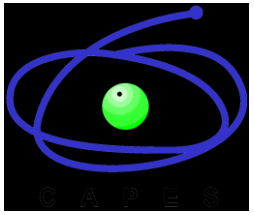

Approaches for Integration in System of Systems: A Systematic Review

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Summary

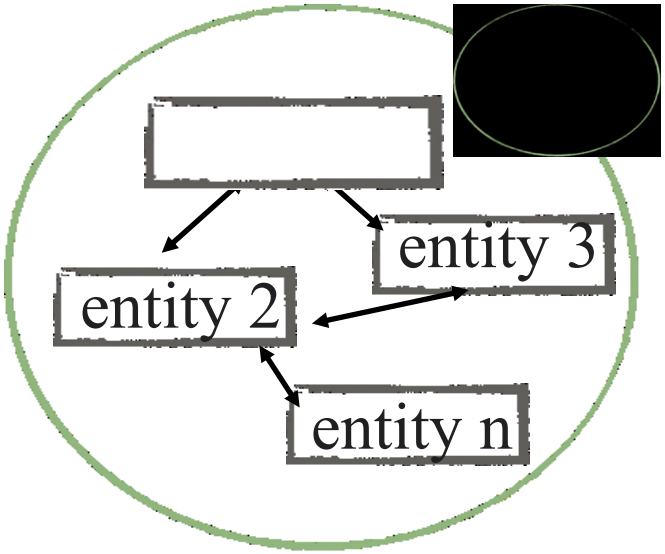
- 1. Introduction
- 2. Planning
- 3. Execution
- 4. Data Mapping
- 5. Results
- 6. Conclusions

1. Introduction

- System of Systems – SoS;

SoS is a collection of independent entities and their assembled relationships to form a whole, greater than the sum of the parts (Boardman e Sauser, 2006).

- System of Sytems Integration – SoSI;
  - Series of new challenges



1. Introduction/Motivation

- SoS:
  - Under the control of different organizations
  - Different geographic locations
  - Emergent behavior
- Difficulties: integration and adaptation to various emergent behaviors;
- Interoperability: sharing information semantically compatible and then process or manage this information.
- Goal of this Systematic Review(SR): to gather primary studies that propose techniques/approaches/tools for systems integration on the SoS context.

2. Planning

- Research questions:
  - **RQ1. How has the integration between CS's of a SoS been investigated?**
    - Evidence forms of integration in the SoS context , identifying for example: problems, approaches, techniques, solutions and advantages for integrating CS's of a SoS.
  - **RQ2. In this type of study, which kind of tool has been used to aid in the integration of the constituent systems?**
    - Characterize when possible, tools that aid in the integration of the CS'S of a SoS.

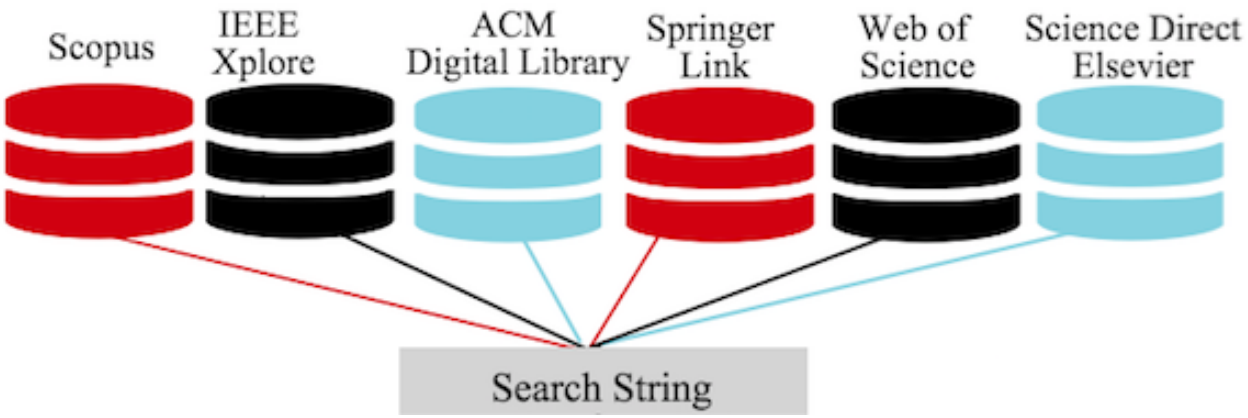
2. Planning (cont.)

