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A multi-scale modelling perspective for SoS architectures

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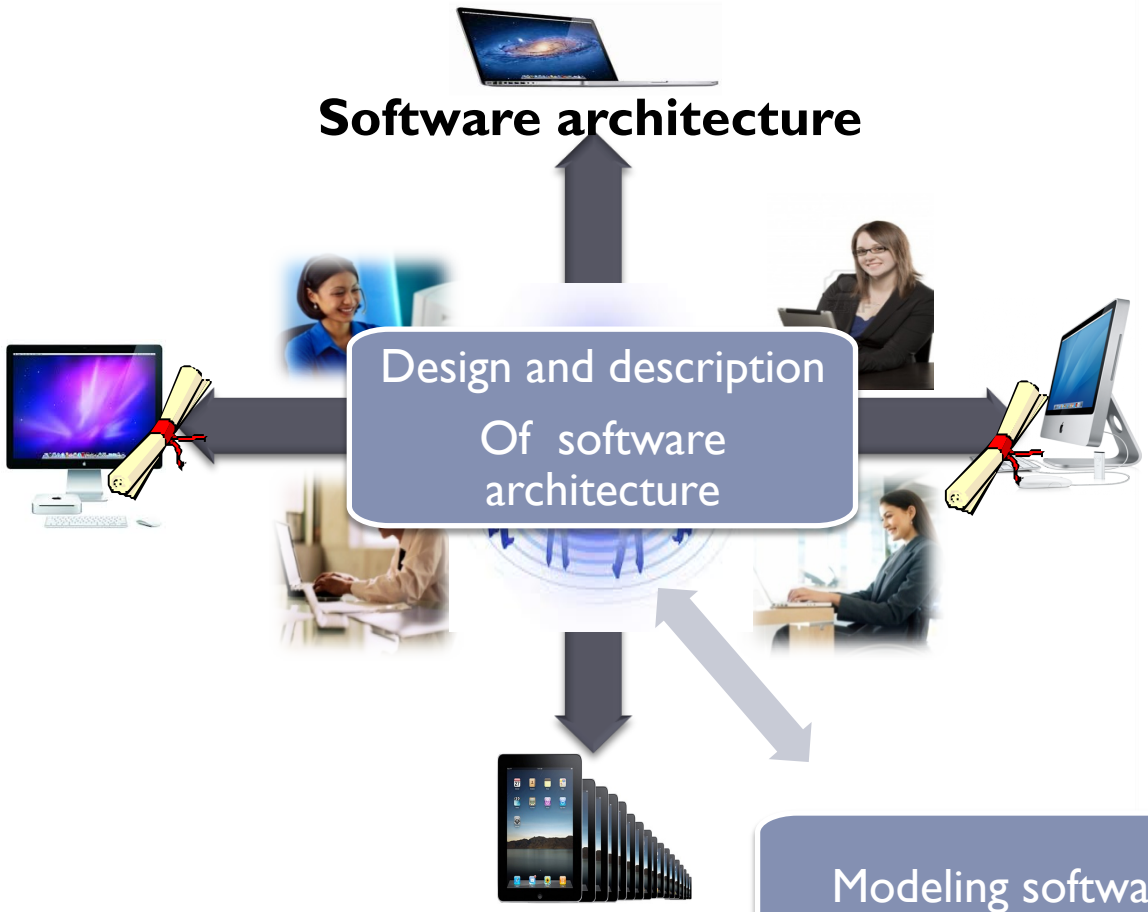
Overview

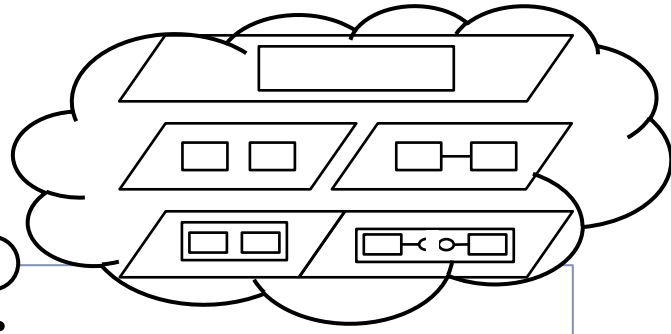
- The Context
- The Problem
- Objectives
- Approach
  - Multiscale approach description
  - Scale definition
  - Refinement process
- State of the art of SoS
- Contributions
- Conclusion and future work

The general Context of our study



The Problem

- How to handle software Systems of Systems complexity?
- How to describe software architectures to facilitate their validation at different description levels?



