27. Interlude: Thread API

Operating System: Three Easy Pieces

Thread Creation

- How to create and control threads?

```
#include <pthread.h>

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

  - `thread`: Used to interact with this thread.
  - `attr`: Used to specify any attributes this thread might have.
    - Stack size, Scheduling priority, …
  - `start_routine`: the function this thread start running in.
  - `arg`: the argument to be passed to the function (`start routine`)
    - *a void pointer* allows us to pass in *any type of* argument.

Thread Creation (Cont.)

- If `start_routine` instead required another type argument, the declaration would look like this:
  - An integer argument:

```
int
pthread_create(…, // first two args are the same
                  void*  (*start_routine)(int),
                  int    arg);
```

  - Return an integer:

```
int
pthread_create(…, // first two args are the same
                  int  (*start_routine)(void*),
                  void*    arg);
```

Example: Creating a Thread

```
#include <pthread.h>

typedef struct __myarg_t {
        int a;
        int b;
} myarg_t;

void *mythread(void *arg) {
        myarg_t *m = (myarg_t *) arg;
        printf("%d %d\n", m->a, m->b);
        return NULL;
}

int main(int argc, char *argv[]) {
        pthread_t p;
        int rc;

        myarg_t args;
        args.a = 10;
        args.b = 20;
        rc = pthread_create(&p, NULL, mythread, &args);
        …
}
```

Wait for a thread to complete

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

- `thread`: Specify which thread *to wait for*
- `value_ptr`: A pointer to the return value
  - Because `pthread_join()` routine changes the value, you need to pass in a pointer to that value.

Example: Waiting for Thread Completion

```
1   #include <stdio.h>
2   #include <pthread.h>
3   #include <assert.h>
4   #include <stdlib.h>
5
6   typedef struct __myarg_t {
7       int a;
8       int b;
9   } myarg_t;
10
11  typedef struct __myret_t {
12      int x;
13      int y;
14  } myret_t;
15
16  void *mythread(void *arg) {
17      myarg_t *m = (myarg_t *) arg;
18      printf("%d %d\n", m->a, m->b);
19      myret_t *r = malloc(sizeof(myret_t));
20      r->x = 1;
21      r->y = 2;
22      return (void *) r;
23  }
24
```

Example: Waiting for Thread Completion (Cont.)

```
25  int main(int argc, char *argv[]) {
26      int rc;
27      pthread_t p;
28      myret_t *m;
29
30      myarg_t args;
31      args.a = 10;
32      args.b = 20;
33      pthread_create(&p, NULL, mythread, &args);
34      pthread_join(p, (void **) &m);  // this thread has been
                                        // waiting inside of the
                                        // pthread_join() routine.
35      printf("returned %d %d\n", m->x, m->y);
36      return 0;
37  }
```

Example: Dangerous code

- Be careful with how values are returned from a thread.

```
1   void *mythread(void *arg) {
2       myarg_t *m = (myarg_t *) arg;
3       printf("%d %d\n", m->a, m->b);
4       myret_t r; // ALLOCATED ON STACK: BAD!
5       r.x = 1;
6       r.y = 2;
7       return (void *) &r;
8   }
```

  - When the variable `r` returns, it is automatically de-allocated.

Example: Simpler Argument Passing to a Thread

- Just passing in a single value

```
1   void *mythread(void *arg) {
2       int m = (int) arg;
3       printf("%d\n", m);
4       return (void *) (arg + 1);
5   }
6
7   int main(int argc, char *argv[]) {
8       pthread_t p;
9       int rc, m;
10      pthread_create(&p, NULL, mythread, (void *) 100);
11      pthread_join(p, (void **) &m);
12      printf("returned %d\n", m);
13      return 0;
14  }
```

Locks

- Provide mutual exclusion to a critical section
  - Interface

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

  - Usage (w/o *lock initialization* and *error check*)

```
pthread_mutex_t lock;
pthread_mutex_lock(&lock);
x = x + 1; // or whatever your critical section is
pthread_mutex_unlock(&lock);
```

    - No other thread holds the lock → the thread will acquire the lock and enter the critical section.
    - If another thread hold the lock → the thread will not return from the call until it has acquired the lock.

Locks (Cont.)

- All locks must be properly initialized.
  - One way: using `PTHREAD_MUTEX_INITIALIZER`

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
```

  - The dynamic way: using `pthread_mutex_init()`

```
int rc = pthread_mutex_init(&lock, NULL);
assert(rc == 0); // always check success!
```

Locks (Cont.)

- Check errors code when calling lock and unlock
  - An example wrapper

```
// Use this to keep your code clean but check for failures
// Only use if exiting program is OK upon failure
void Pthread_mutex_lock(pthread_mutex_t *mutex) {
    int rc = pthread_mutex_lock(mutex);
    assert(rc == 0);
}
```

- These two calls are used in lock acquisition

```
int pthread_mutex_trylock(pthread_mutex_t *mutex);
int pthread_mutex_timelock(pthread_mutex_t *mutex,
                           struct timespec *abs_timeout);
```

  - trylock: return failure if the lock is already held
  - timelock: return after a timeout

Locks (Cont.)

- These two calls are also used in lock acquisition

```
int pthread_mutex_trylock(pthread_mutex_t *mutex);
int pthread_mutex_timelock(pthread_mutex_t *mutex,
                           struct timespec *abs_timeout);
```

  - `trylock`: return failure if the lock is already held
  - `timelock`: return after a timeout or after acquiring the lock

Condition Variables

- **Condition variables** are useful when some kind of signaling must take place between threads.

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

  - `pthread_cond_wait`:
    - Put the calling thread to sleep.
    - Wait for some other thread to signal it.
  - `pthread_cond_signal`:
    - Unblock at least one of the threads that are blocked on the condition variable

Condition Variables (Cont.)

- A thread calling wait routine:

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t init = PTHREAD_COND_INITIALIZER;

pthread_mutex_lock(&lock);
while (initialized == 0)
        pthread_cond_wait(&init, &lock);
pthread_mutex_unlock(&lock);
```

  - The wait call releases the lock when putting said caller to sleep.
  - Before returning after being woken, the wait call re-acquire the lock.

- A thread calling signal routine:

```
pthread_mutex_lock(&lock);
initialized = 1;
pthread_cond_signal(&init);
pthread_mutex_unlock(&lock);
```

Condition Variables (Cont.)

- The waiting thread **re-checks** the condition in a while loop, instead of a simple if statement.

```
pthread_mutex_t lock = PTHREAD_MUTEX_INITIALIZER;
pthread_cond_t init = PTHREAD_COND_INITIALIZER;

pthread_mutex_lock(&lock);
while (initialized == 0)
        pthread_cond_wait(&init, &lock);
pthread_mutex_unlock(&lock);
```

  - Without rechecking, the waiting thread will continue thinking that the condition has changed *even though it has not*.

Condition Variables (Cont.)

- Don't ever to this.
  - A thread calling wait routine:

```
while(initialized == 0)
        ; // spin
```

  - A thread calling signal routine:

```
initialized = 1;
```

  - It performs poorly in many cases. → just wastes CPU cycles.
  - It is error prone.

Compiling and Running

- To compile them, you must include the header `pthread.h`
  - Explicitly link with the pthreads library, by adding the `-pthread` flag.

```
prompt> gcc -o main main.c -Wall -pthread
```

  - For more information,

```
man -k pthread
```

- Disclaimer: This lecture slide set was initially developed for Operating System course in Computer Science Dept. at Hanyang University. This lecture slide set is for OSTEP book written by Remzi and Andrea at University of Wisconsin.