KOÇ UNIVERSITY

Synchronization-II Semaphores

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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**

Atomic Memory Operations in C++

- std::atomic<T> template

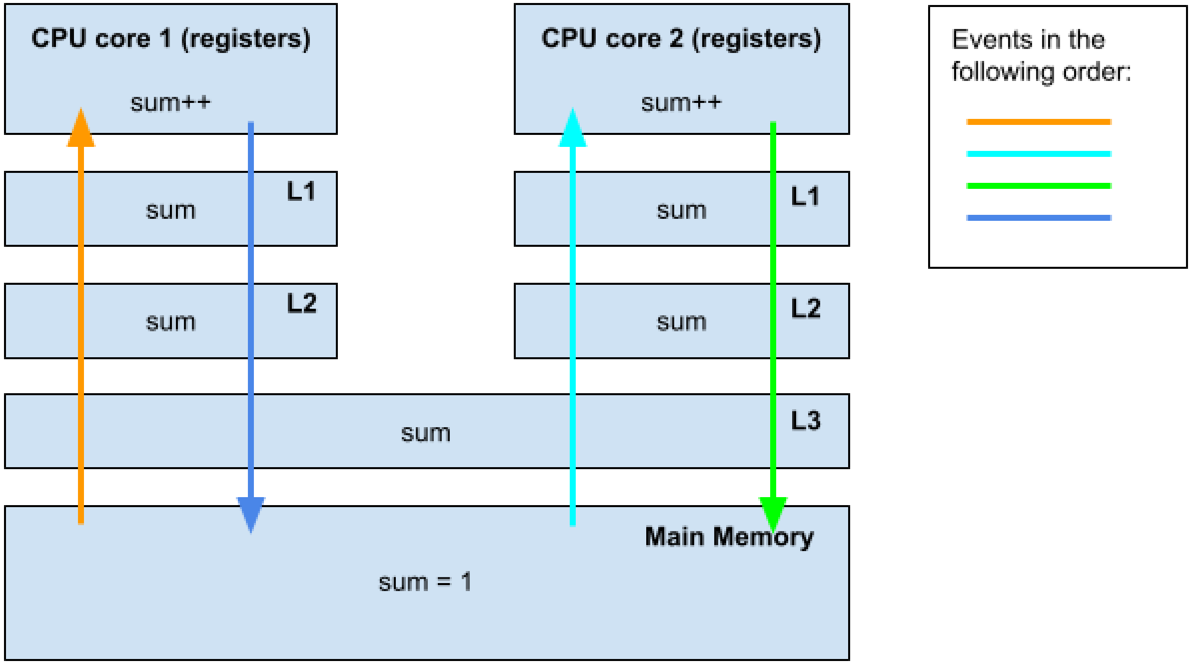
  Defined in header <atomic>

  - Examples: **std::atomic<int>, std::atomic<bool>, std::atomic<unsigned int>**
  - Each instantiation of atomic template creates a variable with atomic data type.
  - When instantiated, std::atomic provides the appropriate atomic operations depending on the data type, i.e. integer or floating-point type.
- Atomic operation library

