UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

CS423 MP1 Walkthrough

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What You Need

Required Items

- Completed MP0.
- Able to read, write, and debug program codes written in C language.

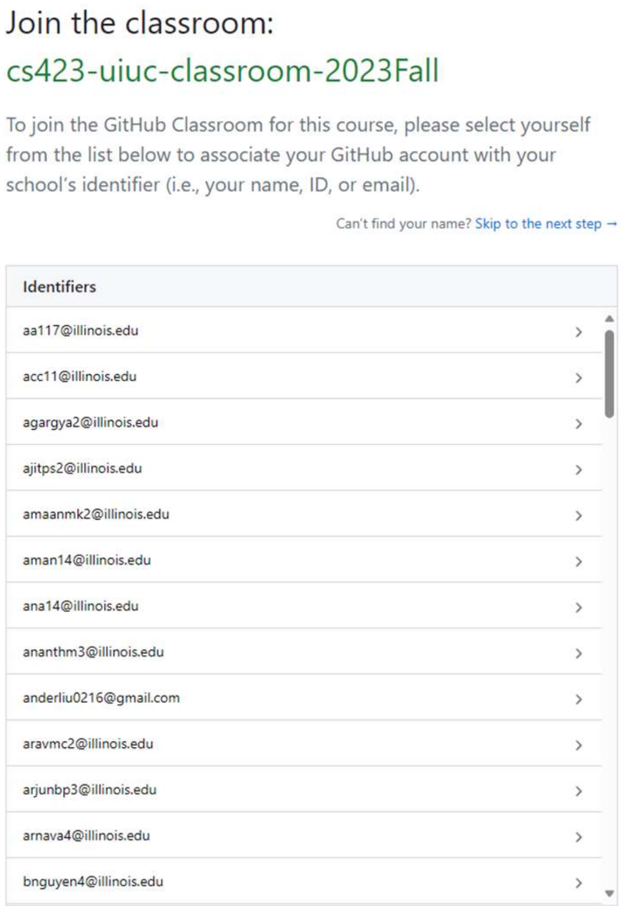
Recommended Items

- Have a handy code editor.
  - If you need some recommendations: VSCode, Neovim, or GNU Emacs
- Use Linux Kernel Documentation to help you understand concepts.
  - https://www.kernel.org/doc/html/v5.15/index.html
- Use Elixir Cross Referencer to help you go through codes.
  - https://elixir.bootlin.com/linux/v5.15.127/source

Get Your Starter Code

Accept the Assignment on GitHub Classroom First.

- Go to this link: https://classroom.github.com/a/P4KJTn7f
- Login your GitHub account and find your Email.
- Accept the assignment.
- The starter code will be available in the repo created.



