Formal-methods support for runtime adaptation in role-based systems

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Knowledge System

Analyse

Plan

Monitor

Execute

System
Outline

**State of the Art**

**Contributions**
- PMC-based Decision Making
- Statistical Analysis of Decider Performance

**Experiments**

**Conclusion**
State of the Art

System-verification

Verify system properties at the design stage, like:

- Resilience (Cámara and de Lemos (2012))
- Safety (Güdemann, Ortmeier, and Reif (2006))
- Performance (M. Becker, Luckey, and S. Becker (2013))
State of the Art

System-verification

Verify system properties at the design stage, like:

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Decision making

Effective decision making by computing expected consequences of decisions
State of the Art

System-verification

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- Performance (M. Becker, Luckey, and S. Becker (2013))

Decision making

Effective decision making by computing expected consequences of decisions

Main Challenge
Complexity of system representation
Decision making with Formal Methods

- Accuracy
- Tradeoff
- Memory
Decision making with Formal Methods

- simulation reduction (Calinescu et al. (2011))
- statistical methods (Iftikhar and Weyns (2014))
Decision making with Formal Methods

- simulation reduction (Calinescu et al. (2011))
- statistical methods (Iftikhar and Weyns (2014))
- Parametric Model Checking (Filieri, Ghezzi, and Tamburrelli (2011))
- Pre-computation of Scenarios (Saller, Lochau, and Reimund (2013))
Contributions
Fundamental Concept

- Adaptive system
- Monitoring & Analysis
- Execution
- Plan

PMC-supported decision making
Fundamental Concept

Adaptive system

Monitoring & Analysis

Execution

Plan

PMC-based offline Analysis on system model
Fundamental Concept

Adaptive system

Monitoring & Analysis

Plan

Execution

PMC-based offline Analysis on system model

Database
Fundamental Concept

Adaptive system

Monitoring & Analysis

Execution

PMC-supported decision making

PMC-based offline Analysis on system model

Database
PMC-based Decision Making

- System model
- Metrics to compute
- Probabilistic Model Checking
- Results
Objective of the Decider

Split the global objective into multiple local metrics.
Objective of the Decider

Split the **global objective** into multiple **local metrics**
Objective of the Decider

Split the **global objective** into multiple **local metrics**

Local Metrics

- $Pr(P_1)$
- $Exp(E_1)$
- $\vdots$
Objective of the Decider

Split the global objective into multiple local metrics

Global Objective

- keep $P_1 \geq 0.9$
- minimise $E_1$
- ...

Local Metrics

- $Pr(P_1)$
- $Exp(E_1)$
- ...

Objective of the Decider

Split the **global objective** into multiple **local metrics**

**Global Objective**

**Strategy**
- keep $P_1 \geq 0.9$
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- $Pr(P_1)$
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PMC-based Decision Making

- System model
- Metrics to compute
- Probabilistic Model Checking
- Results
PMC-based Decision Making

- System model
- Probabilistic Model Checking
- Local optimization metrics
- Results
PMC-based Decision Making

family of system instances → family model → Probabilistic Model Checking → Results

local optimization metrics

Probabilistic Model Checking
Family Model

Core Model

1

Environment 1

Environment 2

Environment 3

Plan 1

Plan 2

Plan 3
Family Model

Context

Environment 1

Environment 2

Environment 3
Family Model

Adaptation

Context

Core Model
Family Model

Adaptation

Context

Adaption

Plan 1

Plan 2

Plan 3
Family Model

- Adaptation
- Context
- Core Model
- Monitor

Environment 1
Environment 2
Environment 3

Adaptation
Context
Monitor
Family Model

Adaptation  →  Context

Core Model

Environment 1
Environment 2
Environment 3

Plan 1  →  Plan 2  →  Plan 3

Monitor
PMC-based Decision Making

- Family of system instances
- Family model
- Probabilistic Model Checking
- Local optimization metrics
- Results
PMC-based Decision Making

- Family of system instances
- Family model
- Local optimization metrics
- Probabilistic Model Checking
- Database
# Database

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<td>...</td>
<td>...</td>
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</tbody>
</table>
Fundamental Concept

Adaptive system

Monitoring & Analysis

PMC-supported decision making

Execution

PMC-based offline Analysis on system model

Database
Objective of the Decider

Split the **global objective** into multiple **local metrics**

**Global Objective**

**Strategy**

- keep $P1 \geq 0.9$
- minimise $E1$

**Local Metrics**

- $Pr(P1)$
- $Exp(E1)$
- :
Fundamental Concept

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Statistical Analysis of Decider Performance

1. Execute
2. Plan
3. Monitor & Analyse
4. running System

Feedback loop: Execute -> Plan -> Monitor & Analyse -> running System -> Execute
Statistical Analysis of Decider Performance

Runtime System Model

Execute

Plan

Monitor & Analyse
Statistical Analysis of Decider Performance

- Execute
- Plan
- runtime System Model
- Monitoring System State

Activation of plan features
Statistical Analysis of Decider Performance

- Execute
- runtime System Model
- Monitoring System State
- Database Lookup
Statistical Analysis of Decider Performance

Activation of plan features

runtime System Model

Monitoring System State

Database Lookup
Experiments
Tooling

Implemented using the modelling language ProFeat\textsuperscript{1} and the Model Checker Prism\textsuperscript{2}.

\textsuperscript{1}Chrszon et al. (2018)
\textsuperscript{2}Kwiatkowska, Norman, and Parker (2011)
Tooling

Implemented using the modelling language ProFeat\textsuperscript{1} and the Model Checker Prism\textsuperscript{2}.

