

System Administration

Week 03, Segment 1
The Boot Process & the MBR

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<https://stevens.netmeister.org/615/>

>> NetBSD/x86 BIOS Boot, Revision 5.11 (Fri Feb 14 00:06:28 UTC 2020) (from NetBSD 9.0)
>> Memory: 639/1047552 k

- 1. Boot normally
- 2. Boot single user
- 3. Drop to boot prompt

Choose an option; RETURN for default; SPACE to stop countdown.
Option 1 will be chosen in 5 seconds.

Booting up a web server

- power on hardware
- POST and other hardware initialization
- first stage boot loader
- second stage boot loader
- hypervisor kernel dom0 starts

- domU is started
- guest OS kernel starts
- kernel initializes (virtual) hardware

physical host

virtual host

Booting up a web server

-
- The diagram illustrates the boot process of a web server across three nested levels:
- physical host** (outermost layer, red border): power on hardware, POST and other hardware initialization, first stage boot loader, second stage boot loader, hypervisor kernel dom0 starts.
 - virtual host** (middle layer, purple border): domU is started, guest OS kernel starts, kernel initializes (virtual) hardware.
 - user space** (innermost layer, green border): init(8) (or similar) starts, system processes / daemons start, web server runs, binds network socket, serves content.
- A large brace on the right side groups all three levels together, indicating they occur sequentially on the same physical hardware.



American
Megatrends

www.ami.com

AMI BIOS (C) 2007 American Megatrends, Inc.

ASUS P5KPL ACPI BIOS Revision 0603

CPU : Intel(R) Pentium(R) Dual CPU E2180 @ 2.00GHz

Speed : 2.51 GHz Count : 2

Press DEL to run Setup

Press F8 for BBS POPUP

DDR2-667 in Dual-Channel Interleaved Mode

Initializing USB Controllers .. Done.

3584MB OK

(C) American Megatrends, Inc.

64-0603-000001-00101111-022908-Bear lake-A0820000-Y2KC

- ▶ Standard CMOS Features
- ▶ Advanced BIOS Features
- ▶ Advanced Chipset Features
- ▶ Integrated Peripherals
- ▶ Power Management Setup
- ▶ PnP/PCI Configurations
- ▶ PC Health Status

- ▶ Frequency/Voltage Control
- Load Fail-Safe Defaults
- Load Optimized Defaults
- Set Supervisor Password
- Set User Password
- Save & Exit Setup
- Exit Without Saving

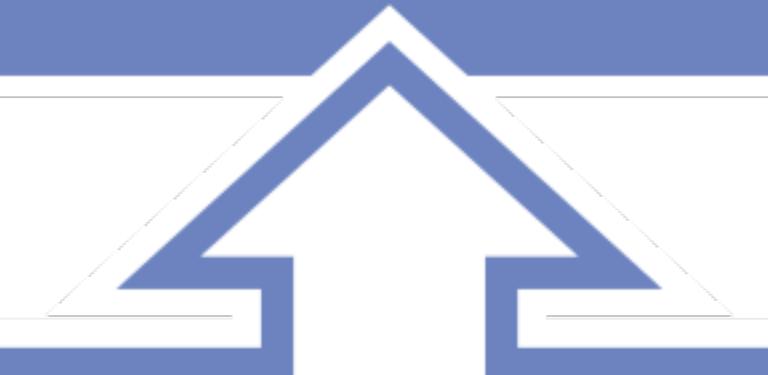
Esc : Quit

F10 : Save & Exit Setup

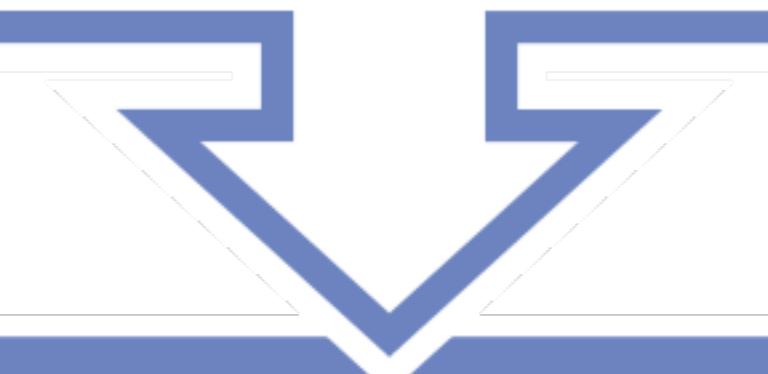
↑ ↓ → ← : Select Item

Time, Date, Hard Disk Type...

