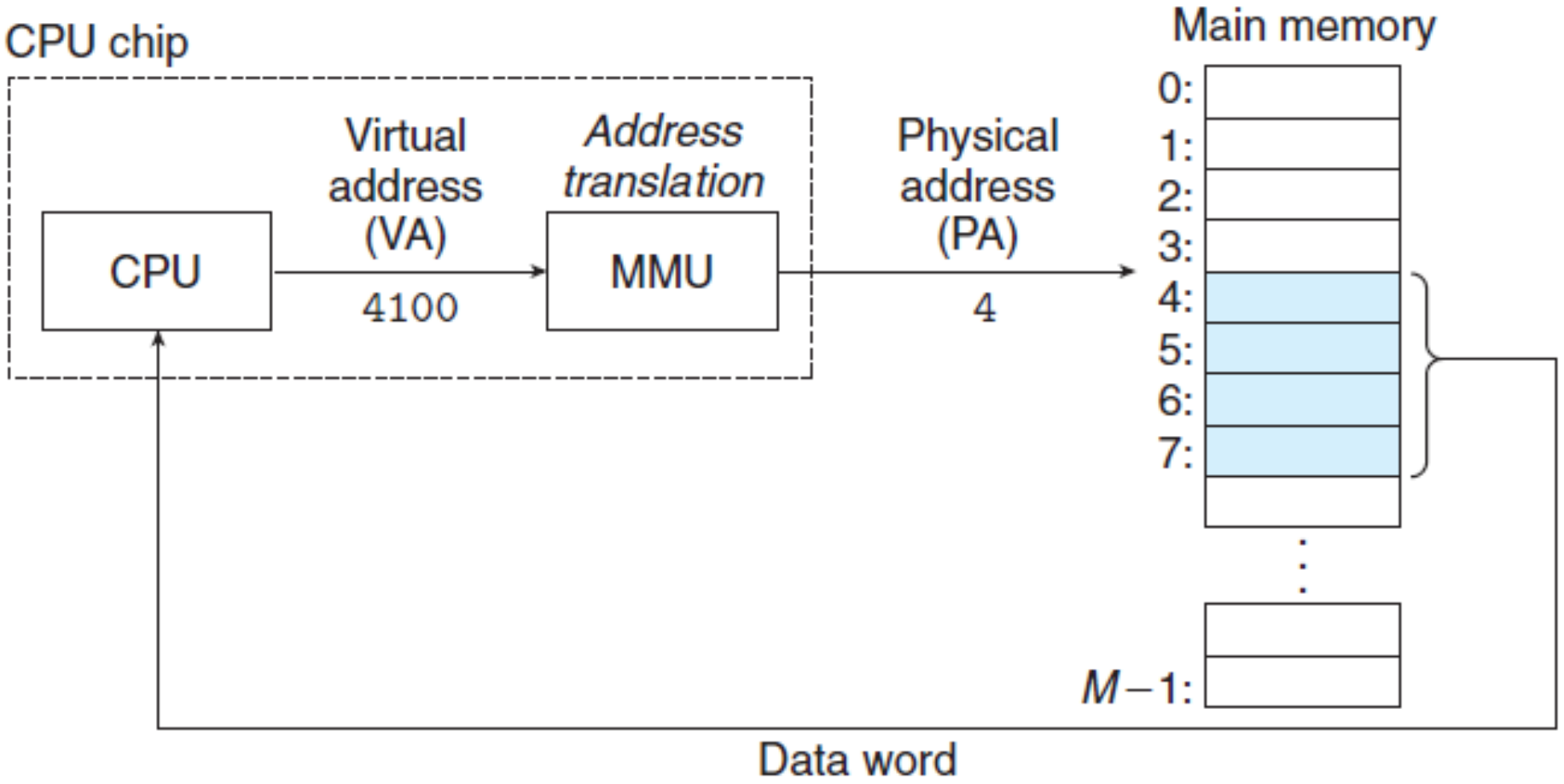
Virtual Memory



Randal E. Bryant and David R. O'Hallaron. 2010. Computer Systems: A Programmer's Perspective (2nd. ed.). Addison-Wesley Publishing Company, USA.

Consider a Scenario

- Main Memory
  - Size of Main Memory = 64 Bytes
  - Frame Size = 4 Bytes
  - Number of Frames = 64/4 = 16

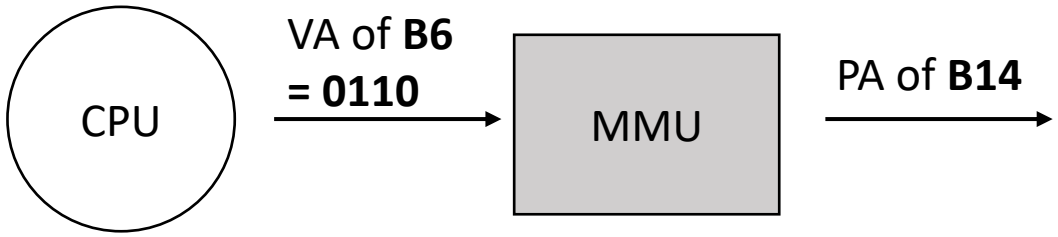
- Process
  - Size of Process = 16 Bytes
  - Page Size = 4 Bytes
  - Number of Pages = 16/4 = 4

Paging

How does the MMU get the Physical address of B14 in Main Memory?!!

