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Real-Time and Concurrent Programming

Lecture 4 (F4):

Monitors: synchronized, wait and notify

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Monitors and synchronized objects

Upcoming Monitor content

- Language construct for synchronization of threads
- More practical than semaphores
- Fits in well with object orientation
- Supported by synchronized in Java
- Signaling supported inside locked objects

Mutual exclusion as part of interface

In-line use of semaphores for mutual exclusion

Disadvantage: `take`/`give` tends to get spread out through the entire program (learned from exercise 1).

Abstract data-types for mutual exclusion

Principle: `take`/`give` part of (mutually exclusive) methods that are kept together with the hidden data.

Monitor: Such a data-type with mutually exclusive access-functions is called a *Monitor*.

Monitors (objects & concept)

- In OOP we use classes as a (more powerful) mean to accomplish abstract data-types.
- Objects with such mutually exclusive methods are then monitor objects.

For a class like `Account`:

```
class Account {
  // ...
  void deposit(int a){
    mutex.take();
    balance += a;
    mutex.give();
  }
}
```

the monitor concept is implemented by using semaphores.

Monitor == Semaphore

Semaphores and Monitors are equivalent since:

- Semaphores (for threads but not for interrupt routines) can be (and are in standard Java) implemented by a monitor (with methods `take` and `give`).
- Monitors can be implemented by semaphores, for a given set of threads (using one `MutexSem` per monitor, and one `CountingSem` for each thread per monitor).

Thus, a specific implementation using one mechanism can (even if hard) always be reimplemented using the other.

Use the right technique depending on the problem to solve!

Language support for Monitors

Problem: Using semaphores requires (too much) discipline.

Idea: Provide support via language constructs.

Degree of language support:

- None [C/C++]: Manual calls (as with mutex; take/give) using library functions. Object-orientation may simplify usage.
- Explicit per method[Java]: Declared property of methods (language and run-time support).
- Implicit per task [Ada]: Declared property of class (implicitly applies to all methods and data).

"None", i.e. no support, results in more complicated programming.
"Implicit" language support safest and simplest but can limit applicability.
"Explicit" with mutually exclusive methods is the pragmatic Java approach.

Abstractions

Thread:
Performs execution using a processor.

Execution state:
Thread status stored in context.

Mutual exclusion:
Restriction on context switching

In Java we have

- threads represented by objects of type Thread,
- state of execution as in sequential programming,
- `synchronized` methods for mutual exclusion.

The purpose of abstractions is to cope with complexity...

Objects and concurrency

Object properties		Implicit mutual exclusion of methods		Comment
Thread	Exec. state	No	Yes	
No	No	Object [1]	Monitor [2]	Passive objects
No	Yes	Coroutine [3]	'Co-monitor' [4]	Not in Java
Yes	No	— [5]	— [6]	Not useful
Yes	Yes	Thread-object [7]	Task [8]	Active objects

[1] The objects as in object oriented programming.
[2] The monitors we accomplish by using `synchronized`.
[3] Named Fibers (by Microsoft) when managed by OS.
[7] Our active objects, not being monitors too!
[8] Avoid; less practical and not supported in Java.

Object categories

- Thread object:
  - Active object (if started but not terminated); drives execution.
  - Don't call me, I'll call you!
- Monitor object:
  - Mutually exclusive methods, e.g., by using synchronized.
  - Should be passive; do not mix monitors and threads!
- Plain passive object:
  - Thread safe by reentrant methods (java.lang.Math)
  - Explicitly thread unsafe; to be used by a single thread (java.util.HashSet)
  - Implicitly thread unsafe; has to be assumed if not documented.

Java-supported monitors

- In Java: Critical region/block/method is declared using the keyword `synchronized` for methods[1] or objects[2].
- Unfortunately, neither classes nor attributes can be declared `synchronized`; discipline required.

