Simulation

Discrete event systems

Discrete event simulation 1

- Consider systems with finitely many components.
- Each component has only finitely many states.
- Components interact through events.
- Event takes place at a particular time (it has no duration).

Discrete event simulation 2

- Event can change states, generate other events (for the same or later time).
- Typical structural components
  - ”machine resources” (busy/free)
  - ”human resources” (busy/free)
  - ”raw materials” (availability/quantity)
  - ”products” (stage of production/availability)
- Events are actions or beginnings and endings of activities

Wash machine

- Components of car wash
  - Wash machine (free/busy)
  - Queuing space (M available slots)
  - Clients (unwashed/being washed/washed)
- Events
  - Client arrival/departure
  - Wash start/end
  - Entering/leaving the queue
- Some events occur always together

Main simulation functionalities 1

- Simulation software has 5 main functionalities
  - Description of model structure
    - System parts -> state variables
    - Interaction logic -> ”flow chart”
    - Event logic-> ”code”
  - Random processes
    - Random numbers from desired distribution
  - Collecting and reporting statistics
    - Visualisation, confidence intervals, analysis

Main simulation functionalities 2

- Time management
  - Advancing the clock event by event
  - Activating events in right order
- Management of simulation experiment
  - Starting/ending simulation
  - Adding/removing events
  - Controlled replication of experiments

Main simulation functionalities 3

- Some functions are common to all models and experiments
  - Time management
  - Random numbers
  - Data collection and reporting
- Some are model and case dependent
  - Model structure and logic
  - Control flow in (series of) experiment(s)

Simulation paradigms

- Different approaches to simulation
  - Event based
    - State changes linked to certain time
  - Process based
    - Life cycle of events related to a system component.
  - Activity based
    - Activities that tie up resources of system components
  - Agent based
    - ”Intelligent” entities able to commit and coordinate activities
- These lead to different model/code structures
  - Fit for different modelling situations

Event based simulation

- Event routines have central role
  - One routine for each type of event
  - Model logic is in the event routines
  - Event routines can change state variables and create event notices.
  - Scheduler manages event notices (time, event)
- One routine at a time is active.

Process/object based s.

- Subprocesses as objects with own state variables and event routines.
  - All actions related to a system component are within a single object
- Specific methods to communicate with Scheduler and other objects.
  - No separate event notices
- Several processes (virtually) active simultaneously (threads, coroutines).

Activity based s.

- Logic within activity routines
  - Each routine is linked to some resource
  - Two interfaces
    - Activation (if conditions are true, then reserve the resource and fix ending time)
    - Passivation: free the resource at given time
- All activities are scanned systematically
    - If conditions are true, routine is activated.
    - If no routine activates, time is incremented to next known ending time.

Agent based s.

- Synthesis of process and activity based approaches
  - Key entities modeled as ”intelligent” agents
  - Actions related to entity collected to agent script
  - Instead of a preprogrammed life cycle a set of subactions and ability to select appropriate ones for the situation
  - Agent’s personal activity list
  - Coordination between entities using agent communication instead of simulation object methods
  - Typically employed in cases where there are many similar interacting entities (agent population) that create emergent behavior

Simulation

Event based simulation

Event based simulation

- Historically the oldest approach
- Logic is within sequentially executed routines
  - Easy to implement with any procedural language
  - Logic gets easily fragmented
    - Successive/dependent events are in separate routines

Wash machine (event b.)

- At least two types of events (arrival and departure (see introduction))
  - Both events can reserve the machine and generate departure
  - Potential maintainability problem
- Use 4 atomic events
    - Arrival (generates the client)
    - Start (reserve the resource and start service)
    - End (end service, free resource)
    - Departure (exits the client)

