ECE 598 – Advanced Operating Systems
Lecture 3

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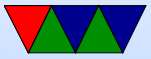
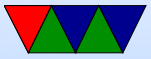
Announcements

- HW#1 was posted, due on Thursday.
- Will have the loaner Pis ready soon.



Booting a System

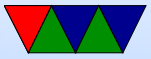
- Why is it called booting?
- Most likely source is the idea of “Pulling oneself up by ones bootstraps”, i.e., getting somewhere by starting with nothing



Simple Booting

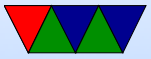
- Simplest systems have code in ROM.
  The CPU initializes, points the Program Counter to a known location, and starts executing.

- The STM32L boards in ECE271 do something similar; code is in flash, reset vector (at offset 0) points at code to start. press reset, runs reset vector, up to you to do everything else.



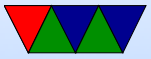
Firmware

- Low-level code (often written in assembly language) that initializes the system.
- Often in ROM/EEPROM/FLASH
- Boot firmware initializes system.
  - Init RAM? Set it up (often over i2c), clear out random or old contents (if a soft reboot). This part operates without memory or stack to use, tricky.
  - Init other hardware. I/O, serial ports, keyboard, display, etc.



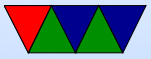
- Load code to boot. Where from? Hard-disk, floppy, network (PXE), CD/DVD, USB, SD-card, etc. Old days: tape, paper-tape, console switches?

- Might have other interfaces: boot selection/configuration screen?
- Some firmware provides routines for hardware to use, for things like accessing disks, writing to screen, reading keyboard, initializing security, etc.
- Firmware development is hard. Not all corner-cases well tested (can it boot Windows? Ship it). Kernel and Firmware devels have antagonistic relationship.



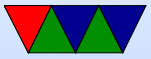
Booting on x86

- Firmware
  - BIOS original firmware. 16-bit. Dates back to CP/M days. Provided booting and a library for accessing I/O. (MS-DOS a thin layer over BIOS).
  - These days EFI and uEFI replacing it, 32/64-bit. Written in higher level language.
  - Firmware provides other interfaces, like power management, ACPI, device enumeration, etc.
  - x86 firmware can use SMM mode which allows

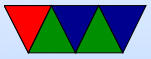


secret/hidden code running behind the scenes for things like hardware emulation (USB keyboards) and power management.

- Firmware traditionally loaded a 512Byte bootsector (last two bytes 0x55 0xAA) to 0x7c00 and jumped to it. This "first stage" then had enough code to load a more complex "second stage"
- The bootloader (GRUB is a common one on x86 Linux) then loads the operating system. Provides nice graphical interface often (to select images) and a console for setting command line arguments and even browsing for

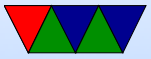


kernel images.



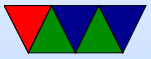
Loading Linux

- Linux is usually on disk, sometimes a separate boot partition. Complicated because blocks might not be contiguous on disk.
- Some Linux images can be loaded directly, without need of bootloader.
- Linux image itself can be complex
  - Linux image, "vmlinux" (why called that? historical, unix, vm unix)
  - decompresser and compressed image (zImage,



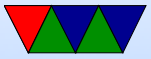
bzImage, uIMage, etc)

- When building, the kernel image is taken, stripped, compressed. piggy "piggyback" code put on, as well as decompressor. Originally floppy boot code stuck on beginning as well.
- Different entry points. On x86 BIOS boots into 16-bit. EFI and bootloaders can jump into 32/64
- So optionally boots in 16-bit mode. Switches to 32-bit mode. If 64-bit, optionally switch to 64-bit Decompressed kernel to 0x10 0000 (might have to move decompress code). (above 1MB. Why? 640k)



What about initrd?

