The Lookahead in a User-Transparent Conservative Parallel Simulator

Presentation of the Results of the PhD Dissertation

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Outline

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• Present State
• Thesis Objectives
• Simulator Design
• Cumulative Timestamp Prediction
• Cumulative Message Pre-Sending
• Experimental Verification and Results
• Conclusions
Motivation

Discrete Event Simulation (DES)

• Instantaneous state changes (events)
• State trajectory over time
• Event calendar and the sequential simulation algorithm

Motivation for Parallel Discrete Event Simulation (PDES)

• Real systems of ever increasing scale and complexity
  ⇒ ever increasing demand for high-performance simulation
  (computational time/memory)
• Interoperability of naturally distributed simulators
• Scientific curiosity: in spite of high degree of parallelism in models they are difficult to simulate in parallel
Parallel Discrete Event Simulation (PDES)

- Decomposition into submodels (logical processes)
  
- Submodel structure
  - sequential local executive
  - communication via timestamped messages
Synchronization

• Unsynchronized local times
  ⇒ causality error

• Synchronization methods
  – numerous approaches, conservative and optimistic
  – no clear favorite

• The YAWNS method (Yet Another Windowing Network Simulator)
  – scalable

• Lookahead in YAWNS
  – message pre-sending
  – conditional timestamp prediction $\delta$
Present State (cont.)

Discrepancies between DES and PDES

• Low impact of PDES in general DES, search for reasons
  – necessity to worry with low level PDES intricacies
  – ignorance of standard modeling methodologies
  – different “languages”
  – ...

• Proposed directions
  – application specific libraries
  – parallel simulation languages
  – support for shared state
  – automatic parallelization
Thesis Objectives

Observations

• Integrating established modeling methodologies into PDES
• Focus on large scale systems ⇒ scalability
• Importance of the lookahead

Objectives

• User-transparent parallel simulator design with support for large scale models

• Methods for compound submodels, with YAWNS synchronization
  – cumulative timestamp prediction
  – cumulative message pre-sending

• Experimental verification and performance evaluation
Simulator Design

The Modeling Approach

• Hierarchical decomposition
• Combined structural and behavioral model description
• Modularity of components, closure under composition

Parallel Execution

• Library of model components
• Components with / without lookahead
• Automatic translation, the user sees just one model
• Cooperation between users and PDES experts
Cumulative Timestamp Prediction

Idea

• Components provide
  – conditional timestamp $\delta$
  – delay (timestamp increment) $\sigma$

• Required
  – conditional timestamp $\delta_{SM}$ of the submodel
Cumulative Timestamp Prediction (cont.)

**General Solution:** **DeltaSM Algorithm**

```plaintext
begin
SOL = ∅;
foreach (c ∈ C_{SM})
    γ_c(t) = δ_c(t); Q.insert(c);
while (∃ x ∈ C_{out} such that x ∉ SOL ) {
    c = Q.get_min();
    foreach (x ∈ SUCC_c)
        if (γ_x(t) > γ_c(t) + σ_x(γ_c(t))) {
            γ_x(t) = γ_c(t) + σ_x(γ_c(t));
            Q.sort(x);
        }
    SOL = SOL ∪ {c};
}
δ_{SM}(t) = min_{∀c ∈ C_{out}} (γ_c(t));
end
```

- Derived from Dijkstra’s shortest path algorithm
- Can compute exact δ_{SM} or lower bound on it
- Hierarchical models first transformed using the FHG transform
Cumulative Message Pre-Sending

Idea

Submodel SM

c1

e1

Internal events

t1

c2

e2

Internal events

t2

• Non-cumulative pre-sending: $t_2$ time units ahead of time

• $e_2$ processed at the same time as $e_1$

$\Rightarrow$ Cumulative pre-sending: $t_1 + t_2$ time units ahead of time
Cumulative Message Pre-Sending (cont.)

The Method: Immediate Message Forwarding (IMF)

• Conditions
  – special component construction with F-events
    ⇒ IMF-capable components
  – timestamp order of input messages
    ⇒ IMF-enabled components

• Simulation executive support
  – identification of IMF-enabled components
    ⇒ The IEE algorithm
  – higher priority of F-events

• Other properties
  – applicable to hierarchical models
  – applicable to other synchronization schemes
Experimental Verification and Results

Objectives of the Experiments

• Verification of the simulator design and of the feasibility of developed methods
• Measurement of performance contribution of cumulative lookahead

Experimental Models

• Closed networks of 64 nodes decomposed into 8 submodels
• 2 or 4 components within a node
• Parameters
  – topology (ring, mesh, hypercube, fully connected)
  – node type (QNet2, QNet4, PHold)
  – time distribution (const, shifted exp, exp)
  – time distribution ratio (3:7, 7:3)
  – initial arrivals per node (1, 4, 16)
  – lookahead level (2 non-cumulative, several cumulative)
Experimental Verification and Results (cont.)

Performance Measures

• Average time window size (ATWS)
• Average number of events per window (ANEW)

Results

• Performance depends on parameters
• Up to 57-fold increase of ATWS
Conclusions

Fulfilment of the Objectives

• Parallel simulator design
  – hierarchical model decomposition/composition
  – user transparency through component re-use
  – no “logical process” model view
  – LLG transformation

• Cumulative timestamp prediction:
  – the DeltaSM algorithm
  – proof of its properties
  – its complexity analysis
  – FHG transformation for hierarchical models
Conclusions (cont.)

Fulfilment of the Objectives (cont.)

• Cumulative message pre-sending
  – Immediate message forwarding
  – conditions for IMF and its applicability
  – IEE algorithm
  – cumulative timestamp prediction based on min. delays
  – applicability to other synchronization methods
  – IMF in hierarchical models

• Experimental verification and evaluation
  – verification of the simulator design
  – verification of the feasibility of cumulative lookahead
  – measurement of performance contribution
    ⇒ cumulative lookahead can significantly contribute
Conclusions (cont.)

Thesis Contributions Summary

- Theoretical: in-depth study of the issue of cumulative lookahead
- Practical: simulator providing a solution to PDES modeling problems

Possible Future Directions

- Application of cumulative lookahead in more models
- Implementation and evaluation of cumulative lookahead in other synchronization methods
- Analytical evaluation of cumulative lookahead