CS111, Lecture 16
The Monitor Pattern

CS111 Topic 3: Multithreading, Part 1

<u>Topic 3: **Multithreading**</u> - How can we have concurrency within a single process? How does the operating system support this?

Multithreading Introduction → Race conditions and locks → Condition Variables → Trust, Race Conditions and Multithreading Patterns → The Monitor Pattern

Lecture 12 | **Lecture 13** | **Lecture 14** | **Lecture 15** | **This Lecture**

assign4: ethics exploration + implementing 2 *monitor pattern classes* for 2 multithreaded programs.

Plan For Today

- Monitor pattern
- **Example:** Bridge Crossing
- Unique Locks
- assign4

```
cp -r /afs/ir/class/cs111/lecture-code/lect16 .
```

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```

Monitor Design Pattern

The monitor pattern is a design pattern for writing multithreaded code, where we associate a single lock with a collection of related variables, e.g. a class.

- For a multithreaded program, we can define a class that encapsulates the key multithreading logic and make an instance of it in our program.
- This class will have 1 mutex instance variable, and in all its methods we'll lock and unlock it as needed when accessing our shared state, so multiple threads can call the methods
- We can add any other state or condition variables we need as well – but the key idea is there is **one mutex** protecting access to all shared state, and which is locked/unlocked in the class methods that use the shared state.

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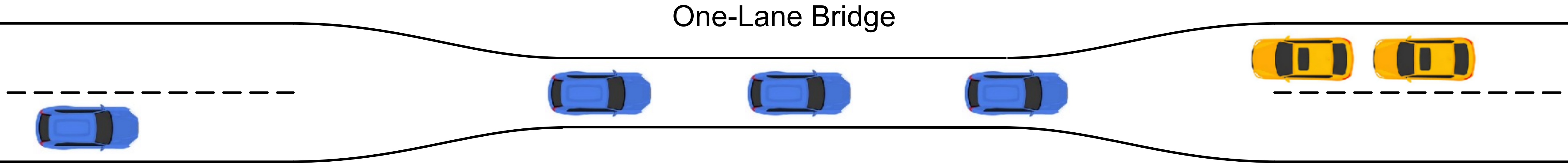
Bridge Crossing



Let's write a program that simulates cars crossing a one-lane bridge.

- We will have each car represented by a thread, and they must coordinate as though they all need to cross the bridge.
- A car can be going either east or west
- All cars on bridge must be travelling in the same direction
- Any number of cars can be on the bridge at once
- A car from the other direction can only go once the coast is clear

Bridge Crossing

A car thread would execute one of these two functions:

```
static void cross_bridge_east(size_t id) {
    approach_bridge(); // sleep
    // TODO: wait until no cars going westbound
    driveAcross(); // sleep
    // now we have crossed
}

static void cross_bridge_west(size_t id) {
    approach_bridge(); // sleep
    // TODO: wait until no cars going eastbound
    driveAcross(); // sleep
    // now we have crossed
}
```

Arriving Eastbound

Key task: a thread needs to wait for it to be clear to cross.

E.g. car going eastbound:

- If other cars are already crossing eastbound, they can go
- If other cars are already crossing *westbound*, we must wait

“Waiting for an event to happen” -> condition variable!

For going east, we are waiting for the event ”no more cars are going westbound”.

State

What variables do we need to create to share across threads?

- 1 mutex to lock shared state
- Condition variable (for waiting to go east)
- ?? (for going east)
- Condition variable (for waiting to go west)
- ?? (for going west)

```
static void cross_bridge_east(size_t id) {
    approach_bridge(); // sleep
    // TODO: wait until no cars going westbound
    driveAcross(); // sleep
    // now we have crossed
}

static void cross_bridge_west(size_t id) {
    approach_bridge(); // sleep
    // TODO: wait until no cars going eastbound
    driveAcross(); // sleep
    // now we have crossed
}
```

Respond on PollEv: pollev.com/cs111
or text CS111 to 22333 once to join.

What last two pieces of state/shared variables do we need?

Nobody has responded yet.

Hang tight! Responses are coming in.

State

What variables do we need to create to share across threads?

- 1 mutex to lock shared state
- Condition variable (for waiting to go east)
- Counter of cars crossing east
- Condition variable (for waiting to go west)
- Counter of cars crossing west

```
static void cross_bridge_east(size_t id) {
    approach_bridge(); // sleep
    // TODO: wait until no cars going westbound
    driveAcross(); // sleep
    // now we have crossed
}

static void cross_bridge_west(size_t id) {
    approach_bridge(); // sleep
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```

Live Coding: Bridge Crossing

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Unique Locks

- It is common to acquire a lock and hold onto it until the end of some scope (e.g. end of function, end of loop, etc.).
- There is a convenient variable type called ***unique_lock*** that when created can automatically lock a mutex, and when destroyed (e.g. when it goes out of scope) can automatically unlock a mutex.
- Particularly useful if you have many paths to exit a function and you must unlock in all paths.

leave_eastbound

We lock at the beginning of this function and unlock at the end.

```
void Bridge::leave_eastbound(size_t id) {
    bridge_lock.lock();
    n_crossing_eastbound--;
    if (n_crossing_eastbound == 0) {
        none_crossing_eastbound.notify_all();
    }
    print(id, "crossed", true);
    bridge_lock.unlock();
}
```

leave_eastbound

We lock at the beginning of this function and unlock at the end.

```
void Bridge::leave_eastbound(size_t id) {
    unique_lock<mutex> lock(bridge_lock);
    n_crossing_eastbound--;
    if (n_crossing_eastbound == 0) {
        none_crossing_eastbound.notify_all();
    }
    print(id, "crossed", true);
}
```

Auto-locks permitsLock here

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    }
    print(id, "crossed", true);
}
```

Auto-unlocks permitsLock here (goes out of scope)

arrive_eastbound

```
void Bridge::arrive_eastbound(size_t id) {
    bridge_lock.lock();
    print(id, "arrived", true);
    while (n_crossing_westbound > 0) {
        none_crossing_westbound.wait(bridge_lock);
    }
    n_crossing_eastbound++;
    print(id, "crossing", true);
    bridge_lock.unlock();
}
```

arrive_eastbound

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void Bridge::arrive_eastbound(size_t id) {
    unique_lock<mutex> lock(bridge_lock);
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    }
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    print(id, "crossing", true);
}
```

Use it with CV instead of original lock (it has wrapper methods for manually locking/unlocking!)

arrive_eastbound

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    unique_lock<mutex> lock(bridge_lock);
    print(id, "arrived", true);
    while (n_crossing_westbound > 0) {
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Assign4

Assign4: ethics exploration + implementing 2 *monitor pattern classes* for 2 multithreaded programs.

- Data structures can be used to store condition variables or state
- Structs also helpful to bundle state together and make multiple instances of structs
- Note: when you add elements to C++ data structures (e.g. vector, queue, set, map) it inserts *copies*.
- **condition variables cannot be copied**. E.g. cannot create a condition variable and push onto vector.
- **For two above bullets:** consider how pointers can help!

Recap

- Monitor pattern
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Lecture 16 takeaway: The monitor pattern combines procedures and state into a class for easier management of synchronization. Then threads can call its thread-safe methods!

Next time: how does the OS run and switch between threads?

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```