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Research and Education

Biomedical and Health Informatics Research and Education at the University of Washington

Abstract: Although an extensive medical informatics research program as well as courses and training experiences in biomedical informatics have existed at the University of Washington (UW) for many years, a formal home did not exist until 1997 when the Division of Biomedical Informatics was created in the Department of Medical Education, School of Medicine. Since that time the expansion of the research, service and teaching programs has been rapid with a key milestone being a university commitment to provide funding, space and faculty to support the development of a new graduate program in Biomedical and Health Informatics.

Hallmarks of the biomedical and health informatics program at the University of Washington include:

- Strong shared belief that informatics research can contribute to the improvement of healthcare and health;
- Large, multidisciplinary faculty including faculty from computer science, library and information science as well as the health sciences schools (dentistry, medicine, nursing, pharmacy, and public health and community medicine);
- Comprehensive research and development partnership with the University of Washington Medical Centers information systems group and the UW Primary Care Network to move research from the laboratory to operational clinical systems;
- Extensive and diverse regional setting in which to study information needs and develop informatics solutions in primary care settings;
- Lack of barriers to interdisciplinary research and teaching.

1. Biomedical Informatics Research

For many years, the University of Washington (UW), has had a cadre of medical informatics research faculty whose research programs range from structural informatics and imaging to integrated systems design, telemedicine and clinical informatics. An important feature of our research program has been a strong partnership with the University of Washington Medical Centers Information Systems organization with a resulting critical flow of informatics research findings to application in the clinical setting. Since the University of Washington School of Medicine serves a five-state region, including also Wyoming, Alaska, Montana and Idaho (the WWAMI program), affiliate faculty from WWAMI Universities participate in the informatics program. In addition, the WWAMI region serves as a testbed in which to research, develop and evaluate innovative informatics interventions.

A number of the UW research groups and programs are described below with websites referenced to provide additional information.

1.1 Integrated Advanced Information Management System(IAIMS)

IAIMS is a National Library of Medicine Program to assist health-related schools, organizations and libraries in planning, developing and implementing systems that make it possible for health-care workers to gain access to the information they need for problem solving and learning. IAIMS is a two-phase process. Phase I involves institution-wide planning and policy analysis; Phase II is a full-scale implementation of the plans. The University of Washington Health Sciences Center (UWHSC) successfully com-

pleted its planning phase in 1993, and in 1994 was awarded a five-year implementation grant from the National Library of Medicine to implement the University of Washington's long-range plan (healthlinks.washington.edu/iaims). The Health Sciences Center, which includes the Schools of Dentistry, Medicine, Nursing, Pharmacy, Public Health and Community Medicine, and Social Work, as well as the University of Washington and Harborview Medical Centers, has thus been engaged in comprehensive integrated information systems planning and development for over 10 years. The result has been a strategic plan for linkages of key clinical, educational and research databases and systems, a robust state-of-the-art high-speed network connecting all areas of the Health Sciences Center, as well as implementation of a number of sophisticated resources in support of easy desktop access to decision-support tools for clinicians, researchers, faculty, librarians and staff. Key products and programs enabled by the IAIMS process include: MINDscape, the Medical Centers computer-based medical record, described further below, Healthlinks, a web-based filtered view of tools, information resources and tools (healthlinks.washington.edu) and an academic program, the Division of Biomedical Informatics. Although federal funding for the IAIMS program ends in 2000, the IAIMS legacy will live on at UW [1-3].

1.2 Clinical Informatics Research and Development

The UW informatics faculty collaborates closely with the Medical Centers Information Systems (MCIS) group on a number of projects. The focus of these projects is to bring informatics research findings to the point of care and to integrate access to both clinical information and medical knowledge. At the core of this collaboration is the central clinical data repository (MIND - Medical Information Networked Databases). MIND is a UW-developed production database containing the following information on all patients seen at the UW affiliated medical centers: patient demographics, insurance coverage, clinician-selected problem list entries, ICD-9 diagnoses, all transcriptions, selected pharmacy records, allergies, immunizations, automatically generated clinical alerts, stay/visit data, CPT procedure codes, laboratory data, radiology reports. The key components of the MIND system are an Ingres relational database, DECRAD radiology system, SunQuest laboratory system, Intellus transcription system, and links to the EMTEK and EPIC clinical information systems.

