An Automatic and Intelligent System for Integrated Healthcare Processes Management

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Abstract. In this work, an automatic and intelligent system for integrated healthcare processes management is developed on a constraint based system. This project has been carried out in collaboration with a real assisted repro-duction clinic. Our goal is to improve the efficiency of the clinic by facilitating the management of the integrated healthcare system. This is very important in an environment in which the healthcare processes present complex temporal and resource constraints.

Keywords: Constraint programming · Clinical guidelines · Integrated healthcare processes · Process management

1 Introduction

In recent years, process management as a mechanism to increase the excellence and the quality of organizations is a fact globally accepted. Healthcare organizations are not an exception. In fact, healthcare process management is essential to (1) ensure an adequate patient care and (2) facilitate the work of health professionals in an area where decision-making based on the best biomedical knowledge which is available is essential [1].

The management of these processes is closely related to the term of integrated healthcare processes (IHPs). IHPs or clinical guidelines are a textual definitions of healthcare processes and a group of clinical decision rules. In certain circumstances, these IHPs support health professionals to make a decision about the health care of their patients [2]. In short, an IHP aims to improve the quality and the safety of patient healthcare and to reduce both the variability in clinical practice and the health costs [2, 3].

However, modeling such guides is a complex task due to the following reasons:

- They are defined in natural language.
- They don´t follow any standard.

- It is difficult to model the constraints (e.g., time and resources) of a healthcare process in existing standards for process modelling, e.g., Business Process Model and Notation (BPMN).

Since there are multitude of variables and constraints that must be met in a healthcare process, it is difficult to find a healthcare environment that uses a user-centered automatic process management system. This type of systems includes, among other functionalities, the management of appointments, i.e., activities which require the availability of both patients and doctors simultaneously. The management of appointments is another conflicting point in the health systems due to the overload of patients that the sector suffers.

Nowadays, appointment systems can be a source of dissatisfaction for both patients and health care professionals [4]. Patients often complain about the lack of availability, i.e., number of visits allowed per day. However, such availability is directly related to the duration of each appointment. Therefore, the increase of the availability reduces the time which is invested in each patient. In summary, the appointment scheduling systems are at the intersection between efficiency and the time to access to the health services. As a result, it is complex to model an appointment management system.

In addition, for assigning an appointment to a patient, it is necessary to know (1) the IHP and the constraints or relations that exits between their activities, (2) the next activity that should be performed (i.e., the patient's clinical history) and (3) the availability of resources. Given this complexity, health professionals usually have to manage the appointments in a manual way. Therefore, health professionals often are overloaded with administrative tasks instead of taking care of patients' health [5].

In this scenario, this paper focuses on developing a decision support tool based on Constraint Programming (CP) [6] with the aim of enhancing the performance of the health sector i.e., reducing costs and improving the access to health services and quality of the health care.

In addition, decision support systems have already been applied successfully in other service industries, such as airlines, car rental agencies and hotels [7].

For this, the current approach introduces an automatic and intelligent system for process management that:

1. Can be adapted to a defined healthcare processes.
2. Considers the resources which are available in the health center.
3. Manages patient appointments based on the demand and regarding the capacity that the resources offer.
4. Optimizes (1) the use of these resources (2) the waiting times that patients can suffer, direct (i.e., time which the patient waits in the health center) and indirect (i.e., period of time between the day that the user asks for the next activity to be performed until the day of its execution), and (3) the satisfaction of timetabling preferences of both the patients and health professionals.

In addition, the proposed system comprises a user interface to facilitate the management of the IHPs by the patient and health professionals. Therefore, health professionals do not need to allocate and communicate the appointments to their patients manually thus alleviating the workload.

Our proposal is designed for a real assisted reproduction clinic located in Seville. Specifically, to the Fertility Study IHP.

The rest of the paper is structured as follows. Section 2 introduces the background, where necessary terms are defined to improve the understanding of our project. In Sect. 3, we explain the development of our prototype, followed by its evaluation in Sect. 4. Section 5 investigates the existence of proposals similar to ours. Finally, we will conclude with conclusions and future work in Sect. 6.

2 Background

2.1 Planning, Scheduling and Constraint Programming

The area of scheduling includes problems in which it is necessary to determine a schedule for a set of activities related by temporal and resource constraints. A schedule states (1) the start and end times of the activities to be executed and (2) the resource which is assigned to perform each activity. Since different activities may require the same resources, they may compete for limited resources (i.e., resource constraints). In scheduling problems, several objective functions are usually considered to be optimized, in most cases related to temporal measures, or considering the optimal use of resources.

