Relaxation of Synchronization Constraints in Parallel Simulation of ATM Networks

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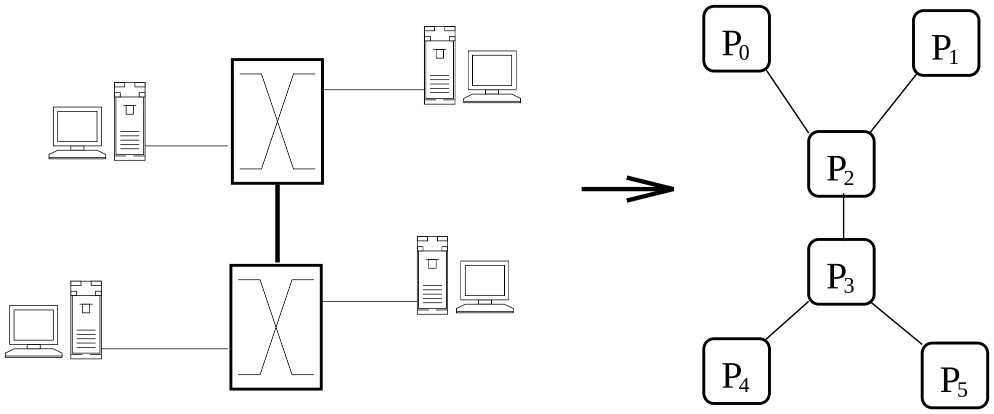
Parallel Simulation and The Process Synchronization Problem

Parallel simulation often requires a physical process of a given physical system to be modelled by a Logical Process (LP). Messages exchanged between LPs represent the interactions between physical processes.



In parallel simulation both event lists and virtual clocks are distributed.

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Causality is required to obtain correct results.

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Since LPs advance at different rate, a synchronization algorithm is needed to respect causality.

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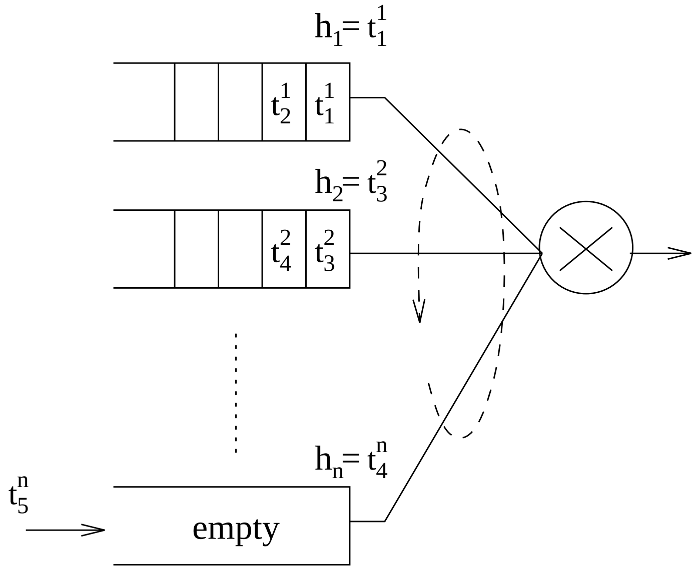
These synchronization mechanisms fall in two categories: **conservative** and **optimistic**.

Conservative Approaches

Conservative algorithms (Chandy-Misra-Bryant) avoid all cases of time errors. An LP is allowed to process an event only if it is determined with certainty that no time errors could occur anymore. If this is not the case the LP blocks.

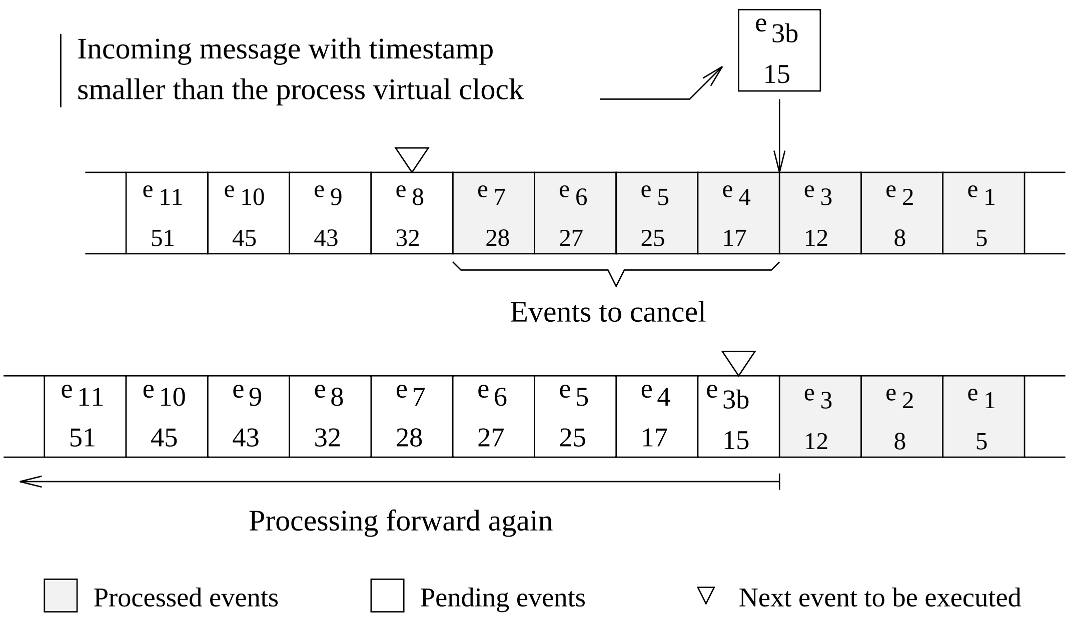
The basic algorithm consists of selecting the input with the smallest vitual clock and to block on an empty queue.