Operating system



Extensible Firmware Interface



Firmware

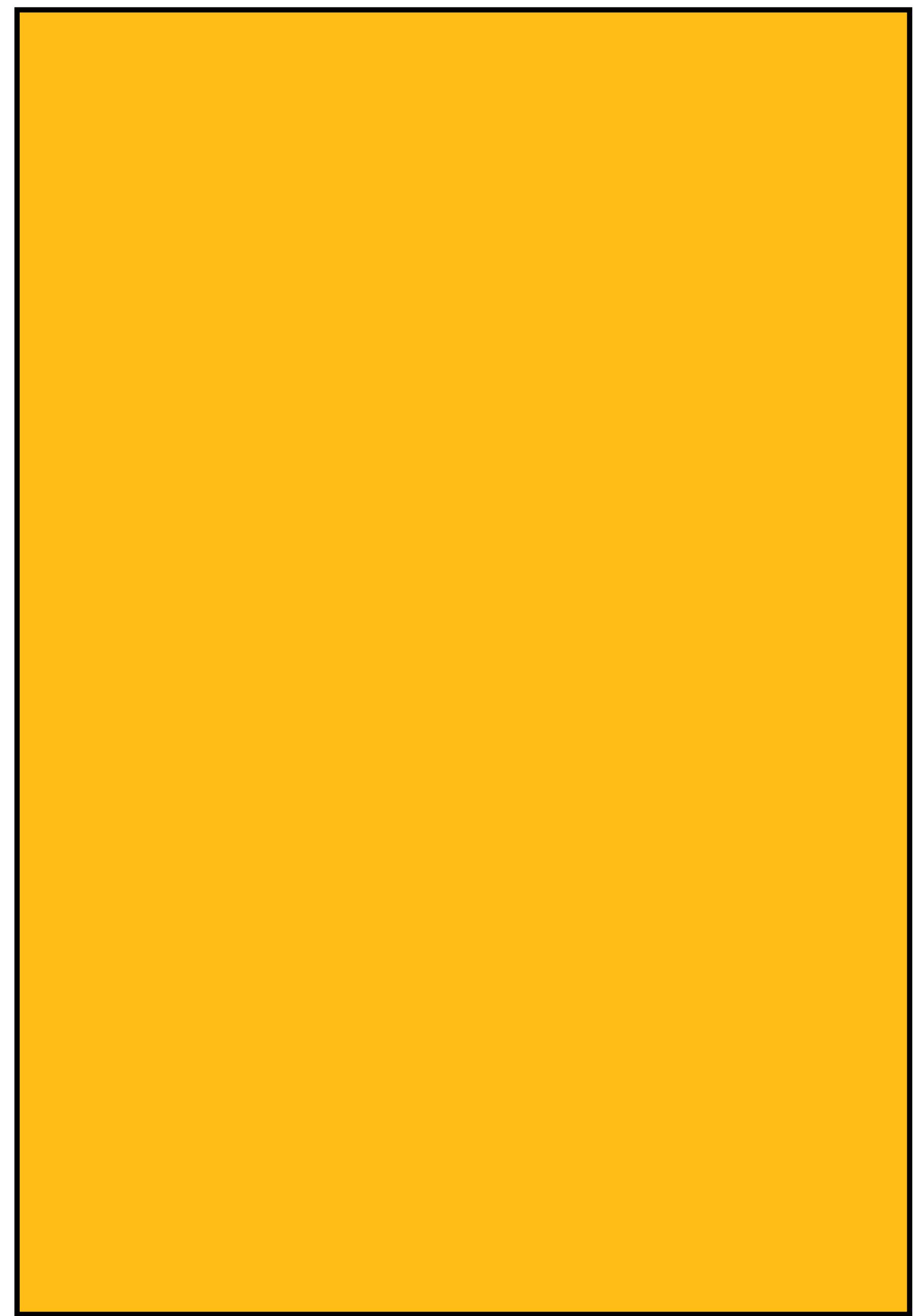
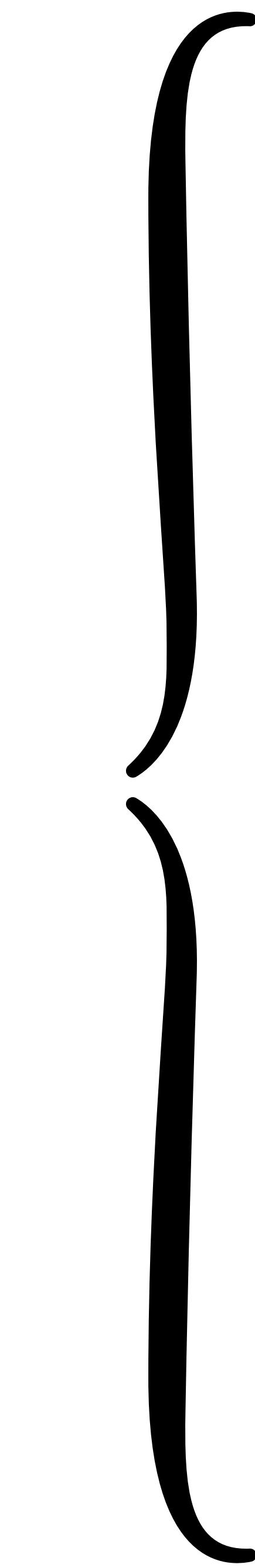
Hardware



