



# Operating Systems

## Synchronization Tools-Part1

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Slides are based on the slides of the main **textbook**.

**Silberschatz**

<https://www.os-book.com/OS10/slide-dir/index.html>



# Background

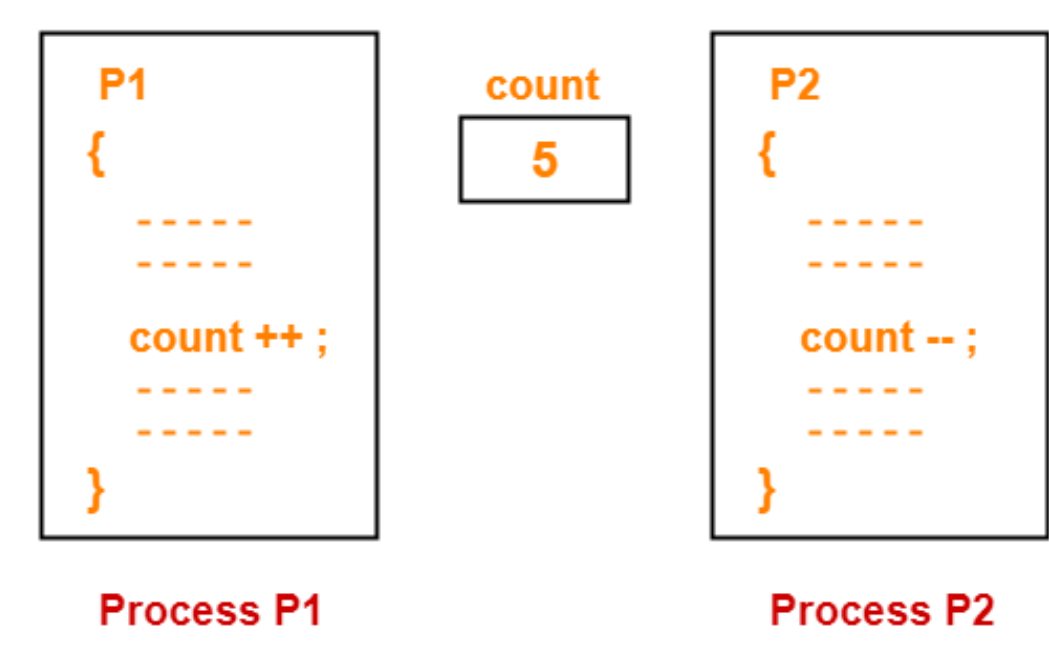
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- **Processes can execute concurrently**
  - May be interrupted at any time, partially completing execution.
- Concurrent access to shared data may result in **data inconsistency**.
- Maintaining data consistency requires mechanisms to ensure the **orderly execution of cooperating processes**.



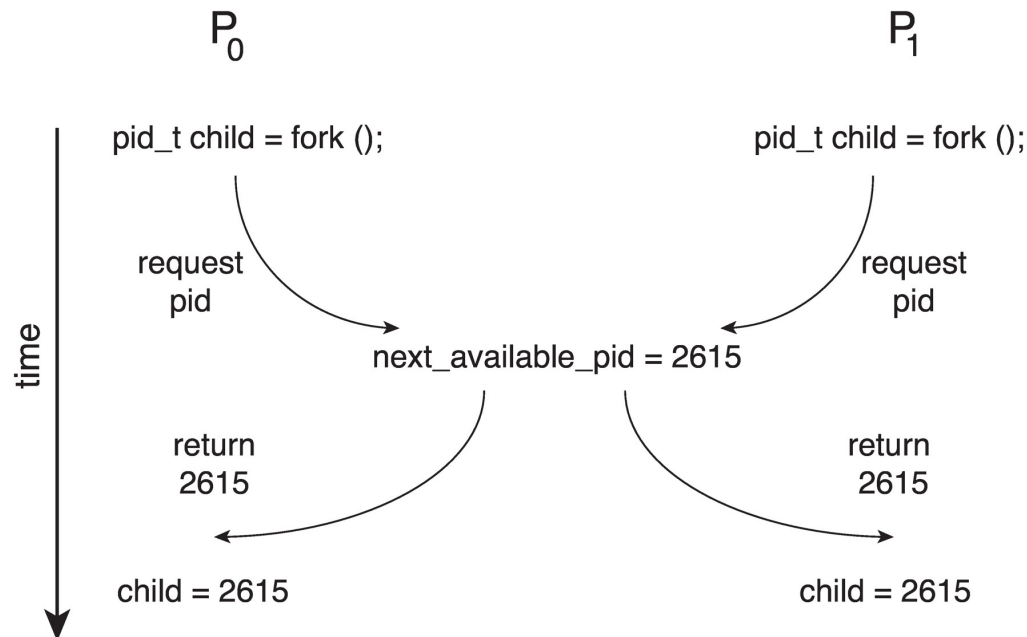
# Background (cont.)

