Universität Siegen

Cost-Sensitive Precomputation of Real-Time-Aware Reconfiguration Strategies based on Stochastic Priced Timed Games

(published in Journal on Software and Systems Modeling, 2024)

Hendrik Göttmann, Birte Caesar, Lasse Beers, Malte Lochau, Andy Schürr, Alexander Fay

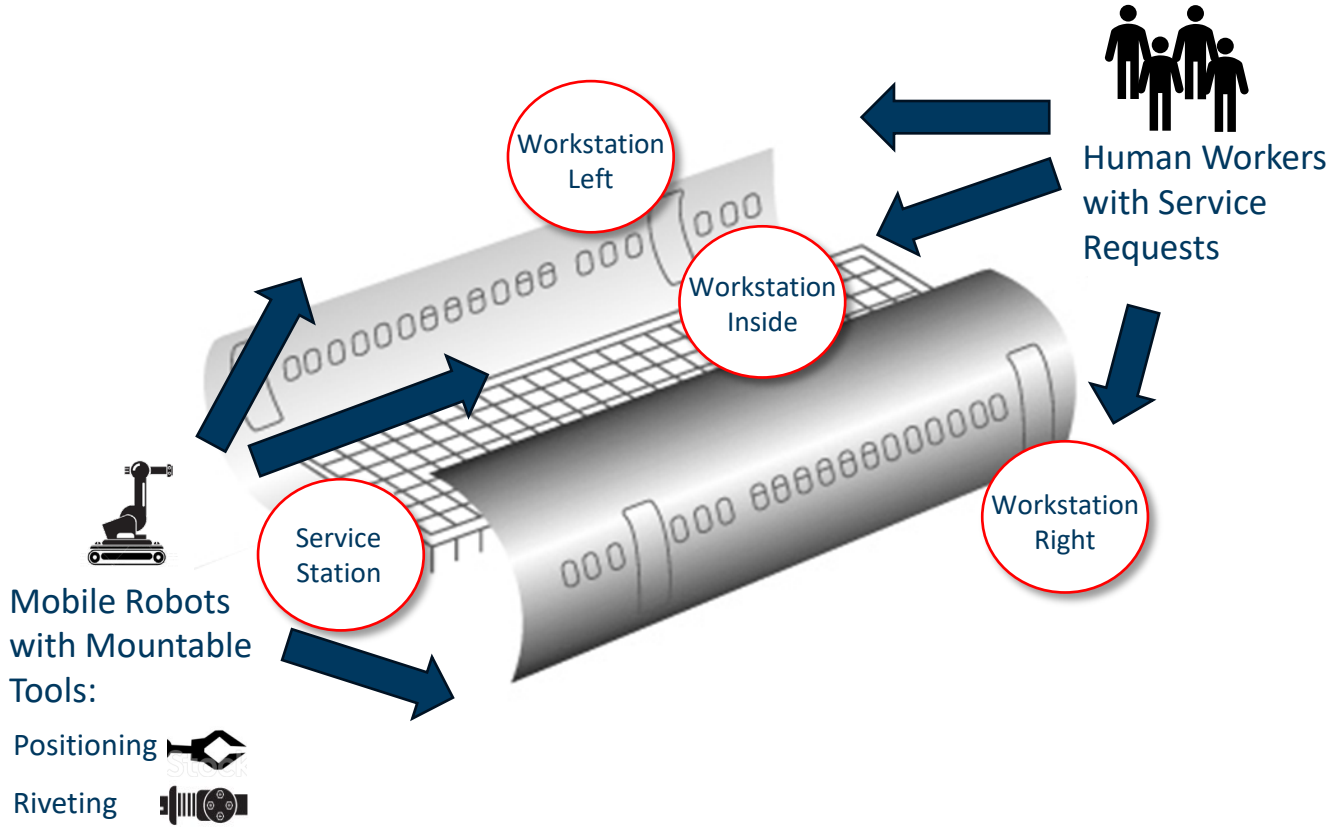
SE 25, Karlsruhe

Funded by DFG Deutsche Forschungsgemeinschaft German Research Foundation

www.uni-siegen.de

Example: Robot Support System for Aircraft Assemblies

[Banku, CC BY-SA 4.0 <https://creativecommons.org/licenses/by-sa/4.0>, via Wikimedia Commons]



