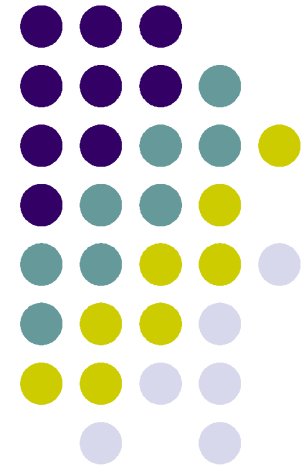
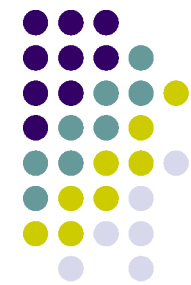


Bootstrapping

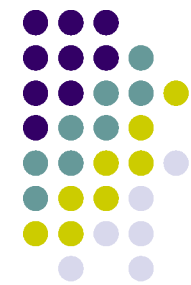
Steve Muckle
Dave Eckhardt





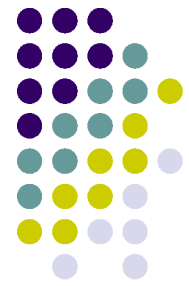
Synchronization

- ♦ Help Wanted
 - C/C++/Linux/control hackers for robot kit project
 - <http://www.cs.cmu.edu/~terk>
 - Possible summer openings hacking for Facilities
 - **Bring me a resume around February**
- ♦ A few good students wanted
 - 15-610 (#include <satya>)



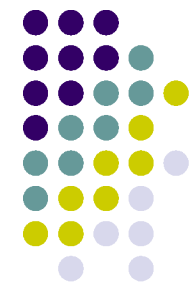
Motivation

- ♦ What happens when you turn on your PC?
- ♦ How do we get to `main()` in `kernel.c`?



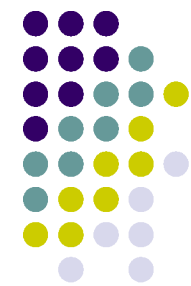
Overview

- ◆ Requirements of Booting
- ◆ Ground Zero
- ◆ The BIOS
- ◆ The Boot Loader
- ◆ Our projects: Multiboot, OSKit
- ◆ BIOS extensions: PXE, APM
- ◆ Other universes: “big iron”, Open Firmware
- ◆ Further reading



Requirements of Booting

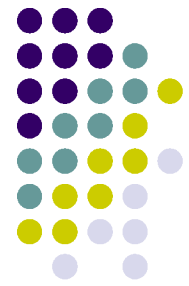
- ◆ Initialize machine to a known state
- ◆ Make sure basic hardware works
- ◆ Inventory hardware
- ◆ Load a real operating system
- ◆ Run the real operating system



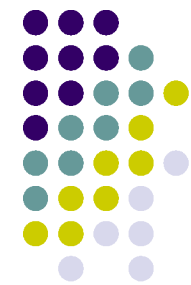
Ground Zero

- ◆ You turn on the machine
- ◆ Execution begins in real mode at a specific memory address
 - Real mode - primeval x86 addressing mode
 - **Only 1 MB of memory is addressable**
 - First instruction fetch address is “end of memory”
 - **0xFFFF0**
 - **Contains a jump to the real BIOS entry point**
- ◆ What’s the BIOS?

Basic Input/Output System (BIOS)

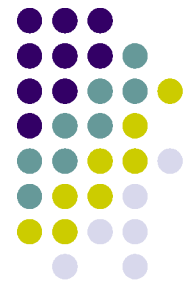


- ◆ Code stored in mostly-read-only memory
 - Flash, previously EEPROM, previously EPROM
- ◆ Configures hardware details
 - RAM refresh rate or bus speed
 - Password protection
 - Boot-device order
- ◆ Loads OS, acts as mini-OS
- ◆ Provides some device drivers to real OS



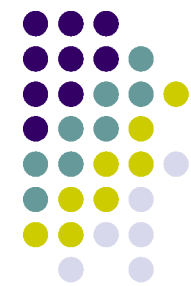
BIOS POST

- ◆ Power On Self Test (POST)
- ◆ Scan for critical resources
 - RAM
 - **Test it (only a little!)**
 - Graphics card – look for driver code at 0xC000
 - Disk – look for driver code at 0xC8000
 - Keyboard
- ◆ Missing something?
 - Beep



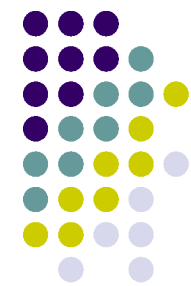
BIOS Boot-Device Search

- ◆ Consult saved settings for selected order
 - “A: C: G:” (maybe PXE)
- ◆ Load the first sector from a boot device
 - could be a floppy, hard disk, CDRROM
 - without a BIOS, we’d be in a bit of a jam
- ◆ If the last two bytes are AA55, we’re set
- ◆ Otherwise look somewhere else
 - If no luck, strike terror into user's heart:
 - **“No Operating System Present”**



