, utilization of the data. It links to the Fairview Health System, which is critical. It provides bioinformatics support. It is helping us link bio-specimens to electronic health records. It’s useful as a research tool for investigators. Because we have a single clinical trial managements system, it’s fundamentally important in our future.”42
Aliferis’ goal, “fully aligned with Bruce Blazar, . . . is to make sure that the CTSI grows and is extremely successful and becomes an engine for success and be a success for everybody. But,” Aliferis continues, “I do not forget that at any time our measure of success will be the broad impact, not just the CTSI which is a major, major achievement and major undertaking but also to make sure that through the CTSI and through everything that we’re doing [that] informatics can really be an agent of progress and change for the benefit of everyone.”

As this book has shown, the University of Minnesota has had a long and impressive history in health informatics. The University’s health informaticians have been educating the next generation of health informaticians since 1966. With funding from 1974 through 2009, the University of Minnesota is the longest continuously funded National Library of Medicine Training Program in health informatics in the United States. There are, as Aliferis notes, “notable figures in informatics in the United States” and internationally “that either were faculty here or are graduates of the training program.” And, the University’s health informaticians have been national and international leaders in core fields in biomedical and health informatics research, including signal processing, database design and development, clinical decision support systems, modeling and simulation studies, home monitoring and telehealth, the development and implementation of standardized terminologies, the evaluation of electronic health records and health information exchange, data mining, natural language processing, and clinical informatics. In addition to using informatics to address the monumental cost, access, continuity, and quality challenges of health care delivery, the future for informatics at the University of Minnesota, explains Aliferis, “will be . . . on the discovery side of things and to make sure that now we can pass the baton from access to data to major discoveries using this data and, also, to integrate more tightly with the research enterprise so that we can become participants and critical collaborators in the production of new scientific knowledge and to push forward projects that without the sophistication of informatics cannot be executed as of now, at least not easily.” With the “rich tradition” in the history of health informatics at the University of Minnesota, Aliferis concludes, “I think the future can be extraordinarily rewarding.”
Hyeoun-Ae Park, PhD, RN, Laël Gatewood Distinguished Lectureship Keynote Speaker at the 50th Anniversary Celebration of Health Informatics at the University of Minnesota, April 29, 2015
source: Photograph by Scott Streble

Health informatics graduate students, Rohini Olson (left) and Elliot Arsoniadis (right), at the 50th Anniversary Celebration of Health Informatics at the University of Minnesota, April 29, 2015
source: Photograph by Scott Streble
Left to Right: Stanley Finkelstein, PhD, Stuart Speedie, PhD, FACMI, Donald Connelly, MD, PhD, FACMI, Lynda Ellis, PhD, John Faughan, MS (alum), and Laël Gatewood, PhD, FACMI, at the 50th Anniversary Celebration of Health Informatics at the University of Minnesota, April 29, 2015

Source: Photograph by Scott Streble

Connie Delaney, PhD, RN, FAAN, FACMI, at the 50th Anniversary Celebration of Health Informatics at the University of Minnesota, April 29, 2015

Source: Photograph by Scott Streble
Beth Madson (left) and Jessica Whitcomb-Trance (right) at the 50th Anniversary Celebration of Health Informatics at the University of Minnesota, April 29, 2015

source: Photograph by Scott Streble
NOTES

INTRODUCTION


13. Ibid.
15. Ibid., 52–53.


37. Ibid.


41. Ibid., 234.

42. For more details on this process, see https://www.amia.org/clinical-informatics-board-review-course/faq (accessed July 23, 2015).


45. Collen, A History of Medical Informatics, 154.

46. Ibid., 38.


50. Collen, A History of Medical Informatics, 42.


52. Collen, A History of Medical Informatics, 42–43.

53. Ibid.


61. Warner interview, Sittig, 8.


68. For additional information on the history of Barnett and MGH’s Laboratory of Computer Science’s research see, [http://www.mghlcs.org/50th-anniversary](http://www.mghlcs.org/50th-anniversary) (accessed July 21, 2015).

69. Colleen interview, Ash and Sittig, 5.


73. Ibid., 162.

74. Ibid., 7.

75. Oral History Interview with Lael Gatewood, Dominique A. Tobbell, August 8 and 13, 2014, University of Minnesota Institute for Health Informatics History Project, 38.

