Influence of different system abstractions on the performance analysis of distributed real-time systems

29. March 2007

Simon Perathoner, Ernesto Wandeler, Lothar Thiele

Computer Engineering and Networks Laboratory
ETH Zürich, Switzerland
Outline

• Motivation

• Abstractions

• Benchmarks

• Conclusions
System level performance analysis

Max.Bufferspace?

Max. CPU load?

Max. end-to-end delay?
Formal analysis methods

Distributed system

Performance values

Abstraction 3

\[ r_i = C_i + \sum_{j \in hp(i)} \left( \frac{r_i}{T_{ij}} \right) C_j \]

Analysis method 3
Motivating questions

• What is the influence of the different models on the analysis accuracy?

• Does abstraction matter?

• Which abstraction is best suited for a given system?

Evaluation and comparison of abstractions is needed!
How can we compare different abstractions?
What makes a direct comparison difficult?

• Many aspects can not be quantified

• Models cover different scenarios:
Intention

Compare models and methods that analyze the timing properties of distributed systems:

• SymTA/S [Richter et al.]
• MPA-RTC [Thiele et al.]
• MAST [González Harbour et al.]
• Timed automata based analysis [Yi et al.]
• …
Approach

- Leiden Workshop on Distributed Embedded Systems: http://www.tik.ee.ethz.ch/~leiden05/

- Define a set of benchmark examples that cover common area

- Define benchmark examples that show the power of each method
Expected (long term) results

- Understand the modeling power of different methods
- Understand the relation between models and analysis accuracy
- Improve methods by combining ideas and abstractions
Contributions

• We define a set of benchmark systems aimed at the evaluation of performance analysis techniques

• We apply different analysis methods to the benchmark systems and compare the results obtained in terms of accuracy and analysis times

• We point out several analysis difficulties and investigate the causes for deviating results
Outline

- Motivation
- Abstractions
- Benchmarks
- Conclusions
Abstraction 1 - Holistic scheduling

Basic concept: extend concepts of classical scheduling theory to distributed systems

Holistic scheduling

FP CPUs + TDMA bus [Tindell et al.] 1994

FP + data dependencies [Yen et al.] 1995

FP + control dependencies [Pop et al.] 2000

Mixed TT/ET systems [Pop et al.] 2002

CAN [Tindell et al.] 1995

EDF offset based [González et al.] 2003

...
Holistic scheduling – MAST tool

Abstraction 2 – The SymTA/S approach

Basic concept: Application of classical scheduling techniques at resource level and propagation of results to next component

Problem: The local analysis techniques require the input event streams to fit given standard event models

Solution: Use appropriate interfaces: EMIFs & EAFs
SymTA/S – Tool
Abstraction 3 – MPA-RTC

Load model

Service model

Arrival curves

Service curves

events

t

availability

t

\alpha^u \quad \alpha^l

\beta^u \quad \beta^l

\Delta
Abstraction 3 – MPA-RTC

\[ [\alpha^l, \alpha^u], [\beta^l, \beta^u], [\alpha'^l, \alpha'^u], [\beta'^l, \beta'^u] \]
Abstraction 4 - TA based performance analysis

Verification of performance properties by model checking (UPPAAL)

Exact performance values

periodic stream

fixed priority scheduling

Swiss Federal Institute of Technology
Computer Engineering and Networks Laboratory
Outline

• Motivation

• Abstractions

• Benchmarks

• Conclusions
Benchmarks

- Pay burst only once
- Complex activation pattern
- Variable feedback
- Cyclic dependencies
- AND/OR task activation
- Intra-context information
- Workload correlation
- Data dependencies
Benchmark 1 – Complex activation pattern

periodic P = 60

periodic P = 5

periodic

period

WCRT T3 ?
Benchmark 1 – Analysis results
Benchmark 1 – Result interpretation

$P_{I3} = 65\,\text{ms}$
Benchmark 1 – Worst case Delay I2-O2
Benchmark 2 – Variable feedback

periodic
P = 100

periodic
P = 5

Max delay?

CPU1 (FP)

T1
C = 2

T2
C = 2

CPU2 (FP)

T3

T4
C = 1

I1

I2

O2

O1

Exec. time C

Max delay?
Benchmark 2 – Analysis results
Benchmark 3 – Cyclic dependencies

I1 → T1 C = 1

T2 C = 4

O1 → T3 C = 4

Max. delay?

CPU1 (FP)

CPU2

periodic with burst P = 10

jitter
Benchmark 3 – Analysis results

Scenario 1: priority T1 = high
priority T3 = low
Benchmark 3 – Analysis results

Scenario 2: priority T1 = low
priority T3 = high

![Diagram showing CPU1 and CPU2 with tasks T1 and T3]
## Analysis times [s]

<table>
<thead>
<tr>
<th>Method</th>
<th>min [s]</th>
<th>med [s]</th>
<th>max [s]</th>
<th>min [s]</th>
<th>med [s]</th>
<th>max [s]</th>
<th>min [s]</th>
<th>med [s]</th>
<th>max [s]</th>
<th>min [s]</th>
<th>med [s]</th>
<th>max [s]</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>MPA-RTC</strong></td>
<td>0.60</td>
<td>1.06</td>
<td>19.72</td>
<td>0.01</td>
<td>0.04</td>
<td>0.04</td>
<td>0.04</td>
<td>0.15</td>
<td>0.30</td>
<td>0.03</td>
<td>0.05</td>
<td>0.20</td>
</tr>
<tr>
<td><strong>SymTA/S</strong></td>
<td>0.05</td>
<td>0.09</td>
<td>1.50</td>
<td>0.03</td>
<td>0.05</td>
<td>0.09</td>
<td>0.03</td>
<td>0.34</td>
<td>0.80</td>
<td>0.06</td>
<td>0.09</td>
<td>0.31</td>
</tr>
<tr>
<td><strong>MAST</strong></td>
<td>-</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td><strong>Timed aut.</strong></td>
<td>18.0</td>
<td>34.5</td>
<td>60.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>52.0</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>5.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td><strong>Simulation</strong></td>
<td>1.0</td>
<td>1.0</td>
<td>1.0</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
<td>&lt; 0.5</td>
</tr>
</tbody>
</table>
Outline

• Motivation

• Abstractions

• Benchmarks

• Conclusions
Discussion

- Approximation of complex event streams with standard event models can lead to poor performance predictions at local level.

- Holistic approaches better in the presence of correlations among task activations (e.g. data dependencies).

- Cyclic dependencies represent a serious pitfall for the accuracy of compositional analysis methods.

- Holistic methods less appropriate for timing properties referred to the actual release time of an event within a large jitter interval.
Conclusions

• The analysis accuracy and the analysis time depend highly on the specific system characteristics

• None of the analysis methods performed best in all benchmarks

• The analysis results of the different approaches are remarkable different even for apparently basic systems

• The choice of an appropriate analysis abstraction matters

• The problem to provide accurate performance predictions for general systems is still far from solved
Thank you!

Simon Perathoner
perathoner@tik.ee.ethz.ch