CS143A
Principles on Operating Systems
Discussion 07:

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TA: Saehanseul Yi (Hans)

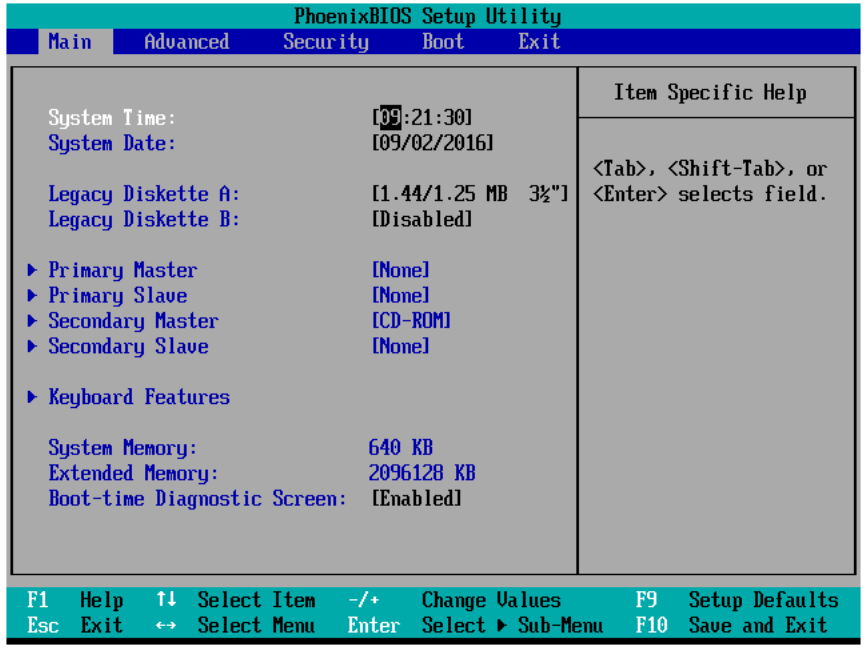
Nov 15, 2019 **3 PM**

Agenda

- Requirements: xv6 installed (i.e. able to execute qemu-system-x86_64)
- HW3 Overview

Booting…

- BIOS → Bootloader(real mode) → kernel (virtual address)
- **BIOS**: check connected devices(Storage, USB, …)
- **Bootloader**: load OS to the memory!
  security check,
  etc…
- **kernel**: when it starts, setting page table, etc.



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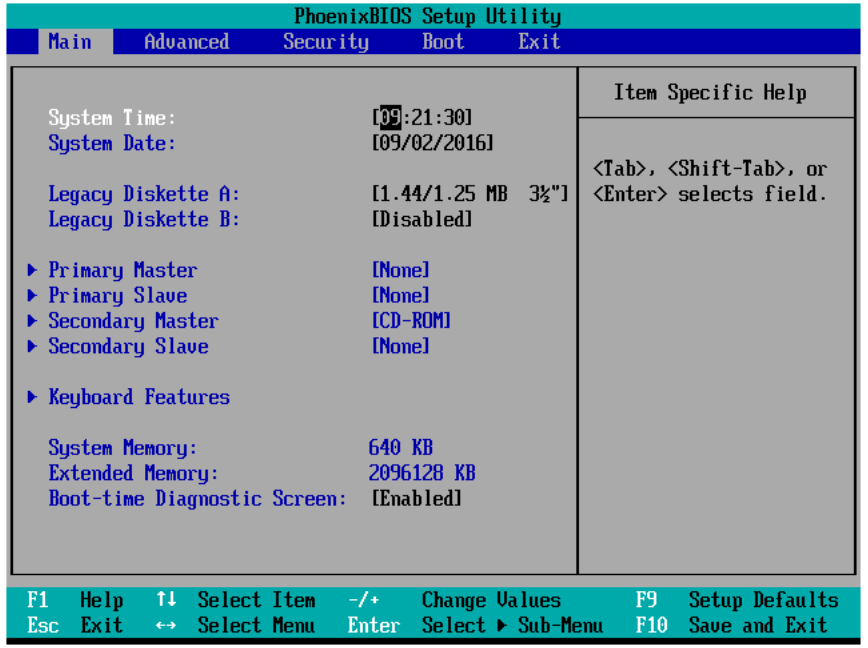

