Modelling & Simulation
Introduction

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About this course

1. About this course
   - Contents
   - Evaluation
2. System
3. Modelling and simulation

Contents

- Introduction: system, model and simulation

- Input-output and state-space modelling

- Taxonomy of systems and models

- M&S of continuous systems

- M&S of discrete event systems

  - Queuing systems

  - by Coloured Petri nets

- Random number generation

- M&S of logic circuits (logic simulation)

Online resources

- **Study materials**
  - http://hron.fei.tuke.sk/~korecko/MAS/

- **Assignments presentations (2016, 2019)**
  - https://www.youtube.com/watch?v=dFaRsnmXnt4&list=PLsgDYGdo42kfqY6miOfzCL0YXu8Nw8NFn
  - https://drive.google.com/file/d/1djp9uJo4dHCnAxpmEAEC9rgf4W7p5y2e/view?usp=sharing
  - https://drive.google.com/file/d/191a6_A3RBlN9Opda9Tu8OA5ZLJMOi2Lz/view?usp=sharing
  - https://drive.google.com/file/d/1Vouw-uRo3clUoA3feznlVjVO6IMxu0nF/view?usp=sharing
  - https://drive.google.com/file/d/1ThFBvxrE8fMfY8kUuUDbdepD2xCIcVbd/view?usp=sharing
  - https://drive.google.com/file/d/1I5Hzys9XdQYqOcU-THyQq-u0dT6BlYcM/view?usp=sharing

Evaluation

- ## Semester – 30 points
  - Assignment (27 points)
  - Activity on practices (3 points)
- ## Exam – 70 points
  - 2 questions (theory)
  - 2 x 35 points

System

1. About this course

2. System
   - Definition
   - Characteristic, elements, subsystem
   - Environment
   - Configuration, parameters, structure
   - Behaviour
   - Systems wrt. Application
   - Systems similarity

3. Modelling and simulation

What others say?

- An aggregation or assemblage of things so combined by nature or man as to form an integral or complex whole.
(Encyclopedia Americana)

- A group of related parts that move or work together.
(Merriam-Webster)

- A set of things working together as parts of a mechanism or an interconnecting network; a complex whole.
(Oxford Dictionary)

- A combination of components that act together to perform a function not possible with any of the individual parts.
(IEEE Standard Dictionary of Electrical and Electronic Terms)

Definition

- An organized, purposeful structure regarded as a whole and consisting of interconnected elements
  - elements = components, entities, factors, members, parts etc.

- An entity, which exists and operates in time and space through the interaction of its parts.

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Characteristic, elements, subsystem

- Basic characteristic of a system
  - elements are interrelated and interdependent
  - displays properties not possessed by any of the individual elements
  - has to be definable

- No element can be divided

- Subsystem = a set of some elements of a system that have common properties

Environment of a system

- **Environment**
  - a set of elements outside the system

- **Significant environment**
  - environment elements related to the system
 - also called system environment

- **Interaction**
  - relation between system and its environment
  - defined by inputs (x) and outputs (y)

Configuration, parameters, structure

- **System configuration**
  - given by number of elements, type of elements and relations (interconnections) between them.
    - This represents qualitative system characteristics

- **System parameters**
  - quantitative system characteristics

- **System structure**
  - defined by system configuration and parameters

System behaviour I

- Given by a realization of system properties

- Observed as a dependency of system outputs on system inputs

u → [S] → y

y = g(u,t)
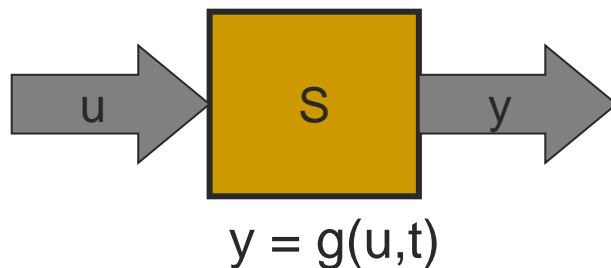
u – input vector
y – output vector
g – function describing system behaviour
t – time

System behaviour II

- **State of a system**
  - a collection of variables necessary to describe the system at any time.

