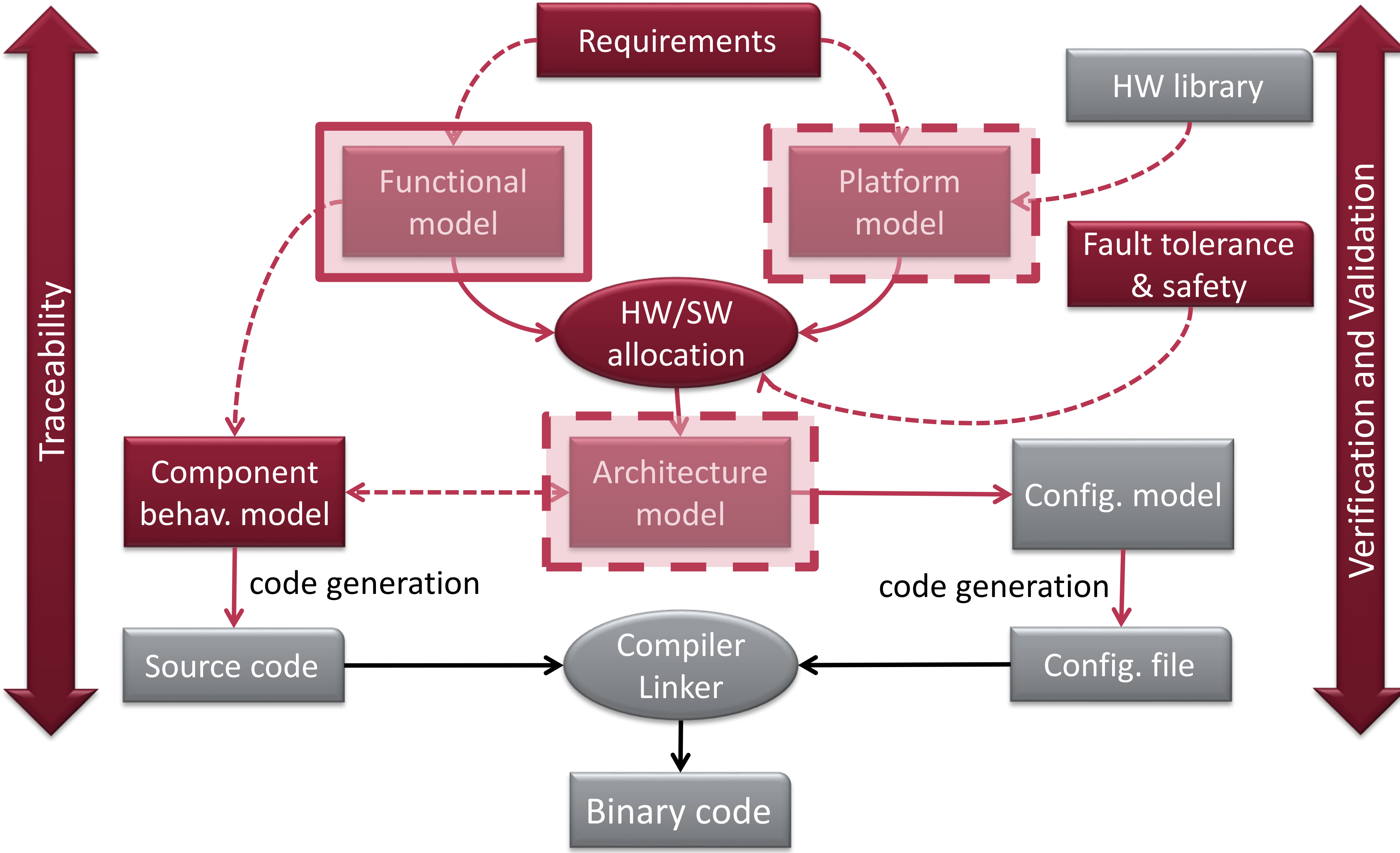
Component Design

Systems Engineering BSc Course

Platform-based systems design



Learning Objectives

Structural modeling

- Understand the **basic notions** of structural modeling in systems engineering
- Understand the role and major **challenges of designing functional architecture**
- Understand **top-down and bottom-up** approaches and when to use them

Blocks as reusable components

- Identify the functional components
- Identify the hierarchical relations between components
- Capture components using the SysML language
- Traceability of functional components
- Modeling component variants and specific instances

Internal structure of blocks

- Identify the communication aspects between components
- Understand the concepts of standard ports and flow ports

Structural Modeling Basics

(As you may recall from the **System Modeling** course...)

- A **Structural Model** is concerned with:
  - which elements form the system,
  - how they are connected/related to each other,
    - especially part-whole relationships (not necessarily physical)
  - and the properties these elements have.
- Examples from information technology
  - Data structures
  - SW components, microservices
  - Network structure
  - SW components running on HW platform

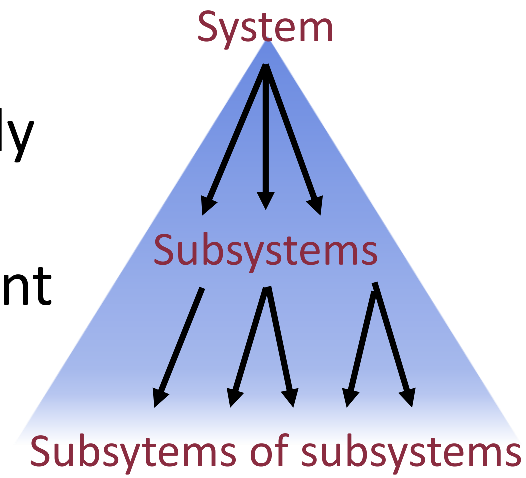
Structural Modeling Basics

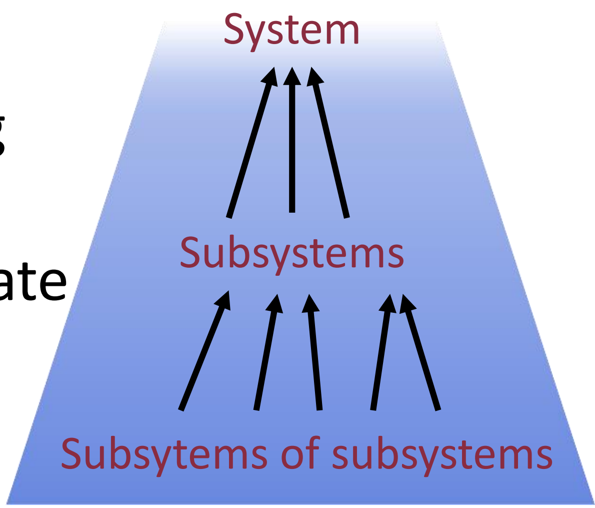
(As you may recall from the **System Modeling** course...)

- A **composite (sub)system** contains elements...
  - ...arranged in a specific way...
  - ...to attain a goal...
  - ...that the individual parts cannot satisfy on their own
- Engineering processes that build structural models
  - **Composition**: building a complex solution from an appropriate arrangement of simpler elements
  - **Decomposition** or **factoring**: breaking up a complex problem or system into simpler parts

Top-down and bottom-up design

- Top-down: using decomposition
  - ☺ When designing a subsystem, its goal is already known
  - ☹ There are no working parts during development
  - ☹ Problems, needs of subsystems revealed late
- Bottom-up: using composition
  - ☺ Subsystems can be tested one-by-one
  - ☺ There are always some working parts during development
  - ☹ Exact roles of the subsystems are revealed late
- (Not only in structural modeling…)
- Meet-in-the-middle approach
- Iterative approaches





SW versus HW Modeling

Requirements

Functional model	Platform model

Most common:

Top-down approach

1. High-level components first
2. Refine them to smaller units
3. Design connections & API

Why top-down?

Most common:

Bottom-up approach

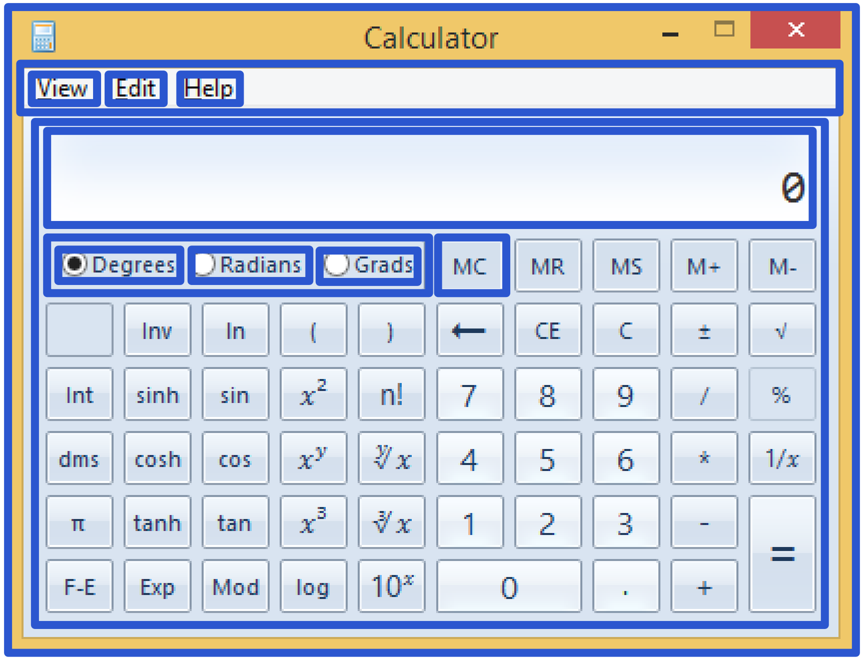
1. HW component library
2. Compose them into larger components
3. Model how they are connected

Why bottom-up?

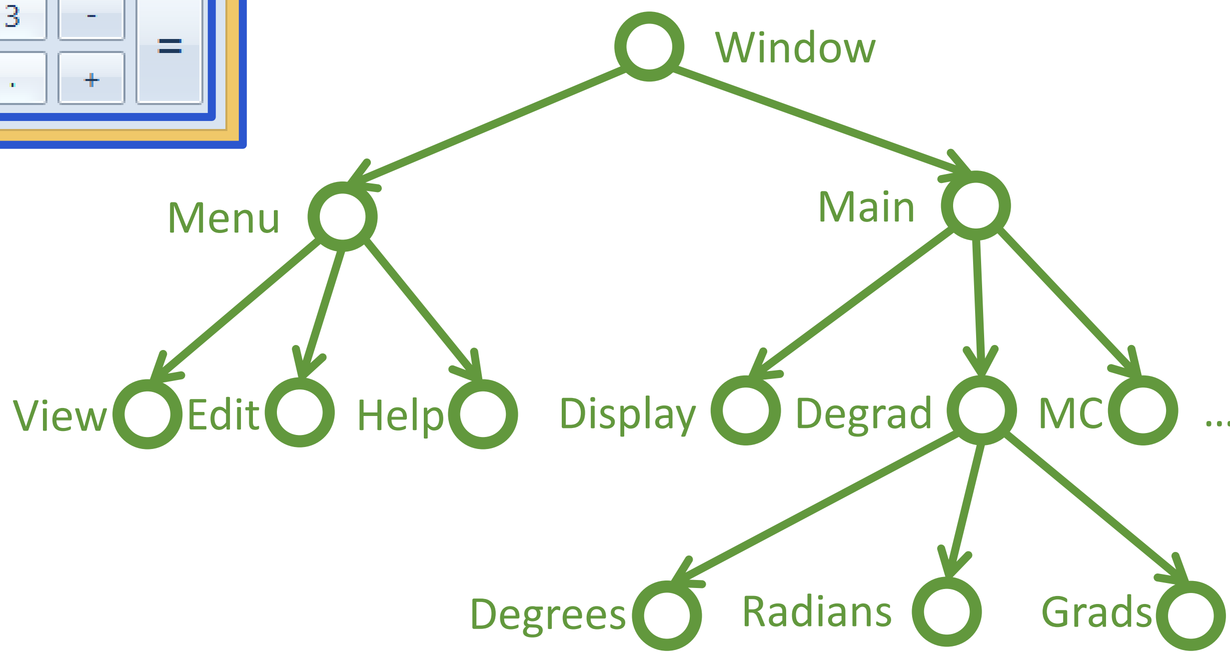
Top-Down Structural Modeling

Iteratively breaking down
complex problems into simpler ones

Graphical User Interface

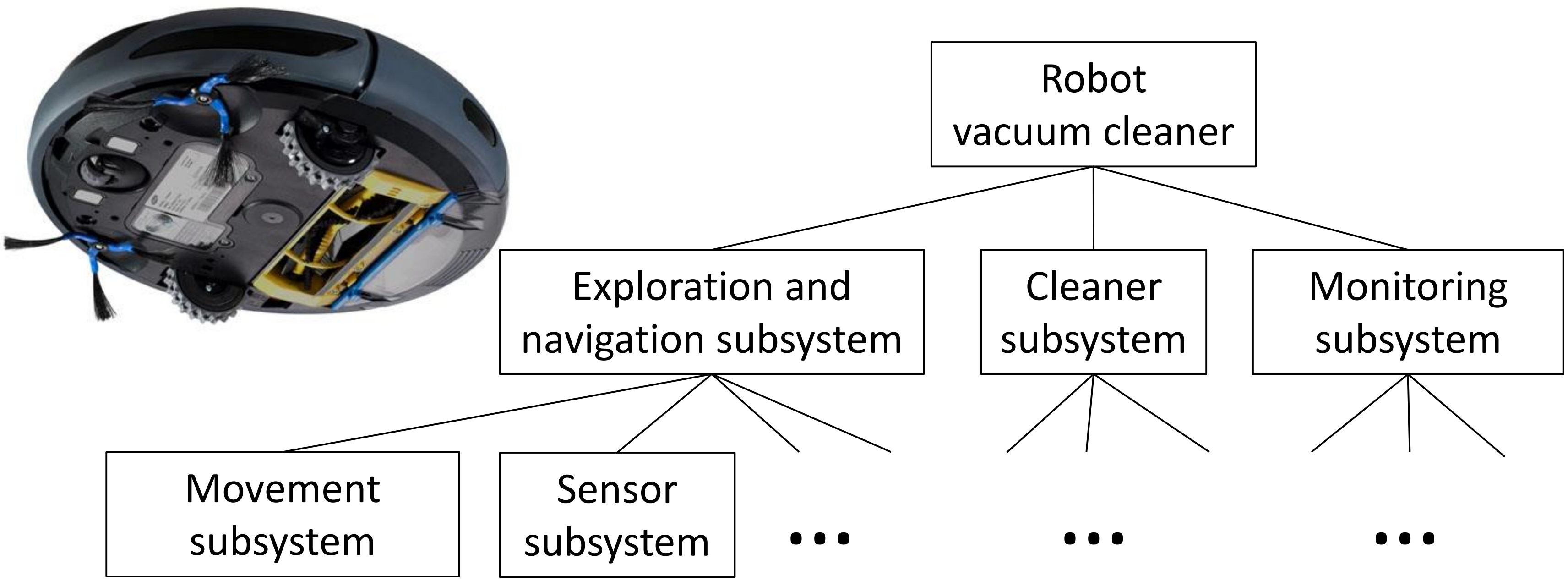


- Top-down design



Embedded System

- **Decomposition** or **factoring:** breaking up a complex problem or system into simpler parts
- Logical decomposition by function (vs. physical)
  - „by function”: what service is provided?



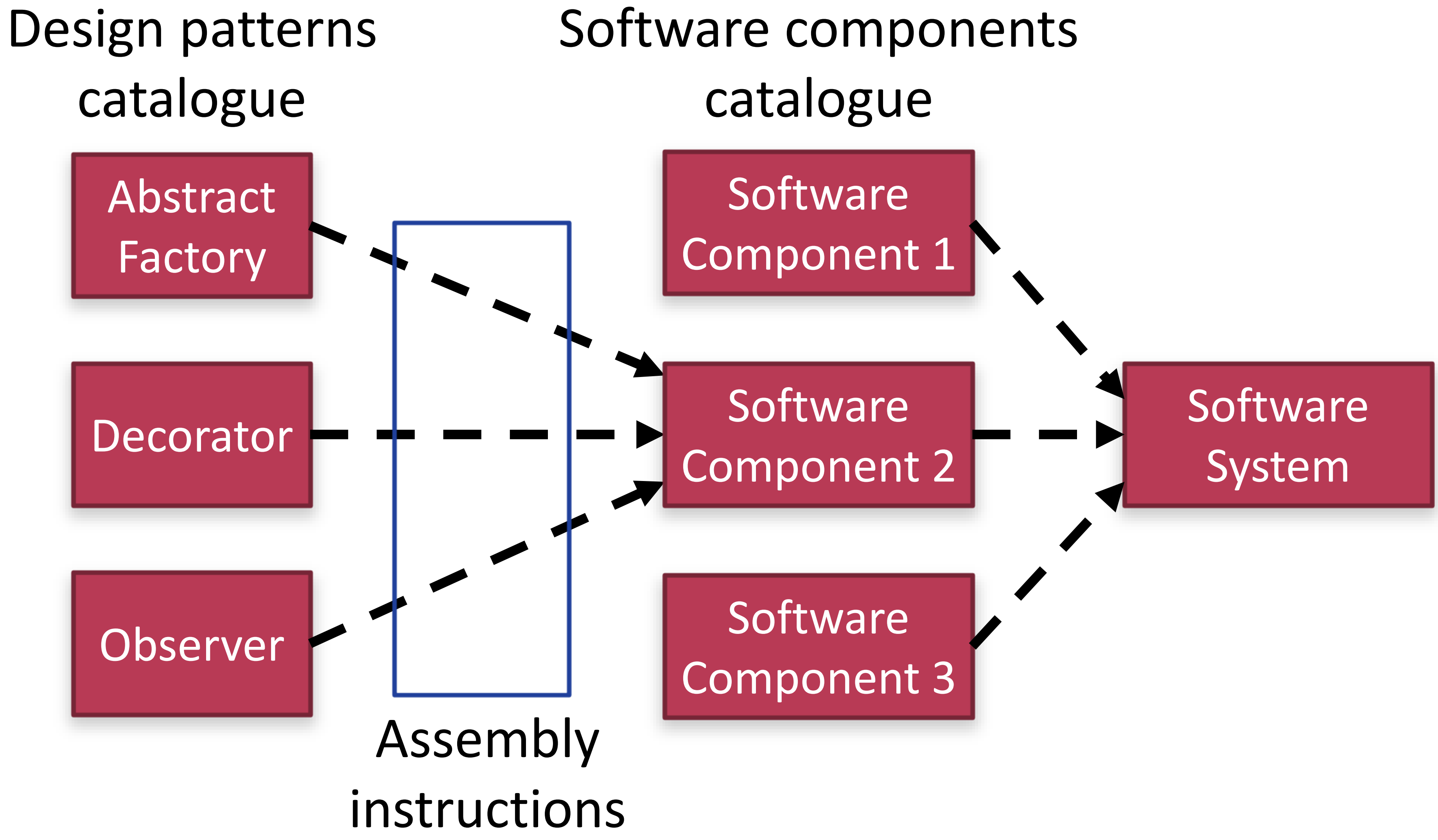
Bottom-Up Structural Modeling

Modeling complex systems
as composites of reusable parts

Composition

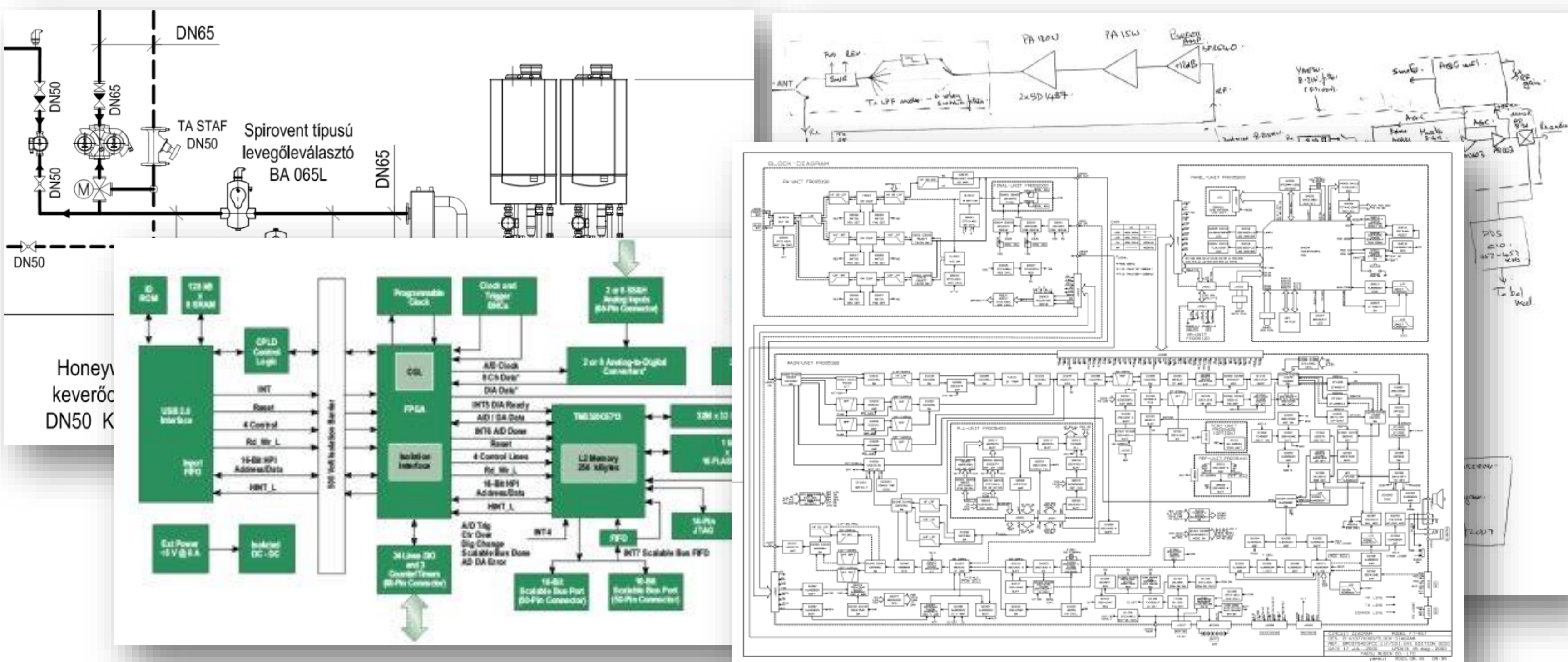
- **Composition**: building a complex solution from an appropriate arrangement of more simple elements
- A **composite (sub)system** contains elements…
  - ...arranged in a specific way…
  - …to attain a goal…
  - …that the individual parts cannot satisfy on their own

