A Systematic Mapping on the Relations between Systems-of-Systems and Software Ecosystems

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Abstract. *Currently, software development organizations have created and maintained their products and services with different technologies to one or more software platforms. This scenario involves different actors of one or more organizations, thus requiring attention for connectivity and dependence on technical, social and business issues. In this perspective, it has been recently suggested that topics of research as Systems-of-Systems and Software Ecosystems represent an effective way to construct large and complex software systems on top of one or more platforms, which are composed by different software products and involve different individuals, groups and organizations. However, these two topics have been separately investigated. Thus, in this paper we conduct a systematic mapping study aiming to identify the relations between these topics and support cooperative and collaborative research. The results showed that there is a relationship between Systems-of-Systems and Software Ecosystems as regards to some technical, social and business aspects.*

1. Introduction

Software stands out as an important element that can provide competitive advantages to organizations. However, currently, software development has become more challenging, as regards to: (i) the development of software-intensive and large-scale system to be used in complex domains in order to meet emergent needs of society and; (ii) the creation of software products, services and processes in collaboration with external partners of the organization. It is remarkable that the global software development crosses the organizational boundaries introducing new challenges to traditional Software Engineering (SE) processes. The concern is not a single product development but rather the development of multiple products (Campbell & Ahmed, 2010), in which different facets and the perspectives of value of its players (e.g., companies, clients, end-users, developers, service providers, supplier, manufacturer and others) should be considered. Thus, such challenges and aspects have been explored in SE due to the need for treatment of technical, economic and social issues.

Regarding the challenges in the development of complex software systems, as pointed out by Maier (1998), in the last years there had been growing interest of researches in a class of software-intensive system development, called Systems-of-Systems (SoS). These systems are heterogeneous, independent, supported by multiple platforms (technologies) and have a decentralized control. Besides, as discussed in Siemieniuch & Sinclair (2014), the collaboration and interoperability among actors, artifacts, companies and communities of these systems are extremely important. In another perspective, these aspects have been discussed in the context of Software Ecosystem (SECO), an effective way to construct large software systems on top of a software platform by composing components developed by actors internal and external to the organization developing the platform (Messerschmitt & Szyperski, 2003; Manikas & Hansen, 2013). In this context, specific treatments for technical, social and business issues are considered (Campbell & Ahmed, 2010). However, SoS and SECO are two research topics that have been still separately investigated, although they can be treated in a complementary way. This paper investigates the relationships between these two research topics by conducting a systematic mapping study complementing the research performed by Santos *et al.* (2014a). The main findings presented in the systematic mapping study reinforce and increase the scope of the discussions presented by Santos *et al* (2014a).

The remainder of this text is organized as follows. In Section 2, we present the research method, describing research questions, inclusion/exclusion criteria, sources of studies, search strategy and data extraction. Section 3 shows the results of this systematic mapping study and their analysis. Finally, in Section 4, the conclusions are presented.

2. Research Method

A systematic literature review and mapping study do not share all research procedures, however similar processes for searching are explicitly defined in the research protocol and reported as part of the outcomes (Kitchenham *et al.*, 2009). In this paper, before starting the search, a protocol was developed to define the main guidelines for conducting the study. This mapping study followed the process defined by Kitchenham and Charters (2007). Summing up, this process presents three main phases: (i) planning; (ii) execution; and (iii) reporting. As part of the review planning, we defined a protocol to detail the search strategy that includes the search string, selection criteria, and data extraction procedures. In the planning, aiming to find relevant studies that addressed SoS and SECO in the same paper, the following research questions (RQs) were established: *(RQ1) What are the main similar characteristics and differences between SoS and SECO?; (RQ2) What are the main areas studied from the perspective of SoS and SECO?; (RQ3) How can SoS benefit from business and social networks? and; (RQ4) What are the main challenges and limitations for SoS from the perspective of SECO?*

