last time (1)

kill() signal sending timing

user ID/group IDs

- used by kernel to determine what to do
- tracked for every process
- libraries/utilities map to names

permission checks in system call handlers

chmod permissions

- user ID (owner) / one group ID / others — read/write/exec

access control list

- list of users/groups — read/write/exec for each

last time (2)

user ID 0 (‘root’, ‘superuser’) — passes all permission checks

login program: runs as user ID 0

- can access password database because user ID 0

set-user-ID programs

- special bit says “run program with owner’s user ID”
- system administrator can setup program to only do ‘safe’ things
- example: sudo: allow only users config file to do things as root
- example: allow users to shutdown only if no one logged in
- system tracks addt’l user ID to help with those checks

anonymous feedback (1)

“Could we have some more office hours at the beginning/middle of the week instead of the end? I feel that it would be more helpful in the case that we have questions concerning the homework. Thank you.”

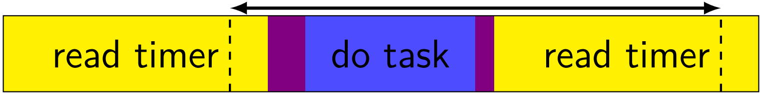
anonymous feedback (2)

"Hello, I feel that the following would be helpful for the entire class as they start/continue to work on the homework: Is it possible for you to explain why the overhead time with clock_gettime() is longer than some of the provided scenarios? Even after incorporating the tips of Section 1.3, it still is longer. Thank you for your help."

could be: system slow during overhead measurement, fast otherwise

also can be task (e.g. empty function call) being optimized away

also I think some are confused about what overhead is:



want to time task part, but timed measured includes extra stuff

anonymous feedback (3)

“Do you mind going over what exactly the read, write, and execute permissions allow?”

regular files:

read — open file for reading

write — open file to write/print (modify contents)

execute — run the file as a program

directories:

read — list directory contents write — add/move/rename files in directory execute (search) — access file/subdirectory within directory (if already know name)

quiz Q2

question: when will control-C terminate program?

answer: when signal handler not setup yet

once sigaction() called, signal handler remains setup until another sigaction/etc. call

quiz Q4

aaa1a/ccc1c: read-only

bbb1b: write3

make bbb1b owner, give owner rw permissions

have aaa1a+ccc1c (and maybe also bbb1b) in group

associate that group w/file + give group r permission only

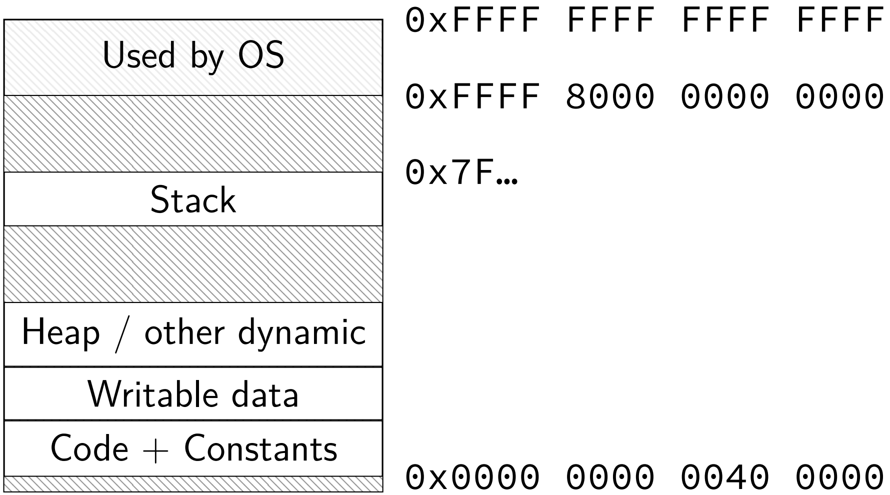
make default permissions nothing

anonymous feedback (4)

“Do you think you could post the recordings on Panopto please? The video player doesn’t allow us to have captions or skip/go back 10/sec intervals”

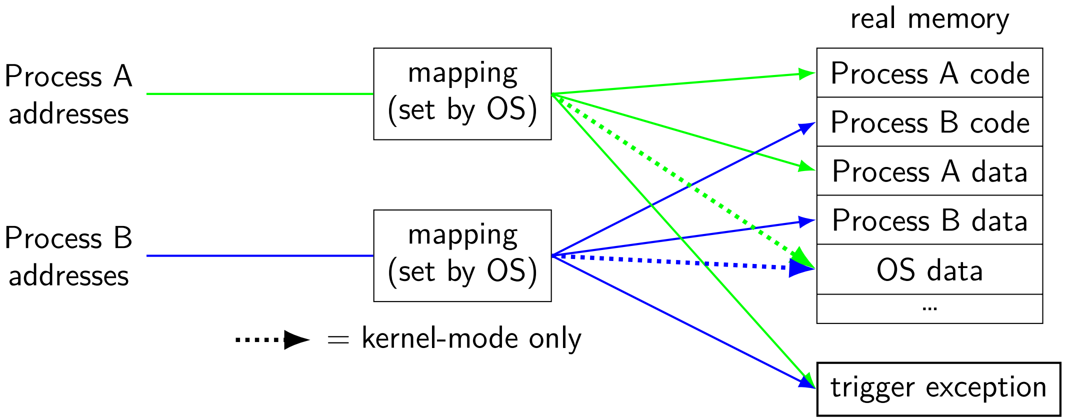
- done
- also should be importing panopto automatic [not great] captions into main viewer

