VGP393C – Week 6

- Agenda:
  - Atomic Operations
  - Non-blocking Algorithms
  - Windows threading API, part 2

Atomic Operations

- What is an “atomic operation”?

Atomic Operations

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> A “set of operations that can be combined so that they appear to the rest of the system to be a single operation...[1]”

- What does this *mean*?

[1] http://en.wikipedia.org/wiki/Atomic_(computer_science)

Atomic Operations

- What is an "atomic operation"?

A "set of operations that can be combined so that they appear to the rest of the system to be a single operation...[1]"

- What does this *mean*?
  - An instruction that performs a read-modify-write cycle that cannot be interrupted or executed out-of-order with respect to other processors in the system
  - Think of it as a really small, hardware implemented critical section

[1] http://en.wikipedia.org/wiki/Atomic_(computer_science)

Atomic Operations

- Example: `TAS` instruction on 68000
  - Reads a byte from a memory location
  - Writes the value back with the high bit set
  - Tests the original high bit and sets the condition codes

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  - Writes a byte from a register to the memory location
  - Stores the byte from memory in the register

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Performed with the bus “locked”

Atomic Operations

- Spin-lock using `XCHG` on x86:

```
        movl        %eax, $1
1:      lock xchg   %eax, [%ebx]
        test        %eax, %eax
        jnz         1
```

Atomic Operations

- Spin-lock using `XCHG` on x86:

```
      movl         %eax, $1
1:    lock xchg    %eax, [%ebx]
      test         %eax, %eax
      jnz          1
```

  - The `lock` prefix is added on later x86 processors and allows other instructions to be atomic

Atomic Operations

- Modern processors support a variety of atomic operations
  - Increment / decrement
  - Add / subtract
  - And, or, xor, etc.
  - Exchange
  - Compare and swap

Atomic Operations

- Compare-and-swap is extremely useful, if a bit complex:

```
bool cmpxchg(int *mem, int compare, int new_value)
{
    if (*mem == compare) {
        *mem = new_value;
        return true;
    } else {
        return false;
    }
}
```

  - We'll see how this is useful in a bit...

Atomic Operations

- Windows API provides interfaces to many of these common operations:
  - `InterlockedIncrement` – Increment a 32-bit int
  - `InterlockedDecrement` – Decrement a 32-bit int
  - `InterlockedExchangeAdd` – Add a value to a 32-bit int and store the result
  - `InterlockedCompareExchange` – Compare memory to a reference value and set memory to new value if it matches the reference
    - Also `InterlockedCompareExchangePointer` and `InterlockedCompareExchange64`

Non-blocking Algorithms

- Atomic operations can be used to implement certain algorithms *without* other synchronization

Non-blocking Algorithms

- Shared counter
  - A counter that can be incremented, decremented, and tested
    - This is how we test for completion in the Mandelbrot generator
  - The increment, decrement, and test operations could be protected using a lock
  - Or...

Non-blocking Algorithms

```
class shared_counter {
public:
    void init(int value)
    {
        count = value;
    }

    bool add(int value)
    {
        return (InterlockedExchangeAdd(& count, value) == 0);
    }

private:
    volatile int count;
};
```

Non-blocking Algorithms

- Most non-blocking algorithms look fairly similar:

```
void non_blocking_foo(volatile int *x)
{
    int old_value, new_value, ref_value;

    do {
        old_value = *x;
        new_value = do_something(old_value);
        ref_value =
            InterlockedCompareExchange(x, new_value,
                                       old_value);
    } while (ref_value != old_value);
}
```

Non-blocking Algorithms

- Non-blocking singly-linked list enqueue:

```
void list::enqueue(node *n)
{
    node *old;

    do {
        n->next = head;
        old =
            InterlockedCompareExchangePointer(&head,
                                              n,
                                              n->next);
    } while (old != n->next);
}
```

Non-blocking Algorithms

- Non-blocking singly-linked list dequeue:

```
node *list::dequeue(void)
{
    node *old, *node, *next;

    do {
        node = head;
        next = node->next;
        old =
            InterlockedCompareExchangePointer(&head,
                                              next,
                                              node);
    } while (old != next);

    return node;
}
```

