



UiT The Arctic University of Norway

Project 4: Inter-Process Communication

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UiT

Spring 2024

Project 4

Project Overview

Project Tasks

Administrative Details

Project 4: Administrative Info (mostly like the others)

- ▶ Mandatory assignment
- ▶ Groups of two
- ▶ Design review
- ▶ Hand-in
 - ▶ Hand-in via Canvas
 - ▶ Code: whole repository (working tree + `.git/` dir)
 - ▶ Report: place in a `report/` directory in your repo
 - ▶ Zip up and upload to Canvas
 - ▶ **New!** Also upload the report PDF separately

Project 4: Inter-Process Communication (IPC)

- ▶ In Project 3:
 - ▶ We had separation between processes and kernel
 - ▶ But we didn't enforce it
- ▶ In Project 4:
 - ▶ We will enforce the separation
 - ▶ But we will build an Inter-Process Communication system
- ▶ You will:
 - ▶ Implement IPC message passing
 - ▶ Complete a keyboard driver
 - ▶ Reimplement sync abstractions to reduce interrupt disable time
 - ▶ Load processes dynamically

Project 4: Environment / Precode

Precode includes our solution to Project 3,
plus many additions to support Project 4.

Project 3	Project 4
All kernel priv (0)	Priv enforced: Kernel (0) vs Process (3)
One address space	Each process has own address space
Atomic via disabling interrupts	Atomic via C <stdatomic.h>
No interaction	Keyboard input + interactive shell
No disk I/O after boot	USB storage drivers
Flat disk image	Image has simple directory of processes

Be warned: Later projects have received less attention

- ▶ You will encounter more old, un-refactored code
- ▶ There will be bugs

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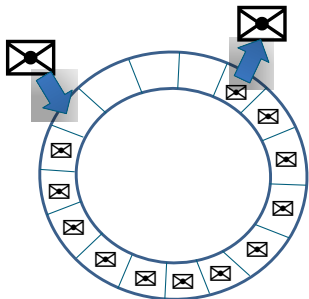
Administrative Details

Tasks Overview

You will:

- ▶ Implement IPC message passing
- ▶ Complete keyboard driver
- ▶ Reduce interrupt disable time (by reimplementing sync abstractions)
- ▶ Load processes dynamically

Task: Implement IPC Message Passing



A ring-buffer as a mailbox

Ring buffer

- ▶ Fixed-size: *bounded buffer*
- ▶ Variable-sized messages
- ▶ First In, First Out (FIFO)

Producer-consumer problem

- ▶ Multiple producers
- ▶ Multiple consumers
- ▶ Blocking operations

Implementation

- ▶ `mbox.[ch]`
- ▶ Struct already defined
- ▶ Locks + condition variables
- ▶ You will write the API functions

Mailbox API

▶ API functions

```
void mbox_init(void);  
int mbox_open(int key);  
int mbox_close(int q);  
int mbox_stat(int q, int *count, int *space);  
int mbox_recv(int q, msg_t *m);  
int mbox_send(int q, msg_t *m);
```

- ▶ Mailboxes identified by integer id (like file descriptors)
- ▶ No other addressing
- ▶ Any process can put a message in a box
- ▶ Any process can remove a message from a box

Task: Complete Keyboard Driver

Chain

```

IRQ 1 -> keyboard_isr_entry -> keyboard_interrupt -> key handlers -> putchar
(hw)      (interrupt_asm.S)   (keyboard.c)         (keyboard.c)   (keyboard.c)
\-----/                                     \-----/
      Provided by precode                               Your task
  
```

Hardware

- ▶ Hardware IRQ 1
- ▶ Read *scan code* from port 0x60

Partial driver

- ▶ keyboard_interrupt: look up scan code in table
- ▶ table has pointers to handler fns
- ▶ handler fns:
 - ▶ test for CTRL / SHIFT / ALT
 - ▶ map scan code to ASCII
 - ▶ call putchar

