

# **Baremetal on the Pi**

**Raspberry Pi A+**

**ARM processor and memory**

**Peripherals: GPIO, timers, UART (gpio, uart)**

**Assembly and machine language (as)**

**C and pointers (gcc)**

**Functions and the stack (gdb)**

**Serial communication and strings (uart, printf)**

**Linking and the memory map (ld, memmap, objcopy)**

**Loading using the bootloader (rbi-install.py, bootloader)**

**Starting (start.s, cstart.c)**

**Tools (git, bash, make, brew)**

# The Force Awakens in You





# Nest thermostat



ifixit



# **Building a Personal Computer**

**In the next 3 weeks you will start to make a full-fledged personal computer.**

**Approach: Connecting your CPU to the graphics processor (GPU) and keyboard**

**Goal: a command console, you can type in commands, and see them on a display.**

# Schedule

**Fri**

Framebuffer

**Mon**

Performance

**Lab/assignment**

Console

**Fri**

Keyboard

**Mon**

holiday

**Lab/assignment**

Keyboard / Console

**Fri**

Interrupts

**Mon**

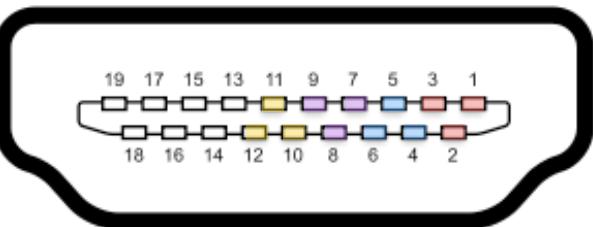
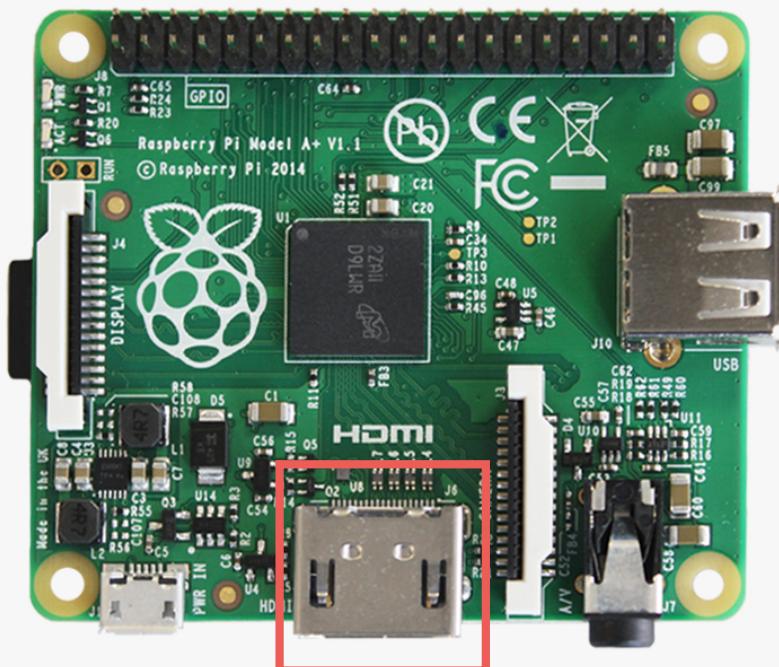
Interrupts

**Lab/assignment**

Fast Console

# **Graphics and Framebuffers**

# HDMI



**Clock**  
**Data 0**  
**Data 1**  
**Data 2**  
**Control**

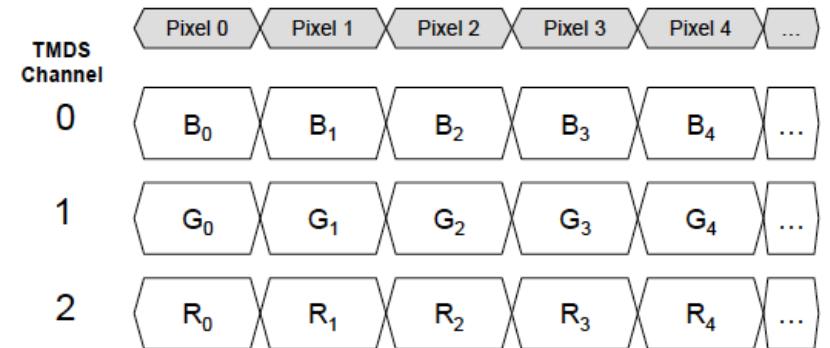
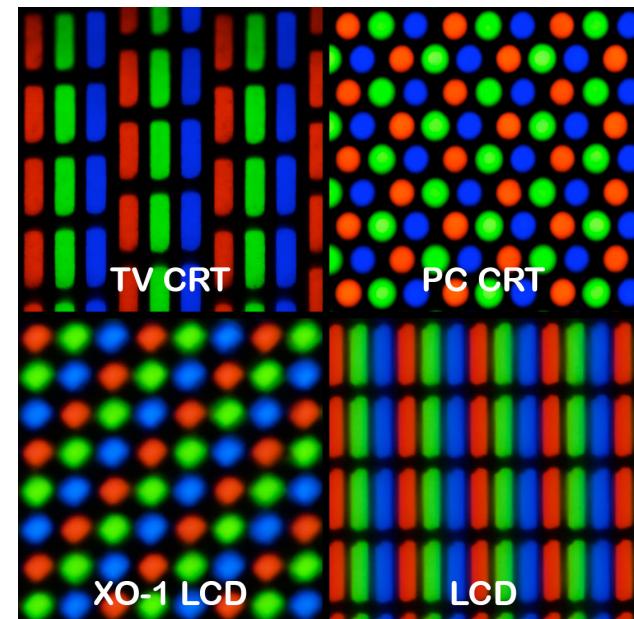


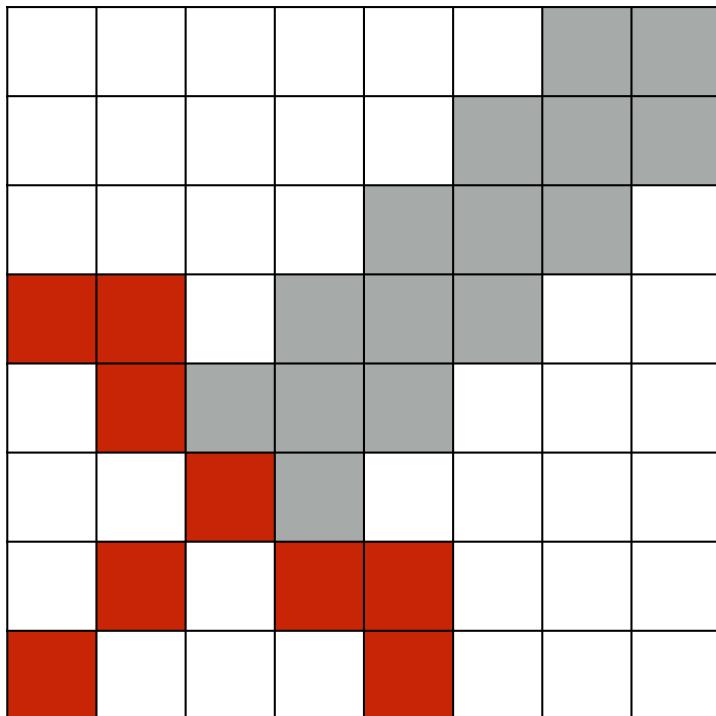
Figure 6-1 Default pixel encoding: RGB 4:4:4, 8 bits/component

