LEMMA: A Language for Easy Medical Models Analysis

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Abstract

Health care systems are becoming extremely complex and expensive. New methods are required to optimize health care processes in order to guarantee high quality standards within the (limited) available resources. Resource optimizations able to preserve the quality of treatments require good models of diagnostic and therapeutic processes.

This paper proposes LEMMA, a new model for medical processes, that mixes formal and informal notations, overcoming the problems of either approaches. LEMMA merges high expressive specific constructs with a formal definition. LEMMA has been validated using a prototype for modeling and analyzing diagnostic processes.

Topics:
Optimization of diagnostic processes, diagnostic and therapeutic processes.

1: Introduction

Health care systems are becoming extremely complex and expensive. New methods are required to optimize health care processes in order to guarantee high quality standards within the (limited) available resources. Resource optimizations, able to preserve the quality of treatments, require good models of diagnostic and therapeutic processes [8]. Medical processes have been modeled in many different ways: natural language [5], object-oriented diagrams [3], graph grammars [6], Petri nets [4]. Informal methods, e.g., natural language, retain ambiguities and provide little support for analyzing the modeled processes. Formal methods, e.g. Petri nets, overcome the problems of informal methods, but are difficult to understand without a specific mathematical background.

This paper proposes LEMMA, a new model for medical processes, which mixes formal and informal notations, overcoming the problems of either approaches. LEMMA is a domain specific graphical language developed by a joined team of computer scientists and professionals of medical science. The notation merges high expressive specific constructs with a formal definition: each element of the notation is given operational semantics by means of high-level timed Petri nets (HLTPNs) [7]. The proposal is based on technology successfully used in software engineering [2, 9]: a user-friendly front-end notation easily accessible with the typical background of physicians, automatically translated onto a formal model used to formally analyze the modeled processes. Physicians define clinical and diagnostic models using an easily understandable language, and they gain all the benefits of the formal representation to assess the diagnostic and therapeutic procedures. The formal representation, i.e., the corresponding Petri net, can automatically be executed and analyzed. LEMMA does not require physicians to be proficient in Petri nets to understand the results.

This paper focuses on LEMMA and related analysis capabilities, that are presented in Section 2. The use of LEMMA to model diagnostic processes is illustrated in Section 3, which briefly describes the environment used to validate the technology, and presents a model of the diagnosis procedure of colon-rectal cancer. The underlying technology is fully described in [1, 2]. The main results presented in this paper and the future development based on them are discussed in Section 4.

2: LEMMA

LEMMA is a graphical operational notation. A LEMMA model consists of a topology, that described the diagnostic paths followed by patients, and a set of symptoms. Symptoms define the cases for which the modeled process is applicable, i.e., they identify the domain of the model. The lexical elements available to design diagnostic processes are: *entry* and *exit points*, *clinical tests*, *sets of clinical tests*, *iterators*, and *selectors*. In this section, the elements of LEMMA are described by presenting their representation and by illustrating their behavior. Due to space limitations, the formal semantics, i.e., the Petri nets that formally define the behavior, is omitted. The full semantics can be found in [1].

2.1 The Notation

In LEMMA, nodes correspond to steps of the diagnostic process; edges model the order in which such steps shall be performed. Patients are the main actors of the processes. Patients undergo a set of steps, in the order given by the edges. Patients enter processes through *entry points* and they leave processes through *exit points*. The status of a patient is coded with a "virtual" health record, that describes the patient anamnesis. Entry points represent the phases during which physicians associate patients with sets of symptoms. These activities are usually carried out through checkups. The path followed by patients in the process depends on their symptoms and the decisions taken by physicians. The results of clinical tests and the symptoms observed when entering the process guide physicians in their choices. The execution of a clinical test is modeled as a request of test followed by the acquisition of the results. All the requests of the same type are processed by the same clinical laboratory. The model of a laboratory can be extended to consider resources.

The arrival of a patient at an exit point is associated with the release of a diagnosis. This diagnosis can either identify a precise problem, and thus lead to a therapeutic process, or suggest for further clinical tests not modeled within the current process, and thus lead to another diagnostic process.

