SYNCHRONIZED THREADED ARCHITECTURE FOR REAL-TIME APPLICATIONS

INTERNSHIP REPORT

Submitted

in partial fulfillment of the requirements for the degree of

BACHELOR OF TECHNOLOGY

in

DEPARTMENT OF COMPUTER SCIENCE AND ENGINEERING

By

PRIYANSHU NIRANJAN [21CS1034]

Internship work at

DEFENCE ELECTRONICS RESEARCH LABORATORY,HYDERABAD-05

Under the external guidance of

Prateek Pande, Scientist ‘E’, DLRL

PUDUCHERRY TECHNOLOGICAL UNIVERSITY

(An Autonomous Institution of Govt. of Puducherry)

(Erstwhile Pondicherry Engineering College)

PUDUCHERRY-605 014, JUNE – 2023

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CERTIFICATE

This is to certify that the dissertation work entitled **"SYNCHRONIZED THREADED ARCHITECTURE FOR REAL-TIME APPLICATIONS"** was carried out by PRIYANSHU NIRANJAN bearing registration number 21CS1034 in partial fulfillment of the requirements for the degree of Bachelor of Technology in Computer Science and Engineering of the Puducherry Technological University, during the academic year 2023-24 is a bonafide record of work carried out under our guidance and supervision.

The results embodied in this report have not been submitted to any other University or Institution for the award of any degree or diploma.

Dr. P. Salini	**Dr. G. Zayaraz**
Associate-Professor	**Professor**
Internal-Guide	**HOD-CSE**

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This is to certify that **PRIYANSHU NIRANJAN (21CS1034)Puducherry Technological University (PTU)**. has undergone internship training from 29 May 2023 to 16 June 2023 in the Defence Electronics Research Laboratory, Hyderabad-05. The project **“Synchronized Threaded Architecture for Real-Time Applications”** is a record of the bonafide work undertaken by him towards partial fulfillment of the requirements for the award of the Degree of B.Tech (Bachelor of Technology) in CSE (Computer Science and Engineering) from**.**He has completed the assigned task satisfactorily.

(PRATEEK PANDE)	(KUMAR GAUTAM)	(JRC SARMA)
Sc ‘E’	Sc ‘G’	Sc ‘F’
Guide	Group Director	Wing Head HRD
DLRL, Hyderabad	DLRL, Hyderabad	DLRL, Hyderabad

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DECLARATION

I hereby declare that the results embodied in this dissertation titled **"Synchronized Threaded Architecture for Real-Time Applications"** is carried out by me during the year 2023in partial fulfillment of the award of B.Tech (Bachelor of Technology) in CSE (Computer Science and Engineering) from **"Puducherry Technological University (PTU), Puducherry".** I have not submitted the same to any other university or organization for the award of any other degree.

Priyanshu Niranjan
21CS1034, CSE
PTU, Puducherry

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ACKNOWLEDGEMENT

This is an acknowledgement of the intensive drive and technical competence of many individuals who have contributed to the success of my project.

I am grateful to Sri N. Srinivas Rao, DS & Director, DLRL, Hyderabad and Sri JRC Sarma, Sc ‘F’, Wing Head HRD and Members of the HRD for granting us permission for the practical training through development of this project in DLRL.

I am immensely thankful to Sri Kumar Gautam,Sc ‘F’, Wing Head, EWPT Wing for giving us this opportunity and also providing the facilities at EWPT Wing, DLRL.

I am obliged and grateful to our external guide Sri Prateek Pande, Sc ‘E’ of EWPT Division, DLRL for his valuable suggestions and sagacious guidance in all respects during the course of our training.

I would like to express our gratitude to our Sponsor member of DLRL, who was very friendly and co-operative.

My sincere thanks are due to Dr. G. Zayraz, Head of the Department, CSE of College Puducherry Technological University, Puducherry, and Dr. P. Salini, the faculty, for the encouragement and guidance provided.

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DLRL PROFILE

DEFENCE ELECTRONICS RESEARCH LABORATORY (D.L.R.L) was established in the year 1962 under the aegis of Defence Research and Development Organization (DRDO), Ministry of Defence, to meet the current and future needs of tri services Army, Navy and Air force equipping them with Electronics Warfare Systems.

DLRL has been entrusted with the primary responsibility of the design and development of Electronic Warfare Systems covering both Communication and RADAR Frequency bands.

DLRL consists of large number of dedicated technical and scientific manpower adequately supported by sophisticated hardware and software development facilities. Computers and dedicated Workstations are extensively used for, design and development of sub-systems. Main software required for various types of applications is developed in-house. The quality assurance group is responsible for quality assurance of software developed for Electronic Warfare Systems.

DLRL has number of supporting and technology groups to help the completion of the projects on time and to achieve a quality product. Some of the supporting and technology groups are Printed Circuited Board Group, Antenna Group, Microwave and Millimeter Wave Components Group, Mechanical Engineering Group, LAN, Human Resource Development Group etc. apart from work centers who carryout system design and development activities.

Long-Term self-reliance in Technologies / Systems has been driving principle in its entire development endeavor to make the nation self-reliant and independent.

In house Printed Circuit Board facilities provide faster realization of the digital hardware. Multi-layer Printed Circuit Board fabrication facilities are available to cater for a high precision and denser packaging.

The Antenna Group is responsible for design and development of wide variety of antennas covering a broad electromagnetic spectrum (HF to Millimeter Frequencies). The Group also develops RADOMES, which meet stringent environmental conditions for the EW equipment to suit the platform.

The MMW Group is involved in the design and development of MMW Sub-systems and also various Microwave Components like Solid State Amplifier, Switches, Couplers and Filters using the latest state-of-the–art technology.

The Hybrid Microwave Integrated Circuit Group provides custom-made microwave components and super components in the microwave frequency region using both thin film and thick film technology.

In the Mechanical Engineering Group the required hardware for EW Systems is designed and developed and the major tasks involved include Structural and Thermal Engineering.

The Technical Information Center, the place of knowledge bank is well equipped with maintained libraries, books, journals, processing etc. Latest Technologies in the electronic warfare around the globe are catalogued and easily accessible.

The Techniques Division of ECM wing is one such work center where design and development of subsystems required for ECM applications are undertaken. ESM Work Centers design and development of DF Rx, Rx Proc etc. for various ESM Systems using state-art-of-the technology by employing various techniques to suit the system requirements by the end users. All the subsystems are designed and developed using microwave, and processor/DSP based Digital hardware in realizing the real time activities in Electronic Warfare

Most of the work centers are connected through DLRL LAN (Local LAN) for faster information flow and multi point access of information critical to the development activities. Information about TIC, stores and general administration can be downloaded easily.

The Human Resource Division play a vital role in conducting various CEP courses, organizing service and technical seminars to upgrade the knowledge of scientists in the laboratory.

DLRL has been awarded ISO 9001:2015 certification for Design and Development of Electronic System of assured quality for Defence Services; utilize advanced and cost effective technology for developing reliable Electronic Warfare systems on time and continuous improvement of quality through involvement of all members.

ABSTRACT

This report presents a Synchronized Threaded Architecture (STA) implemented for real-time applications on the PowerPC architecture in the Linux operating system using the C programming language. The architecture is designed to address the challenges of real-time applications by combining parallel processing and synchronized execution.

Synchronization primitives and communication mechanisms provided by Linux, such as mutexes, condition variables, and semaphores, are utilized to ensure deterministic execution and meet stringent timing requirements.

The report focuses on the design and implementation of the STA in Linux using C. It discusses the thread management, synchronization, and inter-thread communication techniques employed to achieve synchronized execution.

The evaluation of the STA includes performance analysis, measuring the system's ability to meet real-time deadlines and its overall efficiency. The report concludes with a discussion of the implications and potential applications of the synchronized threaded architecture for real-time systems in Linux.

Overall, the implemented STA in Linux using C provides a framework for developing real-time applications with precise timing guarantees. The architecture's ability to exploit parallelism and ensure synchronized execution makes it a valuable tool for meeting the demanding requirements of real-time systems.