program memory



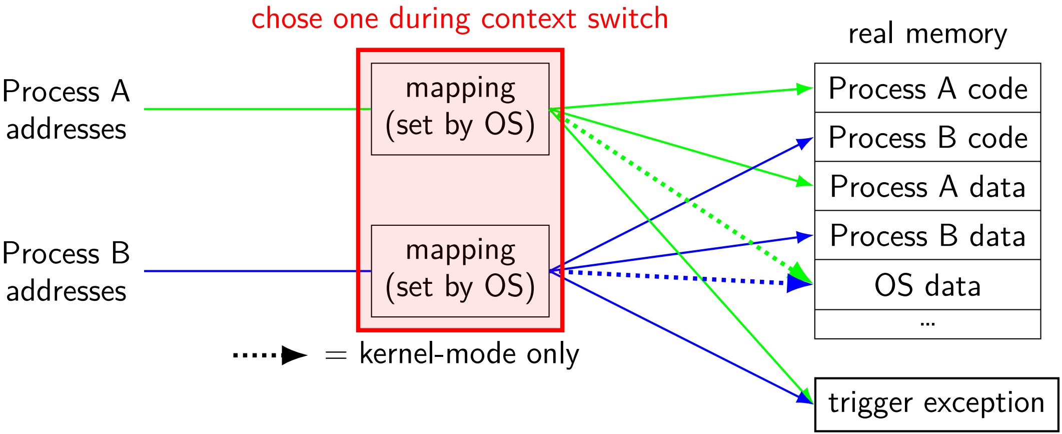
address spaces

illuision of dedicated memory

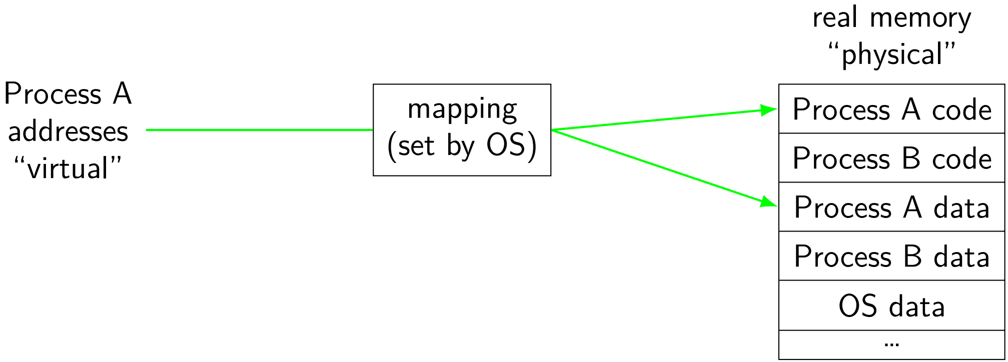


address spaces

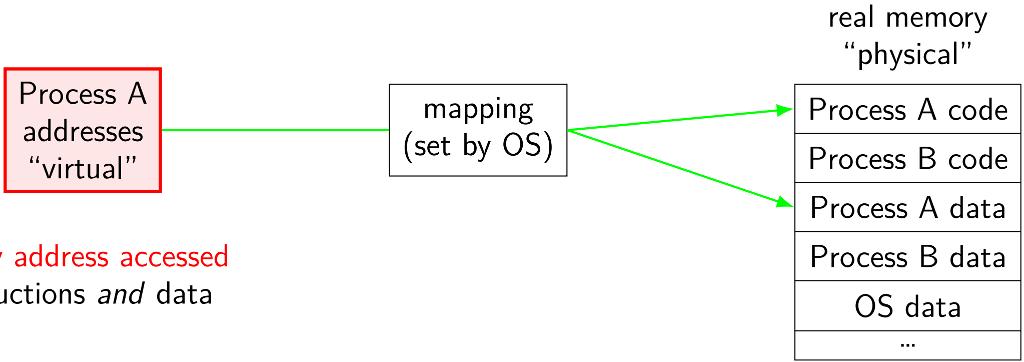
illuision of dedicated memory



address translation

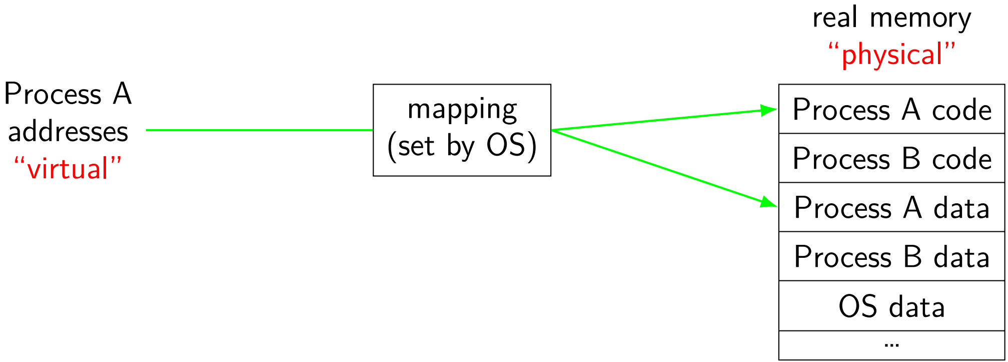


address translation



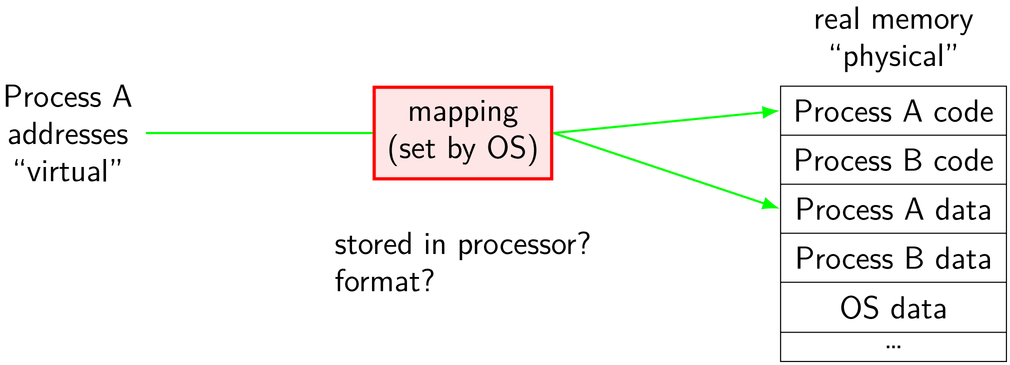
every address accessed
instructions *and* data

address translation

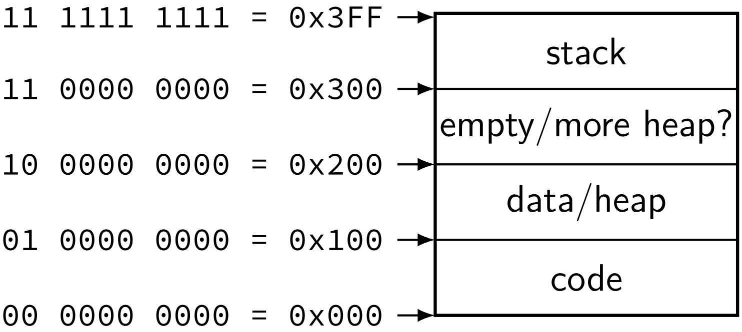


program addresses are 'virtual'
real addresses are 'physical'
can be different sizes!