Figure from High-Definition Multimedia Interface Specification Version 1.3a

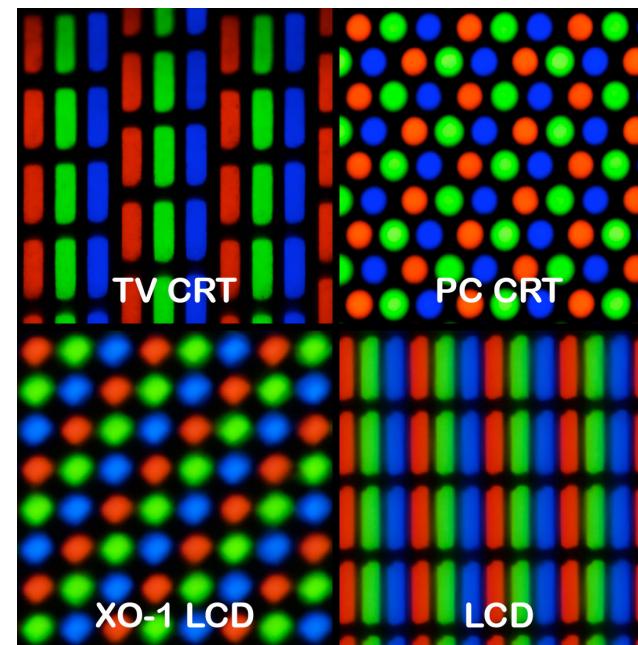


# Displays

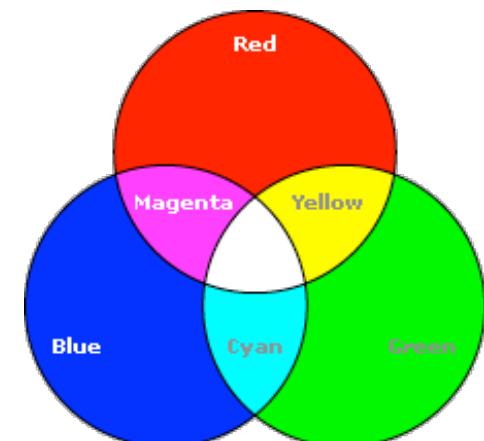
Pixels

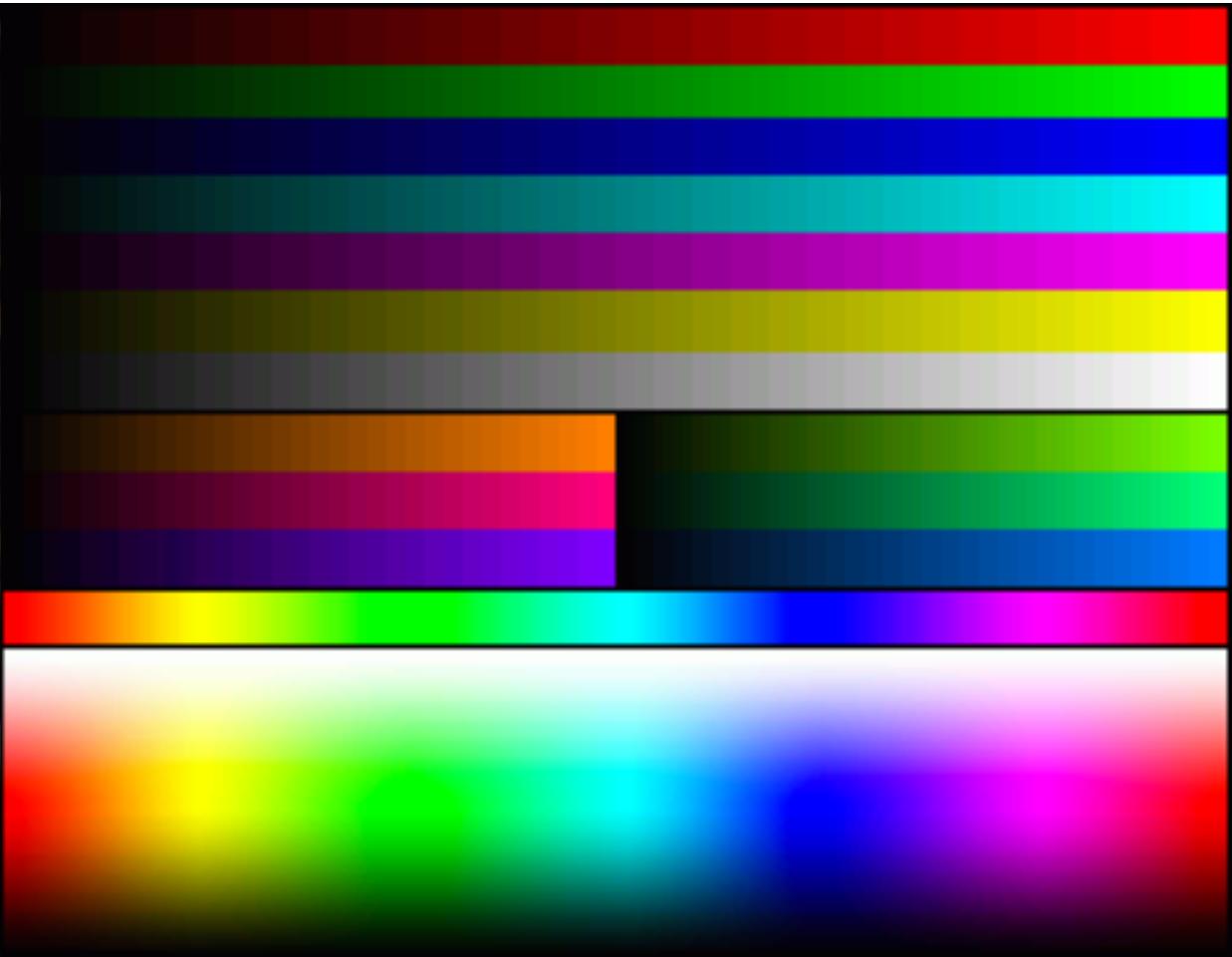


Displays



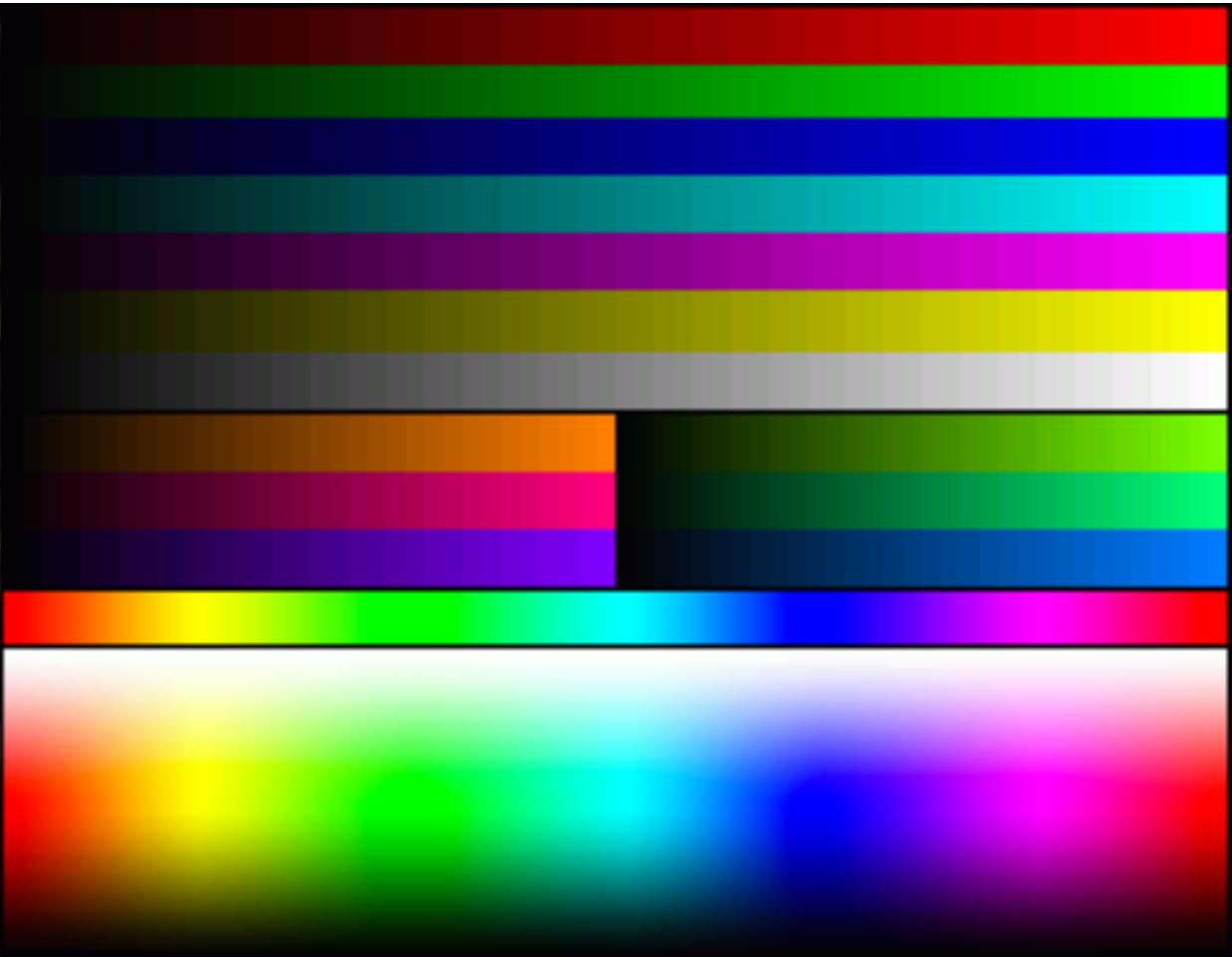
Light





**Framebuffer is an image**

**An image is a 2D array of pixels**



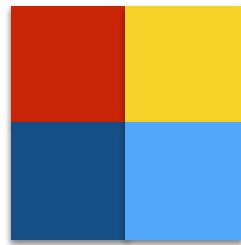
**RGBA pixel (depth=32 bits)**

**Red = 8 bits**  
**Green = 8 bits**  
**Blue = 8 bits**  
**Alpha = 8 bits**

# **Framebuffer Resolution**

**read physical size  
read virtual size  
read pixel depth  
video.c**

**Virtual height**



**Virtual width**

**Note interpolation**

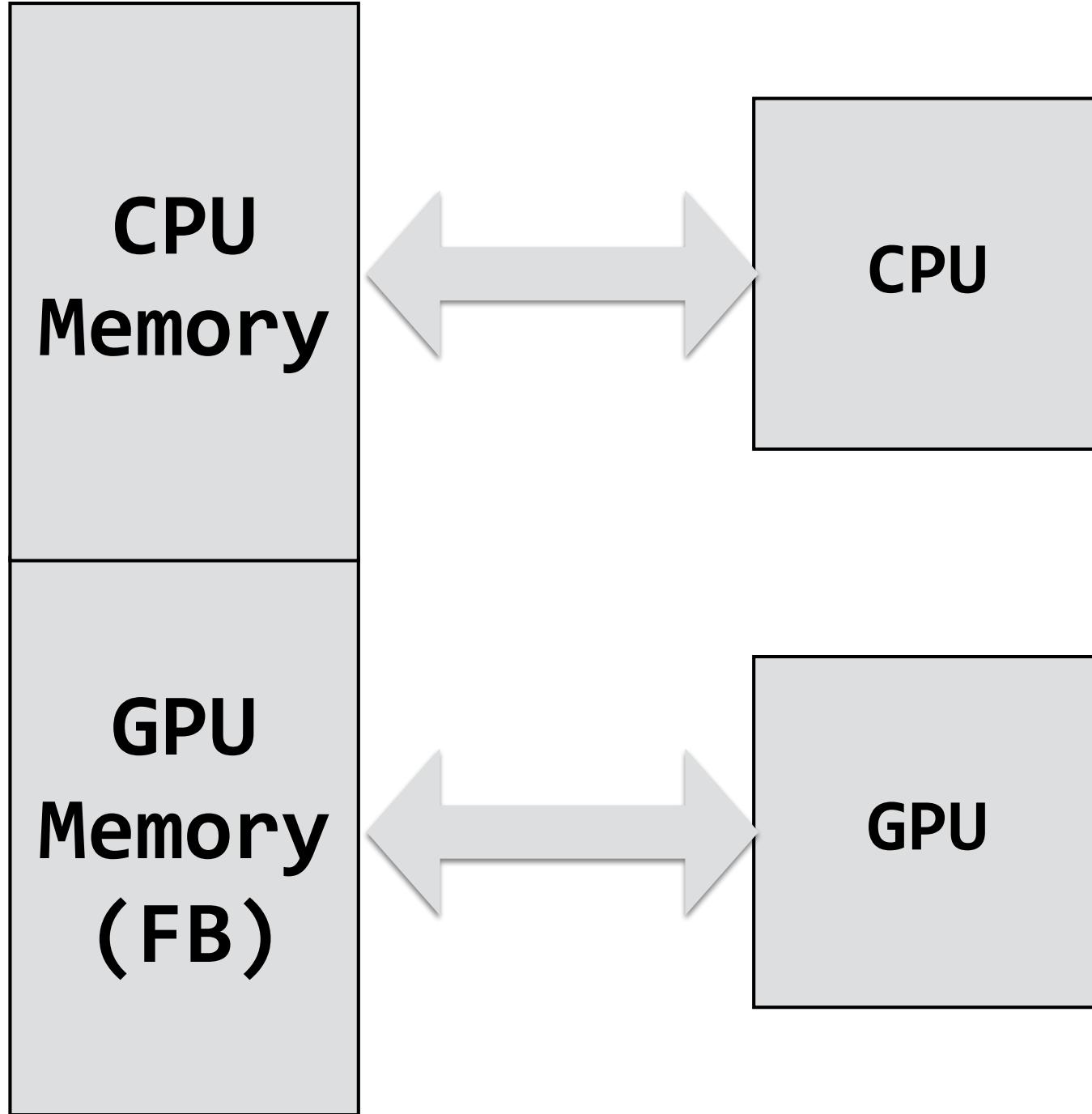


# FB Config Structure

Field	CPU	GPU	Description
width	write	read	Width of physical screen
height	write	read	Height of physical screen
virtual_width	write	read	Width of framebuffer
virtual_height	write	read	Height of framebuffer
pitch	read	write	Bytes/row of framebuffer
depth	write	read	Bits/pixel of framebuffer
x_offset	write	read	X offset of screen in framebuffer
y_offset	write	read	Y offset of screen in framebuffer
pointer	read	write	Pointer to framebuffer
