CS 423
Operating System Design:
MP3 Walkthrough

Purpose of MP3

- **Understand** the Linux virtual to physical page mapping and page fault rate.
- **Design** a lightweight tool that can profile page fault rate.
- **Implement** the profiler tool as a Linux kernel module.
- **Learn** how to use the kernel-level APIs for character devices, vmalloc(), and mmap().

Introduction

- Performance gap between memory and disk
  - Registers: ~1ns
  - DRAM: 50-150ns
  - Disk: ~10ms, hundreds times slower than memory!

- Performance of the virtual memory system plays a major role in the overall performance of the Operating System

- Inefficient VM replacement of pages
  - Bad performance for user-level programs
  - Increasing the response time
  - Lowering the throughput

Page Fault

- Page Fault is a trap to the software raised by the hardware when:
  - A program accesses a page that is mapped in the Virtual address space but not loaded in the Physical memory
- In general, OS tries to handle the page fault by bringing the required page into physical memory.
- The hardware that detects a Page Fault is the Memory Management Unit of the processor
- However, if there is an exception (e.g. illegal access like accessing null pointer) that needs to be handled, OS takes care of that

Page Fault

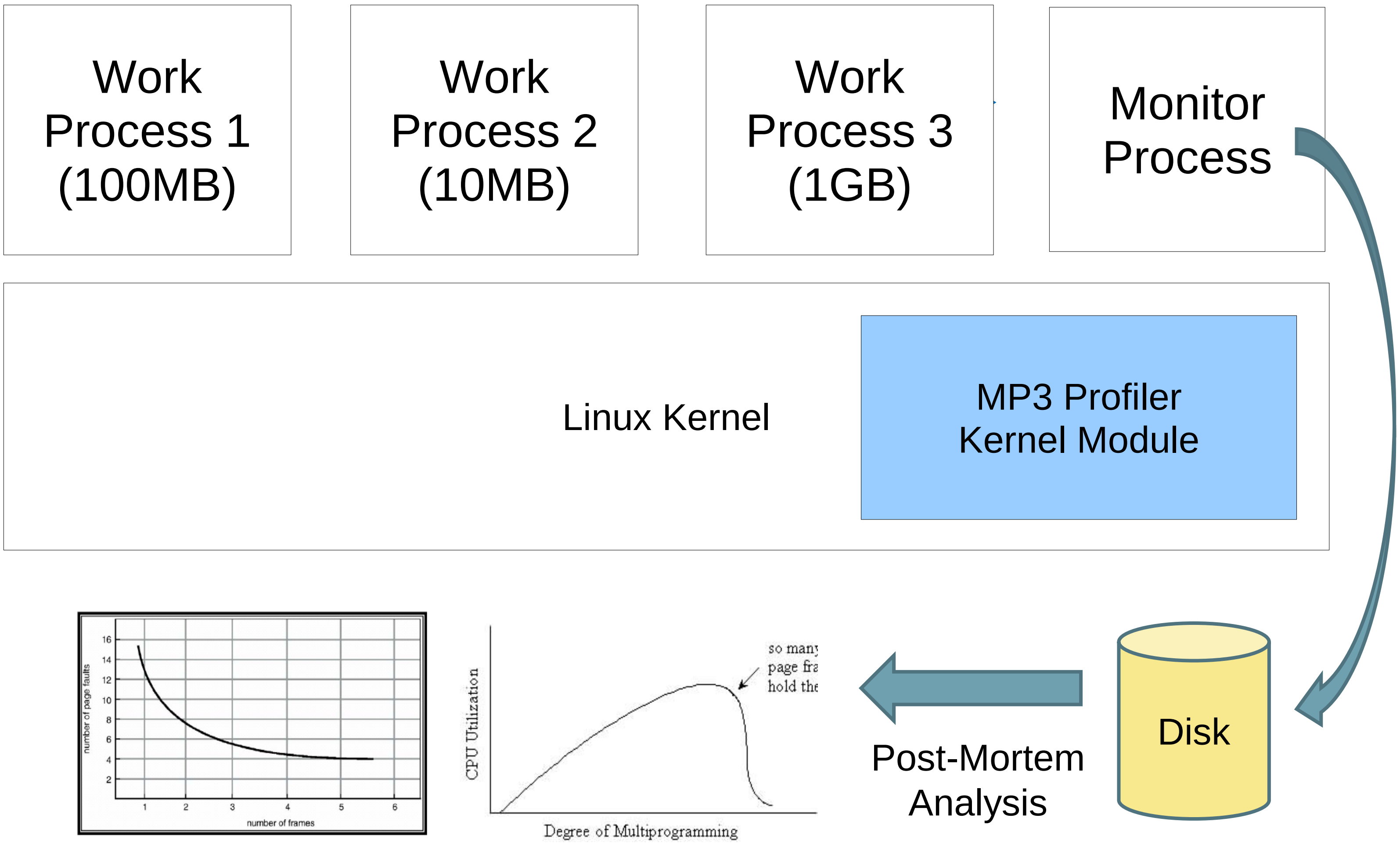
- Major page fault
  - Handled by using a disk I/O operation
  - Memory mapped file
  - Page replacement / Cold Pages
  - **Expensive as they add to disk latency**

