EXITCDSS: A FRAMEWORK FOR A WORKFLOW-BASED CBR FOR INTERVENTIONAL CDSS

Application to Transcatheter Aortic Valve Implantation (TAVI)

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Abstract: The work presented in this paper presents a workflow-based Clinical Decision Support System (CDSS) designed to give case-specific assessment to clinicians during complex surgery or Minimally Invasive Surgerys (MISs). Following a perioperative workflow, the designed software will use a Case-Based Reasoning (CBR) methodology to retrieve similar past cases from a case base to give case-specific advice at any particular point of the process. The graphical user interface allows easy navigation through the whole support progress, from the initial configuration steps to the final results organized as sets of experiments easily visualized in a user-friendly way. The tool is presented giving advice to an example application, a complex minimally invasive surgery which is receiving growing attention lately, the Transcatheter Aortic Valve Implantation (TAVI).

1 INTRODUCTION

Nowadays, medicine and health fields are getting more and more involved with computer science. Among all branches, the main focus of the current research points towards Artificial Intelligence (AI) to improve the performance of Clinical Decision Support Systems (CDSSs). In a general term, CDSSs comprise a large spectrum of systems which provide clinicians, staff, patients, and other individuals with knowledge and person-specific information, intelligently filtered and presented at appropriate times, to enhance health and health care (Berner, 2009).

CDSSs are classified into two main groups, depending on whether they are knowledge-based systems, or nonknowledge-based systems (Berner, 2009). The knowledge-based CDSSs are the most common type of CDSSs used in clinics and hospitals. They are structured around rules mostly in the form of IF-THEN statements. Most of knowledge-based systems consist of three parts, the knowledge base, inference engine, and mechanism to communicate (Wyatt and Spiegelhalter, 1991). The rules are associated with compiled data extracted from a knowledge base. The inference engine combines the rules from the knowledge base with the patient's data. The communication mechanism will allow the system to show the results to the user as well as have input into the system. Nonknowledge-based CDSSs use AI through machine learning techniques, which allow the computer to learn from past experiences and to recognize patterns in the clinical data (Marakas, 1999). Artificial Neural Network (ANN) (Baxt, 1995) and genetic algorithms (Laurikkala et al., 1999) are two common types of nonknowledge-based systems. The fusion of a knowledge base with nonknowledge-based machine learning techniques results into an hybrid system. Hybrid systems extract the best from both methodologies, finally resulting into an overall improvement of the system performance and thus providing an optimal solution for clinical decision support systems (Demmer-Fushman and Lin, 2007). This paper will focus on this kind of hybrid systems, presenting a software framework for CDSS which uses a well-known *lazy learning* technique called Case-Based Reasoning (CBR) (Aamodt and Plaza, 1994) and a past patients case base to asses clinicians.

This paper work presents a workflow-based CDSS designed to give case-specific assessment to clinicians during complex surgery. Following a perioperative workflow, the designed software will use a CBR methodology to retrieve similar past cases from a case base to give case-specific advice at any particular point of the process. The graphical user interface allows easy navigation through the whole support progress, from the initial configuration steps to the final results organized as sets of experiments easily visualized in a user-friendly way. The eXiTCDSS tool is presented giving advice to an example application, assisting a recent complex minimally invasive surgery which is receiving growing attention lately, the Transcatheter Aortic Valve Implantation (TAVI).

This paper is structured as follows. In Section 2 a description of the workflow management during an intervention is detailed. Also, recent applications of CDSS for surgical processes are reviewed. Section 3 introduces the eXiTCDSS framework. In Section 4, the eXiTCDSS demonstrates its performance with its application to a TAVI procedure. Finally, conclusions are included in Section 5.

2 CDSS Integration with Clinical Workflow

Examples of successful applications of CDSSs into clinical workflows comprise computer based patient record systems (Patel et al., 2000), knowledge management systems for biomedical engineering (Rinkus et al., 2004) and computer based training systems in pathology (Crowley et al., 2003). From the successful applications mentioned before it can be extracted that integration with workflow is key to success. How to integrate the CDSS with clinician workflow, however, remains a challenge, in part because there are no current standards for clinical workflow (Das and Eichner, 2010).