76. Oral History Interview with Donald Connelly, Dominique A. Tobbell, August 12 and November 6, 2014, University of Minnesota Institute for Health Informatics History Project, 20.


78. [https://www.amia.org/working-groups/nursing-informatics/history-project](https://www.amia.org/working-groups/nursing-informatics/history-project) (accessed July 24, 2015).


80. Casimir A. Kulikowski, “The 50th Anniversary IMIA History of Medical Informatics Project,” *Acta In-

81. For more on the University of Minnesota Institute for Health Informatics History Project visit the History Project website: http://healthinformatics.umn.edu/history

1. FROM BIOMEDICAL COMPUTING TO HEALTH INFORMATICS

1. Robert Howard to Eugene Johnson, February 19, 1965, University of Minnesota Archives, Collection #1000, Arnold Lazarow Papers, Box 27, folder: Administration - Committee - Computer - Medical School I.


3. November, Biomedical Computing, 88–89.

4. November, Biomedical Computing, 89.

5. November, Biomedical Computing, 97.


8. Ibid.

9. Ibid.

10. Howard and Lazarow to William G. Shepherd, October 9, 1964, University of Minnesota Archives, Collection #1000, Arnold Lazarow Papers, Box 27, folder: Administration - Committee - Computer - Medical School I.

11. Ibid. This memo also discusses whether this should be set up as a renting computer, a sharing computer with the Numerical Analysis Center, or set up as a separate computer facility in the College of Medical Sciences.


15. Howard and Lazarow to William G. Shepherd.


17. Halberg to Lazarow regarding background on Johnson, October 17, 1964, University of Minnesota Archives, Collection #1000, Arnold Lazarow Papers, Box 27, folder: Administration - Committee - Computer - Medical School I.


21. The BDPU had already raised $50,000 from local
funds to put towards renovation costs. Johnson, “Application for Research Grant.”


24. Eugene Johnson, “Request for Support of a Hill Family Foundation Professorship in Biomedical Computing Sciences,” and “Minutes, College of Medical Sciences Computer Committee, October 20, 1966,” University of Minnesota Archives, Collection #1000, Arnold Lazarow Papers, Box 27, folder: Administration - Committee - Computer - Medical School II.


32. Minutes, Meeting of College of Medical Sciences Computer Committee, June 4, 1968, University of Minnesota Archives, Collection #1000, Arnold Lazarow Papers, Box 27, folder: Administration - Committee - Computer - Medical School II.


34. Ibid., 56–57, Details about the BDPU staff’s involvement in the Minnesota Coronary Survey from Laël Gatewood, personal communication, October 23, 2014.


36. On the date of the heart attack, see Ackerman, “Annual Report, 1968,” 44.


41. Ibid.

42. Ibid.

43. Eugene Johnson, Open Letter to Computing Committee, College of Medical Sciences, April 4, 1968, University of Minnesota Archives, Collection #1000, Arnold Lazarow Papers, Box 27, folder: Administration - Committee - Computer - Medical School III.

44. Ibid.

45. Ibid.


47. Ibid., 113–15, quotations from 115.


53. Ibid.
55. Ibid., 7–8.
56. Oral History Interview with Donald Connelly, interview by Dominique A. Tobbell, August 12 and November 6, 2014, University of Minnesota Institute for Health Informatics History Project, 15.
60. Finkelstein interview, Tobbell, 24.
63. Oral History Interview with Martin LaVenture, Dominique A. Tobbell, January 30, 2015, University of Minnesota Institute for Health Informatics History Project, 7.
65. LaVenture interview, Tobbell, 7.
67. Gatewood interview, Tobbell, 37.
69. Gatewood interview, Tobbell, 27.
71. Finkelstein interview, Tobbell, 23.
73. David Brown to Nils Hasselmo, June 6, 1989, University of Minnesota Archives, President’s Office, Collection # 841, Box 371, folder: Academic Units 1989–1990 Health Sciences–Medical School.
74. Gatewood interview, Tobbell, 31.
75. Finkelstein interview, Tobbell, 20–21. See also Oral History Interview with Donald Connelly, Dominique A. Tobbell, August 12 and November 6, 2014, University of Minnesota Institute for Health Informatics History Project, 14.
76. Connelly interview, Tobbell, 24.
78. Gatewood interview, Tobbell, 31.
80. Ibid. The new unit, iMcKesson, specializes in “delivering health care technologies and services to physicians offices and payors.” See: “iMcKesson Appoints Barbara G. Hurtig Senior Vice President, Human Resources.”