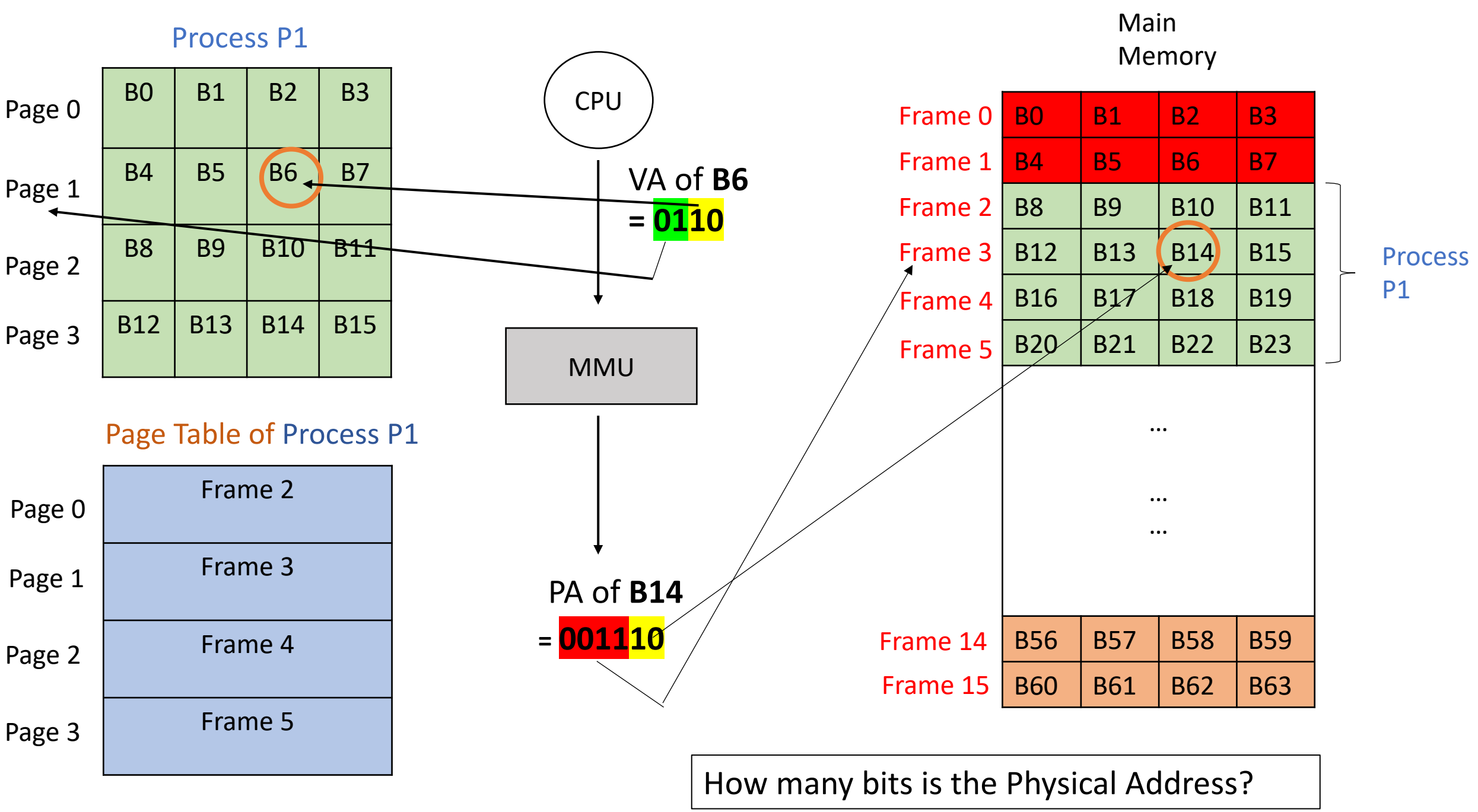
Process P1

Page 0	B0	B1	B2	B3
Page 1	B4	B5	B6	B7
Page 2	B8	B9	B10	B11
Page 3	B12	B13	B14	B15



Main Memory

Frame 0	B0	B1	B2	B3	
Frame 1	B4	B5	B6	B7	
Frame 2	B8	B9	B10	B11	Process P1
Frame 3	B12	B13	B14	B15	
Frame 4	B16	B17	B18	B19	
Frame 5	B20	B21	B22	B23	
	...				
Frame 14	B56	B57	B58	B59	
Frame 15	B60	B61	B62	B63	


Process P1
Page 0
Page 1
Page 2
Page 3
B0
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
CPU
VA of B6
= 0110
MMU
PA of B14
= 001110
Page Table of Process P1
Page 0
Page 1
Page 2
Page 3
Frame 2
Frame 3
Frame 4
Frame 5
Main
Memory
Frame 0
Frame 1
Frame 2
Frame 3
Frame 4
Frame 5
Frame 14
Frame 15
B0
B1
B2
B3
B4
B5
B6
B7
B8
B9
B10
B11
B12
B13
B14
B15
B16
B17
B18
B19
B20
B21
B22
B23
...
...
...
B56
B57
B58
B59
B60
B61
B62
B63
Process
P1
How many bits is the Physical Address?

