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SysML and FMI in INTO-CPS

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Abstract

This deliverable describes how the INTO-CPS SysML profile has evolved during the Year 2 of INTO-CPS project. During Year 1, INTO-CPS SysML profile was mainly focussed on the architectural modelling of Cyber Physical Systems (CPSs). This architectural modelling has evolved during Year 2 and all updates are presented in this document. But the main evolution of the profile during Year 2 consists in the addition of the Design Space Exploration modelling concept also detailed in this deliverable.

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1 Introduction

The INTO-CPS project focuses on the “model-based design” of Cyber-Physical Systems (CPSs). In INTO-CPS, the emphasis is on the utilisation of heterogeneous modelling. A multi-model is the overall model, where each model or sub model can be described using a different modelling notation/language, possibly from a different computational paradigm or domain (as source code or system of mathematical equations for example).

In the INTO-CPS multi-model approach, the design architecture emphasises a decomposition of a system into subsystems, where each subsystem is modelled separately in isolation using a special notation and tool designed for the domain of the subsystem. To allow the design of such multi model, an INTO-CPS SysML profile has been defined under Modelio [1]. Modelio is an Open Source Model Driven Engineering workbench tool, which implements UML2.x metamodel [2] (partially depicted in Figure 1) and SysML [3] standard (as shown in Figure 2).

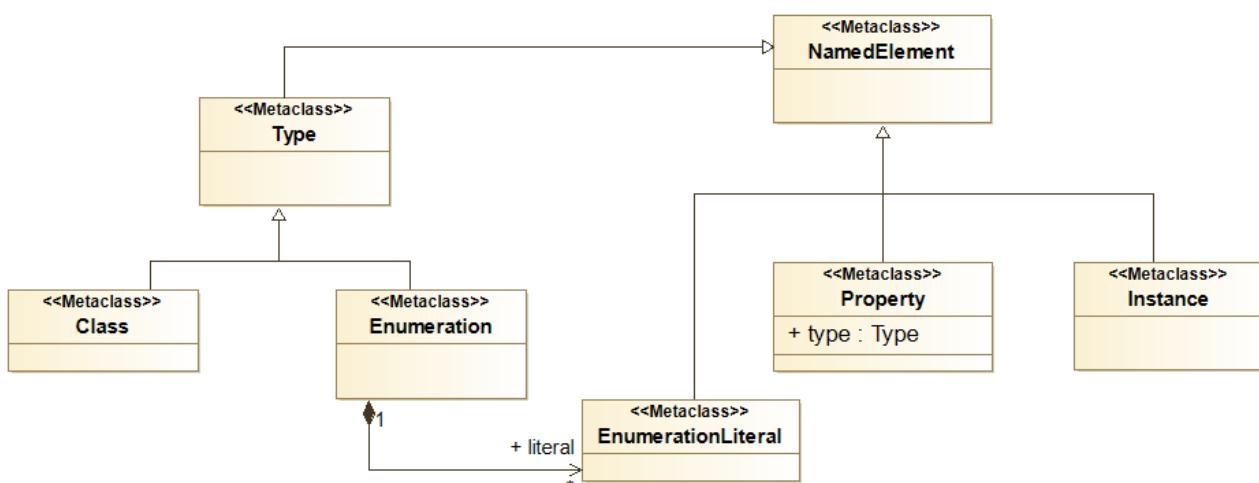


Figure 1: Some UML2.x Metaclasses

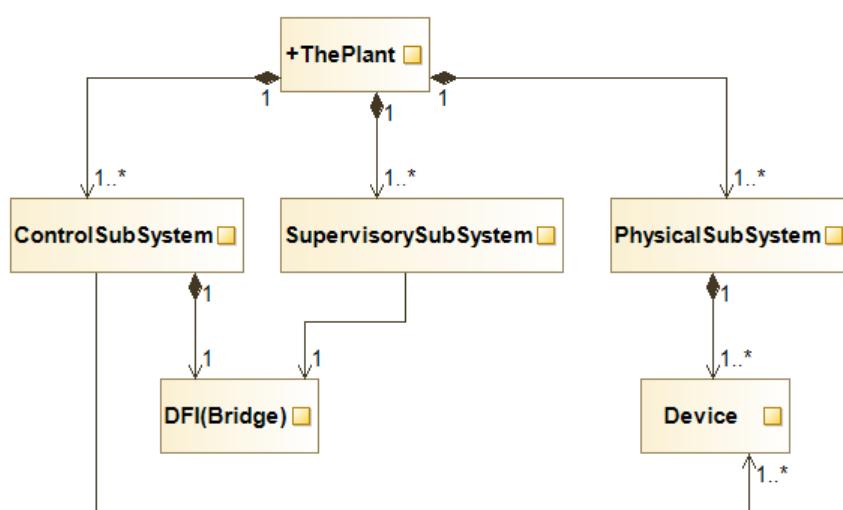


Figure 2: SysML simple example

So UML, its profiling mechanism, and SysML have been used during the first two years of project to extend Modelio and provide a design environment dedicated to INTO-CPS project. In Year 1, the INTO-CPS SysML profile was designed to enable the specification of CPS design architectures [4]. INTO-CPS modelling is focussed, but not limited, to CPS design architectures. During Year 2, INTO-CPS modelling language has been enriched in order to take into account the modelling of Design Space Exploration (DSE) of CPS architectures.

The aim of this deliverable is to take as input the INTO-CPS SysML profile developed during Year 1 and to provide details of its definition at the end of Year 2.

Section 2 describes the updates made in the architectural modelling. Then Section 3 presents the concepts and diagrams defined for DSE modelling. Note that Appendix B provides the entire INTO-CPS SysML profile at XMI format in order to be reused in any other UML/SysML tool.

2 Architectural Modelling

The architectural design of INTO-CPS models is organised around the following logical groups: block, type, instance, library, and diagram. During the Year 2, block, type, and instance group has changed. Figure 3 presents the new block group.