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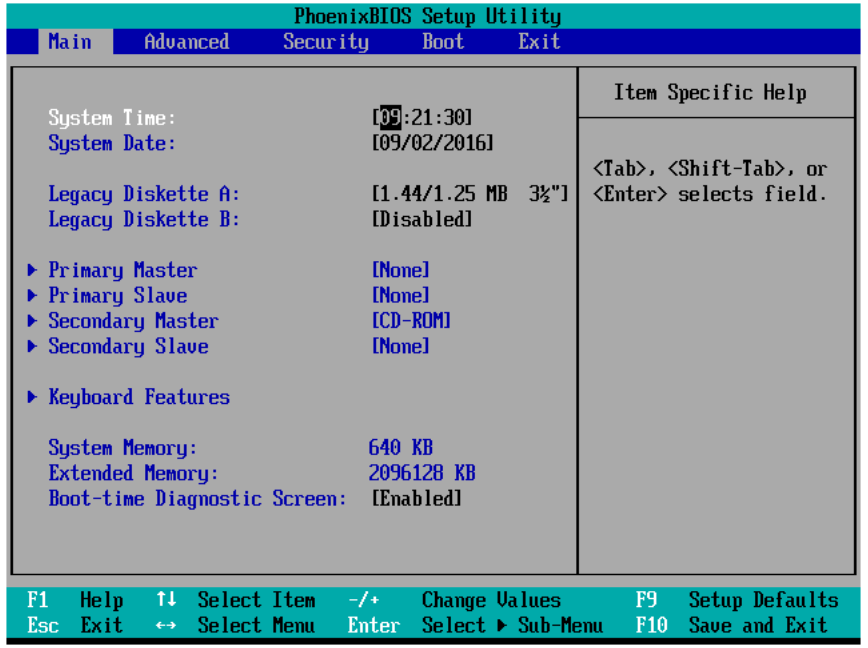
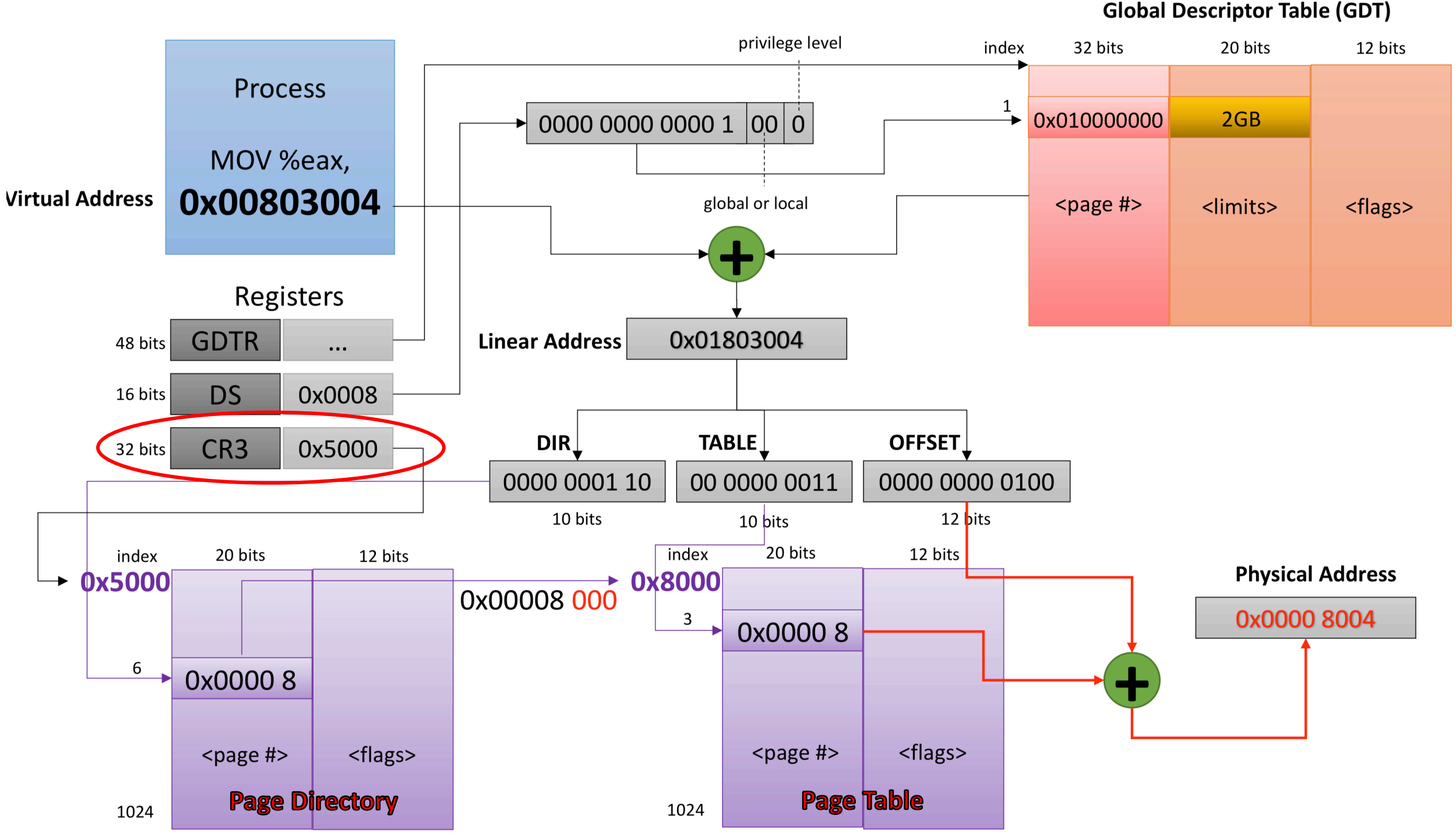