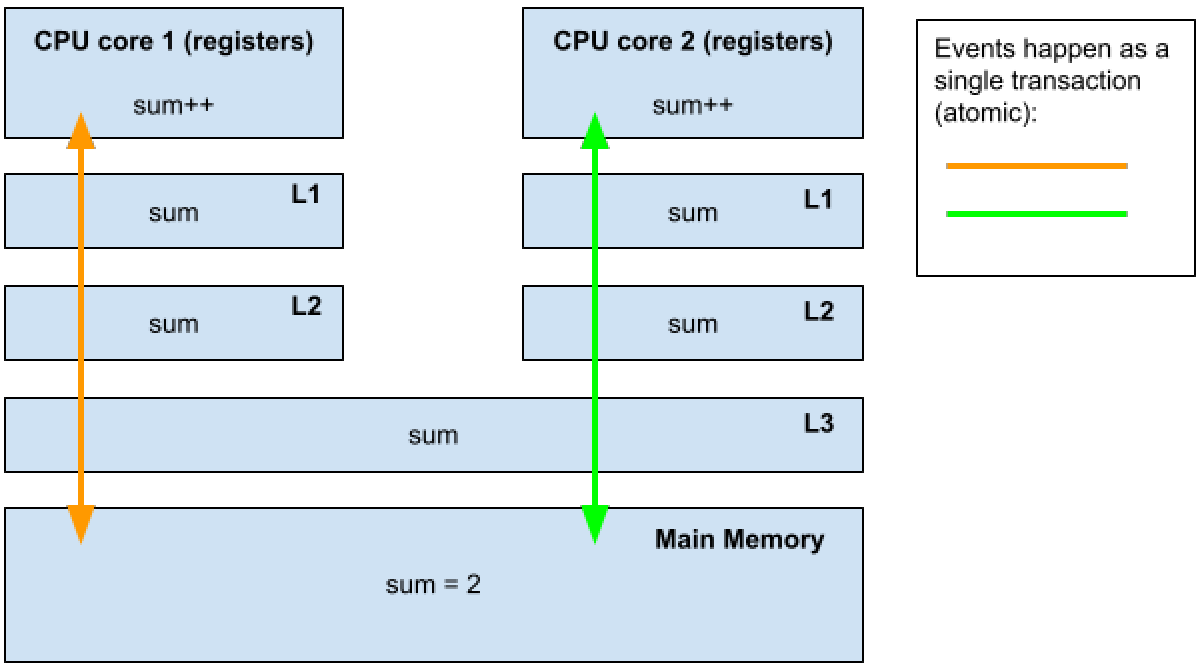
  Defined in header <stdatomic.h>

  - Examples: **atomic_load, atomic_exchange, atomic_fetch_add**
  - Each function supports indivisible atomic operation with regards to other atomic operations involving the same object.

Without atomics



With atomics



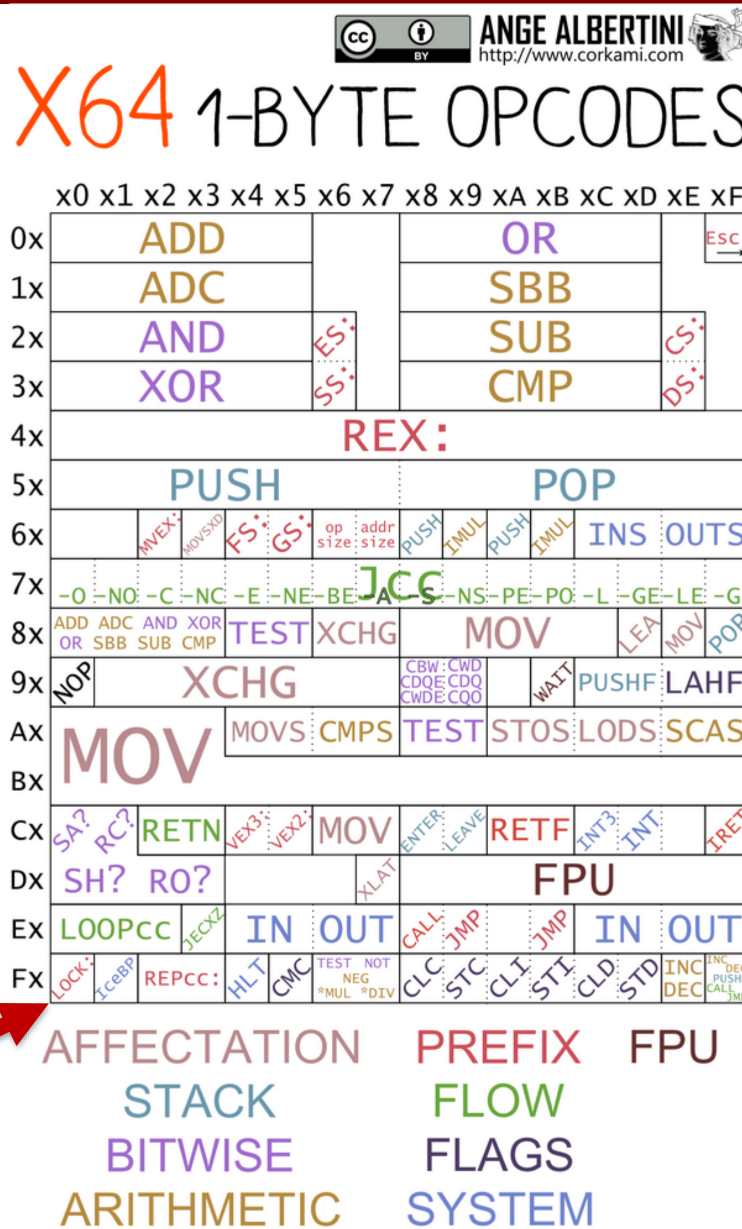
Atomic Memory Operations in Assembly Code

- Lock prefix has to be applied to a following **read-modify-write** type of instructions, e.g. inc, xchg, and addl.
- It guarantees the CPU to have an exclusive ownership of the cache line for the duration of the operation.
- When you instantiate an std::atomic template to an integral type, any **read-modify-write memory** operation to the variable will be preceded by a lock prefix in the compiled assembly/machine code.

```
lock
incl (%ecx)
```

```
lock
addl %ecx, (%aex)
```

x86 & x64 opcode LOCK 0xF0



Semaphore

- A semaphore S is an integer variable that, apart from initialization, is accessed only through two standard atomic operations: **wait**() and **signal**().
- Semaphores were introduced by the Dutch computer scientist Edsger Dijkstra, and such,
  - the **wait**() operation was originally termed **P** (from the Dutch proberen, “to test”);
  - **signal**() was originally called **V** (from verhogen, “to increment”).