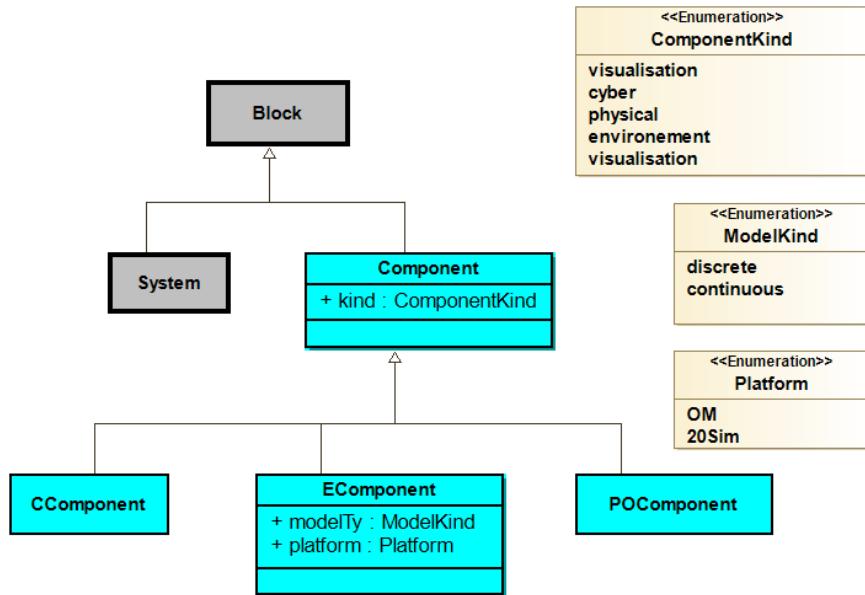


Figure 3: The different kind of blocks

As in the previous version, the INTO-CPS Block stereotype specialises the SysML Block stereotype. In Year 2, a new stereotype called CComponent has been introduced; and two additional options for the ComponentKind enumeration are defined (environment and visualisation). In Year 1, the only possible block composition was a top System Block composed of one or many EComponent; each of these EComponent could be composed of sub POComponent as shown in Figure 4.

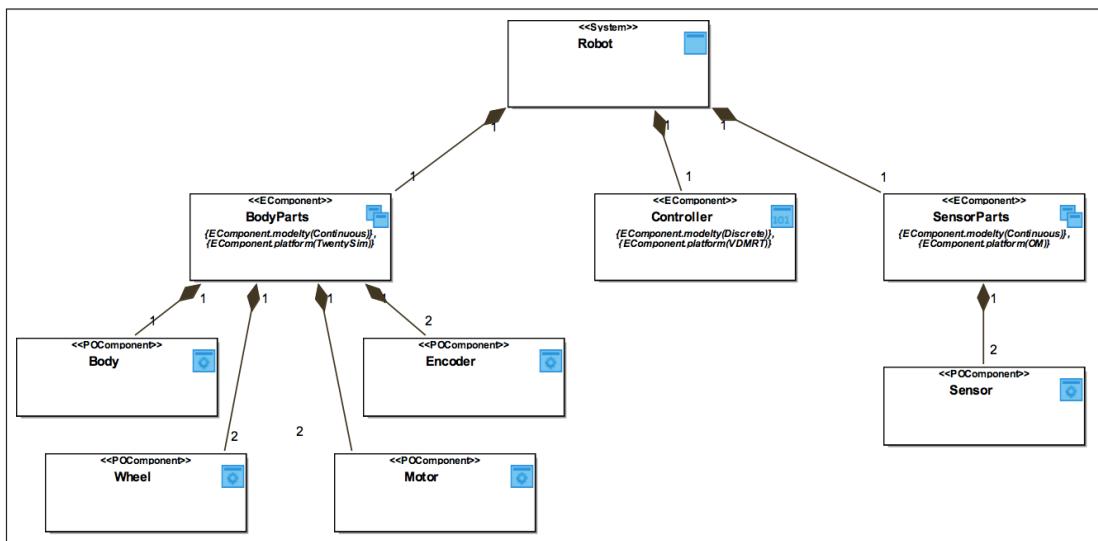


Figure 4: Mandatory block composition in Year 1.

In Year 2, a CPS system is still represented by a top System Block but we would allow more level or freedom in this block decomposition. The CComponent concept has been defined in order to allow this. So a System can be still composed of EComponent but also CComponent. Each CComponent can be decomposed of POComponent or CComponent which can be decomposed, etc. as depicted in Figure 5.