size	read	write	Size of framebuffer in bytes

# **Configure Framebuffer Resolution**

**set physical size  
set virtual size  
set depth  
fb.c**



# **Frame buffer**

**memory split between cpu and gpu**

**config.txt  
memory.c**

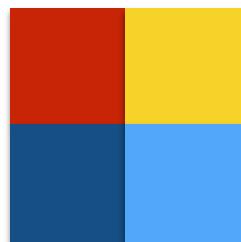
# RGBA Pixel/Color

	0	1	2	3
R	ff	00	00	ff
G	00	ff	00	ff
B	00	00	ff	ff
A				

**Note: red is the first byte (lowest address)**

# Array of unsigned char

```
unsigned char fb[2*2*4];
fb[0] = 0xff; // r
fb[1] = 0x00; // g
fb[2] = 0x00; // b
fb[3] = 0xff; // a
```



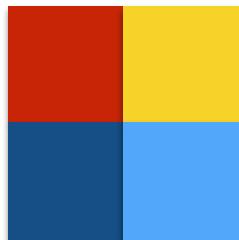
ff	00	00	ff	ff	ff	00	ff	00	00	ff	00	00	ff	ff	00
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

red      yellow      blue      cyan

**Note: (0,0) is the upper left on the monitor**

# Array of unsigned char

```
unsigned char fb[2*2*4];  
fb[rgba + 4*(x + 2*y)] = ...
```



ff	00	00	ff	ff	ff	00	ff	00	00	ff	00	00	ff	ff	00
----	----	----	----	----	----	----	----	----	----	----	----	----	----	----	----

**red**

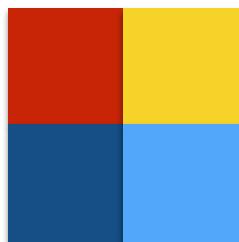
**yellow**

**blue**

**cyan**

# Array of unsigned char

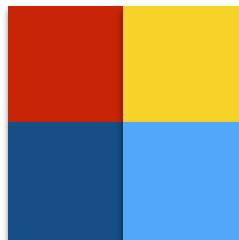
```
unsigned char fb[WIDTH*HEIGHT*DEPTH];  
fb[rgba + DEPTH*(x + WIDTH*y)] = ...
