CSU23016

Concurrent Systems
&
Operating Systems

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with thanks to Mike Brady

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‘Shells’

- A ‘shell’ is a program that allows you to give commands to a computer and get responses.
  - Common GUI-based shells include ‘Finder’ for Mac OS X and ‘Explorer’ for Windows. These are easy to learn but hard to automate.
  - Command-line text-based shell programs are harder to learn, but support a high degree of automation. These are typically accessed through a "console window" program
    - called "Terminal" on Unix/Linux/macOS
    - several, such as "Cmd" or "Powershell", on Windows
  - Common UNIX shell languages are SH, BASH, CSH, TCSH, ASH, ZSH. On Windows, the provided shells use a custom language, and a totally different approach to running programs. However, UNIX shell support is possible
    - try using "Cygwin" (http://www.cygwin.com) or "Windows Subsystem for Linux" (WSL)
    - Or use PuTTY (https://www.putty.org), or similar to make an SSH connection to macneill.scss.tcd.ie

The bash shell

- A early shell, called "sh" was developed for an early version of Unix,
  - by Stephen Bourne, at AT&T.
- A modified free version, called "bash" was written for Linux
  - It's the "Bourne-Again Shell" !
- We will use this shell for this course.
- The Shell Command-Line/Scripting Primer
  - see links in READING content area on Blackboard

Important shell principles

- Shell commands generally invoke programs to so the work:
  - e.g. when you write `ls` on the command line, the shell looks for a program called `ls` in a few designated places. Once if finds the program, it executes it.
- Most programs work with standard character-based input sources and output sinks — 'standard input', 'standard output' and 'standard error'. These are 'pipes' and can be connected to files, the terminal window, other programs, network feeds, etc. By default,
  - standard input ("stdin") is connected to your keyboard.
  - standard output and error ("stdout", "stderr") are connected to your console/terminal window.
- Most of these programs do something simple but very well — to do complex things, you string programs together.

Example: Practical I

1. Download the file `sumofhellos.c`) attached to this practical.

2. Modify line 6 (#define USERNAME "username") to replace username with your TCD username.

3. Compile the code - warnings are OK, but there should be no errors:
   ```
   cc -o sum sumofhellos.c -pthread
   ```

4. Run the executable (your username should appear seven times, as well as some number between 1 and 6 at the end):
   ```
   ./sum
   ```

5. Obtain a log of the compilation and running of the program by either:
   1. selecting it from your terminal window, copying it, and pasting in a text file called `practical1.log`.
   2. Or running the command
      ```
      ./sum > practical1.log
      ```

6. Bundle both your source code and logfile into a "tar" archive
   ```
   tar -r -f P1.tar sumofhellos.c practical1.log
   ```
   This will create a file called `P1.tar`.

7. Submit file `P1.tar` through Blackboard by the deadline.

Follow these steps precisely! This is really what is being assessed.

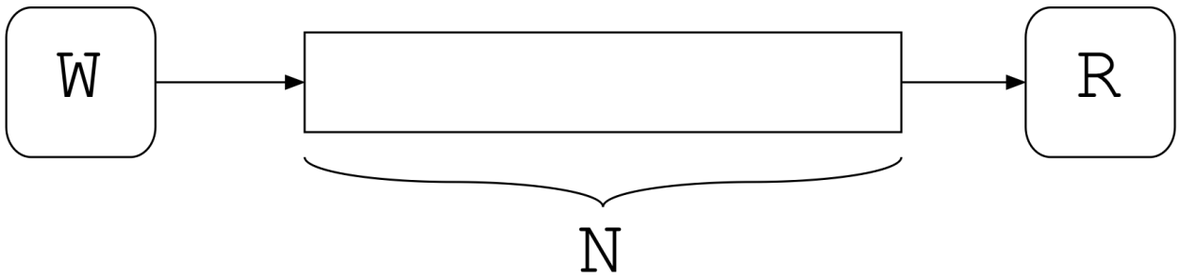
Combining commands

- Multiple commands:
  - Issue a sequence of commands on one line by separating them with a semicolon (“ **;** ”).
- Piping:
  - Using the bar symbol (“ | ”), you can direct (“pipe”) the standard output of one command into the standard input of the next one.
- Redirection:
  - You can redirect standard input to accept the contents of a file using symbol "<", and standard output to go to a file using symbol ">".
- Automation:
  - You can write a text file containing sequence of commands and shell commands and constructs. This can be executed as a *shell script*.

