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Resumo. Este trabalho apresenta um novo mecanismo que permite a escolha entre os protocolos CMB e Time Warp (TW) durante a execução da simulação distribuída. O mecanismo proposto é muito atrativo, pois determinar qual o protocolo mais adequado para um modelo constitui uma tarefa complexa. Nesses casos, o uso de ambos protocolos, conservativos e otimistas, constitui uma boa opção. Dependendo do estado corrente da simulação, o protocolo mais adequado é considerado. O artigo apresenta o mecanismo utilizado para converter do/para protocolo CMB para/do o protocolo TW.

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Abstract. This paper addresses a novel mechanism to allow the choice between the CMB and the Time Warp (TW) protocols during the execution of queuing-based model distributed simulations. The mechanism proposed is very attractive because the choice of the most appropriate synchronisation protocol is a difficult task. Many times the use of both, conservative and optimistic protocols is a good option. In this case, depending on the stage of the current simulation program, the most appropriated protocol is considered. The paper shows the mechanism used to convert from/to the CMB protocol to/from the TW protocol.

1 Introduction

The distributed simulation paradigm considers the system being studied as a set of physical processes that interact to each other. Each of such a process is represented into the distributed simulation program as a logical process and all the interactions among the processes is implemented by means of messages containing the simulation events and the corresponding time of occurrence. These messages are exchanged through communication channels interconnecting the logical processes. The cause/effect relation is guaranteed by means of synchronisation protocols, largely classified as conservative (those that avoid causality errors) and optimistic (those that recover the system when a causality error occurs) [1, 3, 4, 5].

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Several researches have been developed aiming at evaluating the performance reached by both conservative and optimistic protocols (and their variations) under different applications. A common sense is that the lookahead, the inter-process communication platform and the model granularity are the main features leading to the appropriate choice of the synchronisation protocol. However, for many systems these features can become confusing depending on the part or stage of the simulation program considered. Furthermore, the features that can point out which synchronisation protocol should be used change dynamically [6].

Some special mechanisms considering both the conservative and the optimistic approaches have also been proposed (the hybrid protocols [2]) but the number of parameters to be previously adjusted by the user becomes the actual usage of these protocols very hard for a user with low experience.

Thus, the main objective of the research described in this paper is to propose a novel mechanism for the choice between the CMB and the Time Warp (TW) protocols, in a particular queuing-based distributed simulation program during actual execution of the program. Therefore, by using the two widely known synchronisation protocols an user will be able to decide, taking into account the actual behaviour of the distributed simulation program, which protocol is more appropriate to the current context of the simulation program.

2 Manuscript Preparation

Both conservative and optimistic protocols have two main components: the Local Control Mechanism – LCM, which guarantees the execution of the events in the correct timing order and the Global Control Mechanism – GCM, which is responsible for global features such as I/O manipulation, memory management, etc. The choice of a GCM is independent of the LCM, i.e., an LP can choice its synchronisation protocol by selecting the appropriate LCM while the overall model uses a unique GCM [6]. For each class of protocols there is a set of characteristics (data structures, state variables, statistic variables and communication interface structures) that must be considered during the protocol swapping.

A system using the dynamic swapping of protocols must have implementations of both the conservative and the optimistic protocol. When a simulation starts, one of the protocols is chose by the user. During the simulation, its performance is continually evaluated. While the protocol considered presents a good performance, it is maintained. When the performance increases the mechanism for the swapping is activated.

The dynamic swapping of protocols involves two main questions: how to realise the swapping considering the distinct characteristics and how to define the best moment to perform the swapping. Considering these two questions, the mechanism for the protocol swapping can be implemented using the following three processes:

- *the observer processes*: these processes are running concurrently with the logical processes of the simulation. They are responsible for collecting the performance metrics in each process and for sending these data to the management process.
- *the management process:* this process is responsible for the detection of the correct moment for the protocol swapping, based on the information received from the observer processes. Depending on the protocol running, the actual simulation performance is evaluated using different metrics, that are the number of null messages, the number of rollbacks, etc.;
- *the converter processes:* once the management process decides that the protocol swapping must occur, the converter processes (executing in each of the logical processes of the simulation program) will perform the protocol swapping. These processes are always active in the system and issue the basic information about the simulation performance used by the management process to decide the starting of the swapping.

Figure 1 shows the relationship between the logical processes, the observer processes, the converter processes and the manager process. The observer processes are allows active and running together with the logical processes. They collect the data and send to the management process. When this process decides for a protocol swapping, the converter processes are activated. Figure 2 shows these processes during the simulation execution and the protocol swapping.

