Project #2: System Calls

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2026.03.19.

System Calls

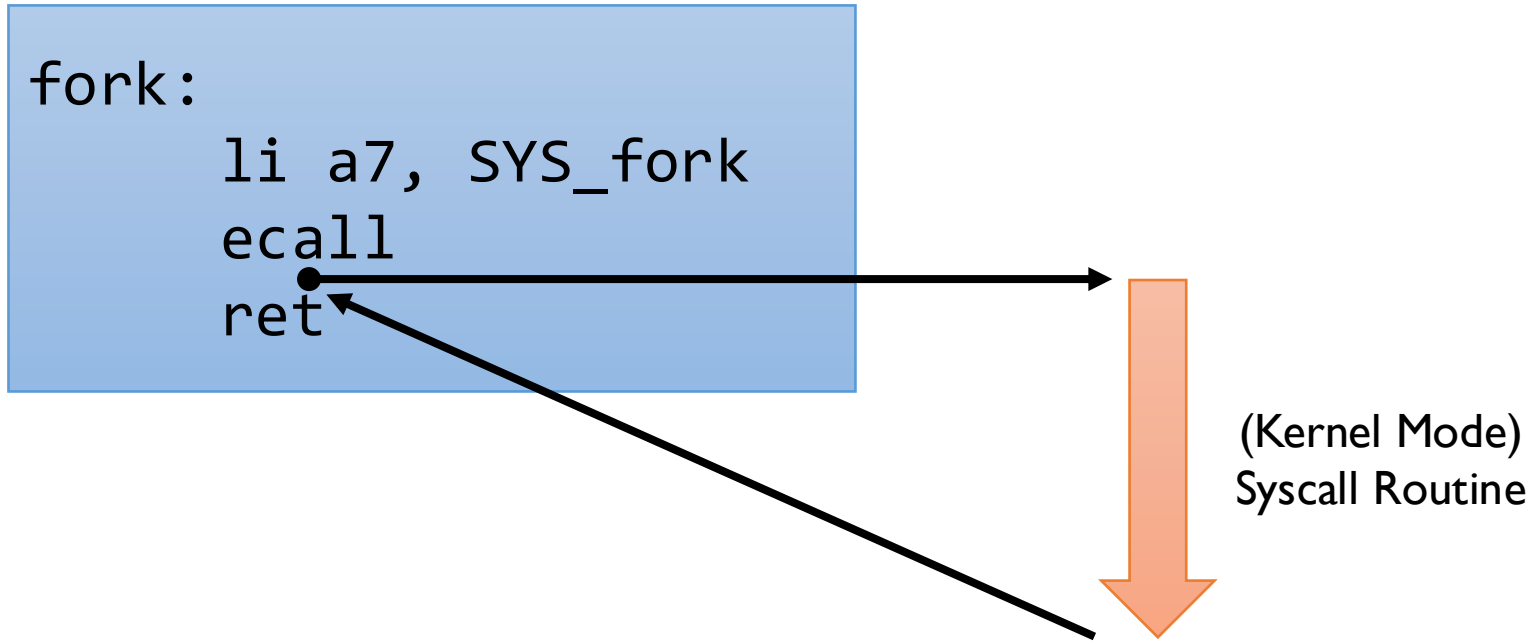
- User applications can access the operating system kernel in a restricted way
- The interfaces that allow user applications to request services from the operating system kernel
- The operating system kernel does the requested task on behalf of user applications

Three RISC-V Privilege Modes

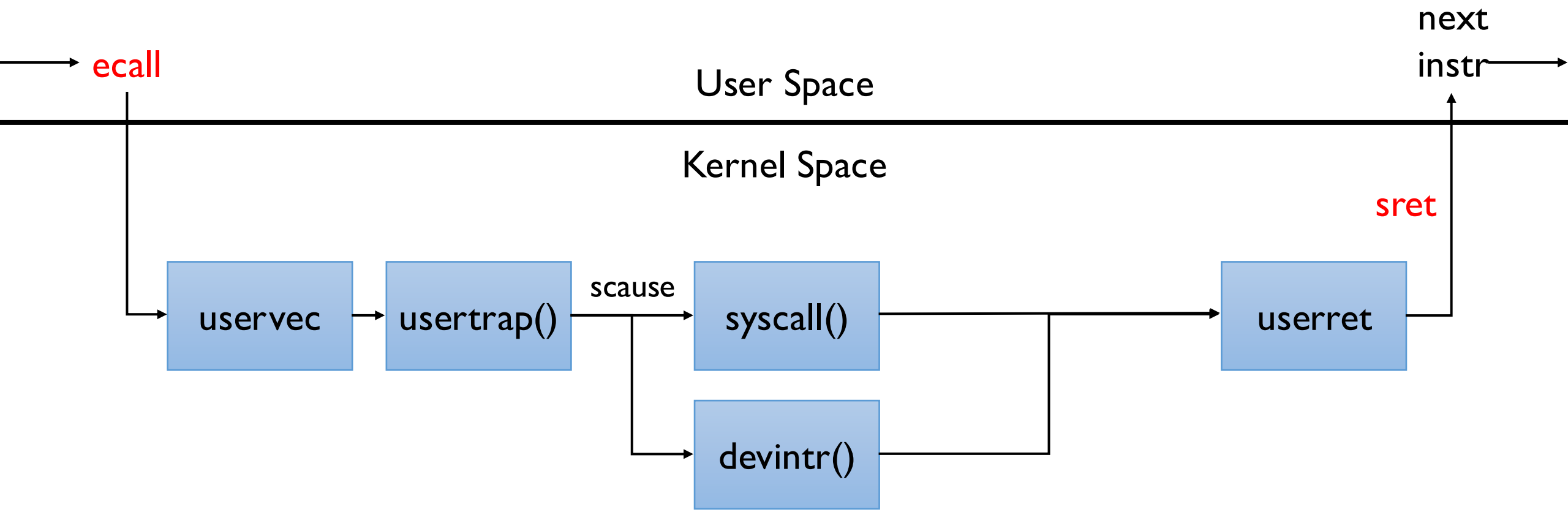
- Machine Mode
  - CPU starts in machine mode
  - Can access all hardware registers
- Supervisor Mode
  - Allowed to execute privileged instructions
    - Enable/Disable interrupts
    - Modify the page table base register
    - …
  - The operating system kernel runs in supervisor mode
- User Mode
  - User processes run in user mode

ecall

- User applications execute the ecall instruction to invoke system calls
- E.g., fork()



Traps from User Space (U-mode → S-mode)



Some Registers

- scause (mcause)
  - Event which caused a trap
- sepc (mepc)
  - Program counter when a trap occurs
- sscratch (mscratch)
  - A dedicated register for use by system (machine) mode
- stvec (mtvec)
  - Pointer to trap vector

What happens on trap

- The RISC-V hart performs all these steps as a single operation
  - Store **`sstatus.SIE`** to **`sstatus.SPIE`**
  - Disable interrupts by setting **`sstatus.SIE`** to 0
  - Store the originated privilege mode (U mode: 0, otherwise, 1) into **`sstatus.SPP`**
  - Copy the **`pc`** into **`sepc`**
  - Set **`scause`** to reflect the trap's cause
  - Set the **`stval`** if necessary (e.g., fault address)
  - Copy **`stvec(which is uservec in xv6)`** to the **`pc`**
  - Start executing at the new **`pc`**