```



ff 00 00 ff	ff ff 00 ff	00 00 ff 00	00 ff ff 00
<b>red</b>	<b>yellow</b>	<b>blue</b>	<b>cyan</b>

# Array of unsigned

```
unsigned fb[2*2];
fb[0] = 0xff0000ff; // x=0, y=0
fb[1] = 0xff00ffff; // x=1, y=0
fb[2] = 0xffff0000; // x=0, y=1
fb[3] = 0xffffffff00; // x=1, y=1
```



ff	00	00	ff	ff	ff	00	ff	ff	00	ff	ff
----	----	----	----	----	----	----	----	----	----	----	----

**red**

**yellow**

**blue**

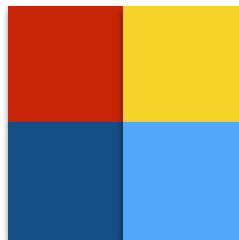
**cyan**

# **Demo**

**clear.c**  
**cleari.c**

# 2D Array of unsigned

```
unsigned fb[2][2];
fb[0][0] = 0xff0000ff;
fb[0][1] = 0xff00ffff;
fb[1][0] = 0xffff0000;
fb[1][1] = 0xfffffff0;
```



ff	00	00	ff	ff	ff	00	ff	ff	00	ff	ff	ff
----	----	----	----	----	----	----	----	----	----	----	----	----

**red**

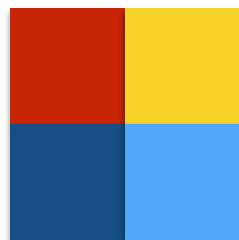
**yellow**

**blue**

**cyan**

# 2D Array of unsigned

```
unsigned (*fb)[2] = (unsigned (*)[2])frame;  
fb[0][0] = 0xff0000ff;  
fb[0][1] = 0xff00ffff;  
fb[1][0] = 0xffff0000;  
fb[1][1] = 0xffffffff00;
```



ff	00	00	ff	ff	ff	00	ff	ff	00	ff	ff
----	----	----	----	----	----	----	----	----	----	----	----

red      yellow      blue      cyan

What is `unsigned *fb[2]`?

