Simulation: introduction

Tran, Van Hoai (hoai@hcmut.edu.vn)
Le, Hong Trang (lhtrang@hcmut.edu.vn)

Faculty of Computer Science & Engineering
HCMC University of Technology

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Outline

1. Introduction and classification
   - Types of simulation
2. Discrete event simulation (DES)
   - SimPy
3. Single queue

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What is simulation?

Definition (Wikipedia)

A simulation is an approximate imitation of the operation of a process or system.

- A widely-used performance analysis method used for any stages
  - System is not available: to predict and compare alternatives
  - System is available: to compare under wider variety of workloads

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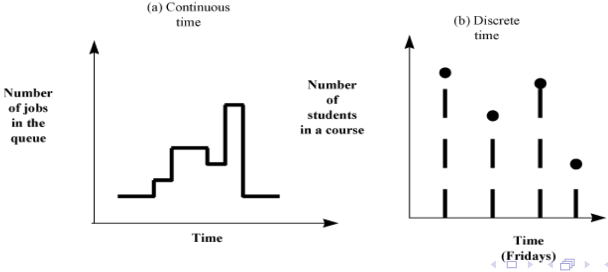
Model developers must be proficient in

- software development
- statistical techniques

Terminology (1)

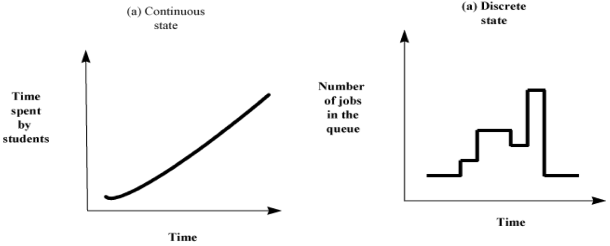
CPU scheduling is used as examples.

- **State variables**: values to define the state of the system
  E.g., length of job queue
- **Event**: something happens to change the system state
  E.g., arrival of a job; beginning of a new execution
- **Continuous-time** and **discrete-time**: whether the system state defined at all times or not.



Terminology (2)

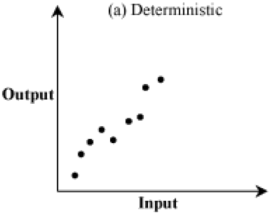
- **Continuous-state** and **discrete-state**: whether the state variables are continuous or discrete.

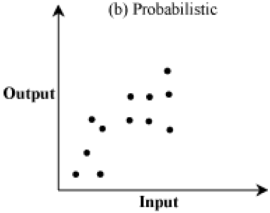


  - Continuous-state model = **Continuous-event model**
  - Discrete-state model = **Discrete-event model**

Terminology (3)

- **Deterministic** and **probabilistic/stochastic** models
  - Deterministic model: output is predicted with certainty
  - Probabilistic model: different output on repetitions for the same set of input parameters



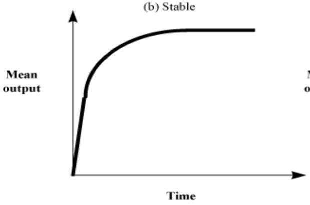


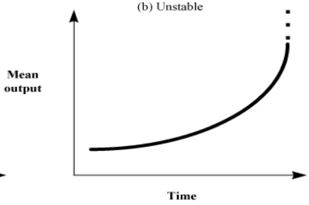
- **Static** and **dynamic** models
  - Static model: time is not variable
  - Dynamic model: system state changes with time

E.g., master-to-energy transformation $E = mc^2$.

