The Statistically Correct Approach to Distributed Simulation of ATM Networks

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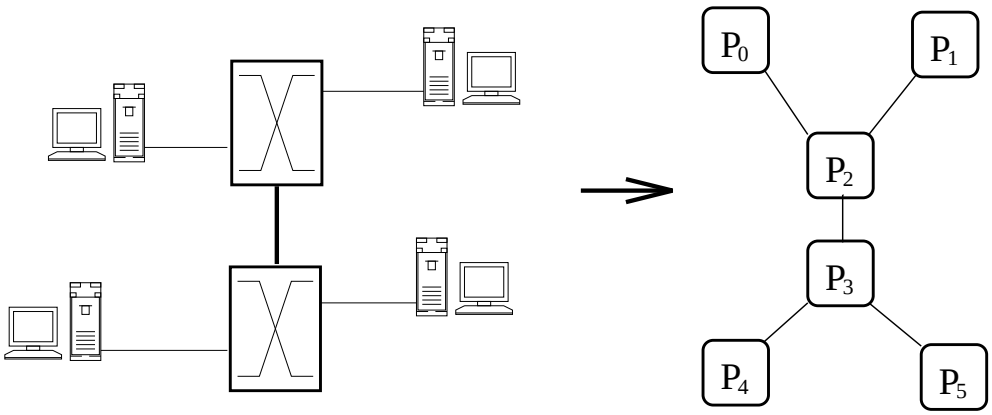
Parallel Simulation and The Process Synchronization Problem

Logical process modeling and Spacial partionning



Both event lists and virtual clocks are distributed.

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Causality is required to obtain correct results.

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A synchronization algorithm is needed to respect causality.

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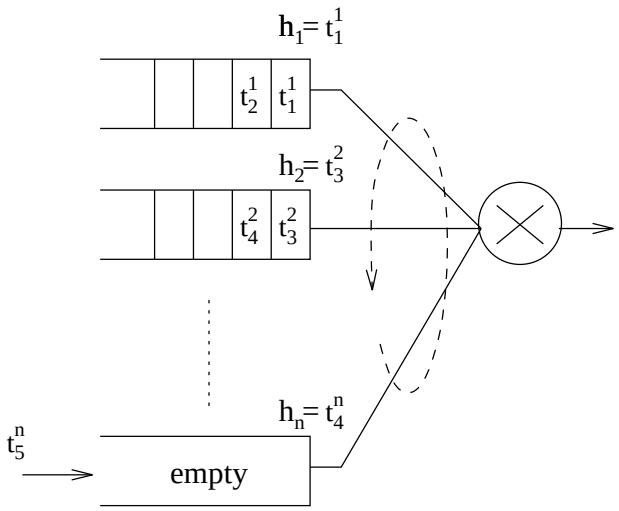
These synchronization mechanisms fall in two categories: **conservative** and **optimistic**.

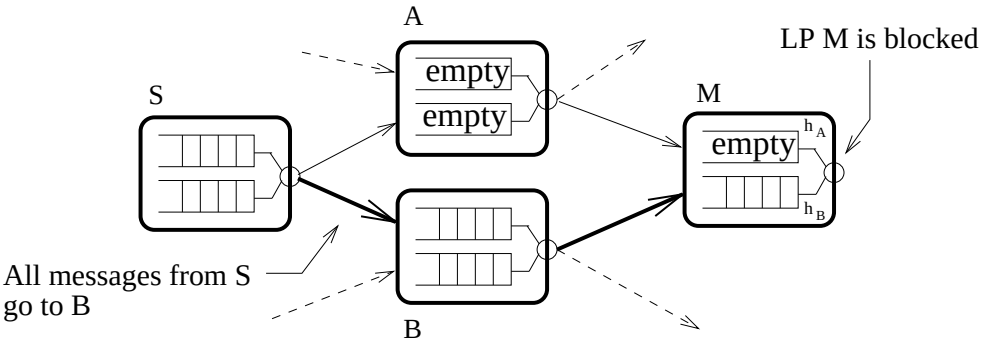
Conservative Approaches

Conservative algorithms (Chandy-Misra-Bryant) avoid all cases of time errors by blocking LPs.

