CSCE 313-200
Introduction to Computer Systems
Spring 2025

Synchronization III

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February 11, 2025

Updates

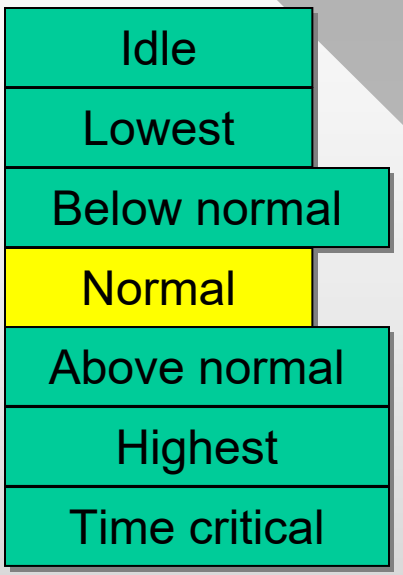
- Midterm on Thursday
  - Covers everything since the beginning of the semester up to and including last Thursday
  - Questions drawn from lectures and homework #1 parts 1-2
  - Material in the book not discussed in class can be ignored
  - Chapter 5 problems (5.1-5.11) might be useful
- Make sure to understand Windows APIs
  - Meaning of parameters, usage in practice, possible errors
  - Reading/writing of pipes, creation of processes
- Be proficient in the 4 types of searches
  - Able to reproduce and discuss the algorithms, understand necessity for the two data structures (i.e., U and D)

Updates

divide by elapsed time

- How to print statistics every 2 seconds?
  - Separate *stats* thread
  - Your wakeup time may be 2.1, 2.5, or 3 seconds apart!
- Make sure to print correct values
  - Printf recommended for progress report
  - Exit room ID when found, distance from rover, steps taken
- Win32/x86 processes max out at ~1400 threads
- Can set thread stack size to 65,536 bytes:
  - Project Properties→Linker→System→Stack Reserve Size
  - Win32: this allows up to 6000 threads, x64: limited by RAM
- All robots initially in the same room with the rover
  - Check discovered set D before dropping initial room into U

Updates



- Priorities
  - Thread priority is based on a combination of two things: process priority class and thread priority level within that class
  - SetPriorityClass() and SetThreadPriority()
- When running a massive amount of threads
  - Set priority of search threads to idle, stats to above normal
- CPU affinity
  - CPU restrictions expressed as bit masks
  - SetProcessAffinityMask(), SetThreadAffinityMask()
- How to set mask to include only CPU 0 and 4?
  - UINT64 mask = 1 + (1 << 4)

Homework #1 (Extra Credit)

- Monster randomly rampages in the cave
  - Eats flybots it can find, jams message transmission
  - Monster caves numbered 1000 and above, only planets 6-7
- If flybot is eaten
  - ReadFile/WriteFile block forever or return errors
  - Must re-insert the room where this happened back at the front of the queue and quit thread that experienced this condition
- Jammed transmission
  - Bogus status, truncated messages, or non-integer number of NodeTuple64s in the response
  - Discard invalid response and retry the room in same thread
- Sending robots to invalid room crashes CC.exe

Homework #1 (Extra Credit)

- Non-blocking pipes with ReadFile/WriteFile
  - Approach below is asynchronous, but not truly overlapped as it keeps only one pending request to the pipe
  - We'll see another version when dealing with file I/O

```
// simple approach to catching timeouts
pipe = CreateFile (..., FILE_ATTRIBUTE_NORMAL|FILE_FLAG_OVERLAPPED, ...);

OVERLAPPED ol; // memset ol to zero

bRet = ReadFile (pipe, ..., NULL, &ol);    // does not return bytesRead
// if bRet is FALSE, check if GetLastError() equals ERROR_IO_PENDING
// if so, ignore the error, continue; otherwise, terminate thread
bRet = WaitForSingleObject (pipe, timeout);
// bRet could be WAIT_TIMEOUT, WAIT_OBJECT_0, or some error
// if successful, obtain the # of bytes read:
GetOverlappedResult (pipe, &ol, ...);
```

- What's a good timeout value?

