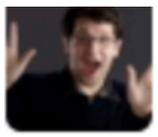
# Operating Systems
## Lecture 10: Memory Virtualisation
## Base & Bounds + Segmentation

Nipun Batra
Aug 24, 2018

# CS stories



**Dion Almaer**
@dalmaer

Following

Hey @duhroach, would be a fun show.... where do all the bytes come from! (And increase in pixels / density etc) :)
m.imgur.com/3TtTwrU

The original NES console was only designed to output images that were 256 wide by 240 high; meaning that the final image that needed to be displayed to the screen was 180kb in size.

Besides that, the NES only had 2kb of RAM. A cartridge itself could could hold 8k to 1mb of game data. So, there was no way to fit the entire game's contents into main memory. Basically, a subset of the 1MB cartridge data must be loaded into the 2kb RAM and used to render the 180kb screen. How does one achieve that?

SpriteSheets.

Sprite sheets contain small tiles of graphics, that are re-used over and over again. For example, below is a remake of the original super mario sprite sheet:

# Administrative

1. 2 - 3 mins CS story at start of lecture - given by you!
    1. Technically interesting tidbit
    2. CS hero - Grace Hopper, Kerninghan …
2. +1 marks
3. Order : Script run by instructor
4. Lecture tomorrow, 25th August, 4 PM, 7/102

# Revision

# Revision

1. Space v/s Time Multiplexing

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2. Direct Physical Memory Multiplexing :

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1. Space v/s Time Multiplexing
2. Direct Physical Memory Multiplexing :
    1. Limited to physical memory

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    2. Fragmentation :

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3. Goals of Memory Management:
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    2. Efficiency

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4. Memory Interface : Load and Store

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4. Memory Interface : Load and Store
5. Abstraction
    1. Decouple physical memory and address

# Hello Assembly

```
void func() {
    int x = 3000; //
    x = x + 3;    //
    ...
```

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Compiler →

# Hello Assembly

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128: movl 0x0(%ebx), %eax
132: addl $0x03, %eax
135: movl %eax, 0x0(%ebx)
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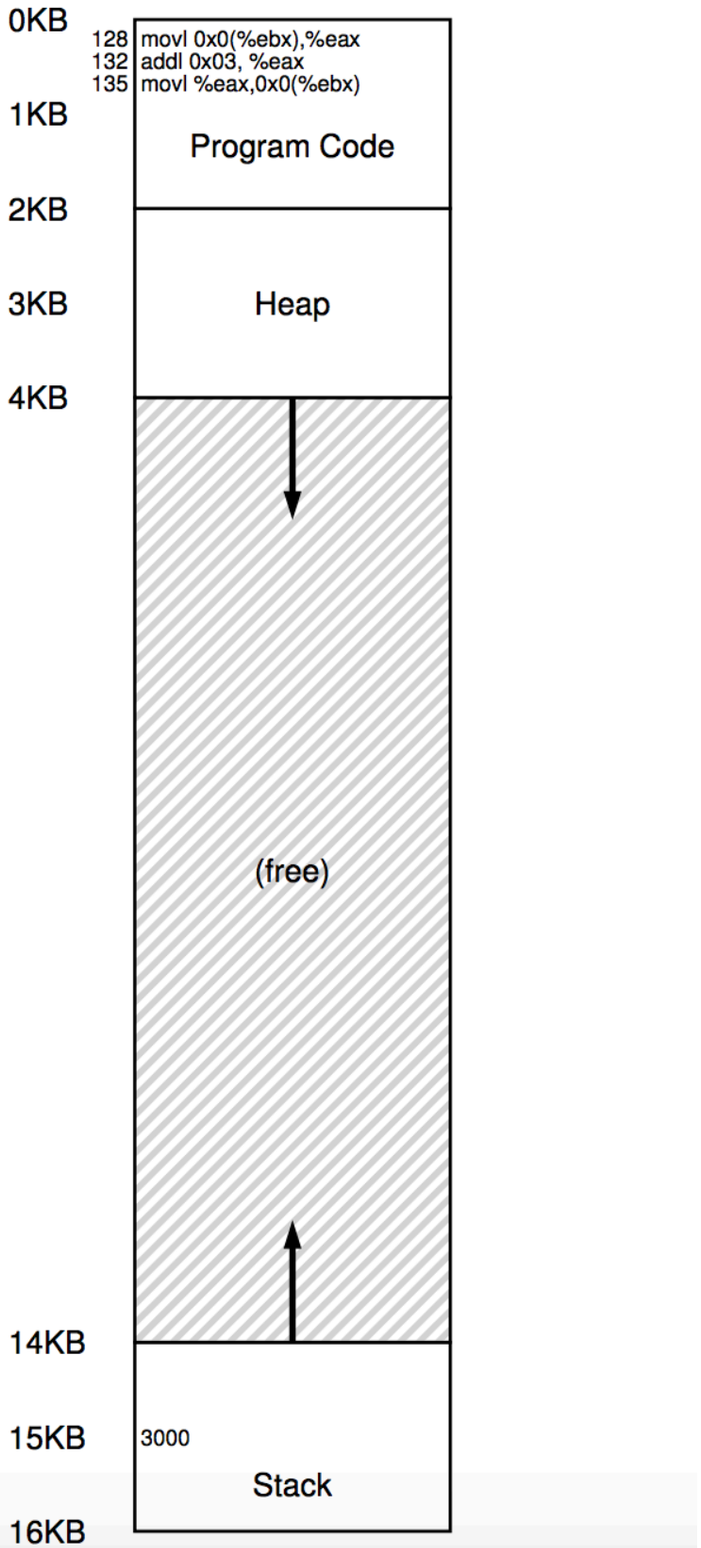


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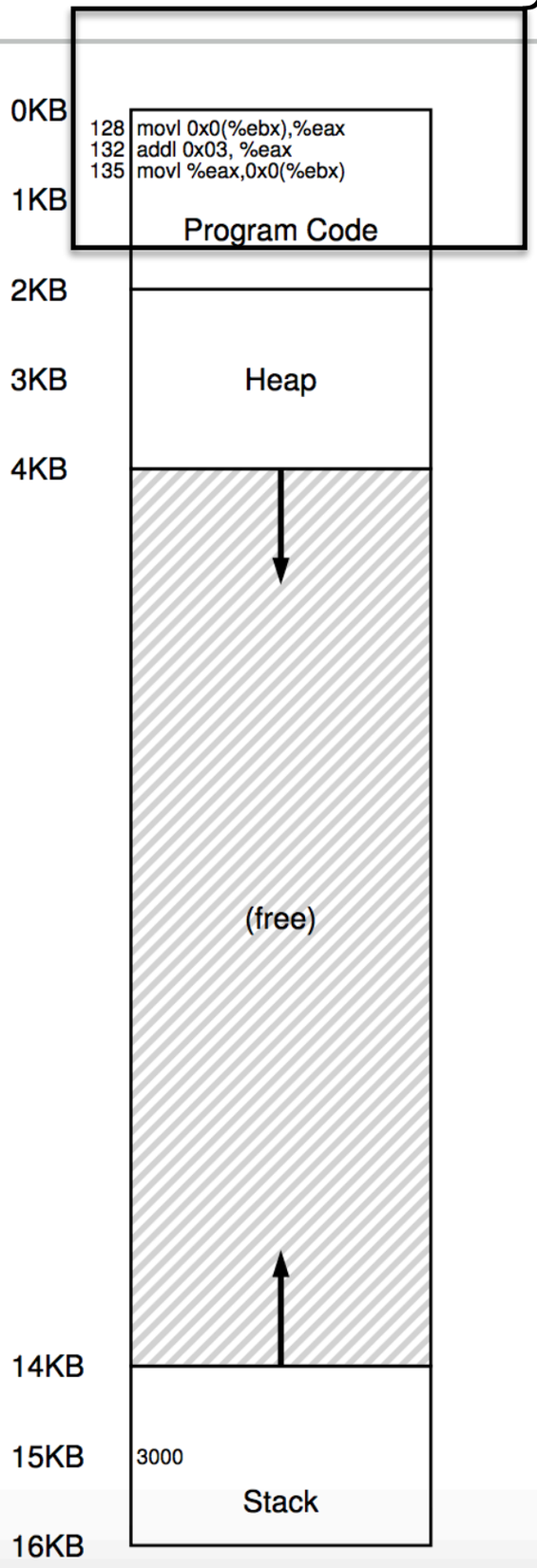


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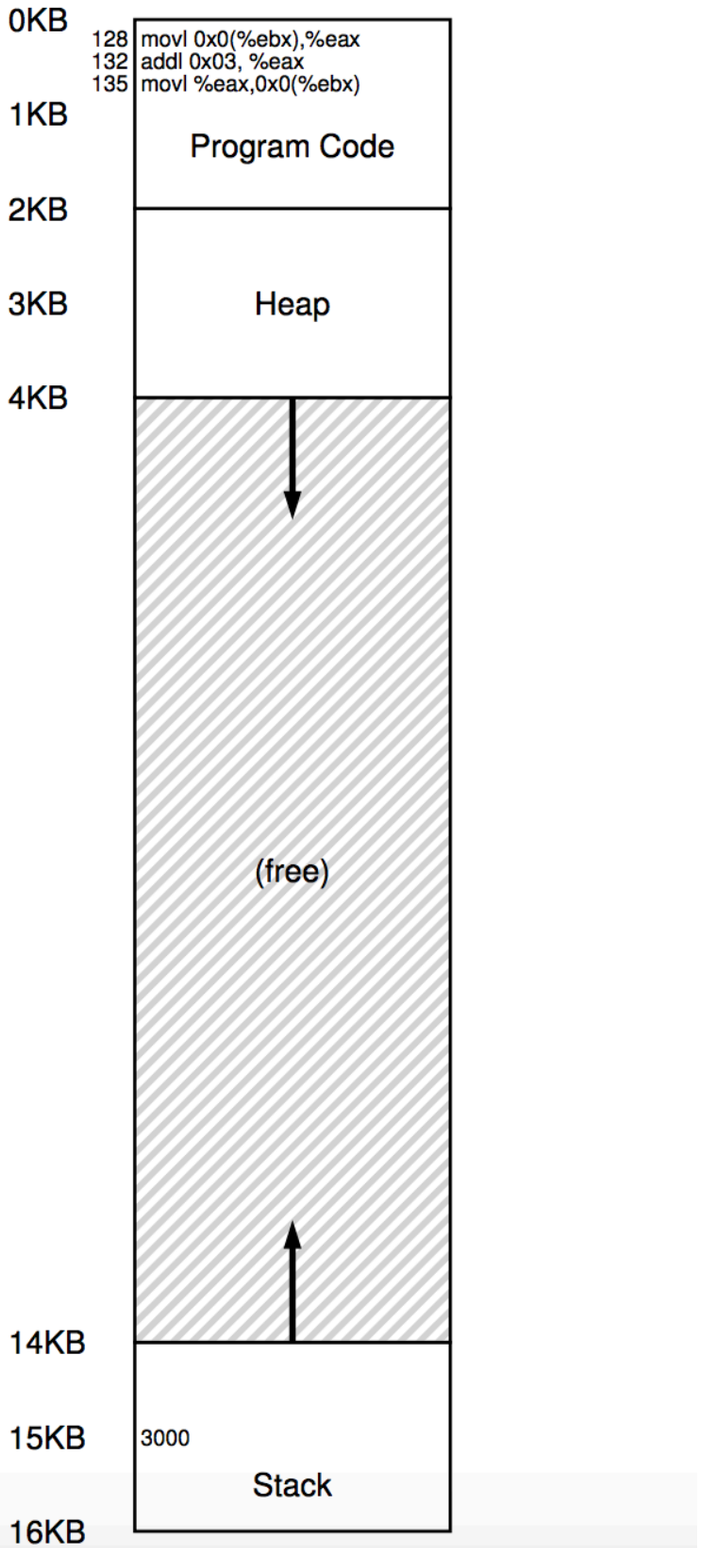


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```
▶ cat hello_world.c
#include<stdio.h>

int main()
{
int x = 10;
x = x + 4;
x = x*4;
return 0;
}
```

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int main()
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int x = 10;
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```
▶ otool -tv hello_world
hello_world:
(__TEXT,__text) section
_main:
0000000100000f90        pushq   %rbp
0000000100000f91        movq    %rsp, %rbp
0000000100000f94        xorl    %eax, %eax
0000000100000f96        movl    $0x0, -0x4(%rbp)
0000000100000f9d        movl    $0xa, -0x8(%rbp)
0000000100000fa4        movl    -0x8(%rbp), %ecx
0000000100000fa7        addl    $0x4, %ecx
0000000100000faa        movl    %ecx, -0x8(%rbp)
0000000100000fad        movl    -0x8(%rbp), %ecx
0000000100000fb0        shll    $0x2, %ecx
0000000100000fb3        movl    %ecx, -0x8(%rbp)
0000000100000fb6        popq    %rbp
0000000100000fb7        retq
```

# Hello Assembly

| Suffix | Name | Size |
|---|---|---|
| B | BYTE | 1 byte (8 bits) |
| W | WORD | 2 bytes (16 bits) |
| L | LONG | 4 bytes (32 bits) |
| Q | QUADWORD | 8 bytes (64 bits) |

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# General Address Translation

Kernel

CPU

MMU

Physical Memory

# General Address Translation

Kernel

CPU

MMU

Physical Memory

Virtual Address

# General Address Translation

Kernel

CPU

MMU

Physical Memory

Virtual Address
0x10102030

# General Address Translation

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CPU

MMU

Physical Memory

Virtual Address

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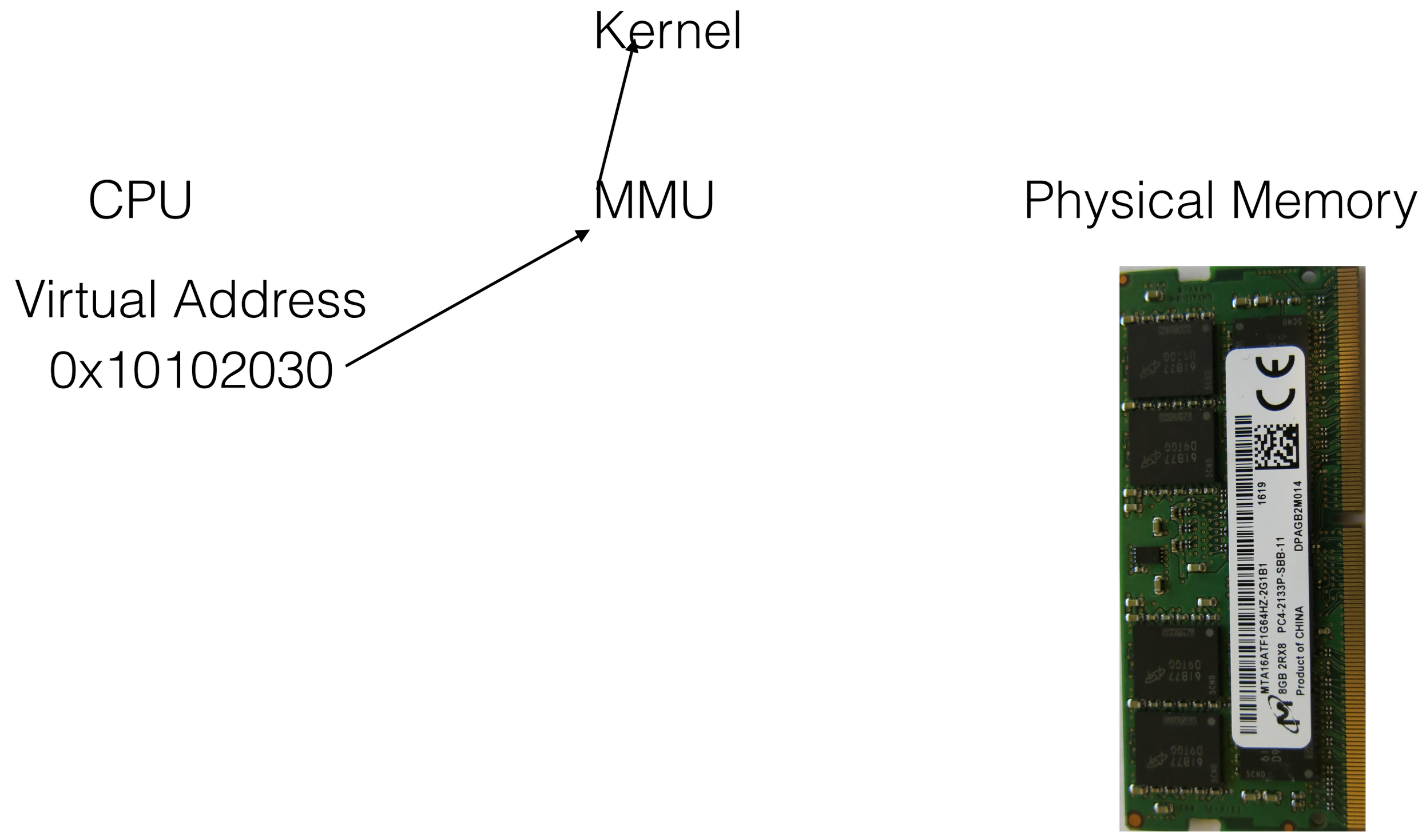

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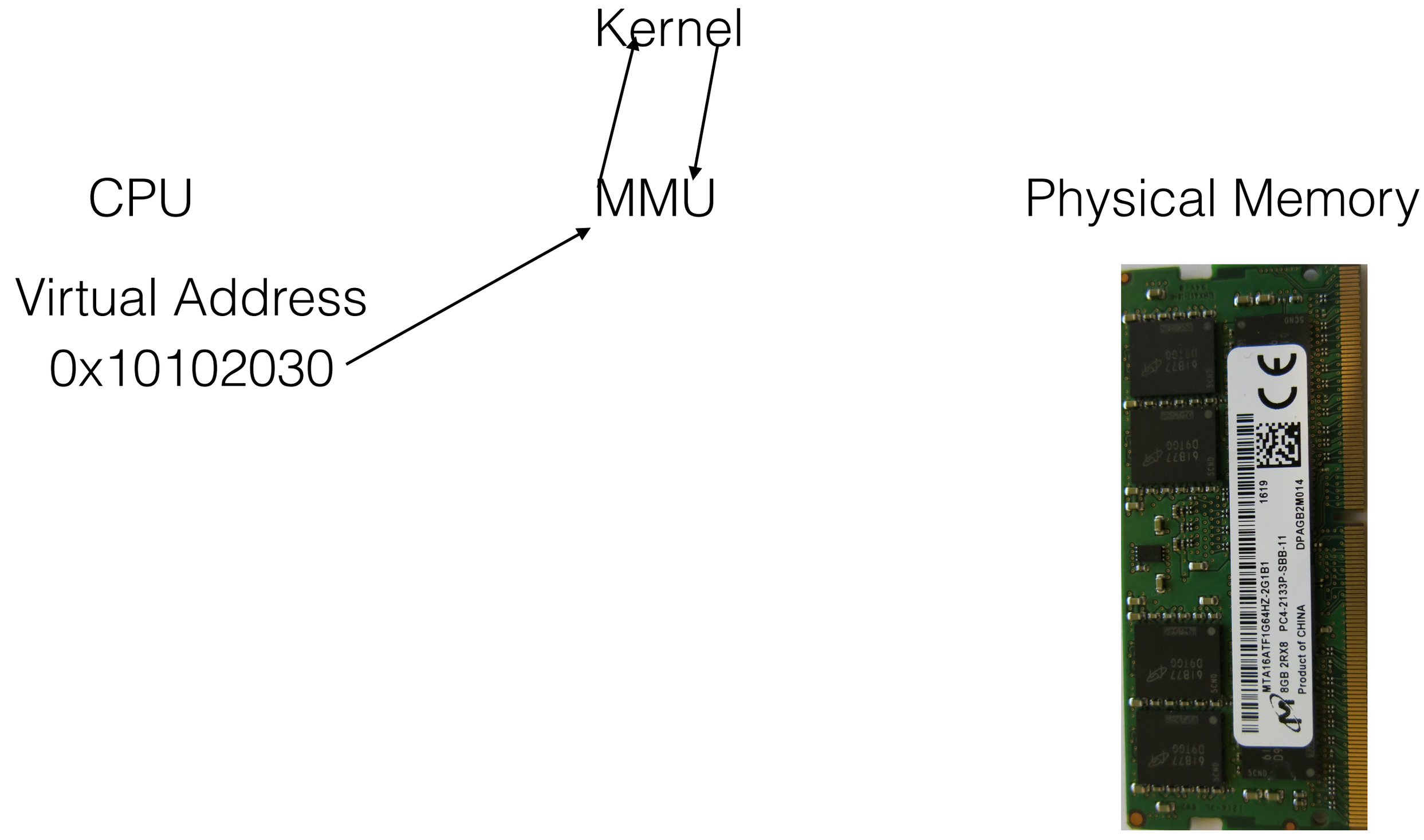

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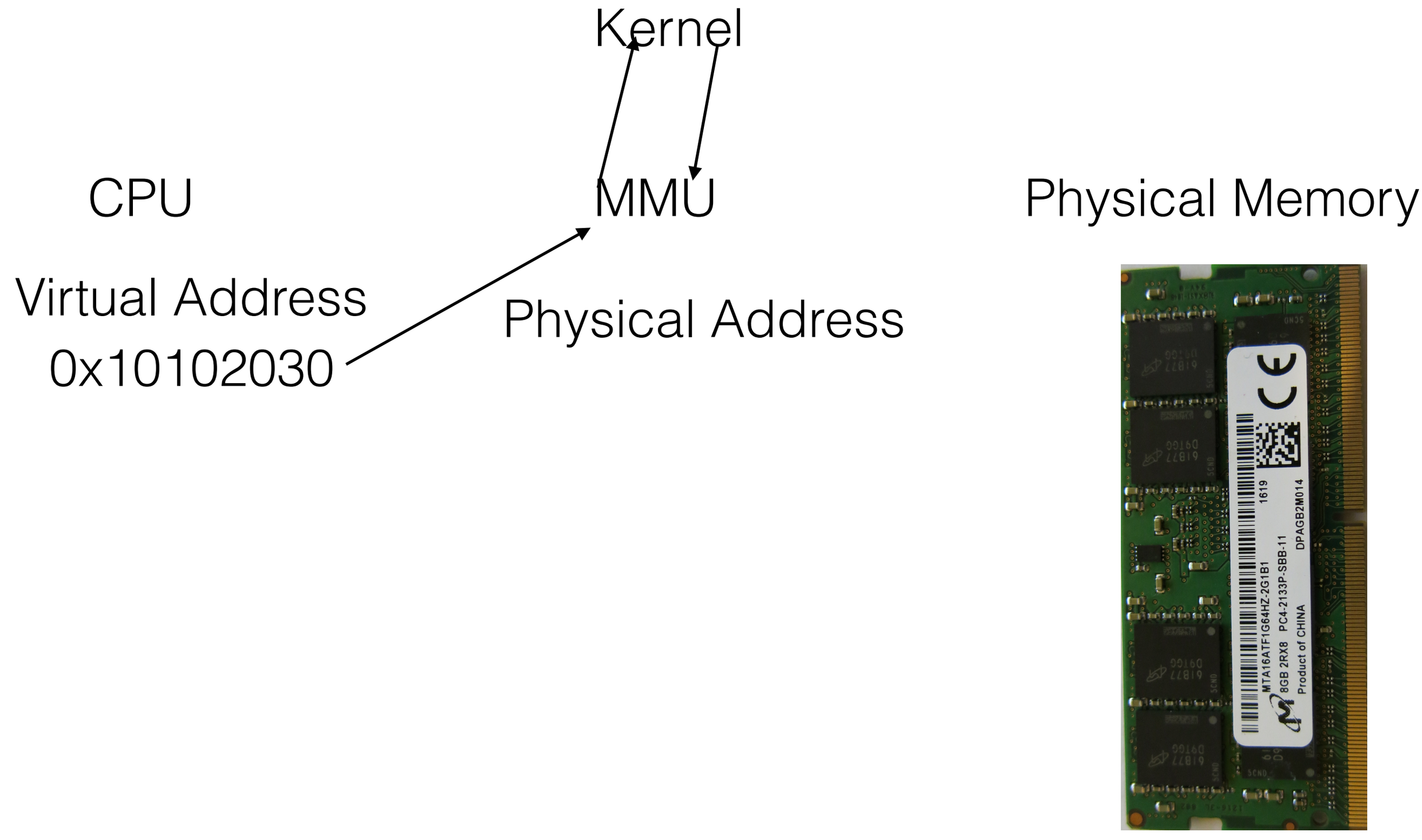

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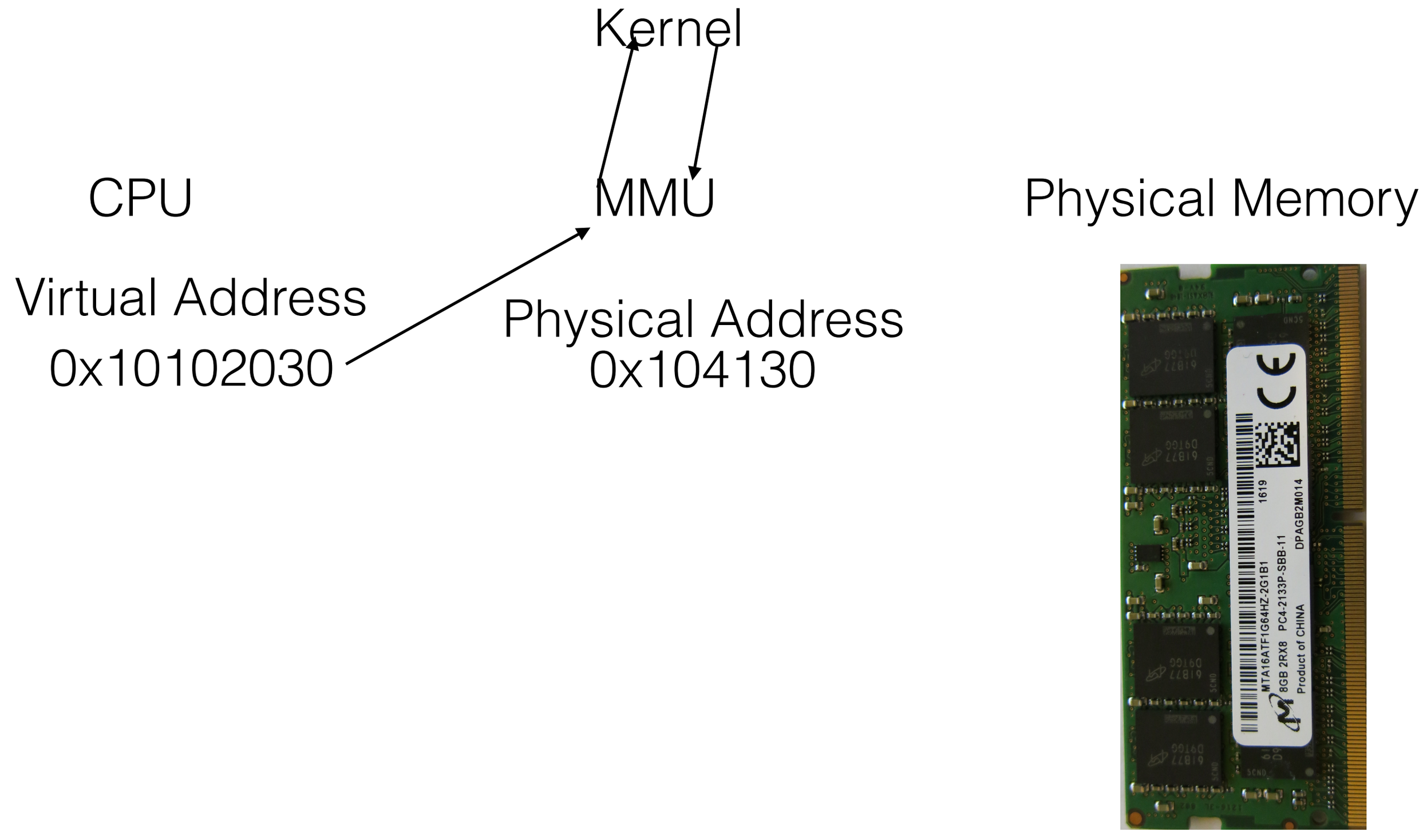

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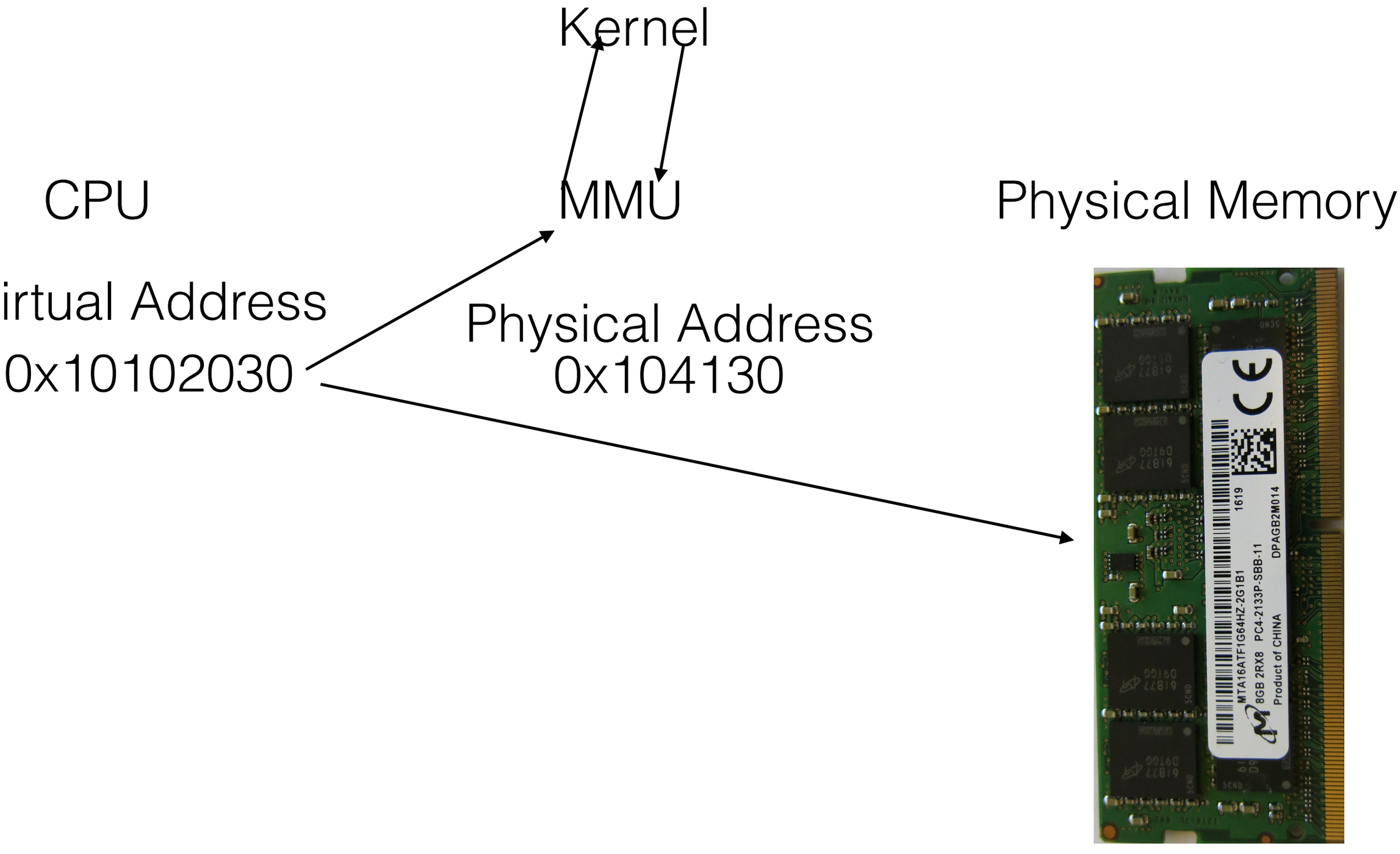

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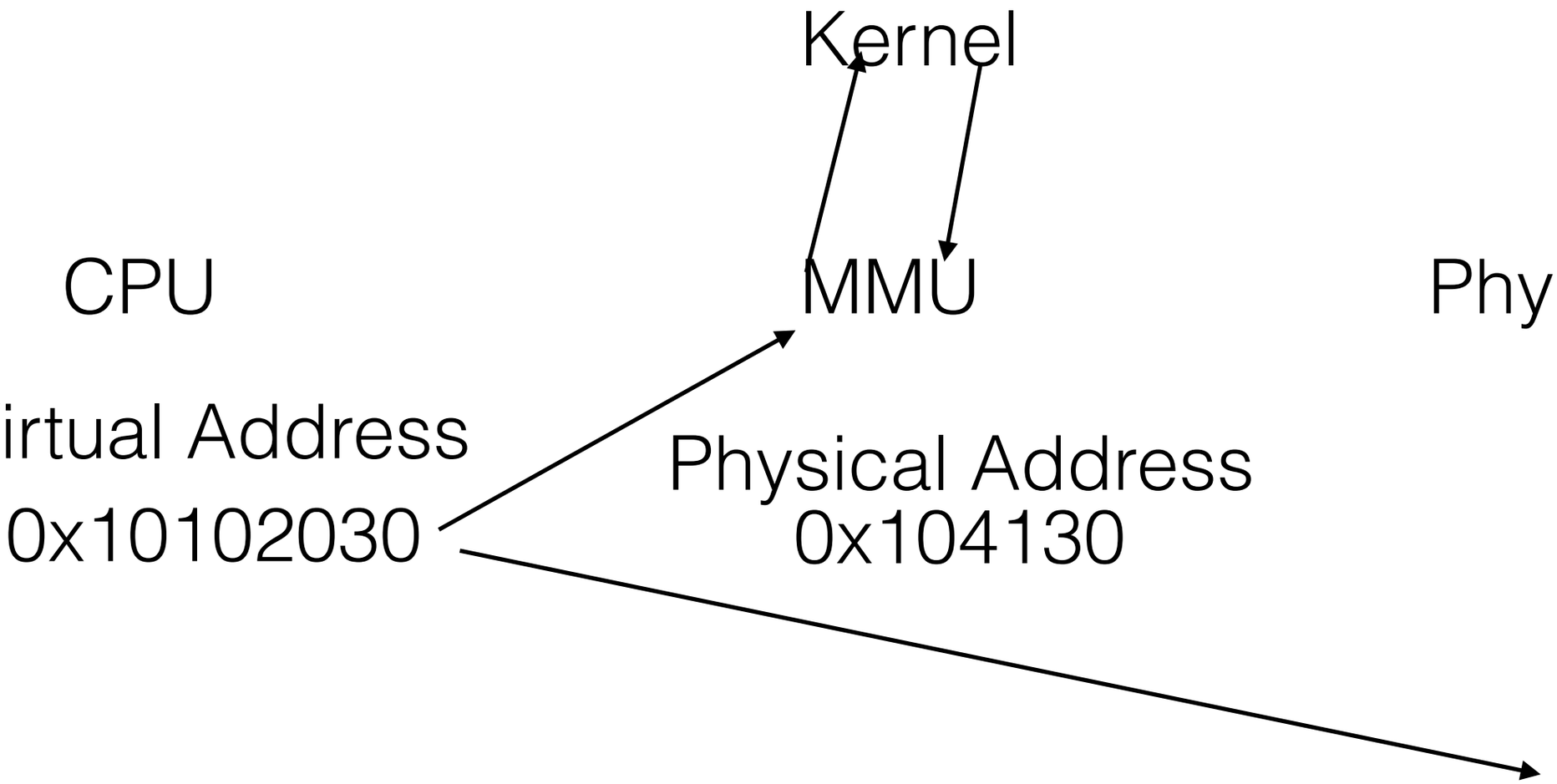
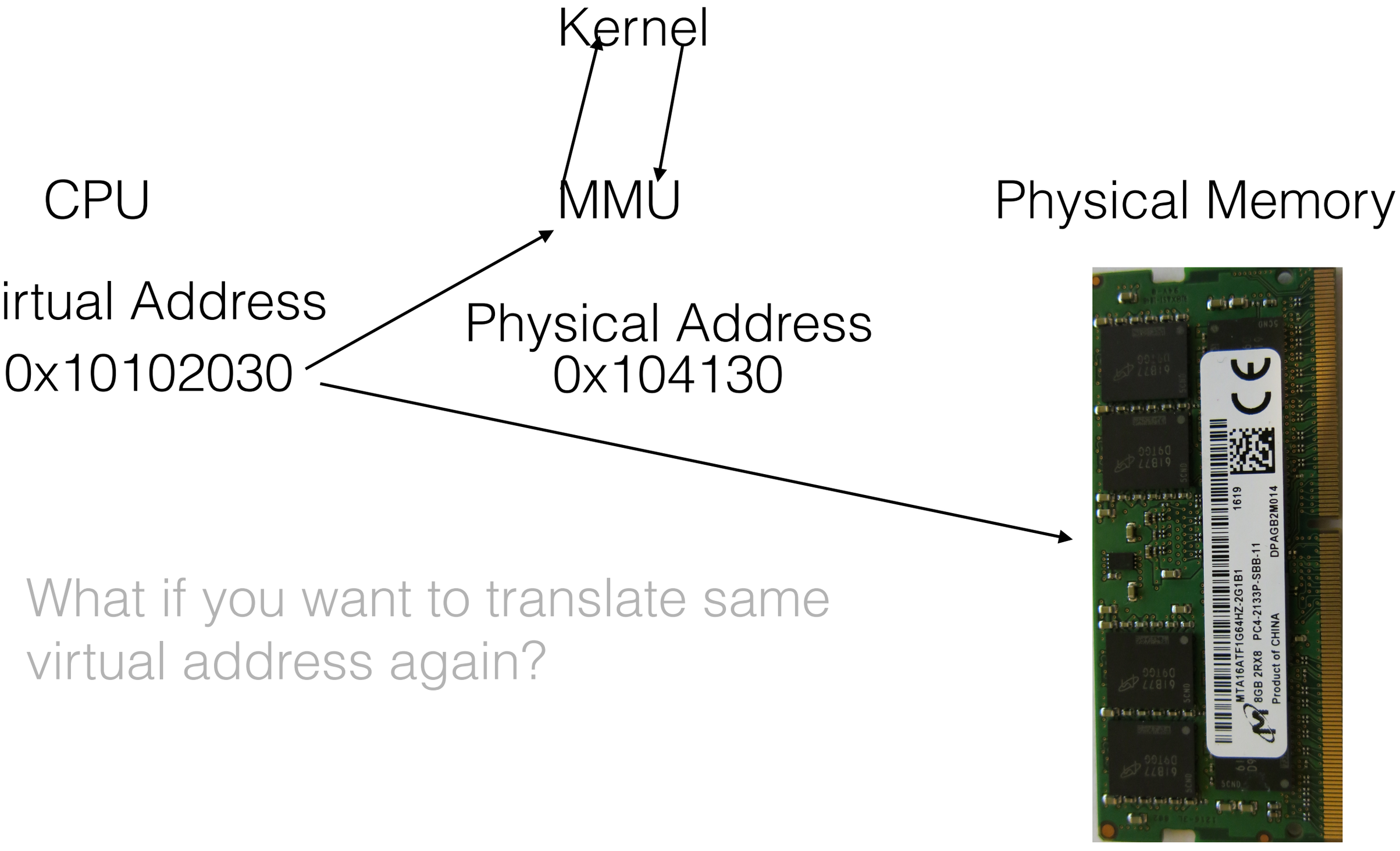




What if you want to translate same virtual address again?