MBR

Sector 0

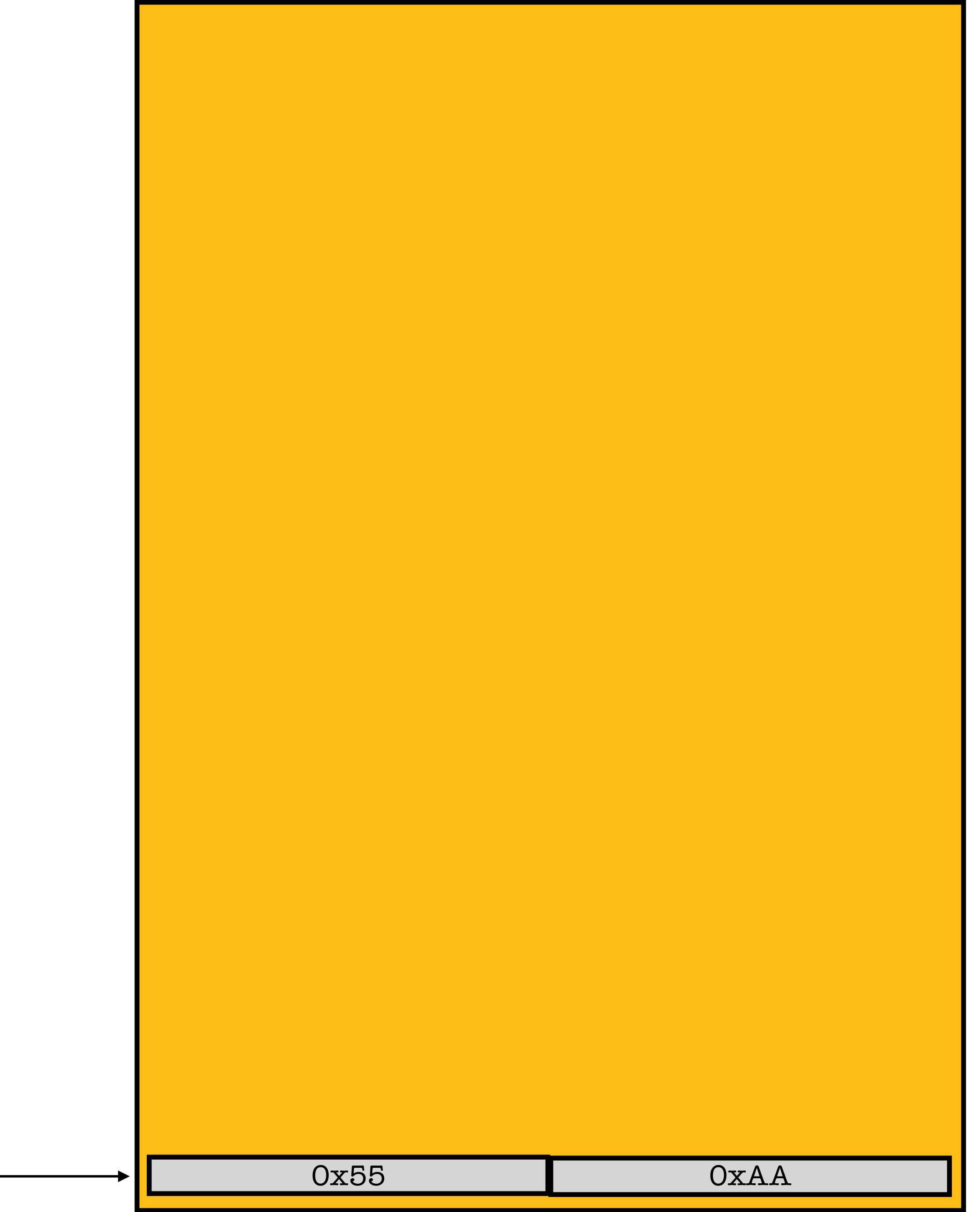
512 bytes



Master Boot Record

- first sector (512 bytes) of storage device

Bytes 510, 511 contain boot signature 0x55 0xAA

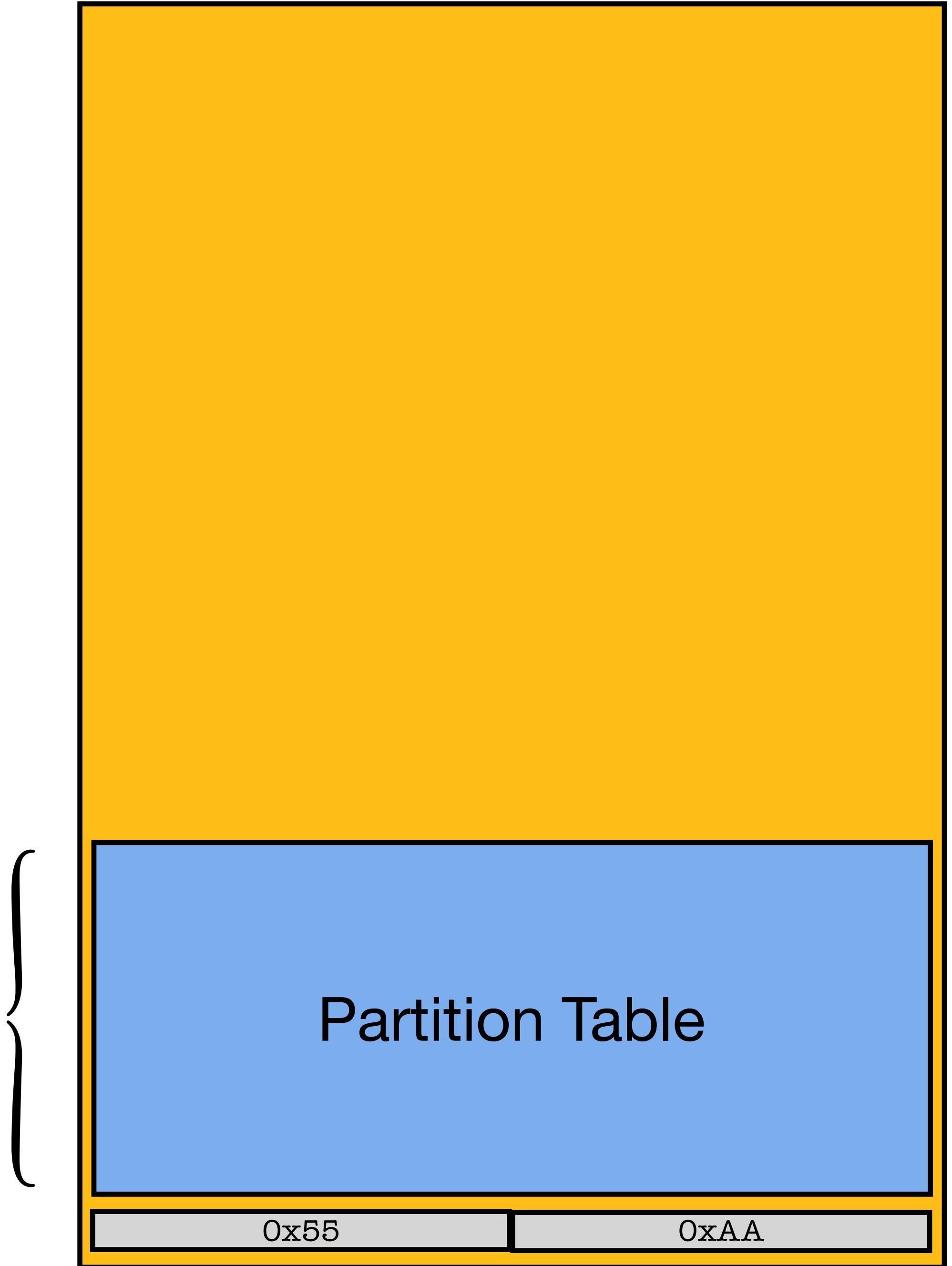


Master Boot Record

- first sector (512 bytes) of storage device
- last two bytes contain boot signature
(0x55, 0xAA)