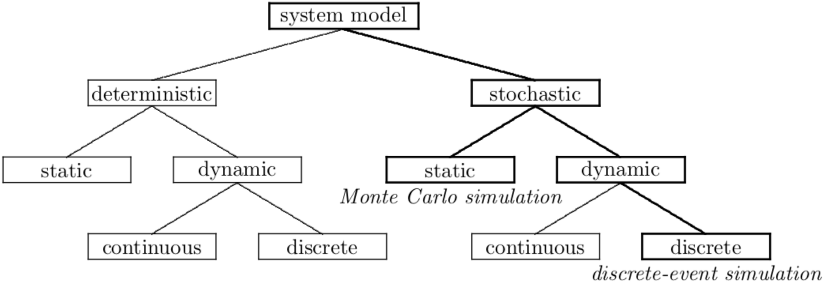
Terminology (4)

- **Open** and **closed** models: *read lecture #5 "queueing networks"*.
- **Stable** and **unstable** models
  - Stable model: dynamic behaviour settles down to a steady state.
  - Unstable model: behaviour is continuously changing.





System model taxanomy (phân loại)



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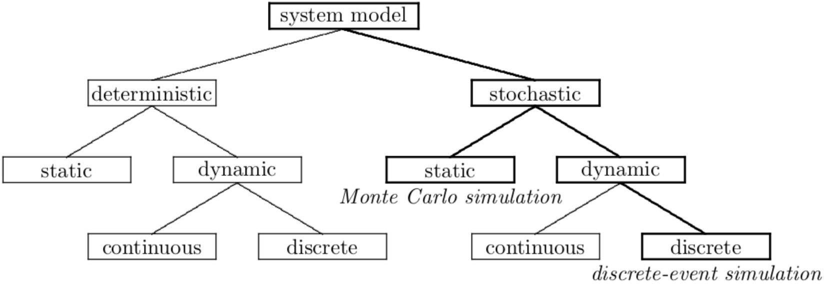

Computer system models

- Continuous time
- Discrete state
- Probabilistic
- Dynamic
- Nonlinear
- Open and closed
- Stable and unstable

Types of simulation

There are different ways to classify simulation types. Below is only one of them.

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   - Used for evaluating nonprobabilistic expressions using probabilistic methods

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3. Trace-Driven Simulation.
   - A simulation using a trace as its input

     E.g., using trace-driven simulation to analyse paging algorithms, cache analysis, CPU scheduling algorithms, deadlock prevention algorithms, etc.

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4. Discrete Event Simulation.

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Definition

A simulation using a discrete-state model of the system.

What is Discrete-Event Simulation (DES) ?

Discrete-Event Simulation is

- Discrete (in state)
- Dynamic (in time)
- Stochastic

DES mostly applied to queueing systems (but not limited to)

- Factory workflow
- Freeway traffic simulation
- Network traffic simulation
- ...

DES categories

- Activity-oriented
  - fixed increment of time
  - time-consuming
- Event-oriented
  - on each event, generate next event and put into event queue and sort
  - simulation time advances to next closed event
  - faster than activity-oriented
- Process-oriented
  - abstract one object into a process
  - easier to maintain as object-oriented approach

