Operating Systems Design

02. Booting

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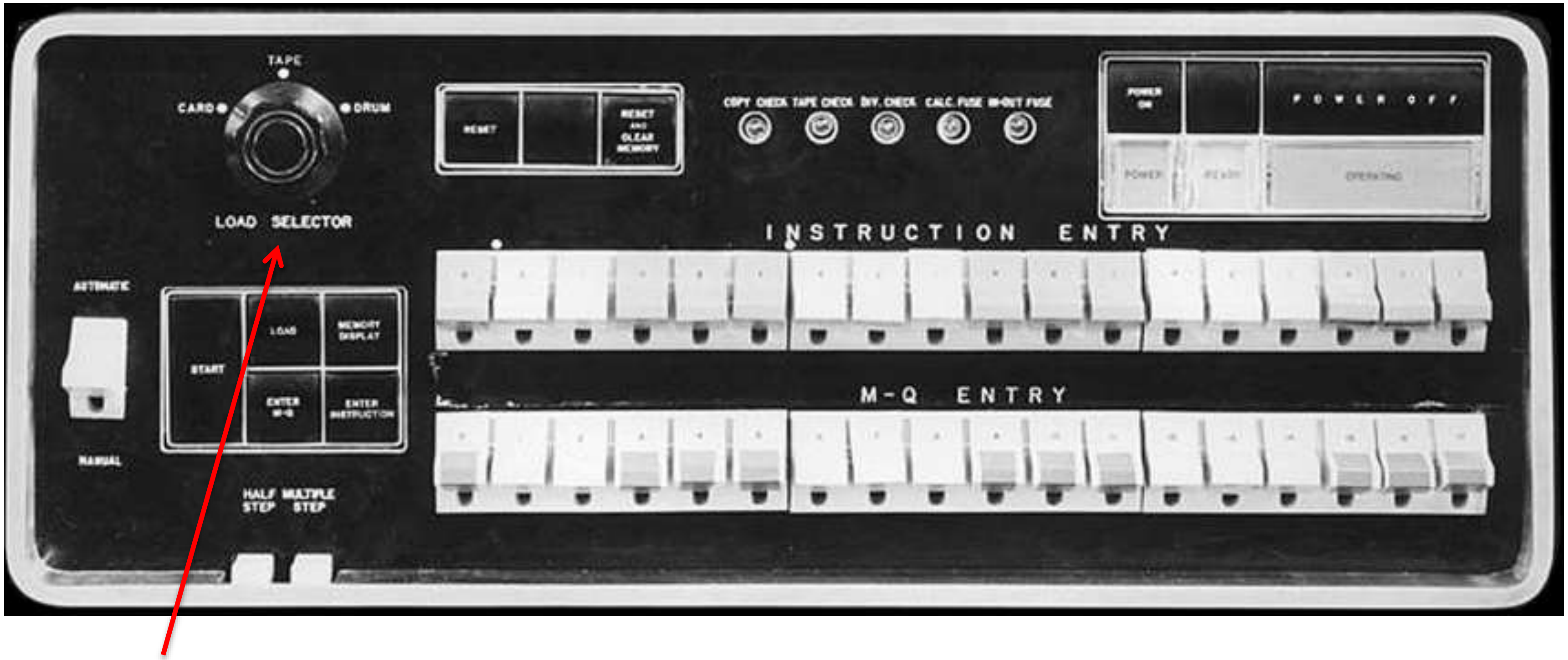
What runs first?

- Boot loader
  - A program that loads a bigger program (e.g., the OS)

