Operating Systems
Memory Virtualisation
Base & Bounds + Segmentation

Nipun Batra

General Address Translation

Kernel

CPU

MMU

Physical Memory

General Address Translation

Kernel

CPU

MMU

Physical Memory

Virtual Address

General Address Translation

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Physical Memory

Virtual Address
0x10102030

General Address Translation

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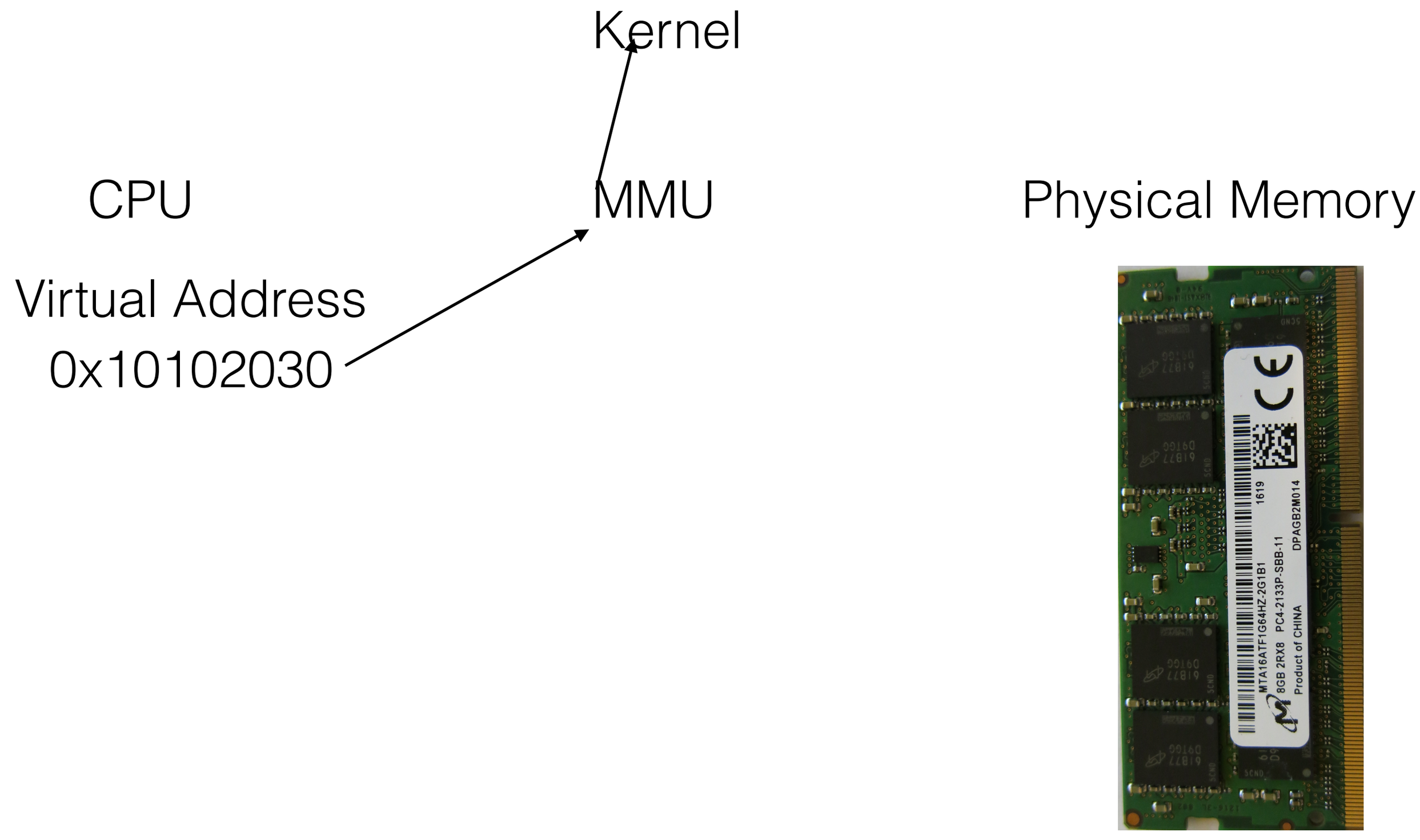

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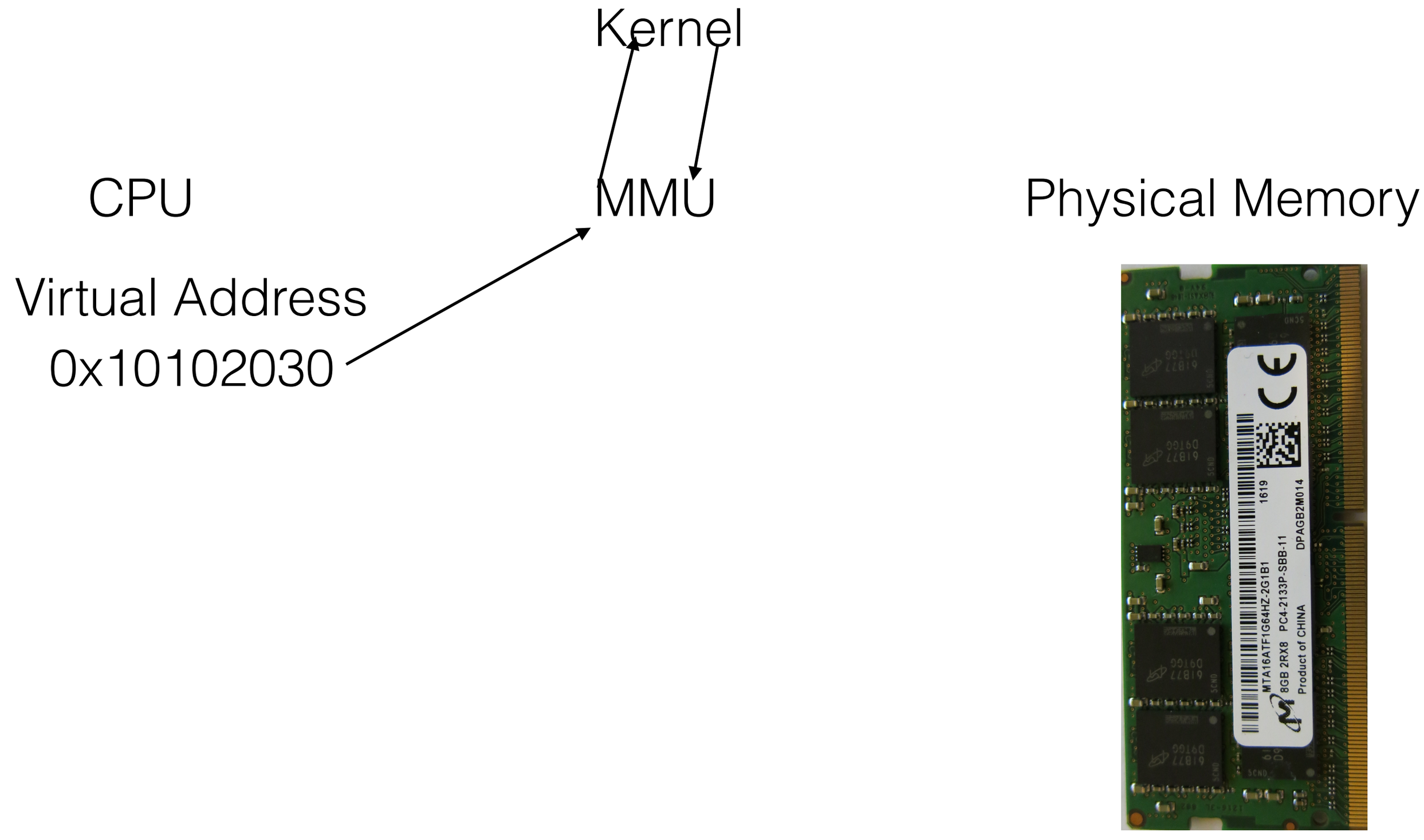

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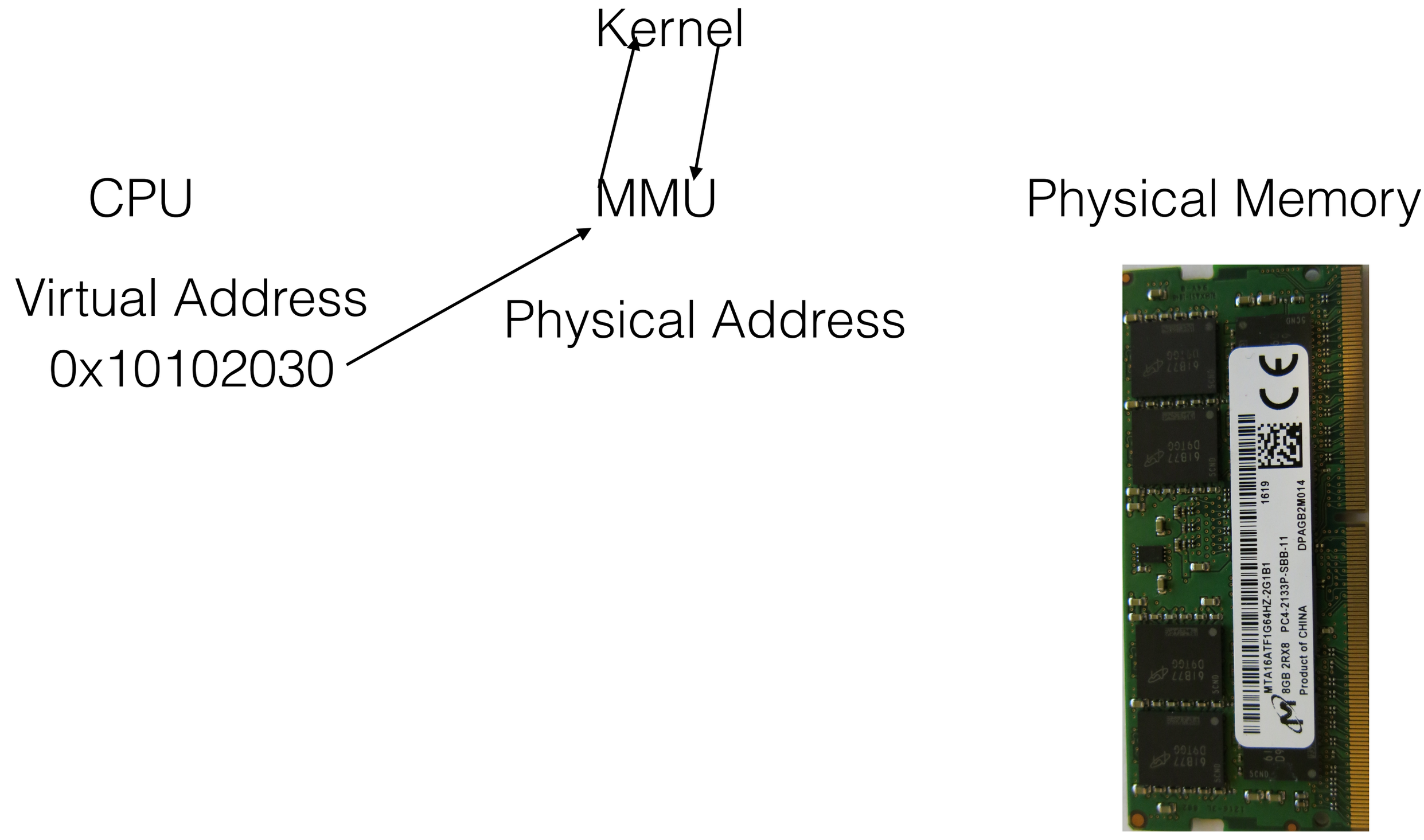

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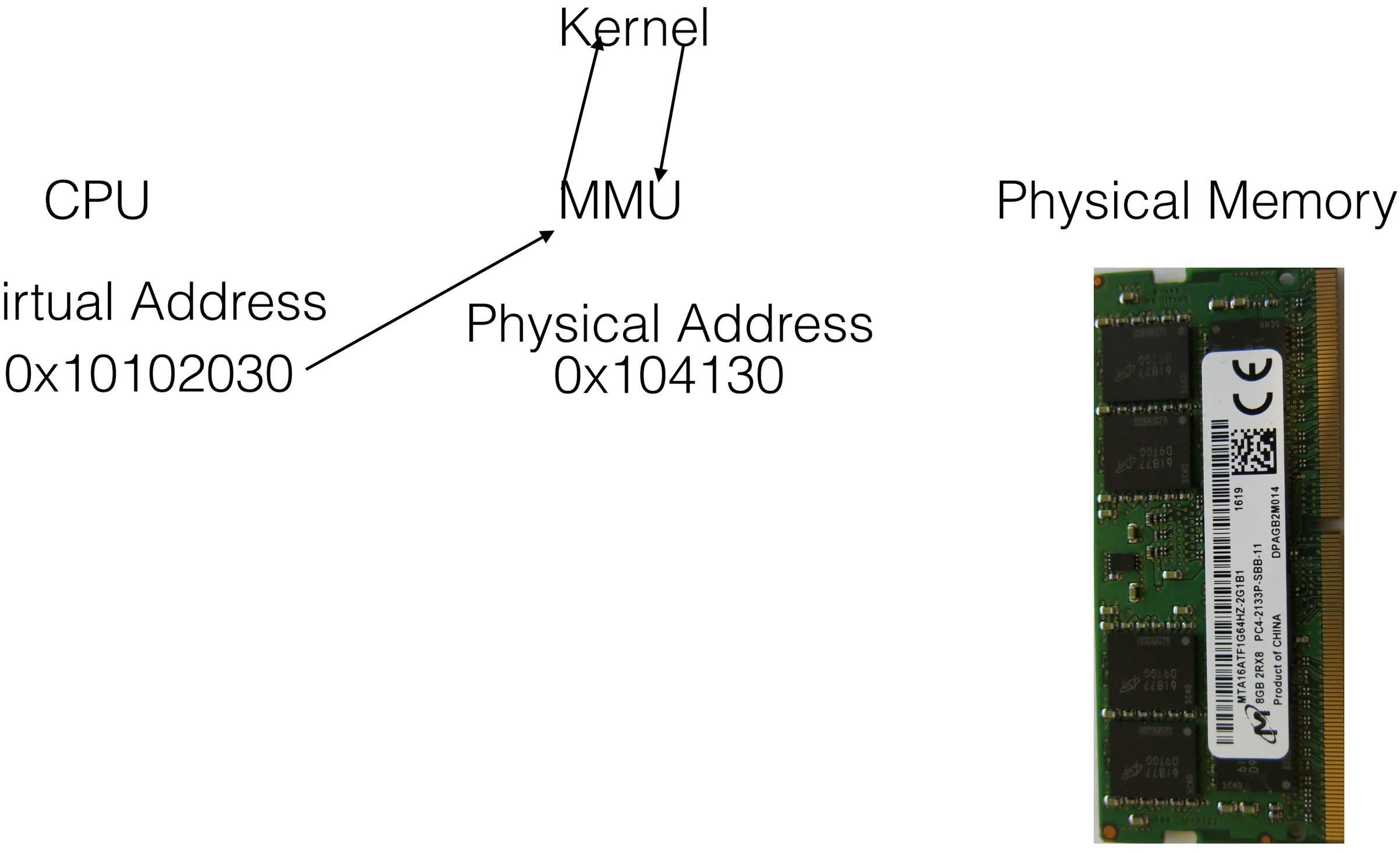

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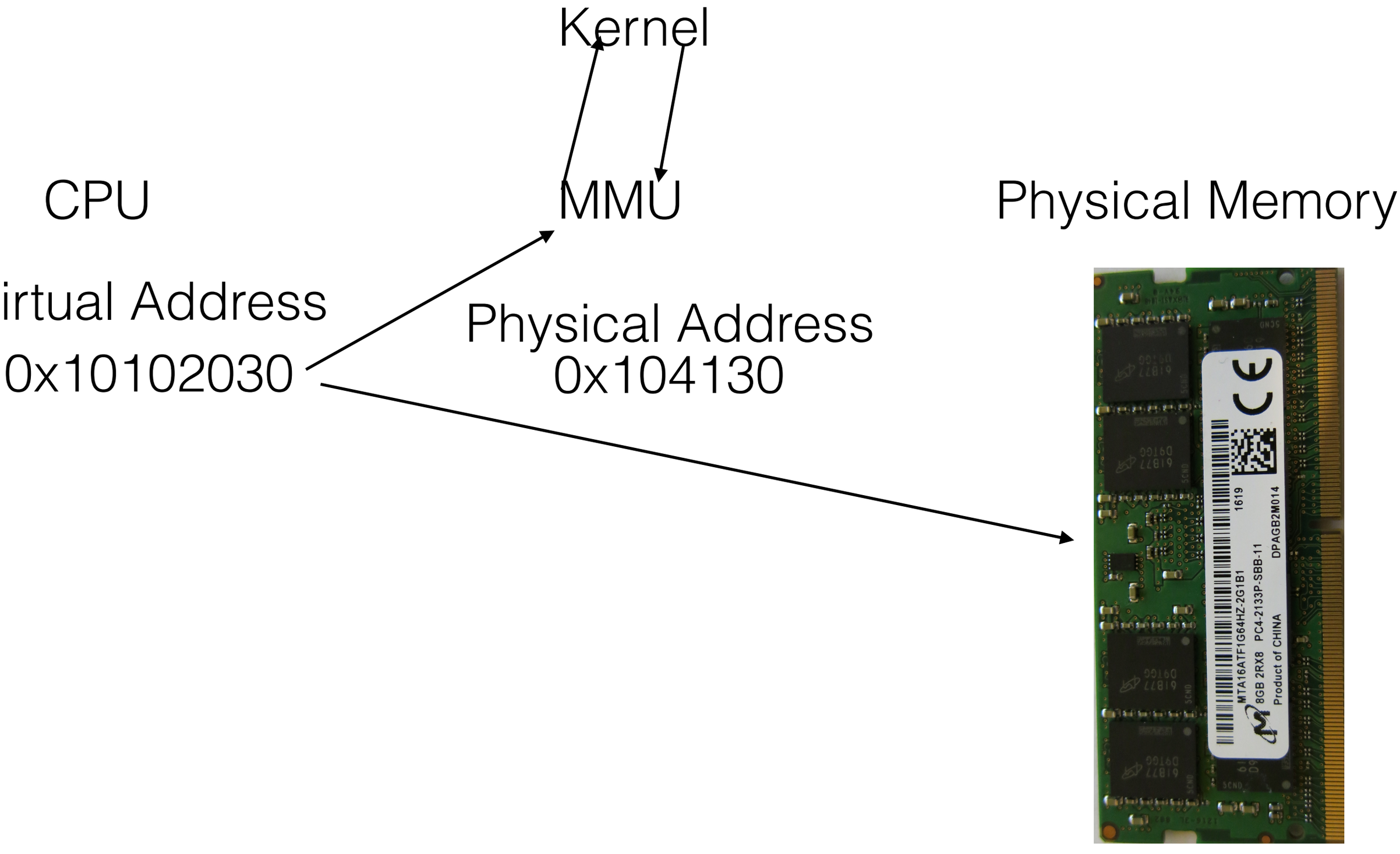

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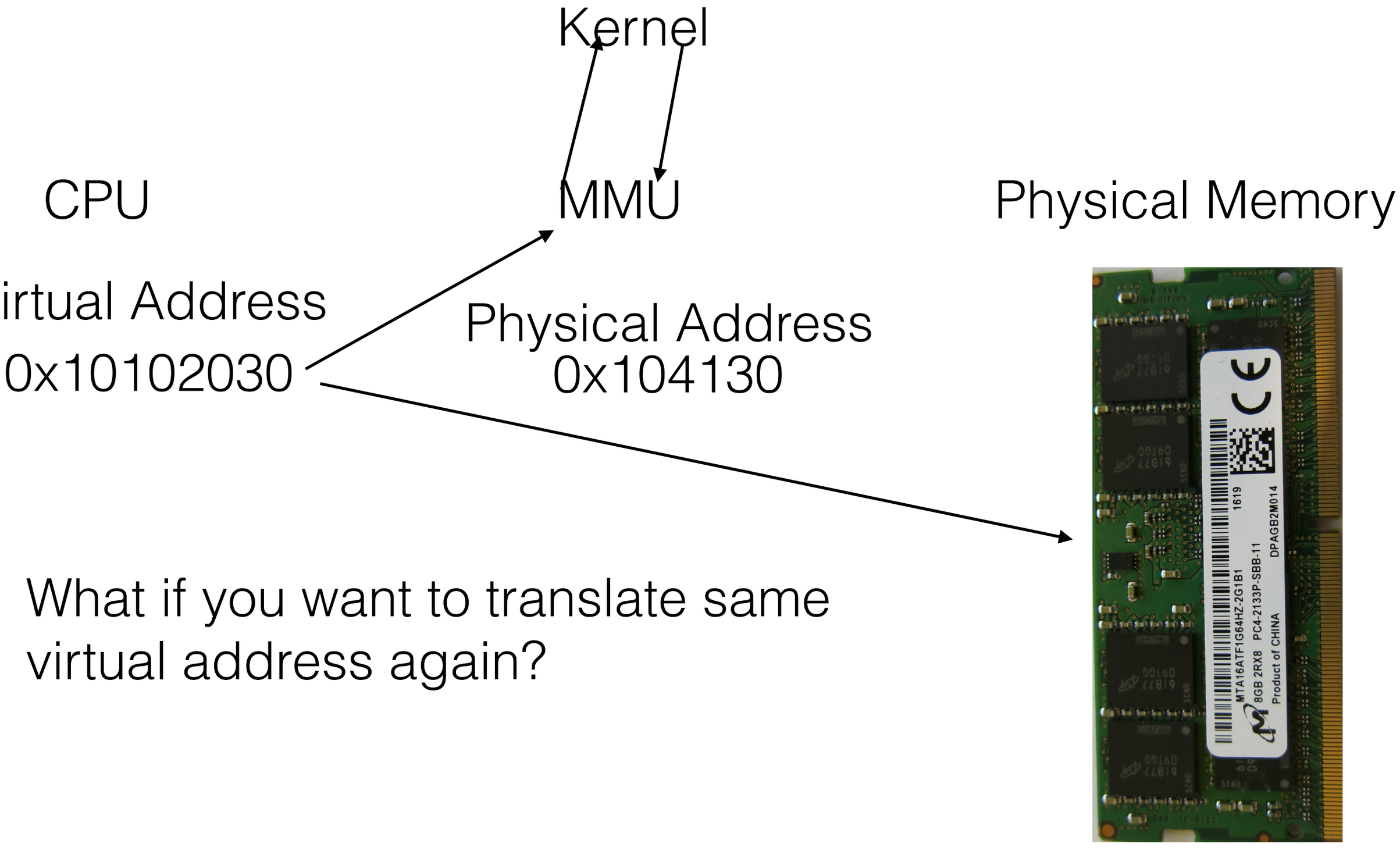

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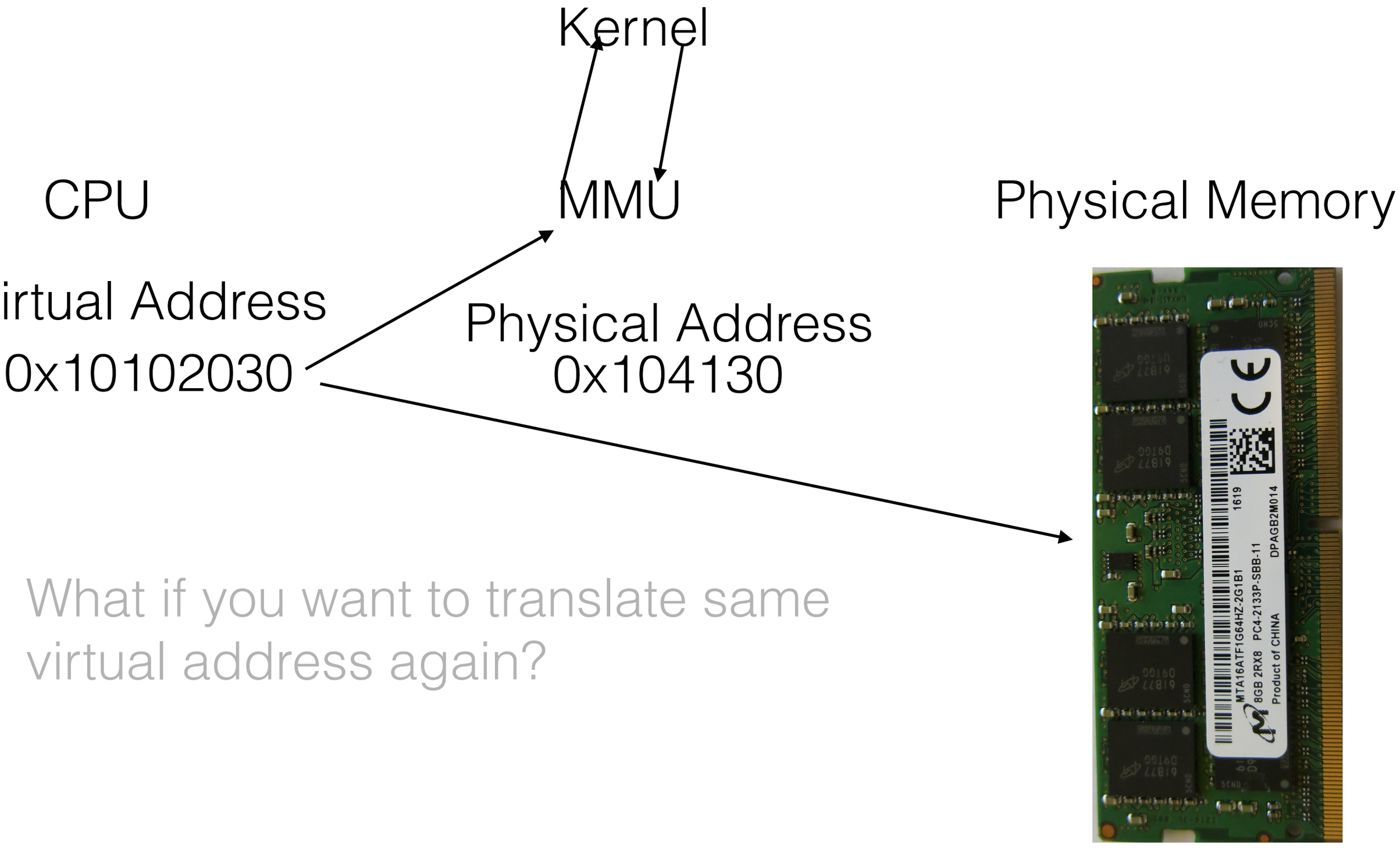

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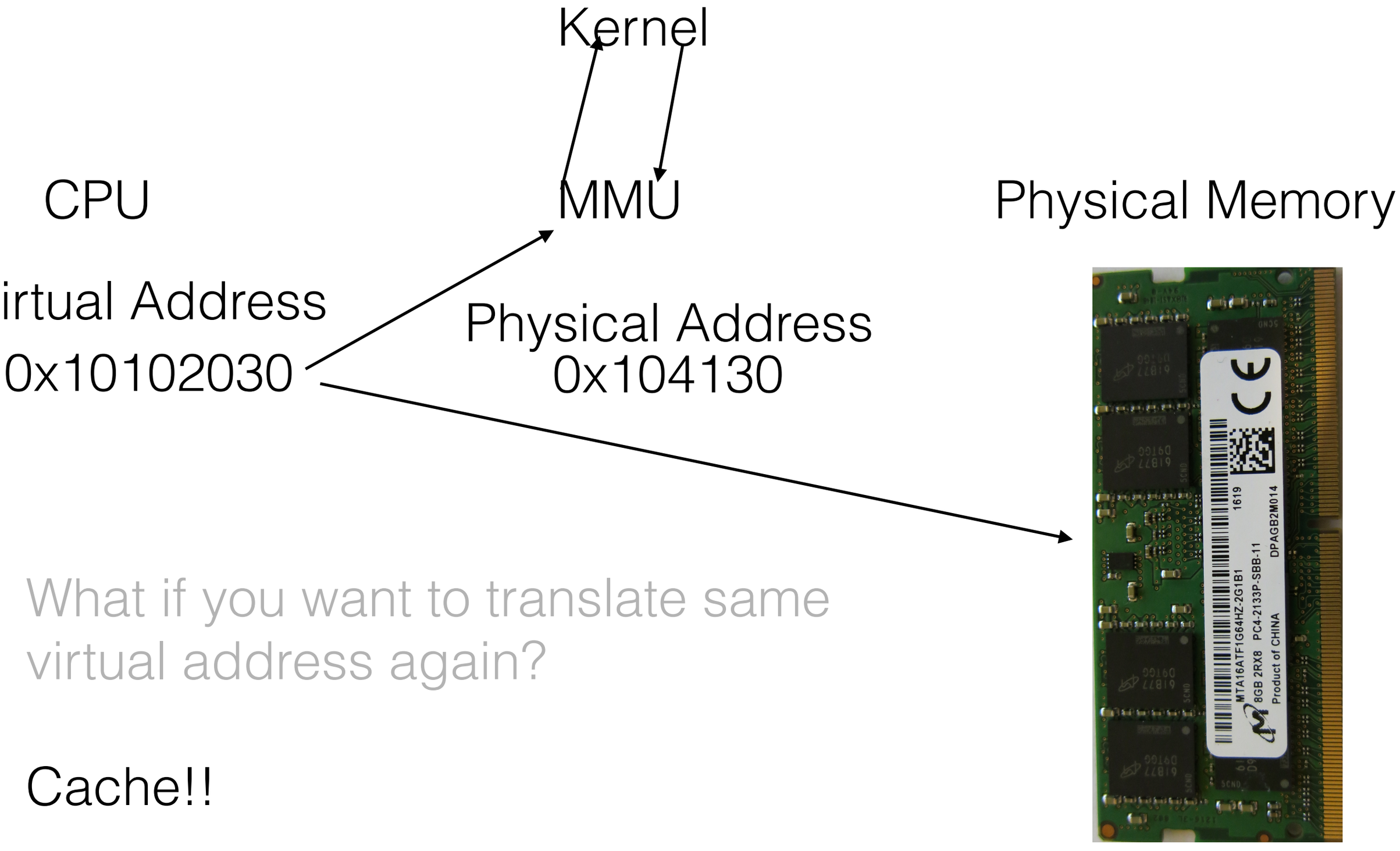
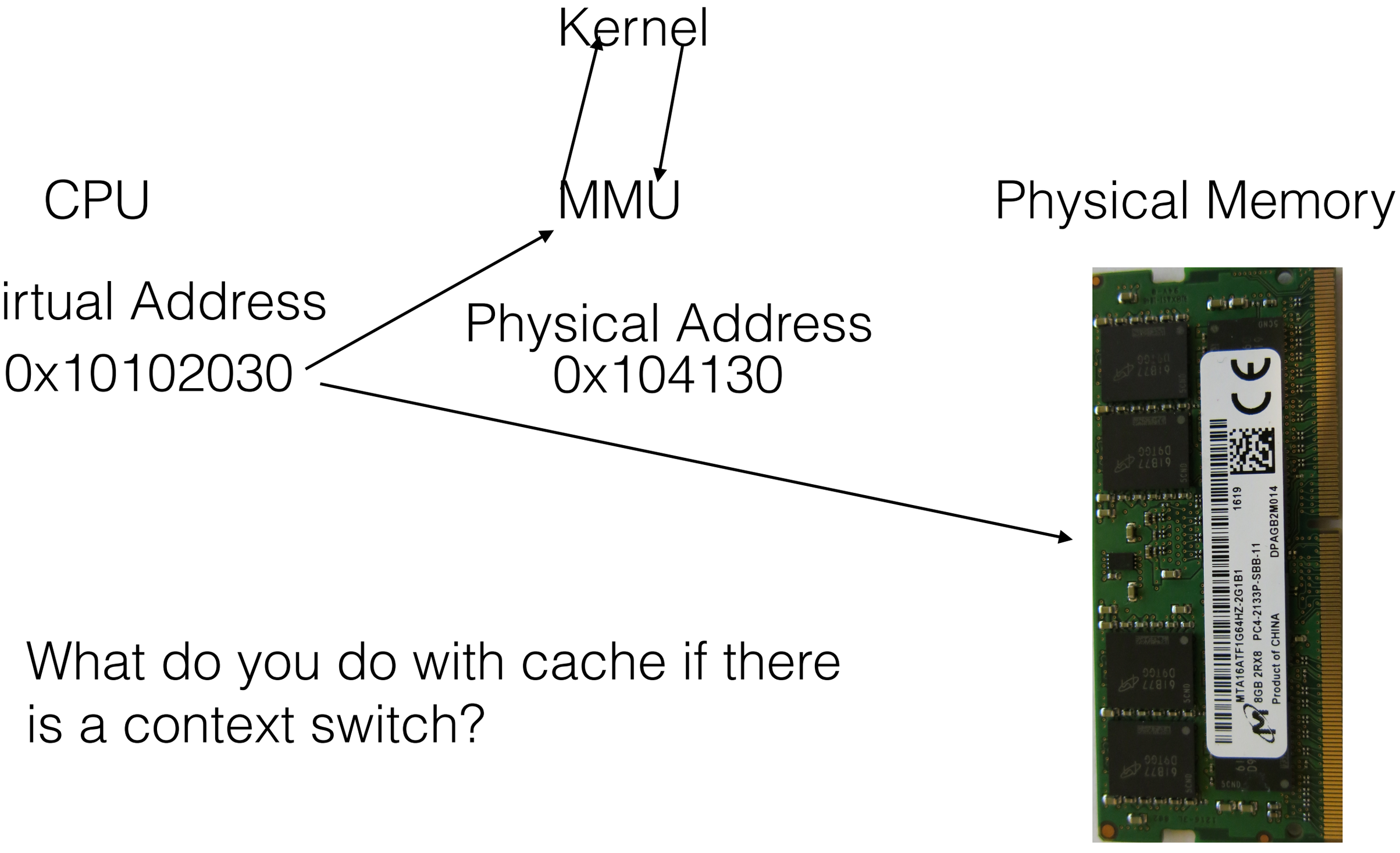


What if you want to translate same virtual address again?

