# ACI650 - Modelos y Simulación

Mario González
*Facultad de Ingeniería y Ciencias Ambientales*
Centro de Investigación, Estudios y Desarrollo de Ingeniería (CIEDI)

UNIVERSIDAD DE LAS AMÉRICAS
Laureate International Universities

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# M. González: Academic and research experience

**2016** Lecturer and researcher at FICA, UDLA.

**2015** Lecturer and researcher at Escuela Politécnica Nacional.

**2014** Lecturer and researcher at Universidad Estatal de Milagro, Ecuador.

**2012** PhD. in Computer Science at Universidad Autónoma de Madrid (UAM).

- PhD. research at Grupo de Neurocomputación Biológica at Escuela Politécnica Superior (EPS).
- Erasmus Mundus PhD. scholarship at Faculdade de Engenharia da Universidade do Porto (FEUP).

**2008** MSc. in Computer Science, at EPS-UAM.

**2004** BSc. in Industrial Engineering at Universidad Nacional de Ingeniería, Nicaragua.

# Now It's your turn!

- What is your name?
- What do you think Modeling and Simulation is useful for?
- What do you expect of this course?
- You are welcome to tell more...

# TOC

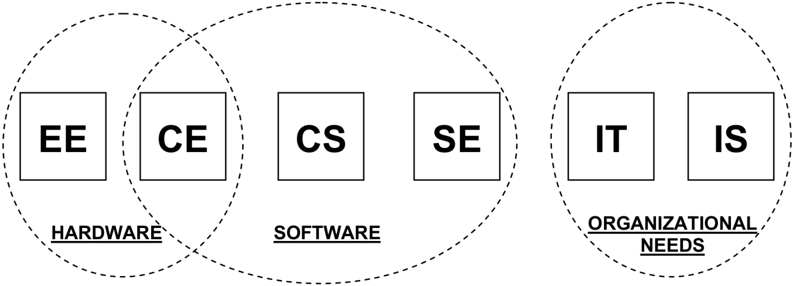
# Learning Objectives

- Gain a high-level awareness of M&S
- When, why, how to do M&S?
- Develop an Appreciation for the Need for Simulation
- Develop Facility in Simulation Model Building
- Understand the expectations for the course
- Gain some exposure to the learning tools we'll be using throughout the course

# Is Computer Science a Natural Science?

- Computer Science is no more about computers than astronomy is about telescopes.
- The computer is a tool in a lot of regards to when people study computation (which is science) unless they have solely applications in mind (which is engineering).
- Computation is what is at the heart of computer science: Computing Science.
- Computer Science is formal science because of its roots in mathematics, i.e. Algorithm design.
- Some branches of CS can relate to natural science: theory of computing around gnomic sequences and how natural computing occurs, or how the brain processes certain things.

# Computing degree programs I



# Computing degree programs II

"**Computer Science** is the study of the theory, experimentation, and engineering that form the basis for the design and use of computers. It is the scientific and practical approach to computation and its applications and the systematic study of the feasibility, structure, expression, and mechanization of the methodical procedures (or algorithms) that underlie the acquisition, representation, processing, storage, communication of, and access to information."

# Computing degree programs III

“**Software engineering** is the application of engineering to the development of software in a systematic method.”

> “...the principal focus of computer science is studying the properties of computation in general, while the principal focus of software engineering is the design of specific computations to achieve practical goals, making the two separate but complementary disciplines.”

**Example.** You have a bag of 27 coins. One of these coins is counterfeit and the rest are genuine. The genuine coins all weigh exactly the same, but the counterfeit coin is lighter. You have a simple balance. How can you find the counterfeit coin while using the scale the least number of times?