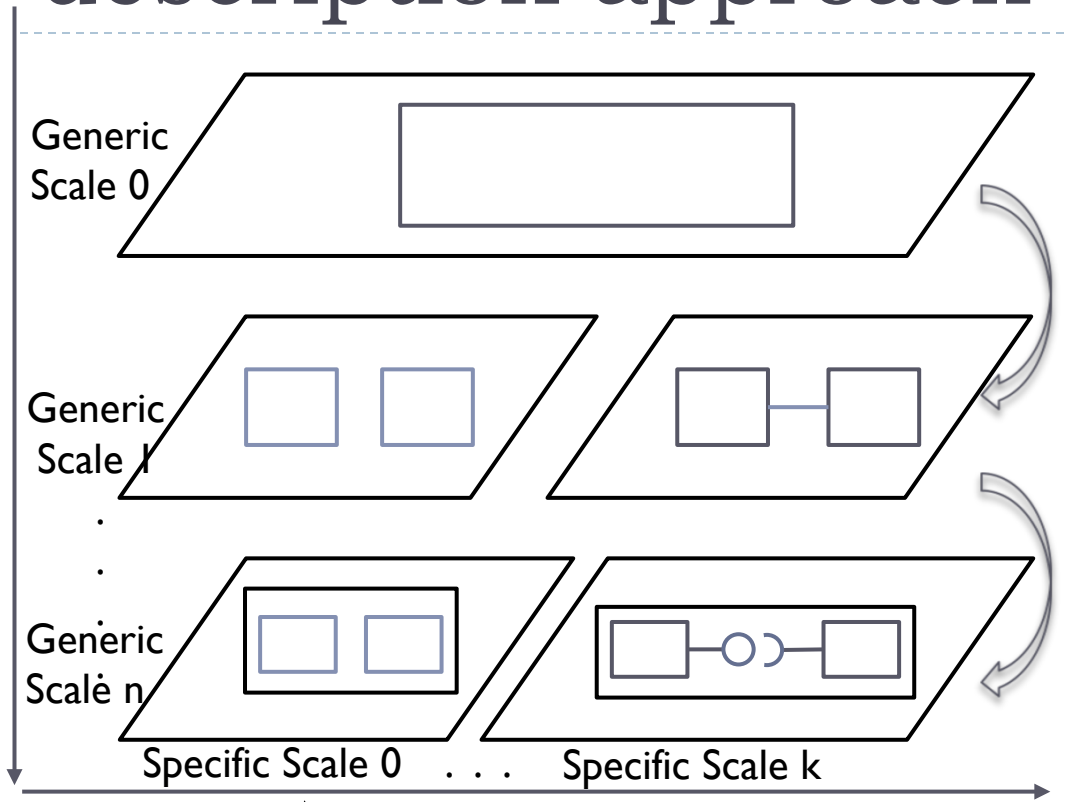
Our proposal:

Consider different architecture descriptions with different levels of modelling details: "the scales"

