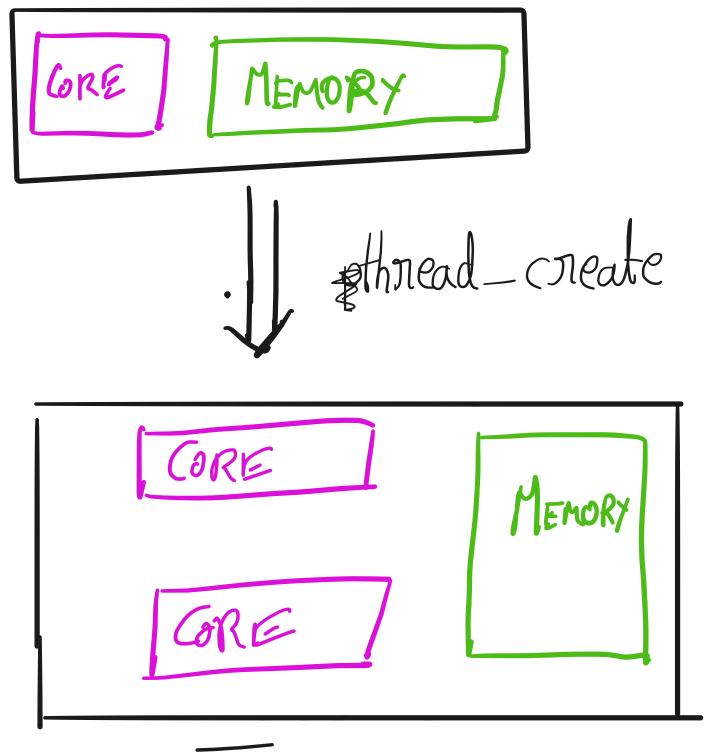
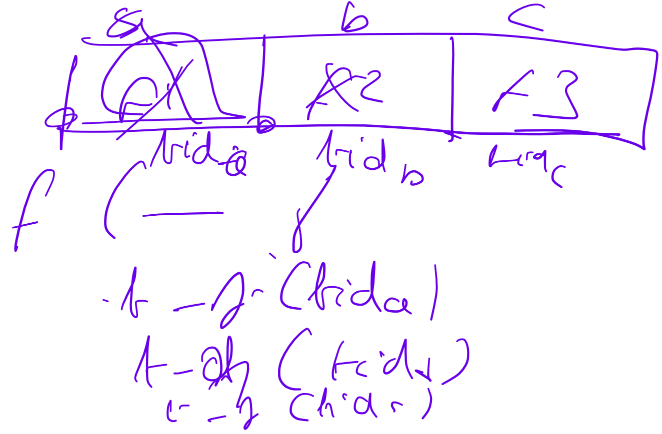
CS202 Lecture 5

- Done with Processes For Now
- Today: Threads + Concurrency

Threads





More precisely

- Each thread gets its own set of registers
- All threads in a process share the same memory.

thread-create → (1) Allocate a stack
(2) Init stack
(3) ~~Create~~ a new process

%rsp
%rip

```
void a(...) {
  for(int i=0;
      i<1<<31;
      i++) {
    exec
  }
}
```

tid thread_create(void (*fn)(void*), void* arg);

void thread_exit();

void thread_join(tid t)

```
int main(...) {
  tid t = TC(&a);
  thread_join(t);
  printf("Done");
}
```

```
void a(void*){
  printf("NT")
}
```

thread_create(&a, NULL)

pthreads:

thread_exit():

Contrast With Processes

- Two threads can concurrently

```
        x=0
  T1     |    T2
x=1;     |  x=2;
         |
      x=       1 or 2
```

```
          x=1
     T1    |    T2
   x++;    |  x*=2;
  ---------+---------
 x=x+1     |  x=x*2
x=
```

2, 3, 4

```
x=0   y=0

if(y==0)  |  if(x==0)
  x=1     |    y=1
          |
x=           y=
```

