



ICSE 2021

Joint 9th International Workshop on Software Engineering for
Systems-of-Systems and

15th Workshop on Distributed Software Development, Software
Ecosystems and Systems-of-Systems

Virtual (originally in Madrid, Spain)

June 3rd, 2021

Experience and Challenges on Modeling and Simulation of Systems-of-Systems Software Architectures

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Federal University of Goiás, Brazil



Outline

- Brief Presentation
- Context and Definitions
- State-of-the-Art and Practice
- Experience on M&S for SoS Software Architectures
- Cases
- Challenges

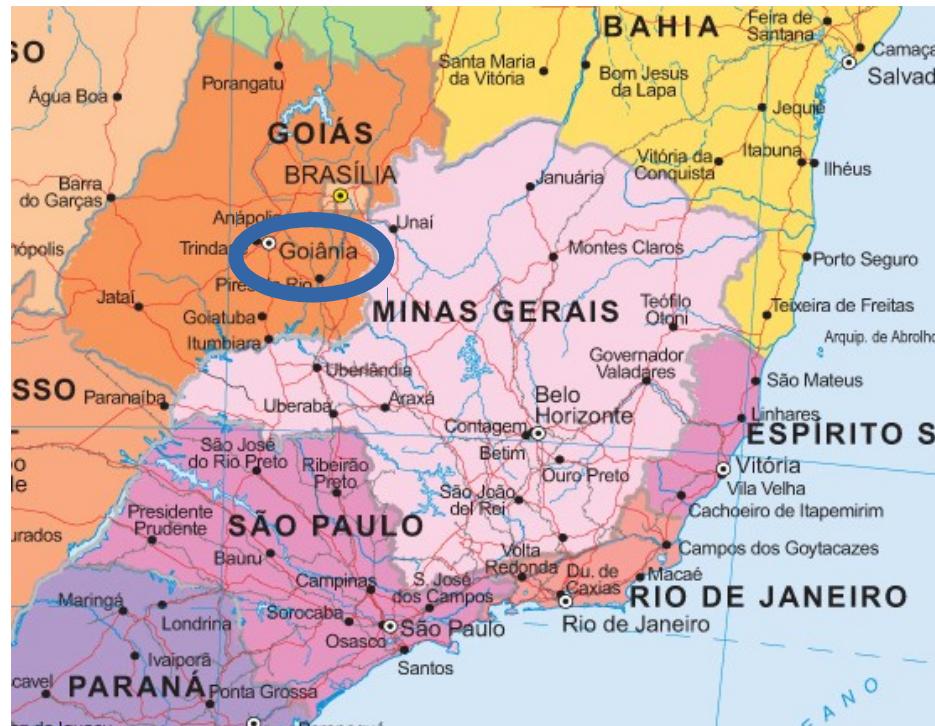
Brief Presentation



Brief Presentation



Brief Presentation



Brief Presentation

<https://ww2.inf.ufg.br/~insight/>



Context and Definitions

- Concepts involved:
 - Systems-of-Systems (SoS)
 - Software Architecture
 - Systems-of-Systems Software Architectures (SoS-SA)
 - Modeling and Simulation (M&S)

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Context and Definitions

- **Systems-of-Systems (SoS)**
 - *“An alliance formed by independent software-intensive systems, called constituents, that interoperate to achieve common goals.”*

Image credits:

Creator:elenabs

Credits:Getty

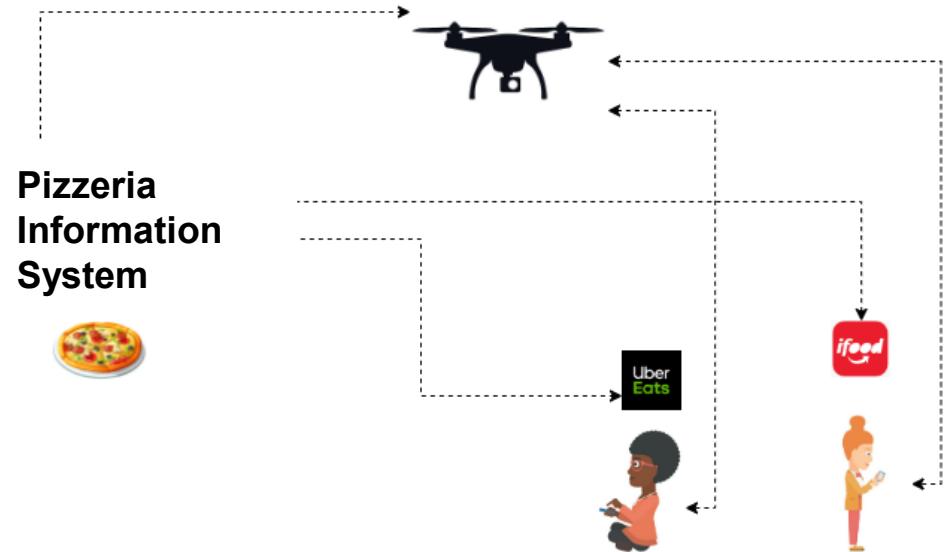
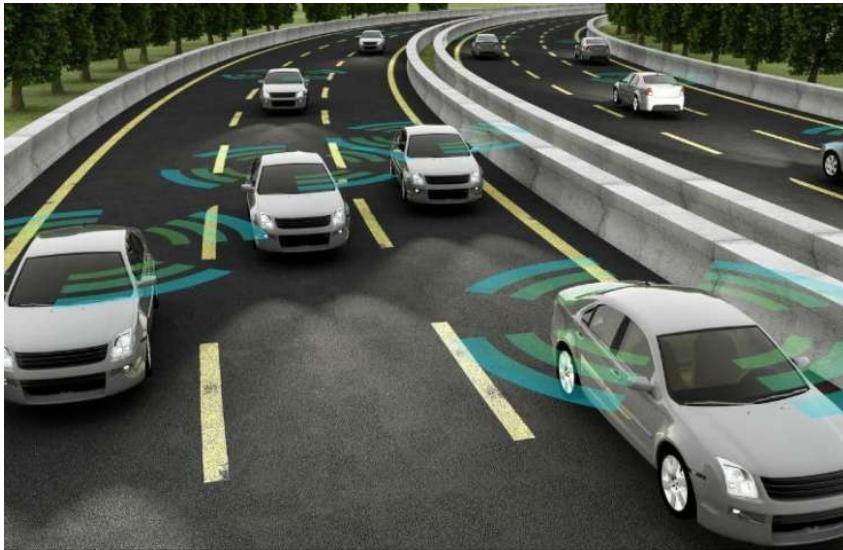
Images/iStockphoto