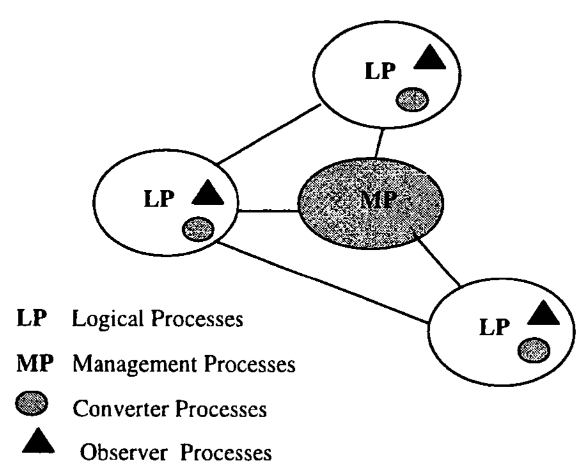

Fig. 1: Relationship between the logical processes, the converter processes, the observer processes and the manager process.

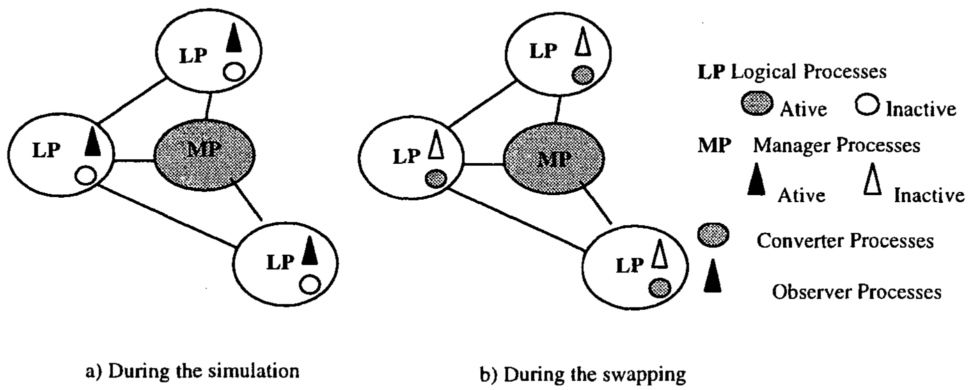

Fig. 2. Processes states.

The swapping of synchronisation protocols is performed by the converter process and can be divided in two steps:

- the guarantee of consistency: the protocol swapping must occur only when the simulation is in a consistent state. If the conversion is from the CMB to the TW protocol, there is no problem because the CMB protocol guarantees that the system will be always in a consistent state. Conversely, if the conversion is from the TW to the CMB protocol, then the system has to perform all required rollbacks before starting the protocol swapping mechanism;
- the simulation structure conversion: it is necessary a careful analysis of the data structures, time variable and communication channels, used in both CMB and TW protocols to define how to manipulate them when swapping from one protocol to the other one. An introduction to this analysis is presented in the next sections.

2.1 Data Structures

The swapping of protocols implies that data structures that do not exist in the CMB environment need to be constructed when the TW protocol is invoked and vice-versa.

- **Future Event List (EVL):** this data structure contains the events scheduled (either locally or remotely) to be executed by the considered process. The events are ordered by their occurrence time and at each simulation iteration a new event (that with the lowest simulation time occurrence) is selected from this list and processed (the simulation time is updated) [7].

- **CMB I/O Channels (IB[i]/OB[j]) -- TW I/O Channels (IB/OB):** the input buffer CMB structures (IB[i]) and the output buffer CMB structures (OB[j]) are responsible for the chronological storage of all messages received or sent in a given communication channel. In the TW these variables are replaced by the pair of structures representing the input buffer (IB) and the output buffer (OB) and the messages are not necessarily stored in chronological order. All the processes will keep all these four structures although they do not need to be active all the time. When the CMB/TW protocol swapping is about to occur a special process will indicate which structure will be responsible for the message storage.
- **TW Message Control (IQ and OQ):** all messages sent or received by a TW process need to be stored for a given period of time because errors can be later detected and those messages are used to correct them by means of the rollback mechanism [3]. This structure does not exist in the CMB. During the conversion from CMB to TW these structures are initialised and during the conversion from TW to CMB these structures must be analysed to guarantee the simulation consistency.
- **Simulation Variable Control (S):** the S data structure stores the local variables and the statistical data that will be presented and analysed at the end of the simulation. This data structure is unique for both protocols.
- **TW Context Control (SS):** this structure stores the values that describe the simulation context. These data include the local clock, the future event list and the S structure. The SS structure must be presented although inactive during the CMB protocol execution. At the moment of swapping the last instances of the structures LVT, EVL and S are passed into the SS structure. The TW garbage collection system is responsible for eliminating the older instances (those considered secure – LVT < GVT).The printing area is 122 mm x 193 mm. The text should be justified to occupy the full line width, so that the right margin is not ragged, with words hyphenated as appropriate. Please fill pages so that the length of the text is no less than 185 mm.

2.2 Communication Channels

The CMB protocol does not provide support for dynamic definition of communication channels. Thus, during the CMB protocol execution the communication channels that will be used in the future by the TW protocol must be provided (although not used). The CMB protocol defines a particular data structure for each communication channel considered (IB[i]). On the other hand, the TW protocol requires only one structure for this task. Therefore, it is required to define which CMB data structure (IB[i]) will be considered during the TW protocol execution phase.