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CONTENTS

CHAPTER-1

Introduction

1.1 PowerPC Architecture

In today's tech landscape, the PowerPC architecture has seen a decline in mainstream relevance compared to other architectures such as x86 and ARM. However, it still maintains a presence in certain niche markets and specialized applications. Here are a few areas where PowerPC remains relevant:

1. Embedded Systems: PowerPC is used in various embedded systems and industrial applications, where its reliability, scalability, and real-time processing capabilities are valued. These applications include automotive systems, aerospace and defense, networking equipment, and telecommunications infrastructure.

2. High-Performance Computing (HPC): PowerPC processors, particularly those based on IBM's POWER architecture, are utilized in high-performance computing clusters and supercomputers. These systems leverage the parallel processing capabilities and high memory bandwidth of PowerPC to deliver substantial computational power for scientific simulations, data analytics, and research.

3. Open Source Community: The open-source RISC-V architecture has gained popularity in recent years. While not directly related to PowerPC, it shares some similarities in terms of open-source design principles and extensibility. Some efforts have emerged to port PowerPC architecture to RISC-V, opening up possibilities for PowerPC-based open-source projects.

Figure 1.1: PowerPC 601 Micro-processor

Although PowerPC is no longer prevalent in consumer-grade computers and mobile devices, its continued use in embedded systems, HPC, and specialized applications demonstrates its enduring relevance in specific domains where its unique features and strengths are still valued.

1.2 Real-Time Applications : Challenges and Implementation

A real-time application, or RTA, is an application that functions within a time frame that the user senses as immediate or current. The latency must be less than a defined value, usually measured in seconds. The use of real-time applications is part of real-time computing.

Real-time applications are often used to process streaming data. Real-time software should have the ability to sense, analyze and act on streaming data as it comes in without ingesting and storing the data in a back-end database. Real-time applications often rely on event-driven architecture to process streaming data asynchronously.

A defining feature of a real-time application is that it must complete real-time tasks within a particular time constraint. Real-time applications are categorized according to the severity of the consequence of failing to operate within a given time constraint.

Real-time application classifications include the following:

1. Hard real-time apps. A hard real-time system causes an entire system to fail if it misses its deadline or time constraint. For example, an industrial safety system with an unacceptable latency may cause the industrial equipment to physically break.

2. Soft real-time apps. With these apps, results degrade after their deadline, whether the deadline is met or not. A video game is an example of a soft real-time system. Video games rely on user input and have limited time to process; degradation is sometimes expected for this reason.

1.3 Multithreaded programming

Multithreading, or multithreaded programming, refers to the concurrent execution of

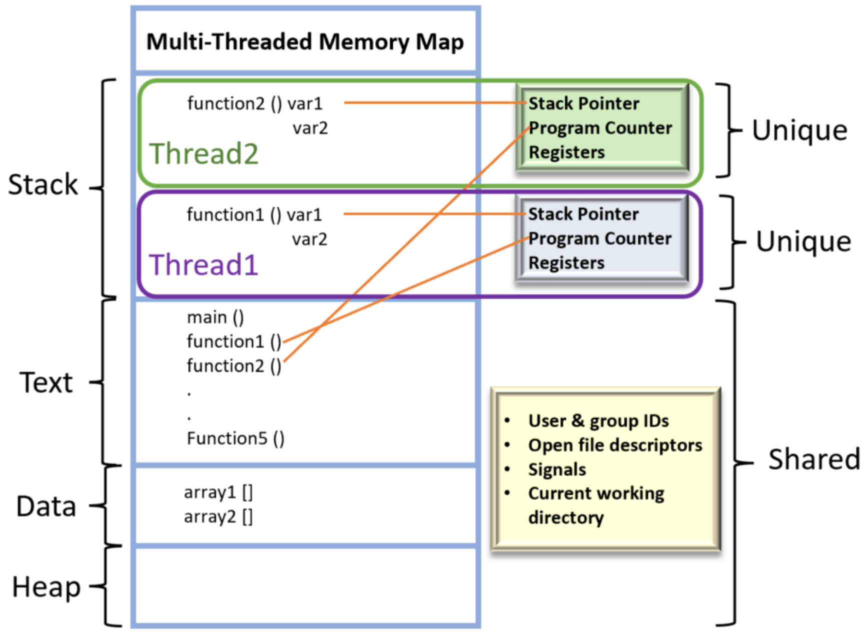

Figure 2.1 : Multi-threaded memory map

multiple threads within a single program. It is the practice of dividing a program into multiple threads that can execute independently and simultaneously, sharing the same resources of the program. Each thread represents a separate flow of control, allowing different parts of the program to execute concurrently.

1.3.1 Advantages of Multithreaded programming

Multithreading enables various benefits, such as:

1. Concurrent Execution: Multiple threads can execute different parts of a program simultaneously, utilizing the available CPU cores or processors effectively. This improves overall performance and responsiveness.
2. Parallelism: Multithreading allows for the execution of multiple threads in parallel, particularly in tasks that can be divided into independent subtasks. This can result in faster execution and improved efficiency on systems with multiple cores.

3. Responsiveness: By using multithreading, a program can remain responsive during time-consuming operations. For example, a user interface can continue to accept user input while a background thread performs intensive computations.

4. Resource Sharing: Threads within a program can share the same memory space and resources, allowing for efficient communication and data sharing between threads. This facilitates coordination and collaboration between different parts of the program.

1.3.2 Disadvantages of Multithreaded programming

Multithreading also introduces challenges, such as race conditions and synchronization issues, which need to be properly managed through techniques like locking, synchronization primitives, and thread-safe programming practices.

Overall, multithreading is a powerful approach to leverage concurrent execution, parallelism, and resource sharing in modern software development, enabling efficient utilization of system resources and enhanced performance.

1.4 POSIX Introduction

POSIX (Portable Operating System Interface) is a set of standard operating system interfaces based on the UNIX operating system. The most recent POSIX specifications -- IEEE Std 1003.1-2017 -- defines a standard interface and environment that can be used by an operating system (OS) to provide access to POSIX-compliant applications. The standard also defines a command interpreter (shell) and common utility programs. POSIX supports application portability at the source code level so applications can be built to run on any POSIX-compliant OS.

1.4.1 Thread Creation and Management

POSIX threads provide a comprehensive set of functions for creating and managing threads in C. The pthreads API allows developers to create, control, and synchronize threads within a program.

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1.4.2 Mutexes (pthread_mutex_t)

Mutexes are used to protect critical sections of code, ensuring that only one thread can access the protected resource at a time.

Mutexes can be initialized using pthread_mutex_init() and destroyed using pthread_mutex_destroy().

To acquire a mutex and enter the critical section, a thread can use pthread_mutex_lock(). If the mutex is already locked by another thread, the calling thread will block until it can acquire the mutex.

To release the mutex and exit the critical section, a thread can use pthread_mutex_unlock().

1.4.2 Semaphores (sem_t)

Semaphores are used for more complex synchronization scenarios, allowing multiple threads to control access to shared resources.

Semaphores can be initialized using sem_init() and destroyed using sem_destroy().

To wait on a semaphore, a thread can use sem_wait(). If the semaphore value is non-zero, it decrements the value and continues execution. Otherwise, the thread blocks until the semaphore value becomes non-zero.

To post or increment the semaphore value, another thread can use sem_post().

CHAPTER 2

Benchmarks for Progress

2.1 Benchmark Methodology

In a synchronized-threaded application, multiple threads are used to achieve parallel execution of tasks while maintaining synchronization between the threads. Here's an overview of the process:

First, the application creates multiple threads using the POSIX Threads (pthreads) library. This library provides a standardized API for managing threads in a Linux environment. The number of threads created depends on the workload and the available system resources.

Next, synchronization mechanisms such as mutexes, semaphores are used to ensure thread synchronization. These mechanisms help prevent race conditions and ensure proper coordination between the threads. The application can create and manage these synchronization objects using the pthreads library.