One of the earliest joint projects created a reminder system to see if this would change compliance with COMAH (Clinical Outcomes Measure Amended HEDIS) measures of primary care performance. Using the MIND repository, the Clinical Reminder and Outcomes Subsystem (CROS) software produces patient profile reports that are linked to charts at all visits to prompt for the collection of the required COMAH data elements. Preliminary results suggest improved compliance rates in the 70 to 80 percent range.

One of the most successful collaborations between the UW informatics research group and MCIS has been the development of MINDscape. MINDscape is a web-based integrated interface to diverse sources of clinical information including both patient-specific information (electronic medical record) as well as medical knowledge (the "digital library") to provide "just in time" information at the point of care. Mindscape was developed at UW to meet clinical information needs both as identified locally and by a review of the literature. Clinical information systems address the need for patient specific information (e.g., "What medications is my patient taking?"). The medical library addresses the need for access to knowledge resources (e.g., "What are dosage and side effects of a certain drug?"). Clinical decision-making at the point of care requires access to both types of information (e.g., "Could my patient's abnormal creatinine be explained by a side effect of the drug they are on?"). Furthermore, clinicians need tools to facilitate managing groups of patients (e.g., "Which of my inpatients has new abnormal lab values?"). These needs drove the development of the MINDscape application which includes: (1) a web interface to patient data (MIND), (2) a summary view integrated by provider, (e.g., a provider can see at a glance summary information about their entire panel of patients) and (3) integrated access to Internet-based knowledge resources.

Security is provided by Secure Socket Layer, session-specific cookies and a custom database application to provide user authentication, manage passwords and log accesses by provider and by patient. MINDscape is the primary tool used by clinicians at the UW affiliated medical centers (UW Medical Center and Harborview Medical Center) to access online patient-specific information. There are currently over 12,000 registered users. On a typical weekday, approximately 1,000 of these users use the system for a total of over 30,000 daily transactions. Work is continuing on enhancing the patient-specific information (adding more information sources such as on-line radiologic images), enhancing the medical knowledge integration, and developing a problem list that will address issues of use of standardized taxonomies and multi-disciplinary access and use [4-7].

1.3 Structural Informatics Program

One of the largest informatics research programs at UW, the Structural Informatics Group, an interdisciplinary team of computer scientists,

engineers and biologists, emphasizes the development of methods for representing, managing, visualizing and utilizing information about the physical organization of the body (http://sig.biostr.washington.edu/). The goal of the program is to develop methods for representing both spatial and symbolic information about the physical organization of the body:

1. To develop Web-accessible computer programs which utilize these representations to solve practical problems in clinical medicine, research and education;
2. To initially apply these representations to the domain of gross anatomy, and to develop applications in education, clinical medicine and research.

In 1990 Jim Brinkley coined the term *Structural Informatics* to describe the kind of work he had been doing throughout his career, work ranging from 3-D ultrasound reconstruction to 3-D protein structure, to current work in gross anatomy. Cornelius Rosse, founder of the structural informatics program in the Department of Biological Structure, School of Medicine, and Jim Brinkley then applied this term to the previously described classification of structural information, concentrating on its application in anatomy. The National Library of Medicine used this term in their long-range report that led to the Visible Human project, and Jim Brinkley expanded on its definition in 1991.

The name of the group was changed to the UW Structural Informatics Group in 1997 to reflect its increasingly technical nature (many of the members are now from computer science or engineering), and to provide room for expansion beyond at least the connotation of anatomy education. The award of a Human Brain Project grant to this group in 1994 was further motivation for the change.

The rationale for structural informatics is based on the fact that a large amount of information in medicine relates to physical structures in the body. Therefore, if we can find ways to represent these structures and their relationships, at levels ranging from gross anatomy to molecules, the resulting structural information framework can serve as a rational basis for organizing medical information. The reason that the field is called "structural informatics" is the hypothesis that the same methods and representations are applicable at all levels of organization, and therefore can be applied at multiple levels once the common problems are recognized.

In order to approach the development of representations for structural information, classification is based along two dimensions: spatial versus symbolic, and data versus knowledge.

1.3.1 Spatial information

This is defined as information that is described in a coordinate system, in one or more dimensions, as for example:

- One dimension; A molecular sequence.
- Two dimensions; A 2-D image.
- Three dimensions; A 3-D volume image, or a 3-D anatomic reconstruction.
- Four dimensions; A time-varying 3-D volume image.

In fact, higher dimensions are possible with multi-spectral images, in which each spatial position (voxel or pixel) has multiple values representing different measured aspects of the underlying structures.

