ALSSE 2017 Oslo

S2ML for X

Prof. Antoine B. Rauzy

Department of Mechanical and Industrial Engineering
Norwegian University of Science and Technology
Trondheim, Norway

&

Chair Blériot-Fabre
CentraleSupélec
Paris, France

Agenda

Model-Based Systems Engineering

System Structure Modeling Language (S2ML)

Model-Based Risk/Safety Assessment

Syntactic Structures

Model Synchronization

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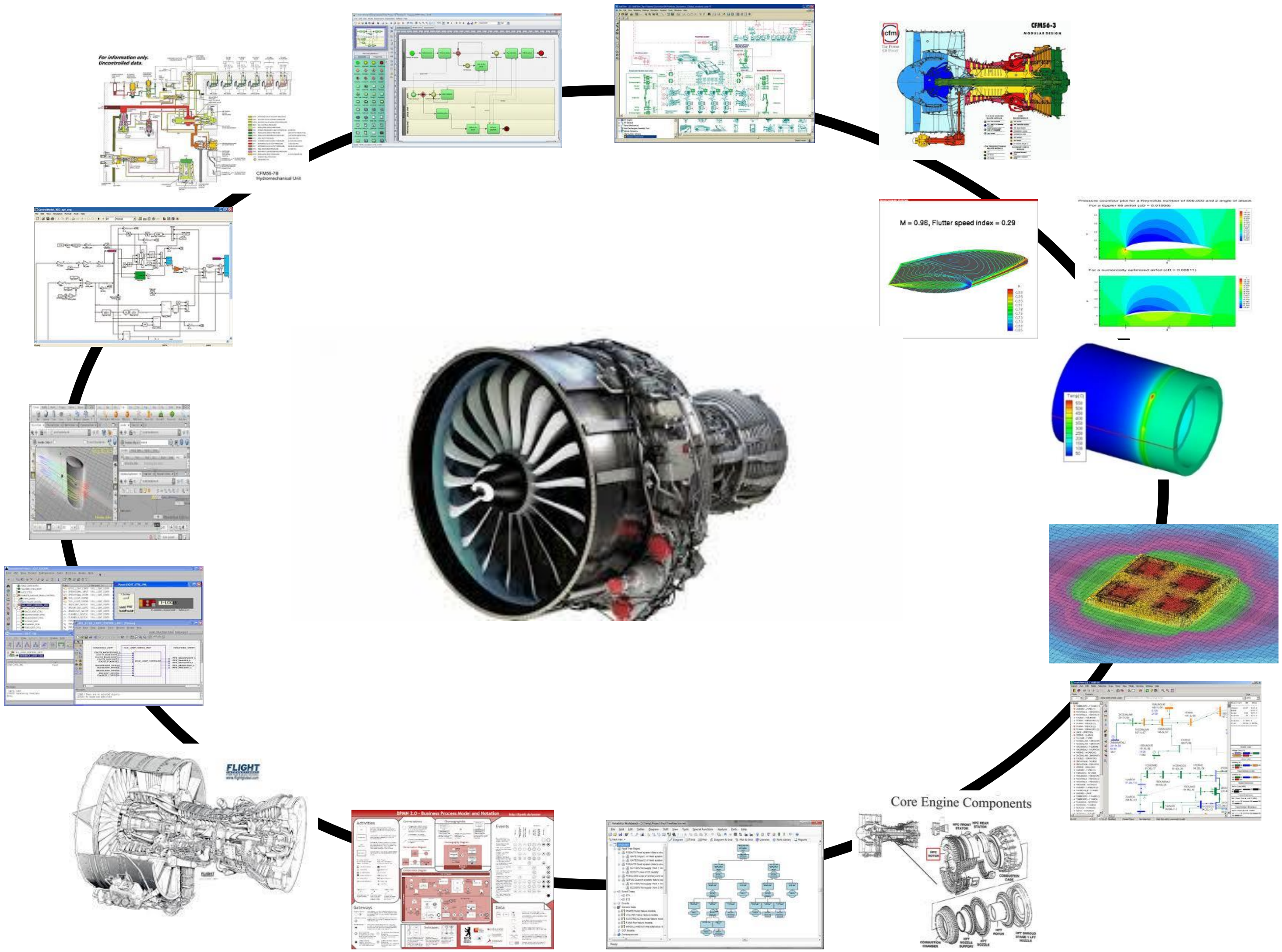
Models Are Everywhere

- The **systems** designed by industry are more and more **complex** and **interconnected**. Not only these **products** are more and more complex but also the **processes** by which they are **designed/produced/operated/decommissioned** and **organizations** that implement these processes are.

- To face this complexity, the different engineering disciplines (mechanics, thermic, electric and electronic, software, architecture…) virtualize their contents to a large extent, i.e. they are designing **models**. We entered the era of:

Model-Based Systems Engineering

- Each system comes with dozens of models. More and more of these models are **embedded** into systems and used for their operation.


For information only.
Uncontrolled data.
CFM56-7B
Hydromechanical Unit
CFM56-3
M = 0.98, Flutter speed index = 0.29
FLIGHT
Core Engine Components

The Science and Engineering of Models

Models must be taken seriously and considered as **first class citizens**. This raises a number of challenges:

- Better understand the **nature** of models and their **roles** in industrial processes.
- Develop the "**Art of Modeling**"(*) in each and every engineering discipline.
- **Manage** models throughout the **life-cycle** of systems.
- Design tools and methods to support the **integration** of engineering disciplines/processes through the integration of models they produce.
- **Teach** and **give taste** of modeling to (future) engineers.
- …

The emerging science of complex systems is the science of models

(*) In reference to Knuth's famous series of books about "The Art of Programming"

Models Engineering

Fact 1: To design a model, we need a **modeling language** (would it be purely graphical), just as to design a program, we need a programming language.

Fact 2: Models of a complex system cannot be simple, otherwise they cannot capture the complexity of the system* (information loss). Therefore, they need to be **structured**, documented, managed… in a word, we need an **engineering of models**.

Questions:

- What is a good modeling language?
- What is a good palette of modeling languages?
- How to manage versions and configurations of models through the life-cycle of systems?
- …

(*) Models of complex systems are simplex, in the sense of A. Berthoz.

Thesis

Behaviors + Structures = Models*

Meaning and practical consequences:

- Any modeling language is the combination of a **mathematical framework** to describe the behavior of the system under study and a **structuring paradigm** to organize the model.
- The choice of the **appropriate mathematical framework** for a model depends on which aspect of the system we want to study
- **Structuring paradigms** are to a very large extent **independent** of the chosen mathematical framework. They can be studied on their own.

