- [ ] 1. Last time
- [ ] 2. Intro to concurrency, continued
- [ ] 3. Managing concurrency
- [ ] 4. Mutexes
- [ ] 5. Condition Variables
- [ ] 6. Semaphores

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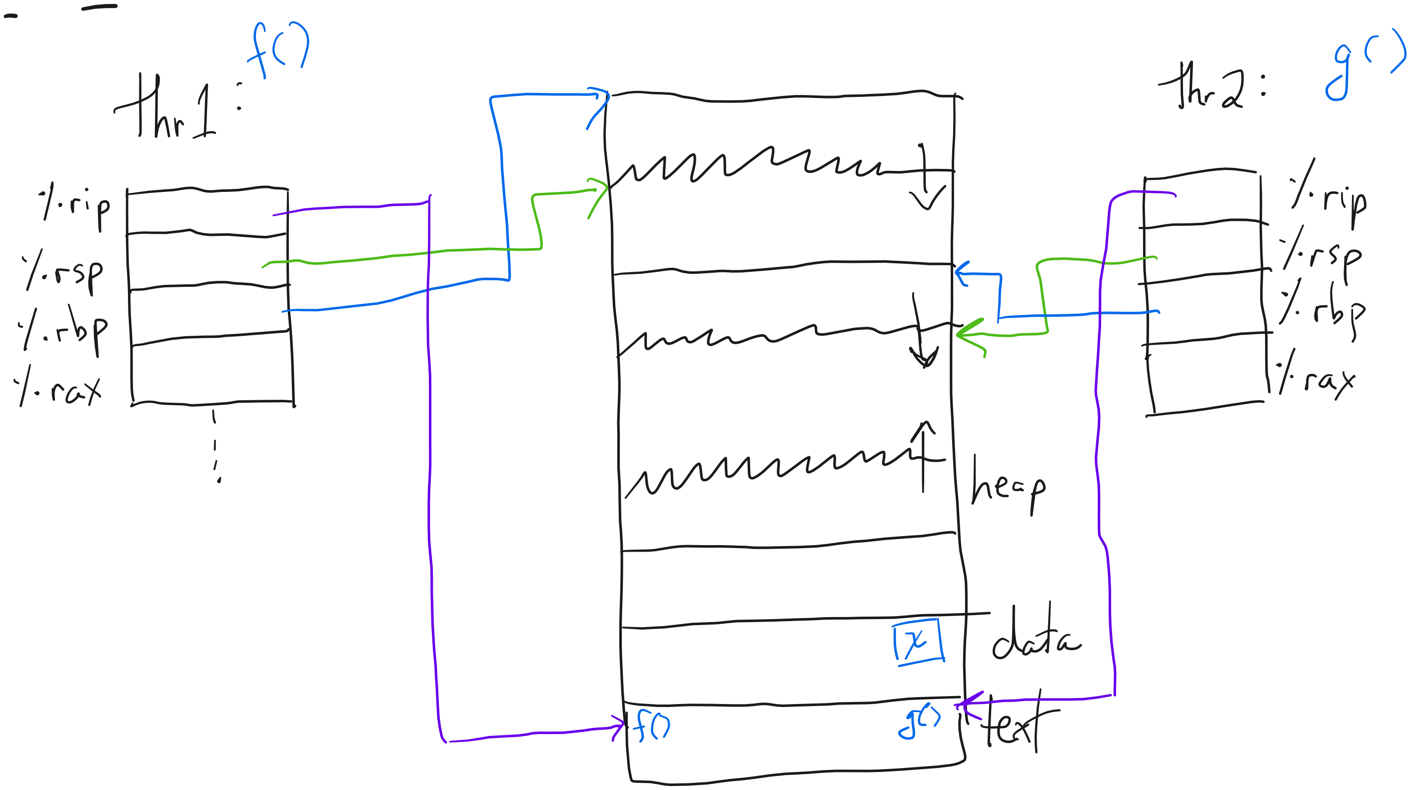
2. Intro to concurrency

