POSIX Threads in a nutshell

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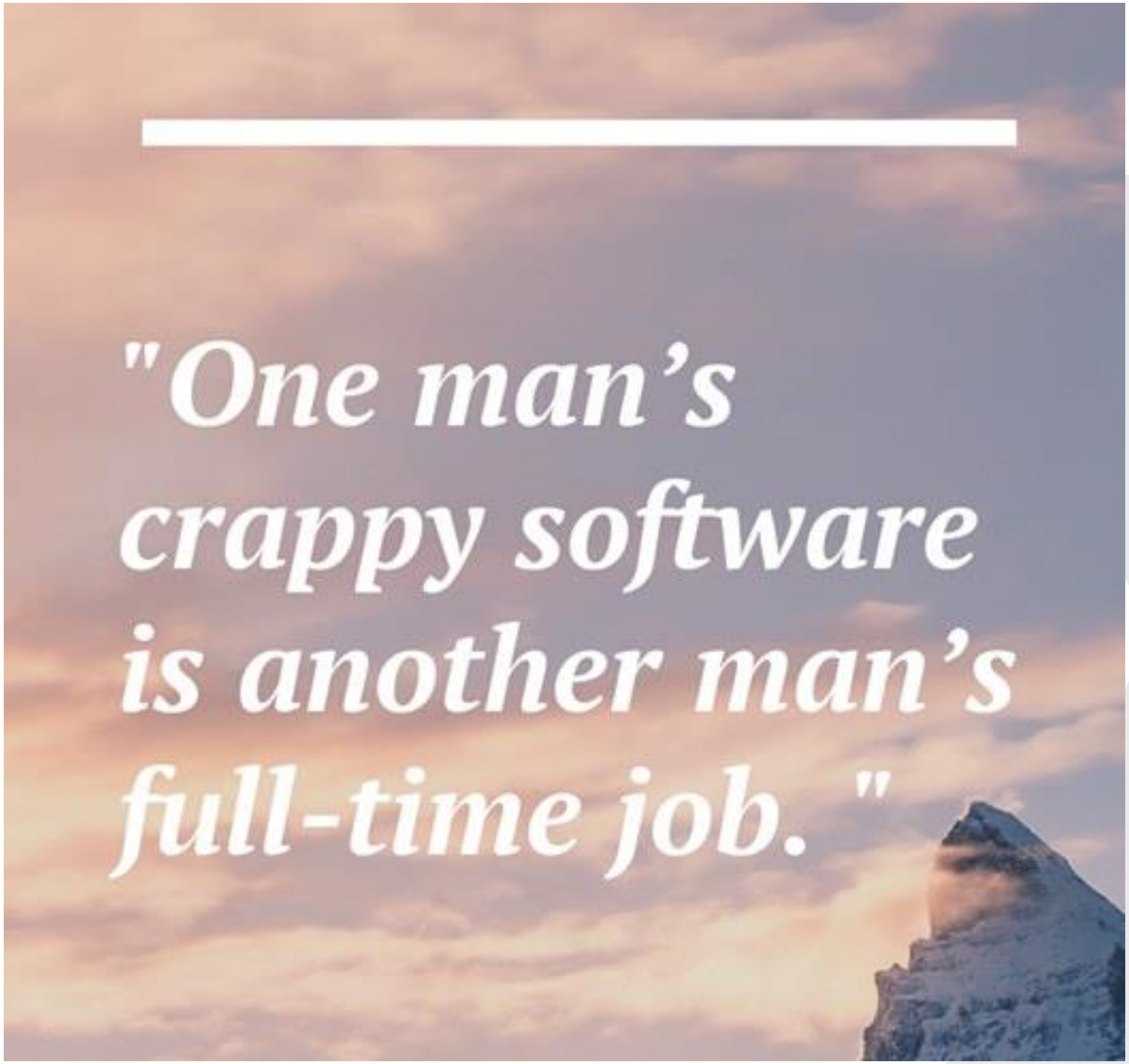
"One man's
crappy software
is another man's
full-time job. "

The POSIX IEEE standard

eng.wikipedia.org

POSIX Threads, usually referred to as PThreads, is an execution model that exists independently from a language, as well as a parallel execution model. It allows a program to control multiple different flows of work that overlap in time.

- Threading API
- Single process
- Shared memory space

pthreads

The POSIX IEEE standard

- Specifies an operating system interface similar to most UNIX systems
  - It extends the C language with primitives that allows the specification of the concurrency

- POSIX distinguishes between the terms process and thread
  - "A process is an address space with one or more threads executing"
  - "A thread is a single flow of control within a process (a unit of execution)"

- Every process has at least one thread
  - the "`main()`" (aka "master") thread; its termination ends the process
  - All the threads share the same address space, and have a private stack

Thread body

- A (P)thread is identified by a C function, called body:

```
void *my_pthread_fn(void *arg)
{
   // Thread body
}
```

- A thread starts with the first instruction of its body
- The threads ends when the body function ends
  - It's not the only way a thread can die

Thread creation

- Thread can be created using the primitive

pthread.h

```
typedef unsigned int pthread_t;

int pthread_create ( pthread_t *ID,
                     pthread_attr_t *attr,
                     void *(*body)(void *),
                     void * arg
                        );
```

- `pthread_t` is the type that contains the thread ID
- `pthread_attr_t` is the type that contains the parameters of the thread
- `arg` is the argument passed to the thread `body` when it starts