[Brunete et al.: Current trends in reconfigurable modular robots design (2017) https://doi.org/10.1177/1729881417710457]

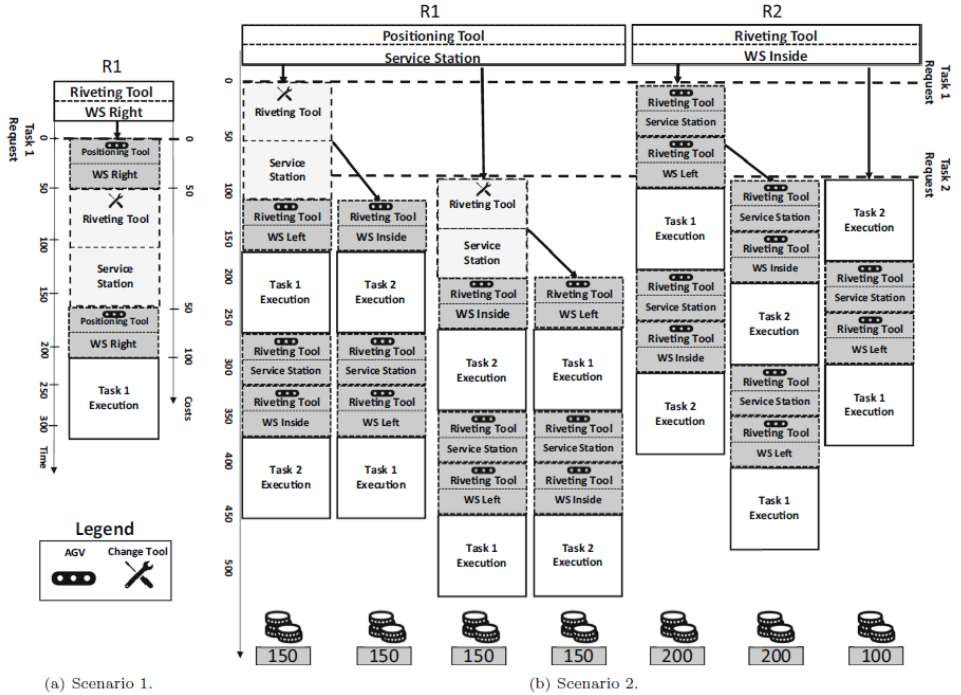
Challenges & Approach

Functional requirements:

- *Reactive/proactive decision procedure to assign robots to service requests.*
- *Continuous reconfiguration of robots to adapt to changing contexts at run-time.*

Non-functional optimization goals:

- *Maximize productivity (maximize utilization of robots / minimize waiting time of workers),*
- *Minimize costs (minimize number of robots / minimize overall energy consumption)*



(a) Scenario 1. (b) Scenario 2.

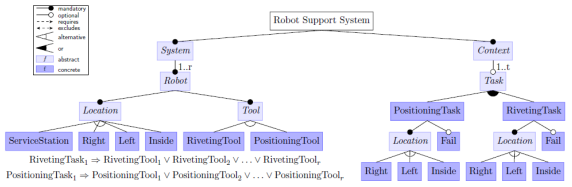
- Entirely deciding assignments of robots to tasks **before** run-time is infeasible due to many sources of **uncertainty**.
- Entirely deciding assignments of robots to tasks **during** run-time is also infeasible due to the **high computational complexity** of the underlying optimization problem.
- Our approach: **Precompute** as many decisions as possible off-line and make final decisions on-line.

