CS444/544
Operating Systems II
Virtualization Summary and Quiz 2 Prep

Yeongjin Jang

Oregon State University

Quiz 2

- Thursday (11/4-11/6 from 8:30am to 11:59pm, unlimited time, 2 trials)
  - Open materials (slides, videos, code, and textbook)
- You will be allowed to have 2 attempts for quiz
  - Uh-oh, a silly mistake, **don't worry**, you can recover in the next trial
- Don't forget about the lab3 due date, on 11/8

Today's Topic

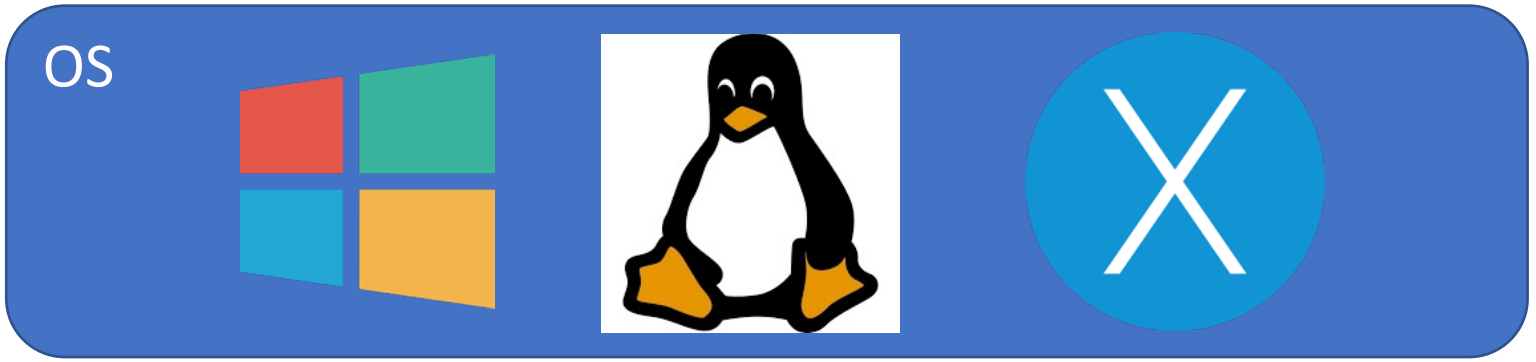
- Virtualization -> Concurrency

- OS Three Easy Pieces
  - Virtualization (memory, process, user/kernel, etc.)
  - Concurrency (multi-threading, multi-process, scheduling, synchronization)
  - Persistence (disk, file, snapshot, etc.)

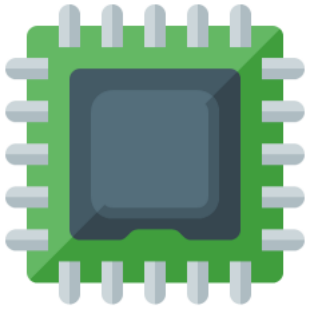
- Do recap on Virtualization

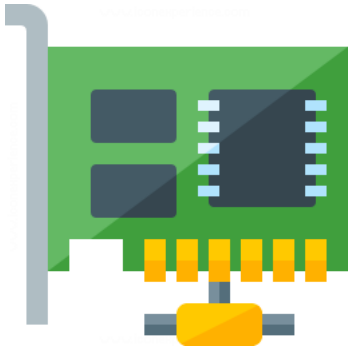
What is an OS?

Applications



Hardware





Memory

Backward compatibility: BIOS will put the code that assumes your CPU as i8086 (a 43-years old 16-bit CPU). So we need to start with 16-bit mode and then enable 32-bit protected mode, paging, etc…
UEFI does not go through this process; they directly starts with 32-bit or 64-bit mode, so OSes do not have to handle these things..

- 8086 Segmentation – Real Mode
  - Address = seg * 16 + offset

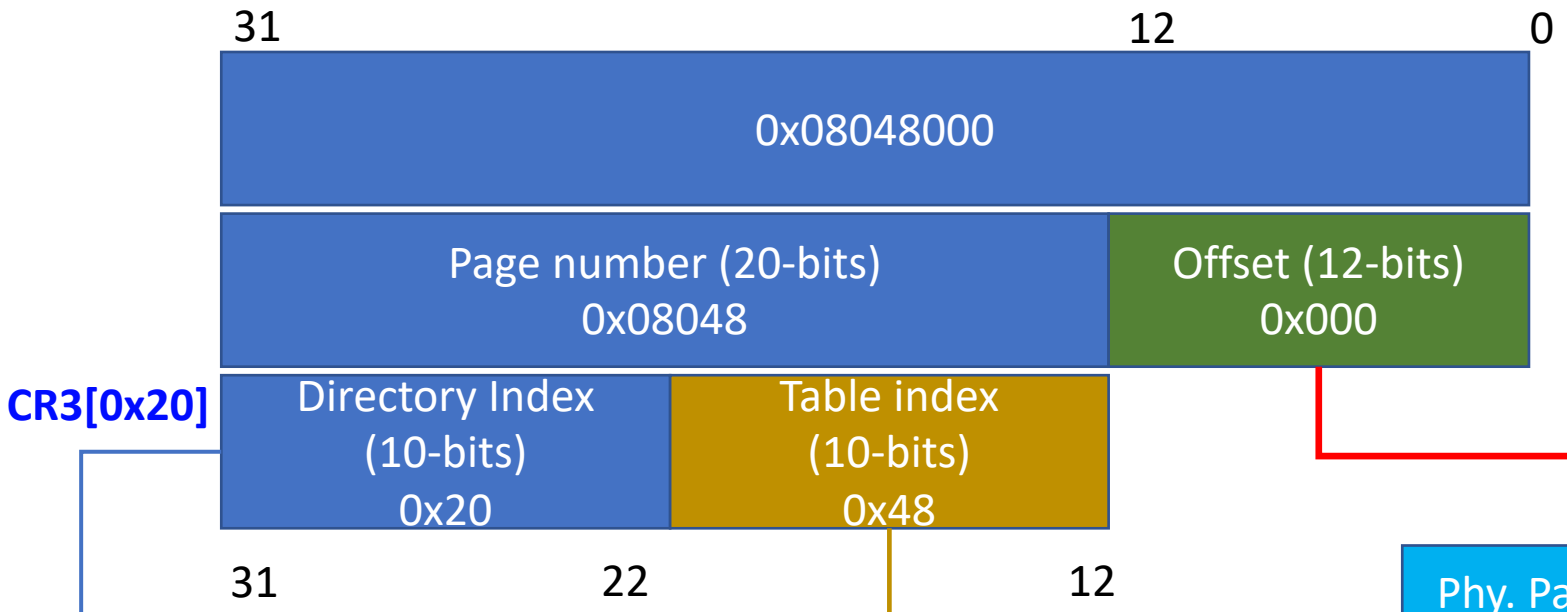
- 80386 Segmentation – Protected Mode
  - GDT defines base and limit
  - seg selects a GDT entry
  - Address = GDT[seg].base + offset

31 16			15 0	
Base 0:15			Limit 0:15	
63 56	55 52	51 48	47 40	39 32
Base 24:31	Flags	Limit 16:19	Access Byte	Base 16:23

Virtual Memory

- Paging
  - When enabled, all memory address will be translated via
  - CR3 -> PDE -> PTE -> Physical Page!

Recap – Page Table & Addr Translation



Virtual	Physical
0x8048000	0x10000
0x8049000	0x11000
0x804a000	0x50000

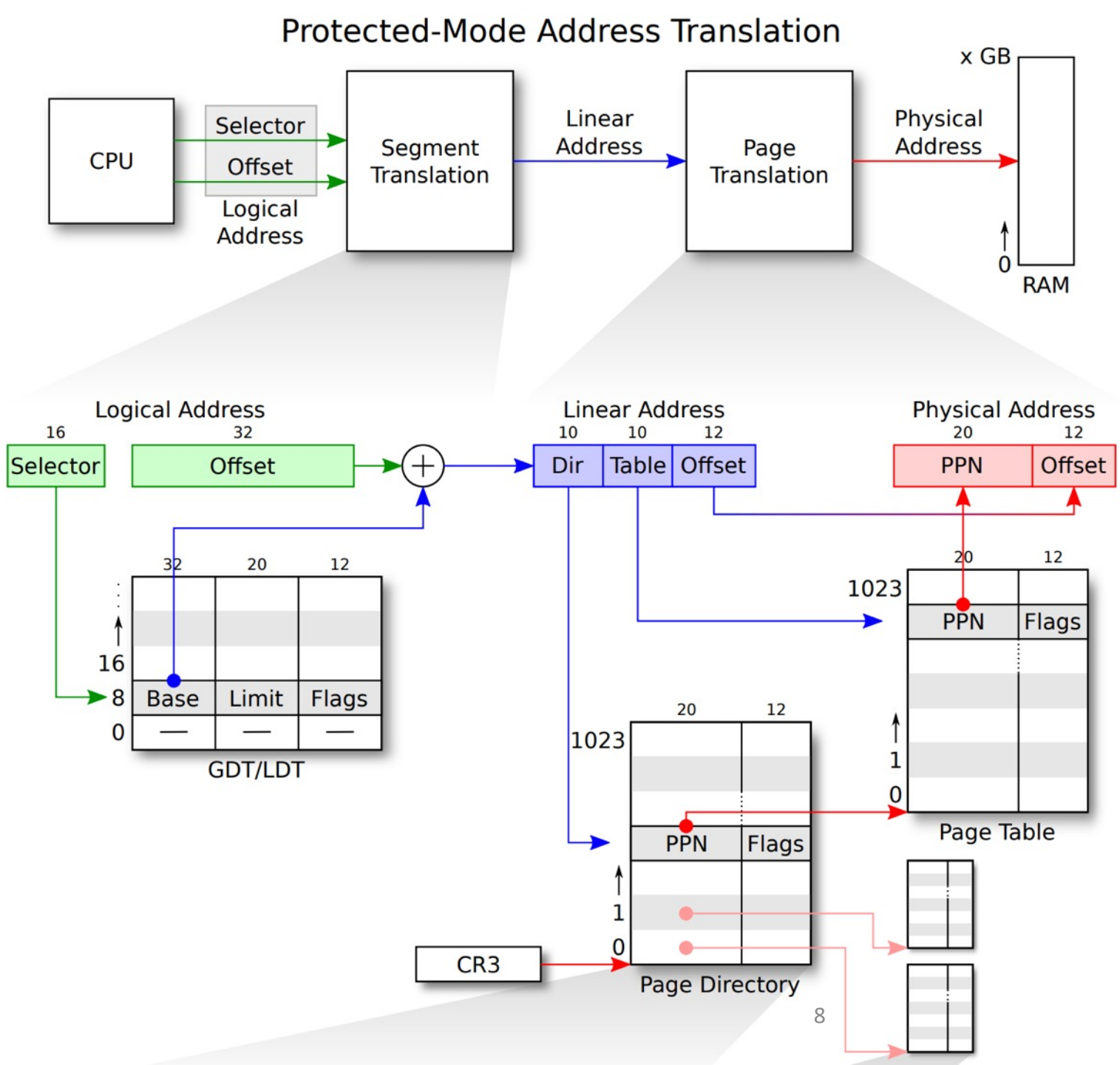
	Page Directory Entry
0	Addr PT
..	Addr PT
0x20	Addr PT
0x3ff	Addr PT

