Discrete Event Simulation Using SimPy

SYS-611: Simulation and Modeling

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Agenda

1. Simulation Software
2. Introduction to SimPy
3. Queuing System Model
4. Inventory System Model
5. Factory System Model

Reading: A.M. Law, “Simulation Software,” Ch. 3 in *Simulation Modeling and Analysis*, 5th Edition, 2013, pp. 181-213.

SimPy Reference Material: http://simpy.readthedocs.io

Developing Simulation Software

Simulation Software

Based on A.M. Law (2013), pp. 186-193

- Two main options for developing simulations:
  - General-purpose programming languages – simulation is a software engineering project
    - Java, C++, C most common in defense domain
  - Simulation packages – simulation is an application in an encompassing software framework/tool
    - General-purpose or application-oriented
- Choosing the best option will depend on the specifics of each problem

Simulation Package Examples

Based on A.M. Law (2013), pp. 186-193

- General-purpose:
  - AnyLogic
  - Arena
  - ExtendSim
  - GPSS (language)
  - Simio
  - Simula (language)
  - SIMUL8

- Application-oriented:
  - *Manufacturing*: FlexSim, ProModel
  - *Communications*: NetSim, OPNET++
  - *Healthcare*: FlexSim
  - *Multi-physics*: Fluent, COMSOL
  - *Controls*: Simulink

Desirable Software Features

Based on A.M. Law (2013), pp. 186-193

- Flexible modeling
- Hierarchical structure
- Usable / graphical user interface
- Command line / headless execution
- Debugging aids
- Rapid feedback (<1s)
- Import/export data
- Serialize/save state
- Low cost
- Cross-platform
- Permissive licenses for extension, distribution
- RNG, statistical tools
- Documentation and user community

Comparison of Simulation Software

Programming Lang.

- Ultimate flexibility
- Interoperability
- Higher performance (if done right)
- High level of control
- Lower infrastructure costs, higher developer costs

Simulation Package

- Easier verification
- Build on existing work
- Easier learning curve
- Execution often optimized
- Higher infrastructure costs, lower developer costs

Introduction to SimPy

SimPy Overview

- **SimPy** is a process interaction-based discrete event simulation package in standard Python
  - Provides application programming interface (API)
  - Distributed under MIT License (permissive)
- Install from Anaconda Command Prompt:

```
pip install simpy
```

- Define processes using Python generators:
  - Each active entity (e.g. customer) has a process
  - Allow shared resources (e.g. servers) and interrupts

SimPy History

- 2003-2008: Version 1.X
  - Inspired by Simula 67 and Simscript
  - Goal: native simulation in Python
- 2009-2012: Version 2.X
  - Object-oriented API
- 2013-Present: Version 3.X
  - Completely rewritten from scratch
  - New and easier-to-use API conforming to community guidelines (PEP 8)

Python: Iterables

http://stackoverflow.com/questions/231767/what-does-the-yield-keyword-do/231855#231855

- An **iterable** is a data structure that allows iteration:

```
my_list = [0,1,4]
for i in my_list:
    print i
```

- Iterables can also be defined with "list comprehension" notation:

```
my_list = [x*x for x in range(3)]
for i in my_list:
    print i
```

Python: Generators

http://stackoverflow.com/questions/231767/what-does-the-yield-keyword-do/231855#231855

- A **generator** is a one-time-use iterable

```
my_generator = (x*x for x in range(3))
for i in my_generator:
    print i
```

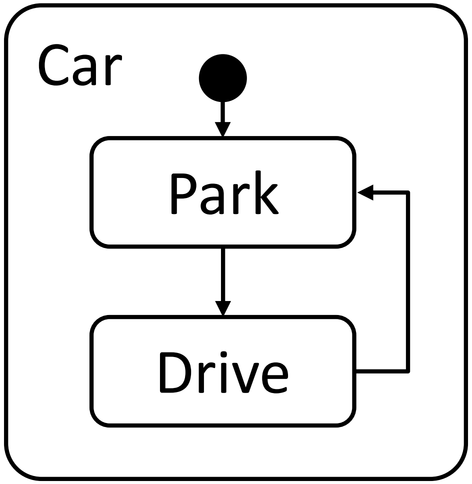
- Generators can also be defined in function notation using the *yield* keyword (similar to *return*):

```
def create_generator():
    for x in range(3):
        yield x*x
my_generator = create_generator()
for i in my_generator:
    print i
```

SimPy Processes

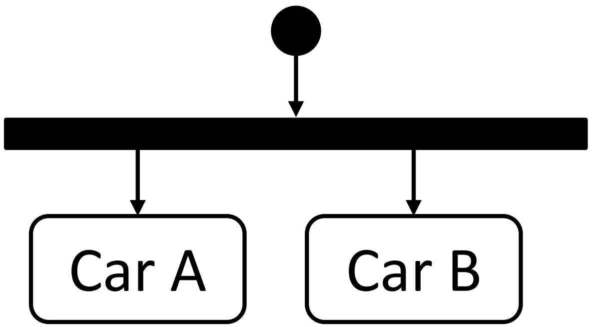
- SimPy uses generators to define processes
  - A process is an activity with > 0 duration

```
import simpy # simpy1.py

def car_process(env):
  while True:
    print 'parking @ {}'.format(env.now)
    yield env.timeout(5.0) # wait 5 hours
    print 'driving @ {}'.format(env.now)
    yield env.timeout(2.0) # wait 2 hours

env = simpy.Environment()
env.process(car_process(env))
env.run(until=15.0)
```