[Filieri et al.: Run-time efficient probabilistic model checking (2011). https://doi.org/10.1145/1985793.1985840]

Configuration Constraints

Reconfiguration Constraints

Specification

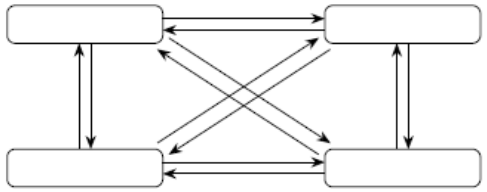


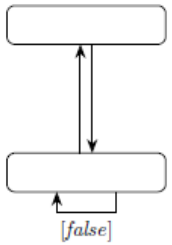
Real-time Constraints

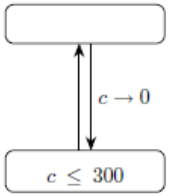
Stochastic Constraints

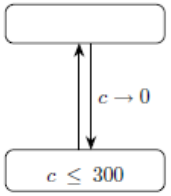
Cost Constraints

Reconfigura-tion Model



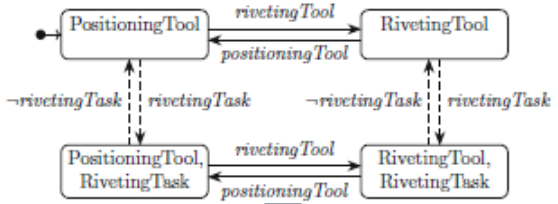




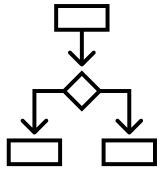


Reconfiguration Decisions

Player 1 (System)

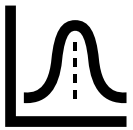


Player 2 (Context)

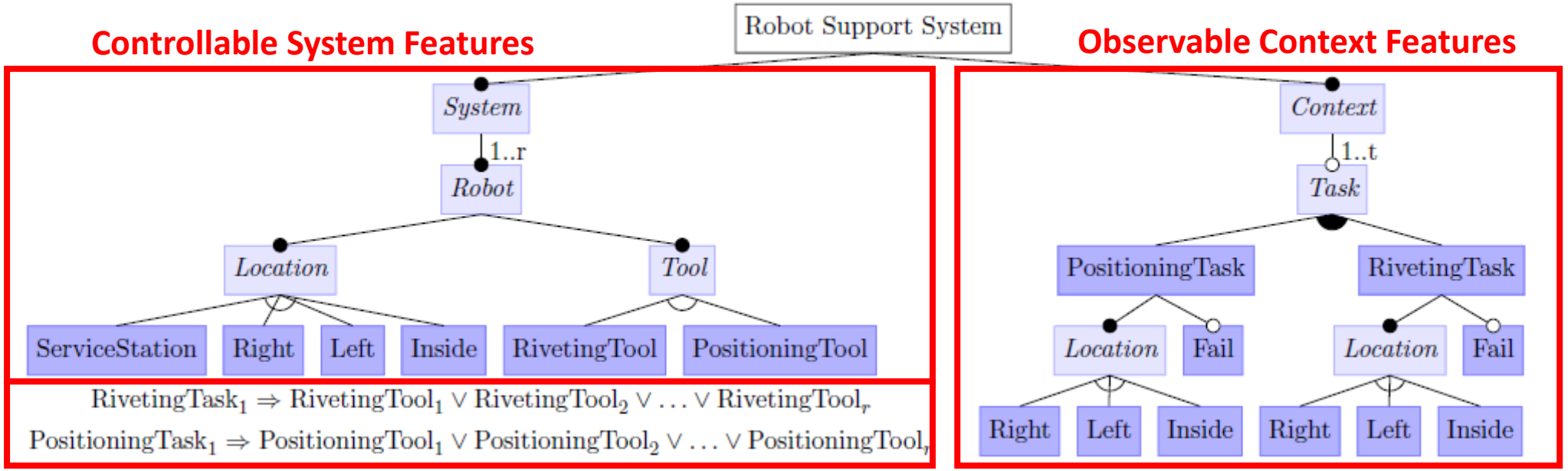


Reconfiguration Decisions

Context Changes



Context-Feature Models

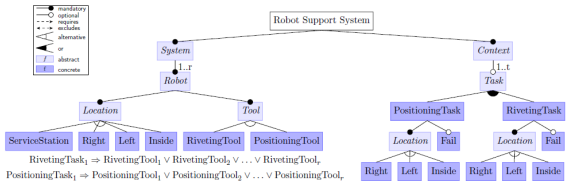


[Hartmann, Trew, T.: Using Feature Diagrams with Context Variability to Model Multiple Product Lines for Software Supply Chains (2008). https://doi.org/10.1109/SPLC.2008.15]