Producers and Consumers

- Essentially a *pipeline* of separate sequential programs.
  - E.g. concatenation of unix commands.
- Programs communicate via buffers.
  - Implemented in different ways, but, e.g.
    - Shared memory, flags, semaphores, etc.
    - Message passing over a network
- Flow of data is essentially one-way.

Imagine a Situation…



- We have a buffer that holds N items, with a counter recording how many items present.
- A 'Producer' writes (W) items to the buffer from time to time, incrementing its counter.
  - if the buffer is full, then the Producer should wait until room is freed up.
- A 'Consumer' reads (R) items from the buffer now and then, decrementing its counter.
  - if the buffer is empty, the Consumer should wait for a new item to arrive
- We could use a mutex to control access to the buffer & counter.

Write/Read behaviour (pseudo-code)

- Write(item,buffer) should do the following:
  - `if full(buffer) then wait_until_room(buffer);`
    `insert(item,buffer).`
- item = Read(buffer) should do the following:
  - `if empty(buffer) the wait_until_something(buffer);`
    `item = extract(buffer).`
- How do we use mutexes here?

Write/Read behaviour (pseudo-code)

- What's wrong with the following?:

  - ```
    lock(mutex);
    if full(buffer) then wait_until_room(buffer);
    insert(item,buffer);
    unlock(mutex).
    ```

  - ```
    lock(mutex);
    if empty(buffer) the wait_until_something(buffer);
    item = extract(buffer);
    unlock(mutex).
    ```

Both will wait forever, because, holding a lock on the mutex **while waiting,** prevents the other from ever getting the lock.

(A situation known as "DEADLOCK" !)

Write/Read behaviour

- We need to be able to:
  - wait for a state-change in global shared state (our buffer+counter),
  - without holding the lock all the time.
- The following does give the Consumer a chance to grab the lock. Will this work?
  -
```
wait = true;
while wait do
  lock(mutex); wait=full(buffer); unlock(mutex)
endwhile;
lock(mutex); insert(item,buffer); unlock(mutex).
```

Here the Producer is rapidly locking, checking, unlocking
- the Consumer risks "STARVATION" !

Mutexes aren't enough!

- Mutexes by themselves prevent efficient solutions
  - particularly when waiting for a resource to be in some specific state before proceeding with an operation on that resource.
- One solution to the previous problem is to require the waiting thread to sleep for a time interval before checking again:
  - ```
    wait = true;
    while wait do
      lock(mutex); wait=full(buffer); unlock(mutex);
      if (wait) then sleep(100);
    endwhile;
    lock(mutex); insert(item,buffer); unlock(mutex).
    ```
- The problem here is it is hard to find an optimal value for the sleep interval
  - why 100 here? why not 50? why not 500?, why not 5 ?(what units of time are they anyway?!)
    ```

Condition Variables

- A generalised synchronisation construct.
- Allows you to acquire mutex lock when a *condition* relying on a shared variable is true and to sleep otherwise.
- The ‘condition variable’ is used to manage the mutex lock and the signalling.
- Slightly tricky.

Condition Variables - Dramatis Personae

- A mutex variable M,
- A shared resource R to be guarded by M,
- A condition variable V,
- A condition C,
- A thread U that wishes to use R, protected by M, on condition that C is true,
- A thread S that will signal V, presumably when it has done something that might indirectly change the value of C.

Condition Variables vs. Conditions

- We need to be careful here to distinguish between "Conditions" and "Condition-Variables".
  - If not, much confusion will ensue
- Condition C
  - This is an application dependent true/false statement about something we want to be true in order to proceed
    - e.g. buffer is not full
- Condition-Variable V
  - this is a complex datastructure provided by a thread library to manage the mutexes and signalling required

From Thread U's POV (1)

- Acquire Mutex M
  - This controls access to R,
  - but also must control access to any shared variables that C depends on.
- if C is true, the mutex can be used as normal.
  - so proceed to access R as planned
- if C is false…

From Thread U's POV (2)

- If C is false, wait for condition variable V to be *signalled*.
- This is tricky, as access to R is controlled by M.
  - So, Mutex M is unlocked,
  - Thread sleeps, to be woken when V is signalled,
  - Then, M is re-acquired.
    - No guarantee you'll get it right away–maybe another thread will.
- So now, if V has been signalled…

From Thread U's POV (3)

- Since V has been signalled, there is a chance that the condition C is now true.
  - but another thread may have slipped in and done something that makes it false again!
- Re-evaluate C:
  - If true, then the mutex is available for you to use,
  - If false, back to previous page.
- Our 'if' needs to be replaced by a 'while'…

From Thread U's POV (4)

- Acquire Mutex M
- While !C
  - Unlock M
  - Wait for V to be signalled
  - Lock M
- process R as planned
- Unlock M (finished)

