A Case Study in Parallel Verification of Component-Based Systems

N. Beneš, I. Černá, J. Sochor, P. Vařeková and B. Zimmerova

Faculty of Informatics, Masaryk University
Brno, Czech Republic

PDMC'08

March 29, 2008

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Motivation

Component-based development as a current trend in SE

- Systems assembled from third-party components
  $\longrightarrow$ issue of correct interaction among components

Parallel verification becomes a need

- Concurrency of a large number of components
  $\longrightarrow$ applicability of sequential verification techniques becomes challenging

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Contribution

1. Identification of the **component-specific properties** defining correctness issues in component-based systems, and their formalization
   - expressed in the logic CI-LTL – an extended version of the action-based Linear Temporal Logic
   - check the validity of the model and the correctness of the system
2. Experimental **application of parallel model checking** to the model of a real system
   - CoCoME modelling example
   - parallel model-checking tool DiVinE

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CoCoME modelling contest

The contest

- **The aim** to evaluate and compare the existing component modelling approaches on a common modelling example
- 18/13 modelling teams, URL http://www.cocome.org
  Organized by A. Rausch, R. Reussner, R. Mirandola, F. Plasil

The Common Component Modelling Example

- A trading system handling sales in a chain of supermarkets
  – interaction with the cashier, inventory, ordering goods, generating reports
- Specification in terms of Java source code (125 classes)
  – to prevent ambiguities in the interpretation of the specification by the teams

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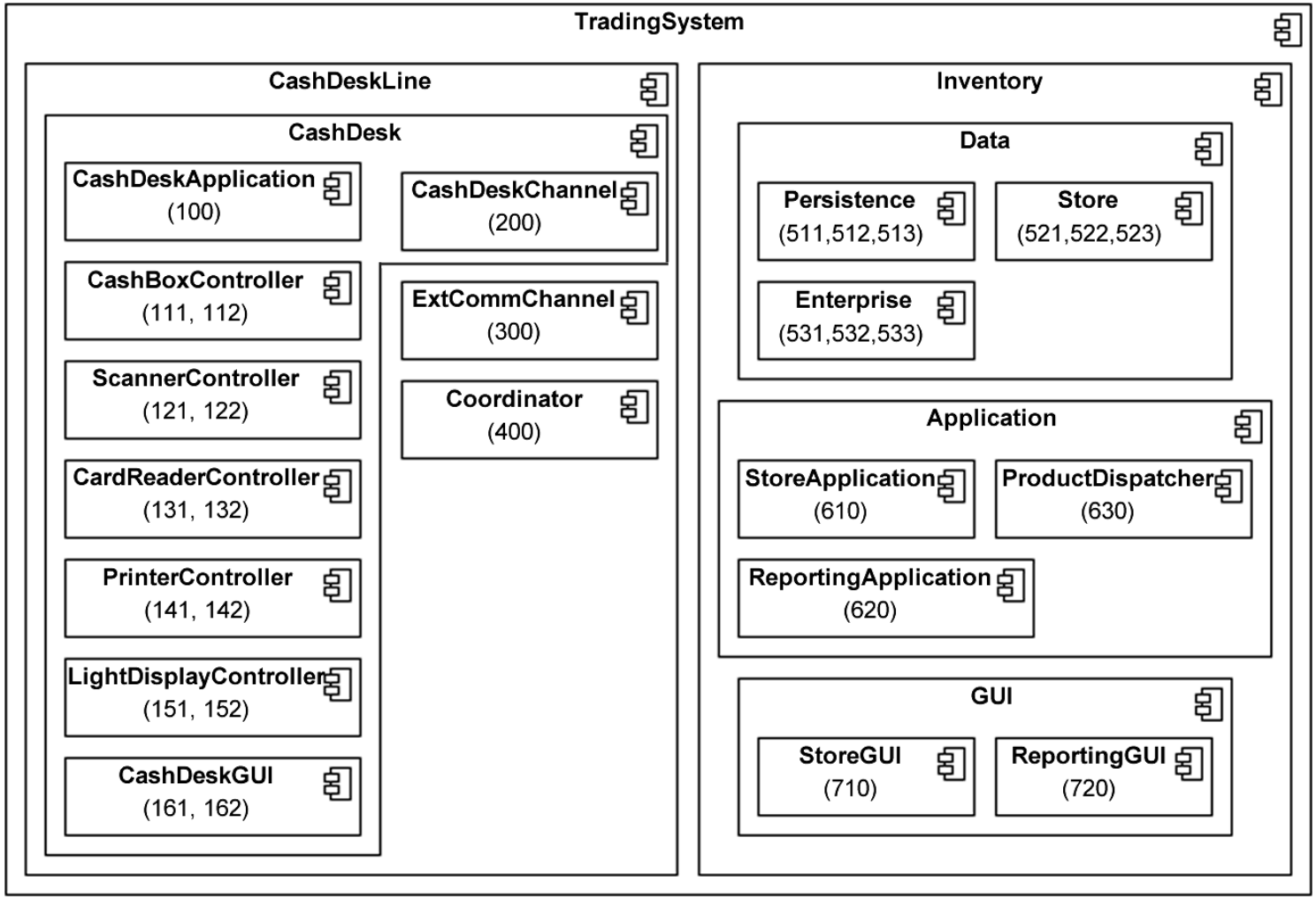
Common Component Modelling Example