The basic conservative algorithm

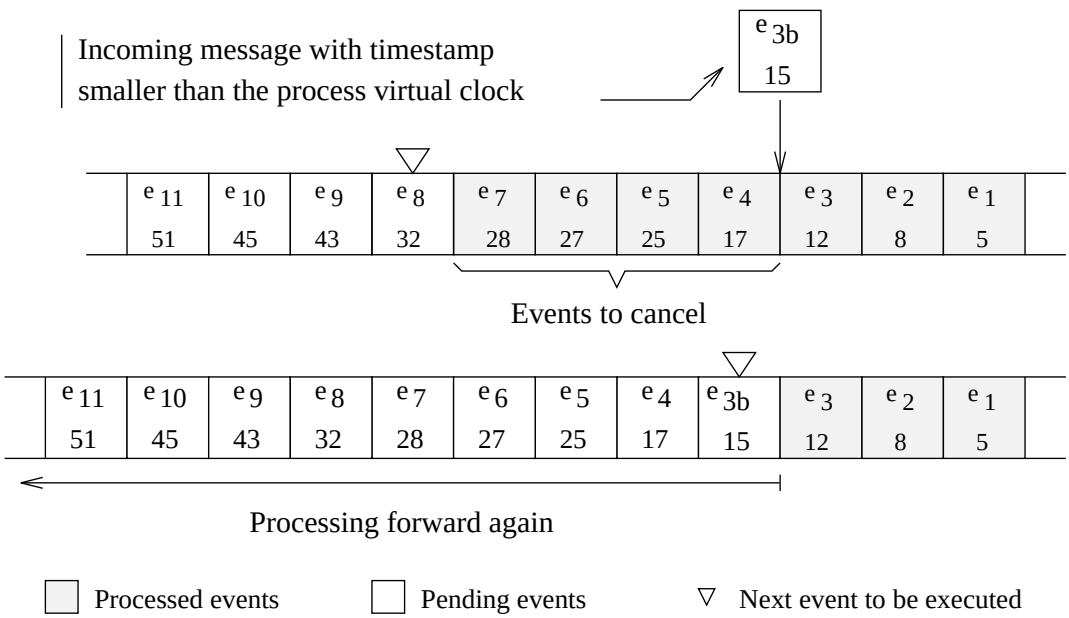


Deadlock → null-messages and lookahead ability



Optimistic Approaches

Optimistic algorithms (Time Warp) implement a rollback mechanism and allow an LP to process all available input messages.



Need of periodic state saving and anti-messages.

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

Relaxation of synchronization constraints

Ensuring causality is very costly

Conservative Approaches:

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

Optimistic Approaches:

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

If the rollback overhead could be lessen, then an optimistic approach is very attractive.

The statistically correct approach relaxes the synchronization constraints.

Some definitions

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

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

Definition 3. *A statistically correct simulation 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 rollback-free if $\forall i, t_{i+1} \geq t_i$. In the same manner, a k-rollback sequence is a sequence where there are k t_i such as $t_i < t_{i-1}$.

The statistically correct approach

- A control function triggers the rollback mechanism.
- Alternative to rollback consists of local estimations based on historical information. Local estimations are very application dependent.
- A different time evolution scheme is used.

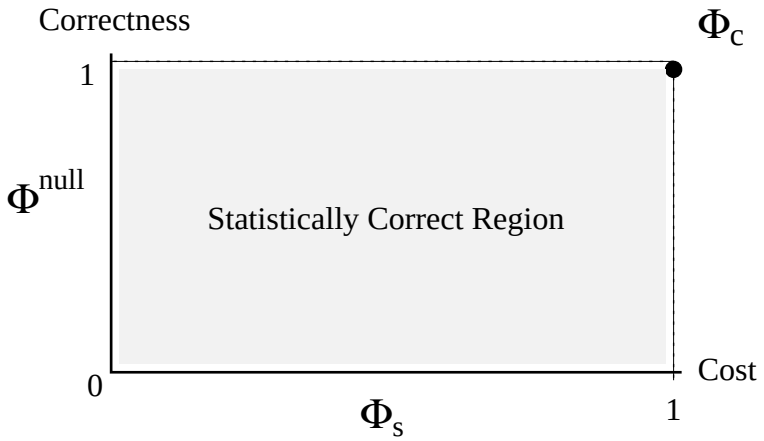
Behavior comparatively to Time Warp

- φ a rollback-free sequence $\rightarrow$ TW_φ and ST_φ are both very-correct simulations.
- φ a rollback sequence $\rightarrow$ TW_φ is a correct simulation and ST_φ is a statistically correct simulation.

