# Simulation

Simulation is experiments with a model of a system

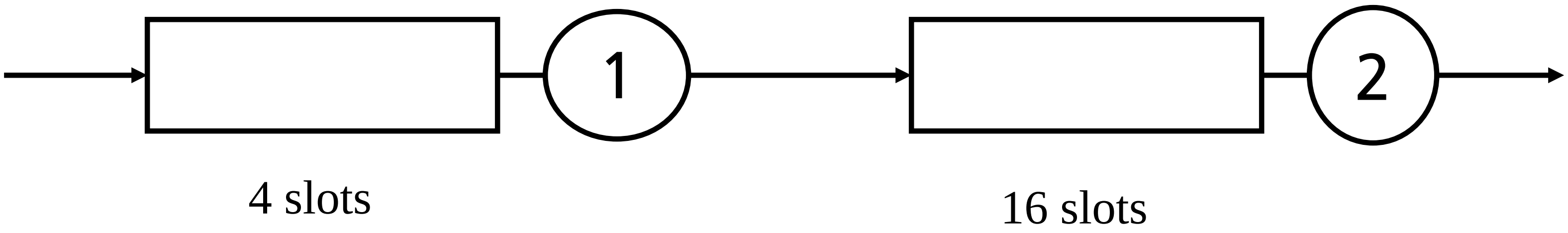
- Event scheduling method
- Process interaction method

# Event scheduling approach

What is needed:

- A state description
- Events
- Rules telling what will happen when an event occurs
- Parameters

# A more complicated example




We want to find

- the mean number of customers in queueing system 1 and 2
- the probability that a customer is rejected when it arrives to queueing system 1

# State description

N1 = number of customers in queueing system 1

N2 = number of customers in queueing system 2

Measuring variables:

- NoOfArrivals (is just what you think!)
- NoRejected (is just what you think!)

This is not state variables in a strict sense but they also have to be updated at certain events!

# Events needed

- ArrivalTo1
- DepartureFrom1
- DepartureFrom2
- Measurement

# Rule for ArrivalTo1

```
void RuleArrivalTo1(){
   NoOfArrivals++;
   If (N1 < 4)
      N1++;
   else
      NoRejected++;
   If (N1 == 1)
      InsertEvent(DepartureFrom1, time + 0.2);
   InsertEvent(ArrivalTo1, time + nextArrival());
}
```

# Rule for DepartureFrom1

```
void RuleDepartureFrom1{
   N1--;
   if (N2 < 16)
      N2++;
   if (N2 == 1)
      InsertEvent(DepartureFrom2, time + 0.1);
   if (N1 >) 0 then
      InsertEvent(DepartureFrom1, time + 0.2);
}
```

# Rule for DepartureFrom2

```
void RuleDepartureFrom2{
    N2--;
    if (N2 > 0)
        InsertEvent(DepartureFrom2, time + 0.1);
}
```

# Rule for Measurement

```
void RuleMeasurement{
   write(file1, N1);
   write(file2, N2);
   InsertEvent(Measurement, time +
     NextMeasurement());
}
```

# Another example

Assume that we want to measure the probability that a customer spends more than 5 seconds in the system.

Then it is not enough to keep track of the number of customers in the queueing system!

Events here are Arrival and Departure.

