Operating Systems – COC 3071L

SE 5th A – Fall 2025

Lab 4: 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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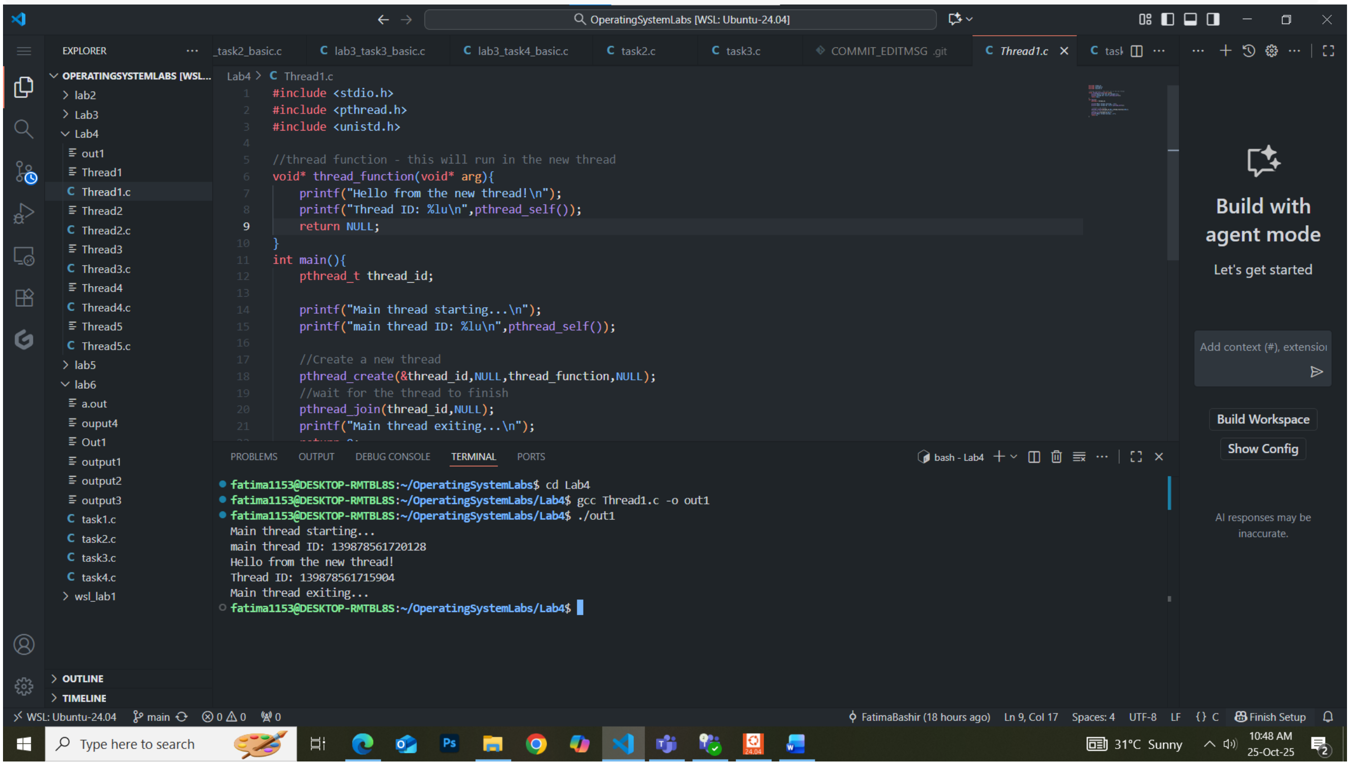
3. C Programs with Threads

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;
}
```

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



OperatingSystemLabs [WSL: Ubuntu-24.04]

Lab4 > Thread1.c

