More System calls and Page faults

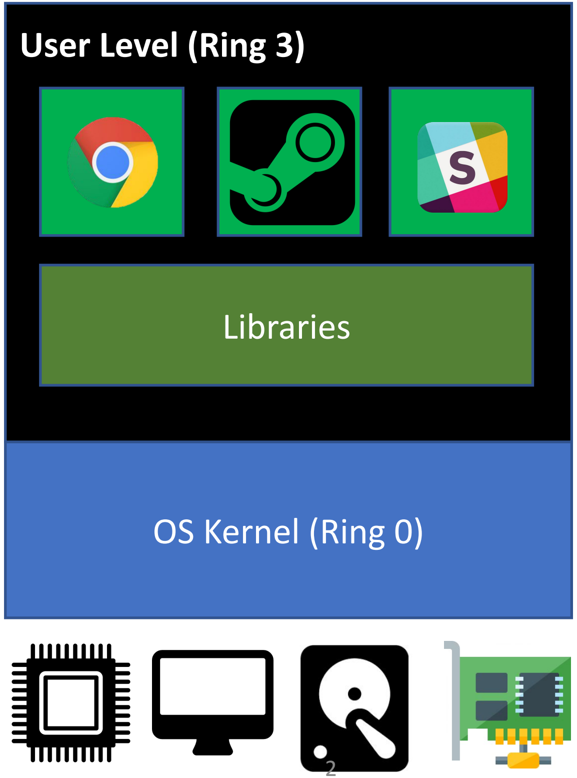
ECE 469, Feb 13

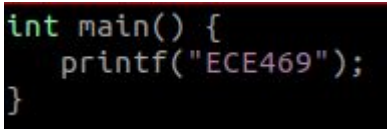
Aravind Machiry

Recap: Syscalls

- An API of an OS
- User-level Application calls functions in kernel
  - Open
  - Read
  - Write
  - Exec
  - Send
  - Recv
  - Socket
  - Etc...

Syscall: User/Kernel communication





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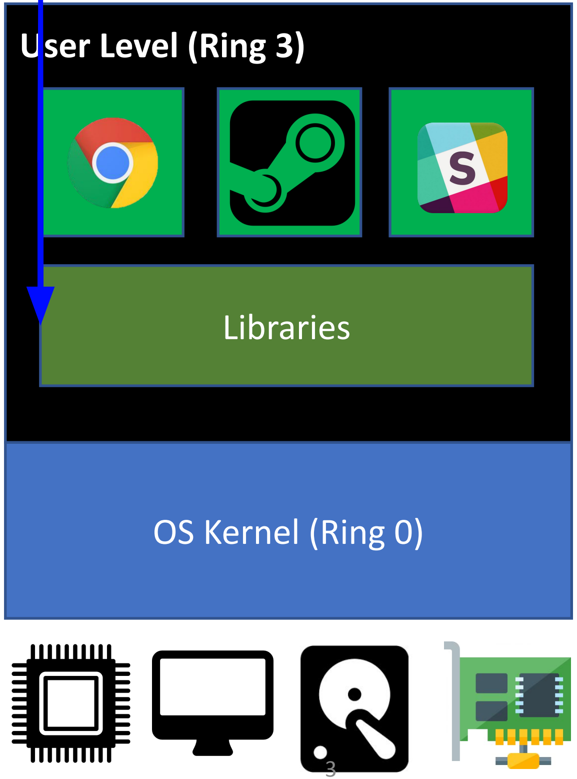
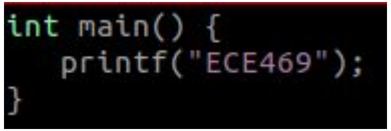
A library call in ring 3





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Syscall: User/Kernel communication

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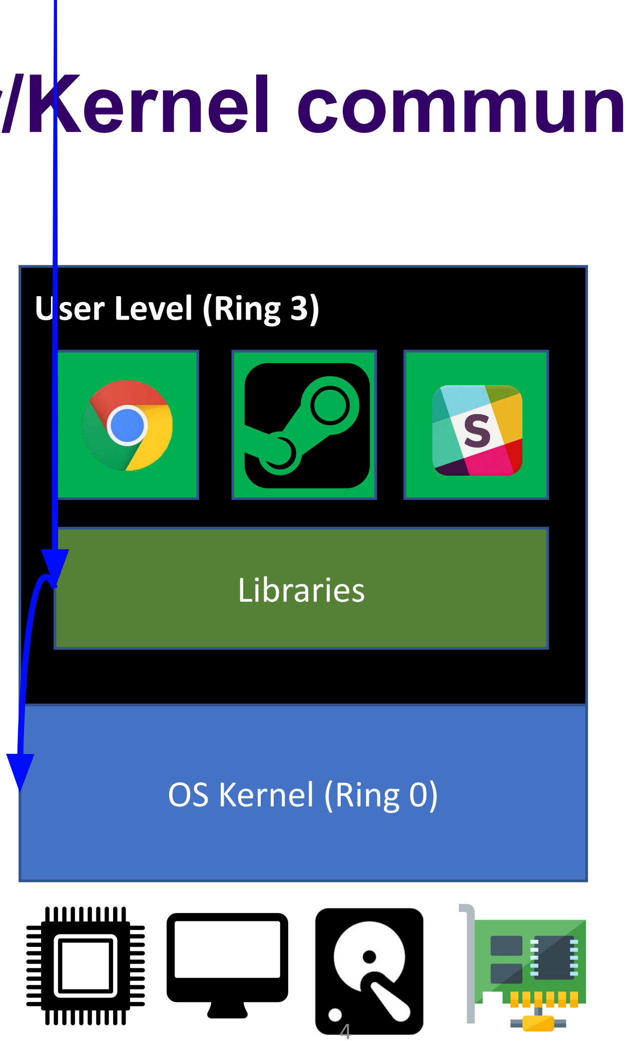
sys_write(1, “ECE469”, 6);

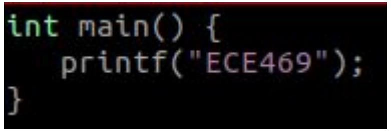
A system call, **From ring 3**



User Level (Ring 3)

Libraries

OS Kernel (Ring 0)



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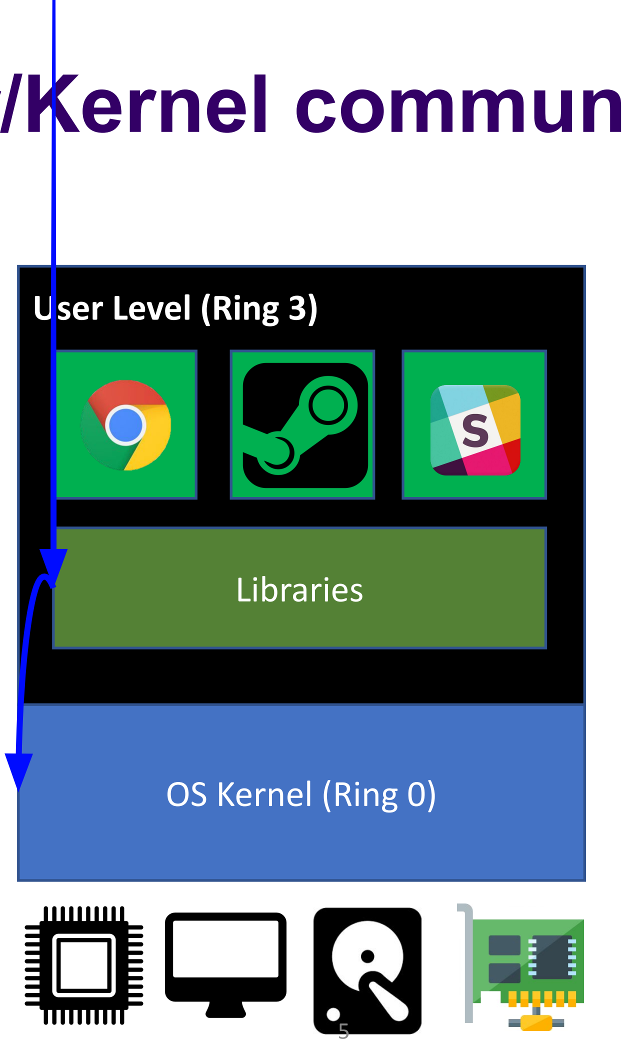

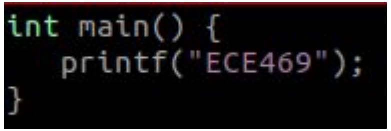

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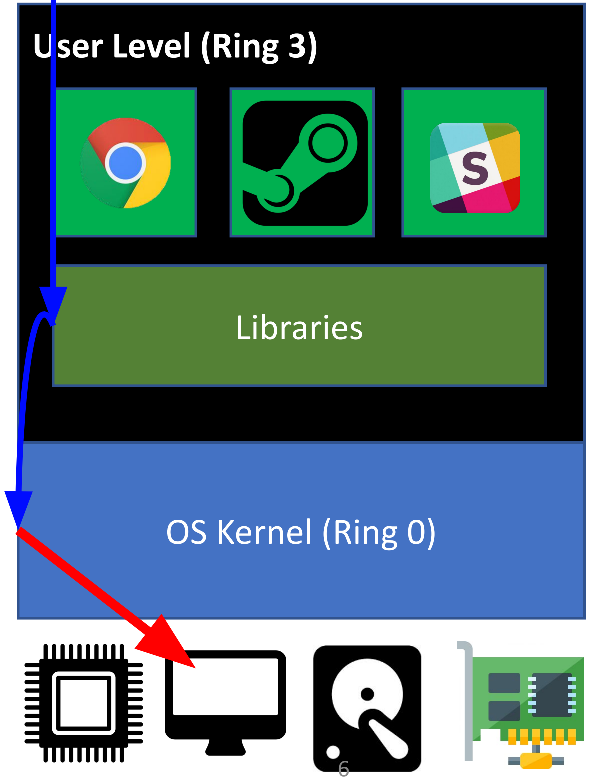

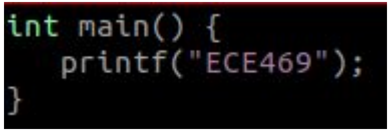

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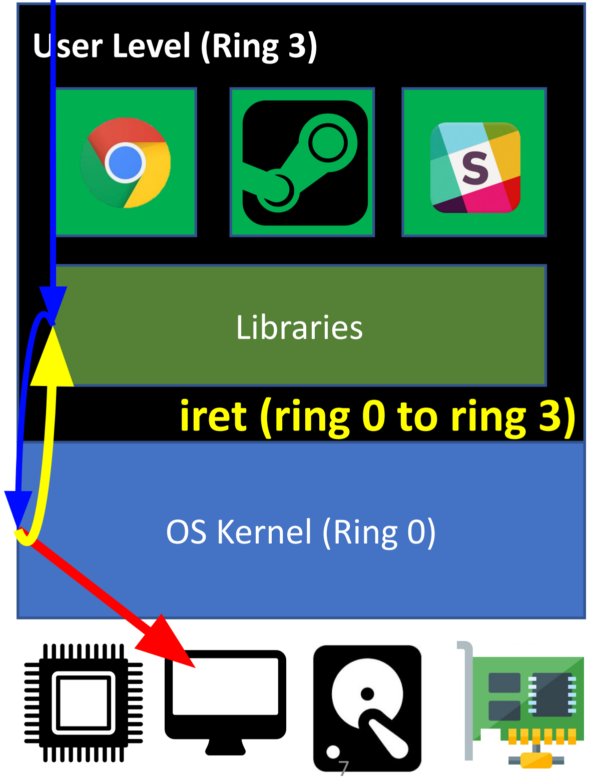

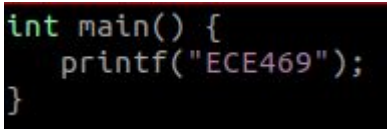

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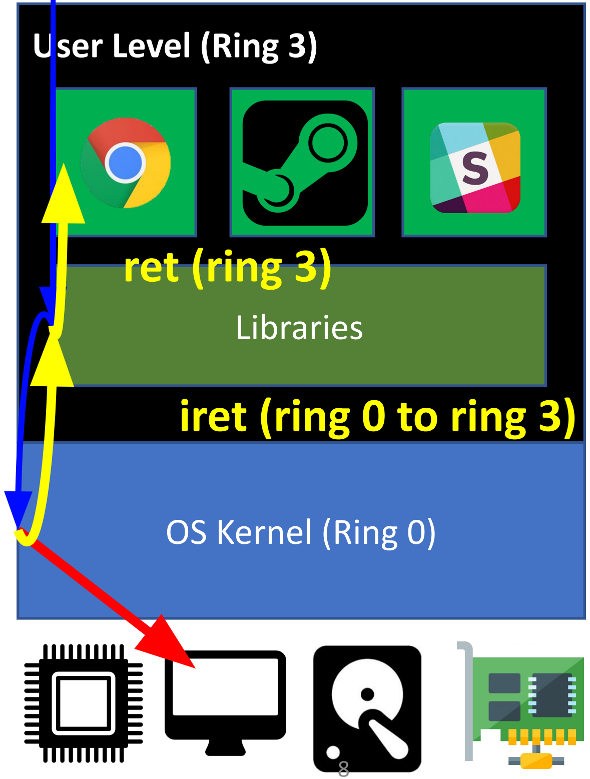

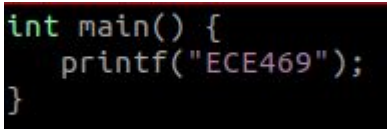

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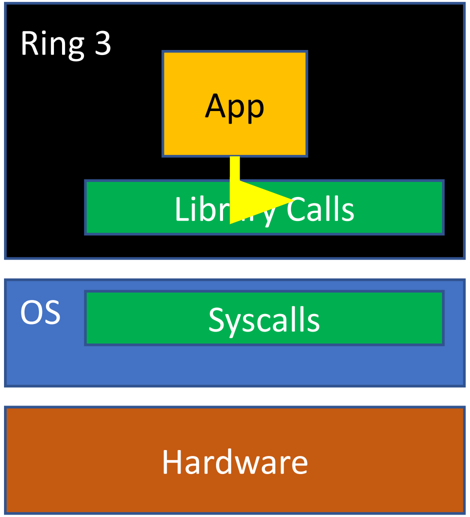
System calls via Interrupt Handler

- Call gate
  - System call can be invoked only with trap handler
    - **`int $0x30` – in JOS**
    - `int $0x80` – in Linux (32-bit)
    - `int $0x2e` – in Windows (32-bit)
    - `sysenter/sysexit` (32-bit)
    - `syscall/sysret` (64-bit)
- OS performs checks if userspace is doing a right thing
  - Before performing important ring 0 operations
  - E.g., accessing hardware..



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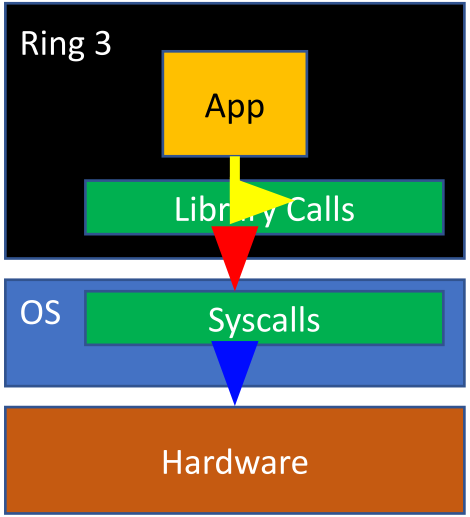

`int $0x30`

`CHECK!!`

- OS performs checks if userspace is doing a right thing
  - Before performing important ring 0 operations
  - E.g., accessing hardware..

