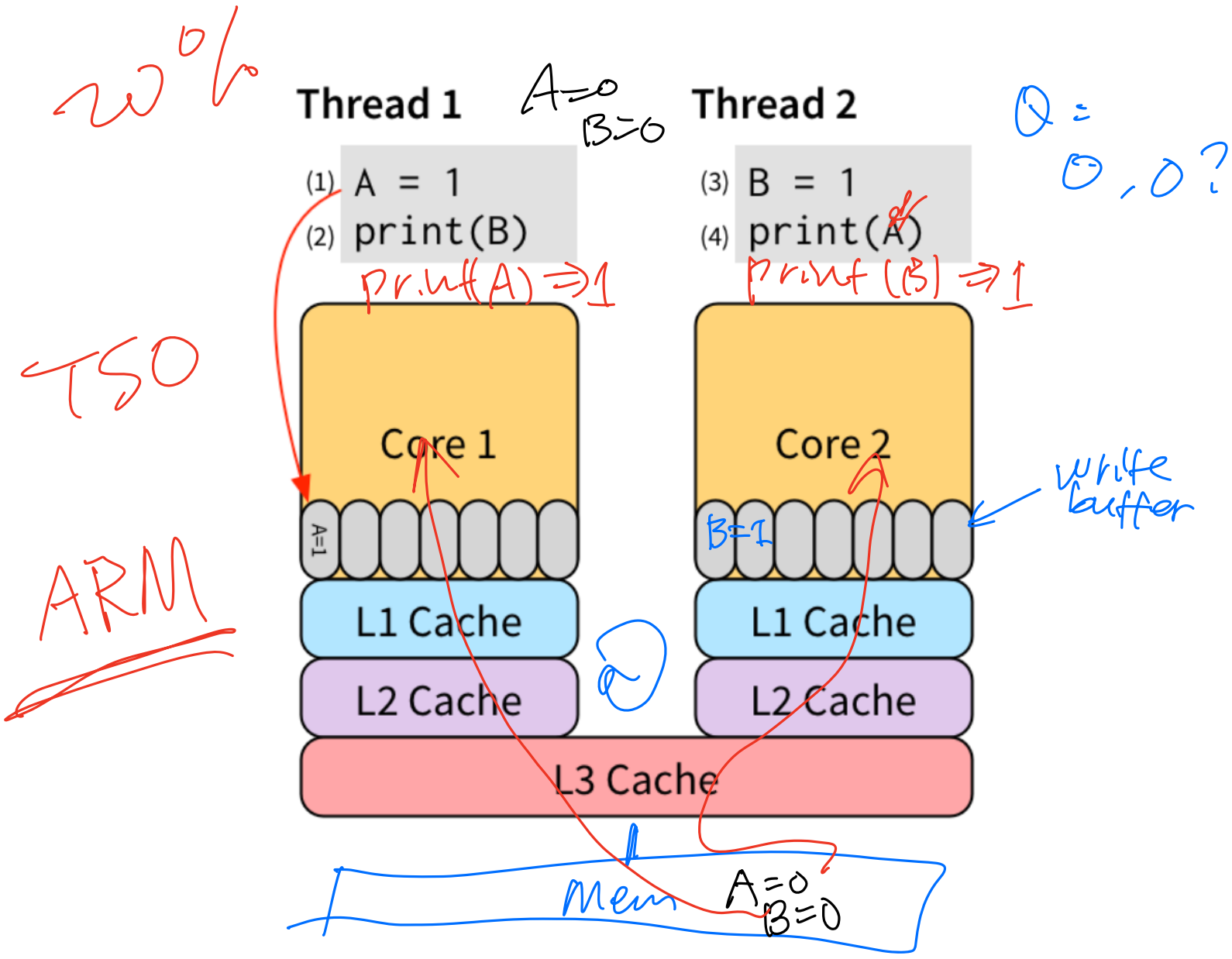


Borrowed from blog "Memory Consistency Model: A Tutorial", James Bornholt.
https://www.cs.utexas.edu/~bornholt/post/memory-models.html

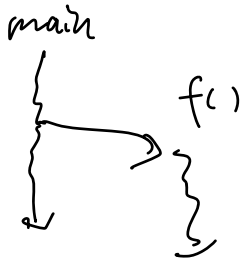
Week 5.b
CS5600
02/08 2023
https://naizhengtan.github.io/23spring/

0. Last time
1. Concurrency and consistency model
2. Managing concurrency
3. Mutexes
4. Condition variables
5. (optional) Bakery algorithm
6. (optional) Semaphores

- threads (vs. processes)

```
void *f(void *xx) {
    sleep(1);
    printf("this is f\n");
    exit(0);
}

int main(){
    pthread_t tid;
    pthread_create(&tid, NULL, f, NULL);
    pthread_join(tid, NULL);  // line X
    printf("this is main\n");
}
```

orphan thread



Q: what you will see?