Software Development by Design Patterns



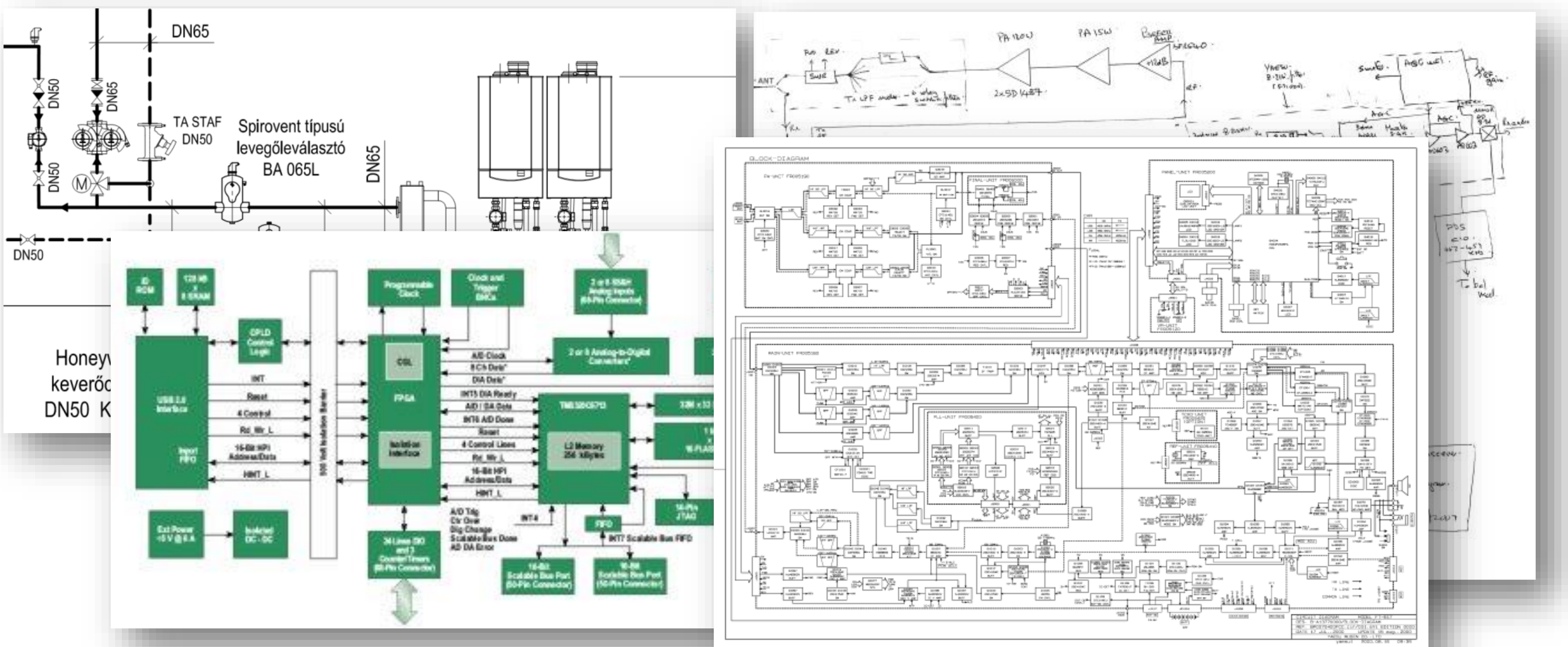
Structural Modeling Roots

- Rich history in a variety of engineering domains
  - Mechanical / hydraulic / chemical / etc.
  - Software and hardware systems
  - **Hybrid systems**



Structural Modeling Roots

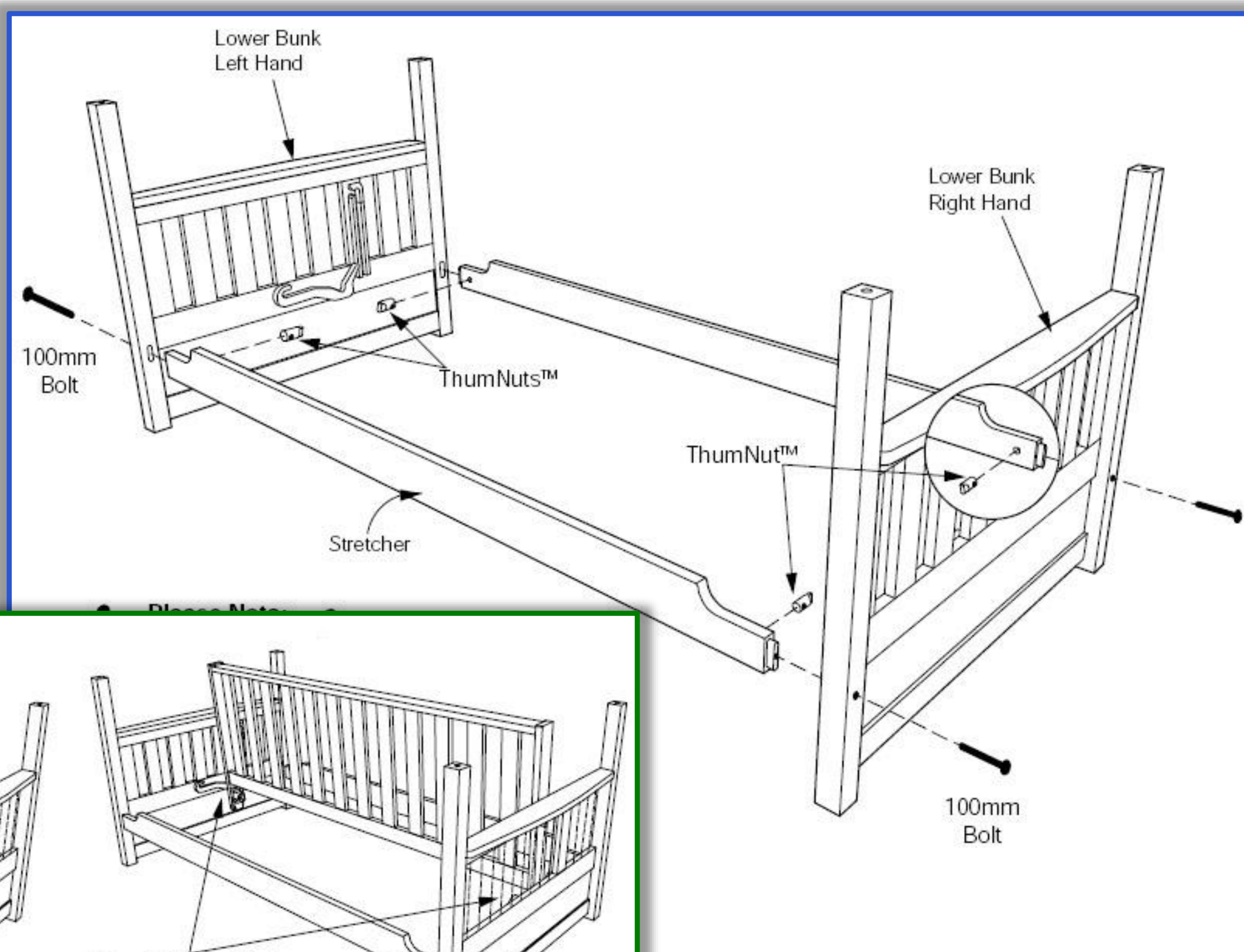
- Composition from *building blocks*…
  - …by hand or with CAD tools (e.g. Matlab Simulink)
  - **Block**: reusable component/subsytem
    with **properties** and **connections**



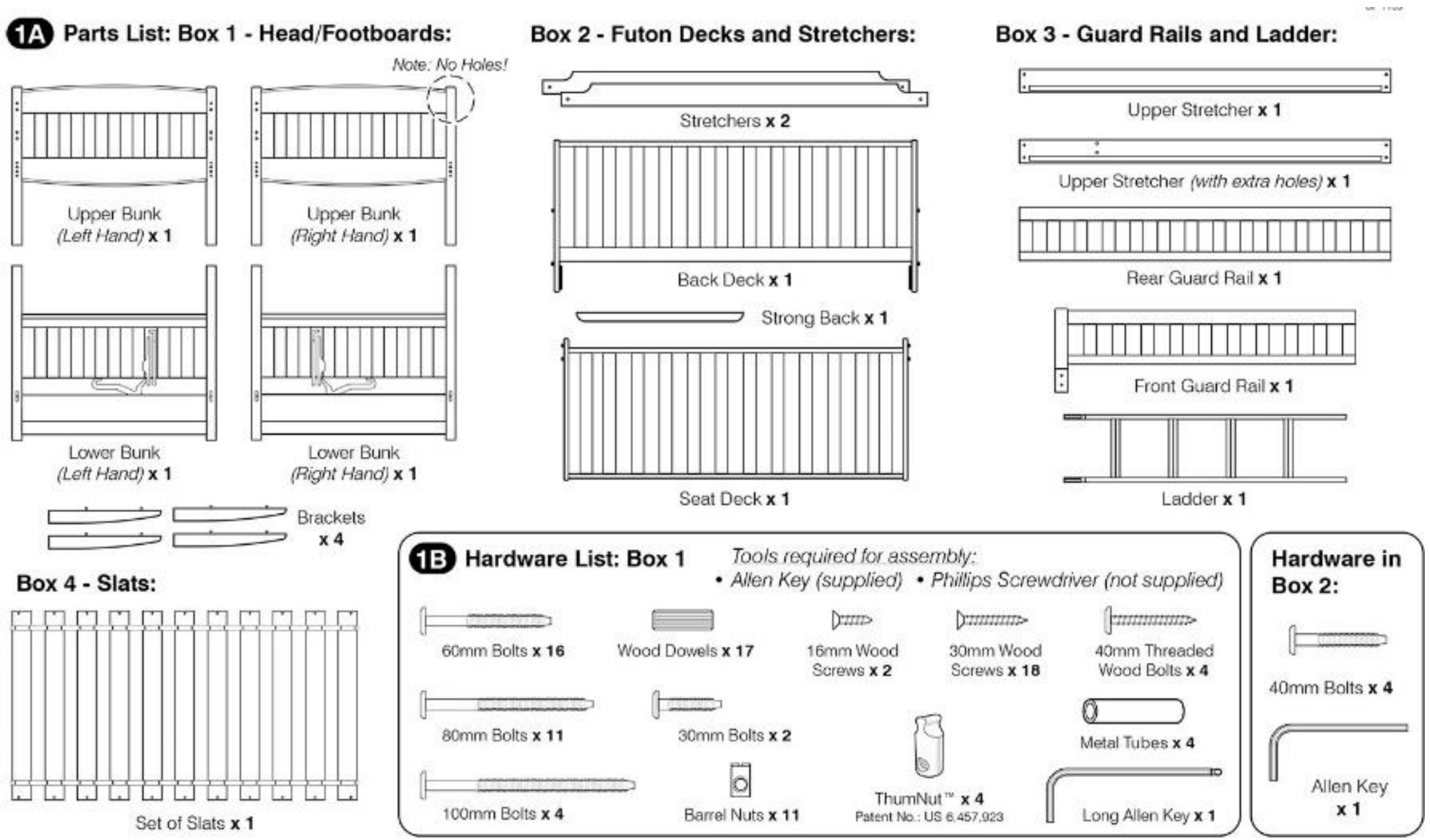
Introduction to Block-based Design

- Composition from *building blocks…*
  - …by hand or with CAD tools (e.g. Matlab Simulink)
  - **Block**: reusable component/subsytem with **properties** and **connections**
- How can we build this complex system?
  - We need a structural model to guide the process

Assembly Instructions

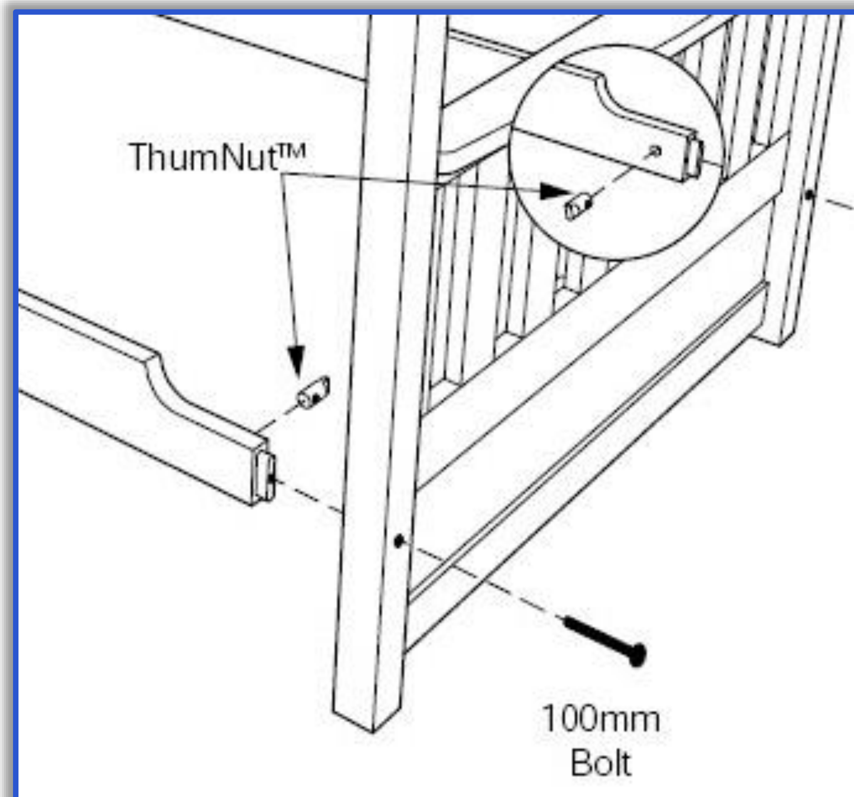


Parts Catalogue

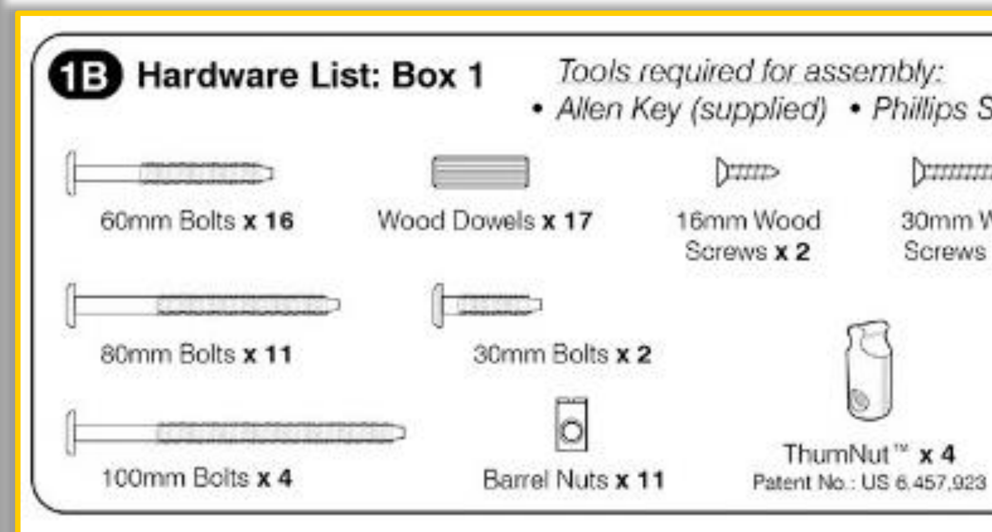


Observations on Block Usage

Blocks/parts are **defined** in a **catalogue** and **used** in **assembly instructions**



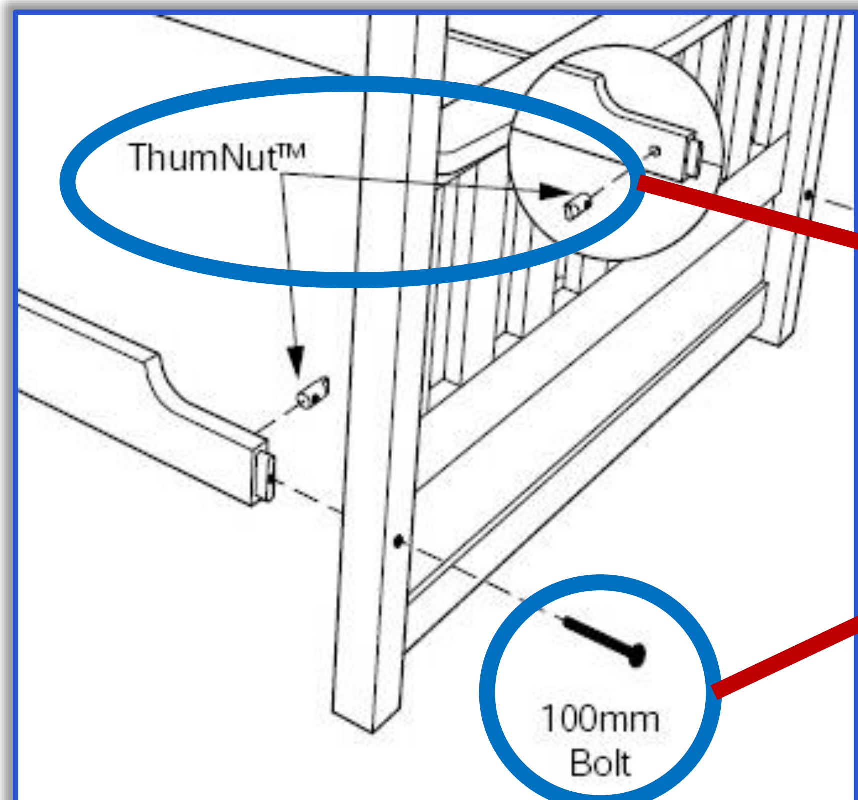
Assembly Instructions



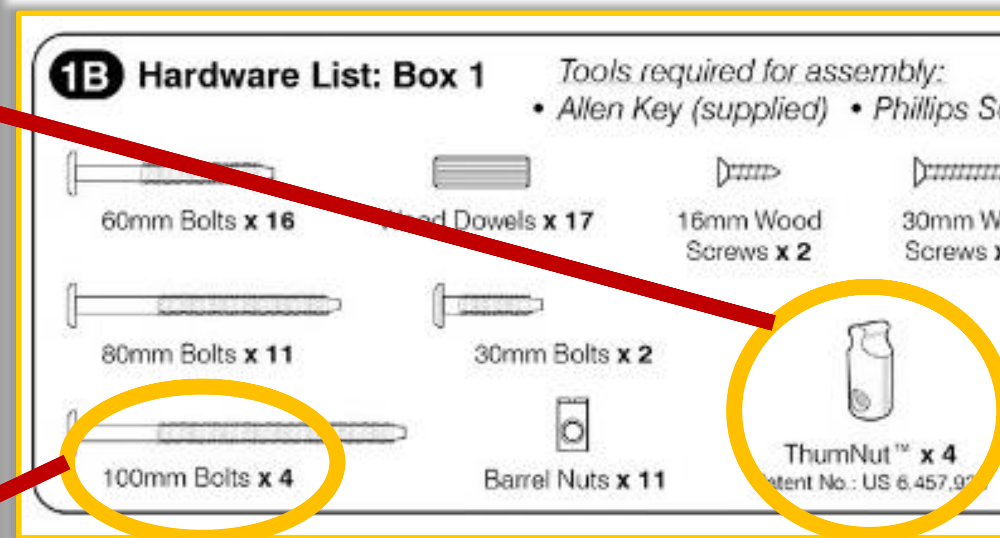
Parts Catalogue

Observations on Block Usage

Building blocks **used** in assembly instructions refer to their **definitions** in the parts catalogue