Concurrency

- Each thread has its own copy of registers

↳ Isolated: One Thread Cannot Manipulate Another's Registers

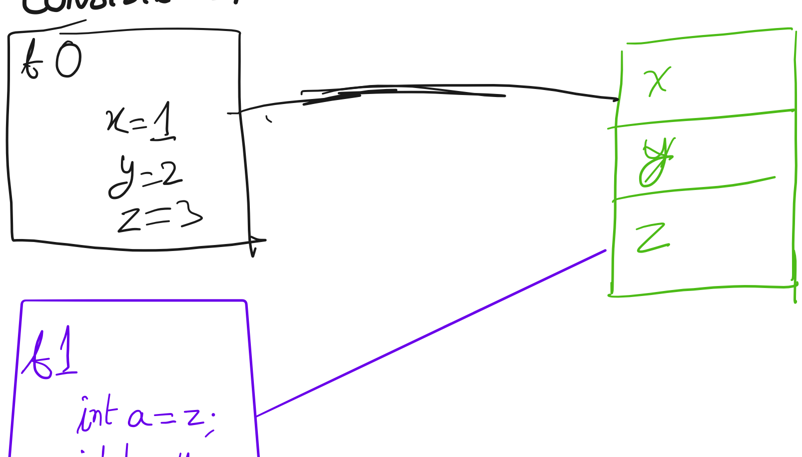
- All Threads In A Process Have Access To The Same Memory
    - ↳ Multiple Changes To Memory At A Time
    - → Many things happening at once
    - ↳ Goal: Find Tools To Build Correct Concurrent Programs

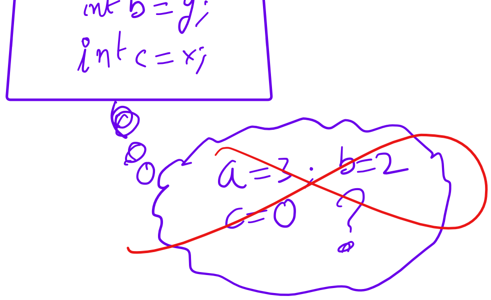
Why?

Some Assumptions

- Thread Stacks Isolated

- Consistency Model





Unless otherwise specified we will adopt

Sequential Consistency

t0	t1	t2	t3
x=5	a=1	x←5	x
y=6	b=2	a←1	a
		b←2	b
		y←6	y

- All threads agree on the order of operations
  (GLOBAL ORDER)

- The order of operations performed by a thread is preserved

CRITICAL SECTIONS

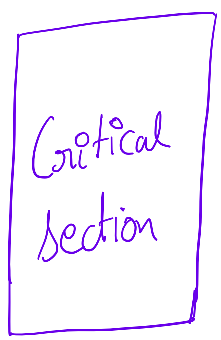
Things that should appear to occur **atomically**

Some concerns

Mutual exclusion

- Progress
- Bounded waiting

Implementing Critical Sections



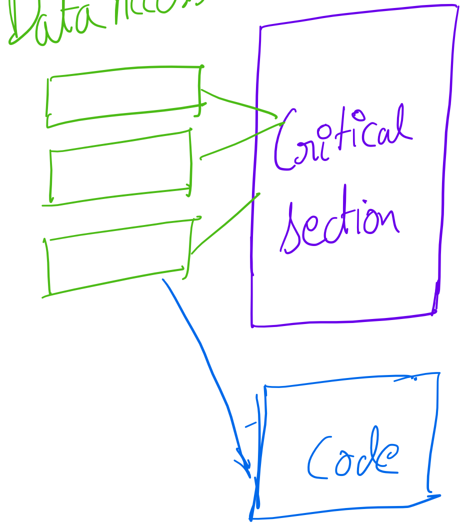
- Single processor: Prevent anything else from running

How?

