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Project #4: `mmap()` with Huge Pages

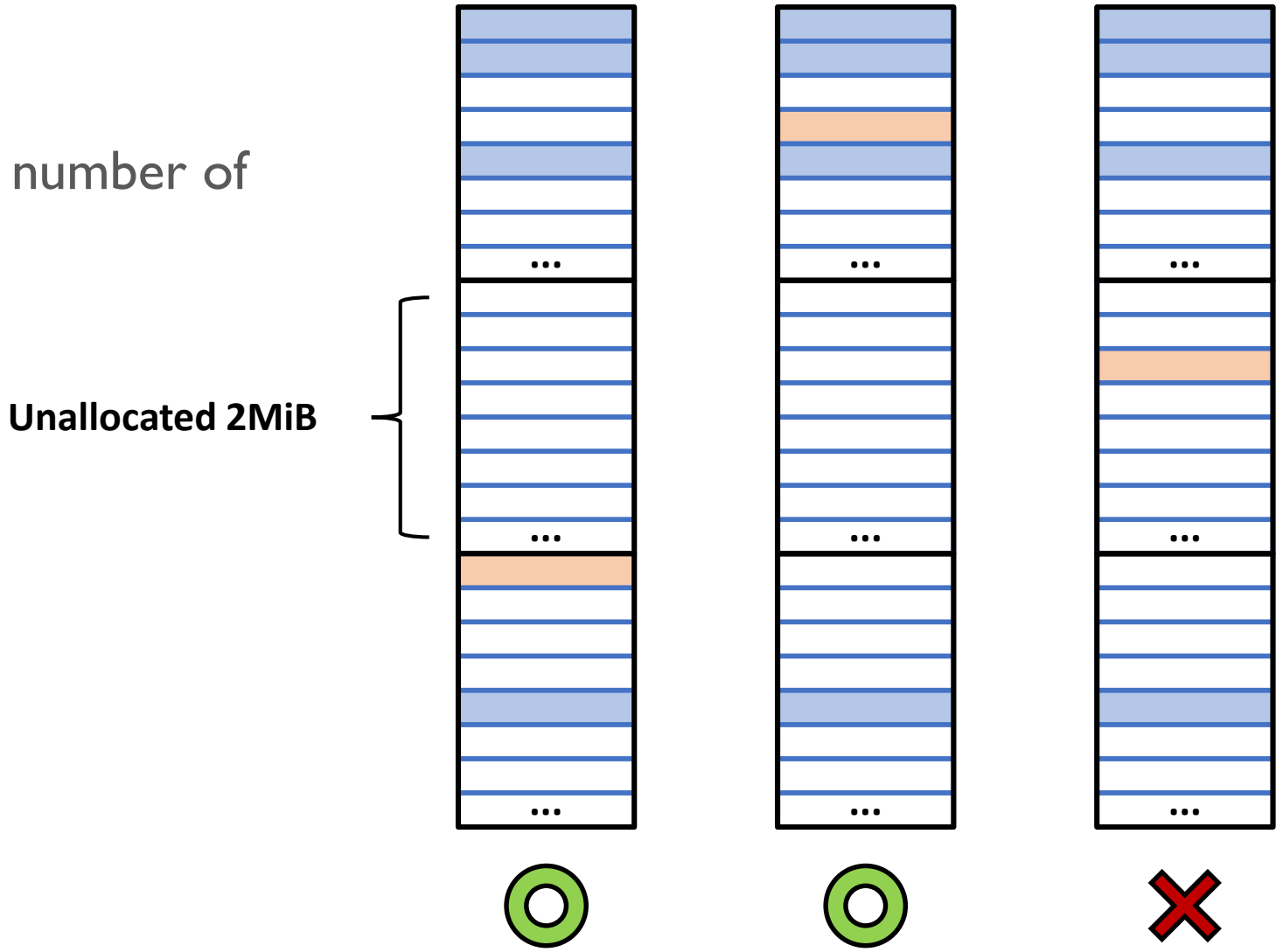
Pages and Huge Pages

- In this project, you need to implement huge page allocation/deallocation
- Base page: 4KiB
- Huge page: 2MiB
- The size of 512 base pages is same as the size of a single huge page

- The new allocator is to support four functions as follows:
  - `void *kalloc();`
  - `void kfree(void *pa);`
  - `void *kalloc_huge();`
  - `void kfree_huge(void *pa);`

Pages and Huge Pages

- Restriction
  - You should maximize the number of allocatable 2MiB frames



Memory Mapping

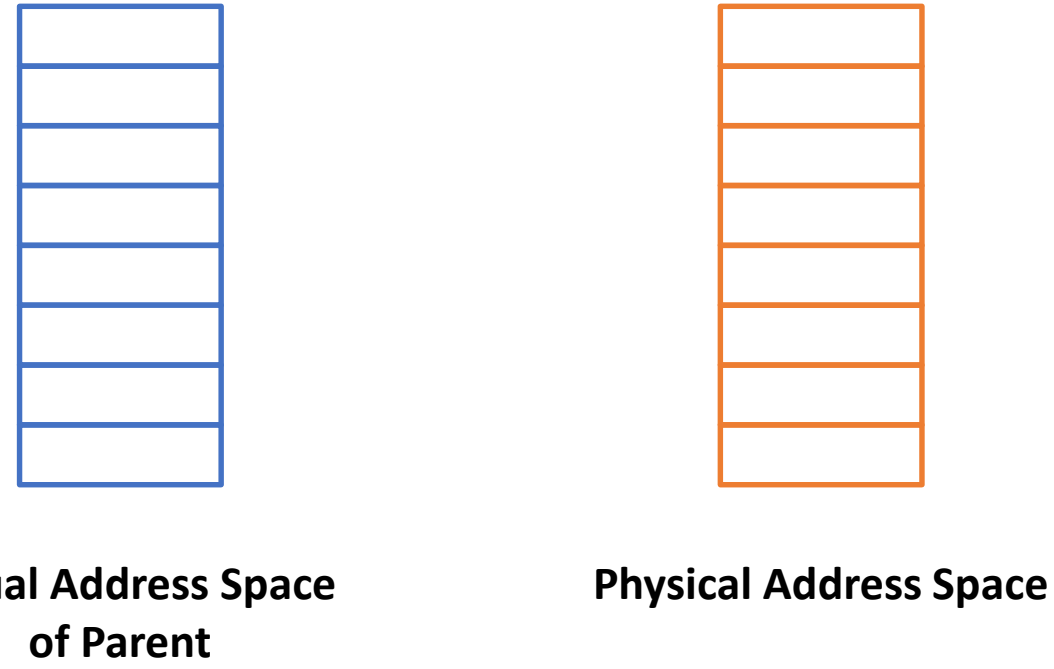
- `mmap()` system call creates a new mapping in the virtual address space

- You need to implement following system calls:
  - `void *mmap(void *addr, int length, int prot, int flags);`
  - `int munmap(void *addr);`

- We only consider anonymous mapping
- You don't have to care about file-backed mapping