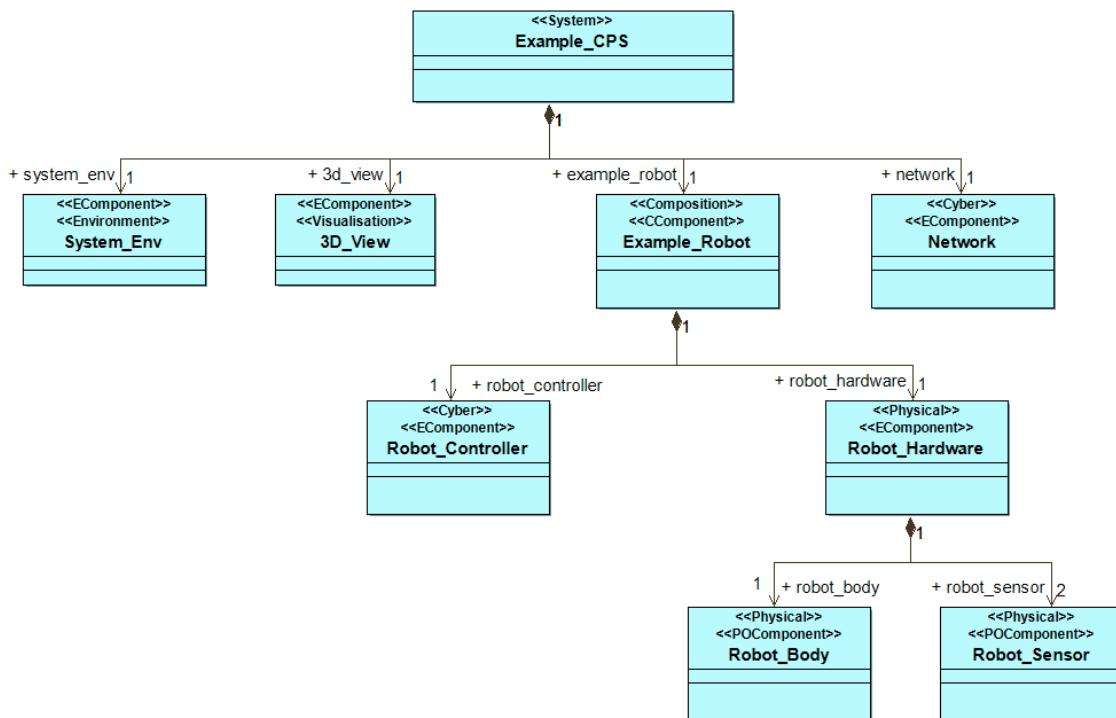


Figure 5: Possible block composition in Year 2.

Even if a CComponent is a kind of Component, it has been defined in order to be a “logical” group of POComponent. By “logical”, we mean that a CComponent can or cannot be a real part of your system; it could be used for design only. In Year 1, all Component could own Variable(s) or FlowPort(s). In Year 2, these “owner” relations have been moved from Component to EComponent and POComponent as shown in Figure 6. The following figure also highlights the fact that FlowPort stereotype has two new attributes - min and max.

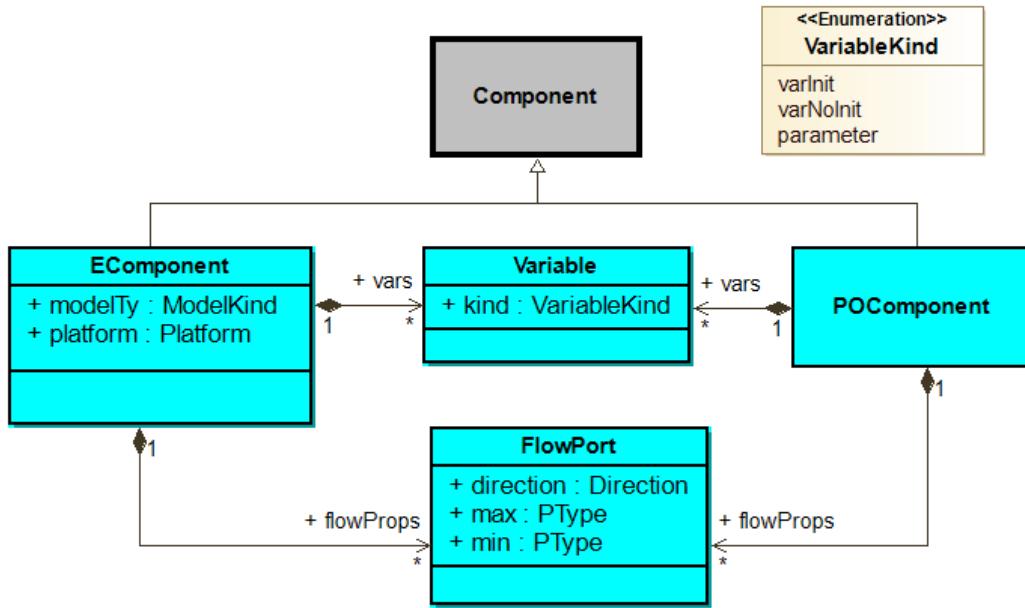


Figure 6: FlowPort and Variable composition

UML makes a distinction between the Class or Type level and the Instance or Object level. This distinction also takes place into the INTO-CPS SysML profile; with the block and type stereotype groups on one hand, and instances group on the other hand. Figure 7 shows the instantiation the type relation existing between Block and BlockInstance. Note that BlockInstance has now an attribute named `isSUT` which will be used in Year3 of the project for test generation and automation.

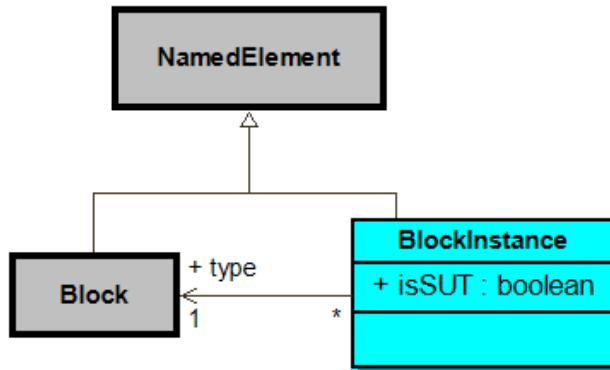


Figure 7: Block Instance

In Figure 8, the **Property** concept is instantiated by **PropertyInstance**. This relation is now derived for **FlowPort** and **Variable** concepts which can be instantiated by **Port** and **VariableInstance** concepts, respectively.