# General Address Translation

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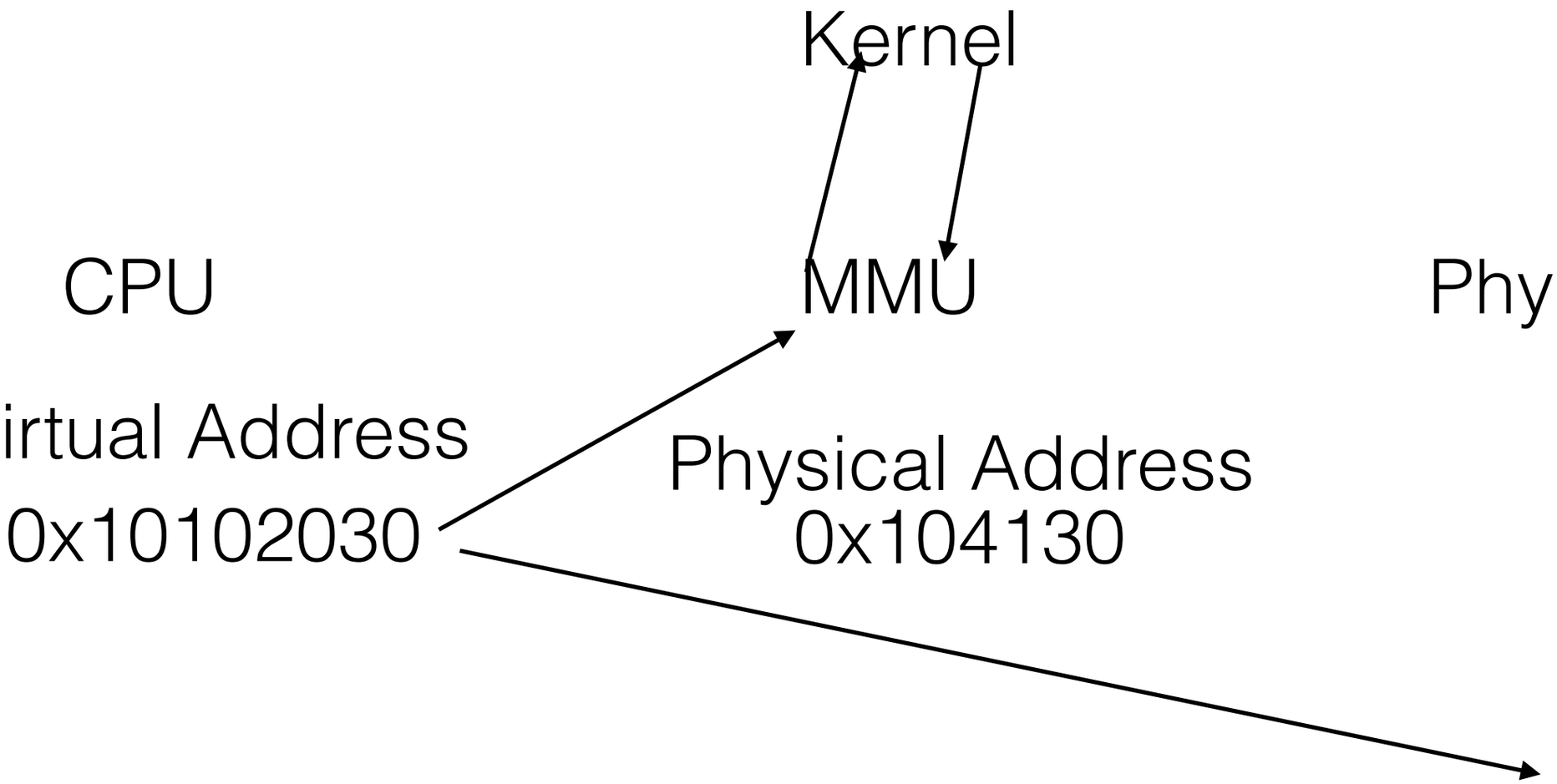
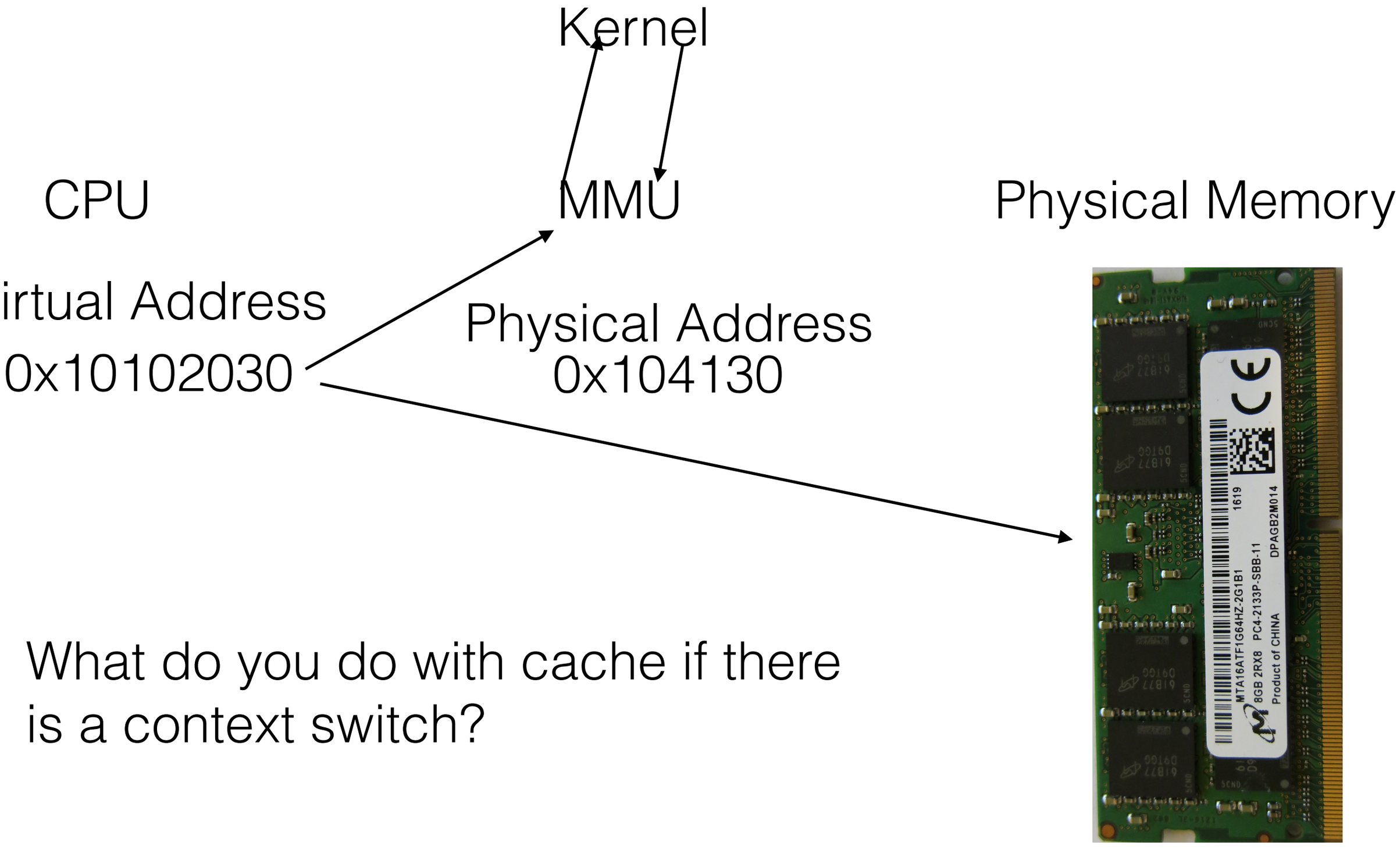



What if you want to translate same virtual address again?

Cache!!

# General Address Translation




What do you do with cache if there is a context switch?

# Dynamic (Hardware-based) Relocation
# Base & Bounds

Kernel

CPU

MMU

Physical Memory

# Dynamic (Hardware-based) Relocation
# Base & Bounds

Kernel

CPU

MMU

Physical Memory

Virtual Address

# Dynamic (Hardware-based) Relocation
# Base & Bounds

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x100

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# Base & Bounds

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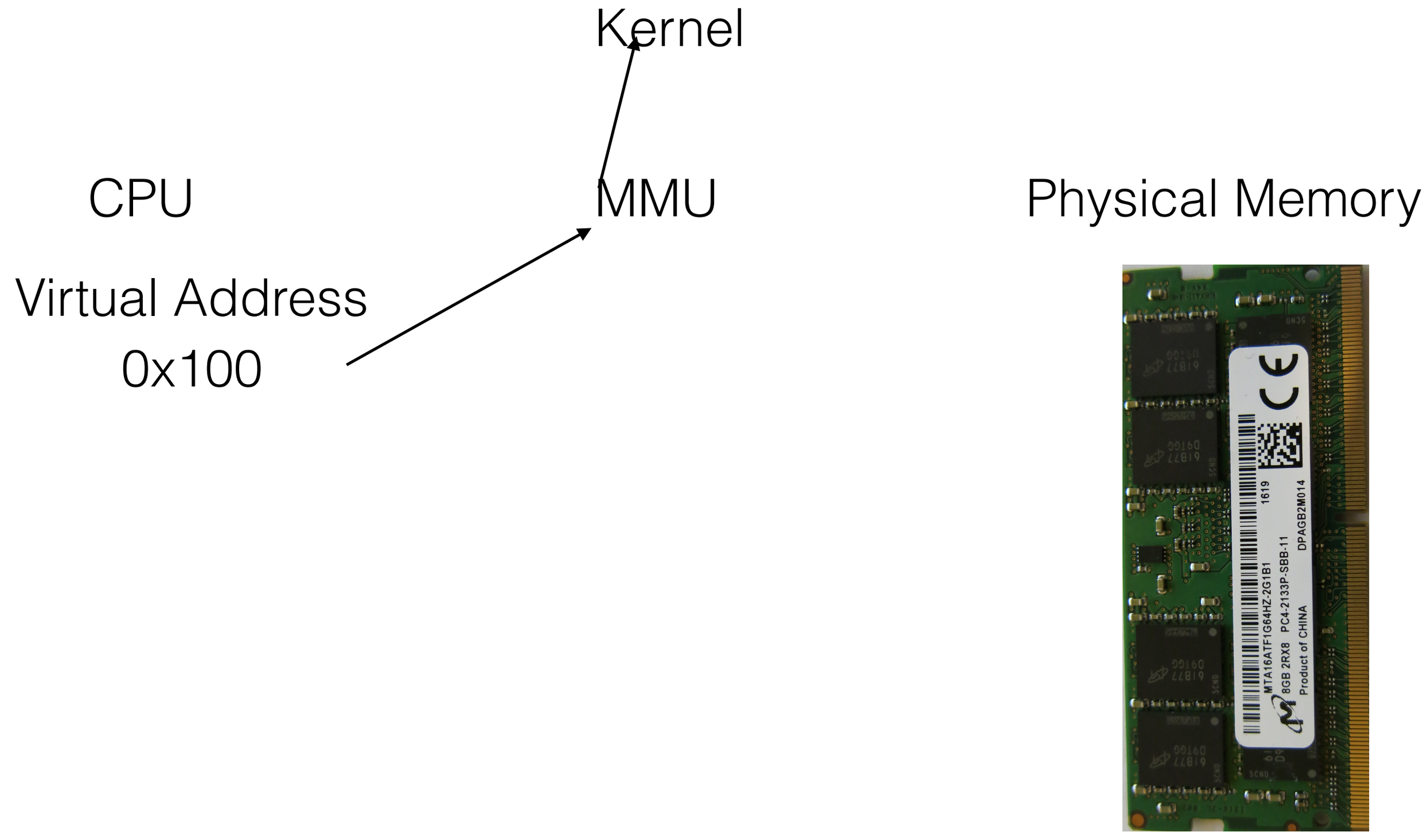

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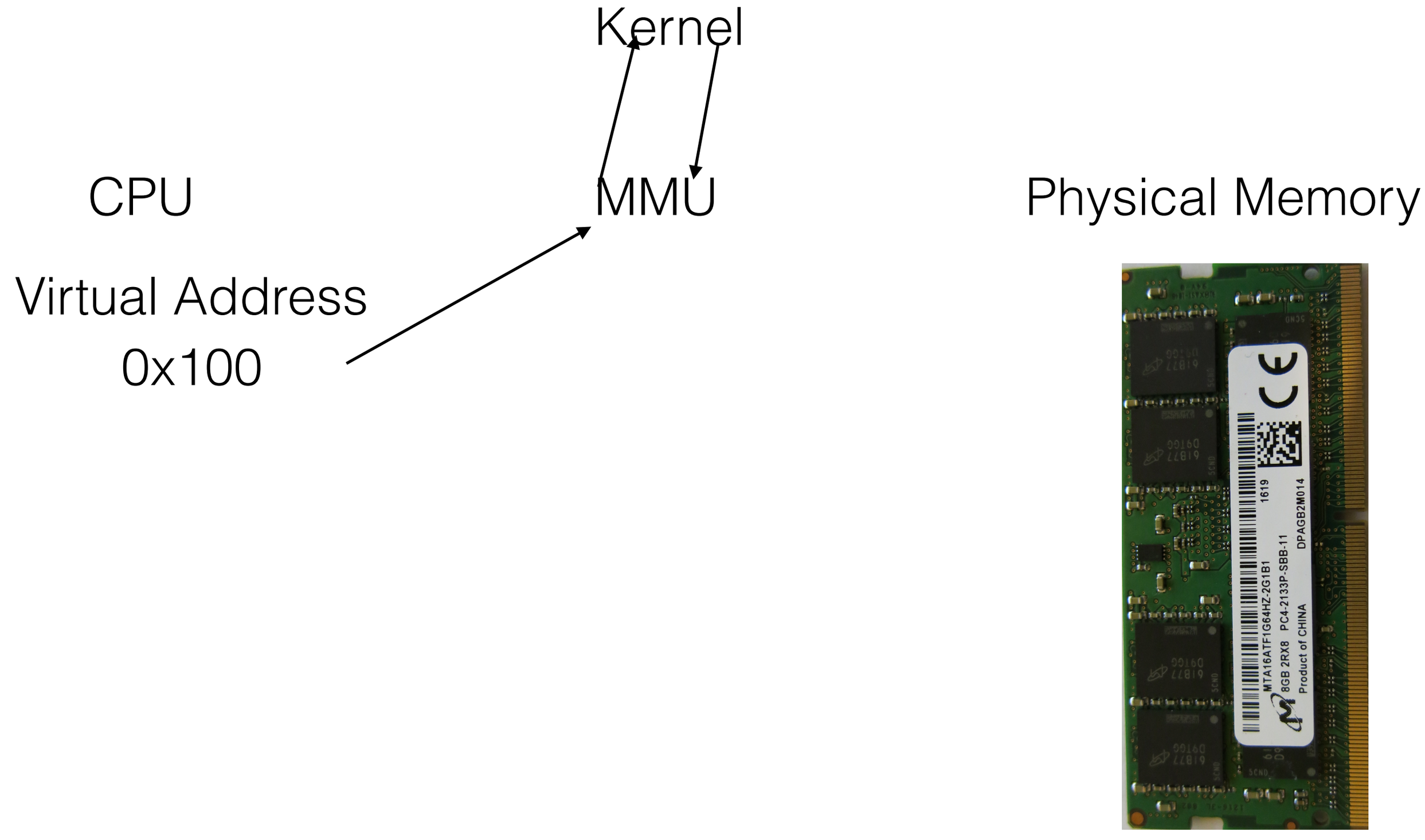

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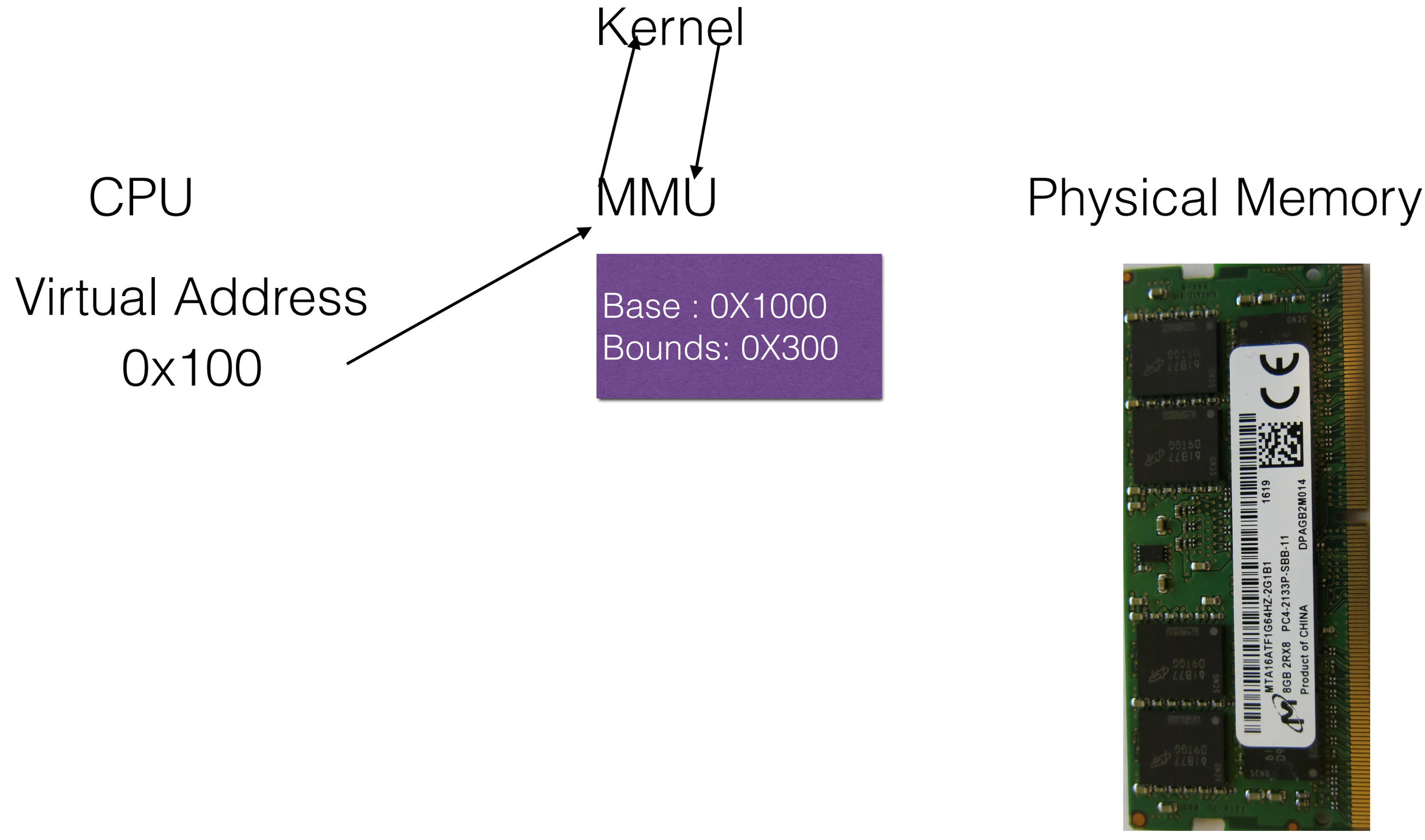

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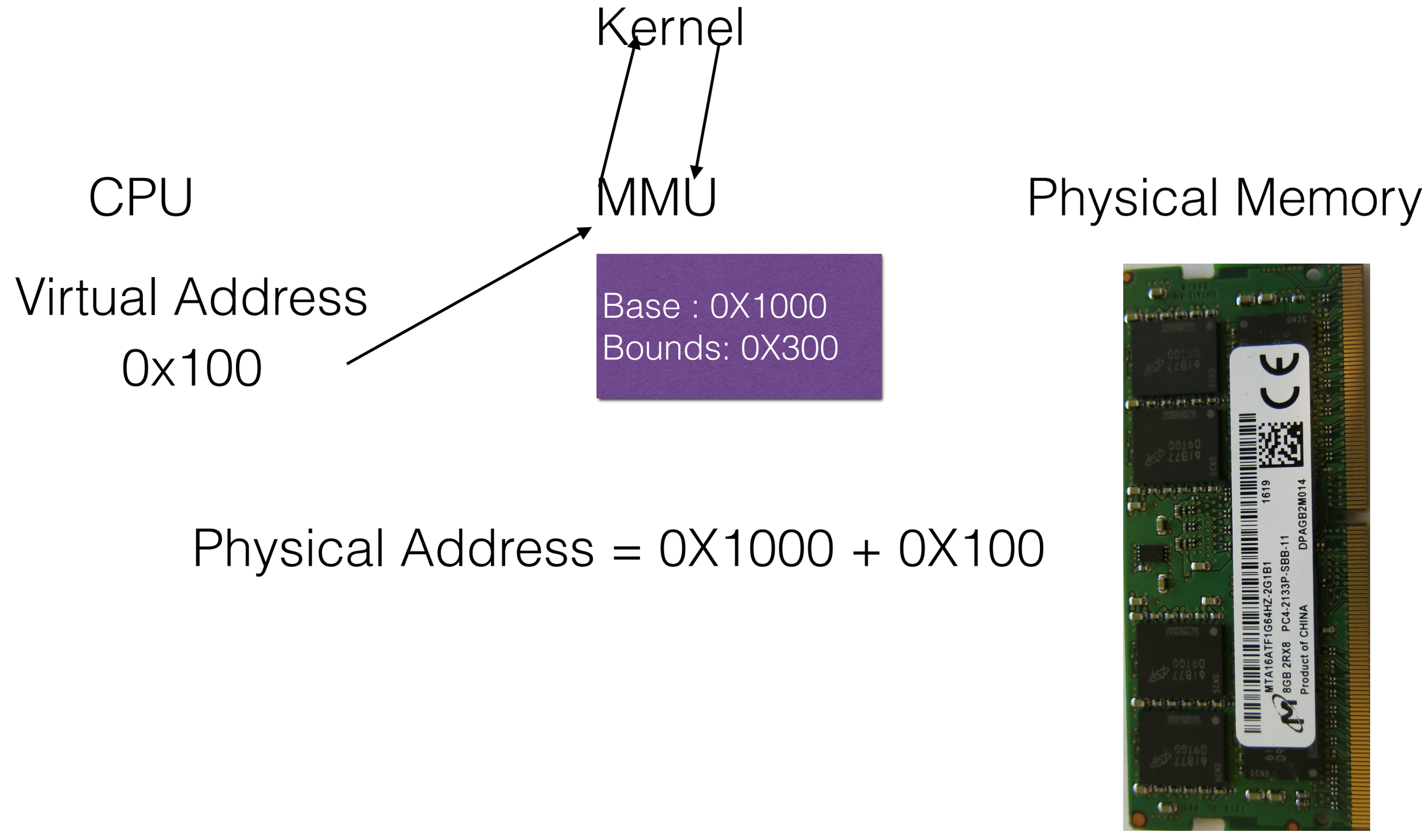

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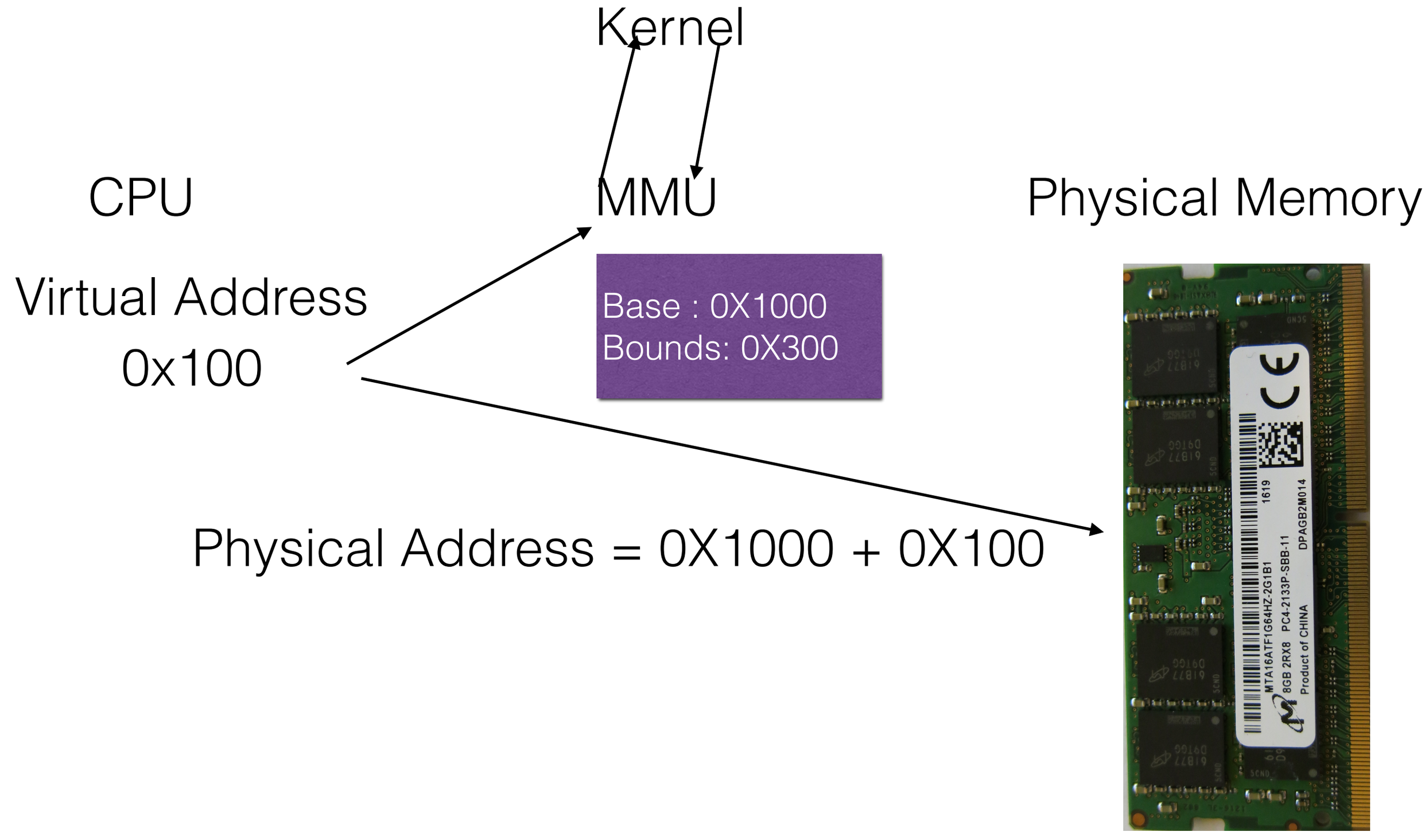

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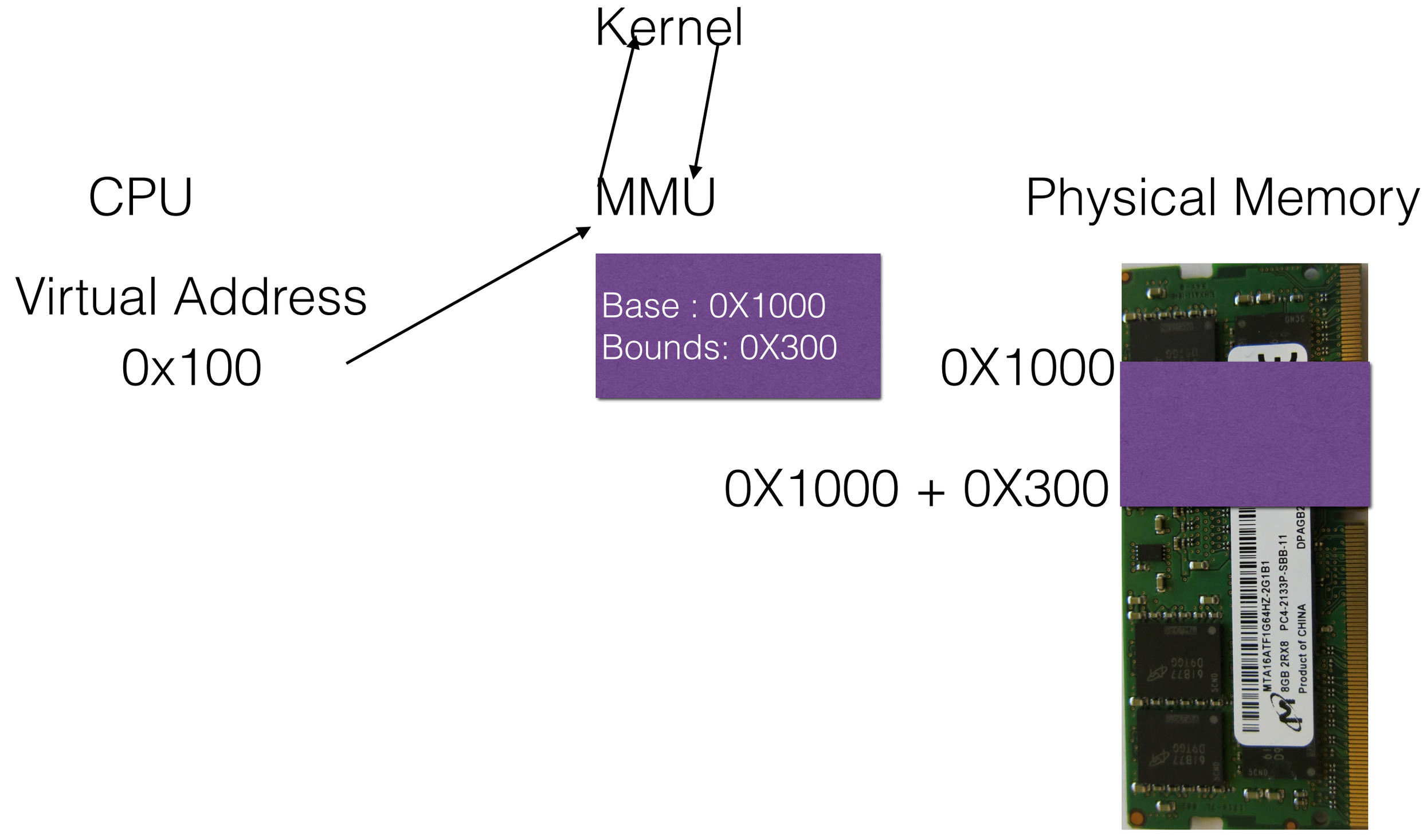

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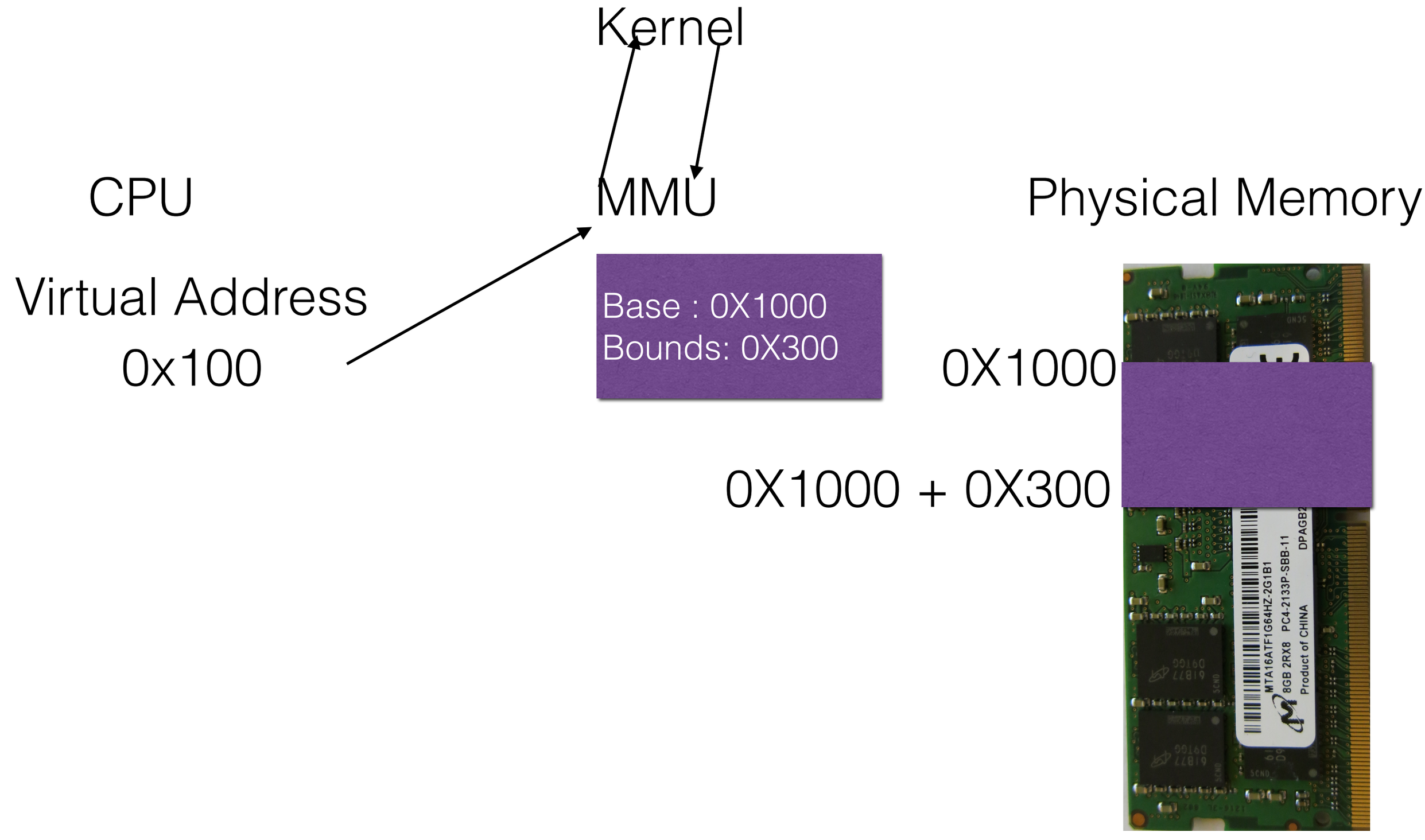

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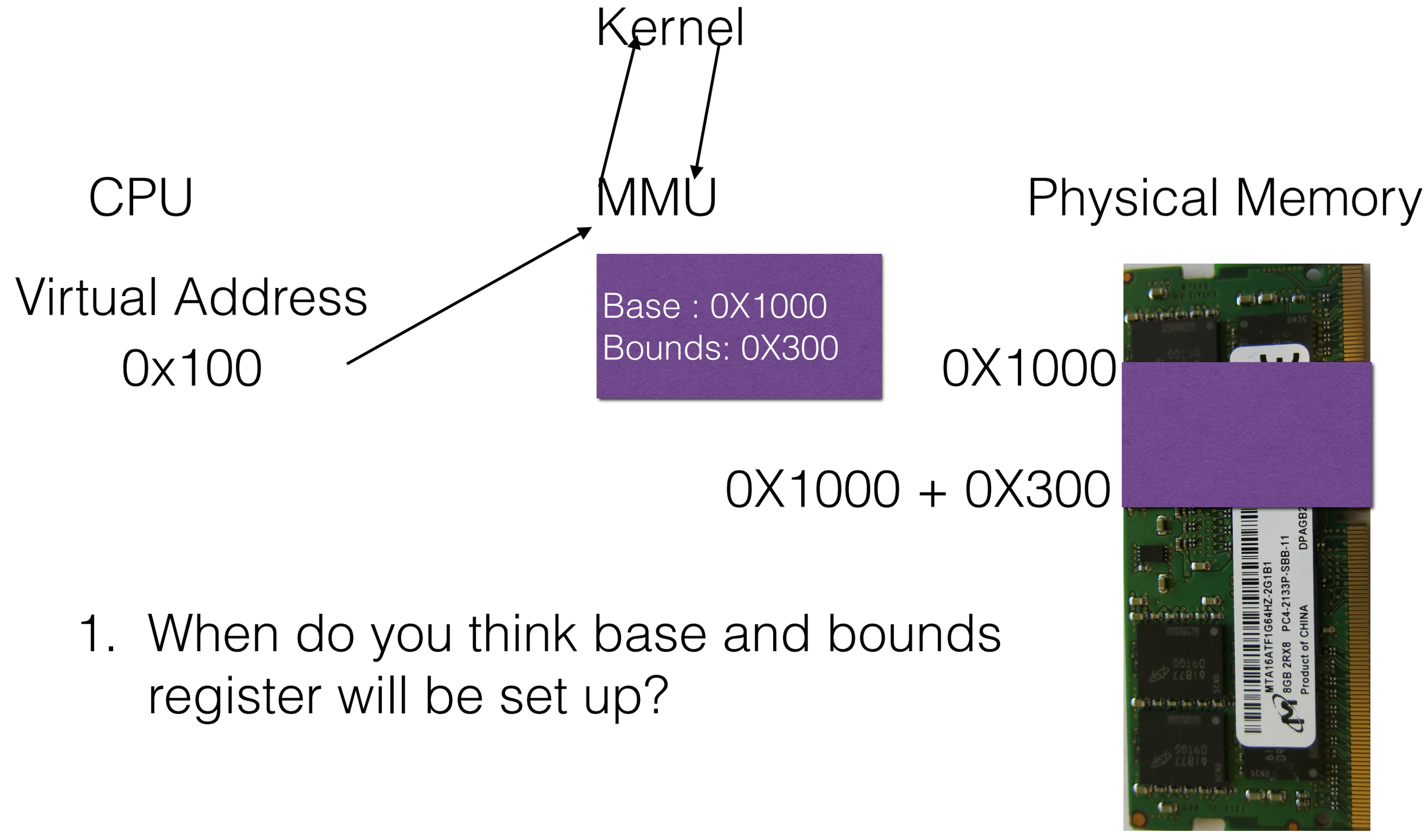
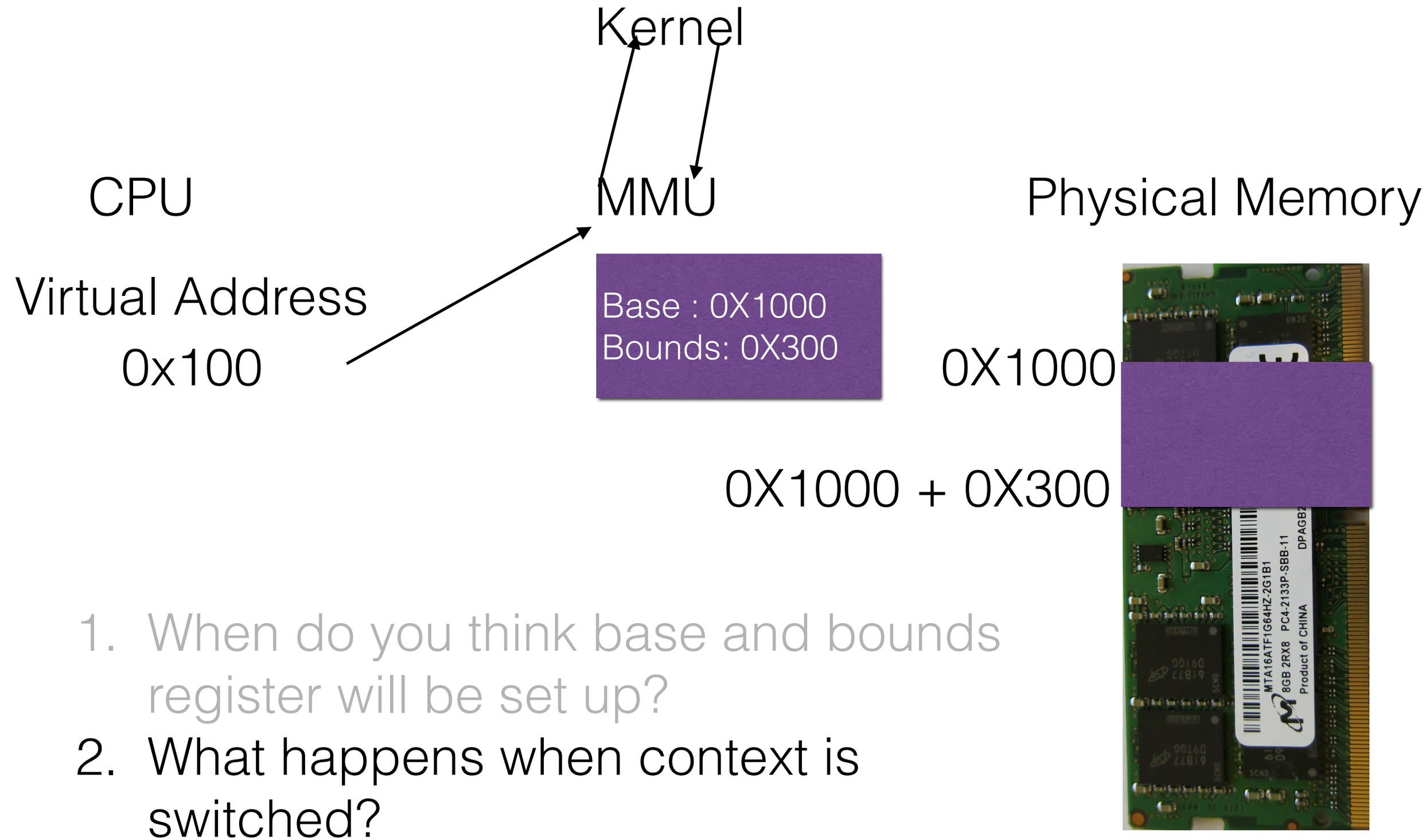



