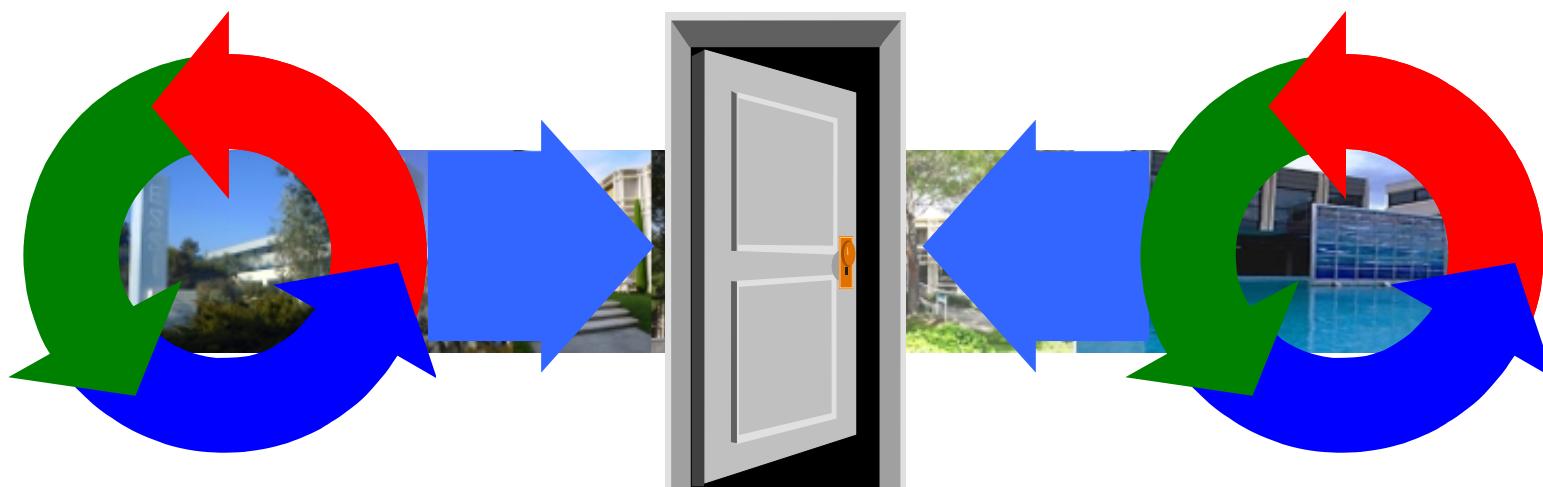


# Moniteurs

[riveill@unice.fr](mailto:riveill@unice.fr)

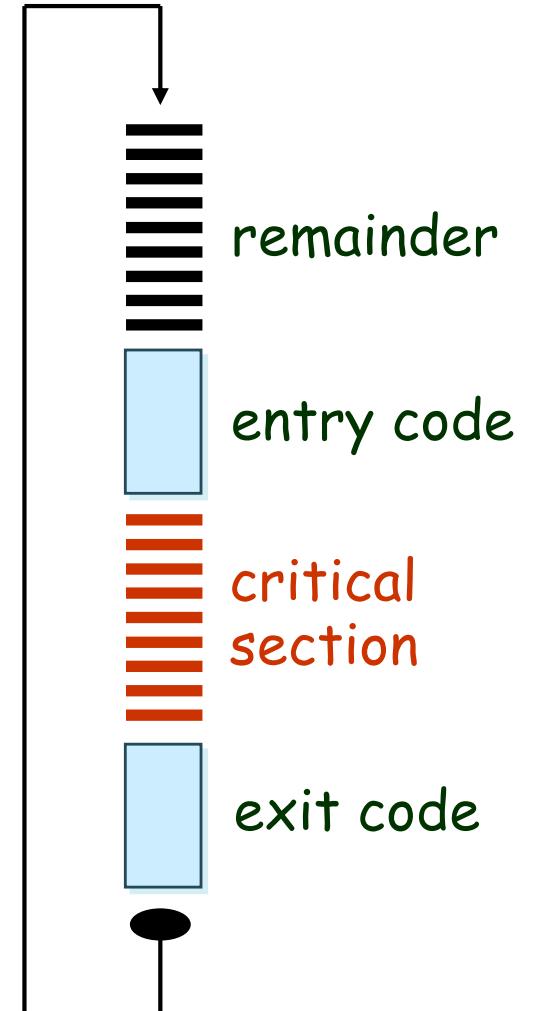
<http://www.i3s.unice.fr/~riveill>



## Rappel du cours précédent (mes fiches de révision)

# The mutual exclusion problem

- **Mutual Exclusion:** No two processes are in their critical sections at the same time.
- **Deadlock-freedom:** If a process is trying to enter its critical section, then some process, not necessarily the same one, eventually enters its critical section.
  - Property of safety
- **Starvation-freedom:** If a process is trying to enter its critical section, then this process must eventually enter its critical section.
  - Property of liveness
  - No assumption time
  - All process execute an equivalent algorithms



# Semaphores

- Semaphores are widely used for dealing with inter-process synchronization in operating systems.  
*Semaphore s* is an 'integer variable' that can take only positive or null values.
- The only operations permitted on *s* are *up(s)* and *down(s)*. Blocked processes are held in a FIFO queue.

*down(s): if s > 0 then* // originally P(s)

decrement *s*

**else**

block execution of the calling process

*up(s): if processes blocked on s then* // originally V(s)

awaken one of them

**else**

increment *s*

# Mise en œuvre d'une section critique

- Solution 1
  - Utilisation d'un verrou
  - En Java : **synchronized** ou class **Lock**
- Solution 2
  - Utilisation d'un mutex
  - Rappel : un mutex est un sémaphore initialisé à 1
  - En Java : class **Semaphore**
- Solution 3
  - Utilisation d'un algorithme par attente active
  - Plus efficace en général mais plus difficile à utiliser  
→ attention au respect des hypothèses : **lectures et écritures atomique**
  - En Java : **volatile** (ne fonctionne pas sur les tableaux)

# Propriétés

- ◆ A **safety property** asserts that **nothing bad** happens.
  - ◆ In complex systems, it is usually better to specify **safety properties** by stating directly what **is** required
    - property** **MUTEX** = (**enter** -> **exit** -> **MUTEX**) .
- A **liveness property** asserts that something **good eventually** happens.
  - A **progress property** asserts that it is *always* the case that an action is *eventually* executed.

```
// enter always executed  
progress L = {enter}  
  
// enter or exit always executed  
progress M = {enter, exit}
```

