Distance teaching of continuous-time modeling and simulation using Modelica

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Outline

1. What is Modelica?

2. Why do I use Modelica for teaching?

3. An example of using Modelica in teaching M&S

Master's Degree (at distance)
in System and Control Engineering

4. InMotion books and MOOC by the UNED group

What is Modelica? (1/2)

Modelica is a non-proprietary modeling language

The first version of Modelica was released in 1997
Actual version: Modelica 3.5

Modelica is intended to:

- Serve as standard language for exchange of models
- Facilitate object-oriented, equation-based modeling

  → Modelica simulation environments automatically manipulate symbolically the model to generate the simulation code
- Promote model reuse, facilitating development of model libraries

https://modelica.org/modelicalanguage.html

What is Modelica? (2/2)

General-purpose language, not tied to a particular physical domain

Models are described in Modelica as a combination of:

- Differential equations with derivative with respect to time
- Algebraic equations
- Discrete-time equations, and events
- Algorithms and functions

There exist mature Modelica tools

- Dymola
- OpenModelica
- Wolfram SystemModeler
- etc.

and many model libraries written in Modelica

Modelica Association - non-profit organization
coordinates development of Modelica

https://modelica.org/modelicalanguage.html

Why do I use Modelica for teaching M&S?

- Well suited for describing the type of models most commonly used in Control Engineering
  - models of multi-domain cyber-physical systems,
  - described as differential-algebraic equations (DAE), and events
- Well suited for explaining to students concepts on
  - Modeling of mixed-domain physical systems
  - Object-oriented modeling methodology
  - Algorithms for DAE analysis (partition, DAE index reduction)
  - Numerical methods for continuous-time models with events
- Practical interest: Modelica is used in academia and industry
- It is also a choice based on my personal preference

An example:

Distance teaching of continuous-time modeling and simulation in the Master's Degree in System and Control Engineering

Master's Degree in System and Control Engineering

2 universities: UNED, and Complutense University of Madrid

Distance learning

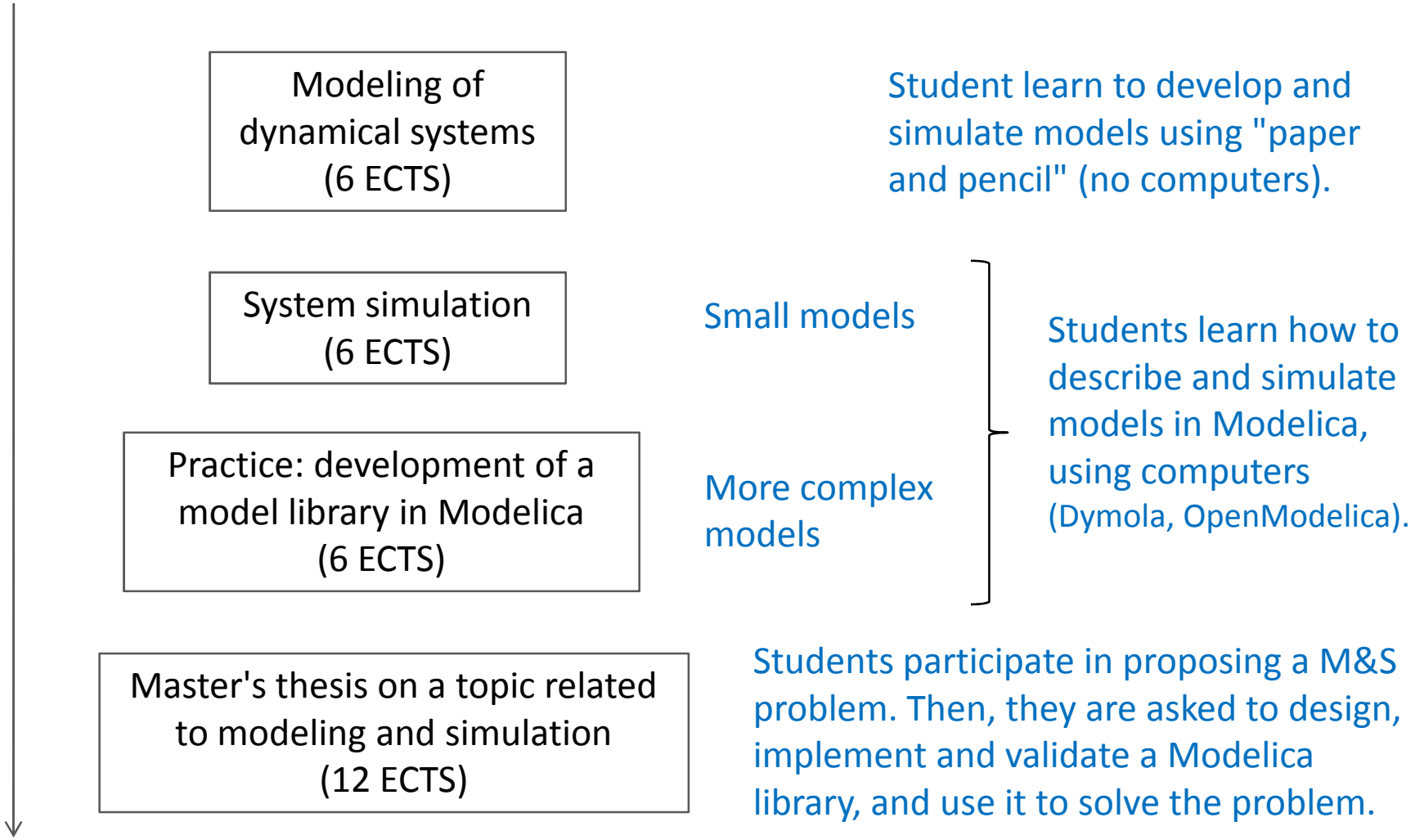
60 ECTS = 8 elective subjects (6 ECTS per subject) + Master's thesis (12 ECTS)

