Mixed-initiative Decision Support for Care Planning Based on Clinical Practice Guidelines

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ABSTRACT. Care Plan On-Line (CPOL) is an intranet based system that supports a "Coordinated Care" model for chronic/complex disease management. CPOL combines provision of solicited and unsolicited advice features based on integration of the electronic medical record (EMR) with its decision support logic. The objective is to support General Practitioners (GPs) in formulating a 12-month care plan of services such that: (a) the plan is proactive and patient-centered; (b) the GP is kept in awareness of project- and disease-specific clinical practice guidelines; and (c) the support integrates with GP workflow in a natural fashion. A key feature of our approach is to blur the distinction of EMR and decision support by presenting guidelines in layers with the top-most being a problem-oriented presentation of patient status, progressing on through to patient-independent supporting evidence. In conjunction with a degree of automated inclusion of care planning services, the system demonstrates mixed user and software initiative. We describe the CPOL deployment setting, the challenges of guideline-based clinical decision support, our approach to guideline delivery, and the CPOL architecture.

RÉSUMÉ. Le système de planification des soins en ligne (CPOL) est un intranet qui repose sur un modèle de gestion des maladies chroniques et complexes. CPOL mélange la fourniture de conseils sollicités ou non à partir de l'intégration d'une base de données médicale (EMR) et de sa propre logique de décision. L'idée est d'aider les généralistes en formulant un plan de soin sur 12 mois tel que : a) le plan est proactif et centré sur le malade; b) l'attention du généraliste est conservé sur le projet et les règles de pratique cliniques concernant la maladie; c) le système s'intègre au travail de façon naturelle. Une des caractéristiques principales de notre travail consiste à rendre invisible la distinction entre la base EMR et l'aide à la décision en présentant les recommandations pratiques en couches, la plus élevée.
1. Introduction

There have been numerous projects to exploit the potential of health information networks (HINs) to provide better quality and cheaper health care [BAL 95]. A disease-specific HIN can effectively deploy innovative technology (decision support, Web, wireless pen-based computing) to coordinate care (e.g., in tuberculosis management [HRI 99]). Moreover, special-purpose decision support systems (DSSs) can provide clinical benefits such as reduction of adverse events and errors that lead to adverse events [RAS 98], [SCO 98]. However, integrated provision of HIN and DSS benefits in a generalised health care context is a more elusive goal.

In this paper we examine the issues of clinical practice guideline delivery and implementation in the context of supporting General Practitioners (GPs) in the SA HealthPlus “Coordinated Care” trial. An intranet-based system, CPOL (Care Plan On-Line), was developed to support GPs in the Coordinated Care setting as described in the next section. CPOL is designed to be flexible to fit the several disease foci of SA HealthPlus and to provide a care model that integrates decision support with the doctor’s workflow. In the following section we describe the challenges of delivering guideline-based decision support, including the issues of doctor control of the process and of uncertainty in human-readable guideline intent. Subsequently, we describe the CPOL software architecture and conclude with a summary of our approach. Further details of CPOL software are given in [WAR 99] and evaluation of its decision support utility is reported in [WAR 01].

2. Deployment setting

The Australian health care system is dominated by federally provided universal health insurance and state supported hospitals with a general absence of “managed care” in the form common in the United States. Coordinated Care is a relatively new concept in Australia, introduced in 1996-97 by the Commonwealth (i.e., federal) Government as a range of trials. One such trial ran from 1997 to 1999 in the state of South Australia, under the control of the SA HealthPlus Unit of the South Australian Department of Human Services. The SA HealthPlus trial focused on patients with
chronic and complex health problems that required high service use. It involved about 4,600 patients with diabetes, respiratory, cardiac conditions and mental illness, enrolled in ten disease-centred projects. Enrolment criteria included multiple hospital emergency events in the past year, a diagnosis appropriate to the project, and willingness to participate.

In SA HealthPlus, each patient nominates a General Practitioner (GP) to act as their Care Coordinator (CC). Being a trial, patients opt into SA HealthPlus through an informed consent process, as they would for a trial of an experimental drug or procedure. The patient consents to the creation of an electronic record for project purposes, to be shared with the CC and a supporting nurse Service Coordinator. At the heart coordination is interchange of information, and thus it is natural to expect electronic patient records and related data networks to play a major role. The SA HealthPlus record includes information collected during the trial, but also includes a merging of metropolitan hospital records and – not normally accessible to health professionals – the records of the Commonwealth Health Insurance Commission which show all reimbursable health services and medications.