The workload of the simulation is divided into smaller tasks, and each thread is assigned one or more tasks to execute. Task partitioning can be based on a static or dynamic load-balancing strategy. In a static approach, tasks are evenly distributed among the threads at the beginning of the simulation. In a dynamic approach, the workload is dynamically divided among the threads during runtime based on their availability and performance.

Once the tasks are assigned, each thread independently executes its allocated tasks. The simulation algorithm determines the specific operations performed by each thread. The threads access shared data structures or communicate with each other using message passing techniques. Proper synchronization is essential to avoid data inconsistencies or conflicts between the threads.

At certain points during the simulation, threads may need to synchronize their execution. This synchronization can be required to exchange data, update shared variables, or wait for specific conditions. Synchronization points are typically implemented using the synchronization primitives provided by the pthreads library, such as mutex locks or condition variables. These synchronization points ensure that threads coordinate their activities and progress through the simulation in a controlled manner.

Overall, running a synchronized-threaded application in a PowerPC Linux environment involves creating threads, using synchronization mechanisms, partitioning tasks, executing tasks in parallel, and coordinating the threads through synchronization points. This approach allows for efficient utilization of system resources and improved performance in simulations and other parallel applications.

2.2 Milestone 1: Thread Formation: Thread Creation and Joining

2.2.1 Introduction: Overview of Thread Creation and Joining

The given code demonstrates the use of POSIX libraries to create and manage threads in a multi-threading program. When creating a thread, the pthread_create function is used with four arguments to specify the thread's attributes, such as the thread identifier, attributes, start routine, and arguments. These arguments are filled in to create the desired thread.

To synchronize the main thread with the child threads and wait for their completion, the pthread_join function is used. It takes two arguments: the thread identifier of the thread to be joined and a pointer to retrieve the exit status of the joined thread.

2.2.2 Source Code

The following demonstrates the thread creation and joining them

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

void* ui_ThreadFunction1(void* arg){
    printf("Thread 1 is executing\n");
    pthread_exit(NULL);
}

void* ui_ThreadFunction2(void* arg){
    printf("Thread 2 is executing\n");
    pthread_exit(NULL);
}

int main(){
    pthread_t ui_Thread1, ui_Thread2;

    // Create a new thread
    pthread_create(&ui_Thread1, NULL, ui_ThreadFunction1, NULL);
    pthread_create(&ui_Thread2, NULL, ui_ThreadFunction2, NULL);

    // Wait for the thread to finish
    pthread_join(ui_Thread1, NULL);
    pthread_join(ui_Thread2, NULL);

    printf("Thread has finished\n");
    return 0;
}
```

2.2.3 Analysis of the Source-code

The given source code demonstrates the creation and joining of two threads using `pthread_create` and `pthread_join` functions. Here's an analysis of the code:

1. The code includes the necessary headers `stdio.h` and `pthread.h` for standard input/output and pthread library functions, respectively.

2. Two thread functions are defined: `thread_function1` and `thread_function2`. These functions are responsible for the execution of each thread. They print a message indicating the thread number that is executing and then call `pthread_exit` to terminate the thread.

3. The `main` function initializes two thread identifiers `thread1` and `thread2` of type `pthread_t`.

4. Two threads are created using `pthread_create`. The first thread is created by passing the thread identifier `thread1`, the default thread attributes (`NULL`), the thread function `thread_function1`, and `NULL` as the argument.

5. Similarly, the second thread is created by passing the thread identifier `thread2`, the default thread attributes (`NULL`), the thread function `thread_function2`, and `NULL` as the argument.

6. The `pthread_join` function is called twice to wait for both threads to finish their execution. This ensures that the main thread waits until both threads complete before proceeding further.

7. Finally, a message is printed indicating that the threads have finished, and the `main` function returns 0 to indicate successful execution.

Overall, the code creates two threads, each executing its respective thread function, and then waits for both threads to finish before printing a completion message. This allows for concurrent execution of the threads and synchronization with the main thread.

2.3 Milestone 2: Bridging Threads: Sharing Data via a Global Variable

2.3.1 An Overview Sharing Data among Threads via a Global Variable

In this milestone, exploring the concept of sharing data among threads via a global variable is demonstrated. A global variable is a variable that is declared outside of any function and can be accessed by any part of the program. By making a variable global, it becomes visible and modifiable by all threads, enabling them to share information and synchronize their operations.

Using a global variable for data sharing has its advantages. It offers a simple and straightforward mechanism for communication between threads. Threads can read from and write to the global variable directly, eliminating the need for complex data structures or inter-thread communication mechanisms. Moreover, the global nature of the variable allows easy access to shared data without the need for explicit passing of parameters.

2.3.2 Source Code

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

int ui_SharedData = 0;

void* ui_ThreadFunction1(void* arg) {
    ui_SharedData++;
    pthread_exit(NULL);
}

void* ui_ThreadFunction2(void* arg) {
    ui_SharedData += 2;
    pthread_exit(NULL);
}

void* ui_ThreadFunction3(void* arg) {
    ui_SharedData += 3;
    pthread_exit(NULL);
}

int main() {
    pthread_t thread1,thread2,thread3;

    // Create multiple threads
    pthread_create(&thread1, NULL, ui_ThreadFunction1, NULL);
    pthread_create(&thread2, NULL, ui_ThreadFunction2, NULL);
    pthread_create(&thread3, NULL, ui_ThreadFunction3, NULL);
    // Wait for all threads to finish
    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);
    pthread_join(thread3, NULL);

    printf("Shared data value: %d\n", ui_SharedData);
    return 0;
}
```

2.3.3 Analysis of the Source-code

The provided source code demonstrates the usage of threads to manipulate a shared data variable `ui_SharedData`. Here's an analysis of the code:

1. The code includes the necessary headers `stdio.h` and `pthread.h` for standard input/output and pthread library functions, respectively.

2. There is a global variable `ui_SharedData` of type integer that represents the shared data among the threads.

3. Three thread functions `ui_ThreadFunction1`, `ui_ThreadFunction2`, and `ui_ThreadFunction3` are defined. Each function performs a different operation on the shared data variable:

- `ui_ThreadFunction1` increments the `ui_SharedData` by 1.
- `ui_ThreadFunction2` increments the `ui_SharedData` by 2.
- `ui_ThreadFunction3` decrements the `ui_SharedData` by 3.

4. The `main` function initializes an array of thread identifiers `threads` of type `pthread_t` to hold three threads.

5. Three threads are created by calling `pthread_create` with each thread function and passing `NULL` as the argument.

6. The `pthread_join` function is called within a loop to wait for each thread to finish its execution. This ensures that the main thread waits until all three threads have completed before proceeding further.

7. Finally, the updated value of `ui_SharedData` is printed to display the final result after all thread operations.

It's worth noting that since the shared data `ui_SharedData` is accessed and modified concurrently by multiple threads, proper synchronization mechanisms such as locks or mutexes should be implemented to prevent data race conditions and ensure the correctness of the shared data.

2.4 Milestone 3: Sharing Data through Shared Resource Utilization

2.4.1 An Overview: Sharing Data through Shared Resource Utilization

The milestone focuses on sharing data among threads using shared resource utilization. Instead of relying on global variables or data structures, this approach allows threads to access and modify a shared resource directly.