1.3.2 Symbolic information

This is all the other kinds of structural information: anatomic terminology, definitions, glossaries, and semantic relationships. The symbolic information gives meaning to the corresponding spatial information. In an anatomy, histology or molecular biology textbook spatial information is generally conveyed by pictures, whereas symbolic information is conveyed by text. However, this distinction is not precise because symbolic information (e.g., "anterior to") can describe spatial information as well.

Structural information is also classified along the dimension of data versus knowledge. Structural knowledge is information about classes of objects, as opposed to structural data, which is information about single objects. For example, data might be an individual reconstruction of a single kidney, whereas knowledge might be a model which describes the range of variation of all normal kidneys. Or, data might be the medical record of a patient with diabetes, while knowledge might be the characteristics of all patients with diabetes.

A conceptual framework for organizing structural information, and for making that information accessible to problem-solving programs has been designed. Structural information is represented in four kinds of information resources that are made available over the Internet by means of one or more structural information servers. These servers are accessed by both authoring client programs, for entering new information into the resources, and by end-user programs for utilizing the information. At the present time the resources are concerned primarily with gross anatomy, although it is believed that these methods will apply at other levels as well [8-10].

1.4 Genetic Database Research and Development

The Human Genome project is generating a huge amount of information of growing importance to health-care providers and patients. Already, new gene discoveries resulting from the Human Genome project have led to advances in genetic testing that can improve medical care and expand personal choices for individuals with inherited disorders. This is no longer a problem just for geneticists - primary care providers and non-genetics spe-

cialists are equally impacted. Clinicians in domains ranging from pediatrics to neurology to oncology all need up-to-date systematic information on the rapidly changing arena of genetic testing. In response to this need, researchers in informatics and genetics at UW have created a centralized resource on genetic testing for specific diseases for clinicians and patients. The two databases that make up this resource are the GeneTests™ database of available genetic tests (the "yellow pages"–www.genetests.org) and the GeneClinics™ database containing information on the application of clinical genetic testing (the "user's manual"–www.geneclinics.org). GeneTests is a relational database with web-based tools for distributed maintenance of content that as of August 1999 lists 667 diseases for which genetic testing is available along with contact information for 419 laboratories offering these tests. GeneClinics is an expert-authored, peer-reviewed on-line electronic information resource consisting of concise descriptions of specific inherited disorders ("disease profiles") as well as authoritative, current information on the role of genetic testing in the diagnosis, management, and genetic counseling of patients with these inherited conditions. GeneClinics is growing rapidly with the goal of a listing in GeneClinics for each disease for which genetic testing is available. GeneClinics content is obtained from expert authors using "smart templates" in common wordprocessing formats, which are automatically converted to XML. Subsequently, discrete data elements (such as genes, products, loci, disease prevalence, mode of inheritance) are manually marked up and the resulting XML document is stored in an object-oriented database. The loading of the database from the XML is possible since the XML schema (DTD) maps to the schema of the underlying object-oriented database. The contents of the database are subject to peer review prior to "publication". Publication consists of rendering the contents of the database in HTML for searching and display via the Web. The contents of the database are regularly updated by the expert authors in conjunction with the GeneClinics editorial staff. The GeneClinics database is semi-automatically linked via data elements such a gene, locus and product to other on-line genetic information resources including primary genomic databases [11].

1.5 Telemedicine

The application of technologies in support of delivery of healthcare over larger distances has been a key focus of UW informatics faculty for a number of years. The testbed for these telemedicine applications has been the WWAMI area (Washington, Wyoming, Alaska, Montana, and Idaho), an area covering one quarter of the entire United States. An early Tele-WWAMI project focused on feasibility and acceptability issues related to televideoconferencing and involved six rural sites throughout the WWAMI region with three partner sites in Seattle: (UW Medical Center, the Harborview Medical Center (county hospital and tertiary trauma center), and the Children's Hospital and Regional Medical Center. The current generation of telemedicine research is much more broadly based and seeks to bring the fruits of the integrated systems work done under the IAIMS program beyond the walls of the Medical Centers. The National Library of Medicine funded the Bench to Bedside and Beyond Regional Telemedicine Testbed project and focuses on evaluation of efficacy and impact in the following areas: (a) televideoconferencing, (b) store/forward tele-dermatology, (c) access to on-line knowledge resources, (d) tele-public health, (e) radiology imaging, (f) security, authorization and authentication issues. We have deployed tools and applications in these areas and are in the midst of our evaluation process. New research directions include a focus on health applications of the Next Generation Internet in the context of distributed comprehensive cancer care.