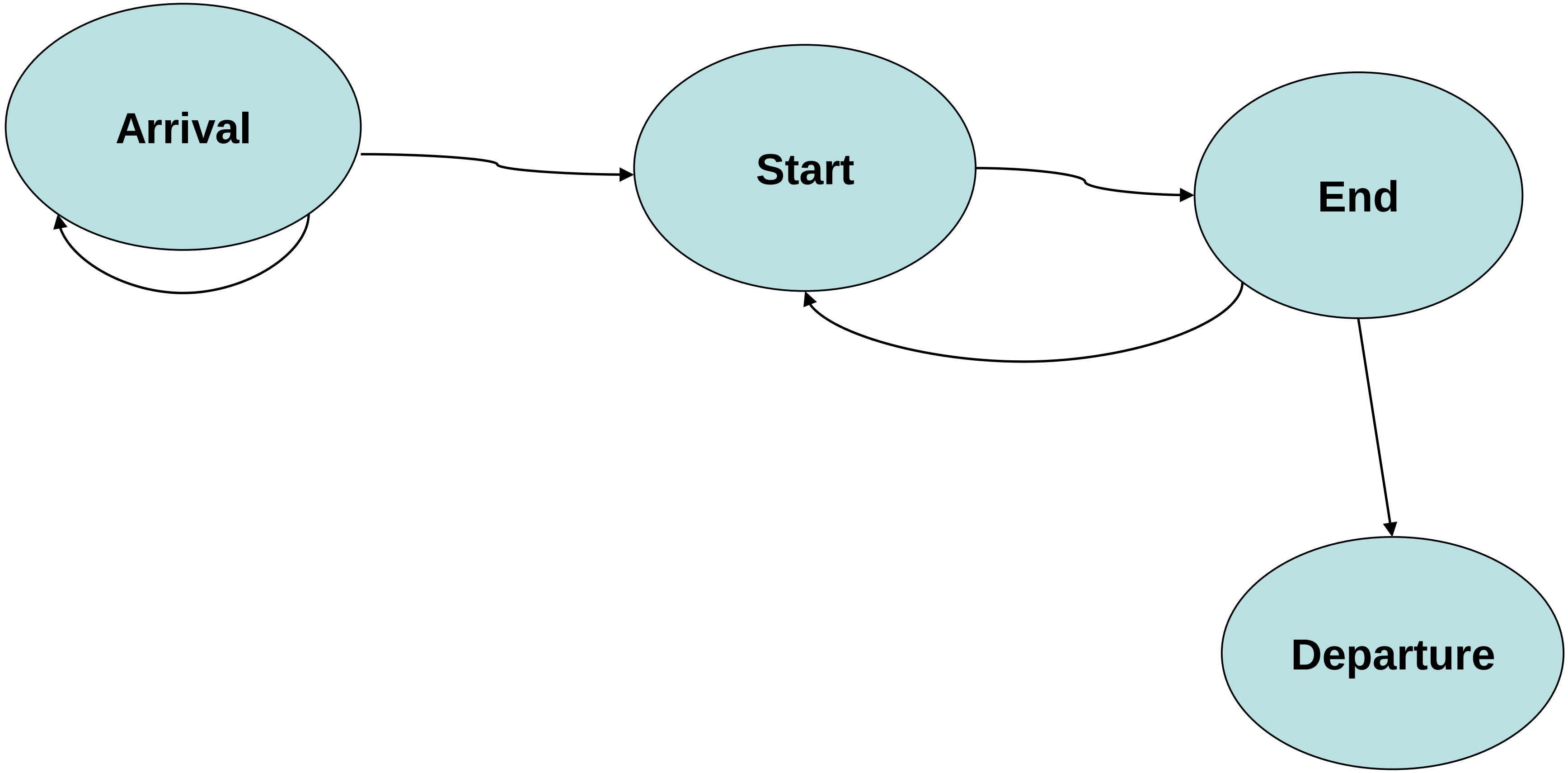
Wash machine 2

- Arrival
  - If queue not full
    - Create new client and put to the queue
    - Create a Start-event
  - Create new Arrival event (for later time)
- Start
  - If machine is free and clients in the queue
    - Take client from queue
    - Set machine busy
    - Create an End-event (for later time)

Wash machine 3

- End
  - Set machine free
  - Create Departure-event (for same time)
  - Create Start-event (for same time)
- Departure
  - Collect needed information from the client (if any)
  - Remove client

Wash machine



Wash machine - implementation

- Using OES (JavaScript based environment for object-event based simulation modeling, sim4edu.com)
- One `ObjectType` (WashStation), 4 `EventType:s` (classes with specific routines)
- For events `EventType` (Arrival, Start, End, Departure)
- Events create new events and push them to `EventList`
- Simplistic implementation
  - No tracking of individual clients -> no need to maintain queues etc
- This implementation is for older version (1.1) of OES!