81. Oral History Interview with Stuart Speedie, Dominique A. Tobbell, September 11, 2014, University of Minnesota Institute for Health Informatics History Project, 10.


83. Finkelstein interview, Tobbell, 23.

84. Gatewood interview, Tobbell, 31.


86. Connelly interview, Tobbell, 16.

87. Ibid., 12.


89. Ibid., 30.


91. Cerra interview, Tobbell, 42.


93. Connelly interview, Tobbell, 21.

94. Cerra interview, Tobbell, 42.

95. Speedie interview, Tobbell, 19.

96. The Health Sciences Libraries is comprised of the Biomedical Library, the Veterinary Medical Library, and the Owen H. Wangensteen Historical Library of Biology and Medicine.

97. Connelly interview, Tobbell, 21.


99. Cerra interview, Tobbell, 43.

100. “Managing the Interface Between the Institute for Health Informatics and the AHC Colleges and Schools,” December 9, 2009, 3–4.


103. Speedie interview, Tobbell, 20.

104. Stuart Speedie, personal communication, February 8, 2015.

105. Cerra interview, Tobbell, 42. See also Oral History Interview with Christopher Chute, Dominique A. Tobbell, September 26, 2014, University of Minnesota Institute for Health Informatics History Project, 21: “I think the whole CTSA went down that year because of the informatics component, which I was part of.”

106. “Statement by University of Minnesota General Counsel Mark Rotenberg regarding indictments,” University News Service, March 9, 2011.

107. Ibid.

108. Ibid.

109. Ibid.


114. In January 2015, Saif Khairat joined the Univer-
sity of North Carolina at Chapel Hill as assistant professor in the School of Nursing.


124. Ibid.


126. Ibid., quotation from S13.


131. LaVenture interview, Tobbell, 18.

132. Ibid.


134. LaVenture interview, Tobbell, 19.


137. LaVenture interview, Tobbell, 19.


141. American Nurses Association Board of Directors, “Position Statement: Inclusion of Recognized Terminologies Supporting Nursing Practice within Electronic
Health Records and Other Health Information Technology Solutions," March 19, 2015.

142. LaVenture interview, Tobbell, 19.

143. LaVenture interview, Tobbell, 21.

144. LaVenture interview, Tobbell, 28. For more on the collaboration between MDH and IHI and AHC more broadly, see Sripriya Rajamani, Bonnie L. Westra, Karen A. Monsen, Martin LaVenture, and Laël Cranmer Gatewood, “Partnership to Promote Interprofessional Education and Practice for Population and Public Health Informatics: A Case Study,” Journal of Interprofessional Care (22 June 2015) Early online: 1–7.


2. Training the Next Generation of Health Informaticians


6. Oral History Interview with Laël Gatewood, Dominique A. Tobbell, August 8 and 13, 2014, University of Minnesota Institute for Health Informatics History Project, 28.


8. Ibid.


12. After the DHCS was established in 1991, its faculty members also served on the graduate faculty of the kinesiology graduate program. Laël Gatewood, personal communication, June 8, 2015.


16. Laël Gatewood, personal communication, June 8, 2015.


18. Gatewood interview, Tobbell, 7.


21. Ibid., 12.


25. Ibid., 70.

26. Ibid., 71.

27. Ibid., 72–74.

28. Ibid., 94.

29. Oral History Interview with Stuart Speedie, Dominique A. Tobbell, September 11, 2014, University of Minnesota Institute for Health Informatics History Project, 17–18.

30. Oral History Interview with Donald Connelly, Dominique A. Tobbell, August 12 and November 6, 2014, University of Minnesota Institute for Health Informatics History Project, 22.


