Lecture 8

Processes concurrency - mutual exclusion

Race condition

- In concurrent/parallel systems, a race condition can occur when multiple processes or threads read and write data so that the final result depends on the order of execution of instructions in the multiple processes/threads.

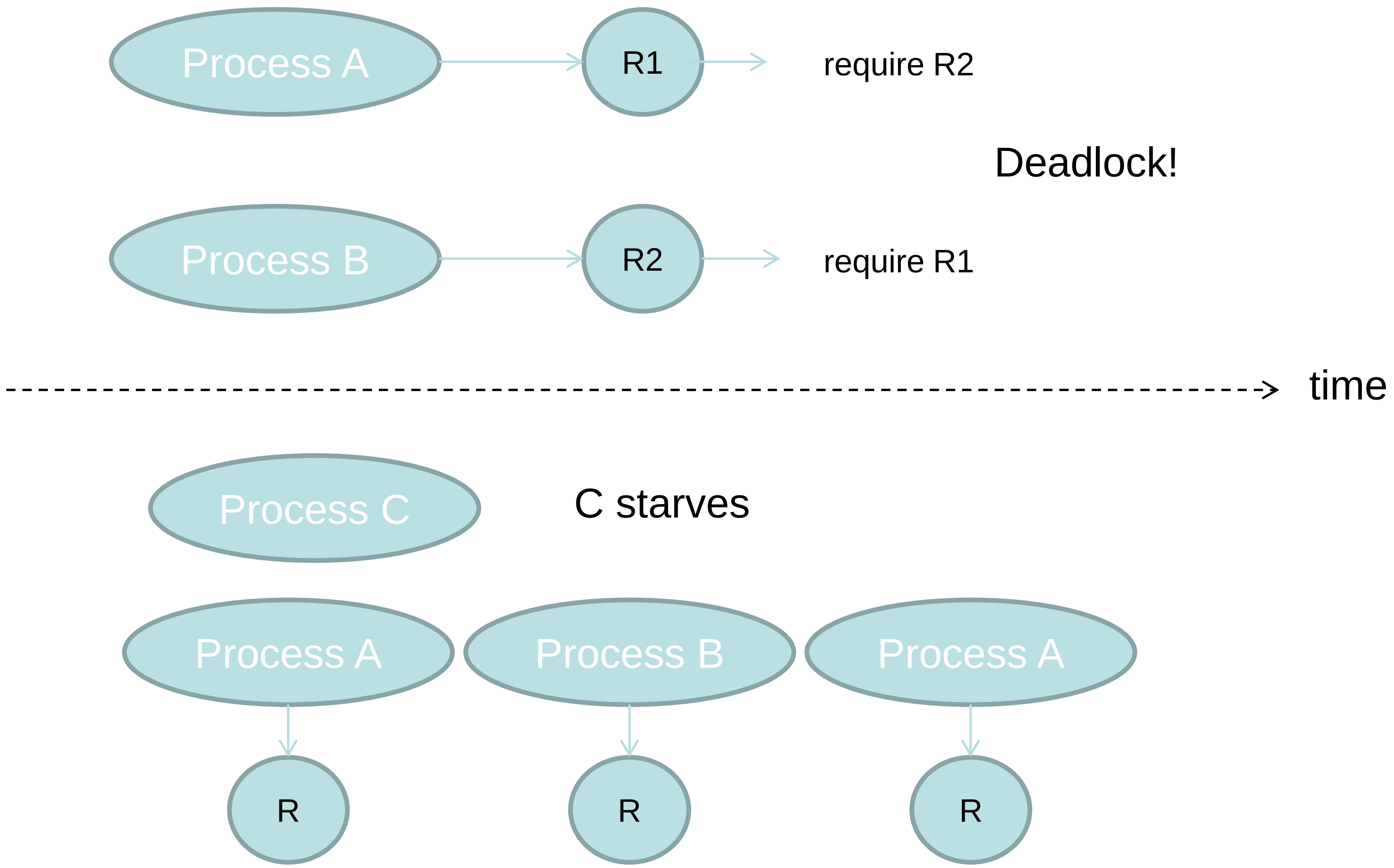
- Example: processes P1 and P2 share global variables a and b with initial values a = 2 and b = 4.
  - P1 has the instruction a = a + b
  - P2 has the instruction b = a + b
- Due to concurrency, the final values of a and b depend on the order of execution of the two instructions:

  a = 6, b = 10, or b = 6 and a = 8

Process interaction

- In a computer system, the following situations occur:
  1. processes run independently of each other, but they compete for resources;
  2. processes share resources, e.g., a queue;
  3. processes cooperate together, one process' results depending of other processes' execution data.