2.3 Time Variables

During the protocol swapping the following variables must be taken into account:

- **Local Virtual Time Horizon (LVTH):** this time, used in the CMB protocol, consists of the lowest time value corresponding to the messages stored in the input gates (CC[i]) for each communication channel. In the TW this value has no meaning once the messages are received through a unique communication channel.
- **Local Virtual Time (LVT):** once the protocol swapping can only be performed when the simulation is a consistent state, the local virtual time is a value that has to be kept despite the protocol considered during the swapping process.
- **Global Virtual Time (GVT):** the CMB protocol does not consider the global virtual time as happens in the TW protocol. This problem is overcome by considering the global virtual time available to any logical process either being a CMB or a TW process.

All data structures used by the logic processes in the CMB and TW protocols must be present in the system considering the dynamic swapping mechanism. Depending on the synchronisation protocol that is going to be used, after the change moment, a subset of these structures will be considered. The figure 3 shows the structure of a logical process using the dynamic swapping mechanism.

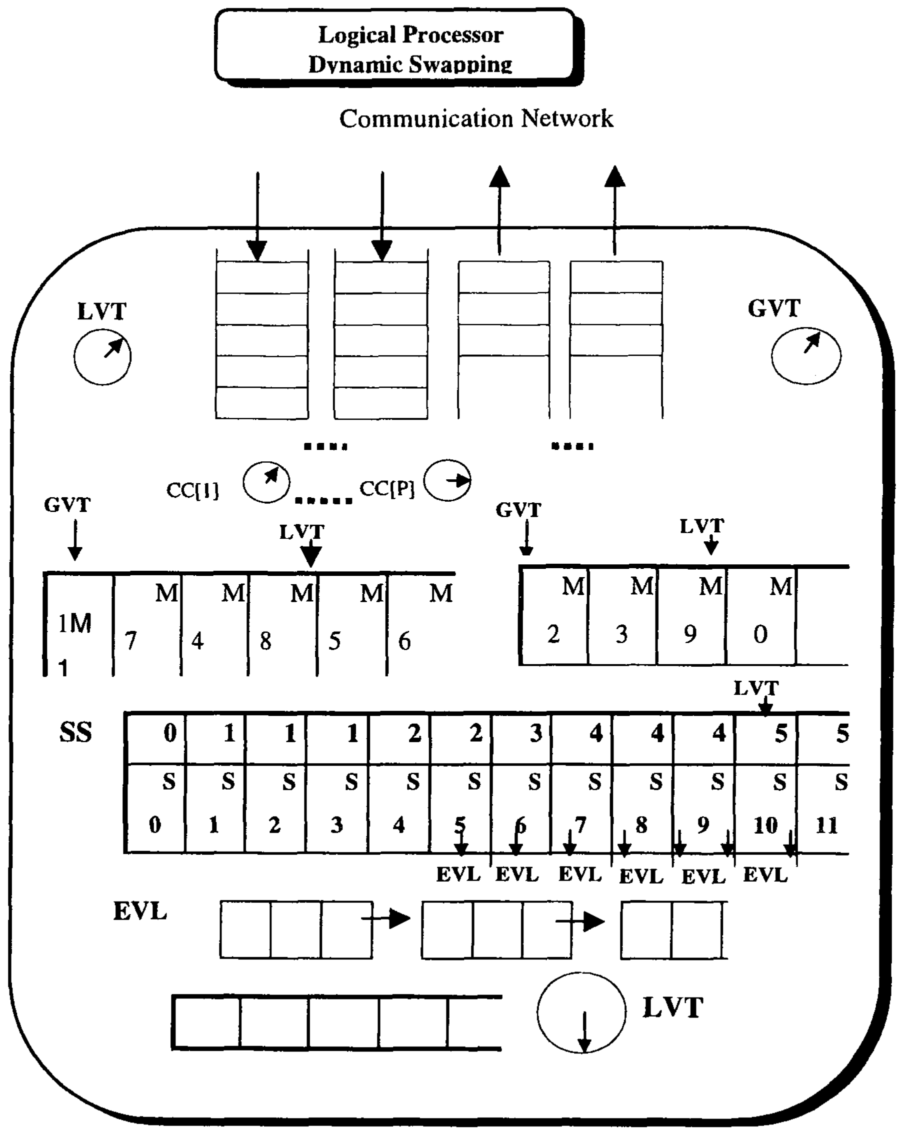

Fig. 3. Data structures of the system using the Dynamic Swapping Mechanism.

3 Conclusions and Remarks

Defining the best synchronisation protocol for a given model is clearly a difficult task. Additionally to the model features it must be considered that the behaviour of the system being simulated can change dynamically during the simulation execution. Therefore, the idea of swapping the synchronisation protocol during the simulation execution is very attractive, because it can potentially produce better overall simulation performance. The decision of when to realise the protocol swapping and the way the conversion from one protocol to another one is done are both difficult and attractive research issues.

This paper presents a mechanism to convert from the CMB to the TW protocol and vice-versa. It is shown that introducing three control processes (the management, the observer and the converter processes) and a slight adaptation on the data structures used on both protocols this can be reached.

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