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

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Virtual Address

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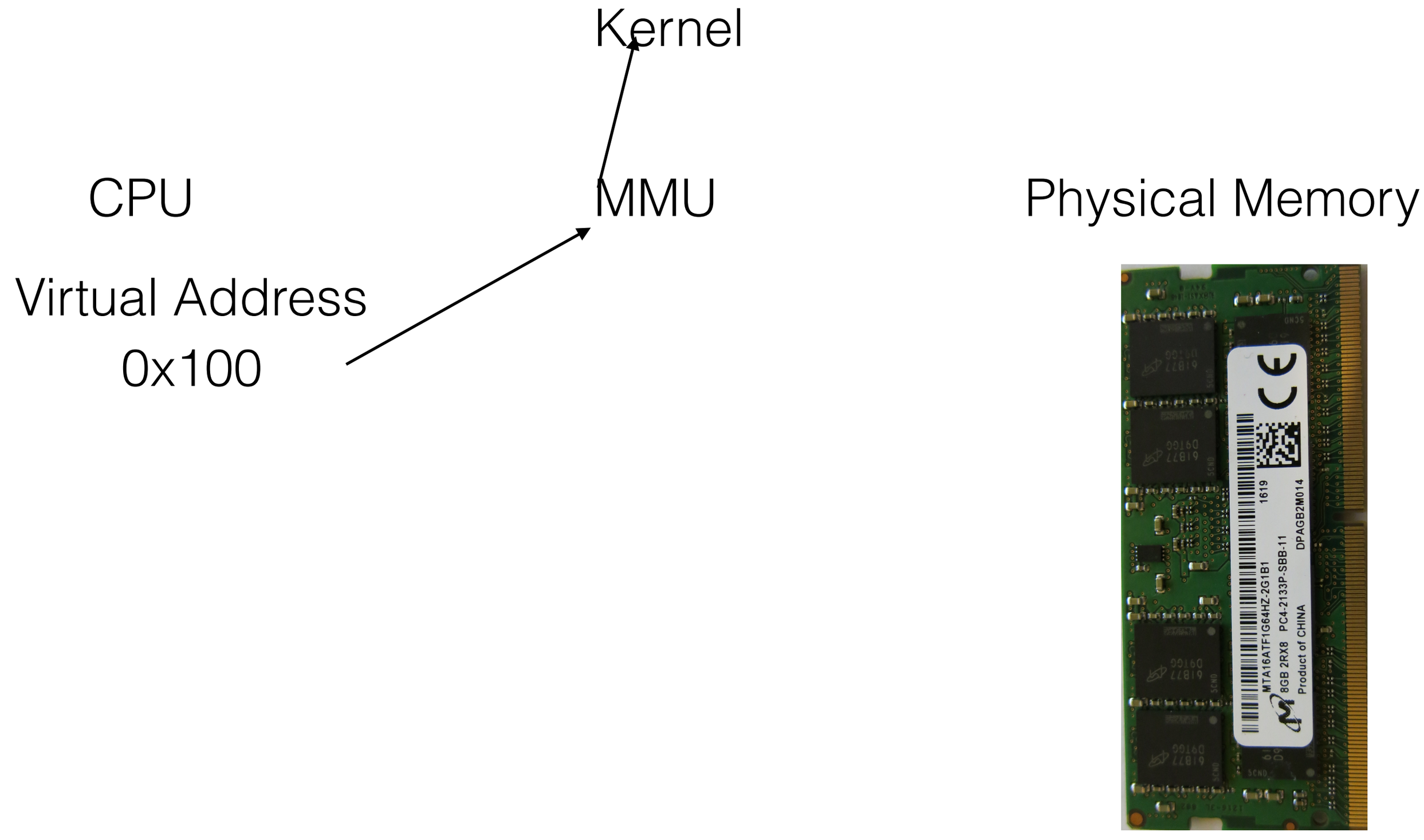

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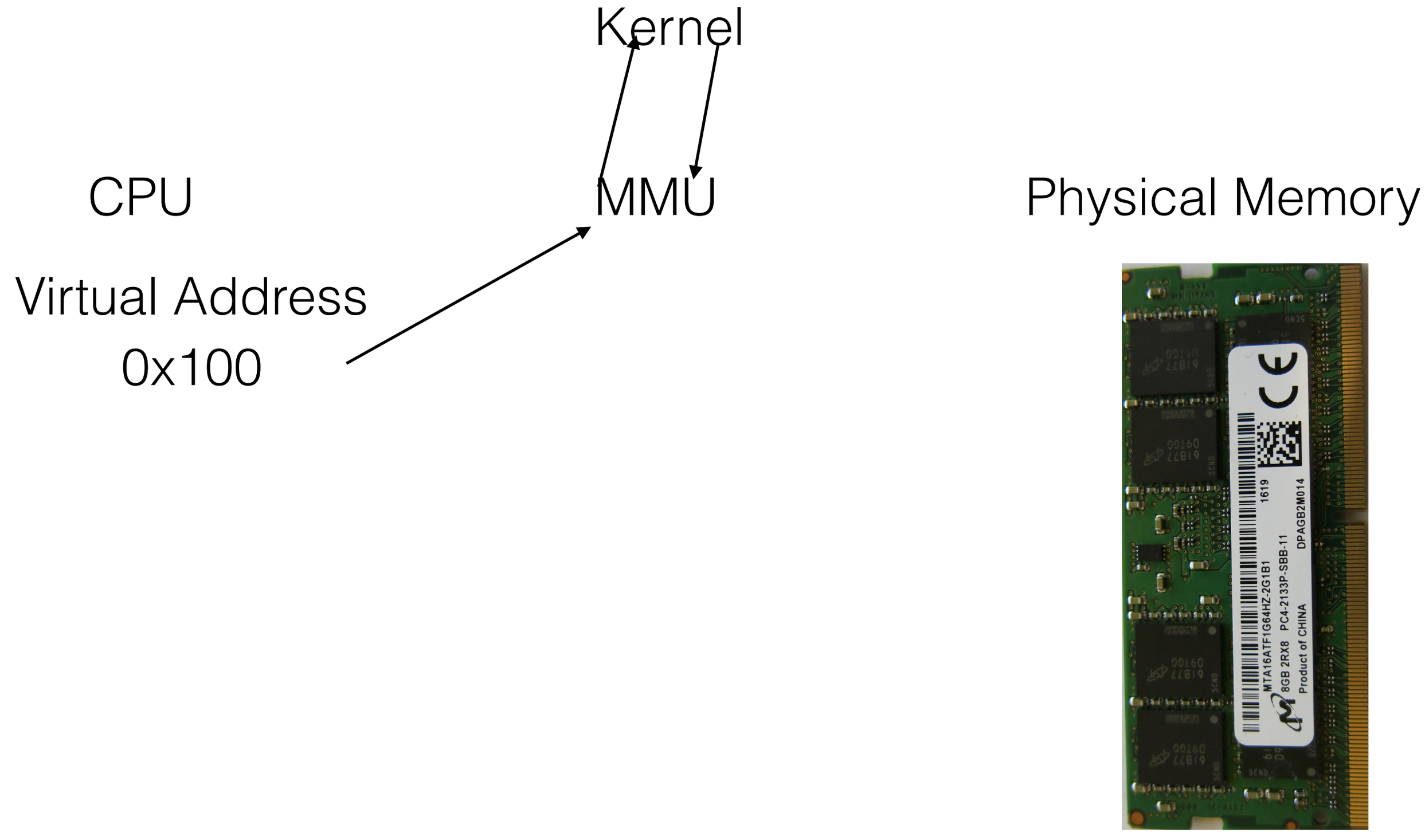

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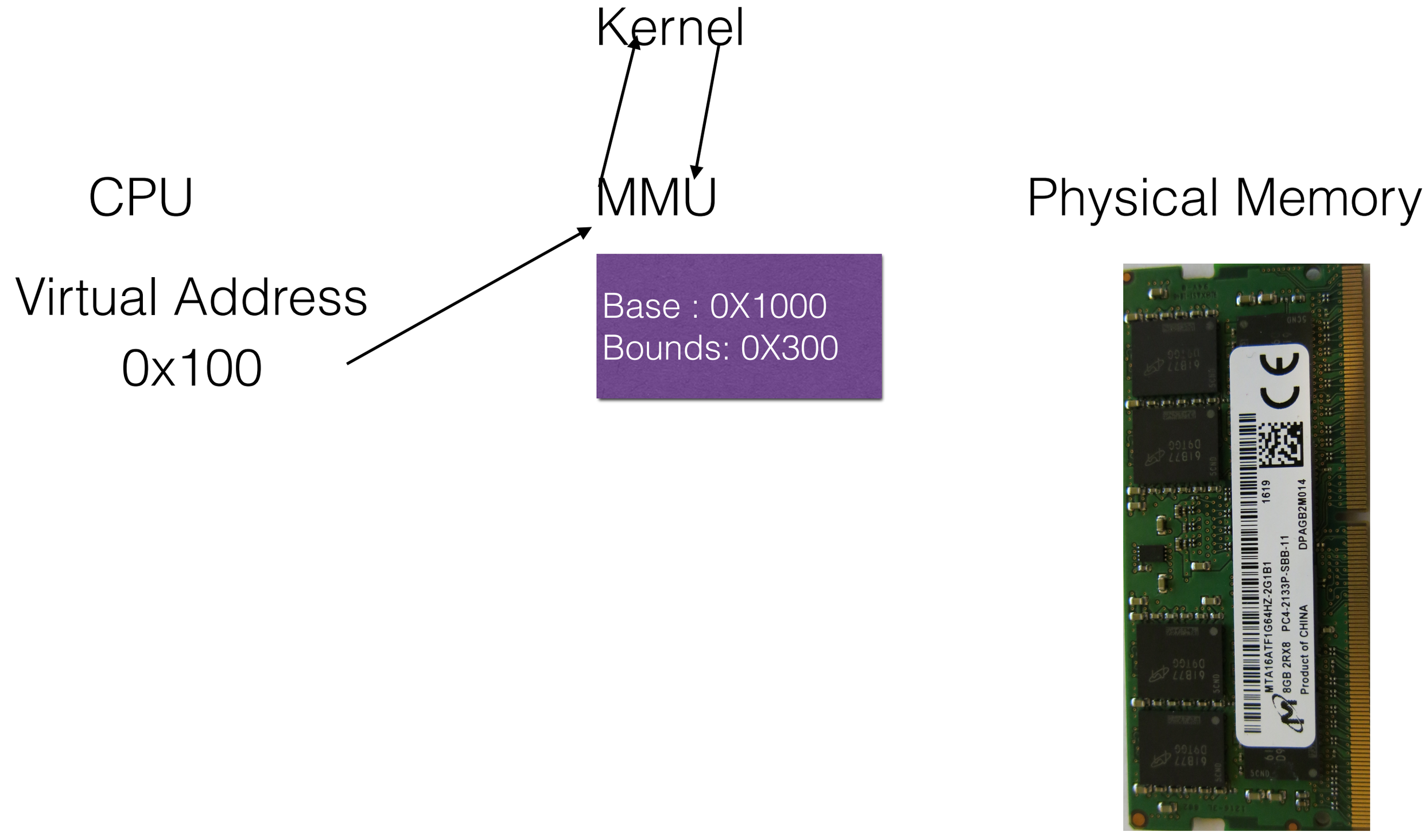

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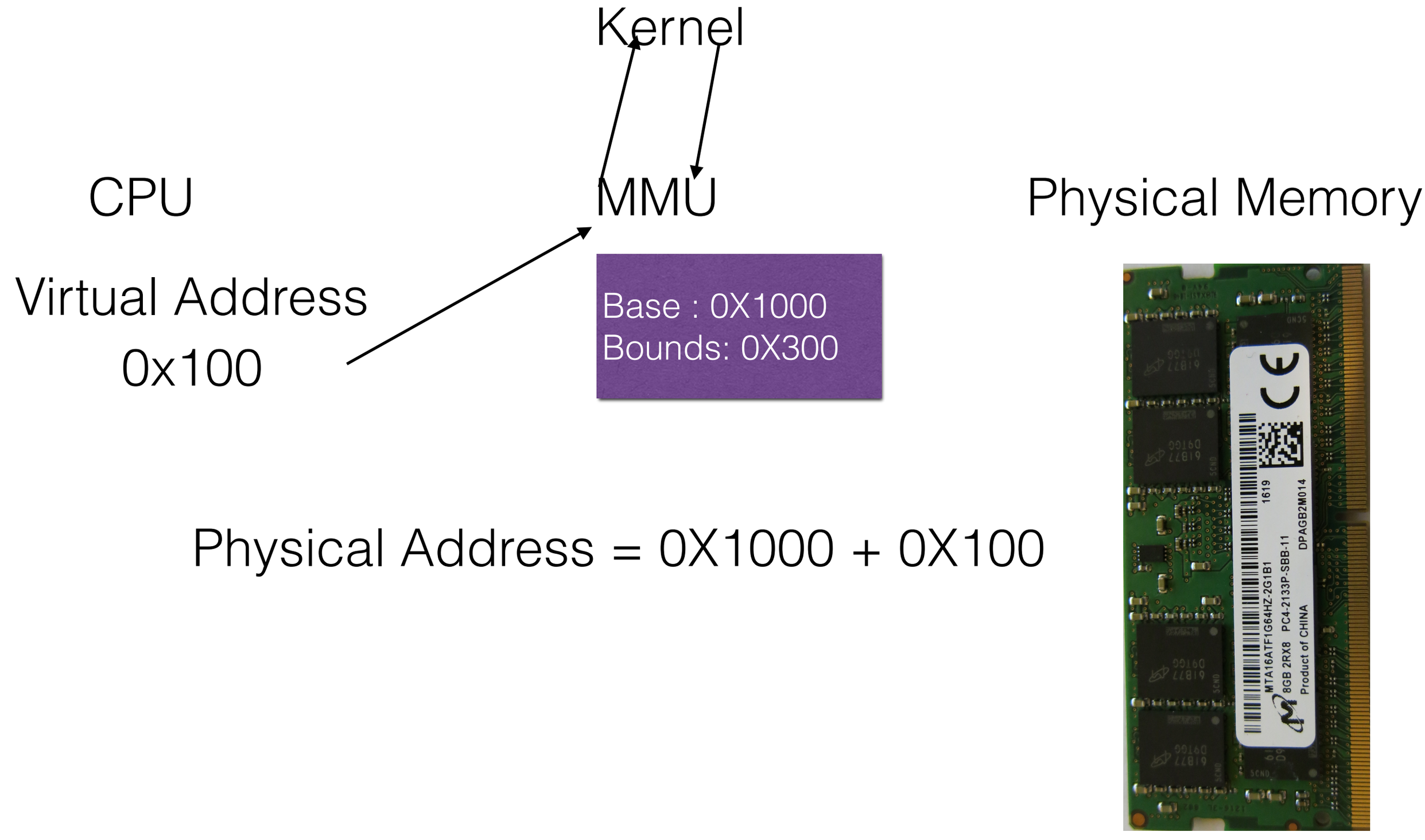

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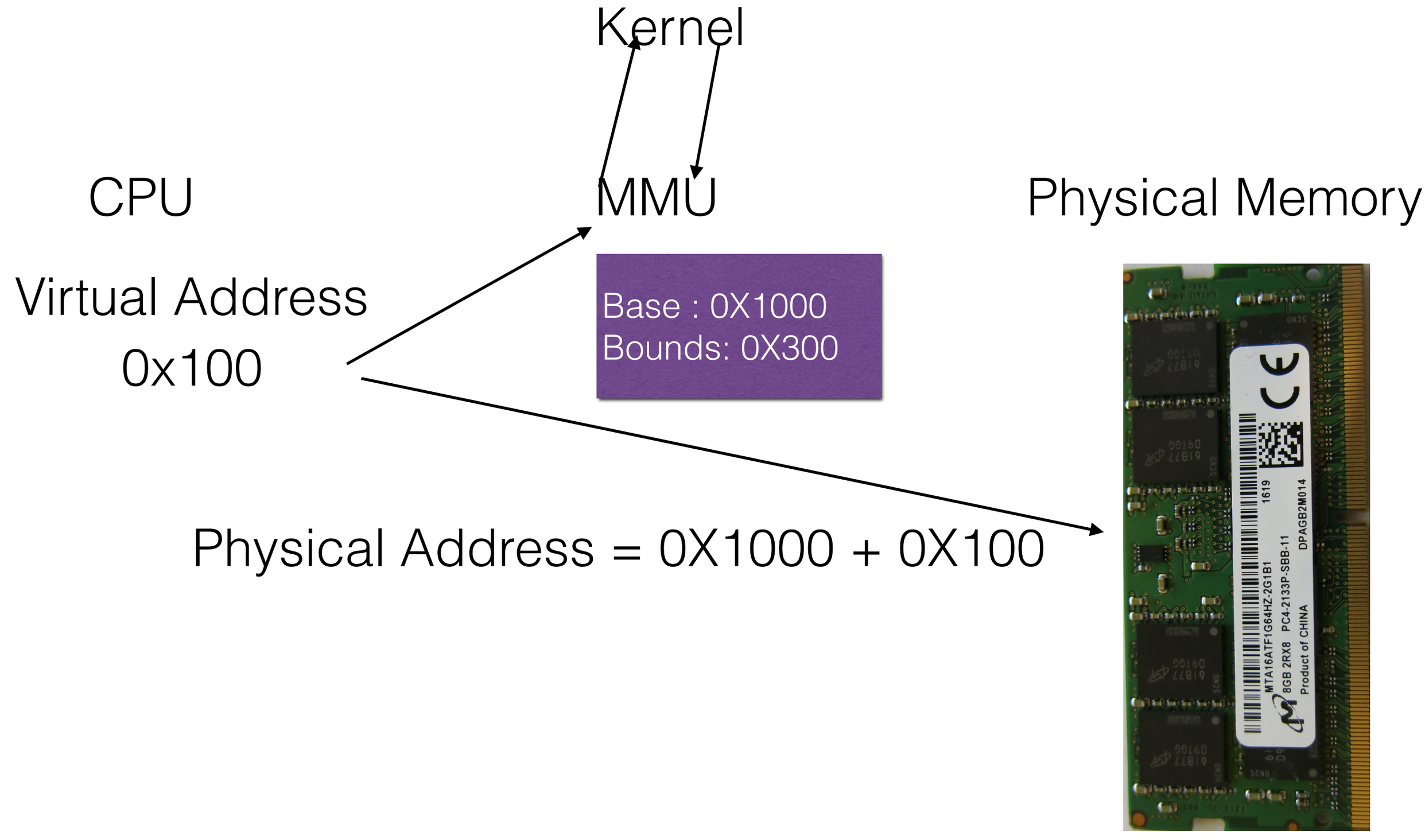

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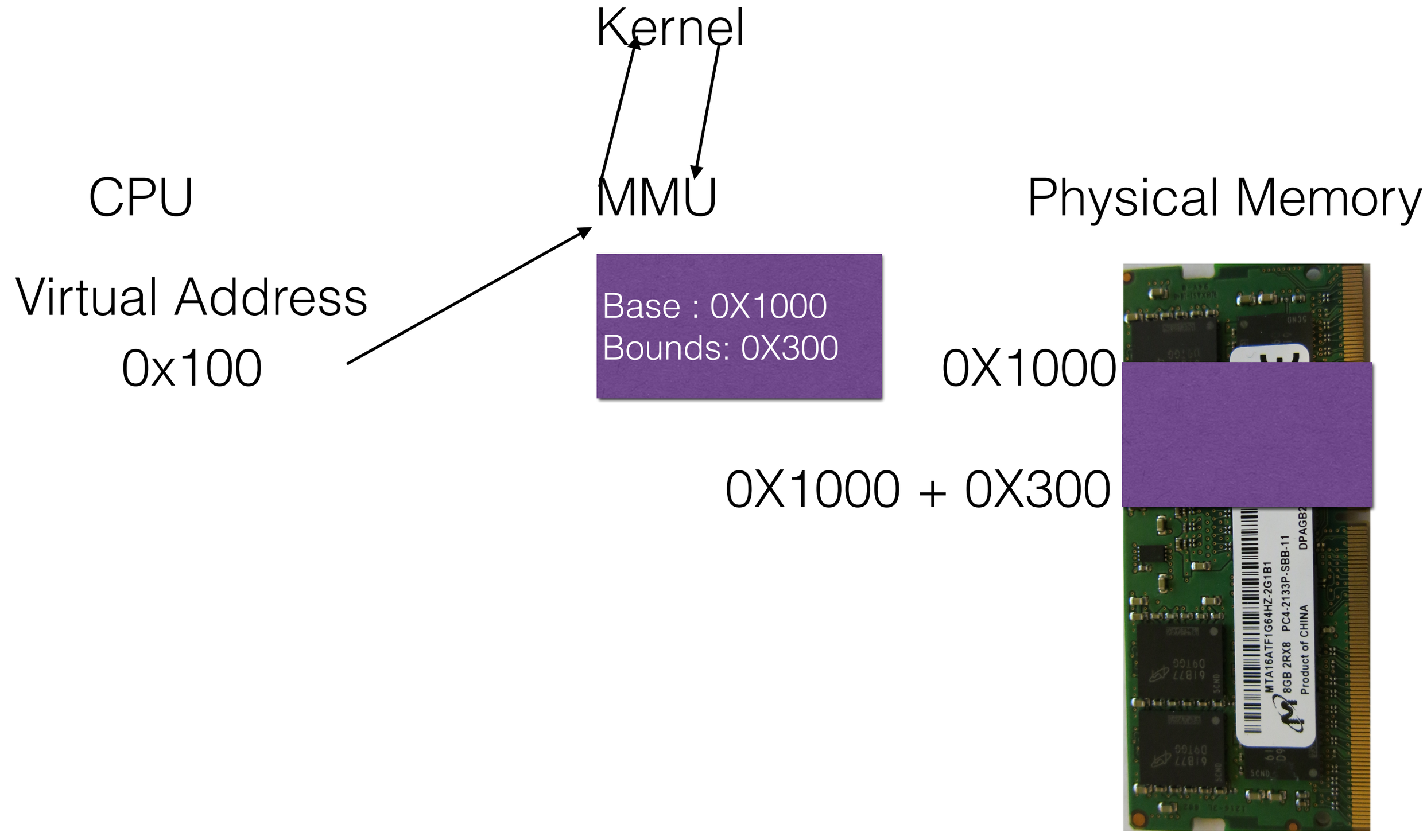

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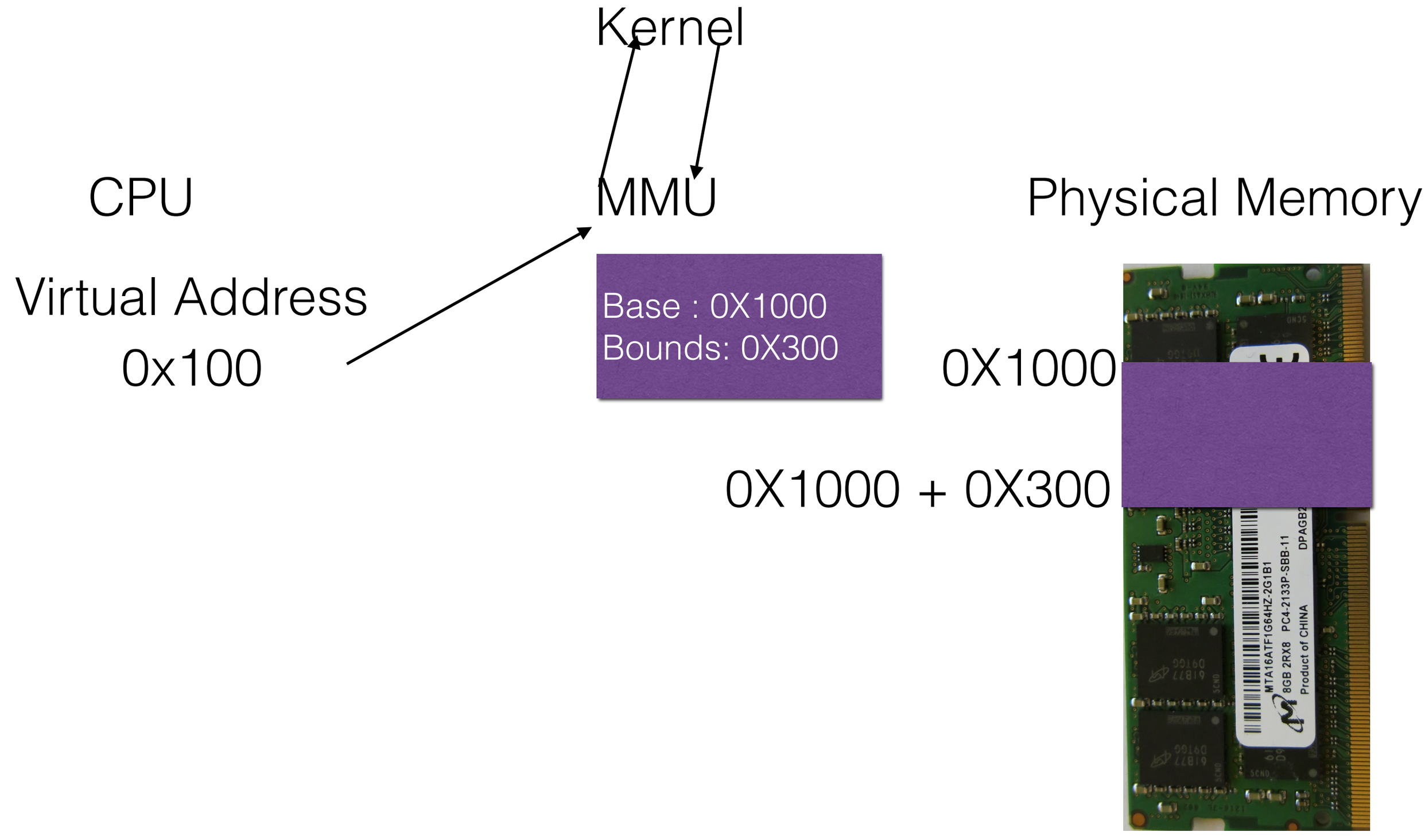

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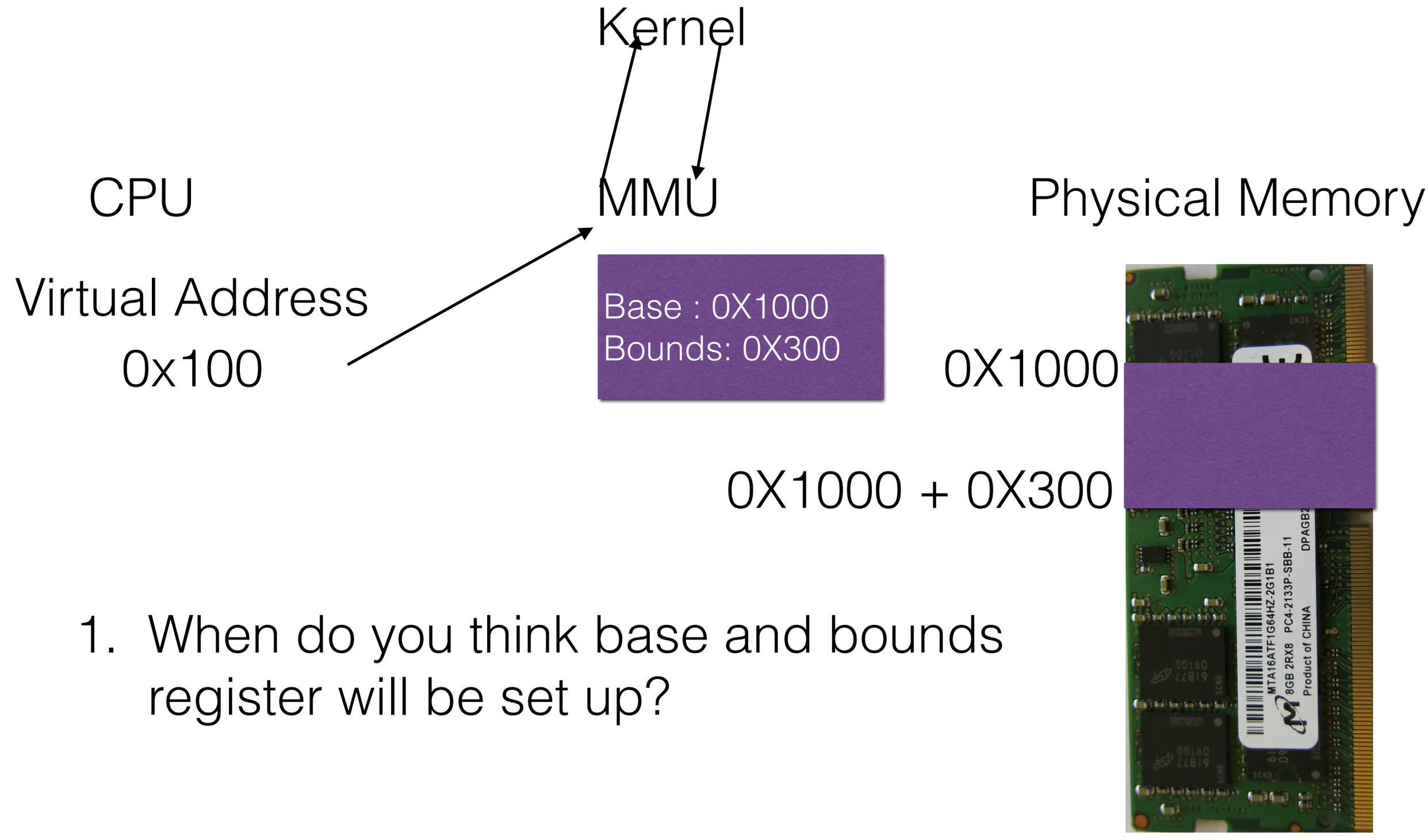

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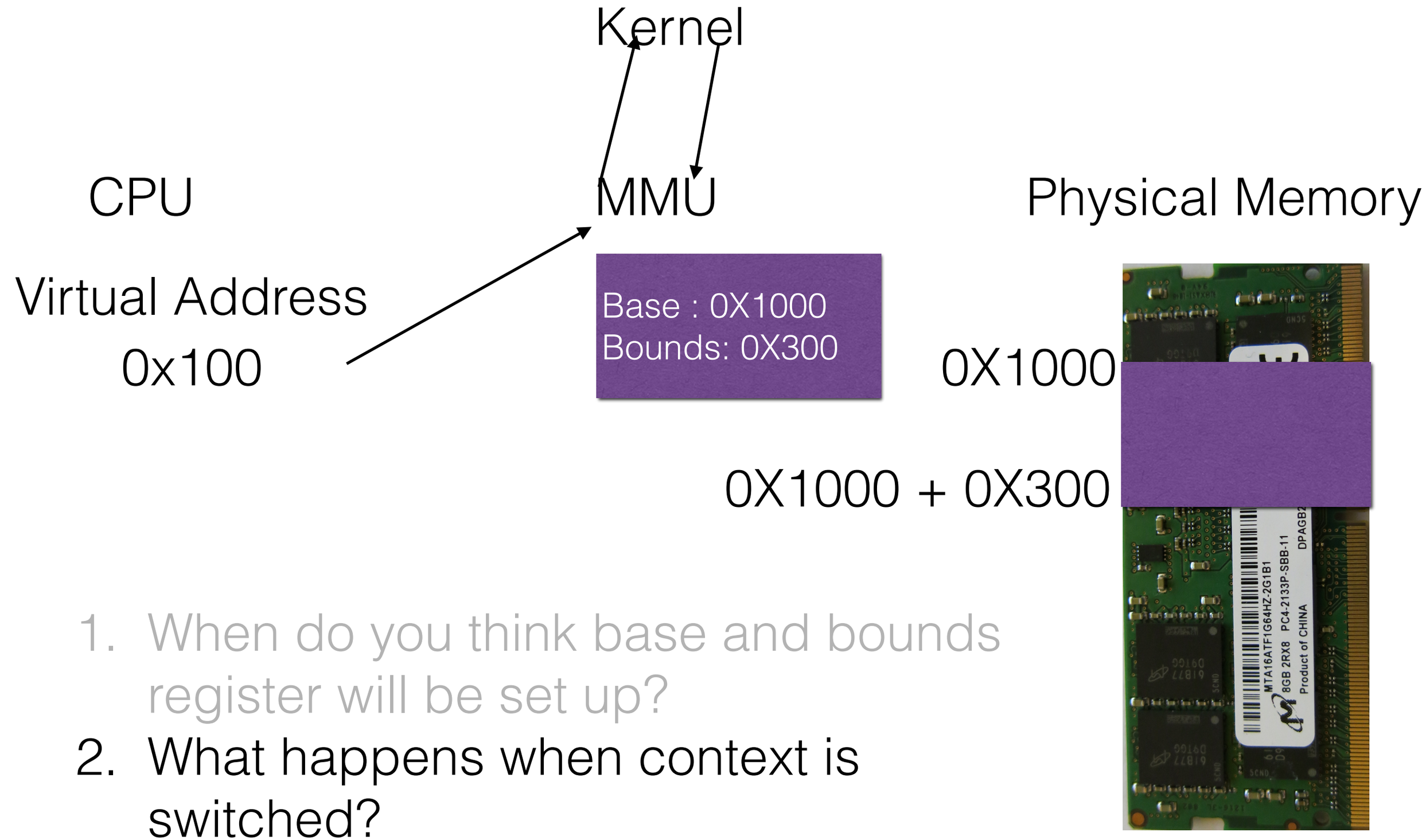

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2. What happens when context is switched?

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    2. Ensures process only accesses its own space

Dynamic (Hardware-based) Relocation

Physical Address = Virtual Address + Base

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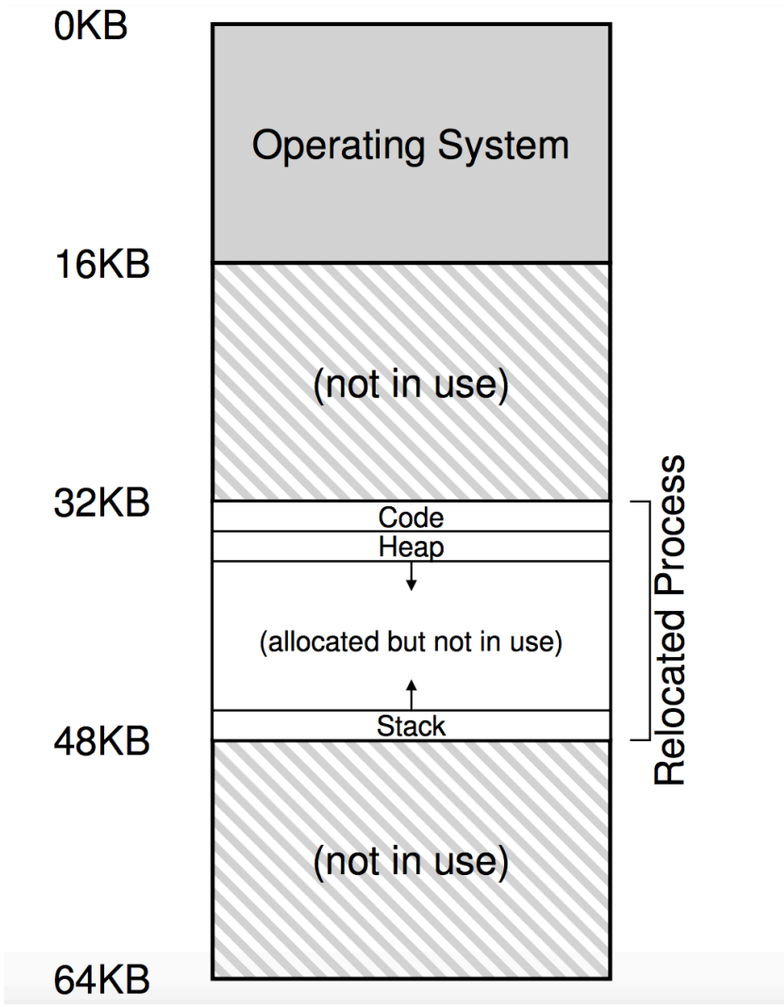

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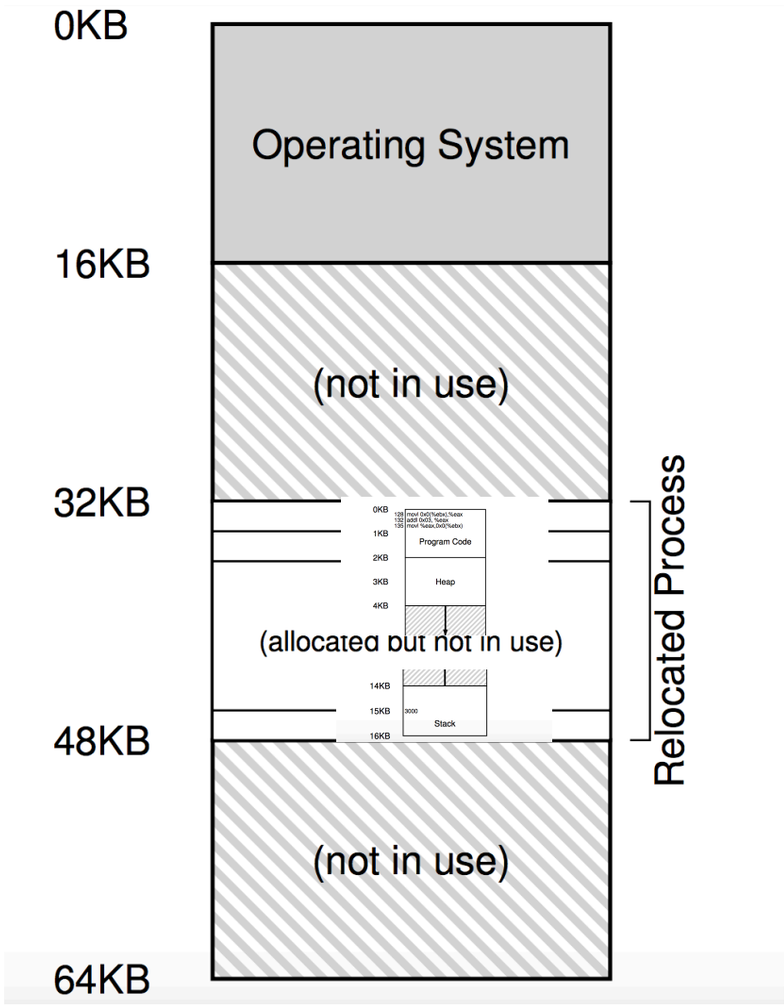

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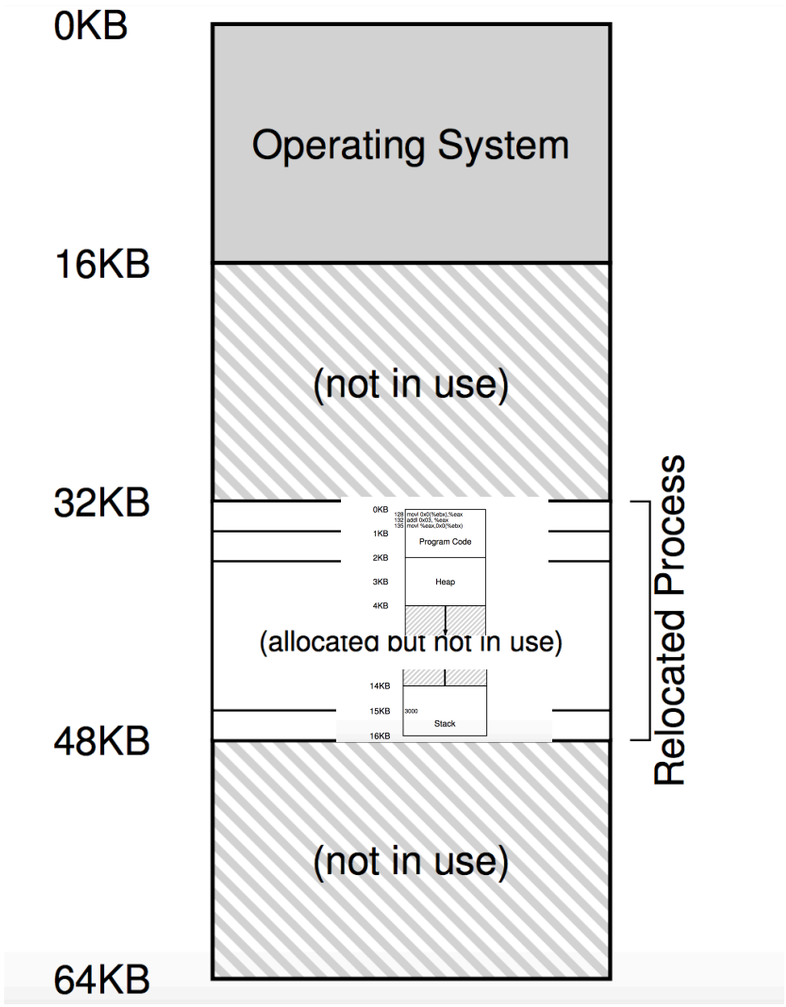

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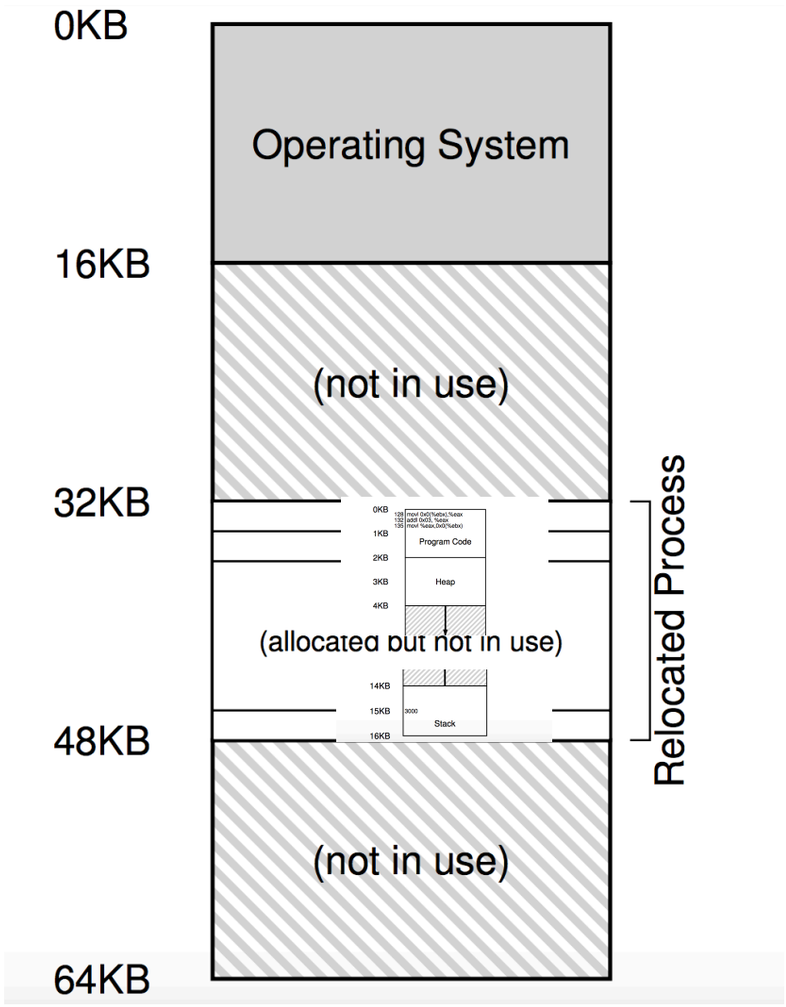

