Introduction to Computer Simulations

Computer Simulations

Computer simulation is the process of making a computer behave the same as ...whatever it is we are interested in.

- Atoms
- Cooling metal alloy
- A society of voters
- Climate change
- A galaxy

Computer Simulations

Simulations have applications across a range of disciplines:

Physics – solids, gases, fluids, solar systems

Chemistry – molecular dynamics

Biology – gene networks, predator-prey populations

Sociology – socio networks, opinion propagation

Technology – internet traffic, local networks

Management – queuing, workflow models

Finance & Economics – stock markets, supply-demand

Computer Simulations

Computer simulations allow us to observe the behaviour of these systems at (relatively) low cost.

Other methods of investigating these systems may involve complicated theoretical research or experimental research with potentially expensive equipment.

Computer Simulations

There are some definitions of simulations:

"The representation of the dynamic behaviour of the system by moving it from state to state in accordance with well-defined operating rules." – A. Alan B. Pritsker (1984)

"We can therefore define simulation as the technique of solving problems by the observation of the performance, over the time, of a dynamic model of the system." – Bernard P. Zeigler (1976)

"A simulation is a method for implementing a model." – Defense Acquisition University

Computer Simulations

To create a computer simulation to approximate a system, a model of that system must first be made. These are most often mathematical models.

"A model is a description of some system intended to predict what happens if certain actions are taken"

– Bratley, Bennet & Schrage (1987)

Models

Modelling is a large discipline in itself and creating a system requires a lot of mathematical ability and understanding of the system.

Models are usually composed of variables and relationships between them. Exactly what these variables represent and what the relationships between them are can vary.

Models

The variables of the model must represent the *state* of the system. The state is split into different components to represent the different parts of the system. These are sometimes called *model components*.

For example:

A car in a traffic simulator may have a *position*, a *size* and a *velocity*.

Models

The relationships between these model components define the behaviour of the system. Going back to our previous example some rules may be:

- The position of the car changes based on the velocity.
- If the distance to the car in front is less than X, decelerate.

Models

The types of relationships depend on the type of model. Some categories of model include:

Linear vs Nonlinear

Static vs Dynamic

Explicit vs Implicit

Discrete vs Continuous

Deterministic vs Probabilistic

Models

Models are also limited in the accuracy with which they describe the model. The usefulness of a model depends on a number of factors

- model validity
- level of simplification
- credibility
- tractability

Models

When using computer simulations, it is important to understand the limitations of the model you are using. A simulation (no matter how accurate) cannot provide useful results if the model is not suitable for the system you are studying.

A model is considered valid if the system it describes *sufficiently near* to the real system.

Models

For example:

Newton's Laws of Motion are a perfectly suitable model for describing the behaviour of object in our natural environment.

However, they are not sufficient to describe objects that are travelling extremely fast or extremely large – like Mercury for instance.

Simulations

Models are approximations of a real system (for the most part). Simulations approximate the behaviour of the system described by the model.

For example:

An object travelling according to Newton's Laws of Motion.

Simulations

This type of model describes a system that continuously changes with time. Computers don't do things continuously so we resort to using a time-step to jumping forward in time repeatedly.

This is an approximation of the model because we are simulating a continuous system with discrete time-steps.

Continuous Simulations

Continuous simulations (like our example) are simulations that compute models that change continuously (usually over time). This type of simulation is extremely common in the physical sciences.

Continuous simulation and *discrete event simulation* are usually considered the two main categories of simulation.

Continuous Simulations

Continuous simulations are most often based on models described by *ordinary differential equations (ODEs)* or *partial differential equations (PDEs)*.

Because computers are limited to discrete calculations, these simulations update the system with discrete time-steps.

Continuous Simulations

To do this, the continuous model must be integrated over that time-step to calculate the total change in each of the variables representing our model.

There are a number of different numerical methods that can be used for this purpose.

(more on this later).

Discrete Event Simulations

The other main category of simulations are discrete event simulations. This type of simulation is no longer computing a continuously changing system but one that considers discrete events.

For example – a stock exchange

Discrete Event Simulations

A stock exchange could be modelling by a set of agents (traders) that perform discrete events (buy and sell).

There is still a time component to this simulation but there are no variables in the state of the system that need to be continuously modelled over time.

Discrete Event Simulations

This type of model is generally easier to simulate on a computer because they consist of a set of discrete events and changes.

Computers are good a doing discrete calculations.

Summary

Models describe *systems* that are approximations of real systems.

Simulations are programs that approximate systems described by *models.*

Modeling and Simulation: The Computer Science of Illusion

- Stanislaw Raczynski, Wiley (2006)