Characterization and construction of emerging behaviors in Systems of Systems

1. Scientific and technological objectives

The context of systems of systems

The increasing complexity of our socio-economical environment has resulted in a growing need for technical systems supporting human activities. For example, we interact throughout the day with many systems (such as transport, telecommunications, energy distribution or health) which are now absolutely essential for our society functioning. Other systems work on a casual basis (normally "invisible") while having however a role equally important (crisis management, homeland security, defense, etc.). These systems rely on many devices, which can be fixed or mobile, more or less interconnected and intelligent such as phones or all kinds of sensors.

In the context of the pervasiveness of these systems and their increasing interconnection, there is a necessity for making them cooperate in order to provide the user with new or required services, highly consistent with the activities of individuals and of companies. We want to mobilize this "services capital" in an opportunistic and unanticipated manner. This may be in response to an unexpected event involving the safety of persons or goods, or to meet requests for actions or information. It may also simply reflect an unexpected but pressing and imperative evolution of an existing task to adapt it to a new context or for new uses. From this mandatory need for real and unanticipated cooperation between existing systems (not only data exchange) comes the major interest in the concept of system of systems.

A system of systems (SoS) is an integration of some systems independent and interoperable, which can be interconnected for a period of time in order to ensure a certain purpose. In practice, systems of systems are complex software-intensive systems. The systems pre-exist to the need to be covered. More importantly, they were designed independently from the purpose sought. They also continue to be operated, maintained and managed by the different organizations from which they come, and may evolve independently. But they must, for a given period of time and in an unanticipated way, share information and interoperate for the purpose sought can emerge.

There exists, in the literature, a number of criteria to determine if a system falls within the SoS paradigm. Following Maier (98), usually five criteria are retained: 1) operational independence of system, 2) managerial independence of these systems, 3) geographical distribution, 4) the existence of emergent behaviors, and finally 5) evolutionary development process. Some implicit criteria can be added to this definition, such as openness and dynamicity, especially with the fact that a system hitherto unknown, may enter into a cooperation, or another can get out (for any reason whatsoever: be stopped, crashed, no longer be reachable, etc.) which results in a loss that can be in a smooth (gradual) or sharp manner, loosing features and / or non-functional properties (e.g. performance).

In addition to these criteria that help to determine if a system is a SoS, it is common to distinguish four main classes of SoS according to their increasing level of decentralized control mode: *directed* (an authoritative subsystem defines, launches and controls the SoS), *acknowledged* (a dominant subsystem achieves by consensus and negotiation adhesion for the necessary collaboration), *collaborative* (the subsystems of equal importance agree to a common higher purpose) and finally *virtual* (the interaction of the subsystems brings out intentionally or not useful or harmful services). But the boundary between these classes is considered by many to be blurred in the literature. Worse, a SoS can during its life and / or for certain parts of it, oscillate between these characteristics and management methods.

The project objectives

If issues related to systems of systems are known since a long time, the field of research is, however, still relatively unexplored. In particular, a common generic conceptual framework needs to be developed. For example, the European T-AREA-SOS project has finalized a strategic agenda of research topics to be covered. Among the identified themes of this agenda, there are: characterization and description of the SoS, establishment of theoretical foundations, emergence, multilevel modeling, measurement and definition of metrics, evaluation of SoS, definition and evolution of SoS architectures, prototyping SoS, study of compromises in SoS engineering, SoS safety, human aspect, and finally the study of SoS "Energy-efficient".

The proposed research addresses many of these issues, specifically to enable the characterization of SoS, that is to say their ability to produce an expected functionality with given quality of service conditions. To contribute to general issues regarding SoS, our goal is to provide a platform to describe, characterize and simulate systems of systems. Its purpose is to provide assistance to future developers. Without being limited to the class of SoS addressed, we aim at studying first the two first classes (directed and acknowledged SoS) and then the final two.

If the role of a systems architect is to build correctly the system to be realized, that of systems of systems architect should be to choose the right systems in an open environment and thus to discover them, organize and regulate their collaboration with suitable "contracts". In this context, it is essential to ensure that the future SoS will be able to exhibit the expected properties (features) with the expected levels of quality (quality of service, and more generally non-functional properties). This is part of a greater complexity than in "classical" system engineering because some properties are the result of unintentional emergence: appearance of a new property, non reducible by addition of those of its components, properties resulting from complex interactions between the subsystems. The provided tools will have to detect and treat emerging behaviors with detrimental effect and enhance at the contrary favorable emergent behaviors. The concepts and tools offered in this platform will also include the need for openness and dynamicity of configurations.