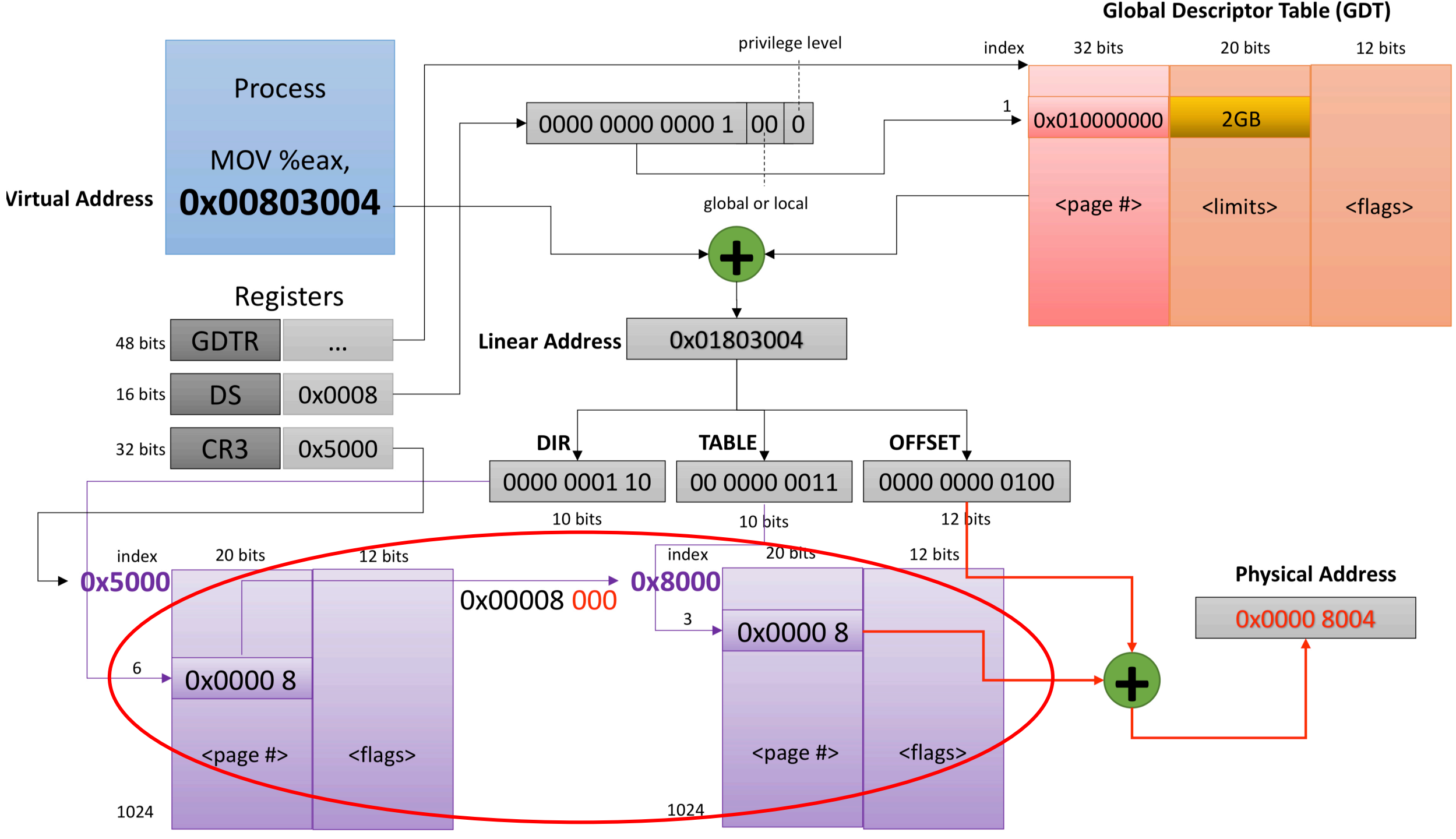
  main.c, boot.asm, …
  we will create new page tables
  and replace the ones created in boot.asm



