CS 238P
Operating Systems
Discussion 7

Today’s agenda

- Solving midterm from winter 2018

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the mapping look like?

1. Basic page tables.

Consider the following 32-bit x86 page table setup.

`%cr3 holds 0x00000000.`

The Page Directory Page at physical address 0x00000000:

```
PDE 0: PPN=0x00001, PTE_P, PTE_U, PTE_W
PDE 1: PPN=0x00002, PTE_P, PTE_U, PTE_W
PDE 2: PPN=0x00001, PTE_P, PTE_U, PTE_W
```

... all other PDEs are zero

The Page Table Page at physical address 0x00001000 (which is PPN 0x00001):

```
PTE 0: PPN=0x00003, PTE_P, PTE_U, PTE_W
PTE 1: PPN=0x00004, PTE_P, PTE_U, PTE_W
```

... all other PTEs are zero The Page Table Page at physical address 0x00002000:

```
PTE 0: PPN=0x00005, PTE_P, PTE_U, PTE_W
PTE 1: PPN=0x00004, PTE_P, PTE_U, PTE_W
```

... all other PTEs are zero

Question 1.a: Basic page tables

Problem description:

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PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

PT at address 0x2000:

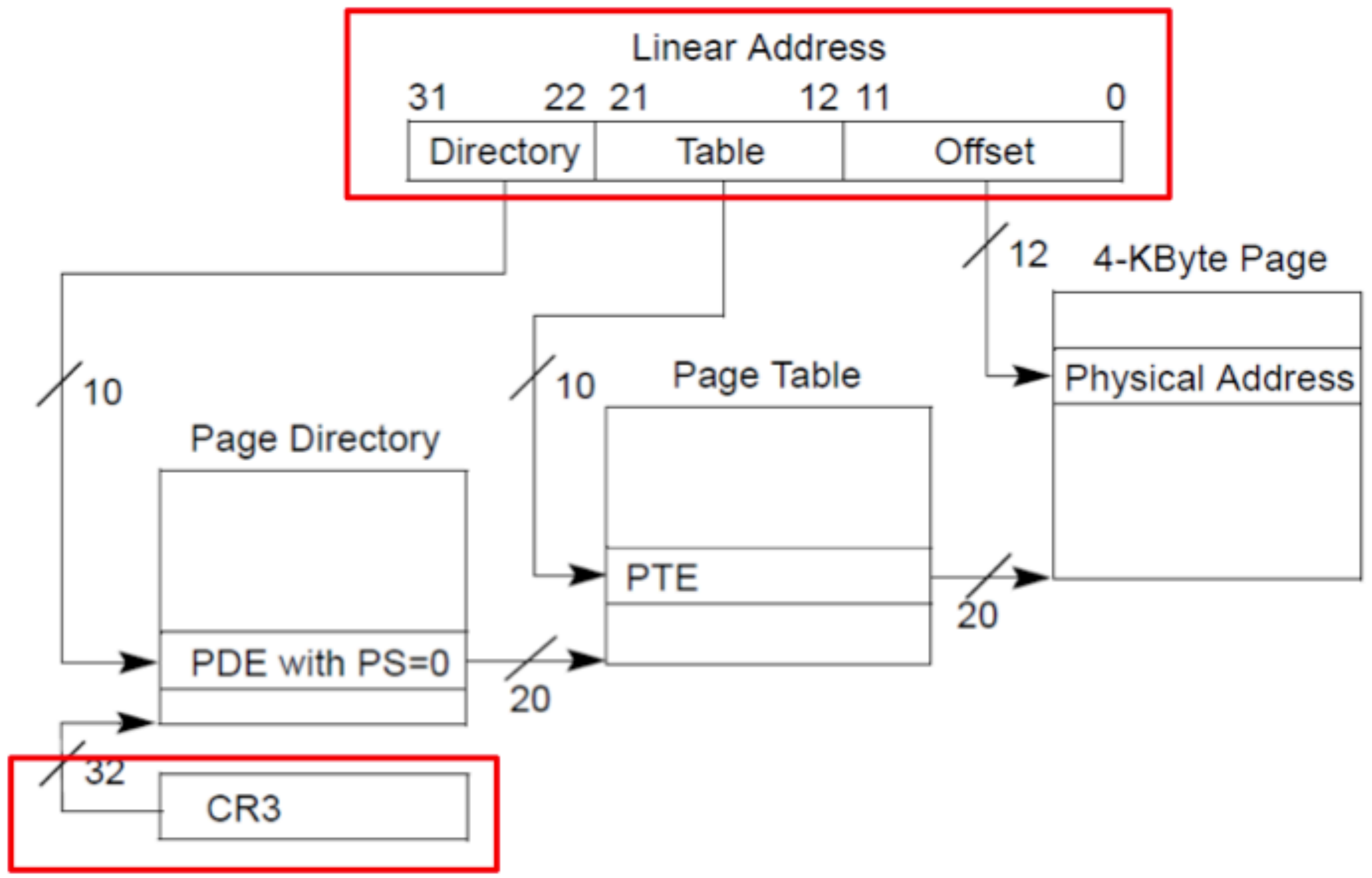
0 -> 0x5

1 -> 0x4

Question: what is the mapping look like?