Copyright:elenabs



Context and Definitions

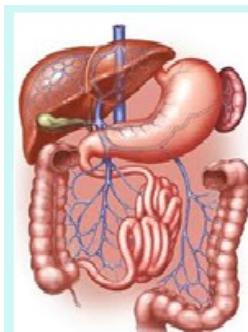
- Systems have received **software** to become **smarter**
- Systems have been interconnected



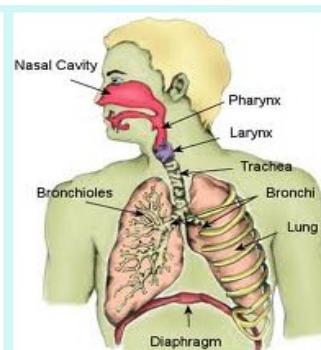
Context and Definitions

Systems-of-Systems

- It's not such a weird idea



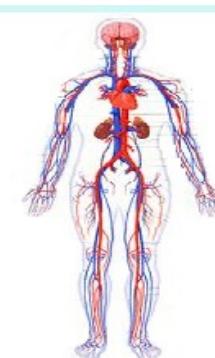
Digestive System



Respiratory System



Nervous System



Circulatory System

By the way, those systems even do interoperate!

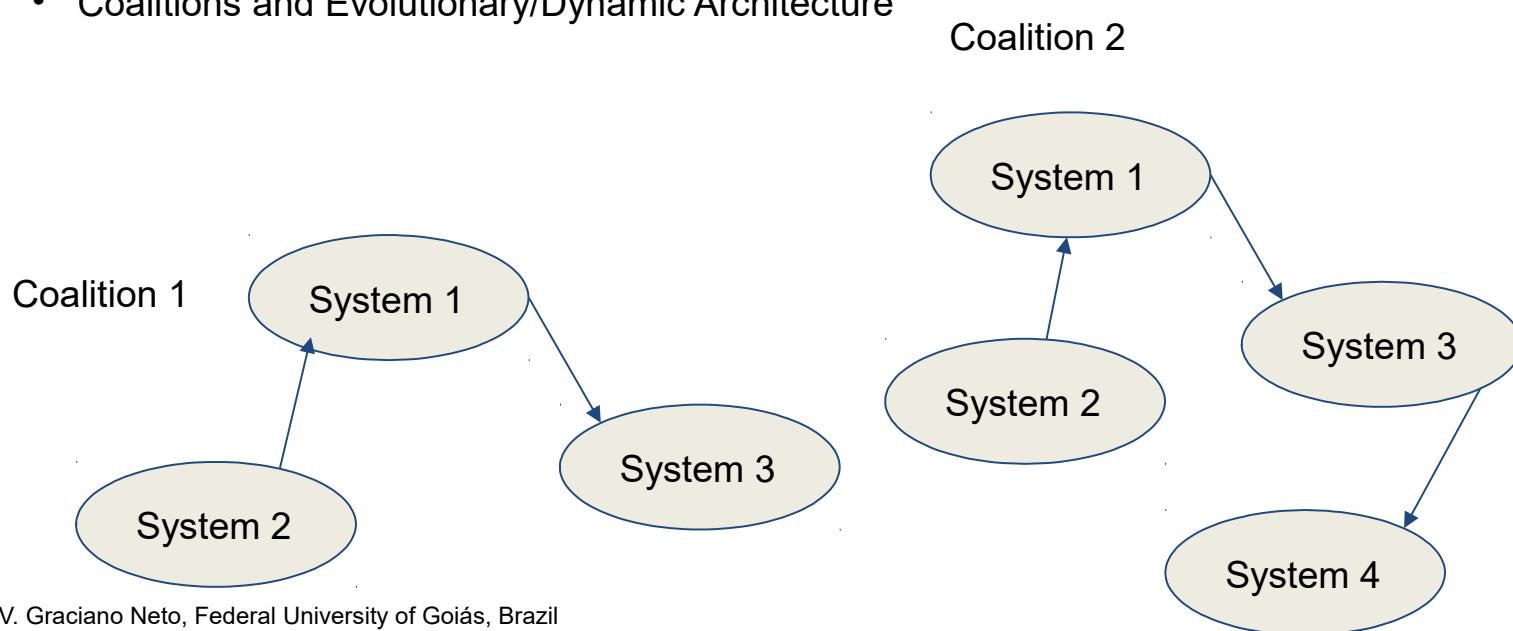
Context and Definitions

- As a result of systems interoperability, **Systems-of-Systems** have emerged
 - Operational and Managerial Independence of Constituent Systems
 - Emergent Behaviors
 - Dynamic/Evolutionary
 - Architectures
 - Distribution



Context and Definitions

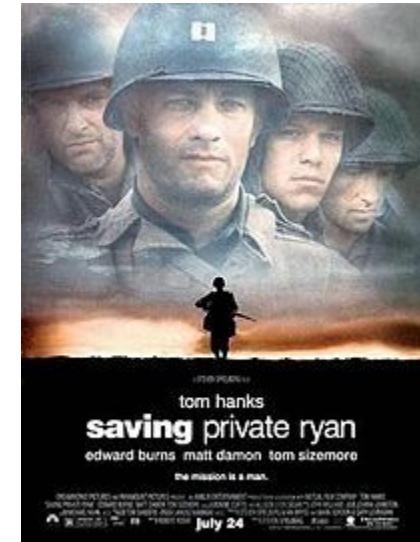
- **Systems-of-Systems**
 - Important Concepts
 - Coalitions and Evolutionary/Dynamic Architecture



Context and Definitions

- **Systems-of-Systems**

- Important Concepts
 - Goals/missions
 - Mission => Goal
 - An activity that can be partitioned into smaller operational tasks assigned to constituents with matching capabilities.