Implementing Syscalls in JOS

- See kern/syscall.c
- `void sys_cputs(const char *s, size_t len)`
  - Print a string in s to the console
- `int sys_cgetc(void)`
  - Get a character from the keyboard
- `envid_t sys_getenvid(void)`
  - Get the current environment ID (process ID)
- `int sys_env_destroy(envid_t)`
  - Kill the current environment (process)

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Required for Implementing scanf, printf, etc…

Passing arguments to Syscalls

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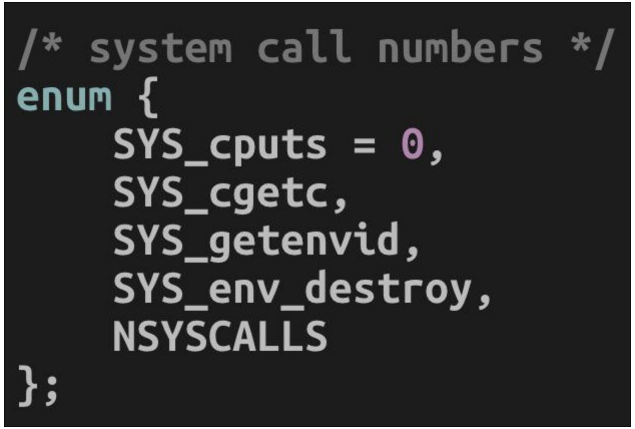
General Purpose Registers!!!

Passing arguments to Syscalls

- In JOS
  - eax = system call number
  - edx = 1st argument
  - ecx = 2nd argument
  - ebx = 3rd argument
  - edi = 4th argument
  - esi = 5th argument
- E.g., calling sys_cputs(“asdf”, 4);
  - eax = 0
  - edx = address of “asdf”
  - ecx = 4
  - ebx, edi, esi = not used
- And then
  - Run `int $0x30`



```
/* system call numbers */
enum {
	SYS_cputs = 0,
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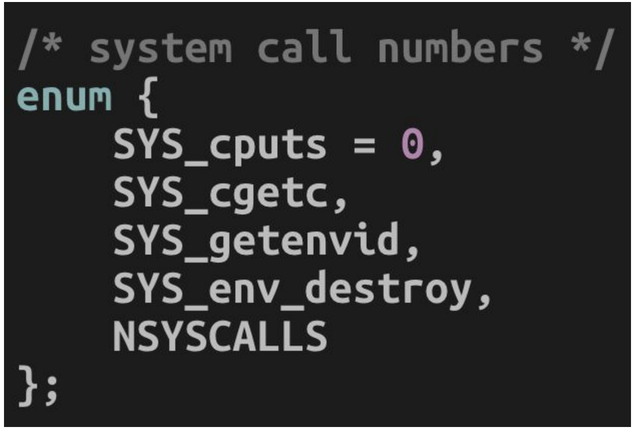

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Will add more as
our lab implementation progresses

Passing arguments to Syscalls

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  - eax = system call number
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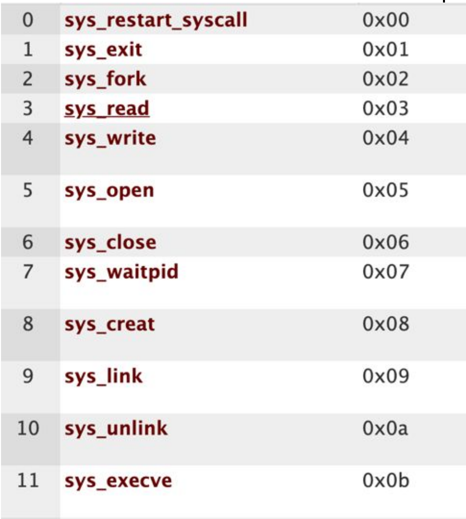
- See table
  - https://syscalls.kernelgrok.com/ : lists 337 system calls…



0	sys_restart_syscall	0x00
1	sys_exit	0x01
2	sys_fork	0x02
3	sys_read	0x03
4	sys_write	0x04
5	sys_open	0x05
6	sys_close	0x06
7	sys_waitpid	0x07
8	sys_creat	0x08
9	sys_link	0x09
10	sys_unlink	0x0a
11	sys_execve	0x0b

Handling arguments to Syscalls

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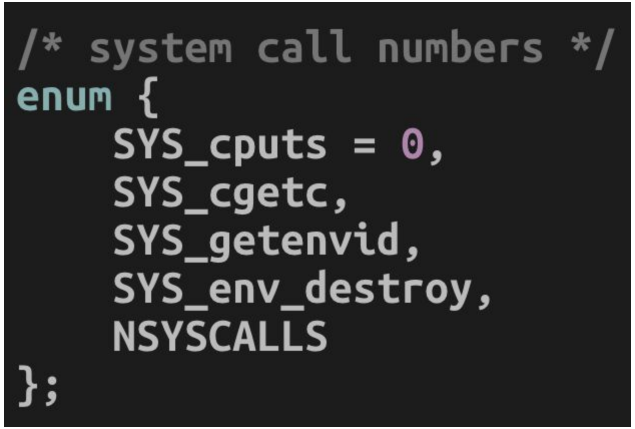
- And then
  - Run `int $0x30`
- At interrupt handler
  - Read syscall number from the eax of tf
    - syscall number is 0 -> calling SYS_cputs
  - Read 1st argument from the edx of tf
    - Address of “adsf”
  - Read 2nd argument from ecx of tf
    - 4
  - call sys_cputs(“asdf”, 4) // in kernel



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Invoking Syscalls

- Set all arguments in the registers
    - Order: edx ecx ebx edi esi

- int $0x30 (in JOS)
    - Software interrupt 48

- int $0x80 (in 32bit Linux)
    - Software interrupt 128

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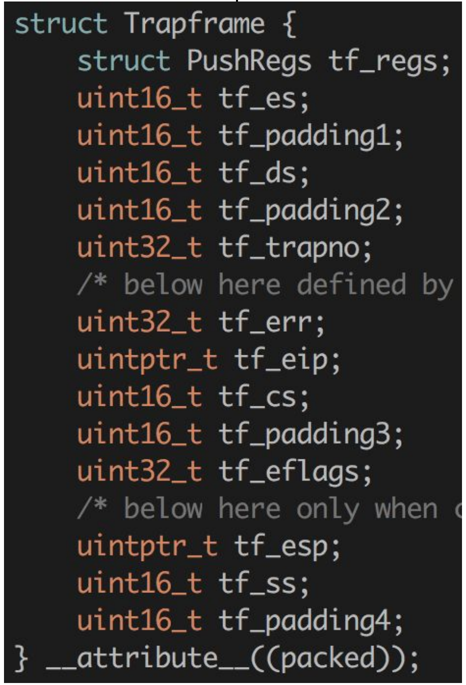

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Handling Syscalls in Kernel

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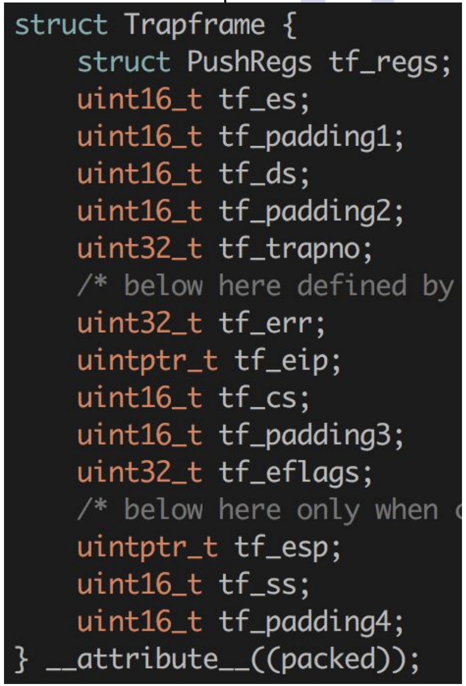

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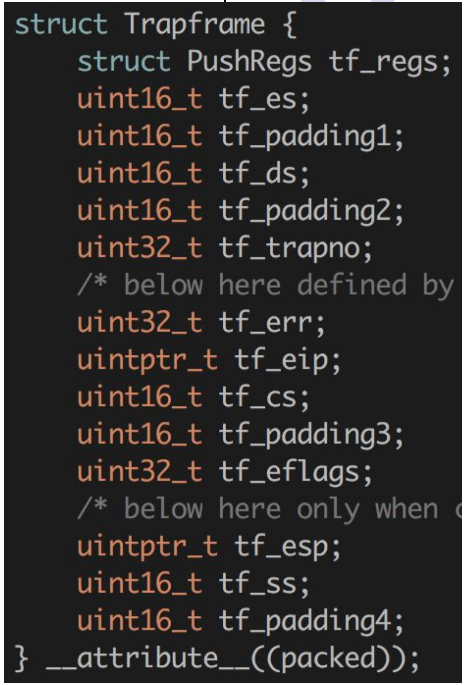

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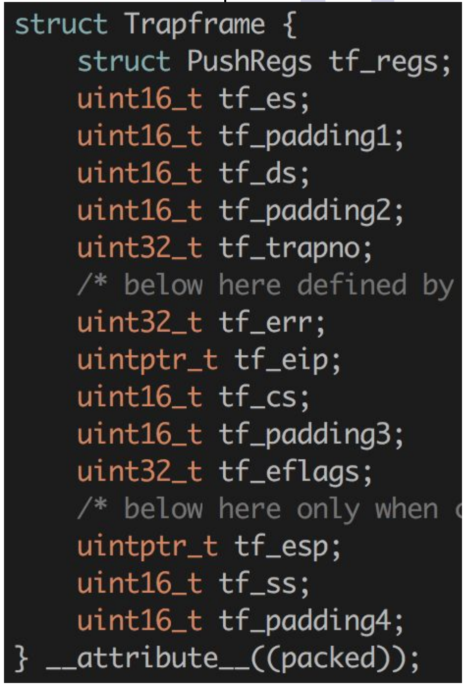

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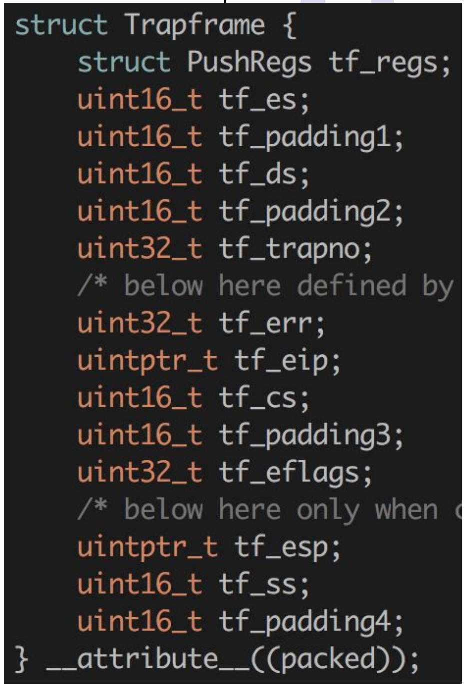

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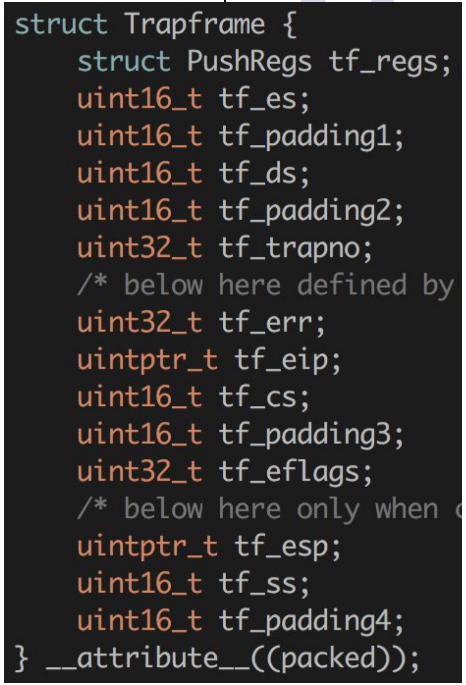
- trap_dispatch()



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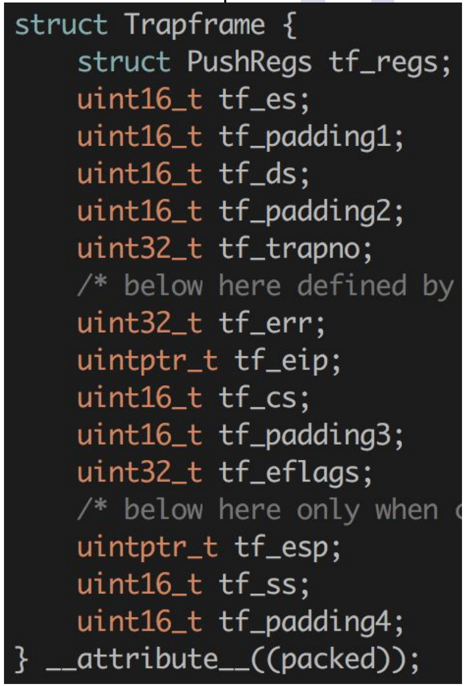

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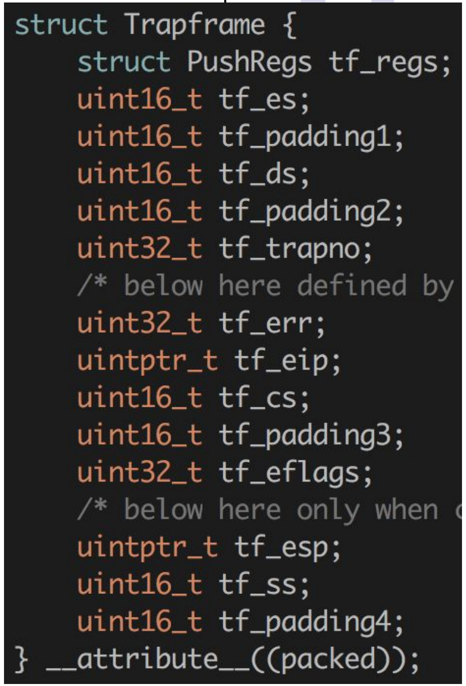
  - Get registers that store arguments from struct Trapframe *tf
  - Call syscall() using those registers
    - This syscall() is at kern/syscall.c



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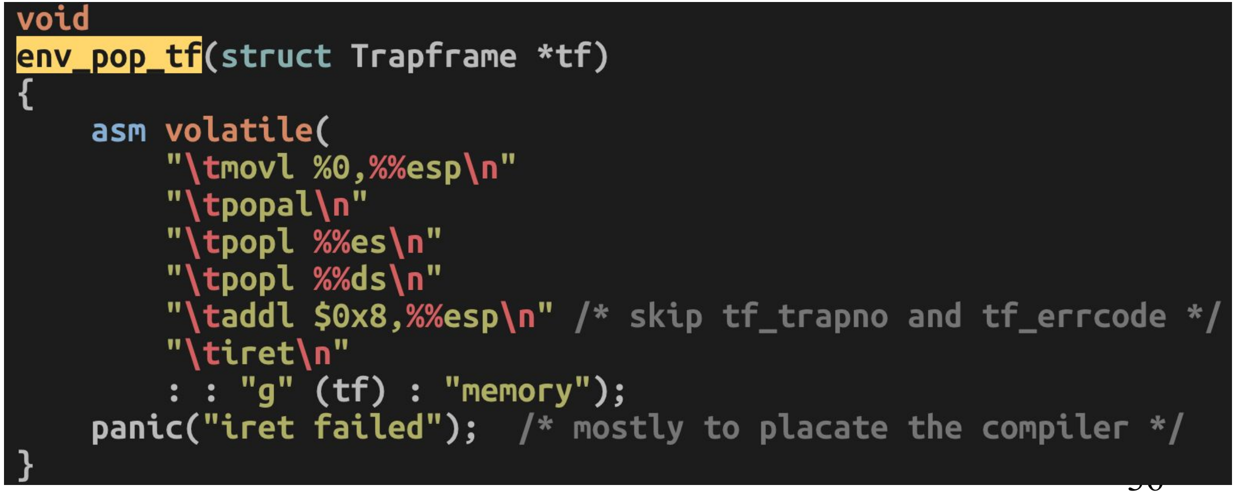
- env_pop_tf()



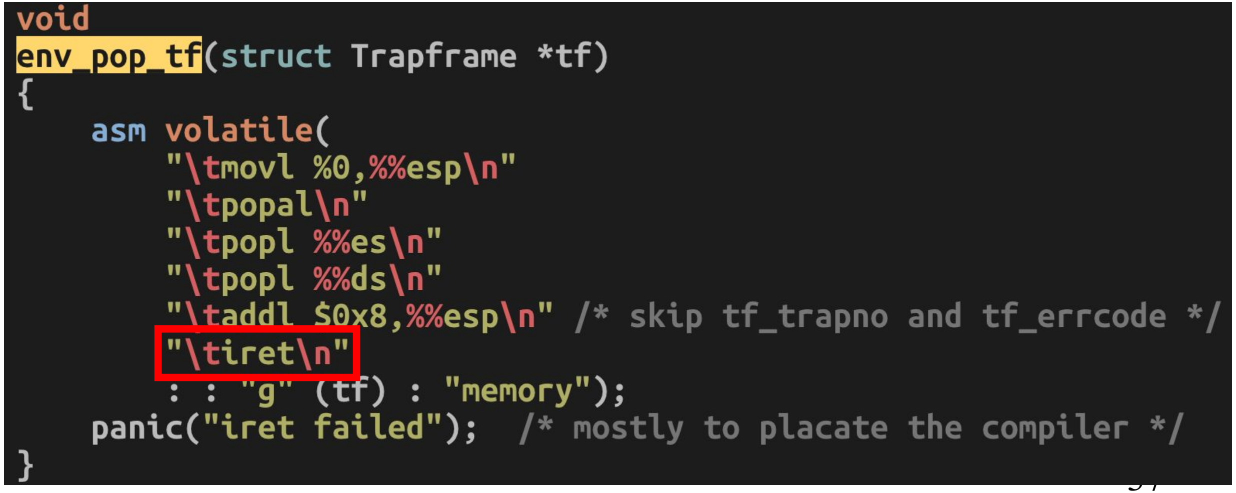
```
void
env_pop_tf(struct Trapframe *tf)
{
	asm volatile(
		"\tmovl %0,%%esp\n"
		"\tpopal\n"
		"\tpopl %%es\n"
		"\tpopl %%ds\n"
		"\taddl $0x8,%%esp\n" /* skip tf_trapno and tf_errcode */
		"\tiret\n"
		: : "g" (tf) : "memory");
	panic("iret failed");  /* mostly to placate the compiler */
}
```

Syscall Return from Kernel

- Finishing handling of syscall (return of syscall())

- trap() calls env_pop_tf()
  - Get back to the user environment!

- env_pop_tf()
  - Runs `iret`



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Syscall Return from Kernel

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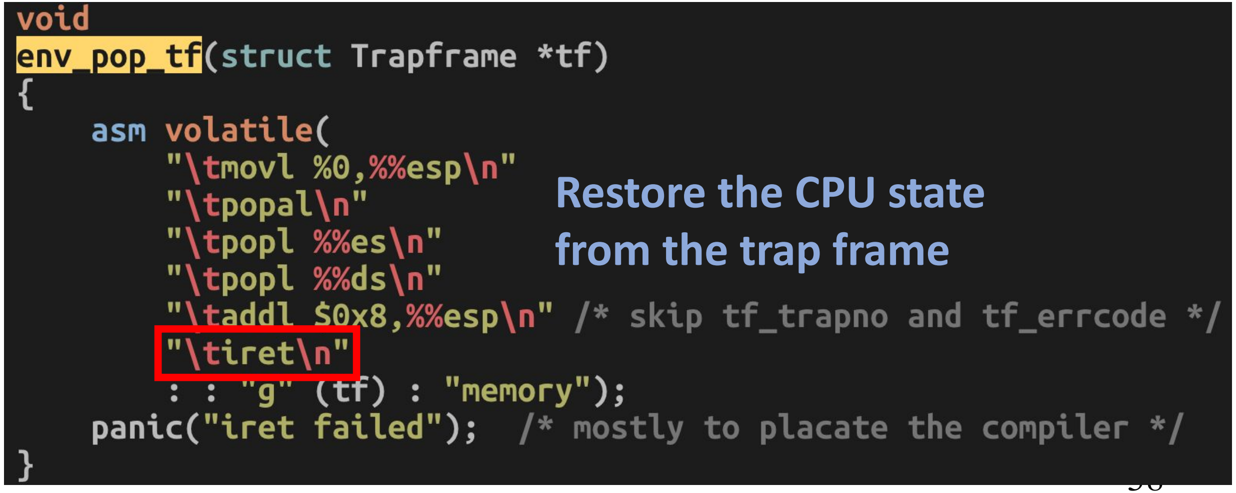

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Restore the CPU state from the trap frame

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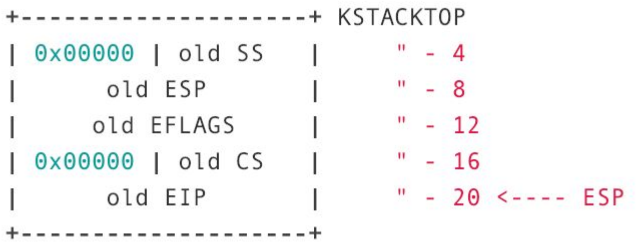