address translation



toy program memory



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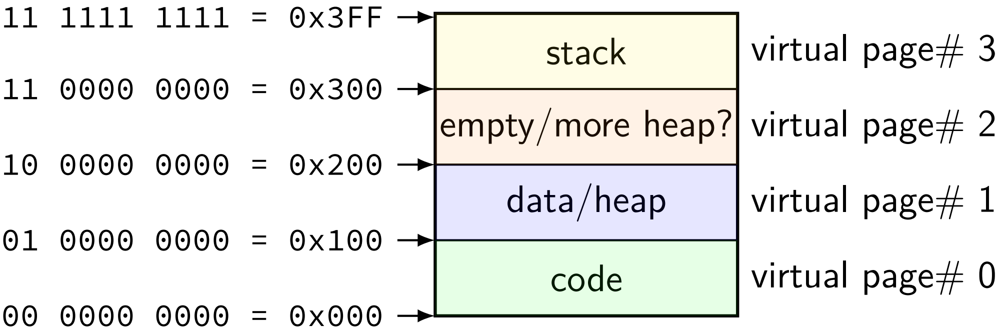
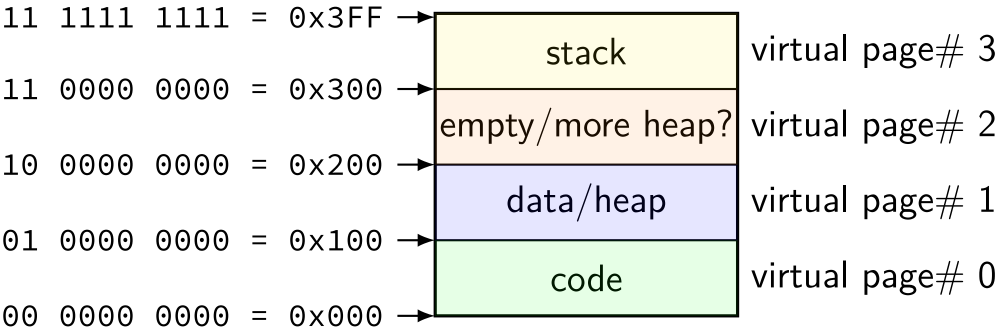
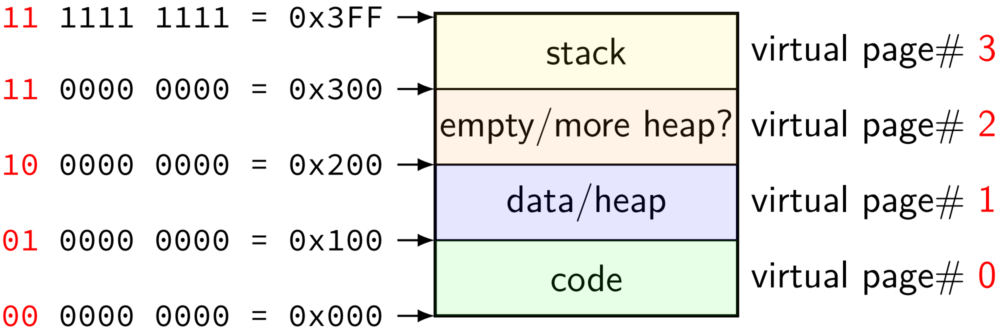


toy program memory



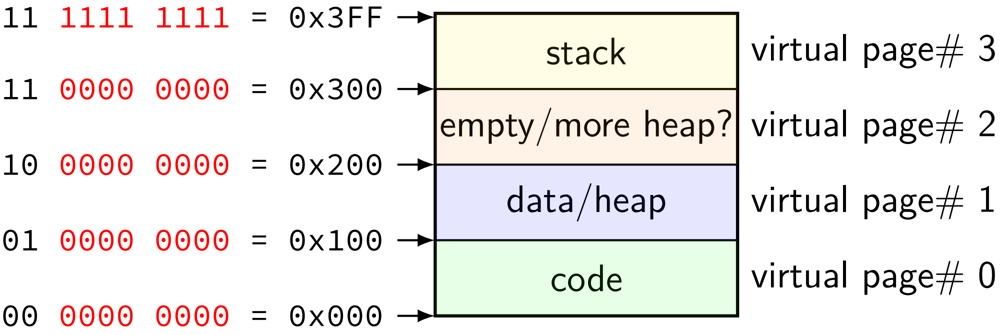
divide memory into pages (2^8 bytes in this case)
"virtual" = addresses the program sees

toy program memory



page number is upper bits of address
(because page size is power of two)

toy program memory



rest of address is called page offset

toy physical memory

real memory
physical addresses

111 0000 0000 to 111 1111 1111
001 0000 0000 to 001 1111 1111
000 0000 0000 to 000 1111 1111

program memory
virtual addresses

11 0000 0000 to 11 1111 1111
10 0000 0000 to 10 1111 1111
01 0000 0000 to 01 1111 1111
00 0000 0000 to 00 1111 1111

