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Medical Decision Support via the Internet: PRO*forma* and Solo

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Abstract

This paper describes the development and application of an integrated technology to support the authoring of intelligent medical knowledge services, such as decision and guideline support, and disseminate them over the Internet. Decision support and guideline enactment are provided by the PROforma technology which is described in detail elsewhere. Solo is a communications infrastructure that supports the delivery of PROforma services over the Internet using a web browser. The PROforma-Solo technology brings together techniques from knowledge engineering and artificial intelligence with software engineering and the Internet to flexibly support decision making and patient management at the point of care. A variety of clinical applications have been implemented and are briefly described.

Keywords:

Decision support; clinical guidelines; Internet; interchange formats; PRO*forma*

Introduction

Computers are now widely used in all areas of healthcare. Until recently applications have been more concerned with administrative than clinical roles. However, the clinical role is expected to increase significantly over the coming years, as governments and healthcare agencies and institutions seek to provide more consistent and high quality care, optimise resource use and contain costs, and help health professionals work together more effectively. New technologies such as intranets, extranets, electronic health records (EHR) and guideline-based clinical decision support systems are likely to play an important part in achieving these objectives.

Clinical guidelines and protocols have been found to improve clinical practice [1] and are increasingly being recognised as an important means by which evidence-based practice can be translated into routine healthcare. Computer-based decision support centred on the use of electronic guidelines has also been shown to be capable of providing significant assistance in improving clinical outcome [2].

There is now a major interest in the use of advanced clinical decision support and "intelligent" guideline technologies and applications and the development of standards to support these services. The first technical approach to this problem was the Arden Syntax [3] which is widely used to provide basic decision support capabilities, particularly in the US. More recent research aims to extend the scope of these technologies, to support research protocols, clinical workflow, care pathways and other relatively complex tasks.

The PRO*forma* guideline representation language [4] and associated software for the authoring and enactment of electronic clinical guideline applications (Figure 1) is one technology for providing task-based knowledge services. The language has sound formal foundations [5] and the technology has been used to develop a number of applications. Other approaches include the Guideline Interchange Format (GLIF) under development by the Intermed Collaboratory in the US [6], the ASBRU technology being developed by Shahar, Miksch and others [7], and the PRODIGY 3 technology for the management of chronic diseases [8].

The Internet is increasingly being used by healthcare providers and has the potential to become a fundamental tool and infrastructure in 21st century healthcare [9, 10]. Clinical intranets are becoming established in hospitals and offer significant advantages by providing direct delivery of patient information, inter-departmental communication and other services at or near the point of care with a consistent, standard user interface. The Internet can also facilitate the integration of legacy systems and extend the scope of existing applications by providing a means of linking different services via messaging and browser technologies.

This paper brings these three themes together, describing work which is aimed at delivering PRO*forma*-based decision support, guidelines, care pathways and other knowledge-based services to the point of care via the Internet, providing flexible and interactive capabilities by means of standard web browsers.

A brief description of PRO*forma*

PRO*forma*[1] is a formal knowledge representation language that is capable of capturing the logical and procedural content of a guideline, protocol, care pathway etc. in the form of a set of "tasks" that can be interpreted or "enacted" by a computer. The PRO*forma* language supports four main classes of task:

Action: any unitary task required for a patient's care, ranging from a simple injection to a complex surgical procedure.

Enquiry: an action whose principal function is to return information, from data entered in a form on a screen to a complex computer-based imaging function.

Decision: any kind of medical choice, such as a decision about a patient's diagnosis, treatment, prognosis, level of risk, need for referral, etc.

Plan: a set, or a sequence, of tasks carried out over time, to achieve some clinical objective. PRO*forma* is defined recursively over plans so that an application can include a hierarchical task structure of any complexity.

PRO*forma* applications are developed using an integrated set of graphical design and testing tools, shown in Figure 1.

