Parallel and Distributed Simulation

Introduction and Motivation

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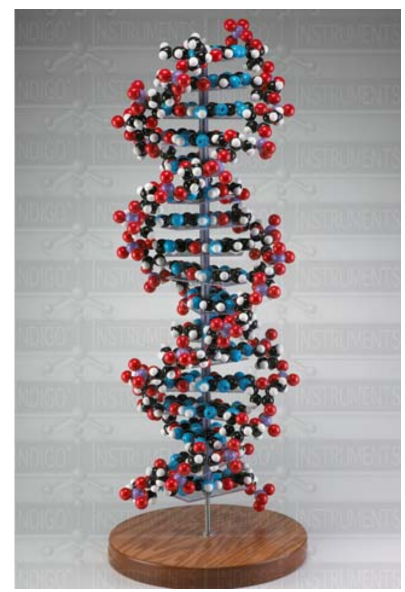
What is a model?



Models and Systems

Definitions

- *System Under Investigation* *(SUI) or* *Physical System*
  - The real or imagined system that is to be modeled
- Model
  - Representation or abstraction of the SUI
  - A description of observed behavior, simplified by ignoring certain details. [www.learnthat.com]
- Here, we are interested in models of *dynamic systems*, i.e., systems that exhibit behavior over time
  - "… a dynamic system is a collection of interacting *entities* that produces some form of behavior that can be observed over an interval of time." [Birta, Arbez, p. 3]

Computer Simulation?

A computer simulation is a computer program that uses computation to construct a representation of the behavior of a model of a particular system over time.

Computer simulations build on purely mathematical models in science, technology and entertainment.

Why Simulate?

- Observing an operational system may be
  - Too expensive (e.g., computer chips)
  - Too dangerous (e.g., forest fires or chemical spills)
  - Too disruptive (e.g., traffic signal timing)
  - Too time consuming (e.g., weather)
  - Not possible (e.g., creation of the universe)
  - Morally or ethically unacceptable (e.g., spread of a disease)
  - Parts of the system may not be observable (e.g., internals of a silicon chip or biological system)

Uses of simulations

- Analyze systems before they are built
  - Reduce number of design mistakes
  - Optimize design
- As a replacement for purely mathematical representations to explore physical systems
- Analyze operational systems
- Create virtual environments for training, entertainment