- Minor page fault
  - Handled without using a disk I/O operation
  - malloc(), copy_on_write(), fork()

Effect of Page Fault on System Performance

- Major Page Fault are much more expensive. How much?
  - HDD average rotational latency : 3ms
  - HDD average seek time: 5ms
  - Transfer time from HDD: 0.05ms/page
    - Total time for bringing in a page = 8ms= 8,000,000ns
  - Memory access time: 200ns
  - Thus, Major Page Fault is **40,000** times slower

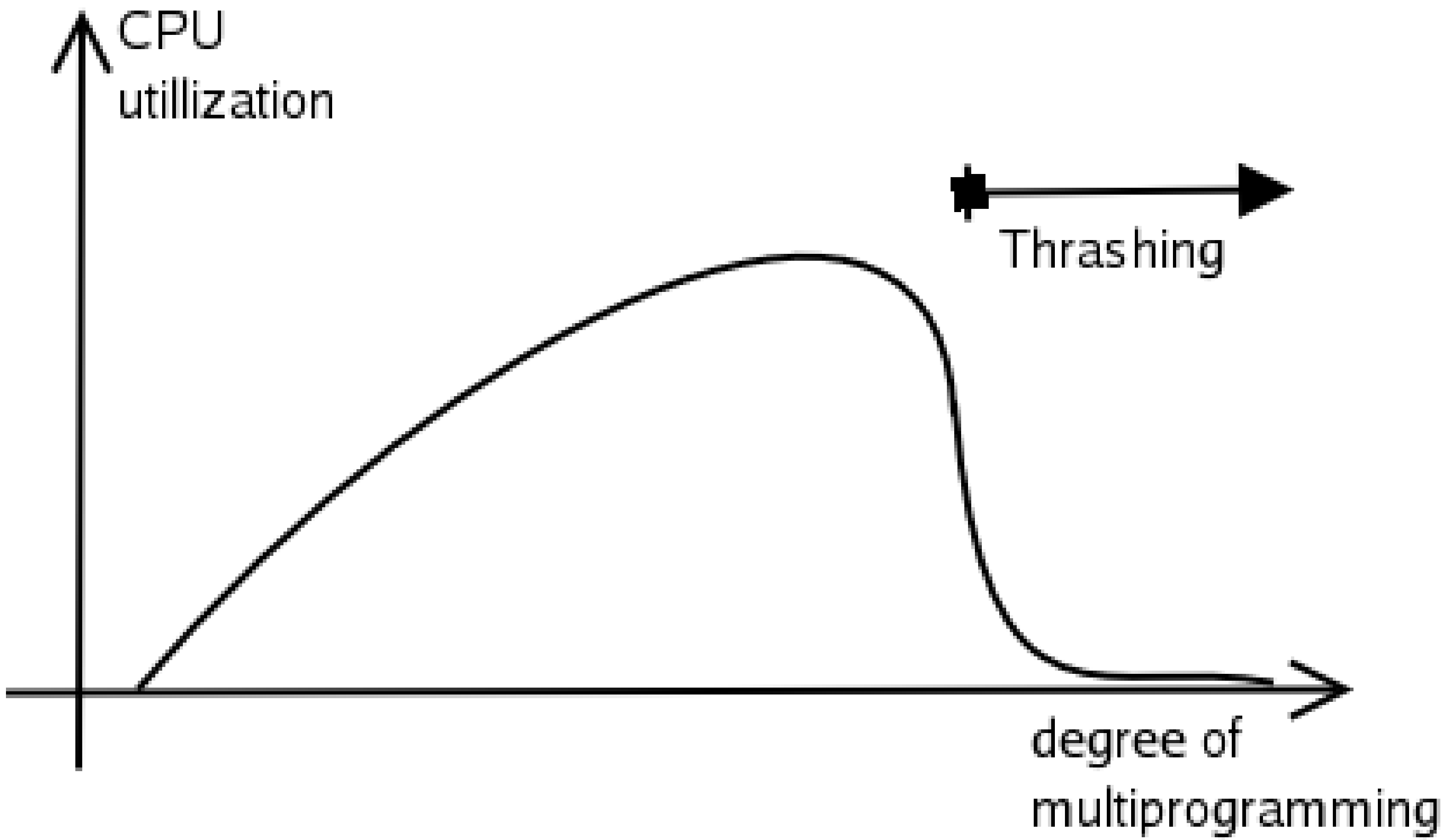
MP3 Overview



Metric

- Major page fault
- Minor page fault
- CPU utilization
  - Calculated as a rate
    - For task T: $U_T = \frac{cpu\ time_T}{wall\ time} = \frac{stime_T + utime_T}{jiffies}$
    - stime: Time spent in kernel space
    - utime: Time spent in user space