Multiple Processes

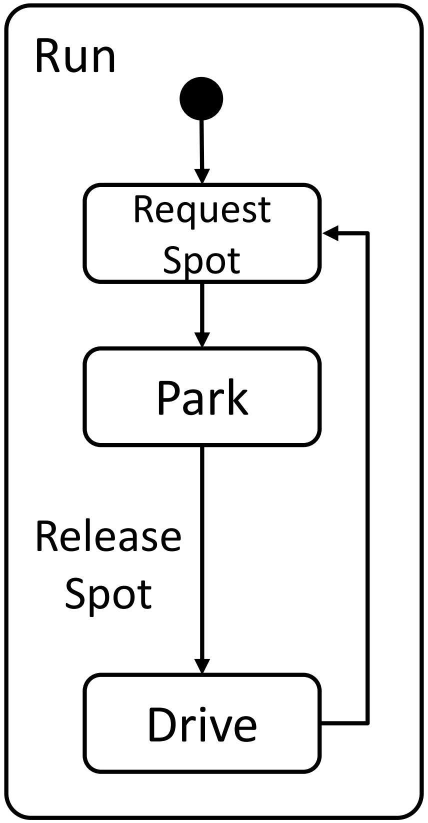
```
import simpy # simpy2.py

def car_process(env, name, t_park, t_drive):
  while True:
    print '{} parking @ {}'.format(
      name, env.now)
    yield env.timeout(t_park)
    print '{} driving @ {}'.format(
      name, env.now)
    yield env.timeout(t_drive)

env = simpy.Environment()
env.process(car_process(env, 'A', 5.0, 2.0))
env.process(car_process(env, 'B', 3.0, 3.0))
env.run(until=15.0)
```



Process-oriented SimPy

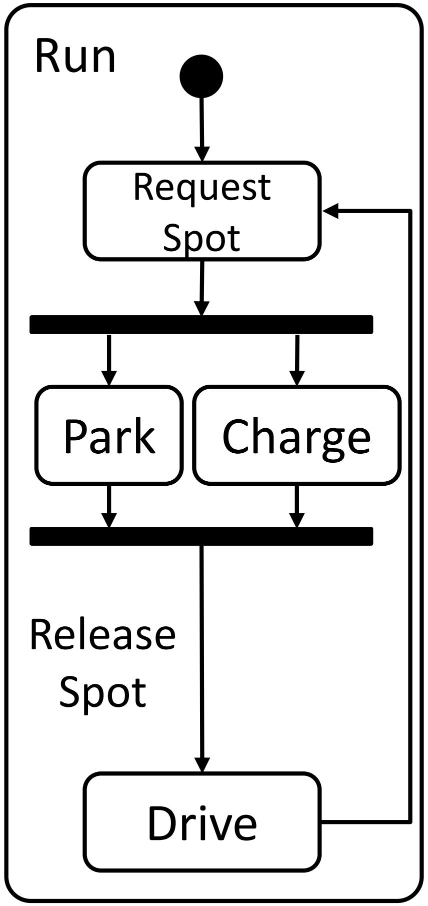
```
import simpy # simpy3.py

def car_park(env, name, duration):
  yield env.timeout(duration)

def car_drive(env, name, duration):
  yield env.timeout(duration)

def car_run(env, name, t_park, t_drive):
  while True:
    yield env.process(car_park(env, name, t_park))
    yield env.process(car_drive(env, name, t_drive))

env = simpy.Environment()
env.process(car_run(env, 'A', 5.0, 2.0))
env.process(car_run(env, 'B', 3.0, 3.0))
env.run(until=15.0)
```

Shared Resources




```
import simpy # simpy4.py

def car_park(env, name, duration):
  yield env.timeout(duration)

def car_drive(env, name, duration):
  yield env.timeout(duration)

def car_run(env, name, lot, t_park, t_drive):
  while True:
    with lot.request() as request:
      yield request
      yield env.process(car_park(env, name, t_park))
    yield env.process(car_drive(env, name, t_drive))

env = simpy.Environment()
single_lot = simpy.Resource(env, capacity=1)
env.process(car_run(env, 'A', single_lot, 5.0, 2.0))
env.process(car_run(env, 'B', single_lot, 3.0, 3.0))
env.run(until=15.0)
```