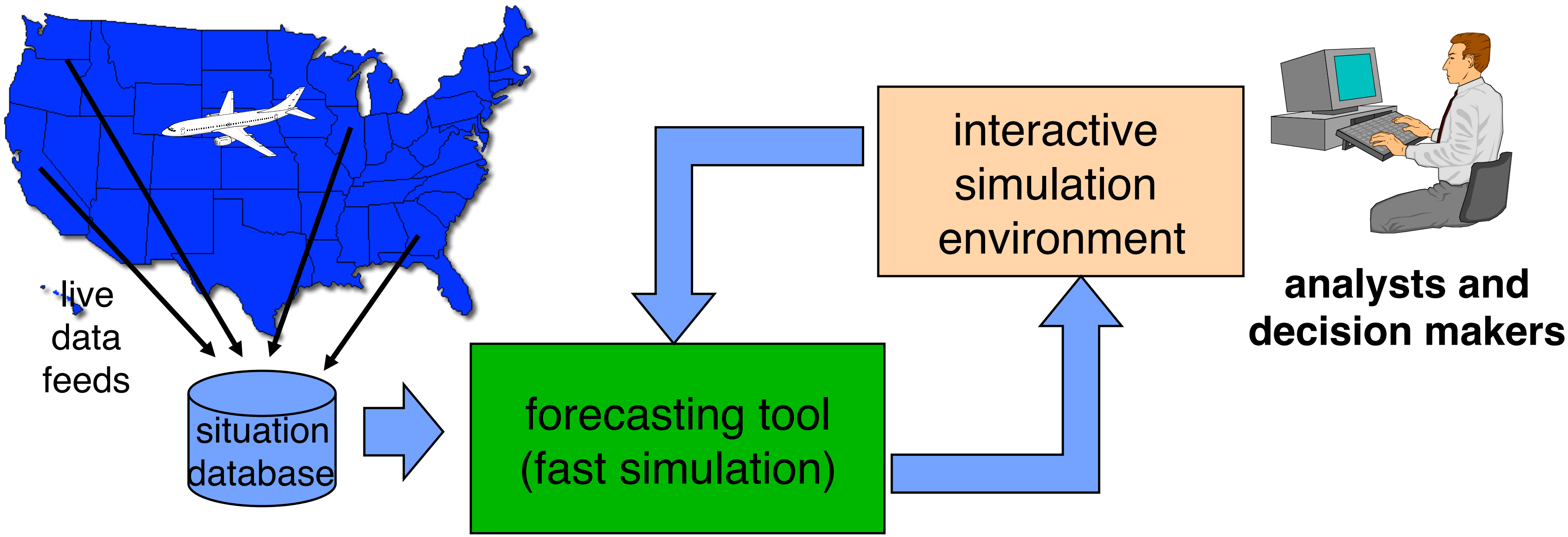
Applications: System Analysis

"Classical" application of simulation to analyze, design, optimize systems

- Weather, climate, astrophysics
- Aerospace, automotive design
- Telecommunication networks
- Transportation systems
- Microelectronics, computer systems
- Battlefield simulations
- Ecological systems
- Manufacturing systems
- Logistics
- …

Focus typically on planning, system design

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

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

- Adversaries and helpers, e.g., video games
  - Automated
  - Semi-automated
- Physical phenomena
  - Trajectory of objects
  - Buildings “blowing up”
  - Environmental effects on environment (e.g., rain washing out terrain)

Applications: Test and Evaluation

Simulation widely used to interact with physical components, e.g., to test and evaluate their behavior (sometimes called emulation)

- Electronic circuits (in circuit emulation)
- Communication networks
- Defense applications

Historical Overview

- 1940's – Computer simulation in Manhattan Project to model nuclear detonation
- 1950's – Analog computers commercially available and used for continuous simulations (solving differential equations)
- 1960's – The digital computer offers an alternative to the analog computer and provides a means for simulating discrete event systems incorporating stochastic phenomena
  – Simula: First object-oriented programming language
- 1970's and 80's – Numerous modeling and simulation applications are developed
- 1980's and 90's – emergence of parallel and distributed simulation (e.g., SIMNET, simulation standards)
- 1960's and beyond – Chaos, complex systems, networks

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

	Real machines	Simulated machines
Real people	Live	Virtual
Simulated people	? (hardware in the loop)	Constructive

- Types of simulation
  - *Live*: real people operating real equipment
  - *Virtual*: real people operating simulated equipment (often referred to as a "simulator," e.g., a flight simulator)
  - *Constructive*: simulated people operating simulated equipment
- Major application areas
  - Analysis: Wargaming, logistics
  - Training: Platform level, Command level
  - Test and evaluation: Hardware-in-the-loop

