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Measure processes execution time

Project

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Contents

1 Introduction **3**
1.0.1 Context 3
1.0.2 Specifications 3
1.0.3 Objectives 3

2 Bibliographic study **5**
2.0.1 What is benchmark? 5
2.0.2 What is microbenchmark? 5

3 Analysis **8**
3.0.1 Programming languages used: 9
3.0.2 Memory access and allocation: 9
3.0.3 Threads 10
3.0.4 User Interface 11

4 Design **13**

5 Implementation **16**
5.1 Compilation and Running 16

6 Testing and validation **19**
6.1 Testing Objectives 19
6.2 Testing Strategy 19
6.3 Validation Process 19
6.4 Results and Analysis 19

7 Conclusion **22**
7.1 Summary 22
7.2 Key Findings 22
7.3 Significance 22

Chapter 1

Introduction

1.0.1 Context

The overarching goal of this project is to develop a program that can comprehensively assess memory allocation, memory access efficiency, thread creation speed, thread context switching overhead, and thread migration performance across various programming languages, including C, C++, and Java. By examining these critical aspects, the project aims to provide a thorough evaluation of each language's strengths and weaknesses in real-world scenarios.

1.0.2 Specifications

This project comprises three distinct components, each implemented in one of the programming languages: C, C++, and Java. Each component is responsible for carrying out specific tasks independently, with the results being recorded in separate files. To facilitate easy comparison, an intuitive user interface will be created, allowing users to initiate all three projects simultaneously, store the results in files, and display the outcomes for comparative analysis with the click of a button.

1.0.3 Objectives

The objectives of this project are as follows: Language Comparison: To evaluate and compare the performance of memory allocation, memory access, thread creation, thread context switching, and thread migration across the programming languages C, C++, and Java. Isolation of Language-Specific Effects: To isolate and understand how language-specific features and libraries influence the efficiency and ease of implementation for memory management and multithreading.

Meeting 1

- Discuss and finalize the project plan.
- Create a detailed plan specifying tasks and milestones.
- Set deadlines for each task.
- Decide on the programming languages to be used (Java, C, C++).

- Brainstorm and share initial ideas for the project.

Meeting 2

- Work on the Java part of the project.
- Troubleshoot any issues that arise.
- Discuss potential solutions for handling interfaces in the project.
- Begin documenting the C and C++ portions of the project.

Meeting 3

- Continue coding for C++.
- Start implementing the interface for the project.
- Review progress and address any challenges encountered.

Meeting 4

- Write the code for C.
- Work on improving documentation for C and C++.
- Continue working on the interface code.

Meeting 5

- Dedicate this meeting to documentation.
- Compile and organize documentation for the entire project.
- Write documentation for Java, C, C++, and the interface.

Meeting 6

- Continue with documentation.
- Focus on creating a user-friendly guide or manual.
- Create a binding that connects the different components of the project.

Meeting 7

- Review the entire project planning process.
- Ensure all project tasks have been completed.

Chapter 2

Bibliographic study

2.0.1 What is benchmark?

A benchmark is a test that measures the performance of hardware, software, or computer. These tests help compare how well a product may do against other products. A computer benchmarking program works by running a series of well-defined tests on the PC to measure its performance.

2.0.2 What is microbenchmark?

A microbenchmark is either a program or routine to measure and test the performance of a single component or task. Microbenchmarks are used to measure simple and well-defined quantities such as elapsed time, rate of operations, bandwidth, or latency. Typically, microbenchmarks were associated with the testing of individual software subroutines or lower-level hardware components such as the CPU and for a short period of time.

"In contrast, the generation of microbenchmarks with a given set of dynamic properties is a complex task. The dynamic properties are directly affected by the static microbenchmark properties as well as the architecture on which the microbenchmark is run. Examples of dynamic properties include instructions per cycle, memory hit/miss ratios, power, or temperature."

- A microbenchmark always pertains to a very small amount of code. Hence, they're incredibly fast to implement.
- With that said, you need to make sure you're using them in the right place. Implementing microbenchmarks in instances where they aren't necessary is a waste of time.
- A well-defined quantity like rate of operations: Bandwidth, Latency, The amount of time elapses between X and Y.

