27th annual INCOSE international symposium

Adelaide, Australia

July 15 - 20, 2017

A Simplified SysML-Based Approach for Modeling Complex Systems

MBSE Grid

www.incose.org/symp2017

Authors

Aurelijus Morkevičius, PhD,
Head of Solutions @ No Magic
aurelijus.morkevicius@nomagic.com

Co-chair
and one of the leading architects for the current
*OMG **UPDM/UAF** standard development group*

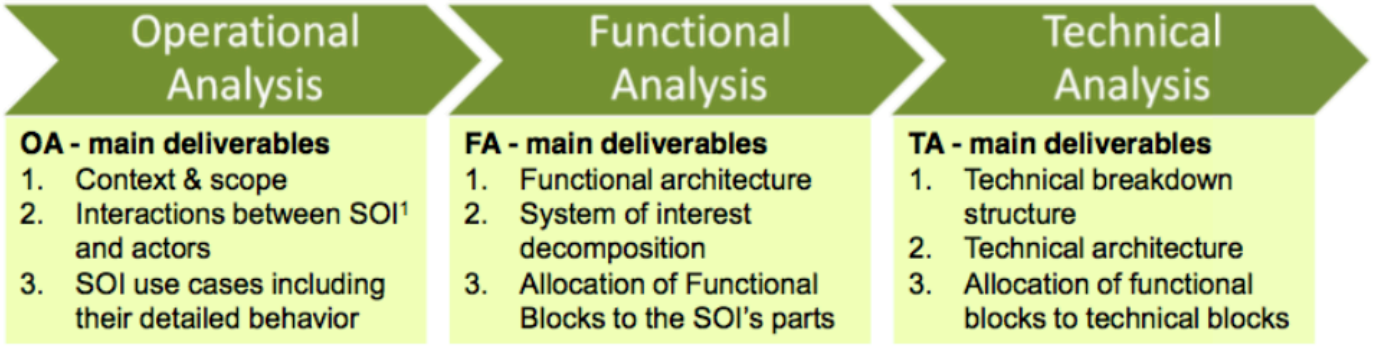
Holds PhD. in Informatics Engineering

Motivation

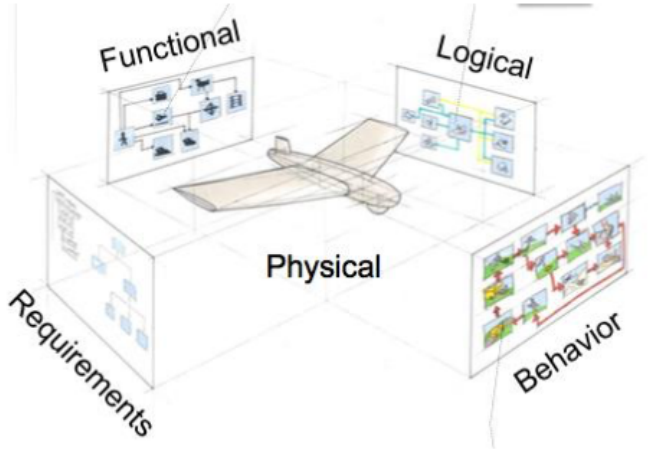
- It is common misunderstanding in MBSE, that SysML as modeling language is enough to successfully apply MBSE
- Modeling language is just the language, and must be combined with a methodology to be useful
- Quite a few methods available for MBSE
- The ones that exist are too abstract for solving a real-world problem

Idea

- Decade working on standardization of military frameworks (UPDM, NAF, DoDAF, MODAF, UAF)
- Expertise acquired working on real-world projects in transportation and defense industries

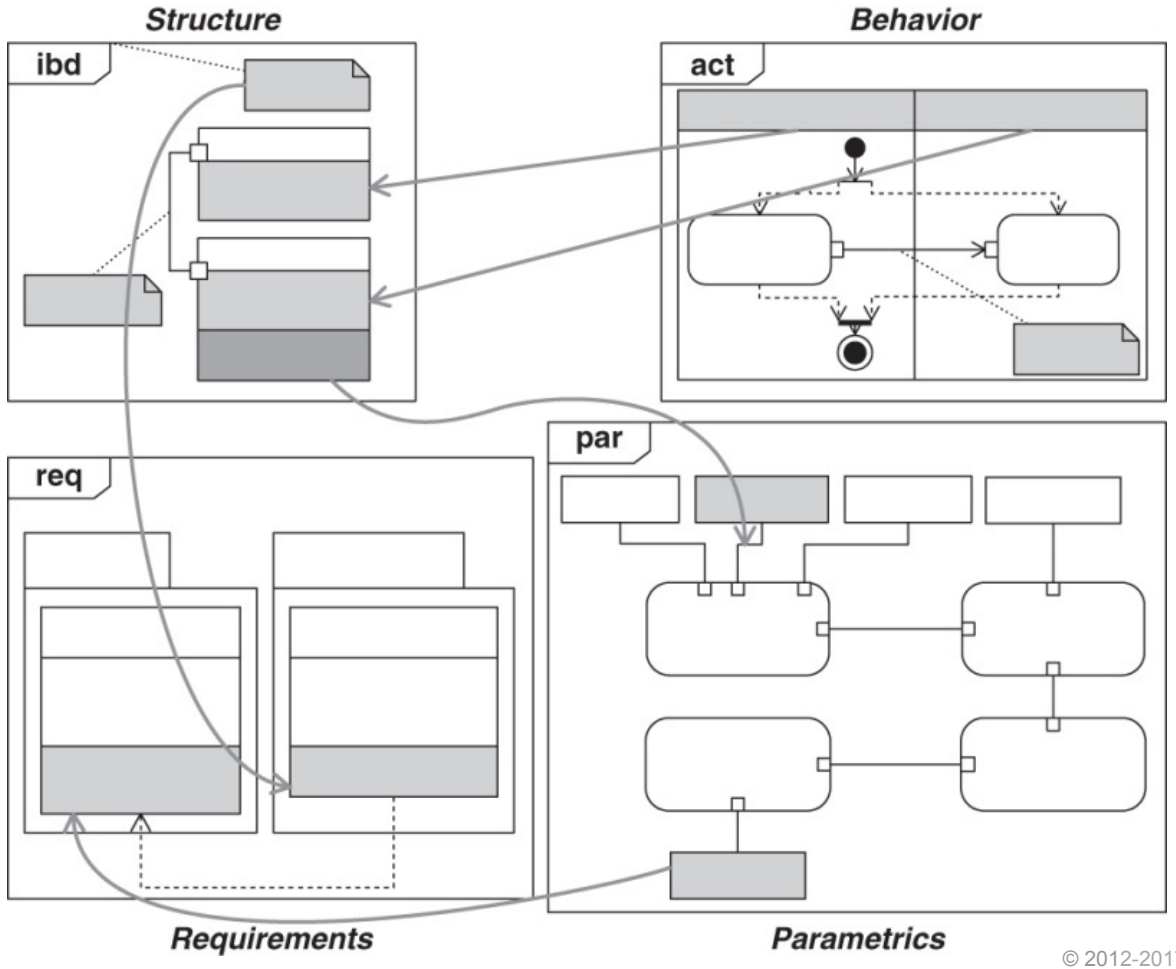


Bombardier Transportation System Modeling Method (Naas et al., 2015)



KDA System Architecture Framework

The Four Pillars of SysML



MBSE Grid

			Pillar			
			Requirements	Behavior	Structure	Parametrics
Layer of Abstraction	Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
		White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
	Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Case Study: Vehicle AC Unit

Problem Domain: Black Box

Domain		Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

- Black-box perspective describes the SoI as a whole
- In this perspective, stakeholder needs, functions expected from the SoI, user scenarios, SoI interaction with environment, and measurements of effectiveness are defined
- The operational analysis of the system is performed

Stakeholder Needs

Domain			Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Stakeholder Needs

- captures stakeholder requirements, regulations, policies, principles, and internal guidelines to develop a system
- in Requirements Engineering process this is the raw information elicited from the user that needs to be refined, first by analysing, second by specifying more detailed system requirements

Stakeholder Needs

Add New | Add Nested | Add Existing... | Delete | Remove From Table

Criteria

Scope (optional): 1 Stakeholder Needs | Filter:

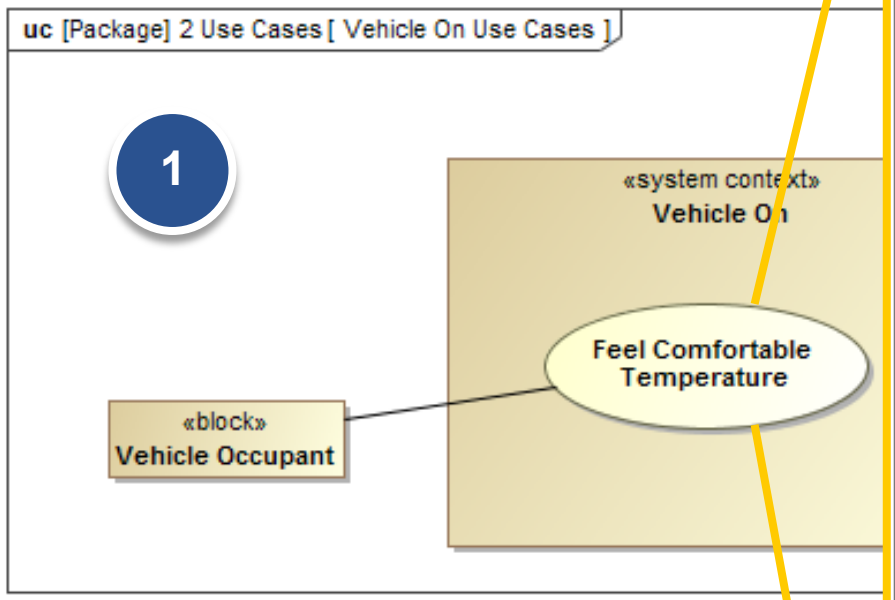
#	Name	Text
1	SN-1 User Needs	
2	SN-1.1 Setting Temperature	It must be possible to set and maintain desired temperature in the cabin.
3	SN-1.2 Heat and Cool Modes	Unit shall be able to heat and cool.
4	SN-1.3 Noise Level	Climate control unit in max mode shall not be louder than engine.
5	SN-1.4 Climate Control Mass	Mass of the unit shall not exceed 5 percent of the total car mass.

