Operating Systems
CS220

Lecture 12

Process Synchronization

1st June 2021

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Process Synchronization

- The Critical-Section Problem
- Synchronization Hardware
- Semaphores
- Classical Problems of Synchronization

Process Synchronization

- Processes may be **independent** or **cooperating**
- Cooperating process can affect or be affected by other processes

- Cooperating process can share data
  - Inter-Process communication in case of heavy-weight processes
  - Same logical address space in case of threads
  - Message passing

Why synchronization?

- When we have multiple processes running at the same time (i.e. **concurrently**) we know that we must protect them from one another
  - E.g. protect one process' memory from access by another process
- But, what if we want to have those processes/ threads cooperate to solve a single problem?
  - E.g. one thread that manages, the mouse and keyboard, another that manages the display and a third that runs your programs
  - In this case, the processes/threads must be **synchronized**

The Synchronization Problem

- Multiple processes may be sharing a common storage
  - Common Main memory
  - Or Common File
  - Or Common xyz
- The nature of the common storage does not change the nature of the problem
- "Common storage" is an abstract concept
- Implementation may differ

Problem with Concurrency

- Just like shuffling cards, the instructions of two processes are interleaved ***arbitrarily***
- For cooperating processes, the order of some instructions are irrelevant. However, certain instruction combinations must be prevented
- For example:

Process A	Process B	concurrent access
A = 1;	B = 2;	does not matter
A = B + 1;	B = B * 2;	important!

- A ***race condition*** is a situation where two or more processes access shared data concurrently. Result differs depending on who wins the race to it!

The Synchronization Problem

- Concurrent access to shared data may result in data inconsistency

- Maintaining data consistency requires mechanisms to ensure the orderly execution of cooperating processes

The Synchronization Problem

- One process/thread should not get into the way of another process/thread when doing critical activities

- Proper sequence of execution should be followed when dependencies are present
  - A produces data, B prints it
  - Before printing B should wait while A is producing data
  - B is dependent on A

The Synchronization Problem

- The problem relates to both Threads and Processes as data sharing can be using
  - IPC in case of heavy-weight processes
  - Same logical address space in case of threads
- Same solutions exists
- The only difference could be the level at which the solution is applied
  - Kernel level
  - User level
- From now on threads and processes both mean the same i.e. "Execution path", unless otherwise specified