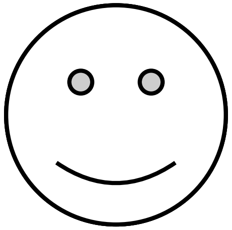
Process Interaction




```
import simpy # simpy5.py

def car_charge(env, name, duration):
  yield env.timeout(duration)

def car_park(env, name, duration):
  yield env.timeout(duration)

def car_drive(env, name, duration):
  yield env.timeout(duration)

def car_run(env, name, lot, t_park, t_drive, t_charge):
  while True:
    with lot.request() as request:
      yield request
      parking = env.process(car_park(env, name, t_park))
      charging = env.process(car_charge(env, name, t_charge))
      yield parking & charging
    yield env.process(car_drive(env, name, t_drive))

env = simpy.Environment()
single_lot = simpy.Resource(env, capacity=1)
env.process(car_run(env, 'A', single_lot, 5.0, 2.0, 6.0))
env.process(car_run(env, 'B', single_lot, 3.0, 3.0, 2.0))
env.run(until=15.0)
```

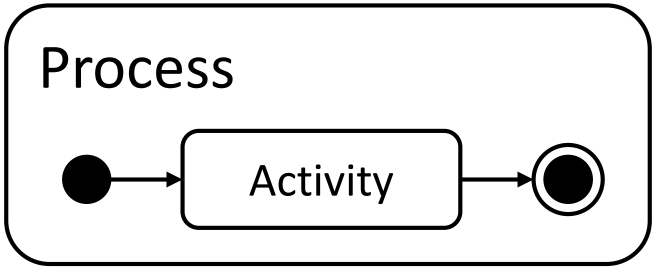
SimPy Example: Queuing Model

Queuing System

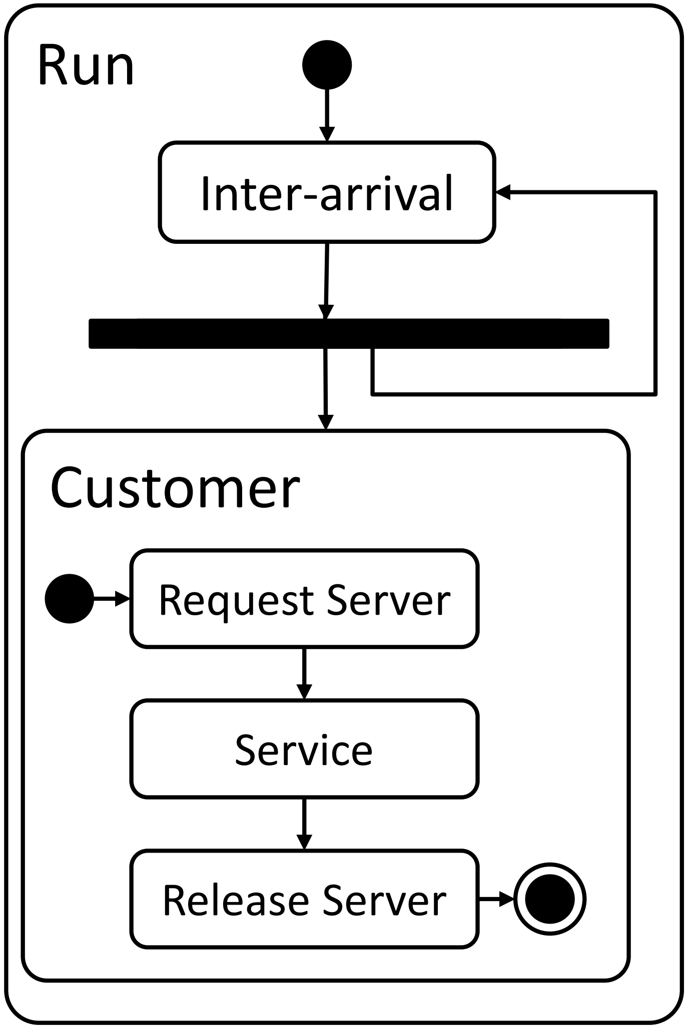


Queuing System Model

- Queuing system specification:
  - $n = 1$ server, $C = \infty$ queue capacity
  - Customer inter-arrival period $x \sim \text{exponential}(\lambda = 3)$
  - Service time $y \sim \text{exponential}(\mu = 4)$
- **What are the processes and activities?**



Queuing Model Activity Diagram




```
import simpy # QueuingSystem.py
import numpy as np

def cafe_run(env, servers, _lambda, _mu):
  while True:
    yield env.timeout(
        np.random.exponential(1./_lambda))
    env.process(customer(env, servers, _mu))

def customer(env, servers, _mu):
  with servers.request() as request:
    yield request
    yield env.timeout(
      np.random.expeonential(1./_mu))

env = simpy.Environment()
servers = simpy.Resource(env, capacity=1)
env.process(cafe_run(env, servers, 3.0, 4.0))
env.run(until=10)
```

Recording Observations

```
def cafe_run(env, servers, _lambda, _mu):
  while True:
    yield env.timeout(
        np.random.exponential(1./_lambda))
    env.process(customer(env, servers, _mu))

wait_q = []
wait_t = []

def customer(env, servers, _mu):
  with servers.request() as request:
    t_arrive = env.now
    yield request
    t_served = env.now
    wait_q.append(t_served - t_arrive)
    yield env.timeout(
      np.random.exponential(1./_mu))
    t_depart = env.now
    wait_t.append(t_depart - t_arrive)
```

