CME 213, ME 339—Spring 2021

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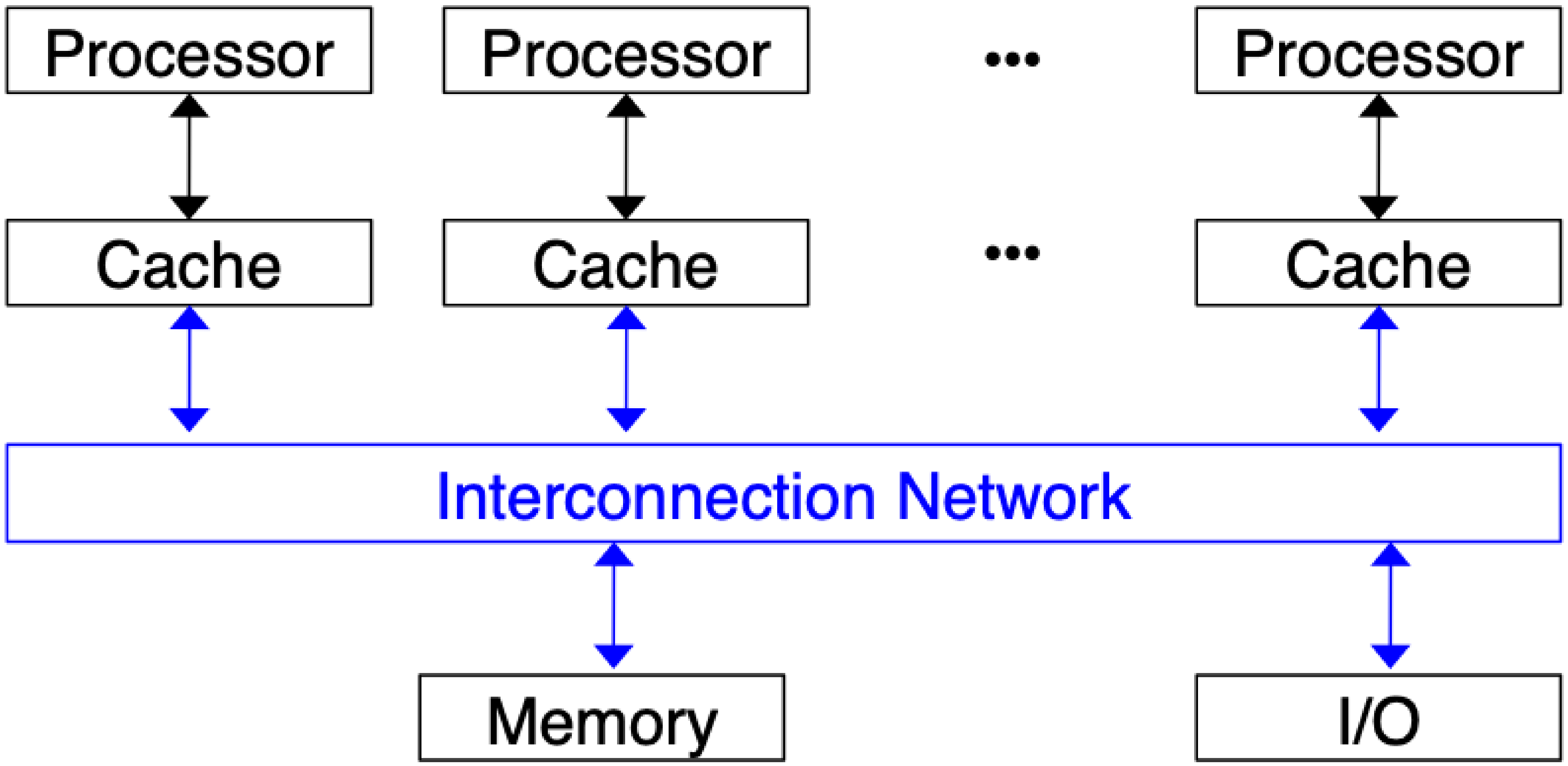
"Computers are getting smarter all the time. Scientists tell us that soon they will be able to talk to us. (And by 'they', I mean 'computers'. I doubt scientists will ever be able to talk to us.)"
(Dave Barry)

Shared Memory Processor

Schematic

- A number of processors or cores
- A shared physical memory (global memory)
- An interconnection network to connect the processors with the memory


Processor
Processor
•••
Processor
Cache
Cache
•••
Cache
Interconnection Network
Memory
I/O

Process

Process: program in execution

Comprises: the executable program along with all information that is necessary for the execution of the program.

