A modular kernel for the Raspberry Pi: Project Specification

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Thomas Archbold
1602581
University of Warwick

Background

In most operating systems, many design decisions are made in order to keep things simple for the user, by keeping most of the technical details hidden. In most cases, this is an appropriate approach: needlessly offering more choices for low-level tasks that are usually handled by the operating system, such as CPU scheduling algorithms, would only serve to confuse the average user. It may actually be detrimental to the security and the stability of the system by opening up more opportunities for errors to be introduced. This more insulated approach does mean, however, that the user never really knows what is going on "under the hood", and indeed whether greater performance can be achieved by making *different* fundamental decisions. Furthermore, a number of operating systems exist for the Raspberry Pi, some focusing on ease-of-installation, others on Internet of Things integration, such as the NOOBS [1] Linux distribution or the Windows 10 IoT Core distribution [2]. Yet, none exist to serve as an experimental operating system, designed as a testbed for making and changing these low-level behaviours. This project aims to fill this gap for the operating systems enthusiast, one who wishes to test for themselves the different approaches to CPU scheduling, interprocess communication, and filesystems. It will give the user the ability to alter the fundamental ways in which their machine operates by compiling different modules to handle different tasks, enabling for a more flexible operating system where such things can be tweaked at any point.

Main goal

The goal of this project is to create a modular operating system for the Raspberry Pi 2 Model B that is capable of loading different modules at compilation time to tackle CPU scheduling, interprocess communication, and filesystems in a variety of ways. Specifically, it must have some way to run and switch between multiple processes using a CPU scheduler; to use both shared memory and message passing for interprocess communication; to create, read, update, and delete files and directories using a custom filesystem; and to interface with the SD card for permanent/mass storage. To achieve this, it must implement an interface for compiling different modules, similar to Linux's `insmod`, `rmmod`, and Kbuild system [3, 4]. Furthermore, as executing processes forms a key functional requirement for the project, there must be a convenient way to load programs into memory and begin their execution. A solution to this is to implement a basic shell/command interpreter.

Finally, a key objective of this project will be to get the operating system to work entirely on real hardware, and not solely in an emulated environment. This includes booting from the SD card installed in the Raspberry Pi. As the boot process is handled by the Pi's System on Chip (SoC), so booting will be possible without writing a custom bootloader. On top of booting from it, the operating system must interact with the SD card in conjunction with a filesystem for permanent/mass storage. Finally, it must be capable of taking input from a keyboard connected via USB, and printing output to a physical screen via its HDMI port.

The kernel

Configurable modules

The project must implement the following as modules, which may be configured at compilation time by the user:

- CPU Scheduling:
  - First Come First Served
  - Round Robin
  - Shortest Job First
  - Shortest Remaining Time First
  - Priority Scheduling (preemptive and non-preemptive)
  - Lottery Scheduling
- Interprocess Communication
  - Message passing
  - Shared memory
- Filesystem
  - persistent
  - load-on-request

Stretch goals

Some stretch goals which should be implemented to show understanding of more complex structures would be some more intricate scheduling algorithms, including the following [5, 6, 7, 8, 9]:

- Completely Fair Scheduler
- Multiple Queue Skiplist Scheduler, MuQSS
- Multilevel Queue and Multilevel Feedback Queue
- $\mathcal{O}(n)$ Scheduler
- $\mathcal{O}(1)$ Scheduler

In order to give the operating system more purpose and to increase usability, the collection of relatively simple programs on offer should be extended, including a mix of long running CPU- and I/O-bound programs. This will mean that the relative performance of the schedulers may be seen more easily. While the Not Recently Used (NRU) algorithm will be used for page replacement due to its low overhead and decent performance, other algorithms could be explored and implemented as modules. These may include: First-In-First-Out (to highlight its poor performance), the Clock Page Replacement algorithm, and the Least Recently Used algorithm [10].

Further extensions

Beyond these goals, further extensions would focus on increasing the usability of the system, and start to shape it into one which someone might actually use to get things done. One of the simpler ways to achieve this would be to write a text editor. Additionally, implementing networking into the operating system would vastly increase its usability and general usefulness. Such goals are rather far-fetched given the time frame of the project, but would form meaningful projects later in the life of the operating system.

