KOÇ UNIVERSITY

Synchronization-III
Semaphores

Didem Unat

Lecture 10

COMP304 - Operating Systems (OS)

Mutex Locks

```
do {
   acquire lock
      critical section
   release lock
      remainder section
} while (true);
```

```
acquire() {
   while (!available)
      ; /* busy wait */
   available = false;;
}

release() {
   available = true;
}
```

- Software interface for locks
- Calls to **acquire()** and **release()** must be atomic
  - implemented via hardware atomic instructions
- But this solution requires **busy waiting**
  - And also called a **spinlock**

Semaphores

- We want to be able to write more complex constructs
  - need a language to do so. We define semaphores which we assume are atomic operations.
- Semaphores are more general synchronization tools
  - Operating System Primitive
  - Two standard atomic operations modify semaphore variable S: wait() and signal()

```
WAIT ( S ):

    while   ( S  <=  0 );
    S  =  S  -  1;
```

```
SIGNAL ( S ):

    S  =  S  +  1;
```

- As given here, these are not atomic as written in "macro code". We define these operations, however, to be atomic (Protected by a hardware lock.)

Critical Section for n Processes

- Shared semaphore:

  semaphore mutex = 1; //initial value

- Process Pi:

```
do {
    wait(mutex)
        critical section
    signal(mutex)
        remainder section
} while (true);
```

Shared Account Balance Example

```
semaphore mutex = 1;

proc_0() {
   . . .
   /* Enter the CS */
   wait(mutex);
     balance += amount;
   signal(mutex);
   . . .
}

proc_1() {
   . . .
   /* Enter the CS */
   wait(mutex);
    balance -= amount;
   signal(mutex);
   . . .
}
```

//CS stands for critical section

Semaphore as a general synchronization tool

- Provides mutual exclusion

```
Semaphore S =  1;    //  initialized to 1 or initialized to # of resources
wait (S);
    Critical Section
signal (S);
```

- Counting semaphore – integer value can range over an unrestricted domain
  - For example: resources in the hardware: semaphore is initialized to number of printers
- Binary semaphore – integer value can range only between 0 and 1; can be simpler to implement
  - This is the same as mutex locks

Semaphore as a general synchronization tool

- Semaphores can be used to force synchronization (precedence) if the **preceeder** does a signal at the end, and the **follower** does wait at beginning.

For example, here we want P1 to execute before P2.

- Execute B in P_j only after A executed in P_i
- Use semaphore flag initialized to **0**

Code:

P_i	P_j
⋮	⋮
A	wait(flag)
signal(flag)	B

Classical Problems of Synchronization

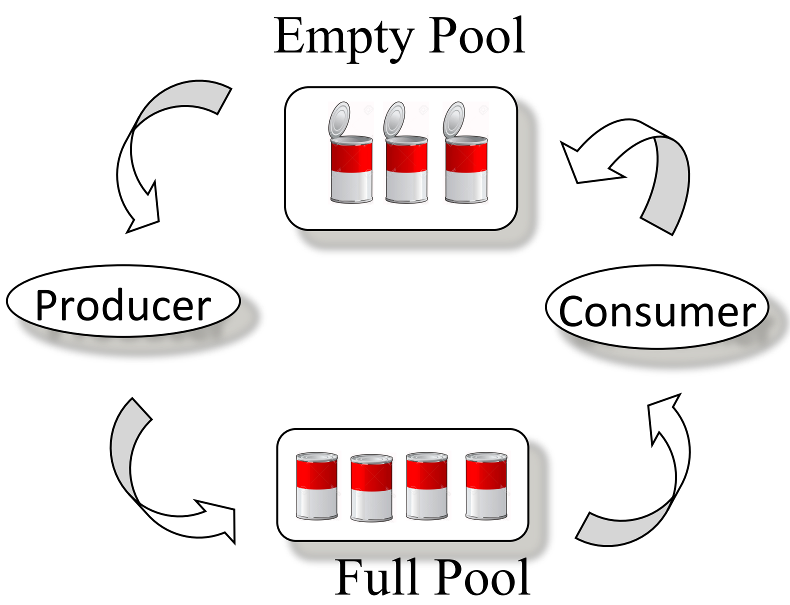
- Bounded-Buffer Problem
- Readers and Writers Problem
- Dining Philosophers Problem

These classical problems are used for testing newly proposed synchronization methods.