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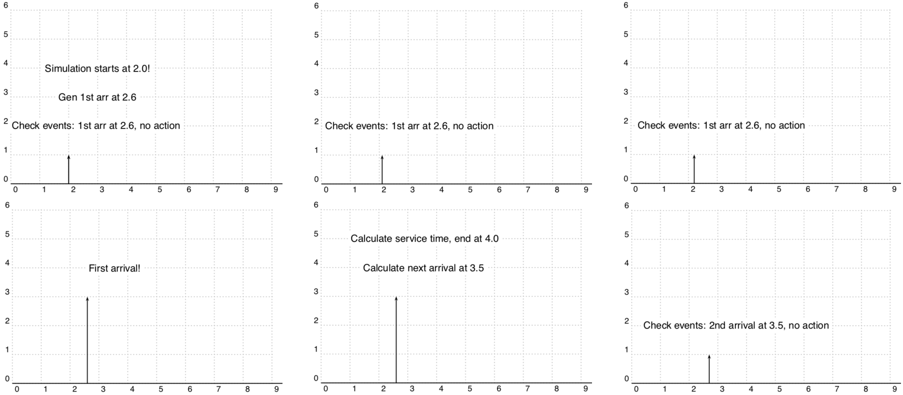
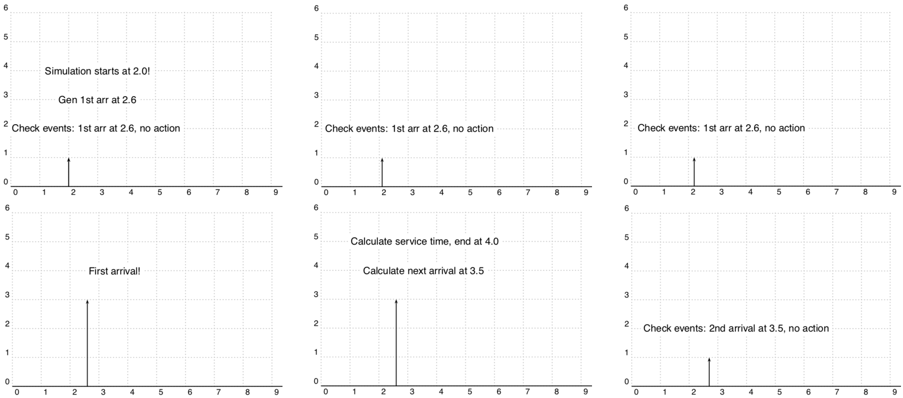
  - **SimPy is here**

Activity-oriented

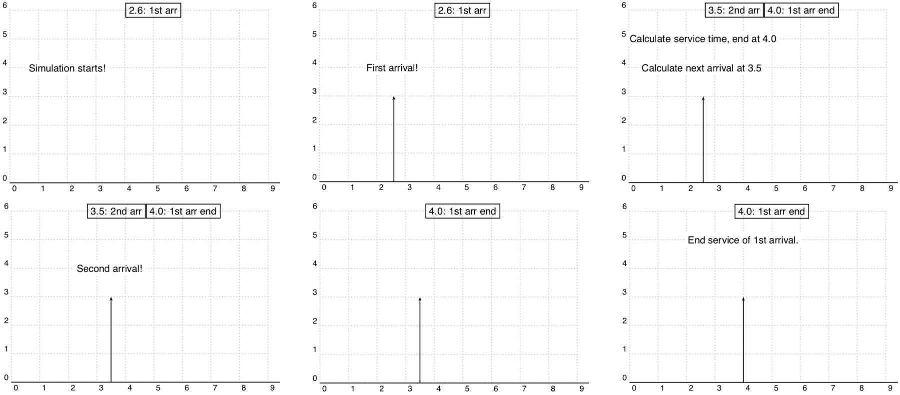


Activity-oriented

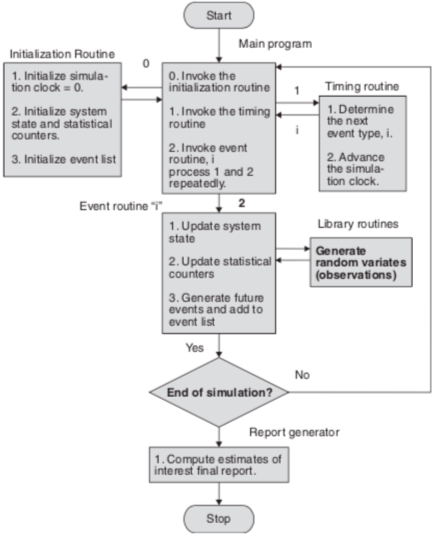


Much time for redundant checks of the unchanged state

Event-oriented



Event-oriented DES architecture



Process-oriented (1)