```
+--------------------+ KSTACKTOP
| 0x00000 | old SS   |     " - 4
|      old ESP       |     " - 8
|     old EFLAGS     |     " - 12
| 0x00000 | old CS   |     " - 16
|      old EIP       |     " - 20 <---- ESP
+--------------------+
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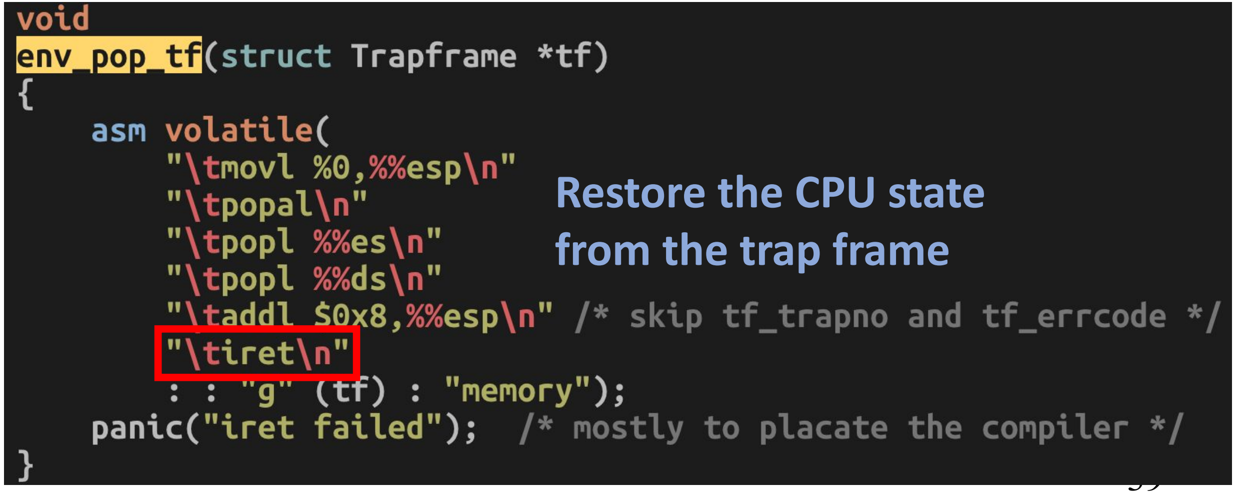

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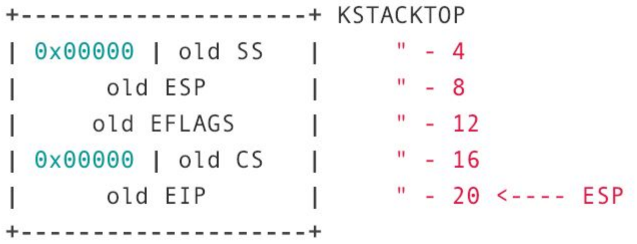

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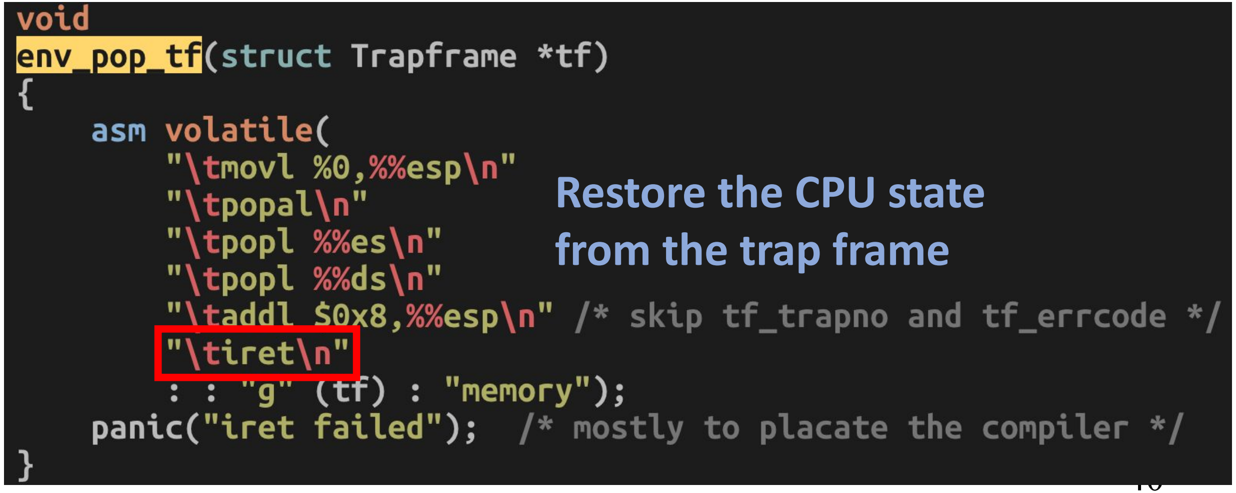
- Back to Ring 3!



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Restore the CPU state from the trap frame

System call Execution

- Execution…
- int $0x30
- Call trap gate
- Handle trap!
- Pop context
- iret
- Execution resumes…

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Ring 3

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Ring 0

- Execution resumes…

Ring 3

Page faults

- Occurs when paging (address translation) fails
  - !(pde&PTE_P) or !(pte&PTE_P): Present bit not set
    - **Automated extension of runtime stack**
  - Write access but !(pte&PTE_W): access violation
  - Access from user but !(pte&PTE_U): protection violation

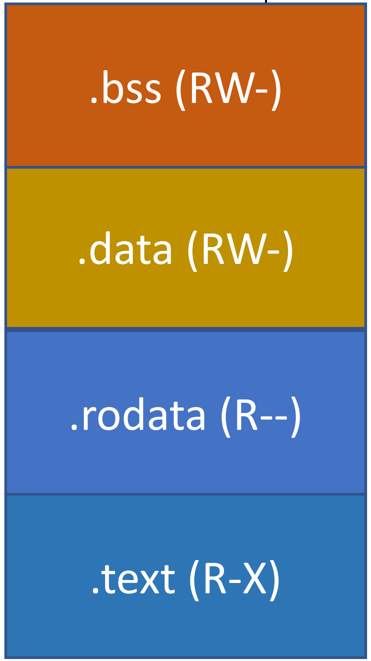
Page faults Handling (2): Copy-On-Write (CoW)

- Copy-on-Write (CoW)
  - Technique to reduce memory footprint
  - Share pages read-only
  - Create a private copy when the first write access happens

- Memory Swapping
  - Use disk as extra space for physical memory
  - Limited RAM Size: 16GB?
  - We have a bigger storage: 1T SSD, Hard Disk, online storage, etc.
  - Can we store some ‘currently unused but will be used later’ part into the disk?
    - Then we can store only the active part of data in memory

Program in Memory

- .text
  - Code area. Read-only and executable
- .rodata
  - Data area, Read-only and not executable
- .data
  - Data area, Read/Writable (not executable)
  - Initialized by some values
- .bss (uninitialized data)
  - Data area, Read/Writable (not executable)
  - Initialized as 0



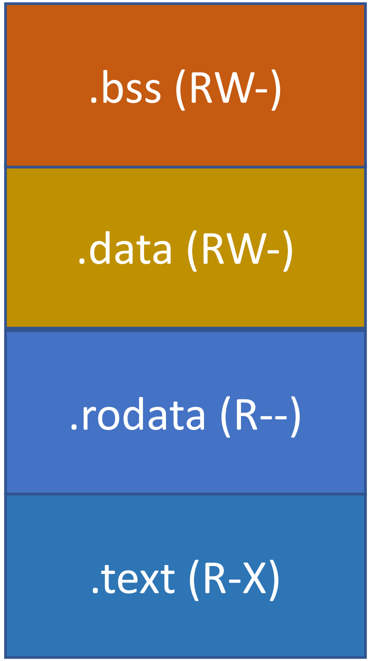
.bss (RW-)

.data (RW-)

.rodata (R--)

.text (R-X)

Running same program multiple times



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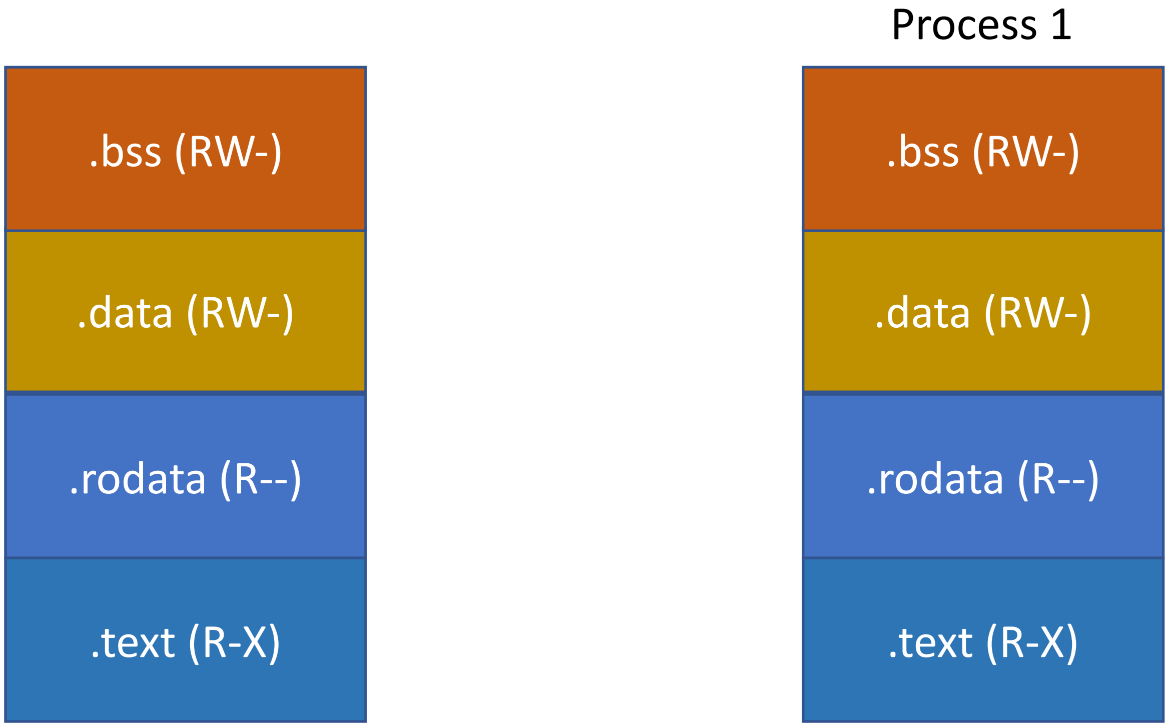

Process 1

.bss (RW-)

.data (RW-)

.rodata (R--)

.text (R-X)

.bss (RW-)

