Virtual Memory

EEL 3713C: Digital Computer Architecture

Quincy Flint

[Ionospheric Radio Lab in NEB]

Outline

1. Memory Problems

- Not enough memory
- Holes in address space
- Programs overwriting

2. What is Virtual Memory?

- Layer of indirection
- How does indirection solve above
- Page tables and translation

3. How do we implement VM?

- Create and store page tables
- Fast address translation

4. Virtual Memory and Caches

 Prevent cache performance degradation when using VM

Virtual Address [32 bit]

Virtual Page Number 20 bits Page Offset 12 bits

TLB [2-entries big]

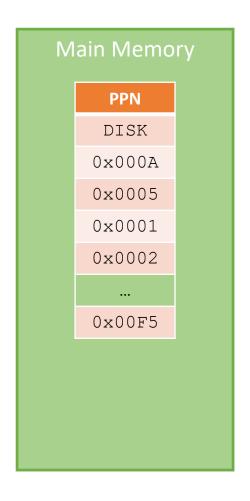
Tag Physical Page #

Physical Address [28 bits]

Physical Page Number 16 bits Page Offset 12 bits

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address

12-bit Page Offset [Index]

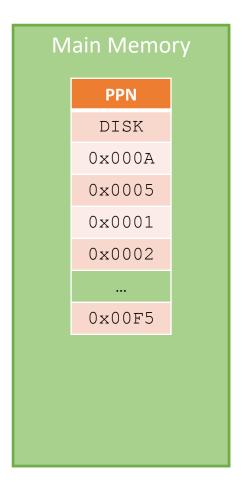
Virtual Address [32 bit]

Virtual Page Number	Page Offset	
31	12 11	0

TLB [2-entries big]			
Tag Physical Page #			

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0



Virtual Address [32 bit]



TLB [2-entries big]

Tag Physical Page #

0x0 0001 0x000A

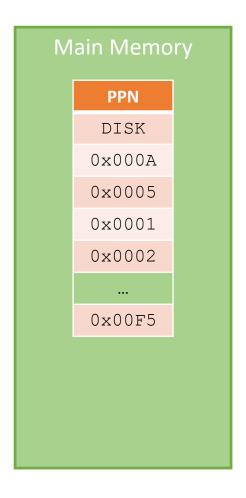
1 entry already filled

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00003 103

Virtual Address [32 bit]

	Virtual Page Number		Page Offset	
3	31	12	11	0

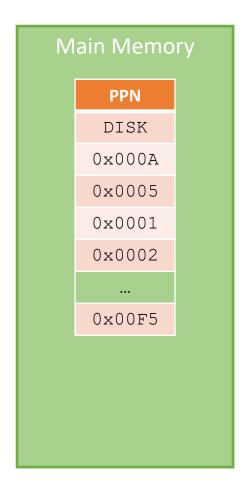
TLB [2-entries big]				
Physical Page #				
A000x0				

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00003 103

Virtual Address [32 bit]

_	Virtual Page Number		Page Offset	
3		12	11	0

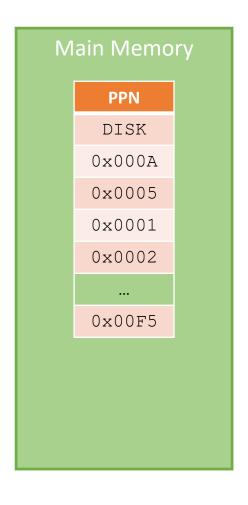
TLB [2-entries big]				
Tag	Physical Page #			
0x0 0001	A000x0			

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00003 <u>103</u>

Virtual Address [32 bit]

	Virtual Page Number		Page Offset	103	
3	5 I	2	11		0

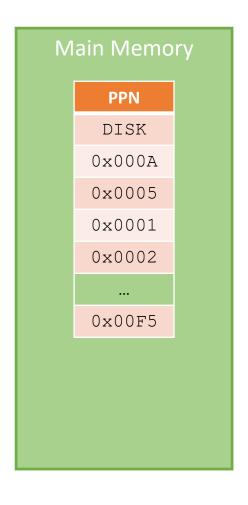
Tag Physical Page	TLB [2-entries big]				
Tag Physical Page #					
0x0 0001 0x000A					

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

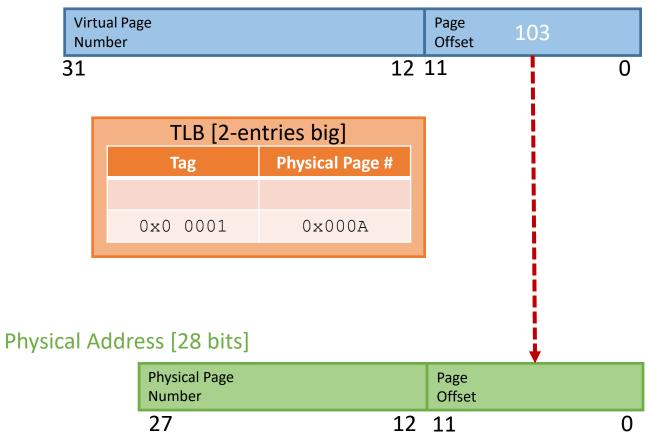
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



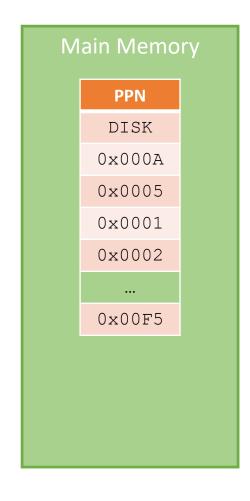
VA: 0x00003 <u>103</u>

Virtual Address [32 bit]



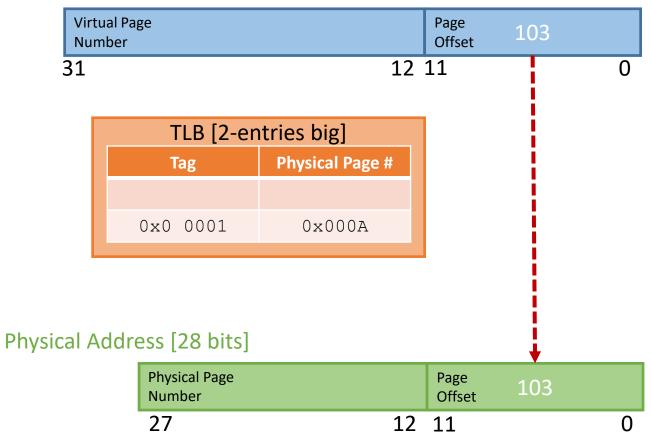
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



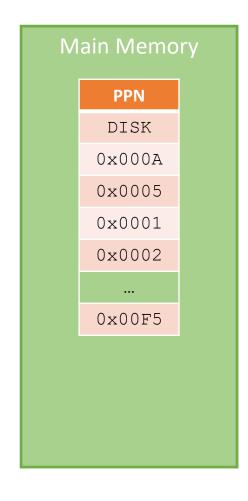
VA: 0x00003 <u>103</u>

Virtual Address [32 bit]



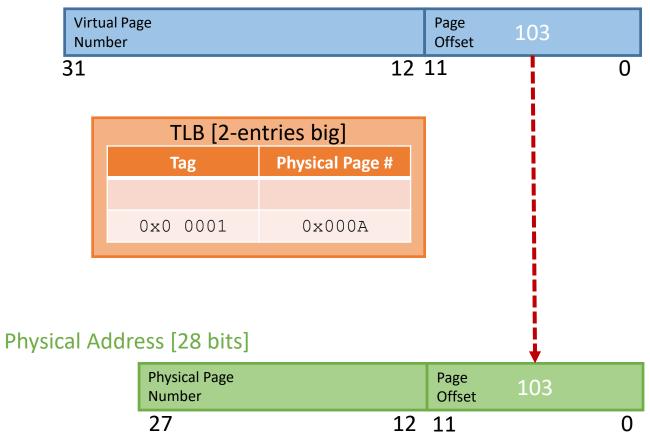
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



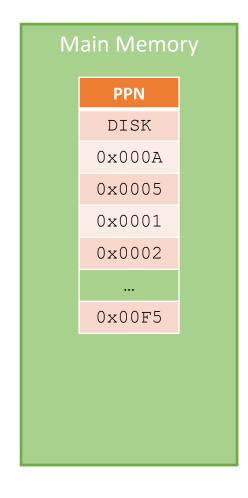
VA: 0x<u>00003</u> 103

Virtual Address [32 bit]



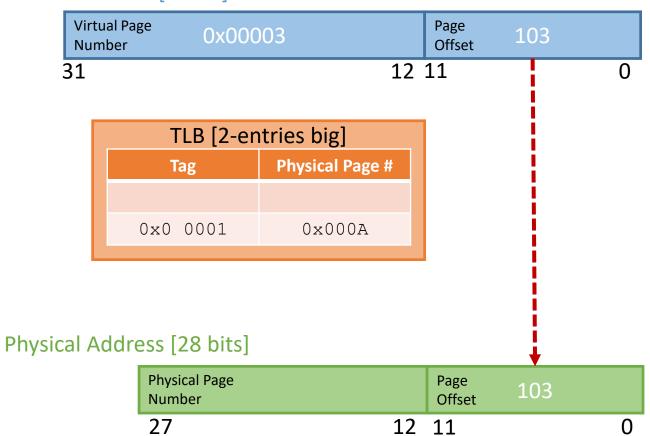
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



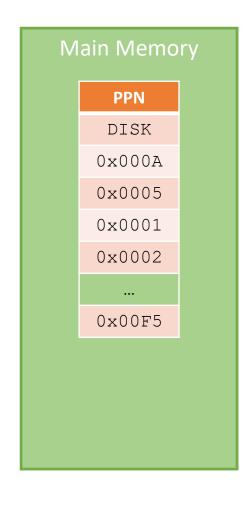
VA: 0x<u>00003</u> 103

Virtual Address [32 bit]



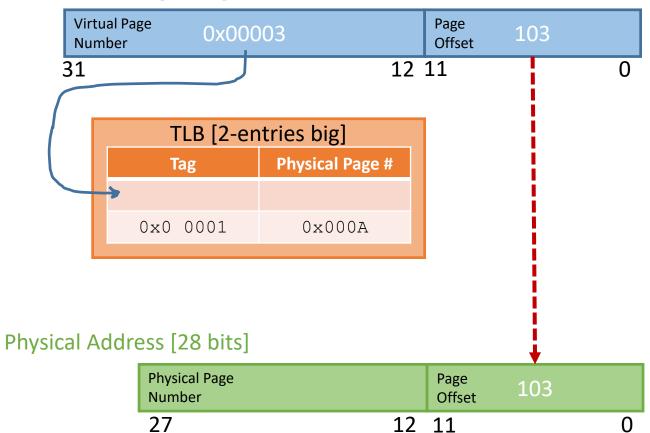
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



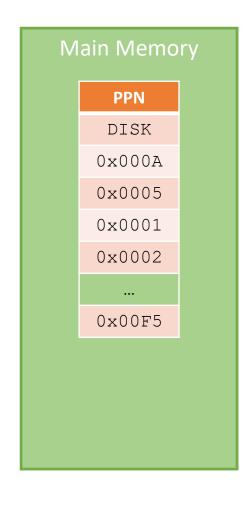
VA: 0x<u>00003</u> 103

Virtual Address [32 bit]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



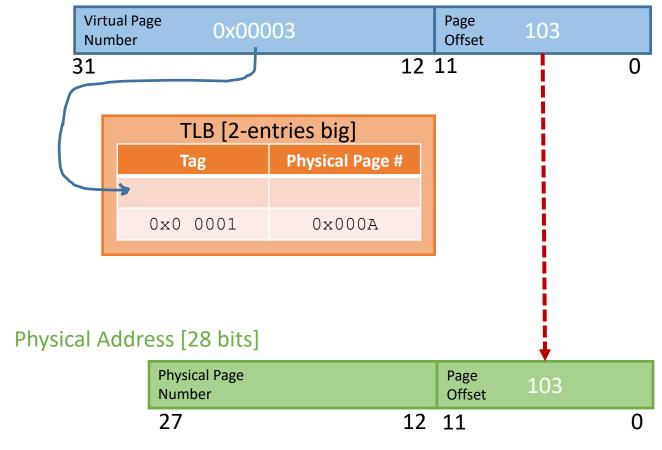
Virtual Address [32 bit]

VA: 0x00003 103

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



Main Memory PPN DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

Compulsory Miss!