Valdemar V. Graciano Neto, Flávio Horita, Everton Cavalcante, Adair Rohling, Jamal El-Hachem, Daniel Santos, and Elisa Y. Nakagawa. 2018. **A Study on Goals Specification for Systems-of-Information Systems: Design Principles and a Conceptual Model.** In Proceedings of the XIV Brazilian Symposium on Information Systems (SBSI'18).

Context and Definitions

- Concepts involved:
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Context and Definitions

- **Software architecture**
 - Backbone of any well-succeeded software product
 - Structure (main parts and how connected) + Behavior + Environment;
 - Achieve quality attributes orilities: reliability, availability, security, performance...
 - Architectural representation/description: views, UML, SysML.

Nakagawa, E. Y., Gonçalves, M., Guessi, M., Oliveira, L. B., & Oquendo, F. (2013, July). *The state of the art and future perspectives in systems of systems software architectures*. In Proceedings of the First International Workshop on Software Engineering for Systems-of-Systems (pp. 13-20).

Context and Definitions

- Concepts involved:
 - Systems-of-Systems (SoS)
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 - **Systems-of-Systems Software Architectures (SoS-SA)**
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Context and Definitions

- Software Architecture: Structure + Behavior + Environment

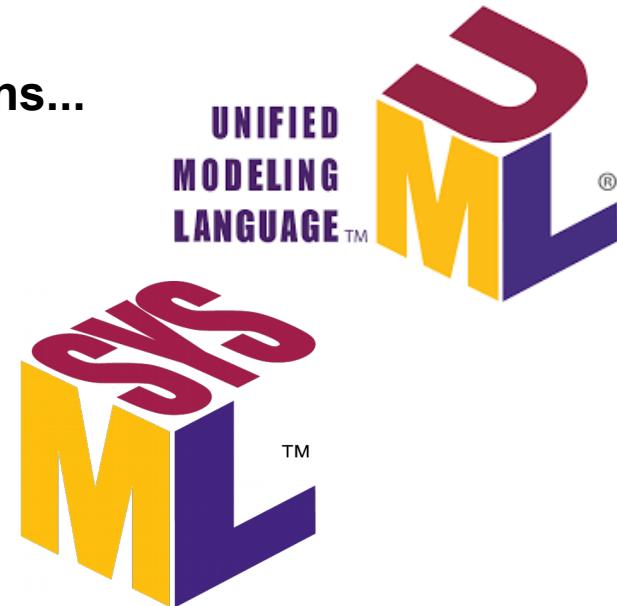
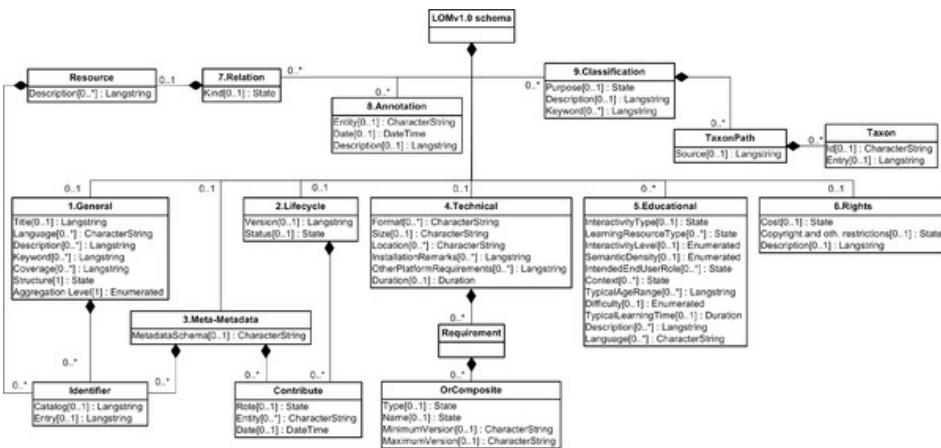


- A SoS software architecture is:

SoS Software Architecture (SoS-SA):
**Structure (Constituents' software elements
+ interoperability links) + Behaviors +
Environment**

Context and Definitions

- SoS has a **dynamic architecture**
- But Software Engineering uses **static notations...**



Guessi, M., V. V. Graciano Neto, T. Bianchi, K. R. Felizardo, F. Oquendo, and E. Y. Nakagawa. (2015), April. *“A systematic literature review on the description of software architectures for systems of systems”*. In 30th SAC, pp. 1433–1440. Salamanca, Spain, ACM.

Context and Definitions

- Limitations of UML and SySML
 - Represent single systems (not multiple systems)
 - Static notations
 - Architectural evolutions outdate the documentation

Context and Definitions

- However, SoS-SA require...
 - Executable notations and models
 - Precision
 - Formalism to deal with complexity (several constituents and links)
 - Formal basis for V&V
 - Reliability in representation
 - Representation of structure and behavior
 - Representation of the surrounding environment
 - Prediction at design-time

Context and Definitions



**WE NEED EXECUTABLE
MODELS TO REPRESENT
DYNAMIC/EVOLUTIONARY
ARCHITECTURES!**

BUT WHICH ONES?

Context and Definitions

- Some options:
 - [models@runtime](#) (GEMOC, xUML, ...)
 - Digital Twins
 - Simulation models

Context and Definitions



OK!

**LET'S USE SIMULATION
MODELS!**

Context and Definitions

- But why Simulation models for SoS-SA, particularly DEVS?
 - Formal definition
 - Java-based tools
 - Match with SoS-SA representation requirements
 - Executable
 - Visual
 - It enables to represent multiple systems and
 - Data exchange
 - ...



Context and Definitions



**BUT WHAT EXACTLY IS A
SIMULATION?**

Context and Definitions

- Concepts involved:
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Context and Definitions

- Simulation:

“A simulation is the imitation of the operation of a real-world process or system over time.”

“Simulation is performing goal directed experiments with models of dynamic systems.”

