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Master's Thesis

Computer Science and Engineering
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Ing. Martin ÚblARMv6 Processor Emulator for
Raspberry Pi Environment

Abstract

This paper examines the potential of emulating Raspberry Pi Zero, a selected example of one of the most widely adopted architectures for embedded systems — the ARM architecture. The initial chapters delve into a general introduction to the ARM architecture, highlighting its profound significance evidenced by billions of electronic that leverage it. Transitioning to the second part, the thesis addresses the benefits of utilizing an ARM emulator, delineating overall requirements, and reviewing existing methodologies. The second part centers on the development of a custom Raspberry Pi Zero emulator whose functionality is systematically tested using a set of examples pertinent to operating system development. The thesis concludes with an objective evaluation of the emulator's performance, identifying its key benefits, and suggesting areas for further enhancements.

Introduction

ARM stands out as one of the most widely embraced computer architectures, finding application across a diverse range of domains. Its utility extends from low-power solutions and affordable microcontrollers to real-time applications and safety-critical systems, encompassing fields such as medical devices, the automotive industry, and aviation. Furthermore, ARM plays a significant role in personal computers and the cell phone industry, currently powering more than 99% of the world's smartphones.

Emulating such an extensively adopted architecture can assist in illustrating concepts of computer organization and operating systems. Additionally, it offers advantages in the field of software development, particularly when immediate access to a development board may not be feasible. Furthermore, it provides a layer of abstraction, allowing developers to experiment with potentially risky code without the concern of damaging real hardware.

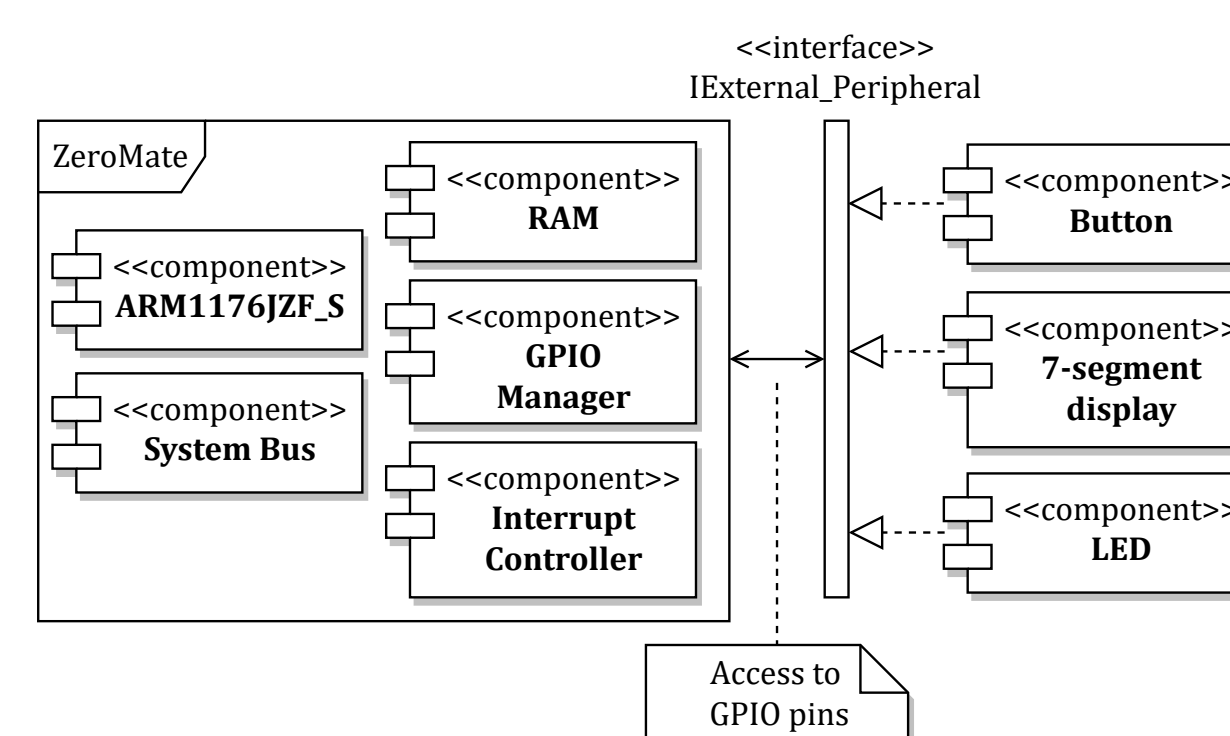
Existing Solutions

Several available solutions, such as QEMU, CPUlator, and ARMSim#, can be employed for emulating ARM architecture. However, as the thesis concludes, their emulation capabilities may be limited, as most of them lack some of the more advanced system-related features, such as the ability to switch CPU modes or implement paging, which is indispensable in operating system development. Consequently, the thesis aimed to develop an extensible Raspberry Pi Zero emulator capable of emulating KIV-RTOS, an educational real-time operating system developed at the University of West Bohemia.

Proposed Solution – ZeroMate

ZeroMate was developed to address the challenges associated with existing solutions. It was

meticulously designed in a modular fashion, enabling users to seamlessly connect custom-party peripherals such as displays, sensors, and actuators. These peripherals can be developed independently of the core system, providing users with flexibility and customization options.



(1) ZeroMate's public interface for external peripherals

It was created with the aim of giving users a comprehensive visual overview of the entire system, allowing them to examine the current contents of various core components, such the CPU registers and RAM. Furthermore, it offers insights into the current configurations of various BCM2835 peripherals, including the GPIO pins, interrupt controller, ARM timer, MiniUART, BSC (I²C), and more. Moreover, it boasts support for fundamental debugging features, thereby simplifying the debugging processes for cross-compiled applications. Additionally, the emulator incorporates coprocessor support, empowering users to harness features like floating-point numbers or virtual addressing.

Testing & Achieved Results

The core of the emulator underwent rigorous testing through an extensive suite of unit tests, addressing its fundamental yet crucial functionalities that other parts of the system heavily depend on. Unit tests cover approximately 78% of the core's functionality. Functional testing integrated different components of the emulator, working alongside to execute specific tasks, such as blinking an LED using a timer interrupt or scheduling processes running in userspace. The final phase of testing, system testing, was conducted by students enrolled in the KIV/OS to assess its overall usability in practice. Using KIV-RTOS, the emulator average speed of emulation was calculated to be 4.84 mega instructions per second.

Instruction type	Impact on performance	
	[avg. execution time [s] * absolute count]	
Single data transfer	46.3	
Data processing	31.6	
Branch	4.2	
Extend	2.8	
Block data transfer	2.2	
Software interrupt	0.6	
Branch and exchange	0.3	
Store return state	0.1	

(2) Top 8 most performance-affecting ARM instructions