1. When do you think base and bounds register will be set up?

# Dynamic (Hardware-based) Relocation
# Base & Bounds




1. When do you think base and bounds register will be set up?
2. What happens when context is switched?

# Dynamic (Hardware-based) Relocation

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1. Base and Bound registers

# Dynamic (Hardware-based) Relocation

1. Base and Bound registers
2. Allows:

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2. Allows:
    1. Place address space anywhere in memory (not just at location 0)

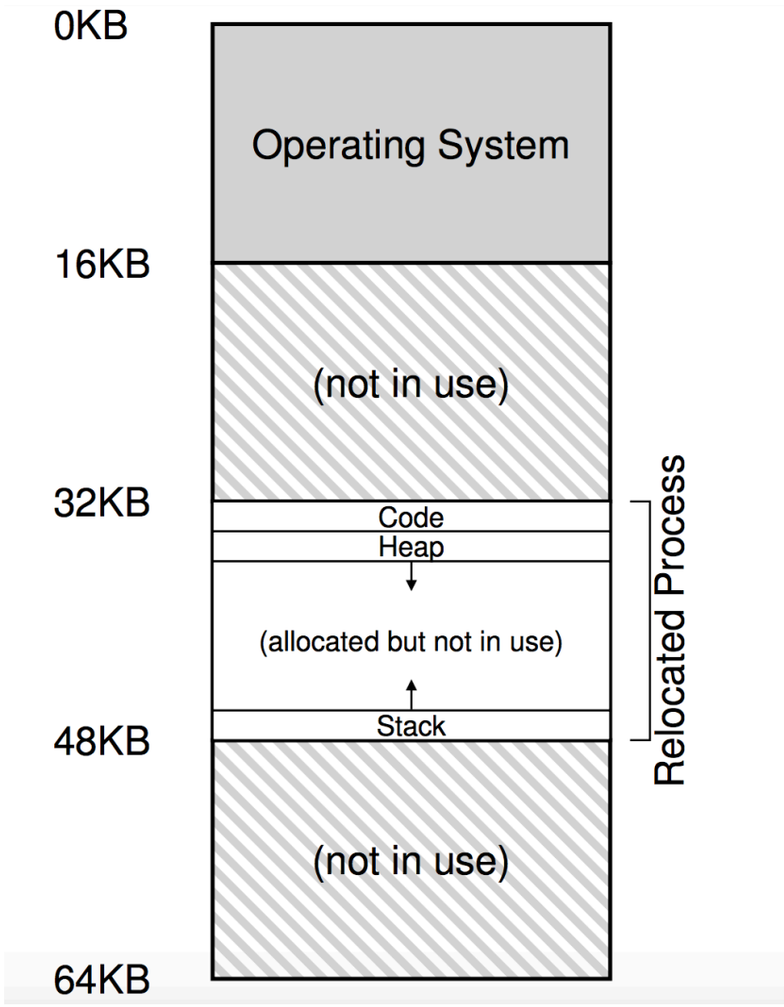
# Dynamic (Hardware-based) Relocation

1. Base and Bound registers
2. Allows:
    1. Place address space anywhere in memory (not just at location 0)
    2. Ensures process only accesses its own space

# Dynamic (Hardware-based) Relocation

Physical Address = Virtual Address + Base

# Dynamic (Hardware-based) Relocation

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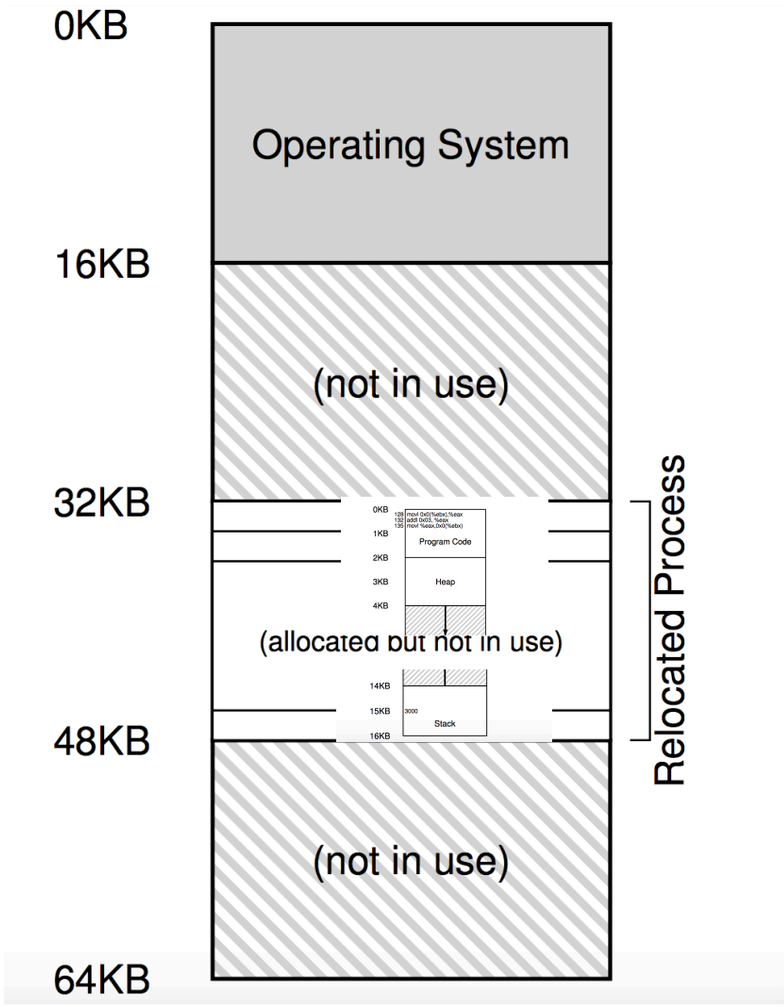


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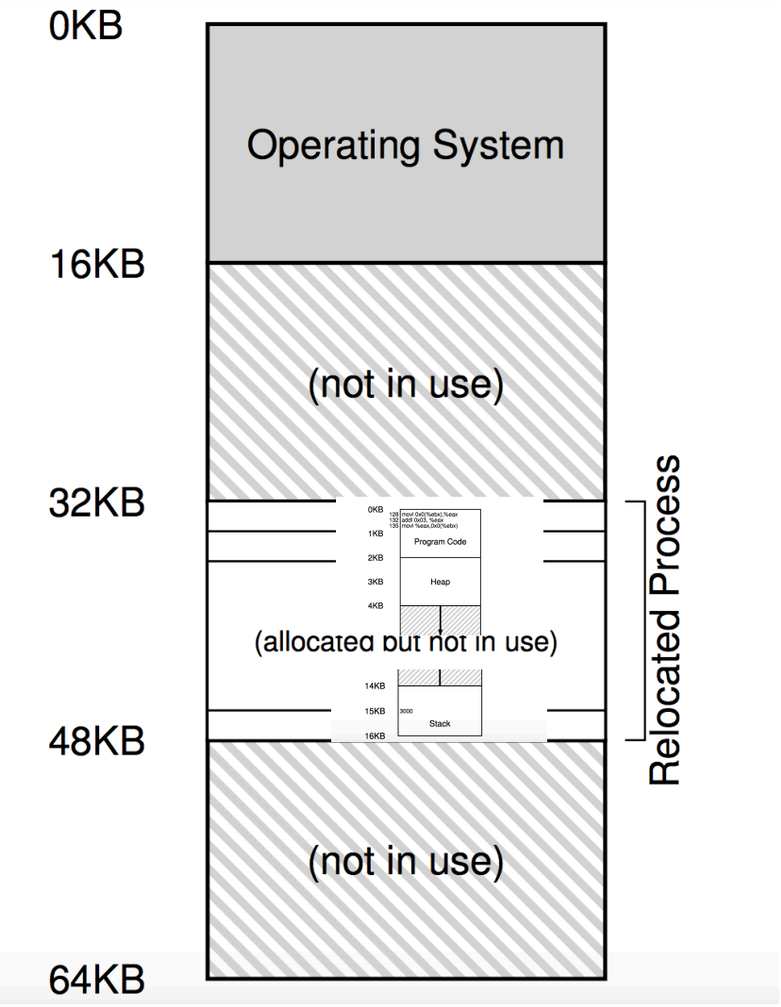
# Dynamic (Hardware-based) Relocation

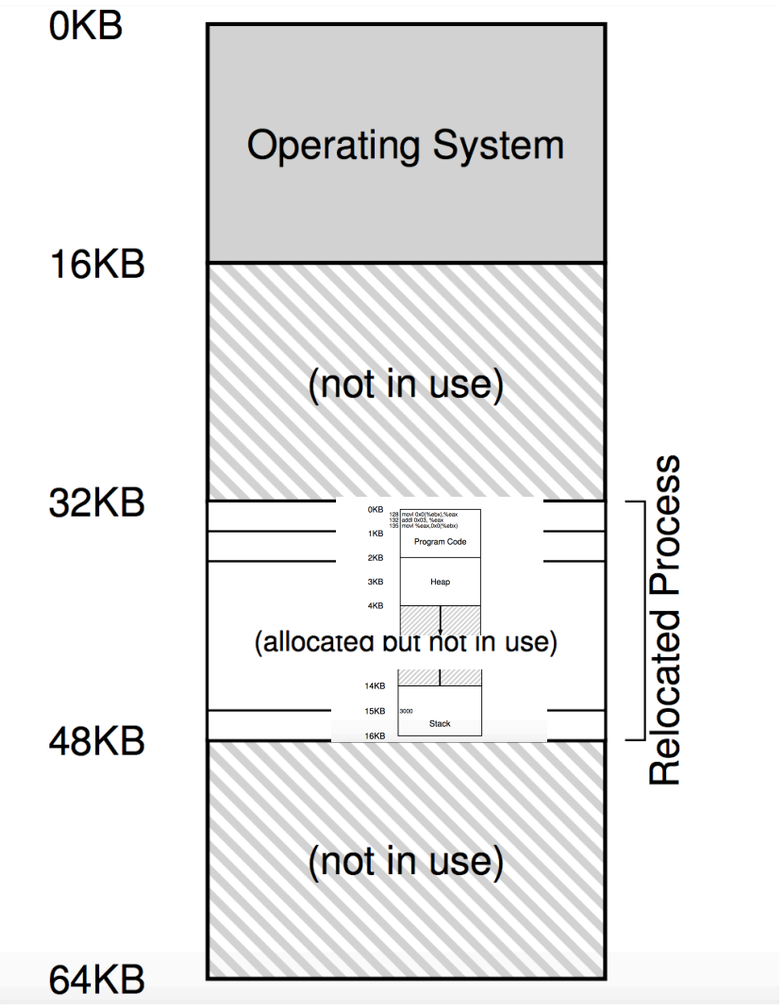
1. Base




Physical Address = Virtual Address + Base

# Dynamic (Hardware-based) Relocation

1. Base
    1. OS decides where in physical address to load the address space




**Physical Address = Virtual Address + Base**

# Dynamic (Hardware-based) Relocation

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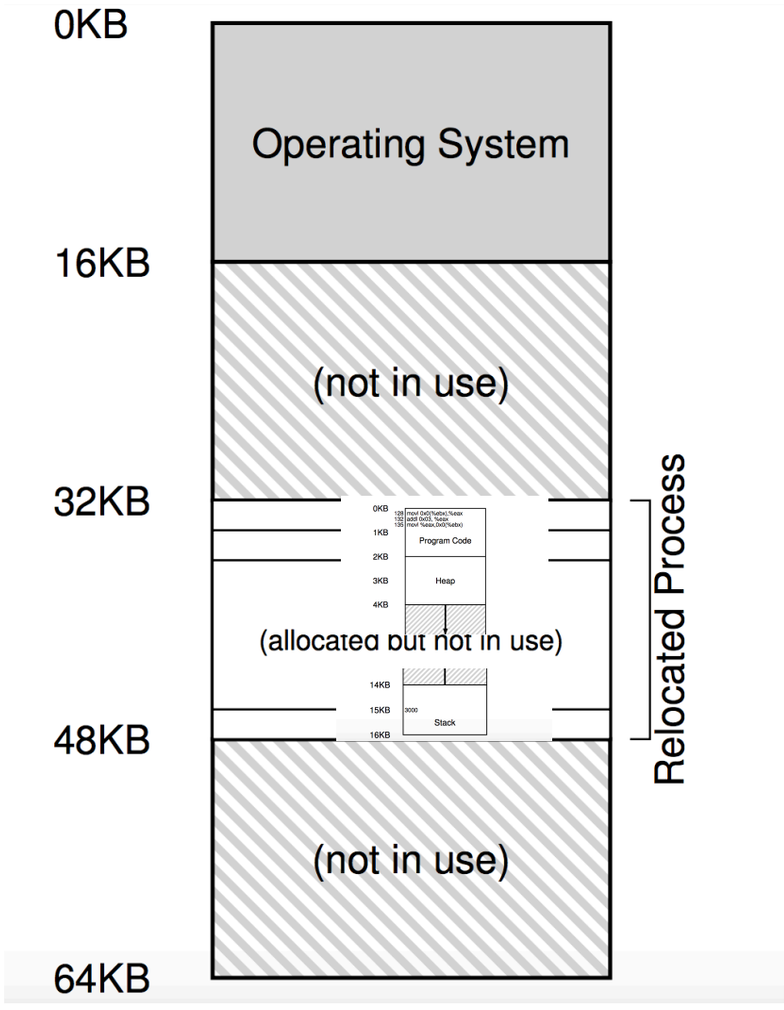
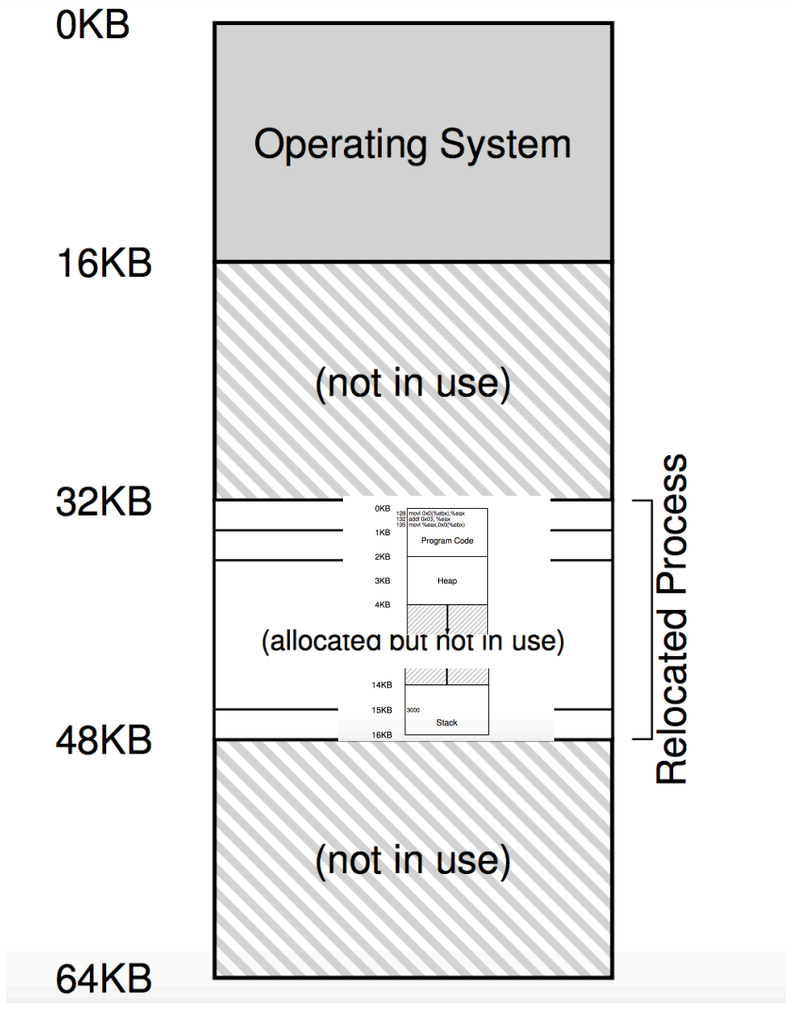
    2. In previous example, base is …?




Physical Address = Virtual Address + Base

# Dynamic (Hardware-based) Relocation

1. Base
    1. OS decides where in physical address to load the address space
    2. In previous example, base is …?
    3. Ans: 32 KB




Physical Address = Virtual Address + Base

# Example Revisited

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    1. Relocation happens at runtime
    2. Can change the address even after creation
    3. Why would you do that? How would you do that?

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    2. Can change the address even after creation
    3. Why would you do that? How would you do that?

# Example Revisited

128: movl 0x0(%ebx), %eax

1. PC points to 128
2. Fetch instruction :
    1. Physical Address = Base + Virtual Address = 32K + 128 = 32896
3. Execute load:
    1. Data resides in Virtual Address 15 KB
    2. Fetch data from 32 KB + 15 KB = 47 KB
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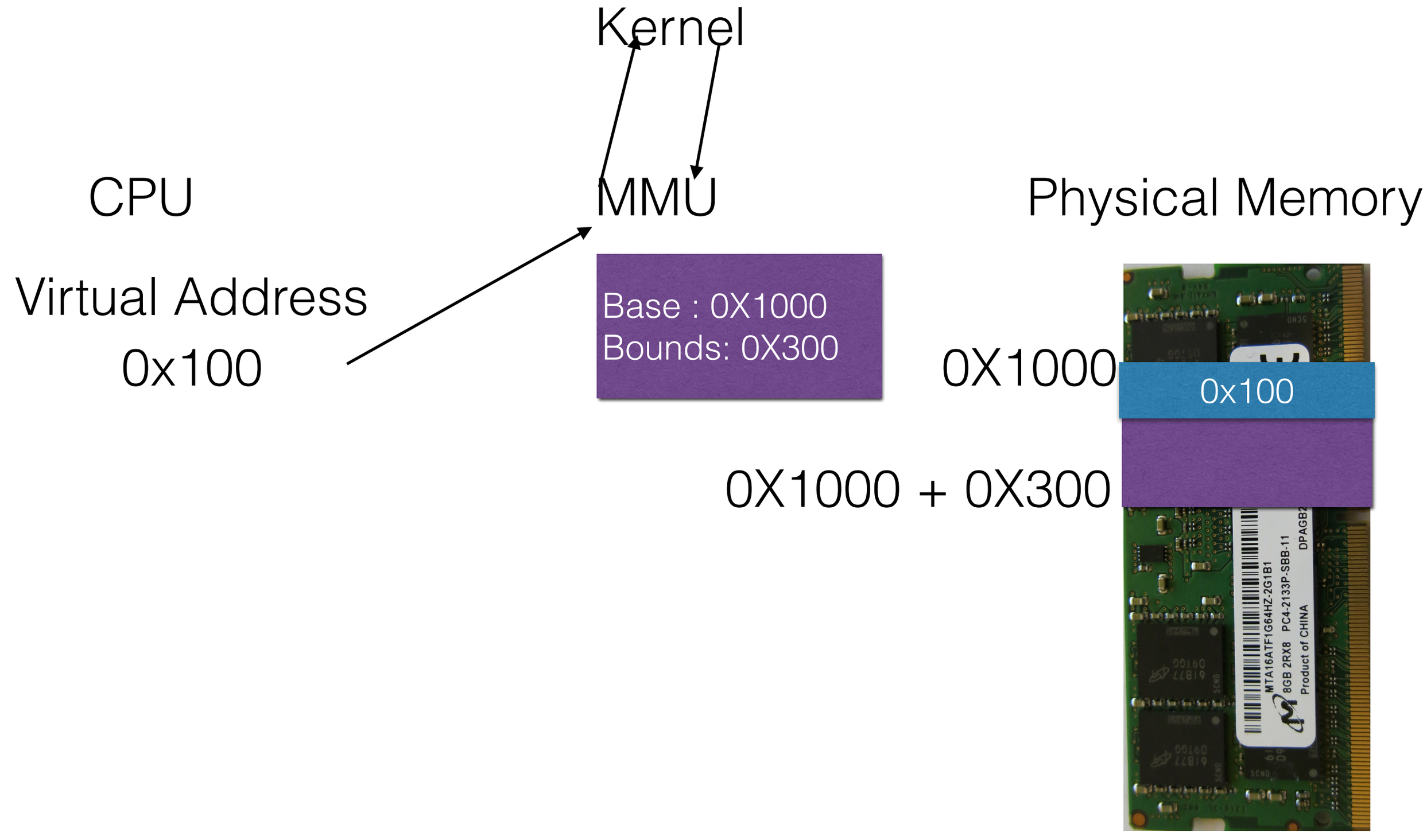
# Dynamic (Hardware-based) Relocation
# Base & Bounds



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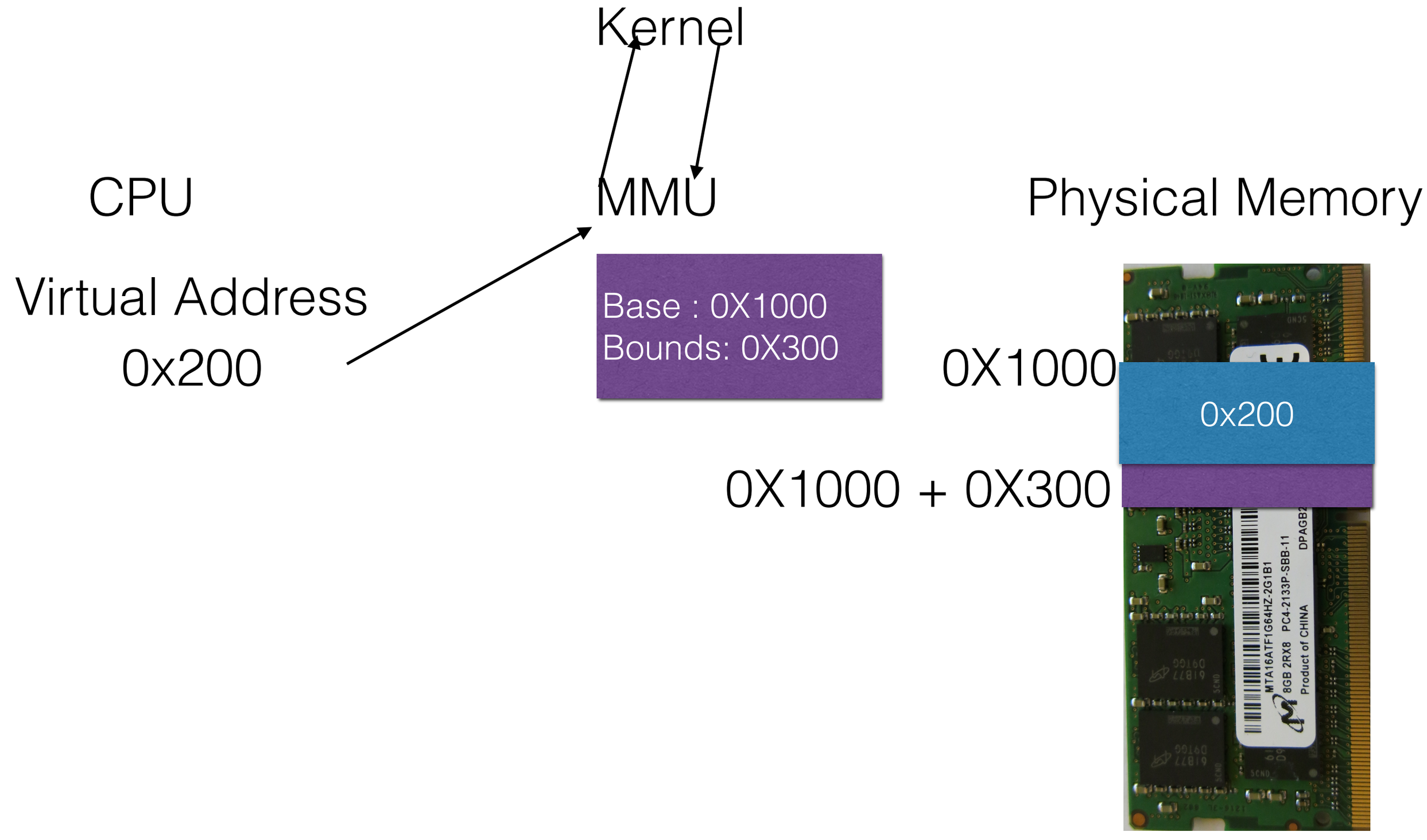

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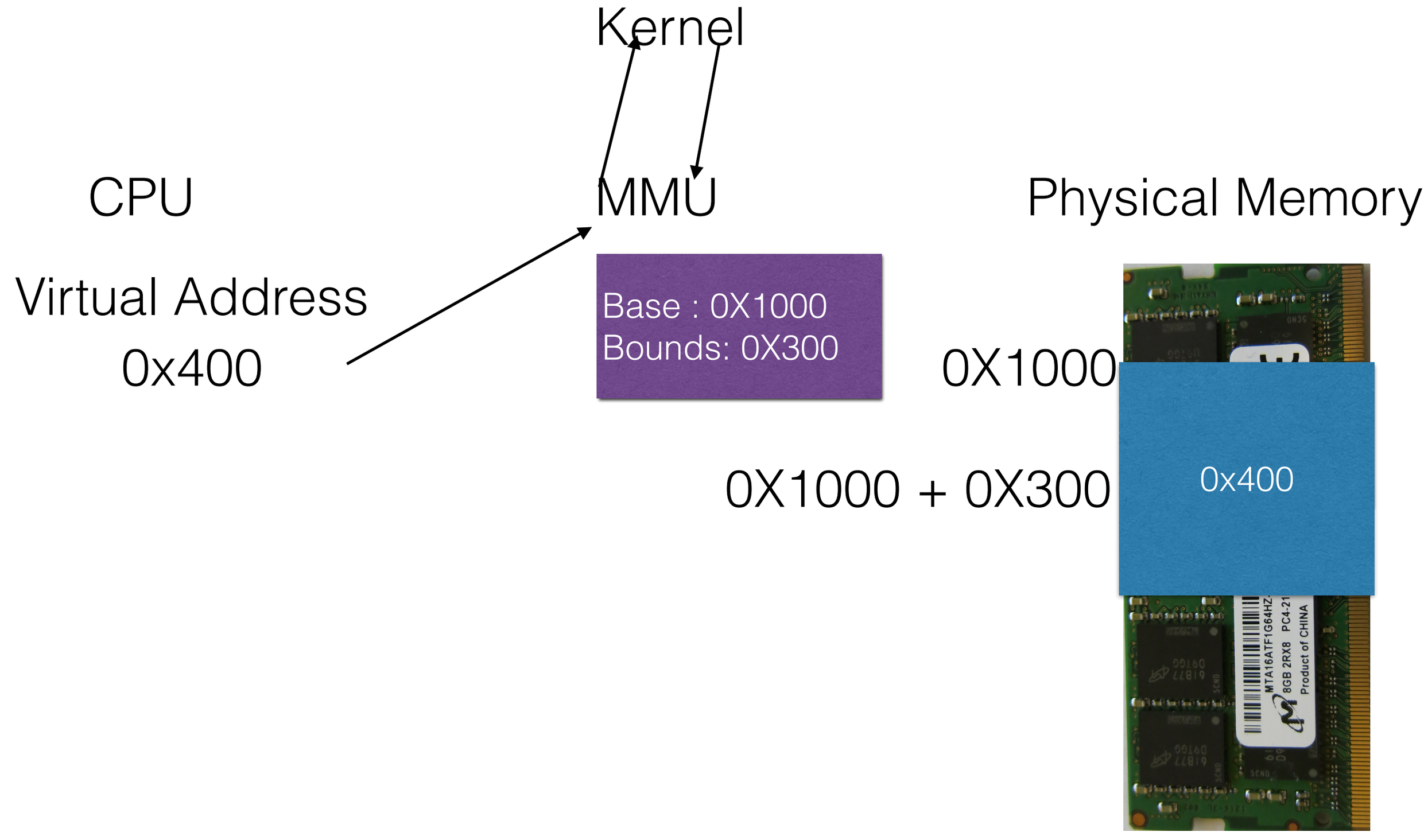

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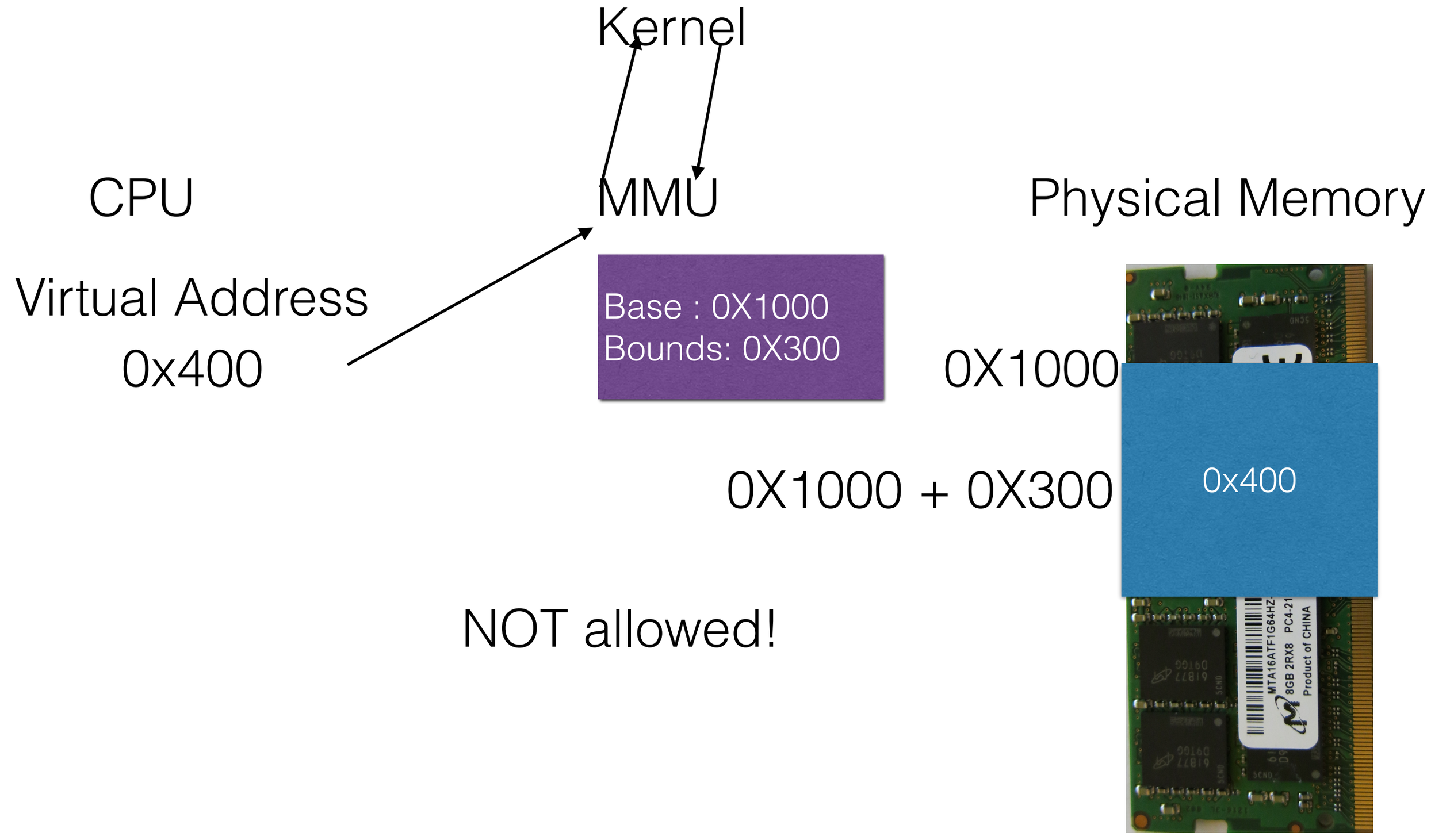

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| Base/bounds registers | |
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| Ability to raise exceptions | *When processes try to access privileged instructions or out-of-bounds memory* |

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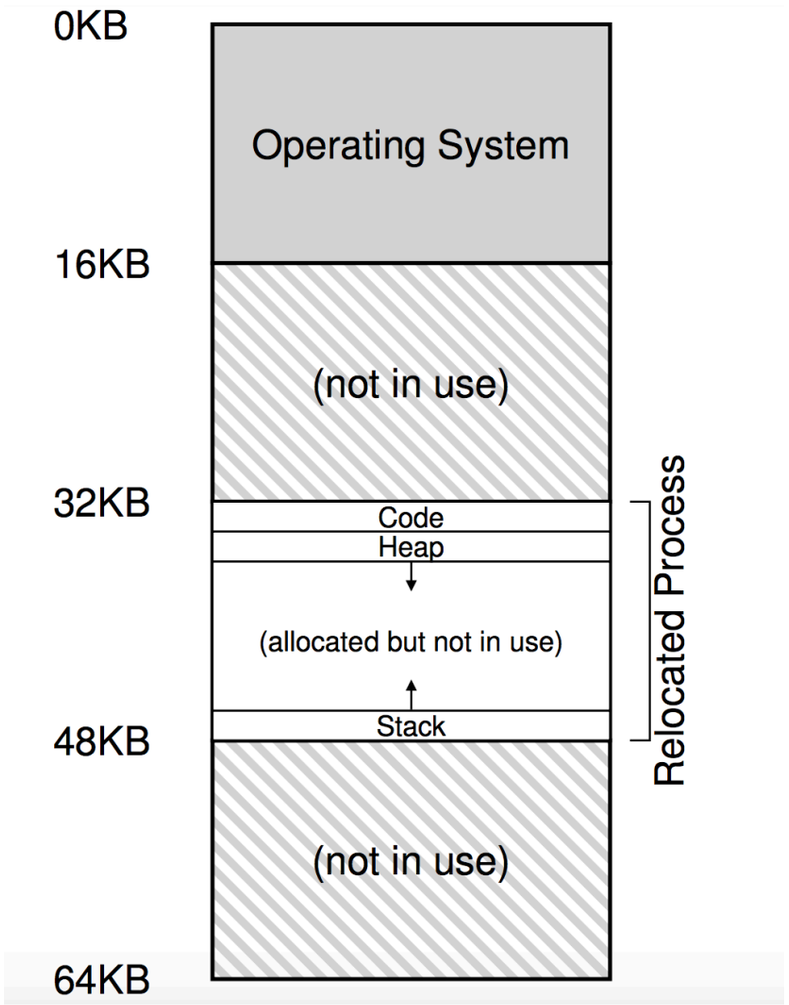
Base

Base + Bound



# Base & Bounds : Cons

1. Contiguous block of memory needed in physical memory

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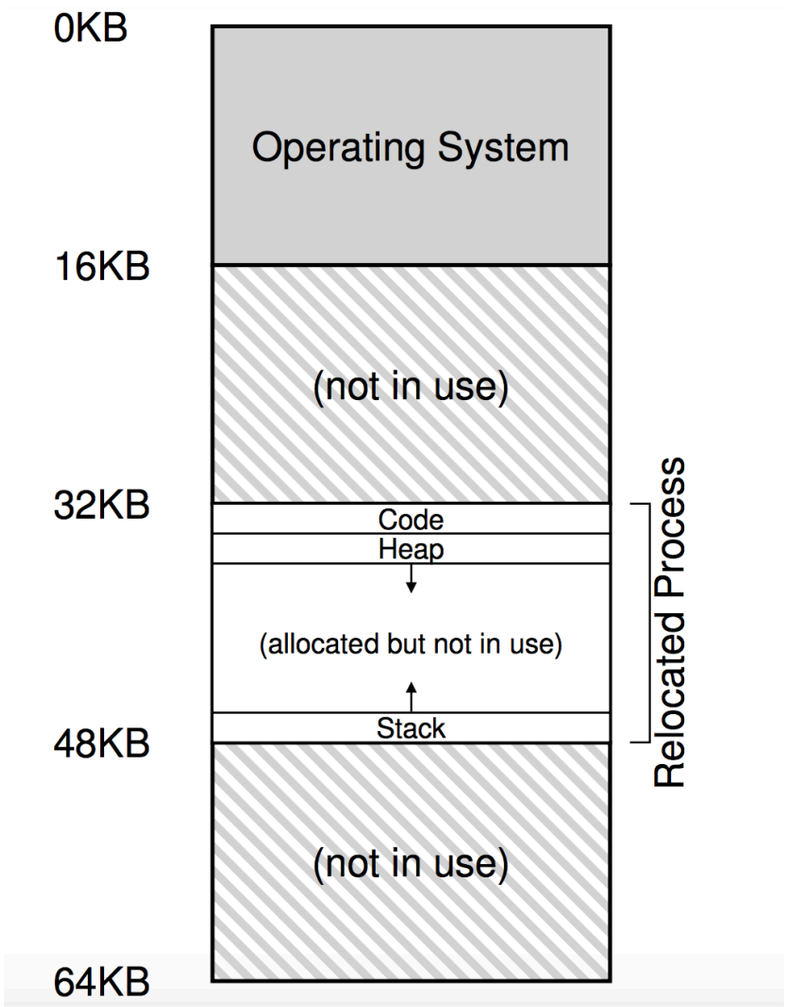
Base + Bound



