CSCE 313-200
Introduction to Computer Systems
Spring 2023

Synchronization III
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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**

- 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 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

divide by elapsed time
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?

- \( \text{UINT64 mask} = 1 + (1 << 4) \)
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 handle
  - We’ll see another version when dealing with file I/O

```c
// 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:

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

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

deadlocks because it attempts to decrement s twice

works fine as this thread already owns the mutex
**Mutex**

• Examples (cont’d):

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
}

thread₁ blocks temporarily, then gets unblocked by thread₂

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

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

thread₁ deadlocks if thread₂ runs first; how to fix this?

thread₁ fails to unlock mutex owned by thread₂
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

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

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

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

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

- **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**
  - Unlocking with ReleaseMutex() and signaling with SetEvent()

- **Resetting events**
  - ResetEvent()
**Unbounded Producer-Consumer**

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

![Diagram](image)

- 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

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

- PC v1.1

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

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

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

```java
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

```
Queue Q;
Mutex m;
Semaphore sema = {0, ∞};
Consumer() {
    while (true) {
        sema.Wait();
        m.Lock();
        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

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

```c
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

```java
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);
  }
}
```

```java
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)

```cpp
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:

```java
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 simultaneously ready

• 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

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

• More complete version:

```cpp
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

should the event be manual or auto?