toy physical memory

real memory

physical addresses

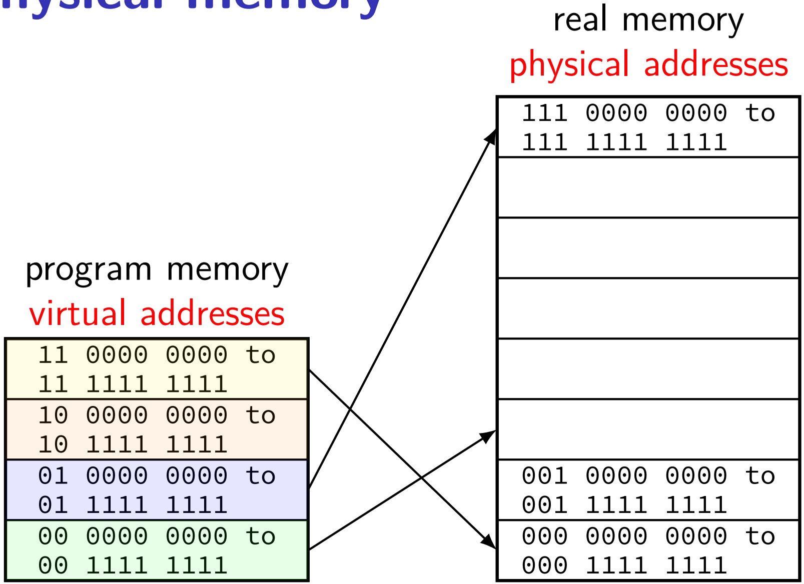
111 0000 0000 to 111 1111 1111	physical page 7
001 0000 0000 to 001 1111 1111	physical page 1
000 0000 0000 to 000 1111 1111	physical page 0

program memory

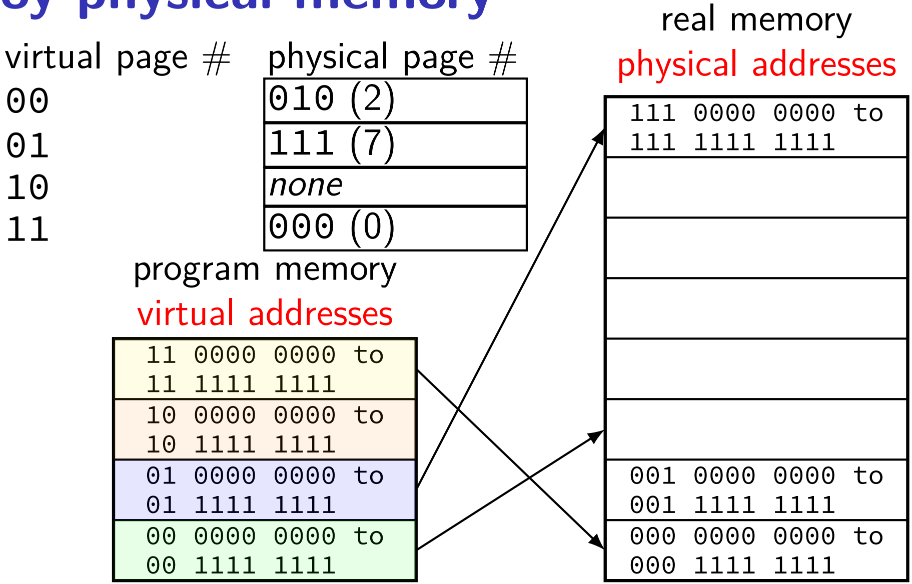
virtual addresses

11 0000 0000 to 11 1111 1111
10 0000 0000 to 10 1111 1111
01 0000 0000 to 01 1111 1111
00 0000 0000 to 00 1111 1111

toy physical memory



toy physical memory



toy physical memory

page table!

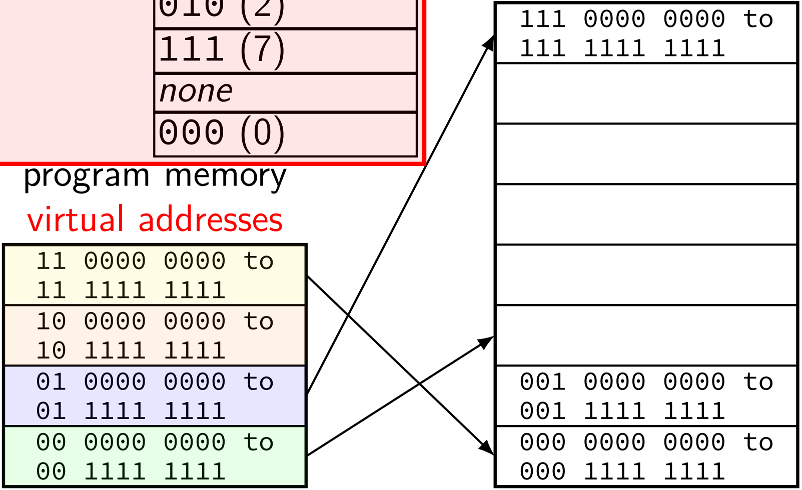
virtual page #	physical page #
00	010 (2)
01	111 (7)
10	*none*
11	000 (0)

