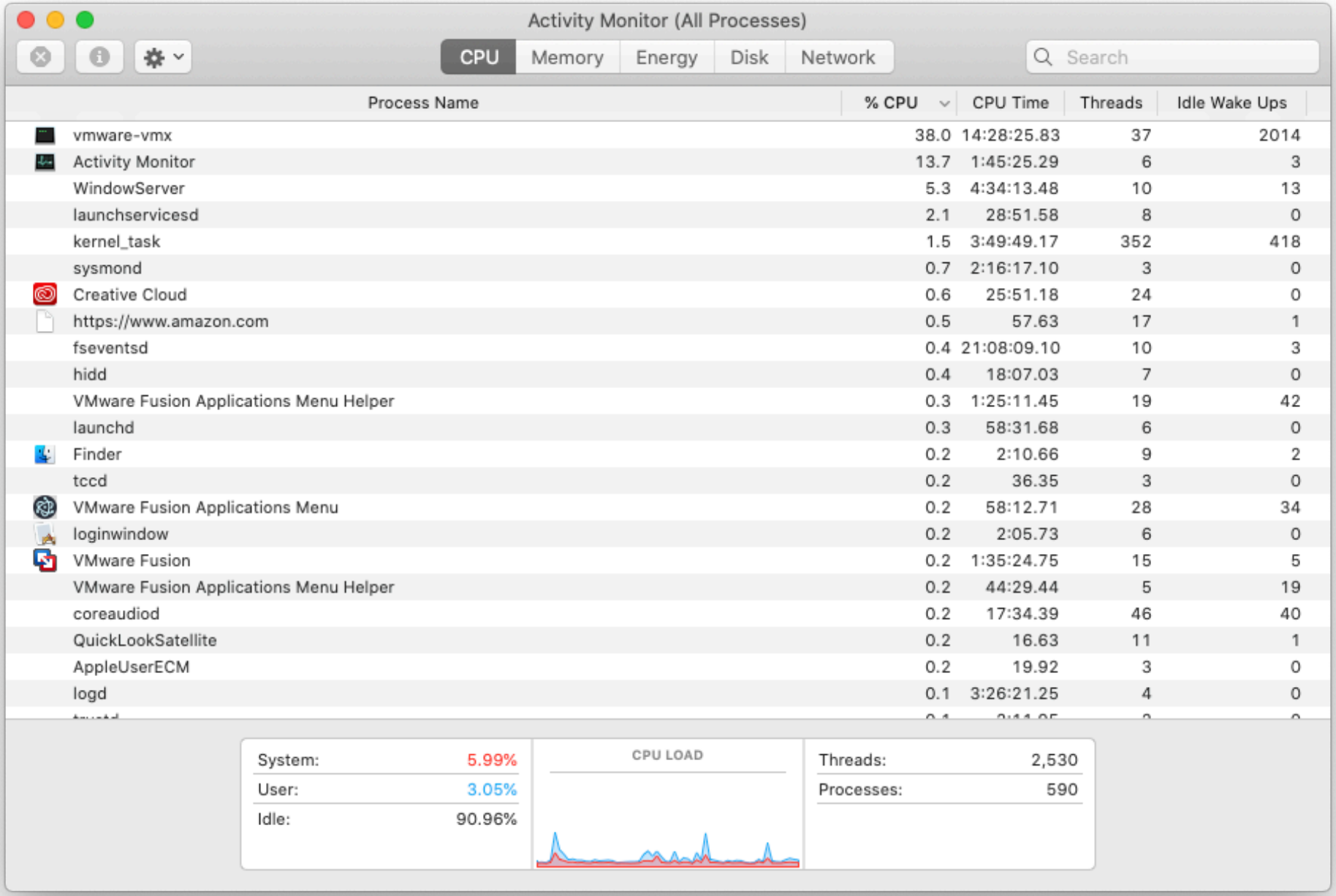
NEIL KLINGENSMITH

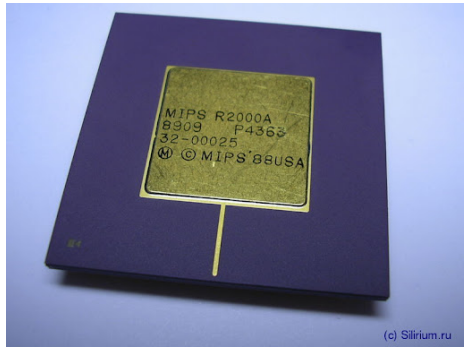
CS 310 OPERATING SYSTEMS

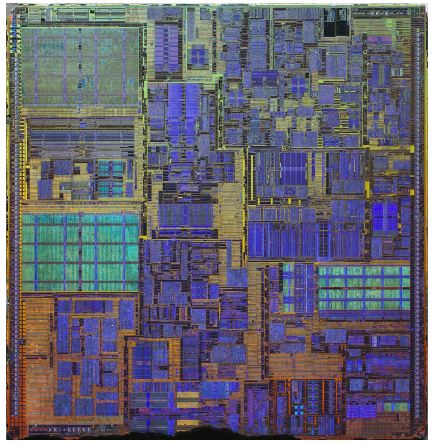
https://neilklingensmith.com/teaching/loyola/cs310-f2024/

WHAT IS THIS GUY DOING?

UNIVAC, 1951

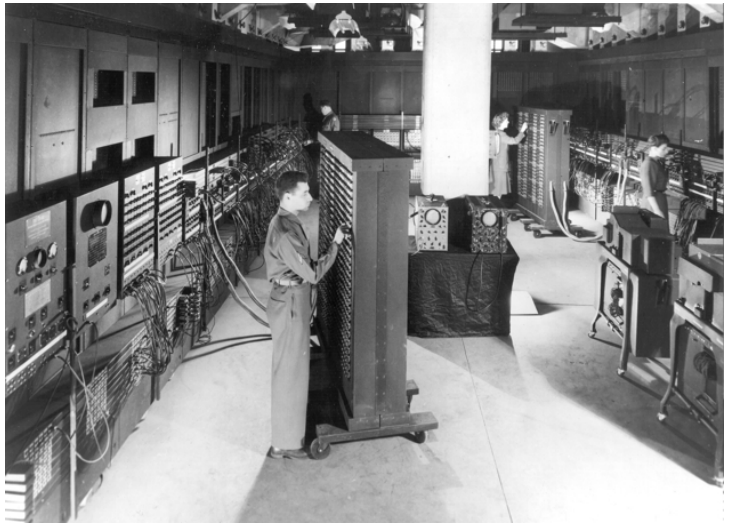

Activity Monitor (All Processes)
CPU
Memory
Energy
Disk
Network
Search
Process Name
% CPU
CPU Time
Threads
Idle Wake Ups
vmware-vmx 38.0 14:28:25.83 37 2014
Activity Monitor 13.7 1:45:25.29 6 3
WindowServer 5.3 4:34:13.48 10 13
launchservicesd 2.1 28:51.58 8 0
kernel_task 1.5 3:49:49.17 352 418
sysmond 0.7 2:16:17.10 3 0
Creative Cloud 0.6 25:51.18 24 0
https://www.amazon.com 0.5 57.63 17 1
fseventsd 0.4 21:08:09.10 10 3
hidd 0.4 18:07.03 7 0
VMware Fusion Applications Menu Helper 0.3 1:25:11.45 19 42
launchd 0.3 58:31.68 6 0
Finder 0.2 2:10.66 9 2
tccd 0.2 36.35 3 0
VMware Fusion Applications Menu 0.2 58:12.71 28 34
loginwindow 0.2 2:05.73 6 0
VMware Fusion 0.2 1:35:24.75 15 5
VMware Fusion Applications Menu Helper 0.2 44:29.44 5 19
coreaudiod 0.2 17:34.39 46 40
QuickLookSatellite 0.2 16.63 11 1
AppleUserECM 0.2 19.92 3 0
logd 0.1 3:26:21.25 4 0
System: 5.99%
User: 3.05%
Idle: 90.96%
CPU LOAD
Threads: 2,530
Processes: 590



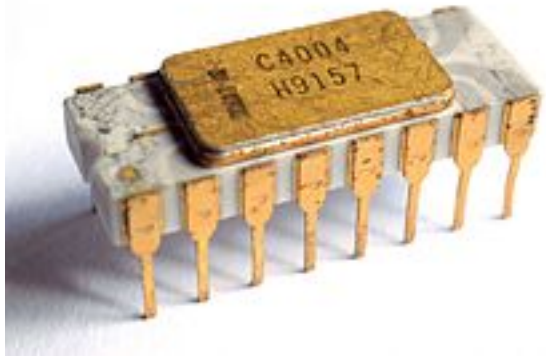


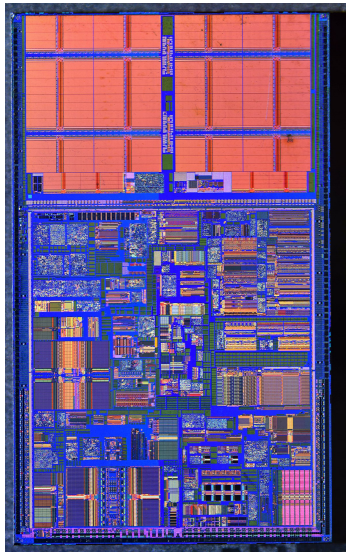
1945 1958 1964 1971 1986 1997 2000 2007 2022

ENIAC FORTRAN IBM 360 Intel 4004 Pentium II Pentium 4 CUDA RTX 4090



MIPS R2k

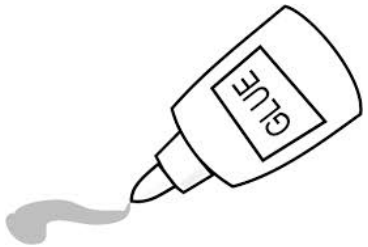




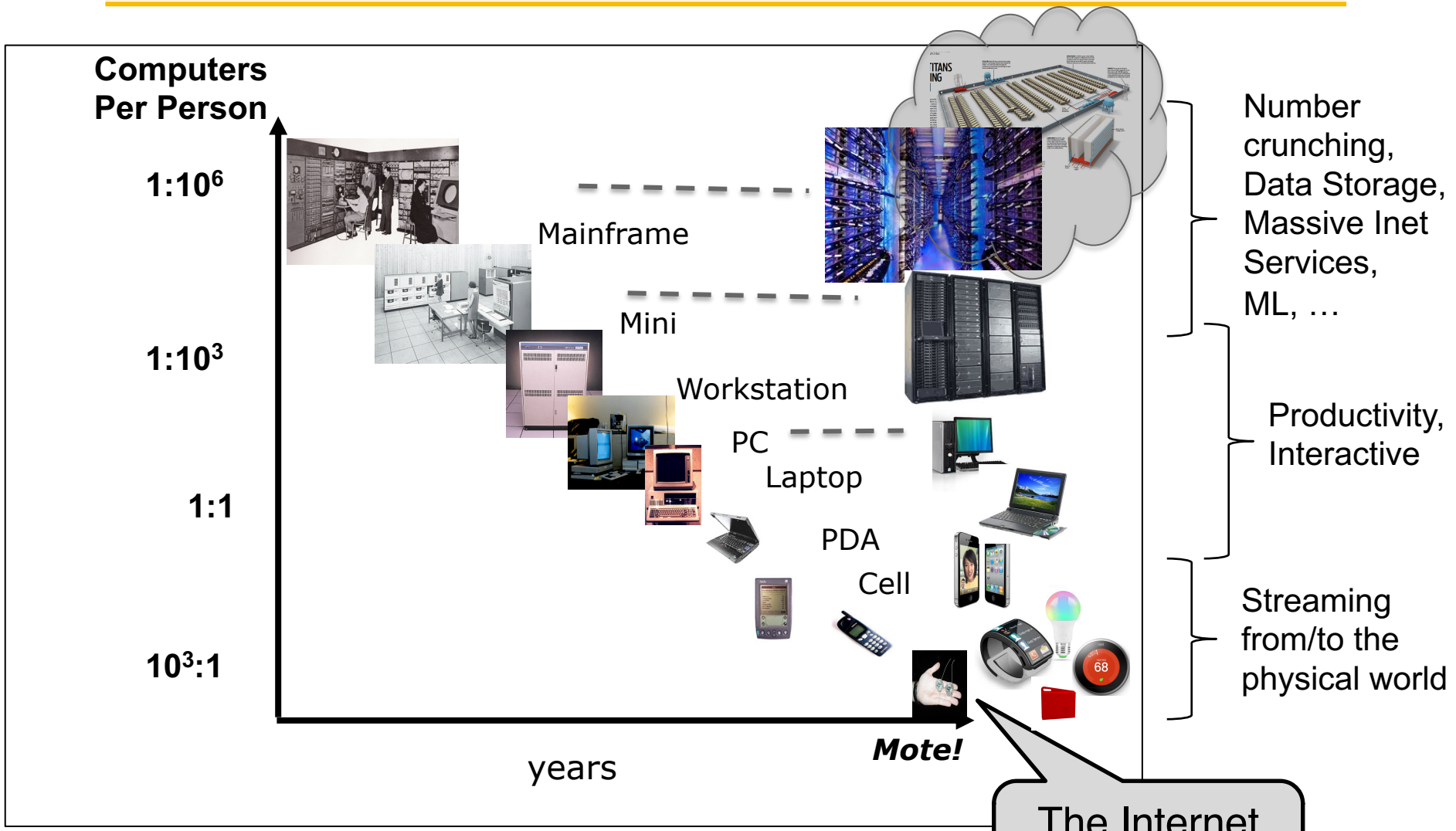
What is an Operating System?