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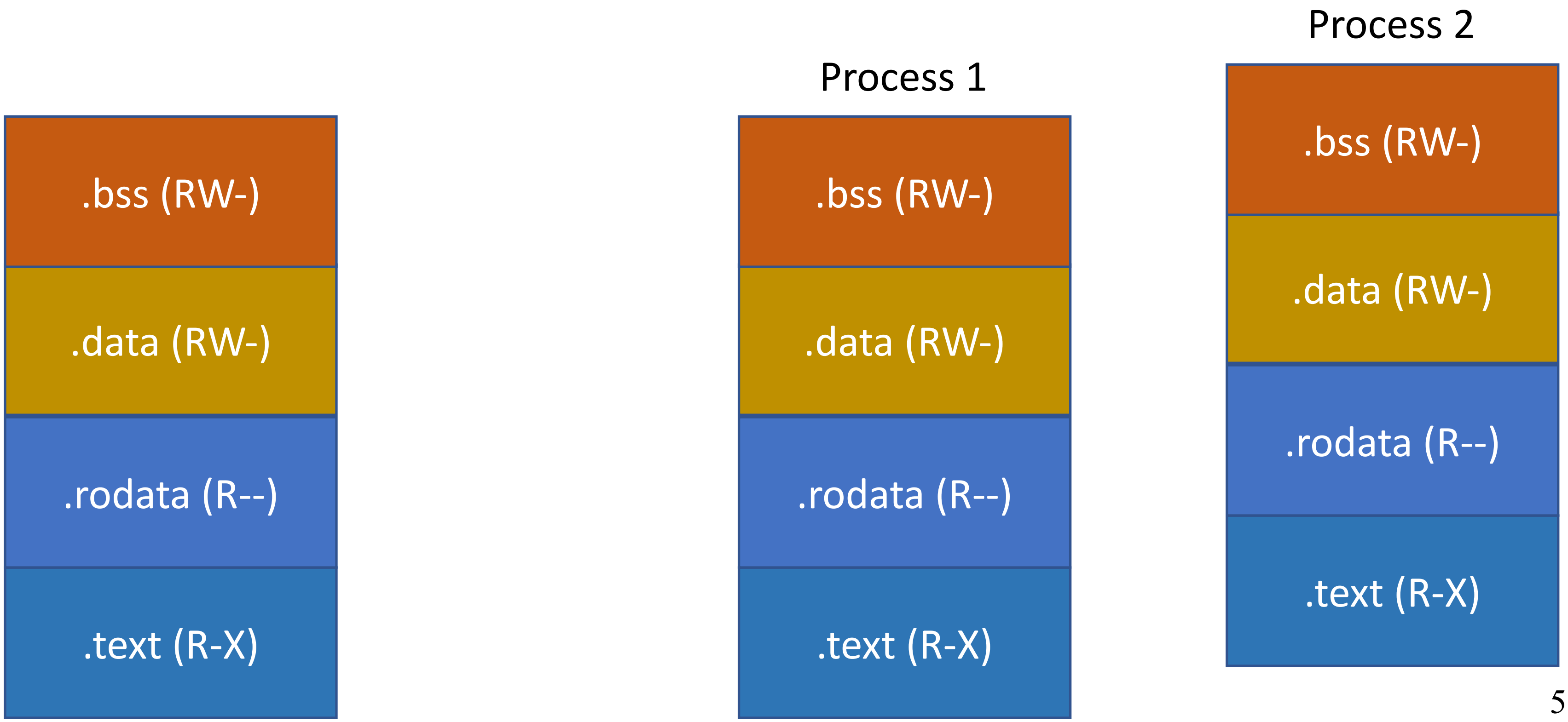
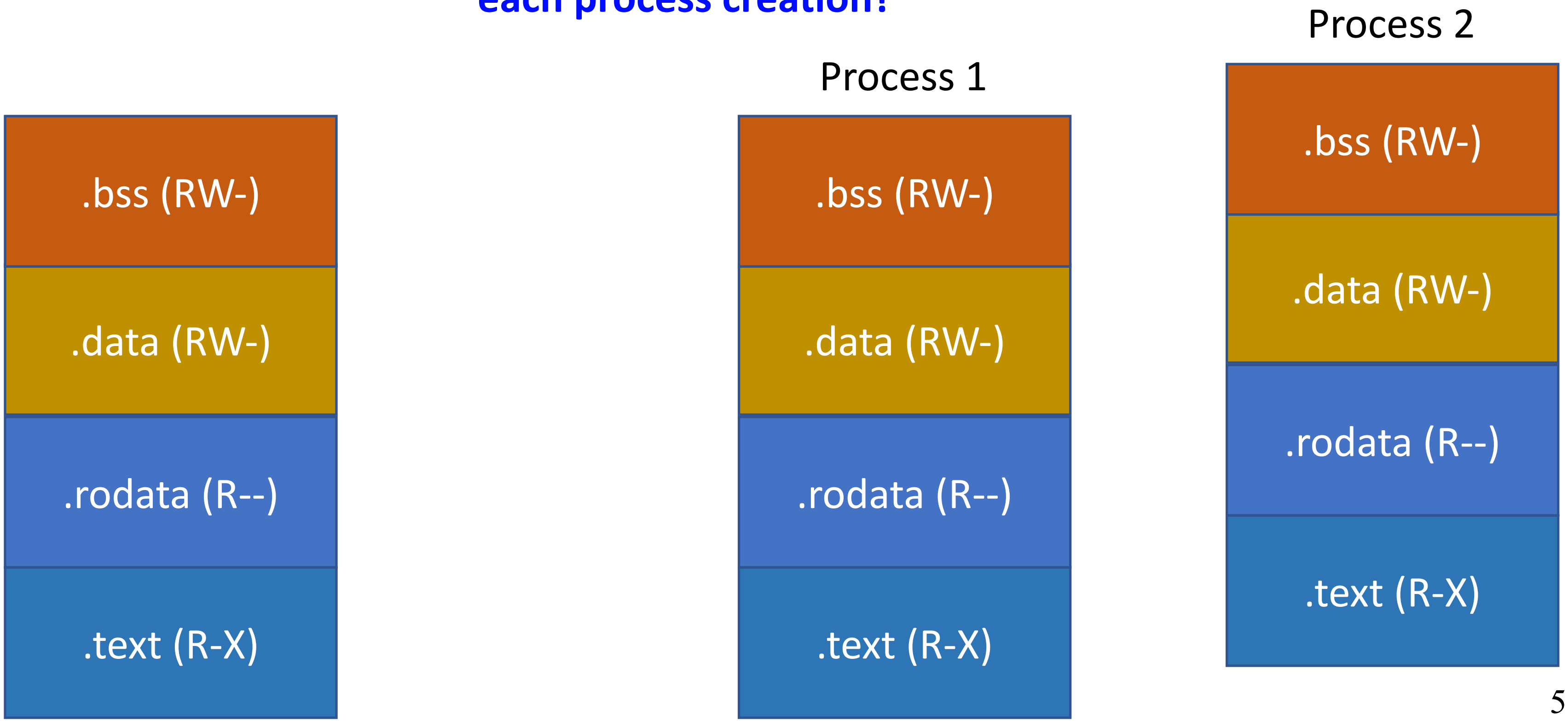


Running same program multiple times

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



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.text (R-X)

Process 1

.bss (RW-)

.data (RW-)

.rodata (R--)

.text (R-X)

Process 2

.bss (RW-)

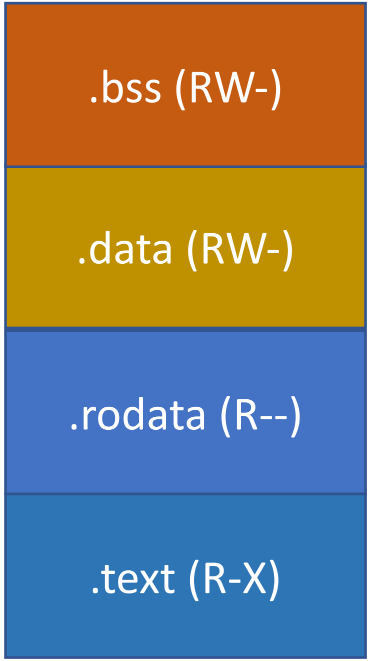
.data (RW-)

.rodata (R--)

.text (R-X)

Sharing pages by marking read-only

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



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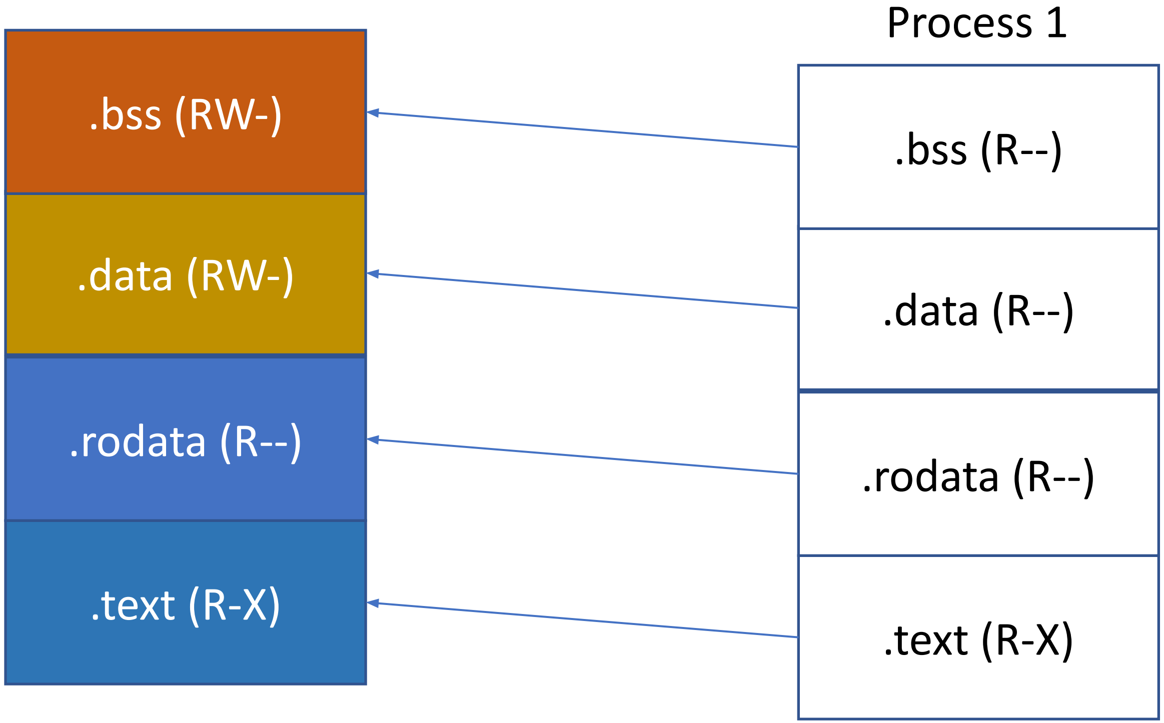

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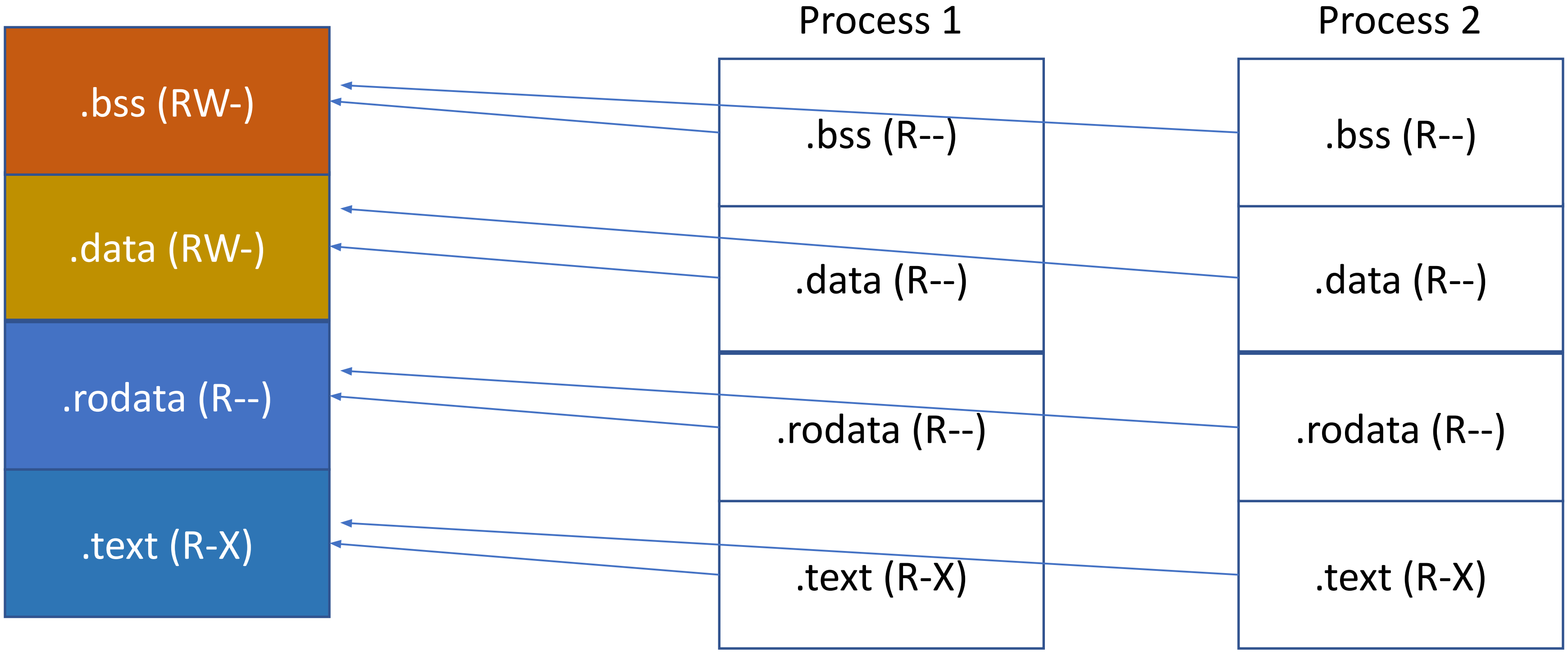
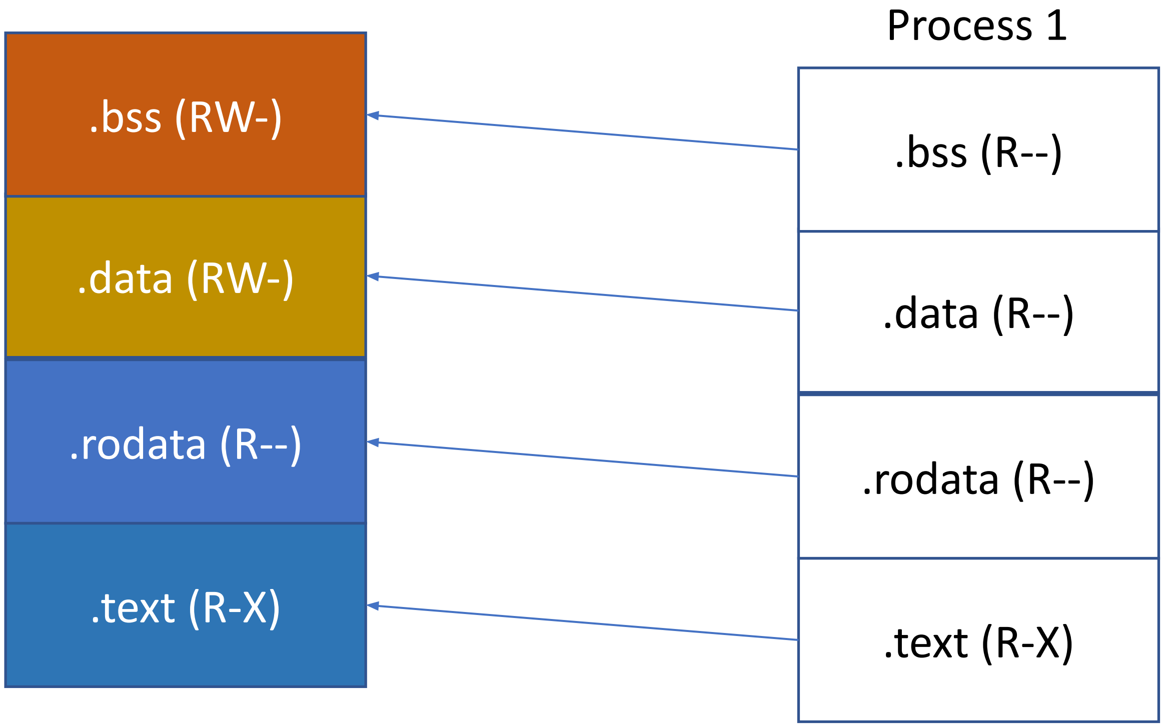


What about writes?