64 bytes

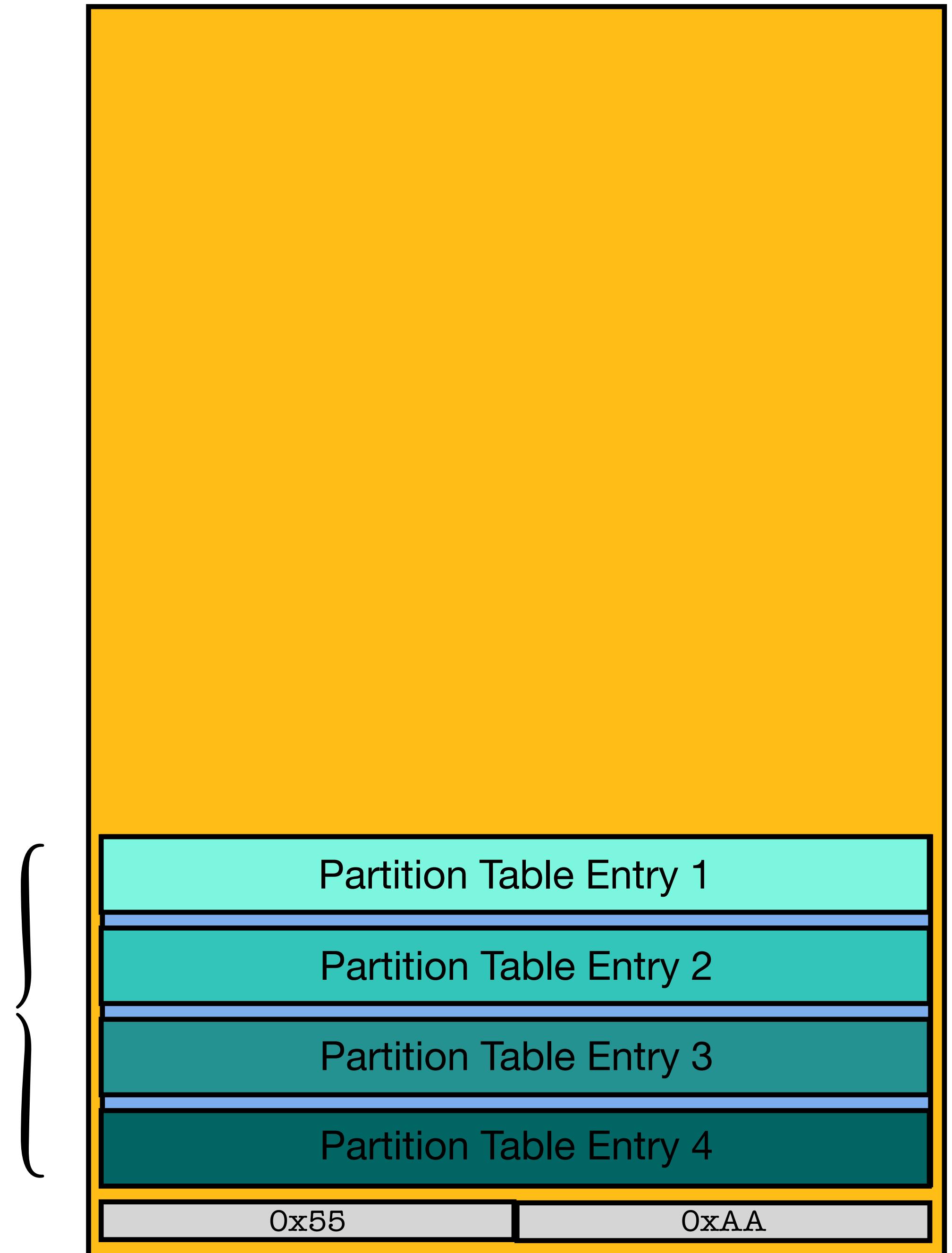
Bytes: 446 - 509



Master Boot Record

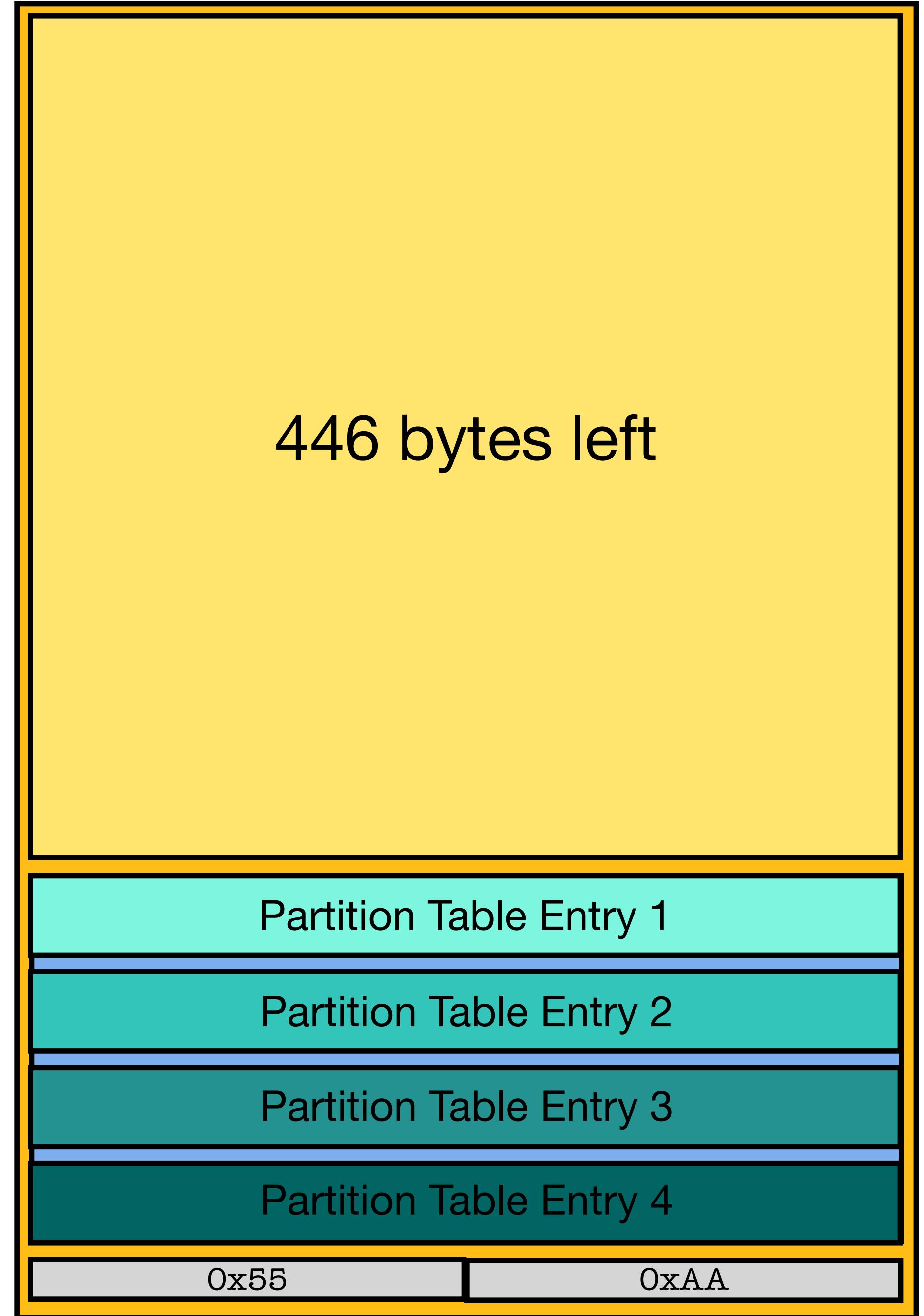
- first sector (512 bytes) of storage device
- last two bytes contain boot signature
(0x55, 0xAA)
- 64 bytes allocated for partition table

64 bytes = 4 * 16 bytes



Master Boot Record

- first sector (512 bytes) of storage device
- last two bytes contain boot signature (0x55, 0xAA)
- 64 bytes allocated for partition table
- 4 “primary partitions”, 16 bytes each



Master Boot Record

- first sector (512 bytes) of storage device
- last two bytes contain boot signature (0x55, 0xAA)
- 64 bytes allocated for partition table
- 4 “primary partitions”, 16 bytes each
- 446 bytes for stage 1 boot loader

```
1100011101010111010101101  
011001101000000000000010110  
1010111100111000011010101101  
110001101011101001010101000  
011110011000010110000111111  
01011111011111011010001100  
1010111000011010011100101011  
100010110001001100010101101  
00011000110101101011011011  
111011011000011001010001001  
1011111101110100010001100011  
1111110001011110110111110111  
0001110011011010111000100110  
0111001100111011100001011011  
00110101011111001011000111  
11100001100011010011010001
```