Approach and work method

The concepts and tools proposed in this study will base their cooperation mechanisms on the notion of role. Role appears to us a fundamental concept for defining and manipulating SoS. It substitutes the concept of cooperating system to that of cooperating logical role, the role may be materialized dynamically by a system having potentially the role. A role (e.g. the ability to provide a service) is a concept, which may be parameterized by various contextual factors (status, geographic location, or the mode of operation). We will use the conceptual, linguistic, methodological and technological tools from the model driven engineering approach in order to build a description language for SoS together with associated tools: SysML, meta-tools and meta-languages, concepts of architectural patterns. The patterns in particular will be first-class entities facilitating reuse, but also the characterization of organization modes. The project will also build from models of communication and cooperation described firstly in Multi-Agent Systems and in Service-Oriented Systems.

The development of the platform will be in two phases:

- First, the definition of an initial expression framework based on SysML (System Modeling Language) and a formal language such as a process algebra supporting dynamicity, respectively for defining systems and communications;
- Then following a progressive enrichment approach, this initial framework will be completed with structured patterns of possible interactions between systems according to levels of increasing complexity.

Specifically, we identify several levels of interaction:

- Level 1: based on the sharing of information between subsystems, enabling the potential acquisition by any system, if necessary, of a common vision. The exchange can be based on the paradigm of query (pull) or the selective dissemination publish/subscribe (push);
- Level 2: addition of interactions based on the orchestration of roles through an orchestrator related to a particular expected feature. Roles can be provided by dynamically determined components. Interactions between orchestrator and roles obey to the principle of request / response service;
- Level 3: addition of choreographies that can be achieved by the cooperation of two or N systems embodying specific roles. There is not anymore the necessity of a centralized orchestrator associated to a feature, and the interactions between roles can be as complex as necessary.

Levels 2 and 3 correspond to a large extent (but not one to one, however) to the requirements of both directed and acknowledged SoS management classes. Level 3 also offers perspectives, but to a lesser extent, for the control of the two other classes of SoS (collaborative and virtual SoS).

For each level, the different communications and possible cooperation will be implemented in the library of the platform. Patterns of generic systems will be identified, together with construction tools for characterization and analysis of 1) behaviors related to features to ensure, and 2) non-functional aspects and qualities expected (including performance, availability, etc.). Thereby, different levels and types of cooperation will be modeled, defined in the platform, simulated and characterized. One of the final goals of the project is, through the capitalization patterns, to succeed characterizing emergent behaviors through the gradual enrichment of communication and interaction modes between systems.

The study of several real cases studies is a priority to complete this project. It will guide the design of the proposed platform, highlighting recurring generic issues while providing the material to apply and demonstrate the proposed concepts. We have identified three representative and diverse application contexts, which are respectively:

1. The multi-modal logistics. It concerns the cooperation of systems within a multimodal logistics platform. Systems relate to different actors involved at a given time (information systems providers, clients, mobile phones, drivers...). Various benefits are expected from a SoS, including precise synchronization between different chain actors, fluidity of flows (grants freight) or help the urban vehicle penetration.

2. A sensors network of various types. It concerns the dynamical creation of a web application implementing a given mission in a world of given sensors. The subsystems concern various fixed and mobile sensors with various technological backgrounds, autonomous and managing information. An application domain is home automation.

3. A federation of intelligent urban systems. It concerns the design of a system modeling a city with robots and subsystems at several locations exchanging information. These systems facilitate the work of robots, providing them with various information as possible works or the color of traffic lights at an intersection or the opening hours or the quantity available of a product in a store.

2. Presentation of the consortium

The project will involve three research groups.

1. ArchWare team, IRISA, University of South-Britanny

IRISA (Institute for research in computer science and random systems) is a mixed research unit (UMR 6074) in computer science, applied mathematics and signal and image processing. The UMR is organized around 7 departments. The ArchWare research team integrated the department D4 (Language and Software Engineering) in 2012 (http://www.irisa.fr/recherche/equipes.html). The main project of the team is focused on scientific and technical challenges raised by the design of "systems of systems" (SoS).

Isabelle Borne (Professor) and Régis Fleurquin (Assistant Professor HDR) led research work on the modeling and meta modeling of component architectures as well as on the descriptions of software architectures by means of languages of description of architecture (ADL) and languages for pattern-oriented software architectures. The project will be coordinated by the ArchWare research team.

2. **CEDRIC Laboratory of CNAM (Conservatoire National des Arts et Métiers)**

Nicole Levy (Professor) and Yann Pollet (CNAM Professor) of CEDRIC Laboratory at CNAM work in particular on non-functional properties of software architectures, development methods of product families and semantic algebra composition of services. Yann Pollet is an expert for the European Community in the field of SOS.