- **Activity**
  - a time period of specified length

- **Event**
  - an instantaneous occurrence that may change the state of the system

- **endogenous** (activity or event) - occurs within a system

- **exogenous** - occurs in the system environment

Systems similarity

- System S1 is similar to system S2 when they have similar properties.
  - S2 is a model of S1
  - We can study S2 and apply the results to S1

- Similarity
  - in behaviour
  - in structure
    - in structure => in behaviour

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Modelling and simulation

1. About this course
2. System

3. Modelling and simulation
   - Modelling
   - Models
   - Simulation
   - Modelling and simulation tasks
   - Modelling and simulation process
   - Simulation system

Modelling

- Modelling
  - = process of producing a model
- Model
  - representation of
    - the construction (structure) and
    - working (behaviour)

    of a system of interest.
  - similar to but simpler than the system
  - good model = judicious trade-off between realism and simplicity

Models

- Physical model
  - a smaller or larger physical copy of an object.
  - similarity in structure and in behaviour.
- Mathematical model
  - behaviour description by means of mathematical apparatus
  - similarity in behaviour.
  - Can be used for
    - formal analysis (analytical computations)
    - creating simulation model
- Simulation model
  - the mathematical model transformed to an executable program.
  - similarity in behaviour.

Models

Original

Physical

$$\hat{\beta}_1 = \frac{(n[\sum_{i=1}^{n} X_{1i}Y_i] - (\sum_{i=1}^{n} X_{1i})(\sum_{i=1}^{n} Y_{1i}))}{(\sum_{i=1}^{n} X_{1i}^2) - (\sum_{i=1}^{n} X_{1i})^2} = \frac{\sum_{i=1}^{n}(X_{1i} - \bar{X}) - (Y_{1i} - \bar{Y})}{\sum_{i=1}^{n}(X_{1i} - \bar{X})^2}$$

$$\hat{\beta}_0 = \frac{\sum_{i=1}^{n} Y_i - \hat{\beta}_1 \sum_{i=1}^{n} X_{1i})}{n} = \bar{Y} - \hat{\beta}_1 \bar{X}$$

$$R^2 = \frac{\sum_{i=1}^{n}(\hat{y}_i - \bar{y})^2}{\sum_{i=1}^{n}(y_i - \bar{y})^2}$$

Mathematical (a part of)

Simulation

- Manipulation of a model in such a way that it operates in time or space

- The purpose of the manipulation is to study properties of the original

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Modelling and simulation tasks I

- **System analysis**
  - The original exists, mathematical model is known
  - Simulation model and experiments are used for example for optimization.
- **System synthesis**
  - A mathematical model exists, simulation model is created from it.
  - The real system is constructed on the basis of simulation and subsequent modifications of the model.

Modelling and simulation tasks II

- **System identification**
  - The original exists, a task is to find its mathematical model.
  - The extreme case is "black box problem"
    - we can control inputs and read outputs
    - we have to determine the function g.

$$y = g(u,t)$$
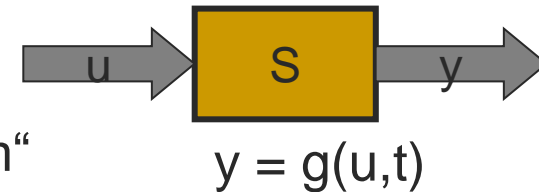
- **System simulator**
  - part of the system is in its original form, part in the form of a simulation model.
  - The task is to interconnect them.
  - i.e. flight trainer

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M&S Process I

1. Problem formulation.
2. Setting of objectives and overall project plan.
   1. Here it should be determined whether simulation is an appropriate technique
3. Model conceptualization.
   1. Creation of mathematical or conceptual (i.e. no strictly defined) model of the system
4. Data collection.
   1. about the original system
   2. Occurs simultaneously with model conceptualization.

M&S Process II

5. ## Model translation.
   - creation (programming) of a simulation model of the system.

6. ## Verification
   - checking whether the simulation model corresponds to the mathematical or conceptual one.

7. ## Validation
   - determination that a model is an accurate representation of the original system.

8. ## Simulation experiments and analysis of results

Simulation system

- Simulation program (simulator)
  - software for creating simulation models and defining and performing simulation experiments.
  - in some cases it has the same as the simulation model

- Simulation language
  - for simulation models and experiments description

- Simulation system
  - simulation program + simulation language

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