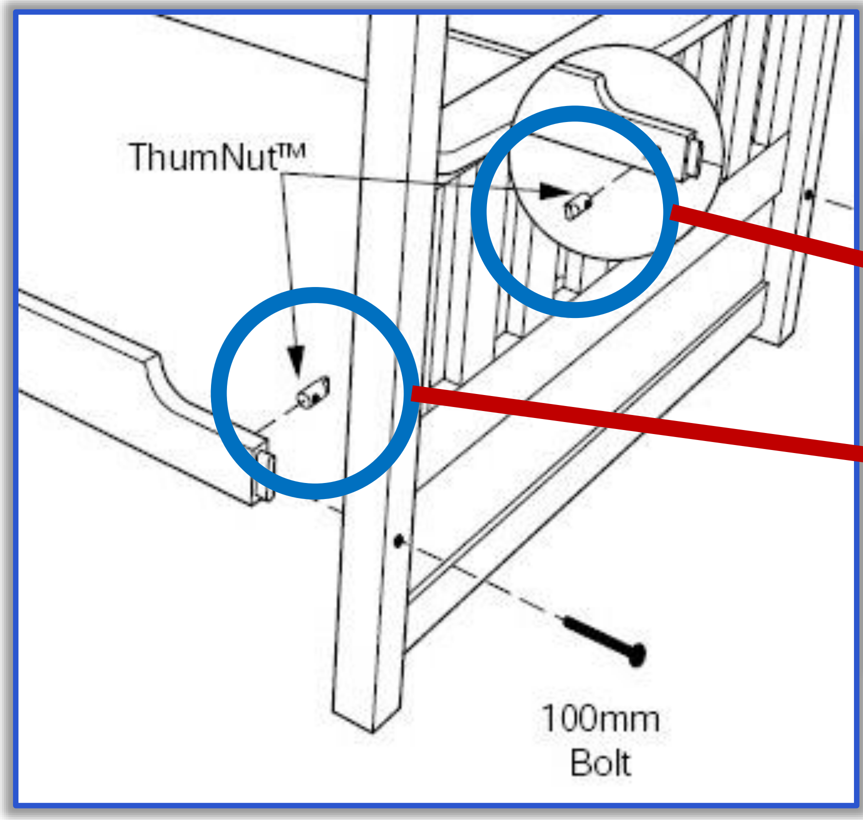
Assembly Instructions



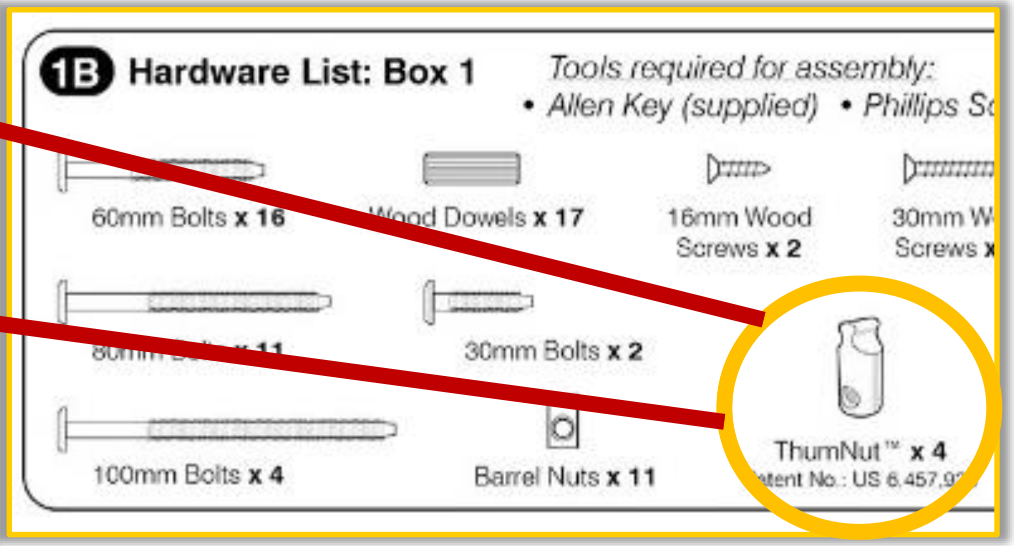
Parts Catalogue

Observations on Block Usage

The same **part definition** can be **used** multiple times in different **roles**



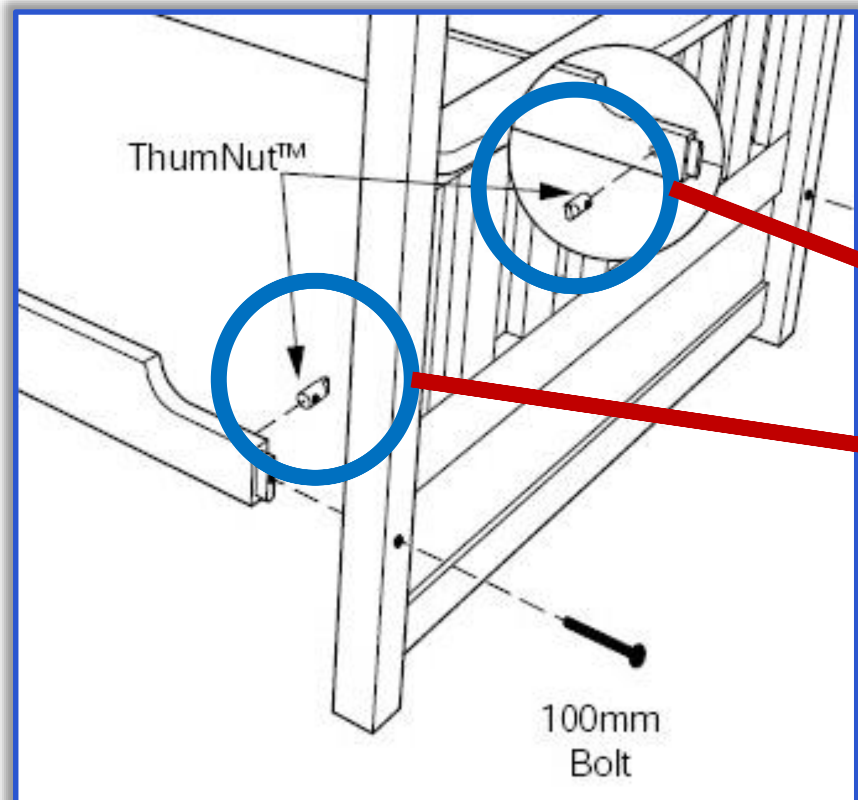
Assembly Instructions



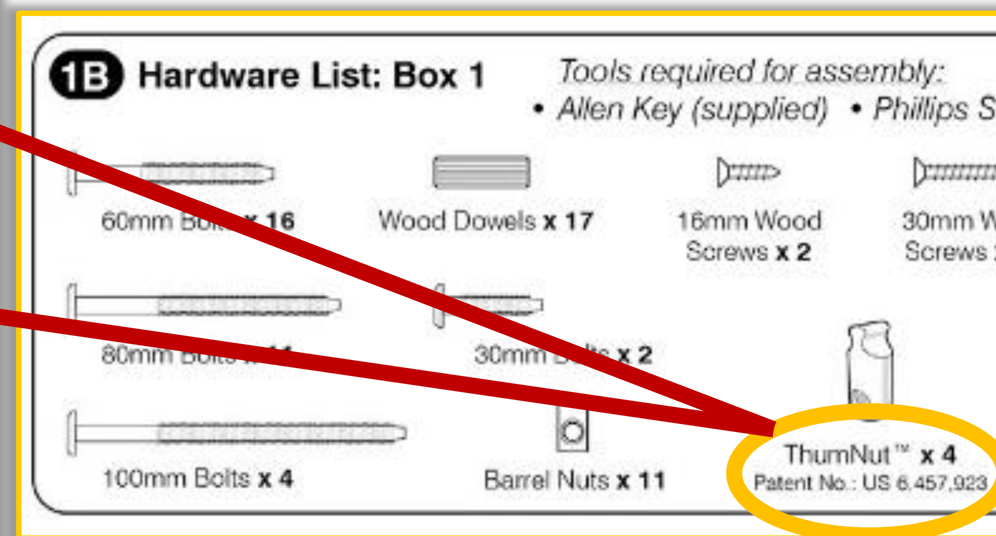
Parts Catalogue

Observations on Block Usage

Block **properties** may be characteristic to the…
definition (e.g. *patent no.*), use (e.g. *orientation*),
or run-time (e.g. *stress*)

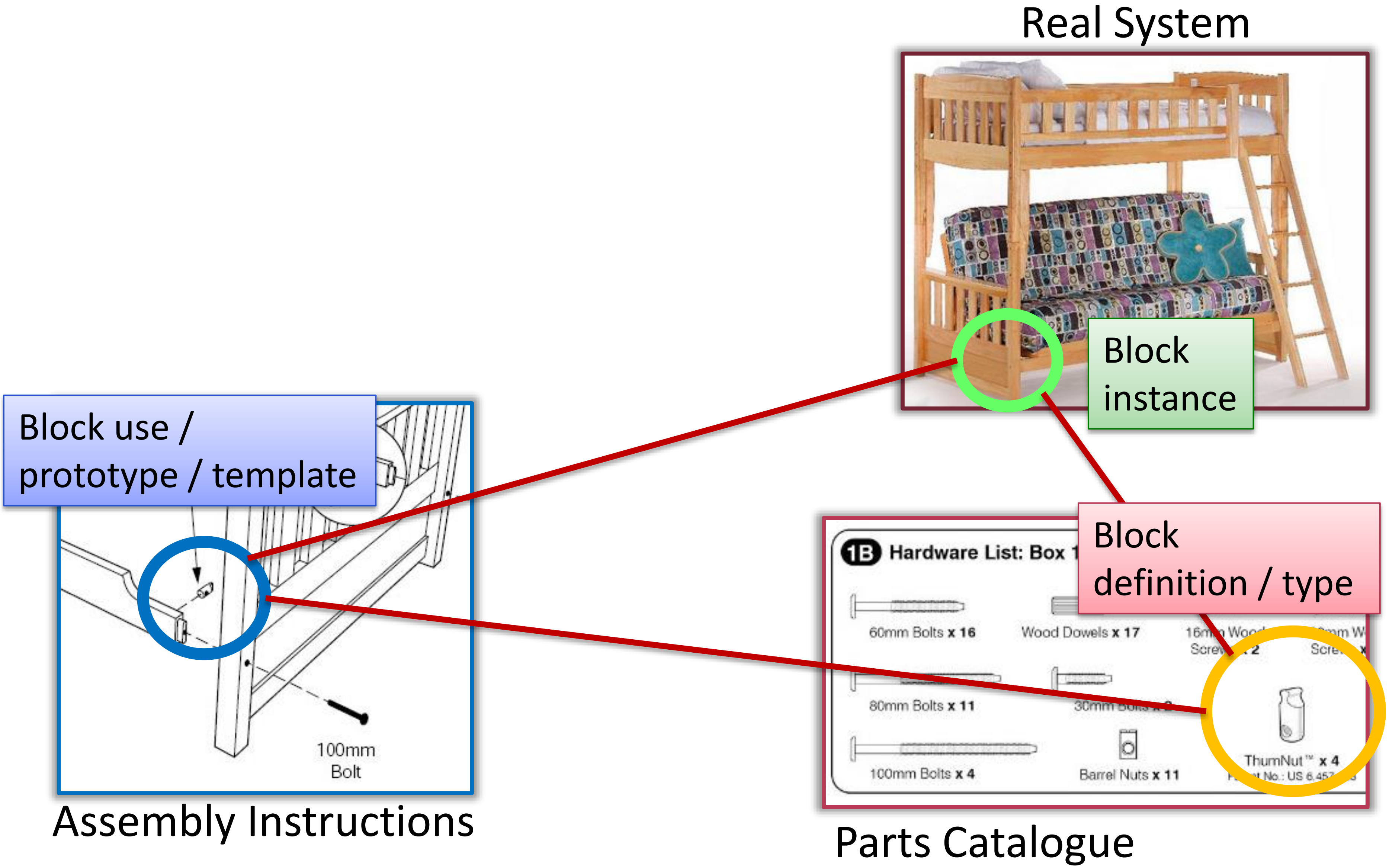


Assembly Instructions



Parts Catalogue

Definition and Use



Definition and Use

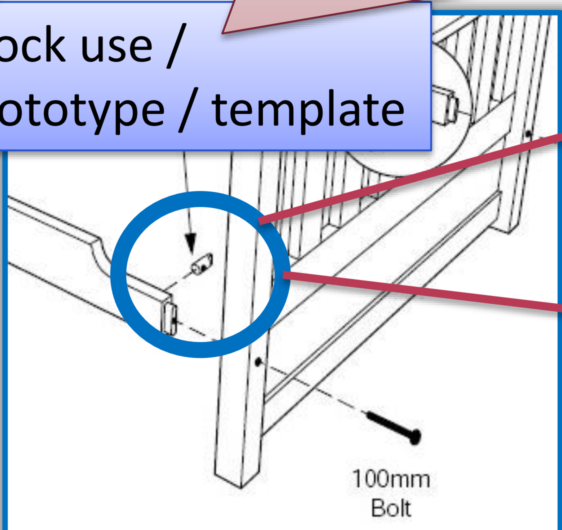
Real System

Not AN INSTANCE of the block type
as it may be instantiated multiple times in different ways for each bed frame

Not THE TYPE of the block instance
(may be *a type* - a refined specialization)
as the focus is on its ROLE within a composite

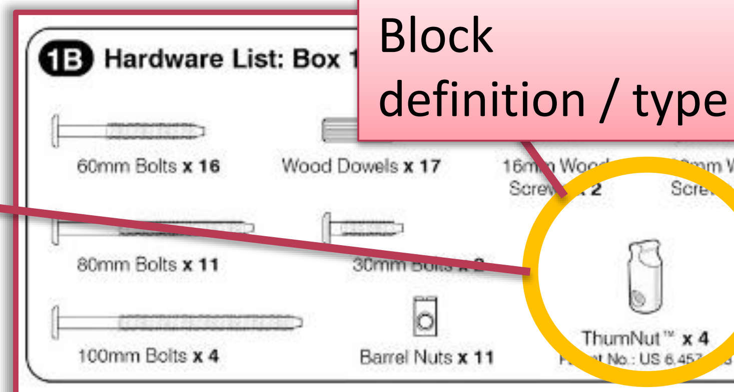
Block use / prototype / template

Block instance



Assembly Instructions

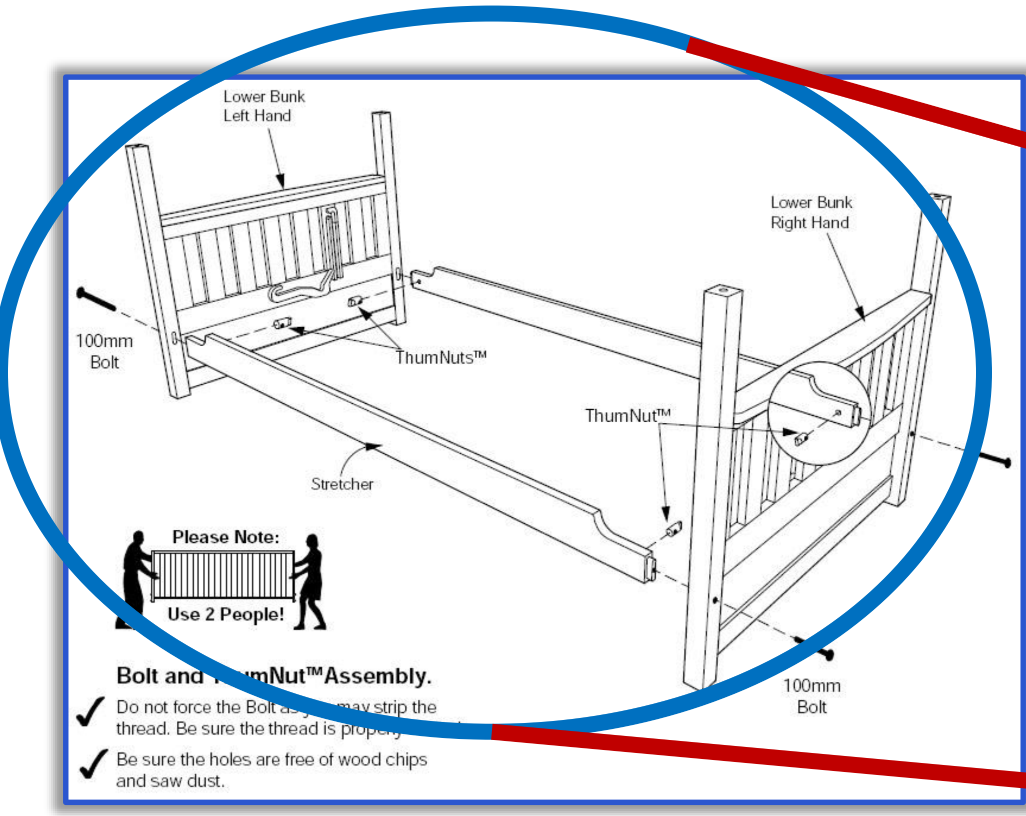
Block definition / type



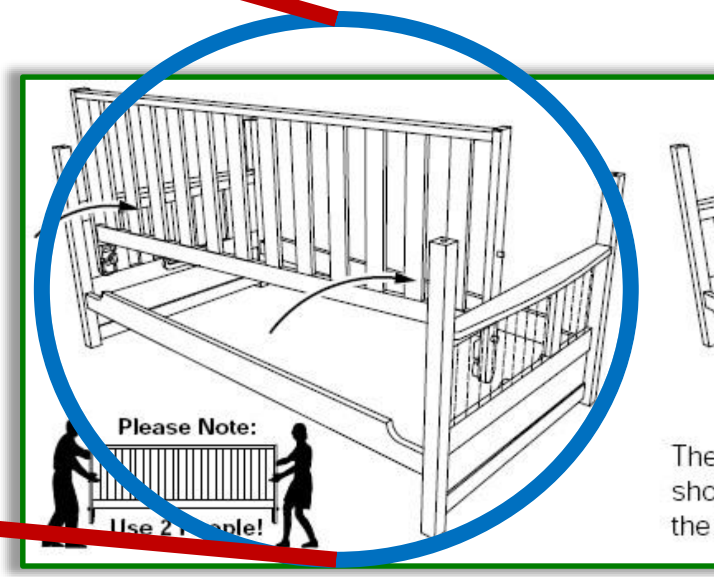
Parts Catalogue

Observations on Block Usage

Some parts may themselves be composites, (de)composed with separate assembly instructions