To Do:

Measure:

1. Memory allocation

2. Memory access (static and dynamic)
3. Thread creation
4. Thread context switch
5. Element addition to list
6. Element removal from list
7. List reversal

How to measure time in:

- **Java:** Use either `System.currentTimeMillis()` - this method returns time in milliseconds, or use `System.nanoTime()` which is more precise but can overflow if there are very long execution times. If needed, convert milliseconds to nanoseconds. Use JMH (Java Microbenchmarking Harness), which allows you to perform microbenchmarks on specific code sections. It is a Java library and a framework that provides a standardized and effective way to create, run, and analyze microbenchmarks.
- **C:** Use the `clock()` function from the `<time.h>` header. Calculate execution time by subtracting the start time from the end time and then converting to seconds by dividing by `CLOCKS_PER_SEC` and multiplying by 1000 to transform into milliseconds. However, this method is not so accurate. For more precise results, use `clock_gettime`. The time is calculated in nanoseconds and should be converted into milliseconds. This method provides high precision for measuring very short execution times.
- **C++:** Use the `<chrono>` library to measure time intervals. Use `high_resolution_clock` as the clock source to record start and end times. Use `high_resolution_clock::now()` to record the current time and use `duration_cast` to convert the duration to milliseconds.
- **Python:** To measure time in nanoseconds in Python for general cases, you can use the texttttime module. However, it's important to note that the precision of the timing measurements may be limited by the underlying system's clock resolution.In Python, the time module offers two main functions for measuring time with nanosecond precision: `time_ns()` and `perf_counter_ns()`(available in Python 3.7 and later). These functions return the current time in nanoseconds as an integer. However, despite their high precision, the actual accuracy of the measurements may be limited by the system's clock resolution.

Thread context switch:

Thread switching is a type of context switching from one thread to another thread in the same process. Thread switching is very efficient and much cheaper because it involves switching out only identities and resources such as the program counter, registers, and stack pointers.

Thread context switching takes place when the CPU saves the current state of the thread and switches to another thread of the same process.

Element addition to list

In many programming languages, including popular ones like Python, Java, C, and JavaScript, indices for arrays or lists start at 0, following a zero-based system. However, it's essential to recognize that indexing conventions can vary. When adding elements to a list, different languages offer various methods, such as append() and insert() in Python. The choice of method depends on the specific language and the desired outcome, so it's crucial to adapt based on the programming language and the program's requirements.

Element removal from list

In programming languages like Python, Java, C, and JavaScript, arrays or lists often start with a zero-based indexing system. When removing elements from a list, the method varies by language. In Python, for example, you can use remove() or pop() to eliminate specific values or elements at a particular index. Choose the appropriate method based on the language and your program's requirements. Understanding the indexing conventions and available methods is crucial for effective list manipulation.

List reversal

In programming, many languages offer methods to reverse a list. Commonly used methods include reverse() in Python, which inverts the order of elements in-place, and Collections.reverse() in Java for reversing a list. However, not all languages have dedicated reverse methods. In such cases, you can use other approaches like iterating through the list and swapping elements from both ends. The specific method depends on the programming language you're using. When reversing a list, consider the available options in your chosen language and select the one that best suits your needs. Understanding these language-specific methods is essential for effective list manipulation in your code.

Chapter 3

Analysis

To measure memory allocation, memory access, thread creation, thread context switch, and thread migration in a Java project, you would typically use a combination of profiling tools, monitoring libraries, and custom instrumentation. The architecture would involve integrating various components and tools to gather the required metrics.

Java Application: This is a Java application where you want to measure memory allocation. It includes Java code.

Custom Instrumentation: This component includes custom code that will be added to the application to measure memory allocation. It can utilize Java's memory management functions or custom logic to monitor memory allocation.

Memory Allocation Data: Custom instrumentation records memory allocation data, which includes information such as allocated memory size, timestamps, and any other relevant details.

Data Collection & Storage Component: This component is responsible for collecting and storing the memory allocation data generated by the Java application. It handles the data collection process and ensures its proper storage.

Visualization & Analysis Tools: These tools are responsible for analyzing and visualizing the memory allocation data.

Static Memory: Static memory allocation occurs when memory is reserved at compile-time and remains fixed throughout the program's execution. In C and C++, static allocation typically involves declaring variables with a fixed size using keywords like `int`, `char`, or custom data structures. In Java, the equivalent would be objects created at compile-time or with fixed sizes, typically using primitive data types or pre-allocated arrays.

Dynamic Memory: Dynamic memory allocation occurs when memory is allocated at runtime and can be resized as needed. In C and C++, this is achieved using functions like `malloc`, `calloc`, `realloc`, and `free`. In Java, dynamic memory allocation is primarily managed by the Java Virtual Machine (JVM), and you create objects using `new` or through data structures like `ArrayList` or dynamic arrays.

3.0.1 Programming languages used:

- **C:** C is a cross-platform language that can be used to create high-performance applications.
- **C++:** The main difference between C and C++ is that C++ supports classes and objects, while C does not. C++ allows software developers to define their own data types and manipulate them using functions and methods.
- **Java:** Java is a widely-used programming language for coding web applications. It is multi-platform, object-oriented, and network-centric, serving as a platform in itself. Java is a fast, secure, and reliable programming language suitable for coding mobile apps, enterprise software, big data applications, and server-side technologies.
- **Python:** Python is a versatile, high-level programming language known for its readability and simplicity. It supports multiple paradigms, including procedural, object-oriented, and functional programming. Python is widely used for web development, data science, artificial intelligence, automation, and scripting.