Shared Mapping

- `mmap()`

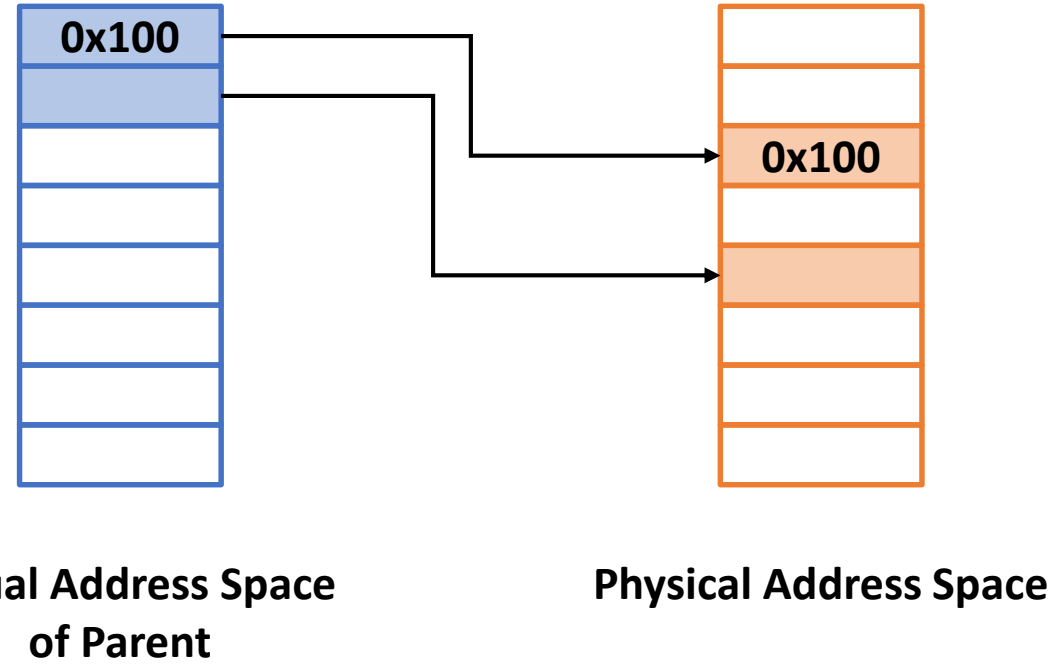


Virtual Address Space of Parent

Physical Address Space

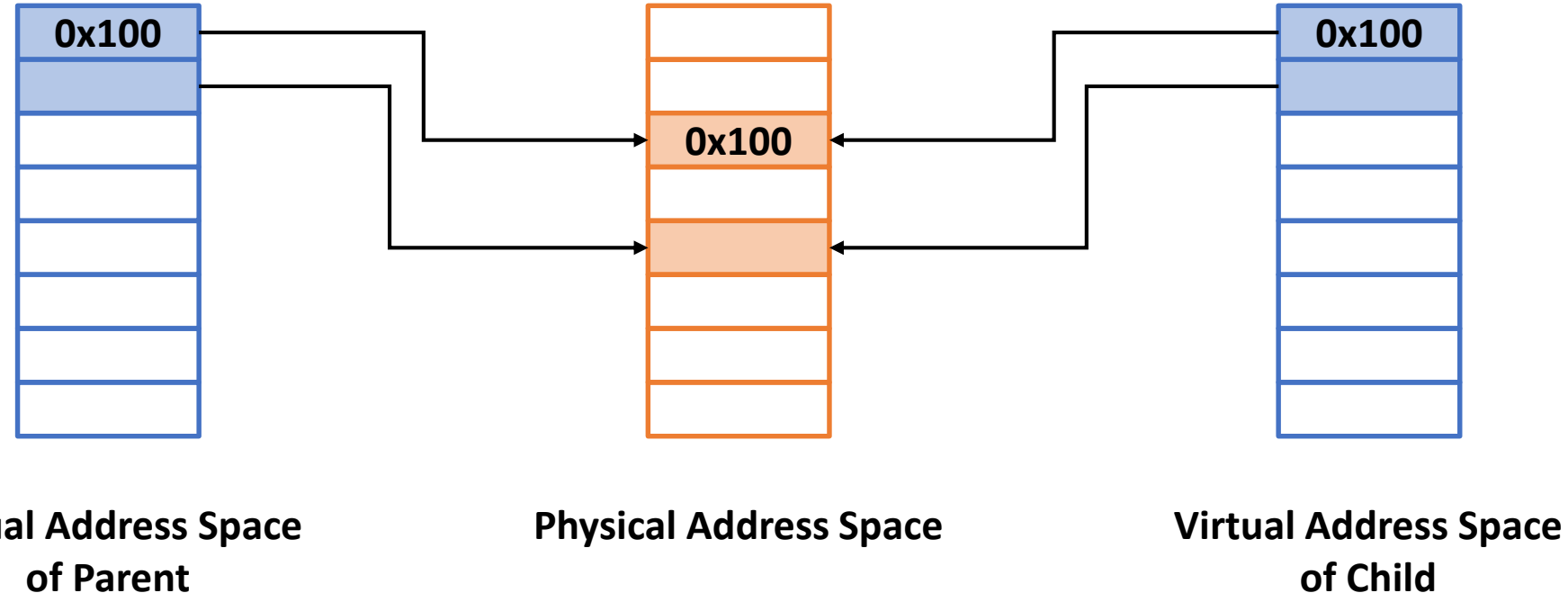
Shared Mapping

- Parent writes 0x100
  - Assume that each `mmap()`-ed page is writable



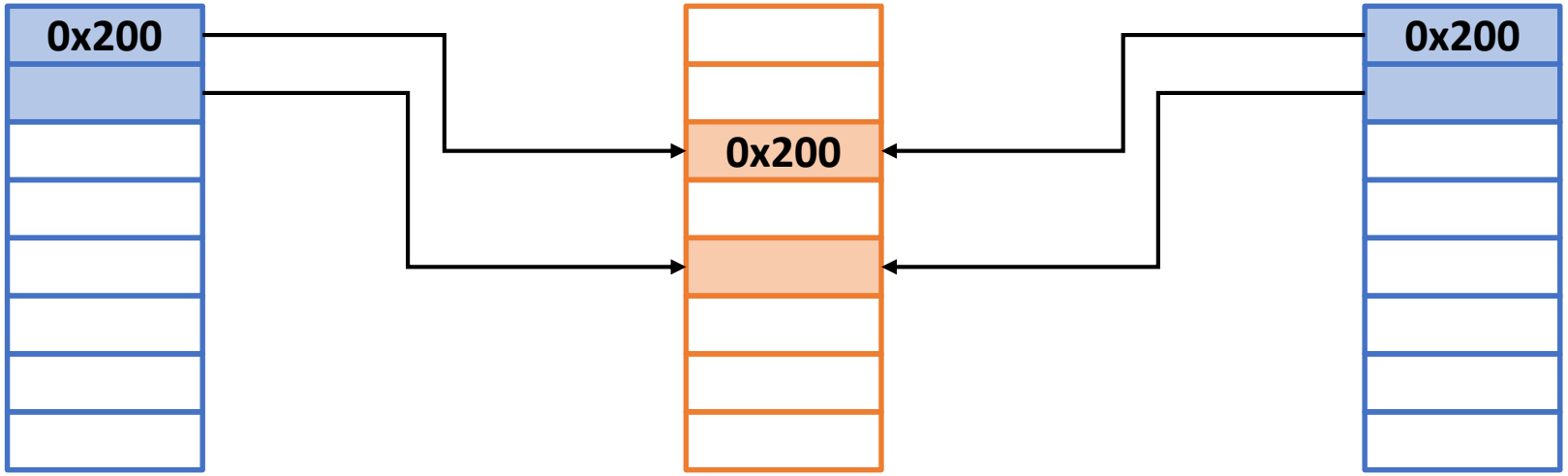
Shared Mapping

- `fork()`



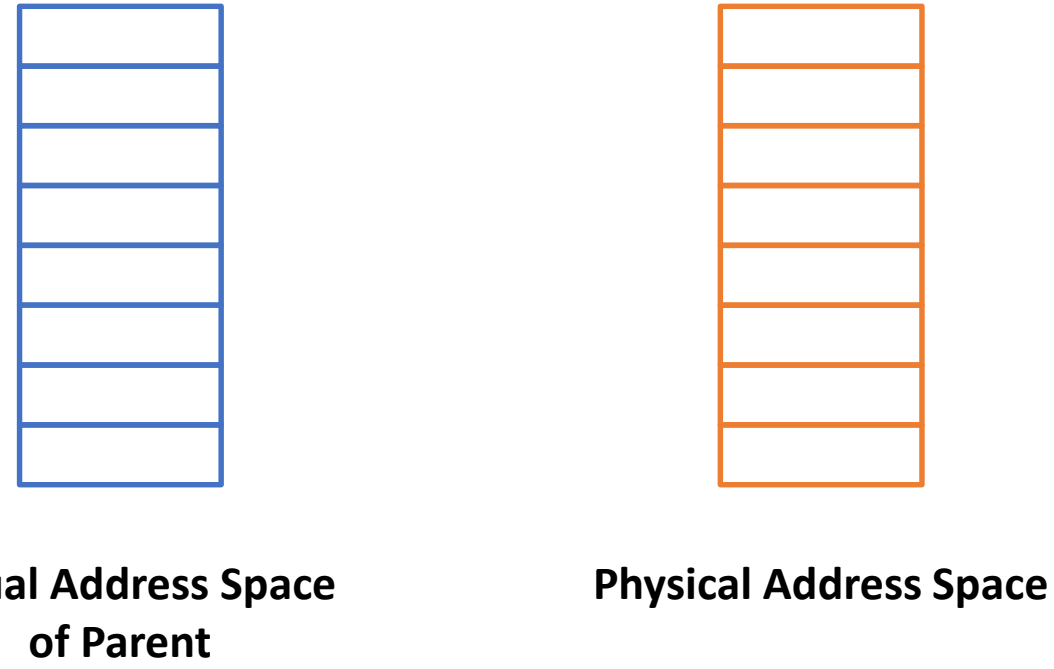
Shared Mapping

- Child writes 0x200
  - Assume that each `mmap()`-ed page is writable



Private Mapping

- `mmap()`

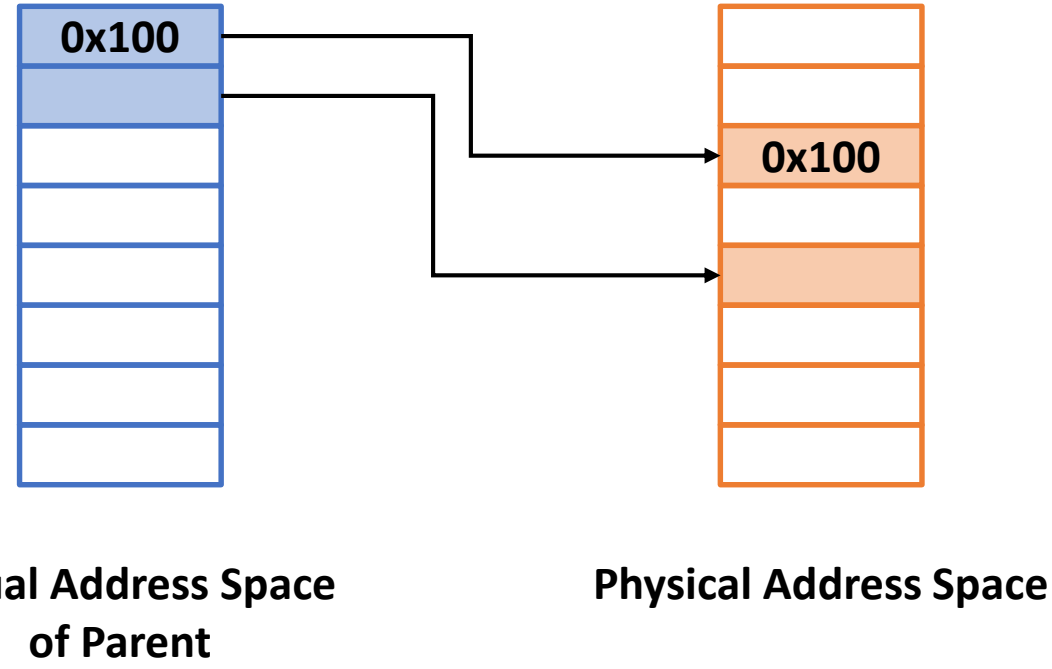


Virtual Address Space of Parent

Physical Address Space

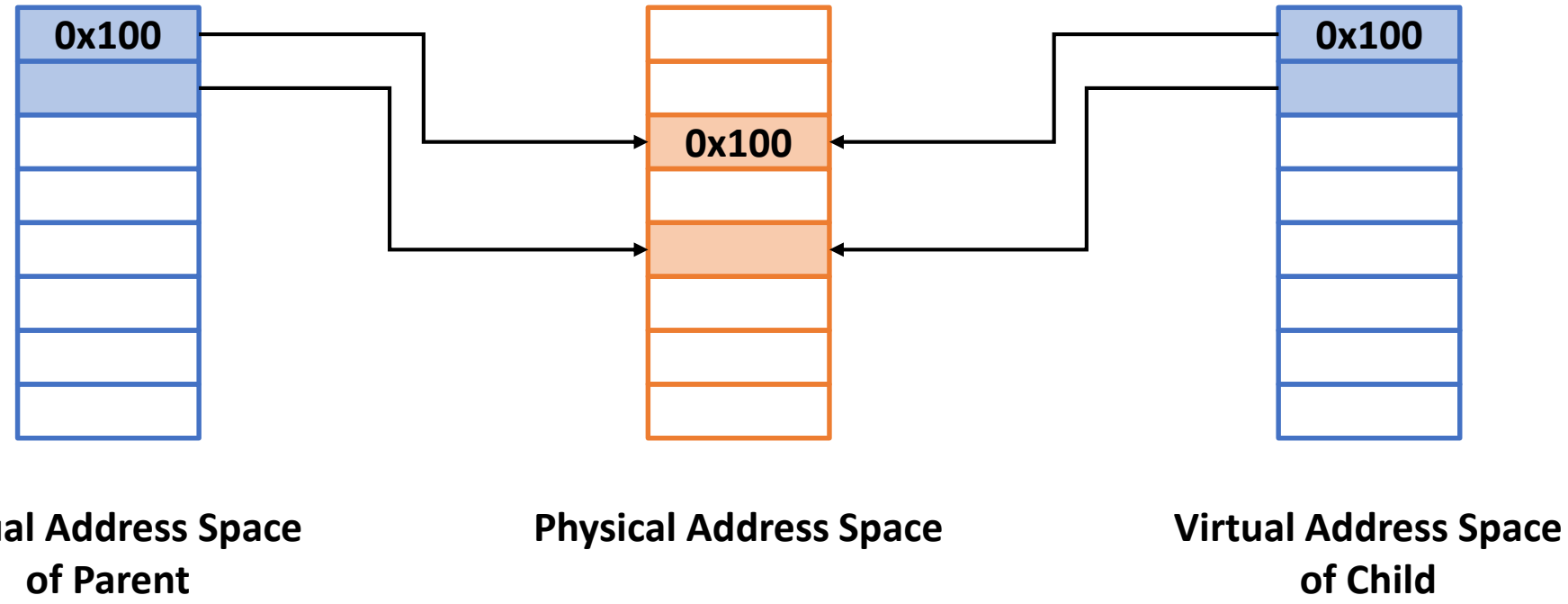