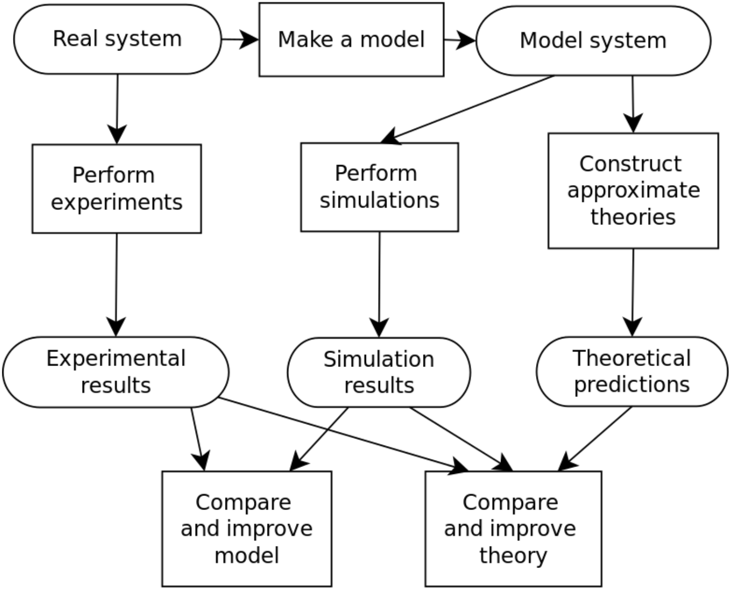
# What is Modeling and Simulation?

- Modeling: represents knowledge about system structure and behavior
- Simulation: emulates real behavior
  - cost, danger
  - what-if scenarios
  - **optimization**

# Modeling and Simulation

- is Systems Theory, Control Theory
- is Numerical Analysis, Computer Algebra
- is Computer Science, Artificial Intelligence
- is Operations Research
- is Application Domain: Mechanical Engineering, climatology, etc.

# Modeling and Simulation process



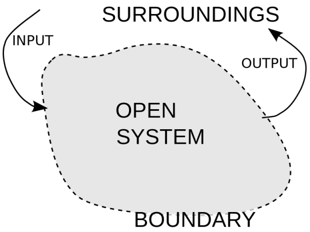
# What is a Model?

- A Representation of an object, a **system**, or an idea in some form other than that of the entity itself (Robert Shannon).
- Model operation can be studied, and from this, properties concerning the behavior of the actual system can be inferred.
- A model is similar to but simpler than the **system** it represents.
- A model is a replica of a system **(detail)**, physical or mathematical, that have (**or part of**) the properties and functions of the system.
- A good model is a judicious trade-off between realism and simplicity.

Del Rigor en la Ciencia (Jorge Luis Borges)

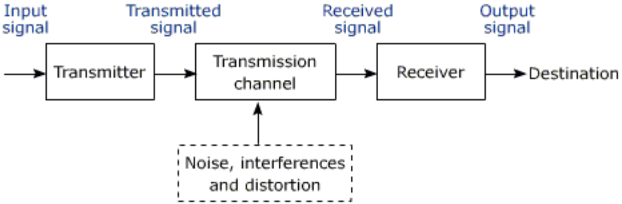
# What is a system?

- A system is a set of interacting or interdependent component parts forming a complex/intricate whole towards the accomplishment of some purpose.
- We build simplified representations (models) of the system in order to understand it and to predict or impact its future behavior.
- The models may define the structure and/or the behavior of the system.
- Open systems have input and output flows, representing exchanges of matter, energy or information with their surroundings (environments). Systems can be also closed, and isolated.



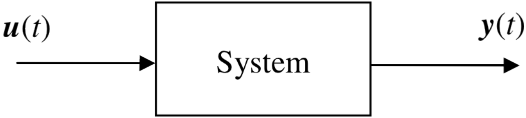
# In a system/model we can identify

- Input (independent variables)
- Output (dependent variables)
- Processor
- Control (local, global)
- Feedback
- Boundary
- Surroundings (environment)



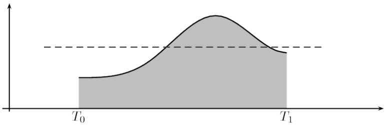
# System/model types I

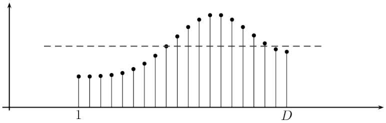
- **Static:** a system that does not vary with time (bridge), or change instantaneously
  - A system is said to be static if its output y(t) depends only on the input $u(t)$ at the present time $t$
  - A static system is also referred to as a memoryless system since its output response $y(t)$ is not influenced by the past of input $u(t)$
- **Dynamic:** one that varies with time (e.g. biological/ecological systems).
  - The output $y(t)$ of a dynamic system will be affected by the input $u(\tau)$ for $\tau \leq t$, i.e., not only by the input $u(t)$ at the present time but also its past $u(\tau)$ for $\tau < t$.