PDE[0x48]

	Page Table Entry
0	Addr PT
0x48	0x10000
0x49	0x11000
0x4a	0x50000

Phy. Page number (20-bits)	Offset (12-bits)
0x10000	0x000

```
pde_t * pd = KADDR(lcr3());
pte_t *pt = KADDR(PTE_ADDR(pd[PDX(va)]))
physaddr_t paddr = PTE_ADDR(pt[PTX(va)]) + PGOFF(va)
```

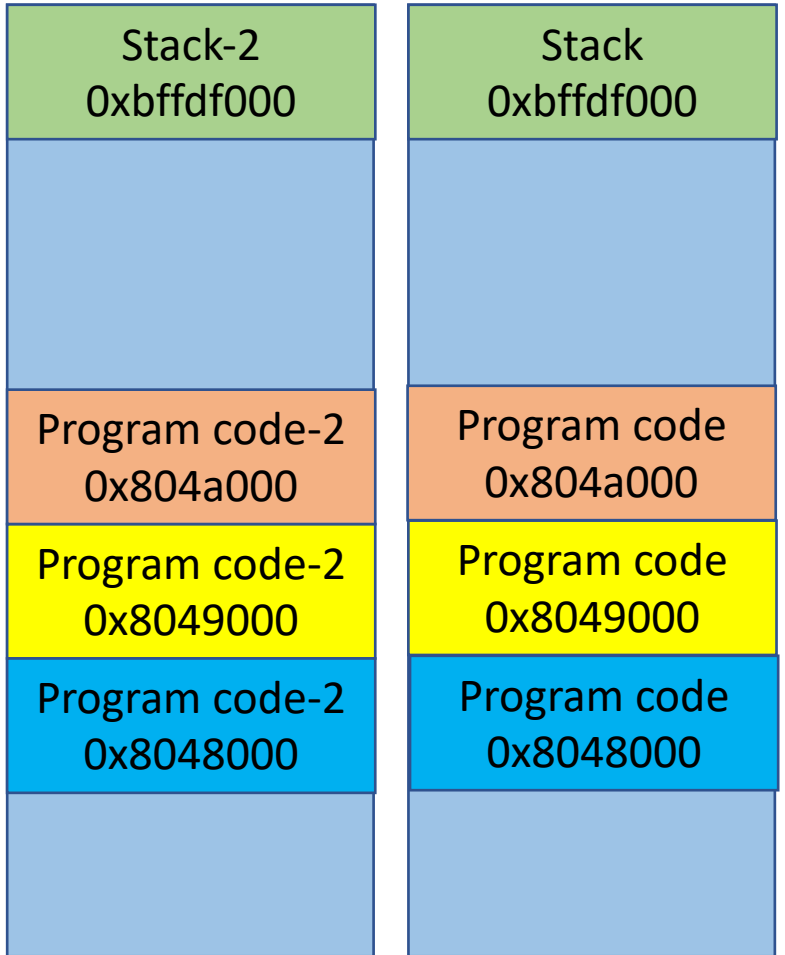

Protected-Mode Address Translation
CPU
Selector
Offset
Logical Address
Segment Translation
Linear Address
Page Translation
Physical Address
x GB
0
RAM
Logical Address
16
32
Selector
Offset
32
20
12
16
8
0
Base
Limit
Flags
GDT/LDT
Linear Address
10
10
12
Dir
Table
Offset
Physical Address
20
12
PPN
Offset
20
12
1023
PPN
Flags
1
0
Page Table
20
12
1023
PPN
Flags
1
0
Page Directory
CR3

Why Virtual Memory?

- Three goals
  - Transparency: does not need to know system's internal state
    - Program A is loaded at 0x8048000. Can Program B be loaded at 0x8048000?
  - Efficiency: do not waste memory; manage memory fragmentation
    - Can Program B (288KB) be loaded if 288 KB of memory is free, regardless of its allocation?
  - Protection: isolate program's execution environment
    - Can we prevent an overflow from Program A from overwriting Program B's data?

Paging: Virtual Memory

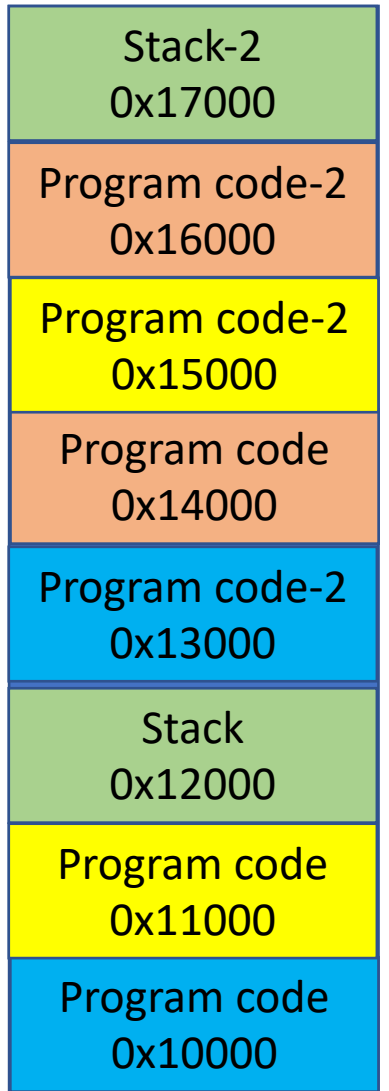
- Having an indirect table that maps virt-addr to phys-addr



Virtual	Physical
0x8048000	0x10000
0x8049000	0x11000
0x804a000	0x14000
0xbffdf000	0x12000
…	…

Virtual-2	Physical-2
0x8048000	0x13000
0x8049000	0x15000
0x804a000	0x16000
0xbffdf000	0x17000
…	…

Physical Memory

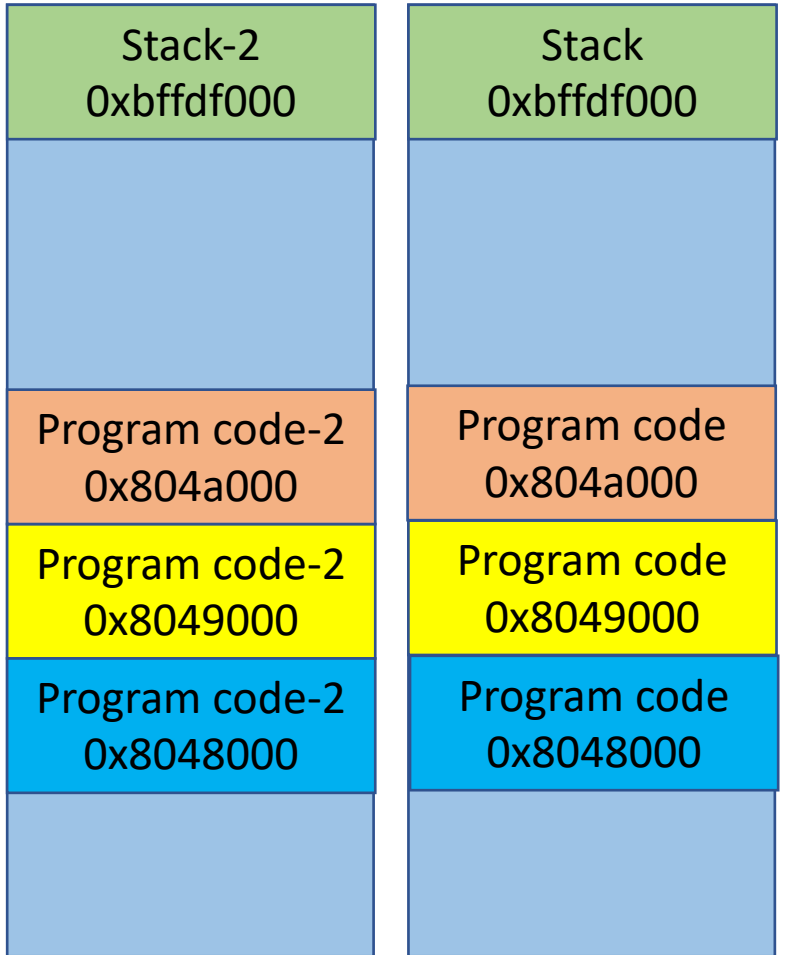


Transparency: does not need to know system's internal state

Program A is loaded at 0x8048000.

Can Program B be loaded at 0x8048000?