Tuncer Ören, Bernard P. Zeigler, Andreas Tolk (Eds.). SCS - MSBoK Guide: The Body of Knowledge of Modeling and Simulation Guide. The Society For Modeling and Simulation International. 2021. <Ongoing Work>

State-of-the-Art and Practice

- More than Simulation...

Modeling & Simulation... Modeling for Simulation

“The act of simulating something first requires a model to be developed...”

State-of-the-Art and Practice

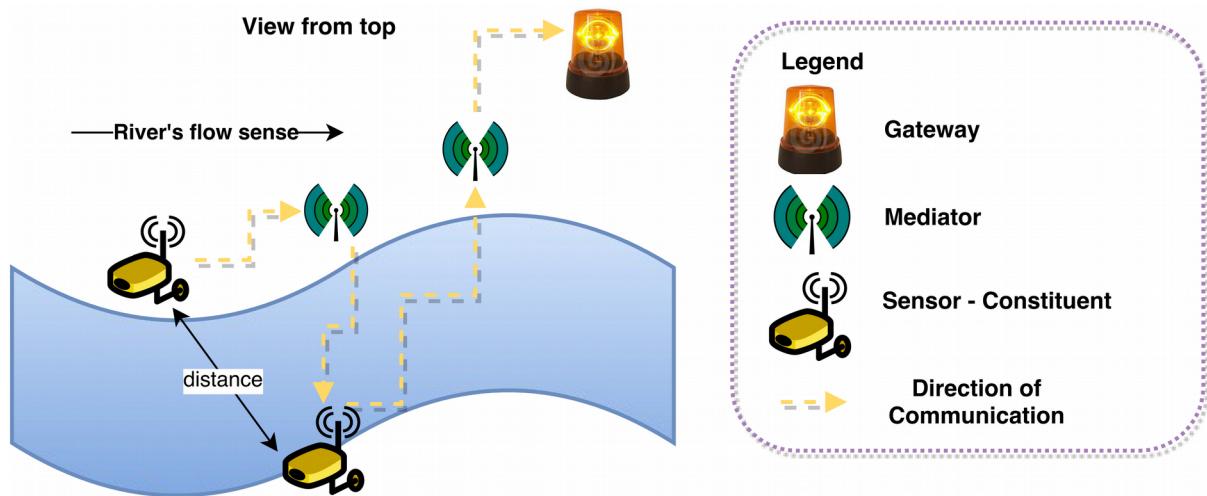
- Examples of Simulation formalisms/techniques:
 - MATLAB
 - DEVS
 - Systems Dynamics
 - Multi-Agent Based Simulation (JADE framework, NETLogo)
 - FERAL (Fraunhofer Institute)

State-of-the-Art and Practice

- Simulation in the Context of Software Engineering:
 - Breno França's work
 - Breno Bernard Nicolau de França, Guilherme H. Travassos: **Are We Prepared for Simulation Based Studies in Software Engineering Yet?** CLEI Electron. J. 16(1) (2013)
 - Breno Bernard Nicolau de França, Guilherme Horta Travassos: **Experimentation with dynamic simulation models in software engineering: planning and reporting guidelines.** Empir. Softw. Eng. 21(3): 1302-1345 (2016)
 - Verónica Bogado's work
 - Verónica Bogado, Silvio Gonnet, Horacio Pascual Leone: **A Discrete Event Simulation Model for the Analysis of Software Quality Attributes.** CLEI Electron. J. 14(3) (2011)
 - Verónica Bogado, Silvio Gonnet, Horacio Pascual Leone: **Modeling and simulation of software architecture in discrete event system specification for quality evaluation.** Simulation 90(3): 290-319 (2014)

Experience on M&S for SoS Software Architectures

- Simulation example with DEVS:
 - Link: <https://vimeo.com/164825145>



Valdemar Vicente Graciano Neto, Carlos Eduardo de Barros Paes, Lina Maria Garcés Rodriguez,
Milena Guessi, Wallace Manzano, Flávio Oquendo, Elisa Yumi Nakagawa:
Stimuli-SoS: a model-based approach to derive stimuli generators for simulations of systems-of-systems software architectures. J. Braz. Comput. Soc. 23(1): 13:1-13:22 (2017)

Experience on M&S for SoS Software Architectures



YES!

**BUT SOFTWARE ENGINEERS
DO NOT LIKE STATE MACHINES
AND PORTS AND EVENTS!**



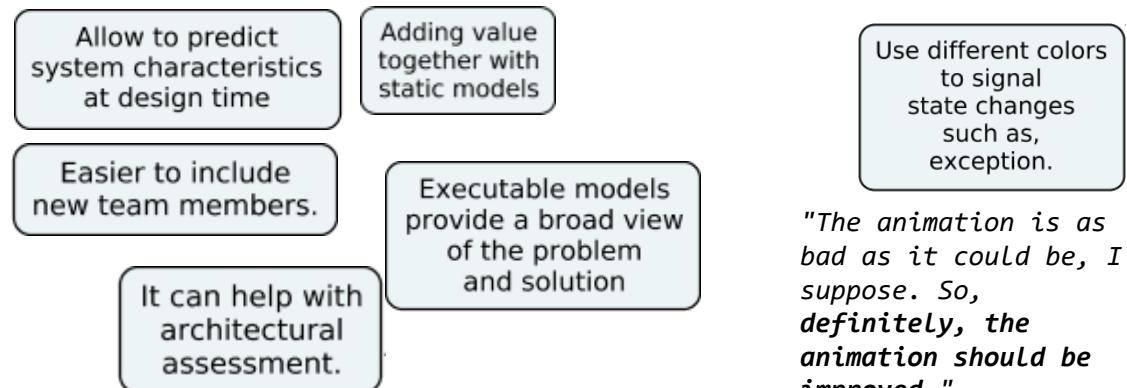
By the way...

- Survey with Software Engineering Professionals about using DEVS for solving problems

- 58 participants (44 from Brazil, 14 from other countries; 28 from Academy and 30 from Industry)
 - Findings:

- "This can be useful in a team meeting to show what the software should do, so that the whole team can **better understand** what needs to be done." [Participant 37]

- "The **understanding of the model** becomes clearer and more didactic." [Participant 43]



"The animation is as bad as it could be, I suppose. So, definitely, the animation should be improved."