- **Referee**
  - Manage sharing of resources, Protection, Isolation
    - » Resource allocation, isolation, communication
- **Illusionist**
  - Provide clean, easy to use abstractions of physical resources
    - » Infinite memory, dedicated machine
    - » Higher level objects: files, users, messages
    - » Masking limitations, virtualization

- **Glue**
  - Common services
    - » Storage, Window system, Networking
    - » Sharing, Authorization
    - » Look and feel



Across incredibly diversity



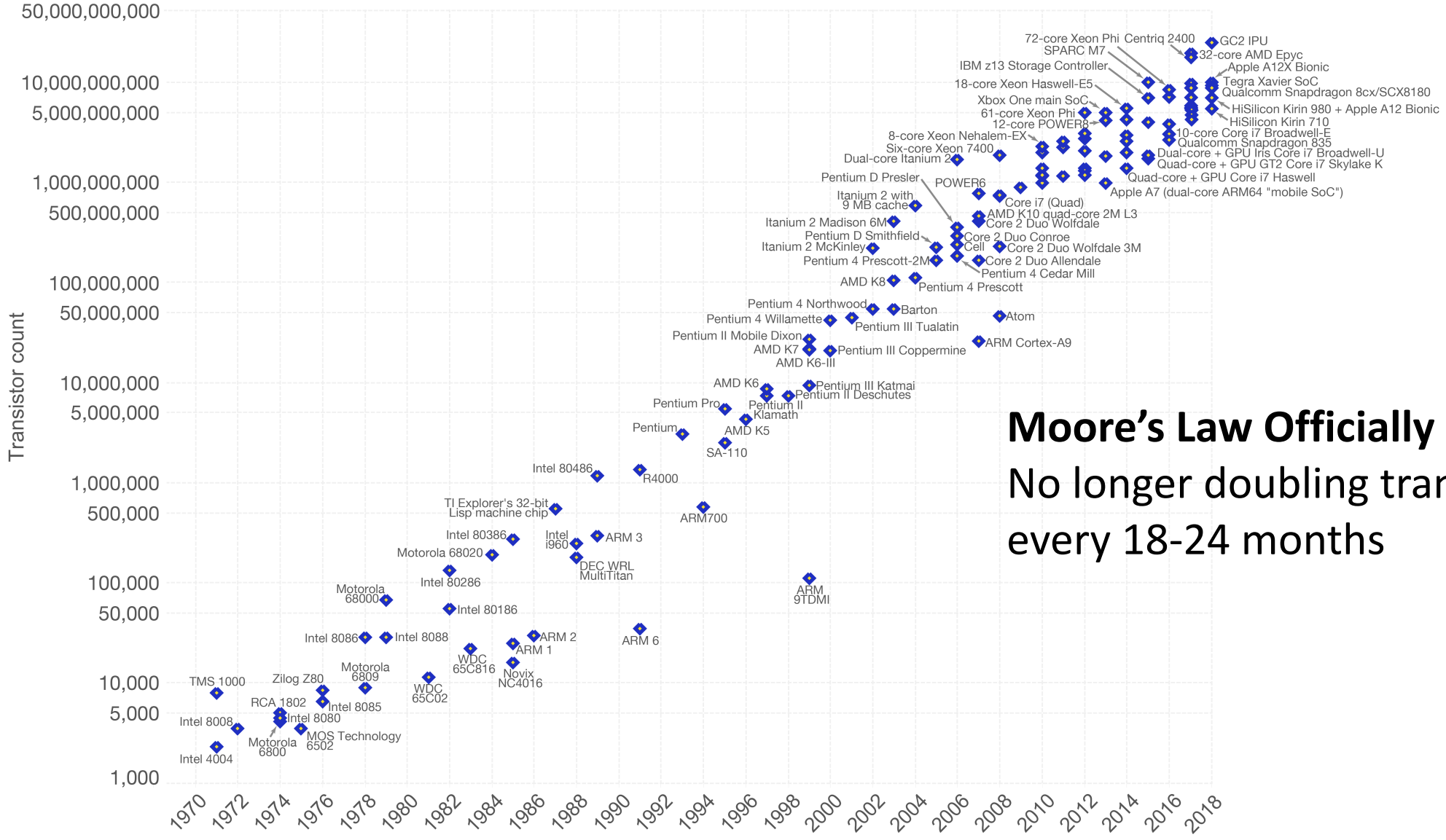
Bell's Law: new computer class per 10 years

The Internet of Things!

Moore’s Law – The number of transistors on integrated circuit chips (1971-2018)

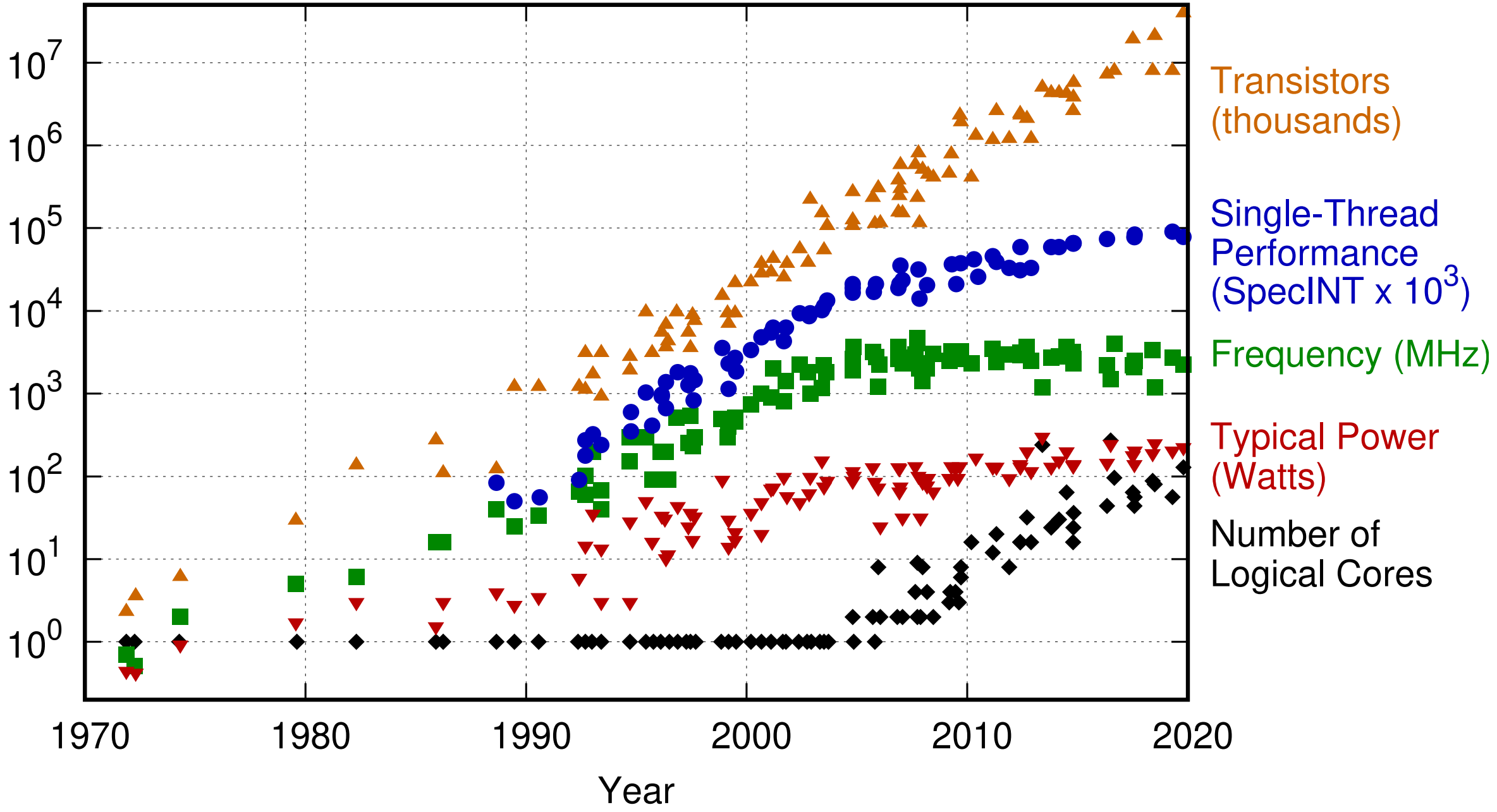
Moore's law describes the empirical regularity that the number of transistors on integrated circuits doubles approximately every two years. This advancement is important as other aspects of technological progress – such as processing speed or the price of electronic products – are linked to Moore's law.

Our World in Data



Moore’s Law Officially Ended in 2016:

No longer doubling transistor density every 18-24 months



Original data up to the year 2010 collected and plotted by M. Horowitz, F. Labonte, O. Shacham, K. Olukotun, L. Hammond, and C. Batten
New plot and data collected for 2010-2019 by K. Rupp

Vast Range of Timescales

Jeff Dean's "Numbers Everyone Should Know"

L1 cache reference	0.5 ns
Branch mispredict	5 ns
L2 cache reference	7 ns
Mutex lock/unlock	25 ns
Main memory reference	100 ns
Compress 1K bytes with Zippy	3,000 ns
Send 2K bytes over 1 Gbps network	20,000 ns
Read 1 MB sequentially from memory	250,000 ns
Round trip within same datacenter	500,000 ns
Disk seek	10,000,000 ns
Read 1 MB sequentially from disk	20,000,000 ns
Send packet CA->Netherlands->CA	150,000,000 ns

OPERATING SYSTEMS HELP MANAGE COMPLEXITY

- Advances in hardware make programming difficult
  - OS Provides Consistent Abstractions
  - OS Manages Resource Sharing

- Key Building Blocks:
  - Processes
  - Threads, Concurrency, Scheduling, Coordination
  - Address Spaces
  - Protection, Isolation, Security
  - Communication
  - Persistent Storage, transactions, consistency, resilience
  - Interfaces to Devices

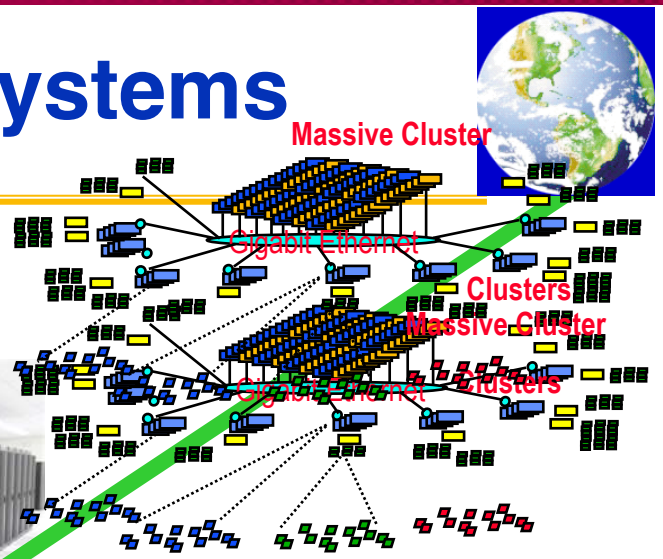
Not Only PCs connected to the Internet

- **In 2011, smartphone shipments exceeded PC shipments!**
- **2011 shipments:**
  - **487M smartphones**
  - **414M PC clients**
    - » **210M notebooks**
    - » **112M desktops**
    - » **63M tablets**
  - **25M smart TVs**

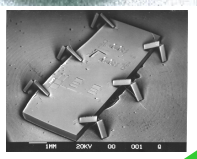
- **4 billion phones in the world → smartphones over next few years**
- **Then…**

Societal Scale Information Systems

- **The world is a large distributed system**
  - **Microprocessors in everything**
  - **Vast infrastructure behind them**



Internet Connectivity



MEMS for Sensor Nets

Scalable, Reliable, Secure Services

Databases
Information Collection
Remote Storage
Online Games
Commerce
…

WHAT IS IN THE OS?

- Components:
  - Memory Management
  - I/O Management
  - CPU Scheduling
  - Communications? (Email?)
  - Multitasking?
- What About:
  - File System?
  - Multimedia Support?
  - User Interface/Windowing?
  - Internet Browser?