(*) In reference to Wirth's seminal book "Algorithms + Data Structures = Programs"

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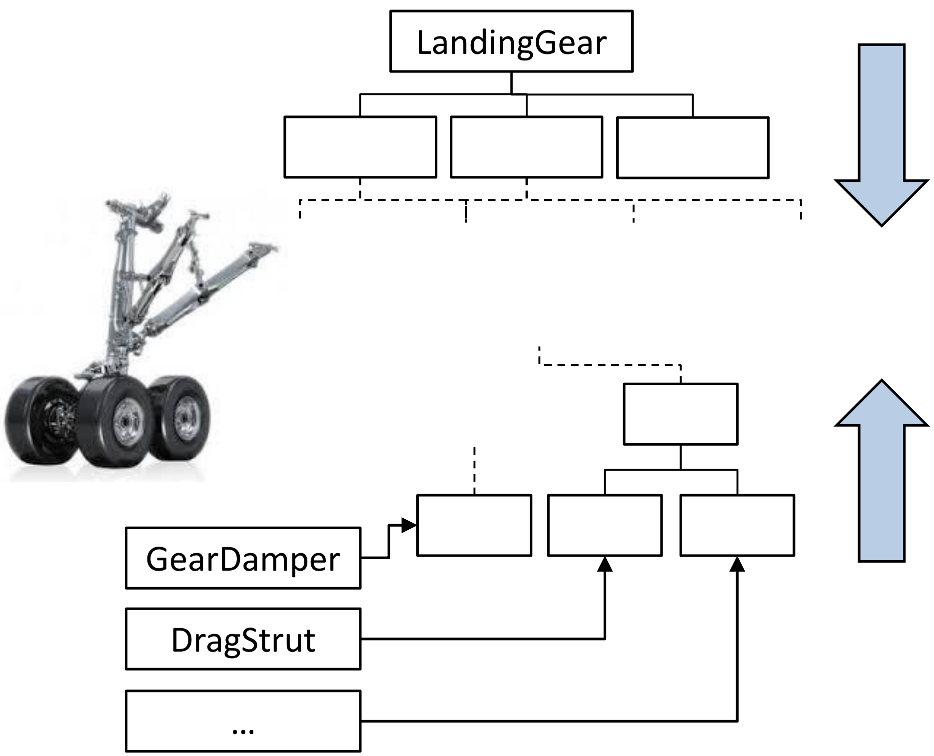
S2ML

S2ML: **System Structure Modeling Language**

- A **structuring paradigm** that unifies the two dominant structuring paradigms for modeling languages, i.e. **object-orientation** and **prototype-orientation**.
- A **modeling language** on its own, dedicated to architecture description.



- Top-down model design
- System level
- Reuse of modeling patterns
- Prototype-Orientation

- Bottom-up model design
- Component level
- Reuse of modeling components
- Object-Orientation

system architecture

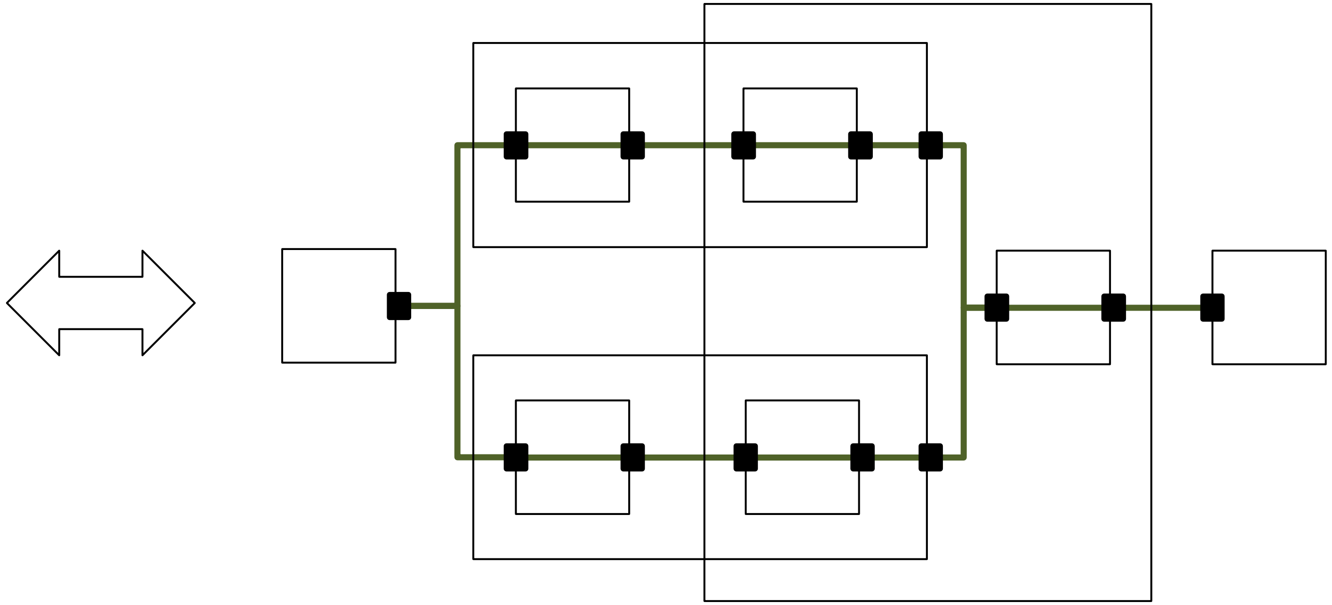
safety

Multiphysics simulation

S2ML Promise: 1) Models of Structures

S2ML aims at providing a **necessary and sufficient language** to describe the **functional and/or physical structures of systems**.

system

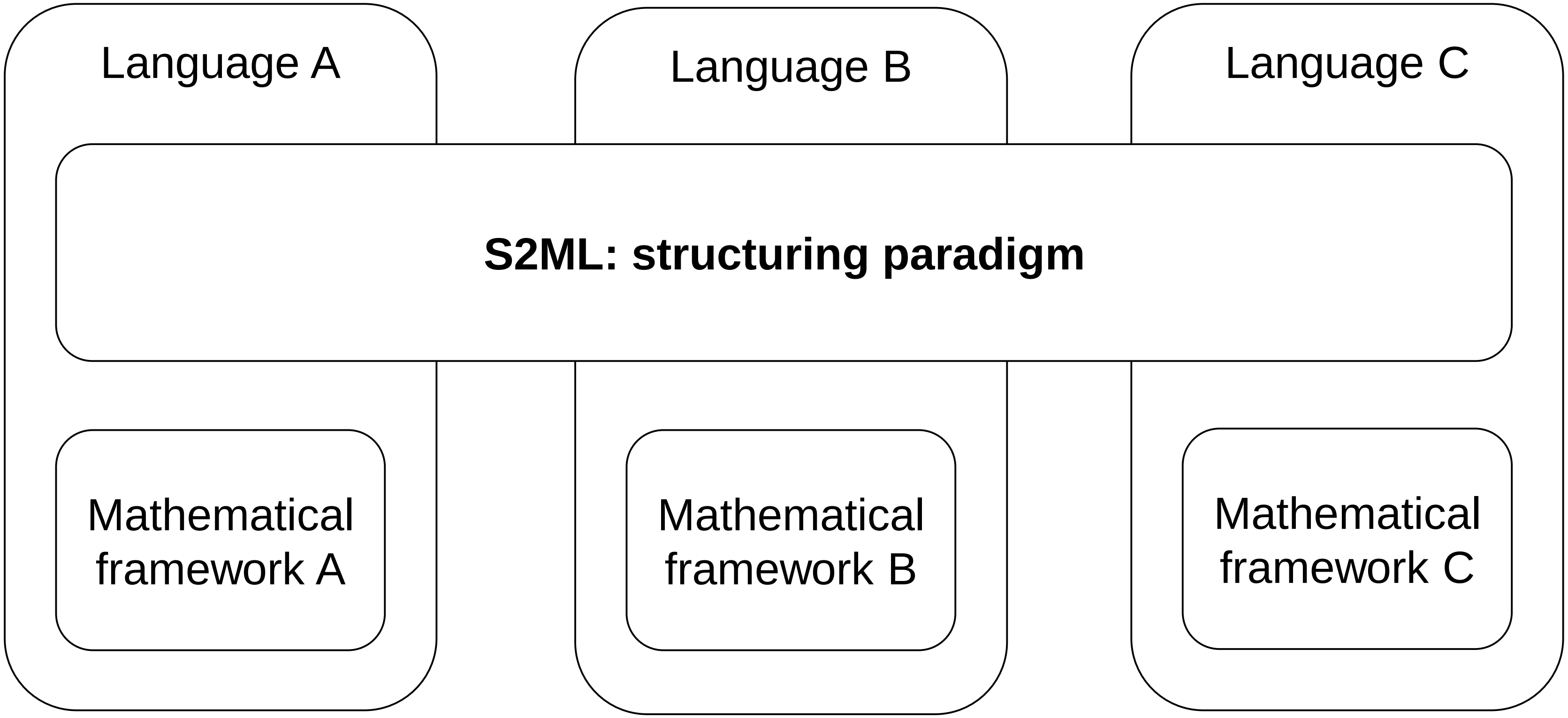


(representation of the) S2ML model

Describing the structure of a system is a **modeling process** that aims at architecting the system, i.e. eventually at improving the comprehension / specification of that system.