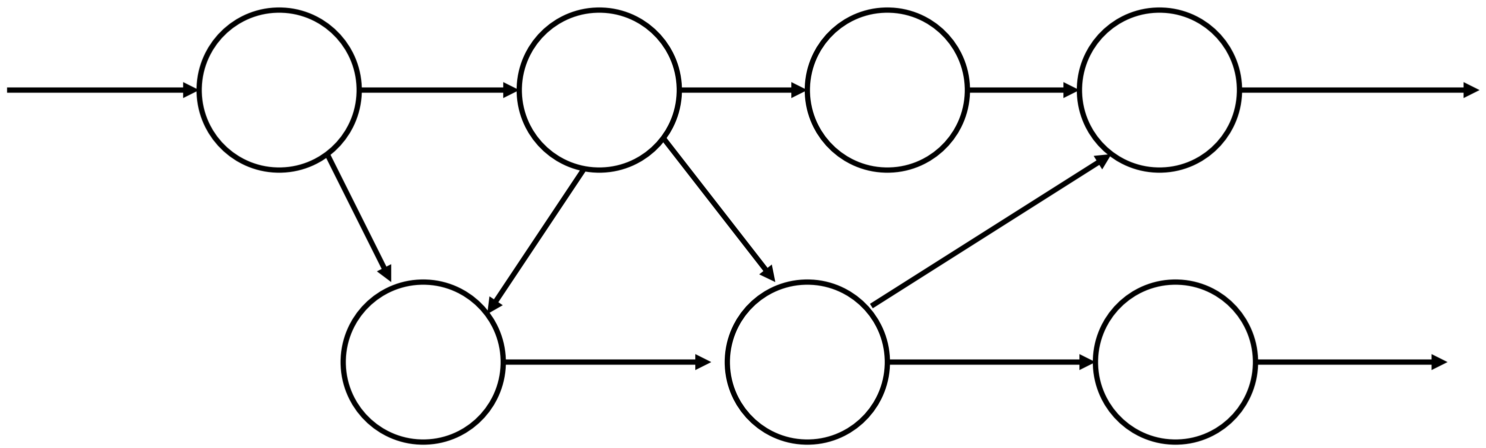
# The state of this system

In this case the state can be a list where we can store customers and mark them with their arrival time:

→ 8.3 6.2 5.3 4.4 2.4 →

**Can be implemented by a double linked list or a vector**

# Drawback of event scheduling



Assume that we have a complicated network with many nodes. The network can model e.g. a computer network, material flow or luggage handling. The nodes are similar.

# Drawbacks

- Many different events or events with attributes are needed
- It is difficult to change the system, a change in one of the nodes affects the programs global variables and rules
- It is more natural to think of such a problem as entities flowing through the network, than to think about events

# What we would like

We would like to

- create a template for the nodes and customers
- That when the program executes, instances of the nodes and customers are created
- set parameters to the instances when they are created

# The solution

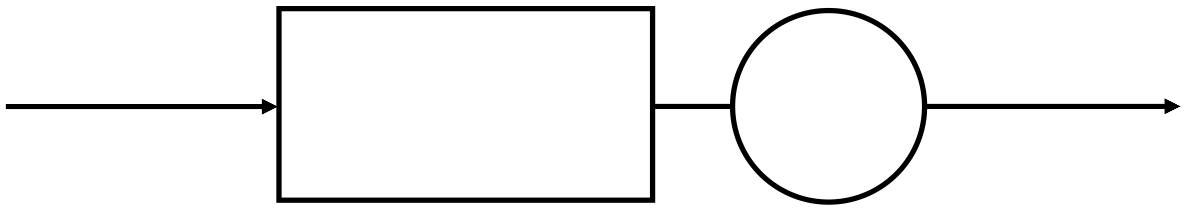
One way of solving this is the

*process interaction method*

# Processes in simulation

- In simulation a *process* is something that does something
- A process has some *internal state*
- Processes communicate by sending *signals* to each other
- Signals have a name and can carry information
- When a signal arrives to a process some *activity* is trigged
- During an activity the state of the receiving process might be changed and signals may be sent
- When a signal is sent the sender assigns it an *arrival time*

# An example



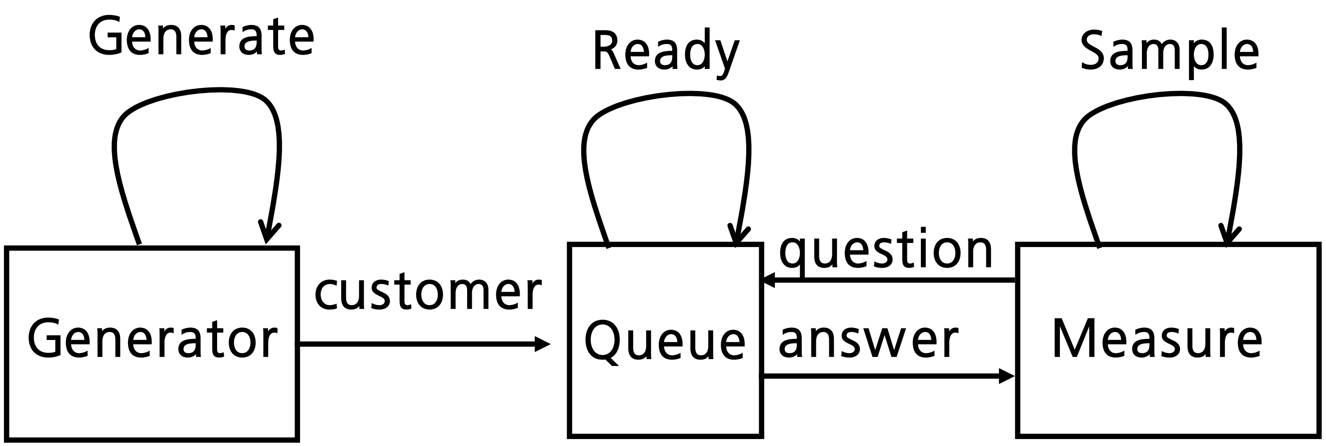
Assume that we want to describe a queueing system with the process interaction method.