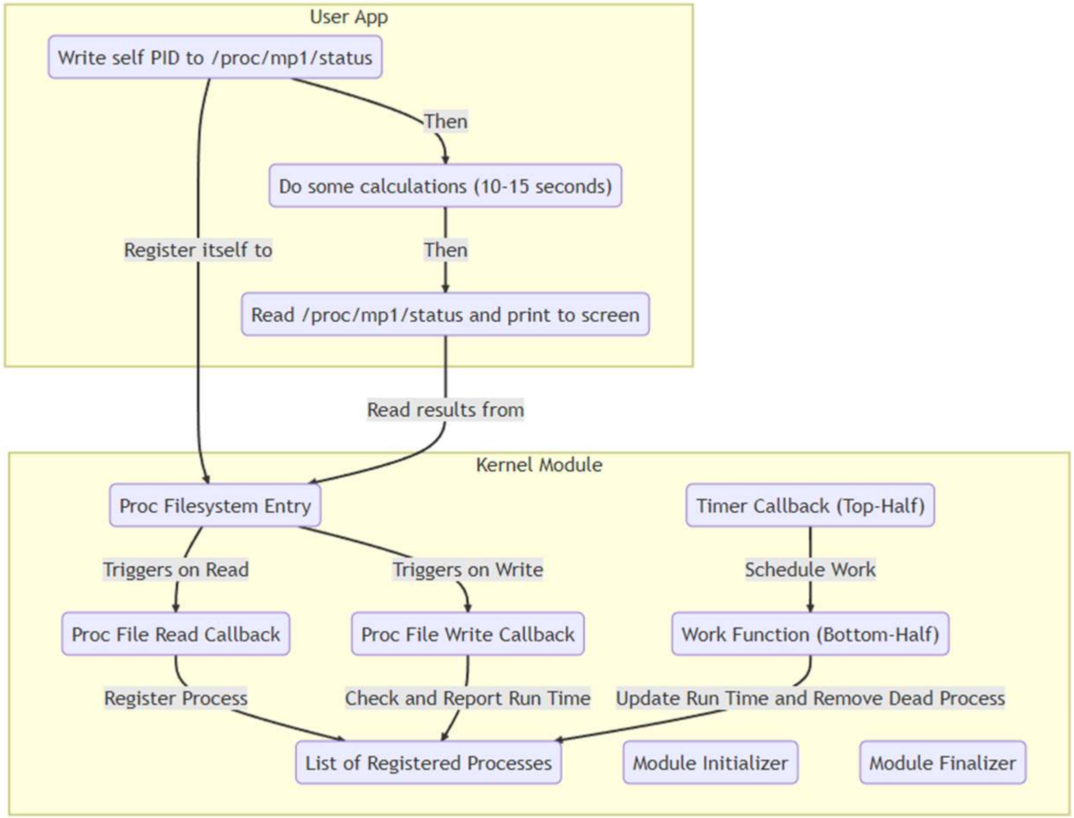
About Kernel Programming

- Lack of Isolation
  - Unhandled exception in a user program: The program dead
  - Unhandled exception in the kernel: The system dead
- Preemption is not Always Available
  - Infinite loop and dead locks are fatal
  - Make sure you use loops and locks carefully
- Lack of User Library
  - You will deal with a new set of functions (e.g. `kmalloc, printk, snprintf`)
- No Floating Points
  - You will destroy user program's calculation results

The Task

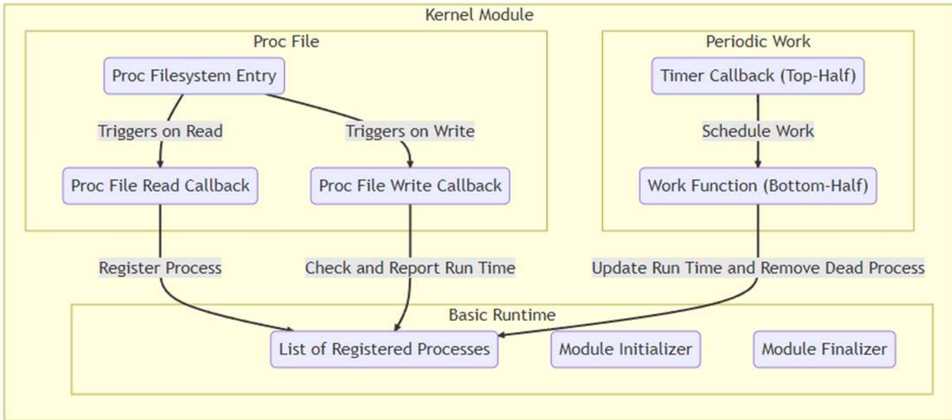
- A **kernel module** that measures the User Space CPU Time (User Time) of processes.
  - It allows **multiple** processes to register themselves and monitor their CPU usage concurrently
- A **user program** that does some work and then checks its User Time.
  - It communicates with your kernel module to **register** itself and **read** User Time info.
- The kernel module and user program communicates via a **Proc Filesystem Entry**.
- A **README** file to briefly introduce the tasks you have done.

Component Overview



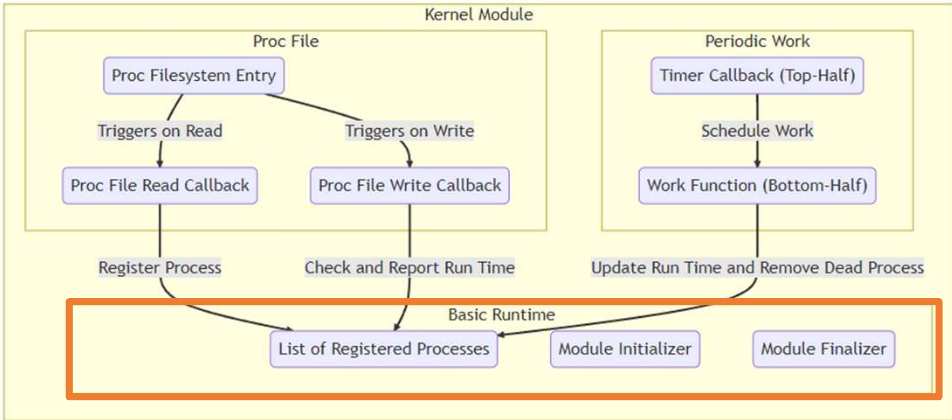
The Kernel Module

- The kernel module should be your main focus. It contains three parts:
  - A **Basic Runtime** to track user program lists and do init/uninit jobs.
  - A **Proc Filesystem Entry** to hand read and write requests for user programs
  - A **Periodic Work** to update User Time for programs.



