MONITORS

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Monitors

- Semaphore is a low level primitive because its is unstructured
- In case of large systems being built, using semaphores alone, the responsibility for the correct use of semaphores would be diffused among all the implementations of the system
- Monitors provide a structured concurrent programming primitive that concentrates the responsibility for correctness into modules

Monitors

- Monitors are generalizations of ***kernel*** or ***supervisor*** found in operating systems, where critical sections such as the allocation of memory are centralized in a privileged program
- Monitors are decentralized versions of the monolithic kernels
- A separate monitor is defined for each object or related group of objects that requires synchronization

Monitors

- If operations of the same monitor are called by more than one process, the implementation ensures that these are executed under mutual exclusion
- If operations of different monitors are called, their executions can be interleaved
- Monitors have become an extremely important synchronization mechanism because they are a natural generalization of the ***object*** of OOP, which encapsulates data and operation declarations within a ***class***

Monitors

- Objects of a class can be allocated at runtime and the operations of the class invoked on the fields of the object
- Monitor adds the requirement that only one process can execute an operation on an object at any one time

Monitors

- While the fields of the object may be declared either ***public*** (directly accessible outside the class) or ***private*** (accessible only by operations declared within the class), the fields of a monitor are all ***private***.
- This ensures that the fields of a monitor are accessed consistently
- Implementations of monitors in programming languages are quite different from one another

Monitors

Algorithm 7.1: Atomicity of monitor operations

```
monitor CS
    integer n ← 0

    operation increment
        integer temp
        temp ← n
        n ← temp + 1
```