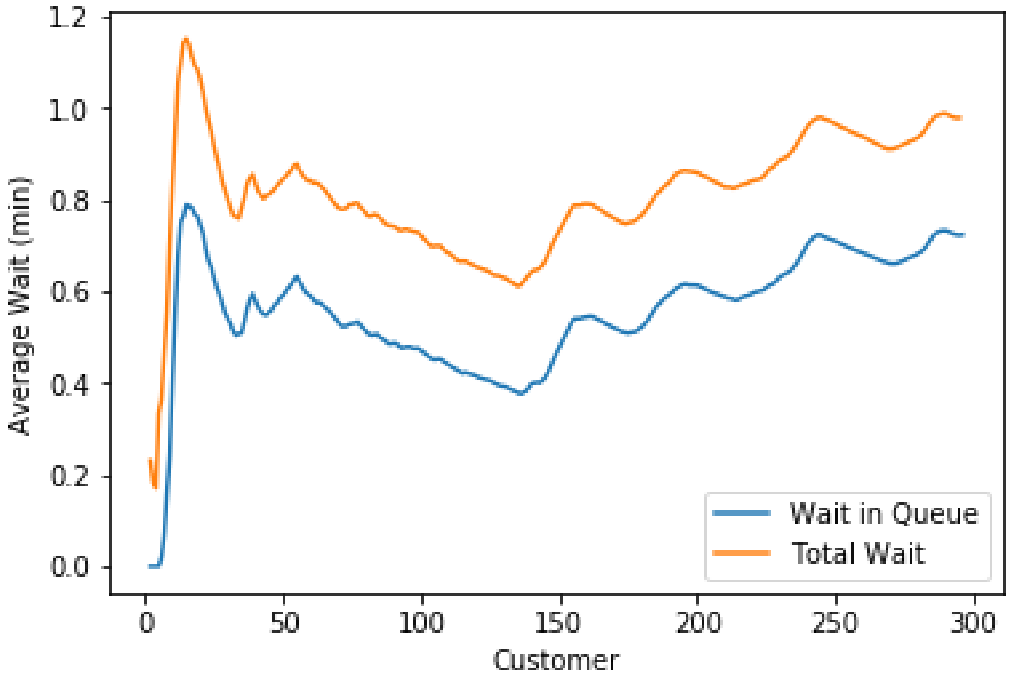
- Append to data lists during processes
- Example shown relies on local variables
- Better to pass in as generator arguments

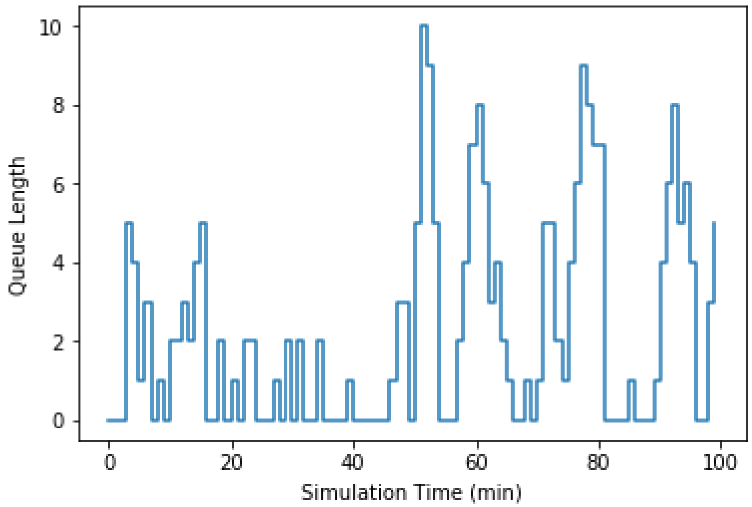
Process Monitoring

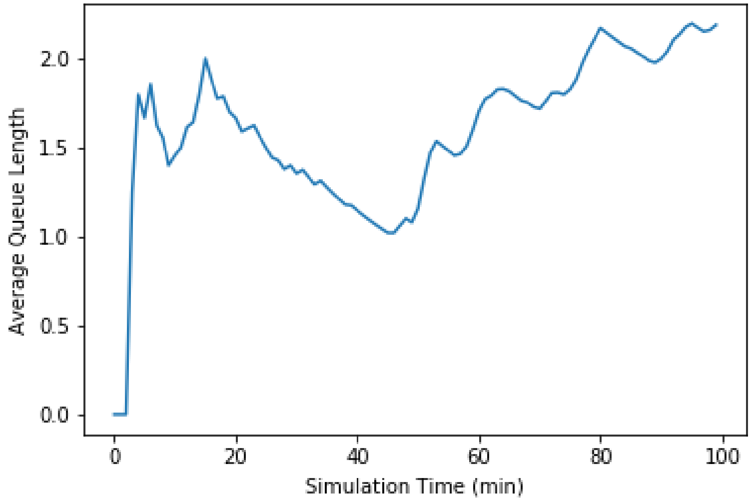
```
obs_time = []
queue_length = []

def observe(env, servers):
  while True:
    obs_time.append(env.now)
    queue_length.append(len(servers.queue))
    yield env.timeout(1.0)

env = simpy.Environment()
servers = simpy.Resource(env, capacity=1)
env.process(cafe_run(env, servers, 3.0, 4.0))
env.process(observe(env, servers))
env.run(until=10)
```