Thrashing



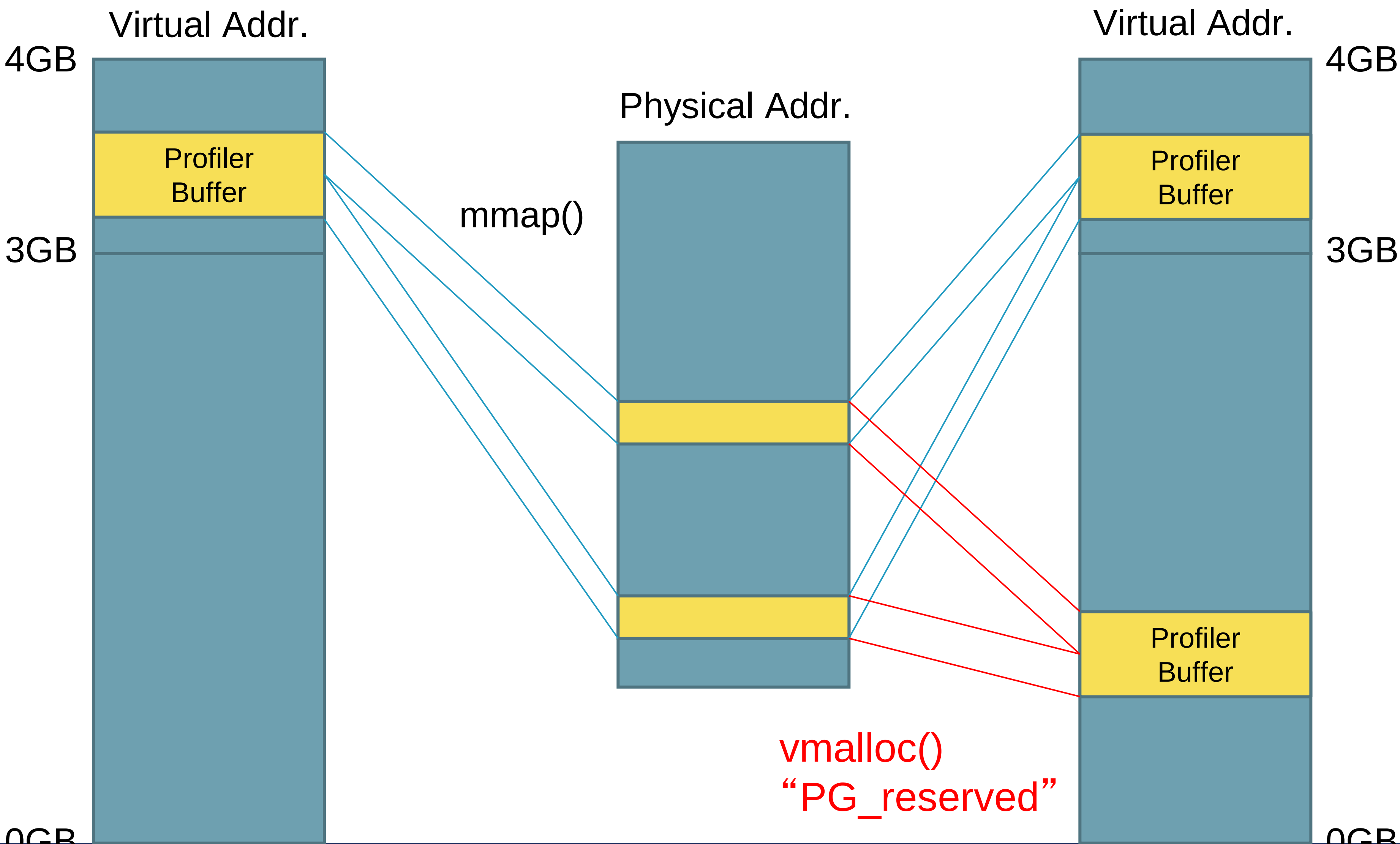
Measurement

- Accuracy of Measurement
  - Many profiling operations are needed in a short time interval.

- Copy to user space causes a significant performance overhead

- Solution: Use Shared Memory

Memory Map


Virtual Addr.
4GB
Profiler
Buffer
3GB
0GB
mmap()
Physical Addr.
Virtual Addr.
4GB
Profiler
Buffer
3GB
Profiler
Buffer
0GB
vmalloc()
"PG_reserved"

Char Device and Shared Memory

- A character device driver is used as a control interface of the shared memory
  - Map Shared Memory (i.e., mmap()): To map the profiler buffer memory allocated in the kernel address space to the virtual address space of a requesting user-level process
- Shared memory
  - Normal memory access: Used to deliver profiled data from the kernel to user processes

