Simulation & Modeling

Event-Oriented Simulations

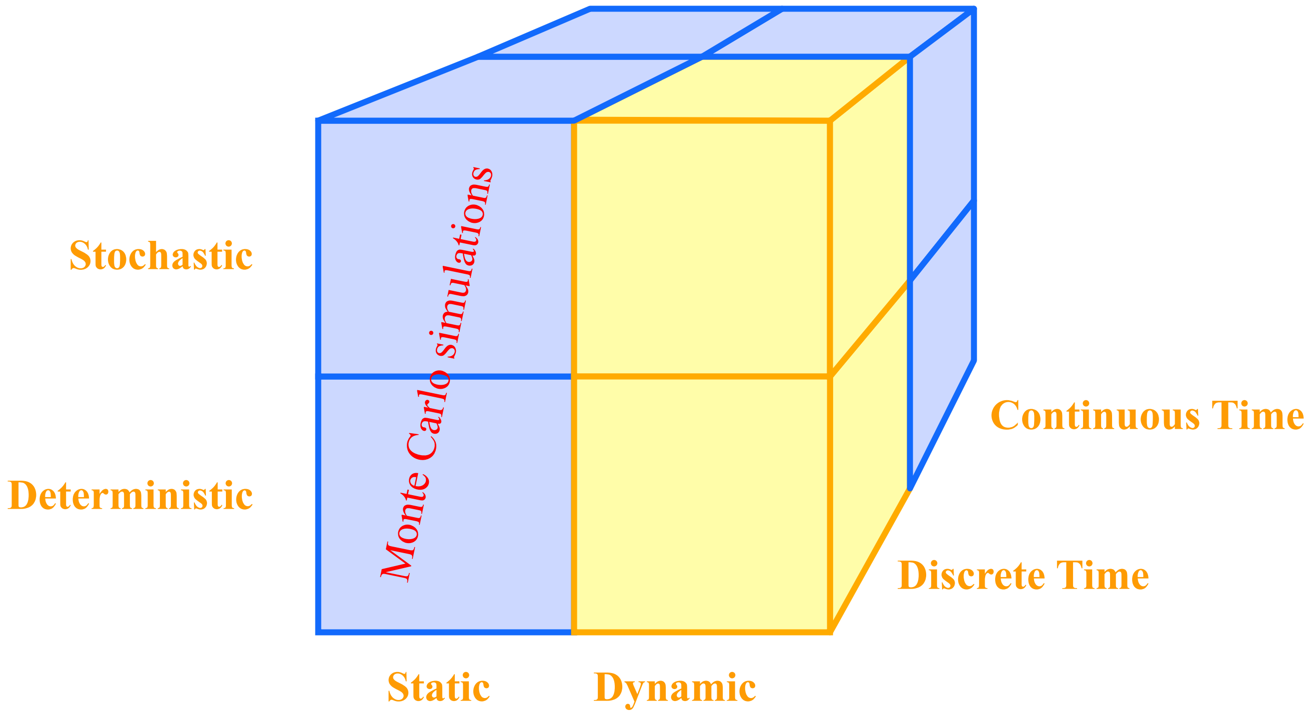
Maria Hybinette, UGA

Outline

- Simulation modeling characteristics
- Concept of Time
- A DES Simulation (Computation)
- DES System = model + simulation execution
- Data Structures
- Program (Code)

Basic concepts

- Simulation modeling characteristics
- The Concept of Time
- Static or dynamic models
- Stochastic, deterministic or chaotic models
- Discrete or continuous change/models
- Aggregates or Individuals


Stochastic
Deterministic
Monte Carlo simulations
Continuous Time
Discrete Time
Static
Dynamic

Monte Carlo Methods

- Generate Inputs randomly from a probability distribution
- Perform a deterministic computation on the input (repeat this step).
- Aggregate result (run multiple times with a different sample on the input) to 'approximate' the 'real' value.

http://en.wikipedia.org/wiki/Monte_Carlo_method

Static or dynamic models

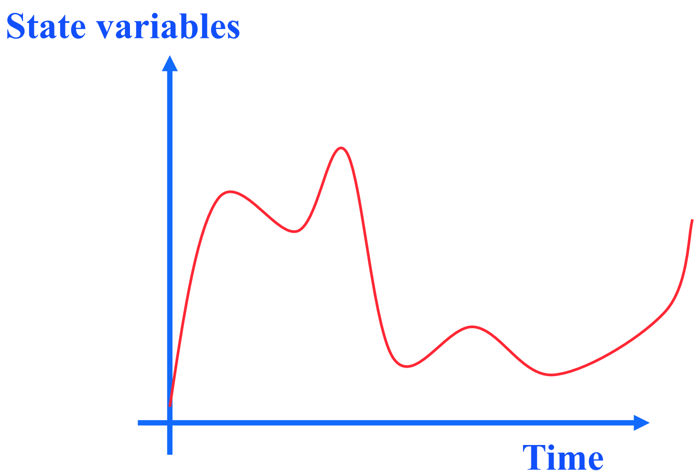
- **Dynamic**:
  - » **State variables change over time**
  - » **System Dynamics, Discrete Event, Agent-Based**
- **Static**:
  - » **Snapshot(s) at a single point in time**
  - » **Monte Carlo simulation (large number of input samples, compute & aggregate results, time doesn't change), optimization models**

Deterministic, Stochastic or Chaotic

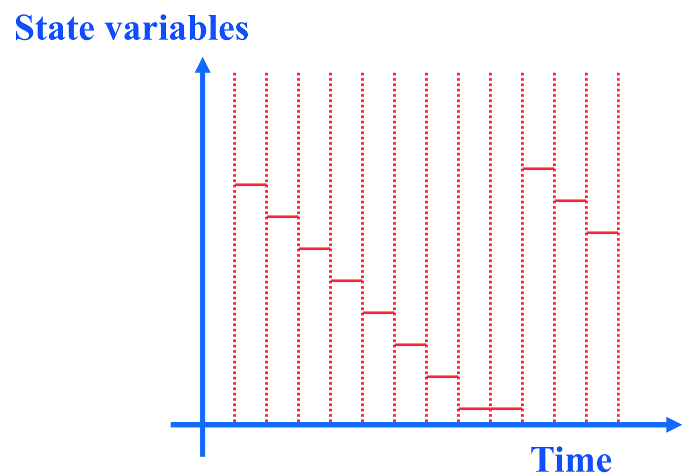
- **Deterministic**:
  - » Predictive behavior. The system is perfectly understood, then it is possible to predict precisely what will happen.
  - » Repeatable
- **Stochastic**:
  - » behavior cannot be entirely predicted.
- **Chaotic**:
  - » deterministic model with a behavior that cannot be entirely predicted. Depends so sensitively on the system's initial conditions so that in effect it cannot be predicted.