The control function

The control function decides when the rollback mechanism should be used

It is possible to span the continuum of correctness according to the cost of the control

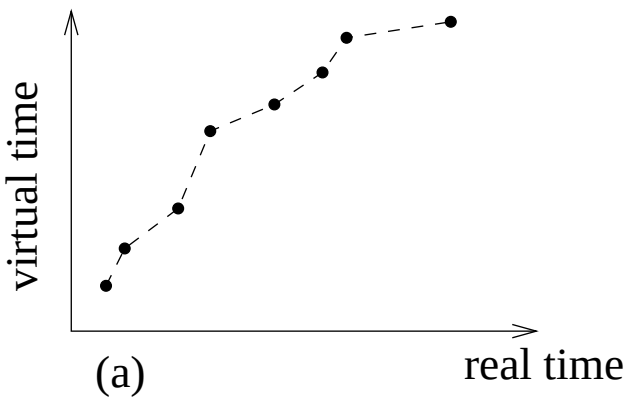


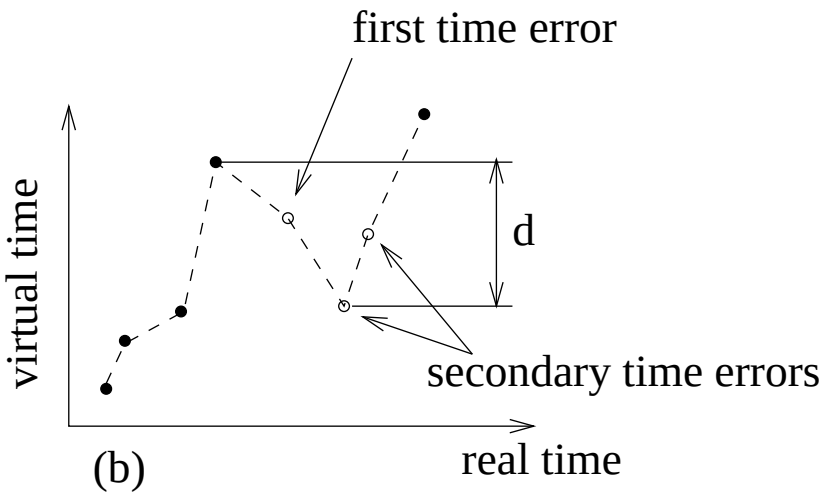
- The null control $\rightarrow$ no cost
- The distance-based control $\rightarrow$ cost depending on the threshold

Time evolution

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

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





(a) a traditional approach, (b) the statistically correct approach.

Computation of local estimations

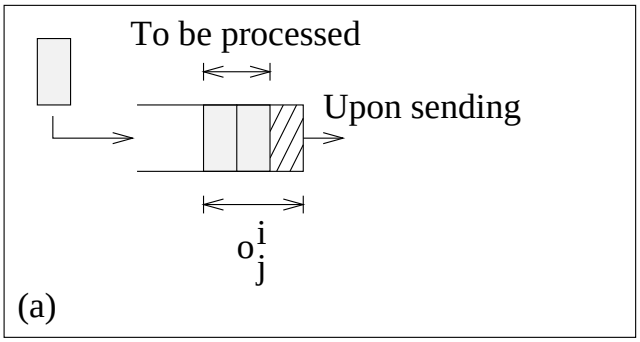
- Let L_s be the list of saved states
- Let $S_i = (o_1^i, o_2^i, last_1^i, last_2^i, n_r^i, n_s^i)$ be the ith saved state. A saved state S_i has a timestamp T_i.

