A Patient Workflow Management System Built on Guidelines

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To provide high quality, shared, and distributed medical care, clinical and organizational issues need to be integrated. This work describes a methodology for developing a Patient Workflow Management System, based on a detailed model of both the medical work process and the organizational structure. We assume that the medical work process is represented through clinical practice guidelines, and that an ontological description of the organization is available. Thus, we developed tools 1) for acquiring the medical knowledge contained into a guideline, 2) to translate the derived formalized guideline into a computational formalism, precisely a Petri Net, 3) to maintain different representation levels. The high level representation guarantees that the Patient Workflow follows the guideline prescriptions, while the low level takes into account the specific organization characteristics and allow allocating resources for managing a specific patient in daily practice.

INTRODUCTION

A big challenge for medical organizations is to increase productivity and to reduce costs without adversely affecting patient care quality. It is now a well-agreed opinion that the quality of care depends not only on the care providers' professional skills but also on the level of collaboration inside the organization.

During last years, supporters of the so called evidence-based medicine put a great effort in improving clinical practice by means of Guidelines (GLs), defined as "systematically developed statements to assist practitioner and patient decisions about appropriate health care for specific circumstances"[1]. GLs are usually developed by authoritative panels of experts, who reach a consensus after a complex process, involving careful literature reviews, personal communications, and eventually a Consensus Conference. GLs should avoid dissimilarities, malpractice, and resource waste in the patient treatment. However, to be effectively implemented within an organization, such as a certain hospital or an outpatient department, a GL requires a customization process, taking into account the organization characteristics, such as structures, commitments, roles, policies and preferences[2]. In fact, existing health care information systems do not relate to organizational issues, unlike industrial and commercial realities, where the concept of Workflow Management (WfM) has become crucial. A Workflow Management System (WfMS) is "a system that completely defines, manages, and executes workflow processes through execution of software whose order of execution is driven by a computer representation of the workflow process logic"[3], i.e. it provides a dynamic model of the process of interest, with all the involved entities explicitly defined, so as to make it possible to simulate the process evolution, to clarify where and when information and/or resources are produced and consumed, etc.. In this paper we propose a methodology for building decision support systems that integrate the two different aspects of health care delivery: clinical procedures and organizational functioning. This methodology is suitable when clinical procedures may be described through clinical practice GLs (which provide the Wf process logic) and when a model of the organization is available, specifying roles, responsibilities, resources, etc. The resulting systems could be defined as *Patient Workflow Management Systems* (PWfMS). The patient care is in general a distributed activity, thus the system has been designed to be implemented on the Internet/Intranet and the user interface is written in Java and HTML. As a test bench for the proposed methodology, we used a generic GL to manage Acute Myeloid Leukemia (AML) in children[4]. In the following, this GL will be referred as "AML-GL".

THE SYSTEM COMPONENTS

Formalized GLs and organizational models under-lying each clinical procedure are the two basic components to build a PWfMS. Thus, the framework we are developing embeds the following basic tools:

i) an Editing Tool to support the clinical expert in specifying GLs according to a formal representation;
ii) a Translating Tool, from the GL to a Wf Model;
iii) a Low Level Wf Builder, providing for each medical procedure the corresponding site specific Wf.

In addition, we assume that both the medical and the organizational domains are described through an ontology, that specifies the relevant entities and the relationships among them[5]. In the following the three mentioned tools will be described.