Page Table Recap

- Two-level structure in x86
  - four or more levels in x64—larger memory space to cover
  - “Page Directory”-”Page Table”-”Physical Address”
- CR3 contains the base address of the page directory


Global Descriptor Table (GDT)
Process
MOV %eax,
0x00803004
Virtual Address
privilege level
index
32 bits
20 bits
12 bits
0000 0000 0000 1
00
0
1
0x010000000
2GB
<page #>
<limits>
<flags>
global or local
Registers
48 bits
GDTR
...
16 bits
DS
0x0008
32 bits
CR3
0x5000
Linear Address
0x01803004
DIR
TABLE
OFFSET
0000 0001 10
00 0000 0011
0000 0000 0100
10 bits
10 bits
12 bits
index
20 bits
12 bits
0x5000
6
0x0000 8
<page #>
<flags>
1024
Page Directory
0x00008 000
0x8000
3
0x0000 8
<page #>
<flags>
1024
Page Table
Physical Address
0x0000 8004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Downloading the source files

- *wget --recursive --no-parent <URL>*
  or equivalently, *wget -r -np <URL>*

Makefile

- Don’t read from the start—Follow the targets(recipes) of interest
- **$(patsubst %.asm, build/%.o, $(assembly_source_files)**
  this converts (compiles) .asm to .o
- **$(patsubst %.c, build/%.o, $(c_source_files))**
  Likewise, this converts .c to .o

Boot.asm for VGA Hello World..

- Follow the instructions in HW3 description..

If you don't want to bother with all that, here's the final code:

```
global start

section .text
bits 32
start:
    mov word [0xb8000], 0x0248 ; H
    mov word [0xb8002], 0x0265 ; e
    mov word [0xb8004], 0x026c ; l
    mov word [0xb8006], 0x026c ; l
    mov word [0xb8008], 0x026f ; o
    mov word [0xb800a], 0x022c ; ,
    mov word [0xb800c], 0x0220 ;
    mov word [0xb800e], 0x0277 ; w
    mov word [0xb8010], 0x026f ; o
    mov word [0xb8012], 0x0272 ; r
    mov word [0xb8014], 0x026c ; l
    mov word [0xb8016], 0x0264 ; d
    mov word [0xb8018], 0x0221 ; !
    hlt
```

Checkpoint #1: sanity check boot.asm

- When ‘make qemu’, you should be able to see “Hello World”
- if you get qemu error, try to switch the machine(e.g. Circinus-30 -> Circinus-31)
- Or open another terminal, and type *killall qemu-system-i386*
- To quit QEMU VGA screen(virtual monitor), ESC+2 and then type quit

Boot.asm for paging…

- Follow the instructions in HW3 description..