Private Mapping

- Parent writes 0x100
  - Assume that each `mmap()`-ed page is writable



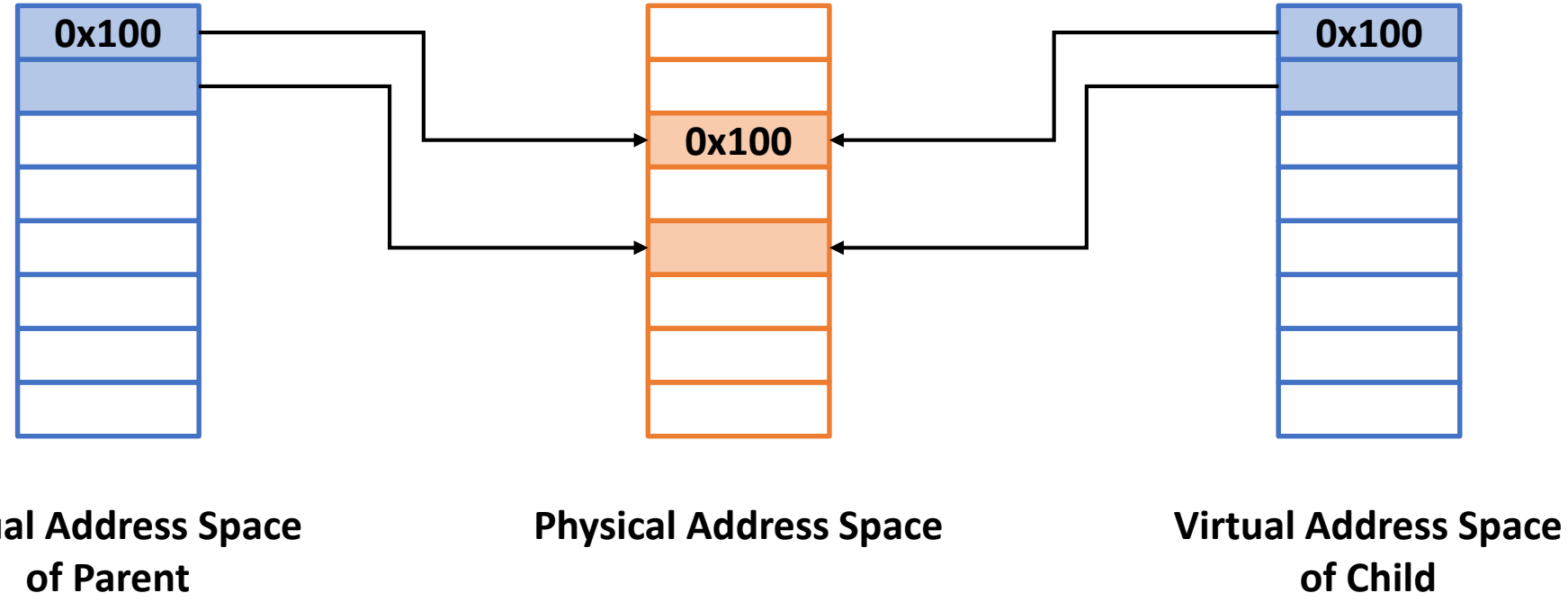
Private Mapping

- `fork()`



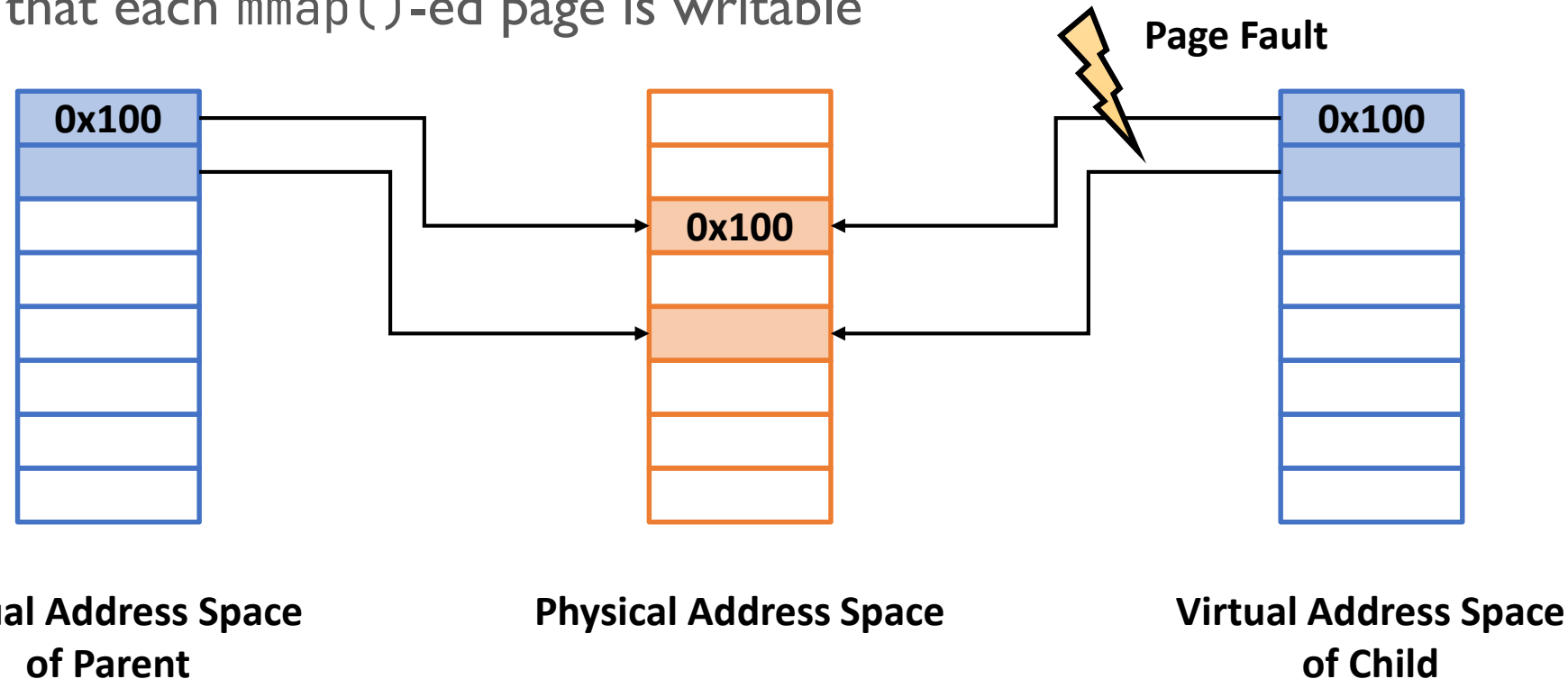
Private Mapping

- Child reads the content
  - Result: 0x100



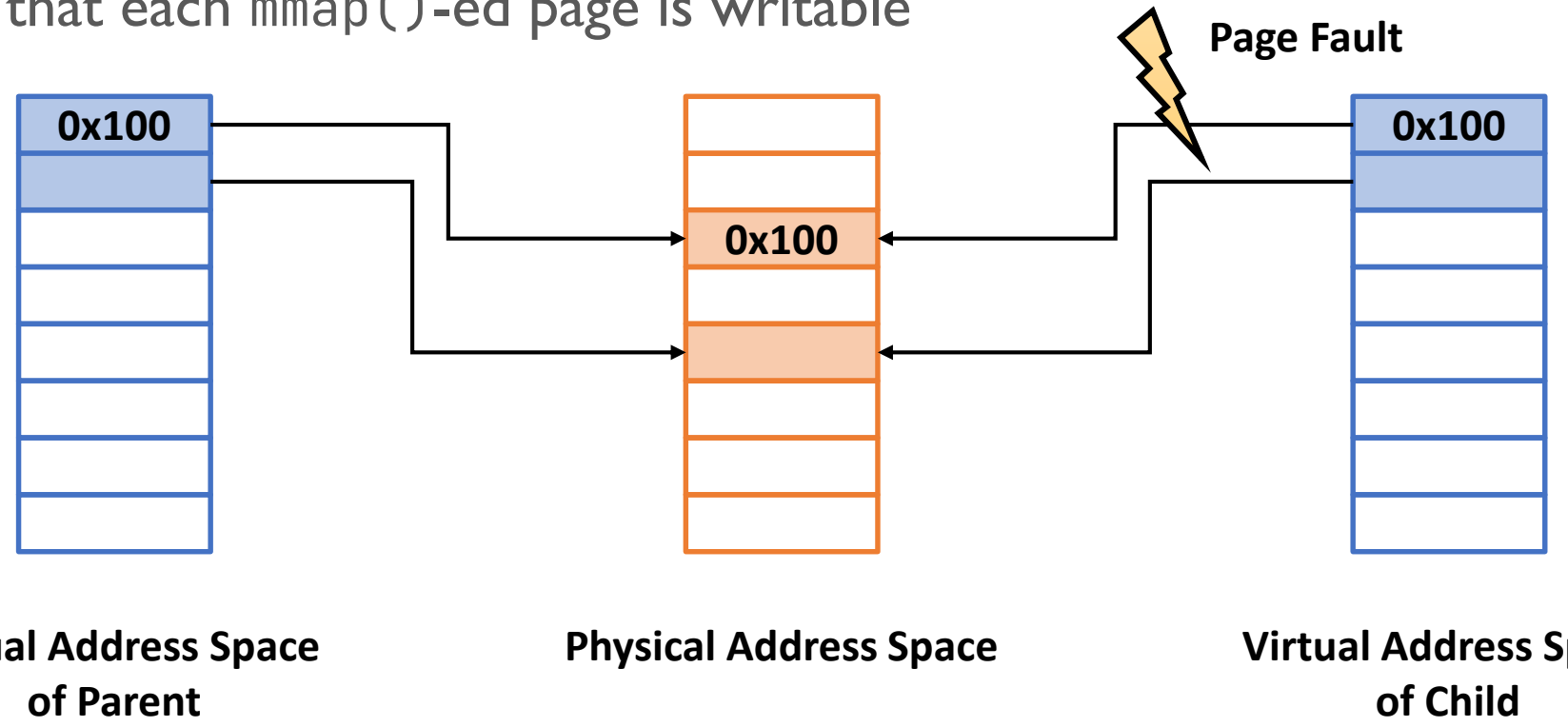
Private Mapping

- Child writes 0x200
  - Assume that each `mmap()`-ed page is writable



Private Mapping

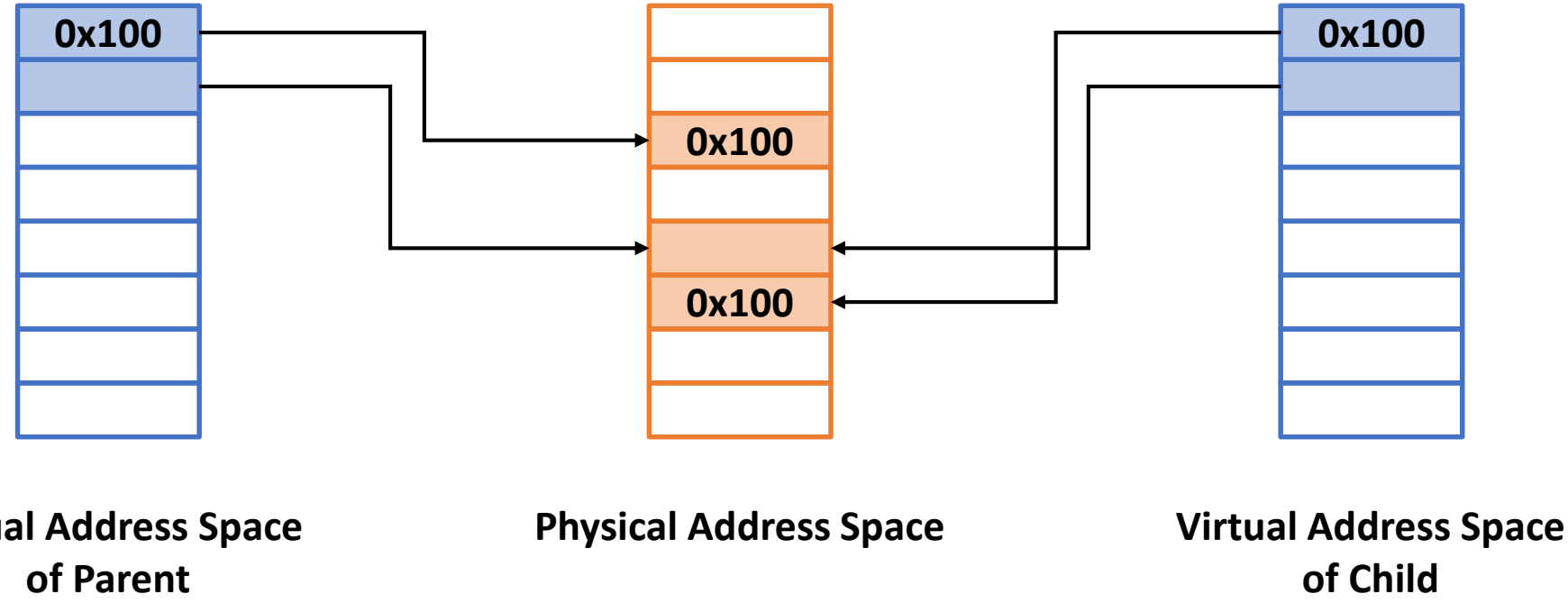
- Child writes 0x200
  - Assume that each `mmap()`-ed page is writable



