Program Supervision in Medical Imagery

M. Crubézy†, S. Moisan†, F. Aubry‡,
J. van den Elst†, V. Chameroy‡

† INRIA Sophia Antipolis
2004 route des Lucioles
F-06902 Sophia Antipolis, France
email: mcrubezy@sophia.inria.fr
Fax: +33 93 65 69 39
Tel: +33 93 65 78 47

‡ INSERM U66
91 Boulevard de l'Hopital
F-75634 Paris, France
email: aubry@imed.jussieu.fr
Fax: +33 1 53 82 84 00
Tel: +33 1 53 82 84 48

Keywords: Knowledge-based program supervision, medical imaging, data representation, planning.

Abstract

Image processing in the fields of medical diagnosis and therapy follow-up is a challenging issue because of the complexity of the knowledge involved in describing the data and reasoning mechanisms a radiologist uses. A methodological radiologist would be helped if a system could schedule and execute operations and reason on data and user-goals, leaving him with the result interpretation. In this article we show what knowledge is needed to perform the supervision (that is planning and control of execution) of medical image processing programs, and how this knowledge should be described and structured. Our aim is to develop a program supervision tool to help a user in the manipulation of data and programs specific to medical imagery. It must therefore offer a framework to describe knowledge on data, programs and reasoning processes, as well as planning, execution and control mechanisms adapted to the expert in medical image processing. For this purpose, we have developed a constructive modelisation for data description that enables encapsulating knowledge where it is useful for program supervision and we propose a hybrid planning strategy.

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1 Introduction

The aim of medical imaging is to support a medical expert in her/his diagnostic, therapeutic or surgical activities by providing qualitative, quantitative, morphological or functional information from 2D images or 2D image sequences. While qualitative information may be obtained by simple visual inspection of these images, quantitative information is the result of image processing. It is often difficult for a user to run the complex medical image processing programs in the most suitable way to solve a particular problem. This activity implies to know how to select, to order, and to execute these programs. *Program supervision* consists in the automation of the management of program libraries, freeing the user of doing this job manually. We are interested in the use of knowledge-based systems for program supervision in medical imagery. In this article we show what knowledge is needed to perform the supervision of medical image processing programs, and how this knowledge should be described and structured.

Section 2 explains the need for knowledge-based program supervision in medical imagery. Then section 3 details the basic principles of program supervision. Sections 4 and 5 present the specific structures needed for medical imagery concerning both data description and program planning. Finally, section 6 compares our proposal with some existing approaches.

2 The Medical Imagery Framework

Image processing in the fields of medical diagnosis and therapy follow-up is a challenging issue because of the complexity of the knowledge involved in describing the data and reasoning mechanisms a radiologist uses. It is not possible to represent this knowledge in an exhaustive way. Consequently, data such as dynamic sequences of medical images, issued for example from nuclear medecine (NM) or magnetic resonance imaging (MRI) techniques, and programs that process them involve new interests in data representation and process scheduling.

On the one hand medical imagery is concerned with various data types (e.g. images, sequences) and different viewpoints on them. Therapeutic, interventional or functional analysis tasks often require image sequence acquisition. Image sequences are sets of 2D images sorted by space (tomographic images that represent virtual slices of an organ), time (dynamic sequences that represents an organ movement or the evolution of a physiological process), energy, or combinations of these.

On the other hand medical imagery deals with numerous, imprecise and incomplete image manipulation goals that are either methodological or clinical.

Our aim is to develop a program supervision system to help the user in the manipulation of data and programs specific to medical imagery. It must therefore offer a framework to describe knowledge on data, programs and reasoning processes, as well as planning, execution and control mechanisms adapted to the expert in medical image processing.

Our reference application concerns chemotherapy follow-up (as opposed to diagnosis) either by NM or MRI dynamic sequences, which presents the advantage to be well defined as a protocol [6]. This application is based on the Factor Analysis of Medical Image Sequences (FAMIS) [7], which performs a functional analysis of an image sequence, with respect to a mathematico-statistical model of the analysed process. A methodological radiologist would be helped if a system could schedule and execute operations and reason on data and user-goals, leaving him with the result interpretation.

The approach we propose is based on our previous work in program supervision applied to image processing in different domains [10],[9] and in particular in medical imagery [2]. IQSS [2] mainly focusses on the knowledge representation for program supervision, but it lacks the control of execution of the programs. Given the specification of a knowledge base for specific data and program library, a tool like OCAPI [4] can generate a dedicated knowledge-based system. It provides a hierachical skeleton-based planner using simple data descriptions. Due to the complexity of both data and planning strategy in medical imagery, neither OCAPI nor IQSS cover all our needs.