The institution has recognized the value of telemedicine and we are working with administration to operationalize telemedicine and move it from the research and development arena to a standard part of the toolkit for delivering healthcare in a diverse, regionally distributed environment.

2. Biomedical and Health Informatics Graduate Program

A recently funded development effort to build an interdisciplinary graduate program in Biomedical and Health Informatics at the University of Washington involves the collaboration of over 30 faculty from 21 departments in seven schools and colleges. The participating schools and colleges are: the School of Medicine, the College of Engineering, the School of Library and Information Science, the School of Nursing, the School of Public Health and Community Medicine, the School of Pharmacy, and the School of Dentistry. The graduate program director is Ira Kalet. The Head of the Division of Biomedical Informatics is Sherrilynne Fuller (healthlinks.washington.edu/dbi). A steering committee with representation from each of the participating schools and colleges provides leadership and guidance and ensures that the evolving program supports the students and needs of the participating schools. An external advisory committee of academic informatics leaders will review and evaluate the program from a national perspective. We are planning to admit the first Master's students in the Fall, 2000 and the first Ph.D. students in 2001.

The objectives of the UW graduate program in Biomedical and Health

informatics are:

1. To offer the highest quality academic degree program that will prepare students for careers in research and teaching, information management in health care, the health care computing industry, and public health;
2. Through the activities of students and trainees, to foster and enhance interdisciplinary collaboration in biomedical and health informatics research and related areas;
3. To provide opportunities for undergraduate students to obtain advanced instruction and knowledge about careers and career pathways in biomedical and health informatics and to participate in biomedical informatics research projects. Through these opportunities for undergraduates, we hope to promote a broader understanding of the vital role of informatics in medicine and health care;
4. To offer pre- and postdoctoral training opportunities for students who seek experiential learning in the context of a variety of healthcare settings.

2.1 Course of Study

A key goal of the program is recruitment and admission of students with diverse academic backgrounds. Individuals may enter the program with a strong background in computer science, library and information science, other science or engineering fields, or in one or more biological or health related disciplines. To provide a unified curriculum in this program is itself a challenge. Students will study a common intellectual core, requiring competency in biomedical sciences, computer science, statistics and decision analysis, information retrieval and management, information systems design, the principles of clinical medicine, the nature of health care and public health systems, and the synergistic nature of these component parts. Within biomedical informatics itself, students will be knowledgeable in clinical information systems, discipline-specific decision support and modeling systems, medical imaging, and medical and health education.

The curriculum is designed to assure a strong foundation in three areas: (1) Biology and Health provides an understanding of the relevant biological, clinical, organizational, research and educational concepts and issues; (2) Computing and Information Science assures an adequate level of technical skill and understanding of the principles of computer science, information management and information technology; (3) Biomedical and Health informatics covers the program area itself. Because of the highly interdisciplinary nature of the proposed program, the applicants for this program will be a heterogeneous group. Some will have strong backgrounds in computer science with only a modest background in biomedical science. Others will be strong in biology or medicine, with little computing experience. The curriculum addresses the diversity of background by providing flexible options for each student to acquire a strong background in all areas of the curriculum.

Courses and seminars will be open to, and will encourage enrollment by, graduate students in related programs, including Library and Information Science, Nursing, Medicine, Pharmacy, Public Health and Community Medicine, Bioengineering, Computer Science, as well as undergraduates considering a career in biomedical informatics. The involvement of these students will generate new ideas for research projects, e.g., nursing students will learn about clinical databases and knowledge representation in a clinical decision-support course. They may see an opportunity to apply data mining to discover new interactions between treatment of illness, social conditions, and cultural attitudes. Computer science students interested in advancing the state of software design will take a course on clinical information systems and see an opportunity to apply a new design idea to represent curve shapes in electrocardiogram data, or do pattern matching to automate analysis of these data. Library and information science students taking the same course will see opportunities to research health information needs and workflow of primary care clinicians in order to improve the design of information management and decision-support systems.

In a typical two year program of study the students will take one course each quarter in each of the three focal areas. Students who choose the thesis option will add to this a master's thesis. Students who choose the non-thesis option will take an additional nine credits of courses other than thesis credits and will prepare a project report. All students will attend the medical informatics research seminar in which UW faculty, other researchers and advanced students present reports on their current research projects. The Informatics Seminar Series began in 1990 and was the first credit medical informatics course developed at UW. From the beginning this was an interdisciplinary course jointly offered by the Department of Medical Education in the School of Medicine and the Department of Health Services in the School of Public Health and Community Medicine.