# System/model types II

- **Discrete:**
  - Systems whose state is discrete and changes at particular time point and then remains in that state for some time. E.g. Queue system in a bank: number of customers is discrete (integer), number of customers only changes when someone enters/leaves the bank.
- **Continuous**
  - Systems which state changes continuously over time.
  - E.g. the amount of liquid in a tank and/or its temperature.
  - Such a system can be described by differential equations.
  - In continuous simulation we solve these equations numerically.



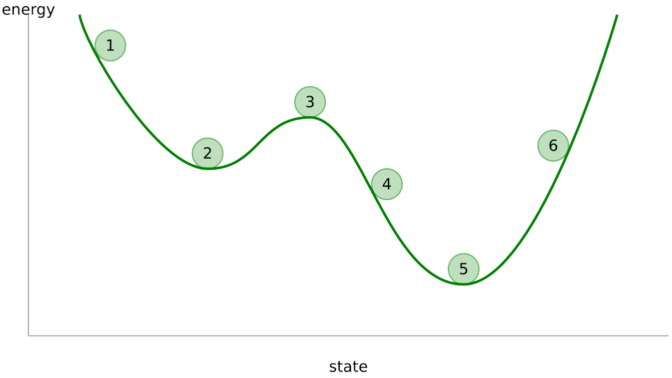



# System/model types III

- **Deterministic system:**
  - is a system in which no randomness is involved in the development of future states of the system.
  - A deterministic model will thus always produce the same output from a given starting condition or initial state.
- **Stochastic system:**
  - In a stochastic system, one or more parts of the system has randomness associated with it.
  - Unlike a deterministic system, for example, a stochastic system does not always produce the same output for a given input.
- Give examples of deterministic and stochastic systems.

# System/model types IV

- **System stability:**
  - A system in a stable state will stay in the same state until something from the outside changes the system.
  - States 2, 3, and 5 are stable (2 and 3 are metastable).
  - We can identify (slow/fast) transient states, and (asymptotically) steady states.



# Components of a system/model I

- **Entity:** object of interest in the system. E.g. Customers at a bank.
- **Attribute:** property of an entity. E.g. account balance.
- **Activity:** represents a time period of specified length. Collection of operations that transform the state of an entity. E.g. Making bank deposits.
- **State of a system:** collection of variables necessary to describe the system at any time, relative to the objectives of the study.
- **Event:** instantaneous occurrence that may change the state of the system. E.g.: arrival, beginning of a new execution, departure.

# Components of a system/model II

- **Progress of the system:** studied by following the changes in the state of the system
- **State variables:**
  - Define the state of the system.
  - Can restart simulation from state variables.
  - E.g.: length of the job queue.
- **Process:** Sequence of events ordered on time
- It is possible to build discrete simulation models using events, process and activity as reference.

# Example of System and components

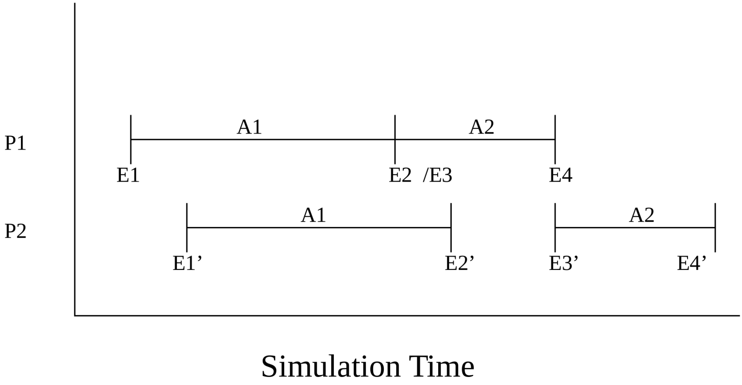
| System | Entities | Attributes | Activities | Events | State Variables |
|---|---|---|---|---|---|
| Banking | Customers | Account Balance | Making deposits | Arrival, Departure | # of busy tellers, # of customer in queue |

- State Variables may change continuously (continuous sys.) over time or they may change only at a discrete set of points (discrete sys.) in time.