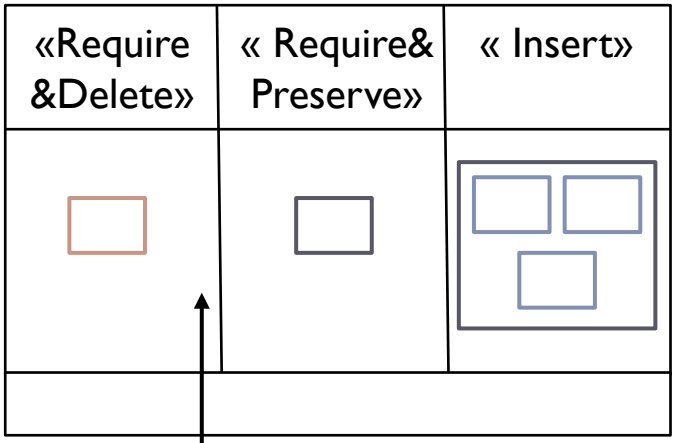
Our Work Objectives

- Provide solutions for modeling software architectures
  - To facilitate their validation at different description levels
  - To Validate through case studies for Systems of Systems (ERCMS, PMS, IAD)
- Propose a design approach
  - Organized around a set of architectural transformation rules
  - Based on SysML visual notations
- Present a multi-scale modeling approach for SoS architecture description for
  - Mastering the description details complexity
  - Validating through involving intrinsic or mission-specific properties
    - Allow the validation while remaining tractable w.r.t. complexity
    - Ensure the model correctness w.r.t. SysML description

The implemented Multiscale description approach (Eclipse Plugin)



Model transformation operations (Graph Matching & Transformation: GG semantics)



Validation (crrectness of description, correctness of the system)
Rule-oriented description technique
Model transformation rules
Vertical and horizontal refinement process

The Refinement Process

Start by modelling the first scale by a given **coarse grain description** using a **SysML block diagram**

This diagram is refined through model transformation operations (**Horizontal** and **vertical** refinements)
A model refinement executes the "Insert" transformation operation to add new **blocks** and **connections**

Transit from one scale to another by a **refinement of composition** enriching its architecture

Reach a **fine-grain description** representing the necessary details

What are Scales

- A « **generic » description scale** "**GS_n**" (enriched with vertical refinements)
  - Is a model that provides additional details of design that pertain to "**GS_{n+1}**"
  - Is a description level that allows the architect to:
    - Describe the necessary details to understand the SoS architecture and to validate the associated properties
- Under each generic description scale there are several **specific description scales** (Horizontal refinement)
  - Providing more details of a given SysML current description

What is an SoS?

- A set of collaboratively integrated systems that possess two additional properties:
  - Operational independence of the constituents
  - Managerial independence of the constituents

  (Maier, M.W.: *Architecting principles for systems-of-systems*, 1998)
- A composition of systems in which its constituents, themselves systems, are separately discovered, selected and composed
  - To form a more complex system that performs a mission not possible by one of the constituent systems alone, i.e., it creates an emergent behavior

SoS intrinsic characteristics

- Operational Independence
  - The constituents of an SoS can execute independently
- Managerial Independence
  - The constituents of an SoS are separately integrated but manage their own resources independently
- Evolutionary Development
  - The SoS can evolve over time to respond to changing characteristics.
- Emergent Behavior
  - The SoS is capable to deliver new functions that are obtained from the composition of its constituents rather than from a singular constituent
- Geographic Distribution
  - The constituent systems are geographically extended in such a way interaction between them is limited to information exchange