- Create simple process to take observations at fixed times
- Example shown relies on local variables
- Better to pass in as generator arguments

Queuing System Results

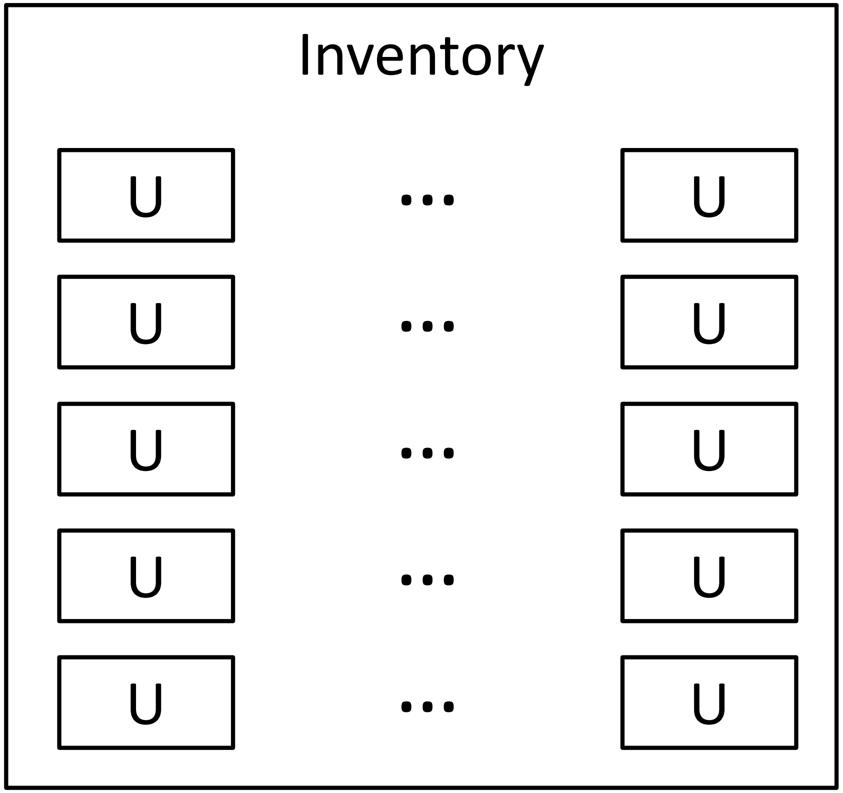


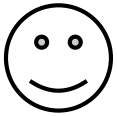


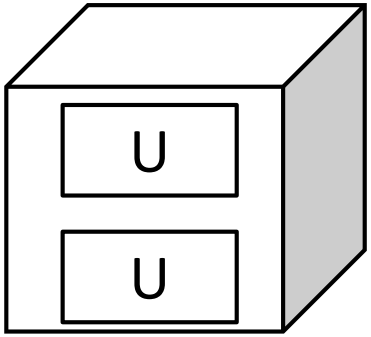


SimPy Example: Inventory Model

Inventory System



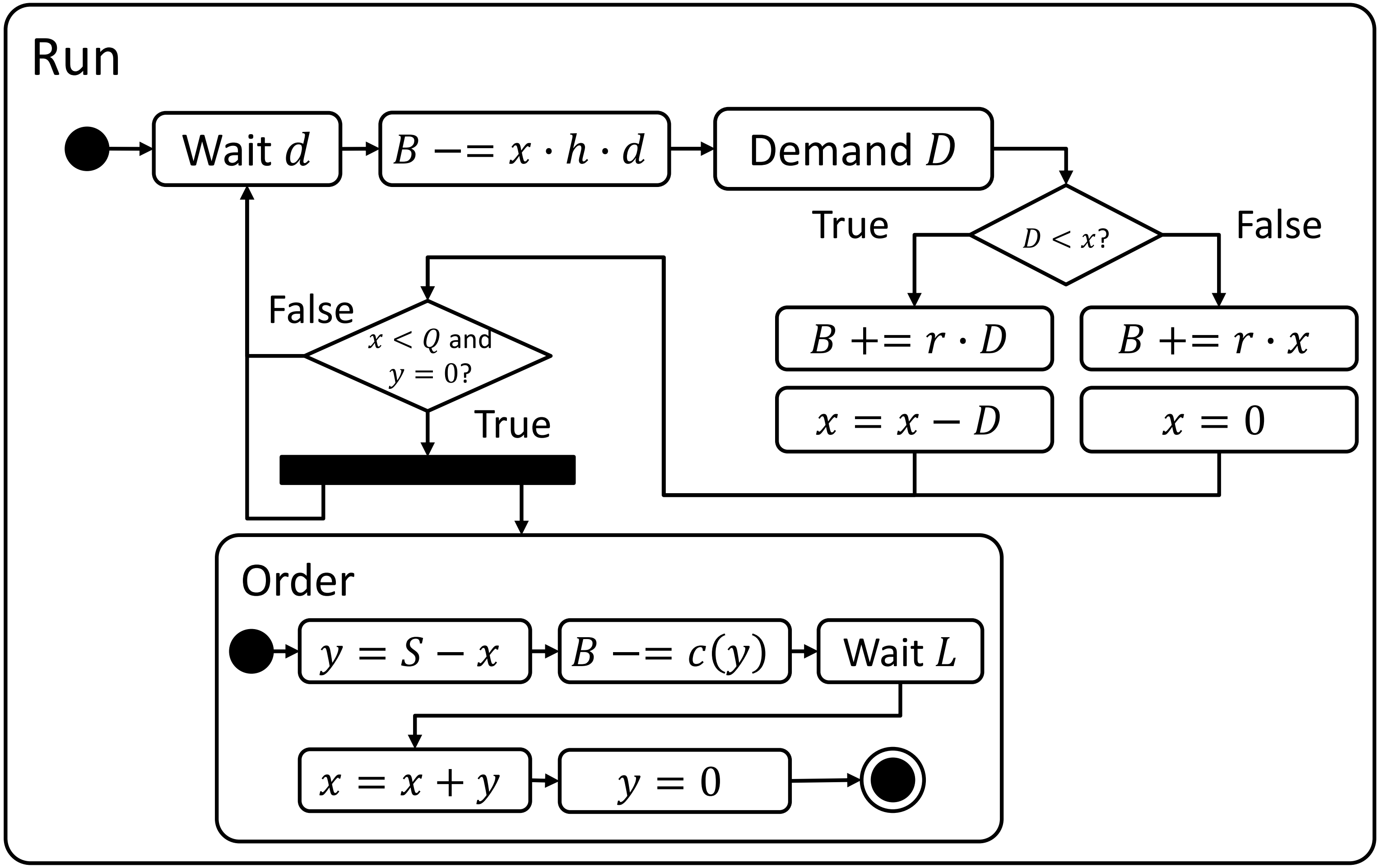




Inventory System Model

- Inventory system specification:
  - Sell products for $r = 100$ (can only sell those in stock)
  - Customer inter-arrival period $d \sim \text{exponential}(\lambda = 5)$
  - Each customer demands $D \sim \text{uniform}(1,4)$ products
  - Order policy (Q, S): if inventory is $x < Q$, order $y = S - x$
  - Costs $c(y) = 50y$ to order y units
  - Delay of $L = 2$ days until delivery
  - Holding cost of $h = 2$ per item per day