- How can Process 1 write on .bss??



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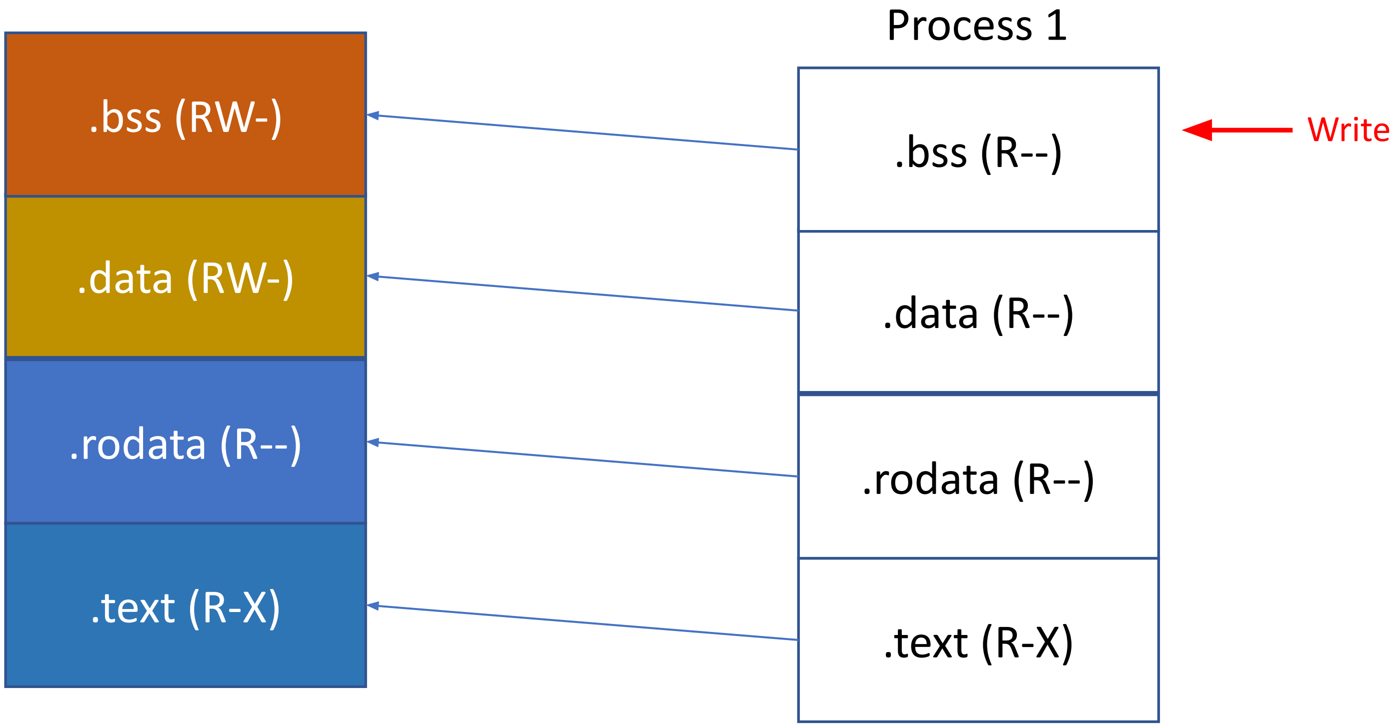

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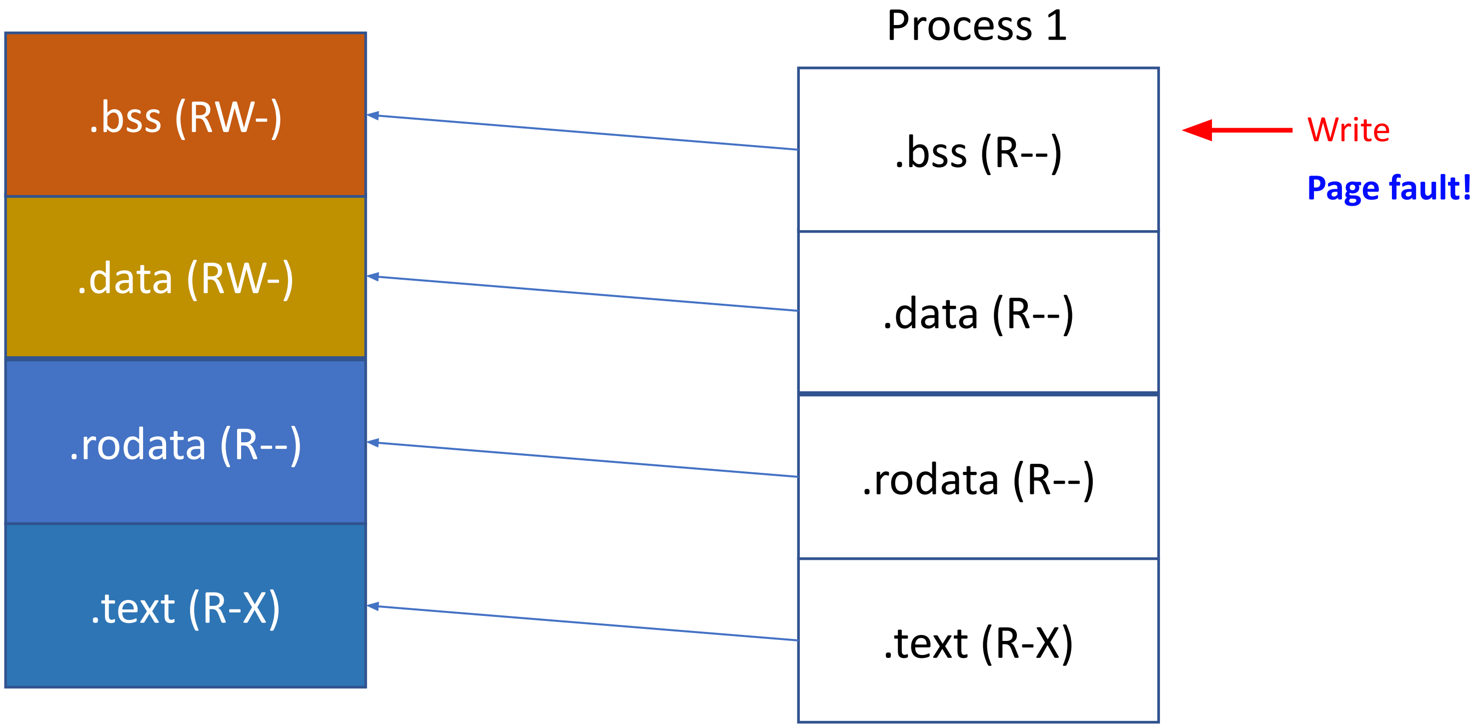

Handling writes: Copy-on-Write

- Read CR2
  - A fault from one of the shared location!
- Read Error code
  - Write on read-only memory
    - Hmm… the process requires a private copy! (we actually mark if COW is required in PTE)

- ToDo: create a writable, private copy for that process!
  - Map a new physical page (page_alloc, page_insert)
  - Copy the contents
  - Mark it read/write
  - Resume…

Handling writes: Copy-on-Write

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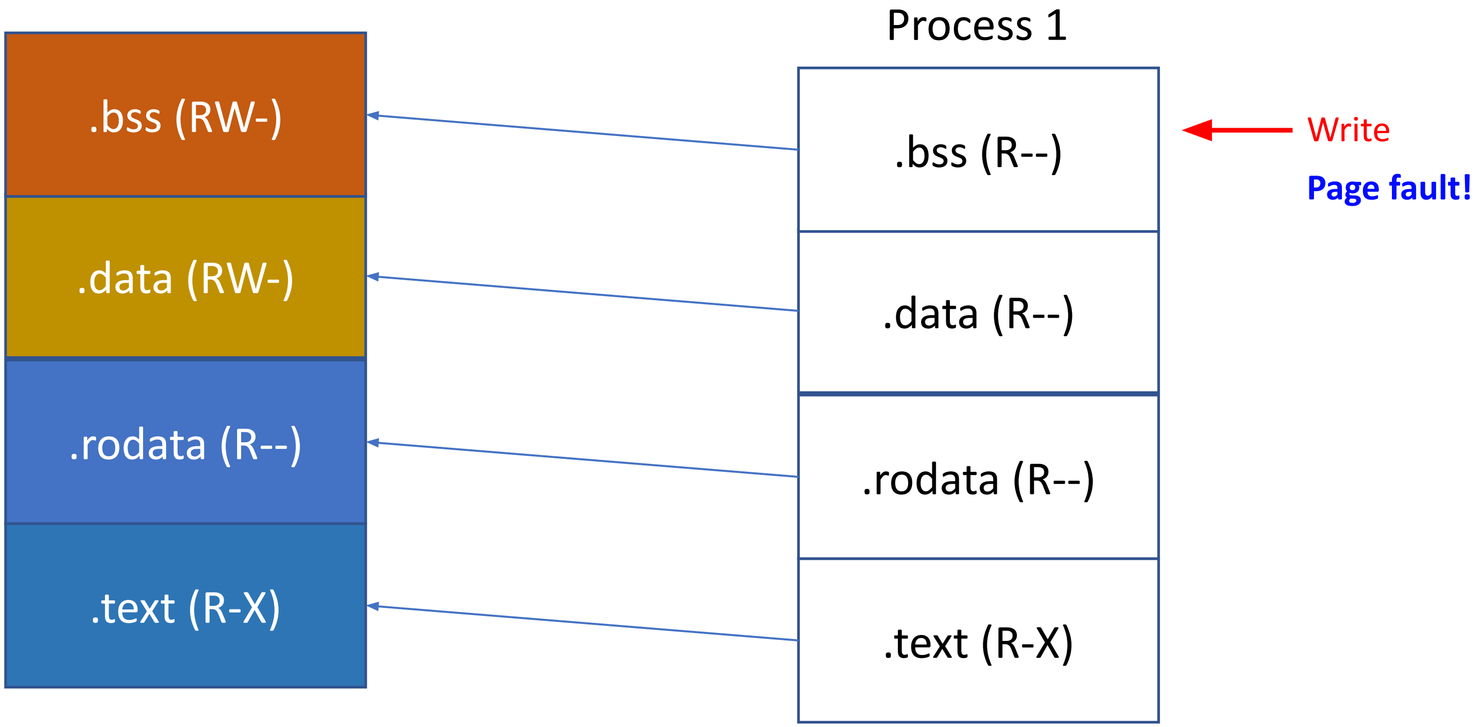

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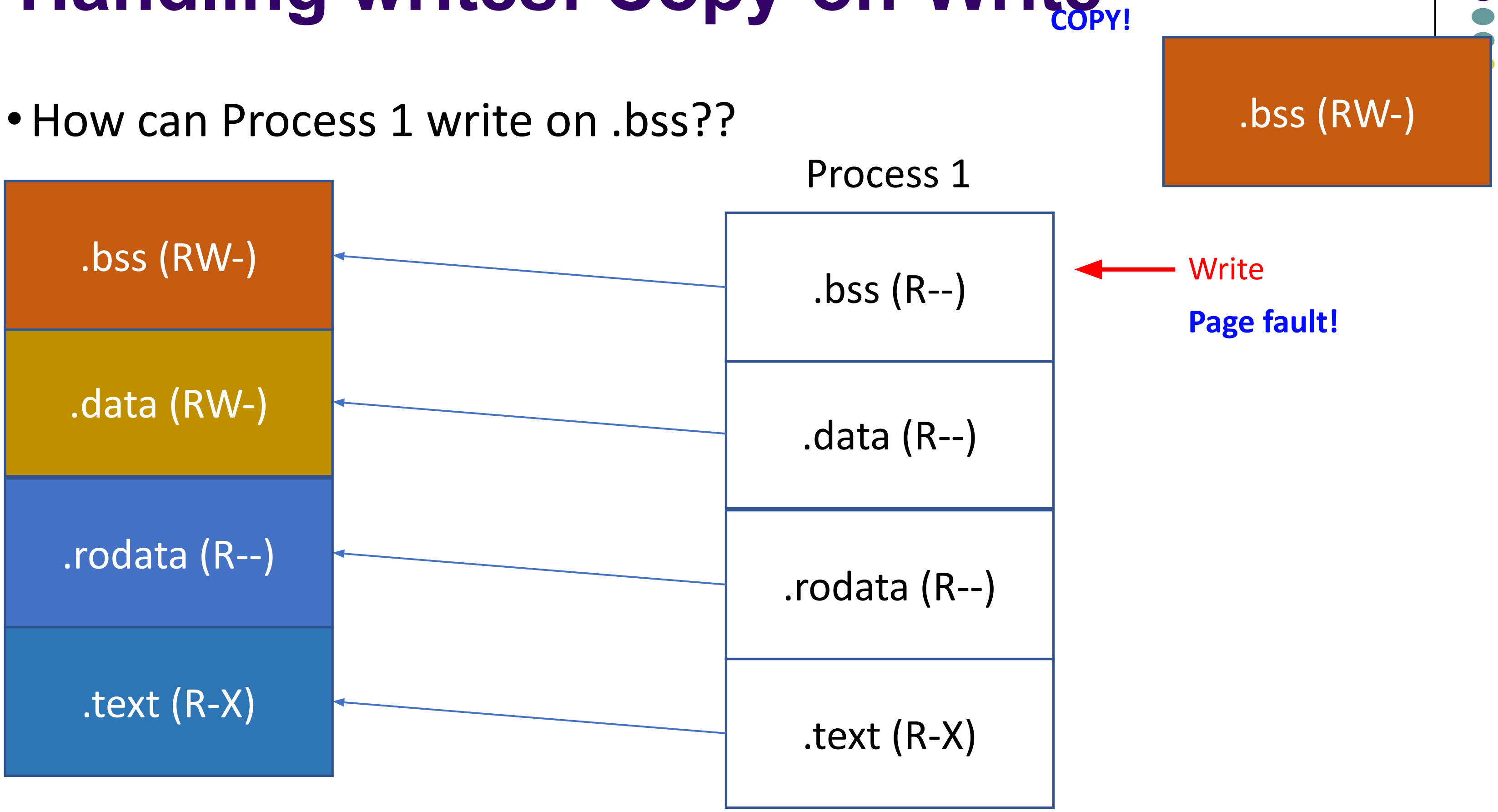