The page fault is due to permission violation, because the page table entry indicates that the page is read-only, although the page appears to be writable to the user application.

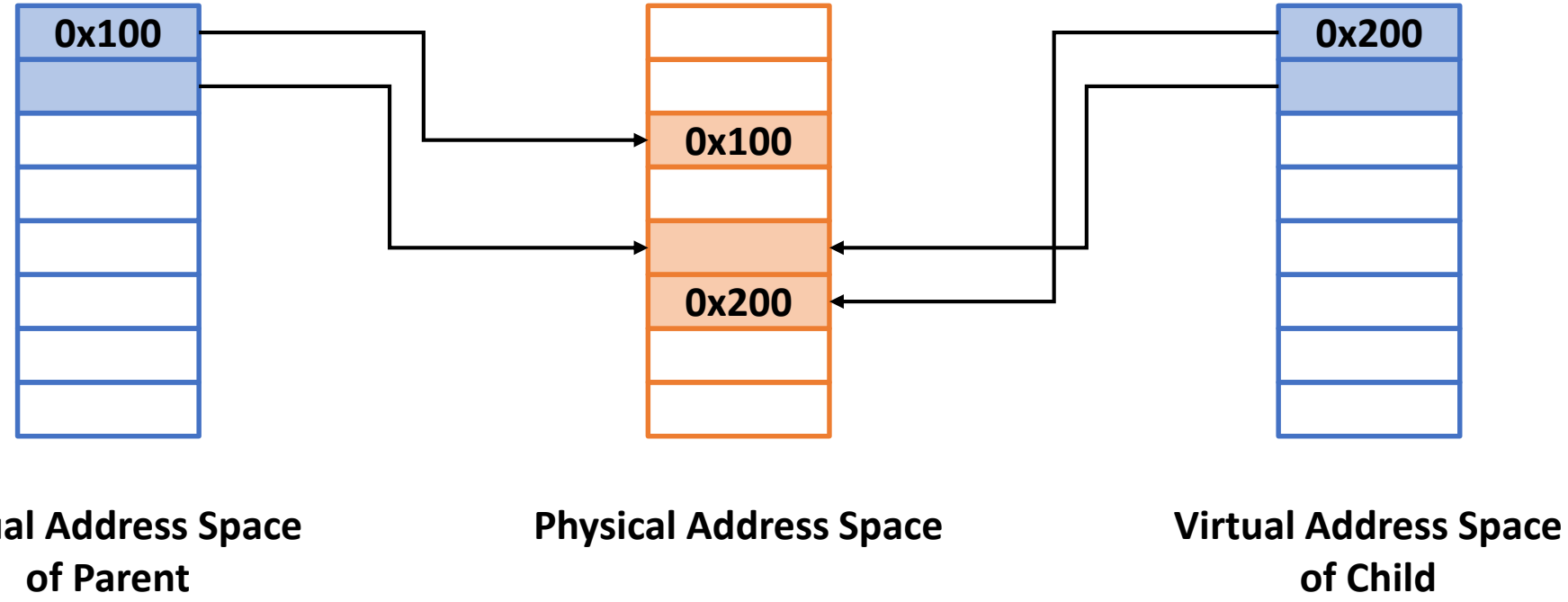
Private Mapping

- Page fault handling
  - Copy-on-write



Private Mapping

- Child writes 0x200 (Retry)
  - Assume that each `mmap()`-ed page is writable



Cleanup

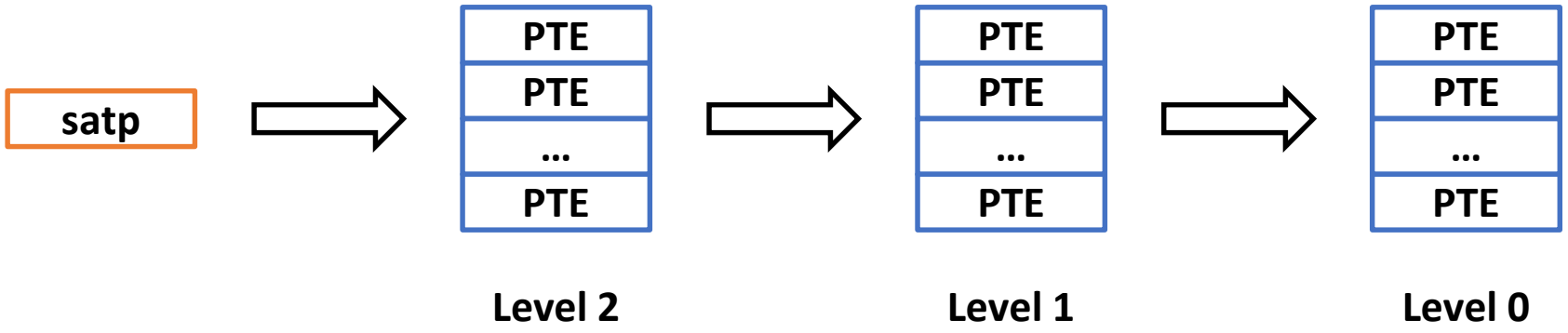
- All of the `mmap()`-ed regions should be unmapped on process termination

- Memory unmapping does not always require memory deallocation
  - When should we deallocate physical pages in case of shared mapping?
  - When should we deallocate physical pages in case of private mapping?

