Lecture (4-5): Modeling and Simulations (Why, What and How)

Why do we care about simulations?

What is simulation?

4.1 Simulation

- A computational model of some phenomena
- More than a set of equations, or the solution of an equation at
- a particular point
- Ability to try out different scenarios, look at different situations,
    - ask "what if" questions

Example: Car Simulation

4.1.1 Applications

- Car design (model-based design)
- Road design
- Driver education
- Entertainment

4.1.2 Things we can simulate. . .

- Physics of car motion
- Terrain or ground
- Controls and displays

4.1.3 Benefits

- Evaluate car designs under different driving conditions
- Easy to carry out many designs iterations

Example: Military Simulation

4.1.4 Scenario

- Army uses tank simulations for tank designs

- Simulated tanks are pitched against each other in simulated
- battles comprising thousands of soldiers
- Designs that survive go to the prototype stage

4.1.5 Assumptions about simulation

- Tank simulations relied upon data gather during a war, which had a lot of tank-vs-tank battles
- Second war didn't see much tank-vs-tank action; gorilla
- warfare, road-side bombs, etc.
- The tanks that were designed for tank-vs-tank battle didn't
- perform well under these conditions

4.1.6 Why do we build simulations?

- Validate a model or a theory
- Perform experiments that are too expensive or too dangerous to carry out
- Training
- Model-based design
- Decision making and problem solving
- Education

4.2 Validate a model or a theory

- Need some evidence that our theory is correct
- Does it behave the way we think it should?
- Does it mimic the real world?
- Where is it inaccurate?

4.2.1 Performing experiments

- Simulations can be cheaper than real experiments, and give the same results

- What will happen in the case of severe weather? Don’t want to actually destroy buildings or kill people!
- Control of nuclear reactors, pollution of water bodies, global warming, etc.

4.2.2 Model-based design

- Producing prototypes is expensive, eliminate poor designs quickly using simulation
- Fine tune designs, test different parameter combinations quickly
- Try the design in real situations to see how it will perform

4.3 Decision making and problem solving

- Even with a mathematical model the optimal solution may not be obvious
- May not be able to mathematically solve the problem
- What is the best number of bank tellers under particular conditions?
- How should an assembly line be configured?

4.4 Education

- Show how something works, rather than talk about it
- Students can explore the model, try different things
- Active learning, see how the simulation responds, try theories and ideas
- Can build the simulation themselves

4.5 Training

- Real equipment is expensive and dangerous
- Replicate training situations, such as bad weather and emergency situations
- Instructor can provide better feedback, pause the simulation and explain the problem
- More access to simulator than the real thing
- No ability to train on real thing, space program

4.6 Building simulations

- Requirements
- Modeling
- Data Collection
- Implementation
- Validation
- Use

4.6.1 Requirements

- Why are we building the simulation?
- How will it be used?
- We need to know what the problem is before we can start building a model and implementing the simulation
- The people who want the simulation can tell us how it will be used, what they need it for

4.6.1.1 Gathering requirements

- Problem statement
- Background material, standards, etc.
- Accuracy of the simulation
- Time requirements, how fast must the simulation run?
- Important parameters
- Output

4.6.2 Modeling

- We need to develop a model of the phenomena that we are simulating
- How the system changes over time
- How does it react to different events
- Two main classes of models

- Continuous systems simulations
- Discrete event systems simulations
- Continuous and DES simulations can be combined to construct hybrid simulations

4.6.3 Continuous systems simulations

- View time as a continuous variable
- Differential equations describe how the *state* evolves over time
- Inputs are parameters, which can be controlled by the user

Continuous systems simulations: Example

Car simulator

- Variables: speed, heading, amount of fuel, etc.
- Inputs: steering wheel position, force on gas and brake pedals, road conditions, etc.
- Model: differential equations that take into account the forces (engine thrust, ground friction, etc.) acting on the car

4.6.4 Discrete event systems simulations

- These focus on *events*
- Everything is based on the occurrence of events, which occur at discrete points in time
- An event often leads to more events in the future, and so on
- Events can begin to accumulate at some object, forming queues, and output is usually the average time the system takes to process an event
- Quite often involve statistics, probability distributions and queuing theory
- Can be used to model computer systems and networks

Discrete event systems simulations: Example

Automated Teller's Machines (ATM)

- Customers entering a bank
- What percentage of these customers use an ATM
- What do they use ATM for: withdrawals or deposit
- How long do they spend at the ATM
- When do these customers leave the ATM

4.6.5 Data collection

- Most models will have parameters and input data
- Need to collect this information before you can implement or run the model
- Sometimes the information is easy to collect, such as different physical constants, just a matter of looking it up in a book
- Other types of data won't be readily available, average time for a teller to process a customer
- You may need to set up an experiment to collect the data, monitor bank tellers for several days and collect statistics

4.6.5.1 Data collection as a part of the simulation results

- In some cases, you may even need to guess, the data becomes part of the simulation problem?
- What values give reasonable results?

4.6.5.2 Consistency in data collection

Keep an eye on units

- With physical constants they must all use the same set of units, if not you will need to do conversions
- Equations won't work if the constants have different units, they will produce incorrect values
- This is a major source of errors

4.6.5.3 in data collection

Keep an eye on the process used to collect data

- In some cases if the data isn't collected in the same location it may not fit together, must be from same population
- In the bank example, all statistics should be captured in the same bank. Different banks could process customers in different ways, so mixing the statistics could produce meaningless results.
- This could be one of the hardest problems in simulation development

4.6.6 Implementation

Produce a computer program for the simulation

4.6.6.1 Continuous system simulations

- In the case of continuous system simulations this usually involves writing the program for the simulation
- We will use the open-source physics framework that provides most of the program code
- We still need to convert the differential equations into program code, build the interface to the simulation

4.6.6.2 Discrete event simulations

- Discrete event simulations are a bit easier, standard programs exists for performing the simulation
- Must still describe the system to be simulated, the events and the objects that process the events
- Programs produce standard statistics
- May still need to program if you need something special

4.6.6.3 Implementation considerations

- Implementation effort depends upon simulation application

- For some applications implementation is relatively easy, put something together quickly a let it run
- Often the case if the results aren't time sensitive, can afford to wait for the simulation to finish

4.7 Validation

- Before we can use a simulation we need to validate it, determine whether it is giving the correct values
- If the simulation is wrong, we don't want to use the results
- There are several ways that we can do this, the easiest is to compare the results to known values
- I If there is a special case where the output is known, then check
- this case
- Run the simulation in parallel with the real world
- Use known inputs, the current situation and see if the simulation predicts what actually happens

Example: input today's weather conditions, and see if tomorrow's weather prediction is correct

- This only works if you can capture the required input
- See if the simulation predicts known behavior
- If you know that a particular condition arises under certain circumstance, then see if the simulation produces similar results
- Not the best validation, but shows whether the simulation is going in the right direction

4.8 Use

- In some cases the simulation will only be used a few times to answer a particular set of questions

- In other cases it will be used on a daily basis, in this case may need to update the simulation as conditions change