36. Ibid.

37. Ibid.


42. Gateswood interview, Tobbell, 29.


47. Eugene Ackerman to Vincent F. Maturi, June 15, 1972, Institute for Health Informatics Records, 1967–2008, University of Minnesota Archives, Box 1, Folder: Training Grant Application 1971–1972. It should be noted that the proposal was approved by the Health Services Training Study Section following revisions based on the recommendations of Site Visit Team; see Vincent Maturi to Eugene Ackerman, December 7, 1971. Institute for Health Informatics Records, 1967–2008, University of Minnesota Archives, Box 1. Folder: Training Grant Application 1971–1972.
50. Ibid.
51. Ibid.
54. Finkelstein interview, Tobbell, 19.
55. Gatewood interview, Tobbell, 17.
58. Connelly interview, Tobbell, 13.
59. Gatewood interview, Tobbell, 18.
60. Connelly interview, Tobbell, 13.
62. Ibid., 45.
63. Ibid., 46–48.
70. Gatewood interview, Tobbell, 18.
73. Oral History Interview with Milton Corn, Dominique A. Tobbell, September 4, 2014, University of Minnesota Institute for Health Informatics History Project, 11.
75. Gatewood interview, Tobbell, 21.
78. Gatewood interview, Tobbell, 21.
79. Oral History Interview with Christopher Chute, Dominique A. Tobbell, September 26, 2014, University of Minnesota Institute for Health Informatics History Project, 5.


82. Ibid., 7.

83. Chute interview, Tobbell, 7.

84. Corn interview, Tobbell, 10.

85. Ibid., 11.

86. Ibid., 17.


88. Corn interview, Tobbell, 11–12.


91. Finkelstein interview, Tobbell, 20–21. See also, Connelly interview, Tobbell, 14.


94. Ellis interview, Tobbell, 14.

95. Chute interview, Tobbell, 8.

96. Corn interview, Tobbell, 19.


101. Database of University of Minnesota NLM Training Grant Fellows, developed by Elizabeth Lindemann.

102. Gatewood interview, Tobbell, 21.

103. See n. 24, 32–34.


114. http://www.ucdenver.edu/academics/colleges/
3. Innovations in Health Informatics Research, 1965–2005

1. Oral History Interview with Donald Connelly, Dominique A. Tobbell, August 12 and November 6, 2014, University of Minnesota Institute for Health Informatics History Project, 7–8.


3. Ibid.

4. Ibid.


9. Ibid., quotations from 50, 59.


18. Ibid., 35.


20. Ibid.

21. Oral History Interview with Lynda Ellis, Dominique A. Tobbell, July 9, 2014, University of Minnesota Institute for Health Informatics History Project, 11.


24. Ibid.


26. Ellis interview, Tobbell, 11.


28. Ellis interview, Tobbell, 11–12.


31. For example, chemically an alcohol can be converted to an aldehyde (two different chemical compounds). One biotransformation rule in the Pathway Prediction System will be triggered when it is given an alcohol, and will cause the system to convert it to an aldehyde. There may be several rules for each chemical moiety, and they may have priority over one another. Lynda Ellis, personal communication, February 24, 2015.


37. Connelly interview, Tobbell, 7.

38. Connelly interview, Tobbell, 8.


41. Connelly interview, Tobbell, 8.

42. Connelly interview, Tobbell, 9–10.


46. Connelly interview, Tobbell, 10.


48. Connelly interview, Tobbell, 10.
49. Connelly interview, Tobbell, 10.
52. Connelly interview, Tobbell, 10. For details about the updated clinical workstation, supported in part by the NLM Research Training in Medical Informatics grant and by a grant from the National Heart, Lung, and Blood Institute (HL-41086), see Donald Connelly, Bruce Sielaff, and Keith Willard, “A Clinician’s Workstation for Improving Laboratory Use: Integrated Display of Laboratory Results,” American Journal of Clinical Pathology (1995) 104(5): 243–52.
53. Connelly interview, Tobbell, 14.
55. Ibid., quotation from 541.
56. Connelly interview, Tobbell, 10.
58. Ibid., quotation from 545.
63. Colleen, A History of Medical Informatics, 134–35.
64. Connelly interview, Tobbell, 11.
70. Oral History Interview with Laël Gatewood, Dominique A. Tobbell, August 8 and 13, 2014, University of Minnesota Institute for Health Informatics History Project, 12.
74. Ibid., 19.
75. Ibid., 8.
77. Gatewood interview, Tobbell, 13.
88. Oral History Interview with Martin LaVenture, Dominique A. Tobbell, January 30, 2015, University of Minnesota Institute for Health Informatics History Project, 10.
91. LaVenture interview, Tobbell, 11.
95. Gatewood interview, Tobbell, 16.
96. Ramón A.-A. Erhardt, Reinhard Scheinder, and


104. Oral History Interview with Christopher Chute, Dominique A. Tobbell, September 26, 2014, University of Minnesota Institute for Health Informatics History Project, 8.