3.0.2 Memory access and allocation:

In C:

- Use standard C library functions like `malloc` and `calloc` for dynamic memory allocation.
- Measure memory allocation by tracking the size of memory blocks allocated and monitor memory usage over time.
- Utilize memory analysis and profiling tools to identify issues related to memory access, such as buffer overflows and uninitialized memory.

In C++:

- In C++, you can use operators like `new` and `delete` for dynamic memory allocation. Prefer smart pointers like `std::shared_ptr` and `std::unique_ptr` to manage memory automatically.
- To measure memory allocation, you can override the global `new` and `delete` operators to record allocations and deallocations or use libraries like `tcmalloc` or `jemalloc`.

In Java:

- In Java, memory allocation is managed by the Java Virtual Machine (JVM). Objects are created using the `new` keyword, and memory is automatically managed, including garbage collection.
- To measure memory allocation, consider using Java Profiling.

In Python:

- Python manages memory automatically through a built-in garbage collector. Memory allocation and deallocation are handled by the Python interpreter.

- Python supports dynamic typing and has a dynamic memory allocation model. You create objects using standard Python syntax, and memory management is handled transparently.
- To profile memory usage in Python, tools like `memory_profiler` or integrated profilers can be used.

3.0.3 Threads

In C:

- In C, you can create threads using the POSIX threads (`pthread`) library or other threading libraries like `libuv`. Measure thread creation time by recording the start and end times of thread creation and calculating the elapsed time.
- To measure thread context switch time, you can use clock functions to record the timestamp before and after a context switch occurs. By subtracting these timestamps, you can determine the time taken for a context switch.
- Thread allocation in C typically involves dynamic memory allocation for thread stacks. You can use memory profiling tools to monitor memory allocation patterns for thread stacks.

In C++:

- In C++, you can create threads using the C++ Standard Library's `<thread>` and `<mutex>` headers. Measure thread creation time similarly to C, by recording start and end times during thread creation.
- Measuring thread context switch in C++ can be done similarly to C, by timestamping before and after context switches.
- Thread allocation in C++ is usually managed by the operating system. You can monitor memory allocation by profiling the memory usage of thread stacks.

In Java:

- In Java, create threads using the `Thread` class or the `ExecutorService` framework. To measure thread creation time, record timestamps before and after thread creation and calculate the elapsed time.
- Java threads are managed by the JVM, and you cannot directly measure context switch times. However, you can monitor thread behavior using profilers and analyze the results to identify context switches.
- In Java, memory allocation for thread stacks is managed by the JVM. You can monitor memory allocation patterns using Java profilers, such as VisualVM or Java Mission Control.

In Python:

- In Python, threading can be achieved using the `threading` module. Create threads by instantiating the `Thread` class and overriding the `run` method. Measure thread creation time similarly to other languages.

- Python's Global Interpreter Lock (GIL) limits concurrent execution of threads. To measure thread context switch time, consider using external tools, as Python's GIL affects thread scheduling.
- Thread allocation in Python is managed by the interpreter. Monitor memory allocation using Python's built-in tools or external memory profilers.

3.0.4 User Interface

The user interface will consist of a frame featuring a selection area for choosing the specific measurement to be performed. It will also include a "Start" button, a "Clear" or "Reset" button, and a Results Panel where the selected results will be displayed.

To enhance the visual appeal and user-friendliness of the application, consider incorporating various styles and themes. Additionally, it's advisable to provide tooltips and context-sensitive help for users, helping them grasp the nature of each measurement type and the importance of the results.

Moreover, offer users the capability to export the measurement outcomes to a file, such as CSV or PDF, enabling further analysis and record-keeping. To present measurement statistics, utilize tables or charts for improved data visualization.

Java Swing tutorial is a part of Java Foundation Classes (JFC) that is used to create window-based applications. It is built on the top of AWT (Abstract Windowing Toolkit) API and entirely written in Java.

Swing is a Java Foundation Classes [JFC] library and an extension of the Abstract Window Toolkit [AWT]. Swing offers much-improved functionality over AWT, new components, expanded component features, and excellent event handling with drag-and-drop support.

3.5 Data Models

A CSV (Comma-Separated Values) file is a simple and widely used file format for storing structured data, primarily in a plain text format. CSV files are used to represent tabular data, making them easy to create, read, and manipulate. Each line in a CSV file typically corresponds to a row of data, and the values within a row are separated by commas (or other specified delimiters).

Designing the user interface (UI) of your program in Java typically involves creating a graphical user interface (GUI) for your software application. Java provides a robust and platform-independent way to create GUI applications using libraries and frameworks such as Swing and JavaFX. For a user-friendly presentation of the results, I'd utilize JFreeChart and XChart libraries to generate charts and graphs.

