CS202 (003): Operating Systems Concurrency V

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Most of the materials covered in this slide come from the lecture notes of Mike Walfish's CS202

Quiz Time!

Last Time

Deadlock

```
       T1:                    T2:
acquire(mutexA);       acquire(mutexB);
acquire(mutexB);       acquire(mutexA);

// do some stuff       // do some stuff

release(mutexB);       release(mutexA);
release(mutexA);       release(mutexB);
```

Example 1

Deadlock

```
class M {
    private:
        Mutex mutex_m;
        // instance of monitor N
        N another_monitor;

        // Assumption: no other objects
        // in the system hold a pointer
        // to our "another_monitor"

    public:
        M();
        ~M();
        void methodA();
        void methodB();
};
```

```
class N {
    private:
        Mutex mutex_n;
        Cond cond_n;
        int navailable;

    public:
        N();
        ~N();
        void* alloc(int nwanted);
        void free(void*);
}
```

Example 2: Code see handout

M:

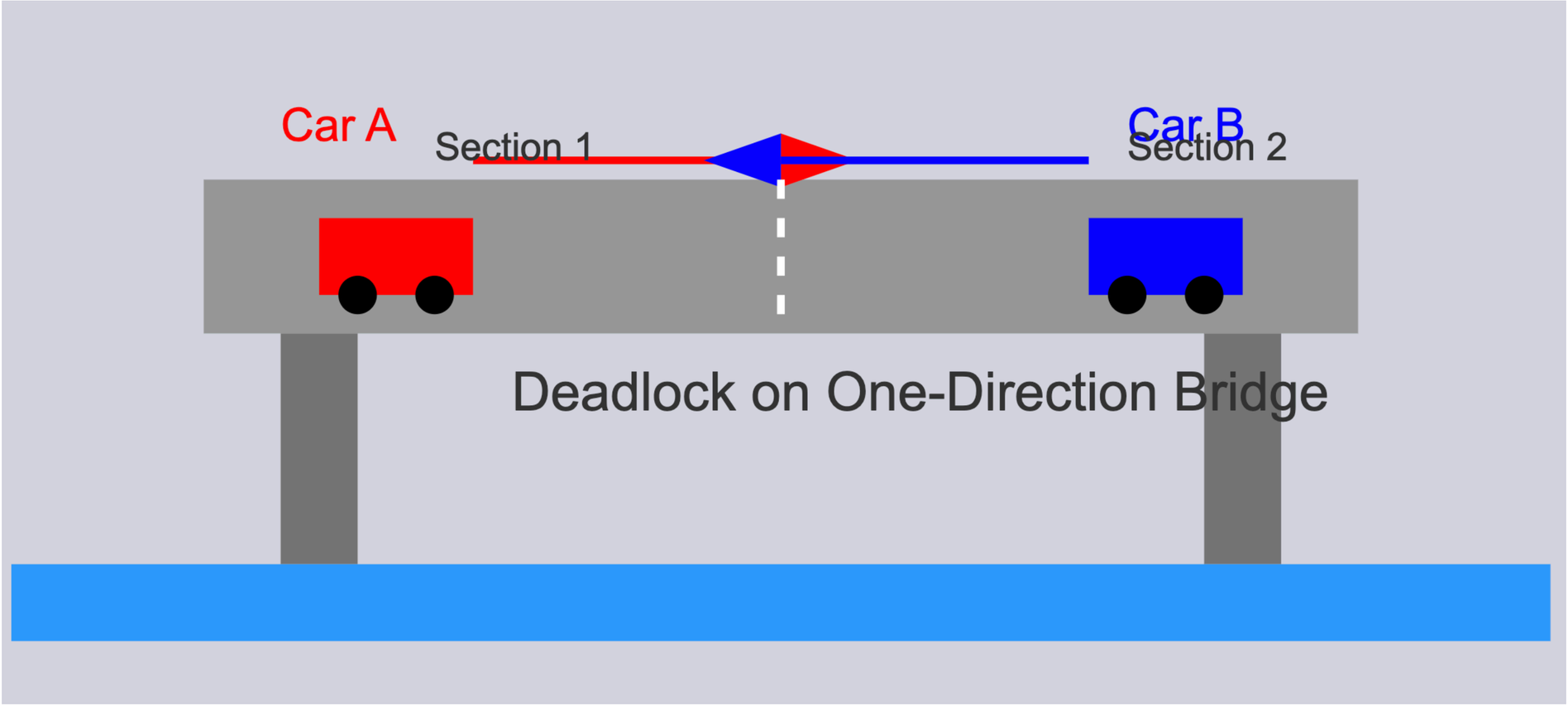
```
acquire(&mutex_m);
 n.alloc(nwanted)
```

```
acquire(&mutex_m);
```