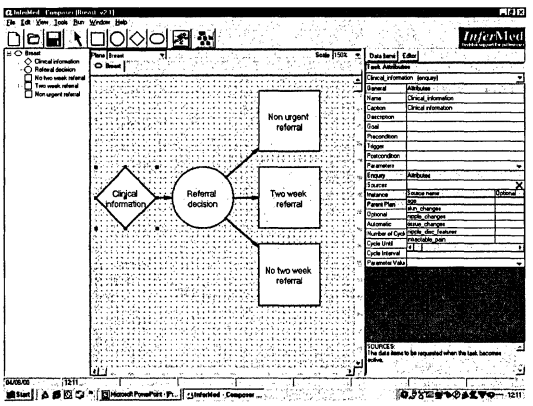

Figure 1 - A simple PROforma guideline to support the referral of patients suspected of having breast cancer being developed using the commercial toolkit (InferMed's Arezzo® toolkit, see www.infermed.com). The PROforma standard includes a set of standard icons for tasks (e.g. enquiries are represented by diamonds, decisions by circles and scheduling constraints by arrows)

The PRO*forma* toolkit supports a well-defined development methodology for designing and supporting clinical processes. First we define the high-level structure using a task-drawing tool (centre of Figure 1). Plans, decisions, actions etc can be composed into arbitrarily complex networks. Then the details of each task are added using standard editing tools (e.g. the tabular editor on the right of Figure 1).

A distinguishing feature of the PRO*forma* format is the simplicity and intuitiveness of the underlying task model. PRO*forma* has proved to be very versatile, and can seemingly capture an indefinite range of clinical tasks including decision-making under uncertainty, scheduling of tests and other actions over time, generating reminders for patient data collection, and monitoring of adverse events, and the management of complex clinical trials, in a range of knowledge domains, user environments and clinical settings.

A range of applications has been successfully built to support patient care and clinical research using the PRO*forma* technology. Applications include CAPSULE, a system for advising on routine prescribing [11]; RAGs a system designed to support the assessment of risk of familial breast and ovarian cancer in a primary care setting [12]; ARNO, a pain control system for cancer sufferers, built for St. Christopher's Hospice, London; RetroGram^{TM}, a system for advising on medication for HIV+ patients and MACRO, a system for running Internet-based multicentre clinical trials (see www.infermed.com). Objective evaluations of selected systems have demonstrated their potential to improve clinical practice and resource usage [11, 12].

A more recent application, ERA, has been developed to assist general practitioners in the UK in making decisions about whether or not to refer suspected cancer patients for specialist care. Among the requirements for this application are the ability to maintain the referral guidelines centrally (since they are intended to be used nationally) and also to link to other services such as on-line booking systems, electronic patient record (EPR) systems and prescribing, data gathering and auditing systems. These requirements are naturally met using an Internet technology designed to permit PRO*forma* applications over the world-wide-web.

Running guidelines over the Internet

The early PRO*forma* guideline applications, like CAPSULE, RAGs and RetroGram^{TM} were designed to run with customised user interfaces on standalone workstations. To meet the requirements of ERA and similar applications we have developed a generic communications infrastructure, Solo, which permits clinical guidelines driven by a PRO*forma* enactment engine to be run in distributed environments such as the Internet.

Solo is made up of three main components, each of which helps control and validate the communications flow between the WWW client and server and the PRO*forma* enactment engine running the application. Figure 2 summarises the architecture.

[1] PRO*forma* and its associated technology were the main results of the EU 4th Framework PROMPT project (HC 1041), completed in 1999.

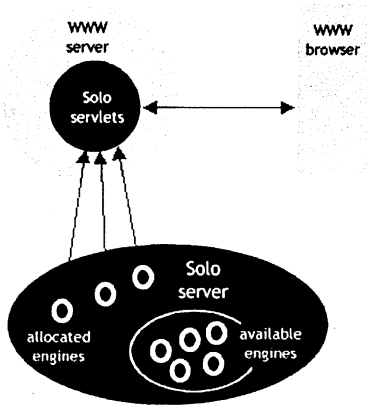

Figure 2 - Solo architecture

The Solo Java server manages a pool of available PRO*forma* enactment engines. It allocates an engine at the initiation of an enactment session, monitors its use over the course of that session and frees the instance at the conclusion of the session.

Solo Java servlets work alongside the WWW server, supporting data management and exchange between the web browser and a PRO*forma* engine during guideline enactment.

