Test

07: MMIO Buses

Engr 315: Hardware / Software Codesign

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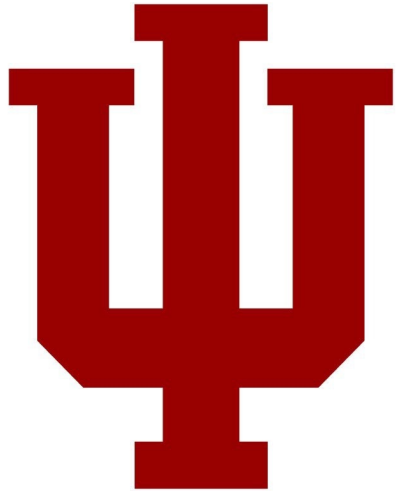
Indiana University



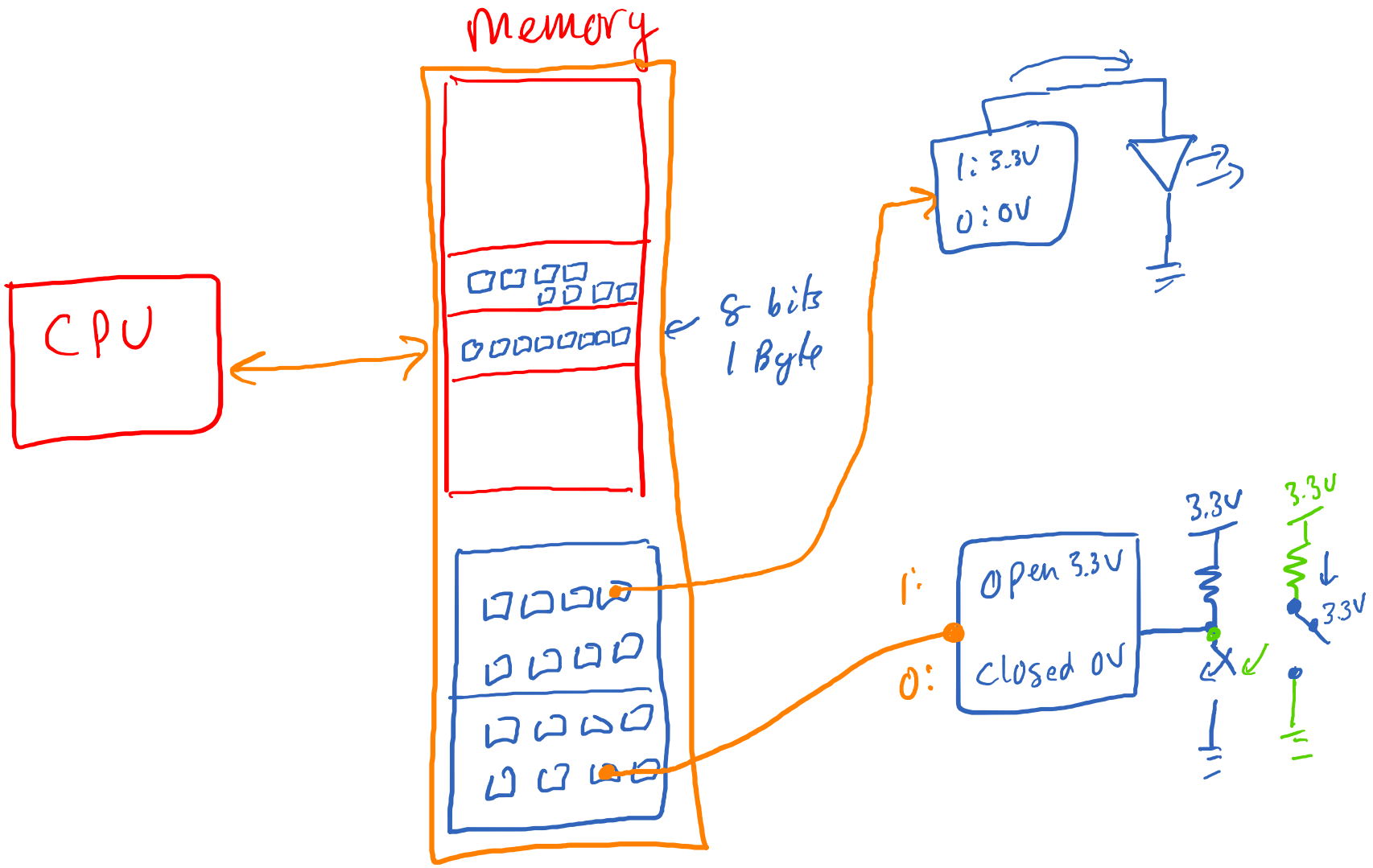
Announcements

- P2 is extended to Tuesday night
- P3 is out
- Planning on in-person lab tomorrow (so far)
- p4 (under development)
  (C) (maybe Python?)

Optimizations thus far

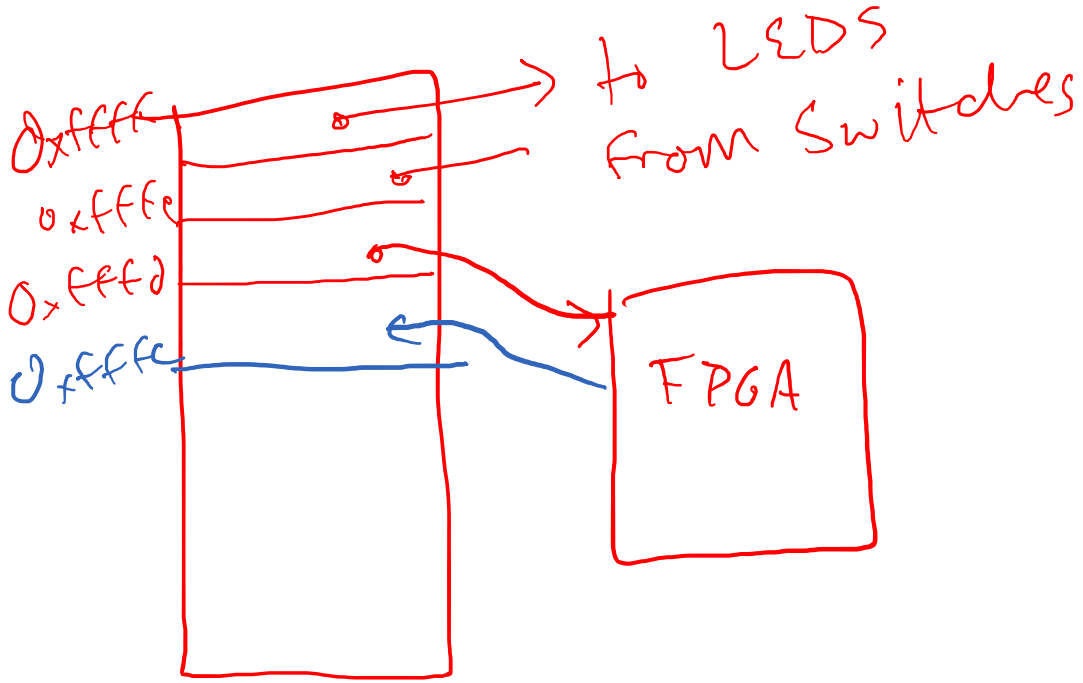
- Algorithmic complexity
- Removing redundant computation
- ~~Multithreading~~
- ~~Multiprocessing*~~
- Python/C/Asm Interfacing
- Map to Hardware

Review: Memory-Mapped I/O



Memory-Mapped I/O

- I/O devices pretend to be memory
- Devices accessed with native CPU load/store instructions



MMIO Store from C

```
#define LED_ADDR 0xffff
uint32_t * LED_REG = (uint32_t *)(LED_ADDR);
(*LED_REG) = 0x1;
```

MMIO Load from C

```
#define SW_ADDR 0xfffe
uint32_t * SW_REG = (uint32_t *)(SW_ADDR);
int y = (*SW_REG);
```

Use `volatile` for MMIO addresses!

```
#define SW_ADDR 0xfffe
volatile uint32_t * SW_REG = (uint32_t * SW_ADDR);

int quit = (*SW_REG);
while(!quit)
{
     //more code
     quit = (*SW_REG);
}
```

`volatile` Variables

- `volatile` keyword tells compiler that the memory value is subject to change randomly.

