

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
-

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.

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.

```
#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) {
```

```

// 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:

```
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**:

```
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

```
#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"};

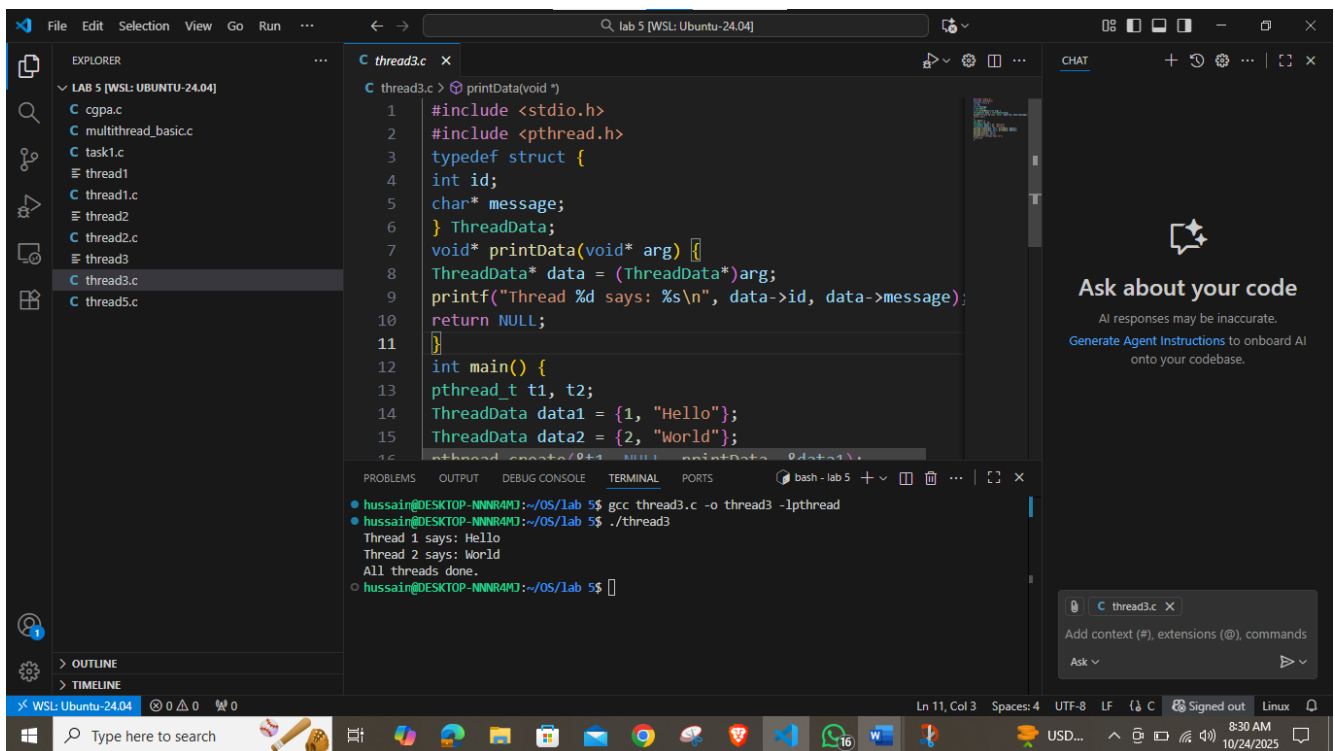
    pthread_create(&t1, NULL, printData, &data1);
    pthread_create(&t2, NULL, printData, &data2);