Thread attributes

- Thread attributes specifies the characteristics of a thread
  - We won't see this; leave empty
- Attributes must be initialized and destroyed - always

pthread.h

```
int pthread_attr_init(pthread_attr_t *attr);

int pthread_attr_destroy(pthread_attr_t *attr);
```

Thread termination

- A thread can terminate itself calling

pthread.h

```
void pthread_exit(void *retval);
```

- When the thread body ends after the last "`}`", `pthread_exit()` is called implicitly
- Exception: when `main()` terminates, `exit()` is called implicitly

Thread IDs

- Each thread has a unique ID

pthread.h

```
pthread_t pthread_self(void);
```

- The thread ID of the current thread can be obtained using

pthread.h

```
int pthread_equal( pthread_t thread1,
                   pthread_t thread2 );
```

- Two thread IDs can be compared using

Joining a thread

- A thread can wait the termination of another thread using

pthread.h

```
int pthread_join ( pthread_t th,
                   void **thread_return);
```

- It gets the return value of the thread or `PTHREAD_CANCELED` if the thread has been killed

- By default, every thread must be joined
  - The join frees all the internal resources
  - Stack, registers, and so on

Example

Let's
code!

- Filename: `ex_create.c`
- The demo explains how to create a thread
  - the `main()` thread creates another thread (called `body()`)
  - the `body()` thread checks the thread Ids using `pthread_equal()` and then ends
  - the `main()` thread joins the `body()` thread
- When compiling under gcc & GNU/Linux, remember
  - the `-lpthread` option!
  - to add `#include "pthread.h"`

- Credits to PJ

Semaphores

Semaphores

A semaphore is a counter managed with a set of primitives

It is used for

- Synchronization
- Mutual exclusion (critical sections)

POSIX Semaphores can be

- Unnamed (local to a process)
- Named (shared between processed through a file descriptor – we won't see them)

Unnamed semaphores

Operations permitted:

- initialization /destruction
- blocking wait / nonblocking wait
  - counter decrement
- post
  - counter increment
- counter reading
  - simply returns the counter

Initializing a semaphore

- The `sem_t` type contains all the semaphore data structures

```
int sem_init(sem_t *sem, int pshared, unsigned int value);
```

  - `pshared` is `0` if `sem` is not shared between processes

```
int sem_destroy(sem_t *sem)
```

  - It destroys the `sem` semaphore

Semaphore waits

```
int sem_wait(sem_t *sem);
int sem_trywait(sem_t *sem);
```

- Under the hood..
- If the counter is greater than 0 the thread does not block
  - `sem_trywait` never blocks

Other semaphore primitives

```
int sem_post(sem_t *sem);
```

- It increments the semaphore counter
- It unblocks a waiting thread

```
int sem_getvalue(sem_t *sem,int *val);
```

- It simply returns the semaphore counter

Example(s)

Let's code!

Filename: `critical-section.c`

- In this example, semaphores are used to implement mutual exclusion in the output of a character in the console

Filename: `producer-consumer.c`

- In this example, semaphores are used to implement producer-consumer synchronization

PThreads scheduling

Scheduling algorithms

- The POSIX standard specifies in `sched.h` *at least* two scheduling strategies which can be used, identified by the symbols `SCHED_FIFO` and `SCHED_RR`
  - Other scheduling policies may be supported by each particular implementation, under the symbol `SCHED_OTHER`

POSIX specifies a Fixed Priority scheduler with at least 32 priorities (0 to 31)

- Every priority corresponds to a queue, where all the threads with the same priority are inserted
- The first ready thread in the highest non-empty priority queue is selected for scheduling and becomes the running thread

POSIX and priorities

thread priorities can be specified at creation time into the thread attributes

```
int pthread_attr_setschedpolicy
                 (pthread_attr_t *a, int policy);
```

- policy can be SCHED_RR, SCHED_FIFO or SCHED_OTHER

```
int pthread_attr_setschedparam
                 (pthread_attr_t *attr,
                  const struct sched_param *param);
```

- The priority field is param.sched_priority

Real-Time and UNIX

- UNIX systems usually schedule all its threads at low priorities
- When a RT thread is created, it always preempts all the other applications (i.e. the X server, and all the other demons)
- For that reason,
  - real-time computations have to be limited
  - **only root** can use the real-time priorities

Example

Let's code!

- Filename: `ex_rr.c`
- The demo explains the behavior of the RT priorities and of the other policies
- The `main()` thread creates a high priority thread that activates a low priority thread and two medium priority threads
- The medium priority threads are scheduled with policies `SCHED_RR` and `SCHED_FIFO`
- When compiling under gcc & GNU/Linux, remember
  - the `-lpthread` option!
  - to add `#include "pthread.h"`

- Credits to PJ

How to run the examples

Let's code!

- Download the `Code/` folder from the course website

- Compile

```
$ gcc code.c -o code -lpthread
```

- Run (Unix/Linux)

```
$ ./code
```

- Run (Win/Cygwin)

```
$ ./code.exe
```

References

Course website

- http://hipert.unimore.it/people/paolob/pub/Industrial_Informatics/index.html

My contacts

- paolo.burgio@unimore.it
- http://hipert.mat.unimore.it/people/paolob/

Resources

- https://computing.llnl.gov/tutorials/pthreads/
- http://man7.org/linux/man-pages/man7/pthreads.7.html
- A "small blog"
  - http://www.google.com