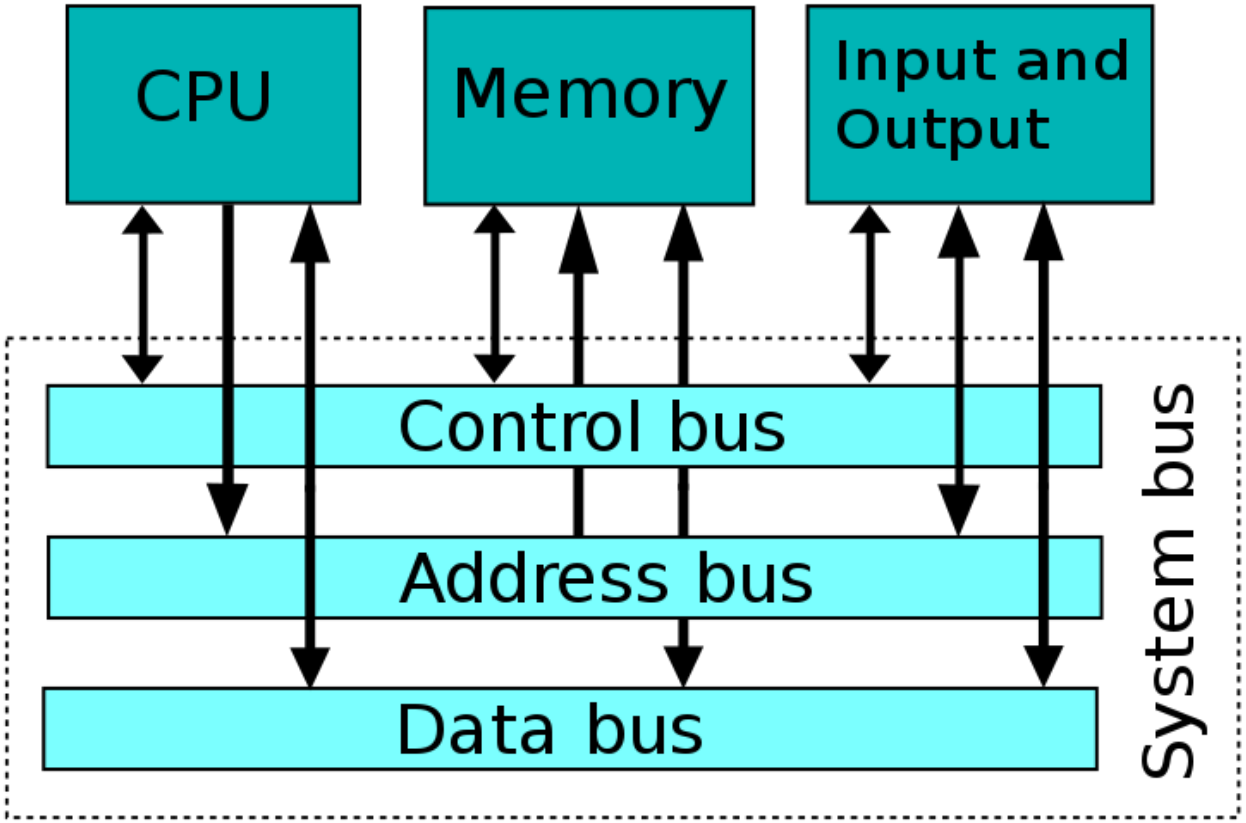
- Use `volatile` for all MMIO memory. The values change randomly!

Use **`volatile`** for all MMIO memory.

(hint: P4)

What do the CPU and Memory need to communicate?

The System Bus



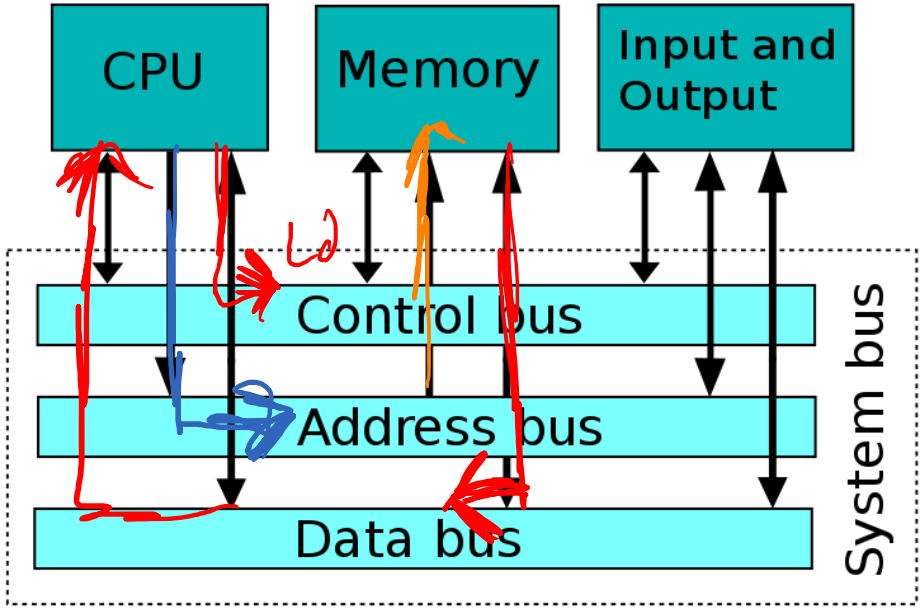
Bus terminology review

- A "transaction" occurs between an "*initiator*" and "*target*"
- Any device capable of being an initiator is said to be a "*bus master*"
  - In many cases there is only one bus master (*single master* vs. *multi-master*).
- A device that can only be a target is said to be a "slave device".

Transaction Steps

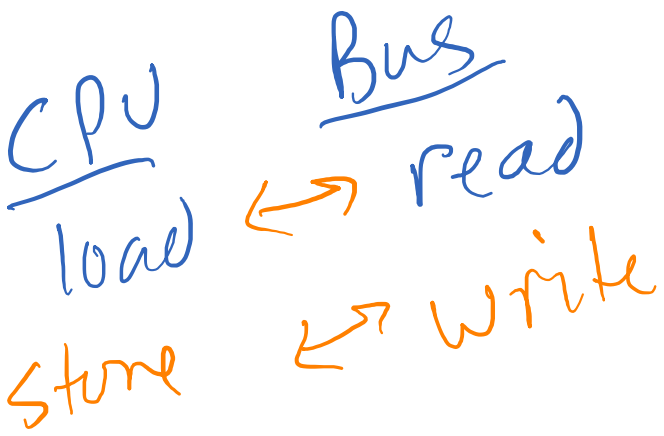
- CPU wants to load data from Memory

- CPU wants to store data to I/O



Hypothetical Bus Example

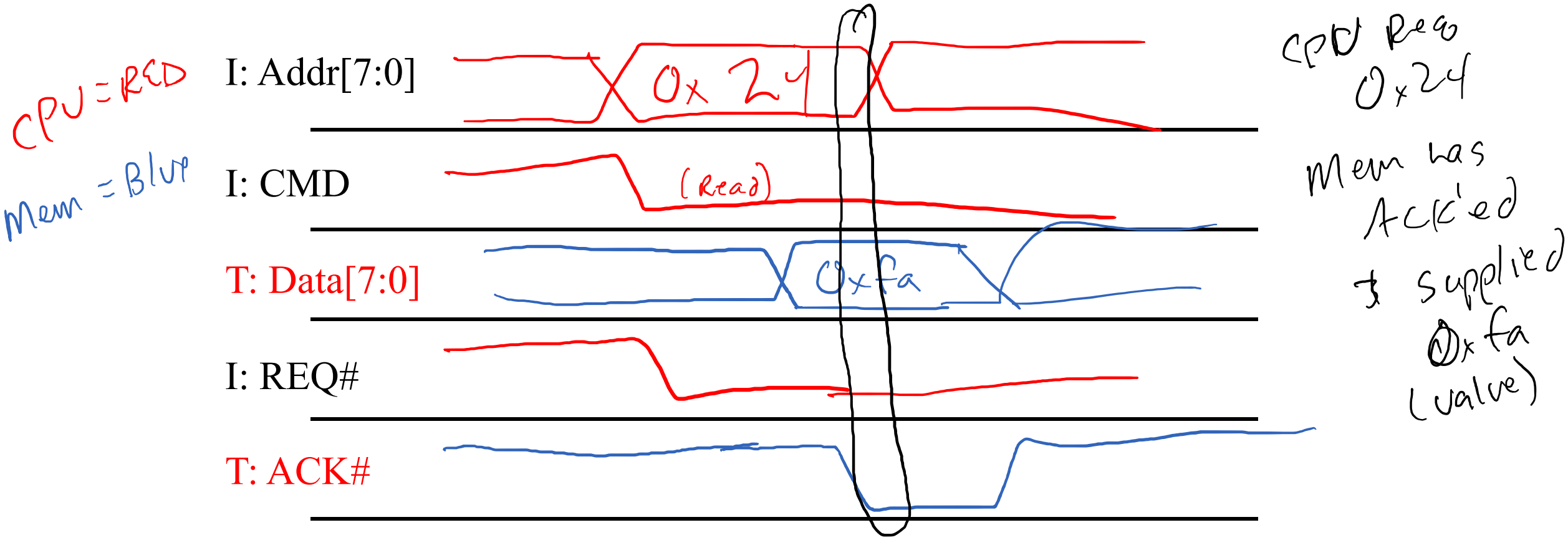
- Characteristics
  - Asynchronous (no clock) – hay, why no?
  - One Initiator and One Target
- Signals
  - Addr[7:0], Data[7:0], CMD, REQ#, ACK#
    - CMD=0 is read, CMD=1 is write.
    - REQ# low means initiator is requesting something.
    - ACK# low means target is acknowledging the job is done.



CMD=0 is read, CMD=1 is write.
REQ# low means initiator is requesting.
ACK# low means target is acknowledging.