The lexicon of LEMMA is summarized in Table 1. *Clinical tests* model the execution of medical investigations. These investigations can be described with clinical tests with either two outcomes (positive or negative) or four outcomes (positive, negative, null or undefined). Investigations are executed in medical laboratories. Different models of laboratories can be used to study different properties of diagnostic processes.

Clinical tests can be grouped in *sets of clinical tests* to model the execution of sets of investigations in unspecified order. The number and the semantics of exit points of *sets of clinical tests* are defined by physicians. Since the number of combinations grows exponentially in the number of investigations, physicians can refer to default rules to simplify the definition of the semantics. For example, physicians can consider positive outcomes dominant on other outcomes. In this case, a single positive outcome determines a positive result regardless of the outcomes of the other tests.

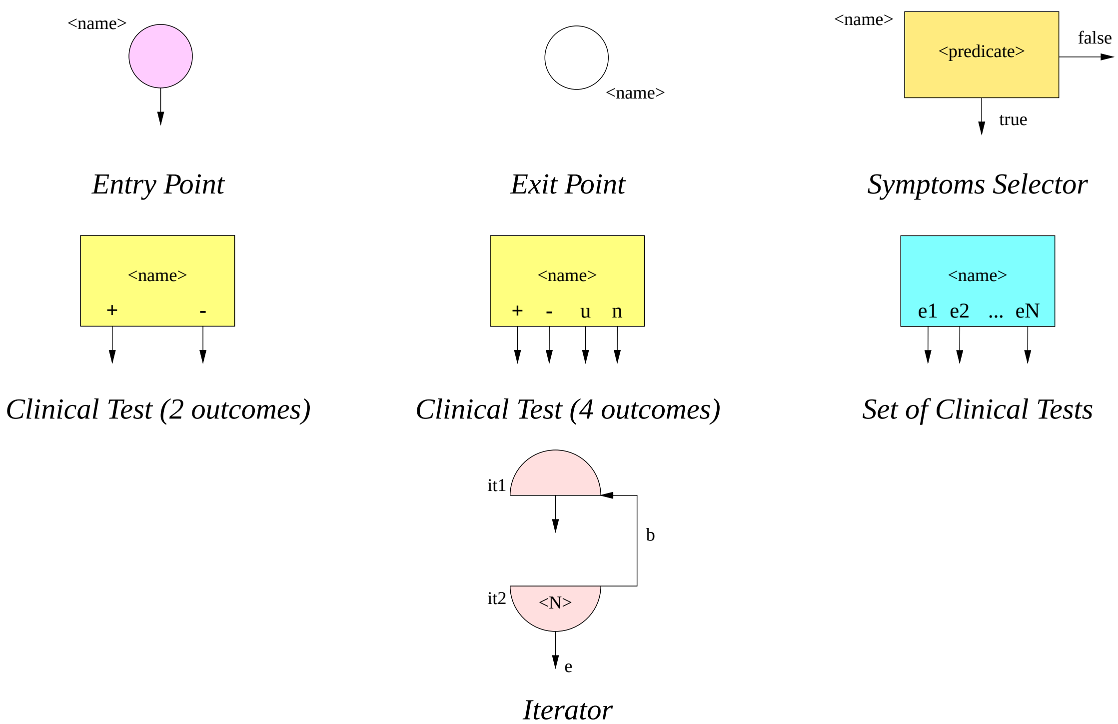

Table 1. The lexicon of LEMMA.

Symptoms selectors are split points of diagnostic paths. They determine the path to be followed by patients. The decisions are taken by comparing the symptoms of the patients with the symptoms associated with the selector. *Symptoms selectors* are defined by means of predicates, that describe the condition that leads to exit *true*. This predicate is coded by listing the symptoms that must be present, and the ones that must be absent.

Iterators govern the flow of patients through subprocesses. They indicate the maximum number of times a sequence of steps has to be undertaken to complete the process.

2.2 Analysis Capabilities

LEMMA models can be validated through the execution or the analysis of the underlying HLTPNs. The results of executing or analyzing the semantic HLTPNs are suitably displayed in LEMMA.