A: this is f \n
this is main \n

B: this is f \n

C:
this is main \n
this is f \n

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

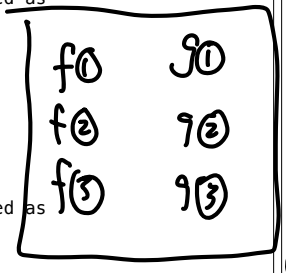
```
int y = 12;

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?

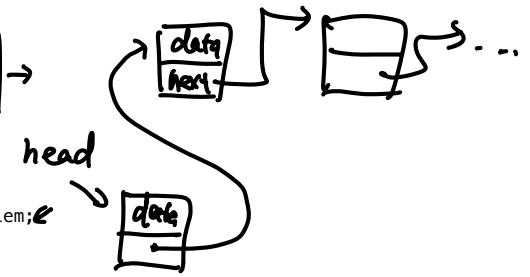


X = 1, 2, or 3.

X = X+1 ⇒

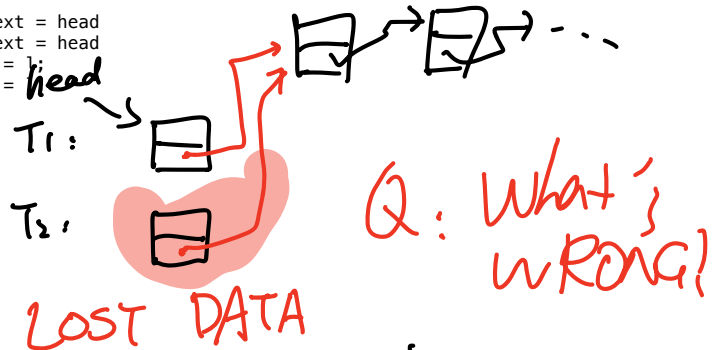
2. Linked list example

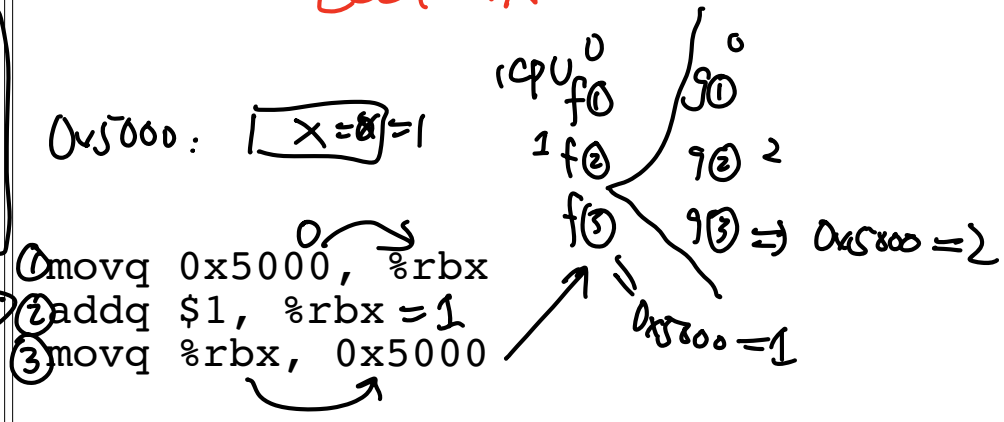
```
struct List_elem {
    int data;
    struct List_elem* next;
};