- In chapter 4, when we considered the Bounded Buffer problem with use of a counter that is updated concurrently by the producer and consumer, which **lead to race condition**.

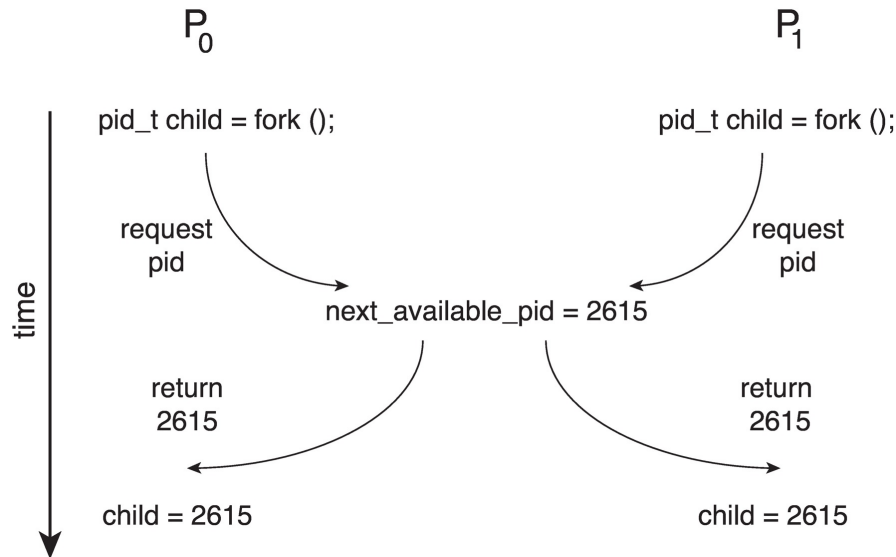


# Race Condition

- Processes  $P_0$  and  $P_1$  are creating child processes using the **fork()** system call.
- Race condition on kernel variable `next_available_pid` which represents the next available process identifier (pid)



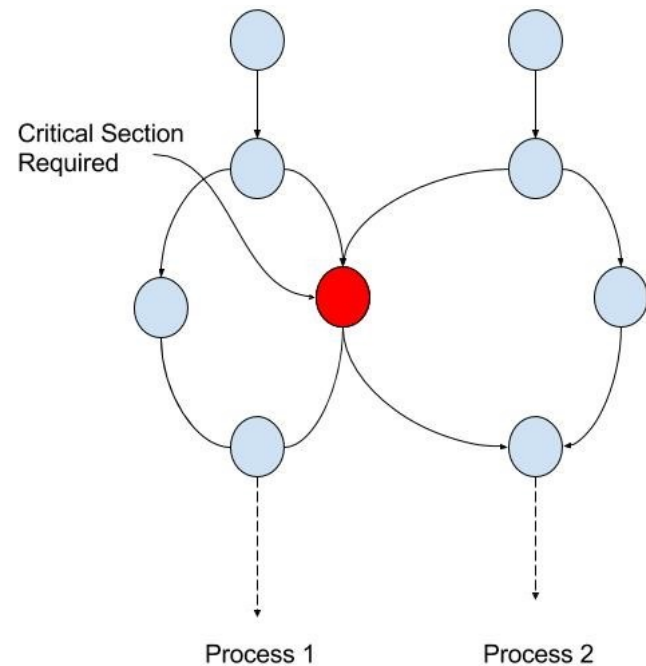
# Race Condition (Cont.)