```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");
```

```
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs$ cd Lab4
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ gcc Thread1.c -o out1
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out1
Main thread starting...
main thread ID: 139878561720128
Hello from the new thread!
Thread ID: 139878561715904
Main thread exiting...
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$
```

Compile and run:

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

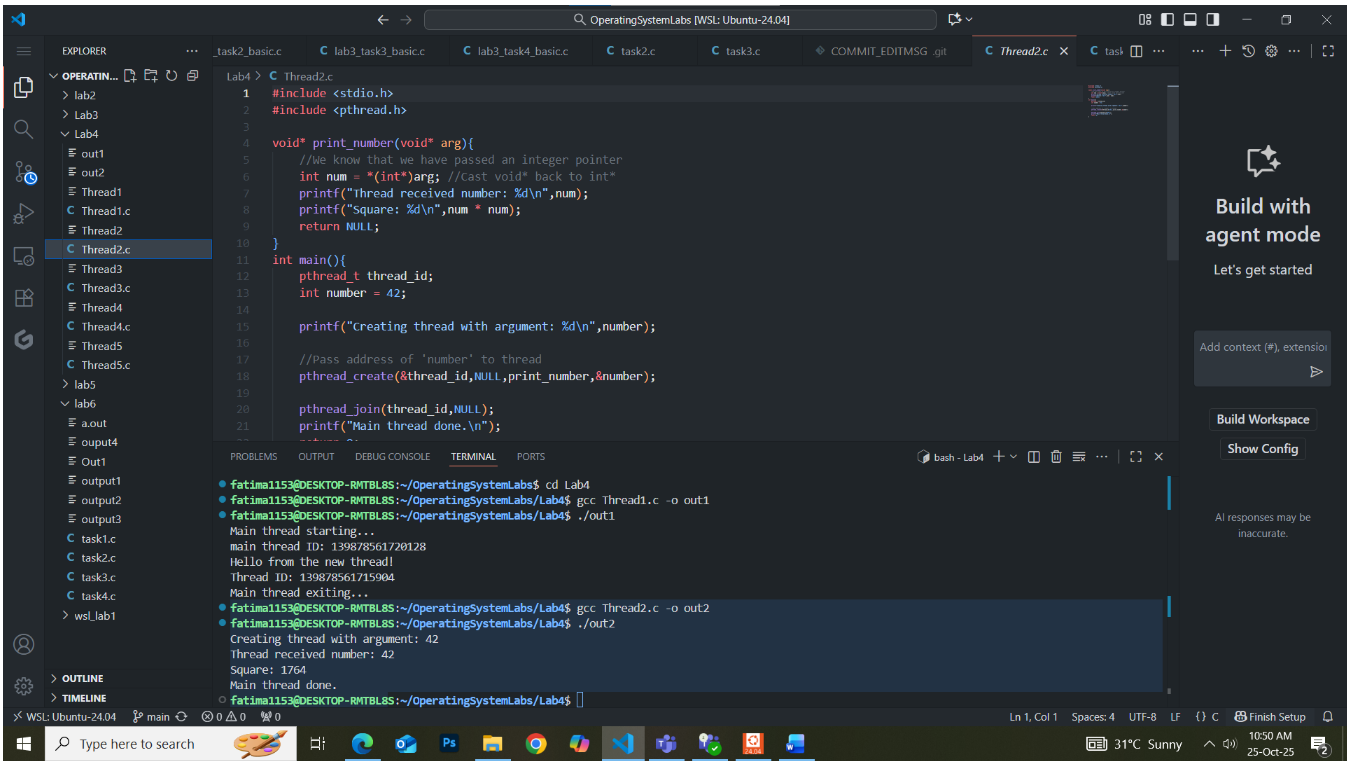
Program 2: Passing Arguments to Threads

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
```



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

void* print_number(void* arg){
    //We know that we have 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");
```