If there is no synchronization

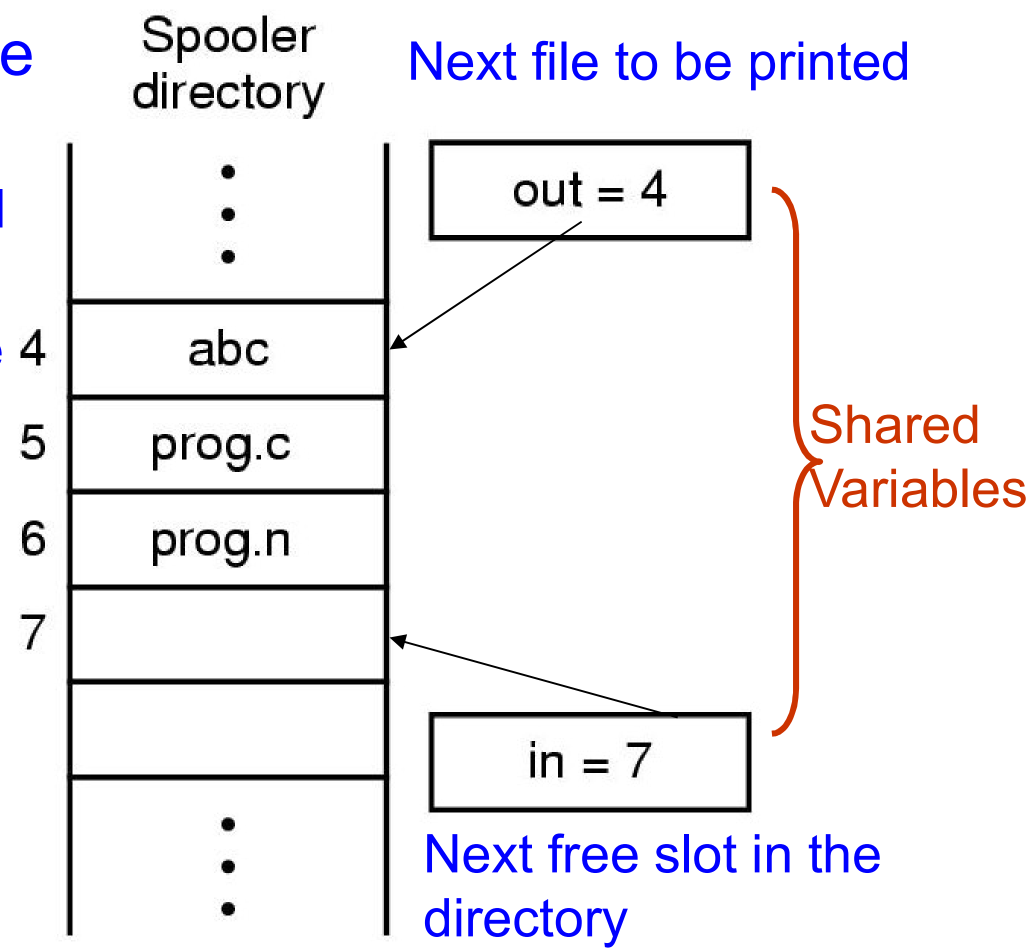
Example Print Spooler

- If a process wishes to print a file it adds its name in a **Spooler Directory**
- The **Printer process**
  - Periodically checks the spooler directory
  - Prints a file
  - Removes its name from the directory

Example Print Spooler

If any process wants to print a file it will execute the following code

1. Read the value of `in` in a local variable `next_free_slot`
2. Store the name of its file in the `next_free_slot`
3. Increment `next_free_slot`
4. Store back in `in`



Example Print Spooler

Let A and B be processes wh… …t their files

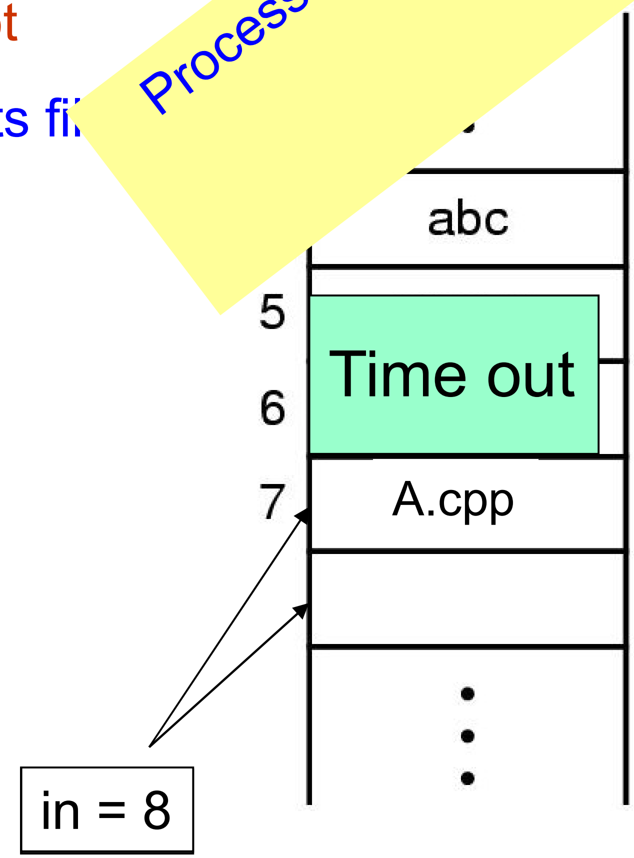
Process B will never receive any output

Process A

1. Read the value of in in a local variable next_free_slot
2. Store the name of its fi… in the next_free_slot
3. Increment next_free_slot
4. Store back in in

Process B

1. Read the value of in in a local variable next_free_slot
2. Store the name of its file in the next_free_slot
3. Increment next_free_slot
4. Store back in in