# **Demo**

# **grid.c**

# **Double-Buffering**

# **Double Buffering**

**Writing directly to screen can cause flickering**

**Solution: Double buffering**

- Two buffers: back-buffer and front-buffer**
- Front-buffer is being display**
- Draw into back-buffer**
- Swap buffers to update display**

# Single Buffer

Virtual Width



# Double Buffer

Virtual Width

2\*Virtual Height



# Display Top Buffer

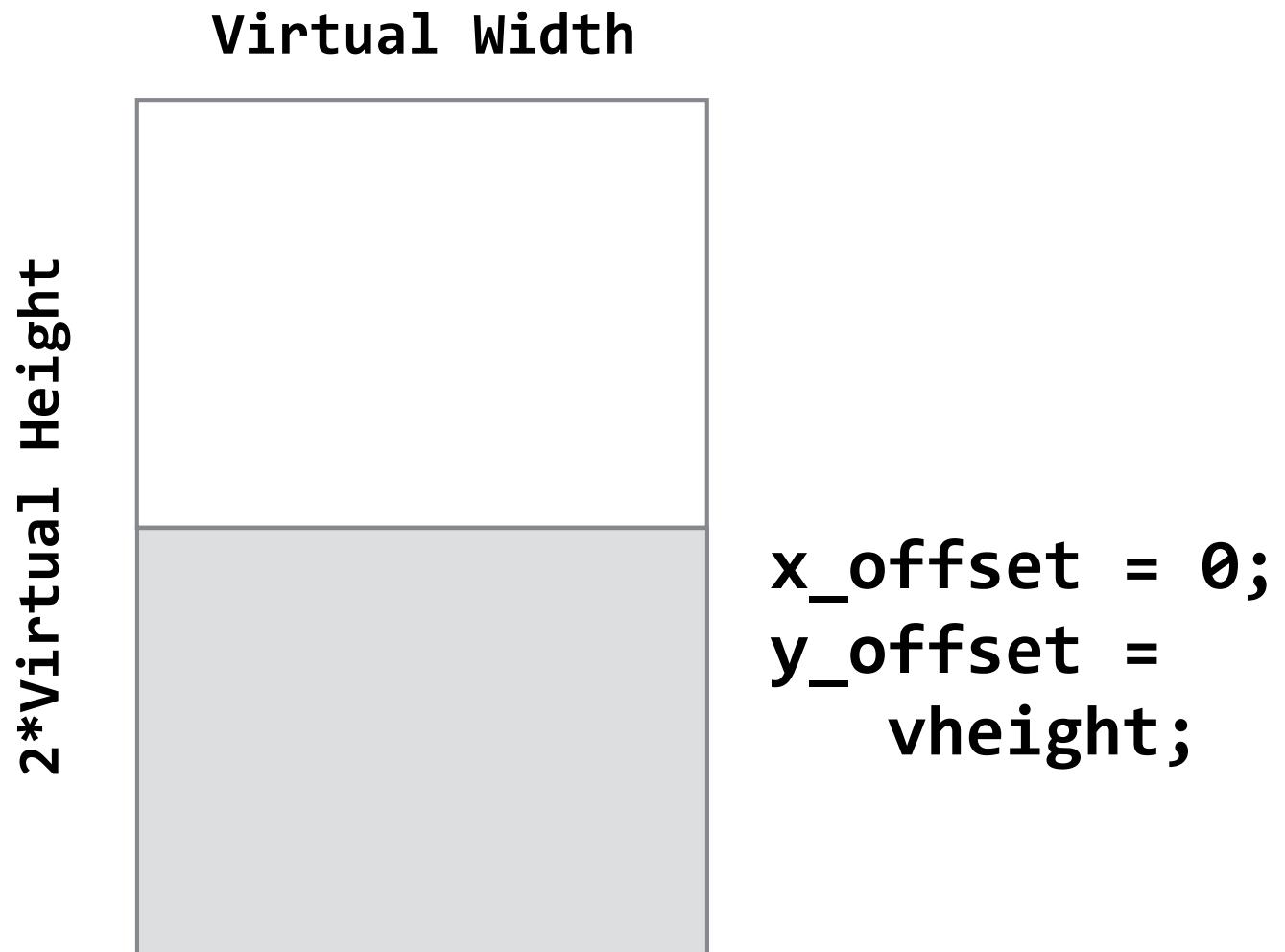
Virtual Width

2\*Virtual Height



x\_offset = 0;  
y\_offset = 0;