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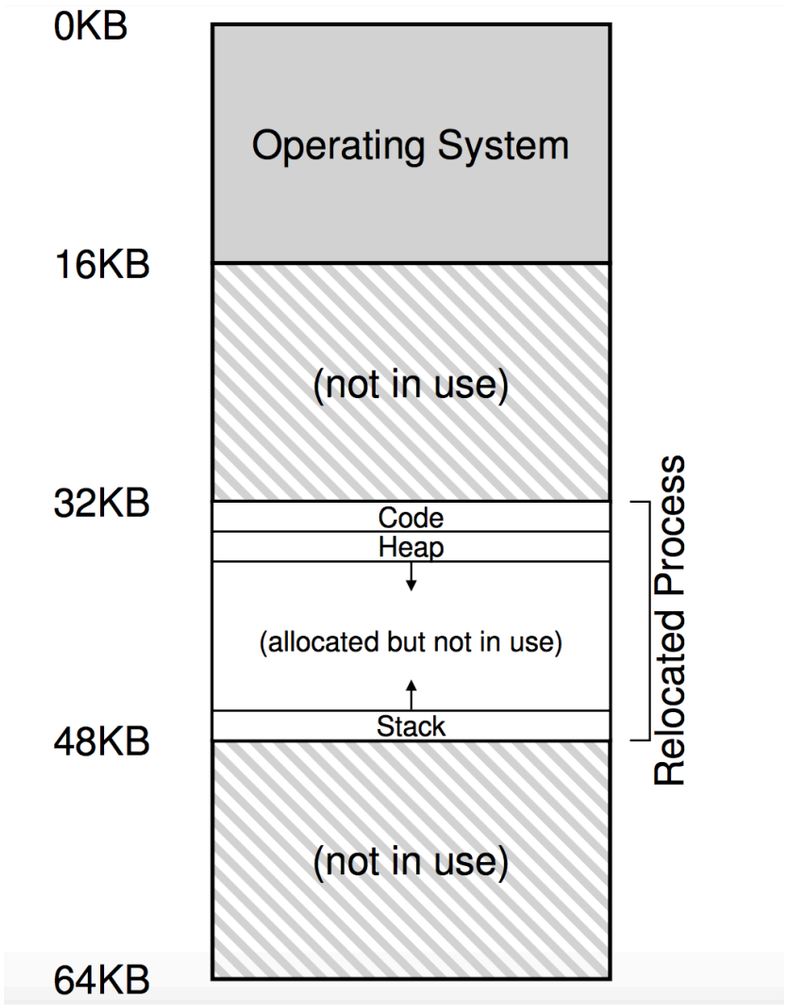

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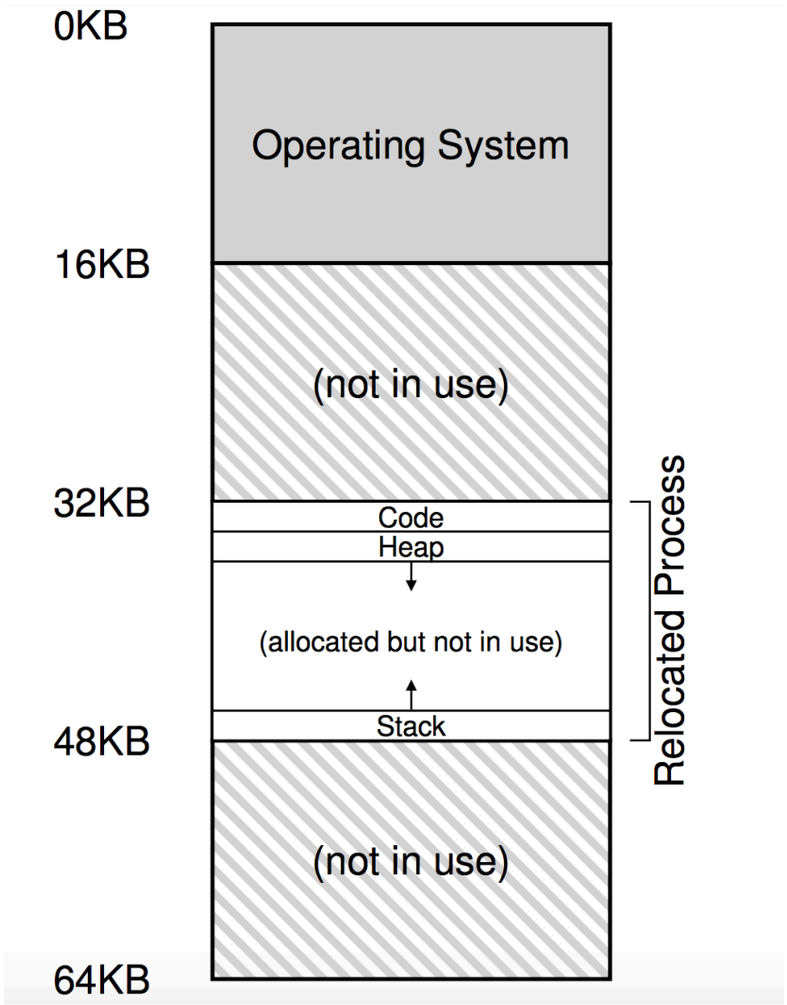

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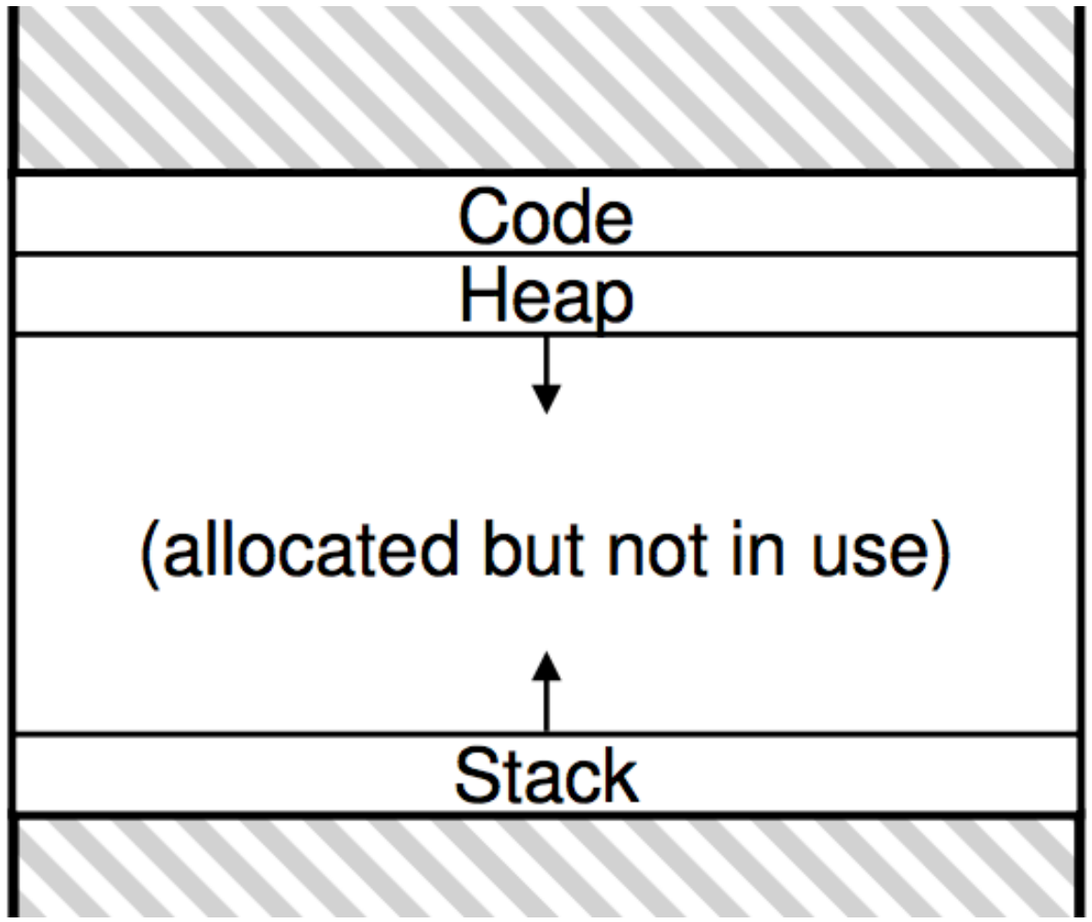
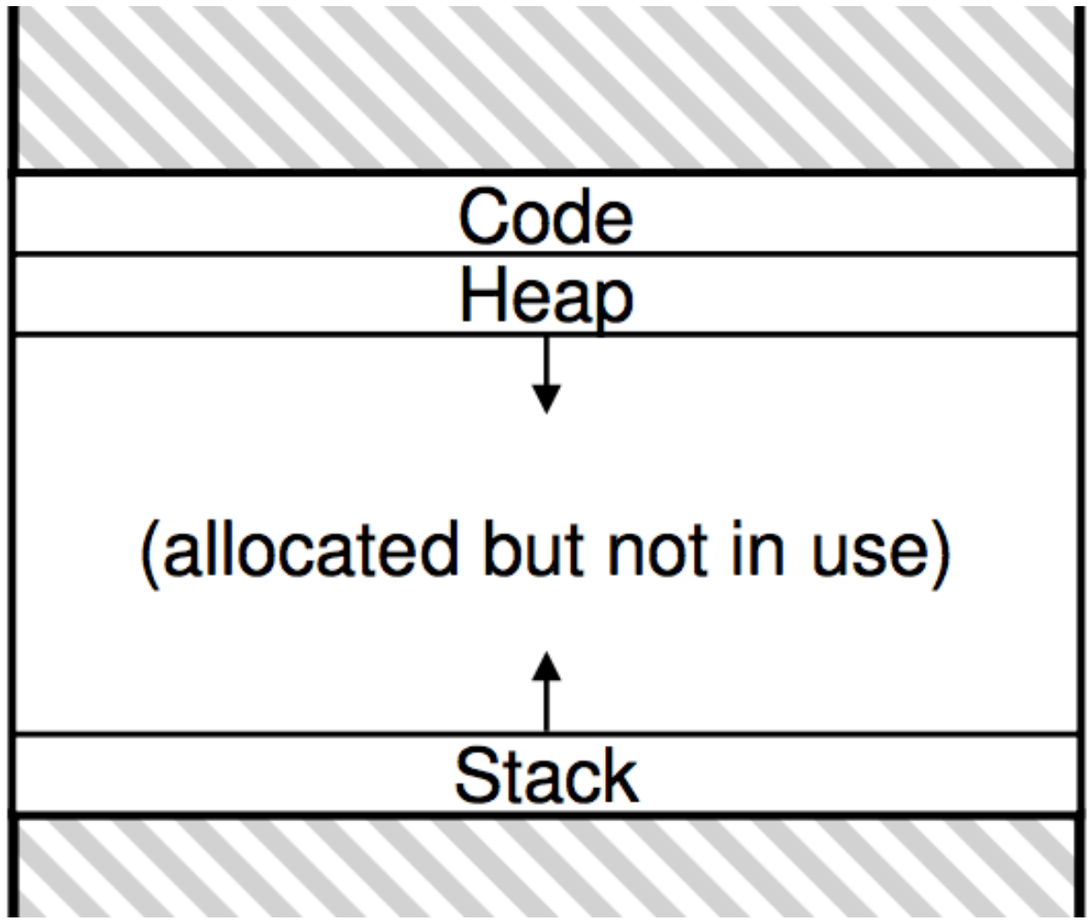


# Segmentation

Base for Code

Base + Bound for Code



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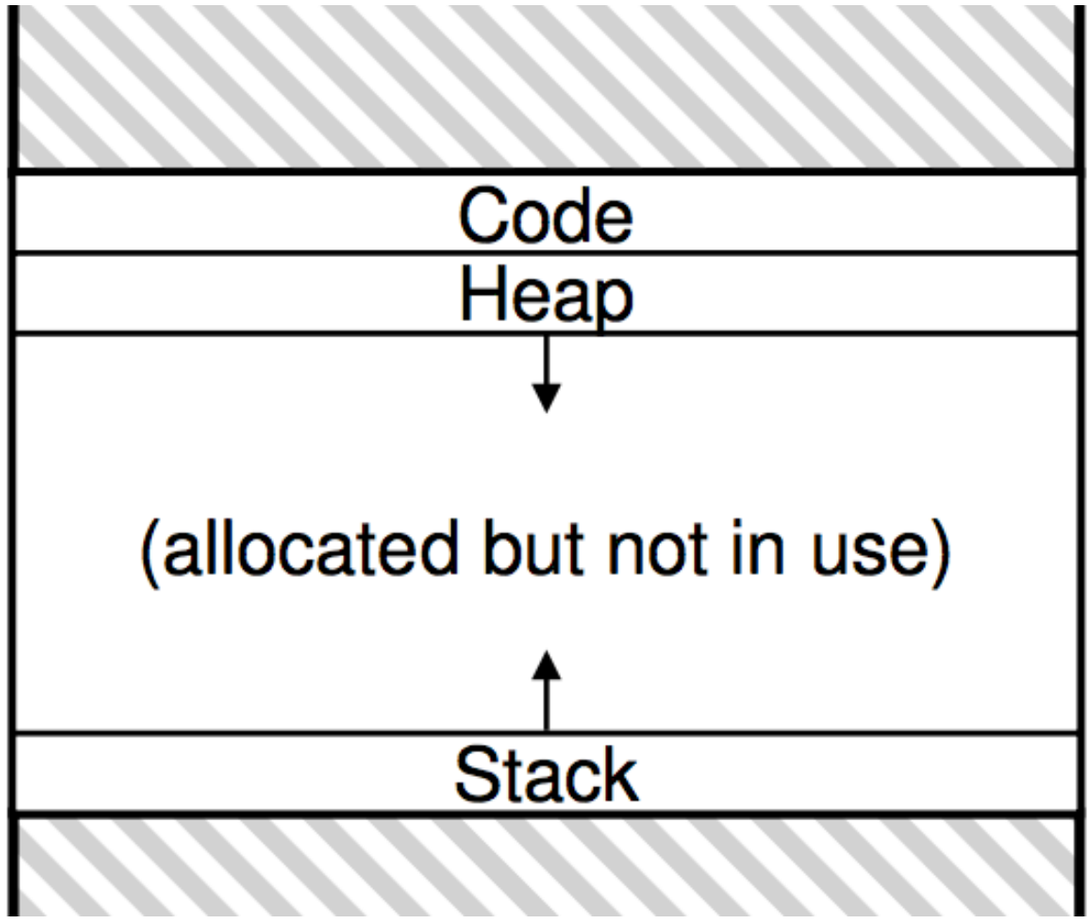

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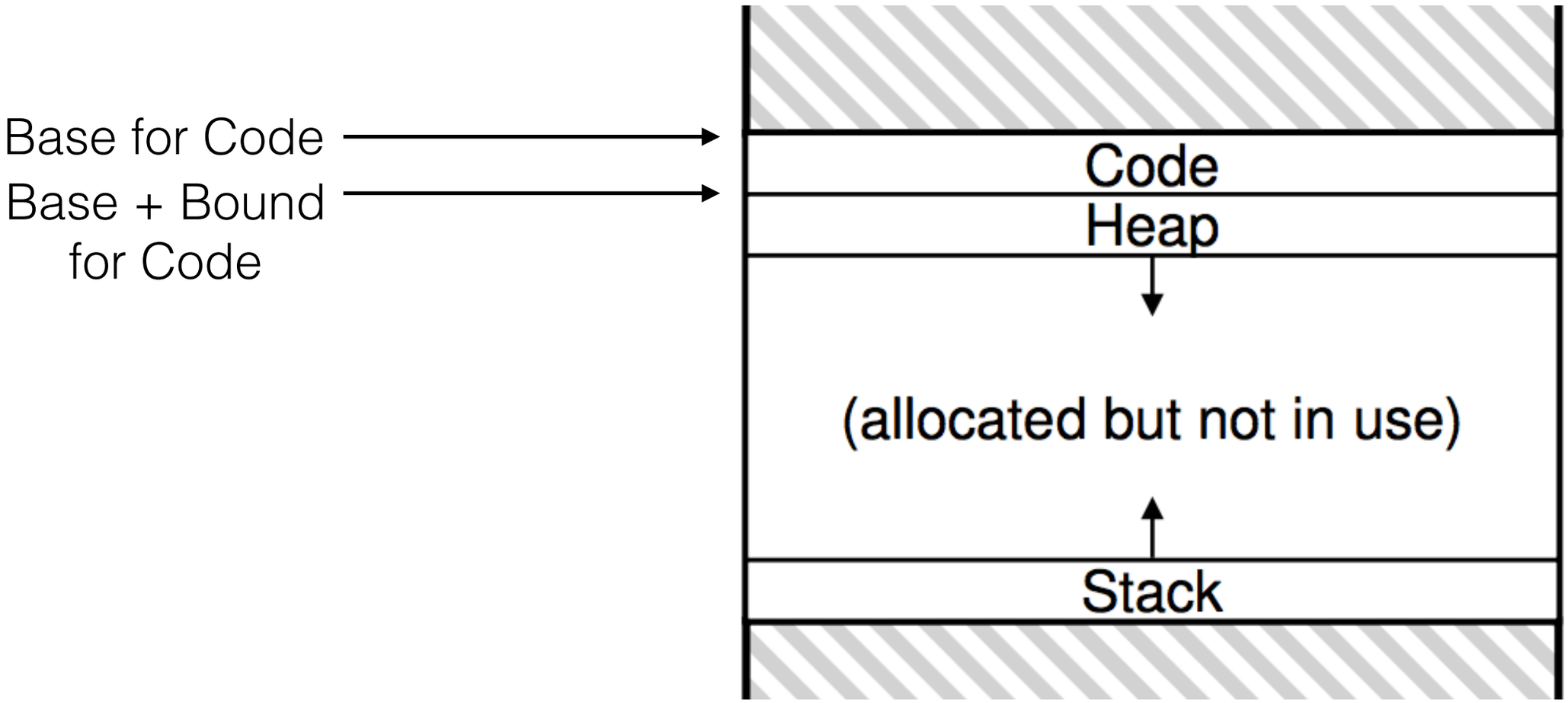

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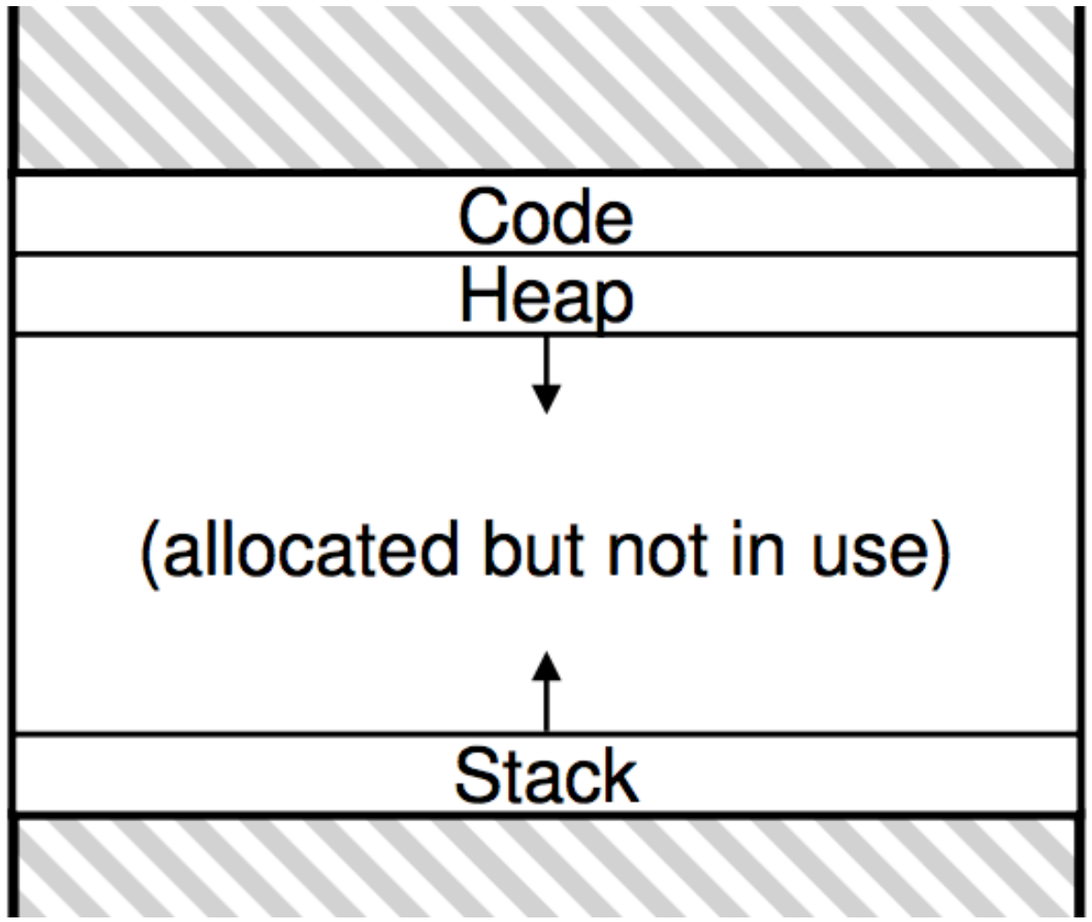

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Base for Heap
Base + Bound
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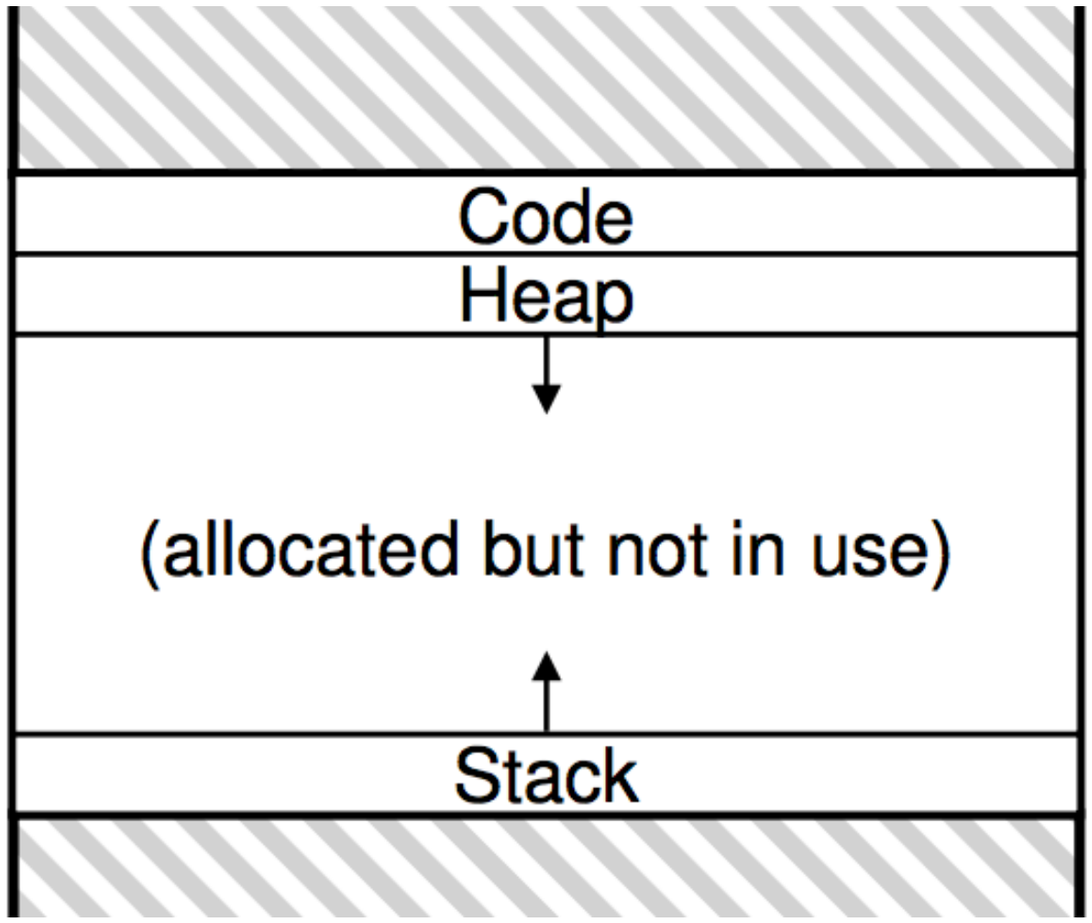

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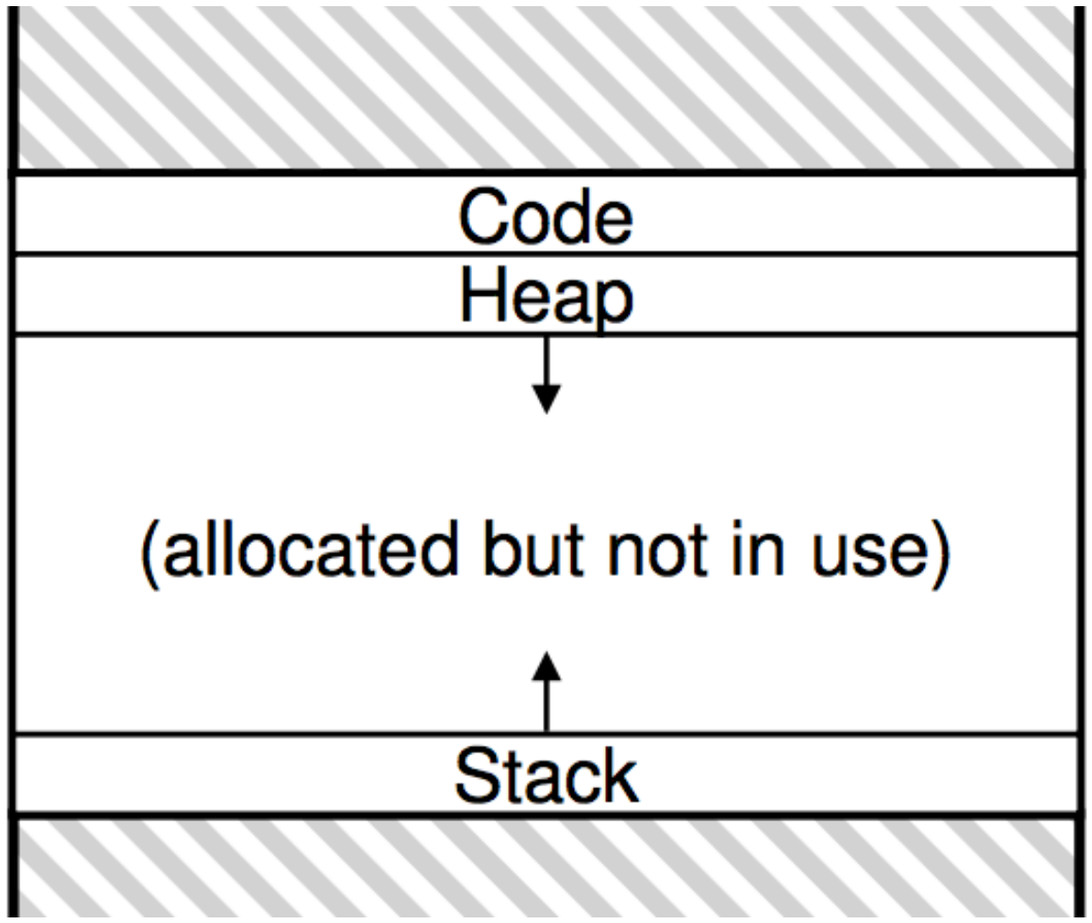

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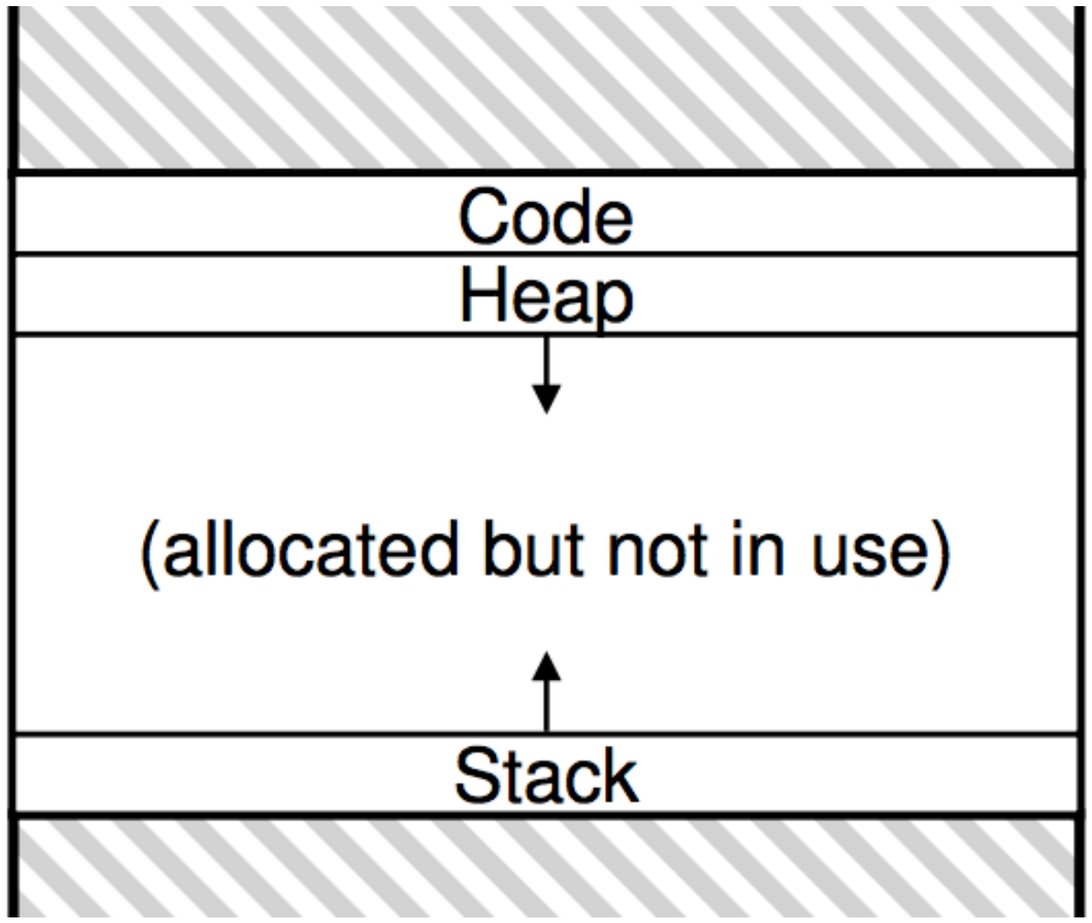

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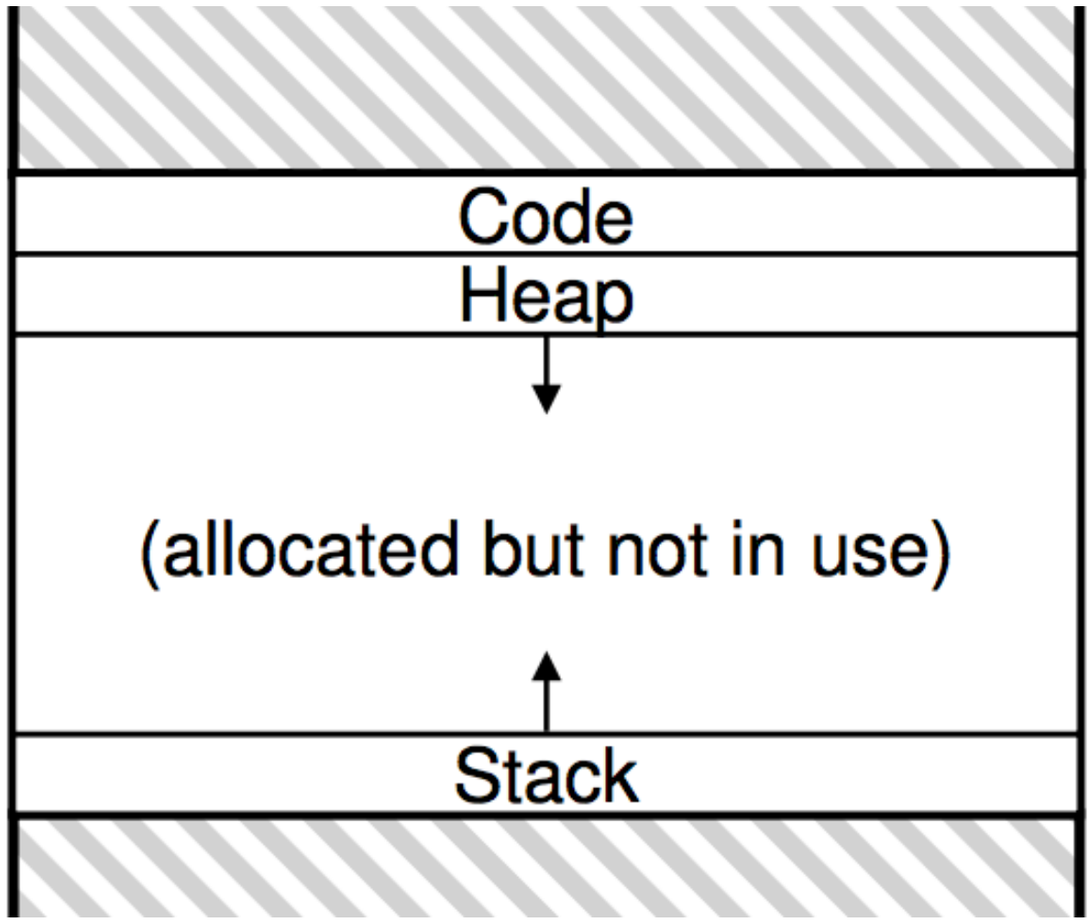

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Base + Bound for Stack

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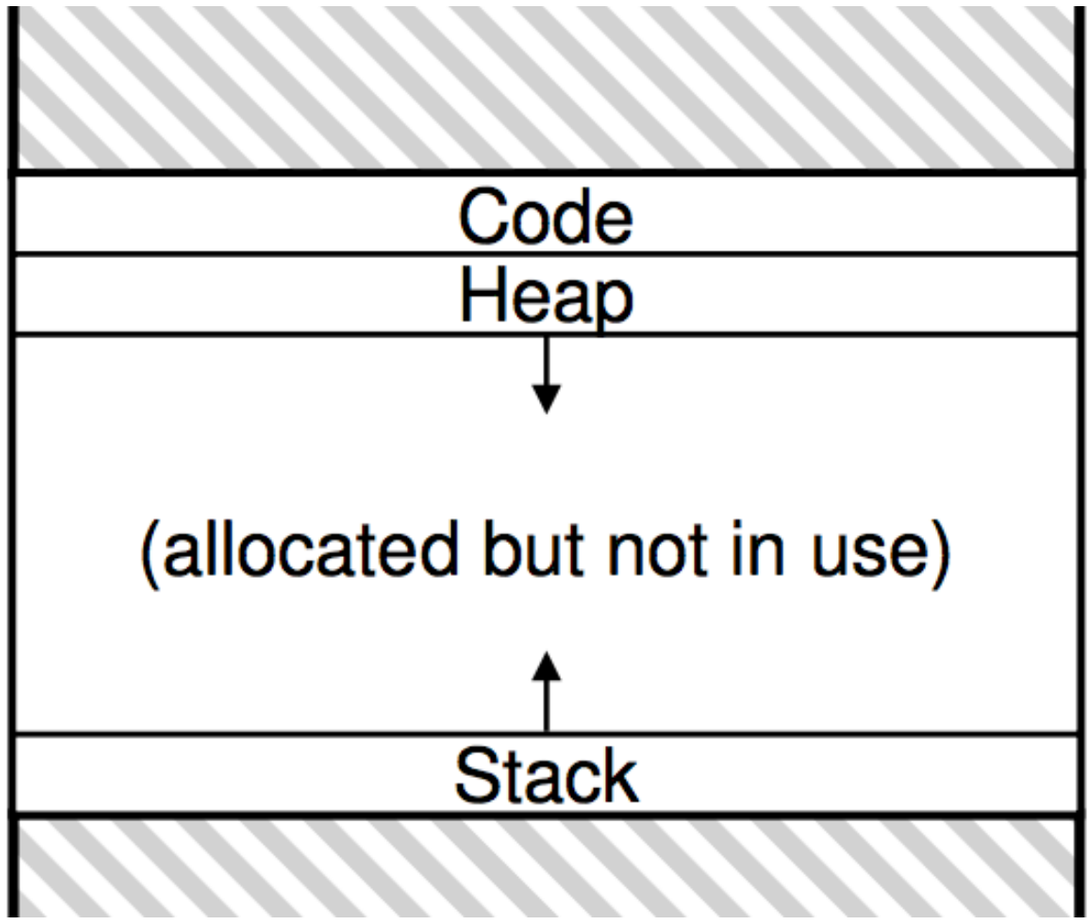

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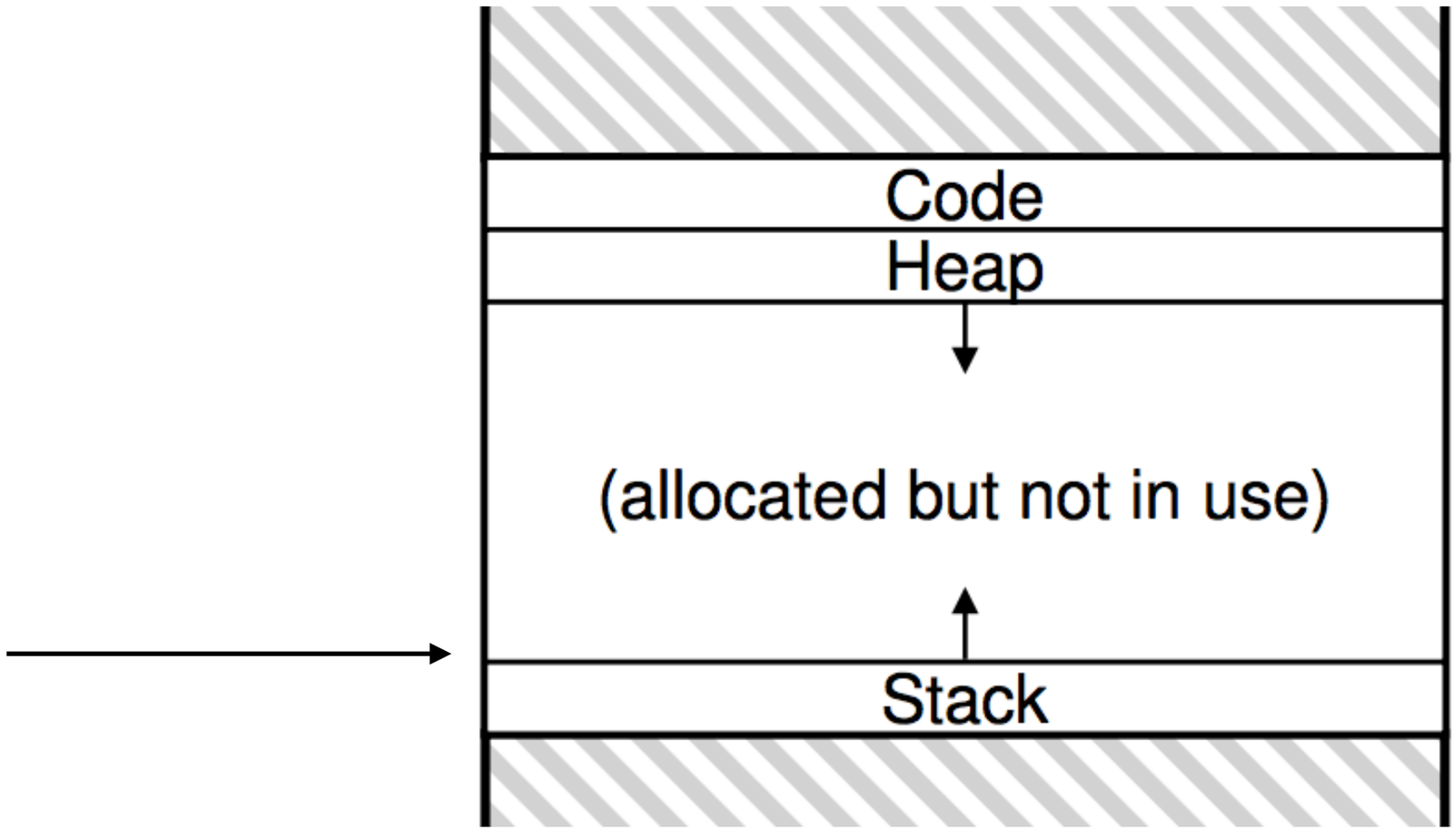