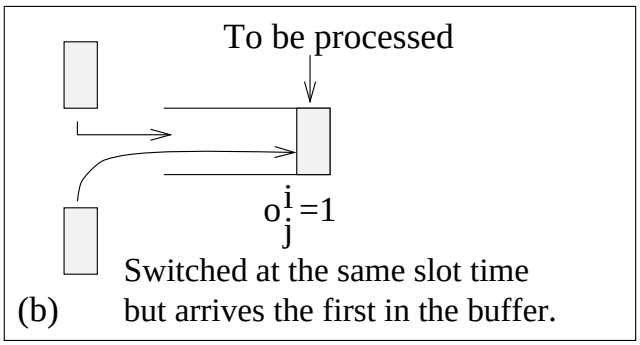
Estimation algorithm at the switch process:

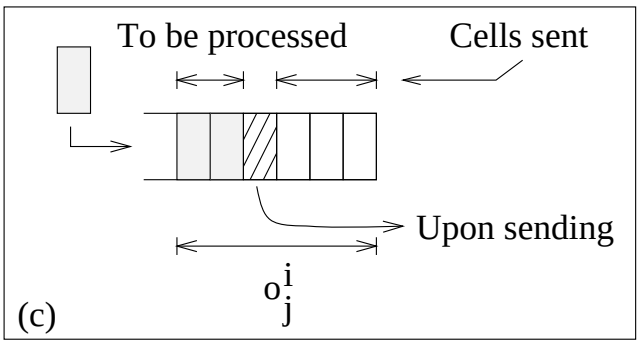
1. Gets the first state before time t from L_s.
2. Determines the output j, derives the date of departure t_d of this new cell by computing its waiting time and schedules an $< SEND, t_d >$ event for itself.
3. Inserts the new state in the list just before S_i.
4. Re-evaluates all states S_k with $k > i + 1$.

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

New process state S_{i+1}

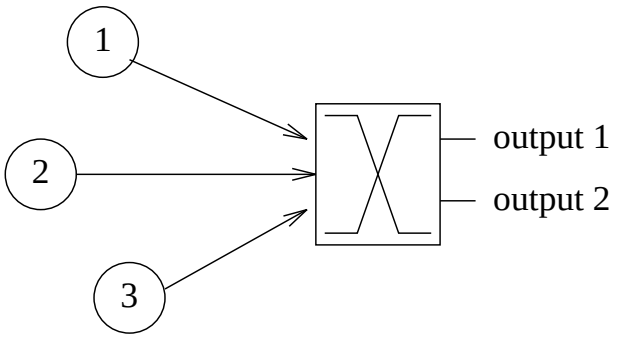
- Step 3
$$\begin{cases} o_j^{i+1} = max\{o_j^i - (t - T_i), 0\} + 1 \\ last_j^{i+1} = t \\ n_r^{i+1} = n_r^i + 1 \\ n_s^{i+1} = n_s^i + min\{o_j^i, t - T_i\} \end{cases}$$