Categories of SoSs

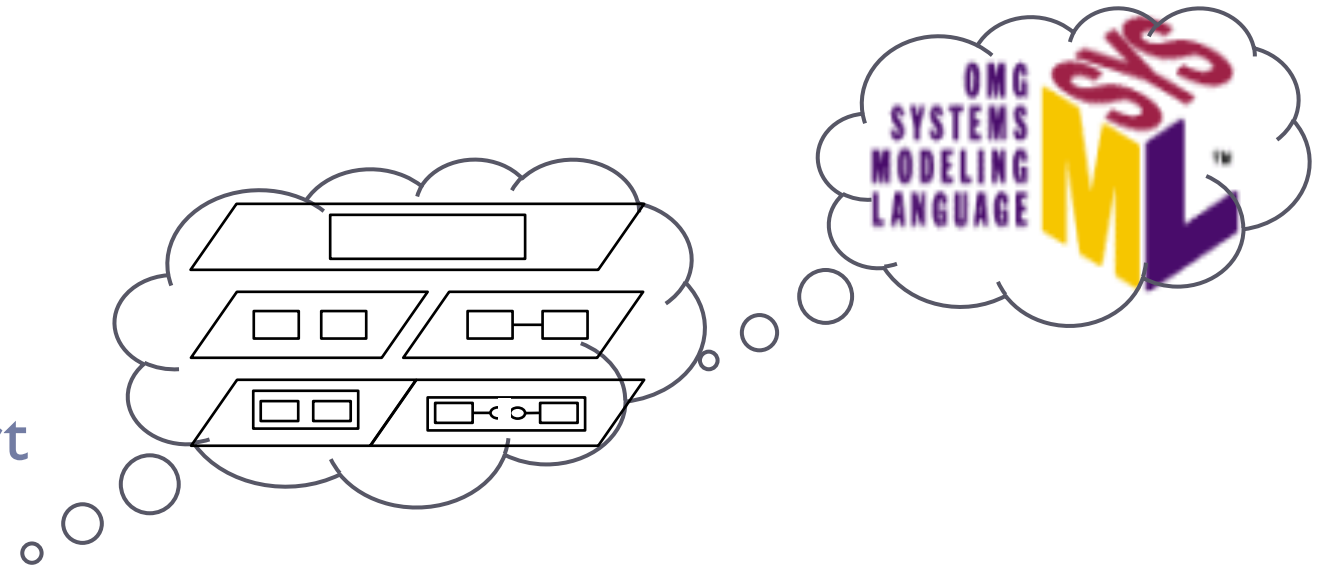
- Directed SoS (eg. The Integrated Air Defense System)
  - A set of systems that operate subordinated to the central purpose
  - The constituent systems maintain an ability to operate independently
  - The operational mode is subordinated to the central managed purpose
- Collaborative SoS
  - a set of systems that collaborate to fulfill the agreed central purposes
- Virtual SoS
  - lack a central management authority and a centrally agreed purpose for the SoS
- Acknowledged SoS
  - Recognized objectives,
  - A designated manager

SystemModeling Language (SysML)