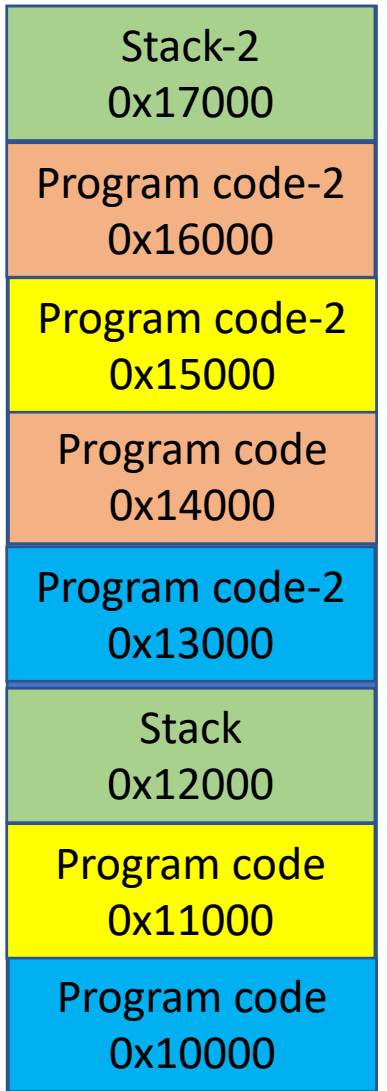
- Having an indirect table that maps virt-addr to phys-addr



Virtual	Physical
0x8048000	0x10000
0x8049000	0x11000
0x804a000	0x14000
0xbffdf000	0x12000
…	…

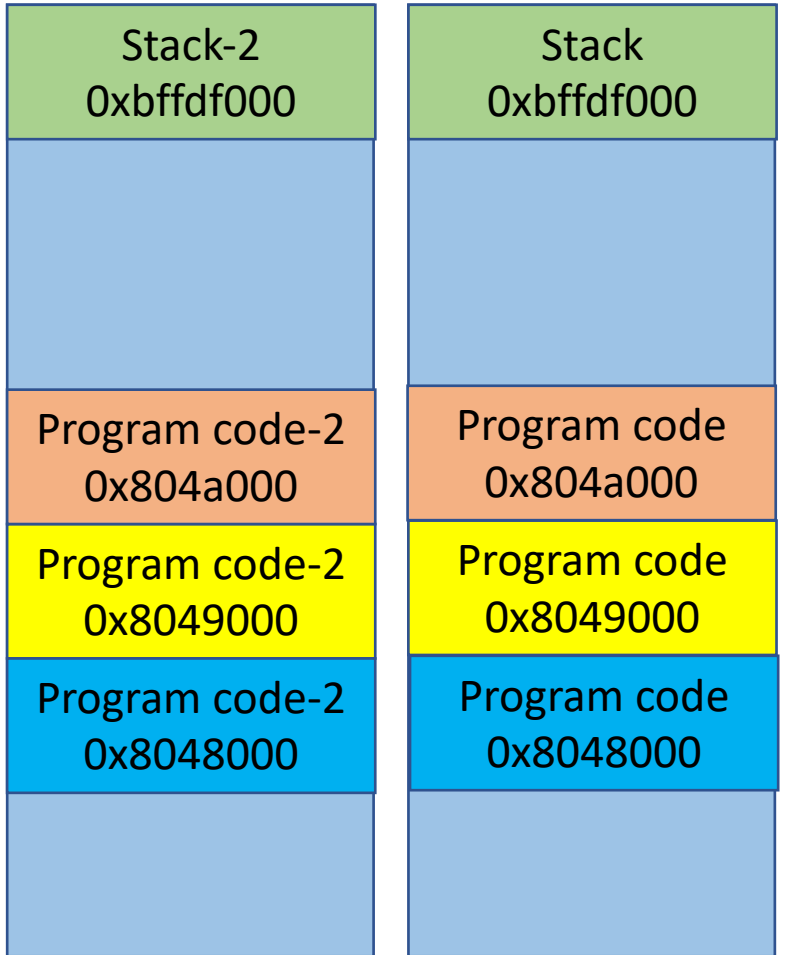
Virtual-2	Physical-2
0x8048000	0x13000
0x8049000	0x15000
0x804a000	0x16000
0xbffdf000	0x17000
…	…

Physical Memory



Efficiency: do not waste memory
Can Program B (288KB) be loaded if
only 288 KB of memory is free, regardless of its allocation?

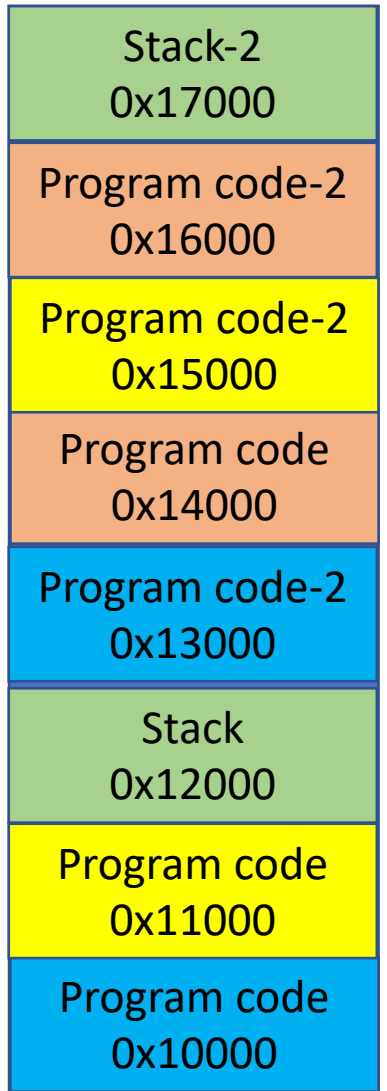
- Having an indirect table that maps virt-addr to phys-addr



Virtual	Physical
0x8048000	0x10000
0x8049000	0x11000
0x804a000	0x14000
0xbffdf000	0x12000
…	…

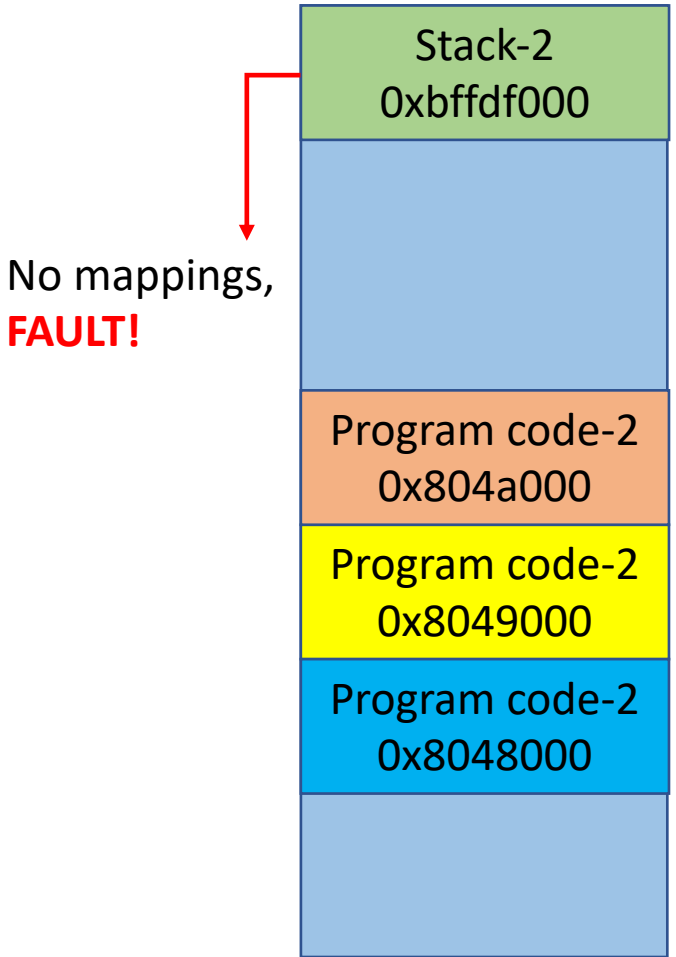
Virtual-2	Physical-2
0x8048000	0x13000
0x8049000	0x15000
0x804a000	0x16000
0xbffdf000	0x17000
…	…

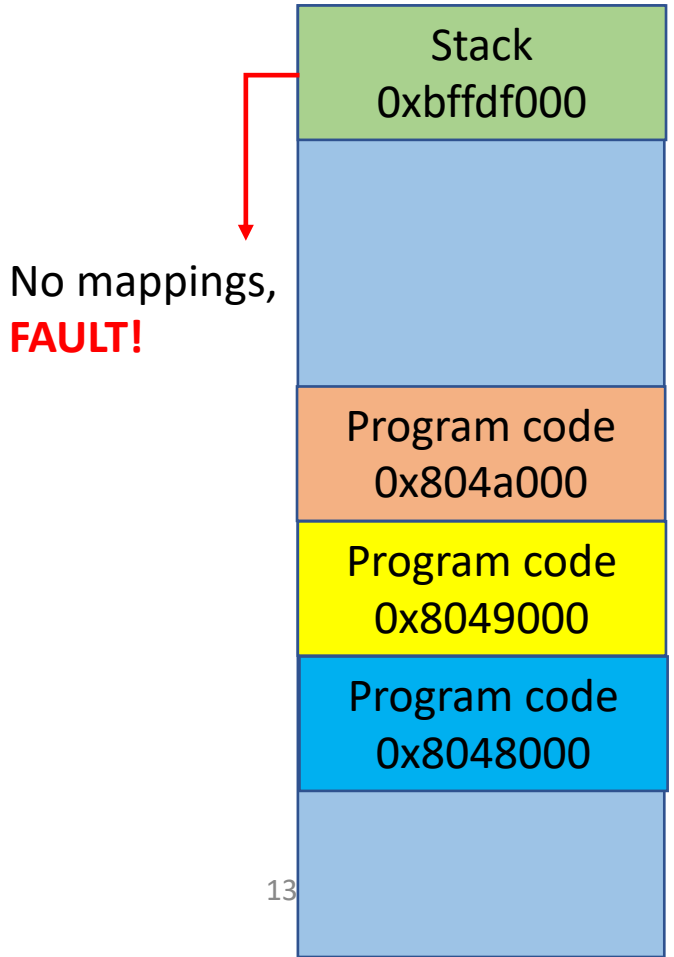
Physical Memory



Protection: isolate program's execution environment

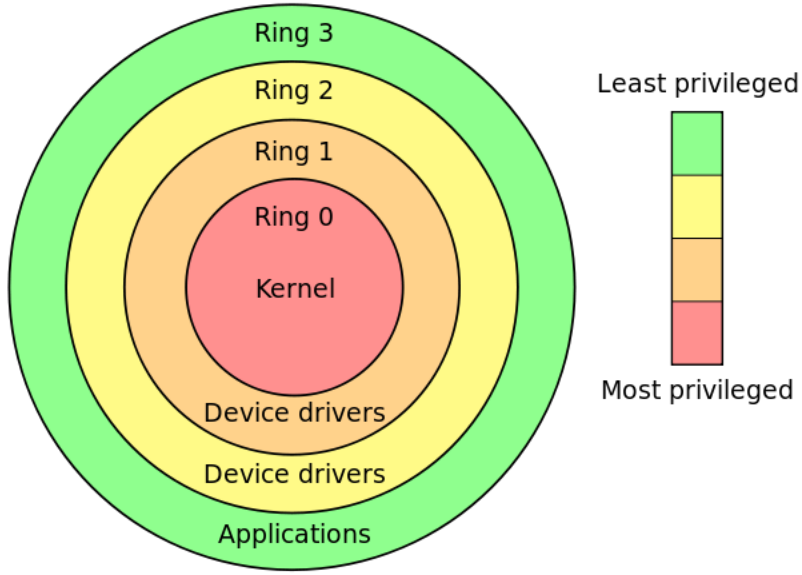
Can we prevent an overflow from Program A from overwriting Program B's data?