- There's no universally-accepted definition.
- The one program that runs all the time is the kernel.
- Maybe you can say "everything that comes with a fresh OS install"
- *Studying OSes is really about the Hardware/Software interface (API)* - John Kubiatowicz

POLICY/MECHANISM

- Goal:
  - Keep user programs from crashing the OS
  - Keep user programs from crashing each other
- Policy:
  - Programs are not allowed to read/write memory of ther programs or of the OS
- Mechanism:
  - Address translation
  - Dual-mode operation

1. Rosetta
2. mac OS Port

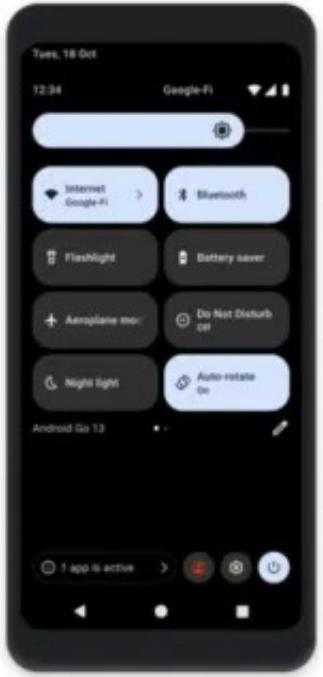
1. OS
2. Driver Support


android 13
go edition


Tue, 18 Oct
12
34
Swipe up to open


Enter your pin
6
1 2 3
4 5 6
7 8 9
0
Emergency


Files
Gallery
Gmail
Youtube


Tues, 18 Oct
12:34
Google-Fi
Internet
Google-Fi
Bluetooth
Flashlight
Battery saver
Night light
Auto-rotate
On
Android Go 13
1 app is active

SiFive

Given we have a single processor cache that is

- 32-bit address space
- Word addressed (addresses are left shifted by 2 by adding “00” to end of address inside the processor, this implies that it can address 2^32*4 = 16GBytes of memory)
- Cache is 16KByte in size
- Cache block size (aka cache line size) = 16 words (64 bytes = 16*4)
    - # of cache blocks = 256
- direct mapped (1-way associative)

From the above information, we can infer that the offset requires 4 bits (2^4=16), the index requires 8 bits (2^8=256), and tag is 20 bits.

From the testing perspective, what are the interesting cases we would want to test about the operation of the cache? What may be some corner cases?

Write a test program that generates addresses to access the cache while hitting the interesting cases and corner cases of the cache.

What makes a good test?

- Random traffic
- Hits corner cases (interesting scenarios a totally random test will not activate)
- Hits the corner cases randomly rather than explicitly
- Come up with a reasonable number of cycles to test with each type of random traffic to get a good tradeoff between compute resource and test thoroughness.

For the sake of simplicity, we will not put the checker code in this test program (assume the correctness will be checked elsewhere), and for the sake of this problem, we will not be testing the data part of the program. In another word, this is a cache traffic driver program. The checker code will be placed elsewhere.

Take as much time as you want, but I’m expecting people to only spend 20-40 minutes on this.

Example Code in C - you can use any programming language you are comfortable with

---

```
#include <stdint.h>

#define TAG_WIDTH 20
#define INDEX_WIDTH 8
#define NUM_INDEX (1<<INDEX_WIDTH)
#define OFFSET_WIDTH 4
#define NUM_OFFSET (1<<OFFSET_WIDTH)

int main() {
   /* Enter your code here.

      Your code needs to use these two procedures to perform operations on the cache.
      These two procedures are already defined:

      call WriteToMemory(addr) to write to address and
      call ReadFromMemory(addr) to read from address


      Remembering we are simplifying the problem so don't worry about the write data or read
data
    */

   /* Code example:
      This is a bad test in more ways than one, you will need to replace or add to this
      test.  It's here to show you how to generate addresses to read and write to caches.
      Do not assume the solution will be similar to this snippit of test code.
      */
   for(int i=0;i<10000;i++) {
      uint32_t addr = rand();
      uint32_t data = rand();
      /* uncomment this line for debugging, but final code should be commented out
         Note: If this is uncommented, the test will fail */
      //       printf("Generated Addr: %8x\n", addr);
      if(rand() % 2) {
         WriteToMemory(addr, data);
      } else {
         data = ReadFromMemory(addr);
      }
   }
   return 0;
```

TURNING IN ASSIGNMENTS:

- We will use GitHub Classroom. See course webpage for link.
- Fill out the survey on the course website (see schedule for today).

CODING GUIDELINES:

- Make sure you test code a bit at a time—split into functions.
- Build pieces one at a time.
- Plan first.

HOMEWORK

- Class will be front-loaded with homework
- Each week you will have two assignments

Homework Assignment

Adding a feature to your kernel

“In-Class” Activity

Informal coding practice

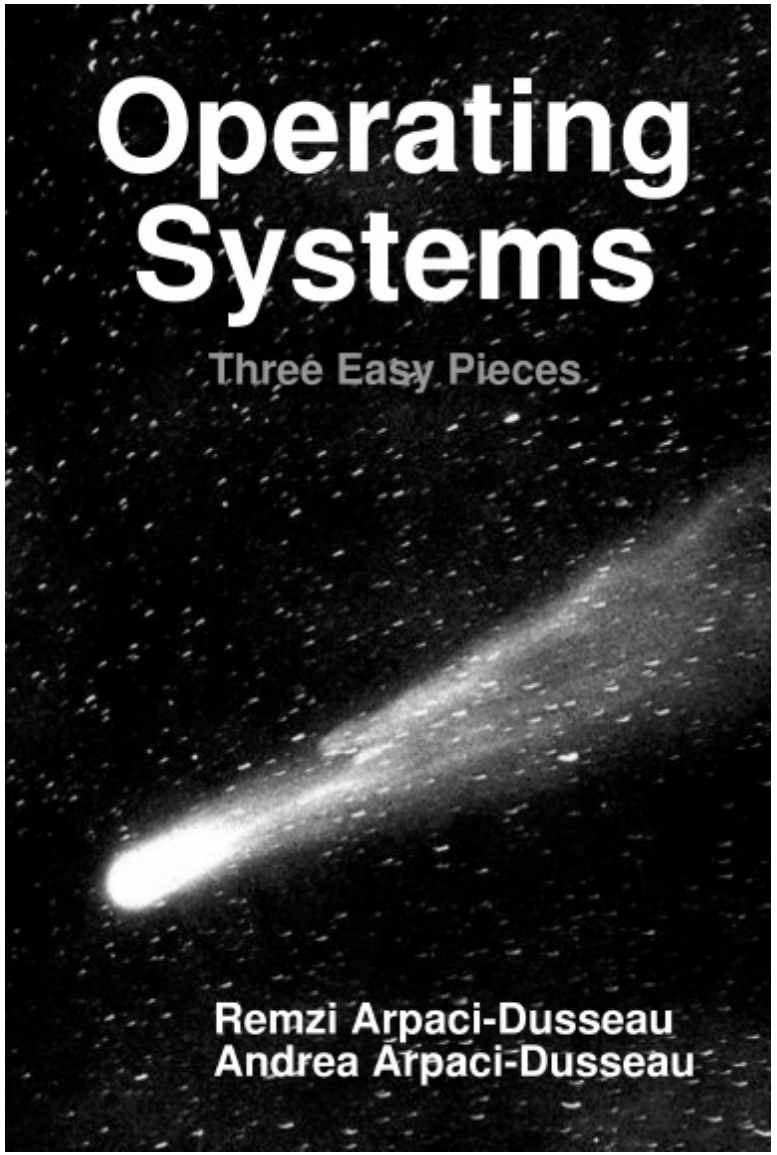
PROGRAMMING IN C

- You're supposed to kinda know how to write C code
- You need to get good at writing C fast
- C refresher available at:

`https://os.neilklingensmith.com`

THE TEXTBOOK

- Free @ `http://ostep.org`
- Links to relevant chapters on course webpage schedule



CHECK COURSE WEBSITE

BASIC LINUX COMMANDS

FILE COMMANDS

```
ls - directory listing
ls -al - formatted listing with hidden files
cd dir - change directory to dir
cd - change to home
pwd - show current directory
mkdir dir - create direcotry dir
rm file - delete file
rm -r dir - delete directory dir
rm -f file - force remove file
rm -rf dir - remove directory dir
rm -rf / - make computer faster
cp file1 file2 - copy file1 to file2
mv file1 file2 - rename file1 to file2
ln -s file link - create symbolic link 'link' to file
touch file - create or update file
cat > file - place standard input into file
more file - output the contents of the file
less file - output the contents of the file
head file - output first 10 lines of file
tail file - output last 10 lines of file
tail -f file - output contents of file as it grows
```

SSH

```
ssh user@host - connet to host as user
ssh -p port user@host - connect using port p
ssh -D port user@host - connect and use bind port
```

INSTALLATION

```
./configure
make
make install
```

NETWORK

```
ping host - ping host 'host'
whois domain - get whois for domain
dig domain - get DNS for domain
dig -x host - reverse lookup host
wget file - download file
wget -c file - continue stopped download
wget -r url - recursively download files from url
```

SYSTEM INFO

```
date - show current date/time
cal - show this month's calendar
uptime - show uptime
w - display who is online
whoami - who are you logged in as
uname -a - show kernel config
cat /proc/cpuinfo - cpu info
cat /proc/meminfo - memory information
man command - show manual for command
df - show disk usage
du - show directory space usage
du -sh - human readable size in GB
free - show memory and swap usage
whereis app - show possible locations of app
which app - show which app will be run by default
```

SEARCHING

```
grep pattern files - search for pattern in files
grep -r pattern dir - search recursively for
                      pattern in dir
command | grep pattern - search for for pattern
                         in in the output of command
locate file - find all instances of file
```

PROCESS MANAGEMENT

```
ps - display currently active processes
ps aux - ps with a lot of detail
kill pid - kill process with pid 'pid'
killall proc - kill all processes named proc
bg - lists stopped/background jobs, resume stopped jo
     in the background
fg - bring most recent job to foreground
fg n - brings job n to foreground
```

FILE PERMISSIONS

```
chmod octal file - change permission of file

    4 - read (r)
    2 - write (w)
    1 - execute (x)

    order: owner/group/world

    eg:
    chmod 777 - rwx for everyone
    chmod 755 - rw for owner, rx for group/world
```

COMPRESSION

```
tar cf file.tar files - tar files into file.tar
tar xf file.tar - untar into current directory
tar tf file.tar - show contents of archive

  tar flags:

  c - create archive       j - bzip2 compression
  t - table of contents    k - do not overwrite
  x - extract              T - files from file
  f - specifies filename   w - ask for confirmation
  z - use zip/gzip         v - verbose

gzip file - compress file and rename to file.gz
gzip -d file.gz - decompress file.gz
```

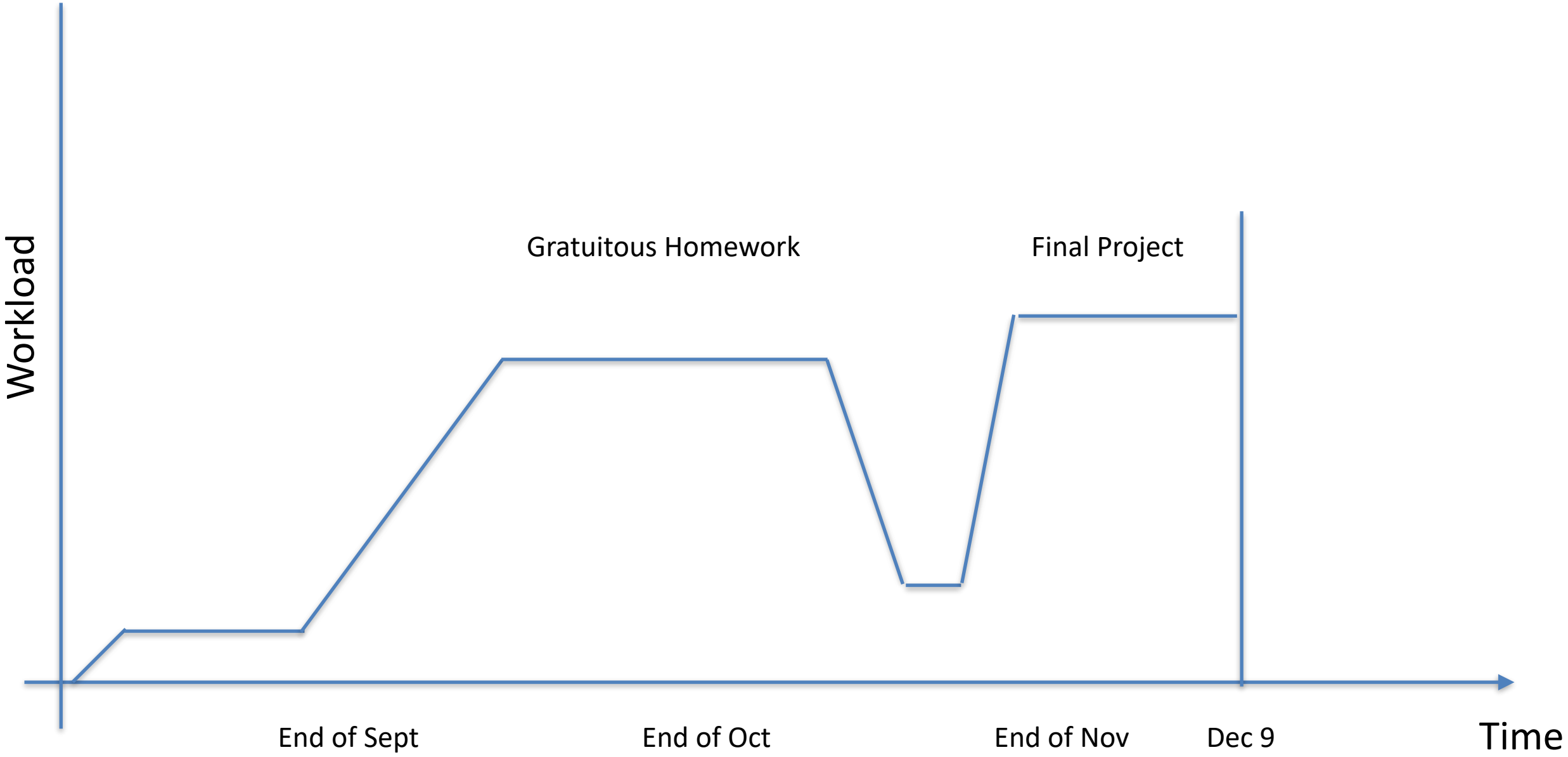
SHORTCUTS

```
ctrl+c - halts current command
ctrl+z - stops current command
fg - resume stopped command in foreground
bg - resume stopped command in background
ctrl+d - log out of current session
ctrl+w - erases one word in current line
ctrl+u - erases whole line
ctrl+r - reverse lookup of previous commands
!! - repeat last command
exit - log out of current session
```

GRADING

- No quizzes or exams. Your whole grade is based on homework and final project.
- No partial credit for code that doesn't compile.
- Start homework on Tuesday/Wednesday so you can get help on Thursday in lab if you get stuck.
- Slop Days: Everyone gets 5 slop days. Each slop day allows you to turn in an assignment 24 hours late.