- Unless there is a mechanism to prevent  $P_0$  and  $P_1$  from accessing the variable `next_available_pid` **the same pid** could be assigned **to two different processes!**

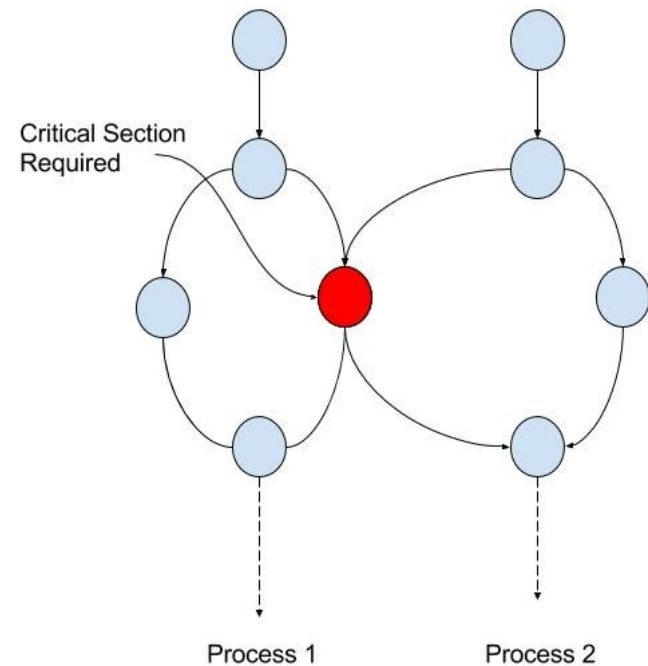
# Critical Section Problem

- Consider system of  $n$  processes  $\{p_0, p_1, \dots, p_{n-1}\}$
- Each process has **critical section** segment of code
  - Process may be changing common variables, updating table, writing file, etc.



# Critical Section Problem

- When one process in critical section, no other may be in its critical section.
- Critical section problem is to design protocol to solve this.





# Critical Section

- Each process
  - must ask permission to enter critical section in **entry section**,
  - may follow critical section with **exit section**,
  - then **remainder section**.

do {

*entry section*

critical section

*exit section*

remainder section

} while (true);

- General structure of process  $P_i$



# Requirements for solution to critical-section problem

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**1. Mutual Exclusion**

**2. Progress**

**3. Bounded Waiting**



# 1- Mutual Exclusion

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- If process  $P_i$  is executing in its critical section, then no other processes can be executing in their critical sections.
- No two processes simultaneously in critical region.



## 2- Progress

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- 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.
- No process running outside its critical region may block another process.



# 3- Bounded Waiting

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- 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
- **No process must wait forever to enter its critical region.**



# Interrupt-based Solution

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- Entry section: disable interrupts
- Exit section: enable interrupts
  
- Will this solve the problem?
  - What if the critical section is code that runs for an hour?
    - ▶ Can some processes starve -- never enter their critical section.
  - What if there are two CPUs?



# Software Solution 1

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- Two process solution.
- Assume that the load and store machine-language instructions are atomic; that is, cannot be interrupted.
- The two processes share one variable:
  - int *turn*;
  - *turn* indicates whose turn it is to enter the critical section.



# Algorithm for Process $P_i$

---

```
while (true) {  
    while (turn == j);  
  
    /* critical section */  
    turn = j;  
  
    /* remainder section */  
  
}
```



# Algorithm for $P_0$ and $P_1$

---

Initially turn = 0

```
while (TRUE) {  
    while (turn != 0)    /* loop */ ;  
    critical_region();  
    turn = 1;  
    noncritical_region();  
}
```

(a)

(a) Process 0.

```
while (TRUE) {  
    while (turn != 1)    /* loop */ ;  
    critical_region();  
    turn = 0;  
    noncritical_region();  
}
```

(b)

(b) Process 1.