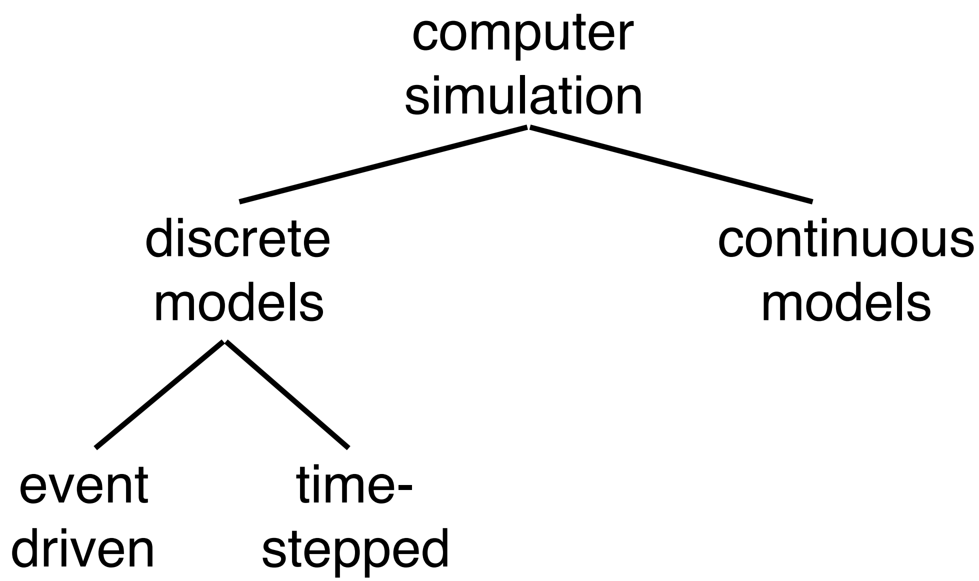
Continuous vs. Discrete

- Discrete Time
  - State of the system is viewed as changing at discrete points in time
  - An event is associated with each state transition
    - Each event has a time stamp
- Continuous Time
  - State of the system is viewed as changing continuously across time
  - System typically described by a set of differential equations
- Distinction is conceptual; in practice, continuous simulations discretize the time axis

Discrete Event Simulation

- State changes can occur at irregular points in time
- In practice, one can always discretize the time scale and map a discrete event simulation to a time stepped model
- On a deeper level, is time discrete or continuous?