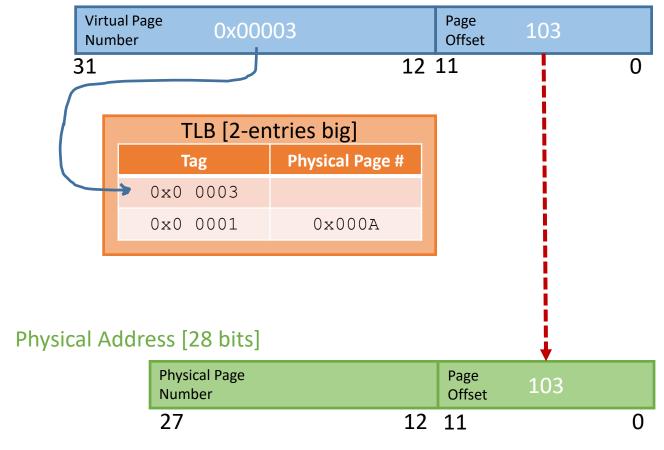
VA: 0x00003 103

Virtual Address [32 bit]

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



Main Memory PPN DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

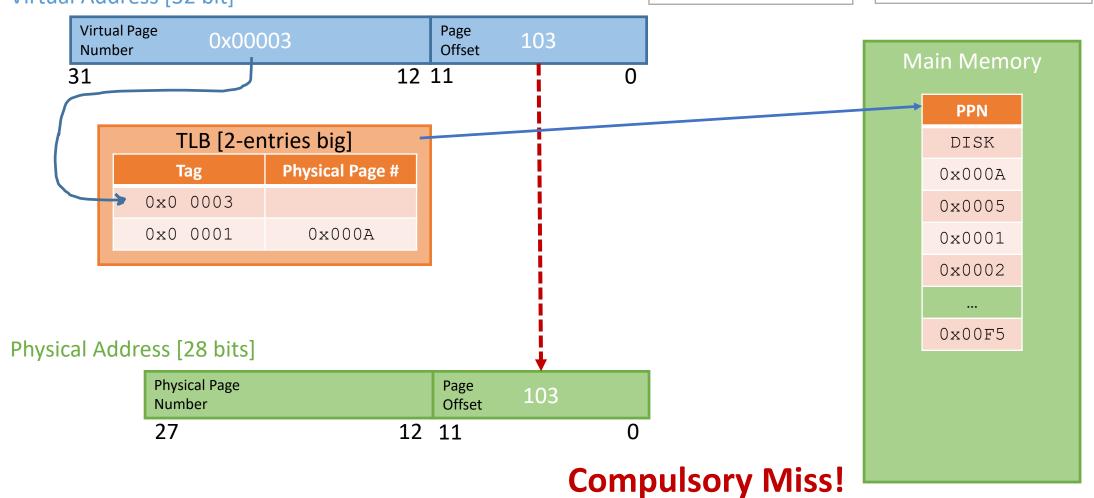
Compulsory Miss!

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]

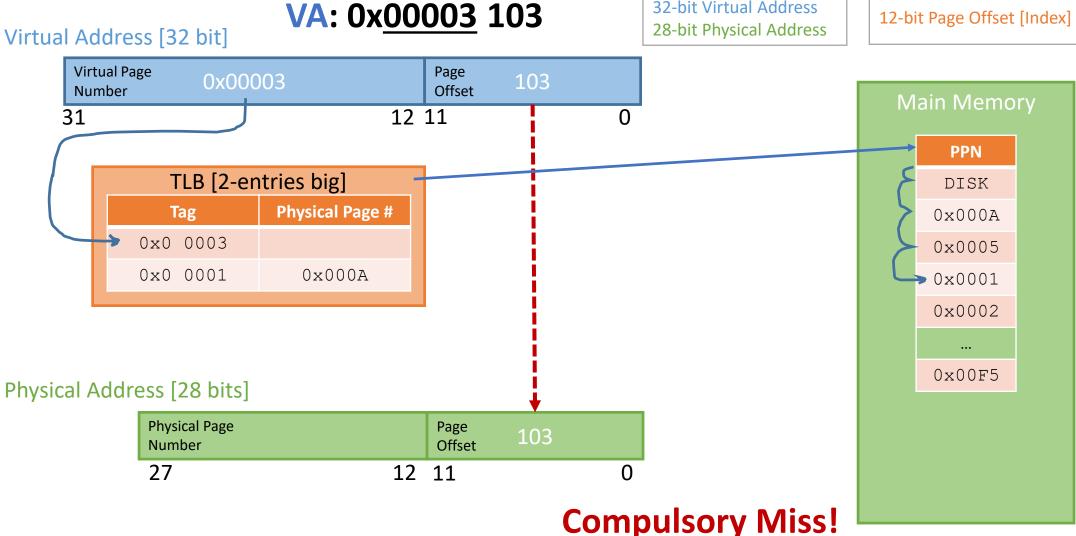
VA: 0x<u>00003</u> 103



32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address

Computer Specs:



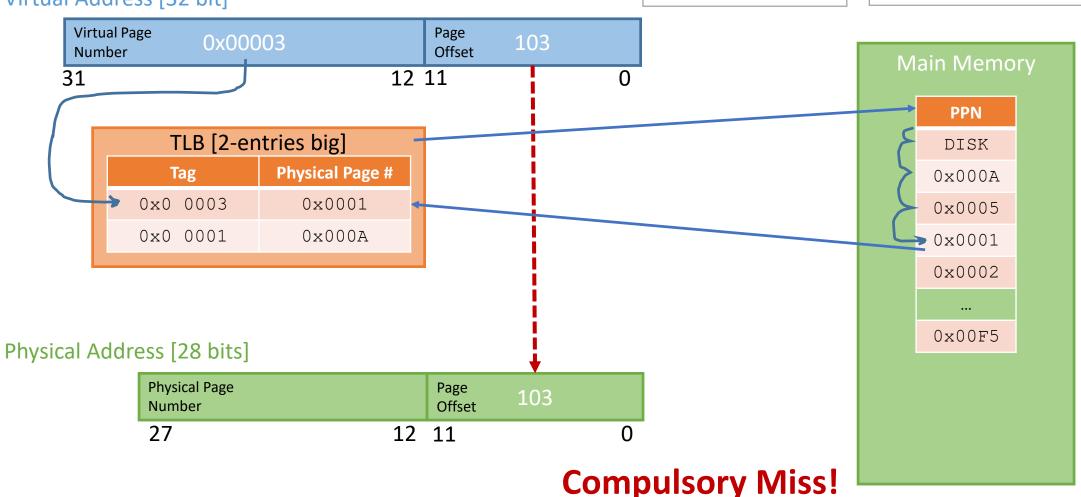
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

Computer Specs:

12-bit Page Offset [Index]

VA: 0x<u>00003</u> 103



32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

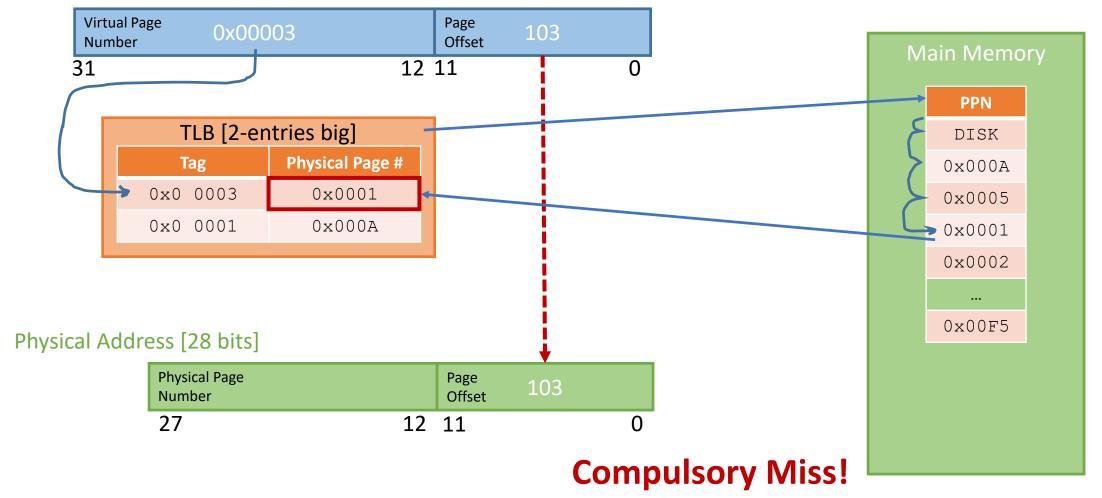
Computer Specs:

VA: 0x<u>00003</u> 103

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]

Virtual Address [32 bit]



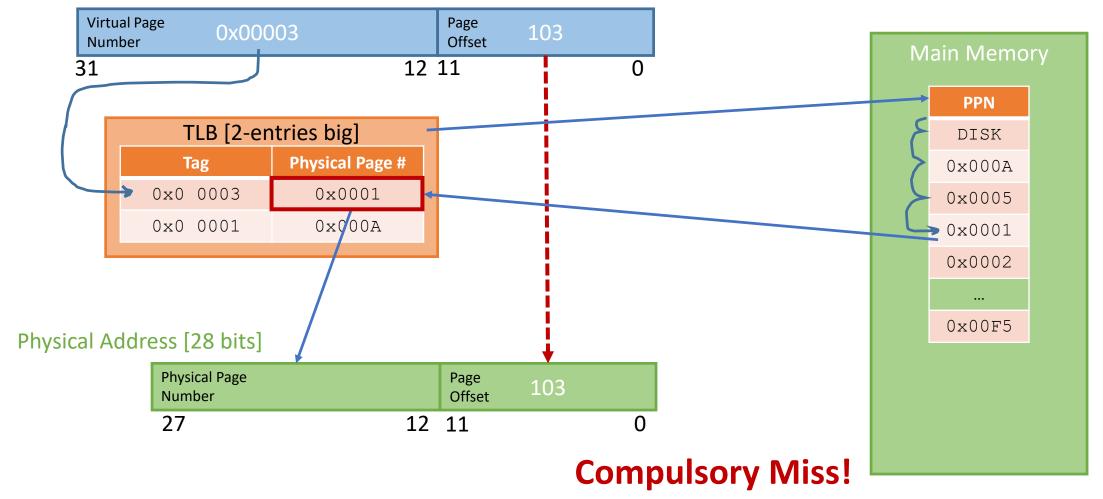
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

VA: 0x<u>00003</u> 103

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]

Virtual Address [32 bit]