Configuration Constraints

Reconfiguration Constraints

Specification

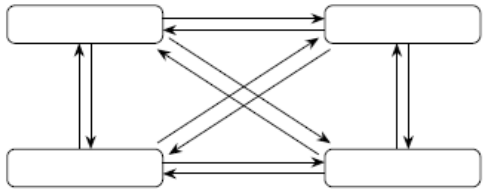


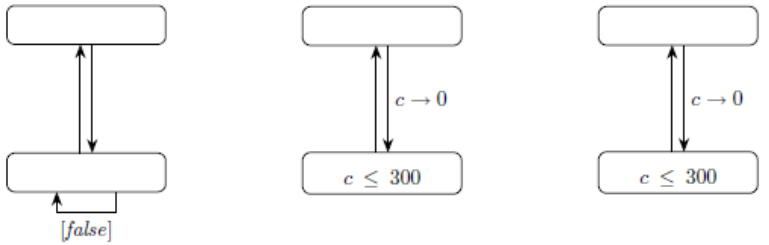
Real-time Constraints

Stochastic Constraints

Cost Constraints

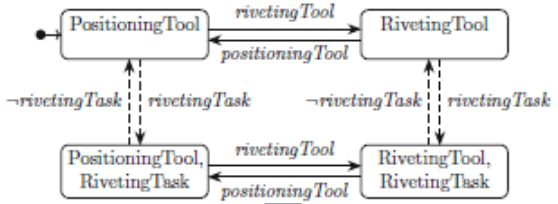
Reconfigura-tion Model



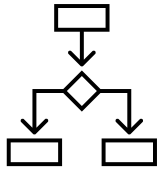


Reconfiguration Decisions

Player 1 (System)

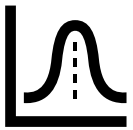


Player 2 (Context)



Reconfiguration Decisions

Context Changes



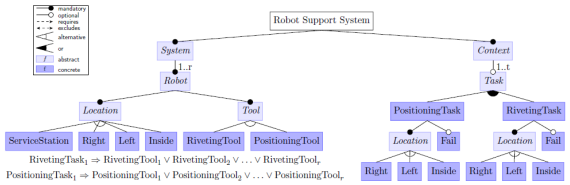
Reconfiguration Constraints

- Logical Constraint: Forbidden Reconfiguration — $[Left \rightarrow Right]\ false$
- Real-time Constraint: Duration of Robot Movement — $[Left \rightarrow ServiceStation]\ setup(30)$
- Real-time Constraint: Duration of Tool Change — $[ServiceStation \wedge PositioningTool \rightarrow ServiceStation \wedge RivetingTool]\ setup(50)$
- Stochastic Constraint: Probability of Task Requests — $[\neg Task \rightarrow Task]\ normal(30,5)$
- Cost Constraint: Energy Consumption of Tool Change — $[PositioningTool \rightarrow RivetingTool]\ cost(1)$
- Cost Constraint: Penalty for Unfinished Task — $[Task]\ cost(2)$