Coordinated Care is meant to emphasize evidence-based, best-practice medicine. Clinical practice guidelines (hereafter clinical guidelines or simply guidelines) are standardized specifications for care developed by a formal process that incorporates the best scientific evidence of effectiveness with opinions of experts in the fields [LEA 90]. Thus, the overall movement to consolidate clinical trial findings into guidelines (as compared to relying chiefly on opinion, tradition and personal experience) is part of a trend called “evidence based medicine,” and practice in accordance with guidelines is termed “best practice medicine.” In general, guidelines have been developed in an effort to reduce escalating health care costs without sacrificing quality and have been shown to improve health care outcomes when followed [GRI 93]. Doctors can exhibit wild variation (and hence a lack of evidence-based best practice) in the extent to which they favour particular remedies [WAL 93]. To be effective, guidelines need to be integrated into the physician's decision-making process in daily practice [LAM 94].

To support best practice in SA HealthPlus, project-specific guidelines are compiled by Care Mentor groups comprised of specialists, GP opinion leaders, nurses, social workers and consumer advocates. These include base care plans of "A-level" services that are recommended to achieve adequate monitoring indexed by the patient's disease and severity. For example, 12 GP visits a year and an annual foot examination by a podiatrist are part of the base care plan for a diabetic with high severity. There are also “B-level” services which are to be included in a more discretionary fashion if indications from the medical literature appear to be met. For instance, bone density measurement should be conducted for patients with bone-thinning risk factors, such as being a post-menopausal female or having large doses of corticosteroids used in treatment of lung disease.
One of the goals of Coordinated Care is to facilitate the proactive planning of interventions instead of a crisis reaction approach. With the support of a Service Coordinator, the CC has the responsibility to formulate a 12-month plan of services. Prior to formulating the plan, a project-specific initial medical assessment is conducted and a problem and goals statement in the patient's own words is taken. The project-specific base care plan of A-level services is indexed from the assessment results. The CC then uses their judgement, supplemented by a project-specific guideline booklet, to select additional "B-level" services to tailor the base care plan to individual patient needs. The CC is the ultimate arbiter (guidelines are not immutable laws) of the care plan, and may also increase or decrease the intensity of A-level services as they see fit and in accordance with patient preferences.

The HealthPlus Coordinated Care model represents a change in practice and, in its initial paper-based incarnation, introduces a burden of novel paper flows and forms. But it also provides an opportunity for exploring novel software solutions that largely eliminate the extra flow of physical paper, and at the same time provide GPs with the benefits of computer-based decision support. An overview and ongoing evaluation of SA HealthPlus is reported in [COM 00].

3. Challenges to clinical practice guideline delivery

Challenge 1. Information Overload.

In their task of care planning, CCs are expected to follow the "best-practice" guidelines that have been formulated by the Care Mentor groups and distributed in the form of booklets. However, it is probably naïve to expect GPs to follow or even remember guidelines with relatively narrow focus (care planning is usually performed on a yearly basis) in addition to other materials on their desktops – policies, referral protocols, government circulars, adverse drug effect warnings, etc. Such guidelines may simply contribute to the GP's "information overload" [NOO 98], [HAN 99]. To be maximally effective, guidelines need to be integrated into the GP's routine workflow [ZIE 98], and the advice has to be patient-specific and provided at the time and place of consultation [GRI 93], [SHI 97].