# Correctness of the Software Solution

---

- **Mutual exclusion is preserved**

- $P_i$  enters critical section only if:

$$\text{turn} = i$$

- **turn cannot be both 0 and 1 at the same time**

- It **wastes** CPU time

- So we should avoid busy waiting as much as we can.

- **Can be used** only when the waiting period is expected to be **short**.



# Correctness of the Software Solution (cont.)

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- However there is a problem in the above approach!
  - What about the **Progress** requirement?
  - What about the **Bounded-waiting** requirement?



# Correctness of the Software Solution (cont.)

- $P_0$  leaves its critical region and sets turn to 1, enters its non-critical region.
- $P_1$  enters its critical region, sets turn to 0 and leaves its critical region.
- $P_1$  enters its non-critical region, quickly finishes its job and goes back to the while loop.
- Since turn is 0, process 1 **has to wait** for process 0 to finish its non-critical region so that it can enter its critical region.
- This violates the **second condition (progress)** of providing mutual exclusion.

Initially turn = 0

```

                                P0
while (TRUE) {
    while (turn != 0)
        critical_region();
    turn = 1;
    noncritical_region();
}
```

```

                                P1
while (TRUE) {
    while (turn != 1)
        critical_region();
    turn = 0;
    noncritical_region();
}
```



# How About this solution?

---

```
//Algorithm for  $P_i$   
while (true){
```

```
    turn = i;  
    while (turn == j);
```

```
    /* critical section */
```

```
    turn = j;
```

```
    /* remainder section */
```

```
}
```

# How About this solution?

```
//Algorithm for P0  
while (true){
```

```
    turn = 0;  
    while (turn == 1);
```

```
/* critical section */
```

```
    turn = 1;
```

```
/* remainder section */
```

```
}
```

```
//Algorithm for Pi  
while (true){
```

```
    turn = 1;  
    while (turn == 0);
```

```
/* critical section */
```

```
    turn = 0;
```

```
/* remainder section */
```

```
}
```

No mutual exclusion

# How About this solution?

```
//Algorithm for P0  
while (true){
```

```
    turn = 0;  
    while (turn == 1);
```

```
/* critical section */
```

```
    turn = 1;
```

```
/* remainder section */
```

```
}
```

```
//Algorithm for P1  
while (true){
```

```
    turn = 1;  
    while (turn == 0);
```

```
/* critical section */
```

```
    turn = 0;
```

```
/* remainder section */
```

```
}
```

No mutual exclusion

# Why No Mutual Exclusion?

```
//Algorithm for P0
while (true){
    turn = 0;
    while (turn == 1);
```

Context Switch

```
//Algorithm for P1
while (true){
```

```
    turn = 1;
    while (turn == 0);
```

```
/* critical section */
```

```
    turn = 1;
```

```
/* remainder section */
```

```
}
```



```
/* critical section */
```

```
    turn = 0;
```

```
/* remainder section */
```

```
}
```



# Peterson's Solution

---

- The previous solution solves the problem of one process blocking another process while its outside its critical section.
- Peterson's Solution is a neat solution with busy waiting, that defines the procedures for entering and leaving the critical region.



# Peterson's Solution (cont.)

---

- Two process solution
- Assume that the **load** and **store** machine-language instructions are **atomic**; that is, cannot be interrupted.
- The two processes share two variables:
  - `int turn;`
  - `boolean flag[2]`



# Peterson's Solution (cont.)

---

- The **variable turn** indicates whose turn it is to enter the **critical section**.
- The **flag array** is used to indicate **if a process is ready to enter the critical section**.
  - $\text{flag}[i] = \text{true}$  implies that process  $P_i$  is ready!