# Display Bottom Buffer



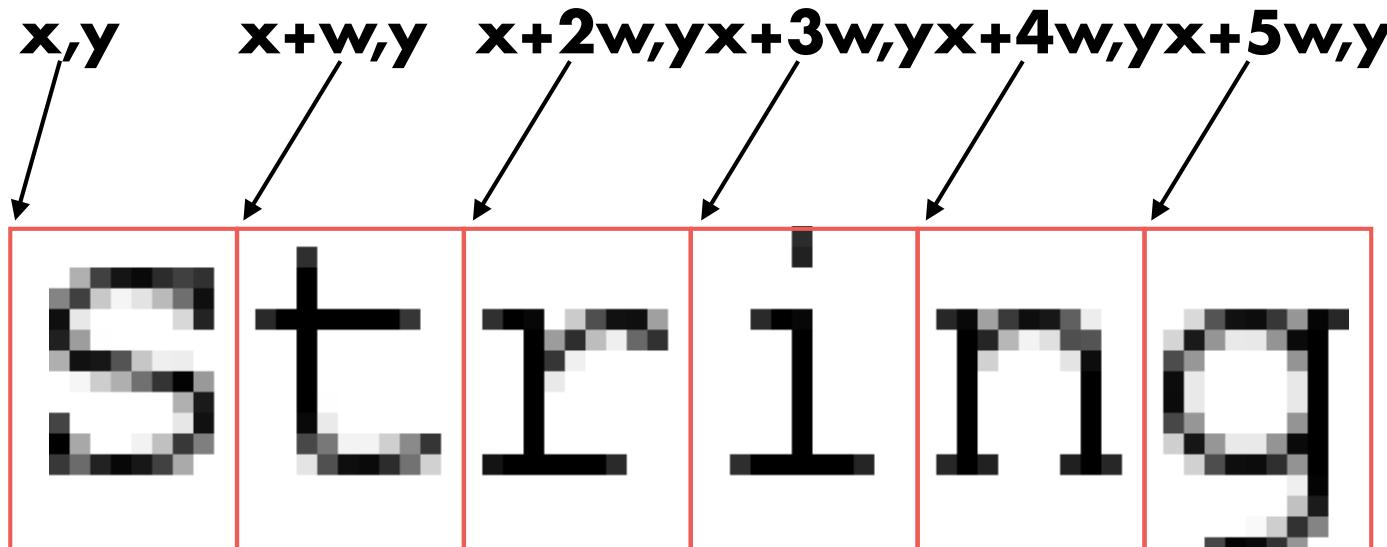
**Text**

**hello.c**

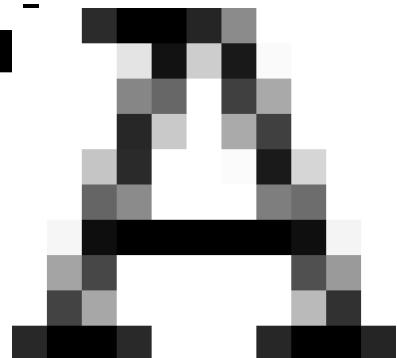
# Drawing Text

**Fonts: monospaced vs. proportional**

**String: a series of characters**



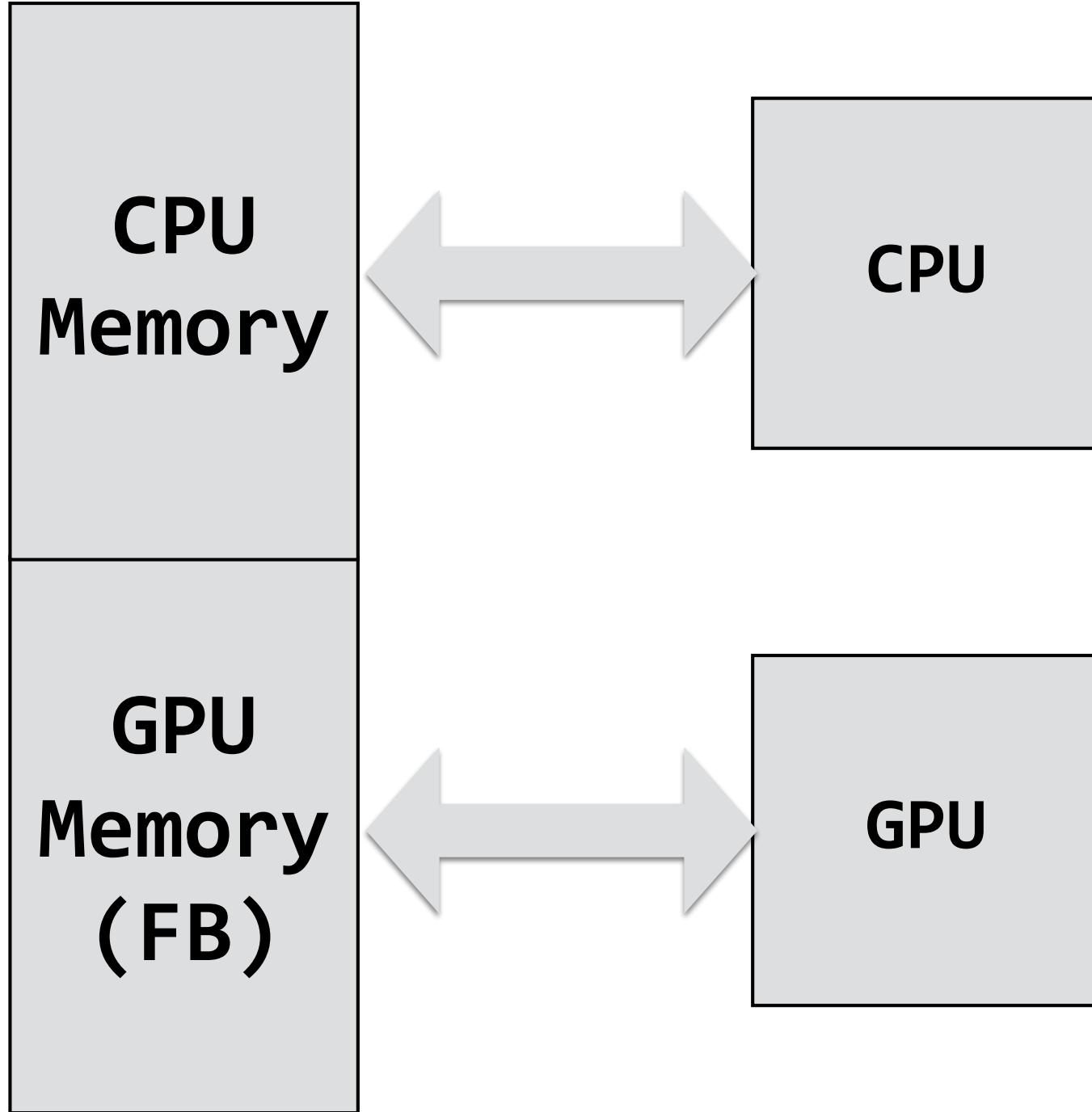
```
char str[7];
str[0] = 'S';
str[1] = 't';
str[2] = 'r';
str[3] = 'i';
str[4] = 'n';
str[5] = 'g';
str[6] = 0;
```