Tout ce qui est dans les transparents  
précédents est supposé être connu

# Monitor

# monitors & condition synchronization

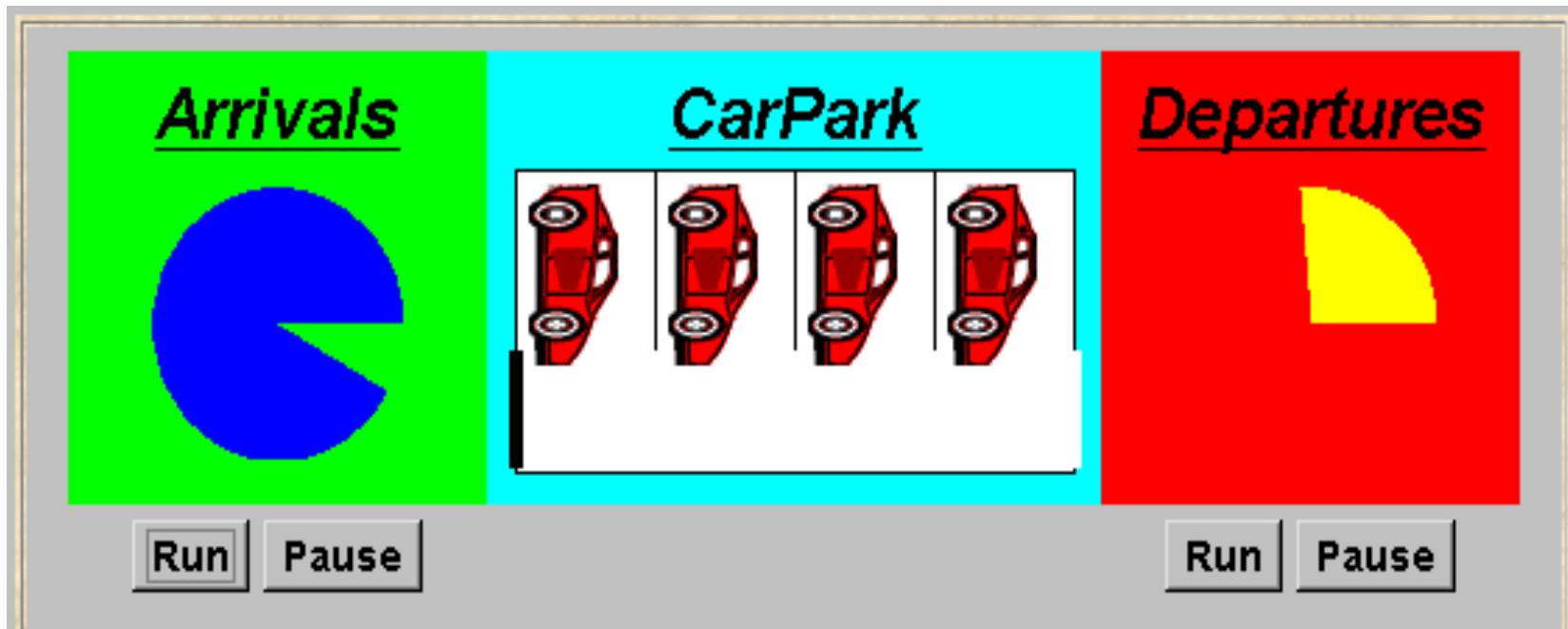
- **Concepts:** monitors
  - encapsulated data + access procedures
  - mutual exclusion + condition synchronization
  - single access procedure active in the monitor
  - nested monitors
- **Models:** guarded actions
- **Practice:** private data and synchronized methods (exclusion).
  - `wait()`, `notify()` and `notifyAll()` for condition synch.
  - single thread active in the monitor at a time

# Moniteur versus sémaphore

- Deux concepts différents pour un même objectif
  - Faire coopérer des processus
  - Sémaphore
    - Inventé par Edsger Dijkstra en 1962
    - Implémenté dans de très nombreux systèmes d'exploitation
  - plutôt système d'exploitation / moins structurants
  - Moniteur
    - Définie par C. A. R. Hoare en 1974
    - Implémenté par Per Brinch Hansen en 1975 dans une version concurrente du langage Pascal
  - plutôt langage / plus structurants
- En général, on n'utilise pas les 2 concepts en même temps
  - Les effets d'un outil sur l'autre ne sont généralement pas spécifiés

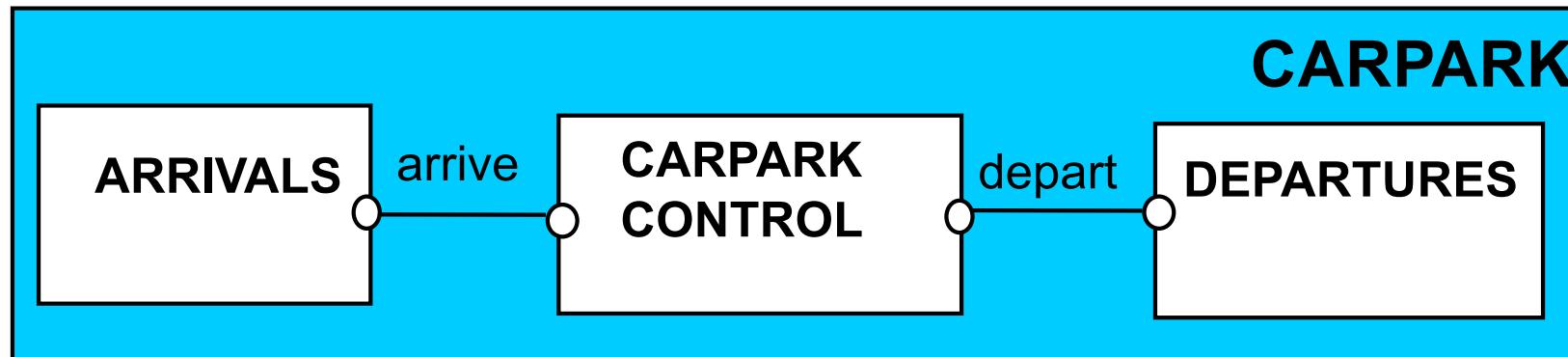
# Condition synchronization

- A controller is required for a carpark, which only permits cars to enter when the carpark is not full and does not permit cars to leave when there are no cars in the carpark. Car arrival and departure are simulated by separate threads.



# carpark model

- ◆ Events or actions of interest?
  - arrive and depart
- ◆ Identify processes
  - arrivals, departures and carpark control
- ◆ Define each interactions (structure).



