NATURAL-LANGUAGE PROCESSING FOR COMPUTERIZED PATIENT MEDICAL RECORDS

Proposal for the Multidisciplinary Pilot Project Program

1 PRINCIPAL INVESTIGATORS:

1. William J. Rapaport, Associate Professor, Department of Computer Science, 226 Bell Hall, North Campus, 645-3180 x 112, rapaport@cs.buffalo.edu

2. Stuart C. Shapiro, Professor, Department of Computer Science, 226 Bell Hall, North Campus, 645-3180 x 125, shapiro@cs.buffalo.edu

3. Peter Winkelstein, Clinical Assistant Professor, Department of Pediatrics, Children's Hospital of Buffalo, 219 Bryant St., Buffalo, NY 14222, 853-7900 x 240, pwinkels@ubmedb.buffalo.edu

2 GOAL:

- Production of a preliminary natural-language interface and knowledge-representation and reasoning system for a computerized patient medical record.

- Rapaport and Shapiro will supply the expertise in natural-language processing and knowledge representation and reasoning, using the SNePS knowledge-representation and reasoning system.

- Winkelstein will supply the expertise in the structure of patient records and the requisite kinds of input and output.

3 EXTERNAL REFEREES:

1. Medical Informatics:
   (a) G. O. Barnett, M.D., Laboratory of Computer Science, Massachusetts General Hospital, Boston, MA 02114.
   (b) W. R. Hersh, M.D., Oregon Health Sciences University, 3181 SW Sam Jackson Park, Portland, OR 97201.
   (c) J. Loonsk, M.D., Office of Information Services, School of Medicine, University of North Carolina, UNC Hospitals, Chapel Hill, NC 27514.
   (d) C. A. Sneiderman, M.D., Ph.D., National Library of Medicine, Bethesda, MD 20894.
2. Knowledge Representation and Natural-Language Processing:
   (a) Prof. James Allen, Department of Computer Science, University of Rochester, Rochester, NY 14627.
   (b) Prof. Selmer Bringsjord, Department of Philosophy, Psychology and Cognitive Science, and Department of Computer Science, Rensselaer Polytechnic Institute, Troy, NY 12180.
   (c) Prof. Lenhart Schubert, Department of Computer Science, University of Rochester, Rochester, NY 14627.
   (d) Prof. Yorick Wilks, Department of Computer Science, University of Sheffield, Regent Ct, Portobello Rd, Sheffield S1 4DP, U.K.

4 TIME REQUIRED FOR COMPLETION: 1 year.

5 AMOUNT OF FUNDING REQUESTED: $20,000

6 PROPOSED DATE FOR FULL EXTERNAL PROPOSAL: 9/98

7 POTENTIAL EXTERNAL SPONSORS:

National Science Foundation, National Library of Medicine, National Institutes of Health, National Institute of Mental Health, all of which have demonstrated an interest in natural-language processing of medical information.

8 PROJECTED AVERAGE ANNUAL BUDGET AND TIME FRAME FOR FULL PROJECT:

Budget:

salaries:	Rapaport, 2 summer months	$ 14,671
	Shapiro, 2 summer months	$ 23,149
	Winkelstein, 20% of full salary	$ 19,760
	2 RAs, 12 mos, $10,500 aca. yr.	$ 28,000
fringes:	Rapaport:	$ 2,934
	Shapiro:	$ 4,630
	Winkelstein:	$ 6,126
	2 RAs:	$ 1,960
travel to conferences:		$ 10,000
supplies		$ 500
publication costs		$ 500
computer charges to CS		$ 6,941
indirect costs		$ 63,160
Total		$182,330

Time Frame: 2–3 years

9 EXPECTED COLLABORATIONS WITH OTHER INSTITUTIONS:

None foreseen at this time.

10 KEYWORDS:

medical informatics, natural-language processing, computerized patient records, medical discharge summaries

11 RESEARCH PROPOSAL:

One of the major goals in the application of computers to medicine (medical informatics) is to produce a computerized patient record (CPR). Ideally, the CPR would contain all of a patient's medical information in a secure, reliable fashion that would allow clinicians ready access to the data needed to make informed medical decisions. In addition, computer-encoded medical data in the CPR could be used as input to an array of support programs. For example, reminders to perform routine screening, warnings of drug interactions, or even suggested diagnoses could be provided to clinicians by a computer based on the data entered into the CPR.

