Quantitative investigation of certain properties of slot mechanisms

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Abstract. The slot asynchronous communication mechanisms (ACMs) have been studied in qualitative detail in their main properties — data coherence and data freshness. Certain other properties have so far been regarded as inevitable consequences of synchronisation-free data communications via shared memory and not studied. In this paper, possible methods and techniques for the investigation of these properties in a quantitative manner are discussed. The capability of carrying out such investigations is important for the comparative studies of different classes of ACMs and the formation of a general theory of ACMs.

The problem

The class of data communication mechanisms described and studied by Simpson [1] are designed for transferring data between completely synchronisation-free processes. The mechanisms employ from one to four data areas (called *slots*), implied to be in memory shared between the writer and the reader. Some of the mechanisms have logic in the form of control variables to steer the writer and reader to prevent them from accessing the same slot simultaneously and to cause the reader to obtain the most up-to-date data provided by the writer. The reader and writer are not subject to any relative timing constraints and thus are completely temporally independent without the need for synchronisation, wait states or arbitration in the conventional, request/grant, sense. The general organisation of these types of mechanisms is shown in Fig 1. They will be referred to as *slot mechanisms* in this paper.

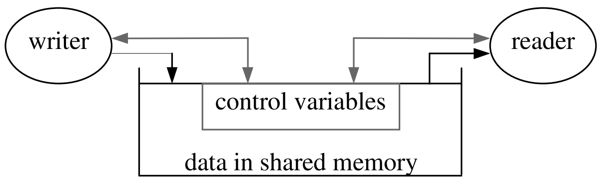

Fig 1 Schematic of slot mechanisms using shared memory and possibly control variables.

Various studies [2, 3, 4, 5] have shown that the four-slot mechanism possesses two important properties, *data coherence* and *data freshness*. However, such issues as *data loss* and *re-reading of previously acquired data* are referred to as "inevitable consequences of synchronisation-free data communication" and not studied further.

Although applications may be found where such phenomena as data loss and re-reading of old data do not matter very much, to establish a more comprehensive picture of ACMs these properties should be studied, preferably in a quantitative manner, as the coherence and freshness properties have been proved qualitatively.

As other studies are beginning to show [6], synchronisation-free ACMs may be designed that, with a relaxed requirement of data freshness, provide ways of "tuning" the rates of data loss and/or re-reading of old data quantitatively. The slot mechanisms as they are do not possess the design flexibility to provide for these kinds of adjustments. It would still be useful to study their data loss and re-reading properties for the purpose of comparing them with those of other designs.

The starting point

From earlier work, full Petri net models of the slot mechanisms are available [4, 5]. Although these were established primarily for studying the data coherence and data freshness properties, they do contain the full transition systems of the mechanisms, thereby capable of generating the full state space from which information on data loss and re-reading may be obtained. In addition, software programs used in earlier studies are available for possible modification and further use [7].

The properties

Simpson's definitions of data coherence and data freshness can be found in [2]. In this paper these definitions are accepted.

Definition 1 Data loss

Data loss occurs when an item of data generated by the writer becomes ultimately unavailable for the reader, before the reader has obtained it. The data loss rate is the average ratio of the number of data items lost and the total number of data items generated by the writer.

Definition 2 Data re-reading

Re-reading of previously read data occurs when the reader obtains an item of data, which it has already obtained in a previous cycle. The data re-reading rate is the average ratio of the number of re-read data items and the total number of data items read.

In a synchronisation-free ACM of finite size, the former must occur if the writer is faster than the reader, and the latter must occur if the reader is faster than the writer. Quantitatively, the rates of data loss and re-reading should depend on a number of factors, the most likely ones being the ratio between the average writer and reader cycle times and the structure of the ACM in question.