105. Chute interview, Tobbell, 14.

106. The Multi-Institutional Testbed for Clinical Vocabulary project “examined whether clinical descriptions of patients could be compared among different care environments and demonstrated the critical importance of having comparable patient data. They enhanced development of terminologies that are used by many health care providers and fostered the development of clinical concept navigation tools for integration into clinical record systems.” http://archive.ahrq.gov/research/sep05/0905RA43.htm (accessed April 12, 2015).


108. Chute interview, Tobbell, 8.


110. Chute interview, Tobbell, 8–9.

111. Chute interview, Tobbell, 13.


123. Oral History Interview with Stanley Finkelstein, Dominique A. Tobbell, July 23, 2014, University of Minnesota Institute for Health Informatics History Project, 8.


126. Finkelstein interview, Tobbell, 10–11.

127. Finkelstein interview, Tobbell, 10–11.


129. Finkelstein interview, Tobbell, 11.

130. Finkelstein interview, Tobbell, 11.

131. Finkelstein interview, Tobbell, 11.


134. Finkelstein interview, Tobbell, 12.


141. Finkelstein oral history, 8–9.


145. Speedie interview, Tobbell, 15.


149. Oral History Interview with Stuart Speedie, Dominique A. Tobbell, September 11, 2014, University of Minnesota Institute for Health Informatics History Project, 15.


151. Speedie interview, Tobbell, 15.


154. Gatewood interview, Tobbell, 16.

4. INNOVATIONS IN HEALTH INFORMATICS RESEARCH, 2006–2015


3. Committee on Quality of Health Care in America, Institute of Medicine, Crossing the Quality Chasm: A New


8. Ibid., 2–3.

9. Ibid., 5–6.


21. Ibid., quotation from 163–64.


25. Ibid.


27. Ibid., quotation from 305.

28. Ibid., quotation from 308.


42. Ibid., quotation from 341.


50. Speedie interview, Tobbell, 19.

51. Speedie interview, Tobbell, 19.


54. Connelly and Speedie, “Research Plan.”

55. Speedie, “The Impact of Health Information Exchange.”

56. Donald Connelly and Stuart Speedie, “Revised Evaluation Plan: A Community-Shared Clinical Abstract to Improve Care,” Agency for Health Research and Quality, undated.

57. Speedie interview, Tobbell, 19.


60. Ibid.

61. Stuart Speedie, personal communication, July 1, 2015.


78. Westra, Solomon, and Ashley, “Use of the Omaha System Data,” 94.


80. Ibid., quotation from 648.

81. Ibid., quotations from 653, 655.


83. Ibid., quotation from 57.


86. Ibid., quotation from 72.


88. Tom Clancy email to Dominique Tobbell, July 13, 2015.
89. Tom Clancy email to Dominique Tobbell, July 13, 2015.


93. Ibid., quotation from 76. For a review of this history and an example of a major work in this field, see Naomi Sager, Margaret Lyman, Christine Bucknall, Ngo Nhan, and Leo J. Tick, “Natural Language Processing and the Representation of Clinical Data,” Journal of the American Medical Informatics Association (1994): 142–60.


104. Ibid., quotations from 134, 138.


113. Ibid.


### 5. The new era of Health Informatics at the University of Minnesota

1. Oral history interview with Constantin F. Aliferis by Dominique A. Tobbell, June 8, 2015, University of Minnesota Institute for Health Informatics History Project, 6.


5. Aliferis interview, Tobbell, 6.


7. Aliferis interview, Tobbell, 7.


10. Aliferis interview, Tobbell, 7.

11. Aliferis interview, Tobbell, 7.


15. Aliferis interview, Tobbell, 7.


17. Ibid., 670.


23. Oral history interview with Bruce Blazar, Domi-
nique A. Tobbell, July 9, 2015, University of Minnesota Institute for Health Informatics History Project, 8.


33. Aliferis interview, Tobbell, 16.


35. Aliferis interview, Tobbell, 11.

36. Aliferis interview, Tobbell, 15.


38. Aliferis interview, Tobbell, 14.


40. Aliferis interview, Tobbell, 16.

41. Blazar interview, Tobbell, 7, 9.

42. Blazar interview, Tobbell, 7.

43. Aliferis interview, Tobbell, 16.

44. Aliferis interview, Tobbell, 16.

45. Aliferis interview, Tobbell, 18.
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AAMSI. See American Association for Medical Systems and Informatics (AAMSI)

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