In such context, constraint programming (CP) supplies a suitable framework for dealing with planning and scheduling problems [6]. To solve a problem through CP, it needs to be modelled as a constraint satisfaction problem (CSP, cf. Definition 1).

Definition 1 CSP. A CSP P = (V, D, C) is composed of a set of variables V, a set of domains D which is composed of the domain of values for each variable of V, and a set of constraints C between variables, so that each constraint represents a relation between a subset of variables and specifies the allowed combinations of values for these variables.

3 Our Proposal

Figure 1 show an overview of the architecture which is proposed in the current approach. For this, an automatic and intelligent system was developed (cf. Fig. 1(1)) to execute and manage the activities of an IHP. On the one hand, the system uses the information stored in the database of the health centre (cf. Fig. 1(2)). On the other hand, the system has been integrated with a user interface (cf. Fig. 1(3)). Thus, users of the system (i.e., patients and healthcare professionals) can request the following activity to be per-formed and know their details.

In a first step, after carrying out an exhaustive analysis of the operation of the IHP in its sanitary environment (cf. Fig. 1(a)), an analyst models the IHP as a CSP (cf. Definition 1). For this, is necessary to model the following:

- The phases of the considered IHP including their duration and the type of professional that must perform them.
- The temporal constraints which exist between the different phases.

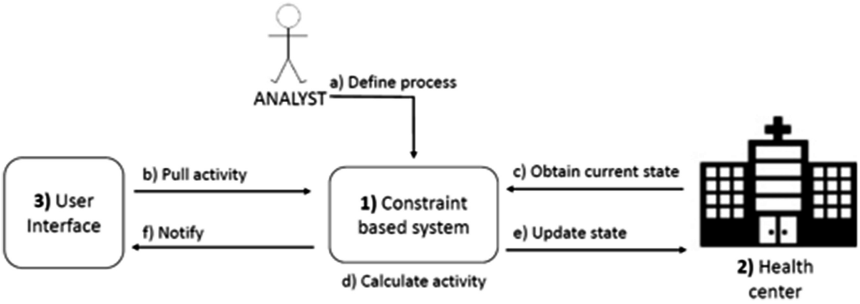

Fig. 1. Overview of the proposal

- The resources of the sanitary environment, contemplating their working hours.
- The state of the health center, taking into account the clinical history of the patients (i.e., the phases of the IHP that the patients have already performed, when they were executed and which resource performed them) and the occupation time of the health professionals.

Once the IHP is modeled in the system, the clients can ask for their next activity to be performed (cf. Fig. 1(b)) through a user interface. This request is sent to the system using a web service architecture.

In order to know the next activity to do by the user, the system must receive the current status of the health center (cf. Fig. 1(c)). Such status includes the patient records and the availability of the different resources between other information.

Thereafter, the proposed system obtains the best schedule for the following activity (cf. Fig. 1(d)) to be carry out by the user. Such calculus considers the clinical history of the user, the information defined in the IHP, the occupation of the resources and both temporal and resources constraints that may present the activity.

Calculated the next activity to be carried out by the user, the system sends the information of this new activity to the system of the health center to update it (cf. Fig. 1 (e)). In a similar way, such activity information is notified to the requesting customer which is shown through the user interface (cf. Fig. 1(f)).

3.1 Implementation Details

The integration of the proposed intelligent system with external systems (i.e., the user interface and a healthcare center) was performed on a scalable web service architecture. In this way, we will favor the ability to connect with other external systems.

In order to model the activities of an IHP we based upon previous proposals [8, 9] where a constraint-based language is defined.

For the development of the intelligent system, we use the constraint-based system (i.e., a system which solves CSP, cf. Definition 1) IBM ILOG CPLEX Optimization Studio (CPLEX) [10] together with the CPLEX CP Optimizer complement [11]. This tool provides for efficient mechanisms to deal with scheduling problems as well as temporal and resources constraints. CPLEX provides a high-level object which can be used to encapsulate activities. Such object is called interval variable. An interval variable has a start, an end and a length. Moreover, an interval variable may be optional, i.e., it may or may not appear in the planning.

Regarding the management of resources, CPLEX includes cumulative function expressions, which can be used to model resource usage functions over time and its limiting capacity.

To model the restrictions that exist between the phases of an IHP, we use high-level constraints on the interval and cumulative function variables. For example, the precedence constraints, which ensure the fulfillment of the precedence and temporal restrictions between the activities of the IHP.

4 Evaluation

In this project the intelligent management system was applied (cf. Fig. 1(1)) for the IHP of Fertility Study (cf. Fig. 2) followed in a real clinic of assisted reproduction since it is a representative process for applying our approach.