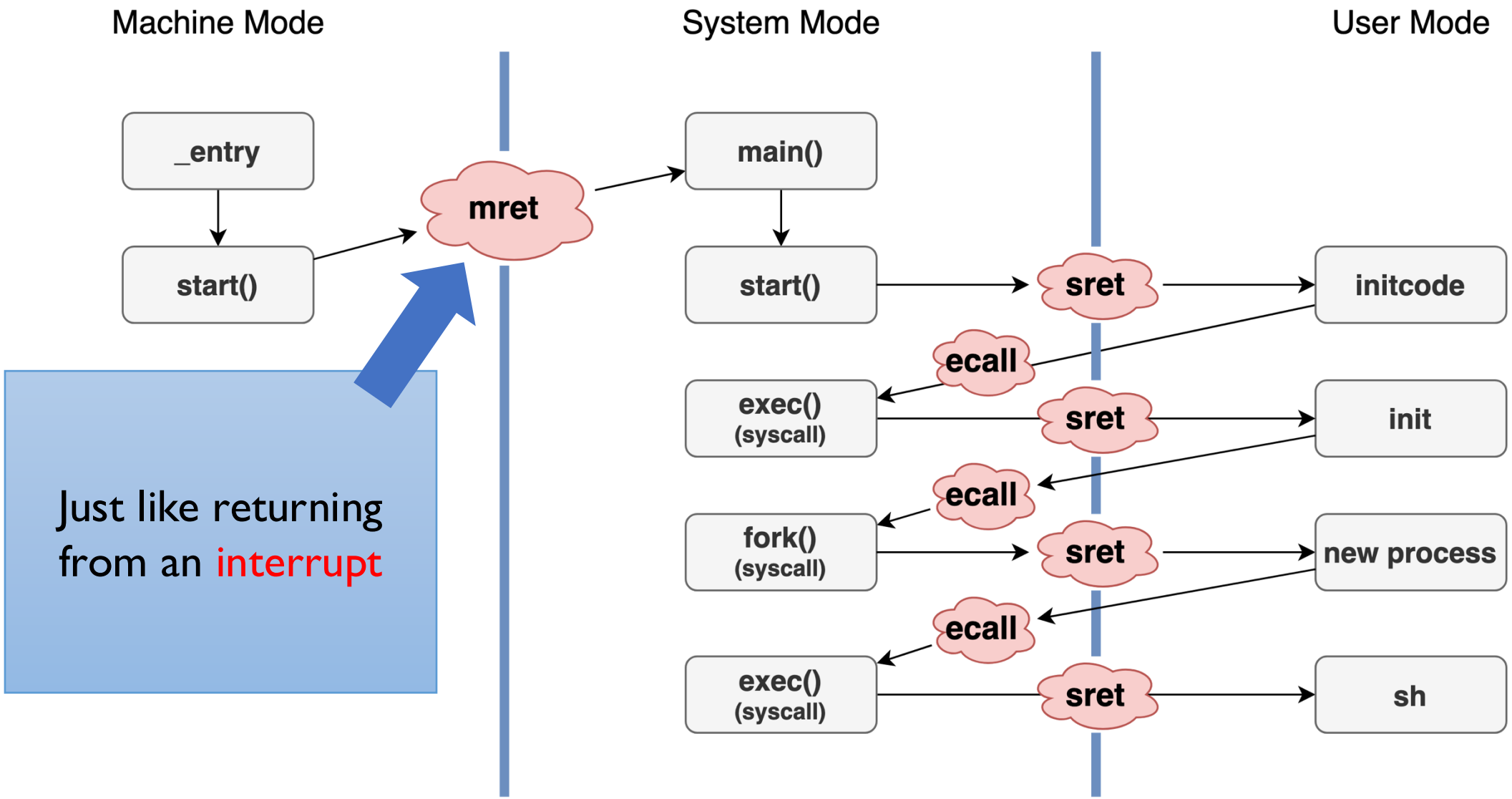
What happens on sret

- The RISC-V hart performs all these steps as a single operation
  - Restore **`sstatus.SIE`** from **`sstatus.SPIE`**
  - Restore the originated privilege mode from **`sstatus.SPP`**
  - Enable interrupts by setting **`sstatus.SIE`** to 1
  - Copy the **`sepc`** into **`pc`**
  - Start executing at the new **`pc`**

Trap Delegation

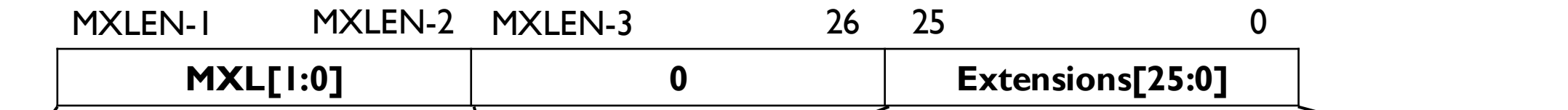
- By default, all traps are handled in S-mode
- Register medeleg and mideleg can set certain traps to be processed dire ctly by a lower privilege level (S-mode)
- Setting a bit in medeleg or mideleg will delegate the corresponding trap, when occurring in S-mode or U-mode, to the M-mode trap handler.

xv6 booting


Machine Mode
System Mode
User Mode
_entry
start()
mret
main()
start()
sret
initcode
ecall
exec()
(syscall)
sret
init
ecall
fork()
(syscall)
sret
new process
ecall
exec()
(syscall)
sret
sh
Just like returning
from an interrupt

misa (machine ISA) register

- Machine-level control and status register(CSR) in RISC-V architecture
- Read-write register reporting the base integer width of the processor (e.g. RV32 or RV64) and the set of enabled ISA extensions



MXL	ISA width
1	RV32
2	RV64
3	Reserved

Bit	Character	Description
0	A	Atomic instructions
8	I	Base integer instruction set
12	M	Integer multiply/divide extension

System Reset

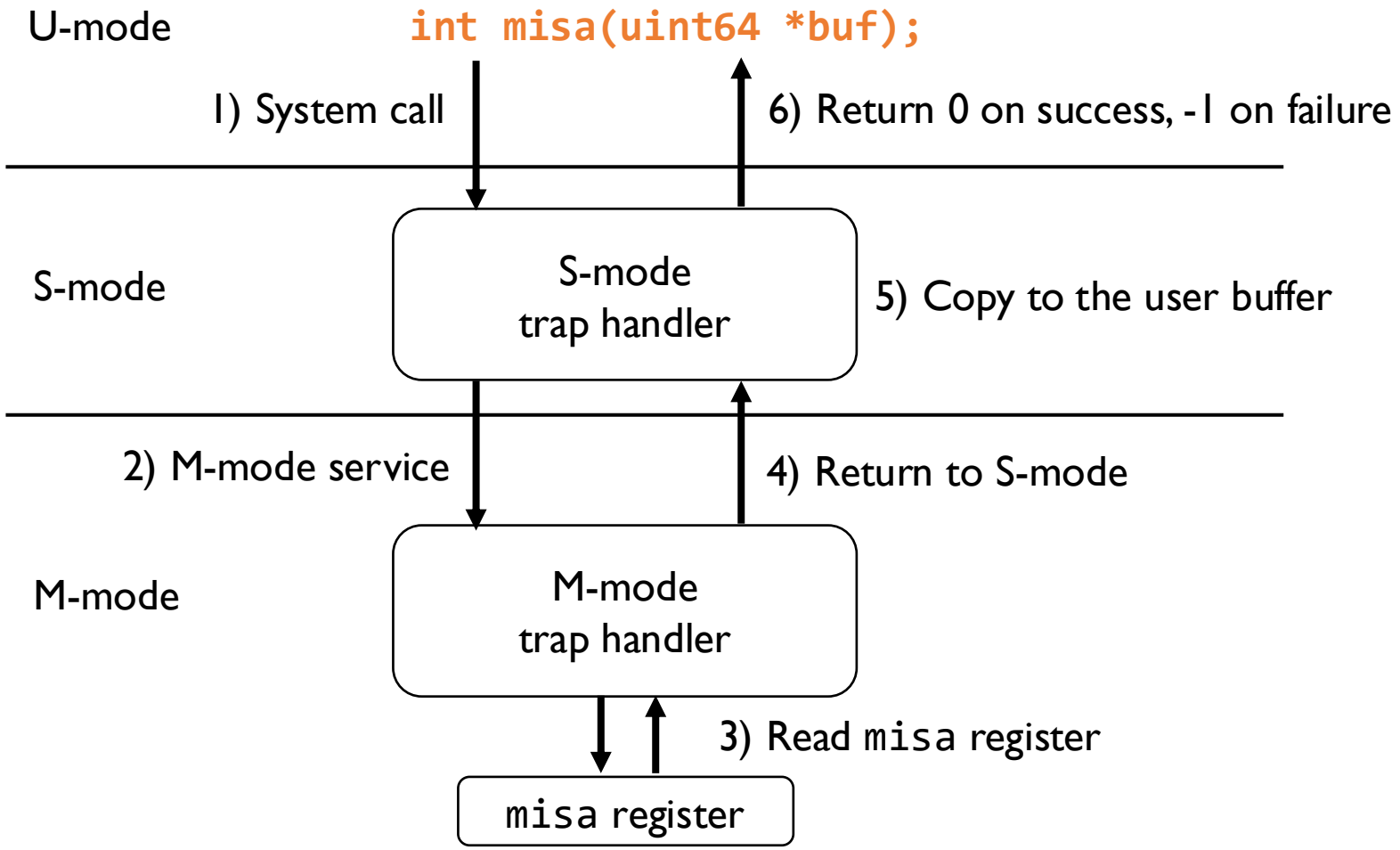
- QEMU's RISC-V virt machine emulates SiFive Test device (finisher)
- SiFive Test device
  - Located at physical address 0x100000
  - Can be accessed by memory-mapped I/O store
  - Guest can write 32-bit value 0x7777 to the device register (0x100000) for system reset request

Project 2

- Your task is to implement misa() and reset() system calls
- The system call number of misa(), reset() is already assigned to 22, 23 in the kernel/syscall.h file
- You can access `misa` register and finisher device only in M-mode
- Implement privilege level transition between M-mode and S-mode

Project #2-1 misa() system call (60 points)

- Return the value of the RISC-V `misa` register



Project #2-1 misa() system call (60 points)