Aiming to include only studies contributing for this mapping study, two kinds of selection criteria were defined: inclusion and exclusion criteria. The inclusion criteria adopted were: (1) only studies written in English; (2) studies dealing and referencing any of the subjects related to SECO and SoS in their title, abstract or keywords, which contribute for answering one or more RQs; (3) technical reports, master and doctorate theses. The exclusion criteria were: (1) repeated studies found in different search engines (in this case, just one study was considered); (2) duplicate studies reporting similar results (in this case, only the most complete study was considered); (3) description of proceedings; and (4) inaccessible studies. Regarding the procedures about the search, in this study both electronic and manual search procedures were used. The justification for not uniquely using electronic search procedures is supported by Kitchenham's *et al*. (2009) recommendations that emphasize the use of a manual search to obtain a broader list of potential studies to review. Moreover, another reason was due to the fact that SECO and SoS represent recent research subjects; thus, a manual search brings extra confidence that more relevant studies might be found. The electronic search was conducted using the Scopus search engine. The reason for selecting this digital library is because it is an important repository for research in Computer Science area. The manual search was focused on 3 repositories, the International Workshop on Software Ecosystems (IWSECO), ACM Workshop on Software Engineering for Systems-of-Systems and the Workshop on Distributed Software Development, Software Ecosystems and Systems-of-Systems. In addition, the manual search was performed on Google Scholar.

Table 1. The search string used to execute the systematic mapping

TITLE-ABS-KEY ((("software ecosystem*" OR "software supply network" OR "software vendor*" OR "software supply industry" OR "industry platform*" OR "ecosystems") AND ("system-of-systems" OR "system of systems" OR "systems-of-systems" OR systems of systems)) AND ("features" OR "feature" OR "characteristic" OR "characteristics" OR "difference" OR "differences" OR "similarity" OR "similarities" OR "relationship" OR "implication" OR "consequence" OR "significance" OR "benefits" OR "impacts" OR "business" OR "business networks" OR "social" OR "social networks" OR "area" OR "subject area" OR "subject field" OR "field"))

An approach was used to derive terms from the research questions to create the search string, therefore the strategy was: (1) derive the main search terms; (2) check the keywords from relevant studies already known; and (3) find synonyms and relevant keywords. After that, Boolean operators OR and AND were used to incorporate them into the search string. The first segment consisted of synonyms of SECO and SoS; the second was derived from the main RQ terms. Table 1 shows the final search string. Regarding the conduction phase, relevant studies was identified through stages as the following. First the string search was applied in the search engine previously mentioned. The automatic search found 71 papers, and the application of selection criteria was limited to studies' title, abstract, and keywords. This information was read and only 15 papers were available for download. Finally, after reading them, the list was reduced to 8 papers. Regarding the manual search, the selection process was similar to the automatic search. This search found 7 papers, and from these the list was reduced to 3. Thus, in total, 11 papers were considered relevant for this systematic mapping study.

To support the extraction of data from the papers, the Zotero Standalone tool was used (https://www.zotero.org/). Some spreadsheets were created to support the process of papers selection in the stage of inclusion and exclusion criteria application. Thus, for each one of them a form was created to record details on how it answered the four research questions, by extracting pieces of relevant text. The Appendix shows the complete list of selected studies enumerated from S1 to S11. For each studies an identifier (ID) was defined, being used to reference the mapping along the text.

3. Results and Considerations

In this section, we report and discuss the answers for each RQ. Due to space limitation, only some of the main findings and their discussions are presented:

Answers to RQ1 (similar characteristics and differences)

Table 2 presents the main similar characteristics between SoS and SECO identified in the studies. A remarkable result is that many studies (S1, S2, S 4, S5, S10 and S11) have linked the similarities between SoS and SECO to the existence of multiple products (e.g., software systems) over one or more technological platforms. Besides that, some studies (S2, S3, S4, S5, S7, S8 and S9) have linked this relation to the interaction between the different actors that can exist in a SoS and SECO, and some business aspects (S3, S4, S9 and S10).