Partition Table Entry 1

Partition Table Entry 2

Partition Table Entry 3

Partition Table Entry 4

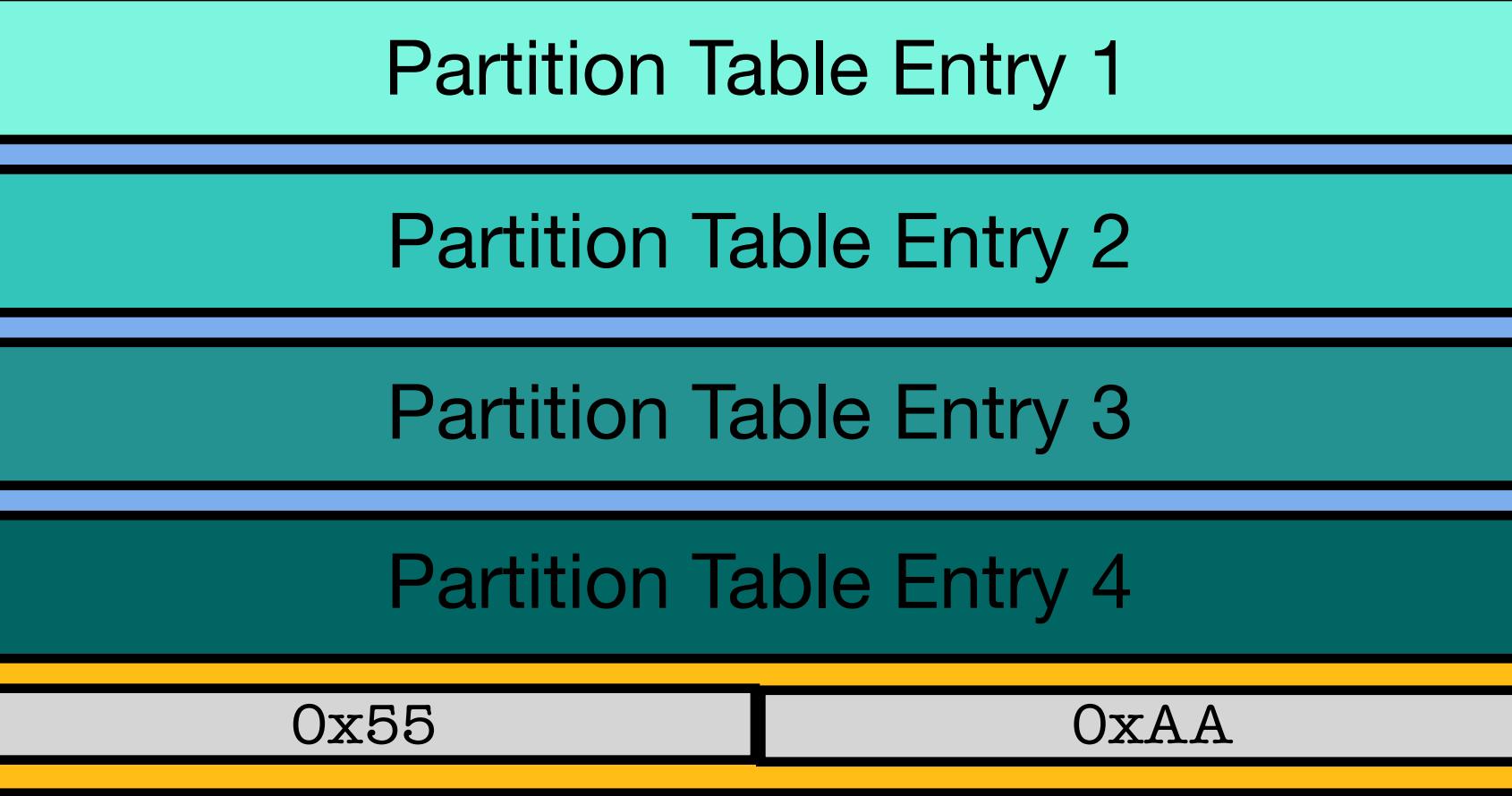
0x55

0xAA

Master Boot Record

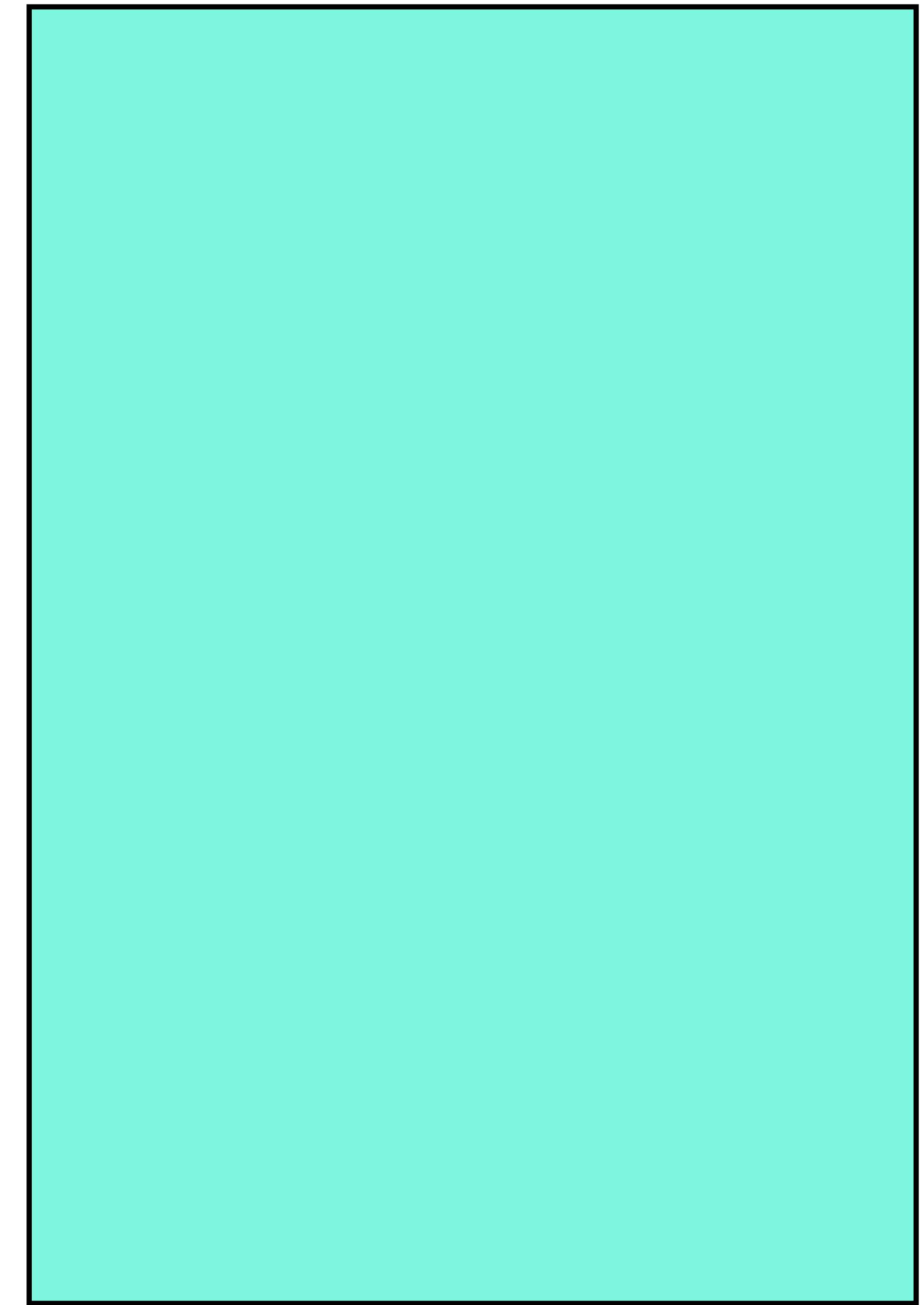
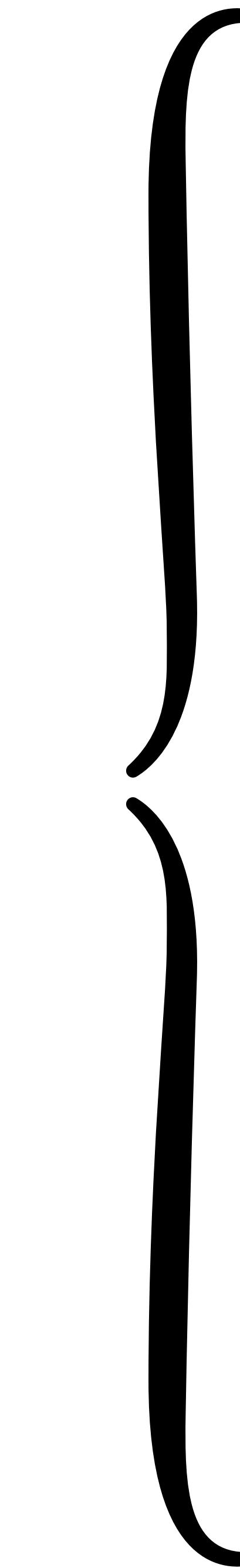
- first sector (512 bytes) of storage device
- last two bytes contain boot signature (0x55, 0xAA)
- 64 bytes allocated for partition table
- 4 “primary partitions”, 16 bytes each
- 446 bytes for stage 1 boot loader
- *stage 1* may reach into other sectors of first track or jump to boot code found on the OS partition for *stage 2*

```
1100011101010111010101101  
011001101000000000000010110  
1010111100111000011010101101  
110001101011101001010101000  
011110011000010110000111111  
01011111011111011010001100  
1010111000011010011100101011  
100010110001001100010101101  
00011000110101101011011011  
111011011000011001010001001  
1011111101110100010001100011  
1111110001011110110111110111  
0001110011011010111000100110  
0111001100111011100001011011  
00110101011111001011000111  
11100001100011010011010001
```