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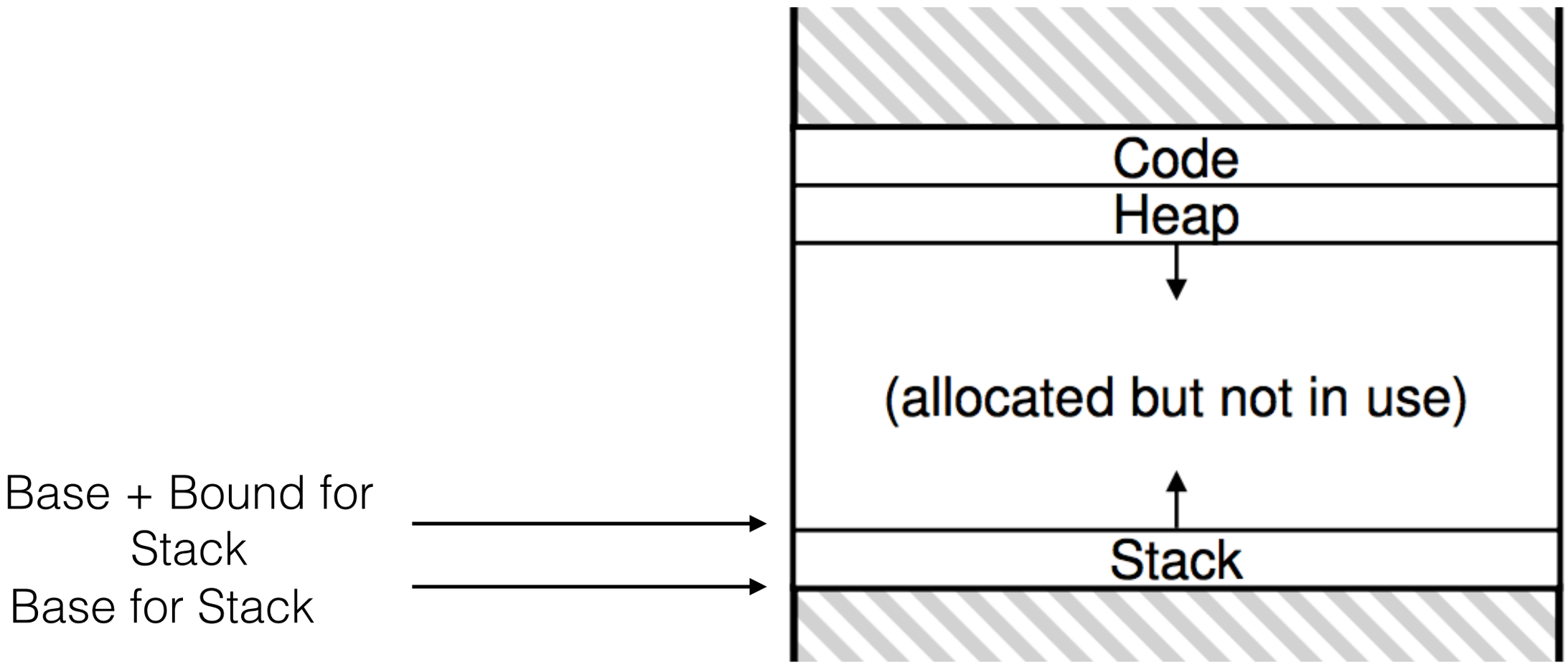

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MMU

Physical Memory

Virtual Address

0x100

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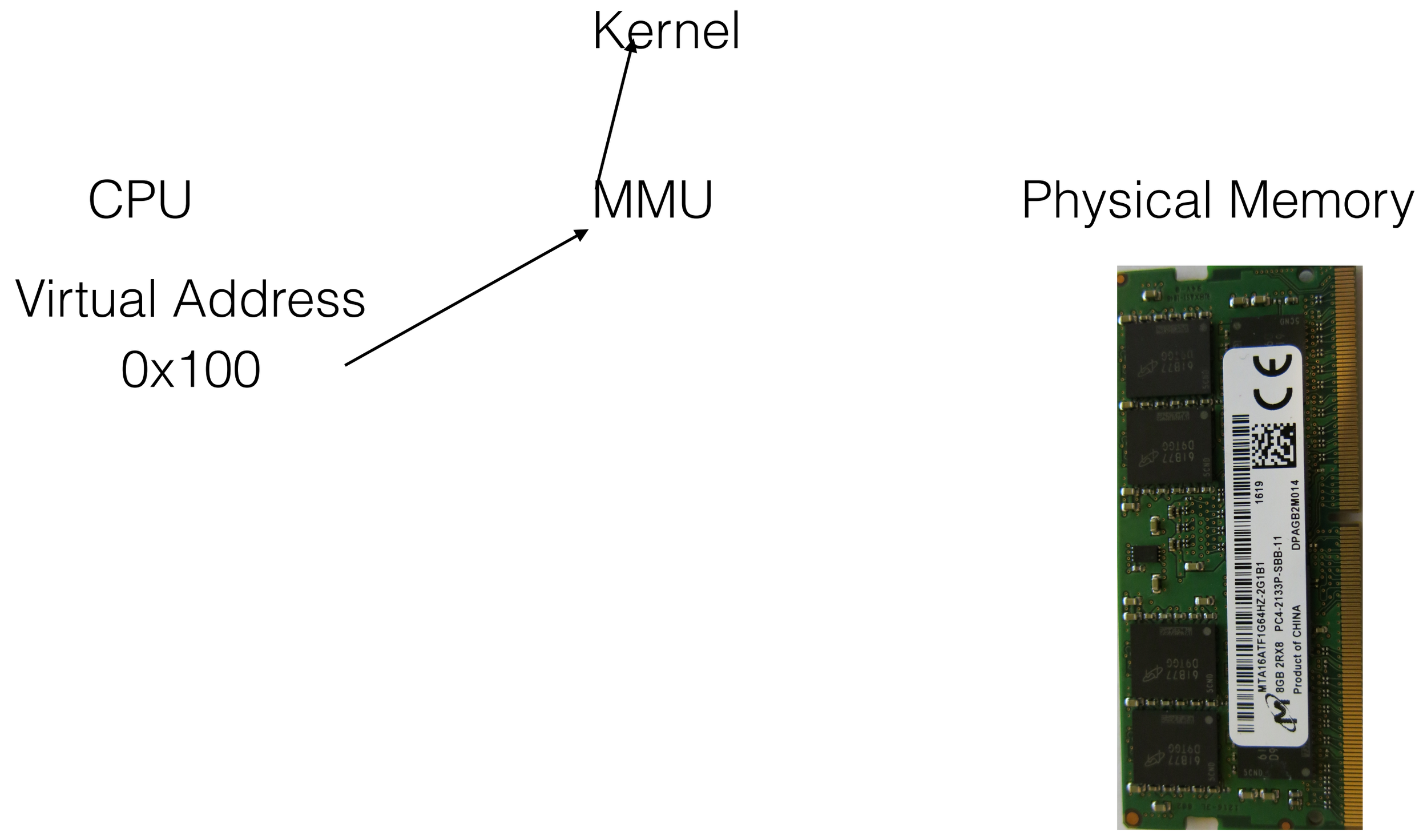

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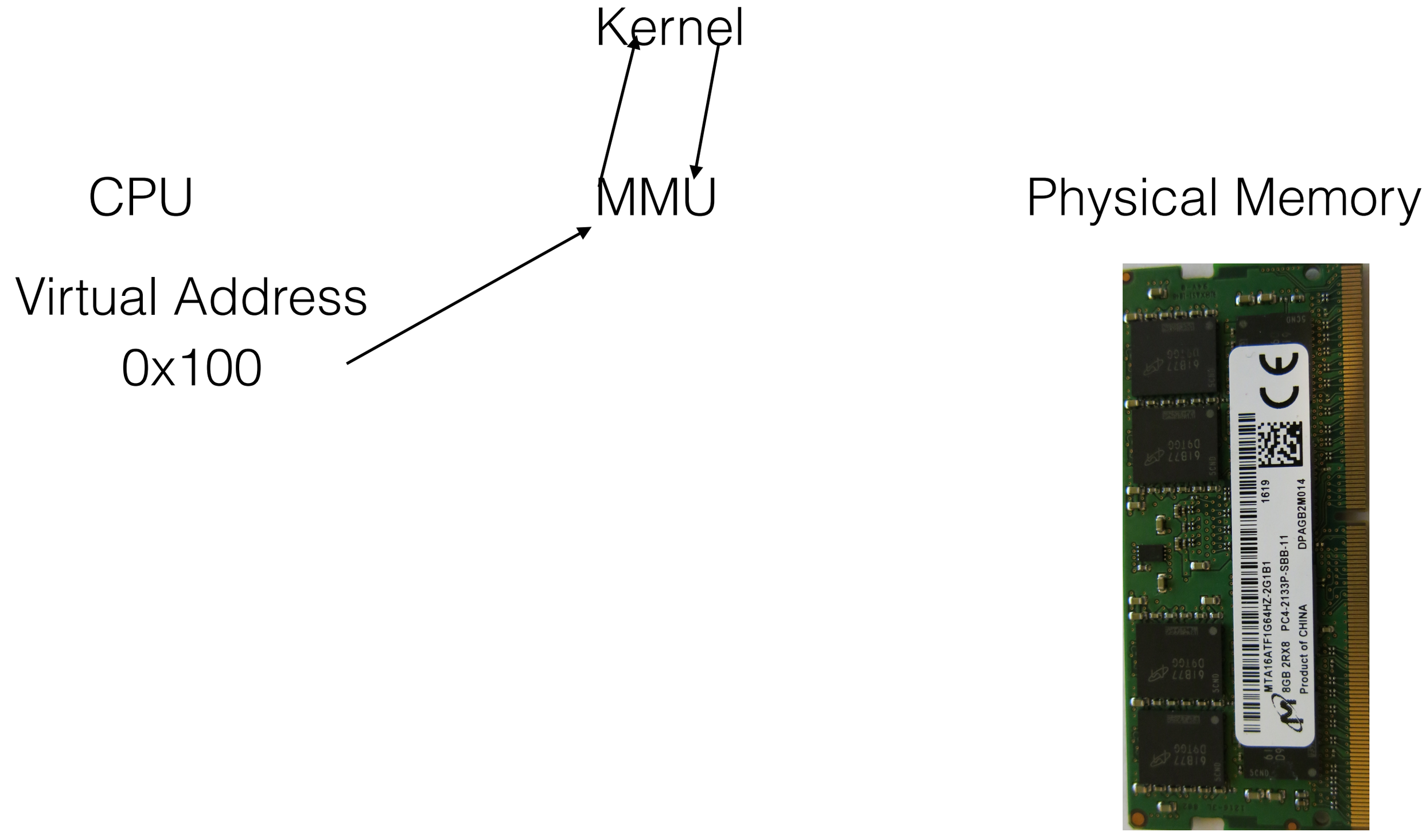

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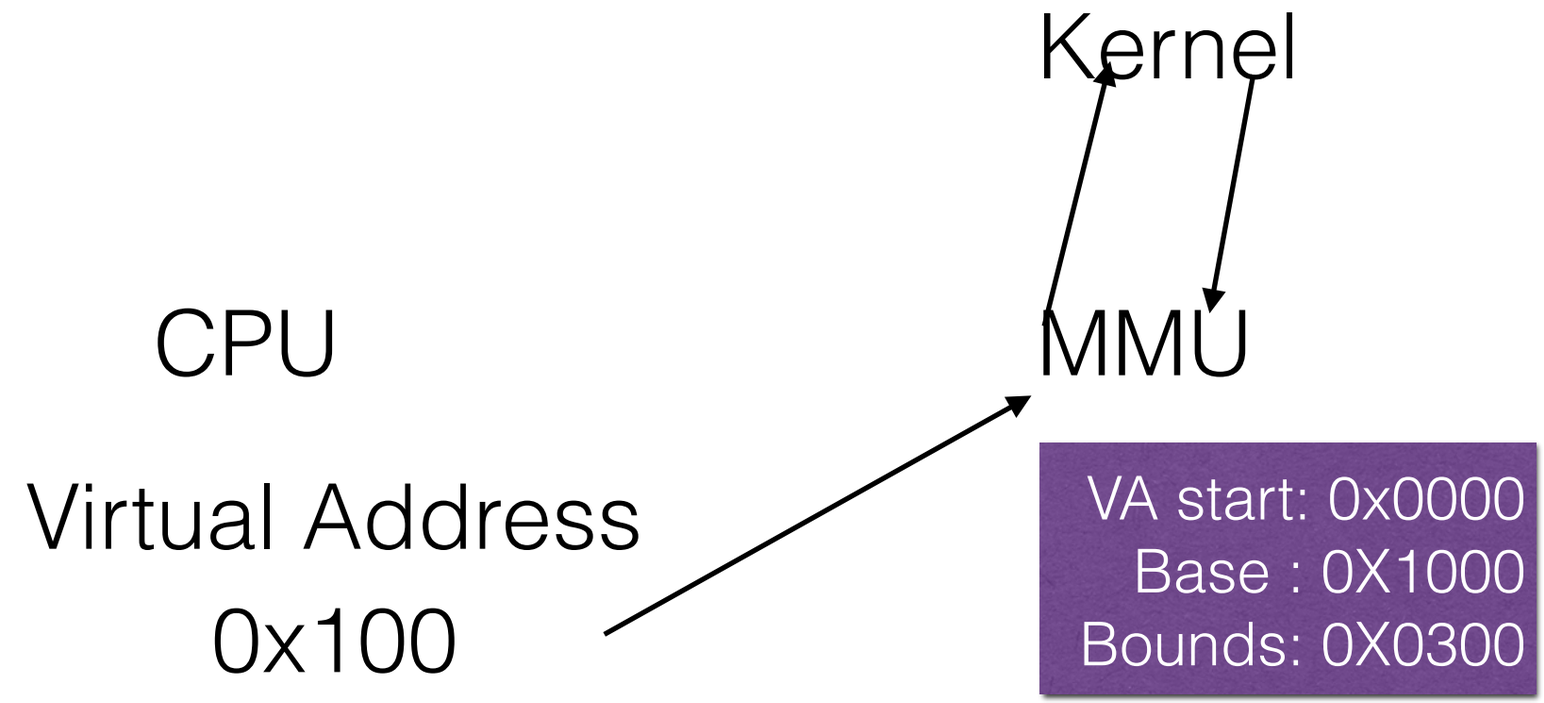


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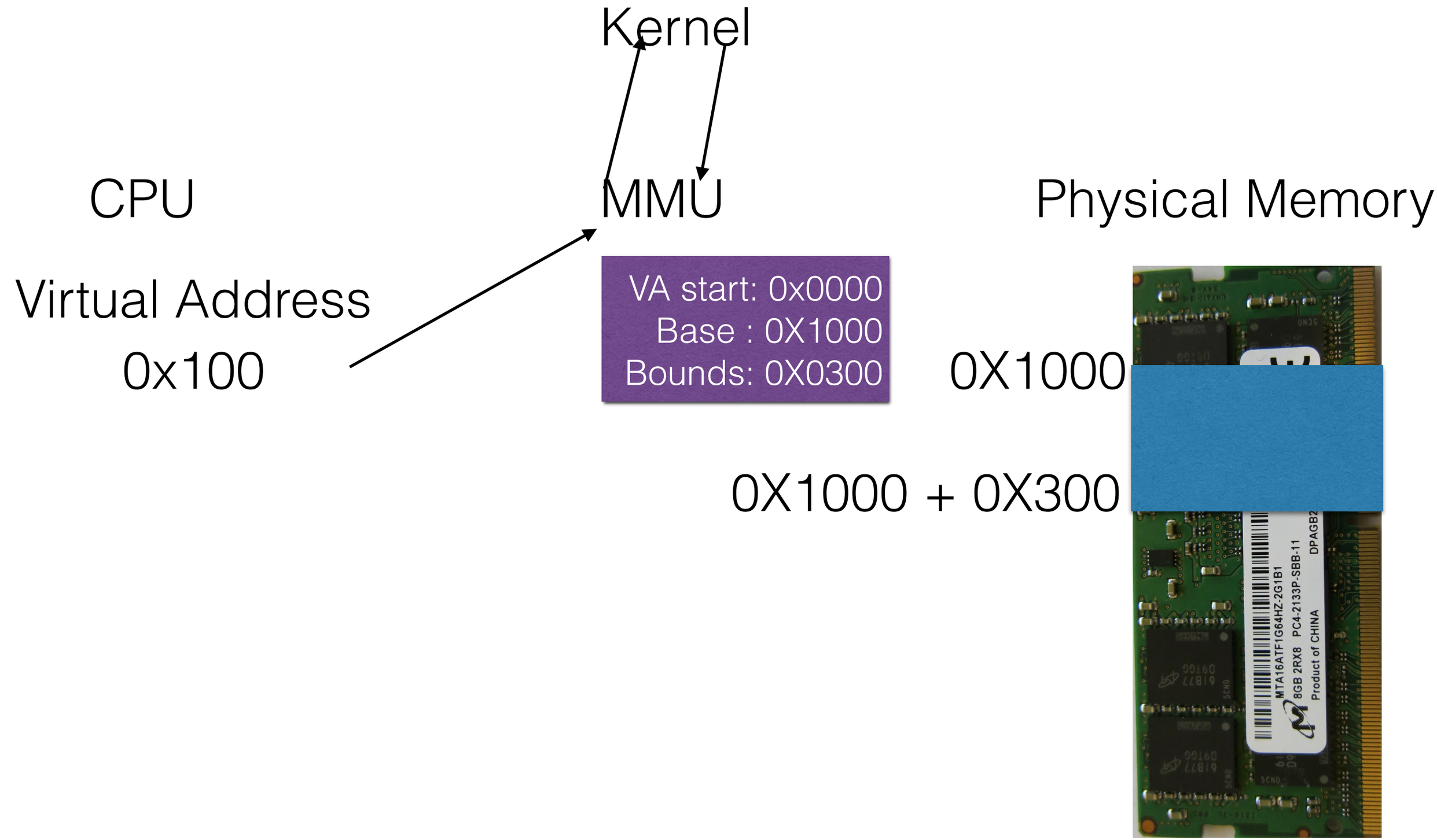

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Bounds: 0X0300

0X1000

0X1000 + 0X300


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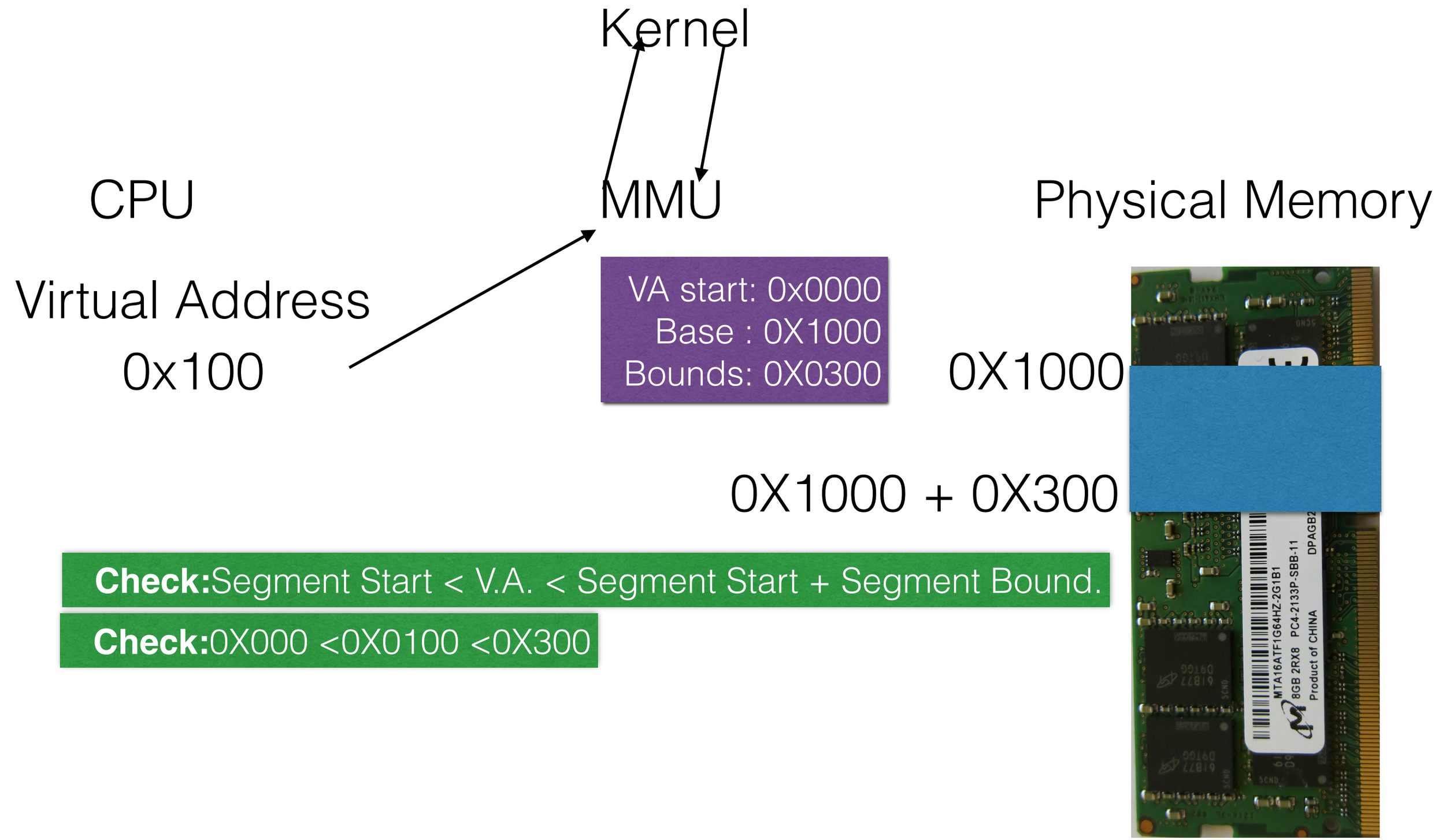

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Physical Address = (0x0100 - 0x0000) + 0x1000

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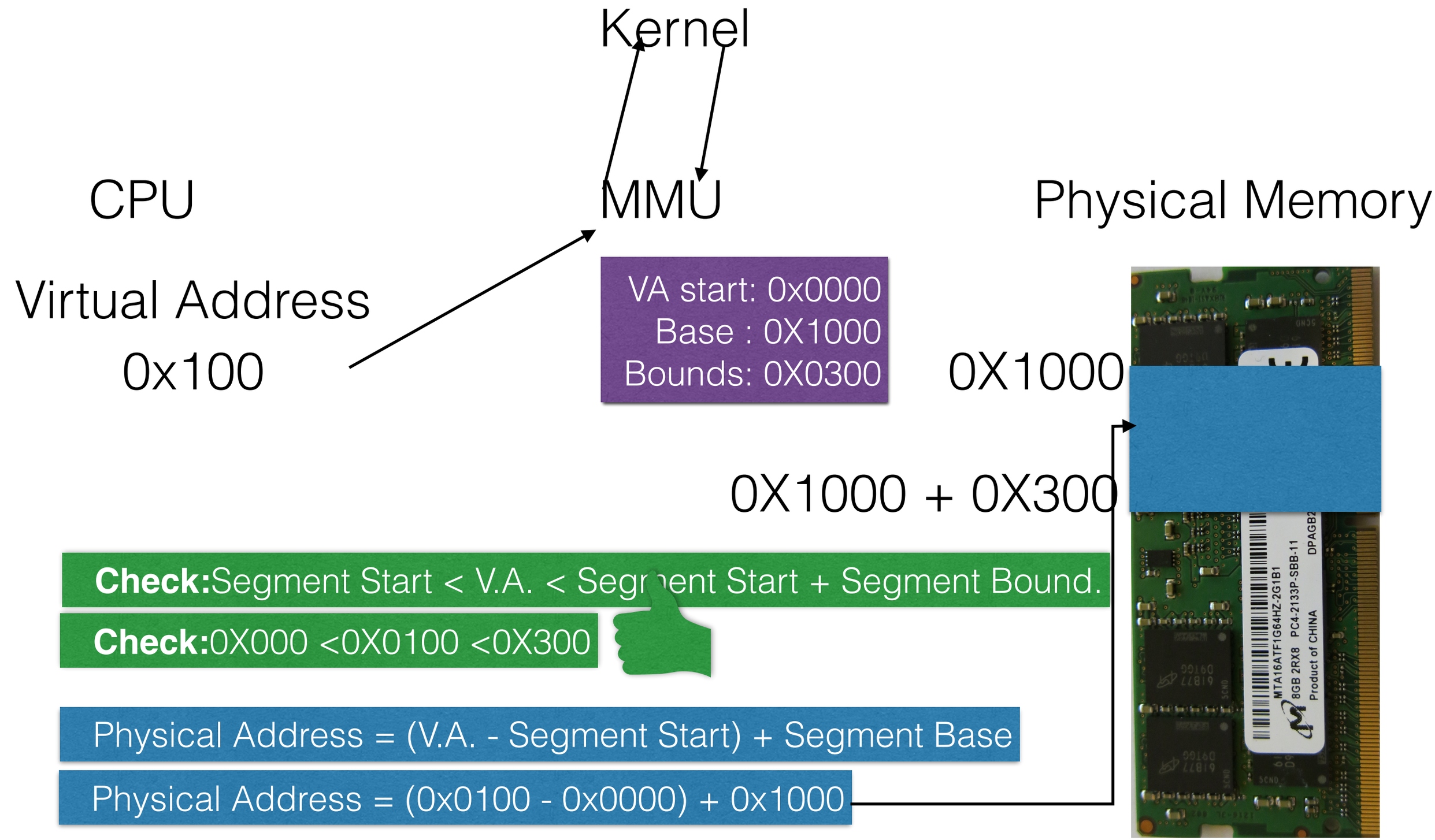

# Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x2400

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MMU

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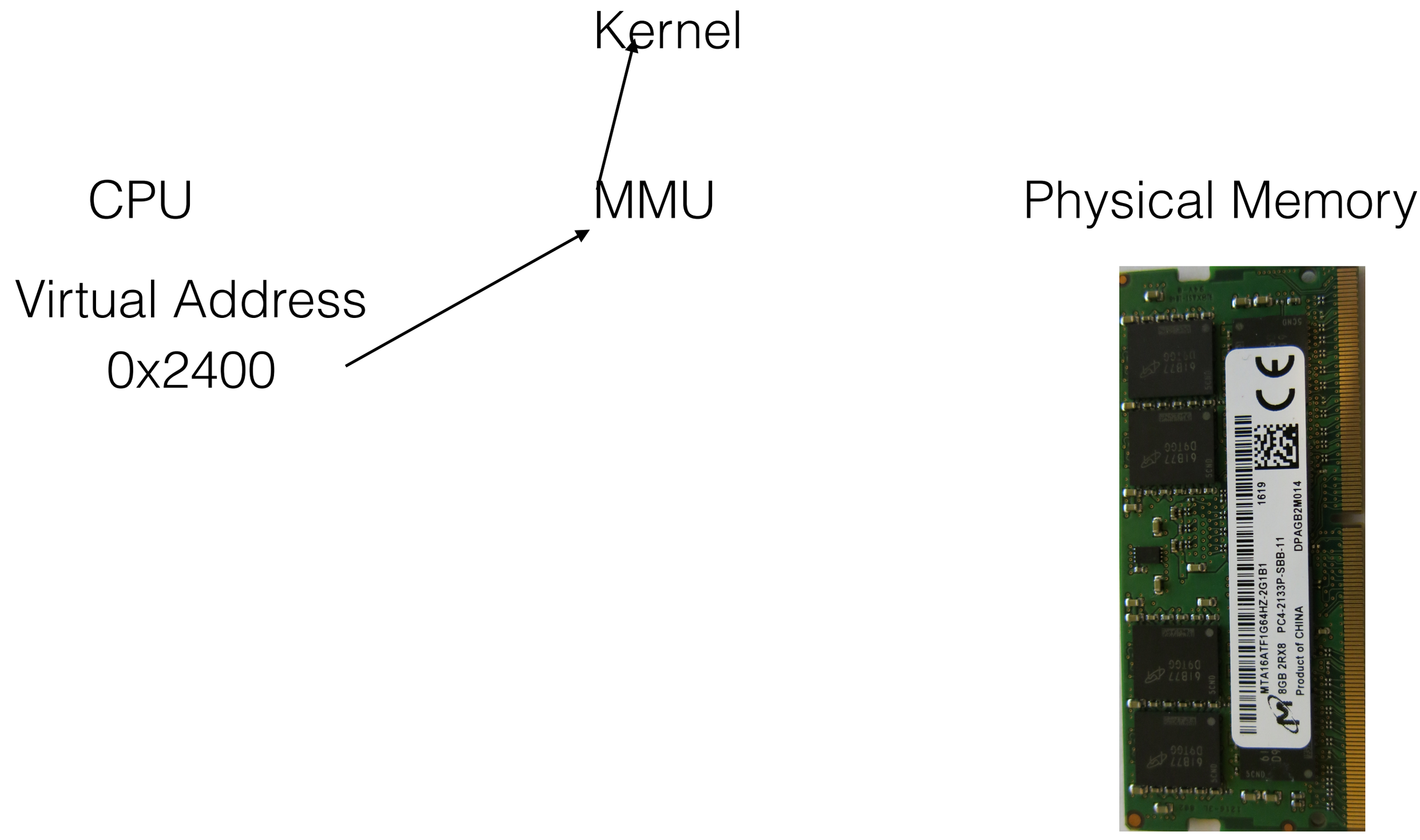

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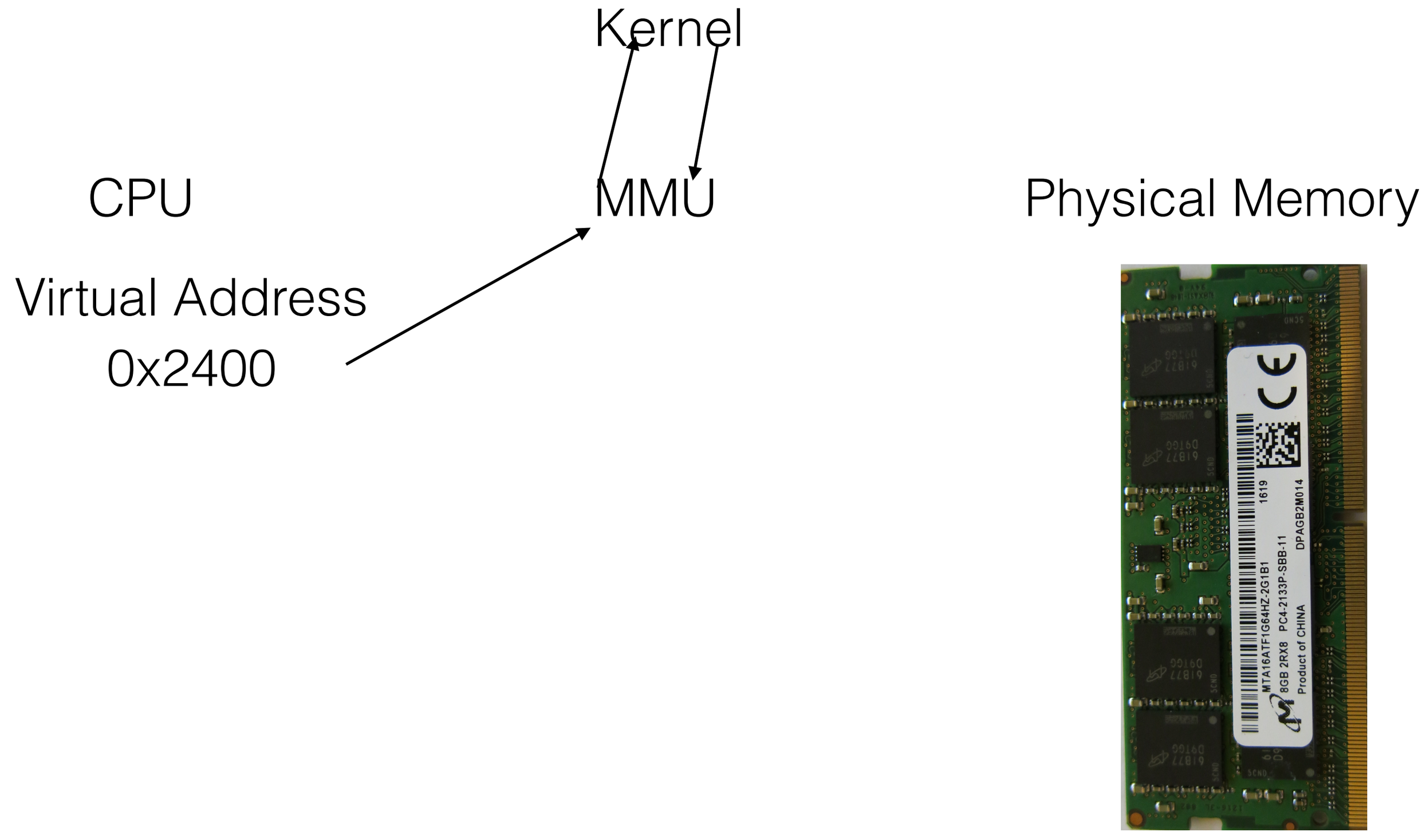

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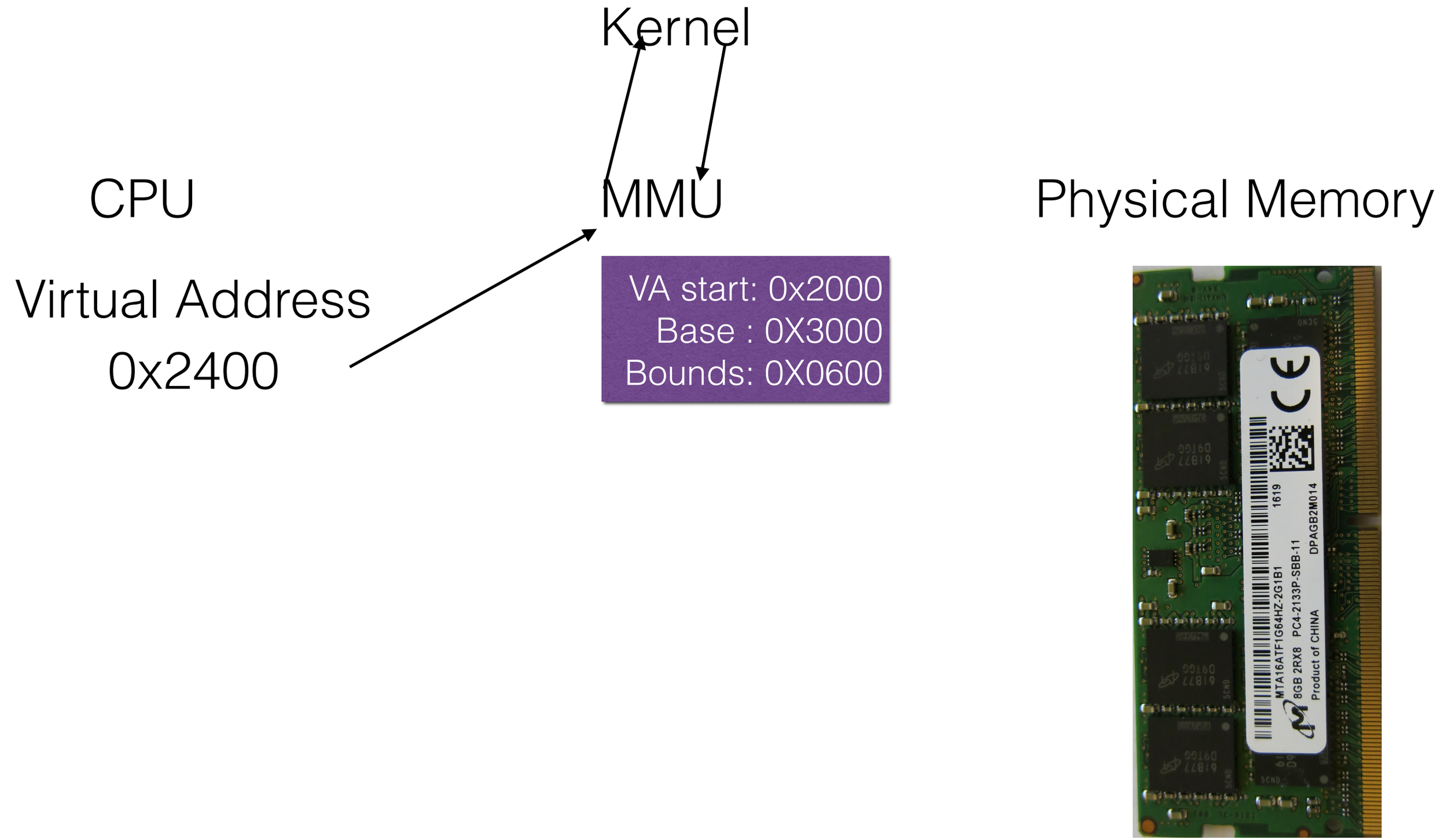

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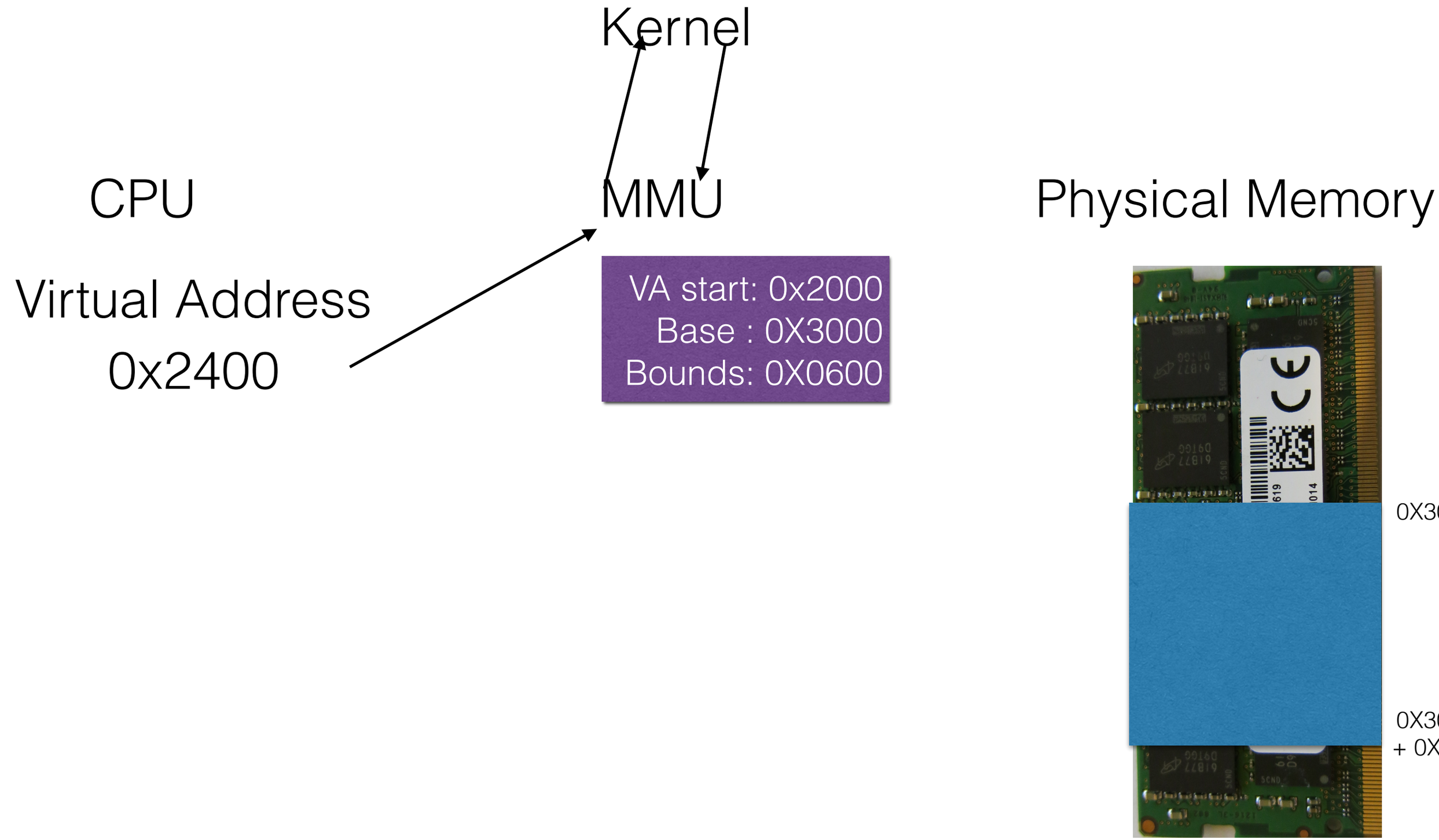