Out-of-scope

Features which will not be implemented in th eproject include graphical user interfaces and any form of security. Graphics would increase the complexity of the project too much, and provide too little reward, to be considered a worthwhile goal. While security would be easier to implement, for example by following suit of Linux's permissions interface [**?**], it would again detract attention from features more in line with the project's goals. After all, the operating system produced will only be experimental and designed for use by one user, and as such security will be an unnecessary feature.

Hardware

The Raspberry Pi 2 Model B's technical specifications are as follows:

- 900 MHz quad-core ARM Cortex-A7 CPU
- 1GB RAM
- 40 GPIO pins
- 4 USB ports
- Full HDMI port
- MicroSD card slot
- 100 Base Ethernet
- VideoCore IV graphics Core
- Combined 3.5mm audio jack and composite video
- Camera interface (CSI)
- Display interface (DSI)

The main reason for choosing to work with the Raspberry Pi was due to its simple boot process, which is detailed below. In particular, as it is handled entirely by its SoC, it means a custom bootloader capable of loading the kernel into memory and transferring control to it will need not be written. The motivation behind opting for the Raspberry Pi 2 Model B specifically was because of its prior availability to the author, and meant some other model need not be bought when it came to running on real hardware. The Raspberry Pi 1, 2, and 3 use the Broadcom BCM2835, BCM2836, and BCM2837 respectively, and the underlying architecture behind these chips are identical. The only difference from the 2's chip to the BCM2835 is that the ARM1176JZF-S processor has been replaced with a quad-core Cortex-A7 cluster [11]. Similarly, this chip only differs from the BCM2837 in that this Cortex-A7 cluster is replaced by a quad-core ARM Cortex A53 (ARMv8) cluster [12]. This is all to say that the differences between the different versions of the Pi are likely to be insignificant when compared with the focus of the project, in that it is concerned with producing an operating system simply for *some* version of the Pi.

A note about the Raspberry Pi's boot process

Methodology

The methodology best suited to the project will be a mix between a plan-driven and agile approach; the basic requirements of the system will not change over the course of the project, and furthermore there will be a rigid structure with regards to dependencies that the project is likely to abide by (for example, the system will have to boot before implementing memory management before implementing scheduling algorithms). Therefore, the early stages of the project will benefit from a plan driven approach, most likely an Incremental one to allow for some choice in what to implement, as opposed to the more restrictive structure of a Waterfall methodology. After the foundations have been implemented successfully, the project is likely to open up and take a more agile approach; Scrum cycles are likely to be useful dedicating a large portion of concentration implementing one feature, or fixing specific bugs, at one time, in an incremental manner.