# Algorithm for Process $P_i$

---

```
while (true) {
```

```
    flag[i] = true;  
    turn = j;  
    while (flag[j] && turn == j);
```

```
    /* critical section */
```

```
    flag[i] = false;
```

```
    /* remainder section */
```

```
}
```

# Correctness of Peterson's Solution

---

- Provable that the three CS requirement are met:

1. Mutual exclusion is preserved

$P_i$  enters CS only if:

either  $\text{flag}[j] = \text{false}$  or  $\text{turn} = i$

2. Progress requirement **is satisfied**

3. Bounded-waiting requirement **is met**

# Peterson's Solution

```
//P0
```

```
while (true){  
  
    flag[0] = true;  
  
    turn = 1;  
  
    while (flag[1] && turn == 1);  
  
    /* critical section */  
  
    flag[0] = false;  
  
    /* remainder section */  
  
}
```

```
//P1
```

```
while (true){  
  
    flag[1] = true;  
  
    turn = 0;  
  
    while (flag[0] && turn == 0);  
  
    /* critical section */  
  
    flag[1] = false;  
  
    /* remainder section */  
  
}
```



# Peterson's Solution and Modern Architecture

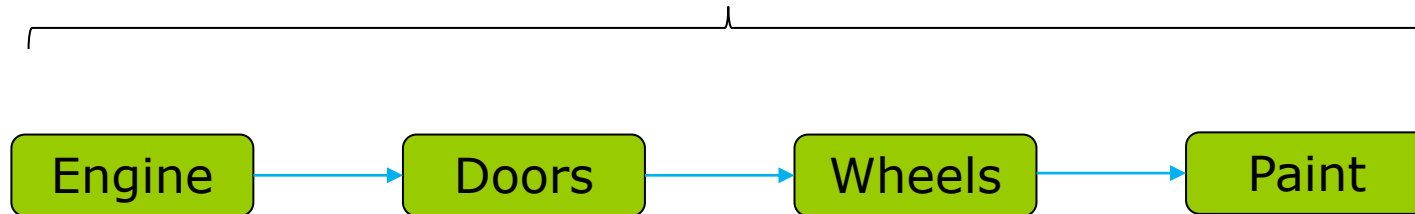
---

- Although useful for demonstrating an algorithm, Peterson's solution **is not guaranteed to work on modern architectures.**
- To improve performance, **processors and/or compilers may reorder operations that have no dependencies.**
- Understanding why it **will not work** is useful for better understanding race conditions.



# Pipeline Example

Four station, each takes 5 mins



Work list:

Manufacture Car-1

Test Car-1

Manufacture Car-2

Test Car-2

Manufacture Car-3

Test Car-3

Manufacture Car-4

Test Car-4



# Pipeline Example (cont.)

Time	Engine	Doors	Wheels	Paint	
5	Car-1				
10		Car-1			
15			Car-1		
20				Car-1	For test →
25	Car-2				
30		Car-2			
35			Car-2		
40				Car-2	For test →
45	Car-3				
50		Car-3			
55			Car-3		
60				Car-3	For test →
65	Car-4				
70		Car-4			
75			Car-4		
80				Car-5	For test →

# Pipeline Example (cont.)

---

- Let's **reorder** the work list:

List of works:

Manufacture Car-1

Manufacture Car-2

Manufacture Car-3

Manufacture Car-4

Test Car-1

Test Car-2

Test Car-3

Test Car-4



# Pipeline Example (cont.)

- Let's reorder the works

List of works:

Manufacture Car-1

Manufacture Car-2

Manufacture Car-3

Manufacture Car-4

Test Car-1

Test Car-2

Test Car-3

Test Car-4

Time	Engine	Doors	Wheels	Paint	
5	Car-1				
10	Car-2	Car-1			
15	Car-3	Car-2	Car-1		
20	Car-4	Car-3	Car-2	Car-1	For test →
25		Car-4	Car-3	Car-2	For test →
30			Car-4	Car-3	For test →
35				Car-4	For test →