Table 2. Similar characteristics between SoS and SECO

Characteristics	Study ID
Existence of multiple products (software systems) over one or more technological platforms, in which they can operate in different environments to provide a final service	1, 2, 4, 5, 10, 11
Existence of platforms, software and artifacts developed by internal and external actors, who can have different perspectives of value	10, 11
Existence of decentralized/distributed systems	7
Many key social aspects, such as: the importance given to interaction and collaboration and communication among the different internal or external actors of the SECOs and SoS	2, 3, 4, 5, 7, 8, 9, 10, 11
Some key aspects of business, such as: the importance given to prioritization of business goals and requirements, in order to support the design and knowledge on software architecture; innovation from the involvement of players (organizations and individuals), thus, enabling the creation of an ecosystem that is more sensitive to the market trends; competitive environment, where players demand increase of connected systems and services connected, efficiency, productivity and quality, and also reduced costs, time-to-market, and delivery.	3, 4, 9, 10
Architectural stability of the platforms of a SECO can be compared to the operational independence of the SoS	1, 2

Regarding the differences, none addresses an explicit difference between SoS and SECO. Although, some studies pointed out complementary aspects and comparison between the two topics. In studies S2 and S10, the authors emphasize that SECO can be seen as an application domain for SoS. S4 mentioned that SECO provides a complementary organizational view for development of SoS. In S9 the authors pointed out that SoS is a type of SECO. For S8, the term SoS is now becoming more common as cyber ecosystems or more conveniently community ecosystems refer to systems of collaborating communities.

Answers to RQ2 (main areas)

Table 3. The main areas studied in SoS and SECOs

Areas	Study ID
Interaction and relationship among the players of a community	1, 2, 3, 4,5, 8, 10
Technical aspects linked to design of architecture software systems and/or platforms, such as: connectivity and modularity between systems and components; heterogeneity of hardware and software; geographically distributed software systems; the use of techniques to support the analysis of software architecture and; and the architecture documentation	3, 4,5,7,9,10, 11
Evolution, assessment and sustainability of the platforms and their respective software products	1, 8, 10, 11
Opening of the architecture of platforms and software products	2, 4, 6
Goals, processes and business models	1, 2, 3, 4, 9, 10
Reuse of software and components	3, 6, 11
Quality attributes (mainly: connectivity, interoperability, security, testability, stability, flexibility, robustness e integrity)	1, 2, 3, 4, 5, 9, 11
License of software and components	2, 3, 6
Innovation of products and services	5, 7

The main areas studied in SoS and SECO are presented in Table 3. A notable result is that, even if succinctly, technical, social and business aspects are discussed in the same paper. Nevertheless, the studies focus more on technical aspects linked to design of software systems and/or platforms architecture (S3, S4, S5, S7, S9, S10 and S11), communication and collaboration among the players (S1, S2, S3, S4, S5, S8 and S10), quality attributes both required in SoS as SECOs (S1, S2, S3, S4, S5, S9 and S11), and on goals, processes and business models (S1, S2, S3, S4, S9 and S10). Other studies address issues linked to evolution, assessment and sustainability of platforms, opening of platforms and software products, reuse of software and components, license of software and components and innovation of products and services.

Answers to RQ3 (benefiting from business and social networks)

Following the main benefits that business and social networks can provide to the development of SoS are presented.

Most studies (S1, S4, S5, S6, S7, S8 and S11) point out that business and social networks can enable the creation of a community between internal actors and from third parties that cooperate and share technical knowledge, in order to provide technical solutions collaboratively to support the design and sustainability of the architecture of SoS constituent systems. Other benefits found in some studies point out that providing a potential to structure collaborative business models and processes in order to consider the different perspectives of value of players (S1, S2, S3, S4 and S8), as well as opportunities to minimize and amortize costs and technical and business risks (S4, S9, S8 and S1).

In this perspective, some studies also point out that business and social networks increase possibilities to innovate products and services these systems (S1, S2, S4, S5 and S10), help analyze demands, strategies of marketing and production (S2, S4 and 8), and enable a better understanding of its constituent systems architecture (e.g., its product line) to support reuse of software and components (S6 and S11).The social and business networks can provide many benefits to the SoS development. These are similar to those addressed by Santos *et al*. (2014b) in the SECO context, as for example: (i) the visibility and mapping of connections between people, or between people and organizations - it is possible to access the knowledge of members in a network, and sometimes their contacts; (ii) the bigger power of propagation on products and services; and (iii) new market niches and the trading of new products. Thus, the benefits found in these studies are associated to the three dimensions (i.e., technical, social and business) considered in SECO.