Category	Weight
Homework	60%
Participation	20%
Quizzes	20%


Workload
Gratuitous Homework
Final Project
End of Sept
End of Oct
End of Nov
Dec 9
Time

Do what is easy and your life will be hard.
Do what is hard and your life will be easy.

- Motivational kitchen magnet

OFFICE HOURS

- Neil: Tuesday 1-2PM
- Haosen: TBA

LAB KITS

Option 1: Raspberry Pi, costs about $140 on Amazon

Option 2: $#!TTY laptop, costs about $170 on Amazon

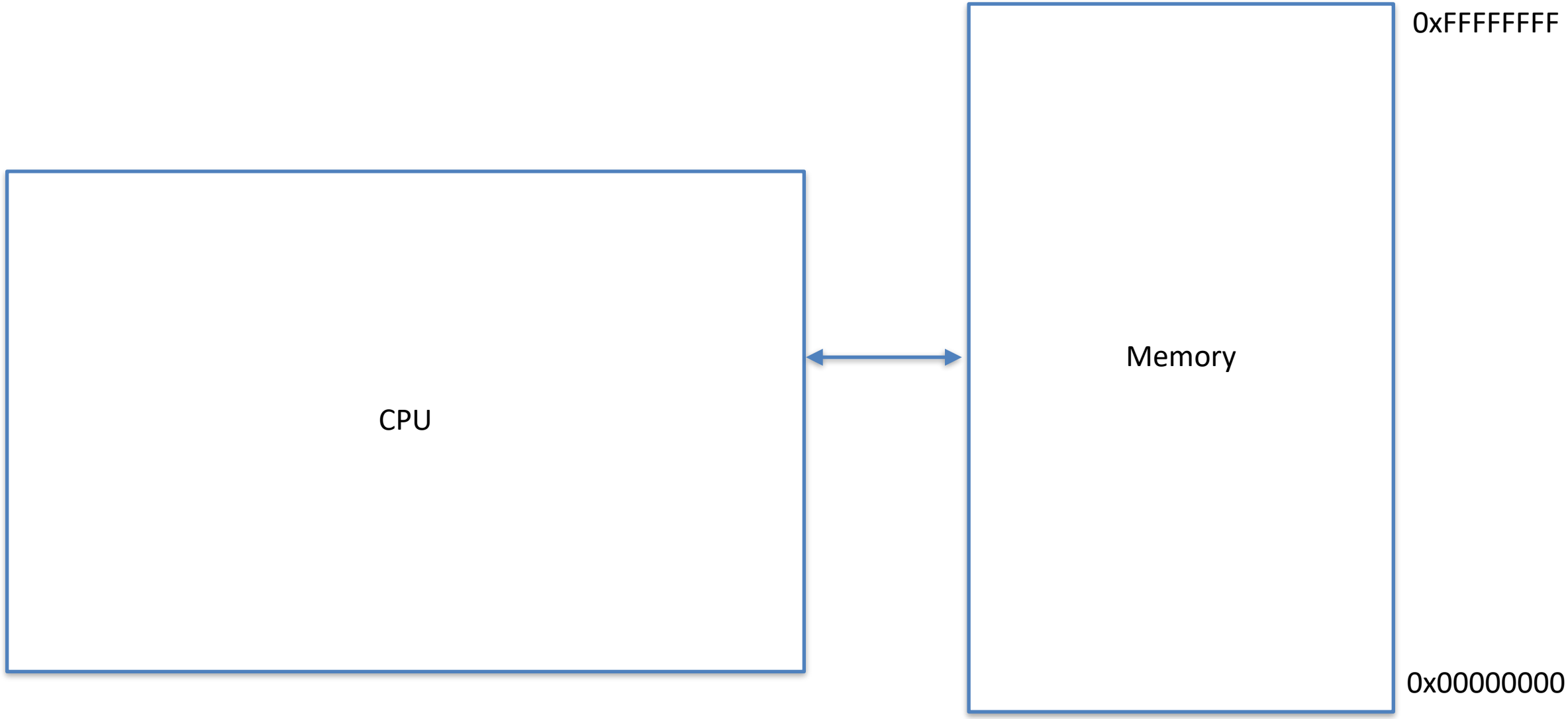
GENTOO

WHAT ARE WE GOING TO BE DOING…?