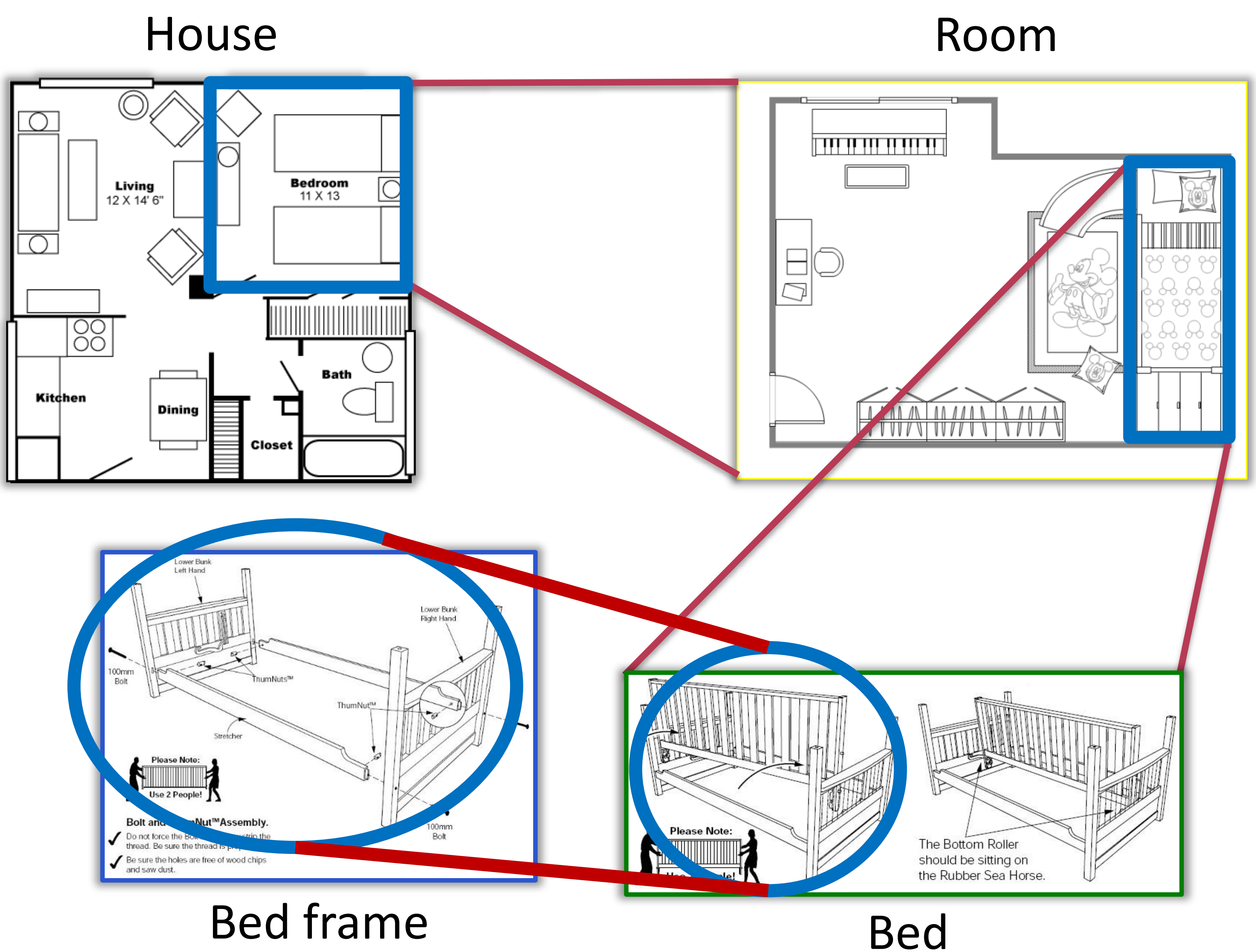


Assembly Instructions 1



Assembly Instructions 2

Hierarchical Definition and Use

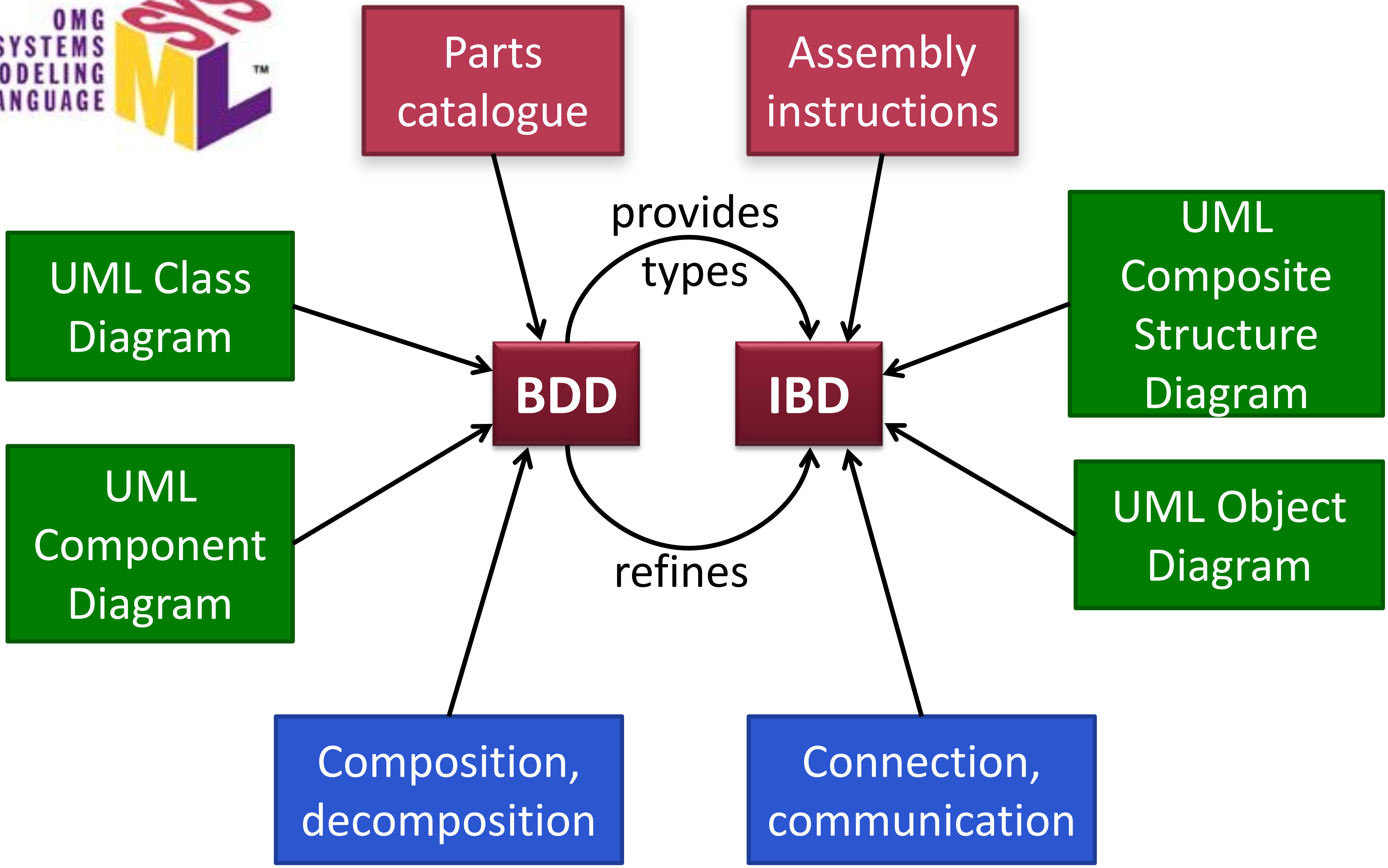


Structural Modeling in SysML

Structural Modeling in UML vs SysML

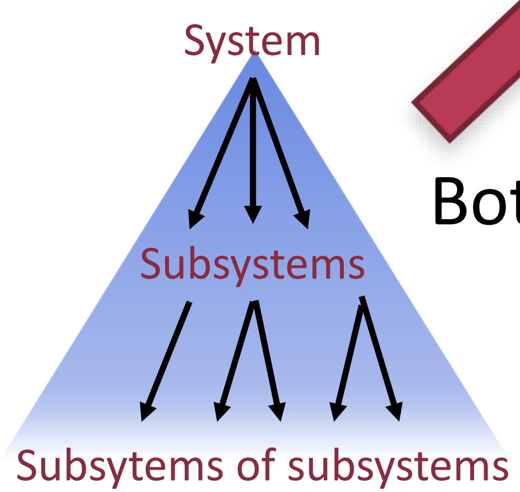
- **UML**: Software Engineering terminology
  - Blocks ≅ Classes or Components
  - Parts Catalogue ≅ Class Diagram, Component Diagram
  - Assembly Instructions ≅ Composite Structure Diagram
- **SysML**: more general engineering terminology
  - Blocks are called **blocks** ☺
    - Merging UML Class and Component features
    - Extensions: flow ports, physical dimensions, etc.
  - Parts Catalogue ≅ <u>Block Definition Diagram</u> (**BDD**)
  - Assembly Instructions ≅ <u>Internal Block Diagram</u> (**IBD**)

Block Definition Diagram vs Internal Block Diagram

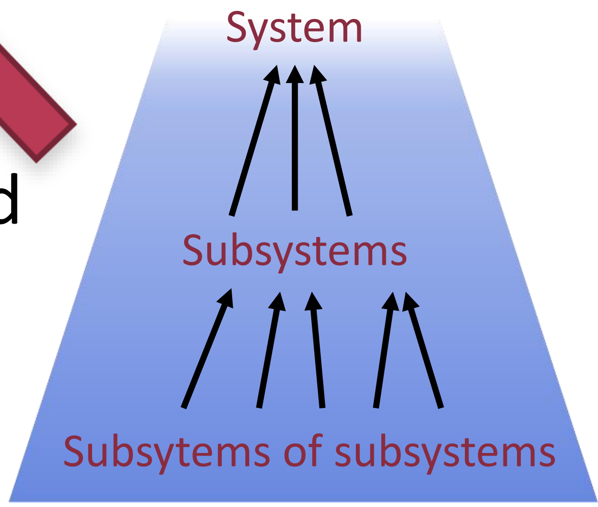


Top-down and bottom-up design in SysML

is only a language

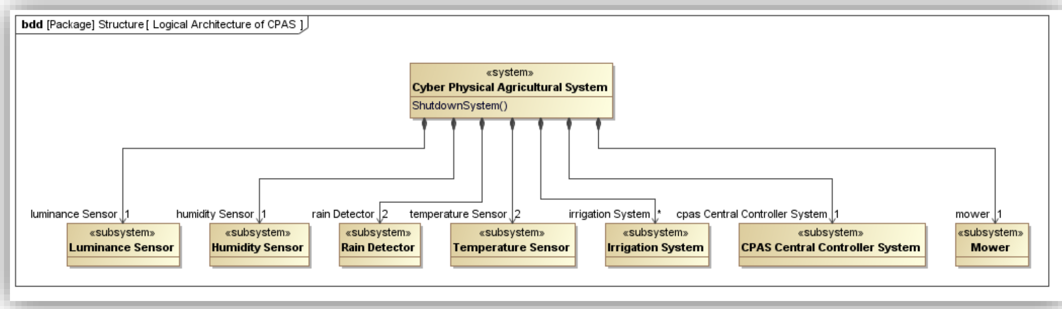


Both approaches can be used
(even at the same time:
meet-in-the-middle)

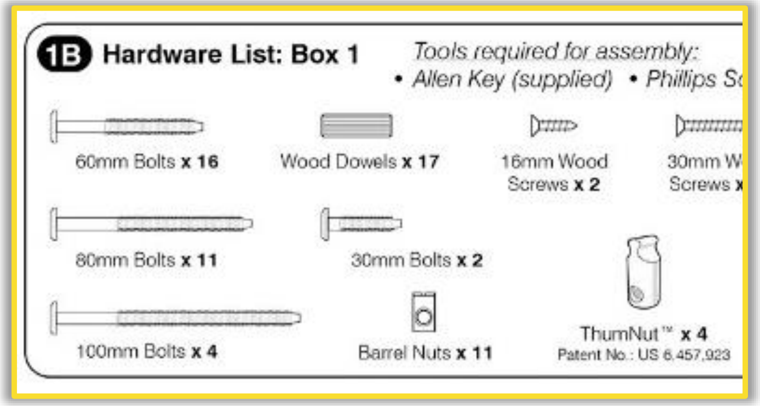


Application to Functional Architecture

- Blocks are **functional units** (components)
  - SW modules, microservices, devices, peripherals, etc.
  - Part-whole relationship ≠ physical containment
  - Connecting blocks ≠ physical linkage
    - Dependencies
    - Information flow
- Don't confuse with…
  - ANSI C functions
  - Functional programming
  - Modeling of functional requirements



Block Definition Diagram (**BDD**)

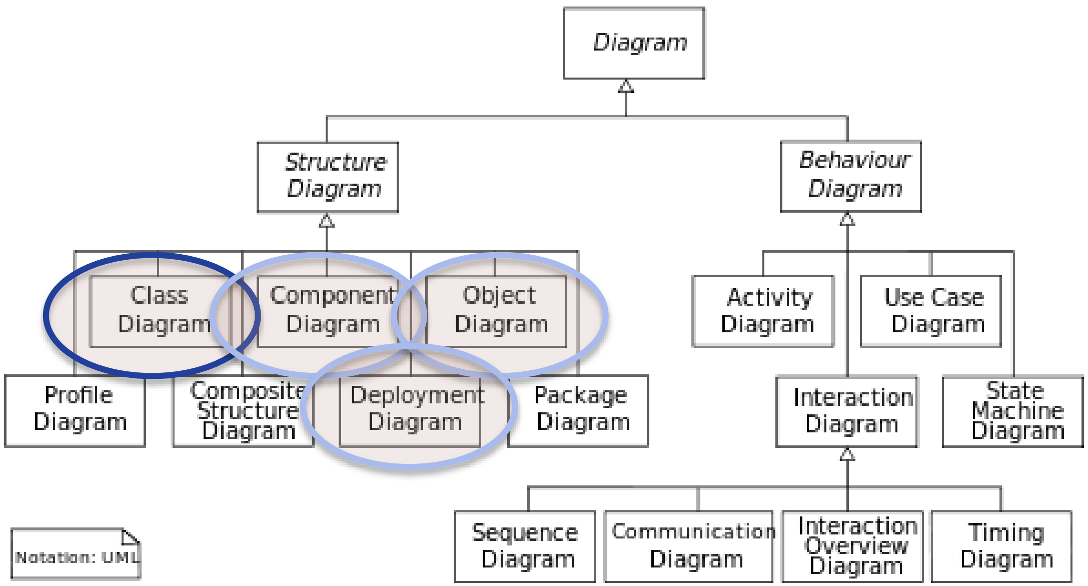


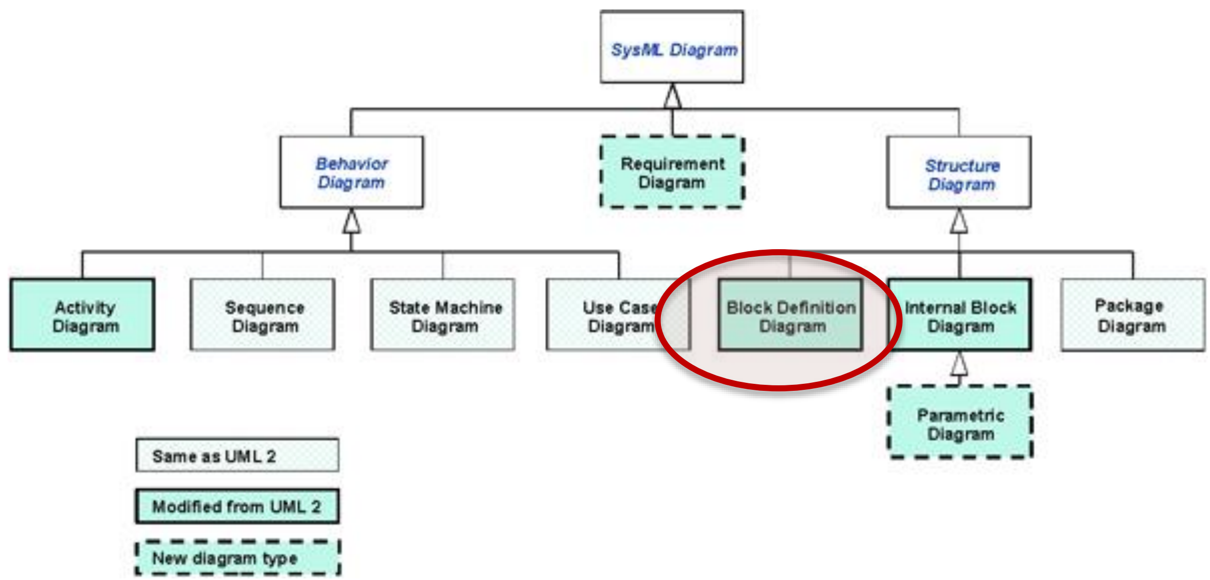
Parts Catalogue

Block Definition Diagram Overview

Block Definition Diagrams

Block Definition Diagram (BDD)





Block nodes

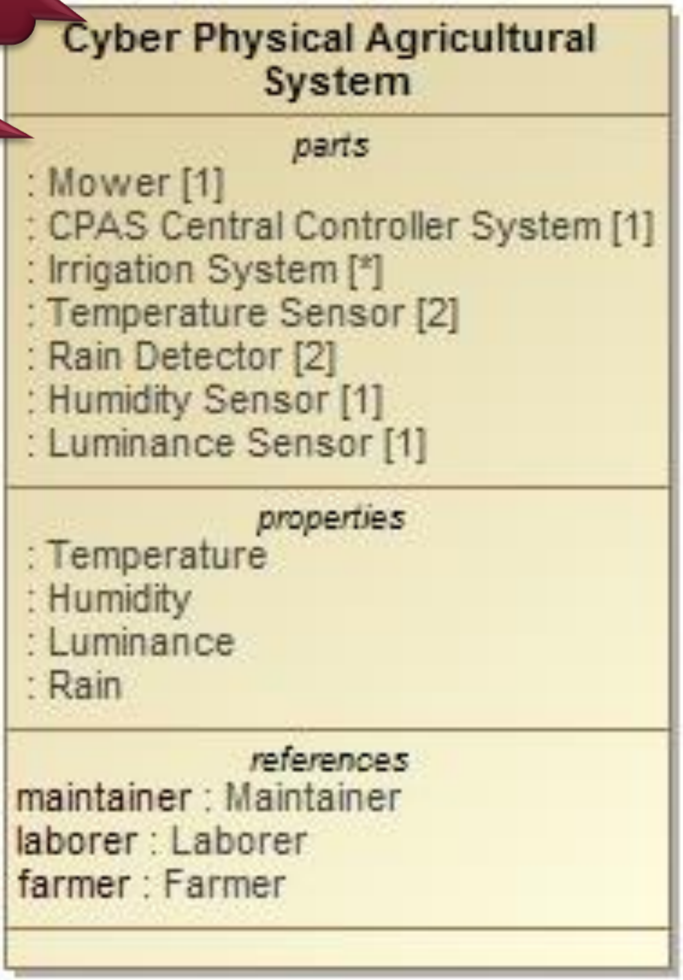
- Basic structural elements
- Anything can be a block
  - System, Subsystems
  - Hardware
  - Software
  - Data
  - Person
  - Flowing object
- UML class with a <<block>> stereotype

optional on a **bdd**

Block node compartments

Name
(can have special characters)

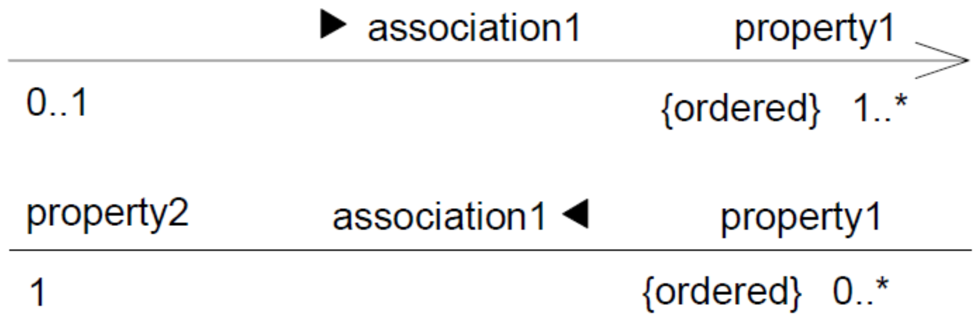
parts
Compartment



- Parts - contained blocks
- References – referenced blocks
- Values – like UML attributes
- Constraints
- Ports
- Etc…
- Can be hidden on a diagram

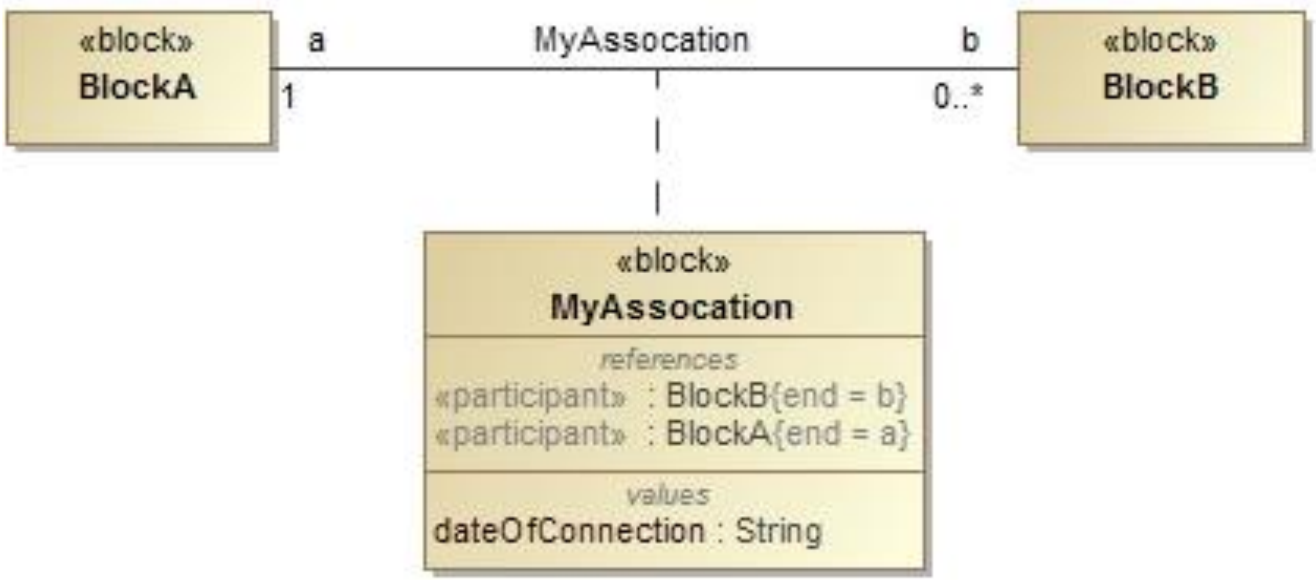
(Reference) Association

- Represents a relationship between two blocks
  - Undirected: reference property in both blocks
  - Directed: reference only in one block
- End properties: role name, multiplicity, constraints
- (Not mandatory: **ibd** connectors may be untyped)



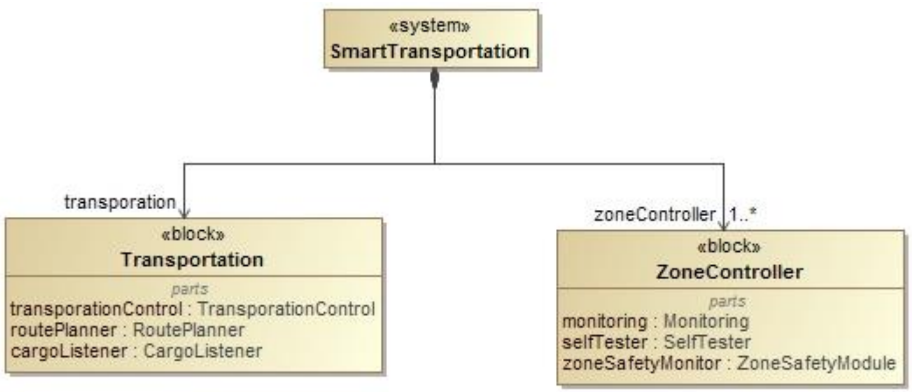
Association Block

- Association represented by a block possibly with structural properties

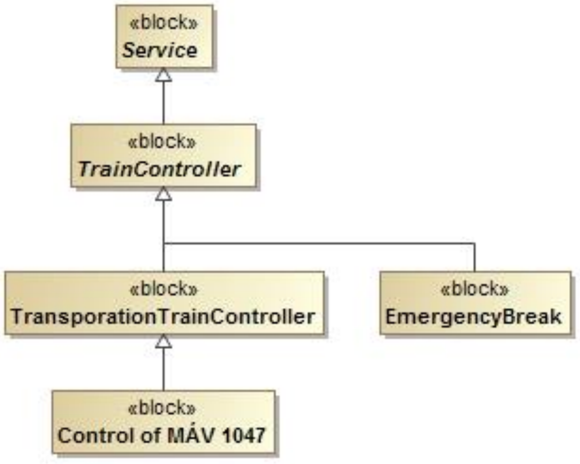


Composition vs Generalization (often missused)

- Composition
  - Container component owns the contained components
  - Container component aggregates all features of contained components



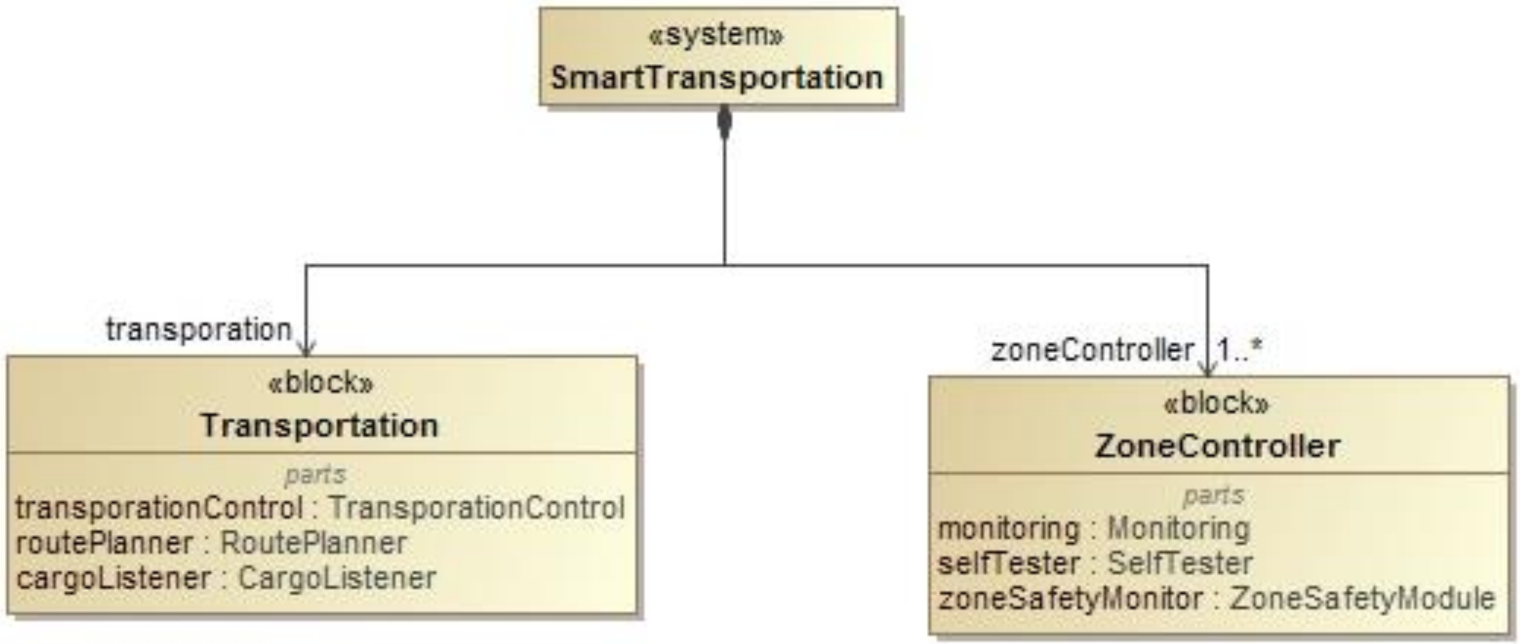
- Generalization
  - Components share common features besides other properties
  - Component can be used interchangeably with descendant components



