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On the history of Discrete Event Systems

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ABSTRACT

The purpose of this article is to provide a viewpoint of the development of the field of Discrete Event Systems (DES). Necessarily incomplete, because of the breath of topics and richness of research results, this paper is mainly presented from a System Theory-Automatic Control (AC) perspective. Written with a certain emphasis at the dawn of the discipline, the following five articles of this special section of the journal provide essential complements on its evolution along the four last decades. Starting with the identification of three basic threads along which many developments took place, the multidisciplinary and dynamic character of DES and the diversity of formalisms and techniques that are used are stressed.

A *Discrete Event System* (DES) is a dynamic system whose behavior is characterized by abrupt changes in the value of its *state*, which takes discrete values, from a possibly infinite set. The state evolution is due to the occurrence of *events*; in other words, a DES is a *discrete-state* and *event-driven* system. The theory and engineering of DES started to develop following several partially disjointed, but complementary threads. A key feature common to all these developments is that over the years they have addressed the modeling, analysis, and synthesis of human-made systems (for manufacturing, work-flow, transportation, communication, etc.). Nevertheless, applications in the fields of population dynamics, epidemiology or biochemistry, for example, are becoming increasingly important.

Logic controllers, discrete event simulation, and performance evaluation and control are presented as three threads along which many developments in the field of DES took place. Nevertheless, it can be said that they intertwine in different ways. Consequently, in this article the multidisciplinary character of DES and the variety of formalisms, of concepts, and of techniques are pointed out. We focus mainly on two particular decades. First, the period from the mid-50s to the mid-60s, in which the field was established and a major change already took place. Then, the decade of the ’80s that saw a reformulation of the domain from a broader, more ambitious perspective. Finally, some elements of the activity in the DES community are recalled.

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Due to the breadth of the subject addressed by this special section of the journal and the natural brevity of the discussions contained in the five contributions that follow, it can be said that they provide “aerial views” about “continents” of the field; in similar terms, the present pages try to offer an “astronautical view”; so the field may appear as the image of a “blue planet”.

1. Some historical threads

We highlight three main threads. The first deals with *logic controllers*. At the beginning, the second and third threads focused on *performance* of timed models. All three were initially centered on *analysis* problems, the natural extension and main goal have been later to deal with their control, *synthesis* problems. Because of its historical and practical importance, discrete event *simulation* is mentioned in a separate thread; it concerns *path-based* techniques. The last thread (performance evaluation and control) is more centered on *analytical* and *algorithmic* approaches. In all three threads modeling formalisms play a central role.

1.1. On the formalization of logic controllers

Automata capture the logical and sequential behavior of systems. Centered on *Automata Theory* and its application to the formalization of *logic controllers*, a first thread can be characterized by two —“early”— symposia sponsored by IFAC (see Fig. 1).

Fig. 1. The cover of the first volumes of the *IFAC Symposium on Discrete Systems* held in Riga (1974) and in Dresden (1977). The proceedings of both symposia were edited in five volumes.

1.1.1. Two early simposia on discrete systems

The *International Symposium on Discrete Systems* in Riga (according to the Potsdam Conference of 1945, Latvia belonged at that time to the USSR) was attended in September–October 1974 by 262 persons representing 72 organizations. The proceedings consisted of five volumes entitled:

1. Plenary papers. Synthesis of discrete systems;
2. Diagnostics and reliability of discrete systems;
3. Automation of synthesis. Cellular arrays;
4. Probabilistic automata. The collective behavior of automata. General problems in Automata Theory; and
5. Out-of-the programmed papers [sic].

Among the keywords listed in these proceedings one finds terms like stability, discrete control, realization, state reduction and state assignment in asynchronous sequential machines, or decomposition of finite automata. These topics were complemented with many others, for instance: reachability and controllability of discrete systems,[1] testing and self-testing, (totally self-)checking and diagnostic, fault detection and localization, state identifiers, regular expressions, hierarchy of languages, asymptotic behaviors or model composition; also, but very rarely: Petri nets or queuing networks.