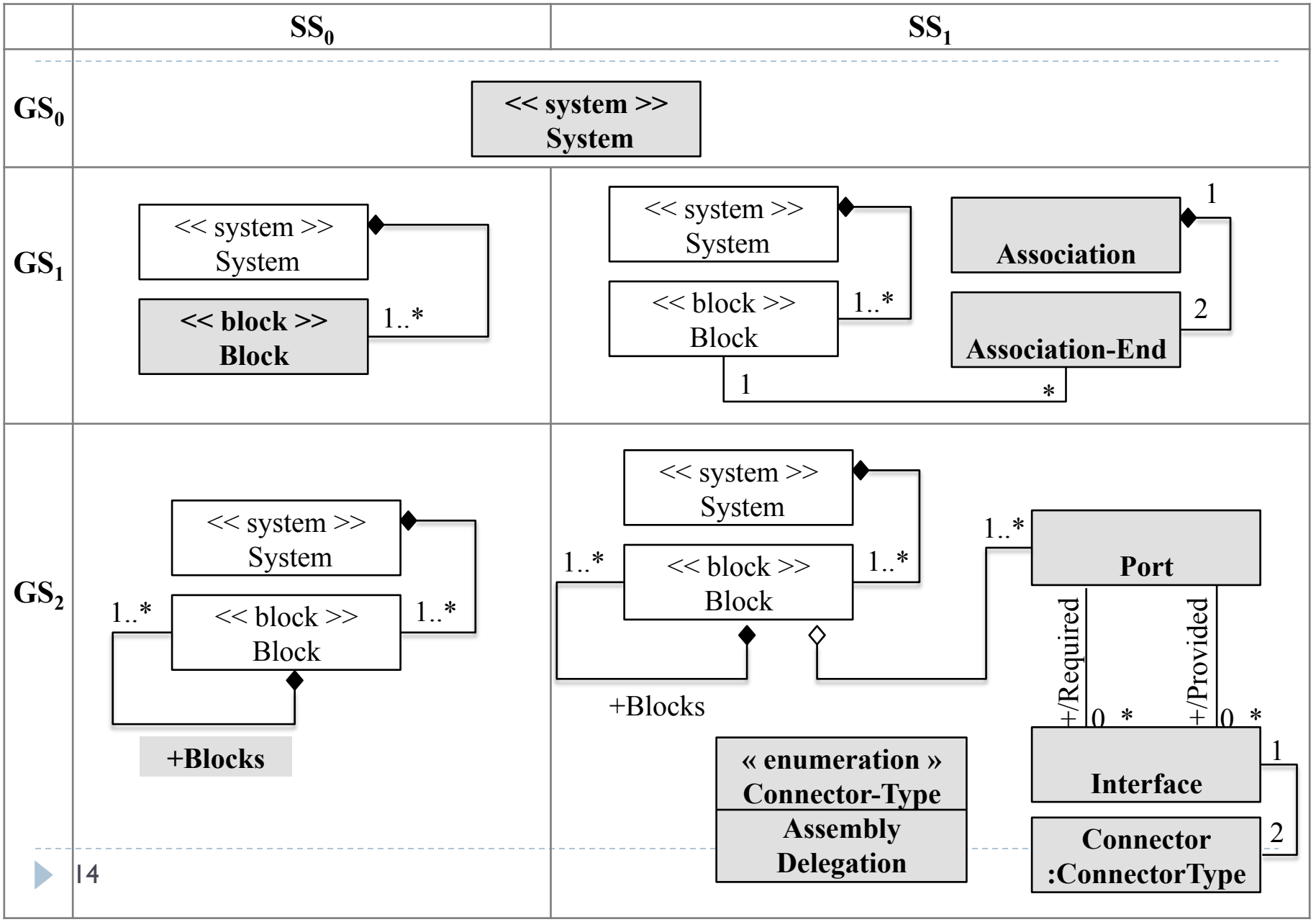
- A graphical modelling language
  - Is based on UML
  - Involves modelling blocks instead of modelling classes
- The **block definition diagram (bdd)**
  - Allows us to give a structural description of the system
  - Describes the relationship among blocks (e.g., composition, association, specialization)
- The **internal block diagram (ibd)**
  - Is a white box view of a block
  - Describes the internal structure of system in terms of parts, ports and connectors.

Overview

- Context
- Problematic
- Objectives
- Approach
- State of the art
- Contribution
  - SysML Metamodel
  - Model transformation operations
  - Verification rules for model traceability
  - Use case: Application to the Integrated Air Defense SoS
- Conclusion and perspectives



SysML Metamodel



SysML Metamodel

- GS_0 defines the **whole system** by its name
- The beginning of traceability (System requirements are specified)

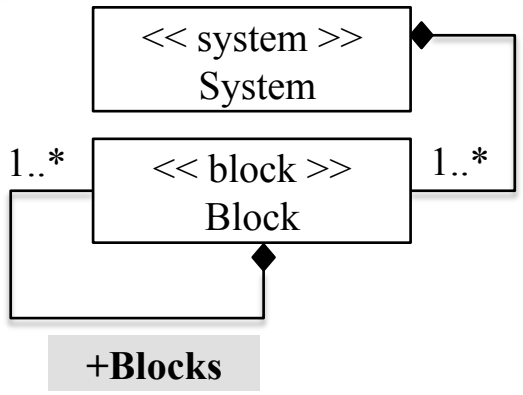
- Two horizontal refinements are associated with GS_1
  - $\{GS_1, SS_0\}$ shows **all blocks** that **compose** the system
  - $\{GS_1, SS_1\}$ describes the **links** between those blocks