A critical aspect of the CPR is the encoding of the medical data. The advantage of the CPR over paper records lies in the ability to easily extract, and incorporate into a deductive knowledge base (KB), information from the CPR. It must be possible to perform searches (queries) on the medical data. This can only be accomplished if the data is organized in a uniform way. Some medical data lend themselves naturally to encoding in a computer. Strictly numerical data, such as blood pressure, height, weight, and temperature, can be readily processed. Query parameters can be easily specified. There is, however, a large body of medical information that is not easily encoded, namely the clinician's notes.

Clinical notes are usually free-text, often with little structure and irregular grammar. They contain many terms from a specialized vocabulary and grammar (e.g, the use of 'present' as a non-transitive verb, as in "The child presented to the hospital with the heart murmur"), often with multiple ways of specifying the same concept. There are often misspellings, errors in wording, and mistranscribed words in dictated notes (e.g., the name 'Kay Seal' for the chemical 'KCl' (potassium chloride)). This makes the process of encoding clinical notes difficult. Although this data could be simply recorded in the CPR, it would lose much of its potential. The free text must be transformed into an organized, standard format so that it can be used as input to both queries and support programs. The computer must in some sense "understand" the note so that it can then answer questions about the medical data. This, in fact, will be our methodology: to get a knowledge-representation and reasoning (KRR) system to read and "understand" a medical discharge summary in the way a human would, so that the system can then be queried, and give answers, in the way a human would. From this, a more standardized KB can be constructed.

Questions that a clinician would want answered by information in a patient's medical record typically involve data scattered throughout the record. For example, if a child presents with a urinary tract infection (UTI), a clinician would want to know if there have been any other episodes of UTIs, any previous urine studies, any radiographic studies, any family history or past medical history of kidney problems, any history of chronic medical problems, etc. Much of this information, in a paper record, is contained in clinical notes of one sort or another. It is always time-consuming, and often impossible, to find all of the information needed in the paper record. Some information may be illegible, misplaced, or incomplete. This is one of the chronic roadblocks to providing care that clinicians face. One major benefit of the CPR is the ability to remove this roadblock. An effective CPR should be able to abstract the information that a clinician needs from multiple sources and present it in an organized way. The computer should do the "thumbing through the chart" and do it more accurately, completely, and rapidly than a clinician. To perform this task, the computer must be able to find the important information in clinical notes. This requires that the computer be able to recognize multiple ways of referring to the same information (e.g., many synonyms, abbreviations, and grammatical forms), as well as be able to make inferences about what information is related (e.g., urine cultures and UTIs).

Current commercial CPR programs commonly use two methods for dealing with clinical notes. One is to simply capture the free text in an unprocessed form. This fails to provide any of the benefits that CPRs have over paper records. The information in the clinical notes is essentially lost to the computer. There is no attempt made to understand the text or to allow anything but simple word searches on the information it contains. A clinician can only obtain the medical data in the notes by paging through the record and reading the entered text. This is essentially no different than a paper record and may even be less efficient. The second method is to control the vocabulary that clinicians can use. Instead of allowing free-text entry, a clinician is forced to use terms selected from a defined list. Although this makes the task of encoding data trivial, it severely limits the ability of the clinician to express the nuances of the medical findings. Some hybrid systems have been tried, involving a controlled vocabulary with free-text comment fields, but these systems inherit all of the problems of the two methods. Neither approach is entirely satisfactory. An ability to interpret the natural language of the clinical note is, although more difficult than either method described, the only method that promises to deliver the benefits from computerization of the medical record.

We hope to contribute to the effort of understanding free-text clinical notes by using techniques from artificial intelligence (AI) and computational linguistics (or natural-language processing (NLP)). NLP by computer has been used in many different contexts. Its goal is to obtain information from free text, and hence is ideally suited to be applied to problem of the clinical note in the CPR.

