Semaphores

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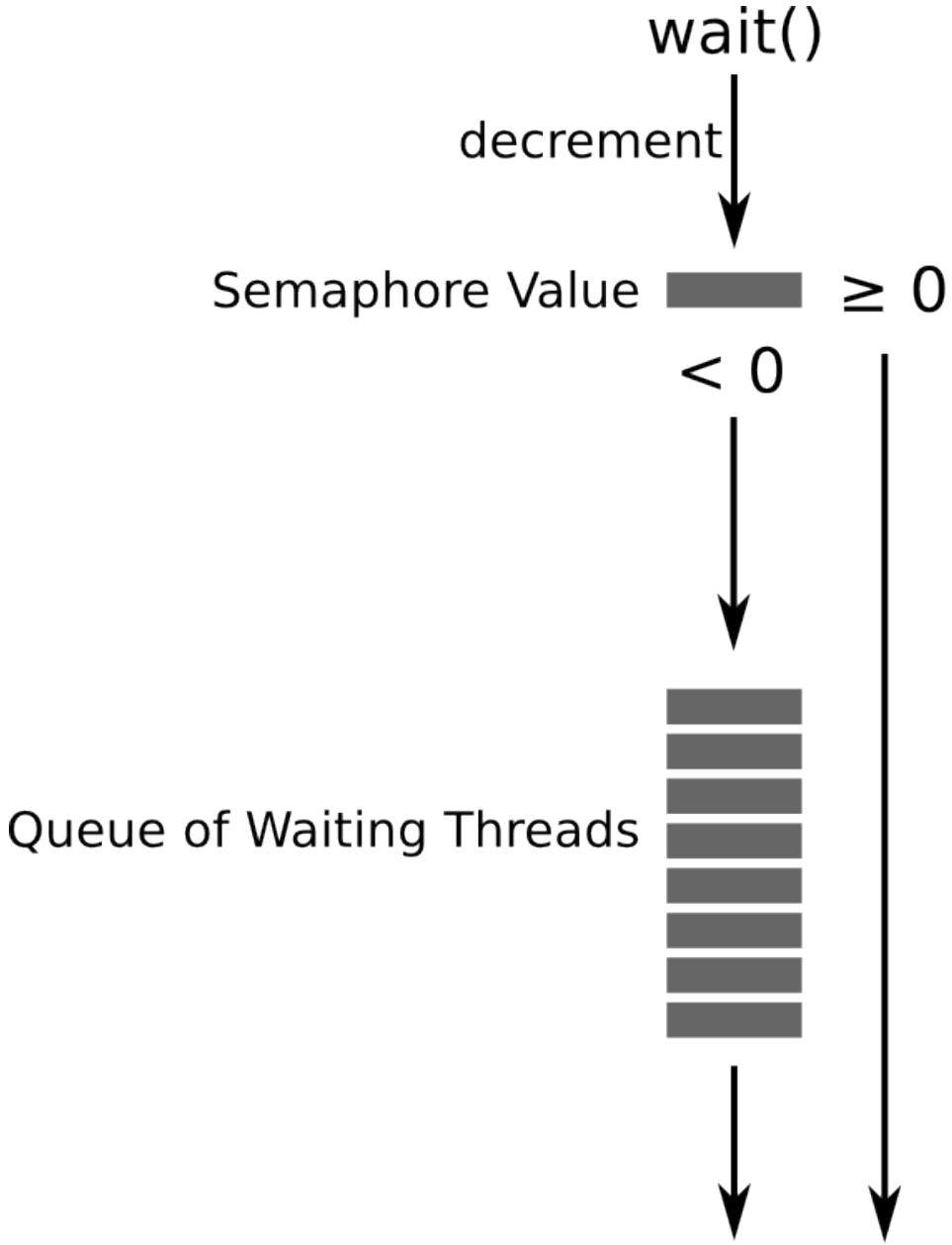
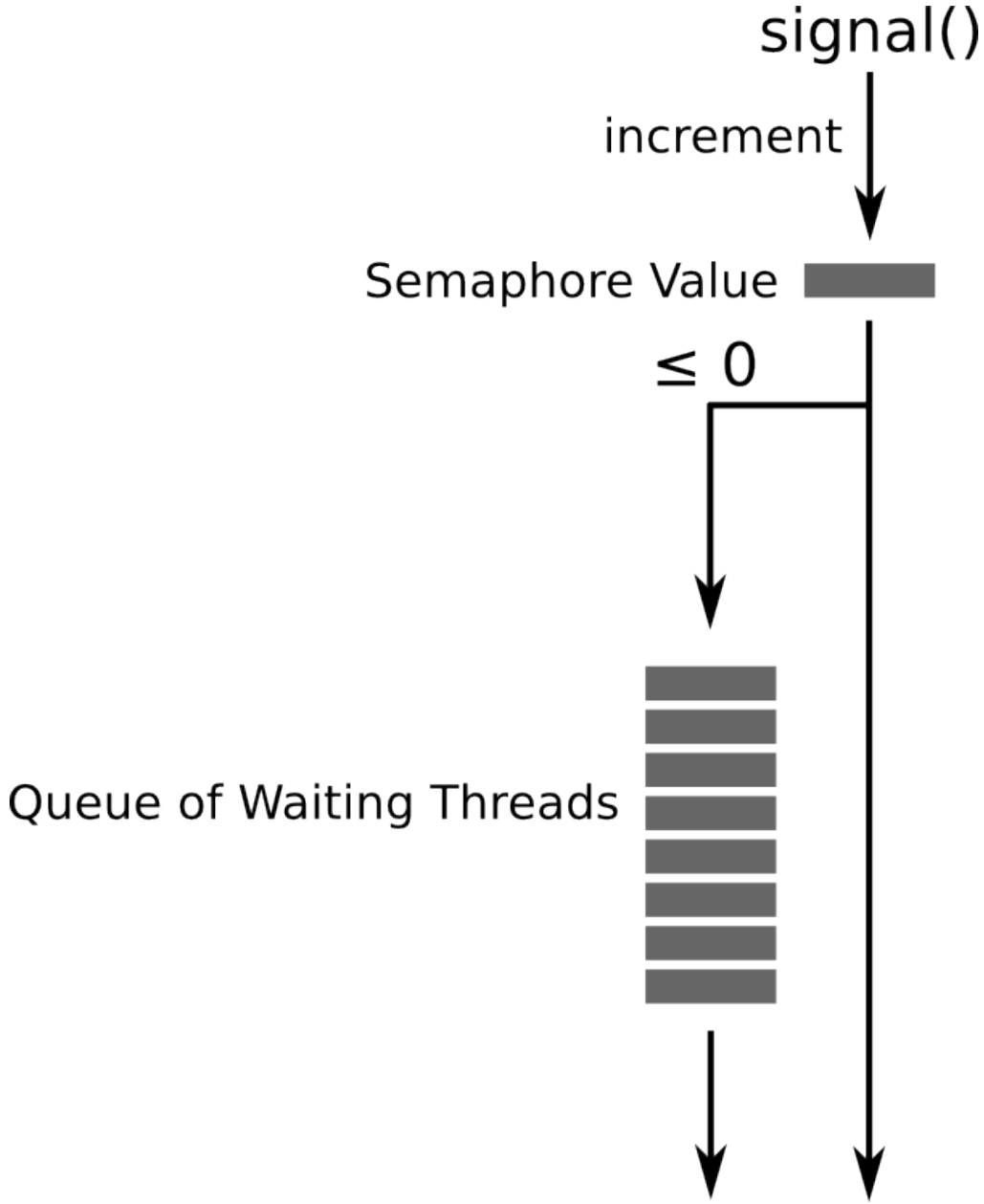
Semaphores