- **What are the processes and activities?**

Inventory Model Activity Diagram

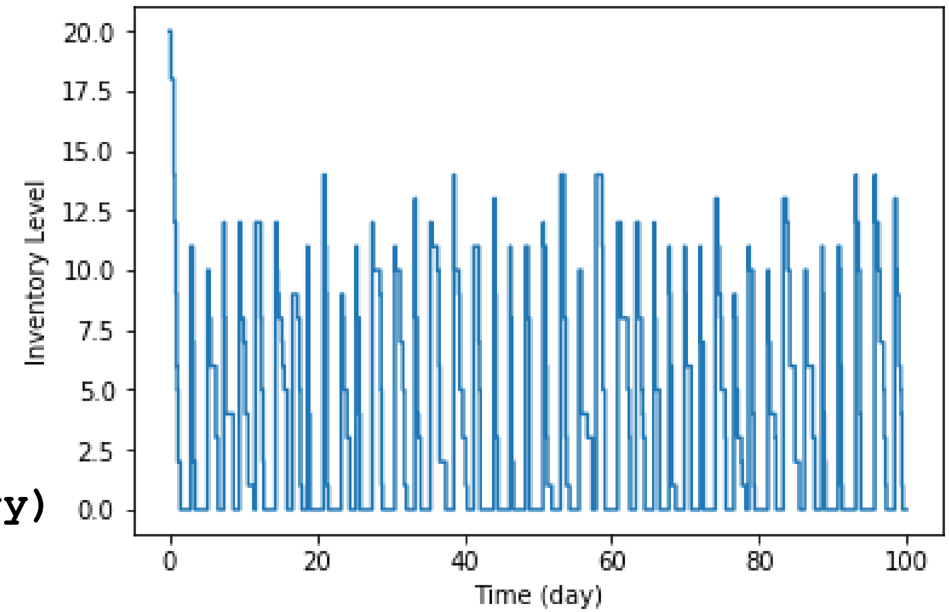


Inventory Model Python

```
import simpy # InventoryModel.py
import numpy as np

def warehouse_run(env, order_threshold, order_up_to):
  global inventory, balance, num_ordered
  inventory = order_target
  balance = 0
  num_ordered = 0
  while True:
      interarrival = np.random.exponential(1/5.0)
      yield env.timeout(interarrival)
      balance -= 2.00*inventory*interarrival
      demand = np.random.randint(1, 4+1)
      if inventory > demand: num_sold = demand
      else: num_sold = inventory
      balance += 100.00*num_sold
      inventory -= num_sold
      if inventory < order_threshold and num_ordered == 0:
        env.process(handle_order(env, order_up_to - inventory))
```