Use Cases

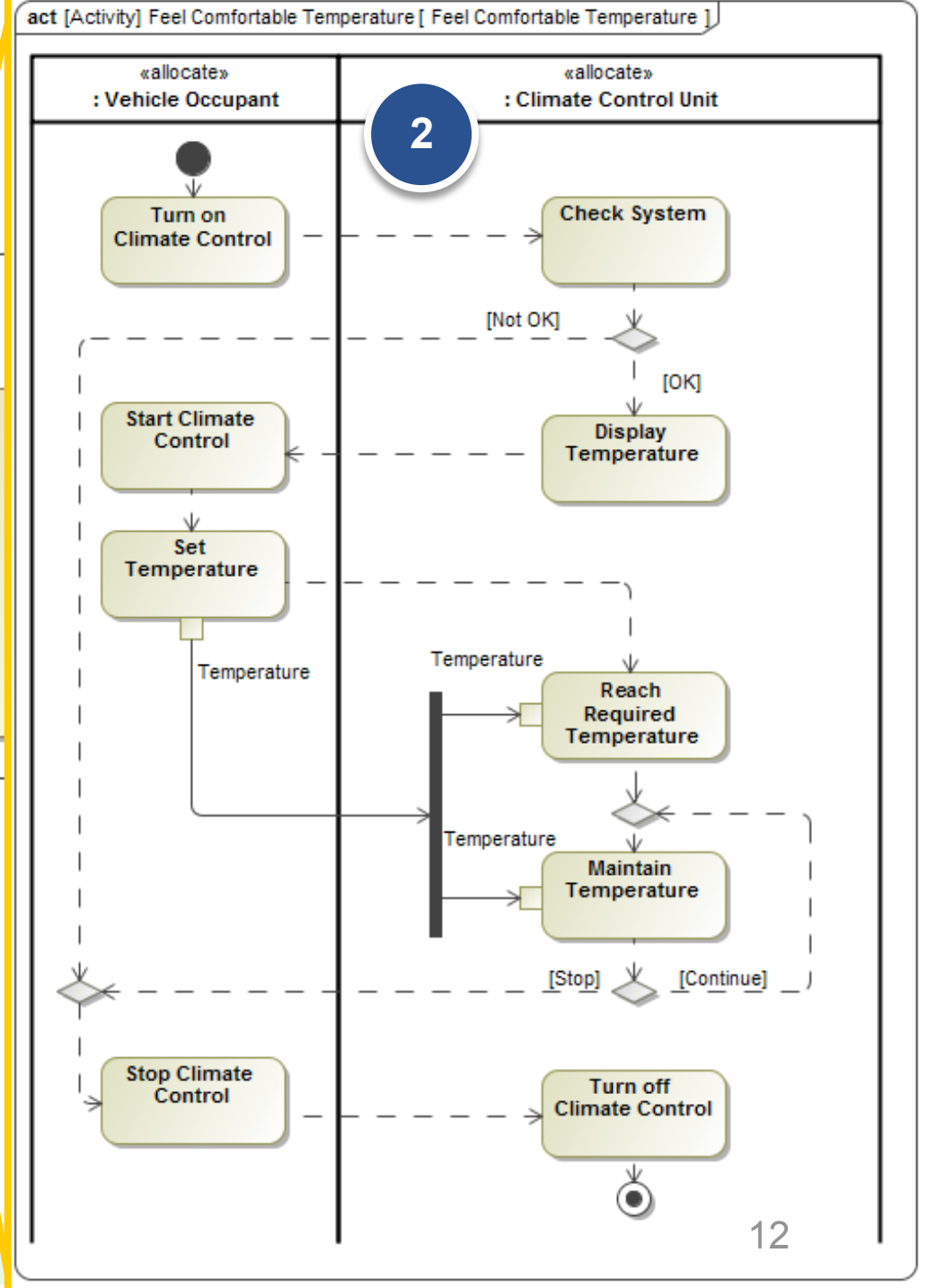
Domain			Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Use Cases

- captures refinement of functional user needs in a form of a use case specification



- includes use case scenarios defining flow of events inside the use case as well as the other additional information, e.g. prerequisites, constraints, etc.

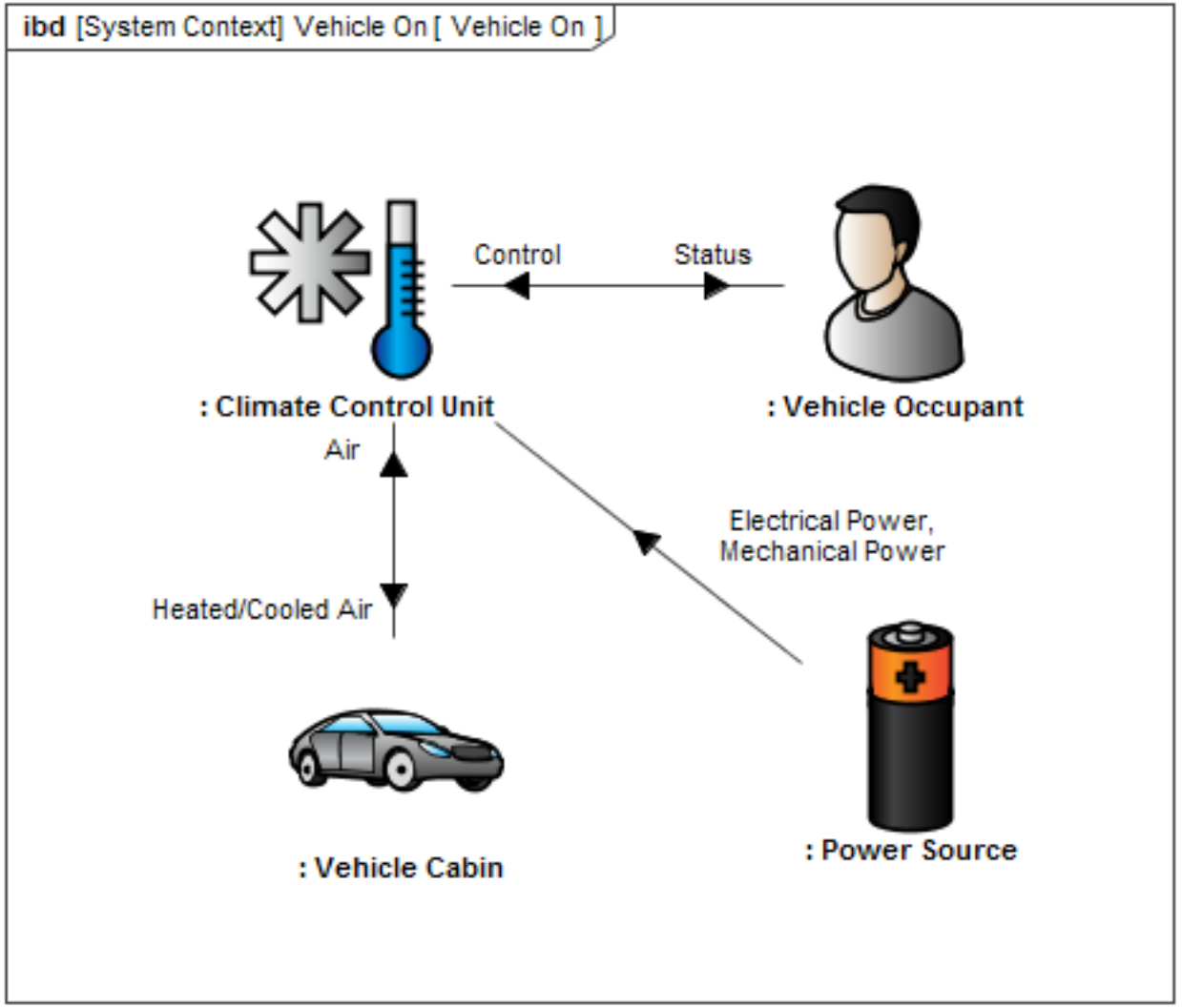


System Context

Domain			Requirements	Behavior	Structure	Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

System Context

- captures how SoI interacts with its environment
- origins of such model can be found in DoDAF, known as High Level Operational Context (HLOC)
- the purpose of the model is to depict high level interfaces needed for the system to communicate with its environment, e.g. GUI, UI, TCP/IP etc.
- can be supplemented with domain concept model

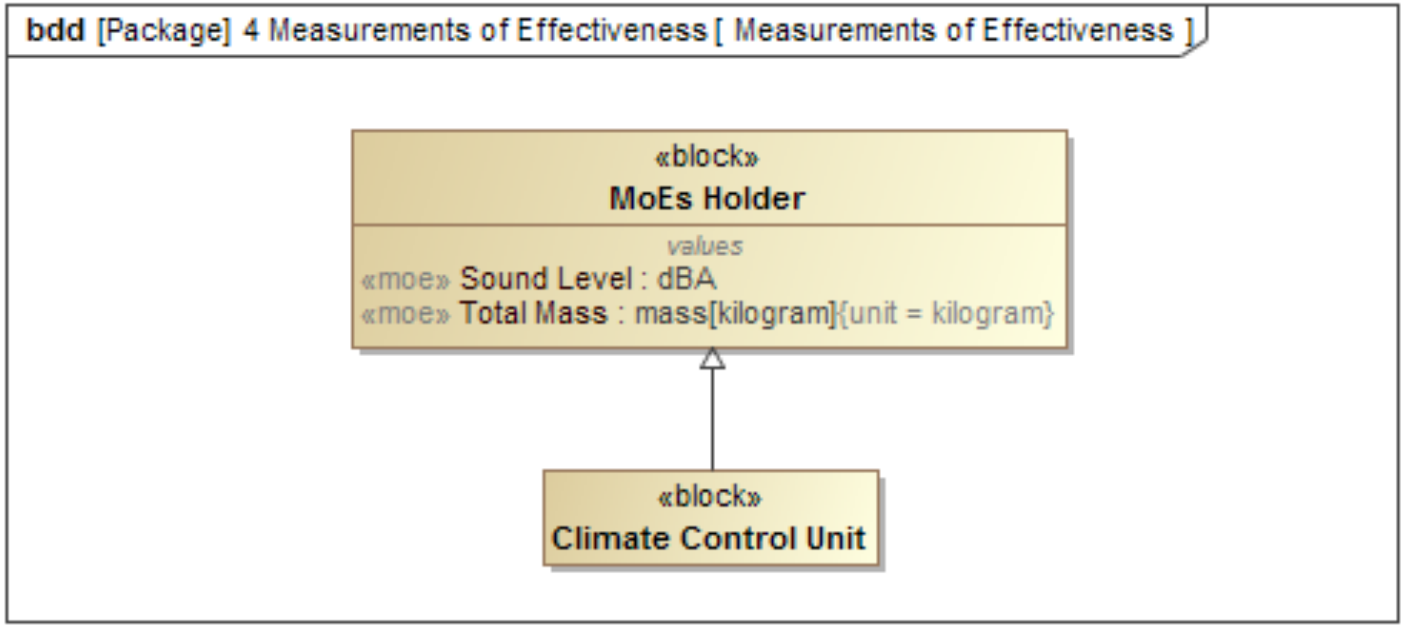


Measurements of Effectiveness

Domain			Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Measurements of Effectiveness