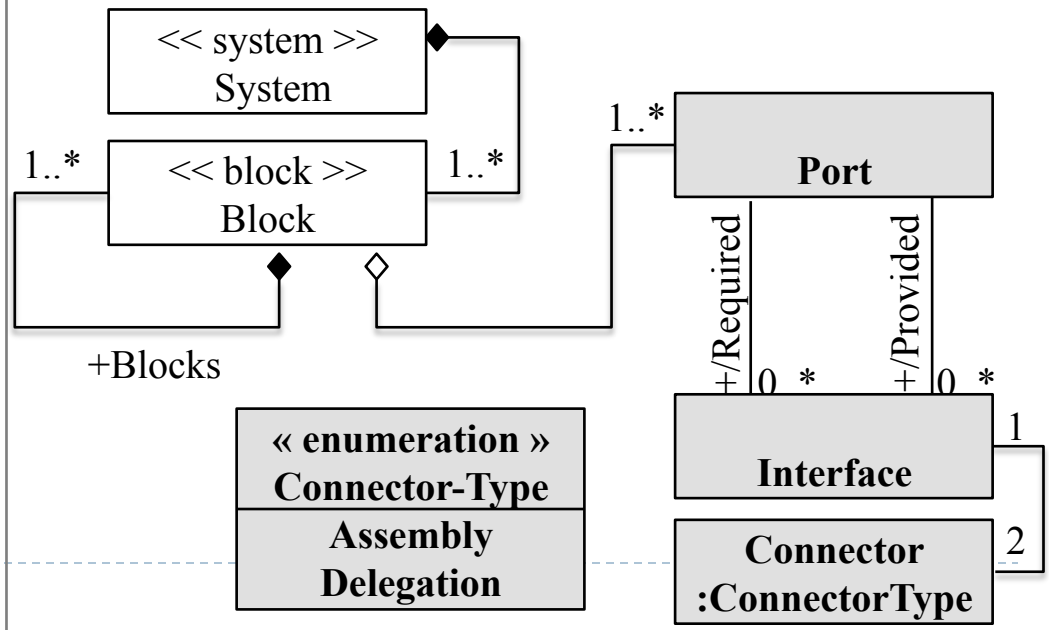
- Two specific scales are associated with GS_2
  - $\{GS_2, SS_0\}$ presents **composite** for blocks
  - $\{GS_2, SS_1\}$ identifies the list of:
    - **Communication ports** for each composite block
    - **Interfaces** for communication ports, and
    - **Connections** between the system constituents