Successful self-adaptation on Prism case-study models:

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Tooling

Implemented using the modelling language ProFeat\textsuperscript{1} and the Model Checker Prism\textsuperscript{2}.

Successful self-adaptation on Prism case-study models:

- Real Time Voltage Scaling (Kwiatkowska, Norman, and Parker (2005))
- Human in the Loop UAV Mission Planning (Feng et al. (2015))
- Network Virus Infection (Kwiatkowska, Norman, Parker, and Vigliotti (2009))

\textsuperscript{1}Chrszon et al. (2018)
\textsuperscript{2}Kwiatkowska, Norman, and Parker (2011)
Experiment Scenario

Adaptive DBMS
Experiment Scenario

Adaptive DBMS
Experiment Scenario

Adaptive DBMS

- Adaptation
  - Cores
  - Frequency
  - Hyper-Threading

Tasks vs. Time (t)
Global Objective

- **Reduce Energy Costs**

  - **Schedule**: \( \text{Pr} \left( \text{all tasks computed} \right) \)
  - **Costs**: \( \text{Exp} \left( \text{Costs} \right) \)
  - **Budget**: \( \text{Pr} \left( \text{all tasks computed} \land \text{costs in budget} \right) \)
Global Objective

Compute all tasks
Global Objective

Compute all tasks

reduce Energy Costs
Global Objective

Compute all tasks  \hspace{5cm} \text{Trade-off} \hspace{5cm} \text{reduce Energy Costs}

- **Global Objective**
  - **Reduce Energy Costs**
  - Compute all tasks
  - Schedule: $\text{Pr}(\text{all tasks computed})$
  - Costs: $\text{Exp}(\text{Costs})$
  - Budget: $\text{Pr}(\text{all tasks computed} \land \text{costs in budget})$
Global Objective

Compute all tasks $\xrightarrow{\text{Trade-off}}$ reduce Energy Costs

Schedule: $Pr(\text{all tasks computed})$
Global Objective

- **Global Objective**
  - **Reduce Energy Costs**
  - **Compute all tasks**
  - **Trade-off**
  - **Schedule:** $\Pr(\text{all tasks computed})$
  - **Costs:** $\Exp(\text{Costs})$
Global Objective

Compute all tasks

Trade-off

reduce Energy Costs

Schedule: $Pr(\text{all tasks computed})$

Costs: $Exp(\text{Costs})$

Budget: $Pr(\text{all tasks computed} \land \text{costs in budget})$
Experimental Setup

- Environment
Experimental Setup

- Environment
- lookahead

![Bar chart showing tasks over time](chart.png)

<table>
<thead>
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<th>time</th>
<th>tasks</th>
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<tbody>
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<tr>
<td>2</td>
<td>3</td>
</tr>
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<td>3</td>
<td>1</td>
</tr>
<tr>
<td>4</td>
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</tbody>
</table>
Experimental Setup

- Environment
- lookahead
- time between decisions
Experimental Setup

- Environment
- lookahead
- time between decisions
- noise-factor
Experimental Setup

- Environment
  - lookahead
  - time between decisions
- noise-factor
- Strategy

Max-Schedule:

- maximise Schedule

Filter-Schedule:

- minimise Costs

Max-Budget:

- keep Schedule $\geq 0$
- maximise Budget

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Experimental Setup

- Environment
- lookahead
- time between decisions
- noise-factor
- Strategy
  - ▶ Max-Schedule

Max-Schedule:

maximise Schedule

mininise Costs
Experimental Setup

- Environment
- lookahead
- time between decisions
- noise-factor
- Strategy
  - Max-Schedule
  - Filter-Schedule

Filter-Schedule:

keep Schedule $\geq 0.9$

minimise Costs
Experimental Setup

- Environment
- lookahead
- time between decisions
- noise-factor
- Strategy
  - Max-Schedule
  - Filter-Schedule
  - Max-Budget

Max-Budget:

maximise Budget

minimise Costs
Effect of Lookahead

Lookahead: *
Decisions: *
Noise: 0
Strategy: Max-Budget
Effect of Noise

Lookahead: 10
Decisions: *
Noise: *
Strategy: Max-Budget

![Bar chart showing effect of noise]

Graph showing budget changes with noise-factor:
- Optimum
- Decide every step
- Decide every 2 steps
- Decide every 3 steps

0 0.2 0.4 0.6 0.8 1
noise-factor

0 0.2 0.4 0.6 0.8 1
Budget
Strategy Comparison

Lookahead: *
Decisions: every step
Noise: 0
Strategy: *

Lookahead

Schedule

Costs

Max-Schedule

Max-Schedule
Strategy Comparison

Lookahead: *
Decisions: every step
Noise: 0
Strategy: *

[Graphs showing schedule and costs over lookahead for Max-Schedule and Filter-Schedule]
Strategy Comparison

Lookahead: *
Decisions: every step
Noise: 0
Strategy: *

![Chart showing comparison between schedules and costs over lookahead.]

- Schedule:
  - Max-Schedule
  - Filter-Schedule
  - Max-Budget

- Costs:
  - Max-Schedule
  - Filter-Schedule
  - Max-Budget
Conclusion
Conclusion

- Decision making approach using offline PMC
Conclusion

- Decision making approach using offline PMC
- Analysis tool using statistic MC
Conclusion

- Decision making approach using offline PMC
- Analysis tool using statistic MC
Conclusion

- Decision making approach using offline PMC
- Analysis tool using statistic MC

Paper in progress
Conclusion

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Paper in progress

Further analysis:
- effects of environmental changes
Conclusion

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Paper in progress

Further analysis:
- effects of environmental changes
- separating global objective in local metrics
Related Work I


Related Work II


Related Work III