Another major issue in electronic guideline implementation is the delivery of the advice. A "good tool" should be transparent to the user [COX 93]. – the user should be focused on the task, not the tool. Moreover, medical practitioners hold ultimate responsibility for their decisions and quite rightly reject systems that try to force decisions they themselves are not comfortable in accepting. The doctor has to be viewed as the primary source of decisions and therefore should intellectually control the process of computer-based (or rather, computer-enhanced) consultation. It is interesting that the development of expert system technology was motivated by medical problems, and yet has not made significant inroads on actual use in the medical domain [MIL 90].
In order to be successful, a medical DSS has to be fully integrated into doctors' daily workflow, be transparent to the users, yet provide some form of advice when needed [ZIE 98]. Browsing is a popular form of decision support where the system is passive, and while providing useful decision information, is not called upon to produce an explicit decision per se. Combining Electronic Medical Record (EMR) with active DSS (i.e., where the system formulates a recommendation) is important in two ways. Firstly, an increasing number of clinicians are using EMRs as their routine tool for collecting and keeping clinical information. Secondly, EMRs can provide a DSS, built on top, with the data required to generate the advice. Integration of the active DSS and EMR at the data level eliminates the need for data entry just for the sake of getting advice, a commonly cited obstacle for adopting DSS by clinicians [ZIE 98]. Integration at the interface level would allow doctors to use the DSS without restructuring their workflow, much as they currently use EMRs. Using a DSS ceases to be a separate activity and would complement routine work with the EMR. Ideally, active forms of decision support should be transparently layered on top of the EMR in order not to obstruct access to patient data and other forms of passive decision support.

Decision support advice may be solicited or unsolicited by the user. Solicited advice (i.e., decision aids initiated by the user) can be active (and inherently patient-specific) or passive (patient-specific or general). Unsolicited advice is initiated by the system and is always active [BEM 97]. Alerts and reminders are well known forms of unsolicited advice. Both solicited and unsolicited advice are important and have to be incorporated into the system in a complimentary way.

If the advice is solicited, the intention of the system user is usually known, and the appropriate information can be displayed. The challenge of unsolicited advice is that the user's state of mind is unknown. Based on relevant clinical data, the system can generate hundreds of potentially useful pieces of advice, most of which will be inappropriate in this particular moment. Not displaying the advice would nullify the purpose of the system. The key problem is how to deliver the advice in such a way that the user could take it if relevant and ignore it otherwise.

Horvitz [HOR 99] describes principles of mixed-initiative user interfaces that blend user-solicited action (as initiated, for instance, by direct manipulation actions such as a mouse click) and interface agency. A particularly relevant aspect of Horvitz's theory is a model of the expected utility of an action, A, initiated by the user interface agent given evidence, E:

\[
eu(A \mid E) = p(G \mid E)u(A \mid G) + p(\neg G \mid E)u(A \mid \neg G)
\]

where \(p(G \mid E)\) is the probability that the user has a goal, G, given evidence of user intent, E; \(u(A \mid G)\) is the utility of the user interface agent taking action, A, to achieve G given that G is in fact a goal of the user; and \(u(A \mid \neg G)\) is the (lower) utility of the agent taking action A when G is not the user's goal. Horvitz refines this model to include an intermediate agent action, D, where the agent engages the user
in dialog to clarify user goals. Such an action D has higher utility (lower cost) than immediately taking action A to affect the goal G when the user did not intend that goal, \( u(D|\neg G) > u(A|\neg G) \). In clinical practice, we consider the cost of \( A|\neg G \) to be almost prohibitively high (low utility). This owes to the undesirability of having a machine "practice medicine" (due to the unsuitability of the machine as a bearer of clinical responsibility) and the known negative reaction of clinicians to systems that present themselves as "experts" [Mit 90].

\textit{Challenge 3. Uncertainty in Guideline Intent.}

For passive decision support, guidelines are implemented as direct translation of text narratives [LIE 95]; however, for active decision support (\textit{i.e.}, providing patient-specific advice [BAR 87]) guidelines should be written in a simple "If-Then-Else" format with all of the parameters strictly defined using routinely collected clinical data [SHI 97]. Such restructuring of guideline statements is a significant challenge [GOR 97], where uncertainty in text narratives plays a major role [WAR 00].

Lack of clarity of content in clinical guidelines is a major obstacle. When closely examined, the guidelines "often prove to be either high-level overviews, or simplified idealisations which reduce a range of alternative decision-making pathways in a single normative sample." They are not intended to be literally and directly applied, they specify a "mixture of procedural and criterion-based knowledge, which the clinicians are tacitly expected to adjust and adapt according to the specific of a case" [GOR 97]. "Waffling statements, such as "in certain circumstances," "under some conditions" and "some experts advise" cannot be computed until the circumstances and conditions are defined precisely" [ZIE 98].