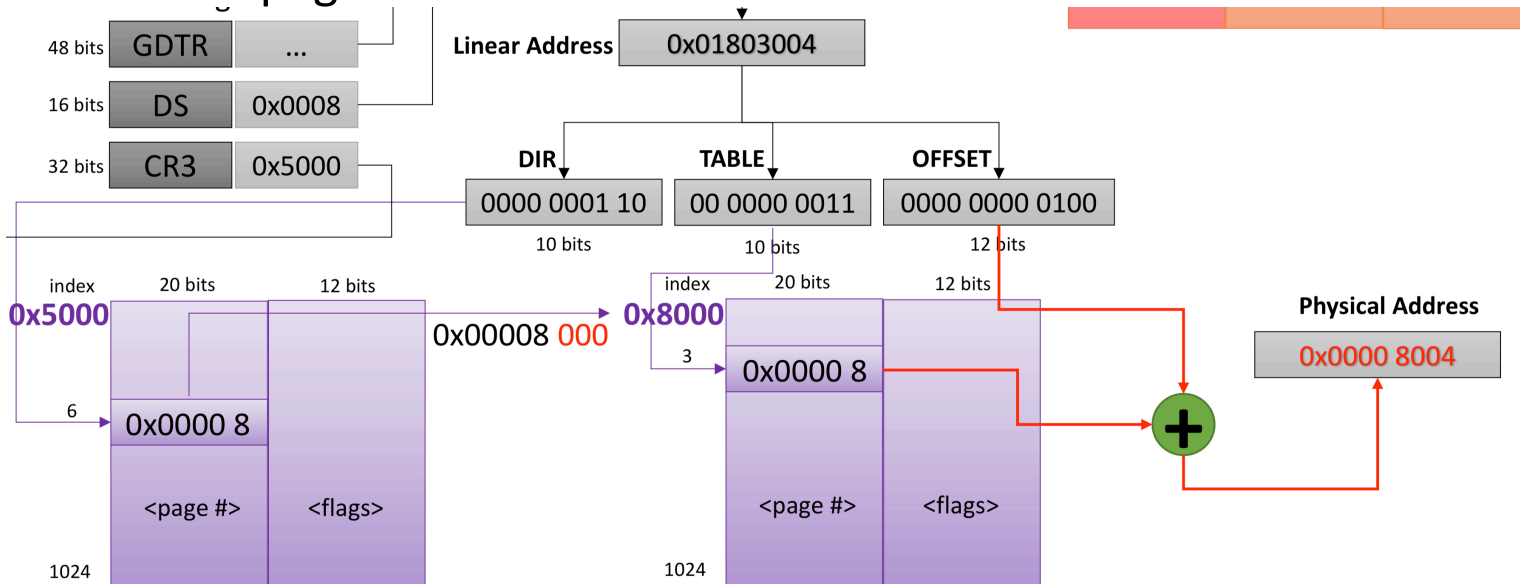
Checkpoint #2: sanity check main.c

- Print “Hello World” after call main
  - Only if main() works fine, it will print Hello World to VGA
  - comment out hlt()
  - uncomment hlt() before submitting to Gradescope

What is 4 MB, 4KB

- We are using **4KB-size page** table which can map **4MB of physical memory**
- $4KB = 4 * 2^{10} = 4 * 1024 \approx 4 * 1000$
- $4MB = 4 * 2^{20} = 4 * 2^{10} * 2^{10} = 4KB * 1024$
- Each entry of page table is 4 bytes
- There are 1024 entries in a page table → 4KB !!