The Kernel Module – Basic Runtime

- An **initializer** that allocates memory, lock, list, etc. when loading the module.
- An **finalizer** that deallocates the resources you allocated when unloading the module.
- A **Linked List** to store the User Times of registered processes.

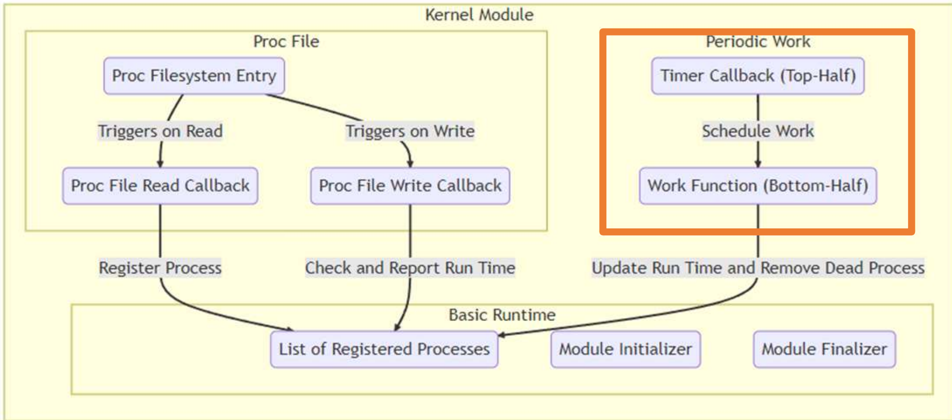


The Kernel Module – Basic Runtime

- The **initializer** will be automatically called when inserting your module into a Linux kernel.
  - The entry point is provided in the **starter code**.
- The **finalizer** will be automatically called when unloading your module.
  - The entry point is provided in the **starter code** as well.
- To store the User Times of registered processes, you should use the **Linked List**.
  - The length of list is unknown during compile time.
  - Items may be removed from the middle of the list. (You may want to remove dead processes from the list)
  - You can check `include/linux/list.h` for Linux APIs on Linked List operations.
  - You can check references of the APIs in Elixir Cross Referencer to see their real-world use cases for better understanding.

The Kernel Module – Periodic Work

- Set a **Timer** in kernel to update the User Time of processes periodically (once per 5 seconds).
- The Timer will invoke a **Callback** when it is due.
- The Callback should use **Workqueue** to enqueue a Worker to do the real job.
- The **Worker** will be automatically called on a kernel thread when it is leaving the queue.



The Kernel Module – Periodic Work

- Why so complex?
  - The registered process list may be very long.
  - It may also needs to wait on locks.
  - It is better not blocking the Timers for too long as this may affect other Timers in the system.

- Where to look at:
  - Timer API is defined in `include/linux/timer.h`
  - Workqueue API is defined in `include/linux/workqueue.h`
  - A good use case is `samples/ftrace/sample-trace-array.c#L24-L44,L79-L80`
  - Challenge: Linux Timer only fires once, how to make it fire multiple time in a fixed interval?
  - Answer: In the Timer Callback, modify the timer itself to fire again after another 5 seconds.

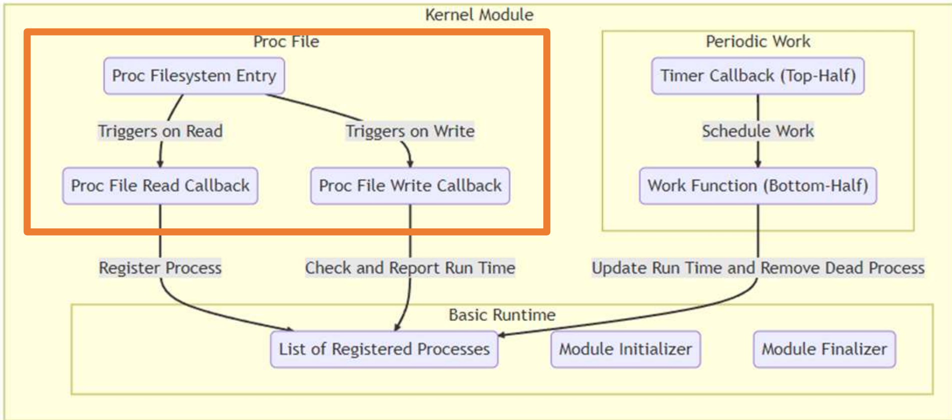
The Kernel Module – Periodic Work

- What to do in the Timer Callback?
  - **Reset** the **Timer** so that it can fire again after another 5 seconds
  - **Enqueue** a **Worker** onto the Workqueue