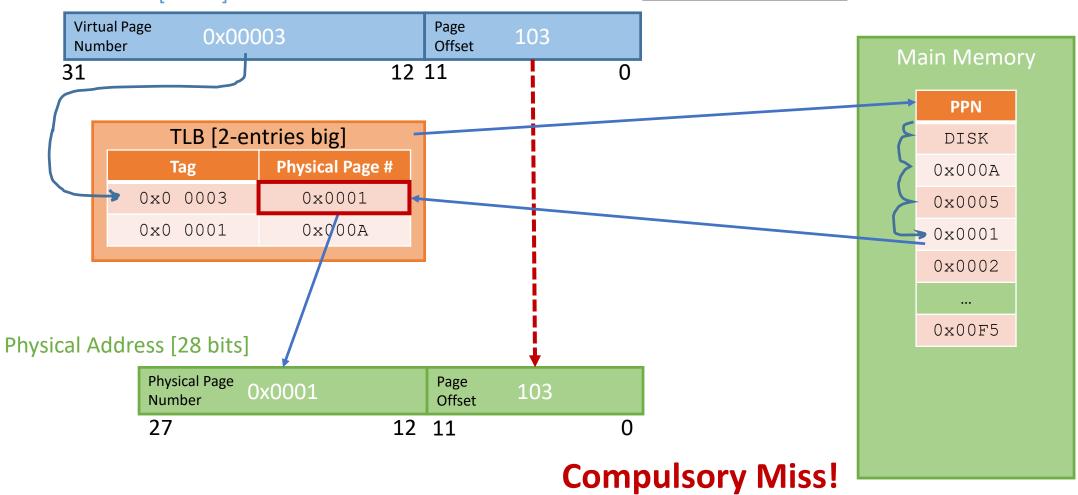
VA: 0x00003 103

Virtual Address [32 bit]

Computer Specs:
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]

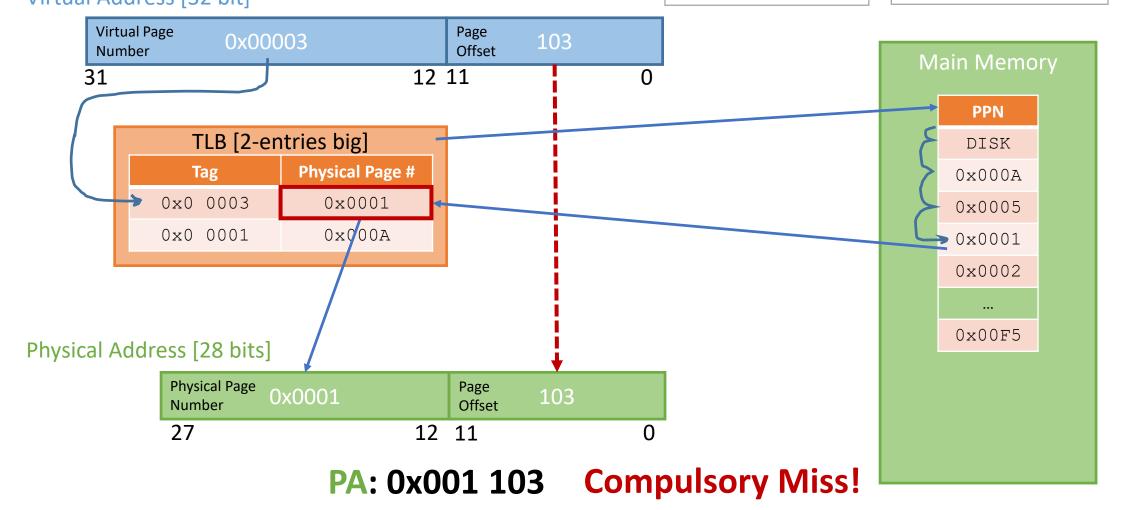


Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]

VA: 0x<u>00003</u> 103



VA: 0x00004 555

Virtual Address [32 bit]

Virtual Page Number		Page Offset	
31	12	11	0

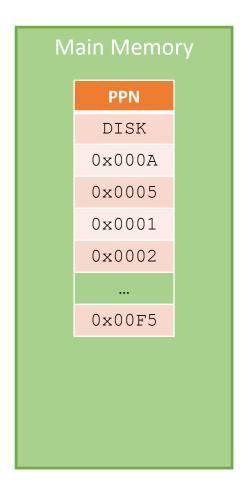
TLB [2-entries big]			
Tag	Physical Page #		
0x0 0003	0x0001		
0x0 0001	0x000A		

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00004 555

Virtual Address [32 bit]

_	Virtual Page Number		Page Offset	
3		12	11	0

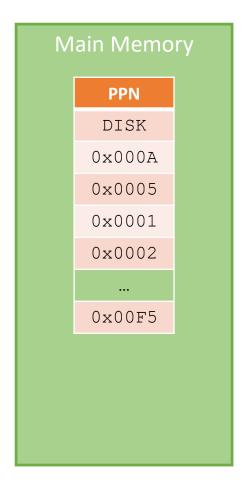
Tag Physical P	age #
	age m
0x0 0003 0x000)1
0x0 0001 0x000)A

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00004 <u>555</u>

Virtual Address [32 bit]

	Virtual Page Number	Page Offset	555	
3		11		0

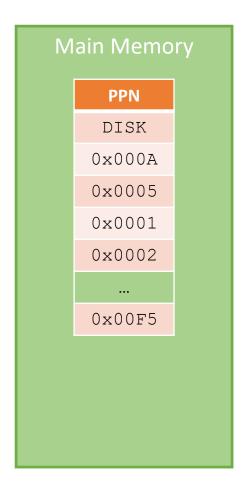
Tag Physical P	age #
	age m
0x0 0003 0x000)1
0x0 0001 0x000)A

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

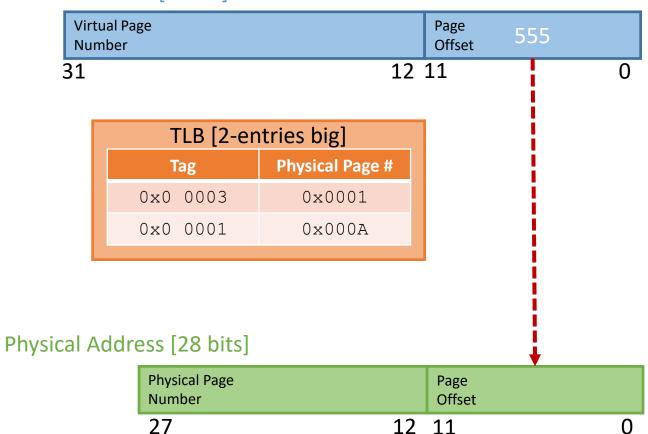
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



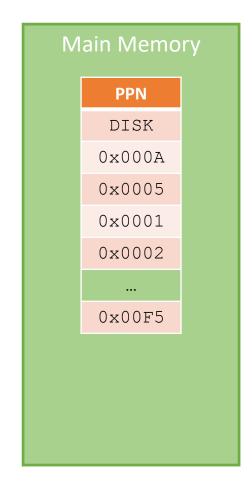
VA: 0x00004 <u>555</u>

Virtual Address [32 bit]



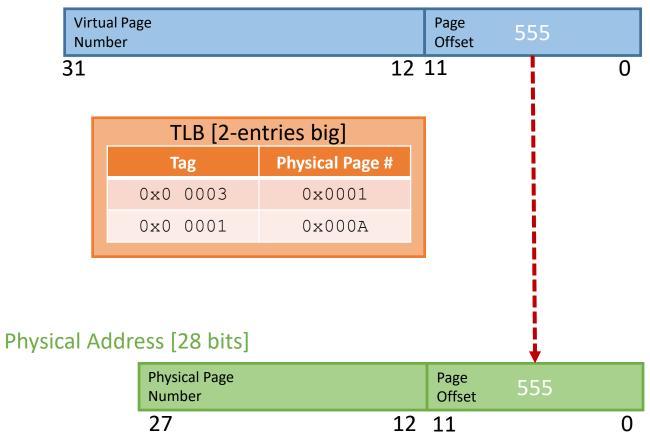
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



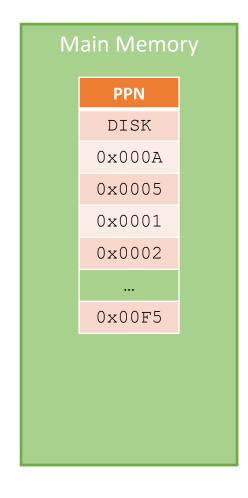
VA: 0x00004 555

Virtual Address [32 bit]



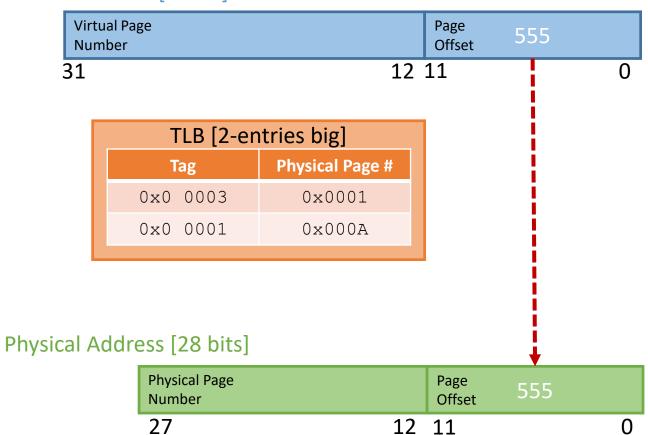
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



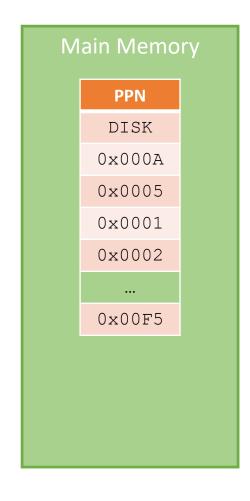
VA: 0x00004 555

Virtual Address [32 bit]



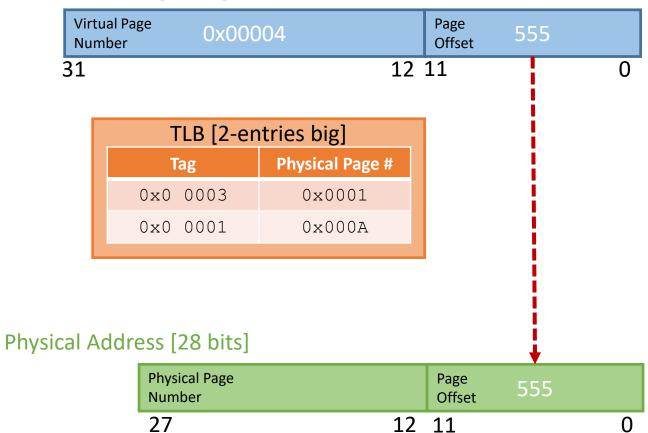
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



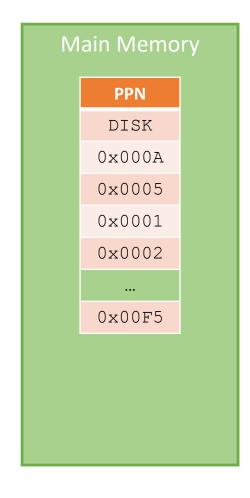
VA: 0x00004 555

Virtual Address [32 bit]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00004 555

Virtual Address [32 bit]

 Virtual Page Number
 0x000004
 Page Offset
 555

 31
 12 11
 0

 TLB [2-entries big]

