RUST : A SAFE AND EFFICIENT OS PARADIGM

A PROJECT REPORT

Submitted by

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CERTIFICATE

Certified that this project report "**RUST : A SAFE AND EFFICIENT OS PARADIGM**" is the bonafide work of "**HISHAM C (RCE20CS022)** of Department of Computer Science and Engineering in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology in Computer Science and Engineering under the APJ Abdul Kalam Technological University during the year 2023-2024.

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Mission

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- To provide a learning ambience to enhance problem solving skills, leadership qualities, team spirits and ethical responsibilities with a commitment to lifelong learning.
- To establish industry institute interaction activities to enhance the entrepreneurship skills

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PO3.Design/Development of Solutions: Design solutions for complex engineering problems and design system components or processes that meet the specified needs with appropriate consideration for the public health and safety, and the cultural, societal, and environmental considerations.

PO4.Conduct Investigations of Complex Problems: Use research-based knowledge and research methods including design of experiments, analysis and interpretation of data, and synthesis of the information to provide valid conclusions for complex problems:

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PO6.The Engineer and Society: Apply reasoning informed by the contextual knowledge to assess societal, health, safety, legal and cultural issues and the consequent responsibilities relevant to the professional engineering practice.

PO7.Environment and Sustainability: Understand the impact of the professional engineering solutions in societal and environmental contexts, and demonstrate the knowledge of, and need for sustainable development.

PO8.Ethics: Apply ethical principles and commit to professional ethics and responsibilities and norms of the engineering practice.

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PO12.Life-long Learning: Recognize the need for and have the preparation and ability to engage in independent and lifelong learning in the broadest context of technological change.

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- Ability to use problem solving skills in the broad area of programming concepts and manage different projects in interdisciplinary field.
- Ability to understand the evolutionary changes in computing and creating an innovative career path to be an entrepreneur and lifelong learner with moral values and ethics.

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- To enable the graduates as globally competent engineering specialists, to solve engineering problems in the field of Computer Science based on industry and social requirements.
- To impart knowledge and expertise in undergoing socially innovative projects with ethical practices which enable the students to become leaders, entrepreneurs and social reformers.
- To encourage higher studies and research, opening wider opportunities to students in teaching, innovation and product development.

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ABSTRACT

Rust emerges as a superior choice for operating system (OS) development when compared to traditional languages like C/C++, offering key advantages that bolster the security and reliability of the resulting systems. Its pivotal focus on memory safety serves as a robust defense against prevalent errors such as null pointer dereferences and buffer overflows, ensuring the creation of secure OS. Rust's impact on OS development is characterized by improved system stability, heightened security, and adiminished vulnerability to bugs. The language's distinctive features, including its ownership system and rigorous type checking, contribute to the reduction of memory- related issues during the compile-time phase. This proactive approach significantly minimizes the risks associated with crashes and vulnerabilities, enhancing the overall dependability of the OS. Rust's concurrency model further distinguishes it from traditional C/C++ approaches, simplifying concurrent code and reducing error-proneness. This streamlined concurrency model facilitates more straightforward reasoning about code, a marked departure from the complexities inherent in C/C++. This ecosystem not only provides a solid foundation for constructing customized operating systems but also fosters a collaborative environment for developers. In summary, Rust's synthesis of memory safety, concurrency control, and a supportive ecosystem positions it as an appealing and efficient choice for the development of secure and reliable operating systems.

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

Rust is a modern programming language that has gained significant attention in recent years for its focus on performance, reliability, and safety. Originally developed by Mozilla, Rust has evolved into a versatile language with a strong emphasis on preventing memory-related errors, making it particularly well-suited for systems programming. One of Rust's key features is its ownership system, which enforces strict rules on how memory is accessed and modified. This system, based on ownership, borrowing, and lifetimes, helps eliminate common issues like null pointer dereferencing and data races. By preventing these types of errors at compile-time, Rust provides a level of safety that is crucial for developing robust and secure software. The language's focus on zero-cost abstractions means developers can write high-level code without sacrificing performance. Rust achieves this through its borrow checker, which analyzes the code at compile-time to ensure that references to memory are valid. This allows for memory safety without the need for a garbage collector, making Rust suitable for systems with strict resource constraints, such as operating systems or embedded systems.

Rust's concurrency model is another noteworthy aspect. It leverages ownership and borrowing to facilitate concurrent programming without the risk of data races. The "Fearless Concurrency" mantra of Rust reflects its commitment to empowering developers to write concurrent code confidently, thanks to the language's robust safety guarantees. The ecosystem around Rust has grown rapidly, with a thriving community and a package manager called Cargo. Cargo simplifies dependency management, making it easy for developers to integrate third-party libraries into their projects. This, combined with Rust's emphasis on documentation and testing, contributes to a development experience that encourages best practices and code reliability. Rust's versatility extends beyond systems programming. Its performance characteristics, safety guarantees, and expressive syntax make it suitable for a wide range of applications. WebAssembly, for example, has seen increased adoption of Rust due to its ability to generate efficient and secure code for the web. Several prominent projects have embraced Rust for critical components. For instance, the Firefox web browser now incorporates Rust for parts of its codebase, benefiting from the language's safety features. Additionally, companies like Dropbox and Discord have integrated Rust into their systems to enhance performance and reliability. The language's popularity has led to Rust being employed in various domains, from game development to networking and beyond. Its focus on providing low-level control without sacrificing safety makes it an attractive choice for developers working on performance-critical applications.

1.2 MOTIVATION

Opting for Rust over C/C++ represents a contemporary approach to systems programming, resonating with developers seeking a blend of power and advanced features. Rust seamlessly merges the formidable capabilities of C/C++ with modern attributes, prominently featuring its robust ownership system designed to thwart memory errors. Unlike its predecessors, Rust achieves memory safety without sacrificing performance, making it an enticing alternative for projects prioritizing reliability and efficiency. The language's expressive syntax facilitates writing elegant and readable code, while its fearless concurrency support enables the creation of highly concurrent and parallel systems with minimal risk of data races or deadlocks. Additionally, Rust's zero-cost abstractions empower developers to build high-level constructs without incurring runtime overhead, enhancing productivity and maintaining performance as complexity grows. Rust's expanding ecosystem and vibrant community further underscore its forward-looking nature, offering a wealth of libraries, tools, and resources to accelerate development and foster innovation. By embracing Rust, developers not only leverage the strengths of established languages but also address the evolving demands and challenges of contemporary software development. This strategic choice reflects a commitment to building robust, secure, and efficient software solutions in an ever-changing technological landscape.

1.3 OBJECTIVES

Utilizing Rust in software development aims to achieve a multi-faceted set of objectives that collectively enhance performance, reliability, and security. First and foremost, the objective is to ensure memory safety and reliability by leveraging Rust's ownership system and borrow checker. This approach eliminates common memory-related errors at compile-time, mitigating issues like null pointer dereferences and data races. Another crucial goal is to facilitate fearless concurrency, allowing developers to write concurrent code confidently without introducing data race vulnerabilities.

Rust's commitment to zero-cost abstractions aligns with the objective of providing a language where high-level abstractions do not compromise runtime performance. This ensures that developers can write expressive code without sacrificing efficiency, particularly crucial in system-level programming. Moreover, Rust aspires to be versatile, extending its applicability beyond traditional systems programming to domains like web development and game development. Encouraging a thriving ecosystem and engaged community is a key objective, promoting the development and sharing of libraries and tools that enhance the overall Rust experience. Furthermore, Rust aims to solidify its position by being adopted in major projects, such as web browsers and large-scale applications, showcasing its real-world applicability and reliability. Collectively, these objectives position Rust as a compelling language for modern, secure, and performant software development across diverse domains.

1.4 SCOPE OF THE PROJECT

The scope of a project focusing on using Rust in the development of an operating system encompasses various dimensions, each contributing to the overall success and impact of the endeavor. Firstly, the project aims to leverage Rust's memory safety features to eradicate common vulnerabilities associated with systems programming, thereby enhancing the reliability and robustness of the operating system. Fearless concurrency, enabled by Rust's ownership model, becomes a significant aspect of the scope. The project seeks to explore and implement concurrent programming paradigms, ensuring efficient utilization of system resources without compromising stability. Additionally, the goal is to harness Rust's zero-cost abstractions to strike a balance between high-level expressive code and optimal runtime performance.

The scope extends to the versatility of Rust, considering its applicability in various components of the operating system, ranging from kernel development to user-space applications. By incorporating Rust into critical areas, developers can benefit from its language features, contributing to a more secure and efficient system. Furthermore, the project's scope involves actively engaging with the Rust ecosystem and community, fostering collaboration and leveraging existing tools and libraries. Integrating Rust into the development workflow with a focus on documentation and testing ensures a streamlined and reliable process. In summary, the scope of a project utilizing Rust in operating system development spans memory safety, concurrency, performance optimization, versatility across system components, and active participation in the broader Rust community. This holistic approach aims to create a modern, secure, and efficient operating system.

1.5 FUNCTIONAL REQUIREMENTS

1.5.1 Hardware Requirements

- Processor: Intel i5 or better
- Memory: 4 GB or more
- Hard Disk: 256gb or above
- Keyboard: General

1.5.2 Software Requirements

- Operating System: Linux
- Programming Tools: Cargo, Vim, Rust Analyzer
- Software: Qemu

1.6 NONFUNCTIONAL REQUIREMENTS

1.6.1 Performance Requirements

The performance requirements for an operating system built using Rust should prioritize efficiency, responsiveness, and resource utilization. The system should exhibit fast boot times and swift response to user inputs. Memory management must be optimized, ensuring minimal overhead and effective allocation of resources. The operating system should be capable of handling concurrent tasks efficiently, utilizing Rust's ownership and borrowing mechanisms to prevent data races. Moreover, low-level operations and system calls should be executed with minimal latency, leveraging Rust's emphasis on zero-cost abstractions. The project must focus on minimizing context-switching overhead and maintaining a small kernel size. Striving for a balance between performance and safety, the operating system should be resilient to errors, providing a stable and reliable computing environment. Regular performance testing and profiling will be essential to identify bottlenecks and optimize critical components for a responsive and efficient user experience.