- We used the following data extraction form
  - F1- What is the purpose of the study regarding the integration of SoS?
    - F1.1- What SoS integration contribution was addressed?
  - F2- What is the application domain that has been targeted on the integration of SoS?
    - F2.1- What kind of SoS was used?
      - F2.1.1- Which features of the SoS were detailed?
    - F2.2- Which problems related to the integration of SoS were addressed?
    - F2.3- What are the advantages of using the concepts of SoS to integrate systems?
  - F3- Does the study mention any integration tool?

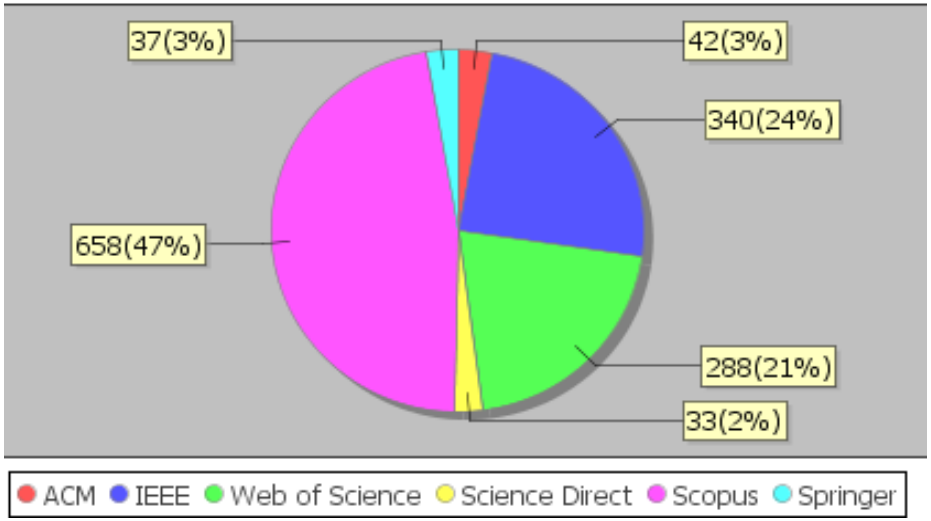
2. Planning (cont.)

- *Search string*:

(({system of system} OR {systems of systems} OR {System-of-systems} OR {systems-of-systems}) AND (integration OR collaboration OR composition OR interoperability))