We propose to extract medical information from one form of clinical notes, the medical discharge summary (MDS). MDSs are the dictated reports of hospital stays for individual patients. The summaries we will use are the dictated reports of hospital stays for individual pediatric patients at the Children's Hospital of Buffalo. They contain a concise report of the events leading to hospital admission, the course of the patient's care in the hospital, and the outcome of the stay. The dictations are made by the resident physicians caring for the patient after discharge. They have been transcribed into text files as part of the usual process of patient documentation and are thus available to us in computer-readable form. Because there are many residents, the discharge summaries will have a variety of styles and formats. We will use MDSs dictated for patients of one of us (Winkelstein) that cover a range of diagnoses. We wish to extract such information as:

Chief Complaint (presenting problem),
History of Present Illness,
Past Medical History,
Family History,
Physical Exam Findings,
Laboratory Findings,
Admission Diagnosis,
Admission Management Plan,
Admission Condition,
Hospital Course,
Discharge Diagnosis,
Discharge Plan,
Discharge Condition.

This represents the key medical data that a clinician would wish to know about a hospital stay. It is currently available in the paper record only in the form of a printed copy of the dictation.

In this pilot project, we plan to demonstrate that the NLP and KRR techniques of SNePS, developed by some of us (Shapiro, Rapaport; see below), can be applied to the medical field. We will extend this existing technology so that we can obtain organized medical information from sample MDSs. Future directions for this research would include increasing the number of MDSs processed, processing other forms of clinical notes (e.g., dictated progress notes), incorporating the extracted data into a CPR, and interfacing the extracted data to support programs (e.g., diagnosis-generation systems).

SNePS, the Semantic Network Processing System, is a KRR system that has an English lexicon, morphological analyzer/synthesizer, and a generalized augmented-transition-network parser-generator for NLP that, rather than building an intermediate parse tree, translates English input directly into a semantic interpretation represented as a propositional semantic network (Rapaport 1988, 1991; Shapiro 1982, 1989; Shapiro & Rapaport 1995). Nodes in a SNePS network represent concepts, linked by labeled arcs. All information, including propositions, is represented by nodes; propositions about propositions can be represented without limit. Arcs form the underlying syntactic structure of SNePS. Arc-paths can be defined for path-based inference, including property inheritance within generalization hierarchies. Nodes and represented concepts are in 1-1 correspondence. This uniqueness principle guarantees that nodes are shared whenever possible and that nodes represent intensional objects (e.g., concepts, propositions, properties, and objects of thought) (Shapiro & Rapaport 1987, 1991). SNePS's inference package accepts rules for deductive and default reasoning, allowing the system to infer "probable" conclusions in the absence of contrary information. When combinations of asserted propositions lead to a contradiction, the SNeBR belief-revision package allows the system to remove from the inconsistent context one or more of those propositions (Martins & Shapiro 1988). Once a premise is no longer asserted, the conclusions that depended on it are no longer asserted in that context.

In the pilot project, we plan to develop a grammar and lexicon for semantic and pragmatic interpretation of the MDSs in such a way that the desired information can be extracted easily. I.e., the input to our system will be on-line MDSs; the output will be a deductive KB of desired information; and the intervening NLP and KRR algorithms will be supplied by SNePS. Without such a pilot project, it would be impossible to foresee difficulties that may arise. For example, a review of some recent medical-informatics literature indicates that there are bottlenecks in identifying certain noun phrases in MDSs (Evans et al. 1996, Johnson & Friedman 1996, Spackman & Hersh 1996). On the other hand, the extant literature suggests that no one has yet attempted to use a robust KRR system on such medical data, although there are similar projects that use newspaper stories: e.g., Chinchor et al. 1993. However, these projects, no matter how robust they may be, seem to us to be insufficiently "cognitive". In the medical informatics field, most researchers seem to be using straightforward NLP software to process the records (e.g., Spackman & Hersh 1996). However, no one seems to be using more advanced AI techniques that would allow the computerized record to be used as a deductive KB. Such a KB could not only be queried in natural language by users, but could be expected to perform inferences on its "knowledge", thus being able to reason about the information in the medical record and serve as an "intelligent agent" in assisting physicians in their diagnoses. In addition, a KRR system that has some background knowledge of medical information and jargon ought to be able to handle the frequent "switching" between "medical English" and standard English that we have found in the MDSs and overcome many of the parsing problems discussed in the literature. Thus, we expect the pilot project to result in a set of clear open research problems for which a full proposal would be written.