p	**q**
p1: CS.increment	q1: CS.increment

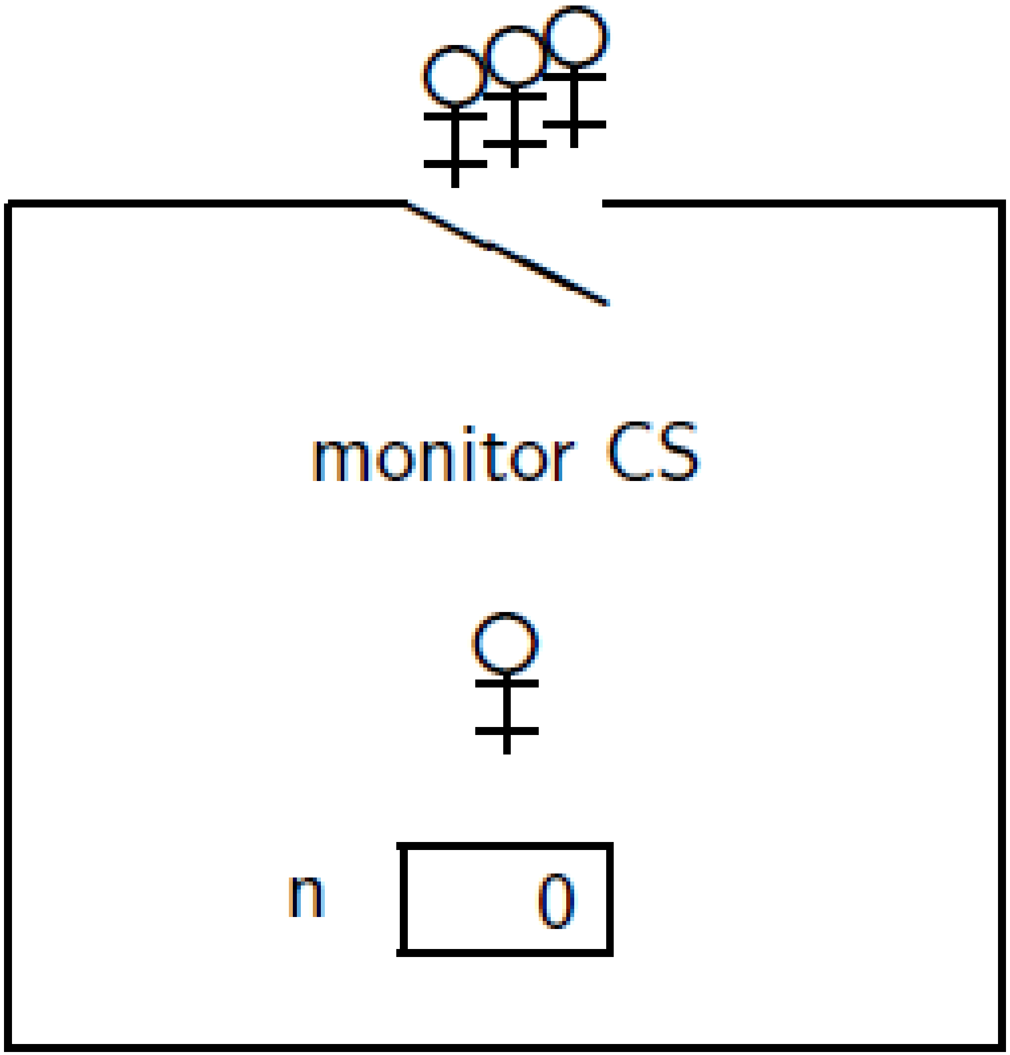
Monitors

- Monitor CS contains one variable **n** and one operation **increment**
- Two statements are contained within this operation, together with the declaration of a local variable
- The variable **n** is not accessible outside the monitor
- Two processes **p** and **q**, each call the monitor operation **CS.increment**

Monitors

- Only one process can execute the monitor operation and as mutual exclusion is ensured in access to the variable
- As one process is executing the statements of a monitor operation, the other statements are waiting outside
- This also solves the critical section problem as a critical section statements can be placed within the operation of a monitor

Monitors



Monitors

- The statements of critical section are encapsulated in the monitor rather than replicated in each process
- The synchronization is implicit and does not require the wait and signal statements
- Monitor is a static entry and not a dynamic process … It is a set of operations that just sit there (keep waiting) waiting for a process to invoke one of them

Monitors

- There is an implicit lock on the door to the monitor, ensuring only one process is inside the monitor at any time
- As with semaphores, if there are several processes attempting to enter a monitor, only one of them will succeed
- There is no explicit queue associated with the monitor entry, so starvation is possible