# Mailbox

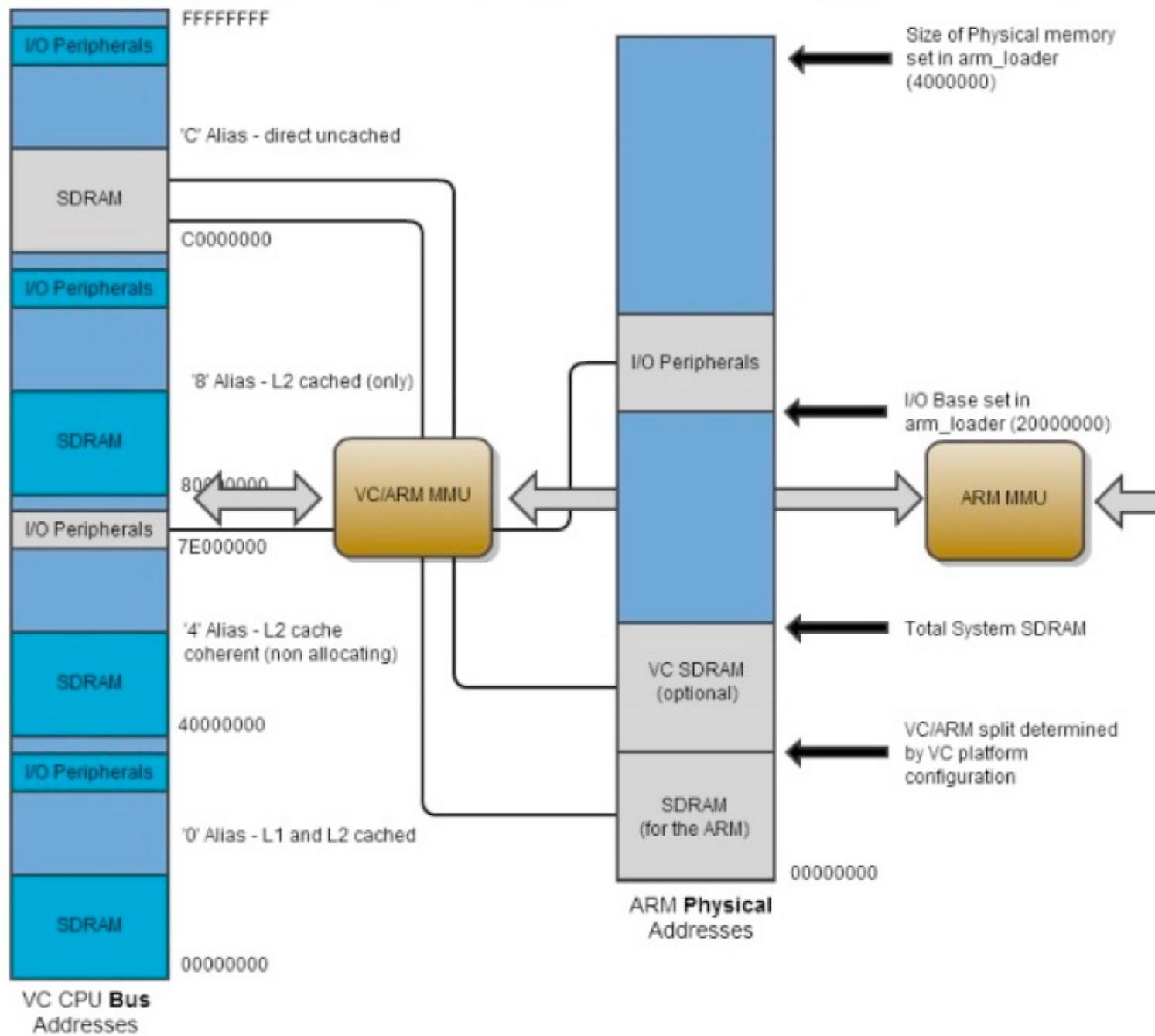
# **CPU and GPU**

**share memory  
config.txt  
memory.c**

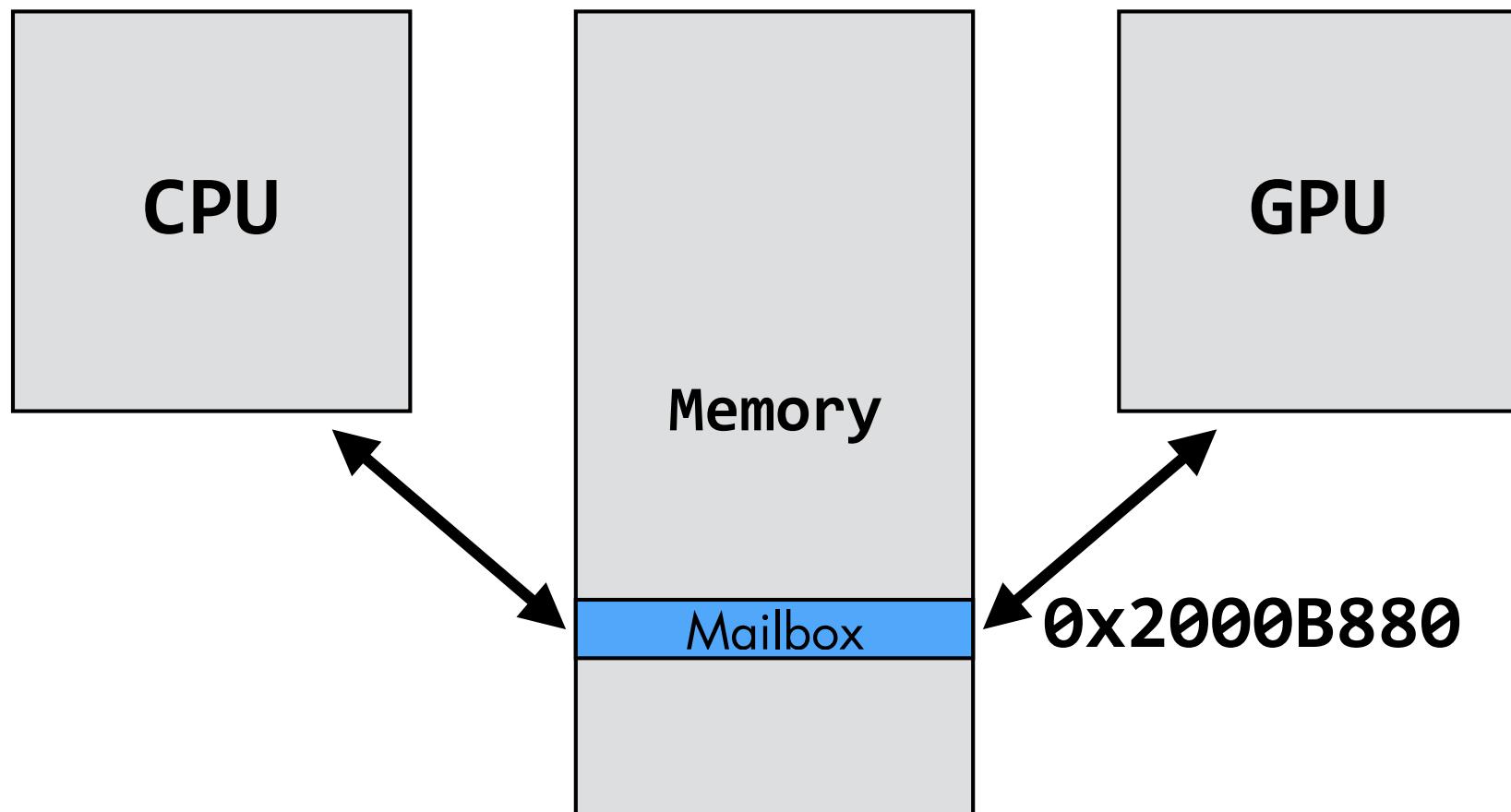




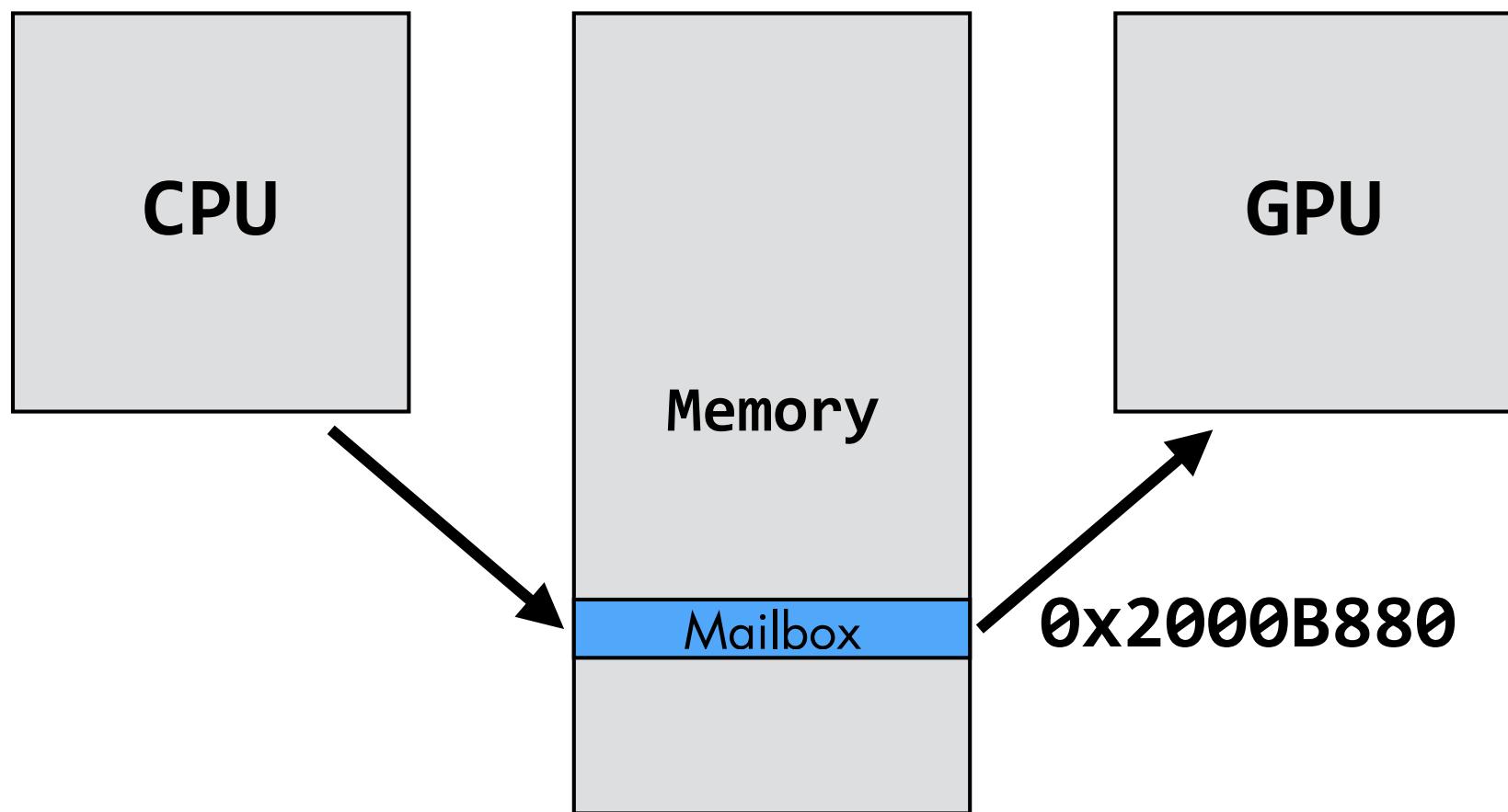
# BCM2835 ARM Peripherals



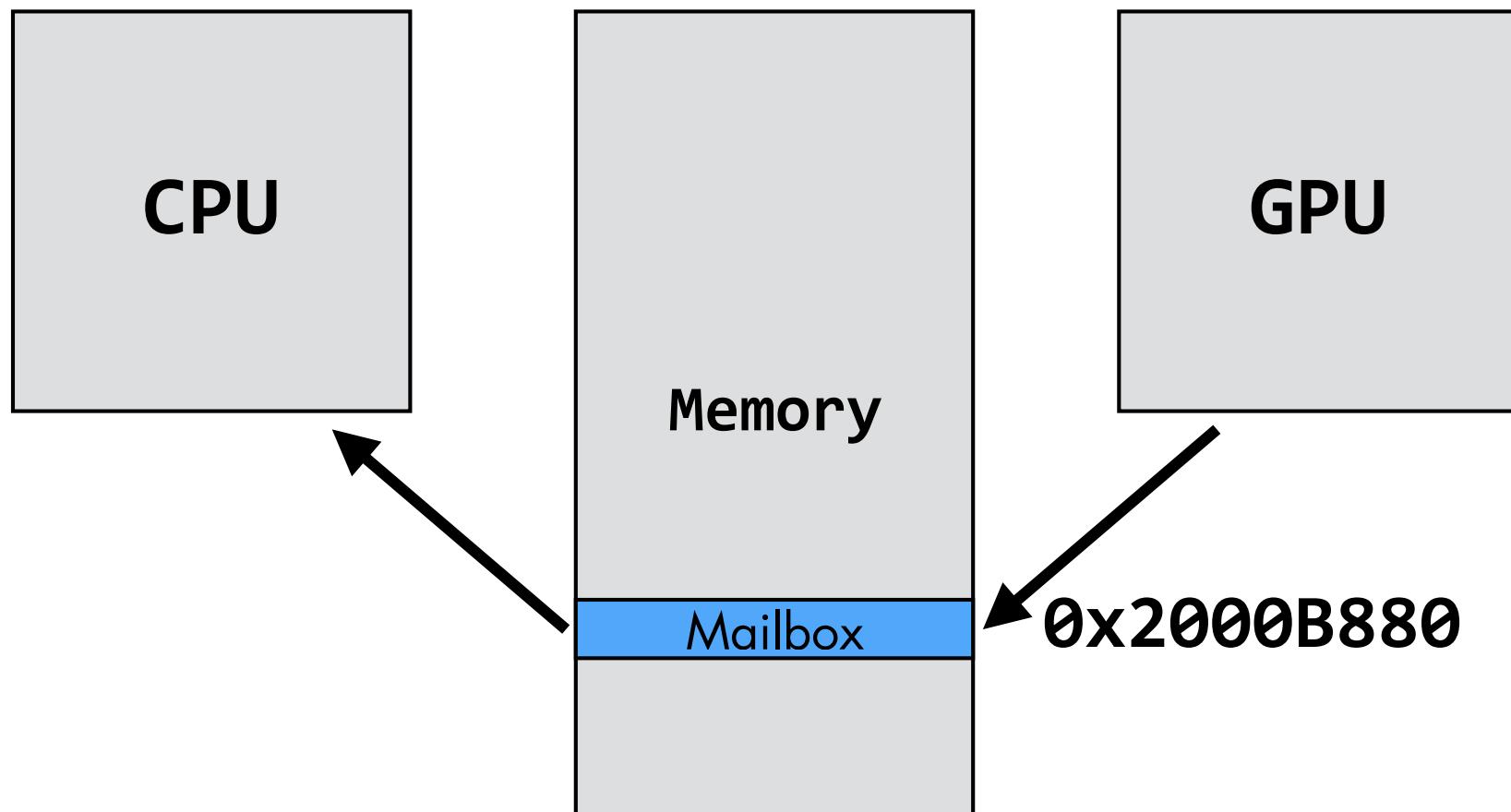
# Mailbox



# CPU Mails GPU



# GPU Mails CPU



# Mailbox Format

Register	Offset	R/W	Use
Read	0x00	R	Destructively read value
Peek	0x10	R	Read without removing data
Sender	0x14	R	Sender ID (bottom 2 bits)
Status	0x18	R	Status bits
Configuration	0x1C	RW	Configuration bits
Write	0x20	W	Address to write data (GPU addr)

F | E

undocumented/unused?

F = Full

E = Empty

# **Framebuffer Overview**

**GPU refreshes the display using a framebuffer**

**The size of the image sent to the monitor is called the physical size**

**The size of the framebuffer image is called the virtual size**

**The CPU and GPU share the memory, and hence the frame buffer**

**The CPU and GPU exchange messages using a mailbox**