 Tag
 Physical Page #

 0x0 0003
 0x0001

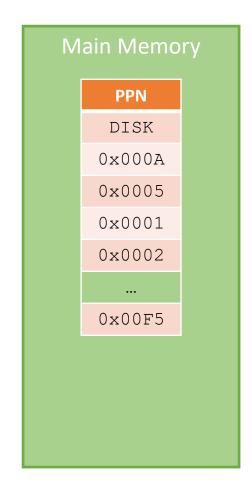
 0x0 0001
 0x0000A

Physical Address [28 bits]

Physical Page Number		Page Offset	555	
27	12	11		0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



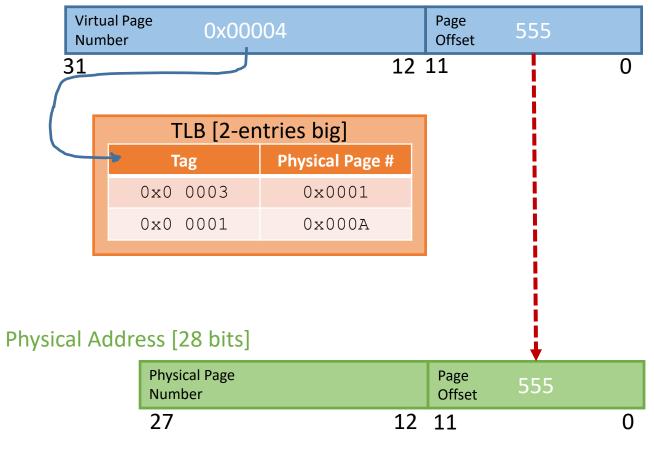
VA: 0x00004 555

Virtual Address [32 bit]

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



Main Memory PPN DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

Capacity Miss!

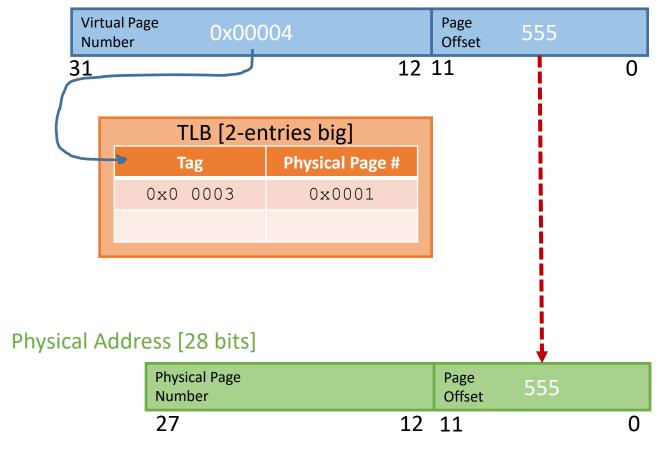
Virtual Address [32 bit]

VA: 0x00004 555

Computer Specs:
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address

12-bit Page Offset [Index]



Main Memory PPN DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

Capacity Miss!

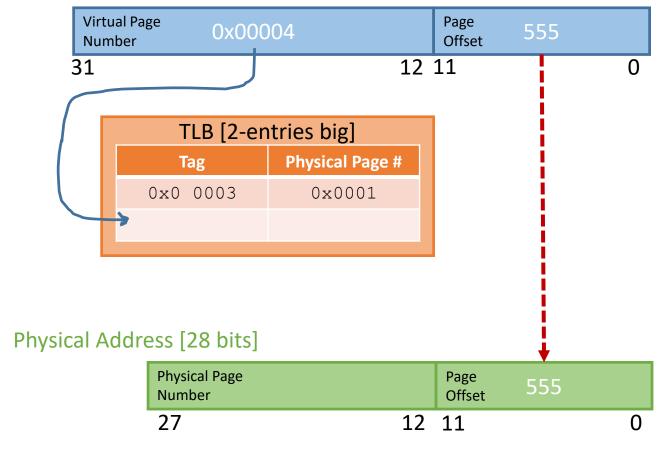
Virtual Address [32 bit]

VA: 0x00004 555

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



Main Memory PPN DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

Capacity Miss!

32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

Computer Specs:

12-bit Page Offset [Index]

VA: 0x<u>00004</u> 555

Virtual Address [32 bit] Virtual Page Page 0x00004 555 Offset Number Main Memory 31 12 11 **PPN** TLB [2-entries big] DISK Physical Page # Tag 0x000A 0x0 0003 0x0001 0x0005 0x0001 0x0002 0x00F5 Physical Address [28 bits] Physical Page Page 555 Number Offset 27 12 11 0 **Capacity Miss!**

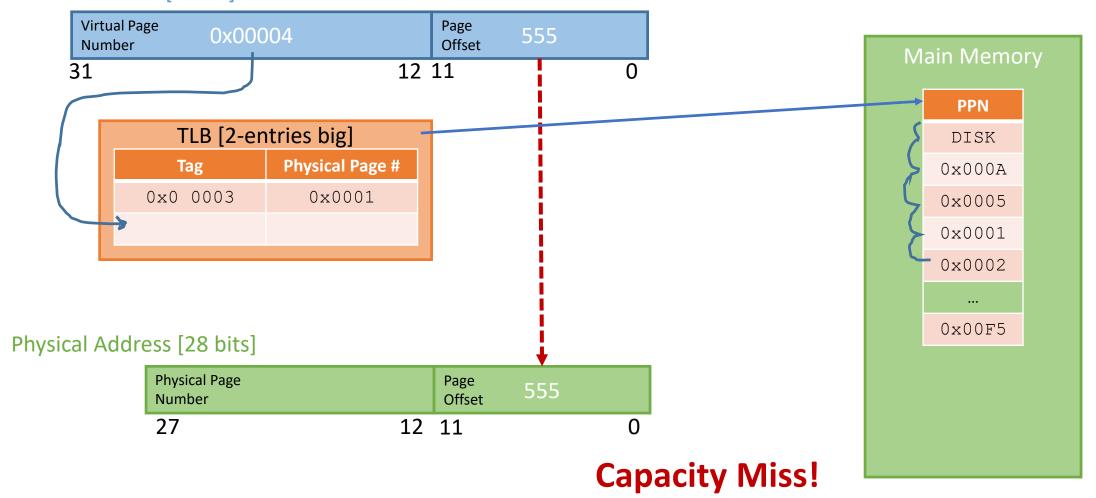
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

Computer Specs:

12-bit Page Offset [Index]

Virtual Address [32 bit]



VA: 0x00004 555

32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

Computer Specs:

12-bit Page Offset [Index]

VA: 0x<u>00004</u> 555

Virtual Address [32 bit] Virtual Page Page 0x00004 555 Offset Number Main Memory 31 12 11 **PPN** TLB [2-entries big] DISK Physical Page # Tag 0x000A 0x0 0003 0x0001 0x0005 0x0001 0x0002 0x00F5 Physical Address [28 bits] Physical Page Page 555 Number Offset 27 12 11 0 **Capacity Miss!**

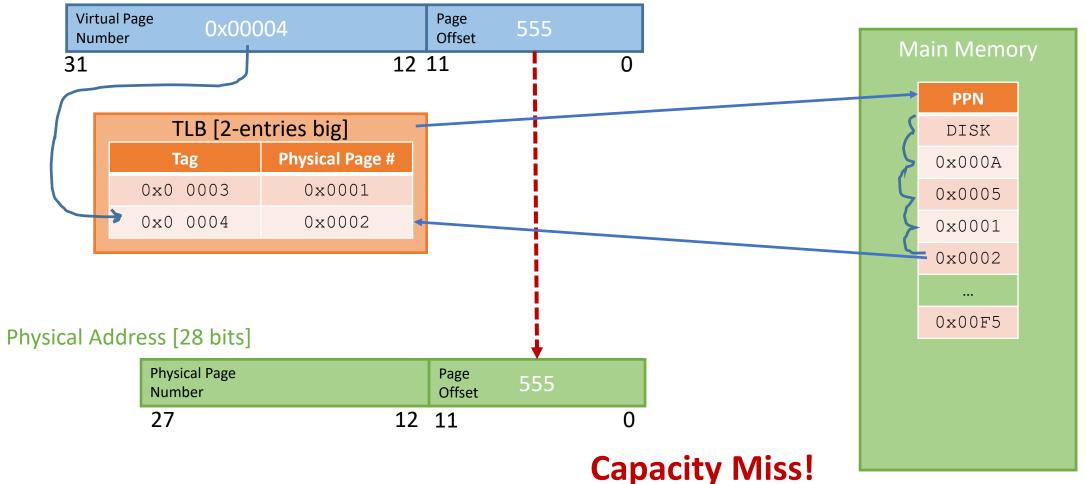
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]

VA: 0x<u>00004</u> 555

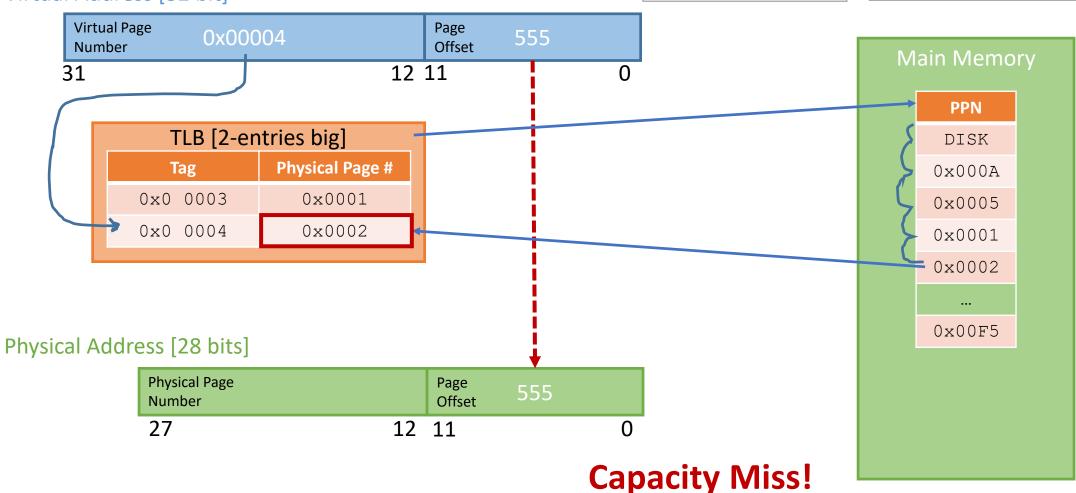
Virtual Address [32 bit]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

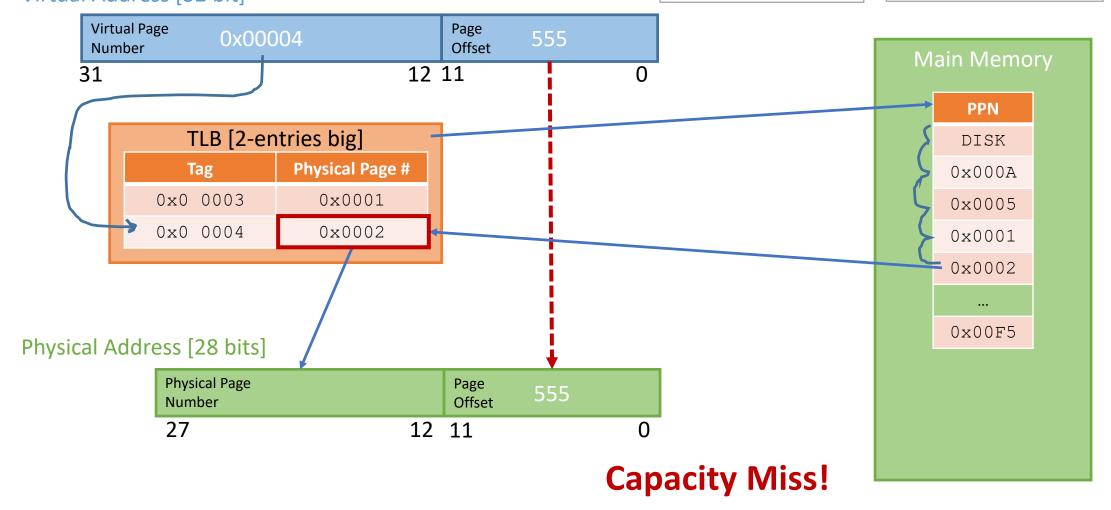
12-bit Page Offset [Index]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address