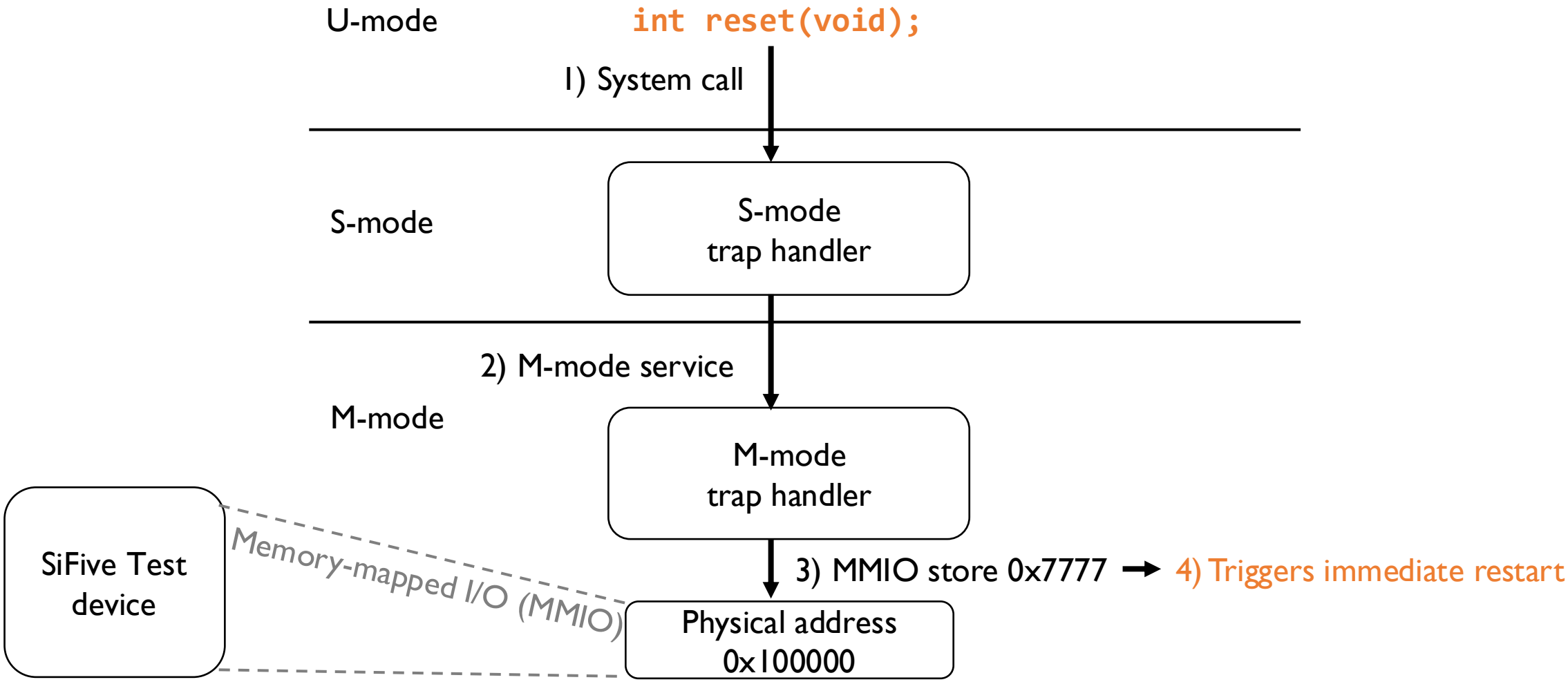
- Retrieve the current value of `misa` without modification

- On success
  - Return 0
  - Store the `misa` register value in argument `*buf`
- On failure

  ex) `*buf` was not a valid writable user pointer
  - Return -1
  - Does not guarantee any valid value in `*buf`

Project #2-2 reset() system call (40 points)

- Reset the machine through the SiFive Test device (finisher device)



Project #2-2 reset() system call (40 points)

- QEMU's finisher device address is already defined in `memlayout.h`;

```
#define FINISHER 0x100000L
```

- On success
  - Machine immediately resets
  - Does not return to the calling process

- On failure
  - Return -1

Restriction

- You are allowed to modify only these files
  - kernel/riscv.h
  - kernel/start.c
  - kernel/machinevec.S
  - kernel/sysproc.c
  - Even if you modify other files, those changes will not be committed on the grading server

- qemu version 8.2.0 or later ($ qemu-system-riscv64 –version)
- Do not change the system call number (22, 23) for misa(), reset()

Submission Guidelines

- "make submit" command to generate a compressed tar file named xv6-{PANUM}-{STUDENTID}.tar.gz in the ../xv6-riscv-snu directory
- You need to submit a report (Design Document) to server
- Up to 30 submissions are permitted
- Only the version marked FINAL will be considered for the project score

Due date

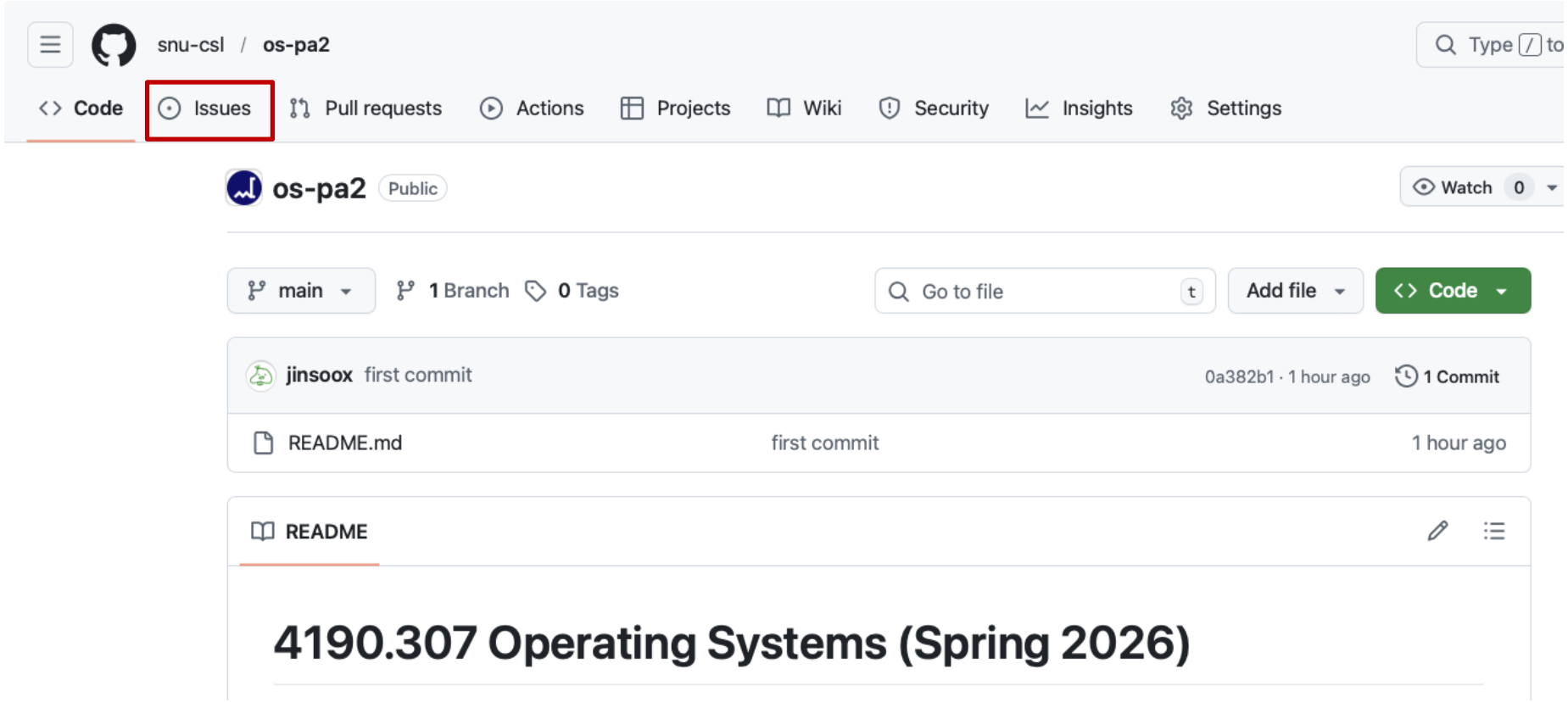
- **Due: 11:59 PM, April 5** (Sunday)
- Only the upload submitted before the deadline will receive the full credit
- 25% of the credit will be deducted for every single day delayed

Slip Days Policy

- You can use up to **3 slip days during this semester**
  - You should explicitly declare the number of slip days you want to use on the QnA board of the submission server before the next project assignment is announced
  - Once slip days have been used, they cannot be canceled later
- Submissions more than 3 days past the due date **will not be accepted**
- We highly recommend for you to save slip days for later projects!

Q&A

- Please post project-related questions on the *Issues* tab of https://github.com/snu-csl/os-pa2
- Do not upload code



Project #2 repo

- Skeleton Code
  - You should work on the pa2 branch of the xv6-riscv-snu repository as follows:

```
$ git clone https://github.com/snu-csl/xv6-riscv-snu
$ git checkout pa2
```

  - `$ make qemu` makes "fs.img" for user programs
    - You can run user program on xv6 shell