Discrete or Continuous models

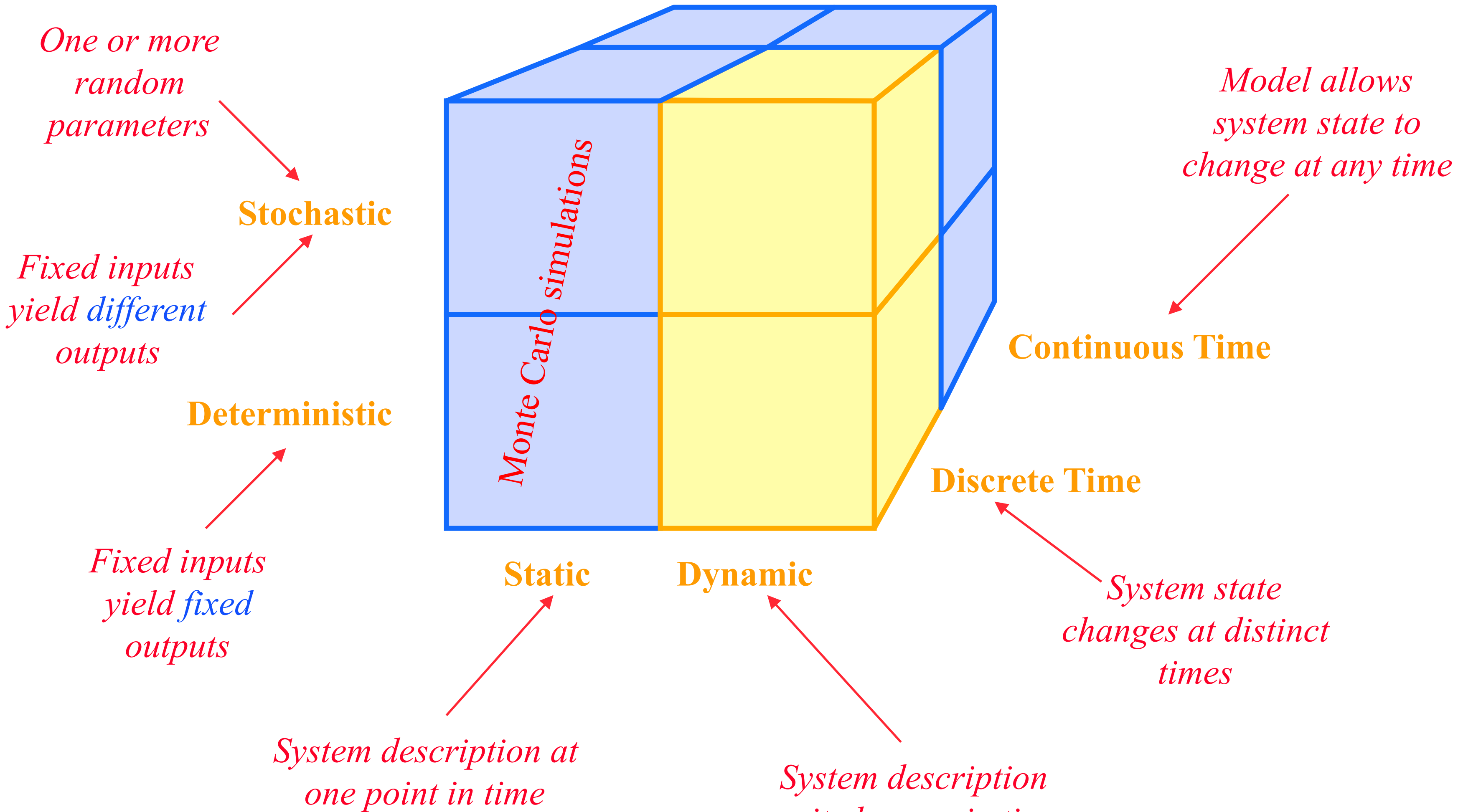
- **Discrete model**:
  - » state variables change only at a countable number of points in time.
  - » These points in time are the ones at which the event occurs/change in state.
- **Continuous model**:
  - » the state variables change in a continuous way, and not abruptly from one state to another.
  - » infinite number of states.



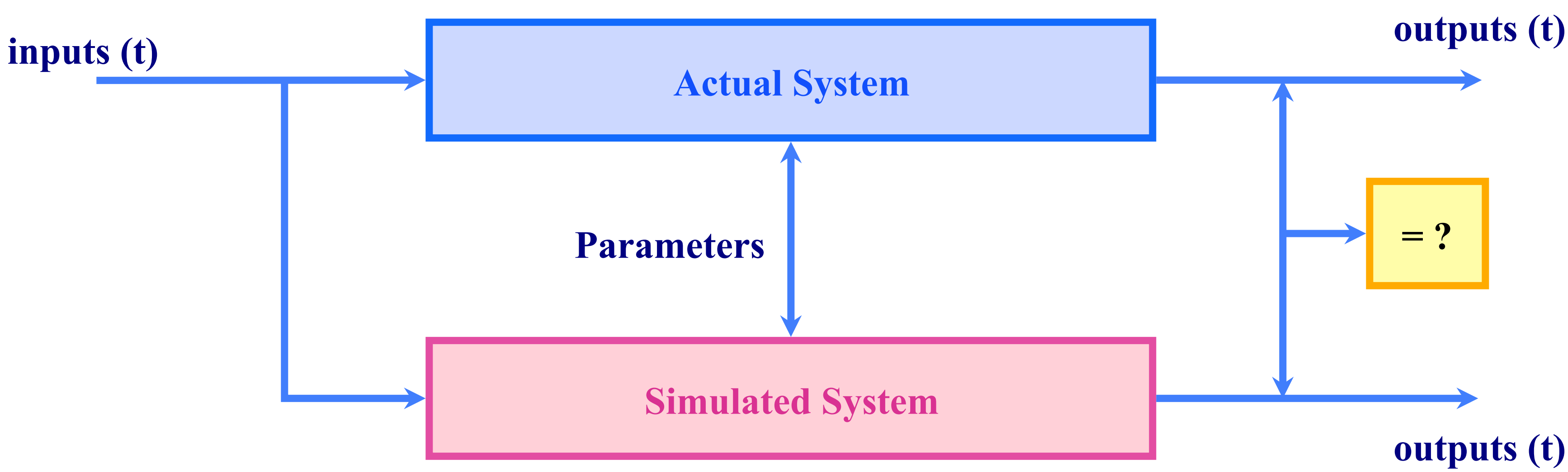
Continuous: State variables change continuously as a function of time
State variables = $f(t)$