While natural languages (\textit{e.g.}, English) are quite suitable to express uncertainty in terms that seem acceptable among humans, present algorithmic languages call for precise recipes, and the translation from the first representation to the second is not straightforward. Various types of uncertainty that may be present in text-based guidelines are:

1. \textit{Lack of information.} Not every observation of relevance to a guideline may be available or has been collected, in which case an educated guess sometimes has to be made. Even if collected, the information can be unreliable.

2. \textit{Non-specificity.} Connected with sizes (cardinalities) of relevant sets. Frequently guidelines refer to "other conditions," "other risk factors," "other significant comorbidities," leaving it up to the doctor to decide what they are. To be translated into an algorithmic language, an explicit list of those conditions is required [ZIE 98].

3. \textit{Probabilistic nature of data and outcomes.} There are few clinical signs that unequivocally point to a medical condition, and therefore to a predefined course of actions. Sensitivity and specificity of most clinical tests are far from ideal, and consequently they point to a likelihood, rather than presence or absence of medical
condition. The words “usually”, “likely”, “commonly”, “possibly”, etc., express this type of uncertainty in text-based guidelines.

4. Vagueness in the formulation of recommendations. What is the meaning of such phrases as “suggested,” “recommended,” “should be strongly considered” or “not routinely warranted?” The guidelines allow for situations in which the recommendation may not be appropriate, without specifying the exact conditions. They urge but not force doctors to follow the recommendations, and thus do not supplant their decision making process.

5. Strife (or discord). Conflicts among the various sets of alternatives. Conflicting guidelines are not necessarily a feature of poor design or lack of expert agreement. For instance, in treating a severely ill infant, there may be no reasonable choice but to employ a drug that is generally contraindicated for young children but that has a proven benefit for similarly afflicted adults. The doctor has to apply judgement and experience in all cases, some of which include operating outside of guidelines or in the presence of conflicting ones.

6. Fuzziness in determination of clinical signs that trigger the guidelines. It can be subjectivity in the assessment of a patient’s symptoms, or in the interpretation of precise objective data, such as laboratory test results or even a patient’s age. What exactly is the size of an “enlarged liver?” What exactly do we mean by “infants” or “middle-aged men?”

Fuzzy logic (FL) is one approach for dealing with various sources of uncertainty [ZIM 96]. The main advantage of FL is that it allows transparency in knowledge representation. Formulation of decision rules mimics human thinking, and fuzzy logic permits one to construct fuzzy algorithms, flexible enough to represent the narratives of clinical guidelines. The key concept of FL is that of partial membership of elements in a set. In contrast to classical, “crisp” sets, where an element either belongs to the set or not, FL allows for degree of belonging to the set, usually real values taken from the range of 0 to 1, with 1 standing for complete membership and 0 for non-membership [ZIM 96].

When guideline statements are translated into If-Then-Else rules, the antecedents of the rules become fuzzy statements involving linguistic rather than numerical variables. Linguistic variables are variables whose range of values are fuzzy sets. The following example illustrates the difference between crisp and fuzzy statement.

If Body Mass Index > 30 then provide dietary advice;

If patient is obese then provide dietary advice.

Even though obesity is often interpreted as BMI > 30, the two preceding statements are not equivalent [WAR 00]. For instance, if the patient is 170 cm tall and weighs 86.6 kg (BMI = 29.96), the rule does not apply. Now let this patient have two cups of tea (300g liquid intake), and his BMI becomes 30.07, suddenly indicating a visit to dietician. Of course, dietary advice is equally applicable in both cases, and thus using classical logic (rule predicate BMI > 30) is not satisfactory.
To incorporate fuzziness, CPOL represents guidelines as fuzzy If-Then rules, and attaches a membership function to each linguistic variable. Methods of construction and calculation of membership functions are reported in [AMA 95]. Aggregation of various fuzzy predicates into one rule is performed with the help of aggregation operators (see [BEL 99] and references therein). A more sophisticated example of guideline translated into a fuzzy rule is:

\[ \text{If} > 10\% \text{ weight loss in 3 months OR BMI} < 20 \]
\[ \text{OR BMI} > 30 \text{ then Dietician visit is indicated} \]

Fuzzy If-Then rules have fuzzy recommendations at the output. These recommendations are translated into the actions being "recommended", "suggested", "strongly advised" etc. The strength of recommendations is conveyed by the appropriate non-verbal clues (e.g., red "!") for strong advice and yellow "?" for a suggestion; illustrated in figure 2 in the next section). We believe that fuzzy logic is a more natural model for the decision to provide an automated alert than a probability model (as per [HOR 99], shown earlier) because the question is more one of "degree" of fit than probability of fit. A more detailed discussion of fuzzy methods is reported in [WAR 00].