Groups of subjects

1. Mathematics and computation
2. Computers and communications
3. Sensors and signal processing
4. Robotics and industrial automation
5. Modeling and simulation ← 2 subjects:
   - Modeling of dynamical systems (6 ECTS)
   - System simulation (6 ECTS)
6. Control
7. Bio-inspired technology
8. Practice ← Development of a model library in Modelica (6 ECTS)
9. Master's thesis ← Modeling and simulation projects (12 ECTS)

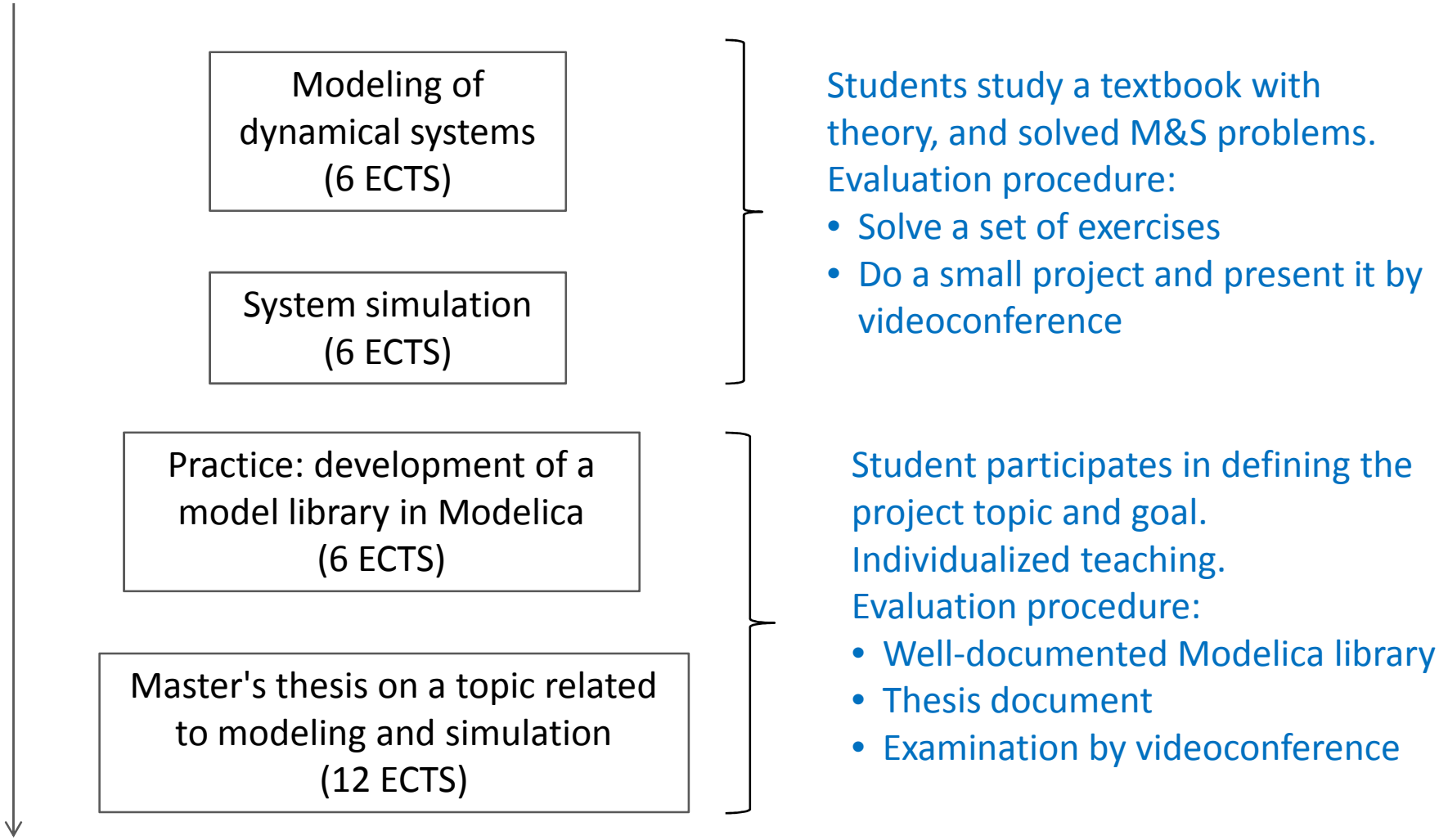
Pedagogical approach