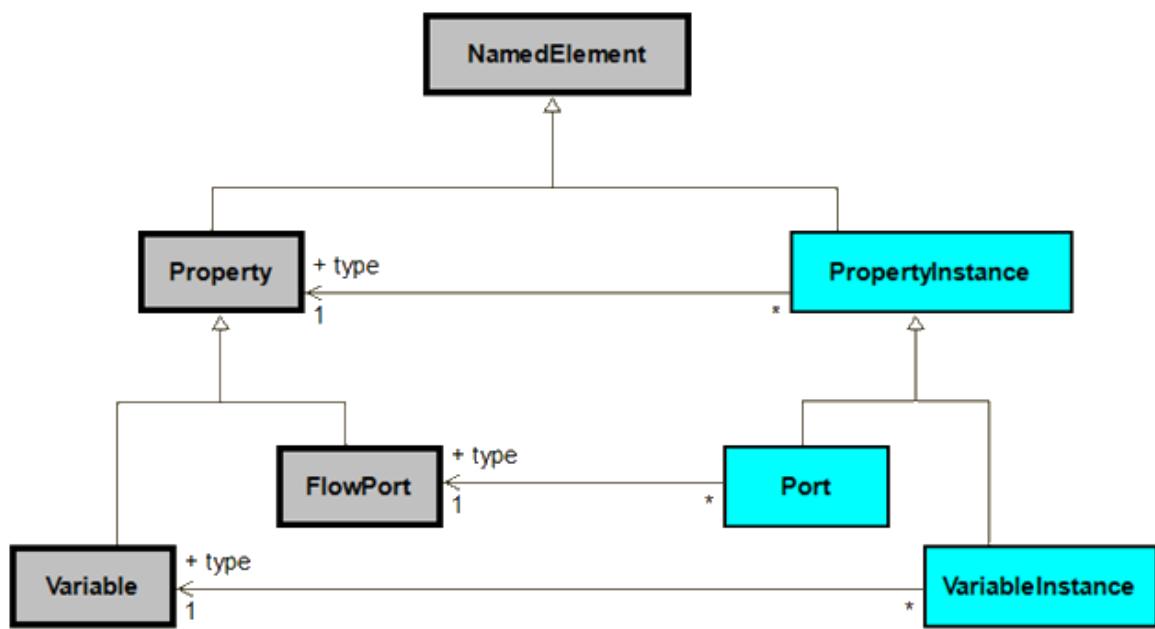


Figure 8: Property instantiation

3 DSE Modelling

3.1 DSE Concept definition

This DSE extension is organised around the following three groups: parameters, objectives, and ranking. All of them are based on specialising the INTO-SysML Block stereotype. Figure 9 presents the parameter group. It introduces the DSEAnalysis block which is the top element of any Design Space Exploration as System is the top element of any System architecture. DSEAnalysis block owns zero to many Parameter block.

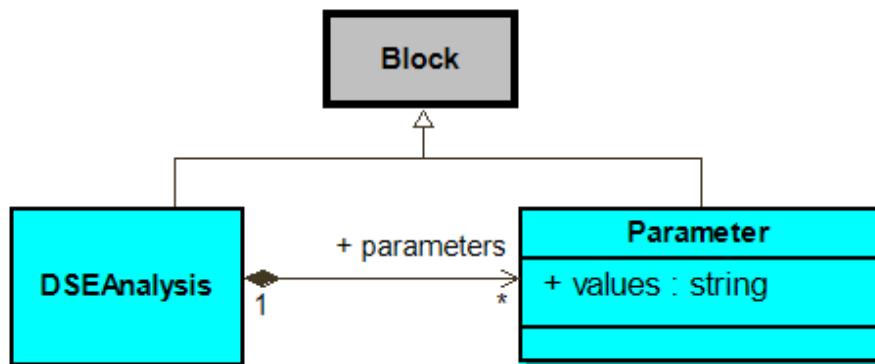


Figure 9: DSEAnalysis and Parameter definition

Figure 10 shows the objective group. The diagram states that a DSEAnalysis block may contain Constraint and ObjectiveConstraint blocks. Objectives contain a collection of FlowPorts, as defined in the architecture part of the INTO-CPS SysML profile.

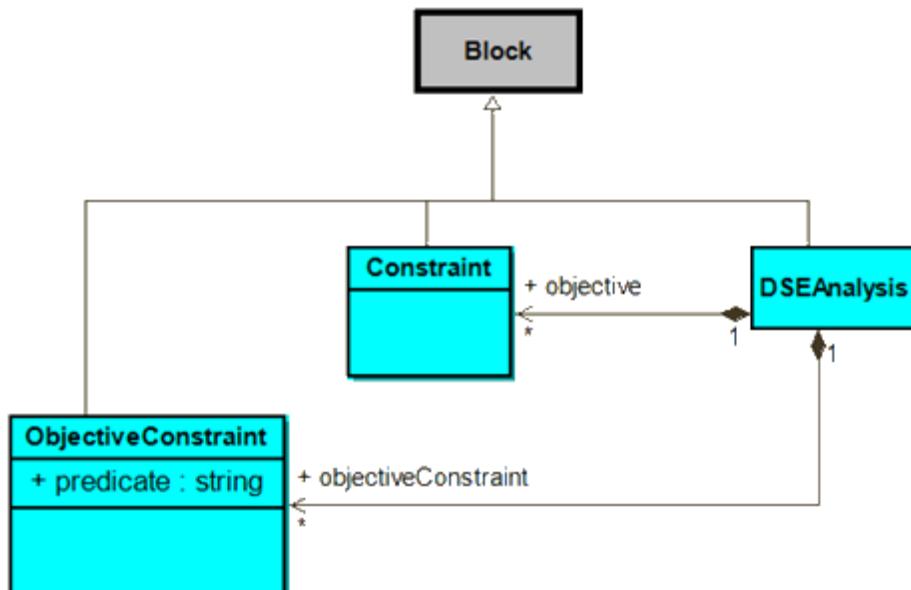


Figure 10: Constraint and ObjectiveConstraint definition



Three kind of Constraint blocks exist cf. Figure 11. Firstly, the SimpleConstraint with a predicate of type String. Secondly, the ExternalScript which made a reference to a file system. Finally, the InternalFunction where the functionTp attribute allow to refer to a predefined function.