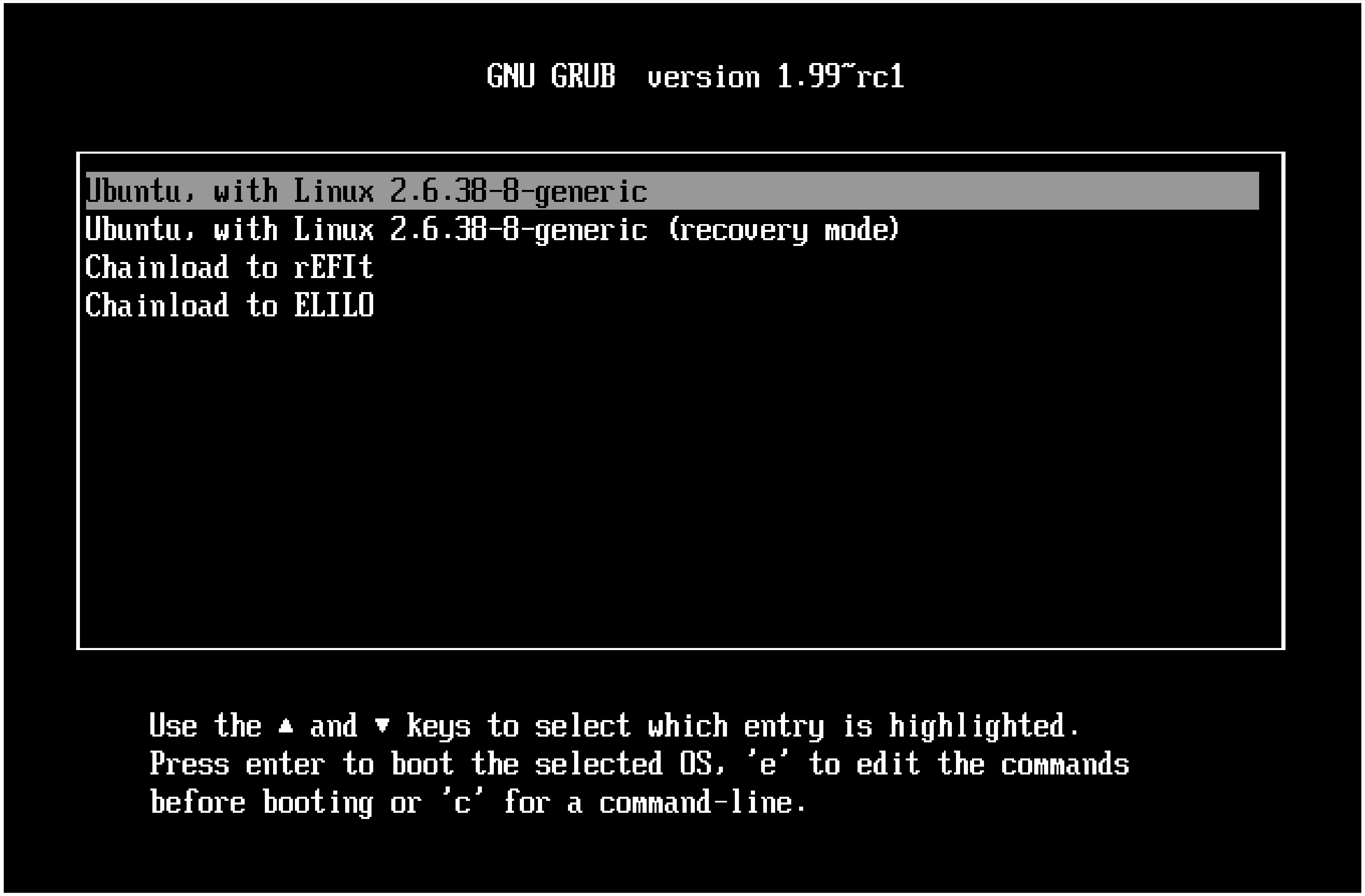
Booting



Load selector: Card, Tape, Drum

http://www.computer-history.info/Page4.dir/pages/IBM.701.dir/images/IBM701.jpg

Booting



```
                GNU GRUB  version 1.99~rc1

 Ubuntu, with Linux 2.6.38-8-generic
 Ubuntu, with Linux 2.6.38-8-generic (recovery mode)
 Chainload to rEFIt
 Chainload to ELILO

    Use the ▲ and ▼ keys to select which entry is highlighted.
    Press enter to boot the selected OS, 'e' to edit the commands
    before booting or 'c' for a command-line.
```

Multi-stage boot loader (chain loading)

- First stage boot loader
  - Often primitive enough that an operator could enter the code via front panel switches … or it could sit in the first block of a disk
- Second stage loader
  - More sophisticated and included error checking
  - Second stage loader may give the user a choice:
    - Different operating systems
    - Boot a test program
    - Enable diagnostic modes (e.g., safe boot) in the OS

Transfer of control

- When the boot loader finishes loading the OS, it transfers control to it
- The OS will initialize itself and load various modules as needed (for example, device drivers and various file systems)

Intel/AMD PC Startup

- CPU reset at startup
- Start execution at `0xfffffff0`
  - Jump instruction to BIOS code in non-volatile memory
    - Near the top of 32-bit addressable memory map
    - *Reset vector:* jump to firmware initialization code
  - Processor starts in Real Mode
    - 20-bit address space (top 12 address lines held high)
    - Direct access to I/O, interrupts, and memory