- semaphore is a shared variable maintained by OS
  - contains an integer and a queue
  - value initialized $>= 0$
- `wait(s)`: wait for a signal on semaphore *s*
  - decrements semaphore, blocks if value < 0
  - if blocked, process put on the queue, suspends until signal is sent
- `signal(s)`: transmit a signal to semaphore *s*
  - increments semaphore
  - if value $<= 0$ then unblock someone
- `wait()` and `signal()` are atomic operations and cannot be interrupted

wait()


wait()
decrement
Semaphore Value
≥ 0
< 0
Queue of Waiting Threads

signal()


signal()
increment
Semaphore Value
≤ 0
Queue of Waiting Threads

Types of Sempahores

- binary semaphore
  - only one process at a time may be in the critical section
- counting semaphore
  - a fixed number of processes > 0 may be in the critical section
- OS determines order that process are released from the queue, but usually FIFO in order to prevent starvation

Using Semaphores

```
1  semaphore s = 1;
2
3  void thread(int i) {
4      while (true) {
5          wait(s);
6          /* critical section */
7          signal(s);
8          /* remainder */
9      }
10 }
```

- semaphore protects critical section
- can set s to > 1 to let more than one process in the critical section
  - $s >= 0$: number that can enter
  - $s < 0$: number that are waiting

Producer Consumer

Producer Consumer

```
1  sem_t lock, numItems, numSpaces;
2  sem_init(&lock,0,1);
3  sem_init(&numItems,0,0);
4  sem_init(&numSpaces,0,BUFFER_SIZE);
```

producer:

```
1  while (True) {
2      produce();
3      sem_wait(&numSpaces);
4      sem_wait(&lock);
5      append();
6      sem_post(&lock);
7      sem_post(&numItems);
8  }
```

consumer:

```
1  while (True) {
2      sem_wait(&numItems);
3      sem_wait(&lock);
4      take();
5      sem_post(&lock);
6      sem_post(&numSpaces);
7      consume();
8  }
```

Looking at the Code ...

1. *What is the purpose of semaphore lock?*
2. *What is the purpose of semaphore numSpaces?*
3. *What is the purpose of semaphore numItems?*
4. *Why are the semaphores initialized to different values?*
5. *Can the producer swap the signals for numItems and lock?*
6. *Can the consumer swap the waits for numItems and lock?*

Important Insights

- two purposes for semaphores
  - mutual exclusion: semaphore *lock* controls access to critical section
  - signalling: semaphore *numSpaces* coordinates the number of spaces in the buffer, so the producer waits if the buffer is full
  - signalling: semaphore *numItems* coordinates the number of items in the buffer, so the consumer waits if the buffer is empty
- avoid race conditions
  - *item* keeps a local copy of the data protected by the semaphore so that it can be accessed later
  - reduces amount of processing inside the critical section
- ordering of semaphores is important