Part (or Composite) Association

- Specifies a strong whole-part hierarchy

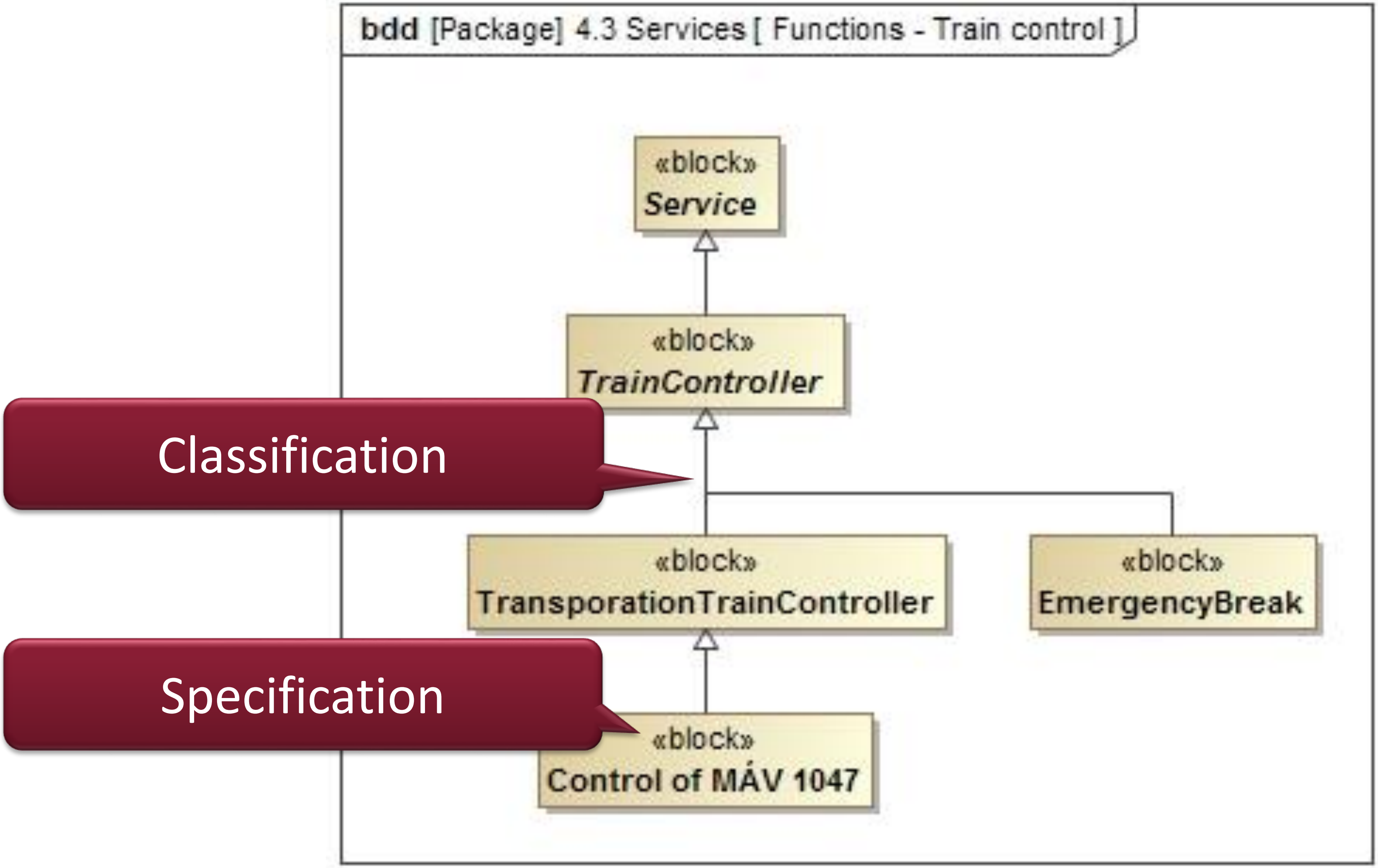
	Denotation	Default multiplicity
Whole end	black diamond	0..1
Part end	role name	1..1



Generalization

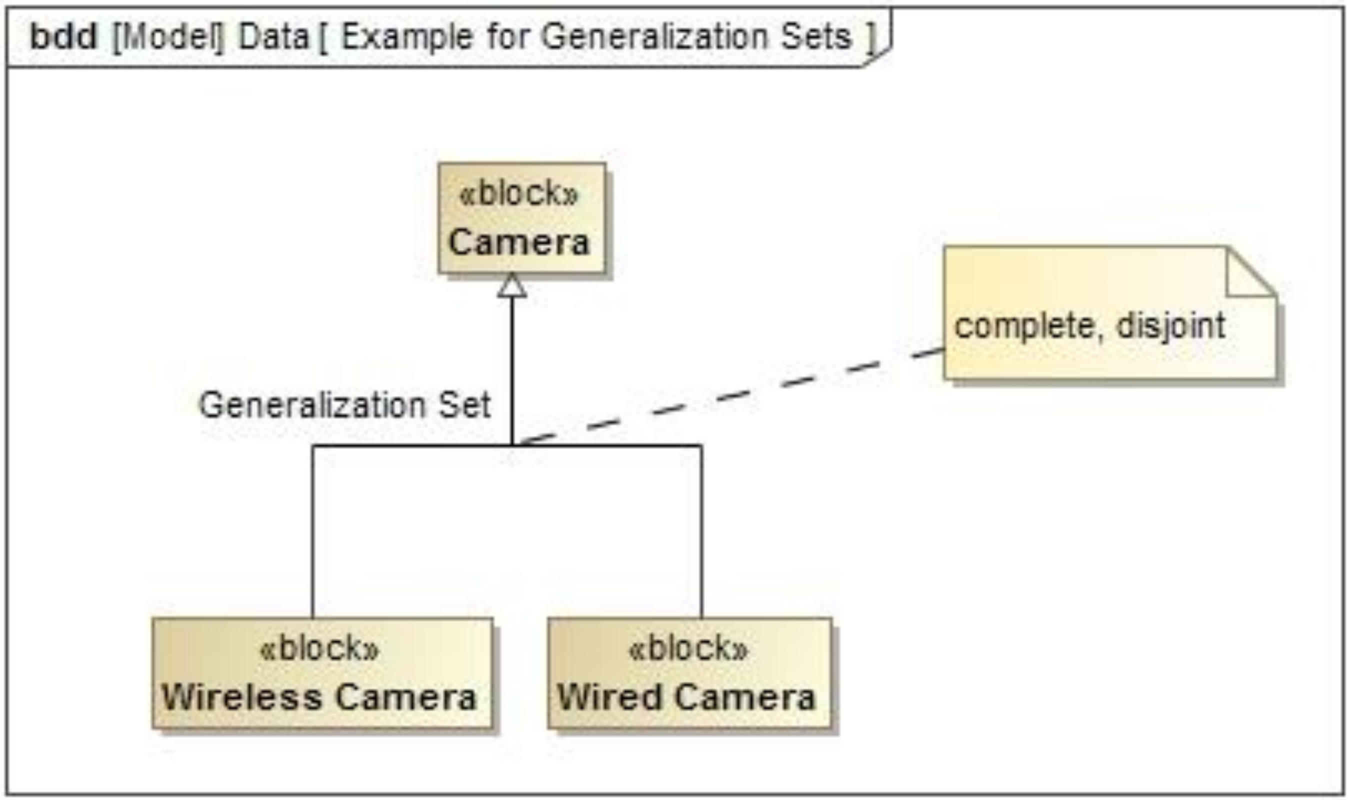
- Similar to OOP, UML
- Main usages
  - Classification (shared role, feature)
  - Specific configurations (specific name, values)
- Adds, defines, redefines properties
- Not just blocks (actors, signals, interfaces, etc.)
- Multiple inheritance is allowed

Generalization



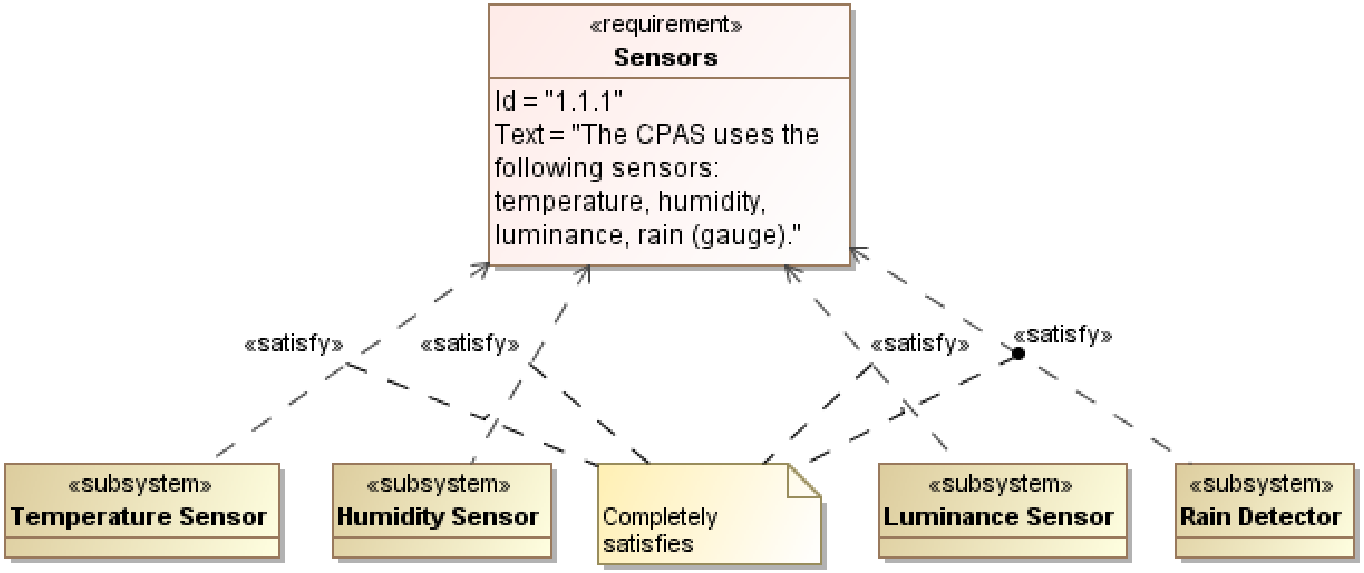
Generalization set

- Generalization relationships, shared *general* end
  - complete – incomplete
  - overlapping – disjoint

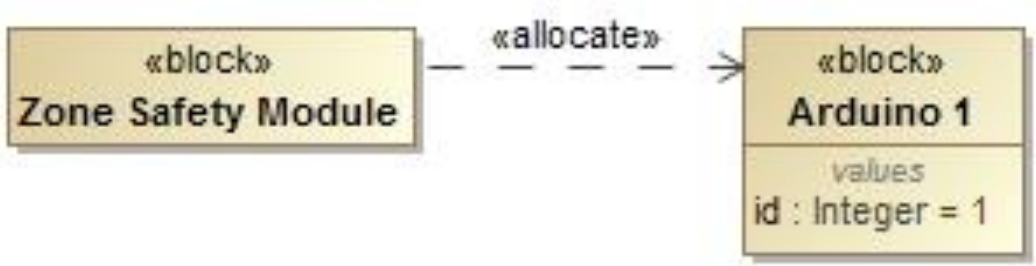


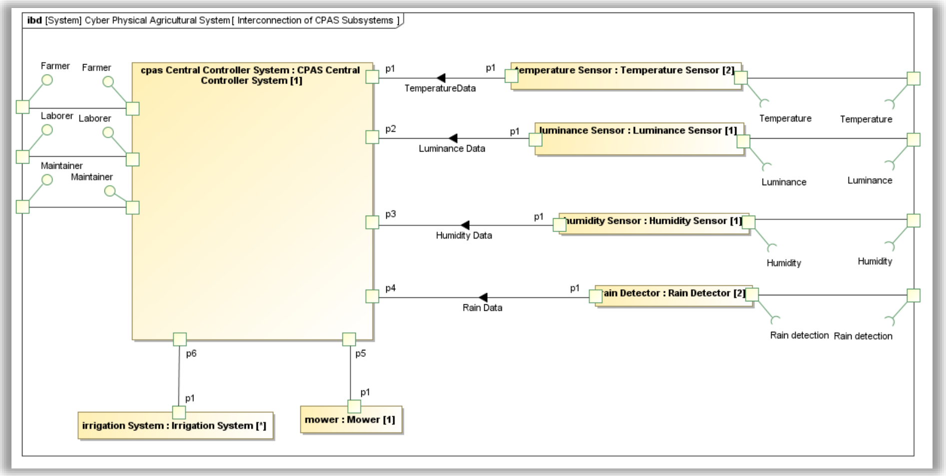
Traceablity of BDDs to other artifacts

- Realizes requirements

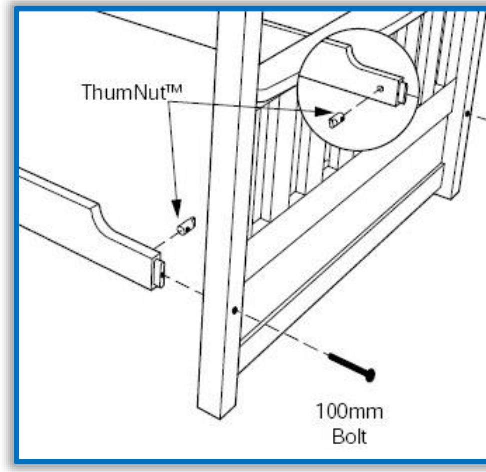


- Allocation (to platform)





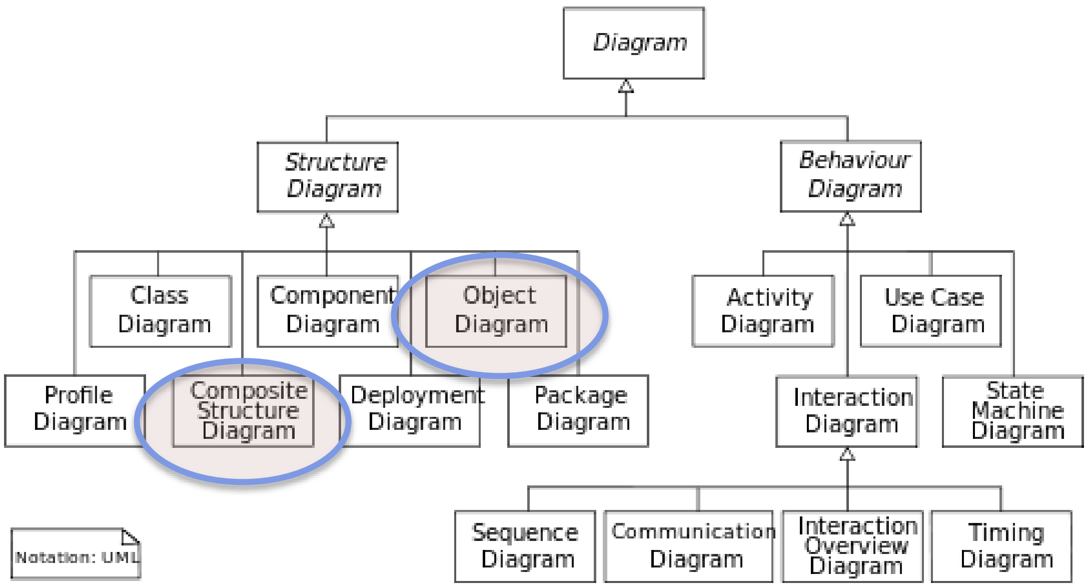
Internal Block Diagrams

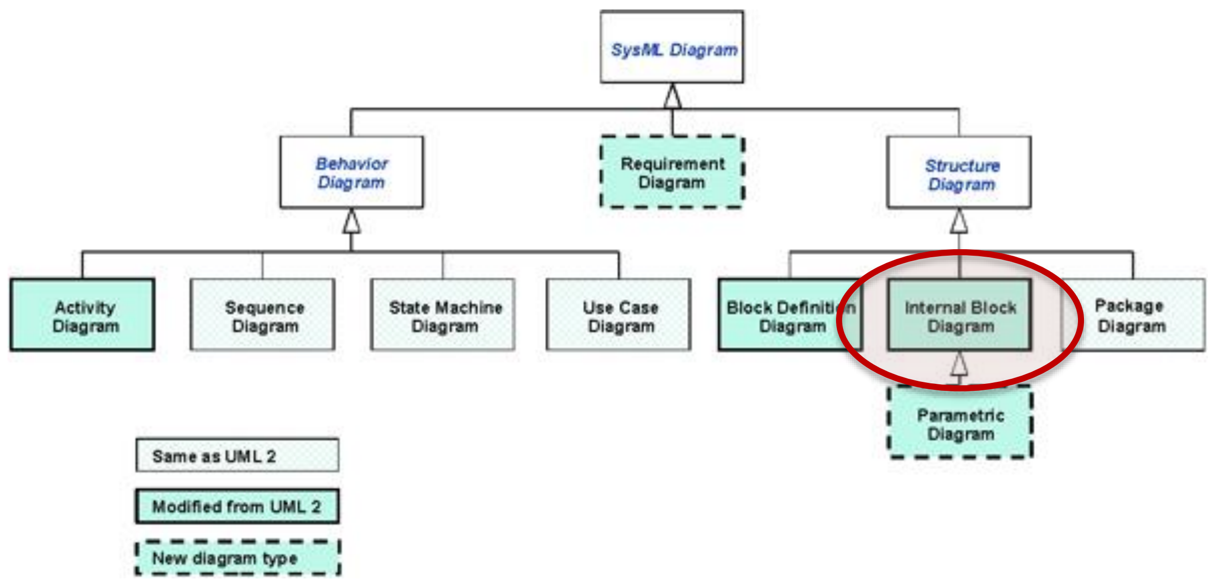


Assembly Instructions

Internal Block Diagram (IBD) Overview

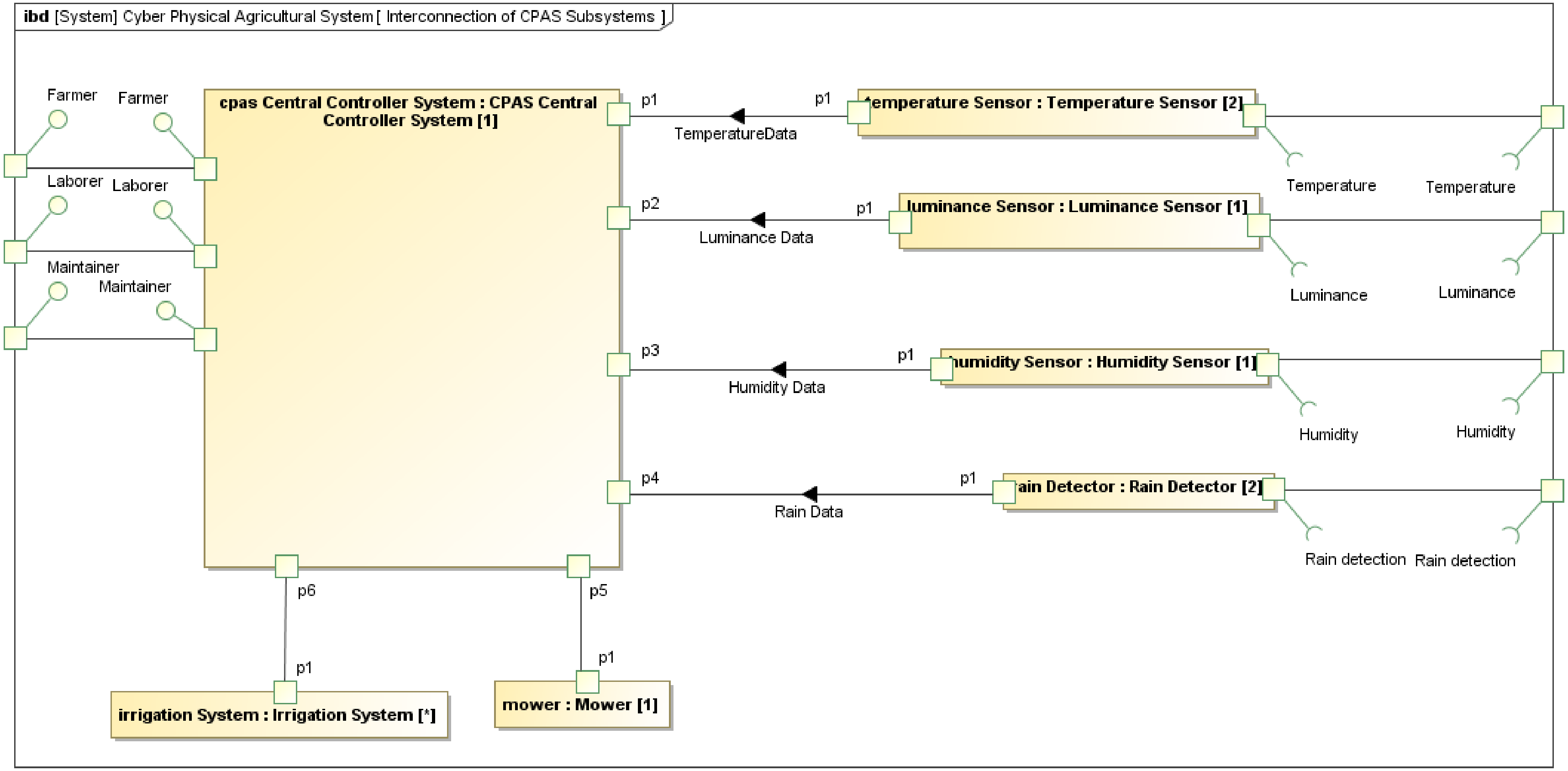
Internal Block Diagram (IBD)





