CSCI 8220
Simulation & Modeling

Introduction and Motivation

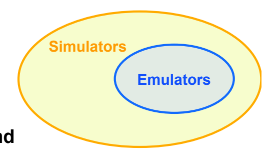
What is a Simulation?

A system that *represents* or *emulates* the behavior of another system over time; a *computer simulation* is one where the system doing the emulating is a computer program

Emulators versus Simulators

Some differentiate between the two and the definitions may vary:

- ***Emulators*** **- Special types of simulators.**
  - » **Emulates a *computer device* or *program*.**
    - – **CAVEAT: Sometimes the definition is fuzzy when something changes from being a simulation and becomes an emulation.**
    - – **Duplicates functions on one system using a different system (some virtual machines do this)**
- **Simulator – more abstract functions**
- **Historically ‘emulator’ meant hardware and ‘simulator’ meant simulating via software**
- **Emulators are imitators**
  - » **100% identical behavior, more self-contained**
  - » **A simulator is something whose behavior can be, in places, different (more abstract) for better or worse.**



Why Do Simulations?

- **Software prototyping**
- **Forecasting/Planning**
- **Training/Education**
- **Analyze processes that have different time spans (days/years/eons)**

Why Do Simulations?

- **Software prototyping**
  - » **Simulations are less costly, safer and more environmental friendly than real world experiments**
    - – Nuclear weapons, automotive structural design – collision testing, experimental surgical procedures

Why Do Simulations?

- **Software prototyping**
- **Forecasting/Planning**
  - » **Use simulation(s) as a decision tool**
    - – Weather forecasting – simulations predicts storm patterns, air-traffic applications – minimize delays

Why Do Simulations?

- Software prototyping
- Forecasting/Planning
- Training/Education
  - » Utilize Virtual Environments
    - – Commercial and military pilots utilize interactive simulations to enhance their flying skills. Networked Simulators to enable military pilots from different geographical regions to participate in one single exercise
  - » Medicine
    - – University of Alberta – doctors in training use simulated patients

Why Do Simulations?

- Software prototyping
- Forecasting/Planning
- Training/Education
- Analyze processes that have different time spans (days/years/eons)
  - » Corrosion testing for automobiles, astronomers may analyze theories that might otherwise take millions of years to verify.

Why Do Simulations?

- Software prototyping
- Forecasting/Planning
- Training/Education
- Analyze processes that have different time spans (days/years/eons)

Classes of Simulation *Applications*

- System Analysis
- On-Line Simulations
- Virtual Environments

Applications: *System Analysis*

"Classical" application of simulation; here, focus on "discrete event" simulation

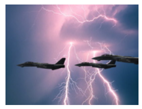
- Telecommunication networks
- Transportation systems
- Electronic systems:
  - » Computer systems & logic circuits
- Battlefield simulations (blue army vs. red army)
- Ecological systems
- Manufacturing systems
- Logistics

Focus typically on planning & system design

Telecommunication networks

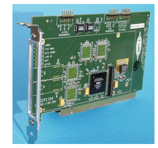
- Evaluate networking hardware, software, protocol and services
- New technologies for networking such as images, data, video in addition to voice forces designers to turn toward simulation tools to aid them.
- Parameters: fiber (more traffic), copper, switches
- Metrics: Cell losses
- Parallel Simulations

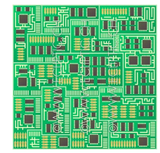
Transportation Systems



- Macro simulations
  - » top-down approach, focusing on the observable behavior of a system.
  - » regenerate the observable behavior in terms of aggregate
  - » Course grain, shorter run-time
- Micro simulations
  - » Bottom-up approach with detailed, rich behaviors for individual entities (e.g., cars, car following behavior).
  - » Fine grained
- Automotive
- Air Traffic Control: Evaluate adding new runways to alleviate congestion

Computer Systems & Logic Circuits





- Uses VHDL hardware description language
- Gate level logic simulations focus on modeling individual circuits for implementing boolean functions and storage elements
- Higher level models for switches, processors, memories and so on → these usually uses benchmark programs on the modeled machine.

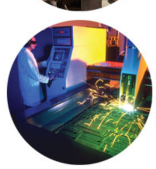
Battlefield Simulations

- Virtual Environments
- Immersive: In-the-loop
  - » Hardware-in-the-loop: evaluate effectiveness of new devices
  - » Software-in-the-loop
  - » Human-in-the-loop
- Geographically distributed training environments

Ecological Systems

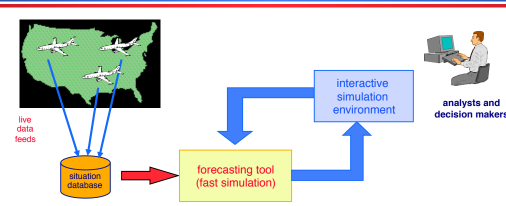
- Micro/Macro simulations
- Insects: Ants & Bees & Locusts: Need scalable simulators
- Evolutionary: Lyme disease

Manufacturing Systems



- Simulations can aid in design and analysis aid for
  - » factory layouts, equipment decisions, operating policies;
  - » Scheduling tool for production processes;
  - » a part of a real-time, on-line control system
- Many commercial simulation tools

Applications: *On-Line Decision Aids*



Simulation tool is used for fast analysis of alternate courses of action in time critical situations
- » Initialize simulation from situation database
- » Faster-than-real`-time execution to evaluate effect of decisions

Applications: air traffic control, battle management

Simulation results may be needed in only seconds

Applications: *Virtual Environments*

Uses: training (e.g., military, medicine, emergency planning), entertainment, social interaction?