real memory

physical addresses

program memory

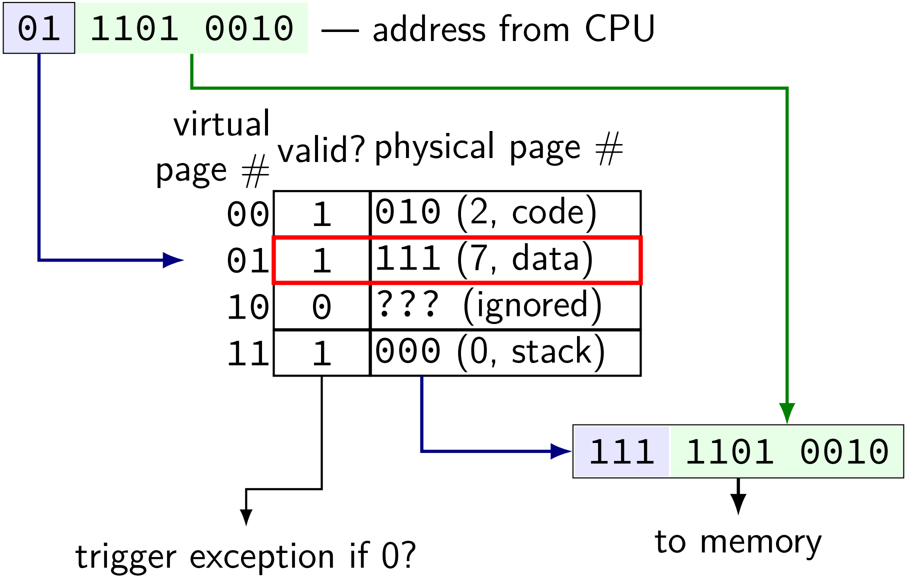
virtual addresses



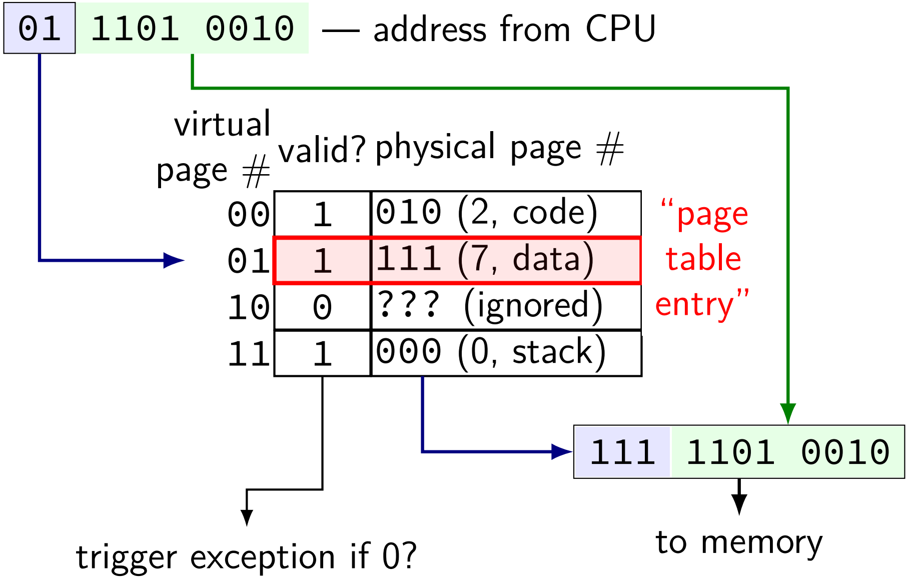
toy page table lookup

virtual page #	valid?	physical page #
00	1	010 (2, code)
01	1	111 (7, data)
10	0	??? (ignored)
11	1	000 (0, stack)

toy page table lookup



toy page table lookup



t "virtual page number" lookup

01 1101 0010 — address from CPU

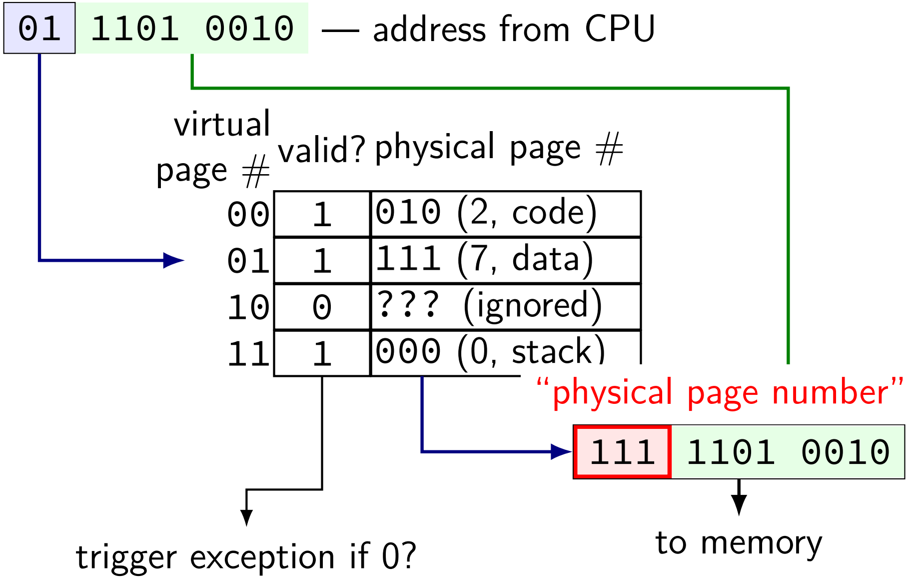
virtual page #	valid?	physical page #
00	1	010 (2, code)
01	1	111 (7, data)
10	0	??? (ignored)
11	1	000 (0, stack)

111 1101 0010

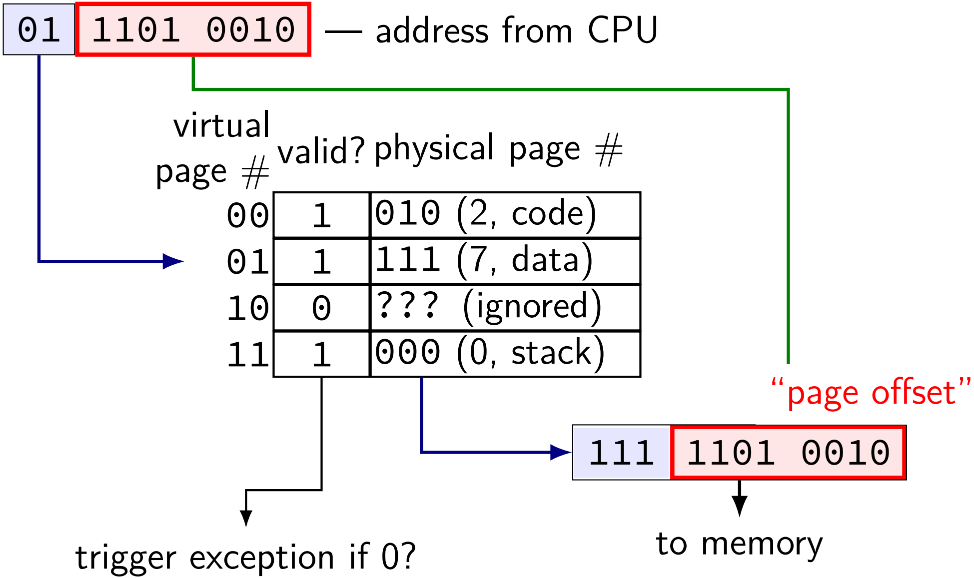
trigger exception if 0?