Thread

Thread: an extension of the process model.

Can be viewed as a "lightweight" process.

A thread may be described as a "procedure" that runs independently from the main program.

In this model, each process may consist of multiple independent control flows that are called **threads**

Imagine a program that contains a number of procedures.

Then imagine these procedures being able to be scheduled to run **simultaneously and/or independently** by the operating system.

This describes a **multi-threaded program.**

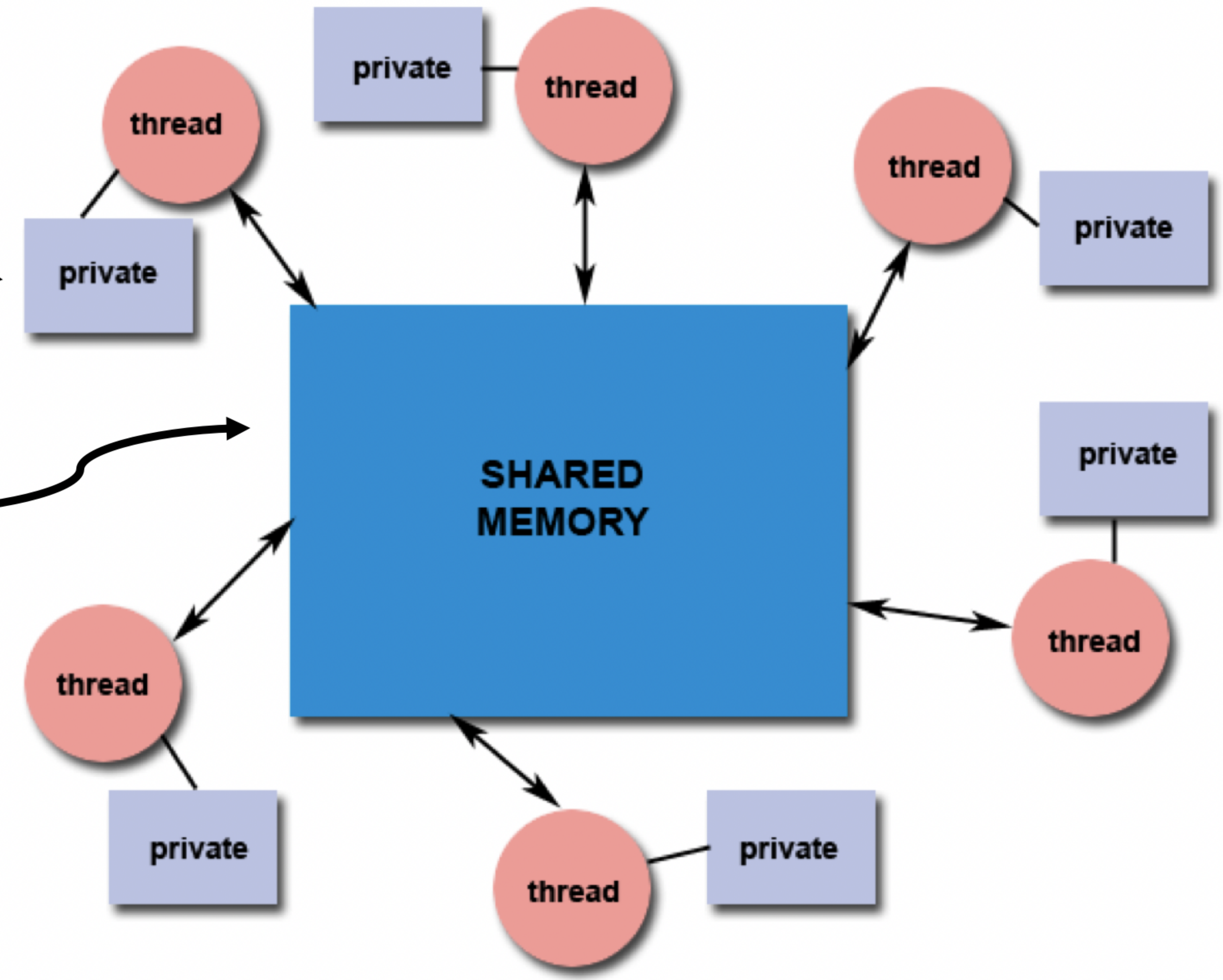
Shared address space

All the threads of one process share the address space of the process, i.e., they have a common address space.

When a thread stores a value in the shared address space, another thread of the same process can access this value.

