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# SUPPORT SYSTEMS FOR DECISION AND NEGOTIATION PROCESSES

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# KNOWLEDGE OF TIME-DEPENDENT SYSTEM BEHAVIOUR: REPRESENTATION AND INFERENCE METHODS

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**Abstract.** The discrete event system models and algorithms are often utilized in artificial intelligence systems for representation of procedural knowledge and knowledge of time-dependent system behaviour. Our recently introduced approach to the real-time discrete event systems modelling and control is proposed as a basis for development of a new method for representation of the above mentioned knowledge and for a new inference method related to it.

**Keywords.** Discrete Event Systems, Time Systems, Artificial Intelligence, Non-Deterministic Systems, Supervision, Qualitative Modelling, Knowledge Representation, Coutrol Systems.

## 1 Introduction

There exists an increasing number of applications where a complex semi-automated process is controlled by human supervisors, e.g. (Naylor and Volz 1987, Silverman 1987)

- nuclear power plants,
- manufacturing systems,
- air traffic control towers,
- satellite control centers.

Intelligent systems can be applied basically at three levels (as a planner, as a high level supervisor and as a controller of a given machine satisfying execution of high-level commands). The controllers deal with such issues as (Shoureshi 1991, Challenges 1987, Naylor and Volz 1987)

- coordination of tasks among different machines,
- control of information flow between various machines and low-level controllers.
- machine control,
- collision avoidance.

There are many difficulties in the mentioned applications (Dorn 1991, Kozák 1991c), mainly incomplete specifications of system behaviours and of constraints to be met and an extreme growth of complexity of models. Discrete event system theory (Ho 1989, Kozák 1991b, Li and Wonham 1988, Ramadge and Wonham 1987, Varaiya and Kurzhanski 1988, Workshop on DES 1991) in conjunction with systems based on artificial intelligence techniques (Åström *et al.* 1986, Bologna and Välisuo 1991. Kuipers 1989. Silverman 1987. Sanfeliu 1989. Lingarkar *et al.*

1990, Narendra 1991) can enlarge area of successful applications of computers in control and supervision, and increase reliability, flexibility and efficiency of the systems. Models of system dynamics and algorithms for design of intelligent systems are very important with respect to both the applications and the present systems theory (Challenges 1987, Shoureshi 1991).

The following three sections give a very brief overview of the discrete event systems theory, models of systems dynamics in AI systems and representation of procedural knowledge. The last section presents outline of our approach to the representation of knowledge of time-dependent system behaviour and to the inference methods related to this knowledge.

## 2 Discrete Event Systems

Real-world discrete event systems can be modelled at two levels of abstraction, logical and temporal (Ho 1989, Kozák 1990a, Varaiya and Kurzhanski 1988, Workshop on DES 1991), i.e. as logical discrete event systems or as temporal discrete event systems. The logical models of discrete event systems do not give any description of time moments at which discrete events are executed. Only time order of events is described. The models of discrete event systems (and also models of other classes of systems) can be further divided into qualitative and quantitative ones (Kozák 1990a). The qualitative models describe a system as a set of possible observations (e.g. Borchard 1985, Kozák 1990a, Li and Wonham 1988, Ostroff and Wonham 1990, Ramadge and Wonham 1987). The quantitative models introduce a measure of system non-determinism (e.g. probabilistic or fuzzy) (Ho 1989 and Levary 1990). We focus on utilization of the qualitative models in the present paper.

The theory of discrete event system control have made a good progress in the last three years. There appear several new results closely related to two main problems, i.e. to an extreme growth of complexity of problems related to systems composed of several interconnected subsystems (Ho 89, Workshop on DES 1991) and to idealized assumptions of time-dependent system activities (Li and Wonham 1988, Ostroff and Wonham 1990, Workshop on DES 1991, Kozák 1991b, 1991d).

Formal languages and graphs play a central role in the logical discrete event formalisms (Ramadge and Wonham 1987, Li and Wonham 1988). The approaches to the temporal discrete event modelling are based on timed Petri nets (Varaiya and Kurzhanski 1987), temporal logic (Ostroff and Wonham 1990), special language properties introduced within the formal language theory (Li and Wonham 1988) or certain new algebraic formalisms (Kozák 1991b, 1991d). Within the present approaches, delays between two subsequent output events as well as communication delays including also decision time of the supervisor are modelled. In addition, a more intricate time-dependent properties as partial controllability or temporal forced events (Kozák 1991e) can be introduced using the approach (Kozák 1990a, 1990b, 1991a, 1991b).

The present results of the discrete event systems theory can be utilized also in multi-level controllers partly based on artificial intelligence methods (Bologna and Välisuo 1991, Dorn 1990, 1991, Gallanti *et al.* 1985, Kozák 1991c, Kuipers 1989, Naylor and Volz 1987, Perkins and Austin 1990, Shoureshi 1991).

## 3 Models of Dynamics

Many models of discrete event dynamics have been introduced. Those include (timed) Petri nets, temporal logic, formal languages, trace theory, calculus of communicating systems and communicating sequential systems. They are used mainly for simulation and verification purposes. Only few of the models can be used for synthesis of control (Ramadge and Wonham 1987) due to strict requirements for proving.