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Modelling language 1/3

Component-Interaction automata language
(or CI automata for short)

- Automata-based language
  – finite state model, infinite executions/traces
- Three types of actions
  – input, output and internal
- Captures important interaction information
  – participants of communication, hierarchy of components
- Flexible composition
  – can be parametrized by architectural assembly, communication strategy
- General to meet various component models
  – by fixing the composition operator and semantics of actions

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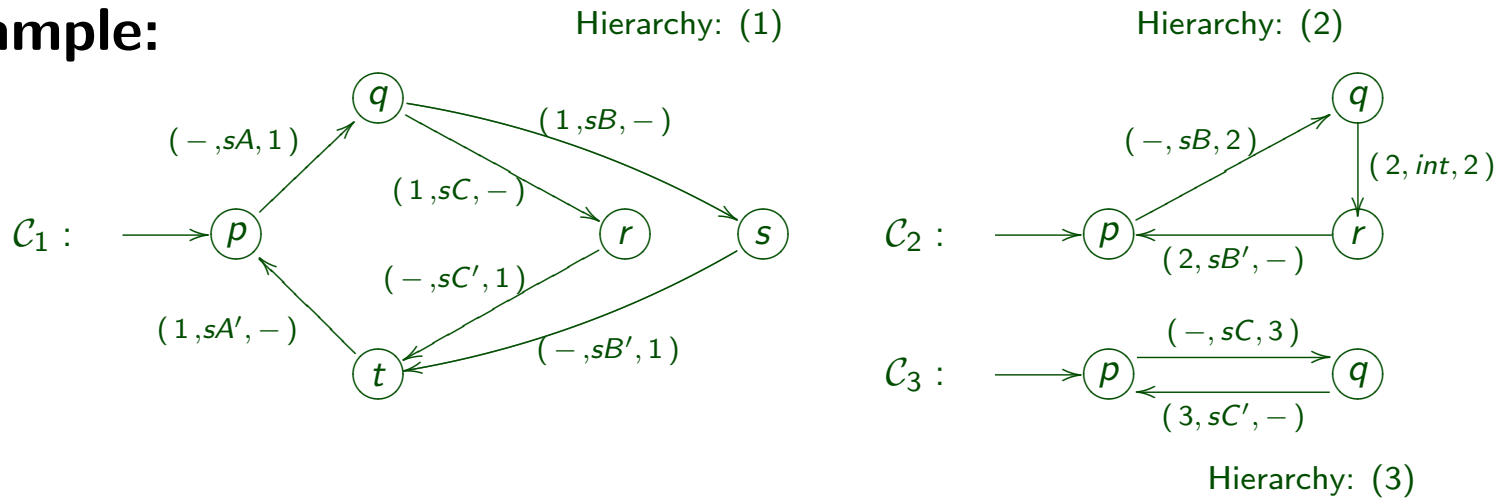
Modelling language 2/3

A component-Interaction automaton

- Finite set of states
- Labeled transitions with structured labels
  (component names, actions)
- Hierarchy of component names

Example:



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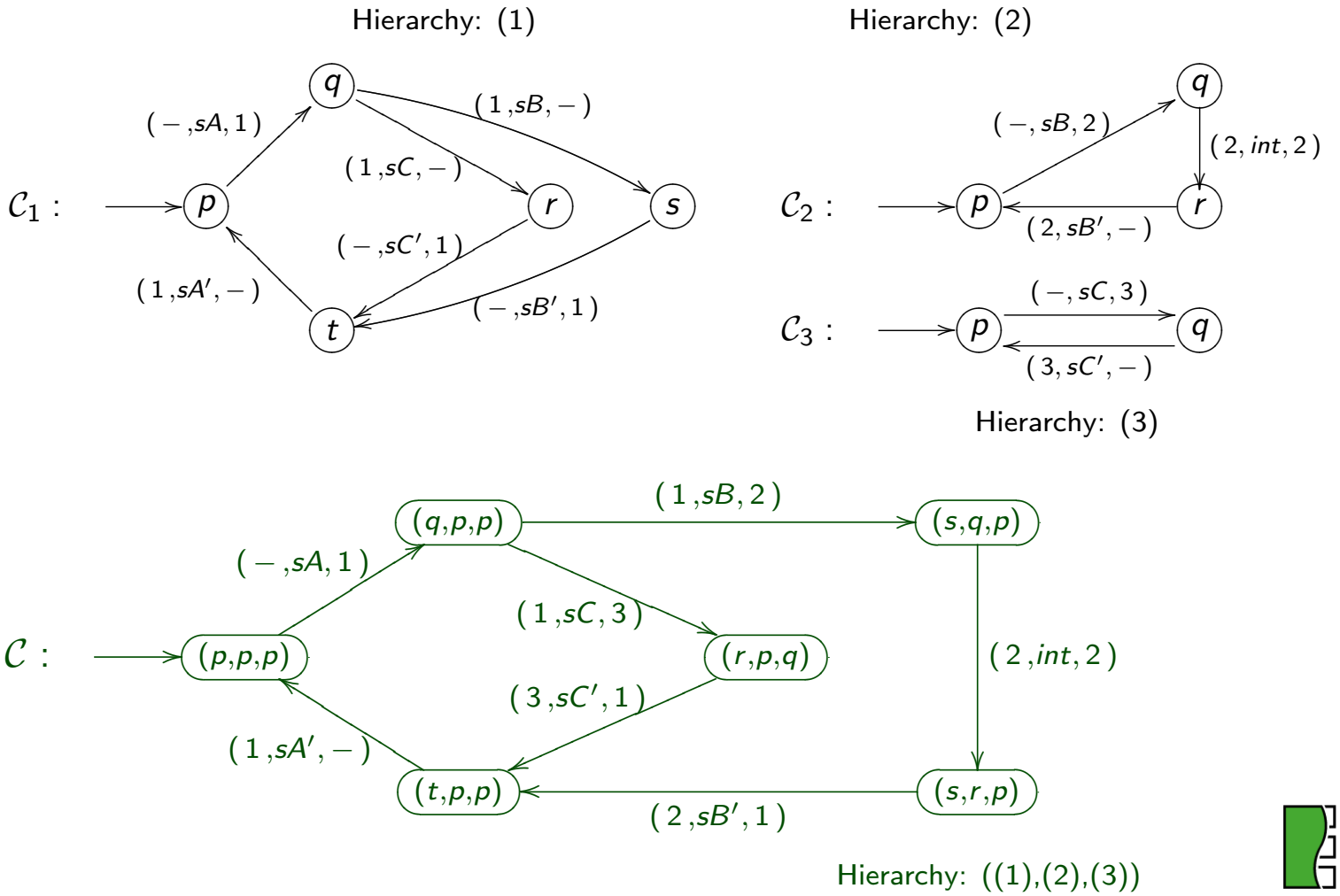
Modelling language

Composition of CI automata $\mathcal{C} = \otimes^{\mathcal{F}}\{\mathcal{C}_1, \mathcal{C}_2, \mathcal{C}_3\}$



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Logic for properties specification

CI-LTL

- extended version of the action based LTL
- motivated by CBSE requirements
- expresses properties about both
  - occurring component interaction (i.e. labels in automata)
  - possible component interaction (i.e. label enabledness)