- What to do in the Workqueue Worker?
  - **Lock** the process list using **Mutex** to prevent race conditions with the Proc File handlers
  - **Iterate** through the registered process **list**
  - **Check** if each process is still **alive** and their up-to-date **User Timer**
  - **Update** the process entry to record the newest User Time if the process is **alive**
  - **Remove** the process from the list if it is **dead**

The Kernel Module – Proc Filesystem Entry

- Allow the user program to communicate with your module and get results. (File perm: 0666)
- Locates at `/proc/mp1/status`. Create the **folder** `/proc/mp1` first, then the **file** `/proc/mp1/status`.
- Read: Report the User Time of all registered processes.
- Write: Register a new process using the PID of the process.



The Kernel Module – Proc Filesystem Entry

- The functions to create Proc Filesystem folders and files are in `include/linux/proc_fs.h`.
  - See `fs/lockd/procfs.c#L70-L92` for a simple real-world use case on creating/destroying Proc Filesystem Entries
  - See `fs/jfs/jfs_debug.c#L20-L52` for a simple real-world use case on handling read/write for Proc Filesystem Entries
- You will need to deal with “user pointers”, i.e. pointers that are unsafe to deference in kernel space.
  - Kernel marks this type of pointers in this format: `void __user *ptr`
  - You need to copy them to/from kernel space to access them safely.
  - Use functions such as `copy_from_user()` or `copy_to_user()` before accessing them to eliminate security warnings.
- You will need to parse and format strings to/from integers
  - Use functions such as `snprintf()` (print to a buffer) or `kstrtoint()` (parse string to int)

The Kernel Module – Proc Filesystem Entry

- Example for Write

```
echo "1" > /proc/mp1/status # register PID 1
```

- Example for Read

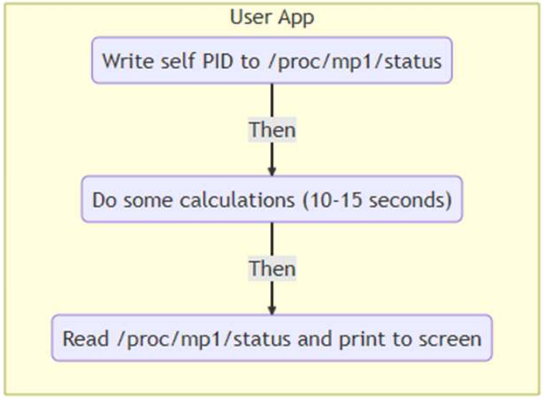
```
# read all registered PIDs and User Times
cat /proc/mp1/status
1: 82902
1728: 3317982
1743: 3421024
```

The Kernel Module – Others

- Use Mutex lock to prevent race conditions between Proc File requests and periodic updates
  - Defined in `include/linux/mutex.h`
- Use Slab allocator to allocate memories
  - Defined in `include/linux/slab.h`
- Don’t worry on checking the liveness and User Time of processes
  - A function will be given to you as a part of the starter code

The User Program

- Get its own PID using `getpid()`
- Register itself to your kernel module via writing the PID to `/proc/mp1/status`
- Do 10-15 sec calculation (provided as a part of starter code)
- Read the User Time output from `/proc/mp1/status`, print to console, and exit



Write a README file

- Edit the `README.md` in your GitHub starter code repo
- Briefly describe how you design and implement each parts of the kernel module
  - E.g. which system API used in what part, how parts interact with each other, anything special with your implementation
- If your code failed to run correctly on the test machine, this will help you get partial grade
- Don't need to be very detailed
- No word limit

Submission

- Push all your works into your GitHub repo (the repo containing your starter code)
- Grading will be based on your last commit pushed before the deadline
- TAs will compile and run your code on a MP0 VM to see if it works

- Deadline: **Sep 26th at 11:59 PM CT**

About MP1

Recap and Q&A