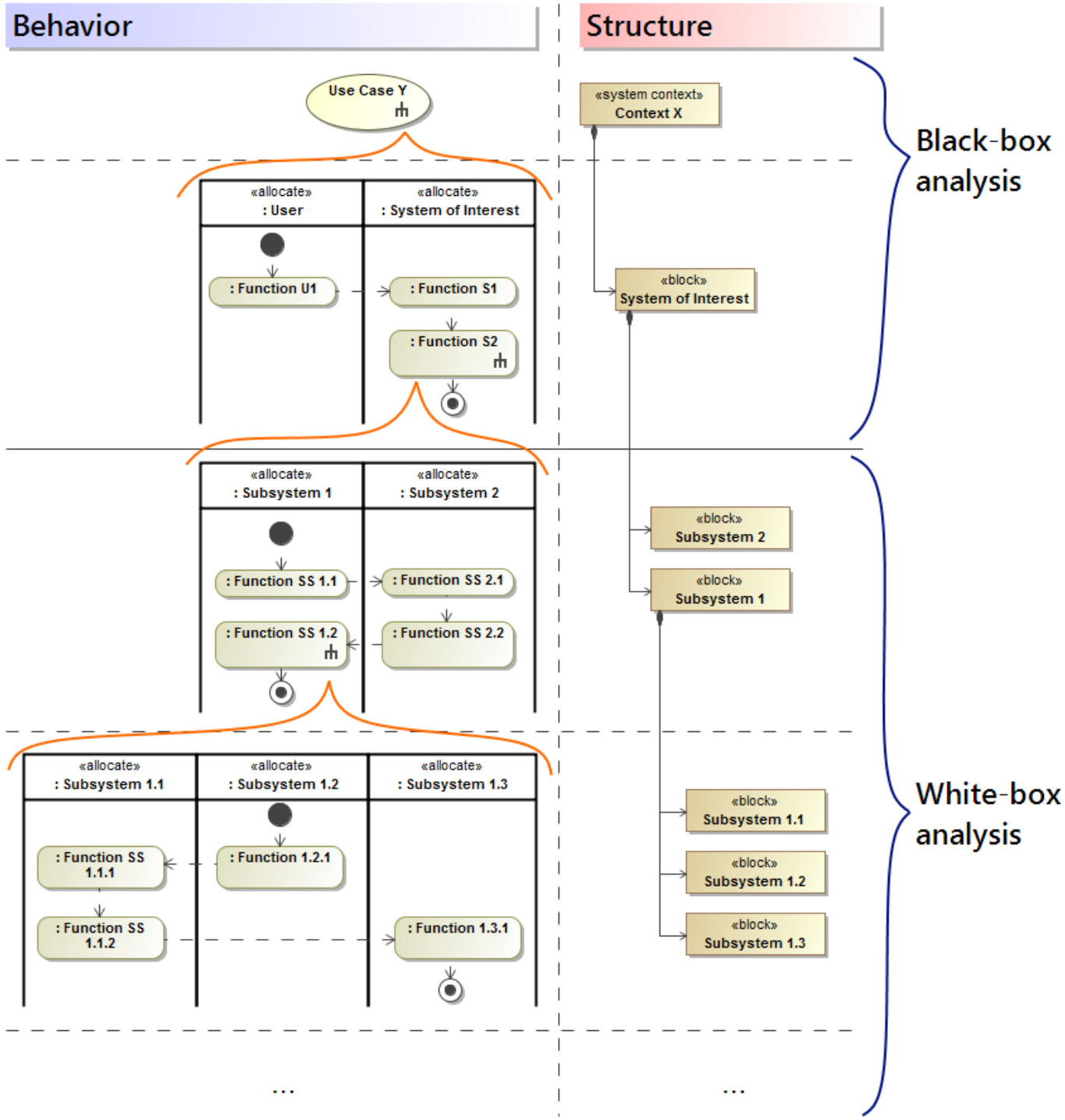
- captures non-functional user set goals for the system expressed in numerical format



Problem Domain: White Box

Domain			Requirements	Behavior	Structure	Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

- White-box perspective, as opposed to the black-box, describes behaviors that are expected from subsystems of the SoI.
- In this perspective, environmental entities, are no longer considered: inputs and outputs of the SoI are delegated to its subsystems
- The result of the white-box analysis is system requirements specification (SRS)


Behavior
Structure
Use Case Y
«system context»
Context X
«allocate»
: User
«allocate»
: System of Interest
: Function U1
: Function S1
: Function S2
«block»
System of Interest
Black-box
analysis
«allocate»
: Subsystem 1
«allocate»
: Subsystem 2
: Function SS 1.1
: Function SS 2.1
: Function SS 1.2
: Function SS 2.2
«block»
Subsystem 2
«block»
Subsystem 1
«allocate»
: Subsystem 1.1
«allocate»
: Subsystem 1.2
«allocate»
: Subsystem 1.3
: Function SS
1.1.1
: Function 1.2.1
: Function SS
1.1.2
: Function 1.3.1
«block»
Subsystem 1.1
«block»
Subsystem 1.2
«block»
Subsystem 1.3
White-box
analysis
...
...

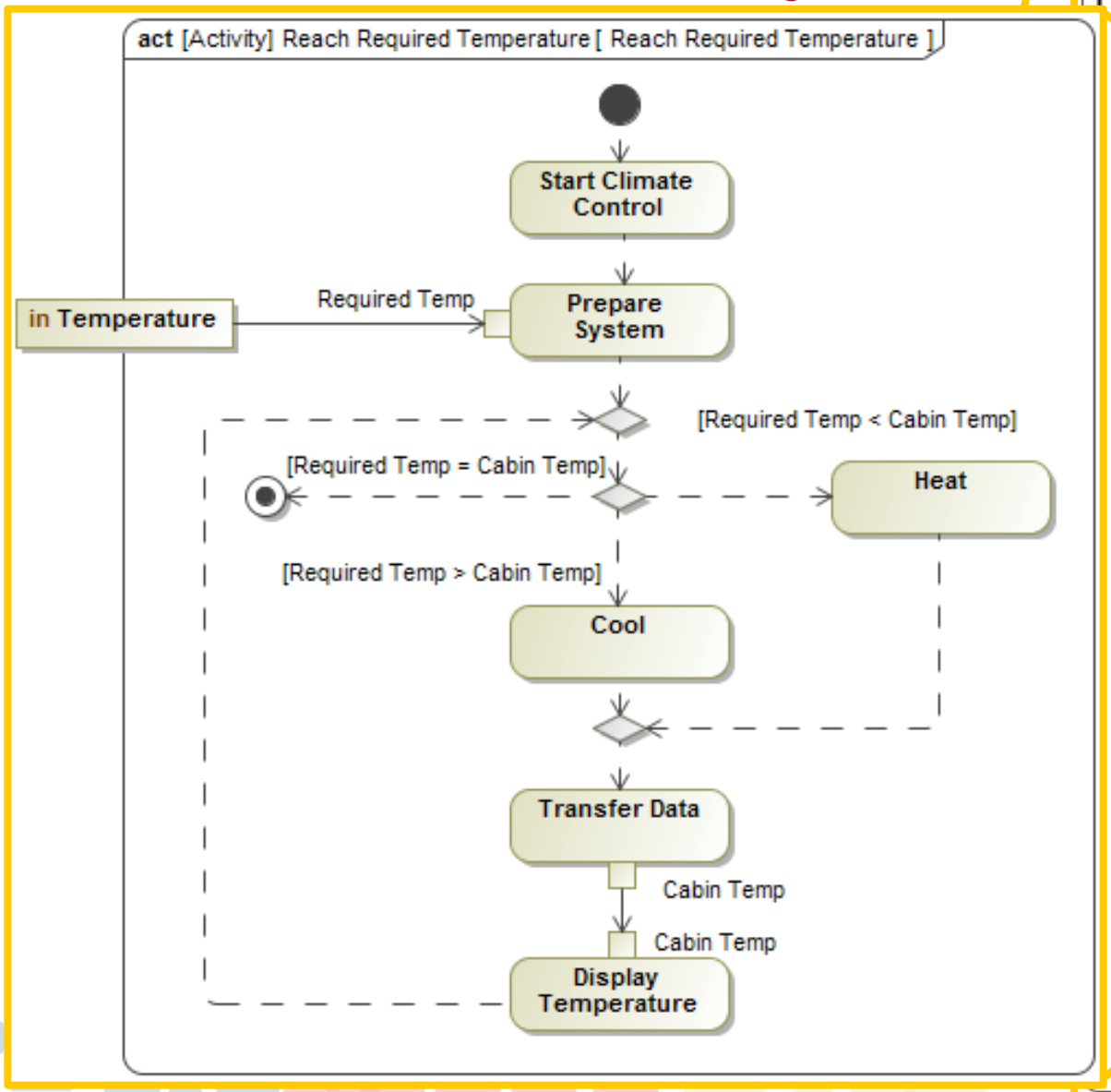
Functional Analysis

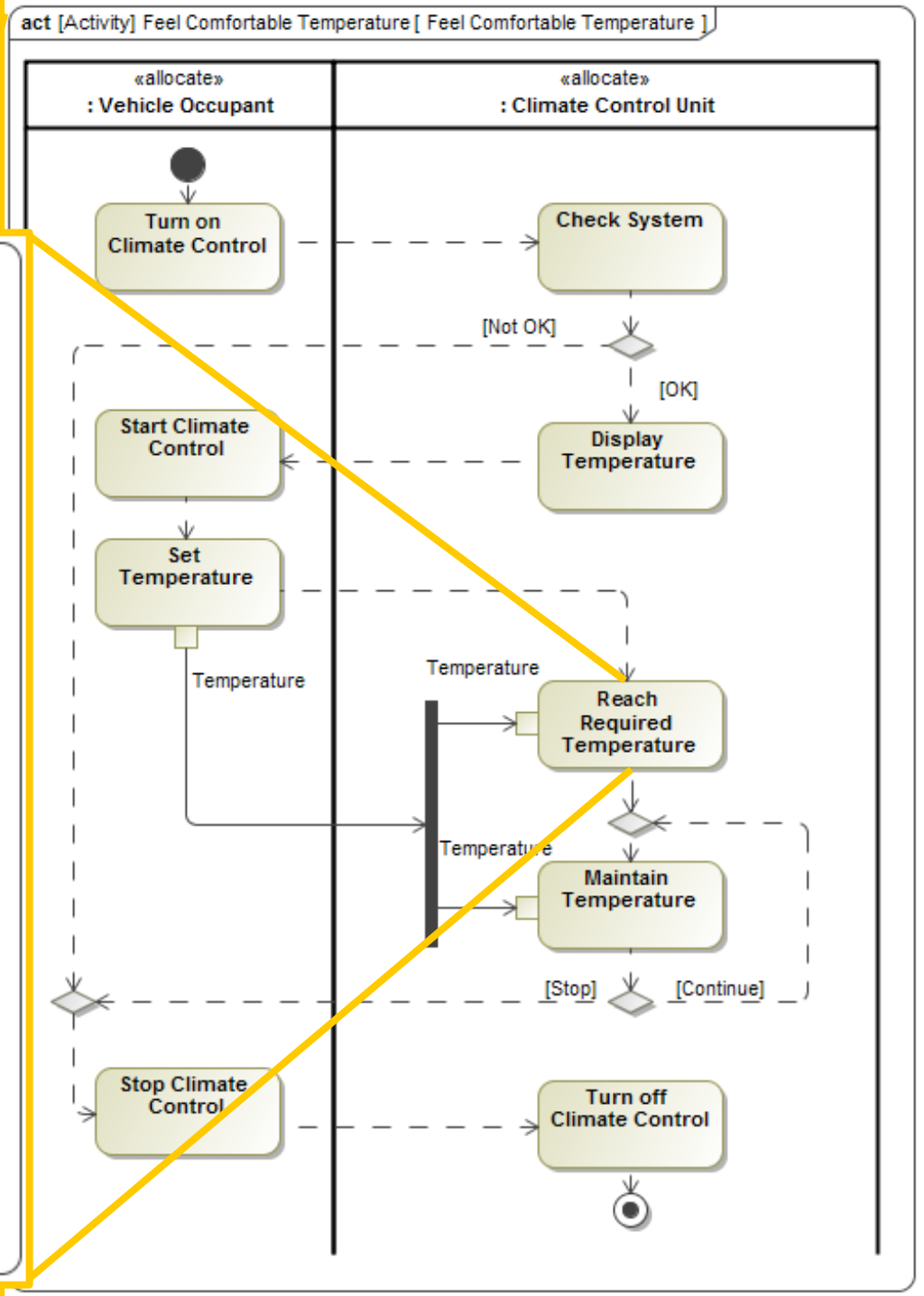
Domain		Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Functional Analysis