```
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs$ cd Lab4
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ gcc Thread1.c -o out1
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out1
Main thread starting...
main thread ID: 139878561720128
Hello from the new thread!
Thread ID: 139878561715904
Main thread exiting...
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ gcc Thread2.c -o out2
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out2
Creating thread with argument: 42
Thread received number: 42
Square: 1764
Main thread done.
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$
```

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.

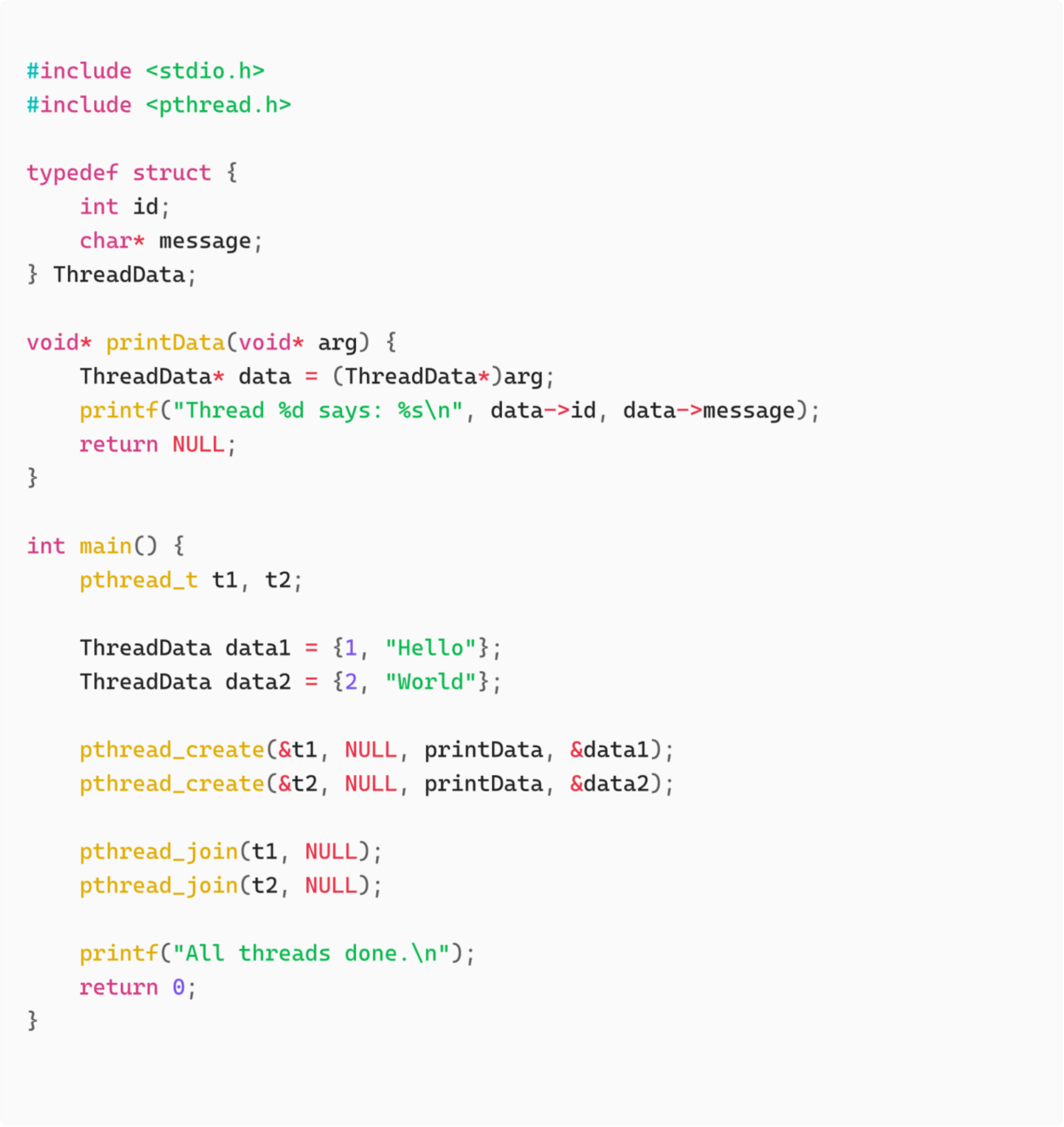
Why use `void*`

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

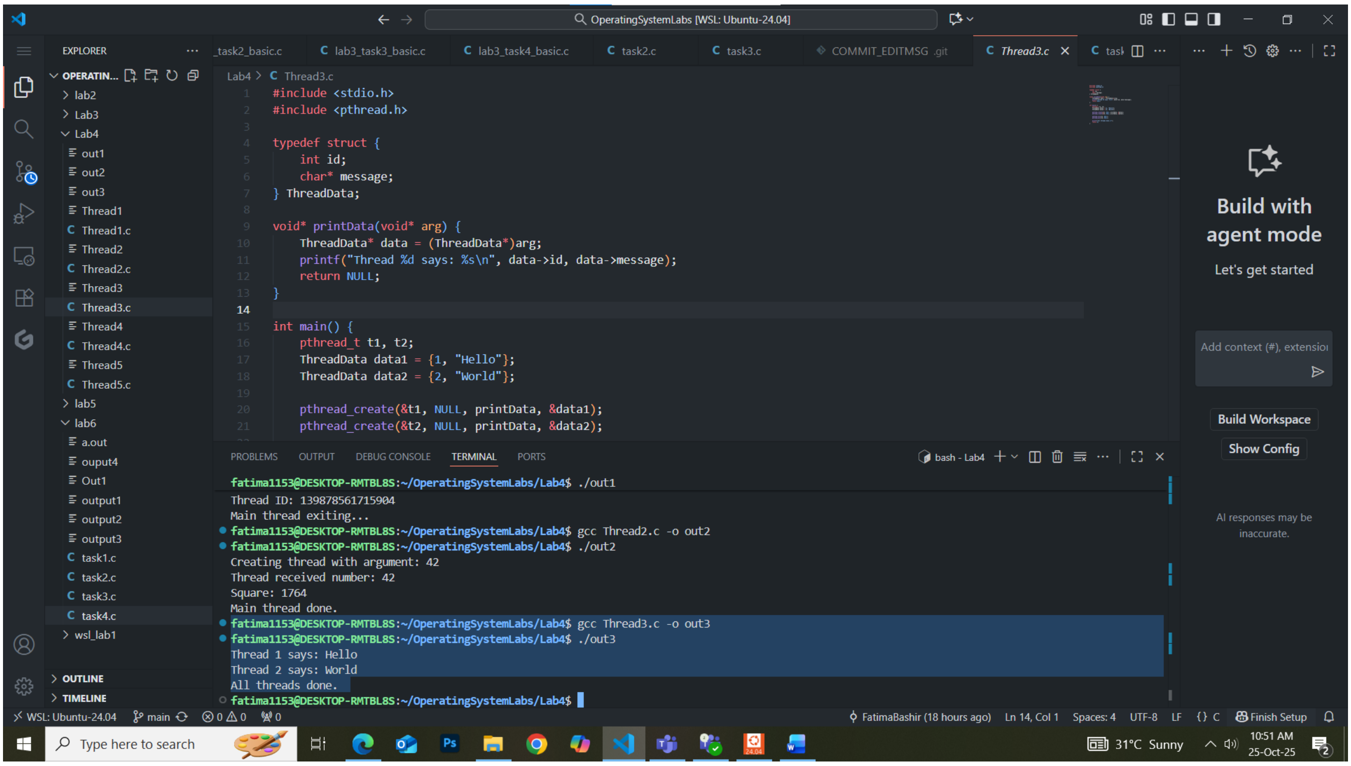
```c
void* function_name(void* arg)
```

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;
}
```