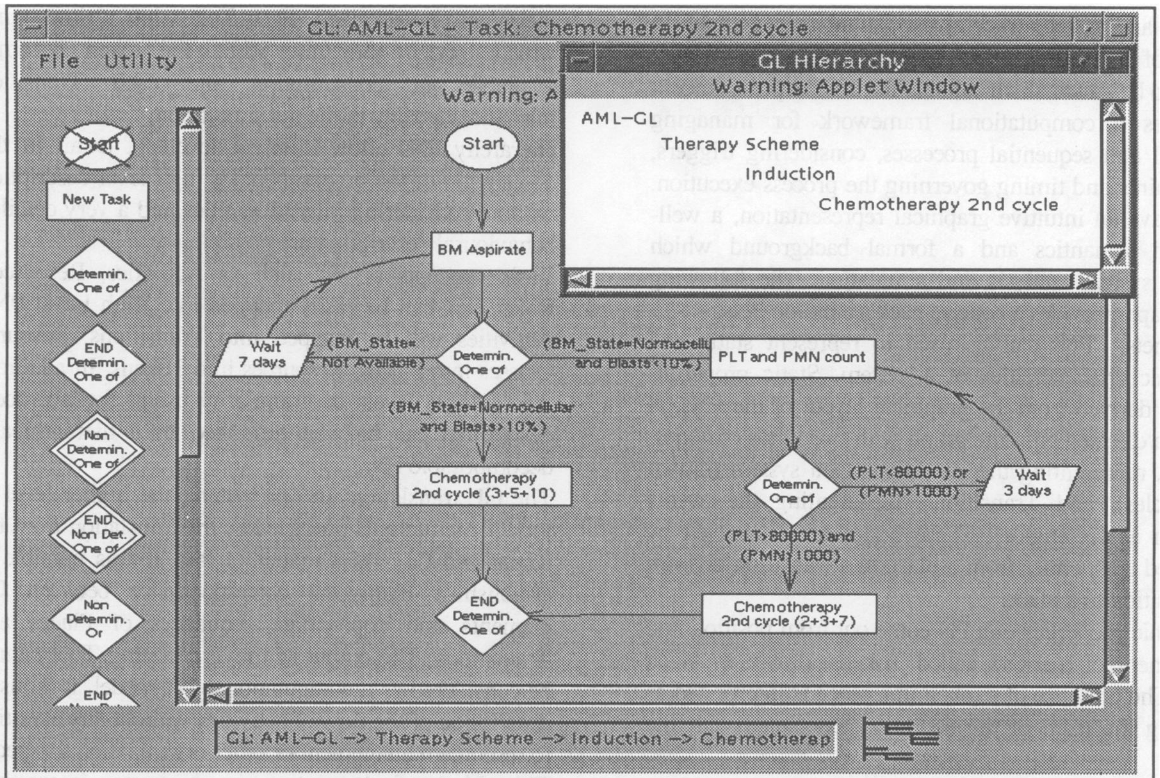

Figure 1 - An interactive session to formalize one of the procedures of the AML-GL.

GUIDELINE FORMALIZATION

The formal representation we have developed is based on the EON Protocol Model[6]; it is a modular, top down structuring of the health care process: each procedure either can be atomic or it can be decomposed into a certain number of sequential or parallel subprocedures. By means of the Editing Tool, all procedures composing a GL are specified, and a computational representation (Lisp structures) is produced, which stores all the attributes specifying them. We distinguish between attributes to describe the procedure (such as Type, Supporting Evidence level, Intention, Activation Condition, etc.) and attributes to allocate it within the GL flow (Next Procedure, Synchronization Conditions, etc.). Fig 1 shows an editing session. Operatively, the GL is built by using the icons shown on the left window. Whenever a new GL is edited, the eligibility conditions must be provided: since it is assumed that a database is available which contains all the information needed for the GL implementation, the system is able to give advice about possible patients eligible for the existing GLs. With respect to the usual GL representation (hypertext, decision tree), this Editing Tool offers some facilities:

1. the user may start by creating some main tasks (exg., for AML management, *Induction Therapy, Post remission Therapy*, *Bone Marrow Transplantation*), and then each task may be iteratively decomposed in subtasks, so describing different abstraction levels;
2. several temporal and logical constraints among tasks are available;
3. two models for representing monitoring tasks are provided: the *passive* monitoring, where a set of variables is measured for a given period, according to a given sampling schedule, until a threshold is reached; the *active* monitoring, where some actions (exg therapeutic interventions) are associated to the measurements. In addition, the link with the patient record allows to perform statistics on the degree of the physician compliance to the GL: in case of non-compliance, the system will store the GL recommendation together with the actual treatment, and the reason for non-compliance. Since each recommendation is associated to a scientific evidence level supporting it, these computations can be performed according to the level degree.

FROM THE GL TO THE WF MODEL

The above described formalization captures the general prescriptive aspects of GLs, but a PWfMS should be specific enough to provide precise indications for each patient and to keep trace of the patient management, in terms of both efficacy and efficiency. Petri Nets[7] (PNs) seem to be a formalism suitable for this purpose, since it provides a computational framework for managing parallel and sequential processes, considering triggers, constraints and timing governing the process execution. PNs have an intuitive graphical representation, a well-defined semantics and a formal background which allows system analysis and simulation. The following paragraph provides a concise background on PNs.