- continuation of functional use case analysis, where focus is internal system functions in some of the techniques known as processes
- functional analysis serves for identification of logical subsystems responsible for a group of functions

Functional Analysis

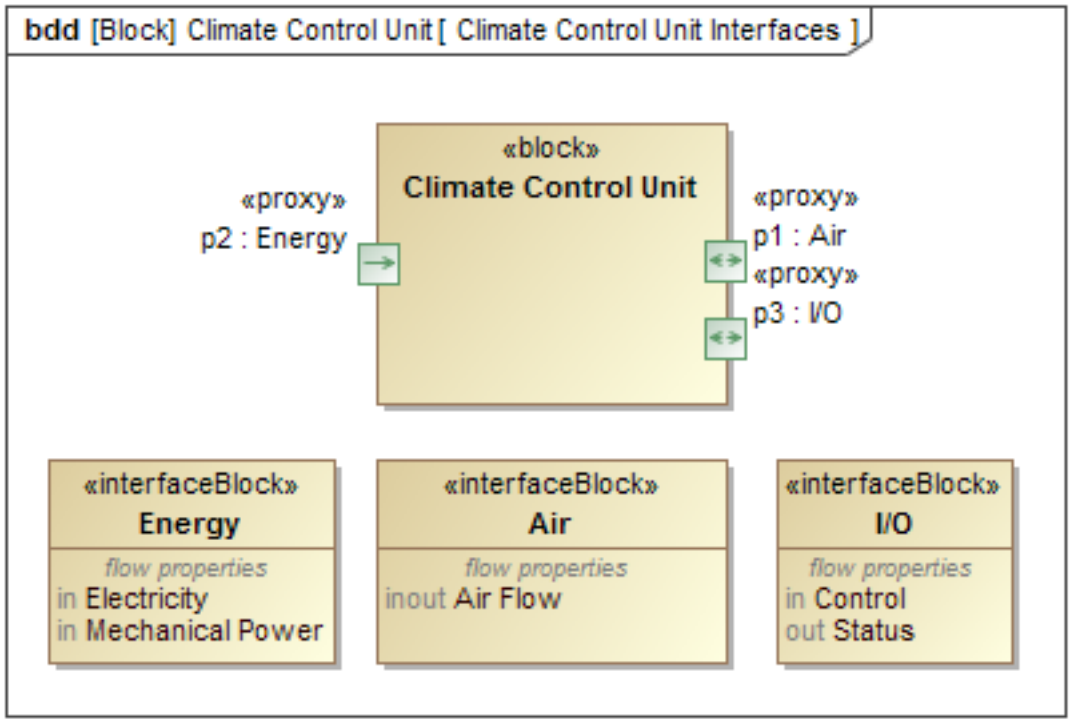




Logical Subsystems Communication

Domain		Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Logical Subsystems Communication



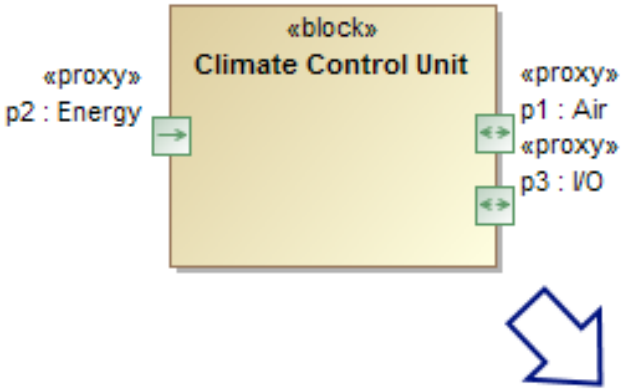
Criteria

Element Type: Port ... Block: Climate Control Uni ...

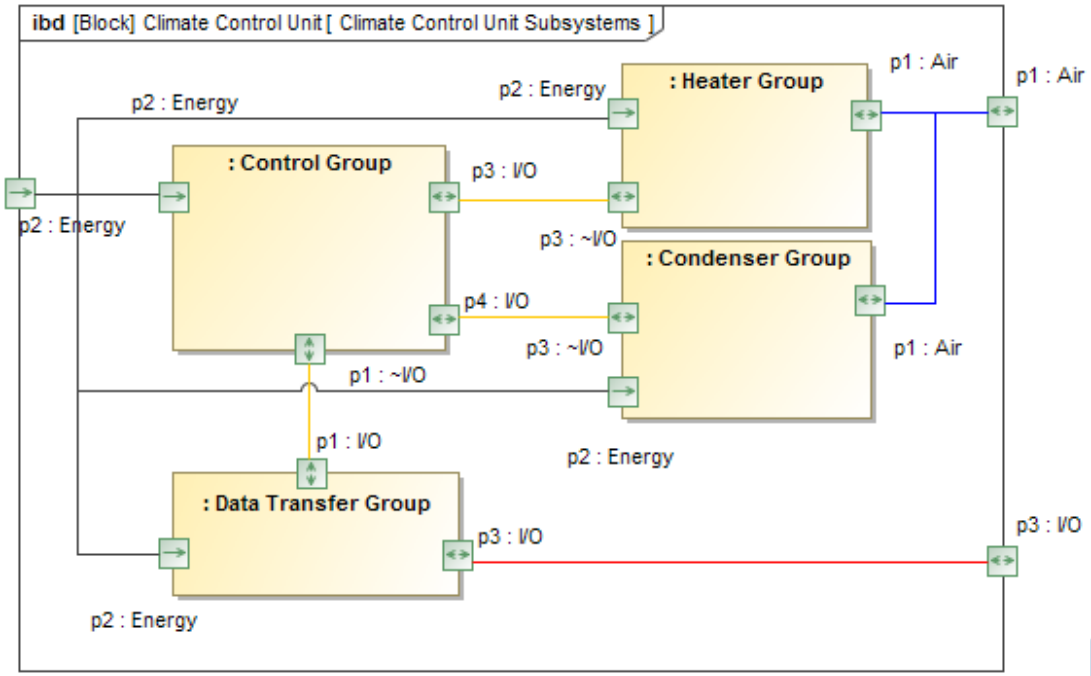
#	Port Name	Port Type	Type Features	Direction
1	p1	Air	F inout Air Flow	inout
2	p2	Energy	F in Electricity F in Mechanical Power	in
3	p3	I/O	F in Control F out Status	inout

- logical interfaces are identified and defined.
- interface control documents (ICD) can be generated.

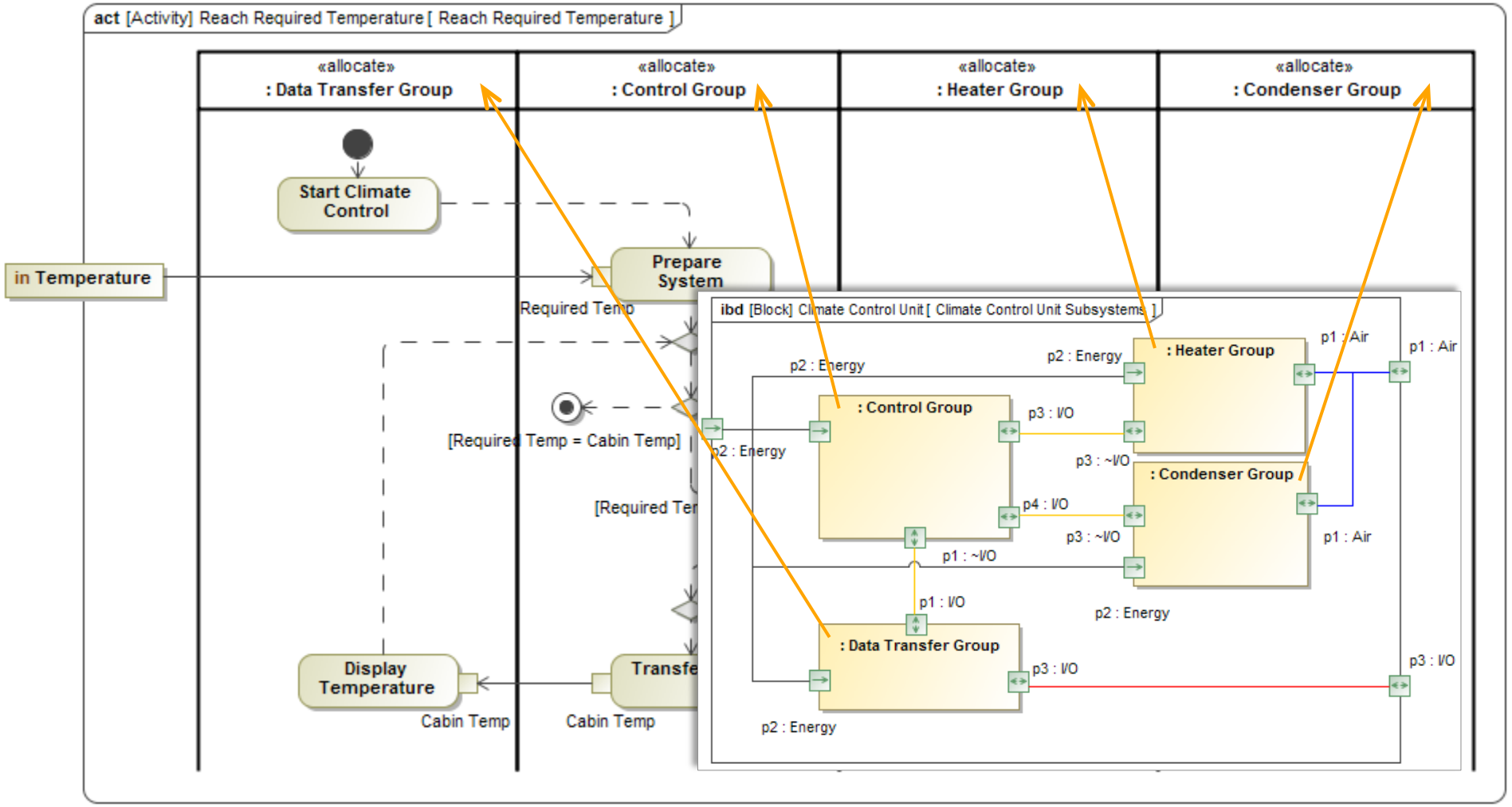
Logical Subsystems Communication



- identified logical subsystems, based on the control and resource flows captured in the functional analysis model, are connected with one another in terms of logical interfaces.