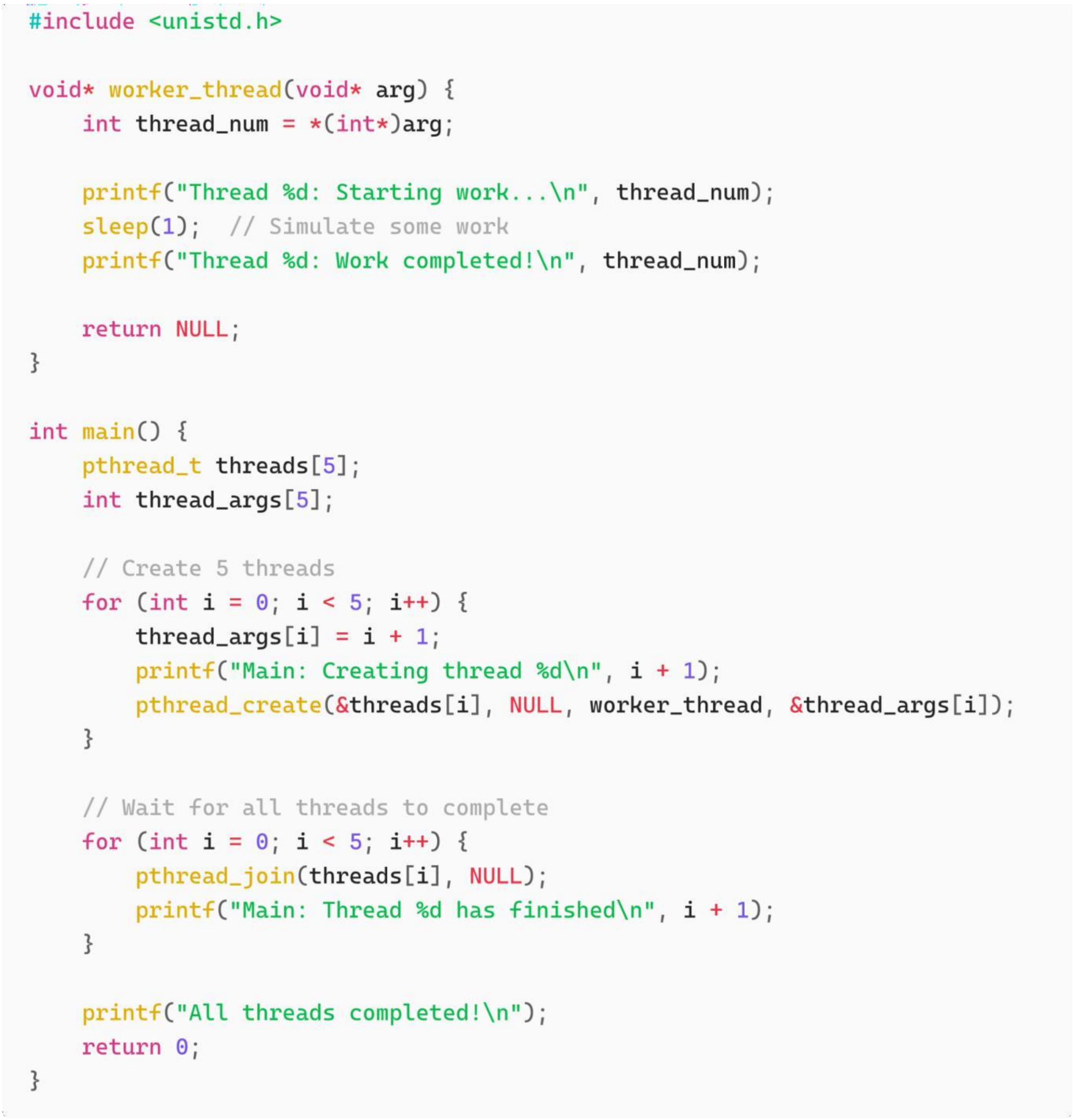
```c
#include <stdio.h>
#include <pthread.h>

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);
```

```
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out1
Thread ID: 139878561715904
Main thread exiting...
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ gcc Thread2.c -o out2
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out2
Creating thread with argument: 42
Thread received number: 42
Square: 1764
Main thread done.
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ gcc Thread3.c -o out3
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out3
Thread 1 says: Hello
Thread 2 says: World
All threads done.
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$
```