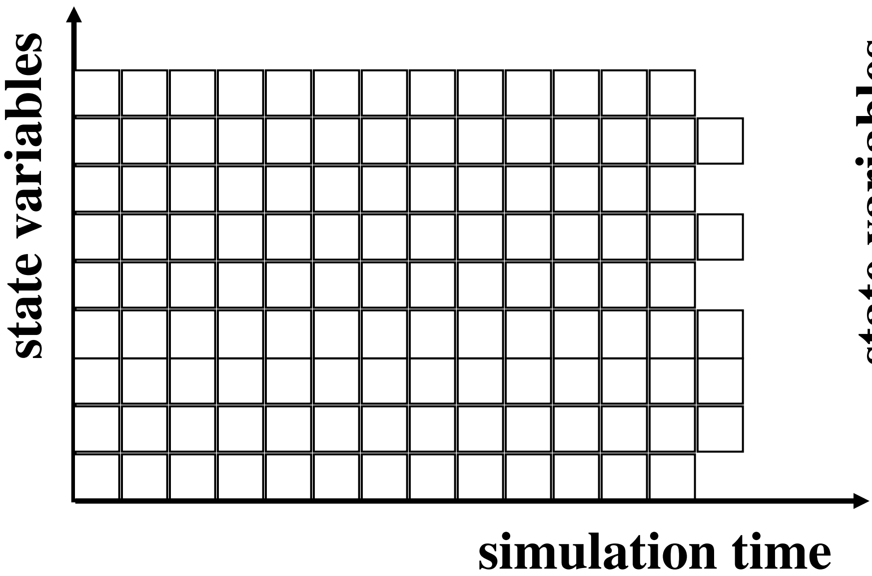
Simulation Taxonomy

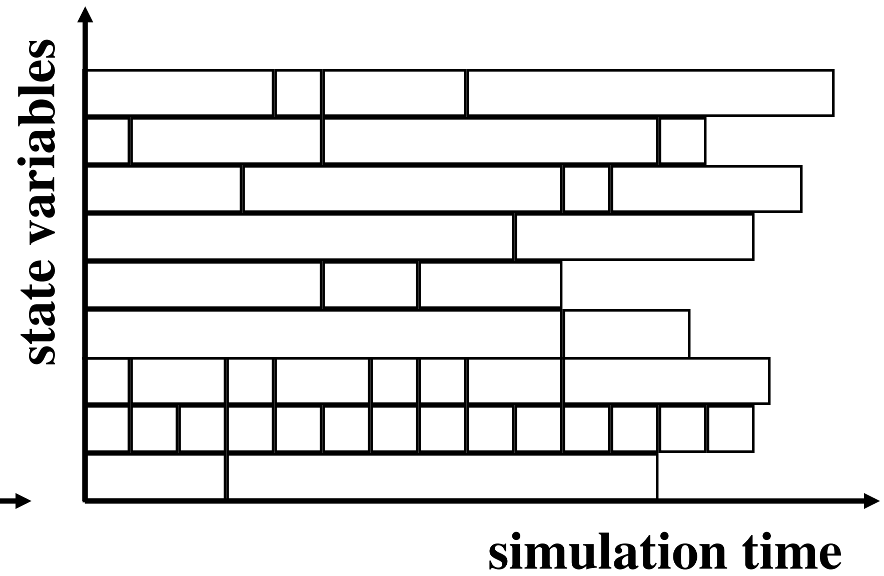


- Continuous time simulation
  - State changes occur continuously across time
  - Typically, behavior described by differential equations
- Discrete time simulation
  - State changes only occur at discrete time instants
  - Time stepped: time advances by fixed time increments
  - Event stepped: time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

Time Stepped vs. Event Stepped

Goal: compute state of system over simulation time





time stepped execution

event driven execution

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

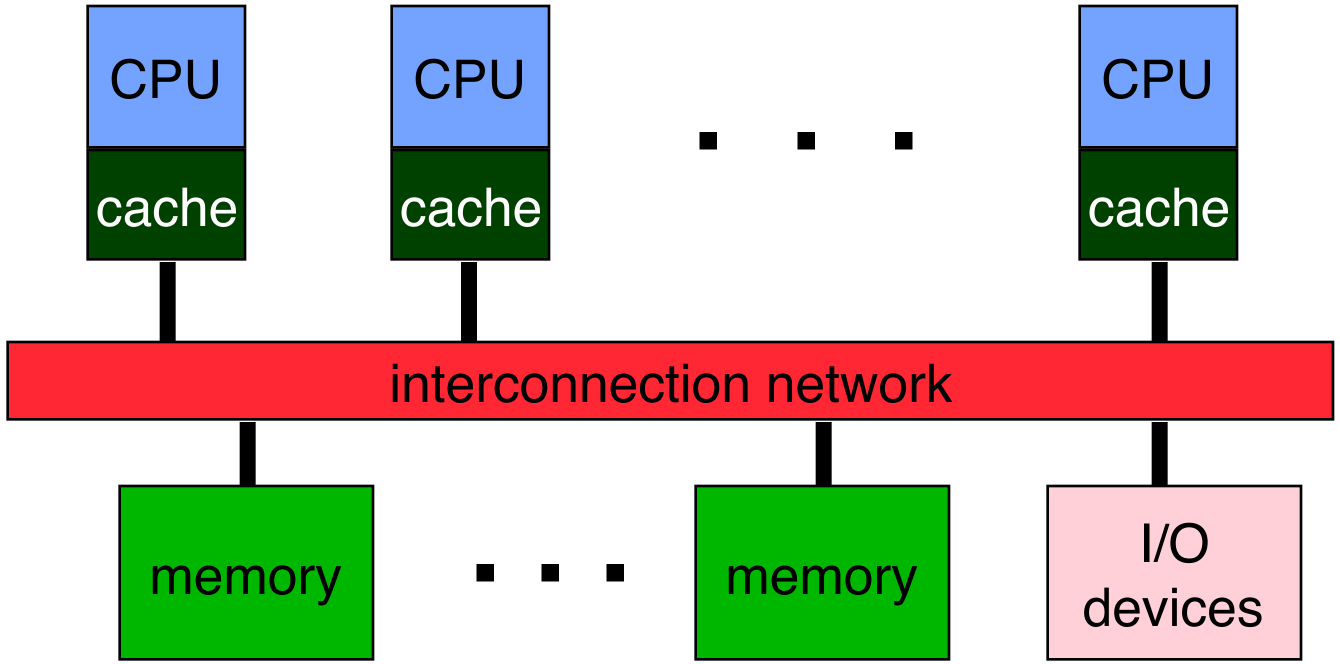
Parallel and Distributed Computers

- Parallel computers (tightly coupled processors)
  - Shared memory multiprocessors
  - Distributed memory multicomputers
- Distributed computers (loosely coupled processors)
  - Networked workstations

	Parallel Computers	Distributed Computers
Physical extent	Machine room	Building, city, global
Processors	Homogeneous	Often heterogeneous
Comm. Network	Custom switch	Commercial LAN / WAN
Comm. Latency (small messages)	A few to tens of microseconds	hundreds of microseconds to seconds