Configuration Constraints

Reconfiguration Constraints

Specification

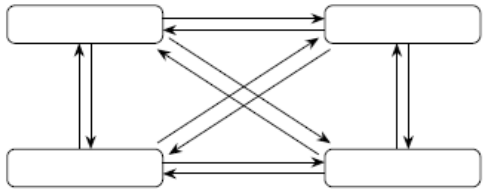


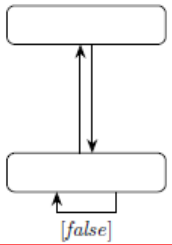
Real-time Constraints

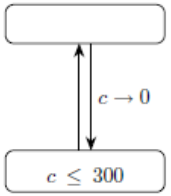
Stochastic Constraints

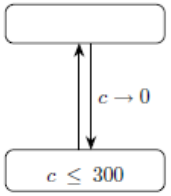
Cost Constraints

Reconfigura-tion Model



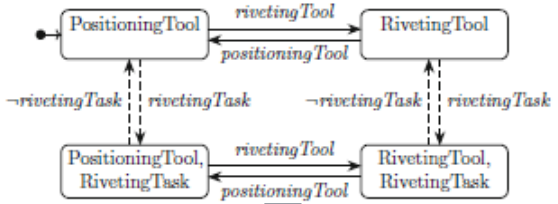




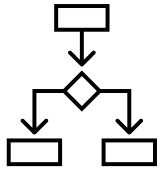


Reconfiguration Decisions

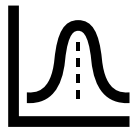
Player 1 (System)



Player 2 (Context)

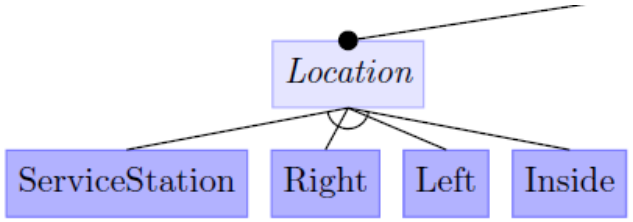


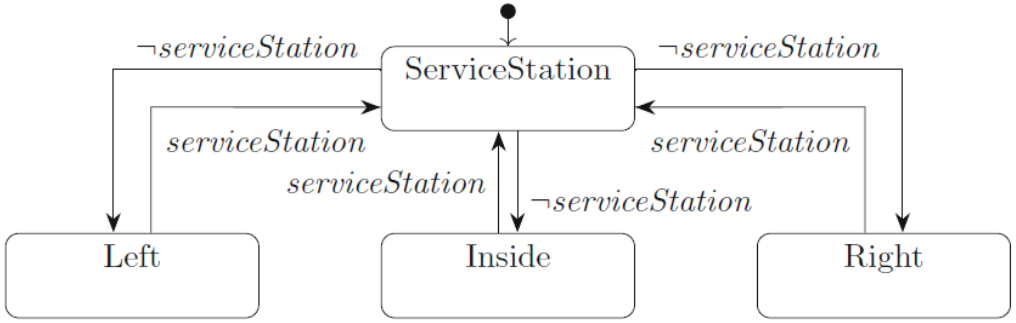
Reconfiguration Decisions



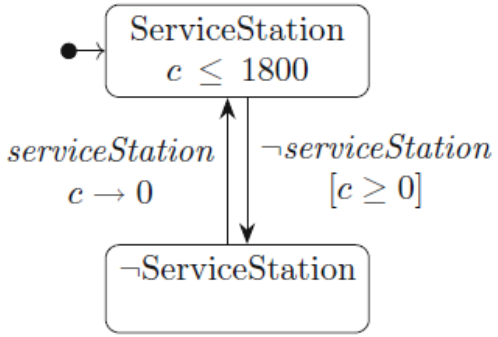
Context Changes

Reconfiguration Model






```
[¬ServiceStation → ServiceStation]
reside(1800)
```

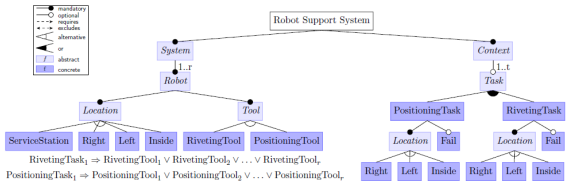


Reconfiguration Core Model | Synchronous Composition | Reconfiguration Constraint Fragments

