Comprehensible Decisions in Complex Self-Adaptive Systems

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Abstract: To cope with uncertain and statically unforeseen environment behaviour of complex systems, self-adaptivity has gained wide acceptance. While adaptation decisions are required to be close to optimal decisions, they at the same time should be efficient, comprehensible, and reusable. To achieve this, we have developed an engineering and analysis approach for self-learning self-adaptive systems based on our notion of timed adaptation rules. Through continuous evaluation and learning, inaccurate rules can be improved and new rules can be learned at run-time to cope with changing environments and system goals. A separate verification phase enables us to provide offline and online guarantees of evolving adaptation logics based on human-comprehensible formal models. Our approach, which incorporates the precise retracing of previous adaptation decisions, enables the understanding of the contexts in which certain adaptation decisions have been made, and assessing whether they have gained their expected effect in time within the system. This comprehensibility of complex decisions in self-adaptive systems enables the precise understanding and reuse of adaptation logics and provides trust in autonomous decision making.

Keywords: Self-Adaptivity; Adaptation Rules; Self-Learning; Comprehensible Adaptation Decisions

Self-adaptivity realised through *MAPE-K* feedback loops [IB04] is a prominent approach to cope with changing environment behaviour and system goals in complex dynamically evolving systems. Such self-adaptive systems separate a managed system from an adaptation layer that continuously *M*onitors the managed system and the environment behaviour, *A*nalyses the need for adaptations, *P*lans suitable adaptation strategies, and *E*xecutes the adaptation plan within the managed system. These MAPE components share a common *K*nowledge base, which they continuously update. While this reference architecture provides abstract means to self-adaptivity, it neither provides concrete knowledge models nor makes adaptation logics itself subject to dynamic evolution.

In [KGG15], we present our approach for self-learning self-adaptive systems, which imposes a structured knowledge base consisting of system and environment parameters (K_{Sys}, K_{Env}), a hierarchical goal model (K_{Goal}), and an adaptation logic (K_{Adapt}) based on timed adaptation rules of the following form: $r : g$ **&** $c_1; c_2; \ldots; c_n \longrightarrow$ *effect* **after** *time*. A rule r is applicable if its guard g is satisfied. If it is chosen by the planner, its commands $c_1, \ldots, c_n$ are applied to the managed system. After a certain amount of *time*, an *effect* is assumed to be observable. We provide a further (meta-)adaptation layer that consists of an *evaluation* of previously applied adaptation rules, *learning* of improved and new

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adaptations rules, and *verification* of the current adaptation logic. For analysis, planning, and learning, we employ distance functions, which we automatically extract from a goal model K_{Goal} [Kl17]. They capture the “distance” from a system context to the system goals.

In the literature, especially analysis and planning for self-adaptive systems have been realised using diverse methods. While techniques such as online planning enable the calculation of optimal plans for a current system context, the underlying decision-making is hard to comprehend. This dramatically limits reusability of adaptation logics. In contrast, timed adaptation rules make adaptation decisions explicit and comprehensible due to their explicit application condition and timed expected effect. At run-time, we employ history information of system and environment parameters together with history information of applied adaptation rules to retrace past adaptation decisions and record whether their expected effect was achieved and in which system contexts. We use this information to evaluate the accuracy of adaptation rules and to dynamically improve the adaptation logic through learning-based mechanisms. As a result, we achieve an updated adaptation logic that consists of more accurate, yet comprehensible, timed adaptation rules. For our verification approach, we extract formal timed automata models from a (possibly partial) system implementation in SystemC [KGG16]. At run-time, we update them using actual environment and system parameters as well as current adaptation rules. This enables us to apply model checking to verify general properties, such as stability of the (updated) adaptation logic. As our formal models are human-comprehensible due to structure-preserving transformations, we not only employ them for offline and online verification, but also for analysing and understanding system and adaptation behaviour throughout the entire system lifecycle.

In summary, our approach for self-learning self-adaptive systems integrates a) comprehensible timed adaptation rules, b) precise retracing of previous adaptation decisions and accuracy evaluation w.r.t. their effects, c) learning-based optimisation of adaptation logics, and d) their analysis based on human-comprehensible models. As a result, we achieve comprehensibility and reusability of complex, dynamically evolving adaptation logics and, thus, provide a basis for trust in autonomous decision-making.

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