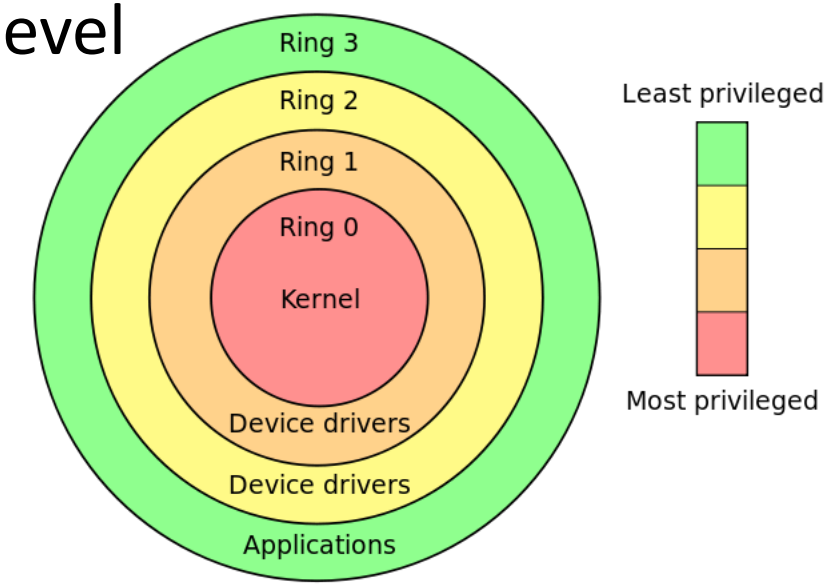
Kernel (Ring 0)

- Runs with the highest privilege level (Ring 0)
- Configures system (devices, memory, etc.)
- Manages hardware resources
  - Disk, memory, network, video, keyboard, etc.
- Manages other jobs
  - Processes and threads
- Serves as trusted computing base (TCB)
  - Set privilege, restrict other jobs from doing something bad, etc.



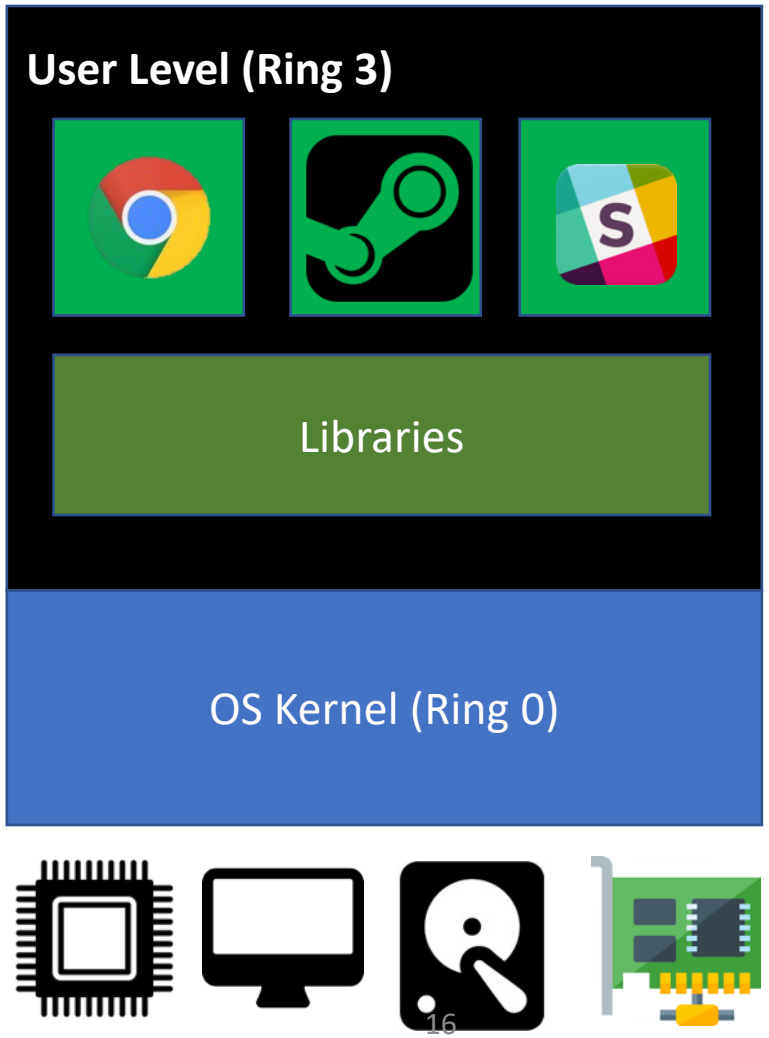
User Level (Ring 3)

- Runs with a restricted privilege (Ring 3)
  - The privilege level for running an application…
- Most of our regular applications runs in this ring level



- Cannot access kernel memory
  - Can only access pages set with PTE_U
- Cannot talk directly to hardware devices
  - Kernel must mediate the access

A High-level Overview of User/Kernel Execution

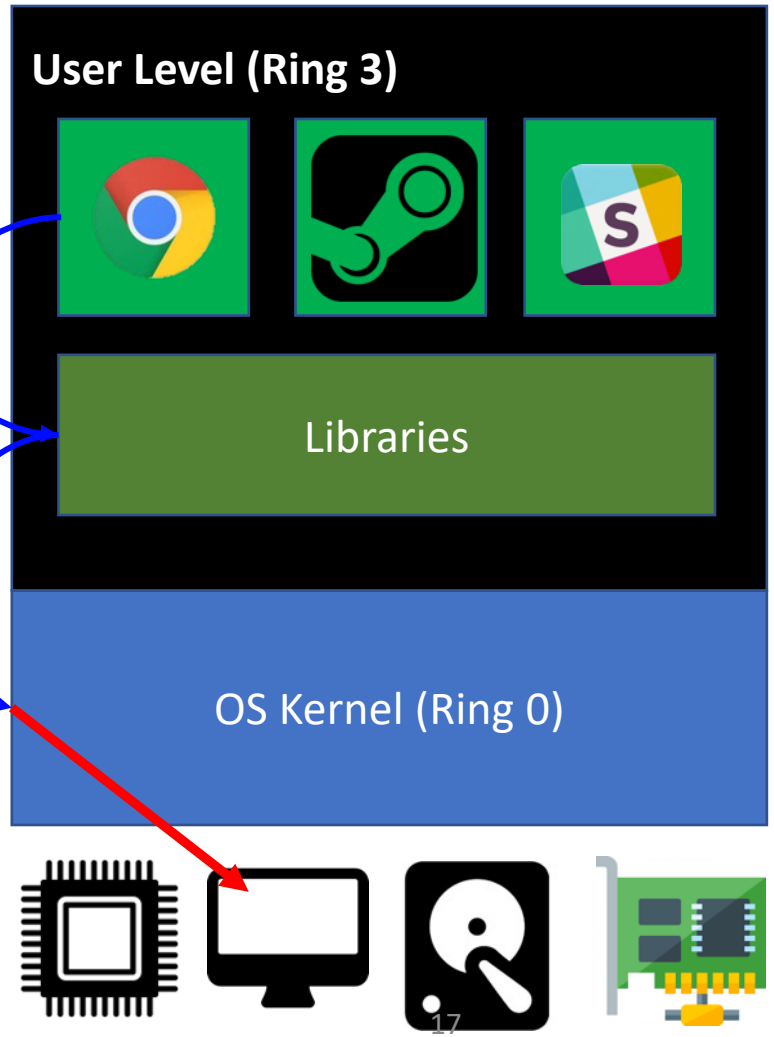


A High-level Overview of User/Kernel Execution

A library call in ring 3 **printf()**

A system call, **sys_write()**
From ring 3 to ring 0

A kernel function **do_sys_write()**



A High-level Overview of User/Kernel Execution

A library call in ring 3 **printf()**

A system call, **sys_write()**
From ring 3 to ring 0

A kernel function **do_sys_write()**

User Execution Strawman 2’