Some Important Byte Conversions

- $1\,KB = 2^{10}B$
- $1\,MB = 2^{20}B$
- $1\,GB = 2^{30}B$
- $1\,TB = 2^{40}B$

Example:

- $2^{34}\,B$
  - $2^{30} * 2^{4}\,B = 2^{4}\,GB = 16\,GB$

Exercise

- Physical Address Space (PAS)
  - Size of Main Memory
- Virtual Address Space (VAS)
  - Size of the process

- PAS = 128 KB
- VAS = 128 KB

- How many bits for PA?
  - 17
- How many bits for VA?
  - 17

Exercise

- Physical Address Space (PAS)
  - Size of Main Memory
- Virtual Address Space (VAS)
  - Size of the process

- PAS = 128 KB
- VAS = 128 KB
- Page Size = 4 KB

- How many bits for the page offset?
  - 12 bits

Exercise

- Physical Address Space (PAS)
  - Size of Main Memory
- Virtual Address Space (VAS)
  - Size of the process

- PAS = 128 KB
- VAS = 128 KB
- Page Size = 4 KB

- How many bits for the page number?
  - (17 – 12) bits = 5 bits
- How many Pages?
  - 2^5= 32

Exercise

- Physical Address Space (PAS)
  - Size of Main Memory
- Virtual Address Space (VAS)
  - Size of the process

- PAS = 128 KB
- VAS = 128 KB
- Page Size = 4 KB

- How many bits for the Frame number?
  - (17 – 12) bits = 5 bits
- How many Frames?
  - 2^5= 32

Exercise

- Physical Address Space (PAS)
  - Size of Main Memory
- Virtual Address Space (VAS)
  - Size of the process

- PAS = 128 KB
- VAS = 128 KB
- Page Size = 4 KB

- How many bits for a Page Table Entry (PTE)?
  - 5 bits

**For this example, we assume that a page table entry contains only the bits to represent the Frame Number.*

Exercise

- Physical Address Space (PAS)
  - Size of Main Memory
- Virtual Address Space (VAS)
  - Size of the process

- PAS = 128 KB
- VAS = 128 KB
- Page Size = 4 KB

- What is the Size of the Page Table?
  - (Number of Pages * Size of a Page Table Entry) = $2^5 * 5$ bits

**For this example, we assume that a page table entry contains only the bits to represent the Frame Number.*

Exercise 2

[$]For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of Virtual Pages	# of Physical Pages(or frames)	PTE[$]	Size of Page Table
1 MB					10		256		

Exercise 2

[$] For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of virtual Pages	# of Physical Pages (or Frames)	PTE[$]	Size of Page Table
1 MB				2^{10}	10		256		

Exercise 2

[$]For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of Virtual Pages	# of Frames	PTE[$]	Size of Page Table
1 MB	**# of Frames * Frame Size = 256 KB**			2^{10}	10		256		

Exercise 2

[$]For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of Virtual Pages	# of Frames	PTE[$]	Size of Page Table
1 MB = 2^20 Bytes	# of Frames * Frame Size = 256 KB =2^18 Bytes	**20 bits**	**18 bits**	2^{10}	10		256		

Exercise 2

[$]For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of Virtual Pages	# of Frames	PTE[$]	Size of Page Table
1 MB = 2^20 Bytes	# of Frames * Frame Size = 256 KB =2^18 Bytes	20 bits	18 bits	2^{10}	10	$\mathbf{2^{(20-10)} = 2^{10}}$	256		

Exercise 2

[$] For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of Virtual Pages	# of Frames	PTE[$]	Size of Page Table
1 MB = 2^20 Bytes	# of Frames * Frame Size = 256 KB =2^18 Bytes	20 bits	18 bits	2^{10}	10	$2^{(20-10)} = 2^{10}$	256 = 2^8	**8 bits**	

Exercise 2

[$] For this example, we assume that a page table entry contains only the bits to represent the Frame Number.

VAS	PAS	VA	PA	Page Size	Page Offset	# of Virtual Pages	# of Frames	PTE[$]	Size of Page Table
1 MB = 2^20 Bytes	# of Frames * Frame Size = 256 KB =2^18 Bytes	20 bits	18 bits	2^{10}	10	$2^{(20-10)} = 2^{10}$	256 = 2^8	8 bits	$\mathbf{2^{10} * 8\ bits}$