GS_0

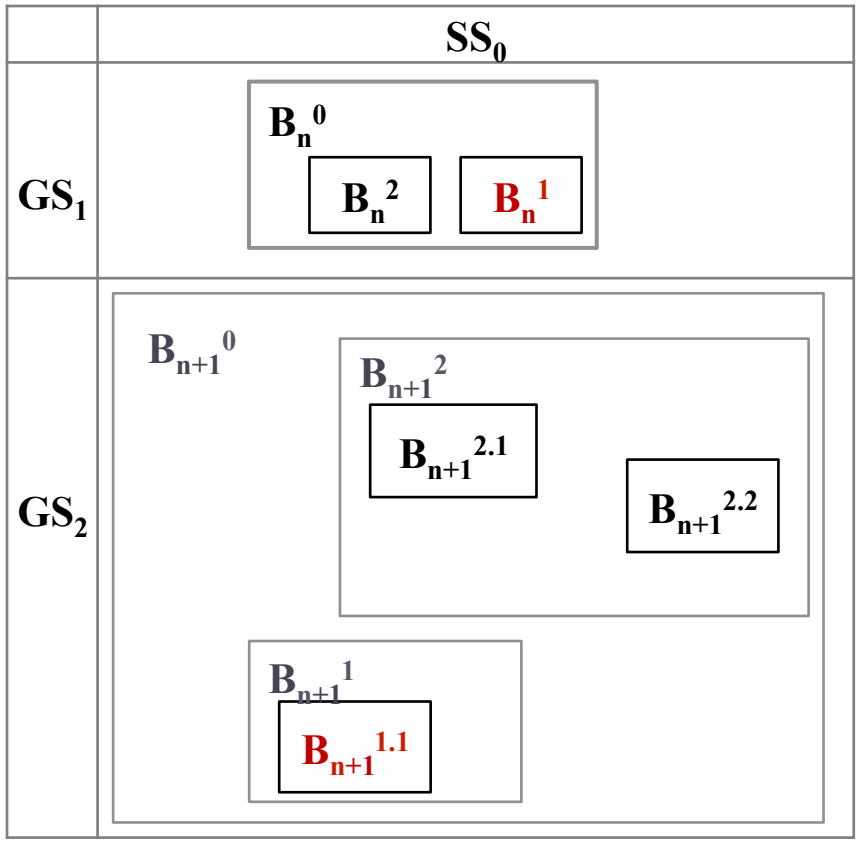
GS_1

GS_2





Verification rules for model traceability (1/2)



Approach with overlap between scales

- Traceability rule for block identification
  - If we keep track of a block, the traceability is trivial, and the identification of the block is preserved
- We note a block by B_n^m
  - n: the scale number (n>=0)
  - m: a cursor on the current block (m >= 0)
  - n, m are decomposed in the next scale
- If we have a block B_n^l, then its composing blocks in the next scale are named $B_{n+1}^{l.l}$ etc.

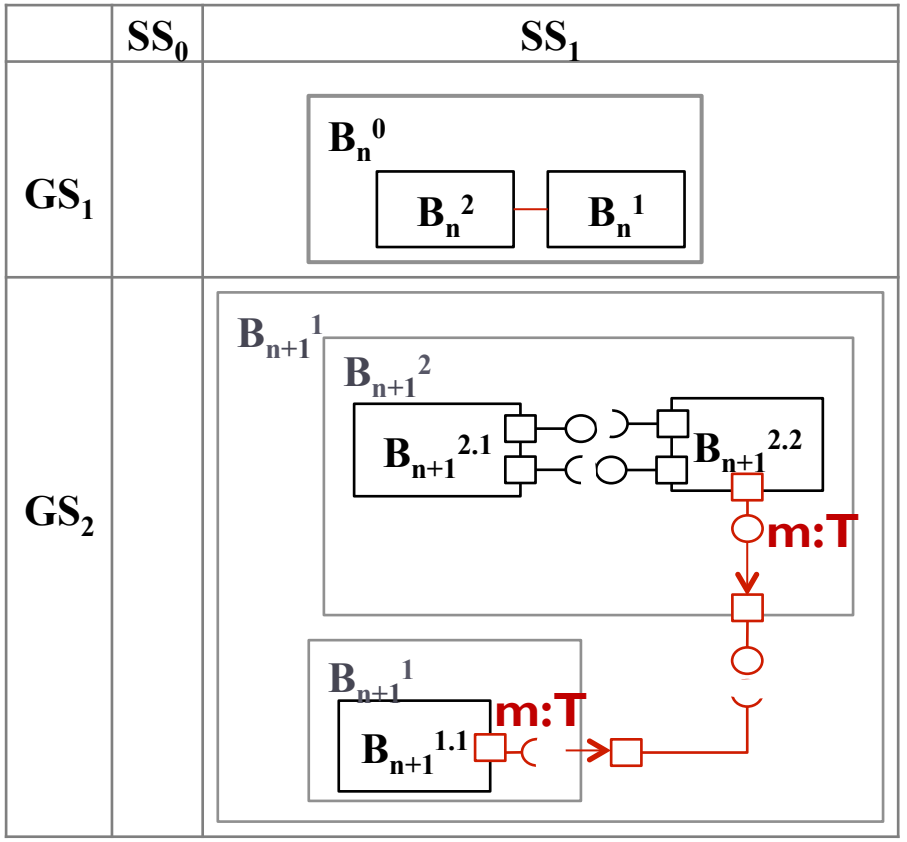
Verification rules for model traceability (2/2)