- *Mutual exclusion*: two or more processes compete for the same resource (i.e. printer); one process gets the control, the other(s) wait their turn. The resource is called *critical resource*, and the section of the program that uses it is a *critical section*.
- When two processes block each other's access to a resource each already acquired, they are *deadlocked*.
- When three or more processes compete for a resource, it is possible to have the control granted only to some of them (i.e. they are high priority), and one or several processes can't get the CPU – they experience *starvation*.


Process A
R1
require R2
Deadlock!
Process B
R2
require R1
time
Process C
C starves
Process A
Process B
Process A
R
R
R

Rules for mutual exclusion

- Mutual exclusion should be applied: only one process is allowed to enter its critical section for one (shared) resource.
- When no process is in a critical section, any process that requests entry to its critical section must be permitted without delay.
- A process that halts outside its critical section must do so without interfering with other processes.
- It must not be possible for a process requiring access to a critical section to be delayed indefinitely – no deadlock or starvation.
- A process stays inside its critical section for a finite time only.
- No assumptions are made about relative process speeds or number of cores.

Semaphores

- Semaphore: a variable that has an integer value upon which three operations can be executed:
  - initialised to a nonnegative integer value.
  - *semWait* operation decrements the semaphore value. If the value becomes negative, the process executing semWait is blocked. Otherwise, the process continues execution.
  - *semSignal* increments the semaphore value. If the resulting value is <= 0, then a process blocked by a semWait operation , if any, is unblocked.
- If the semaphore value is positive, that value equals the number of processes that can issue a wait and immediately continue to execute.
- If the value is 0, the next process to call wait is blocked and the semaphore value goes negative.

Comments

- In general, there is no way to know before a process decrements a semaphore whether it will block or not.
- After a process increments a semaphore and another process gets woken up, both processes proceed running concurrently.
- When a semaphore is signalled, there might be a process (or more) waiting or none. The number of unblocked processes can be one or zero.
- The semWait and semSignal primitives are *atomic*.

```
struct semaphore {
        int count;
        queueType queue;
};
void semWait (semaphore s)
{
        s.count--;
        if (s.count < 0) {
          /* the process is placed in s.queue */;
          /* block this process  */;
        }
}

void semSignal (semaphore s)
{
        s.count++;
        if (s.count < =0) {
          /* remove a process from s.queue */;
          /* place the process in the ready queue  */;
        }
}
```