11.1 References:

1. Chinchor, N.; Hirschman, L.; & Lewis, D.D. (1993), "Evaluating Message Understanding Systems", *Comp. Ling.* 19: 409–449.
2. Evans, D.A.; Brownlow, N.D.; Hersh, W.R.; & Campbell, E.M. (1996), "Automating Concept Identification in the Electronic Medical Record", *Proc. 1996 AMIA*, *J. American Med. Informatics Assoc.*: 388–392.
3. Johnson, S.B., & Friedman, C. (1996), "Integrating Data from Natural Language Processing into a Clinical Information System", *Proc. 1996 AMIA*, *J. American Med. Informatics Assoc.*: 537–541.

4. Martins, J., & Shapiro, S.C. (1988), "A Model for Belief Revision," *Artif. Intell.* 35: 25–79.

5. Rapaport, W.J. (1988), "Syntactic Semantics: Foundations of Computational Natural-Language Understanding," in J.H. Fetzer (ed.), *Aspects of Artificial Intelligence* (Kluwer): 81–131.

6. Rapaport, W.J. (1991), "Predication, Fiction, and Artificial Intelligence," *Topoi* 10: 79–111.

7. Shapiro, S.C. (1982), "Generalized Augmented Transition Network Grammars for Generation from Semantic Networks," *American J. Comp. Ling.* 8: 12–25.

8. Shapiro, S.C. (1989), "The CASSIE Projects: An Approach to Natural Language Competence," in J.P. Martins & E.M. Morgado (eds.), *Proc. 4th Portugese Conf. A.I. (EPIA-89)*, Lecture Notes in A.I. 390 (Springer-Verlag): 362–380.

9. Shapiro, S.C., & Rapaport, W.J. (1987), "SNePS Considered as a Fully Intensional Propositional Semantic Network," in N. Cercone & G. McCalla (eds.), *The Knowledge Frontier* (Springer-Verlag): 262–315.

10. Shapiro, S.C., & Rapaport, W.J. (1991), "Models and Minds: Knowledge Representation for Natural-Language Competence," in R. Cummins & J. Pollock (eds.), *Philosophy and AI* (MIT): 215–259.

11. Shapiro, S.C., & Rapaport, W.J. (1995), "An Introduction to a Computational Reader of Narrative," in Duchan, J.F.; Bruder, G.A.; & Hewitt, L.E. (eds.) (1995), *Deixis in Narrative: A Cognitive Science Perspective* (Erlbaum): 79–105.

12. Spackman, K.A., & Hersh, W.R. (1996), "Recognizing Noun Phrases in Medical Discharge Summaries", *Proc. 1996 AMIA*, *J. American Med. Informatics Assoc.*: 155–158.

12 DETAILED BUDGET:

We are requesting funds for 2 graduate students (if possible, one from Computer Science and one from Pediatrics) to serve as research assistants: \$9,090 stipend/RA + \$909 fringe/RA = \$9,999/RA

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EDUCATION:

Ph.D., 1976, Indiana University (philosophy)
A.M., 1974, Indiana University (philosophy)
M.S., 1984, State University of New York at Buffalo (computer science)
B.A., 1968, University of Rochester (mathematics)

EXPERIENCE:

State University of New York at Buffalo:

Associate Professor of Computer Science (1988–present)
Adjunct Professor of Philosophy (1994–present)
Assistant Professor of Computer Science (1986–1988)
Visiting Assistant Professor of Computer Science (1984–1986)

State University of New York, College at Fredonia:

Associate Professor of Philosophy (1983–1984)
Assistant Professor (1976–1983)

RESEARCH:

Cognitive science, knowledge representation, and computational linguistics. Published over 50 articles in artificial intelligence, cognitive science, computational linguistics, philosophy of mind, and philosophy of language. Review Editor of the journal *Minds and Machines*. Received grants and fellowships from NSF, NEH, and Research Foundation of SUNY for work on cognitive and computer systems for understanding narrative text, the logical foundations of belief representation, and natural-language semantics.