Re-evaluation of all states S_k with $k > i + 1$

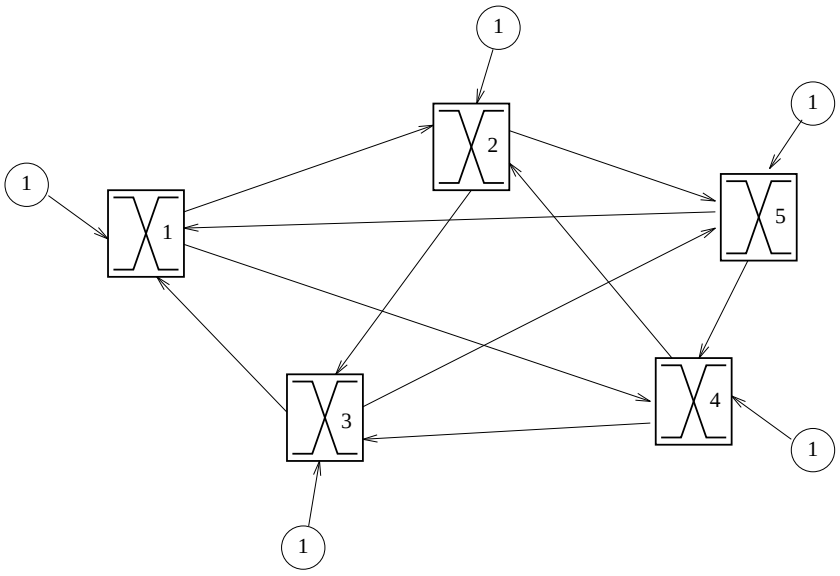
- Step 4
$$\begin{cases} \text{if } T_k - t < o_j^{i+1} \text{ then } o_j^k = o_j^k + 1 \\ \quad \text{else } o_j^k \text{ is unchanged} \\ last_j^k \text{ is unchanged} \\ n_r^k = n_r^k + 1 \\ \text{if } t_d < T_k \text{ then } n_s^k = n_s^k + 1 \\ \quad \text{else } n_s^k \text{ is unchanged} \end{cases}$$

Test cases

Two network configurations are considered.

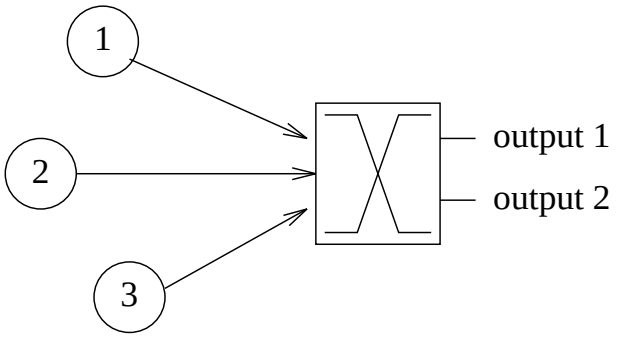


Network configuration for test case 1 & 3



Network configuration for test case 2

Preliminary results - Test 1



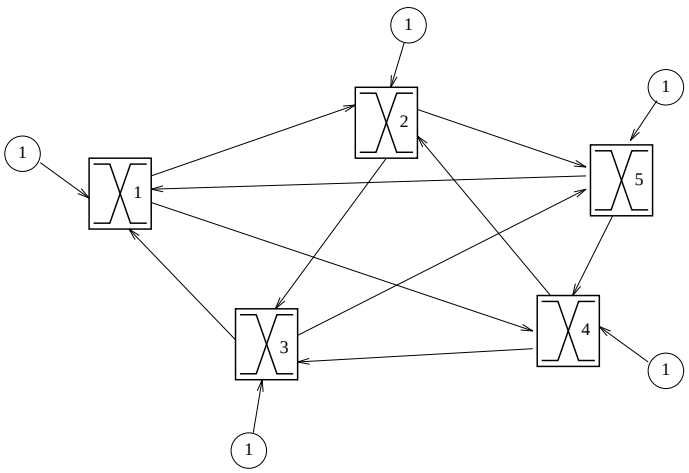
Test case 1	SW1
Buffer 1	0.812
Buffer 2	0.846

Correct simulation

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%

Statistically correct simulation

Preliminary results - Test 2



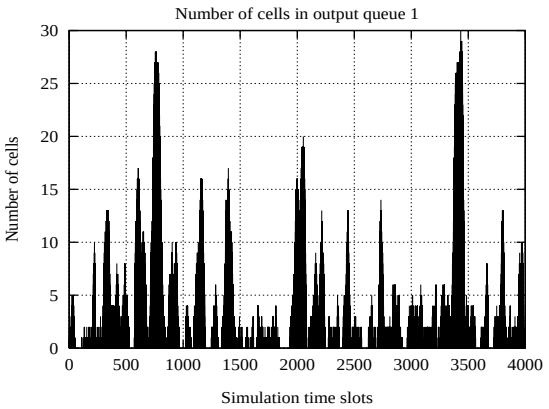
Test case 2	SW1	SW2	SW3	SW4	SW5
Buffer 1	2.584	2.588	2.581	2.572	2.578
Buffer 2	2.578	2.574	2.561	2.558	2.558