Three years later, in March 1977, the meeting of Riga was followed by the *2nd IFAC International Symposium on Discrete Systems*. Initially planned to be held in Leipzig, it finally took place in Dresden. It was particularly devoted to the *Theory and Design of Switching Systems*, and its purpose was explicitly stated to:

> promote the exchange of information on recent research in the fields of switching network theory and of applied automata theory and the application of these theories in solving practical problems.

After a section of plenary papers (P), regular papers were structured in eight sections[2]:

(A) General problems in the synthesis;
(B) Program systems for computer-aided design;
(C) Design using problem-oriented notations;
(D) Realization of switching circuits using complex modules;
(E) Reliability and dynamic behavior;
(F) Fault diagnosis;
(G) Analysis and simulation; and
(H) General problems of switching and automata theory.

Other themes discussed include: optimal control of discrete systems, Petri nets (design methodologies for untimed and timed models, or software implementations and hazards, for example), verification of logical properties on finite automata, binary programming and implementations, hazards and faults, fault-tolerance, reliability and safety, testing complexity, improvement of diagnosability, and reduction of test points (i.e., observable points). Being organized at a time in which the Cold War was “warm”, unfortunately the series stopped with this second symposium. Some years later, the *International Workshops on Discrete Event Systems* (WODES) series started, but in a different scientific, technical, and political context.

To place the above contributions in a broader perspective, it can be said that they mainly follow the lines consolidated during the mid-’50s, when computational models such as Mealy (1955) and Moore (1956) machines were defined to deal with sequential “views” of DES.[3] New synthesis methods emphasized formal procedures rather than informal-intuitive ones. Moreover, the analysis of modeling capabilities of these types of automata is among the main topics of the work carried out at that time. Implementation issues (coding theory, hazard-freeness, etc.) also received a careful attention.

Looking at the changes from the first to the second *Symposium on Discrete Systems*, some elements can be highlighted:

- beyond (sequential) finite state automata, the presence of new *formalisms* became relevant;
- a more intensive use of computers as tools (*Computer Aided Design*, CAD) for modeling, analysis and implementation;
- the appearance of *Programmable Logic Controllers*, PLC); and
- a growing interest in verification and validation issues.

1.1.2. From formalisms to a first confluence in our basic trio of related disciplines

By *formalisms* we mean languages or means of representation (syntax, semantics, analysis theory, etc.) able to express and understand certain abstract and formal “views” (or descriptions) of a given class of systems. With these abstract means of representation, formal models of a concrete system can be built. In other words, each particular instance of a given formalism may describe a specific model. Therefore, formalisms may be seen as *meta-models*.

The *expressiveness* of formalisms may be considered from a theoretical or a practical perspective. In the first case, it refers to the *variety* of systems that can be represented; in the second case, provided the system can be represented, the main concerns are *conciseness and easiness of use*. As a basic trade-off between *expressive power* and *analyzability*, the more a given formalism can express,

[1] A previous work by the same author, G. F. Beckhoff (University of Western Ontario), is entitled “Controllability-Observability type duality relations of finite-state machines”. It is significant to note the purpose of this paper: “It has been generally recognized by people working in coding theory, control theory and other areas, and also by researchers trying to lay a general foundation of systems theory, that there exist fruitful interrelations between Linear Systems Theory and Sequential Machine Theory. In this paper we explore another interesting connection between these two disciplines” (Beckhoff, 1973). As a curiosity, this paper is in the first volume of *Lecture Notes in Computer Science*. Some years later, the same editor gave light to Brauer (1980).

[2] The proceedings were also printed in five volumes: Sections P, A and B, in vol. 1; sections C and D, in vol. 2; sections D and F, in vol. 3; section F, in vol. 4; and sections G and H, in vol. 5.

[3] A seminal work in the formal design of logic controllers is Shannon (1938); in it the Boolean modeling, analysis and synthesis of switching systems is introduced. The motivation of Claude Shannon was clearly stated in the introduction: “In the control and protective circuits of complex electrical systems it is frequently necessary to make intricate interconnections of relay contacts and switches. Examples of these circuits occur in automatic telephone exchanges, industrial motor control equipment and in almost any circuits designed to perform complex operations automatically”. The quantity of works that followed on the hardware implementation of combinatorial and sequential systems is amazing, absolutely out of scope to deal with in this brief historical overview.

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