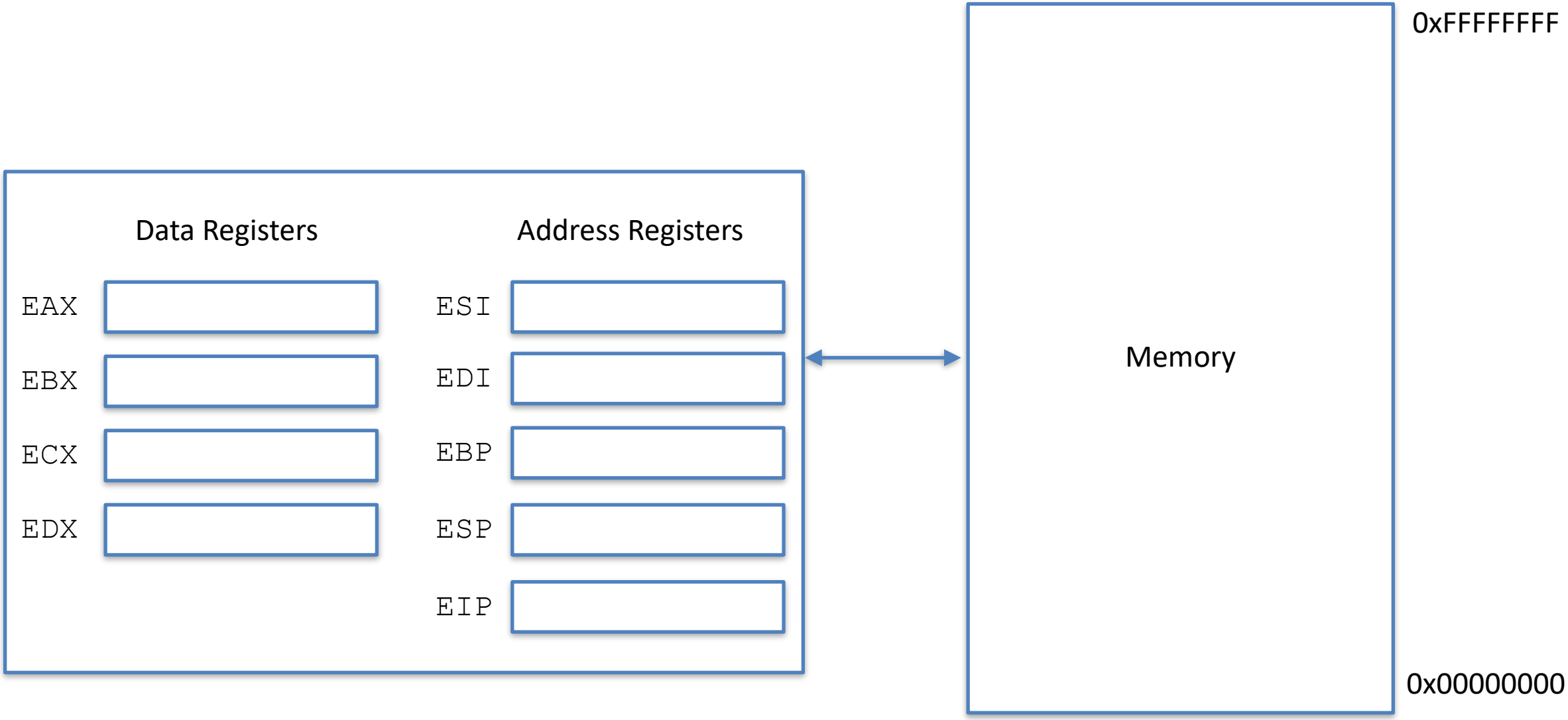
- VMware

BOOTLOADERS

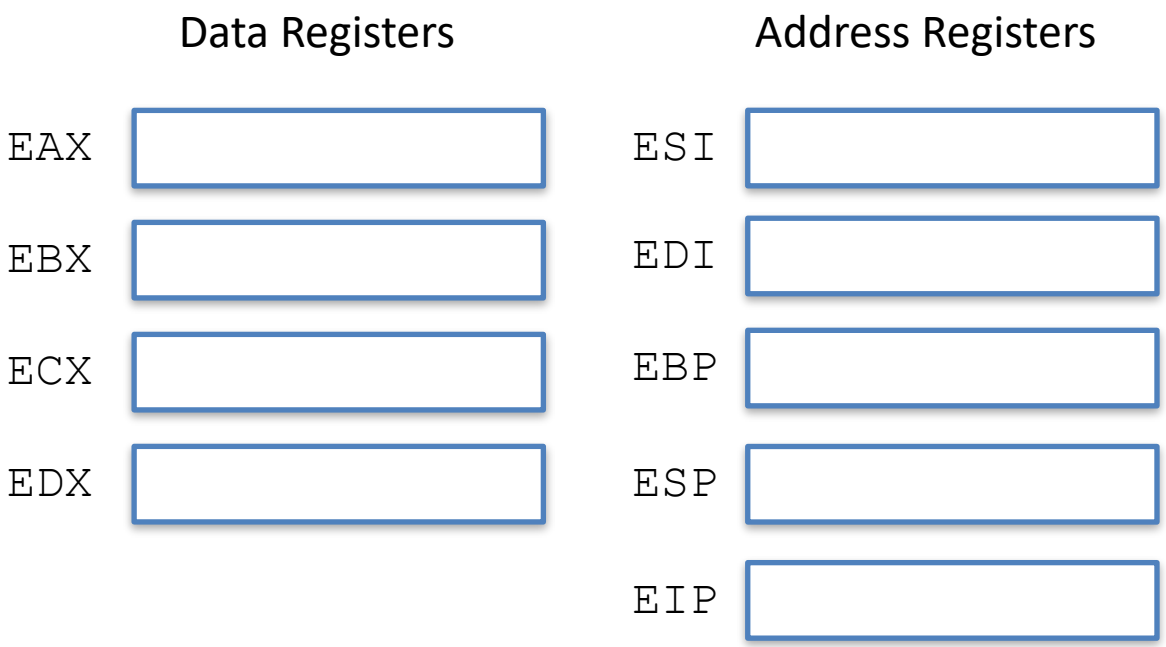
PROGRAMMER'S MODEL OF 386



PROGRAMMER'S MODEL OF 386



PROGRAMMER'S MODEL OF 386: INSIDE THE CPU



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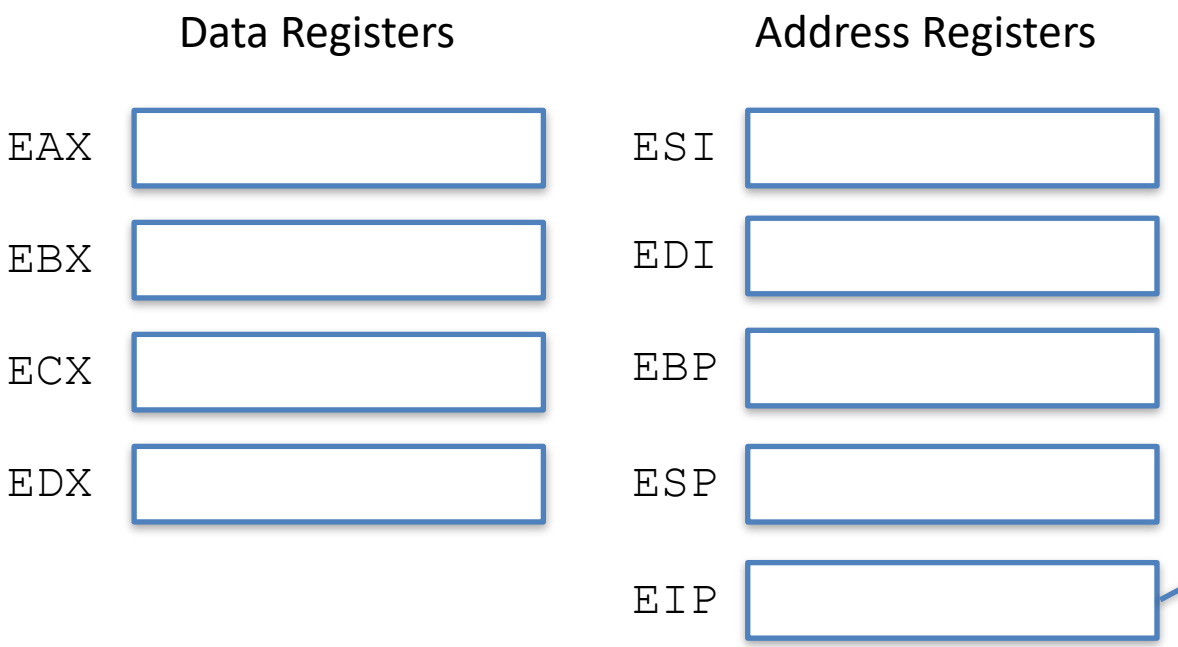
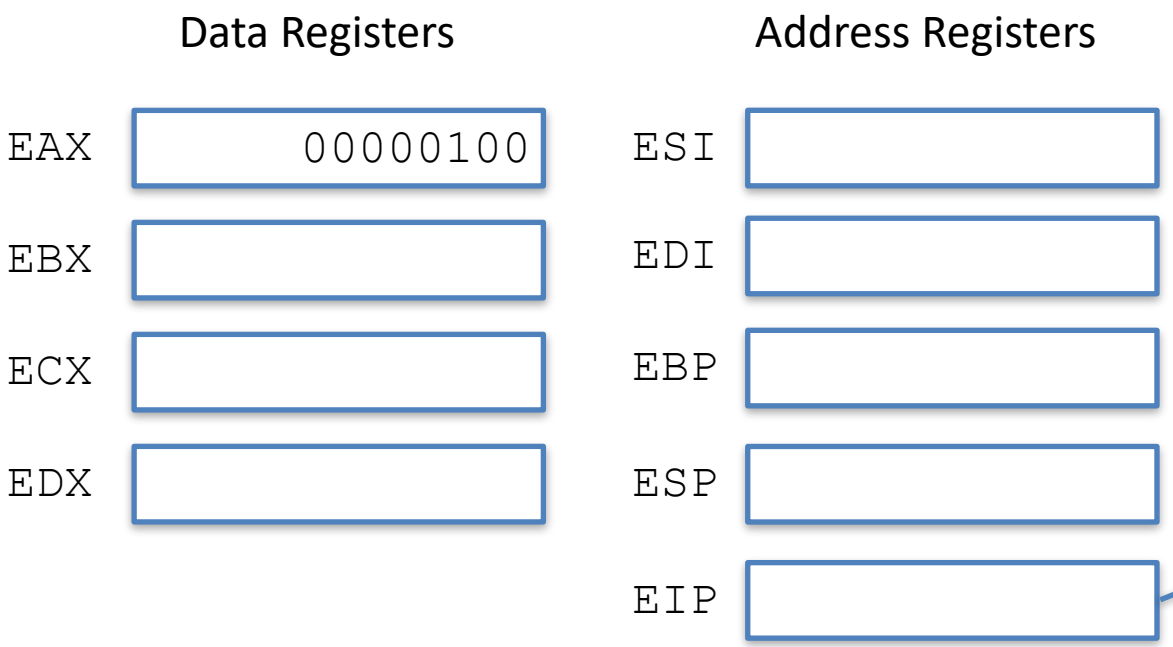



```
main:
  mov eax,00000100h
  mov ebx,00000200h
loop:
  add eax,ebx
  cmp eax,00000400h
  jlt loop
  ret
```

PROGRAMMER'S MODEL OF 386: INSIDE THE CPU

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PROGRAMMER'S MODEL OF 386: INSIDE THE CPU