The methods

Earlier work has shown that the slot mechanisms tend to have complex state spaces with large numbers of states. For instance, the simplest model for the four-slot mechanism has over 1000 individual states. This makes the analysis of data loss and re-reading rates directly from the state graphs a potentially very difficult job. However, each slot mechanism consists of two cycles of operation, the writer and the reader. This means that each state, apart from itself, can only have two subsequent states, one the result of a reader statement and the other a writer statement as shown in Fig 2. The state transition matrix is therefore extremely sparse. As a result a study based on the full state graph using straightforward Markovian techniques may not be impossible, in spite of the size of the state space.

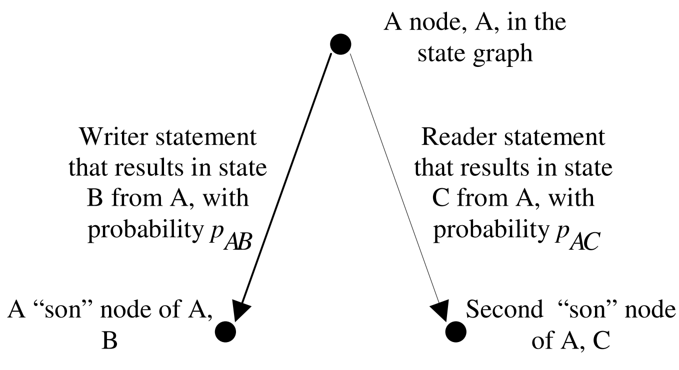

Fig 2 State propagation in a slot mechanism.

The reader and writer accesses on any slot may be modelled by multi-state Markov chains whose transition probability information can be obtained from reader and writer cycle rates and their statistical distributions, as shown in Fig 3. The probability transition matrix of the system can be then derived.

Furthermore, since data loss and data re-reading are only relevant at direct writer and reader accesses to the data slots, and not when control variable values are changed, it can be said that only a limited portion of the total states need direct scrutiny in a study of these properties. The full state space only needs to be generated in the background. The slot mechanisms are also symmetrical. This means that an analysis only needs to be done on one of the slots to obtain the relevant rates. Both these points would simplify the Markovian analysis by spreading the task into a number of sub-steps, thus avoiding the solution of large numbers of simultaneous equations.

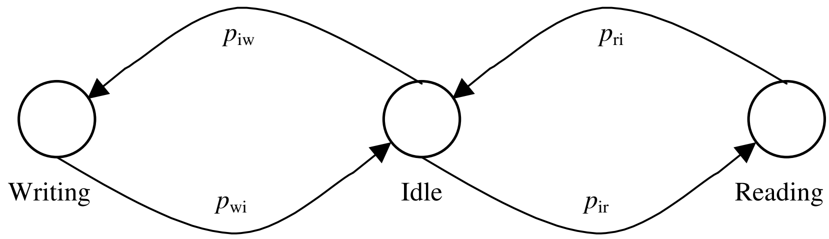

Fig 3 Markov chain of reader and writer accessing actions on a slot.

Earlier work also provided various Petri net models of the slot mechanisms and it should be possible to directly make use of stochastic Petri net (SPN) techniques [8] to study the data loss and re-reading rates.

Since the slot mechanisms are simple algorithms, it is a straightforward process to develop simulation programs for them. These programs only need to be discrete event based with a relative timing management module to produce accurate estimates of the relevant rates.

