CSCI 8220 Simulation & Modeling

Process Oriented Simulation

Review from Last Time

- Motivations to do simulations
- Modeling characteristics
- Time and event driven simulations

Today

- Event-Oriented Simulation (review)
- Process-oriented simulation
  - » Fundamental concepts: Processes, resources
  - » Simulation primitives
  - » Example
  - » Implementation

Event-Oriented World View

Simulation application

state variables

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

Event handler procedures

```
Arrival Event      Landed Event      Departure Event
{                  {                 {
  …                  …                 …
}                  }                 }
```

Simulation executive

Now = 8:45

Pending Event List (PEL): 9:00, 9:16, 10:10

Event processing loop

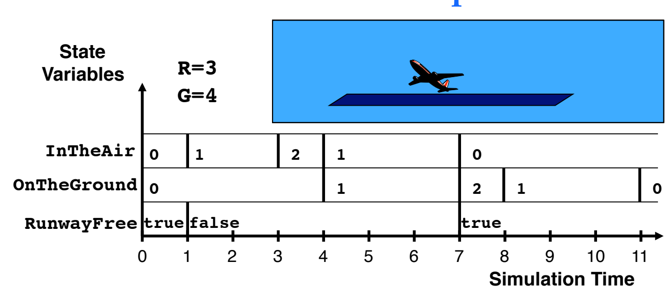
```
while(simulation not finished)
  E = smallest time stamp event in PEL
  Remove E from PEL
  Now := time stamp of E
  call event handler procedure
```


Example: Event-Oriented Air traffic Simulation

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


Execution Example



Processing:

Now	Processing	Time	Event
Now=0		1 3	Arrival F1 Arrival F2
Now=1	Arrival F1	3 4	Arrival F2 Land F1
Now=3	Arrival F2	4	Land F1
Now=4	Land F1	7 8	Land F2 Depart F1
Now=7	Land F2	8 11	Depart F1 Depart F2
Now=8	Depart F1	11	Depart F2
Now=11	Depart F2		

Event-Oriented World View

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

Event handler procedures

```
Arrival      Landed      Departure
 Event        Event        Event
{            {            {
   …            …            …
}            }            }
```

Simulation application

- Event-oriented simulation programs may be difficult to understand and modify:
  - Program organized around state transitions
  - Behavior of an aircraft distributed across multiple event handlers
  - Flow of control among event handlers not obvious
  - Suppose you want to model: Different aircrafts, airlines, pilots – imagine events for each segment (volume) of airspace

Process Oriented

- A simulation process models a specific entity with a well defined behavior.
  - It describes the action performed of the process through out its lifetime.
    - Models a specific entity with well defined behavior and it is encapsulated within the process.
    - Example: an aircraft
- Event oriented view: lifetime of an event is a SINGLE instant in time.
- Process oriented view: lifetime is a time period of the 'process' or 'thread'

Event versus Process Oriented Views

Event Oriented View

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

Arrival      Landed      Departure
 Event        Event        Event
{            {            {
   …            …            …
}            }            }
```

Focus of model is on EVENTS and how they affect the state of the simulation.

Process Oriented View

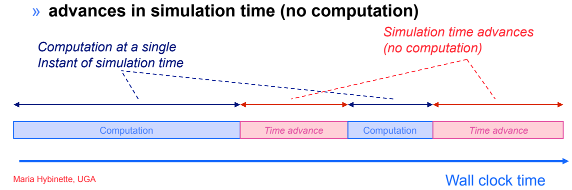
```
state variables
Integer: InTheAir;
Integer: OnTheGround;
Boolean: RunwayFree;

Aircraft1    Aircraft2    AircraftN
{            {            {
Arrive       Arrive       Arrive
Land         Land         Land
Depart       Depart       Depart
}            }            }
```

Entities modeled by processes.

Process Oriented Execution Model

- Focus simulation program around behavior of entities
  - Aircraft: arrives, waits for runway, lands, departs
- Process-oriented simulation
  - Process: *Thread of execution* describing entity behavior over time
  - Resources: Shared resource used by entities (e.g., the runway)
- Execution: alternate between
  - simulation computations at a single instant of simulation time, and
  - advances in simulation time (no computation)



Simulation Primitives

*Primitives needed to **advance simulation time***

- `AdvanceTime(T)` : advance *T* units of simulation time
  - Also called "hold"
  - Example: `AdvanceTime(R)` to model using runway `R` units of simulation time
- `WaitUntil(p)` : simulation time advances until predicate *p* becomes true
  - Predicate based on simulation variables that can be modified by other simulation processes
  - Example: `WaitUntil(RunwayFree)` to wait until runway becomes available for landing
- Other combinations
  - `WaitUntil(p,T)` : Wait up to `T` units of simulation time for predicate `p` to become true
  - Not used in the air traffic example

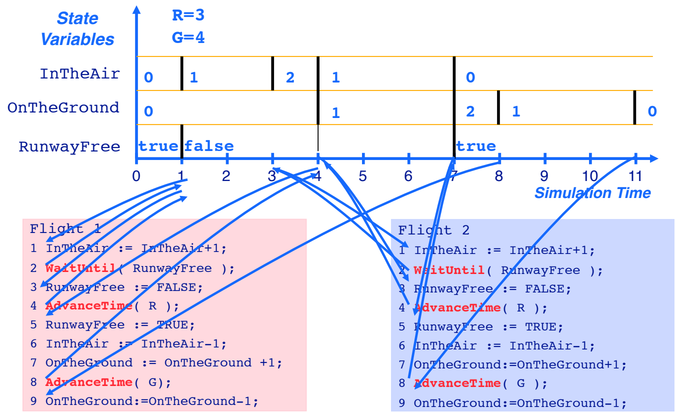
Process Model Example: Aircraft

A new aircraft process is created with each Arrival event