4. Guideline delivery with Care Plan On-Line

4.1. Guideline structuring for decision support

In implementing clinical guidelines into the CPOL system we take a three-tiered approach: advice is delivered in active unsolicited (Status), active solicited (Checklist) and passive (Evidence) forms, all linked together. The Status support provides an extract of the patient's EMR focused on the given clinical concept (figure 3). A summary recommendation is often also included. Quite often the doctor will need no further explanation because they already understand the concepts behind how the status observations link to the recommendation. However, the user can tab from Status to Checklist for more detailed patient-specific advice, which includes the list of guideline criteria that define the logic behind the system suggestion (figure 4), rather than only the more-traditional aggregated conclusion [FOX 91]. Moreover, the Checklist is graphically marked with the direction of patient data vis-à-vis the decision rules. In turn, the Checklist is linked to the Evidence page (figure 5), which is the hypertext translation of the text-based guideline rationale (non-specific to the patient) plus external supporting links. The rationale behind this structuring is to avoid obstructing user workflow when they feel the decision is routine, while at the same time providing them with context-sensitive advice and supporting information when needed.
4.2. Decision framework for system initiative

Two categories of system initiative are available to CPOL: automatically placing a service in the patient's care plan; or in some way alerting the user to consider placing a service in the patient's care plan. In the present implementation, criteria for the former type of initiative are tightly constrained to the base care plan of "A level" services. The automated initiative has the following characteristics:

- The users are aware that it is done and have a name for it (i.e., the "base care plan" of "A level" services);
- The criteria are logically crisp and simple (base care plan services are indexed by primary diagnosis and severity) – in fact, the CCs have a table that documents the base care plan as part of their SA HealthPlus indoctrination materials;
- The user can undo the actions (base care plan services can be removed by direct manipulation); and
- The users associate the action with a group of humans (the Care Mentors) rather than the machine.

The system takes much more liberty with the alerting initiative as this is fundamentally human-moderated (the result is merely to indicate to the CC that they should review some decision support material or consider a decision). Conceptually, alert criteria are based on degree of fuzzy membership of the patient to the guideline recommendation. If the membership is above an initial threshold, $\mu_1$, then a weak alert (denoted graphically by a "?") is attached to all relevant opportunities such as the Service List (see figure 2). If the fuzzy membership is higher than a further threshold, $\mu_2(\mu_2 > \mu_1)$, then a strong alert (denoted by "!") is displayed. This notion is well-illustrated by the bone density screening guideline (see figure 3), where a direct interpretation of the Care Mentor guidelines was to alert for the service if the weighted sum of Strong (weight 2) and Other (weight 1) indications exceeded 5. Other system initiated actions, such as alert popup dialogues are not currently integrated into the fuzzy logic framework, but do represent a further point on the continuum of system initiated responses intermediate to graphical alerts and automated inclusion of services in the care plan.

4.3. Structuring for ubiquity of unsolicited advice

We implement the following unsolicited advice mechanisms in CPOL:

- The use of non-verbal clues to inform the user of the availability and importance or urgency of the advice.
- Facilitating implementation of the decisions consistent with the system advice.
- Providing critical advice when users attempt to implement a decision inconsistent with it.
- Structuring data entry forms in a way that implicitly provides the advice and the rationale for it.
- Dynamically structuring data entry forms in a way that conveys the advice.
- Providing key advice explicitly in computer generated clinical summary or essential data entry forms.

The first mechanism of delivering advice is based on non-verbal clues. These clues include:
- changes in appearance (font, colour, attached pictograms [icons]) of the screen form elements requiring attention,
- pictograms attached to the entry forms that contain elements requiring attention,
- pictograms attached to the elements of the lists that require attention.

Consider figure 1. It shows one of the data entry forms of the CPOL system. The form contains the values of clinical findings and measurements that CCs routinely have to specify. Unknown and obsolete values are clearly marked (with "?" and colour). The system flags abnormal values with the "!" symbol, and prompts to enter the values that are critical – either for diagnosis, treatment or compliance with the guidelines – with a red dot. The forms that contain important information are also marked with a red dot.