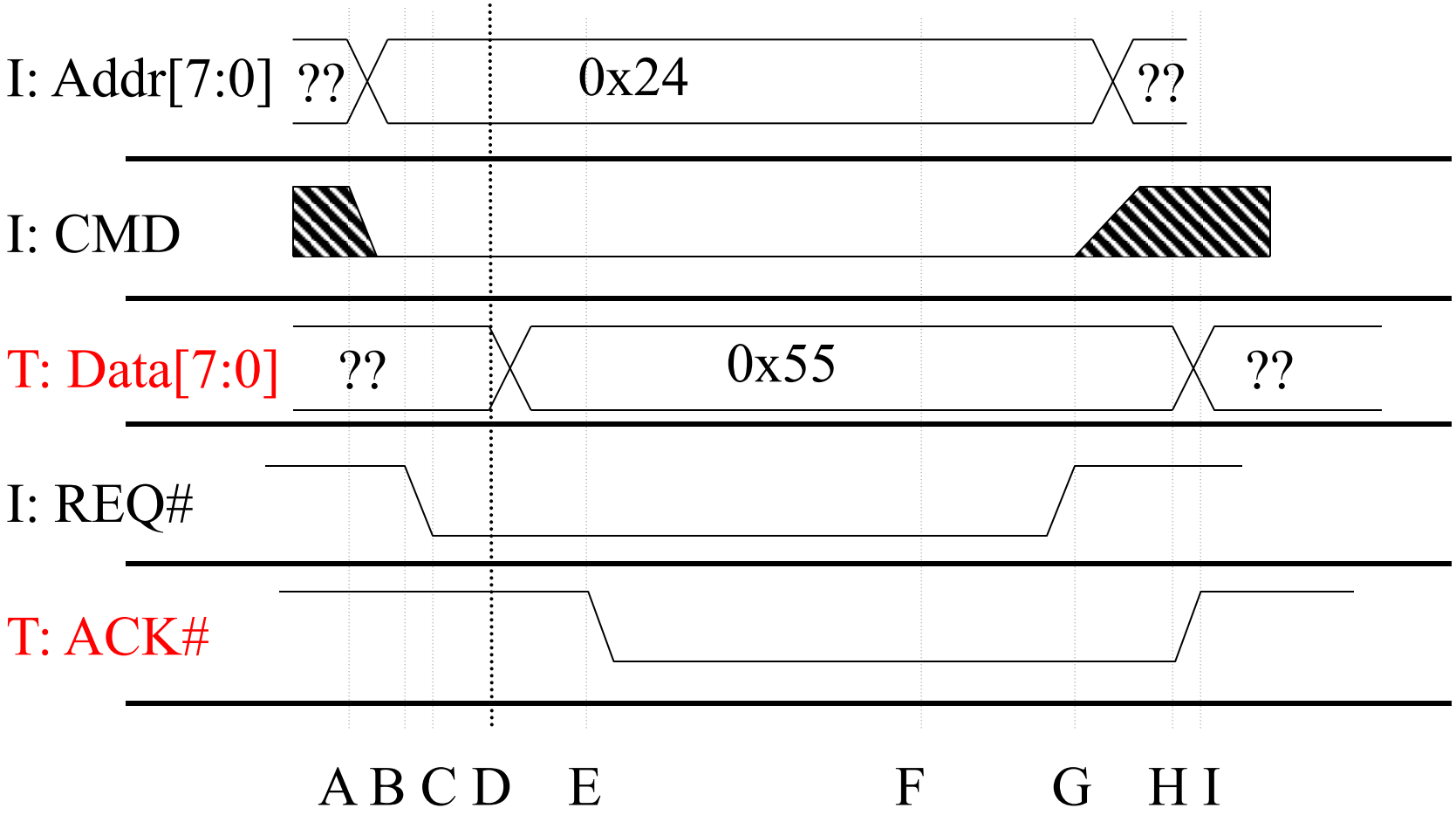
Read transaction

Initiator wants to read location 0x24



Read transaction

Initiator wants to read location 0x24



A read transaction

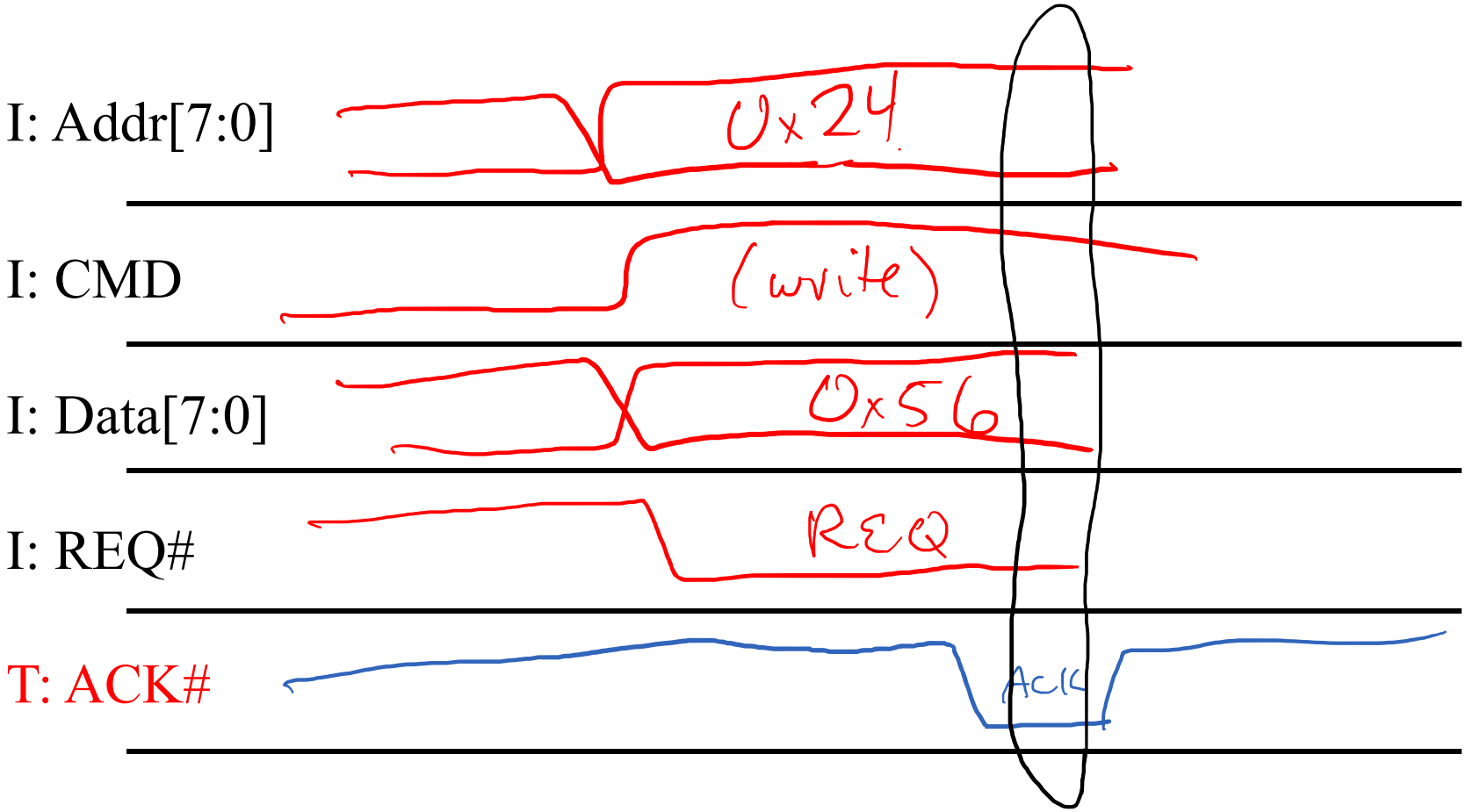
Say initiator wants to read location 0x24

A. Initiator sets Addr=0x24, CMD=0
B. Initiator *then* sets REQ# to low
C. Target sees read request
D. Target drives data onto data bus
E. Target *then* sets ACK# to low
F. Initiator grabs the data from the data bus
G. Initiator sets REQ# to high, stops driving Addr and CMD
H. Target stops driving data, sets ACK# to high terminating the transaction
I. Bus is seen to be idle

CMD=0 is read, CMD=1 is write.
REQ# low means initiator is requesting.
ACK# low means target is acknowledging.

Write transaction

Initiator wants to write 0x56 to location 0x24



Can MMIO behave as memory?

Example peripherals

0x04: Push Button - Read-Only

Pushed -> 1

Not Pushed -> 0

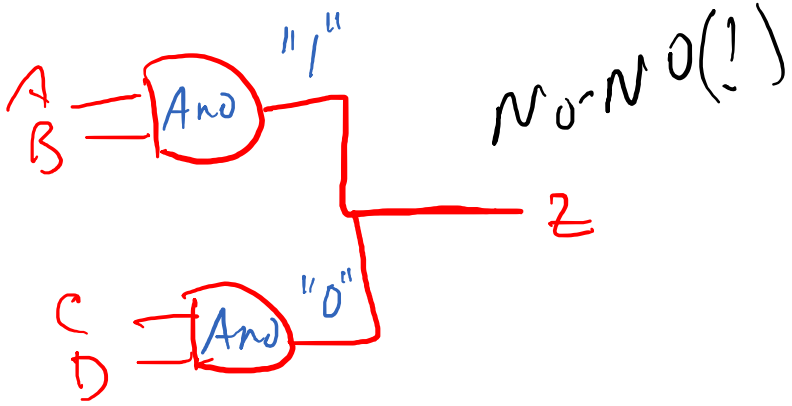
0x05: LED Driver - Write-Only

On -> 1

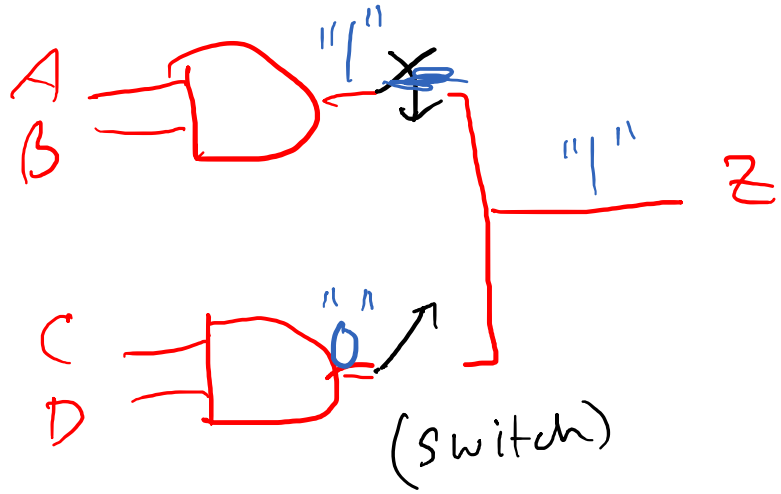
Off -> 0

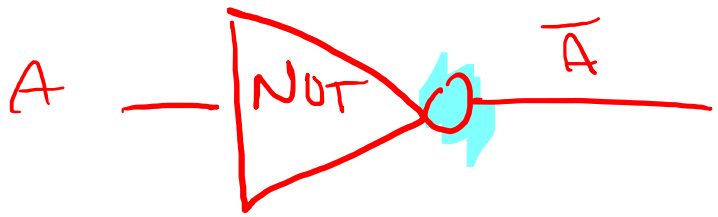
Tri-State Buffer

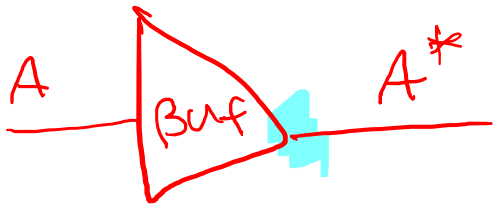
- Drives output when enabled
- Otherwise does not drive output (high-impedance)



NO-NO(!)