Open File: You need to open the CSV file for writing. In C and C++, you typically use functions like `fopen` or `ofstream`. In Java, you can use classes like `FileWriter`.

Write Data: Write the data to the file in CSV format. Each line typically represents a row, and values are separated by commas. The first row often contains column headers.

Close file: After writing the data, it's important to close the file to ensure that changes are saved and that system resources are released.

To measure memory allocation, use Java's built-in memory management and create custom instrumentation. Swing offers a rich collection of UI components, including buttons, labels, text fields, text areas, checkboxes, radio buttons, lists, tables, trees, and more. These components can be customized and combined to create complex interfaces. Swing applications often follow the Model-View-Controller (MVC) architectural pattern, which separates data (Model), UI presentation (View), and user interaction logic (Controller). This promotes code organization and maintainability.

Chapter 4

Design

Define a clear thread management strategy that includes thread creation, execution, and termination. Ensure that threads are started and terminated appropriately and safely. Implement error handling mechanisms, such as exception handling in C++ and exception propagation in Java, to handle thread-specific errors gracefully.

Thoroughly test your threaded application and use profiling tools to identify performance bottlenecks, concurrency issues, and memory usage problems.

Document your thread creation and management strategy. Implement monitoring and logging to track the behavior of threads during runtime.

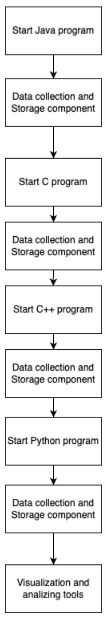

Start Java program
Data collection and Storage component
Start C program
Data collection and Storage component
Start C++ program
Data collection and Storage component
Start Python program
Data collection and Storage component
Visualization and analizing tools

Figure 4.1: Flow of the project

Start Java Program:

- The project begins by executing a Java program.
- The Java program is designed to collect data related to memory allocation, memory access (both static and dynamic), thread creation, thread context switch, element addition to a list, element removal from a list, and list reversal.

Data Collection in Java:

- The Java program collects data for the specified functions.
- For memory-related functions, it records information about memory allocation patterns and access.
- For threading, it measures the time taken for thread creation and context switching.
- For list manipulation, it records data related to element addition, removal, and list reversal.

Start C Program:

- After the Java program completes, the project proceeds to execute a C program.
- The C program is expected to perform the same set of functions as the Java program, collecting data on memory, threading, and list operations.

Data Collection in C:

- Similar to the Java program, the C program collects data for memory, threading, and list functions.
- The data may include memory allocation details, thread creation times, context switch times, and list manipulation statistics.

Start C++ Program:

- Following the C program, the project executes a C++ program.
- The C++ program mirrors the functionality of the Java and C programs, collecting data on memory, threading, and list operations.

Data Collection in C++:

- The C++ program collects data for the specified functions, similar to the Java and C programs.
- It records relevant information about memory, threading, and list operations.

Start Python Program:

- After the C++ program, the project moves on to execute a Python program.
- The Python program is designed to implement the same set of functions for memory, threading, and list operations.

Data Collection in Python:

- The Python program collects data related to memory, threading, and list functions.
- Python, being an interpreted language, may have different characteristics in terms of memory management and threading.

Chart Generation Based on Interface Selection:

- Once data is collected from all programming languages, the project proceeds to generate charts based on the user's interface selection.
- Depending on the selected interface, the project uses libraries like JFreeChart a in Java to create visual representations of the collected data, providing insights into memory usage, threading performance, and list operations.

Conclusion:

- The project concludes with a visual representation of the collected data, allowing users to analyze and compare the performance of memory allocation, threading, and list operations across different programming languages.
- This project involves multi-language programming, data collection, and visualization, providing valuable insights into the performance characteristics of the implemented functions across different programming paradigms.

Chapter 5

Implementation

5.1 Compilation and Running

To compile and run each code, simply click a button on the interface. This action initiates the execution of distinct programs written in Java, C, C++, and Python, facilitated by the `ProcessBuilder`. Each program performs specific operations, and the resulting data is meticulously written to designated files.

After execution, the interface smartly showcases these results, allowing you to effortlessly analyze and compare them. The presentation in the interface is intelligently tailored to the selected programming language and the specific operation you've chosen.

At the core of this process, there's a crucial main function written in Java. Think of it as the director overseeing the entire operation, making sure everything runs smoothly and in harmony.