# Segmentation Example

Kernel

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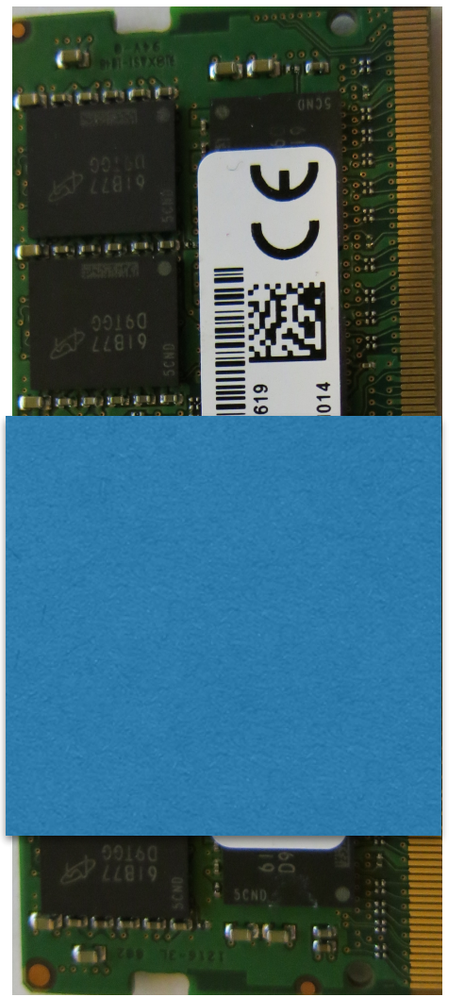
MMU

Physical Memory

Virtual Address

0x2400

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600



0X3000

0X3000
+ 0X600

**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

# Segmentation Example

Kernel

CPU

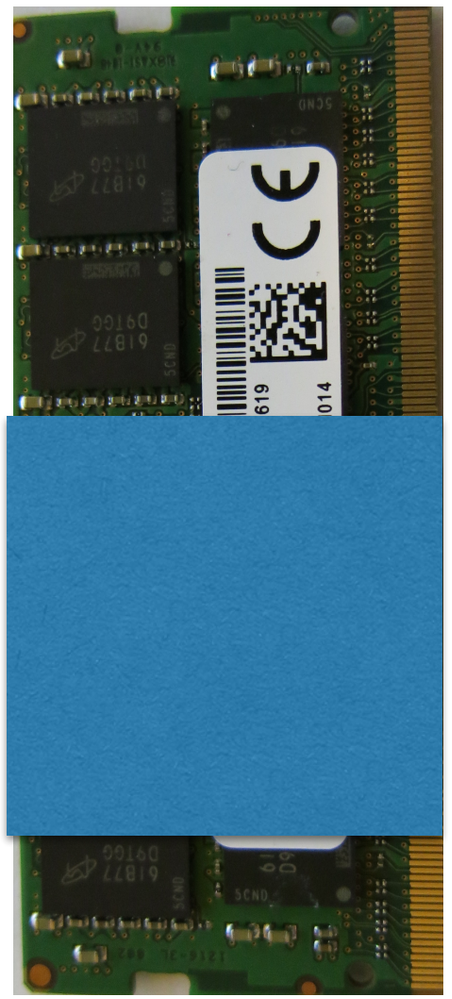
MMU

Physical Memory

Virtual Address

0x2400

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600



0X3000

0X3000
+ 0X600

**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

**Check:**0X2000 <0X2400 <0X2400+0X600

# Segmentation Example

Kernel

CPU

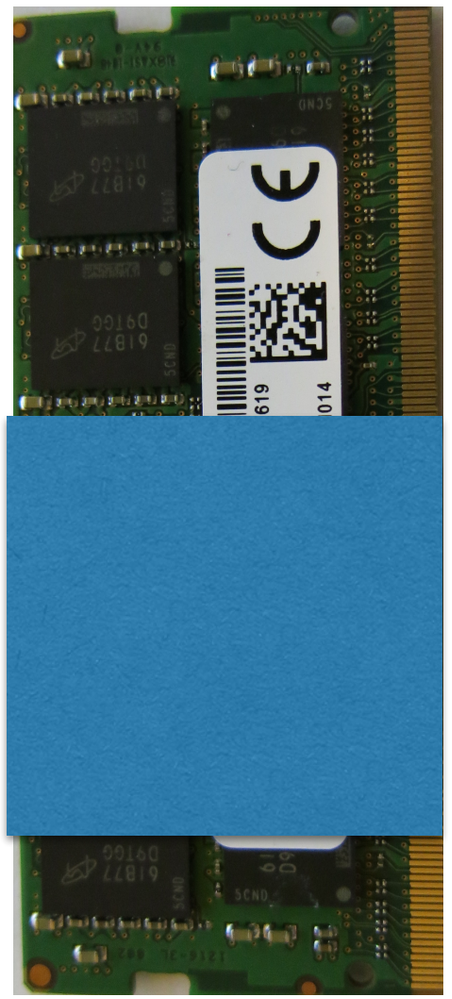
MMU

Physical Memory

Virtual Address

0x2400

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600



0X3000

0X3000
+ 0X600

**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

**Check:**0X2000 <0X2400 <0X2400+0X600

# Segmentation Example

Kernel

CPU

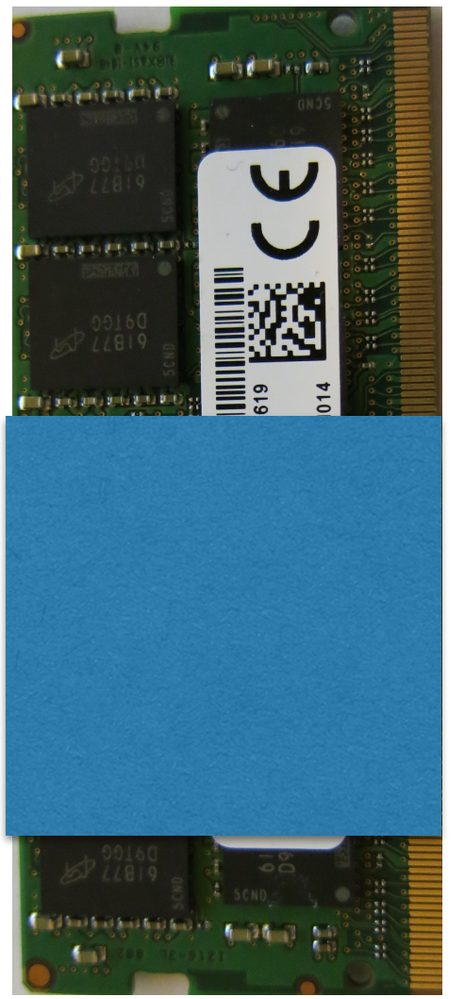
MMU

Physical Memory

Virtual Address

0x2400

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600



0X3000

0X3000
+ 0X600

**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

**Check:**0X2000 <0X2400 <0X2400+0X600

Physical Address = (V.A. - Segment Start) + Segment Base

# Segmentation Example

Kernel

CPU

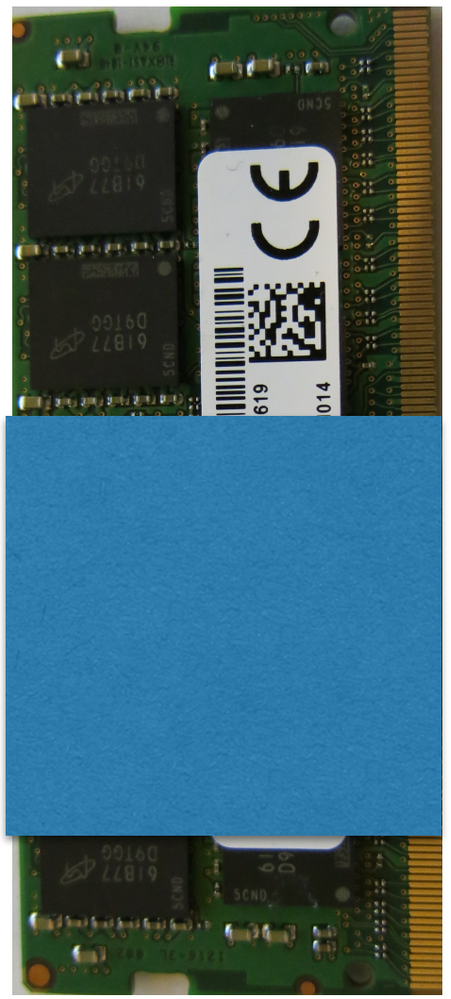
MMU

Physical Memory

Virtual Address

0x2400

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600



0X3000

0X3000
+ 0X600

**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

**Check:**0X2000 <0X2400 <0X2400+0X600

Physical Address = (V.A. - Segment Start) + Segment Base

Physical Address = (0x2400 - 0x2000) + 0x3000

# Segmentation Example

Kernel

CPU

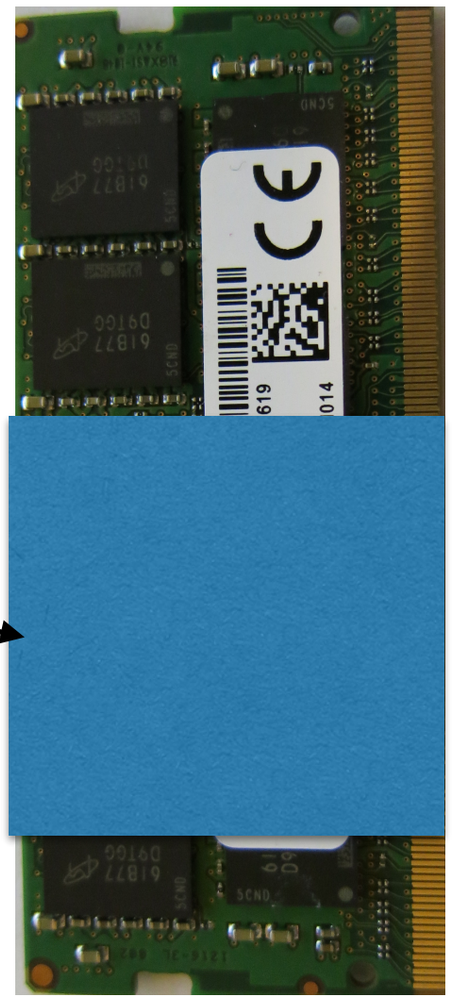
MMU

Physical Memory

Virtual Address

0x2400

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600



0X3000

0X3000
+ 0X600

**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

**Check:**0X2000 <0X2400 <0X2400+0X600

Physical Address = (V.A. - Segment Start) + Segment Base

Physical Address = (0x2400 - 0x2000) + 0x3000

# Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x2700

# Segmentation Example

Kernel

CPU

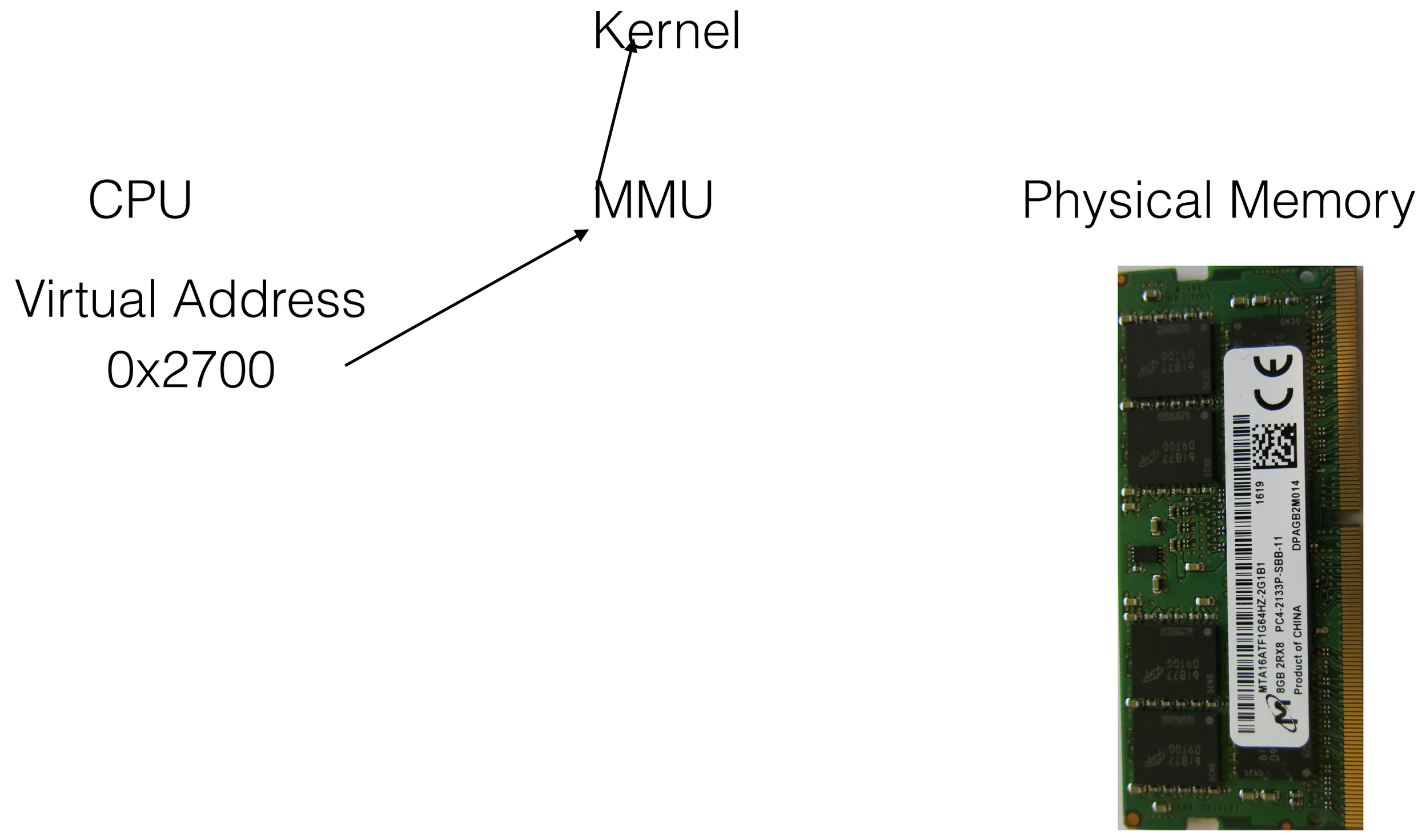
MMU

Physical Memory

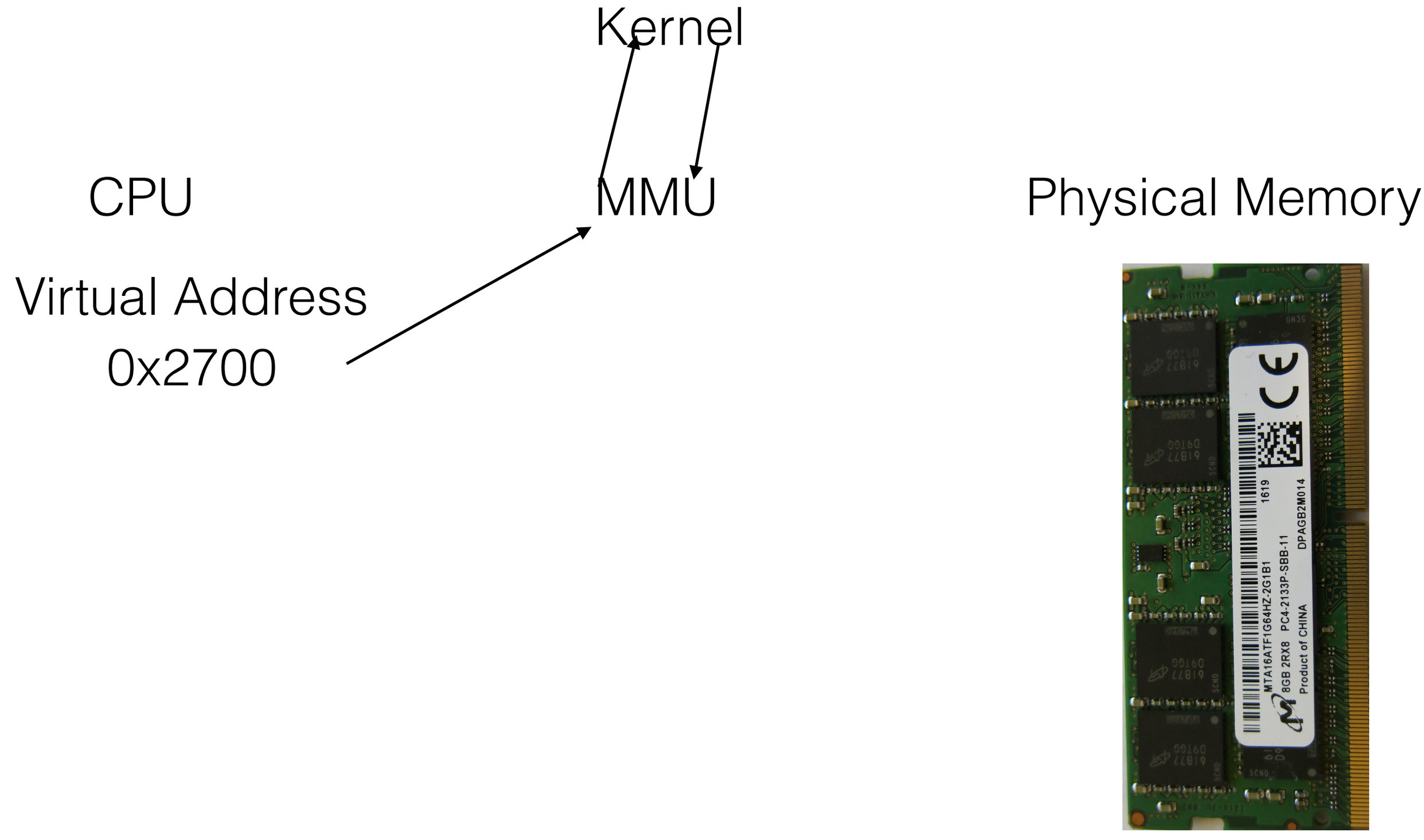
Virtual Address

0x2700

# Segmentation Example



# Segmentation Example



# Segmentation Example

Kernel

VA start: 0x0000
Base : 0X1000
Bounds: 0X0300

CPU

MMU

Physical Memory

Virtual Address

0x2700

# Segmentation Example

Kernel

VA start: 0x0000
Base : 0X1000
Bounds: 0X0300

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600

CPU

MMU

Physical Memory

Virtual Address
0x2700

# Segmentation Example

Kernel

VA start: 0x0000
Base : 0X1000
Bounds: 0X0300

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600

CPU

MMU

Physical Memory

Virtual Address
0x2700


**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

# Segmentation Example

Kernel

VA start: 0x0000
Base : 0X1000
Bounds: 0X0300

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600

CPU

MMU

Physical Memory

Virtual Address
0x2700


**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

# Segmentation Example

Kernel

VA start: 0x0000
Base : 0X1000
Bounds: 0X0300

VA start: 0x2000
Base : 0X3000
Bounds: 0X0600

CPU

MMU

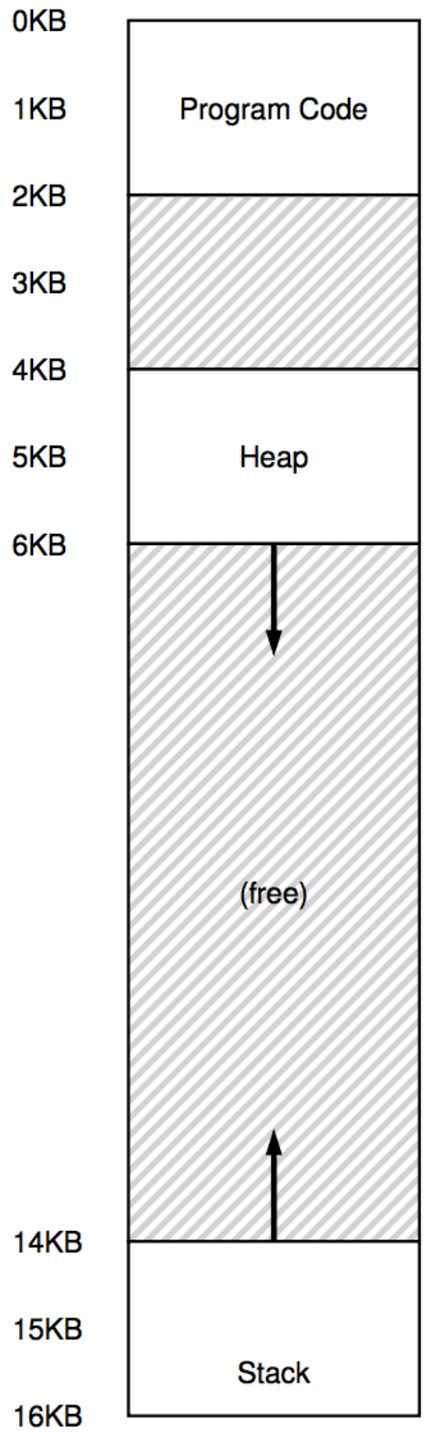
Physical Memory

Virtual Address
0x2700


**Check:**Segment Start < V.A. < Segment Start + Segment Bound.

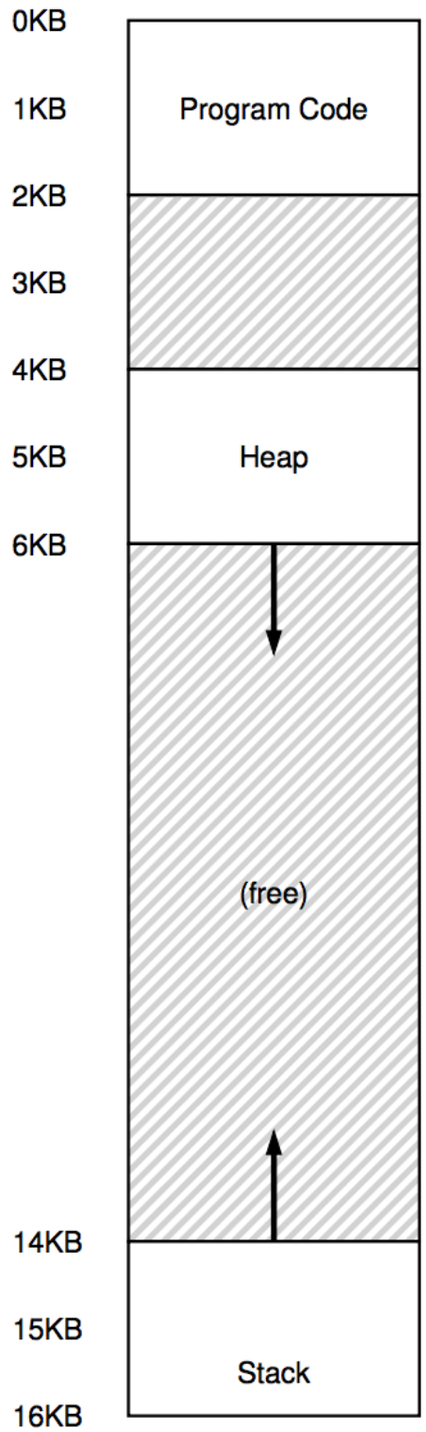
# Segment Reference

Virtual Address Space



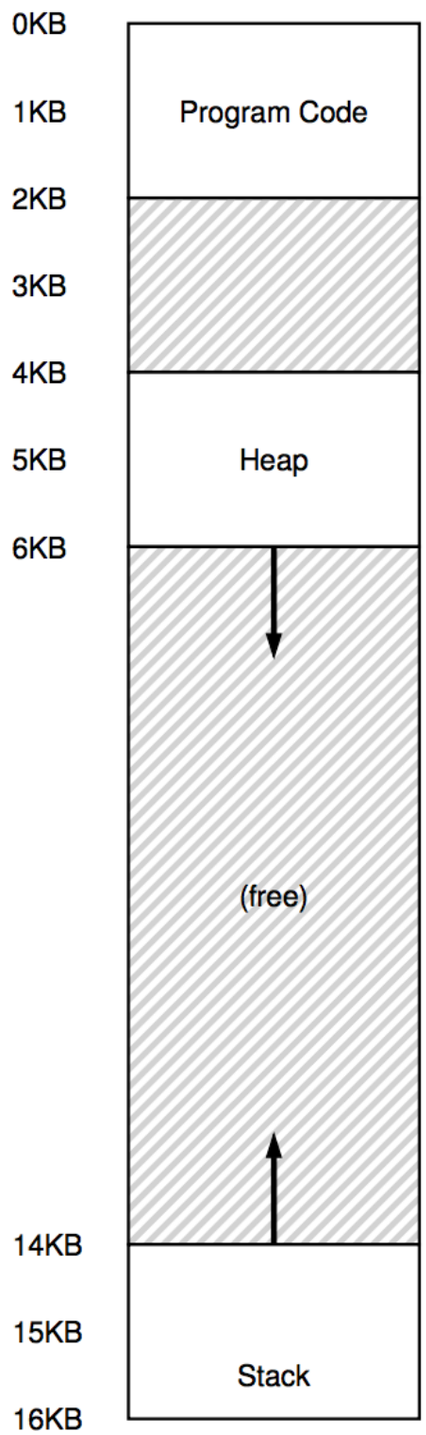
# Segment Reference

Virtual Address Space




# Segment Reference

Virtual Address Space

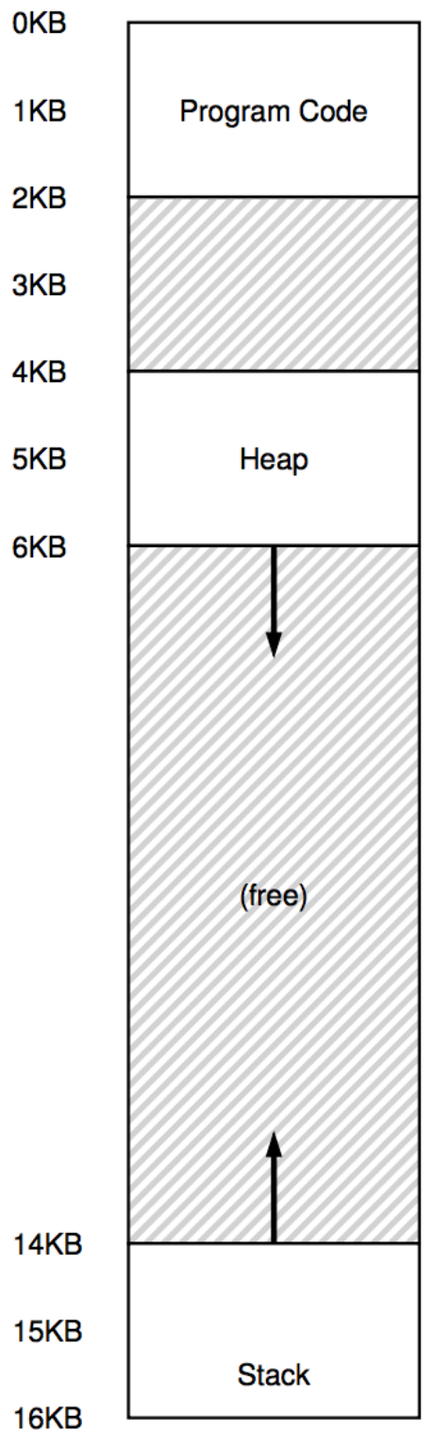



00 | 0000 | 0000 | 0000

11 | 1111 | 1111 | 1111

# Segment Reference

Virtual Address Space

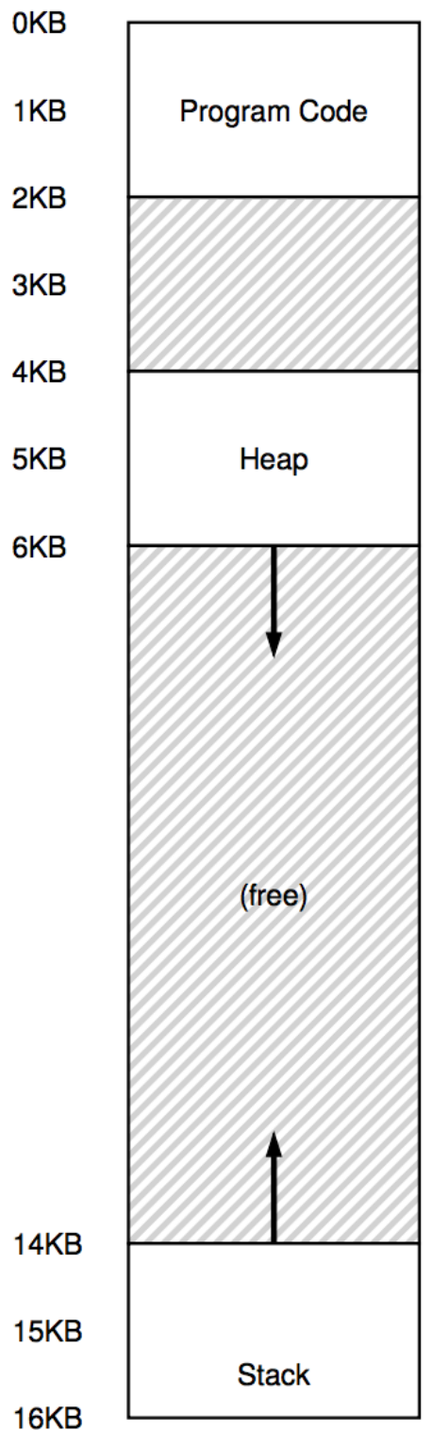



| 00 | 0000 | 0000 | 0000 |
|---|---|---|---|
| 00 | 0111 | 1111 | 1111 |

| 11 | 1111 | 1111 | 1111 |
|---|---|---|---|

# Segment Reference

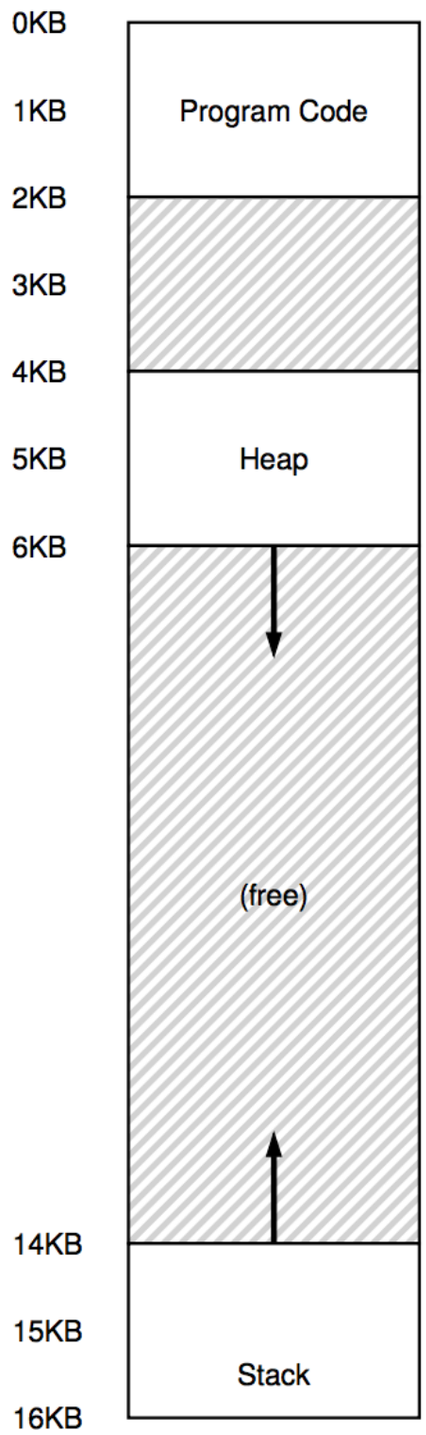
Virtual Address Space




| | | | |
|---|---|---|---|
| 00 | 0000 | 0000 | 0000 |
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 11 | 1111 | 1111 | 1111 |

# Segment Reference

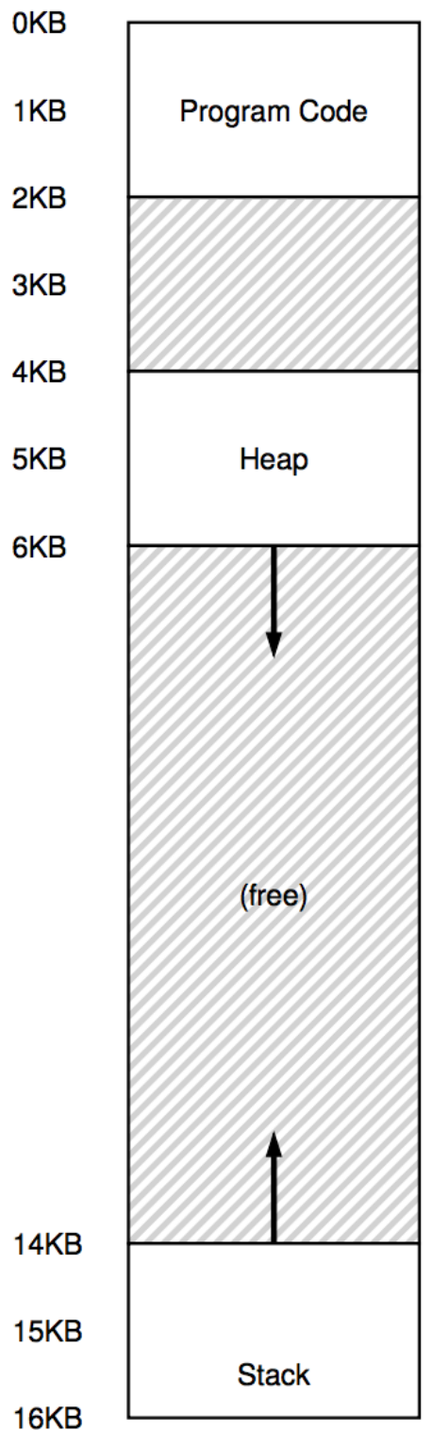
Virtual Address Space




| | | | |
|---|---|---|---|
| 00 | 0000 | 0000 | 0000 |
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 01 | 0111 | 1111 | 1111 |
| 11 | 1111 | 1111 | 1111 |

# Segment Reference

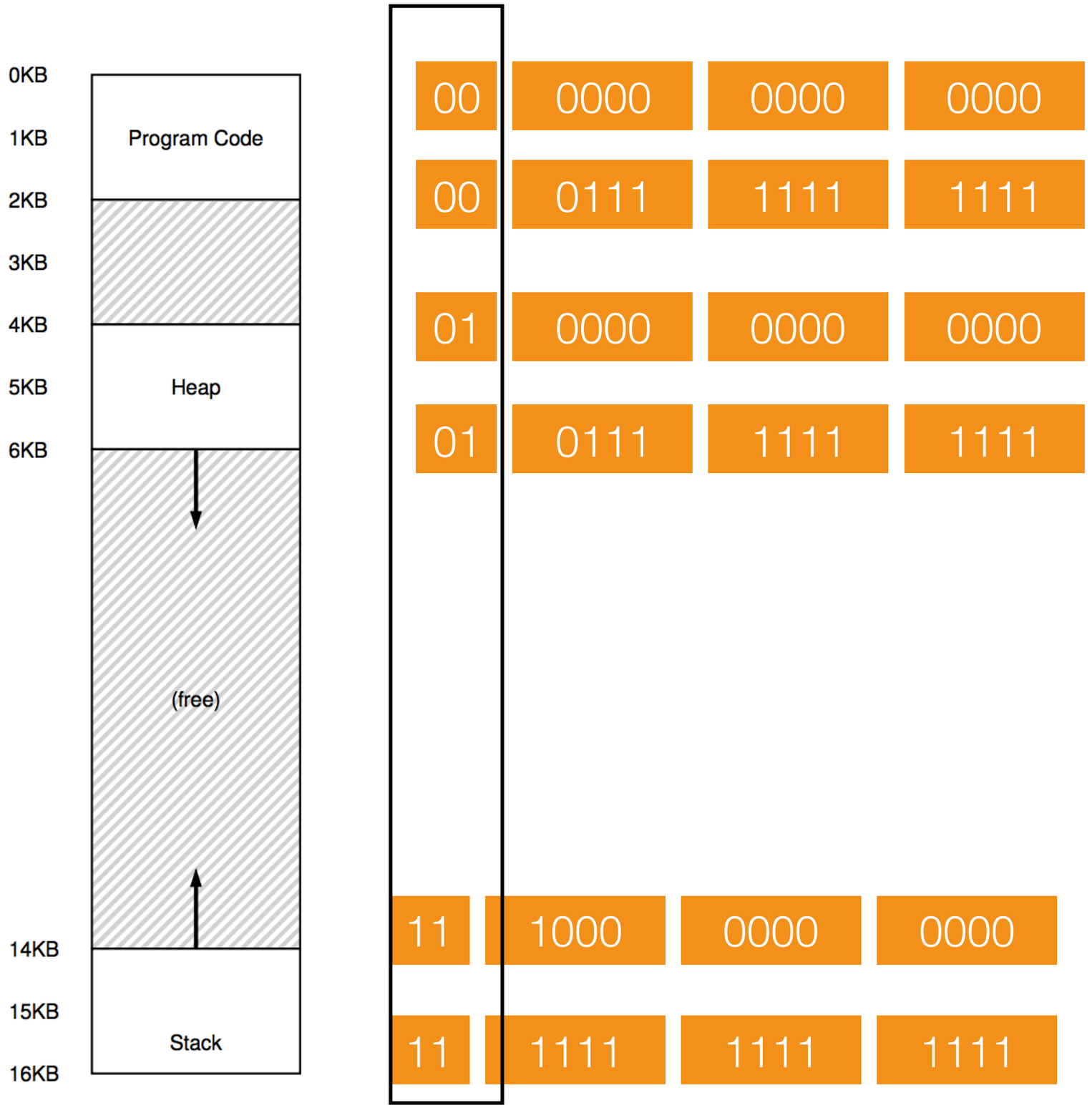
Virtual Address Space




| | | | |
|---|---|---|---|
| 00 | 0000 | 0000 | 0000 |
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 01 | 0111 | 1111 | 1111 |
| 11 | 1000 | 0000 | 0000 |
| 11 | 1111 | 1111 | 1111 |