Sv39

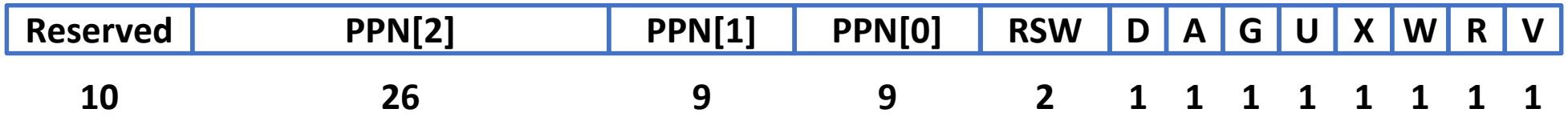
- xv6 uses 39-bit address system called Sv39
- 3-level page table
- It supports 1GiB and 2MiB huge pages
  - If a level 2 entry is a leaf, it represents an 1GiB-sized huge page
  - If a level 1 entry is a leaf, it represents a 2MiB-sized huge page
  - If a level 0 entry is a leaf, it represents a 4KiB base page

Sv39 Page Table



Reserved	PPN[2]	PPN[1]	PPN[0]	RSW	D	A	G	U	X	W	R	V
10	26	9	9	2	1	1	1	1	1	1	1	1

Sv39 Page Table Entry



- Page table entry bits
  - D: Dirty bit
  - A: Access bit
  - G: Global bit
  - U: User bit
  - X: Execute bit
  - W: Write bit
  - R: Read bit
  - V: Valid bit

- If X, W, and R are all 0, the PTE is a pointer to next level

Project #4

- Tips
  - Read Chap. 3 and 4 of the xv6 book to understand the virtual memory subsystem and page-fault exceptions in xv6

Project #4

- Assumptions
  - The range of the target virtual address in `mmap()` is from `PHYSTOP` to `MAXVA-0x10000000`
  - The maximum size in `mmap()` is limited to 64MiB
  - Each process can have up to 4 memory-mapped regions
  - The system can support up to 64 distinct memory-mapped regions in total

- You may assume that no test scenarios break the assumptions

Project #4

- Restrictions
  - On `exit()` or `exec()`, all the memory-mapped regions should be unmapped
  - Your implementation should work on multi-core systems
  - Do not add any other system calls
  - You only need to modify those files in the `./kernel` directory except for the `./kernel/ktest.c` file

Project #4

- Skeleton Code
  - You should work on the `pa4` branch of the `xv6-riscv-snu` repository as follows:

```
$ git clone https://github.com/snu-csl/xv6-riscv-snu
$ git checkout pa4
```

  - The `pa4` branch has three user-level programs (`mmaptest1` ~ `mmaptest3`) which can be built from `./user/mmaptest1.c` ~ `./user/mmaptest3.c`, respectively

Project #4

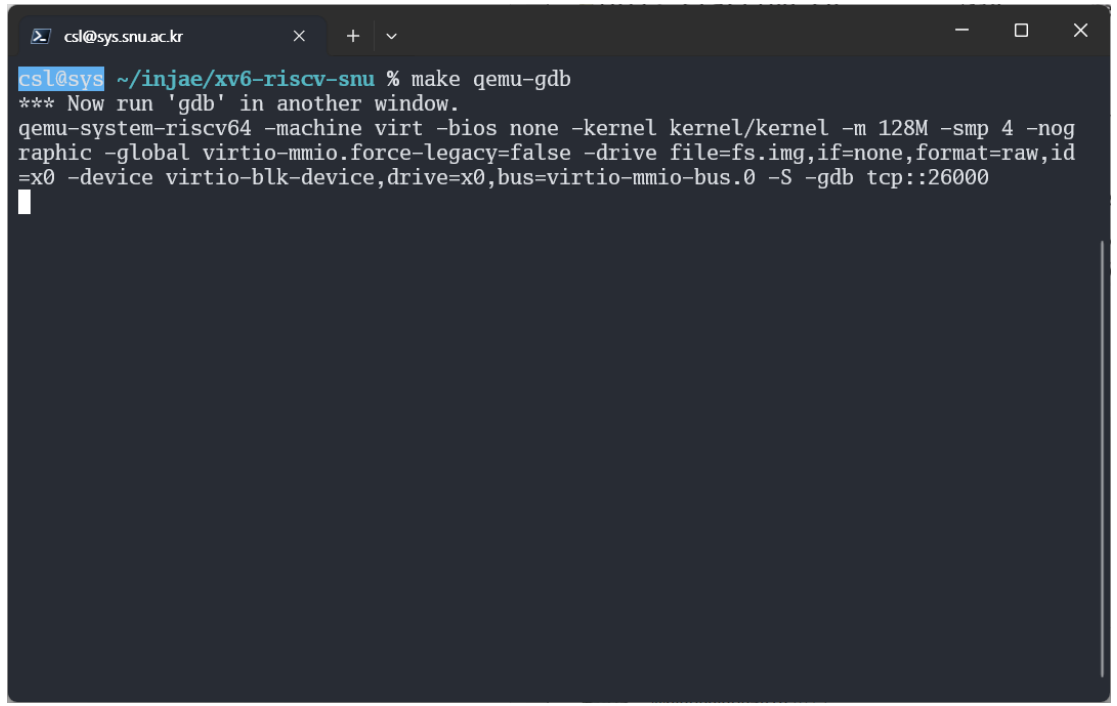
- Due
  - 11:59 PM, November 25 (Saturday)

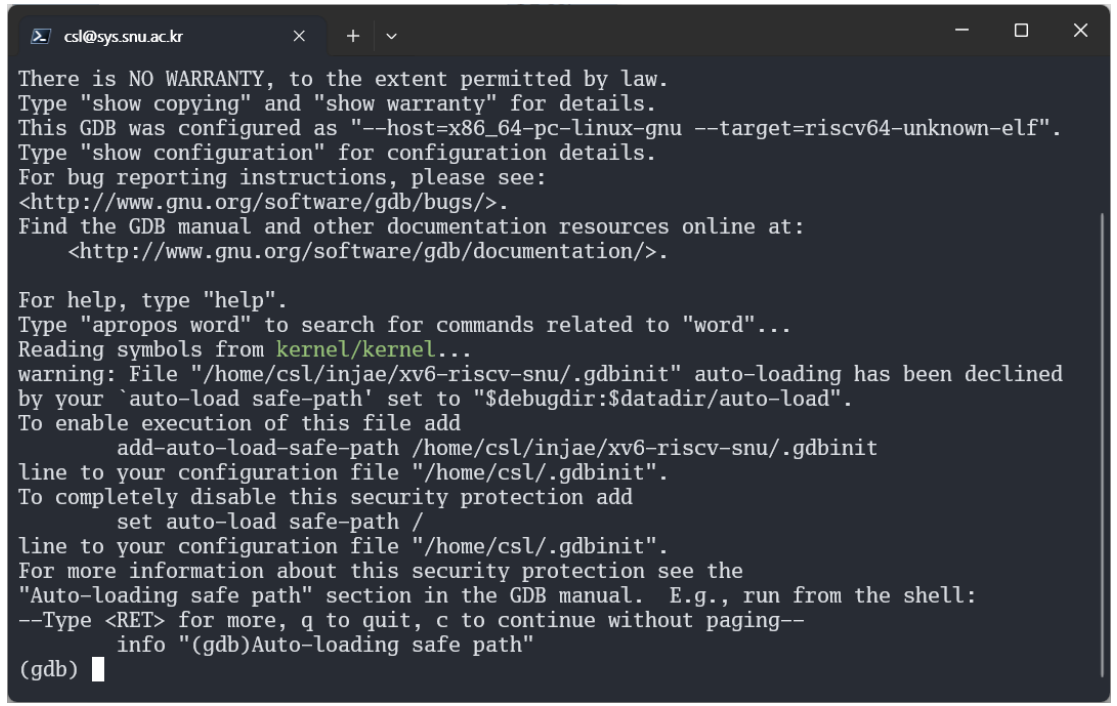
- Submission
  - Run `make submit` command to generate a tarball named `xv6-pa4-{STUDENTID}.tar.gz` in the `xv6-riscv-snu` directory
  - Upload the compressed file to the submission server
  - The total number of submissions for this project will be limited to 30
  - Only the version marked FINAL will be considered for the project score
  - In this project, you need to submit a design report