to memory

toy page table lookup



toy pag “page offset” ookup



on virtual address sizes

virtual address size = size of pointer?

often, but — sometimes part of pointer not used

example: typical x86-64 only use 48 bits

- rest of bits have fixed value

virtual address size is amount used for mapping

address space sizes

amount of stuff that can be addressed $=$ address space size

based on number of unique addresses

e.g. 32-bit virtual address $= 2^{32}$ byte virtual address space

e.g. 20-bit physical addresss $= 2^{20}$ byte physical address space

address space sizes

amount of stuff that can be addressed $=$ address space size

- based on number of unique addresses

e.g. 32-bit virtual address $= 2^{32}$ byte virtual address space

e.g. 20-bit physical addresss $= 2^{20}$ byte physical address space

what if my machine has 3GB of memory (not power of two)?

- not all addresses in physical address space are useful
- most common situation (since CPUs support having a lot of memory)

exercise: page counting

suppose 32-bit virtual (program) addresses

and each page is 4096 bytes (2^{12} bytes)

how many virtual pages?

exercise: page counting

suppose 32-bit virtual (program) addresses

and each page is 4096 bytes (2^{12} bytes)

how many virtual pages?

$2^{32}/2^{12} = 2^{20}$

exercise: page table size

suppose 32-bit virtual (program) addresses

suppose 30-bit physical (hardware) addresses

each page is 4096 bytes (2^{12} bytes)

pgae table entries have physical page $\#$, valid bit, bit

how big is the page table (if laid out like ones we've seen)?

exercise: page table size

suppose 32-bit virtual (program) addresses

suppose 30-bit physical (hardware) addresses

each page is 4096 bytes (2^{12} bytes)

pgae table entries have physical page #, valid bit, bit

how big is the page table (if laid out like ones we've seen)?

2^{20} entries $\times (18 + 1)$ bits per entry

- issue: where can we store that?

exercise: address splitting

and each page is 4096 bytes (2^{12} bytes)

split the address `0x12345678` into page number and page offset:

exercise: address splitting

and each page is 4096 bytes (2^{12} bytes)

split the address `0x12345678` into page number and page offset:

page $\#$: `0x12345`; offset: `0x678`

page tables in memory

where can processor store megabytes of page tables? in memory

page table entry layout (chosen by processor)

valid (bit 15)	physical page # (bits 4–14)	other bits and/or unused (bit 0-3)

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page table
base register

`0x00010000`

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base register

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physical memory

addresses	bytes
0x00000000-1	00000000 00000000
...	
0x00010000-1	00000000 00000000
0x00010002-3	10100010 01100000
0x00010004-5	10000010 11000000
0x00010006-7	10110000 00110000
...	
0x000101FE-F	10001110 10000000
0x00010200-1	10100010 00111010

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page table (logically)

virtual page #	valid?	…	physical page #
0000 0000	0	…	00 0000 0000
0000 0001	1	…	10 0010 0110
0000 0010	1	…	00 0000 1100
0000 0011	1	…	11 0000 0011
…			
1111 1111	1	…	00 1110 1000

physical memory

addresses	bytes
0x00000000-1	00000000 00000000
…	
0x00010000-1	00000000 00000000
0x00010002-3	10100010 01100000
0x00010004-5	10000010 11000000
0x00010006-7	10110000 00110000
…	
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0000 0010	1	…	00 0000 1100
0000 0011	1	…	11 0000 0011
…			
1111 1111	1	…	00 1110 1000

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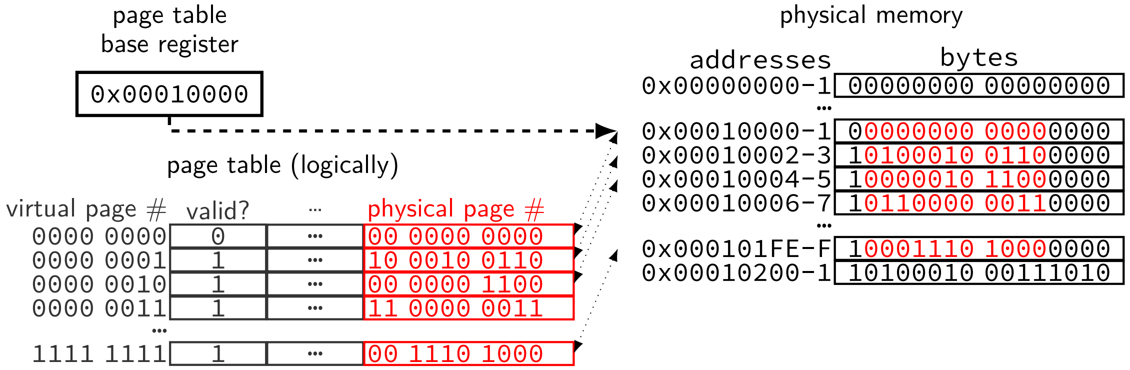

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0000 0011	1	...	11 0000 0011
...			
1111 1111	1	...	00 1110 1000