Project #2 repo

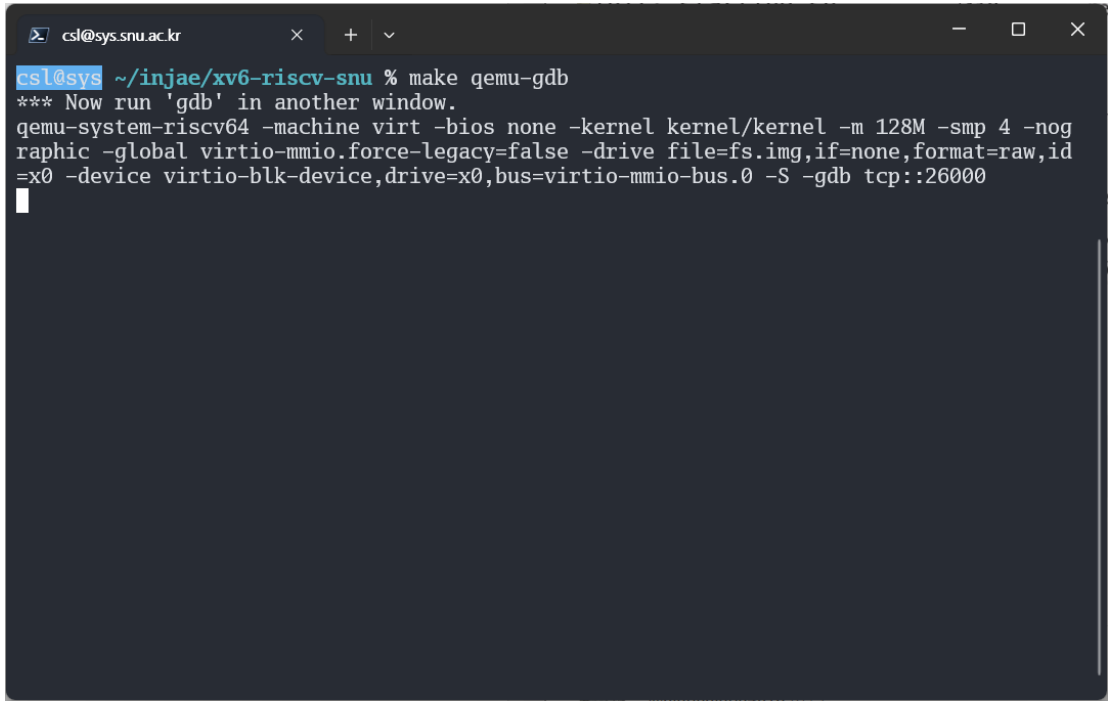
- User-level utility programs
  - The pa2 branch supports user-level utility programs named **misa, reset** which can be built from the user/misa.c, user/reset.c file

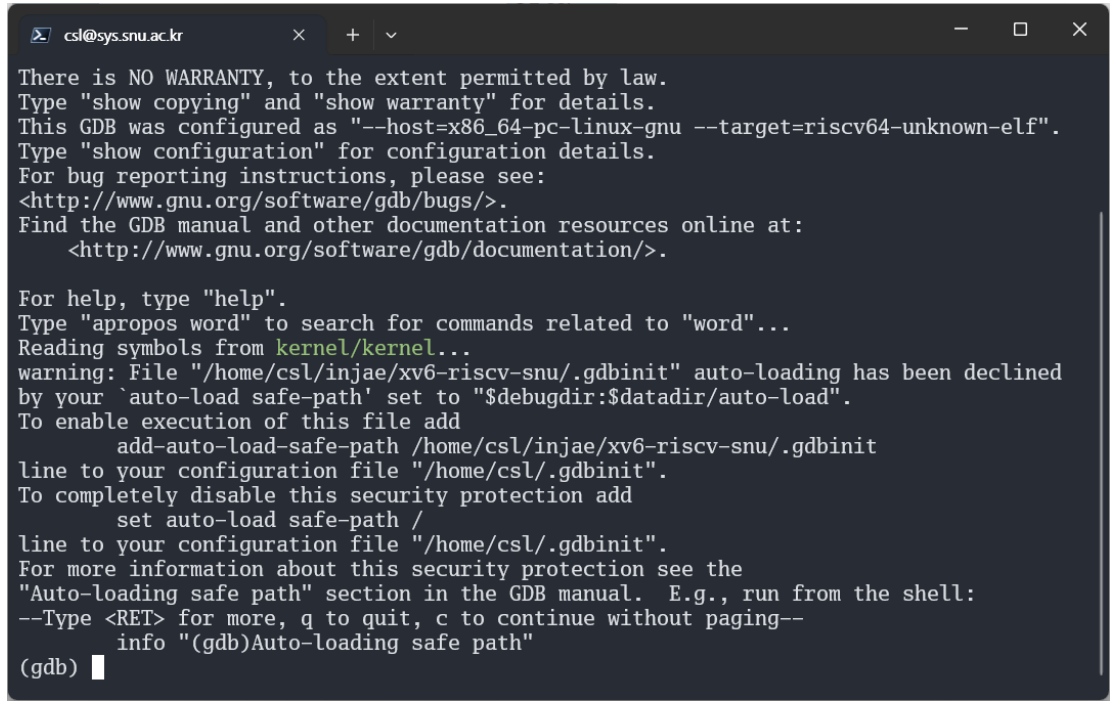
```
hart 2 starting
hart 1 starting
init: starting sh
$ misa
misa: 8000000001411AD A CD F HI   M     S U      (64-bit)
$ reset

xv6 kernel is booting

hart 1 starting
hart 2 starting
init: starting sh
$
```

Using GDB with QEMU

GDB with QEMU (Linux)

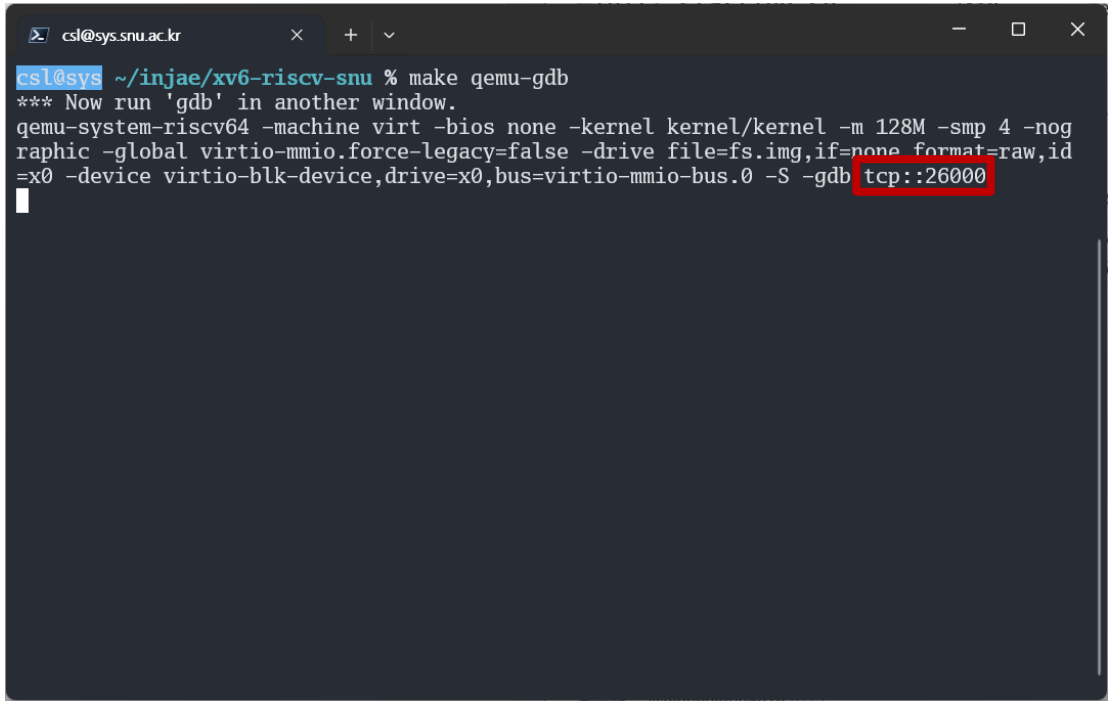
- Run sudo apt install gdb-multiarch
- In the xv6-riscv-snu directory, run make qemu-gdb to run QEMU
- In another shell, run gdb-multiarch ./kernel/kernel

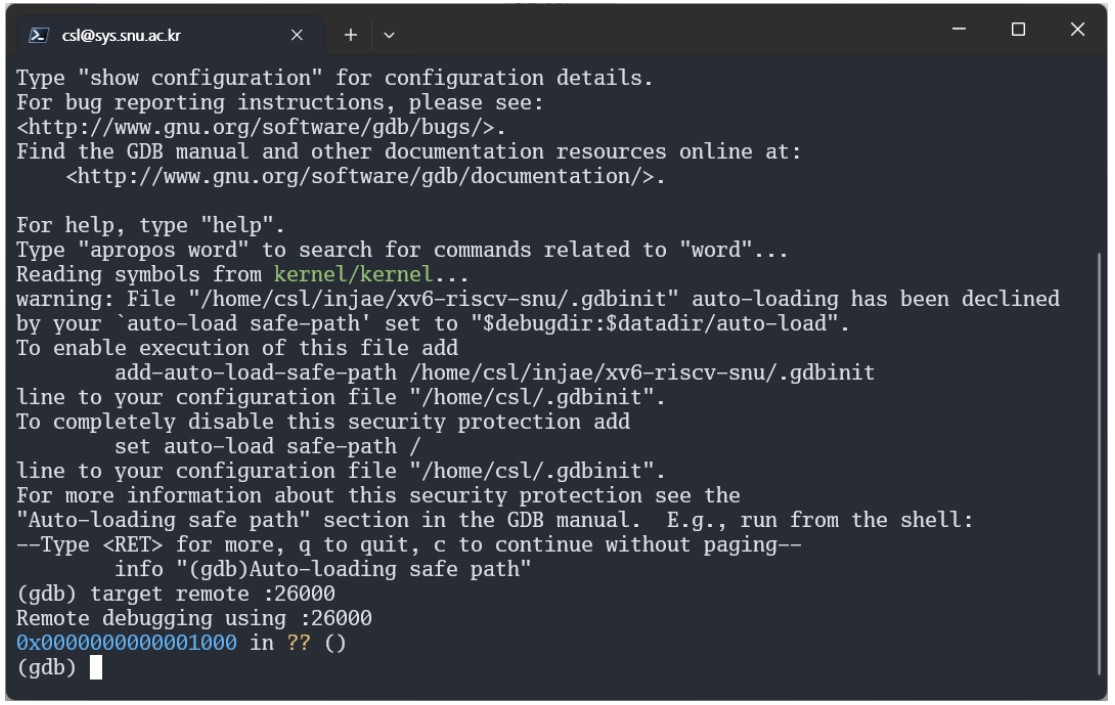




GDB with QEMU (Linux)