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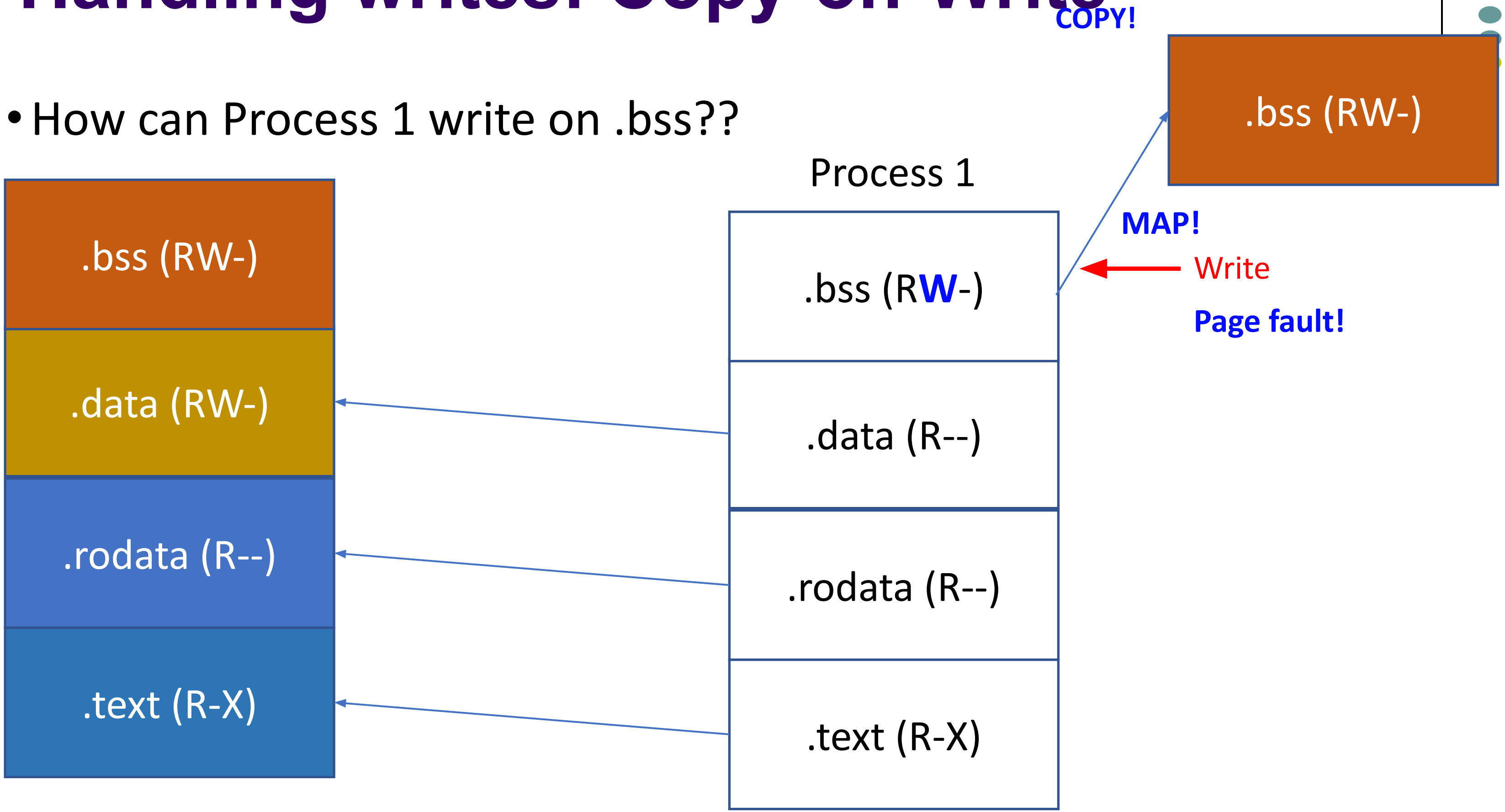

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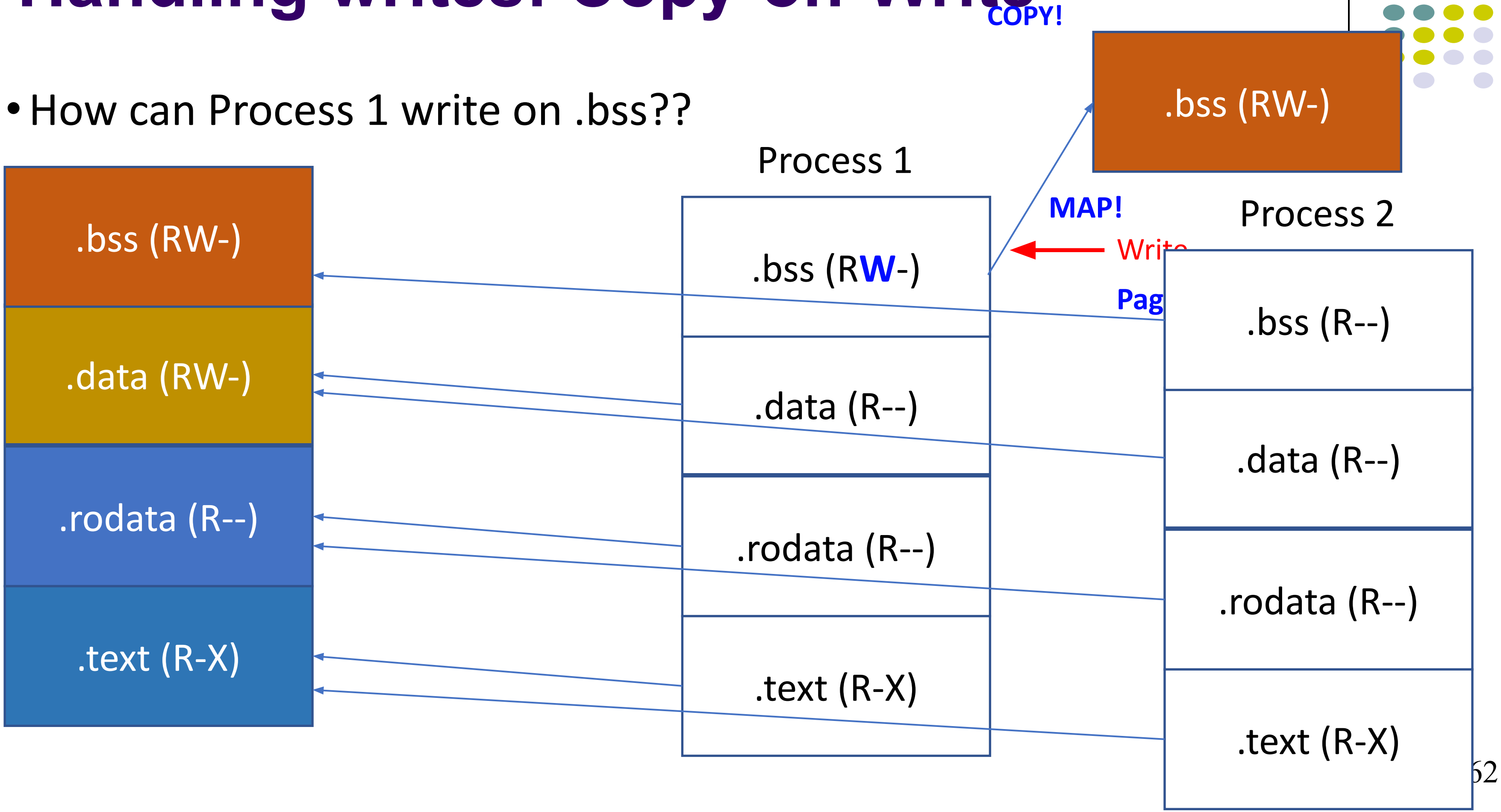

Benefits

- Can reduce time for copying contents that is already in some physical memory (page cache)

- Can reduce actual use of physical memory by sharing code/read-only data among multiple processes
  - 1,000,000 processes, requiring only 1 copy of .text/.rodata

- At the same time
  - Can support sharing of writable pages (if nothing has written at all)
  - Can create private pages seamlessly on write

Benefits

By exploiting page fault and its handler, we can implement copy-on-write, a mechanism that can reduce physical memory usage by sharing pages of same contents among multiple processes.

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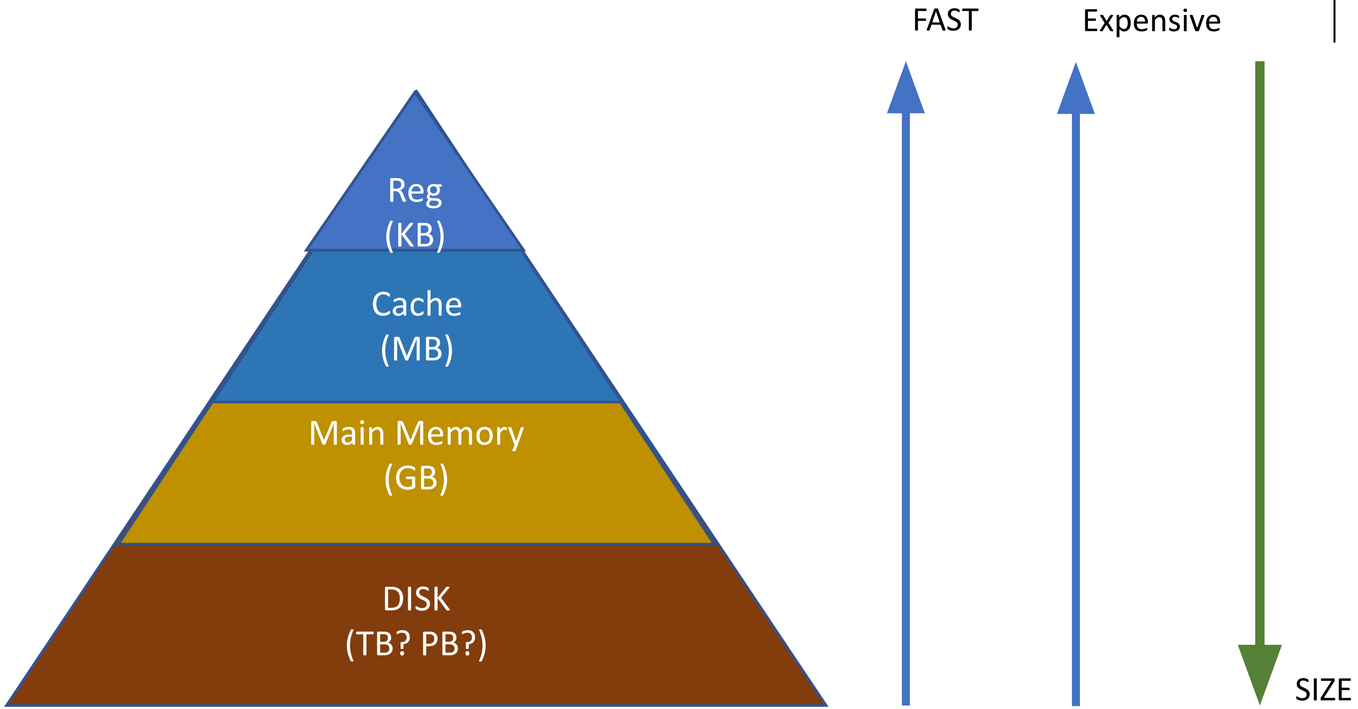
Handling low memory

- 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?