# carpark model

- **Guarded actions** are used to control **arrive** and **depart**.

```
const N = 4
```

```
ARRIVALS = (arrive->ARRIVALS) .
```

```
DEPARTURES = (depart->DEPARTURES) .
```

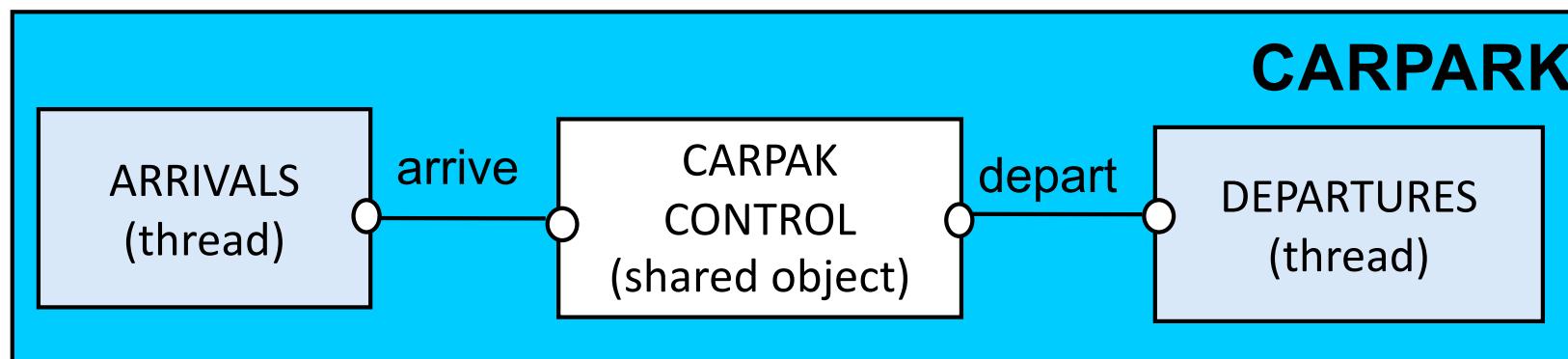
```
CARPARKCONTROL = SPACES[N] ,
```

```
SPACES[i:0..N] = (when(i>0) arrive->SPACES[i-1]
| when(i<N) depart->SPACES[i+1]
) .
```

```
|| CARPARK = (ARRIVALS || CARPARKCONTROL || DEPARTURES) .
```

# carpark program

- ◆ **Model** - all entities are **processes** interacting by actions
- ◆ **Program** - need to identify **threads** and **shared object**
  - ◆ **Thread** - **active** entity which initiates (output) actions
  - ◆ **Shared object** - **passive** entity which responds to (input) actions, need synchronisation
    - ◆ Shared between thread



# Comment mettre en œuvre la synchronisation avec des sémaphores ?

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

- Sémaphore possède
  - 1 compteur
  - 1 primitive (down) qui bloque quand le compteur est à 0
  - 1 primitive (up) qui libère un processus ou incrémente le compteur
- On peut implémenter facilement  

```
CARPARKCONTROL = SPACES[N],  
SPACES[i:0..N] = (when(i>0) arrive->SPACES[i-1]
```

→ Utilisation d'un sémaphore *i*, initialisé à **N**

# Comment mettre en œuvre la synchronisation avec des sémaphores ?

- Pour l'autre action **when (*i*<*N*) depart->SPACES [*i*+1]**
  - il faut se ramener dans la même situation i.e.  
**when (*x* > 0) depart -> SPACES [*x*-1]**
- Possible, en introduisant une variable *j* tel que *i+j = N*  
**CARPARKCONTROL = SPACES [*N*] [0],  
SPACES [*i*:0..*N*] [*j*:0..*N*] =  
(when (*i*>0) arrive->SPACES [*i*-1] [*j*+1]  
| when (*j*>0) depart->SPACES [*i*+1] [*j*-1]).**
- Solution finale
  - 2 sémaphores : *i* = Semaphore(*N*) ; *j* = Semaphore(0)

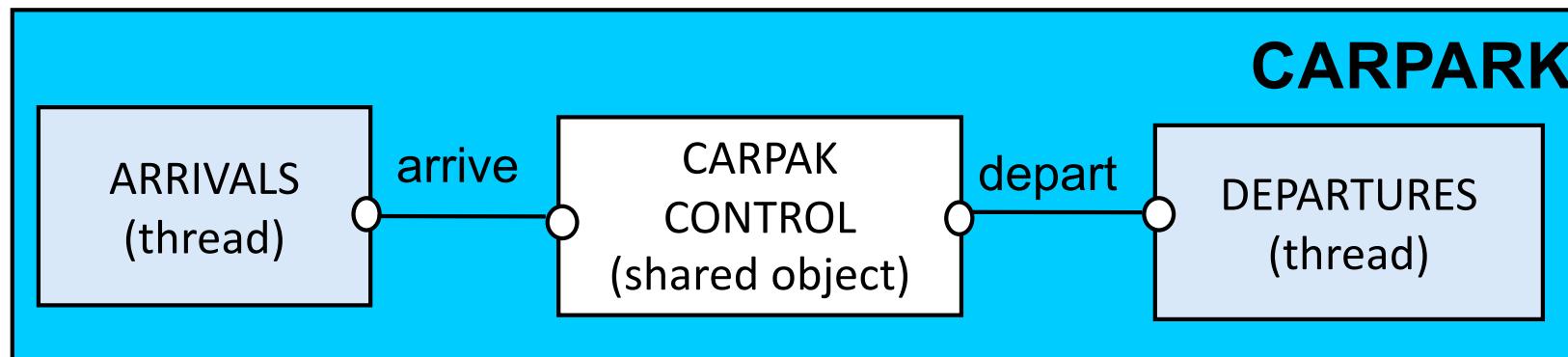
**when (*i*>0) arrive->SPACES [*i*-1] [*j*-1]  
→ down (*i*) ; up (*j*) ; arrive**

