Overview of Simulation

CIS*2460 - Fall 2007

What is simulation?

- Your text defines simulation as “the imitation of the operation of a real-world process over time”
  - generate an artificial history of a process
  - infer insights into the real-world system from the artificial history
- Simulation involves building *models* of *systems* (real or imagined)
  - aid to understanding
  - training/instruction
  - prediction
  - experimentation

Systems

- DEF’N:
  - a set of objects together with relationships and dependencies on one another
- Entities
  - objects within a system
- Attributes
  - properties of objects within a system
- Activities
  - actions performed by objects within a system

Systems (cont.)

- Events
  - changes in the system induced by entity activities
- State
  - the set of all entities, attributes and activities in a system at a given time
  - the *state* of the system changes in response to *events*
- Consider a supermarket as a system
  - identify relevant entities, attributes, activities
  - what events cause a change in the state of this system?

Models

- DEFINITIONS:
  - A simplified description, especially a mathematical one, of a system or process, to assist calculations and predictions
    - Compact Oxford English Dictionary
  - A systematic description of an object or phenomenon that shares important characteristics with the object or phenomenon. Scientific models can be material, visual, mathematical, or computational and are often used in the construction of scientific theories.
    - The American Heritage Science Dictionary
  - A description of observed behaviour, simplified by ignoring certain details. Models allow complex systems to be understood and their behaviour predicted within the scope of the model, but may give incorrect descriptions and predictions for situations outside the realm of their intended use. A model may be used as the basis for simulation.
    - Free On-line Dictionary of Computing

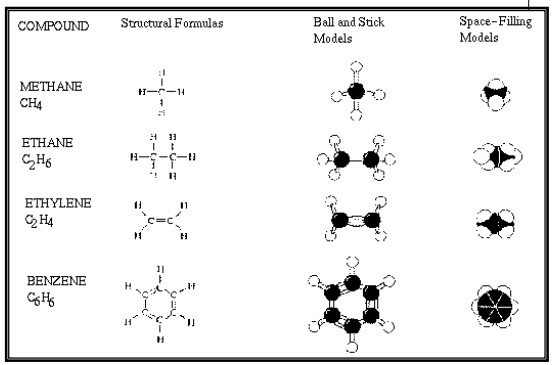
Models

- DEFINITION SUMMARY:
  - an approximation of a *system*
  - to be useful, a model must agree to some degree with the system being modelled
  - physical vs. abstract models

Types of Models

- Structural
  - modeling an object
    - blueprint of a house
    - structure of a molecule
- Procedural
  - modelling a time dependent process
    - UML modeling software
    - modeling a chemical reaction
    - equation of motion
    - computer simulation

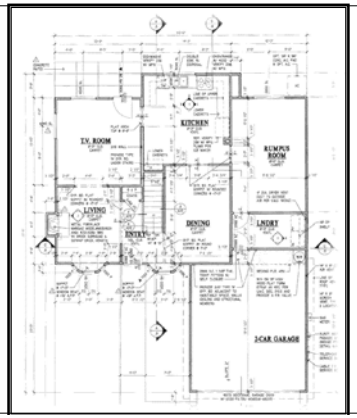
Structural: modeling an object



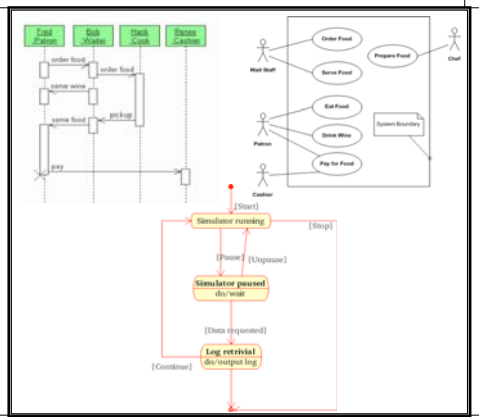
structure of a molecule

Structural: modeling an object

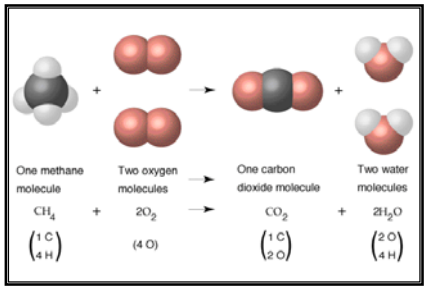
House Blueprint



Procedural: UML



Procedural: modeling a chemical reaction



Procedural: equation of motion

$$\rho \frac{D\mathbf{u}}{Dt} = \rho \left(\frac{\partial \mathbf{u}}{\partial t} + \mathbf{u} \cdot \nabla \mathbf{u} \right) = -\nabla P,$$

Fluid Dynamics Equations

Types of Models (cont.)