Operators

- possible interaction (in a state) $\mathcal{E}(l)$
- actual interaction (on a path) $\mathcal{P}(l)$
- LTL operators – next $\mathcal{X}\,\Phi$, until $\Phi\ \mathcal{U}\ \Psi$, and $\Phi \wedge \Psi$, not $\neg\,\Phi$

Example $\mathcal{G}\ (\mathcal{E}(1, a, 2) \Rightarrow \mathcal{F}\,\mathcal{P}(1, a, 2))$

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Model of the system

Structure of the model

- 140 primitive CI automata,
- composed hierarchically – 34 composite automata, 6 levels
- complemented with a usage profile of the Cashier

State space of the model

- Without usage profile
  - over 322 millions of states (60 GB of memory)
- With usage profile
  - 749 340 reachable states, 3 181 473 reachable transitions

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Verification of the model

Correctness of the system

- Local deadlocks of components
  – one of the components cannot move further
- Blocking of components
  – temporary blocking of a component
- Infinite loops in the model
  – finite `for`/`while` cycles traversed infinitely-many times
- Use-case scenarios
  – presence of a particular scenario (sequence of actions) in the system

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Verification of the model 2/2

Validity of the model

- checking safety of considered abstractions
- simplification of the communicational scheme
- internal behaviour of primitive components
- checked via a number of test cases translated into CI-LTL

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Selected properties 1/3

Property 4 (Local deadlock on one action). It cannot happen that the *CashDeskApplication (100)* is ready to send a notification to the *CashDeskChannel (200)* saying that it received the *SaleStartedEvent*, but the *CashDeskChannel* is never ready to accept the notification.

$$[\mathcal{FP}(100, oESS'', -)] \vee \mathcal{G}[\mathcal{E}(100, oESS'', -) \Rightarrow \mathcal{FE}(100, oESS'', 200)]$$

property	states	transitions	memory	time	result
prop4	749 343	3 181 479	532 MB	67 s	holds

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Selected properties 2/3

Property 7 (Blocking of a component). It cannot happen that the *CashDeskApplication (100)* is ready to send a notification to the *CashDeskChannel (200)* saying that it received the *SaleStartedEvent*, but the *CashDeskChannel* is not right in the current state ready to accept the notification.

$$[\mathcal{FP}(100, oESS'', -)] \vee \mathcal{G}\neg[\mathcal{E}(100, oESS'', -) \wedge \neg\mathcal{E}(100, oESS'', 200)]$$

property	states	transitions	memory	time	result
prop7	1 498 671	6 362 935	688 MB	534 s	holds not

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Selected properties 3/3

Use Case scenarios

1. Cash Payment
2. Unsuccessful Card Payment
3. Successful Card Payment

property	states	transitions	memory	time	result
uc1	19 362 460	81 959 821	4 204 MB	5 141 s	found
uc2	11 670 924	49 165 124	2 694 MB	3 203 s	found
uc3	11 680 736	49 202 320	2 698 MB	3 098 s	found

