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Sequence of decisions on discrete event systems modeled by Petri nets with structural alternative configurations

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ABSTRACT

The management of certain systems, such as manufacturing facilities, supply chains, or communication networks implies assessing the consequences of decisions, aimed for the most efficient operation. This kind of systems usually shows complex behaviors where subsystems present parallel evolutions and synchronizations. Furthermore, the existence of global objectives for the operation of the systems and the changes that experience the systems or their environment during their evolution imply a more or less strong dependence between decisions made at different time points of the life cycle. This paper addresses a complex problem that is scarcely present in the scientific literature: the sequences of decisions aimed for achieving several objectives simultaneously and with strong influence from one decision to the rest of them. In this case, the formal statement of the decision problem should take into account the whole decision sequence, making impractical the solving paradigm of "divide and conquer". Only an integrated methodology may afford a realistic solution of such a type of decision problem. In this paper, an approach based on the formalism of the Petri nets is described, several considerations related to this problem are presented, a solving methodology based on the previous work of the authors, as well as a case-study to illustrate the main concepts.

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1. Introduction

Real and complex systems, regarded as discrete event systems, may require a decision making process to be useful for certain applications, such as industrial manufacturing, supply chain, computer systems, and communication networks. The decisions may be more or less difficult to make, regarding the system itself, the considered application, and the objectives to be achieved. For allowing the decision making, the discrete event system should present one or several freedom degrees or undefined characteristics leading to an undefined discrete event system [12].

These undefined characteristics may belong to the behavior or to the structure of the system. Several solving methodologies can be considered. In order to develop a more or less general procedure for solving the decision-making problem it is convenient to represent the decision-making problem in a formal language.

Moreover, simulation consists of a technique for trying to foresee the future behavior of the system, under specific initial conditions, that can cope with a broad range of systems and configurations.

For this reason, simulation is a broadly used methodology for understanding the complex behavior of some real systems as an important stage in the processes for efficient decision-making. In a general field of application, not only restricted to discrete event systems, some significant applications of simulation have been developed, such as the ones described in the next two paragraphs.

Ref. [7] describes a decision support system for flood control management based on simulation. The simulation of a complex system such as a truck is presented by Getmanskiy et al. [6] in order to understanding better the dynamics of the vehicle, the non-stationary heat conduction and the stress distribution.

There is a large field of application of decision-support systems based on simulation in medicine. For example, Zasadaa et al. [26] describe an open source environment based on simulation in order to support the clinical decision making for the treatment of a wide range of diseases.

Before proceeding with a stage of simulation for decision making, it is necessary to develop a model of the given system in a formal language. Moreover, as it has been mentioned before, it is also convenient to represent formally the decision problem itself. As a result, the simulation process can be included in a process

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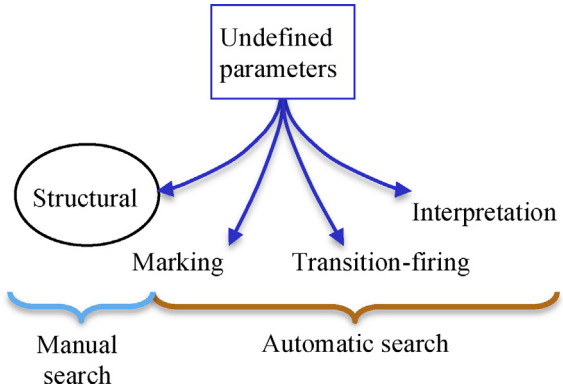

Fig. 1. Classic optimization approach.

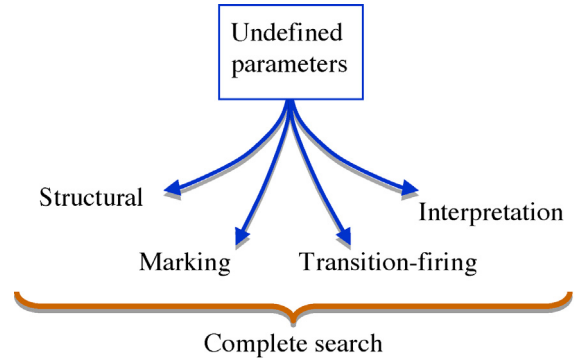

Fig. 2. Fully automatic search for optimization.

for searching for the best solution of the decision problem. This approach leads naturally to an optimization problem [12].