Shared Memory Multiprocessors

Many examples: Sun, Dell, SGI, etc.



programming model: shared variables; synchronization via locks

Processor 1

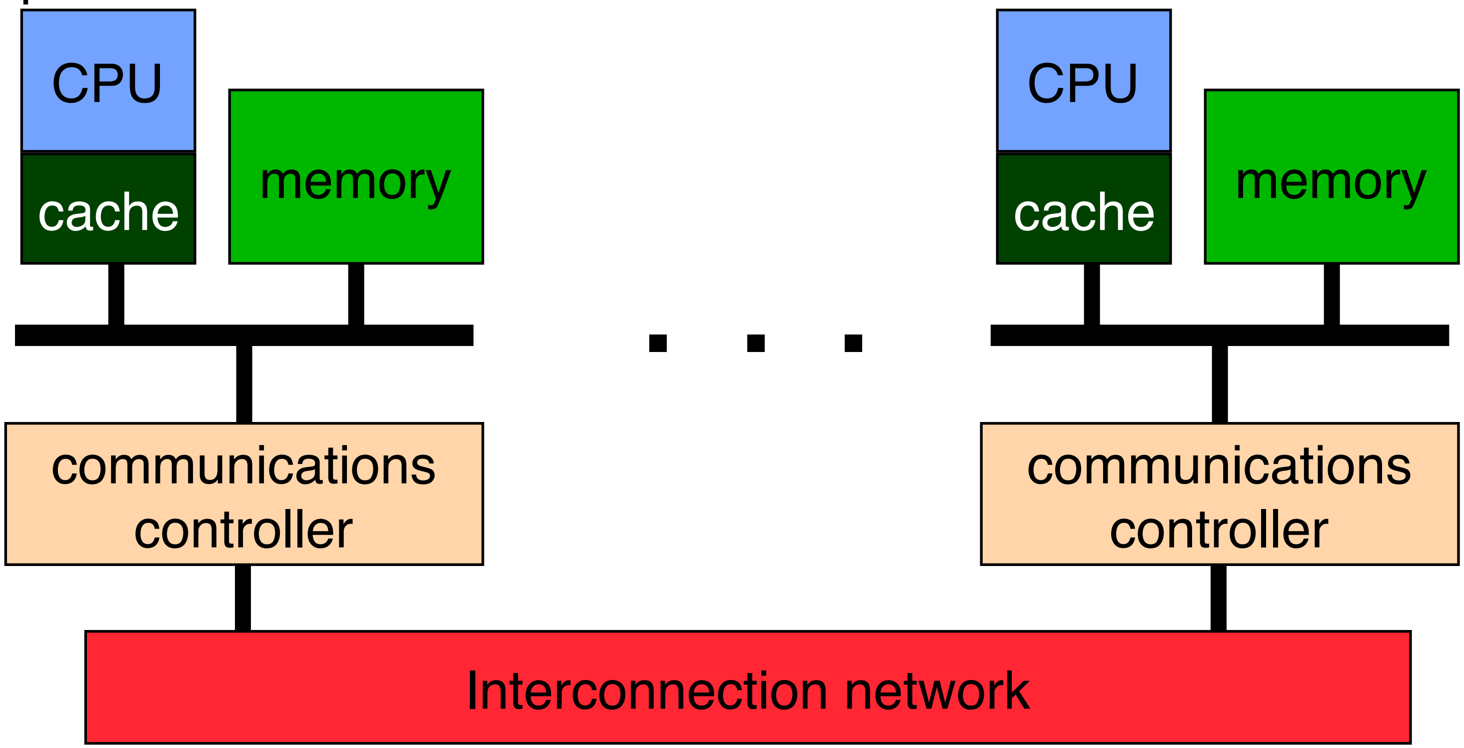
```
{ shared int i; L
…
Lock (L)
i = i + 1;
Unlock (L)
…
}
```

