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INTRODUCTION TO THE SPECIAL ISSUE

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This is a special issue of *Applied Artificial Intelligence* on Intelligent Control and Planning. The term *intelligent control* has emerged to characterize a suite of new methods, techniques, and architectures that are used to control complex, highly autonomous processes, tasks, and systems. Since the late 1980s a significant number of publications have appeared that address this new paradigm. Recently, efforts have been undertaken by the Institute of Electrical and Electronics Engineers (IEEE) Technical Committee on Intelligent Control to identify and elucidate the main issues of the various research agendas pursued by the theorists and practitioners. The resulting report (Antsaklis, 1994) provides an excellent review of such issues. It casts intelligent control in a global view of control theory and practice. Traditional notions of control refer to techniques designed to control systems with behavior that is modeled by differential and difference equations. Over the years, limitations of such methods have been well recognized. In essence, certain control problems cannot be solved using classical mathematical frameworks. Thus came the intelligent approaches that build upon and, in part, subsume conventional techniques in order to solve such problems.

As pointed out in Antsaklis (1994), the definition of intelligent control is multifaceted. The underlying processes (being controlled) have typically a different nature than those addressed by conventional methods. They are usually described by combined discrete and continuous modelling formalisms. This has led to the development of hybrid systems approaches. In intelligent control, the separation between the controller and the plant (the system being controlled) is not as distinct as it is in classical approaches. It is possible that the control laws become part of the plant specification.

Viewed from the control goal perspective, intelligent control addresses more general objectives, for instance, tasks that can be defined in a high-level specification, such as "replenish fuel in tank #1." These types of control problems typically involve planning under uncertainty, adaptation, and learning. Thus, techniques from the areas of computer science, operations research, and cognitive science are often employed to handle such situations. This is especially prominent in highly autonomous systems where planning in unknown or changing environments is the basis for successfully carrying out control objectives.

Planning itself is a discipline where a significant record of accomplishment is well documented. It is typically characterized as an activity that searches for and

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schedules sequences of actions (plans) designed to attain or satisfy a certain goal. Planning has been in the mainstream of Artificial Intelligence (AI) research for the last three decades. Anderson (1995) gave a thorough review of AI planning approaches. They are categorized as *classical* and *universal planning*. This distinction adequately reflects the evolution and shifting focus of the field. The conventional AI planners (e.g., STRIPS) assumed complete information about the domain and results of the actions, a static planning universe, and unlimited resources of the planner. These assumptions do not hold well in complex, changing environments with a high degree of uncertainty. Therefore, new paradigms are being pursued; they are called *universal* planning. These new planning methods employ the emerging concepts and methodologies in which distributed agent architectures are defined for reasoning about and executing actions in highly dynamic environments. This in turn requires that the planning algorithms be integrated into a larger scheme of control scheduling and control. Initial efforts on such an integrative view are summarized in Sycara (1993).

This special issue of *Applied Artificial Intelligence* comprises articles that focus on the new approaches to control and planning. The first two papers address the intelligent control paradigm. The remaining articles discuss the reasoning aspects of planning and provide a general desiderata for a simulation environment to design intelligent agents.

In the paper "The Symbolic-Numeric Interface: A Zosteric Approach," Danès and Aguilar-Martin provide a novel technique for handling a dynamical system's response to a combined, quantitative/qualitative inputs. In the article "Event-Based Intelligent Control Using Endomorphic Neural Network Model," Jung, Kim, and Park augment the event-based control paradigm with techniques that increase the controller's adaptability and flexibility.

In the paper "Spatial Reasoning via Active Observation," Venkatesh, Kieronska, and Smith describe a model that is the basis for an autonomous agent to elicit knowledge about its environment. This approach is well suited for planning and control in environments with a world model that is not known beforehand. The paper by Anderson and Evans, "A Generic Simulation System for Intelligent Agent Designs," presents a simulation environment for design and testing of intelligent agents. The environment facilitates virtual prototyping of alternative agent designs.

For supplemental reading, the reader is referred to the bibliographical items given below.

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THE SYMBOLIC-NUMERIC INTERFACE: A "ZOSTERIC" APPROACH

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This paper is an attempt to tackle the problem of the characterization of the response of a dynamical system submitted to inputs represented by intervals, its initial state and some of its parameters also possibly being described in that way. Such a problem may occur when some parts of a complex device are modelized numerically and receive as inputs some signals provided by the qualitative simulation of other—often ill-known—parts. The proposed approach imbeds it in optimal control problems with constraints. This allows a full treatment of continuous time-invariant systems and leads to a well-posed optimization problem in the general case. Some application results for elementary systems with interval-valued parameters are given, and a first stage in the treatment of QSIM-like inputs is discussed. All the required theoretic background in optimal control theory is detailed so that the paper is self-contained.

The first attempts to implement Knowledge-Based Supervision were a mere connection of a classical supervisor, data logger or SCADA package, with a first generation Expert System. The knowledge of the operators of the plant was represented by means of rules; this knowledge was given by plant experts, not process experts. If some real-time improvement might be observed, it was only because of its systematization and reproducibility, greater for the computer than for the man, but this procedure could not, in any way, be compared with the information given by the simulation of a dynamical process represented by its differential equations.

It is obvious that the operator's knowledge is only a small part of the available knowledge about the plant, the process, and the controllers. Most of the extra knowledge can be elicited by inquiring of the designers and other process experts and should be expressed in form of differential equations, simulation models of the process, or of subprocesses with several precision and scales.

Two problems arise: (1) how to represent the qualitative variables, and (2) how to predict the qualitative responses of the dynamical models.

In qualitative modelling, the values of a variable are replaced by symbols, taken from a finite dictionary, that represent subsets of its possible range. The most elementary approach is to split the real line into the three subsets $(-\infty, 0[$, $\{0\}$, $]0, +\infty)$—correspond-

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