CS 202, Spring 2015
Handout 2 (Class 3)

1. Example to illustrate interleavings: say that thread A executes f() and thread B executes g(). (Here, we are using the term "thread" abstractly. This example applies to any of the approaches that fall under the word "thread".)

a. [this is pseudocode]

```
int x;

int main(int argc, char** argv) {

    tid tid1 = thread_create(f, NULL);
    tid tid2 = thread_create(g, NULL);

    thread_join(tid1);
    thread_join(tid2);

    printf("%d\n", x);
}

void f()
{
    x = 1;
    thread_exit();
}

void g()
{
    x = 2;
    thread_exit();
}
```

What are possible values of x after A has executed f() and B has executed g()? In other words, what are possible outputs of the program above?

b. Same question as above, but f() and g() are now defined as follows:

```
int y = 12;

f() { x = y + 1; }
g() { y = y * 2; }
```

What are the possible values of x?

c. Same question as above, but f() and g() are now defined as follows:

```
int x = 0;
f() { x = x + 1; }
g() { x = x + 2; }
```

What are the possible values of x?

2. Linked list example

```
struct List_elem {
    int data;
    struct List_elem* next;
};

List_elem* head = 0;

insert(int data) {
    List_elem* l = new List_elem;
    l->data = data;
    l->next = head;
    head = l;
}
```

What happens if two threads execute insert() at once and we get the following interleaving?

```
thread 1: l->next = head
thread 2: l->next = head
thread 2: head = l;
thread 1: head = l;
```

```
3. Producer/consumer example:

    /*
    "buffer" stores BUFFER_SIZE items
    "count" is number of used slots. a variable that lives in memory
    "out" is next empty buffer slot to fill (if any)
    "in" is oldest filled slot to consume (if any)
    */

     void producer (void *ignored) {
         for (;;) {
             /* next line produces an item and puts it in nextProduced */
             nextProduced = means_of_production();
             while (count == BUFFER_SIZE)
                 ; // do nothing
             buffer [in] = nextProduced;
             in = (in + 1) % BUFFER_SIZE;
             count++;
         }
     }

     void consumer (void *ignored) {
         for (;;) {
             while (count == 0)
                ; // do nothing
             nextConsumed = buffer[out];
             out = (out + 1) % BUFFER_SIZE;
             count--;
             /* next line abstractly consumes the item */
             consume_item(nextConsumed);
         }
     }

    /*
       what count++ probably compiles to:
        reg1 <-- count      # load
        reg1 <-- reg1 + 1   # increment register
        count <-- reg1      # store

       what count-- could compile to:
        reg2 <-- count      # load
        reg2 <-- reg2 - 1   # decrement register
        count <-- reg2      # store
    */

    What happens if we get the following interleaving?

        reg1 <-- count
        reg1 <-- reg1 + 1
        reg2 <-- count
        reg2 <-- reg2 - 1
        count <-- reg1
        count <-- reg2
```



```
4. Some other examples. What is the point of these?

    [From S.V. Adve and K. Gharachorloo, IEEE Computer, December 1996,
    66-76. http://rsim.cs.uiuc.edu/~sadve/Publications/computer96.pdf]

    a. Can both "critical sections" run?

        int flag1 = 0, flag2 = 0;

        int main () {
            tid id = thread_create (p1, NULL);
            p2 (); thread_join (id);
        }

        void p1 (void *ignored) {
            flag1 = 1;
            if (!flag2) {
                critical_section_1 ();
            }
        }

        void p2 (void *ignored) {
            flag2 = 1;
            if (!flag1) {
                critical_section_2 ();
            }
        }

    b. Can use() be called with value 0, if p2 and p1 run concurrently?

        int data = 0, ready = 0;

        void p1 () {
            data = 2000;
            ready = 1;
        }
        int p2 () {
            while (!ready) {}
            use(data);
        }

    c. Can use() be called with value 0?

        int a = 0, b = 0;

        void p1 (void *ignored) { a = 1; }

        void p2 (void *ignored) {
          if (a == 1)
            b = 1;
        }

        void p3 (void *ignored) {
          if (b == 1)
            use (a);
        }
```

CS 202, Spring 2015
Handout 3 (Class 4)

The previous handout gave examples of race conditions. This handout demonstrates the use of concurrency primitives (mutexes, etc.). We are using concurrency primitives to eliminate race conditions (see items 1 and 2a) and improve scheduling (see item 2b).