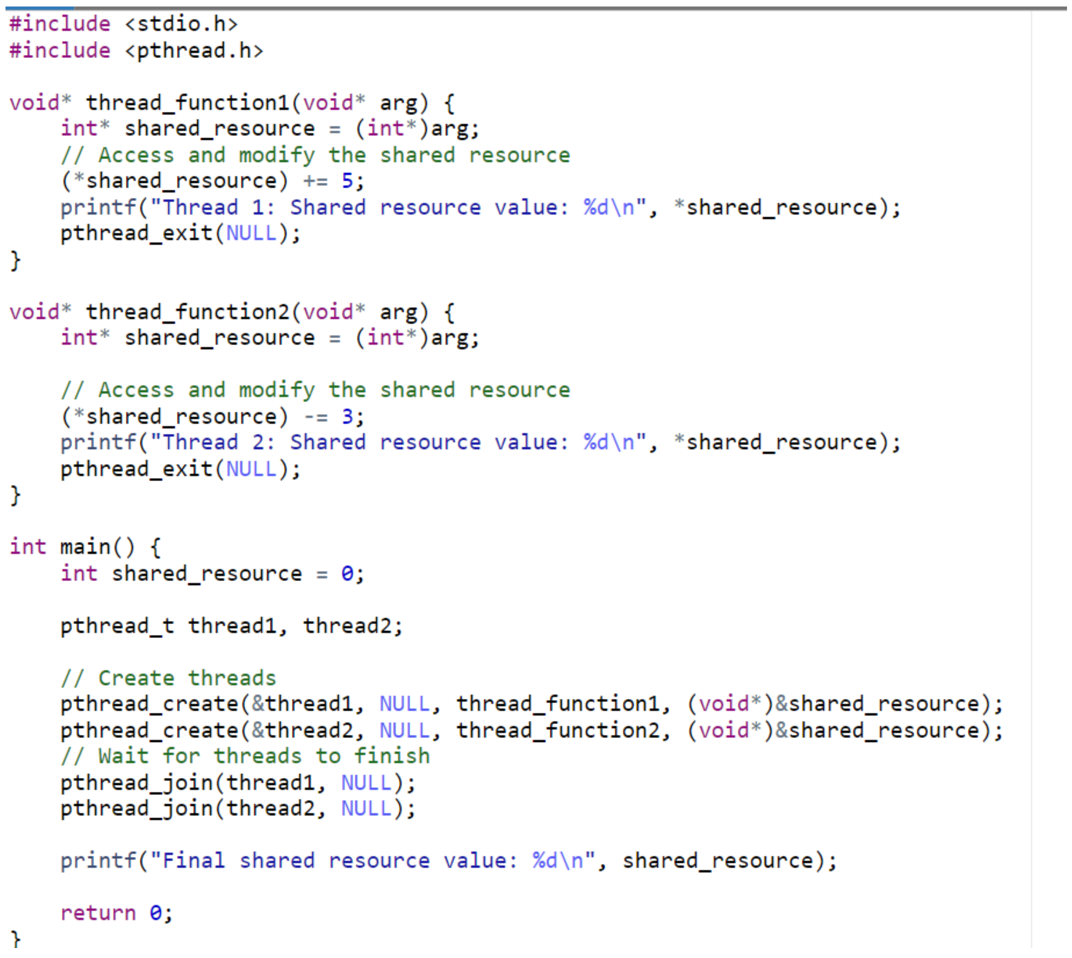
The provided code demonstrates this concept by utilizing a common shared resource in a multi-threaded environment. It begins by creating two threads: `thread1` and `thread2`. Each thread has its own designated function: `thread_function1` and `thread_function2`.

Within these thread functions, the shared resource is accessed and modified accordingly. In `thread_function1`, the shared resource is incremented by 5, while in `thread_function2`, it is decremented by 3. The updated values of the shared resource are printed for each thread.

To ensure proper synchronization and avoid data races, the code utilizes the pthread library. It employs the functions `pthread_create` to create the threads and `pthread_join` to wait for their completion before proceeding. By doing so, the main thread ensures that the shared resource is accessed and modified by the threads in an orderly manner.

In summary, this milestone showcases the utilization of shared resources for data sharing among threads. By allowing threads to directly access and modify a shared resource, it highlights the need for proper synchronization to ensure data integrity and avoid race conditions in multi-threaded environments.

2.4.2 Source-Code



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

void* thread_function1(void* arg) {
    int* shared_resource = (int*)arg;
    // Access and modify the shared resource
    (*shared_resource) += 5;
    printf("Thread 1: Shared resource value: %d\n", *shared_resource);
    pthread_exit(NULL);
}

void* thread_function2(void* arg) {
    int* shared_resource = (int*)arg;

    // Access and modify the shared resource
    (*shared_resource) -= 3;
    printf("Thread 2: Shared resource value: %d\n", *shared_resource);
    pthread_exit(NULL);
}

int main() {
    int shared_resource = 0;

    pthread_t thread1, thread2;

    // Create threads
    pthread_create(&thread1, NULL, thread_function1, (void*)&shared_resource);
    pthread_create(&thread2, NULL, thread_function2, (void*)&shared_resource);
    // Wait for threads to finish
    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);

    printf("Final shared resource value: %d\n", shared_resource);

    return 0;
}
```

2.4.3 Analysis of Source-Code

The provided source code demonstrates the sharing of data among threads without using structs or global variables. It consists of the following key components:

1. Thread Functions:

- The `thread_function1` and `thread_function2` functions represent the two threads in the program.

- Each thread function takes a `void*` argument, which is cast to an `int*` to access the shared resource.

- Inside the thread functions, the shared resource is modified by adding 5 in `thread_function1` and subtracting 3 in `thread_function2`.

- The updated value of the shared resource is printed for each thread.

2. Main Function:

- The `main` function is the entry point of the program.

- It declares a local variable `shared_resource` and initializes it to 0.

- Two thread identifiers, `thread1` and `thread2`, are declared using `pthread_t`.

- The `pthread_create` function is called twice to create the threads.

- The shared resource's address, cast to `void*`, is passed as an argument to each thread function.

- After creating the threads, the `pthread_join` function is used to wait for each thread to finish execution.

- Finally, the value of the shared resource is printed to display the final result.

3. Analysis:

- The code demonstrates a simple approach to sharing data among threads without using structs or global variables.

- By passing the address of the shared resource as a void pointer argument, the threads can directly access and modify the shared resource.

- However, it is important to note that this code does not include any synchronization mechanisms to ensure thread safety. Without proper synchronization, data races may occur when multiple threads access and modify the shared resource simultaneously.

- To ensure thread safety, synchronization techniques such as locks, mutexes, or atomic operations should be employed to provide mutual exclusion and prevent data races.

In summary, the provided code offers a basic illustration of sharing data among threads without structs or global variables. However, for practical applications, additional synchronization mechanisms should be implemented to ensure thread safety when multiple threads access and modify shared resources concurrently

2.5 Milestone 4: Data Sharing with Circular Queues

2.5.1 An Overview: Data sharing with Queues

In multi-threaded programming, efficient and reliable sharing of data among threads is a critical requirement. Achieving this without relying on global variables or complex data structures can be challenging. In this context, the code presented in milestone 4.2.3 introduces an alternative approach known as "Shared Resource Utilization" to facilitate data sharing among threads.

The code utilizes semaphores and a circular queue to implement this approach. Three threads (Thread A, Thread B, and Thread C) are created, each with its specific role in the data sharing process. These threads interact with shared resources through synchronization using semaphores.

By analyzing and understanding this code, we can gain valuable insights into how threads can effectively share data using shared resource utilization techniques, eliminating the reliance on global variables. This approach promotes better modularity, encapsulation, and thread-safety in multi-threaded programs.

2.5.2 Source-Code

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

#define QUEUE_SIZE 100

sem_t semaphore1, semaphore2;

int uiQueue1[QUEUE_SIZE];
int uiFront1 = -1;
int uiRear1 = -1;

int uiQueue2[QUEUE_SIZE];
int uiFront2 = -1;
int uiRear2 = -1;

void enqueue(int value, int* uiQueue, int* uiFront, int* uiRear)
{
    if ((*uiFront == 0 && *uiRear == QUEUE_SIZE - 1) || (*uiRear ==
(*uiFront - 1) % (QUEUE_SIZE - 1)))
    {
        printf("Queue is full. Overflow condition.\n");
        return;
    }

    if (*uiFront == -1)
        *uiFront = *uiRear = 0;
    else if (*uiRear == QUEUE_SIZE - 1 && *uiFront != 0)
        *uiRear = 0;
    else
        (*uiRear)++;

    uiQueue[*uiRear] = value;
}

int dequeue(int* uiQueue, int* uiFront, int* uiRear)
{
    if (*uiFront == -1)
    {
        printf("Queue is empty. Underflow condition.\n");
        return -1;
    }

    int value = uiQueue[*uiFront];

    if (*uiFront == *uiRear)
        *uiFront = *uiRear = -1;
    else if (*uiFront == QUEUE_SIZE - 1)
        *uiFront = 0;
    else
        (*uiFront)++;

    return value;
}

void *thread_function1(void *arg)
{
    int *arg_ptr = (int *)arg;

    while (1)
    {
        sem_wait(&semaphore1);
        (*arg_ptr)++;
        enqueue(*arg_ptr, uiQueue1, &uiFront1, &uiRear1);
        printf("Thread A: %d\n", *arg_ptr);
        sem_post(&semaphore2);
        usleep(250000);
    }

    return NULL;
}

void *thread_function2(void *arg)
{
    while (1)
    {
        sem_wait(&semaphore2);

        int value = dequeue(uiQueue1, &uiFront1, &uiRear1);
        enqueue(value, uiQueue2, &uiFront2, &uiRear2);

        printf("Thread B - Queue 1: %d\n", value);

        usleep(250000);
        sem_post(&semaphore1);
    }

    return NULL;
}

void *thread_function3(void *arg)
{
    while (1)
    {
        sem_wait(&semaphore2);

        int value = dequeue(uiQueue2, &uiFront2, &uiRear2);
        printf("Thread C - Queue 2: %d\n----------------\n", value);

        usleep(250000);
        sem_post(&semaphore1);
    }

    return NULL;
}

int main()
{
    pthread_t thread1, thread2, thread3;
    unsigned int retval = 0;

    sem_init(&semaphore1, 0, 1);
    sem_init(&semaphore2, 0, 0);

    pthread_create(&thread1, NULL, thread_function1, &retval);
    pthread_create(&thread2, NULL, thread_function2, NULL);
    pthread_create(&thread3, NULL, thread_function3, NULL);

    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);
    pthread_join(thread3, NULL);
    sem_destroy(&semaphore1);
    sem_destroy(&semaphore2);

    return 0;
}
```