Bounded-Buffer Problem

- Buffer size: buffer can hold **n** items
- Binary semaphores
  `semaphore mutex;`
- Counting semaphores

  `semaphore full, empty;`



Initially:

`full = 0, empty = n, mutex = 1`

This is the same producer / consumer problem as before. But now we'll do it with signals and waits. Remember: a **wait decreases** its argument and a **signal increases** its argument.

Bounded-Buffer Problem

- Empty and Full are counting semaphores

```
producer:
do {
      /* produce an item in nextp */
      wait (empty);            /* Do action     */


       /* add nextp to buffer   */


      signal (empty);

  } while(TRUE);
```

```
consumer:
do {
      wait (full);


       /* remove an item from buffer to nextc */


      signal (full);

      /* consume an item in nextc */
   } while(TRUE);
```

Signals are wrong!
Producer (consumer)
needs to wake up the
consumer (producer)!

Bounded-Buffer Problem

- **Mutex** is binary semaphore, Empty and Full are counting semaphores

```
producer:
do {
      /* produce an item in nextp */
      wait (empty);          /* Do action     */

       /* add nextp to buffer   */

      signal (full);

  } while(TRUE);
```

Does this work for multiple producers and consumers?

Only works for one producer and consumer. Need the mutex to prevent multiple producers writing into the same buffer.

```
consumer:
do {
      wait (full);

       /* remove an item from buffer to nextc */

      signal (empty);

      /* consume an item in nextc */
   } while(TRUE);
```

Bounded-Buffer Problem

- **Mutex** is binary semaphore, Empty and Full are counting semaphores

```
producer:
do {
      /* produce an item in nextp */
      wait (empty);           /* Do action     */
      wait (mutex);           /* Buffer guard*/

       /* add nextp to buffer  */

      signal (mutex);
      signal (full);

   } while(TRUE);
```

```
consumer:
do {
      wait (full);
      wait (mutex);

       /* remove an item from buffer to nextc */

      signal (mutex);
      signal (empty);

      /* consume an item in nextc */
   } while(TRUE);
```

We need a mutex in addition
to empty and full semaphores because
we are operating on the same buffer

Semaphores

- **Spinlocks** (mutexes) are useful in a system since no context switch is required
- A disadvantage of mutex solutions so far:
  - they all require **busy waiting**.
- To overcome busy waiting → blocking a process

No busy waiting (blocking) Semaphores

- With each semaphore there is an associated waiting queue:
  - Keeps list of processes waiting on the semaphore

- Two operations:
  - Block – place the process invoking the operation on the appropriate waiting queue if semaphore == false
  - Wakeup – Wakes up one of the blocked processes upon getting a signal and places the process to ready queue

Blocking Semaphores

```
typedef struct {
    int     value;
    struct process *list; /* list of processes waiting on  S  */
} SEMAPHORE;
```

```
SEMAPHORE s;
wait(s) {
      s.value = s.value  -  1;
      if (  s.value  <  0 ) {
         add this process to s.list;
         block ();
      }
}
```

Block – place the process invoking the operation on the appropriate waiting queue if semaphore is not available

```
SEMAPHORE s;
signal(s)  {
      s.value = s.value  +  1;
      if (  s.value  <=  0 )  {
         remove a process P from s.list;
         wakeup(P);
      }
}
```

Wakeup – Wakes up one of the blocked processes upon getting a signal and places the process to ready queue

Deadlock and Starvation

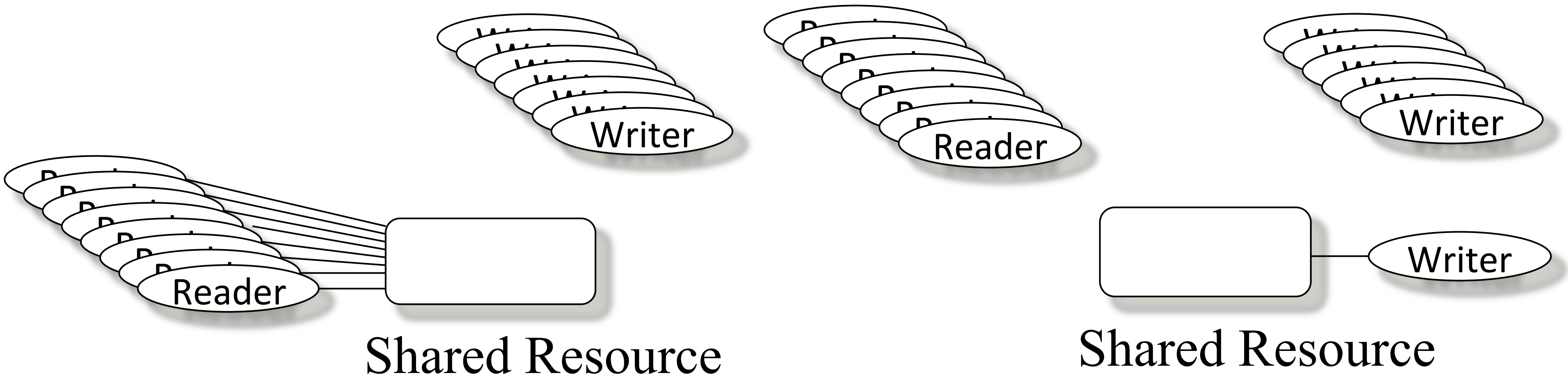
- **Deadlock** – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes.
- Let S and Q be two semaphores initialized to 1