Discrete: State variables change at discrete times

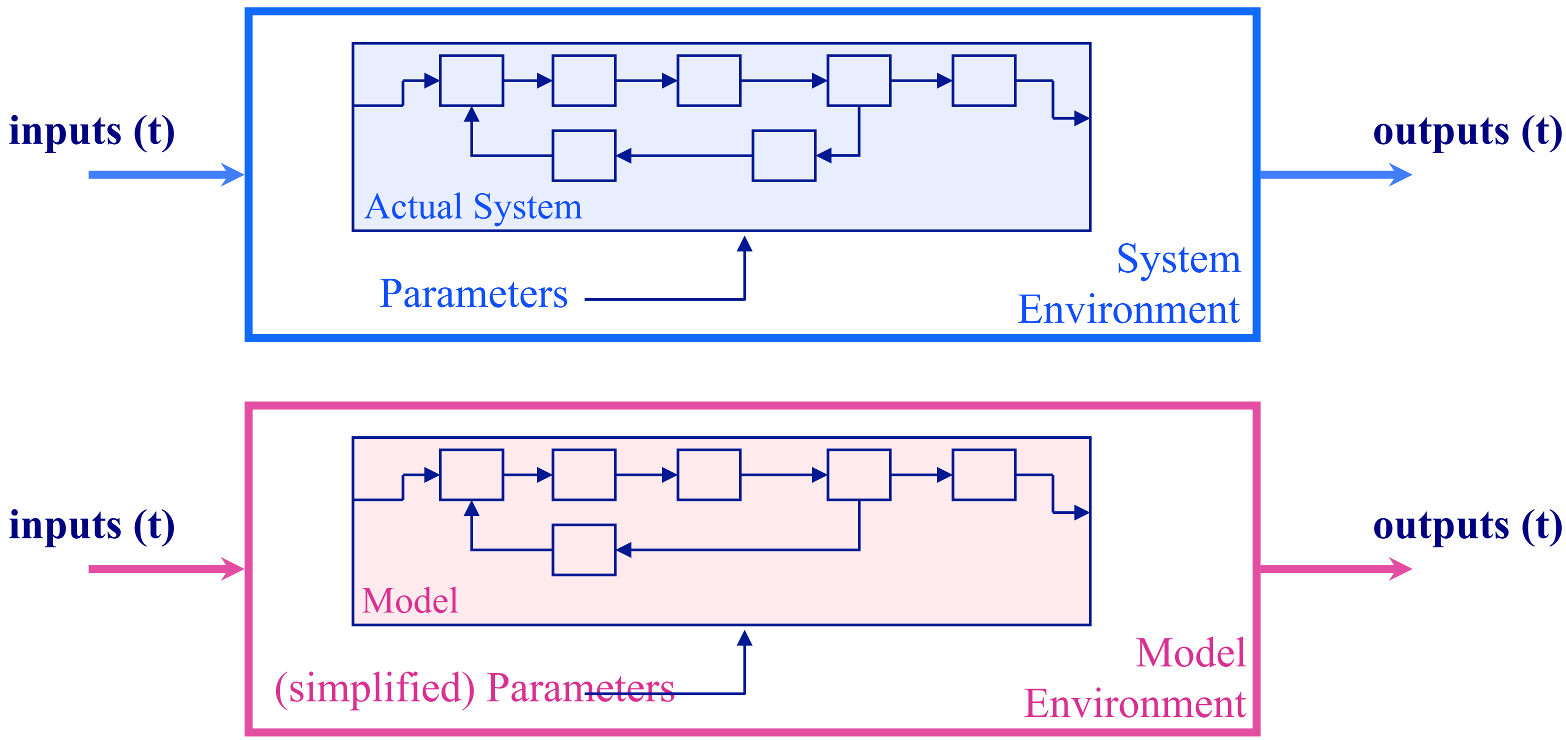

One or more random parameters
Stochastic
Fixed inputs yield different outputs
Deterministic
Fixed inputs yield fixed outputs
Monte Carlo simulations
Static
Dynamic
System description at one point in time
System description as it changes in time
Model allows system state to change at any time
Continuous Time
Discrete Time
System state changes at distinct times

Simulation



- Simulated system imitates operations of actual system over time
- Artificial history of system can be generated and observed
- Internal (perhaps unobservable) behavior of system can be studied
- Time scale can be altered as needed
- Conclusion about actual system characteristics can be inferred

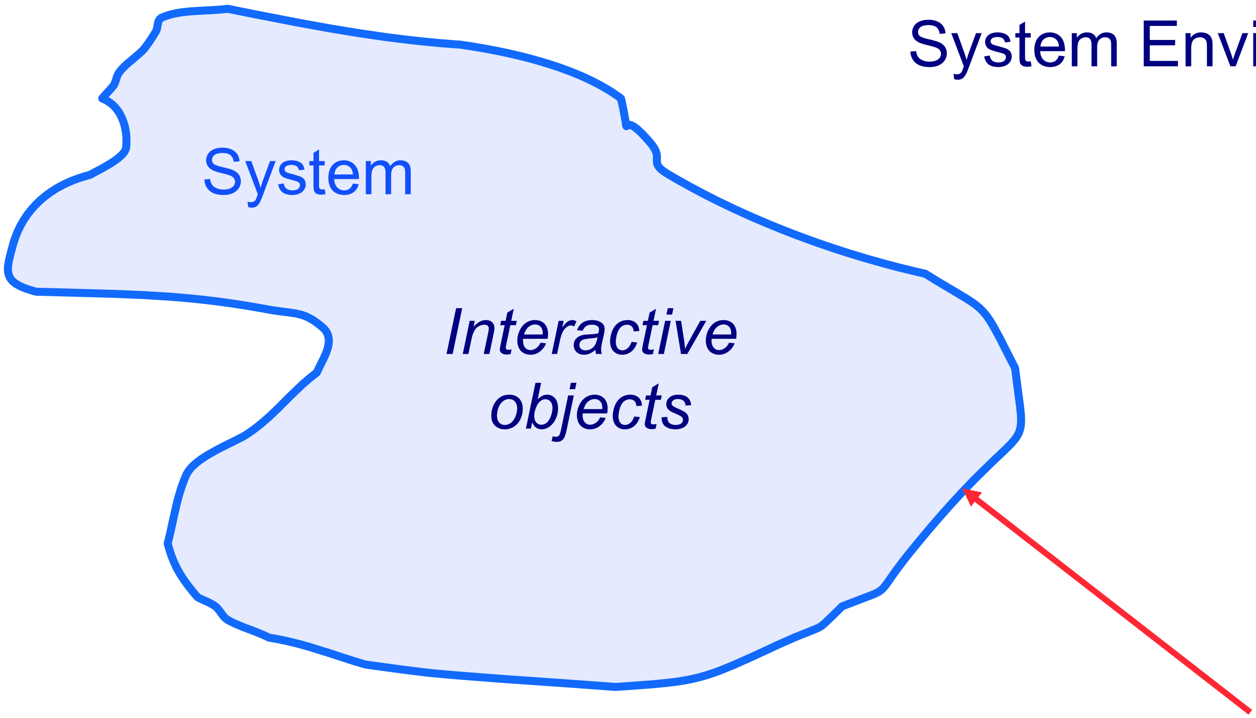
What is a simulation model?