# The processes we need

One process

- representing the queueing system
- generating customers
- measuring the number of customers in the queueing system

# The processes and signals




*Generate*, *Ready* and *Sample* are delayed

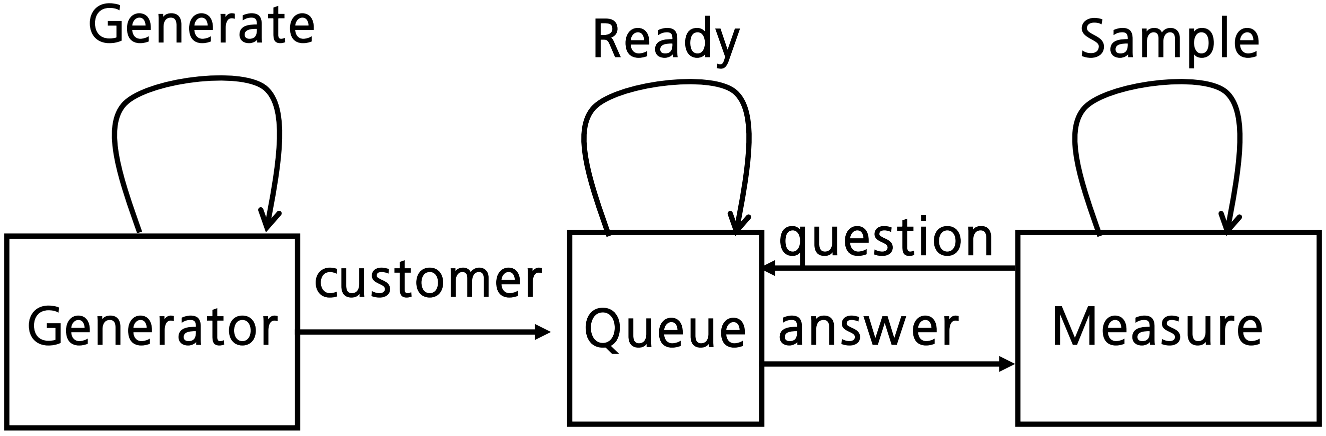
*answer* has a parameter, the number of customers.

# The internal state of the processes

- **Generator**: no internal state needed
- **Queue**: N = number of customers
- **Measure**: no internal state needed

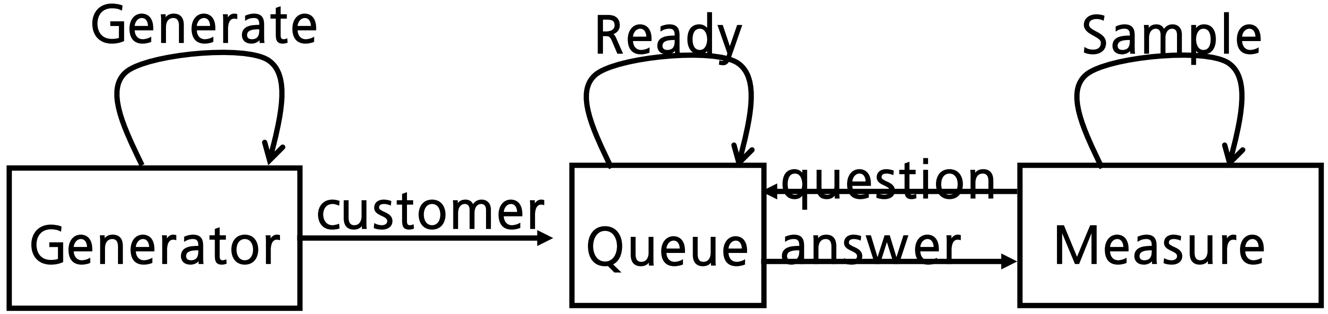
# Activity of Generator

```
if received signal = generate {
    SendSignal(customer, Queue, time);
    SendSignal(generate, Generator, time + Exp(4));
}
```