1.1. The paradigm of the Petri nets

Different formal languages can be chosen for modeling a given discrete event system. For example, it may be considered queuing networks, finite state machines or automata, Petri nets, or generalized semi-Markov processes [16].

In this case, the paradigm of the Petri nets has been selected for several reasons. First of all, an undoubted advantage of Petri nets is the double graphical and matrix-based representation. This particular feature of the Petri nets makes them very intuitive and powerful for structural analysis, as well as for performance evaluation and simulation.

A second interesting characteristic of the Petri nets is their natural way to represent complex behaviors that include parallelism and synchronizations [22], and for the body of knowledge in the field of the Petri nets, which has been developed in the last decades [3].

In any decision problem, the concerned system should present one or several freedom degrees, allowing choosing different alternative configurations as a result of a decision. These freedom degrees or undefined characteristics of the original discrete event system can be expressed in the resulting model by means of undefined parameters, leading to the concept of undefined Petri net [10].

The parameters of a Petri net can play different roles and, subsequently, may be classified accordingly into different types, such as structural, marking, transition-firing, or interpretation parameters. Structural parameters are related to the structure of the Petri net model, whereas the other types are associated to its behavior.

An overview of different approaches for solving an optimization problem based on an undefined Petri net can be found in Ref. [11]

1.2. Optimization processes

The mentioned methodologies for solving a decision problem based on an undefined Petri net include several classic approaches.

One of them performs an automatic search of the optimal values for certain type of parameters, while others, usually the structural ones, are selected manually. In fact, this approach is inspired in the paradigm of “divide and conquer”, where the manual search of structural configurations for the system leads to independent subproblems, solved by automatic means.

In Fig. 1, a representation of the main types of parameters in an undefined Petri net have been shown, as well as the these which are selected manually or automatically, respectively, in a classic optimization process.

On the other hand, the methodology proposed in Ref. [11] performs a single automatic search for all types of parameters, as it can be seen in Fig. 2.

This fully automatic search presents, among others, the following advantages:

(a) The absence of manual search implies that expensive, highly trained, and experienced staff is not required for choosing manually the best alternative structural configurations for the system.
(b) The automatic search applies the same non-subjective criteria for the exploration of the solution space and the selection of the best values for the undefined parameters.
(c) The solution space for an automatic search is unique, allowing a search to avoid the exploration of non-promising regions, while a manual choice of the regions of the solution space to be explored may lead to waste time in non-promising areas or skip promising ones.
(d) The methodology allows a parallelization of the subprocesses that may develop an optimization process faster than the application of the “divide and conquer” paradigm [14].

Fig. 2 shows the main idea of full automated search of the optimal values for the parameters of the Petri net of all types.

This approach, based on a single optimization process has been applied for decisions corresponding to a limited period of time in the evolution of the discrete event system. This period may be related to a stage in the design process [29] of the system or a change in the configuration of the freedom degrees of the system or in the freedom degrees themselves [13].

In the mentioned period of time, the structure of the system remains constant, but other non-structural parameters may change their values. One example of sequence of decisions that can be solved by the optimization methodologies described in the previous paragraphs is the resolution of actual or effective conflicts arisen in the evolution of the Petri net.

The conflicts are associated to a group of transitions that can fire in an exclusive manner, that is to say, at a given time any of them can fire but not all of them. Subsequently, it is necessary to decide which transitions should fire. The conflicts can be solved by the sequential assignment of values to the priorities associated to the involved transitions. The transition-firing parameters, such as the priorities of the transitions, are not structural parameters and actual problems, where their values are the goal of an optimization problem, are the scheduling of the production in a manufacturing facility or the planning of the conveying of the parts in it [19].

In the mentioned cases, the optimization process can be solved with the objective of solving the decision problem for a given structural configuration of the system. As a result, a solution can be obtained, where all the undefined parameters will take specific

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