# Simulation world views

- **Pure Continuous Simulation:** of a physical system that continuously tracks system response according to a set of equations typically involving differential equations.
- **Pure Discrete Simulation:** models the operation of a system as a discrete sequence of events in time.
  - Event-oriented
  - Activity-oriented
  - Process-oriented
- **Combined** Discrete / Continuous Simulation

# Events, activities, processes



# Event vs process oriented views

## Event oriented view

State variables

```
Integer: InTheAir;
Integer: OnTheGround;
Boolean: RunwayFree;
```

```
Arrival        Landed         Departure
  Event          Event          Event
{              {              {
   …              …              …
}              }              }
```

Entities modeled by event handlers

## Process oriented view

State variables

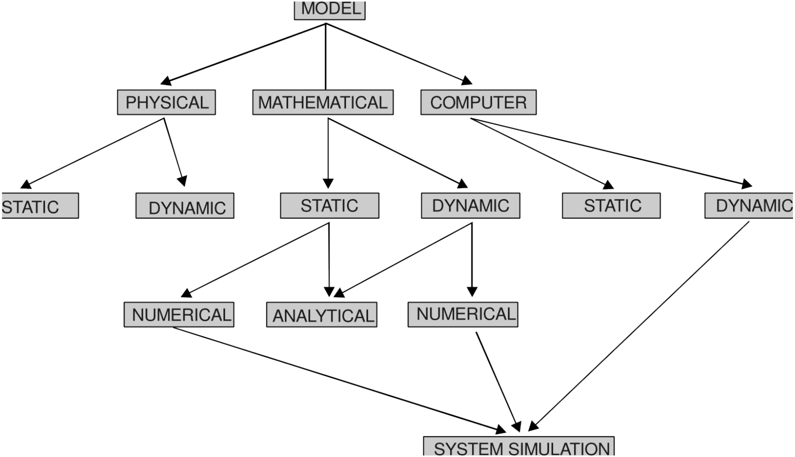
```
Integer: InTheAir;
Integer: OnTheGround;
Boolean: RunwayFree;
```

```
Aircraft 1     Aircraft 2     Aircraft n
{              {              {
  Arrive         Arrive         Arrive
  Land           Land           Land
  Depart         Depart         Depart
}              }              }
```

Entities modeled by processes

- Think of how the activity oriented view can be represented.

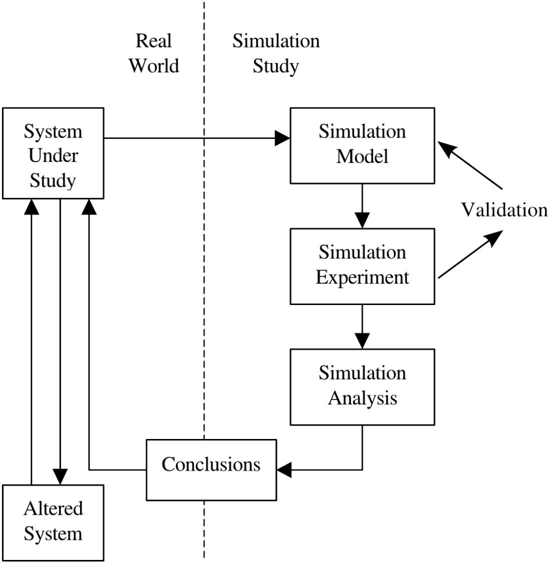
# Model types


MODEL
PHYSICAL
MATHEMATICAL
COMPUTER
STATIC
DYNAMIC
STATIC
DYNAMIC
STATIC
DYNAMIC
NUMERICAL
ANALYTICAL
NUMERICAL
SYSTEM SIMULATION

# What is Simulation?

- Simulation is the process of designing a model of a real system and conducting experiments with this model for the purpose either of understanding the behavior of the system or evaluating various strategies for the operation of the system.
- A Simulation of a system is the operation (change) of a model, which is a representation of that system.
- The model can be reconfigured and experimented with.