Non-blocking Algorithms

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    do {
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            InterlockedCompareExchangePointer(&head,
                                              next,
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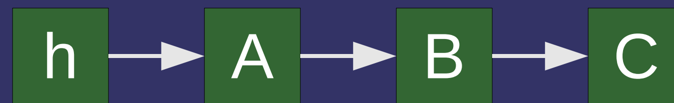
    } while (old != next);

    return node;
}
```

WRONG!

Non-blocking Algorithms

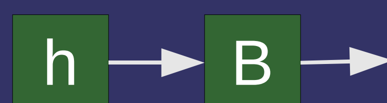
First thread:
fetch `head` → `&A`
fetch `A.next` → `&B`



Second thread:

pop `A`; pop `B`; push `A`;

`cmpxchg(&head, &B &A)` → success!



Non-blocking Algorithms

First thread:
fetch `head` → `&A`
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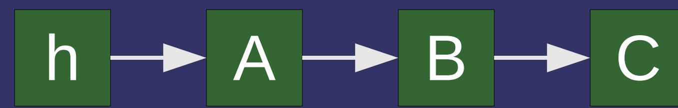
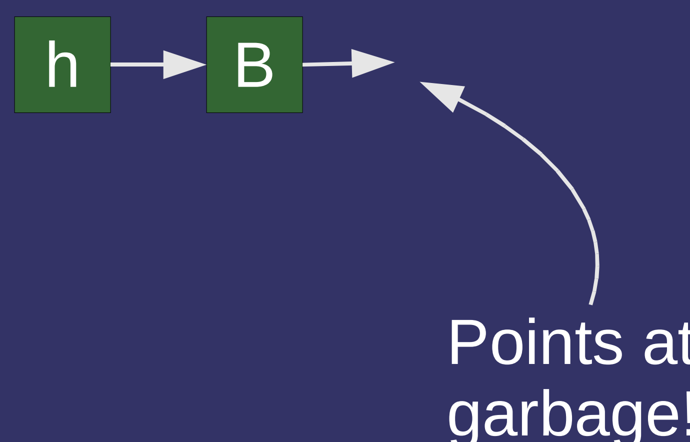


Second thread:

pop `A`; pop `B`; push `A`;

`cmpxchg(&head, &B`
`&A)` → ~~success!~~
FAIL!



Non-blocking Algorithms

- For singly-linked lists, Windows provides `SLIST_HEADER`
  - `InitializeSListHead`
  - `InterlockedPushEntrySList`
  - `InterlockedPopEntrySList`
  - `InterlockedFlushSList`
  - Only available on Windows XP / Windows Server 2003 and later

Non-blocking Algorithms

- Very active area of research
  - Search for “nonblocking algorithm”
- Generally a very hard problem
  - Be wary of race conditions

Break

22-August-2008

Thread Pools

- Programs using the Fork / Join pattern often need to dynamically create and destroy lots of threads
  - High performance overhead
    - May spend more time managing threads than doing work!
  - If threads interact with the outside work (perform I/O) statically creating a few threads and a work queue may not be sufficient
  - Here a *thread pool* is the answer

Thread Pools

- A group of threads are created that feed off a work queue
  - If the queue gets too long, more threads are created
  - If the queue is empty for a long period, threads are destroyed

Thread Pools

- Several important factors in the algorithm[1]:
  - create too many threads and resources are wasted and time also wasted creating the unused threads
  - destroy too many threads and more time will be spent later creating them again
  - creating threads too slowly might result in poor client performance (long wait times)
  - destroying threads too slowly may starve other processes of resources

[1] http://en.wikipedia.org/wiki/Thread_pool_pattern

Thread Pools

- Thread pools are generally difficult to implement correctly and tune
  - Starting with Windows 2000, the system provides one for you
  - Add new tasks with:

```
BOOL QueueUserWorkItem(
    LPTHREAD_START_ROUTINE func,
    PVOID cointext,
    ULONG flags);
```

  - I/O threads should set `WT_EXECUTEINIOTHREAD` in `flags`
    - See the MSDN entry for more details

Thread Priority

- Each thread has a *priority*
  - Windows always runs “ready” threads with the highest priority first
  - High priority threads can *hog* the system and *starve* low priority threads

Thread Priority

- Set a thread's priority:

```
BOOL SetThreadPriority(
    HANDLE thread,
    int new_priority);
```

  - `new_priority` is a value between 0 and 31 or a symbolic constant:
    - `THREAD_PRIORITY_TIME_CRITICAL`
    - `THREAD_PRIORITY_HIGHEST`
    - `THREAD_PRIORITY_ABOVE_NORMAL`
    - `THREAD_PRIORITY_NORMAL`
    - `THREAD_PRIORITY_BELOW_NORMAL`
    - `THREAD_PRIORITY_LOWEST`
    - `THREAD_PRIORITY_IDLE`

Processor Affinity

- Threads are typically scheduled to run on any available processor, preferring the last processor where it was scheduled
  - Has good cache performance
  - All things being equal, this is the best choice
  - In some applications, all things are not equal
    - And by “things” we mean threads

Processor Affinity

- Consider a system with two processors, two I/O threads, and two compute threads
  - Depending on when threads are created, both compute threads may end up on the same processor
  - Since the I/O threads are often idle, this is not optimal
  - If we could tell the system to schedule an I/O thread and a compute thread on each CPU, we would win

Processor Affinity

- Two ways to modify affinity:
  - Specify the set of processors where a thread can be scheduled
  - Specify the optimal or “ideal” processor for a thread
    - On some NUMA systems, this can also set the preferred processor *node*

Processor Affinity

- Windows uses `SetThreadAffinityMask` to set the mask of processors where the thread can be scheduled:

```
DWORD_PTR SetThreadAffinityMask(
    HANDLE hThread,
    DWORD_PTR dwThreadAffinityMask);
```

Processor Affinity

- Set the ideal processor:

```
DWORD WINAPI SetThreadIdealProcessor(
    HANDLE hThread,
    DWORD dwIdealProcessor);
```

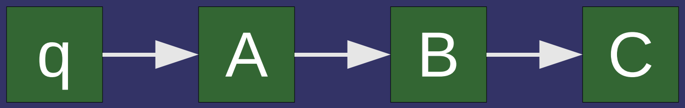
  – Windows will schedule the thread on that processor *whenever possible*
    – MSDN entry is pretty vague as to what that means

Processor Affinity

- How to use?
  - Create threads in the “idle” state
  - Set initial affinity to separate I/O and compute threads
  - Start threads running

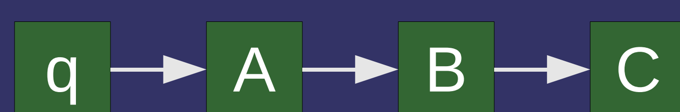
Thread-Local Storage

- Consider a fair lock implementation
  - Each waiting thread is added to a queue
  - When the lock is released, the first waiting thread wakes up
  - If a thread tries to acquire the lock and the lock is held or there are waiters, it is added to the end of the queue



Thread-Local Storage

- Fair-lock queue contains each thread *at most once*
  - Naive implementation is to allocate a node, add it to the queue
  - Nodes are released when the waiter is removed from the queue
  - This causes extra node management overhead
    - We really just want an node per thread that is persistent



Thread-Local Storage

- We want some sort of *thread-local storage*
  - Create a handle with a global ID
  - In each thread, associate some storage with that handle
    - In the fair-lock implementation, it would be the node structure
  - Code that uses the TLS obtains the per-thread storage using the handle

Thread-Local Storage

- Create a handle:

```
DWORD TlsAlloc(void);
```

- Release a handle:

```
BOOL TlsFree(DWORD dwTlsIndex);
```

- Set per-thread storage associated with handle:

```
void TlsSetValue(DWORD dwTlsIndex, void *data);
```

- Get per-thread storage associated with handle:

```
void *TlsGetValue(DWORD dwTlsIndex);
```

- See MSDN for more details
  - http://msdn.microsoft.com/en-us/library/ms686991(VS.85).aspx

Next week...

- Common multi-threading problems
  - Dead-lock / live-lock
  - Priority inversion
  - Lock contention
  - Thread-safe libraries
  - Cache abuse / memory bandwidth

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