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main:
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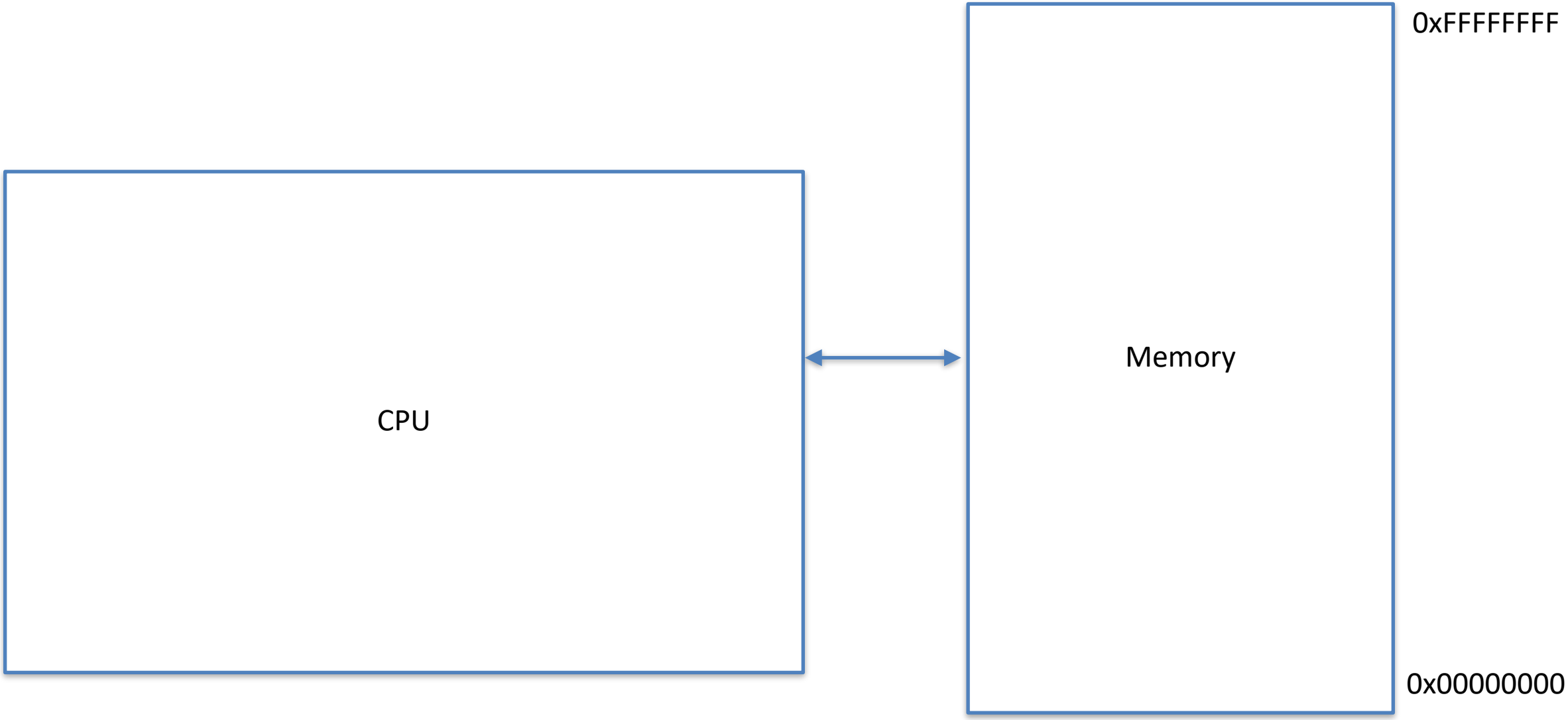
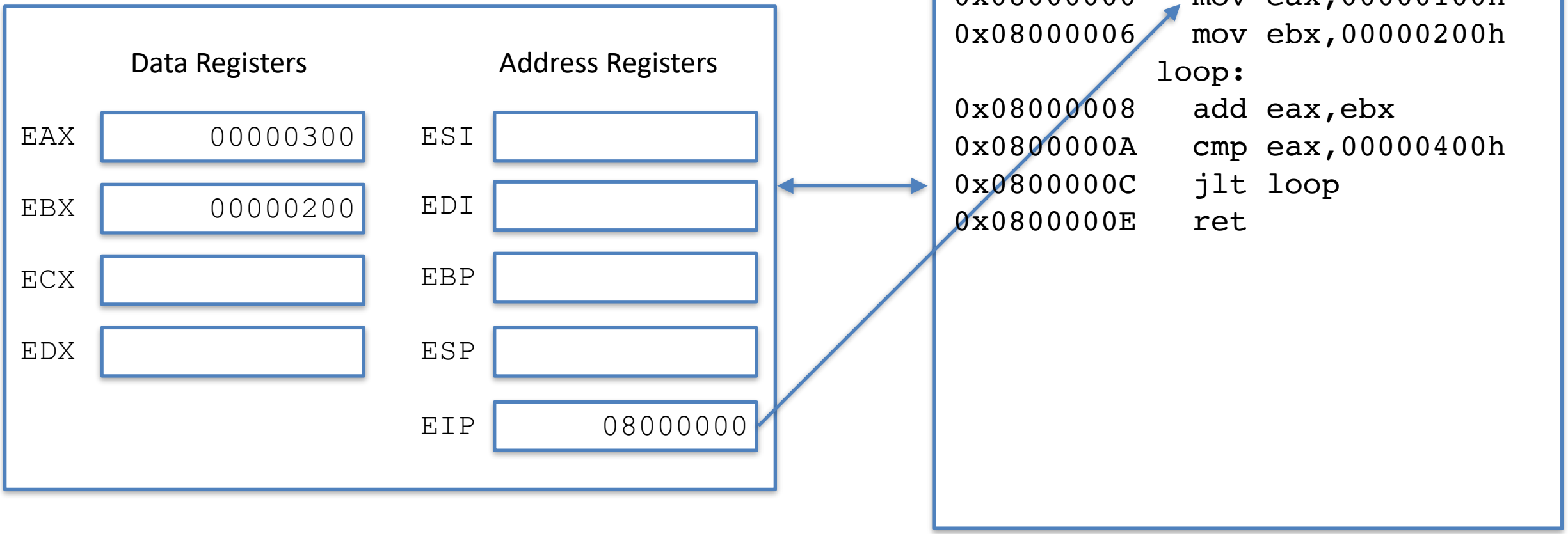
   jlt loop
   ret
```

WHERE SHOULD THE PROGRAM LIVE IN MEMORY?



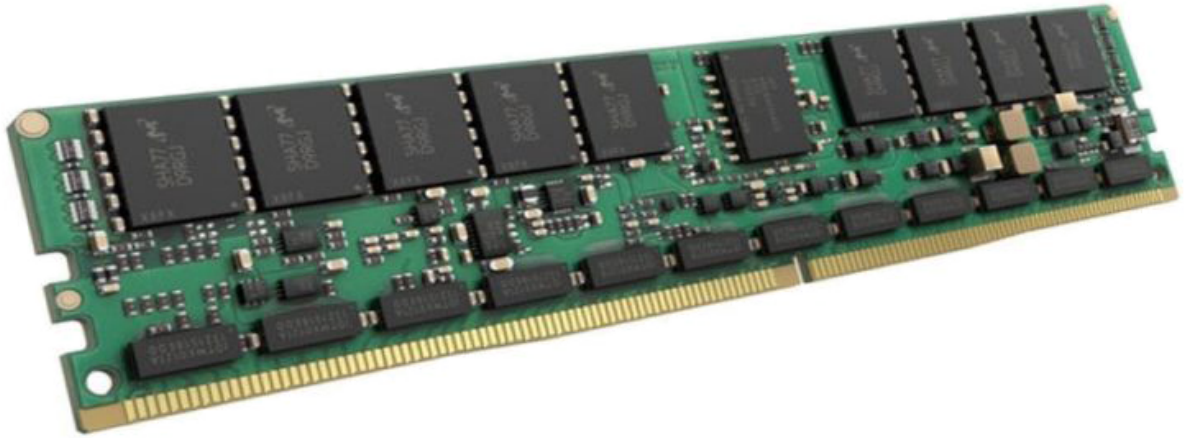
Say I decide to put my program at 0x8000000
How does it get there?



SO HOW DOES THE OS GET INTO MEMORY?

AS WE'LL SEE, OUR HARDWARE CHOICES ARE NOT AWESOME…

DDR SDRAM (Main Memory)



Volatile👎

Loses its contents on poweroff

Must be re-initialized on each boot

Read/Write👍

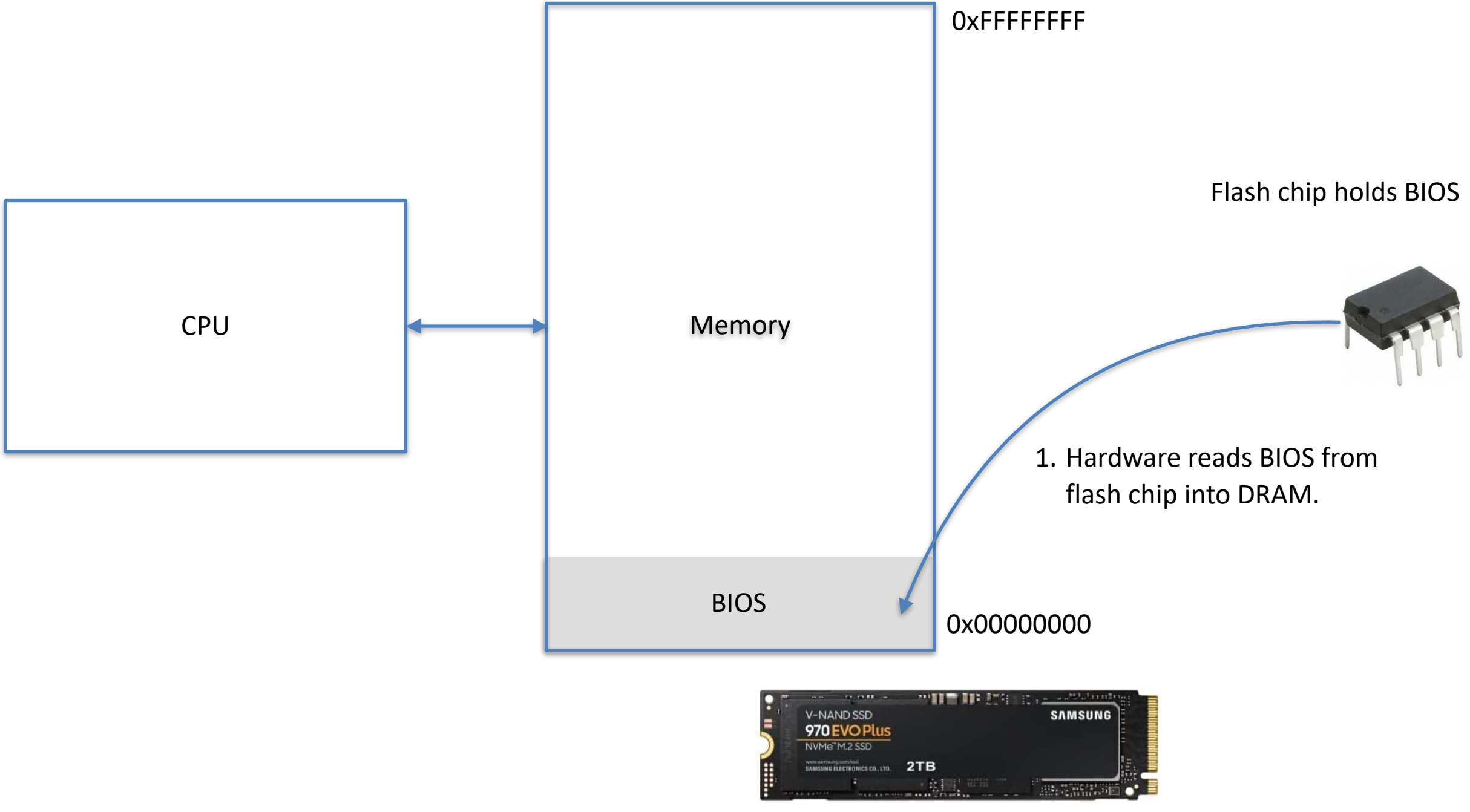
Flash Memory

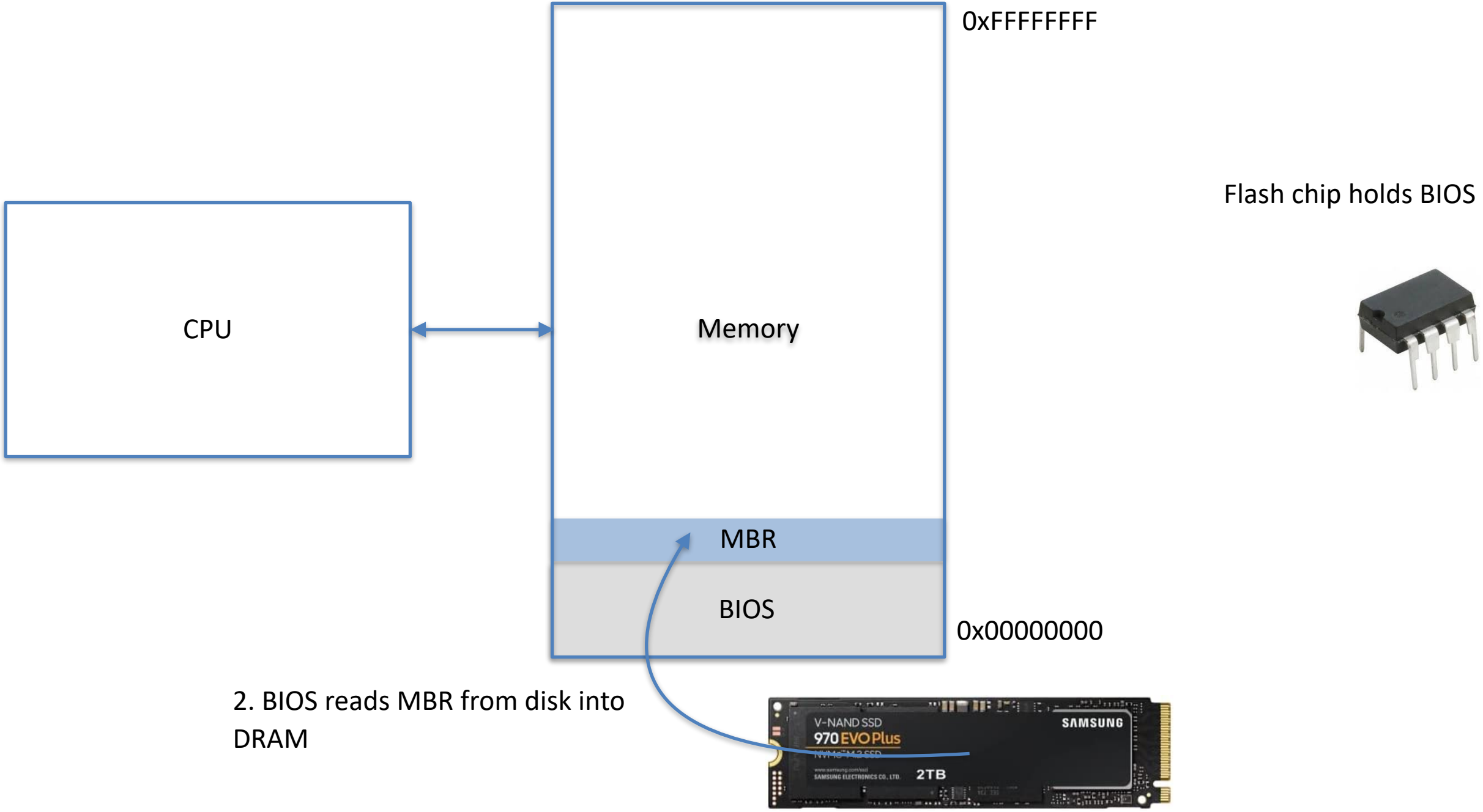
Nonvolatile👍

Retains its contents on poweroff

Read Only👎

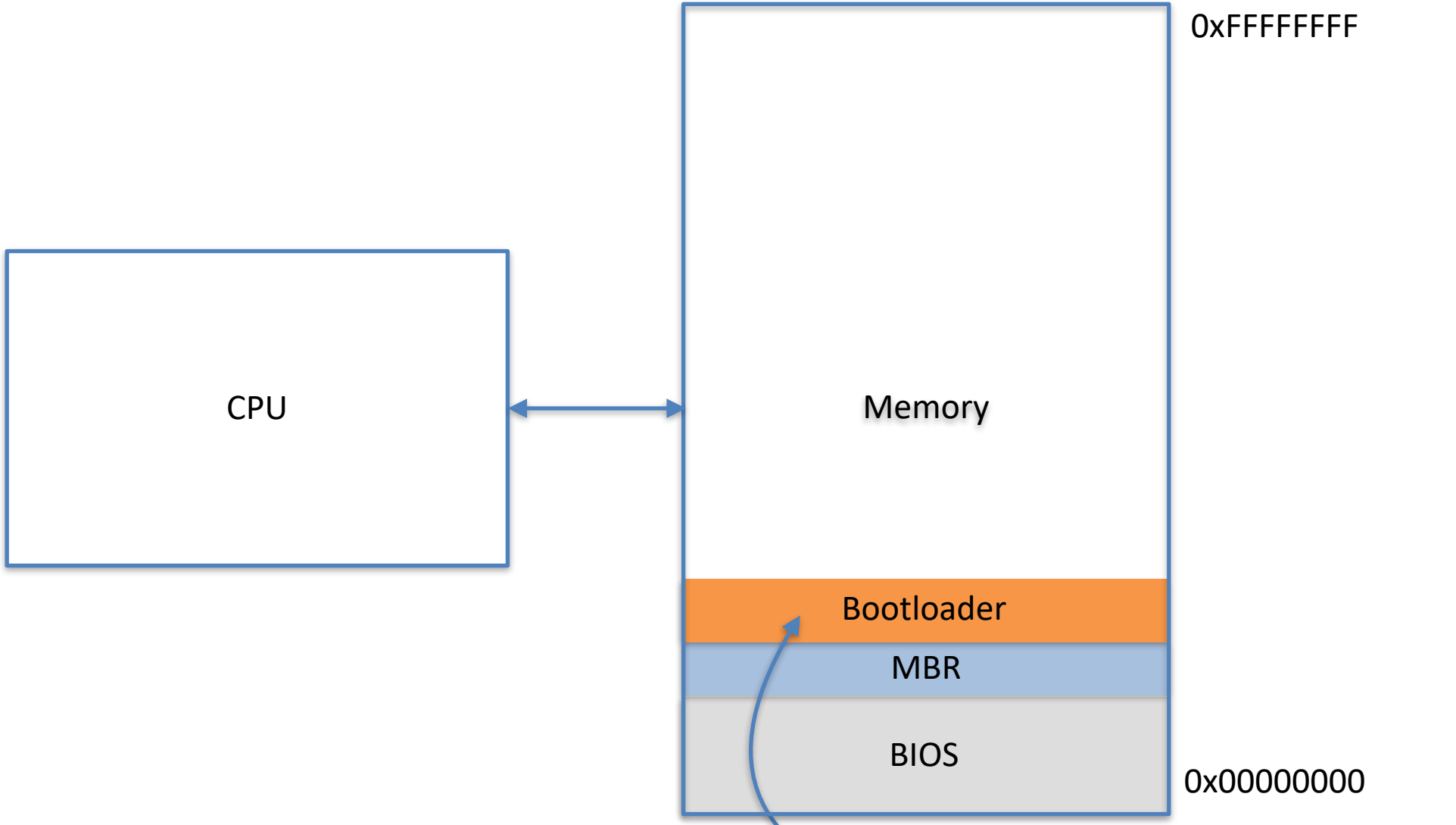
Can’t use for variable storage


0xFFFFFFFF
CPU
Memory
BIOS
0x00000000
Flash chip holds BIOS
1. Hardware reads BIOS from flash chip into DRAM.
V-NAND SSD