3 Program supervision

Program supervision consists in the automation of the management of program libraries that contain a large number of programs. To perform a certain task, a subset of these programs is chosen, ordered and applied. Many libraries of programs have been written by specialists in many different domains. It is usually very hard for non-specialists to apply them. Artificial intelligence techniques can be used to guide a non-specialist with the application of the programs in various working environments.

In program supervision, different phases can be identified that can be completely or only partly automated. *Planning* aims at building a plan, i.e. a sequence of steps, corresponding to operators (or actions) to be executed. The actual *execution* of these actions is usually followed by an *evaluation* of the results. In case of bad results, this may lead to a *repair* phase, that modify the plan. These four phases are usually interleaved.

A program supervision system must encapsulate knowledge about the programs and the planning strategy. In particular, important concepts that may provide information to improve planning efficiency must be described. These descriptions have to be as close as possible to the experts model, which facilitates knowledge acquisition. Some of them are listed below.

A *goal* describes, by means of constraints, the suitable properties that must hold in a state of the world to decide that a certain objective is achieved.

Plan elements correspond to operators (abstract or real) which perform actions and manipulate data. They are represented by [12] a function or purpose (e.g. "factor estimation", or "segmentation"), characteristics (e.g. "resource consumption"), pre- and post-conditions (e.g. "first image must be subtracted from the sequence"), and a description of their input/output data and parameters (e.g. type, range or obtention means). Terminal plan elements contain a reference to actual programs and how to activate these programs. Plan elements also contain various criteria, e.g. to initialize and adjust their argument values before their application, and to evaluate output arguments after application.

In some cases, plan elements may be organized in predefined *plan schemes* that are partial skeletons of plans. They correspond to networks of possible connections between plan elements, in order to achieve a given goal. These connections can be e.g. choice, sequence, or iteration. Plan schemes contain information about data flow between their elements, together with tactical knowledge i.e. criteria to decide how to cross the network.

This descriptive knowledge is used during planning. For example information on the function, characteristics, description of arguments, and pre/post-conditions of plan elements is usefull for selection purposes.

Due to the great diversity of planning problems, many different planning techniques exist. A distinction, important in our case, is made between hierarchical and non-hierarchical planning. Hierarchical planning is based on a hierarchical description of the data and operators. A hierarchical planner first constructs an abstract plan, then refines it for a particular situation. Hierarchical planning is prefered in program supervision, mainly because the expert often thinks in terms of abstract plan schemes.

A program supervision hierarchical planner works on a tree representing abstraction levels between operators (abstract and real ones). The relations between those abstraction levels denote either specialization (choice) or decomposition. A plan step corresponds to the execution of an operator of the tree with a particular parameter instantiation.

4 Data description in medical imagery

For application domains involving complex data, such as images in medical imagery, it is important to describe the data types in a clear, structured and understandable way to allow a program supervisor to take necessary decisions. We have identified our data model from experiences both in medical imagery, and in program supervision. These experiences not only concern our personal work, but also those presented in other approaches to program supervision (like [8], [5], [3]), and to medical image description theories [1]. The need of complex data types occured because in program supervision the data are not only entities that are manipulated by the programs, but also provide the program supervisor with information about how to choose and plan the programs, how to initialise parameters, etc.

The great variety of image acquisition techniques and medical examinations (e.g. organs observed, pathologies examined, patient, contrast media used) implies many different types of medical images. They are related to clinical goals (e.g. "chemotherapy follow-up") as well as more methodologic goals (e.g. "physiological functions estimation"), which define the type of image (or image sequence) to analyse and the processing to perform.

An exhaustive data description is both difficult to define and non-evolutive. So, we have developed a constructive approach that enables encapsulating knowledge where it is useful [1]. For the application domain of medical image processing we have therefore predefined a data categorization allowing an expert to construct the necessary data type for a particular application. We distinguish five different viewpoints on data, as shown in figure 1, that have been chosen for their appropriateness in automatic image processing program supervision. So our description is not exhaustive, just sufficient to describe

