

CONTROL OF DISCRETE EVENT PROCESSES

Michael J. Denham

School of Computing, Kingston Polytechnic
Kingston upon Thames, Surrey, U.K.

SUMMARY

This paper considers the problem of devising an adequate theory in which the behaviour of flexible manufacturing systems, at the level of coordination and control of a set of interacting, communicating concurrent processes, can be modelled and analysed. Existing approaches to a solution are reviewed and the outline of a proposed new approach based on some recent concepts such as object oriented systems is described.

INTRODUCTION

There has been an increased interest in the last few years in the study of the control of discrete event processes, perhaps owing to the potential application in distributed computer networks, communication systems and advanced computer controlled manufacturing systems. Approaches taken to the problem by control theorists include perturbation analysis techniques¹ and algebraic methods based on the theory of regular languages². There is also a related activity by theoretical computer scientists to develop theories and methods for representing and analysing systems which display discrete event behaviour. Such systems include computer operating systems, multiple processor systems and communication protocols. In each case, the objective is to ensure that the system behaviour conforms to some prespecified pattern. For a system which is composed of a number of interacting processes, the problems include coordination and synchronization of the actions of individual or sets of processes, controlling the access to shared resources and ensuring safe operation of the system under abnormal conditions, e.g. process failure.

In the case of a flexible manufacturing system, the operational control of the system can be divided into three levels. At the lowest level, individual processes are directed by local controllers to carry out a specified task in an autonomous manner. The problem of coordinating these individual concurrent actions is that of the next level of controller, which initiates such actions and monitors their execution. It also receives input from the highest level controller, the scheduler, which determines the overall sequence of tasks to be carried out by the system. The problem which we are concerned with is that of representing and analysing the behaviour of the system at the middle level of coordination of the constituent processes and their action in response to a request to perform a specified schedule. The primary requirement is therefore for a theory in which the behaviour of a number of concurrent, interacting discrete event processes can be represented and analysed and which provides a basis for the development of techniques for synthesising the behaviour of such systems.

EXISTING APPROACHES TO THE PROBLEM

The theory of Petri nets³ has formed an important basis for the modelling and analysis of such systems for several years, in particular computer and

communication systems behaviour. More recently, Petri nets have been used to model flexible manufacturing systems⁴. Simple state transition networks, and the associated theory of regular languages and finite state automata, have also been used to describe concurrent system behaviour. In particular, a number of results have been obtained recently on the structural properties of controlled discrete event processes modelled in this way^{5,6}. The approach uses a control mechanism in which a controller process monitors transitions in the controlled process and effects control by enabling or preventing transitions in the latter. The results obtained are analagous with those of geometric control theory, in particular the existence of and method for synthesising a "minimally restrictive" supervisory controller, which meets certain constraints such as the absence of deadlock in the controlled system.

There are fundamental problems associated with both these approaches. Firstly, their use in modelling the behaviour of any reasonably complex system leads to a cumbersome model which is difficult to understand conceptually and for which the computational requirement for exhibiting and analysing system behaviour increases exponentially with the size of the system. Secondly, the production of a computer program which reliably and accurately reproduces the behaviour of the net theory based model is an ad hoc process which is prone to human error. In other words, there is no associated programming language which has a formal semantics in the same theory, or one directly related to that in which the model was created. It should be noted that the computational and complexity problem has been tackled in the state transition network approach using a modular approach⁷, but this is only effective in certain restricted cases.

Whilst Petri nets have been used extensively for modelling computing systems, more recently there have been a number of new developments within the computer science community of alternative theories and methods for representing concurrent processes and their behaviour. Perhaps the most notable amongst these are those techniques based on temporal logic⁸ and Milner's calculus of communicating systems (CCS)⁹. The application of temporal logic to discrete event control problems has recently been considered⁹, and the substantial body of knowledge which has been generated in recent years by theoretical computer scientists in this area should prove useful in pursuing this approach¹⁰. However there are significant structural analysis and synthesis problems to be solved, in particular modular techniques for system synthesis. Also no programming language for concurrent systems has its semantics defined in a temporal logic framework, creating problems in the implementation of the required controlled system behaviour.

In the last few years CCS has been applied in particular to modelling communication protocols, e.g. for OSI networks, and a language, LOTOS, based on CCS

has been designed for writing system descriptions in this formulation. The use of CCS for modelling other types of communicating systems, including manufacturing systems, is intuitively appealing, since the approach taken is to represent the system as a set of agents or processes which interact or communicate through specified input or output ports. The observable behaviour of each individual process is represented by a behaviour expression, which is essentially derived from the operational behaviour of the process expressed as a finite state automata or state transition network. Specific transitions are linked to input or output ports and processes interact through the interconnection of ports. The theory supplies a set of operations for the composition of the behaviour expressions of the processes, in relation to their concurrent operation and specified interconnection structure, to produce a behaviour expression for the system. This expression can then be analysed to determine various structural properties of the system behaviour, for example that the system does not enter a deadlock situation or that there is a fair access by all processes to shared resources.

At present, it appears that the analysis of systems described in CCS form is restricted to those systems in which the interaction is simply that of synchronization of transitions in individual processes. In such a system, when a process wishes to perform an action which must be synchronized with an action in another process, it signals that process through its corresponding output port and waits until it receives a responding signal which indicates that the related process is in a state to allow the synchronizing action to take place. The two actions then occur in the respective processes. This can be extended to more than two processes. In this simple form of communication, the exchange of data between processes is not permitted. However, a preliminary investigation of the application of the CCS theory to modelling supervisory controllers for discrete event systems, as defined by Wonham and Ramadge⁵, indicates that many of the results obtained by them on the structural properties of such systems, can be restated in this framework. It is not yet clear whether the inherently modular form of systems described in CCS will provide any further insight into solving the computational problems associated with the synthesis of controllers previously experienced. It is clear that application of the composition rules of CCS for systems of any real complexity leads to large behaviour expressions for the system.

PROPOSED ALTERNATIVE APPROACH

From the above review of existing approaches, and a knowledge of the requirements of the modelling and control analysis and synthesis problem, it is clear that there are two major criteria for an adequate theory. The first is that it must allow the model of the system to be constructed in a naturally modular way, i.e. the model must be able to be built from objects which are in correspondence with natural objects within the system, for example production processes. A set of rules for composing these objects must be provided, together with a method for reducing the complexity of the composite model, retaining only those aspects which are necessary for describing and analysing the behaviour of the system for the purpose of controller design. The theory must permit the development of both analysis and synthesis methods. Secondly, it must be possible to design a language which can be used by the system designer to create the model, and which has the underlying theory as its formal semantics. This implies that the language is itself object orientated, i.e. that the language can

directly refer to the naturally occurring objects in the system and their interconnection.

At present there are few object oriented languages which can model concurrent system behaviour. One of these is EPSILON, which has been designed as a system description language, with manufacturing systems as one envisaged area of application.¹¹ A disadvantage of the language is its complex syntactic structure. A strong advantage however is that its semantics can be defined in terms of the theory of coloured Petri nets.¹² These have the same descriptive power as Petri nets but are more concise. There has also been recent work to apply coloured Petri nets in the control of flexible manufacturing systems¹³. Early investigations into this approach indicate that it could provide the theoretical basis for the required control analysis and synthesis methods to be developed and current work is proceeding in this direction.⁴ Unfortunately, shortage of space has prevented any presentation here of the theoretical development of this approach.

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