Figure 2 shows a list of generic services that can be part of Care Plan (if moved to the right list which constitutes the patient’s Individualised Care Plan). The system signals the services that are consistent with its advice with a "?" or red "!", depending on the strength of the advice. The user can invoke the explicit advice if interested with a mouse click. In both cases, the users will not miss the fact that the advice is available (they can even interpret the advice if the meaning of the pictograms is fixed), yet they are not overwhelmed by the explicit textual information detailing the advice. Moreover, they are not required to acknowledge the advice (as they would be if the reminder were implemented as a prompt or a message box).

Caution should be taken when using graphical elements, such as colours and icons, because their excessive use gives data entry forms a distracting “Christmas tree” effect. Shneiderman [SNE 98] suggests using no more than four colours on any screen, and no more than seven colours per application. Moreover, the meaning of graphical elements must be consistent throughout the application. If possible, one should use the elements whose meaning is traditional or inherited from the user’s environment. To satisfy these requirements, the elements we use in CPOL are: ? (possible/marginal alert), ! (alert), • (red dot for attention/alert), ↑ (“elevated”), X (false) and ✔ (true).

The second mechanism of delivering advice consists in making it slightly easier to implement the system advice compared to other options (e.g., by placing the most likely options first in the selection list and marking them with icons). This
mechanism does not impose the advice on the user – any other option can be freely selected. It does not require acknowledgement and it does not interfere with the workflow.

The third way to provide unsolicited advice is to make it at the time when an inconsistent (from the system’s viewpoint) decision is attempted. At this point the system provides the advice explicitly, asking for confirmation. Simultaneously it provides the rationale for the advice. When the users perform such an operation, they are warned and prompted to confirm their decision. An example of this is using soft boundaries when the user is prompted to enter a numerical value (such as blood pressure or \( O_2 \) saturation). CPOL allows users to enter the numerical values in a predefined range and warns (but accepts) if the values are outside the range. The erroneous input will be detected, yet the user can insist on entering the value.

![Image]

**Figure 1.** Care Plan On-Line (CPOL) initial medical assessment display showing alert flags (● and !)

The fourth mechanism consists in embedding the advice into the data entry forms. This is done by carefully wording the forms or by structuring the data fields in a semantically meaningful way, like grouping indications and contraindications under appropriate headings. When it is not possible to prepare such forms in advance, the fifth method, consisting in dynamically restructuring data forms, is
employed. The appearance of the form depends on the circumstances it is viewed in (mainly on patient’s current symptoms).

Figure 2. CPOL client display showing SA HealthPlus services with patient’s problems & goals summary

Figure 3. CPOL guideline Status display with service timeline control
Finally, the advice can be provided through the use of forms that cannot be missed (i.e., it disrupts the interface dialog). For example, before submitting the data and the Care Plan, a reminder of missing pieces of information (such as current blood pressure reading) can be displayed. This action is a translation of the guideline statement "Record blood pressure every visit if...", and is triggered only if the criteria are satisfied.

5. System architecture

CPOI is implemented as a Client-Server system, with the transactions occurring via TCP/IP over the South Australian Government’s Statenet intranet. Users log in to CPOI, providing SA HealthPlus-specific username and password, from South Australian Department of Human Services (DHS) workstations or through ISPs via modem. (Security is obviously an issue for state systems, including the health IT operated by the state, and thus one must gain access to Statenet by being logged into a government LAN [in a government building] or via a password-protected gateway.).

The CPOI Web server is itself an ODBC client on the DHS local area network to the SA HealthPlus database, upon which the Web server performs both read and update operations. Thus a two-way gateway to the SA HealthPlus database, allowing only transactions as constrained by the CPOI client and the users’ roles, is provided. The SA HealthPlus relational database, in addition to receiving on-line updates through CPOI, is updated by local sessions to enter information from paper forms, by automated updates from metropolitan hospital database systems, and from periodic data extracts from the Commonwealth Health Insurance Commission and other contributing agencies.

CPOI’s EMR architecture, a subschema of the overall SA HealthPlus relational database, adhere to many of the concepts of the Good Electronic Health Record (GEHR) model [CHI 99]. A salient requirement of GEHR is that data items are never overwritten; rather they are only updated — achieving a history of observations, such as one might have for blood pressure — or corrected (with the original value remaining persistently stored, with date and identity of recorder, for medico-legal audit).