Petri nets. PNs can be used to represent static and dynamic characteristics of a system. Static properties can be derived from the graphical layout of the PNs. A PN is a directed bipartite graph with two kinds of nodes: Places, representing the conditions of a system (drawn as circles), and Transitions, representing the events (drawn as rectangles). These nodes are connected by directed arcs, either from a place to a transition or from a transition to a place.

Dynamic properties of a PN come out from position and movement of markers called Tokens, drawn as black dots. The presence of a token in a place is interpreted as holding the truth of the condition associated with the place.

Although classic PNs have extensively been used in process-centered environments, their modeling power was limited. During last years, High Level PNs[3], i.e. PNs extended with colour, time and hierarchy, have been introduced, together with packages to manage them (we use Design/CPN[8] to model, analyze and simulate High Level PNs). In Coloured PNs, Tokens are differentiated by colour, i.e. each Token can assume a certain value called Colour from a given set of values whenever it reaches a particular Place. It is possible to introduce constraints on the Colour Tokens need to show to fire a given Transition. These constraints are called Guards. In Timed PNs, the temporal behaviour of the system is described. Each Token has a time-stamp which models the time when the token becomes available for consumption and each Transition introduces a delay in the net simulation.

Hierarchy PNs allow different levels of detail in the description of the process: both a high level description without considering internal entities and a very detailed behavioural description are possible.

Basic concepts of Wf such as Activities, Resources, Roles, etc., can be easily mapped into High Level PNs: Activities will be mapped into Transitions, Resource Classes into Places, Resources into Tokens. In addition, the multiple levels of granularity useful for a process description can be well described by a hierarchically decomposable PN.

The GL translation. In our system, the higher level of the PN hierarchy is produced by the translation from the formalized GL. As a matter of fact, it was possible to establish a biunivocal correspondence between GL elements and appropriate sequences of Places and Transitions. The output of the Translating Tool cannot be considered as a computational Wf model, it is just a description of the flow of activities without any attention to resource management or other organizational aspects. This kind of description is, however, interesting, because it assures that the medical policies proposed by a GL and their management are consistent. If we consider the AML-GL and in particular the procedure described as "2nd Cycle" in Fig. 1, the corresponding output of the Translating Tool is shown in Fig. 2. Each subprocedure ("Wait" nodes included) in the GL is represented by a Transition-Place pair, while the start-node is the Input Place of the PN. The "DETERMIN ONE OF" node does not introduce any element in the PN, but it affects its structure by means of constraints on the involved Transitions. In this case, each condition which labels an arc exiting the "DETERMIN ONE OF"

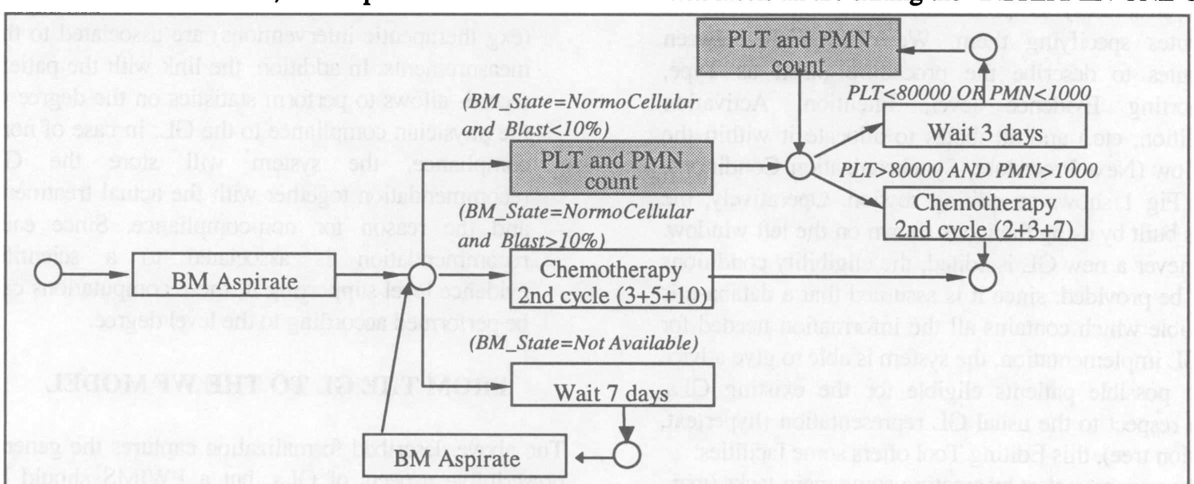

Figure 2 - The Petri Net obtained by translating the formalized guideline.