Chapter 5: Roadmap

5.1 Concurrency

5.2 Hardware mutex

5.3 Semaphores

5.4 Monitors

5.5 Messages

5.6 Reader-Writer

Mutex

- Windows kernel mutex has semantics close to a binary semaphore 2.0, with two exceptions:
  - Repeated mutex lock from the same thread does not block it
  - Mutex can only be unlocked by the thread that locked it
- Examples:

```
Semaphore semaX = {1, 1}; // (s,max)
Thread () {
        semaX.Wait();     // P
        semaX.Wait();     // P
}
```

deadlocks because it attempts to decrement s twice

```
Mutex m;          // unlocked
Thread () {
        m.Lock();
        m.Lock();
}
```

works fine as this thread already owns the mutex

Mutex

- Examples (cont'd):

thread$_1$ deadlocks if thread$_2$ runs first; how to fix this?

```
Semaphore semaX = {1, 1}; // (s,max)
Thread1 () {
        semaX.Wait();     // P
        semaX.Wait();     // P
}
```

```
Semaphore semaX = {1, 1}; // (s,max)
Thread2 () {
        // some initialization
        semaX.Release();   // V
}
```

thread$_1$ blocks temporarily, then gets unblocked by thread$_2$

```
Mutex m;
Thread1 () {
        m.Unlock(); // does nothing
}
```

```
Mutex m;      // initially unlocked
Thread2 () { // thread2 runs first
        m.Lock();
        // long critical section
}
```

thread$_1$ fails to unlock mutex owned by thread$_2$

Event

```
class Event {
        int     s;      // state
        int     mode;
        List    blocked;
        Wait (); Set (); Reset ();
}
```

- The last standard synchronization primitive is an event
  - An event can be in two states: signaled (1) and non-signaled (0) just like a binary semaphore
- However, it also has two possible modes of operation
  - AUTO = binary semaphore
  - MANUAL = event stays signaled until manually reset

```
Event::Wait() {
    if (s == NOT_SIGNALED)
        // block current thread
    else if (mode == AUTO)
        s = NOT_SIGNALED;
}
```

```
Event::Reset() {
        s = NOT_SIGNALED;
}
```

```
Event::Set() {
    if (blocked.size() > 0)
        if (mode == AUTO)
            // unblock 1 thread
        else
            // unblock all threads
            s = SIGNALED;
    else
        s = SIGNALED;
}
```

Windows APIs

```
HANDLE WINAPI CreateSemaphore(
  __in_opt  LPSECURITY_ATTRIBUTES
                lpSemaphoreAttributes,
  __in      LONG lInitialCount,
  __in      LONG lMaximumCount,
  __in_opt  LPCTSTR lpName );
```

- Semaphore
  - Security is NULL as always
  - Name can be used when multiple processes need to open the same object
- Wait (i.e., P)
  - WaitForSingleObject()
  - Returns WAIT_OBJECT_0 when ready
  - WAIT_TIMEOUT if timeout
  - Otherwise, an error
- Release (i.e., V)
  - ReleaseSemaphore(N)
- CreateMutex/CreateEvent
  - Can specify if this thread initially owns the mutex and initial state for event
- Locking done with WaitForSingleObject()
  - Unlocking with ReleaseMutex() and signaling with SetEvent()
- Resetting events
  - ResetEvent()

Unbounded Producer-Consumer

- Producer-consumer is probably the most frequently encountered synchronization problem in programming
  - Will be solved using semaphores and mutexes
- Start with the unbounded version

- Producer threads create new items and deposit them into the shared buffer/queue
  - Consumer threads read from the buffer and process them
- Note that in some applications the same thread may act as producer and consumer at different times
  - This is the case in homework #1

Unbounded Producer-Consumer

- Several attempts to create a solution
  - PC v1.0

```
Queue Q;
Producer() {
    while (true) {
        // make item x
        Q.add (x);
    }
}
```

```
Queue Q;
Consumer() {
    while (true) {
        if (Q.size() > 0)
            x = Q.pop();
            // consume x
    }
}
```

  - PC v1.1

```
Queue Q;
Mutex m;
Producer() {
    while (true) {
        // make item x
        m.Lock();
        Q.add (x);
        m.Unlock();
    }
}
```

```
Queue Q;
Mutex m;
Consumer() {
    while (true) {
        m.Lock();
        if (Q.size() > 0)
            x = Q.pop();
            // consume x
        m.Unlock();
    }
}
```

problems?