Although there is no universally agreed upon definition of the term *workflow*, for the purpose of this article, we have taken the workflow definition stated in (Carayon et al., 2010) which defines a clinical workflow as *a modular sequence of tasks, with a distinct beginning and end, performed for the specific purpose of delivering clinical care*. In order to implement a workflow-based CDSS, tasks, timing and involved subprocesses must by identified first. Therefore, the proposed workflow has been specified at up to four level of detail: 1) clinical workflow, 2) phase, 3) task, and 4) attribute. Figure 1 shows a schematic workflow of an exemplified operative process where the previously mentioned levels have been illustrated. The first level of the workflow represents the particular workflow itself. The second level describes the *phases*, being a phase the primordial division of the specific clinical workflow. For the particular example shown in Figure 1, each phase corresponds to the pre, intra, and post-operative periods. In the same way, every phase has been split into *tasks*, a task being any particular step taken during each phase e.g. apply anesthesia, initial puncture location or valve final placement. Each task has a different number of distinguishable items or *attributes* associated. These attributes refer to all the important values or considerations that the medical staff will take into account during the resolution of a task. The attributes can be described as numerical data, text data, categorical data, and boolean data. As numerical data it can be considered blood count, coagulation parameters, age, size, or specific physiologic measurements. The text data comprises those textual items regarding the patient's pathological or surgical history as well as possible allergies. The categorical, in fact ordered categorical data, comprises attributes which measure a certain degree of intensity, e. g. amount of calcification or valve regurgitation while the boolean data confirms or denies the presence of an attribute, for example the vascular tortuosity or the existence of coronary flow damage. During the intervention execution and according to the current information being generated, the CDSS has to be capable to identify the phase, the task, and the attributes involved. Then, the software will use the CBR engine to retrieve the most similar cases to the current one. The framework eXiTCDSS presented in this article provides the required tools to define a case structure for any clinical procedure based on a workflow.

3 The eXiTCDSS Framework

Case-Based Reasoning (CBR) is a technique of artificial intelligence that attempts to solve a given problem within a specific domain by adapting established solutions to similar problems (Aamodt and Plaza, 1994). CBR has been formalized for purposes of reasoning and learning based on the exploitation of existing similar historical records as humans do. It has been argued that CBR is not only a powerful method for computer reasoning, but also a pervasive behavior in everyday human problem solving; or, more radically, that all reasoning is based on past cases personally experienced. These features make CBR a good contender for any decision support system.

Four main phases of action are defined in the CBR methodology: *retrieve, reuse, revise and retain*. For example, in TAVI, a case base contains information about patients that have been operated in the past. Using this case base, a CBR system is able to give advice to future TAVI cases by following the four phases: retrieve, reuse, revise and retain. First, in the retrieve phase, the current case is compared with all the past experiences in the case base, and the most similar are recovered. Given a target problem, during the retrieve step, cases from memory that are relevant to solving

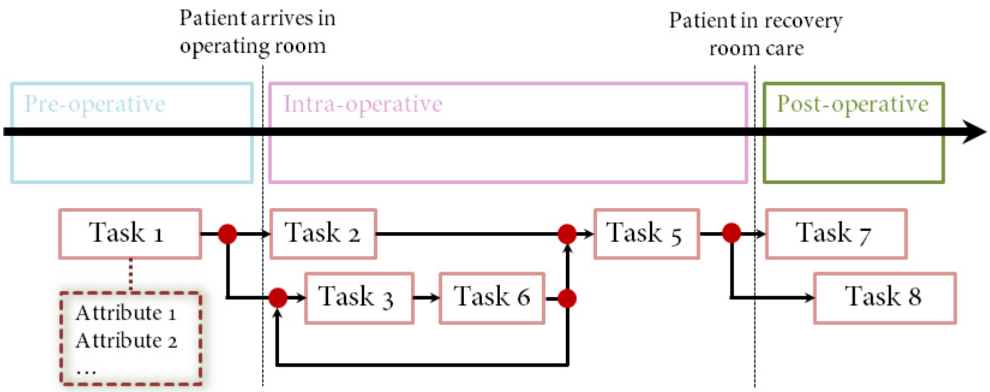

Figure 1: Schematic workflow showing an exemplified operative process.