```
pthread_lock(&m)
while (!C) {
   // m is locked by U here
   pthread_cond_wait(&v,&m)
   // m is locked by U here
}
… access and modify R …
pthread_unlock(&m)
```

Thread S (1)

- Thread U is the 'user' of the condition variable V.
- If the condition is not true, U unlocks V's mutex M and sleeps, waiting for some other thread S to signal V and thereby waking U to check the condition again.

Thread S (2)

- Acquire Mutex M

```
pthread_lock(&m)
```

- Do something that affects R (and indirectly C)

```
Do something to R
```

- Signal the condition variable

```
pthread_cond_signal(&v)
```

  - This will awaken a thread that is waiting on the condition variable.

- Unlock Mutex M

```
pthread_unlock(&m)
```

My head hurts !

- Pthreads are not simple, nor straightforward
- There are (literally) a ***lot*** of moving parts!
- There are some key concepts that we need to understand
- The Lawrence Livermore tutorial gives a comprehensive overview
  - linked to from Blackboard, in the "READING/POSIX Threads" content area

“Formalising” Pthreads

- It will help to have a “formal” description of the PThread API calls we use.
- Why “formal” and not formal?
  - A Formal approach would use some form of mathematical logic to give a precise, unambiguous description of the API behaviour and usage.
    - We won’t go that far!
  - This “Formal” approach will state the properties needed using careful natural language

Properties of Interest

- Prototypes: types of values passed to and returned from API calls
  - Sometimes referred to as "(type-)signatures".
- Pre-Conditions: what needs to be true when we call an API function
- Post-Conditions: what will be true when we return from an API call
  - Provided the Pre-Condition was satisfied when it was called (!!)
- Invariants: what should always be true.
- In what follows,
  - we describe properties observed by the thread that calls the pthread function under discussion

pthread_mutex_init()

- Prototype: `int pthread_mutex_init( pthread_mutex_t *`
  `, const pthread_mutexattr_t * );`
- Call: `rc = pthread_mutex_init( &mymutex, NULL );`
- Precondition: None.
- Postcondition: `mymutex` is initialised, and unlocked.
- Invariant: all mutex variables (should be) initialised before use

pthread_mutex_lock()

- Prototype: `int pthread_mutex_lock( pthread_mutex_t * );`
- Call: `rc = pthread_mutex_lock( &mymutex );`
- Precondition: `mymutex` was initialised.
- Postcondition: `mymutex` is locked, and the calling thread "owns" that lock.
  - time may have passed if another thread owned the lock when this thread made the call.
- Invariant:
  - When a mutex is unlocked, no thread "owns" it.
  - When a mutex is locked, exactly one thread "owns" it.

pthread_mutex_unlock()

- Prototype: `int pthread_mutex_unlock( pthread_mutex_t * );`
- Call: `rc = pthread_mutex_unlock( &mymutex );`
- Precondition: `mymutex` is locked and calling thread "owns" that lock
- Postcondition: this thread no longer "owns" the lock
- Invariant:
  - When a mutex is unlocked, no thread "owns" it.
  - When a mutex is locked, exactly one thread "owns" it.

pthread_cond_init()

- Prototype: `int pthread_cond_init( pthread_cond_t *, const pthread_condattr_t * );`
- Call: `rc = pthread_cond_init( &myconvar, NULL );`

- Precondition: None.
- Postcondition: `myconvar` is initialised, and has not been "signalled".
- Invariant: all condition variables (should be) initialised before use

pthread_cond_wait()

- Prototype:
```
int pthread_cond_wait( pthread_cond_t *
                     , pthread_mutex_t * );
```
- Call:
```
rc = pthread_cond_wait( &myconvar, &mymutex );
```
- Precondition:
  - `myconvar` is initialised, and `mymutex` is locked.
  - the calling thread "owns" the lock
- Postcondition: `mymutex` is locked, and the calling thread "owns" that lock.
  - time may have passed until another thread signalled to `myconvar`.
- Invariant: ?

pthread_cond_signal()

- Prototype: `int pthread_cond_signal( pthread_cond_t * );`
- Call: `rc = pthread_cond_signal( &myconvar );`
- Precondition:
  - a previous call to `pthread_cond_wait`, usually by some other thread, has associated `myconvar` with `mymutex`.
  - `mymutex` is locked and "owned" by the calling thread.
- Postcondition:
  - a signal has been sent to `myconvar` to tell it to wake a thread sleeping on. on it.
  - `mymutex` is still locked and "owned" by the calling thread.
- Invariant: ?