Logical Subsystems Communication



MoEs for Subsystems

Domain		Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

MoEs for Subsystems

- In this cell, MoEs for one or more subsystems of the SoI are specified to make further refinements of non-functional stakeholder needs
- This cell is optional, as you might not need to specify MoEs additional to those defined for SoI

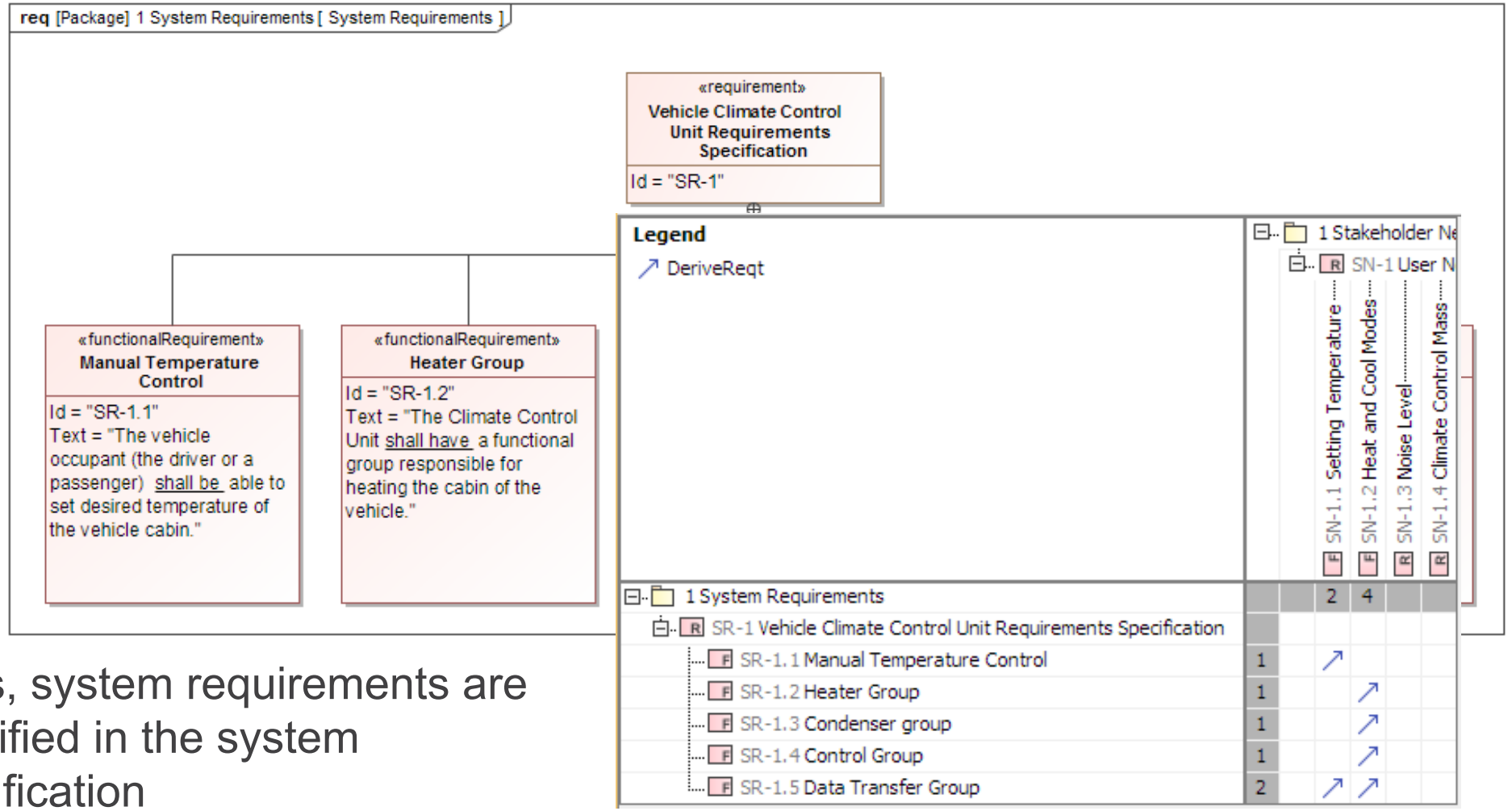
System Requirements

Domain			Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

System Requirements

Inputs:

- user needs
- functional analysis
- logical interfaces
- MoEs.

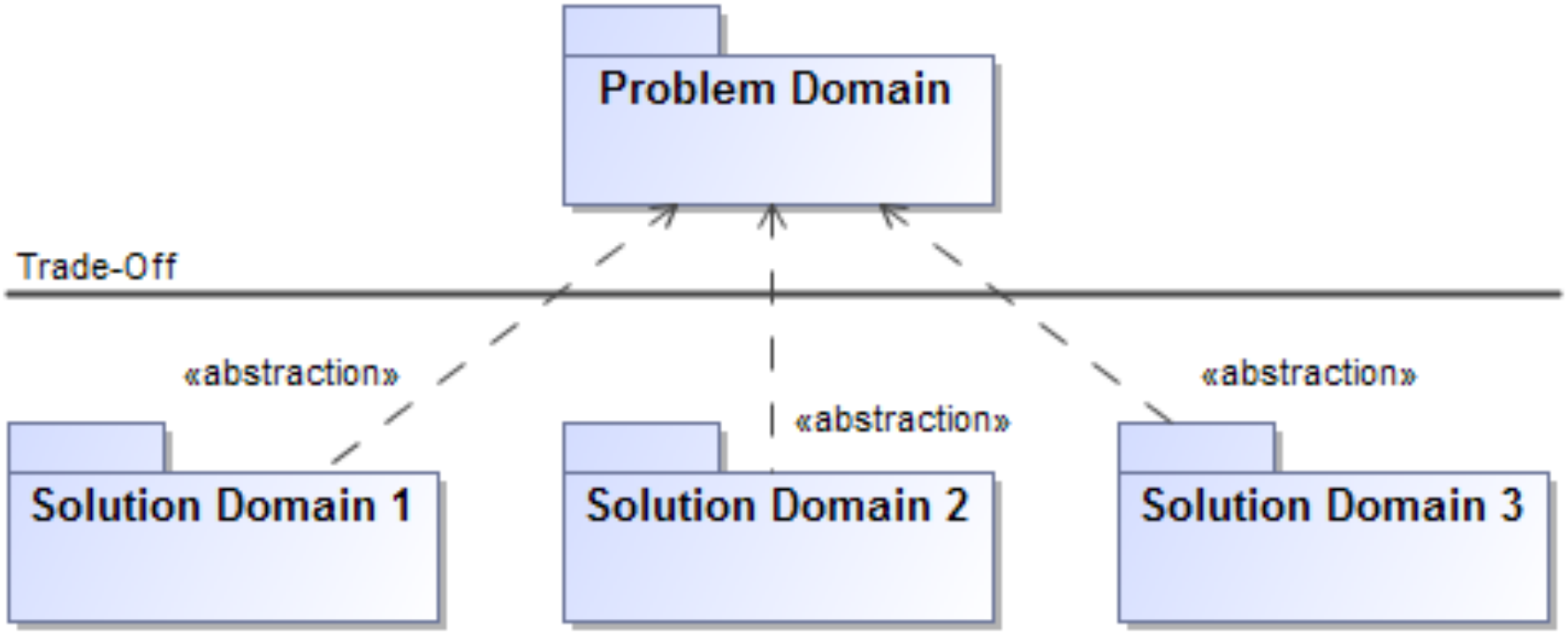


- by analysing inputs, system requirements are identified and specified in the system requirements specification

Solution Domain

Domain			Requirements	Behavior	Structure	Parametrics
	Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
		White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
	Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