- **An abstraction of a real system**
- **Simplified assumptions are used to capture (only) important behaviors**

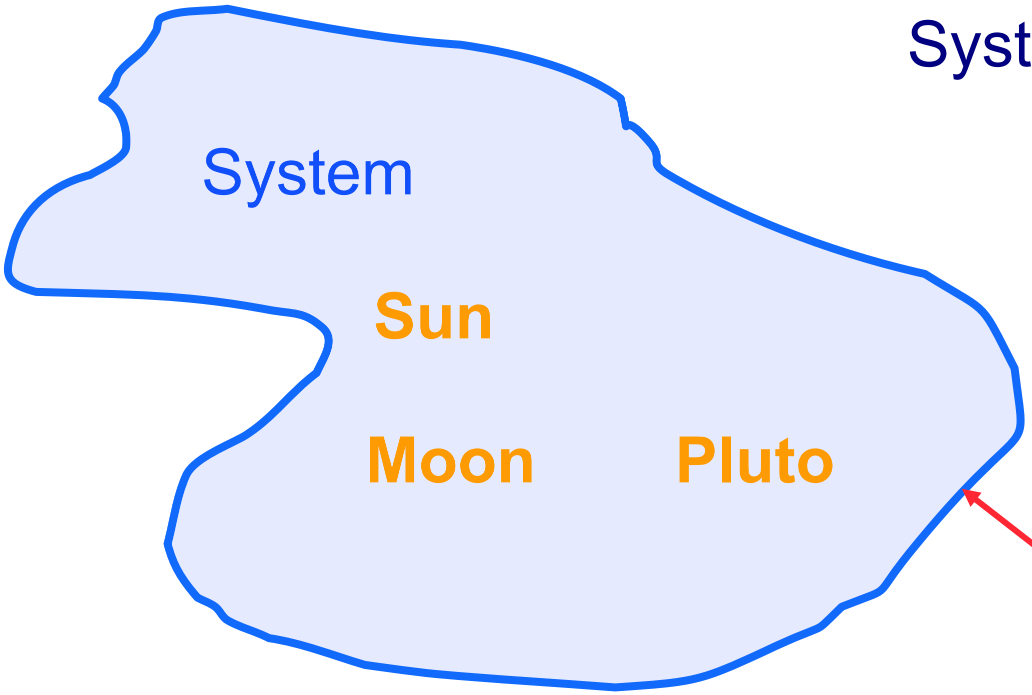
System' s Modeling

System Environment



Placing the system boundary
is the first difficult task in modeling

System's Modeling



System Environment

Earth?

Asteroids?

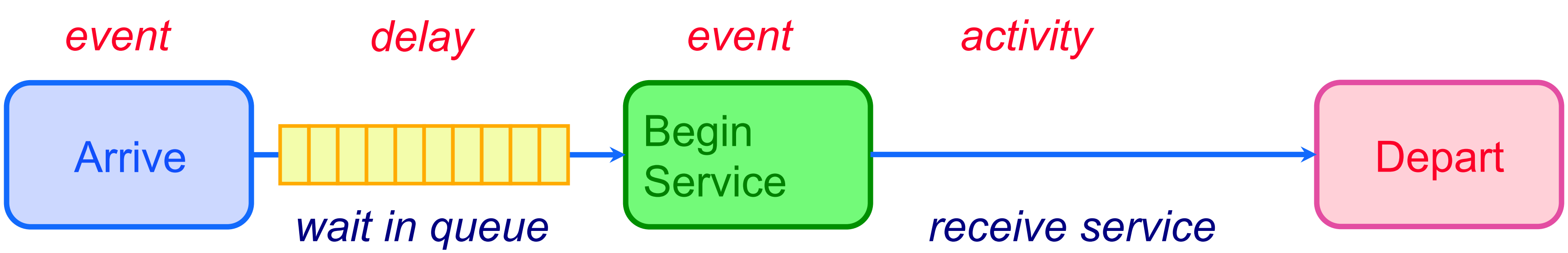
Placing the system boundary
is the first difficult task in modeling

Entities, Attributes and Activities...

- An entity is an object of interest in the system
  - » Example: Customer Manager Cashier
- An attribute is a (relevant) property of an entity
  - » Example: Account balance Gender Skills
- Attributes are state variables

Activities & Delays

- **An activity… … is a duration of a known (expected) length**
  - » **Example: drink coffee, serve customers**
  - » **Activities form part of the model specification**
  - » **Inter-arrival time, service time**
  - » **Deterministic or stochastic (probabilistic)**
- **A delay… … is a duration of unknown length**
  - » **waiting time in queue**
- **Delays form part of the simulation results**
  - » **Example: waiting time in queue**
  - » **Delays form part of the simulation** results



State and State Variables

- The (system) state
  - » complete
  - » minimal
  - » contains sufficient information to describe the system at any point in time.
- A state variable
  - » Describes a portion of the state.
  - » Length of a queue, activity of a manager (sleeping, drinking coffee)

Events

- Event:
  - » Occurrence
  - » Instantaneous
  - » May change the state
- Example single server queue:
  - » Arrival -- while the server is busy, so queue length is incremented by 1;
  - » Departure -- the completion of service

Conditional and Primary Events

- Primary Events
  - » Scheduled at a certain time
  - » Arrival of customers
- Conditional Events
  - » triggered by a certain condition becoming TRUE -- a completion of a delay
  - » Customers moving from queue to service