Correct simulation

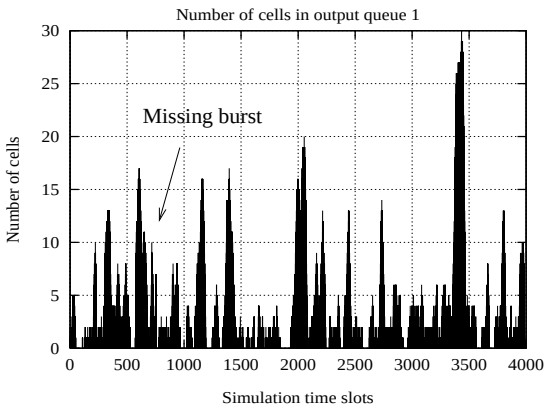
Test case 2	SW1	SW2	SW3	SW4	SW5
F. time error	93	109	113	98	112
S. time error	135	157	151	137	148
Buffer 1	2.425	2.374	2.421	2.385	2.463
Buffer 2	2.383	2.436	2.401	2.434	2.395
Correctness	93.84%	91.73%	93.80%	92.72%	95.53%
Correctness	92.43%	94.63%	93.75%	94.04%	93.62%

Statistically correct simulation

Preliminary results - Test 3
On-Off sources



Correct simulation



Statistically correct simulation

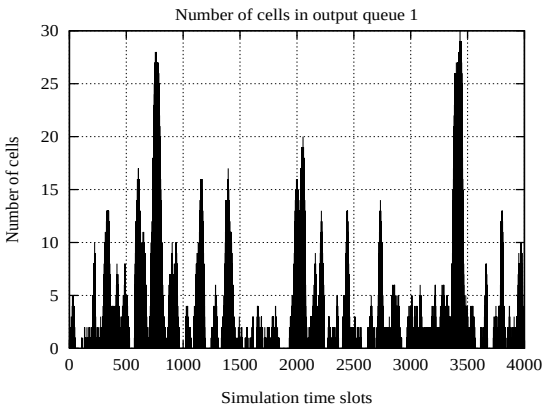
Test case 3	SW1
Buffer 1	3.975
Buffer 2	3.938

Correct simulation

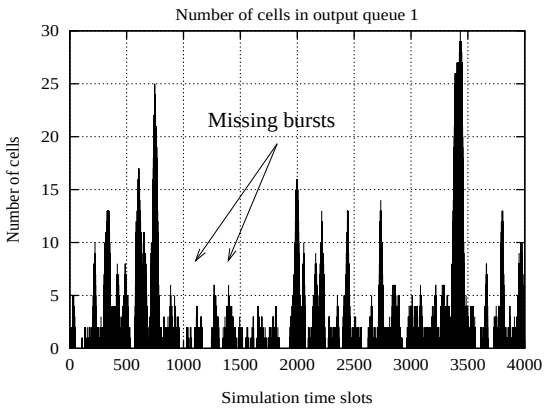
Test case 3	SW1
First time error	2
Secondary time error	123
Buffer 1	3.682 $\rightarrow$ 92.62%
Buffer 2	3.881 $\rightarrow$ 98.55%

Statistically correct simulation

Preliminary results - Test 3
On-Off sources



Correct simulation



Statistically correct simulation

Test case 3	SW1
Buffer 1	3.975
Buffer 2	3.938

Correct simulation

Test case 3	SW1
First time error	9
Secondary time error	317
Buffer 1	3.400 $\rightarrow$ 85.53%
Buffer 2	3.521 $\rightarrow$ 89.41%

Statistically correct simulation

Conclusion and Perspectives

- A new approach is proposed for parallel simulation where total correctness is not always required.
- Causality constraints are relaxed following a given control function. Application dependent estimations are used in most cases instead of rolling back.
- We want to reduce the simulation cost while keeping a reasonable level of accuracy. Preliminary tests with only use of local estimations give favorable results.
- However, local estimations work only if the problem if well-shaped.
- Accuracy is not predictable yet.
- Further studies should address the use of a distance-based control.