3C03 Concurrency: Semaphores and Monitors

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Goals

- *Introduce concepts of*
  - *Semaphores*
  - *Monitors*
- *Implementation in Java*
  - *synchronised methods and private attributes*
  - *single thread active in the monitor at any time*
  - *wait, notify and notifyAll*

Semaphores

- *Introduced by Dijkstra' in 1968*
- *ADT with counter and waiting list*

P/Wait/Down:

```
if (counter > 0)
  counter--
else
  add caller to
  waiting list
```

S/Signal/Up:

```
if (threads wait)
  activate waiting
  thread
else
  counter++
```


Semaphores and Mutual Exclusion

- *One semaphore for each critical section*
- *Initialize semaphore to 1.*
- *Embed critical sections in wait/signal pair*
- *Example in Java:*

```
Semaphore S=new Semaphore(1);
S.down();
<critical section>
S.up();
```

Demo: Semaphores

Evaluation of Semaphores

+ Nice and simple mechanism
+ Can be efficiently implemented
+ Available in every programming language
– Too low level of abstraction
– Unstructured use of signal and wait leads to spaghetti synchronisation
– Error prone and errors are dangerous
  – Omitting signal leads to deadlocks
  – Omitting wait leads to safety violations

Semaphore in Java

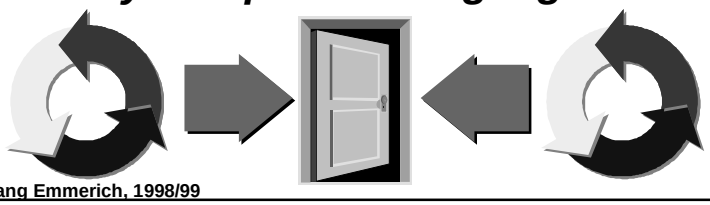
```
class Semaphore {
  private int value_;
  Semaphore (int initial) {
      value_ = initial;
  }
  synchronized public void up() {
    ++value_;
    notify();
  }
  synchronized public void down() {
   while (value_== 0) {
    try {wait();} catch(InterruptedException e){}
   }
   --value_;
  }
}
```

Critical Regions

- *Guarantee mutual exclusion by definition*
- *Note subtle difference to critical sections*
- *language features implement critical regions*
- *Example: Java synchronised method*

Monitors

- *Hoare's response to Dijkstra's semaphores*
  - *Higher-level*
  - *Structured*
- *Monitors encapsulate data structures that are not externally accessible*
- *Mutual exclusive access to data structure enforced by compiler or language run-time*



Monitors in Java

- *All instance and class variables need to be* `private` *or* `protected`
- *All methods need to be* `synchronised`
- *Example: semaphore implementation*
- *Use of Monitors: Carpark Problem*

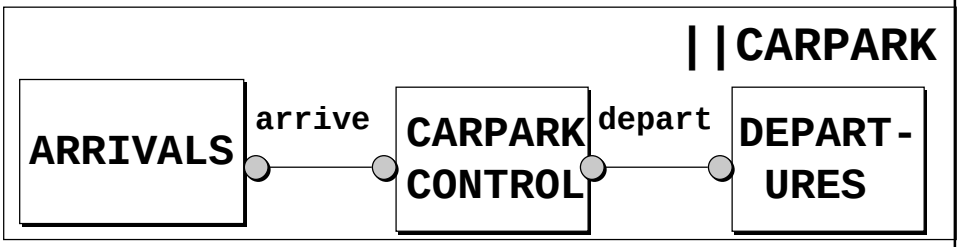
Carpark Problem

- *Only admit cars if carpark is not full*
- *Cars can only leave if carpark is not empty*
- *Car arrival and departure are independent threads*

Demo: CarPark

Carpark Model

- ***Events or actions of interest:***
  - ***Arrive and depart***
- ***Processes:***
  - ***Arrivals, departures and carpark control***
- ***Process and Interaction structure:***



Carpark FSP Specification

```
CARPARKCONTROL(N=4) = SPACES[N],
SPACES[i:0..N] =
       (when(i>0) arrive-> SPACES[i-1]
       |when(i<N) depart-> SPACES[i+1]
       ).
ARRIVALS = (arrive-> ARRIVALS).
DEPARTURES = (depart-> DEPARTURES).
||CARPARK =
 (ARRIVALS||CARPARKCONTROL||DEPARTURES).
```

LTSA

Java Class Carpark

```
public class Carpark extends Applet  {
 final static int N=4;
 public void init() {
  CarParkControl cpk = new CarParkControl(N);
  Thread arrival,departures;
  arrivals=new Thread(new Arrivals(cpk));
  departures=new Thread(new Departures(cpk));
  arrivals.start();
  departures.start();
 }
}
```


Java Classes Arrivals & Departures

```
public class Arrivals implements Runnable {
    CarParkControl carpark;
    Arrivals(CarParkControl c) {carpark = c;}
    public void run() {
     while (true) carpark.arrive();
   }
}
class Departures implements Runnable {
 ...
 public void run() {
    while (true) carpark.depart();
}
```

Java Class CarParkControl (Monitor)

```
class CarParkControl {// synchronisation?
  private int spaces;
  private int N;
  CarParkControl(int capacity) {
    N = capacity;
    spaces = capacity;
  }
  synchronized public void arrive() {
    … -- spaces; … } {// Block if full?
  synchronized public void depart() {
    … ++ spaces; …   {// Block if empty?
  }
}
```


Problems with CarParkControl

- *How do we send arrivals to sleep if car park is full?*
- *How do we awake it if space becomes available?*
- *Solution: Condition synchronisation*

Summary

- *Semaphores*
- *Monitors*
- *Next session:*
  - *Java condition synchronization*
  - *Relationship between FSP guarded actions and condition synchronization*
  - *Fairness and Starvation*