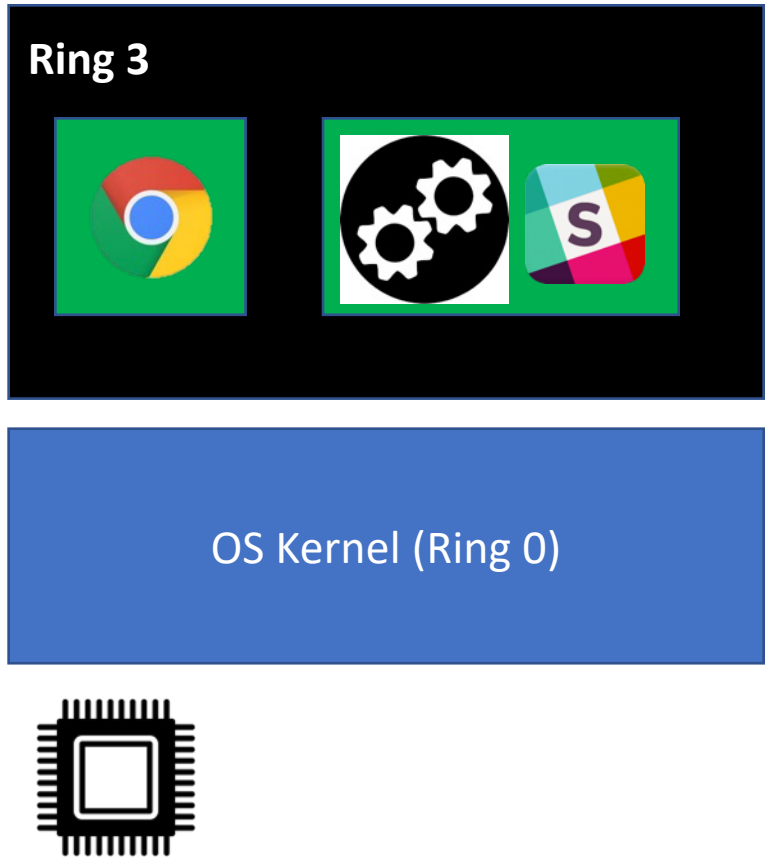
- What if a process runs

```
int main() {
    while(1);
}
```

Too long

No such yield()

Much wait



User Execution Strawman 2’

- What if a process runs

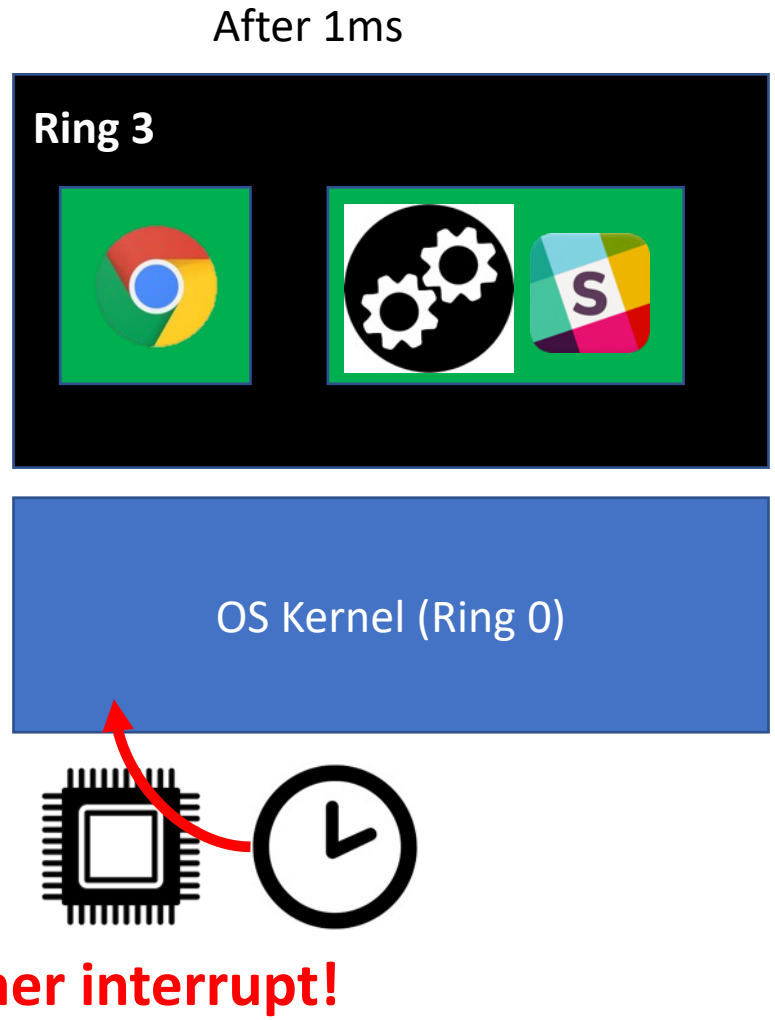
```
int main() {
    while(1);
}
```

Too long

Recap: Timer Interrupt and Multitasking

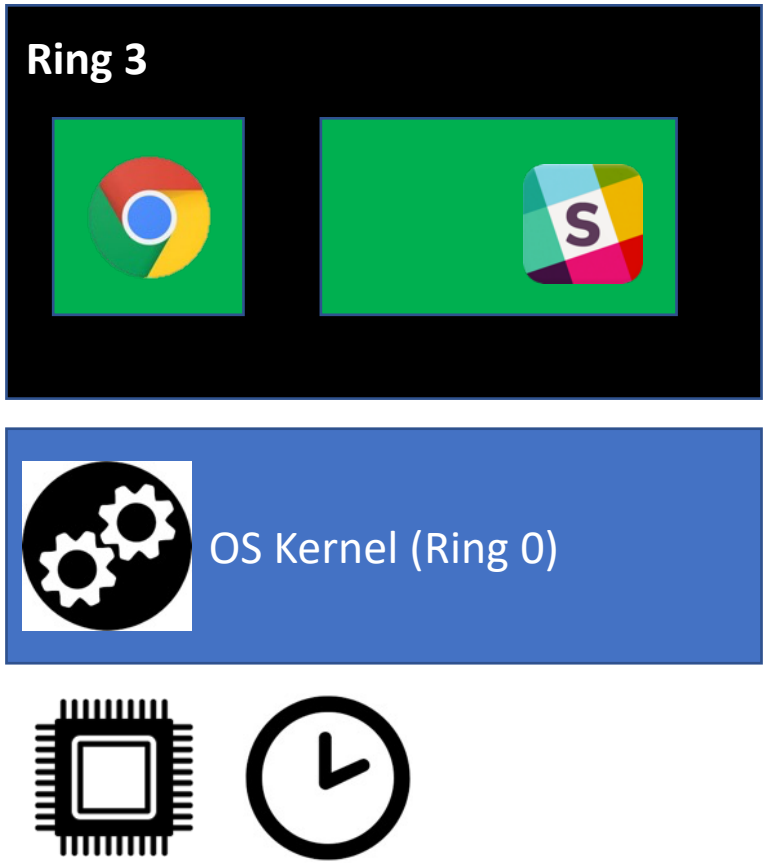
- Preemptive Multitasking (Lab 4)

- CPU generates an interrupt to force execution at kernel after some time quantum
  - E.g., 1000Hz, on each 1ms..



Recap: Timer Interrupt and Multitasking

- Preemptive Multitasking (Lab 4)
- CPU generates an interrupt to force execution at kernel after some time quantum
  - E.g., 1000Hz, on each 1ms..
- Guaranteed execution in kernel
  - Let kernel mediate resource contention



Recap: Timer Interrupt and Multitasking

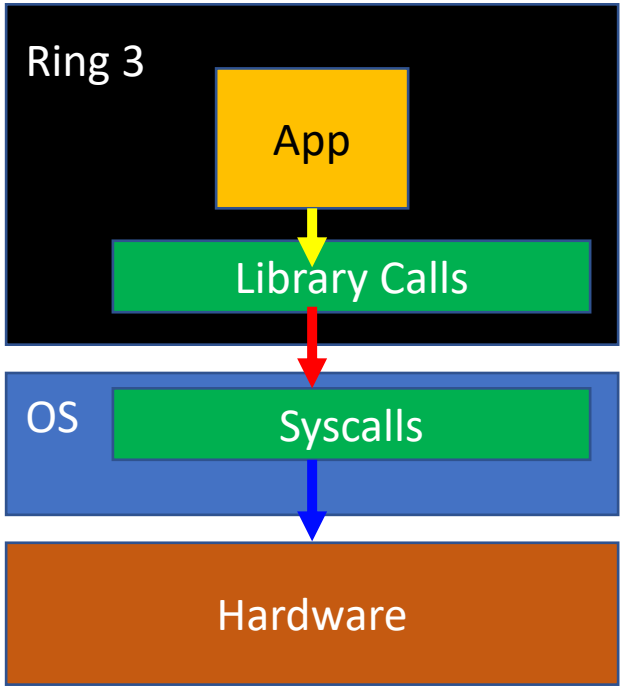
- Preemptive Multitasking (Lab 4)
- CPU generates an interrupt to force execution at kernel after some time quantum
  - E.g., 1000Hz, on each 1ms..
- Guaranteed execution in kernel
  - Let kernel mediate resource contention

User/Kernel Switch

- System call
  - User calls Kernel APIs
  - Kernel mediates API access (checks legitimacy at call gate)
- How switch?
  - At the call gate, store trap frame
    - Stores all registers, and other states
  - On returning to user (iret)
    - Restore all information from trap frame

`int $0x30`

CHECK!!