Each quarter every student will be assigned to a faculty mentor for independent study credit. In this way, each student is assured in the first two years of becoming closely acquainted with at least six faculty members in the program. The independent study may consist of a series of readings and a short paper, or a programming project, or other activities to acquaint the student with the faculty member's area of expertise.

2.2 Biology and Health Focal Area

Courses in Foundations of Biology,

Clinical Medicine and Health Care Delivery and Organizations are new courses which will address the Biology and Health focal area. Foundations of Biology will cover fundamental concepts of molecular biology and the conduct of biological research. It provides the background to understand, for example, the content of genetic databases. Clinical Medicine will provide an overview of concepts and issues in the clinical arena for those informatics students without a clinical background. Health Care Delivery and Organizations provides an understanding of the organization, functioning, and performance of the health-care and public health systems including the economic, social, technological, and political factors that affect the health system. These latter two are essential material to be able to design and evaluate computer systems in a medical/health-care context.

2.3 Computing and Information Science Focal Area

The Computing and Information Science courses include some existing courses and some new ones. Our goal is to create a sequence that will develop programming skills, and gain an understanding of the computing environment (operating systems, networks, databases), principles of information retrieval and management systems, and concepts of artificial intelligence. Three existing courses: Computing Concepts for Biomedical Informatics, Information Retrieval Systems, and Artificial Intelligence, address some of these topics. New courses to be created are: a course on database systems and a programming projects course, which will primarily be a laboratory course utilizing the laboratory facilities of the program.

2.4 Biomedical and Health Informatics Focal Area

In the domain area, Biomedical and Health Informatics, Introduction to Biomedical Informatics provides a survey of the concepts, application areas and historical foundations of biomedical informatics. Critically Appraising and Applying Evidence in Health Care, addresses appraisal of clinical information from literature, strengths and weaknesses of data, analyses, study design/applicability to a current patient's problem. It is important background for students working on decision-support systems. Where does the knowledge come from that goes into medical expert systems? How reliable is it? New courses will be developed to provide depth in areas that are surveyed in the introductory course. These are the bridge to research so students will choose according to their research interests from among them. They address a wide range of areas of application of computing to medicine and health care. Clinical Decision-Support Systems addresses quantitative and symbolic decision models (multiple logistic regression, decision analysis, Bayesian reasoning, belief networks, heuristics and their biases, decision tables, flowcharts, rule-based systems, neural networks, intelligent agents) and also psychology of judgment and decision making. Research and Evaluation Methods in Informatics is important for projects that build, deploy and evaluate computer systems in clinical or other health-care settings. Medical Imaging Informatics provides an overview of the organization of medical image data, retrieval and display of images, application to telemedicine, integration of images in medical record systems. Thesaurus Design introduces vocabulary and data dictionary issues and potential solutions in health care. Structural Informatics covers the representation of human anatomy concepts and relationships in frames and semantic networks, and derivation of anatomic objects from images and related concepts. Clinical Information Systems describes the concepts, uses and problems in design of the computer-based medical record. Telemedicine addresses the use of high-speed networks to provide new kinds of information access over wide areas for remote consultation. This includes the problems of information protection, authorization and organization of the practice of telemedicine. Integrated healthcare systems design looks broadly at the experience of IAIMS institutions nationally, lessons learned and strategies for leading such systems development across a distributed healthcare enterprise.

2.5 Types of Degrees and Training

The new UW Biomedical and Health Informatics program will offer both the research-oriented and professional Master's degree beginning in 2000 as well as a Ph.D. program. Graduates will have a strong background for careers in health-care institutions, as software developers or managers in industry, and in research both in the academic centers and in industry. In addition we will continue to offer mentoring opportunities in biomedical informatics, from short-term preceptorships to long-term fellowships in a variety of settings from primary care clinics and specialty care settings to public health clinics and libraries.

3. Conclusion

The Biomedical and Health Informatics program at the University of Washington has evolved over a number of years with rapid growth since the creation of the Division of Biomedical Informatics in 1997. We will continue our research focus in areas of existing strength including clinical informatics, structural informatics, imaging informatics, integrated systems design and telemedicine as well as build upon new areas of faculty research interest such as applications of the Next Generation Internet.

The new graduate informatics degree program will enhance and synergize the existing interdisciplinary research and training activities in biomedical and health informatics and, we hope, will contribute outstanding informatics professionals and researchers who can continue to evolve the vital area of biomedical and health informatics.

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