Unbounded Producer-Consumer

- Ver 1.0 crashes on access to shared queue if used by multiple threads
- Ver 1.1 busy-spins waiting for queue to be non-empty
- Idea: assign a counting semaphore to control how many threads may attempt to read from the Q
  - PC v1.2

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Producer() {
    while (true) {
        // make item x
        m.Lock();
        Q.add (x);
        sema.Release();
        m.Unlock();
    }
}
```

problems?

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Consumer() {
    while (true) {
        sema.Wait ();
        m.Lock();
        // no need to check Q.size
        x = Q.pop();
        m.Unlock();
        // consume x outside
        // the critical section
    }
}
```

Unbounded Producer-Consumer

- Ver 1.2 releases consumer on semaphore, which then gets immediately blocked on mutex; not efficient
  - PC v1.3

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Producer() {
    while (true) {
        // make item x
        m.Lock();
        Q.add (x);
        m.Unlock();
        sema.Release();
    }
}
```

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Consumer() {
    while (true) {
        sema.Wait ();
        m.Lock();
        // no need to check Q.size
        x = Q.pop();
        m.Unlock();
        // consume x outside
        // the critical section
    }
}
```

- What if N items are produced in each iteration?

Unbounded Producer-Consumer

- If producer is bursty (i.e., generates many items at once), then ver 1.3 is also inefficient
  - PC v1.4

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Producer() {
    while (true) {
        // make x[0],..., x[N-1]
        m.Lock();
        for (i = 0; i < N; i++)
            Q.add (x[i]);
        m.Unlock();
        // Windows allows batch
        // release
        sema.Release(N);
    }
}
```

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Consumer() {
    while (true) {
        sema.Wait ();
        m.Lock();
        // no need to check Q.size
        x = Q.pop();
        m.Unlock();
        // consume x outside
        // the critical section
    }
}
```

Homework #1

- Multi-threaded search algorithm (rough idea)

```
Mutex m;                          // not locked initially
Semaphore sema = {0, nMax};       // how to choose nMax?

Search::Run (...)                 // each thread runs this
{
    while (true) {
        // consumer starts here ----------
        sema.Wait ();
        m.Lock();
        x = U->pop();
        m.Unlock();

        // contact the robot and obtain x's neighbors

        // producer starts here -------------
        counter = 0;              // local variable that counts new neighbors
        m.Lock();
        for (each y = neighbor of x)
            if (D->CheckAdd(y) == false)
                U->add (y);
                counter ++;
        m.Unlock();
        sema.Release(counter);
    }
}
```

how does this terminate?

Homework #1

- How about this:

```
Event eventQuit;              // initially not signaled
...
{
    {     ...

          // contact the robot and obtain x's neighbors
          if (x == exitNode)
              eventQuit.Signal();

          // producer starts here -------------
          ...
    }
}
```

- Other conditions when we can signal termination?
  - U is empty and no more deposits into it are possible
- How to react to eventQuit?
  - Near the end, most threads will be blocked on semaphore

Homework #1

- In order to wait on two objects (i.e., semaphore and event), we need
  - bWaitAll = false means any of the handles can wake up this thread
  - Otherwise, all handles must be simulataneously ready

```
DWORD WINAPI WaitForMultipleObjects(
  __in  DWORD nCount,
  __in  const HANDLE *lpHandles,
  __in  BOOL bWaitAll,
  __in  DWORD dwMilliseconds );
```

- When handle `lpHandles[k]` is triggered, this function returns `WAIT_OBJECT_0 + k`
- The order of handles in the array is important!
  - If multiple handles are simultaneously in the signaled state, the return value indicates the first of them

Wrap-up

should the event be manual or auto?

- More complete version:

```
Mutex m;              // not locked initially
Semaphore sema = {0, nMax};
Event eventQuit;         // signaled to quit
int activeThreads = 0;  // shared
Search::Run(...) {
    while (true) {
        // need to quit or work?
        if (WaitAny (eventQuit, sema)
                              == eventQuit)
            break;
        m.Lock();
        x = U->pop();
        activeThreads ++;
        m.Unlock();

        // check if x is the exit
        if (x == exitNode)
            eventQuit.Signal();
            continue;
        int counter = 0;   // local var
        // deposit neighbors ----------
        m.Lock();
        for (each y = neighbor of x)
            if (D->CheckAdd (y) == false)
                U->add (y);
                counter ++;
        activeThreads --;
        if (U->size() == 0 &&
                  activeThreads == 0)
            eventQuit.Signal();
        m.Unlock();
        if (counter > 0)
            sema.Release(counter);
    }
}
```

- How to count *running* threads?
  - Printouts must include both running and active threads