2.5.3 Analysis of Source-Code

1. Data Structures:

- Two circular queues (`queue1` and `queue2`) are implemented using arrays to store the shared data between the threads.

- Two sets of indices (`front1`/`rear1` and `front2`/`rear2`) are maintained to keep track of the queue's front and rear positions.

2. Semaphore Initialization:

- Two semaphores (`semaphore1` and `semaphore2`) are initialized using the `sem_init` function.

- `semaphore1` is initialized with a value of 1, representing mutual exclusion for access to shared resources.

- `semaphore2` is initialized with a value of 0, indicating that initially, Thread B and Thread C must wait for Thread A to produce data.

3. Thread Functions:

- `thread_function1` (Thread A) increments a shared variable `retval` and enqueues it into `queue1`.

- `thread_function2` (Thread B) dequeues an element from `queue1`, performs some operation on it, and enqueues the result into `queue2`.

- `thread_function3` (Thread C) dequeues an element from `queue2` and performs some operation on it.

4. Thread Interaction:

- Thread A signals Thread B by posting on `semaphore2` after enqueuing a value into `queue1`.

- Thread B waits on `semaphore2` until it is signaled by Thread A. It then performs the necessary operations on the dequeued value from `queue1` and enqueues the result into `queue2`.

- Thread C waits on `semaphore2` until it is signaled by Thread B. It dequeues a value from `queue2` and performs the desired operations.

5. Thread Synchronization:

- The use of semaphores (`semaphore1` and `semaphore2`) ensures proper synchronization between threads.

- `semaphore1` is used to allow exclusive access to shared resources. Only one thread can access the critical section at a time.

- `semaphore2` is used for signaling and waiting between Thread A, Thread B, and Thread C. It ensures that threads wait for each other before performing their respective operations.

6. Thread Termination and Semaphore Destruction:

- The `pthread_join` function is used to wait for the termination of all three threads.

- Once all threads have completed their execution, the semaphores are destroyed using `sem_destroy`.

By analyzing this code, It can observed how shared resource utilization, along with proper synchronization using semaphores, enables the sharing of data among threads without the need for global variables or complex data structures.

CHAPTER 3
Simulation on General System

3.1 Architecture of the system

The following flowchart demonstrates the execution of threads asynchronously by the utilization of array as buffers and using synchronization techniques such as 'semaphores' and mutual exclusion parameter 'mutexes'.

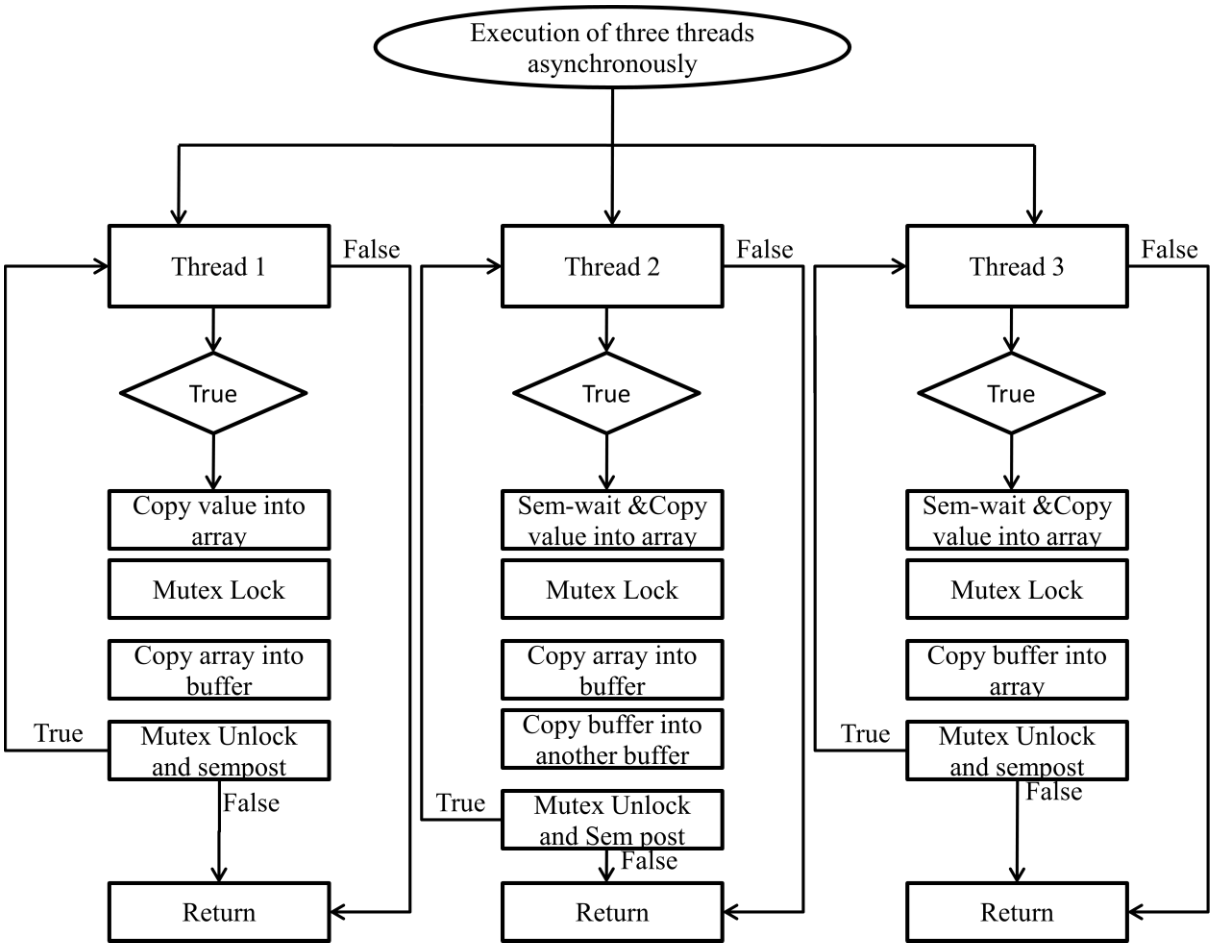


Figure 3.1**:** Flowchart of Multi-threaded application

The given code is an example of a multi-threading program in C that utilizes pthreads and semaphores for synchronization. It consists of three threads: Thread 1, Thread 2, and

Thread 3. These threads communicate with each other through shared buffers and synchronization mechanisms.