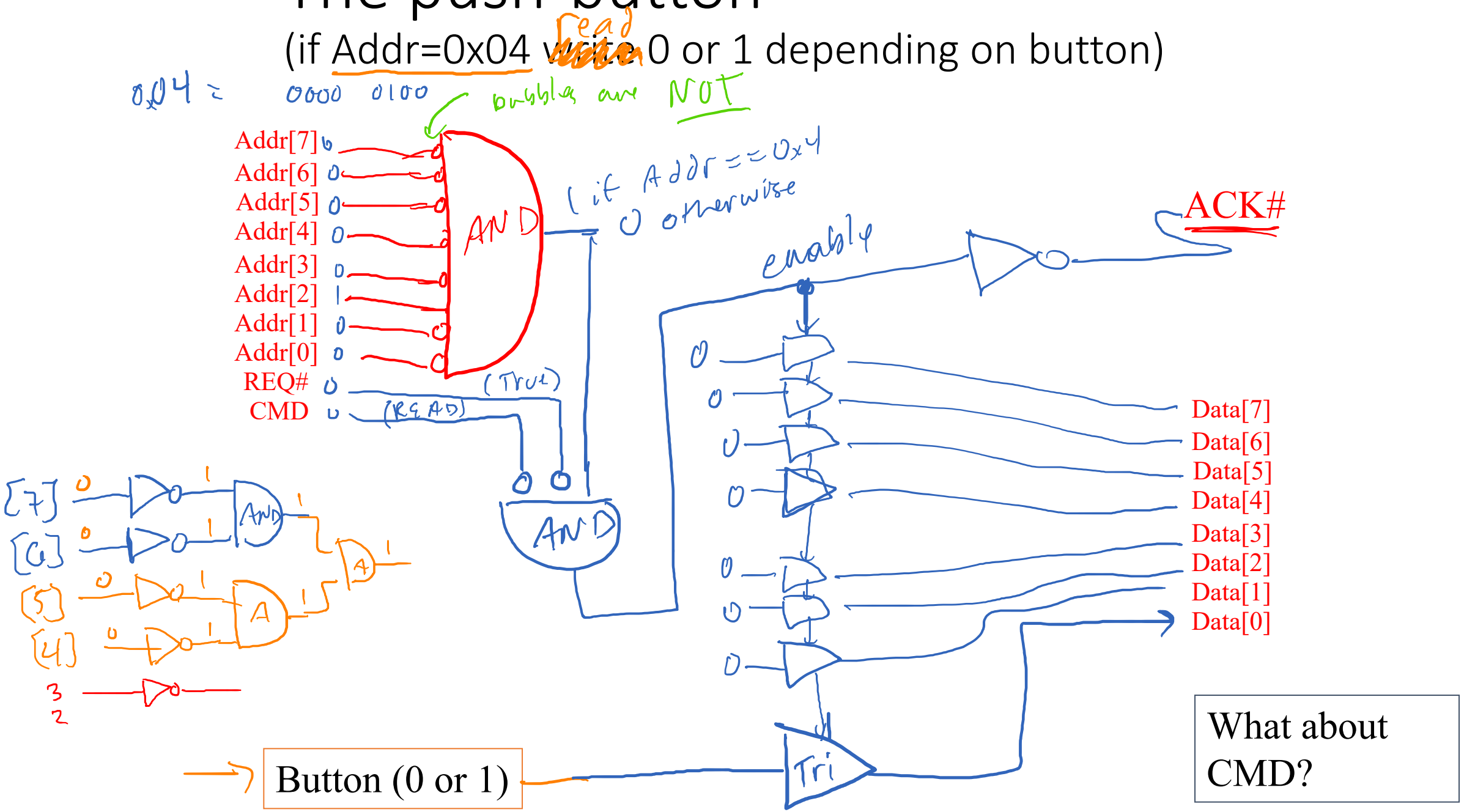




A	A*
0	0
1	1

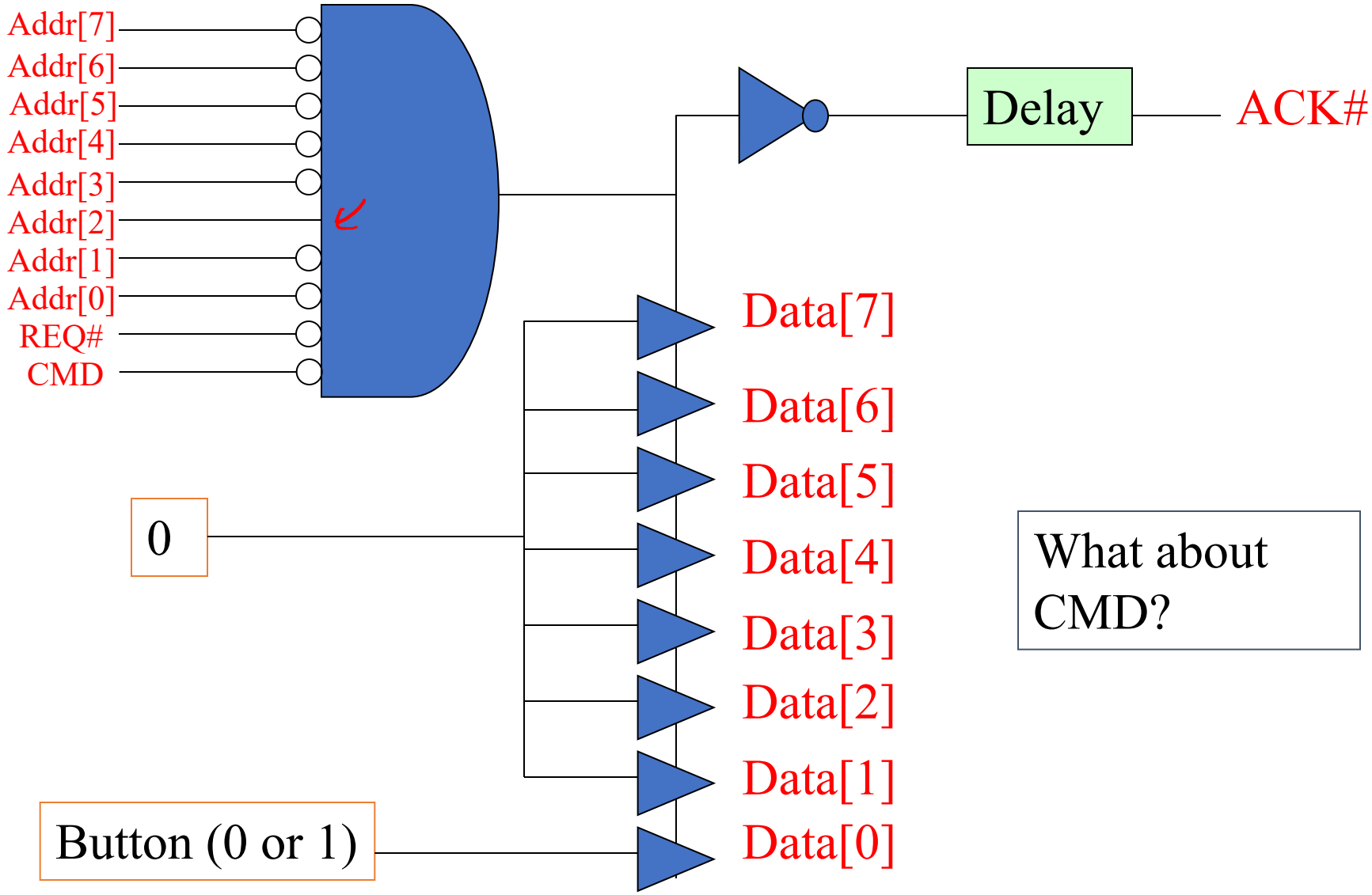
The push-button

(if Addr=0x04 write 0 or 1 depending on button)



The push-button

(if Addr=0x04 ~~write~~ read 0 or 1 depending on button)



The LED

(1 bit reg written by LSB of address 0x05)