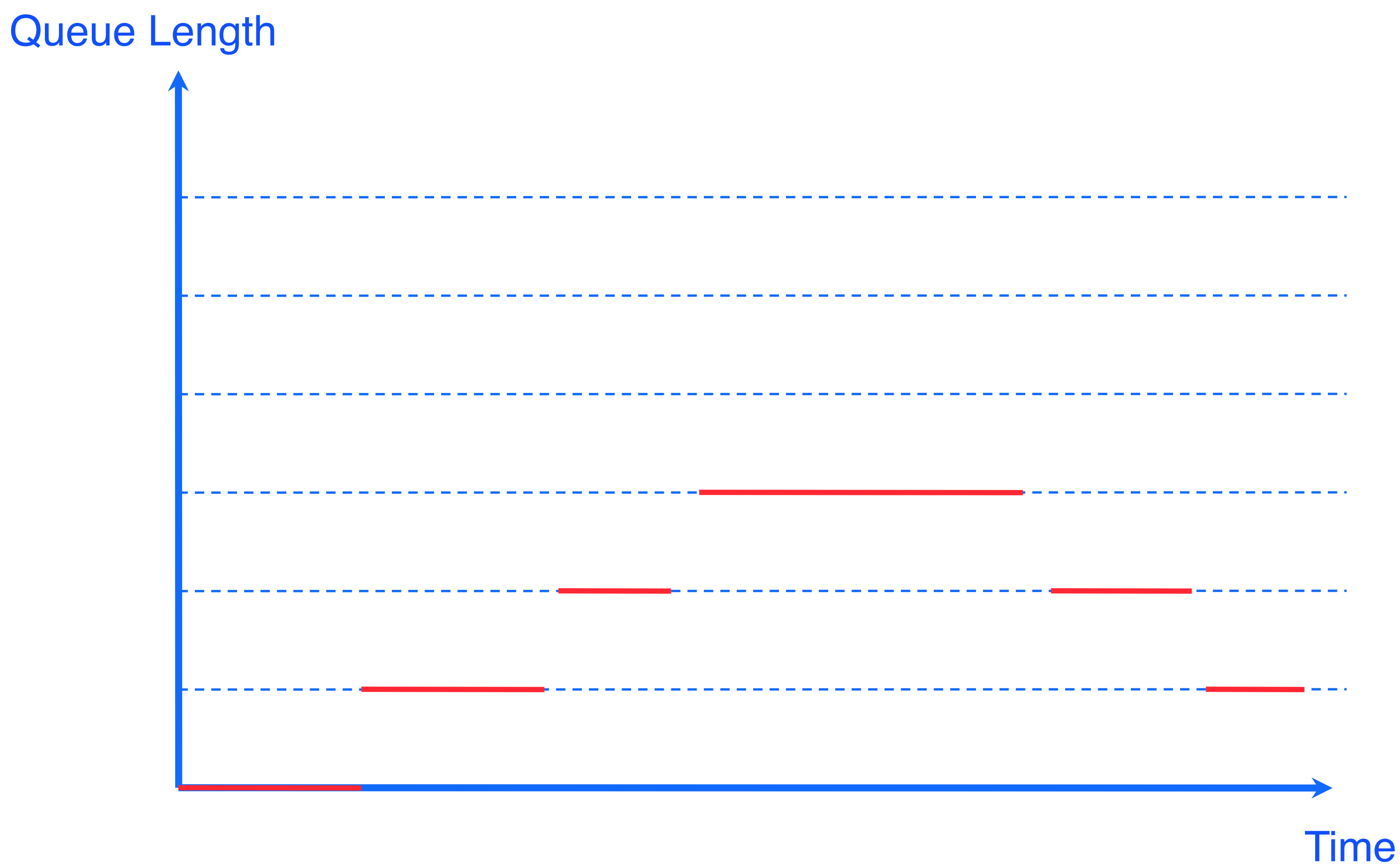
How to create a DES?

- DES Modeling raises the following questions?
  - How does each event affect system state and attributes?
  - How are activities defined?
    - What events mark beginning and the end?
    - What condition (if any) most hold?
  - How are delays defined?
  - How is the simulation initialized?

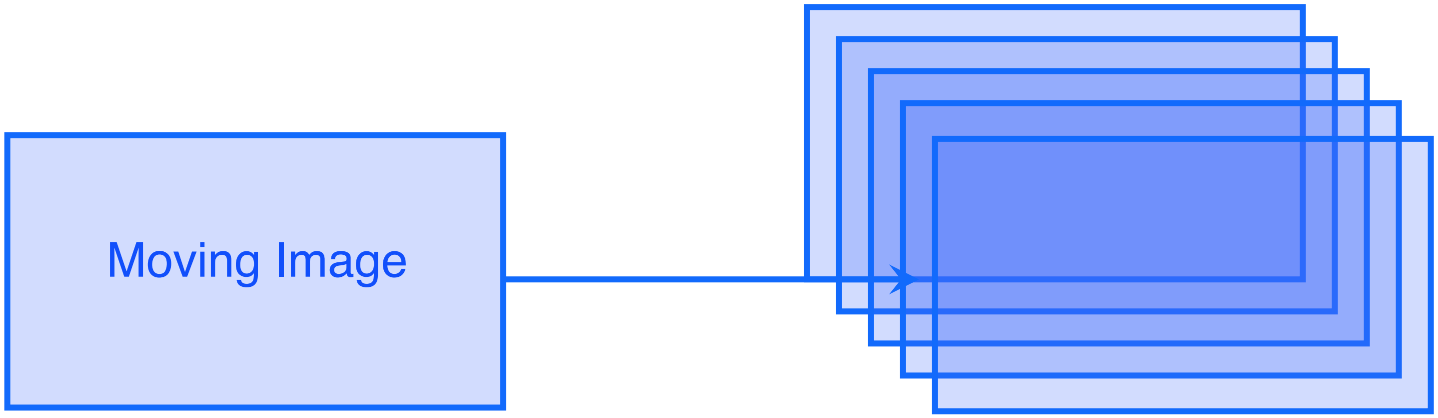
A Simulation classic

- Single-server Queue at a bank
- One possible problem formulation:
  - "customer have to wait too long in my bank"
- Objective:
  - Determine the effect of an additional cashier
- Data needed:
  - inter-arrival time of customers
  - Service times

