Concurrency: Threads
CSE 333 Spring 2019

Instructor: Justin Hsia

Teaching Assistants:
Aaron Johnston       Andrew Hu       Daniel Snitkovskiy
Forrest Timour       Kevin Bi        Kory Watson
Pat Kosakanchit      Renshu Gu       Tarkan Al-Kazily
Travis McGaha
Administrivia

- Exercise 17 released today, due Wednesday (6/5)
  - Concurrency via pthreads

- hw4 due Thursday (6/6)
  - Submissions accepted until Friday (6/7)

- Final is Wednesday (6/12), 12:30-2:20 pm, ARC 147
  - Review Session: Sunday (6/9), 4-6:30 pm, ECE 125
  - Two double-sided, handwritten sheets of notes allowed
  - Topic list and past finals on Exams page on website

- Please fill out the course evaluations for lecture and your section!
Creating and Terminating Threads

- **int pthread_create(***
  
  *thread*,
  
  const *attr*,
  
  void* (*start_routine)(void*),
  
  void* *arg)*;

- Creates a new thread, whose identifier is place in *thread, with attributes *attr (NULL means default attributes)

- Returns 0 on success and an error number on error (can check against error constants)

- The new thread runs **start_routine(arg)**

- **void pthread_exit(void* retval);**

- Equivalent of **exit(retval);** for a thread instead of a process

- The thread will automatically exit once it returns from **start_routine()**
What To Do After Forking Threads?

- **int pthread_join(pthread_t thread, void** **retval);**
  - Waits for the thread specified by `thread` to terminate
  - The thread equivalent of `waitpid()`
  - The exit status of the terminated thread is placed in `**retval`

- **int pthread_detach(pthread_t thread);**
  - Mark thread specified by `thread` as detached – it will clean up its resources as soon as it terminates
Concurrent Server with Threads

- A single *process* handles all of the connections, but a parent *thread* dispatches (creates) a new thread to handle each connection
  - The child thread handles the new connection and then exits when the connection terminates

- See `searchserver_threads/` for code if curious
Multithreaded Server

client

server

connect

accept()
Multithreaded Server

client

pthread_create()

pthread_detach()

server

pthread_create()

pthread_detach()
Multithreaded Server

server

accept()
Multithreaded Server

client

server

pthread_create()
Multithreaded Server

shared data structures

server

client

client

client

client

client

client
Thread Examples

- See `cthread.c`
  - How do you properly handle memory management?
    - Who allocates and deallocates memory?
    - How long do you want memory to stick around?

- See `pthread.cc`
  - More instructions per thread = higher likelihood of interleaving

- See `searchserver_threads/searchserver.cc`
  - When calling `pthread_create()`, `start_routine` points to a function that takes only one argument (a `void*`)
    - To pass complex arguments into the thread, create a struct to bundle the necessary data
Why Concurrent Threads?

- **Advantages:**
  - Almost as simple to code as sequential
    - In fact, most of the code is identical! (but a bit more complicated to dispatch a thread)
  - Concurrent execution with good CPU and network utilization
    - Some overhead, but less than processes
  - Shared-memory communication is possible

- **Disadvantages:**
  - Synchronization is complicated
  - Shared fate within a process
    - One “rogue” thread can hurt you badly
Data Races

- Two memory accesses form a data race if different threads access the same location, and at least one is a write, and they occur one after another
  - Means that the result of a program can vary depending on chance (which thread ran first?)
Data Race Example

- If your fridge has no milk, then go out and buy some more
  - What could go wrong?

- If you live alone:

- If you live with a roommate:
Data Race Example

- Idea: leave a note!
  - Does this fix the problem?

A. Yes, problem fixed
B. No, could end up with no milk
C. No, could still buy multiple milk
D. We’re lost…
Threads and Data Races

- Data races might interfere in painful, non-obvious ways, depending on the specifics of the data structure.

- **Example**: two threads try to read from and write to the same shared memory location.
  - Could get “correct” answer
  - Could accidentally read old value
  - One thread’s work could get “lost”

- **Example**: two threads try to push an item onto the head of the linked list at the same time.
  - Could get “correct” answer
  - Could get different ordering of items
  - Could break the data structure!
Synchronization

- **Synchronization** is the act of preventing two (or more) concurrently running threads from interfering with each other when operating on shared data
  - Need some mechanism to coordinate the threads
    - “Let me go first, then you can go”
  - Many different coordination mechanisms have been invented (see CSE 451)

- Goals of synchronization:
  - **Liveness** – ability to execute in a timely manner (informally, “something good happens”)
  - **Safety** – avoid unintended interactions with shared data structures (informally, “nothing bad happens”)

Lock Synchronization

- Use a “Lock” to grant access to a critical section so that only one thread can operate there at a time
  - Executed in an uninterruptible (i.e. atomic) manner

- Lock Acquire
  - Wait until the lock is free, then take it

- Lock Release
  - Release the lock
  - If other threads are waiting, wake exactly one up to pass lock to

Pseudocode:

```java
// non-critical code
lock.acquire();
// critical section
lock.release();
// non-critical code
```
Milk Example – What is the Critical Section?

- What if we use a lock on the refrigerator?
  - Probably overkill – what if roommate wanted to get eggs?

- For performance reasons, only put what is necessary in the critical section
  - Only lock the milk
  - But lock all steps that must run uninterrupted (i.e. must run as an atomic unit)

```
fridge.lock()
if (!milk) {
    buy milk
}
fridge.unlock()
```

```
milk_lock.lock()
if (!milk) {
    buy milk
}
milk_lock.unlock()
```
pthreads and Locks

- Another term for a lock is a **mutex** (“mutual exclusion”)
  - `pthread.h` defines datatype `pthread_mutex_t`

- `int pthread_mutex_init(pthread_mutex_t* mutex, const pthread_mutexattr_t* attr);`
  - Initializes a mutex with specified attributes

- `int pthread_mutex_lock(pthread_mutex_t* mutex);`
  - Acquire the lock – blocks if already locked

- `int pthread_mutex_unlock(pthread_mutex_t* mutex);`
  - Releases the lock

- `int pthread_mutex_destroy(pthread_mutex_t* mutex);`
  - “Uninitializes” a mutex – clean up when done
pthread Mutex Examples

- See `total.cc`
  - Data race between threads

- See `total_locking.cc`
  - Adding a mutex fixes our data race

- How does this compare to sequential code?
  - Likely slower – only 1 thread can increment at a time, but have to deal with checking the lock and switching between threads
  - One possible fix: each thread increments a local variable and then adds its value (once!) to the shared variable at the end
Your Turn! (pthread mutex)

- Rewrite `thread_main` from `total_locking.cc`:
  - It need to be passed an `int*` with the *address* of `sum_total` and an `int` with the number of times to loop (in that order)
  - Increment a local sum variable `NUM` times, then add it to `sum_total`
  - Handle synchronization properly!
C++11 Threads

- C++11 added threads and concurrency to its libraries
  - `<thread>` – thread objects
  - `<mutex>` – locks to handle critical sections
  - `<condition_variable>` – used to block objects until notified to resume
  - `<atomic>` – indivisible, atomic operations
  - `<future>` – asynchronous access to data
  - These might be built on top of `<pthreads.h>`, but also might not be

- Definitely use in C++11 code if local conventions allow, but pthreads will be around for a long, long time
  - Use pthreads in current exercise