3. **LISV (laboratory of Engineering Systems of Versailles (LISV) / university of Versailles Saint -Quentin-en-Yvelines**

Interactive robotics team of LISV laboratory conducts both theoretical and experimental work that characterizes the applied and multidisciplinary approach of robotics. Amar Ramdane Cherif (Professor) works on the functional and non-functional aspects of the various components of robotic interactive systems in order to make new contributions at the level of the integration and the adaptation to the context. Eric Monacelli (Assistant Professor HDR) works in particular on requirement analysis and evaluation protocols of the multidisciplinary systems.

Our proposal includes several partners with complementary skills on modeling, functional and non - functional systems, semantic knowledge representation, ontology and process algebra. We have already worked on the context of the unifying software architectures. These technical skills are required for the project to build a description language for SoS and its associated tools. Indeed we need to: use SysML for modeling, apply meta-languages and meta-tools to extend this language, design specific SoS architecture patterns, use the formal modeling together with a process algebra language supporting dynamicity. We will also need for the case study the skills of LISV laboratory in the engineering of complex multidisciplinary systems, especially in analysis, modeling, design of such systems which are special cases of SoS.

Recent publications of the participants:

- M.T. Ton That, S.Sadou, F.Oquendo, I.Borne (2013) Composition-centered architectural pattern description language, European Conference on Software Architecture ECSA 2013, Montpellier, France.
- T.Gherbi, I.Borne, D.Meslati (2013) Towards an MDE Methodology to Develop Multi-Agents Systems including Mobile Agents, Proceedings of the 8th International Conference on Evaluation of Novel Software Approaches to Software Engineering, Angers, France, 4-5 july, 2013.
- K.Hassam, S .Sadou, V.Le Goahec, R.Fleurquin (2011)Assistance System for OCL Constraints Adaptation during Metamodel Evolution, *15th European Conference on Software Maintenance and Reengineering (CSMR), 2011*, Mar 2011, Oldenburg, Germany. Proceedings of the 15th European Conference on Software Maintenance and Reengineering (CSMR'2011), pp. 151 – 160
- S. Allier, S. Sadou, H. Sahraoui, R. Fleurquin. "From Object-Oriented Applications to Component-Oriented Applications via Component-Oriented Architecture". 9th Working IEEE/IFIP Conference on Software Architecture (WICSA'2011), Boulder, Colorado, USA, June, 2011, IEEE publisher
- Salma Hamza, Salah Sadou and Régis Fleurquin (2013) Measuring Qualities for OSGi Component-Based Applications". 13th International Conference on Quality Software (QSIC'2013), Nanjing, China, July 29—30, 2013, IEEE publisher.
- Nicole Levy, Francisca Losavio, Yann Pollet (2013) Architecture et qualité de systèmes logiciels, Chapitre du livre à paraître "Architectures logicielles", Ed. M. Oussalah, chapitre 7, Hermès.
- Francisca Losavio, Oscar Ordaz, Nicole Levy, Anthony Baïotto (2013) Graph Modelling of a Refactoring Process for Product Line Architecture Design. In proceedings of the Latin American Computing Conference (CLEI 2013)
- Yann Pollet (2010) An Algebra of Ontology Properties for Service discovery and composition in Semantic Web, In Book *Ontology Theory, Management and Design: Advanced Tools and Models*, F. Gargouri and W. Jaziri (Eds.), Chapter 4, Information Science Reference Publisher, pp 98-118. Plublished by IGI Global. ISBN: 978-1-61520-859-3. March 2010. (http://business-technologysolution.com/reference/details.asp?ID=36259)
- Jérôme Dantan, Yann Pollet, Salima Taibi (2013) The G.O.A.L. Approach. A Goal-Oriented Algebraic Language. Proceedings of the 8th International Conference on Evaluation of Novel Approaches to Software Engineering. 6 July 2013, Angers, France
- S. Dourlens, A. Ramdane-Cherif and E. Monacelli (2013) Tangible Ambient Intelligence with Semantic Agents in Daily Activities, 2012, in Journal of Ambient Intelligence and Smart Environments (JAISE), Vol 5, n°4, pp 351-368.
- S. Dourlens, A. Ramdane-Cherif and E. Monacelli(2013) Multi Levels Semantic Architecture for Multimodal Interaction, in Applied Intelligence journal (APIN) by Springer, vol.38, n°4, June 2013, pp.586-585

References

- Maier (98) Architecting principles for systems-of-systems, Systems Engineering, vol 1, n°4, pp. 267-284, 1998.

European projects references:

- [T-areaSoS] https://www.tareasos.eu/
- [COMPASS] http://www.compass-research.eu/
- [ROAD2SOS] http://www.road2sos-project.eu/cms/front_content.php