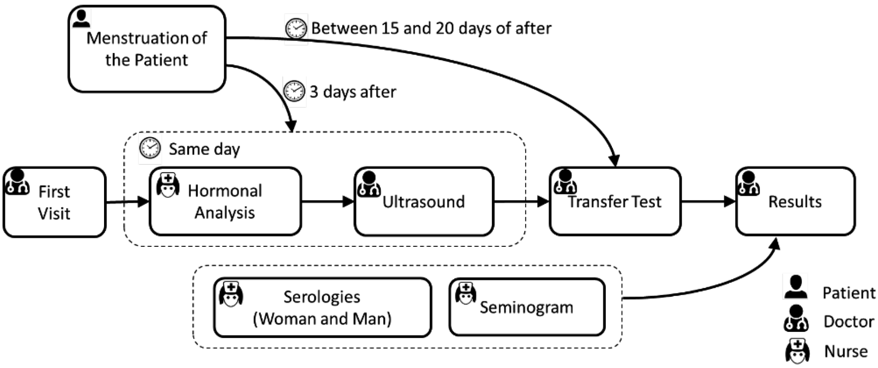

Fig. 2. IHP of Fertility Study

As can be seen, the healthcare process of Fertility Study presents a set of sequential activities. Among some of the activities, there are some temporal relationships (i.e., constraints). These temporal restrictions are represented in the Fig. 2 by a clock. For example, the activities Hormonal Analysis and Ultrasound must be done in the same day and, specifically, three days after the end of the patient's menstruation. In addition, each activity is restricted to being performed by a specific role (i.e., doctor, nurse or patient). These restrictions are an implementation challenge and must be strictly achieved.

Once IHP is analysed, it is modelled as a CSP. Thereafter, it is integrated in the proposed system with the actual clinic, so the system can calculate the following activity that any user requests.

However, it was not possible to carry out a formal validation of the system because only one healthcare process was modeled. Nevertheless, we have test our system with a data base of 25 patient's histories. The system suggested correctly the next activity of the patient that ask for it in the period of one month.

In conclusion, we obtained good impressions in this prototype, so it is presumed to obtain promising results in the continuation of this project.

5 Related Work

In this section, we present the existing works on the intelligent management of PAI in health centers. For this purpose, we did a systematic review of the literature, i.e., a method proposed by Kitchenham [12] that allows us to identify, evaluate and interpret relevant research data in a specific research area. This methodology is highly recommended in software engineering.

The focus was on the following challenging points in the appointments management of health environments:

- Patient waiting time (direct and indirect waiting times)
- Cancellations
- Absence of the patient
- Prioritization of emergencies.

Considering these key points, the Research Questions are detailed in Table 1.

Table 1. Research questions

Research questions
RQ1. Are there currently applications that use dynamic programming to help manage patients in the healthcare environment?
RQ2. Are the user's preferences taken into account when making a user activity?
RQ3. What health environments have adopted dynamic programming for managing user activities? Differences to keep in mind?
RQ4. How does the non-presentation of the patient influence? And the previous cancellation?
RQ5. Is the time between the request of the next activity and the day of the activity (indirect time) taken into account?
RQ6. How to manage emergencies and their priorities?

To respond to such RQs, articles from relevant bibliographic sources (e.g., Google Scholar, IEEE, Scopus and PubMed) are used. In these sources a variety of searches are performed about different keywords (e.g., health, dynamic, appointment, programming, scheduling or review).

Some different combinations or boolean expressions of keywords were made for the search (e.g., health dynamic scheduling, dynamic scheduling software health, health dynamic scheduling review or health dynamic appointment scheduling).

Once the searches were performed, articles were discarded based on defined inclusion/exclusion criteria (e.g., publications since 2006, inclusion of keywords, non-duplicates, relevant number of citations, etc.). Finally, 8 papers [13–20] are included in the review. In spite of obtaining articles of more than five years of antiquity, they are very useful to respond to the RQs. To summarize, the results obtained for the RQs are presented below.

RQ1. Are there currently applications that use dynamic programming to help manage patients in the healthcare environment?

No article has been found about the implementation of this technique in a real sanitary environment.

RQ2. Are the user's preferences taken into account when making a user activity?

Considering the user preferences is a fundamental idea [9] that should not be overlooked. Such preferences directly affect the probability of a user delaying an activity or even cancelling it. This relationship is totally logical, because if the user's preferences are not taken into account, is probably that they lose the interest in their appointment.

