Operating Systems – COC 3071L

SE 5th A – Fall 2025

Lab 5: Introduction to Threads

1. Introduction to Threads

1.1 What is a Thread?

A **thread** is the smallest unit of execution within a process.

- A **process** can have multiple threads running concurrently
- All threads within a process share:
  - Memory space (code, data, heap)
  - File descriptors
  - Process ID
- Each thread has its own:
  - Thread ID (TID)
  - Stack
  - Program counter
  - Register set

Real-world analogy:

- **Process** = A restaurant kitchen
- **Threads** = Multiple cooks working together in the same kitchen, sharing ingredients and equipment

1.2 Threads vs Processes – Quick Comparison

Feature	Process	Thread
Memory	Separate memory space	Shared memory space
Creation	Expensive (fork)	Lightweight (pthread_create)
Communication	IPC needed (pipes, etc.)	Direct (shared variables)
Context Switch	Slower	Faster
Independence	Fully independent	Dependent on parent process

When to use threads?

- When tasks need to share data frequently
- For parallel execution within the same application
- When you need lightweight concurrency

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2. POSIX Threads (pthreads) Library

In Linux, we use the **POSIX threads (pthreads)** library for thread programming.

2.1 Compilation Requirements

When compiling programs with threads, you **must** link the pthread library:

```
gcc program.c -o program -lpthread
```

The `-lpthread` flag links the pthread library.

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3. C Programs with Threads

Program 1: Creating a Simple Thread

Objective: Create a thread and print messages from both main thread and new thread.

```c
#include <stdio.h>
#include <pthread.h>
#include <unistd.h>

// Thread function - this will run in the new thread
void* thread_function(void* arg) {
    printf("Hello from the new thread!\n");
    printf("Thread ID: %lu\n", pthread_self());
    return NULL;
}

int main() {
    pthread_t thread_id;

    printf("Main thread starting...\n");
    printf("Main Thread ID: %lu\n", pthread_self());

    // Create a new thread
    pthread_create(&thread_id, NULL, thread_function, NULL);
```

```
    // Wait for the thread to finish
    pthread_join(thread_id, NULL);

    printf("Main thread exiting...\n");
    return 0;
}
```

Compile and run:

```
gcc thread1.c -o thread1 -lpthread
./thread1
```

Explanation:

`pthread_t thread_id`

This creates a **variable** to hold the thread's ID (like a file descriptor or process ID).
It's just a handle the OS uses to manage the thread.

`pthread_create(&thread_id, NULL, thread_function, NULL)`

Let's decode the four parameters:

Parameter	Type	Meaning
`&thread`	`pthread_t*`	Where the new thread ID will be stored
`NULL`	`pthread_attr_t*`	Thread attributes (priority, stack size, etc.) — `NULL` means default
`myThread`	`void* (*start_routine)(void*)`	Function to run in the new thread
`NULL`	`void*`	Pointer passed to the function for data

- `pthread_join()` → Waits for thread to finish (like `wait()` for processes)
- `pthread_self()` → Returns the thread ID of calling thread

Program 2: Passing Arguments to Threads

Objective: Pass data to a thread function.

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

void* print_number(void* arg) {
```

```c
    // We know that we've passed an integer pointer
    int num = *(int*)arg;  // Cast void* back to int*
    printf("Thread received number: %d\n", num);
    printf("Square: %d\n", num * num);
    return NULL;
}

int main() {
    pthread_t thread_id;
    int number = 42;

    printf("Creating thread with argument: %d\n", number);

    // Pass address of 'number' to thread
    pthread_create(&thread_id, NULL, print_number, &number);

    pthread_join(thread_id, NULL);

    printf("Main thread done.\n");
    return 0;
}
```

Compile and run:

```
gcc thread2.c -o thread2 -lpthread
./thread2
```

Important Notes:

- The 4th argument of `pthread_create()` is passed to the thread function
- It's a `void*` pointer, so you can pass any data type
- Remember to cast it properly inside the thread function

Here's what happens step by step:

```c
int value = *(int*)arg;
```

1. `(int*)arg` — cast `void*` back to `int*`.
2. `*(int*)arg` — dereference the pointer to get the integer value it points to.

Why use `void*`

The thread function must have the **standard signature**:

```c
void* function_name(void* arg)
```

That's because threads can accept *any* data type — integers, structs, arrays, etc. `void*` acts like a universal pointer type.

If you need to pass multiple variables, you wrap them in a `struct` and pass a pointer to it.

Program 3: Passing Multiple Data

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

typedef struct {
    int id;
    char* message;
} ThreadData;

void* printData(void* arg) {
    ThreadData* data = (ThreadData*)arg;
    printf("Thread %d says: %s\n", data->id, data->message);
    return NULL;
}

int main() {
    pthread_t t1, t2;

    ThreadData data1 = {1, "Hello"};
    ThreadData data2 = {2, "World"};

    pthread_create(&t1, NULL, printData, &data1);
    pthread_create(&t2, NULL, printData, &data2);

    pthread_join(t1, NULL);
    pthread_join(t2, NULL);

    printf("All threads done.\n");
    return 0;
}
```

Compile and run:

```
gcc thread3.c -o thread3 -lpthread
./thread3
```

Program 4: Thread Return Values

Objective: Get return values from threads.

```c
#include <stdio.h>
#include <pthread.h>
#include <stdlib.h>

void* calculate_sum(void* arg) {
    int n = *(int*)arg;
    int* result = malloc(sizeof(int));  // Allocate memory for result

    *result = 0;
    for (int i = 1; i <= n; i++) {
        *result += i;
    }

    printf("Thread calculated sum of 1 to %d = %d\n", n, *result);
    return (void*)result;  // Return the result
}

int main() {
    pthread_t thread_id;
    int n = 100;
    void* sum;

    pthread_create(&thread_id, NULL, calculate_sum, &n);

    // Get the return value from thread
    pthread_join(thread_id, &sum);

    printf("Main received result: %d\n", *(int*)sum);

    free(sum);  // Don't forget to free allocated memory
    return 0;
}
```

Compile and run:

```
gcc thread5.c -o thread5 -lpthread
./thread5
```

Key Points:

- Thread functions return `void*`
- Use `pthread_join()` to retrieve the return value
- Remember to free any dynamically allocated memory

4. Basic Multithreading

4.1 What is Multithreading?

- **Multithreading** means running multiple threads *concurrently* to perform different tasks within the same process.
- It allows:
  - Faster program execution on multi-core CPUs
  - Better resource utilization
  - Improved responsiveness (e.g., in GUIs or servers)

Example use cases:

- A web server handling multiple client requests simultaneously
- A program performing computation and I/O in parallel

Program 1: Creating and Running Multiple Threads

Objective:
Create multiple threads that execute independently and print messages concurrently.

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

void* worker(void* arg) {
    int thread_num = *(int*)arg;
    printf("Thread %d: Starting task...\n", thread_num);
    sleep(1);  // Simulate some work
    printf("Thread %d: Task completed!\n", thread_num);
    return NULL;
}

int main() {
    pthread_t threads[3];
    int thread_ids[3];

    for (int i = 0; i < 3; i++) {
        thread_ids[i] = i + 1;
        pthread_create(&threads[i], NULL, worker, &thread_ids[i]);
    }

    for (int i = 0; i < 3; i++) {
```

```
        pthread_join(threads[i], NULL);
    }

    printf("Main thread: All threads have finished.\n");
    return 0;
}
```

Compile and run:

```
gcc multithread_basic.c -o multithread_basic -lpthread
./multithread_basic
```

Explanation:

- Three threads execute the same function concurrently.
- Output order may vary because threads run in parallel.
- Demonstrates *basic multithreading behavior* and *non-deterministic execution order*.

Program 2: Demonstrating a Race Condition

Objective: What happens when multiple threads modify a shared variable **without synchronization**.

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

int counter = 0;  // Shared variable

void* increment(void* arg) {
    for (int i = 0; i < 100000; i++) {
        counter++;  // Not thread-safe
    }
    return NULL;
}

int main() {
    pthread_t t1, t2;

    pthread_create(&t1, NULL, increment, NULL);
    pthread_create(&t2, NULL, increment, NULL);

    pthread_join(t1, NULL);
    pthread_join(t2, NULL);

    printf("Expected counter value: 200000\n");
```

```c
    printf("Actual counter value:   %d\n", counter);

    return 0;
}
```

Compile and run:

```
gcc race_condition.c -o race_condition -lpthread
./race_condition
```

Observation:

- The final `counter` is often **less than 200000**.
- This happens because both threads read and write `counter` simultaneously — a **race condition**.

Concept introduced:

> When multiple threads access shared data without control, results become unpredictable.
> Synchronization will be used to solve this.