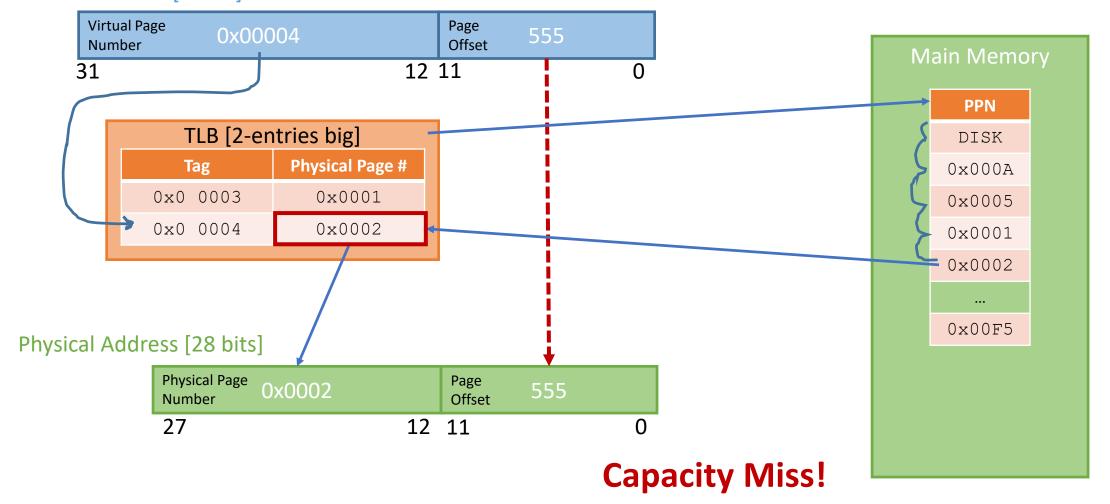
12-bit Page Offset [Index]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

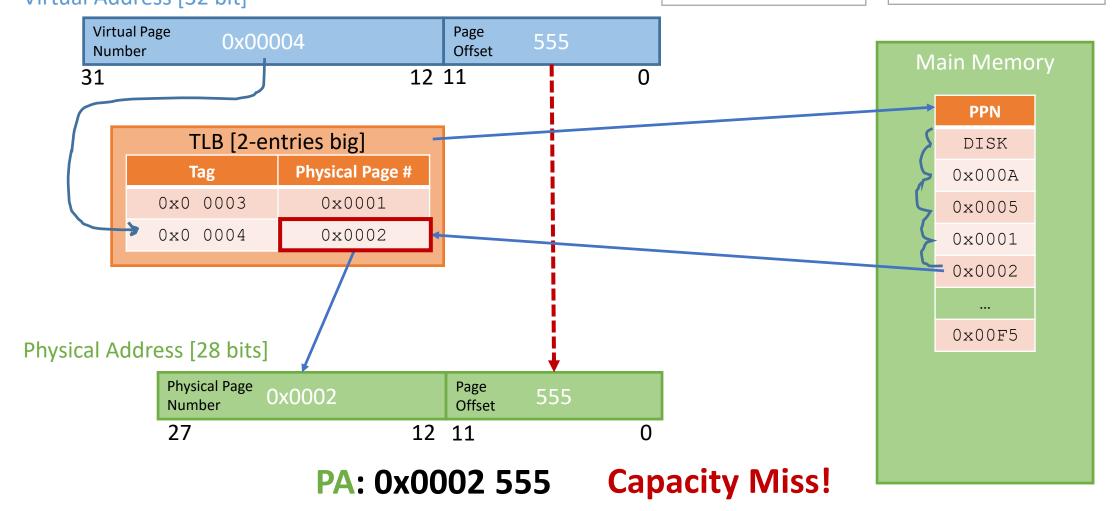
12-bit Page Offset [Index]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address

12-bit Page Offset [Index]



VA: 0x00003 099

Virtual Address [32 bit]

	Virtual Page Number		Page Offset	
3	31	12	11	0

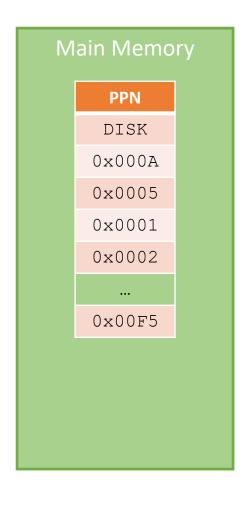
Tag Physical Page # 0x0 0003 0x0001	TLB [2-e	ntries big]
0x0 0003 0x0001	Tag	Physical Page #
	0x0 0003	0x0001
0x0 0004 0x0002	0x0 0004	0x0002

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00003 099

Virtual Address [32 bit]

	Virtual Page Number		Page Offset	
-	31	12	11	0

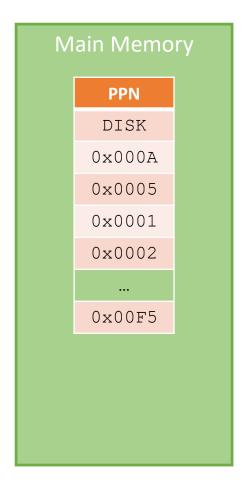
Tag	Physical Page #
0x0 0003	0x0001
0x0 0004	0x0002

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00003 <u>099</u>

Virtual Address [32 bit]

	Virtual Page Number		Page Offset	099	
-	31 12	2 :	11		0

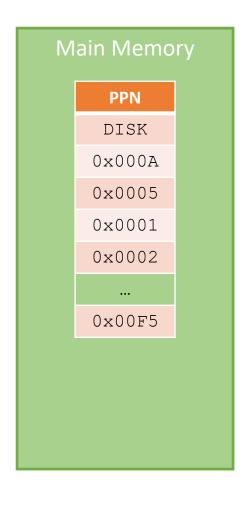
Tag Physical Page # 0x0 0003 0x0001	TLB [2-er	itries big]
	Tag	Physical Page #
	0x0 0003	0x0001
0x0 0004 0x0002	0x0 0004	0x0002

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

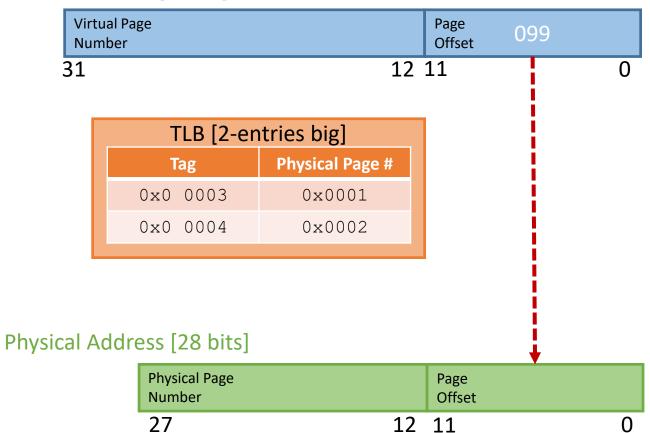
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



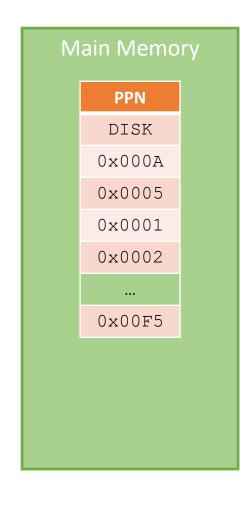
VA: 0x00003 099

Virtual Address [32 bit]



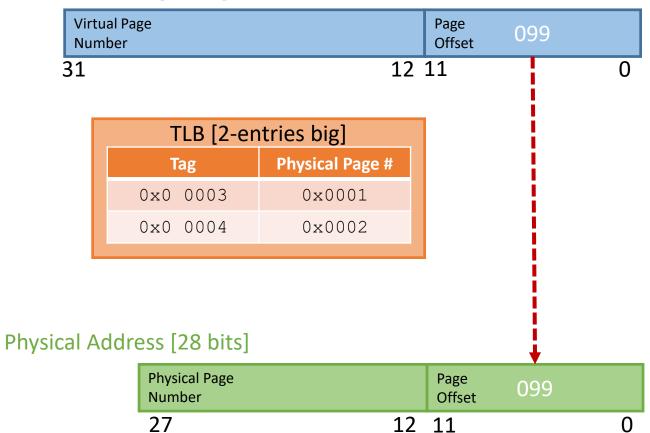
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



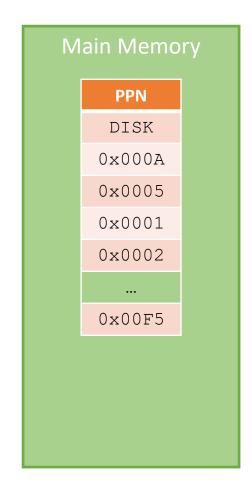
VA: 0x00003 <u>099</u>

Virtual Address [32 bit]



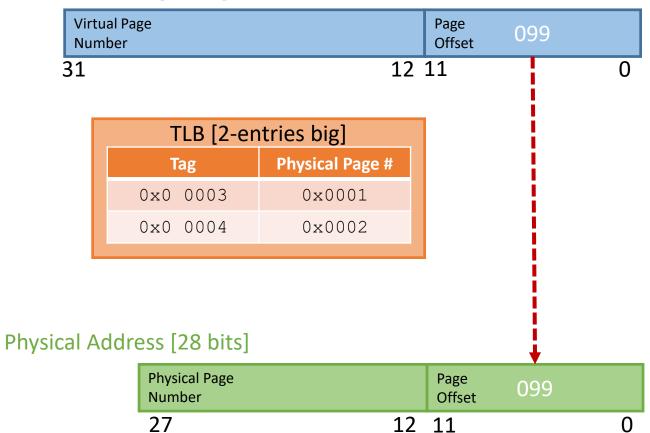
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



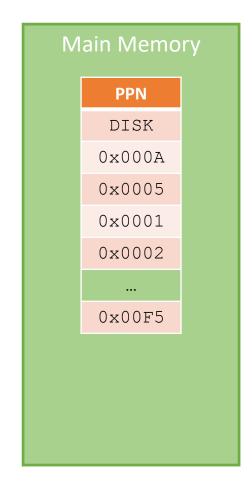
VA: 0x00003 099

Virtual Address [32 bit]