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...	
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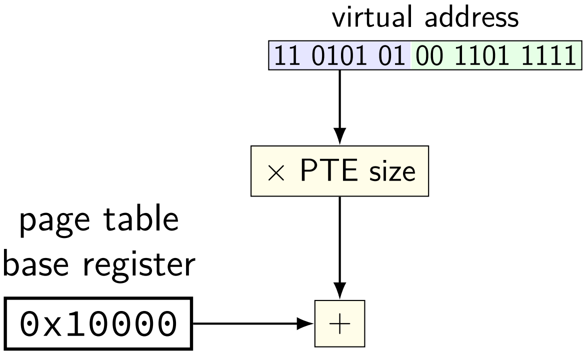
0x00010200-1	10100010 00111010

memory access with page table

virtual address

11 0101 01	00 1101 1111

memory access with page table



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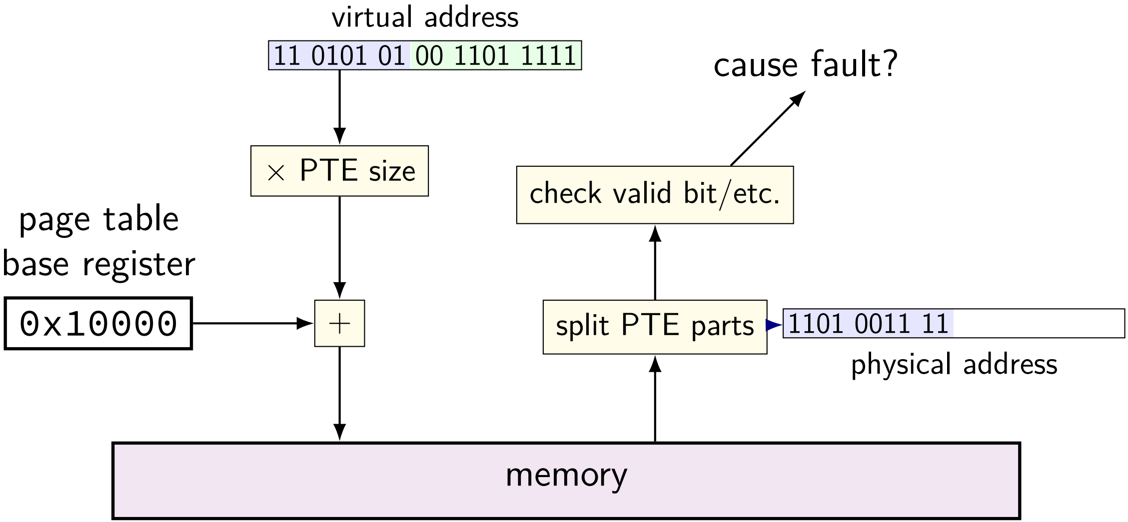

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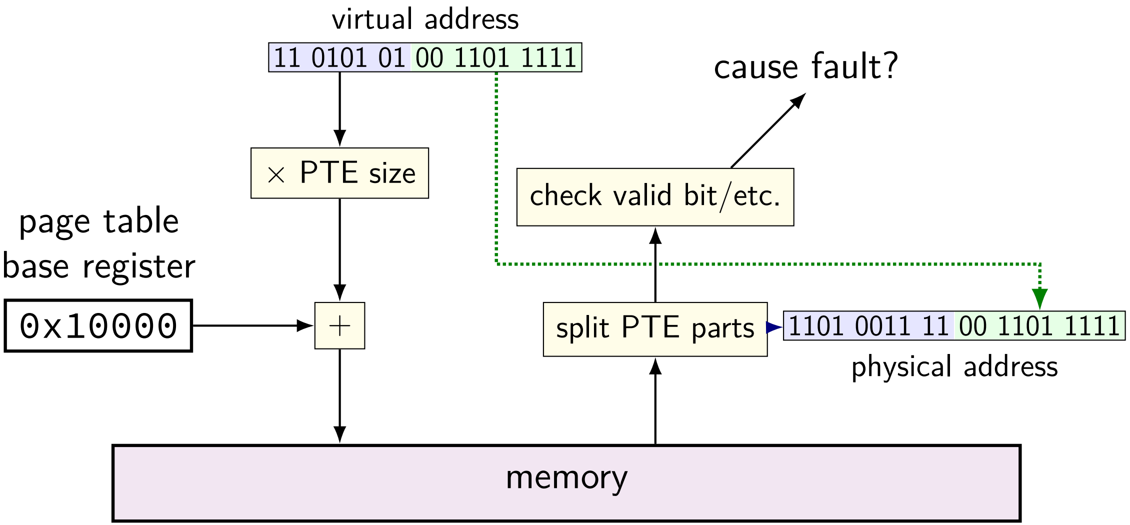

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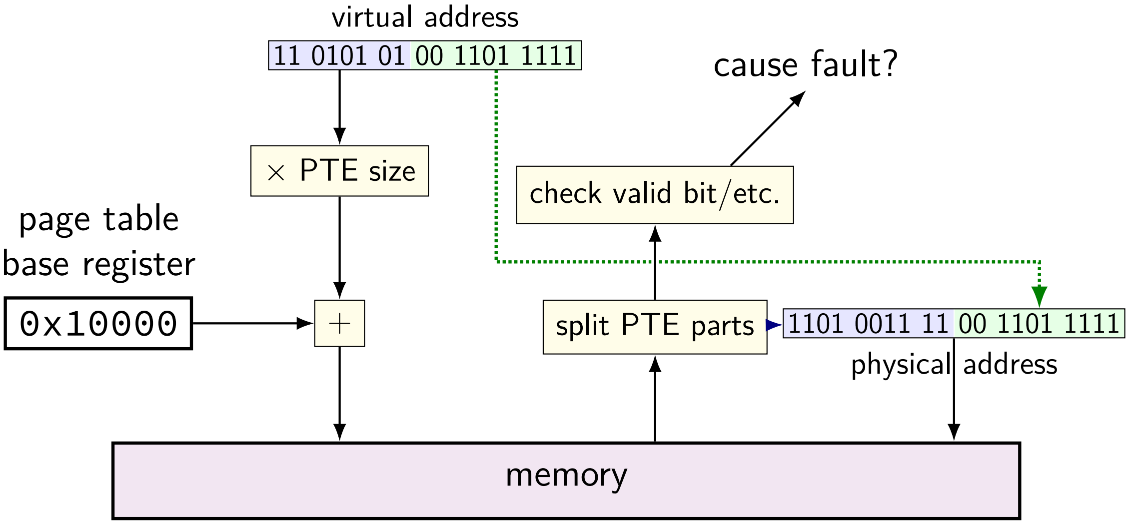

