A Foundation for Engineering Decentralized Self-Adaptive Software Systems

Danny Weyns
Linnaeus University Sweden, Katholieke Universiteit Leuven
Contact: danny.weyns@lnu.se

Website: http://homepage.lnu.se/staff/daweaa/projects/FEDERATES.htm

Our society extensively relies on the qualities of software systems. Examples are the availability of software for media and the robustness of software for manufacturing. Due to the increasing complexity and dynamicity of software systems, assuring the required software qualities constitutes a huge challenge. Self-adaptation is widely recognized as an effective approach to deal with this challenge. Self-adaptation enables a software system to adapt itself to changes in the environment or user requirements in order to achieve particular quality goals. Despite substantial achievements in the field, major scientific and technical gaps must be addressed to enable adaptations that cannot be realized by one centralized entity. The overall goal of the FEDerAteS project was to study and develop a systematic formally founded approach for engineering decentralized self-adaptive systems. The project has achieved this goal in four parts.

I. Foundations of self-adaption. In the first part, we performed several systematic studies of the literature to identify: (i) the claims that researchers make about self-adaptation and the evidence that is provided for these claims [1,2], (ii) the state of the art in the use of formal methods in self-adaptive systems [3], (iii) the use of variability as a principle mechanism for realizing self-adaptation [4], and finally (iv) the state of the art on handling uncertainty in self-adaptive systems [5]. From these studies, we performed a controlled experiment that provides evidence that external feedback loops improve the design of self-adaptive systems [6], and we developed a principle model that integrates adaptation with evolution as a basis for sustainability [7].

II. Engineering principles of self-adaptation in decentralized systems. In the second part, we studied various patterns for decentralized control in self-adaptive systems [8]. We studied the use of self-adaptation principles in the design of multi-agent and service-based systems [9]. We consolidated an architecture framework for collective intelligent systems that include humans in the loop based on several project with industry partners [10]. Finally, we outlined a research roadmap on middleware support for engineering decentralized adaptive systems [11].

III. Assurances using formal techniques. In part three, we consolidated a formally specified unifying reference model for self-adaptive systems (FORMS) that provides a common vocabulary for the domain [12]. We applied formal approaches in case studies in the domain of intelligent traffic monitoring and mobile learning [13, 14] and consolidated the knowledge derived from these studies in a set of formally specified design templates for self-adaptive systems [15]. These studies also contributed to the notion of “perpetual assurances” that describes an enduring process where man and machine interact to provide guarantees for self-adaptive systems operating under uncertainty [16]. ActivFORMS is a concrete instantiation of perpetual assurances [17, 18].

IV. Applications. We validated the research results in various application domains, including a robotic system [17], a mobile application for digital storytelling [19], a remote e-health system for elderly [20], and a collaborative mobile learning application [21]. The remote e-health system has been accepted as an exemplar for research on self-adaptive systems [22].

The project had generated substantial socio-economic impact via follow-up projects. In particular, Push The Line (funding Vinnova Sweden) and BoConnect (funding Kamprad Foundation Sweden) focused on the challenges of the growing population of elderly people. While it is generally acknowledged that innovation in ICT will play a key role in tackling the challenges in this area, the adoption of technologies has not taken off yet, mainly because a lack of reliability of the solutions. In these projects we took a holistic perspective and put

reliability of assistive technologies central: from a user, technological, and organizational perspective. The project contributed with a set of reliable assistive services supporting elderly people at home, incl. tele-monitoring and remote rehabilitation. The project results provided invaluable input to both public partners (Kalmar and Växjö municipalities in South Sweden) and companies (e.g. Sigma IT -technology provider- and Wexnet -network provider).

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