The monitor concept by use of Java

```
class Account {
  // ...
  synchronized void deposit(int a){
    balance += a;
  }
}
```

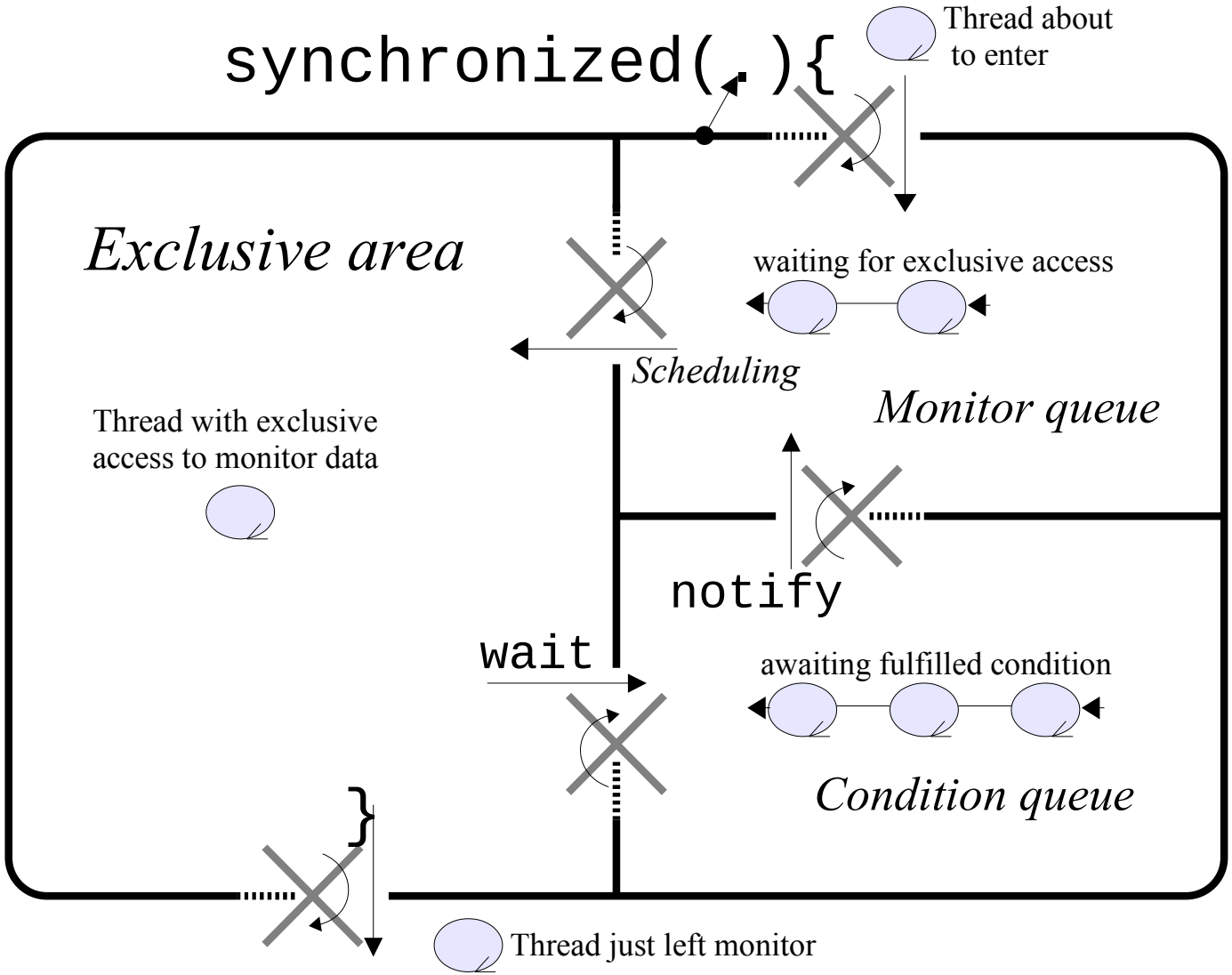
[1] Meaning `method(arg){synchronized(this){...}}`

[2] `synchronized(obj){...}` locks `obj` for running the ... code, but do not use.

synchronized - wait - notify

Condition queue

In addition to locking the object for exclusive access (mutex): Temporarily unlock until someone signals that the state has changed:



Notification is stateless; put any needed state in monitor

A CountingSem has state

```
Thread1      Thread2
   |            |
s.take();       |
   |         s.give();
   |            |
```

to be compared with

```
Thread1      Thread2
   |            |
   |         s.give();
s.take();       |
   |            |
```

Thread1 continues in both cases since the internal state (counter) reflects the give.