$next\_free\_slot_a = 7$

$next\_free\_slot_b = 7$

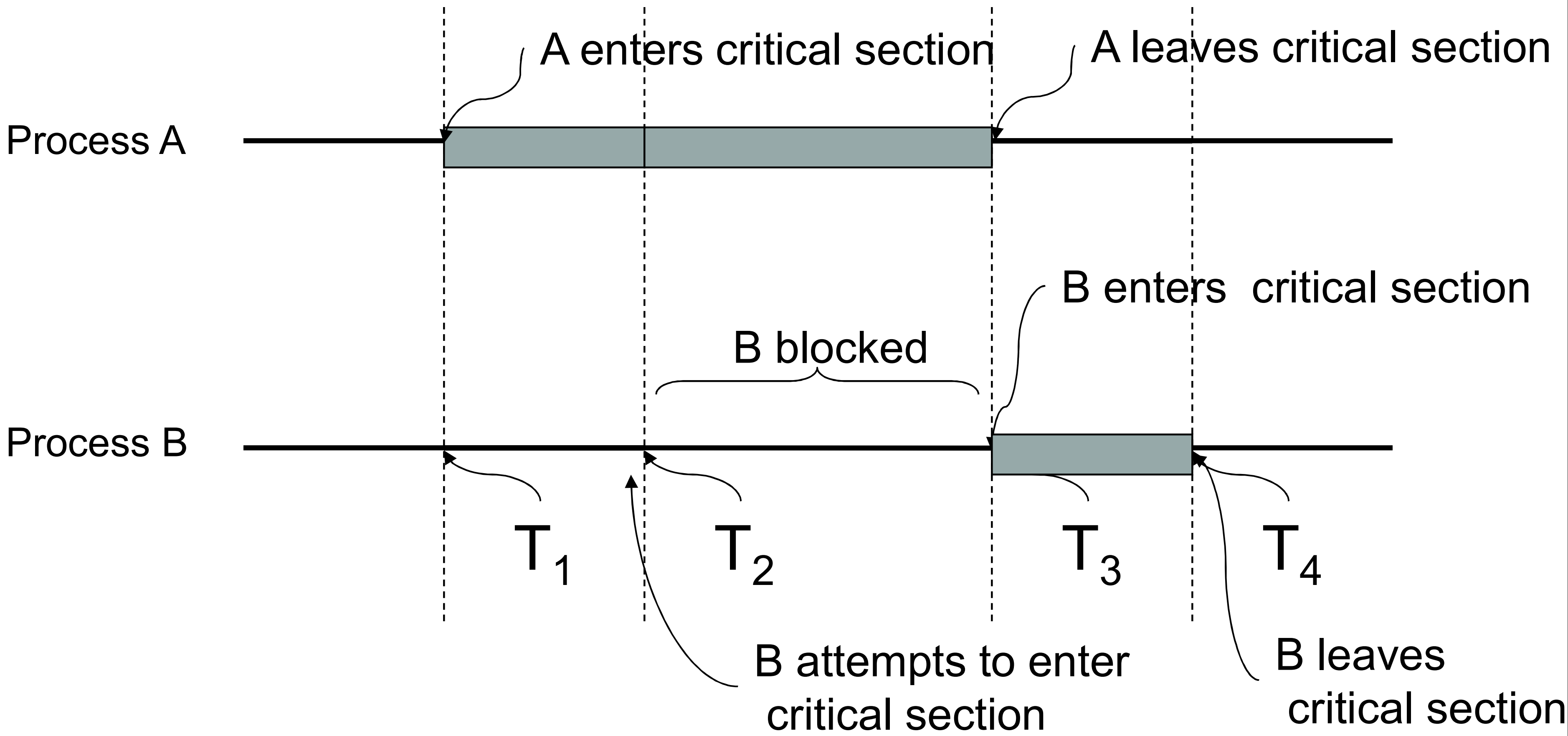
Race condition

- A situation where several processes access and manipulate the same data concurrently, and the outcome of the execution depends on the particular order in which the access takes place, is called **race condition.**
  - Debugging is not easy
  - Most test runs will run fine
  - To prevent race conditions, concurrent processes must be **synchronized**

Reason behind Race Condition

- Process B started using one of the shared variables before process A was finished with it.
- At any given time a Process is either
  - Doing internal computation => no race conditions
  - Or accessing shared data that can lead to race conditions
- Part of the program where the shared memory is accessed is called **Critical Region**
- Races can be avoided
  - **If no two processes are in the critical region at the same time.**

Critical Section



Mutual Exclusion

At any given time, only one process is in the critical section

Critical Section

- Avoid race conditions by not allowing two processes to be in their critical sections at the same time

- We need a mechanism of mutual exclusion

- Some way of ensuring that one process, while using the shared variable, does not allow another process to access that variable

Critical Section

- In fact we need four conditions to hold.
    1. No two processes may be simultaneously inside their critical sections
    2. No assumptions may be made about the speed or the number of processors
    3. No process running outside its critical section may block other processes
    4. No process should have to wait forever to enter its critical section
- It is difficult to devise a method that meets all these conditions.