5 MOST RECENT REFEREED JOURNAL PUBLICATIONS:

1. Rapaport, W. J. (1991), "Predication, Fiction, and Artificial Intelligence", *Topoi* 10: 79–111.
2. Shapiro, S. C., & Rapaport, W. J. (1992), "The SNePS Family", *Computers and Mathematics with Applications* 23: 243–275.
3. Rapaport, W. J. (1993), "Because Mere Calculating Isn't Thinking", *Minds and Machines* 3: 11–20.
4. Rapaport, W. J.; Shapiro, S. C.; & Wiebe, J. M. (forthcoming, 1997), "Quasi-Indexicals and Knowledge Reports", *Cognitive Science*, Vol. 21.
5. Rapaport, W. J. (forthcoming), "How Minds Can Be Computational Systems", *Journal of Experimental and Theoretical Artificial Intelligence*.

OTHER PUBLICATIONS RELATED TO PILOT PROJECT (5 MAXIMUM):

1. Rapaport, W. J. (1986), "Logical Foundations for Belief Representation", *Cognitive Science* 10: 371–422.
2. Shapiro, S. C., & Rapaport, W. J. (1987), "SNePS Considered as a Fully Intensional Propositional Semantic Network", in N. Cercone & G. McCalla (eds.), *The Knowledge Frontier* (New York: Springer-Verlag): 262–315.
3. Rapaport, W. J. (1988), "Syntactic Semantics: Foundations of Computational Natural-Language Understanding", in J. H. Fetzer (ed.), *Aspects of Artificial Intelligence* (Dordrecht, Holland: Kluwer): 81–131.
4. Peters, S. L., & Rapaport, W. J. (1990), "Superordinate and Basic Level Categories in Discourse", *Proc. 12th Annual Conf. Cognitive Science Soc.* (Hillsdale, NJ: Erlbaum): 157–165.
5. Shapiro, S. C., & Rapaport, W. J. (1995), "An Introduction to a Computational Reader of Narratives", in J. F. Duchan, G. A. Bruder, & L. E. Hewitt (eds.), *Deixis in Narrative* (Hillsdale, NJ: Erlbaum): 79–105.

CURRENT RESEARCH SUPPORT: None.

PROPOSALS CURRENTLY UNDER REVIEW: None.

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EDUCATION:

Ph.D., 1971, University of Wisconsin (Computer Sciences)
M.S., 1968, University of Wisconsin (Computer Sciences)
S.B., 1966, Massachusetts Institute of Technology (Mathematics)

EXPERIENCE:

State University of New York at Buffalo:

Chair of Department of Computer Science (1984–90, 1996–present)
Professor of Computer Science (1983–present)
Associate Professor of Computer Science (1978–83)
Assistant Professor of Computer Science (1977–78)

Indiana University, Bloomington, IN:

Associate Professor of Computer Science (with tenure, on leave) (1977–78)
Assistant Professor of Computer Science (1972–77)
Visiting Assistant Professor of Computer Science (1971–72)

University of Wisconsin, Madison, WI:

Lecturer of Computer Science (1971)

RESEARCH:

Prof. Shapiro's research interests are in artificial intelligence, cognitive science and computational linguistics, specifically, knowledge representation, reasoning, and natural language processing. He is a Fellow of the American Association for Artificial Intelligence, past Chair of ACM's Special Interest Group on Artificial

Intelligence, Conference Chair of The Sixth International Conference on the Principles of Knowledge Representation and Reasoning, and is author or coauthor of over 150 technical articles and reports.

5 MOST RECENT REFEREED JOURNAL PUBLICATIONS:

1. S. S. Ali and S. C. Shapiro, Natural language processing using a propositional semantic network with structured variables. *Minds and Machines 3,* 4 (November, 1993), 421–451.
2. Deepak Kumar and Stuart C. Shapiro, The OK BDI Architecture. *International Journal of Artificial Intelligence Tools 3,* 3 (March, 1994), 349–366.
3. Stuart C. Shapiro, Computationalism. *Minds and Machines 5,* 4 (November, 1995), 517–524.
4. Stuart C. Shapiro, Formalizing English. *International Journal of Expert Systems 9,* 1 (1996) 151–171.
5. William J. Rapaport, Stuart C. Shapiro, & Janyce M. Wiebe, Quasi-Indicators and Knowledge Reports. *Cognitive Science,* in press.