# Schematic of a simulation study



# Model building and Simulation steps I

Step 1. Identify the problem.
Step 2. Formulate the problem.
Step 3. Collect and process real system data.
Step 4. Formulate and develop a model.
Step 5. Validate the model.
Step 6. Document model for future use.
Step 7. Select appropriate experimental design.
Step 8. Establish experimental conditions for runs.
Step 9. Perform simulation runs.
Step 10. Interpret and present results.
Step 11. Recommend further course of action.

See Maria, A. (1997, December). Introduction to modeling and simulation. In Proceedings of the 29th conference on Winter simulation (pp. 7-13). IEEE Computer Society.

# Model building and Simulation steps II

**How to develop a simulation model?**

Step 1. **Identify the problem.**
- Enumerate problems with an existing system.
- Produce requirements for a proposed system.

Step 2. **Formulate the problem.**
- Select bounds of the system (part of the problem to be studied).
- Define the objective of the study.
- Define performance measures (to evaluate model and system configurations).
- Formulate hypothesis about system performance.
- Decide the time frame of the study.

# Model building and Simulation steps III

Step 3. **Collect and process real system data.**

- Collect data on system specifications.
- Input variables and performance of existing system.
- Identify source of randomness in the system (stochastic input variables).
- Select appropriate input probability distribution for each stochastic input variables (parameter estimation, distribution fitting).

Step 4. **Formulate and develop a model.**

- Develop schematics and network diagrams of the system (how are interrelated the system parts, entities flow).
- Translate these conceptual models to simulation software.

# Model building and Simulation steps IV

Step 5. **Validate the model.**

- Compare the model's performance under known conditions with the performance of the real system.
- Perform statistical inference tests.
- Evaluate the model with experts.

Step 6. **Document model for future use.**

- Document objectives, assumptions and input variables in detail.
- Document variables/states for control purpose.

# Model building and Simulation steps V

## How to design a simulation experiment?

Step 7. **Select appropriate experimental design.**

- Select a performance measure
- Select the input variables than influence it.
- Define levels of the input variables (min, max).
- Beware of the Combinatorial explosion.
- Document configuration-response of the tests.

Step 8. **Establish experimental conditions for runs.**

- Does the system needs a pre-run.
- Will the system reach a steady-state.
- Terminating or a non- terminating simulation run.
- Select appropriate starting conditions.
- Select the length run.
- Ceteris paribus simulation: keep all input variables fixed except by the one under study.
- Decide the number of independent runs.

Step 9. **Perform simulation runs.**

# Model building and Simulation steps VI

## How to perform a simulation analysis?

Step 10. **Interpret and present results.**

- Compute numerical estimates (e.g. mean, confidence intervals) of the desired performance measure for each configuration.
- Test hypothesis about the system performance.
- Display graphics of the output data (pie charts, histograms).
- Comment and discuss results, give conclusions.

Step 11. **Recommend further course of action.**

- Plan further experiments (precision).
- Perform Sensitivity analysis.
- Implementation in the real system.

# What we need (to do M&S)

- Knowledge of the system under investigation
- System analyst skills (model formulation)
- Model building skills (model Programming)
- Data collection skills
- Statistical skills
  - input/output data representation
  - design of experiments
- Management skills (to get everyone in the same direction)

# Involve the end user

- M&S is a selling job!
- Does anyone believe the results?
- Will anyone put the results into action?
- The end user (your customer) can (and must) do the steps above, so you must convince him.
- He must believe it is HIS Model!

It is hard to sell M&S to the Industry (sometimes, somewhere).

# Choose the appropriate simulation tools I

1. Build Model in a General Purpose Language

   Advantages

   - Little or no additional software cost
   - Universally available (portable)
   - No additional training

   Disadvantages

   - Every model starts from scratch
   - Very little reusable code
   - Long development cycle for each model

   Examples: C, C++, Java, Python.