Thread 1 continuously writes data to `i_Buffer1`, which serves as a buffer for transferring data to Thread 2. Thread 2 waits for a semaphore signal from Thread 1, locks a mutex to ensure exclusive access, reads data from `i_Buffer1`, writes it to `i_Buffer2`, and then releases the mutex. Thread 3 waits for a semaphore signal from Thread 2, locks the mutex, and processes the data read from `i_Buffer2`.

The main function initializes the mutex and semaphores, creates the threads, waits for them to finish execution using `pthread_join`, and finally destroys the mutex and semaphores to release the associated resources.

In summary, this code demonstrates a generic multi-threaded program with three threads (Thread 1, Thread 2, and Thread 3) communicating through shared buffers and synchronization mechanisms to achieve thread-safe data transfer and processing. The use of semaphores and mutex ensures proper synchronization among the threads, allowing them to execute concurrently while maintaining data integrity.

3.2 Implementation

```
#include <stdio.h>
#include <stdlib.h>
#include <pthread.h>
#include <unistd.h>
#include <semaphore.h>
#define ui_Size 100

int i_Buffer1[ui_Size];
int i_Buffer2[ui_Size];

pthread_mutex_t tu_Mutex;
sem_t tu_Semaphore1, tu_Semaphore2;

void *sr_Thread1(void *arg)
{
    int ui_I, ui_J, ui_Loopcounter, i_Array1[4];
    ui_J = 0;
    ui_Loopcounter = 0;

    // loop running indefintely , has to stopped by the user
    while (1)
    {
        for (ui_I = 0; ui_I < 4; ui_I++)
        {
            i_Array1[ui_I] = ui_Loopcounter;
        }
        // Locking the mutex
        pthread_mutex_lock(&tu_Mutex);
        for (ui_I = 0; ui_I < 4; ui_I++)
        {
            i_Buffer1[ui_J] = i_Array1[ui_I]; // Transferring data 
from array1 to the buffer assigned for transferring to Thread 2
            ui_J++;
        }

        pthread_mutex_unlock(&tu_Mutex);
        // Unlock a mutex.
        if (ui_J >= ui_Size)
        {
            ui_J = 0;
        }
        printf("LoopCounter of thread A :%d\n----------------------
-\n", ui_Loopcounter);
        ui_Loopcounter++;
        usleep(250000);
        sem_post(&tu_Semaphore1);
    }
    pthread_exit(NULL);
}

void *sr_Thread2(void *arg)
{
    int ui_I, ui_J, ui_Loopcounter, i_Array2[4];
    ui_J = 0;
    ui_Loopcounter = 0;

    while (1)
    {
        sem_wait(&tu_Semaphore1);
        // Locking the mutex
        pthread_mutex_lock(&tu_Mutex);

        for (ui_I = 0; ui_I < 4; ui_I++)
        {
            i_Array2[ui_I] = i_Buffer1[ui_J]; // Transferring data 
from i_Buffer1 to array2
            i_Buffer2[ui_J] = i_Array2[ui_I]; // Transferring data 
from array2 to the buffer assigned for transferring to Thread 3
            ui_J++;
        }

        pthread_mutex_unlock(&tu_Mutex);
        // Unlocking the mutex
        if (ui_J >= ui_Size) // Buffer reached its max ui_Size

        {
            ui_J = 0; // Re-initializing the value of j and over-
writing data in it
        }

        for (ui_I = 0; ui_I < 4; ui_I++)
        {
            printf("| Array from A to B: %d|\n", i_Array2[ui_I]);
        }
        printf("------------------------\nLoopCounter of thread B
:%d\n------------------------\n", ui_Loopcounter);
        ui_Loopcounter++;
        usleep(250000);
        sem_post(&tu_Semaphore2);
    }
    pthread_exit(NULL);
}

void *sr_Thread3(void *arg)
{
    int ui_I, ui_J, ui_Loopcounter, i_Array3[4];
    ui_Loopcounter = 0;
    ui_J = 0;

    while (1)
    {
        sem_wait(&tu_Semaphore2);
        // Locking the mutex
        pthread_mutex_lock(&tu_Mutex);

        for (ui_I = 0; ui_I < 4; ui_I++)
        {
            i_Array3[ui_I] = i_Buffer2[ui_J]; // Transferring data
from i_Buffer2 to array3
            ui_J++;
        }

        pthread_mutex_unlock(&tu_Mutex);
        // Unlocking the mutex
        if (ui_J >= ui_Size) // Buffer reached its max ui_Size

        {
            ui_J = 0; // Re-initialijing the value of j and over-
writing data in it
        }

        for (ui_I = 0; ui_I < 4; ui_I++)
        {
            printf("| Array from B to C: %d|\n", i_Array3[ui_I]);
        }
        printf("------------------------\nLoopCounterof thread C
:%d\n------------------------\n", ui_Loopcounter);
        ui_Loopcounter++;
        usleep(250000);
    }
    pthread_exit(NULL);
}

int main()
{
    pthread_t ul_Thread1, ul_Thread2, ul_Thread3; // Three threads
are taken here
```

```
    pthread_mutex_init(&tu_Mutex, NULL); // Initializing mutex
attributes to NULL

    sem_init(&tu_Semaphore1, 0, 0); // initialize the semaphore
w.r.t the parameter if its being shared among processes and its
initial value
    sem_init(&tu_Semaphore2, 0, 0);

    pthread_create(&ul_Thread1, NULL, sr_Thread1, NULL); // The
pthread_create() function starts a new thread in the calling process
    pthread_create(&ul_Thread2, NULL, sr_Thread2, NULL);
    pthread_create(&ul_Thread3, NULL, sr_Thread3, NULL);

    pthread_join(ul_Thread1, NULL); // The pthread_join() function
waits for the thread specified by thread to terminate
    pthread_join(ul_Thread2, NULL);
    pthread_join(ul_Thread3, NULL);

    pthread_mutex_destroy(&tu_Mutex); // Destroying the mutex to
free memory
    sem_destroy(&tu_Semaphore1);      // Free resources associated
with semaphore object tu_Semaphore1
    sem_destroy(&tu_Semaphore2);

    return 0;
}
```

3.3 Simulation on development environment

The system setup comprises Windows 10 Pro as the base operating system, utilized alongside VirtualBox, a virtualization software. Windows 10 Pro provides a user-friendly interface and is well-suited for professional use. With the help of VirtualBox, the user can create and manage virtual machines, thereby enabling the utilization of a Linux environment. This setup allows for the seamless integration of Windows and Linux, providing the user with the benefits of both operating systems.

The base- Operating system has the following architecture:

1. It has 11th generation Intel® Core ™ with i7-1165G7, 4 Core(s) and 8 logical processor(s). It has 16GB RAM (Random Access Memory).
2. It has Microsoft Windows 10 Pro Operating System.
3. It is an x64-based PC with a CPU clock rate of 2.8GHz.

The Virtual Box and the Linux environment are described:

1. Oracle® VM VirtualBox® Version 7.0.4 is used in implementation of the Linux environment.
2. Kali-Linux Version 2022.4 is being used to implement the task.

3. The Kali-Linux Version utilized is an Ubuntu 64-bit system and the code is compiled and executed in the Terminal emulator.

