CS 3204
Operating Systems

Lecture 12

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Announcements

- Project 2 due March 20
- Regroup if necessary
  - Read post on how to move CVS forward
- Won't give detailed milestones this time, but:
  - recommend that you reach the point where "write" works (see 3.2 Suggested Order of Implementation) by March 1
- Reading assignment 2.2-2.4
- Help sessions:
  - Thursday 7-9pm PAM 2028 tonight
  - Friday 5-7pm PAM 2028
  - Note different times Thursday vs. Friday

Linking and Loading

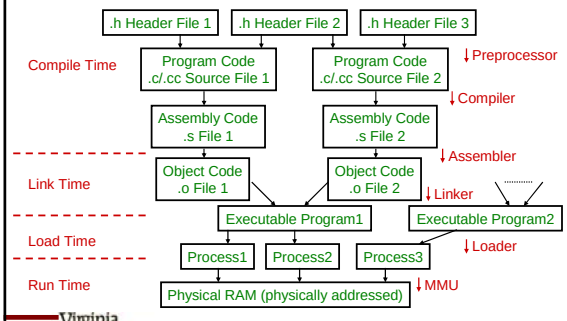
Today: what you need to know for Project 2 (and life)

- Compiling, Linking, Loading
  - Where are my variables?
  - How are programs loaded into memory?
- Virtual Memory Basics
  - How do addresses get checked and how do they get mapped?
  - What happens on a context-switch?

Accessing Information

- All information a program reads/writes is stored somewhere in memory
- Programmer uses symbolic names:
  - local variables, global variables, assembly constants
- CPU instructions use virtual addresses:
  - absolute addresses (at 0xC0000024)
  - relative addresses (at $esp – 16)
- Actual memory uses physical addresses:
- Big Question: who does the translation & when?

The Big Picture



Step 1: Compilation

```
int initialized_variable = 1;
int zero_initialized_variable;

int global_function(int argument)
{
   volatile int local_variable = 1;
   return argument
      + local_variable
      + initialized_variable
      + zero_initialized_variable;
}
```

whereismystuff.c

```
.data
initialized_variable:
   .long  1
```

```
.comm   zero_initialized_variable,4,4
```

```
global_function:
   pushl   %ebp
   movl    %esp, %ebp
   subl    $16, %esp
   movl    $1, -4(%ebp)     /* local_variable */
   movl    -4(%ebp), %eax
   addl    8(%ebp), %eax  /* argument */
   addl    initialized_variable, %eax
   addl    zero_initialized_variable, %eax
   leave
   ret
```

whereismystuff.s

- Compiler resolves local variable names (and struct field offsets!)

Step 2: Assembly

```
global_function:
   pushl   %ebp
   movl    %esp, %ebp
   subl    $16, %esp
   movl    $1, -4(%ebp)     /*
```

```
RELOCATION RECORDS FOR [.text]:
OFFSET   TYPE              VALUE
00000015 R_386_32          initialized_variable
0000001b R_386_32          zero_initialized_variable

Contents of section .data:
 0000 01000000                    ....
```

```
00000000 <global_functi
   0:   55                      push   %ebp
   1:   89 e5                   mov    %esp,%ebp
   3:   83 ec 10                sub    $0x10,%esp
   6:   c7 45 fc 01 00 00 00    movl   $0x1,0xfffffffc(%ebp)
   d:   8b 45 fc                mov    0xfffffffc(%ebp),%eax
  10:   03 45 08                add    0x8(%ebp),%eax
  13:   03 05 00 00 00 00       add    0x0,%eax  // initialized_variable
  19:   03 05 00 00 00 00       add    0x0,%eax  // zero_initialized_variable
  1f:   c9                      leave
  20:   c3                      ret
```

whereismystuff.o

Step 3: Linking

```
0804837c <global_function>:
 804837c: 55                      push   %ebp
 804837d: 89 e5                   mov    %esp,%ebp
 804837f: 83 ec 10                sub    $0x10,%esp
 8048382: c7 45 fc 01 00 00 00    movl   $0x1,0xfffffffc(%ebp)
 8048389: 8b 45 fc                mov    0xfffffffc(%ebp),%eax
 804838c: 03 45 08                add    0x8(%ebp),%eax
 804838f: 03 05 80 95 04 08       add    0x8049580,%eax
 8048395: 03 05 88 95 04 08       add    0x8049588,%eax
 804839b: c9                      leave
 804839c: c3                      ret
```

whereismystuff (.exe)

- Linker resolves global addresses, stores instructions for loader in executable
  - Key: linker links multiple, independently assembled .o files into executable
  - Must decide on layout & then assign addresses & relocate

Step 4: Loading (Conceptual)

ELF Header:
-start address 0x080482d8

BSS:
- size & start of zero initialized data

Data:

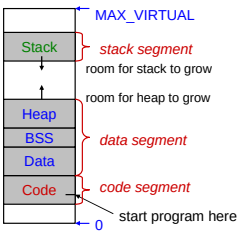
```
Contents of section .data:
 8049574 00000000 00000000 88940408 01000000  ................
```

Code:

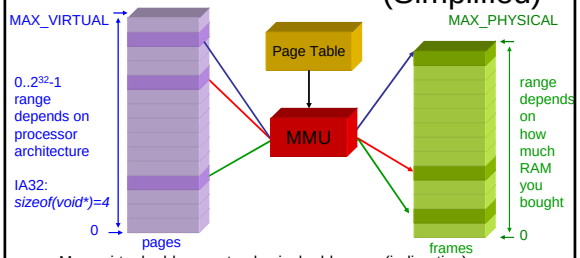
```
0804837c <global_function>:
 804837c: 55                      push   %ebp
 804837d: 89 e5                   mov    %esp,%ebp
 804837f: 83 ec 10                sub    $0x10,%esp
 8048382: c7 45 fc 01 00 00 00    movl   $0x1,0xfffffffc(%ebp)
 8048389: 8b 45 fc                mov    0xfffffffc(%ebp),%eax
 804838c: 03 45 08                add    0x8(%ebp),%eax
 804838f: 03 05 80 95 04 08       add    0x8049580,%eax
 8048395: 03 05 88 95 04 08       add    0x8049588,%eax
 804839b: c9                      leave
 804839c: c3                      ret
```

- Executable = set of instructions stored on disk for loader
  - consists of sections

- Picture compiler & linker had in mind when building executable
  - sections become segments

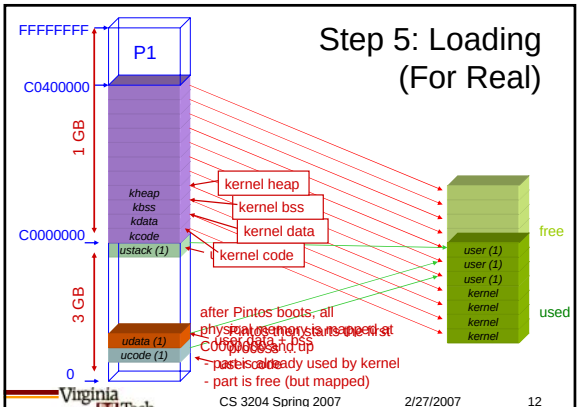


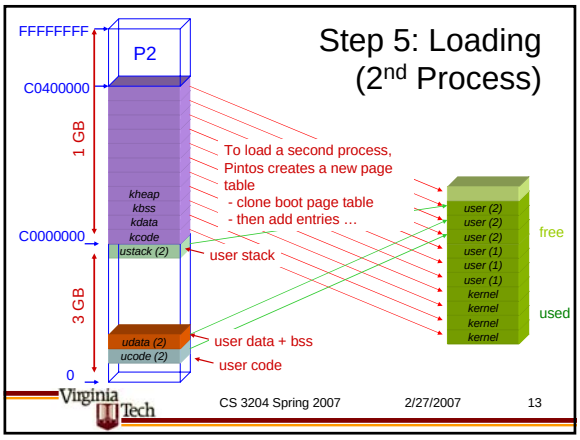
Virtual Memory & Paging (Simplified)



- Maps virtual addresses to physical addresses (indirection)
  - x86: page table is called *page directory* (one per process)
  - mapping at page granularity (x86: 1 page = 4 KB = 4,096 bytes)

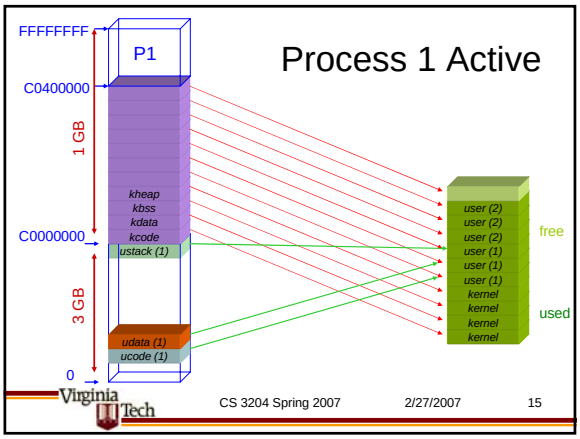
Step 5: Loading (For Real)

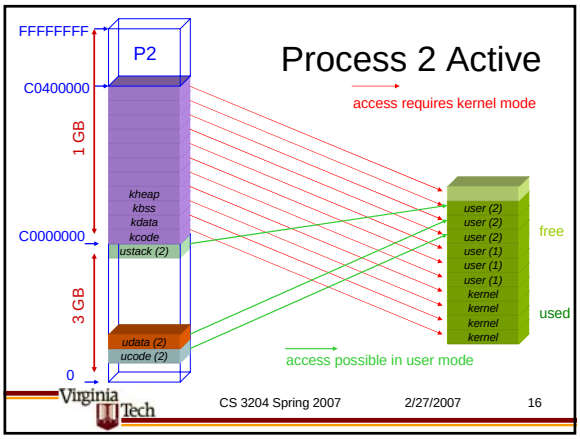




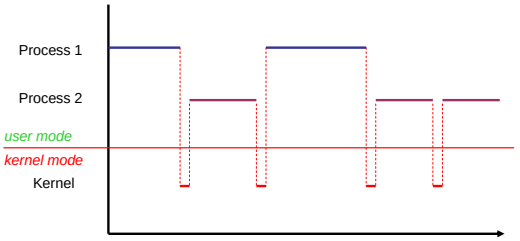
Context Switching

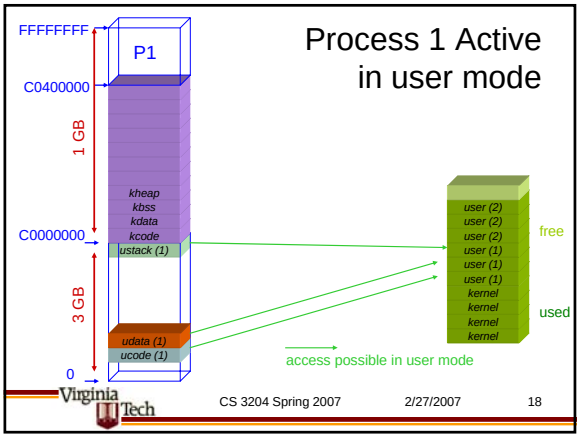
- Each process has its own *address space*
  - This means that the meaning of addresses (say 0x08c4000) may be different depending on which process is active
  - Maps to different page in physical memory
- When processes switch, address spaces must switch
  - MMU must be reprogrammed

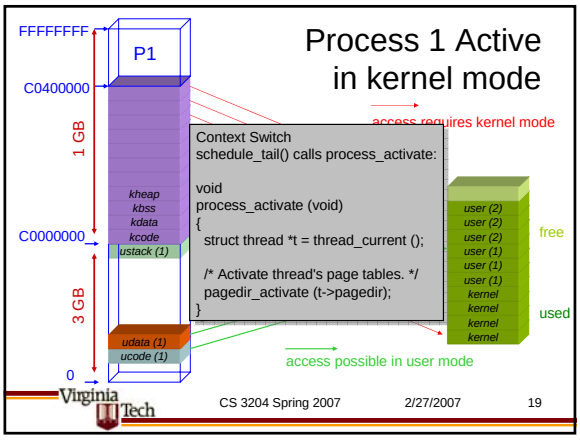


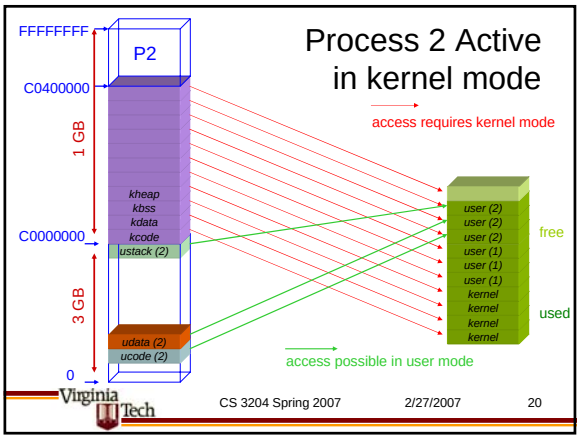


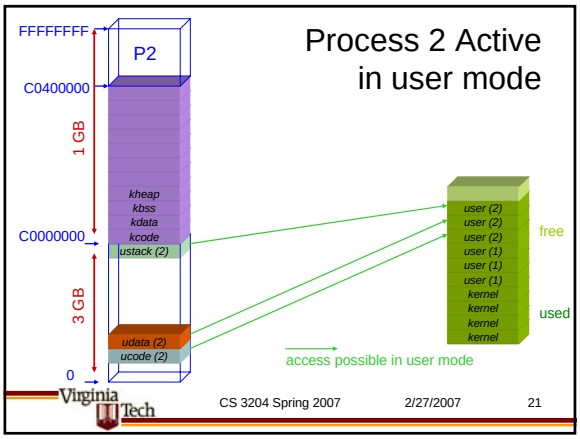
Context Switching











Summary

- All you have to do in Project 2/3/4 is:
  - Be aware of what memory is currently accessible
    - Your kernel executes in kernel mode, so you can access all memory (if you use >C000000 addresses)
    - But you must set it up such that your programs can run with the memory you allow them to access (at <C0000000)
- Don't let user programs fool you into accessing other processes' (or arbitrary kernel) memory
  - Kill them if they try
- Keep track of where *stuff* is
  - Virtually (toolchain's view):
    - below C0000000 (PHYS_BASE) user space
    - above C0000000 (PHYS_BASE) kernel space
  - Physically (note: "physical" addresses are represented as 0xC0000000 + phys_addr in Pintos b/c of permanent mapping)

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