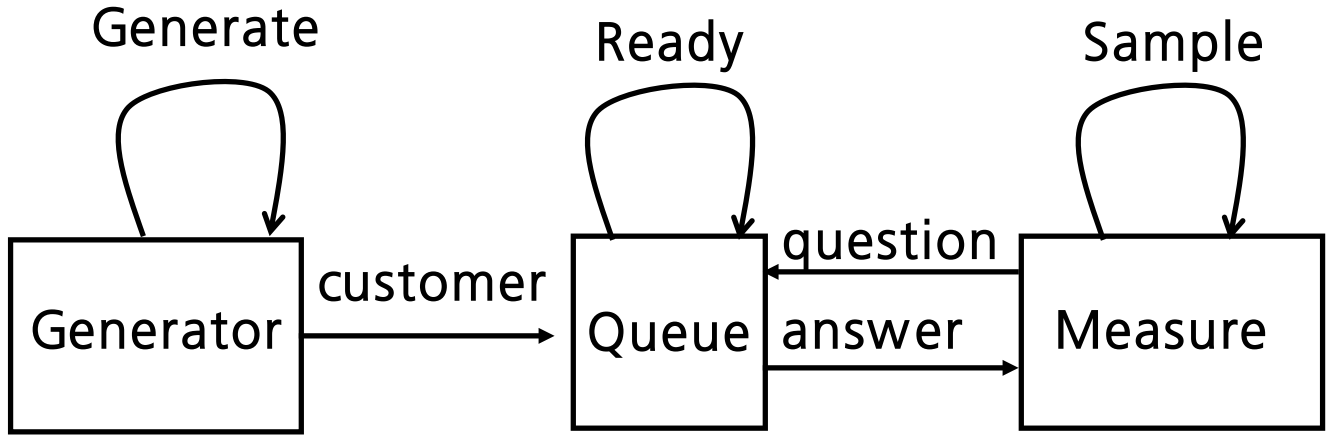
# Activity of Queue

```
if received signal = customer{
   N := N + 1;
   if N = 1 then
      SendSignal(ready, Queue, time + Exp(2));
}
else if received signal = ready{
   N := N – 1;
   if N > 0 then
      SendSignal(ready, Queue, time + Exp(2));
}
else if received signal =  question{
   SendSignal(answer(N), Measure, time);
}
```



# Activity of Measure

```
If received signal = sample {
   SendSignal(question, Queue, time);
   SendSignal(sample, Measure, time + Exp(10));
}
else if received signal = answer {
   Extract N from signal answer;
   write(outfile, N);
}
```



# Some problems we must solve

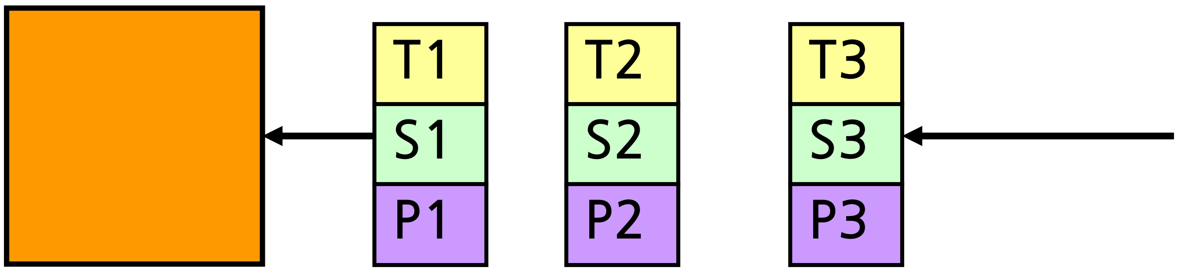
- How to keep track of time in the system
- How to make sure that signals arrive at the right time

**Observe that it is not a question of real time!**

Time is just updated when a signal arrives. It does not have any values in between.

# Signal list

Each process has a signal list. It is very similar to the event list in the event scheduling method.