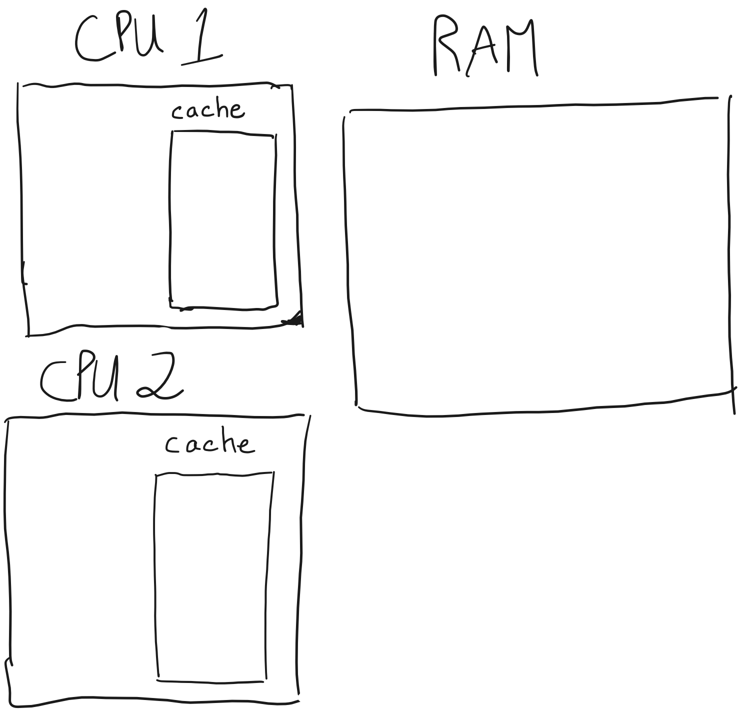
- panels 1-3 on handout03: all examples of "race conditions" (uncontrolled access to shared memory)
- hardware makes the problem harder (see panel 4)

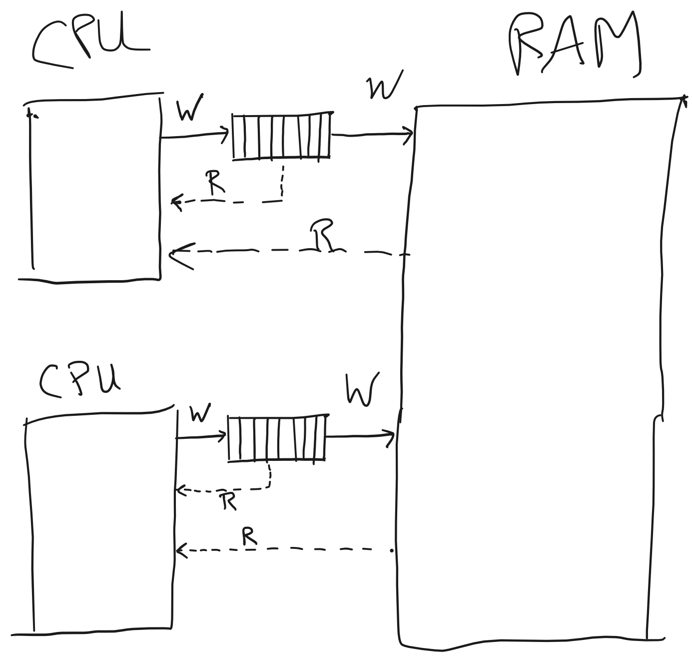


Threads share memory, but they have their own "execution context" (registers and stack).

To the programmer, it "feels like" multiple things are happening at once in the program.

memory consistency





3. Managing concurrency

a. Critical sections: the concept: "protect from concurrent execution".

   i. mutual exclusion
   ii. progress
   iii. bounded waiting

b. Protecting critical sections

   lock() / unlock()
   enter() / leave()
   acquire() / release()

Implementing critical sections

c. Implementing critical sections

(i) single-CPU machine : enter() → disable interrupts

leave() → enable interrupts

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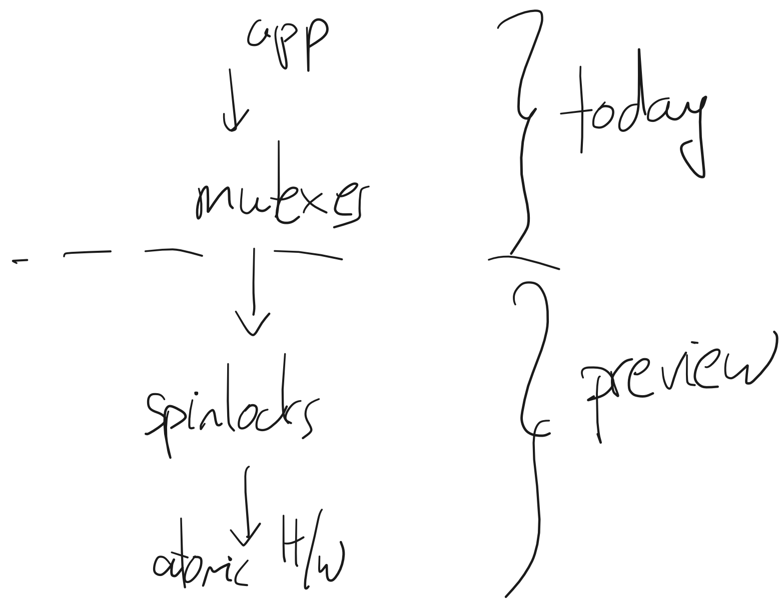
4. Mutexes



5. Condition variables

```
cond_init (Cond*, ...);

cond_wait(Mutex* m, Cond*);

cond_signal (Mutex* m, Cond*);

cond_broadcast(Mutex* m, Cond*);
```

CS 202
Handout 4 (Class 5)

The handout from the last class 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.
```