Students' itinerary through M&S subjects



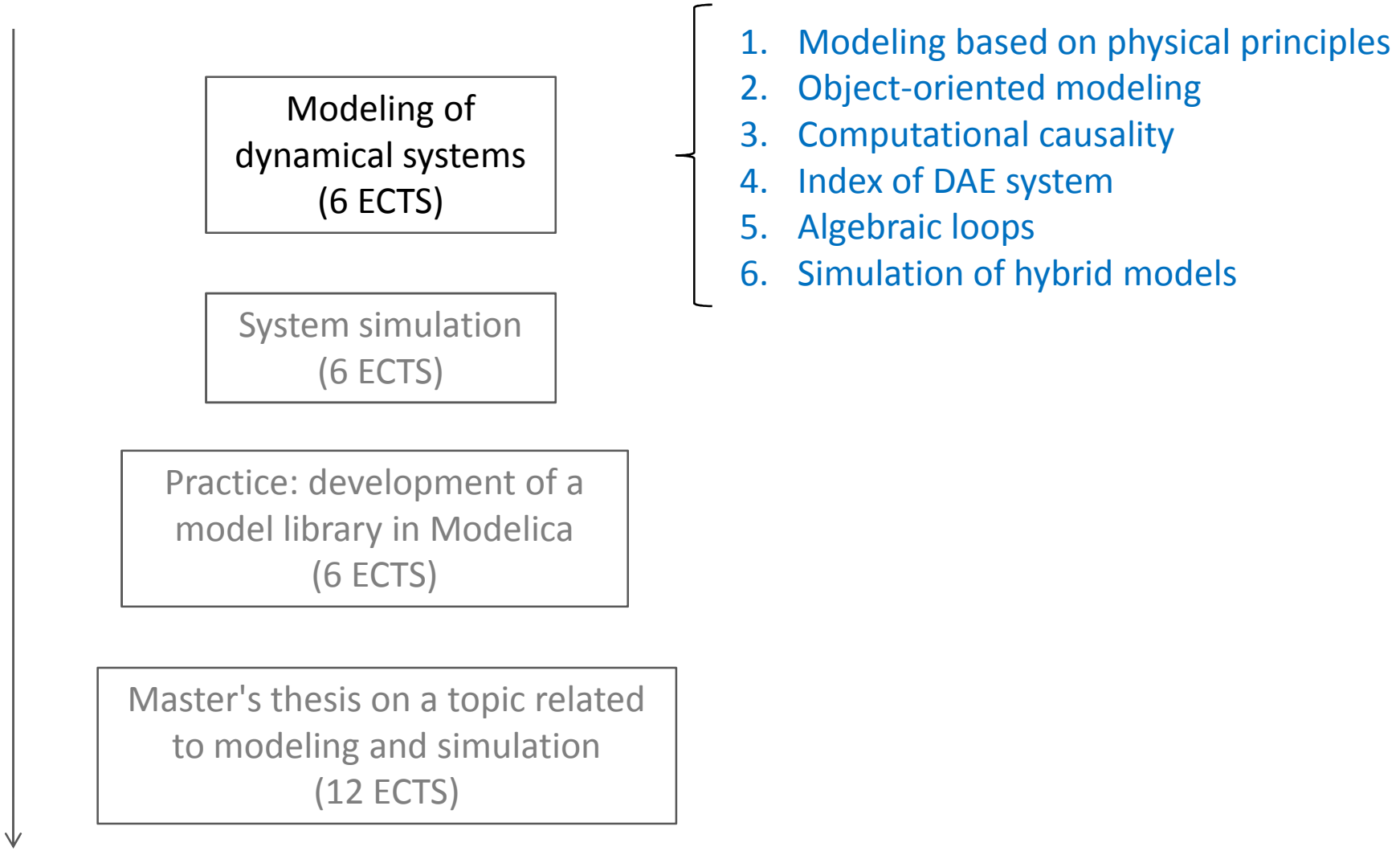
Teaching methodology

Students' itinerary through M&S subjects



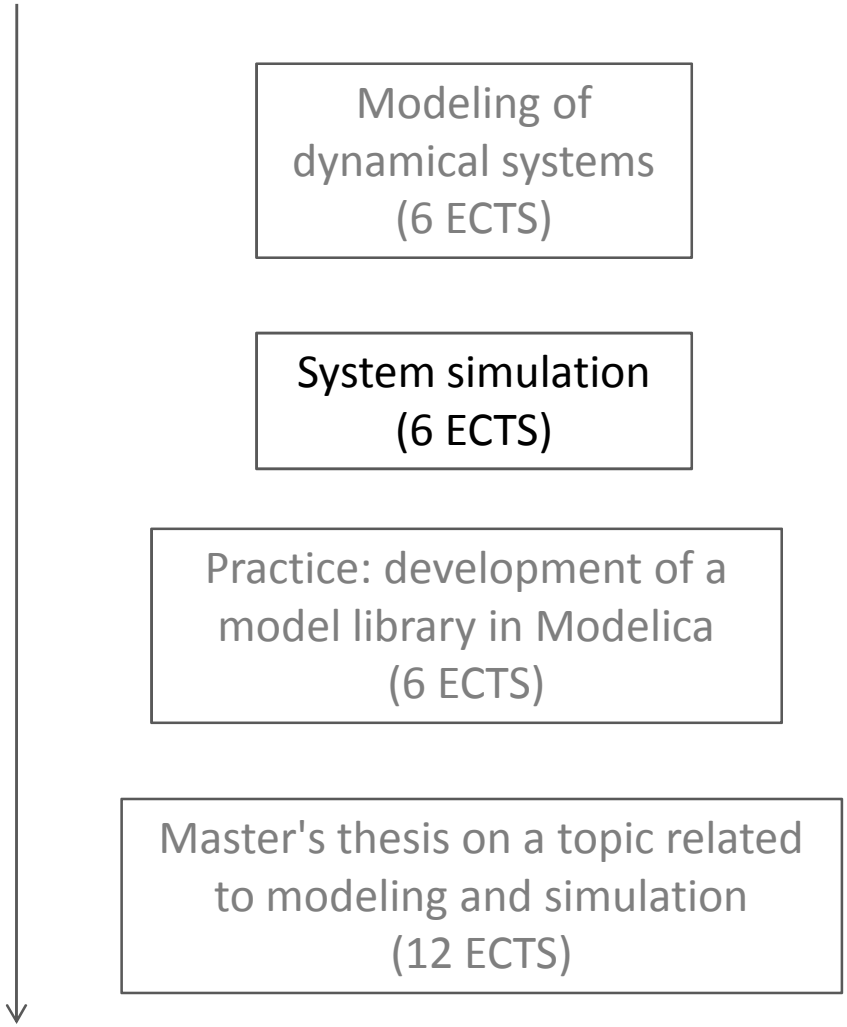
Contents (1/2)

Students' itinerary through M&S subjects



Contents (2/2)