Function	**Description**
measureMemoryAllocationTime	Measures the time taken to allocate memory for an array of a given size. Returns the elapsed time in nanoseconds.
measureStaticMemoryAccess	Measures the time taken to access elements in a statically allocated array. Returns the elapsed time in nanoseconds.
measureDynamicMemoryAccess	Measures the time taken to dynamically allocate and access elements in an array. Returns the elapsed time in nanoseconds.
measureThreadCreation	Measures the time taken to create a thread and wait for its completion. Returns the elapsed time in nanoseconds.
measureThreadContextSwitch	Measures the time taken for a context switch between two threads. Uses synchronized blocks and notifications. Returns the elapsed time in nanoseconds.
measureElementAdditionToList	Measures the time taken to add an element to an ArrayList. Returns the elapsed time in nanoseconds.
measureElementRemovalFromList	Measures the time taken to remove an element from an ArrayList. Returns the elapsed time in nanoseconds.
measureListReversal	Measures the time taken to reverse the elements in an ArrayList. Returns the elapsed time in nanoseconds.

Table 5.1: Measurements Function in Java

Function	**Description**
measureMemoryAllocationTime	Measures the time taken to allocate memory for an array of a given size. Returns the elapsed time in nanoseconds.
measureStaticMemoryAccess	Measures the time taken to access elements in a statically allocated array. Returns the elapsed time in nanoseconds.
measureDynamicMemoryAccess	Measures the time taken to dynamically allocate and access elements in an array. Returns the elapsed time in nanoseconds.
measureThreadCreation	Measures the time taken to create a thread and wait for its completion. Returns the elapsed time in nanoseconds.
measureThreadContextSwitch	Measures the time taken for a context switch between two threads using synchronized blocks and notifications. Returns the elapsed time in nanoseconds.
measureElementAdditionToList	Measures the time taken to add an element to an ArrayList. Returns the elapsed time in nanoseconds.
measureElementRemovalFromList	Measures the time taken to remove an element from an ArrayList. Returns the elapsed time in nanoseconds.
measureListReversal	Measures the time taken to reverse the elements in an ArrayList. Returns the elapsed time in nanoseconds.

Table 5.2: Measurements Function in C

Function	**Description**
measureMemoryAllocationTime	Measures the time taken to allocate memory for an array of a given size using dynamic memory allocation. Returns the elapsed time in nanoseconds.
measureStaticMemoryAccess	Measures the time taken to access elements in a statically allocated array. Returns the elapsed time in nanoseconds.
measureDynamicMemoryAccess	Measures the time taken to dynamically allocate and access elements in an array. Returns the elapsed time in nanoseconds.
measureThreadCreation	Measures the time taken to create a thread and wait for its completion. Returns the elapsed time in nanoseconds.
measureThreadContextSwitch	Measures the time taken for a context switch between two threads using std::async. Returns the elapsed time in nanoseconds.
measureElementAdditionToList	Measures the time taken to add an element to a std::vector. Returns the elapsed time in nanoseconds.
measureElementRemovalFromList	Measures the time taken to remove an element from a std::vector. Returns the elapsed time in nanoseconds.
measureListReversal	Measures the time taken to reverse the elements in a std::vector. Returns the elapsed time in nanoseconds.

Table 5.3: Measurements Function in C++

Function	**Description**
measureMemoryAllocationTime	Measures the time taken to allocate memory for an array of a given size. Returns the elapsed time in nanoseconds using a list.
measureStaticMemoryAccess	Measures the time taken to access elements in a statically allocated list. Returns the elapsed time in nanoseconds.
measureDynamicMemoryAccess	Measures the time taken to dynamically allocate and access elements in a list. Returns the elapsed time in nanoseconds.
measureThreadCreation	Measures the time taken to create a thread and wait for its completion using the threading module. Returns the elapsed time in nanoseconds.
measureThreadContextSwitch	Measures the time taken for a context switch between two threads using ThreadPoolExecutor. Returns the elapsed time in nanoseconds.
measureElementAdditionToList	Measures the time taken to add an element to a list. Returns the elapsed time in nanoseconds.
measureElementRemovalFromList	Measures the time taken to remove an element from a list. Returns the elapsed time in nanoseconds.
measureListReversal	Measures the time taken to reverse the elements in a list. Returns the elapsed time in nanoseconds.

Table 5.4: Measurements Function in Python

Chapter 6

Testing and validation

6.1 Testing Objectives

The primary objectives of the testing phase include:

- Validating the functionality of the system.
- Identifying and resolving software defects and issues.
- Assessing the performance of the application under various scenarios.

6.2 Testing Strategy

The testing strategy adopted for this project encompasses key elements such as unit testing, integration testing, system testing, and acceptance testing.

6.3 Validation Process

To validate the system, 1000 tests were conducted, covering a range of scenarios and functionalities. The results were analyzed to ensure the system's compliance with user requirements and expectations.

6.4 Results and Analysis

The testing phase resulted in the identification of several issues and defects. Each identified issue was thoroughly analyzed, and corrective measures were implemented. Performance metrics, including response times and resource utilization, were measured and analyzed.