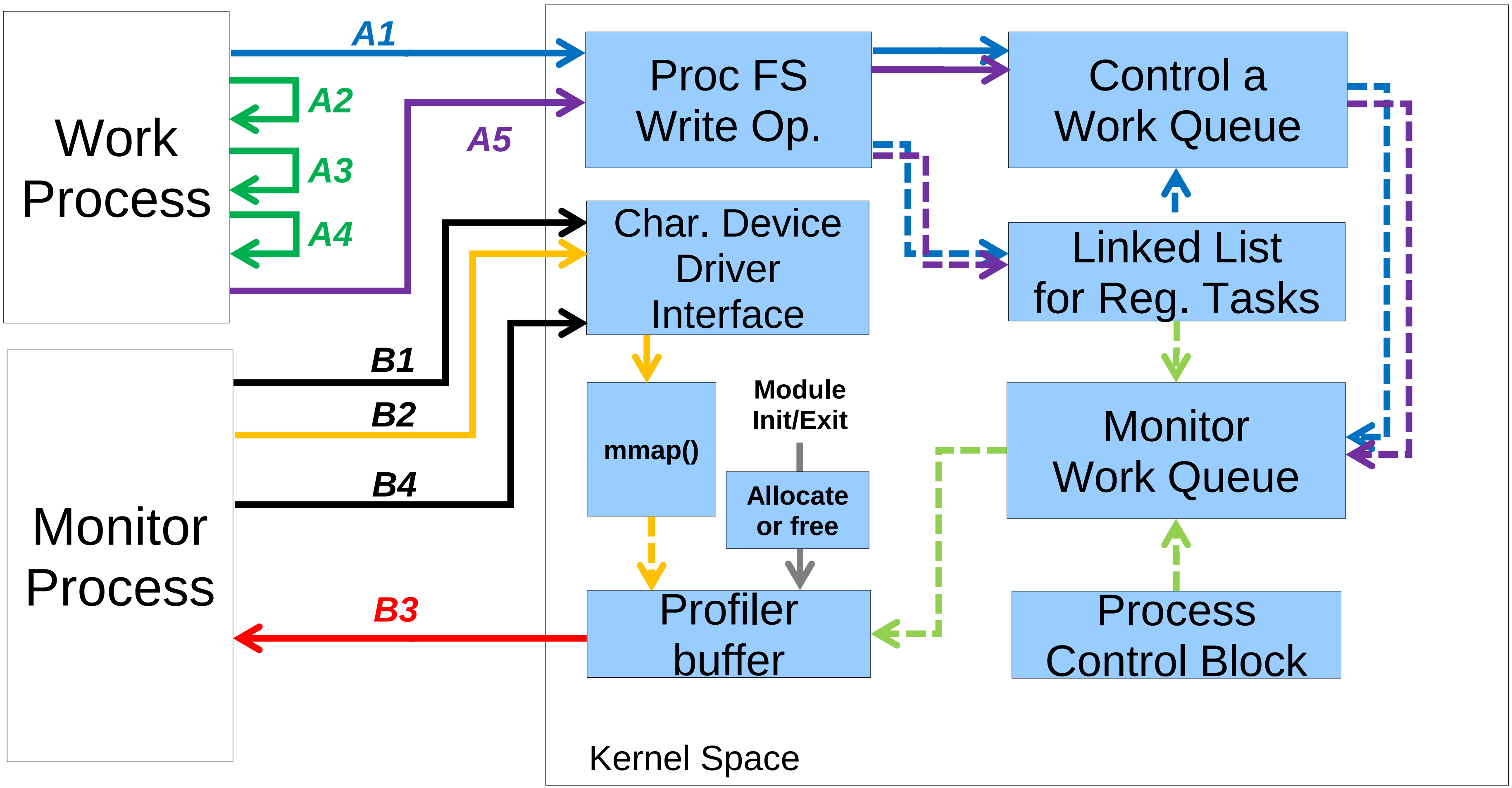
Interface of Kernel Module

- Three types interfaces between the OS kernel module and user processes:
  - a Proc file
  - a character device driver
  - a shared memory area

Proc File System

- Proc filesystem entry (/proc/mp3/status)
  - Register: Application to notify its intent to monitor its page fault rate and utilization.
    - ‘R <PID>’
  - Deregister: Application to notify that the application has finished using the profiler.
    - ‘U <PID>’
  - Read Registered Task List: To query which applications are registered.
    - Return a list with the PID of each application

MP3 Design



A1. Register *A2. Allocate Memory Block* *A3. Memory Accesses* *A4. Free Memory Blocks*
A5. Unregister **B1. Open** **B2. mmap()** **B3. Read Profiled Data** ***B4. Close***

Workload

- Work program (given for case studies)
  - A single threaded user-level application with three parameters: memory size, locality pattern, and memory access count per iteration
    - Allocates a request size of virtual memory space (e.g., up to 1GB)
    - Accesses them with a certain locality pattern (i.e., random or temporal locality) for a requested number of times
    - The access step is repeated for 20 times.
  - Multiple instances of this program can be created (i.e., forked) simultaneously.