**when (*j*>0) depart->SPACES [*i*+1] [*j*-1]  
→ down (*j*) ; up (*i*) ; depart**

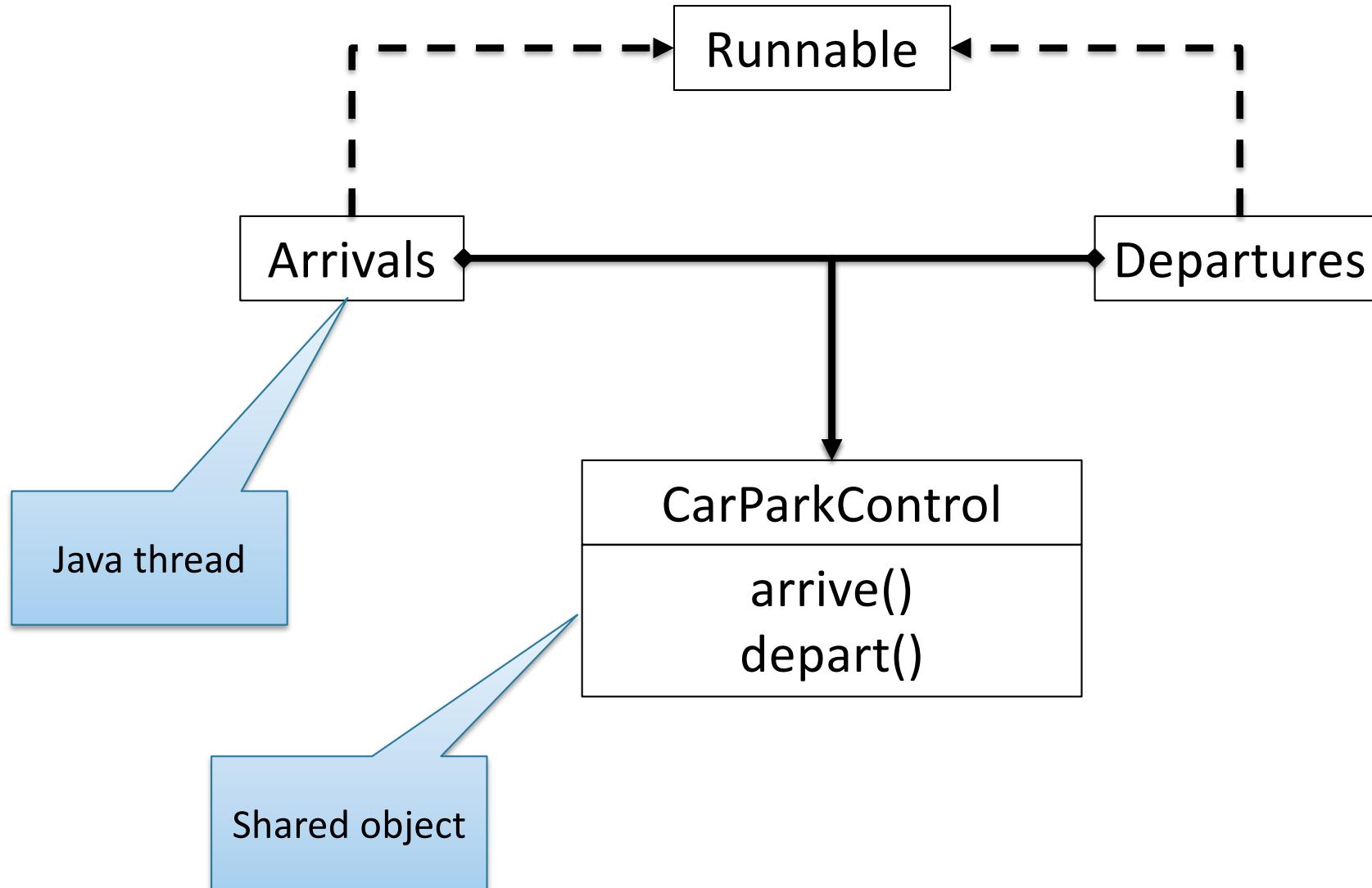
# carpark program

## Another implementation with monitor

- ◆ **Model** - all entities are **processes** interacting by actions
- ◆ **Program** - need to identify **threads** and **shared object**
  - ◆ **thread** - **active** entity which initiates (output) actions
  - ◆ **monitor** - **passive** entity which responds to (input) actions
    - ◆ Shared between thread



# Autre approche en utilisant un objet moniteur



# carpark program

- The **active** entities of the model
  - **Arrivals** and **Departures** (FSP model)
  - Are implemented in Java by a thread (implement **Runnable** interface)
- The **passive** entity of the model
  - **CarParkControl** (FSP model)
  - **Provides the control** (condition synchronization)
  - Are implemented in Java by a **shared object**
- All instances of these are created by the **main()** method

```
public void main() {  
    CarParkControl c = new CarParkControl(Places);  
    arrivals.start(new Arrivals(c));  
    departures.start(new Departures(c));  
}
```

# carpark program - Arrivals and Departures threads

```
class Arrivals implements Runnable {  
    CarParkControl carpark;  
  
    Arrivals(CarParkControl c) {carpark = c;}  
  
    public void run() {  
        try {  
            while(true) {  
                ThreadPanel.rotate(330);  
                carpark.arrive();  
                ThreadPanel.rotate(30);  
            }  
        } catch (InterruptedException e) {}  
    }  
}
```

Similarly  
**Departures** which  
calls  
**carpark.depart()**  
.

- How do we implement the control of **CarParkControl**?

# Carpark program - CarParkControl monitor

```
class CarParkControl {  
    protected int spaces;  
    protected int capacity;  
  
    CarParkControl(int n)  
        {capacity = spaces = n; }  
  
    synchronized void arrive() { condition synchronization?  
        ... --spaces; ...  
    }  
  
    synchronized void depart() {  
        ... ++spaces; ...  
    }  
}
```

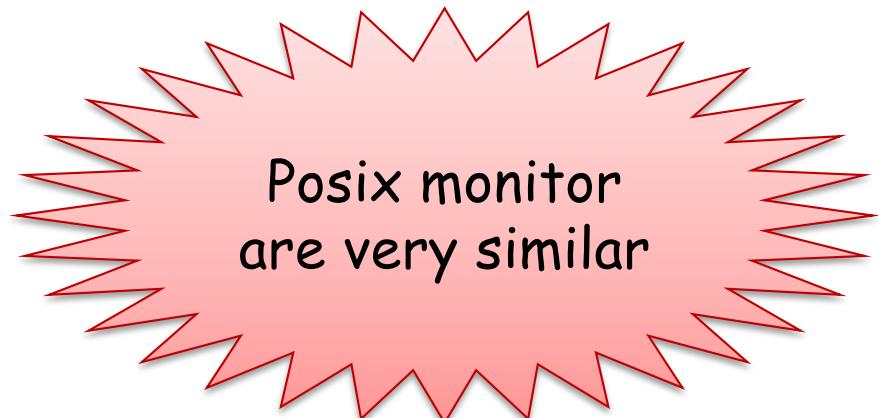
*mutual exclusion by synchronized methods*

*block if full? (spaces==0)*

*block if empty? (spaces==N)*

# Hoare Monitor = Mutex + Condition variables

- **Mutex**
  - Ensure mutual exclusion execution of the procedures
- Condition synchronisation/**Condition variables**
  - **Primitive** to block or restart process execution
- There are mainly three main operations on condition variables:
  - **wait c, m**, where:
    - **c** is a condition variable
    - **m** is a mutex (lock)
  - **signal c**
  - **broadcast c**



# Java monitor

- Mutex
  - Use **synchronized method**
- Condition synchronization

- Java provides a thread **wait set** per monitor with the following methods:

```
public final void wait() throws  
InterruptedException
```

- Waits to be notified by another thread. The waiting thread releases the synchronization lock associated with the monitor.
- When notified, the thread must wait to reacquire the monitor before resuming execution.

```
public final void notify()
```