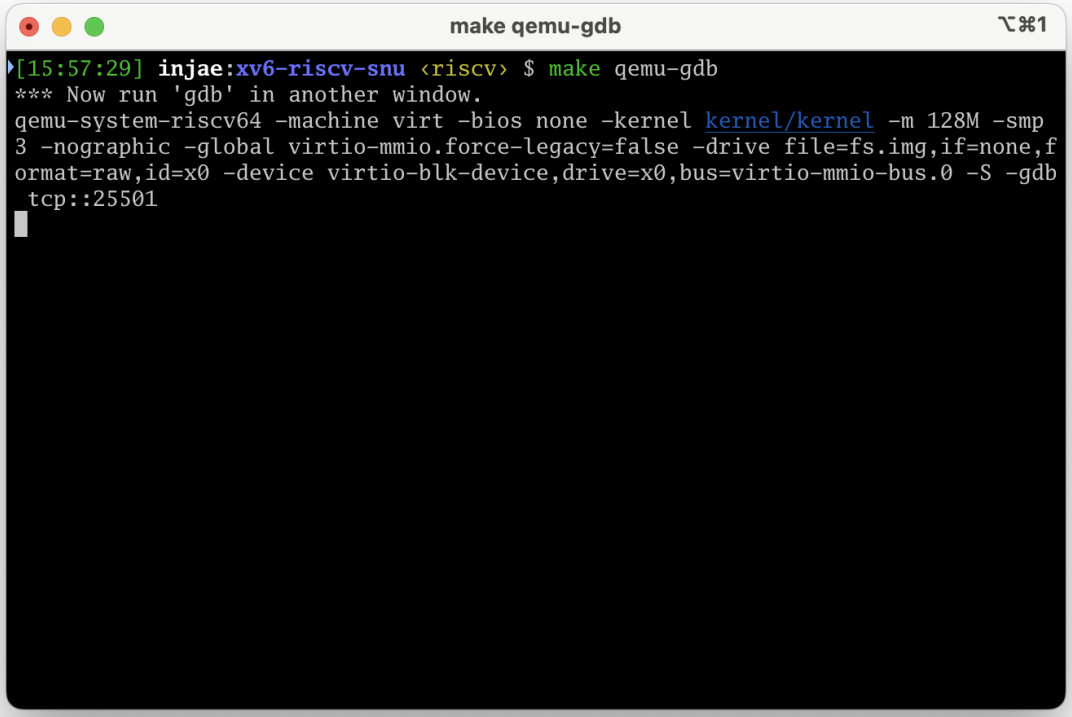
- In GDB, enter target remote :<port>
- You can find TCP port in the QEMU log

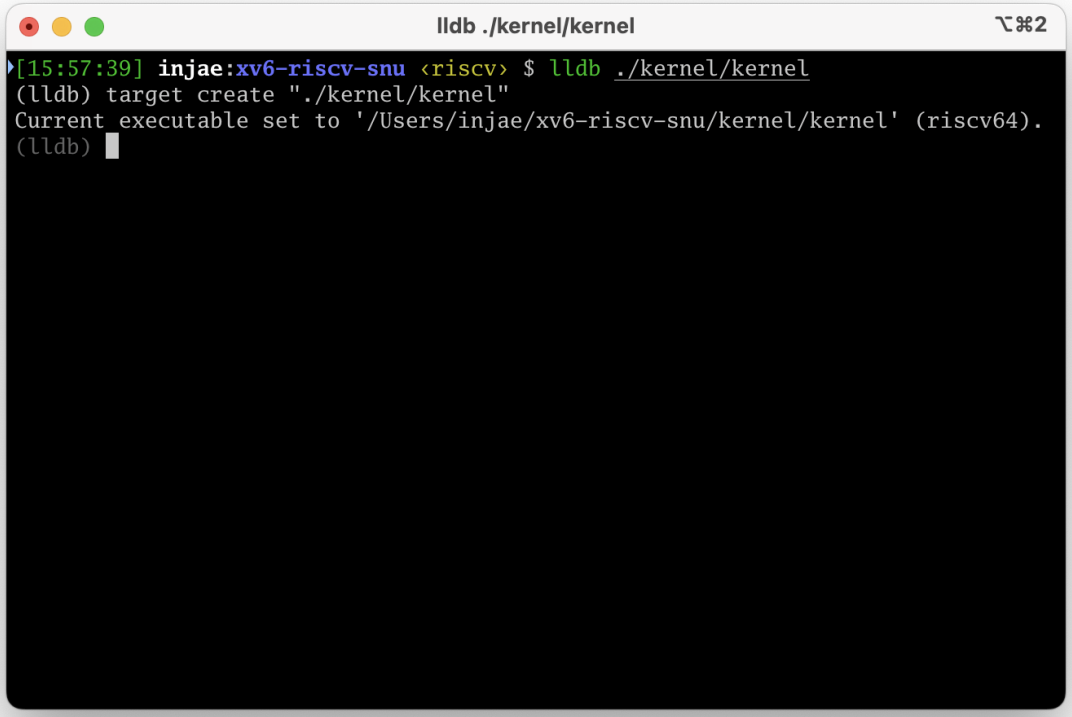




GDB with QEMU (MacOS)

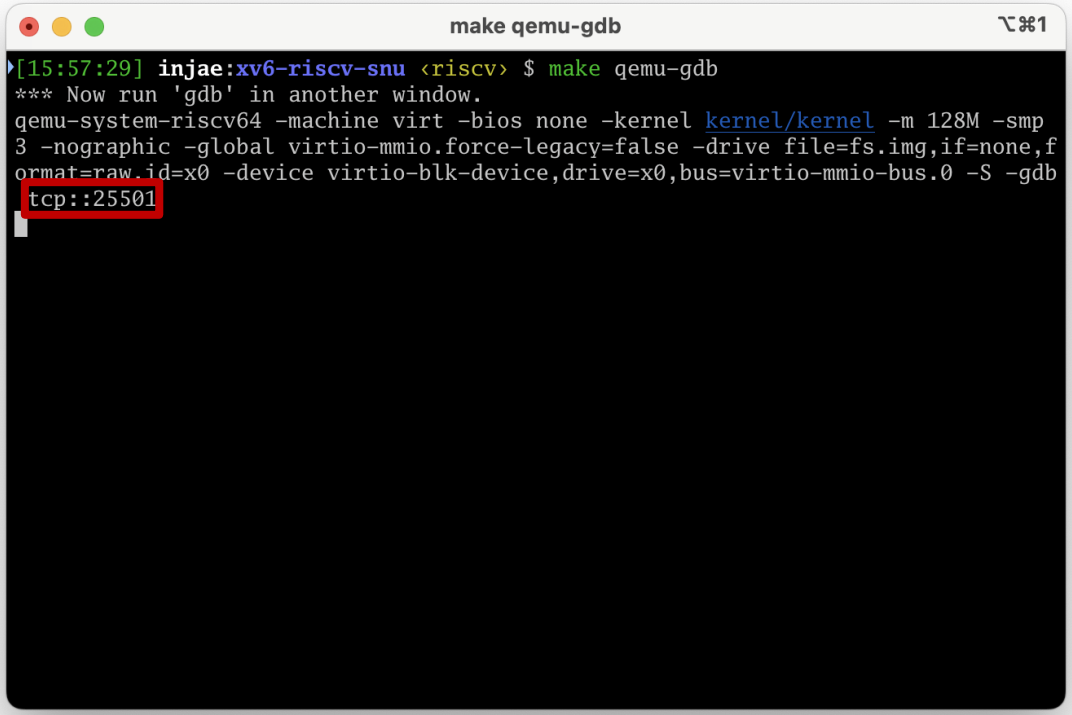
- In the xv6-riscv-snu directory, run make qemu-gdb to run QEMU
- In another shell, run lldb ./kernel/kernel