Remind virtual to physical address mapping:

Page translation



Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

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0 -> 0x3

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PT at address 0x2000:

0 -> 0x5

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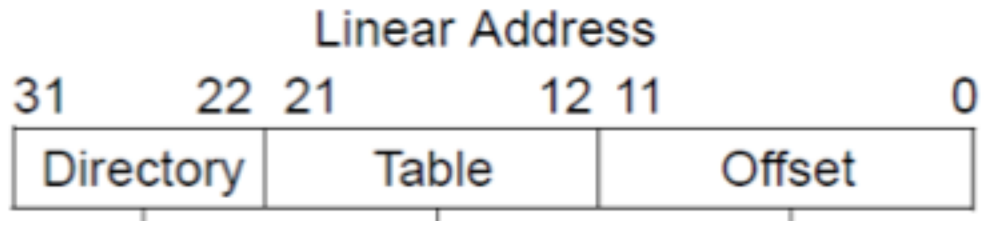
Question: what is the mapping look like?

Remind virtual to physical address mapping:



Bits 31-22 can be either 0x0, 0x1, 0x2

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

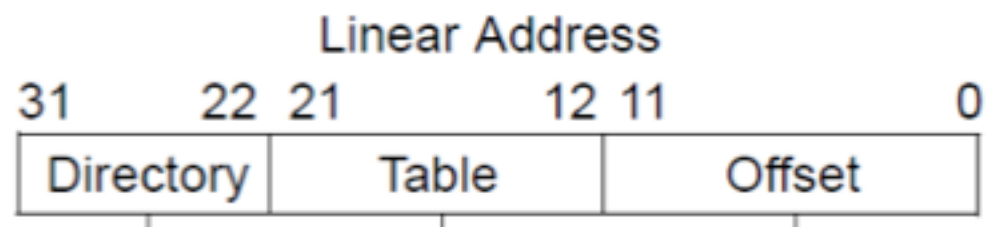
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the mapping look like?

Remind virtual to physical address mapping:



If bits 31-22 are 0x0:

Look at the page table (PT) at address 0x1000

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

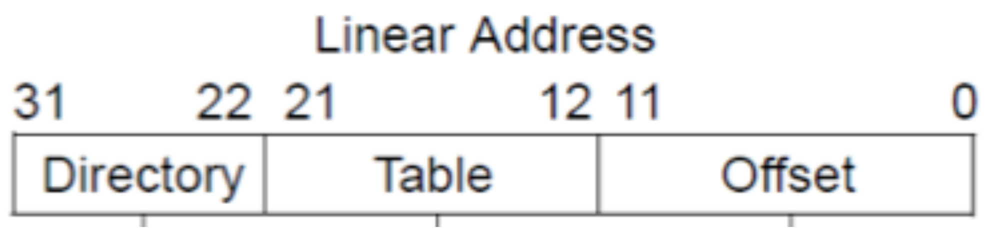
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the mapping look like?

Remind virtual to physical address mapping:



If bits 31-22 are 0x0:

Look at the page table (PT) at address 0x1000

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

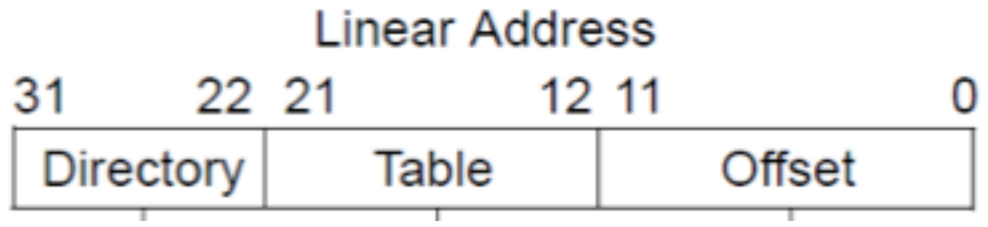
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the mapping look like?

Remind virtual to physical address mapping:



Page table (PT) at address 0x1000 has 2 entries 0x0 and 0x1 (all other zeros) =>

bits 21-12 can be either 0x0 or 0x1

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

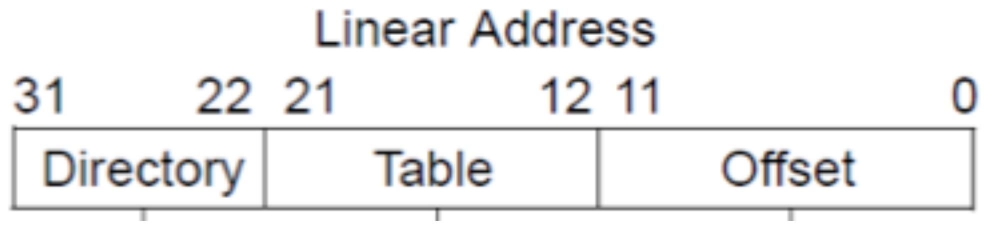
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

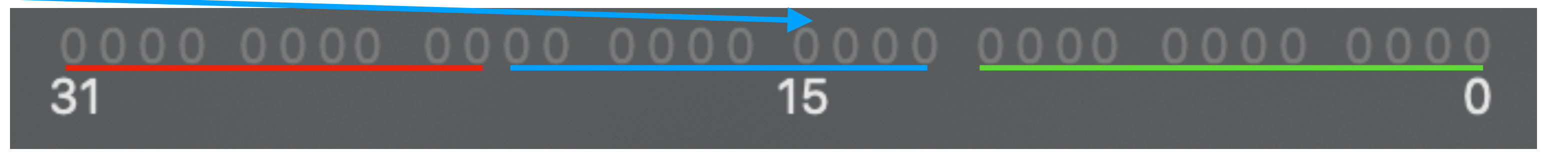
Question: what is the mapping look like?