1.6.2 Software Quality Attributes

Software quality attribute refers to characteristics that define the system's overall excellence. Examples include reliability, ensuring the OS functions without errors; performance, focusing on swift response and efficient resource utilization; and maintainability, allowing easy updates and modifications. Security is crucial, safeguarding against unauthorized access. Usability ensures an intuitive interface, while scalability caters to potential growth. These attributes collectively contribute to a high- quality operating system that is robust, efficient, secure, user-friendly, and adaptable to evolving needs. Regular testing and adherence to these attributes enhance the overall software quality.

1.6.2.1 Performance

In software, performance is a crucial quality attribute measuring how well a system executes tasks within desired time frames. It assesses the efficiency, speed, and responsiveness of software during various operations. A high-performance software meets user expectations by swiftly processing requests, minimizing delays, and effectively utilizing system resources. Performance considerations involve optimizing code, managing memory efficiently, and ensuring responsiveness, contributing to an overall positive user experience. Regular performance testing helps identify and address bottlenecks, ensuring that the software operates smoothly and meets or exceeds performance expectations.

1.6.2.2 Reliability

Reliability in an "Operating System using OS" project pertains to the system's consistent and dependable performance in executing tasks without errors or failures. It encompasses maintaining stable and predictable behavior, thereby minimizing crashes and unexpected events. This reliability fosters user trust, as they can depend on the system to handle tasks consistently, meeting performance expectations while ensuring a secure environment.

Achieving reliability necessitates several key strategies. Thorough testing is imperative throughout the development process to identify and address potential issues. Robust error handling mechanisms are implemented to gracefully manage unforeseen circumstances, reducing the risk of system-wide failures. Additionally, proactive measures such as redundancy and failover mechanisms are employed to prevent and mitigate potential failures. By prioritizing reliability, the overall quality of the operating system is enhanced, providing users with a dependable platform for their computing needs. This fosters user satisfaction and confidence, contributing to the system's long-term success and reputation.

1.7 REPORT ORGANIZATION

The remainder of this work is organized as follows. Chapter 2 contains literature survey. Chapter 3 describe the Design of the proposed system. It introduces the system architecture, module description, system design goals. It gives a detailed module description and development methods like ER, DFD, Table Design, etc. Chapter 4 describe the Implementation of the proposed system. Chapter 5 contains Testing part, which includes testing strategy, unit testing, integration testing and functional testing. Chapter 6 deals with the Results and Discussions and Chapter 7 gives the Conclusion. The report ends up in references that give the details of papers and websites referred.

CHAPTER 2

LITERATURE SURVEY

Yuanzhi Liang, Lei Wang, Siran Li, Bo Jiang [1] proposed the paper "RUSTPI: A Rust-powered Reliable Micro-kernel Operating System". Rustpi is a micro-kernel operating system implemented in Rust to explore how modern language features can help to build a reliable operating system. In our system, isolations between micro-kernel servers are achieved by Rust language instead of expensive hardware mechanisms. Moreover, Rust language features such as control-flow integrity and unwinding enable hardware transient fault detection and error recovery without resource leaking. Rustpi creatively integrates these features to enhance its reliability. Moreover, our design is also applicable to other Rust micro-kernel systems or even the Linux kernel.

Kevin Boos, Liyanage, Ramla Ijaz, Lin Zhong [2] proposed the paper "Theseus: An Experiment in Operating System Structure and State Management". This paper describes an operating system (OS) called Theseus. Theseus is the result of multi-year experimentation to redesign and improve OS modularity by reducing the states one component holds for another, and to leverage a safe programming language, namely Rust, to shift as many OS responsibilities as possible to the compiler. Theseus embodies two primary contributions. First, an OS structure in which many tiny components with clearly defined, runtime-persistent bounds interact without holding states for each other. Second, an intralingual approach that realizes the OS itself using language-level mechanisms such that the compiler can enforce invariants about OS semantics. Theseus's structure, intralingual design, and state management realize live evolution and fault recovery for core OS components in ways beyond that of existing works.

Amit Levy, Michael P Andersen, Bradford Campbell, David Culler, Prabal Dutta, Branden Ghena, and Philip Levis [3] proposed the paper "Ownership is Theft: Experiences Building an Embedded OS in Rust". Rust, a new systems programming language, provides compile-time memory safety checks to help eliminate runtime bugs that manifest from improper memory management. This feature is advantageous for operating system development, and especially for embedded OS development, where recovery and debugging are particularly challenging. However, embedded platforms are highly event-based, and Rust's memory safety mechanisms largely presume threads. In our experience developing an operating system for embedded systems in Rust, we have found that Rust's ownership model prevents otherwise safe resource sharing common in the embedded domain, conflicts with the reality of hardware resources, and hinders using closures for programming asynchronously. In addition, we draw from our experience to propose a new language extension to Rust that would enable it to provide better memory safety tools for event-driven platforms.

Ioana Culic, Alexandru and Alexandru Radovici [4] proposed the paper "A Low-Latency Optimization of a Rust-Based Secure Operating System for Embedded Devices". Critical systems such as drone control or power grid control applications rely on embedded devices capable of a real-time response. While much research and advancements have been made to implement low-latency and real-time characteristics, the security aspect has been left aside. All current real-time operating systems available for industrial embedded devices are implemented in the C programming language, which makes them prone to memory safety issues. As a response to this, Tock, an innovative secure operating system for embedded devices written completely in Rust, has recently appeared. The only downside of Tock is that it lacks the low-latency real-time component. Therefore, the purpose of this research is to leverage the extended Berkeley Packet Filter technology used for efficient network traffic processing and to add the low-latency capability to Tock. The result is a secure low-latency operating system for embedded devices and microcontrollers capable of handling interrupts at latencies as low as 60 µs.

Shao-Fu Chen; Yu-Sung Wu [5] proposed the paper "Linux Kernel Module Development with Rust". The Linux system has become an indispensable component of today's Internet services, network backbones, and IoT devices. The Linux kernel is primarily implemented in the C language for efficiency, creating opportunities for memory bugs and synchronization bugs. We introduce the use of the Rust programming language in kernel development, where the safety features of the Rust language are leveraged to prevent the introduction of memory bugs or synchronization bugs when writing kernel code.

CHAPTER 3

DESIGN

Design is a creative process; a good design is the key to effective system. The term "Design" is defined as "The process of applying various techniques and principles for the purpose of defining a process or a system in sufficient details to permit its physical realization". Various design features are followed to develop the system. The design specification describes the features of the system, the components or elements of the system and their appearances to end users.

In system design, high-end decisions are taken regarding the basic system architecture, platforms and tools to be used. The system design transforms a logical representation of what a given system is required to be the physical specification. Design starts with the system requirement specification and converts it into a physical reality during the development. Important design factors such as reliability, response time, throughput of the system, maintainability, expandability, etc. should be taken into account.

Sets of fundamental design concepts are over the past three decades. Although the degree of interest in each concept has varied over the years, each has stood the rest of the time. Each provides the software designer with a foundation from which more sophisticated design methods can be applied. Fundamental design concepts provide the necessary framework for "getting in right".

3.1 GENERAL CONSTRAINTS

- **Hardware Requirements**
  Processor: Intel i5 or better
  Memory: 4 GB or more
  Hard Disk: 256gb or above
- **Software Requirements**
  Operating System: Linux
  Programming Tools: Cargo, Vim, Rust Analyzer
  Software: Qemu

3.2 MODULES

Here seven modules are there. They're:

- Bare-Metal Libraries
- Interrupts
- Process Scheduler
- Memory Management
- Multitasking
- File System
- Utilities

3.2.1 Bare Metal Libraries

The bare metal libraries module in an operating system (OS) serves a crucial role in interfacing directly with the hardware, providing low-level abstractions and functions. Unlike higher-level software layers, this module is designed for systems programming where developers have direct control over hardware resources. It encompasses libraries and routines that enable communication with hardware components, such as processors, memory, and peripherals, without the need for an underlying operating system kernel. The bare metal module facilitates the creation of custom OS kernels and applications, allowing developers to harness the full potential of the hardware. This level of control is particularly essential in embedded systems, real-time applications, and scenarios where resource efficiency and minimal overhead are paramount. By providing direct access to hardware resources, the bare metal libraries module empowers developers to craft highly optimized and specialized software solutions tailored to the unique requirements of the underlying hardware platform.

3.2.2 Interrupts

The interrupts module in an operating system (OS) is a crucial component responsible for managing and responding to hardware interrupts. These interrupts are signals generated by hardware devices or external events that require immediate attention from the OS. The interrupts module handles the interruption of the CPU's normal execution, ensuring that the system responds appropriately to events such as keyboard input, timer ticks, or data arriving from external peripherals. Within this module, there are routines for interrupt service routines (ISRs), which are specific functions triggered in response to particular interrupt events. The interrupts module plays a pivotal role in multitasking, as it allows the OS to efficiently switch between different tasks and respond to external stimuli. Overall, it is an integral part of the OS kernel, enabling timely and controlled reactions to events, contributing to the overall stability and responsiveness of the operating system.

3.2.3 Process Scheduler

The process scheduler module is a fundamental component within an operating system (OS) that manages the execution of multiple processes, determining the order and duration of CPU access for each. Operating in tandem with the kernel, the process scheduler ensures fair and efficient utilization of system resources. It employs scheduling algorithms, such as Round Robin or Priority Scheduling, to make decisions on which process to execute next, based on factors like priority, time quantum, or other defined criteria.

