CSE451 Basic Synchronization
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Lecture #7

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Today

- With all these threads running around sharing the same address space (i.e., memory), how do we keep them from mangling each other?
- With specific synchronization primitives

Do We Really Need to Synchronize?

- Yes and no
- You can build a system and run a long long time before hitting a synchronization bug. And maybe your application or user doesn't care.
- But for truly robust systems you need to synchronize your data structures to ensure their consistency

A very simple example

- Assume a global queue with two fields a flink and a blink
- Here is some sample code to add to the queue

```
LIST_ENTRY Queue;
NewEntry = new(…)
NewEntry->flink = Queue.flink;
NewEntry->blink = &Queue;
NewEntry->flink->blink = NewEntry;
NewEntry->blink->flink = NewEntry;
```

- Now let threads execute the above code at the same time
- Where's the problem?
- The problem goes all the way down to the machine instructions

Synchronization

- Basic Problem Statement:

  If two concurrent processes are accessing a shared variable, and that variable is read, modified, and written by those processes, then the variable must be controlled to avoid erroneous behavior.
- Even simple push and pop stack operations need synchronization

```
Push(s,I) { s->stack[++(s->index)] = I; }
Pop(s) { return (s->stack[(s->index)--]); }
```

Even ignoring stack limit tests these routines need synchronization in a multi-threaded environment

Another Example (the ATM)

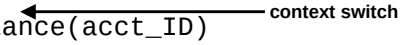
- Suppose each cash machine transaction is controlled by a separate process, and the withdraw code is:

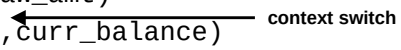
```
cur_balance=get_balance (acct_ID)
withdraw_amt=read_amount_from_ATM()
if withdraw_amt>curr_balance then error
curr_balance=curr_balance - withdraw_amt
put_balance (act_ID,curr_balance)
deliver_bucks(withdraw_amt)
```

- Now, suppose that you and your s.o. share an account. You each to to separate cash machines and withdraw $100 from your balance of $1000.

ATM Example Continued

```
you: curr_balance=get_balance(acct_ID)
you: withdraw_amt=read_amount()
you: curr_balance=curr_balance-withdraw_amt
so: curr_balance=get_balance(acct_ID)
so: withdraw_amt=read-amount()
so: curr_balance=curr_balance-withdraw_amt
so: put_balance(acct_ID,curr_balance)
so: deliver_bucks(withdraw_amt)
you: put_balance(acct_ID,curr_balance)
you: deliver_bucks(withdraw_amt)
```





- What happens and why?

Problems

- A problem exists because a shared data item (curr_balance) was accessed without control by processes that read, modified, and then rewrote that data.
- We need ways to control access to shared variables.

Ways to Solve The Synchronization Problem

- Only have one thread do everything
- Semaphores (a classic text book solution and the one we cover first)
- Spinlocks
- Interlocked Operations
- Mutexes
- Events
- “EResource” an NT’ism that I’m particularly fond of

Where Can We Actually Use Synchronization?

- Both in the kernel and in user mode
  - A good thing too because we need it in both places
  - In the kernel most any trick is available for us to use
  - In user mode our choices are a bit more limited
- Some synchronization methods are kernel mode only and some can be used in both modes.
- Kernel mode only because of some tricks use the protected instruction set

Semaphores

- Dijkstra, in the THE system, defined a type of variable and two synchronization operations that can be used to control access to critical sections.
- First, what is a critical section?
- Dijkstra defined a semaphore as a synchronization variable that is manipulated atomically through operations *signal(s)* (a V operation) and *wait(s)* (a P operation).
- To access a critical section, you must:

```
wait(s); // wait until semaphore is available
  <critical section code>
signal(s); // signal others to enter
```

Semaphore Implementations

- Associated with each semaphore is a count indicating the state of the semaphore
  1. > 0 means the semaphore is free or available
  2. <= 0 means the semaphore is taken or in use
  3. < 0 means there is a thread waiting for the semaphore (its absolute value is the number of waiters)
- Also associated with each semaphore is a queue of waiting threads.
- If you execute *wait* and the semaphore is free, you continue; if not, you block on the waiting queue.
- A *signal* unblocks a thread if it's waiting.