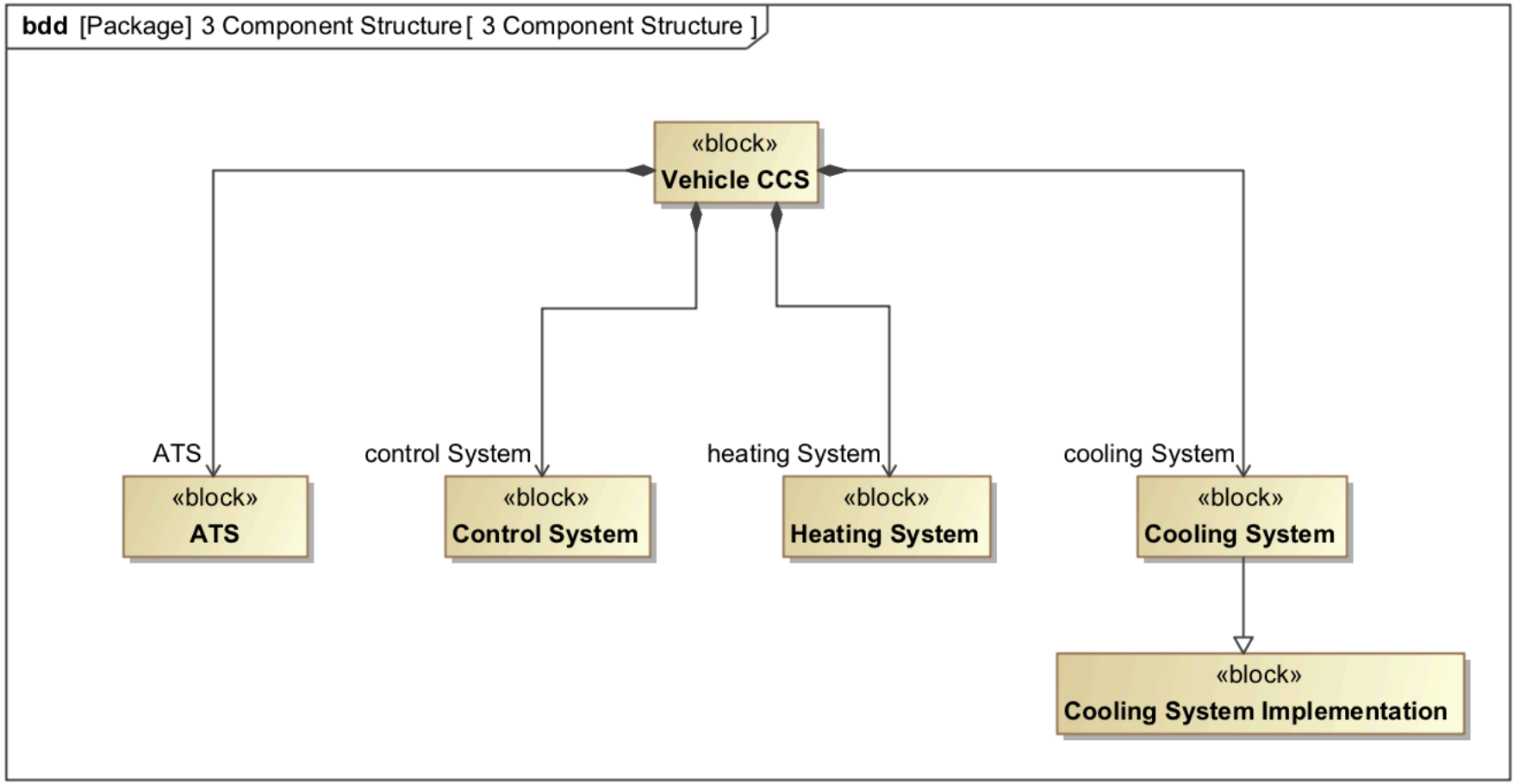
Trade-off Analysis



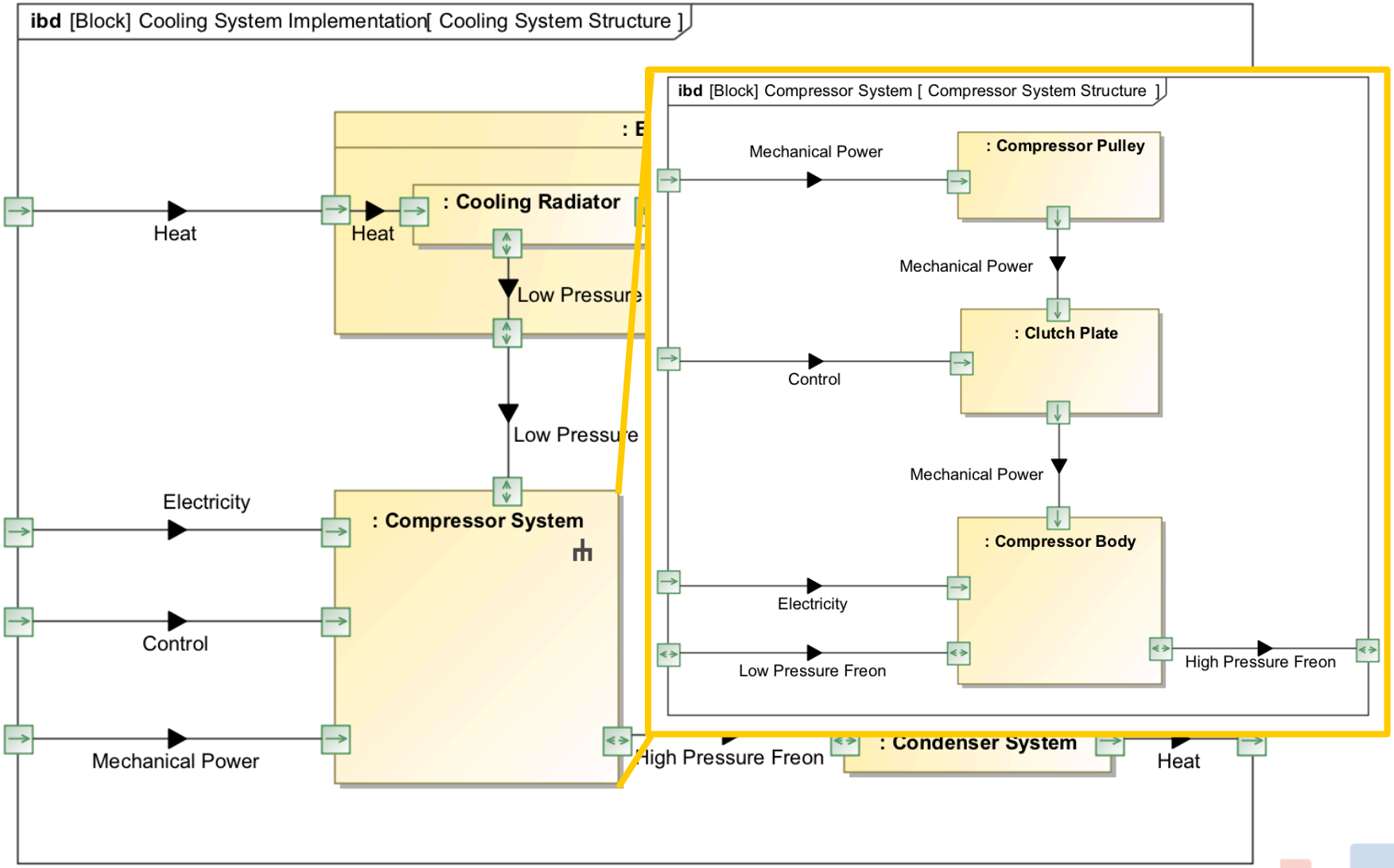
Component Structure

Domain			Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Component Structure



Component Structure

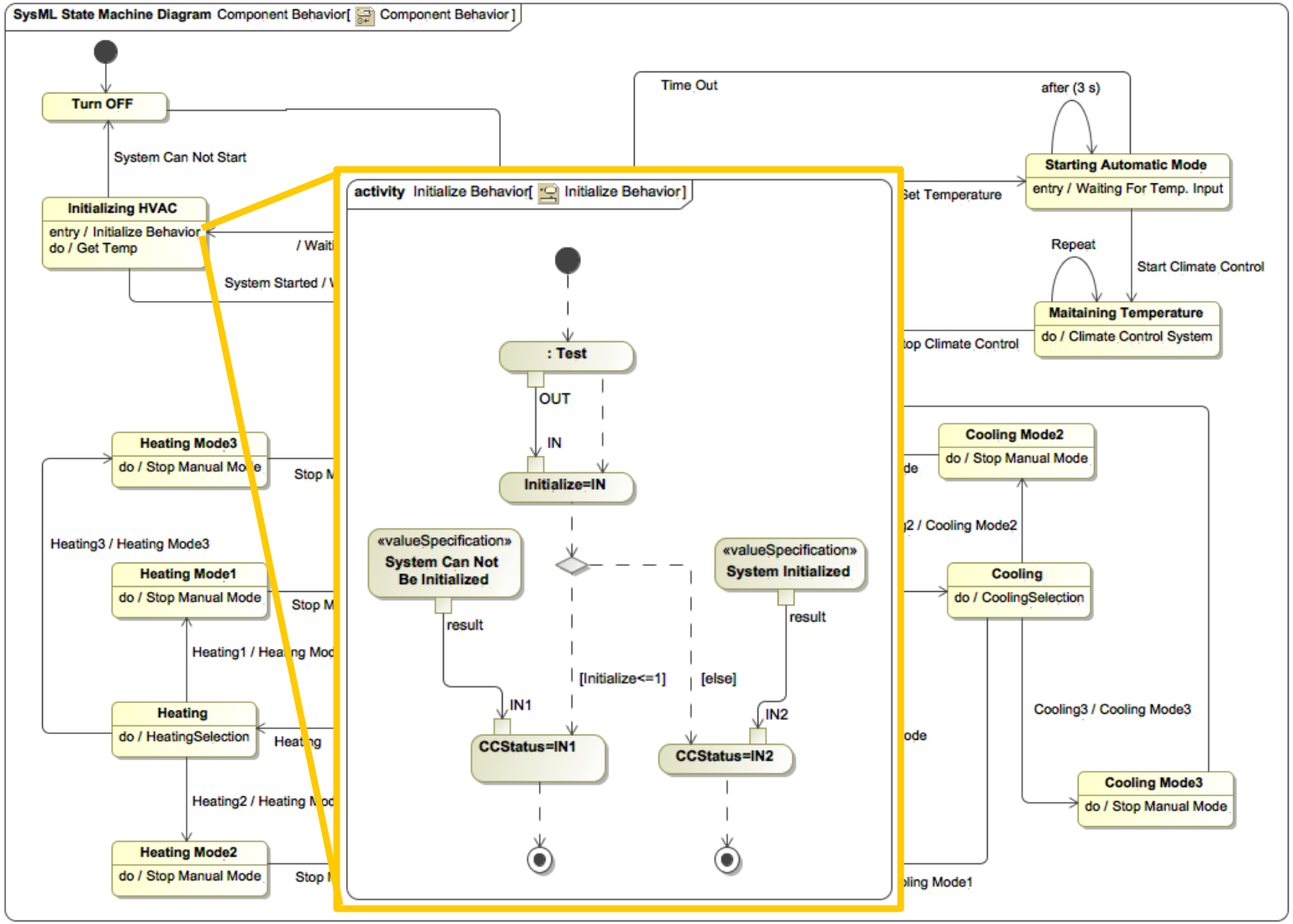


Component Behavior

Domain			Requirements	Behavior	Structure	Parametrics
Problem	Black Box		**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box		**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution			**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Component Behavior

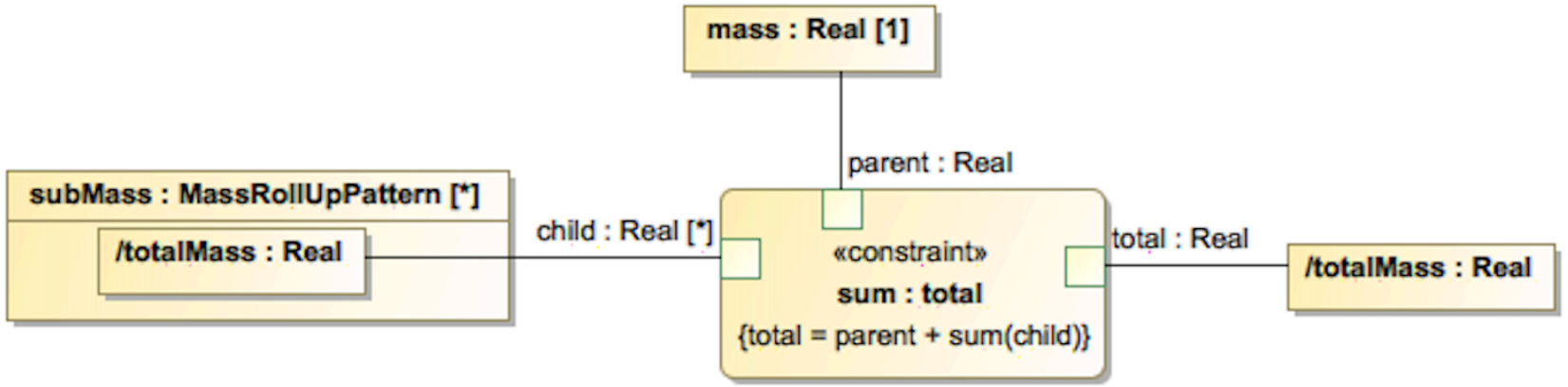
- captures a detailed behaviour of a system/ subsystem/component defining its states and actions, e.g. algorithm, operation call, signal handling, etc.
- a detailed behaviour is a subject of simulation.