User/Kernel Switch

- Interrupts
  - Could come from hardware (when it is not a software interrupt)
  - Think about the timer interrupt
    - Let OS do context switch!
- Steps
  - Stops current process (stores trapframe)
  - Runs kernel for handling the interrupt (refer to IDT)
  - Resumes previous (or new) process (iret)

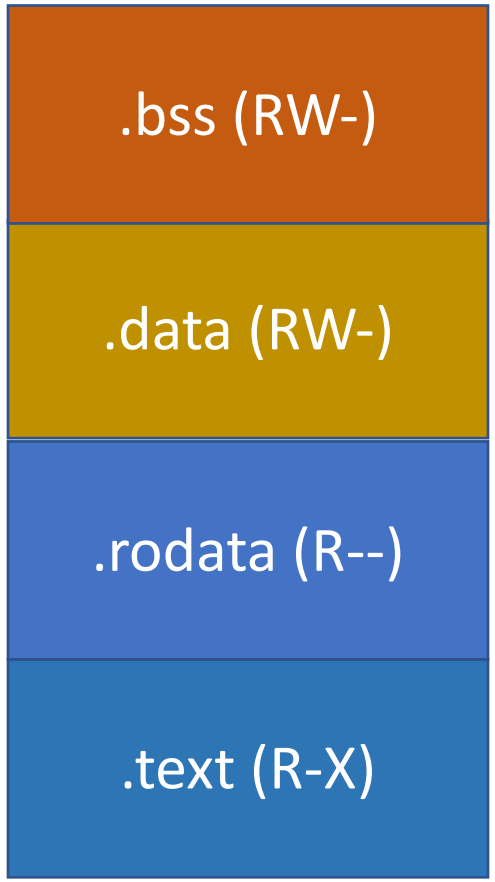
Faults

- An error that OS can recover
- Example
  - Page fault
  - Copy-on-write fork
  - Swapping

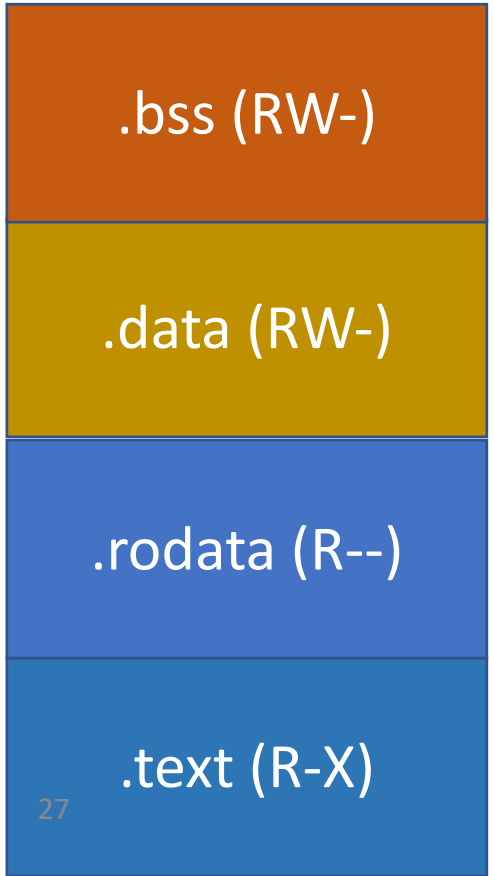
Copy-on-Write Sharing

Do we need to copy the same data for each process creation?

