OS lab3 report

牛庆源 PB21111733

1. 实验目的与内容

- **part1**:使用显式空闲链表实现一个64位堆内存分配器（使用两种搜索算法，实现堆内存的动态扩容和实时的分配器内存使用情况统计），学会以动态链接库的形式制作库并使用（已给出）。
- **part2**:了解Linux系统虚拟内存的管理方式，了解VMA并遍历统计VMA，了解多级页表机制，完成一个从虚拟地址到物理地址的转换函数，了解Linux页面置换算法，统计页面冷热并输出图表观察，了解用户内存地址空间的分部并将用户进程中的数据转储至外存。

2. 实验平台

- VMware
- linux-4.9.263
- vscode

3.实验过程

part1 代码补全

1. **void mem_init(void)**

```
void mem_init(void)
{
   mem_start_brk = sbrk(MAX_HEAP); // 调用sbrk初始化mem_start_brk
   mem_brk = mem_start_brk;
   mem_max_addr = mem_start_brk + MAX_HEAP; // 堆增长空间大小为MAX_HEAP
}
```

2. **void *mem_sbrk(int incr)**

```
void *mem_sbrk(int incr)
{
    char *old_brk = mem_brk;
    if(old_brk + incr <= mem_max_addr) // 增长后没有超过最大值
        mem_brk += incr;     // 直接增长
    else
    {
        sbrk(MAX_HEAP); // 用sbrk扩容MAX_HEAP大小
        mem_max_addr += MAX_HEAP;    // 最大值也相应扩容MAX_HEAP
        mem_brk += incr;     // 增长
    }
    return (void *)old_brk;
}
```

3. **static void *find_fit_first(size_t asize)**

```
static void *find_fit_first(size_t asize)
{
   size_t bp = free_listp;
   while(bp != 0) // 遍历
   {
        if(GET_SIZE(HDRP(bp)) > asize) // 找到
            return (void *)bp;
        bp = GET_SUCC(bp);
   }
   return NULL; // 没找到
}
```

4. **static void* find_fit_best(size_t asize)**

```
static void* find_fit_best(size_t asize)
{
    size_t bp = free_listp;
    size_t bestp = 0;
    int flag = 0;
    while(bp != 0)  //遍历
    {
        if (GET_SIZE(HDRP(bp)) > asize)
            if (flag == 0)
            {   // 首次赋值
                bestp = bp;
                flag = 1;
            }
            else
            {   // 更新bestp
                if (GET_SIZE(HDRP(bp)) <= GET_SIZE(HDRP(bestp)))
                    bestp = bp;
            }
        bp = GET_SUCC(bp);
    }
    if(bestp == 0) // best一直没变
        return NULL;
    else    // best被更新过
        return (void *)bestp;
}
```

5. **static void place(void *bp, size_t asize)**

```
static void place(void *bp, size_t asize)
{
    size_t bsize = GET_SIZE(HDRP(bp));
```

```
    size_t prev_alloc = GET_PREV_ALLOC(HDRP(bp));
    delete_from_free_list(bp);
    if(bsize - asize < MIN_BLK_SIZE)
    {
        // 修改当前块和下一个块的头部信息
        PUT(HDRP(bp), PACK(bsize, prev_alloc, 1)); // 当前块分配
        PUT(HDRP(NEXT_BLKP(bp)), GET(HDRP(NEXT_BLKP(bp))) | 0x2); // 下一个块的前邻
居块分配
    }
    else
    {
        PUT(HDRP(bp),PACK(asize, prev_alloc, 1));   // 当前块分配
        char *new_bp = NEXT_BLKP(bp);
        size_t new_size = bsize - asize;    // 分隔出的空闲块大小
        PUT(HDRP(new_bp), PACK(new_size, 1, 0)); // 当前块空闲（头指针）
        PUT(FTRP(new_bp), PACK(new_size, 1, 0)); // 当前块空闲（尾指针）
        coalesce(new_bp);
    }
}
```