Approach with scale separation

- Rules for decomposing links between blocks
  - If a link is divided according to its identifiers (Producer Consumer), then a trace of the link decomposition is added

- **Rule1:** If $\mathbf{B_n}^1$ is a Consumer, then the link between $\mathbf{B_n}^1$ and $\mathbf{B_n}^2$ in $\mathbf{GS_n}$ will be transformed into an assembly connection in $\mathbf{GS_{n+1}}$ extending from the source $\mathbf{B_{n+1}}^{2.2}$ to the target $\mathbf{B_{n+1}}^{1.1}$

- **Property**: ∀ **B** ε **{Producers}**, ∃ **C** ε **{Consumers}** such taht ∀ **m:T** (a message with a type T) sent by **B** **m:T** is received by **C**



Application to Integrated Air Defense (IAD)

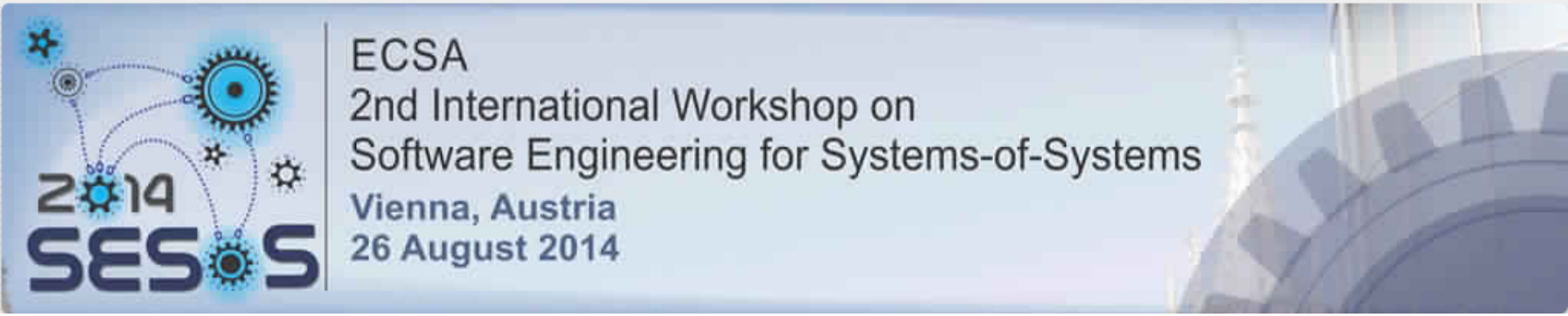
- Application of the model transformation rules to the IAD SoS
- Verification of the model traceability properties during the refinement process
- Illustration of the block diagrams for generic and specific description scales scales
  - GS_0 illiustrates The Integrated Air Defense system as a directed SoS
  - $\{GS_1, SS_0\}$ presents the constituent systems as blocks (Ground Force, Air Force, and Maritime Force)
  - $\{GS_1, SS_1\}$ shows the internal communications between these systems as associations between blocks
  - $\{GS_2, SS_0\}$ represents composites of each constituent system.
    - Eg. Ground force is composed of Surveillance radars, command and control site, anti-aircraft artillery, and anti-aircraft weapons (Short Range Air Defense (SHORAD), and HIgh to Medium Air Defense (HIMAD))
  - $\{GS_2, SS_1\}$ represents the internal connections to express the communication between all blocks that received orders from the Command and Control block.

Conclusion

- a multi-scale approach for software architectures at **the conceptual level**
- SysML notations at **the architectural style level**
- the state of the art on how SoS architecture modelling have been addressed.
- refinement rules through model transformation techniques
- verification rules for model traceability
- Implemenation of an eclipse plugin

Ongoing/Future work

- Updating the state of the art in order to contribute to the area of SoS
- Considering the need and relevance of these large and complex systems
- Applying the multi-scale approach to other use cases for modeling Systems of Systems architectures
- Automated generation of Event-B specification for properties verification using theorem prover techniques



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