A Java wrapper encapsulates each PRO*forma* engine running a guideline application. It manages communications between the guideline and the Solo servlets. The Java wrappers and CORBA technology ensure interoperability between PRO*forma* guideline applications, written in Prolog, and web browser technologies.

An integrated technology for guideline authoring and WWW enactment

Together PRO*forma* and Solo support the complete cycle of guideline development and delivery over the WWW. The PRO*forma* guideline representation format captures the knowledge content of guidelines; PRO*forma* enactment software runs the applications and Solo provides the communications components and the WWW user interface for the application.

During a guideline enactment session, the clinical user is guided along the "pathways" of a guideline relevant for a specific patient. Data are entered as requested to enable a patient profile to be built up, decisions to be made and courses of action to be proposed.

Figure 3 illustrates the use of the ERA applications in providing decision support on whether to refer a patient suspected of having lung cancer.

Together, PRO*forma* and Solo form a powerful tool to support generalised decision making and process management by computer at the point of need. We anticipate that they will also provide the core technology to support the enactment of guideline applications on the new technologies that are expected to become widespread in healthcare, such as mobile PDAs connected remotely to hospital Intranets.

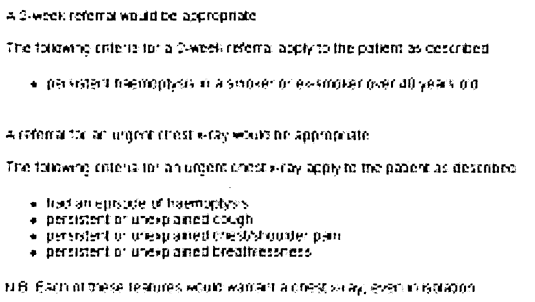

Figure 3 - Preferred management options proposed at the conclusion of a lung cancer guideline enactment session.

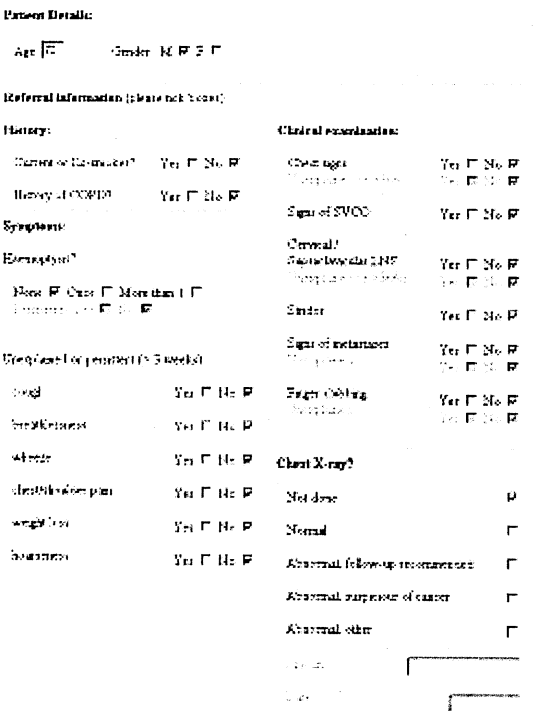

Figure 4 - Data gathering for a PROforma guideline - an enquiry requesting information concerning a patient suspected of being at risk of lung cancer

Demonstrator applications

This technology has formed the basis of several demonstrator applications. ERA is the most complete to

date, providing an implementation of the UK Department of Health's "Referral Guidelines for Suspected Cancer" [13], to support General Practitioners in identifying those patients with suspected cancer that should be referred under the two-week standard. Part of this application, a guideline for the early referral of patients with suspected lung cancer is illustrated in Figure 4. The figure shows a web-based data entry screen for a PRO*forma* guideline task - an enquiry - requesting information concerning a patient with possible lung cancer.

Figure 4 also shows how default values can be automatically inserted into data element entry fields on a page when a guideline is initiated. The user is allowed to revert to these at any time. Page parsing functions ensure that customised WWW pages remain valid if a guideline is modified without its associated web pages being updated; Solo will warn the user if, for example, data elements are requested which are no longer required by the guideline. Further, new data elements required by an updated guideline for which customised pages have not been designed will be automatically built and appended to these pages.