[Participant 18]

Bruno Gabriel Araújo Lebtag, Paulo Gabriel Teixeira, Rodrigo Pereira dos Santos, Davi Viana, Valdemar Vicente Graciano Neto: **Evaluating the Understandability and Expressiveness of Simulation Executable Models with Professionals: Obtaining perceptions from researchers and practitioners for improving quality of models.** SBQS 2020: 12:1-12:10

Experience on M&S for SoS Software Architectures

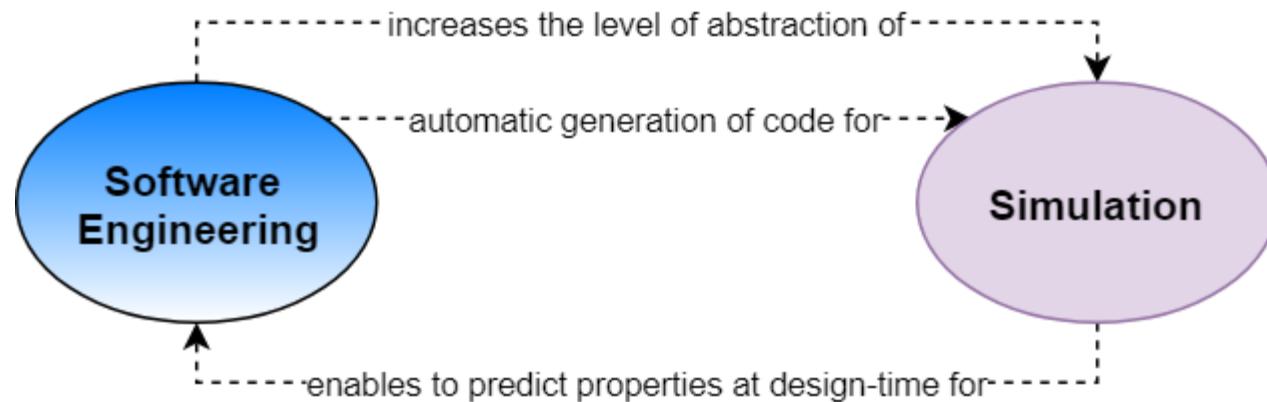


OK!

So let's combine software engineering static notations/models with executable simulation!

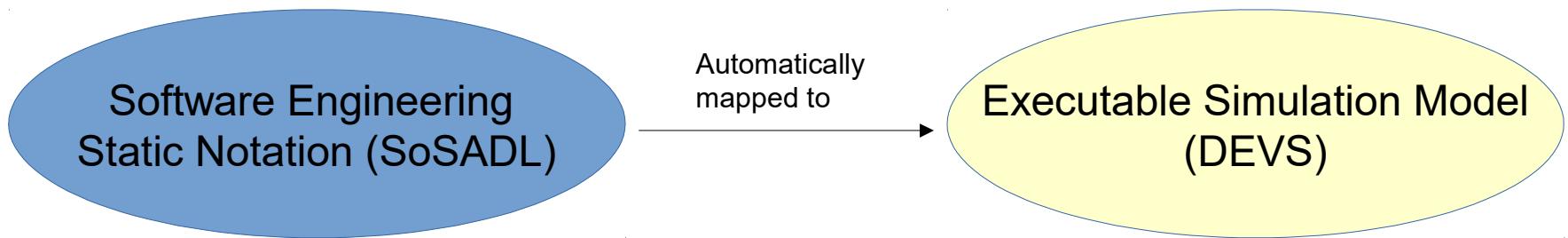
Experience on M&S for SoS Software Architectures

A synergy between Modeling AND Simulation (M&S)