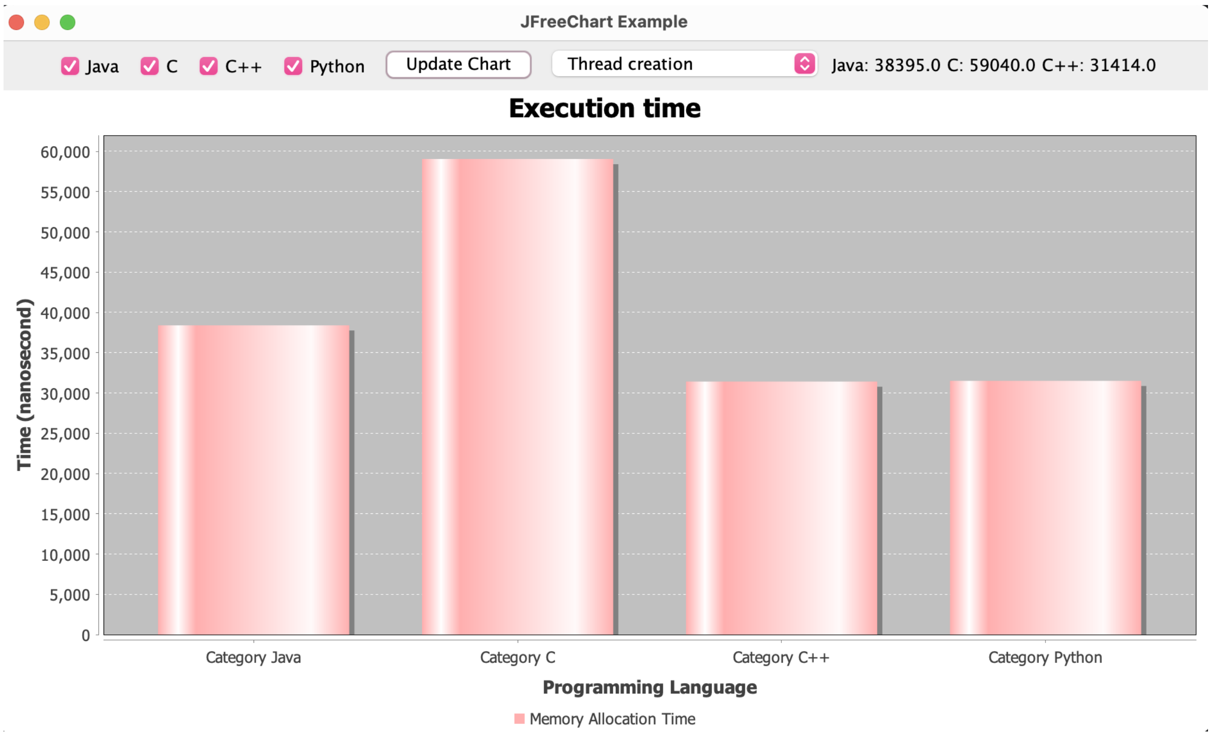


Figure 6.1: Evaluating Thread Creation Across All Programming Languages