Keyboard Interface with OS: putchar

Precode

- ▶ Maps keyboard scan code to ASCII
- ▶ NB: US keyboard layout

putchar

- ▶ Put character into mailbox
- ▶ How exactly? Up to you

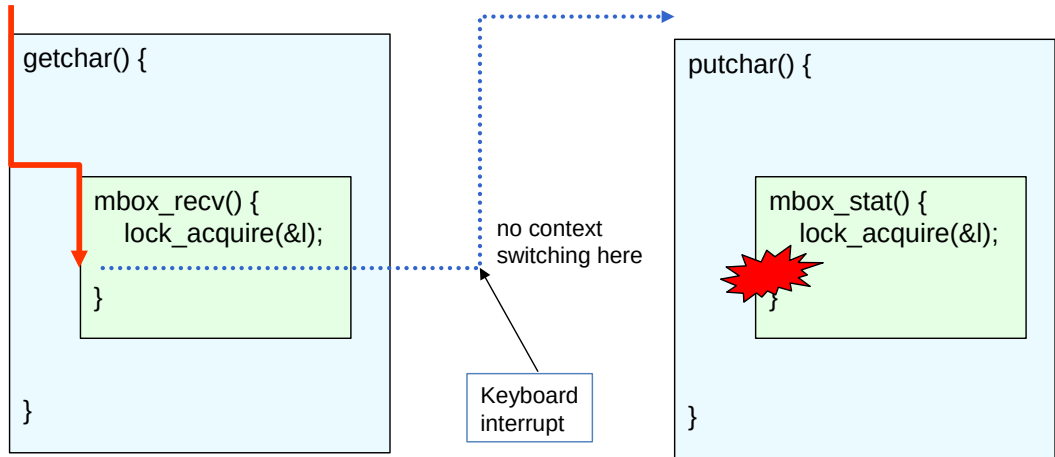
Classic producer/consumer problem

- ▶ Single producer. Or is it multiple?
- ▶ One source of input: keyboard
- ▶ But interrupt occurs in context of different threads/processes
- ▶ Multiple consumers. Or is it single?
- ▶ Any process can pull ASCII messages off of the mailbox
- ▶ But in practice it will usually just be the shell

Keyboard: Subtle Points

- ▶ Producer must not block
 - ▶ This is important for a keyboard handler
 - ▶ Why is this?
 - ▶ Solution: drop key if buffer is full
 - ▶ Check before send: `mbox_stat` before `mbox_send`
 - ▶ Need check + send to be atomic. Why?
- ▶ What if `getchar` is interrupted by a keyboard interrupt?
 - ▶ Why is this a problem?
 - ▶ Solution: disable interrupt. But where?
- ▶ ↑ Design review questions ↑

Keyboard: Deadlock Danger



`getchar` interrupted by keyboard interrupt

Task: Reduce Interrupt Disable Time

- ▶ Interrupts should be disabled as little as possible
 - ▶ Potential to lose hardware events
 - ▶ Interrupt controller will wait for CPU, but...
 - ▶ What if another key comes in before you handle the first?
 - ▶ What if another timer event fires before you handle the last?
- ▶ Where can we reduce?
 - ▶ Scheduler? Too difficult to rewrite this time
 - ▶ Sync abstractions? ...

Rewriting Sync Abstractions

- ▶ In Project 3, we achieved atomicity by disabling interrupts
- ▶ Alternative: atomic test-and-set
 - ▶ C standard `<stdatomic.h>` provides `atomic_flag` type
 - ▶ `atomic_flag_test_and_set()`
 - ▶ `atomic_flag_clear()`
 - ▶ Compile atomic CPU instructions
- ▶ Use atomic-test-and-set to build a spinlock

```
spinlock_acquire(atomic_flag *flag) {  
    while(atomic_test_and_set(flag)) yield();  
}
```

```
spinlock_release(atomic_flag *flag) {  
    atomic_flag_clear(flag);  
}
```

- ▶ Use spinlocks to implement locks, condvars, etc.

Using Spinlocks: An Example

Via interrupt disable

```
static void lock_acquire(lock_t *l)
{
    nointerrupt_enter();
    while (l->locked) {
        block(&l->wait_queue);
    }
    l->locked = true;
    nointerrupt_leave();
}
```

Via spinlock

```
static void lock_acquire(lock_t *l)
{
    spinlock_acquire(&l->spinlock);
    while (l->locked) {
        block(&l->wait_queue, &l->spinlock);
    }
    l->locked = true;
    spinlock_release(&l->spinlock);
}
```

- ▶ block takes lock param
 - ▶ Releases before blocking
 - ▶ Re-acquires before returning
- ▶ This is no longer in the precode
- ▶ Should it be? Possible regression?

Task: Load Processes Dynamically

- ▶ In Project 3, all programs loaded at startup
- ▶ In Project 4, we will load them dynamically
- ▶ For dynamic loading, we need:
 1. Separate address space for each process
 2. Memory manager
 3. Disk format that lists processes
- ▶ These are provided in precode

You will implement...

readdir()

1. Load process-directory sector
2. Return data to shell for parsing

loadproc()

1. Allocate physical memory
2. Read code/data from disk
3. Pass mem info to `create_process()`

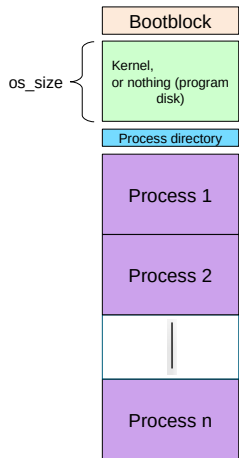
Loading Need 1: Separate Address Spaces

- ▶ Privilege enforcement via Global Descriptor Table
 - ▶ Descriptors for kernel-level code/data (ring 0)
 - ▶ Descriptors for user-level code/data (ring 3)
 - ▶ Precode `pcb` struct now has CS/DS fields
 - ▶ In-kernel threads: CS/DS point to kernel-level descriptors
 - ▶ User processes: CS/DS point to user-level descriptors
- ▶ Separate address spaces for user processes
 - ▶ Process loaded to virtual address `0x100 0000`
 - ▶ GDT Task State Segment to help with task switching
 - ▶ Precode will handle the details
 - ▶ You just need to implement physical page allocation
 - ▶ In Project 5 you will get into the details

