COMP1521 25T1

Week 10 Lecture 1

Concurrency, Parallelism and Threads and Revision

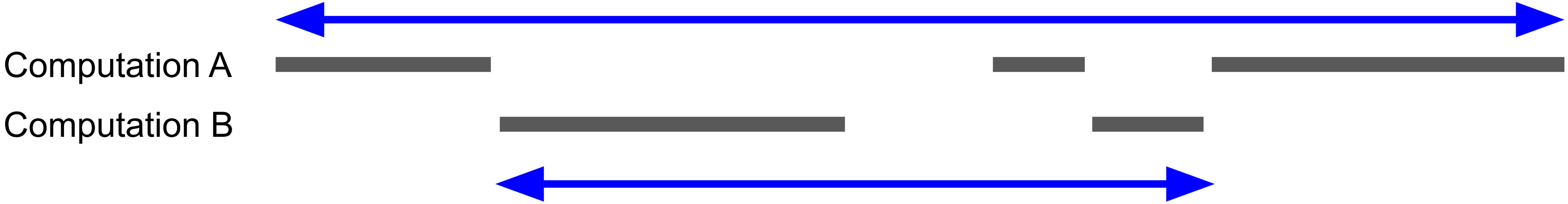
Adapted from Xavier Cooney,
Andrew Taylor and John Shepherd's slides

Today's Lecture

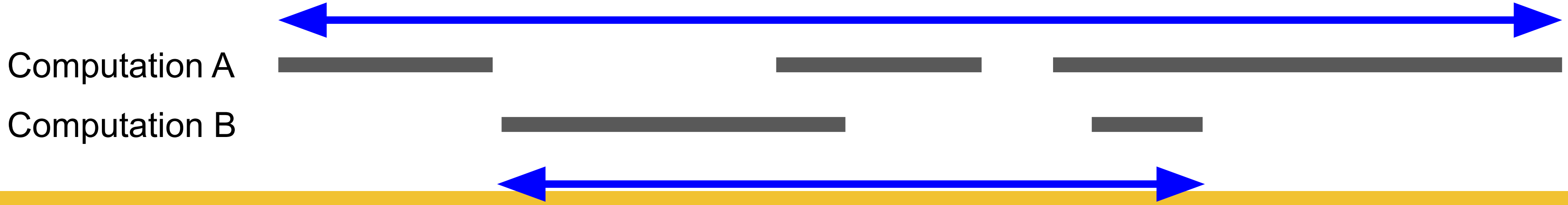
- Concurrency
  - Recap
  - Atomics
- Revision
  - Files
  - Processes

Concurrency & Parallelism

Concurrency: Multiple computations with *overlapping* time periods. Does not *have* to be simultaneous.



Parallelism: Multiple computations executing *simultaneously*.



Threads: concurrency *within* a process

- Threads allows us to create concurrency *within* a process
- Threads within a process *share* the address space:
  - threads share code
  - threads share global variables
  - threads share the heap (`malloc`)
  - cheap communication!
- Some other process state is shared
  - environment variables, file descriptors, current working directory, …

Threads: concurrency *within* a process

- Threads allows us to create concurrency *within* a process
- Each thread has a separate execution state
  - Separate registers, separate program counter
- Each thread has a separate stack
  - but a thread can still read/write to another thread's stack
- Each thread gets its own copy or errno!

Using POSIX Threads (pthreads)

- POSIX Threads is a widely-supported threading model
- Provides an API/model for managing threads (and synchronisation)

```
#include <pthread.h>
```

- Sometimes need **`-pthread`** when compiling
- C11 and later also provides a model/API similar to pthreads
  - Has some small differences with pthreads, and generally less-supported and less used (for now…)

Creating threads with `pthread_create`

```
int pthread_create(pthread_t *restrict thread,
                   const pthread_attr_t *restrict attr,
                   void *(*start_routine)(void *),
                   void *restrict arg);
```

- Starts a new thread running `start_routine(arg)`
- An ID for the thread is stored in `thread`
- Thread has attributes specified in `attr` (NULL if you don't want special attributes)
- Returns 0 if OK, otherwise an error number (**does not set errno!**)
- Analogous to ***posix_spawn***.