3. Execution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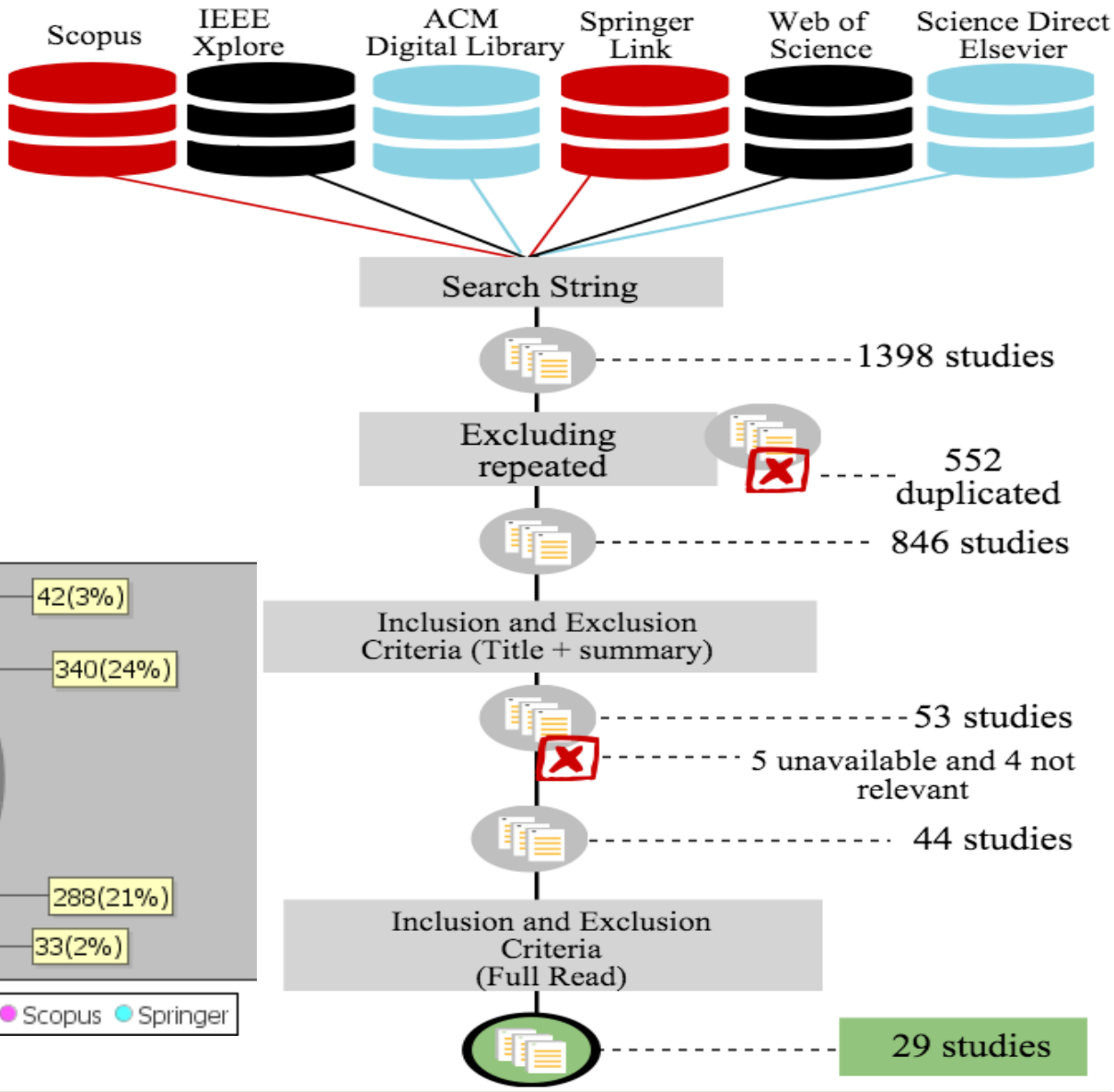
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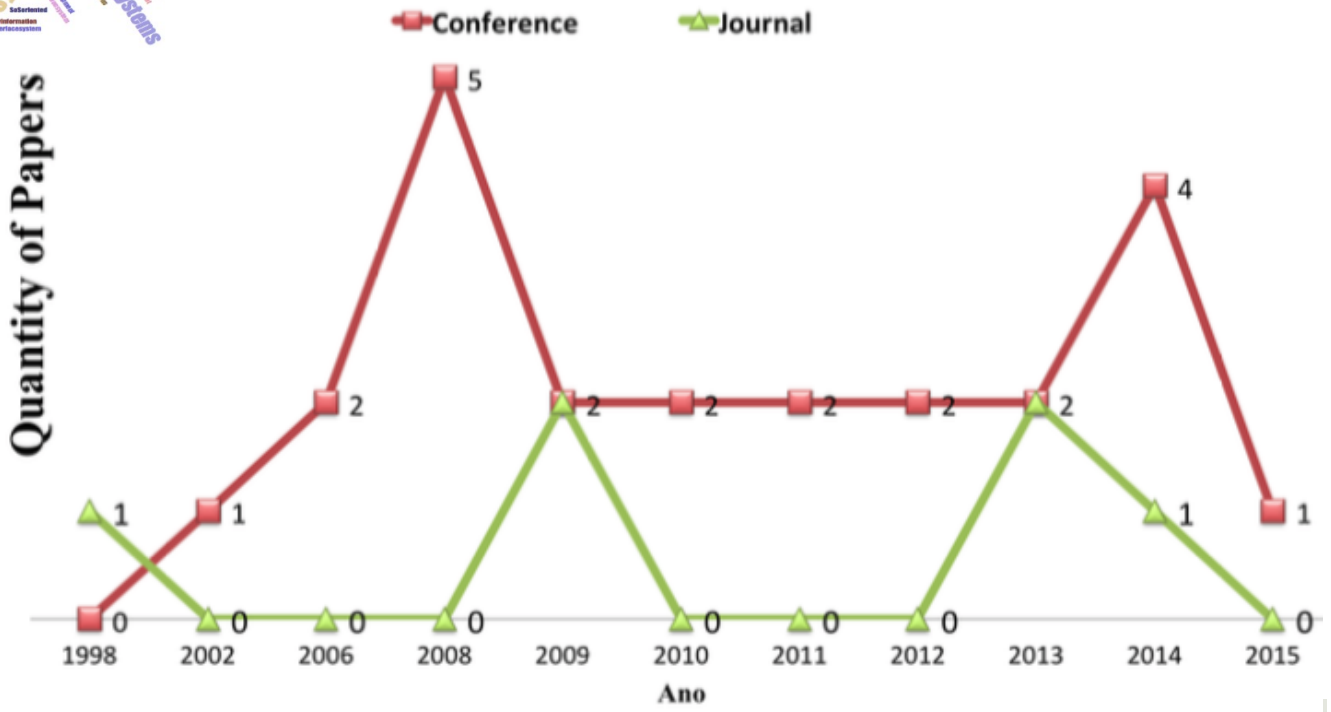
1398 studies
Excluding repeated
552 duplicated
846 studies
Inclusion and Exclusion Criteria (Title + summary)
53 studies
5 unavailable and 4 not relevant
44 studies
Inclusion and Exclusion Criteria (Full Read)
29 studies