Loading Need 2: Memory Manager

- ▶ Pool of physical pages
 - ▶ 4 KiB per page
 - ▶ 1 MiB pool
- ▶ You implement: `alloc_memory()`
 - ▶ Get pages from the pool
- ▶ Extra challenge: implement `free_memory()`

Loading Need 3: Disk Format that Lists Processes



Updated disk format with process directory

- ▶ Add a process directory after the kernel
- ▶ Very simple process directory format:
 - ▶ List of (location, size) pairs, both `int`
 - ▶ No names. Processes identified by index
 - ▶ Process 0: shell
 - ▶ Process 1: process1 (plane)
 - ▶ ...
- ▶ Kernel will load processes dynamically
 - ▶ Initiated by shell
 - ▶ `load 1: load process1 (plane)`
 - ▶ `load 2: load process2 (math)`
 - ▶ ...
- ▶ In diagram: "Program disk"?
 - ▶ Old feature to hot-swap floppies
 - ▶ No longer working

Implementing Loading

USB storage support (precode)

- ▶ Precode provides a basic USB storage driver (`kernel/usb/**`)
- ▶ Key header for you: `scsi.h`
 - ▶ `scsi_read()`: reads one 512-byte sector
 - ▶ `scsi_write()`: writes one 512-byte sector
- ▶ For now, only reading

Loading a program: `loadproc()` (you)

- ▶ Read process directory: `readdir()` (you)
- ▶ Allocate pages for code + data: `alloc_memory()` (you)
- ▶ Also allocate pages for stack
- ▶ Read process sectors: `scsi_read()` (precode)
- ▶ Initialize a `pcb` struct: `create_process()` (precode)

Implementation Help: “Given” Files

- ▶ This project has many pieces that lean on each other
 - ▶ Hard to develop and test one without the others
- ▶ “Given” files: Compiled binaries of working implementations:
 - ▶ `mbox.given.o`: IPC mailboxes
 - ▶ `keyboard.given.o`: keyboard driver
 - ▶ `sync.given.o`: sync abstractions
 - ▶ `pcb.given.o`: dynamic loading
- ▶ Lines in `Makefile.common`: Uncomment to use given files

```
KERNEL_OBJS := $(KERNEL_OBJS:kernel/mbox.o=kernel/mbox.given.o)
KERNEL_OBJS := $(KERNEL_OBJS:kernel/keyboard.o=kernel/keyboard.given.o)
KERNEL_OBJS := $(KERNEL_OBJS:kernel/sync.o=kernel/sync.given.o)
KERNEL_OBJS := $(KERNEL_OBJS:kernel/pcb.o=kernel/pcb.given.o)
```

- ▶ Careful with headers: Some changes may break given files

Extra Challenges

- ▶ Free memory when a process exits
- ▶ Use a more interesting allocation algorithm
 - ▶ Make it more like a proper `malloc`
- ▶ Implement new commands in the shell:
 - ▶ `ps`: list running processes
 - ▶ `kill`: stop a running process
 - ▶ Suspend / resume a process
- ▶ To really go above and beyond, get creative:
 - ▶ You have input now. You could write a simple game
 - ▶ Try switching to VGA graphics mode
 - ▶ Write a better shell

Project 4

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Procedure is (Mostly) the Same as Other Projects

- ▶ Design reviews start on Monday (!!)
- ▶ Code
- ▶ Report
- ▶ Hand in via Canvas: zip up entire repository plus report
- ▶ **New!** Also upload the report PDF separately

Report

- ▶ Structure: scientific paper
- ▶ Length: around 4 pages
- ▶ Citations: required
 - ▶ You must cite sources you use
 - ▶ At the very least, you should have the textbook as a source
- ▶ File format: PDF
- ▶ AI tools: discouraged but not banned. Use must be declared
- ▶ **New!** See Howto doc and template in repository
 - ▶ `doc/how-to-write-a-report.md`: gives more guidelines and advice
 - ▶ `report/latex-src/template.tex`: LaTeX tutorial / template
 - ▶ If you use the template, be sure to remove all existing content

Hand In via Canvas

- ▶ Put your report in your repository, under a `report/` dir
 - ▶ Report should be a PDF format
 - ▶ If you write in Word or other WYSIWYG word processor, export to PDF
- ▶ Zip up your entire repository (code tree + report + `.git/` dir)
- ▶ Submit via Canvas
 - ▶ Upload zip
 - ▶ **New!** Also upload report PDF
 - ▶ Having both makes it easier for us to grade