Wash machine - implementation

- 4 event (sub)routines
- For events `EventType` (Arrival, Start,End, Departure)
- For bookkeeping `EventNotice(Time, Event)`
- Event list to keep `EventNotice`
  - Methods
    - `NextEvent`
    - `AddEvent (Time, Event)`
    - `(RemoveEvent (Event))`
- Queue
  - No real queue implemented for the clients

Wash machine - main

```
Initialize
T=0;
AddEvent(ArrivalTimeDistribution(),Arrival);
While (T< TMax) \\ (ending condition)
  Notice=NextEvent();
  T=Notice.Time;
   CASE Notice.Event of
    …
    \\ call for corresponding event routine
  END CASE
End While
```

CustomerArrival

```
properties: {"washStation": {range: "WashStation"}},
methods: {"applyRule": function () {
      var srvTm=0, events = [];
      sim.stat.arrivedCustomers++;
      if(this.washStation.queueLength >1){
            this.washStation.lostClients++;}
      else {
           this.washStation.queueLength++;
           events.push( new StartService({occTime: this.occTime,washStation:
    this.washStation}));}
   return events;}}
// Any exogenous event type needs to define a static function "recurrence"
CustomerArrival.recurrence = function () {
 return rand.exponential(0.12); };
// Any exogenous event type needs to define a static function "createNextEvent"
CustomerArrival.createNextEvent = function (e) {
 return new CustomerArrival({
     occTime: e.occTime + CustomerArrival.recurrence(),
     washStation: e.washStation });
```

StartService

```
properties: {"washStation": {range: "WashStation"}},
methods: {"applyRule": function () {
  var srvTm=0, events = [];
  if (this.washStation.queueLength >0 &&
  !this.washStation.working) {
      this.washStation.working=true;
      srvTm = WashStation.serviceDuration();
      events.push( new EndService({
            occTime: this.occTime + srvTm,
            serviceTime: srvTm,
            washStation: this.washStation}));}
 return events;}}
```

EndService

```
properties: {"washStation": {range: "WashStation"},
   "serviceTime": {range: "nonNegativeNumber"}},
methods: {"applyRule": function () {
    var events = []
   this.washStation.queueLength--;
   this.washStation.working=false;
   events.push( new StartService({
      occTime: this.occTime,
      washStation: this.washStation}));
    events.push( new CustomerDeparture({
           occTime: this.occTime ));
    sim.stat.totalServiceTime += this.serviceTime;
return events;}}
```

CustomerDeparture

```
properties: {},
  methods: {"applyRule": function () {
      var events = [];
      sim.stat.departedCustomers++;
      return events;
      }
 }
```

Observations

- Event creation/event notice requires different data depending on event and its needed properties
  - References to objects dealt with, time information,etc
- Modelling customer times would need customer object and queues etc for them
- Many possibilities to model the needed time logging (customer based, service based, event notice based)

Simulation

Event based harbor network

Container harbors

- Main events
  - Ship i arrives to harbor j
    - Ship i to queue of harbor j at time t
    - Try to start loading (if queue empty)
  - Loading begins at a dock
    - Ship i from queue, dock k reserved, loading end event for time t2

Container harbours

- Main events
  - Unloading of the ship ends
    - Dock k becomes free at t3
    - Try to start loading (if ships in queue)
  - Ship leaves for the next harbor
    - Ship i is scheduled to arrive to harbor j' at t4

Questions ?

- Main events
  - Ship i arrives to harbor j
    - Ship i enters the queue of j at time t
    - What information is contained in the event notice. How the rest is communicated.
  - Unloading begins
    - Ship i taken from the queue, dock k reserved, end unloading –event for time t1
    - Is reference to dock k needed, where to keep link to ship i

Questions?

- Main events
  - Unloading ends
    - Dock k becomes free at time t3
    - Where is knowledge about the dock, about the ship
  - Ship leaves for next harbor
    - Arrival of ship i to harbor j’ is scheduled at time t4
    - Who knows the value of j’ for ship i

Event notices

- For traditional languages event notices are problematic
  - Static data types
  - Limited amount of information can be communicated
- Use of objects and inheritance helps
  - Inherited notice class for each type of event