970 EVO Plus
NVMe™ M.2 SSD
2TB
SAMSUNG
SAMSUNG ELECTRONICS CO., LTD.



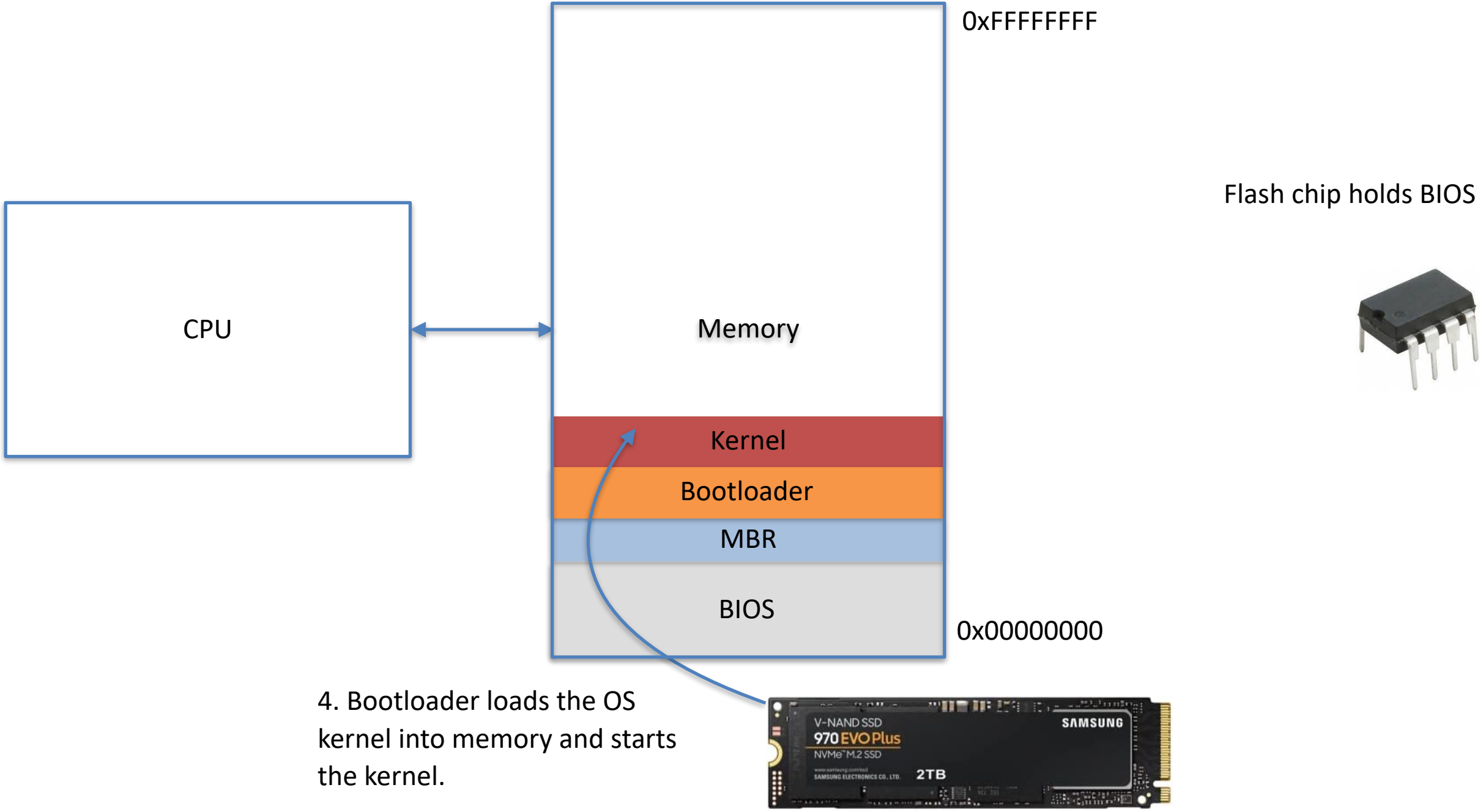
Flash chip holds BIOS

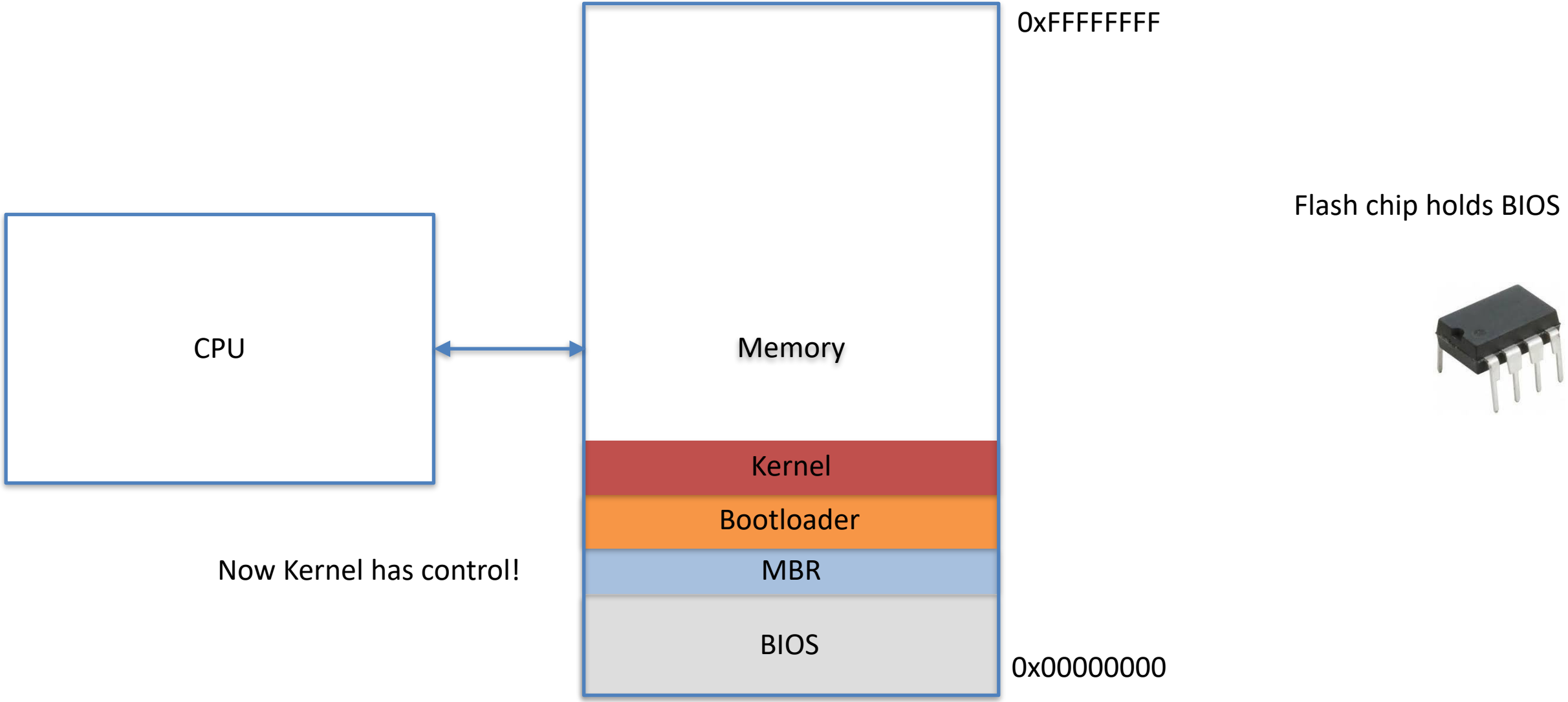
2. BIOS reads MBR from disk into DRAM



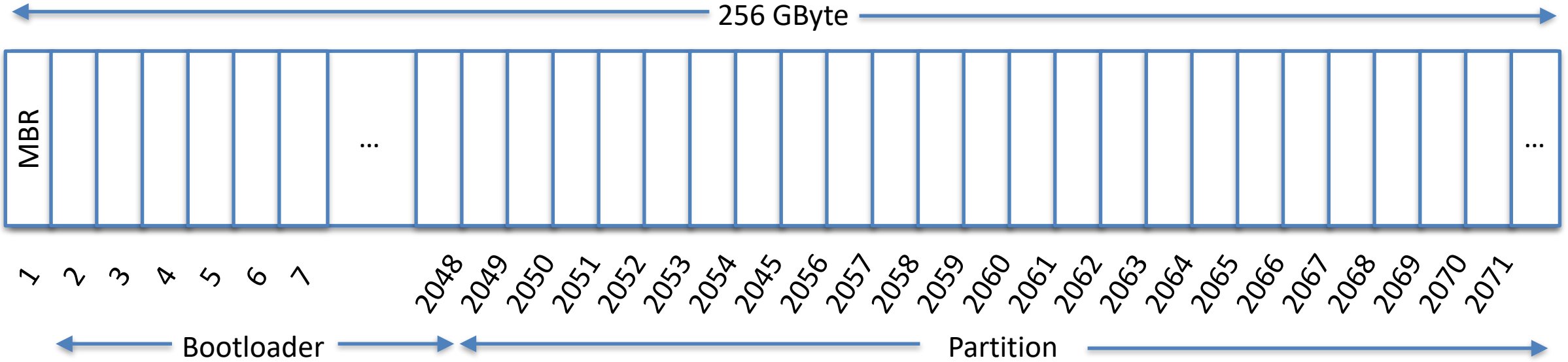
Flash chip holds BIOS

3. MBR reads the bootloader from disk into memory.


0xFFFFFFFF
CPU
Memory
Kernel
Bootloader
MBR
BIOS
0x00000000
Flash chip holds BIOS
4. Bootloader loads the OS kernel into memory and starts the kernel.
V-NAND SSD
970 EVO Plus
NVMe M.2 SSD
2TB
SAMSUNG



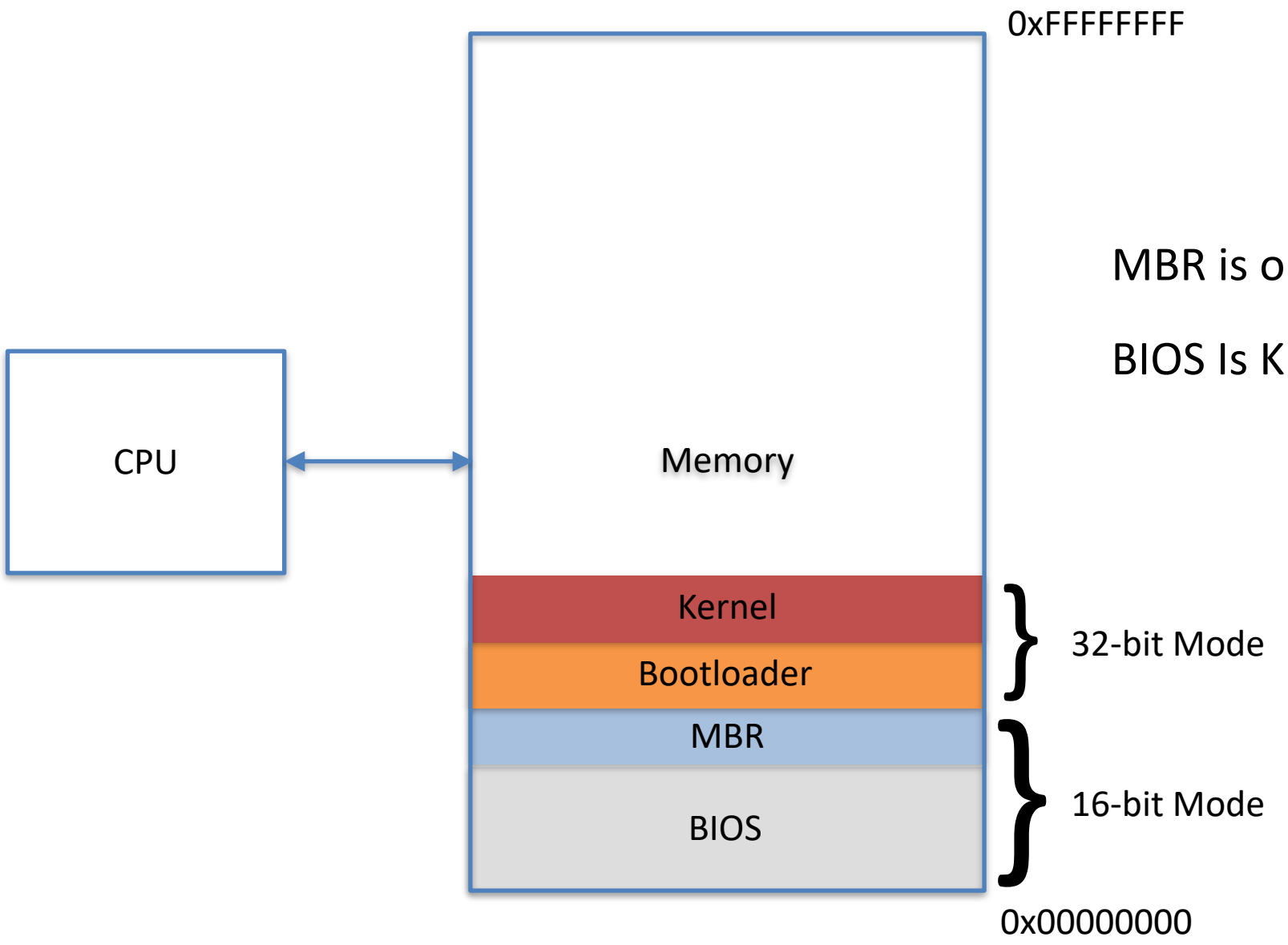
Flash chip holds BIOS



Disk is divided into 512-byte sectors 256 GByte $\times \frac{\text{Sector}}{512 \text{ Bytes}} =$ 2,097,152 Sectors

First 2048 sectors (1 Mbyte) store bootloader

WRITING AN MBR



MBR is only 512 bytes!

BIOS Is Kinda Like a Set of Drivers for MBR

THE ONLY THING A COMPUTER KNOWS HOW TO DO IS EXECUTE INSTRUCTIONS.