However, few articles discuss this subject. Only three articles [9, 15, 19] of the eight contemplated mention the preferences of the patient, two theoretically and one experimental. According to [15], this may be due to the complex mathematical models of arduous computation that we obtain if we consider the needs of patients. I.e., it is difficult to model the user's preferences.

RQ3. What health environments have adopted dynamic programming for managing user activities? Differences to keep in mind?

Practically all studies have been done in all possible health areas: outpatient's clinics, external consultations, nursing, treatment and surgery.

Several articles related to the Ambulatory environment were found, followed closely by the External Consultations. Both domains are very similar. On the contrary, Surgery and Treatment are more hostile environments. For example, for treatments, we include the articles [16, 19], which are intended to manage appointments for the treatment of chemotherapy and radiotherapy respectively. In this scenario, times are essential to ensure the best saving percentage. Moreover, cancellations and delays have a great impact on costs because they are expensive treatments.

About surgery, thanks to one of our basic articles [9] we know the difficulty to model an appointment management system for that environment. The main impediment is the impossibility of generalizing the operating times.

In treatment and surgery environment, managing emergencies is vital, so the waiting time for an emergency must be minimized, without neglecting or disfavouring the other patients.

RQ4. How does the non-presentation of the patient influence? And the previous cancellation?

The experimental study introduced in [16] reinforces the idea of the close relationship between the time from the request of the appointment to the date of the appointment, and the probability of cancellation or absence. However, [16, 17, 19] coincide in the following: if we try to minimize the probability of cancellation, paradoxically the time increases. Therefore, the experimental studies presented are not conclusive because there isn´t an efficient technique that attack this problem.

RQ5. Is the time between the request of the next activity and the day of the activity (indirect time) taken into account?

On the one hand, only [16] performs experimental tests trying to minimize the indirect time. On the other hand, [14] claim to continue making experimental tests that contemplating the indirect time and elaborate a study of the reason for such cancellations or absences.

RQ6. How to manage emergencies and their priorities?

Although five of the articles selected [13, 15, 17–20] perform experimental tests attending urgencies, only two of them [17, 18] consider their prioritization.

This studies warn of the complexity of modelling a dynamic appointment management system that accepts urgency. [13, 17–20], save certain time zones to be used for emergencies. However, if these are not used, it is a waste of time, with its consequent influence on costs. In addition, such time reservation increases the time lag between the day that the patient asked for an appointment and the day of the provided appointment which is an undesirable fact. Therefore, it is necessary to keep on researching.

6 Conclusions

In this article, we propose an automatic system of intelligent management of IHPs implemented on a constraint-based system (i.e., CPLEX), which facilitates the modeling of temporal and resource constraints presented in the activities of IHPs.

To the best of our knowledge (cf. Sect. 5) there no exists any direct implementation of intelligent management of IHP systems in health environments.

Our proposal is satisfactory for the sanitary environment of application (cf. Sect. 4) where we can observe the following advantages:

- Healthcare professionals have quick access to the information, thus, avoiding the need to resort to (1) the clinical history of the patient—to know his situation—and (2) the clinical guidelines—which are subjective due to their textual definition—, to know what decision should be taken about the problem of the patient. With our proposal, the health professional quickly knows the situation of the patient and based on it, what activity should be performed.
- Efficient management of the health center. Regarding to the management of IHPs, an intelligent system is in charge of (1) managing efficiently the access to the health service by the patients as well as (2) organizing the schedules of the activities of the IHP in the health center.
- The health sector provides a service that involves a high cost. Therefore, it is important to optimize the management of health centers, not necessarily with the aim of saving, but to provide a better service with the same resources.
  Additionally, optimizing patient waiting times, the efficiency of the sector is enhanced, avoiding possible cancellations and oblivions, and improving health care.
- Healthcare professionals should not be in charge of managing the activities, investing all their working hours to the health care of their patients.

Consequently, the validity and usefulness of these systems in health services is demonstrated.

7 Future Works

Regarding the intelligent management of IHPs, it is important to consider the possibility that a user cancel their activity, is delayed or even does not show up. In these cases, the use of these intelligent systems is very useful since, under a correct design, they can replan the activities. In this way, the intelligent system would improve the efficiency of the sanitary environment. Therefore, we pretend to study its design and implementation in future projects.

In addition, it is interesting to analyse what happens if the health entity has not free resources, i.e., health professionals without free gaps in their schedule of work to attend patients. Therefore, we plan to study how should behave our system in this real situation.

Furthermore, we want to continue modeling other IHPs in our intelligent system in other to generalize the validity of our system.

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