Two Versions of Semaphores

- Semaphores from last time (simplified):

```
wait (s):                 signal (s):

s = s – 1                 s = s + 1
if (s < 0)                if (s ≤ 0)
    block the thread          wake up one of
    that called wait(s)       the waiting threads
otherwise
    continue into CS
```

- "Classical" version of semaphores:

```
wait (s):                 signal (s):

if (s ≤ 0)                if (a thread is waiting)
    block the thread          wake up one of
    that called wait(s)       the waiting threads
s = s – 1                 s = s + 1
continue into CS
```

- Do both work? What is the difference??

Implementing Semaphores

- Implementing semaphores using *busy-waiting*:

```
wait (s):                 signal (s):

while (s ≤ 0)             s = s + 1
  do nothing;
s = s – 1
```

- Evaluation:
  - ✘ Waiting threads wastes time *busy-waiting* (doing nothing useful, wasting CPU time)
  - ✘ The code inside wait(s) and signal(s) is a critical section also, and it's not protected
  - ✘ Doesn't support a queue of multiple blocked threads waiting on the semaphore (why is this bad?)

Implementing Semaphores (cont.)

- Implementing semaphores (not fully) by *disabling interrupts*:

```
wait (s):                 signal (s):

disable interrupts        disable interrupts
while (s ≤ 0)             s = s + 1
  do nothing;
s = s – 1
enable interrupts         enable interrupts
```

- Evaluation:
  - ✔ Protects code inside wait(s) and signal(s)
  - ✘ Waiting threads wastes time *busy-waiting*
  - ✘ Doesn't support queue of blocked threads waiting on the semaphore
  - ✘ Users can't disable interrupts
  - ✘ Can interfere with timer, which might be needed by other applications
  - ✘ Doesn't work on multiprocessors

Implementing Semaphores (cont.)

- Implementing semaphores (not fully) using a *test&set instruction*:

```
wait (s):                   signal (s):

while (test&set(lk)!=0)     while (test&set(lk)!=0)
  do nothing;                    do nothing;
while (s ≤ 0)               s = s + 1
  do nothing;
s = s – 1
lk = 0                      lk = 0
```

- Operation:
  - Lock “lk” has an initial value of 0
  - If “lk” is free (lk=0), test&set atomically:
    - reads 0, sets value to 1, and returns 0
    - loop test fails, meaning lock is now busy
  - If “lk” is busy (lk=1), test&set atomically:
    - reads 1, sets value to 1, and returns 1
    - loop test is true, so loop continues until someone releases the lock

Implementing Semaphores (cont.)

- Test&set is an example of an atomic *read-modify-write* (RMW) instruction
  - RMW instructions atomically read a value from memory, modify it, and write the new value to memory
    - Test&set — on most CPUs
    - Exchange — Intel x86 — swaps values between register and memory
    - Compare&swap — Motorola 68xxx — read value, if value matches value in register r1, exchange register r1 and value
- Evaluation:
  - ✔ Can be made to work, even on multiprocessors (although there may be some cache consistency problems)
  - ✘ Waiting threads wastes time *busy-waiting*
  - ✘ Doesn't support queue of blocked threads waiting on the semaphore

Semaphores in Nachos

- The class Semaphore is defined in **threads/synch.h** and **synch.cc**
  - The classes Lock and Condition are also defined , but their member functions are empty (implementation left as exercise)
- Interesting functions:
  - Semaphores:
    - Semaphore::Semaphore( ) — creates a semaphore with specified name & value
    - Semaphore::P( ) — semaphore wait
    - Semaphore::V( ) — semaphore signal
  - Locks:
    - Lock::Acquire( )
    - Lock::Release( )
  - Condition variables:
    - Condition::Wait( )
    - Condition::Signal( )

Semaphores in Nachos

```
void
Semaphore::P()
{
   IntStatus oldLevel = interrupt->
      SetLevel(IntOff);    // disable interrupts

   while (value == 0) {        // sema not avail
      queue->                  // so go to sleep
          Append((void *)currentThread);
      currentThread->Sleep();
   }

   value--;                 // semaphore available,
                            // consume its value

   (void) interrupt->    // re-enable interrupts
      SetLevel(oldLevel);
}
```

Semaphores in Nachos (cont.)

```
void
Semaphore::V()
{
   Thread *thread;

   IntStatus oldLevel = interrupt->
      SetLevel(IntOff);

   thread = (Thread *)queue->Remove();
   if (thread != NULL) // make thread ready,
              // consuming the V immediately
      scheduler->ReadyToRun(thread);

   value++;

   (void) interrupt->SetLevel(oldLevel);
}
```