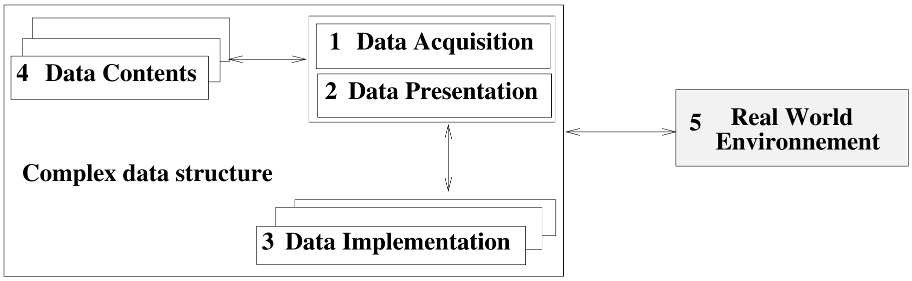

Figure 1: Data model for medical image processing program supervision.

necessary information for the program supervision process.

Data acquisition concerns the acquisition parameters of the data. Examples are the physical space and time properties of a temporal image sequence, the physical source (e.g. PET, MRI, X-Ray CT-Scan) and the type of the signal acquired on an image (e.g. X-ray, gamma-ray, spin-echo), the noise type (e.g. gaussian, Poisson) of an image, and the relative position between the patient and the image source. From this information, many other characteristics of the data can be deduced (e.g. statistical properties of the data, rough estimation of constrast, resolution or noise level).

Data presentation concerns the way the image is observed. It describes for instance visualisation parameters, like the size of the image, the number of images in a sequence, or the noise level. This information can be changed in the data by adaptation processing, according to the way the data has to "look like" for major processing.

Data implementation is composed of coding information (about the way the data is structured) and physical location (e.g. file in which the image is stored).

Data contents concern the objects that are present in the image, described in geometrical, topological and spatial terms and not in terms of their relations with the observed objects. Here can be expressed both information about what should be found in the image and what is really present in the image (e.g. number of objects in an image, colour or shape of objects, or relations between them, such as symmetry or overlap).

Finally the *real world environnement* describes both observed real objects and acquisition objects. It can be related to information of the other levels. Acquisition objects are for example the image source: type of camera, noise level, type of physical process for signal acquisition. Information at this level influences data acquisition parameters. For example, the type of camera specifies the resolution of the acquired image. Observed objects that can be described are for example the anatomical region examined (kidney, heart, etc), with its composition (bony, vascular, etc), or its structure (e.g. mono-organic or double-organic), or the type of the observed phenomenon (e.g. tumoral, healthy).

Such a data model enables us to take into account the different levels of planning described in the next section. Data acquisition information, fixed once and for all, together with data contents information, is used in the global planning, where the successive transformations of the data are described. Data presentation information enables refining the plan in reaction to real execution parameters. Finally, data implementation is needed when data is actually accessed to.

5 Hybrid Planning Strategy for Medical Imagery

From our experience, the planning strategy of an expert in medical imagery is generaly divided in two phases. First, the expert defines abstract static decompositions associated to goals. This enables to plan coarse steps in a global way with respect to image data (and their parameters). For this phase no information about executable programs or data flow is used.

A second phase, driven by concrete data and execution constrainsts, provides dynamic choice criteria to select and combine the adequate programs that will fullfil the plan. If needed, intermediate goals are dynamically created to adapt execution conditions to programs utilisation constraints.

For example, FAMIS method great lines are well defined and unlikely to change much from one execution to another. It reduces a medical image sequence to its significant information, in terms of the estimated underlying physiological functions ("factors"), active in the examined organ, associated to their spatial distribution[7]. It can therefore be coarsly decomposed in four major steps: *segmentation* first focuses the further analysis on the pertinent signal, *orthogonal analysis* then reduces information to its noisyless expression. Next, *oblic analysis* closely approximates the physiological factors under domain constraints, like necessary positivity of the solutions, for example. Last, *information presentation* processes the physiological factors and their spatial distribution, reported on the image sequence.

Besides these four fixed steps, possible pre- and post-processing phases can dynamically be added. For example, pre-processing to correct patient movements, and post-processing to compare the results of FAMIS on pathological and corresponding healthy parts of an organ.

Therefore we find it relevant to develop a hybrid planner, mixing skeletal planning for global description of the plan and partial ordered planning to adapt it to real conditions.

Strategic principles have to be defined to :

- select plan elements with respect to their purpose, when they are not prefixed in the plan.

- verify the compatibility between the types of the data present and the data the selected plan element can process.
- create intermediate steps to adapt execution context to the constraints of the selected plan element.

Such principles enable to mention only systematic steps in the treatment, avoiding the description of all possible plans.