A notify is stateless

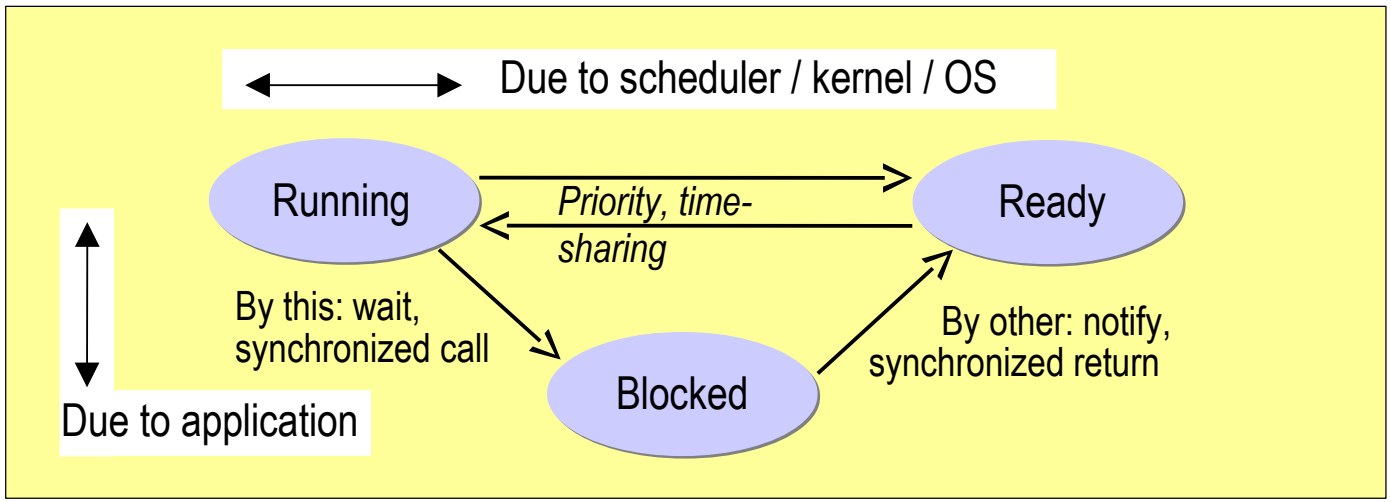
```
Thread1      Thread2
   |            |
wait();         |
   |         notify();
   |            |
```

to be compared with

```
Thread1      Thread2
   |            |
   |         notify();
wait();         |
   |            |
```

Thread1 waits until next notification;
The `notify` is forgotten, unless appropriate state variables exist in the monitor.