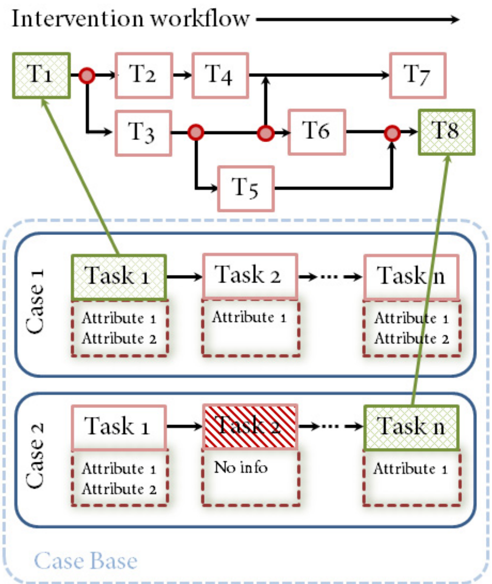

Figure 2: Case structure and retrieval process along the operative workflow.

it are recovered. A case is a whole although usually two parts can be identified according to the problem to be solved: problem and solution space. Problem space can incorporate specific case information and also contextual information useful for solving the problem whereas solution space incorporates information directly related with the solution for solving the problem. Next, in the reuse phase, a solution to the current case is determined based on the solutions found in the retrieved cases, which are mapped to target the actual problem. This may involve adapting the solution as needed to fit the new situation. Third, the computed solution is evaluated in the revise phase. Finally, the retain phase analyzes whether to retain the case in the case base.

When the intervention begins, parallel to the workflow progression described in Figure 2, the CBR mechanism retrieves specific and contextual problem information of similar past cases. Such assessment step determines which cases address problems most similar to the current problem, to identify them as starting points for solving the new problem. Once the operation ends, clinicians proceed with the new case revision, which evaluates and adjusts the adapted solutions and, if suitable, the new case will be retained with the system learning from the situation by storing the result as a new case for future use. The software has been designed to work either on-line inside the Operation Room (OR) or off-line, as a knowledge database for patient study.

As the eXiTCDSS framework goes beyond pure CBR prototyping and aims to support workflow-oriented decision support, other elements are required in addition to the basic CBR modules. In order to manipulate the data, a common representation of cases is required. Also, three main components are distinguished: the workflow editor, the CBR engine and the results navigator. These components are described next.

3.1 Case representation

eXiTCDSS requires a plain Coma Separated Value (CSV) file to handle the data. Each row corresponds to a case, and each column to attributes of the cases. The first four rows describe the attributes as follows. The first row corresponds to the attribute descriptions (for example, ”Annular calcification”). The second row corresponds to the attribute name (usually in a compressed form, as for example, ”Annularcalcification”). The third row corresponds to the attribute type (-1 ignore, 0 boolean, 1 numerical, 2 textual, 3 categorical). The fourth row corresponds to the attribute weight (relevance). This representation covers most of the data used in medical applications and is easy to manage and general enough to be used by any of the current CBR techniques (mainly distance functions).

3.2 The workflow editor

To support a workflow-oriented CDSS software, a *workflow editor* tool has been developed inside the main application so that users can define a workflow file. All the needed features to describe any type of workflow are displayed in a window independent interface that can be accessed from the tools label in the top area of the main window frame of the platform. This functionality includes a shapes menu with all the types of boxes, containers and arrows used to define the workflow structure with all the needed phases and tasks. The created figures are editable and colorable, with a label for its identification. After the structure definition, on the right side of the window, the user proceeds with the attributes-to-task association. By loading the CSV file presented in Section 3.1, the user can access to all the attributes which define a patient's case and associate them to its correspondent task of the workflow. Once the workflow creation is completed, the workflow file is saved as an Extensible Markup Language (XML) file which can be loaded later on by the eXiTCDSS main application in order to proceed with the project development.