Students' itinerary through M&S subjects



1. Introduction to Modelica
2. Continuous-time atomic models
3. Hybrid atomic models
4. Inheritance and composition
5. Development of model libraries
6. Experimentation with models

Teaching material (1/4)

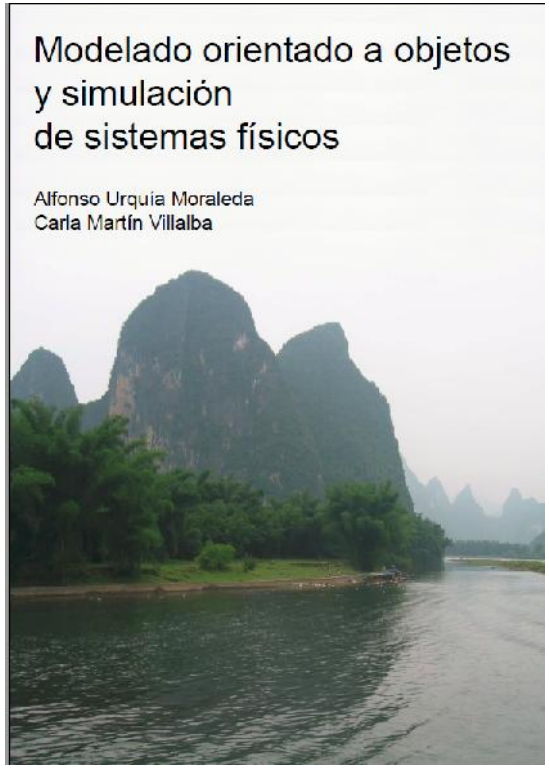
Students' itinerary through M&S subjects

Modeling of dynamical systems (6 ECTS)

System simulation (6 ECTS)

Practice: development of a model library in Modelica (6 ECTS)

Master's thesis on a topic related to modeling and simulation (12 ECTS)



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Cellier, F.E.; Kofman, E.: "*Continuous System Simulation*". Springer, 2006.

+

A selection of papers

Teaching material (2/4)

Compulsory readings

- Broenink, J.F.: Introduction to Physical Systems Modelling with Bond Graphs.
- Åström, K.J.; Elmqvist, H.; Mattsson, S.E.: Evolution of continuous-time modeling and simulation.
- Elmqvist, H.; Mattsson, S.E.; Otter, M.: Modelica - An international effort to design an object-oriented modeling language.
- Cellier, F.E.; Kofman, E.: Continuous System Simulation. Springer. Chapters 7 and 9.
- Elmqvist H.; Otter M.; Cellier F.E.: Inline integration: a new mixed symbolic/numeric approach for solving differential algebraic equation systems.
- Elmqvist H.; Mattsson S.E., Olsson H.: New methods for hardware-in-the-loop simulation of stiff models.
- Schiela A.; Olsson H.: Mixed-mode integration for real-time simulation.
- Elmqvist, H.; Cellier, F.E.; Otter M.: Object-oriented modeling of hybrid systems.
- Johansson, K.H.: The quadruple-tank process: a multivariable laboratory process with an adjustable zero.

Teaching material (3/4)

Complementary readings

- H. Olsson; M. Otter; S.E. Mattsson; H. Elmqvist (2008). Balanced models in Modelica 3.0 for increased model quality.
- R. Franke at al. (2009). Stream Connectors - An extension of Modelica for device-oriented modeling of convective transport phenomena.
- M. Otter; F. Casella (2009). Overview and rationale for Modelica stream connectors.
- M. Otter et al. (2009). A new formalism for modeling of reactive and hybrid systems.
- H. Elmqvist et al. (2012). State machines in Modelica.
- M. Otter; B. Thiele; H. Elmqvist (2012). A library for synchronous control systems in Modelica.
- H. Elmqvist; M. Otter; S.E. Mattsson (2012). Fundamentals of synchronous control in Modelica.
- F. Casella; M. Sielemanny; L. Savoldelli (2011). Steady-state initialization of object-oriented thermo-fluid models by homotopy methods.
- Modelica Association (2000). Tutorial of Modelica 1.4.