Answers to RQ4 (main challenges and limitations)

Through the studies (S1, S2, S4, S5, S7, S9 and S10) it was observed that the establishment of efficient organizational strategies and business models with partners is one the main challenge and limitation for SoS from the perspective that involves a partner community (SECO). It was also observed that business aspects in SoS still seem to be a great challenge.

In addition, several technical concerns were observed, such as: assessment, evolution and stability of the software architectures of the SoS and platform interfaces (S1, S2, S3, S7, S9 and S11); compliance with quality attributes (S2, S3, S4, S9 and S11), which are required in the context SoS (Santos *et al*., 2015); lack of tools and adequate technical infrastructure to support technical decision-making, perform verification and validation activities and, the evolution of the platforms architecture and/or its software systems (S1, S4 and S5); lack of tools and adequate technical infrastructure to support the interaction and communication of a collaborative community (S8); opening of SoS platforms and/or of its constituent systems (S1, S2, S4 and S6), in which one of the concerns should be security, as discussed by Barbosa *et al*. (2013) in the SECO context, by opening its architecture, a software application might suffer attacks that operate from inside or outside the organization; difficulty in reuse (S3, S6 and S11), because as pointed out by Botterweck (2013) an approach for variability management and systematic reuse in SoS is required and in this sense the Product Line Engineering (PLE) is relevant and helpful, however generally there is little discussion in the PLE literature regarding SoS. In another perspective, Werner (2009) emphasizes that well-known software reuse approaches such as Component-Based Development and Software Product Line can lead companies to SECO. In this direction, we believe that if software components are reused more widely in the SoS context, some of the reuse benefits can be achieved, such as: increased reliability, reduced costs and potentially increased agility in evolving to meet the emergent behavior of these systems. But, in this case challenge is to realize the benefits of this approach when individual components are heterogeneously licensed (S1 and S6), in which each potentially with a different license, rather than with a single license (Scacchi & Alspaugh, 2012) as in SoS. Another challenge pointed out was the heterogeneity of ecosystems, platforms and its constituent systems (S1), in which we can consider as the responsible for all challenges and limitations described above.

4. Conclusion

As previously discussed, it is observed that the solutions for SECO and SoS are still individually proposed by isolated teams in order to meet particular domain-oriented problems. But, as identified in this mapping study there are similar characteristics and complementary aspects between SoS and SECO, showing that there are opportunities for cooperative and collaborative research between these two topics.

The findings presented in this systematic mapping study reinforce and increase the scope of the discussions presented by Santos *et al.* (2014a), since it was possible to more clearly identify the relationships between these two topics. As can be seen, our results showed that the relationships between them are associated to specific issues of the three dimensions of a SECO. In addition, we identified the main areas studied within this context, the possible benefits that a SoS can achieve from business and social networks, and the main challenges and limitations. This systematic mapping study pointed out that most areas studied in this context are linked to technical aspects. As such, according to Klein & McGregor (2013), the concept of architecture has been amplified to the so-called SoS or industry platform, in order to help the comprehension of architecture in SECO. This kind of platform provides support to a set of systems that need to interact to form a SoS (Maier, 1998). These are complex, interdisciplinary systems whose functionalities and purposes can dynamically evolve, encompassing several new challenges to be developed.