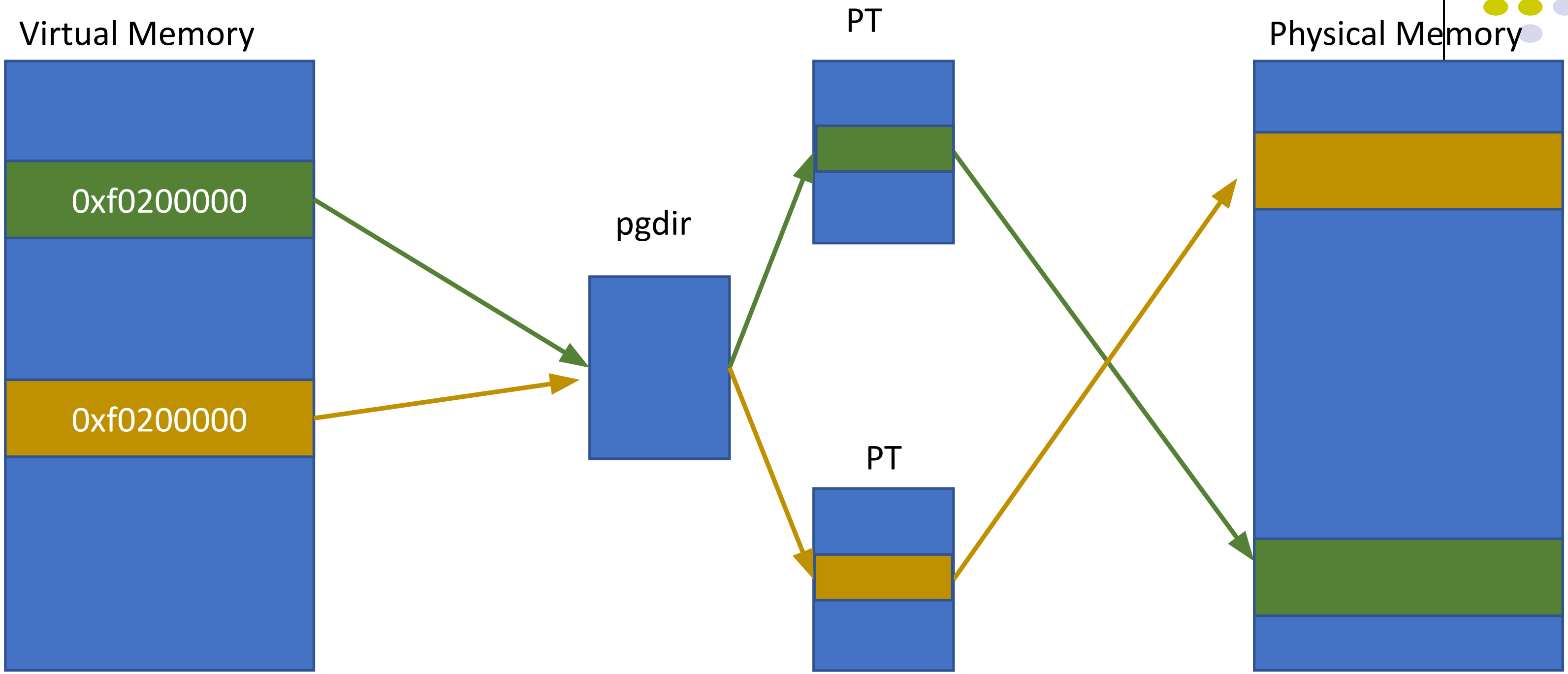
Memory Hierarchy



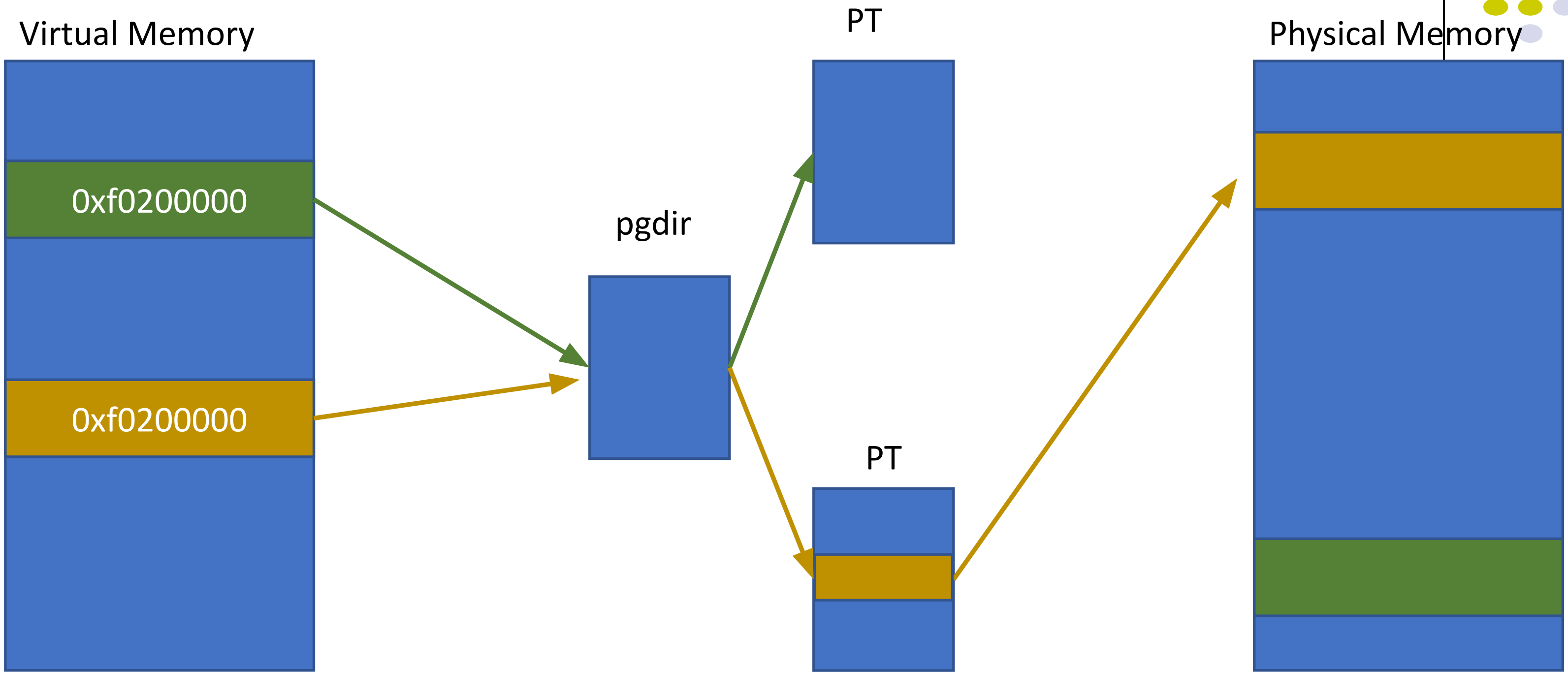
Memory Swapping

- Use disk as backing store under memory pressure

Memory Swapping



Memory Swapping - Removing a page



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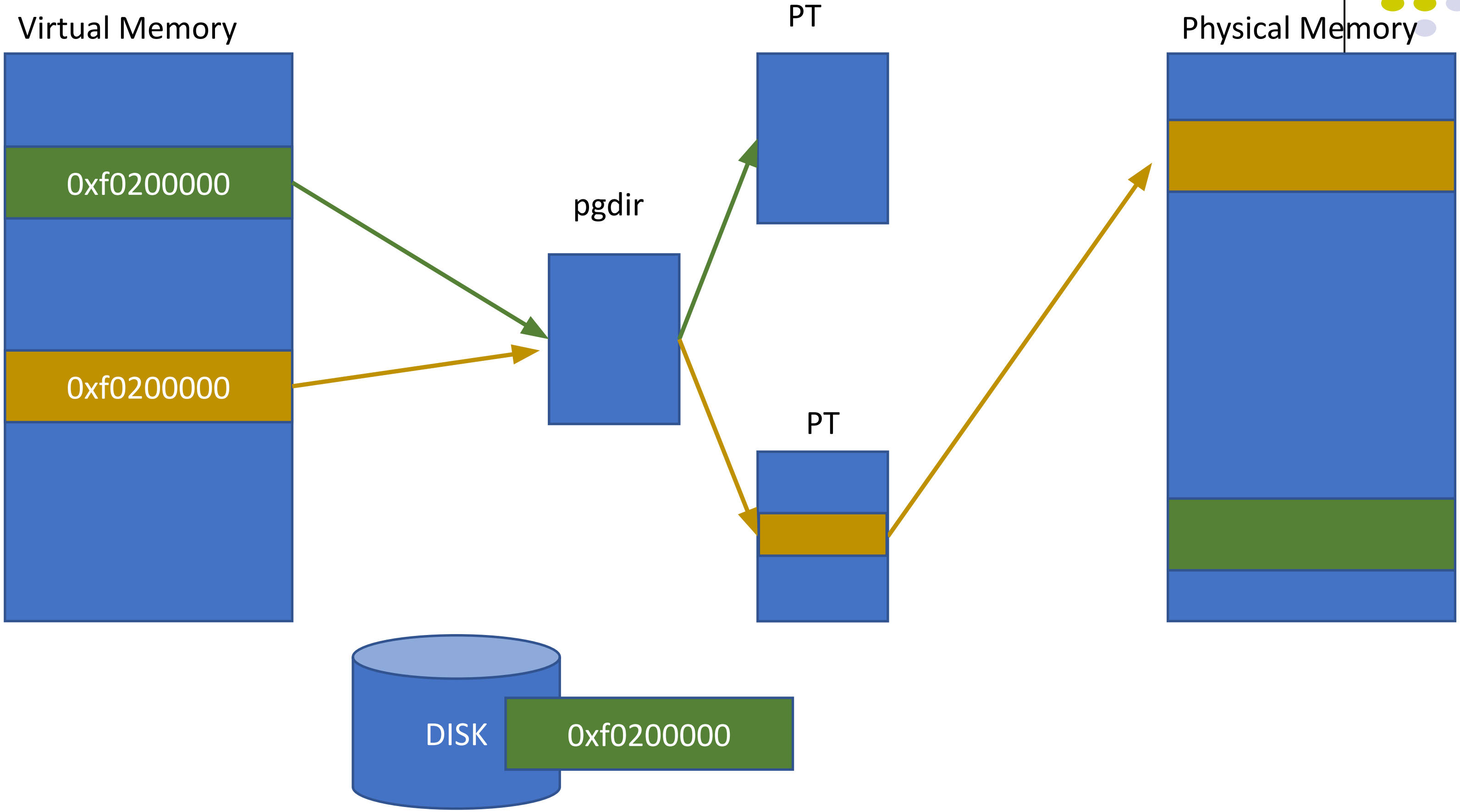

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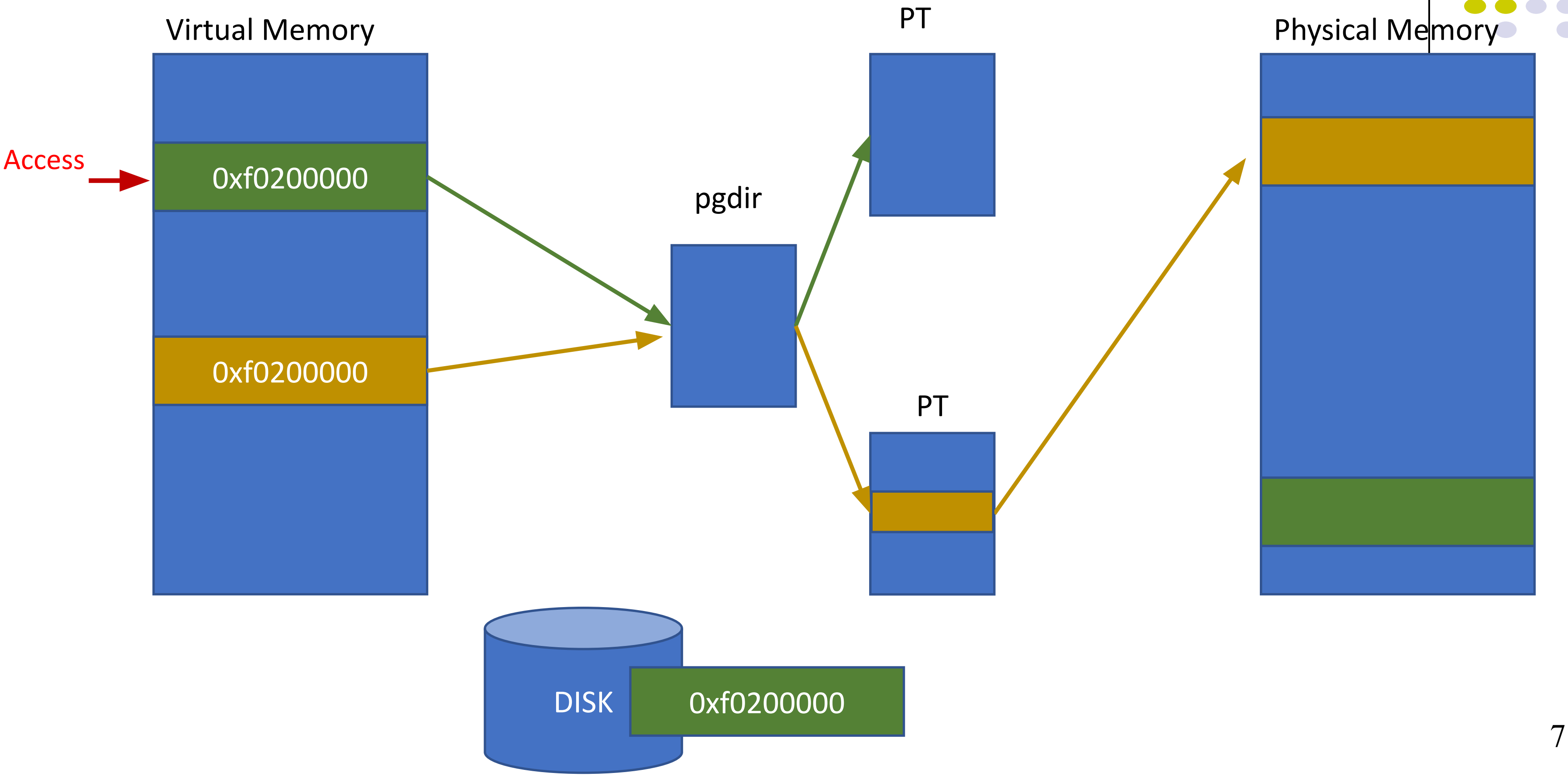

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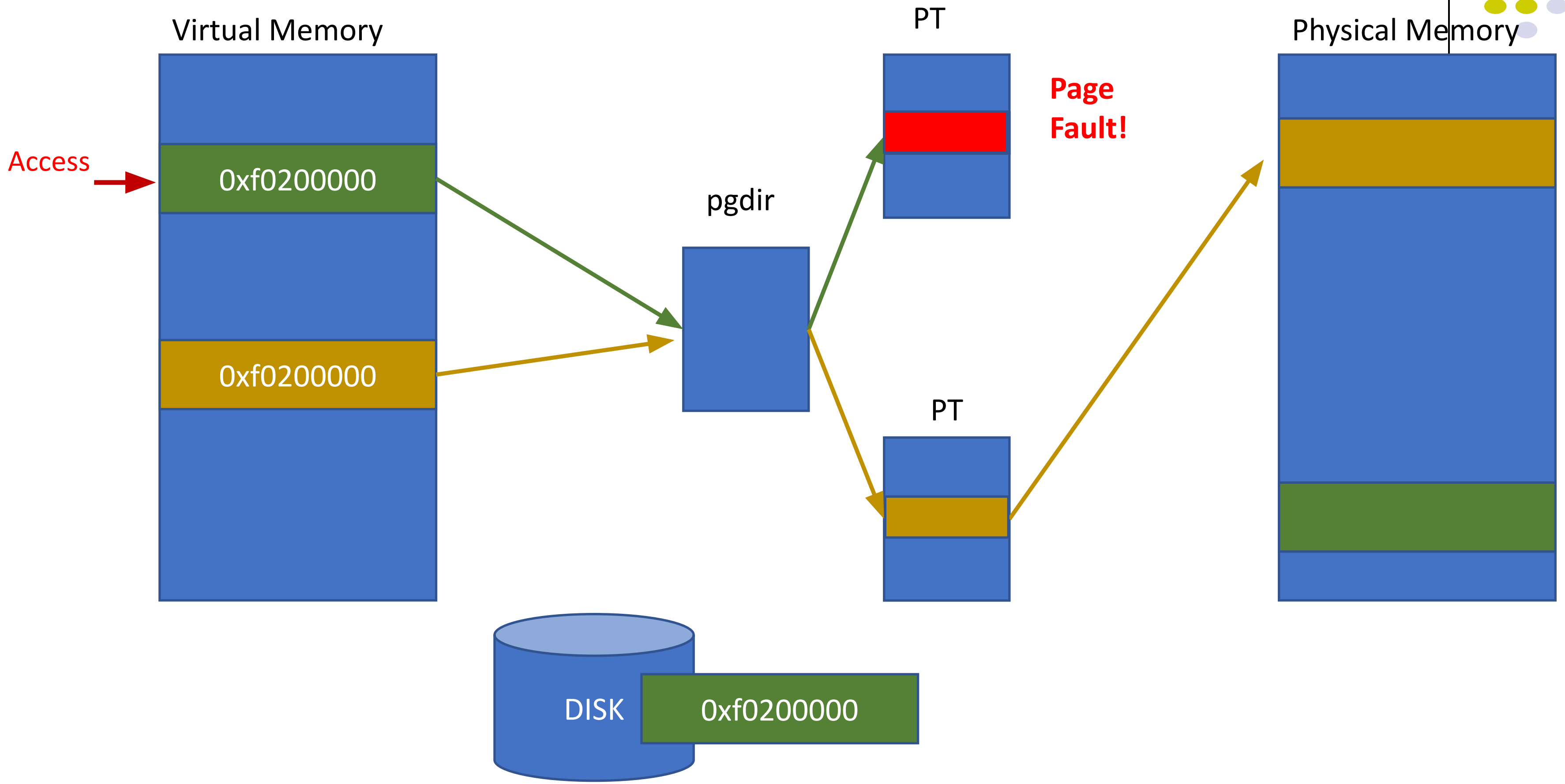

Swapping - Transparently load page from disk

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- Map it and then continue!

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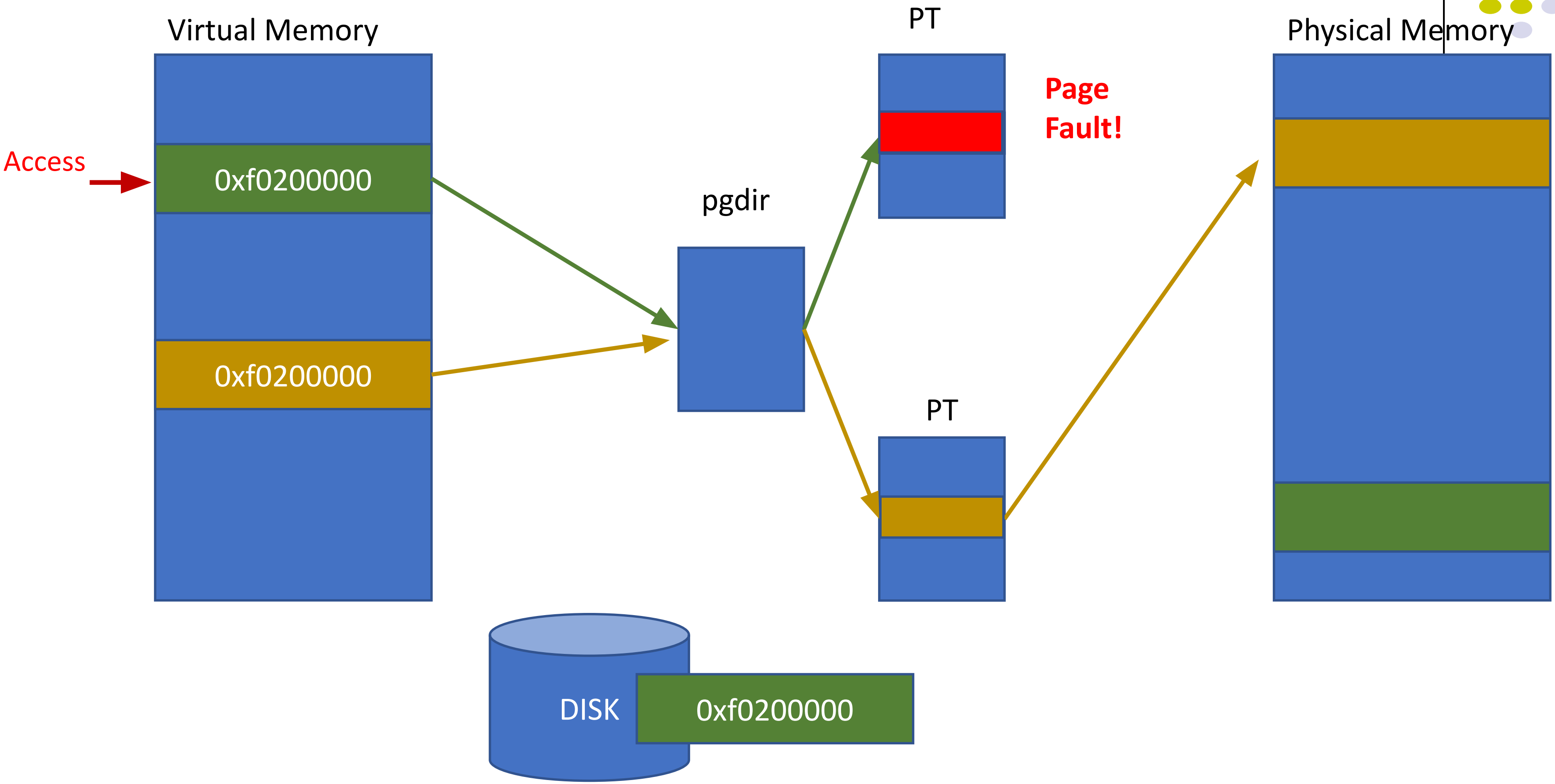