The executions of the underlying HLTPNs are displayed through the LEMMA interface by associating firings of HLTPN transitions with animations of the corresponding LEMMA elements. The executions (simulations) are initiated by inserting patients with specific symptoms in the models. Such initializations are translated into corresponding initializations of the underlying HLTPNs. Animations are given by moving patients through the paths of the diagnostic models according to the firings of the corresponding transitions. Transition firings are driven by the symptoms of the patients, the outcomes of the clinical investigations and the choices of physicians. An example of animation is presented in Figure 1, which shows the process for the diagnosis of colon-rectal cancer with a patient at exit point *diagnosis* and the diagnostic path followed by the patient suitably highlighted.

Syntactic and semantic correctness of LEMMA models can formally be analyzed by checking the syntax and the semantics of the corresponding HLTPNs. Syntactic analysis checks the syntactic consistency and the completeness of the elements and their connections. It can reveal the absence of required elements, e.g., *entry* and *exit points*, open input/outputs, e.g., unconnected outputs of clinical tests, wrong connections, e.g., wrong sequences of clinical tests within iterators. Semantic analysis can identify incorrect states or paths that could be wrongly reached or executed. Examples of semantic errors, that can be identified on the underlying HLTPNs, are dead paths and wrong chains of selectors. Dead paths, i.e., paths that can never be taken, correspond to inaccuracies or errors in the models. Incorrect chaining of selectors can introduce unforeseen or wrong combinations of symptoms that would wrongly guide patients in the models.

Cognitive analysis allows physicians to retrieve information about their diagnostic models, such as specific sequencing among sets of clinical tests, the required number of specific clinical tests, the average time spent by a patient in the model. Statistic and timing analysis can provide optimization criteria, e.g., they can suggest the optimal order of clinical tests for minimizing the hospitalization of patients, thus reducing costs without affecting the quality of the process. A detailed explanation of available techniques is given in [1].

3: Case Study

LEMMA has been validated through a prototype, that has been used to check the usability of the notation on the field, and to validate the modeling and analysis of diagnostic processes.

The prototype is composed of an editor for LEMMA, an automatic translator from LEMMA to HLPTNs and vice-versa, a HLTPN executor, and a HLTPN analyzer. The editor, used by medical professionals to construct and check their diagnostic models, provides users with the usual editing functionalities. The translator is a customization of the generic translator described in [2]. HLTPNs are executed and analyzed using Cabernet [10].

3.1 A Model of the Diagnosis Procedure of Colon-Rectal Cancer

The prototype has been employed to validate a protocol of the diagnosis procedure of colon-rectal cancer [5]. The original description in natural language was "interpreted" according to daily practice to solve ambiguities.

Symptoms are grouped into three classes, general, first order, and second order symptoms, according to the different selection procedures suggested in the original documentation. The diagnosis of colon-rectal cancer requires the following clinical tests: occult blood testing, rectumscopy and double contrast barium enema – performed together – and colonscopy. The order of execution of rectumscopy and double contrast barium enema is irrelevant from the diagnostic viewpoint. The overall evaluation of the two aforementioned clinical tests is given by the dominance of the positive result. Physicians indicate that colonscopy can lead immediately to a diagnosis, while the other tests must be completed by further clinical investigations. The LEMMA model of the diagnosis procedure of colon-rectal cancer is shown in Figure 1.

Patients enter the process from the only available entry point, and can follow either one of the four different diagnostic paths, identified by the four main streams in the model. The first path can result in either a diagnosis or a request for further investigation with respect to respiratory system; the second path besides releasing a diagnosis can move the patient to another unspecified diagnostic process. The third path always releases a diagnosis, while the fourth path, i.e., the one identified by exit *false* from all the selectors, guides directly the patient to another process.