Modeling Aspect

*Breaks down a **composite block** into **part blocks** that make up the whole*

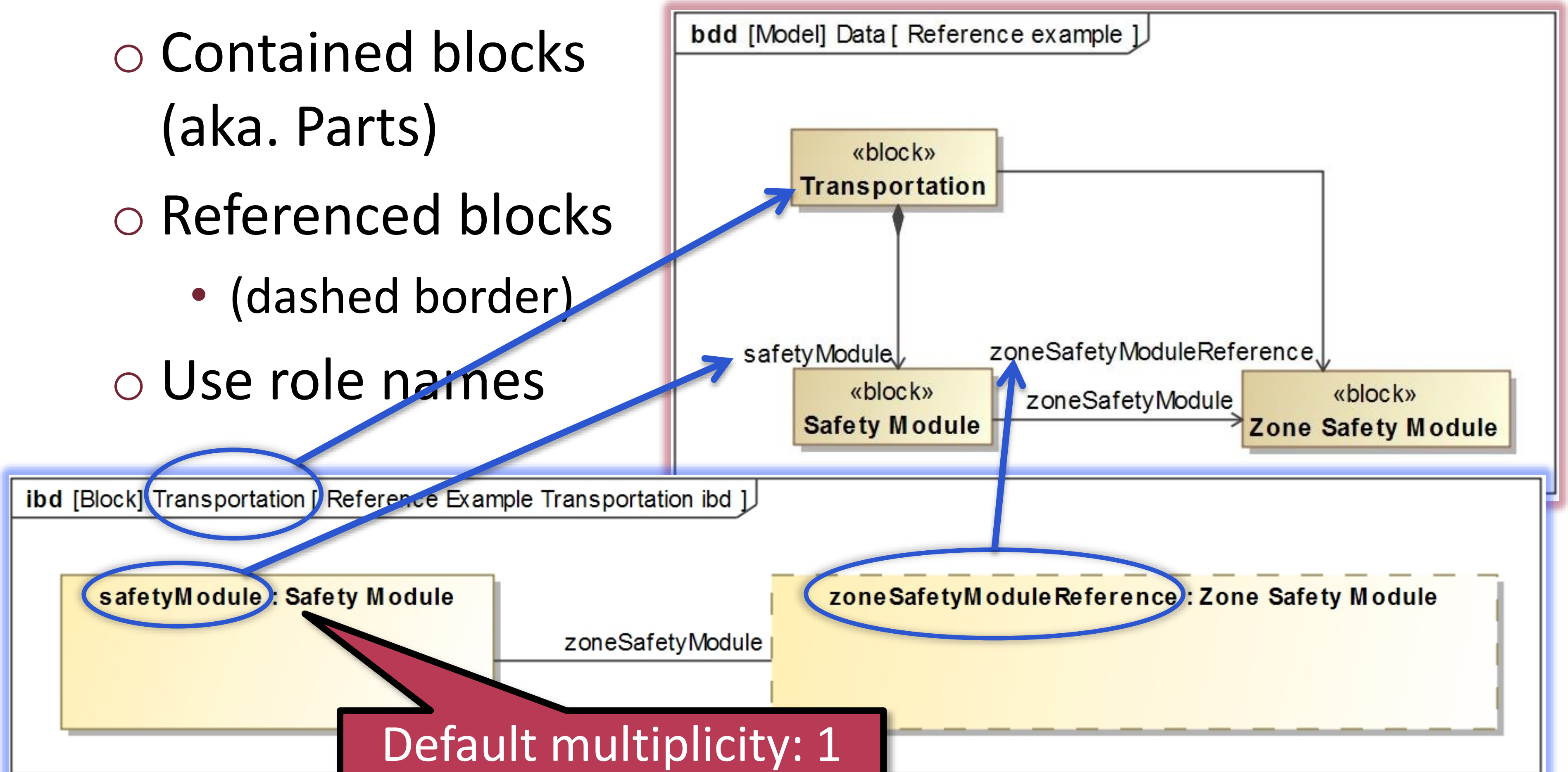


Objectives

- Describe a **composite block** as connected parts
  - Use contained and referenced blocks defined in a **bdd**
  - Use associations and interaction points (ports)
  - Specify connectors (incl. data flow) between parts
    - (Item flows can be mapped to object flows in activities)
  - Specify property restrictions
- Define a template (instance specification)
  - Semantics: if you instantiate the composite block…
    - …you will also have the following parts…
    - …arranged in a specific way

Blocks on IBD

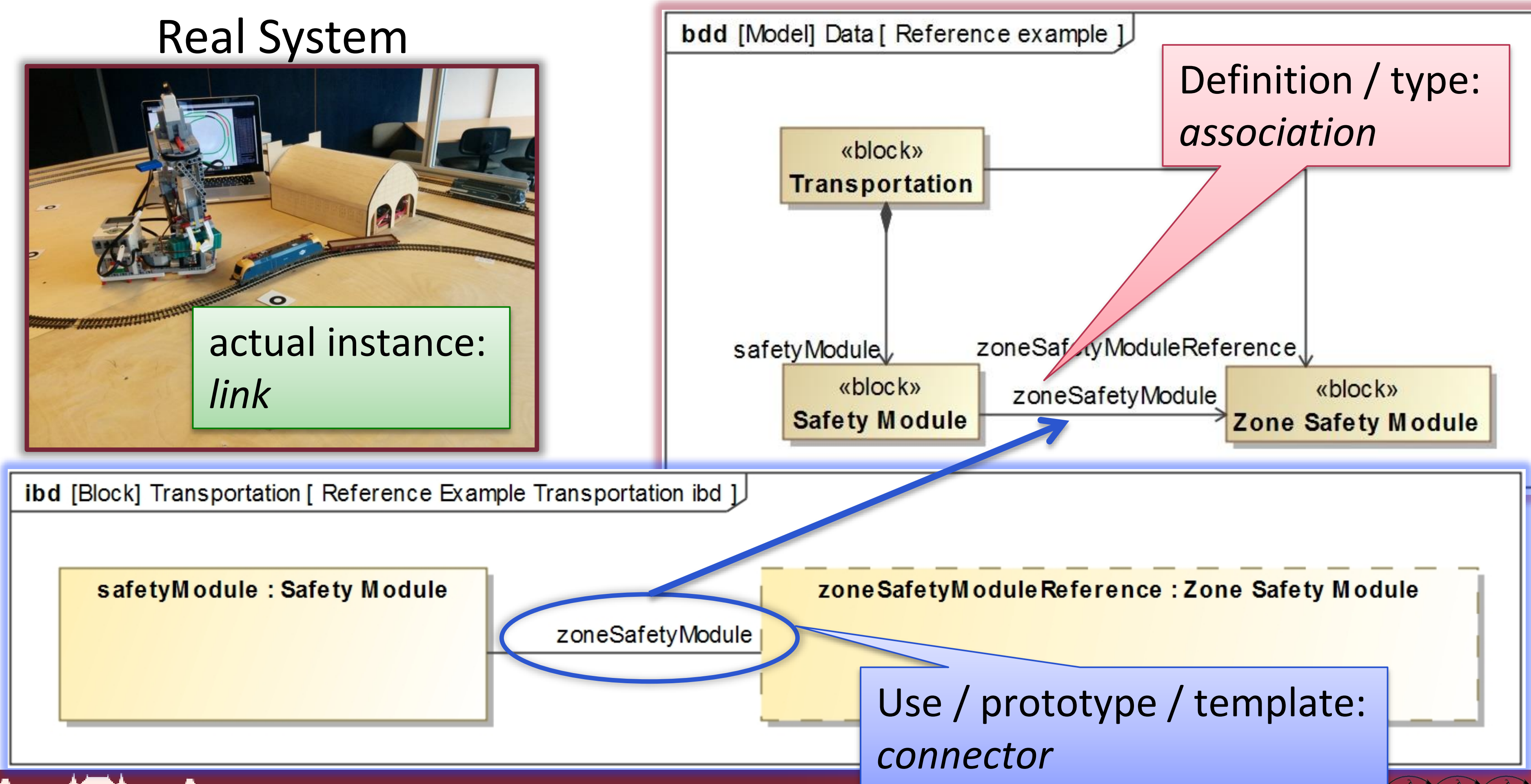
- The *entire* **ibd** represents a block
- Instance specifications (templates / prototypes)
  - Contained blocks (aka. Parts)
  - Referenced blocks
    - (dashed border)
  - Use role names



Connectors

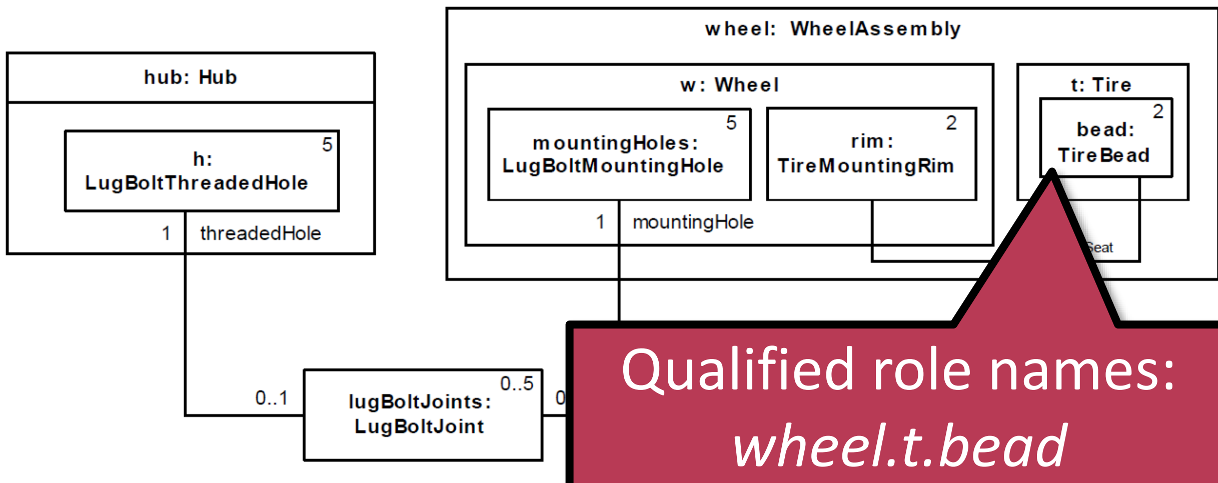
- Connectors between blocks (or compatible ports)
- Optionally typed by an assocication from a **bdd**

Real System



Nested blocks

- Nested blocks
  - Block structure is expanded in an embedded **ibd**
  - Commonly used on **ibd**s
    - (Sometimes on **bdd**, in the *structure* compartment)



- Encapsulation
  - Connectors can cross block boundary
  - Mark the block *encapsulated* to forbid this

Ports and Interfaces

Internal Block Diagram (IBD)

Ports

- What is a port?
  - Interaction points with external entities limiting and differentiating the possible connection types

REST API:

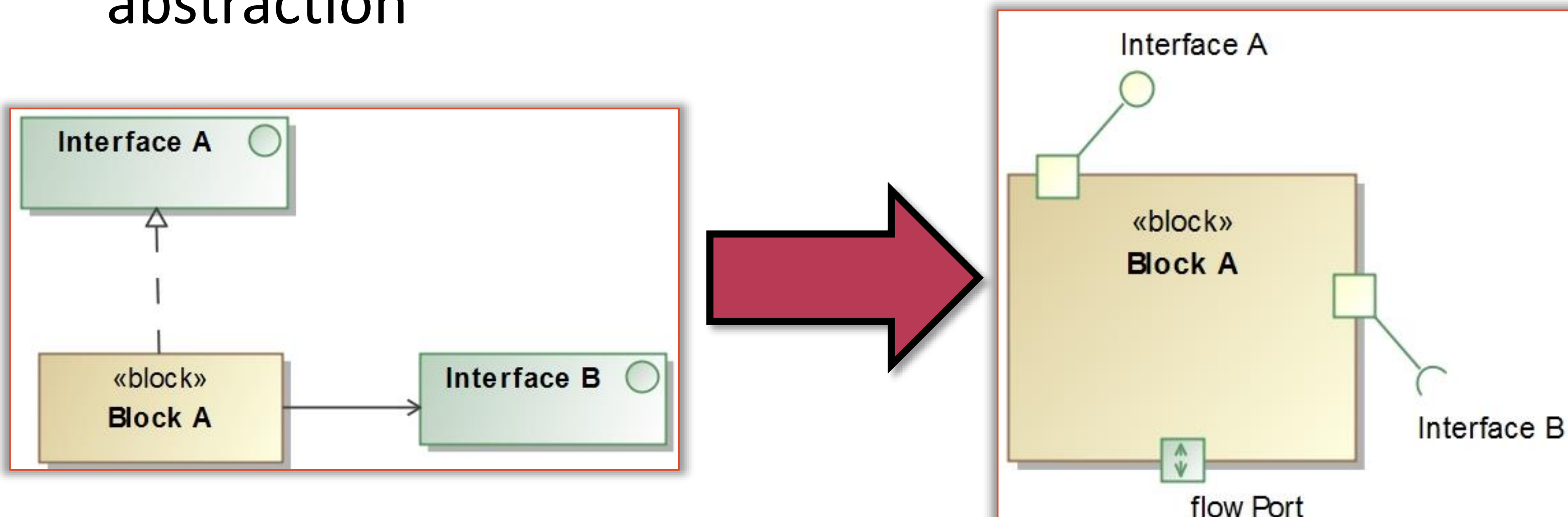
Method	URL	Payload	Result
POST	/api/InventoryItem	CreateInventoryItemCommand (input)	Creates a new inventory item
GET	/api/InventoryItem	InventoryItemListDataCollection (output)	Returns all items
PUT	/api/InventoryItem/{id}	RenameInventoryItemCommand (input)	Renames an item

Ports

- What is a port?
  - Interaction points with external entities limiting and differentiating the possible connection types

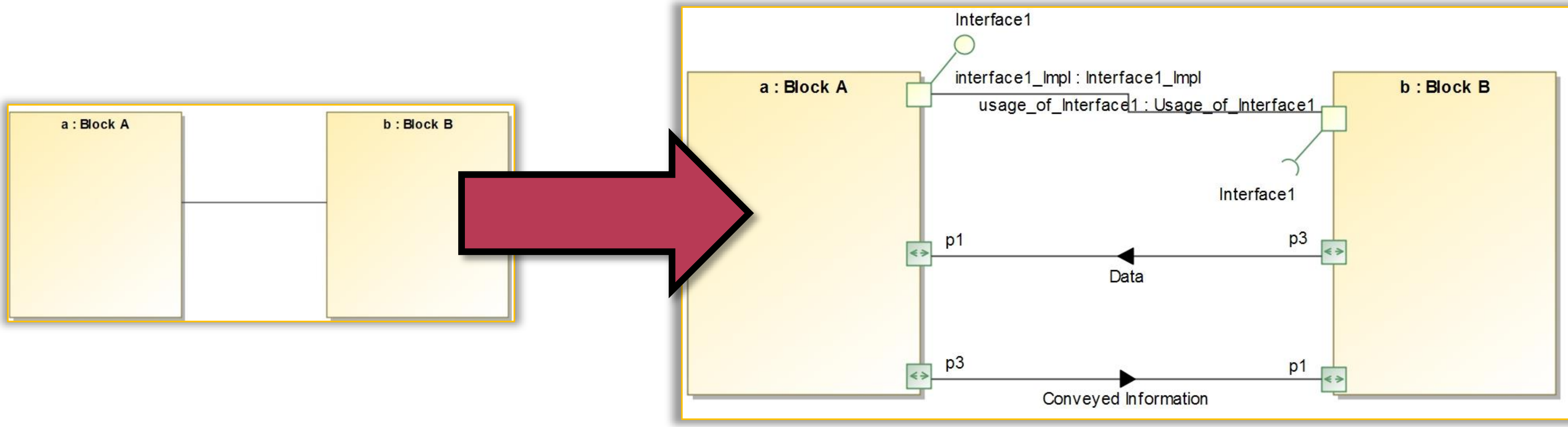
Reasons to Use Ports 1

- Bottom-up method
  - Problem: specify how a designed component can be used in a context
  - A solution would be to realize or require an interface
  - Ports take this responsibility over for better abstraction



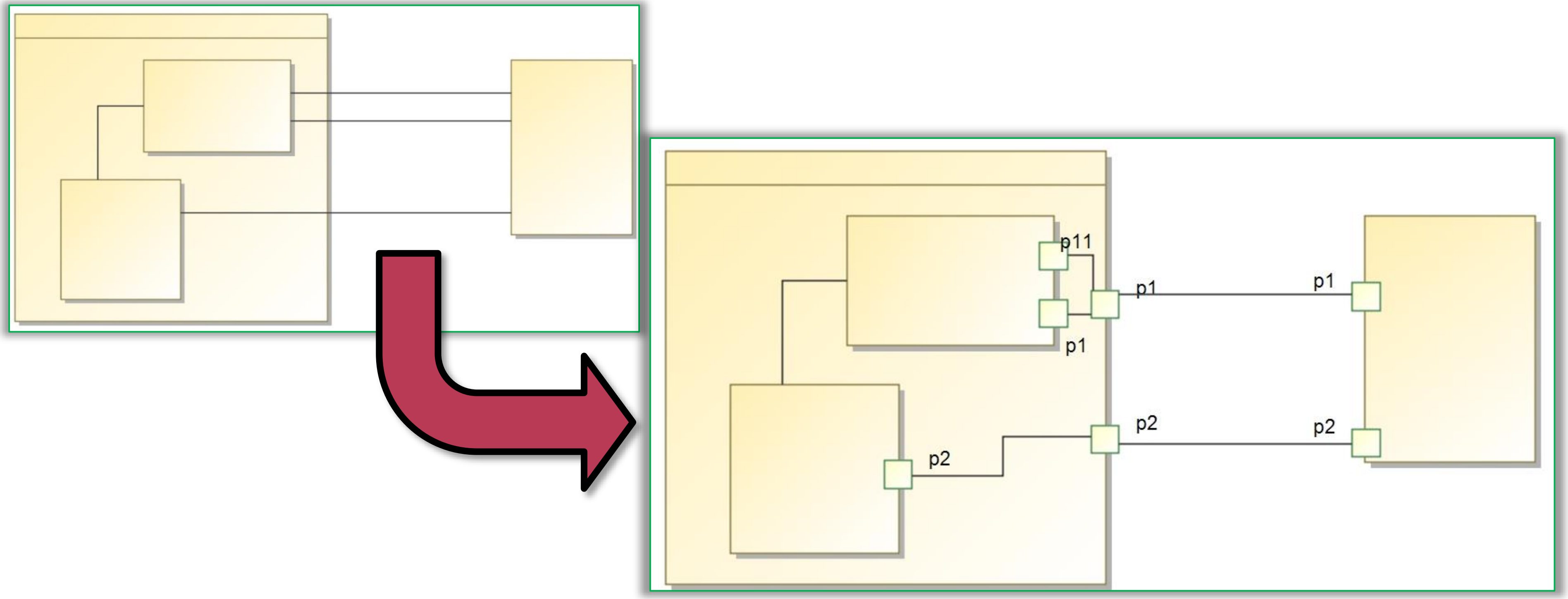
Reasons to Use Ports 2

- Top-down method
  - Problem: connections are not detailed enough and need to be refined
  - Ports can be used to refine connections iteratively



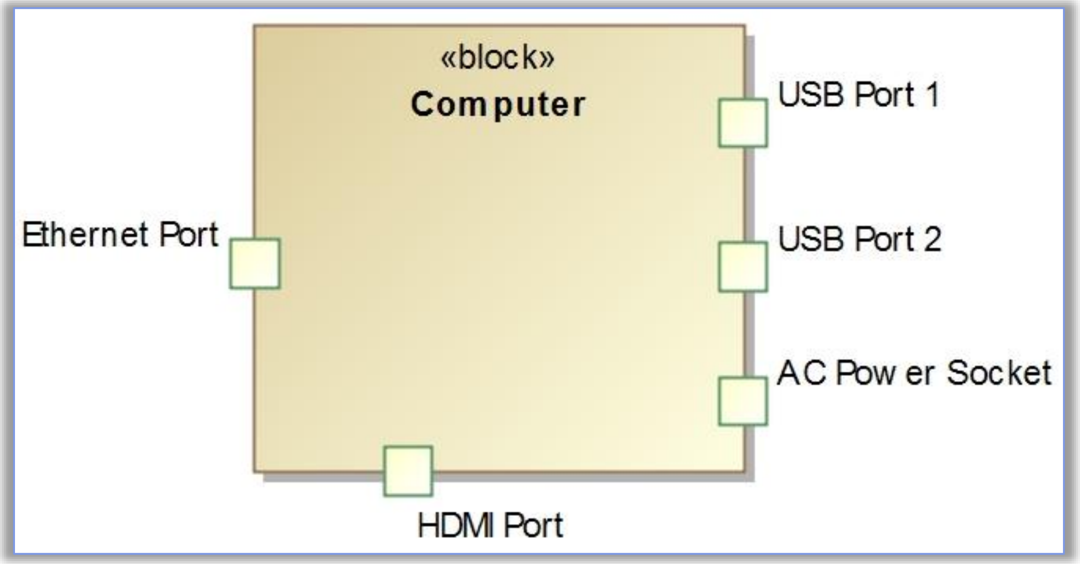
Reasons to Use Ports 3

- Encapsulation
  - Problem: connections that cross the block boundary may reduce maintainability
  - Use ports to hide the internal structure of a block