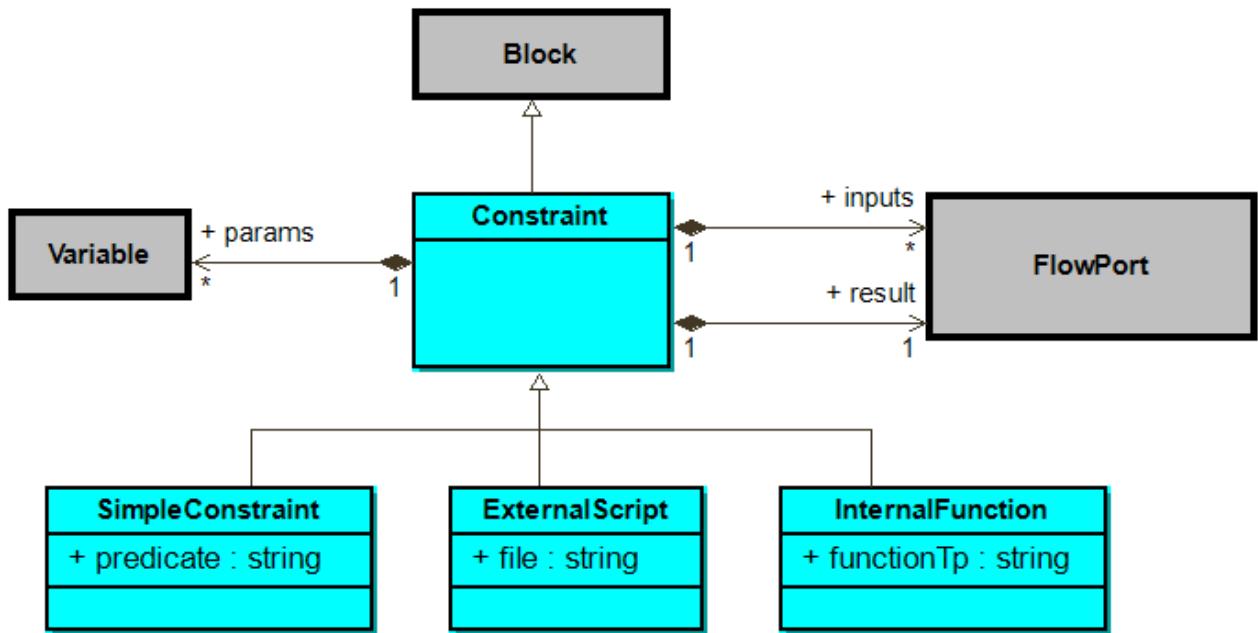


Figure 11: SubConstraint definition

Figure 12 shows how Constraint and its Property (Variable or FlowPort) can be instantiated in order to be reused in many analyses.

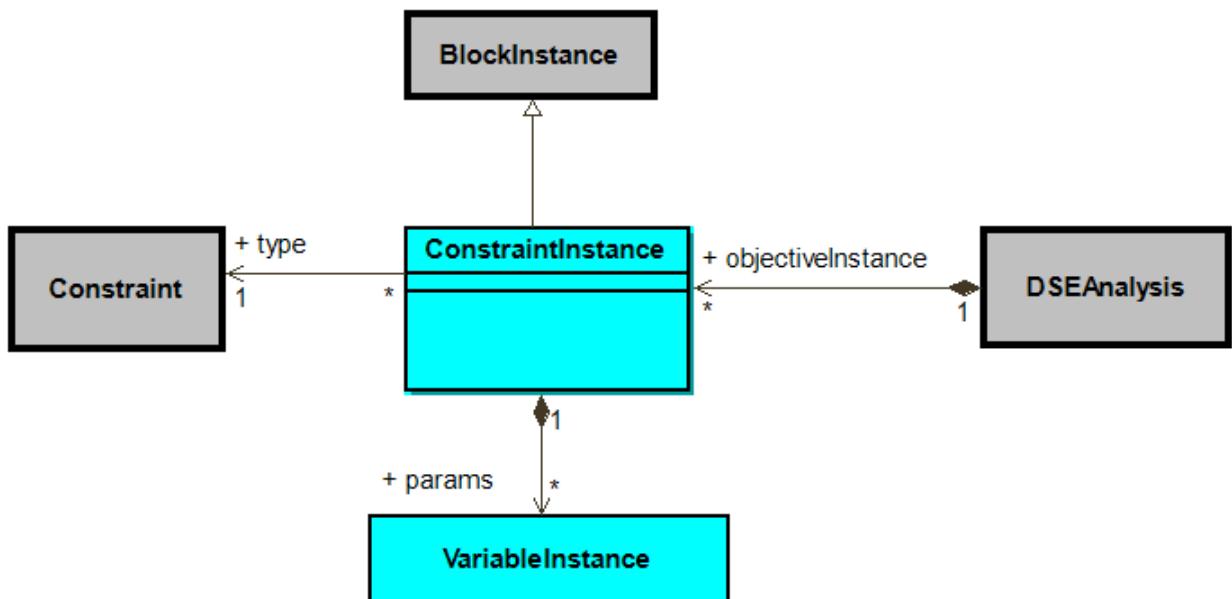


Figure 12: Constraint instantiation



To explore the design space, DSE must be able to make references to System PropertyInstance. These PropertyInstances, owned by ConstraintInstances, can be source of Reference to other PropertyInstance part of the System cf. Figure 13.

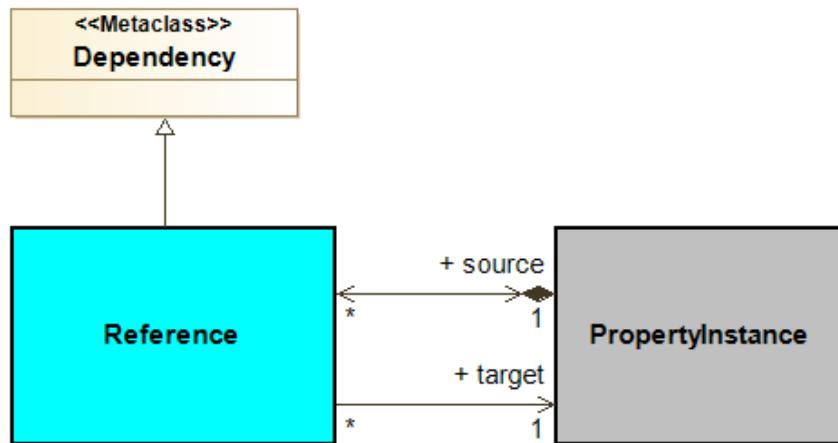


Figure 13: Reference definition

The final group, ranking, is defined in Figure 14. Again, the DSEAnalysis element contains a Ranking attribute of Pareto or FunctionalCost value. Weight attribute of Variable allow to specify the contribution of each Variable for the ranking evaluation. Note that to be valid a DSEAnalysis must have at least one Variable playing the role of ranking parameter.