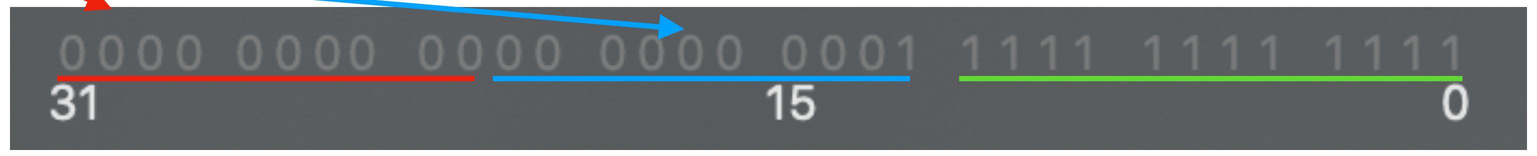
Remind virtual to physical address mapping:



Lets sum up the first PD entry range:

It maps addresses from 0x0 to 0x1FFF

0x0 = 0b 

0x1FFF = 0b 

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

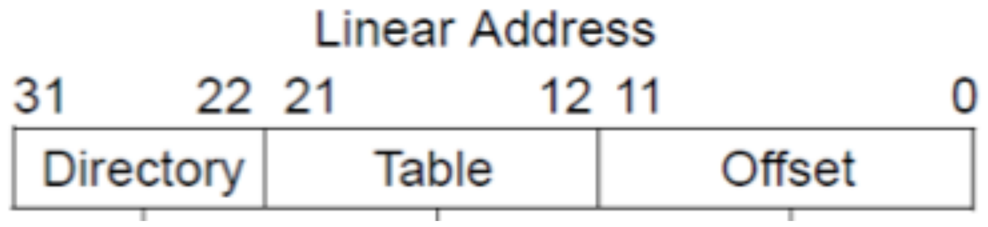
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the mapping look like?

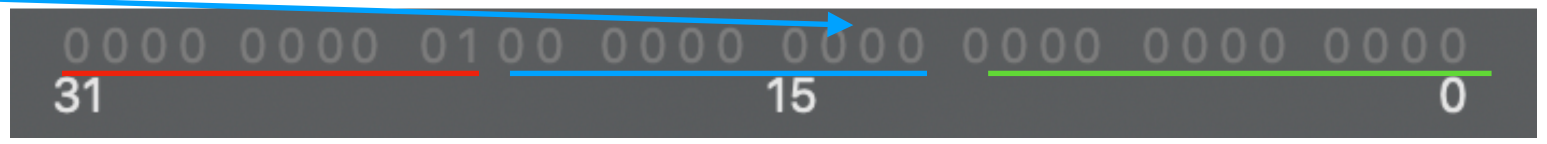
Remind virtual to physical address mapping:



Second PD entry range:

It maps addresses from 0x400000 to 0x401FFF

0x400000 = 0b



0x401FFF = 0b

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

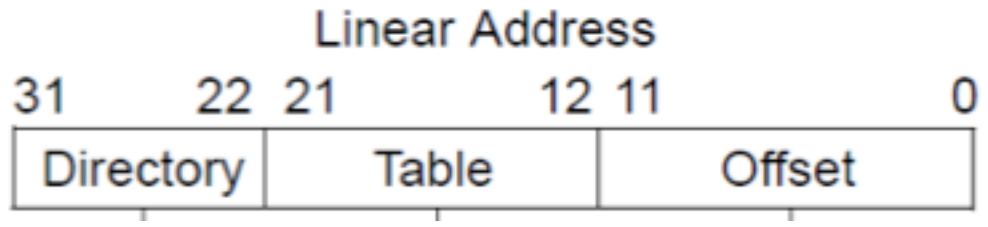
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

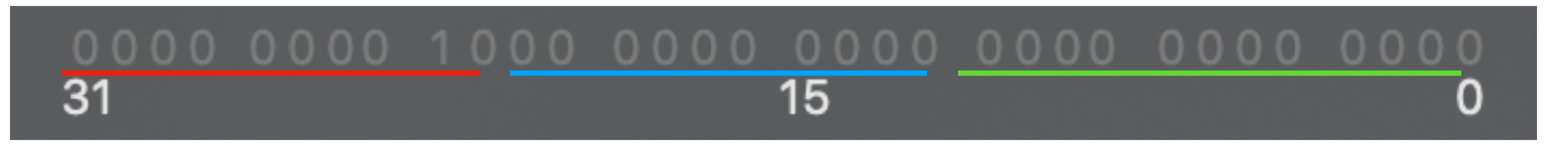
Question: what is the mapping look like?

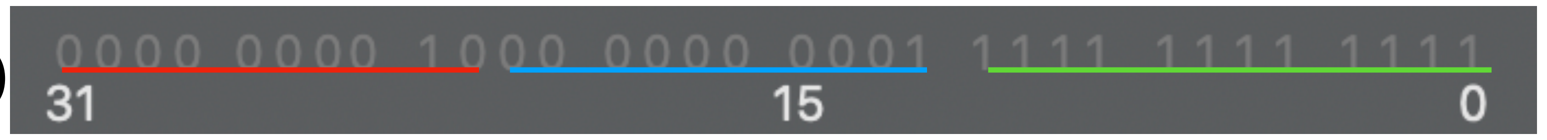
Remind virtual to physical address mapping:



Third PD entry range:

It maps addresses from 0x800000 to 0x801FFF

0x800000 = 0b 

0x801FFF = 0b 

Question 1.a: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

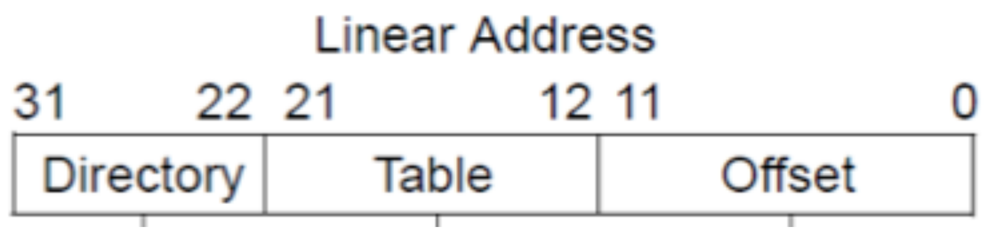
PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: which virtual addresses are mapped