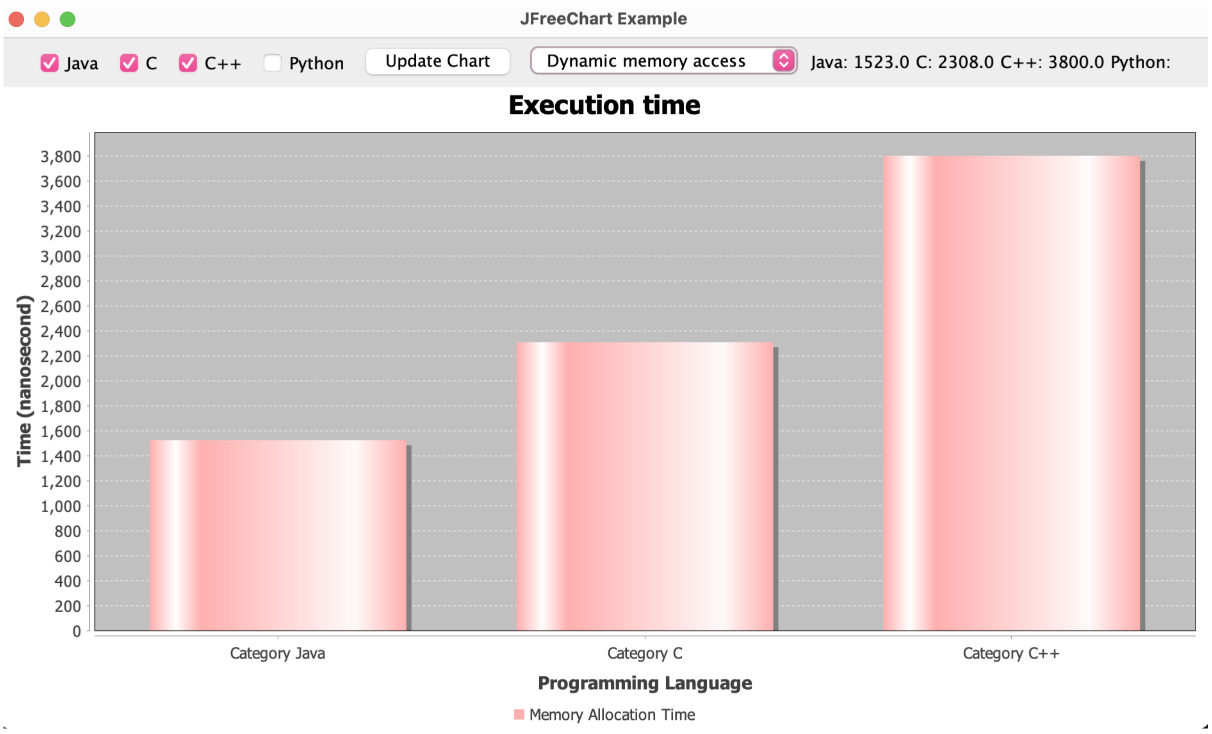
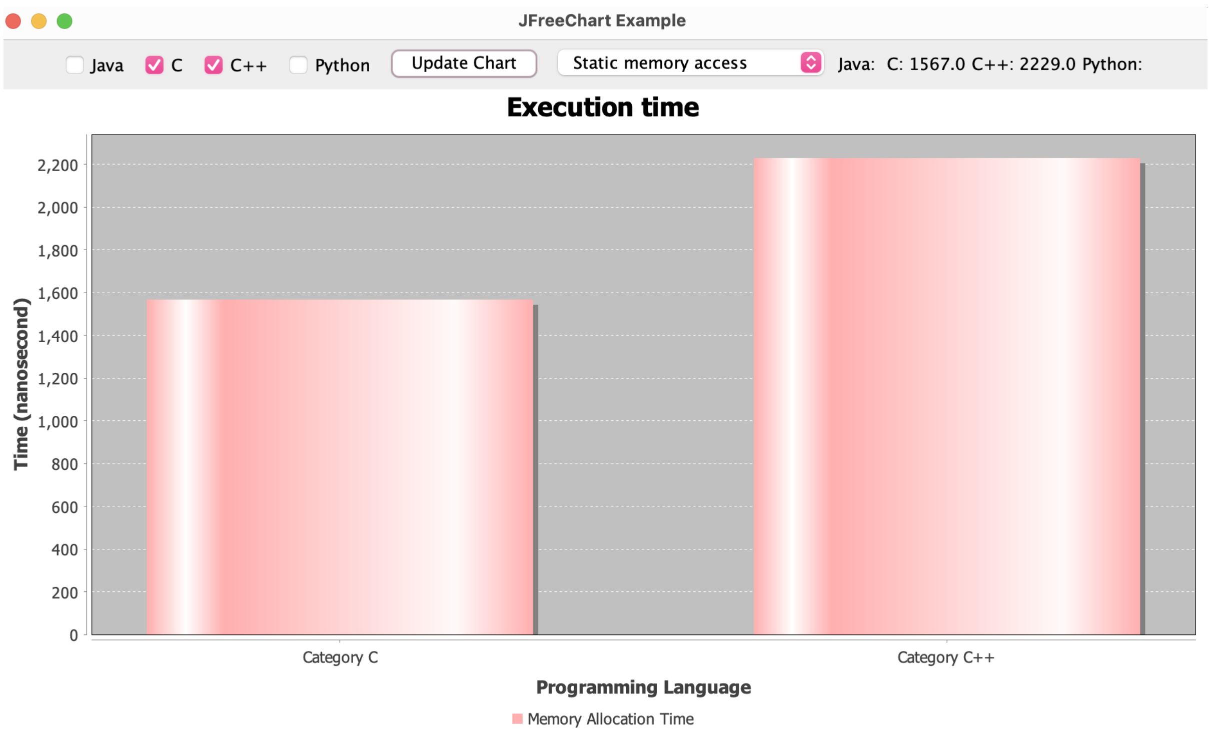
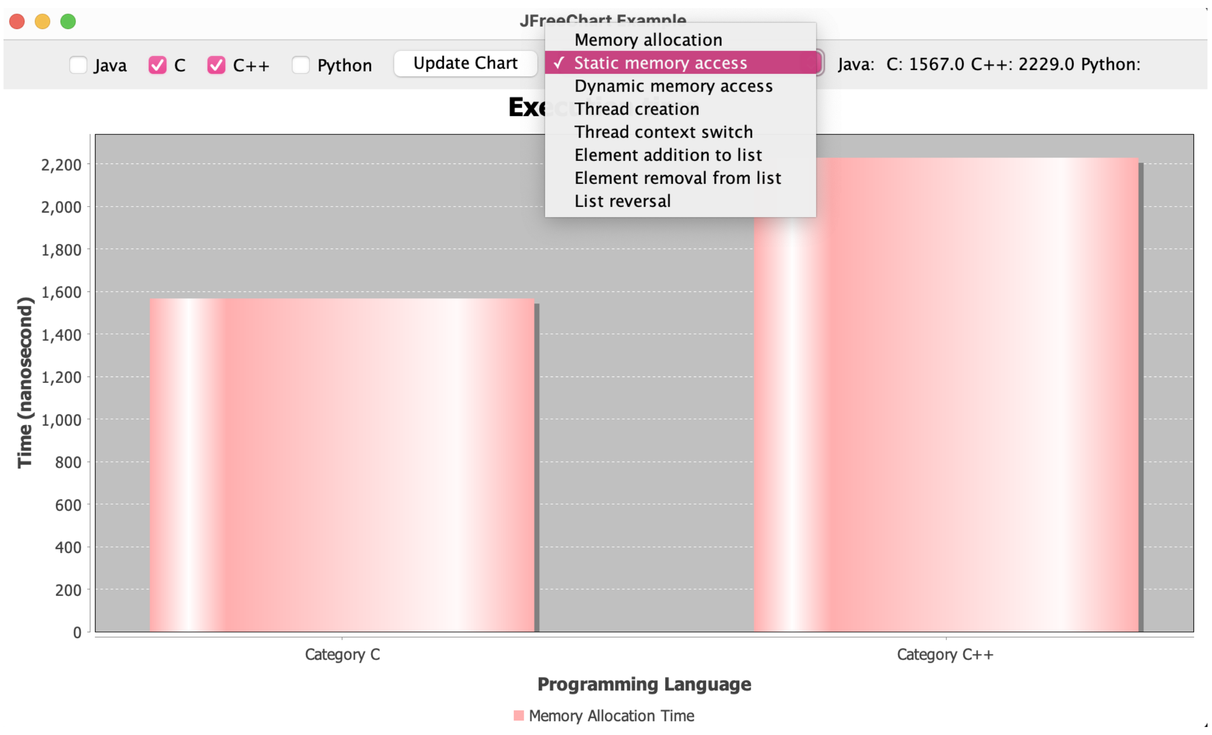