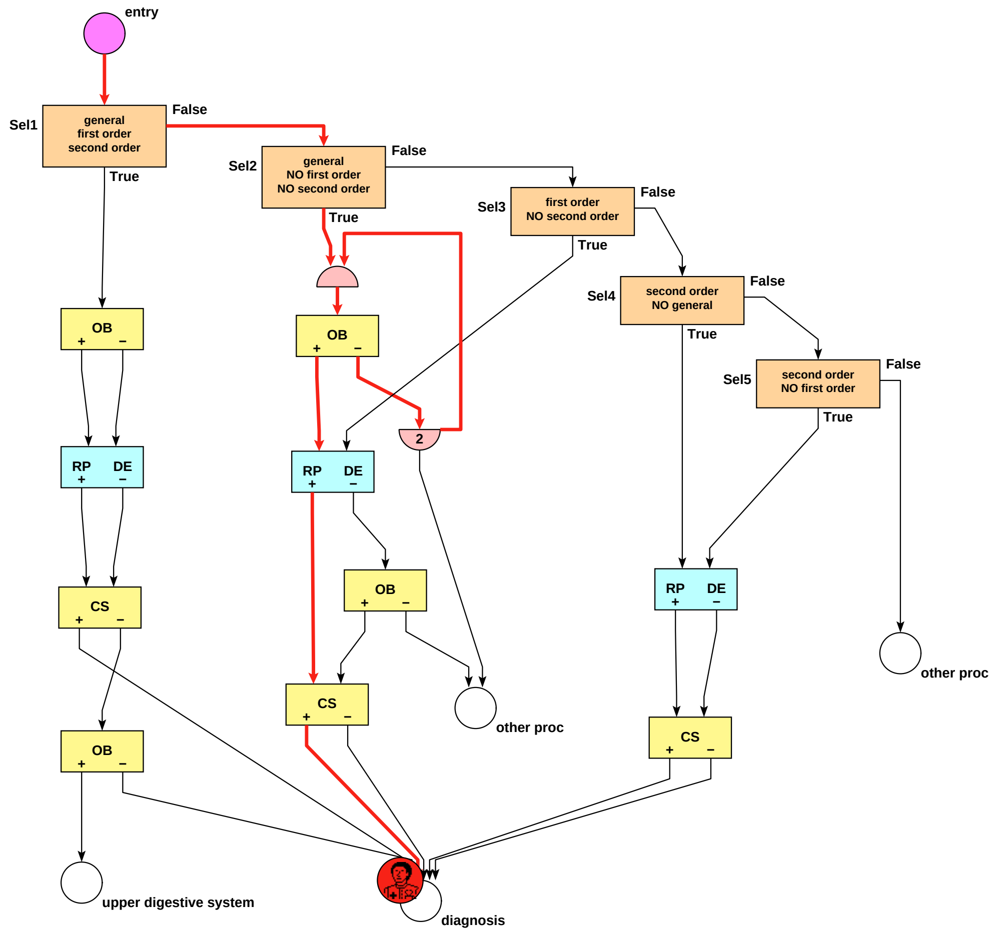

Figure 1. LEMMA model of the diagnosis procedure of colon-rectal cancer.

3.2: Validation

The LEMMA model of the diagnosis procedure of colon-rectal cancer has been executed and analyzed using the techniques described in Section 2.2. The model of Figure 1 is syntactically correct: it comprises one entry point and four exit points and all the elements are correctly connected. Semantic analysis highlighted that there are no infinite loops and no dead paths, and the iterator is properly used. Cognitive analysis suggested a possible misinterpretation of `sel5`. Exit *true* is not reachable by a patient with second order symptoms, but without the general and first order ones. According to this situation, a patient reaches exit *true* of `sel4`, which leads to the same element in which a patient could arrive from exit *true* of `sel5`.

4: Conclusions

This paper presents LEMMA, a new notation for diagnostic and therapeutic processes. LEMMA is given formal semantics through the dual language approach described in [1, 2]. In this way LEMMA models can be syntactically and semantically analyzed.

LEMMA has been validated on real case studies, that show its suitability for modeling diagnostic processes and its usability in a medical environment. The analyses performed on the case studies have been extremely useful to check the correctness of the models.

We are currently improving LEMMA by adding new elements to widen the set of processes that can be described. We plan to increase analysis functionalities by integrating the LEMMA supporting environment into a more general framework to include additional information to drive the diagnostic processes.

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