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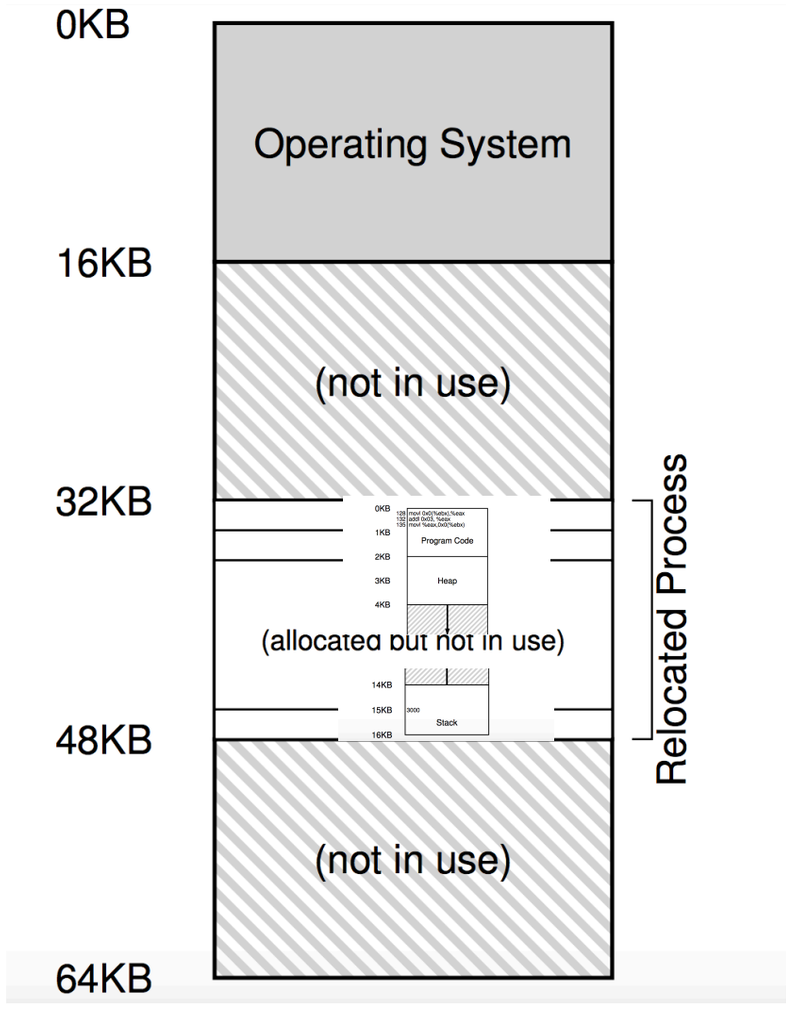

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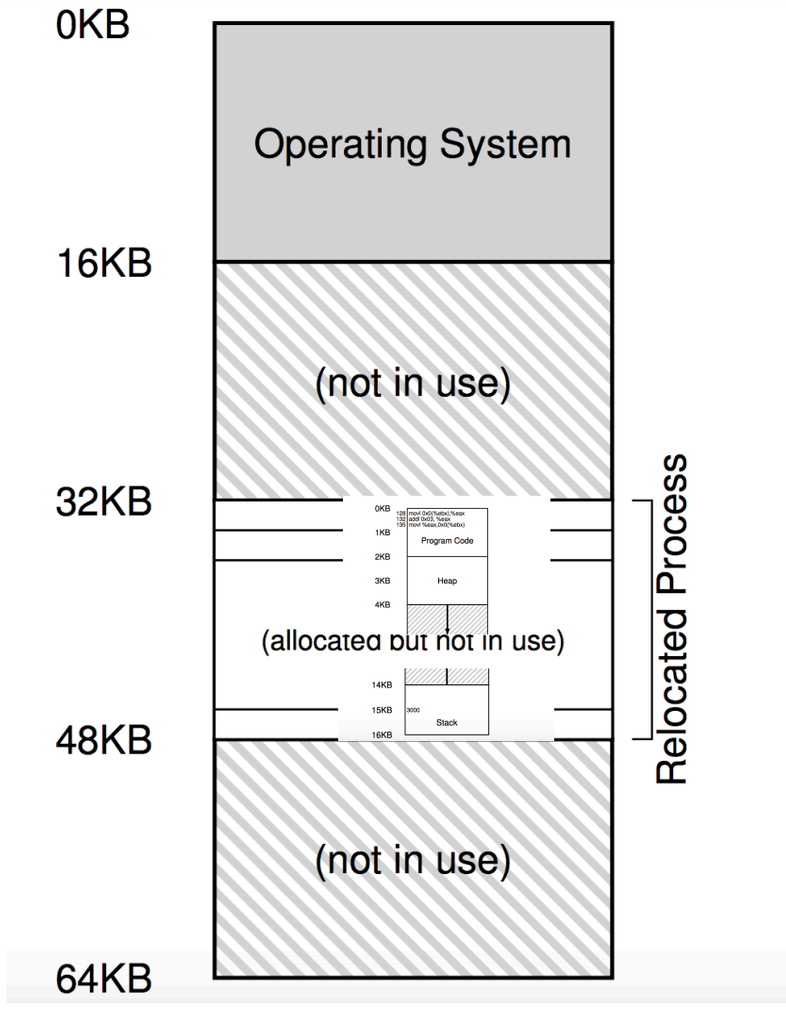
    3. Ans: 32 KB



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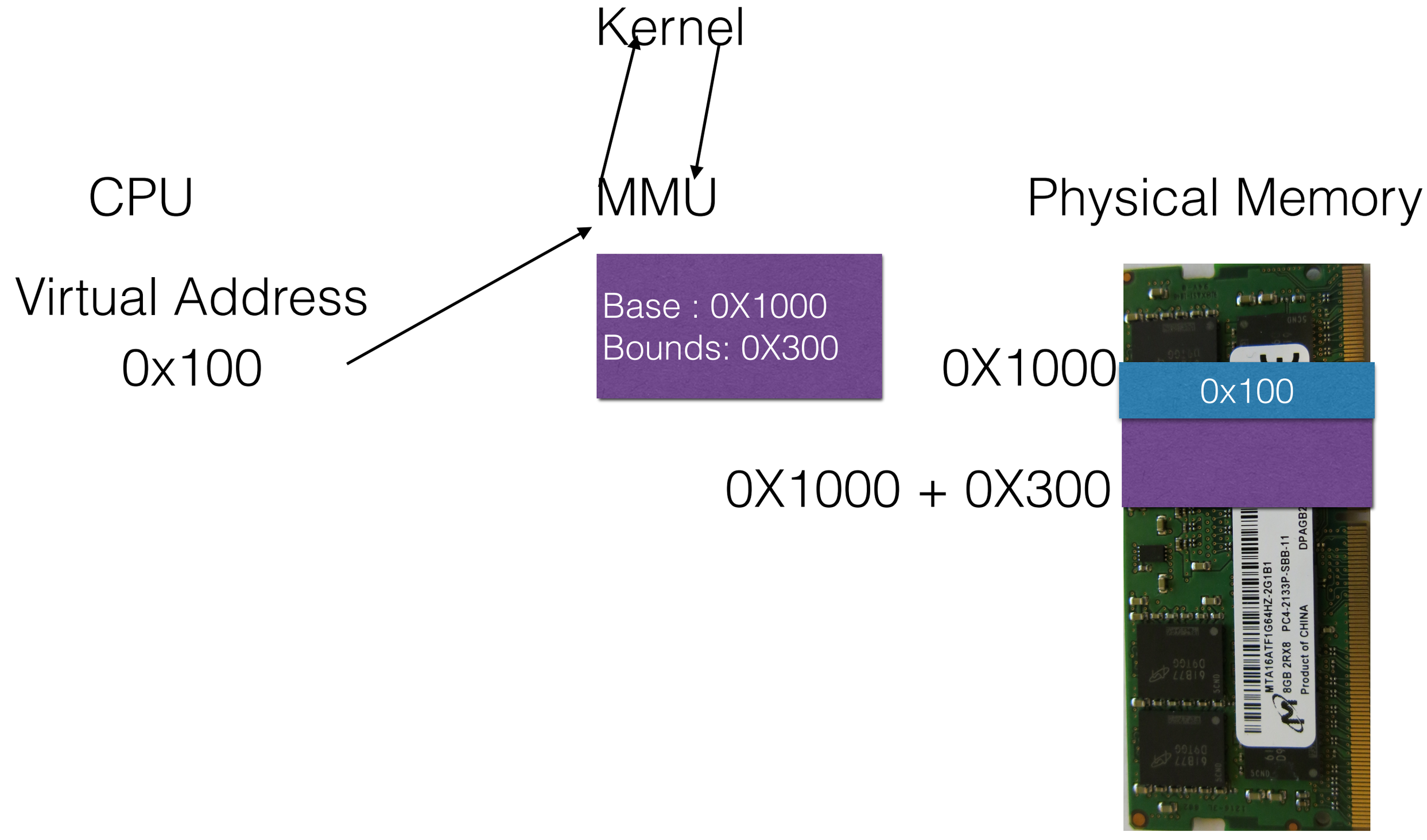

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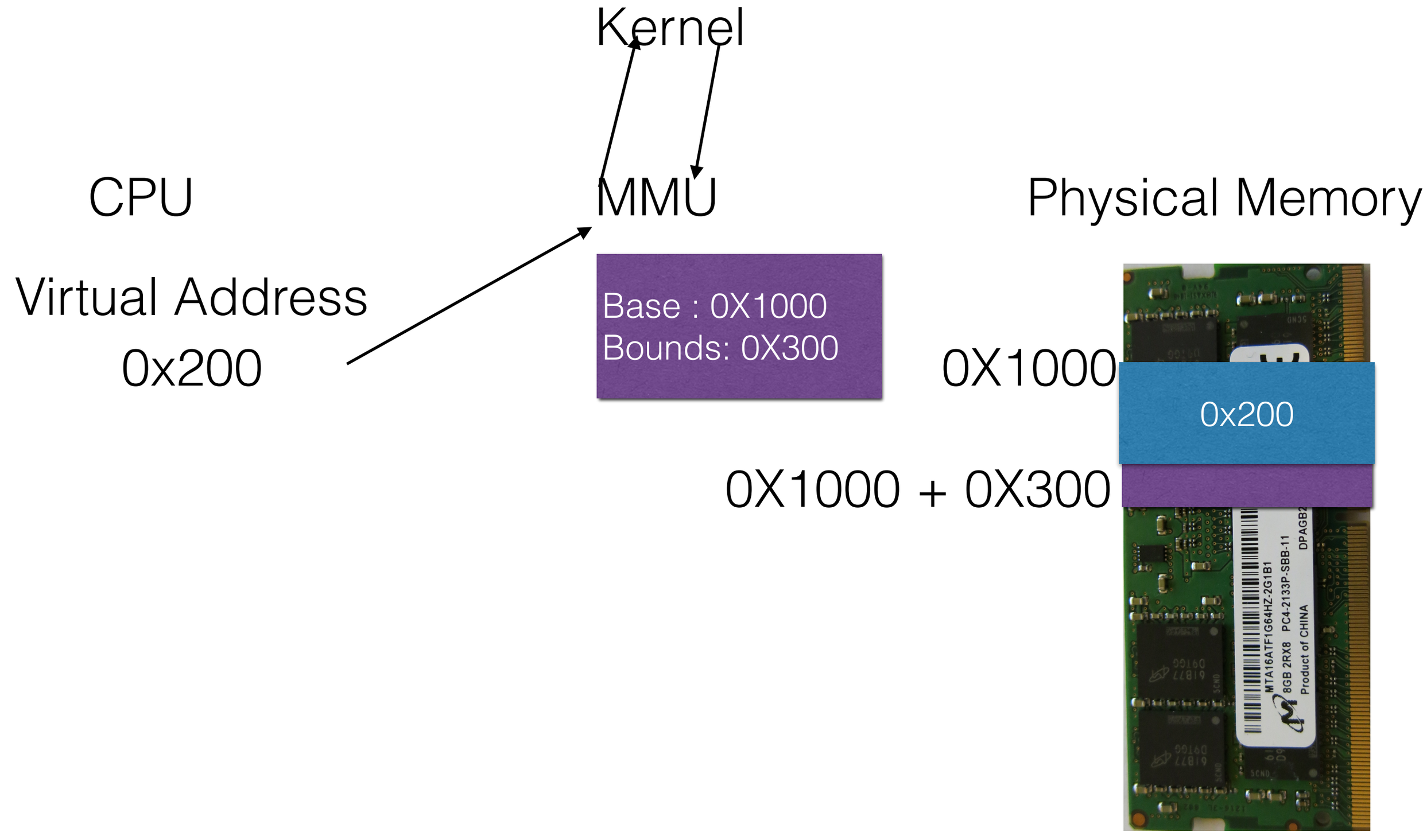

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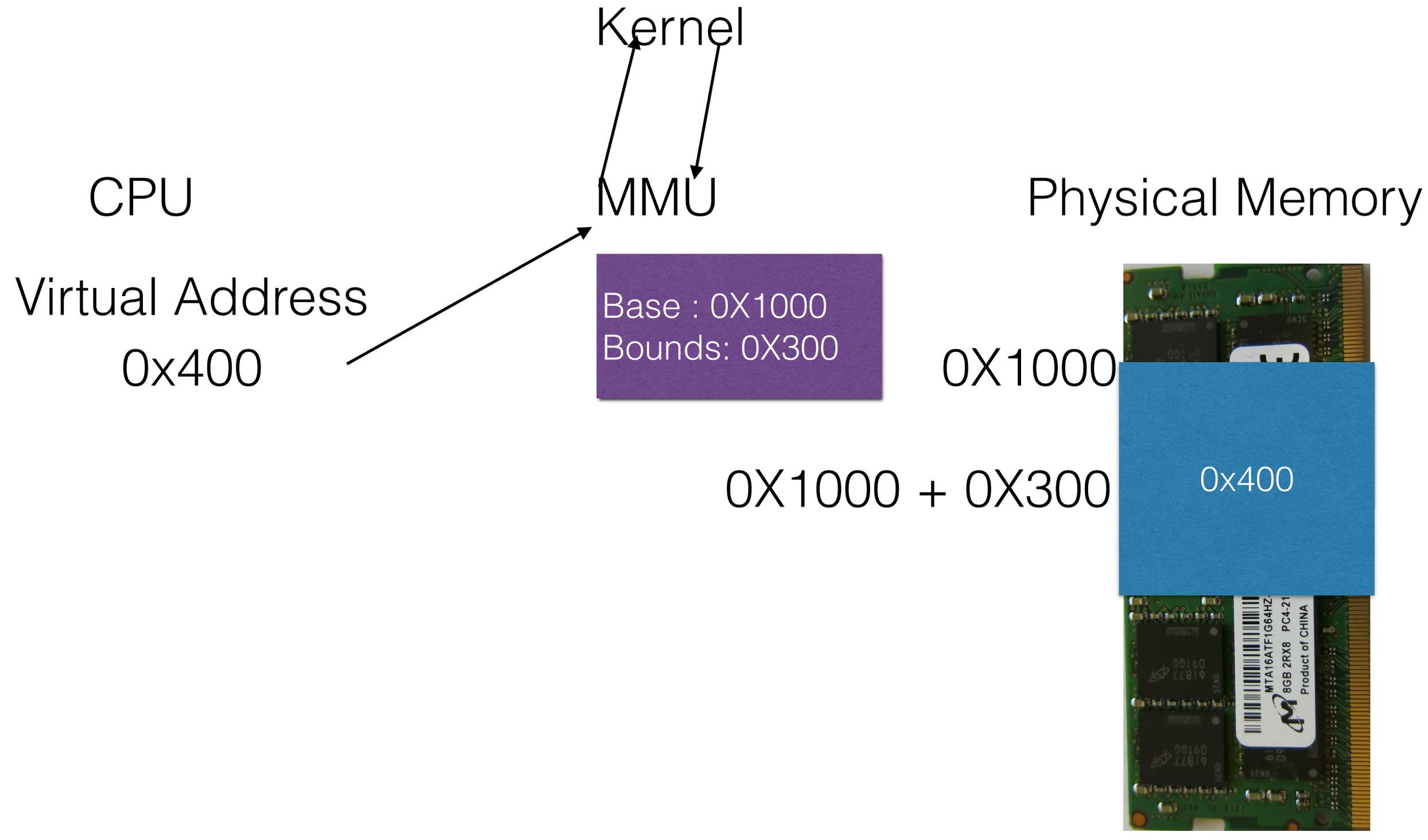

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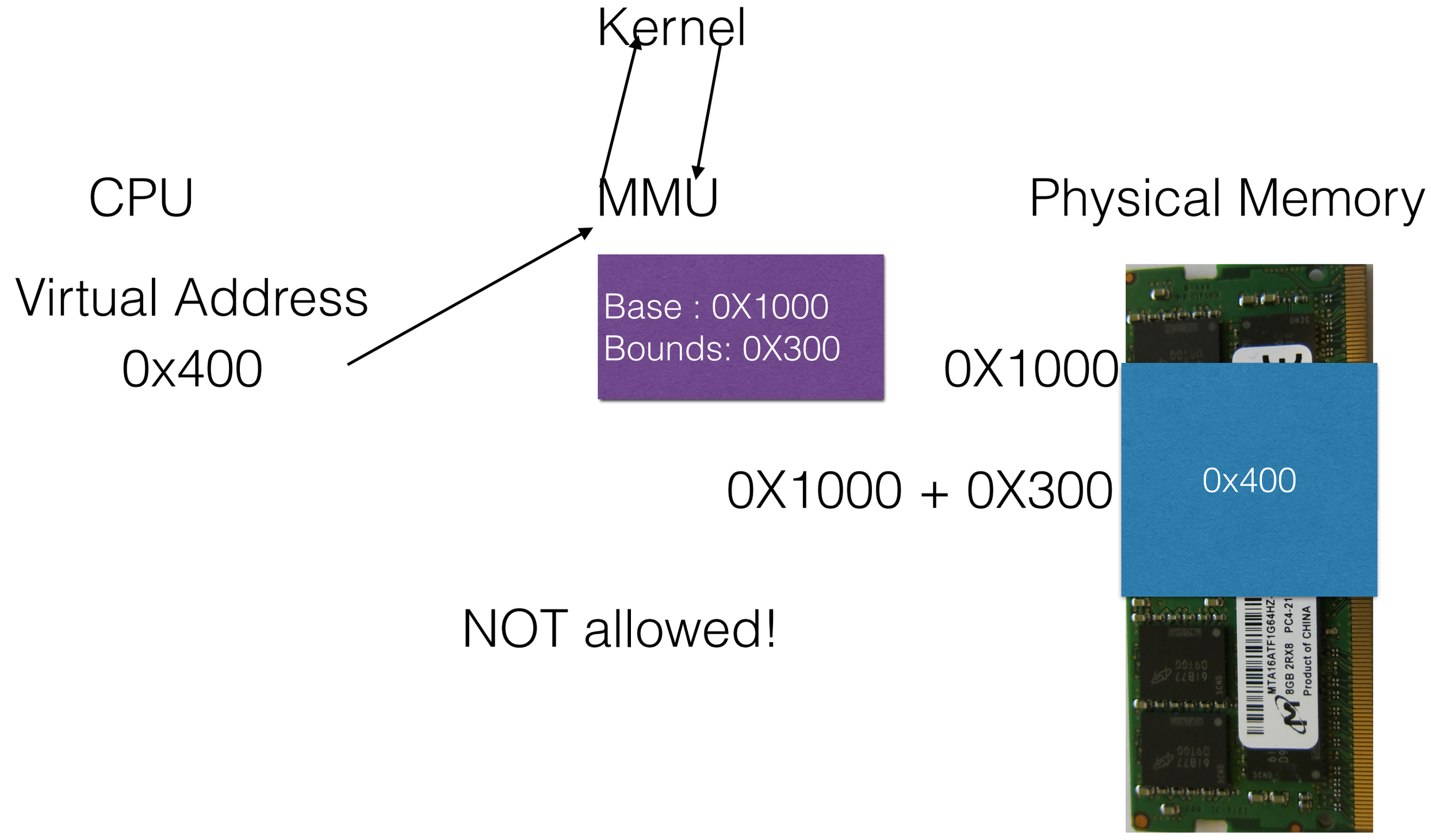

Hardware Requirement for Dynamic Relocation

Hardware Requirements	Notes
Privileged mode	
Base/bounds registers	
Ability to translate virtual addresses and check if within bounds	
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Ability to raise exceptions	*When processes try to access privileged instructions or out-of-bounds memory*

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    1. Terminate offending process

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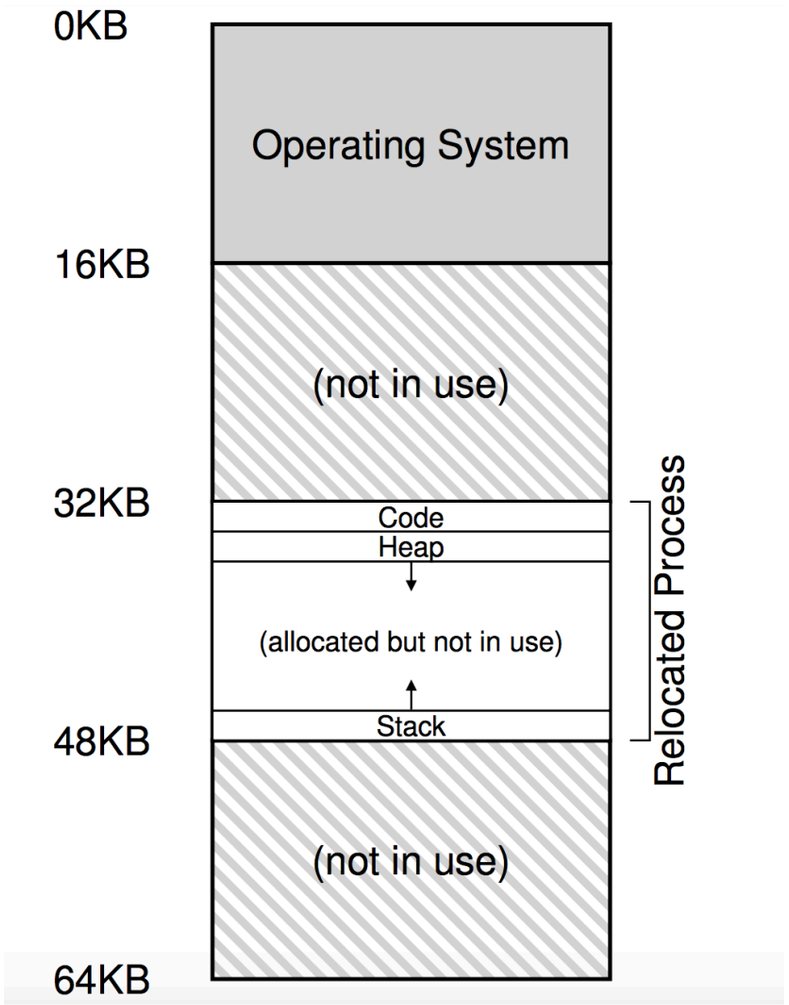
Base

Base + Bound



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1. Contiguous block of memory needed in physical memory

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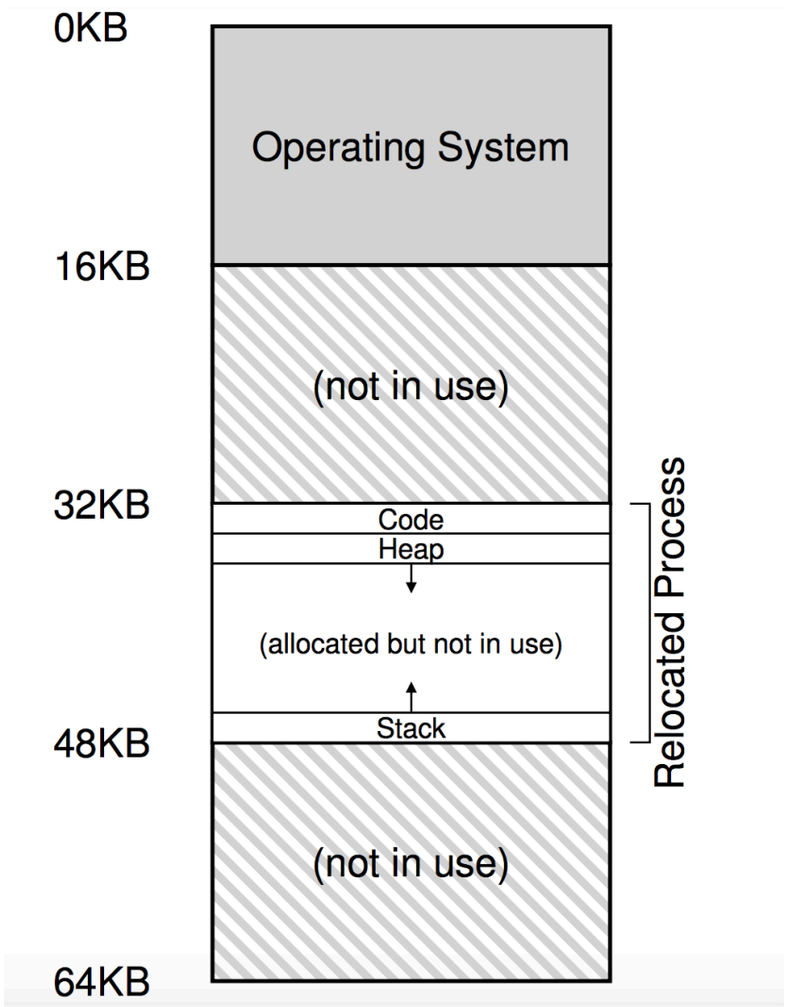
Base + Bound

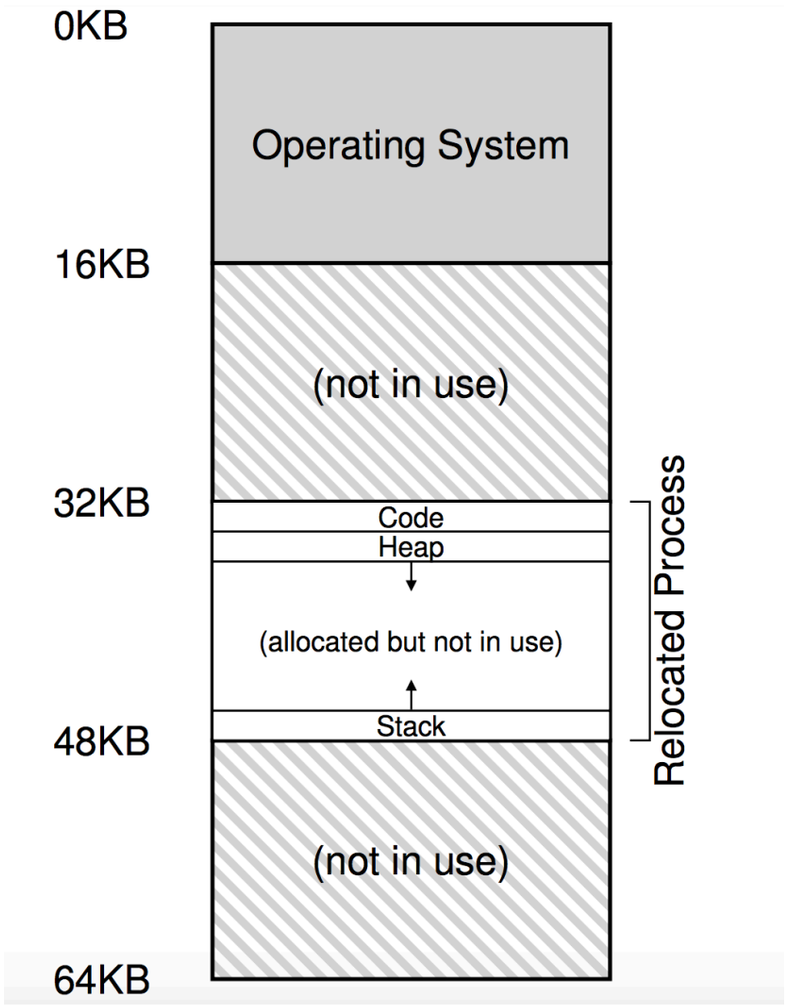


Base & Bounds : Cons

1. Contiguous block of memory needed in physical memory
    1. Internal fragmentation

Base

Base + Bound

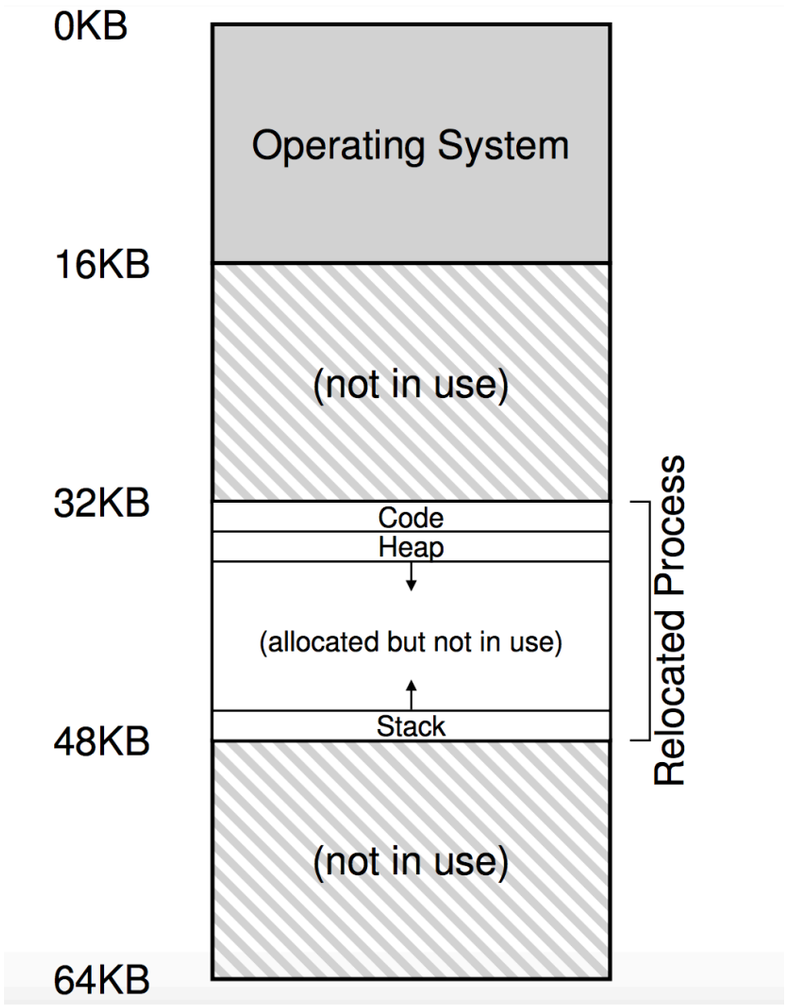


Base & Bounds : Cons

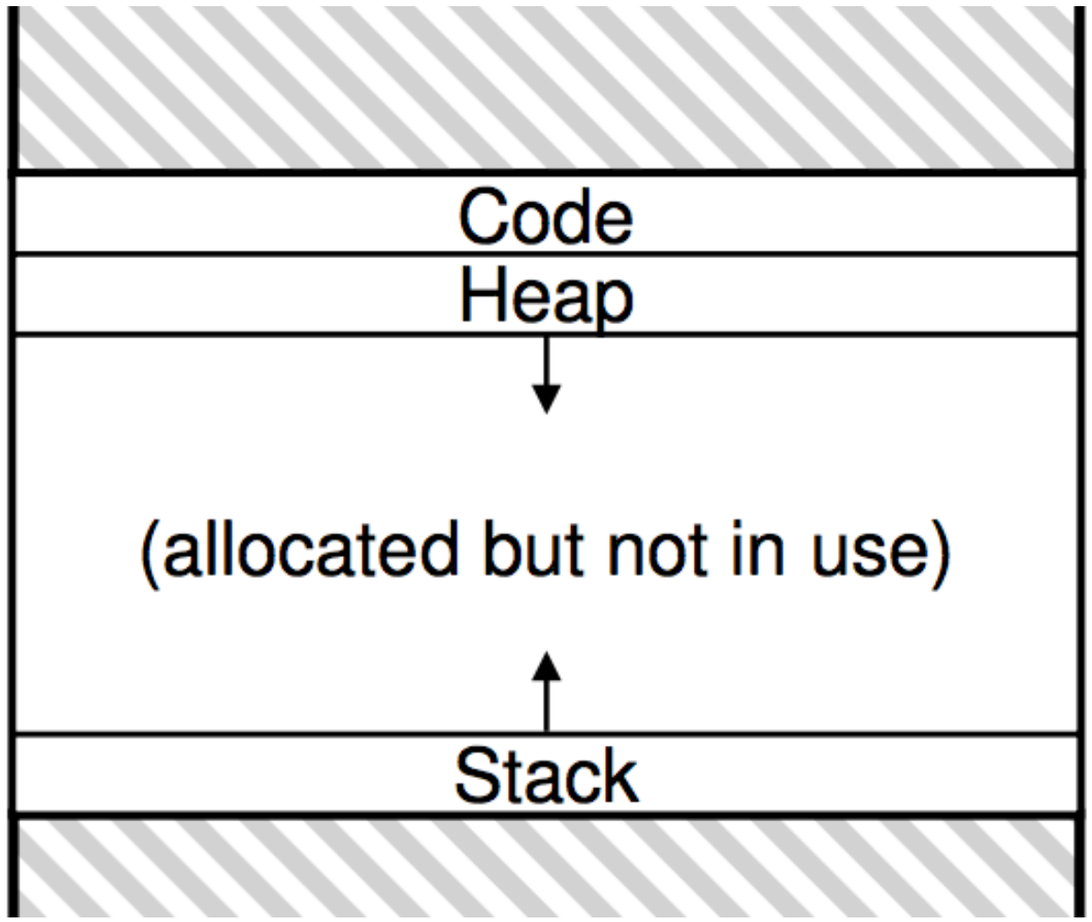
1. Contiguous block of memory needed in physical memory
   1. Internal fragmentation
   2. External fragmentation