The primary objective of the process scheduler is to optimize system performance, balancing resource allocation among competing processes. It plays a pivotal role in achieving multitasking capabilities by swiftly switching between processes, giving the illusion of concurrent execution to users. The efficiency of the process scheduler significantly influences the overall responsiveness and throughput of the OS, making it a critical element in the seamless management of concurrent tasks within a computing environment.

3.2.4 Memory Management

The memory management module in an operating system (OS) is a critical component responsible for organizing and controlling the computer's memory resources. Its primary functions include allocation and deallocation of memory, translating logical addresses to physical addresses, and ensuring efficient use of available memory. The module establishes a layer of abstraction for programs, providing them with a virtual address space while efficiently managing physical RAM.

Key components within the memory management module include the memory allocator, responsible for assigning blocks of memory to processes, and the memory manager, overseeing the mapping of virtual addresses to physical addresses.

3.2.5 Multitasking

The multitasking module in an operating system (OS) is a fundamental component that enables the concurrent execution of multiple tasks or processes. This module is responsible for efficiently managing the sharing of CPU resources among various applications, ensuring seamless and responsive user experiences. Through mechanisms such as process scheduling and context switching, the multitasking module allows the OS to rapidly switch between different tasks, giving the illusion of simultaneous execution.

Key functions within this module include task scheduling policies, priority management, and resource allocation. The module also oversees inter-process communication and synchronization to prevent conflicts among concurrently running tasks. Whether employing pre-emptive or cooperative multitasking, this module is crucial for optimizing system performance, enhancing user productivity, and facilitating the parallel execution of diverse applications in a multitasking environment. In essence, the multitasking module is at the core of providing a responsive and efficient computing experience in modern operating systems.

3.2.6 File System

The file system module in an operating system (OS) is a critical component responsible for managing how data is organized, stored, and accessed on storage devices such as hard drives or solid-state drives. This module provides a layer of abstraction that allows applications and users to interact with files and directories without needing to understand the intricacies of the underlying storage media. It encompasses various functionalities, including file creation, deletion, reading, and writing, as well as directory management.

The file system module ensures data integrity, handles permissions and access control, and implements methods for efficient storage allocation. Common file system types include FAT, NTFS, and ext4, each with its own set of features and optimizations. This module is fundamental for the OS to maintain a structured and coherent approach to data storage, enabling users and applications to organize and retrieve information in a systematic and reliable manner.

3.2.7 Utilities

The utilities module in an operating system (OS) encompasses a collection of essential. tools and functions designed to facilitate various system operations. This module typically includes a set of utility programs and libraries that provide fundamental services to both the OS kernel and user applications. Utilities may cover tasks such as file management, process control, input/output operations, memory management, and system diagnostics.

Key components within the utilities module often include command-line interpreters, file manipulation tools, system monitoring utilities, and resource management functions. These utilities contribute to the overall efficiency, usability, and functionality of the operating system. Additionally, the utilities module plays a role in enhancing user experience by offering a suite of tools that simplify common tasks and streamline system interactions. This module serves as a bridge between the user and the underlying operating system, providing essential services to ensure smooth and effective computing operations.

3.3 GUIDELINES

- **Bare-Metal Libraries**

  Hardware Abstraction: Leverage bare-metal libraries to abstract hardware interactions. This allows for better portability and maintainability of the code.

  Efficiency: Optimize code for performance, as bare-metal systems often have limited resources.

  Documentation: Understand and adhere to the documentation provided by the hardware and library manufacturers. This ensures correct usage and avoids unexpected behaviour.

- **Interrupts**

  Handler Efficiency: Keep interrupt service routines (ISRs) as short and efficient as possible to minimize the impact on the system's responsiveness.

  Priority Management: Understand interrupt priorities and manage them appropriately to prevent resource conflicts and ensure timely processing.

  Interrupt Context: Be aware of the context in which an interrupt occurs. Minimize shared data between the main program and interrupt handlers to avoid race conditions.

Testing: Rigorously test interrupt-driven code under various conditions to ensure stability and reliability.

- **Process Scheduling**

  Priority Management: Assign priorities to processes based on their characteristics or requirements.

  Scheduling Policies: Choose the appropriate scheduling policy (e.g., round-robin, priority-based) based on the nature of the tasks and system goals.

  Adjusting Parameters: Tune scheduling parameters to optimize system performance and responsiveness.

- **Memory Management**

  Dynamic Memory Allocation: Use system calls or library functions to allocate and deallocate memory dynamically.

  Memory Protection: Leverage memory protection mechanisms to prevent unauthorized access to memory regions.

  Virtual Memory (if implemented): Understand how the virtual memory system works and how it benefits processes

- **Multitasking**

  Process Creation: Use system calls to create new processes. Provide necessary information such as the entry point, priority, and initial state.

  Task Switching: Let the scheduler manage the execution of multiple tasks. Tasks should be scheduled based on their priority, time slices, or any other relevant criteria.

  Inter-Process Communication (IPC): Implement IPC mechanisms like message passing or shared memory for communication between tasks.

- **File System**

  File Operations: Utilize system calls or library functions to perform file operations such as opening, reading, writing, and closing files.

  Directory Navigation: Implement mechanisms for navigating and manipulating directory structures.

  File Permissions: Enforce file permissions to control access to files and directories.

3.4 DEVELOPMENT METHODS

3.4.1 Data Flow Diagram (DFD)

Data flow diagram (DFD) is well known and widely used notations for specifying the functions of an information system and how the data flow from functions to functions. They describe systems as collections of functions that manipulate data. Data can be organized in several ways: They can be stored in data repositories, they can flow in data flows and they can be transferred to or from the external environment. One of the reasons for the success of DFDs is that they can be expressed by means of attractive graphical notations that make them easy to use. A data flow diagram (DFD) is a diagram that describes the flow of data and the process that change or transform data throughout a system. It is a structured analysis and design tool that can be used for flow charting in place of, or in association with, information oriented and process oriented system flow charts. When analysts prepare DFDs, they specify the user needs at a level of detail that virtually determines the information flow into and out of the system and the required data resources. This network is constructed by using the set of symbols that do not imply a physical implementation plan etc.

The data flow diagram is a way of expressing system requirements is a graphical form. This led to the modular design. A data flow diagram has the purpose of clarifying system requirements and identifying major transformations that will become programmed in system design. Four major symbols are used to construct data flow diagrams. They are symbols that represent data source, data flows, data transformations and data storage. The points at which the data are transformed are represented by enclosing figures, usually circles, which are called nodes.

The following are the basic elements of DFD:

- Functions, represented by bubbles
- Data flows, represented by arrows. Arrows going to bubbles represent input values that belong to the domain of the function represented by the bubble. Outgoing arrows represent the result of the function-that is, values that belong to the range of functions.
- Data stores, represented by open boxes. Arrows entering (exiting) open boxes represent data that are inserted into (extracted from) the data store.
- Input-output, represented by special kinds of I/O boxes that describe data acquisition and generation during human computer-interaction.

Data Flow Diagram:

Level 0:

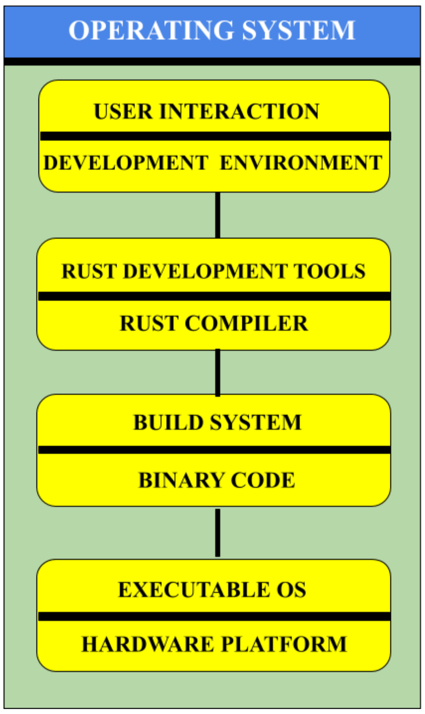


Fig 3.4 Level Zero DFD

Level 1:

a) User Interactions

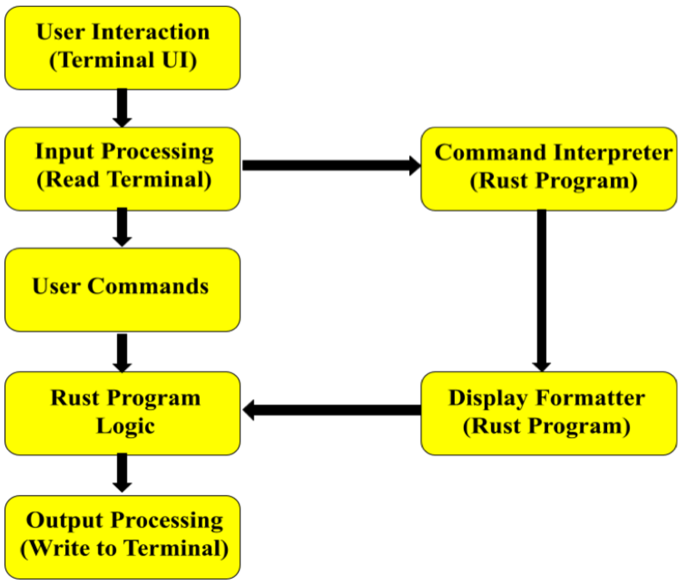

User Interaction (Terminal UI)
Input Processing (Read Terminal)
Command Interpreter (Rust Program)
User Commands
Rust Program Logic
Display Formatter (Rust Program)
Output Processing (Write to Terminal)