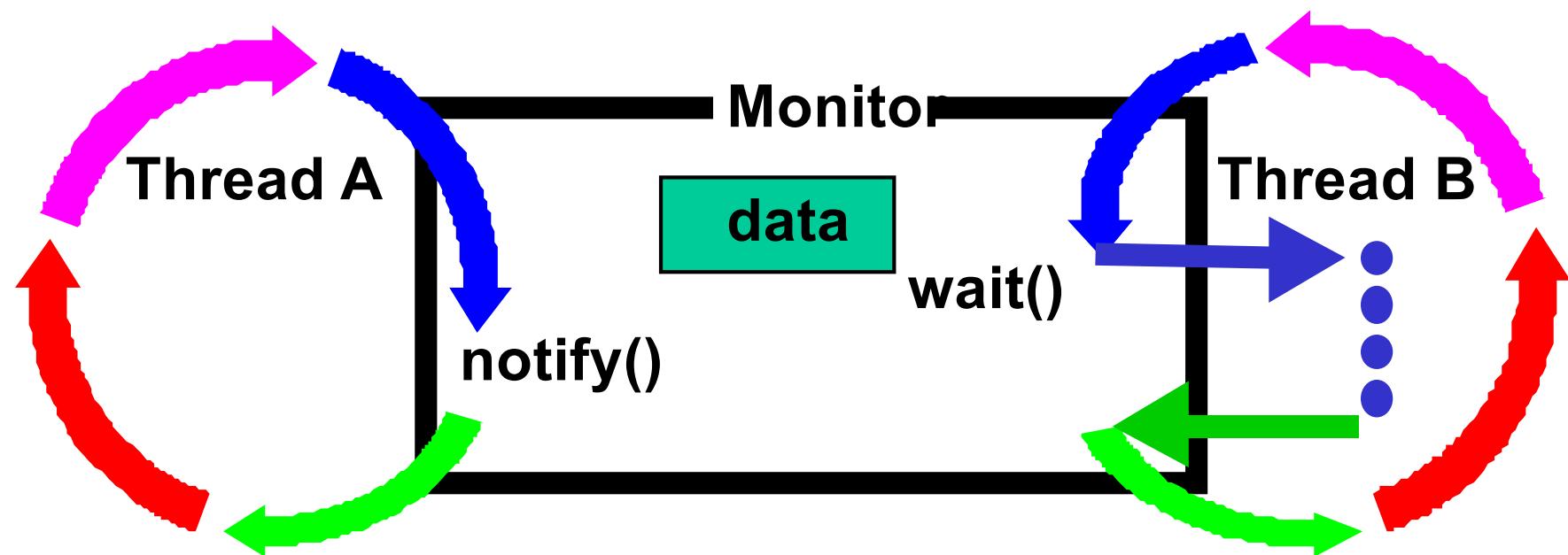
- Wakes up a single thread that is waiting on this object's wait set.

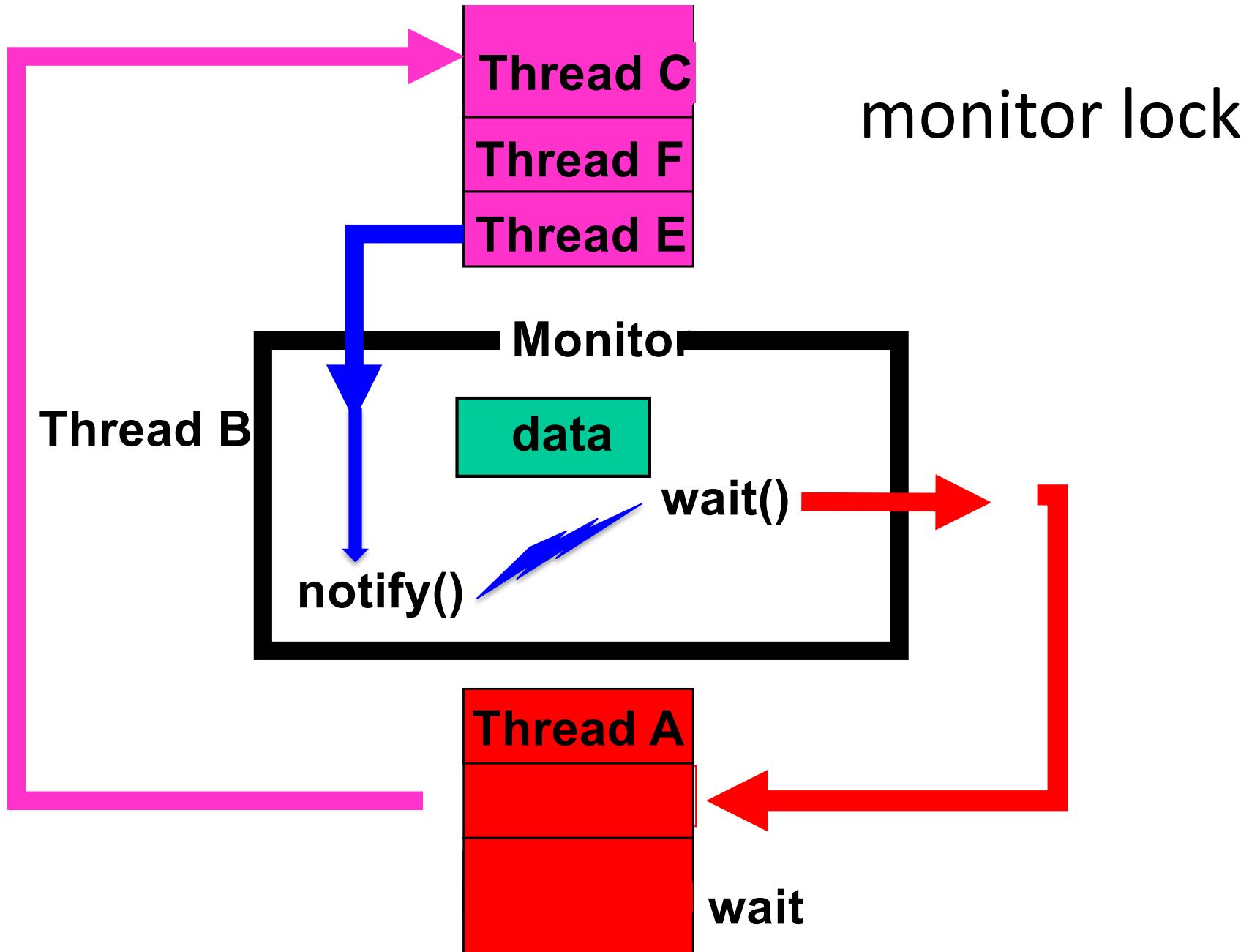
```
public final void notifyAll()
```

- Wakes up all threads that are waiting on this object's wait set.

# condition synchronization in Java

- We refer to a thread *entering* a monitor when it acquires the mutual exclusion lock associated with the monitor and *exiting* the monitor when it releases the lock.  
**Wait()** - causes the thread to exit the monitor, permitting other threads to enter the monitor.





# condition synchronization in Java

- FSP:

when *cond* act -> NEWSTAT

- Java:

```
public synchronized void act()  
throws InterruptedException  
{  
    while (!cond) wait();  
    // modify monitor data  
    notifyAll()  
}
```

- The **while** loop is necessary to retest the condition *cond* to ensure that *cond* is indeed satisfied when it re-enters the monitor.
- **notifyAll()** is necessary to awaken other thread(s) that may be waiting to enter the monitor now that the monitor data has been changed.