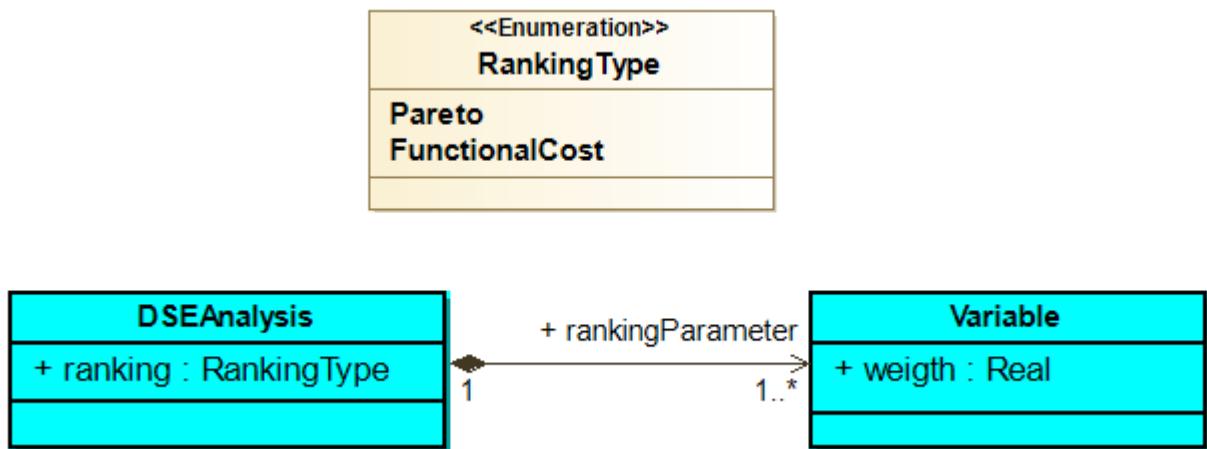


Figure 14: DSE Ranking elements

3.2 DSE Diagrams definition

As shown in Figure 15, the DSE part of the INTO-CPS SysML profile defines five kinds of diagrams, the Parameter Diagram (PD), the Parameter Connection Diagram (PCD), the Objective Diagram (OD), the Objective Connection Diagram (OCD), and the Ranking Diagram (RD).

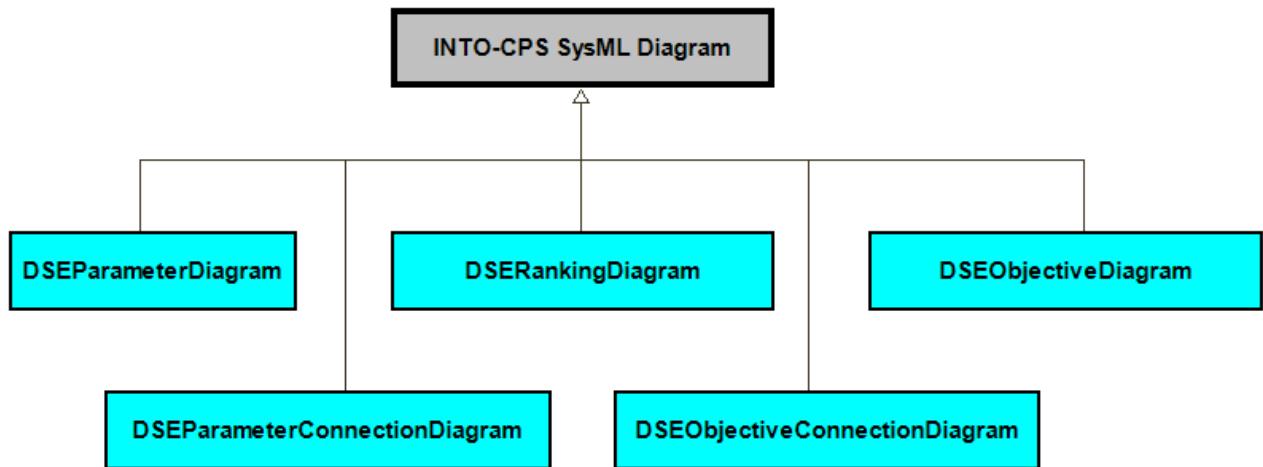


Figure 15: DSE INTO-CPS/SysML diagrams

Each of them has been designed to model, respectively, the Parameters and their connections, the Objectives and their connections, and the Ranking of a DSEAnalysis. The following screenshot i.e. Figure 16, Figure 17, Figure 18, Figure 19, and Figure 20 have been made, in the context of the Line Following Robot example, to depicted DSE diagrams. More details can be found in D3.2.a deliverable [5] but Figure 16 states that a DSEAnalysis named DSE_Example is composed of four Parameters respectively named S1_X, S1_Y, S2_X, S2_Y.