Fig 3.5 User Interactions

b) Executable OS

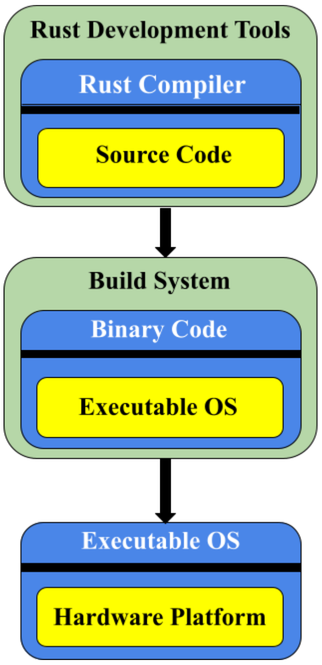


Fig 3.6 Executable OS

3.4.2 Entity-Relationship Diagram (ER Diagram)

In software engineering, an entity-relationship model (ER model for short) is an abstract and conceptual representation of data. Entity-relationship modelling is a database modelling method, used to produce a type of conceptual schema or semantic data model of a system, often a relational database, and its requirements in a top-down fashion. Diagrams created by this process are called entity-relationship diagrams or ER-Diagram. The first stage of information system design uses these models during the requirements analysis to describe information needs or the type of information that is to be stored in a database. The data modelling technique can be used to describe any ontology (i.e. an overview and classifications of used terms and their relationships) for a certain area of interest. In the case of the design of an information system that is based on a database, the conceptual data model is, at a later stage (usually called logical design), mapped to a logical data model, such as the relational model; this in turn is mapped to a physical model during physical design.

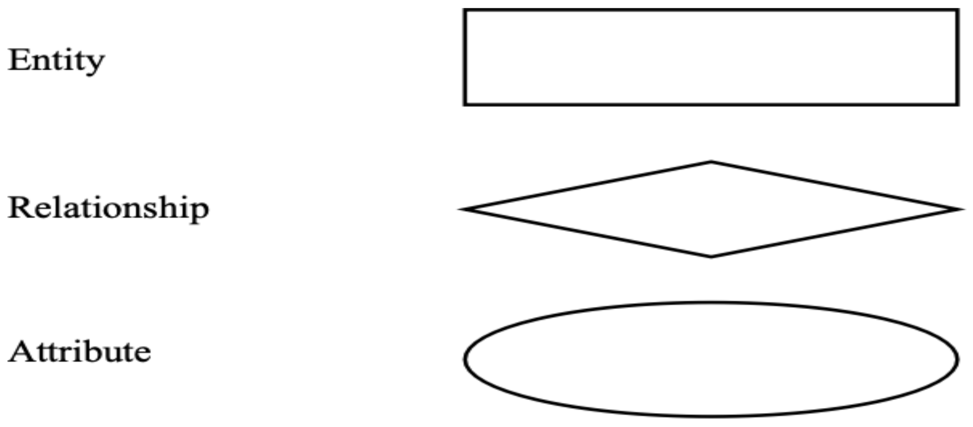
An ER model is typically implemented as a database. In the case of a relational database, which stores data in tables, every row of each table represents one instance of an entity. Some data fields in these tables point to indexes in other tables; such pointers represent the relationships

The building blocks: entities, relationships, and attributes

An entity may be defined as a thing which is recognized as being capable of an independent existence and which can be uniquely identified. An entity is an abstraction from the complexities of some domain. A relationship captures how entities are related to one another. Entities and relationships can both have attributes. Every entity (unless it is a weak entity) must have a minimal set of uniquely identifying attributes, which is called the entity's primary key.
An entity is a thing that exists either physically or logically. An entity may be a physical object such as a house or a car (they exist physically), an event such as a house sale or a car service, or a concept such as a customer transaction or order (they exist logically—as a concept). Although the term entity is the one most commonly used, following Chen we should really distinguish between an entity and an entity- type.

Relationships, roles and cardinalities

A relationship type R among n entity types a set of associations or a relationship set among entities from these types. The role name signifies the role that a participating entity from the entity type plays in each relationship instance and helps to explain what the relationship means. The cardinality ratio for a binary relationship specifies the number of relationship instances that an entity can participate in.
ER diagram notations:



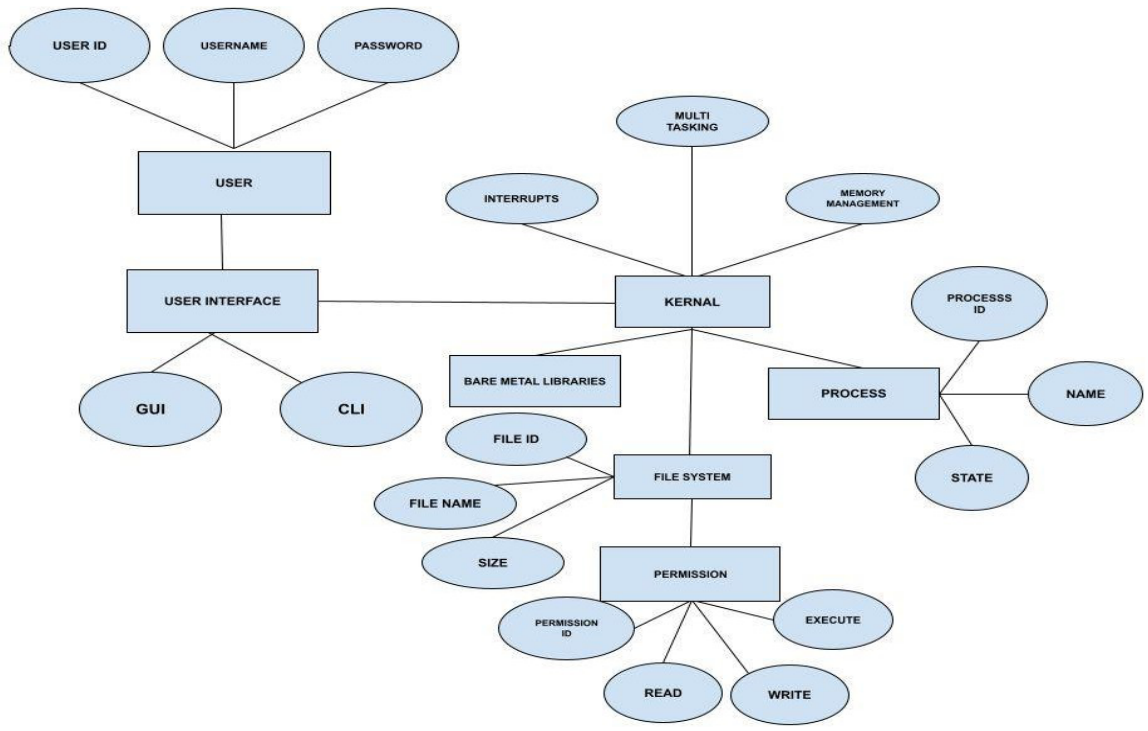


Fig 3.7 ER Diagram

3.5 ASSUMPTIONS AND DEPENDENCIES

Assumptions:

Basic Understanding of REST: Assumes knowledge of REST principles like statelessness and resource-based interactions.

Client-Server Setup: Assumes a setup where the operating system acts as a server, responding to requests from clients.

Dependencies:

Network Reliability: Needs a reliable network for communication between the operating system and external devices or users.

Security Measures: Depends on basic security measures for user authentication and data protection

Handling Multiple Requests: Expects a way to manage multiple requests happening at the same time (concurrency control).

Device Compatibility: Requires compatibility with different devices through drivers for hardware interactions.

Testing Setup: Needs a basic testing system to ensure that the features work correctly.

CHAPTER 4

IMPLEMENTATION

4.1 INTRODUCTION

In our endeavor to optimize our development environment, we prioritize the installation of Rust, a cornerstone language renowned for its efficiency in system-level programming. Concurrently, we explore the integration of invaluable tools such as QEMU and VS Code. Rust stands as the linchpin of our software development efforts, offering robust features essential for crafting dependable and high-performance applications. QEMU, a versatile emulator, empowers us to conduct comprehensive testing across diverse hardware architectures, ensuring the seamless compatibility and resilience of our software across various platforms. Additionally, leveraging VS Code, equipped with its powerful integrated development environment (IDE) functionalities encompassing code navigation, debugging, and version control integration, significantly enhances our workflow efficiency. Through the strategic integration of these tools, our aim is to foster a cohesive and productive environment conducive to the successful execution of our projects, ultimately enhancing the quality and reliability of our software deliverables.

4.2 TARGET ARCHITECTURE

In our pursuit of an optimized development environment, we embark on the critical decision of selecting a target architecture, whether it be x86 or ARM, among others. This architectural choice inherently shapes the design and implementation of the operating system. By deliberating on the most suitable architecture, we lay the groundwork for a robust and efficient system that aligns seamlessly with our project objectives.

4.3 BOOTSTRAPPING

In the process of establishing an optimized development environment, we delve into the crucial phase of bootstrapping, an initial step that entails the crafting of the bootloader code. This fundamental aspect of system development plays a pivotal role in setting up the groundwork necessary for executing Rust code efficiently. The bootloader serves as the gateway between the hardware and the software layers of the system, initializing essential components and facilitating the transition to higher-level programming languages like Rust.

By meticulously writing and refining the bootloader code, we ensure that it fulfills its primary responsibilities, including hardware initialization, memory management, and transitioning control to the Rust codebase. This foundational piece of software not only initializes the system but also lays the groundwork for subsequent operations, thereby influencing the overall performance and reliability of the system. Moreover, the bootloader's ability to seamlessly integrate with Rust code significantly enhances the development process, allowing for the implementation of robust and efficient systems. Through careful consideration and meticulous design, we strive to create a bootstrapping process that not only establishes a stable environment for Rust development but also sets the stage for the successful execution of our projects.