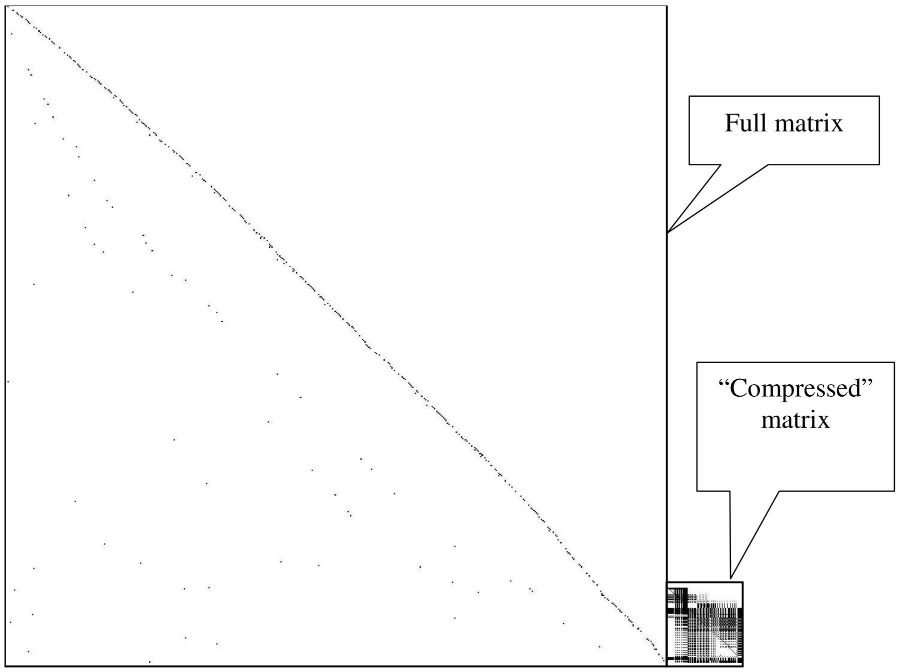

Fig 4 The shapes of the state transition matrices of the four-slot mechanism.

Preliminary work

A simulation program has been developed that treats the slot mechanism as discrete event systems without representation of hard timing. Relative timing that determines which event is to occur next at any state is managed by a separate module that keeps track of the writer and reader's consumption of waiting time since last action. An event is treated as atomic and not capable of being interleaved by other events. Any fine-tuning of interleaving detail can be accomplished by stretching out an event to two with a distinct state added in the middle, in the style of [9].

Random number generating routines based on different distributions can be "plugged into" the program so that different statistical behaviours of reader and writer cycles may be investigated.

This program has been run a number of times and a reasonable collection of data has been gathered on the data loss and re-reading rates of the four-slot mechanism. This data has helped in establishing some of the observations given in [6].

Software used in previous work [7] has been extended and modified to investigate the state space of the four-slot mechanism. By concentrating on the reader and writer direct access states on single slots the state transition matrix has been "compressed" into a more manageable size of 126×126. A way of calculating all the necessary probability data to fill this matrix without losing details given by the full matrix has been developed. The shapes of the full state transition matrix of over 1000 states and the "compressed" matrix of 126×126 are shown in Fig 4, where the dots denote the positions of the non-zero elements.

Future work and acknowledgement

If theoretical means to an investigation exist, simulations should be used to provide supporting evidence only. Therefore a study purely based on simulations is not enough for the problem at hand.

The study based on tools and experiences obtained from earlier work, by combining Petri net models and additional probability information for state transitions, shows promise. It has been shown that the size of the problem can be managed by spreading the task into a number of sub-steps. Based on the authors' knowledge of the state of the art in numerical techniques, the current problems are of a size that would not necessitate special treatments or workarounds. What remains to be done is resolving the relationship between the probability information for each state transition and the statistical distribution of the reader and writer cycles, and the related coding.

The authors are not familiar with SPN techniques and the tools available associated with these techniques. This angle remains very much worth exploring. Fundamentally, if the theoretical basis remains the same, i.e., Markovian principles, both the state-graph based approach used so far and any SPN based technique should produce similar results. This assumes, of course, that the size of the problem does not cause difficulties.

As shown in [6], the development of a sound method for the study of qualitative properties of slot mechanisms contributes significantly to the establishment of a general theory on ACMs.

Mr Ian Clark of the Department of Electronic Engineering, King's College London is thanked for many hours of work modifying and tuning programs at the authors' behest so that this work can be done.

This work is part of on-going studies at King's College London and the University of Newcastle into asynchronous communication algorithms and mechanisms. FX is supported by EPSRC grant GR/L93775 (project COMFORT at NCL) and BL by a Royal Society Fellowship.

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