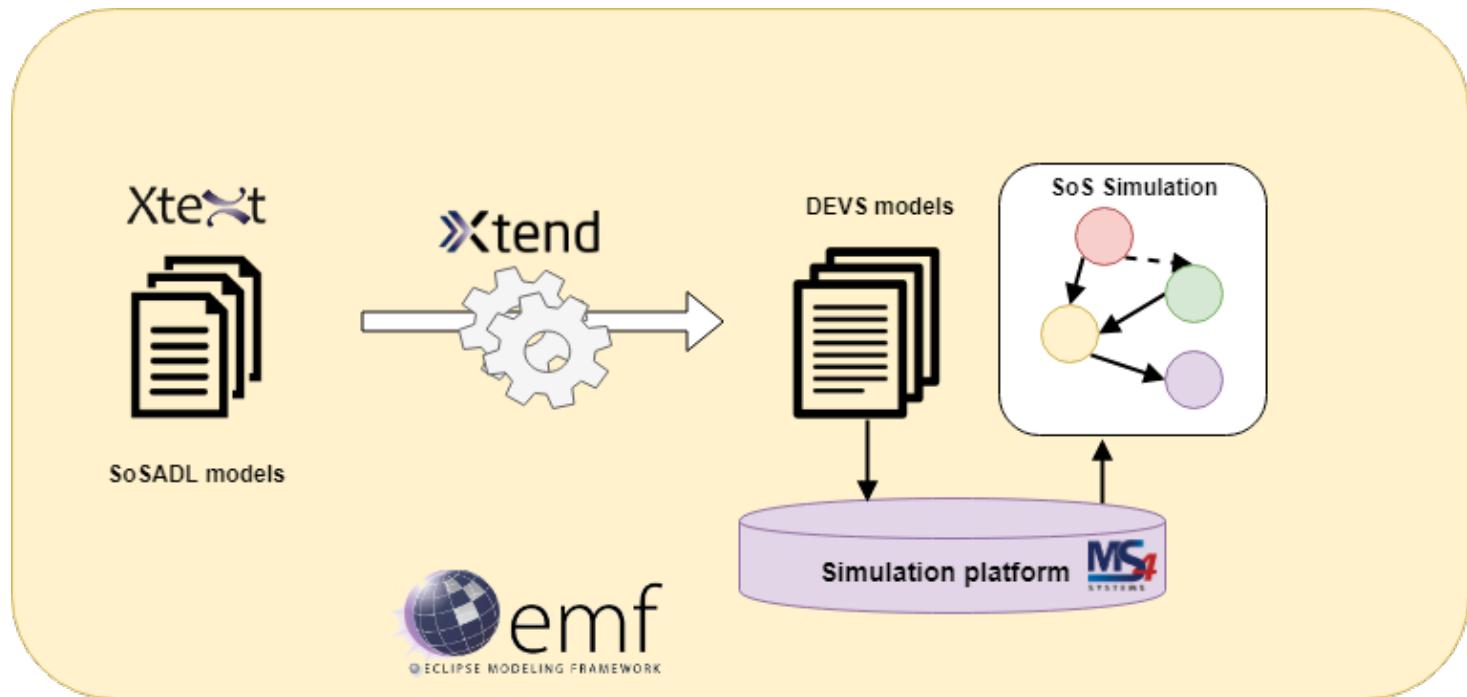


Experience on M&S for SoS Software Architectures

A synergy between Modeling AND Simulation (M&S)



Experience on M&S for SoS Software Architectures



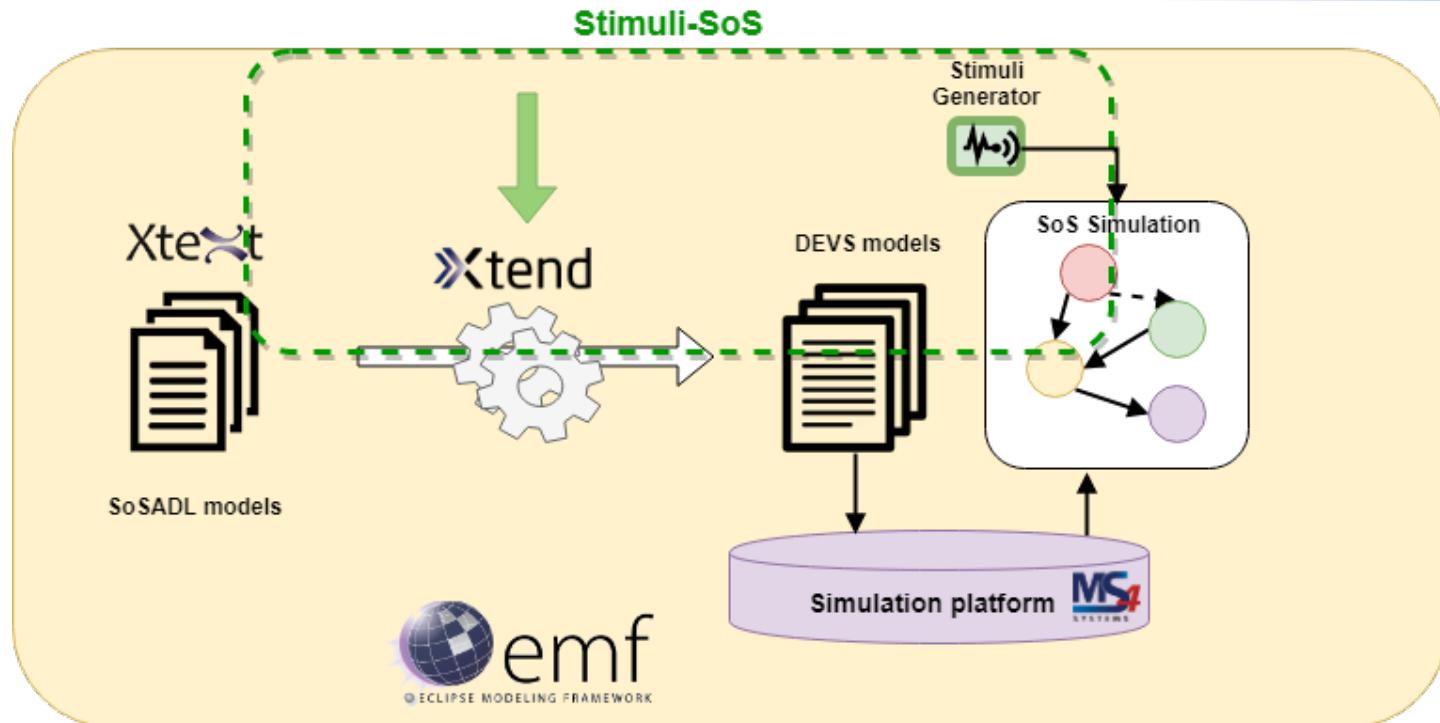
Experience on M&S for SoS Software Architectures



**But we also needed to represent
the environment!!!**

(the experimental frame in M&S
world)