Base

Base + Bound



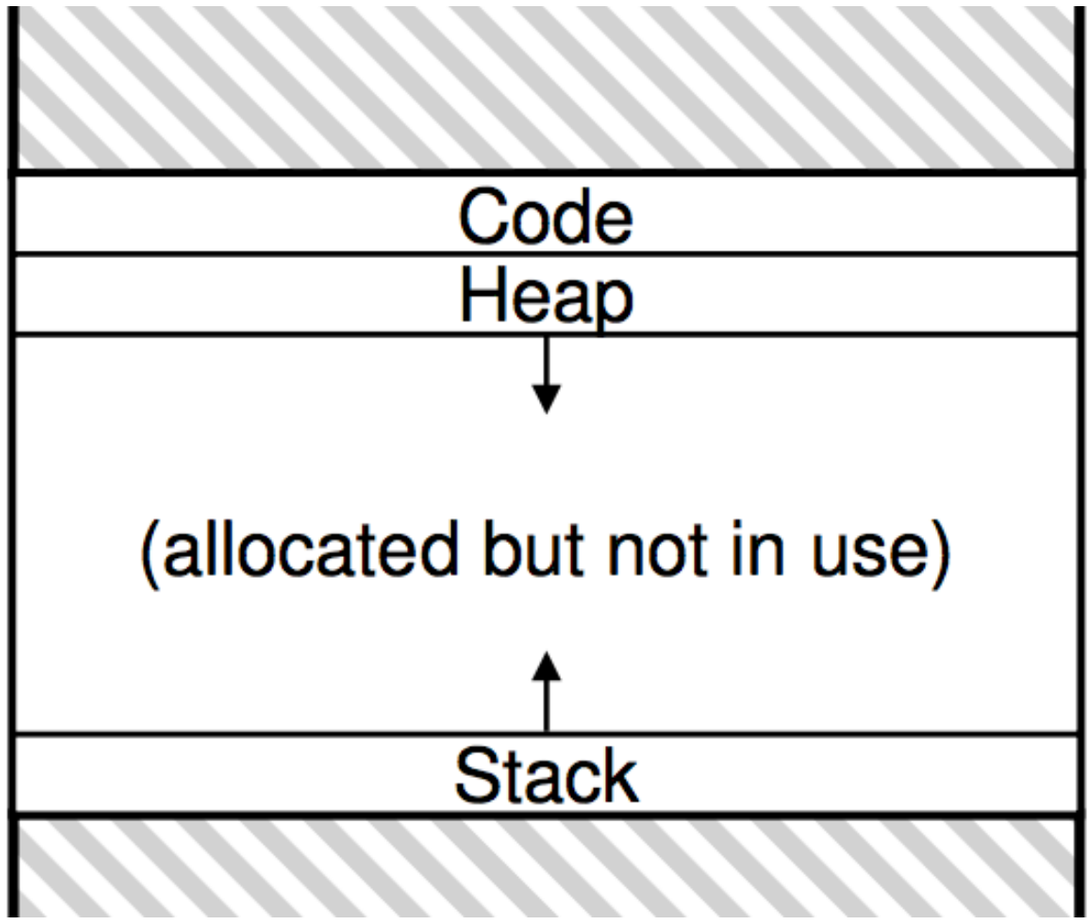
Segmentation



Segmentation

Base for Code

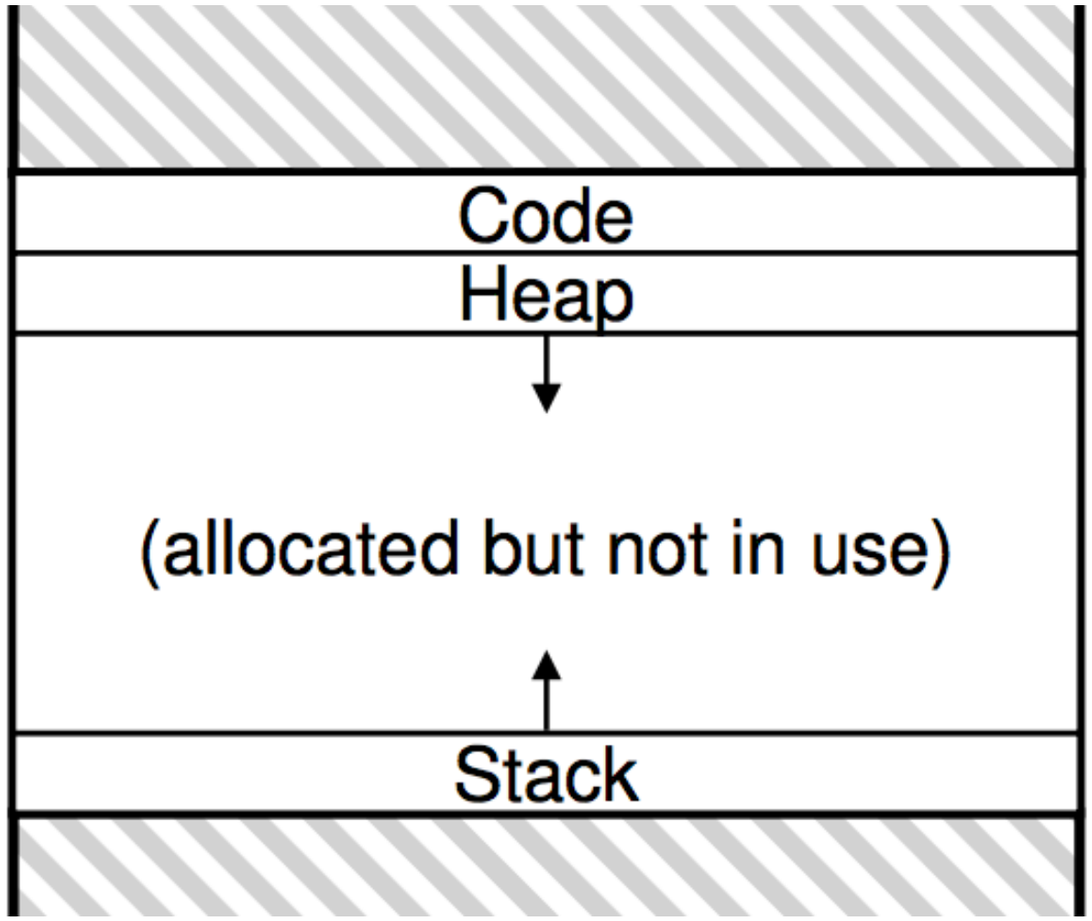
Base + Bound for Code



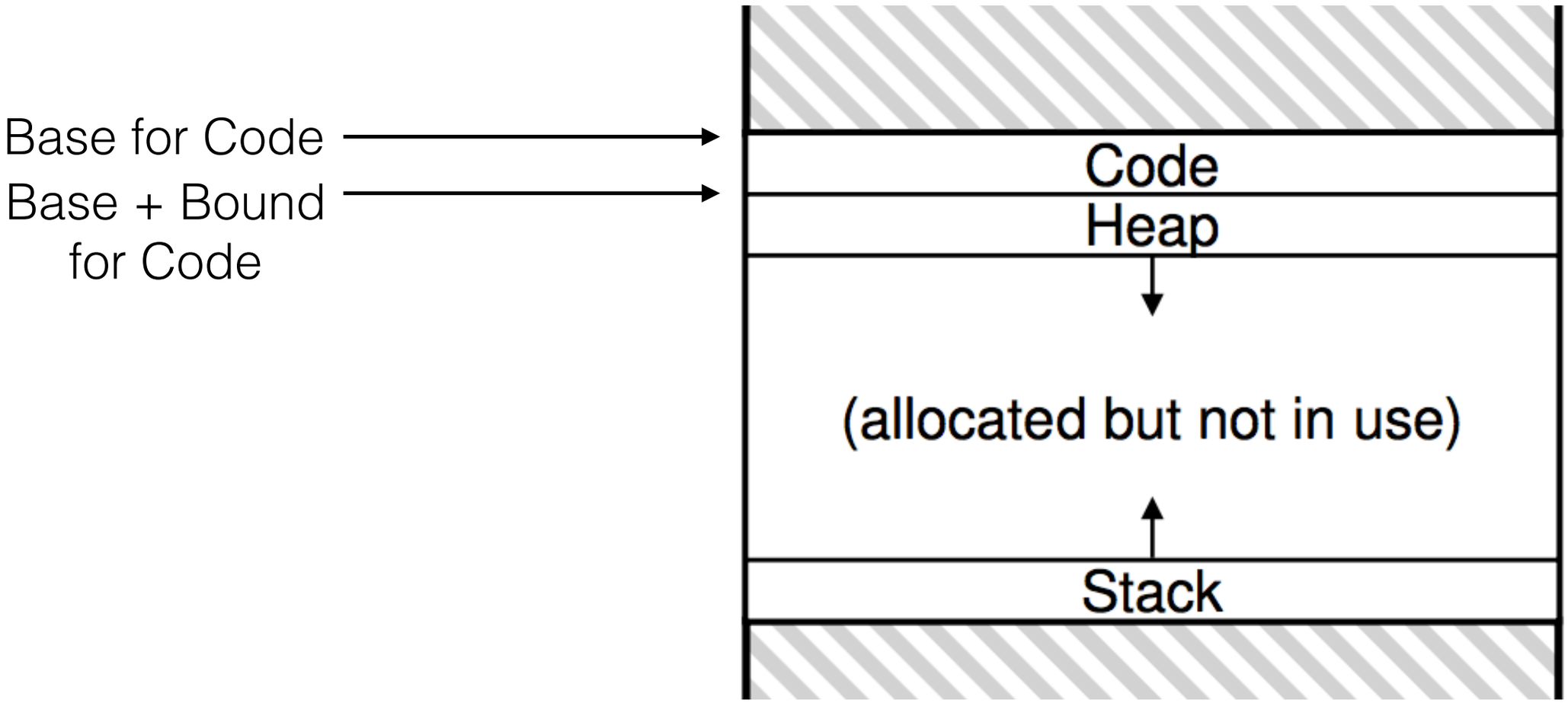
Segmentation

Base for Code

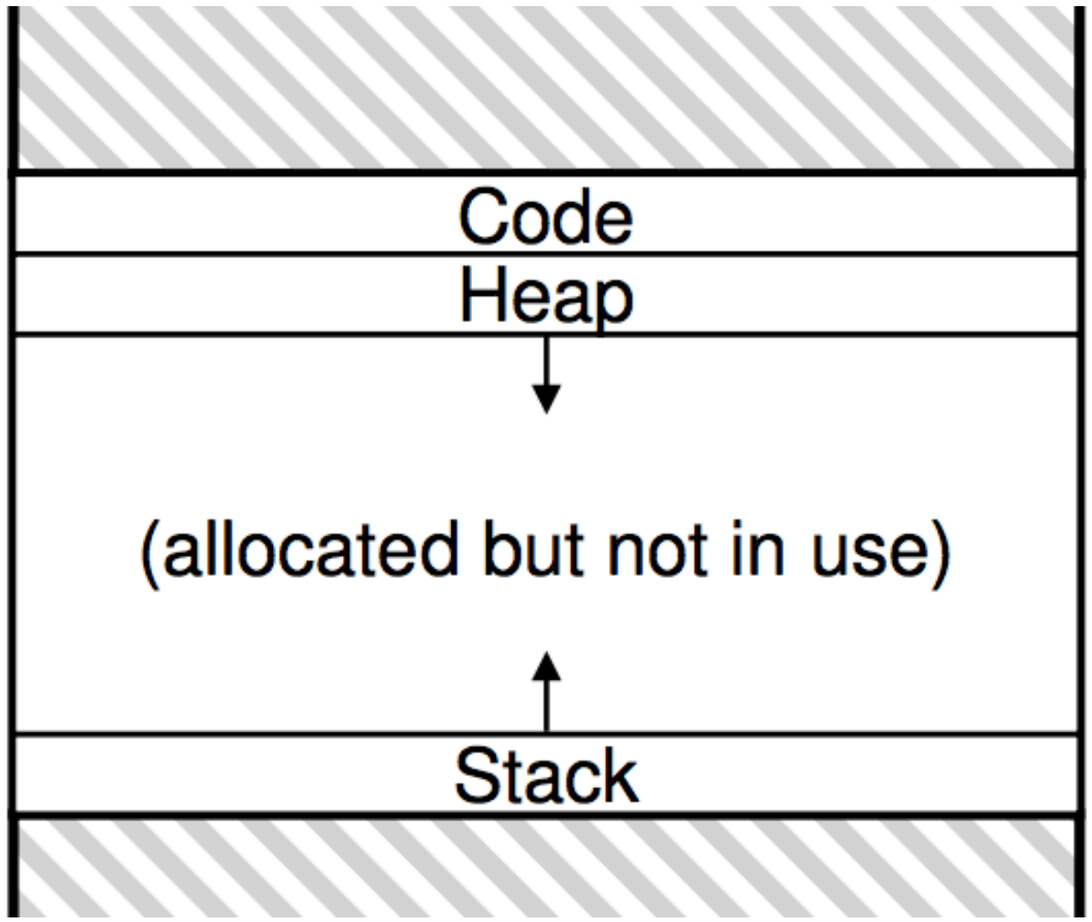
Base + Bound
for Code



Segmentation

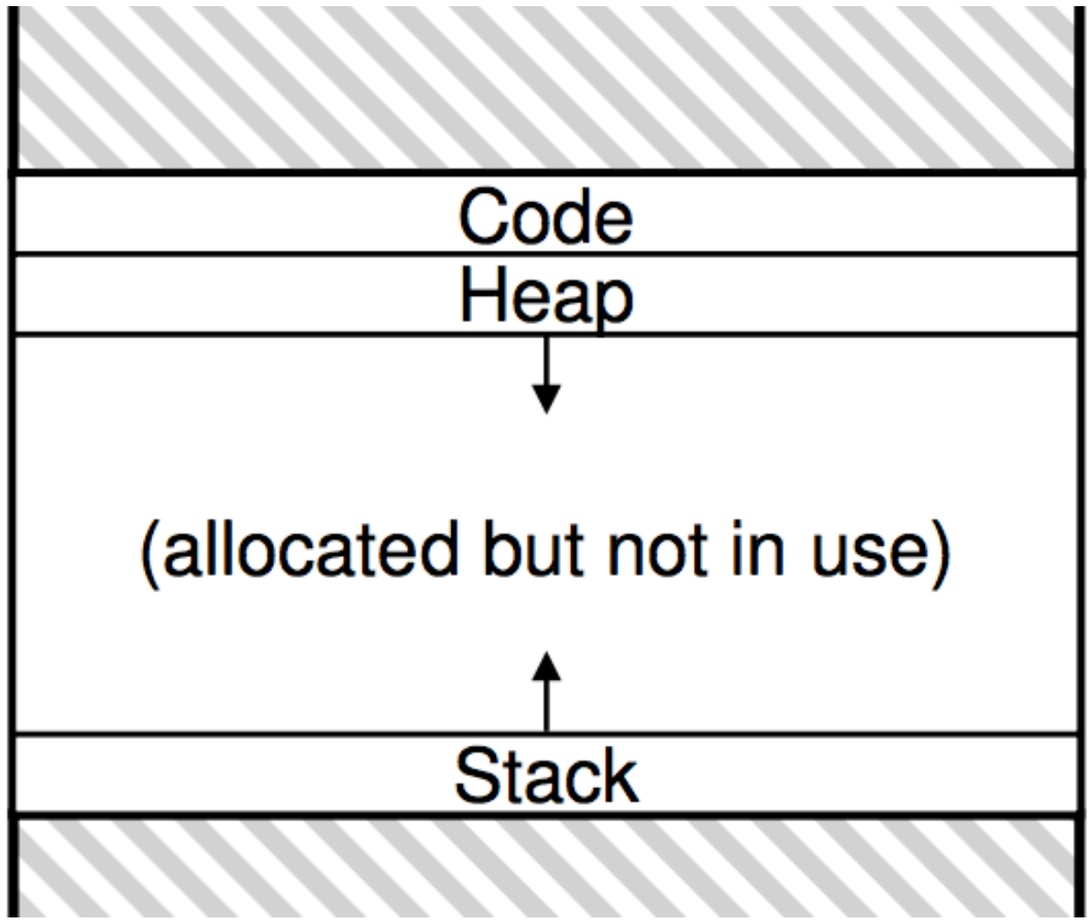


Segmentation



Segmentation

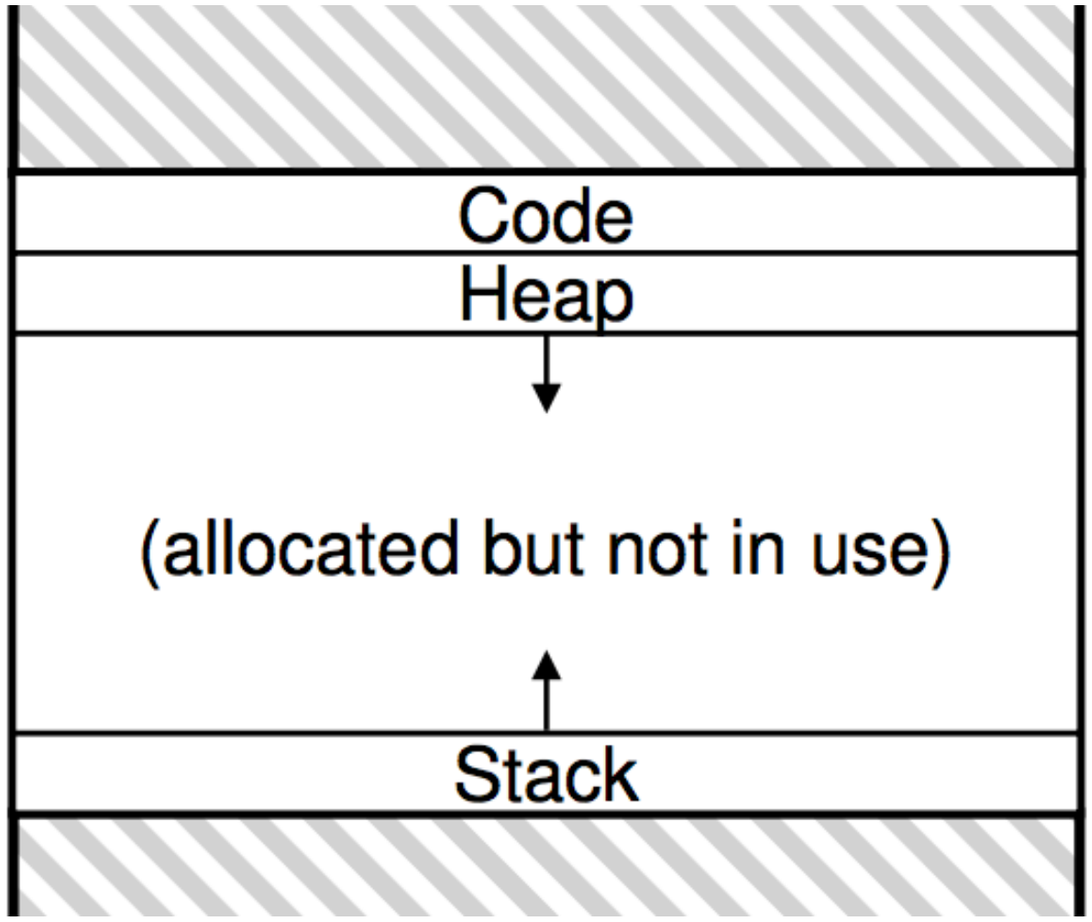
Base for Heap
Base + Bound
for Heap



Segmentation

Base for Heap

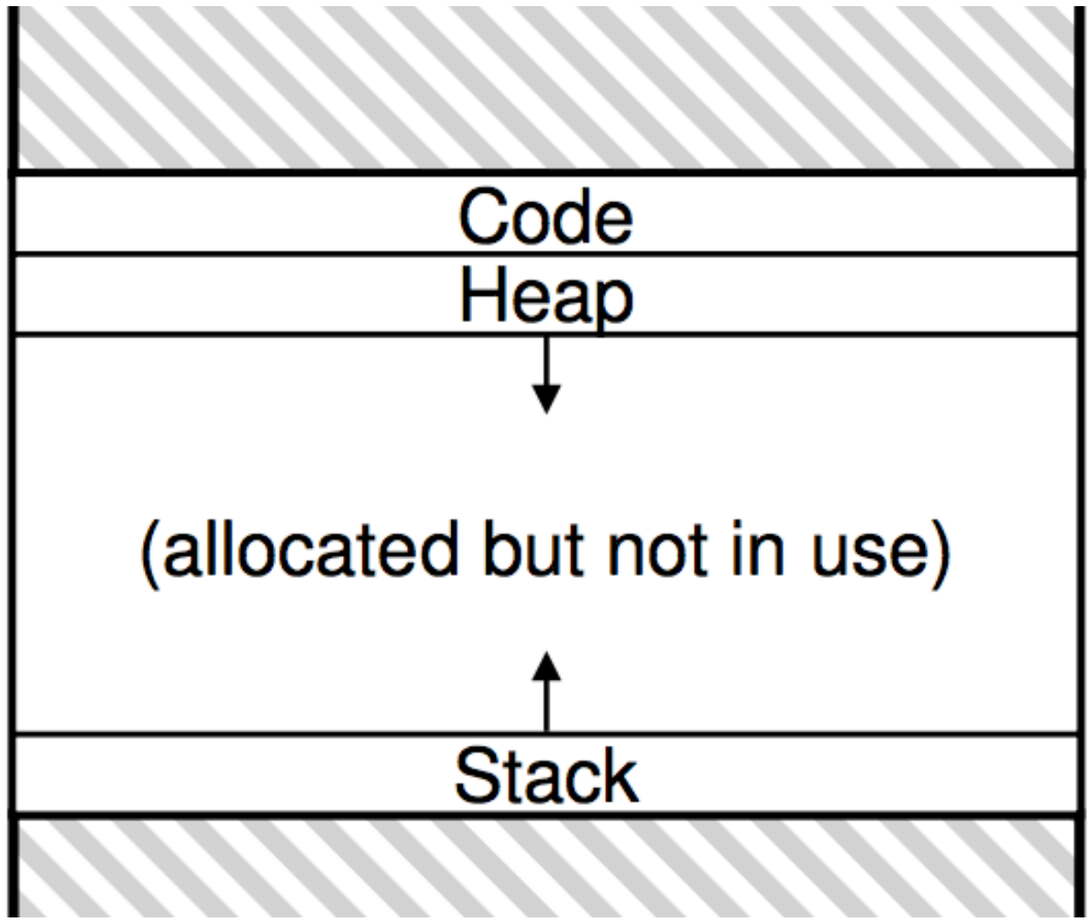
Base + Bound for Heap



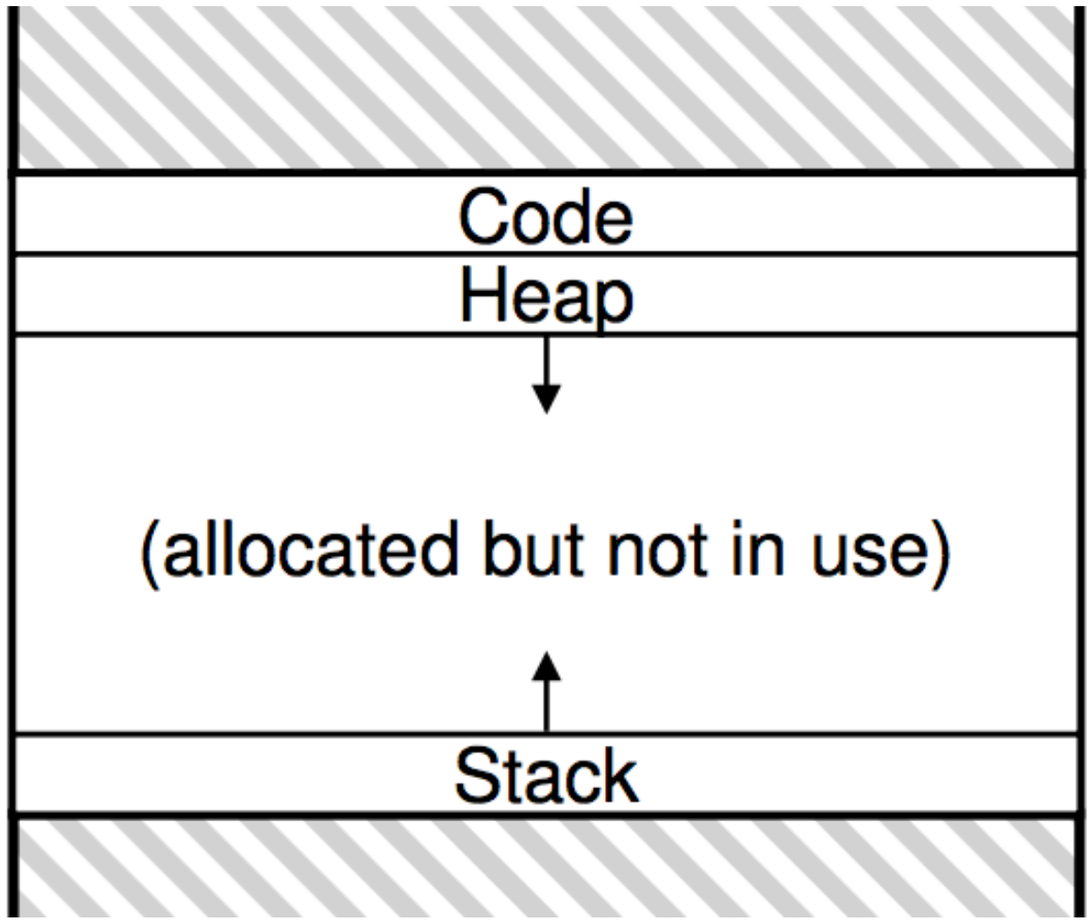
Segmentation

Base for Heap

Base + Bound for Heap



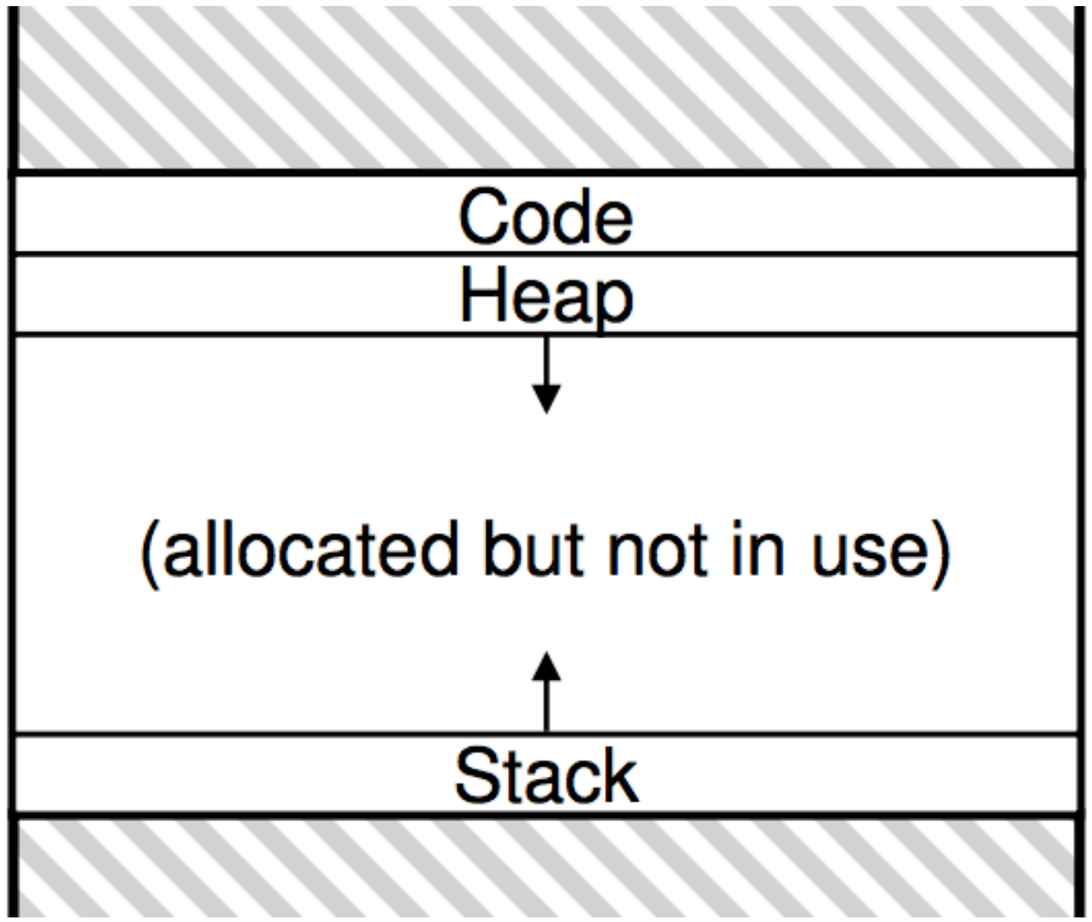
Segmentation



Segmentation

Base + Bound for Stack

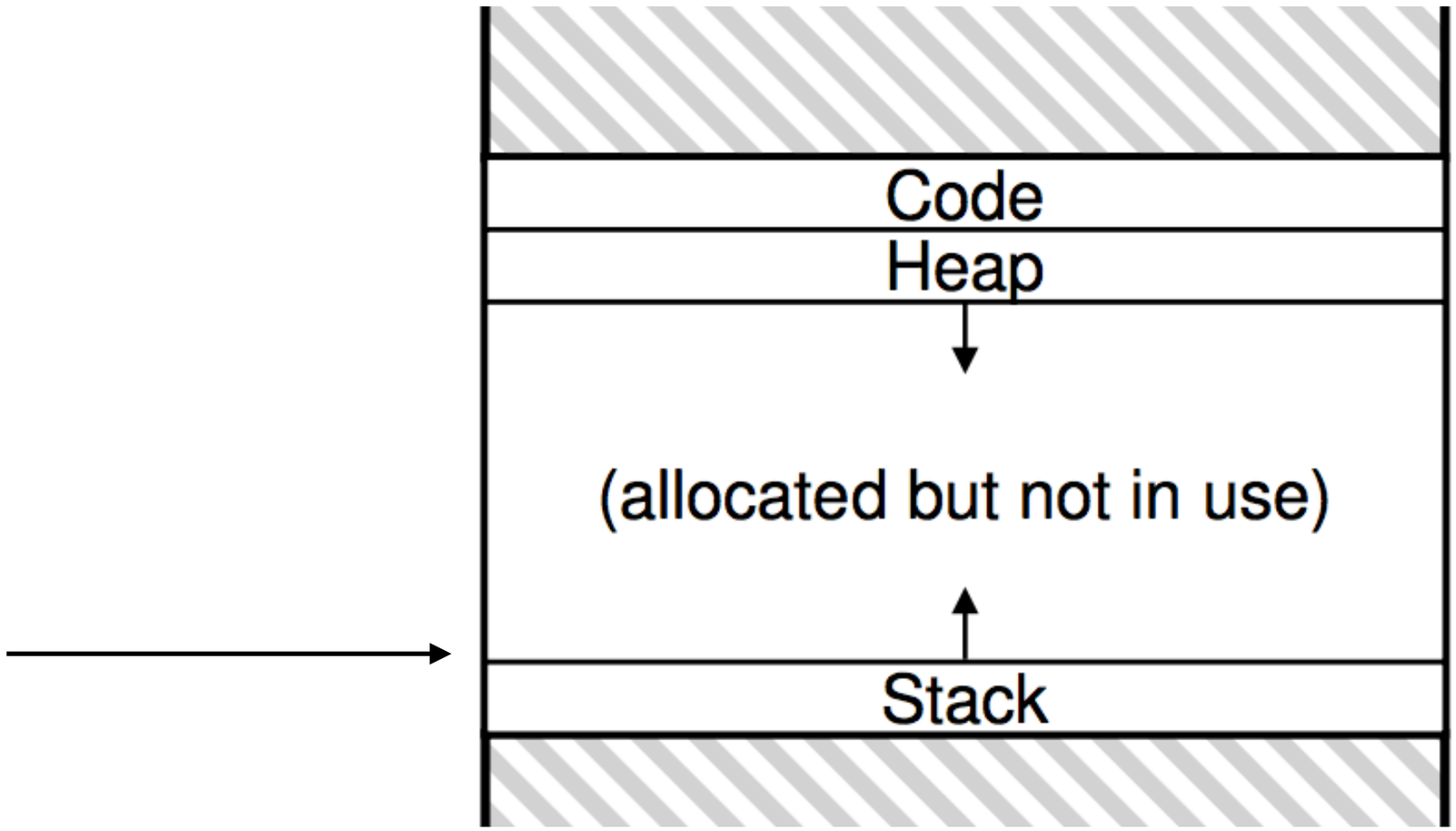
Base for Stack



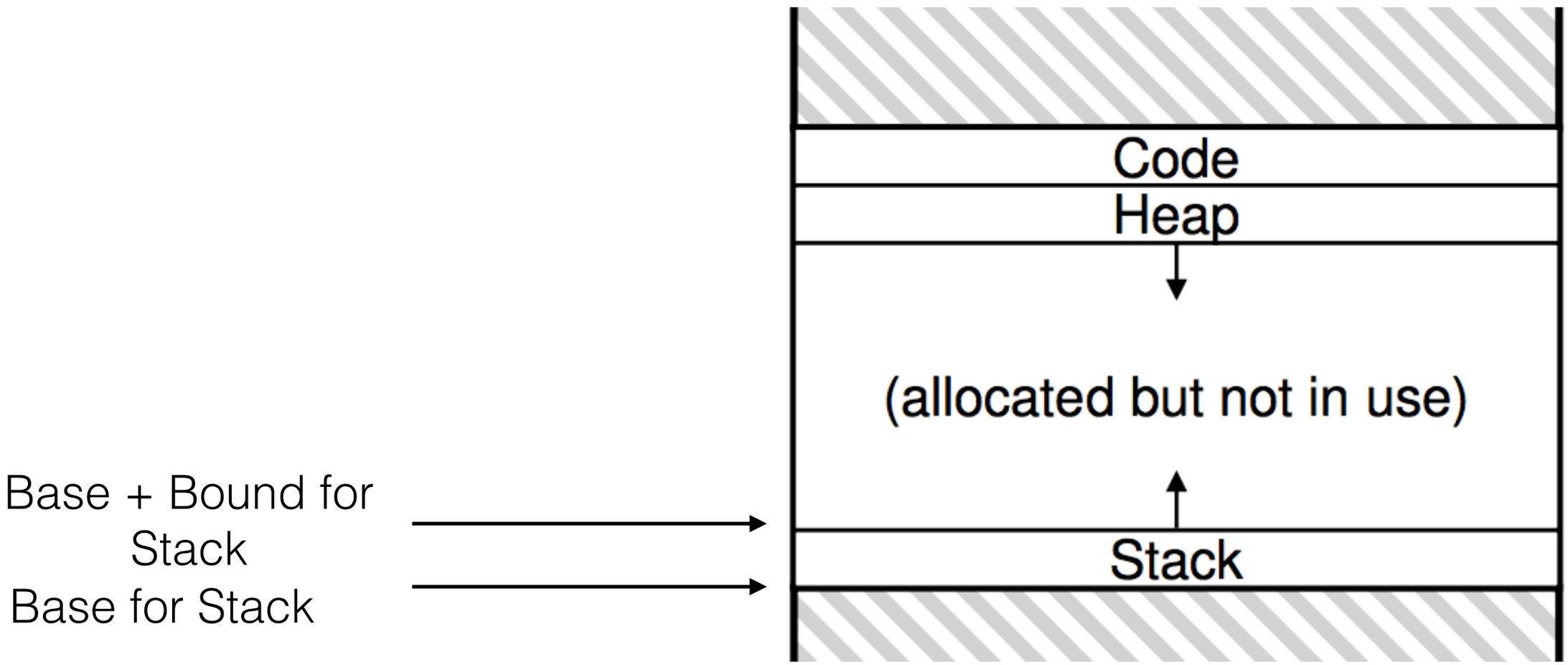
Segmentation

Base + Bound for Stack

Base for Stack



Segmentation



Segmentation

Segmentation

1. Multiple bases and bounds per process. Each of them called a segment.

Segmentation

1. Multiple bases and bounds per process. Each of them called a segment.
    1. Each segment can have own size

Segmentation

1. Multiple bases and bounds per process. Each of them called a segment.
    1. Each segment can have own size
    2. Each segment can have own permissions:

Segmentation

1. Multiple bases and bounds per process. Each of them called a segment.
    1. Each segment can have own size
    2. Each segment can have own permissions:
        1. Code would be?

Segmentation

1. Multiple bases and bounds per process. Each of them called a segment.
    1. Each segment can have own size
    2. Each segment can have own permissions:
        1. Code would be?
3. Each segment can have direction of growth!

Segmentation : Mini Guide (TLDR version)

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1. Each segment has:

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)
    2. Base physical address

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)
    2. Base physical address
    3. Bound

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)
    2. Base physical address
    3. Bound
2. **Check:** Virtual Address is OK if it inside some segment, or for some segment:

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)
    2. Base physical address
    3. Bound
2. **Check:** Virtual Address is OK if it inside some segment, or for some segment:
    1. Segment Start < V.A. < Segment Start + Segment Bound.