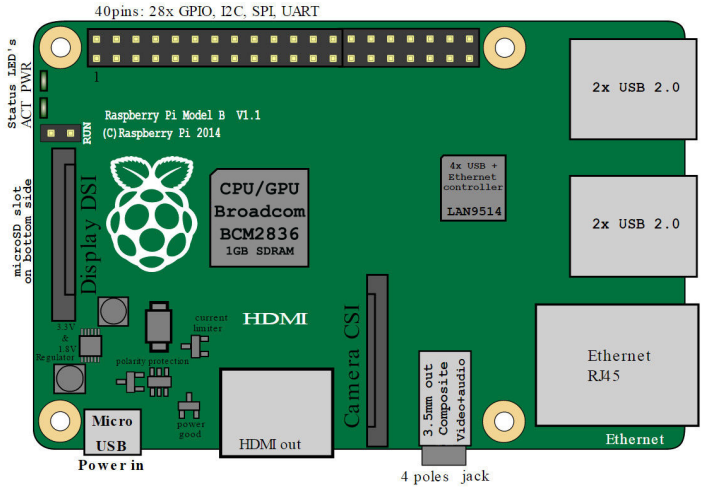


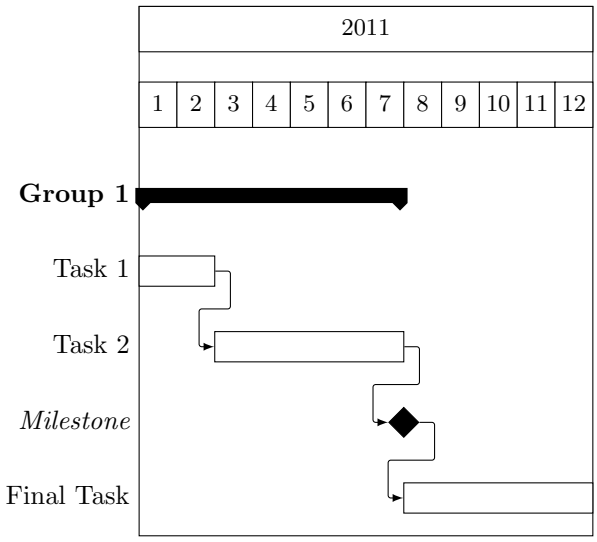
Figure 1: Raspberry Pi 2 Model B

Throughout the project, weekly meetings will be held with the supervisor in order to discuss any current problems and talk through approaches to solutions (especially for the more complex ones), the overall progress of the project, as well as the direction in which it is headed. It would also be at this time that progress is compared with the timetable, and any notes and adjustments are made dynamically in order to fully stay on top of the work.

Testing

The project will be tested in an incremental manner. Especially to begin with, it is vital that some systems operate correctly before moving on and developing other areas. As the project progresses and its complexity increases, unit tests will be written to systematically cover all, or at least most, likely paths of execution, and to account for each of these. The most fundamental requirement to fulfill while testing the solution will be stability, that is to say, whether the system is able to safely switch between different modules and continue operation. Of course, the solution must also be correct: the user must be able to switch dynamically between the different modules, and the system must react accordingly. There must be a way to verify that the system is indeed operating in the way that is expected from the user, and again, unit tests and verification software must be produced to ensure this.

Timetable



Technologies

The following technologies will be used by the project:

- Git - version control
- Github - to access the project from multiple sources, as well as to back it up
- C - the language in which most of the operating system will be implemented
- ARM assembly - used when C is unavailable/inappropriate [13]
- GCC cross compiler for ARM EABI - for cross compiling for the target processor, the Cortex-A7
- QEMU - for emulating the Pi to allow quicker and safer testing [1]
- Make - used to speed up the build process

Resources

The following documentation will be used throughout for reference to the architecture of the Cortex-A7 processor and its intruction set:

- Cortex-A7 MPCore Technical Reference Manual
- ARM Cortex-A Series Programmer's Guide
- Broadcom BCM2835 ARM Peripherals Manual

Legal, social, ethical, and professional considerations

All software used to build the project is available to use under the GNU Public License. Throughout the project's development, some testing will be required from people other than the creator, to gain informal feedback especially with regards to usability; these people are likely to be friends and colleagues, hence the social, ethical, and professional issues are insignificant.

[1] Note that QEMU does not simulate timing of execution, and so some testing will eventually need to be done on real hardware

References

[1] "Noobs." https://www.raspberrypi.org/downloads/noobs/. Page accessed: 2018-10-08.

[2] "An overview of windows 10 iot core." https://docs.microsoft.com/en-us/windows/iot-core/windows-iot-core. Page accessed: 2018-10-08.

[3] "insmod(8) - linux man page." modprobe://linux.die.net/man/8/insmod. Page accessed: 2018-10-03.

[4] "Kbuild: the linux kernel build system." https://www.linuxjournal.com/content/kbuild-linux-kernel-build-system. Page accessed: 2018-10-09.

[5] "Cfs scheduler." https://www.kernel.org/doc/Documentation/scheduler/sched-design-CFS.txt. Page accessed: 2018-10-03.

[6] "Kernel patch homepage of con kolivas." www.users.on.net/~ckolivas/kernel/. Page accessed: 2018-10-03.

[7] A. Silberschatz, P. B. Galvin, and G. Gagne, *Operating System Concepts*, ch. 5: Process Scheduling. Wiley, 9 ed., 2014.

[8] . Page accessed: 2018-08-30.

[9] . Page accessed: 2018-08-30.

[10] A. S. Tanenbaum and A. S. Woodhull, *Operating Systems: Design and Implementation*, ch. 4: Memory Management. Pearson, 3 ed., 2009.

[11] "Bcm2836." https://www.raspberrypi.org/documentation/hardware/raspberrypi/bcm2836/README.md. Page accessed: 2018-10-08.

[12] "Bcm2837." https://www.raspberrypi.org/documentation/hardware/raspberrypi/bcm2837/README.md. Page accessed: 2018-10-08.

[13] "C: Things c can't do." https://wiki.osdev.org/C#Things_C_can.27t_do. Page accessed: 2018-08-30.