Simulation Results

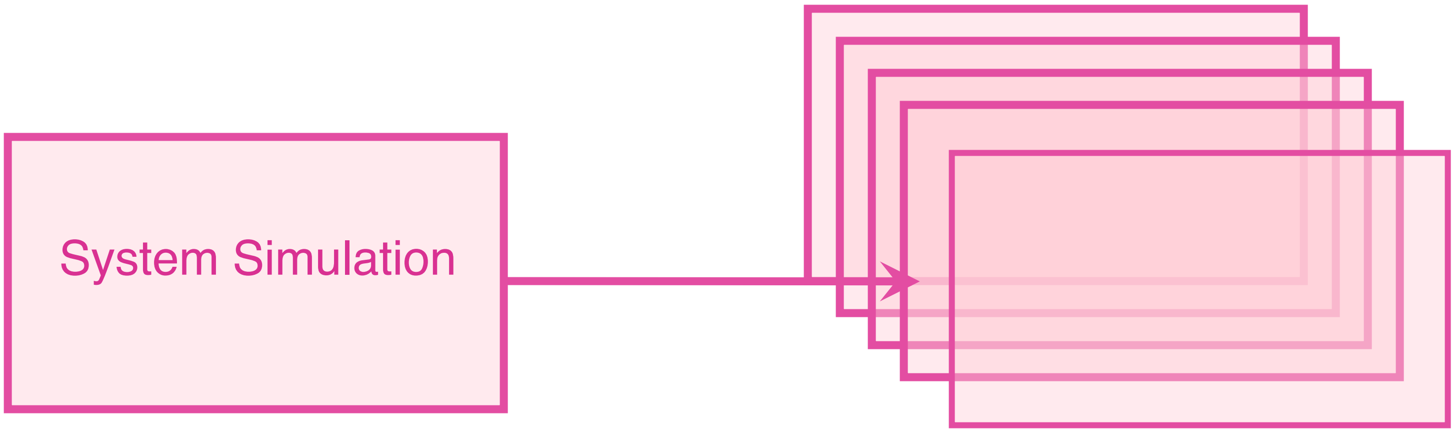


Movie



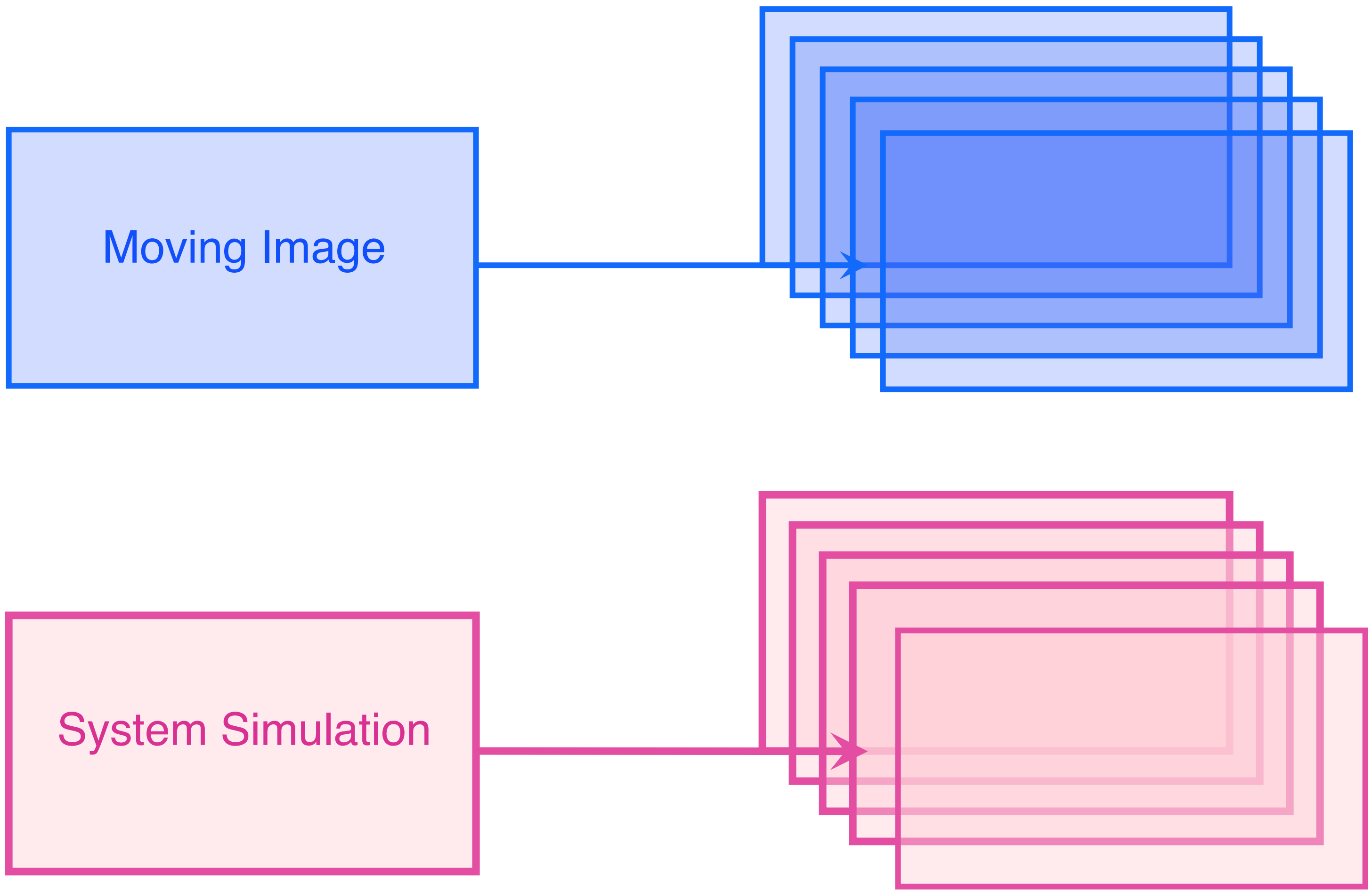
- **Series of still images, sufficient to convey recognizable motion**

System Snapshots



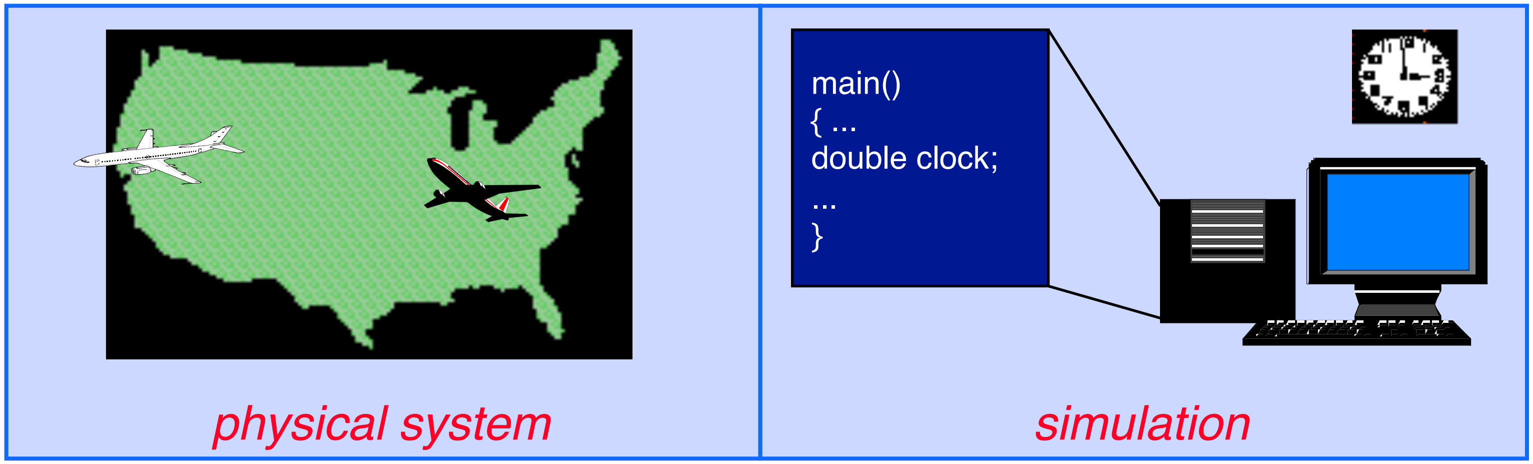
- Series of system snapshot
  - » system state
  - » activities in progress
  - » end time