# CarParkControl - condition synchronization

FSP

```
CARPARKCONTROL = SPACES[N],  
SPACES[spaces:0..N] = (when(spaces>0) arrive -> SPACES[spaces-1]  
|when(spaces<N) depart -> SPACES[spaces+1]).
```

Java

```
class CarParkControl {  
    protected int spaces;  
    protected int N;  
    CarParkControl(int n) { N=spaces=n; }  
  
    synchronized void arrive() throws InterruptedException {  
        while (spaces<=0) wait();  
        --spaces;  
        notifyAll();  
    }  
  
    synchronized void depart() throws InterruptedException {  
        while (spaces>=N) wait();  
        ++spaces;  
        notifyAll();  
    }  
}
```

# CarParkControl - condition synchronization

## FSP

```
CARPARKCONTROL = SPACES[N],  
SPACES[spaces:0..N] = (  
    when(spaces>0) arrive -> SPACES[spaces-1]  
    | when(spaces<N) depart -> SPACES[spaces+1]).
```

## Java

```
class CarParkControl {  
    protected int spaces;  
    protected int N;  
    CarParkControl(int n) { N=spaces=n; }  
  
    synchronized void arrive() throws InterruptedException  
{  
        while (spaces<=0) wait();  
        --spaces;  
        notifyAll();  
    }  
  
    synchronized void depart() throws InterruptedException {  
        while (spaces>=N) wait();  
        ++spaces;  
        notifyAll();  
    }  
}
```

# CarParkControl - condition synchronization

## FSP

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

## Java

```
class CarParkControl {  
    protected int spaces;  
    protected int N;  
    CarParkControl(int n) { N=spaces=n; }  
  
    synchronized void arrive() throws InterruptedException {  
        while (spaces<=0) wait();  
        --spaces;  
        notifyAll();  
    }  
  
    synchronized void depart() throws InterruptedException {  
        while (spaces>=N) wait();  
        ++spaces;  
        notifyAll();  
    }  
}
```

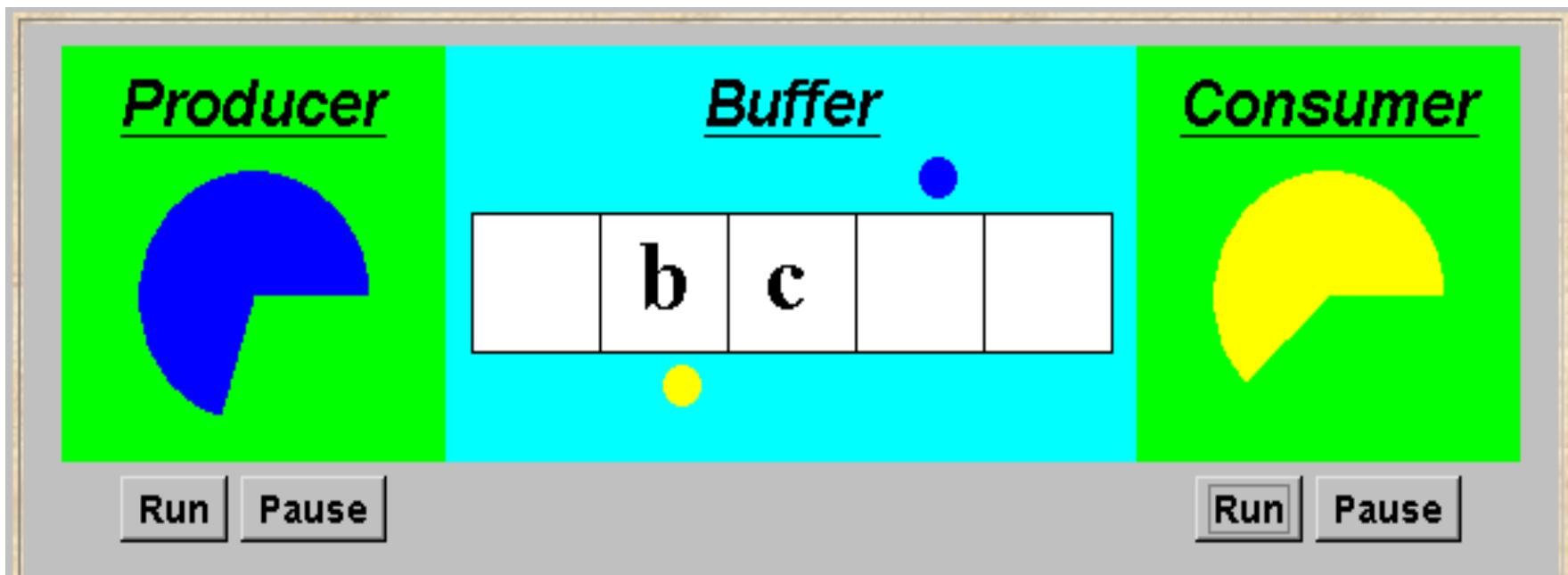
# Summary – Monitors

- **Modelling**
  - **Active** entities (that initiate actions) are implemented as **threads**.
  - **Passive** entities (that respond to actions) are implemented as **monitors**.
- **Concurrency**
  - Each guarded action in the model of a monitor is implemented as a **synchronized** method which uses a while loop and **wait()** to implement the guard. The while loop condition is the negation of the model guard condition.
  - Changes in the state of the monitor are signaled to waiting threads using **notify()** or **notifyAll()** .
  - **Rmq:** Java implement only one variable condition
- if you want more variable conditions
  - package **java.util.concurrent.lock**
  - Declare one Lock (**lock()**, **unlock()**) + many conditions (**signal()**, **await()**)
  - **Attention :** signal & await must necessarily be within an area protected by a lock

Nesteed monitor  
or nesteed semaphore  
or nesteed Lock

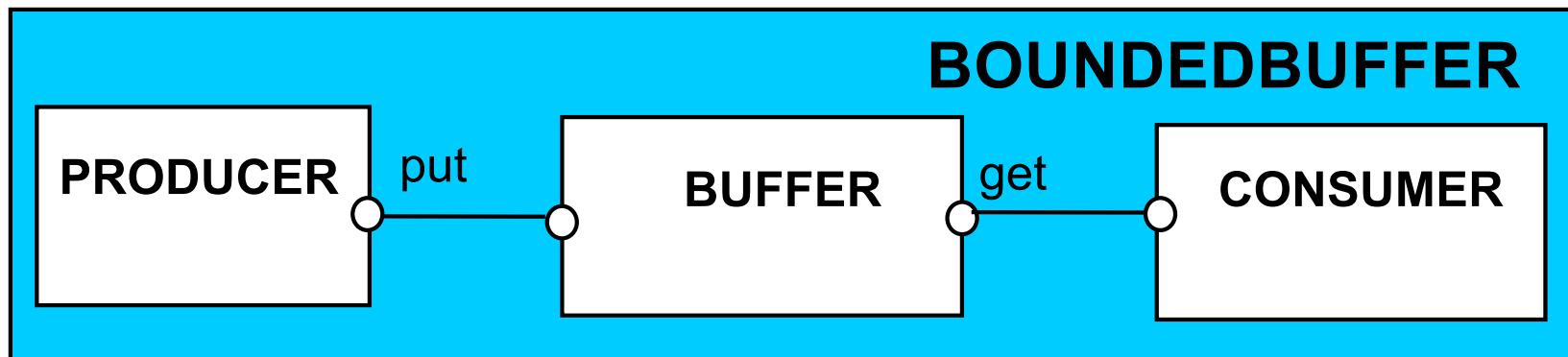
# Bounded Buffer

- A bounded buffer consists of a fixed number of slots. Items are put into the buffer by a *producer* process and removed by a *consumer* process. It can be used to smooth out transfer rates between the *producer* and *consumer*.