Simulations are often used in virtual environments to create dynamic computer generated entities

- Adversaries and helpers in video games
- Defense: Computer generated forces (CGF)
  - Automated forces
  - Semi-automated forces
- Physical phenomena
  - Trajectory of projectiles
  - Buildings “blowing up”
  - Environmental effects on environment (e.g., rain washing out terrain)

Virtual Environments vs. Analysis

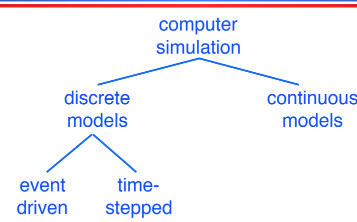
Typical Characteristics	Analysis	Virtual Environments
Typical Objective	Quantitative Analysis of complex systems	Create realistic or entertaining representation
Execution Pacing	As-fast-as-possible	Real-time
Human Interaction	If included, often external observer	Integral to controlling entities
Accuracy	Statistically correct results	Human perception plays a large role

Simulation Fundamentals

A computer simulation is a computer program that models the behavior of a physical system over time.

- Program variables (state variables) represent the current state of the physical system
- Simulation program modifies state variables to model the evolution of the physical system over time.

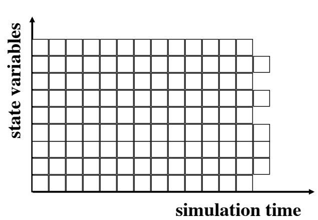
Simulation Taxonomy



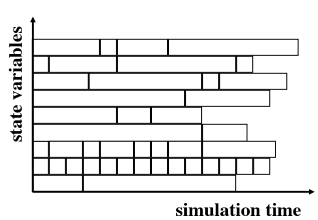
- Continuous time simulation
  - State changes occur continuously across time
  - Typically, behavior described by differential equations
- Discrete time simulation
  - State changes only occur at discrete time instants
  - Time stepped: time advances by fixed time increments
  - Event stepped: time advances occur with irregular increments

Time Stepped vs. Event Stepped

Goal: compute state of system over simulation time

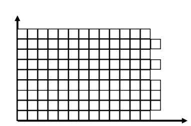


time stepped execution



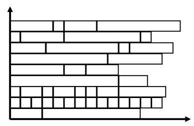
event driven execution

Time Stepped Execution (Paced)



```
while( simulation not completed )
{
    Wait Until( W2S( wallclock time ) ≥ current simulation time )
    Compute state of simulation at end of this time step
    Advance simulation time to next time step
}
```

Event Stepped Execution (DES)



```
while( simulation not completed )
{
   Remove smallest time stamped event from event list
   Set simulation time clock to time stamp of event
   Execute event handler in application to process event
}
```


Parallel / Distributed Simulation

Parallel (distributed) simulation refers to the technology concerned with executing computer simulations over computing systems containing *multiple* processors

- Tightly coupled multiprocessor systems
- Workstations interconnected via a network (e.g., the Internet)
- Handheld computers with wireless links

Why Execute Over Multiple CPUs?

- Reduced model execution time
  - » Up to N-fold reduction using N CPUs
- May not have enough memory on a single machine
- Scalable performance
  - » Maintaining the same execution speed for bigger models/ virtual environments by using more CPUs
  - » Particularly important in virtual environments
- Geographically distributed users and/or resources (e.g., databases, specialized equipment)
  - » Co-location is expensive! May be impractical
- Integrate simulations running on different platforms
  - » Network rather than port
- Fault tolerance
  - » Not as easy as it might seem!

Enable Simulation of Big Models

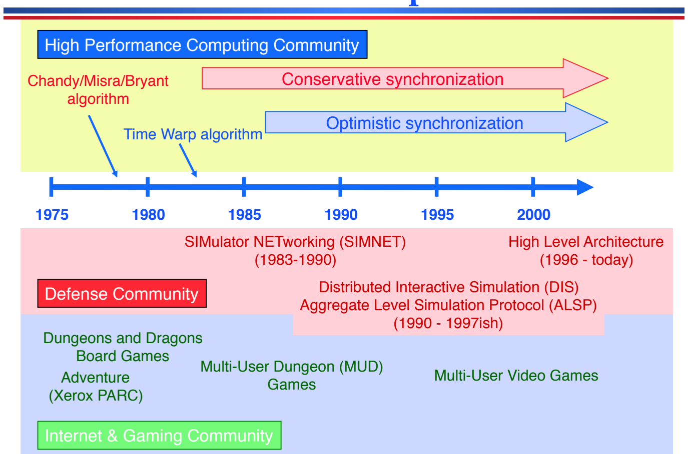
Cell level simulation of an ATM (packet) network

- Simulate one hour of network operation
- Network with 1000 links
- 155 Mbits/second links @ 20% utilization
- 53 byte packets (cells)
- One simulator event per cell transmission (link)
- 500 K events / second simulator speed

150 hours for a single simulation run!

- Larger, more complex networks?
  - » Next Generation Internet: Million nodes
- Higher link bandwidths

Historical Perspective



Summary: *DES*

- Simulation is seeing widespread use in system design and management, as decision aids, and in creating virtual worlds for training or entertainment
- Fundamental concepts: State, changing state across simulation time
  - » Continuous vs. discrete time simulations
  - » Here, focus on discrete event simulation

Summary: *PDES*

- Reasons for distributing the execution of simulations over multiple computers include
  - » Performance
  - » Geographical distribution
  - » Easier integration of systems (interoperability), reuse
- Parallel/Distributed simulation technologies developed largely independently in different R&D communities
  - » High performance computing
  - » Defense
  - » Internet and gaming