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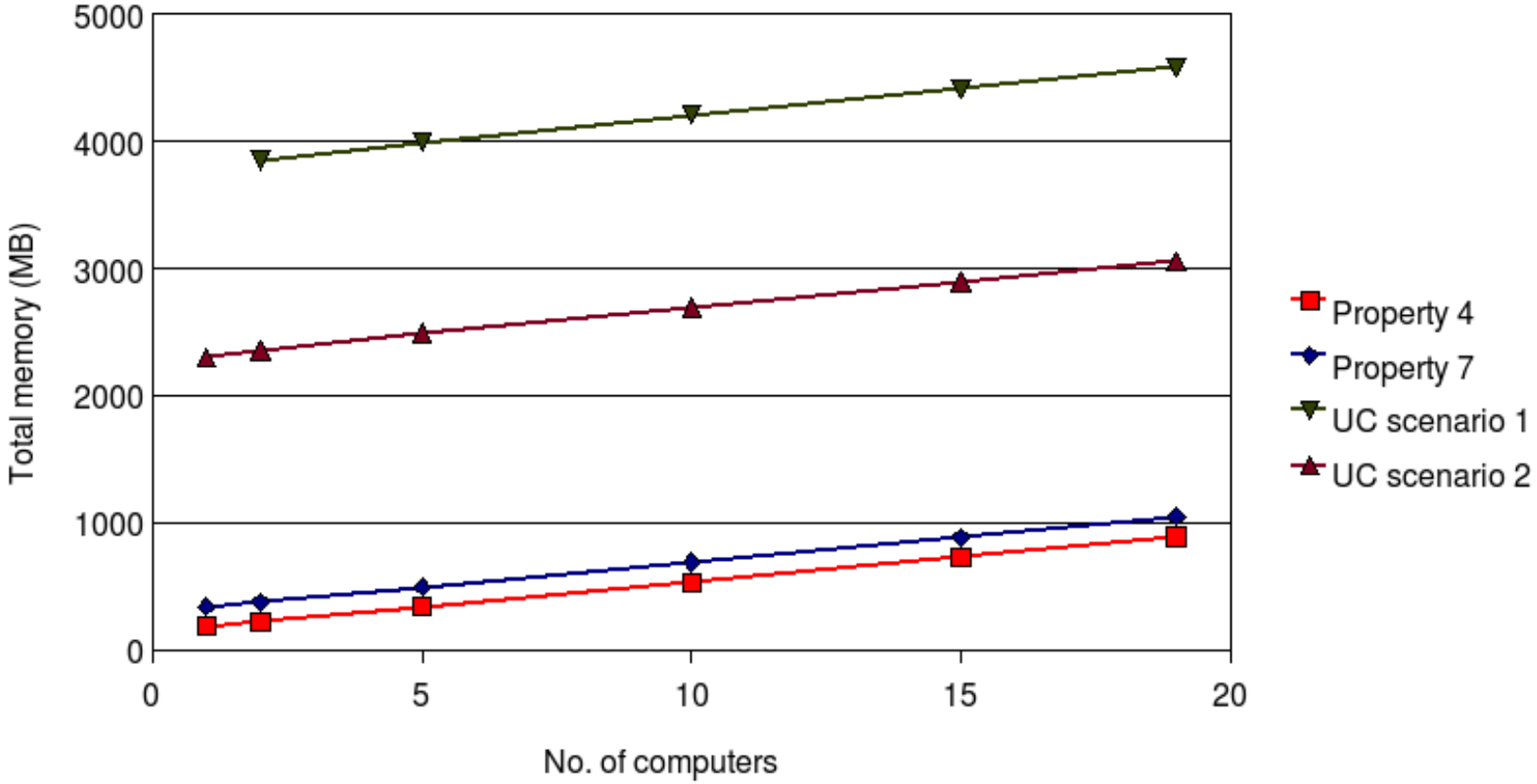
Effect of the parallelization

Memory consumption depending on the number of computers



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Effect of the parallelization