    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.

```
#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;
}

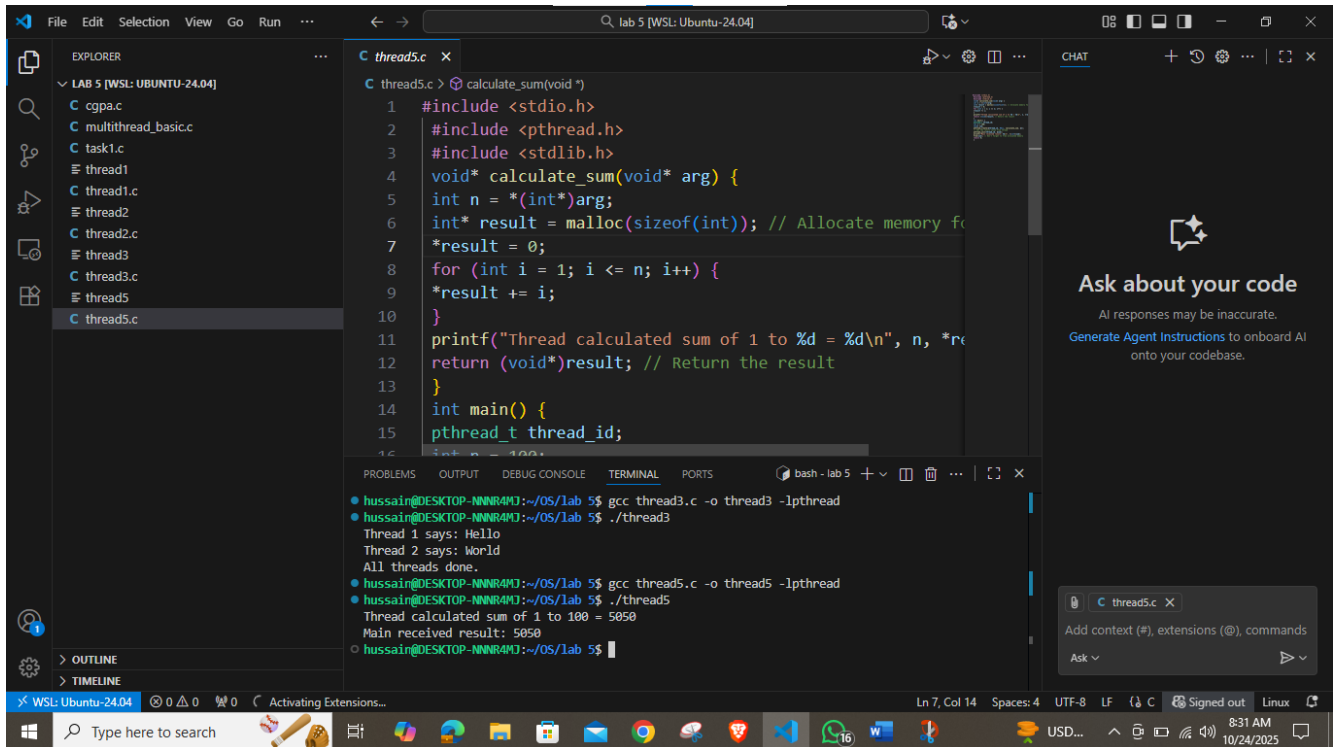
```

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

```

The screenshot shows the Visual Studio Code editor with the file `multithread_basic.c` open. The code defines a worker function and a main function that creates three threads. The terminal output shows the execution of the program, demonstrating concurrent execution of three threads and their completion order.

```

1  #include <stdio.h>
2  #include <pthread.h>
3  #include <unistd.h>
4  void* worker(void* arg) {
5      int thread_num = (int) arg;
6      printf("Thread %d: Task completed!\n", thread_num);
7      sleep(1); // Simulating work
8      printf("Thread %d: Task completed!\n", thread_num);
9      return NULL;
10 }
11 int main() {
12     pthread_t threads[3];
13     int thread_ids[3];
14     for (int i = 0; i < 3; i++) {
15         thread_ids[i] = i + 1;
16         pthread_create(&threads[i], NULL, worker, (void*) thread_ids[i]);
17     }
18     for (int i = 0; i < 3; i++) {
19         pthread_join(threads[i], NULL);
20     }
21     printf("Main thread: All threads have finished.\n");
22     return 0;
23 }

```