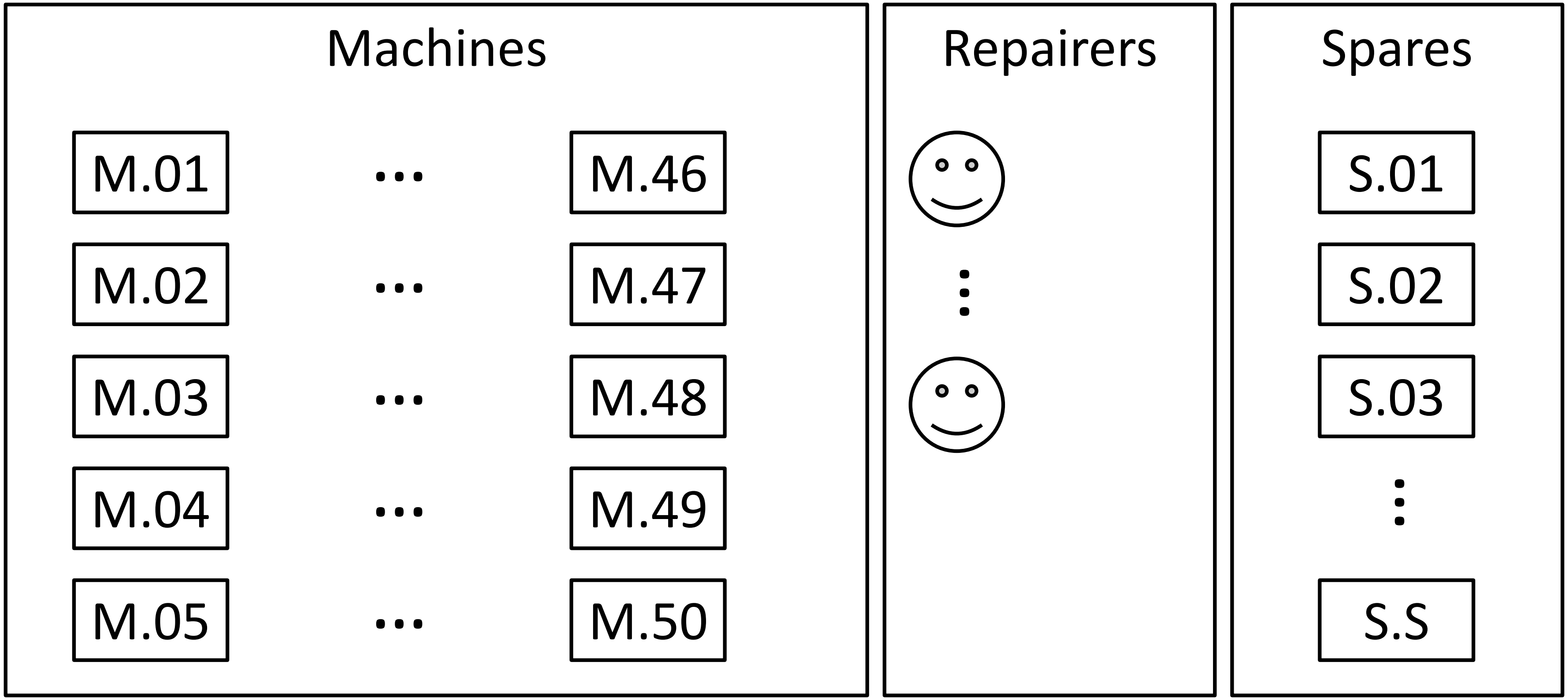
Inventory Model Python (cont.)

```
def handle_order(env, quantity):
  global inventory, balance, num_ordered
  num_ordered = quantity
  balance -= 50.00*quantity
  yield env.timeout(2.0)
  inventory += quantity
  num_ordered = 0

obs_time = []
inventory_level = []

def observe(env):
  while True:
    obs_time.append(env.now)
    inventory_level.append(inventory)
    yield env.timeout(0.1)

env = simpy.Environment()
env.process(warehouse_run(env, 10, 20))
env.process(observe(env))
env.run(until=5.0)
```