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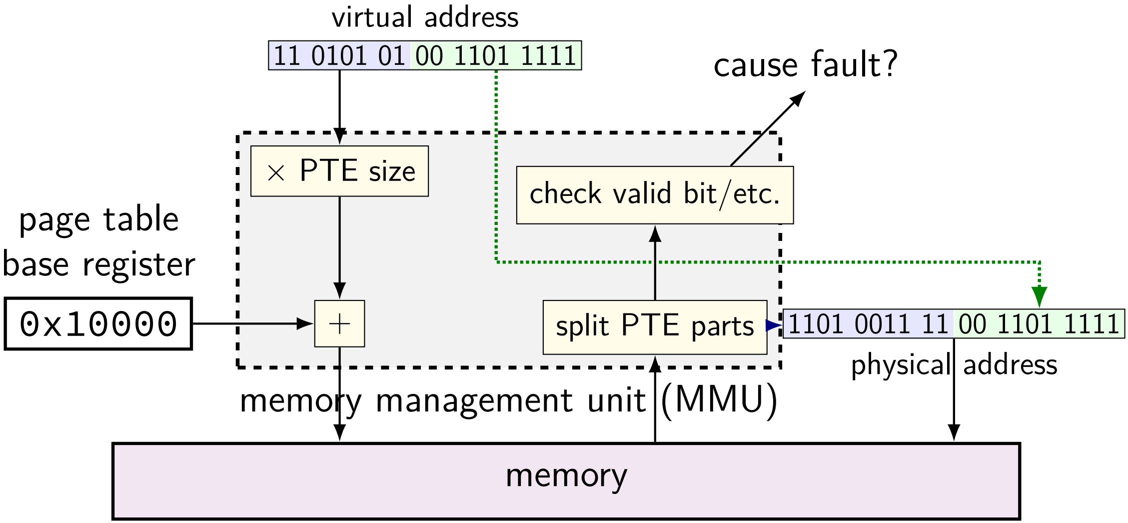

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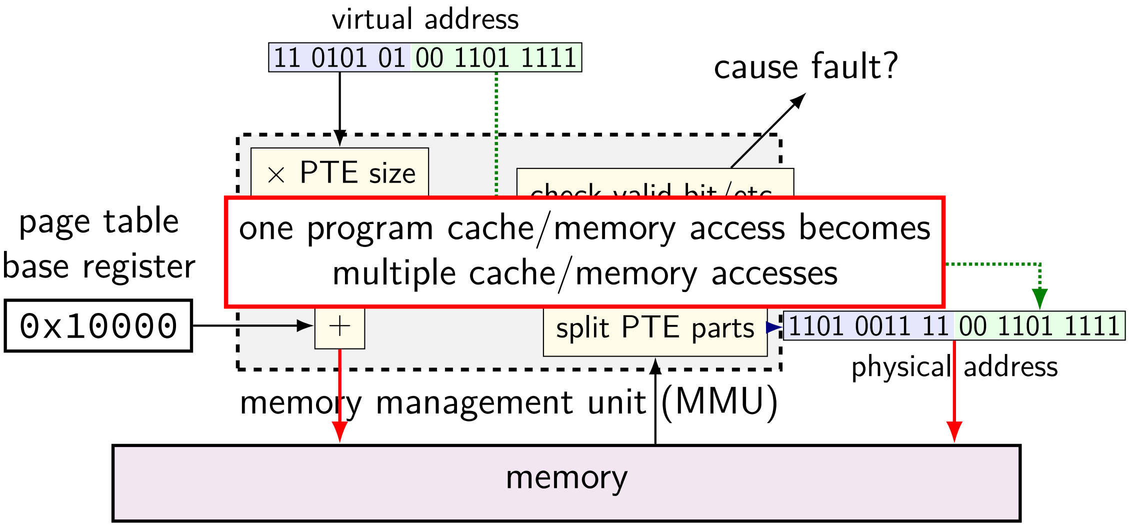

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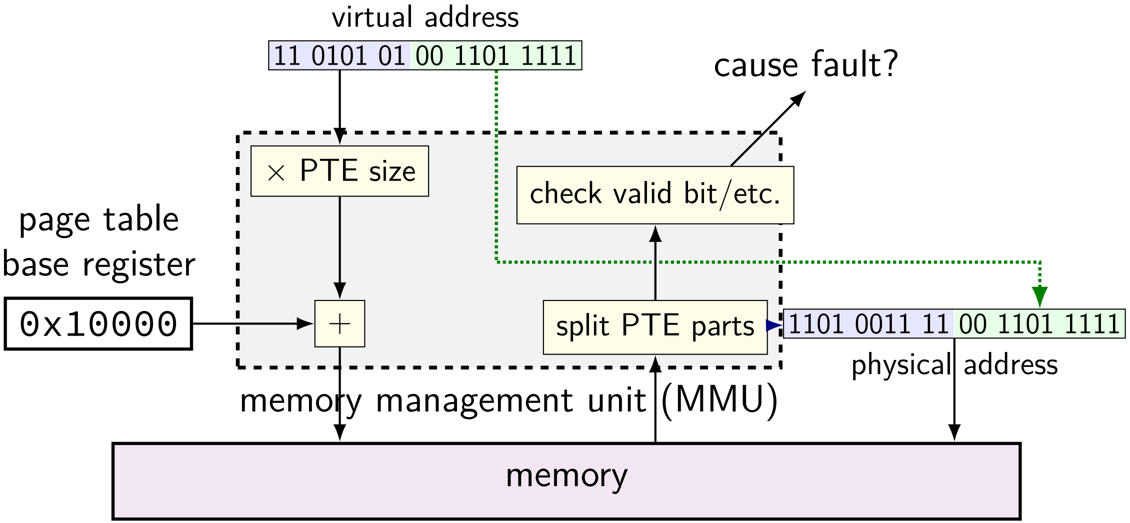

backup slides