Evaluating Knowledge Aggregation with Subjective Logic in Multi-Agent Self-Adaptive Cyber-Physical Systems

Bachelor thesis

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Context

Modern society has become increasingly reliant on Cyber-Physical Systems (CPSs). Therefore, these systems need to act reliably while facing different uncertain and changing internal and external (contextual) conditions. As a response to these changes and uncertainties, self-adaptive CPSs (SACPSs) can adjust their behavior or structure at run-time. In architecture-based self-adaptation [1, 2, 3, 4], a self-adaptive system—including SACPS—is comprised of a *managed element* and an *adaptation logic*. The managed element is the system that gains adaptation capabilities, and it can be either a software system or a CPS. The adaptation logic is the element that provides adaptation capabilities. It is commonly implemented using the MAPE-K (monitor, analyze, plan and execute on shared knowledge) closed feedback loop [1, 5, 6]. The knowledge in the adaptation logic can either be specified by the engineers of the system during the design of the system, or it can be obtained during run-time or system operation by monitoring the environment and integrating the observations with the existing knowledge base, based on which the next system's actions are decided. The process of incorporating the new observations with the existing knowledge base becomes even more complex when the observations are made by multiple decentralized CPSs and are not only uncertain but also partial and potentially conflicting. As a result, to build the knowledge, the need for run-time observations aggregation and reasoning emerges [7, 8].

Prior work

In our previous work [7, 8], based on an extended work of two master theses [9, 10], we have presented a methodology for knowledge aggregation and reasoning in multi-agent SACPSs (MA-SACPSs) that deals with reasoning on uncertain, partial, and conflicting observations. Concretely, our approach uses Subjective Logic (SL) [11, 12] to update the knowledge in the adaptation logic at run-time by aggregating observations of the context made by each CPSs. We have shown and evaluated the effectiveness of the proposed approach through extensive controlled experiments on an in-house, simulated, ROS-based multi-robot system. The robotics system was developed based on a previously created model problem in which multiple robots explore and attain tasks that are continuously appearing in a room with unknown patterns and locations. In the prior conducted experiments, we ran simulations under different settings, controlling various aspects of the system: (i) the SL aggregation schemes for knowledge aggregation, (ii) the number and the properties of the robots (e.g., the false negative (FN) and false positive (FP) observations of the robots), (iii) the appearance of the tasks in the room (i.e., the context), (iv) the threshold with which the detected tasks are propagated as goals for the robots, etc. However, in all the experiments, we held constant the dimension and the layout (e.g., corridors, walls, etc.) of the room in which the robots operate.

Goal

The goal of this bachelor thesis is three-fold:

The first goal is a systematic analysis on the technical and conceptual similarities, as well as the differences between sensor fusion and knowledge aggregation and reasoning with subjective logic in self-adaptive CPSs.

Furthermore, the current implementation of the system uses the knowledge aggregation with the subjective logic to achieve the "best", most complete representation of the dynamic and uncertain context (i.e., the room in which the robots operate) at a specific time. Concretely, the aggregated knowledge is the most complete knowledge of the current state of the context (i.e., the room), and the planning phase of the MAPE-K loop—regarding which tasks are assigned and attained by each robot—is only done based on this knowledge. In previous work [13], we investigated how considering different run-time models improves the planning phase. The preliminary experiments that we conducted as part of that implementation and research, even showed an improved local path planning (how the robots traverse towards the assigned tasks), when multiple run-time models are considered. Therefore, as a second goal in this thesis, we are interested in re-running and analysing the same set of experiments as explained in the previous section, just this time using different run-time models for the planning phase, which are updated based on the aggregated knowledge with subjective logic.

And finally, as a third goal, we are interested in analysing the sensitivity of the formulas for the Binomial Subjective Opinion $w_x = (b_x, d_x, u_x, a_x)$ (see Definition 1 and Section IV.A in [8]), based on which we define the subjective options for the agents. We are interested in potentially investigating how changing different values for the belief b_x, disbelief d_x, the uncertainty mass u_x and the base rate a_x impact the overall aggregation process.

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Working Plan

1. Get familiar with:
   - the theory of subjective logic
   - our prior work on knowledge aggregation with subjective logic
   - the implementation of the ROS multi-agent robotics system
   - the existing evaluation and data analysis
2. Goal 1: Research on related work on different information and sensor fusion approaches
3. Goal 2 and 3: Design different experiments and experimental setups considering both of the goals
4. Goal 2 and 3: Conduct the controlled experiments and collect data
5. Goal 2 and 3: Analyse data and draw conclusions from the experiments
6. Write the final report.

Pre-requisite

- Good Python skills
- Good analytical and data analysis skills
- Ideally, previous knowledge and experience with ROS
- Ideally, previous experience with conducting evaluations of scientific contributions

Deliverables

- Source code of the implementation and the evaluation scripts.
- The collected data.
- 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 report written in conformance with TUM guidelines.

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