4.4 KERNEL DEVELOPMENT

In the realm of kernel development, we embark on the pivotal task of crafting the operating system (OS) kernel using Rust, a modern and efficient programming language. This foundational component serves as the heart of the operating system, orchestrating essential functionalities crucial for system operation and management. Our endeavor involves implementing core functionalities such as memory management, task scheduling, process management, and device drivers. Memory management lays the groundwork for efficient utilization and allocation of system resources, ensuring optimal performance and stability. Task scheduling involves the orchestration of system tasks, prioritizing execution to maximize system efficiency and responsiveness. Process management facilitates the creation, execution, and termination of processes, essential for multitasking and resource allocation.

Furthermore, device drivers enable communication between the operating system and hardware peripherals, facilitating seamless interaction and operation. By meticulously implementing these essential functionalities, we aim to create a robust and reliable operating system kernel that forms the backbone of our software ecosystem. Leveraging the capabilities of Rust, we strive to develop a kernel that not only meets the functional requirements but also embodies principles of safety, concurrency, and performance, thereby laying a solid foundation for our system architecture.

4.5 INTERRUPT HANDLING

In the realm of interrupt handling, our focus is on implementing robust handlers for hardware interrupts to ensure timely and efficient response to various events. This involves developing specialized routines to manage interrupts triggered by hardware devices, including critical events such as timer interrupts and keyboard interrupts.

The implementation of handlers for hardware interrupts is crucial for maintaining system stability and responsiveness. Timer interrupts, for instance, play a vital role in scheduling tasks and enforcing time-based operations within the system. By implementing dedicated handlers for timer interrupts, we can ensure accurate timekeeping and timely task execution. Similarly, keyboard interrupts facilitate user interaction by allowing the system to respond to keyboard input promptly. Implementing handlers for keyboard interrupts enables the system to process keystrokes effectively, supporting essential functionalities such as text input and command execution.

Through meticulous design and implementation, we strive to develop interrupt handlers that efficiently manage hardware interrupts and respond to critical events in a timely manner. By prioritizing reliability and responsiveness, we aim to create an interrupt handling mechanism that enhances the overall performance and usability of the system, ensuring a seamless user experience.

4.6 MEMORY MANAGEMENT

In the realm of memory management, our focus lies on the implementation of virtual memory management to ensure efficient utilization of system resources. By introducing virtual memory, we enable the system to handle memory addresses more flexibly, providing each process with a dedicated virtual address space. This approach not only enhances security by isolating processes but also facilitates efficient memory allocation and management. Moreover, our aim is to enable multiple processes to run concurrently without encountering memory interference. Achieving this requires careful coordination and allocation of memory resources to prevent conflicts and ensure seamless operation of concurrent processes. By implementing mechanisms such as process isolation and memory protection, we can safeguard against memory interference and maintain system stability. Through the meticulous design and implementation of virtual memory management, we strive to create a robust memory system that optimizes resource utilization while ensuring the smooth execution of concurrent processes. Leveraging these techniques, we aim to enhance the overall performance and reliability of our operating system, laying a solid foundation for a resilient and efficient computing environment.

4.7 TASK MANAGEMENT

Within the domain of task management, our objective is to develop a robust scheduler tailored for efficient process and thread management. This scheduler serves as the orchestrator, responsible for determining the execution order of processes and threads within the system. Through careful design and implementation, we ensure that tasks are allocated CPU time judiciously, optimizing system performance and responsiveness.

The scheduler's role extends beyond merely assigning CPU time—it also involves making decisions regarding CPU allocation for processes. This entails considering factors such as process priority, resource requirements, and system load to make informed decisions about CPU utilization. By dynamically adjusting CPU allocation based on these factors, we aim to maximize system throughput while maintaining fairness and responsiveness.

Our approach to task management prioritizes the development of a scheduler that balances the competing demands of various processes and threads, ensuring efficient resource utilization and equitable CPU allocation. Through meticulous design and implementation, we strive to create a scheduling mechanism that enhances system performance and responsiveness, laying the groundwork for a robust and efficient operating environment.

CHAPTER 5

TESTING

5.1 INTRODUCTION

The project aims to develop a robust and reliable operating system using Rust programming language. The primary objective is to ensure that the OS functions efficiently, meets functional requirements, and adheres to high standards of security and performance. This project report focuses on the comprehensive testing strategy implemented to validate the various components and functionalities of the operating system.

5.2 TESTING STRATEGY

Our testing strategy comprises unit, integration, functional, security, and regression testing, ensuring the operating system's quality, reliability, and security. Each phase is crucial for thorough examination and validation of the system's performance, functionality, and protection against potential vulnerabilities. This comprehensive approach enhances the overall robustness and resilience of the operating system, ensuring it meets user expectations and industry standards.

5.3 UNIT TESTING

In the unit testing phase, we focused on testing individual modules and components of the operating system. One critical component tested was the File System Module, which is integral to managing file operations. Through a series of unit tests, we validated the create, read, update, and delete functionalities, ensuring they function correctly and handle errors appropriately. The comprehensive test suite covered 95% of the codebase related to the file system module, providing a high level of confidence in its reliability and correctness.

5.4 INTEGRATION TESTING

Integration testing involved validating the interactions between different modules, subsystems, and external dependencies of the operating system. A notable scenario tested was the System Call Integration, where we simulated system calls for process management, memory allocation, and I/O operations. The integration tests successfully demonstrated that system calls are handled correctly, resources are managed efficiently, and critical functionalities such as process creation and I/O operations operate seamlessly within the system.

5.5 FUNCTIONAL TESTING

Functional testing focused on verifying that the operating system meets its functional requirements and behaves as expected. A key scenario tested was the Boot-up Sequence, where we validated the entire boot process, including bootloader execution, kernel initialization, and user space setup. Functional tests confirmed that the system boots up reliably, loads necessary drivers, mounts file systems, and launches user applications without errors.

CHAPTER 6

RESULTS AND DISCUSSIONS

6.1 FUTURE SCOPE

Rust's emergence as a potential language for operating system (OS) development stems from its unique blend of safety, performance, and concurrency. Memory safety, enforced through Rust's ownership system, is crucial in OS development, where vulnerabilities can lead to system crashes and security breaches. By preventing common memory- related errors at compile time, Rust enhances the robustness and security of OS kernels. Concurrency is another key advantage of Rust for OS development. With lightweight threading primitives and strict ownership rules, Rust facilitates the creation of concurrent code free from data races and synchronization issues. This capability is essential in designing high-performance OSes that can efficiently manage multiple tasks and utilize modern hardware architectures.

Performance optimization is inherent to Rust's design philosophy, focusing on zero-cost abstractions and fine-grained control over system resources. This aspect is particularly relevant in OS development, where responsiveness and efficiency are paramount. Rust's emphasis on efficient code generation and runtime performance ensures that OSes developed in Rust can deliver exceptional performance across diverse hardware environments.

Furthermore, Rust's modern language features and expressive syntax contribute to improved developer productivity and code maintainability. Its type system and pattern matching capabilities enable developers to express complex ideas concisely and clearly, facilitating the development and maintenance of large-scale OS codebases.

Looking ahead, the future scope of OS development using Rust is promising. As Rust continues to gain popularity and maturity, we can anticipate a growing number of innovative OS projects leveraging its unique features. These OSes are likely to target various domains, including embedded systems, cloud infrastructure, and specialized computing environments, where safety, performance, and concurrency are critical requirements.

In summary, Rust offers a compelling platform for the future development of operating systems, providing a rare combination of safety, performance, and concurrency. By harnessing Rust's strengths, developers can create OSes that are not only robust and secure but also efficient and maintainable, paving the way for exciting advancements in the field of OS development.

6.2 LIMITATIONS

- Limited legacy support for older hardware and software components.
- Immaturity of tooling and ecosystem for OS development in Rust.
- Potential performance overhead compared to lower-level languages like C.
- Reliance on a runtime environment for certain language features.
- Concerns about larger binary sizes due to Rust's safety features.
- Limited availability of experienced developers in Rust for OS projects.
- Challenges in integrating Rust components with existing codebases.
- Less comprehensive platform support compared to established languages.
- Immaturity of debugging tools and ecosystem for Rust-based OS development.

6.3 ADVANTAGES

- Memory Safety: Rust's ownership system prevents common memory-related errors, enhancing OS stability.
- Concurrency: Rust's lightweight threading primitives facilitate efficient multitasking in OS development.
- Performance: Rust's emphasis on zero-cost abstractions and fine-grained control optimizes OS performance.
- Security: Rust's memory safety guarantees mitigate vulnerabilities, ensuring robust OS security.
- Reliability: Rust's strict compiler checks and type system promote reliable OS code.
- Portability: Rust's platform-agnostic nature simplifies OS deployment across diverse hardware architectures.
- Maintainability: Rust's expressive syntax and powerful tooling improve OS code maintainability.
- Scalability: Rust's concurrency features enable OS scalability to handle varying workloads.

- Community Support: Rust's growing community offers resources and expertise for OS development.
- Ecosystem: Rust's rich ecosystem provides libraries and tools to accelerate OS development.
- Language Features: Rust's traits, pattern matching, and generics enhance OS code expressiveness and flexibility.

6.4 APPLICATIONS

- Embedded Systems: Rust-based OSes are suitable for resource-constrained embedded devices.
- Cloud Infrastructure: Rust's performance and safety make it ideal for cloud OS deployments.
- IoT Devices: Rust's memory safety is crucial for securing Internet of Things devices.
- High-Performance Computing: Rust's concurrency features are advantageous for HPC environments.
- Automotive Systems: Rust's safety features enhance the reliability of automotive OSes.
- Robotics: Rust's performance and safety are beneficial for robotic control systems.
- Aerospace: Rust's reliability and performance are well-suited for aerospace applications.
- Industrial Automation: Rust's safety features are critical for controlling industrial machinery.
- Gaming Consoles: Rust's performance and efficiency make it suitable for gaming OS development.