3.3 The CBR engine

All the information required to set up a CBR system according to user requirements is stored in the configuration file. The CBR engine is responsible for reading this file, extracting the selected XML and CSV files, methods and parameters and, finally, calling and executing the related CBR algorithms. Therefore, once the configuration file is set, the eXiTCDSS loads the patient case base and the associated workflow file. Then, the engine compares the stored cases with the current patient data, and selects the most similar cases from the case base. There are local and global similarity measures. Local similarity measures compare two attribute values. Global similarity measures combine different local similarity outcomes to determine the similarity between two cases. The application allows the user to track the different tasks of the intervention workflow with its associated attributes while consulting the case base. In addition, the software offers the possibility to load/save different attributes pre-selection. These *presets* allow clinicians to look for similarities between cases by just working with a specific set of attributes or only considering a single phase of the workflow, for example for carrying out patient studies during the pre-operative phase. As output of the retrieve phase, the CBR engine creates a distance matrix that depicts the similitude between the new case and the cases in the case base. This matrix is shown in the results navigator window.

3.4 The results navigator

The *results navigator* window contains a table with the most similar cases to the current case. The results table contains some features to enhance decision support. Thus, clinicians can rearrange the resultant table to see the most and the least similar cases to the current case. Also, if the medical staff needs additional information for decision making, every case of the case base is linked to its complete clinical history where clinicians can consult any image or file. Finally, the results window allows the user to choose the number of similar cases to the current case to retrieve. Possibilities include selecting the k-nearest neighbors or selecting the cases with a similarity degree higher than a pre-fixed threshold.

One of the most significant advances of using a CBR engine is that the knowledge database is continuously updating. Thus, new, revised cases will be added to the case base for future use. eXiTCDSS has been developed using the Java language. It is compatible with the Linux and Windows OS.

4 EXITCDSS SUPPORTS TRANSCATHETER VALVE IMPLANTATION

In Transcatheter Aortic Valve Implantation (TAVI) (Webb and Cribier, 2011), a synthetic valve is transported to the heart through a small hole made in groin. This procedure can be compared to that performed when placing a stent, or performing balloon angioplasty. This technique was first developed in Europe, where it was initially performed in 2002. Since then, more than 10000 patients have benefited from it and the results have shown the procedure to be effective in improving functioning in the patients with severe aortic stenosis. In the recent years TAVI is assuming a major role in the routine management of patients with aortic stenosis and now TAVI is considered the standard in patients who are not candidates for conventional surgical Aortic Valve Replacement (AVR). On the basis of almost 10 years of experience TAVI also appears to be a reasonable option for some operable, but high-risk patients. Nevertheless considerable work needs to be done before TAVI is expanded into

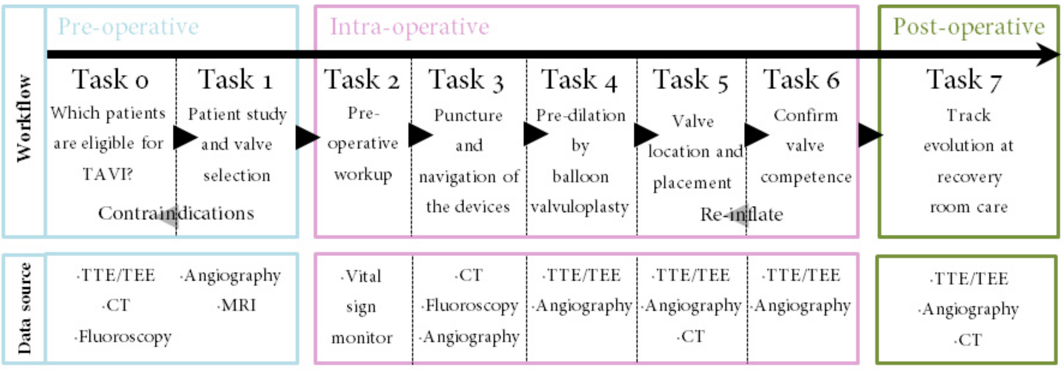

Figure 3: TAVI workflow showing tasks and data source where attributes are extracted from.