$T_i$ = arrival time of signal

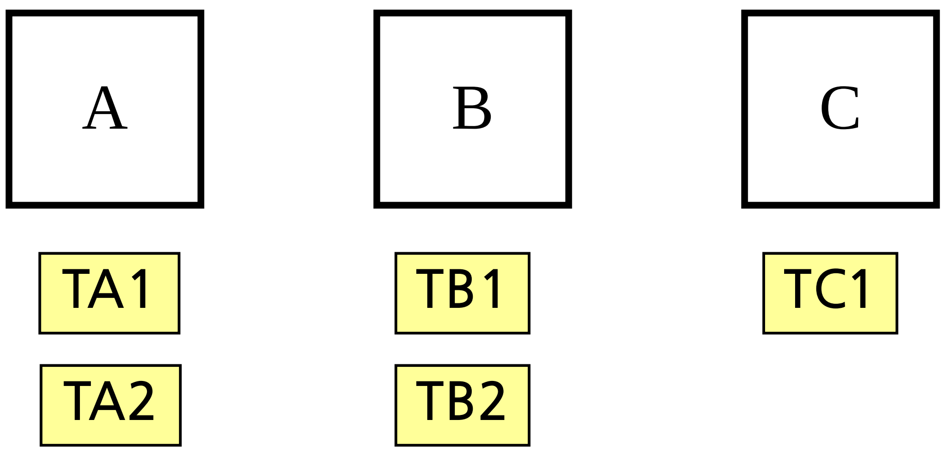
$S_i$ = what kind of signal this is (the name of the signal)

$P_i$ = parameters of the signals (if any)

$T_1 < T_2 < T_3 <$ etc

# Process list

Processes with signals in their signal lists are organized in a process list. Only the arrival times of the signals are shown here.




The process list is sorted so that $TA_1 < TB_1 < TC_1 <$ etc

# How the process interaction method works

1. Remove the first process from the process list (call it A)
2. Remove the first signal in A:s signal list
3. Process the activities
4. If there are any signals left in A:s signal list, sort it into the process list again
5. If simulation shall continue, go to 1

# What to do when a process gets a signal

Assume that process B gets a signal.

- ✓ Sort the signal into process B:s signal list.
  - If the signal list was empty before the signal arrived, B shall be sorted into the process list.
  - If the signal list was not empty, B is already in the process list.
    - If the signal is put first in B:s signal list, B might have to change its place in the process list.

# An example, the queuing system (1)

Time = 0
Generator: (3,arrival)
Measure: (10, sample)

Queue: [N=0] () Queue is not in the process list!

⇩

Time = 3

Queue: [N=0] (3,customer)
Measure: (10, sample)
Generator: (11, generate)

# An example, the queuing system (2)

Time = 3

Queue: [N=0] (3,customer)
Measure: (10, sample)
Generator: (11, generate)

Time = 3

Measure: (10, sample)
Generator: (11, generate)
Queue: [N=1] (12,ready)

# An example, the queuing system (3)

Time = 3

Measure: (10, sample)
Generator:  (11, generate)
Queue: [N=1] (12,ready)

⇩

Time = 10

Queue: [N=1](10,question)(12,ready)
Generator:  (11, generate)
Measure: (20, sample)

# An example, the queuing system (4)

Time = 10

Queue: [N=1](10,question) (12,ready)
Generator:  (11, generate)
Measure: (20, sample)

⇓

Time = 10

Measure: (10, answer) (20, sample)
Generator:  (11, generate)
Queue: [N=1](12,ready)

# An example, the queuing system (5)

Time = 10

Measure: (10, answer) (20, sample)
Generator:  (11, generate)
Queue: [N=1](12,ready)

⇩

Time = 10

Generator:  (11, generate)
Queue: [N=1](12,ready)
Measure: (20, sample)

# The steps in constructing a process interaction simulation program

Which

- processes are needed?
- variables are needed to describe the state of the processes?
- signals are needed?
- information (besides its name) shall a signal contain?
- activity shall occur when a signal arrives at a process?

When these questions are answered, it is not difficult to write a process interaction simulation program!

**Time spent thinking on these questions will save a lot of time later!**

# A further wish

- We would like to define process types, e.g. generator and queue. When we start a program we would like to create as many instances of these types as we need.

- In this way we can create a library of processes that can be reused. This is one more advantage of the process interaction approach.

# Only one signal list

- It is possible to use just one signal list in a program
- In that case the implementation of a process interaction simulation program is very similar to a event scheduling simulation program