P_0	P_1
wait(S);	wait(Q);
wait(Q);	wait(S);
⋮	⋮
signal(S);	signal(Q);
signal(Q)	signal(S);

- **Starvation** – indefinite blocking. A process may never be removed from the semaphore queue in which it is suspended.
- May occur if we add and remove processes from the list in LIFO order or based on priority.

Readers and Writers Problem

- A data set is shared among a number of concurrent processes
  - Readers – only read the data set; they do not perform any updates
  - Writers – can both read and write.
- Problem
  - Allow multiple readers to read at the same time.
  - Only one single writer can access the shared data at a time.



Readers/Writers Problem

Locks:

- are **shared** (for the readers) and **exclusive** (for the writer).

Two possible (contradictory) guidelines can be used:

- No reader is kept waiting unless a writer holds the lock (the readers have precedence).
  - First readers problem
- If a writer is waiting for access, no new reader gains access (writer has precedence).
  - Second readers problem

Can starvation occur on either of these rules?

First-Readers Problem

Favoring readers over writers

```
semaphore rdwrt = 1;
semaphore cntmutex = 1;
int readcount = 0;
```

```
Writer:
do {
     wait( rdwrt );
       /*   writing is performed    */
     signal(  rdwrt  );

} while(TRUE);
```

```
Reader:
do {
        wait( cntmutex );                /* Allow 1 reader in entry*/
        readcount = readcount + 1;
        if readcount == 1 then
            wait(rdwrt );               /* 1st reader locks writer */
        signal( cntmutex );

            /*   reading is performed   */

        wait( cntmutex );
        readcount = readcount - 1;
        signal( cntmutex );
        if readcount == 0  then
            signal(rdwrt );             /*last reader frees writer */

} while(TRUE);
```

~~A reader might be reading while a writer is writing at the same time or two writers can perform their writes!~~

How can that happen?

First-Readers Problem

Correct Implementation, Favoring readers over writers

```
semaphore rdwrt = 1;
semaphore cntmutex = 1;
int readcount = 0;
```

Writer:

```
do {
      wait( rdwrt );
        /*   writing is performed     */
      signal(  rdwrt   );

} while(TRUE);
```

Reader:

```
do {
       wait( cntmutex );                  /* Allow 1 reader in entry*/
       readcount = readcount + 1;
       if readcount == 1 then
          wait(rdwrt );                 /* 1st reader locks writer */
       signal( cntmutex );

          /*   reading is performed   */

       wait( cntmutex );
       readcount = readcount - 1;
       if readcount == 0  then
          signal(rdwrt );               /*last reader frees writer */
       signal( cntmutex );

} while(TRUE);
```

Quiz

- Many events on campus take place in SGKM. Assume that the show room can only allow N many people. As soon as N audience are in the room, the staff will not accept another incoming audience until an existing audience leaves the event.

- Explain how semaphores can be used by the staff to limit the number of people in the SGKM event room.
- Show your pseudo-code.

Solution

- Semaphore is initialized to the number of allowable people in SGKM. When a reservation is accepted, the acquire() method is called; when someone leaves the event, the release() method is called. If the system reaches the number of allowable people, subsequent calls to acquire() will block until an existing person leaves the event and the release method is invoked.

Reading

- Read Chapter 6

- Acknowledgments
  - These slides are adapted from
    - Öznur Özkasap (Koç University)
    - Operating System and Concepts (9th edition) Wiley
    - Jerry Breecher