System Snapshots



Time

- ***Physical system:*** actual or imagined system being modeled
- ***Simulation***: a system that emulates the behavior of a physical system



- **physical time**: time in the physical system
  - » Noon, December 31, 1999 to noon January 1, 2000
- **simulation time**: representation of physical time within the simulation
  - » floating point values in interval [0.0, 24.0]
- **wallclock time**: time during the execution of the simulation, usually output from a hardware clock
  - » 9:00 to 9:15 AM on September 10, 1999

Simulation Time

Simulation time *is defined as a totally ordered set of values where each value represents an instant of time in the physical system being modeled.*

- **For any two values of simulation time T_1 representing instant P_1, and T_2 representing P_2:**
- **Correct ordering of time instants**
  - » **If $T_1 < T_2$, then P_1 occurs before P_2**
  - » **9.0 represents 9 PM, 10.5 represents 10:30 PM**
- **Correct representation of time durations**
  - » **$T_2 - T_1 = k (P_2 - P_1)$ for some constant k**
  - » **1.0 in simulation time represents 1 hour of physical time**

Modes of Execution

- **As-fast-as-possible execution (unpaced):** no fixed relationship necessarily exists between advances in simulation time and advances in wallclock time
- **Real-time execution (paced):** each advance in simulation time is paced to occur in synchrony with an equivalent advance in wallclock time
- **Scaled real-time execution (paced):** each advance in simulation time is paced to occur in synchrony with S * an equivalent advance in wallclock time (e.g., 2 x wallclock time)

Converting from wallclock to Simulation Time:

Simulation Time = W2S(W) = T_0 + S * (W - W_0)

W = wallclock time; S = scale factor

W_0 (T_0) = wallclock (simulation) time at start of simulation

(assume simulation and wallclock time use same time units)

Discrete Event Simulation

Discrete event simulation: *computer model for a system where changes in the state of the system occur at discrete points in simulation time.*

Fundamental concepts:

- **system state (state variables)**
- **state transitions (events)**

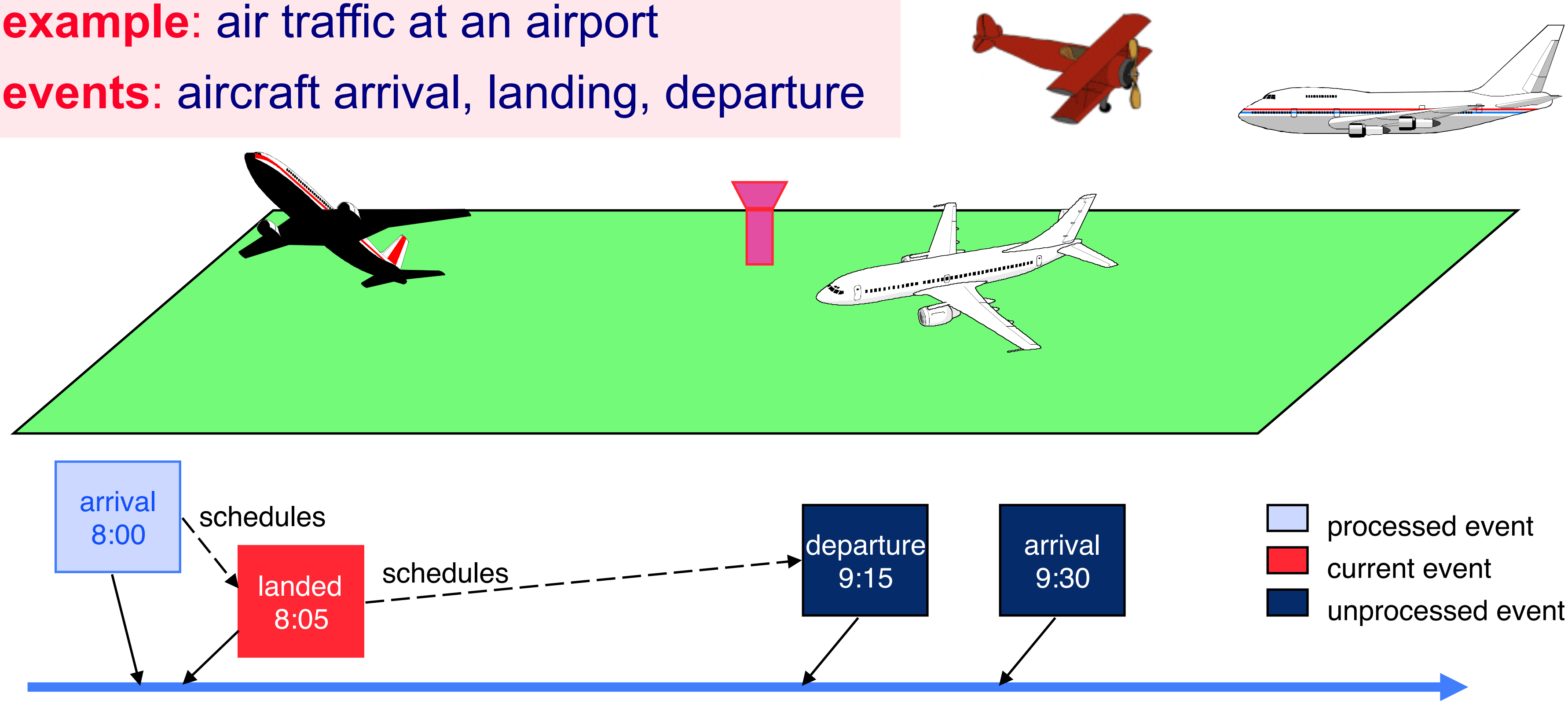
A DES computation: can be viewed as a *sequence of event computations,* with each event computation is assigned a (simulation time) time stamp. Each event computation can

- **modify state variables**
- **schedule new events**

Discrete Event Simulation Computation

example: air traffic at an airport

events: aircraft arrival, landing, departure



- **Unprocessed events are stored in a pending event list**
- **Events are processed in time stamp order**

Discrete Event Simulation System

model of the physical system

Simulation Application
- state variables
- code modeling system behavior
- I/O and user interface software

calls to schedule events ↓

calls to event handlers ↑

Independent of the simulation application

Simulation Executive
- event list management
- managing advances in simulation time

Event-Oriented World View

Event handler procedures

state variables

```
Integer: InTheAir;
Integer: OnTheGround;
Boolean: RunwayFree;
```

```
Arrival
  Event
{
    …
}
```

```
Landed
  Event
{
    …
}
```

```
Departure
  Event
{
    …
}
```

