

# Non-monotonic Reasoning under Uncertainties and Runtime Conflict Solving in Multi-Agent Self-Adaptive Cyber-Physical Systems

Master's Thesis

**Supervisor:** Prof. Dr. Alexander Pretschner

**Advisor:** Ana Petrovska

**Email:** {alexander.pretschner, ana.petrovska}@tum.de

**Phone:** +49 (89) 289 - 17830

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Fakultät für Informatik  
Lehrstuhl 4  
Software & Systems Engineering  
Prof. Dr. Alexander Pretschner

Boltzmannstraße 3  
85748 Garching bei München

Tel: +49 (89) 289 - 17830  
<https://www4.in.tum.de>

## Context

Modern software systems, such as cyber-physical systems (CPSs), operate in complex and dynamic environments. With the continuous and unanticipated change in the operational environment, these systems are subjected to a variety of uncertainties. Self-adaptive CPSs (SACPSs) can adjust their behavior or structure at run-time as a response to the changes in their perceived environment.

Self-adaptation is commonly realized through a MAPE-K feedback loop incorporating newly derived knowledge obtained by the sensed data from the run-time monitoring, during the operation of decentralized SACPSs. However, to build the knowledge, the need for run-time observations' aggregation and reasoning emerges, since the observations made by the decentralized systems might be conflicting [1].

In a previous master thesis [2], we propose an approach and domain-independent framework for knowledge aggregation in SACPSs that can deal with inaccurate, partial, and conflicting observations. Concretely, our approach uses Subjective Logic to build knowledge by aggregating partial observations of the context made by each agent in a decentralized multi-agent SACPSs.

## Goal

Our multi-agent SACPSs is implemented in ROS and simulated in Gazebo [3, 2]. The current implementation of the system, supports realistic sensing of objects in the context where the CPSs, in our case the robots, operate. Namely, to make the sensing more realistic, we have added noise to the data generated from the LiDAR sensors, according to the standardized noise values from real robots [4], using a built-in noise model from Gazebo. However, the noise model from Gazebo, it is not demonstrative enough for our use case, as it only adds noise only at the border of the sensor range, and not within the sensor range as initially anticipated. Having sensor noise within the sensor range would result in false positive and/or false negative observations, which are the primary triggers of conflicting observation. For example, a false positive would be a model of the task that does not exist in the "reality" of the simulator but can be observed by a robot, and vice versa for false positives. Resolving conflicting observations originating from faulty sensors and inaccurate observations was the core motivation for aggregating information and building knowledge with subjective logic. Therefore, with the current implementation, we cannot evaluate the strengths and the usefulness of our approach to its full extend. To address the issue, the current architecture of the approach needs to be extended accordingly. Consequently, adding false positives and false negative observations is the first goal of the thesis.

The second goal is conducting controlled experiments and evaluating the effectiveness of the proposed approach in different setups, with and without knowledge aggregation, and with and without adaptation, according to previously defined performance metrics.

Additionally, the information aggregation with subjective logic is based on the fusing of subjective opinions. Since representing beliefs and opinions has a long tradition in artificial intelligence and multi-agent systems, we want to investigate how other logics perform in comparison to the subjective logic. Finally, the third and final goal of the thesis is to investigate, understand, and compare how knowledge aggregation with subjective logic differs from reasoning with other logics. For instance, belief revision [5, 6], or other non-monotonic logics [7, 8, 9]. Which logic performs better? Under which circumstances and setups? Why? Are there any computational implications of the choice of logic? These are just a few of the questions in which we are interested in finding answers.



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## Working Plan

1. Get familiar with the theory of Subjective Logic.
2. Understand the current implementation of the framework, together with further theoretical details of how Subjective Logic was used in the previous thesis.
3. Implement false positive and false negative observations.
4. Conduct controlled experiments and evaluation.
5. Investigate and get familiar with other comparable logics.
6. Implement knowledge aggregation with at least one another logic.
7. Evaluate and compare the results.
8. Write the thesis report.

## Pre-requisite

- Good Python and C/C++ skills
- Ideally, previous knowledge and experience with ROS

## Deliverables

- Source code of the implementation.
- Technical report with comprehensive documentation of the implementation, i.e. design decision, architecture description, API description and usage instructions. Usually as part of the gitlab documentation.
- Final thesis report written in conformance with TUM guidelines.

## References

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