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;
```





```
86
87  3. Producer/consumer example:
88
89      /*
90          "buffer" stores BUFFER_SIZE items
91          "count" is number of used slots. a variable that lives in memory
92          "out" is next empty buffer slot to fill (if any)
93          "in" is oldest filled slot to consume (if any)
94      */
95
96      void producer (void *ignored) {
97
98          for (;;) {
99              /* next line produces an item and puts it in nextProduced */
100             nextProduced = means_of_production();
101             while (count == BUFFER_SIZE)
102                 ; // do nothing
103             buffer [in] = nextProduced;
104             in = (in + 1) % BUFFER_SIZE;
105             count++;
106         }
107     }
108
109     void consumer (void *ignored) {
110         for (;;) {
111             while (count == 0)
112                 ; // do nothing
113             nextConsumed = buffer[out];
114             out = (out + 1) % BUFFER_SIZE;
115             count--;
116             /* next line abstractly consumes the item */
117             consume_item(nextConsumed);
118         }
119     }
120
121     /*
122         what count++ probably compiles to:
123             reg1 <-- count # load
124             reg1 <-- reg1 + 1 # increment register
125             count <-- reg1 # store
126
127         what count-- could compile to:
128             reg2 <-- count # load
129             reg2 <-- reg2 - 1 # decrement register
130             count <-- reg2 # store
131     */
132
133     What happens if we get the following interleaving?
134
135         reg1 <-- count
136         reg1 <-- reg1 + 1
137         reg2 <-- count
138         reg2 <-- reg2 - 1
139         count <-- reg1
140         count <-- reg2
141
```



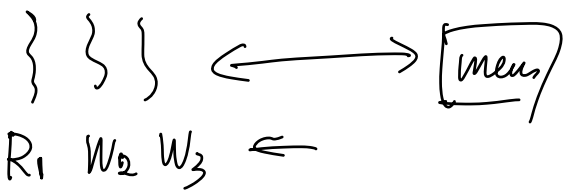
```
142
143 4. Some other examples. What is the point of these?
144
145     [From S.V. Adve and K. Gharachorloo, IEEE Computer, December 1996,
146     66-76. http://sadve.cs.illinois.edu/Publications/computer96.pdf]
147
148     a. Can both "critical sections" run?
149
150         int flag1 = 0, flag2 = 0;
151
152         int main () {
153             tid id = thread_create (p1, NULL);
154             p2 (); thread_join (id);
155         }
156
157         void p1 (void *ignored) {
158             flag1 = 1;
159             if (!flag2){
160                 critical_section_1 ();
161             }
162         }
163
164         void p2 (void *ignored) {
165             flag2 = 1;
166             if (!flag1){
167                 critical_section_2 ();
168             }
169         }
170
171     b. Can use() be called with value 0, if p2 and p1 run concurrently?
172
173         int data = 0, ready = 0;
174
175         void p1 () {
176             data = 2000;
177             ready = 1;
178         }
179         int p2 () {
180             while (!ready) {}
181             use(data);
182         }
183
184     c. Can use() be called with value 0?
185
186         int a = 0, b = 0;
187
188         void p1 (void *ignored) { a = 1; }
189
190         void p2 (void *ignored) {
191           if (a == 1)
192             b = 1;
193         }
194
195         void p3 (void *ignored) {
196           if (b == 1)
197             use (a);
198         }
```

Race conditions (1 cpu) ⇒ multi-core

Sequential Consistency

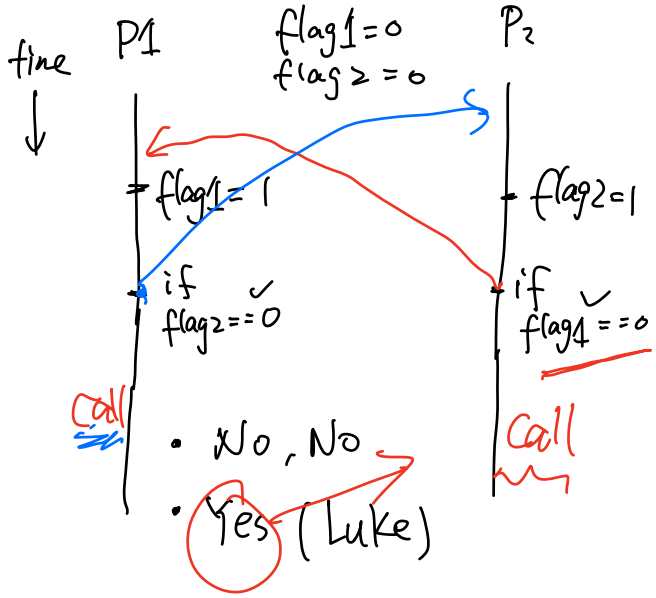
∃ seq exec of the ops. s.t.

seq exec ≡ what you've seen.



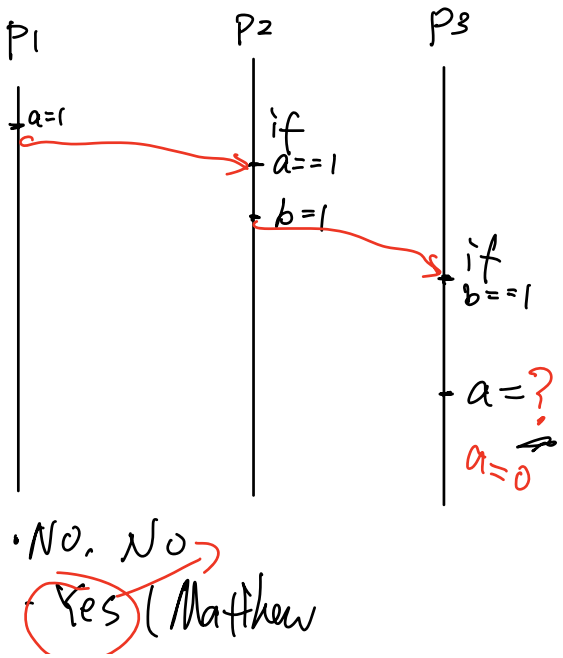
6 {
- $R_1 W_2 W_3$
- $R_1 W_3 W_2$
- $W_2 R_1 W_3$
- $W_2 W_3 R_1$
- $W_3 R_1 W_2$
- $W_3 W_2 R_1$

handout 4.a.



4.c

a=0, b=0



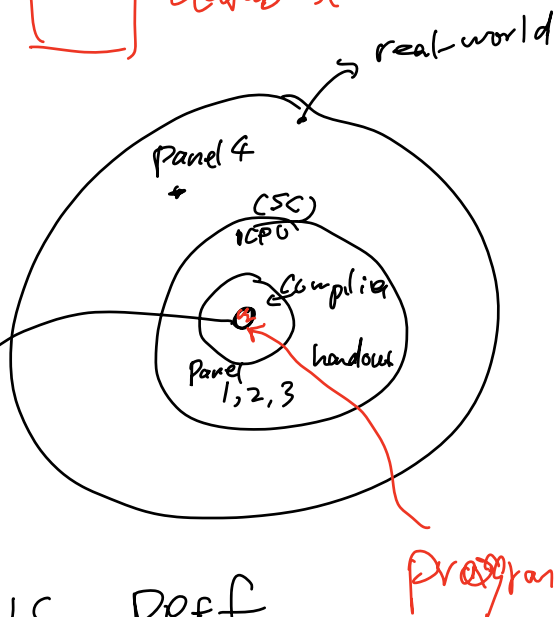
```
int x = 0;  // a global variable