The ERA data collection task is shown in a customised user interface enactment page, but the core technology supports the automatic generation of standard web pages. If pages for a specific application have not been separately developed, Solo follows predefined style sheet directives to dynamically build all necessary data entry forms and web pages, adhering to a standard look-and-feel. In this way, PRO*forma*-generated guidelines can be run as soon as they are loaded onto a suitable server. Dynamically generated pages can be captured by the user for future use, allowing the technology to be used as a rapid application user interface development tool.

Customised pages can significantly enhance the usability and functionality of an application. Additional features can range from static charts and images to dynamically adjustable widgets.

Solo applications to date, including the ERA system, primarily use the textual and multimedia capabilities of HTML and JavaScript for customising PRO*forma* web interfaces. More sophisticated applications currently under development use Sun Corp's Java technology. Applications developed to date include:

- JavaRAGs a system for genetic risk assessment (Figure 5) which can be used to construct a family tree dynamically over the WWW and, as the system is integrated with the RAGs risk assessment guideline, data and information collected can be sent to the PRO*forma* server to provide patient-specific advice.
- JavaCadmium (Figure 6) processes mammograms and analyses breast tissue density as part of a breast cancer screening assessment. JavaCadmium is linked to an enquiry task in a PRO*forma* screening protocol and demonstrates the potential for the PRO*forma* engine to link to external data acquisition devices and legacy systems.

PRO*forma* and Solo can offer clinical services explicitly, such as expert system functions to help a user to decide whether to consult a doctor or carry out a medical risk assessment. Alternatively, they can be transparent to the user, running invisibly in the background as "autonomous agents", for hazard monitoring, managing auxhiliary systems, etc. [5]. The autonomous functions can also support an "expermedia" model of intelligent navigation of web pages. This is an extension of Rada's concept of "expertext" [14] in which autonomous reasoning functions or agents can be substituted for conventional navigation links. These can seamlessly carry out tasks on behalf of the user, or intelligently select web pages, sites or third party services by making decisions about what will be of most interest or relevance to the user.

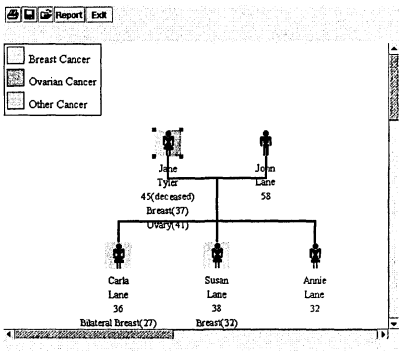

Figure 5 - Java implementation of the RAGs genetic risk assessment application

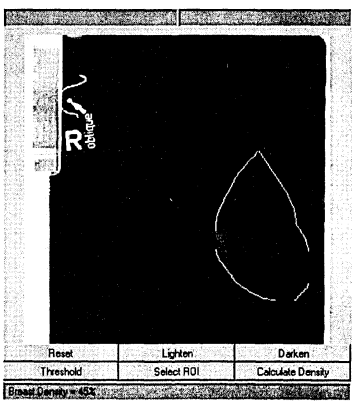

Figure 6 - Java implementation of the CADMIUM breast cancer screening application

Current activities

A number of evaluation projects of the PRO*forma* and Solo technology and applications are underway. ERA is being integrated with hospital and primary care computerised

systems to form part of the NHS Information Authority's electronic booked admissions pilot project, and the Primary Care branch of the National electronic Library for Health (NeLH-PC) will be hosting a quantitative usability and design study of ERA.

Further, in partnership with the Royal London Hospital, the PRO*forma* and Solo technology is being integrated with an ORACLE EHR system to manage protocol compliance as part of a leukaemia trial.

Conclusion

This paper has reported on the integration of PRO*forma* decision support and disease management technology with Solo, a communications infrastructure that supports the delivery of PRO*forma* services over the Internet using a web browser user interface. The technology allows clinical decision-making, scheduling, planning and other task execution capabilities to be developed and then managed through a standard browser without requiring any separate software development or installation.

Preliminary investigations encourage us to believe that the technology and applications, have considerable potential to support quality and consistency in the care process, help to improve resource usage, data collection and clinical audit, and can add significant value to current Internet technologies by bringing knowledge based decision support and intelligent guidelines directly to the point of care.

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