BIOS Boot-Sector Launch

- ◆ Boot sector is copied to 0x7C00
- ◆ Execution is transferred to 0x7C00
- ◆ Extra step for hard disk or CD-ROM
 - Boot sector (“MBR”) knows about partitions
 - **Moves itself elsewhere in memory**
 - **Loads active partition's boot sector at 0x7C00**
- ◆ Now we're executing the bootloader – the first “software” to execute on the PC



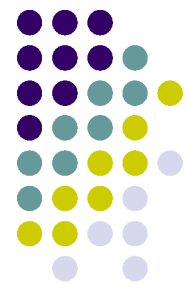
Bootloader

- ◆ Some bootloaders designed to load one OS
- ◆ Others give you a choice of which to load
- ◆ Some are small and have a simple interface
 - “F1 FreeBSD F2 Windows”
- ◆ Some are large, contain GUI, shell prompt
- ◆ We use GRUB
 - <http://www.gnu.org/software/grub/>



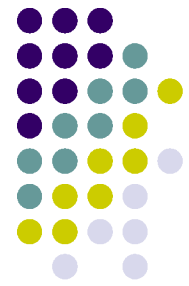
Bootloader's Job

- ♦ Mission: load operating system
- ♦ From where?
 - “/boot/sokoban.gz” is easier said than done
 - May need to understand a file system
 - **Directories, inodes, symbolic links!**
 - May need to understand multiple file systems
 - **Single disk may contain more than one**
 - **Layout defined by “partition label”**
 - ...and “extended partition label”
- ♦ But...but...boot loader is 510 bytes of code!



Multi-Stage Boot Loader

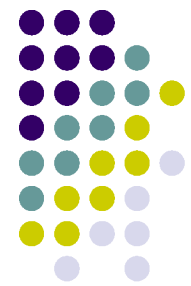
- ♦ GRUB is larger than one sector
- ♦ First sector, loaded in by the BIOS...
 - ...just loads the rest of the boot loader
 - **“GRUB Loading stage2”**
- ♦ GRUB then presents boot menu
- ♦ OS-load challenge
 - BIOS runs in real mode – only 1 meg of RAM!
 - OS may be larger than 1 meg
 - **Linux – often; Windows – absolutely!**



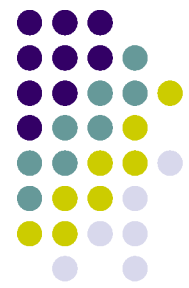
Brain-switching

- ♦ Switch back and forth between real and protected mode
 - Real mode: BIOS works, can drive disk
 - Protected mode: can access lots of memory
- ♦ Switching code is tricky
 - Somewhat like OS process context switch
 - Roughly 16 carefully-crafted instructions each way
- ♦ Load done: jump to the kernel's entry point
 - How do we know the kernel's entryptpoint?

Entry Point, Binary Format, ...



- ♦ Can't we just jump to the beginning?
- ♦ Probably not
 - If kernel is a “regular executable” it begins with an “executable file header” (e.g., ELF)
 - If the OS has the concept of “BSS”, the zeroes aren't in the file...
- ♦ Loading the bytes into RAM isn't enough
 - We must understand, mutate them



Multiboot Specification

- ♦ Attempt to define “portable kernel format”
- ♦ Multiboot “standard”
 - Kernel specifies entry point &c
- ♦ The multiboot header must be located in the first 8192 bytes
- ♦ This is the mysterious multiboot.o...

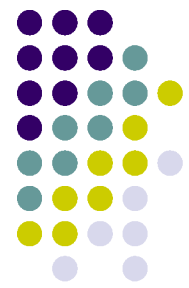
0x1badb002
flags
checksum
Header_addr
load_addr
load_end_addr
bss_end_addr
entry_addr

410 “Pebbles” (from OSkit)



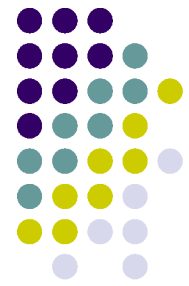
- ♦ Entry point is asm function in multiboot.o
- ♦ This calls the first C function, multiboot_main