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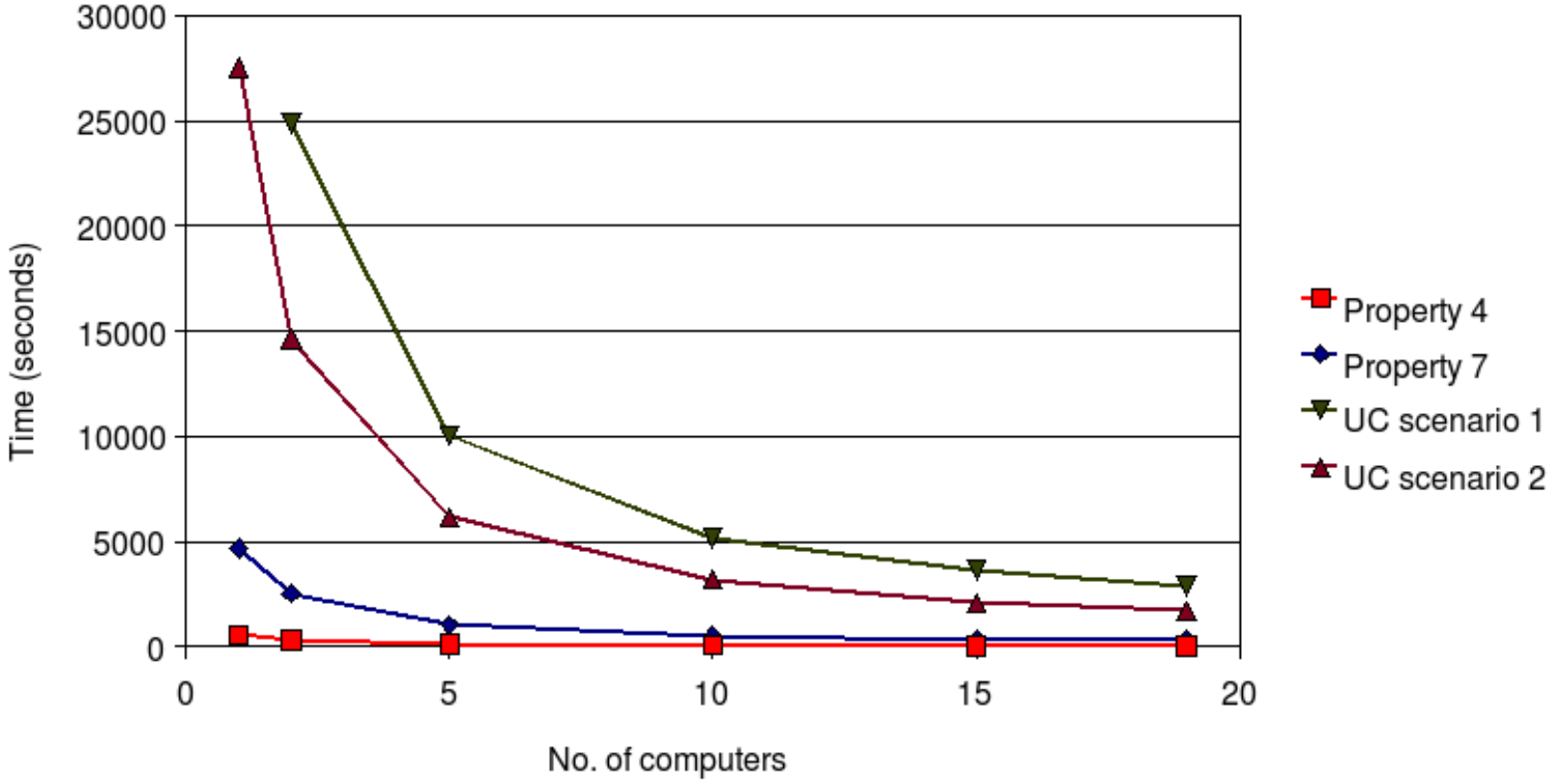

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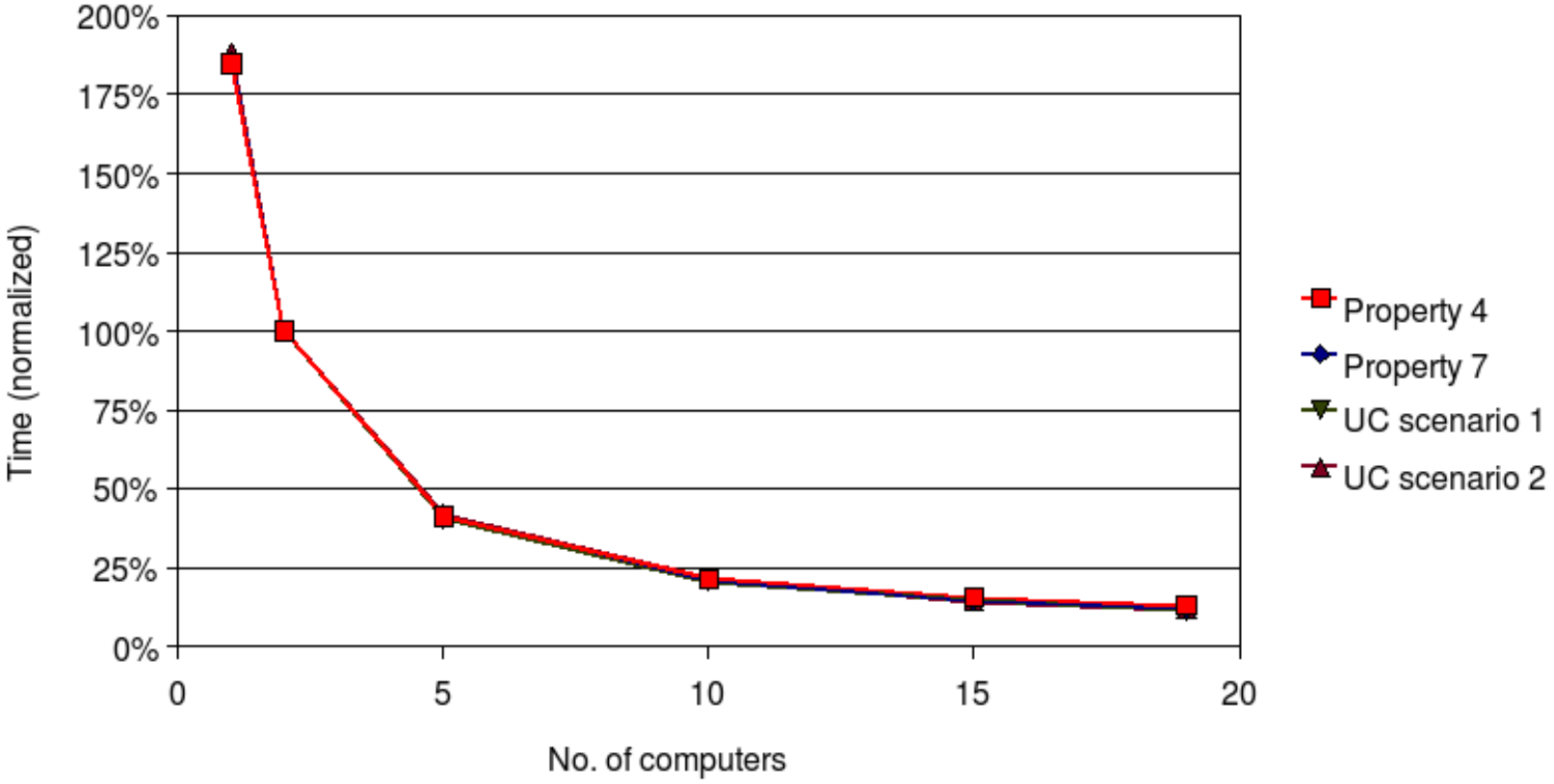