The Critical-Section Problem

- Each process has a code segment, called *Critical Section (CS)*, in which the shared data is accessed.

- Problem – ensure that when one process is executing in its CS, no other process is allowed to execute in its CS.

The Critical-Section Problem

- Only 2 processes, P0 and P1
- General structure of process Pi (other process Pj)

do {

entry section

critical section (CS)

exit section

reminder section

} **while (1)**;

- Processes may share some common variables to synchronize their actions

Solution to Critical-Section Problem

- There are 3 requirements that must stand for a correct solution:
  1. **Mutual Exclusion**
  2. **Progress**
  3. **Bounded Waiting**

Solution to CS Problem – Mutual Exclusion

1. **Mutual Exclusion** – If process P_i is executing in its critical section, then no other processes can be executing in their critical sections.

- Implications:
  - Critical sections better be focused and short.
  - Better not get into an infinite loop in there.

Solution to CS Problem – Progress

2. **Progress** – If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the process that will enter the critical section next cannot be postponed indefinitely:
   - If only one process wants to enter, it should be able to.
   - If two or more want to enter, one of them should succeed.
   - No deadlock
   - No process in its remainder section can participate in this decision

Solution to CS Problem – Bounded Waiting

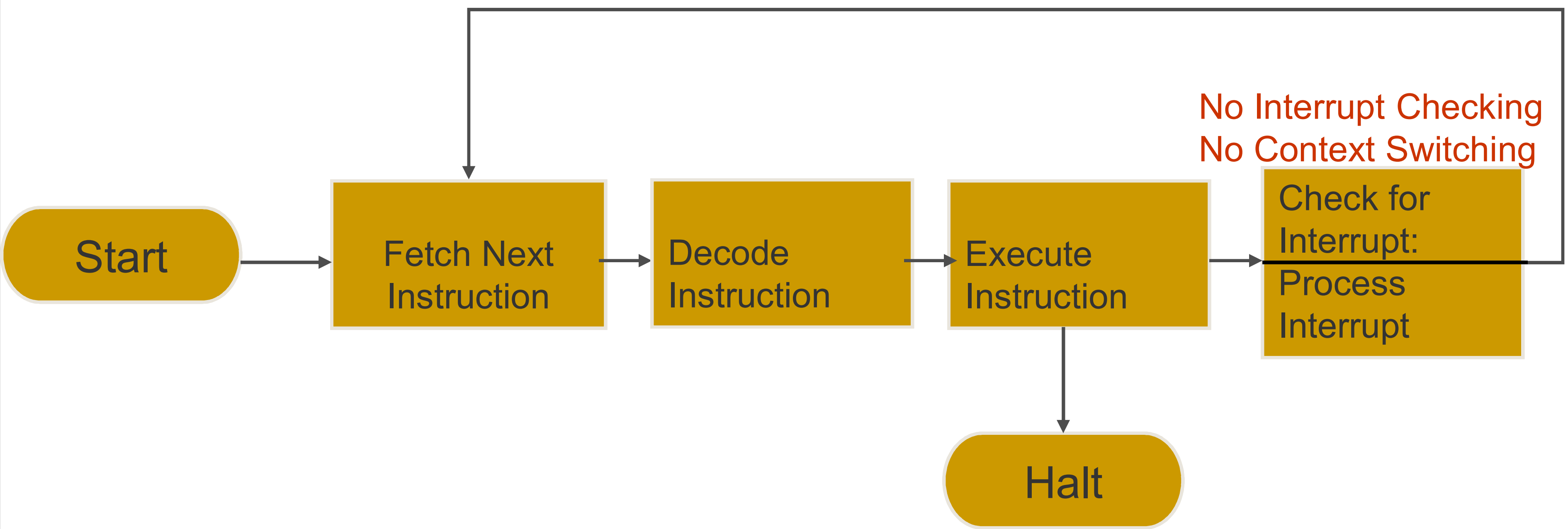
3. **Bounded Waiting** – A bound must exist on the number of times that other processes are allowed to enter their critical sections after a process has made a request to enter its critical section and before that request is granted.
   - Assume that each process executes at a nonzero speed.
   - No assumption concerning relative speed of the *n* processes.
   - Deterministic algorithm, otherwise the process could suffer from starvation