To compile and run a program in Kali Linux, follow these steps:

1. Open a terminal in Kali Linux.
2. Navigate to the directory where your program file is located using the `cd` command. For example, if your program is in the "test_project" folder, you can use the following command:
   ```
   cd /path/to/test_project
   ```
3. Check that the program file is present in the current directory using the `ls` command.
4. Compile the program using the appropriate compiler command. For example, if your program is written in C and saved in a file named "final.c", you can compile it using the following command:
   ```
   gcc -o final final.c
   ```

   This command uses the GCC compiler to compile the "final.c" file and generate an executable named "final".
5. If the compilation is successful and there are no errors, you can proceed to run the program by executing the generated executable. Use the following command:
   ```
   ./final
   ```

   This command will execute the compiled program and display any output or results produced by it.

By following these steps, the program Final.c is compiled and executed on the Kali-Linux environment producing the expected output.

```
┌──(kali㉿kali)-[~]
└─$ cd "/home/kali/Documents/Project_1"

┌──(kali㉿kali)-[~/Documents/Project_1]
```

```
└─$ ls
a.out   Day_1   Day_2   Day_3   Day_4   Day_5   Day_6   Day_7   Final   Final.c
Solutions

┌──(kali㉿kali)-[~/Documents/Project_1]
└─$ gcc Final.c -lpthread

┌──(kali㉿kali)-[~/Documents/Project_1]
└─$ ./Final
LoopCounter of thread A :0
------------------------
LoopCounter of thread A :1
------------------------
| Array from A to B: 0|
| Array from A to B: 0|
| Array from A to B: 0|
| Array from A to B: 0|
------------------------
LoopCounter of thread B :0
------------------------
LoopCounter of thread A :2
------------------------
| Array from A to B: 1|
| Array from A to B: 1|
| Array from A to B: 1|
| Array from A to B: 1|
------------------------
LoopCounter of thread B :1
------------------------
| Array from B to C: 0|
| Array from B to C: 0|
| Array from B to C: 0|
| Array from B to C: 0|
-------------------------
LoopCounterof thread C :0
-------------------------
| Array from B to C: 1|
| Array from B to C: 1|
| Array from B to C: 1|
| Array from B to C: 1|
-------------------------
LoopCounterof thread C :1
-------------------------
LoopCounter of thread A :3
------------------------
| Array from A to B: 2|
| Array from A to B: 2|
| Array from A to B: 2|
| Array from A to B: 2|
------------------------
LoopCounter of thread B :2
------------------------
LoopCounter of thread A :4
------------------------
| Array from A to B: 3|
| Array from A to B: 3|
| Array from A to B: 3|
| Array from A to B: 3|
------------------------
LoopCounter of thread B :3
------------------------
| Array from B to C: 2|
| Array from B to C: 2|
| Array from B to C: 2|
| Array from B to C: 2|
-------------------------
LoopCounterof thread C :2
-------------------------
LoopCounter of thread A :5
------------------------
| Array from A to B: 4|
| Array from A to B: 4|
| Array from A to B: 4|
| Array from A to B: 4|
------------------------
LoopCounter of thread B :4
------------------------
^C
```

CHAPTER 4
Porting on Target Hardware

4.1 Target environment description

To compile and execute a program on the target hardware which comprises of a Q or IQ PowerPC-based platform with a Linux kernel version 3.8.13 (32-bit), follow these steps:

1. Create a new file named "Final.c" in a folder named "test_project".

2. Open the terminal and navigate to the "test_project" folder using the `cd` command.Verify that the "Final.c" file is present in the folder.

3. Set up the PowerPC architecture for compilation. Use the compiler specific to PowerPC, which is typically named "-ppce6500-fsl-linux".

4. Run the following command in the terminal:
```
-ppce6500-fsl-linux-gcc -m32 -o final Final.c
```
In this command, we specify the compiler (`-ppce6500-fsl-linux-gcc`) followed by the `-m32` flag to indicate 32-bit architecture. The output binary is named "final", and the source file to be compiled is "Final.c".

5. Proceed to execute the program by running the following command in the terminal:
```
./final
```

This command will execute the compiled binary file and display the output, if any, generated by the program.

By following these steps, you can compile and run your "Final.c" program on a Q or IQ PowerPC-based platform with a Linux kernel version 3.8.13 (32-bit).

The following figure 4.1 demonstrates on how the compiler of type ‘ppce6500-fsl-linux-gcc’ is set

```
[root@localhost Meta_Data]# cd test_project/
[root@localhost test_project]# ls
Final.c
[root@localhost test_project]# . /opt/fsl-
networking/<PPC_ARCH_NAME>/environment-setup-ppce6500-fsl-linux
```

Figure 4.1: Setting the compilation configuration

The following figure 4.2 demonstrates on compiling the given program in the Q or IQ PowerPC-based platform.

```
[root@localhost test_project]# powerpc-fsl-linux-gcc  -m32 -mhard-
float -mcpu=e6500 --sysroot=/opt/fsl-
networking/<PPC_ARCH_NAME>/sysroots/ppce6500-fsl-linux Final.c -o
Final -lpthread
[root@localhost test_project]# ls
Final  Final.c
```

Figure 4.2: Compiling the given program

4.2 Output on Target Hardware

In the given configuration of a Q or IQ PowerPC-based platform with a Linux kernel version 3.8.13 (32-bit), executing the "Final.c" program would produce the expected output. The program's execution would take place within the PowerPC architecture, utilizing the provided Linux kernel version.