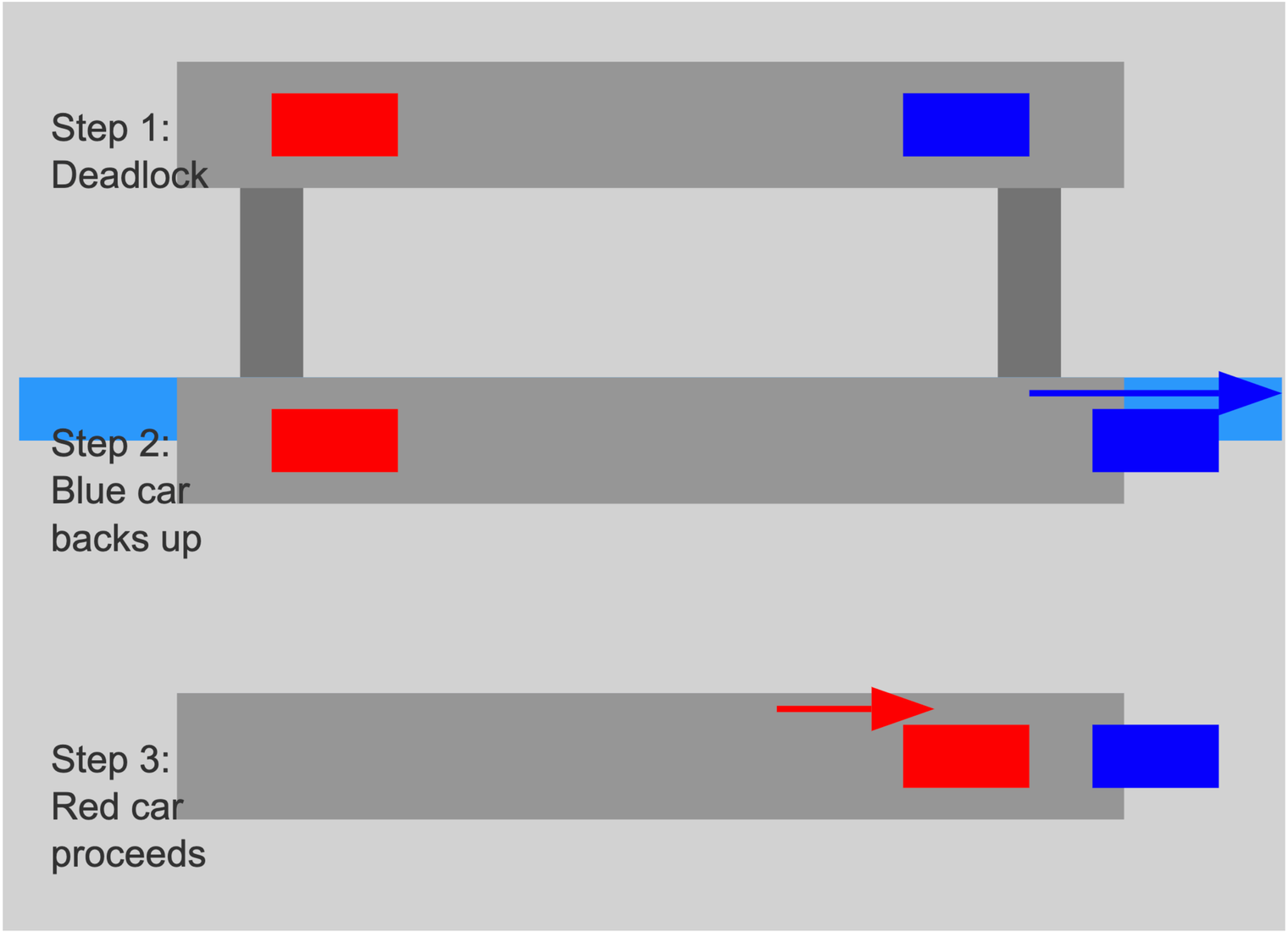
N:

```
acquire(&mutex_n)
navailable < nwanted
release(&mutex_n)
```