Semaphore Operations

```
typedef struct _SEMAPHORE {
    int Value;
    List of waiting threads WaitList;
} SEMAPHORE, *PSEMAPHORE;

VOID Wait( PSEMAHPORE s ) {
    s->Value = s->Value - 1;
    if (s->Value < 0) {
        add this thread to s->WaitList;
        block current thread;
    }
}

VOID Signal( PSEMAPHORE s ) {
    s->Value = s->Value + 1;
    if (s->Value <= 0) {
        remove a thread T from s->WaitList;
        wakeup T;
    }
}
```

Signal and Wait must be atomic

Example: Reader/Writer Problem

- Basic Problem:
  - An object is shared among several threads, some which only read it, and some which write it.
  - We can allow multiple readers at a time, but only one writer at a time.
  - How do we control access to the object to permit this protocol?

A Simplistic Reader/Writer Semaphore Solution

```
SEMAPHORE wrt;    // control entry to a writer or first reader
SEMAPHORE semap;  // controls access to readcount
int readcount;    // number of active readers

write process:
  wait(wrt);    // any writers or readers?
    <perform write operation>
  signal(wrt);  // allow others

read process:
  wait(semap);  // ensure exclusion
    readcount = readcount + 1;  // one more reader
    if (readcount = 1) { wait(wrt); } // we're the first
  signal(semap);
    <perform reading>
  wait(semap);  // ensure exclusion
    readcount = readcount – 1;  // one fewer reader
    if (readcount = 0) { signal(wrt); } // no more readers
  signal(semap)
```

Reader/Writer Solution Notes

- Note that:
  1. The first reader blocks if there is a writer; any other readers who try to enter will then block on *semap*.
  2. Once a writer exists, all readers will fall through.
  3. The last reader to exit signals a waiting writer.
  4. When a writer exits, if there is both a reader and writer waiting, which goes next depends on the scheduler.

Semaphore Types

- In general, there are two types of semaphores based on its initial value
  - A binary semaphore guarantees mutually exclusive access to a resource (only one entry). The binary semaphore is initialized to 1. This is also called a mutex semaphore, but not everything you hear called a mutex is implemented as a semaphore
  - A counted semaphore represents a resource with many units available (as indicated by the count to which it is initialized). A counted semaphore lets a thread pass as long as more instances are available.

Example: Bounded Buffer Problem

- The Problem:

  There is a buffer shared by *producer* processes, which insert into it, and *consumer* processes, which remove from it.

  The processes are concurrent, so we must control their access to the (shared) variables that describe the state of the buffer.

Simple Bounded Buffer Semaphore Solution

```
SEMAPHORE mutex;     // mutual exclusion to shared data
SEMAPHORE empty = n; // count of empty buffers
SEMAPHORE full = 0;  // count of full buffers

producer:
  wait(empty);   // one fewer buffer, block if none available
  wait(mutex);   // get access to pointers
    <add item to buffer>
  signal(mutex); // done with pointers
  signal(full);  // note one more full buffer

consumer:
  wait(full);    // wait until there's a full buffer
  wait(mutex);   // get access to pointers
    <remove item from buffer>
  signal(mutex); // done with pointers
  signal(empty); // note there's an empty buffer
    <use the item>
```

Things to Remember About Semaphores

- A very common synchronization primitive
- Two main elements a count and a list of waiters
- Two types counted and binary semaphore
- Other synchronization operations can be built on top of semaphores

Next Time

- Semaphores are great and used all over the place, but it's not the only game in town
- Next time we'll look at a few other useful synchronization primitives