S2ML Promise: 2) Structure of Models

S2ML aims at providing a **structuring paradigm** of system engineering modeling languages.



Structuring helps to design, to debug, to share, to maintain and to synchronize models.

Why not SysML?

SysML is a graphical notation, derived from UML, to address system modeling. It provides two types of diagrams to represent structures: Definition Block Diagrams and Internal Block Diagrams (1). It could thus be a candidate formalism for our purpose. However,

- A model, which is a **mathematical object**, should not be confused with its **graphical representations**. Even though graphical representations are excellent supports for the **communication** amongst stakeholders, they are able to represent only **partially** the models, except for formalisms with very low (or very ambiguous) expressiveness. Moreover, there may be **several graphical representations** of the same concept, each more or less convenient in a given context.
- SysML **lacks** of some **essential structuring constructs**.

(1) Parametric Diagrams and Package Diagrams cannot be used directly to represent structures, although they are considered also as structural.

Why not SysML?

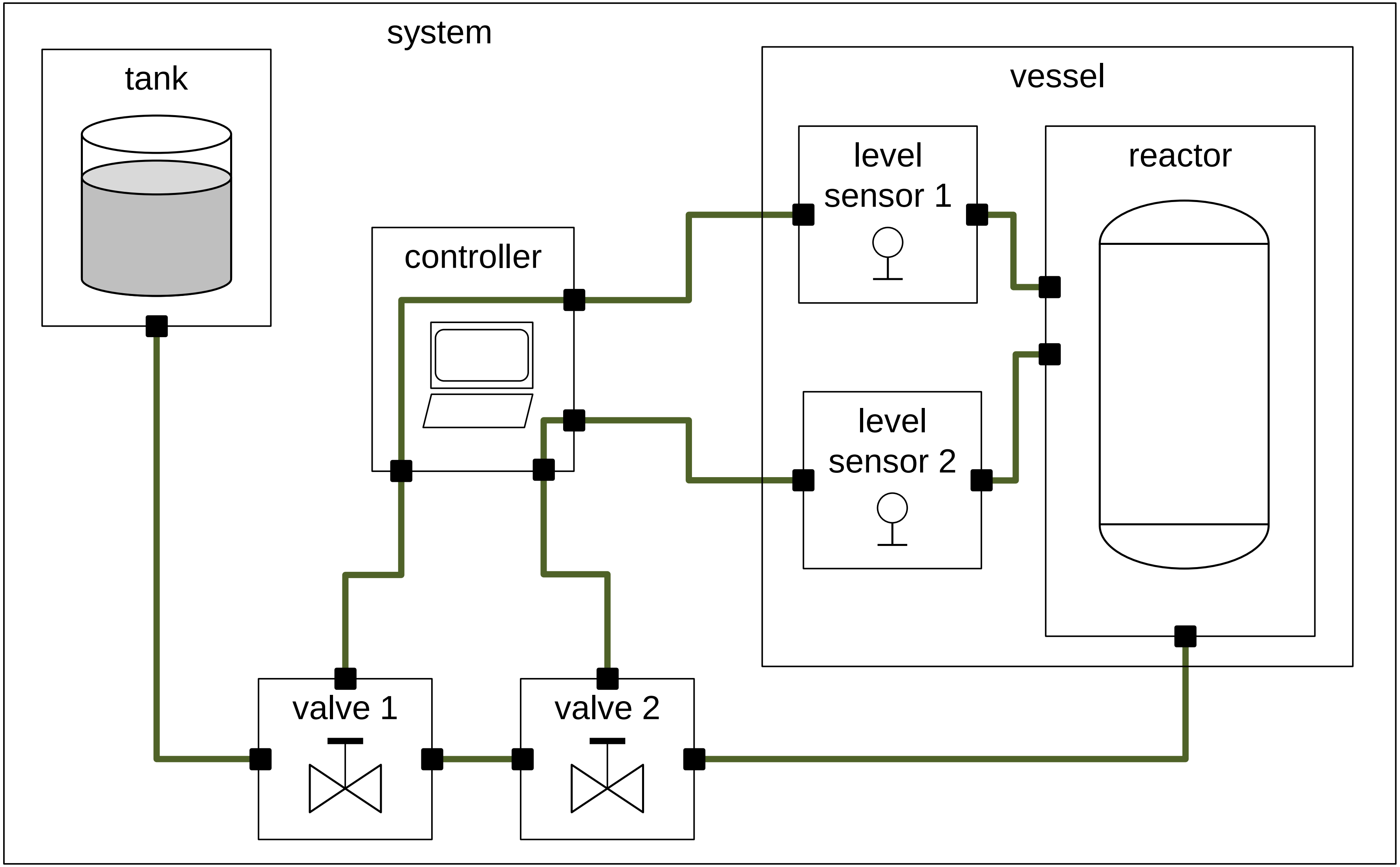
In a word:

- Graphical representations are a very good communication mean. Therefore, we shall use SysML graphics and vocabulary as much as possible.
- However:

Concepts should come first

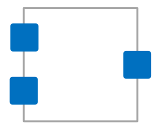
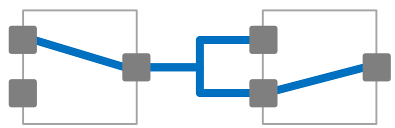
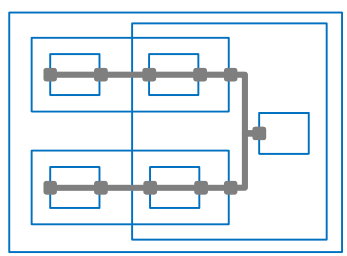
S2ML aims at proposing a minimal yet sufficient set of concepts to represent structures of systems and to structure models.