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)
    2. Base physical address
    3. Bound
2. **Check:** Virtual Address is OK if it inside some segment, or for some segment:
    1. Segment Start < V.A. < Segment Start + Segment Bound.
3. **Translate**: For the segment that contains this virtual address:

Segmentation : Mini Guide (TLDR version)

1. Each segment has:
    1. Start virtual address (VA)
    2. Base physical address
    3. Bound
2. **Check:** Virtual Address is OK if it inside some segment, or for some segment:
    1. Segment Start < V.A. < Segment Start + Segment Bound.
3. **Translate**: For the segment that contains this virtual address:
    1. Physical Address = (V.A. - Segment Start) + Segment Base

Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x100

Segmentation Example

Kernel

CPU

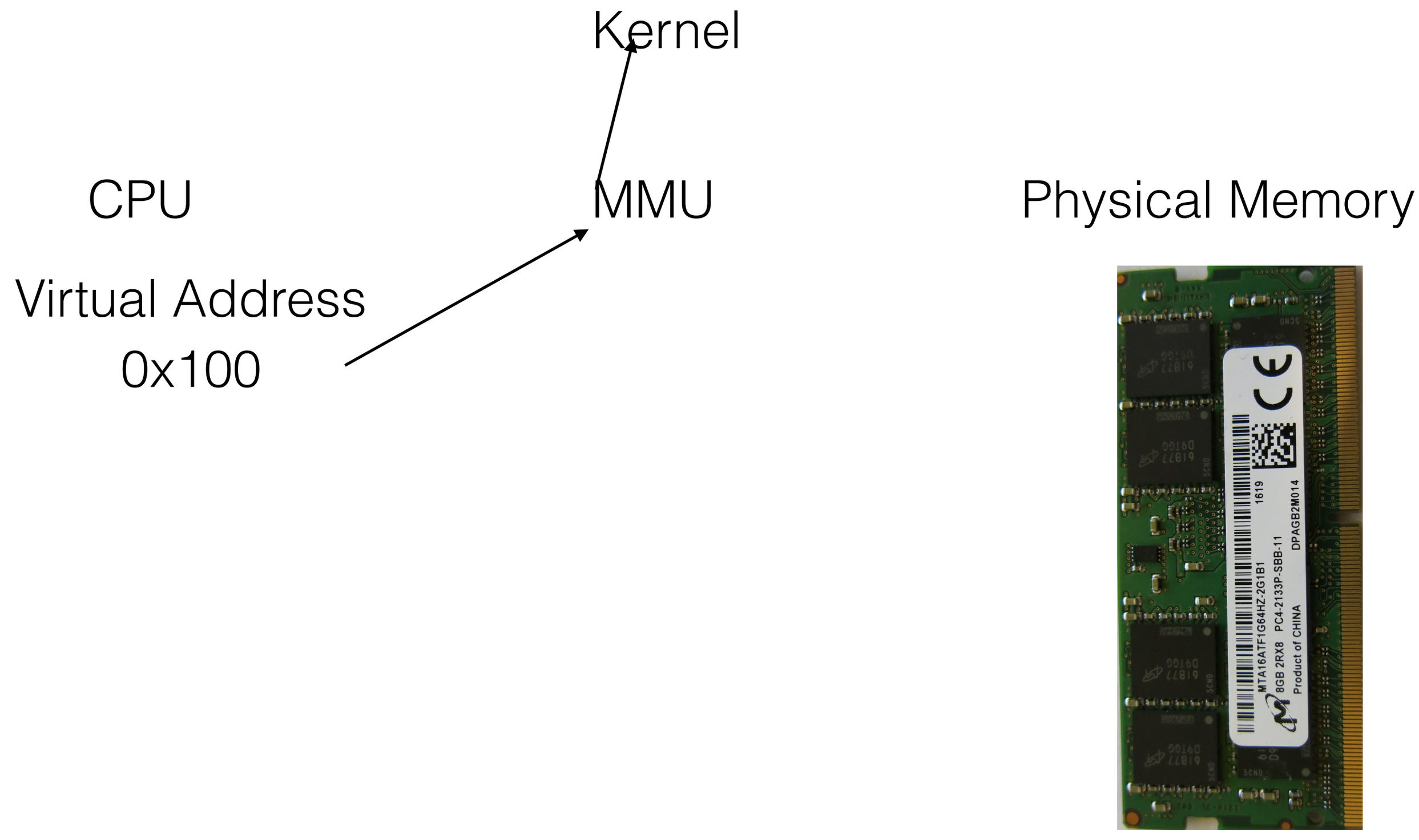
MMU

Physical Memory

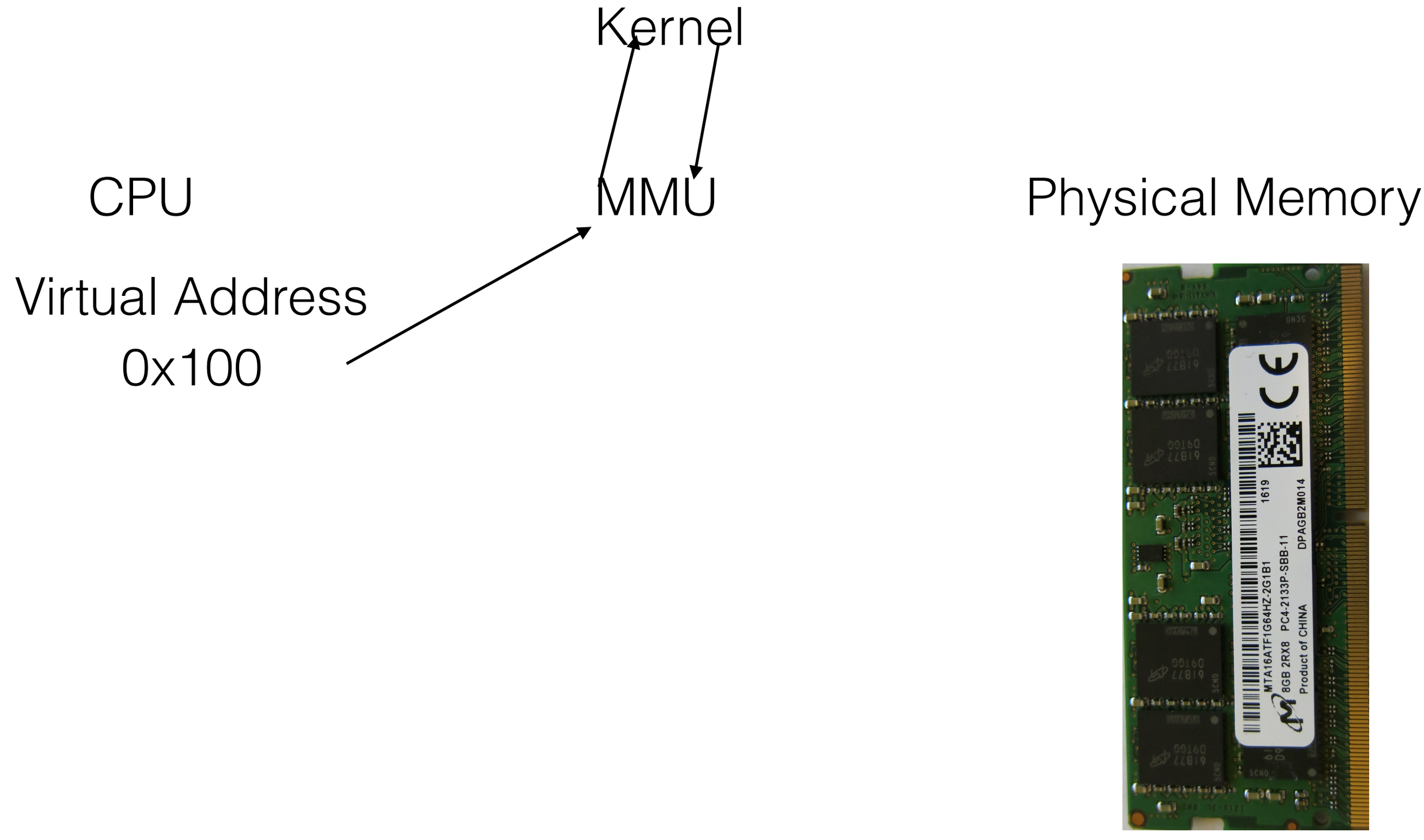
Virtual Address

0x100

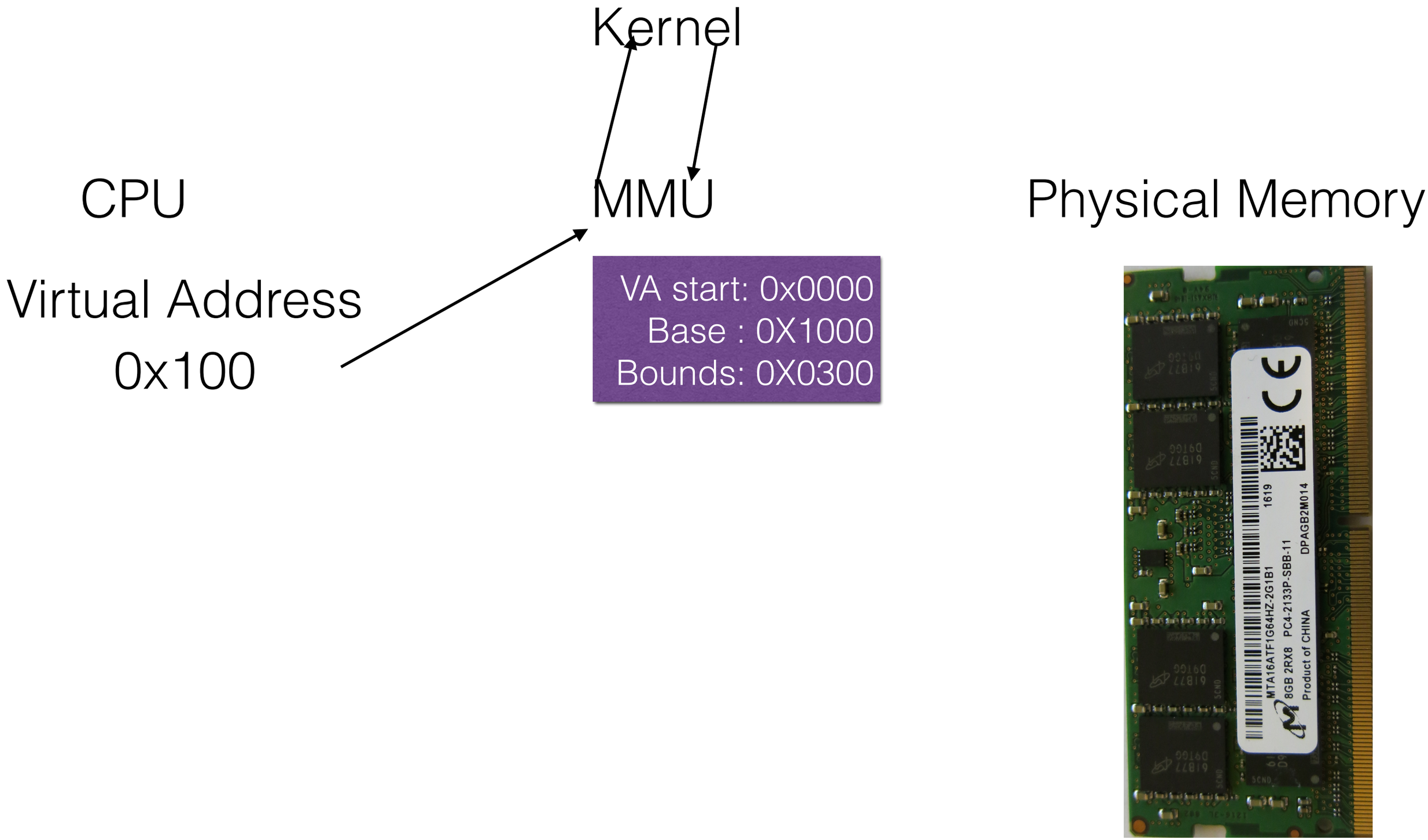
Segmentation Example



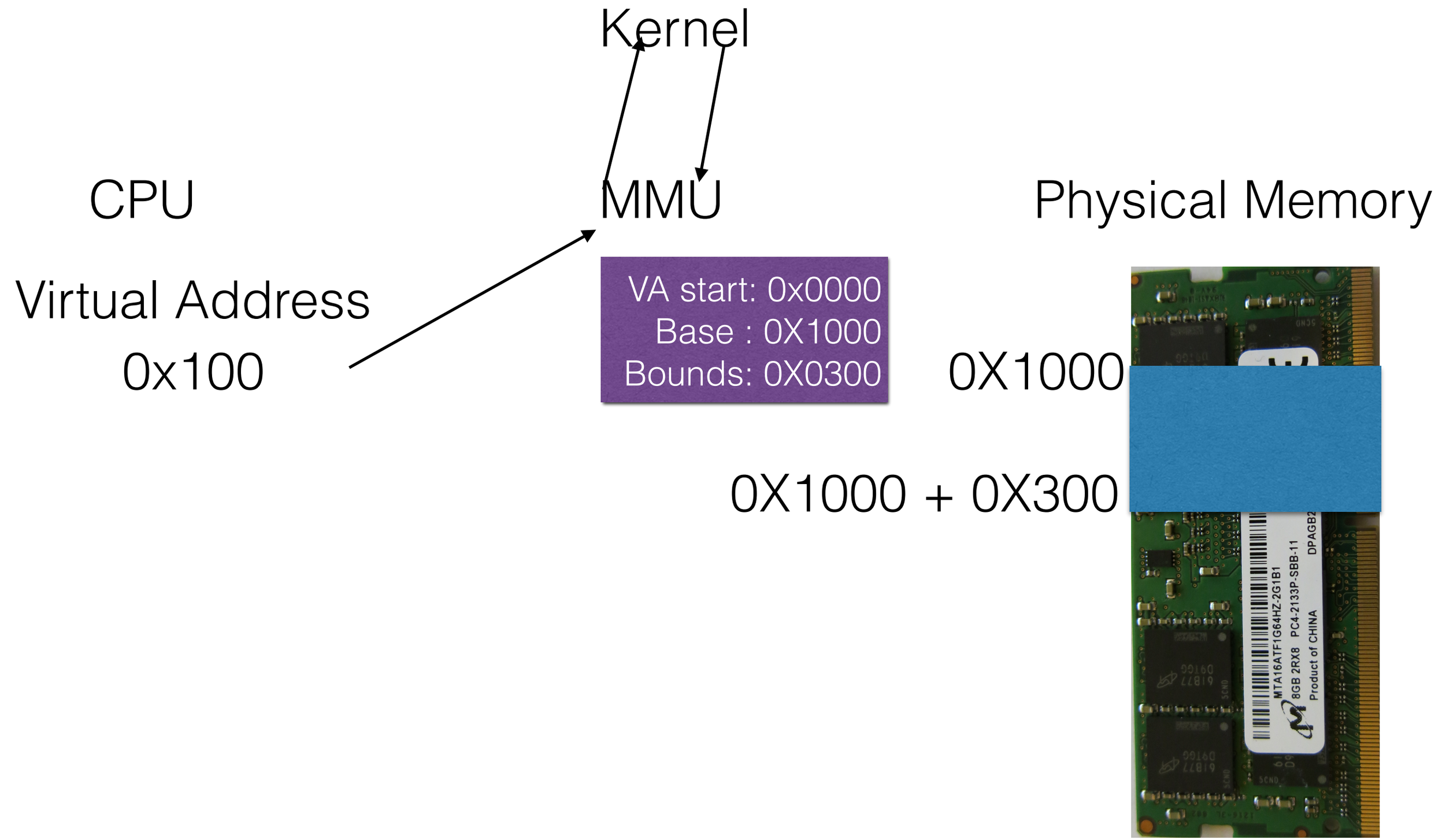
Segmentation Example



Segmentation Example



Segmentation Example



Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x100

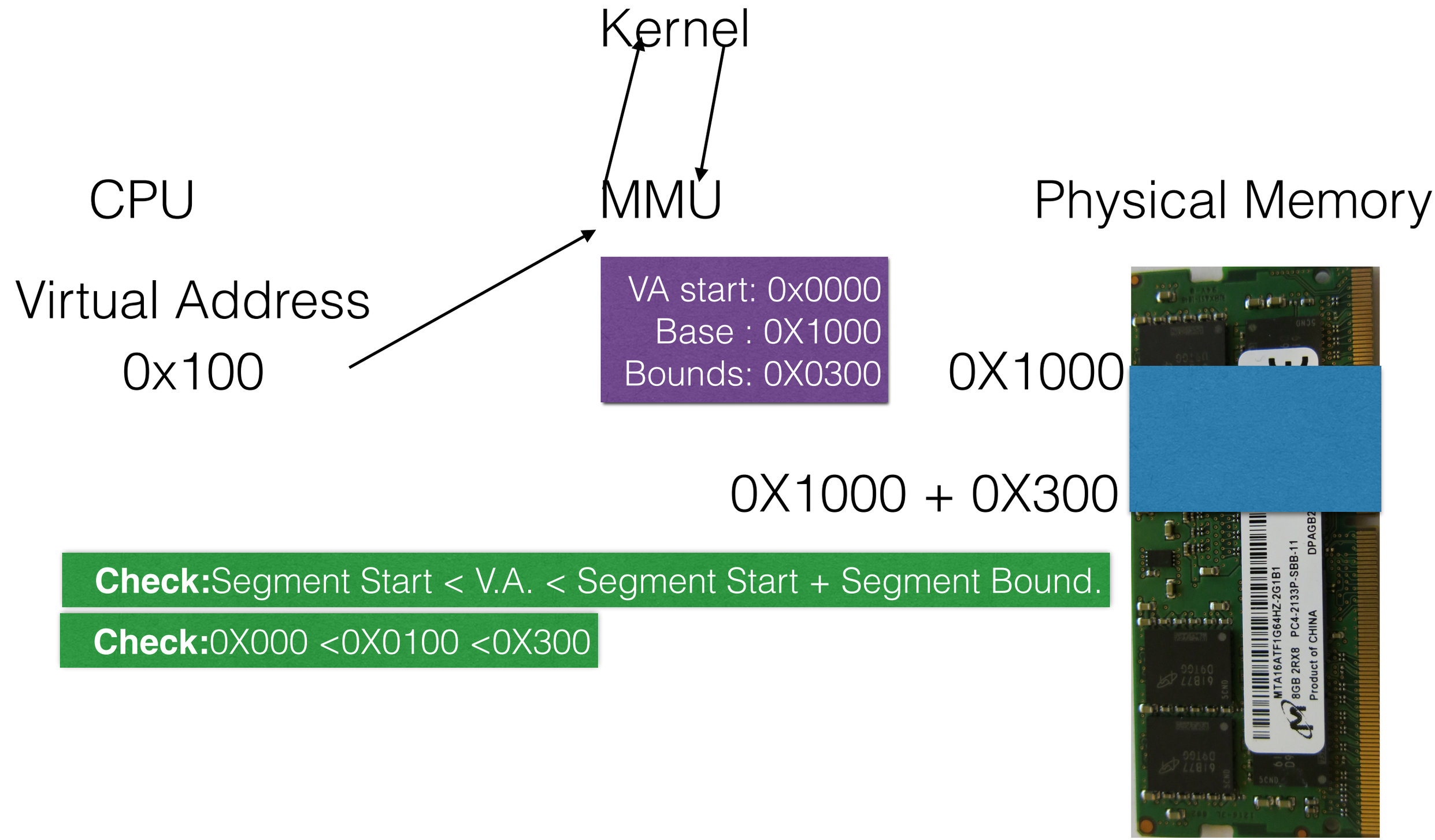
VA start: 0x0000
Base : 0X1000
Bounds: 0X0300