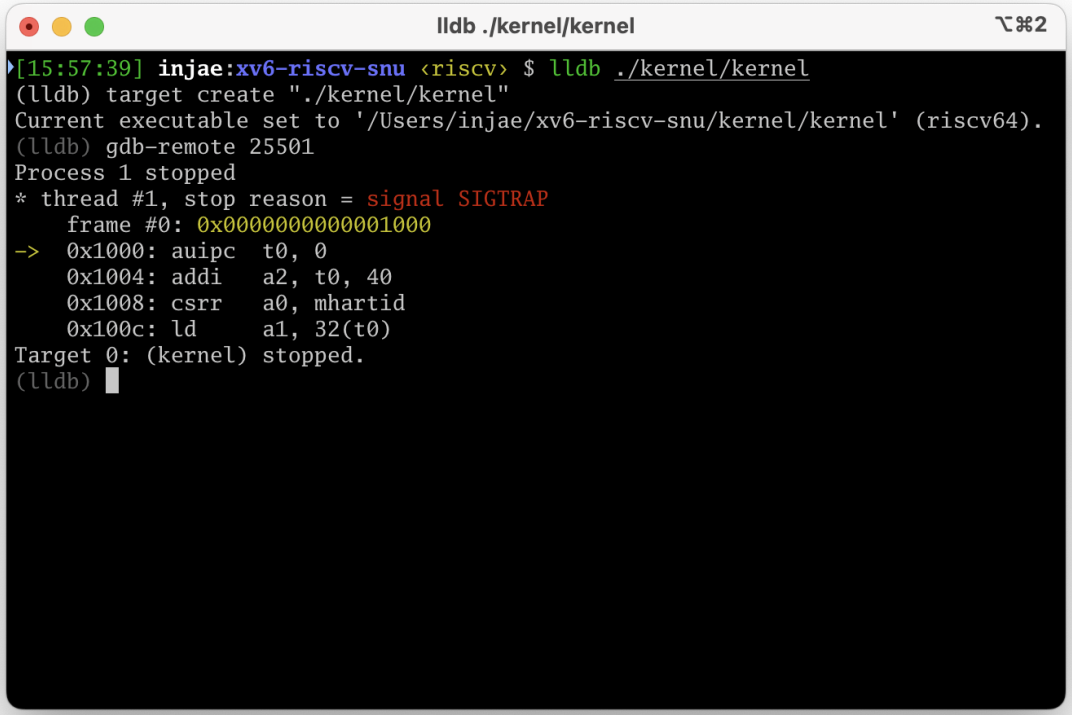




GDB with QEMU (MacOS)

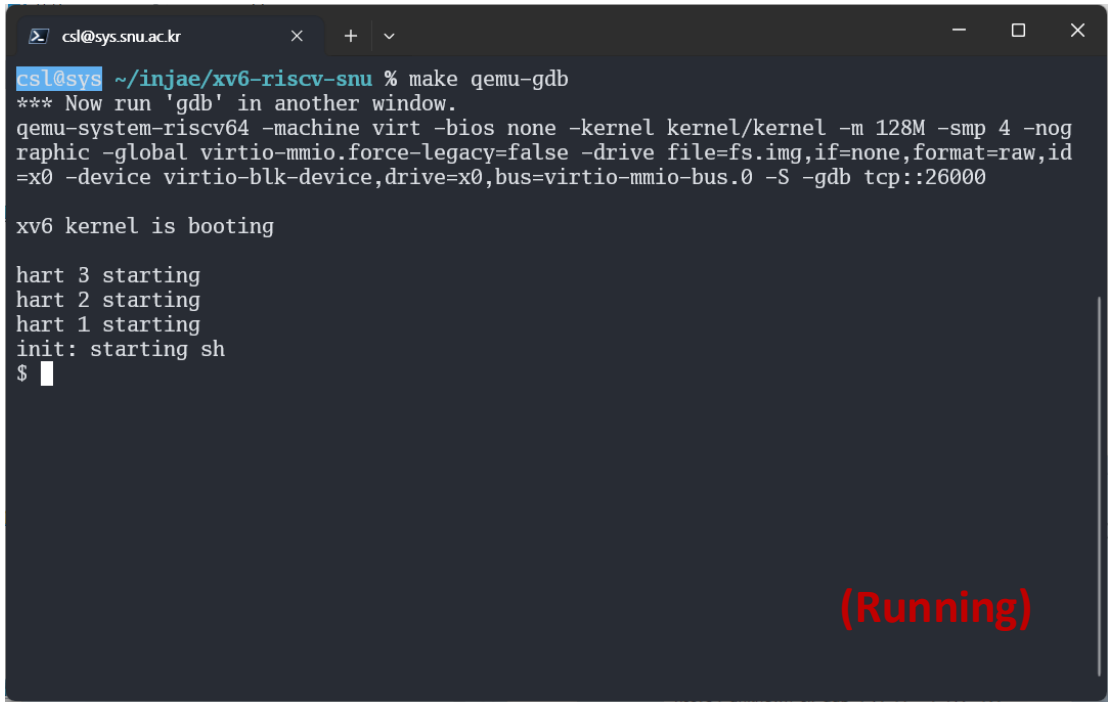
- In LLDB, enter gdb-remote <port>
- You can find TCP port in the QEMU log

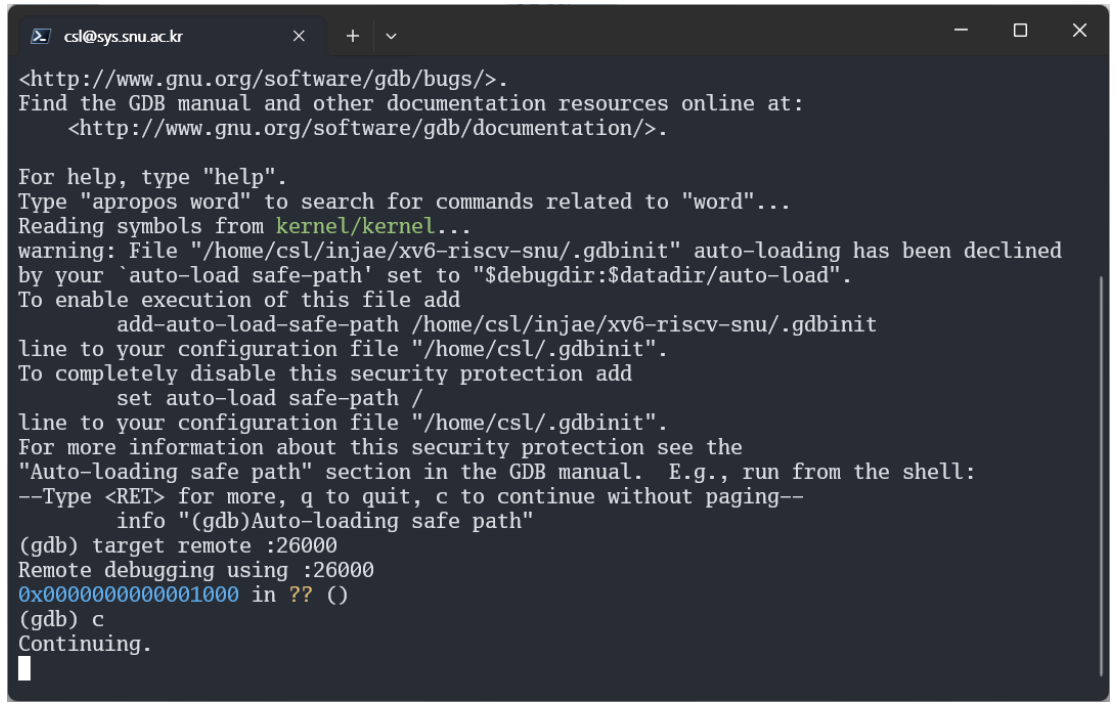




GDB with QEMU

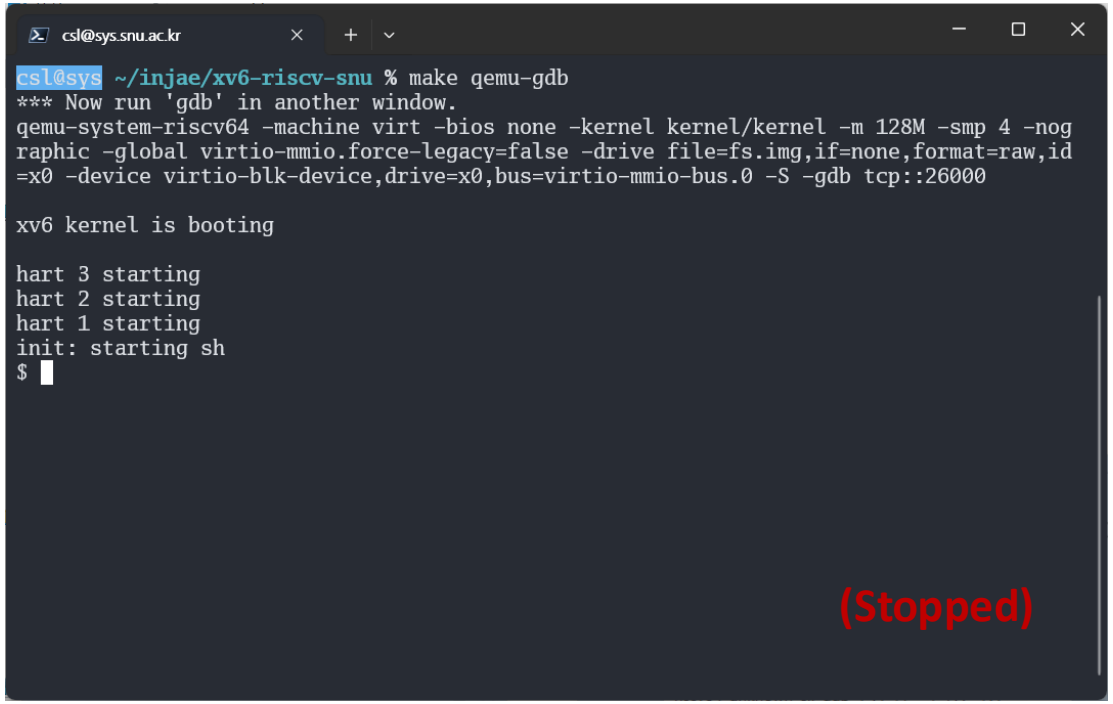
- The xv6 virtual machine has stopped at 0x1000 (the very beginning of the text section)
- To execute shell, enter `c` in GDB