BIOS

- BIOS = Basic Input/Output System
- Found in Intel-based 16- and 32-bit PCs
- Code resident in ROM or non-volatile flash memory
- Background: CP/M (MS-DOS was almost a clone)
  - Console Command Processor (CCP): *user interface*
  - Basic Disk Operating System (BDOS): *generic code*
  - Basic Input/Output System (BIOS): *all the device interfaces*

PC Startup

- BIOS executes:
  - – Power-on self-test (POST)
  - – Detect video card's BIOS – execute video initialization
  - – Detect other device BIOS – initialize
  - – Display start-up screen
  - – Brief memory test
  - – Set memory, drive parameters
  - – Configure Plug & Play devices: PCIe, USB, SATA, SPI
    - Assign resources (DMA channels & IRQs)
  - – Identify boot device:
    - Load block 0 (Master Boot Record) to `0x7c00` and jump there

Booting Windows (NT/Windows 20xx,7,8)

- BIOS-based booting
  - The BIOS does *not* know file systems but can read disk blocks
- MBR = Master Boot Record = Block 0 of disk (512 bytes)
  - Small boot loader (chain loader, ≤ 440 bytes)
  - Disk signature (4 bytes)
  - Disk partition table (16 bytes per partition * 4)
- BIOS firmware loads and executes the contents of the MBR
- MBR code scans through partition table and loads the Volume Boot Record (VBR) for that partition
  - Identifies partition type & size
  - Contains Instruction Program Loader that executes startup code
  - IPL reads additional sectors to load BOOTMGR (Windows 7, 8)
    - The loader is called NTLDR for Windows NT, XP, 2003

Booting other systems on a PC

- Example: GRUB (Grand Unified Boot Loader)
- MBR contains GRUB Stage 1
  - Or another boot loader that may boot GRUB Stage 1 from the Volume Boot Record
- Stage 1 loads Stage 2
  - Present user with choice of operating systems to boot
  - Optionally specify boot parameters
  - Load selected kernel and run the kernel
  - For Windows (which is not Multiboot compliant),
    - Run MBR code or Windows boot menu
    - Multiboot specification:
      - Free Software Foundation spec on loading multiple kernels using a single boot loader

Good-bye BIOS: PCs and UEFI

- ~2005: Unified Extensible Firmware Interface (UEFI)
  - Originally called EFI; then changed to UEFI
    You still see both names in use
- Created for 32- and 64-bit architectures
  - Including Macs, which also have BIOS support for Windows
- Goal:
  - Create a successor to the BIOS
    - no restrictions on running in 16-bit 8086 mode with 20-bit addressing

UEFI Includes

- Preserved from BIOS:
  - Power management (Advanced Configuration & Power Interface, ACPI)
  - System management components from the BIOS
- Support for larger disks
  - BIOS only supported 4 partitions per disk, each up to 2.2 TB per partition
  - EFI supports max partition size of 9.4 ZB (9.4×10^{21} bytes)
- Pre-boot execution environment with direct access to all memory
- Device drivers, including the ability to interpret architecture-independent EFI Byte Code (EBC)
- Boot manager: lets you select and load an OS
  - *No need for a dedicated boot loader (but they may be present anyway)*
  - *Stick your files in the EFI boot partition and EFI can load them*
- Extensible: extensions can be loaded into non-volatile memory