Monitoring Program

- Monitor application is also given
  - Requests the kernel module to map the kernel-level profiler buffer to its user-level virtual address space (i.e., using mmap()).
    - This request is sent by using the character device driver created by the kernel module.
  - The application reads profiling values (i.e., major and minor page fault counts and utilization of all registered processes).
  - By using a pipe, the profiled data is stored in a regular file.
    - So that these data are plotted and analyzed later.

Deferring Work

- It is common in kernel code to defer part of the work
- E.g. Interrupt handler code
  - Some or all interrupts are disabled when handling it
  - While handling one, we might lose new interrupts
  - So, make the handling as fast as possible
  - Top half
  - Bottom half

- Better performance because :
  - quick response to interrupts
  - by deferring non-time-sensitive part of the work to later

Work Queue

- Bottom-half mechanism used to defer work
- Work queues run in process context.
  - Work queues can sleep, invoke the scheduler, and so on.
  - The kernel schedules bottom halves running in work queues.
- The work queue execute user’s bottom half as a specific function, called a work queue handler or simply a work function.
- Linux provides a common work queue but you can also initialize your own

Creating/Destroying a Work Queue

- In order to create a work queue, you need to:
  - Call the create_workqueue() function
  - Which returns a workqueue_struct reference
  - *struct workqueue_struct *create_workqueue(name);*

- It can later be destroyed by calling the destroy_workqueue() function
  - *void destroy_workqueue(struct workqueue_struct *);*

Creating/Destroying a Work Queue

- The work to be added to the queue is
  - Defined by struct work_Struct
  - Initialized by calling the INIT_WORK() function
  - *INIT_WORK(struct work_struct *work, func);*

- Now that the work is initialized, it can be added to the work queue by calling one of the following:
  - *int queue_work(struct workqueue_struct *wq, struct work_struct *work);*
  - *int queue_delayed_work(struct workqueue_struct *wq, struct work_struct *work, unsigned long delay);*

Creating/Destroying a Work Queue

- Flush_work(): to flush a particular work and block until the work is complete
  - *int flush_work(struct work_struct *work);*

- Flush_workqueue(): similar to flush_work() but for the whole work queue
  - *int flush_workqueue(struct workqueue_struct *wq);*

Creating/Destroying a Work Queue

- Cancel_work(): to cancel a work that is not already executing in a handler
  - The function will terminate the work in the queue
  - Or block until the callback is finished (if the work is already in progress in the handler)
  - *int cancel_work_sync(struct work_struct *work);*

- Work_Pending(): to find out whether a work item is pending or not
  - *work_pending(work);*

Character Device Driver

- Initialize data structure
  - *void cdev_init(struct cdev *cdev, struct file_operations *fops);*

- Add to the kernel
  - *int cdev_add(struct cdev *dev, dev_t dev, unsigned int count);*

- Delete from the kernel
  - *void cdev_del(struct cdev *dev);*

Character Device Driver

```
static int my_open(struct inode *inode, struct file *filp);

static struct file_operations my_fops = {
    .open = my_open,
    .release = my_release,
    .mmap = my_mmap,
    .owner = THIS_MODULE,
};
```

Memory Map

- Gets Page Frame Number
  - pfn = vmalloc_to_pfn(virt_addr);

- Maps a virtual page to a physical frame
  - remap_pfn_range(vma, start, pfn, PAGE_SIZE, PAGE_SHARED);

  (see http://www.makelinux.net/ldd3/chp-15-sect-2)

More Questions?

- Office hours

- Piazza