

# LINUX 实验报告

## Project 2

课 程 名 称: Linux 操作系统实践  
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## 目录

(一) Project 2a:Malloc & Free .....	3
一、 实验目的 .....	3
二、 问题重述 .....	3
三、 算法设计 .....	4
(二) Project 2b:xv6 Scheduler .....	8
一、 实验目的 .....	8
二、 问题重述 .....	8
三、 算法设计 .....	8
四、 测试结果 .....	14

# (一) Project 2a: Malloc & Free

## 一、实验目的

1. To understand the nuances of building a memory allocator.
2. To do so in a performance-efficient manner.
3. To create a shared library.

## 二、问题重述

In this project, you will be implementing a memory allocator for the heap of a user-level process. Your functions will be to build your own `malloc()` and `free()`.

Memory allocators have two distinct tasks. First, the memory allocator asks the operating system to expand the heap portion of the process's address space by calling either `sbrk` or `mmap`. Second, the memory allocator doles out this memory to the calling process. This involves managing a free list of memory and finding a contiguous chunk of memory that is large enough for the user's request; when the user later frees memory, it is added back to this list.

This memory allocator is usually provided as part of a standard library and is not part of the OS. To be clear, the memory allocator operates entirely within the virtual address space of a single process and knows nothing about which physical pages have been allocated to this process or the mapping from logical addresses to physical addresses; that part is handled by the operating system.

When implementing this basic functionality in your project, we have a few guidelines. First, when requesting memory from the OS, you must use `mmap()` (which is easier to use than `sbrk()`). Second, although a real memory allocator requests more memory from the OS whenever it can't satisfy a request from the user, your memory allocator must call `mmap()` only **one** time (when it is first initialized).

Classic `malloc()` and `free()` are defined as follows:

- `void *malloc(size_t size)`, which allocates `size` bytes and returns a pointer to the allocated memory. The memory is not cleared.
- `void free(void *ptr)`, which frees the memory space pointed to by `ptr`, which must have been returned by a previous call to `malloc()` (or `calloc()` or `realloc()`). Otherwise, or if `free(ptr)` has already been called before, undefined behaviour occurs. If `ptr` is `NULL`, no operation is performed.

For simplicity, your implementations of `mem_alloc()` and `mem_free()` should basically follow what `malloc()` and `free()` do; see below for details.

You will also provide a supporting function, `mem_dump()`, described below; this routine simply prints which regions are currently free and should be used by you for debugging purposes.

### 三、算法设计

#### 1. 声明、结构体及全局变量

```
int m_error;
int has_initd = 0;

typedef struct node
{
    int size;
    struct node *next;
}node;

node* headfree;
int tot_size;
```

`pg_size` 记录一个页的大小，以便舍入存储区域大小为页的倍数。

`m_error` 记录错误信息。

`has_initd` 保证 `meminit` 只被调用一次。

`node` 结构体为链表中存储的节点，指向一块连续的存储区域。`node` 中 `size` 为用户可用的区域的大小。

`headfree` 为链表头指针。

`tot_size` 为总共申请的存储区域大小，每次用户申请前需检查是否超出总大小。

#### 2. 初始化

`mem_init` 中输入需要的存储大小，并申请内存，初始化内存，该函数仅调用一次。

```
int mem_init(int size_of_region)
{
    m_error = 0;
    pg_size = getpagesize();
    if(size_of_region <= 0 || has_initd){
        m_error = E_BAD_ARGS;
        return -1;
    }
}
```

```

size_of_region += (pg_size - size_of_region % pg_size) % pg_size;
int fd = open("/dev/zero", O_RDWR);
headfree = mmap(NULL, size_of_region, PROT_READ | PROT_WRITE, MAP_PRIVATE, fd, 0);
if(headfree == MAP_FAILED){ perror("mmap"); exit(1); }
close(fd);
tot_size = size_of_region;
headfree->size = tot_size - sizeof(node);
has_initd = 1;
return 0;
}

```

### 3. 分配

mem\_alloc 申请 size 大小的连续存储区域，并选择查找方式。

以下代码根据不同查找方式找到符合条件的存储区域的头指针。

```

case M_BESTFIT:
{
    int mn = tot_size + 10;
    while(p != NULL){
        if(p->size >= size){
            if(p->size < mn){
                mn = p->size;
                res = p;
            }
        }
        p = p->next;
    }
    break;
}
case M_WORSTFIT:
{
    int mx = -1;
    while(p != NULL){
        if(p->size > mx){
            mx = p->size;
            res = p;
        }
        p = p->next;
    }
    if(res != NULL && res->size < size)res = NULL;
    break;
}

```

```

}
case M_FIRSTFIT:
{
    while(p != NULL){
        if(p->size >= size){
            res = p;
            break;
        }
        p = p->next;
    }
    break;
}
}

```

得到指针后进行后续处理，由于以链表方式存储，因此需要修改链表头指针，前驱指针，后继指针，并判断是否加入新的指针，修改存储区域大小。

```

if(res->size > size + sizeof(node)){
    node* np = res + size + sizeof(node);
    np->size = res->size - size - 2 * sizeof(node);
    np->next = res->next;
    if(res == headfree){
        headfree = np;
    }
    else{
        p = headfree;
        while(p != NULL){
            if(p->next == res){
                p->next = np;
                break;
            }
            p = p->next;
        }
    }
}
else{
    if(res == headfree){
        headfree = res->next;
    }
    else{
        p = headfree;
        while(p != NULL){
            if(p->next == res){
                p->next = res->next;
                break;
            }
        }
    }
}

```

```

        }
        p = p->next;
    }
}
}
res->size = size;
return (void*)res;
}

```

#### 4. 释放

mem\_free 函数释放存储空间，并合并连续的存储区域，判断如果两个连续指针指向连续的存储区域，则合并两个指针。

```

int mem_free(void *pptr)
{
    if(pptr == NULL)return 0;
    node* ptr = (node*)pptr;
    if(ptr < headfree){
        if(headfree < ptr + ptr->size + sizeof(node)){
            return -1;
        }
        node* tmp = headfree;
        headfree = ptr;
        ptr->next = tmp;
        if(ptr->next != NULL && ptr + ptr->size + sizeof(node) == ptr->next){
            ptr->size += ptr->next->size + sizeof(node);
            ptr->next = ptr->next->next;
        }
    }
    else{
        node* p = headfree;
        while(p != NULL){
            if(p < ptr && (p->next > ptr))break;
            p = p->next;
        }
        if(p == NULL)return -1;
        if(p + p->size + sizeof(node) > ptr || (p->next != NULL && ptr + ptr->size + sizeof(node) > p->next))
            return -1;
        ptr->next = p->next;
        p->next = ptr;
        if(ptr->next != NULL && ptr + ptr->size + sizeof(node) == ptr->next){
            ptr->size += ptr->next->size + sizeof(node);

```

```

        ptr->next = ptr->next->next;
    }
    if(p + p->size + sizeof(node) == ptr){
        p->size += ptr->size + sizeof(node);
        p->next = ptr->next;
    }
}
return 0;
}

```

## (二) Project 2b:xv6 Scheduler

### 一、实验目的

1. To understand code for performing context-switches in the xv6 kernel.
2. To implement a basic MLFQ scheduler.
3. To create system call that extract process states.

### 二、问题重述

In this project, you'll be implementing a simplified **multi-level feedback queue (MLFQ)** scheduler in xv6.

The basic idea is simple. Build an MLFQ scheduler with four priority queues; the top queue (numbered 3) has the highest priority and the bottom queue (numbered 0) has the lowest priority. When a process uses up its time-slice (counted as a number of ticks), it should be downgraded to the next (lower) priority level. The time-slices for higher priorities will be shorter than lower priorities. The scheduling method in each of these queues will be round-robin, except the bottom queue which will be implemented as FIFO.

### 三、算法设计

观察原来的 xv6 代码，发现原来的 `schedule()` 函数是进程调度函数，每个 `timer tick` (即一次 `for` 循环) 从 `ptable` 的 `proc` 数组里选取一个下标最靠前的处于 `runnable` 的进程进行调度。

对题目的要求进行总结：

- ①有 4 个队列，队列 3 优先级最高 (每次新建立的进程进入队列 3)，队列 0 优



优先级最低。前三个队列中采用时间片轮转法(时间片分别为 8, 16, 32 time ticks), 最后一个队列采取 FIFO。

如果在前三个队列时间片用完了, 就降低一个优先级, 进入序号低的队列。

②每次 timer tick 结束之后, 进程不管有没有用完时间片都要 yield 一次放弃 CPU, 如果此时有优先级更高的进程, 就会选取优先级高的进程, 否则继续执行, 直到时间片用完或者执行完毕/阻塞。所以我们要实现的是**抢占式多级反馈队列**。

③对于后 3 个队列的进程, 没有被调度的时间分别大于 160, 320, 500 timer ticks 时, 便出现饥饿现象, 会升一个优先级, 进入序号高的队列。

为了实现以上功能, 可以对 结构体 proc 扩充定义:

```
struct proc {
    uint sz;                // Size of process memory (bytes)
    pde_t* pgdir;           // Page table
    char *kstack;           // Bottom of kernel stack for this process
    enum procstate state;    // Process state
    volatile int pid;        // Process ID
    struct proc *parent;     // Parent process
    struct trapframe *tf;    // Trap frame for current syscall
    struct context *context; // switch() here to run process
    void *chan;              // If non-zero, sleeping on chan
    int killed;              // If non-zero, have been killed
    struct file *ofile[NOFILE]; // Open files
    struct inode *cwd;        // Current directory
    char name[16];           // Process name (debugging)
    int priority;
    int waited_ticks[NPriority];
    int used_ticks[NPriority];
    int que0_ticks;
};
```

由于进行了扩充, 所以在 allocproc() 中加入相应的初始化:

```
p->priority = NPriority - 1;
p->que0_ticks = 0;
for(int i = 0; i < NPriority; i++){
    p->waited_ticks[i] = 0;
    p->used_ticks[i] = 0;
}
```

其中, waited\_ticks 记录在每个队列里已经等待的 ticks(waited\_ticks 不

会累加,所以当某个进程被调用时,waited\_ticks 会被置为 0),waited\_ticks 的记录有 3 点用处:

- ①对应于之后系统调用中 pstat 里的 wait\_ticks[NPROC][4];
- ②来判断该进程在该队列中是否发生饥饿;
- ③前三个队列是用时间片轮转法实现调度的,当选取某个队列 q 中的进程进行调度时,对应于选取 wait\_ticks[q] 最大的进程,即**每次选取队列中等待时间最长的进程**。

因为对于一个队列来说,我们每次都选取队首的元素,而队首的元素一定是这个队列中等待时间最长的,示例如下:

P1	P2	P3
----	----	----

按照入队顺序为 P1, P2, P3, 那 P1 的等待时间一定是最长的,但如果一个进程时间片没有用完被抢占了或者被阻塞了不能继续占有 CPU,相当于从队首删去,加入队尾。

比如 P1 执行了一半时间片,但是 CPU 被抢占了,当优先级更高的进程执行完毕之后,执行的顺序应该如下:

P2	P3	P1
----	----	----

但是对于第 0 个队列,是不能根据 wait\_ticks 进行判断的,因为队首的 wait\_ticks 可能很低(不久前被执行),队尾的 wait\_ticks 也可能很低(刚刚入队)。

也不能拿 used\_ticks 进行判断。比如队列中有一个进程 A 执行了 100 ticks,这时候进入了一个进程 B,按照 FIFO 应该先执行完 A 再执行 B,但是若是 B 之前在第 0 个队列中执行了 200 ticks,是发生饥饿了之后进入前一个队列,现在又回来了,那么 B 的 used\_ticks 就会比 A 大。

所以在结构体中新定义了一个 que0\_ticks,记录这个进程进入第 0 个队列的总时间,即无论处于 runnable 还是 running 都要计时,当发生饥饿进入上一个队列时,计时会清空。当进入第 0 个队列,计时开始。每次选取 que0\_ticks 最大的,即满足 FIFO。

所以 scheduler 修改如下(详情见注释):

```
void
scheduler(void)
{
    struct proc *p;
    struct proc *pr[NPriority];
    int nd_sched = 0;
    proc = 0;
    for(;;){
```

```

// Enable interrupts on this processor.
sti();

// Loop over process table looking for process to run.
acquire(&ptable.lock);
// nd_sched=0 表示当前进程时间片没有用完,也没有进程升队,只需要查看有没有优先级
// 更高的进程加入
if(proc != NULL && !nd_sched){
    for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
        if(p->state != RUNNABLE)continue;
        if(p->priority > proc->priority){
            nd_sched = 1;
            break;
        }
    }
}

// nd_sched = 1 进程时间片用完,或者有进程升队,或者有优先级更高的进程加入
if(proc == NULL || nd_sched){
    for(int i = 0; i < NPriority; i++)pr[i] = NULL;
    for(p = ptable.proc; p < &ptable.proc[NPROC]; p++){
        if(p->state != RUNNABLE)continue;
        if(p->priority == 0){ //第 0 个队列选择入队时间最长的
            if(pr[0] == NULL || p->que0_ticks > pr[0]->que0_ticks){
                pr[0] = p;
            }
        }
        else{ //1,2,3 队列选择等待时间最长的
            if(pr[p->priority] == NULL
                || p->waited_ticks[p->priority] > pr[p->priority]->waited_ticks[p->priority]){
                pr[p->priority] = p;
            }
        }
    }
    nd_sched = 0;
}

for(int i = NPriority - 1; i >= 0; i--){ //选择优先级最高的队列
    if(pr[i] != NULL){
        proc = pr[i];
        break;
    }
}

if(proc == NULL){
    release(&ptable.lock);
}

```

```

        continue;
    }
    for (p = ptable.proc; p < &ptable.proc[NPROC]; p++){    //第 0 个队列增加入队时间
        if(p->priority == 0 && (p->state == RUNNABLE || p->state == RUNNING)){
            p->que0_ticks++;
        }
        if(p->pid == proc->pid){
            continue;
        }
        if (p->state == RUNNABLE) {    //1,2,3 队列非调度进程增加等待时间
            p->waited_ticks[p->priority]++;
        }
        if ((p->priority == 0 && p->waited_ticks[p->priority] == 500)    //判断饥饿
            || (p->priority != 0 && p->waited_ticks[p->priority] == 10*mxtick[p->priority])) {
            if(p->priority != NPriority - 1){
                p->priority++;
                p->que0_ticks = 0;
            }
        }
    }
    }
    for(int i = 0; i < NPriority; i++){    //被调度队列等待时间清空
        proc->waited_ticks[i] = 0;
    }
    proc->used_ticks[proc->priority]++;
    if(proc->used_ticks[proc->priority] % mxtick[proc->priority] == 0 && proc->priority != 0){    //判断是不是到达时间片
        nd_sched = 1;
        proc->priority--;
    }

    switchvm(proc);    //开始调用
    proc->state = RUNNING;
    swtch(&cpu->scheduler, proc->context);
    switchkvm();

    if(proc->state != RUNNABLE){    //判断调用完状态
        nd_sched = 1;
    }
    release(&ptable.lock);
}
}

```

补充完了 `schedule()` 函数，还有一个任务是增加系统调用 `getpinfo()`，

①这个函数的 body 定义在 proc 中，需要将传入的结构体填入进程的信息，成功返回 0，失败返回-1，如下实现：

```
int getpinfo(struct pstat *pst){
    if(pst == NULL)return -1;           //-1 表示失败
    struct proc *p;
    int i;
    for(i = 0, p = ptable.proc; i < NPROC && p < &ptable.proc[NPROC]; i++, p++){
        if(p->state == SLEEPING || p->state == RUNNABLE || p->state == RUNNING)
            pst->inuse[i] = 1;
        else pst->inuse[i] = 0;
        pst->pid[i] = p->pid;
        pst->priority[i] = p->priority;
        pst->state[i] = p->state;
        for(int j = 0; j < NPriority; j++){ //用新增的变量去初始化 pst
            pst->ticks[i][j] = p->used_ticks[j];
            pst->wait_ticks[i][j] = p->wait_ticks[j];
        }
    }
    return 0;
}
```

由于使用了 pst, 需要在 proc.c 加入头文件：

```
#include "pstat.h"
```

②在sysfile.c加入系统调用的函数 sys\_getpinfo，为了将参数从用户空间传入内核空间，使用了argptr函数：

```
int
sys_getpinfo(void)
{
    struct pstat *p;
    if(argptr(0, (void*)&p, sizeof(*p))<0) return -1;
    return getpinfo(p);
}
```

③在 usys.S 中增加 sys\_getpinfo 的宏定义：

```
SYSCALL(getpinfo)
```

④上面要用到 sys\_getpinfo，所以在 include/syscall.h 中添加定义。

```
#define SYS_getpinfo 23
```

⑤在 IDT 表中添加相应的中断描述符，在 kernel/syscall.c 中添加。

```
[SYS_getpinfo] sys_getpinfo,
```

⑥添加了上述中段描述符之后，是要在 kernel/sysfunc.h 添加声明。

```
int sys_getpinfo(void);
```

⑦要供用户使用的话，在 user.h 加入 pstat 和 int getpinfo(struct pstat\*)

```
int getpinfo(struct pstat*);
```

## 四、测试结果

```
woria@ubuntu: ~/Downloads/project2btest
Summary:
test build PASSED
(build xv6 using make)

test getpinfo PASSED (10 of 10)
(Workload: Check getpinfo works
Expected: pstat fields filled by getpinfo)

test test_ptable PASSED (10 of 10)
(Workload: Checks getpinfo mirrors ptable
Expected: init, sh, tester are in the ptable)

test single_job_long PASSED (10 of 10)
(Workload: Single long running process (spinning)
Expected: Single long job should use up all time ticks of level 0-2 and running at the lowest priority)

test new_process PASSED (10 of 10)
(Workload: Parent process runs until at lowest, fork child process
Expected: Child process gets scheduled at the higher priority than parent)

test stress_test PASSED (10 of 10)
(Workload: Fill the ptable multiple times with new processes.
Expected: OS does not fail to allocate processes)

test multiple_jobs PASSED (10 of 10)
(Workload: Synchronous workload varying tick workload. (Spin duration)
Expected: Verify each process only runs for the allotted amount of time at each level. (ie. p3 - 8 ticks, p2 - 16 ticks, p1 - 32 ticks, etc.))

test multiple_jobs_wait_times PASSED (10 of 10)
(Workload: Synchronous workload varying tick workload. (Spin duration)
Expected: Verify each process only waits for the expected amount of time 10x before being bumped up to higher priority except p = 3)

test round_robin PASSED (10 of 10)
(Workload: 4 processes running long running workloads (spinning)
Expected: All processes have used up the timer ticks in level 3, 2 and 1 - executes in round robin fashion)

test priority_boost PASSED (10 of 10)
(Workload: 2 processes running long running workloads
Expected: A priority boost of the parent process after waiting for child to execute)

Passed 10 of 10 tests.
Overall 10 of 10
Points 90 of 90
woria@ubuntu:~/Downloads/project2btest$
```