6 Comparison with existing approaches

Already at the origins of medical imagery automation, tools that enable complex processing and hide implementation details from the user were developed. Such tools should provide flexibility in the use and construction of complex processing. But early systems did not provide this flexibility in a dynamic way. For example, the system CL/ONE, developed in the late 70's and later applied to medical image processing in nuclear medecine [11] proposed original solutions for choice and command of programs together with the initialisation of their parameters, enabling the reuse of programs and applications in different contexts. However, this system did not provide sufficiently intelligent mechanisms of planning and reasoning, nor rich possibilities to express descriptive or strategic knowledge. Recently, several intelligent systems have been developed for specific application domains, as well as for more general purposes. All these systems propose a more or less fine data description, and contain additional information for program supervision.

VISIPLAN [8] is an interactive object centered hierarchical planner for composing biomedical image analysis processes. The planning is guided by the objects to analyse that are visible in the image (e.g. the brain and brain regions to detect multiple sclerosis). First an abstract plan is composed of actions that sequentially focus the attention on different reference objects. Then, this abstract plan is refined by scheduling five predefined tasks. VISIPLAN does not contain mechanisms for automatic evaluation and adaption during execution. The planning knowledge is described by a semantic network and production rules. It includes the description of the data and additional information for program supervision. The advantage is that the expert is free to define whatever is necessary for a given application. The disadvantage however is the lack of structure, which on turn does not allow an easy comprehension between a novice end-user and the system.

BORG [5] has been tested on an application in medical imagery for segmentation of cytological images. Knowledge about programs and program supervision is described in independent and autonomous modules, called knowledge sources, allowing an opportunistic approach to plan construction. The system performs opportunistic hierarchical planning using five predefined decomposition levels: requests, tasks, functionalities, procedures and operators. BORG also contains knowledge for automatic evaluation of program results. Images are defined by means of attribute-value list describing physics about image formation (e.g. acquisition conditions, type of camera), perceptual information (e.g. homogeneous background, texture of objects, size of objects) and knowledge about the semantics of the scene (relations between objects).

MVP [3], the multimission VICAR planning system, first reduces an image processing problem using decomposition methods and then solves the resulting subproblems using operator planning techniques. Despite the fact that it was not developed for medical imaging applications, it still has a hybrid planner. MVP contains no knowledge to perform automatic evaluation and adaptation during execution and does not address the problem of data description. Programs are described in terms of their preconditions (required to be true before an action can be executed) and effects (true after an action is executed).

Contrary to the approaches mentioned above, we prefer to impose a predefined categorisation of the different types of knowledge, like an image description structure, and knowledge categories for decomposition, choice, initialisation, and automatic evaluation and adaption. This provides a clear and structured description of the data, real-world objects and programs, that still leaves the expert free to add all the necessary information for a particular purpose. This enables easy knowledge expression, because the model is close to the domain expert one and easy comprehension between an end-user and the system. Concerning the planning mechanisms, VISIPLAN is based on two predefined decompositions while BORG has five predefined decomposition levels, but the decompositions themselves are dynamically created by the system. In MVP only the first top-level decomposition is predefined, which is followed by dynamic planning. We adopt the same hybrid approach as MVP, with the only difference that in our case the dynamic planning is based on information described in the image acquisition and image contents, while this information is not necessarily present in MVP. Moreover, all the mentioned systems lack the knowledge to perform automatic evaluation and adaptation during execution (BORG contains knowledge for automatic evaluation of program results, but doesn't detail how this is used). On the contrary, we propose to include this kind of knowledge in our system.

7 Conclusion

This work is at the boundary between medical imagery and artificial intelligence. The concerns that occur with medical image processing program planning enrich our program supervision model, and provide us with guidelines to develop software tools.

The non-exhaustiveness of data description as well as the mixed reasoning mechanisms involved in medical imagery led us to focus on two points: data description and planning strategy. We have proposed a constructive modelisation of the data, that consists of five viewpoints on data information and a hybrid planning strategy.

At present, we have already developed a first version of a hybrid planning kernel, written in Lisp, using the concepts presented in section 4 and 5. The frame formalism has been chosen to represent most of them, whereas production rules are used to represent the different criteria which are associated to plan elements, goals, or plan schemes. These criteria are applied along the reasoning process, for example to sort a set of potential plan elements from a repository. We are also working on a data description language for the expert to specify a knowledge base. Our future work will cover data description implementation, including the notion of viewpoints and refinements on the planning and error reparation strategy mechanisms.

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