# Instruction Pipeline

---

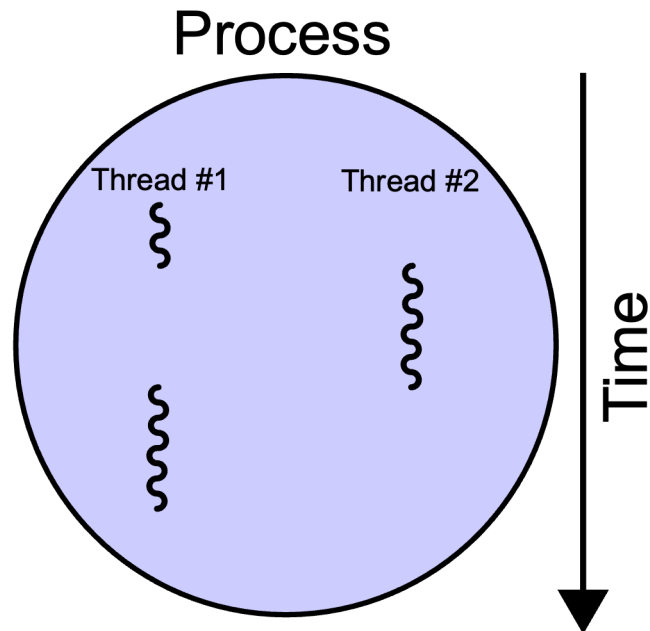
Cycles	Fetch	Decode	Execute	Save
1	Inst 1			
2	Inst 2	Inst 1		
3	Inst 3	Inst 2	Inst 1	
4	Inst 4	Inst 3	Inst 2	Inst 1
5		Inst 4	Inst 3	Inst 2
6			Inst 4	Inst 3
7				Inst 4

Source: <http://users.cs.fiu.edu/~downeyt/cop3402/pipeline.html>



# Peterson's Solution and Modern Architecture

- For **single-threaded** this is **ok** as the result will always be the same.
- For multithreaded the **reordering may produce inconsistent or unexpected results!**



# Modern Architecture Example

---

- Two threads share the data:

```
boolean flag = false;  
int x = 0;
```

- Thread 1 performs

```
while (!flag);  
    print x
```

- Thread 2 performs

```
x = 100;  
flag = true
```

- What is the expected output?

100

# Modern Architecture Example (cont.)

---

- However, since the variables `flag` and `x` **are independent** of each other, the instructions:

```
flag = true;
```

```
x = 100;
```

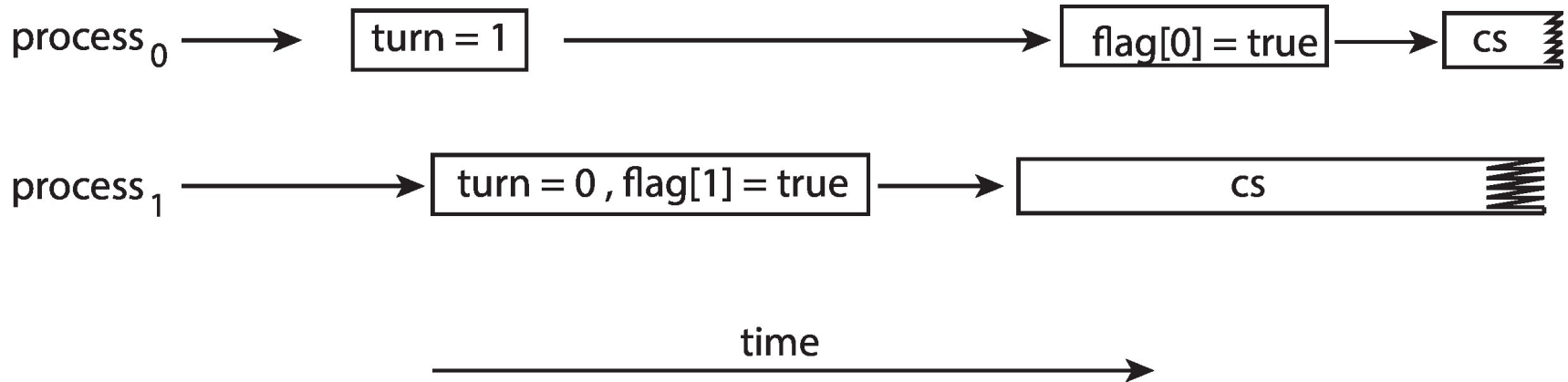
for Thread 2 may be reordered

- **If this occurs, the output may be 0!**



# Peterson's Solution Revisited

- The effects of instruction reordering in Peterson's Solution



- This allows both processes to be in their critical section at the same time!
- To ensure that Peterson's solution will work correctly on modern computer architecture we must use **Memory Barrier**.