Lab 3: Page Tables

■ 实验目的

了解虚拟内存和页表。修改页表用来加速系统调用、找到哪些页表被访问过等。

■ 实验准备

「1」准备lab3源码.

「2」建议先阅读xv6 book的「Chapter 3」以及相关的代码文件.

> * ***kernel/memlayout.h***, which captures the layout of memory.
> * ***kernel/vm.c***, which contains most virtual memory (VM) code.
> * ***kernel/kalloc.c***, which contains code for allocating and freeing physical memory.

《深入理解计算机系统》第九章 虚拟内存

■ Part A: Speed up system calls

Some operating systems (e.g., Linux) speed up certain system calls by sharing data in a read-only region between userspace and the kernel. This eliminates the need for kernel crossings when performing these system calls. To help you learn how to insert mappings into a page table, your first task is to implement this optimization for the **getpid()** system call in xv6.

When each process is created, map one read-only page at USYSCALL (a virtual address defined in *memlayout.h*). At the start of this page, store a struct usyscall (also defined in *memlayout.h*), and initialize it to store the PID of the current process. For this lab, **ugetpid()** has been provided on the userspace side and will automatically use the USYSCALL mapping. You will receive full credit for this part of the lab if the ugetpid test case passes when running pgtbltest.

memlayout.h

```
//   ...
//   USYSCALL (shared with kernel)
//   TRAPFRAME (p->trapframe, used by the trampoline)
//   TRAMPOLINE (the same page as in the kernel)
#define TRAPFRAME (TRAMPOLINE - PGSIZE)
#ifdef LAB_PGTBL
#define USYSCALL (TRAPFRAME - PGSIZE)

struct usyscall {
  int pid;  // Process ID
};
#endif
```

ulib.c

```
#ifdef LAB_PGTBL
int
ugetpid(void)
{
  struct usyscall *u = (struct usyscall *)USYSCALL;
  return u->pid;
}
#endif
```

Hints:

- You can perform the mapping in proc_pagetable() in *kernel/proc.c*.
- Choose permission bits that allow userspace to only read the page.
- You may find that mappages() is a useful utility.
- Don't forget to allocate and initialize the page in allocproc().
- Make sure to free the page in freeproc().

预期结果：

```
$ pgtbltest
ugetpid_test starting
ugetpid_test: OK
```

■ Part B: Print a page table

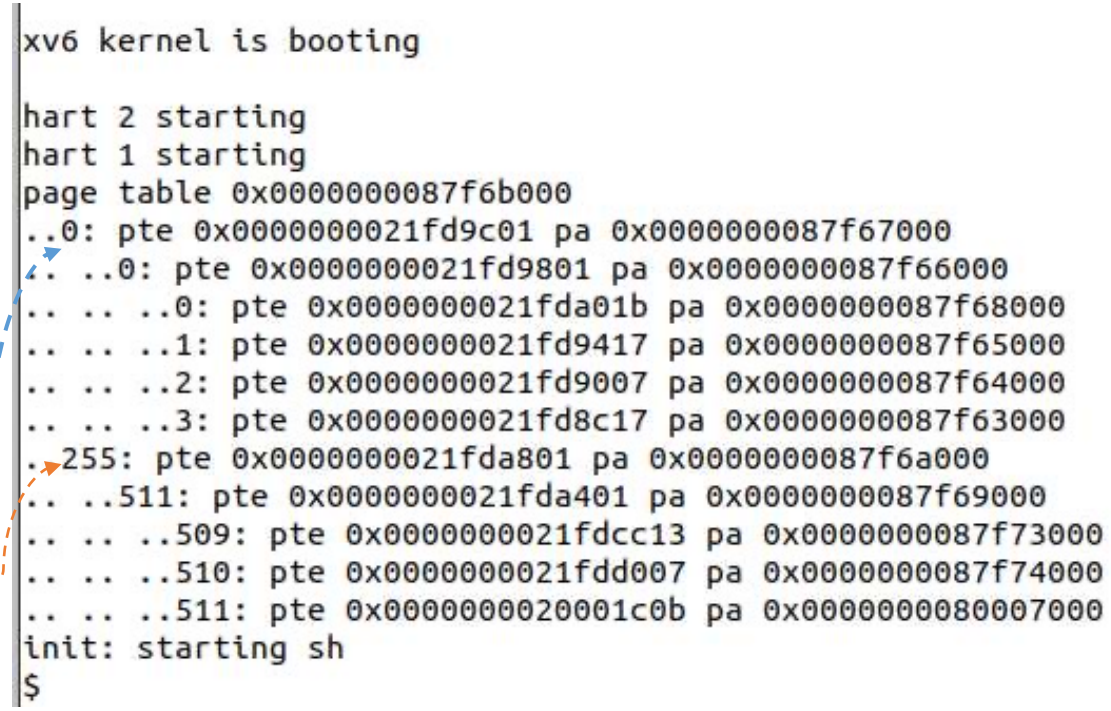
Write a function that prints the contents of a page table.

Define a function called **vmprint()**. It should take a pagetable_t argument, and print that pagetable in the format described below. Insert if(p->pid==1) vmprint(p->pagetable) in *exec.c* just before the return argc, to print the first process's page table.

Print format:

The first line displays the argument to vmprint. After that there is a line for each PTE, including PTEs that refer to page-table pages deeper in the tree. Each PTE line is indented by a number of ".." that indicates its depth in the tree. Each PTE line shows the PTE index in its page-table page, the pte bits, and the physical address extracted from the PTE. Don't print PTEs that are not valid.

In the example, the top-level page-table page has mappings for entries 0 and 255. The next level down for entry 0 has only index 0 mapped, and the bottom-level for that index 0 has entries 0, 1, and 2 mapped.



Hints:

- You can put vmprint() in *kernel/vm.c*.
- Use the macros at the end of the file *kernel/riscv.h*.
- The function freewalk may be inspirational.
- Define the prototype for vmprint in *kernel/defs.h* so that you can call it from *exec.c*.
- Use **%p** in your printf calls to print out full 64-bit hex PTEs and addresses as shown in the example.

■ Part C: Detect which pages have been accessed

Some garbage collectors (a form of automatic memory management) can benefit from information about which pages have been accessed (read or write). In this part of the lab, you will add a new feature to xv6 that detects and reports this information to userspace by inspecting the access bits in the RISC-V page table. The RISC-V hardware page walker marks these bits in the PTE whenever it resolves a TLB miss.

Your job is to implement **pgaccess()**, a system call that reports which pages have been accessed. The system call takes three arguments. First, it takes the starting virtual address of the first user page to check. Second, it takes the number of pages to check. Finally, it takes a user address to a buffer to store the results into a bitmask (a datastructure that uses one bit per page and where the first page corresponds to the least significant bit). You will receive full credit for this part of the lab if the pgaccess test case passes when running pgtbltest.

page table

number=4

&bitmask=0b0000

0b0101

	Page	PTE_A
3		0
2		1
1		0
0		1

预期结果：

```
init: starting sh
$ pgtbltest
ugetpid_test starting
ugetpid_test: OK
pgaccess_test starting
pgaccess_test: OK
pgtbltest: all tests succeeded
$ QEMU: Terminated
```

Hints:

- Read pgaccess_test() in *user/pgtlbtest.c* to see how pgaccess is used.
- Start by implementing sys_pgaccess() in *kernel/sysproc.c*.
- You'll need to parse arguments using argaddr() and argint().
- For the output bitmask, it's easier to store a temporary buffer in the kernel and copy it to the user (via copyout()) after filling it with the right bits.
- It's okay to set an upper limit on the number of pages that can be scanned.
- walk() in *kernel/vm.c* is very useful for finding the right PTEs.
- You'll need to define PTE_A, the access bit, in *kernel/riscv.h*. Consult the RISC-V privileged architecture manual to determine its value.
- Be sure to clear PTE_A after checking if it is set. Otherwise, it won't be possible to determine if the page was accessed since the last time pgaccess() was called (i.e., the bit will be set forever).
- vmprint() may come in handy to debug page tables.

■ 实验提交

1. 实验代码文件夹（提交前请 make clean）.
2. 实验报告（中文即可，PDF格式），需包含以下内容：
   （1）实验实现的思路，相关代码截图，最终测试结果的截图.
   （2）问题回答.
   （3）实验中碰到何种问题，如何解决的.
   （4）实验感想.
3. 实验截止日期：2022年11月8日晚22点，请按时提交.
4. 提交邮箱：各班级助教邮箱.

请将1、2放入一个文件夹，命名为：学号 + 姓名 + oslab3.zip.

注：请独立完成实验内容，如果参考或借鉴了网上回答或代码，请在实验报告中标注.

THANKS