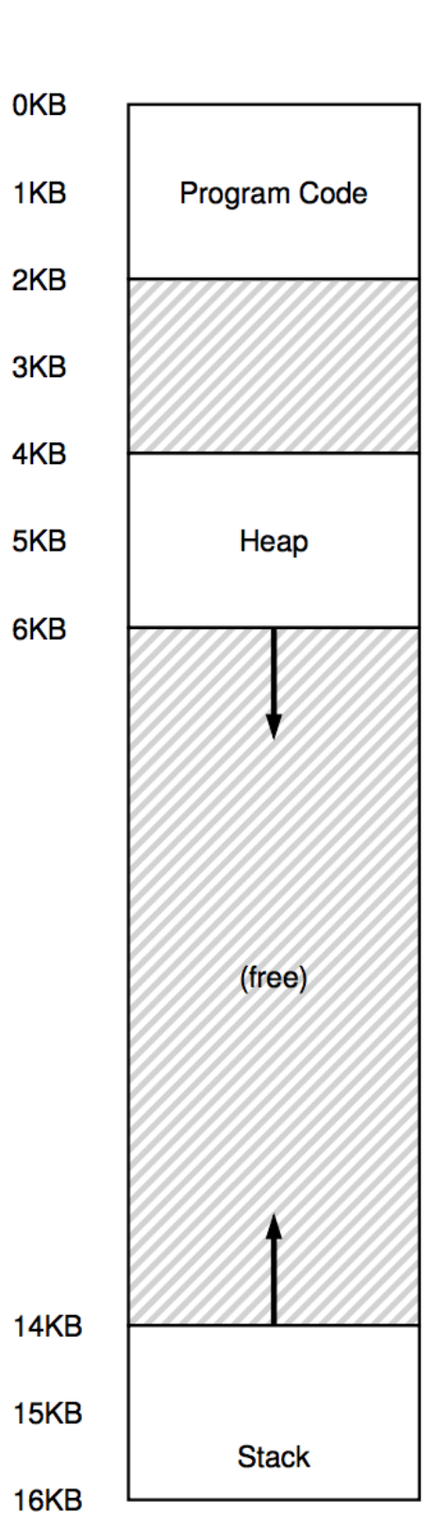
# Segment Reference

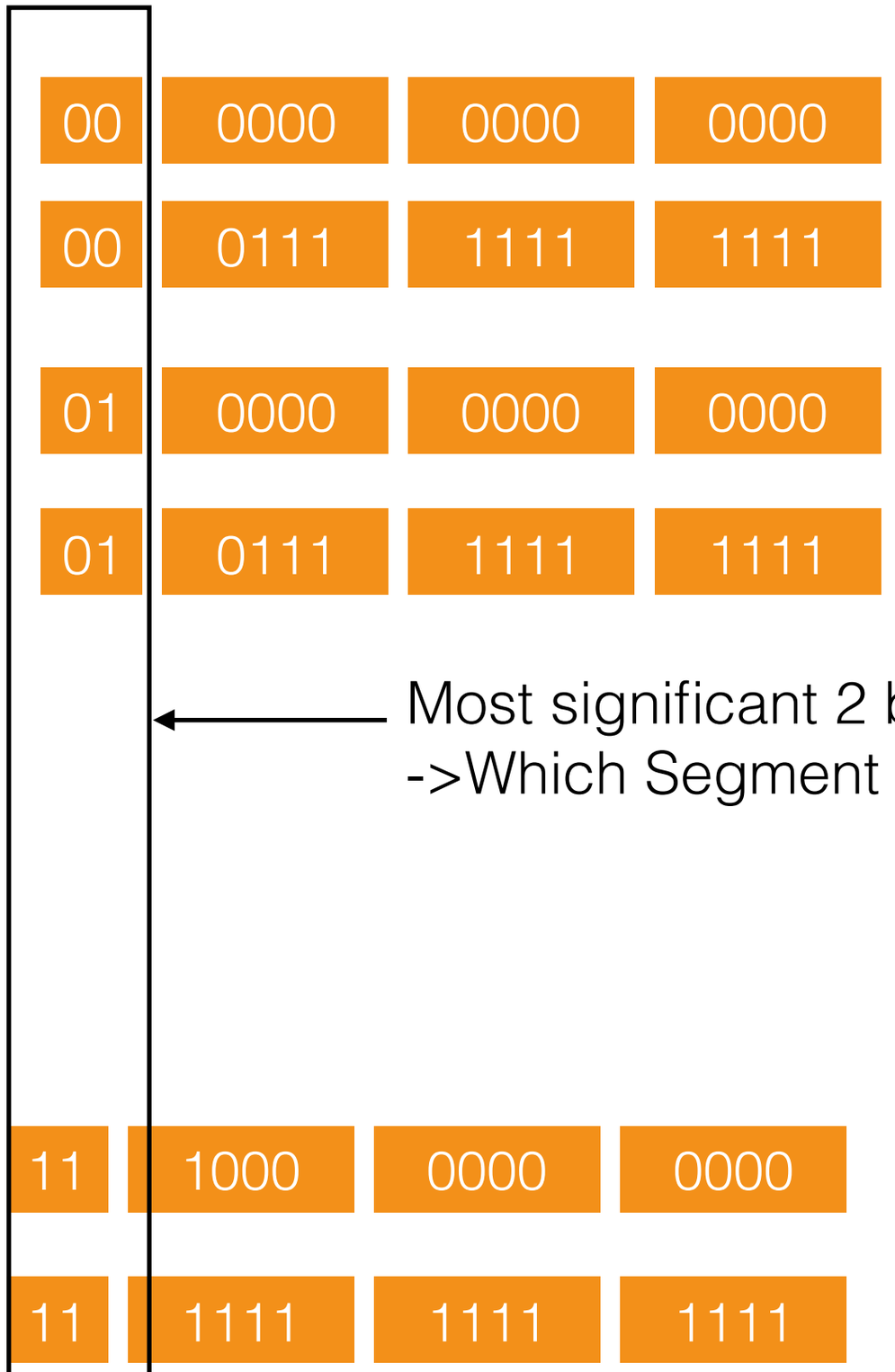
Virtual Address Space



# Segment Reference

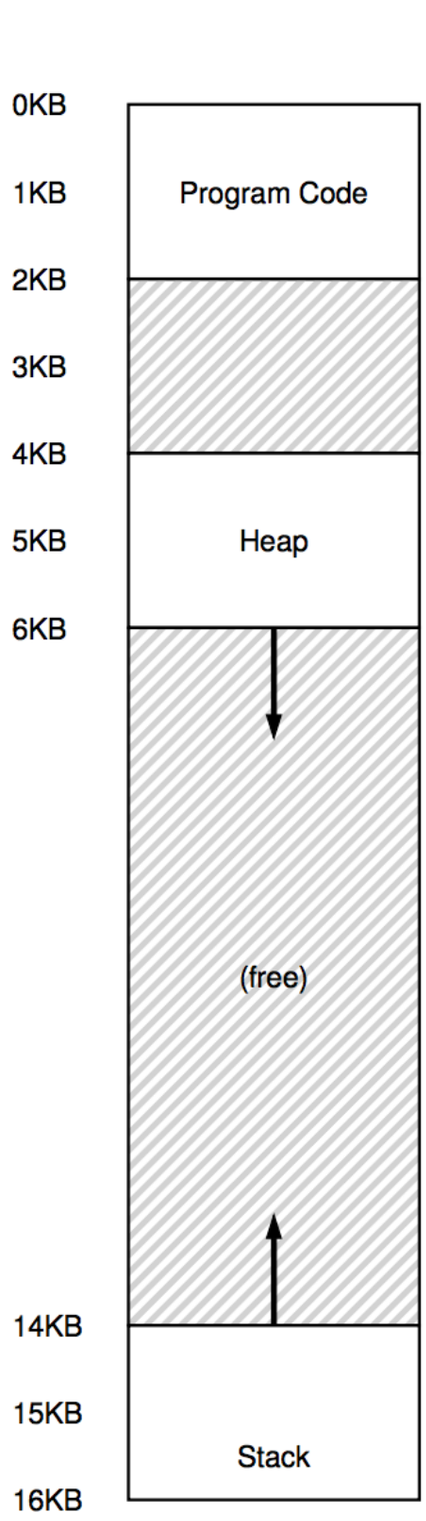
Virtual Address Space

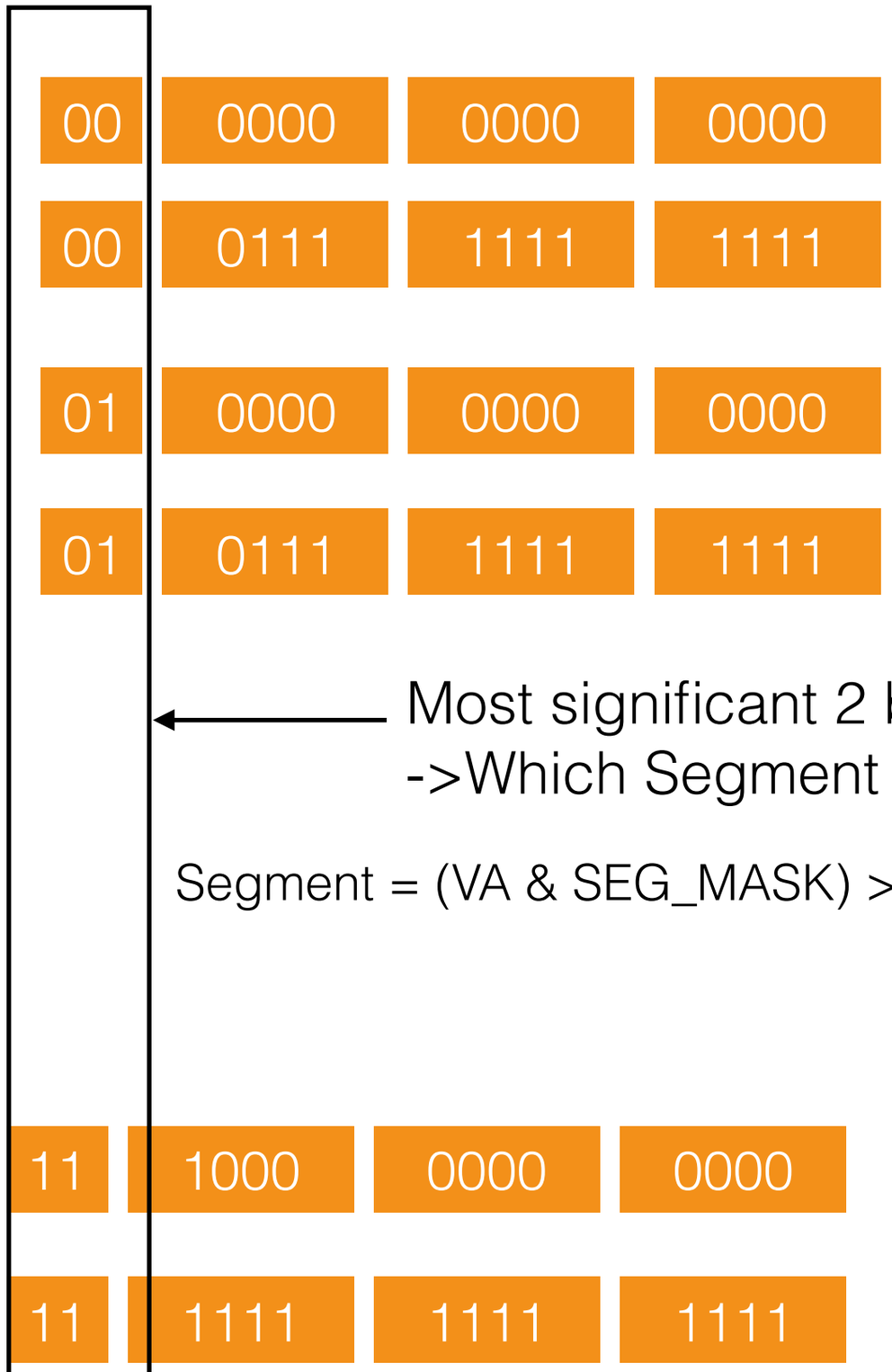


# Segment Reference

Virtual Address Space



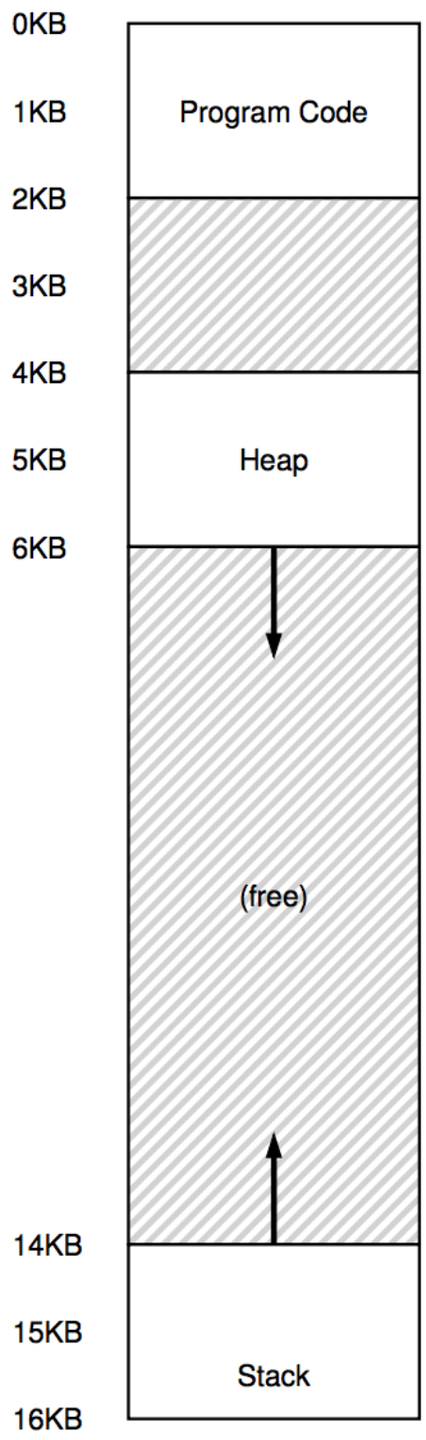



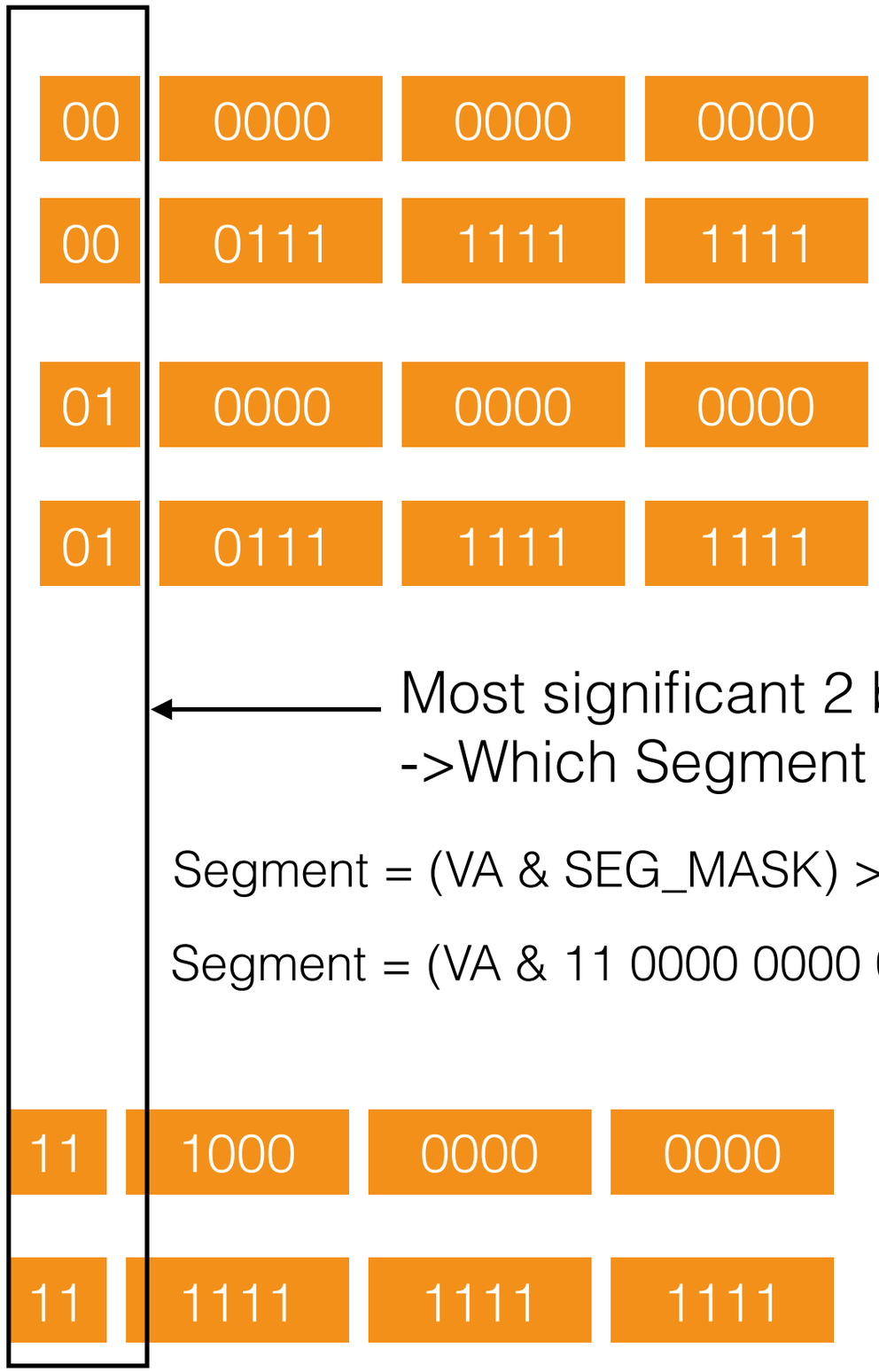

Most significant 2 bits
->Which Segment

Segment = (VA & SEG_MASK) >>SEG_SHIFT

# Segment Reference

Virtual Address Space



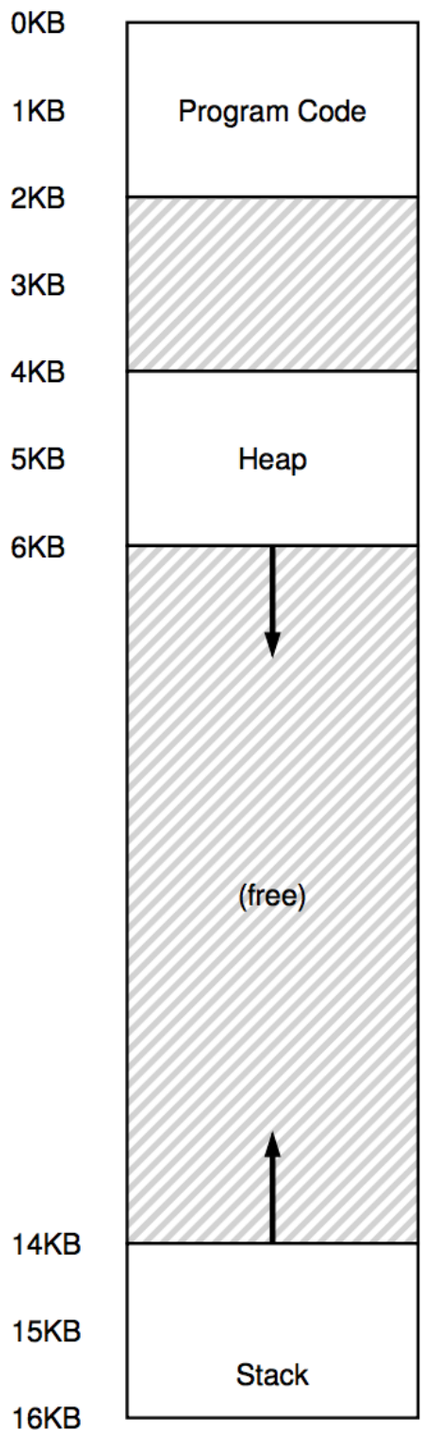




Most significant 2 bits
->Which Segment

Segment = (VA & SEG_MASK) >>SEG_SHIFT

Segment = (VA & 11 0000 0000 0000) >>12

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

01 0111 1111 1111

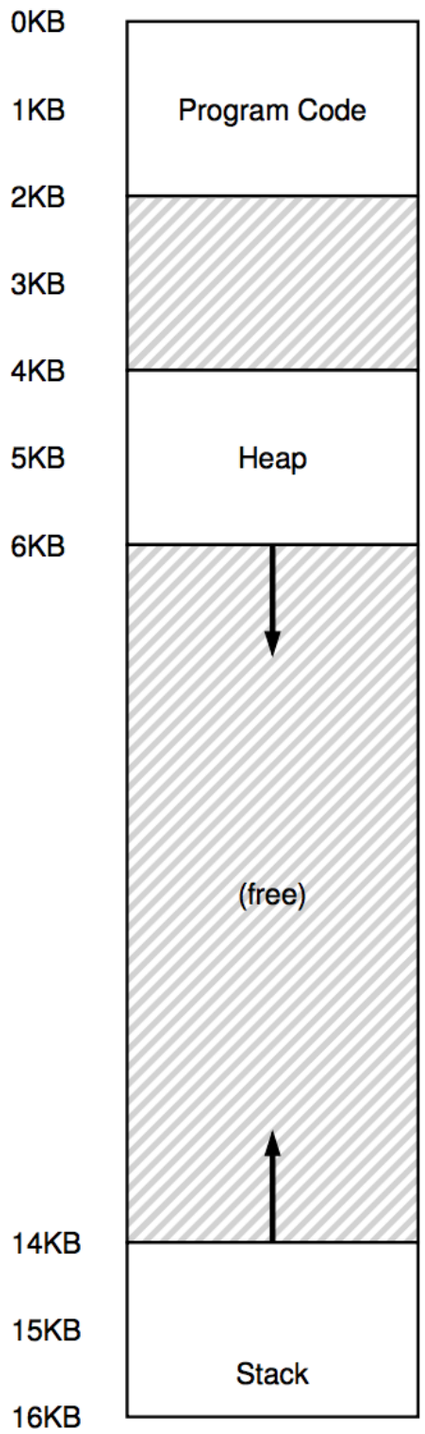
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference

00 | 0000 | 0000 | 1010




00 | 0000 | 0000 | 0000

00 | 0111 | 1111 | 1111

01 | 0000 | 0000 | 0000

01 | 0111 | 1111 | 1111

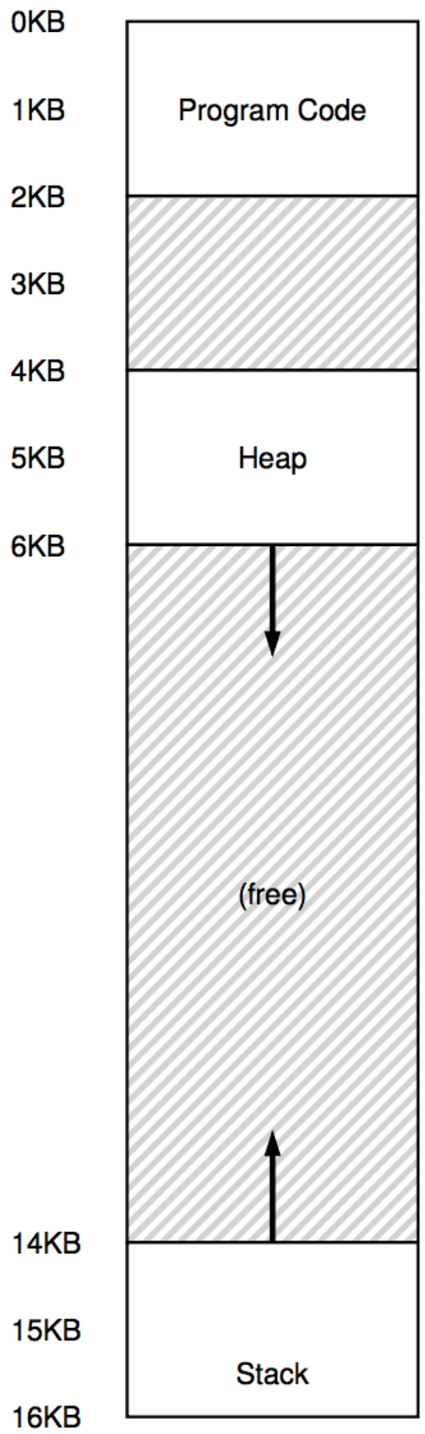
Segment = (VA & 11 0000 0000 0000) >>12

11 | 1000 | 0000 | 0000

11 | 1111 | 1111 | 1111

# Segment Reference

| 00 | 0000 | 0000 | 1010 |
|---|---|---|---|
| 11 | 0000 | 0000 | 0000 |

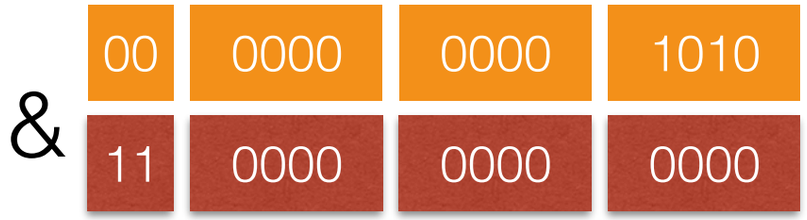


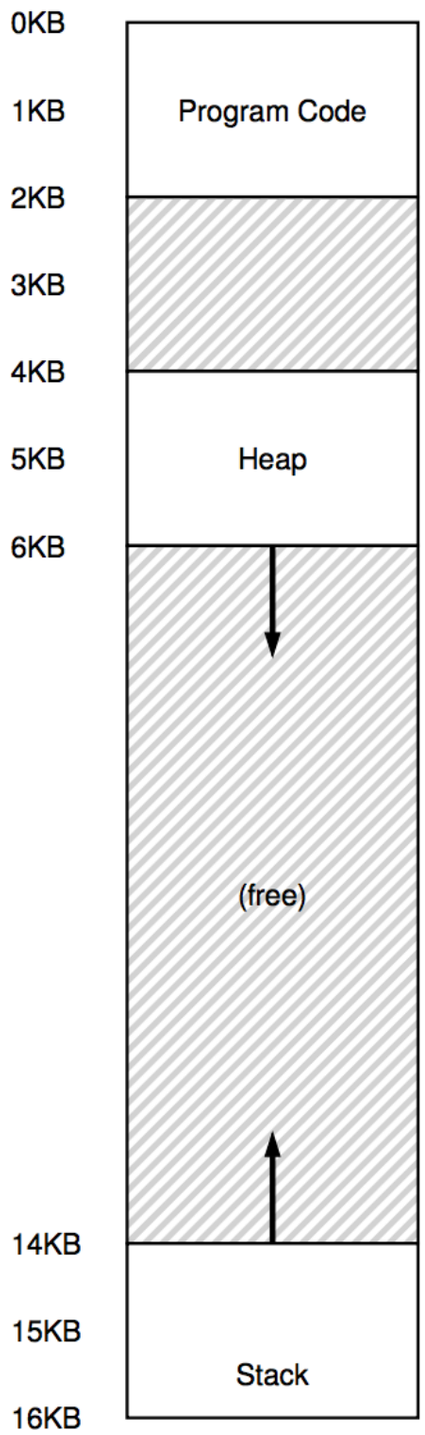

| 00 | 0000 | 0000 | 0000 |
|---|---|---|---|
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 01 | 0111 | 1111 | 1111 |

Segment = (VA & 11 0000 0000 0000) >>12

| 11 | 1000 | 0000 | 0000 |
|---|---|---|---|
| 11 | 1111 | 1111 | 1111 |

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

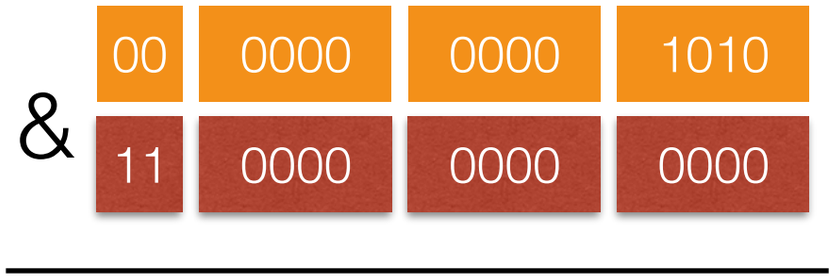
01 0111 1111 1111

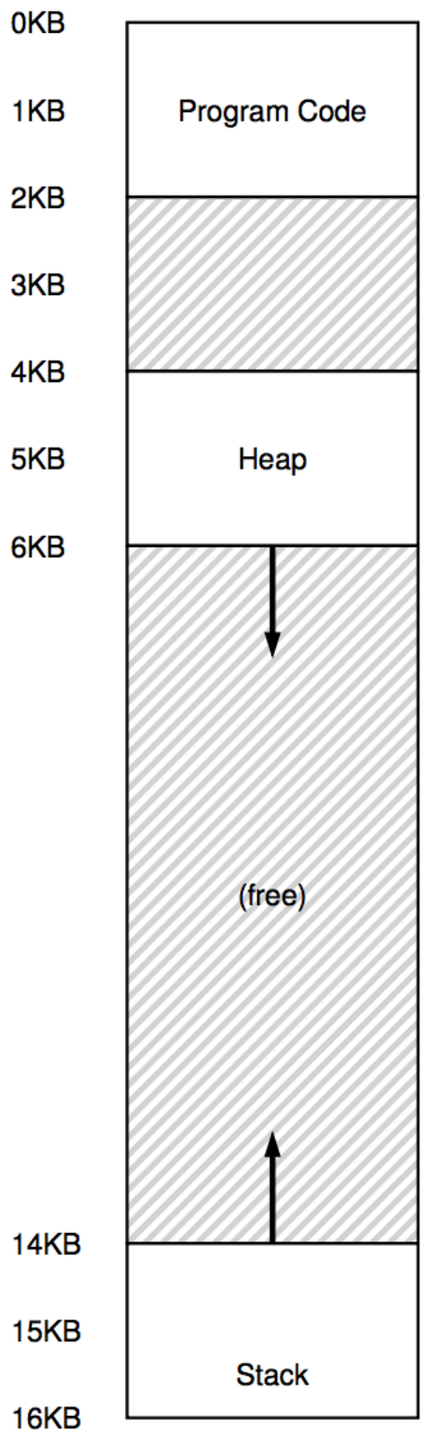
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

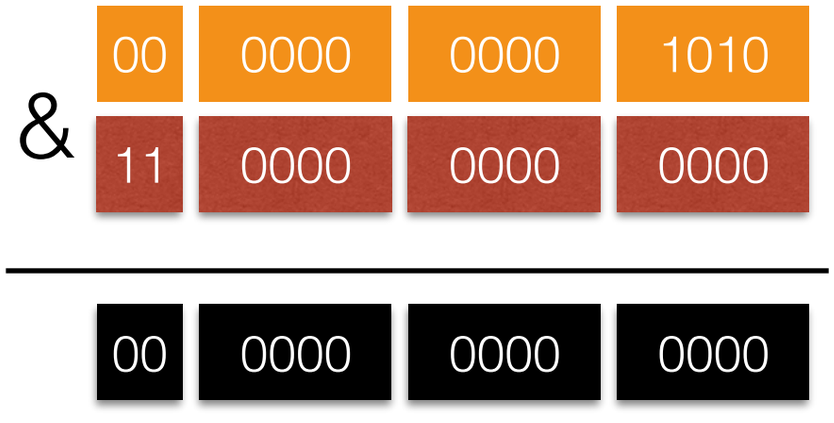
01 0111 1111 1111

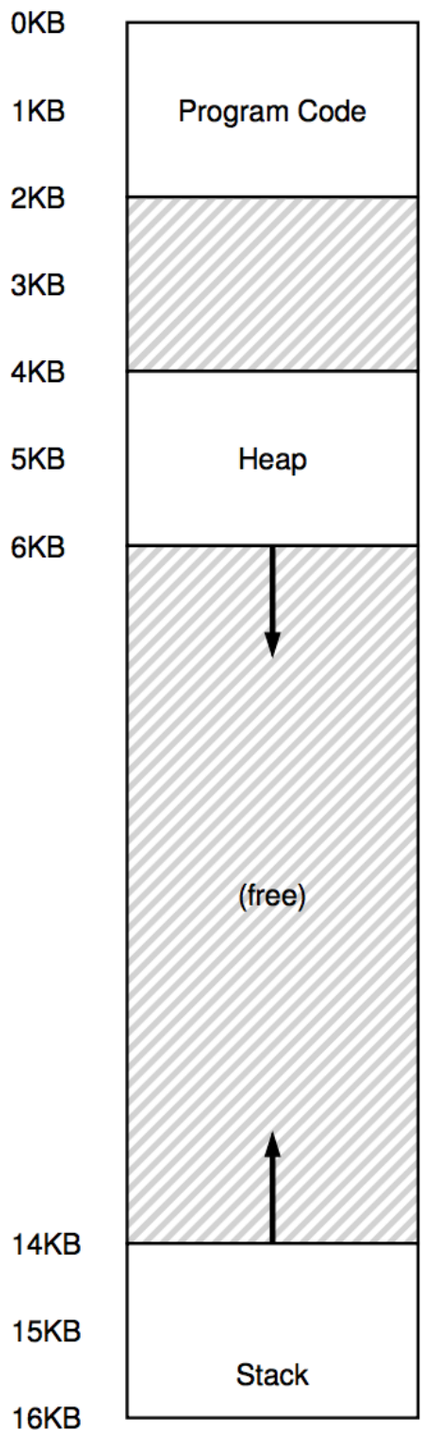
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

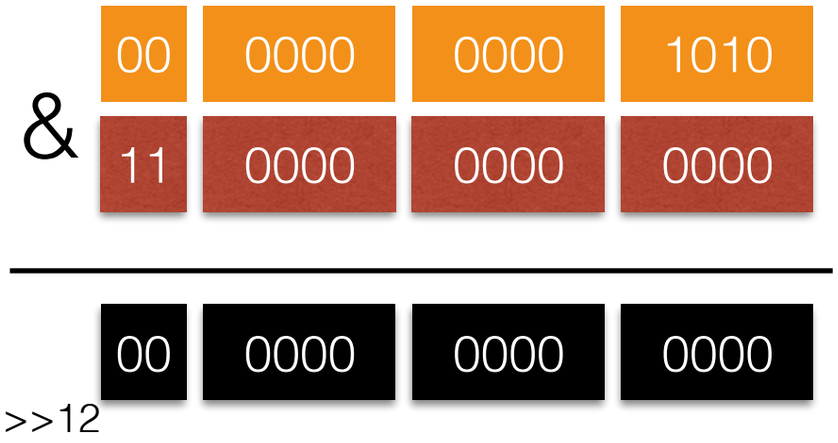
01 0111 1111 1111

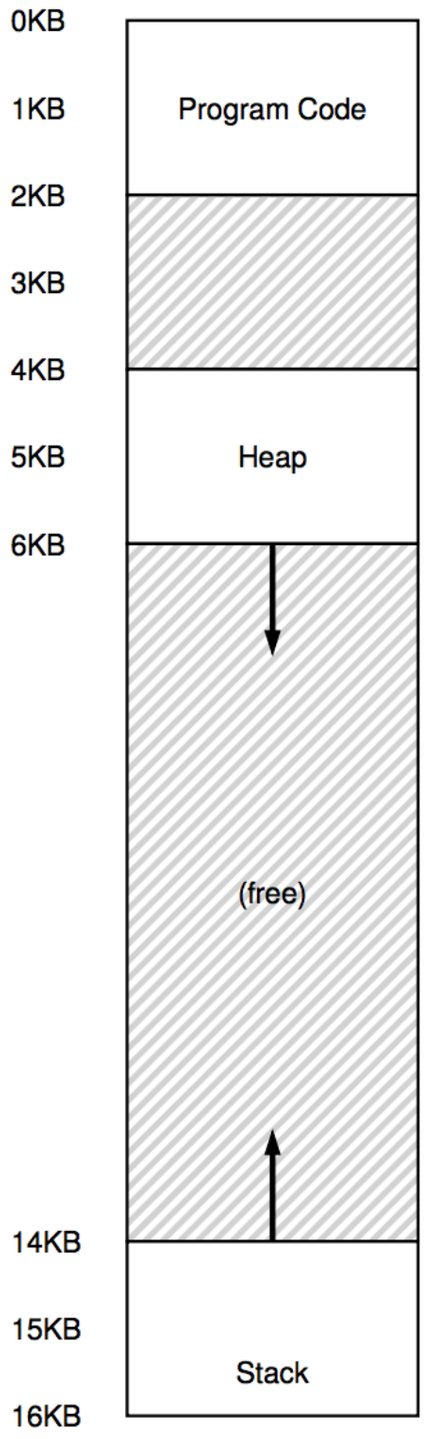
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