Implementing Mutual Exclusion

1. Disabling Interrupts
2. Lock Variables
3. Strict Alternation

Disabling Interrupts

- The problem occurred because the CPU switched to another process due to clock interrupt
- Remember the CPU cycle



Disabling Interrupts

- Solution: A Process
  - Disable interrupts before it enters its critical section
  - Enable interrupts after it leaves its critical section
- CPU will be unable to switch a process while it is in its critical section
- Guarantees that the process can use the shared variable without another process accessing it
- Disadvantage:
  - Unwise to give user processes this much power
  - The computer will not be able to service useful interrupts
  - The process may never enable interrupts, thus (effectively) crashing the system
- However, the kernel itself can disable the interrupts

Lock Variables: Software Solution

- Before entering a critical section a process should know if any other is already in the critical section or not
- Consider having a FLAG (also called lock)
- FLAG = FALSE
  - A process is in the critical section
- FLAG = TRUE
  - No process is in the critical section

```
// wait while someone else is in the
// critical region
1. while (FLAG == FALSE);
// stop others from entering critical region
2. FLAG = FALSE;
3. critical_section();
// after critical section let others enter
//the critical region
4. FLAG = TRUE;
5. noncritical_section();
```

FLAG = FALSE

Lock Variables

Process 1

```
1.while (FLAG == FALSE);
2.FLAG = FALSE;
3.critical_section();
4.FLAG = TRUE;
5.noncritical_section();
```

Process 2

```
1.while (FLAG == FALSE);
2.FLAG = FALSE;
3.critical_section();
```

Timeout

No two processes may be simultaneously inside their critical sections

Process 2 ‘s Program counter is at Line 2

Process 1 forgot that it was Process 2’s turn

Solution: Strict Alternation

- We need to remember "Who's turn it is?"
- If its Process 1's turn then Process 2 should wait
- If its Process 2's turn then Process 1 should wait

Process 1

```
while(TRUE)
{
  // wait for turn
  while (turn != 1);
  critical_section();
  turn = 2;
  noncritical_section();
}
```

Process 2

```
while(TRUE)
{
  // wait for turn
  while (turn != 2);
  critical_section();
  turn = 1;
  noncritical_section();
}
```

Strict Alternation

Turn = 1

Process 1

```
While(1)
1.while (Turn != 1);

2.critical_section();

3.Turn = 2;
4.noncritical_section();
```

Process 2

```
While(1)
1.while (Turn != 2);

2.critical_section();

3.Turn = 1;
4.noncritical_section();
```

Timeout

Only one Process is in the Critical Section at a time

Process 2 's Program counter is at Line 2

Process 1 Busy Waits

Strict Alternation

Process 1

```
while(TRUE)
{
  // wait
  while (turn != 1);
  critical_section();
  turn = 2;
  noncritical_section();
}
```

Process 2

```
while(TRUE)
{
  // wait
  while (turn != 2);
  critical_section();
  turn = 1;
  noncritical_section();
}
```

- Can you see a problem with this?
- Hint : What if one process is a much faster than the other

turn = 1

Strict Alternation

Process 1

```
while(TRUE)
{
  // wait
  while (turn != 1);
  critical_section();
  turn = 2;
  noncritical_section();
}
```

Process 2

```
while(TRUE)
{
  // wait
  while (turn != 2);
  critical_section();
  turn = 1;
  noncritical_section();
}
```

- Process 1
  - Runs
  - Enters its critical section
  - Exits; setting turn to 2.
- Process 1 is now in its non-critical section.
- Assume this non-critical procedure takes a long time.
- Process 2, which is a much faster process, now runs
- Once it has left its critical section, sets turn to 1.
- Process 2 executes its non-critical section very quickly and returns to the top of the procedure.

turn = 1

Process 1

```
while(TRUE)
{
  // wait
  while (turn != 1);
  critical_section();
  turn = 2;
  noncritical_section();
}
```

Process 2

```
while(TRUE)
{
  // wait
  while (turn != 2);
  critical_section();
  turn = 1;
  noncritical_section();
}
```

- Process 1 is in its non-critical section
- Process 2 is waiting for turn to be set to 2
- In fact, there is no reason why process 2 cannot enter its critical region as process 1 is not in its critical region.