Addr[7]
Addr[6]
Addr[5]
Addr[4]
Addr[3]
Addr[2]
Addr[1]
Addr[0]
REQ#
CMD

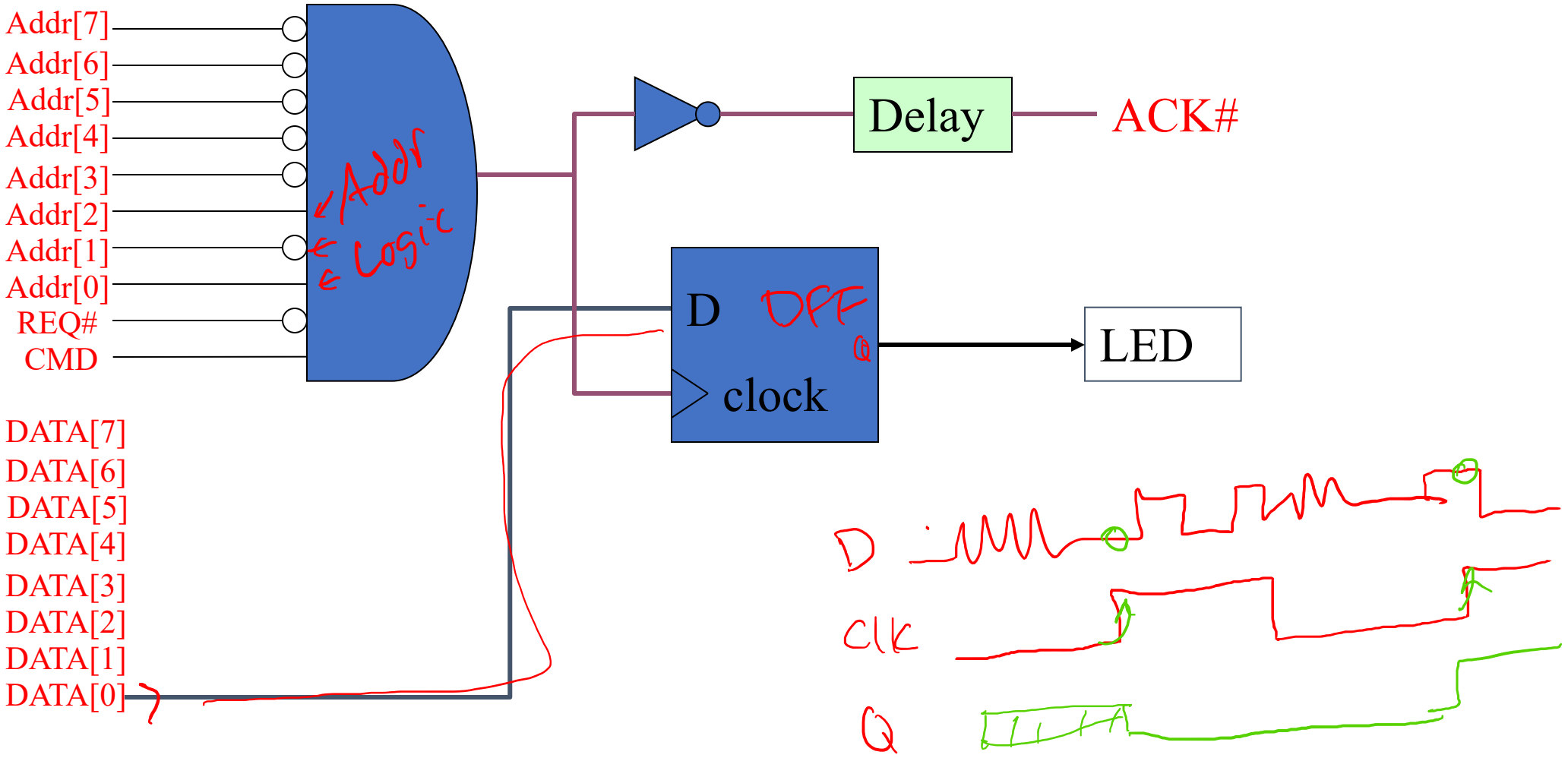
DATA[7]
DATA[6]
DATA[5]
DATA[4]
DATA[3]
DATA[2]
DATA[1]
DATA[0]

ACK#

LED

The LED

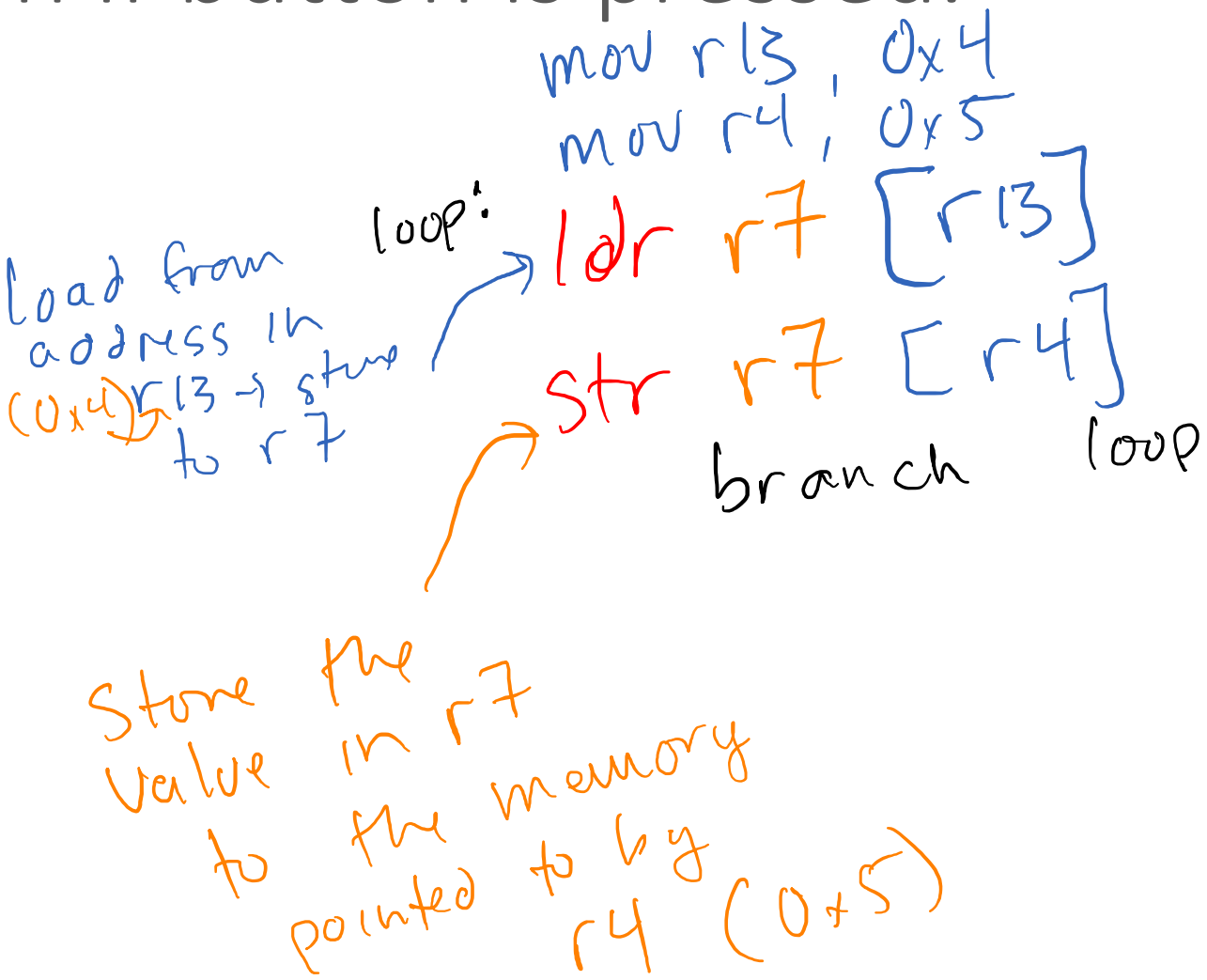
(1 bit reg written by LSB of address 0x05)



Let's write a simple C program to turn the LED on if button is pressed.

Peripheral Details

- 0x04: Push Button - Read-Only
  - Pushed -> 1
  - Not Pushed -> 0
- 0x05: LED Driver - Write-Only
  - On -> 1
  - Off -> 0



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Peripheral Details

- 0x04: Push Button - Read-Only
  - Pushed -> 1
  - Not Pushed -> 0
- 0x05: LED Driver - Write-Only
  - On -> 1
  - Off -> 0

```
#define PB 0x04
#define LED 0x05

int main() {

register int val;

for (;;) {
    val = *(volatile uint32_t *)(PB);
    *(volatile uint32_t *)(LED) = val;
}
}
```

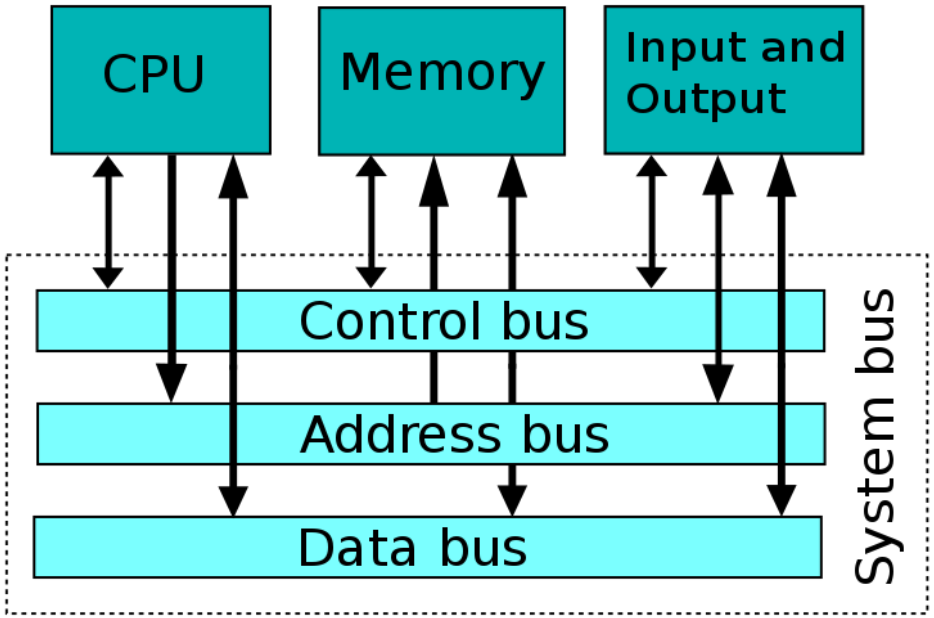
In ASM:

```
        mov r0, #0x4   % PB
        mov r1, #0x5   % LED
loop:   ldr r2, [r0, #0]
        str r2 [r1, #0]
        b loop
```