Private storage

Data exchange



Threads

Threads are everywhere

- C++ threads (11): `std::thread`
- C threads: `Pthreads`
- Java threads: `Thread thread = new Thread();`
- Python threads:
  `t = threading.Thread(target=worker)`
- Cilk: `x = spawn fib (n-1);`
- Julia: `r = remotecall(rand, 2, 2, 2)`
- OpenMP

C++ threads exercise

Open the file `cpp_thread.cpp`

Type `make` to compile

`thread` constructor

```
thread t2(f2, m);
```

Creates a thread that will run function `f2` with argument `m`

Reference argument

```
thread t3(f3, ref(k));
```

If a reference argument needs to be passed to the thread function, it has to be wrapped with `std::ref`.

`thread` join

```
t1.join();
t2.join();
t3.join();
```

Calling thread waits (blocks) for `t1` to complete
(i.e., finishes running `f1`)

Required before results of `t1` calculations become "usable"

Complete exercise with `t4` and `f4`

```
void f4() { /* todo */ }

int main(void)
{
    thread t4(); // todo
    // call f4() using thread t4; add m and k */
}
```

How can we "return" values from asynchronous functions?

Difficulty: these functions can run at any time

1. How do we allocate resources to store return value?
2. How do we query the return value?

Answer

Use `promise` and `future`

`promise`

Holds value to be returned

`future`

Allows to query the value

promise/future exercise

Open `cpp_thread.cpp`

accumulate()

```
void accumulate(vector<int>::iterator first,
                vector<int>::iterator last,
                promise<int> accumulate_promise)
{
    int sum = 0;
    auto it = first;
    for (; it != last; ++it)
        sum += *it;
    accumulate_promise.set_value(sum); // Notify future
}
```

main()

```cpp
promise<int> accumulate_promise; // Will store the int
future<int> accumulate_future = accumulate_promise.get_future();
thread t5(accumulate, vec_1.begin(), vec_1.end(),
          move(accumulate_promise));
// move() will "move" the resources allocated for accumulate_promise

// future::get() waits until the future has a valid result and retrieves it
cout << "result of accumulate_future [21 expected] = "
     << accumulate_future.get() << '\n';
```

promise/future exercise

Complete 2nd part of `cpp_thread.cpp`

`max_promise` and `get_max()`

What is the point of `promise` and `future`?

Why not use a reference and set the value?

The function associated with a thread can run at any time.

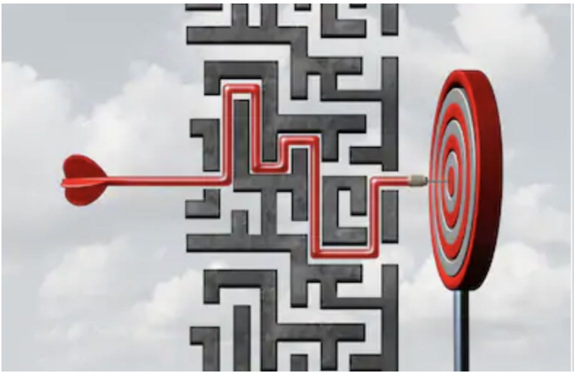
So to make sure a variable has been updated,

we need to use `my_thread.join()`

`promise`/`future` is a more flexible mechanism

As soon as `set_value` is called on the `promise`,

the value can be acquired using the `future` `promise`/`future` allow flexible and efficient communication between threads



See for more information

https://en.cppreference.com/w/cpp/thread/thread

Thread coordination

The risks of multi-threaded programming

A well-known bank company has asked you to implement a multi-threaded code to perform bank transactions