Waiting for threads with `pthread_join`

```
int pthread_join(pthread_t thread, void **retval);
```

- Waits for `thread` to terminate, if it hasn't already terminated
- Return/exit value of thread placed in `*retval`
- Analogous to `waitpid`

- When **main** returns, *all* threads terminate

Unsafe Access to Global Variables

Demo: bank_account_broken.c

Incrementing a global variable is **NOT** an atomic operation

```c
int bank_account;

void *thread(void *a) {
    // ...
    bank_account++;
    // ...
```

```
la   $t0, bank_account
lw   $t1, ($t0)
addi $t1, $t1, 1
sw   $t1, ($t0)
.data
bank_account:  .word 0
```

Global Variables and Race Condition

If bank_account = 42 and two threads execute concurrently

```
la      $t0, bank_account
# {| bank_account = 42 |}
lw      $t1, ($t0)
# {| $t1 = 42 |}
addi    $t1, $t1, 1
# {| $t1 = 43 |}
sw      $t1, ($t0)
# {| bank_account = 43 |}
```

```
la      $t0, bank_account
# {| bank_account = 42 |}
lw      $t1, ($t0)
# {| $t1 = 42 |}
addi    $t1, $t1, 1
# {| $t1 = 43 |}
sw      $t1, ($t0)
# {| bank_account = 43 |}
```

Oops! We lost an increment.
Threads share global variables!

Data race example | Xavier

Global Variables and Race Condition

If bank_account = 100 and two threads execute concurrently

```
la      $t0, bank_account
# {| bank_account = 100 |}
lw      $t1, ($t0)
# {| $t1 = 100 |}
addi    $t1, $t1, 100
# {| $t1 = 200 |}
sw      $t1, ($t0)
# {| bank_account = ...? |}
```

```
la      $t0, bank_account
# {| bank_account = 100 |}
lw      $t1, ($t0)
# {| $t1 = 100 |}
addi    $t1, $t1, -50
# {| $t1 = 50 |}
sw      $t1, ($t0)
# {| bank_account = 50 or 200 |}
```

- This is a critical section.
- We don’t want two threads in the critical section
    - We must establish mutual exclusion.

A solution: mutexes

- We need a way of guaranteeing *mutual exclusion* for certain shared resources (such as ***bank_account***)
- We associate each of those resources with a ***mutex***
- Only one thread can hold a mutex, any other threads which attempt to lock the mutex must wait until the mutex is unlocked
- So only one thread will be executing the section between the mutex lock and the mutex unlock

```
int pthread_mutex_lock(pthread_mutex_t *mutex);
int pthread_mutex_unlock(pthread_mutex_t *mutex);
```

bank_account_mutex.c

```
int bank_account=0;
pthread_mutex_t bank_account_lock=PTHREAD_MUTEX_INITIALIZER;

void *add_100000(void*argument){
    for (int i = 0; i < 1000000; i++) {
        pthread_mutex_lock(&bank_account_lock);
        // only one thread can execute this
        // section of code at any time
        bank_account = bank_account + 1;
        pthread_mutex_unlock(&bank_account_lock);
    }
```

Atomics

- With hardware support, we can avoid data races without needing to use locks!
- In C, we can use 'atomic types', which guarantee that certain operations using them will be performed *atomically* (indivisibly) ⇒ no data race!
- Also avoids overhead of mutexes
- And since no locks are involved, we can't introduce deadlock
- Atomics don't solve all concurrency problems
- There are still some subtle problems (which we don't cover in COMP1521)

Atomics

- Declaring an atomic variable
  - `atomic_int x = 10;`
  - `x += 1;` // Will be done atomically
  - `x = x + 1;` //Will NOT be done atomically!!!!
- A subset of functions in **stdatomic.h**:
  - atomic_fetch_add
    - `atomic_int x = 10;`
    - `int old = atomic_fetch_add(&x, 1);`
  - atomic_fetch_sub
  - atomic_fetch_or, atomic_fetch_xor, atomic_fetch_and

Add code with atomic in it

```c
atomic_int bank_account = 0;

void *add_100000(void *argument) {
    for (int i = 0; i < 100000; i++) {
        // NOTE: This *cannot* be `bank_account = bank_account + 1`,
        // as that will not be atomic!
        // However, `bank_account++` would be okay
        // `atomic_fetch_add(&bank_account, 1)` would also be okay
        bank_account += 1;
    }
```

Concurrency is really complex!

- This is just a taste of concurrency!
- Other fun concurrency problems/concepts: livelock, starvation, thundering herd, memory ordering, semaphores, software transactional memory, user threads, fibers, etc.

- A number of courses at UNSW offer more:
    - COMP3231/COMP3891: [Extended] operating systems
    - COMP6991: Solving Modern Programming Problems with Rust
    - … and more!

Revision

- File revision:
  - Find files in a directory with given properties
  - Search through subdirectories for broken symlinks
- Process revision:
  - Create a simple shell using posix_spawn

What we learnt Today

- Concurrency and threads
  - recap
  - atomics
- Revision
  - Files
    - Stat
    - Reading a directory
    - Reading a file
    - sub - directory traversal
  - Processes
    - Simple shell

Next Lecture

Find out about the Final Exam!

Feedback Please!

Your feedback is valuable!

If you have any feedback from today's lecture, please follow the link below or use the QR Code.

Please remember to keep your feedback constructive, so I can action it and improve your learning experience.

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