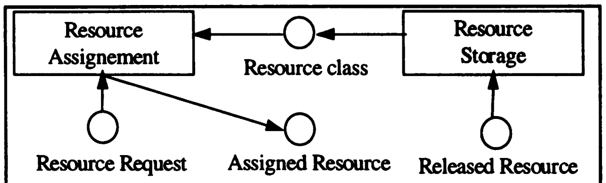

Figure 3 - The PN model of the Resource Manager

node becomes Guard of the following subprocedure. Similar translating rules can be applied to other elements used to formalize GLs. This High Level PN can now be used as one of the inputs of the Low Level Wf Builder, together with other knowledge components which describe the organizational context.

THE LOW LEVEL WORKFLOW BUILDER

To each medical procedure the corresponding Wf must be associated, given a proper conceptual description of the clinical unit in terms of organization, resources, preferences and policies (i.e. an ontological description). In other words, while the Translating Tool described in the previous paragraph produces a PN representing the sequence of the procedures, as they are described in the general GL, the Low Level Wf Builder details each procedure according to the specific organization within which the procedure will be performed. To this aim the Wf is decomposed into elementary process steps, called Activities. Every process Activity requires a resource with a particular role description to perform it. Usually in an organization there are different kinds of resources administrated by different managers. For this reason we divided resources into classes and we let the *Resource Manager* (Fig. 3) control the allocation of each Resource. The system is triggered by activities sending the token "Resource Request" colored with specific resource it is asking for. As soon as the resource is available, it becomes assigned. When the activity terminates, the resource manager is informed, the resource is released and stored back.

Given that each medical activity can be used within several different processes and that it is always, probably, performed in the same way inside the same organization, all these subsystems describing activities should be stored in a PN Library. Each organization has its own PN Library. Let us consider the PN in Fig. 4, it can be considered as the subsystem exploiting the medical procedure labeled "PLT and PMN count" as is within a particular organization: "Blood drawing", "PLT and PMN counting" and "Result reporting" are the three atomic tasks. Two resource classes are required: Nurses and Analysts. From the ontological description, all the subclass partitions (i.e. the possible values of the tokens' color) for a generic resource class can be derived, for example the resource class "Nurses" has three subclasses: "Generic-Nurses", "Head-Nurses" and "Professional-Nurses". The particular kind of resource required is controlled by the proper Resource Manager. The subsystem's output is usually represented by one or more information added to the input token: in this case the input is the token "patient" described as a vector of clinical findings, the output is the same vector with two more values, corresponding to the PLT value and PMN value.

THE PATIENT WORKFLOW MANAGEMENT

A WfMS is a distributed knowledge based system because it uses knowledge about procedures and rules that apply in different locations within the organization. The knowledge about Wf activities, participants, resources is used together with knowledge about their relationships, in order to make an appropriate description of the health care processes. This "knowledge distribution" is reflected by the multi-layer structure which can be found in our system. As shown in Fig. 5, each layer provides a different kind of knowledge, which can be used either as an input for the WfMS, or to structure the overlying knowledge layer. Let us consider the contents of each level:

1) the Wf Layer stores High Level PNs used to represent health care processes, like the ones described in Fig. 2.

2) the Information Layer is represented by two information repositories: the HIS and a PNs Library.