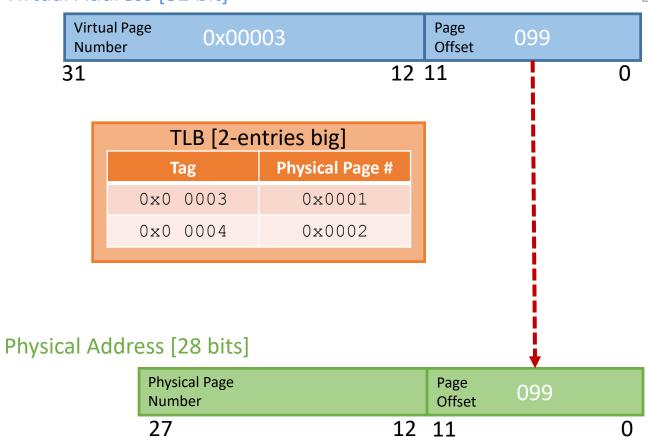
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



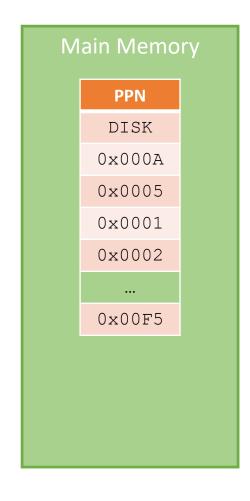
VA: 0x00003 099

Virtual Address [32 bit]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



27

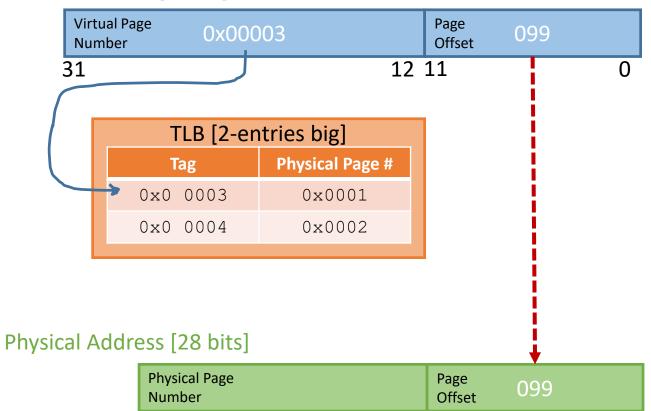
VA: 0x00003 099

12

11

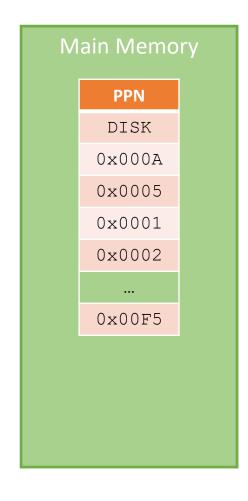
0

Virtual Address [32 bit]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



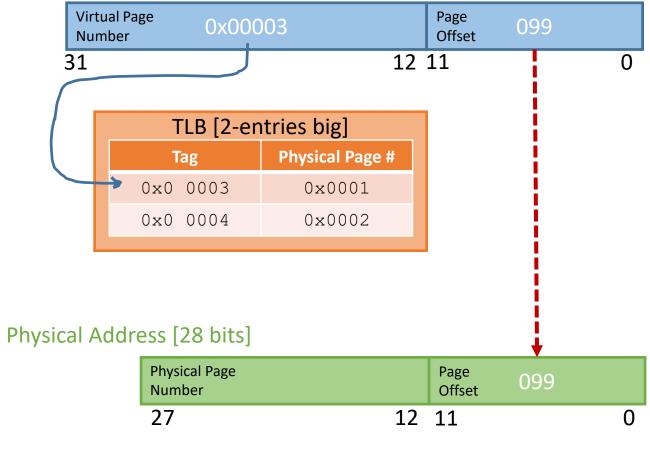
VA: 0x00003 099

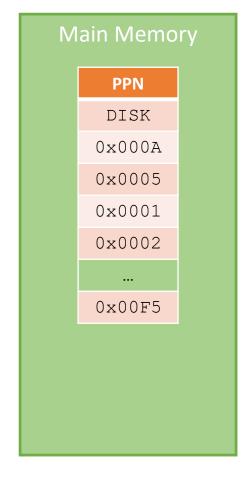
Virtual Address [32 bit]

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



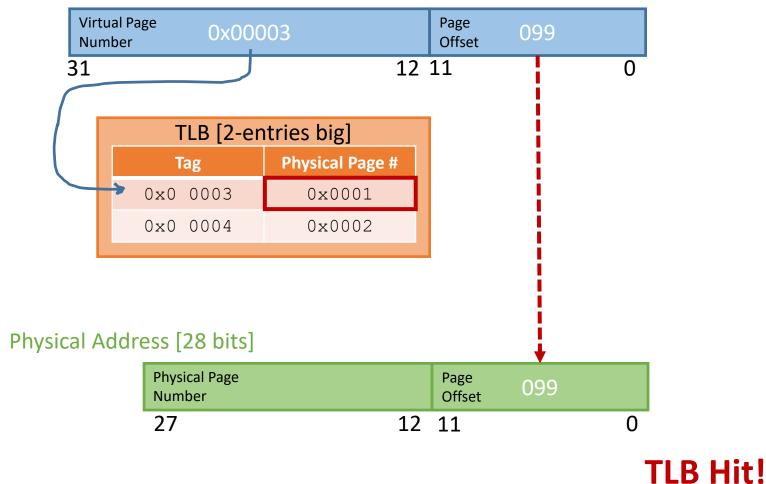


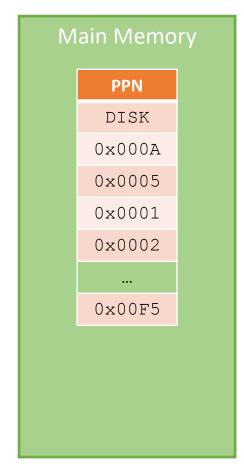
Virtual Address [32 bit]

VA: 0x00003 099

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address





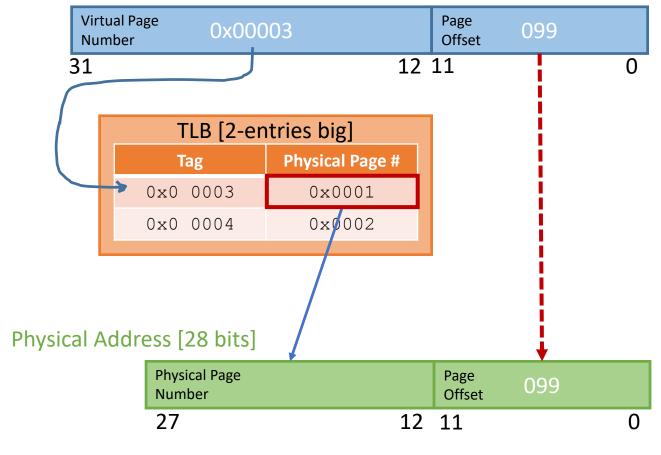
Virtual Address [32 bit]

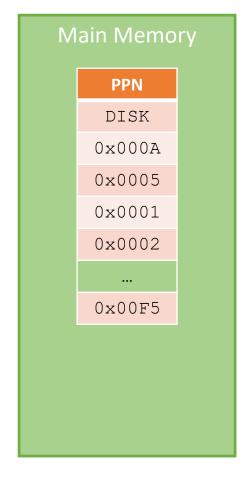
VA: 0x00003 099

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]





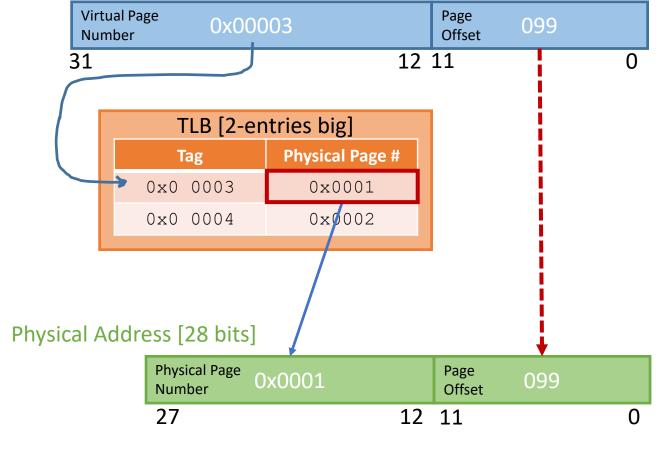
Virtual Address [32 bit]

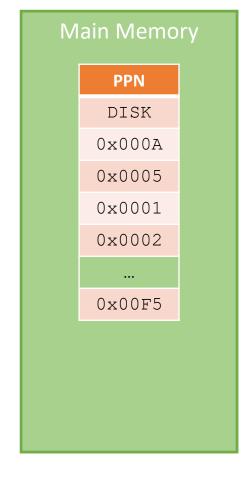
VA: 0x<u>00003</u> 099

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address

12-bit Page Offset [Index]





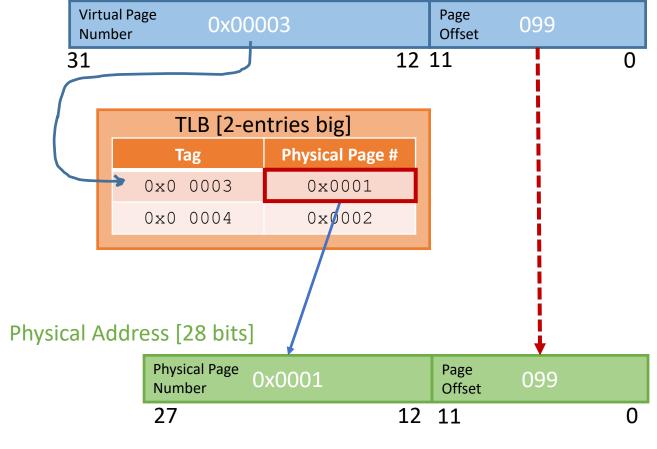
Virtual Address [32 bit]

VA: 0x00003 099

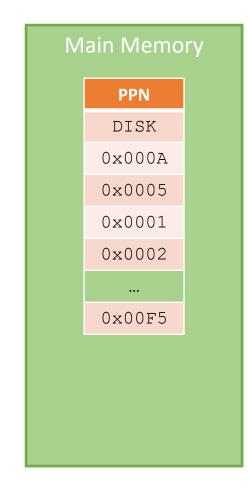
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



PA: 0x0001 099



VA: 0x00000 123

Virtual Address [32 bit]

Virtual Page Number		Page Offset	
31	12	11	0

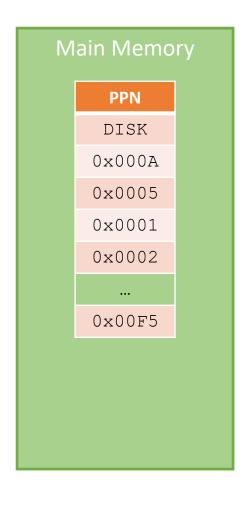
Tag Physical Page # 0x0 0003 0x0001	TLB [2-e	ntries big]
0x0 0003 0x0001	Tag	Physical Page #
	0x0 0003	0x0001
0x0 0004 0x0002	0x0 0004	0x0002

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address





Computer Specs:

32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]

Virtual Address [32 bit]

Virtual Page Number	Page Offset	
31	12 11	0

VA: 0x00000 123

 TLB [2-entries big]

 Tag
 Physical Page #

 0x0 0003
 0x0001

 0x0 0004
 0x0002

Q: What is the **PA** associated with this **VA**?

