POSIX Threads

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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 in that address space"
  - "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

The PThread library

- ✓ The pthread primitives are usually implemented into a pthread library
- ✓ All the declarations of the primitives cited in these slides can be found into `sched.h`, `pthread.h` and `semaphore.h`
  - Use `man` to get on-line documentation
- ✓ When compiling under gcc & GNU/Linux, remember the `-lpthread` option!

PThread creation, join, end

PThread body

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

```
void *my_pthread_fn(void *arg)
{
   ...
}
```

- ✓ 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

```
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
  - Stack size and address
  - Detach state (joinable or detached)
  - Scheduling parameters (priority, …)

- ✓ Attributes must be initialized and destroyed
  - `int pthread_attr_init(pthread_attr_t *attr);`
  - `int pthread_attr_destroy(pthread_attr_t *attr);`

Thread termination

- A thread can terminate itself calling

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

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

- ✓ Two thread IDs can be compared using

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

Joining a thread

- ✓ A thread can wait the termination of another thread using

```
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

Joining a thread (2)

- A thread which does not need to be joined has to be declared as detached
- 2 ways to have it:
  - While creating (in father thread) using `pthread_attr_setdetachstate()`
  - The thread itself can become detached calling in its body `pthread_detach()`
- Joining a detached thread returns an error

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

- *Credits to PJ*

Pthread cancellation

Killing a thread

- ✓ A thread can be killed calling

```
int pthread_cancel(pthread_t thread);
```

- ✓ When a thread dies its data structures will be released
  - By the join primitive if the thread is joinable
  - Immediately if the thread is *detached*
  - Why?

PThread cancellation

- ✓ Specifies how to react to a kill request
- ✓ There are two different behaviors:
  - deferred cancellation

    when a kill request arrives to a thread, the thread does not die. The thread will die only when it will execute a primitive that is a cancellation point. This is the default behavior of a thread.
  - asynchronous cancellation

    when a kill request arrives to a thread, the thread dies. The programmer must ensure that all the application data structures are coherent.

Cancellation states and cleanups

- The user can set the cancellation state of a thread using:

```
int pthread_setcancelstate(int state,int *oldstate);
int pthread_setcanceltype(int type, int *oldtype);
```

- The user can protect some regions providing destructors to be executed in case of cancellation

```
int pthread_cleanup_push(void (*routine)(void *),
                         void *arg);
int pthread_cleanup_pop(int execute);
```

Cancellation points

- ✓ The cancellation points are primitives that can potentially block a thread
- ✓ When called, if there is a kill request pending the thread will die
  - `void pthread_testcancel(void);`
  - `sem_wait`, `pthread_cond_wait`, `printf` and all the I/O primitives are cancellation points
  - `pthread_mutex_lock`, is NOT a cancellation point
    - Why?
- ✓ A complete list can be found into the POSIX Standard

Cleanup handlers

- ✓ The user must guarantee that when a thread is killed, the application data remains coherent.

- ✓ The user can protect the application code using cleanup handlers
  - A cleanup handler is an user function that *cleans up* the application data
  - They are called when the thread ends and when it is killed

Cleanup handlers (2)

```
void pthread_cleanup_push (void (*routine)(void *),
                           void *arg);
void pthread_cleanup_pop (int execute);
```

- They are pushed and popped as in a stack
- If `execute!=0` the cleanup handler is called when popped
- Ihe cleanup handlers are called in LIFO order

Example

Let's code!

- ✓ Filename: `ex_cancellation.c`
- ✓ Highlights the behavior of:
  - Asynchronous cancellation
  - Deferred cancellation
- ✓ Explains the cleanup handlers usage

POSIX semaphores

Semaphores

- ✓ A semaphore is a counter managed with a set of primitives
- ✓ It is used for
  - Synchronization
  - Mutual exclusion
- ✓ POSIX Semaphores can be
  - Unnamed (local to a process)
  - Named (shared between processed through a file descriptor)

Unnamed semaphores

- ✓ Mainly used with multithread applications
- ✓ 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
- ✓ `sem_wait` is a cancellation point

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

Let's code!