Remind virtual to physical address mapping:



Final answer:

0x0 - 0x1FFF

0x400000 - 0x401FFF

0x800000 - 0x801FFF

Question 1.b: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the virtual address of PD

Page directory is at PHYSICAL address 0x0

You need to find a mapping from some virtual address into physical 0x0

Question 1.b: Basic page tables

Problem description:

cr3 = 0x0

PD at address 0x0:

0 -> 0x1

1 -> 0x2

2 -> 0x1

PT at address 0x1000:

0 -> 0x3

1 -> 0x4

Is equal 0x0?

PT at address 0x2000:

0 -> 0x5

1 -> 0x4

Question: what is the virtual address of PD

How to find it?

1. Look through page table mappings. You need to find an entry which map to 0x0
2. If you found, traverse to page directory and find index of the PDE corresponding for this PT
3. Create an address.
    1. Index in PD - first 10 bits
    2. Index in PT - middle 10 bits
    3. Offset - last 12 bits of physical address of PD (in our case 0x0)

If haven't found - there is no mapping

Question 2.a: Stack and calling conventions

Problem description:

int foo(int a) {

...   <- stopped here

}

int bar(int a, int b) { ...

foo(...); ...

}

int baz(int a, int b, int c) { ...

foo(...); ...

}

Question: What is in the stack?

Stack:

0x8010b5b8: ...

0x8010b5b4: 0x00010074

0x8010b5b0: 0x00000002

0x8010b5ac: 0x00000001

0x8010b5a8 0x80102e80

0x8010b5a4: 0x8010b5b8

0x8010b5a0: 0x80112780

0x8010b59c: 0x00000001

0x8010b598: 0x80102e32

0x8010b594: 0x8010b5a4   <-- ebp

0x8010b590: 0x00000000   <-- esp

To solve remember how stack looks like in general when you just entered a function:

1. First local variable
2. …
3. Last local variable
4. esp
5. ebp
6. Last function arg
7. ….
8. First function arg
9. Return address
10. Local variables   <- caller
11. Old ebp   <- caller

Question 2.a: Stack and calling conventions

Problem description:

```
int foo(int a) {

...                    <- stopped here

}

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foo(...); ...

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```

To solve remember how stack looks like in general when you just entered a function:

1. ~~First local variable~~ Don’t have
2. ~~...~~ Don’t have
3. ~~Last local variable~~ Don’t have
4. esp
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```

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4. ~~esp~~ Already done
5. ~~ebp~~ Already done
6. ~~Return address~~
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Question 2.a: Stack and calling conventions

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```
int foo(int a) {
...                    <- stopped here
}
int bar(int a, int b) { ...
foo(...); ...
}
int baz(int a, int b, int c) { ...
foo(...); ...
}
```

Question: What is in the stack?

Stack:

0x8010b5b8: ...

0x8010b5b4: 0x00010074

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0x8010b5ac: 0x00000001

0x8010b5a8 0x80102e80

0x8010b5a4: 0x8010b5b8

0x8010b5a0: 0x80112780

0x8010b59c: 0x00000001 Argument a of foo

0x8010b598: 0x80102e32 Return address

0x8010b594: 0x8010b5a4 <-- ebp

0x8010b590: 0x00000000 <-- esp

To solve remember how stack looks like in general when you just entered a function:

1. ~~First local variable~~ Don't have
2. ~~...~~ Don't have
3. ~~Last local variable~~ Don't have
4. ~~esp~~ Already done
5. ~~ebp~~ Already done
6. ~~Return address~~
7. ~~Last function arg~~
8. ....
9. ~~First function arg~~
10. Local variables <- caller
11. Old ebp <- caller

Question 2.a: Stack and calling conventions

Problem description:

int foo(int a) {

...   <- stopped here

}

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foo(...); ...

}

int baz(int a, int b, int c) { ...

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}

Question: What is in the stack?

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0x8010b5b8: ...

0x8010b5b4: 0x00010074

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0x8010b5ac: 0x00000001

0x8010b5a8 0x80102e80

0x8010b5a4: 0x8010b5b8

0x8010b5a0: 0x80112780

0x8010b59c: 0x00000001   Argument a of foo

0x8010b598: 0x80102e32   Return address

0x8010b594: 0x8010b5a4   <-- ebp

0x8010b590: 0x00000000   <-- esp

To solve remember how stack looks like in general when you just entered a function:

1. ~~First local variable~~   Don't have
2. ~~...~~   Don't have
3. ~~Last local variable~~   Don't have
4. ~~esp~~   Already done
5. ~~ebp~~   Already done
6. ~~Return address~~
7. ~~Last function arg~~
8. ~~....~~
9. ~~First function arg~~
10. Local variables   <- caller
11. Old ebp   <- caller

Question 2.a: Stack and calling conventions

Problem description:

```
int foo(int a) {
...                    <- stopped here
}
int bar(int a, int b) { ...
foo(...); ...
}
int baz(int a, int b, int c) { ...
foo(...); ...
}
```

Question: What is in the stack?