```
/* simulate aircraft arrival, circling, and landing */
Integer: InTheAir;
Integer: OnTheGround;
Boolean: RunwayFree;

1  InTheAir := InTheAir + 1;
2  WaitUntil( RunwayFree );        /* circle */
3  RunwayFree := FALSE;            /* land */
4  AdvanceTime( R );
5  RunwayFree := TRUE;
   /* simulate aircraft on the ground */
6  InTheAir := InTheAir - 1;
7  OnTheGround := OnTheGround + 1;
8  AdvanceTime( G );
   /* simulate aircraft departure */
9  OnTheGround := OnTheGround - 1;
```

Execution Example



Implementation

Process-oriented simulations are built over event oriented simulation mechanisms (event list, event processing loop)

- **Lifetime of a simulation process consists of a sequence of event computations.**
- **Event computation: computation occurring at an instant in simulation time**
  - » **Execution of code section ending with calling a primitive to advance simulation time**
- **Computation threads**
  - » **Typically implemented with co-routine (threading) mechanism**
- **Simulation primitives to advance time**
  - » **Schedule events**
  - » **Event handlers resume execution of processes**

Aircraft Process

Identify computation associated with each simulation event

```
/* simulate aircraft arrival, circling, and landing */
Integer: InTheAir;
Integer: OnTheGround;
Boolean: RunwayFree;

1  InTheAir := InTheAir + 1;
2  WaitUntil( RunwayFree );        /* circle */
3  RunwayFree := FALSE;            /* land */
4  AdvanceTime( R );
5  RunwayFree := TRUE;
   /* simulate aircraft on the ground */
6  InTheAir := InTheAir - 1;
7  OnTheGround := OnTheGround + 1;
8  AdvanceTime( G );
   /* simulate aircraft departure */
9  OnTheGround := OnTheGround - 1;
```

Aircraft Arrival (lines 1–2)

Aircraft Landing (lines 3–4)

Aircraft On The Ground (lines 5–8)

Aircraft Departs (line 9)

Implementation: *AdvanceTime(T)*

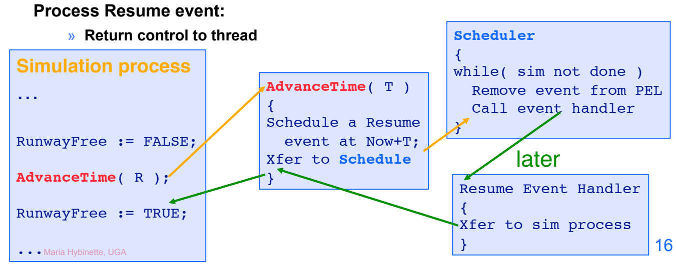
Causes simulation time in the process to advance by T units

Execute `AdvanceTime(T)`:

- » **Schedule Resume event at time `Now+T`**
- » **Suspend execution of thread**
- » **Return execution to event scheduler program**

Process Resume event:

- » **Return control to thread**



Implementation: *WaitUntil*(p)

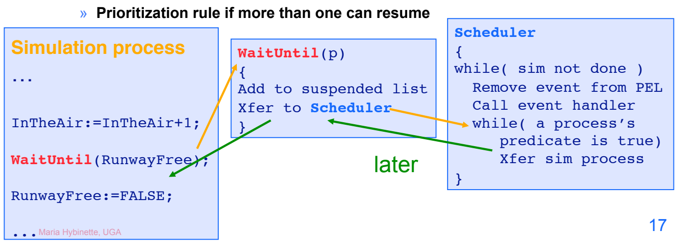
Suspend until predicate p evaluates to true

Execute `WaitUntil( p )`:

- » **Suspend execution of thread, record waiting for p to become true**
- » **Return execution to event scheduler program**

Main scheduler loop

- » **For each suspended process, check if execution can resume**
- » **Prioritization rule if more than one can resume**



Additional Notes

- **Theoretically, both views are equivalent:**
  - » **Process-oriented simulations can be transformed to event-oriented simulations and vice versa**
- **Practically, runtime performance differs:**
  - » **Event-oriented views typically execute faster than process-oriented views**

Summary

- Process-oriented simulation typically simplifies model development and modification
- Requires threading (e.g., co-routine) mechanism
- Additional complexity and computation overhead to suspend and resume simulation processes