1. Protecting the linked list......

```
        Mutex list_mutex;

        insert(int data) {
            List_elem* l = new List_elem;
            l->data = data;

            acquire(&list_mutex);

            l->next = head;
            head = l;

            release(&list_mutex);
        }
```


2. Producer/consumer revisited [also known as bounded buffer]

   2a. Producer/consumer [bounded buffer] with mutexes

```
     Mutex mutex;

     void producer (void *ignored) {
         for (;;) {
             /* next line produces an item and puts it in nextProduced */
             nextProduced = means_of_production();

             acquire(&mutex);
             while (count == BUFFER_SIZE) {
                release(&mutex);
                yield(); /* or schedule() */
                acquire(&mutex);
             }

             buffer [in] = nextProduced;
             in = (in + 1) % BUFFER_SIZE;
             count++;
             release(&mutex);
         }
     }

     void consumer (void *ignored) {
         for (;;) {

             acquire(&mutex);
             while (count == 0) {
                release(&mutex);
                yield(); /* or schedule() */
                acquire(&mutex);
             }

             nextConsumed = buffer[out];
             out = (out + 1) % BUFFER_SIZE;
             count--;
             release(&mutex);

             /* next line abstractly consumes the item */
             consume_item(nextConsumed);
         }
     }
```

```
    2b. Producer/consumer [bounded buffer] with mutexes and condition variables

         Mutex mutex;
         Cond nonempty;
         Cond nonfull;

         void producer (void *ignored) {
             for (;;) {
                 /* next line produces an item and puts it in nextProduced */
                 nextProduced = means_of_production();

                 acquire(&mutex);
                 while (count == BUFFER_SIZE)
                    cond_wait(&nonfull, &mutex);

                 buffer [in] = nextProduced;
                 in = (in + 1) % BUFFER_SIZE;
                 count++;
                 cond_signal(&nonempty, &mutex);
                 release(&mutex);
             }
         }

         void consumer (void *ignored) {
             for (;;) {

                 acquire(&mutex);
                 while (count == 0)
                    cond_wait(&nonempty, &mutex);

                 nextConsumed = buffer[out];
                 out = (out + 1) % BUFFER_SIZE;
                 count--;
                 cond_signal(&nonfull, &mutex);
                 release(&mutex);

                 /* next line abstractly consumes the item */
                 consume_item(nextConsumed);
             }
         }


        Question: why does cond_wait need to both release the mutex and
        sleep? Why not:

            while (count == BUFFER_SIZE)  {
                release(&mutex);
                cond_wait(&nonfull);
                acquire(&mutex);
            }
```



```
    2c.  Producer/consumer [bounded buffer] with semaphores

        Semaphore mutex(1);             /* mutex initialized to 1 */
        Semaphore empty(BUFFER_SIZE);   /* start with BUFFER_SIZE empty slots */
        Semaphore full(0);              /* 0 full slots */

        void producer (void *ignored) {
             for (;;) {
                 /* next line produces an item and puts it in nextProduced */
                 nextProduced = means_of_production();

                /*
                 * next line diminishes the count of empty slots and
                 * waits if there are no empty slots
                 */
                 sem_down(&empty);
                 sem_down(&mutex);  /* get exclusive access */

                 buffer [in] = nextProduced;
                 in = (in + 1) % BUFFER_SIZE;

                 sem_up(&mutex);
                 sem_up(&full);   /* we just increased the # of full slots */
             }
         }

         void consumer (void *ignored) {
             for (;;) {

                 /*
                  * next line diminishes the count of full slots and
                  * waits if there are no full slots
                  */
                 sem_down(&full);
                 sem_down(&mutex);

                 nextConsumed = buffer[out];
                 out = (out + 1) % BUFFER_SIZE;

                 sem_up(&mutex);
                 sem_up(&empty);   /* one further empty slot */

                 /* next line abstractly consumes the item */
                 consume_item(nextConsumed);
             }
         }

        Semaphores *can* (not always) lead to elegant solutions (notice
        that the code above is fewer lines than 2b) but they are much
        harder to use.

        The fundamental issue is that semaphores make implicit (counts,
        conditions, etc.) what is probably best left explicit. Moreover,
        they *also* implement mutual exclusion.

        For this reason, you should not use semaphores. This example is
        here mainly for completeness and so you know what a semaphore
        is. But do not code with them. Solutions that use semaphores in
        this course will receive no credit.
```