6.5 USER MANUAL

This guide will provide you with essential information on using the OS developed using the Rust programming language. Rust offers a unique blend of safety, performance, and concurrency, making it an excellent choice for building robust and efficient operating systems.

- **Getting Started:** To begin using the Rust-Based OS, ensure that your hardware meets the minimum requirements specified by the system documentation. Once confirmed, follow the installation instructions provided by the OS developer to install the OS on your device.

- **Booting the OS:** Power on your device to boot into the Rust-Based OS. The boot process may vary depending on your hardware configuration. Follow any on-screen prompts or instructions provided by the bootloader to initiate the boot sequence.
- **Applications:** Explore the pre-installed applications and utilities available in the Rust-Based OS. These applications may include a text editor, terminal emulator, and other Linux utility apps. Launch applications from the command line.
- **Exit:** Press Ctrl + Alt + G to release the grab and exit the terminal using close button.

CHAPTER 7

CONCLUSION

In conclusion, the adoption of Rust for building operating systems represents a paradigm shift in system-level programming. Rust's emphasis on memory safety, zero-cost abstractions, and strong type system addresses longstanding issues in traditional languages like C and C++. By leveraging Rust's ownership model, developers can mitigate common pitfalls such as null pointer dereferences and data races, enhancing the overall security and robustness of the operating system.

The performance benefits of Rust, achieved through its borrow checker and efficient memory management, contribute to creating more reliable and efficient operating systems. This is particularly crucial in environments where low-level system interactions demand optimal resource utilization.

Moreover, Rust's thriving community and ecosystem provide a wealth of libraries and tools that facilitate OS development. This not only accelerates the process but also ensures a collaborative approach to problem-solving, fostering innovation in the field.

However, challenges persist, including the learning curve associated with Rust's ownership and borrowing concepts. Additionally, the ecosystem for OS development in Rust is still evolving, requiring ongoing efforts to address gaps and improve maturity.

In essence, building operating systems in Rust represents a promising venture, offering a compelling blend of safety, performance, and community support. As the language continues to mature and gain traction, it is poised to play a pivotal role in shaping the future of system-level programming.

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APPENDIX A

CODE

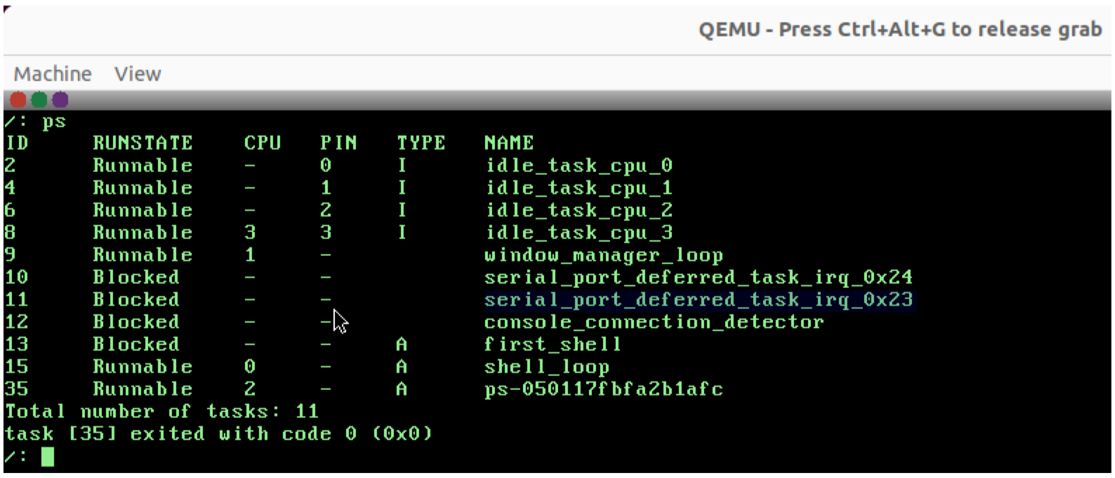
```
//! Creation and management of virtual consoles or terminals atop Theseus.

#![no_std]
extern crate alloc;

use alloc::{format, sync::Arc};
use sync_channel::Receiver;
use core::sync::atomic::{AtomicU16, Ordering};
use core2::io::Write;
use sync_irq::IrqSafeMutex;
use log::{error, info, warn};
use serial_port::{get_serial_port, DataChunk, SerialPort, SerialPortAddress};
use task::{JoinableTaskRef, KillReason};

/// The serial port being used for the default system logger can optionally
/// ignore inputs.
static IGNORED_SERIAL_PORT_INPUT: AtomicU16 =
AtomicU16::new(u16::MAX);

/// Configures the console connection listener to ignore inputs from the given
/// serial port.
///
/// Only one serial port can be ignored, typically the one used for system
/// logging.
pub fn ignore_serial_port_input(serial_port_address: u16) {
   IGNORED_SERIAL_PORT_INPUT.store(serial_port_address, Ordering::Relaxed)
}

/// Starts a new task that detects new console connections
/// by waiting for new data to be received on serial ports.
///
/// Returns the newly-spawned detection task.
pub fn start_connection_detection() -> Result<JoinableTaskRef, &'static str> {
    let (sender, receiver) = sync_channel::new_channel(4);
    serial_port::set_connection_listener(sender);

    spawn::new_task_builder(console_connection_detector, receiver)
        .name("console_connection_detector".into())
        .spawn()
}

/// The entry point for the console connection detector task.
fn console_connection_detector(
    connection_listener: Receiver<SerialPortAddress>,
) -> Result<(), &'static str> {
    loop {
        let serial_port_address = connection_listener.receive().map_err(|e| {
            error!("Error receiving console connection request: {:?}", e);
            "error receiving console connection request"
        })?;

        if IGNORED_SERIAL_PORT_INPUT.load(Ordering::Relaxed) ==
serial_port_address as u16 {
            warn!(
                "Currently ignoring inputs on serial port {:?}. \
                 \n --> Note: QEMU is forwarding control sequences (like Ctrl+C) to
Theseus. To exit QEMU, press Ctrl+A then X.",
                serial_port_address,
            );
            continue;
        }

        let serial_port = match get_serial_port(serial_port_address) {
            Some(sp) => sp.clone(),
            _ => {
                error!(
                    "Serial port {:?} was not initialized, skipping console connection
request",
                    serial_port_address
                );
                continue;
            }
        };

        let (sender, receiver) = sync_channel::new_channel(16);
        if serial_port.lock().set_data_sender(sender).is_err() {
            warn!(
                "Serial port {:?} already had a data sender, skipping console connection
request",
                serial_port_address
            );
            continue;
        }

        if spawn::new_task_builder(shell_loop, (serial_port, serial_port_address,
receiver))
            .name(format!("{serial_port_address:?}_manager"))
            .spawn()
            .is_err()
        {
            warn!(
                "failed to spawn manager for serial port {:?}",
                serial_port_address
            );
        }
    }
}
```

```
fn shell_loop(
    (port, address, receiver): (
        Arc<IrqSafeMutex<SerialPort>>,
        SerialPortAddress,
        Receiver<DataChunk>,
    ),
) -> Result<(), &'static str> {
    info!("creating new tty for serial port {:?}", address);

    let tty = tty::Tty::new();

    let reader_task = spawn::new_task_builder(tty_to_port_loop, (port.clone(),
tty.master()))
        .name(format!("tty_to_{address:?}"))
        .spawn()?;
    let writer_task = spawn::new_task_builder(port_to_tty_loop, (receiver,
tty.master()))
        .name(format!("{address:?}_to_tty"))
        .spawn()?;


    let new_app_ns = mod_mgmt::create_application_namespace(None)?;

    let (app_file, _ns) =

mod_mgmt::CrateNamespace::get_crate_object_file_starting_with(&new_app_ns,
"hull-")
            .expect("Couldn't find hull in default app namespace");

    let path = app_file.lock().get_absolute_path();
    let task = spawn::new_application_task_builder(path.as_ref(),
Some(new_app_ns))?
        .name(format!("{address:?}_hull"))
        .block()
        .spawn()?;

    let id = task.id;
    let stream = Arc::new(tty.slave());
    app_io::insert_child_streams(
        id,
        app_io::IoStreams {
            discipline: Some(stream.discipline()),
            stdin: stream.clone(),
            stdout: stream.clone(),
            stderr: stream,
        },
    );

    task.unblock().map_err(|_| "couldn't unblock hull task")?;
    task.join()?;

    reader_task.kill(KillReason::Requested).unwrap();
    writer_task.kill(KillReason::Requested).unwrap();

    // Flush the tty in case the reader task didn't run between the last time the
    // shell wrote something to the slave end and us killing the task.
    let mut data = [0; 256];
    if let Ok(len) = tty.master().try_read(&mut data) {
        port.lock()
            .write(&data[..len])
            .map_err(|_| "couldn't write to serial port")?;
    };

    // TODO: Close port?

    Ok(())
}
```