Cooling System



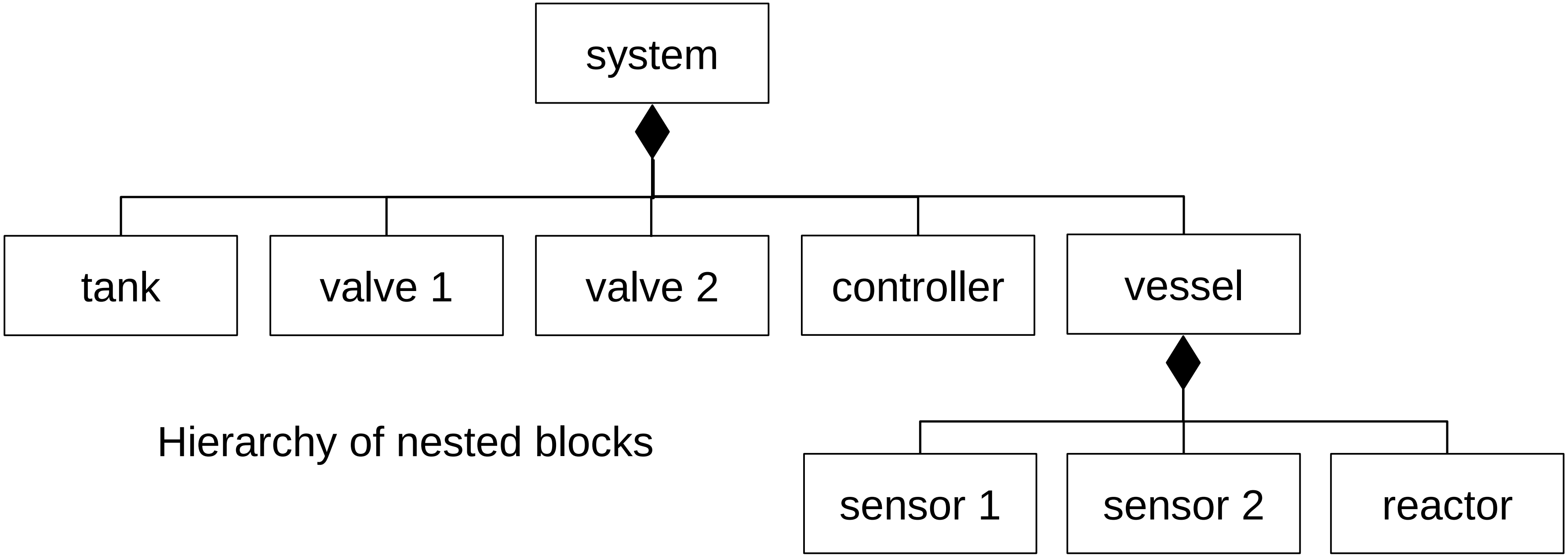
Basic Components

S2ML is made of the following basic components.

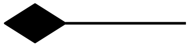
Component	Representation	Role
Ports		Ports are basic objects of models, e.g. variables, events, equations, transitions…
Connections		Connections are used to describe relations existing between ports.
Blocks		Blocks are containers. They can contain ports, connections and other blocks.

Blocks as Prototypes & Composition

A block is a **container** for ports, connections and other blocks. Each block is a **prototype**: it has a unique occurrence in the model.
The block “system” **composes** the blocks “tank”, “valve 1”… The block “reactor” **is part of** the block “vessel”.



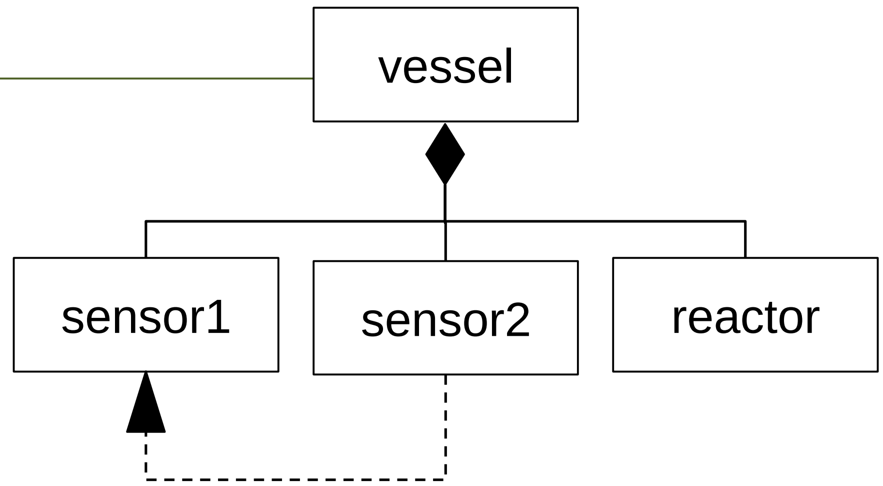
Hierarchy of nested blocks



composition

Cloning

A system may contain similar components, e.g. the sensors or the valves of our example. The corresponding copy then contains several copies of the same block.
A first way to avoid duplicating the description of a block consists in **cloning** an already existing block.

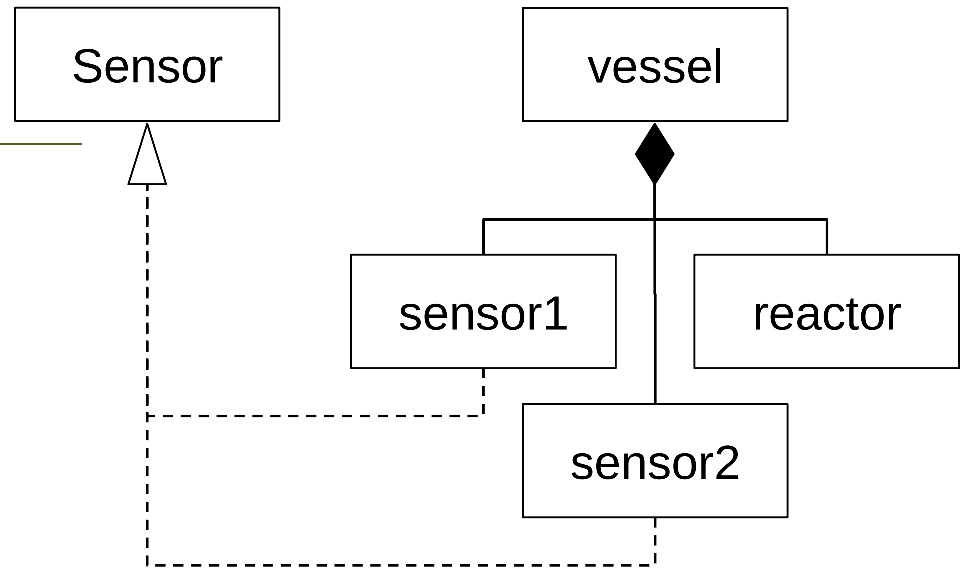



```
block vessel
    block sensor1
        port input, output;
    end
    block sensor2 clones sensor1;
    end
    block reactor
        port output1, output2;
    end
    connection [sensor1.input, reactor.output1];
    connection [sensor2.input, reactor.output2];
    …
end
```

cloning
(of a block)

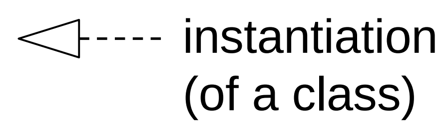
Classes and Instances

A second way to avoid duplicating the description of a block consists in declaring a model of the duplicated block in a separate modeling entity, so-called a **class**, and then in **instantiating** this class.