0X1000

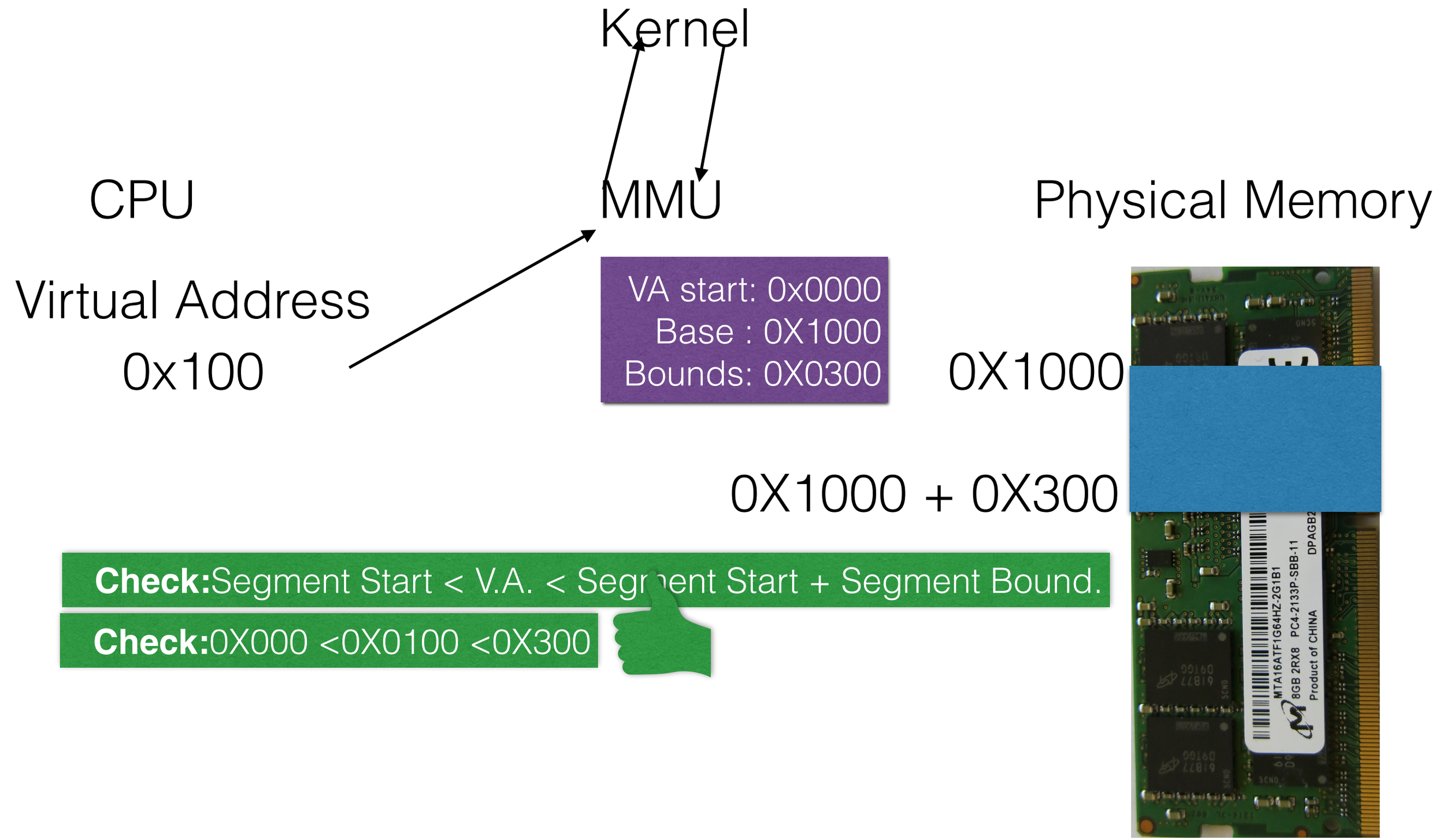
0X1000 + 0X300

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

Segmentation Example



Segmentation Example



Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x100

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

0X1000

0X1000 + 0X300

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

Check:0X000 <0X0100 <0X300

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

Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x100

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

0X1000

0X1000 + 0X300

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

Check:0X000 <0X0100 <0X300

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

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

Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x100

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

0X1000

0X1000 + 0X300

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

Check:0X000 <0X0100 <0X300

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

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

Segmentation Example

Kernel

CPU

MMU

Physical Memory

Virtual Address

0x2400

Segmentation Example

Kernel

CPU

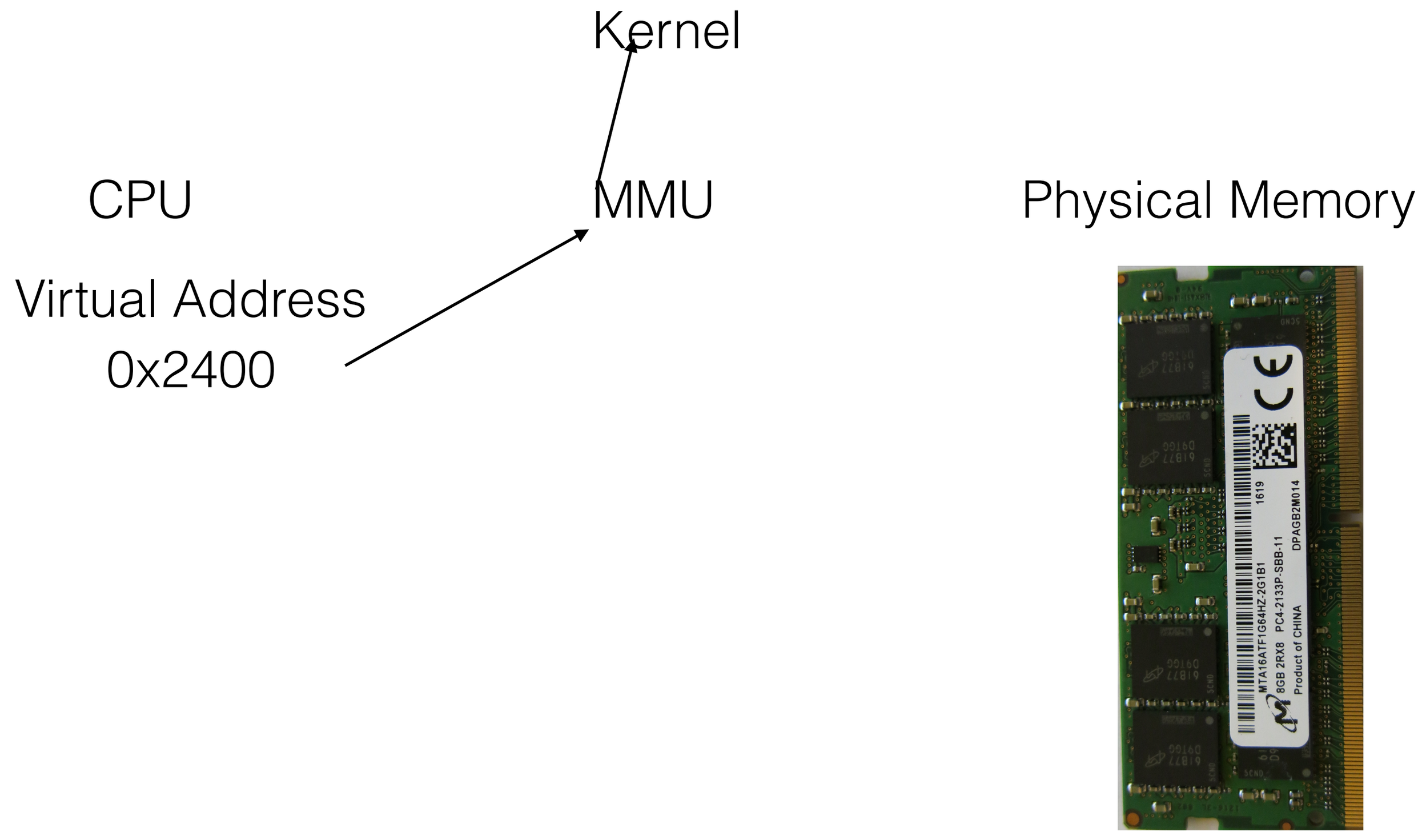
MMU

Physical Memory

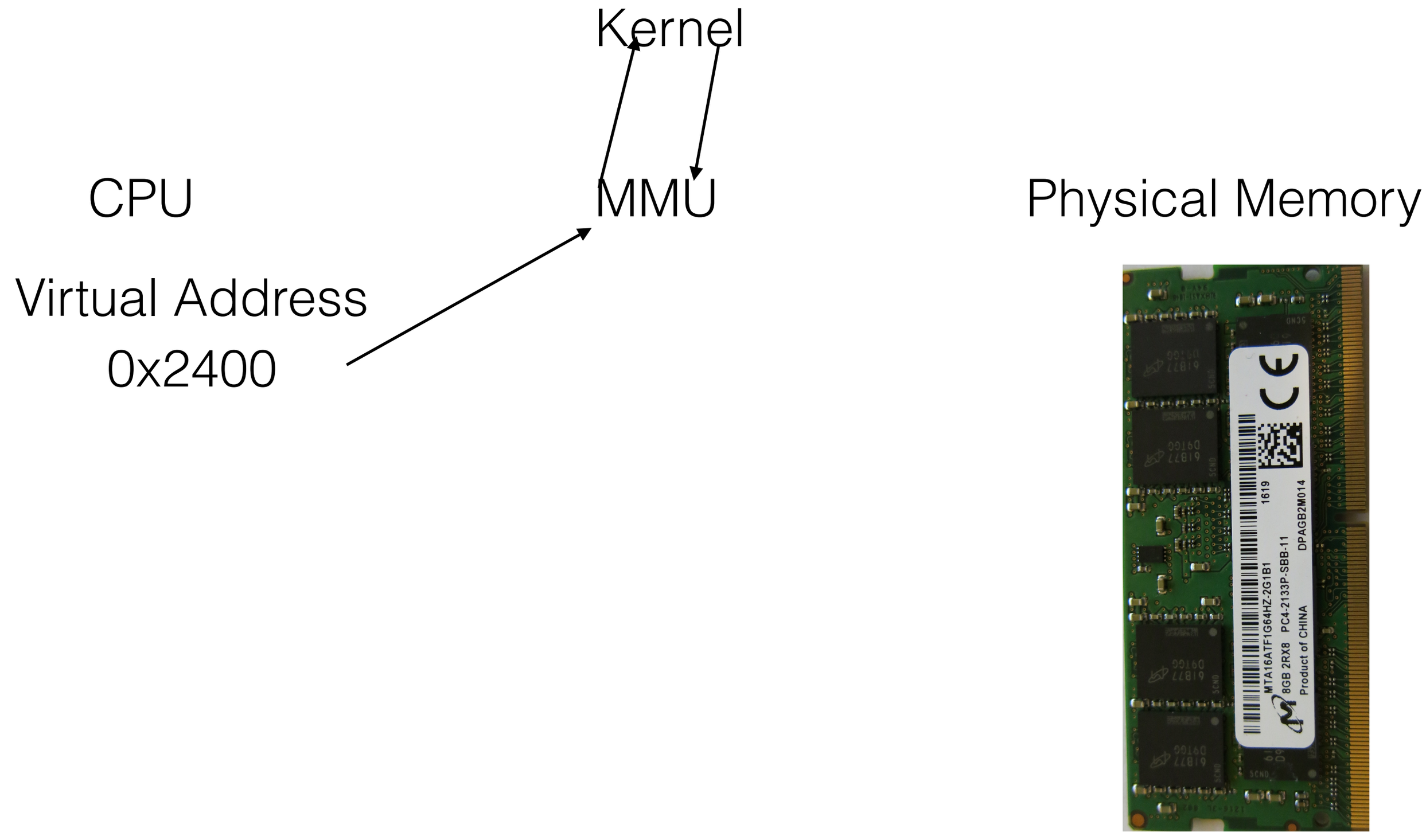
Virtual Address

0x2400

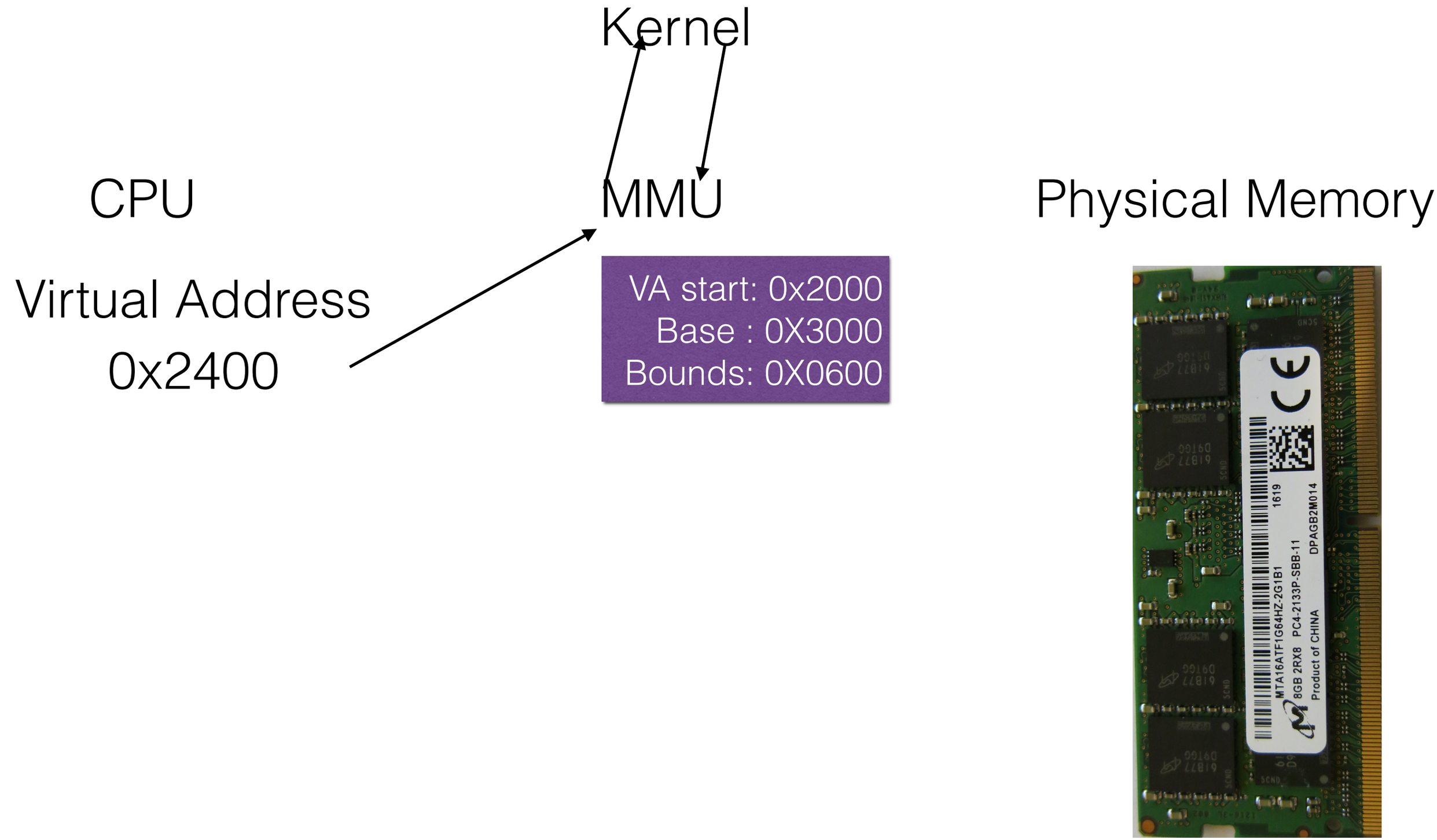
Segmentation Example



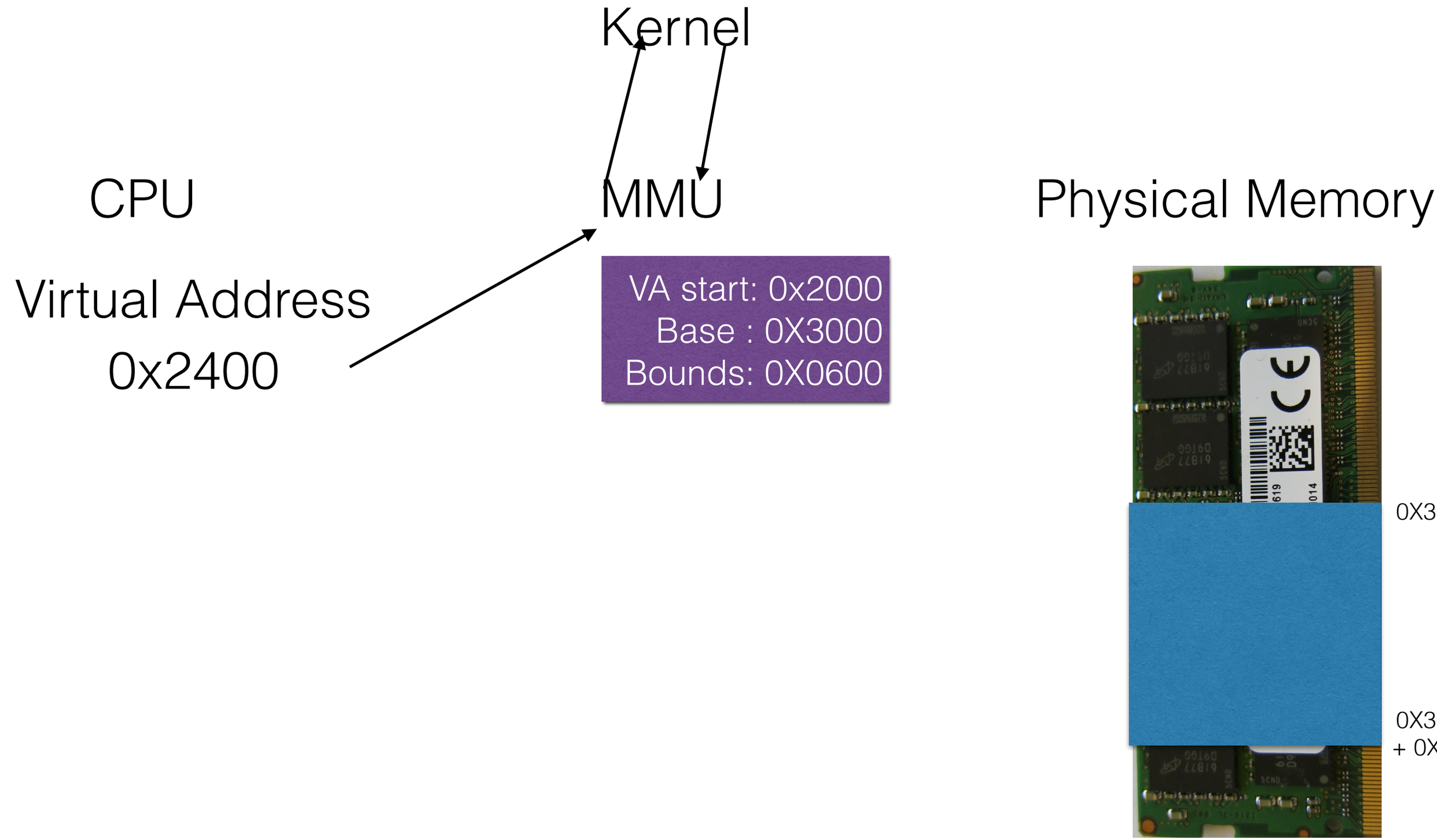
Segmentation Example



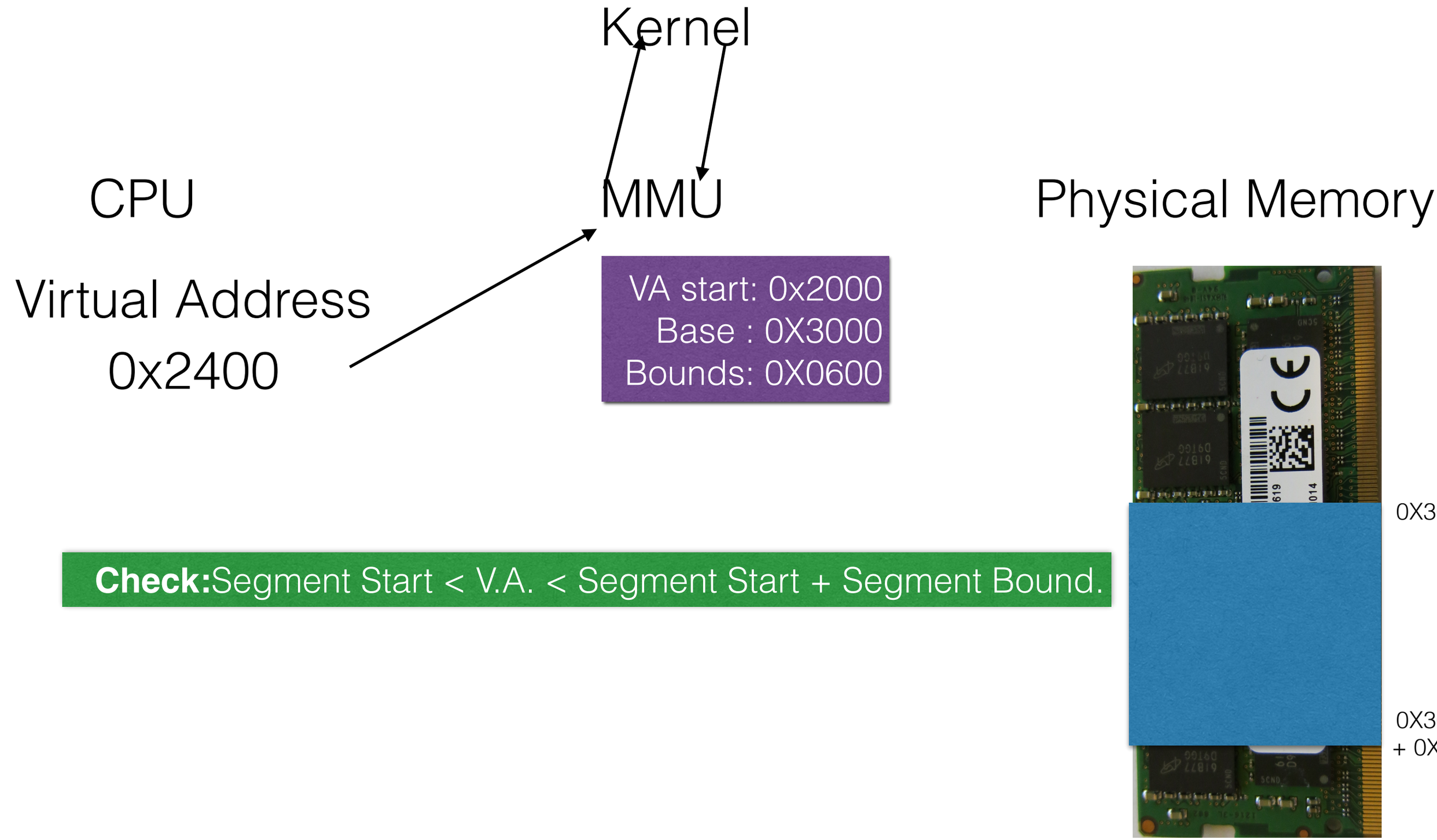
Segmentation Example



Segmentation Example

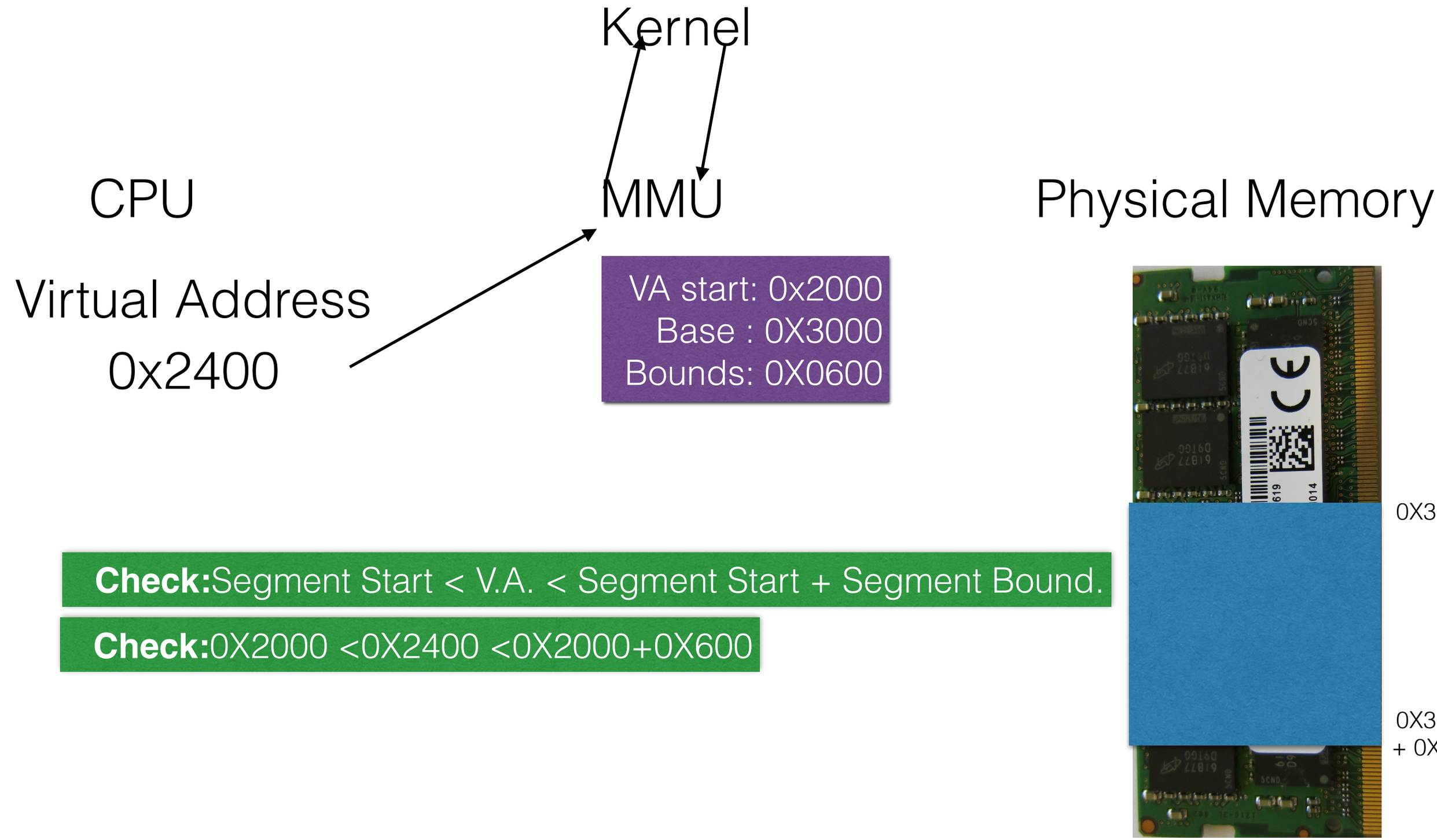


Segmentation Example



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

Segmentation Example



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

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

Segmentation Example

Kernel

CPU

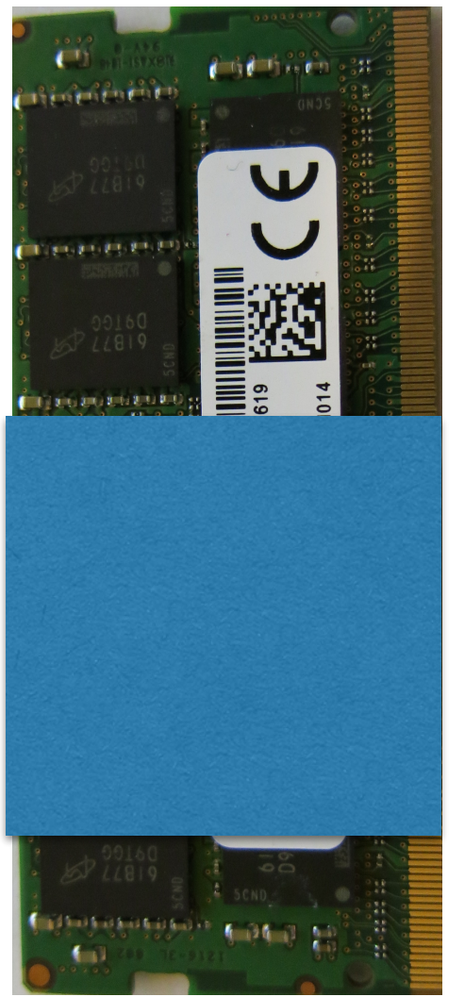
MMU

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 <0X2000+0X600

Segmentation Example

Kernel

CPU

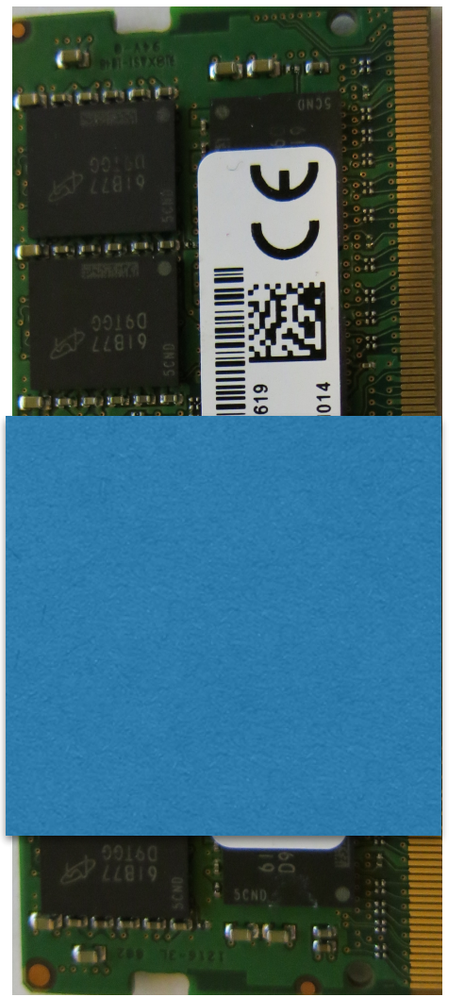
MMU

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 <0X2000+0X600

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

Segmentation Example

Kernel

CPU

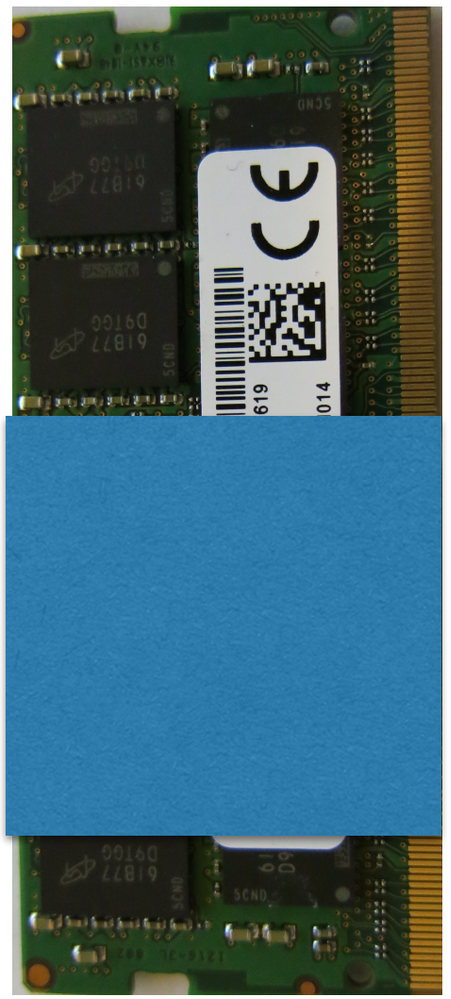
MMU

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 <0X2000+0X600

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

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

Segmentation Example

Kernel

CPU

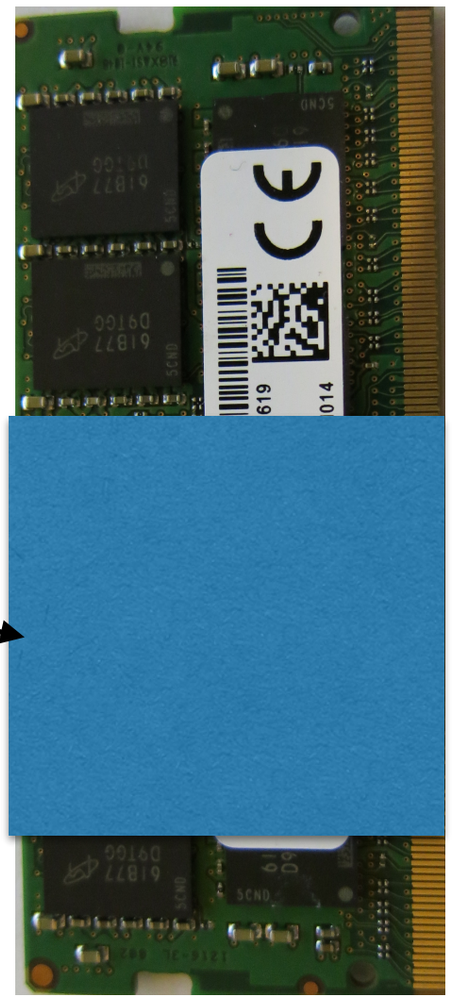
MMU

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 <0X2000+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

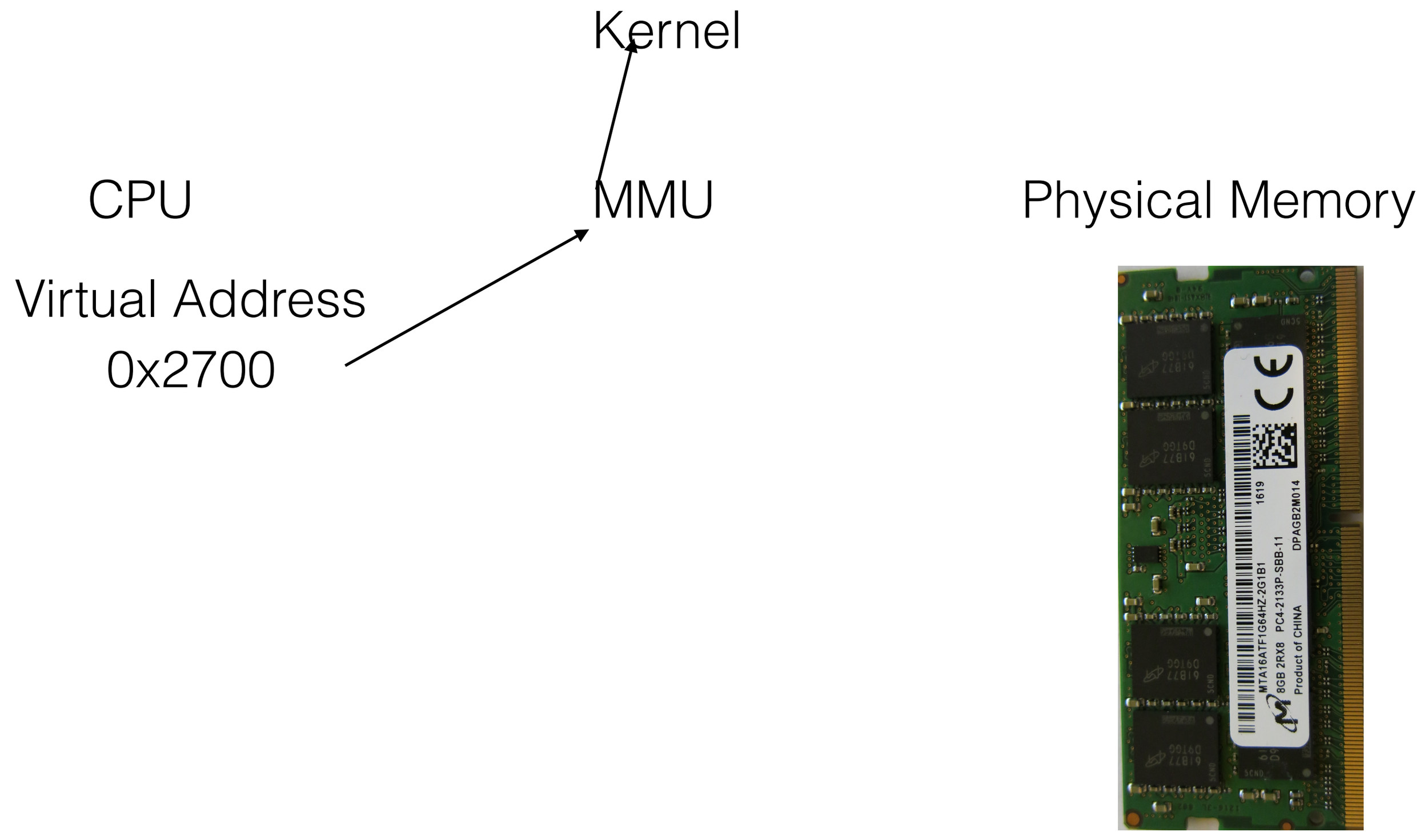
MMU

Physical Memory

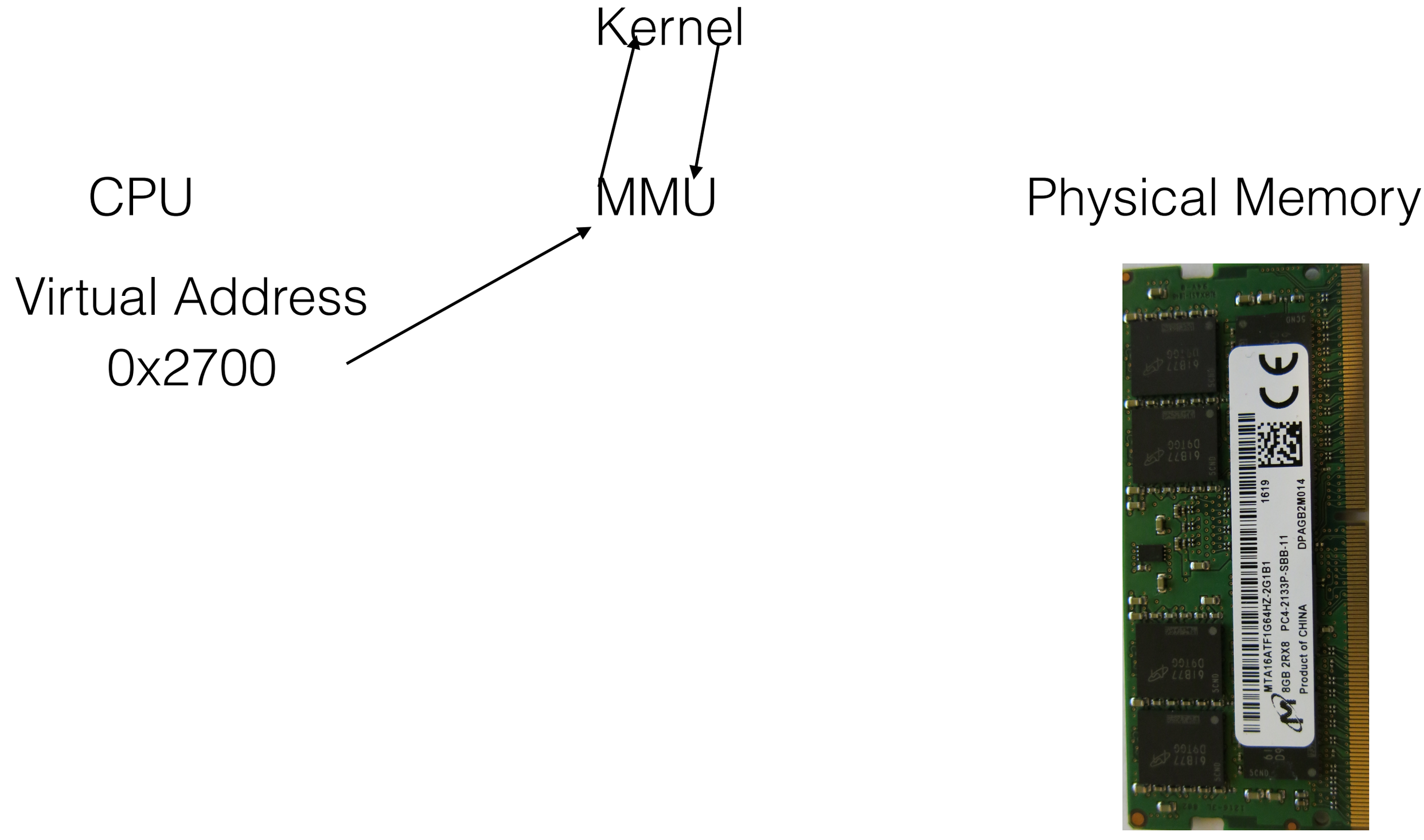
Virtual Address

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

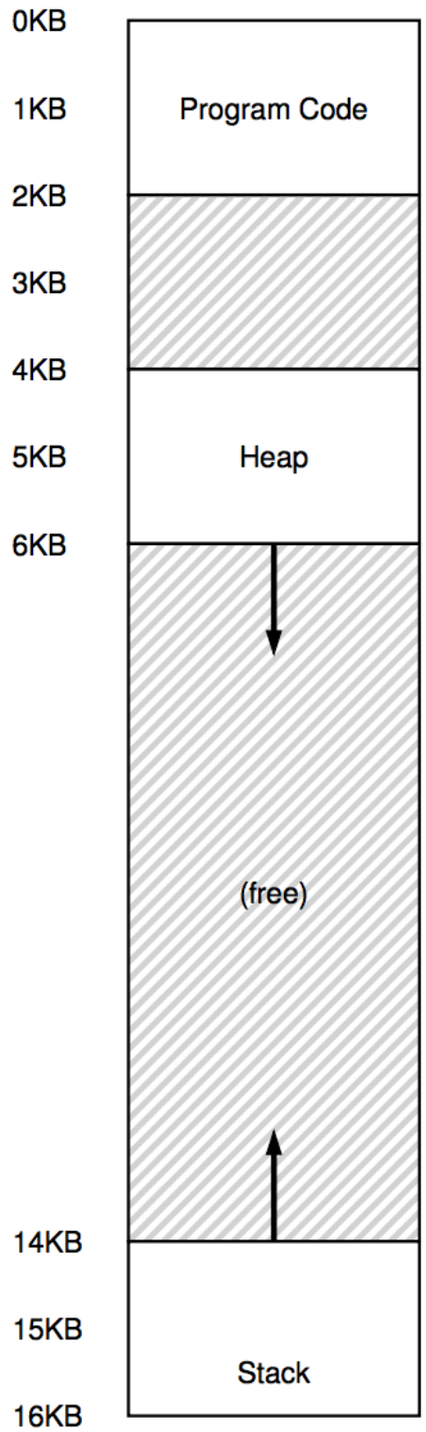
Physical Memory

Virtual Address
0x2700

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

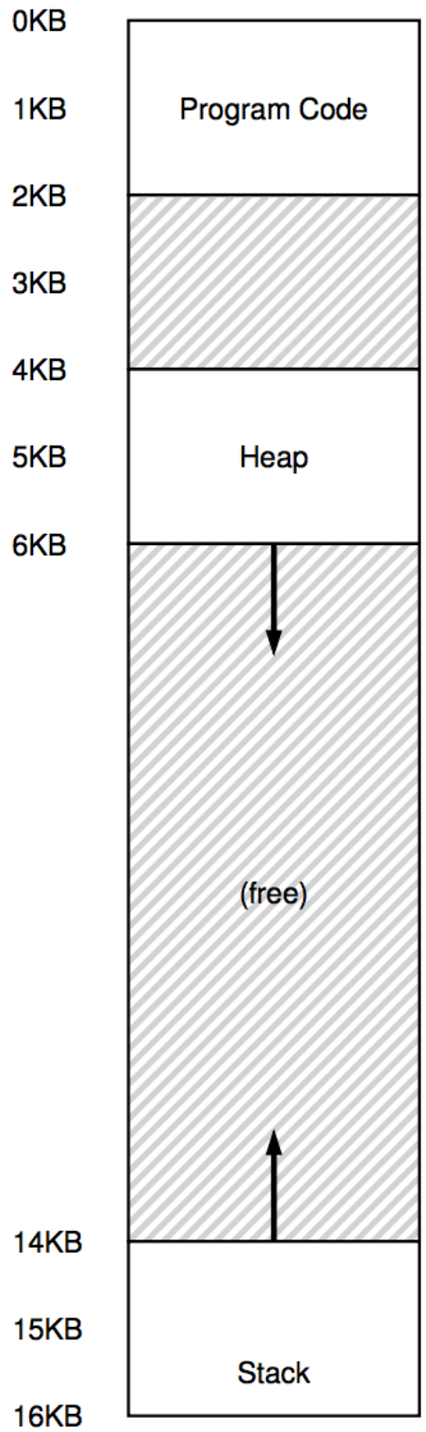
Segment Reference

Virtual Address Space



Segment Reference

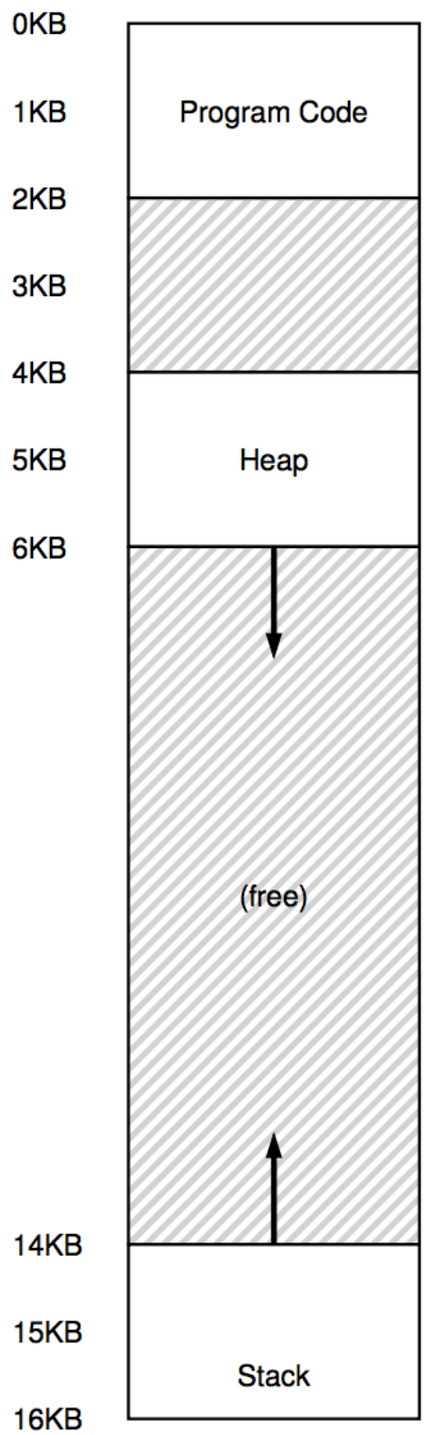
Virtual Address Space



11 | 1111 | 1111 | 1111

Segment Reference

Virtual Address Space

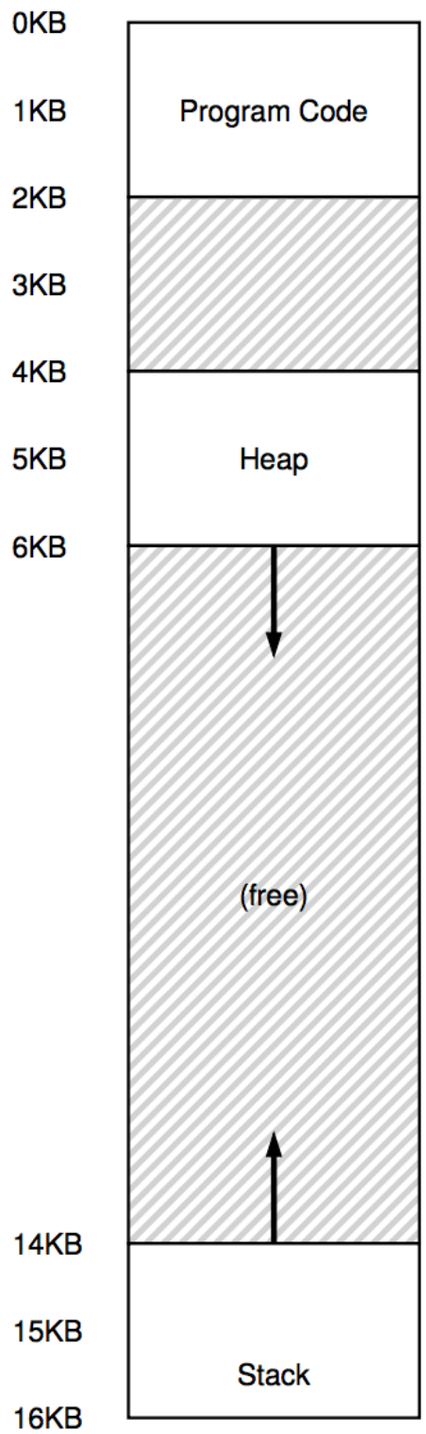


00 0000 0000 0000

11 1111 1111 1111

Segment Reference

Virtual Address Space

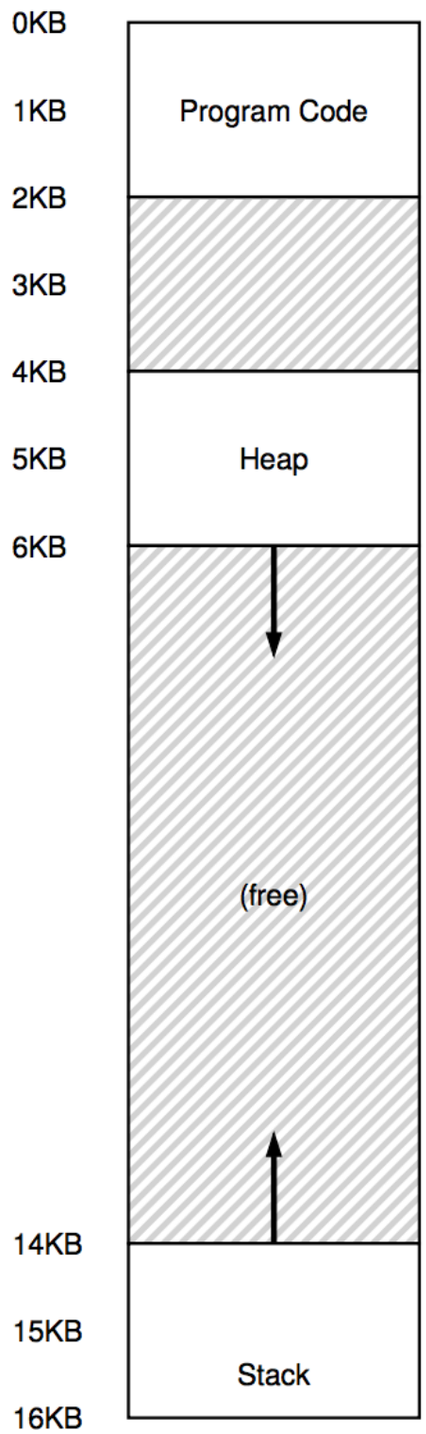


00	0000	0000	0000
00	0111	1111	1111

11	1111	1111	1111

Segment Reference

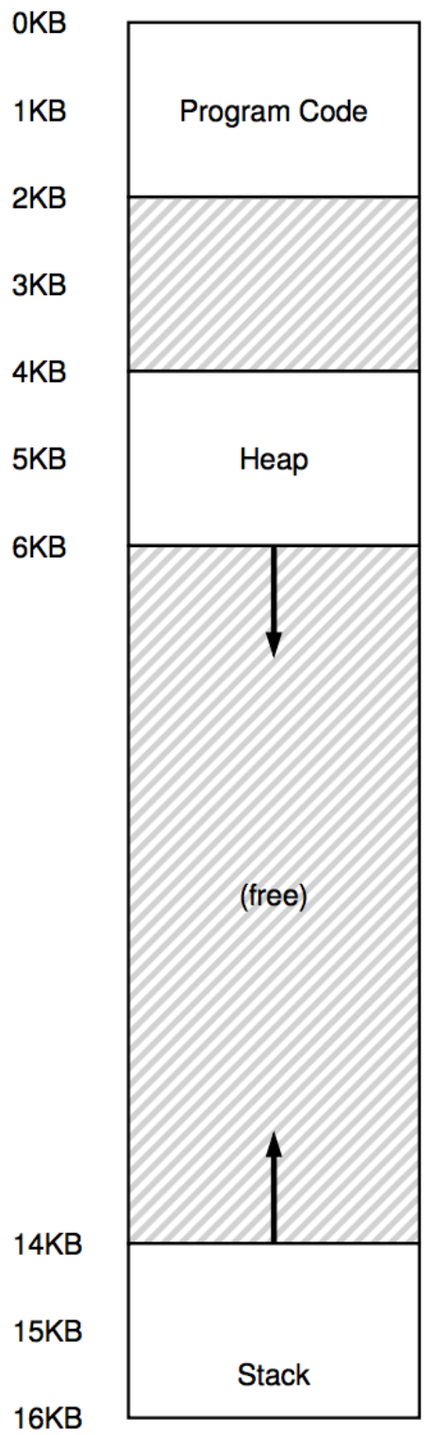
Virtual Address Space



00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
11	1111	1111	1111

Segment Reference

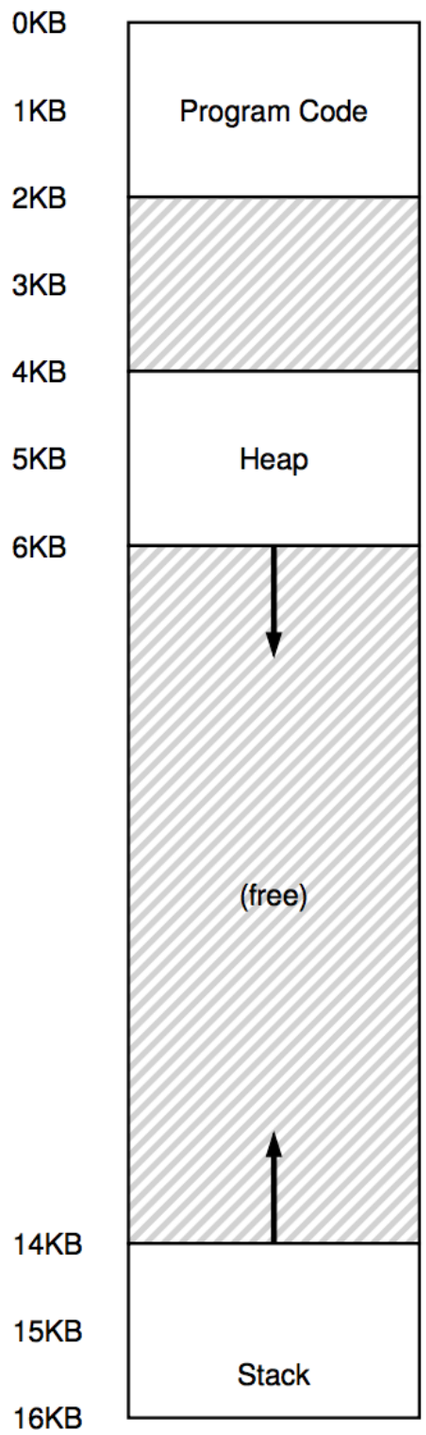
Virtual Address Space



00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
01	0111	1111	1111
11	1111	1111	1111

Segment Reference

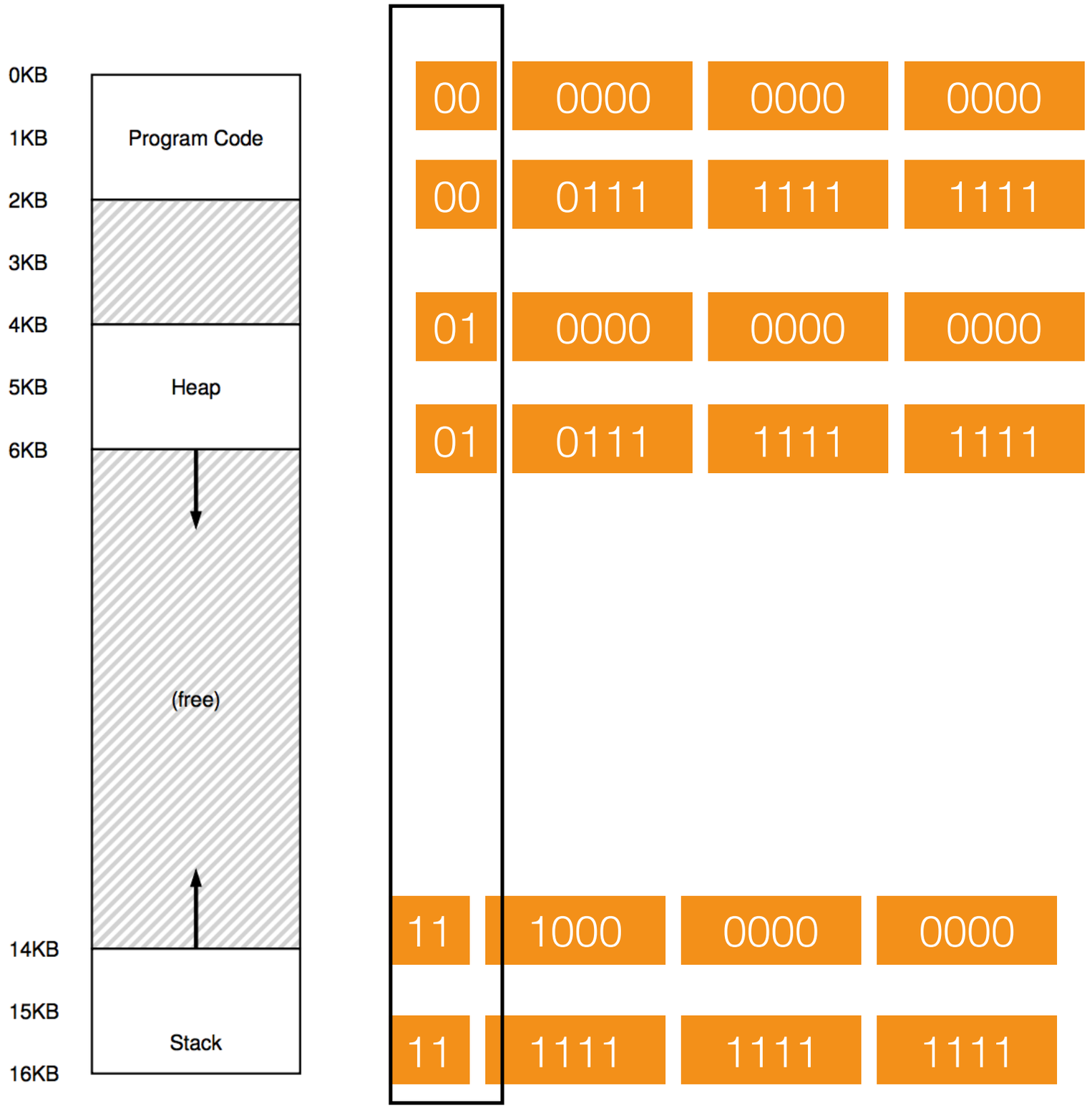
Virtual Address Space



00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
01	0111	1111	1111
11	1000	0000	0000
11	1111	1111	1111