This scheme ensure correct execution order but can deadlock. Null-messages are used to artificially advance the simulation time in order to avoid the deadlock of process.

Optimistic Approaches

In optimistic algorithms (Time Warp) an LP can process all available input messages but implement a rollback mechanism to recover from time errors when they occur.



State saving and anti-messages are introduced to allow the rollback mechanism that consists of:

1. Restoring the process state
2. Sending anti-messages to other processes
3. Re-executing events in the right order.

Need of a relaxation of synchronization constraints

Ensuring causality is very costly. Traditional approaches have many drawbacks.

CONSERVATIVE APPROACHES:

- need static topology,
- present a high null-message/real message ratio.

OPTIMISTIC APPROACHES:

- are greatly limited by the overhead of the rollback mechanism,
- present a high risk of cascaded rollbacks.

If rollbacks could be avoided, then an optimistic approach is very attractive.

$\downarrow$

The statistically correct approach relaxes the synchronization constraints in order to avoid rollbacks.

Some definitions

Definition 1. *A* <u>*very-correct simulation*</u> *is a simulation where events are processed by an LP in increased timestamp order with no time errors.*

Definition 2. *A* <u>*correct simulation*</u> *is a simulation where some time errors have occurred but have all been corrected by a rollback mechanism.*

Definition 3. *A* <u>*statistically correct simulation*</u> *denotes a simulation where some time errors have occurred but not all of them have been corrected.*

Definition 4. *Let* φ *be a finite sequence of* n *events* $< e_i, t_i >$ *where* t_i *is the timestamp of event* e_i*.*

A sequence is said to be <u>*rollback-free*</u> *if* $\forall i, t_{i+1} \geq t_i$*. In the same manner, a* <u>k*-rollback*</u> *sequence is a sequence where there are* k t_i *such as* $t_i < t_{i-1}$*.*

The statistically correct approach

The statistically correct approach is very optimistic and avoids rollbacks with use of:

- local estimations based on historical information to
  - produce correct output messages,
  - re-evaluate the process' saved states,
- a different time evolution scheme.

Behavior comparatively to Time Warp

- if φ is a rollback-free sequence then TW_φ and ST_φ are both very-correct simulations. We will have $TW_\varphi = ST_\varphi$.

- if φ is a rollback sequence then TW_φ is a correct simulation. On the other hand, ST_φ is a statistically correct simulation. In most case, we will have $TW_\varphi \neq ST_\varphi$.

Computation of local estimations

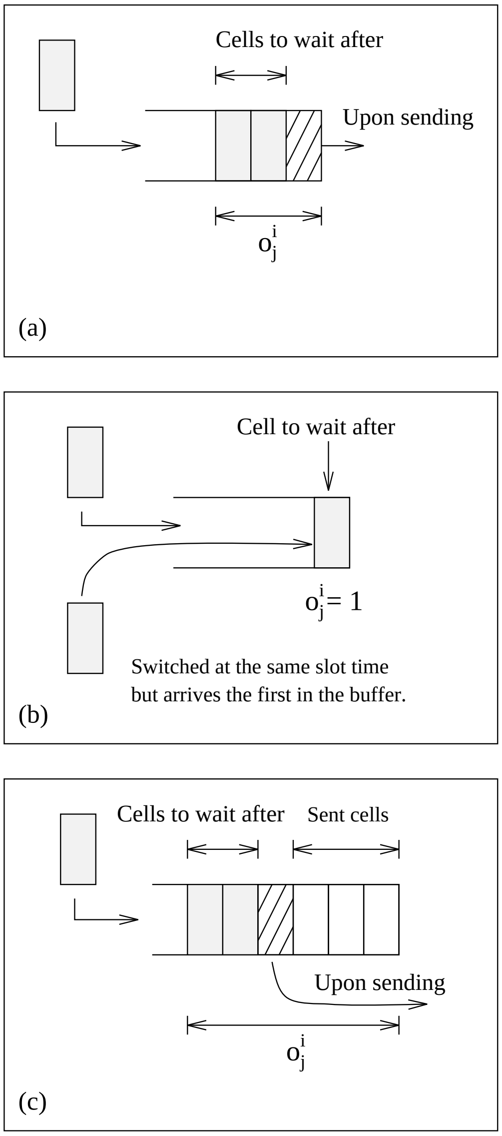
- Let L_s be the list of saved states
- Let $S_i = (o_1^i, o_2^i, last_1^i, last_2^i, n_r^i, n_s^i)$ be the ith saved state. A saved state S_i has a timestamp T_i.