The necessity to adapt the user interface to individual user and project needs prompted us to use a thin client, able to present to the user a number of data entry forms explicitly defined on the server. In contrast to the systems that use a WWW browser and dynamic HTML pages, we implemented the client module as a native MS Windows application (developed in Microsoft Visual C++) that receives all the data it needs in one transaction. The advantage of this approach is the sub-second response time to user’s actions, greater stability and possibility to work off-line. Yet the CPOI client application has its own WWW browser window, which allows us to take advantage of the browsing approach as well (chiefly for the Evidence pages).
All patient data is centrally stored, thus enabling us to support the concept of a "virtual" record, which can be simultaneously accessed by various users at different locations.

<table>
<thead>
<tr>
<th>Patient Details</th>
<th>Past Events</th>
<th>Medical review</th>
<th>Medications</th>
<th>Problems and Goals</th>
<th>Services</th>
<th>Guidelines</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cardiac Guidelines</td>
<td>Cholesterol</td>
<td>Status</td>
<td>Evidence</td>
<td>Aim: Total Cholesterol &lt; 4.5 ( \times ) LDL &lt; 3.5 ( \times ) HDL &gt; 1 ( \checkmark ) triglycerides &lt; 2.0 ( \times )</td>
<td>Check every 3-6 months if abnormal ( \checkmark )</td>
<td>Consider dietary therapy ( \checkmark )</td>
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<tr>
<td>Dietician and Diet/Weight/Exercise</td>
<td>GP Visit</td>
<td>IF: Received Dietary Therapy ( \checkmark ) AND</td>
<td>After two readings of Total Cholesterol &gt; 5.5 mmol/L ( \times )</td>
<td>OR</td>
<td>HDL &lt; 1 mmol/L ( \checkmark ) AND Total Cholesterol &gt; 5.0 mmol/L ( \checkmark ) OR</td>
<td>triglycerides &gt; 2.5 mmol/L ( \times ) AND HDL &lt; 1 mmol/L ( \checkmark )</td>
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<tr>
<td>Hypertension</td>
<td>Smoking Cessation</td>
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<td>- Diabetes Guidelines</td>
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<td>Respiratory Guidelines</td>
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<td>- ECG Visit</td>
<td>Flu Vaccination</td>
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<td>- GP Visit</td>
<td>Pharmacy review</td>
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<td>- HealthPlus Services</td>
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Figure 4. CPOL guideline checklist display with guideline index

The key to integrating decision support and workflow in CPOL is the close relationship between the patient data, clinical knowledge and the Coordinated Care "business model" as illustrated in figure 6. The character of a given disease-specific project is dictated by its choice of forms (unique ones such as the Initial Medical Assessment and ongoing assessment, as well as HealthPlus-wide ones such as the Events, Medications and Services forms). When a CPOL client requests a particular patient, the server determines that patient's project membership and then assembles the applicable forms populated with the relevant instances of the clinical observations required for those forms. Nearly all data display/entry information is manifest through these forms, including all the tabs on the main screen and the clinical guidelines.

Clinical guideline decision rules and alert flags are also implemented as classes of observation (the same as a blood pressure reading) via the facility to define observations as functions of other observations. The rules from the knowledge base that govern the active decision support are written in a Prolog-like functional language (as recommended by [FOX 91]) and are also stored in the SA HealthPlus relational database on the server side. The current implementation requires separate specification of weak and strong alert criteria, although these are conceptually
unified by degree of fuzzy membership. Implementing this unification is a useful direction for future development since it would allow the user to globally tune the system’s responsiveness based on configurable values of $\mu_1$ and $\mu_2$ (see prior section). The client application possesses an in-built interpreter of the rule language. This server-side, database-driven representation scheme gives the opportunity to include new observations and parameters into the EMR, change the knowledge base rules, and update the user interface centrally without updating the client software.