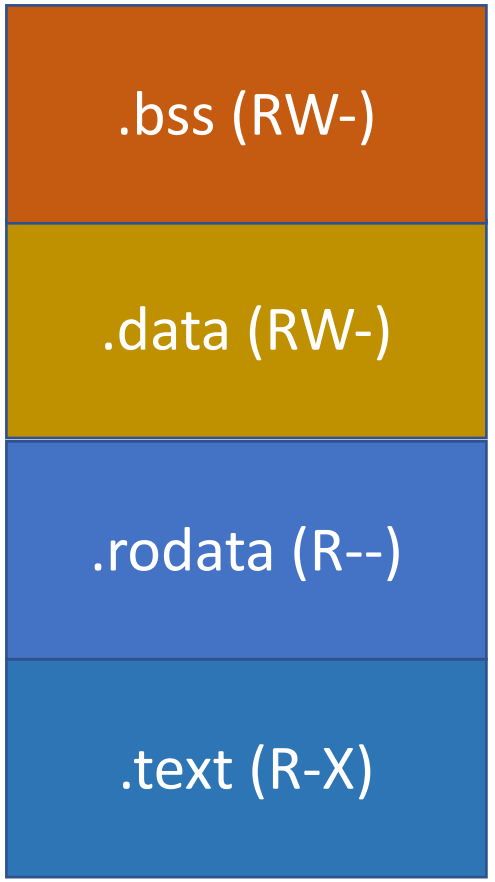
- Store one copy of file in the memory



Process 1

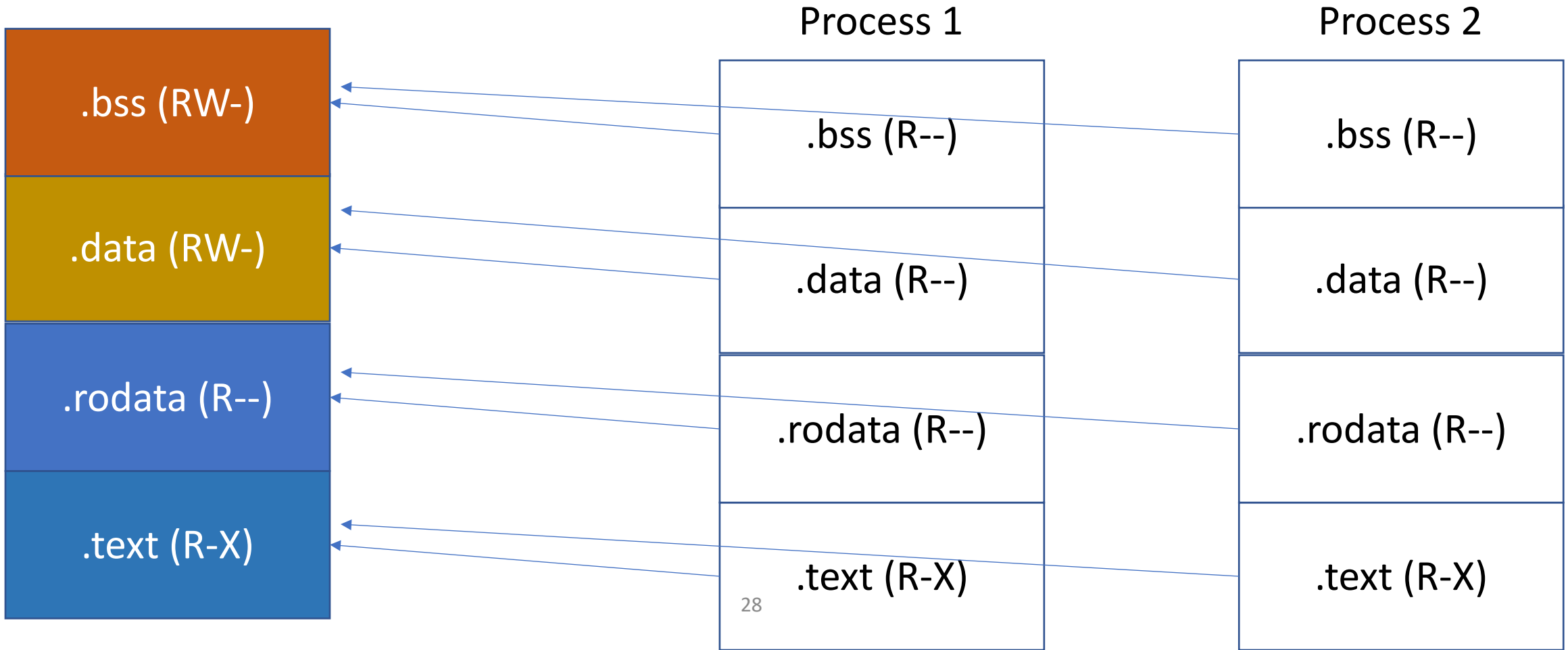


Process 2



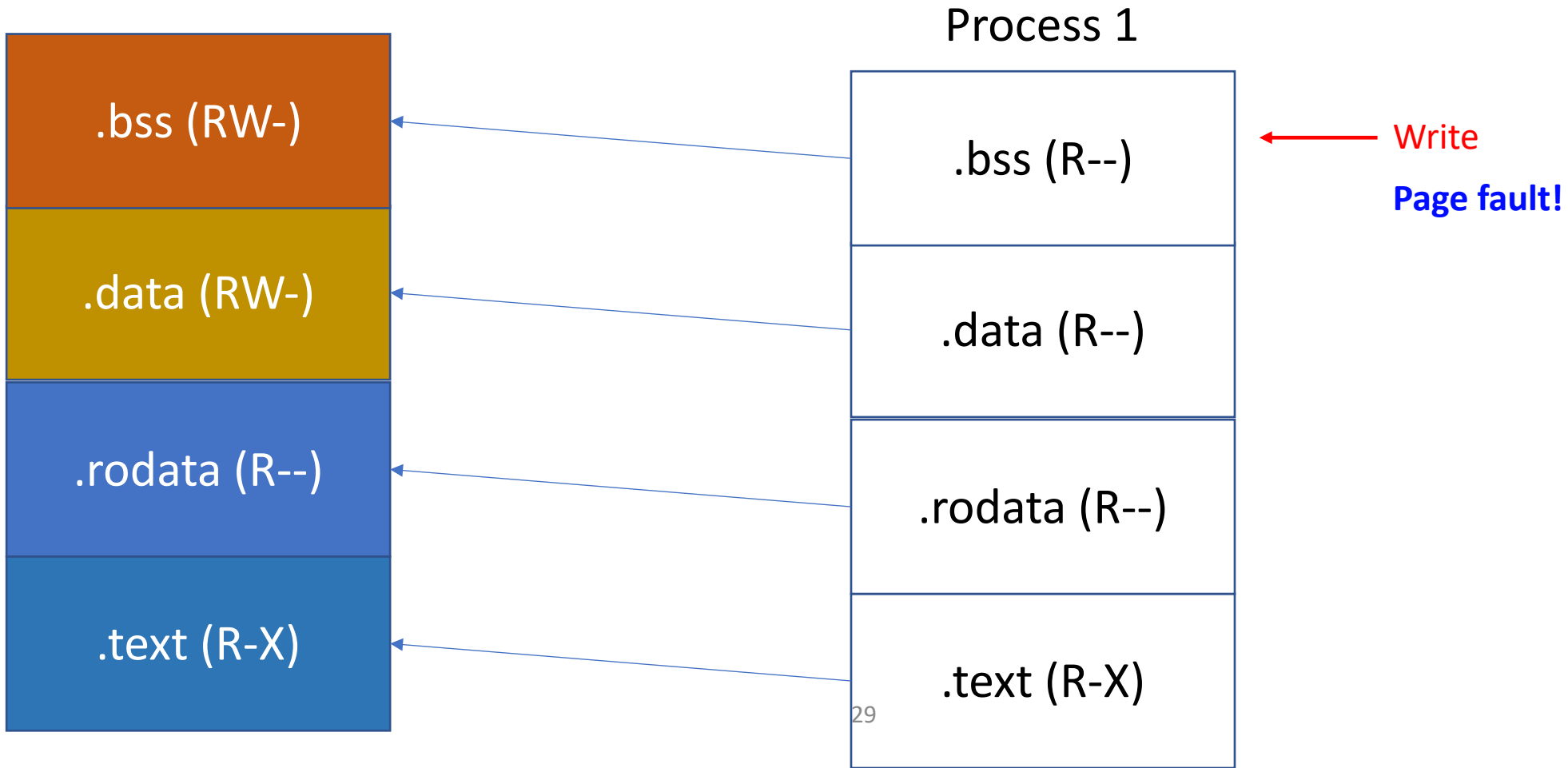
Sharing by Read-only

- Set page table to map the same physical address to share contents



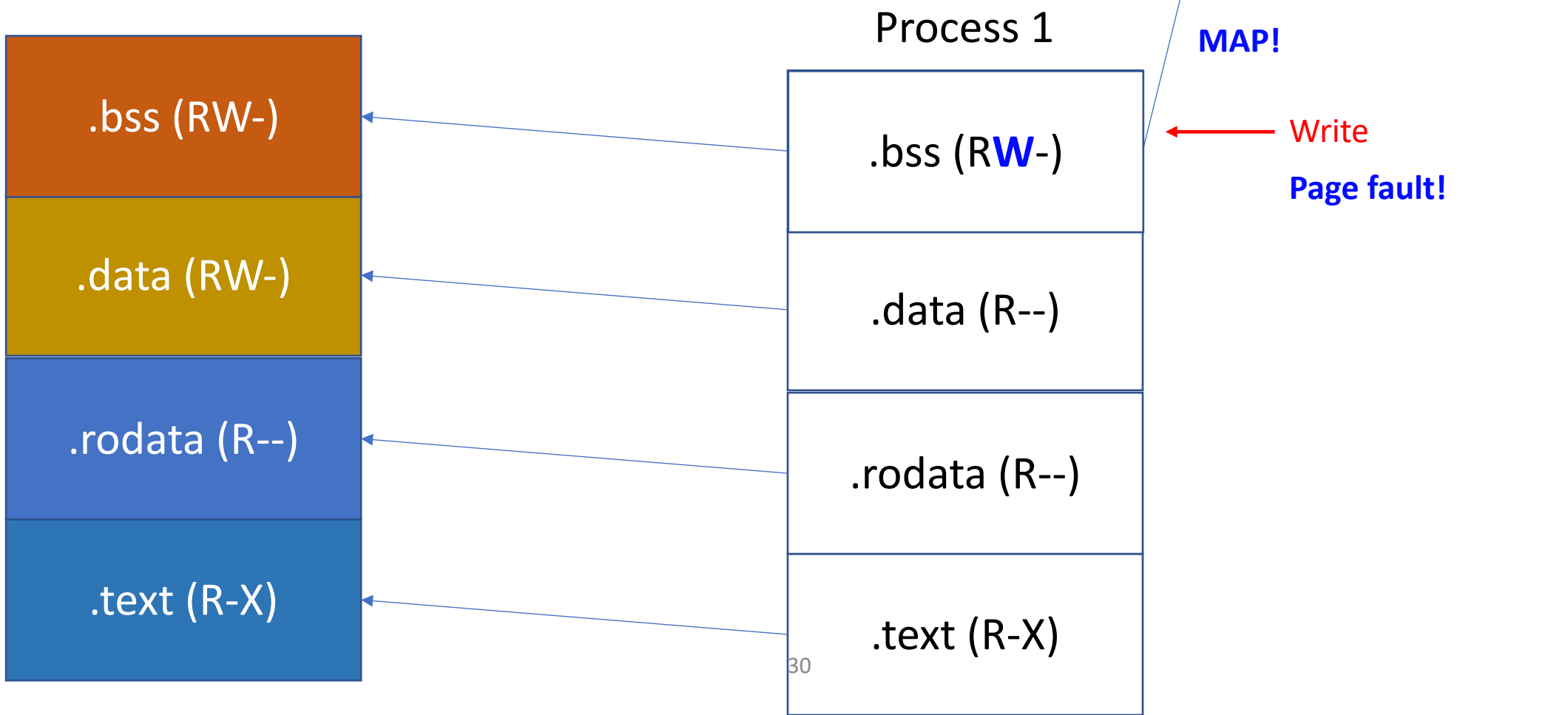
Generate a Page Fault on Writing Attempt

- How can Process 1 write on .bss??



Copy-on-Write

- How can Process 1 write on .bss??



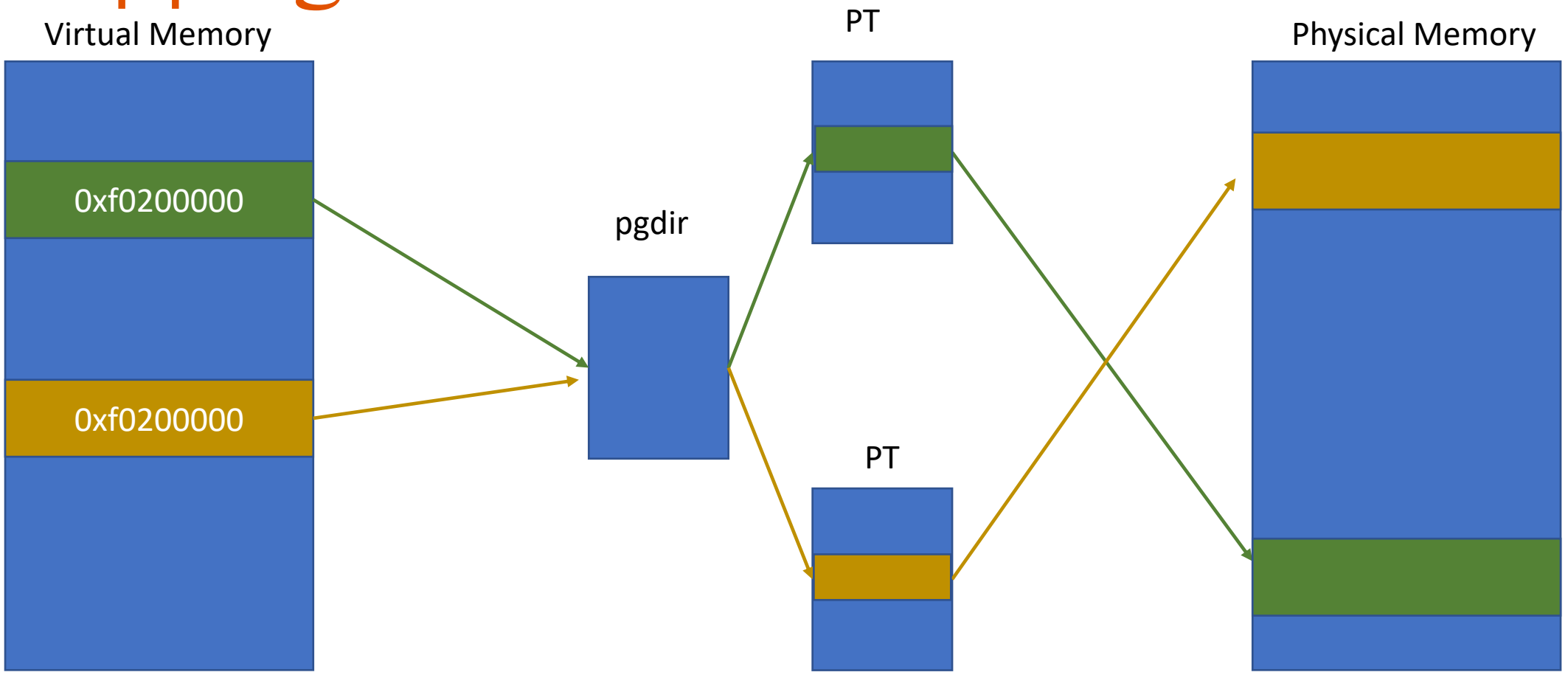
A Challenge of Having Small Physical Memory

- Suppose you have 8GB of main memory

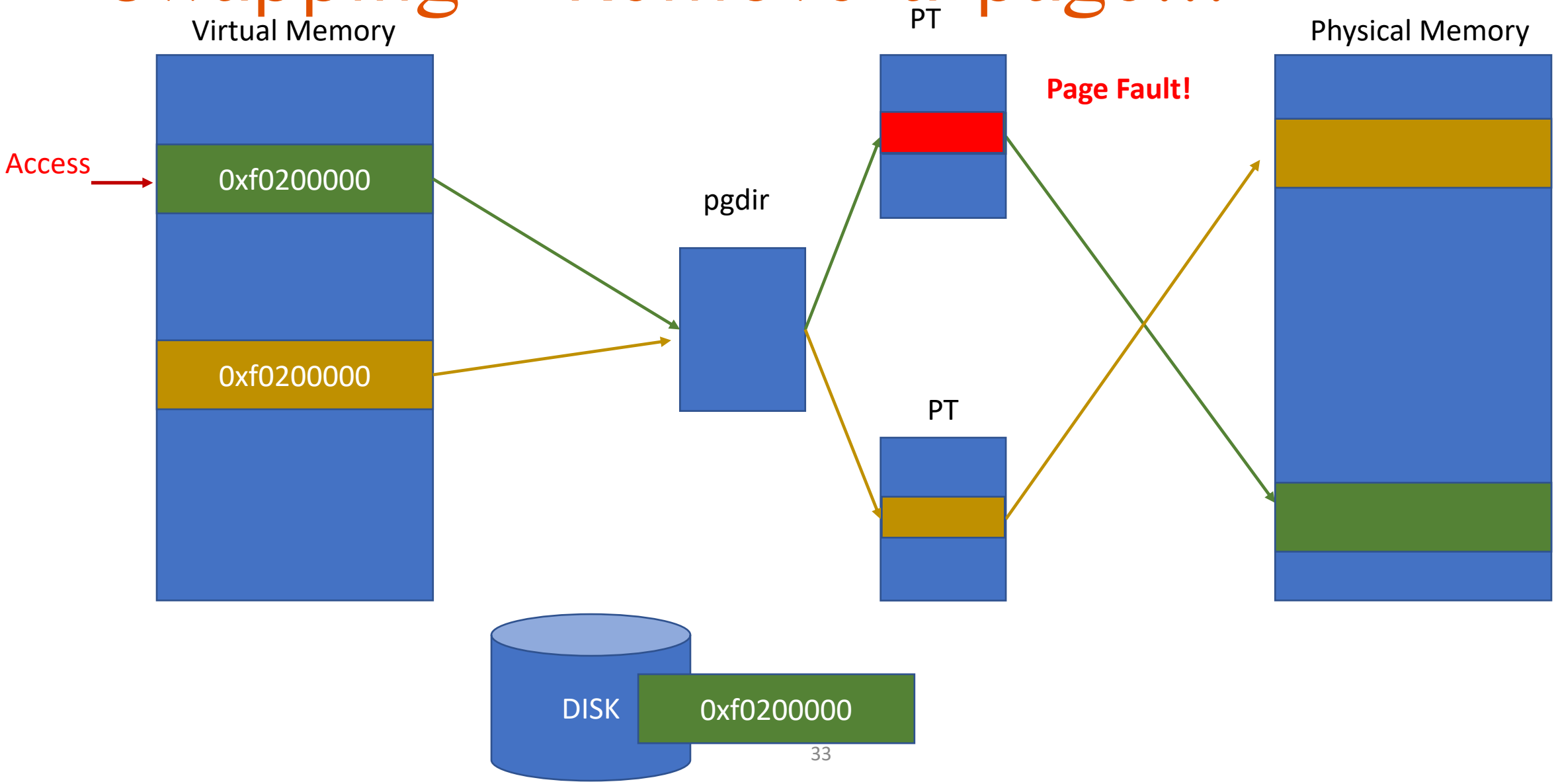
- Can you run a program that its program size is 16GB?
  - Yes, you can load them part by part
  - This is because we do not use all of data at the same time