OTHER PUBLICATIONS RELATED TO PILOT PROJECT (5 MAXIMUM):

1. J. G. Neal and S. C. Shapiro, Knowledge-based parsing. In L. Bolc, Ed. *Natural Language Parsing Systems.* Springer-Verlag, Berlin, 1987, 49–92.
2. S. C. Shapiro, The CASSIE projects: an approach to natural language competence. In J. P. Martins & E. M. Morgado, Eds. *EPIA 89: 4th Portugese Conference on Artificial Intelligence Proceedings. Lecture Notes in Artificial Intelligence 390.* Springer-Verlag, Berlin, 1989, 362–380.
3. S. C. Shapiro and W. J. Rapaport, The SNePS family. *Computers & Mathematics with Applications 23,* 2–5 (January–March, 1992), 243–275.
4. S. C. Shapiro and W. J. Rapaport, An Introduction to a Computational Reader of Narratives. In J. Duchan, G. Bruder, and L. Hewitt, Eds. *Deixis in Narrative: a Cognitive Science Perspective,* Lawrence Erlbaum, Hillsdale, NJ, 1995, 79–105.

5. Susan M. Haller and Stuart C. Shapiro, IDP — An interactive discourse planner. In G. Adorni & M. Zock, Eds. *Trends in Natural Language Generation: An Artificial Intelligence Perspective. Lecture Notes in Artificial Intelligence 1036.* Springer-Verlag, Berlin, 1996, 144–167.

CURRENT RESEARCH SUPPORT:

- “Intelligent Agent Integration,” Unisys/ARPA, $40,583/year.
- “Development of Foveal Gaze Control in GLAIR,” Amherst Systems/NASA, $50,638/year.
- “Genetically Programmed Dextrous Manipulator,” Apple Aid/ONR, $13,816/year.

PROPOSALS CURRENTLY UNDER REVIEW:

“Pragmatic Question Answering” is to be submitted to N.S.F. by February 21, 1997. The budget is not yet formulated.

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EDUCATION:

Board Certified in Pediatrics by American Board of Pediatrics
Residency in Pediatrics completed 6/93, Children's Hospital of Buffalo
M.D., 1990, State University of New York at Buffalo
M.S., 1982, State University of New York at Stony Brook (astronomy)
B.S., 1979, University of Rochester (physics and astronomy)

EXPERIENCE:

Clinical Assistant Professor of Pediatrics (1994–present), State University of New York at Buffalo
Medical Director (1994–present), West Side Health Center and Towne Gardens Health Center, Buffalo, NY
Chief Resident (1993–1994), Children's Hospital of Buffalo
Senior Computer Programmer (1982–1986), Axcom Ltd, Los Angeles, CA

RESEARCH:

Medical Ethics, Medical Informatics

5 MOST RECENT PUBLICATIONS:

1. Winkelstein, Peter (1996), "Failure of Patients to Return to Clinic Drops Immunization Rate from over 90% to 75% in Inner-City Buffalo", *New York State Pediatricial* (Fall 1996).
2. Winkelstein, Peter (1996), "Assessment of Immunication Rates in Inner-City Buffalo", *New York Family Physician* 48:4.

3. Winkelstein, Peter (1996), "Negoitating towards Death", *Sh'ma* 26/508, 3.

4. Winkelstein, Peter (1994), "Thoughts on the Case of Baby K", *Trends in Health Care, Law, & Ethics* 9:1, 41.

5. Winkelstein, Peter et al. (1983), "A Determination of the Composition of the Saturnian Stratosphere using the IUE", *Icarus* 54: 309–318.

OTHER ITEMS RELATED TO PILOT PROJECT (5 MAXIMUM):

1. Winkelstein, Peter (1996), "Using ODBC to Link a Legacy System with Multiple Applications", poster talk, American Medical Informatics Association Fall Symposium, Washington, DC.

2. Feld, Leonard G., & Winkelstein, Peter (1995), "Fluids and Electrolytes", computer-aided instruction program, Health Sciences Consortium, Chapel Hill, NC.

3. Winkelstein, Peter (1995), "A Prescription-Writing Tool for a Primary Care Pediatric Office", electronic poster talk at the SCAMC meeting of the American Medical Informatics Association, New Orleans, LA.

CURRENT RESEARCH SUPPORT: None

PROPOSALS CURRENTLY UNDER REVIEW: None