Program 4: Multiple Threads

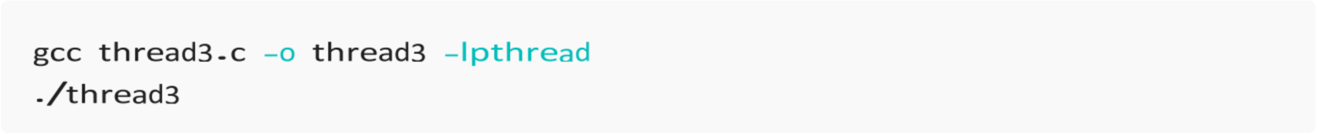
Objective: Create multiple threads executing the same function.

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

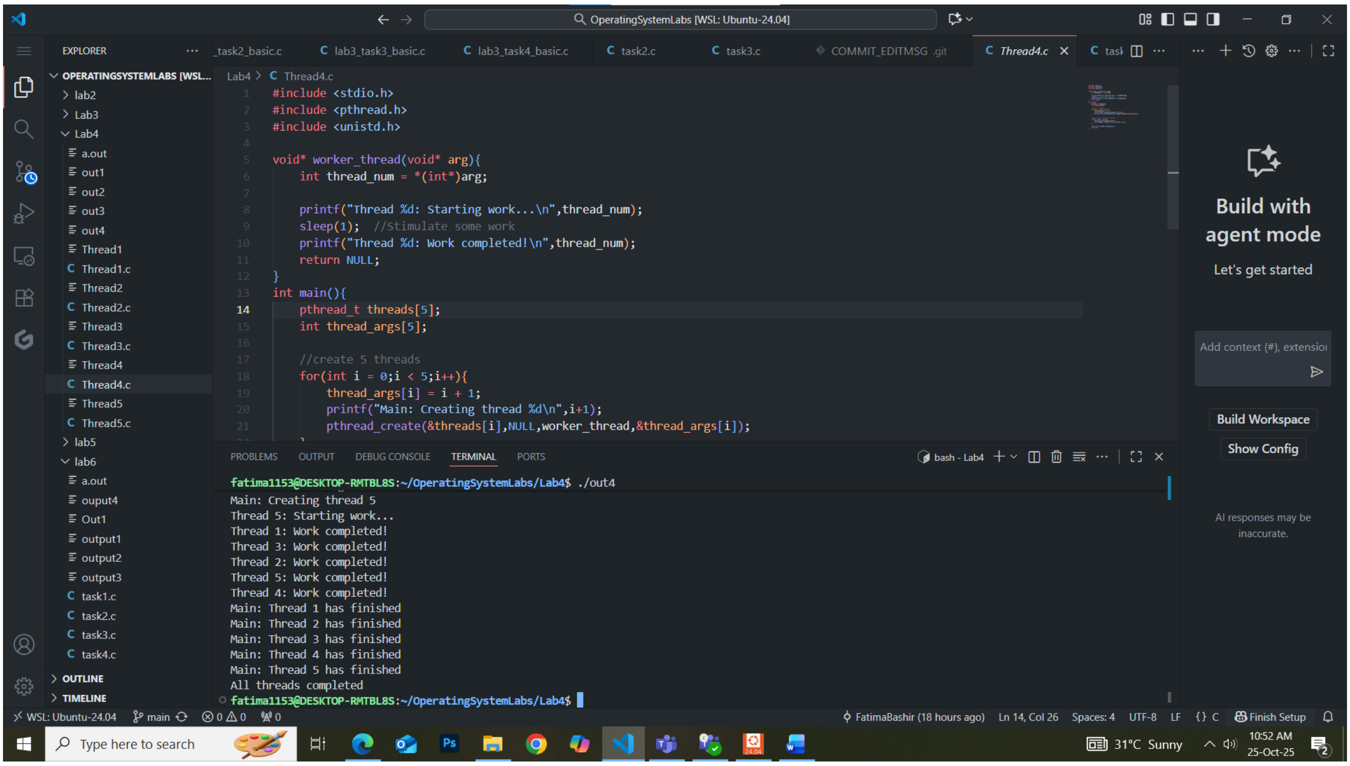


```c
#include <unistd.h>

void* worker_thread(void* arg) {
    int thread_num = *(int*)arg;

    printf("Thread %d: Starting work...\n", thread_num);
    sleep(1);  // Simulate some work
    printf("Thread %d: Work completed!\n", thread_num);

    return NULL;
}

int main() {
    pthread_t threads[5];
    int thread_args[5];

    // Create 5 threads
    for (int i = 0; i < 5; i++) {
        thread_args[i] = i + 1;
        printf("Main: Creating thread %d\n", i + 1);
        pthread_create(&threads[i], NULL, worker_thread, &thread_args[i]);
    }

    // Wait for all threads to complete
    for (int i = 0; i < 5; i++) {
        pthread_join(threads[i], NULL);
        printf("Main: Thread %d has finished\n", i + 1);
    }

    printf("All threads completed!\n");
    return 0;
}
```

Compile and run:



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



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

void* worker_thread(void* arg){
    int thread_num = *(int*)arg;

    printf("Thread %d: Starting work...\n",thread_num);
    sleep(1);  //Stimulate some work
    printf("Thread %d: Work completed!\n",thread_num);
    return NULL;
}
int main(){
    pthread_t threads[5];
    int thread_args[5];

    //create 5 threads
    for(int i = 0;i < 5;i++){
        thread_args[i] = i + 1;
        printf("Main: Creating thread %d\n",i+1);
        pthread_create(&threads[i],NULL,worker_thread,&thread_args[i]);
```