Multiple Processors

- Trickier

- Mutexes

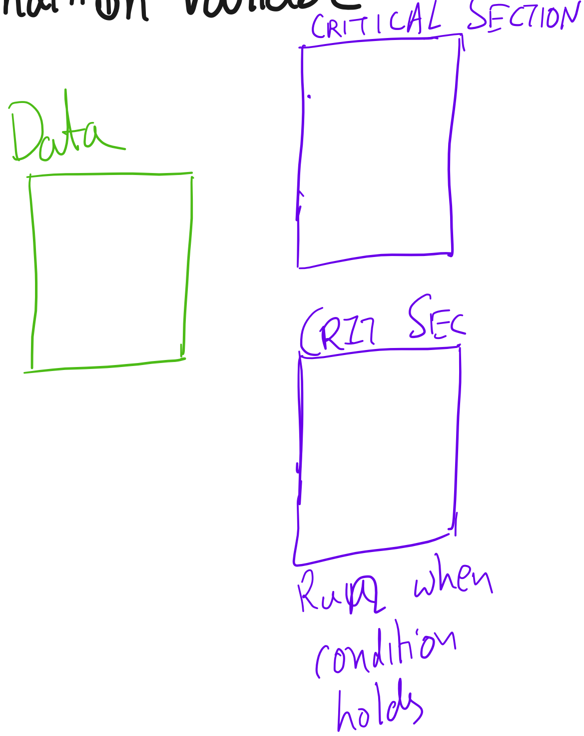


↳ Mutual Exclusion

lock

unlock

Condition Variable



cond_init (cond*)

cond_wait (Mutex*m, Cond*)

cond_signal

cond_broadcast

```
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Handout 3

1. Example to illustrate interleavings: say that thread tid1 executes f()
and thread tid2 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 tid1 has executed f() and tid2 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?
```
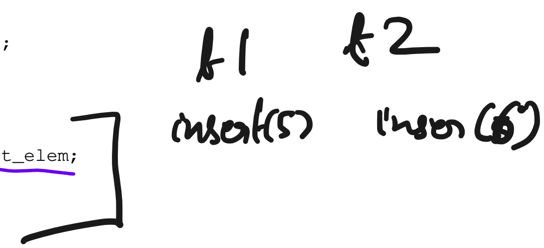
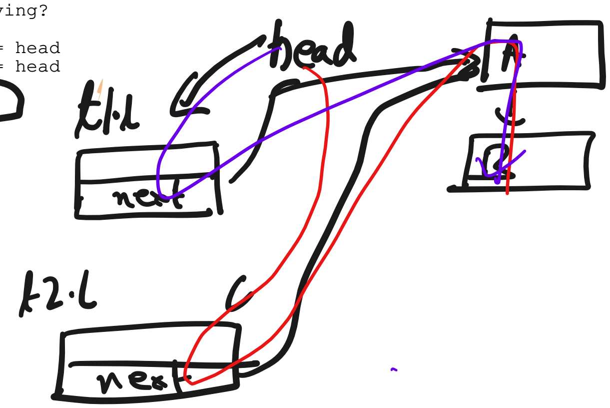



```
2. Linked list example

    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);
        }
```

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Handout 4

Handout 3 gave examples of race conditions. The following panels demonstrate 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

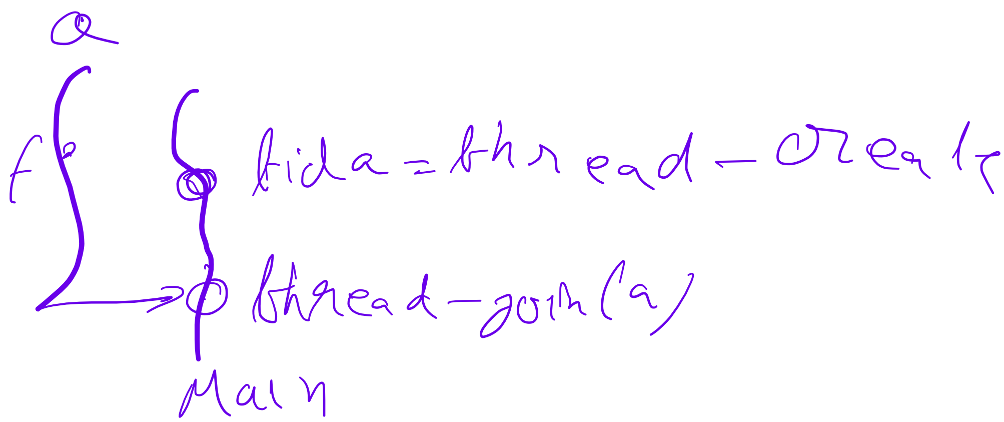
```
     Mutex mutex;

     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.
```

tid a = thread-create(f, NULL);



tid a = thread-create(. . .)

tid b = thread-create(. . .)