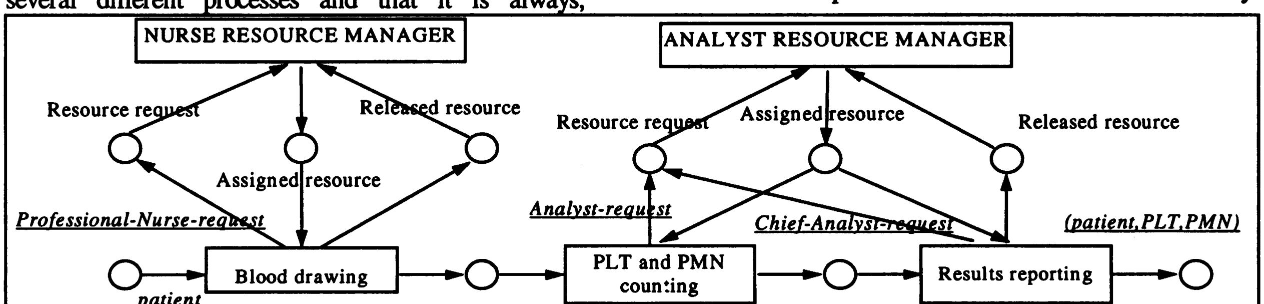

Figure 4 - The subsystem describing in detail the site specific medical procedure "PLT and PMN count"

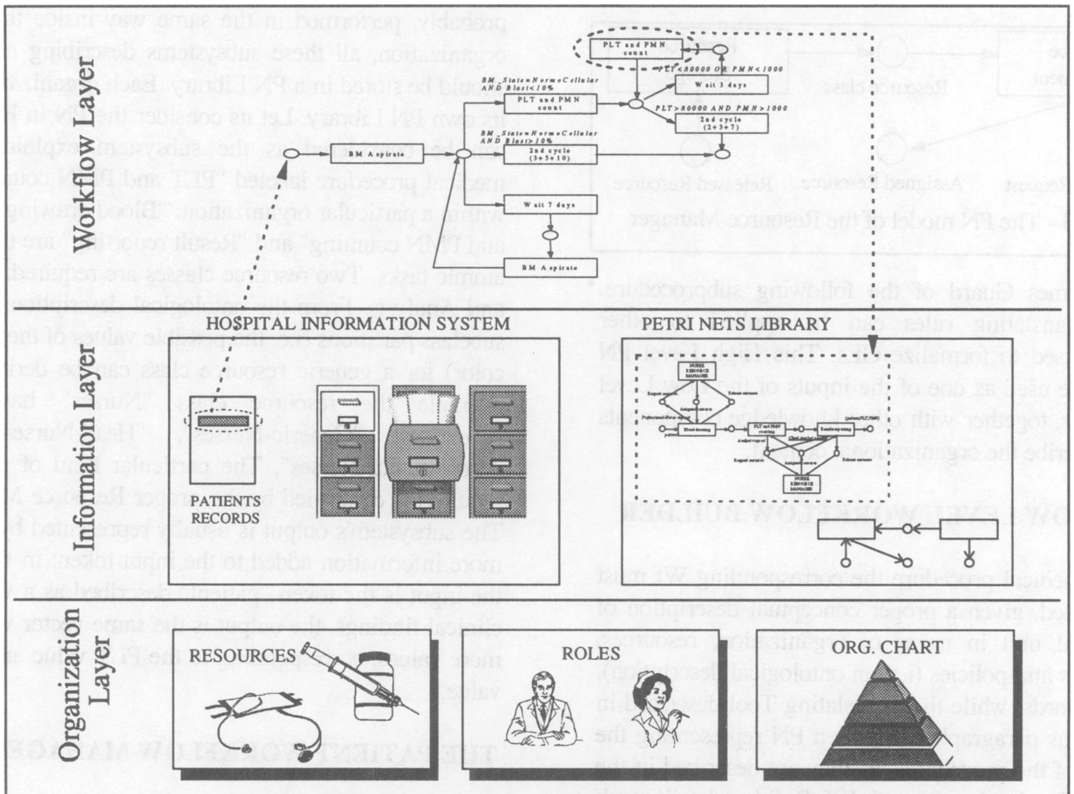

Figure 5 - The multi-layer structure of the system

The latter contains a detailed description of medical activities by means of the PNs formalism (i.e. the low level PNs described in Fig. 4).

3) the Organizational Layer stores an ontological description of the health care unit organization, where roles, resources, preferences, policies are made explicit. The WfMS will use the resulting PN as its input model.

CONCLUSION

We propose a method of modeling clinical Wf processes where expertise in medical care can be completely separated from expertise in organizational structure. We believe this methodology will improve easy maintenance of an accurate Wf model in face of changes both in clinical processes and in the organizational structure. No data exist, in the authors' knowledge, about the application of similar methodologies to real-world health care settings. Thus, the next step of the research will involve data collection about user satisfaction and effective care improvement.

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