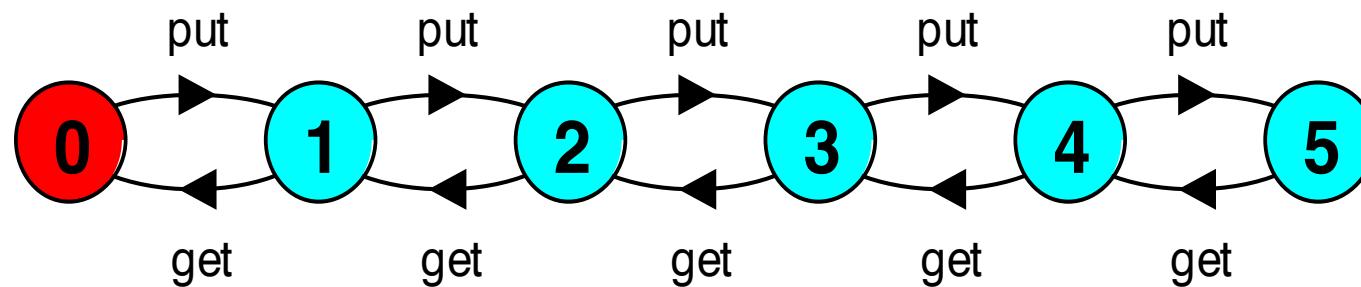


# bounded buffer - a data-independent model

- The behaviour of BOUNDED BUFFER is independent of the actual data values, and so can be modelled in a data-independent manner.



- LTS:



# bounded buffer - a data-independent model

```
const N = 5
BUFFER = COUNT[0],
COUNT[i:0..N]
    = (when (i<N) put->COUNT[i+1]
      |when (i>0) get->COUNT[i-1]
    ) .

PRODUCER = (put->PRODUCER) .
CONSUMER = (get->CONSUMER) .

||BOUNDEDBUFFER = (PRODUCER||BUFFER||CONSUMER) .
```

# bounded buffer program - producer process

```
class Producer implements Runnable {  
    Buffer buf;  
    String alphabet= "abcdefghijklmnopqrstuvwxyz";  
  
    Producer(Buffer b) {buf = b; }  
  
    public void run() {  
        try {  
            int ai = 0;  
            while(true) {  
                ThreadPanel.rotate(12);  
                buf.put(alphabet.charAt(ai));  
                ai=(ai+1) % alphabet.length();  
                ThreadPanel.rotate(348);  
            }  
        } catch (InterruptedException e) {}  
    }  
}
```

Similarly **Consumer**  
which calls  
**buf.get()**.

# bounded buffer program

## Solution 1 : buffer monitor

```
public interface Buffer <E> {...}

class BufferMonitor <E> implements Buffer <E> {
    ...
    public synchronized void put(E o)
        throws InterruptedException {
        while (count>=size) wait();
        buf[in] = o; ++count; in=(in+1)%size;
        notifyAll();
    }
    public synchronized E get()
        throws InterruptedException {
        while (count<=0) wait();
        E o = buf[out];
        buf[out] = null; --count; out=(out+1)%size;
        notifyAll();
        return (o);
    }
}
```

# bounded buffer program

## Solution 2 : buffer semaphore

```
class BufferSemaphore <E> implements Buffer <E> {  
    Semaphore full; //counts number of items  
    Semaphore empty; //counts number of spaces  
    SemaBuffer(int size) {  
        this.size = size; buf =(E[])new Object[size];  
        full = new Semaphore(0);  
        empty= new Semaphore(size);  
    }  
    public synchronized void put(E o) throws InterruptedException {  
        empty.down();  
        buf[in] = o;  
        ++count; in=(in+1)% size;  
        full.up();  
    }  
    public synchronized E get() throws InterruptedException {  
        full.down();  
        E o = buf[out]; buf[out]=null;  
        --count; out=(out+1)% size;  
        empty.up();  
        return (o);  
    }  
}
```

# nested synchronization - bounded buffer semaphore model

```
const Max = 5
range Int = 0..Max

SEMAPHORE ...as before...

BUFFER =  (put -> empty.down ->full.up ->BUFFER
           |get -> full.down ->empty.up ->BUFFER
           ).

PRODUCER = (put -> PRODUCER).

CONSUMER = (get -> CONSUMER).

||BOUNDED BUFFER = (PRODUCER || BUFFER || CONSUMER
                     || empty:SEMAPHORE(5)
                     || full:SEMAPHORE(0)

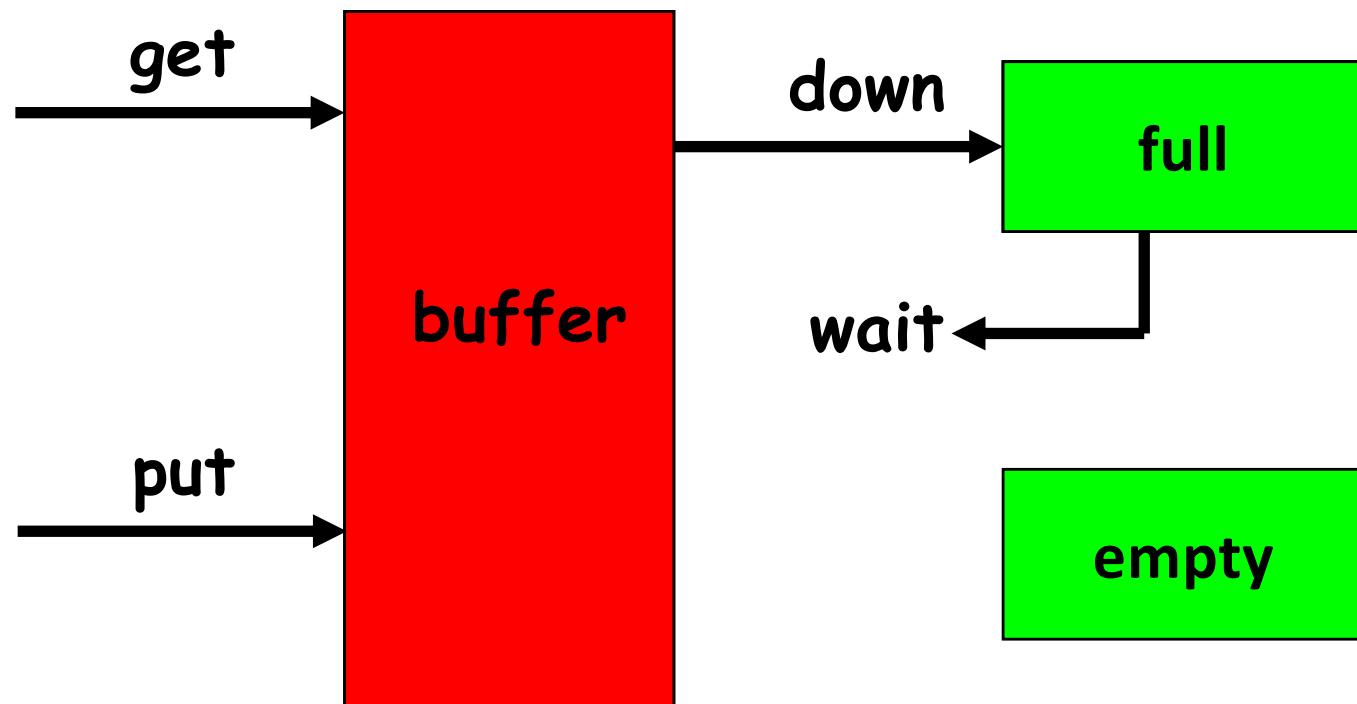
                     ) @{put, get}.
```