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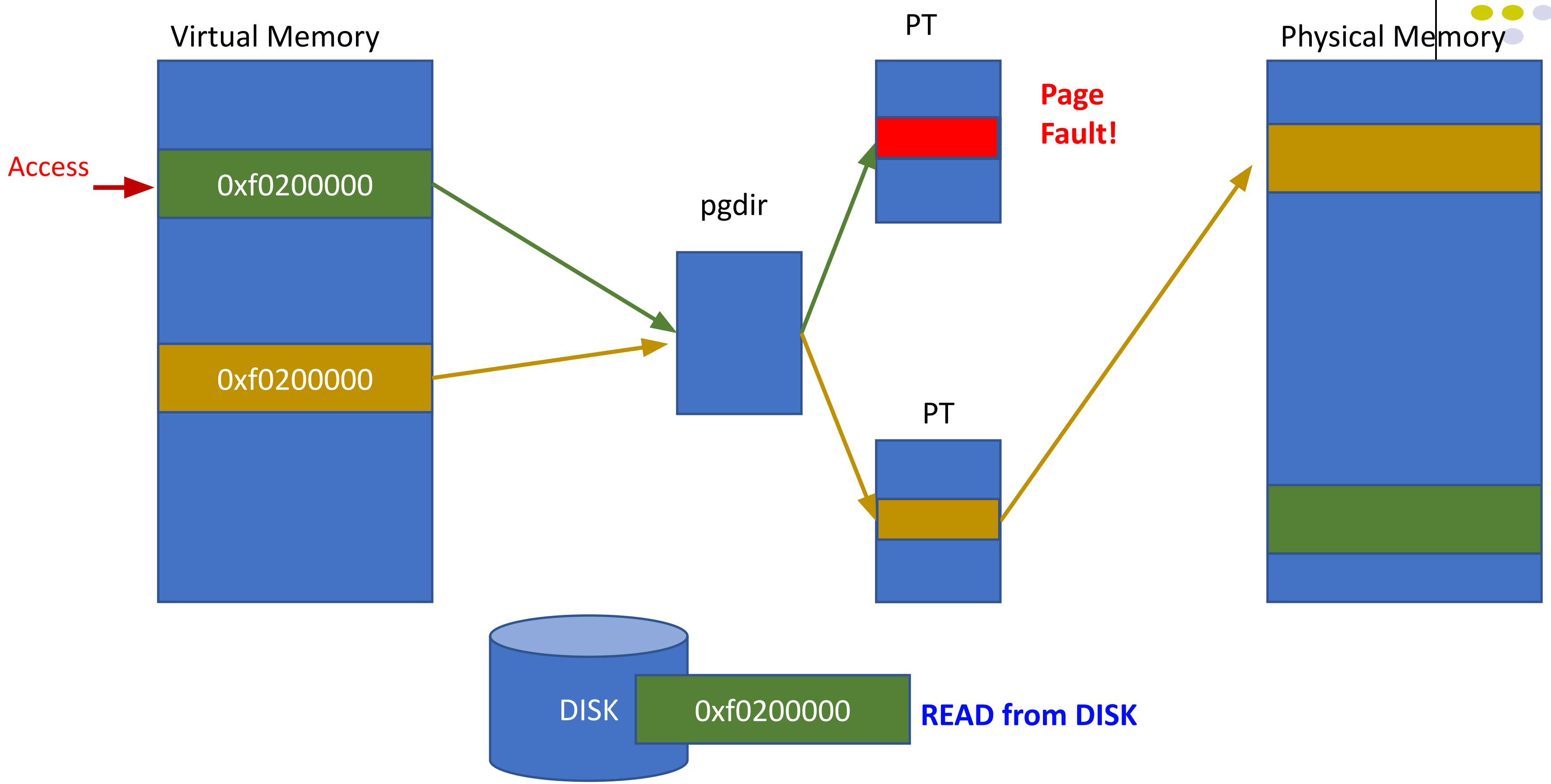

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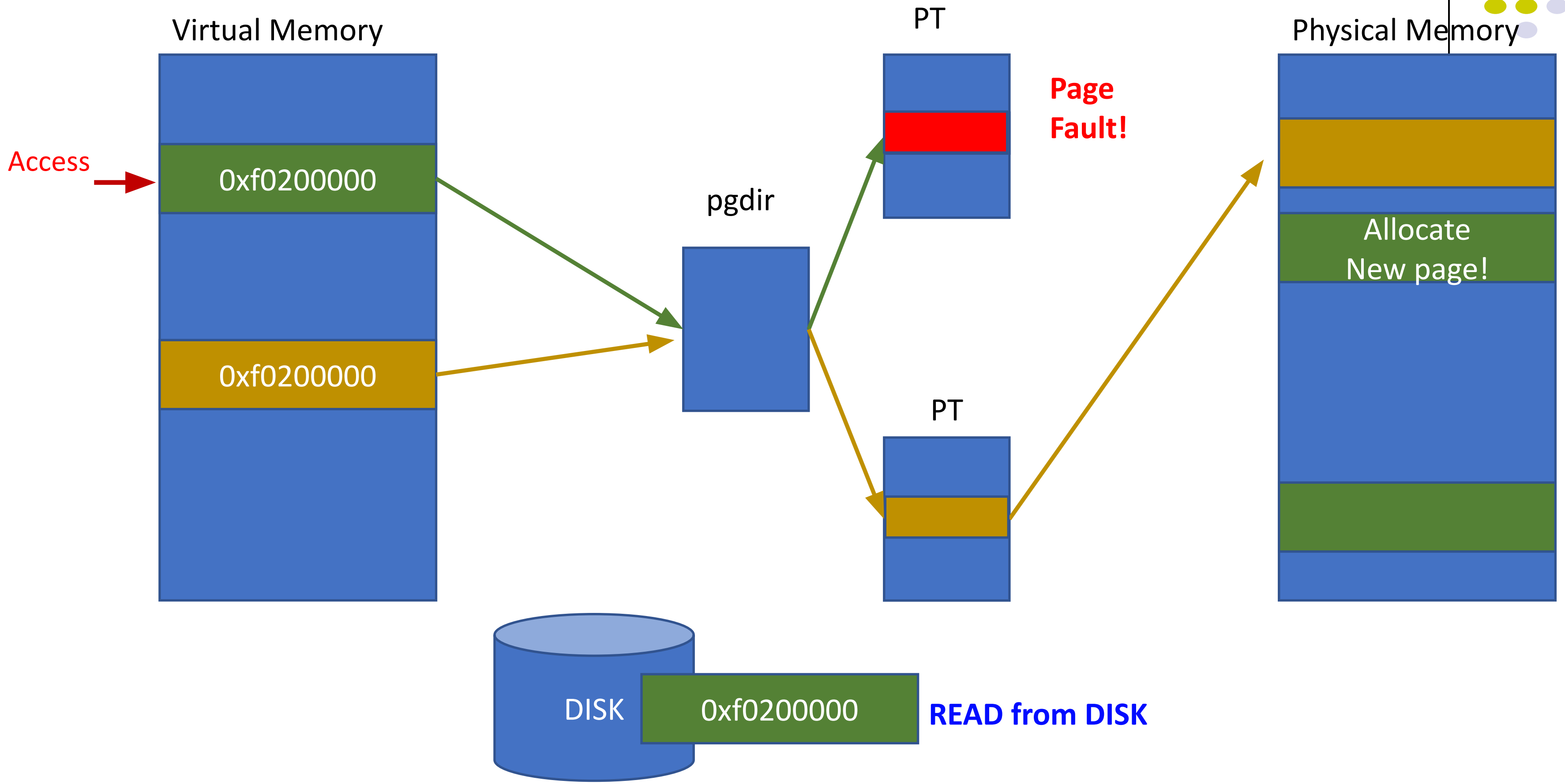

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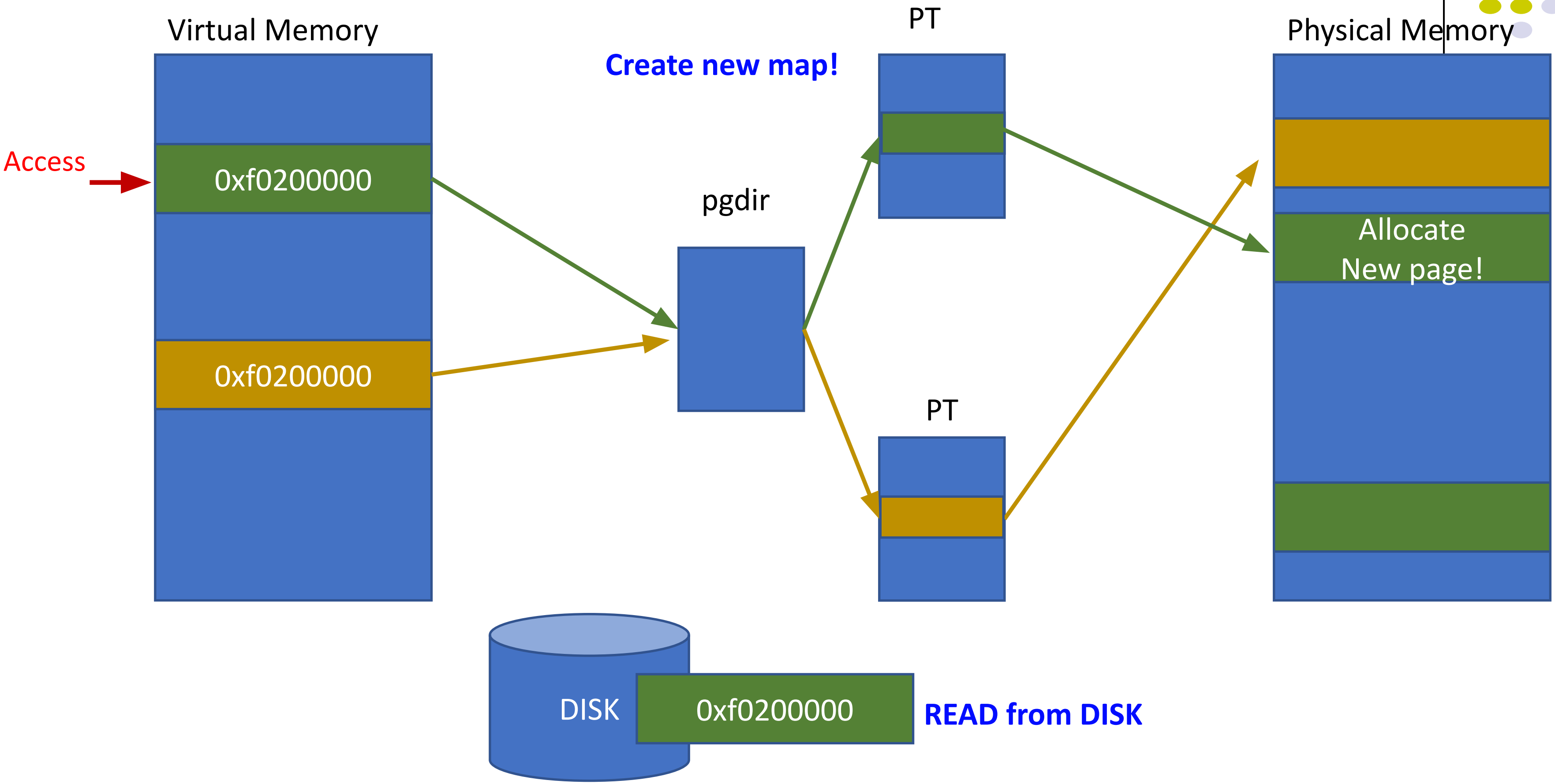

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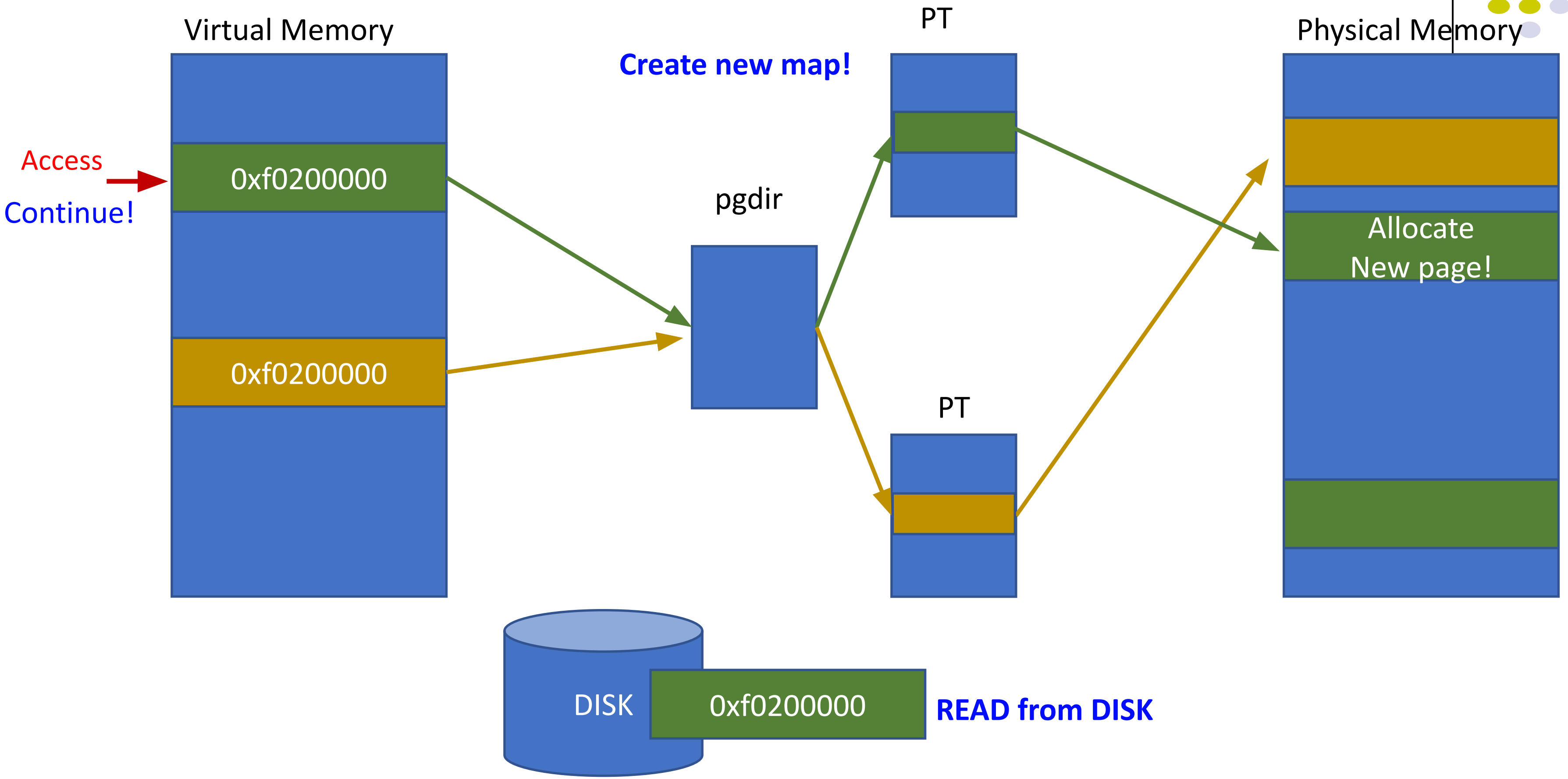

Page Fault

- Is generated when there is a memory error (regarding paging)
- Is an exception that can be recovered
  - And user program may resume the execution

- Is useful for implementing
  - Automatic stack allocation
  - Copy-on-write (will do in Lab4)
  - Swapping