Component Parameters

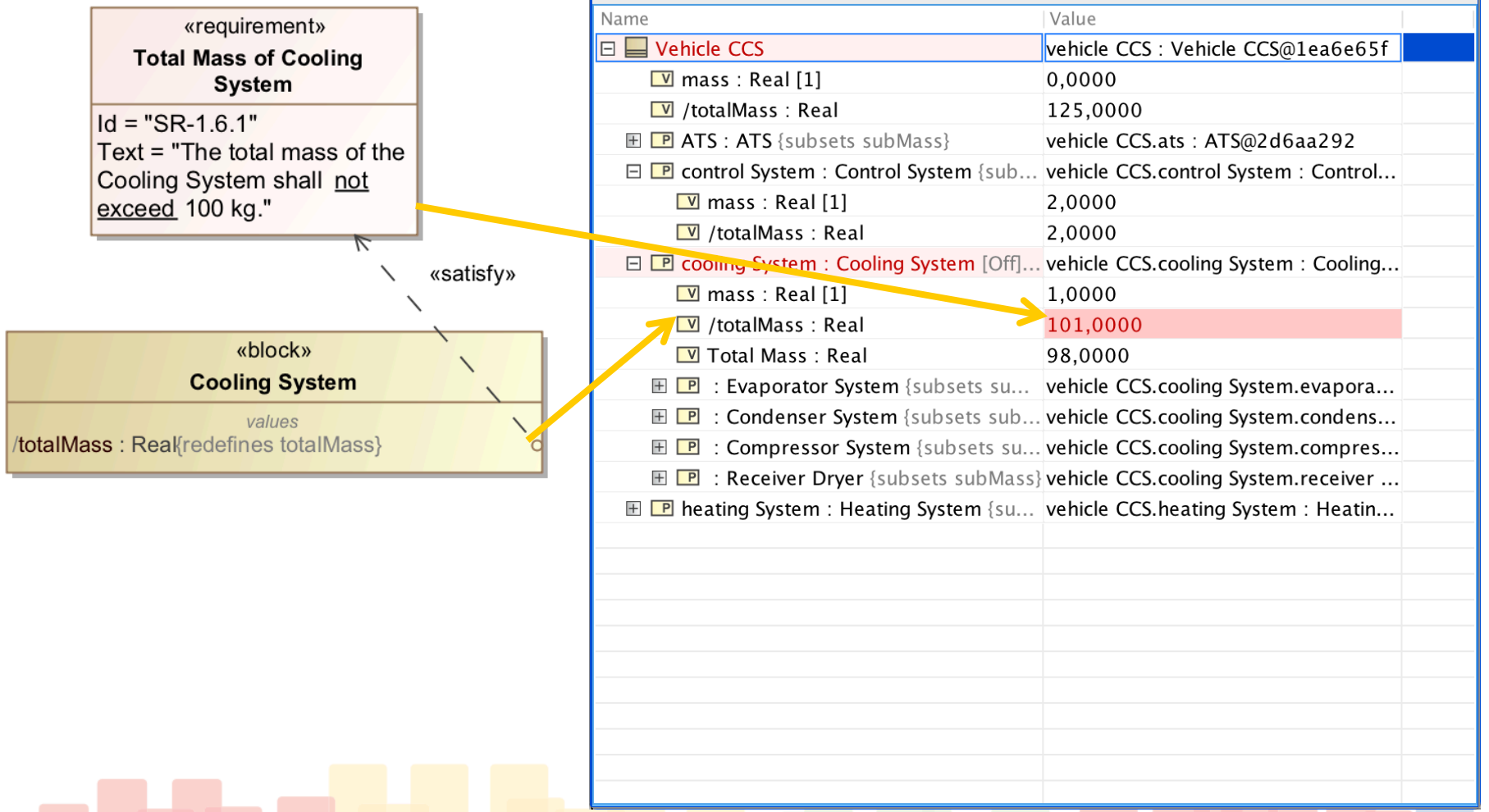
Domain		Pillar: Requirements	Pillar: Behavior	Pillar: Structure	Pillar: Parametrics
Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
Problem	White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Component Parameters



#	Name	totalMass : Real	mass : Real
1	vehicle CCS	125.0	0.0
2	vehicle CCS.ats	10.0	10.0
3	vehicle CCS.cooling System	101.0	1.0
4	vehicle CCS.cooling System.evaporator System	15.0	0.0
5	vehicle CCS.cooling System.evaporator System.metering Orifice	7.0	7.0
6	vehicle CCS.cooling System.evaporator System.cooling Radiator	8.0	8.0
7	vehicle CCS.cooling System.condenser System	20.0	20.0
8	vehicle CCS.cooling System.compressor System	63.0	0.0
9	vehicle CCS.cooling System.compressor System.compressor Pulley	14.0	14.0
10	vehicle CCS.cooling System.compressor System.clutch Plate	14.0	14.0
11	vehicle CCS.cooling System.compressor System.compressor Body	35.0	35.0
12	vehicle CCS.cooling System.receiver Dryer	2.0	2.0
13	vehicle CCS.heating System	12.0	12.0
14	vehicle CCS.control System	2.0	2.0