Using GDB with QEMU

GDB with QEMU

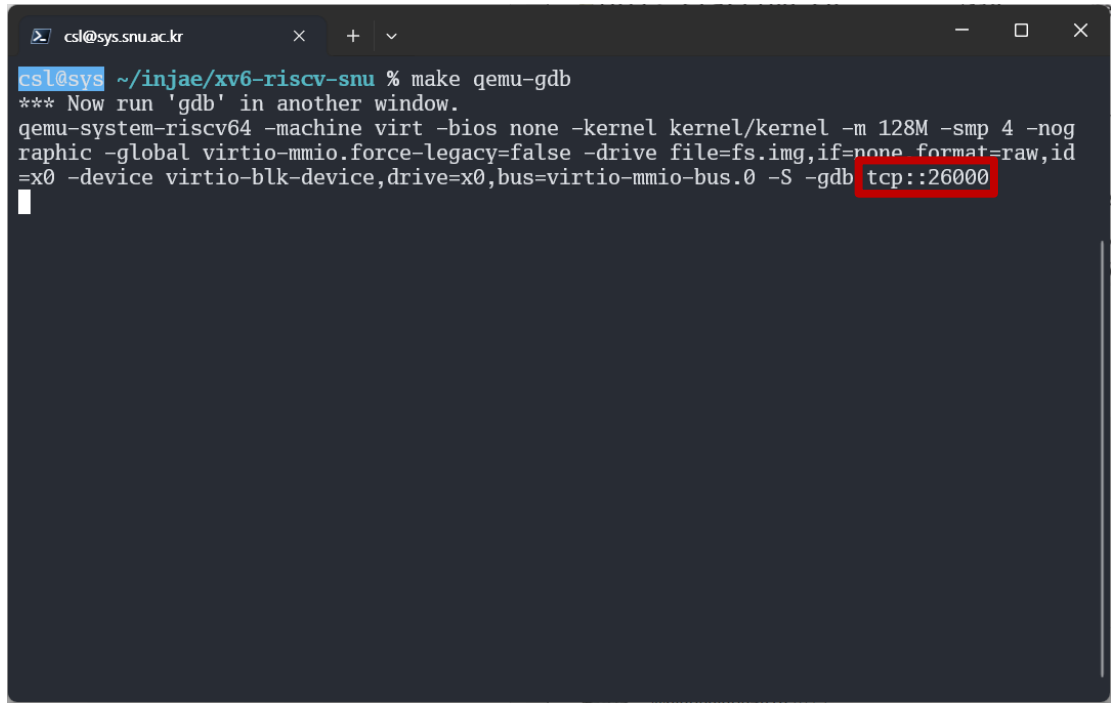
- In the `xv6-riscv-snu` directory,
- Run `make qemu-gdb` to run QEMU
- In another shell, run `riscv64-unknown-elf-gdb ./kernel/kernel`

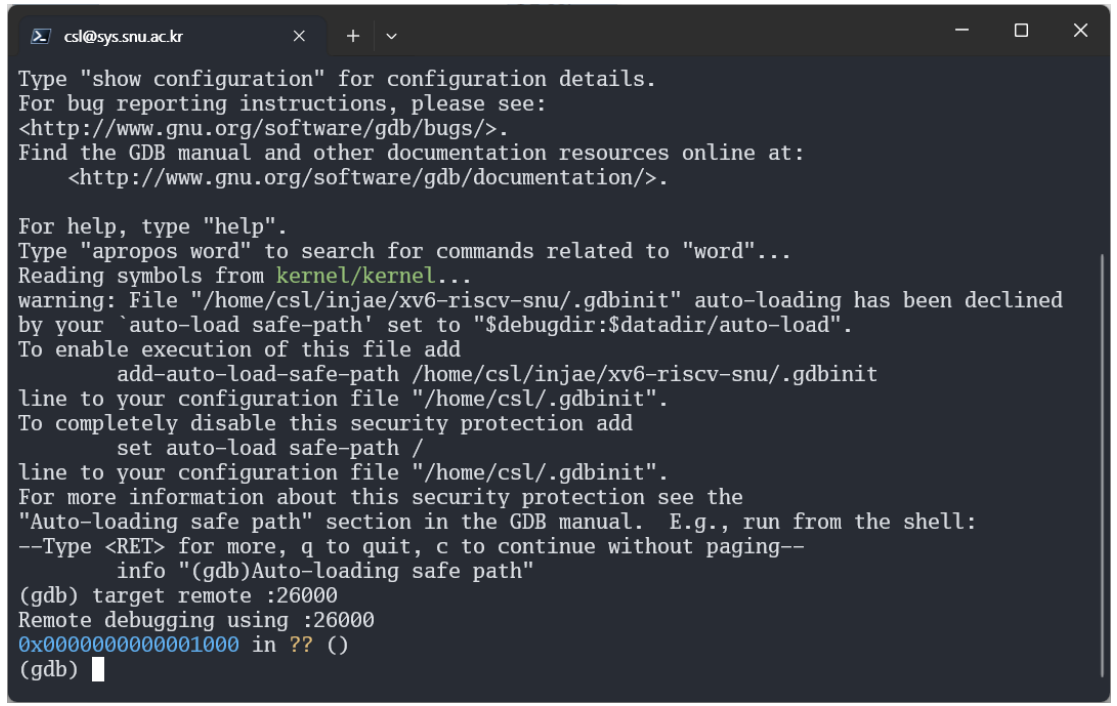




GDB with QEMU

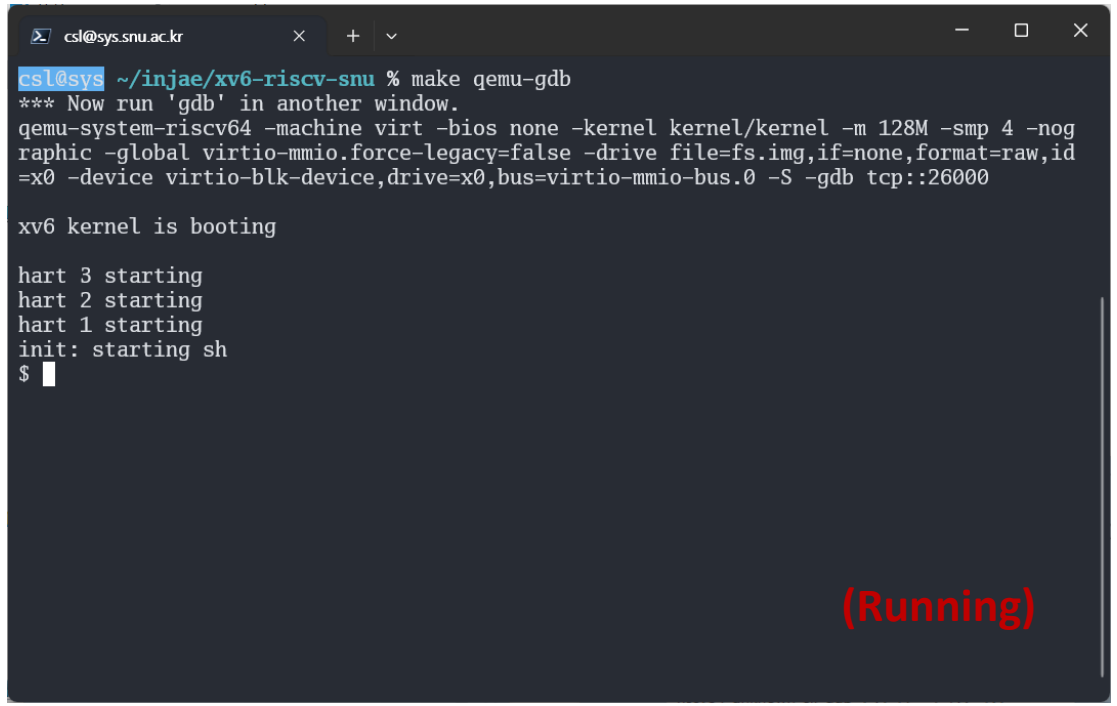
- In GDB, enter `target remote :<port>`
- You can find TCP port in the QEMU log