Upon reception of an outdated cell reception event we use the following estimation algorithm at the switch process:

1. Gets the first state before time t from L_s. The retrieved state is S_i with $T_i \leq t < T_{i+1}$.
2. Determines the output j, derives the date of departure t_d of this new cell by computing its waiting time and schedules an $< SEND, t_d >$ event for itself.
3. Inserts the new state in the list just before the retrieved state S_i (so at index $i+1$; all state indexes are incremented).
4. Re-evaluates all states S_k with $k > i+1$.

Computation of t_d

■ Step 2 $\begin{cases} \text{if } t = last_j^i \text{ then } t_w = max\{o_j^i - 1, 1\} \\ \text{else } t_w = max\{o_j^i - 1 - (t - T_i), 0\} \\ t_d = t + t_w + 1 + 1 \end{cases}$



New state and state re-evaluation

The new process state S_{i+1} after the processing of the <RECV,t > message is saved at index $i+1$ and we have:

■ Step 3
$$\left\{\begin{array}{l} o_j^{i+1} = max\{o_j^i - (t - T_i), 0\} + 1 \\ last_j^{i+1} = t \\ n_r^{i+1} = n_r^i + 1 \\ n_s^{i+1} = n_s^i + min\{o_j^i, t - T_i\} \end{array}\right.$$

Re-evaluation of all states S_k with $k > i+1$ is done as follows:

■ Step 4
$$\left\{\begin{array}{l} \text{if } T_k - t < o_j^{i+1} \text{ then } o_j^k = o_j^k + 1 \\ \quad \text{else } o_j^k \text{ is unchanged} \\ last_j^k \text{ is unchanged} \\ n_r^k = n_r^k + 1 \\ \text{if } t_d < T_k \text{ then } n_s^k = n_s^k + 1 \\ \quad \text{else } n_s^k \text{ is unchanged} \end{array}\right.$$

Time evolution

The processing of a past message is done in what we call an *estimation environment*.

The first time error blocks the process virtual time at time t_{now} and initiates an estimation environment.

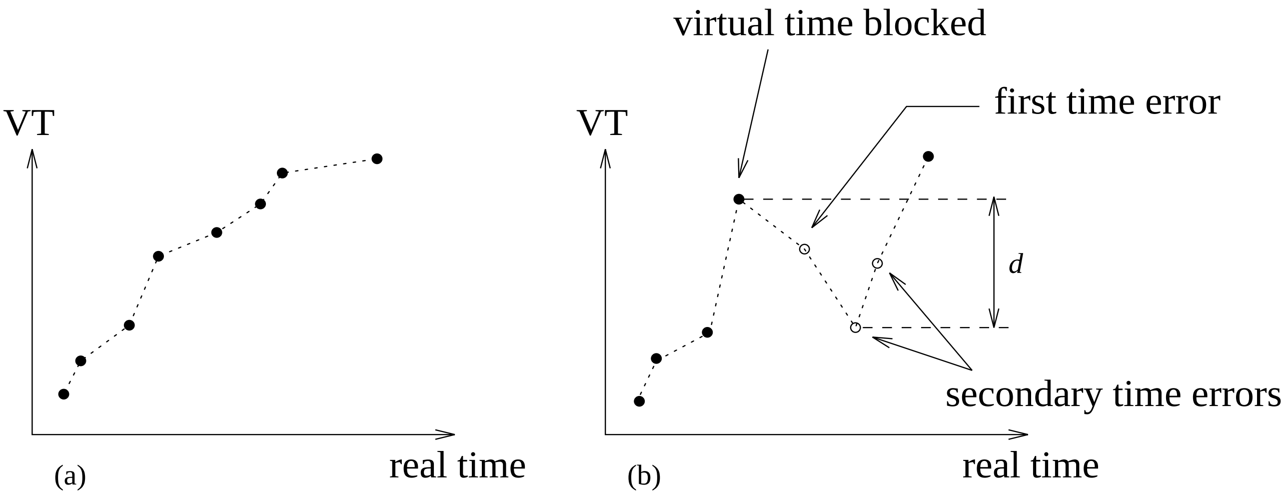


Figure 1: (a) a traditional approach, (b) the statistically correct approach.