To view the output of the program, you would need to run it using the command ./final after successfully compiling the "Final.c" source code.

```
[root@localhost test_project]# scp Final
root@XXX.XXX.XXX.XXX:/mnt/disk4
root@XXX.XXX.XXX.XXX's password:
Final
100%   11KB   2.5MB/s   00:00
[root@localhost test_project]# ssh root@XXX.XXX.XXX.XXX
root@XXX.XXX.XXX.XXX's password:
```

```
~ # cd /mnt/disk4
/mnt/disk4 # ./Final
LoopCounter of thread A :0
------------------------
LoopCounter of thread A :1
------------------------
| Array from A to B: 0|
| Array from A to B: 0|
| Array from A to B: 0|
| Array from A to B: 0|
------------------------
LoopCounter of thread B :0
------------------------
LoopCounter of thread A :2
------------------------
| Array from A to B: 1|
| Array from A to B: 1|
| Array from A to B: 1|
| Array from A to B: 1|
------------------------
LoopCounter of thread B :1
------------------------
| Array from B to C: 0|
| Array from B to C: 0|
| Array from B to C: 0|
| Array from B to C: 0|
-------------------------
LoopCounterof thread C :0
-------------------------
LoopCounter of thread A :3
------------------------
| Array from A to B: 2|
| Array from A to B: 2|
| Array from A to B: 2|
| Array from A to B: 2|
------------------------
LoopCounter of thread B :2
------------------------
| Array from B to C: 1|
| Array from B to C: 1|
| Array from B to C: 1|
| Array from B to C: 1|
-------------------------
LoopCounterof thread C :1
-------------------------
LoopCounter of thread A :4
------------------------
| Array from A to B: 3|
| Array from A to B: 3|
| Array from A to B: 3|
| Array from A to B: 3|
------------------------
LoopCounter of thread B :3
------------------------
| Array from B to C: 2|
| Array from B to C: 2|
| Array from B to C: 2|
| Array from B to C: 2|
-------------------------
LoopCounterof thread C :2
-------------------------
LoopCounter of thread A :5
------------------------
| Array from A to B: 4|
| Array from A to B: 4|
| Array from A to B: 4|
| Array from A to B: 4|
------------------------
LoopCounter of thread B :4
------------------------
| Array from B to C: 3|
| Array from B to C: 3|
| Array from B to C: 3|
| Array from B to C: 3|
-------------------------
LoopCounterof thread C :3
-------------------------
LoopCounter of thread A :6
------------------------
| Array from A to B: 5|
| Array from A to B: 5|
| Array from A to B: 5|
| Array from A to B: 5|
------------------------
LoopCounter of thread B :5
------------------------
| Array from B to C: 4|
| Array from B to C: 4|
| Array from B to C: 4|
| Array from B to C: 4|
-------------------------
LoopCounterof thread C :4
-------------------------
LoopCounter of thread A :7
------------------------
| Array from A to B: 6|
| Array from A to B: 6|
| Array from A to B: 6|
| Array from A to B: 6|
------------------------
LoopCounter of thread B :6
------------------------
| Array from B to C: 5|
| Array from B to C: 5|
| Array from B to C: 5|
| Array from B to C: 5|
-------------------------
LoopCounterof thread C :5
-------------------------
LoopCounter of thread A :8
------------------------
| Array from A to B: 7|
| Array from A to B: 7|
| Array from A to B: 7|
| Array from A to B: 7|
------------------------
LoopCounter of thread B :7
------------------------
| Array from B to C: 6|
| Array from B to C: 6|
| Array from B to C: 6|
| Array from B to C: 6|
-------------------------
LoopCounterof thread C :6
-------------------------
LoopCounter of thread A :9
------------------------
| Array from A to B: 8|
| Array from A to B: 8|
| Array from A to B: 8|
| Array from A to B: 8|
------------------------
LoopCounter of thread B :8
------------------------
| Array from B to C: 7|
| Array from B to C: 7|
| Array from B to C: 7|
| Array from B to C: 7|
-------------------------
LoopCounterof thread C :7
-------------------------
LoopCounter of thread A :10
------------------------
| Array from A to B: 9|
| Array from A to B: 9|
| Array from A to B: 9|
| Array from A to B: 9|
------------------------
LoopCounter of thread B :9
------------------------
| Array from B to C: 8|
| Array from B to C: 8|
| Array from B to C: 8|
| Array from B to C: 8|
-------------------------
LoopCounterof thread C :8
-------------------------
LoopCounter of thread A :11
------------------------
| Array from A to B: 10|
| Array from A to B: 10|
| Array from A to B: 10|
| Array from A to B: 10|
------------------------
LoopCounter of thread B :10
------------------------
| Array from B to C: 9|
| Array from B to C: 9|
| Array from B to C: 9|
| Array from B to C: 9|
-------------------------
LoopCounterof thread C :9
-------------------------
LoopCounter of thread A :12
------------------------
| Array from A to B: 11|
| Array from A to B: 11|
| Array from A to B: 11|
| Array from A to B: 11|
------------------------
LoopCounter of thread B :11
------------------------
| Array from B to C: 10|
| Array from B to C: 10|
| Array from B to C: 10|
| Array from B to C: 10|
-------------------------
LoopCounterof thread C :10
-------------------------
LoopCounter of thread A :13
------------------------
| Array from A to B: 12|
| Array from A to B: 12|
| Array from A to B: 12|
| Array from A to B: 12|
------------------------
LoopCounter of thread B :12
------------------------
| Array from B to C: 11|
| Array from B to C: 11|
| Array from B to C: 11|
| Array from B to C: 11|
-------------------------
LoopCounterof thread C :11
-------------------------
^C
/mnt/disk4 # Connection to XXX.XXX.XXX.XXX closed.
[root@localhost test_project]#
```

CHAPTER 5
Multithreading in Real-Time Application

Synchronized-threaded architecture is commonly used in a wide range of real-world applications where timing requirements and responsiveness are crucial. Here are a few examples:

1. Real-time Operating Systems (RTOS): RTOSs are designed to handle time-critical tasks in applications such as aerospace, automotive, industrial automation, and medical devices. Synchronized-threaded architecture is employed to manage multiple tasks with different priorities and deadlines, ensuring timely execution and deterministic behaviour.

2. Robotics and Automation Systems: In robotic systems and factory automation, synchronized-threaded architecture is utilized to control multiple components and subsystems simultaneously. Real-time threads can handle tasks like sensor data acquisition, motion control, and decision-making, enabling precise and coordinated operations.

3. Telecommunications and Networking: Real-time applications in telecommunication and networking, such as voice and video streaming, demand timely processing to maintain quality and minimize latency. Synchronized-threaded architecture helps ensure that packets are processed, routed, and delivered within strict timing constraints.

4. Gaming and Multimedia: Game engines and multimedia frameworks often use synchronized-threaded architecture to handle various tasks concurrently, such as rendering graphics, playing audio, physics simulation, and AI computations. This architecture allows for smooth, responsive gameplay and multimedia playback.

5. Automotive Systems: Modern vehicles employ synchronized-threaded architectures to manage critical tasks like engine control, braking, steering, and safety systems. Real-time threads ensure timely execution of these tasks while accommodating non-real-time tasks like infotainment systems and communication modules.

6. Medical Devices and Healthcare Systems: Real-time requirements are paramount in medical devices and healthcare systems. Synchronized-threaded architecture is used to handle tasks like patient monitoring, diagnostics, drug delivery, and surgical robotic systems, ensuring precise and timely actions.

These are just a few examples, but synchronized-threaded architecture is widely applicable in any system where timing constraints and responsiveness are essential. By using this architecture, developers can build reliable, real-time applications that meet stringent requirements in various domains.

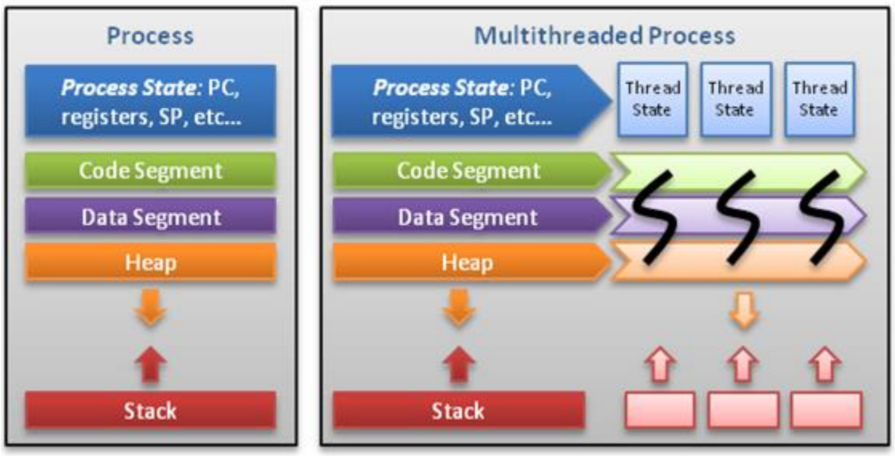


Figure 5.1 : Multithreaded process implementation

CHAPTER 6
Conclusions and Future Scope

6.1 Conclusion

In conclusion, the application has been successfully compiled and executed on both PowerPC and Intel microprocessors. It is a multi-threaded application that utilizes a global buffer for data sharing between threads. Thread synchronization is achieved through the use of semaphores. The implementation ensures that access to shared data occurs in a mutually exclusive manner, preventing any potential data conflicts or race conditions.

By leveraging these techniques, the application effectively achieves efficient and reliable data sharing among threads, without the need for complex data structures or global variables. This approach enhances the overall performance and reliability of the multi-threaded application.

Overall, the successful compilation, execution, and utilization of thread synchronization and shared data access techniques demonstrate the effectiveness of the implemented solution for achieving efficient and reliable multi-threaded programming.

6.2 Future Scope

Multi-threaded applications continue to be crucial in modern computing systems, and there are several avenues for further exploration and enhancement:

1. Performance Optimization: Analyze the program's performance and identify opportunities for optimization, such as reducing synchronization overhead, fine-tuning CPU affinity settings, or exploring parallel algorithms to maximize thread utilization.

2. Scalability: Assess the program's scalability by testing it with a higher number of threads or larger data sets. Evaluate how the application performs under increased workload and identify potential bottlenecks or scalability limitations.

3. Error Handling and Resilience: Enhance the application's error handling capabilities by implementing mechanisms such as thread-safe logging, proper handling of exceptions, and graceful recovery from failures to ensure robustness and resilience.

4. Real-Time Processing: Investigate real-time systems and develop multi-threaded applications that meet stringent timing constraints. This could involve utilizing real-time operating systems, employing priority-based scheduling algorithms, and ensuring determinism in thread execution.

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