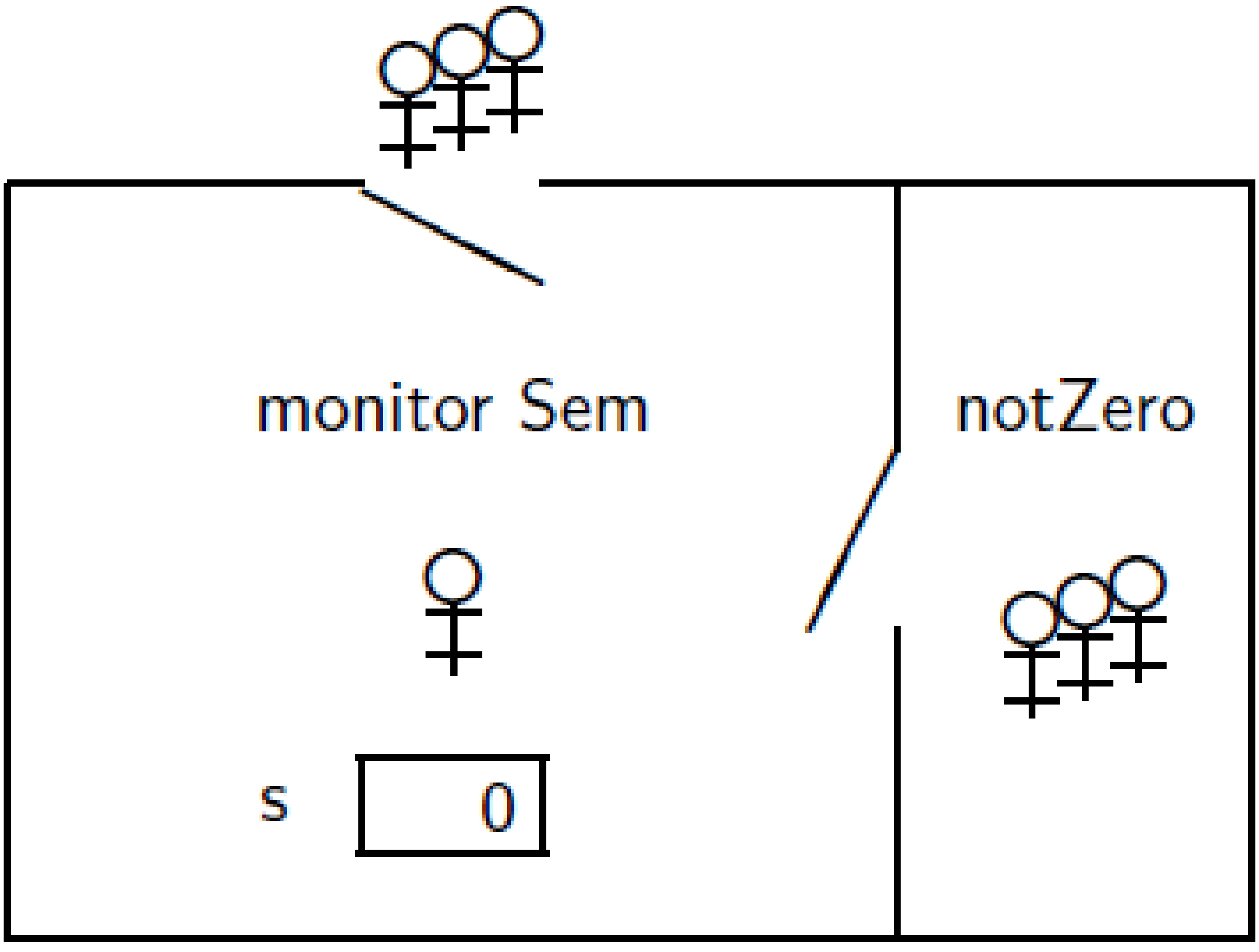
Condition Variables

- Monitor implicitly enforces mutual exclusion to its variables
- Problems in concurrent programming have explicit synchronization requirements
- Two approaches in providing synchronization:
  - Required condition is named by an explicit *condition variable* (called an *event*). Ordinary boolean expressions are used to test the condition
  - Block directly on the expression and let the implementation implicitly unblock a process when the expression is true

Condition Variables

- Condition variables provide a mechanism to wait for events (a “rendezvous point”)
  - Resource available, no more writers, etc.
- Condition variables support three operations:
  - Wait – release monitor lock, wait for C/V to be signaled
    - So condition variables have wait queues, too
  - Signal – wakeup one waiting thread
  - Broadcast – wakeup all waiting threads

Simulating Semaphores



Algorithm 7.2: Semaphore simulated with a monitor

```
monitor Sem
    integer s ← k
    condition notZero
    operation wait
        if s = 0
            waitC(notZero)
        s ← s − 1
    operation signal
        s ← s + 1
        signalC(notZero)
```

p	q
loop forever	loop forever
non-critical section	non-critical section
p1: Sem.wait	q1: Sem.wait
critical section	critical section
p2: Sem.signal	q2: Sem.signal

Simulating Semaphores

- Integer component of semaphore is stored in variable s
- Condition variable cond implements queue of blocked processes
- Condition variables are named with the condition you want to be true
- waitC(notZero) is read as “wait for notZero to be true” and signalC(notZero) is read as “signal thet notZero is true”
- If the value of s is zero, the process executing Sem.wait executes the monitor statement waitC(notZero). The process is said to be blocked on the condition

Simulating Semaphores

- Process executing waitC blocks unconditionally as we assume that the condition has been tested for in the preceding if statement
- As monitor operation is atomic the value of the condition cannot change between testing its value and executing waitC
- When a process executes a Sem.signal operation, it unblocks the first process blocked on that condition
- With each condition variable is associated a FIFO queue of blocked processes

Operations on Condition Variables

waitC(cond)

append p to cond
p.state ← blocked
monitor.lock ← release

empty(cond)

return cond = empty

signalC(cond)

if cond ≠ empty
remove head of
cond and assign to q
q.state ← ready

Semaphore vs Monitor

Semaphore

- Wait may or may not block
- Signal always has an effect
- Signal unblocks an arbitrary blocked process
- A process unblocked by signal can resume execution immediately

Monitor

- WaitC always blocks
- SignalC has no effect if queue is empty
- SignalC unblocks the process at the head of the queue
- A process unblocked by signalC must wait for the signalling process to leave monitor

Algorithm 7.3: Producer-consumer (finite buffer, monitor)

```
monitor PC
    bufferType buffer ← empty
    condition notEmpty
    condition notFull

    operation append(datatype V)
        if buffer is full
            waitC(notFull)
        append(V, buffer)
        signalC(notEmpty)

    operation take()
        datatype W
        if buffer is empty
            waitC(notEmpty)
        W ← head(buffer)
        signalC(notFull)
        return W
```

Producer Consumer

Algorithm 7.3: Producer-consumer (finite buffer, monitor) (continued)			
	producer		**consumer**
	datatype D		datatype D
	loop forever		loop forever
p1:	D ← produce	q1:	D ← PC.take
p2:	PC.append(D)	q2:	consume(D)