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Main Memory PPN DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

VA: 0x00000 123

Virtual Address [32 bit]

_	Virtual Page Number		Page Offset	
3	· •	12	11	0

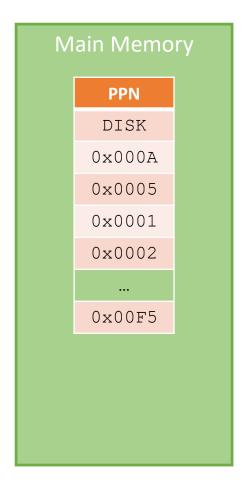
Tag	Physical Page #
0x0 0003	0x0001
0x0 0004	0x0002

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00000 <u>123</u>

Virtual Address [32 bit]

	Virtual Page Number	Page Offset	.23
3	31 12 1	11	0

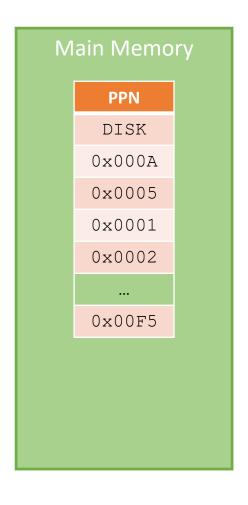
Tag Physical Page # 0x0 0003 0x0001	TLB [2-entries big]				
	Tag	Physical Page #			
00 0004 00002	0x0 0003	0x0001			
0x0 0004 0x0002	0x0 0004	0x0002			

Physical Address [28 bits]

Physical Page Number	Page Offset	
27	12 11	0

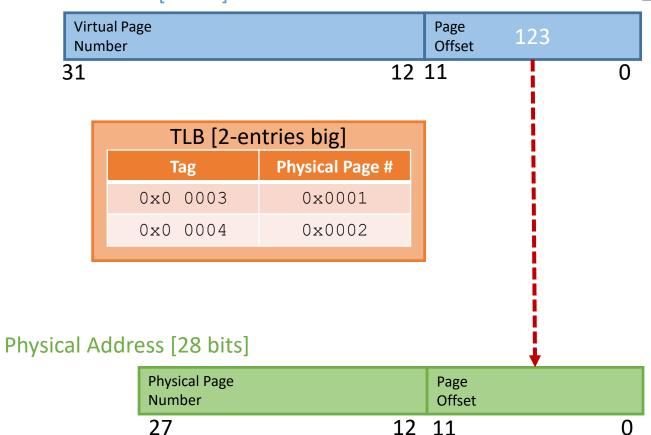
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



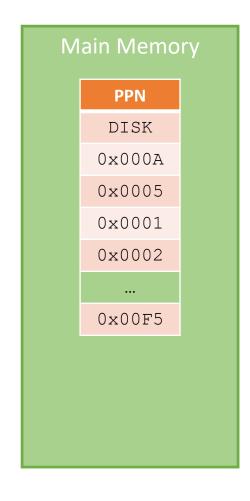
VA: 0x00000 123

Virtual Address [32 bit]



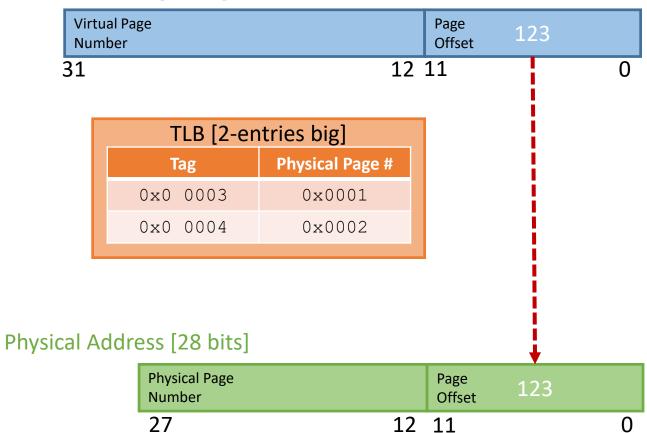
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



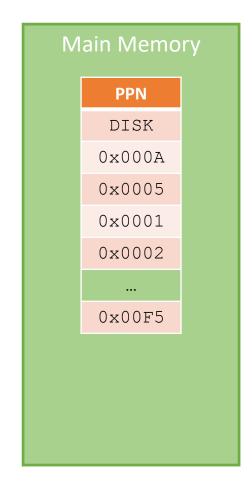
VA: 0x00000 123

Virtual Address [32 bit]



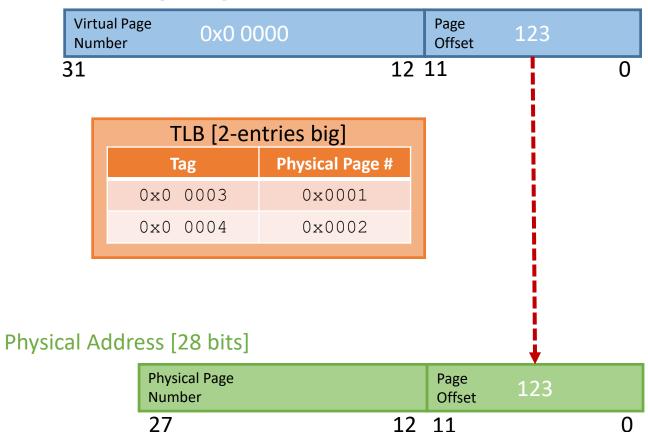
Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



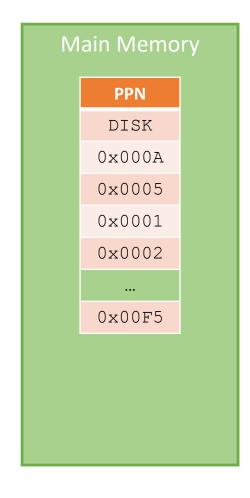
VA: 0x00000 <u>123</u>

Virtual Address [32 bit]



Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address



VA: 0x00000 <u>123</u>

Virtual Address [32 bit]

 Virtual Page Number
 0x0 0000
 Page Offset
 123

 31
 12 11

TLB [2-entries big]
Tag Physical Page #

 0x0
 0003

 0x0
 0004

 0x0
 0002

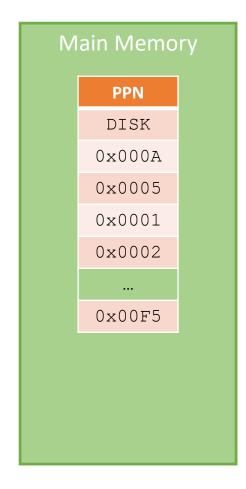
Physical Address [28 bits]

	Physical Page Number	Page Offset	123	
Ī	27 12	11		0

Computer Specs:

32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address28-bit Physical Address

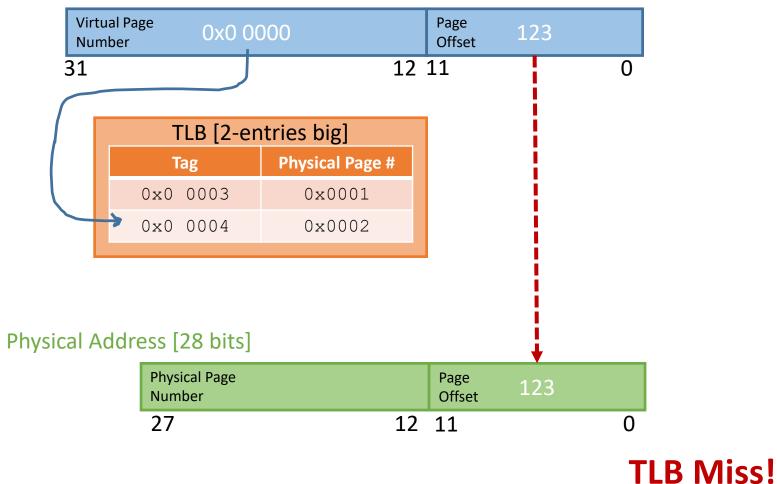


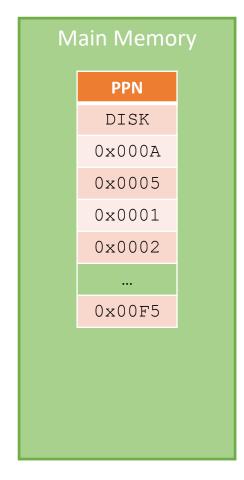
VA: 0x00000 123

Virtual Address [32 bit]

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address





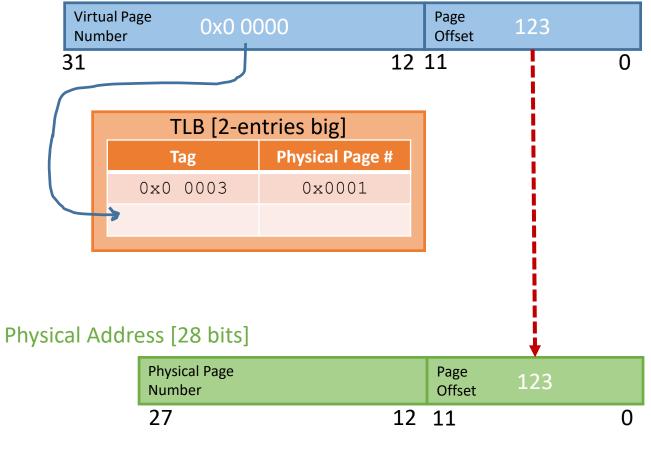
Virtual Address [32 bit]

VA: 0x00000 123

Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]



Main Memory **PPN** DISK 0x000A 0x0005 0x0001 0x0002 0x00F5

TLB Miss!

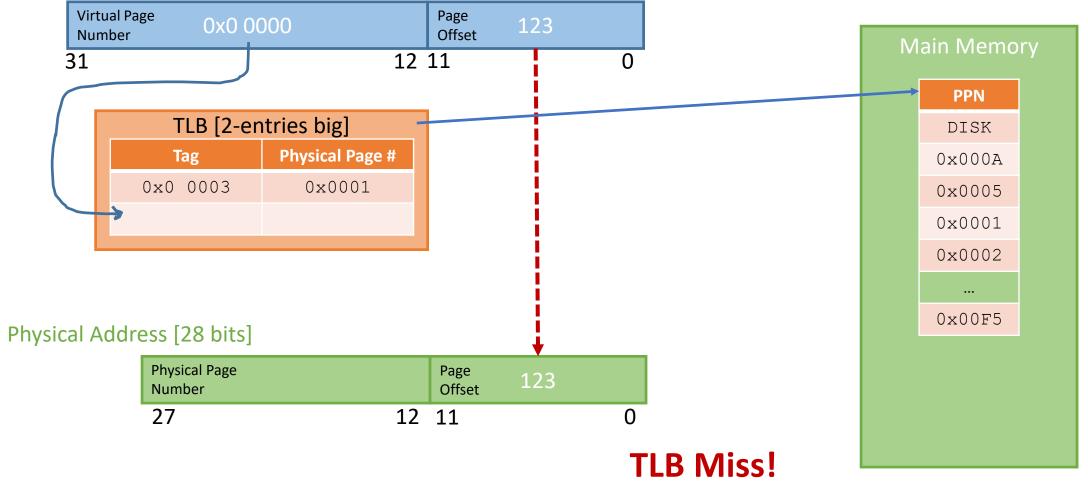
VA: 0x00000 123

Virtual Address [32 bit]

Computer Specs:
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]