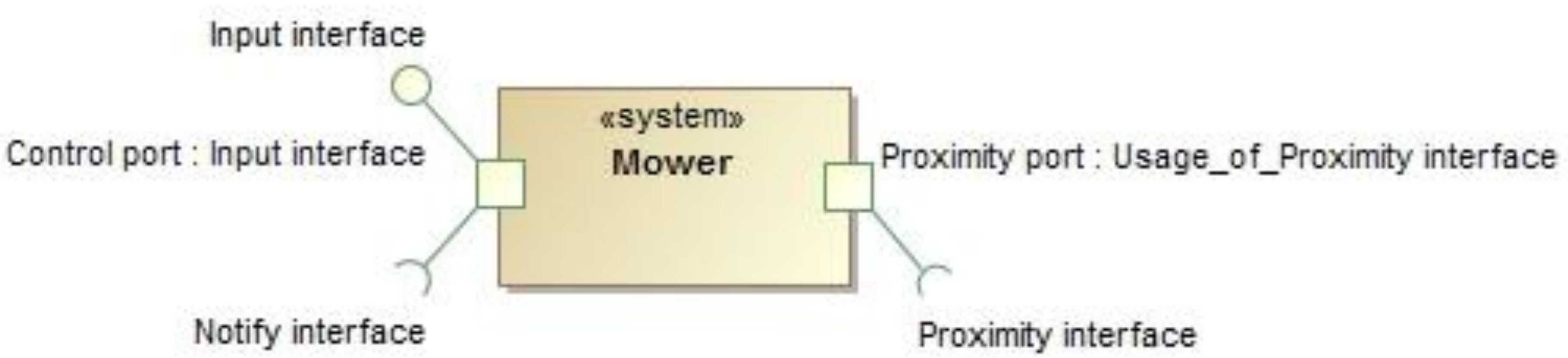
Reasons to Use Ports 4

- Interaction point has a special role
  - Problem: the block has a physical connection point (like AC power socket/plug) or a distinguished behaviour
  - Ports can be typed by a block with its own properties and behaviour



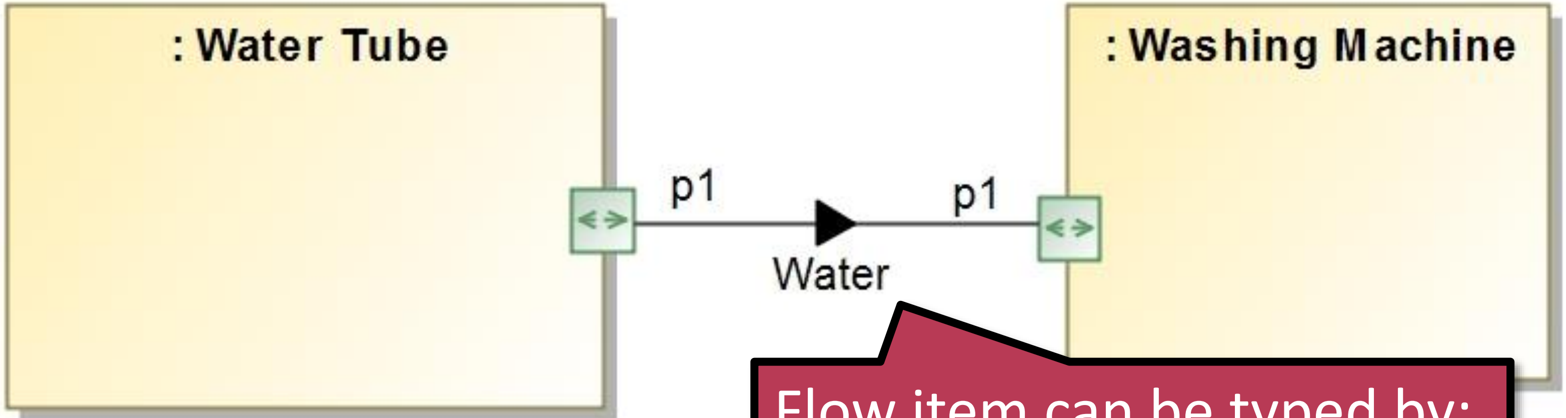
Standard ports

- Uses interfaces for communication
  - Provided interface (ball) – defines a service
  - Required interface (socket) – uses a service
    - A port can have multiple of required ports



Flow ports

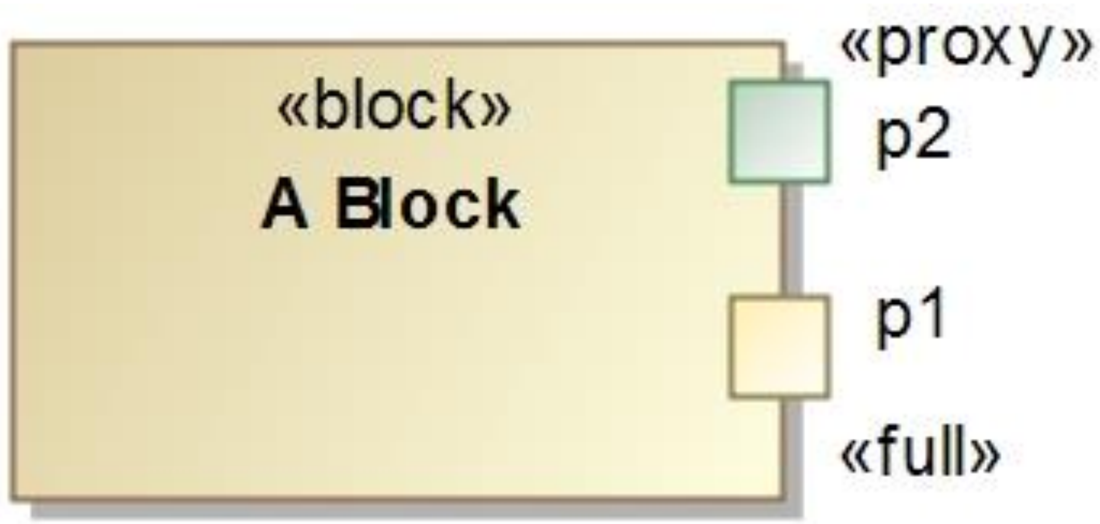
- The connection is described by the flowing item(s) e.g.: data, material, energy, etc.
- Can flow continuously, periodically or aperiodically



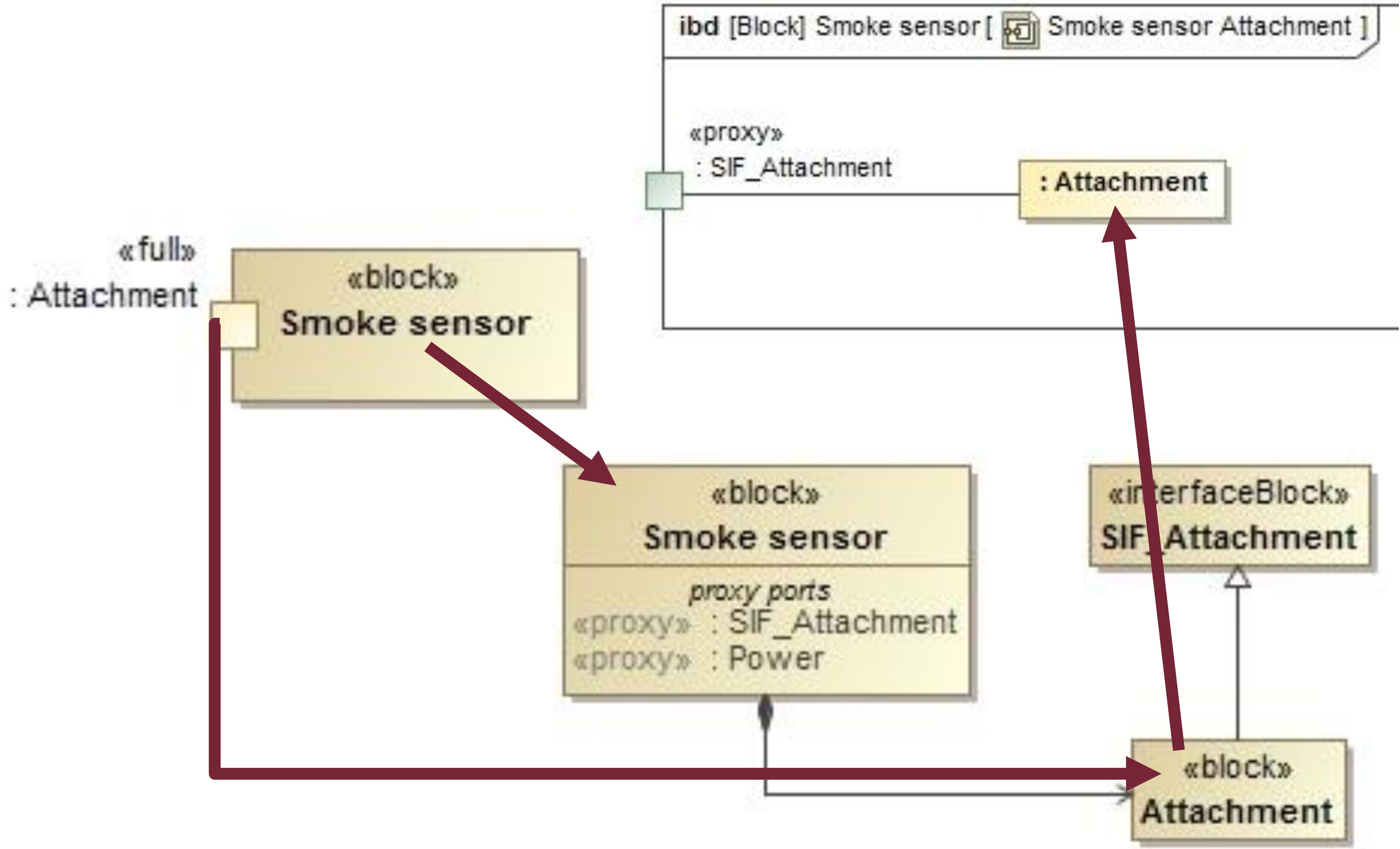
Flow item can be typed by:
- Block,
- Value Type,
- Signal

Full and Proxy Ports

- Since SysML 1.3
- <<Full>> ports can have internal structure and define behaviour
- <<Proxy>> ports do not own any features, it only exposes internal features of the block

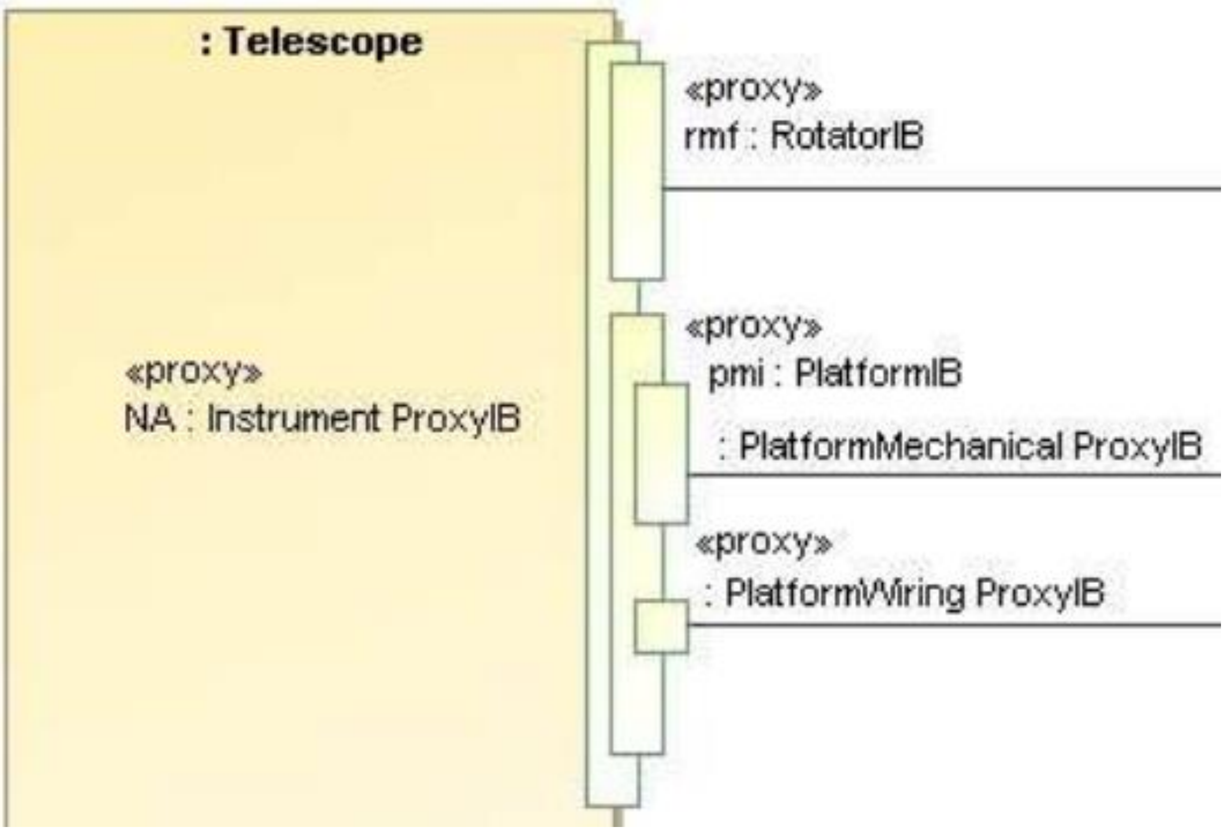


Using Composition instead of Full Port



Nested ports

- (Full) Ports can also have other ports
- Examples
  - a separate port for configuring the behaviour of the port

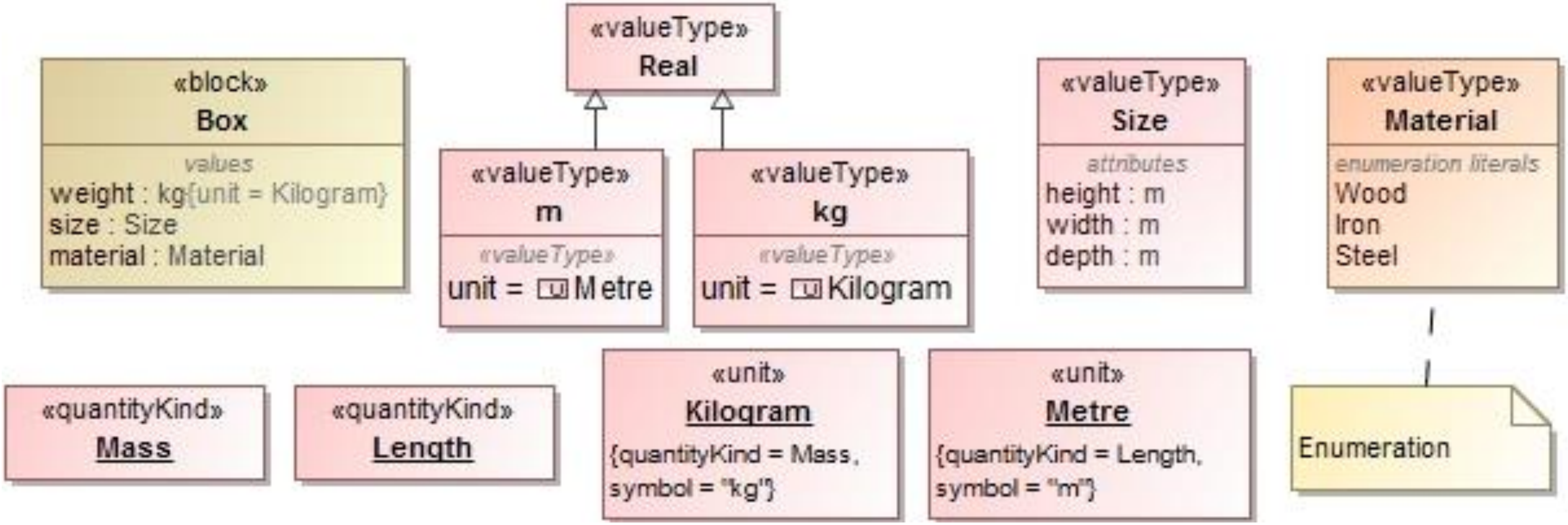


Modeling of logical and phyiscal data

Using block definition diagrams

Value type (Data type)

- Primitives: Boolean, String, Complex, etc.
- Can have Unit and/or QuantityKind (formerly dimension)
  - QuantityKind: Length, Energy, Time, etc.
  - Unit: meter, inch, Watt, secundum, etc.
    - Has a QuantityKind



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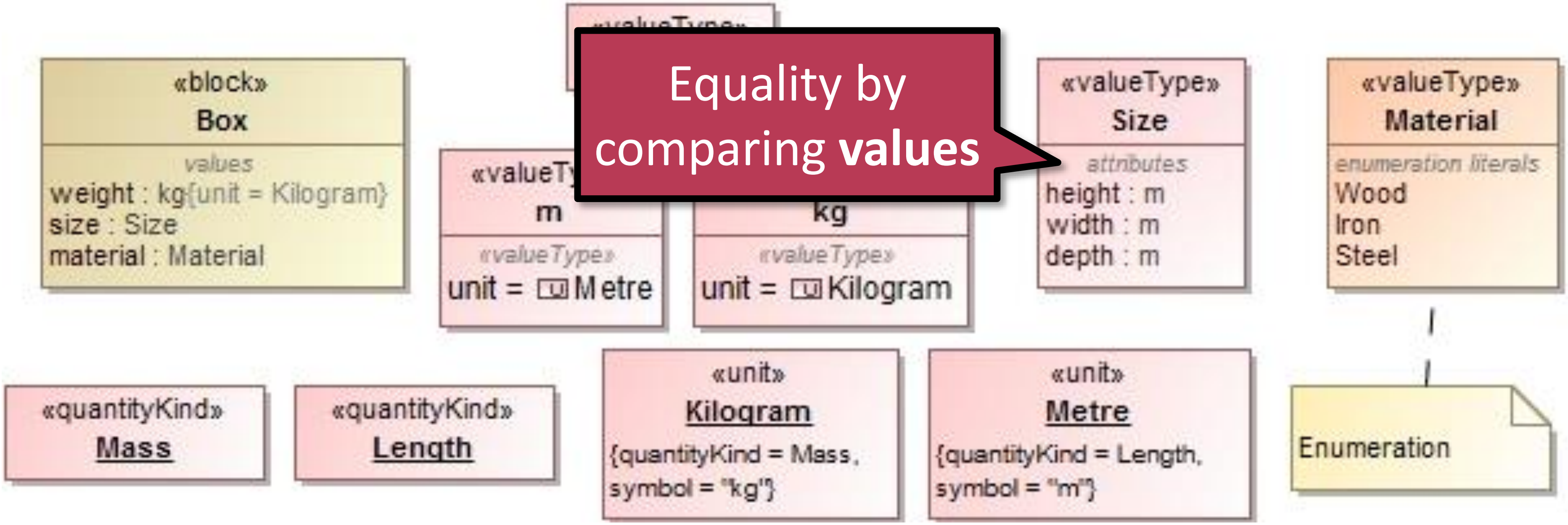
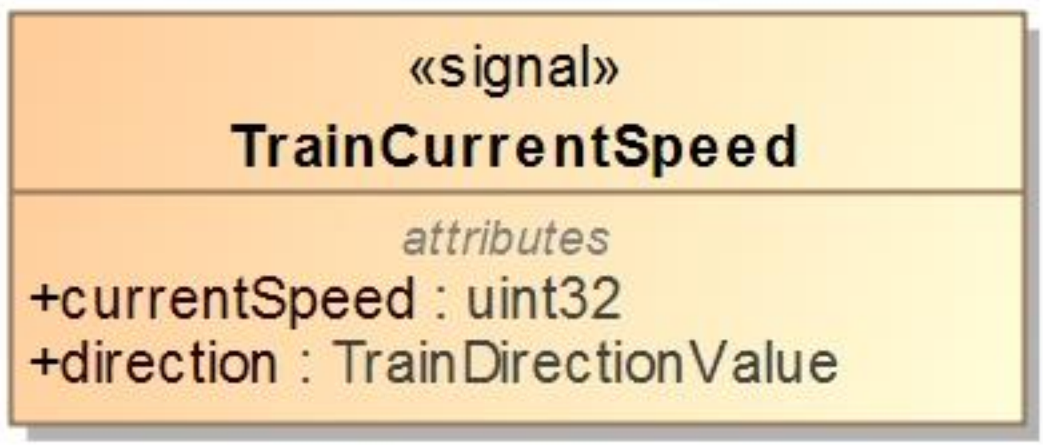


Data of a block

- Blocks can have attributes and/or values
- Value given by / restricted by
  - Definition (bdd)
    - e.g. in a specialized block (motorized =„true”)
  - Use (ibd)
  - Runtime
    - The value may change over time

Signal, Block

- A **signal** defines a message that can be sent and received by a block.
  - Has a set of attributes
  - Used by interfaces