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)
       ; // busy wait
    S--;
}
```

```
signal(S) {
    S++;
}
```

- 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);

- Operating systems often distinguish between **counting** and **binary** semaphores.
  - The value of a **counting semaphore** can range over an unrestricted domain.
  - The value of a **binary semaphore** can range only between 0 and 1.
- Thus, binary semaphores behave similarly to mutex locks.
  - In fact, on systems that do not provide mutex locks, binary semaphores can be used instead for providing mutual exclusion.

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 is 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

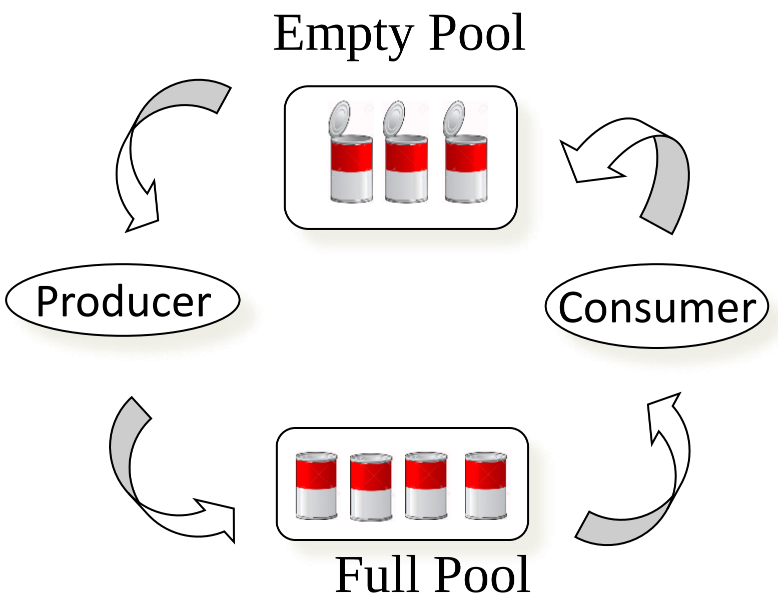
- Bounded-Buffer Problem
- Readers and Writers Problem
- Dining Philosophers Problem

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`

```
int n;
semaphore mutex = 1;
semaphore empty = n;
semaphore full = 0
```

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);
```

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


       /* remove an item from buffer to nextc */


      signal (empty);

      /* consume an item in nextc */
    } 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.

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 multiple producers (hence consumers) 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

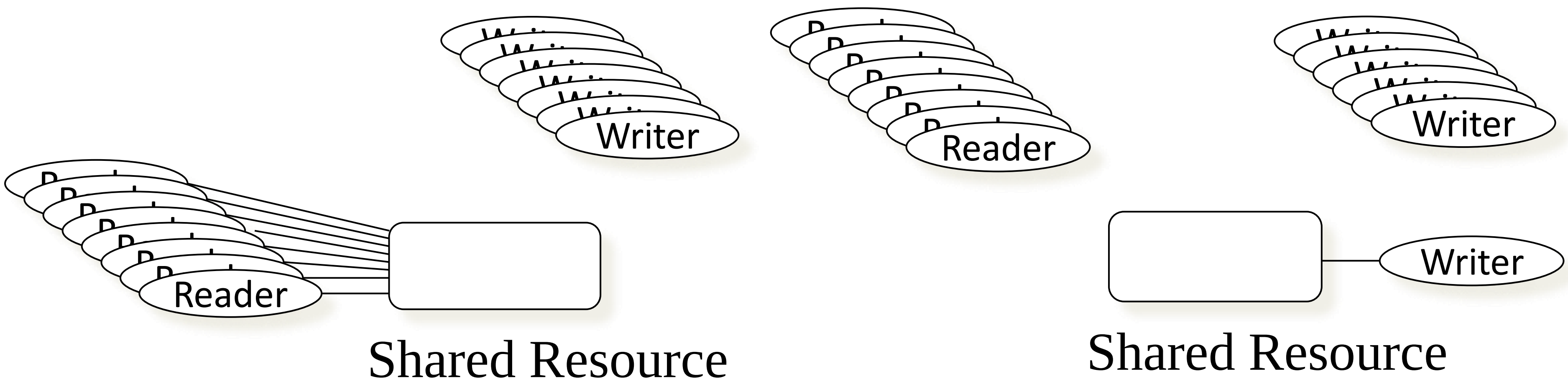
- **Deadlock** – two or more processes are waiting indefinitely for an event that can be caused by only one of the waiting processes.
- Let S and Q be two semaphores initialized to 1

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 rdwrt */
      signal( cntmutex );

         /*   reading is performed   */

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

} while(TRUE);
```

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 rdwrt */
      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 );
       signal( cntmutex );

           /*   reading is performe

       wait( cntmutex );
       readcount = readcount - 1;
       if readcount == 0  then
           signal(rdwrt );
       signal( cntmutex );

} while(TRUE);
```

Assume there are two readers left (r1 and r2). r1 may be interrupted before it checks readcount == 0. The second reader(r2) decrements the readcount from 1 to 0 and both will check readcount==0 and get true, then both send a signal(wrt) allowing two writers or one reader and one writer in the system.

Question

- 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
  - Original slides are by **Didem Unat** which were adapted from
    - Öznur Özkasap (Koç University)
    - Operating System and Concepts (9^{th} edition) Wiley
    - Jerry Breecher