```

hussain@DESKTOP-NNW4W4J:~/OS/lab 5$ gcc multithread_basic.c -o multithread_basic -lpthread
hussain@DESKTOP-NNW4W4J:~/OS/lab 5$ ./multithread_basic
Thread 1: Starting task...
Thread 2: Starting task...
Thread 3: Starting task...
Thread 1: Task completed!
Thread 3: Task completed!
Thread 2: Task completed!
Main thread: All threads have finished.
hussain@DESKTOP-NNW4W4J:~/OS/lab 5$

```

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);

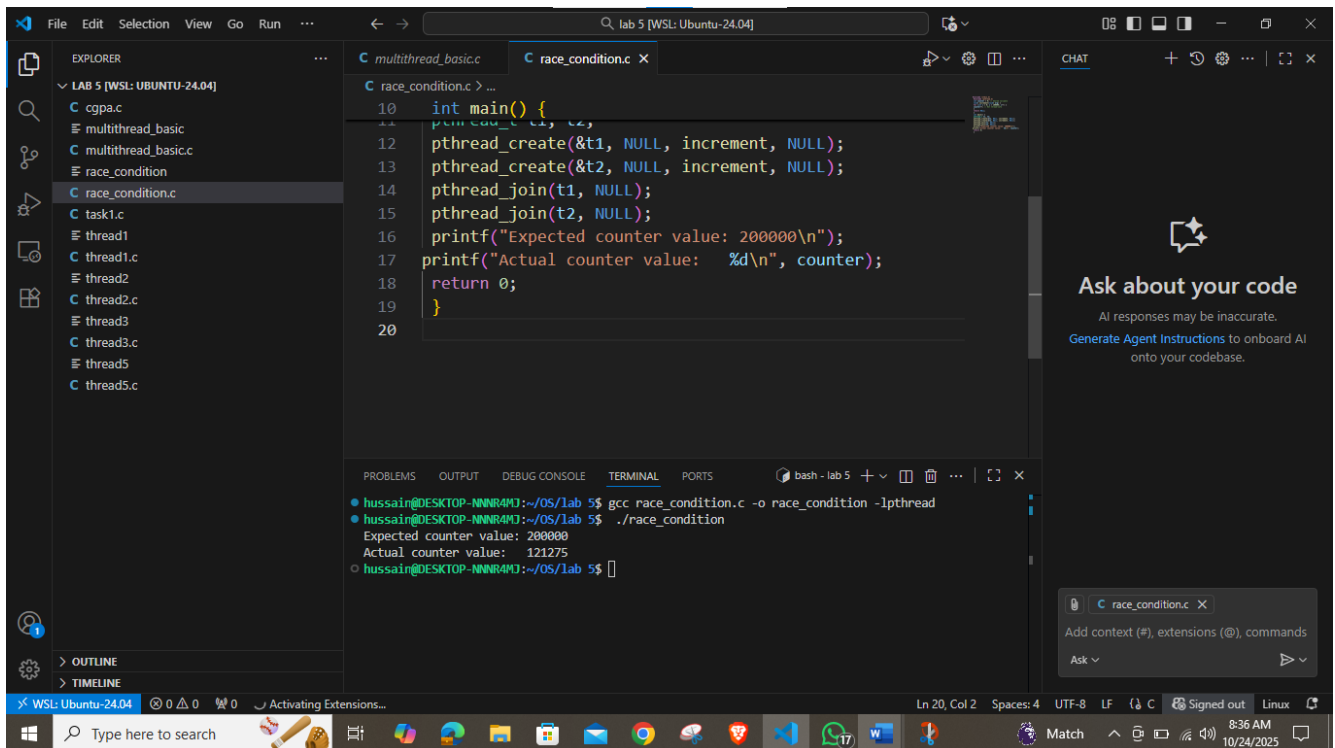
    printf("Expected counter value: 200000\n");
}
```

```
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.