OSkit



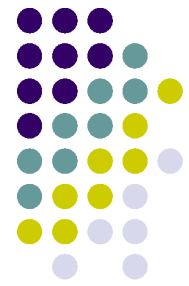
- ♦ multiboot_main() calls:
 - base_cpu_setup(): init GDT, IDT, and TSS
 - base_multiboot_init_mem(): init LMM
 - base_multiboot_init_cmdline()
 - **parse cmdline passed to kernel by bootloader**
 - kernel_main() (at last, your code!)
 - printf(), if kernel_main() ever returns
 - **...kernel main returned with code %d...**

PXE



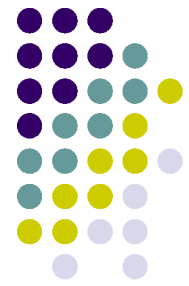
- ♦ Preboot Execution Environment
- ♦ “How a PC should net boot”
 - DHCP extensions to say
 - **“I am a PXE client of DHCP”**
 - **“My machine ID is ... my hardware type is ...”**
 - DHCP server assigns IP address
 - **Instructs client: network settings, TFTP server, file**
 - Client downloads 2nd-stage boot via TFTP
- ♦ PXE libraries for downloaded loader to use
 - **Ethernet, UDP, TFTP**

APM



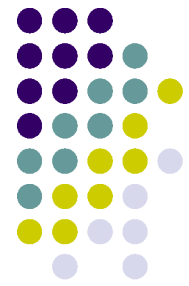
- ♦ Advanced Power Management
- ♦ Problem – Laptop hardware is “special”
 - Lots of power-critical hardware
 - Totally different from one machine to another
 - **Disk spin-down (“standard”, so may be fairly easy)**
 - **Display backlight, processor speed (not so easy)**
 - **South bridge, DRAM controller, keyboard...**
 - Sequencing these in the right order is very machine-specific
- ♦ Problem – user does things (close lid...)

APM



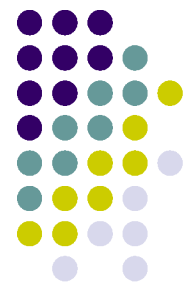
- ♦ Solution - “power kernel”
 - OS asks it to control power hardware
 - Power hardware tells OS about events
 - **Lid closed**
 - **Battery low**
- ♦ Complex rules for messaging back and forth
 - OS required to poll APM periodically
 - **May involve switch to 16-bit mode**
 - Suspend protocol: prepare/commit/abort...

ACPI



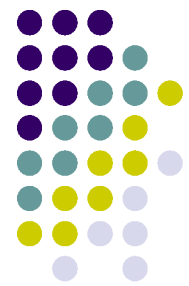
- ♦ Advanced Configuration & Power Interface
 - APM's “big brother”
- ♦ Good news
 - OS gets more understanding, control
 - BIOS provides state-transition tables
- ♦ Bad news
 - What the BIOS tells you is often wrong
 - Lots of “patch the foo entry on machine bar”
workarounds to actually use it

“Big Iron” (mainframes)



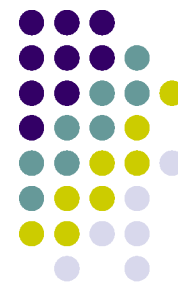
- ♦ “Boot loader” may be a separate machine
 - When main CPU powers on, it does not run code!
 - “Front-end” tasks
 - **Run thorough diagnostics on main machine**
 - **Store OS into its memory**
 - **Set its program counter to entry point**
 - **Turn on instruction fetching**
- ♦ “Front-end” also contains a debugger
 - Useful when your OS crashes

Open Firmware



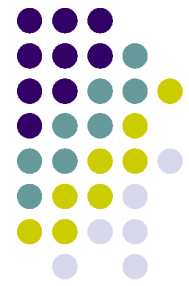
- ♦ Sun & Mac hardware (until June 2005, sigh)
- ♦ Goal: share devices across processor families
 - Ethernet, SCSI disk controller, ...
- ♦ Solution
 - Processor-independent BIOS modules on cards
 - Collection of FORTH methods
 - **test, boot, open, close, read, write, etc.**
- ♦ “Boot ROM” may contain a small debugger
 - Sun, Mac do this... PCs are just starting to catch up

Summary



- ♦ It's a long, strange trip
 - Power on: maybe no RAM, maybe no CPU!!
 - **Maybe beep, maybe draw a sad face**
 - Locate OS
 - Load N stages
 - Tell kernel about the machine and the boot params
 - Provide support to kernel once it's running

Further Reading



- ♦ More BIOS details
 - <http://www.pcguide.com/ref/mbsys/bios/bootSequence-c.html>
 - <http://bioscentral.com/>
- ♦ A real memory tester - memtest86.com
- ♦ Open-source BIOS!
 - www.linuxbios.org
 - openbios.info
- ♦ PXE <ftp://download.intel.com/labs/manage/wfm/download/pxespec.pdf>