# nested monitors - bounded buffer model

- *LTS*A analysis predicts a possible **DEADLOCK**:  
Composing  
potential DEADLOCK  
States Composed: 28 Transitions: 32 in 60ms  
Trace to DEADLOCK:  
get
- The Consumer tries to get a character, but the buffer is empty. It blocks and releases the lock on the semaphore full. The Producer tries to put a character into the buffer, but also blocks. **Why?**
- This situation is known as the ***nested monitor problem***.
  - And occur when a monitor call another monitor

# nested monitors - bounded buffer model

```
synchronized public Object get()
    throws InterruptedException{
    full.down(); // if no items, block!
    ...
}
```



# nested monitors - revised bounded buffer program

- The only way to avoid it in Java is **by careful design**. In this example, the deadlock can be removed by ensuring that the monitor lock for the buffer is not acquired until *after* semaphores are decremented.

```
public void put(E o)
                throws InterruptedException {
    empty.down();
    synchronized(this) {
        buf[in] = o; ++count; in=(in+1)%size;
    }
    full.up();
}
```

# nested monitors - revised bounded buffer model

Incorrect implementation:

```
BUFFER = (put -> empty.down ->full.up ->BUFFER  
| get -> full.down ->empty.up ->BUFFER  
).
```

```
PRODUCER = (put -> PRODUCER) .
```

```
CONSUMER = (get -> CONSUMER) .
```

Correct implementation:

```
BUFFER = (put -> BUFFER  
| get -> BUFFER  
).
```

```
PRODUCER = (empty.down->put->full.up->PRODUCER) .
```

```
CONSUMER = (full.down->get->empty.up->CONSUMER) .
```

# nested monitors - revised bounded buffer model

- The semaphore actions have been moved to the producer and consumer. This is exactly as in the implementation where the semaphore actions are *outside* the monitor .
- ***Does this behave as desired?***

Compose & minimise

Composition:

DEFAULT = CONSUMER || PRODUCER || BUFFER

State Space:  $3 * 3 * 1 = 2^{** 4}$

Composing...

-- States: 9 Transitions: 18 Memory used: 2899K

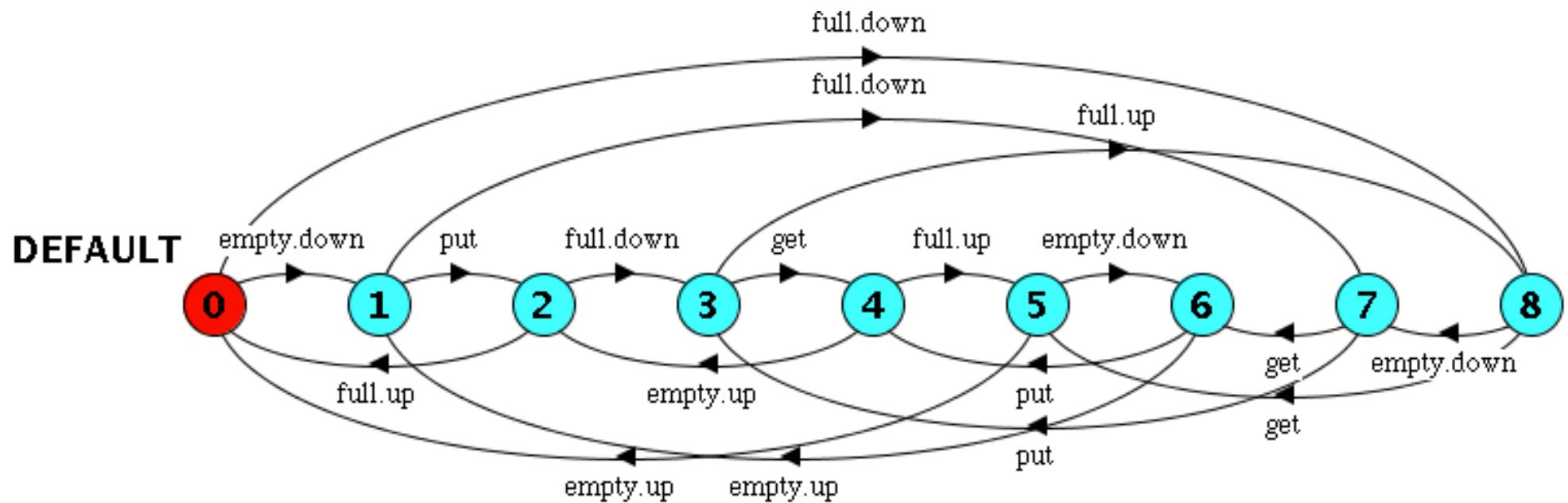
Composed in 36ms

DEFAULT minimising..

Minimised States: 9 in 0ms

**No deadlock detected**

# nested monitors - revised bounded buffer model



# Summary

## ◆ Concepts

- monitors: encapsulated data + access procedures
  - mutual exclusion + condition synchronization
- semaphores: encapsulated counter
- nested synchronisation

## ◆ Model

- guarded actions

## ◆ Practice

- private data and synchronized methods in Java
- monitors
  - `wait()`, `notify()` and `notifyAll()` for condition synchronization
  - single thread active in the monitor at a time : use `synchronized` method
- semaphores
  - `up()`, `down()`

## Q&A

<http://www.i3s.unice.fr/~riveill>