- Each entry can map 4KB of physical memory since it only stores first 20bits out of 32bit address



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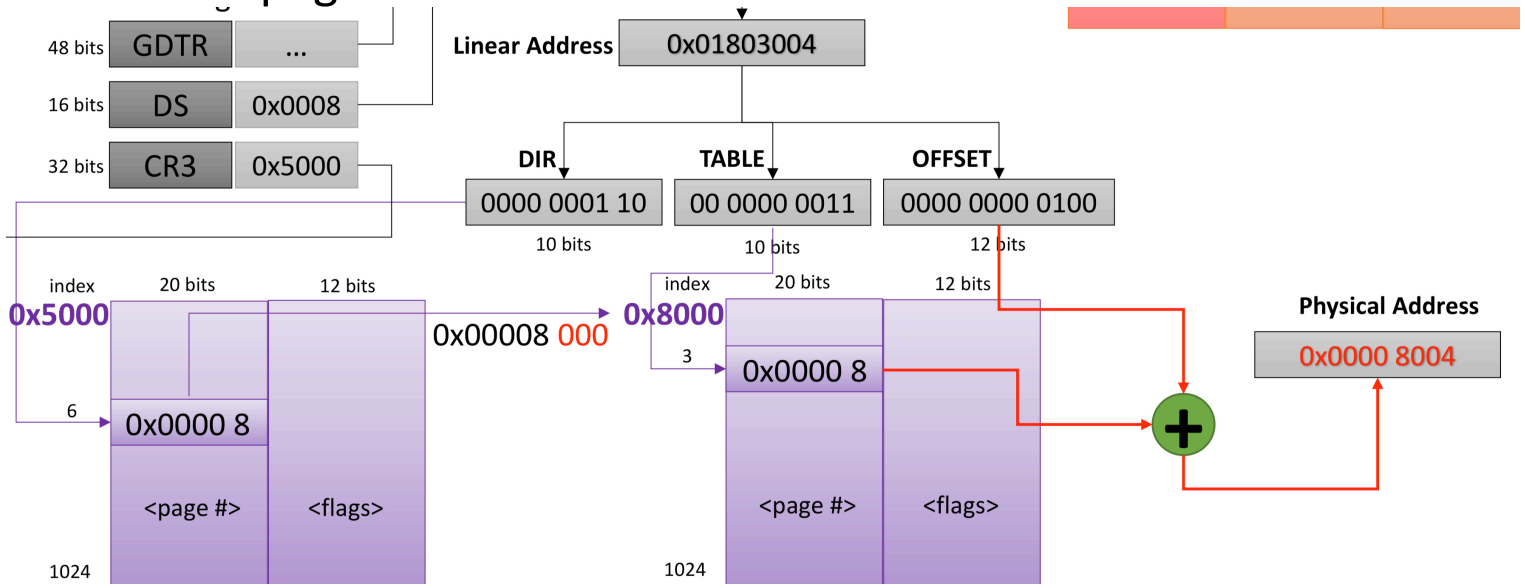