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Lessons learned

Experience and discussion

- Characteristics of the model
  – state space explosion, irregular changes
- Deadlocks in the model
  – unrealistic behaviour
- Local deadlocks and component-blocking properties
  – enabledness operator
- Parallelization
  – effect of parallelization

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Conclusion

Summary of the talk

- Practical application of the parallel verification to a real component-based system
- Identification of a number of typical component specific properties
- Formalization of the properties using the logic CI-LTL
- Demonstration of the parallel CI-LTL verification

Future work

- Reduction techniques
  – the partial-order and the symmetry reduction

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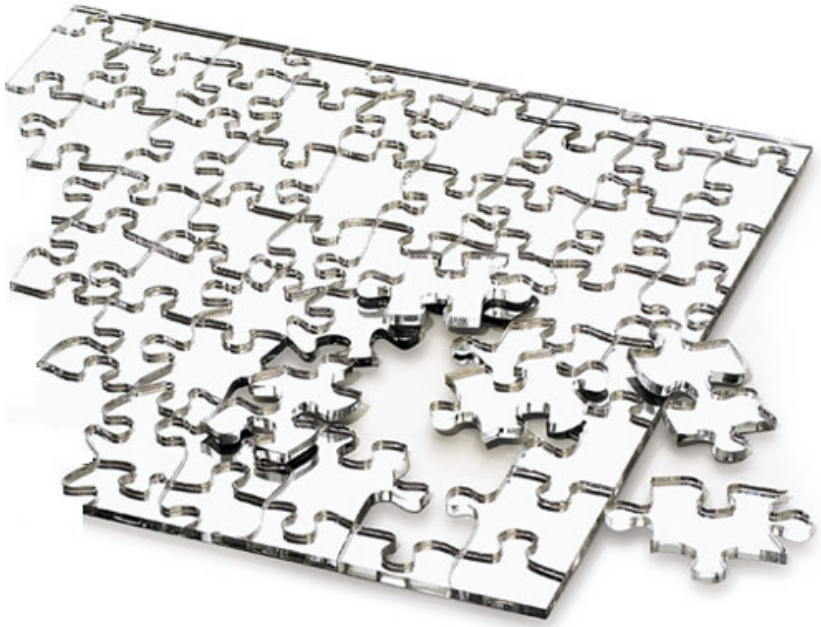
Thank you

Thank you for your attention



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