C340 Concurrency:
Semaphores and Monitors

Wolfgang Emmerich

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***

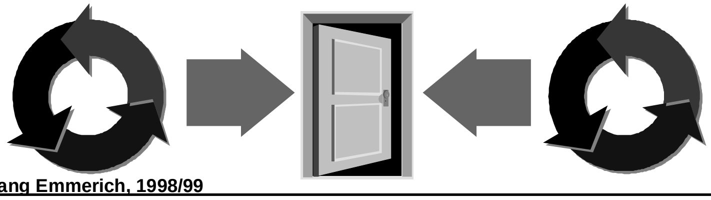
```
class Semaphore {
    private int value_;
    Semaphore (int initial) {
        value_ = initial;
    }
    synchronized public void up() {
        ++value_;
        notify();
    }
    synchronized public void down() {
        while (value_== 0) {
            try {wait();} catch
  (InterruptedException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

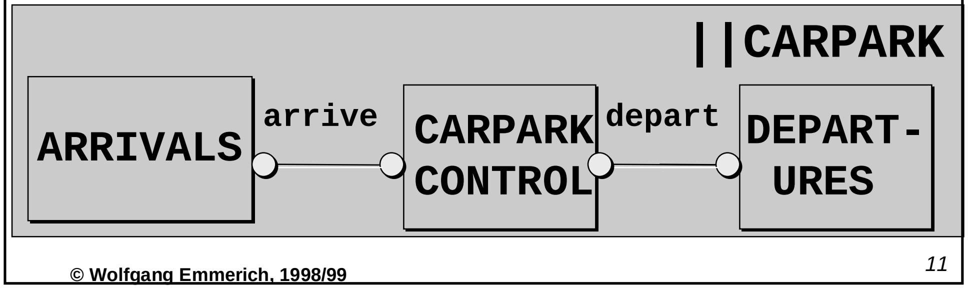
Carpark Problem

- *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

ARRIVALS

arrive

CARPARK CONTROL

depart

DEPARTURES

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***