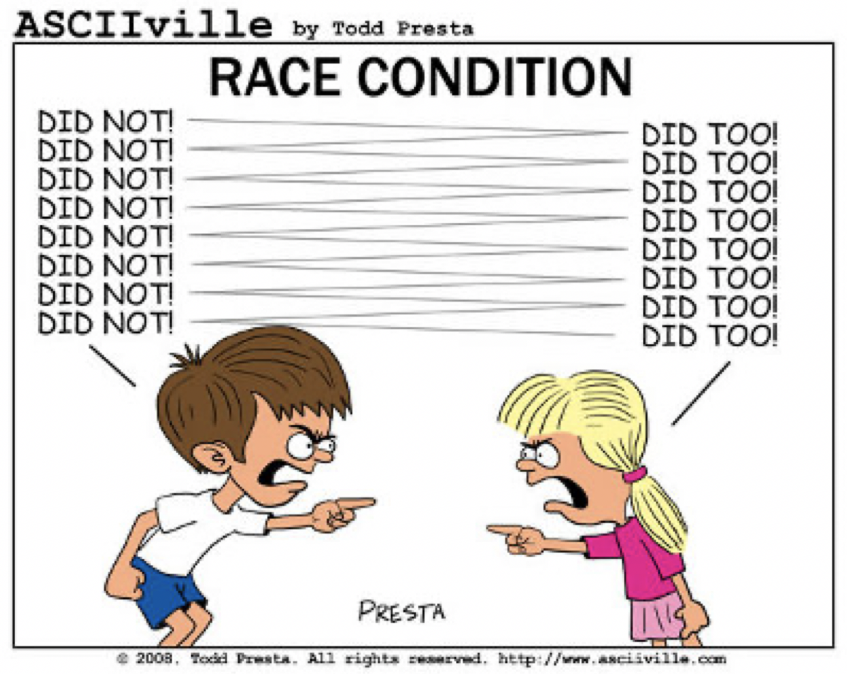
Goal: allow deposits

1. Clients deposit money and the amount gets credited to their accounts.
2. But, a result of having multiple threads running concurrently the following can happen:

Thread 0	Thread 1	Balance
Client requests a deposit	Client requests a deposit	$1000
Check current balance = $1000		
	Check current balance = $1000	
Ask for deposit amount = $100	Ask for deposit amount = $300	
	Compute new balance = $1300	
Compute new balance = $1100	Write new balance to account	$1300
Write new balance to account		$1100

This is called a race condition

The final result depends on the precise order in which the instructions are executed



Race condition

Occurs when you have a sequence like

`READ/WRITE`

or

`WRITE/READ`

performed by different threads

Threads race to fill-up a todo-list

Thread 0	Thread 1
Thread 0 wants to add new to-do item.	
Thread 0 closes lock. Add entry in list.	
	Thread 1 wants to use the lock. It has to wait.
Thread 0 is done with the to-do list. It opens the lock.	
	Thread 1 can close the lock and add entry in list.

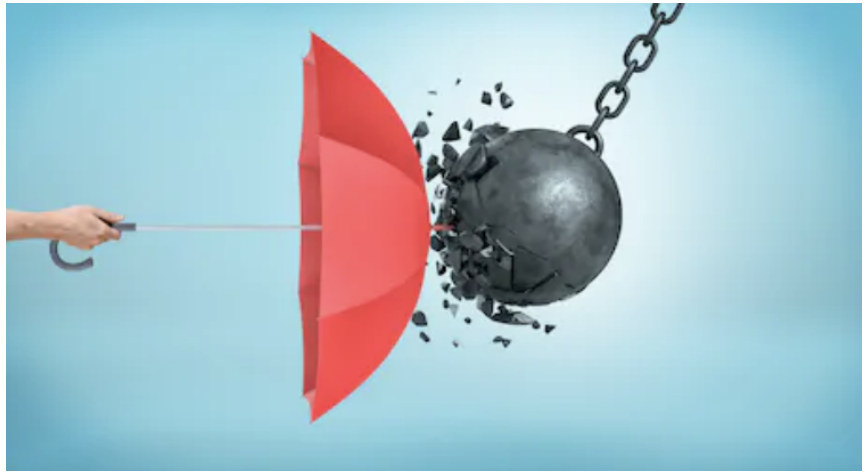
Mutex

A mutex can only be in two states: locked or unlocked.

Once a thread locks a mutex:

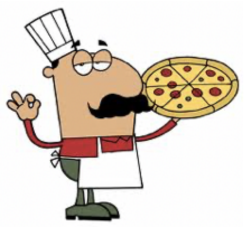
- Other threads attempting to lock the same mutex are blocked.
- Only the thread that initially locked the mutex has the ability to unlock it.

This allows to protect regions of code.



Only one thread at a time can execute that code.

Pizza cook



Receives all the orders.
Prepares all the pizzas.

Ask delivery team to deliver pizzas to customers

Pizza delivery team

- Checks the addresses for customers
- Deliver pizza

Go back; check if there are orders left.

Open `mutex_demo.cpp`

```
void PizzaDeliveryPronto(int thread_id)
{
    g_mutex.lock();
    while (!g_task_queue.empty())
    {
        printf("Thread %d: %s\n", thread_id, g_task_queue.front().c_str());
        g_task_queue.pop();
        g_mutex.unlock();

        Delivery();
        g_mutex.lock();
    }
    g_mutex.unlock();
    return;
}
```