Component Parameters

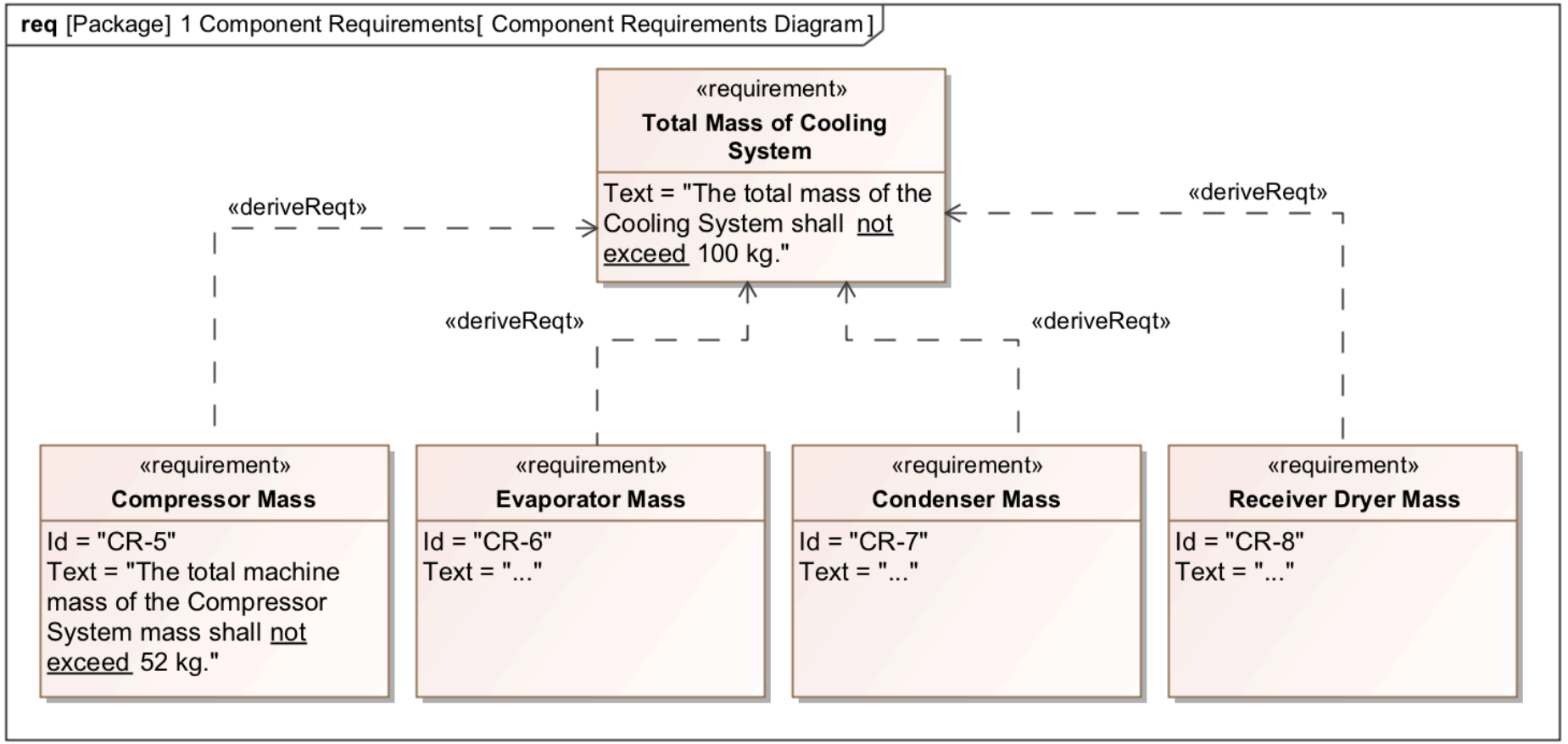


Component Requirements

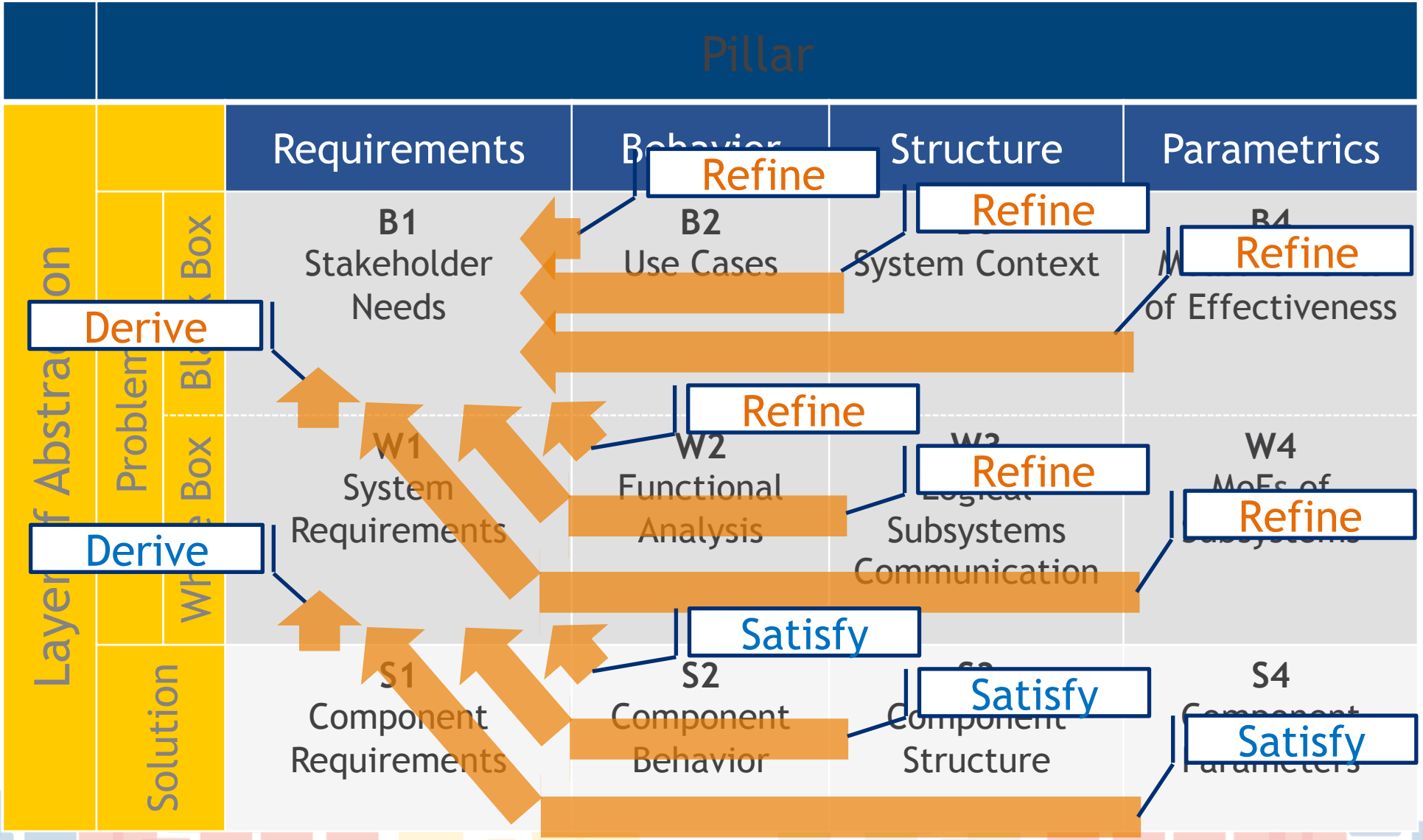
Domain			Requirements	Behavior	Structure	Parametrics
	Problem	Black Box	**B1** Stakeholder Needs	**B2** Use Cases	**B3** System Context	**B4** Measurements of Effectiveness
		White Box	**W1** System Requirements	**W2** Functional Analysis	**W3** Logical Subsystems Communication	**W4** MoEs of Subsystems
	Solution		**S1** Component Requirements	**S2** Component Behavior	**S3** Component Structure	**S4** Component Parameters

Component Requirements

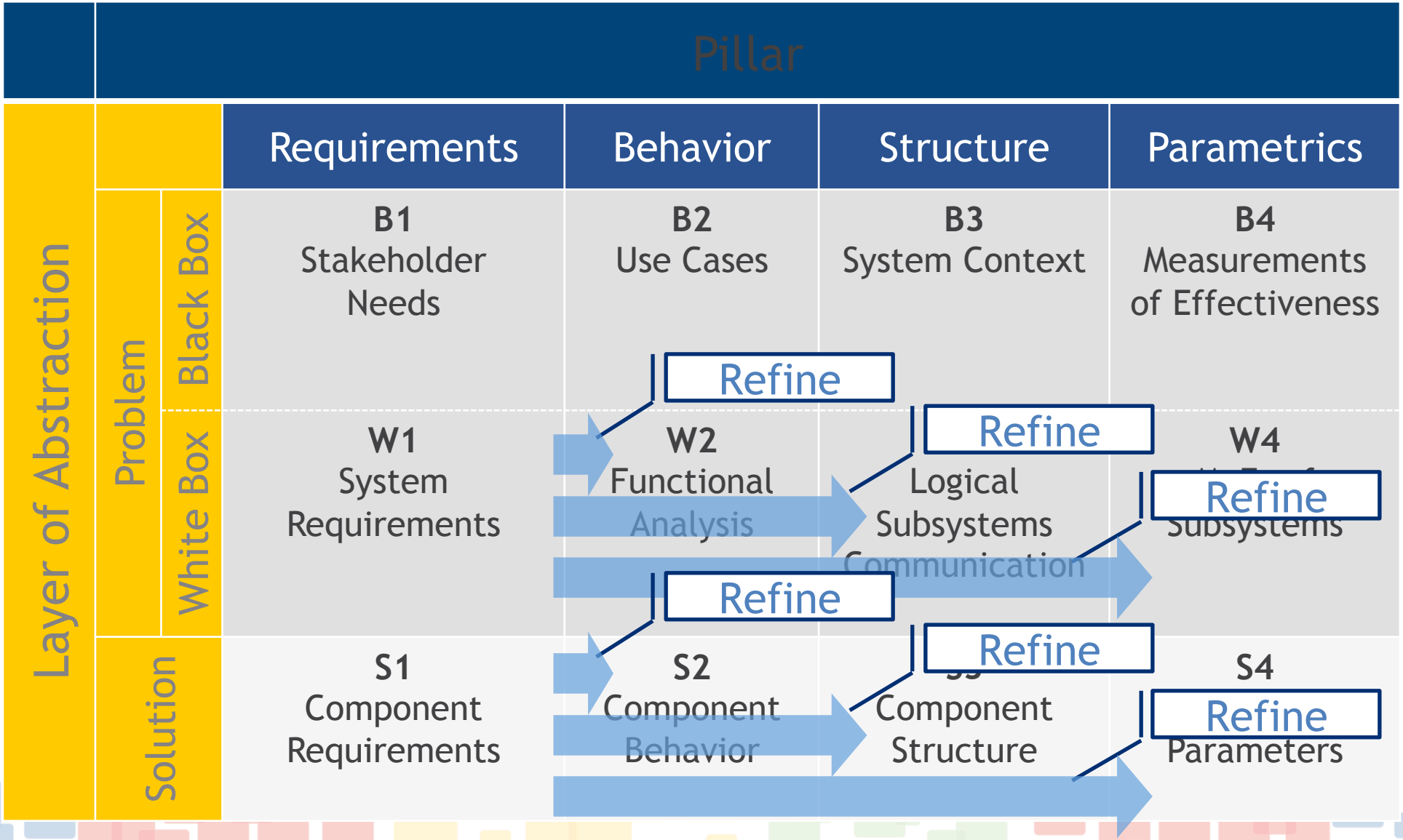
- captures detailed requirements for every identified subsystem/ component
- component requirements are derived from system requirements



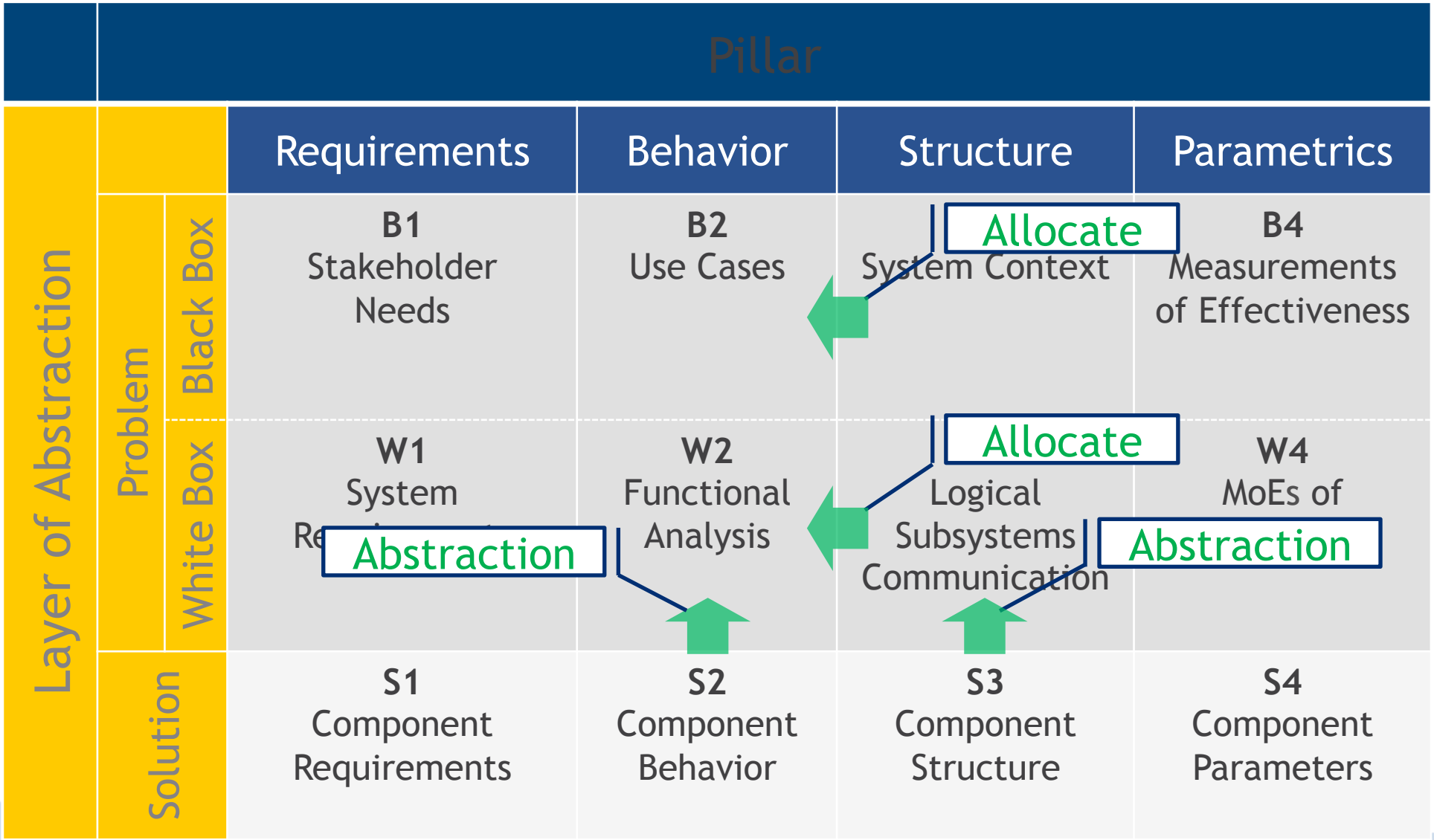
Requirements Traceability



Requirements Traceability



Architecture Traceability



Conclusions and future works

- Analysis of MBSE methods and enterprise architecture frameworks discloses that majority of them are conceptual and thus can hardly be used in combination with systems modeling techniques, such as SysML, in practice.
- In contrast to them, the MBSE Grid approach proposed in this paper is fully compatible with SysML. Based on the transparent system architecture framework,
  - it clearly defines the modeling process
  - reveals what model artifacts should be produced in each step of system specification and design
  - explains how to manage traceability relationships (both horizontal and vertical).
- The case study later in this paper proves applicability of MBSE Grid in combination with MagicDraw toolset, which supports SysML.
- Currently, the MBSE Grid approach is mainly oriented to the creation of a system model. Thus, it will be extended to include support of system variants, engineering analysis, and verification & validation.
- In the farther future, the approach is considered to support a full model lifecycle management, including its creation, usage, and configuration management.

Aurelijus Morkevičius, PhD,
Head of Solutions @ No Magic
aurelijus.morkevicius@nomagic.com

Thank You!

Questions???