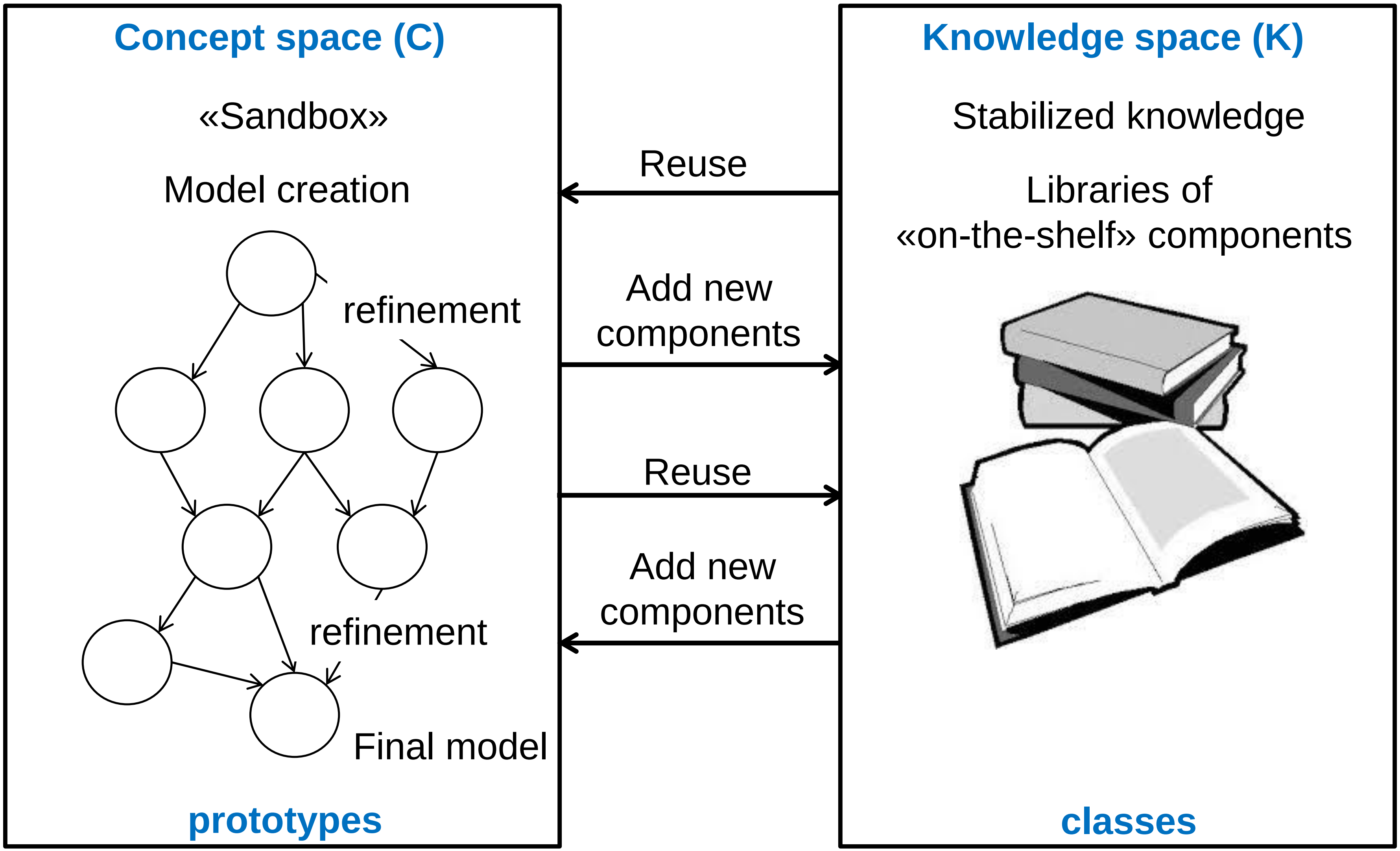



```
class Sensor
    port input, output;
end

block vessel
    Sensor sensor1, sensor2;
    block reactor
        port output1, output2;
    end
    connection [sensor1.input, reactor.output1];
    connection [sensor2.input, reactor.output2];
    …
end
```



Prototypes versus Classes



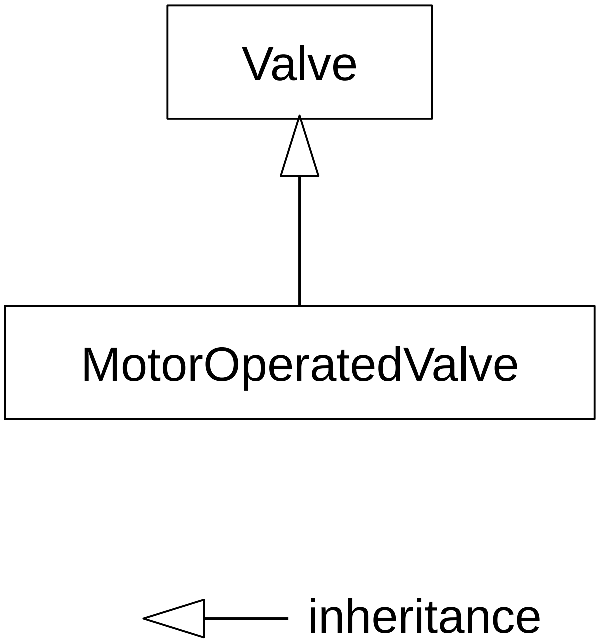
Inheritance

Aside the composition, that defines a "is-part-of" relation, S2ML provides also a **inheritance** mechanism, i.e. a "**is-a**" relation. A class or a block can inherit the content of another class (or another block in the same modeling entity).

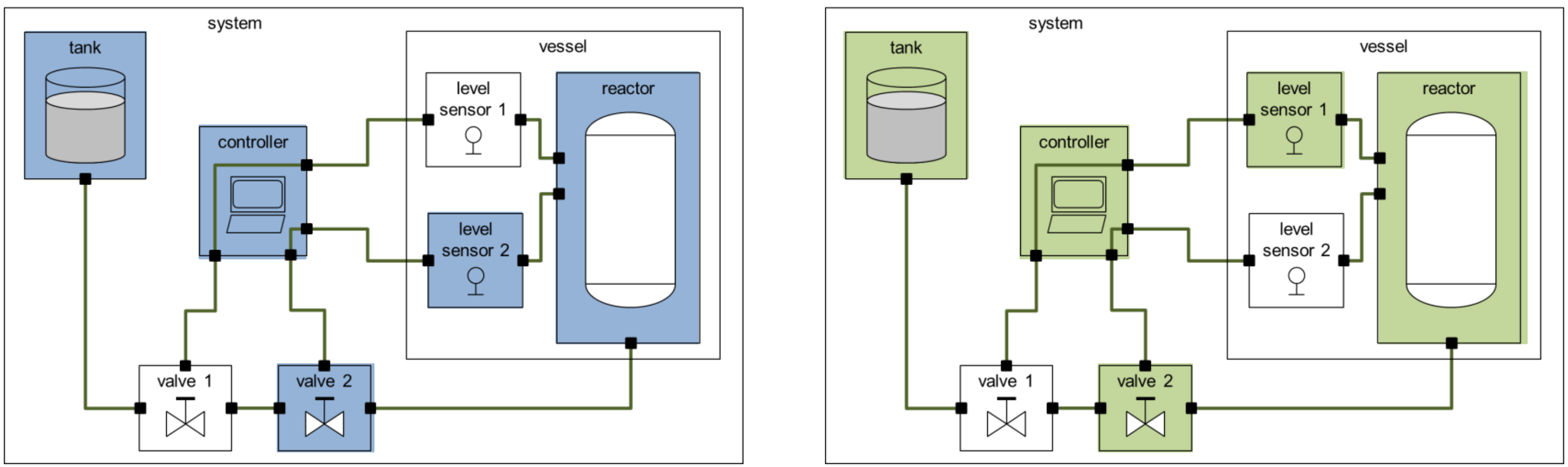
```
class Valve
    port input, output;
end

class MotorOperatedValve extends Valve;
    port inputTorque;
end

block system
    ...
    block MyValve extends Valve;
        ...
    end
    ...
end
```



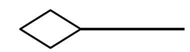
Functional Chains



Aggregation

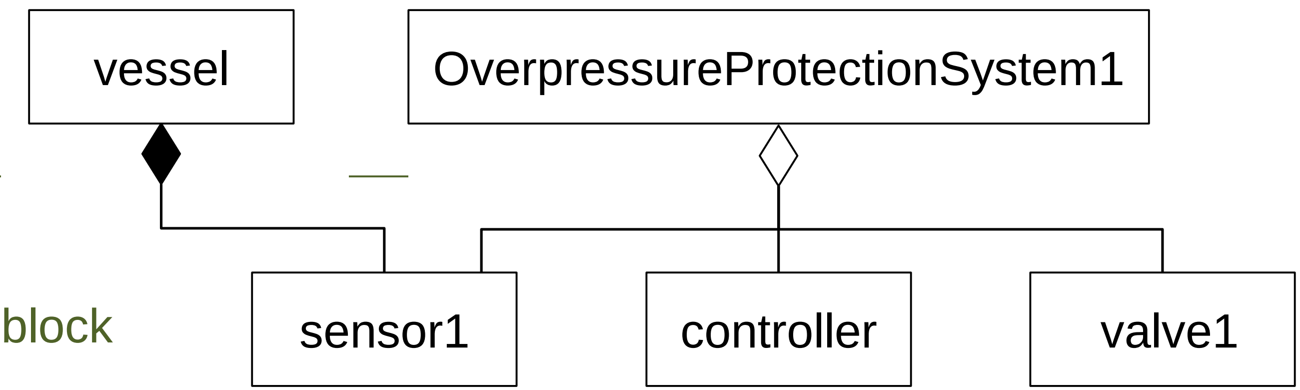
S2ML provides a mechanism for blocks to **use** blocks defined elsewhere in the same modeling entity. The using block **aggregates** the used block. This mechanism is especially useful to describe the so-called **functional chains**.

```
block system
    ...
    block OverpressureProtectionSystem1
        embeds owner.vessel.sensor1 as sensor;
        embeds owner.controller as controller;
        embeds owner.valve1 as actuator;
        ...
    end
    ...
end
```