Experience on M&S for SoS Software Architectures: the ASAS Approach



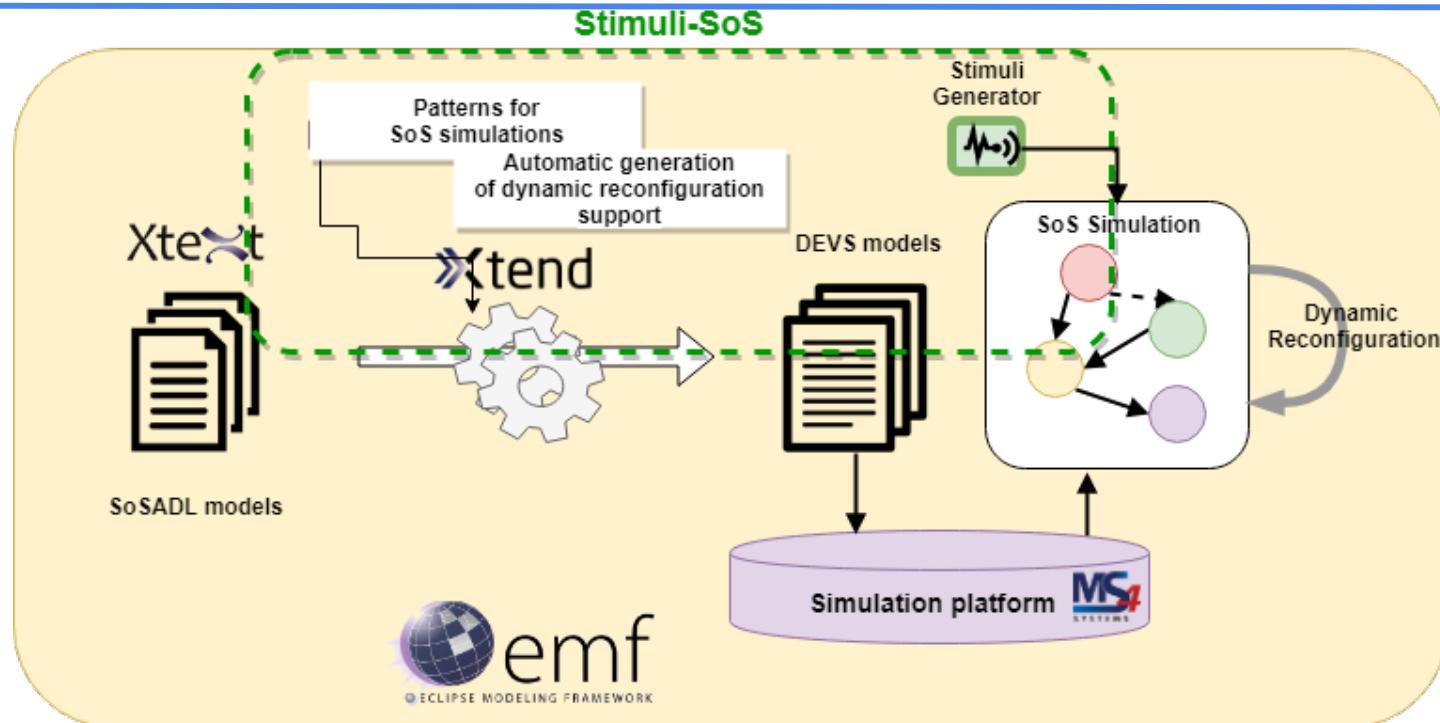
Valdemar Vicente Graciano Neto, et al. **Stimuli-SoS: a model-based approach to derive stimuli generators for simulations of systems-of-systems software architectures.** *J. Braz. Comp. Soc.* 23(1): 13:1-13:22 (2017)

Experience on M&S for SoS Software Architectures



**And we needed to
represent/manage SoS
dynamic/evolutionary
architectures!**

Experience on M&S for SoS Software Architectures: the ASAS Approach



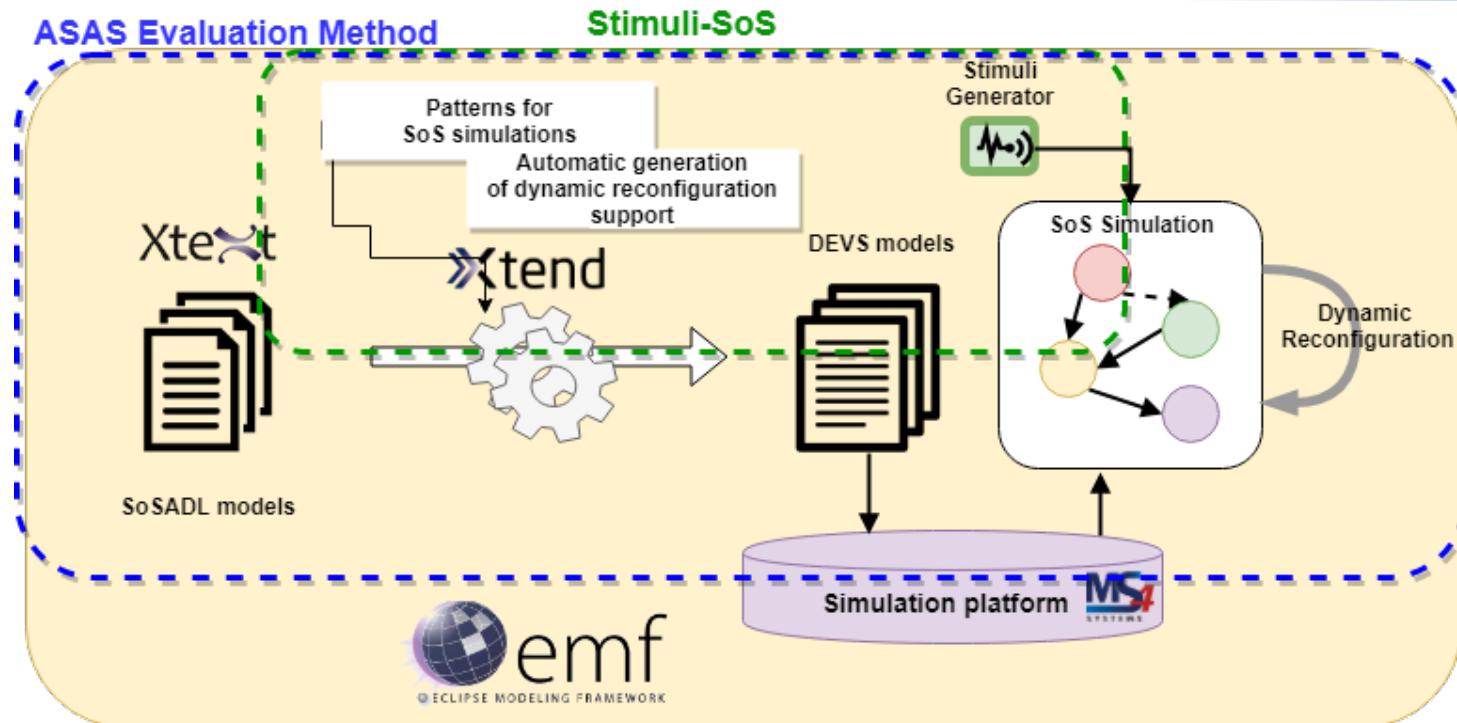
MANZANO, WALLACE ; GRACIANO NETO, VALDEMAR VICENTE ; NAKAGAWA, ELISA YUMI . **Dynamic-SoS: An Approach for the Simulation of Systems-of-Systems Dynamic Architectures**. COMPUTER JOURNAL, v. 62, p. 1-23, 2019.

Experience on M&S for SoS Software Architectures



And we decided to use this approach for evaluation of the SoS software architecture!