- Can your OS do this execution seamlessly to your application?

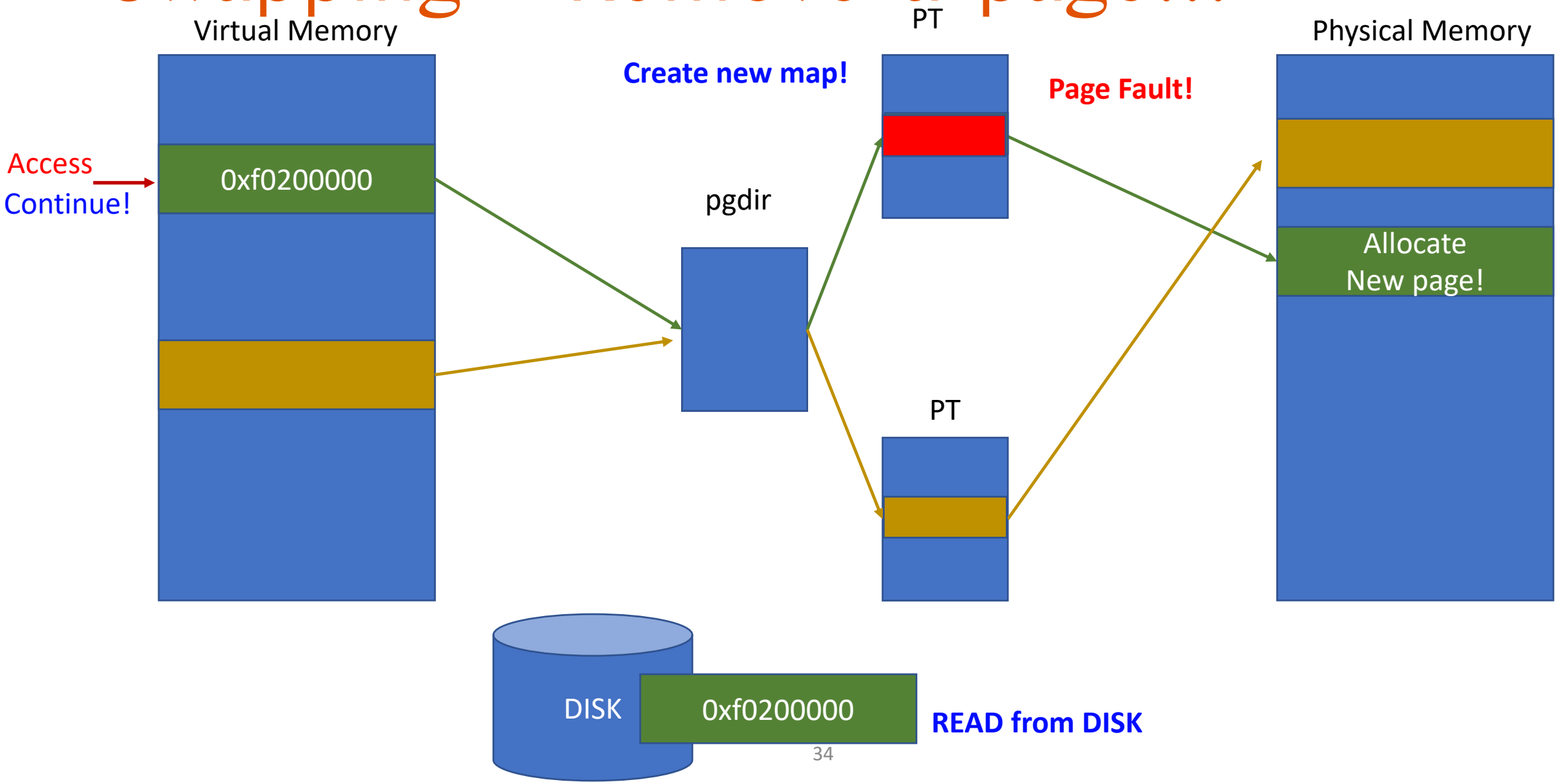
Swapping


Virtual Memory
0xf0200000
0xf0200000
pgdir
PT
PT
Physical Memory

Swapping – Remove a page…



Swapping – Remove a page…



Quiz 2

- Thursday (11/4-11/6 from 8:30am to 11:59pm, unlimited time, 2 trials)
  - Open materials (slides, videos, code, and textbook)
- You will be allowed to have 2 attempts for quiz
  - Uh-oh, a silly mistake, **don't worry**, you can recover in the next trial
- Don't forget about the lab3 due date, on 11/8

Quiz 2 Coverage

- JOS Lab 2 (Virtual Memory Management)
- JOS Lab 3 (User/Kernel, System Call and Interrupt Handling)
- Lecture 8: User/Kernel Context Switch
- Lecture 9: Handling Interrupt & Exceptions
- Lecture 10: System Calls, Call Gate, and Page Fault
- Lecture 11: Virtualization Review

Few Questions

- Memory Protection
  - How an OS/CPU applies access control to memory?
    - Protected mode (DPL), Page directory / page table (permission flags, PTE_W & PTE_U)
  - How an OS kernel protects itself against attacks from application code?
    - Removing PTE_U from PDE or PTE
  - How an OS protects memory area supposed to be read-only from write attempts?
    - Removing PTE_W from PDE or PTE
  - How OS isolates the memory space of a process from others?
    - Having a new page directory / page tables

Few Questions

- Memory Overhead Calculation
  - We have the following mapping for a program. How much of physical memory is required to support virtual to physical address translation for this program (get the minimal total size of page directory and page tables that enables this allocation)?

Area	Start virtual addr	End virtual addr	Size
.text (code)	0x800000	0x804000	0x4000
.data (read/write)	0x900000	0x902000	0x2000
.bss	0xc00000	0xd00000	0x100000

Few Questions

- Memory Overhead Calculation

Area	Start virtual addr	End virtual addr	Size
.text (code)	0x800000	0x804000	0x4000
.data (read/write)	0x900000	0x902000	0x2000
.bss	0xc00000	0xd00000	0x100000

Index	Address range	PTE
0	0x0 ~ 0x400000	invalid
1	0x400000 ~ 0x800000	invalid
2	0x800000 ~ 0xc00000	valid
3	0xc00000 ~ 0x1000000	valid
…	…	Invalid
0x3ff	0xffc00000 ~ 0xffffffff	Invalid

1 page directory: 4KB
2 page tables: 2 * 4KB = 8KB

4KB + 8KB = 12KB

Few Questions

- User / Kernel Switch
  - How OS gets back CPU execution from user while user runs while(1);?
    - Timer interrupt will preempt the execution from user to kernel
  - How a user program access hardware? What OS does for this?
    - OS offers system calls (APIs available in OS)
    - User program invokes system call via generating a software interrupt
    - OS checks access to resources
      - File, network, memory, etc.

Few Questions

- For an interrupt that has an error code,

- Which part of TrapFrame is prepared by the CPU?
  - tf_ss, tf_esp, tf_eflags, tf_cs, tf_eip and tf_err
- Which part of TrapFrame is prepared by JOS?
  - All others: tf_trapno, tf_ds, tf_es, tf_regs

```
+--------------------+ KSTACKTOP
| 0x00000 | old SS   |     " - 4
|      old ESP       |     " - 8
|     old EFLAGS     |     " - 12
| 0x00000 | old CS   |     " - 16
|      old EIP       |     " - 20
|     error code     |     " - 24 <---- ESP
+--------------------+
```

```
struct Trapframe {
    struct PushRegs tf_regs;
    uint16_t tf_es;
    uint16_t tf_padding1;
    uint16_t tf_ds;
    uint16_t tf_padding2;
    uint32_t tf_trapno;
    /* below here defined by
    uint32_t tf_err;
    uintptr_t tf_eip;
    uint16_t tf_cs;
    uint16_t tf_padding3;
    uint32_t tf_eflags;
    /* below here only when c
    uintptr_t tf_esp;
    uint16_t tf_ss;
    uint16_t tf_padding4;
} __attribute__((packed));
```

Few Questions

- Page Fault
  - We run 1,000,000 instances of /bin/bash in our os2 server, running Linux enabled with copy-on-write fork(). How many copies of the code (the read-only part) of /bin/bash exist in the physical memory?
    - One, shared via copy-on-write
  - How an OS can run a program that requires more memory than a machine's physical memory?
    - We can store currently unused memory pages in the disk (swap-out)
    - Accessing to swapped-out pages will generate a page fault
    - The OS can search for swapped-out pages, and fill a page in if exists (swap-in)
    - Resumes user execution!