Multi-Source Knowledge Aggregation in Subjective Logic

Master's Thesis

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Context

Nowadays, the engineering of Cyber-Physical Systems (CPSs) must take into account their dynamic composition into a workflow delivering complex functionality, e.g. new and unanticipated services may become available and/or additional systems are integrated into the workflow [1]. Nevertheless, modern CPSs should be capable of adapting to the environment in which they are immersed and be able to cooperate and collaborate with other CPSs. Self-adaptive systems are widely considered as an effective approach to handle these challenges.

Through self-adaptation, systems are able to adjust their behaviour or structure at runtime as a response to their perceived environment and the system itself [2], while these changes are managed by a continuous feedback loop incorporating the newly derived knowledge [3]. In this context, two new challenges emerge (a) with the continuous and unanticipated change in the environment, the systems are subject to a variety of uncertainties and (b) the knowledge of the participating entities should be aggregated in order to adapt both the individual and global behaviour of the systems.

Researchers have proposed different techniques that handle the uncertainty of the events observed in a system. Bayesian Probability (BP) [4] allows for reasoning with propositions whose truth values are uncertain, and all sources of uncertainty are represented as statistical random variables. In Dempster-Shafer Theory (DST), a generalization of the Bayesian uncertainty framework, it is possible to model the uncertainty and ignorance on evidence supporting a claim, to produce a degree of belief on the existence of the claim [5].

More recently, Subjective Logic (SL) theory has gained prominence because of its capability to deal with the uncertainty of observed events and because it provides a variety of well-defined operations that allow combining opinions from multiple sources. SL can be seen as a framework for artificial reasoning [6, 7] where, unlike traditional binary logic (that only considers true or false values) or probabilistic logic (that considers degrees of truth or falseness), SL explicitly represents the amount of uncertainty on the degree of truth about a proposition in a model called 'subjective opinion' [7]. The idea of explicit representation of uncertainty is inherited from the DST [5, 7] and the interpretation of an opinion in Bayesian perspective is possible by mapping opinions into probability density functions [6].

In SL, observations of the same variable from multiple evidence sources may be combined by applying an SL operator. A source of evidence could be a trust relationship between two actors in a peer-to-peer system, information of an observed system's event or a sensor in a robot; depending on the specific application, an operator with different properties is required [8]. For example, let us consider the statistical evidence of a robot's location; we can use the Cumulative Belief Fusion operator to fuse the observed locations over time to produce an opinion with decreasing uncertainty about the regular locations of the robot. Hence, by applying these operators, we can obtain a shared belief and amount of uncertainty of a set of evidence sources.

Goal

The goal of this thesis is twofold. First, to investigate SL theory and apply the operators it provides to aggregate knowledge from multiple agents; a comprehensive explanation of the theory supporting such operators as well as the reasons why they are selected will be given.

Second, to propose a method to annotate the self-adaptive system's knowledge representation with SL opinions. The proposed method will be applied in a multi-robot use case where two robots are tasked with cleaning a set of locations of a known environment; each robot is aware of the presence of the other in the room, and they should collaboratively act in response to the random appearance of dirt to be clean. The robots must autonomously adapt their individual and collaborative behaviour in spite of the uncertainties introduced by the dynamic and unanticipated changes.

Working Plan

1. Investigate and familiarize with the theory of Subjective Logic.
2. Investigate and familiarize with the state of the art of knowledge representation in self-adaptive systems.
3. Describe the multi-robot use case.
4. Implement SL operators and apply them for multi-source knowledge aggregation in the proposed use case.
5. Propose a method to integrate SL opinions in the knowledge representation of self-adaptive systems.
6. Implement the proposed method in a simulated multi-robot scenario.
7. Write the thesis report.

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.
- Final thesis report written in conformance with TUM guidelines.

References

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