void foo() {
  for (int i=0; i<100; i++) {
    x = 1;
    printf("%d", x);
  }
}

void bar() {
  x = 0;
}
```

thread 1

thread 2

mem model

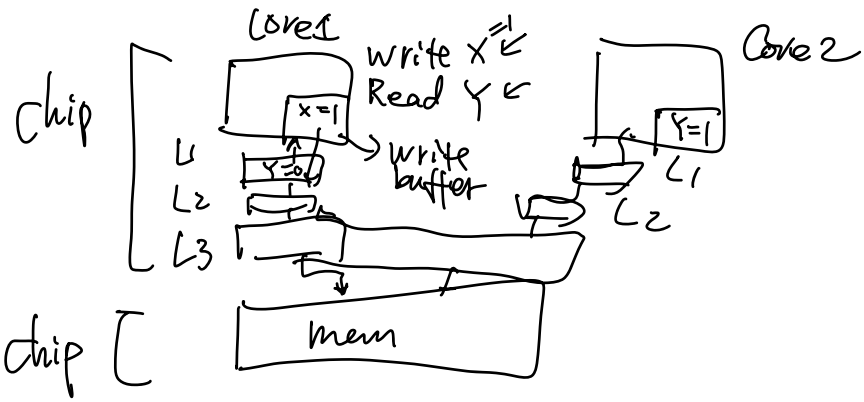
database



expect

trade-off;

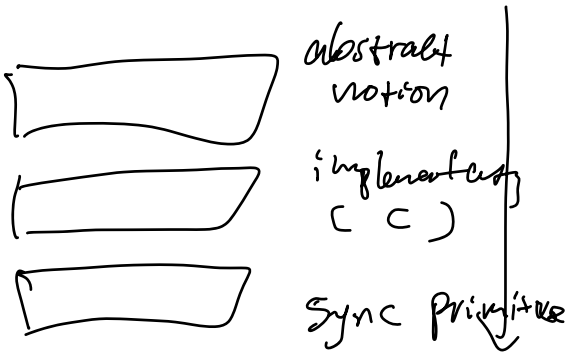
"Correctness" vs. perf

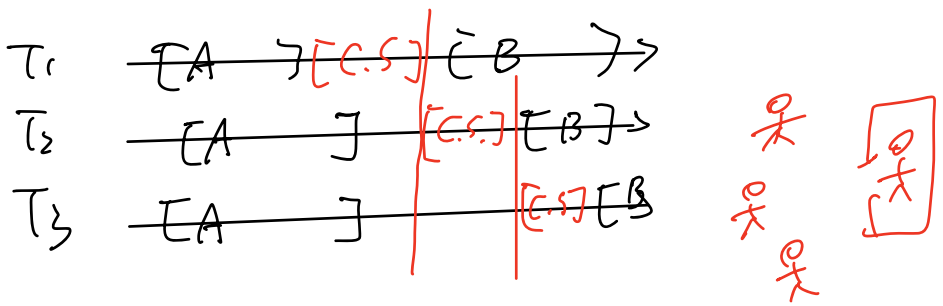


- managing Concurrency.

Critical section → C.S.

A ; [C.S.] ; B





- mutual exclusive
- Progressive ←
- bounded waiting ←