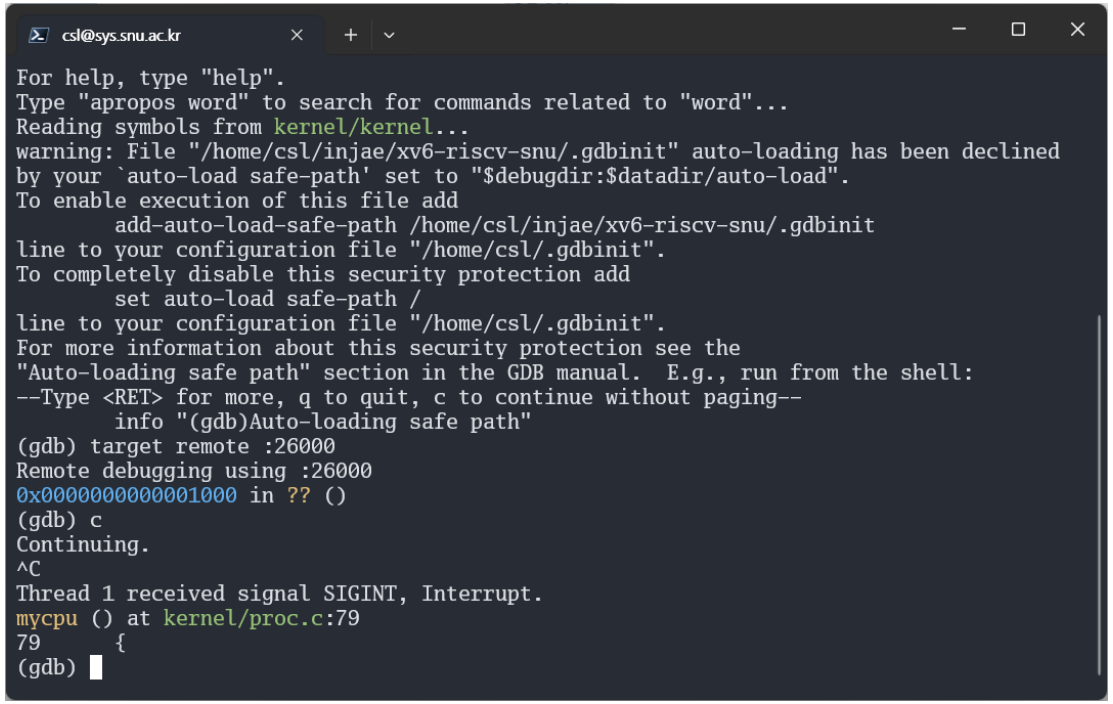




GDB with QEMU

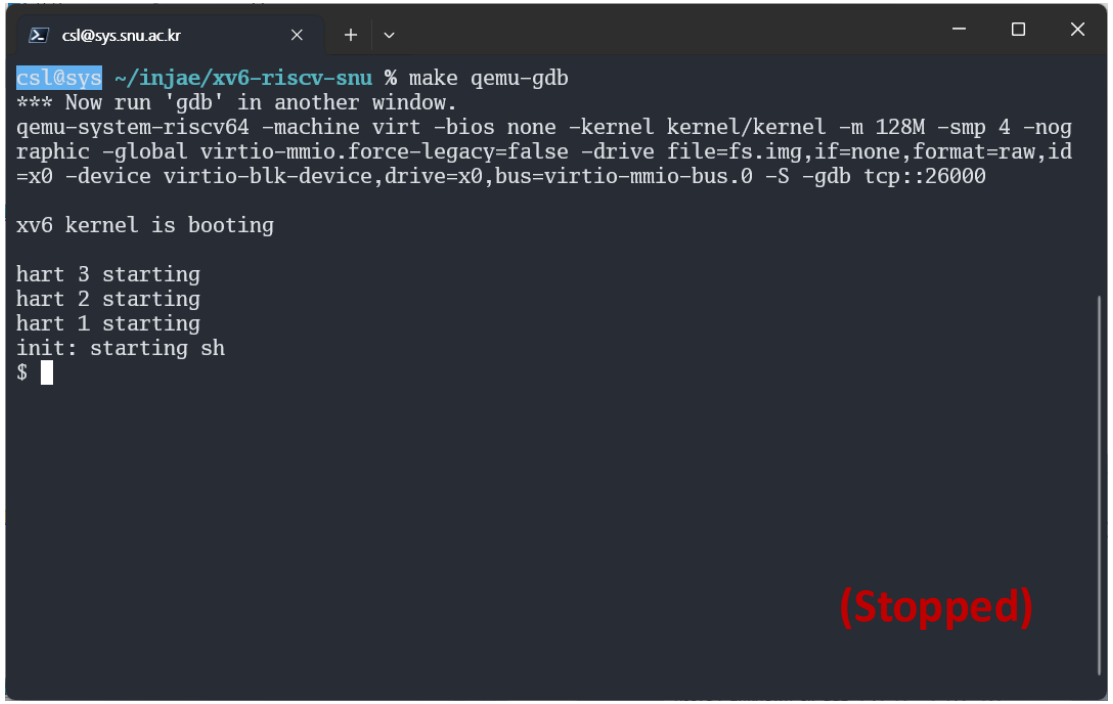
- To stop again, enter Ctrl-C in GDB
  - Cannot input command to shell
- Then the xv6 virtual machine stops immediately

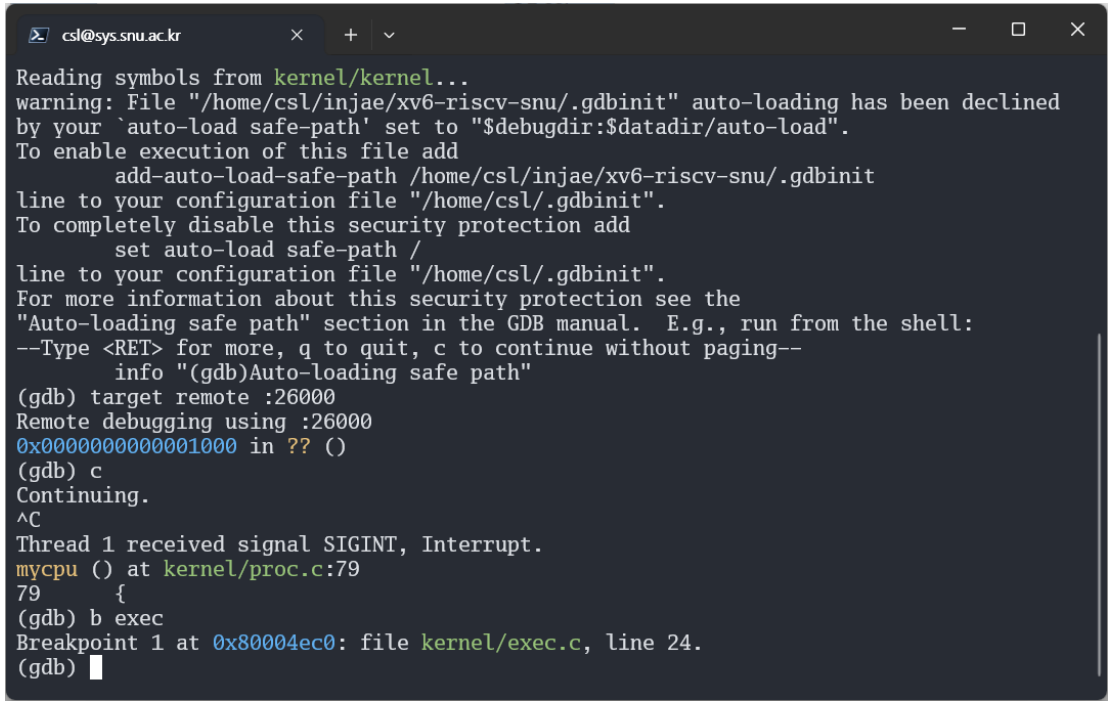




GDB with QEMU

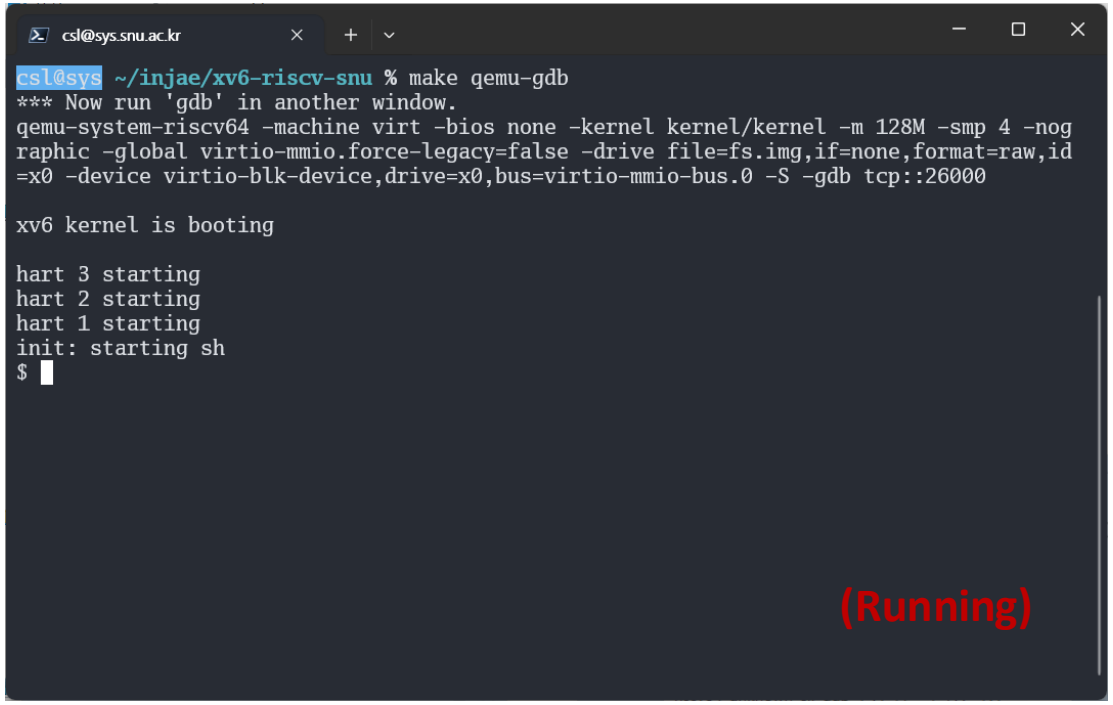
- Let's set a breakpoint at exec()
- Enter b exec in GDB