Configuration Constraints

Reconfiguration Constraints

Specification

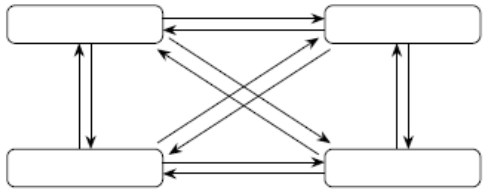


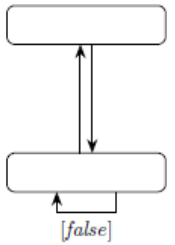
Real-time Constraints

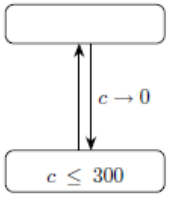
Stochastic Constraints

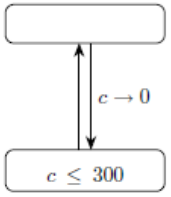
Cost Constraints

Reconfigura-tion Model



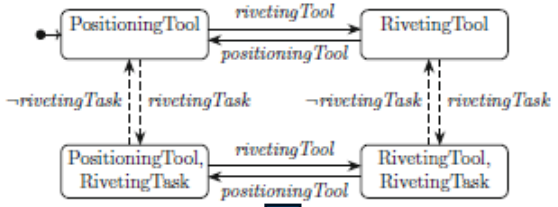




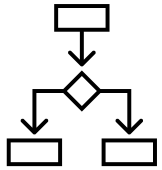


Reconfiguration Decisions

Player 1 (System)

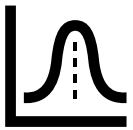


Player 2 (Context)