Execution states, revisited



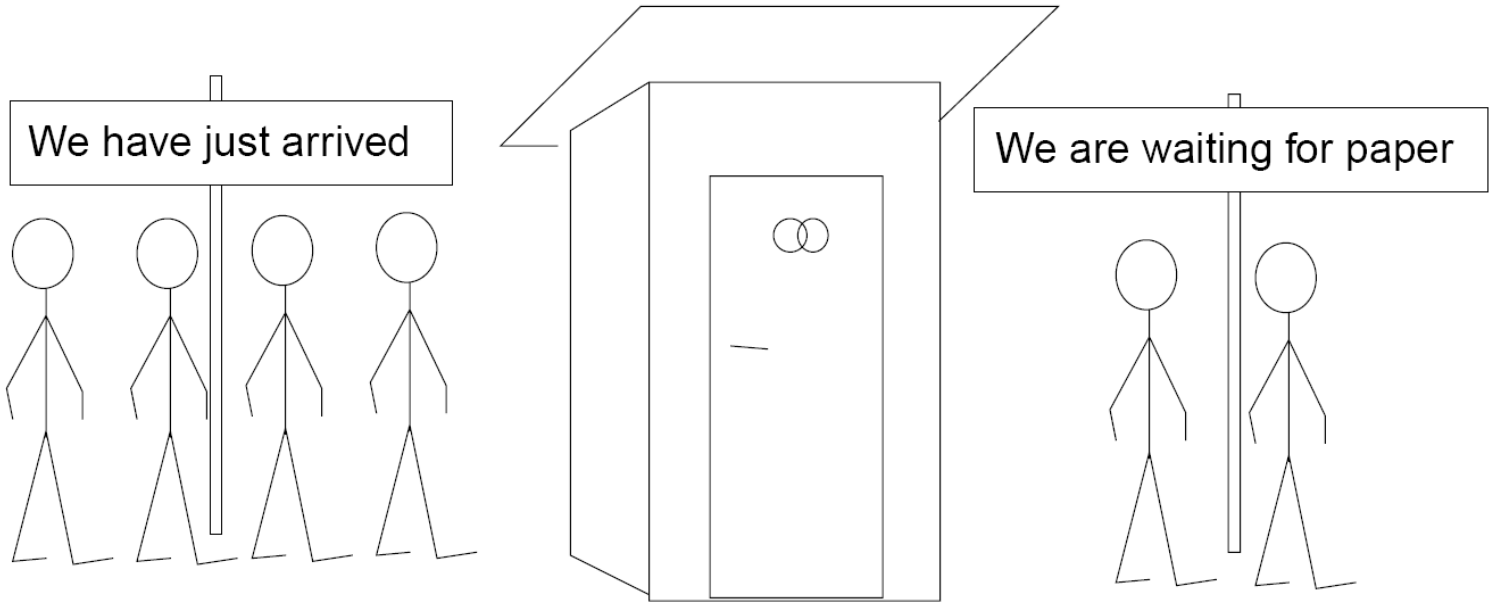
Object methods

- `wait`
- `notify`
- `notifyAll`

Keywords vs. methods

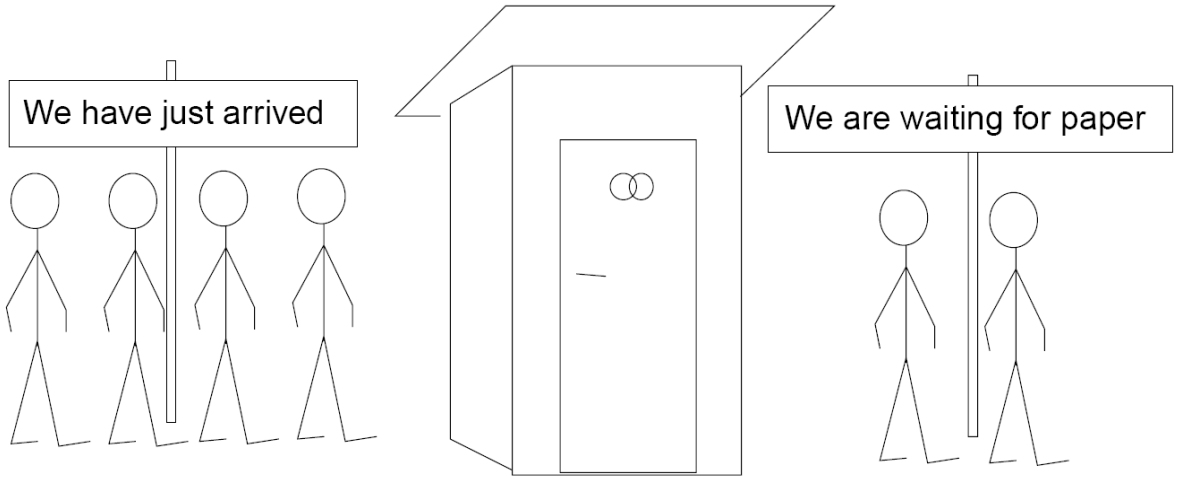
- The keyword synchronized is in language and in JVM
- The Object methods are in `class Object` and in JVM

Monitor conditions - analogy



- Assume shared resource providing three operations: `opA`, `opB`, and `addPaper`.
- Only one can enter at a time, entrance means exclusive access.
- The `opB` requires that paper is available, discovered after entrance.
- Two queues, one for entrance (left) and one for conditions (right).