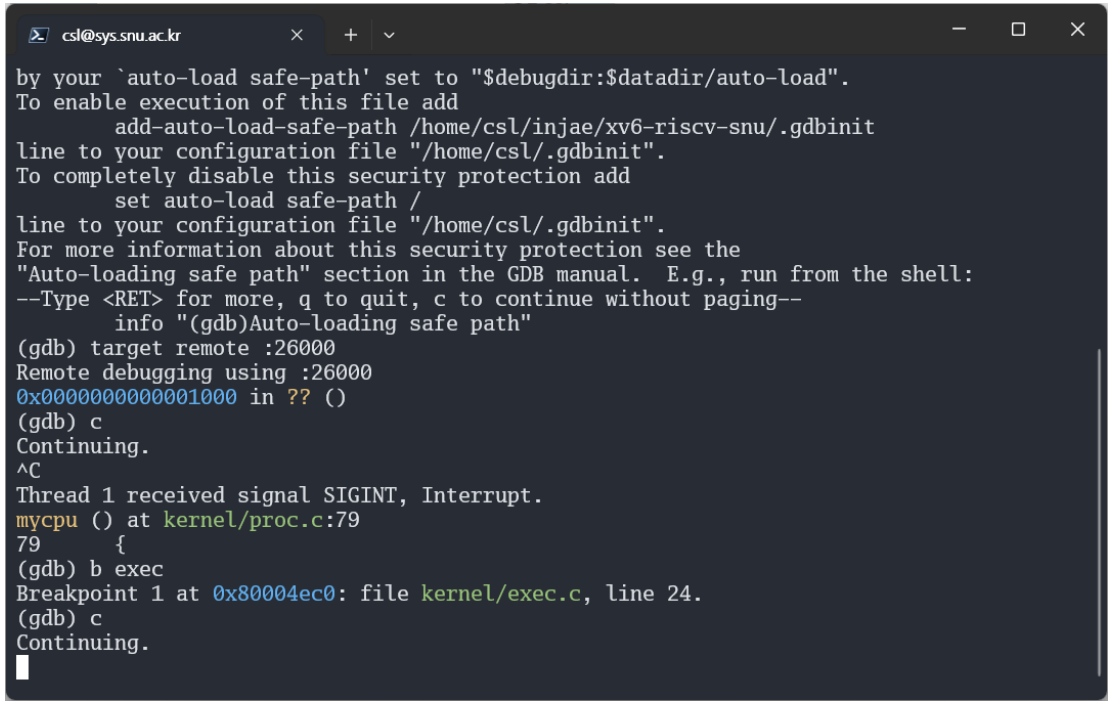




GDB with QEMU

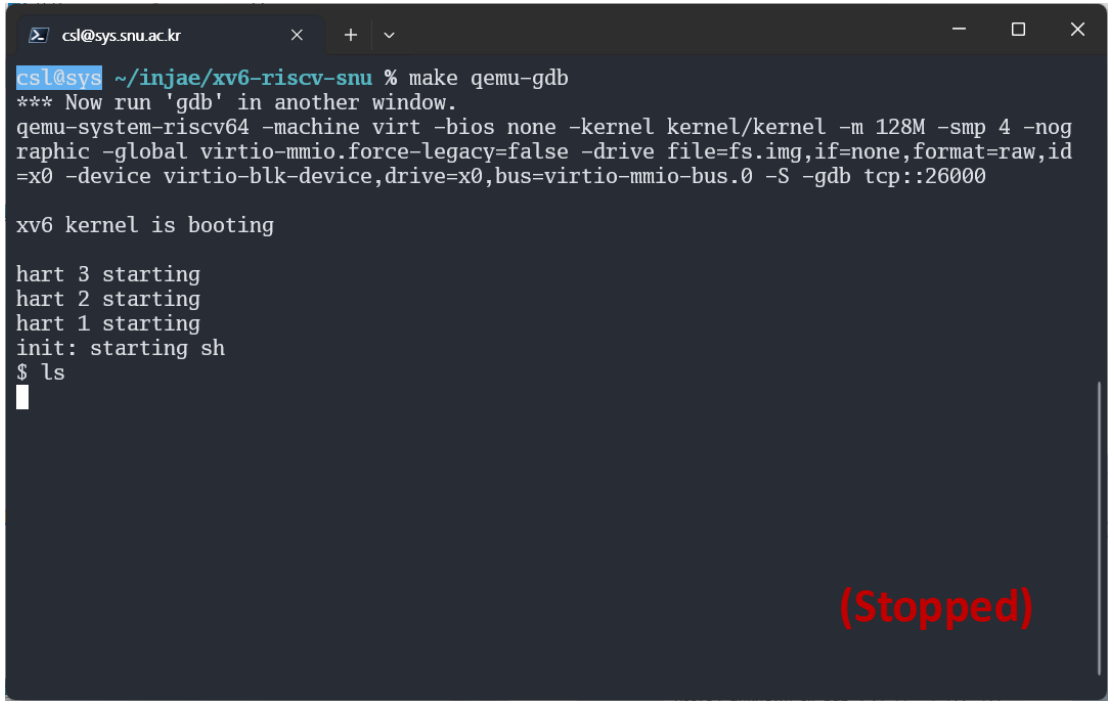
- Enter `c` in GDB to resume the xv6 machine

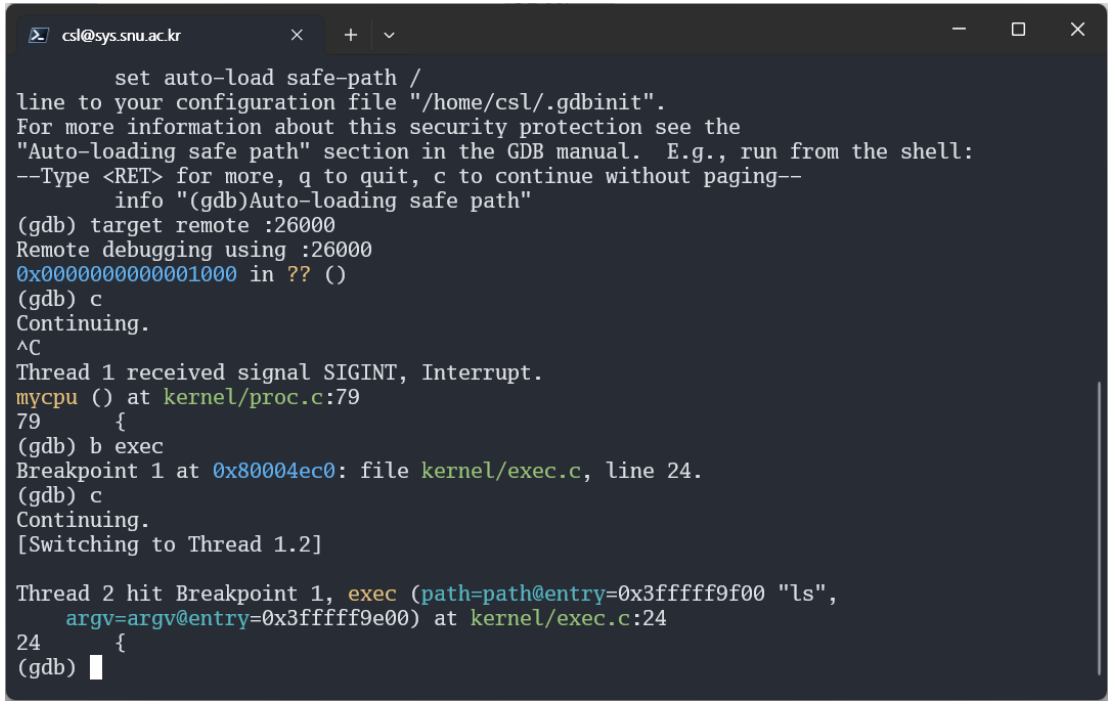




GDB with QEMU

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





Useful GDB commands

- info reg [register name]
- info thread
  - see harts' information
- thread [n]
  - change hart
- bt
  - See call trace

Useful LLDB commands (MacOS)

- register read [register name]
- thread list
  - see harts' information
- thread select [n]
  - change hart
- bt
  - See call trace

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!