4. Data Mapping

CQ	Answers	ID Papers	Total
F1	**Yes**	**S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S24, S25, S26, S27, S28, S29**	**29**
	Partly		0
	No		0
F1.1	**Yes**	**S2, S3, S4, S6, S7, S8, S10, S12, S14, S15, S16, S20, S21, S23, S24, S26**	**16**
	Partly	S11, S13, S22, S25, S27, S28, S29	7
	No	S1, S5, S9, S17, S18, S19	6
F2	**Yes**	**S1, S2, S3, S4, S5, S7, S9, S12, S14, S20, S24**	**11**
	Partly		0
	No	S6, S8, S10, S11, S13, S15, S16, S17, S18, S19, S21, S22, S23, S25, S26, S27, S28, S29	18
F2.1	**Yes**	**S24**	**1**
	Partly		0
	No	S1, S2, S3, S4, S5, S6, S7, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S18, S19, S20, S21, S22, S23, S25, S26, S27, S28, S29	28
F2.1.1	**Yes**	**S5, S6, S19, S24**	**4**
	Partly	S7, S18,	2
	No	S1, S2, S3, S4, S8, S9, S10, S11, S12, S13, S14, S15, S16, S17, S20, S21, S22, S23, S25, S26, S27, S28, S29	23
F2.2	**Yes**	**S4, S9, S12, S14, S17, S20, S24**	**7**
	Partly	S1, S2, S3, S10, S13, S15, S21	7
	No	S5, S6, S7, S8, S11, S16, S18, S19, S22, S23, S25, S26, S27, S28, S29	15
F2.3	**Yes**	**S1, S24**	**2**
	Partly	S9, S16	2
	No	S2, S3, S4, S5, S6, S7, S8, S10, S11, S12, S13, S14, S15, S17, S18, S19, S20, S21, S22, S23, S25, S26, S27, S28, S29	25
F3	**Yes**	**S3, S4, S8, S10, S12, S15, S21**	**7**
	Partly		0
	No	S1, S2, S5, S6, S7, S9, S11, S13, S14, S16, S17, S18, S19, S20, S22, S23, S24,, S25, S26, S27, S28, S29	22

4. Data Mapping (cont.)



5. Results – SR SoSI

- Answer to F1 - What is the purpose of the study regarding the integration of SoS?

	Study proposal				
	Modeling	**Frame-work**	**Ontology**	**Approach**	**Architec-tural pattern**
Total	13	3	1	10	2
ID Paper	S1, S2, S6, S7, S8, S11, S12, S14, S15, S18, S21, S22, S29	S20, S23, S26	S24	S4, S5, S9, S10, S13, S17, S19, S25, S27, S28	S3, S16

5. Results – SR SoSI (cont.)

- Answer to F1.1 - What SoS integration contribution was addressed?
  - S4 (Naqvi et al., 2010): show the importance of learning about the CS's and external influences that each one of them can present. To achieve a successful integration, it is necessary to have knowledge about the features that the CS offers.
  - S16 (Kazman et al., 2013): proposed an architectural pattern to support the software architects in the integration process.
    - Greenfield (there are no restrictions for deployment);
    - Brownfield (changes/adjustments can be made to the CS's to achieve the goal of integration);
    - Closed Source (there is no access to the CS's);

5. Results – SR SoSI (cont.)

- S24 (Madni e Sievers, 2004): presented important concepts for the integration of SoS, such as interoperability, systems integration, type and characteristics of SoS, SOA, SoSI and reuse of CS's.

  - Integration should be part of the overall SoS development lifecycle;
  - Legay Systems: increases the complexity of integration, documentation about them can be not readily available;
  - The form and rigor of Sosi is directly related to the type of SoS;
    - The unmanaged (Virtual) is inherently more difficult to integrate than a managed SoS (Directed).