Emulating Semaphores using Monitors

```
monitor Semaphore_Emulation is

    S: Integer := S0;
    Not_Zero : Condition;

    Procedure Semaphore_Wait is
    begin
        if S=0 then Wait(Not_Zero); end if;
        S := S-1;
    end Semaphore_Wait;

    Procedure Semaphore_Signal is
    begin
        S := S+1; Signal(Not_Zero);
    end Semaphore_Signal;

end monitor
```

Readers Writers Problem

- Similar to Mutex problem where several processes are competing for access to a critical section
- Readers are processes which require to exclude writers but not other readers
- Writers are processes which require to exclude both readers and other writers
- Several processes can read data concurrently, but writing or modifying data must be done under Mutex to ensure consistency of Data

Algorithm 7.4: Readers and writers with a monitor

```
monitor RW
   integer readers ← 0
   integer writers ← 0
   condition OKtoRead, OKtoWrite

   operation StartRead
      if writers ≠ 0 or not empty(OKtoWrite)
         waitC(OKtoRead)
      readers ← readers + 1
      signalC(OKtoRead)

   operation EndRead
      readers ← readers − 1
      if readers = 0
         signalC(OKtoWrite)
```

Algorithm 7.4: Readers and writers with a monitor (continued)

```
operation StartWrite
   if writers ≠ 0 or readers ≠ 0
      waitC(OKtoWrite)
   writers ← writers + 1

operation EndWrite
   writers ← writers − 1
   if empty(OKtoRead)
      then signalC(OKtoWrite)
      else signalC(OKtoRead)
```

reader	writer
p1: RW.StartRead	q1: RW.StartWrite
p2: read the database	q2: write to the database
p3: RW.EndRead	q3: RW.EndWrite

Readers Writers Problem

- Monitor uses 4 variables
  - Readers: The number of threads currently reading the database after successfully executing StartRead but before executing EndRead
  - writers: The number of writers currently writing to the database after successfully executing StartWrite but before executing EndWrite
  - OktoRead: A condition variable for blocking readers until it is “OK to read”
  - OktoWrite: A condition variable for blocking writers until it is “OK to write”

Dining Philosophers Problem

Algorithm 7.5: Dining philosophers with a monitor

```
monitor ForkMonitor
    integer array[0..4] fork ← [2, . . . , 2]
    condition array[0..4] OKtoEat

    operation takeForks(integer i)
        if fork[i] ≠ 2
            waitC(OKtoEat[i])
        fork[i+1] ← fork[i+1] − 1
        fork[i−1] ← fork[i−1] − 1

    operation releaseForks(integer i)
        fork[i+1] ← fork[i+1] + 1
        fork[i−1] ← fork[i−1] + 1
        if fork[i+1] = 2
            signalC(OKtoEat[i+1])
        if fork[i−1] = 2
            signalC(OKtoEat[i−1])
```

Dining Philosophers Problem

Algorithm 7.5: Dining philosophers with a monitor (continued)	
	philosopher i
	loop forever
p1:	think
p2:	takeForks(i)
p3:	eat
p4:	releaseForks(i)

Dining Philosophers Problem

- Monitor maintains an array of fork which counts the number of free forks available to each philosopher
- The takeForks operation waits on a condition variable until two forks are available
- It decrements the number of forks available to its neighbor before leaving the monitor
- After eating, a philosopher calls releaseForks which updates the array fork and checks if freeing these forks makes it possible to signal

What's wrong with Semaphores

- They are essentially shared global variables.
- There is no linguistic connection between the semaphore and the data to which the semaphore controls access.
- Access to semaphores can come from anywhere in a program.
- They serve two purposes, mutual exclusion and scheduling constraints.
- There is no control or guarantee of proper usage.

Monitor – A Formal Definition

- A Monitor defines a lock and zero or more condition variables for managing concurrent access to shared data.
- The monitor uses the lock to insure that only a single thread is active in the monitor at any instance.
- The lock also provides mutual exclusion for shared data.
- Condition variables enable threads to go to sleep inside of critical sections, by releasing their lock at the same time it puts the thread to sleep.

Monitor Operations

- Encapsulates the shared data you want to protect.
- Acquires the mutex at the start.
- Operates on the shared data.
- Temporarily releases the mutex if it can't complete.
- Reacquires the mutex when it can continue.
- Releases the mutex at the end.