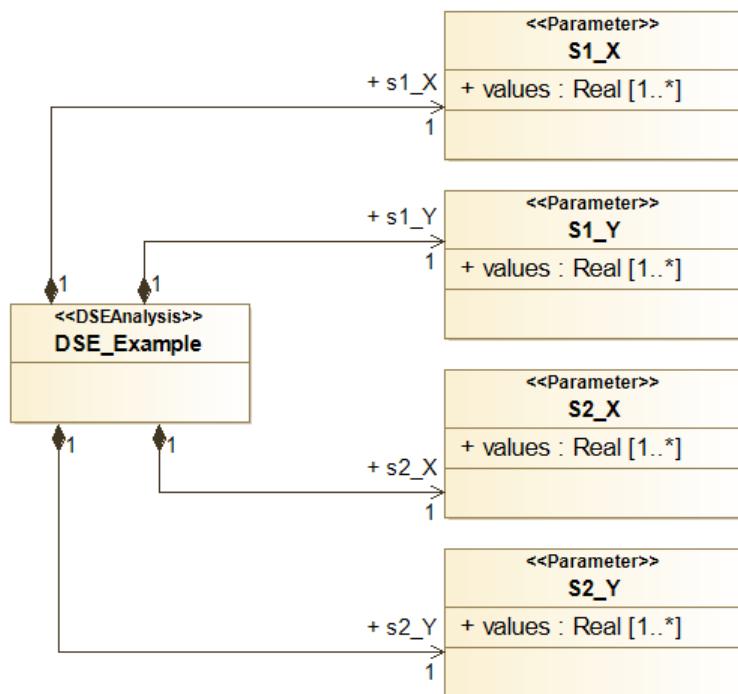


Figure 16: DSE Parameter Definition Diagram example



These four Parameters need to refer to System Parameters in order model where value will be set during DSE. In Figure 17, References have been created between DSE Parameters and System Variables.

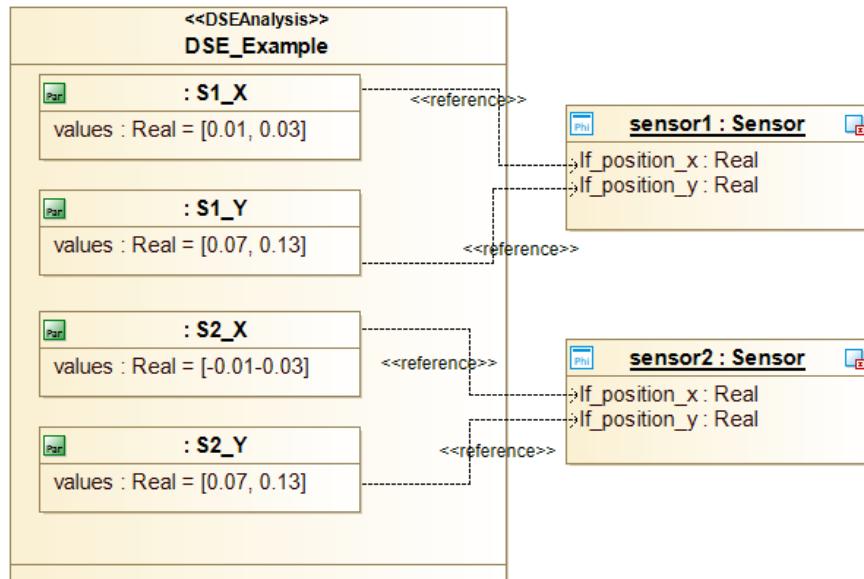


Figure 17: DSE Parameter Connection Diagram example

Figure 18 depicts the fact that four Objectives, respectively named meanSpeed, laptime, maxCrossTimeError, and meanCrossTimeError, compose our DSE_Example DSEAnalysis.

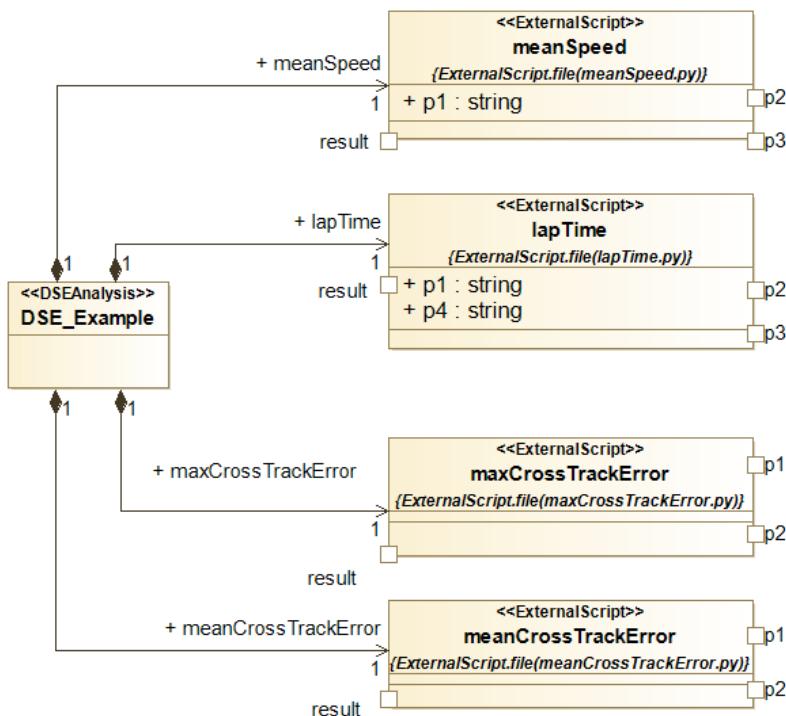


Figure 18: DSE Objective Definition Diagram example



Each of these Objectives own Variables which, as for Parameter, need to refer to System Variable as shown in Figure 19.