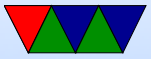
- Jump to startup_32 / startup_64 function
- 16-bit code handles various stuff, gets memory size from BIOS, etc
- 32/64 relies more on boot loader. Has specification for how registers set up, etc.
- relocates decompression code if needed. Sets up stack, clears BSS, Decompresses.
- relocate if needed. why? randomization is one.
- Memory map. Virtual mem. First 896M of physical mem mirrored in top of 32-bit. Why? So kernel can



easily copy to/from. Can convert kernel virt to phys with just subtraction. Complicated if more than that much RAM, have to copy around. HIGHMEM.

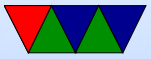
  - space above for vmalloc
  - somewhat more complicated 64-bit
  - kernel just an ELF executable

- Starts Userspace program "init" (old days simple program and shell scripts, these days "systemd")
- Sometimes an "initrd" is included too that has enough drivers to get Linux going and a very minimal filesystem to help with booting before disks/filesystem ready.

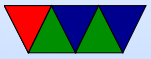


Disk Partitions

- Master Boot Record, Boot Sector
- Followed by partition table
- Way to virtually split up disk.
- DOS GPT – old partition type, in MBR. Start/stop sectors, type
- Types: Linux, swap, DOS, etc

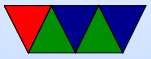


- GPT had 4 primary and then more secondary
- Lots of different schemes (each OS has own, Linux supports many). UEFI more flexible, greater than 2TB



Bootloaders on ARM

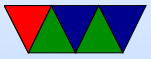
- The most common is uBoot
- uBoot – Universal Bootloader, for ARM and other embedded systems
- Almost like minimal OS
- More of a challenge to write a bootloader for a widely nonstandardized architecture like ARM. (Why is ARM so nonstandardized?)



Uboot Booting

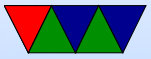
- Most other ARM devices, ARM chip runs first-stage boot loader (often MLO) and second-stage (uboot)

- FAT partition
  Why FAT? (Simple, Low-memory, Works on most machines, In theory no patents despite MS's best attempts (see exfat))
  The boot firmware (burned into the CPU) is smart enough to mount a FAT partition

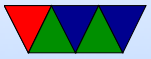


Booting on typical ARM/uboot

- vmlinux. strip. compress. piggy / piggyback. decompression code tacked on convert to zImage. mkuimage converts to uimage suitable for booting with uboot
- No bios really. Bootloader provides all info.
- Modern day Device Tree provides config info for hardware (memory size, interrupts, what hardware is there). This allows possibility of a kernel that will run on many ARM

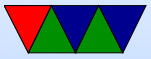


boards (PI, beaglebone, pandaboard, etc) rather than having to have a different hard-coded kernel for each possible platform.

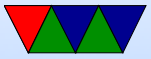


Kernel booting

- Initializes hardware. First part asm. Transition to C as quickly as possible. First thing to initialize. Memory. Then simple in/out. Enable keyboard, simple VGA, serial console. So printk can work.
- Relocates decompression code
- Decompresses
- Parse the resulting ELF file.

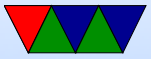


- Apply any relocations
- Jump to entry point

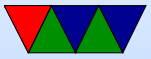


Raspberry Pi Booting

- Unusual (and has changed over the past few years)
- Small amount of firmware on SoC
- ARM 1176 brought up inactive (in reset)
- Videocore loads first stage from ROM. Videocore actually runs its own os (vcos) based on ThreadX RTOS.
- This reads `bootcode.bin` from fat partition on SD card into L2 cache.



- This runs on videocore, enables SDRAM, then loads `start.elf`
- This initializes things, the loads and boots Linux `kernel.img`. (also reads some config files there first)



So how do we start with own OS?

- Make simple binary.
- Compile it with ARM toolchain (cross compile?)
- Replace kernel.img on your memory card.
- Boot into it!
- Easier said than done.
- What kind of setup do you have?