- Representational
  - visual
    - graphical i.e. using diagrams
  - symbolic / mathematical
    - symbolic notation
    - may use mathematical equations
- Physical
  - a simplified representation of an actual system, constructed in the real-world (material)
- Simulation
  - Using the behaviour of one system to form an understanding of the behaviour an analogous system

Simulation Definition Again

- Simulation:
  - the representation of the behavior or characteristics of one system through the use of another system
  - especially a computer program designed for the purpose
    - Origin: 1300; ME simulacion < L simulātiōn - a pretense
    - Random House Unabridged Dictionary
- Computer Simulation
  - Uses the dynamics of an executing algorithm via a program running on a computer to model the dynamics of the system being represented
  - If there is a one-to-one correspondence in the dynamics, the results of the simulation will be identical to the results of the system being represented

Types of Models (cont.)

- Deterministic
  - the rules governing the behaviour of the system are unambiguous, not subject to any random elements
  - possible to exactly predict the state of the model based on its inputs
  - e.g. firing a cannon
    - given velocity, angle, gravity, etc. you can determine where the ball will land
- Stochastic
  - system possesses a random component
  - outcomes can only be described in terms of probabilities
  - e.g. teller service at a bank
    - arrival of customers, and service times for customers vary in an erratic manner

Types of Models (cont.)

- Static
  - system is represented at a specific moment in time
  - Monte Carlo simulation
- Dynamic
  - system is modelled along with changes that occur over time
  - e.g. supermarket with checkout

Types of Models (cont.)

- Discrete
  - state variables associated with the model can only change at a discrete set of points in time
  - e.g. number of customers in a supermarket
    - integer that only changes when customers enter/leave the store
- Continuous
  - state variables change continuously over time
  - e.g. water level in a river
- Note:
  - few systems are completely discrete or continuous
  - a continuous system does not necessarily require a continuous model (and vice versa)

Developing Models

- It has been suggested that modelling is both an art and a science
  - 5 Steps:
    - system identification and statement of the modelling problem
    - mathematical model definition and construction
    - (a priori) mathematical problem analysis, reformulation and solution development
    - computer program design, development and verification
    - model validation, adjustment and use
- Verification and validation (this will haunt you)
  - *verification* of code, *validation* of model
  - must ensure that model is appropriate, and that the code we have written implements what we intended it to

Designing Models (cont.)

- It is rare (often times impossible) to model a system exactly
  - Simplification
    - reduce complexity of a model by making assumptions about the entities/attributes/activities of a system
  - Abstraction
    - isolate the essential attributes of the entities in the system
    - eliminate the unimportant details
- The biggest problems in designing good models:
  - over-simplification and/or over-abstraction
  - must be careful to reason about and justify all assumptions and omissions
    - otherwise our model is faulty
    - it will be neither descriptive nor predictive in a meaningful way

Analyzing Models

- Constructing a good model implies that we understand the system under consideration
  - assuming we understood the system well, and have built a reasonable model, it will naturally have descriptive qualities
  - however may not necessarily predict unexamined phenomena
    - model is 'overfit' to the data
    - i.e. not generalized - not a robust (good) model
- Model Analysis
  - the application of mathematical or computational techniques in order to develop the generalized qualities of our model
  - this is a critical step as it is uncommon to simply want a model that goes through the motions of a system for its own sake
    - we built a model to tell us something new

Validating Models

- Validity
  - the extent to which a model accurately represents a system
  - we must test our models against
    - the known behaviour of the system under consideration
    - future yet unknown behavior of the system,
      - often derived from experiments prompted by the simulation
- Lack of validity might reflect:
  - system poorly (or insufficiently) understood
  - unreasonable assumptions
  - bad (or improperly selected) input
  - implementation errors
- Modelling is ultimately an iterative process
  - if we uncover problems during verification and validation, we must return to considering our assumptions, abstractions, etc.

Simulation as Model Exploration

Example: From individual mate search to population marriage patterns

By Peter M Todd