Threads

Motivation: are processes all we need for useful concurrency?
Threads: Concurrency with shared memory

Advantages/disadvantages of concurrent programs

Advantages
- More responsive
- Interacting with IO
- Higher performance
  - Computers have multiple cores
  - Make progress when one task waits

Disadvantages
- New kinds of bugs
- Race conditions
- Deadlock
- Much more difficult to test, debug

Why do we need concurrency?

Recall: processes create private copies of program state

Why might we want shared access to program state?
Threads: distinct execution, shared memory

- Core idea: allow shared memory, but distinct/concurrent execution

Programs are just data: what data tracks execution?

- Stack
- Heap
- Data
- Code: /usr/bin/bash

Threads need distinct stacks & registers

OS and languages generally allow processes to run two or more functions simultaneously via threading.

- The stack segment is subdivided into 1 stack per thread
- The thread manager time slices and between threads
- Threads often called “lightweight processes”
- Each thread maintains its own stack, but all threads share the same text, data, and heap segments

Processes vs. Threads: what is shared?

<table>
<thead>
<tr>
<th></th>
<th>Processes</th>
<th>Threads</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stack</td>
<td>Not shared (private copies)</td>
<td>Not shared (subdivided)</td>
</tr>
<tr>
<td>Registers</td>
<td>Not shared (kernel tracks)</td>
<td>Not shared (kernel tracks)</td>
</tr>
<tr>
<td>Code (instruction memory)</td>
<td>Shared</td>
<td>Shared</td>
</tr>
<tr>
<td>Heap (dynamic memory)</td>
<td>Not shared (private copies)</td>
<td>Shared</td>
</tr>
</tbody>
</table>

A thread is an independent execution sequence within a single process, with shared dynamic memory

Processes vs. threads

**Threads**

- Easier coordination, operating on shared data
- Lower communication overhead

**Processes**

- Support for distinct programs/code (exec)
- Built-in memory protection

- Since threads have no memory protection, race conditions and deadlocks more likely
Race condition

Thread 1
\[ x = x + 1 \]

Thread 2
\[ x = x \times 2 \]

Assume \( x = 2 \) before this code runs.
What possible values could \( x \) have after this code runs?

- ANSI C doesn't provide native support for threads.
- But **pthreads**, which comes with all standard UNIX distributions, provides thread support.
  - The primary **pthreads** data type is the **pthread_t**, which is a type used to manage the execution of a function within its own thread of execution.
  - The **pthreads** functions we'll need: **pthread_create** and **pthread_join**.

Examine introverts!

- Introverts declares an array of six **pthread_t** handles.
- The program initializes each **pthread_t** (via **pthread_create**) by installing **recharge** as the function each **pthread_t** should execute.
- All thread routines take a **void** * and return a **void** *.
- The **pthread** thread manager’s attention, and we have very little control over what choices it makes when deciding what thread to run next.

Key points of introverts
pthread_join waits

- `pthread_join` is to threads what `waitpid` is to processes.
- The main thread of execution blocks until the child threads all exit. The second argument to `pthread_join` can be used to catch a thread routine's return value.
- If we don't care to receive it, we can pass in `NULL` to ignore it.

Sharing data

- Sharing data can be complicated and dangerous in concurrent execution, but often necessary.
- Concurrent programming often makes use of specific tools to control how data is shared between threads
  - Locking/mutexes
  - Semaphores
  - Condition variables
  - Etc.

Examine robberBaronsBroken!

- How do we know?
  - Printing is out of order at the end
  - Negative value for the `stash`?
- Multiple threads are modifying the global variable `stash`
- Is it possible for two threads to evaluate `stash > 0` as True with only $10000 left and then both subtract from stash?
  - Yep! Say thread A evaluates `stash > 0` and then the thread manager switches to thread B before thread A subtracts the steal money from the `stash`.
  - Thread B executes fully bringing the stash to $0.
  - Thread A resumes execution and subtracts its $10000 bringing the total to -$10000.
  - Yikes!
Mutexes

- A mutex is a **mutual exclusion** object.
- It is a _locking_ mechanism to protect shared data or critical regions of code so that only one thread can be permitted access.
- Here: protect the stash so that only one robber can modify it at a given time.
- We declare a mutex with `pthread_mutex_t`.
- To lock a piece of code, we use `pthread_mutex_lock()`.
  - When a thread tries to acquire a lock, it will either take the lock if it is not being currently used or it will wait until the lock becomes available.
- To unlock a piece of code, we use `pthread_mutex_unlock()`.
  - Only the thread that holds a lock can unlock it.