ARM AXI Bus

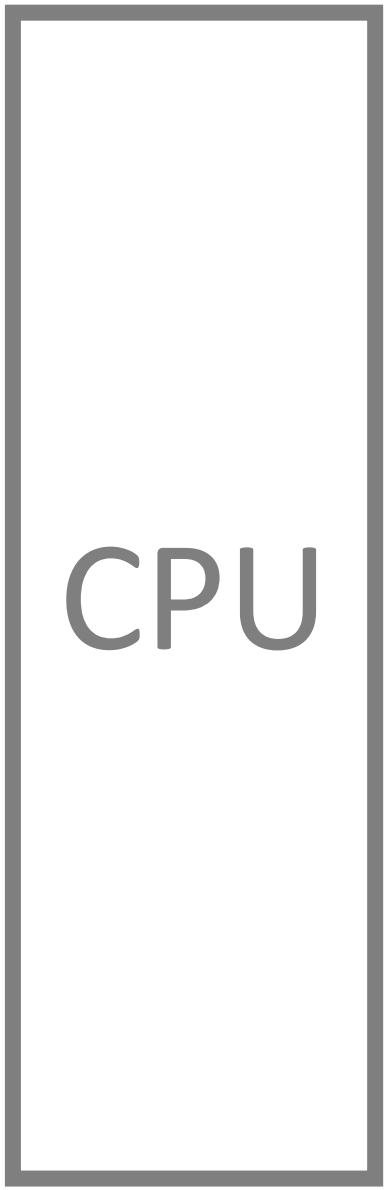
- "Advanced eXtensible Interface" Bus Version 4, "AXI4"
- Three Variants
  - AXI4: Fast but complicated; Memory-mapped
  - AXI4 Lite: Slow but simple; Memory-mapped
  - AXI4 Stream: Fast and simple; Not memory-mapped

Why AXI4 Lite?

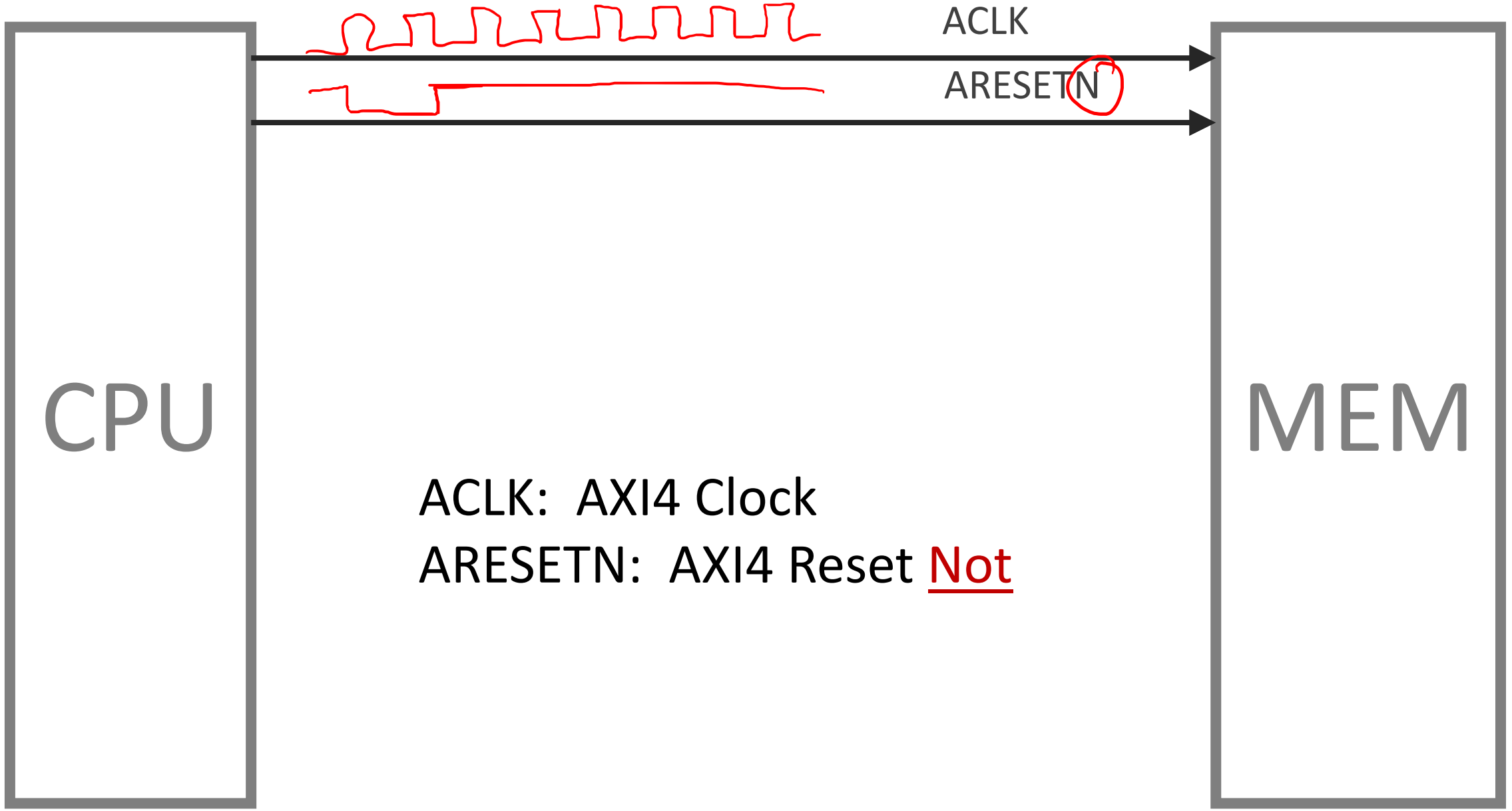


Xilinx AXI Reference Guide:

"AXI4-Lite is a light-weight, single transaction memory mapped interface. It has a small logic footprint and is a simple interface to work with both in design and usage. "