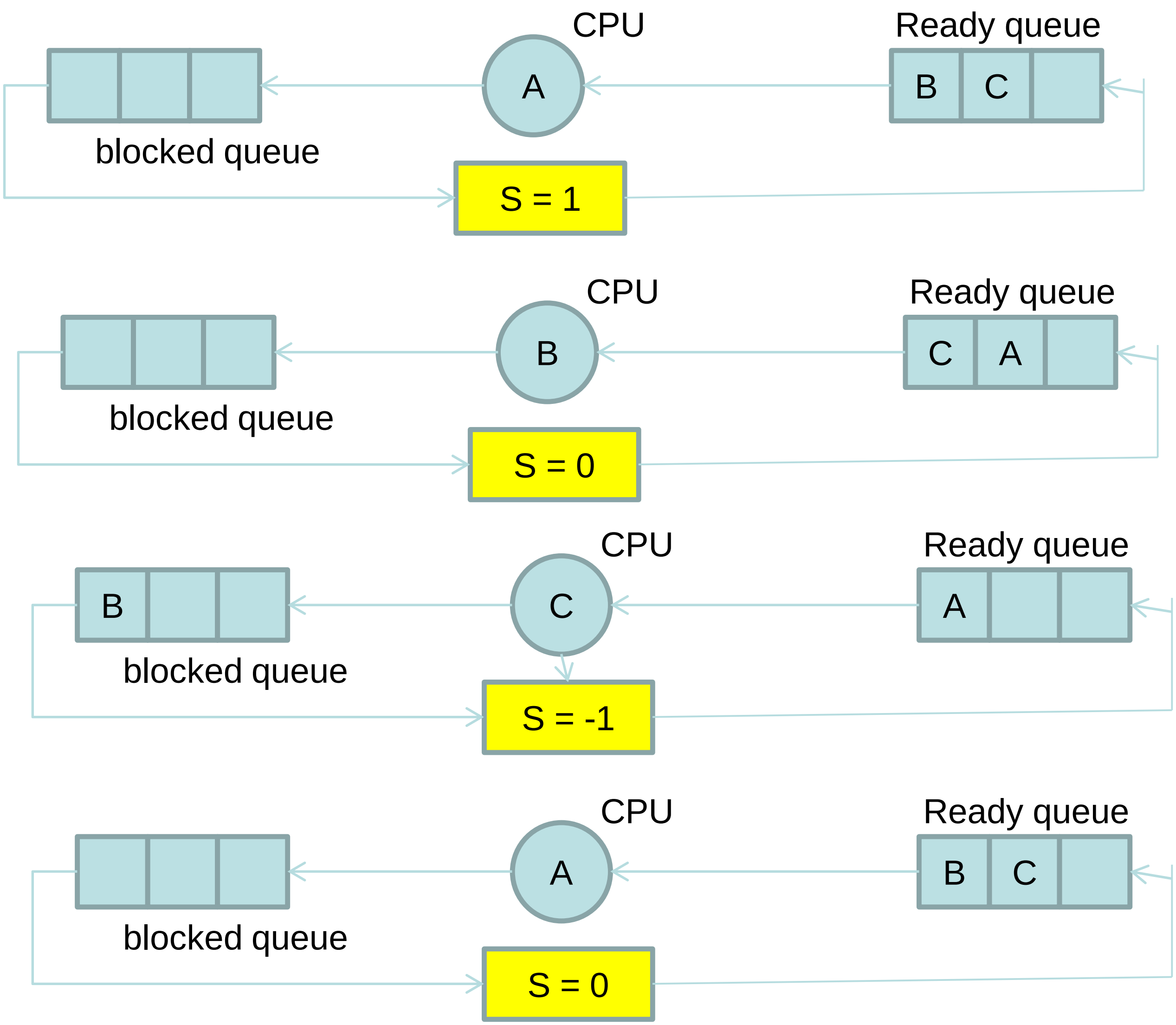
Binary semaphore

- The binary semaphore may only take the values of zero and one.
- Operations:
  - Initialisation: 0 or 1;
  - semWaitB checks the semaphore value. If the value is 0, the process executing semWaitB is blocked, else if value is 1, decrement it and process continues execution.
  - semSignalB checks to see if there is any process blocked. If yes, a process is unblocked, else the value of the semaphore is set to 1.

- Mutex: a binary semaphore for which the same process locks and unlocks the semaphore.

- The queue associated with the semaphore is usually *FIFO* - *strong semaphore*.

- Example: processes A and B depend on results produced by process C.

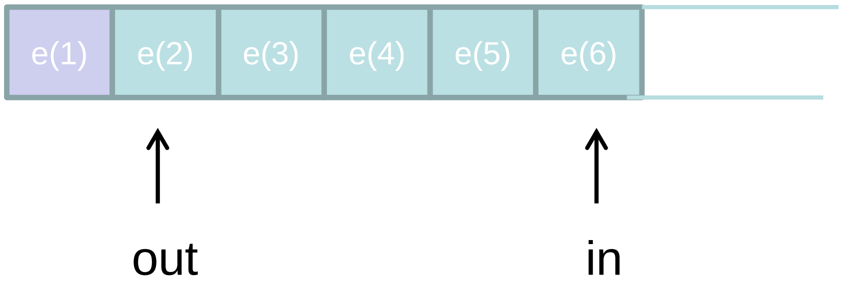


Mutual exclusion with semaphore

```
const int n = /* number of processes */;
semaphore s = 1;
void P(int i)
{
        while (true) {
                semWait (s);
                /* critical section */
                semSignal (s);
                /* other code */
        }
}
void main()
{
        parbegin (P(1), P(2),….P(n));
}
```

Application: Producer/Consumer

- One or more producers place data they create in a buffer. One consumer takes items out of the buffer, one at a time.
- Only one producer or the consumer can access the buffer at a time.
- The problem is to make sure that producers don't try to add data into a full buffer, and that the consumer doesn't try to take data from an empty buffer.
- We assume the buffer is infinite and consists of a linear array of elements.



Producer:

```
while (true) {
    /* produce data  d */;
    e[in] = d;
    in++;
}
```

Consumer:

```
while (true) {
        while (in <= out)
                /* do nothing */
        t = d[out];
        out++;
        /* consume t */;
}
```

```
/* program producer/consumer */
    int n;
    binary_sem s = 1, delay = 0;

    void producer()
    {
        while (true) {
            produce();
            semWaitB(s);
            append();
            n++;
            if (n ==1) semSignalB(delay);
            semSignalB(s);
        }
    }
```

```
void consumer()
    {
        int m;      /*local variable */
        semWaitB(delay);
        while (true) {
            semWaitB(s);
            take();
            n--;
            m = n;
            semSignalB(s);
            consume();
            if (m ==0) semWaitB(delay);

        }
    }
    void main()
    {
        n = 0;
        parbegin (producer, consumer);
    }
```

Questions and problems

- When does a race condition occur?
- List the requirements for mutual exclusion.
- What operations can be performed on a semaphore.
- What is a binary semaphore?
- Adapt the producer/consumer application for a finite buffer.
- What changes are required if there are two or more producers and two or more consumers?

References

- A. S. Tanenbaum and H. Bos: Modern Operating Systems, Pearson, 4th edition, 2014.
- W. Stallings: Operating Systems. Internals and design principles. Pearson, 2012