Teaching material (4/4)

Some more complementary readings

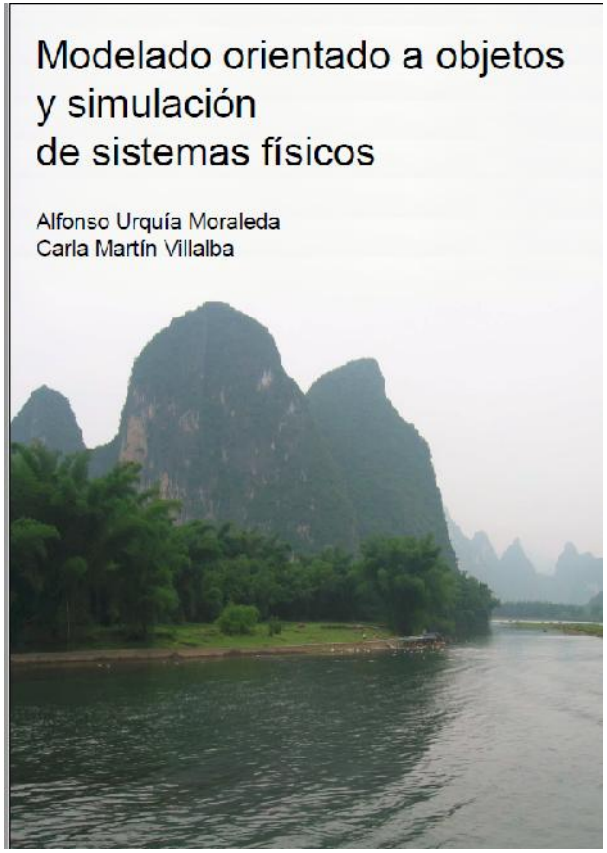
- P. Fritzson (2003). Introduction to modeling and simulation of technical and physical systems.
- H. Elmqvist; S.E. Mattsson; M. Otter (2000). Object-oriented and hybrid modeling in Modelica.
- S.E. Mattsson; H. Olsson; H. Elmqvist (2000). Dynamic selection of states in Dymola.
- M. Otter; H. Olsson (2001). New features in Modelica 2.0.
- S.E. Mattsson; H. Elmqvist; M. Otter; H. Olsson (2002). Initialization of hybrid differential-algebraic equations in Modelica 2.0.
- H. Elmqvist; M. Otter (1994). Methods for tearing systems of equations in object-oriented modeling.
- C.C. Pantelides (1988). The consistent initialization of differential-algebraic systems.
- P. Bunus; P. Fritzson (2002). Methods for structural analysis and debugging of Modelica models.
- P. Fritzson at al. (2002). The open source Modelica project.