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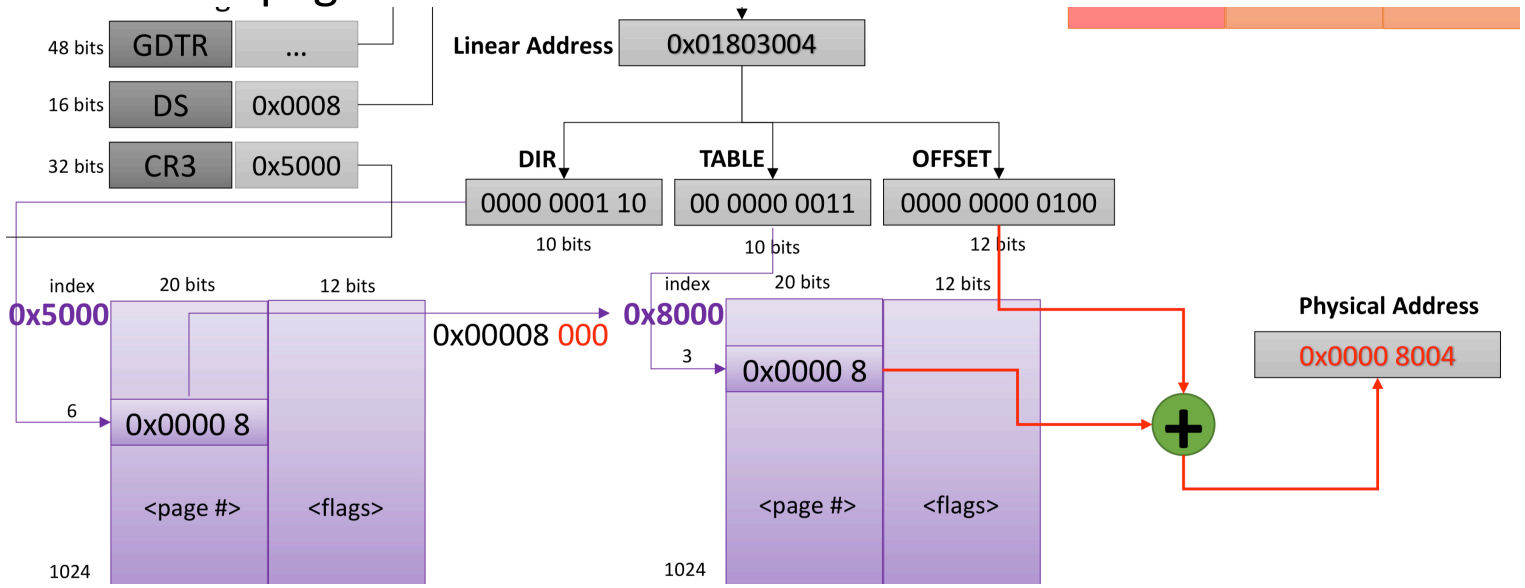
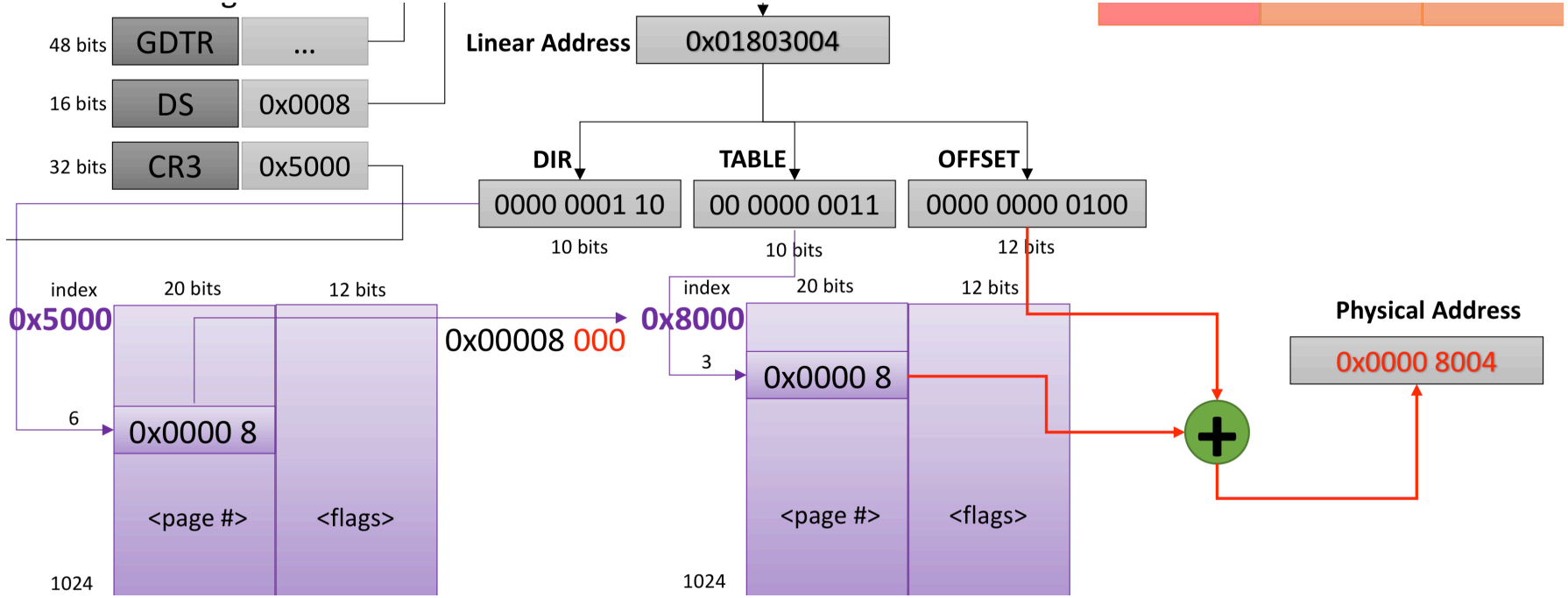
- Each entry can map 4KB of physical memory since it only stores first 20bits out of 32bit address
- 4KB * 1024 entries = 4MB
- 8MB of physical memory? → two page tables
- 256MB of physical memory? → 64 page tables