```
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out4
Main: Creating thread 5
Thread 5: Starting work...
Thread 1: Work completed!
Thread 3: Work completed!
Thread 2: Work completed!
Thread 5: Work completed!
Thread 4: Work completed!
Main: Thread 1 has finished
Main: Thread 2 has finished
Main: Thread 3 has finished
Main: Thread 4 has finished
Main: Thread 5 has finished
All threads completed
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$
```

Observation:

- Notice how threads may not execute in order
- All threads run concurrently
- `pthread_join()` ensures we wait for all threads

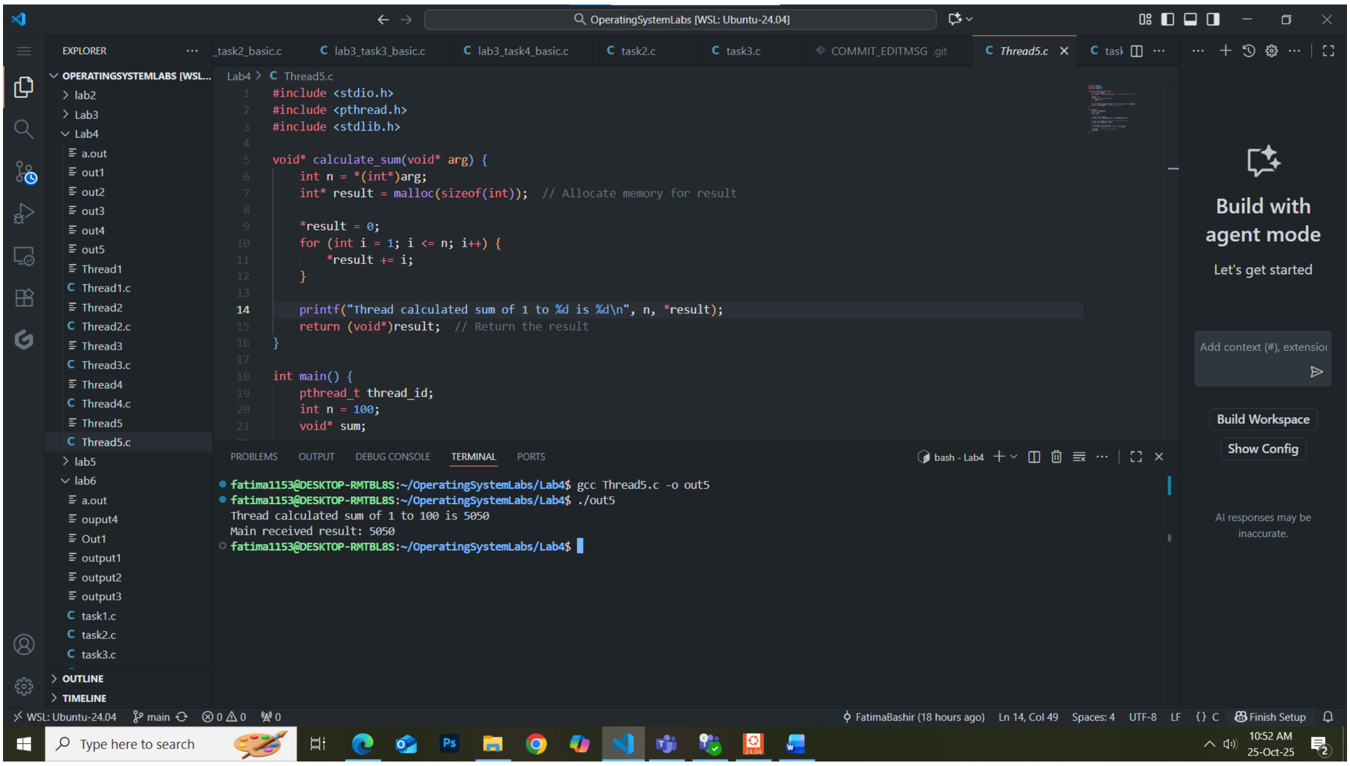
Program 5: Thread Return Values

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 thread4.c -o thread4 -lpthread
./thread4
```



```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 is %d\n", n, *result);
    return (void*)result;  // Return the result
}

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

```
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ gcc Thread5.c -o out5
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$ ./out5
Thread calculated sum of 1 to 100 is 5050
Main received result: 5050
fatima1153@DESKTOP-RMTBL8S:~/OperatingSystemLabs/Lab4$
```

Key Points:

- Thread functions return `void*`
- Use pthre^{a}d_join() to retrieve the return value
- Remember to free any dynamically allocated memory

5. Hands-on Practice Exercises

Exercise 1: Thread Basics

Write a program that:

1. Creates 3 threads
2. Each thread prints its thread ID and a unique message
3. Main thread waits for all threads to complete

Exercise 2: Prime Number Checker

Write a program that:

1. Takes a number as input
2. Creates a thread that checks if the number is prime
3. Returns the result to the main thread
4. Main thread prints whether the number is prime or not