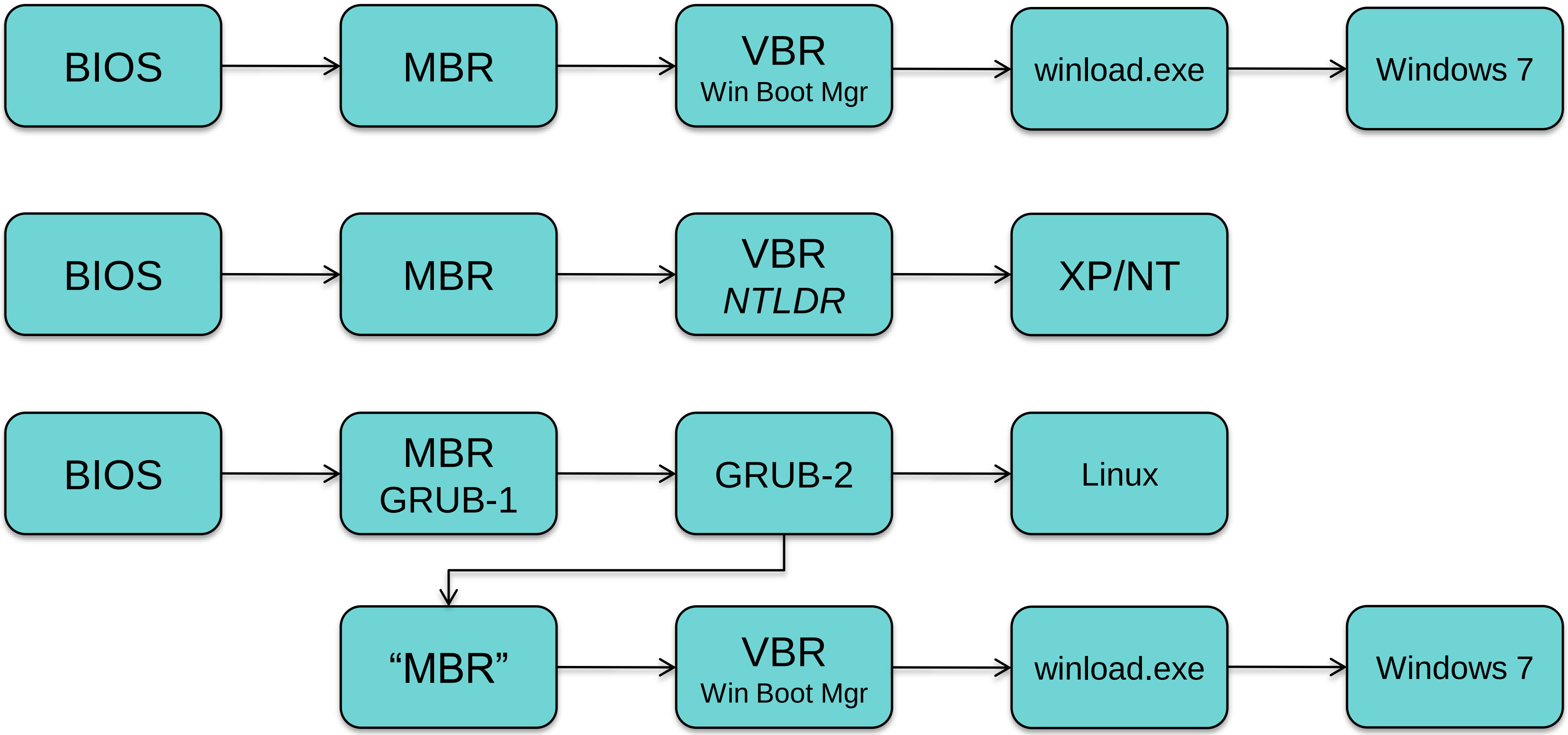
UEFI Booting

- No need for MBR code *(ignore block 0)*
- Read GUID Partition Table (GPT)
  - Describes layout of the partition table on a disk (blocks 1-33)
- EFI understands Microsoft FAT file systems
  - Apple's EFI knows HFS+ in addition
- Read programs stored as *files* in the EFI System Partition:
  - Windows 7/8, Windows 2008/2012 (64-bit Microsoft systems):
    - Windows Boot Manager (BOOTMGR) is in the EFI partition
  - NT (IA-64): IA64ldr
  - Linux: elilo.efi (ELILO = EFI Linux Boot Loader)
  - OS X: boot.efi

Non-Intel Systems

- Power on: execute boot ROM code (typically NOR Flash)
  – Often embedded in the CPU ASIC
- Boot ROM code detects boot media
  – Loads first stage boot loader (sometimes to internal RAM)
  – Initialize RAM
  – Execute boot loader
- Second stage boot loader loads kernel into RAM
  – For Linux, typically GRUB for larger systems
  – uBoot for embedded systems
  – Set up network support, memory protection, security options

Summary


BIOS
MBR
VBR
Win Boot Mgr
winload.exe
Windows 7
BIOS
MBR
VBR
NTLDR
XP/NT
BIOS
MBR
GRUB-1
GRUB-2
Linux
“MBR”
VBR
Win Boot Mgr
winload.exe
Windows 7

Summary

$$\begin{tikzcd}
\text{EFI} \arrow[r] & \text{Windows Boot Manager} \arrow[r] & \text{winload.exe} \arrow[r] & \text{Windows 7/8} \\
\text{EFI} \arrow[r] & \text{elilo.efi} \arrow[r] & \text{Linux} & \\
\text{EFI} \arrow[r] & \text{boot.efi} \arrow[r] & \text{OS X} &
\end{tikzcd}$$

The End