In this sense, the concepts of virtual and collaborative SoS (DoD, 2008) have been discussed in the SECO context, allowing collaboration of different constituent systems and organizations to produce emergent functionalities. In both collaborative and virtual SoS, SECO is more valuable because in these categories there is no strict control over the constituent systems. In a perspective of social and business issues, a SECO provides a complementary organizational view to SoS development, which introduces roles and rules of interaction, collaboration and synergistic capabilities for its constituent systems. From this discussion it is possible to confirm the existence of many similarities between SoS characteristics (Maier, 1998) and SECO technical challenges (Bosch, 2010), which were raised in the research performed by Santos *et al*. (2014a). The operational independence of constituent systems of a SoS can be compared to architectural stability required for SECO platforms as regards to their components, services, and applications. In this case, the strategies of software systems integration and component-based development can be combined to support application programming interface issues. The platform evolution directly depends on the SECO community's emerging requirements and contributions, as well as the adjustments of underlying hybrid business models. It requires explicit modelling of roles in different organizations and the rules that govern their internal and external interactions with respect to each organization, for instance, when an organization collaborates with independent third-party. Thus, SoS evolutionary development should also take into account the business and social issues, and not only the environment's technical issues. In this sense, SoS architecture models should be extended to deal with context variables based on value chains and social networks. In turn, emergent behavior produced by constituent systems of a SoS working together can be linked to the security and reliability in SECO.

Regarding the treats to validity of this study, the main can be associated to: (i) an eventual omission of studies and bias in the extraction data; (ii) the loss of relevant studies due to the lack of agreed terminology for SoS and SECO; (iii) the possible existence of relevant studies that do not mention the keywords that were chosen and; (iv) the number of electronic used databases, since only the Scopus search engine was used in this systematic mapping study. Regarding to bias in the data extraction, some difficulties were faced to extract useful information from the studies found, since many did not explicitly answer the research questions. As future studies, we aim to extend this study by conducting searches on other search engines and, if necessary, perform adjustments in the search string to find more relevant studies, probably addressing other issues that have been discussed by literature, but were not found in this systematic mapping study (e.g., health of SoS-Ecosystem). Moreover, we intend to investigate how SECO platforms can benefit from SoS mindset, which was not in the aim of this study.

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Appendix: The selected studies

ID	Reference
S1	Da Silva Amorim, S. *et al*. (2014) “When Ecosystems Collide: Making Systems of Systems Work.” In: Proceedings of the 2014 European Conference on Software Architecture Workshops. ACM, p. 29.
S2	Axelsson, J. *et al*. (2014) “Characteristics of software ecosystems for Federated Embedded Systems: A case study”. Information and Software Technology, v. 56.11, pp.1457-1475.
S3	Lutz, M. *et al*. (2014) "Service Robot Control Architectures for Flexible and Robust Real-World Task Execution: Best Practices and Patterns." In: Workshop Roboter-Kontrollarchitekturen.
S4	Papatheocharous, E. *et al.* (2013) “Issues and challenges in ecosystems for federated embedded systems.” In: Proc. of the First International Workshop on Software Engineering for Systems-of-Systems (SESoS). ACM, pp. 21-24.
S5	Delicato, F. C. *et al*. (2013) “Towards an IoT ecosystem” In: Proc. of the First International SESoS. ACM, pp. 25-28.
S6	Mattmann, C. *et al*. (2012) “Developing an open source strategy for NASA earth science data systems.” In: IEEE 13th International Conference on Information Reuse and Integration, pp. 687-693.
S7	Chen, H. M., Kazman, R. (2012) “Architecting ultra-large-scale green information systems." In: Green and Sustainable Software (GREENS), 2012 First International Workshop on. IEEE, pp. 69-75.
S8	Hawryszkiewycz, I. T. (2011) “Open Modeling For Designing Community Ecosystems." In: https://opus.lib.uts.edu.au/research/handle/10453/19216. Last accessed on: Jun, 2015.
S9	Kazman, R. *et al.* (2012) “Scaling up software architecture analysis". Journal of Systems and Software, 85.7, pp. 1511-1519.
S10	Santos, R. *et al*. (2014) "On the Relations between Systems-of-Systems and Software Ecosystems." In: WDES 2014, pp. 58-62.
S11	Lytra, I. *et al*. (2015) "Reusable Architectural Decision Models for Quality-driven Decision Support: A Case Study from a Smart Cities Software Ecosystem. In: 3th International SESoS.