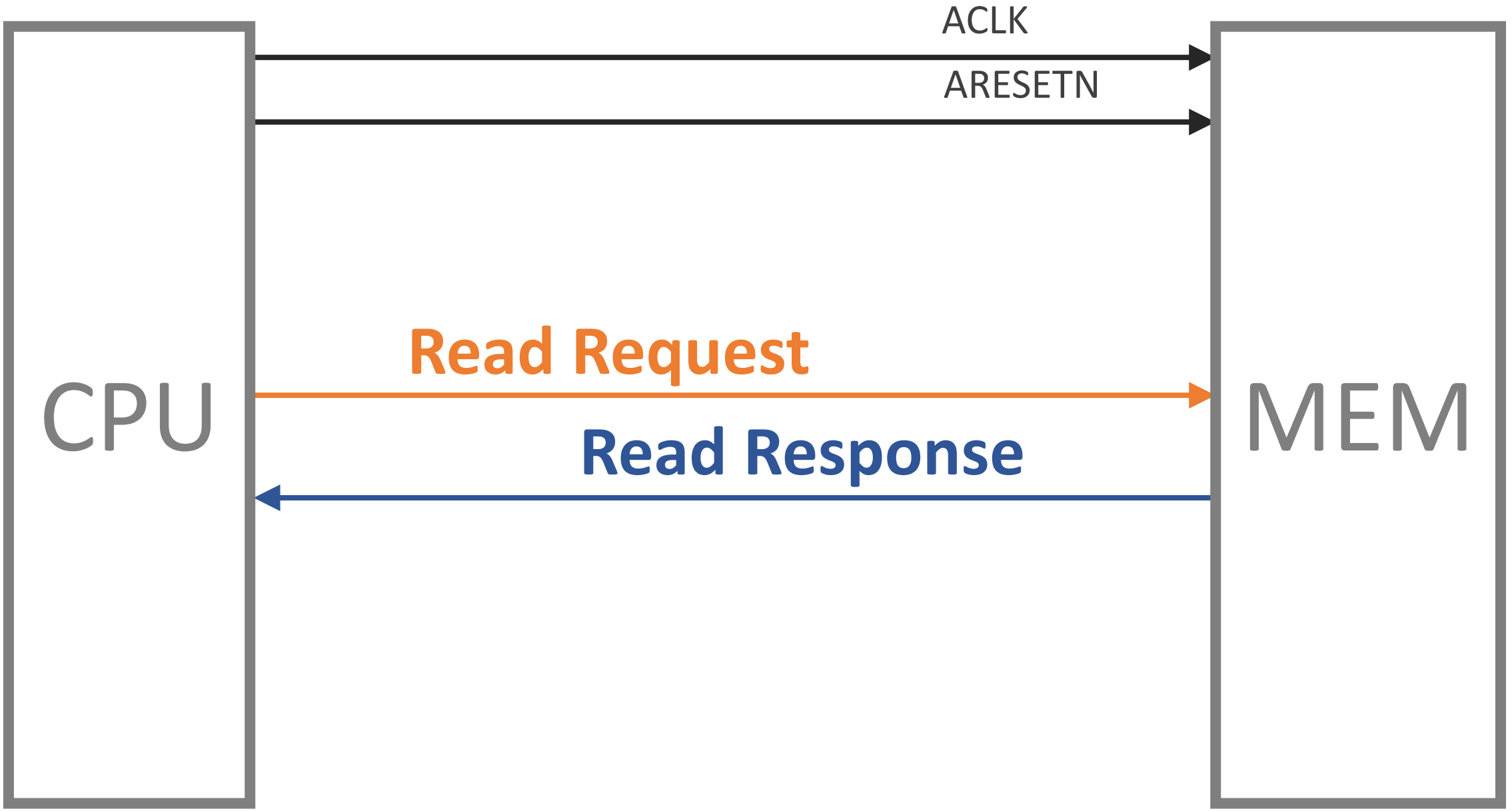

CPU

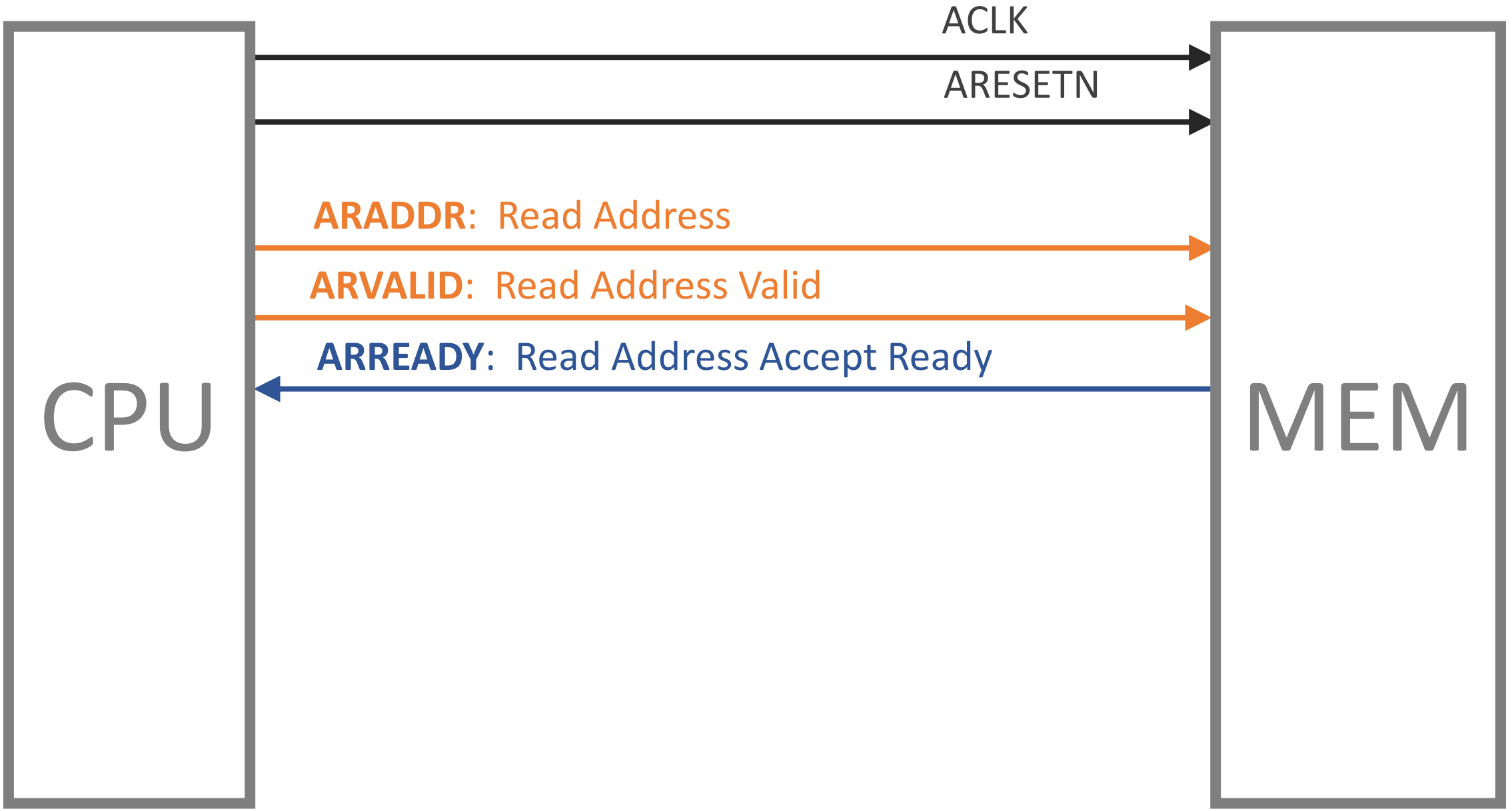

MEM



ACLK: AXI4 Clock

ARESETN: AXI4 Reset Not


ACLK
ARESETN
CPU
Read Request
Read Response
MEM


ACLK
ARESETN
ARADDR: Read Address
ARVALID: Read Address Valid
ARREADY: Read Address Accept Ready
CPU
MEM

AXI4 Handshaking

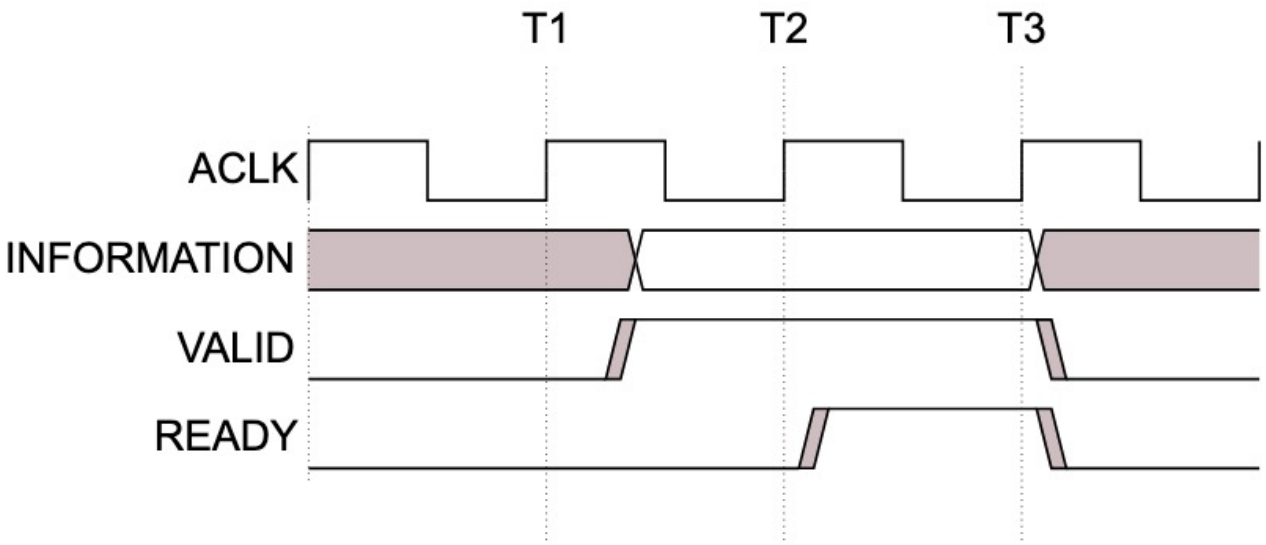
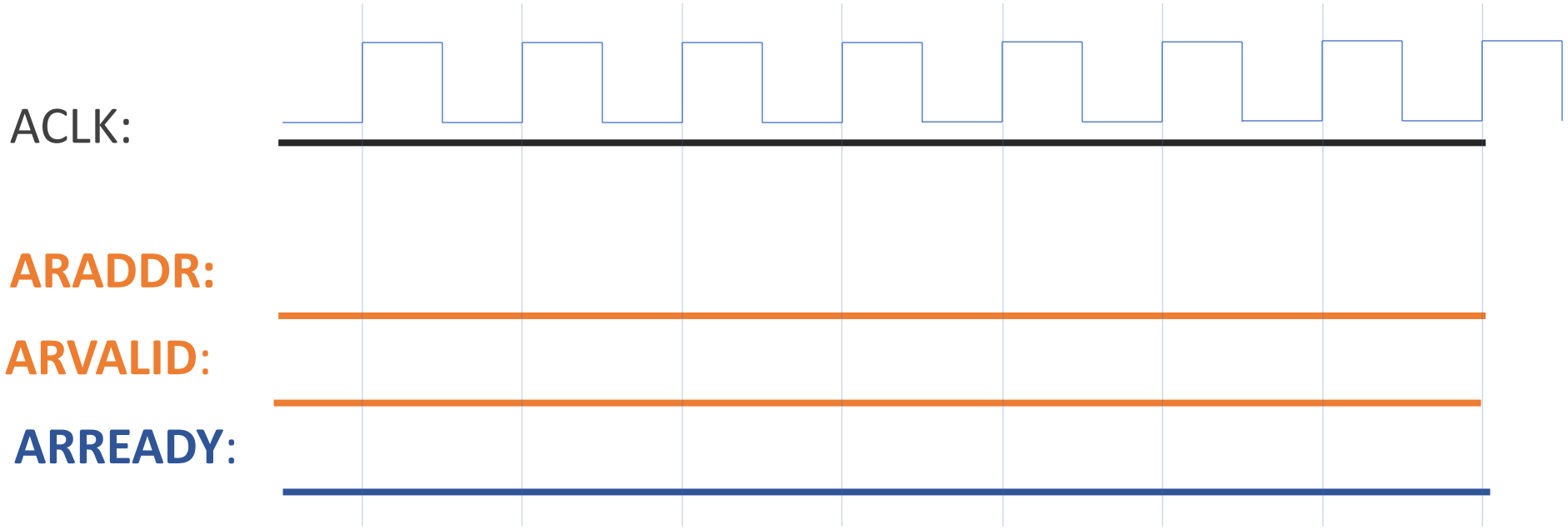
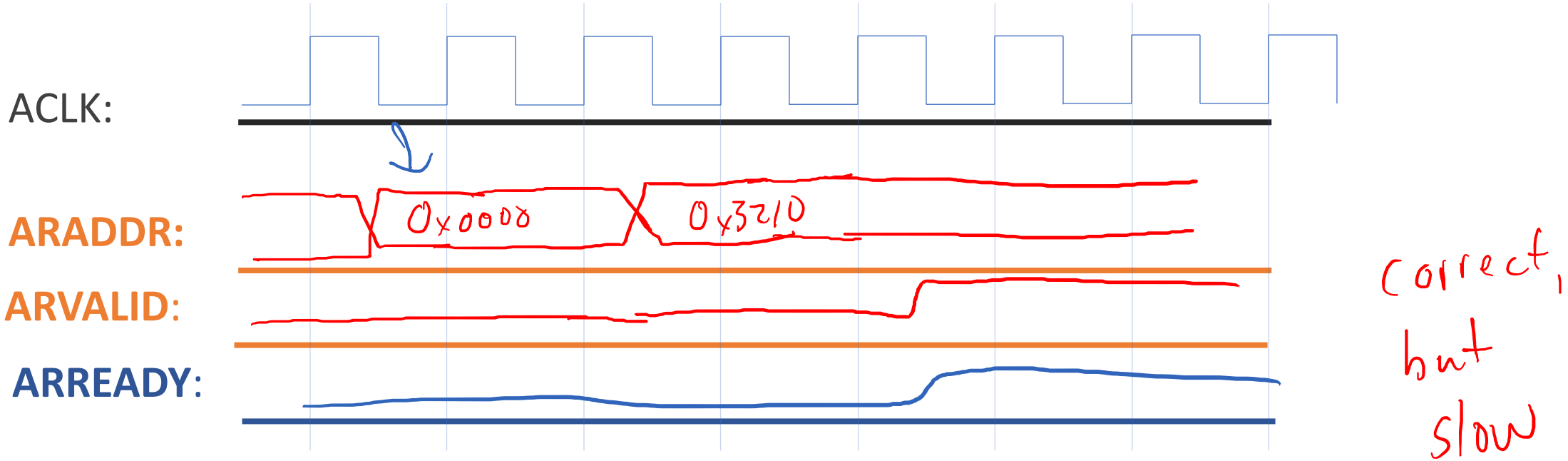


