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# Simulation & Modeling

## Introduction and Motivation



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# 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

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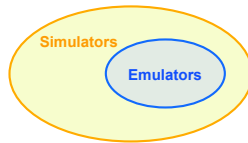
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# Emulators versus Simulators

\*\*\* 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), an x86 emulator – emulates the **full** 'machine' including the processor,.
  - » Emulators are **imitators**
  - » 100% identical behavior, more self-contained
- **Simulator** – more abstract functions
  - » A simulator is something whose behavior can be, in places, different (more abstract) for better or worse.
- Historically 'emulator' meant **hardware** and 'simulator' meant simulating via software



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# Why Do Simulations?

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

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# 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

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# 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

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## 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

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## 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.

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## Why Do Simulations?

- Software prototyping
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## Classes of Simulation *Applications*

- System Analysis
- On-Line Simulations
- Virtual Environments

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## 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

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## 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



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## 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**

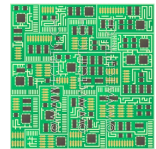
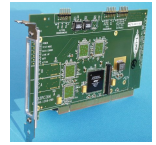


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## Computer Systems & Logic Circuits

- 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.



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## 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**



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## Ecological Systems

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



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## Manufacturing Systems

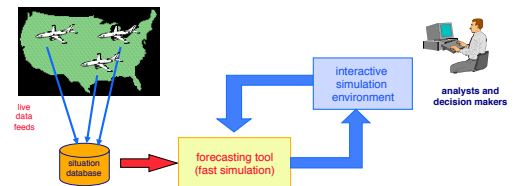
- **Simulations can aid in design and analysis aid for**
  - » factory layouts, equipment decisions, operating policies;
  - » Scheduling tool for production processes;
  - » a part of a real-time, on-line control system
- **Many commercial simulation tools**



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## 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**

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## 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)

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## 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

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## Simulation Fundamentals

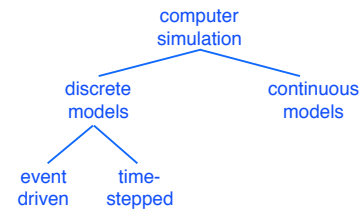
A computer simulation is a computer program that models the behavior of a **physical system** over time.

- 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.

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## Simulation Taxonomy



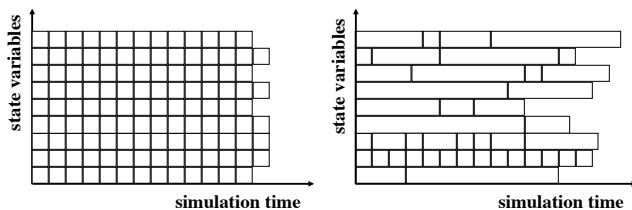
- Continuous time simulation
  - » State changes occur continuously across time
  - » Typically, behavior described by differential equations
- Discrete time simulation
  - » State changes only occur at discrete time instants
  - » Time stepped: time advances by fixed time increments
  - » Event stepped: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

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## Time Stepped vs. Event Stepped

**Goal:** compute state of system over simulation time



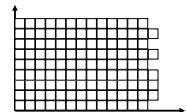
time stepped execution

event driven execution

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## Time Stepped Execution (Paced)



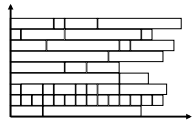
```

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
}
  
```

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## 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
}
```

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## 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

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## 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!

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## 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

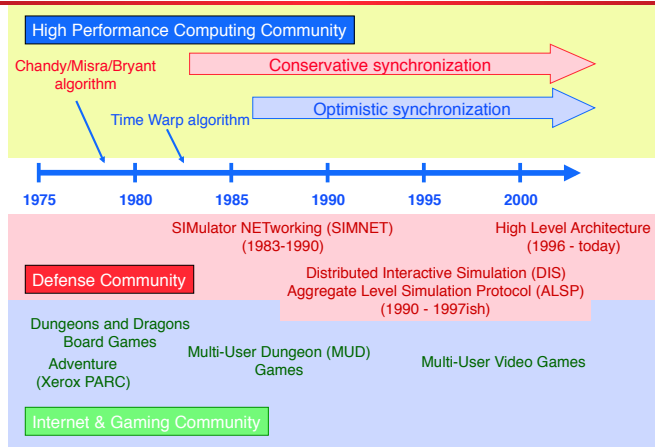
150 hours for a single simulation run!

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

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## 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

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## Summary: *PDES*

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- **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