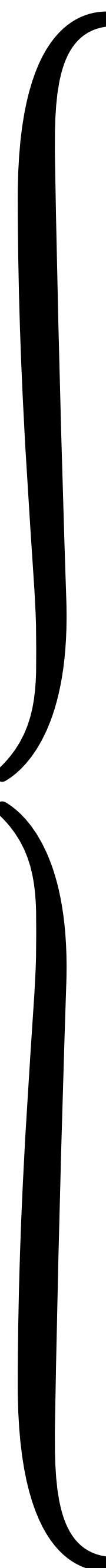
Partition Table Entry

16 bytes



Partition Table Entry

16 bytes



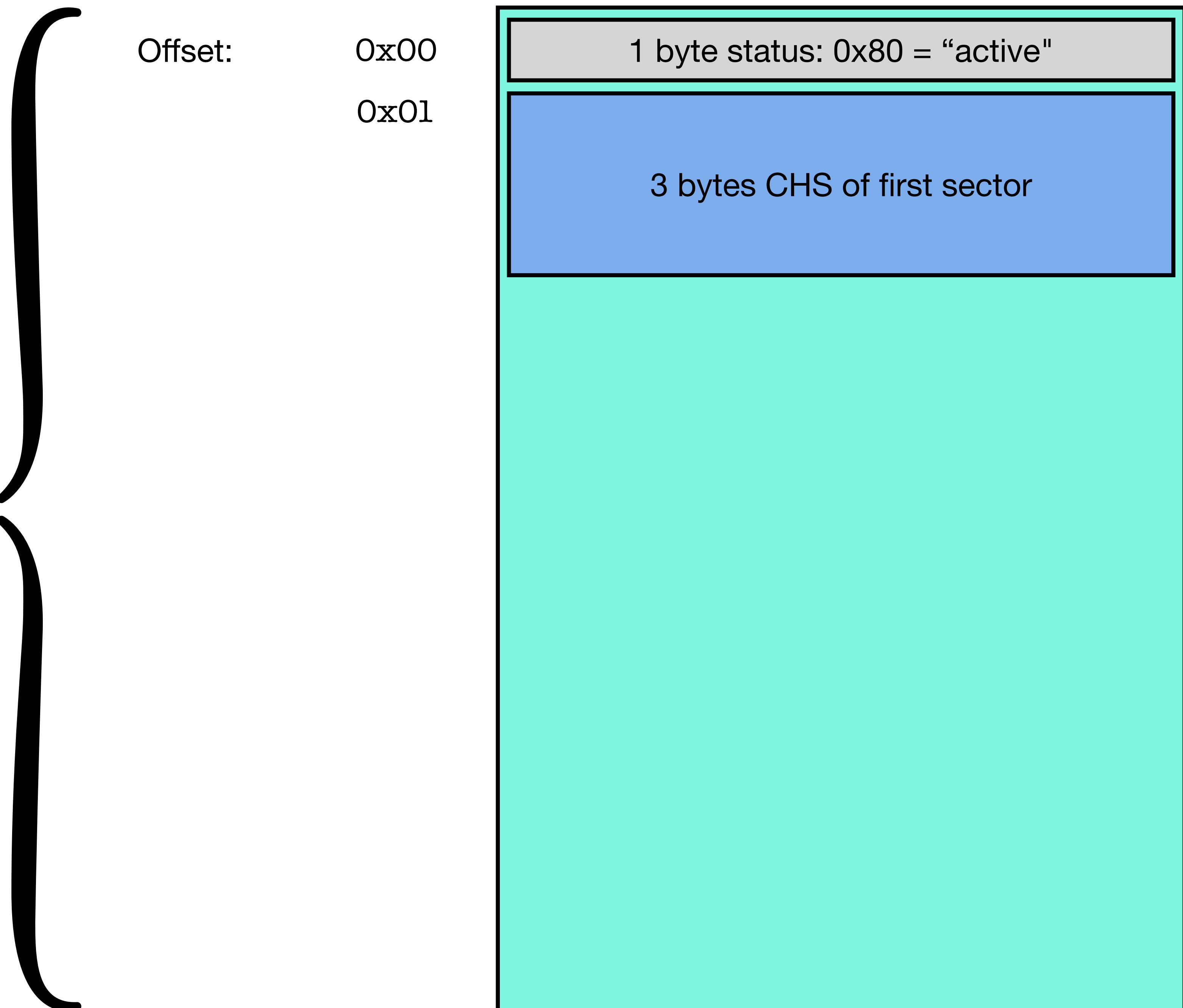
Offset:

0x00

1 byte status: 0x80 = "active"

Partition Table Entry

16 bytes



Limits:

1Byte Head => 2^8 => 256

Partition Table Entry

16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

1

2

3

4

5

6

7

8

9

A

B

C

D

E

F

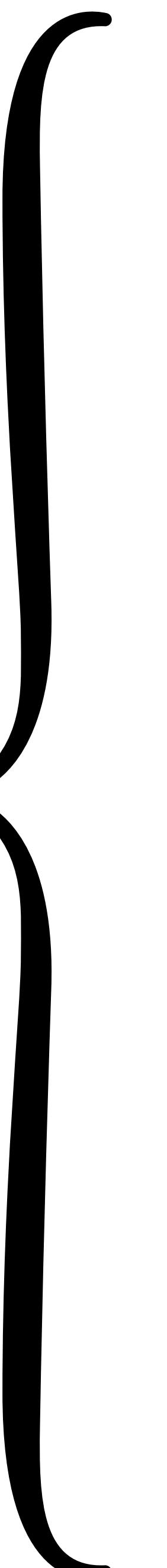
Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

Partition Table Entry

16 bytes



Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

10 Bits Cylinder => 2^{10} => 1024

Partition Table Entry

16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

10 Bits Cylinder => 2^{10} => 1024

Partition Table Entry
16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

0x04

1 byte partition type

Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

10 Bits Cylinder => 2^{10} => 1024

Partition Table Entry

16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

0x04

1 byte partition type

0x05

3 bytes CHS of last sector

Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

10 Bits Cylinder => 2^{10} => 1024

Partition Table Entry

16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

0x04

1 byte partition type

0x05

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

10 Bits Cylinder => 2^{10} => 1024

Partition Table Entry

16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

0x04

1 byte partition type

0x05

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

0x08

4 bytes LBA of first sector

Limits:

1Byte Head => 2^8 => 256

6 Bits Sector => 2^6 => 64

10 Bits Cylinder => 2^{10} => 1024

Partition Table Entry

16 bytes

Offset:

0x00

1 byte status: 0x80 = "active"

0x01

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

0x04

1 byte partition type

0x05

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

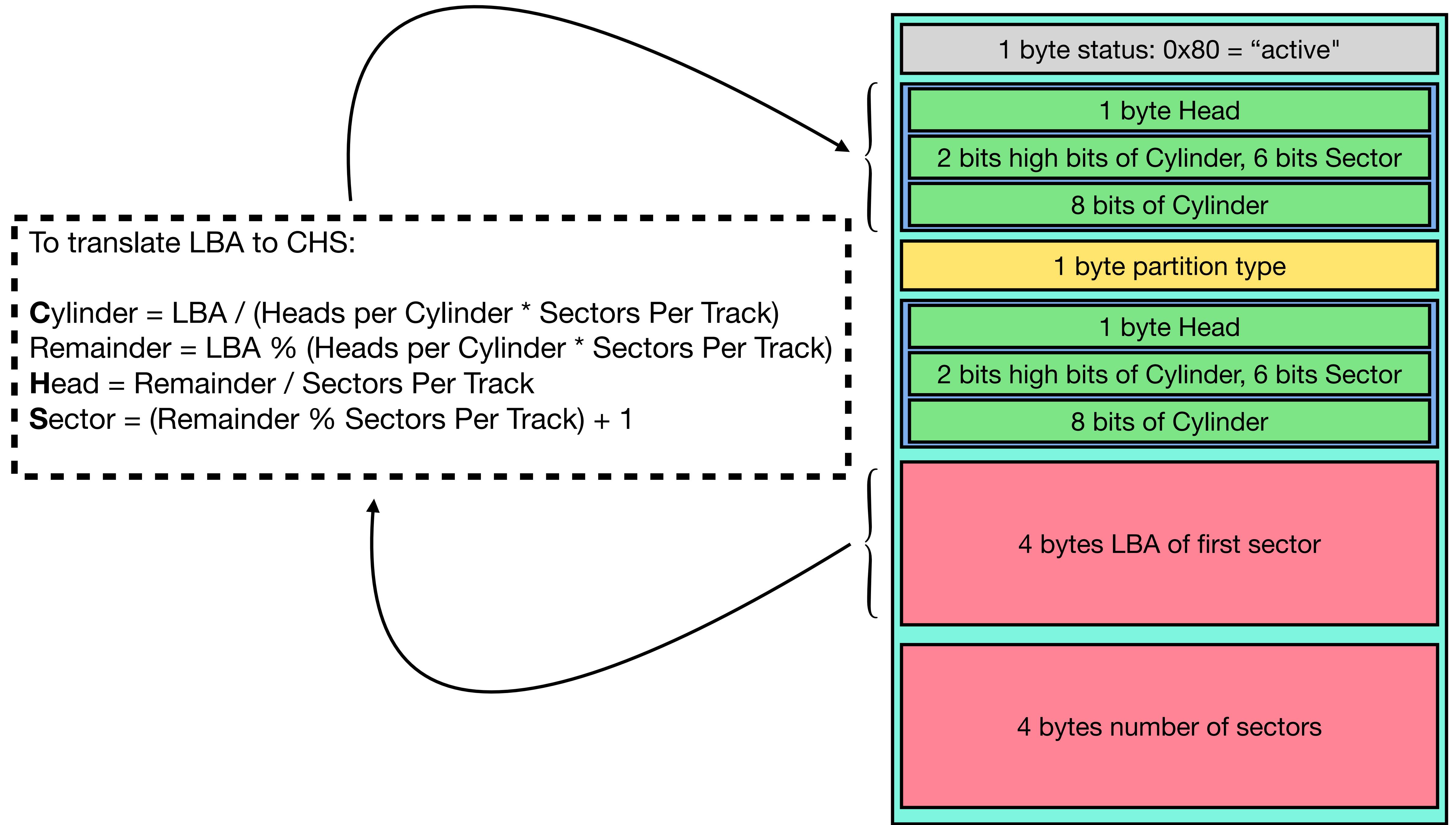
8 bits of Cylinder

0x08

4 bytes LBA of first sector

0x0C

4 bytes number of sectors





laptop\$

laptop\$ curl -X POST https://api.telegram.org/bot1234567890:BAE5iDgJZGzWzVQHdCw/forwardMessage?chat_id=-100123456789&from_chat_id=1234567890&text=Hello%20World!