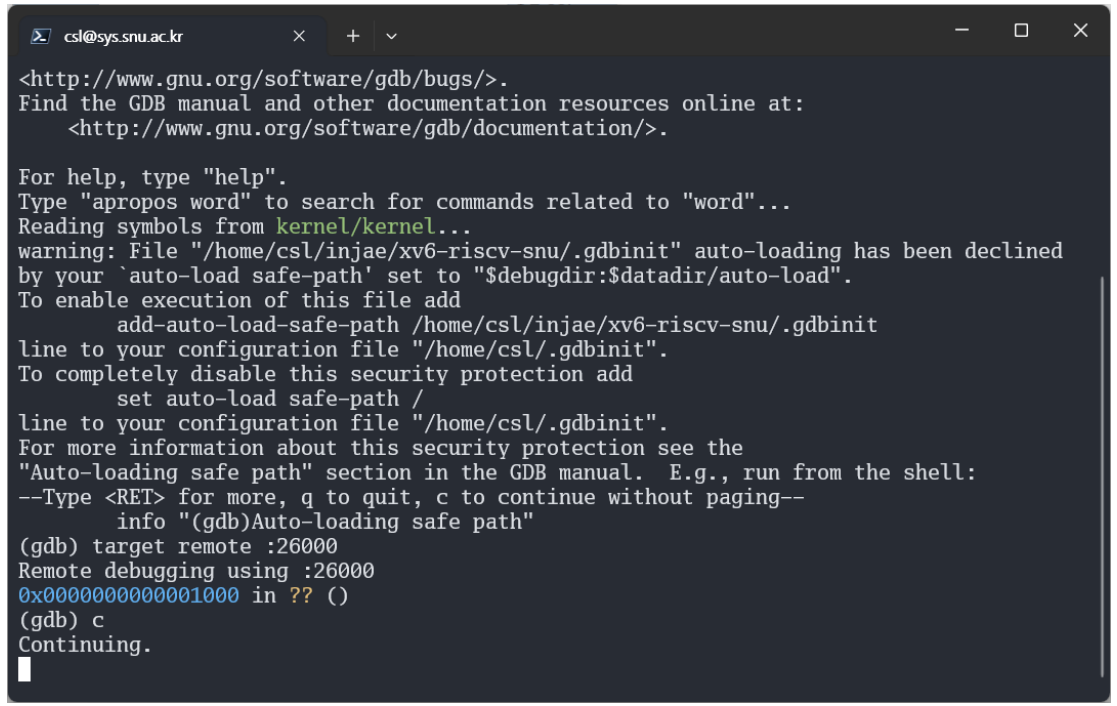




GDB with QEMU

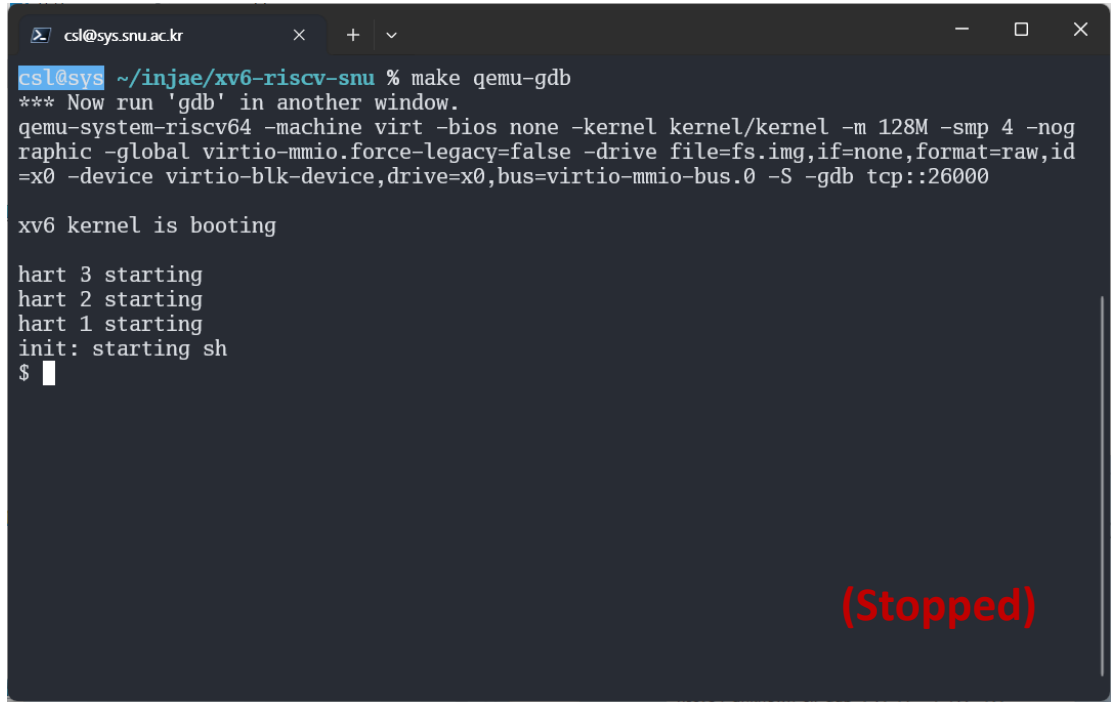
- The xv6 virtual machine has stopped at 0x1000 (the very beginning of the text section)
- To continue, enter `c` in GDB

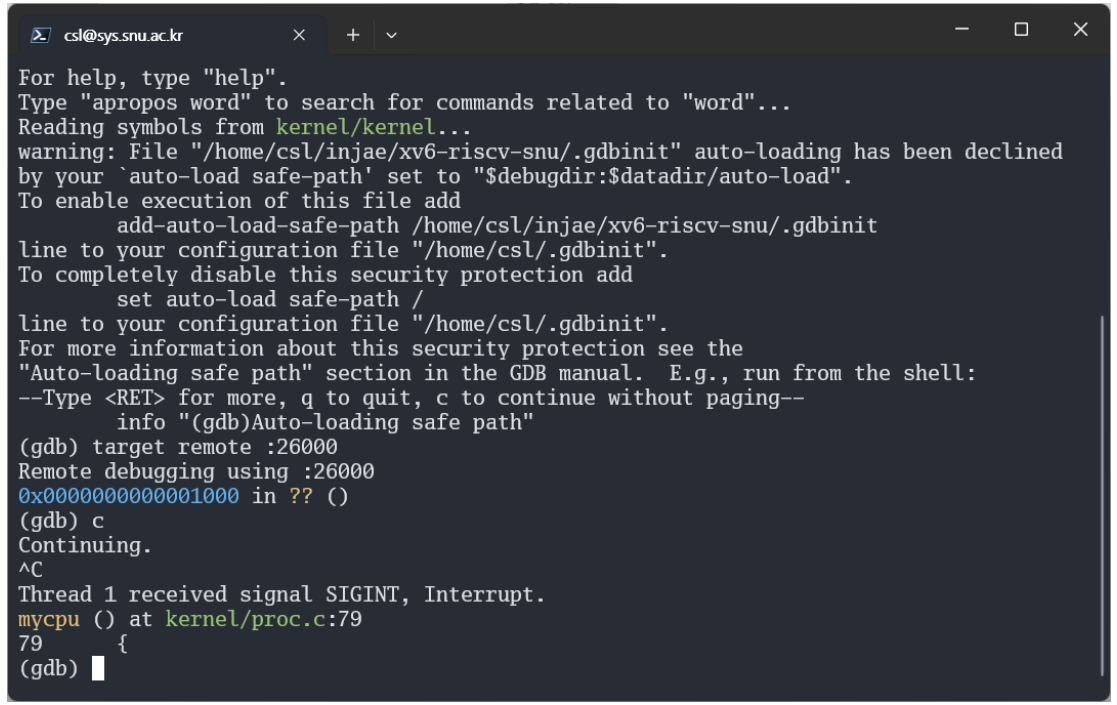




GDB with QEMU

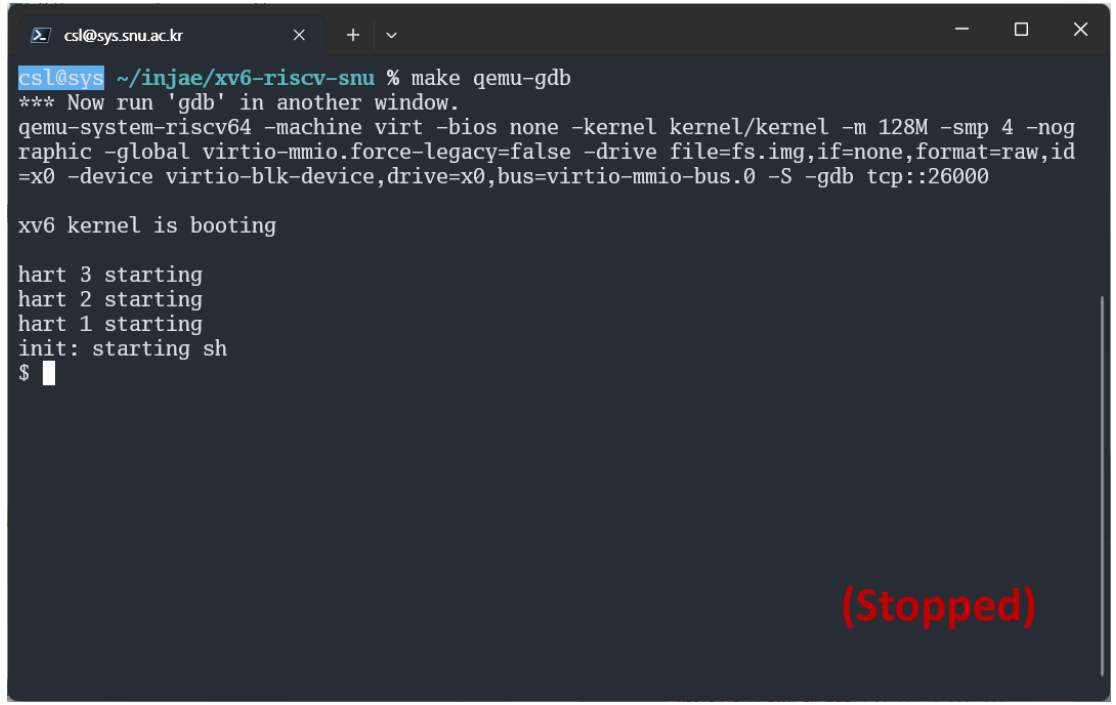
- To stop again, enter `Ctrl-C` in GDB
- Then the xv6 virtual machine stops immediately

