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Precomputing Reconfiguration Strategies based on Stochastic Timed Game Automata

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Abstract: We summarize our paper *Precomputing Reconfiguration Strategies based on Stochastic Timed Game Automata* which has been published in the proceedings of the *25th International Conference on Model Driven Engineering Languages and Systems (MODELS 2022)*.

Keywords: Stochastic Timed Game Automata; Proactive Self-Adaptation; Strategy Synthesis; Statistical Model-Checking

1 Summary

Many recent application domains require software-intense systems with reconfiguration capabilities to be (self-)adaptable to changing contextual situations. As an example, in today's aircraft manufacturing assembly lines, human engineers are supported by mobile robots, offering production capabilities (e.g., mountable toolsets) on demand. Depending on the manufacturing context, requirements on capabilities may change (e.g., from riveting at construction site A to welding at site B) thus requiring robots to repeatedly reconfigure themselves to new contextual situations. Knowledge about occurrences of these contextual situations is only partially available at design time as this information only becomes apparent at runtime. Hence, entirely pre-planning these reconfiguration decisions is infeasible due to the large state space and the high degree of uncertainty about the expected runtime behavior. In contrast, making these highly-complex reconfiguration decisions at runtime may benefit from perfect context knowledge. However, this excludes all non-trivial decision algorithms except greedy-based heuristics as both computing resources and time for decision-making are usually limited at runtime. Furthermore, in addition to functional properties also non-functional properties such as real-time constraints have to be considered, too. For instance, the robot movement, toolset reconfiguration and computing the reconfiguration decision itself each require a certain amount of time ultimately influencing the throughput of the overall production process. Again, uncertainty is an omnipresent issue.

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To cope with these challenges, we rely on concepts from game theory. Both the system and the context act as opponents in a two-player game derived from our reconfiguration model. Our reconfiguration model combines (context) feature models describing the configuration space with a domain specific constraint language providing means to define real-time constraints on reconfigurations (i.e., changing from one configuration of the feature model to another) which cannot be encoded into plain feature models. Additionally, the constraint language supports the specification of stochastic delays given as probability distributions instead of exact values for time bounds as those are unknown at design time. From this reconfiguration specification (i.e., feature model and real-time constraints) we automatically construct a stochastic timed game automaton exactly representing the specified behavior. Based on this game-theoretic reconfiguration model, we are able to precompute winning strategies by means of UPPAAL STRATEGO which enable the system player to make fast look-ups at runtime for presumably best-fitting reconfiguration decisions satisfying the context player. Statistical model-checking further enables us to optimize the strategy w.r.t. non-functional properties like real-time behavior. To summarize, our approach [Gö22] makes the following contributions:

- integrated modeling of real-time reconfigurations comprising uncertain context behaviors based on context feature models,
- application of game theory to synthesize both safe and optimized reconfiguration strategies by means of UPPAAL STRATEGO, and
- investigation of efficiency/effectiveness trade-offs by considering a real-world example of a reconfigurable robot support system for the construction of aircraft fuselages.

2 Data Availability

To foster reproducibility, we provide the tool implementation and the evaluation data of our real-world example online[7].

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Bibliography

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