ECE 3574: Threads

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Useful links for Milestone 3

- Model/View Programming in Qt
  - QStandardItemModel
  - QTableView
- Layout Management in Qt
  - QGridLayout
  - QHBoxLayout
  - QVBoxLayout
- QPushButton
- Exercise 11 would be a good starting point.

Threads

- Today we are going to start looking at threads, multiple executing programs within the same process that share the code segment and heap, but have separate stacks.
    - Threads and OS scheduling
    - C++11 Threads
    - C++11 `std::async`
    - Examples

Threads

- A **thread** is a single executing sequence, consisting of
  - memory (code segment, stack, heap)
  - and state (program counter, registers).
- **Threads** of a process
  - share the code segment and heap,
  - but have separate stacks, and state.

A typical memory layout of a process with two threads

```
   Memory
+----------+ (low address)
|   code   |
+----------+
|   heap   |
|    |     |
|    v     |
|    ^     |
|    |     |
| stack 2  |<-------------- thread 2's stack
|    ^     |
|    |     |
| stack 1  |<-------------- thread 1's stack
+----------+ (high address)
```

Process versus Threads

- Threads get scheduled by the OS
- On most OS's there is no real distinction between threads and processes in the kernel scheduler (e.g. both are **tasks**).
    - From the scheduler's perspective a process is just a single thread.
    - From the virtual memory manger's perspective the address space layout is different.
    - E.g., `struct task_struct` in Linux kernel

Process versus Threads

- This means creation and context switches are faster for threads.
- Heap memory is also shared by default, so no shm_create/size/map/unmap/close required!

C++11 Threads

- All programming languages define details relative to an abstract machine.
- Prior to C++11 threading was platform specific (e.g. posix-threads versus win-threads), the abstract machine was single-threaded.

C++11 Threads

- In C++11 this abstraction was extended to include a memory model that allows the specification to say what a compiler can and cannot do relative to memory.
    - Atomics were added
    - And a standard thread library was added
- We will use it to explore multithreading, then talk about other threading implementations (pthreads and QThread) later.

Creating a thread

```
#include <thread>
class thread;

// Creates thread objects, each represents a single (unique) thread of
// execution.
//    - cannot copy construct a thread
//    - cannot copy assign a thread
// you can move construct and move assign a thread

// Each thread has a unique id within the process:
std::this_thread::get_id()
```

A thread object has an associated function where execution begins

- This is like `main` for the thread. In fact main is the entry point for thread 0.
- The function can take arguments which are passed to the thread constructor.
- Constructing a thread object starts the thread.

After starting a thread you must wait for it to complete before the main thread exitsx

- To wait in a thread to finish (by exiting the thread entry function) you call the `join` method.
    - Why `join`? `fork` vs. `join`
- See hello_thread1.cpp and hello_thread2.cpp.
    - `g++ -pthread hello_thread1.cpp`

Threads share the heap

- Each thread shares the heap, giving them implicit shared memory.
- We will see how to coordinate this in the next few meetings.
- For now, lets see how to use threads as asynchronous functions, using higher-level concepts than the heap.

Promises and Futures

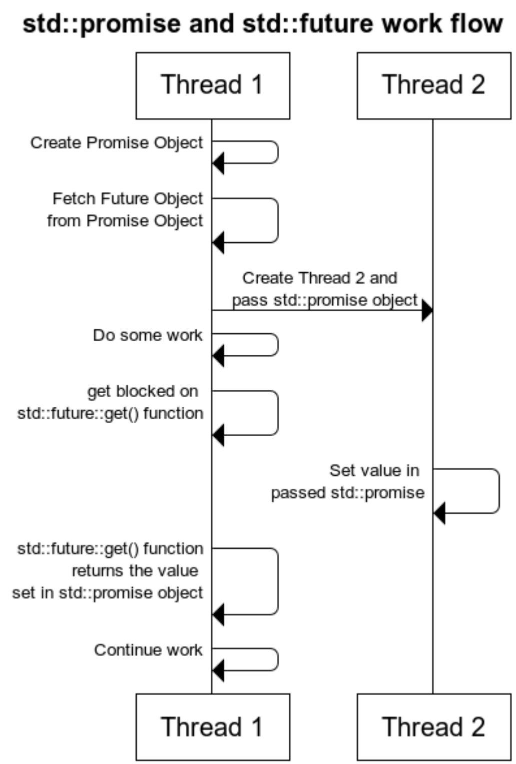
- Conceptually a thread has an input channel and and output channel.
    - `std::promise`, `std::future`
    - Bartosz Milewski

```
#include <future>

// The input channel is represented by a promise:
   std::promise<T>

// The output channel is represented by a future:
   std::future<T>

// Both are objects that have a shared state (empty, ready, invalid),
// synchronized automatically by the C++ library.
```

Example: returning a value from a thread

- We can pass arguments to the thread when we create it. How do we return a value from the thread?
- We use a promise/future together.
- See example: promise_future.cpp (example from Bartosz Milewski)

Promises and Futures workflow



- Source: Bartosz Milewski

What about exceptions thrown in a thread?

- If not caught in the thread, the program terminates.
- But, we can return exceptions in the future, which gets re-thrown automatically by the get call.
- See example: thread_exceptions.cpp.

Promises/Futures are nice, but there is a lot of boilerplate in the code.

- The function `std::async` allows us to just return values from the thread function like from any function, and does the thread creation/join for us!
    - `std::async`
- See example: async_future.cpp

Thread local storage

- Recall the three standard storage specifiers in C++.
    - automatic (stack): exists in block/function scope
    - static (global): exists during the entire program
    - dynamic: exists between new/delete calls
- C++11 adds one more: `thread_local` meaning it exists during thread execution.
- This is like a global for each thread, so has limited uses.
- See example: [thread_local]

How many threads can I run?

- You can get a hint to how many threads can run in parallel using
  - `std::thread::hardware_concurrency()`
- See how_many.cpp
- Note it can sometimes be advantageous to run more threads than the hardware supports, in particular if the task is I/O bound. However, as we will see there is a point of diminishing returns.

Example: asynchronous search version 1

- Lets implement a concurrent binary search.
- See concurrent_binary_search.cpp.
  - std::iota
  - Date and time utilities
- Why isn’t this faster?

Example: asynchronous search version 2

- Lets use a slower (linear) search.
- See concurrent_linear_search.cpp.
- Still not faster?

Example: Concurrent Merge-sort

- See serial_mergesort.cpp and concurrent_mergesort.cpp.
- Note: too many threads is bad for performance.
- More is not always better.
- Concurrent performance often requires adapting based on problem size.

Next Actions and Reminders

- Read about Locking and Semaphores