aggregation

To access to the parent block



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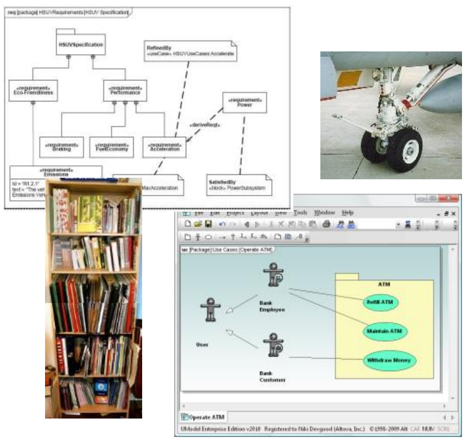
Syntactic Structures

Model Synchronization

Issues with "Classical" Safety Models

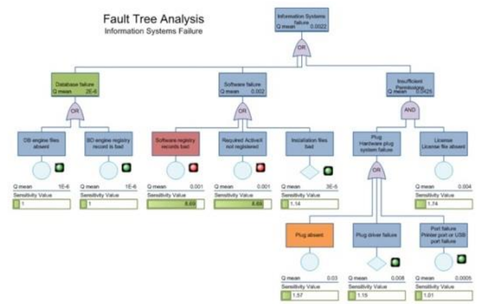
Systems Specifications



Modeling

Requirements, Certification

Models



FMEA, Fault Trees, Markov Chains, Stochastic Petri Nets…

Virtual Experiments

- Failure Scenarii
- Failure Probabilities

Classical modeling formalisms used for safety analyses lack of expressive power and/or are very close to mathematical equations (lack of structure).

→ **Distance** between **systems specifications** and **models**;

→ Models are **hard to design** and even **harder** to **share with stakeholders** and to **maintain** throughout the **life-cycle** of systems.

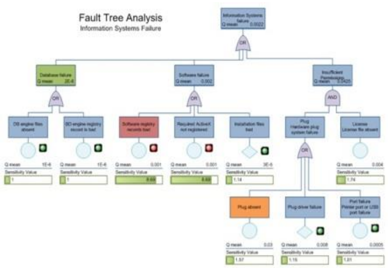
→ Very **conservative** approximations

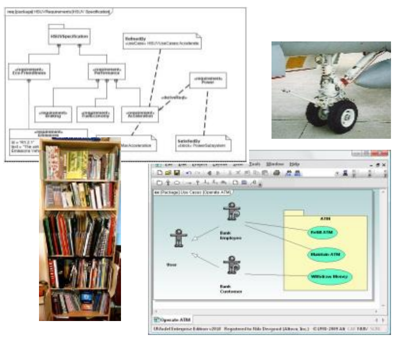
The Promise of Model-Based Safety Assessment

Modeling systems at **higher level** so to reduce the distance between systems specifications and models (without increasing the complexity of calculations).

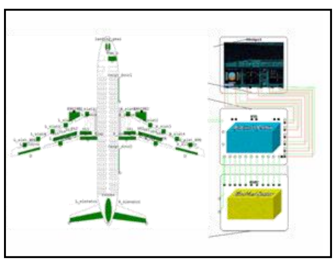
- Ability to **animate/simulate** models: to ease **model validation** and **discussions with stakeholders**;
- One model, several safety goals: to ease **versioning**, **configuration** and **change** management;
- One model, several assessment tools: **versatility** of assessments, **quality-assurance** of results;
- Fine grain analyses: to **avoid over-pessimism**.

Models





Systems Specifications



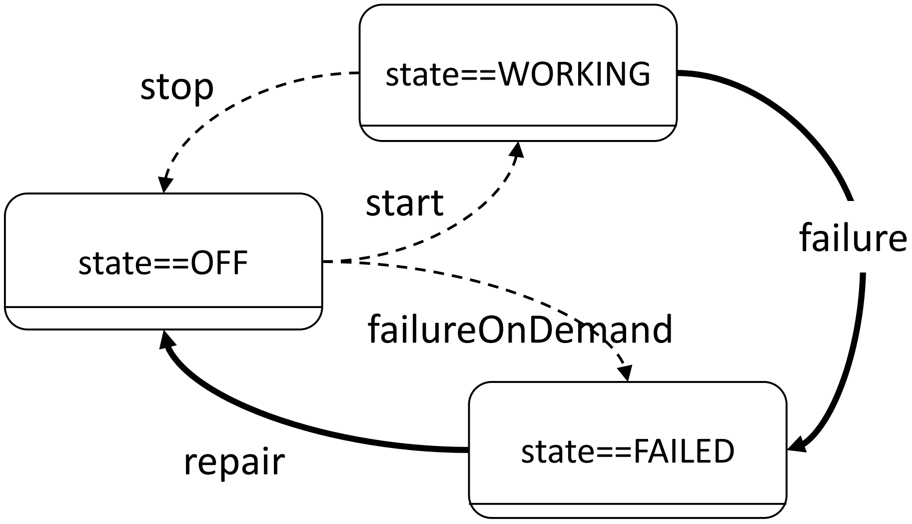
```
class HydraulicPump
 Boolean working (init = false);
 event failure (delay = exponential(lambda));
 transition
   failure: working -> working := false;
end
```

AltaRica 3.0

AltaRica 3.0

Guarded Transitions Systems + S2ML = AltaRica 3.0

Guarded Transitions Systems:
- Are a probabilistic Discrete Events System formalism.
- Are a compositional formalism.
- Generalize existing mathematical framework.
- Take the best advantage of existing assessment algorithms.



AltaRica 3.0 is an optimal modeling formalism

Open-PSA format 3.0

The Open-PSA Initiative

Purpose of Format

The Open PSA model exchange format aims at:

- giving a clear semantics for each and every construct of Probabilistic Safety Assessment (PSA) and Probabilistic Risk Assessment (PRA) models,
- providing a way to exchange models amongst tools,
- making it possible to connect models written in different formalisms.

The version 3.0 of the format encompasses:

- Fault Trees
- Block Diagrams
- Event Trees
- Markov Chains

A module is defined for each of these formalisms.

S2ML + Boolean equations

S2ML + Markov chains

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Taxonomy of Engineering Models

Models are designed at different level of abstraction, for different purposes and in different **modeling formalisms**.

