



Mutex Locks

- Previous solutions are complicated and generally inaccessible to application programmers
- OS designers build software tools to solve critical section problem
- Simplest is mutex lock
- Protect a critical section by first **acquire()** a lock then **release()** the lock
 - Boolean variable indicating if lock is available or not
- Calls to **acquire()** and **release()** must be atomic
 - Usually implemented via hardware atomic instructions
- But this solution requires **busy waiting**
 - This lock therefore called a **spinlock**





acquire() and release()

- ```
acquire() {
 while (!available)
 ; /* busy wait */
 available = false;;
}
```
- ```
release() {  
    available = true;  
}
```
- ```
do {
 acquire lock
 critical section
 release lock
 remainder section
} while (true);
```





# Semaphore

- Synchronization tool that provides more sophisticated ways (than Mutex locks) for process to synchronize their activities.
- Semaphore **S** – integer variable
- Can only be accessed via two indivisible (atomic) operations
  - **wait()** and **signal()**
    - ▶ Originally called **P()** and **V()**
- Definition of the **wait()** operation

```
wait(S) {
 while (S <= 0)
 ; // busy wait
 S--;
}
```

- Definition of the **signal()** operation

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





# Semaphore Usage

- **Counting semaphore** – integer value can range over an unrestricted domain
- **Binary semaphore** – integer value can range only between 0 and 1
  - Same as a **mutex lock**
- Can solve various synchronization problems
- Consider  $P_1$  and  $P_2$  that require  $S_1$  to happen before  $S_2$   
Create a semaphore “**synch**” initialized to 0

P1:

```
 S_1 ;
signal(synch);
```

P2:

```
wait(synch);
 S_2 ;
```

- Can implement a counting semaphore  $S$  as a binary semaphore





# Semaphore Implementation

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- Must guarantee that no two processes can execute the **wait()** and **signal()** on the same semaphore at the same time
- Thus, the implementation becomes the critical section problem where the **wait** and **signal** code are placed in the critical section
  - Could now have **busy waiting** in critical section implementation
    - ▶ But implementation code is short
    - ▶ Little busy waiting if critical section rarely occupied
- Note that applications may spend lots of time in critical sections and therefore this is not a good solution





# Semaphore Implementation with no Busy waiting

- With each semaphore there is an associated waiting queue
- Each entry in a waiting queue has two data items:
  - value (of type integer)
  - pointer to next record in the list
- Two operations:
  - **block** – place the process invoking the operation on the appropriate waiting queue
  - **wakeup** – remove one of processes in the waiting queue and place it in the ready queue
- `typedef struct{  
    int value;  
    struct process *list;  
} semaphore;`





## Implementation with no Busy waiting (Cont.)

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```
wait(semaphore *S) {
 S->value--;
 if (S->value < 0) {
 add this process to S->list;
 block();
 }
}

signal(semaphore *S) {
 S->value++;
 if (S->value <= 0) {
 remove a process P from S->list;
 wakeup(P);
 }
}
```





# 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

$P_0$   
`wait(S);`  
`wait(Q);`  
`...`  
`signal(S);`  
`signal(Q);`

$P_1$   
`wait(Q);`  
`wait(S);`  
`...`  
`signal(Q);`  
`signal(S);`

- **Starvation** – **indefinite blocking**
  - A process may never be removed from the semaphore queue in which it is suspended
- **Priority Inversion** – Scheduling problem when lower-priority process holds a lock needed by higher-priority process
  - Solved via **priority-inheritance protocol**