Since the virtual time is blocked, subsequent messages with timestamp lesser than t_{now} can also produce time errors. We call this last kind of error *secondary time error* as opposed to *first time error*.

Test cases

Two network configurations with exponential traffic sources are considered. Simulation time is fixed to 4000 slots time.

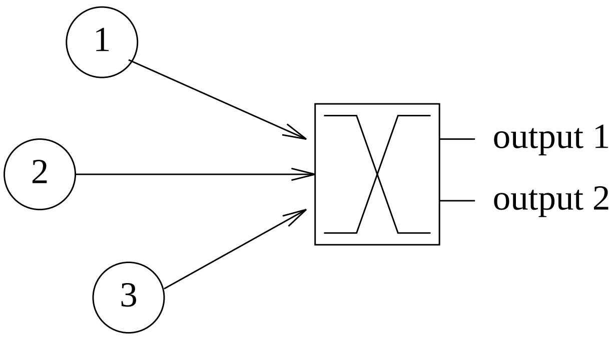


Figure 2: Network configuration for test case 1

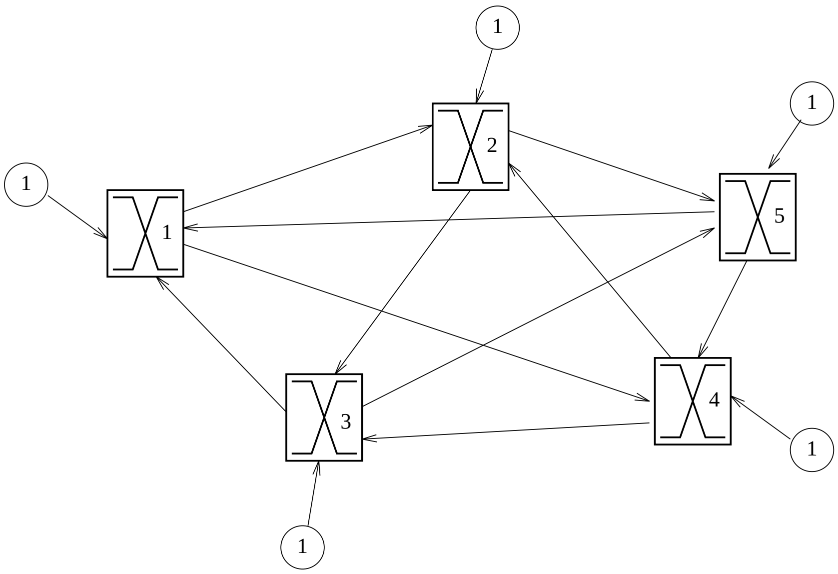


Figure 3: Network configuration for test case 2

Preliminary results - Test 1

Test case 1	SW1
Buffer 1	0.812
Buffer 2	0.846

Table 1: Correct simulation of test 1

Test case 1	SW1
First time error	5
Secondary time error	22
Buffer 1	0.809 $\rightarrow$ 99.63%
Buffer 2	0.841 $\rightarrow$ 99.40%

Table 2: Statistically correct simulation of test 1

- The number of first time errors is small
- Results are very close to the target values obtained by a correct simulation

Preliminary results - Test 2

Test case 2	SW1	SW2	SW3	SW4	SW5
Buffer 1	2.584	2.588	2.581	2.572	2.578
Buffer 2	2.578	2.574	2.561	2.558	2.558

Table 3: Correct simulation of test 2

Test case 2	SW1	SW2	SW3	SW4	SW5
F. time error	93	109	113	98	112
S. time error	135	157	151	137	148
Buffer 1	2.425	2.374	2.421	2.385	2.463
Buffer 2	2.383	2.436	2.401	2.434	2.395
Correctness	93.84%	91.73%	93.80%	92.72%	95.53%
Correctness	92.43%	94.63%	93.75%	94.04%	93.62%

Table 4: Statistically correct simulation of test 2

- We do find that the number of first time errors is much greater.
- However, and it is encouraging, the results obtained have not been dramatically altered.

Conclusion and Perspectives

- A new approach called *statistically correct approach* is proposed for parallel simulation where total correctness is not always required.

- This approach reduces the simulation cost while keeping a reasonable level of accuracy. Early tests with use of local estimations give favorable results.

- In order to make large scale simulations possible in a reasonable amount of time, one should relax the synchronization constraints and accept statistically correct results.

- We are in the process of adding a control that decides whether to use local estimations or the ultimate solution of rolling back.

- Further studies should address the performance and the suitability of a the statistically correct approach under more sporadic traffic sources.

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