Experience on M&S for SoS Software Architectures: the ASAS Approach



Valdemar Vicente Graciano Neto, Lina Maria Garcés Rodriguez, Milena Guessi, Carlos Paes, Wallace Manzano, Flávio Oquendo, Elisa Yumi Nakagawa: **ASAS: An Approach to Support Simulation of Smart Systems**. HICSS 2018: 1-10.

Reporting Cases

ASAS Evaluation



Brazilian Institute for Space Research



Cases

ASAS Evaluation

Launching satellites is expensive.

How to have an estimation if the acquisition of new satellites could improve the actual service?

Space-SoS



Reporting Cases

- Two missions:
 - To perform the environmental data collection; and
 - To obtain pictures from the Amazon region using the satellite.
- Aim: To evaluate how the increase in the number of satellites from one to six would influence on the
 - level of resource competition,
 - percentage of goals met, and
 - impact of number of satellites on the SoS performance as a whole.

Reporting Cases

- Data
 - Obtained from INPE
 - Period between January 1st, 2017 and October 31st, 2017
 - Each DCP station in operation the entire Brazilian territory.
- DEVS simulation model for more than 300 constituents automatically generated
- 34 hours of simulation
- We concluded that
 - an increase in the number of satellites reduced the competition between constituents;
 - justified the acquisition of new satellites by the Brazilian government;
 - reduced data losses.

Valdemar Vicente Graciano Neto, Wallace Manzano, Adair José Rohling, Maurício Gonçalves Vieira Ferreira, Tiago Volpato, Elisa Yumi Nakagawa: Externalizing patterns for simulations in software engineering of systems-of-systems. SAC 2018: 1687-1694

Reporting Cases

- Flood Monitoring;
- Smart Building: Functional Suitability and Cost Acquisition Prediction;
- Space-SoS; and
- Smart Parking: Availability.

#	Study	Domain	SosADL (LOC)	DEVS (LOC)	Maximum Number of Constituents	Total simulation time (hours)
1	(Graciano Neto et al. 2018a)	FMSoS	701	8,563	70	6.33
2	(Manzano et al. 2019)	FMSoS	701	8,563	52	5.33
3	(Graciano Neto et al. 2017)	FMSoS	1,154	56,185	112	6.2
4	(Graciano Neto et al. 2018b)	FMSoS	660	3,332	89	2.6
5	(Manzano et al. 2019)	Smart Building	6,724	219,930	395	9.66
6	(Graciano Neto et al. 2018c)	Space SoS	640	11,195	4	0.72
7	(Graciano Neto et al. 2019)	Space SoS	2,399	128,884	311	27
8	(Manzano et al. 2019)	Space SoS	2,677	378,557	155	21.5
9	(Graciano Neto et al. 2019)	Space SoS	4,014	497,040	258	34
Total			19,670	1,312,249	1,446	133.22

Graciano Neto, V. V., Horita, F. E. A., Santos, R., Viana, D., Kassab, M., Manzano, W., & Nakagawa, E. Y. (2019). **S.O.B (Save Our Budget) - A Simulation-Based Method for Prediction of Acquisition Costs of Constituents of a System-of-Systems**. ISys – Brazilian Journal on Information Systems, 12(4), 6–35. Available at: <http://www.seer.unirio.br/isys/article/view/8421>

MANZANO, Wallace; GRACIANO NETO, Valdemar Vicente; NAKAGAWA, Elisa Yumi. **Dynamic-SoS: An approach for the simulation of systems-of-systems dynamic architectures**. The Computer Journal, v. 63, n. 5, p. 709-731, 2020.

Delécolle, A., Lima, R. S., Neto, V. V. G., & Buisson, J. (2020, June). **Architectural Strategy to Enhance the Availability Quality Attribute in System-of-Systems Architectures: a Case Study**. In 2020 IEEE 15th International Conference of System of Systems Engineering (SoSE) (pp. 93-98). IEEE.

Reporting Cases: Contributions

- A combination of static and dynamic notations via model transformation
- A method for evaluating SoS software architectures
- Combination of simulation models with architectural models
- Prediction of properties at design-time for software engineering for SoS

Remaining Challenges

- Scalability: How to simulate an entire smart city? (Millions of constituents)
 - Processing perspective
 - Visualization perspective

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- How to assure an entire set of quality attributes (safety, security, usability, performance)?

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- Coverage: how to test all the combinations of architectural arrangements a SoS can assume?

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- How to make simulation formalisms and animation more software engineering-like?

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- Coverage: how to test all the combinations of architectural arrangements a SoS can assume?
- How to make simulation formalisms and animation more software engineering-like?
- Simulation Education and Training: multi-professional abilities required
 - Systems Engineering – FERAL case

Before Finishing

III Workshop on Modeling and Simulation of Software-Intensive Systems (MSSiS 2021)

<http://inf.ufg.br/mssis/en/index.html>

Deadline: June 14th, 2021.



The screenshot shows the official website for the III Workshop on Modeling and Simulation of Software-Intensive Systems (MSSiS 2021). The header features the workshop's name and its conjunction with CBSoft 2021. Below the header, there are links for Home, Call for Papers, Committees, Important Dates, Workshop Program, and a Brazilian flag icon. The background of the page includes a photograph of a modern building with large glass windows and a metal roof, with some foliage visible in front.

MSSiS 2021

Software-intensive systems are those in which software is a dominant and essential element. In those systems, software crosscuts all the steps of the software development process. Due to the emergence and rise of novel and increasingly more complex types of systems such as smart cities, cyber-physical systems, systems-of-systems, and software ecosystems, new frontiers of research have been opened to investigate how to provide reliability through modeling of these new systems which are often highly



Before Finishing

Tutorial: Simulation of Software Architectures
of Smart-Ecosystems: Theory and Practice

<https://ww2.inf.ufg.br/~insight/tutorialecsa2021/>

September 13th, 2021.



QUESTIONS





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Virtual (originally in Madrid, Spain)

June 3rd, 2021

Experience and Challenges on Modeling and Simulation of Software Architectures of Systems-of-Systems

Thank you!

Dr. Valdemar Vicente Graciano Neto

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