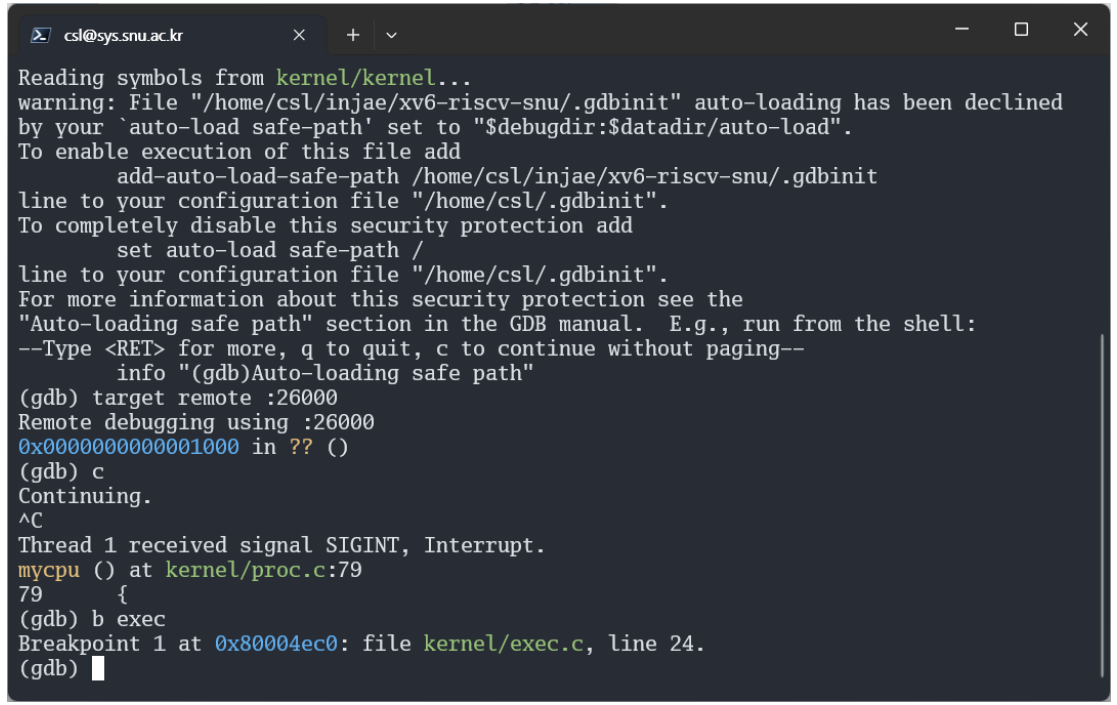




GDB with QEMU

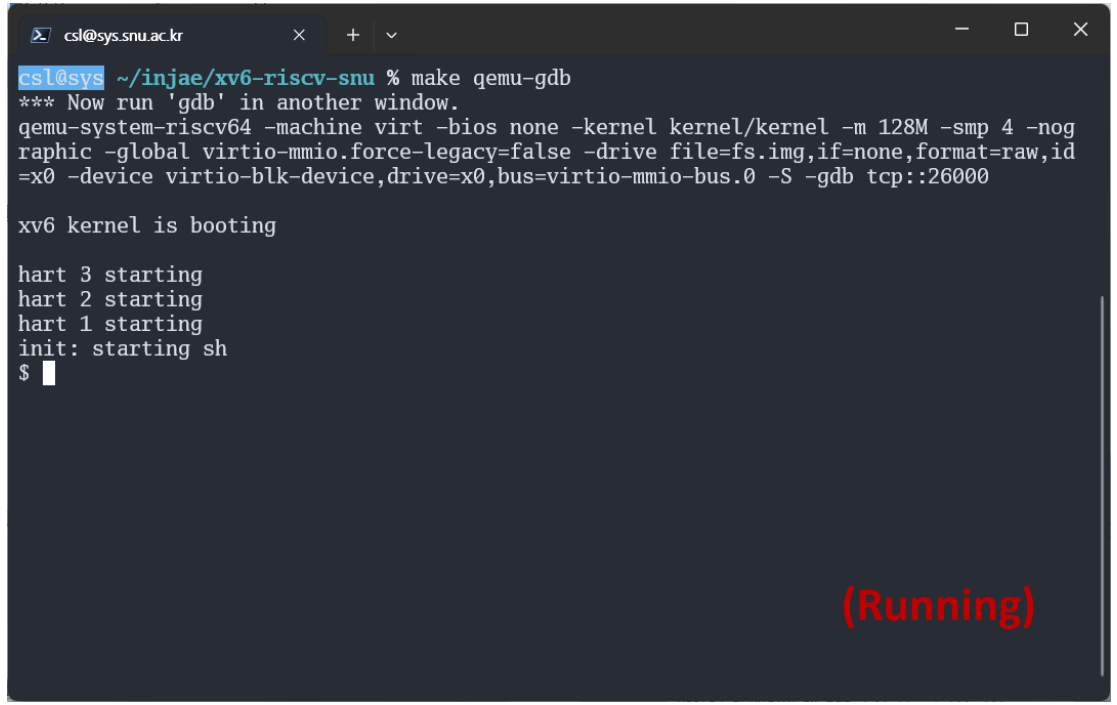
- Let's set a breakpoint at `exec()`
- Enter `b exec` in GDB

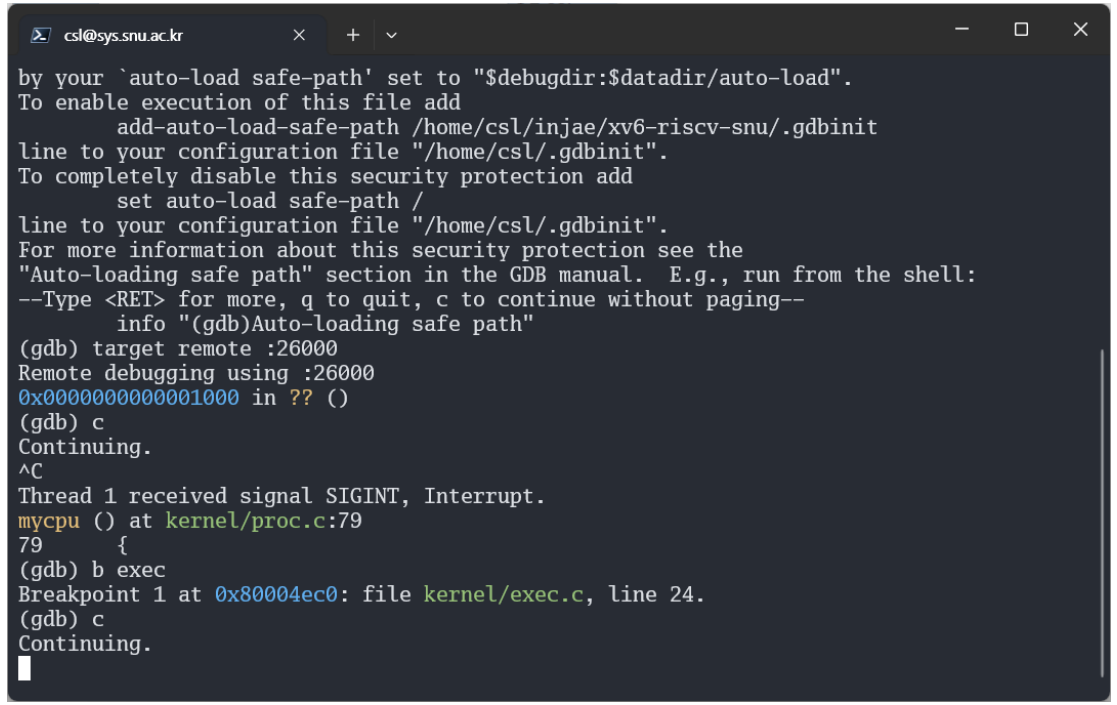




GDB with QEMU

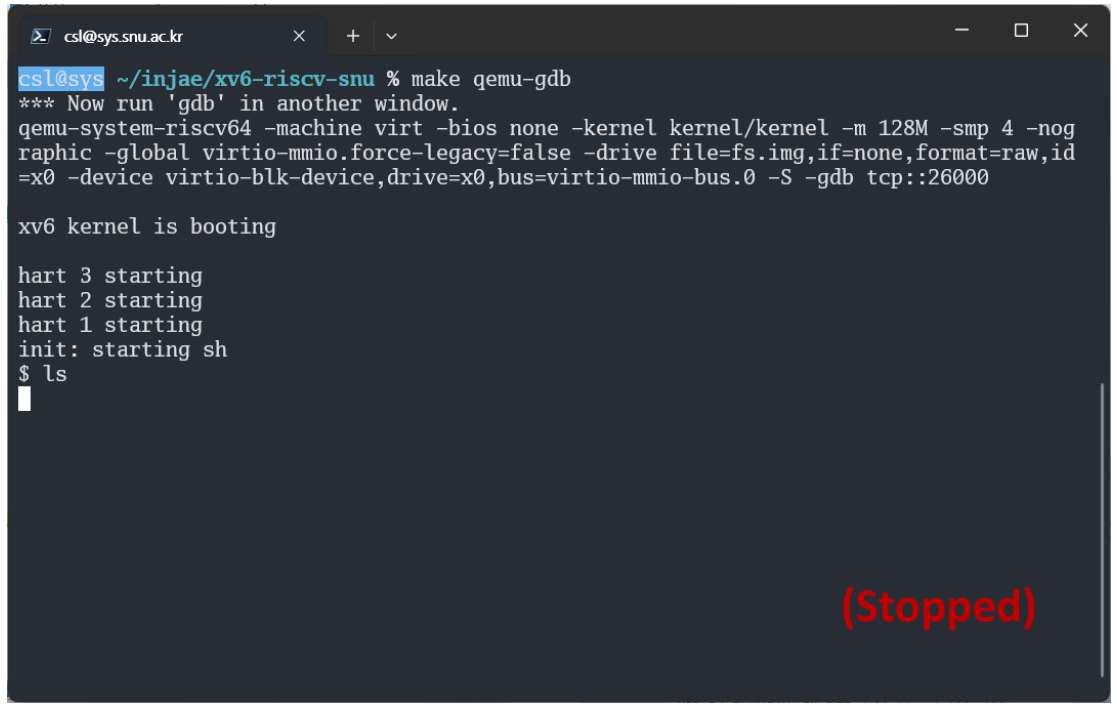
- Enter c in GDB to resume the xv6 machine

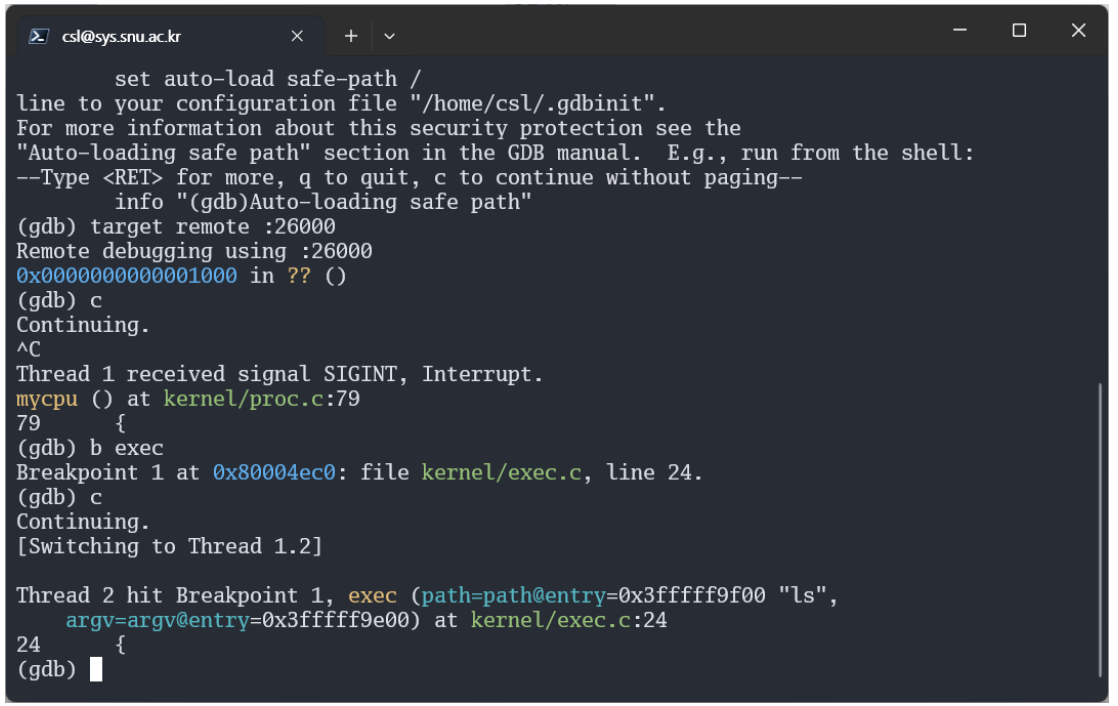




GDB with QEMU

- Run `ls` command in the xv6 machine
- Then the xv6 machine hits the breakpoint and stops right before starting `exec()` function





More about GDB

- To learn GDB in detail, search for GDB on Google
- There are many useful videos about GDB in YouTube
- [JTJ의 리눅스탐험] GDB 활용하기

Thank you!