Coming mainly from the computer science area, the discrete event systems theory has introduced definitions not compatible with the general systems theory. It has caused that almost every attempt to extend an existing model has required to change completely all the related definitions. In Kozák 1990a, a new approach to the qualitative modelling of time systems is introduced. It unifies the definitions required for both the continuous and discrete event systems modelling. Moreover it is suitable for non–deterministic systems with non–numerically valued inputs and outputs.

The necessary and sufficient conditions of feedback controllers and controllable behaviours are proved in a constructive way (Kozák 1990b, 1991a). A new "semistate" technique for modelling systems using the concept of output law is presented in Kozák 1991a. In Kozák 1991b, the conditions are proved under which the information provided by the logical models is sufficient for temporal controller design.

It is very difficult (if not impossible) to estimate a time required for making a decision in expert systems. This time can increase unpredictably in certain states of the controlled system. Thus in order to meet hard real–time requirements new techniques must be developed. There is no commonly accepted methodology for it. Usually neural networks (Narendra 1991) or a certain event calculus are used to describe the system dynamics (Borchard 1985, Dorn 1990, 1991, Gallanti *et al.* 1985, Kuipers 1989). Following the results in discrete event systems control (Ramadge and Wonham 1987, Kozák 1991b) a new controller structure is proposed for intelligent supervisors in Kozák 1991c.

The mentioned discrete event systems theories can serve as a basis for a new generation of dynamic knowledge representation methods.

## 4 Procedural Knowledge

Common–sense knowledge about the real world can be often expressed as a plan how things are done. It can be formalized by means of sequences of actions or by procedures (Georgeff and Lansky 1986, Sanfeliu 1989), in general by system models.

The discrete event system models at both the logical and temporal levels serve as a basis of procedural knowledge representation, e.g. extended automata (Georgeff and Lansky 1986), event graphs (Gallanti *et al.* 1985). Algorithms for solving discrete event control problems (Ho 1989, Ramadge and Wonham 1987, Varaiya and Kurzhanski 1987, Workshop on DES 1991) can be built into the intelligent systems as a procedural knowledge. Parameters of the problems to be solved can be supplied by a rule–based higher level of the system.

As the procedural knowledge gives not only information about the initial and final states but also about (possibly non–deterministic) ways how to achieve the goals, the algorithms representing procedural knowledge can provide also information about the intermediate states of the process, costs related to the different ways of possible solving and some diagnosis in order to support the rule-based decision level.

## 5 Discrete Event Models and Algorithms in Decision–Making Systems

The decision-making system has two basic levels. The top level is rule based and the lower level utilizes discrete event models and algorithms. The formalisms (Ramadge and Wonham 1987, Kozák 1990a, 1990b,1991a, 1991b) are used as a methodology for building models at the lower level and partially at the top level:

- The models can be built step by step by adding axioms corresponding to system properties (Kozák 1990e), also a semistate modelling technique (Kozák 1991a) can be utilized.
- Prototype models can be constructed and verified and hierarchically composed into representation of real situations. The prototype models include modelling of various types of delays (Dorn 1990,1991, Kozák 1991b, 1991d, Pelavin and Allen 1986), partial controllability and observability (Ho 1989, Kozák 1991e, Workshop on DES 1991) and qualitative simulation (Kuipers 1989, Välisuo 1991);

and for design of inference methods:

- Certain theorems in (Kozák 1990a, 1990b, 1991a, 1991b) can be used directly as a meta-knowledge in the rule-based top level.
- For analysis of the prototype models and solving control problems, algorithms can be designed and verified (Ramadge and Wonham 1987, Kozák 1991b, 1991d). The algorithms specify procedural knowledge. Also prototype simulation methods (Kuipers 1989) can be verified within the formalism (Kozák 1990a).

Communication between levels consists of:

- Information about the current state of the lower level. It includes information about possible decision alternatives and their parameters, interpreted data and current status of running tasks.
- Final results of inference of decision tasks provided by the lower level.
- Setting parameters of decision tasks for the lower level.
- Priorities of tasks to be solved by the lower level.
- Advice of urgent actions for the top level.

The lower level is responsible for real data acquisition, their preprocesing and interpretation with respect to built-in models. It solves also tasks formulated at the top level. The top level builds on-line models using previously prepared prototype models by setting the parameters. It also provides explanation and high-level coordination of subtasks solved by the lower level.

The presented scheme of intelligent decision system supports distributed computing of the subtasks (Silverman 1987). The supervisors designed within the approaches (Ramadge and Wonham 1987, Kozák 1991b, 1991d) are utilized to meet hard real-time constraints (Kozák 1991c).

The modelling of discrete event systems within approaches (Ramadge and Wonham 1987, Kozák 1991b) results in finite graphs and mappings describing delays, hidden (or internal events, simultaneous events and other parameters of system dynamics. The simultaneous utilization of the logical and temporal models cuts down computation time preserving at the same time great expressive power.

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