Terminal — 80x24

000000a0	f7 e1 5a 83 e2 3f 01 d0	48 39 e8 74 47 bb aa 55	..Z..?..H9.tG..U
000000b0	b4 41 5a 52 cd 13 b8 65	89 72 a7 81 fb 55 aa 75	.AZR...e.r...U.u
000000c0	a1 f6 c1 01 74 9c 66 89	2e 0b 89 be 03 89 b4 42t.f.....B
000000d0	5a 52 cd 13 b8 41 89 72	89 a0 00 7c 84 c0 74 03	ZR...A.r... .t.
000000e0	a1 fe 7d 3d 55 aa b8 51	89 0f 85 75 ff 66 89 ee	..}={U..Q...u.f..
000000f0	5a e9 0c f3 5a 8a 74 01	8b 4c 02 bb 00 7c b8 01	Z...Z.t..L... ..
00000100	02 eb ce 10 00 01 00 00	7c 00 00 00 00 00 00 00
00000110	00 00 00 45 72 72 6f 72	20 00 0d 0a 00 4e 65 74	...Error ...Net
00000120	42 53 44 20 4d 42 52 20	62 6f 6f 74 00 4e 6f 20	BSD MBR boot.No
00000130	61 63 74 69 76 65 20 70	61 72 74 69 74 69 6f 6e	active partition
00000140	00 44 69 73 6b 20 72 65	61 64 20 65 72 72 6f 72	.Disk read error
00000150	00 4e 6f 20 6f 70 65 72	61 74 69 6e 67 20 73 79	.No operating sy
00000160	73 74 65 6d 00 49 6e 76	61 6c 69 64 20 43 48 53	stem.Invalid CHS
00000170	20 72 65 61 64 00 e8 03	00 be 1a 89 60 ac b4 0e	read.....`....
00000180	bb 01 00 cd 10 ac 84 c0	75 f4 61 c3 00 00 00 00u.a.....
00000190	1c 80 b6 00 00 00 00 00	00 00 00 00 00 00 00 00
000001a0	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
000001b0	00 00 00 00 00 00 00 00	00 00 00 00 e1 b5 80 20
000001c0	21 00 a9 1b 28 f3 00 08	00 00 00 90 3b 00 00 00	!...(.;...
000001d0	00 00 00 00 00 00 00 00	00 00 00 00 00 00 00 00
*			
000001f0	00 00 00 00 00 00 00 00	00 00 00 00 00 00 55 aaU.
00000200			



```
Disk: /dev/rxbd1
NetBSD disklabel disk geometry:
cylinders: 3072, heads: 1, sectors/track: 2048 (2048 sectors/cylinder)
total sectors: 6291456, bytes/sector: 512
```

```
BIOS disk geometry:
cylinders: 391, heads: 255, sectors/track: 63 (16065 sectors/cylinder)
total sectors: 6291456
```

```
Partitions aligned to 16065 sector boundaries, offset 63
```

```
Partition table:
```

```
0: <UNUSED>
```

```
1: <UNUSED>
```

```
2: <UNUSED>
```

```
3: <UNUSED>
```

```
Bootselector disabled.
```

```
No active partition.
```

```
Drive serial number: 0 (0x00000000)
```

```
[ip-10-10-0-43# dd if=/dev/xbd1 count=1 2>/dev/null | hexdump -C
00000000  00 00 00 00 00 00 00 00  00 00 00 00 00 00 00 00  |.....|
```

```
*
```

```
00000200
```

```
ip-10-10-0-43#
```



```
fdisk: Cannot determine the number of heads
```

3 bytes CHS:

```
Disk: /dev/rxbd1
```

```
NetBSD disklabel disk geometry:
```

```
cylinders: 3072, heads: 1, sectors/track: 2048 (2
```

```
total sectors: 6291456, bytes/sector: 512
```

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder

```
BIOS disk geometry:
```

```
cylinders: 391, heads: 255, sectors/track: 63 (16065 sectors/cylinder)
```

```
total sectors: 6291456
```

```
Partitions aligned to 2048 sector boundaries, offset 0
```

```
Partition table:
```

```
0: NetBSD (sysid 169)
```

```
    start 0, size 0, Active
```

```
        beg: cylinder 0, head 0, sector 0
```

```
        end: cylinder 0, head 0, sector 0
```

```
        PBR appears to be bootable
```

```
1: <UNUSED>
```

```
2: <UNUSED>
```

```
3: <UNUSED>
```

```
First active partition: 0
```

```
Drive serial number: 0 (0x00000000)
```

```
ip-10-10-0-43#
```



```
beg: cylinder    0, head   32, sector 33
end: cylinder    0, head    0, sector  0
PBR appears to be bootable
```

```
1: <UNUSED>
2: <UNUSED>
3: <UNUSED>
```

```
First active partition: 0
```

```
Drive serial number: 0 (0x00000000)
```

```
[ip-10-10-0-43# echo $(( 6291455 / 16065 ))
391
```

```
[ip-10-10-0-43# echo $(( 6291455 % 16065 ))
10040
```

```
[ip-10-10-0-43# echo $(( 10040 / 63 ))
159
```

```
[ip-10-10-0-43# export H=$(printf '%x\n' $(( 10040 / 63 )) )
```

```
[ip-10-10-0-43# echo $H
9f
```

```
[ip-10-10-0-43# echo $(( 10040 % 63 + 1 ))
24
```

```
[ip-10-10-0-43# (echo obase=2; echo $(( 10040 % 63 + 1 )));
) | bc
11000
```

```
[ip-10-10-0-43# (echo obase=2; echo 391; ) | bc
110000111
```

```
ip-10-10-0-43#
```

3 bytes CHS:

1 byte Head

2 bits high bits of Cylinder, 6 bits Sector

8 bits of Cylinder



```
fdisk: Cannot determine the number of heads
| Disk: /dev/rxbd1
NetBSD disklabel disk geometry:
cylinders: 3072, heads: 1, sectors/track: 2048 (2048 sectors/cylinder)
total sectors: 6291456, bytes/sector: 512

BIOS disk geometry:
cylinders: 391, heads: 255, sectors/track: 63 (16065 sectors/cylinder)
total sectors: 6291456

Partitions aligned to 2048 sector boundaries, offset 0

Partition table:
0: NetBSD (sysid 169)
    start 0, size 0, Active
        beg: cylinder  0, head 32, sector 33
        end: cylinder 391, head 159, sector 24
        PBR appears to be bootable
1: <UNUSED>
2: <UNUSED>
3: <UNUSED>
First active partition: 0
Drive serial number: 0 (0x00000000)
ip-10-10-0-43#
```

Simplified Boot Sequence

- basic firmware (e.g., BIOS, UEFI, Open Firmware / OpenBoot)
 - **Power-on Self-Test**
 - tests/initializes hardware
- transfer of execution to first-stage boot loader (**Master Boot Record**, **GUID Partition Table**, netbooting, ...)
- second-stage boot loader (e.g., GRUB)
- load kernel
- kernel transfers control to `init(8)`

Note: in virtualized environments, some of these steps are skipped, repeated, or simulated.

Exercises

- Use the ‘aws ec2 get-console-output’ command to get the output from the (virtual) console of different OS instances. Compare, paying particular attention to the filesystem specific parts. Can you explain what’s happening in each?

Sample boot sequences at:

<https://stevens.netmeister.org/615/boot-sequence/>

- How do you know if your system is trustworthy once it boots up? Review “*remote attestation*” of software, “*secure boot*” mechanisms, and “*Trusted Computing*”.

We still haven’t gotten to the filesystem... let’s fix that in our next video.

Links

File Systems and Storage Models:

<https://www.netmeister.org/book/04-file-systems.pdf>

UEFI: https://en.wikipedia.org/wiki/Unified_Extensible_Firmware_Interface

BIOS: <https://en.wikipedia.org/wiki/BIOS>

Booting: <https://en.wikipedia.org/wiki/Bootloader>

Manual pages:

boot(8), disklabel(8), fdisk(8), gpt(8), installboot(8), mbr(8), mbrlabel(8)