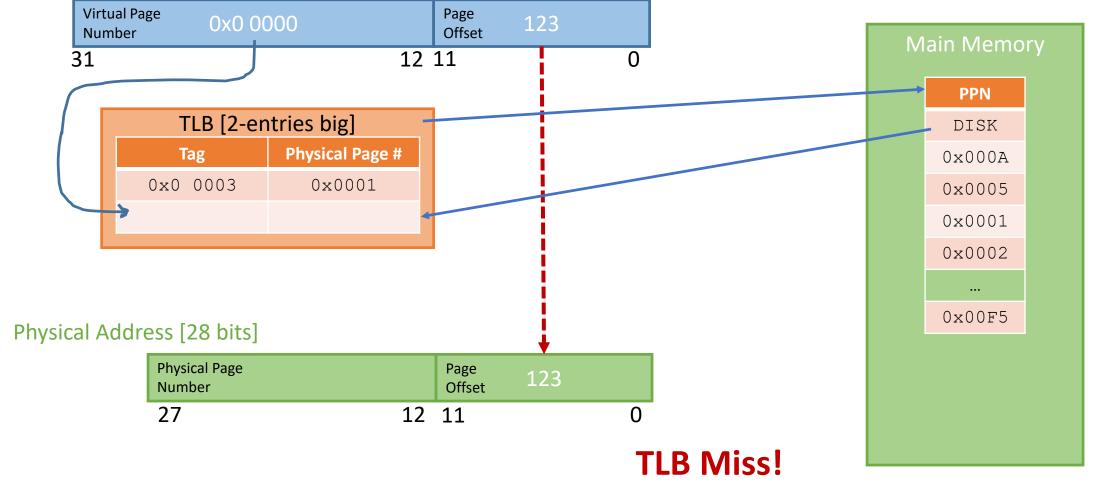
VA: 0x00000 123

Virtual Address [32 bit]

Computer Specs:
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]



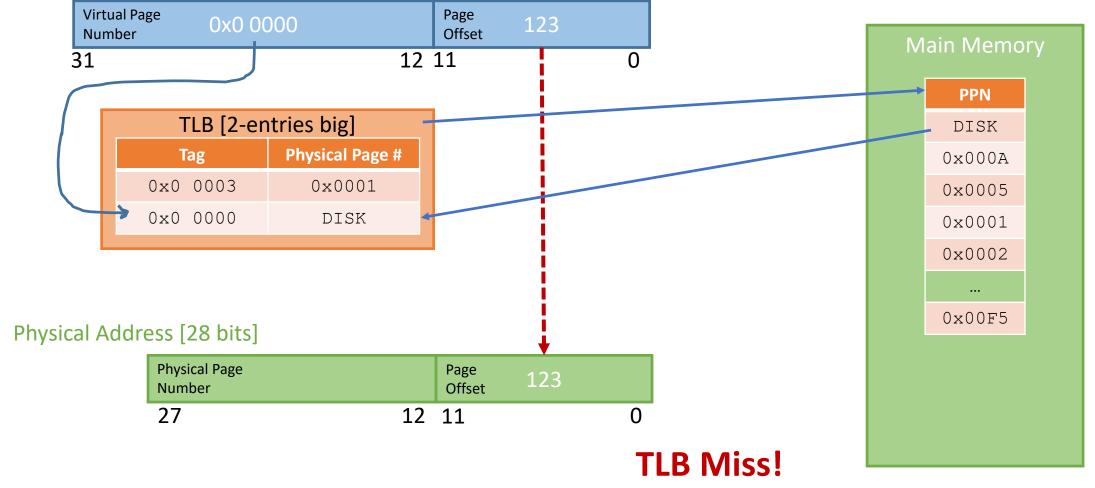
VA: 0x00000 123

Virtual Address [32 bit]

Computer Specs:
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]



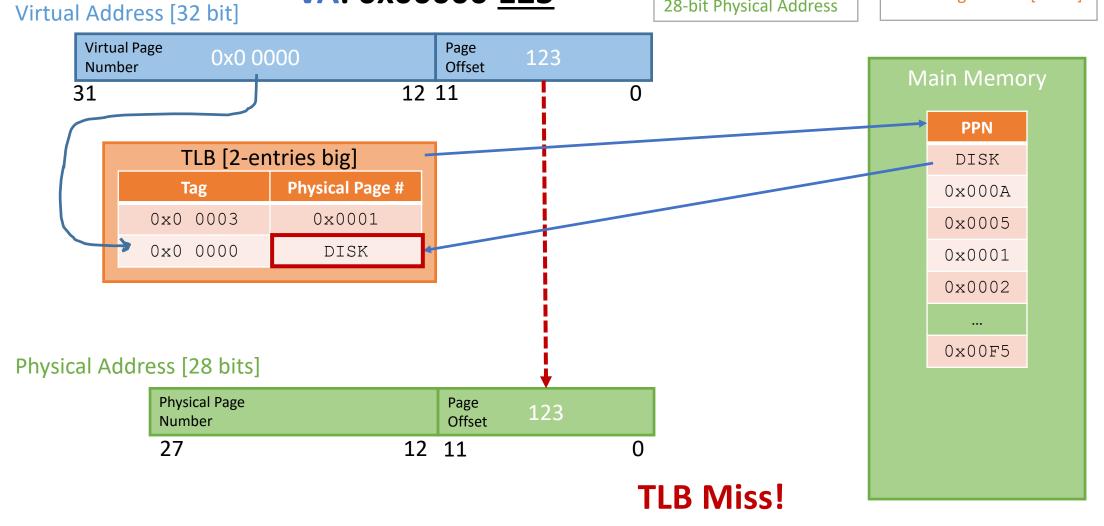
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

Computer Specs:

VA: 0x00000 <u>123</u>

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]



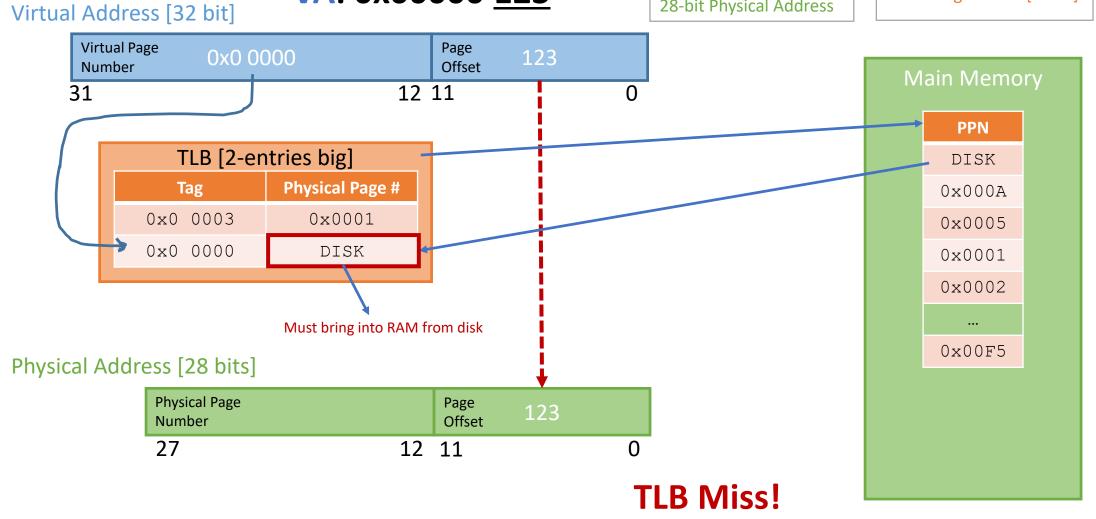
32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB $\,$

Computer Specs:

32-bit Virtual Address
28-bit Physical Address

12-bit Page Offset [Index]

VA: 0x00000 <u>123</u>

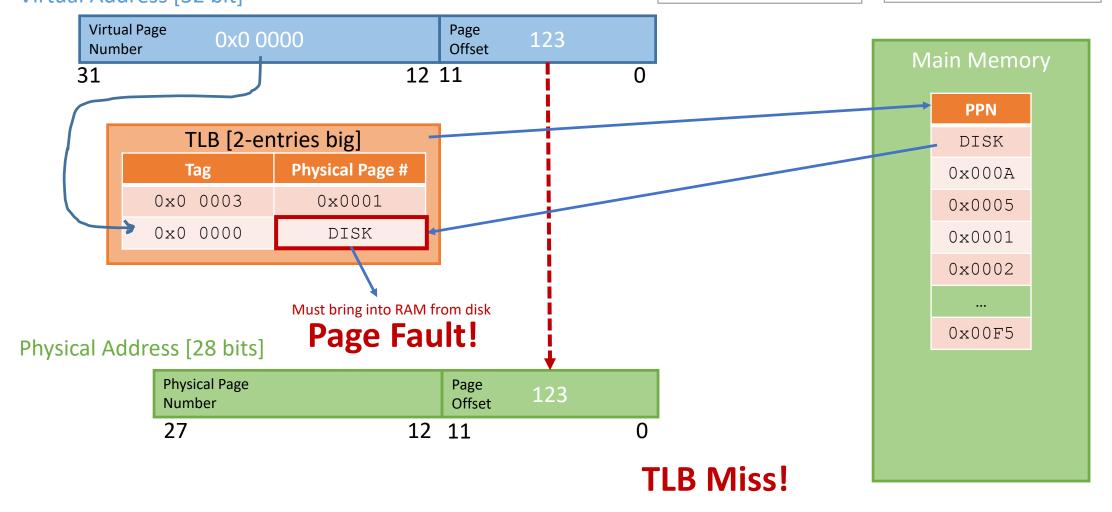


Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]

VA: 0x00000 <u>123</u>

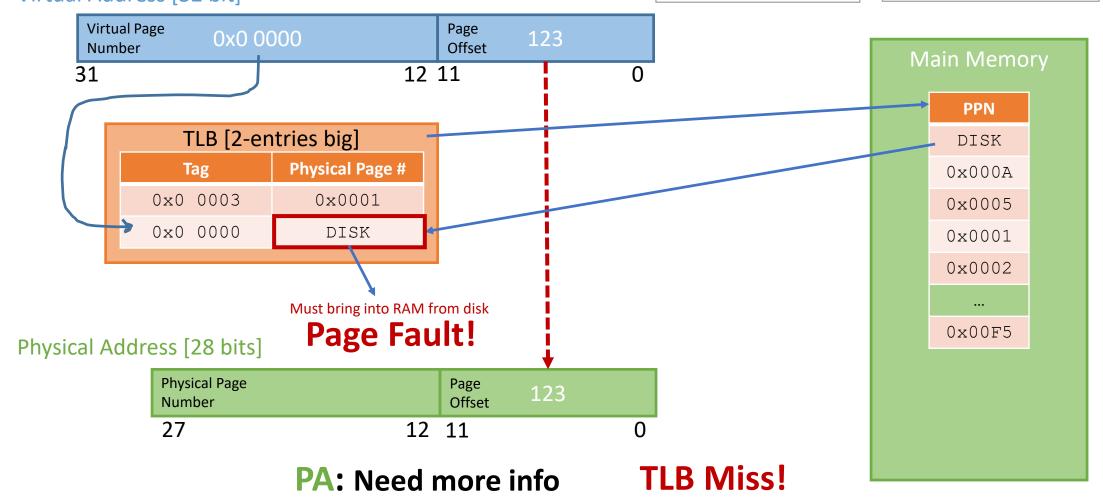


Computer Specs: 32-bit ISA, 256 MB of RAM, 4 kB pages, 2-entry TLB

32-bit Virtual Address 28-bit Physical Address

12-bit Page Offset [Index]

VA: 0x00000 <u>123</u>



References

- David Black-Schaffer: Lecture Series on Virtual Memory
- Patterson, Hennessy: Computer Organization and Design: the Hardware/Software Interface
- Intel Hardware Data-Sheets
- Linux: Anatomy of a Program in Memory