Figure 6.2: Evaluating Memory Access Across Java, C, C++



Java: C: 1567.0 C++: 2229.0 Python:

Figure 6.3: Evaluating Static Memory Access Across C, C++



Java: C: 1567.0 C++: 2229.0 Python:

Figure 6.4: Enumerating All Features and Measurement Possibilities

Chapter 7

Conclusion

7.1 Summary

In summary, this project aimed to understand and compare the execution times of critical processes in Java, C, C++, and Python. Through the development of benchmarking functions targeting memory allocation, memory access, thread operations, and list manipulations, we gained valuable insights into the performance characteristics of each language.

By conducting a series of tests and gathering a substantial amount of data, we were able to analyze trends and variations. The calculated averages provided a concise summary of each language's overall performance in different operations.

7.2 Key Findings

The results showed that each programming language has its own strengths and weaknesses for specific operations. Java excelled in memory allocation, C and C++ performed exceptionally well in memory access, and Python demonstrated flexibility in list operations, even with some performance trade-offs. While the project successfully achieved its primary goal of measuring process execution times, it also highlighted the importance of considering language-specific nuances and trade-offs when selecting a language for specific tasks.

7.3 Significance

This project provides useful insights for developers and decision-makers, helping them choose programming languages based on performance. It underscores the importance of benchmarking and testing to ensure accurate insights into software system performance.

In summary, the project achieved its goals and set the stage for future investigations and optimizations. It adds to the ongoing discussion about the real-world performance of programming languages.

Bibliography

[1] Computer Hope. (n.d.). Benchmark. Retrieved from `https://www.computerhope.com/jargon/b/benchmar.htm`

[2] Springer. (n.d.). Computer Benchmark. Retrieved from `https://link.springer.com/referenceworkentry/10.1007/978-3-319-77525-8_111`

[3] ScienceDirect. (n.d.). Microbenchmarks. Retrieved from `https://www.sciencedirect.com/topics/computer-science/microbenchmarks`

[4] GeeksforGeeks. (n.d.). Difference between Thread Context Switch and Process Context Switch. Retrieved from `https://www.geeksforgeeks.org/difference-between-thread-context-switch-and-process-context-switch/`

[5] Java Revisited. (n.d.). Process and Thread Context Switching: Do You Know the Difference? Retrieved from `https://medium.com/javarevisited/process-and-thread-context-switching-do-you-know-the-difference-updated-8fd93877c`