Stack:

0x8010b5b8: ...	
0x8010b5b4: 0x00010074	
0x8010b5b0: 0x00000002	
0x8010b5ac: 0x00000001	
0x8010b5a8 0x80102e80	
0x8010b5a4: 0x8010b5b8	
0x8010b5a0: 0x80112780	Local var or esp
0x8010b59c: 0x00000001	Argument a of foo
0x8010b598: 0x80102e32	Return address
0x8010b594: 0x8010b5a4	<-- ebp
0x8010b590: 0x00000000	<-- esp

To solve remember how stack looks like in general when you just entered a function:

1. ~~First local variable~~ — Don't have
2. ~~...~~ — Don't have
3. ~~Last local variable~~ — Don't have
4. ~~esp~~ — Already done
5. ~~ebp~~ — Already done
6. ~~Return address~~
7. ~~Last function arg~~
8. ~~....~~
9. ~~First function arg~~
10. ~~Local variables <- caller~~
11. Old ebp <- caller

Question 2.a: Stack and calling conventions

Problem description:

```
int foo(int a) {
...                 <- stopped here
}
int bar(int a, int b) { ...
foo(...); ...
}
int baz(int a, int b, int c) { ...
foo(...); ...
}
```

Question: What is in the stack?

Stack:

0x8010b5b8: ...

0x8010b5b4: 0x00010074

0x8010b5b0: 0x00000002

0x8010b5ac: 0x00000001

0x8010b5a8 0x80102e80

0x8010b5a4: 0x8010b5b8 Old ebp

0x8010b5a0: 0x80112780 Local var or esp

0x8010b59c: 0x00000001 Argument a of foo

0x8010b598: 0x80102e32 Return address

0x8010b594: 0x8010b5a4 <-- ebp

0x8010b590: 0x00000000 <-- esp

To solve remember how stack looks like in general when you just entered a function:

1. ~~First local variable~~ Don't have
2. ~~...~~ Don't have
3. ~~Last local variable~~ Don't have
4. ~~esp~~ Already done
5. ~~ebp~~ Already done
6. ~~Return address~~
7. ~~Last function arg~~
8. ~~....~~
9. ~~First function arg~~
10. ~~Local variables <- caller~~
11. ~~Old ebp <- caller~~

Question 2.a: Stack and calling conventions

Problem description:

```
int foo(int a) {
...                    <- stopped here
}
int bar(int a, int b) { ...
foo(...); ...
}
int baz(int a, int b, int c) { ...
foo(...); ...
}
```

Question: What is in the stack?

Stack:

0x8010b5b8: ...		
0x8010b5b4: 0x00010074	Argument 3 of baz or local variable	
0x8010b5b0: 0x00000002	Argument 2	
0x8010b5ac: 0x00000001	Argument 1	
0x8010b5a8 0x80102e80	Return address	
0x8010b5a4: 0x8010b5b8	Old ebp	
0x8010b5a0: 0x80112780	Local var or esp	
0x8010b59c: 0x00000001	Argument a of foo	
0x8010b598: 0x80102e32	Return address	
0x8010b594: 0x8010b5a4		<-- ebp
0x8010b590: 0x00000000		<-- esp

To solve remember how stack looks like in general when you just entered a function:

1. ~~First local variable~~ — Don't have
2. ~~...~~ — Don't have
3. ~~Last local variable~~ — Don't have
4. ~~esp~~ — Already done
5. ~~ebp~~ — Already done
6. ~~Return address~~
7. ~~Last function arg~~
8. ~~....~~
9. ~~First function arg~~
10. ~~Local variables <- caller~~
11. ~~Old ebp <- caller~~

Question 2.b: Stack and calling conventions

Problem description:

```
int foo(int a) {
...                    <- stopped here
}
int bar(int a, int b) { ...
foo(...); ...
}
int baz(int a, int b, int c) { ...
foo(...); ...
}
```

Question: Can Alice make a conclusion if foo() is called from the context of bar() or baz()

Stack:

0x8010b5b8: ...	
0x8010b5b4: 0x00010074	Argument 3 of baz or local variable
0x8010b5b0: 0x00000002	Argument 2
0x8010b5ac: 0x00000001	Argument 1
0x8010b5a8 0x80102e80	Return address
0x8010b5a4: 0x8010b5b8	Old ebp
0x8010b5a0: 0x80112780	Local var or esp
0x8010b59c: 0x00000001	Argument a of foo
0x8010b598: 0x80102e32	Return address
0x8010b594: 0x8010b5a4	<-- ebp
0x8010b590: 0x00000000	<-- esp

Answer:

We can't decide which function called foo, if ebp in 0x8010b5a4 would point to 0x8010b5b4 then we could say that foo was called from a function that takes two arguments, i.e., bar but since we don't know what is there in 0x8010b5b4 we can't make this decision

Question 3: Process organization

Problem description:

xv6 processes have the following memory layout created as part of the exec() function. First, the kernel allocates pages for the kernel text and data (not that these pages are both executable and writable). Then xv6 allocates two pages: stack and guard. The guard page is made is placed between the stack and the rest of the program to make sure that if the stack overflows the operating system can catch an exception caused by the access to the guard page and terminate the program early.

Question: is it possible to write a C program that escapes the guard page mechanism and accidentally overwrites the text section of the program

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Question: is it possible to write a C program that escapes the guard page mechanism and accidentally overwrites the text section of the program

Answer:

Yes, it is possible to write a C program that escapes the guard page mechanism. If a C program has a local variable that is of size greater than 2 pages, we would skip the guard page and overwrite the text and data section.

Char xv6_hacked[PAGE_SIZE*2];

Int this_variable_is_allocated_in_text_section = 228;

Question 4.a: Physical and virtual memory allocation

Question: How xv6 keep track of available physical memory (using kalloc function)?