Strict Alternation

- What we have is a violation of one of the conditions that we listed above

No process running outside its critical section may block other processes

- This algorithm requires that the processes *strictly alternate* in entering the critical section
- Taking turns is not a good idea if one of the processes is *slower*.

Reason

- Although it was Process 1's **turn**
- But Process 1 was not **interested**.
- Solution:
  - We also need to remember
    - "**Whether it is interested or not?**"

Algorithm 2

- Replace
  - `int turn;`
- With
  - `bool Interested[2];`
- `Interested[0] = FALSE`
  - Process 0 is not interested
- `Interested[0] = TRUE`
  - Process 0 is interested
- `Interested[1] = FALSE`
  - Process 1 is not interested
- `Interested[1] = TRUE`
  - Process 1 is interested

Algorithm 2

Process 0

```
while(TRUE)
{
  interested[0] = TRUE;
  // wait for turn
  while(interested[1]!=FALSE);
  critical_section();
  interested[0] = FALSE;
  noncritical_section();
}
```

Process 1

```
while(TRUE)
{
  interested[1] = TRUE;
  // wait for turn
  while(interested[0]!=FALSE);
  critical_section();
  interested[1] = FALSE;
  noncritical_section();
}
```

Algorithm 2

Process 0

```
while(TRUE)
{
  interested[0] = TRUE;
  while(interested[1]!=
```

Timeout

Process 1

```
while(TRUE)
{
  erested[1] = TRUE;
  le(interested[0]!=FALSE);
```

DEADLOCK

Peterson's Solution

Combine the previous two algorithms:

```
int turn;
bool interested[2];
```

- `Interested[0] = FALSE`
  - Process 0 is not interested
- `Interested[0] = TRUE`
  - Process 0 is interested
- `Interested[1] = FALSE`
  - Process 1 is not interested
- `Interested[1] = TRUE`
  - Process 1 is interested

Algorithm 3: Peterson's Solution

- Two process solution (Software based solution)

- The two processes share two variables:
  - int **turn**;
  - Boolean **interested[2]**

- The variable **turn** indicates whose turn it is to enter the critical section.

- The **interested** array is used to indicate if a process is ready to enter the critical section. **interested[i] = true** implies that process $\mathbf{P_i}$ is ready

Algorithm 3: Peterson's Solution

- **Process Pi**

```
while(TRUE)
{
 interested[i] = TRUE;
 turn = j;
 // wait
  while(interested[j]==TRUE && turn == j );
 critical_section();
 interested[i] = FALSE;
 noncritical_section();
}
```

Algorithm 3: Peterson's Solution

- Meets all three requirements:
  - **Mutual Exclusion**: 'turn' can have one value at a given time (0 or 1)
  - **Bounded-waiting**: At most one entry by a process and then the second process enters into its CS
  - **Progress**: Exiting process sets its 'flag' to false … comes back quickly and set it to true again … but sets turn to the number of the other process

Two-Process Solution to the Critical-Section Problem --- Peterson’s Solution

```
flag[0],flag[1]:=false
turn := 0;
Process P0:
repeat
  flag[0]:=true;
    // 0 wants in
  turn:= 1;
   // 0 gives a chance to 1
  while(flag[1]&&turn==1){};
     CS
  flag[0]:=false;
   // 0 is done
     RS
forever
```

```
Process P1:
repeat
  flag[1]:=true;
    // 1 wants in
  turn:=0;
   // 1 gives a chance to 0
  while(flag[0]&&turn==0){};
     CS
  flag[1]:=false;
   // 1 is done
     RS
forever
```

- The algorithm proved to be correct. Turn can only be 0 or 1 even if both flags are set to true

Drawbacks of Software Solutions

- Complicated to program
- **Busy waiting** (wasted CPU cycles)
- It would be more efficient to ***block*** processes that are waiting (just as if they had requested I/O)
  - This suggests implementing the permission/waiting function in the Operating System
- But first, let's look at some hardware approaches

References

- Operating System Concepts (Silberschatz, 8th edition) Chapter 6