6. **static void *coalesce(void *bp)**

```
static void *coalesce(void *bp)
{
    /*add_to_free_list(bp);*/
    size_t prev_alloc = GET_PREV_ALLOC(HDRP(bp));
    size_t next_alloc = GET_ALLOC(HDRP(NEXT_BLKP(bp)));
    size_t size = GET_SIZE(HDRP(bp));
    if (prev_alloc && next_alloc) /* 前后都是已分配的块 */
    {
       add_to_free_list(bp); // 没有可以合并的块
    }
    else if (prev_alloc && !next_alloc) /*前块已分配，后块空闲*/
    {
        char *next_bp = NEXT_BLKP(bp); // 和后块合并
        size_t next_size = GET_SIZE(HDRP(next_bp));
        delete_from_free_list(next_bp);
        PUT(HDRP(bp), PACK(size + next_size, 1, 0)); // 当前块空闲（头）
        PUT(FTRP(bp), PACK(size + next_size, 1, 0)); //  （尾）
        add_to_free_list(bp);
    }
    else if (!prev_alloc && next_alloc) /*前块空闲，后块已分配*/
    {
        char *prev_bp = PREV_BLKP(bp); // 和前块合并
        size_t prev_size = GET_SIZE(HDRP(prev_bp));
        delete_from_free_list(prev_bp);
        PUT(FTRP(bp), PACK(size + prev_size, GET_PREV_ALLOC(HDRP(prev_bp)), 0));
        PUT(HDRP(prev_bp), PACK(size + prev_size, GET_PREV_ALLOC(HDRP(prev_bp)),
0));
        add_to_free_list(prev_bp);
        bp = prev_bp;
    }
```

```
    else /*前后都是空闲块*/
    {   // 参考前两个else if内容
        char *prev_bp = PREV_BLKP(bp);
        char *next_bp = NEXT_BLKP(bp);
        size_t prev_size = GET_SIZE(HDRP(prev_bp));
        size_t next_size = GET_SIZE(HDRP(next_bp));
        delete_from_free_list(prev_bp);
        delete_from_free_list(next_bp);
        // 扩容块占有前块和后块，所以头部尾部分别修改前块和后块的
        PUT(FTRP(next_bp), PACK((prev_size + size + next_size),
GET_PREV_ALLOC(HDRP(prev_bp)), 0));
        PUT(HDRP(prev_bp), PACK((prev_size + size + next_size),
GET_PREV_ALLOC(HDRP(prev_bp)), 0));
        add_to_free_list(prev_bp);
        bp = prev_bp;
    }
    return bp;
}
```

- 通过修改mm_malloc中的分配策略，分别调用workload测试得到结果：

find_fit_first：

```
before free: 0.999868; after free: 0.223753
time of loop 0 : 399ms
before free: 0.970494; after free: 0.215708
time of loop 1 : 549ms
before free: 0.967134; after free: 0.219046
time of loop 2 : 595ms
before free: 0.963973; after free: 0.217173
time of loop 3 : 601ms
before free: 0.961011; after free: 0.212307
time of loop 4 : 581ms
before free: 0.962702; after free: 0.215033
time of loop 5 : 542ms
before free: 0.960329; after free: 0.213856
time of loop 6 : 551ms
before free: 0.963557; after free: 0.214625
time of loop 7 : 580ms
before free: 0.957874; after free: 0.21242
time of loop 8 : 575ms
before free: 0.967218; after free: 0.21421
time of loop 9 : 562ms
before free: 0.96514; after free: 0.215154
time of loop 10 : 576ms
before free: 0.963841; after free: 0.218346
time of loop 11 : 572ms
before free: 0.966515; after free: 0.216837
time of loop 12 : 599ms
before free: 0.966461; after free: 0.214383
time of loop 13 : 570ms
before free: 0.967506; after free: 0.21579
time of loop 14 : 599ms
before free: 0.962781; after free: 0.215285
time of loop 15 : 587ms
before free: 0.959217; after free: 0.214106
time of loop 16 : 573ms
before free: 0.959343; after free: 0.214788
time of loop 17 : 633ms
before free: 0.959452; after free: 0.213562
time of loop 18 : 571ms
before free: 0.962971; after free: 0.215663
time of loop 19 : 562ms
```

find_fit_best:

```
before free: 0.999868; after free: 0.223753
time of loop 0 : 391ms
before free: 0.996245; after free: 0.22137
time of loop 1 : 2087ms
before free: 0.995636; after free: 0.225444
time of loop 2 : 2195ms
before free: 0.99278; after free: 0.22357
time of loop 3 : 2126ms
before free: 0.989666; after free: 0.218595
time of loop 4 : 2201ms
before free: 0.991216; after free: 0.22129
time of loop 5 : 2153ms
before free: 0.98877; after free: 0.220014
time of loop 6 : 2113ms
before free: 0.991977; after free: 0.220932
time of loop 7 : 2278ms
before free: 0.986383; after free: 0.218687
time of loop 8 : 2161ms
before free: 0.99582; after free: 0.220525
time of loop 9 : 2059ms
before free: 0.993767; after free: 0.221431
time of loop 10 : 2102ms
before free: 0.992171; after free: 0.224709
time of loop 11 : 2133ms
before free: 0.995274; after free: 0.223149
time of loop 12 : 2102ms
before free: 0.99519; after free: 0.220696
time of loop 13 : 2111ms
before free: 0.996343; after free: 0.222161
time of loop 14 : 2117ms
before free: 0.991545; after free: 0.22168
time of loop 15 : 2076ms
before free: 0.987915; after free: 0.220382
time of loop 16 : 2091ms
before free: 0.987803; after free: 0.221085
time of loop 17 : 2137ms
before free: 0.988287; after free: 0.219883
time of loop 18 : 2183ms
before free: 0.99167; after free: 0.222017
time of loop 19 : 2064ms
```

part2 func1~5

1. **func1**

```c
static void scan_vma(void)
{
    printk("func == 1, %s\n", __func__);
    struct mm_struct *mm = get_task_mm(my_task_info.task);
    if (mm)
    {
        // 遍历VMA将VMA的个数记录到my_task_info的vma_cnt变量中
        struct vm_area_struct *vm_tmp = mm->mmap;
        int cnt = 0;
```

```
        while(vm_tmp)   // 遍历vma
        {
            vm_tmp = vm_tmp->vm_next;
            cnt ++;
        }
        my_task_info.vma_cnt = cnt;
        mmput(mm);
    }
}
```

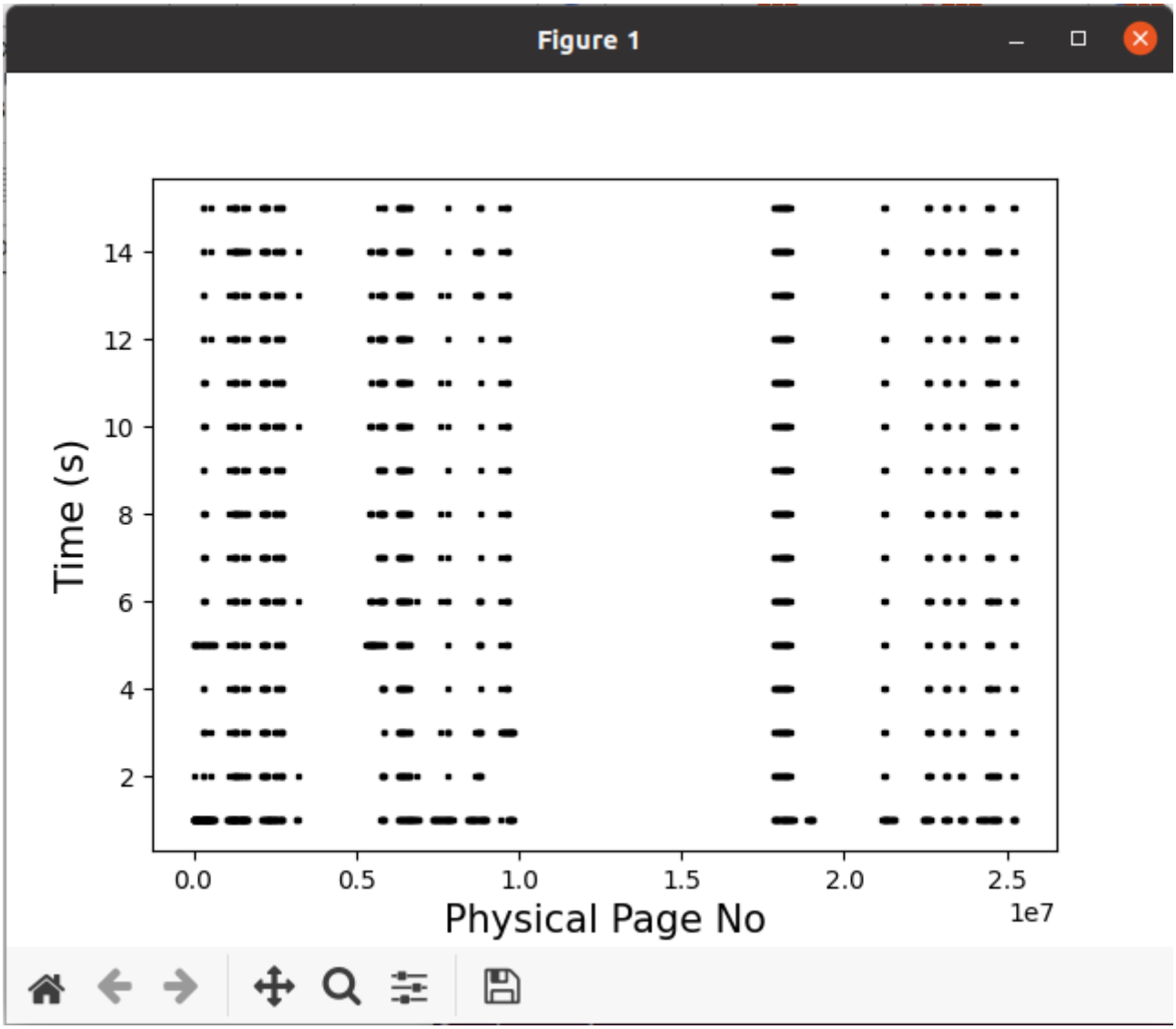
result:

```
qyniu@ubuntu:~/code/lab3/lab3.2$ cat /sys/kernel/mm/ktest/vma
0, 39
```

2. **func2**

```
static void print_mm_active_info(void)
{
    printk("func == 2, %s\n", __func__);
    struct mm_struct *mm = get_task_mm(my_task_info.task);
    if (mm)
    {
        struct vm_area_struct *vm_tmp = mm->mmap;
        while(vm_tmp)   // 遍历vma
        {
            unsigned long virt_addr = vm_tmp->vm_start;
            for ( ; virt_addr <= vm_tmp->vm_end ; virt_addr += PAGE_SIZE) // 遍历
虚拟地址
            {
                struct page *page = mfollow_page(vm_tmp, virt_addr, FOLL_GET);
                if (!IS_ERR_OR_NULL(page)) // 检查page是否非空且有效
                {
                    unsigned long vm_flags;
                    int freq = mpage_referenced(page, 0, (struct mem_cgroup *)
(page->memcg_data), &vm_flags);
                    if(freq > 1)   // 若被访问到(这里不为0即可，大于1的时候得到的结果
好辨认)
                    {   // 地址写入
                        record_one_data(((page->index)*PAGE_SIZE));
                        // page->index是区域内的页索引或是页的线性地址除以PAGE_SIZE
                    }
                }
            }
            vm_tmp = vm_tmp->vm_next;
        }
    }
    flush_buf(1);   // 写入文件
    mmput(mm);
}
```

result:



3. **多级页表遍历**

```
static unsigned long virt2phys(struct mm_struct *mm, unsigned long virt)
{
    struct page *page = NULL;
    // TODO: 多级页表遍历: pgd->pud->pmd->pte, 然后从pte到page, 最后得到pfn
    pgd_t *pgd_tmp = pgd_offset(mm,virt);
    // 每次下一级页表读之前检查这一级是否有效且非空
    if (pgd_none(*pgd_tmp) || pgd_bad(*pgd_tmp))
        return NULL;
    pud_t *pud_tmp = pud_offset((p4d_t *)pgd_tmp,virt); // 强制转换
    if (pud_none(*pud_tmp) || pud_bad(*pud_tmp))
        return NULL;
    pmd_t *pmd_tmp = pmd_offset(pud_tmp,virt);
    if (pmd_none(*pmd_tmp) || pmd_bad(*pmd_tmp))
        return NULL;
    pte_t *pte_tmp = pte_offset_kernel(pmd_tmp,virt);
    if (pte_none(*pte_tmp) || pte_bad(*pte_tmp))
        return NULL;
    page = pte_page(*pte_tmp);
    if (page)
```

```
    {
        return page_to_pfn(page);
    }
    else
    {
        pr_err("func: %s page is NULL\n", __func__);
        return NULL;
    }
}
```

4. **func3**

```
static void traverse_page_table(struct task_struct *task)
{
    printk("func == 3, %s\n", __func__);
    struct mm_struct *mm = get_task_mm(my_task_info.task);
    if (mm)
    {
        struct vm_area_struct *vm_tmp = mm->mmap;
        while (vm_tmp) // 遍历vma
        {
            unsigned long virt_addr;    // 遍历vma中的虚拟地址
            for (virt_addr = vm_tmp->vm_start; virt_addr <= vm_tmp->vm_end ;
virt_addr += PAGE_SIZE)
            {   // 页表遍历
                record_two_data(virt_addr, virt2phys(task->mm, virt_addr));
            }
            vm_tmp = vm_tmp->vm_next;
        }
        flush_buf(1);
        mmput(mm);
    }
    else
    {
        pr_err("func: %s mm_struct is NULL\n", __func__);
    }
}
```

result:

```
27 0x55b30f681000--0x0
28 0x55b30f682000--0x0
29 0x55b30f683000--0x0
30 0x55b30f684000--0x0
31 0x55b30f685000--0x133e7a
32 0x55b30f686000--0x1102f9
33 0x55b30f687000--0x118daa
34 0x55b30f688000--0x118633
35 0x55b30f689000--0x10efdd
36 0x55b30f68a000--0x126f18
37 0x55b30f68b000--0x12d9db
38 0x55b30f68c000--0x11020b
39 0x55b30f68d000--0x110219
40 0x55b30f68e000--0x10f6d7
41 0x55b30f68f000--0x11021c
42 0x55b30f690000--0x10f6df
43 0x55b30f691000--0x11da8c
44 0x55b30f692000--0x138d68
45 0x55b30f693000--0x11034d
46 0x55b30f694000--0x123ae9
47 0x55b30f695000--0x13213c
48 0x55b30f696000--0x13590a
49 0x55b30f697000--0x12b2ee
50 0x55b30f698000--0x13370c
51 0x55b30f699000--0x138b05
52 0x55b30f69a000--0x118637
53 0x55b30f69b000--0x126b32
54 0x55b30f69c000--0x117f9c
55 0x55b30f69d000--0x12ed33
56 0x55b30f69e000--0x13651b
57 0x55b30f69f000--0x135bed
58 0x55b30f6a0000--0x10f6af
59 0x55b30f6a1000--0x13043e
60 0x55b30f6a2000--0x13b17f
```

5. **func4、5**

```
static void print_seg_info(void)
{
    struct mm_struct *mm;
    unsigned long addr;
    printk("func == 4 or func == 5, %s\n", __func__);
    mm = get_task_mm(my_task_info.task);
    if (mm == NULL)
    {
        pr_err("mm_struct is NULL\n");
        return;
    }
    // func4
    for (addr = mm->start_data; addr < mm->end_data; addr += PAGE_SIZE) // 遍历所有地址
    {
        struct vm_area_struct *vm_tmp = find_vma(mm,addr);
        unsigned long virt_addr;
```

```
        for (virt_addr = vm_tmp->vm_start; virt_addr <= vm_tmp->vm_end ; virt_addr
+= PAGE_SIZE) // 遍历所有虚拟地址
        {
            struct page *page = mfollow_page(vm_tmp, virt_addr, FOLL_GET); // 得到
虚拟地址对应的page
            if (!IS_ERR_OR_NULL(page))  // page是否可用
            {
                char* virt_addr1 = kmap_atomic(page); // 得到可以直接访问的虚拟地址
                memcpy(buf,virt_addr1,PAGE_SIZE); // 拷贝到buf
                curr_buf_length += PAGE_SIZE;
                flush_buf(0); // buf数据写入文件
                kunmap_atomic(virt_addr1); // 释放
            }
        }
    }
    // func5 修改了addr的首尾地址
    for (addr = mm->start_code; addr < mm->end_code;addr += PAGE_SIZE)
    {
        struct vm_area_struct *vm_tmp = find_vma(mm,addr);
        unsigned long virt_addr;
        for (virt_addr = vm_tmp->vm_start; virt_addr <= vm_tmp->vm_end ; virt_addr
+= PAGE_SIZE)
        {
            struct page *page = mfollow_page(vm_tmp, virt_addr, FOLL_GET);
            if (!IS_ERR_OR_NULL(page))
            {
                char* virt_addr1 = kmap_atomic(page);
                memcpy(buf,virt_addr1,PAGE_SIZE);
                curr_buf_length += PAGE_SIZE;
                flush_buf(0);
                kunmap_atomic(virt_addr1);
            }
        }
    }
    flush_buf(1);
    mmput(mm);
}
```

result:func4 / func5

4.实验总结

本次实验用两种算法实现了内存分配器，并了解了VMA和页表机制，过程中对Linux系统的内核有了更多的理解。实验内容较多相应时间也比较充足。