Processor 2

```
{ shared int i, L
…
Lock (L)
i = i + 1;
Unlock (L)
…
}
```

Distributed Memory Machines

Examples: IBM



programming model: no shared variables; message passing

Processor 1

```
{int i;
…
Send (2, &i, sizeof(int))
…
}
```

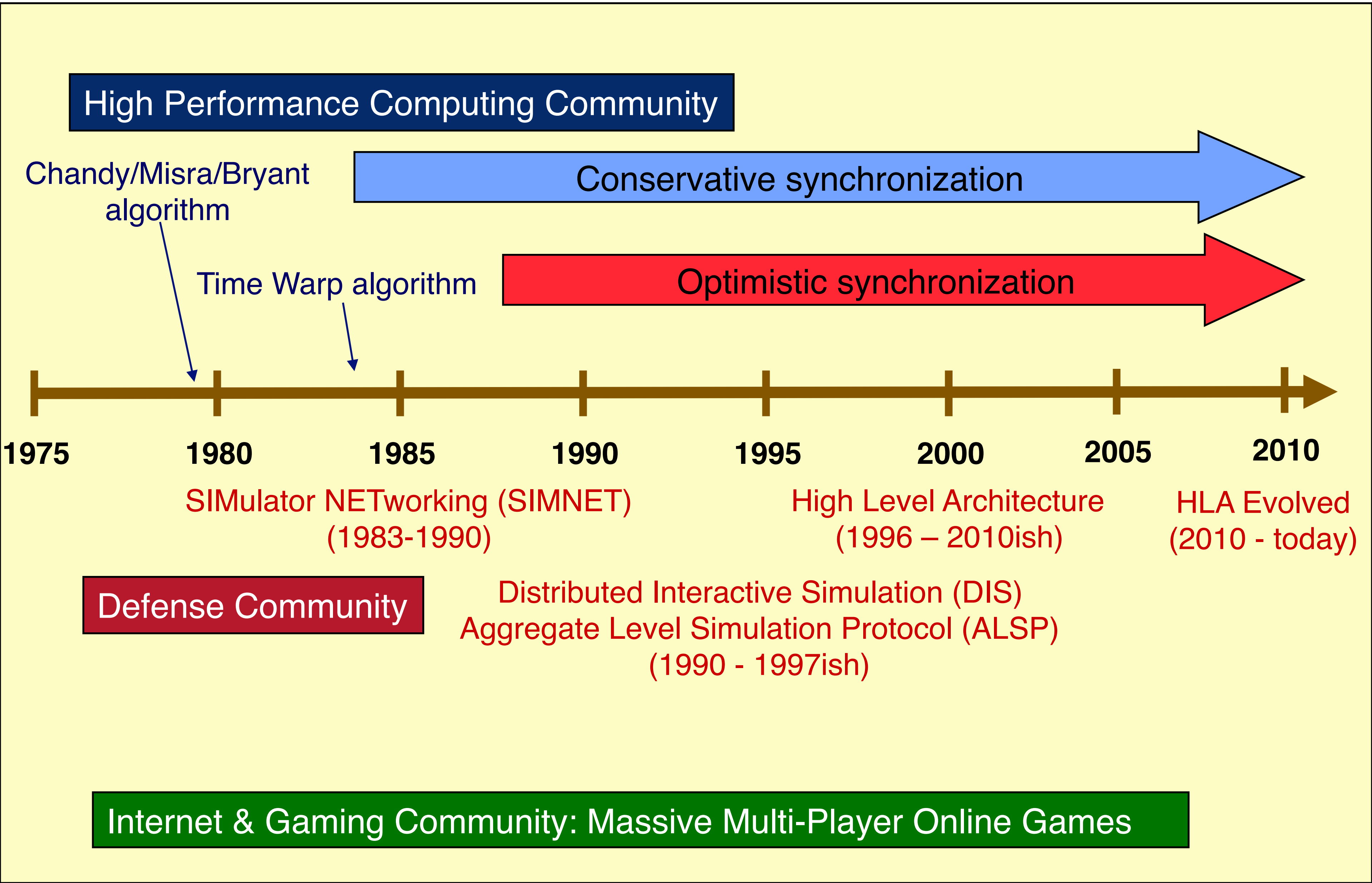
Processor 2

```
{int j;
…
Receive (&j, sizeof(int));
…
}
```

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!

Historical Perspective



Summary

- 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
- 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