Original question: Xv6 uses 234MB of physical memory. But how does it keep track of available physical memory? Specifically, explain the following: the xv6 memory allocator (kalloc()) always returns a virtual address, but how does the allocator know which physical page to use for each virtual address it allocates?

How to solve questions like that:

1. Open xv6 source code: https://github.com/mit-pdos/xv6-public

2. Search for kalloc

3. Open a function and try to understand what's going on

Question 4.a: Physical and virtual memory allocation

Question: How xv6 keep track of available physical memory (using kalloc function)?

```c
// Allocate one 4096-byte page of physical memory.
// Returns a pointer that the kernel can use.
// Returns 0 if the memory cannot be allocated.
char*
kalloc(void)
{
  struct run *r;

  if(kmem.use_lock)
    acquire(&kmem.lock);
  r = kmem.freelist;
  if(r)
    kmem.freelist = r->next;
  if(kmem.use_lock)
    release(&kmem.lock);
  return (char*)r;
}
```

1. Synchronization lock
2. Getting a linked list of available spaces
3. Pop first element from the list
4. Release the lock

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  if(kmem.use_lock)
    release(&kmem.lock);
  return (char*)r;
}
```

How you found out it is a linked list of free spaces?

Look like linked list

```c
struct run {
  struct run *next;
};

struct {
  struct spinlock lock;
  int use_lock;
  struct run *freelist;
} kmem;
```

```c
void
kinit1(void *vstart, void *vend)
{
  initlock(&kmem.lock, "kmem");
  kmem.use_lock = 0;
  freerange(vstart, vend);
}
```

Init function calls freerange

```c
void
freerange(void *vstart, void *vend)
{
  char *p;
  p = (char*)PGROUNDUP((uint)vstart);
  for(; p + PGSIZE <= (char*)vend; p += PGSIZE)
    kfree(p);
}
```

freerange calls kfree on every page available

```c
void
kfree(char *v)
{
  struct run *r;

  if((uint)v % PGSIZE || v < end || V2P(v) >= PHYSTOP)
    panic("kfree");

  // Fill with junk to catch dangling refs.
  memset(v, 1, PGSIZE);