Models to communicate amongst stakeholders

UNIFIED MODELING LANGUAGE

OMG SYSTEMS MODELING LANGUAGE

Models to calculate performance indicators

MATLAB SIMULINK

MODELICA

AltaRica

Models to generate artefacts (via code generation) or physical components (via additive manufacturing)

Informal models, even thought they are written in *standardized notations*, sometimes called *semi-formal*

Formal models, that essentially encode and organize (a given type of) mathematical equations

Thesis

There is an epistemic gap between informal and formal models

Meaning and practical consequences:

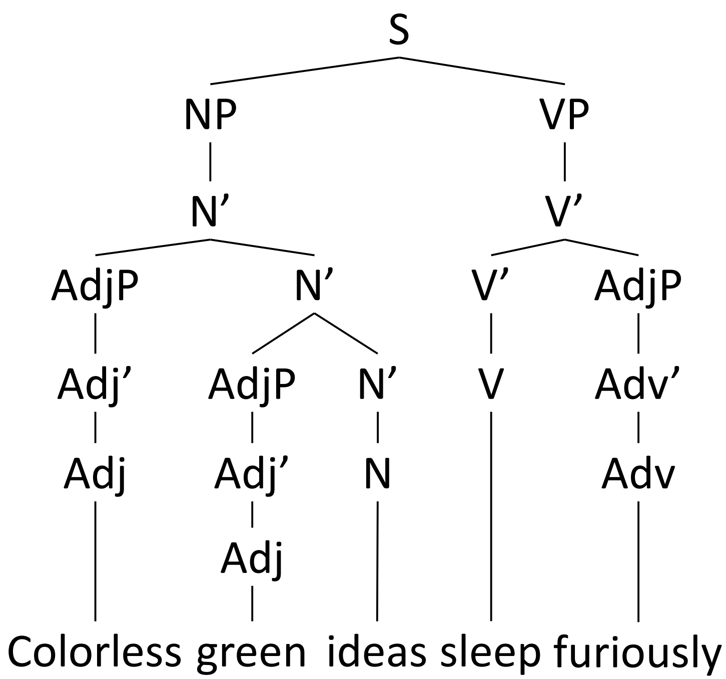
- Informal models and formals models have radically different natures and purposes.

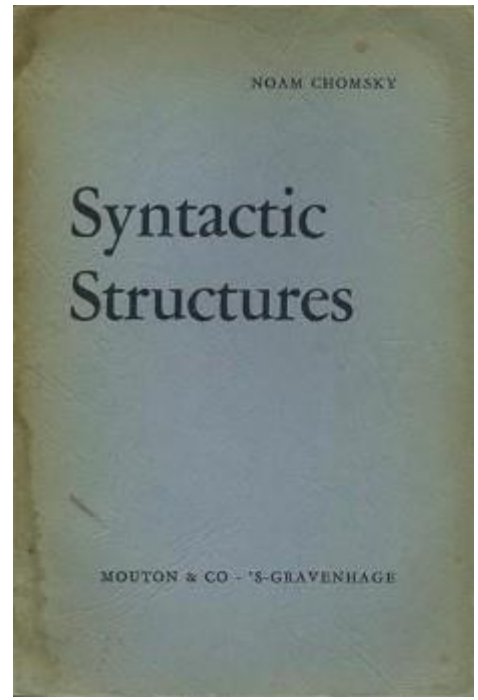
Models to communicate	Models to calculate
Standardized notations	Languages
Pragmatics (external meaning)	Formal semantics (mathematical equations)
Implicit knowledge	Explicit knowledge

- **Both types** of models are **useful**.
- **Passing from informal** models **to formal** ones requires an **engineering process**. This process **cannot be automated**.
- As **informal models** are **computerized**, we can design tools to **process** them.

The Syntactic Point of View

Colorless green ideas sleep furiously

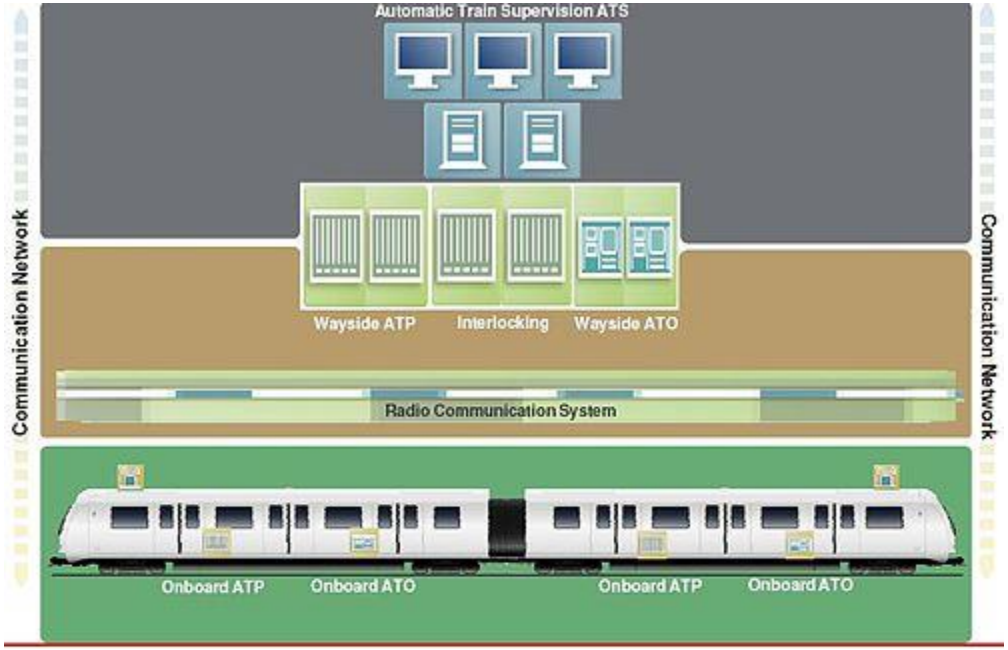




Noam Chomsky (1957)
Syntactic Structures

Reverse Engineering of Textual Specifications

Mélissa Issad PhD Thesis



Siemens CBTC

Technical Specification

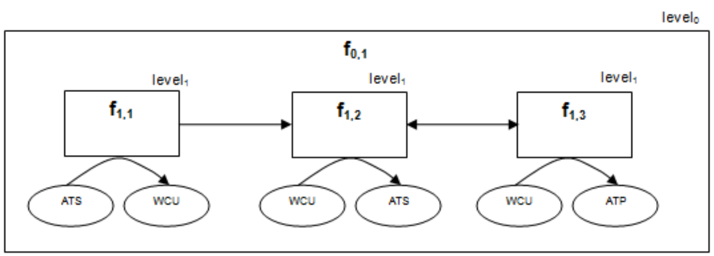
- 6 documents
- ~1000 pages each
- Incomplete
- Mixing levels of abstraction

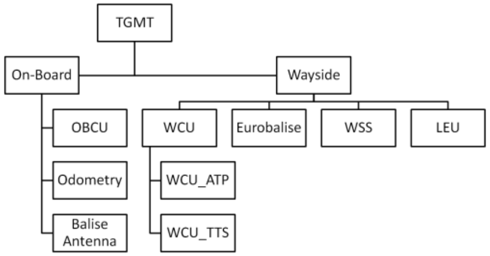
Objective: Safety Assessment

Scenario-Based Approach

Mélissa's proposal:

- Designing scenarios of use is the most efficient way to communicate with experts (system designers & safety analysts)
- Scenarios: formal syntax + pragmatics
- Co-construction of scenarios and model of system architecture

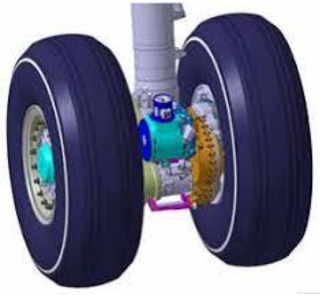




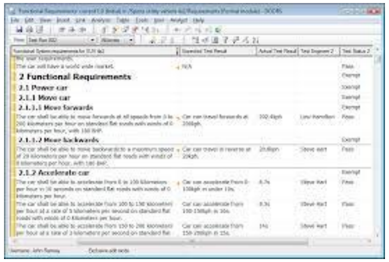
Scola = S2ML + Process Algebra

Requirements Engineering

Benoît Lebeaupin PhD Thesis



Safran Green Taxiing



Corpus of requirements

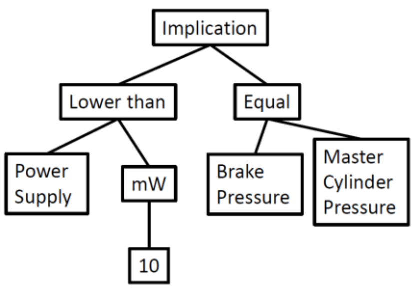
How to check requirements for:

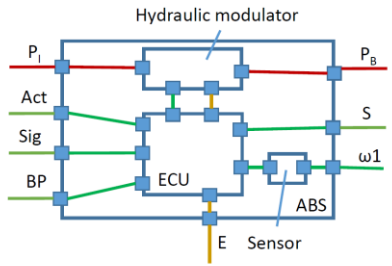
- Clarity?
- Consistency?
- Completeness?
- …

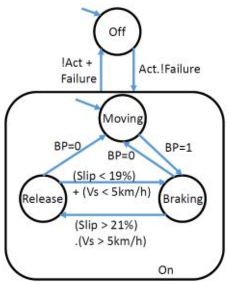
Requirements Engineering

Benoît’s proposal:

- Requirements: syntactic structure + hypertext + pragmatics
- Co-construction of requirements and models of system architecture (S2ML+X)







- Scripts to check syntactic properties of requirements and models

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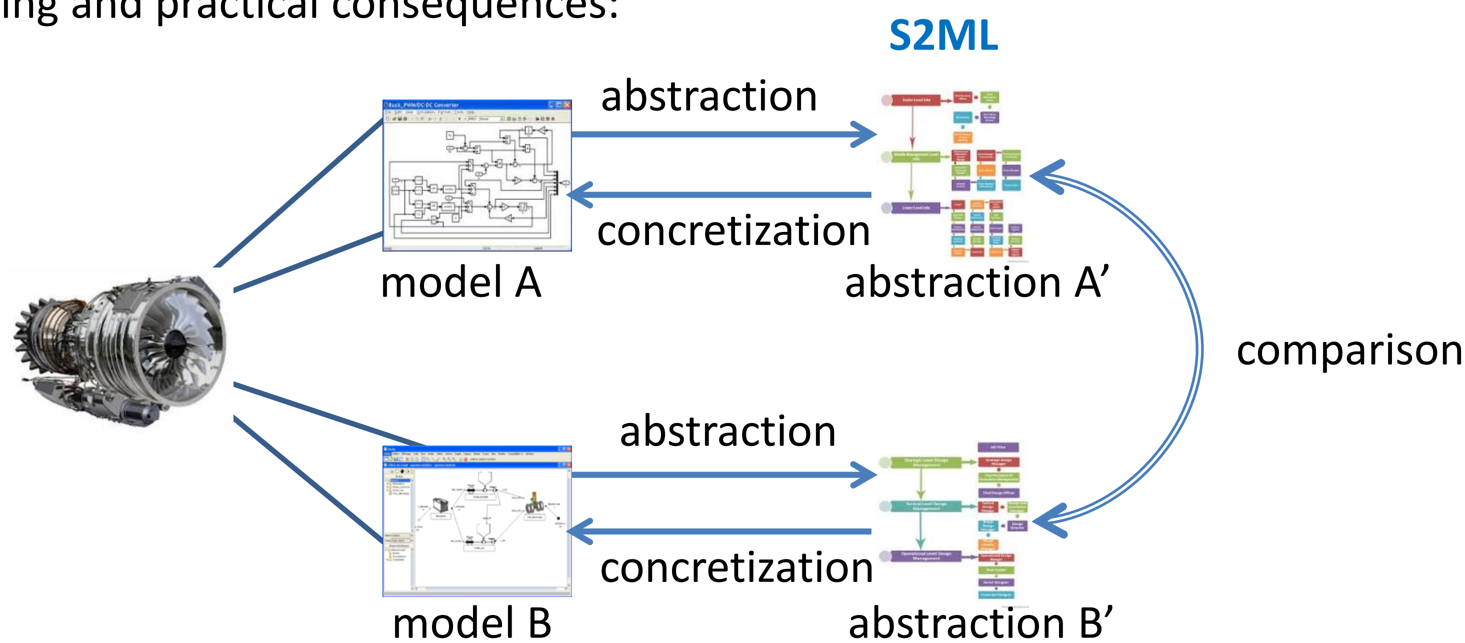
Abstraction + Comparison = Synchronization

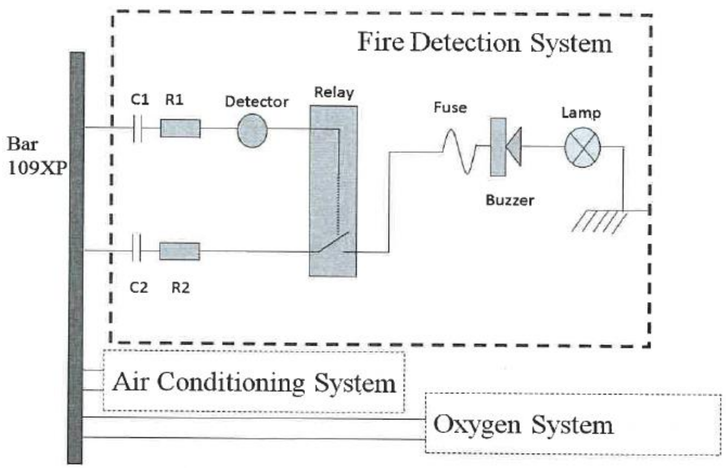
Meaning and practical consequences:



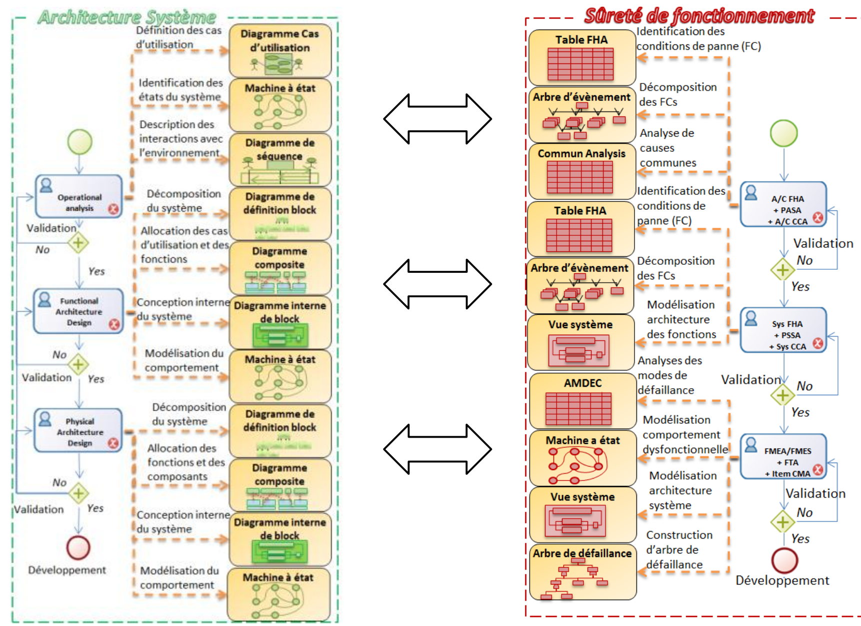
How to agree on disagreements?

Model Synchronization

Anthony Legendre PhD Thesis



Fire Detection System
of a Military Helicopter



- “Schizophrenic” development of MBSE and MBSA processes
- Definition of synchronization points and synchronization needs