- Filename: `ex_sem.c`
- In this example, semaphores are used to implement mutual exclusion in the output of a character in the console.

PThread mutexes

What is a POSIX mutex?

- Likea binary semaphore used for mutual exclusion
  - But.. a mutex can be unlocked only by the thread that locked it
- Mutexes also support some RT protocols
  - Priority inheritance
  - Priority ceiling
  - They are not implemented under a lot of UNIX OS
- Out of scope for this course

Mutex attributes

- ✓ Mutex attributes are used to initialize a mutex

```
int pthread_mutexattr_init (pthread_mutexattr_t *attr);
int pthread_mutexattr_destroy (pthread_mutexattr_t *attr);
```

- ✓ Initialization and destruction of a mutex attribute

Mutex initialization

- ✓ Initialize a mutex with a given mutex attribute

```
int pthread_mutex_init (pthread_mutex_t *mutex,
                        const pthread_mutexattr_t *attr);
```

- ✓ Destroys a mutex

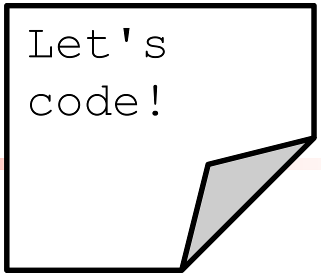
```
int pthread_mutex_destroy (pthread_mutex_t *mutex);
```

Mutex lock and unlock

- ✓ This primitives implement the blocking lock, the non-blocking lock and the unlock of a mutex
- ✓ The mutex lock is NOT a cancellation point

```
int pthread_mutex_lock(pthread_mutex_t *m);
int pthread_mutex_trylock(pthread_mutex_t *m);
int pthread_mutex_unlock(pthread_mutex_t *m);
```

Example



- Filename: `ex_mutex.c`
- This is prev. example written using mutexes instead of semaphores.

pthread condition variables

What is a POSIX condition variable?

- ✓ Used to enforce synchronization between threads
  - A thread into a mutex critical section can wait on a condition variable
  - When waiting, the mutex is automatically released and locked again at wake up
  - The synchronization point have to be checked into a loop!

Condition variable attribute

- ✓ Attributes are used to initialize a condition variable

```
int pthread_condattr_init (pthread_condattr_t *attr);
int pthread_condattr_destroy (pthread_condattr_t *attr);
```

- ✓ These functions initialize and destroy a condition variable

Initializing and destroying a condition variable

- ✓ In order to be used, a condition variable must be initialized

```
int pthread_cond_init (pthread_cond_t *cond,
                       const pthread_condattr_t *attr)
```

- ✓ …and destroyed when it is no more needed

```
int pthread_cond_destroy(pthread_cond_t *cond)
```

Waiting for a condition

```
int pthread_cond_wait (pthread_cond_t *cond,
                       pthread_mutex_t *mutex);
```

- ✓ Every condition variable is implicitly linked to a mutex
  - given a condition variable, the mutex parameter must always be the same
- ✓ The condition wait must always be called into a loop protected by a cleanup handler!!!

Cancellation and mutexes

- Mutexes are not cancellation points
- The condition wait is a cancellation point
- When a thread is killed while blocked on a condition variable, the mutex is locked again before dying
  - The mutex is left locked, and no thread can use it anymore!
  - We must protect the thread from a cancellation
  - A cleanup function that releases the mutex

Signaling a condition

```
int pthread_cond_signal(pthread_cond_t *cond);
int pthread_cond_broadcast(pthread_cond_t *cond);
```

- ✓ These functions wakes up at least one (signal) or all (broadcast) the thread blocked on the condition variable
  - – Nothing happens if no thread is blocked on the condition variable
- ✓ The thread should lock the associated mutex when calling these functions

Example

Let's code!

- ✓ Filename: `ex_cond.c`
- ✓ This is prev. examples written using simulated semaphores obtained using mutexes and condition variables
- ✓ A simulated semaphore is composed by a counter, a mutex and a condition variable
- ✓ The functions lock the mutex to work with the counter and use the condition variable to block