- Based on event-oriented
- Designed into separate processes

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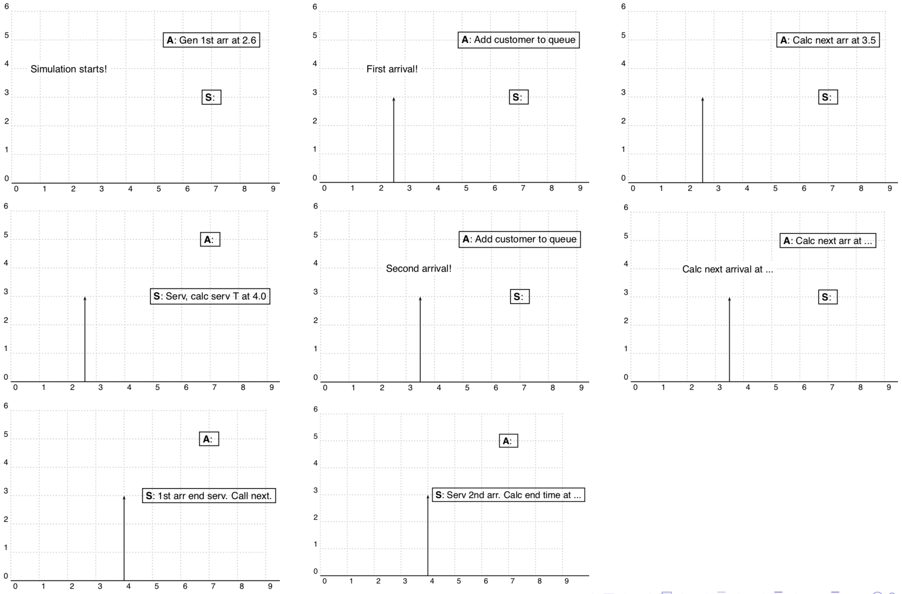
A single queue in process-oriented DES

- **Arrival process**: an infinite loop of the following
  - Calculate next arrival time
  - Sleep until next arrival
  - Add new job to queue
- **Service process**: an infinite loop of the following
  - Sleep until waken by new jobs
  - Serve the queued jobs on waken until there is no job in queue

Process-oriented (2)



- Environment
- Process
- Event
- Resource

```
>>> import simpy
>>>
>>> def clock(env, name, tick):
...     while True:
...         print(name, env.now)
...         yield env.timeout(tick)
...
>>> env = simpy.Environment()
>>>
>>> env.process(clock(env, 'fast', 0.5))
<Process(clock) object at 0x...>
>>> env.process(clock(env, 'slow', 1))
<Process(clock) object at 0x...>
>>>
>>> env.run(until=2)
fast 0
slow 0
fast 0.5
slow 1
fast 1.0
fast 1.5
```

Start simpy environment

Register processes with their events

Run simulation until time of 2

Timeout and processes

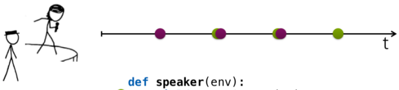
(based on slides of Stefan Scherfke)

Timeout is event


```python
def speaker(env, start):
    until_start = start - env.now
    yield env.timeout(until_start)

    yield env.timeout(30)
```

Process is event, too




```python
def speaker(env):
    yield env.timeout(30)
    return 'handout'


def moderator(env):
    for i in range(3):
        val = yield env.process(speaker(env))
        print(val)
```

Synchronization
(based on slides of Stefan Scherfke)

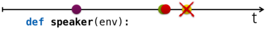
Asynchronous interrupt



```python
def speaker(env):
    try:
        yield env.timeout(randint(25, 35))
    except simpy.Interrupt as interrupt:
        print(interrupt.cause)


def moderator(env):
    for i in range(3):
        speaker_proc = env.process(speaker(env))
        yield env.timeout(30)
        speaker_proc.interrupt('No time left')
```

Condition event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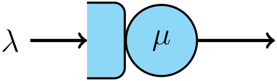
def moderator(env):
    for i in range(3):
        speaker_proc = env.process(speaker(env))
        results = yield speaker_proc | env.timeout(30)