Well-formedness constraints

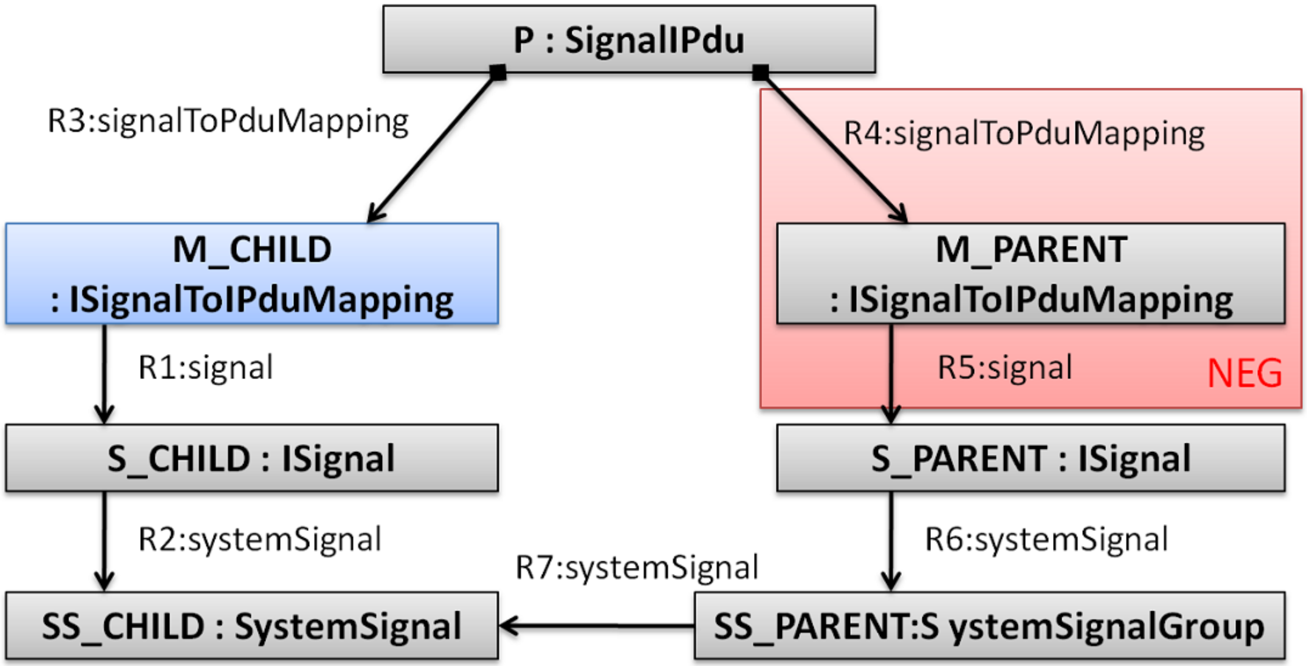
Well-formedness constraints

- Describes additional constraints that should be satisfied on every instance
- Structural constraint
  - A turnout sensor should be connected to exactly one zone controller
- Value constraint
  - The operator should be at least 175 cm tall
  - Components should have a unique name
- Behavioral constraint
  - CPU should receive 12V +- 1V electricity

Motivation: Early validation of design rules

SystemSignalGroup design rule (from AUTOSAR)

- A *SystemSignal* and its group must be in the same *IPdu*
- Challenge: find **violations** quickly in large models
- New difficulties
  - reverse navigation
  - complex manual solution



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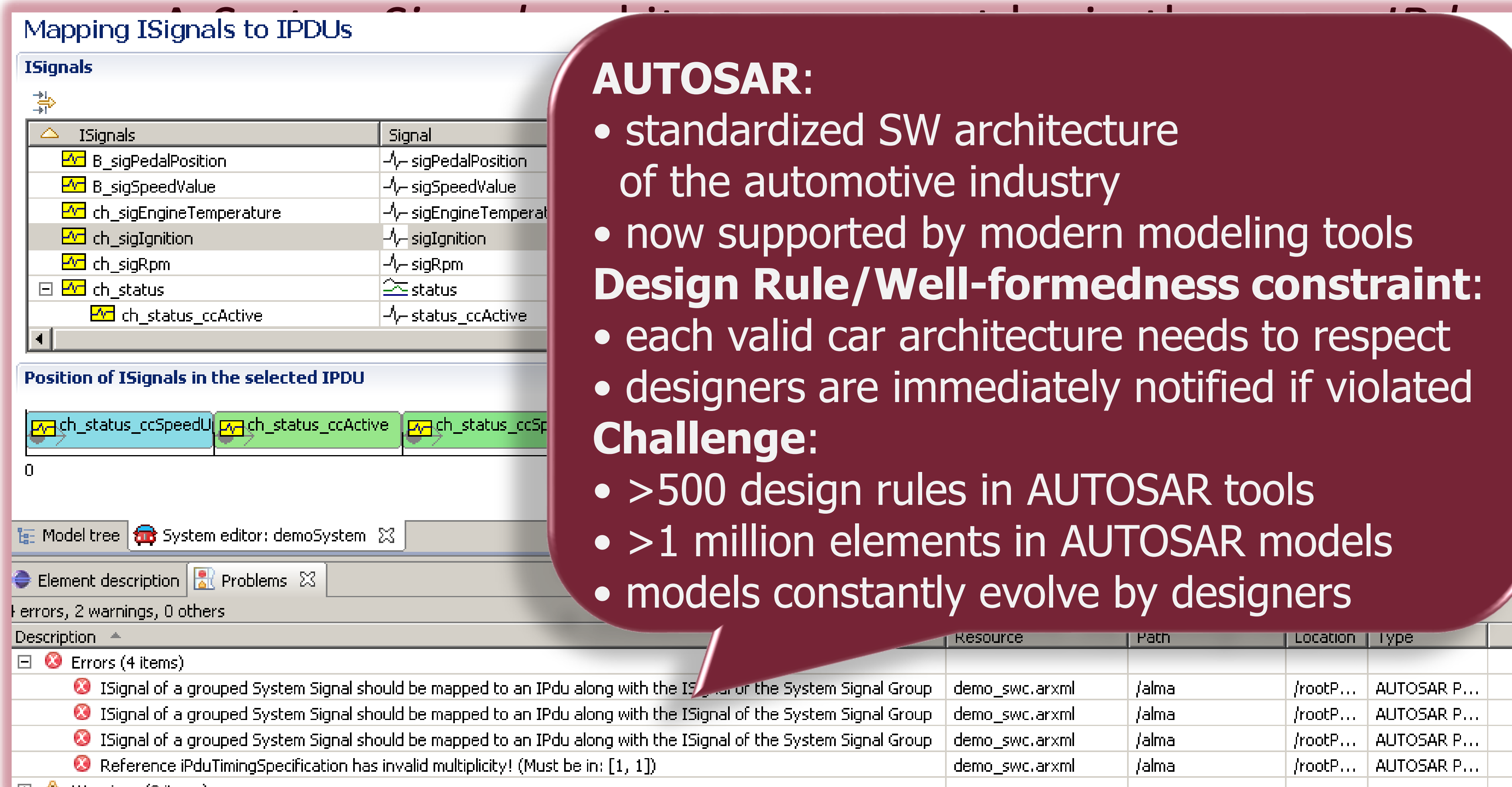
SystemSignalGroup design rule (from AUTOSAR)



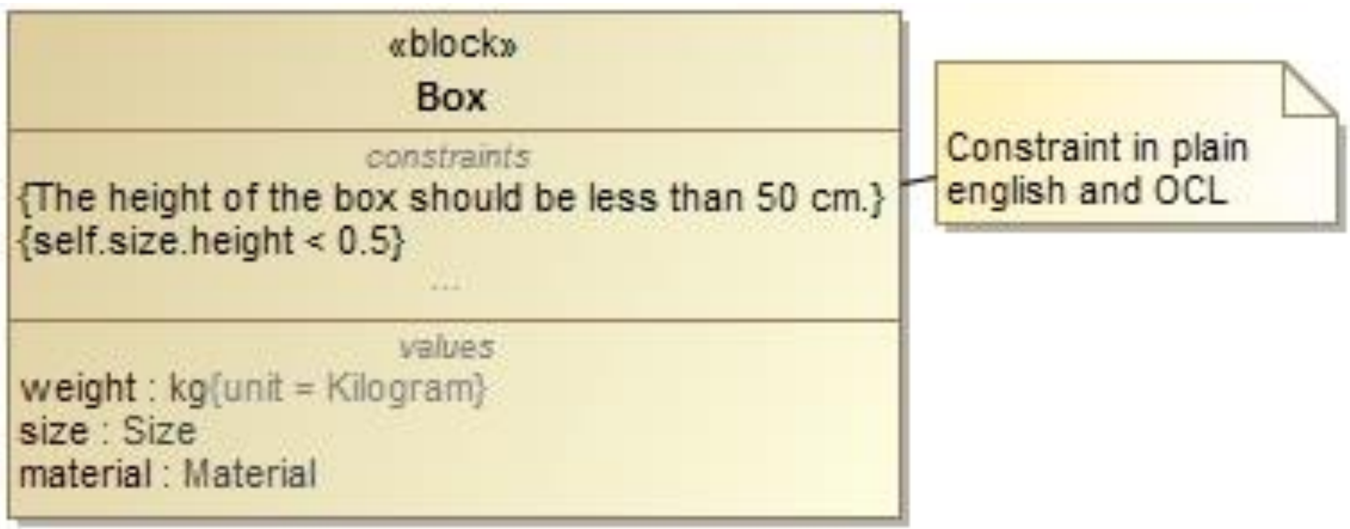
AUTOSAR:
- standardized SW architecture of the automotive industry
- now supported by modern modeling tools

Design Rule/Well-formedness constraint:
- each valid car architecture needs to respect
- designers are immediately notified if violated

Challenge:
- >500 design rules in AUTOSAR tools
- >1 million elements in AUTOSAR models
- models constantly evolve by designers

SysML Constraints

- Different semantics can be used
  - plain english vs formal languages (OCL, Javascript, etc.)
  - formal language can be used for automatic validation
- Can be defined as a separate block with <<constraint>> stereotype

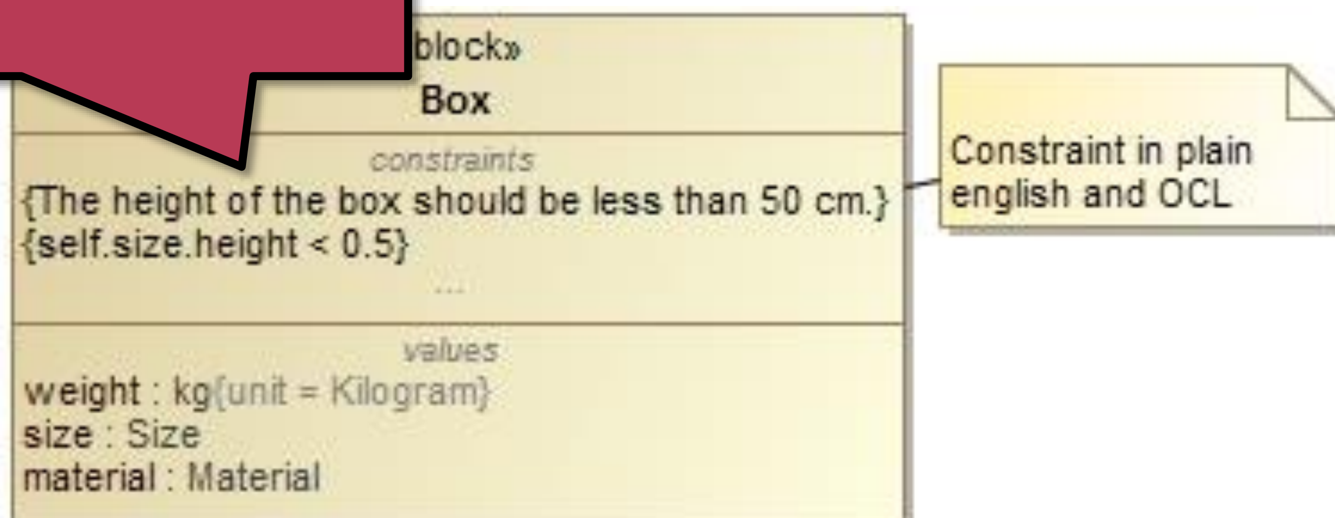


SysML Constraints

- Different semantics can be used
  - ...nguages (OCL, Javascript, etc.)
  - ...used for automatic validation
- ...arate block with ...pe

Don't confuse with SysML Parametrics Diagram!

- Constraints are given by the designers
- Parametrics diagram considers the behaviour of nature (will cover later)



OCL: an OMG Standard

- Object Constraint Language
- Declarative language for defining constraints

- Unique name constraint defined by OCL:
  - ```
    context Component inv:
      Component.allInstances()->
      forAll(c1, c2 |
            c1 <> c2 implies c1.name <> c2.name)
    ```
    ```

VIATRA

- VIATRA is an open source Eclipse project
  - Affiliated with the research group
- VIATRA Query Language
  - Graph pattern matching
  - Can evaluate queries incrementally upon changes
- Unique name constraint defined by VQL
  - ```
    pattern nameCollision(c1, c2){
      Component.name(c1,name1);
      Component.name(c2,name2);
      c1 != c2;
      name1 == name2;}
    ```
    ```

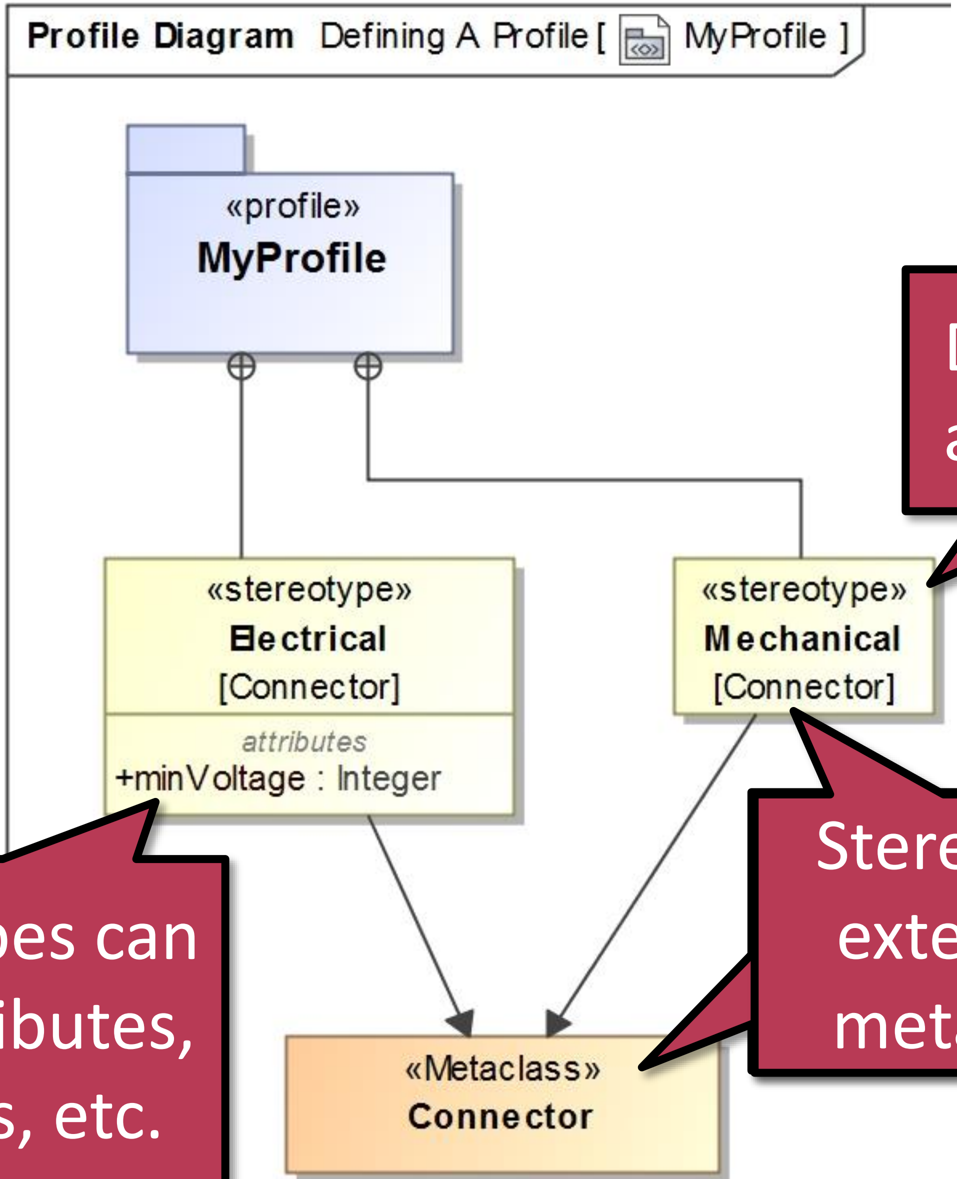
Profiles

for extending UML/SysML

UML Profiles

- Profiles can be used to extend the UML/SysML language.
- Examples
  - SysML is defined as a profile on a subset of UML.
  - SYSMOD (a methodology for SysML) also defines a profile for SysML
  - MARTE (which is an OMG standard) profile is used for modeling real-time and embedded applications.
  - Tools usually support the creation of custom profiles.

Defining a Profile



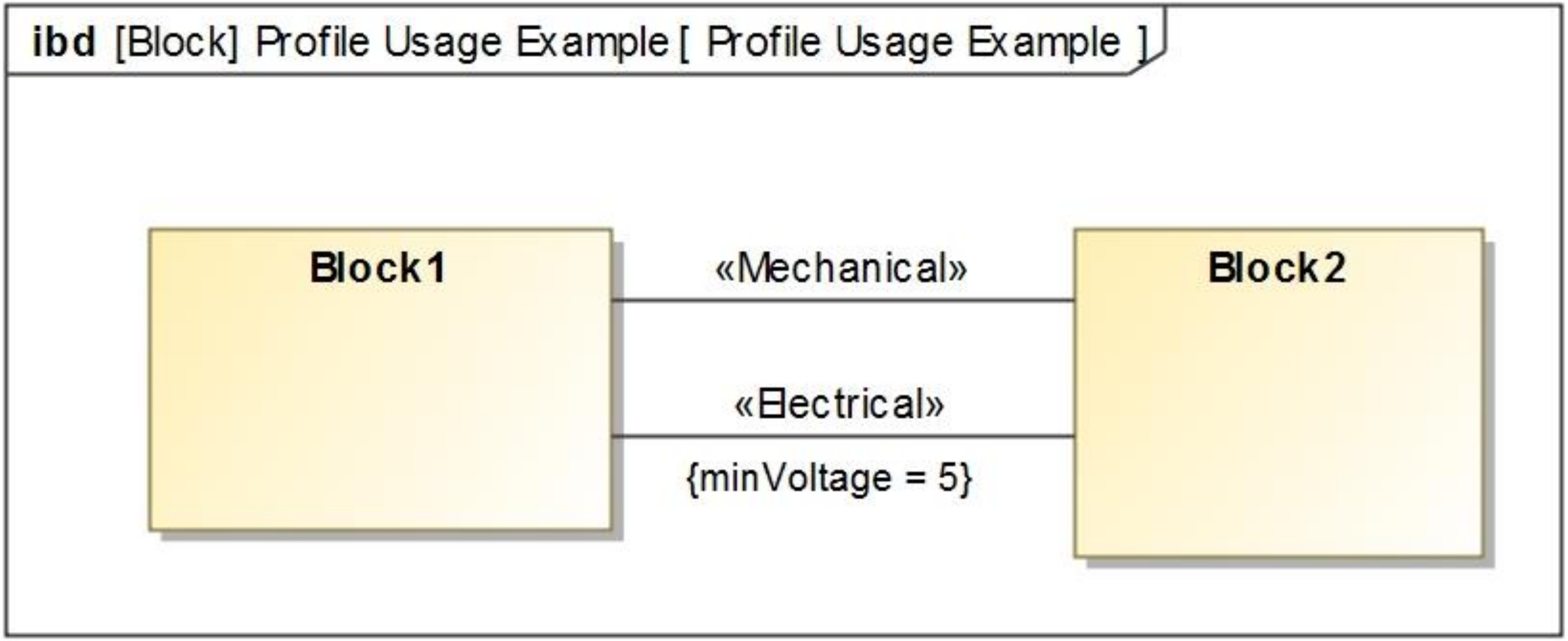
Definition of a stereotype

Stereotypes can have attributes, relations, etc.

Stereotype extends a metaclass

Using a Profile

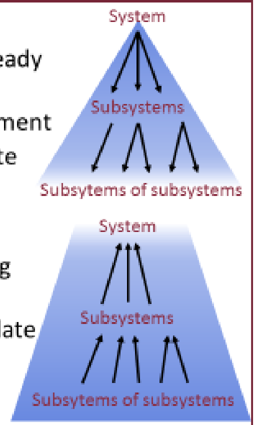
- A profile should be applied to the project to use



Summary

Top-down and bottom-up design

- Top-down: using decomposition
  - ☺ When designing a subsystem, its goal is already known
  - ☹ There are no working parts during development
  - ☹ Problems, needs of subsystems revealed late
- Bottom-up: using composition
  - ☺ Subsystems can be tested one-by-one
  - ☺ There are always some working parts during development
  - ☹ Exact roles of the subsystems are revealed late
- (Not only in structural modeling…)
- Meet-in-the-middle approach
- Iterative approaches



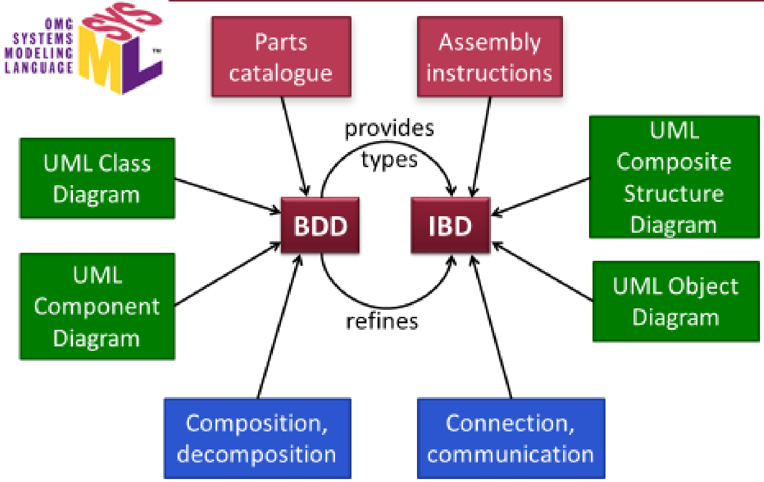
Ports

- What is a port?
  - Interaction points with external entities limiting and differentiating the possible connection types

REST API:

Method	URL	Payload	Result
POST	/api/InventoryItem	CreateInventoryItemCommand (input)	Creates a new inventory item
GET	/api/InventoryItem	InventoryItemListDataCollection (output)	Returns all items
PUT	/api/InventoryItem/{id}	RenameInventoryItemCommand (input)	Renames an item

Block Definition Diagram vs Internal Block Diagram



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