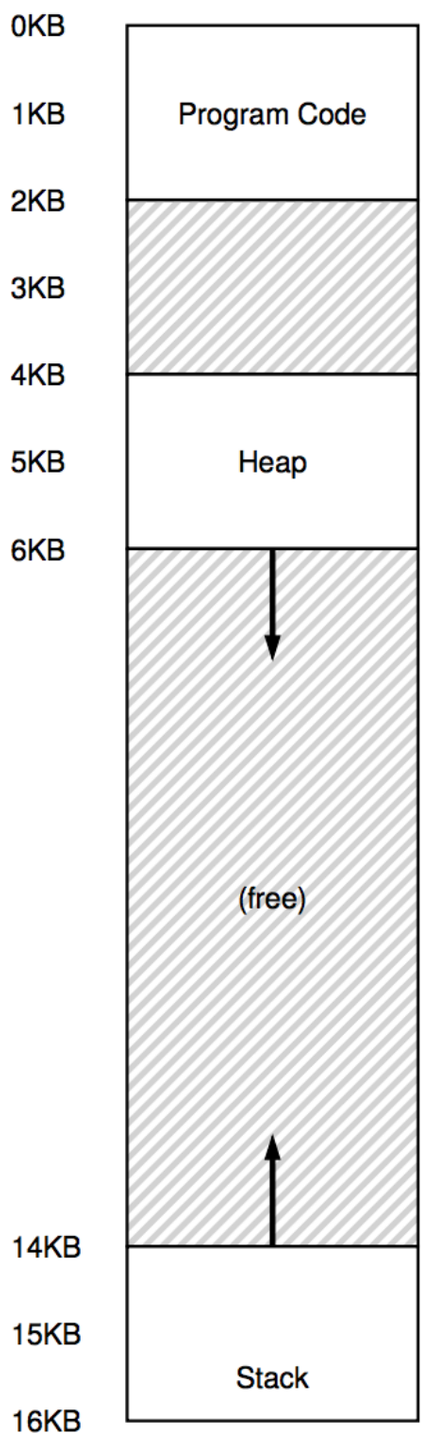
01 0111 1111 1111

Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference


00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

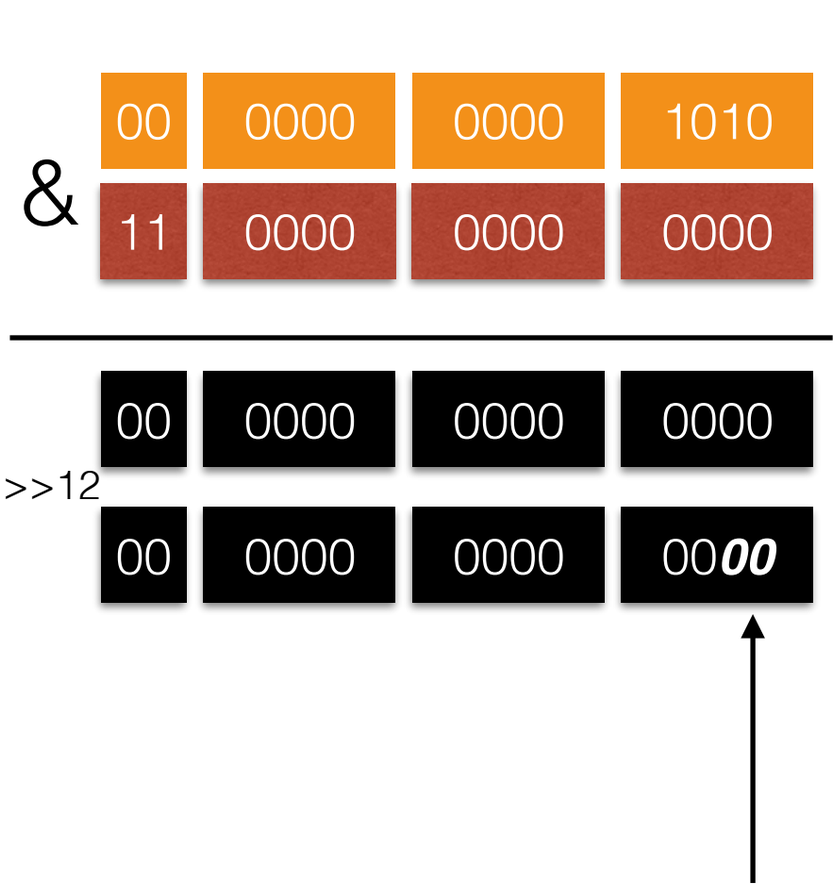
01 0111 1111 1111

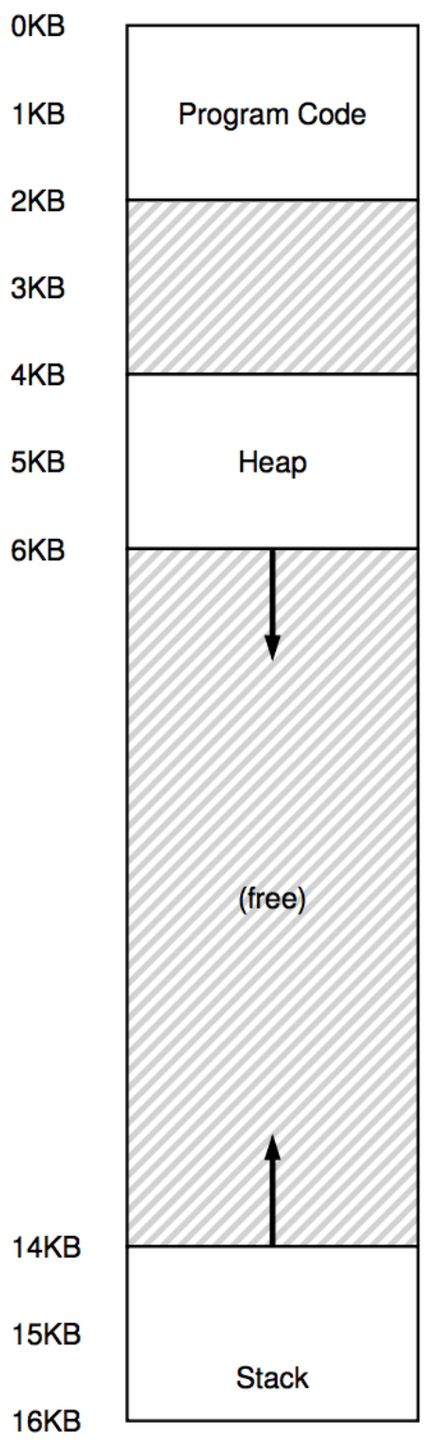
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

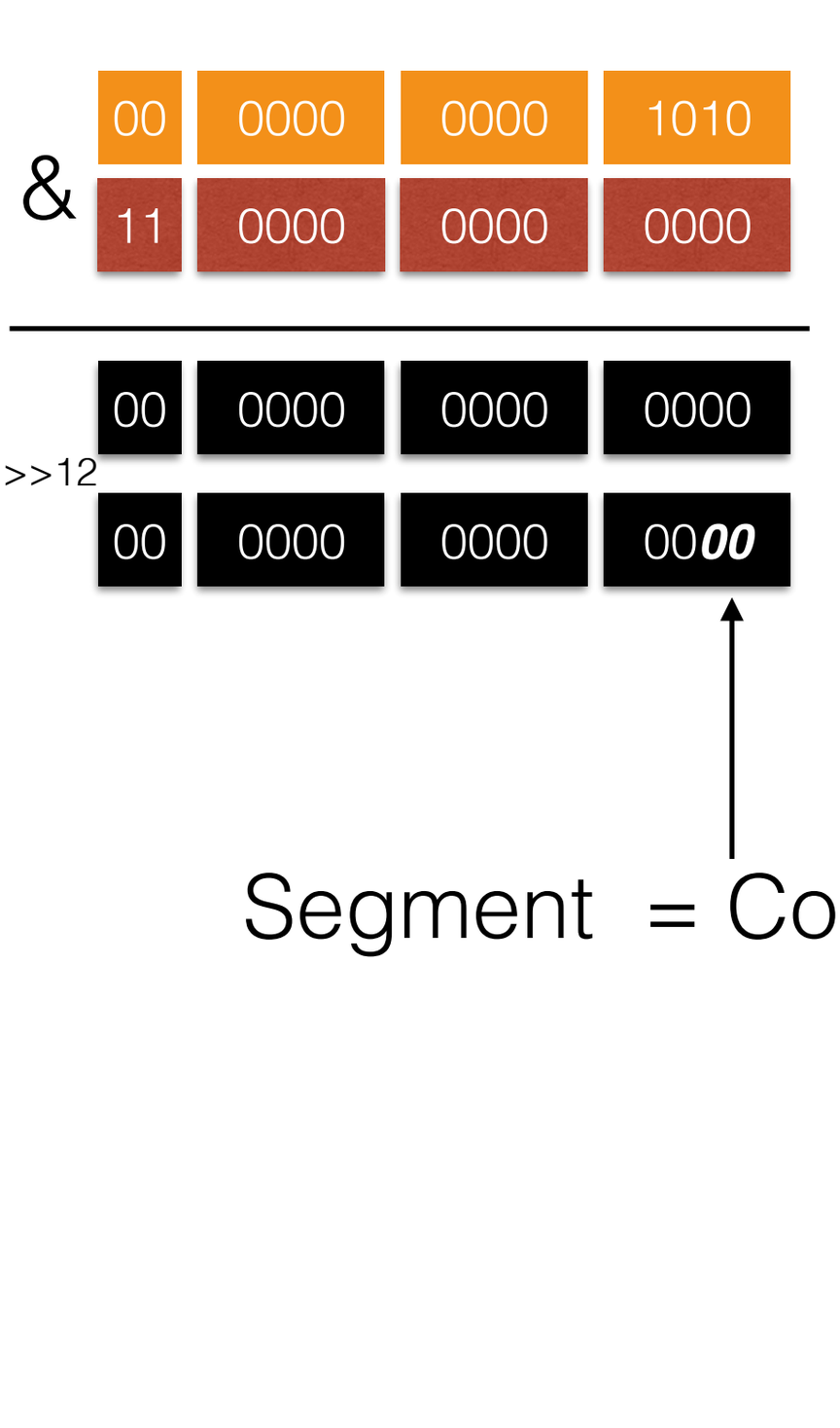
01 0111 1111 1111

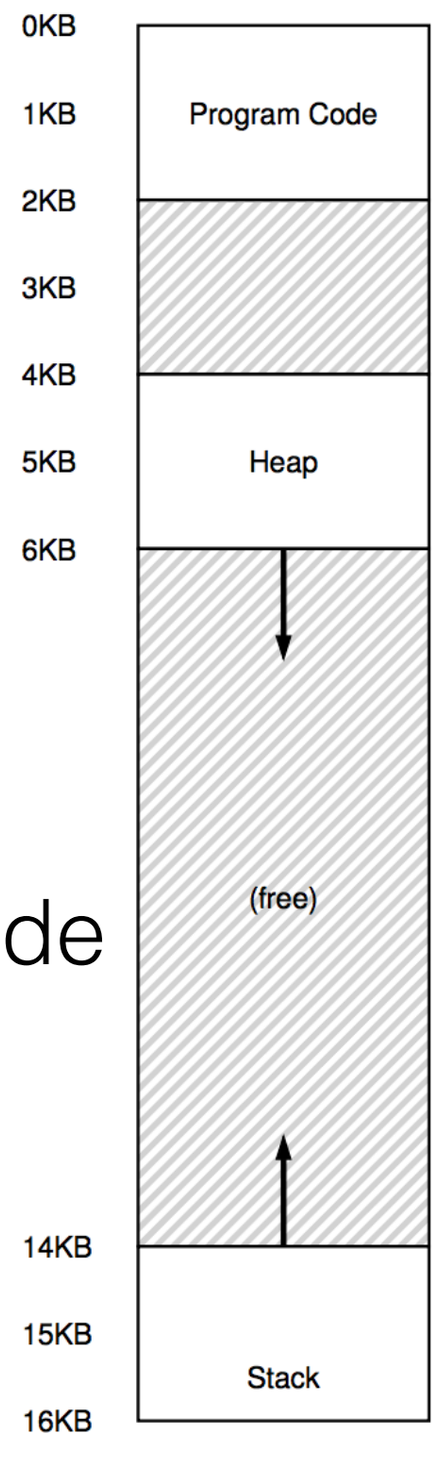
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

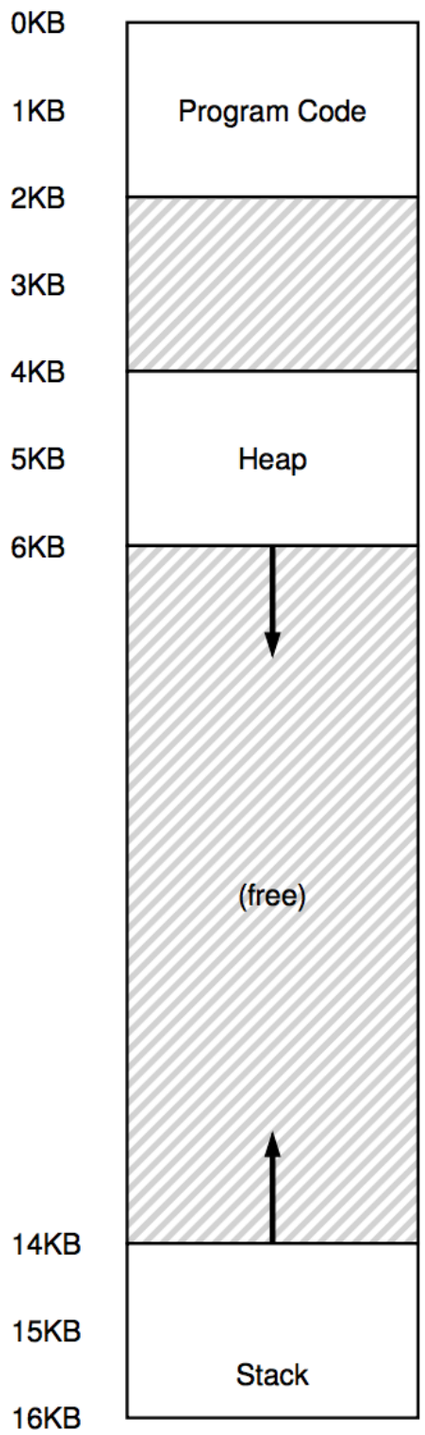
01 0111 1111 1111

Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference



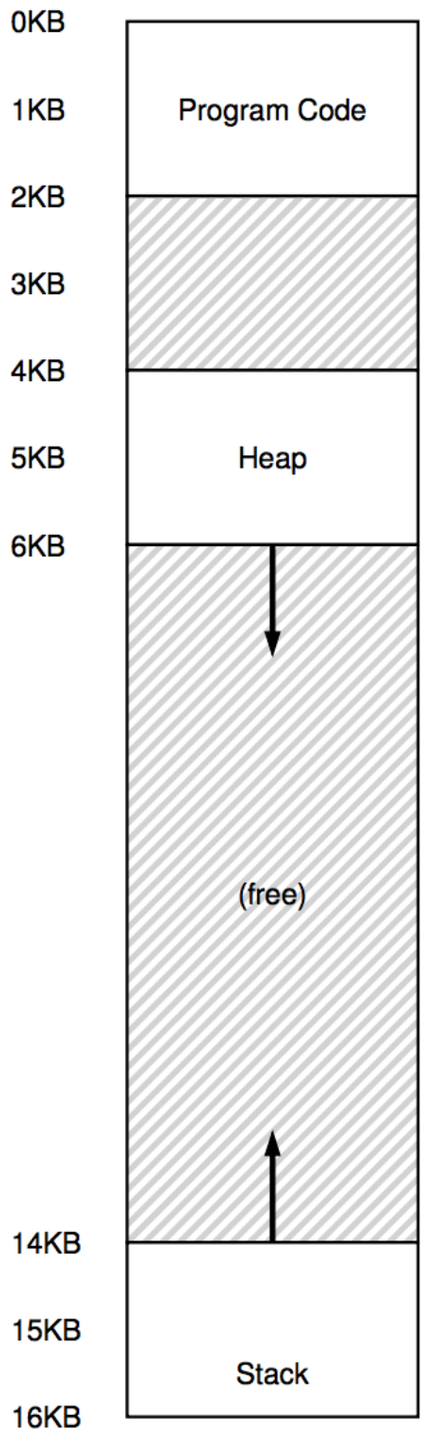

| | | | |
|---|---|---|---|
| 00 | 0000 | 0000 | 0000 |
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 01 | 0111 | 1111 | 1111 |

Segment = (VA & 11 0000 0000 0000) >>12

| | | | |
|---|---|---|---|
| 11 | 1000 | 0000 | 0000 |
| 11 | 1111 | 1111 | 1111 |

# Segment Reference

01 | 0000 | 1010 | 1010




00 | 0000 | 0000 | 0000

00 | 0111 | 1111 | 1111

01 | 0000 | 0000 | 0000

01 | 0111 | 1111 | 1111

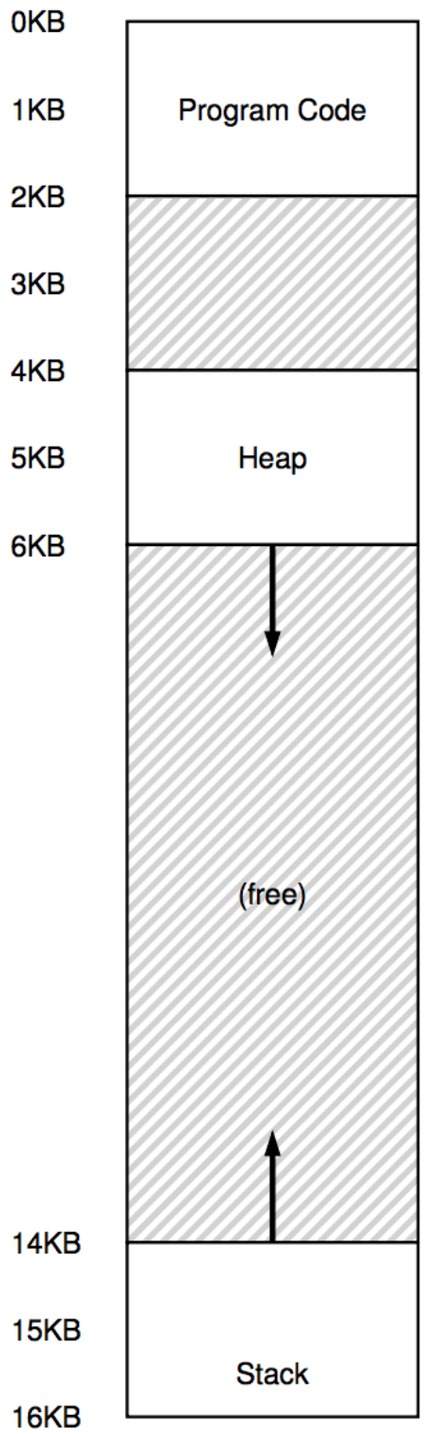
Segment = (VA & 11 0000 0000 0000) >>12

11 | 1000 | 0000 | 0000

11 | 1111 | 1111 | 1111

# Segment Reference

| | | | |
|---|---|---|---|
| 01 | 0000 | 1010 | 1010 |
| 11 | 0000 | 0000 | 0000 |

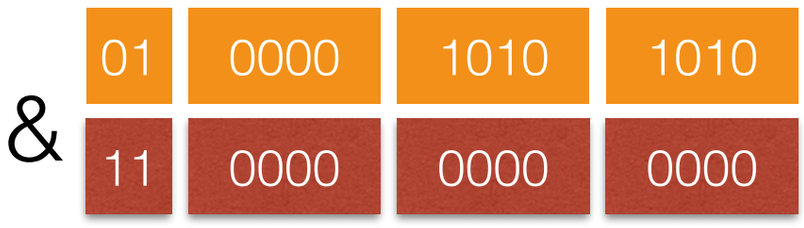


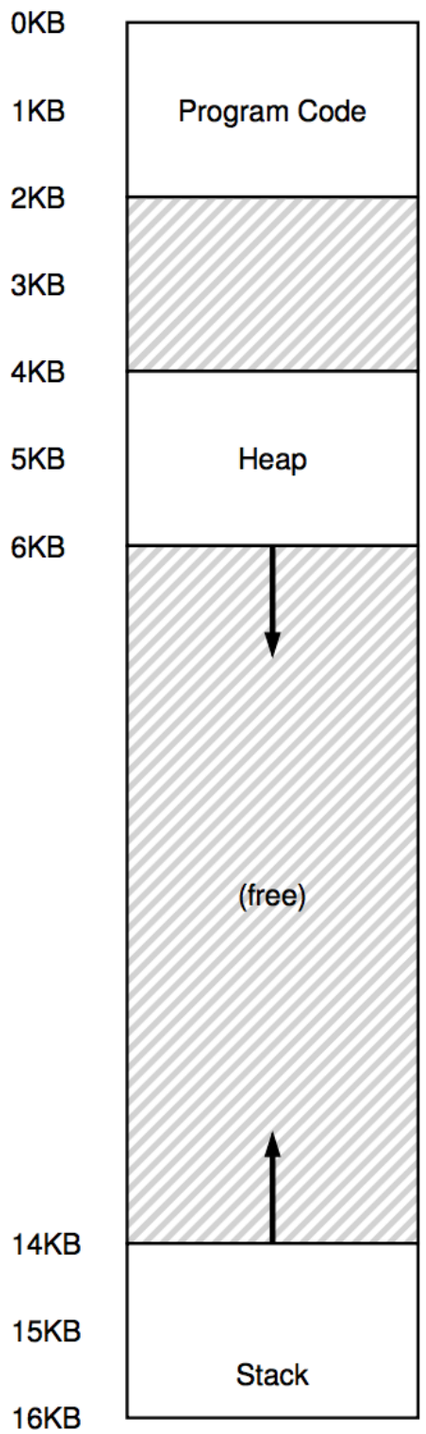

| | | | |
|---|---|---|---|
| 00 | 0000 | 0000 | 0000 |
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 01 | 0111 | 1111 | 1111 |

Segment = (VA & 11 0000 0000 0000) >>12

| | | | |
|---|---|---|---|
| 11 | 1000 | 0000 | 0000 |
| 11 | 1111 | 1111 | 1111 |

# Segment Reference




| | | | |
|---|---|---|---|
| 00 | 0000 | 0000 | 0000 |
| 00 | 0111 | 1111 | 1111 |
| 01 | 0000 | 0000 | 0000 |
| 01 | 0111 | 1111 | 1111 |

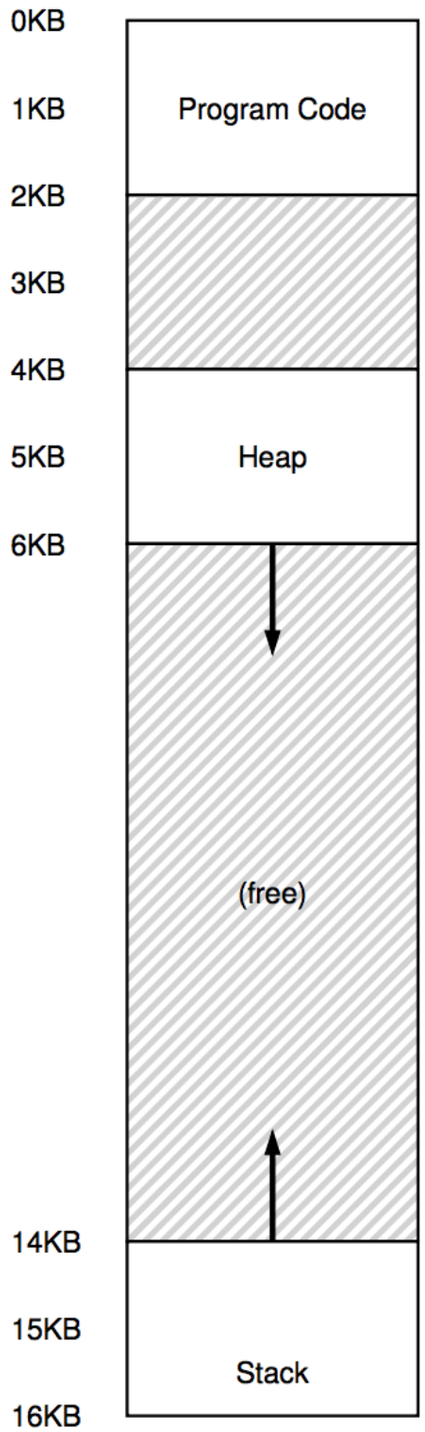
Segment = (VA & 11 0000 0000 0000) >>12

| | | | |
|---|---|---|---|
| 11 | 1000 | 0000 | 0000 |
| 11 | 1111 | 1111 | 1111 |

# Segment Reference

01 0000 1010 1010

& 11 0000 0000 0000




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

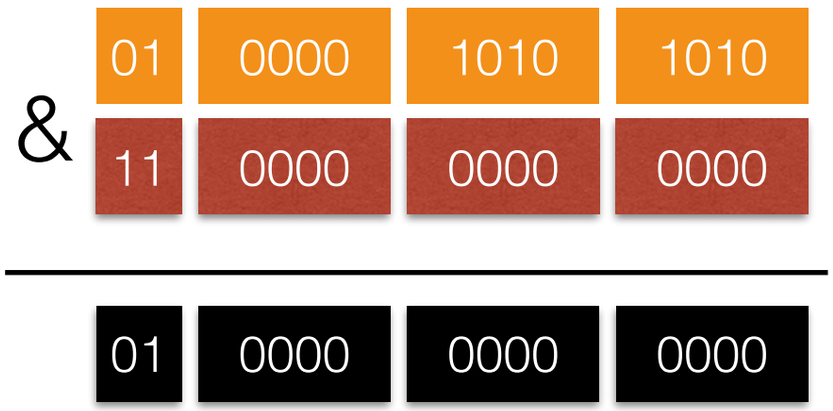
01 0111 1111 1111

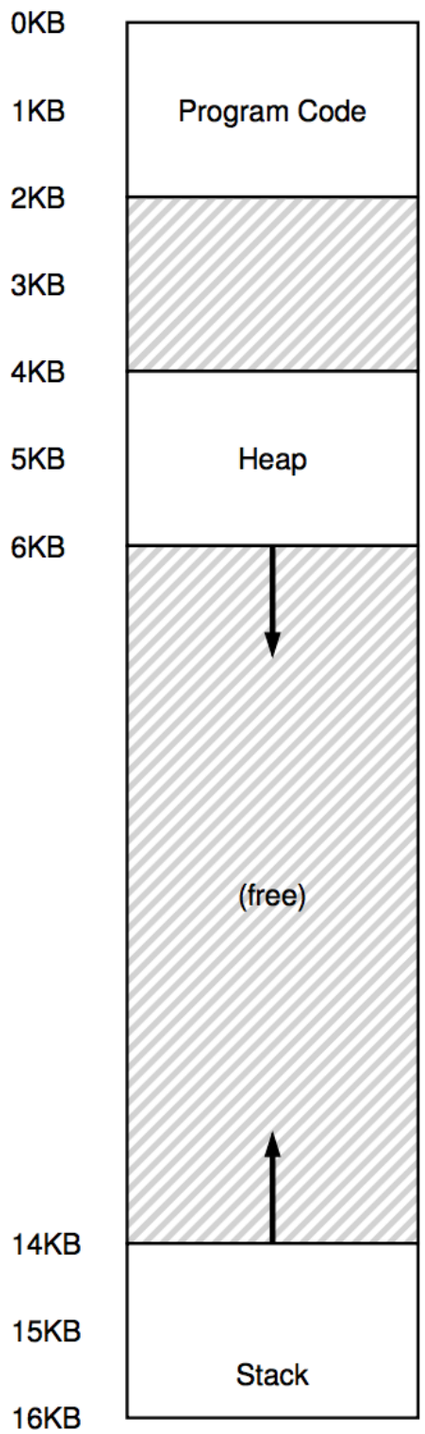
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

01 0111 1111 1111

Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

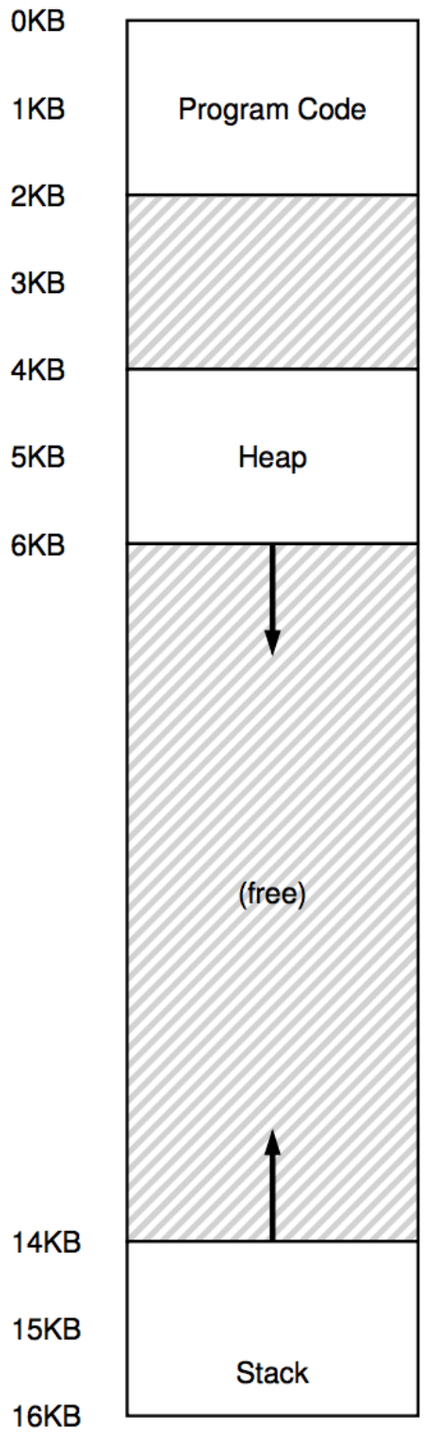
# Segment Reference

01 0000 1010 1010

& 11 0000 0000 0000

01 0000 0000 0000

>>12




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

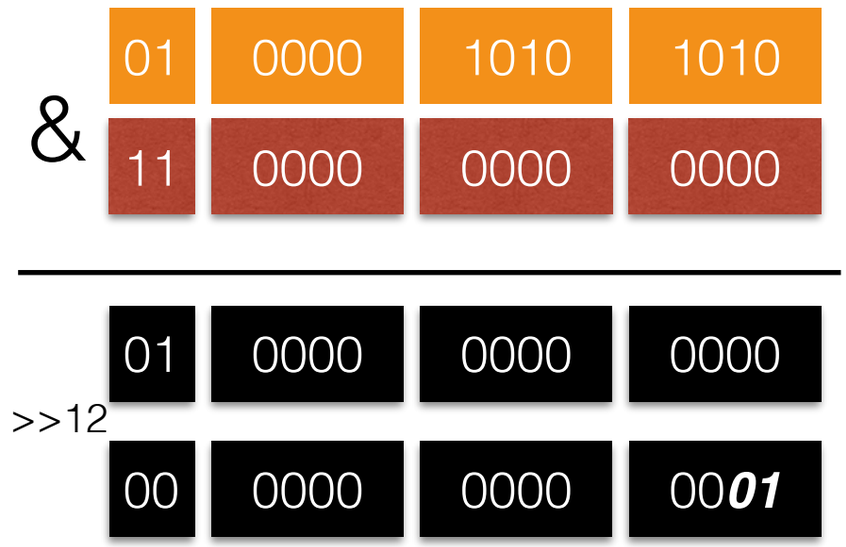
01 0111 1111 1111

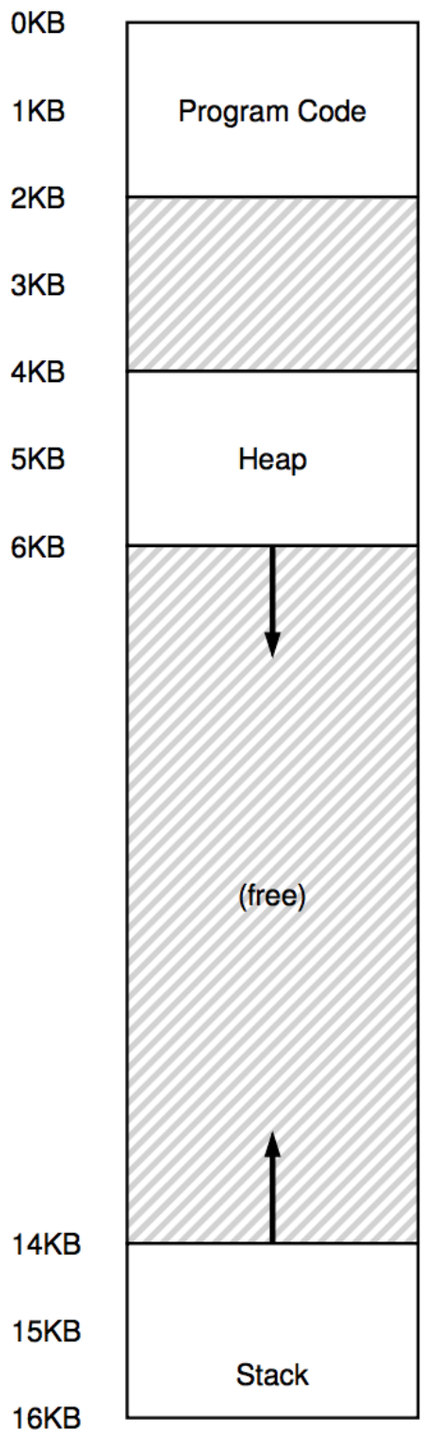
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

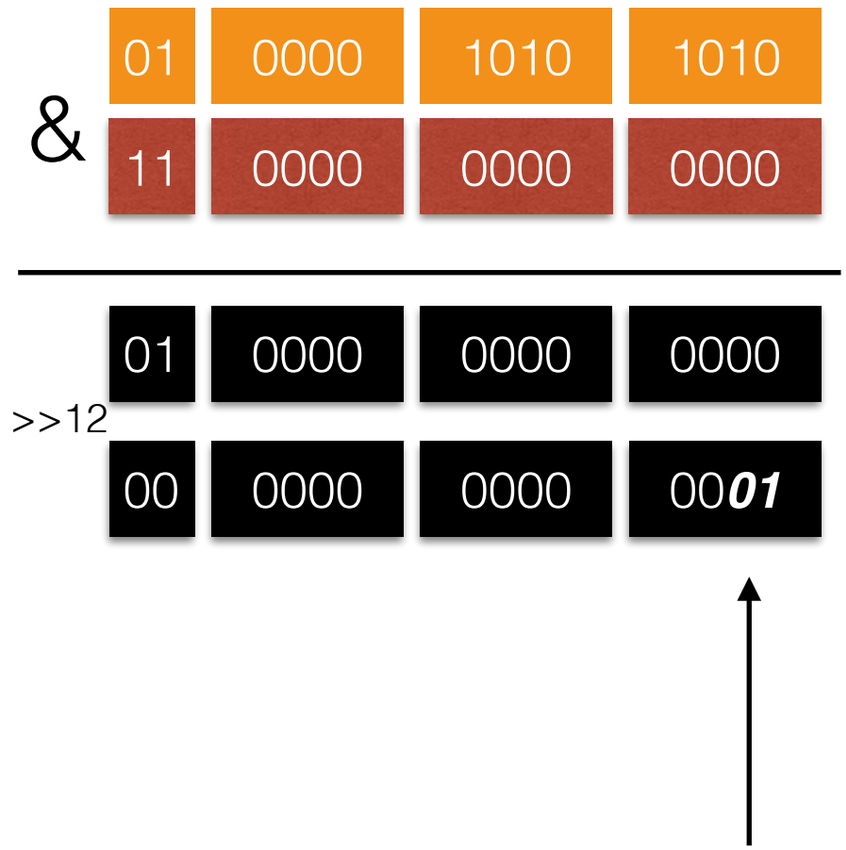
01 0111 1111 1111

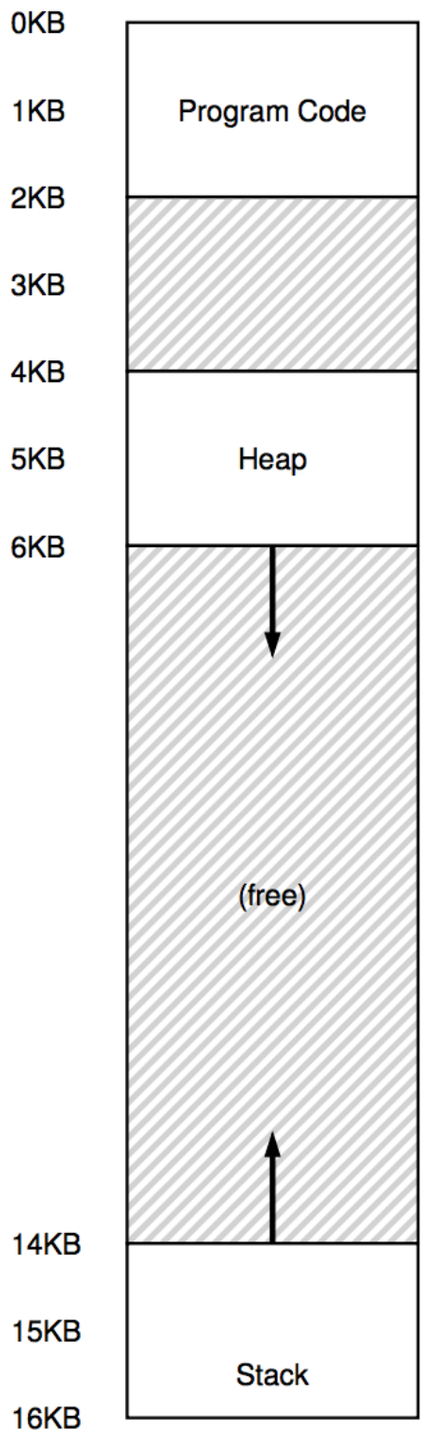
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

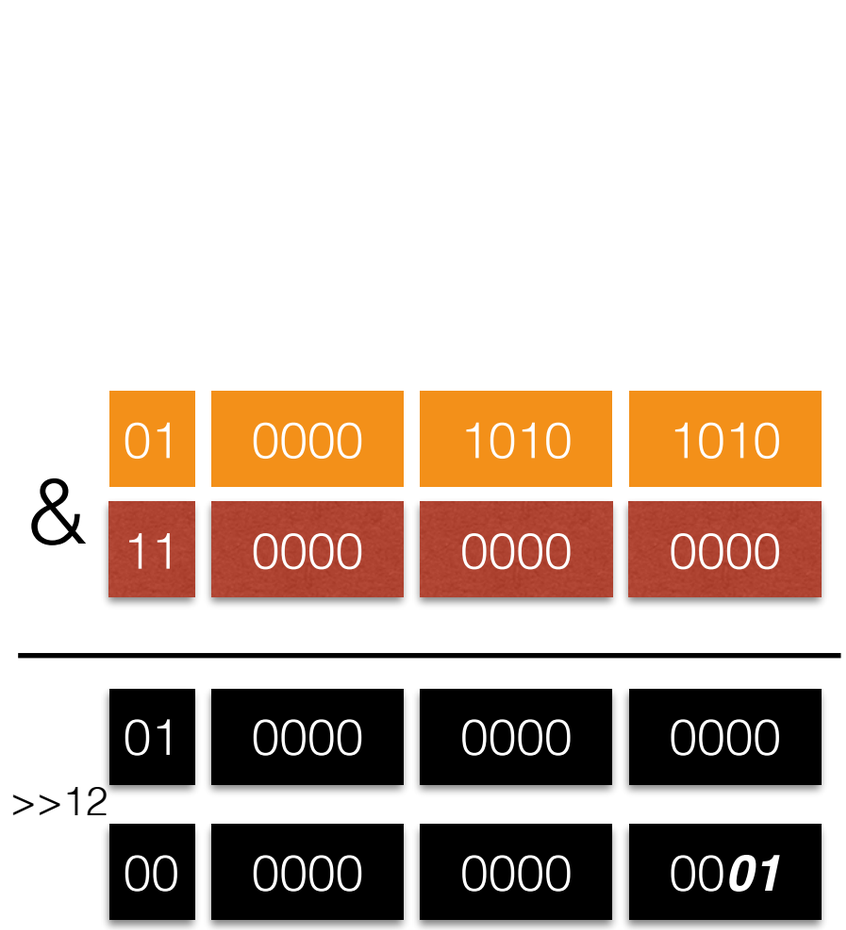
01 0111 1111 1111

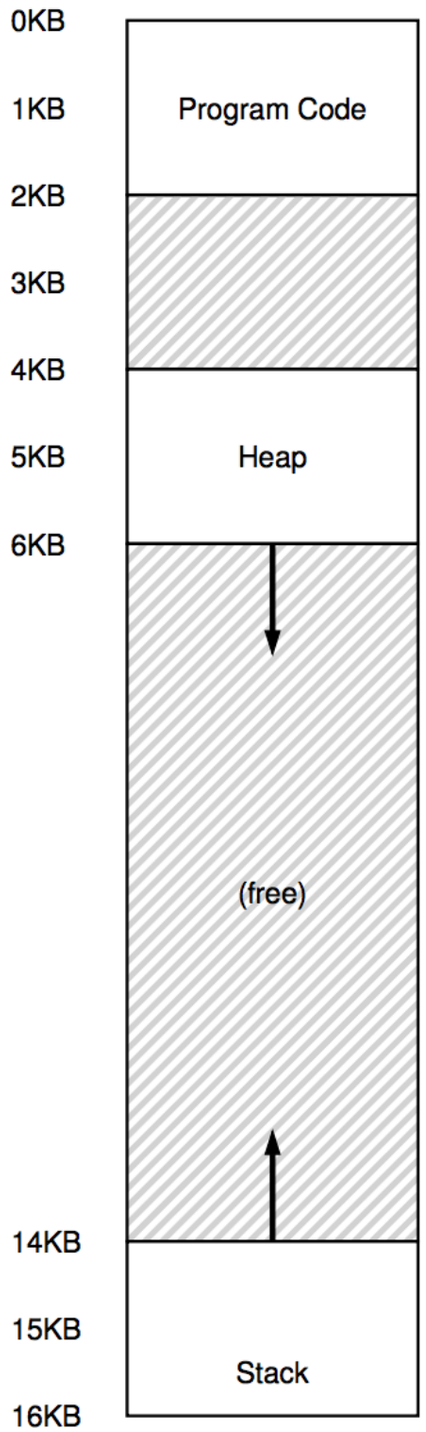
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

# Segment Reference




00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

01 0111 1111 1111

Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111