  if(kmem.use_lock)
    acquire(&kmem.lock);
  r = (struct run*)v;
  r->next = kmem.freelist;
  kmem.freelist = r;
  if(kmem.use_lock)
    release(&kmem.lock);
}
```

Add page into linked list

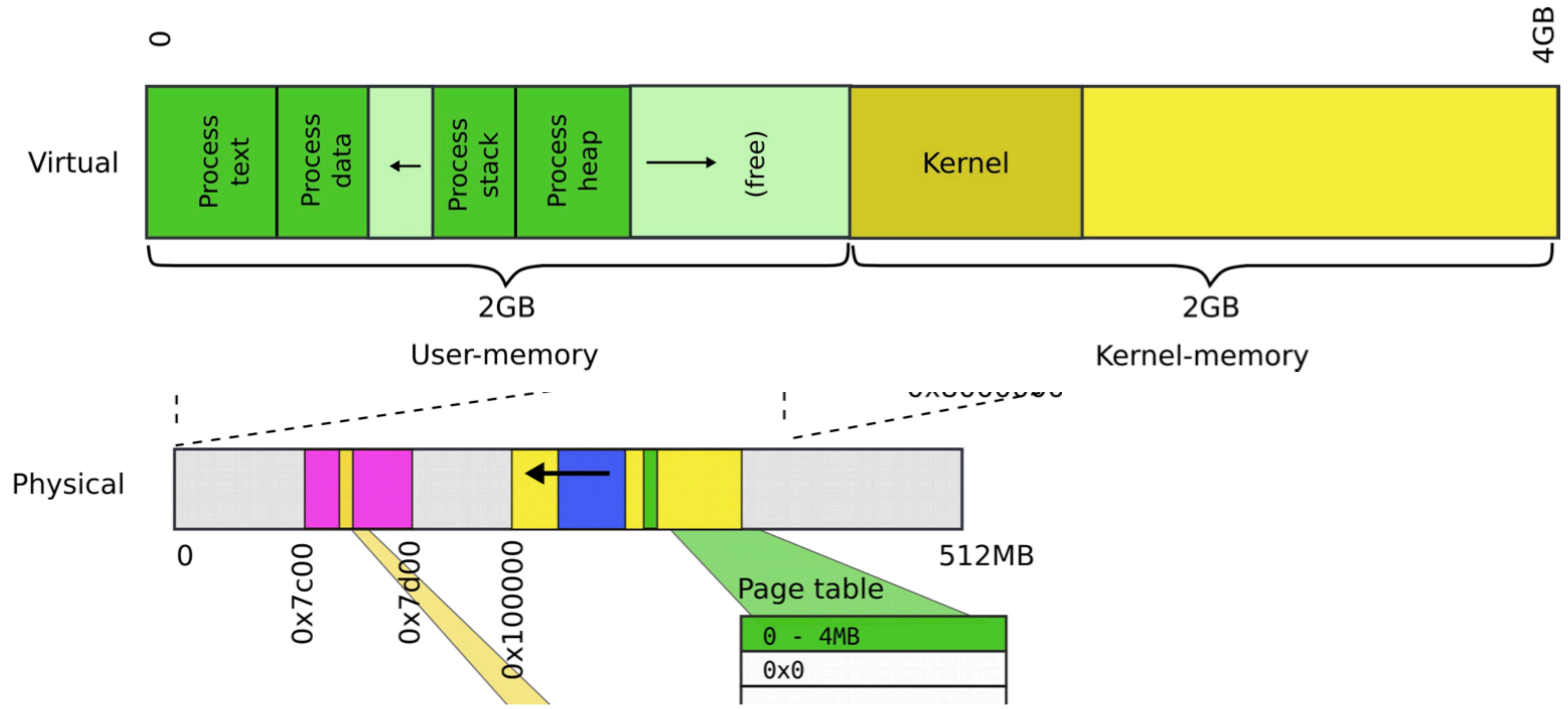
Question 4.b: Physical and virtual memory allocation

Question: Xv6 defines the V2P() macro that allows the kernel to convert between virtual and physical addresses:

#define V2P(a) (((uint) (a)) - KERNBASE)

Does V2P() macro work for virtual addresses that belong to the user part of the address space (i.e., a virtual address inside the user data or stack)?

Kernel memory:



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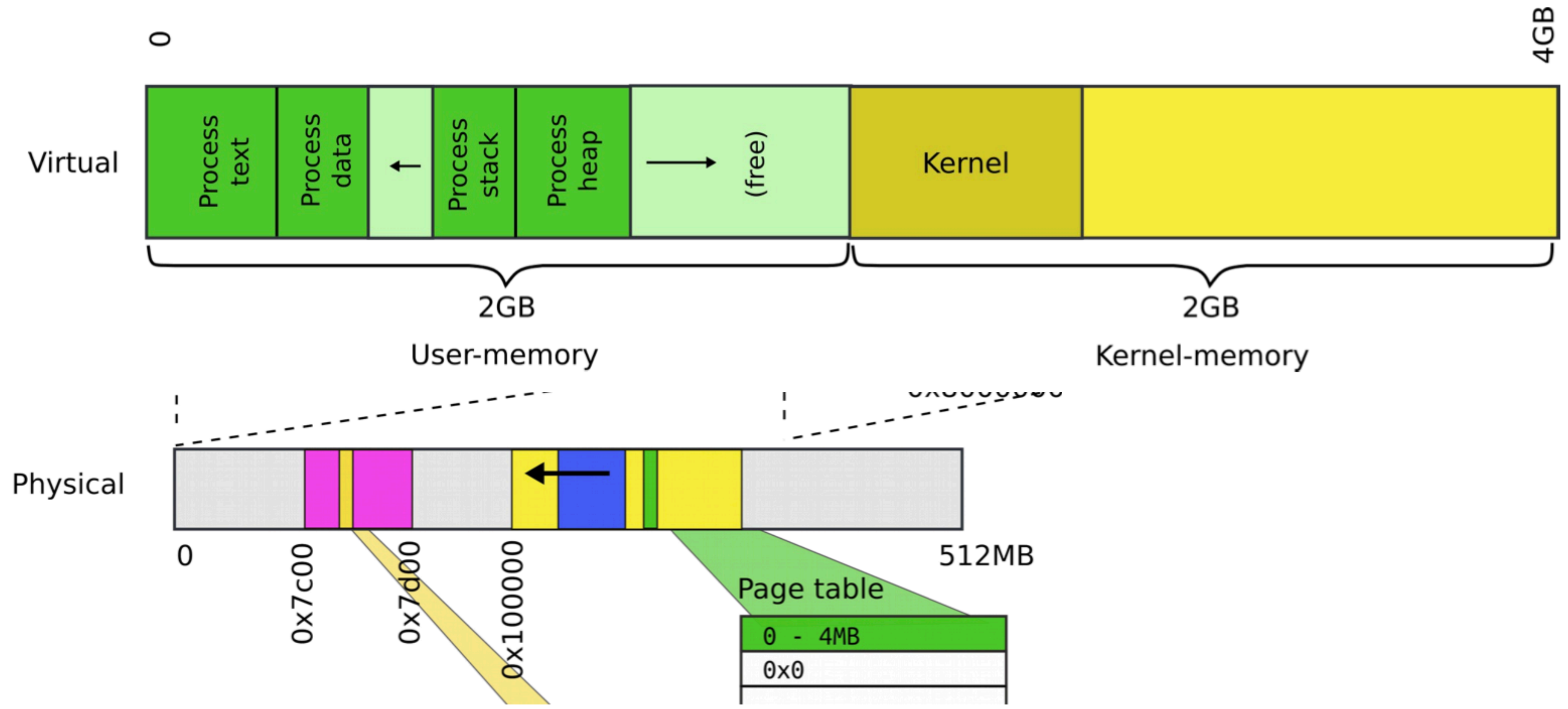

Answer: No, because the V2P mapping for kernel is simple - kernel is physically located at 0x0, but virtually at 2gb. It is not true for user programs. You need to go through page table mechanism

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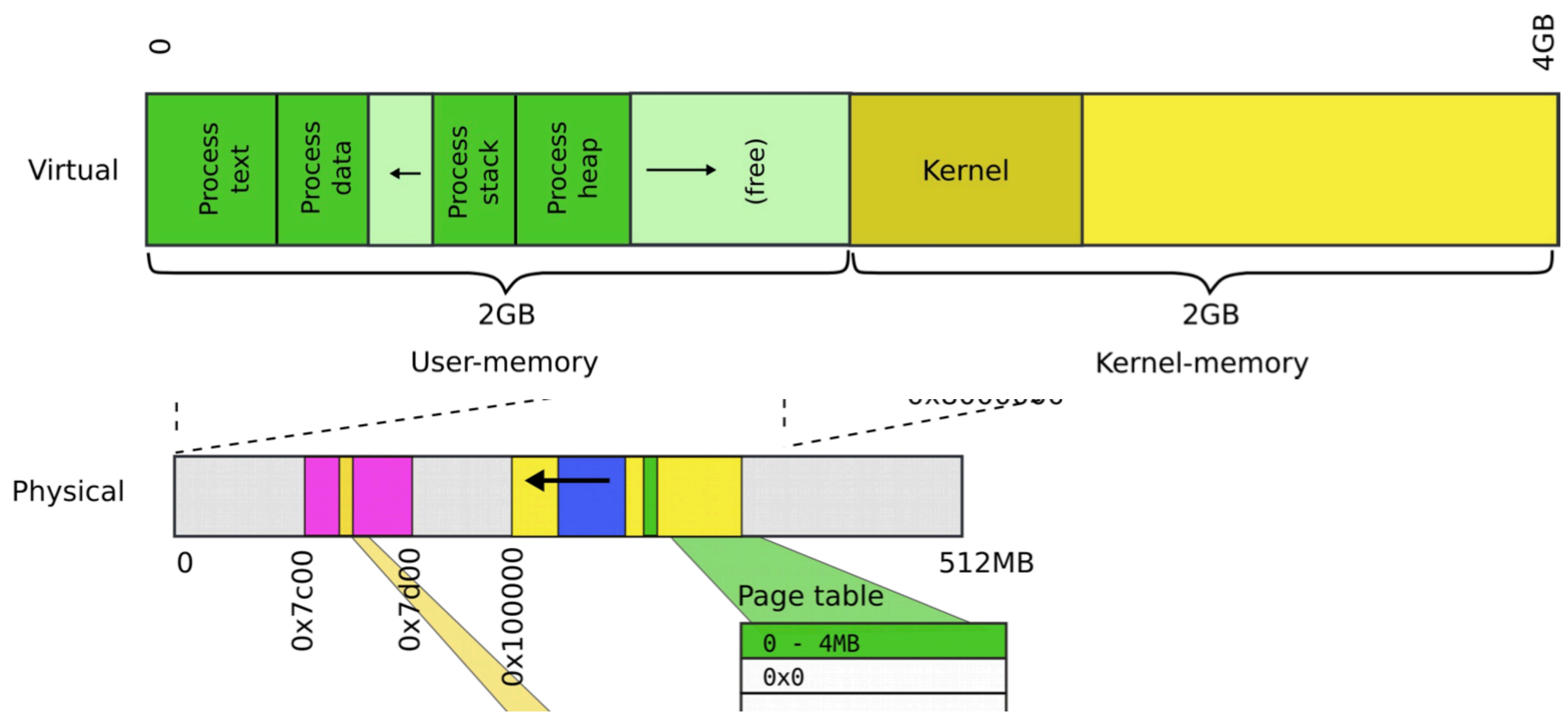

Answer: No, because the V2P mapping for kernel is simple - kernel is physically located at 0x0, but virtually at 2gb. It is not true for user programs. You need to go through page table mechanism

Question 5: Exec and fork

Problem description:

```
#include "param.h"

#include "types.h"

#include "user.h" #include "syscall.h"

   int main() {

     char * message = "aaa\n";

     int pid = fork();

     if(pid != 0){

       char *echoargv[] = { "echo", "Hello\n", 0 };

       message = "bbb\n";

       exec("echo", echoargv);

     }

     write(1, message, 4);

     exit();

}
```

Question: What is the output

The fundamental question here is who would run first child or parent?

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#include "user.h" #include "syscall.h"
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       message = "bbb\n";
       exec("echo", echoargv);
     }
     write(1, message, 4);
     exit();
}
```

Question: What is the output

The fundamental question here is who would run first child or parent?

It is undefined

Answer:

There are two possible outputs:

1.

aaa

Hello

2.

Hello

Aaa

Question 6: Initial page tables

Problem description:

What would be if we remove mapping 0-4MB (Virtual) -> 0-4MB (Physical) from entrypgdir:

```
__attribute__((__aligned__(PGSIZE)))

pde_t entrypgdir[NPDENTRIES] = {

  // Map VA's [0, 4MB) to PA's [0, 4MB)

  // [0] = (0) | PTE_P | PTE_W | PTE_PS,

  // Map VA's [KERNBASE, KERNBASE+4MB) to PA's [0, 4MB)

  [KERNBASE>>PDXSHIFT] = (0) | PTE_P | PTE_W | PTE_PS,

};
```

```
# Entering xv6 on boot processor, with paging off.
.globl entry
entry:
  # Turn on page size extension for 4Mbyte pages
  movl    %cr4, %eax
  orl     $(CR4_PSE), %eax
  movl    %eax, %cr4
  # Set page directory
  movl    $(V2P_WO(entrypgdir)), %eax
  movl    %eax, %cr3
  # Turn on paging.
  movl    %cr0, %eax
  orl     $(CR0_PG|CR0_WP), %eax
  movl    %eax, %cr0

  # Set up the stack pointer.
  movl $(stack + KSTACKSIZE), %esp

  # Jump to main(), and switch to executing at
  # high addresses. The indirect call is needed because
  # the assembler produces a PC-relative instruction
  # for a direct jump.
  mov $main, %eax
  jmp *%eax

.comm stack, KSTACKSIZE
```

How to solve:

1. Open source code
2. Find entrypgdir
3. Try to analyze whats going on

What about those guys? Would they be executed?

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pde_t entrypgdir[NPDENTRIES] = {

  // Map VA's [0, 4MB) to PA's [0, 4MB)

  // [0] = (0) | PTE_P | PTE_W | PTE_PS,

  // Map VA's [KERNBASE,
KERNBASE+4MB) to PA's [0, 4MB)

  [KERNBASE>>PDXSHIFT] = (0) | PTE_P |
PTE_W | PTE_PS,

};
```

Answer:

The code wouldn’t run, because as entry.S would load the page directory all other setup instructions would not be available anymore