5. Results – SR SoSI (cont.)

- Answer to F2 - What is the application domain that has been targeted in the SoS integration context?

Application Domain	Number of Studies	ID Paper
No Specific Application Domain	16	S6, S8, S10, S11, S13, S15, S16, S17, S18, S19, S21, S22, S23, S26, S27, S29
Defence and National Security	4	S3, S4, S14, S20, S28
Military	1	S2
Industrial Automation	1	S5
Aerospace	1	S9
Quality Management	1	S1, S25
Earth Observation System	1	S24
Simulation	1	S7
Auto Adaptation	1	S12
Total	29	

5. Results – SR SoSI (cont.)

- Answer to F2.1 - What kind of SoS was used?
- Of the 29 papers selected for data extraction, only one defined the type of SoS to be used for system integration.
  - According to Madni e Sievers (2014), Directed or Acknowledge SoS are pre-specified, which makes them predictable and consistent with traditional validation and verification methods.
  - Virtual or Collaborative SoS are not pre-specified, which makes them more challenging to integrate.

5. Results – SR SoSI (cont.)

- Answer to F2.1.1 -Which features of the SoS were detailed?
- Operational and managerial independence, evolutionary development, emergent behavior and geographic distribution;
  - Analyzing the 29 papers:
    - only four of them signaled such evaluation, which corresponds to only 13.79% of the studies;
    - Specifically, the papers **S5, S6, S19, S24** demonstrated greater caution in relation to the characteristics to propose any integration solution.
    - There are some other characteristics that have not been mentioned by others, such as: adaptive development, connectivity, autonomy, diversity, reconfiguration, and principles of modularity.

5. Results – SR SoSI (cont.)

- Answer to F2.2 - Which problems related to the integration of SoS were addressed?

- It was observed that 58.33% of the papers cited some problem/difficulty of integration, seven papers responded completely, which corresponds to 24.13% (S4, S9, S14, S17, S20, S24);

  - Managerial;
  - Single Modeling;
  - Complexity of interations;
  - Conplexity of CS's;
  - Collaboration;
  - Incompatibility of interfaces;
  - Evolution;
  - Frequence updates;
  - Documentation;
  - Scripts;

5. Results – SR SoSI (cont.)

- Answer to F2.3 - What are the advantages of using the concepts of SoS to integrate systems?
  - It was observed that 16.66% of the papers cited one advantage when using SoS to integrate and two articles responded completely, which corresponds to 6.89\% of articles.

ID	Advantage
1	Broader involvement of all stakeholders.
2	Reduced use of multiple resources.
3	Development of coherent systems.
4	Unified harmonized standard to solve problems.
5	Improving the cost benefit.
6	It increases flexibility and possibility to include other systems.
7	Improved operational performance together.
8	Increased motivation of staff.
9	Cost reduction and reengineering more efficient.
10	Maintaining the original characteristics of the constituent system.
11	Operational and managerial independence.
12	better scalability.
13	better interoperability.
14	Serviceability.

5. Results – SR SoSI (cont.)

- Answer to F3 - Does the study mention any integration tool?
- It was observed that 29.16\% of the papers cited a tool to integrate CS's of SoS.
  - FireScrum;
  - Mind mapping tool;
  - RDL – Requirements Description Language;
  - Tool chain;
  - SENSE;
  - UPPAAL;
  - DEVS;
  - M-Model;

6. Conclusions

- **Answer to RQ1:**
  - There are several fields of research regarding SoS that are still incomplete and require more researches;
    - For example: SoSI;
  - SoSI has high demand and many challenges;
  - There have been significant contributions that provided relevant information to the SoSI state of the art;

  - The integration between CS's of a SoS has been investigated through the use of SOA (Service-Oriented Architecture);
    - Promising architectural style for SoSI;
    - Approximately 51.72% of the works have explored the use of SOA;

6. Conclusions (cont.)

- **Answer to RQ2:**
  - no system integration tools found in the surrounding context of SoS;
  - Detailed tools before, support any phase of development of SoS;
  - Are not necessarily tools to support integration;
  - Thus, it can be seen that there is a lack of tools to assist in the integration of systems in the context of SoS.

6. Conclusions (cont.)

- Research in System of System Integration (SoSI);
- Individuals and teams working in isolation;
  - It is necessaray to develop more general procedures, techniques and tools;
- Finally, we noted in this review that there are domains, such as reuse environments, that are poorly explored in the research community of SoS → ongoing work

Thank you for your attention!!!

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