Books and MOOC developed by the UNED group within the InMotion project

ERASMUS+ project

http://www.inmotion-project.net

InMotion books by the UNED group



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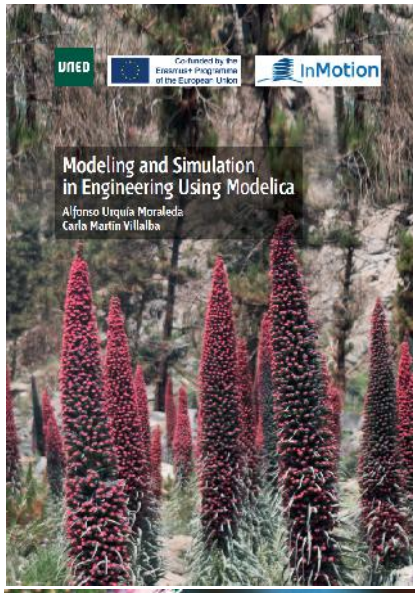
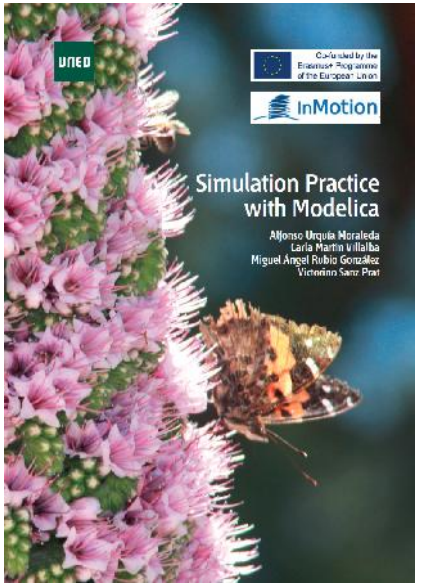
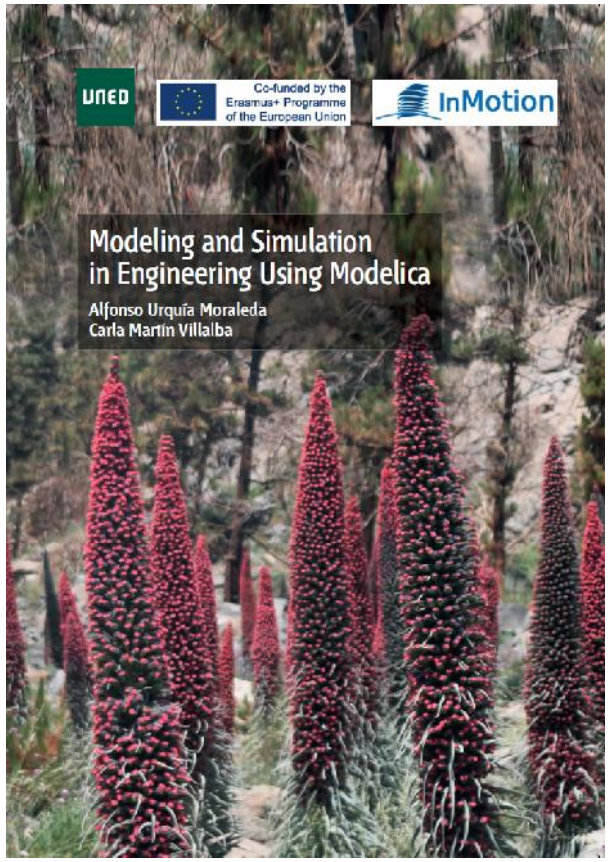
Theory



Assignments



Theory book (1/2)



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http://www.librosuned.com/compras/detalle.aspx?isbn=9788436273090

Theory book (2/2)

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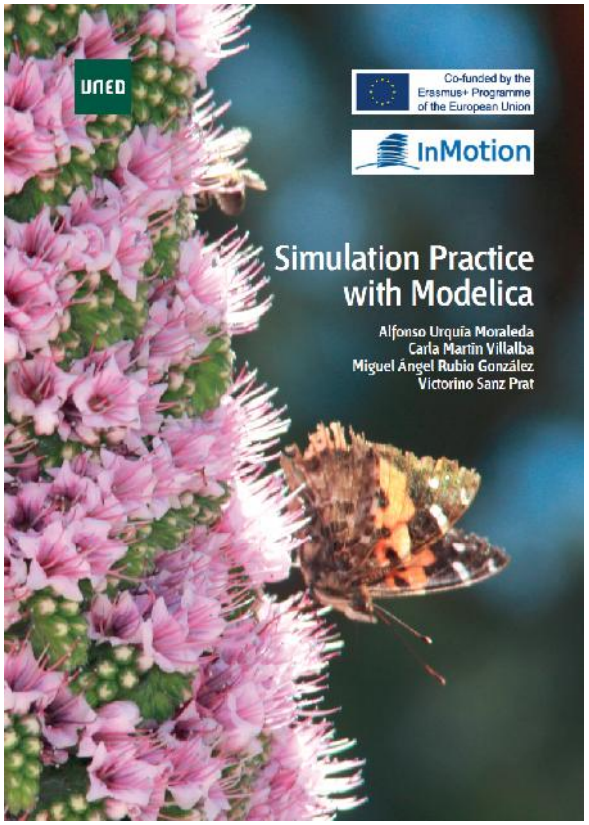
Assignment book (1/2)



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Assignment book (2/2)

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InMotion MOOC by the UNED group

https://iedra.uned.es/courses/course-v1:UNED+Modelsimul_004+2022/about

Students can enroll now

InMotion MOOC offered by UNED abierta

Modeling and simulation in Engineering using Modelica (4ªed. 2022)

- PREFACE
- LESSON 1 - MODELING METHODOLOGY AND TOOLS
- LESSON 2 - CONTINUOUS-TIME ATOMIC MODELS
- LESSON 3 - MODEL LIBRARIES
- LESSON 4 - HYBRID MODELING
- Course assessment survey

Classes Start	**15 February 2022**
Classes End	**30 April 2022**
Estimated Effort	**25 horas**

Thanks for your attention!!