Why align 4096 (4KB)

- 4096 = 0x1000 = 0b 1 0000 0000 0000 (12bits)
- 4096 * 2 = 0x2000 = 0b 10 0000 0000 0000
- 4096 * 135 = 0x87000 = 0b 1000 0111 0000 0000 0000
- Since last 12 bits are always zero, we don't need them (instead, we use 'offset' from linear address)
- Offset field is 12 bits which can represent 4KB space



Target assembly

- Now, the remaining job is implementing page tables in main.c
- You don't need to touch anything else

(2) Map the physical memory to each page table

```
    ; map each P1 entry to a 4KB page
    mov ecx, 0          ; counter variable

.map_pt_table:
    ; map ecx-th PT entry to a huge page that starts at address 4KB*ecx
    mov eax, 0x1000     ; 4KB
    mul ecx             ; start address of ecx-th page
    or eax, 0b00000011 ; present + writable
    mov [pt_table + ecx * 4], eax ; map ecx-th entry

    inc ecx             ; increase counter
    cmp ecx, 1024       ; if counter == 1024, the whole P1 table is mapped
    jne .map_pt_table   ; else map the next entry
```

```
section .bss

align 4096

pt_table:
    resb 4096
ptd_table:
    resb 4096
```

(1) declare page tables and page directory aligned to 4KB

look for __attribute__ ((aligned (xxx)));;

(3) Let ptd_table entries point to the start address of each page table

```
; map first PTD entry to PT table
mov eax, pt_table
or eax, 0b11 ; present + writable
mov [ptd_table], eax
```

```
; move page table address to cr3
mov eax, ptd_table
mov cr3, eax
```

(4) Finally, set the start address of ptd_table to cr3

Why triple fault?

- Many reasons..
- Here, the most common case: when it executes lcr3()
- main.c is using virtual address
- main.c is in **kernel.bin** as well as printk() and other stuff
- kernel is loaded at the 1MB mark as specified in linker.ld
- The current kernel.bin size is 17KB which means main() is accessing the address range of 0x10000 ~ 0x170000
- (for fun) As long as you map this region in page table, the program will run fine (without the last for loop that touches every page, also note that the autograder will check the entire mapping)

Check the result of mapping

- make qemu-gdb-nox
- (qemu) info tlb
- If you can’t scroll, save the output to a file
  make qemu-gdb-nox | tee log.txt

Tips for extra credit(VGA)

```
// Print to the console
void printk(char *str)
{
    int i, c;

    for(i = 0; (c = str[i]) != 0; i++){
        uartputc(c);
    }
}
```

Add something here!

- Print on console && VGA screen
- if printk("Hello") was called, then inside printk(),
- str[0] = 'H' = 0x48 = 72
- Our monitor, the VGA device, is expecting 0x248
  i.e. some flags + character to print
- How can you make 0x48 to 0x248?
- Note that 0x48 = 0x0000 0048 and 0x248=0x0000 0248
- So we need to modify the third hex digit..
- Remember we modified the last two bits when we map physical memory to page tables?