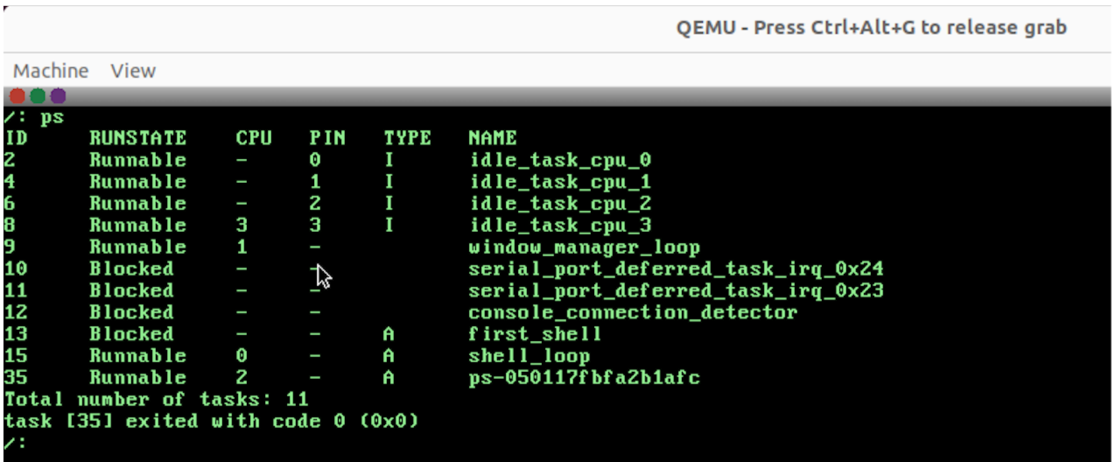
```
fn tty_to_port_loop((port, master): (Arc<IrqSafeMutex<SerialPort>>, tty::Master)) {
    let mut data = [0; 256];
    loop {
        let len = match master.read(&mut data) {
            Ok(l) => l,
            Err(e) => {
                error!("couldn't read from master: {e}");
                continue;
            }
        };

        if let Err(e) = port.lock().write(&data[..len]) {
            error!("couldn't write to port: {e}");
        }
    }
}

fn port_to_tty_loop((receiver, master): (Receiver<DataChunk>, tty::Master)) {
    loop {
        let DataChunk { data, len } = match receiver.receive() {
            Ok(d) => d,
            Err(e) => {
                error!("couldn't read from port: {e:?}");
                continue;
            },
        };

        if let Err(e) = master.write(&data[..len as usize]) {
            error!("couldn't write to master: {e}");
        }
    }
}
```

APPENDIX B

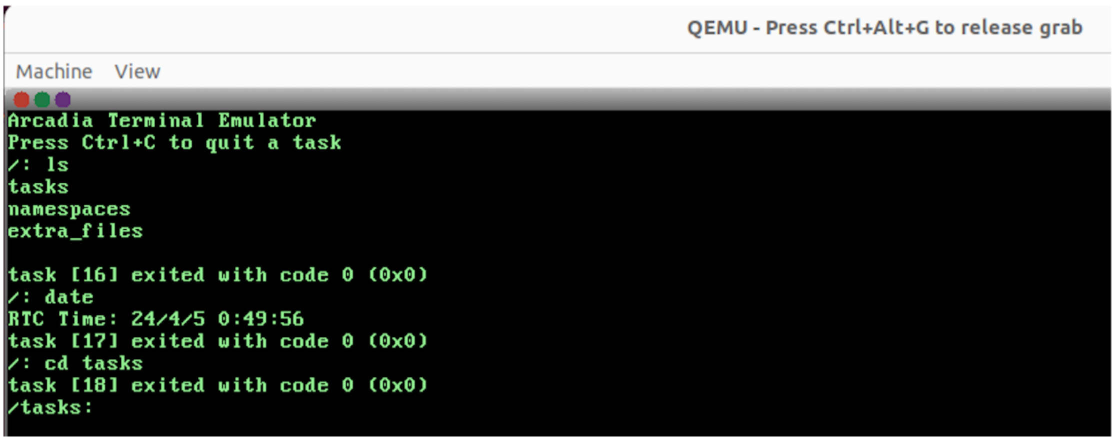
SCREENSHOTS



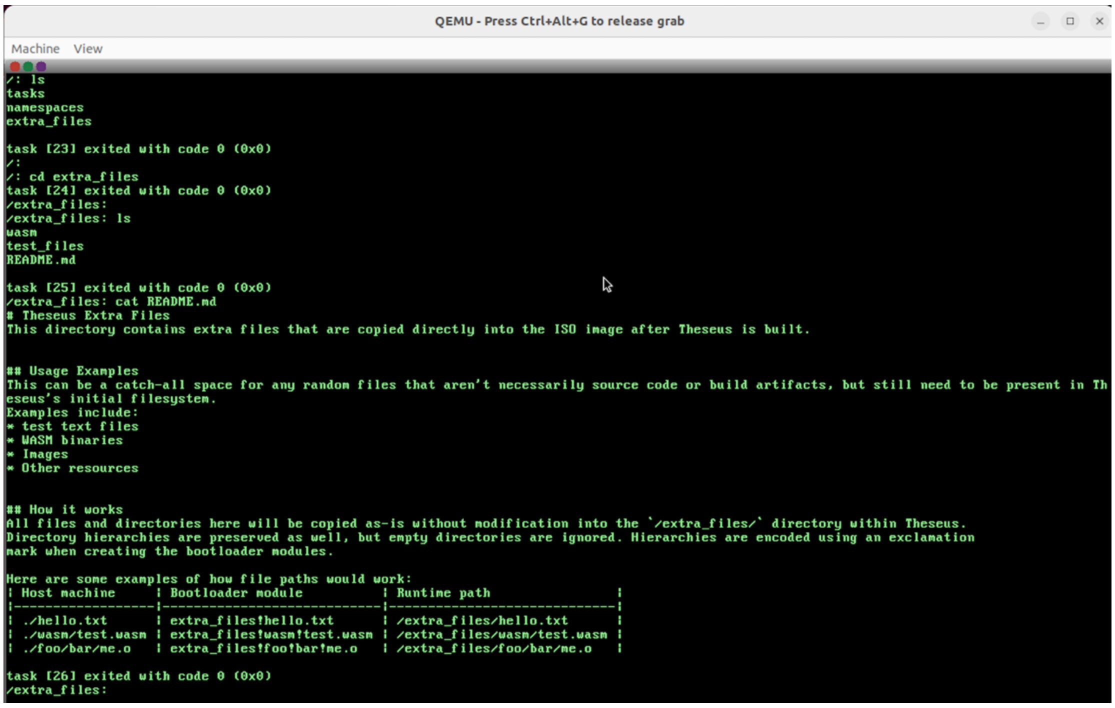
```
/: ps
ID      RUNSTATE    CPU    PIN    TYPE    NAME
2       Runnable    -      0      I       idle_task_cpu_0
4       Runnable    -      1      I       idle_task_cpu_1
6       Runnable    -      2      I       idle_task_cpu_2
8       Runnable    3      3      I       idle_task_cpu_3
9       Runnable    1      -              window_manager_loop
10      Blocked     -      -              serial_port_deferred_task_irq_0x24
11      Blocked     -      -              serial_port_deferred_task_irq_0x23
12      Blocked     -      -              console_connection_detector
13      Blocked     -      -      A       first_shell
15      Runnable    0      -      A       shell_loop
35      Runnable    2      -      A       ps-050117fbfa2b1afc
Total number of tasks: 11
task [35] exited with code 0 (0x0)
/:
```



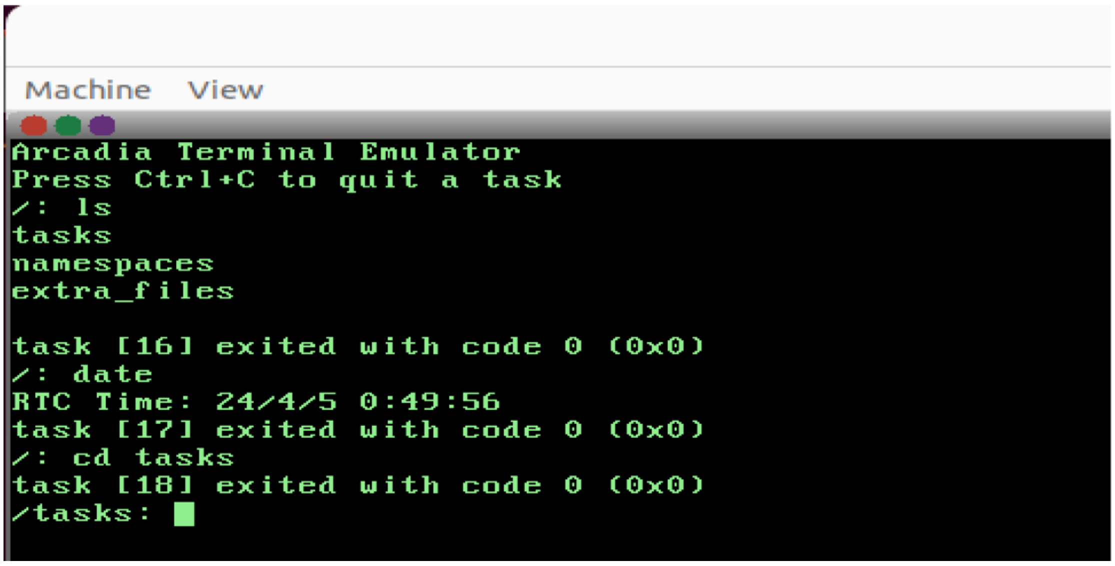
```
/: ps
ID      RUNSTATE    CPU    PIN    TYPE    NAME
2       Runnable    -      0      I       idle_task_cpu_0
4       Runnable    -      1      I       idle_task_cpu_1
6       Runnable    -      2      I       idle_task_cpu_2
8       Runnable    3      3      I       idle_task_cpu_3
9       Runnable    1      -              window_manager_loop
10      Blocked     -      -              serial_port_deferred_task_irq_0x24
11      Blocked     -      -              serial_port_deferred_task_irq_0x23
12      Blocked     -      -              console_connection_detector
13      Blocked     -      -      A       first_shell
15      Runnable    0      -      A       shell_loop
35      Runnable    2      -      A       ps-050117fbfa2b1afc
Total number of tasks: 11
task [35] exited with code 0 (0x0)
/:
```