# Choose the appropriate simulation tools II

2. Build Model in a General Simulation Language

   Advantages

   - Standardized features often needed in modeling
   - Shorter development cycle for each model
   - Assistance in model verification

   Disadvantages

   - Higher software cost
   - Additional training required
   - Limited portability

   Examples: MATLAB/Simulink, GPSS, SIMSCRIPTIII, CSIM, SimPy.

# Choose the appropriate simulation tools III

3. Use a Special Purpose Simulation Package

   Advantages

   - Very quick development of complex models
   - Short learning cycle
   - No programming, minimal errors in usage

   Disadvantages

   - High cost of software
   - Limited scope of applicability
   - Limited flexibility (may not fit your specific application)

   Examples: Arena, Flexsim, MapleSim, Simul8.

# Benefits of simulation

- Obtain a better understanding of the system by developing a mathematical model.
- Test hypotheses about the system for feasibility.
- Time is under our control to compress or expand.
- Experiments with the modeled system does not disrupts the real one.
- Experiment with unknown situations.
- Identify the variables to which the system is more sensitive to
- Discover interrelation between variables.
- Identify bottlenecks in the flow of entities or information.
- Answer What-if questions.

# Simulation pitfalls

- Simulation can be a time consuming and complex exercise.
- Using simulation when an analytic solution is appropriate.
- Modeling requires special training.
- Results can be difficult to interpret.
- Invalid model (80 % is modeling, 20 % is simulation).
- Simulation model too complex or too simple.
- Erroneous assumptions on the real system.
- Using the wrong input probability distribution.
- Replacing a distribution (stochastic) by its mean (deterministic).
- Using the wrong performance measure.
- Bugs in the simulation program.
- Poor schedule and budget planning.

# Simulation applications

- Traffic simulation.
- Human evacuation (fire emergency).
- Applications in financial market, biological systems, Brownian motion.
- Process modeling and simulation in the Industry.
- Flight simulators.
- Robotics simulators.
- Pattern formation in nature.
- Social networks analysis.
- Modeling and simulation of the propagation of diseases / computer viruses.

# Topics (in general)

- Random numbers generation.
- Generating Discrete probability distributions. Generating Continuous Probability Distributions.
- Discrete Events Simulation.
  - Queue systems.
- Verification and validation of simulation models.
- Advanced topics in Simulation.
  - ODE numerical solving.
  - Petri Nets Introduction.
  - Cellular automata (pattern formation).
  - Introduction to complex networks.
- Learn by Doing: Case Studies (Through the whole course).

# Expectations

- Students enrolling in this course should have competent programming skills (language is irrelevant, so long as your code runs on Linux systems) to implement computer code of several hundred lines in length, be aware that the workload in this course is non-trivial.
- Plagiarism and cheating will be considered an academic offense.
- Students are expected and required to have completed the assigned readings in advance of each class.

# Evaluation

- Progress 1
  - Assigment # 1, 10 %
  - Assigment # 2, 10 %
  - Exam 15 %
- Progress 2
  - Assigment # 3, 10 %
  - Assigment # 4, 10 %
  - Exam 15 %
- Progress 3
  - Assigment # 5, 15 %
  - Exam* 15 %
- Progress 3 may be evaluated as a Project. Proposals will be given before mid course.
- **All assignments must be able to run on a Linux system.**

# Exercise

1. Choose and describe a system.
2. List its components, entities, attributes, activities, events, state variables.
3. What type of system is: static/dynamic, discrete/continuous, deterministic/stochastic.
4. Identify the input variables, performance measures (output variables), processor, control, feedback, boundaries and environment.
5. Identify initial states and states of interest.
6. How would you implement the system?
7. **Prepare a 5 minutes presentation to expose your work.**

# Sources and Resources

- CSE808 Modeling and Discrete Simulation.
- Sheldon M. Ross-Simulation, Fifth Edition-Academic Press (2012).
- CS4 (and MSc) Modelling and Simulation.
- Modelado y Simulación de Sistemas Complejos (Prezi).
- Introduction to Modeling and Simulation (Prezi).
- Maria, A. (1997, December). Introduction to modeling and simulation. In Proceedings of the 29th conference on Winter simulation (pp. 7-13). IEEE Computer Society.