SimPy Example: Factory Model

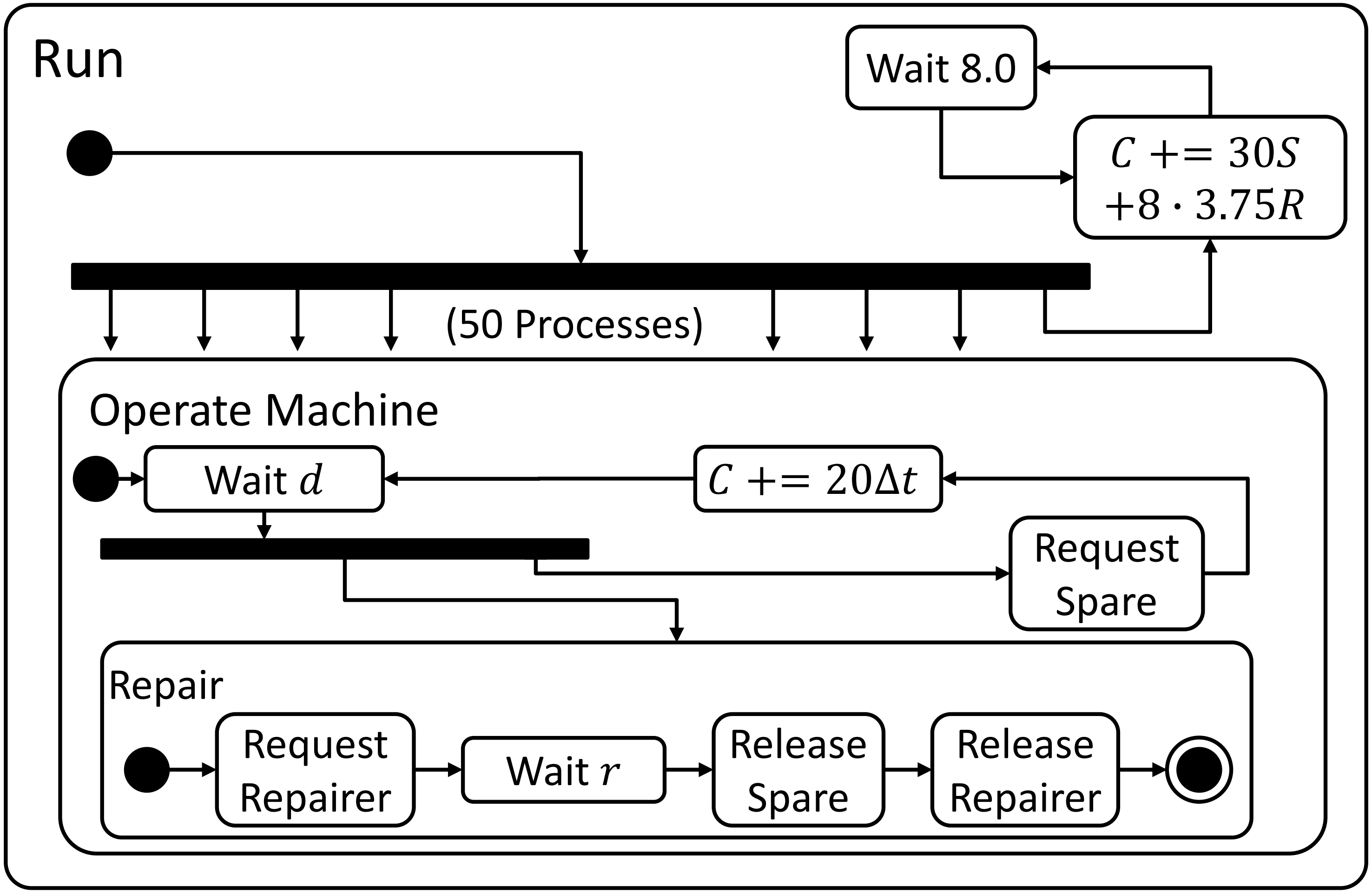
Factory System



Factory System Model

- Factory system specification:
  - $n = 50$ machines working 8 hours/day, 5 days/week
  - Each fails randomly after $d \sim \mathrm{uniform}(132{,}182)$ hours
  - Immediately replace with spare when available
  - Repairer fixes failed machine in $r \sim \mathrm{uniform}(4{,}10)$ hours, returns to spares
  - Hire R repairers at $3.75/hour
  - Purchase S spares at $30/day
  - Costs $20/hour/machine if out-of-service (no spares)
- **What are the processes and activities?**

Factory Model Activity Diagram



Factory Model Python

```
import simpy # FactorySystem.py
import numpy as np

def factory_run(env, repairers, spares):
  global cost
  cost = 0
  for i in range(50):
    env.process(operate_machine(env, i+1, repairers, spares))
  while True:
    cost += 3.75*8*repairers.capacity + 30*spares.capacity
    yield env.timeout(8.0)

def operate_machine(env, machine, repairers, spares):
  global cost
  while True:
    yield env.timeout(np.random.uniform(132, 182))
    time_broken = env.now
    env.process(repair_machine(env, repairers))
    yield spares.get(1)
    cost += 20*(env.now - time_broken)
```

Factory Model Python (cont.)

```
def repair_machine(env, repairers):
  with repairers.request() as request:
    yield request
    yield env.timeout(np.random.uniform(4,10))
    yield spares.put(1)

obs_time = []
obs_spares = []
def observer(env, spares):
  while True:
    obs_time.append(env.now)
    obs_spares.append(spares.level)
    yield env.timeout(1.0)

env = simpy.Environment
repairers = simpy.Resource(env, capacity=3)
spares = simpy.Container(env, init=20, capacity=20)
env.process(factory_run(env, repairers, spares))
env.process(observe(env, spares))
env.run(until=8*5*52)
```