![Figure 5. CPOL guideline evidence display with hyperlinks and conventional references](image)

Figures 1-5 provide examples of CPOŁ screens as seen by the users. Significantly, all screens can potentially serve for both data display and data entry. The guideline Status screen (figure 3) particularly emphasises the dual functionality of CPOŁ screens in being chiefly a problem-oriented data display/data entry screen. However, the Status screen also contains the chief recommendations with respect to the guideline’s topic and the ability to schedule that service in the patient’s care plan. This gives it overlapping functionality with observations and service screens (the extent of overlap being in the hands of the form designers and not dictated by the architecture). In this way, the activities of guideline consultation and doing the record-keeping work of care coordination are blurred, thus integrating the EMR, decision support and health provider workflow.
6. System use

Qualitative observations of pilot users show that GPs find the system reasonably intuitive. Ten GPs of varying computer expertise were all comfortable in undertaking on-line care plan review and update of their patients after a few minutes one-on-one orientation and working through review of a test case. The GPs employ a wide variety of ways to use the system. One unexpected usage path is that GPs often review the guideline index as a checklist of key concepts. Administrative users within the SA HealthPlus unit often found the system more desirable for information review and update than using a traditional Local Area Network (LAN) based database application that they had used from the start of the trial. Nurse users found the online guidelines educational.

Due to the timing of the CPOL implementation being concurrent with the running of the SA HealthPlus Coordinated Care trial, the software was not available to influence initial medical assessment and care planning of patients. An off-line trial of the appropriateness of CPOL triggers in response to a sample of 21 respiratory patient records shows that the system gives alert indicators for care planning actions that are largely in accordance with specialist Care Mentor care planning decisions. Moreover, these alert flags would be informative to GPs, who failed to place into patient care plans about 40% of the activities favoured by Care Mentors [WAR 01]. This can be interpreted as the GPs missing or being unaware of numerous indications for care management action; however, one must balance this view with the fact that GPs also may be more aware of contraindications for action and more considerate of patient preferences for non-action. The CPOL architecture succeeds in projecting the Care Mentor’s intent into the operational care planning user interface; however, like all cultural changes, there are many aspects to actually achieving change in behaviour.

A new round of Coordinated Care trials in Australia as well as an Enhanced Primary Care program featuring care planning and increased patient involvement (all sponsored by the Australian Commonwealth Department of Health and Aged Care) present opportunities for further deployment of this technology.

7. Conclusion

CPOl software integrates the EMR with decision support and the GP’s workflow in conducting the care planning activities for coordinated care of chronic/complex illness. This is done through blurring various traditional distinctions – record review is integrated with decision support, system initiative and user initiative are interlaced, and seeking of decision support is integrated with required patient processing. Multi-layered guidelines are extensively linked from the EMR, including links through graphical alert flags that appear alongside relevant data when alert criteria are met. System initiated action includes the provision of
these alert flags (with varying strength depending of degree of fuzzy membership that the patient has in the guideline indication) and automated inclusion of a base care plan of services in the patient's care plan. The guidelines themselves link back to the EMR with individualised alert markers based on the patient's EMR and the ability to enter patient observations and care plan data directly on the guideline screens.

Medical knowledge is constantly evolving, so one must avoid hardcoding knowledge into the system. Moreover, to support the SA HealthPlus trial, we were required to support ten different disease-specific projects with one system architecture. To address this requirement, the architecture is served to a Windows-based client over TCP/IP with profound reconfigurability of the observation forms, guidelines and alert criteria possible from the central server. In many ways it would be desirable to have a truly thin client (e.g., to use a conventional Web browser), as this would avoid the need to undertake installation on client machines. However, we found that sub-second response to user actions and the ability to form decision alerts based on complex criteria were requirements not easily met in the conventional browsing architecture.

![Diagram of network overview of CPOL representation scheme for data and forms](image)

**Figure 6.** Semantic network overview of CPOL representation scheme for data and forms

The "holy grail" for health information systems research is to facilitate the integration of patient-specific information and decision knowledge into clinical workflow [STE 00]. The method of interaction of data, knowledge and workflow in
CPOL can be thought of as an episode in the quest for this holy grail. Further directions for CPOL and related care planning support software are two-fold. First, we are pursuing the use of CPOL (directly, or as a model) for further primary care initiatives that emphasize proactive management of patients, a number of which are in formative stages in Australia. Second, further research is ongoing with respect to the role of Fuzzy Logic as a more accurate representation method than "crisp" (Boolean) logic for specialist intention in guideline alert criteria (see [BEL 01]).

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8. References