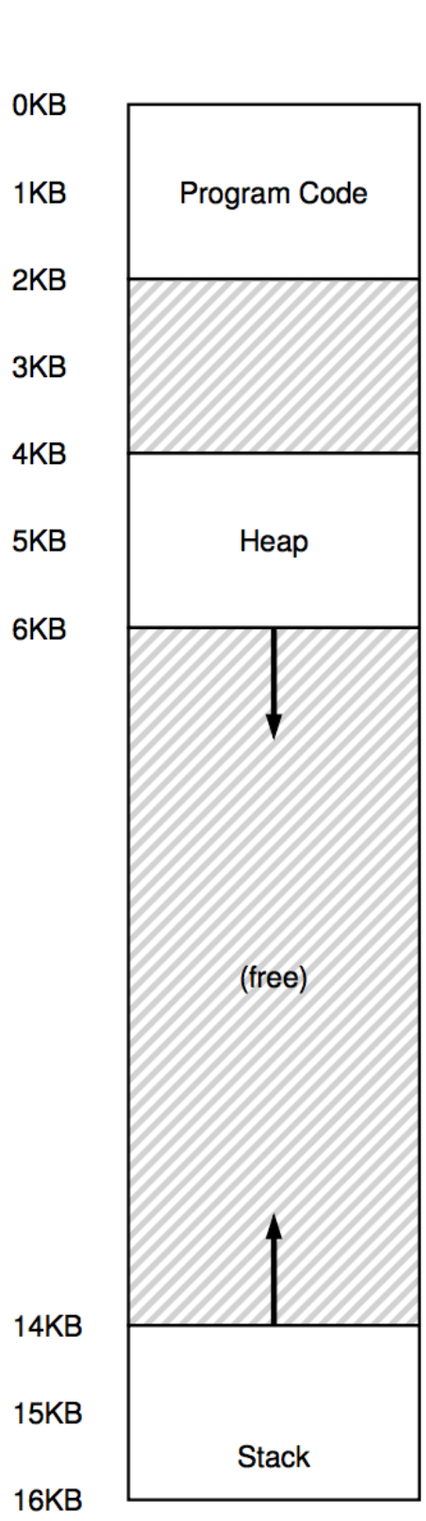
Segment Reference

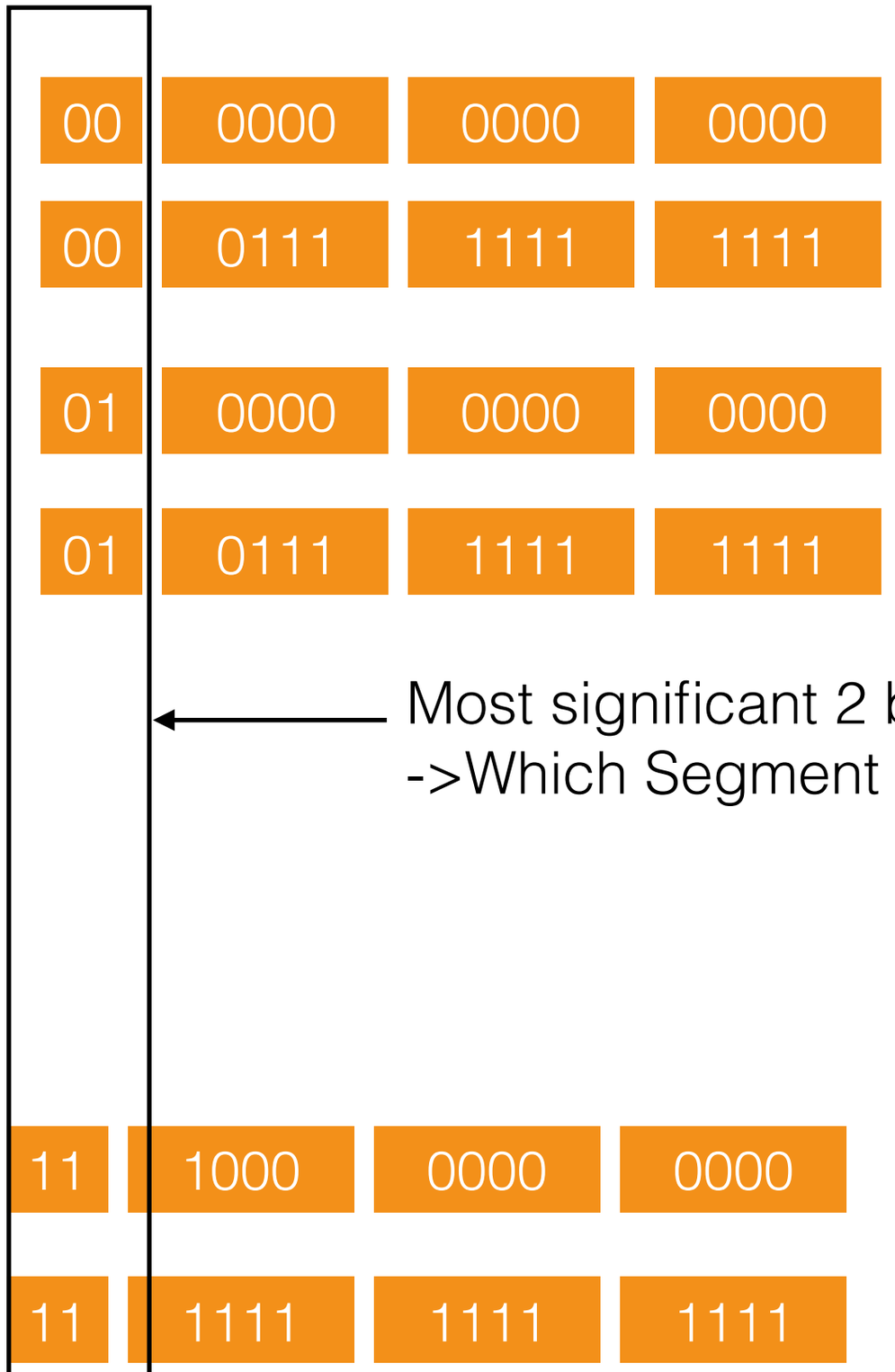
Virtual Address Space



Segment Reference

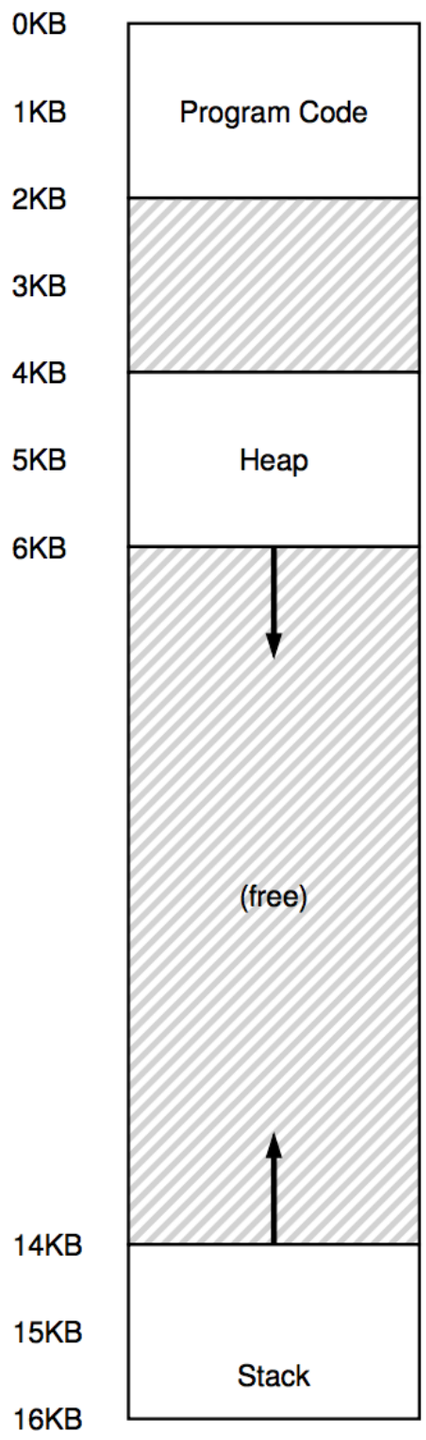
Virtual Address Space

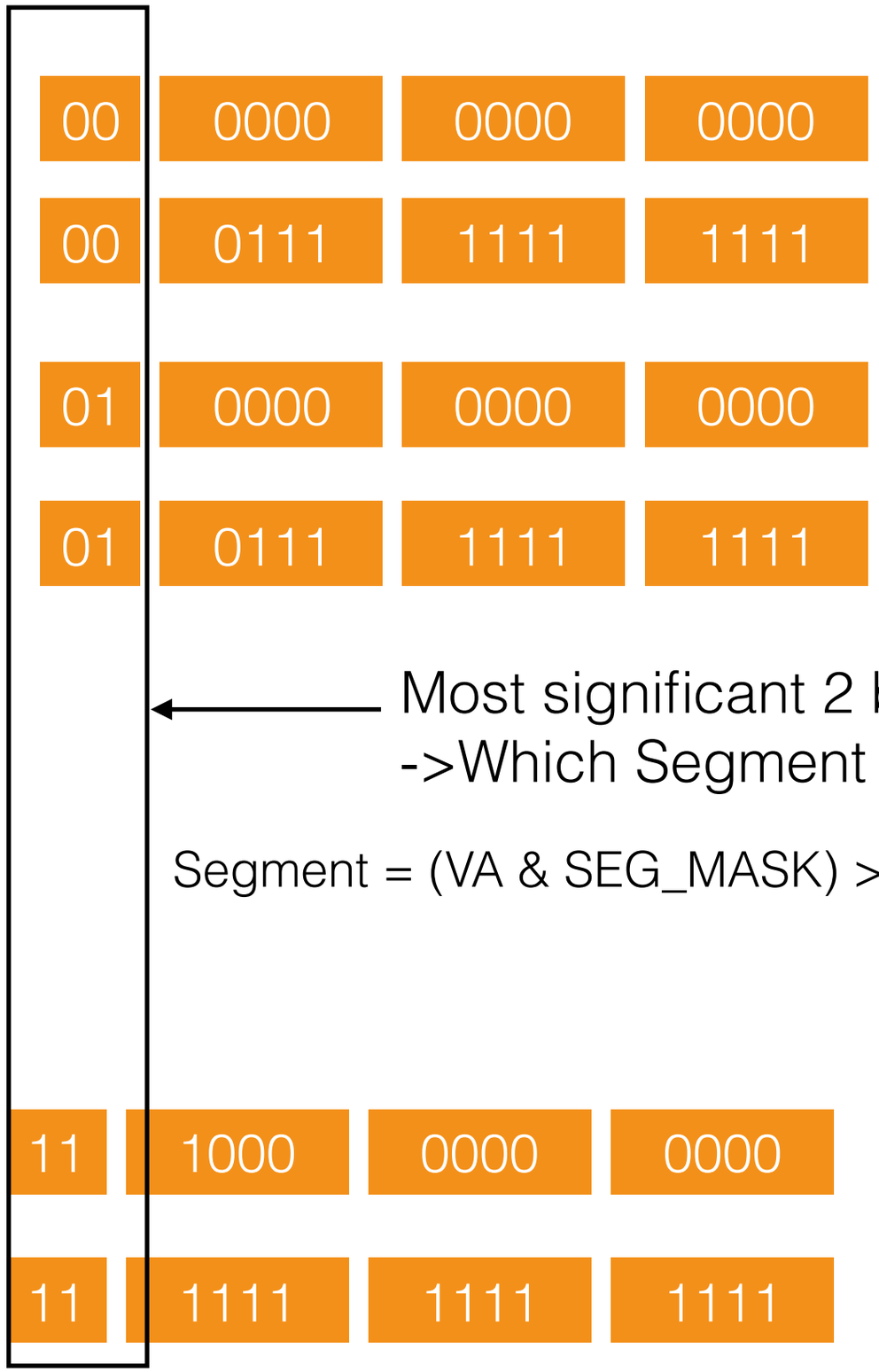




Segment Reference

Virtual Address Space



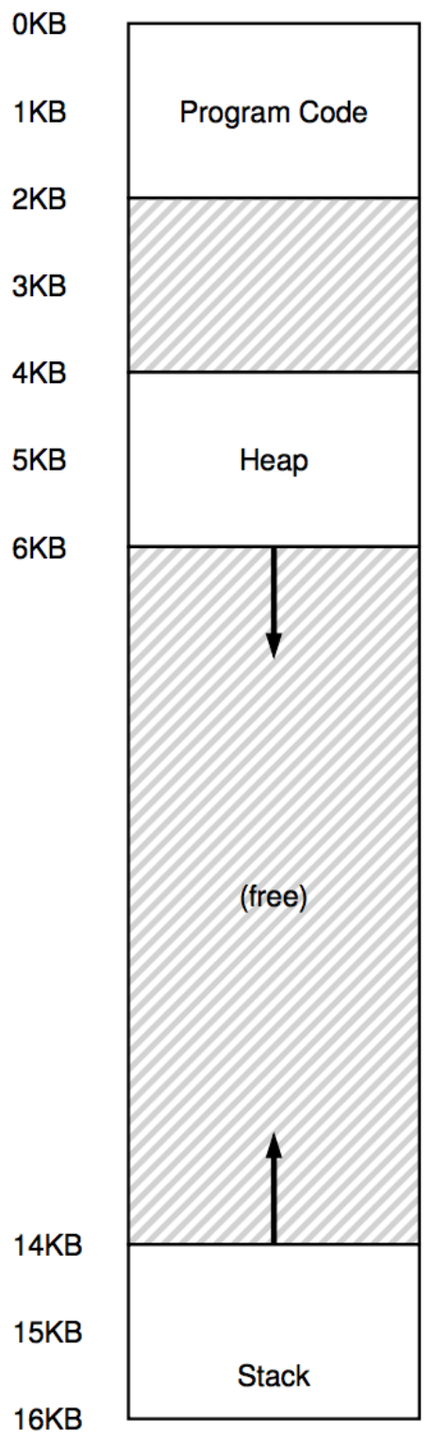


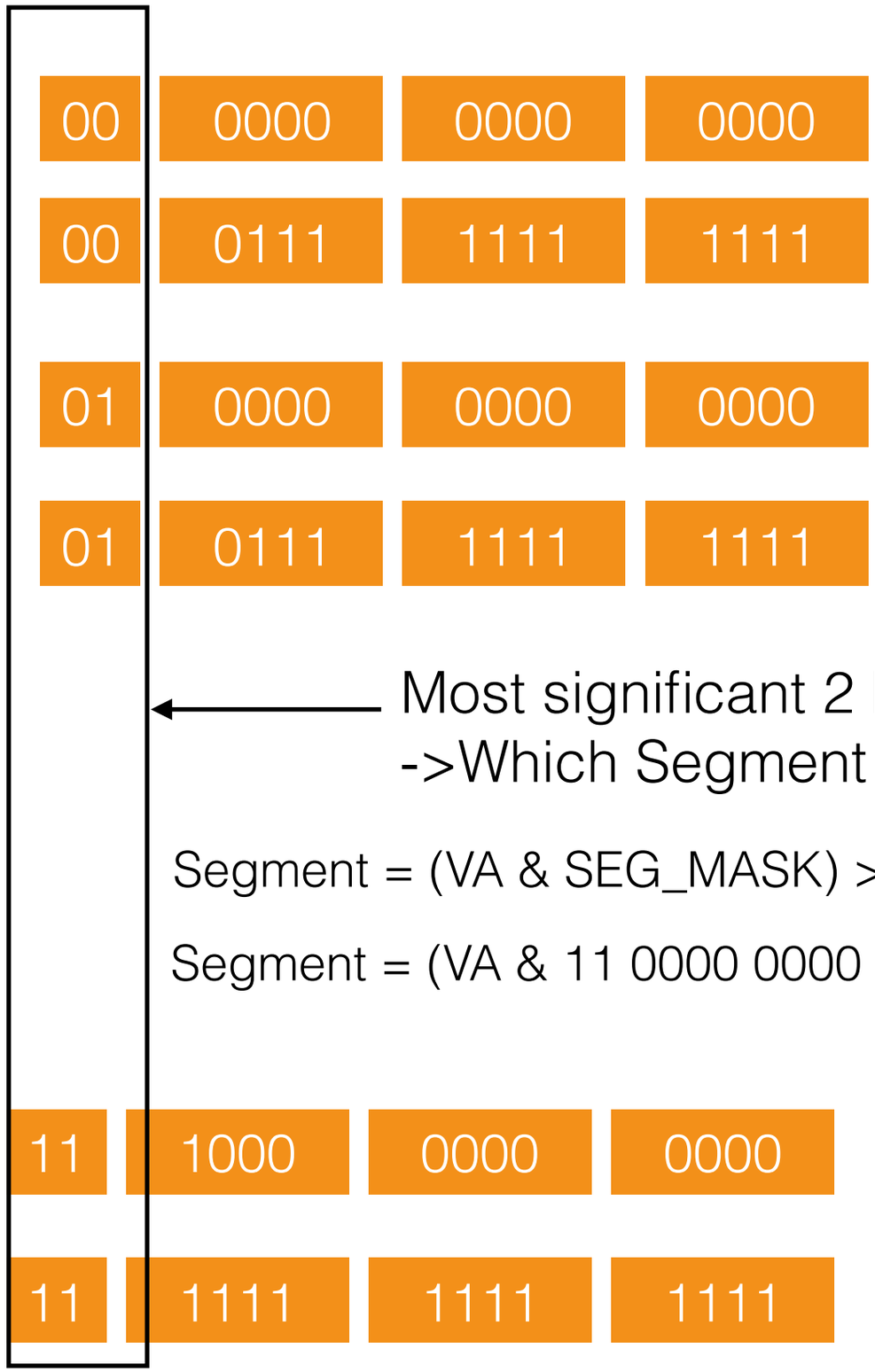
Most significant 2 bits
->Which Segment

Segment = (VA & SEG_MASK) >>SEG_SHIFT

Segment Reference

Virtual Address Space



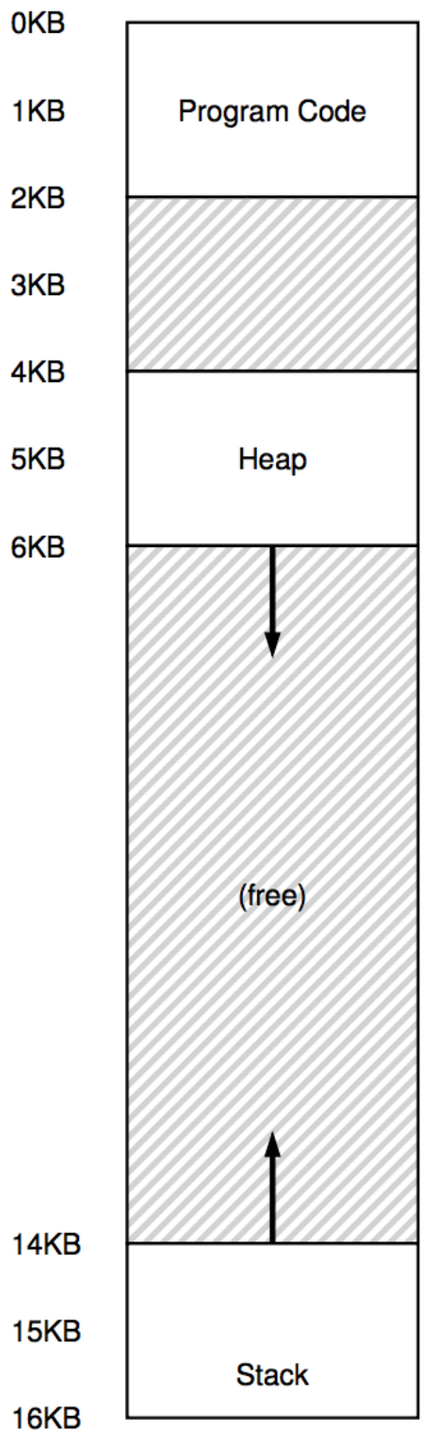


Most significant 2 bits
->Which Segment

Segment = (VA & SEG_MASK) >>SEG_SHIFT

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

Segment Reference



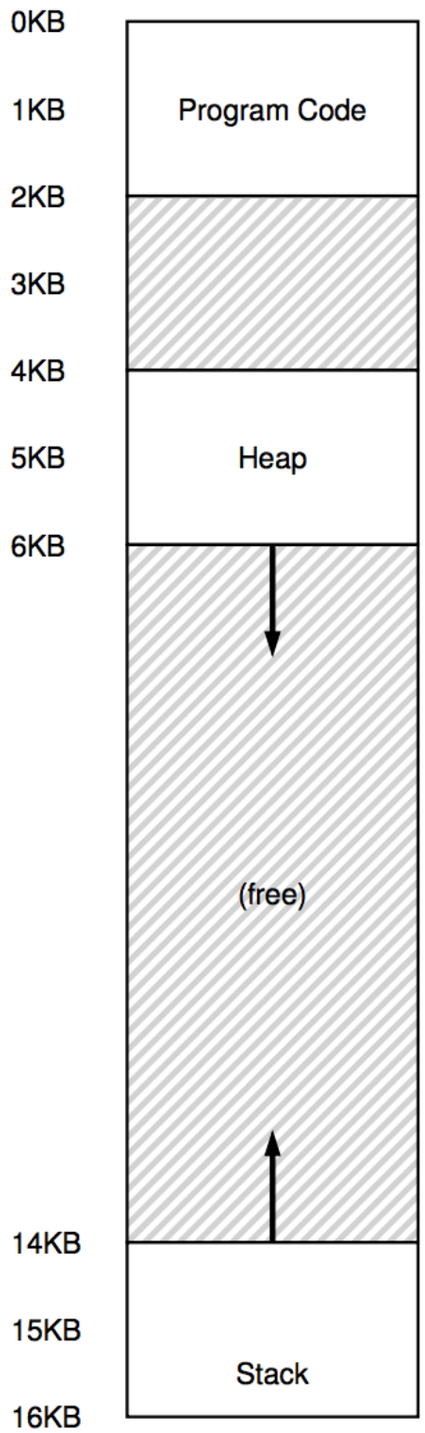
00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
01	0111	1111	1111

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

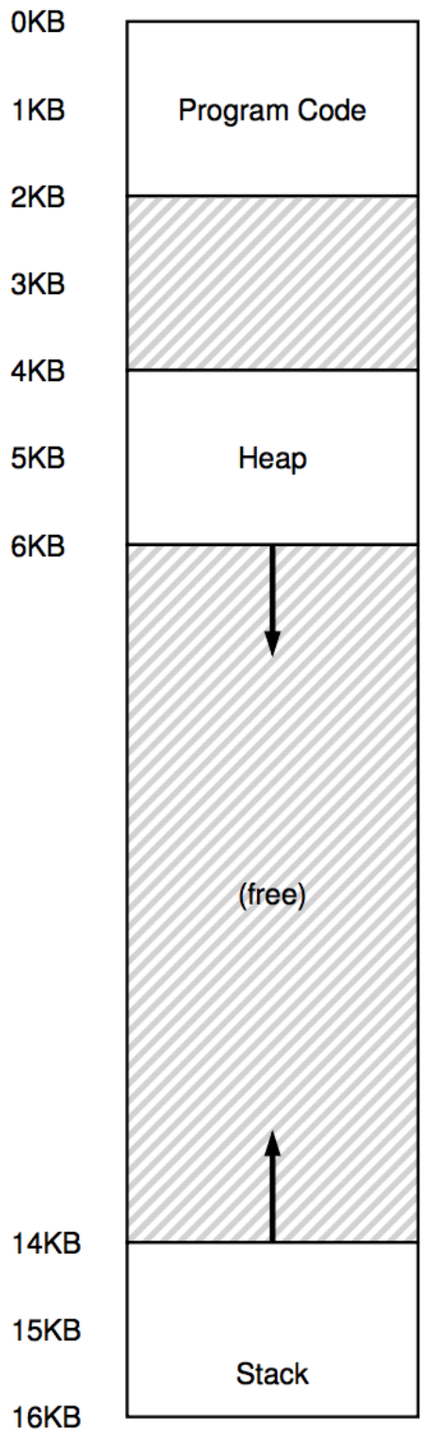
Segment = (VA & 11 0000 0000 0000) >>12

11 | 1000 | 0000 | 0000

11 | 1111 | 1111 | 1111

Segment Reference

00	0000	0000	1010
11	0000	0000	0000

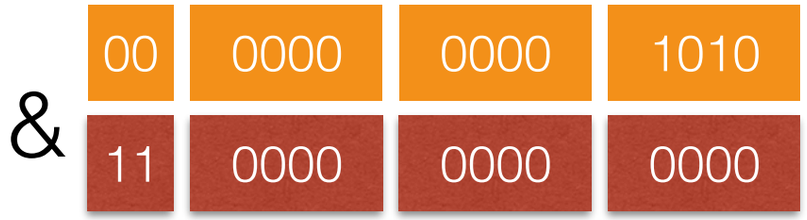


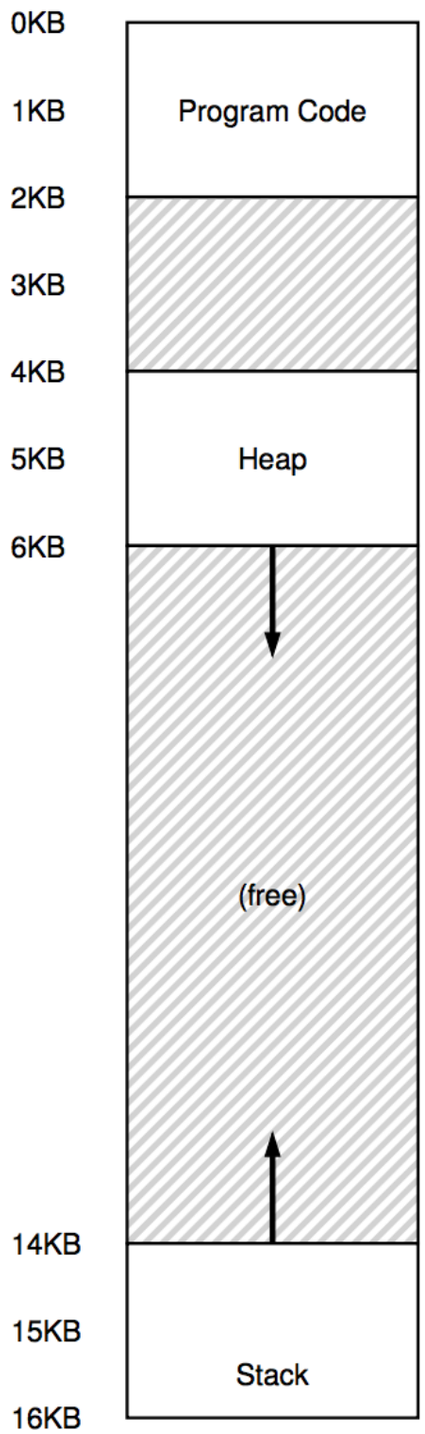
00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
01	0111	1111	1111

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

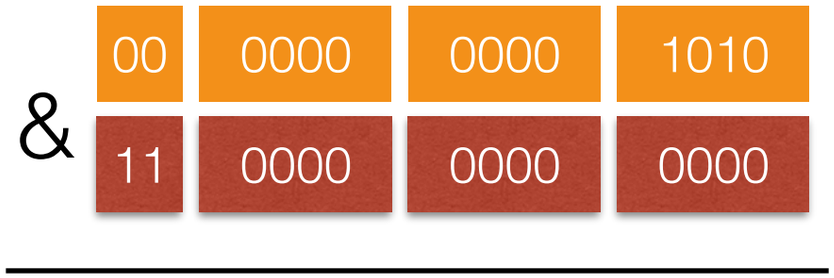
01 0111 1111 1111

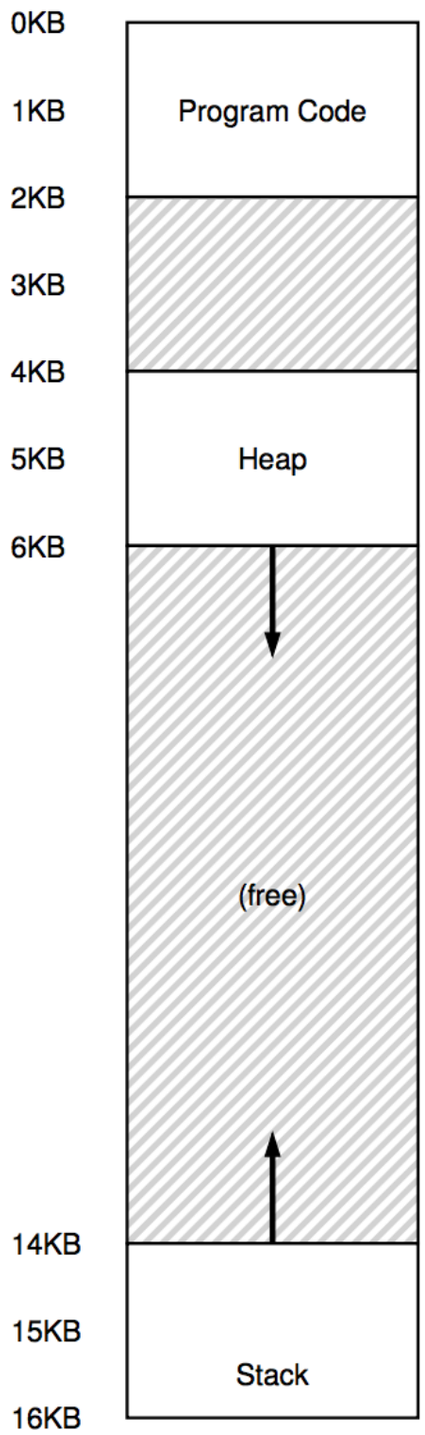
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference





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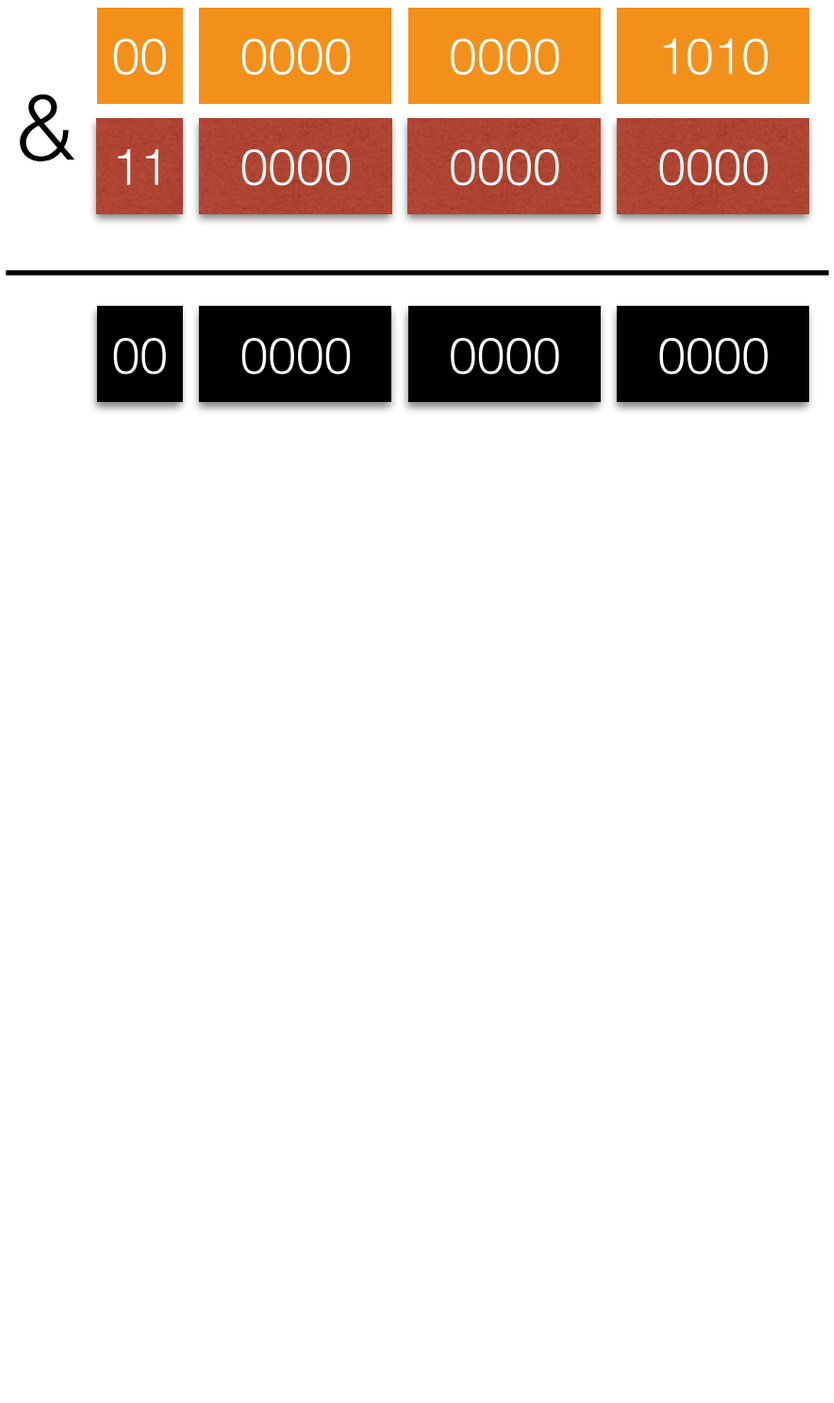
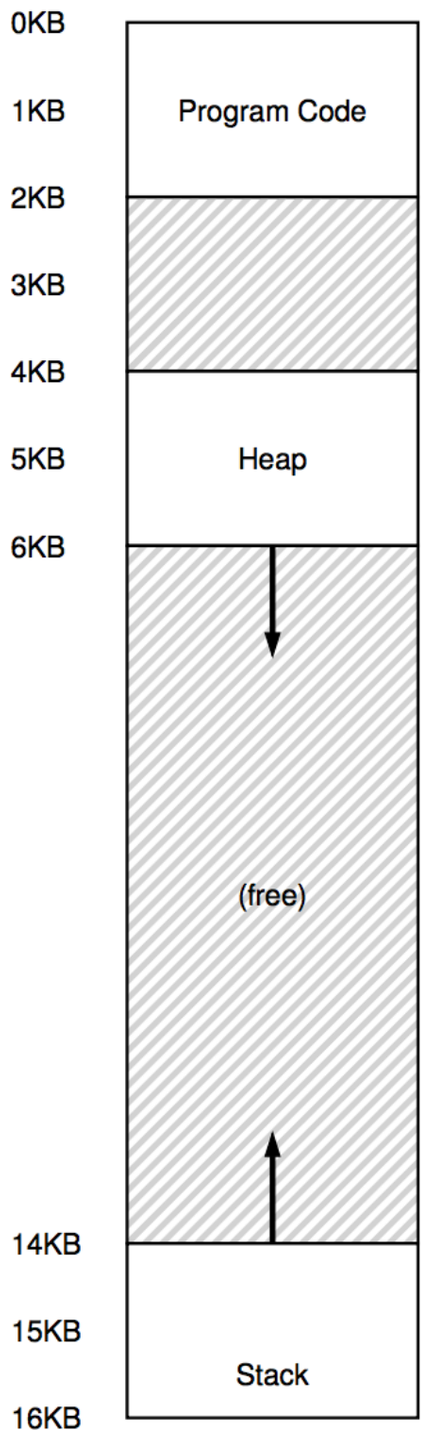
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference





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00 0111 1111 1111

01 0000 0000 0000

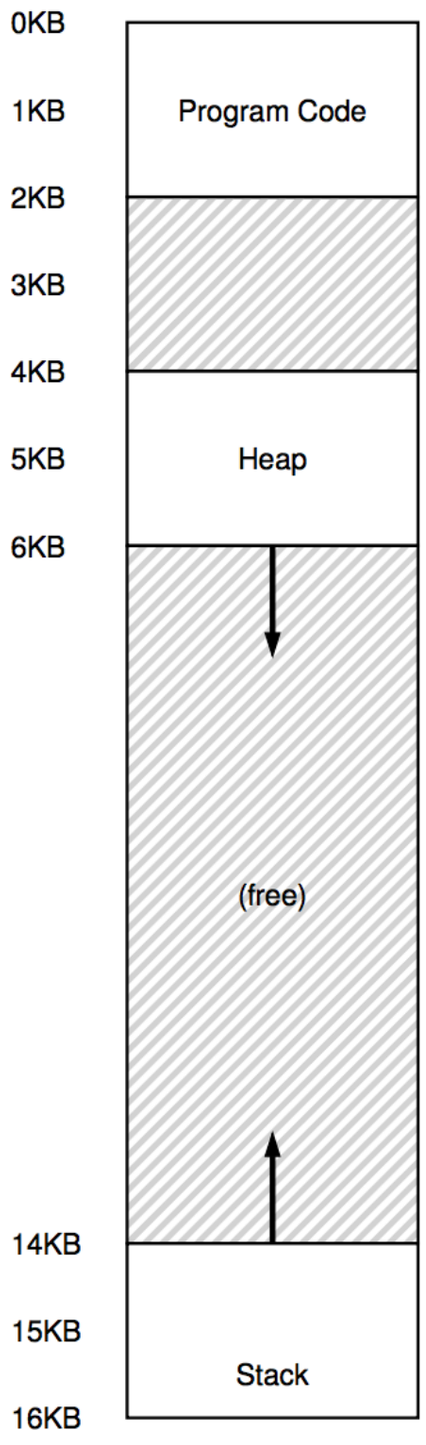
01 0111 1111 1111

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

11 1000 0000 0000

11 1111 1111 1111

Segment Reference



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00 0111 1111 1111

01 0000 0000 0000

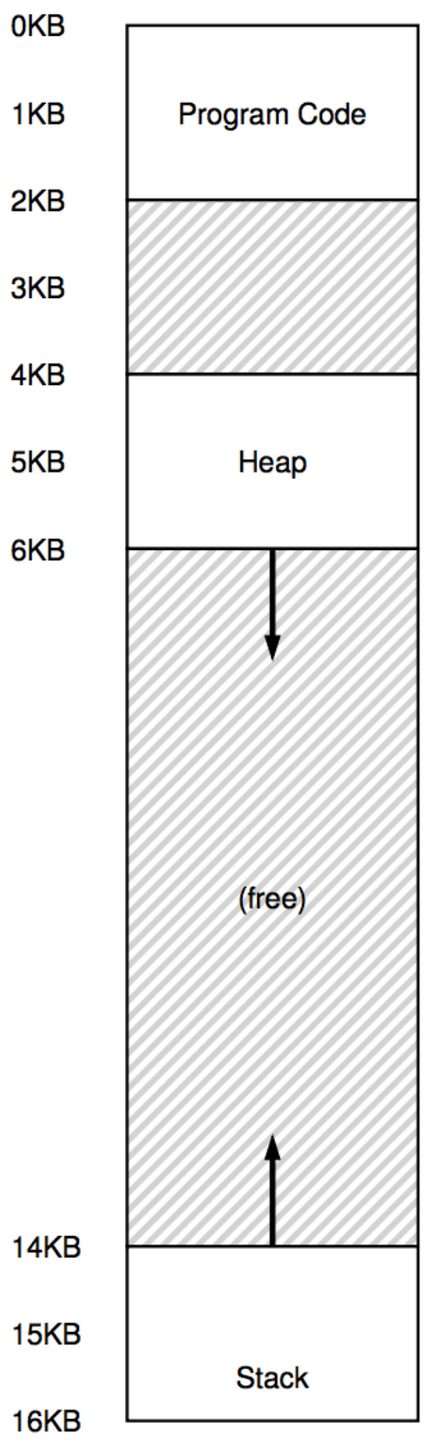
01 0111 1111 1111

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

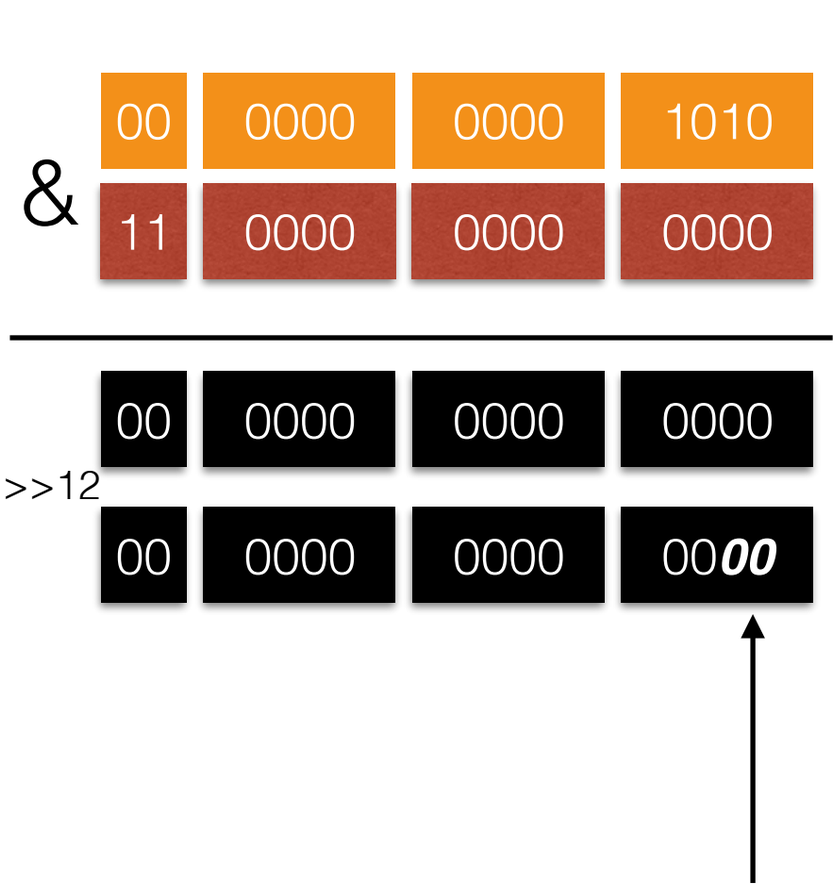
01 0111 1111 1111

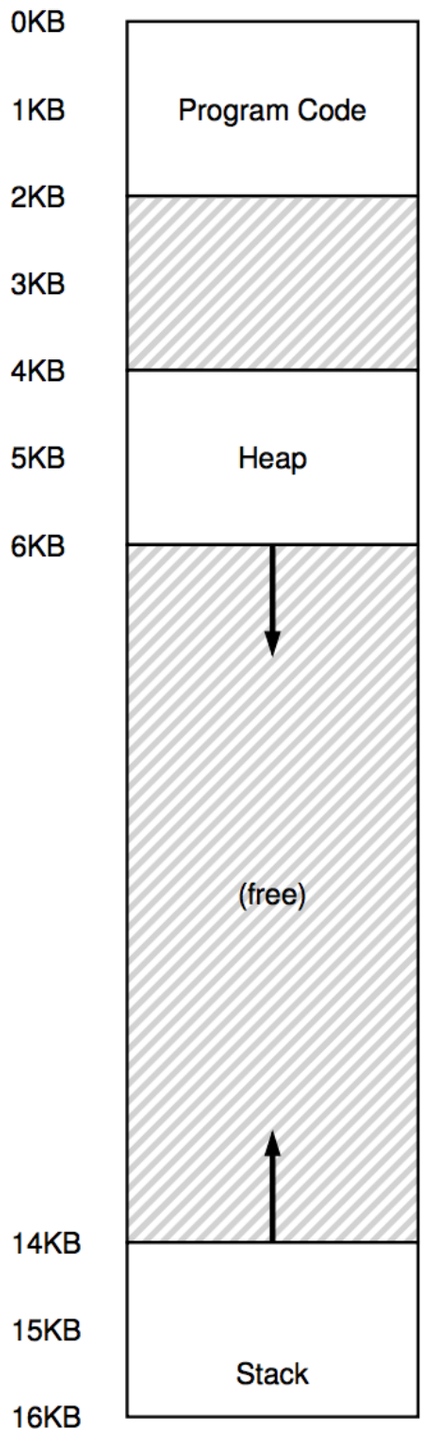
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference





00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

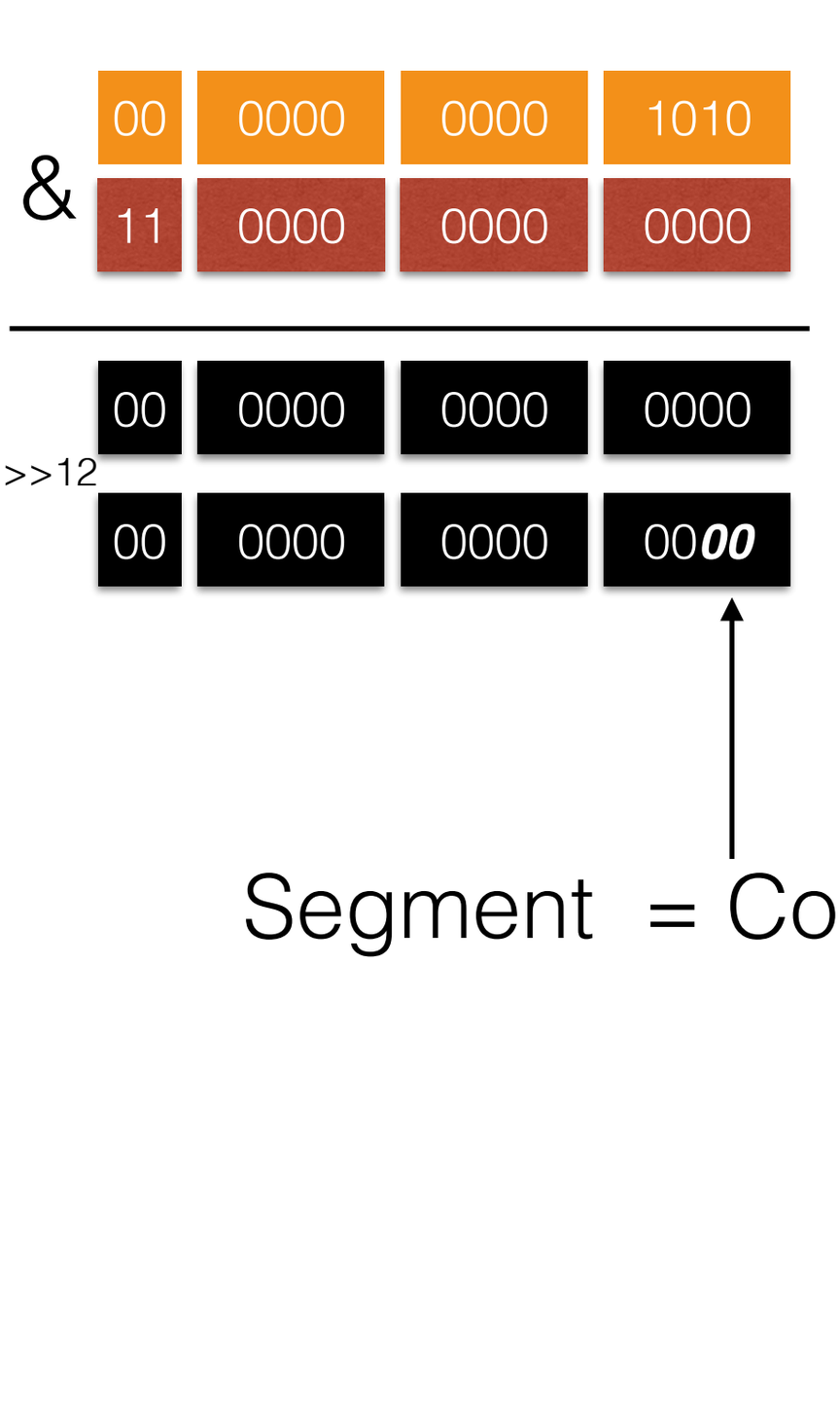
01 0111 1111 1111

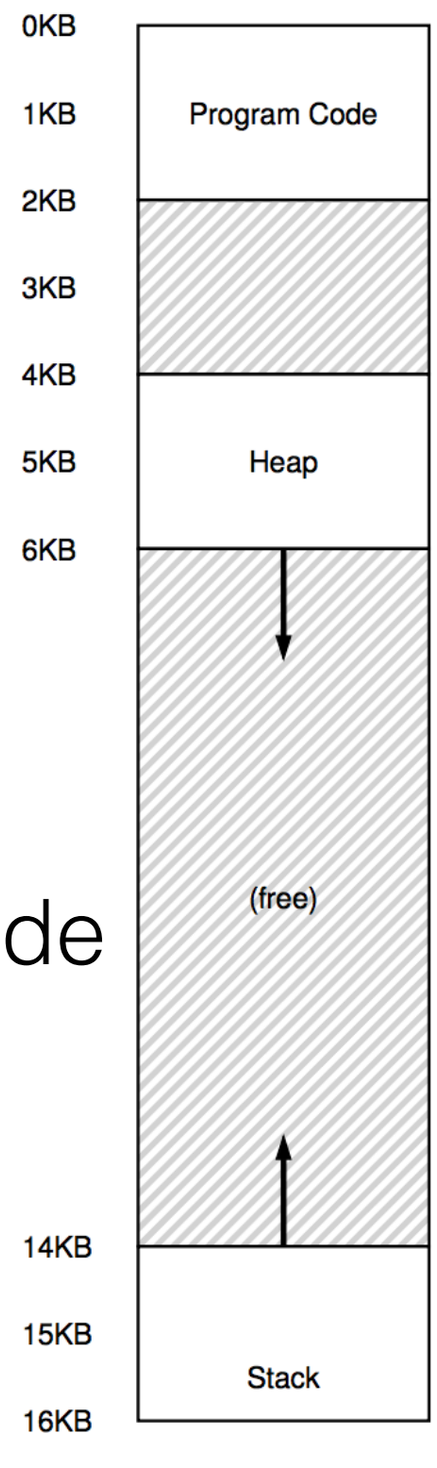
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference





00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

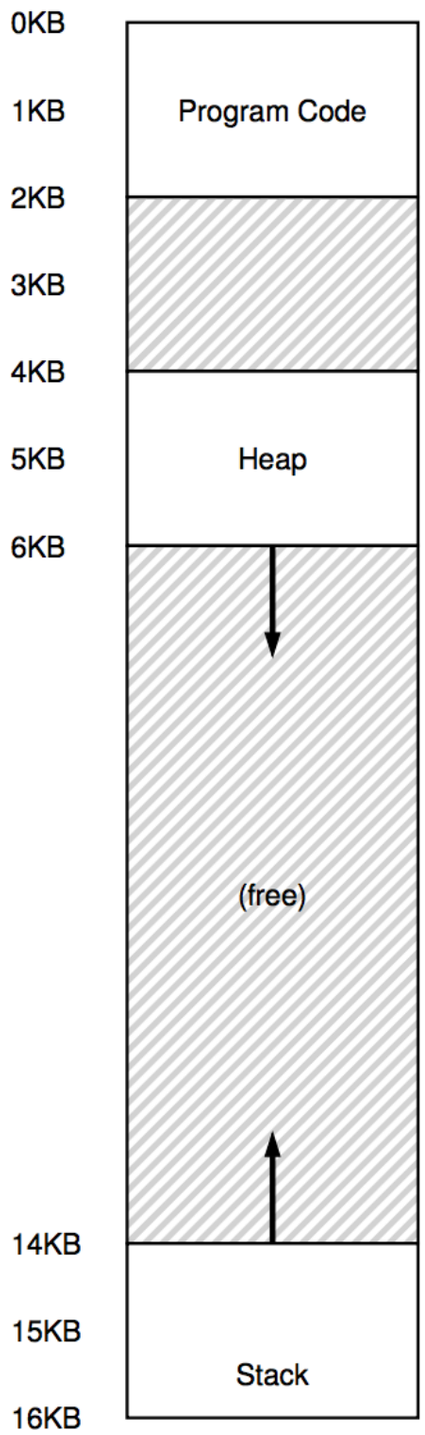
01 0111 1111 1111

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

11 1000 0000 0000

11 1111 1111 1111

Segment Reference



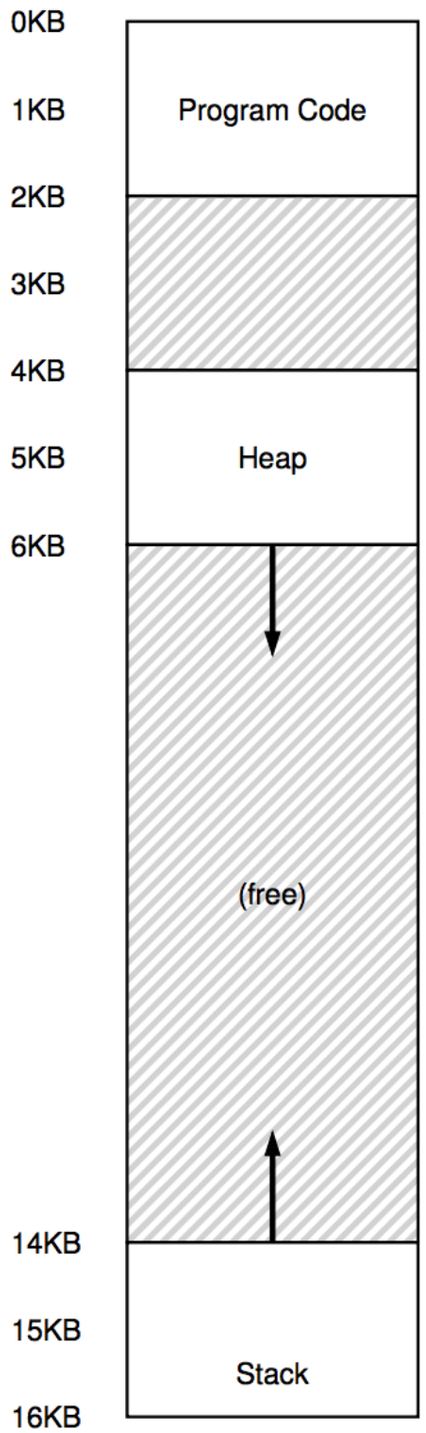
00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
01	0111	1111	1111

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

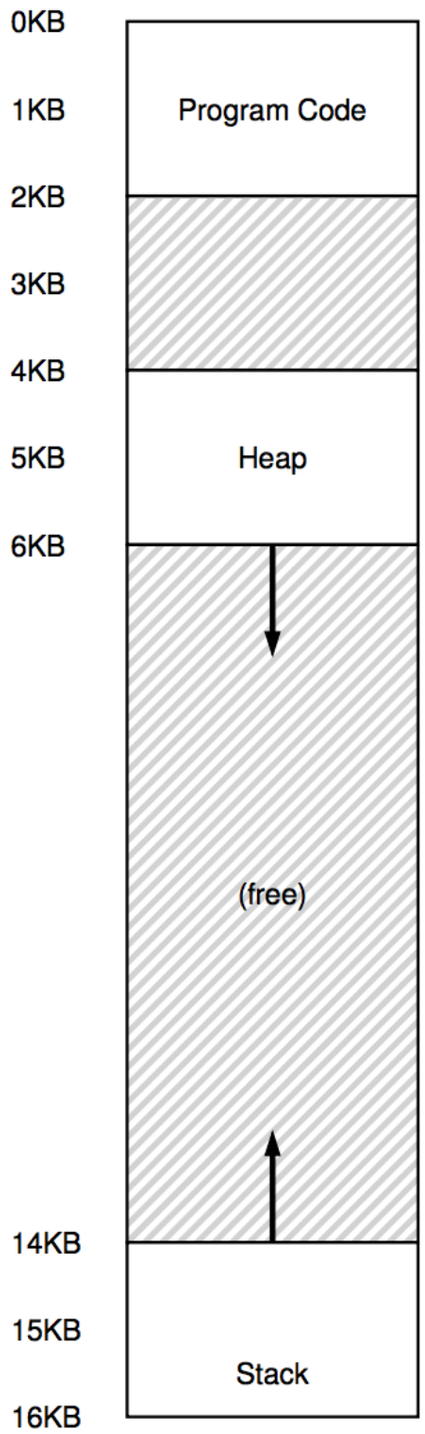
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference

01	0000	1010	1010
11	0000	0000	0000

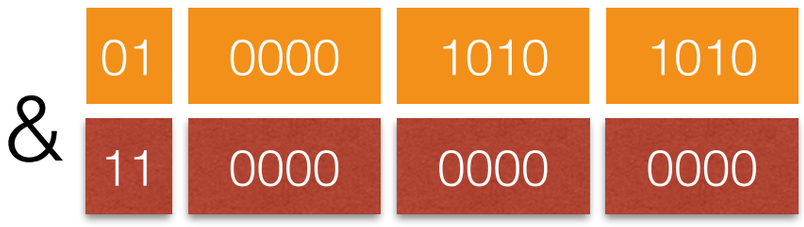


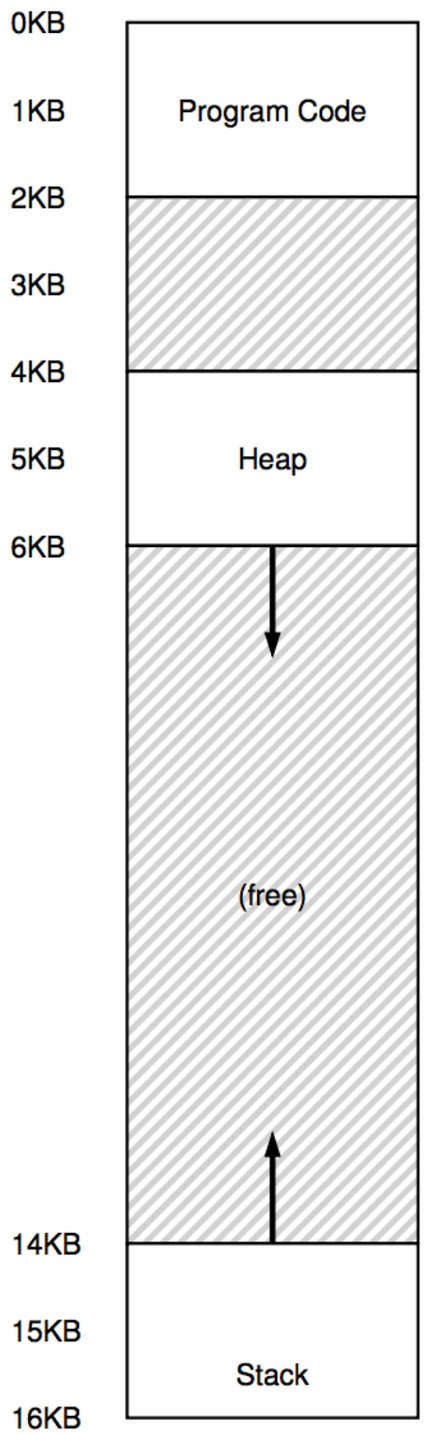
00	0000	0000	0000
00	0111	1111	1111
01	0000	0000	0000
01	0111	1111	1111

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

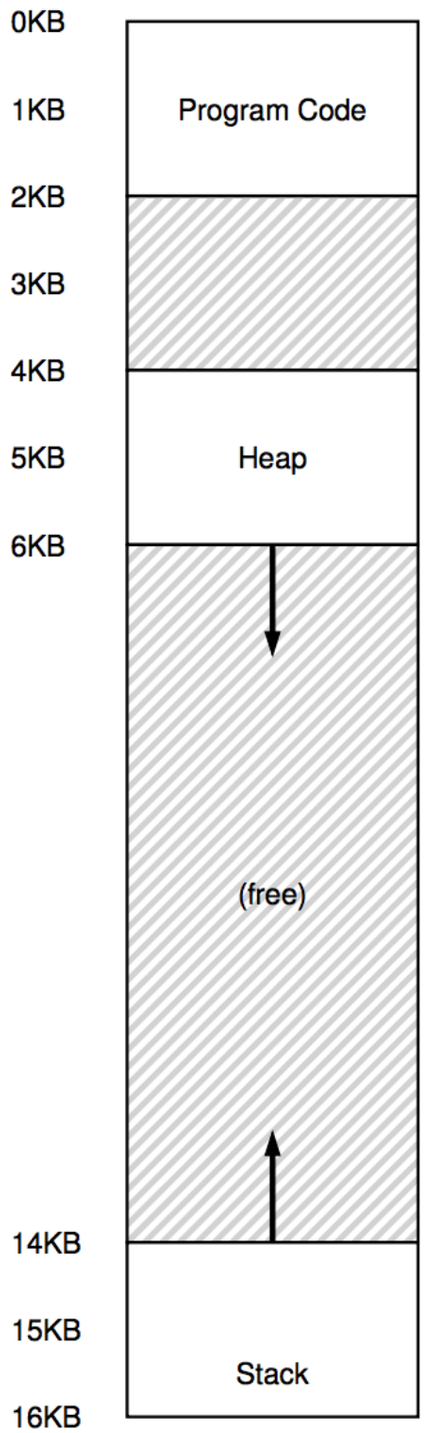
Segment = (VA & 11 0000 0000 0000) >>12

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

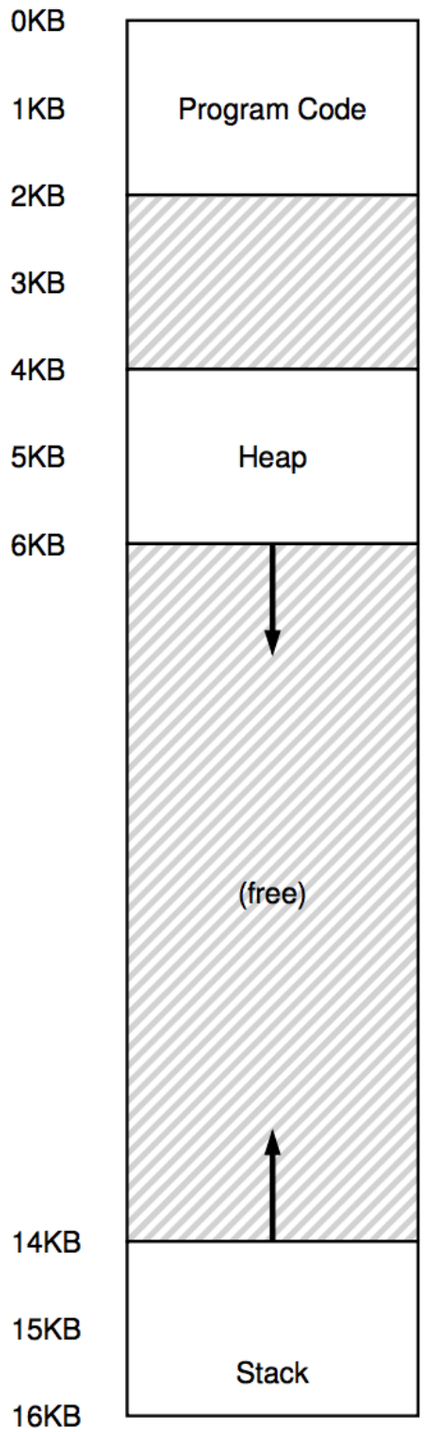
11 1111 1111 1111

Segment Reference

01 0000 1010 1010

& 11 0000 0000 0000

01 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

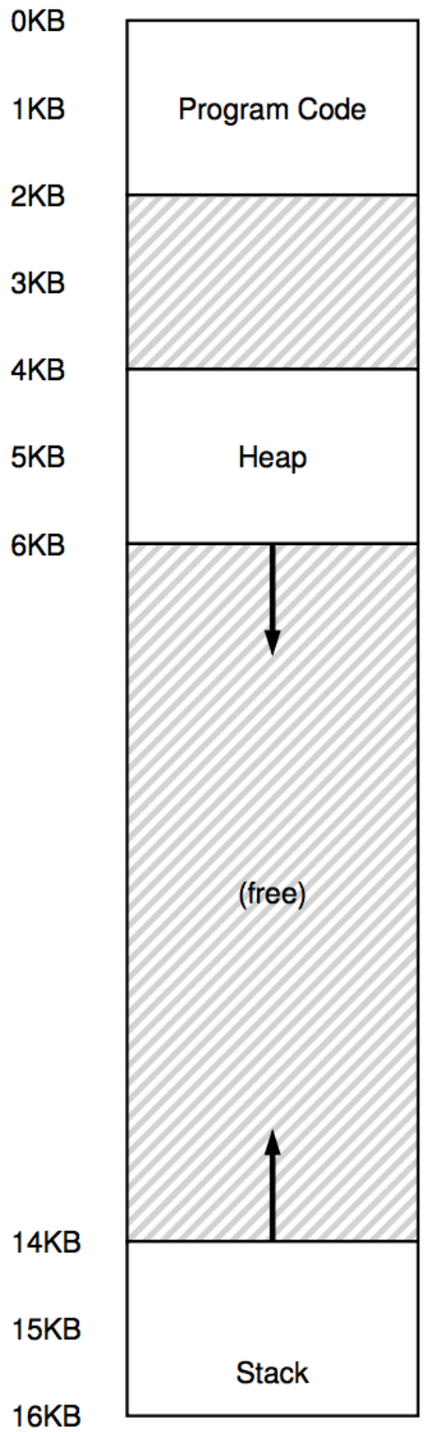
Segment Reference

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

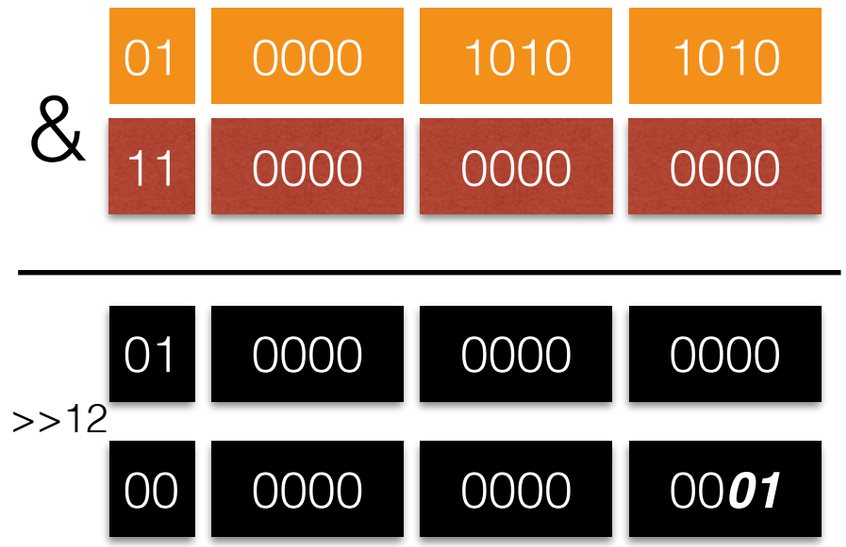
01 0111 1111 1111

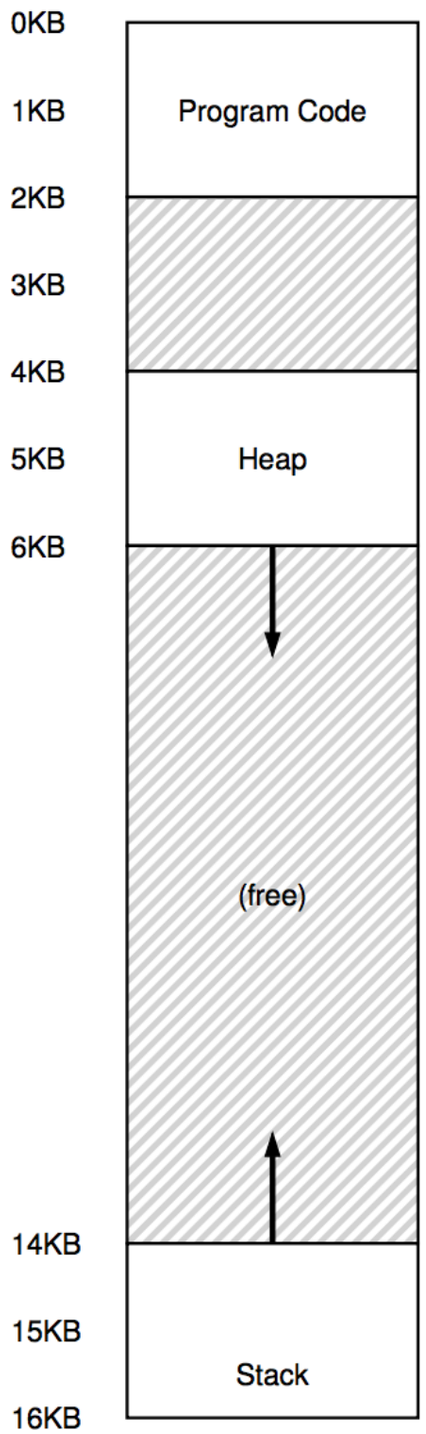
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference





00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

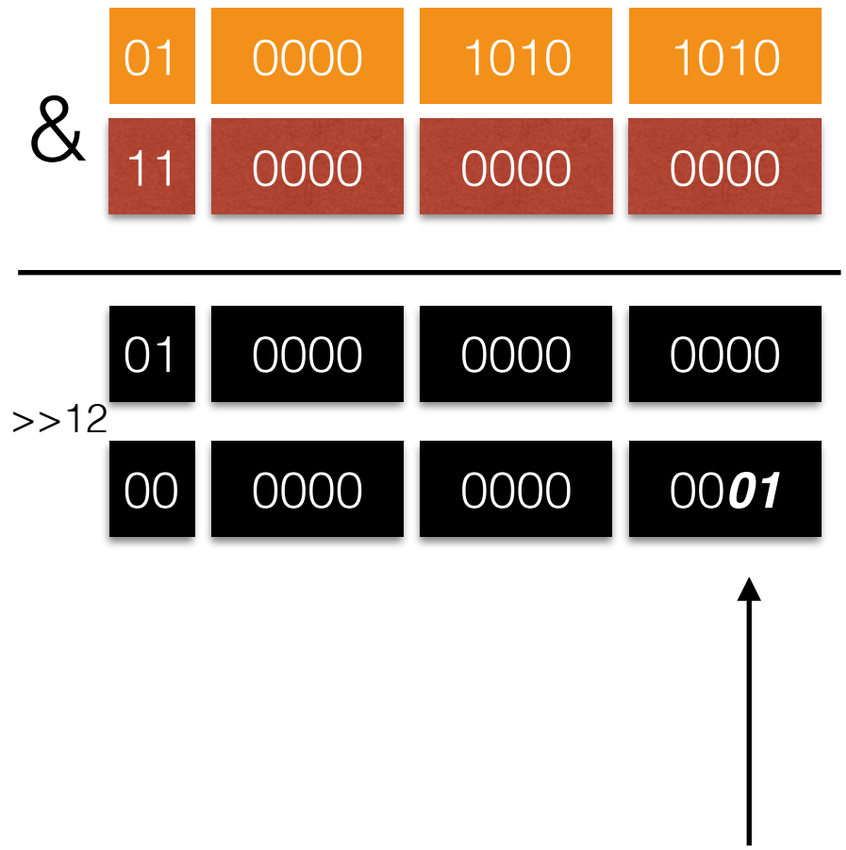
01 0111 1111 1111

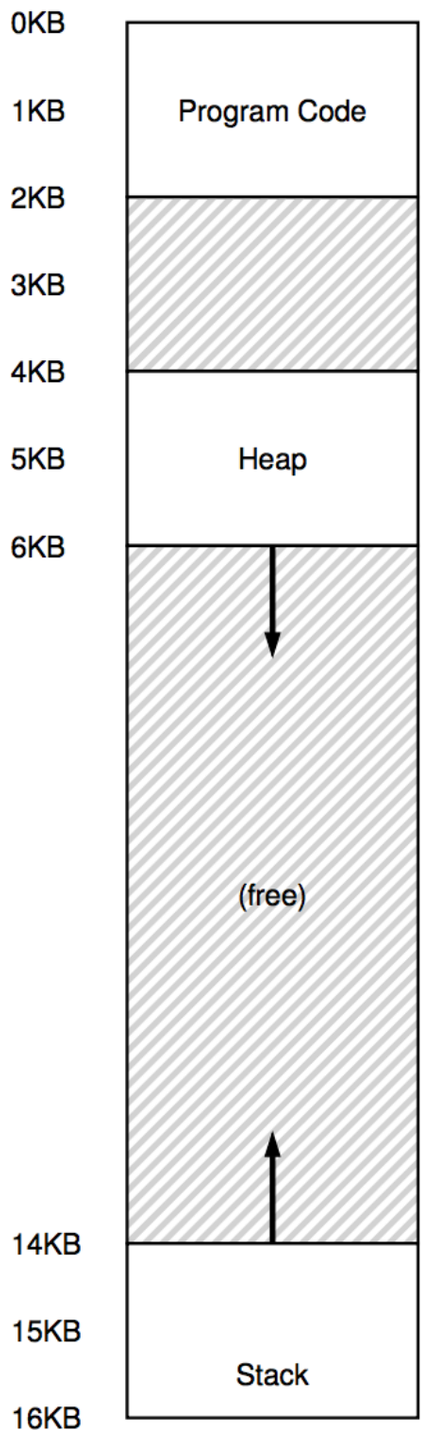
Segment = (VA & 11 0000 0000 0000) >>12

11 1000 0000 0000

11 1111 1111 1111

Segment Reference





00 0000 0000 0000

00 0111 1111 1111

01 0000 0000 0000

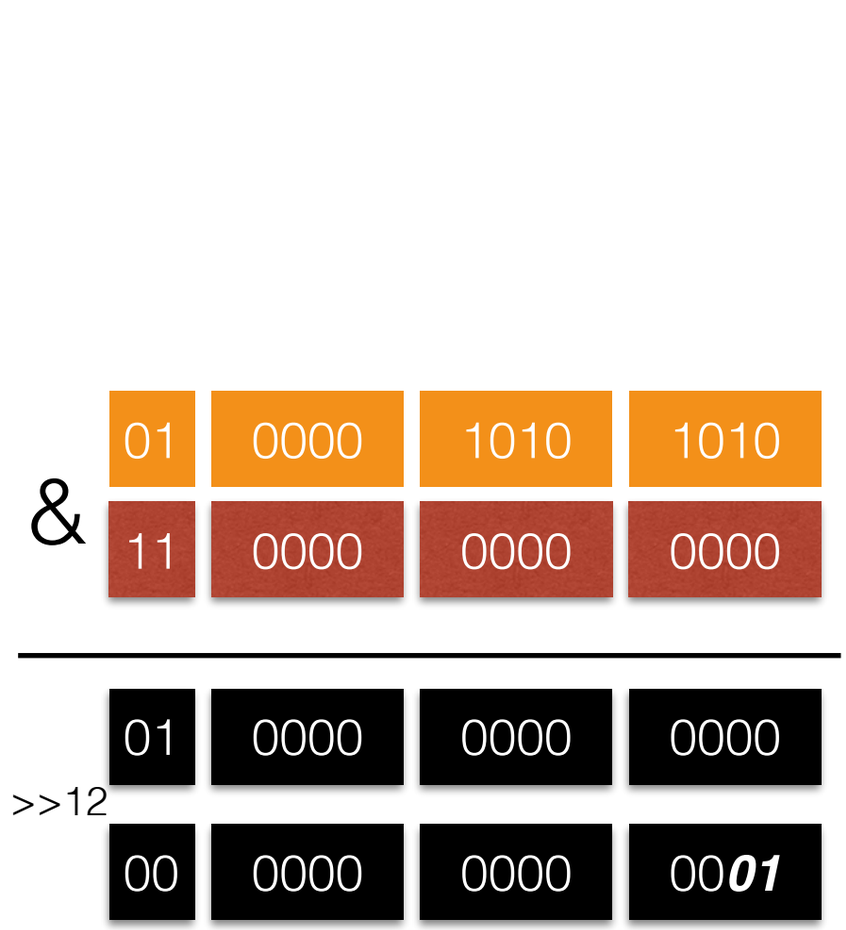
01 0111 1111 1111

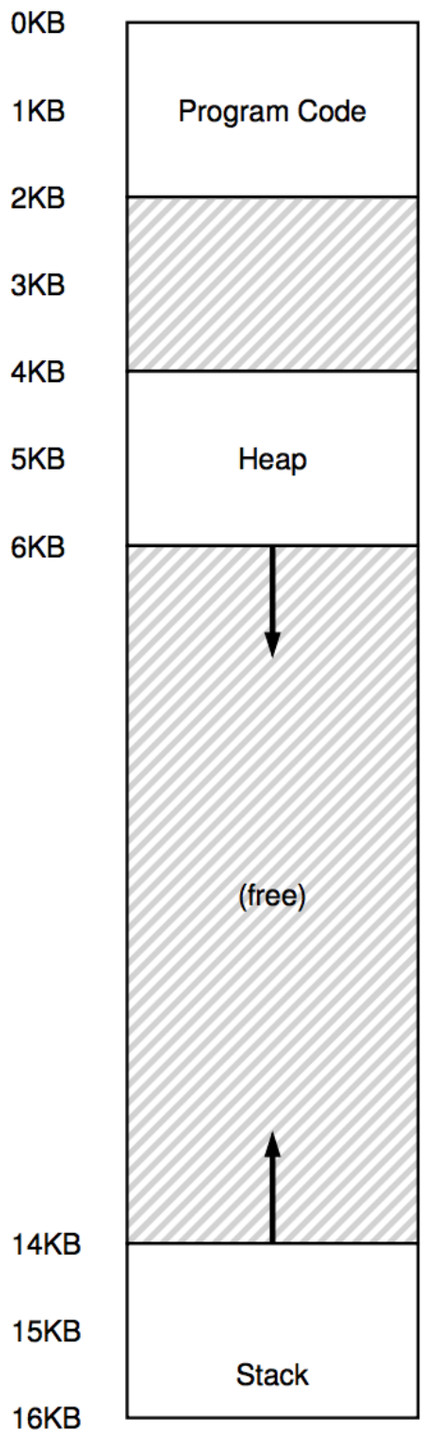
Segment = (VA & 11 0000 0000 0000) >>12

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