CS 326: Operating Systems

Booting Up

Lecture 3

Running a Program

- Let's say you're building your own OS. What's the very first thing we have to do?
  - How do we get a computer to run a program?
- …

Booting Up

- When you turn on your computer, it starts the **boot process**
  - Named for "pulling oneself over a fence by one's bootstraps"
    - Or in other words, doing the impossible
- Booting is a series of tasks that ultimately get the operating system running
- The first thing you (may) see is the POST
  - Power-on Self Test

Award Modular BIOS v6.00PG, An Energy Star Ally
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BIW1M/BIW2M BIOS V1.3

Main Processor : PENTIUM II 910MHz
Memory Testing : 131072K OK + 1024K Shared Memory

Award Plug and Play BIOS Extension v1.0A
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BIOS / UEFI

- After initializing the hardware, your basic input-output system (BIOS) will start iterating through the disks connected to your machine
  - When installing a new OS, you may change the **boot order**
  - On a Mac, you can do this by holding down Option during boot (other machines: F12, Del…)
- Once a bootable disk is found, we proceed to the next boot phase

Master Boot Record

- The first 512 bytes on a hard drive contain the Master Boot Record (MBR)
- The MBR has two parts:
  - **Boot code**
    - Responsible for continuing the boot process
  - **Partition table**
    - Partition: segment of a disk
    - Partition 1: Windows; Partition 2: Linux; etc.
    - Basically contains a pointer to where each partition starts

Finding a Bootable Partition

- The BIOS looks for a disk partition that ends with 0x55AA
  - (Bootable flag)
- It copies the MBR into memory at `0x0000:0x7C00`
  - Segment 0, address 0x7C00
- And finally, it starts executing the first instruction at `0x7C00`.

MBR Contents

Start Address	Contents	Size (bytes)
0x0000	Boot Code	446
0x01BE	Partition Table (16 bytes each)	64
0x01FE	0x55	2
0x01FF	0xAA	2

- Observations:
  - 512 bytes is not a lot of bytes
  - Only four partitions possible

Demo: Booting

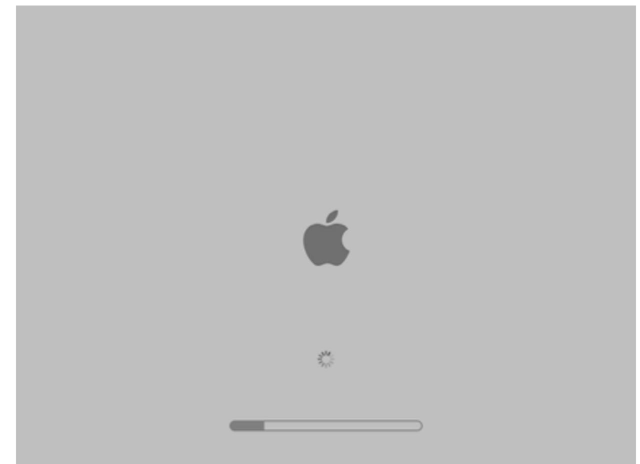
Let’s take a look at a minimal boot code.

Hard-Coded Offsets

- You might be surprised that these offsets are just hard-coded into the system
- However, the BIOS is not particularly smart
  - Originally was a read-only chip (modern motherboards have flashable BIOS)
  - Making the BIOS smarter would make it more complex and more expensive
  - Tend to be specialized for the hardware, unlike OS
- Modern EFI systems add more complexity, but the principle remains the same

Continuing the Boot Process

- We began executing instructions, so we're all done starting the OS, right?
  - Unfortunately, no…
- The first instructions executed are part of the **bootloader**
- The bootloader is a bit smarter than the BIOS, and handles the next steps in the boot process



Bootloader

- The bootloader can understand a variety of file systems
  - Invent a new file system? Add support to the bootloader. No need to modify the hardware ROM
- It can also provide a list of operating systems available in a multi-boot configuration
- ...And it can handle larger disks!
  - The BIOS is limited to a fixed number of partitions and disk sizes

Bootloader Restrictions

- You can only have one bootloader per disk
- Installing one will overwrite another
  - *Windowsssssssss!!!*

Finishing the Boot Process

- The bootloader starts the OS
- In Linux, the next stage stage is represented by an **initial ramdisk** (initrd)
  - Lightweight, mini Linux system image
  - After booting, the first **process** takes over
  - Process: a running instance of a program
- PID 1, also known as **init**, starts the rest of the processes
  - System services, startup tasks, etc
  - Linux: systemd (that's what the systemctl command is controlling!)

PID 1, a.k.a. init

- PID 1 is the direct or indirect ancestor of all other processes
  - When one process launches another, it is that process's **parent**
    - The newly-launched process is the **child**
    - Unfortunately there are no uncle or aunt processes…
  - The kernel or scheduler is usually considered PID 0, but they technically aren't processes.
- Some init implementation can do more or less:
  - System V Init, **systemd**, upstart, launchd, etc.
- You can even write your own!
  - Boot Linux with flag: `init=/path/to/your/init`

Linux: init/main.c

```
/* We try each of these until one succeeds. The Bourne shell can be
 * used instead of init if we are trying to recover a really broken machine. */
if (execute_command) {
  ret = run_init_process(execute_command);
  if (!ret)
    return 0;
  panic("Requested init %s failed (error %d).", execute_command, ret);
}
if (!try_to_run_init_process("/sbin/init") ||
    !try_to_run_init_process("/etc/init") ||
    !try_to_run_init_process("/bin/init") ||
    !try_to_run_init_process("/bin/sh"))  return 0;

panic("No working init found.  Try passing init= option to kernel. "
      "See Linux Documentation/admin-guide/init.rst for guidance.");
```

Process Lineage

```
[malensek@ruby:~]$ ps -ef

UID          PID   PPID  C STIME TTY          TIME CMD
root           1      0  0 Feb21 ?        00:00:57 /usr/lib/systemd/systemd
root           2      0  0 Feb21 ?        00:00:00 [kthreadd]
root           3      2  0 Feb21 ?        00:00:00 [ksoftirqd/0]
root           5      2  0 Feb21 ?        00:00:00 [kworker/0:0H]
root           7      2  0 Feb21 ?        00:01:21 [rcu_sched]
root           8      2  0 Feb21 ?        00:00:00 [rcu_bh]
root           9      2  0 Feb21 ?        00:00:13 [rcuos/0]
root          10      2  0 Feb21 ?        00:00:00 [rcuob/0]

...

malensek     235      1  0 Feb21 tty1     00:00:00 login -- malensek
malensek     282    235  0 Feb21 tty1     00:00:00 bash
```

xv6 Bootloader

- On the RISC-V version of xv6, the emulated hardware provided by QEMU includes a boot ROM
  - This provides a simple bootloader – no need for us to write one.
  - Wait… isn't this the opposite of what we were just talking about?!
    - Yes, but remember the previous discussion was about ***real*** hardware!
- Check out `kernel/entry.S`

xv6 Startup Sequence

1. Bootloader
2. `kernel/entry.S`
3. `kernel/start.c`
4. `kernel/main.c`
5. `user/init.c`

- Generally the same as Linux! But easier to understand…