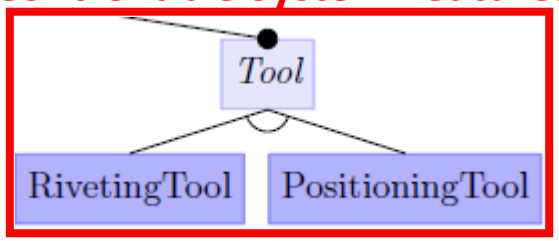
Reconfiguration Decisions

Context Changes

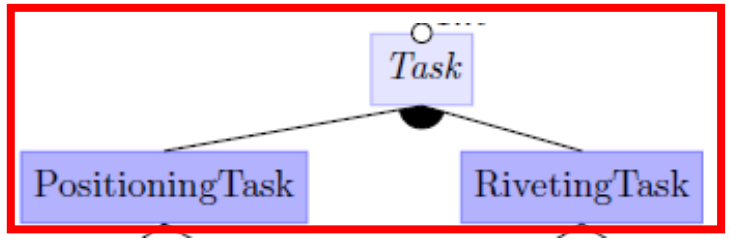


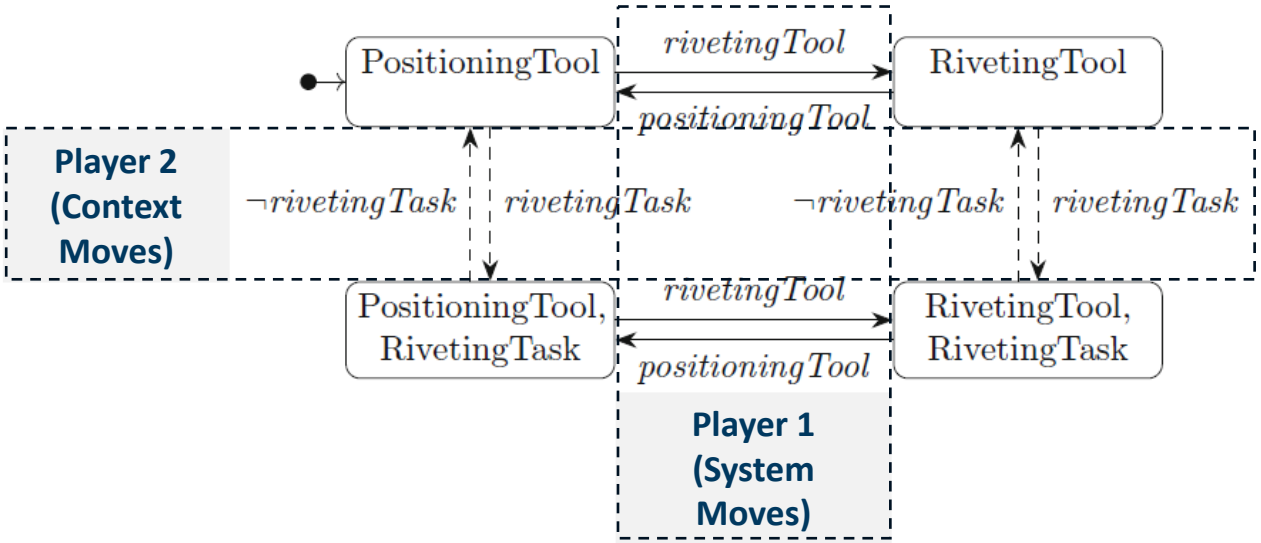
Reconfiguration Game

Controllable System Features



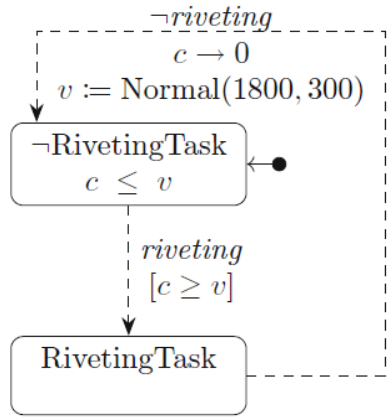
Observable Context Features





Stochastic Priced Timed Game Automaton

```
[¬RivetingTask → RivetingTask]
normal(1800,300)
```



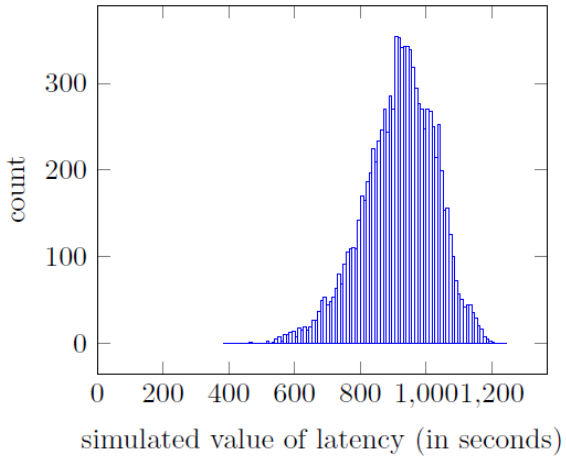
Stochastic Context Changes

Precomputing Reconfiguration Strategies

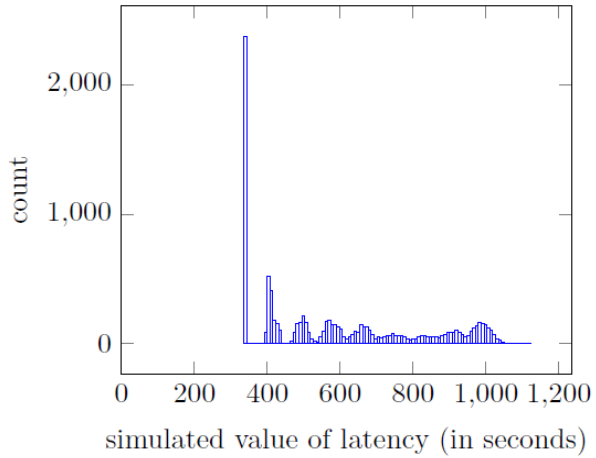
Context Constraint

```
[Task] reside(1200)
```

Winning Strategy



Optimized Strategy



- Winning Strategy Synthesis: Precomputed reconfiguration decisions satisfy critical context requirements for all predicted context changes.
- Optimized Strategy Synthesis: Precomputed reconfiguration decisions additionally try to reach optimality w.r.t. NFP goals.
- UPPAAL Stratego applies statistical model-checking to approximate correct/optimal solutions.

[David et al.: On time with minimal expected costs (2014). https://doi.org/10.1007/978-3-319-11936-6_10]

Outlook

- Develop efficient run-time data structures to deploy reconfiguration strategies on target systems with limited resources.
- Conduct further real-word case studies from communication networks and automation systems.
- Identify needs for extending the reconfiguration constraint modeling language.
- Investigate further counter-measures to cope with the inherent computational complexity of strategy synthesis.

- For more details, have a look into our paper: https://doi.org/10.1007/s10270-024-01195-9
- Contact: malte.Lochau@uni-siegen.de