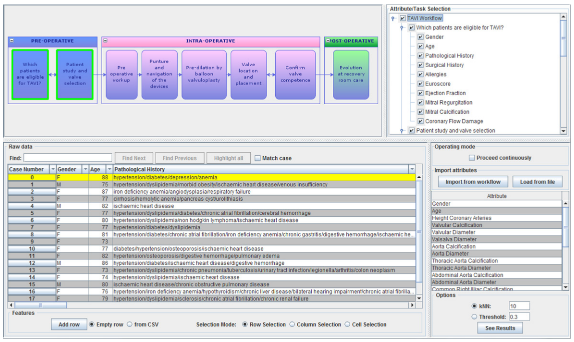

Figure 4: The main working window of the eXiTCDSS support tool.

lower risk groups.

Next lines describe an example application of the eXiTCDSS performance. Figure 3 shows the specific workflow for the TAVI intervention. As can be appreciated, the procedure (from pre-operative to post-operative treatment) is subdivided in 8 different tasks, starting with a study of patient suitability for TAVI in *Task 0*, to *Task 7* where the patient is finally transferred to the Intensive Care Unit (ICU). Parallel to the workflow progress, all the tasks are linked with the different information sources which will provide the necessary attribute data required for defining the patient case model. The TAVI workflow together with the CSV file containing the patient case base are both loaded into the *workflow editor* in order to produce the correspondent XML workflow file. Pre-selected workmods mentioned in Section 3.3 are available at this point so the user can load or save a desired selection of whatever attributes and/or operation tasks he wishes to receive support from.

For demonstration purposes, the application shows its capabilities while giving support to a one particular aspect discussed during Tasks 1 and 2 of a TAVI intervention, which aims to answer a basic question: *Which access?* Nowadays, the most common approaches in TAVI are the transfemoral, the transapical, and the subclavian way. These approaches are selected after studying the patient's profile. The eXiTCDSS support for this demonstration starts by, from all the attributes list available at Task 1 and 2, selecting those ones considered by clinicians as the most relevant for deciding the vascular access (see Figure 4). Next, the case number 0 is selected as the new *query* case from a case base of 20 cases. It is important to remark that, in a real clinical situation, the vascular access of the query case is not known and thus, this attribute has not been selected so it remains unknown for the program. The results offered by the eXiTCDSS application after the retrieve phase are illustrated in Figure 5. The table depicts the 10 most similar cases to the query case based on the similarity distance described in Section 3.3. Also, the vascular access selected in every case is shown. As can be appreciated, the closest cases to the query case used the transfemoral approach, the same approach that was used with the query case. The eXiTCDSS engine retrieves similar transfemoral approaches when asked for a new access way, advising clinicians about which access way is the best based on similarities with past patients. Next, experts will be able to study all the profiles of the retrieved cases or launch another retrieve search based on some other attributes.

5 CONCLUSIONS

This paper presents eXiTCDSS, a workflow-based CDSS designed to give case-specific assessment to clinicians during complex surgery or MISs. The framework facilitates interaction with physicians, which are guided along the application in a user-friendly way. Its workflow structure offers high versatility allowing the clinicians to decide in which steps of the procedure they wish to receive sup-

Case Number	Vascular Access	Distance
0	transfemoral	0,00
5	transfemoral	0,12
1	transfemoral	0,13
6	transfemoral	0,13
2	transfemoral	0,13
3	transfemoral	0,14
16	transapical	0,14
15	transapical	0,14
7	transapical	0,14
14	transapical	0,15
4	transfemoral	0,15

Figure 5: The table shows an ordered list of similar cases to the query case 0.

port. The tasks and attributes selection can easily be saved/loaded into independent files for future use. Although it has been designed to give support to a wide range of interventions, the eXiTCDSS has been initially applied to give support to TAVI interventions. The tool has demonstrated its performance giving support to a specific step of a TAVI procedure with good results. Current work is focused with improving the user interface, specially during the OR phase. Software architecture modifications will provide the application with voice activation and gesture recognition tools. Finally, the feedback received from the numerous physicians consulted has been very positive and the interest showed in this project is encouraging. Clinicians agree that CDSS are of high value specially in recently growing MIS like TAVI where the number of interventions per year is still low compared to common surgery and which also require expert hands due to its complex procedure.

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