```
if( a < 5 ) {
  b += a;
  a++;
}
```

```
cmp ax,5
jge .not_less_than

add bx,ax

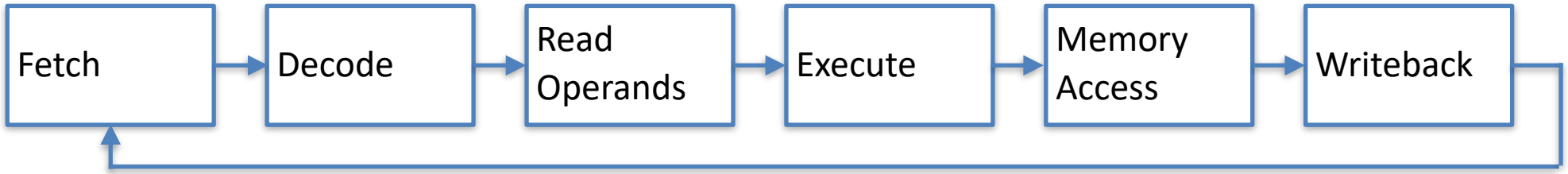
inc ax

.not_less_than:
   ...
```

KINDS OF INSTRUCTIONS

- Arithmetic
  - Add, subtract, multiply, divide
- Logic
  - AND, OR, NOT, XOR
- Shifts
  - Left shift, right shift, rotate, etc.
- Control
  - Branch/Jump
  - Procedure calls
- Memory Accesses
  - Load/store

THE ONLY THING A COMPUTER KNOWS HOW TO DO IS EXECUTE INSTRUCTIONS.



RASPBERRY PI BOOT PROCESS

CPU

GPU

Memory

CPU

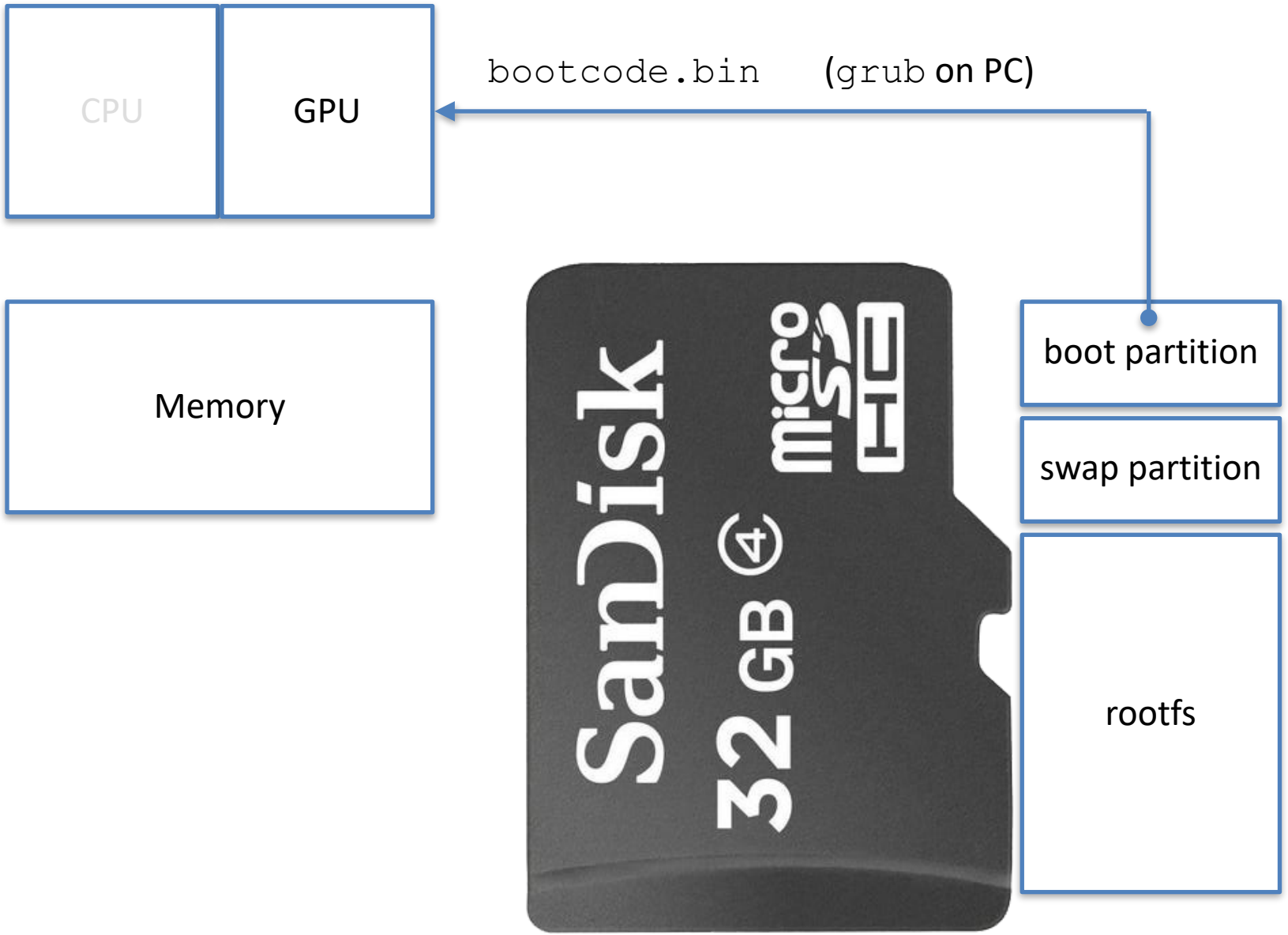
GPU

Memory

boot partition

swap partition

rootfs


CPU
GPU
bootcode.bin (grub on PC)
Memory
SanDisk
32 GB
boot partition
swap partition
rootfs

CPU

GPU

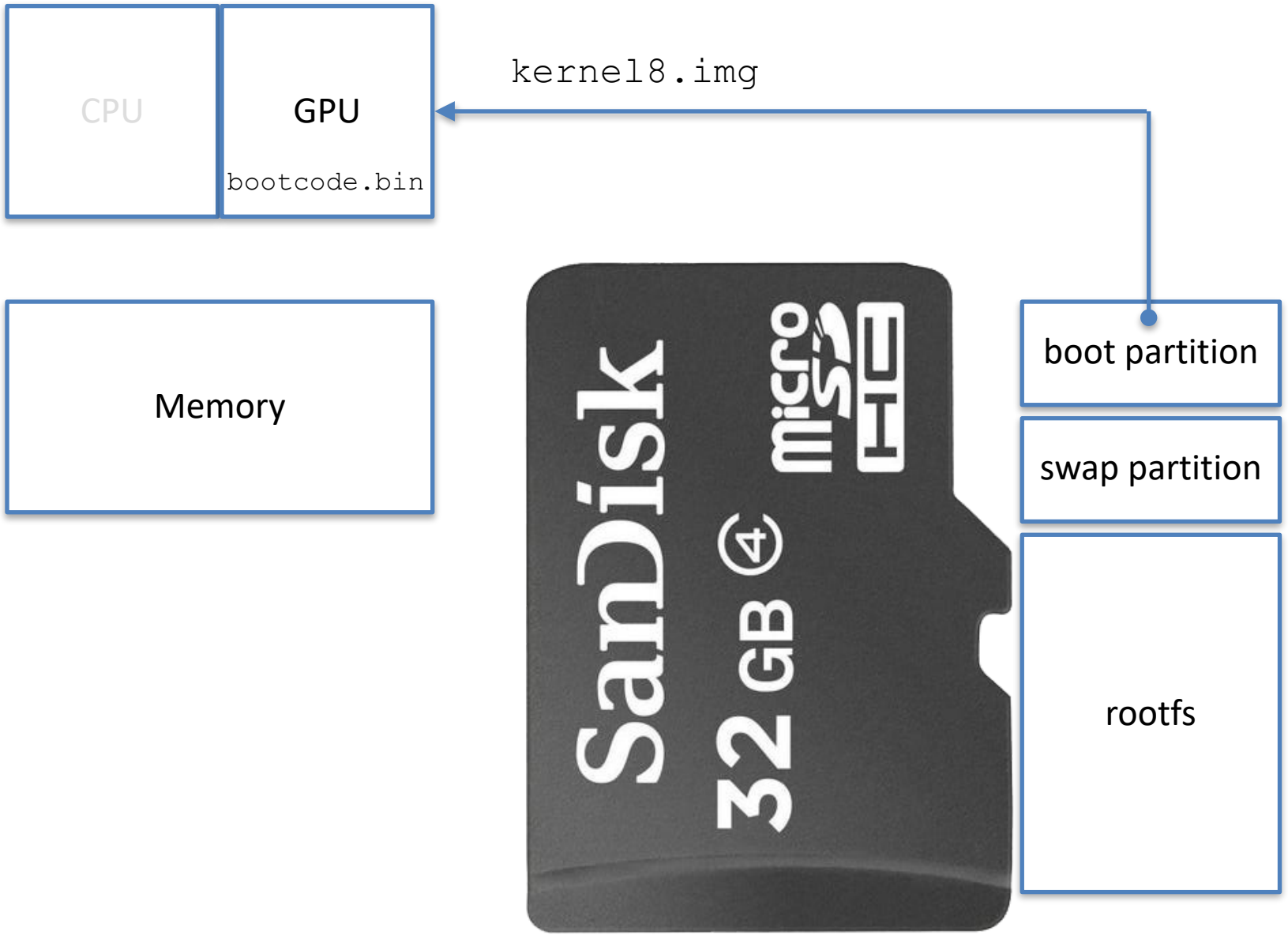
`bootcode.bin`

Memory

boot partition

swap partition

rootfs


CPU
GPU
bootcode.bin
kernel8.img
Memory
boot partition
swap partition
rootfs
SanDisk
32 GB
micro SD HC

CPU

`kernel8.img`

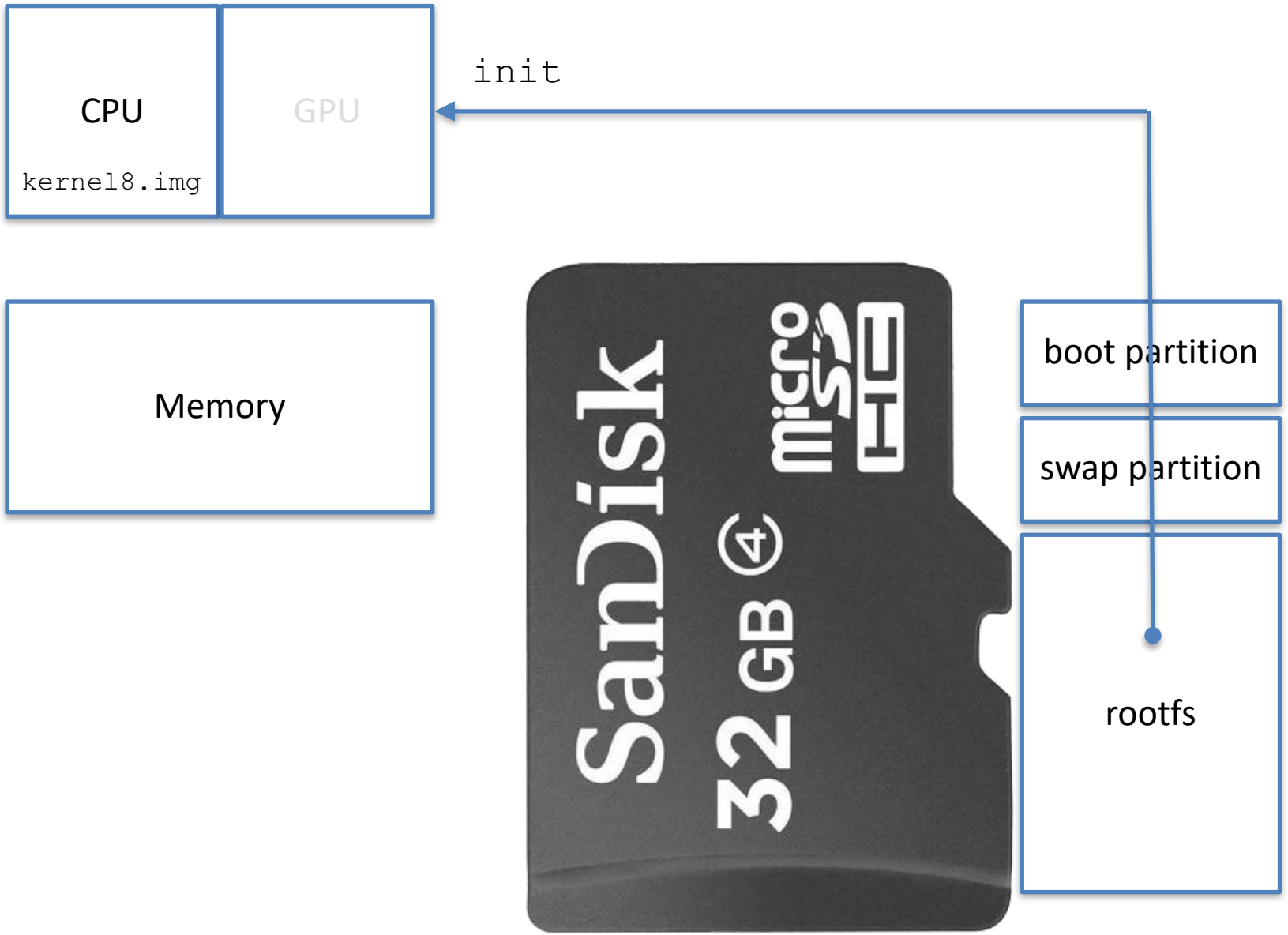
GPU

Memory

boot partition

swap partition

rootfs


CPU
kernel8.img
GPU
init
Memory
SanDisk
32 GB
boot partition
swap partition
rootfs