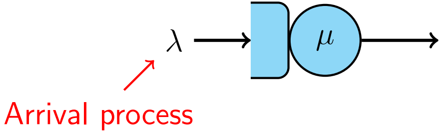
        if speaker_proc not in results:
            speaker_proc.interrupt('No time left')
```

Outline

FIFO queue



FIFO queue



- **Job**: an object of a class
- **Queue of jobs**: list of objects
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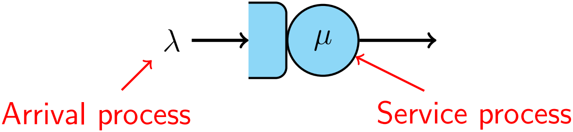

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```
class Job:
    def __init__(self, name, duration):
        self.name = name
        self.duration = duration
```

More attributes could be added in order to collect statistical data, such as

- arrival time
- start time of service

FIFO queue

A queue with single server (service process)

```
class Server:
    def __init__(self, env):
        self.Jobs = list(())
        env.process( self.serve(env) )

    def serve(self, env):
        while True:
            if len( self.Jobs ) == 0 :
                self.serversleeping = env.process( self.waiting( env ))
                yield self.serversleeping
            else:
                j = self.Jobs.pop( 0 )
                yield env.timeout( j.duration )

    def waiting(self, env):
        try:
            print( 'Server is idle at %d' % env.now )
            yield env.timeout(1000)
        except simpy.Interrupt as i:
            print('A new job comes. Server waken up and works now at %d'
                  % env.now )
```

```
class JobGenerator:
  jcnt = 0

  def __init__(self, env, server):
    self.server = server
    env.process( self.jobgen(env) )

  def jobgen(self, env):
    while True:
      job_interarrival = random.randint(1,5)
      yield env.timeout( job_interarrival )

      job_duration = random.randint(2,5)
      self.jcnt += 1
      self.server.Jobs.append( Job('Job %s' %self.jcnt, job_duration) )
      print( 'job %d: t = %d, l = %d' %( self.jcnt, env.now, job_duration ))

      if not self.server.serversleeping.triggered:
        self.server.serversleeping.interrupt( 'Wake up, please.' )
```

```
env = simpy.Environment()
MyServer = Server( env )
MyJobGenerator = JobGenerator( env, MyServer )
env.run( until = 20 )
```

And results

```
Server is idle at 0
job 1: t = 4, l = 2
A new job comes. Server back to work at 4 by 'Wake up, please.'
Server is idle at 6
job 2: t = 9, l = 5
A new job comes. Server back to work at 9 by 'Wake up, please.'
job 3: t = 13, l = 5
job 4: t = 14, l = 3
job 5: t = 19, l = 4
```

M/M/1 queue

Simulation parameters

- Inter-arrival rate: $\lambda = 5$ (jobs/time unit)
- Service rate: $\mu = 8$ (jobs/time unit)
- Simulation time: 5000 (time unit)

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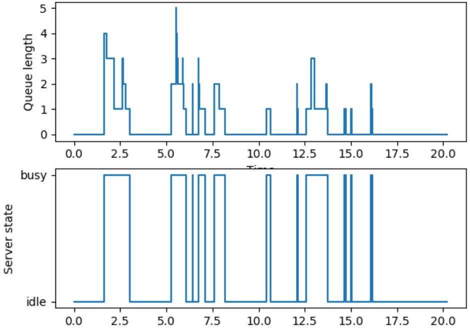
Performance

- Analytical modeling: $\overline{W} = 0.21$ (for validation)
- Simulation modeling: $\overline{W} = 0.19$



- Simulation functions

- Model enhancement

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    - validation: validate single queue model (M/M/1/∞/∞/FIFO)

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  - Statistical report (mean, variance)

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M/M/1 queue

What else should be doned ?

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  - Statistical report (mean, variance)
  - Simulation logging

- Model enhancement

M/M/1 queue

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    - Queueing strategies (FIFO, SJF, priority, round-robin,...)
    - Different types of workload

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