Simulation application

Simulation executive

Now = 8:45

Pending Event List (PEL)

9:00

9:16

10:10

Event processing loop

```
while(simulation not finished)
  E = smallest time stamp event in PEL
  Remove E from PEL
  Now := time stamp of E
  call event handler procedure
```

Example: Air traffic at an Airport

Model aircraft arrivals and departures, arrival queuing

Single runway for incoming aircraft, ignore departure queuing

- `R` = time runway is used for each landing aircraft (constant)
- `G` = time required on the ground before departing (constant)

State:

- `Now:` current simulation time
- `InTheAir`: number of aircraft landing or waiting to land
- `OnTheGround`: number of landed aircraft
- `RunwayFree`: Boolean, true if runway available

Events:

- `Arrival`: denotes aircraft arriving in air space of airport
- `Landed`: denotes aircraft landing
- `Departure`: denotes aircraft leaving

Arrival Events

New aircraft arrives at airport. If the runway is free, it will begin to land. Otherwise, the aircraft must circle, and wait to land.

`R` = time runway is used for each landing aircraft

`G` = time required on the ground before departing

`Now:` current simulation time

`InTheAir`: number of aircraft landing or waiting to land

`OnTheGround`: number of landed aircraft

`RunwayFree`: Boolean, true if runway available

```
Arrival Event:
    InTheAir := InTheAir+1;
    if( RunwayFree )
      RunwayFree:=FALSE;
      Schedule Landed event @ Now + R;
```

Landed Event

An aircraft has completed its landing.

R = time runway is used for each landing aircraft

G = time required on the ground before departing

Now: current simulation time

InTheAir: number of aircraft landing or waiting to land

OnTheGround: number of landed aircraft

RunwayFree: Boolean, true if runway available

```
Landed Event:
    InTheAir := InTheAir-1;
    OnTheGround := OnTheGround + 1;
    Schedule Departure event @ Now + G;
    if( InTheAir > 0 )
      Schedule Landed event @ Now + R;
    else
      RunwayFree := True;
```

Departure Event

An aircraft on the ground departs for a new destination.

`R` = time runway is used for each landing aircraft

`G` = time required on the ground before departing

`Now:` current simulation time

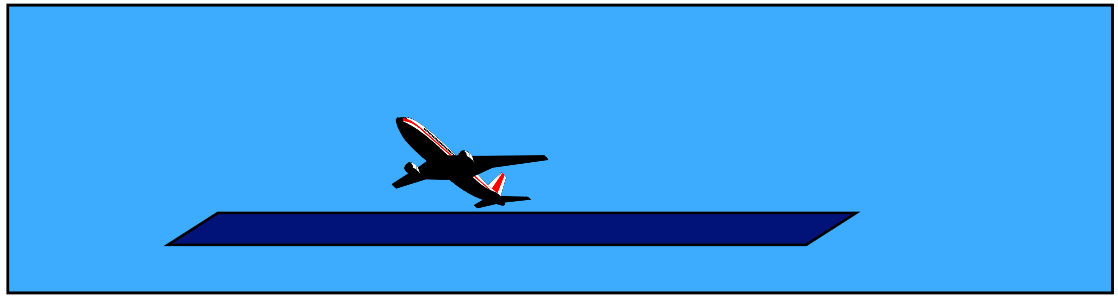
`InTheAir`: number of aircraft landing or waiting to land

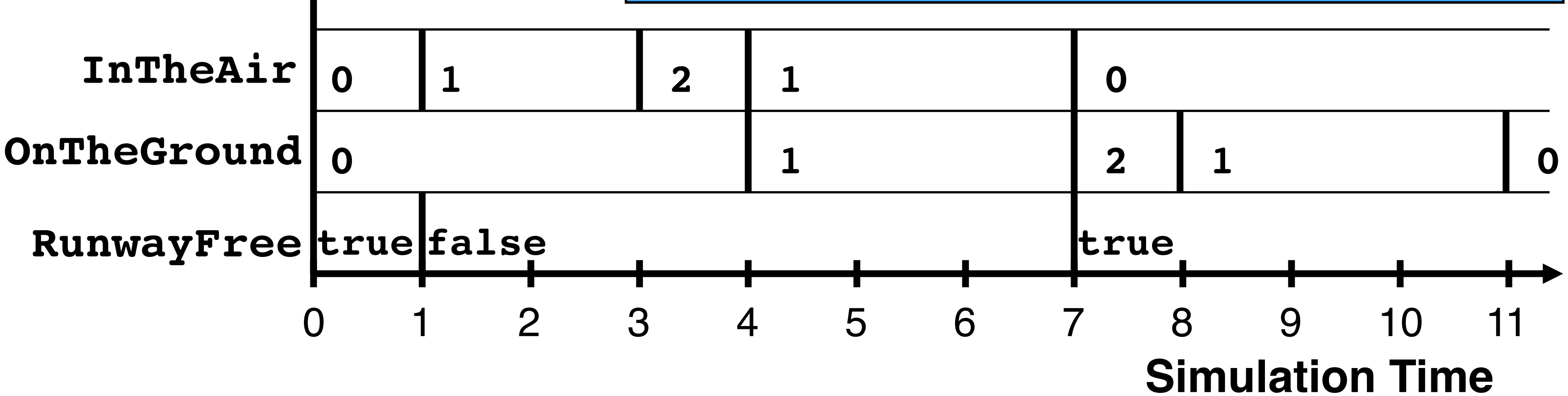
`OnTheGround`: number of landed aircraft

`RunwayFree`: Boolean, true if runway available

```
Departure Event:
    OnTheGround := OnTheGround - 1;
```

Execution Example





Processing:

Time	Event
1	Arrival F1
3	Arrival F2

Now=0

Arrival F1

Time	Event
3	Arrival F2
4	Land F1

Now=1

Arrival F2

Time	Event
4	Land F1
7	Land F2

Now=3

Land F1

Time	Event
7	Land F2
8	Depart F1

Now=4

Land F2

Time	Event
8	Depart F1
11	Depart F2

Now=7

Depart F1

Time	Event
11	Depart F2

Now=8

Depart F2

Time	Event

Now=11

Summary

- Time
  - Important to distinguish among simulation time, wallclock time, and time in the physical system
  - Paced execution (e.g., immersive virtual environments) vs. unpaced execution (e.g., simulations to analyze systems)
- DES computation: sequence of event computations
  - Modify state variables
  - Schedule new events
- DES System = model + simulation executive
- Data structures
  - Pending event list to hold unprocessed events
  - State variables
  - Simulation time clock variable
- Program (Code)
  - Main event processing loop
  - Event procedures
  - Events processed in time stamp order