Synchronization (cont.)

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Synchronization and Scheduling

- Busy-waiting synchronization
  ⇨ Waste CPU on waiting
  - OK if each process/thread has a CPU exclusively
  - What if there are fewer CPUs than processes/threads?
- Blocking (yielding CPU) synchronization
  - Yield the CPU (so other process/thread can make good use) if we must wait
  - Need operating system involvement

Semaphore

- Synchronization tool that does not require busy waiting.
- Semaphore S – integer variable which can only be accessed via two atomic operations:

```
wait(S) or P(S):
    wait until S>0;
    S--;

signal(S) or V(S):
    S++;
```

- Solving the critical section problem:

Shared data:

```
semaphore mutex=1;
```

Process Pi:

```
wait(mutex);
    critical section
signal(mutex);
    remainder section
```

Can you show mutual exclusion?
Can you show deadlock-free?

Semaphore Implementation

- Define a semaphore as a record

```
typedef struct {
    int value;
    proc_list *L;
} semaphore;
```

- Assume two OS operations:
  - `block` suspends the process that invokes it.
  - `wakeup(P)` resumes the execution of blocked process `P`.
- Semaphore operations now defined as (both are atomic):

```
wait(S):
    S.value--;
    if (S.value < 0) {
        add this process to S.L;
        block;
    }
signal(S):
    S.value++;
    if (S.value <= 0) {
        remove a process P from S.L;
        wakeup(P);
    }
```

How to make sure wait(S) and signal(S) are atomic?
So have we truly removed busy waiting?

Mutex Lock (Binary Semaphore)

- Mutex lock – a semaphore with only two states: locked/unlocked
- Semantics of the two (atomic) operations:

```
lock(mutex):
    wait until mutex==unlocked;
    mutex=locked;

unlock(mutex):
    mutex=unlocked;
```

- Can you implement mutex lock using semaphore?
- How about the opposite?

Implement Semaphore Using Mutex Lock

- Data structures:

```
mutex_lock L1, L2;
int C;
```

- Initialization:

```
L1 = unlocked;
L2 = locked;
C = initial value of semaphore;
```

- *wait* operation:

```
lock(L1);
C --;
if (C < 0) {
   unlock(L1);
   lock(L2);
}
unlock(L1);
```

- *signal* operation:

```
lock(L1);
C ++;
if (C <= 0)
   unlock(L2);
else
   unlock(L1);
```

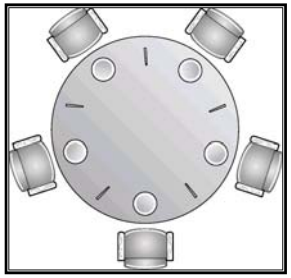

Busy-Wait vs. Blocking Synchronization

- Busy-wait synchronization: software/hardware spin locks
- Blocking synchronization: semaphore, mutex lock, condition variable, …
- When each process/thread has its dedicated CPU
  - Is busy waiting OK?
- When only need to protect a short (bounded size) critical section
  - Is busy waiting OK?
  - Still has the risk of wasting substantial CPU time in waiting, if context switched out in the middle of critical section
- For complex synchronization of unpredictable waiting time
  - Is busy waiting OK?
  - Higher overhead (typically done in the OS, may involve context switch), but no risk of wasting substantial CPU time in waiting

Busy-Wait vs. Blocking Synchronization

- Benefit of blocking:
  - Useful when the waiting time is long
- Cost of blocking:
  - Context switch overhead (cache warmup cost)
- Application does not make the choice, but rather leave it to the OS
  - When a process/thread must wait for synchronization from some other process, should it spin (busy-wait) or block?
- What if you know the waiting time?
  - Spin the waiting time is shorter than the context switch cost; block otherwise
- What if you don't know the waiting time?
  - Spin for the time equal to the context-switch overhead. If not successful, then block.

Dining-Philosophers Problem



- Philosopher i (1 ≤ i ≤ 5):

```
while (1) {
   ...
   eat;
   ...
   think;
   ...
}
```

Eating needs both chopsticks (the left and the right one).

Dining-Philosophers Solution

- Shared data:

```
mutex chopstick[5];
```

- Philosopher i:

```
while(1) {
    ...
    lock(chopstick[i]);
    lock(chopstick[(i+1) % 5]);
    eat;
    unlock(chopstick[i]);
    unlock(chopstick[(i+1) % 5]);
    ...
    think;
    ...
};
```

Deadlock?