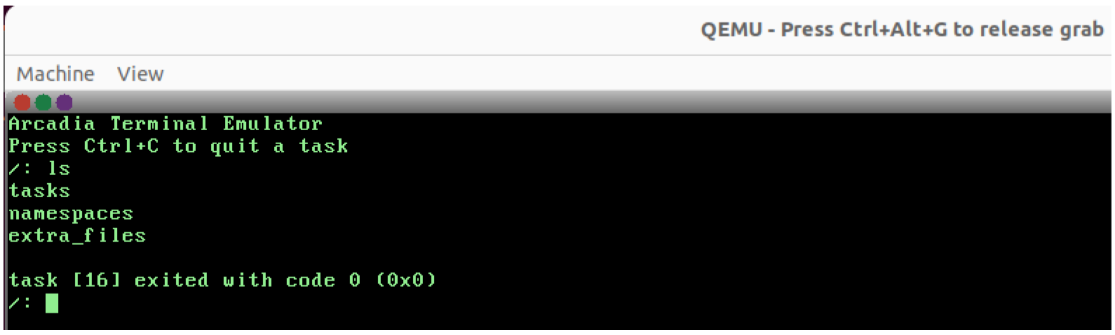
```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/: ls
tasks
namespaces
extra_files

task [16] exited with code 0 (0x0)
/: date
RTC Time: 24/4/5 0:49:56
task [17] exited with code 0 (0x0)
/: cd tasks
task [18] exited with code 0 (0x0)
/tasks:
```



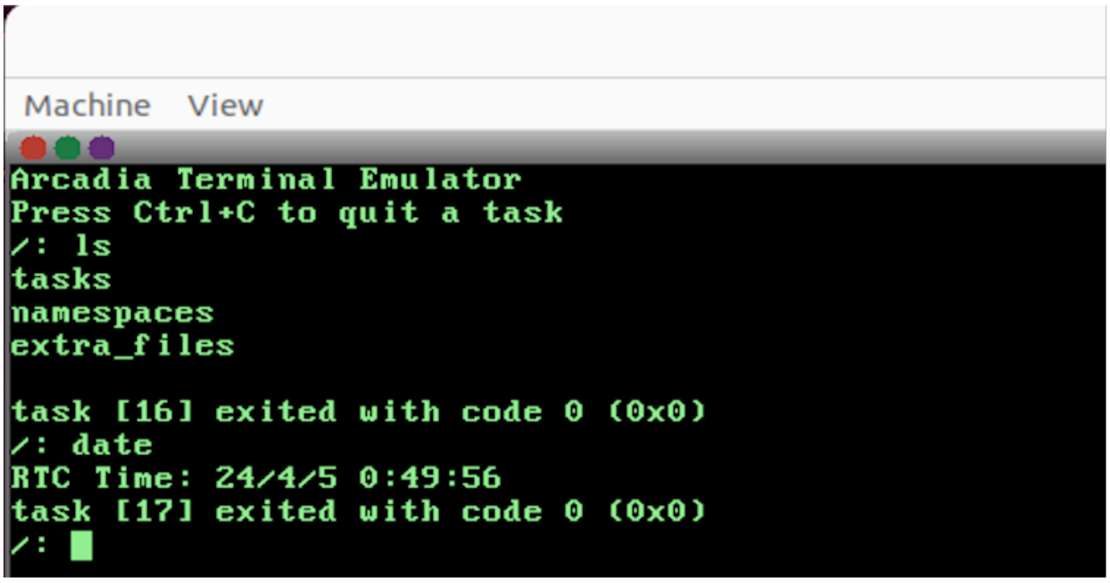
```
/: ls
tasks
namespaces
extra_files

task [23] exited with code 0 (0x0)
/:
/: cd extra_files
task [24] exited with code 0 (0x0)
/extra_files:
/extra_files: ls
wasm
test_files
README.md

task [25] exited with code 0 (0x0)
/extra_files: cat README.md
# Theseus Extra Files
This directory contains extra files that are copied directly into the ISO image after Theseus is built.


## Usage Examples
This can be a catch-all space for any random files that aren't necessarily source code or build artifacts, but still need to be present in Th
eseus's initial filesystem.
Examples include:
* test text files
* WASM binaries
* Images
* Other resources


## How it works
All files and directories here will be copied as-is without modification into the `/extra_files/` directory within Theseus.
Directory hierarchies are preserved as well, but empty directories are ignored. Hierarchies are encoded using an exclamation
mark when creating the bootloader modules.

Here are some examples of how file paths would work:
| Host machine      | Bootloader module           | Runtime path                |
|-------------------|-----------------------------|-----------------------------|
| ./hello.txt       | extra_files!hello.txt       | /extra_files/hello.txt      |
| ./wasm/test.wasm  | extra_files!wasm!test.wasm  | /extra_files/wasm/test.wasm |
| ./foo/bar/me.o    | extra_files!foo!bar!me.o    | /extra_files/foo/bar/me.o   |

task [26] exited with code 0 (0x0)
/extra_files:
```



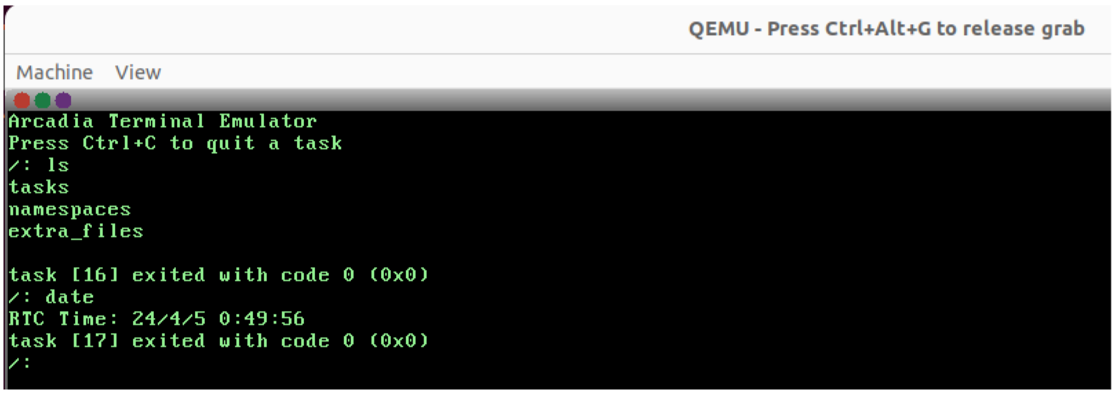
```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/: ls
tasks
namespaces
extra_files

task [16] exited with code 0 (0x0)
/: date
RTC Time: 24/4/5 0:49:56
task [17] exited with code 0 (0x0)
/: cd tasks
task [18] exited with code 0 (0x0)
/tasks:
```



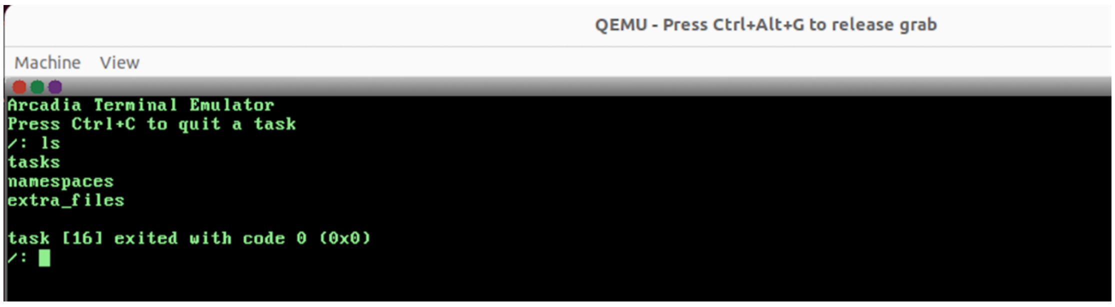
```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/: ls
tasks
namespaces
extra_files

task [16] exited with code 0 (0x0)
/:
```



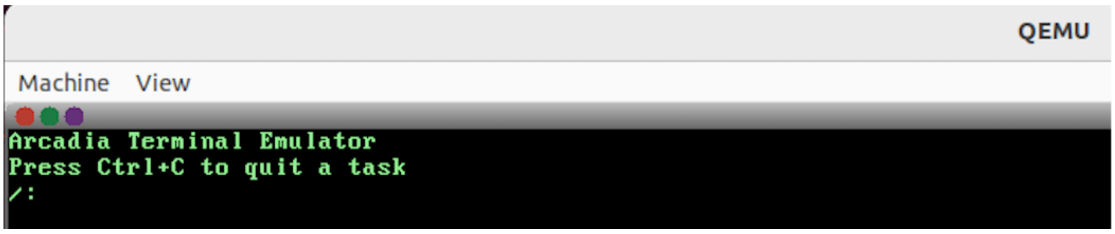
```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/: ls
tasks
namespaces
extra_files

task [16] exited with code 0 (0x0)
/: date
RTC Time: 24/4/5 0:49:56
task [17] exited with code 0 (0x0)
/: █
```



```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/: ls
tasks
namespaces
extra_files

task [16] exited with code 0 (0x0)
/: date
RTC Time: 24/4/5 0:49:56
task [17] exited with code 0 (0x0)
/:
```



```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/: ls
tasks
namespaces
extra_files

task [16] exited with code 0 (0x0)
/: █
```



```
Arcadia Terminal Emulator
Press Ctrl+C to quit a task
/:
```