Deadlock


Car A
Section 1
Car B
Section 2
Deadlock on One-Direction Bridge

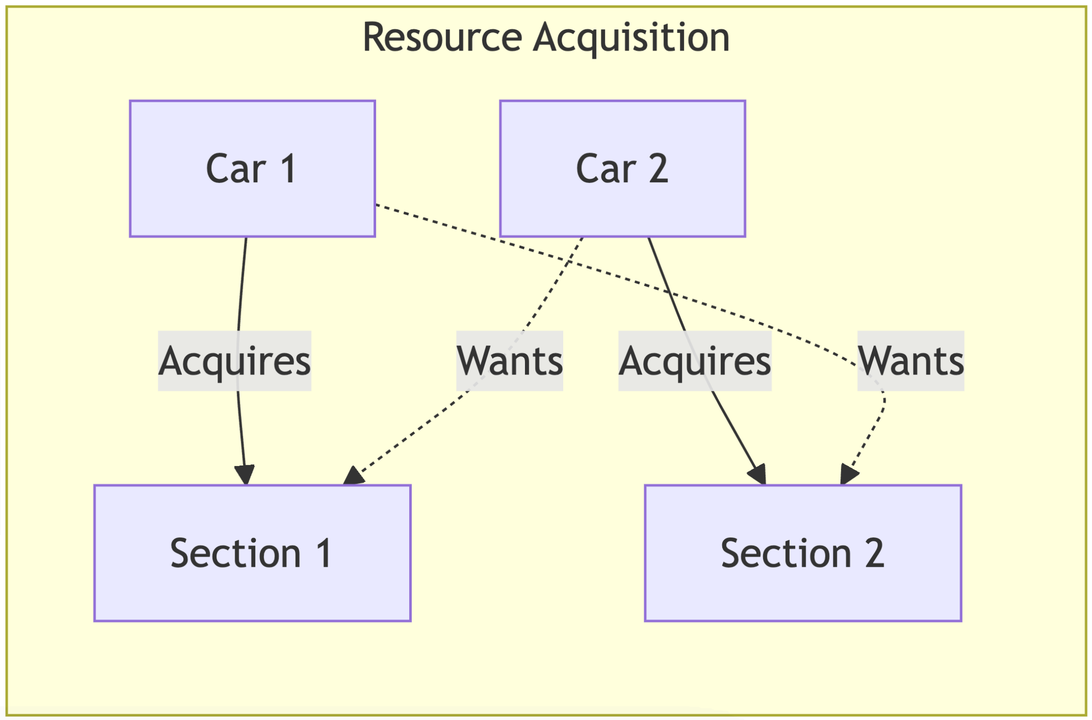
Deadlock


Step 1:
Deadlock
Step 2:
Blue car
backs up
Step 3:
Red car
proceeds

Deadlock

Happens when **all four** conditions are present:

(1) Mutual exclusion
(2) Hold and wait
(3) No pre-emption
(4) Circular wait



Preventing deadlock

Ignore It! — "admit defeat"

Detect & Recover — Works in development, not really viable for production

Avoid Algorithmically — There are ways but we don't cover them in this class[1]

Negate Any of the Conditions

- **Mutual exclusion**: put a queue for accessing resources
- **Hold and wait**: not likely to work
- **No preemption**: not likely to work
- **Circular dependency**: put partial order on locks (=> no cycles)

Static/Dynamic Analysis

Static: detect potential errors without running the code[2]
Dynamic: detect (potential) error during/after execution[3]

Check the following if you are curious:
[1]Section 6.5.3 of Modern Operating Systems (Tanenbaum)
[2]Engler, D. and K. Ashcraft. RacerX: effective, static detection of race conditions and deadlocks.
[3]Savage, S., M. Burrows, G. Nelson, P. Sobalvarro, and T. Anderson. Eraser: a dynamic data race detector for multithreaded programs.

Other progress issues

Starvation

Thread waiting indefinitely
(if low priority and/or resource is contended)

Priority Inversion

T1: **(highest priority)**	**T2:** **(middle priority)**	**T3:** **(lowest priority)**
		hold the lock
start		preempt T3
waiting for lock		
	start	
	running	

Why does T2 control the CPU?

Priority inversion - potential fixes

Solution 1

T1: (highest priority)	T2: (middle priority)	T3: (highest priority)
		hold the lock
start		
waiting for lock		
		finish T3
		release the lock
acquire the lock		
running		
	.....	

Solution 2

T1: (highest priority)	T2: (middle priority)	T3: (lowest priority)
		hold the lock
start		
waiting for lock		
		disable interrupt
		finish T3
		release the lock
acquire the lock		
running		
	.....	

Solution 3

Don't handle it.

Design the code wisely so that only adjacent priority processes/threads share the lock

Performance issues and tradeoffs

Implementation of spinlocks/ mutexes can be **expensive**

Coarse locks **limit** available parallelism

Fine-grained locking leads to **complexity** and hence **bugs**

Mutex costs:

- instructions to execute "mutex acquire"
- sleep/wake up brings resource cost

Only 1 CPU can execute anywhere in the part of your code protected by a lock

See "filemap.c" in handout

Spinlock costs:

- cross-talk among CPUs
- cache line bounces
- fairness issues

But, you should still start with coarse locks!