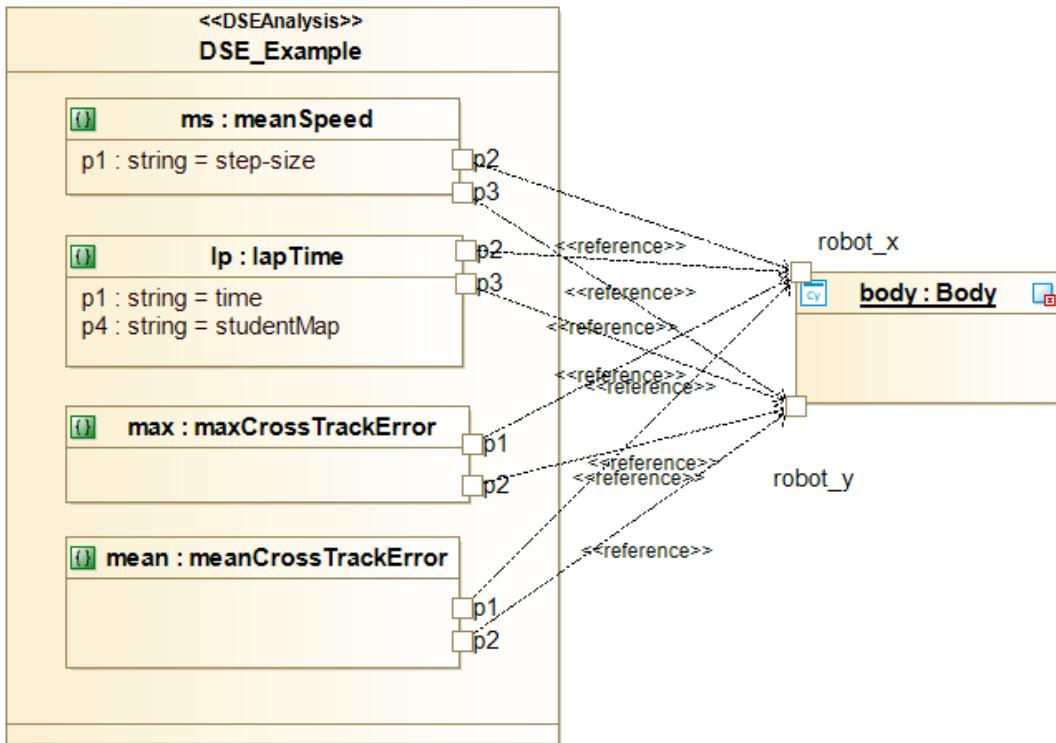


Figure 19: DSE Objective Connection Diagram example

Finally, Figure 20 specifies how the various Co-Simulation performed by DSE will be ranked. A pareto method will be used with two Parameters named lp and mean. Note that both of them have a weight of -1.0.

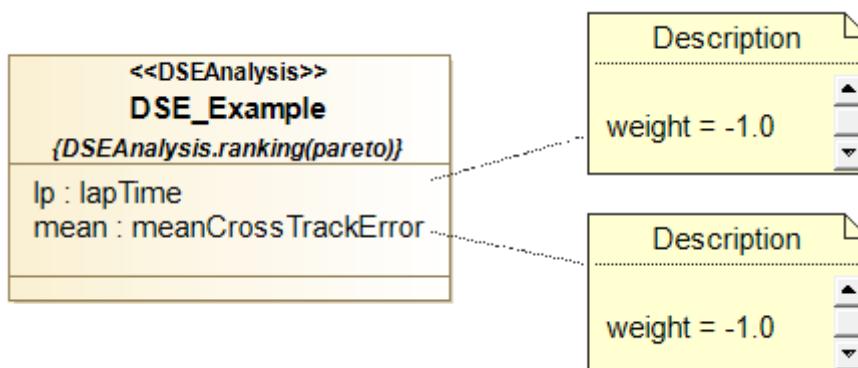


Figure 20: DSE Ranking Diagram example

4 Conclusion

This deliverable provides an overview of the current concepts defined in the INTO-CPS/SysML profile. The deliverable illustrates how the INTO-CPS/SysML architecture modelling has evolved between Year 1 and Year 2. It also shows the progress made by including the DSE modelling.

5 References

- [1] Softeam. Modelio Open-Source Modelling Environment. <http://www.modelio.org/>. 2014.
- [2] Object Management Group (OMG). Unified Modeling Language 2.5. Available: <http://www.omg.org/spec/UML/2.5/>. 2011.
- [3] Object Management Group (OMG). System Modeling Language specification v1.4. Available: <http://www.omg.org/spec/SysML/1.4/>. 2015.
- [4] INTO-CPS. Deliverable D4.1c: SysML and FMI in INTO-CPS. 2015.
- [5] INTO-CPS. Deliverable D3.2a: Method Guidelines 2. 2016.

Appendices

A. List of Acronyms

ASD	Architectural Structure Diagram
CD	Connection Diagram
CPS	Cyber Physical System
DSE	Design Space Exploration
FMI	Functional Mockup interface
MDE	Model Driven Engineering
ODD	Objective Defintion Diagram
OCD	Objective Defintion Diagram
PCD	Parameter Connection Diagram
PDD	Parameter Definition Diagram
RD	Ranking Diagram
SysML	System Modelling Language
UML	Unified Modelling Language
XMI	XML Metadata interexchange
XML	eXtensible Markup Language

B. XMI format

```

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association="_w0OtxMFHEea9lqxQKxvTJw">
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                              <lowerValue xmi:type="uml:LiteralInteger" xmi:id="_w0Ot6cFHEea9lqxQKxvTJw"/>
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    <lowerValue xmi:type="uml:LiteralInteger" xmi:id="_w0OuEcFHEea9lqxQKxvTJw"/>
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  <ownedAttribute xmi:type="uml:Property" xmi:id="_w0OuEsFHEea9lqxQKxvTJw" name="FlowPort_max">
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    <lowerValue xmi:type="uml:LiteralInteger" xmi:id="_w0OuF8FHEea9lqxQKxvTJw"/>
  </ownedAttribute>
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type="_w0PUo8FHEea9lqxQKxvTJw" aggregation="composite" association="_w0PUtcFHEea9lqxQKxvTJw"/>
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association="_w0PUwsFHEea9lqxQKxvTJw">
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  <ownedAttribute xmi:type="uml:Property" xmi:id="_w0PUvMFHEea9lqxQKxvTJw" name="InternalFunction_functionTp">
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    <upperValue xmi:type="uml:LiteralUnlimitedNatural" xmi:id="_w0PUwMFHEea9lqxQKxvTJw" value="1"/>
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  </ownedAttribute>
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association="_w0PUycFHEea9lqxQKxvTJw">
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association="_w0PU0MFHEea9lqxQKxvTJw">
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