2EL6050 – Modelica and bond graph: multi-domain modeling, analysis and simulation

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Department: CAMPUS DE RENNES
Language of instruction: ANGLAIS
Campus: CAMPUS DE RENNES
Workload (HEE): 60
On-site hours (HPE): 35,00
Elective Category : Engineering Sciences
Advanced level : No

Description

This course offers to expand your know-how, as well as your theoretical understanding, of the modeling, analysis and simulation of complex multiphysical systems (e.g.: simulation of drones, building thermal performance, bioreactors…).

Context: technical systems are usually made by **assembling components** (ex. in a car: engine, starter, brakes…) which behavioral models come from **different technical fields** (electrical, mechanical, thermal…). As a result, these components are often mastered by **different people**. The engineering of complex systems therefore raises difficulties in **exchanging and building up models**. This elective aims to learn two commonly used modeling tools to meet these needs: Modelica and bond graphs.

The bond graph is a *graphical description* of energy links between the components of a system. This representation is based on analogies between physical domains (e.g. mechanical inertia ~ electrical inductance). With bond graph modeling, it becomes possible to perform structural analyses of the modeled system, in particular through the core notion of causality. These analyses reveal the *physical functioning* and the *energy exchanges* of the system.

Modelica is a non-proprietary language* used to address the following needs:

- Model systems spanning several physical domains
- Easily build structured models using reusable components
- Collaborate effectively and build up models within a team

*unlike Simulink/Simscape for example

Modelica allows you to easily (e.g. graphically) describe and then simulate the dynamics of complex systems (a few thousand variables). It is thus becoming increasingly popular in industry (building, transportation, electrical networks, etc.).

Thanks to the open source nature of the software being used (OpenModelica), you will be able to freely reuse the know-how of this course in different settings. Beyond Modelica, the acquired skills on model structure and collaboration will be applicable to many other environments.

Quarter number
SG6

Prerequisites (in terms of CS courses)

none

Syllabus

Course schedule:

Bond graph (5 h + 2 h personal work)

- Principles of the bond graph formalism, analogies between domains
    a. procedure for assigning causality
- Analysis of structural properties
- Extraction of the state-space equations

Modelica (14 h + 6 h personal work)

- Introduction to Modelica: brief history, use in industry, principles
- Getting started with Modelica
    - First practical examples: ODE, electrical circuit, mechanics.
    - Analogies between variables: flow and potential
    - Hybrid systems, discontinuity, events (example of a diode rectifier)
- Structuring of models
    - Inheritance and composition
    - Packages
    - Creation of a customized physical component

Versioning (2 h + 1 h personal work, as required)

Depending on students' needs, there will be exercises to help people get started with Git (versioning software) and GitLab (collaborative development platform).

Modeling project (9 h + 18 h personal work)

(*"M³ project": Multiphysics Modeling with Modelica*) in groups of 3–4.

- Examples of project subjects: tidal power plant, drone, fuse, electromagnetic switch. *New in 2020-2021: modeling de dynamics of the COVID-19 disease!*

Final evaluation (2 h, see §Evaluation methods)

Class components (lecture, labs, etc.)

For bond graph, teaching is done through interleaved lectures and exercises.

For Modelica, teaching is done through practical computer-based exercises with concise lectures to introduce key concepts.

In order to enable a practical mastery of these two tools, the focus is on practice through small exercises in the classroom, small exercises in self-study between classes and finally with the final project.

Grading

The evaluation of the elective is based on two activities:

- **Final exam on theoretical aspects**, without documents, on bond graph and Modelica fundamentals (50% of the final grade)
- **Modeling project** (50% of the final grade)
    - A sheet detailing the project's objectives is given at the start of the project. In relation to these objectives, the evaluation criteria are listed in detail.
    - The project grade can be individualized within a group

Moreover, this elective takes place in the form of applied courses where most of the learning happens in the classroom. Participation in class is therefore essential to acquire the knowledge and skills of this elective. The **participation** and the respect of the deadlines thus count for a part of the final grade.

Course support, bibliography

Material of the Modelica course: http://éole.net/courses/modelica/

including an extended list of references:
http://éole.net/courses/modelica/90-references.html

Material of the Bond graph course: slide deck of the teacher *"Bond Graphs - A graphical language for the analysis of multiphysical systems"*.
https://cel.archives-ouvertes.fr/hal-03602684

Michael M. Tiller *"Modelica by Example"*, online book, first published in 2014 an continuously updated since. URL: mbe.modelica.university.

Geneviève Dauphin-Tanguy et al. *"Les bond graphs"*, livre Hermès, 2000.

Resources

Teacher : Pierre Haessig

Computer sessions using the free software OpenModelica

Please note that installing the software under macOS is difficult. It may be necessary to work with a Linux virtual machine. As an alternative, Parallels Desktop (paid) was successfully tested in 2021-2022.

Learning outcomes covered on the course

For bond graph, the course is about learning the concepts of this representation to be able, on simple examples, to:

- model the system by a bond graph
    - including the application of the causality assignment procedure
- analyze the structural properties of the system
- extract the state-space equations

For Modelica, the course objectives are:

- use the Modelica language and the OpenModelica development environment to model and simulate dynamic systems
- know how to reuse standard Modelica models
- structure a complex model into reusable components

- work in a team on a common complex model, with a versioning system (git)

Description of the skills acquired at the end of the course

The skills described above make it possible to validate the following CentraleSupélec engineering skills:

- **C1**: **Analyze, design, and build complex systems** with scientific, technological, human, and economic components. In particular:
    - C1.2: **Modeling**: using and developing the appropriate models, choosing the correct modeling scale and the relevant simplifying assumptions
    - C1.4: **Design**: specify, implement and validate all or part of a complex system (in this course, the “complex system” to be designed is in fact the *Modelica model* of a complex system)
- **C6**: Be operational, responsible, and innovative in the **digital world**. In particular:
    - C6.1: Solve a problem numerically (in particular the simulation of dynamical systems)
    - C6.2: **Design software** (the Modelica model being seen as software)