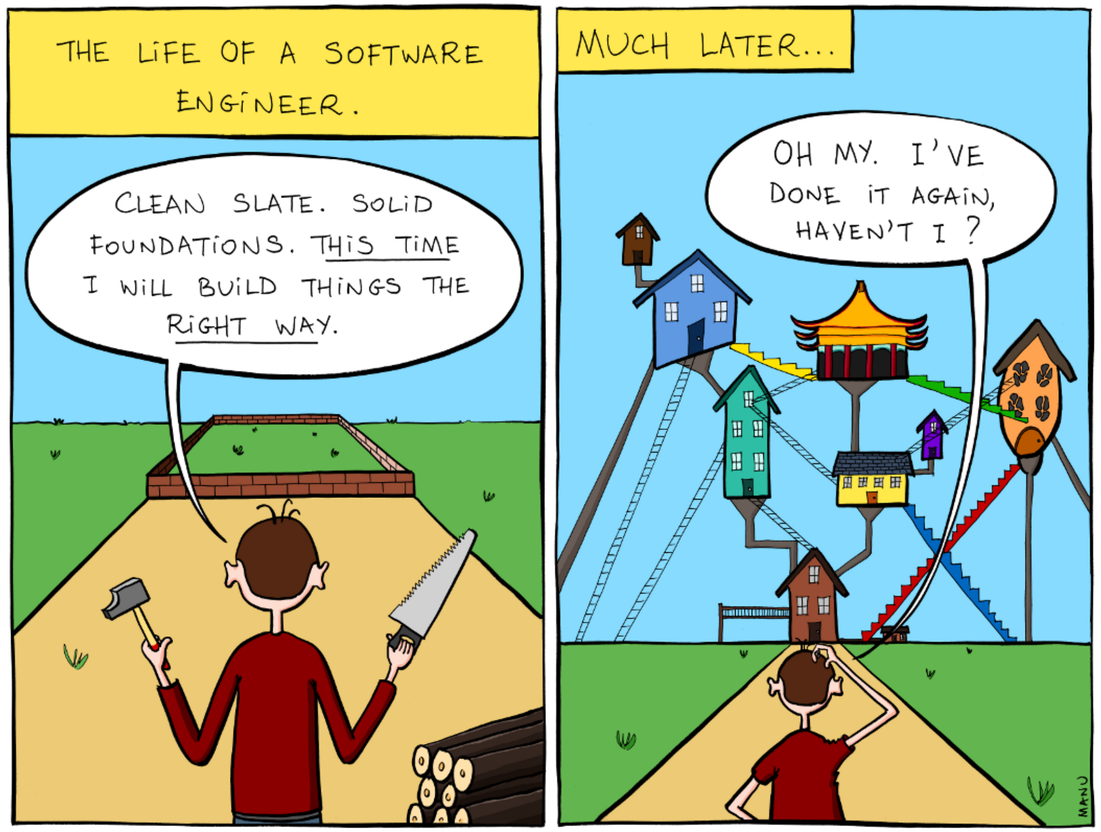
*Look up "MCS locks" if curious

Programmability issues

Loss of modularity

To avoid deadlock, you need to understand how program call each other

You also need to know, whether library functions is thread-safe when you call it. If not, add mutex!



What's the fundamental problem?

Shared memory programming model is hard to use correctly

https://bonkersworld.net/building-software

Some moments of reality about interleaving

Remember sequential consistency?

Modern multi-CPU hardware does not guarantee sequential consistency

https://gunshowcomic.com/648

```
struct foo {
    int abc;
    int def;
};
static int ready = 0;
static mutex_t mutex;
static struct foo* ptr = 0;

void
doublecheck_alloc()
{
    if (!ready) { /* <-- accesses shared variable w/out holding mutex */

        mutex_acquire(&mutex);
        if (!ready) {
            ptr = alloc_foo(); /* <-- sets ptr to be non-zero */
            ready = 1;
        }

        mutex_release(&mutex);

    }
    return;
}
```

Where is the bug?

Yet, if you use mutex correctly…

You don’t have to worry about **arbitrary interleaving**

Critical sections execute atomically

You don’t have to worry about **what hardware is truly doing**

Threading library and compiler do the hard work for you

That does not apply if you do low-level programming

MUST ensure the compiler is not reordering key instructions

MUST know the memory model (of the hardware)

MAY know when to insert memory barriers

```
move $1, 0x10000    # write 1 to memory address 10000
move $2, 0x20000    # write 2 to memory address 20000
MFENCE
move $3, 0x10000    # write 3 to memory address 10000
move $4, 0x30000    # write 4 to memory address 30000
```

If any memory write after **MFENCE** (in program order) is visible to another CPU, then that other CPU also sees all memory writes before the **MFENCE**

"acquire" and "release" in mutexes need memory barriers

"xchg" on x86 includes an implicit memory barrier

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