

# OtFMI, an OpenTURNS module for uncertainties analysis with 0D/1D system models

Michaël Baudin <sup>1</sup>   Audrey Jardin <sup>1</sup>   Mathias Bouquerel <sup>1</sup>  
Anne-Laure Popelin <sup>1</sup>   Audrey Jardin <sup>1</sup>  
Julien Schueller <sup>2</sup>   Sylvain Girard <sup>2</sup>

<sup>1</sup>EDF R&D. 6, quai Watier, 78401, Chatou Cedex - France, [michael.baudin@edf.fr](mailto:michael.baudin@edf.fr)

<sup>2</sup>Phimeca Engineering. 18/20 boulevard de Reuilly, 75012 Paris - France,  
[girard@phimeca.com](mailto:girard@phimeca.com)

October 19th 2017

# Industrial issue

- ▶ EDF uses 0D/1D system models programmed in Modelica as decision support for the conception and operation of its industrial assets.
- ▶ How to apply OpenTURNS' panoply of methods to these models?

# “Regular” models vs 0D/1D system models

“Regular”  
modelling



“Packing”

$$\begin{cases} \dot{\mathbf{x}}(t) = f(\mathbf{x}(t), \mathbf{u}(t), t) \\ \mathbf{y}(t) = g(\mathbf{x}(t), \mathbf{u}(t), t) \end{cases}$$

Equation formulation



Solver  
programming

# “Regular” models vs 0D/1D system models

“Regular”  
modelling



0D/1D  
system modelling



“Packing”



Equation formulation

$$\begin{cases} \dot{\mathbf{x}}(t) = f(\mathbf{x}(t), \mathbf{u}(t), t) \\ \mathbf{y}(t) = g(\mathbf{x}(t), \mathbf{u}(t), t) \end{cases}$$

$$\begin{cases} \dot{\mathbf{x}}(t) = f(\mathbf{x}(t), \mathbf{u}(t), t) \\ \mathbf{y}(t) = g(\mathbf{x}(t), \mathbf{u}(t), t) \end{cases}$$



Solver  
programming



# “Regular” models vs 0D/1D system models

“Regular”  
modelling



0D/1D  
system modelling

Long (minute → hour)

CPU time

Short (second → minute)

2D, 3D

Dimensions

0D, 1D

Discrete versioning

Development rate

Continuous mutation

Numerical analyst, physicist

Actors

Design, process, operation...  
engineer

CFD, finite elements,  
C++, FORTRAN...

Tools

Modelica, Simulink...

# Modelica programming language

- ▶ Modelica is an open language for programming models based on **differential algebraic systems of equations**



- ▶ Equations are written in almost **natural language**, and solved by a multipurpose third party tool.
- ▶ It is object-oriented: available **module libraries** cover most applications
  - ▶ Complex models can be achieved simply by combining this modules using a graphical interface!

# Modelica tools

- ▶ Main tools :
  - ▶ Dymola (Dassault Systèmes, proprietary)
  - ▶ OpenModelica (Open Source Modelica Consortium, open source)
  
- ▶ Functions
  - ▶ Flatten equation systems
  - ▶ Compile to machine code after including a solver
  - ▶ Development environment
  - ▶ Model graphical interface
  - ▶ Basic post-processing...

# OpenModelica, model graphical view





# Piloting models

- ▶ Most OpenTURNS methods apply to functional **black boxes**
  - ▶ Uncertainty propagation and reliability analysis
  - ▶ Sensitivity analysis
  - ▶ Emulation
  - ▶ Parameter estimation



- ▶ We need efficient **input-output data interfaces**,  
a.k.a. *wrappers* in OpenTURNS jargon.

## Functional mock-up interface (FMI)

- ▶ FMI is a standard for input–output data interface for numerical model.



- ▶ A **functional mock-up unit (FMU)** is a black box following the standard.



## OtFMI: integrating FMI support into OpenTURNS

- ▶ The new open source module OtFMI allows transparent use of FMU with OpenTURNS methods.
- ▶ It provides high level classes derived from `ot.PythonFunction`: running an FMU instead of a Python function only requires to **change a single code line!**

```
import otfmi
otfmi.FMUFunction("path/to/fmu",
                  inputs_fmu=["x_1", "x_2", "x_3"],
                  outputs_fmu=["y"])
```

# Implementation overview



# OtFMI graphical interface

## Motivations

- ▶ Provide access to OpenTURNS' methods for Modelica users unfamiliar with Python
- ▶ Considerably ease simple studies

## Issues

- ▶ Modelica models often define **hundreds or thousands of variables**

# OtFMI graphical interface, FMU overview

OTGui - [Modèle physique FMI]

Fichier Vue

Etudes

- OTStudy\_0
  - Modèles physiques
    - PhysicalModel\_0
      - Définition
        - Modèle probabiliste

Propriétés Variables Différentiation

FMU file

Identifiant	bil100partiel_GV_0Unit2_0wlnit
Version FMI	2.0
Outil	Dymola Version 2017 (32-bit), 2016-04-12 (using dassl with tolerance 0.0001)
Plateforme	default
Auteur	
Version	
Copyright	
Date/Heure	2016-07-12T11:49:23Z
GUID	{44d61dd0-e7a1-4166-ada8-ecdc48a166b7}
Nombre de variables	2451
Causalité	paramètre :119, entrée : 0, sortie : 0, locale : 2332

# OtFMI graphical interface, picking inputs and outputs



# Perspectives

- ▶ Most 0D/1D system model are dynamical.  
We need methods for sensitivity analysis and emulation of model with **time series inputs or outputs**.
- ▶ EDF is interested into **data assimilation** with its Modelica models.
- ▶ What are the opportunities of **extending the Modelica language** to support stochastic description of variables?



Thank you for your attention.