Monitor conditions - analogy/scenario



It is the responsibility of the one performing `addPaper` to inform the waiting persons that the state of the object has changed.

Scenario

- The persons (threads) entering the monitor to do opB, but discovers that there is no paper aborts the operation, exits, and waits in a special queue until the condition 'paper is available' will be true.
- Even though there is no paper, other persons are let in to perform opA. Eventually someone arrives who changes the roll of paper after which the waiting persons can be let in again.

Original Hoare Monitor (1974)

Originally defined monitor properties:

- Immediate Resumption; the awakened thread takes control immediately
- The `notify` must be performed last, one thread only is awakened.
- The condition for waiting could be coded:
  `if (!ok) wait();`
- The notifying thread guarantees that the condition being waited for is true.
- Easier to prove that starvation can not occur.
- Does not handle priority for blocked threads.
- The enter queue can be FIFO or (preferably) a priority queue.

Real-time Monitor

We assume these monitor properties:

- High priority threads should be given precedence, even to threads which have been waiting longer (desired starvation risk).
- Immediate resumption not guaranteed (depends on OS/scheduler)
- The condition being waited for might not be true anymore when a blocked thread resumes execution.
- Waiting for a condition must be coded:
  `while (!ok) wait();`
- Use 'notifyAll' to avoid problems (practical - wakes all).
- The notify not necessarily called last in the method.

When previously blocked threads precedes those with same priority + notify last + one level of priority: equivalent with Hoare Monitor.

Basic rules

Coding for concurrency correct programs

- Do not mix a thread and a monitor in the same object/class
  [so you can get assistance from the compiler concerning proper access, which should go over visible methods].
- All public methods should be synchronized
  [and that is not inherited so redo in subclass].
- Wrap thread-unsafe classes by monitor
  [if possibly used by multiple threads].
- Do not use (spread-out) synchronized blocks
  [which are more for limited GUI concurrency].

Details (on board and in book)

- Atomic access of long and double.
- Keyword volatile.
- Attribute for locking: private and final.
- The monitor property (synchronized) is not inherited.
- Subclass blocking.
- The internal lock can be exposed for external synchronization.

Badly implemented buffer

```
class Producer extends Thread
{
  public void run()
  {
    prod = source.get();
    buffer.post(prod);
  }
}
class Consumer extends Thread
{
  public void run()
  {
    cons = buffer.fetch();
    sink.put(cons);
  }
}
```

```
class Buffer
{
  synchronized void post(Object obj)
  {
    if (buff.size()==maxSize) wait();
    if (buff.isEmpty()) notify();
    buff.add(obj);
  }

  synchronized Object fetch()
  {
    if (buff.isEmpty()) wait();
    if (buff.size()==maxSize) notify();
    buff.remove(buff.size());
  }
}
```

The `if (...) wait();` makes the buffer fragile: additional calls of notify or additional interacting threads could course the buffering to fail.

Better buffer

```
class Buffer // Inefficient!!
{
  synchronized void post(Object obj)
  {
    while (buff.size()>=maxSize) {
      wait();
    }
    buff.add(obj);
    notifyAll();
  }

  synchronized Object fetch()
  {
    while (buff.isEmpty()) {
      wait();
    }
    buff.remove(buff.size());
    notifyAll();
  }
}
```

```
class Buffer // Well done.
{
  synchronized void post(Object obj)
  {
    while (buff.size()>=maxSize) {
      wait();
    }
    if (buff.isEmpty()) notifyAll();
    buff.add(obj);
  }

  synchronized Object fetch()
  {
    while (buff.isEmpty()) {
      wait();
    }
    if (buff.size()>=maxSize) notifyAll();
    buff.remove(buff.size());
  }
}
```

The `while (...) wait();` makes the buffer robust with respect to other threads that can access the buffer and change the conditions.

synchronized - wait - notify

For Lab2 & exam

Make sure you understand how threads are interacting via monitors in Java; do understand this figure: