CE 440 Introduction to Operating System

Lecture 13: Pintos Virtual Memory Notes
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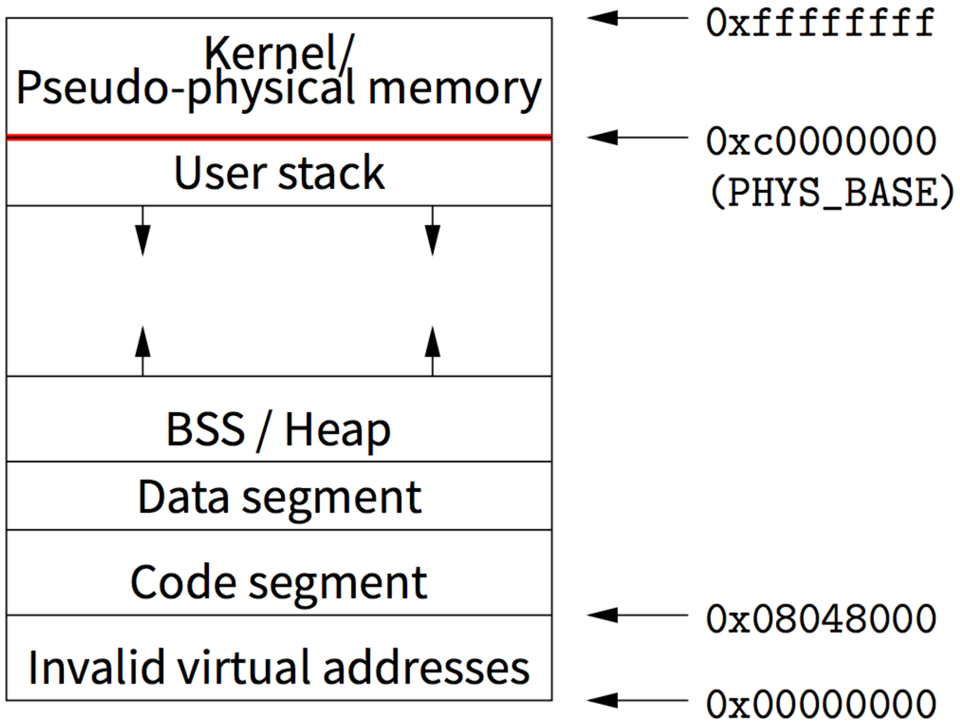
Slides courtesy of Manuel Egele, Ryan Huang and Baris Kasikci

Administrivia

Lab 2 overview session this Friday

- 2:30 - 4:00 PM, PHO305

Pintos Virtual Memory Layout



i.e., the kernel lives in every process' address space!

A process' virtual address space is split into two regions

- The kernel lives in the high memory region, typically highest 1GB, i.e., from 3 to 4 GB.
- The user memory lives in the lower region, typically lower 3 GB, i.e., from 0 to 3 GB.

User Virtual Memory

***Per process*: a new page directory (pagedir) for each process**

```
struct thread
{
    tid_t tid; /* Thread identifier. */
    enum thread_status status; /* Thread state. */
    char name[16]; /* Name (for debugging purposes). */
    uint8_t *stack; /* Saved stack pointer. */
    int priority; /* Priority. */
    struct list_elem allelem; /* List element for all threads list. */
    struct list_elem elem; /* List element. */

    #ifdef USERPROG
        /* Owned by userprog/process.c. */
        uint32_t *pagedir;
    #endif /* Page directory. */

    /* Owned by thread.c. */
    unsigned magic; /* Detects stack overflow. */
};
```

How Is A User Process Started?

```
$ pintos -p ../../examples/echo -a echo -- -f -q run 'echo ec440'
```

```c
static void
run_task (char **argv)
{
    const char *task = argv[1];
    printf ("Executing '%s':\n", task);
#ifdef USERPROG
    process_wait (process_execute (task));
#else
#endif
    run_test (task);
    printf ("Execution of '%s' complete.\n", task);
}
```

How Is A User Process Started?

```
$ pintos -p ../../examples/echo -a echo -- -f -q run 'echo ec440'
```

```
tid_t
process_execute (const char *file_name)
{
    char *fn_copy;
    tid_t tid;

    /* Make a copy of FILE_NAME.
       Otherwise there's a race between the caller and load(). */
    fn_copy = palloc_get_page (0);
    if (fn_copy == NULL)
        return TID_ERROR;
    strlcpy (fn_copy, file_name, PGSIZE);

    /* Create a new thread to execute FILE_NAME. */
    tid = thread_create (file_name, PRI_DEFAULT, start_process, fn_copy);
    if (tid == TID_ERROR)
        palloc_free_page (fn_copy);
    return tid;
}
```

“echo ec440”

Why?

The caller might free the file_name after this function returns!

,e.g., after you implement `exec`.

How Is A User Process Started?

```
$ pintos -p ../../examples/echo -a echo -- -f -q run 'echo ec440'
```

```c
static void
start_process (void *file_name_)
{
    char *file_name = file_name_;
    struct intr_frame if_;
    bool success;

    /* Initialize interrupt frame and load executable. */
    memset (&if_, 0, sizeof if_);
    if_.gs = if_.fs = if_.es = if_.ds = if_.ss = SEL_UDSEG;
    if_.cs = SEL_UCSEG;
    if_.eflags = FLAG_IF | FLAG_MBS;
    success = load (file_name, &if_.eip, &if_.esp);

    /* If load failed, quit. */
    palloc_free_page (file_name);
    if (!success)
        thread_exit ();

    /* Start the user process by simulating a return from an interrupt */
    asm volatile ("movl %0, %%esp; jmp intr_exit" : : "g" (&if_) : "memory");
    NOT_REACHED ();
}
```

How Is A User Process Started?

```
$ pintos -p ../../examples/echo -a echo -- -f -q run 'echo ec440'
```

```c
bool load (const char *file_name, void (**eip) (void), void **esp)
{
    struct thread *t = thread_current ();
    ...

    /* Allocate and activate page directory. */
    t->pagedir = pagedir_create ();
    if (t->pagedir == NULL)
        goto done;
    process_activate ();

    /* Open executable file. */
    file = filesys_open (file_name);
    ...
}
```

```c
void pagedir_activate (uint32_t *pd)
{
    if (pd == NULL)
    pd = init_page_dir;
    asm volatile ("movl %0, %%cr3" : : "r" (vtop
    (pd)) : "memory");
}
```

```c
void process_activate (void)
{
    struct thread *t = thread_current();
    pagedir_activate (t->pagedir);

    /* Set thread's kernel stack for use in processing interrupts. */
    tss_update ();
}
```

After this point, the user virtual memory mappings changed!

Wait

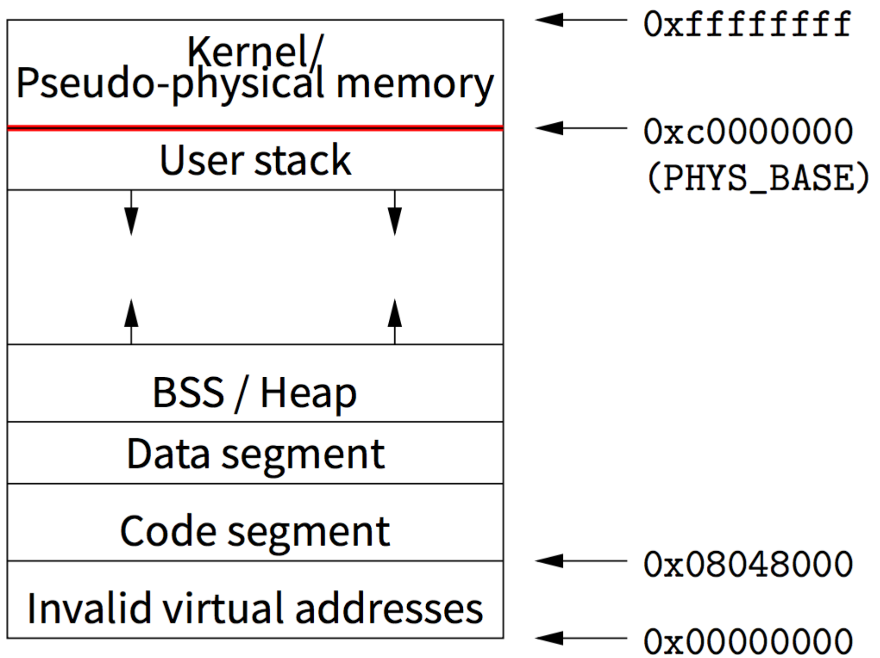
We just changed the user virtual memory mappings, how is it OK for us to still access these variables we created earlier, e.g., file_name?

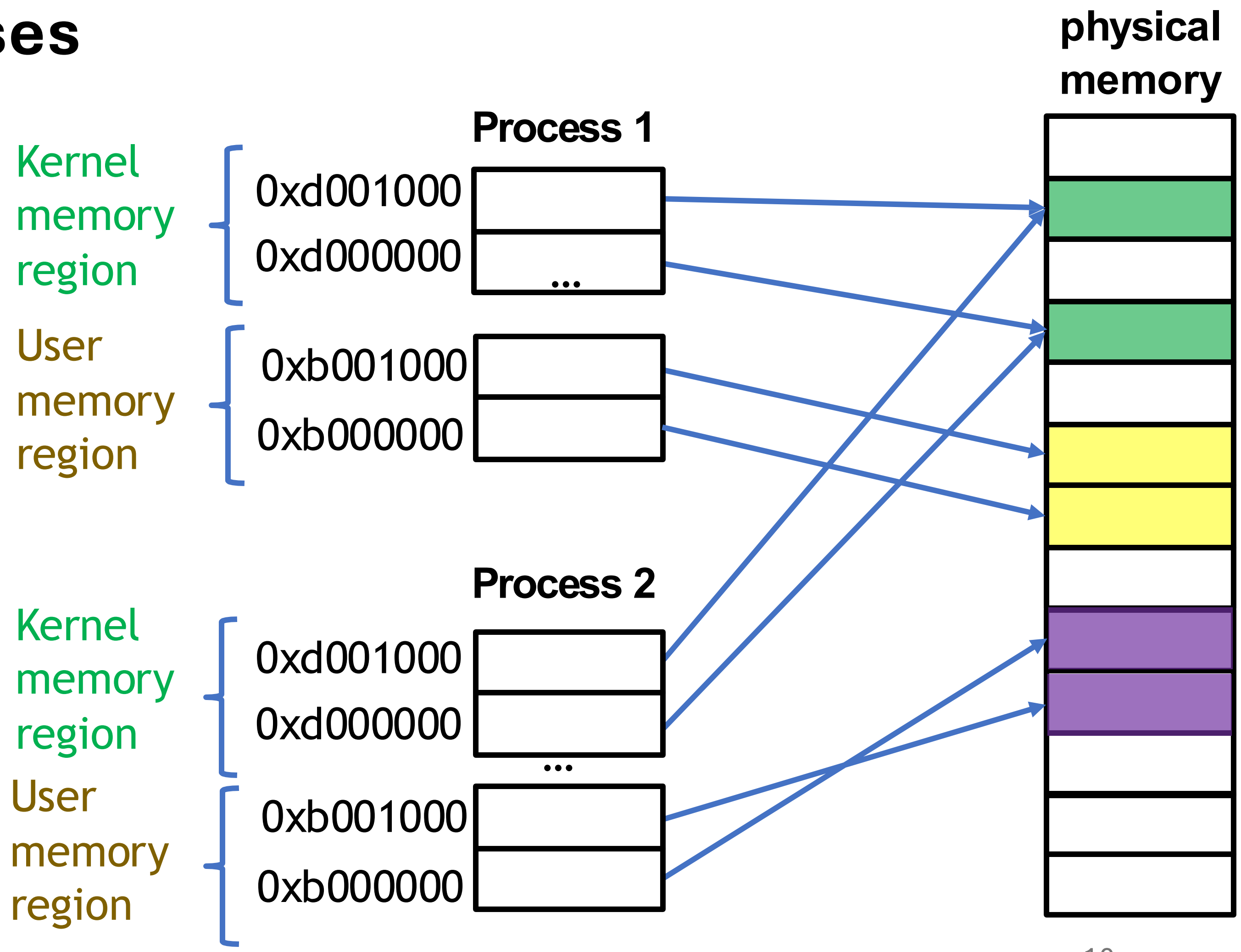
A related concern: how to acess variables across multiple processes?

- e.g., to implement int wait (pid_t *pid*) you want to create a variable in **struct thread** to store some information for a process,
  - e.g., thread->wait_status,
- but how can you read/write this variable from the parent process?

Answer: We're in the Kernel!

The kernel virtual memory mappings are the same across all processes





Answer: We’re in the Kernel!

The kernel virtual memory mappings are the same across all processes

Implications:

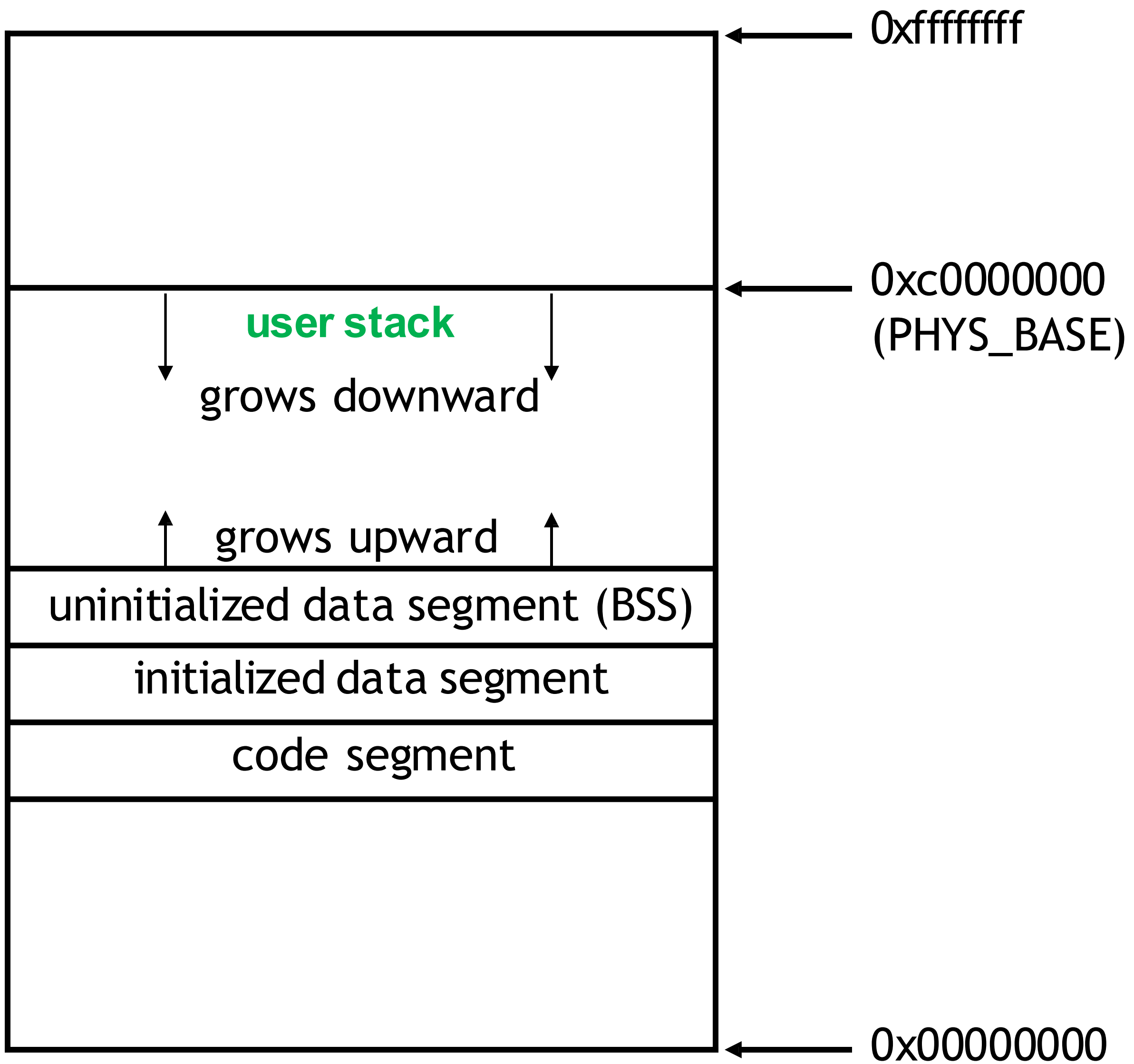
- When we context switch to another process, although it involves changing the page tables, the kernel virtual memory addresses are still valid after the switch
- All objects created in the kernel functions are accessible across processes
  - e.g., **static struct list** all_list;   threadX->wait_status
- Memory for user processes will be freed when a user process exits, but memory objects allocated within the kernel code using malloc should be explicitly freed!

How Is This Implemented?

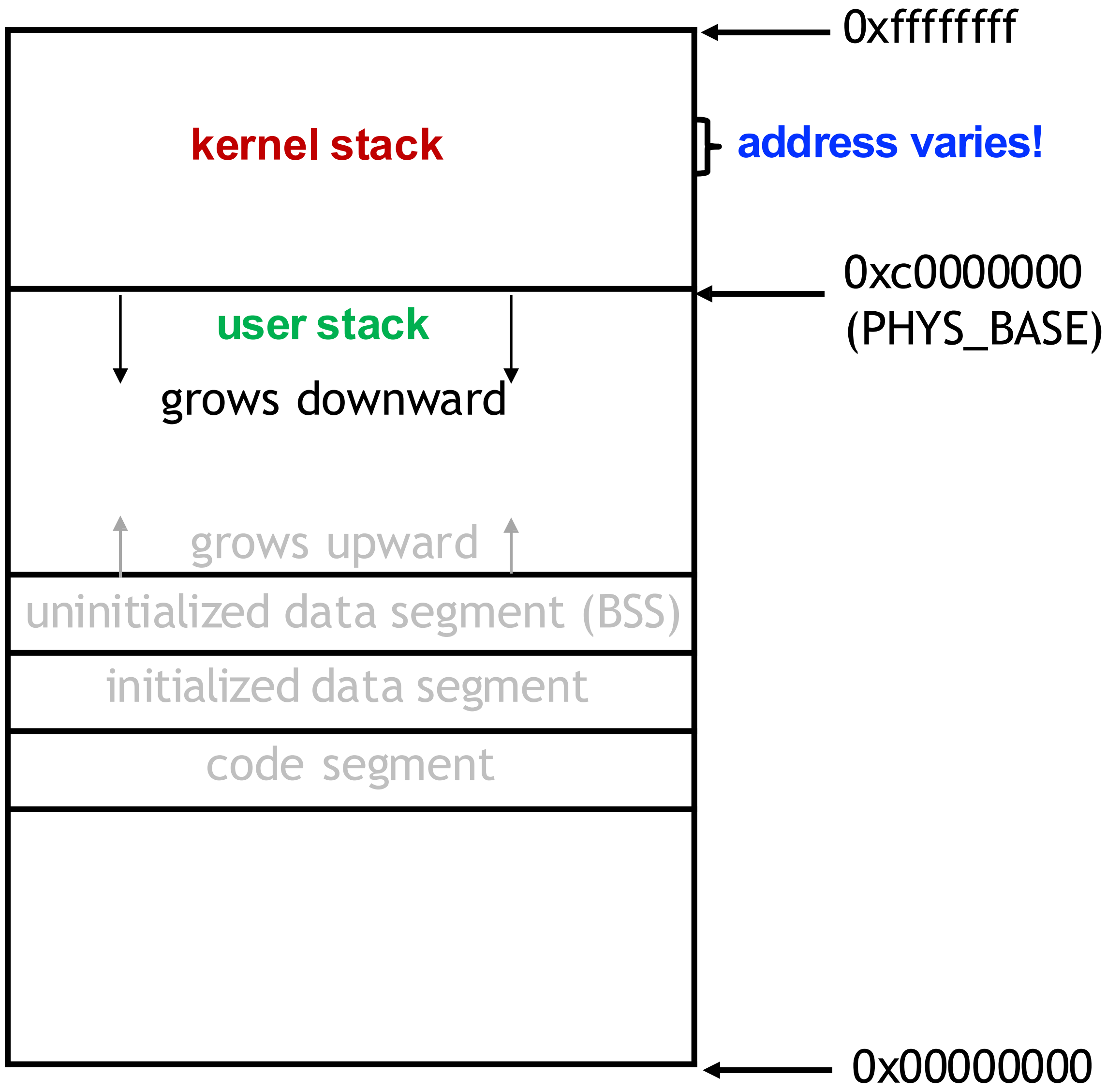
```
bool load (const char *file_name, void (**eip) (void), void **esp)
{
    struct thread *t = thread_current ();
    ...
    /* Allocate and activate page directory. */
    t->pagedir = pagedir_create ();
    if (t->pagedir == NULL)
        goto done;
    process_activate ();

    /* Open executable file. */
    file = filesys_open (file_name);
    ...
}

uint32_t *
pagedir_create (void)
{
    uint32_t *pd = palloc_get_page (0);
    if (pd != NULL)
        memcpy (pd, init_page_dir, PGSIZE);
    return pd;
}
```

Initialized in paging_init() in thread.c

User Stack vs Kernel Stack

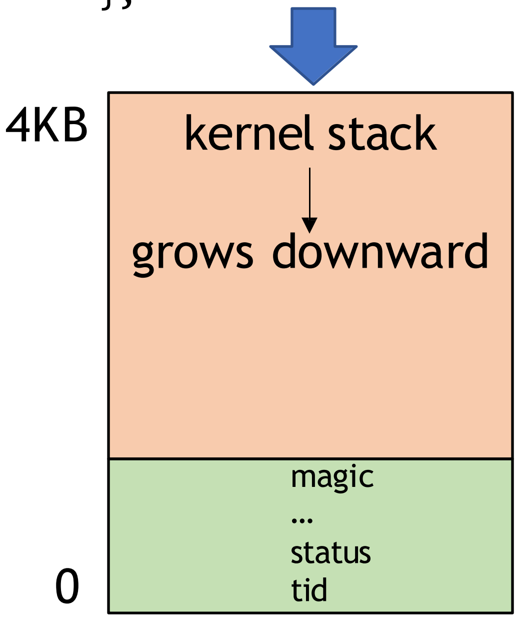


User Stack vs Kernel Stack



A new kernel thread gets a new kernel stack

```
struct thread {
  tid_t tid;
  enum thread_status status;
  …
  unsigned magic;
};
```



Lab 2

Minimal changes to get started:

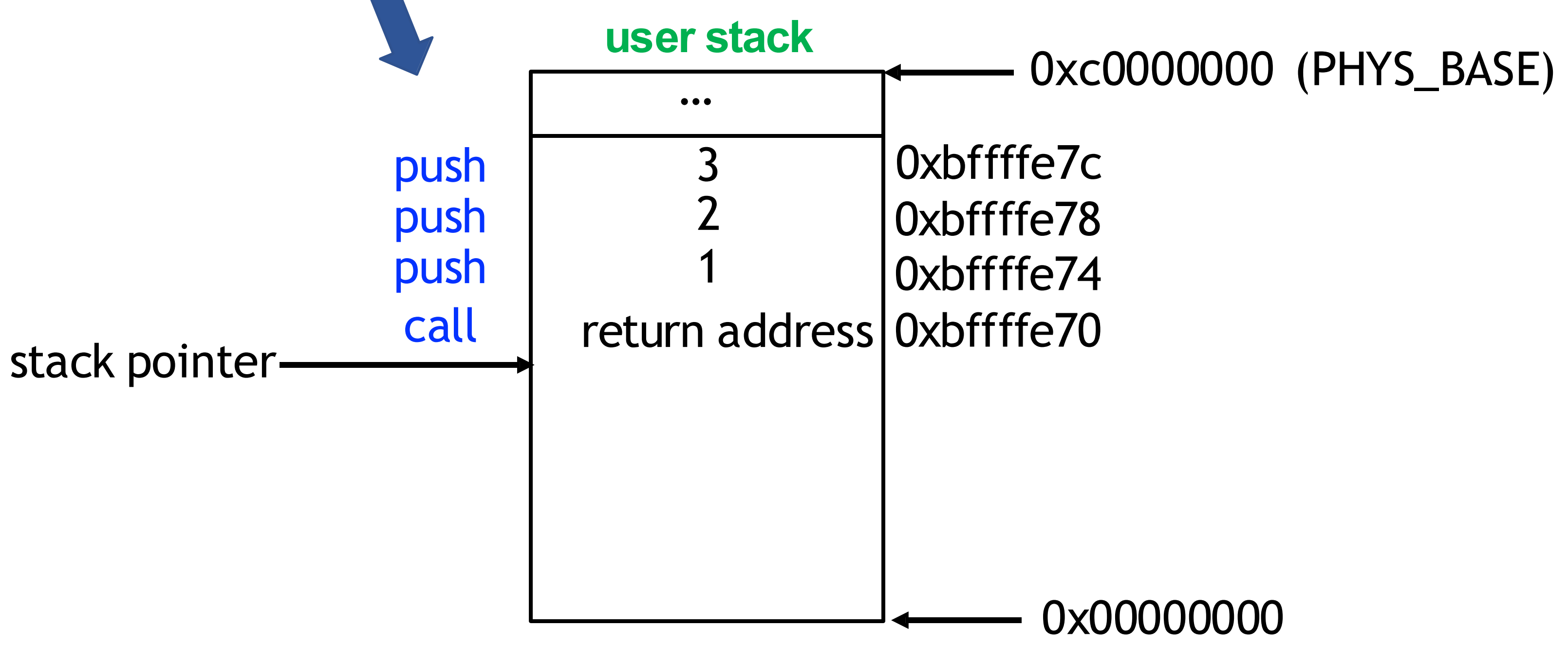
1. setup_stack() `*esp = PHYS_BASE;` → `*esp = PHYS_BASE - 12;`
2. change process_wait() to an infinite loop

Why Setting esp to PHYS_BASE – 12 ?

A temporary setup for obeying x86 calling convention

```c
void bar()
{
  int ret;
  ret = foo(1, 2, 3);
}
```

```c
int foo(int a, int b, int c)
{
  ...
}
```



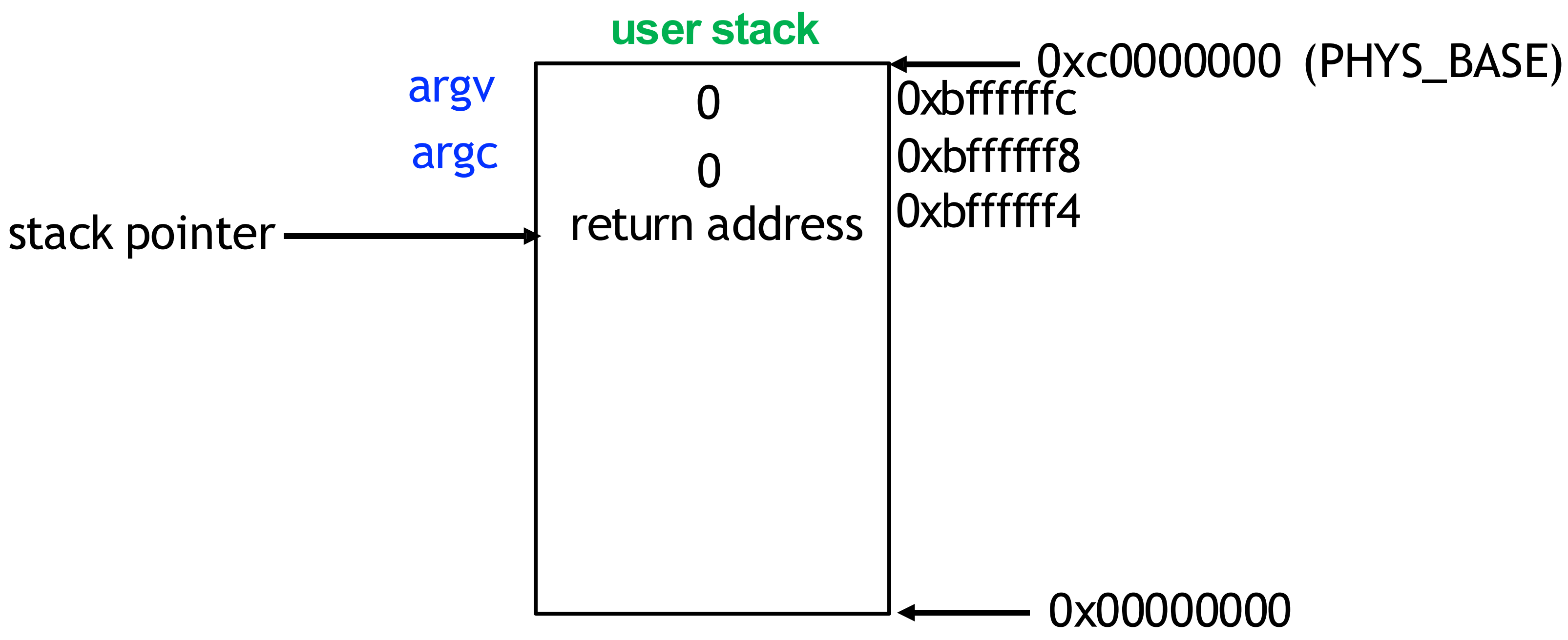
Why setting esp to PHYS_BASE – 12 ?

A temporary setup for obeying x86 calling convention

- Every user program's entry point is:

```
void _start (int argc, char *argv[])
{
  exit (main (argc, argv));
}
```

- Minimal 3 elements on user stack, each 4 bytes = 12



Why setting esp to PHYS_BASE – 12 ?

A temporary setup for obeying x86 calling convention

- Every user program's entry point is:

```
void _start (int argc, char *argv[])
{
  exit (main (argc, argv));
}
```

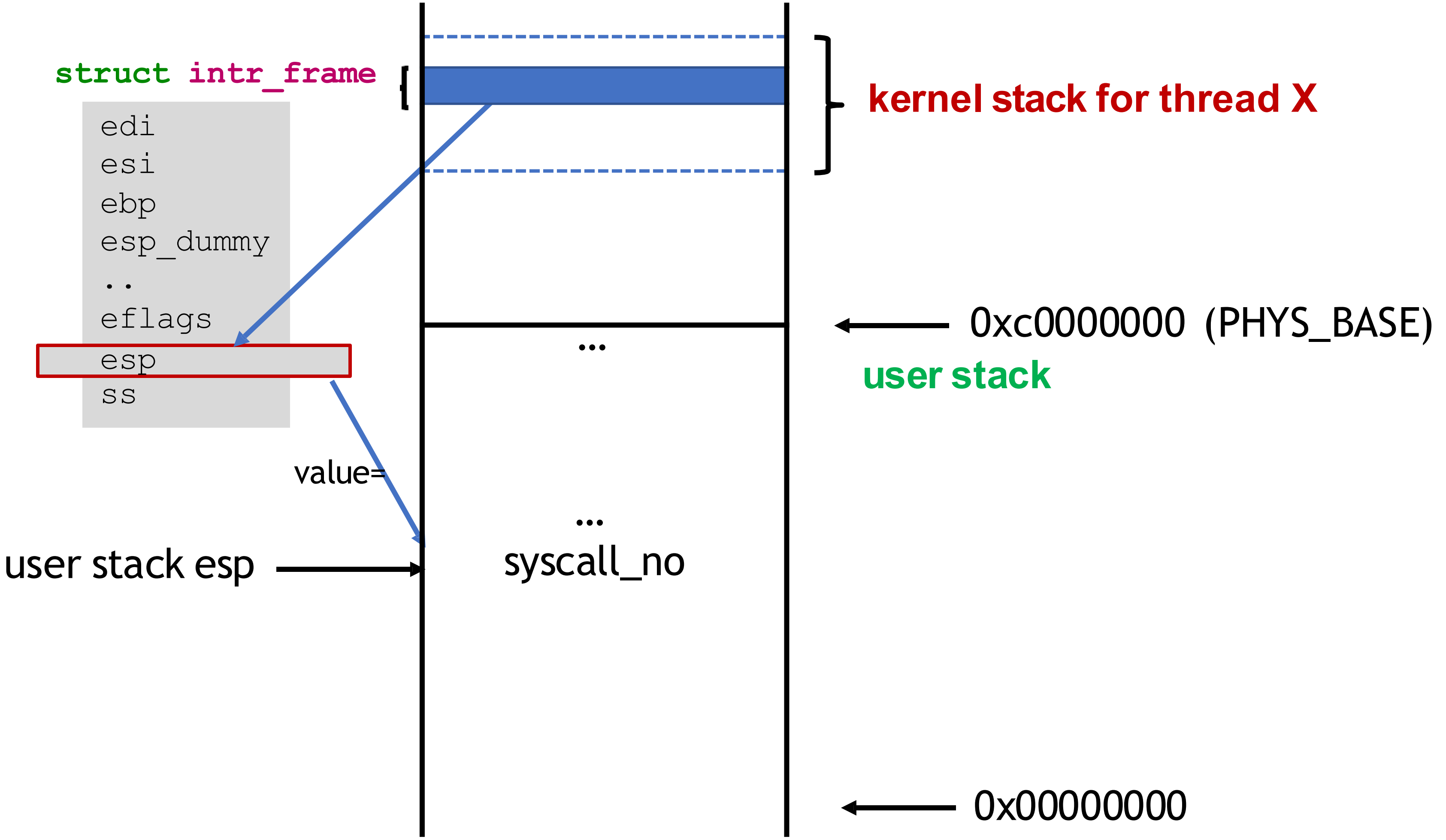
- Minimal 3 elements on user stack, each 4 bytes = 12

Note: this is only a temporary setup

- Once you implement argument parsing, you should set esp correctly based on the actual arguments pushed on the user stack

System Call

Through trap (an interrupt frame)



How to retrieve the syscall no in syscall_handler?

from reading user memory at intr_frame->esp

User Memory Access

Upon system call, *no* page directory switch

- i.e., in sycall_handler, the kernel can directly access user memory by dereferencing it
- However, must carefully check each user memory address for robustness!

Two approaches for checking + accessing user memory

- Software approach: using pagedir methods to check validity of an address
  - Easier (straightforward), but slower
- Hardware approach: leveraging page fault to detect invalid address
  - Fast, a bit more difficult to understand (but not difficult to implement once you figure it out)

Hardware Approach

Try loading the memory from a given address addr

- Assume addr is the function argument

```
movl 4(%esp), %edx;
movzbl (%edx), %eax;
```

→ edx = addr

→ eax = [addr]

- **Problem:** we'll get a page fault if addr is invalid
- **Idea:** let page fault handler inform us, how?

Hardware Approach

Use the given helper function, modify page fault handler

```c
/* Reads a byte at user virtual address UADDR.
   UADDR must be below PHYS_BASE.
   Returns the byte value if successful, -1 if a segfault
   occurred. */
static int get_user (const uint8_t *uaddr)
{
  int result;
  asm ("movl $1f, %0; movzbl %1, %0; 1:"
       : "=&a" (result) : "m" (*uaddr));
  return result;
}
```

compilation

```
get_user:
        movl 4(%esp), %edx;
        movl $1f, %eax;
        movzbl (%edx), %eax;
    1:
        ret
```

- If addr is valid, eax has the value
- If addr is invalid, the page fault handler will
  - set eip to address of label 1 (stored in eax now)
  - set eax to be -1 (0xffffffff);
  - resume to ret

Hardware Approach

Use the given helper function, modify page fault handler

```
/* Reads a byte at user virtual address UADDR.
   UADDR must be below PHYS_BASE.
   Returns the byte value if successful, -1     if a segfault
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static int get_user (const uint8_t *uaddr)
{
  int result;
  asm ("movl $1f, %0; movzbl %1, %0; 1:"
       : "=&a" (result) : "m" (*uaddr));
  return result;
}
```

But what if the value at uaddr is -1? We can't tell if it's invalid or not!

- **Solution:** read one byte at a time!
  - If value is valid, at most can be 255 (0xff)
  - How to represent a valid -1? Read four bytes (call get_user four times), convert to an integer!