Figure A3-2 VALID before READY handshake

AXI4 Lite Read Transaction

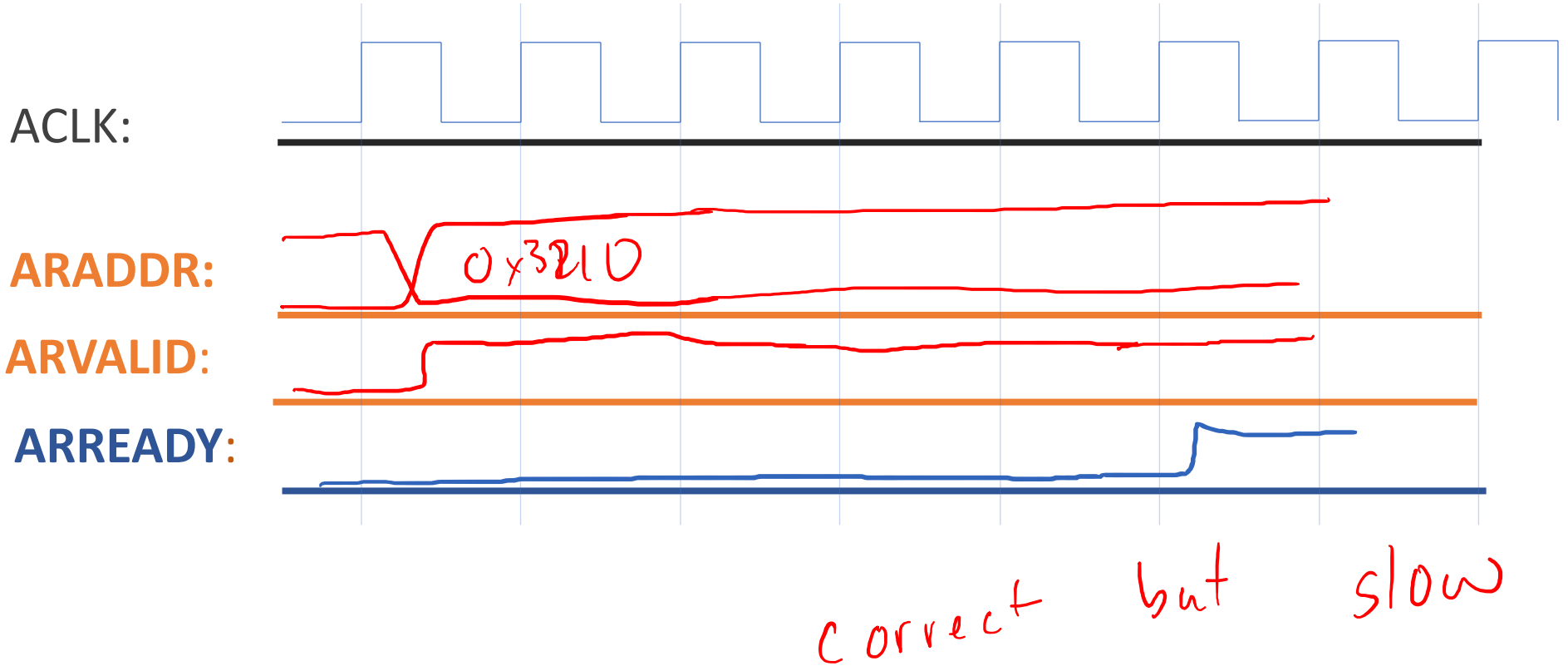


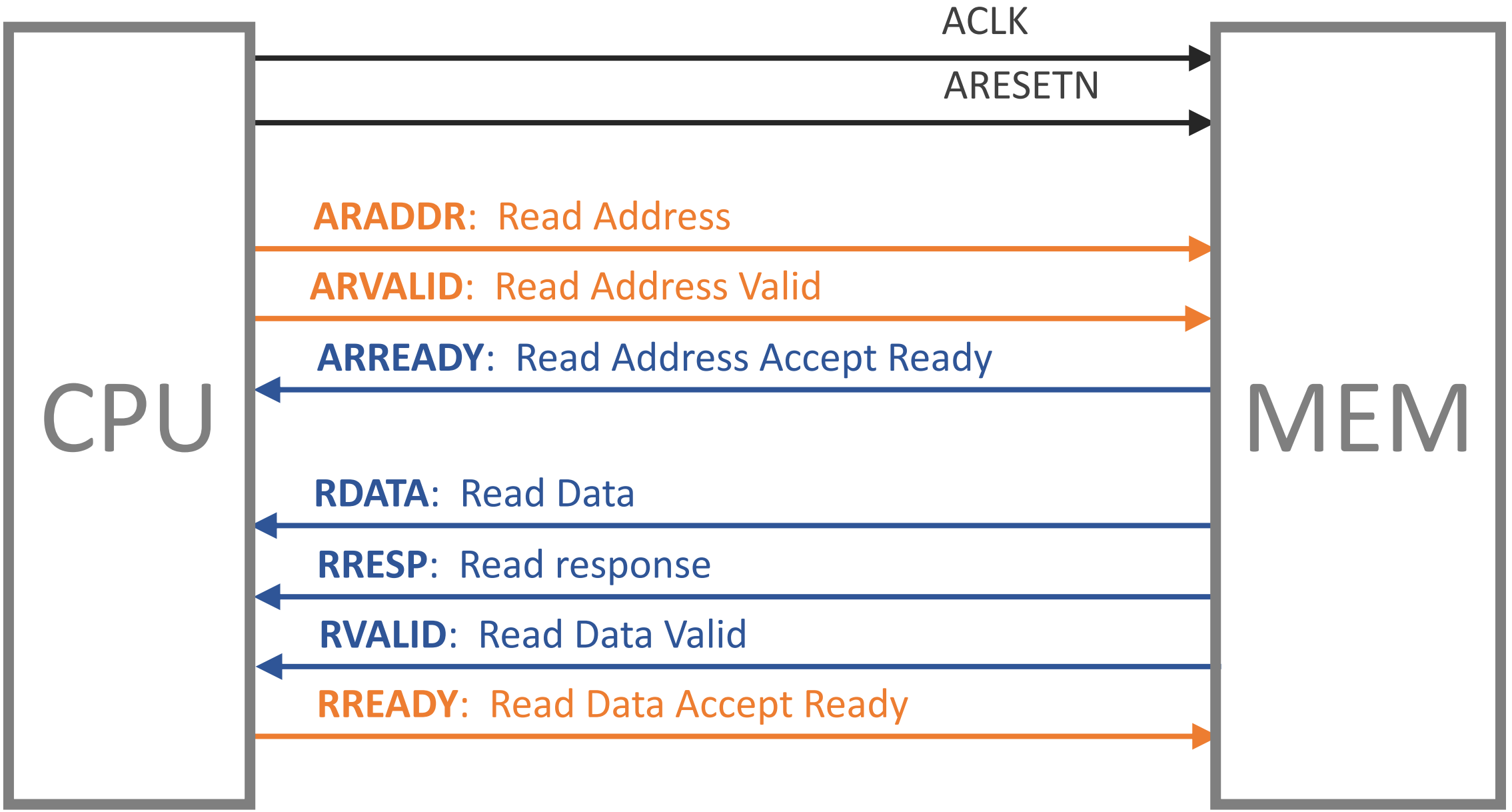
What if?



correct, but slow

What if?




ACLK
ARESETN
ARADDR: Read Address
ARVALID: Read Address Valid
ARREADY: Read Address Accept Ready
CPU
MEM
RDATA: Read Data
RRESP: Read response
RVALID: Read Data Valid
RREADY: Read Data Accept Ready

What is RRESP?

Table A3-4 RRESP and BRESP encoding

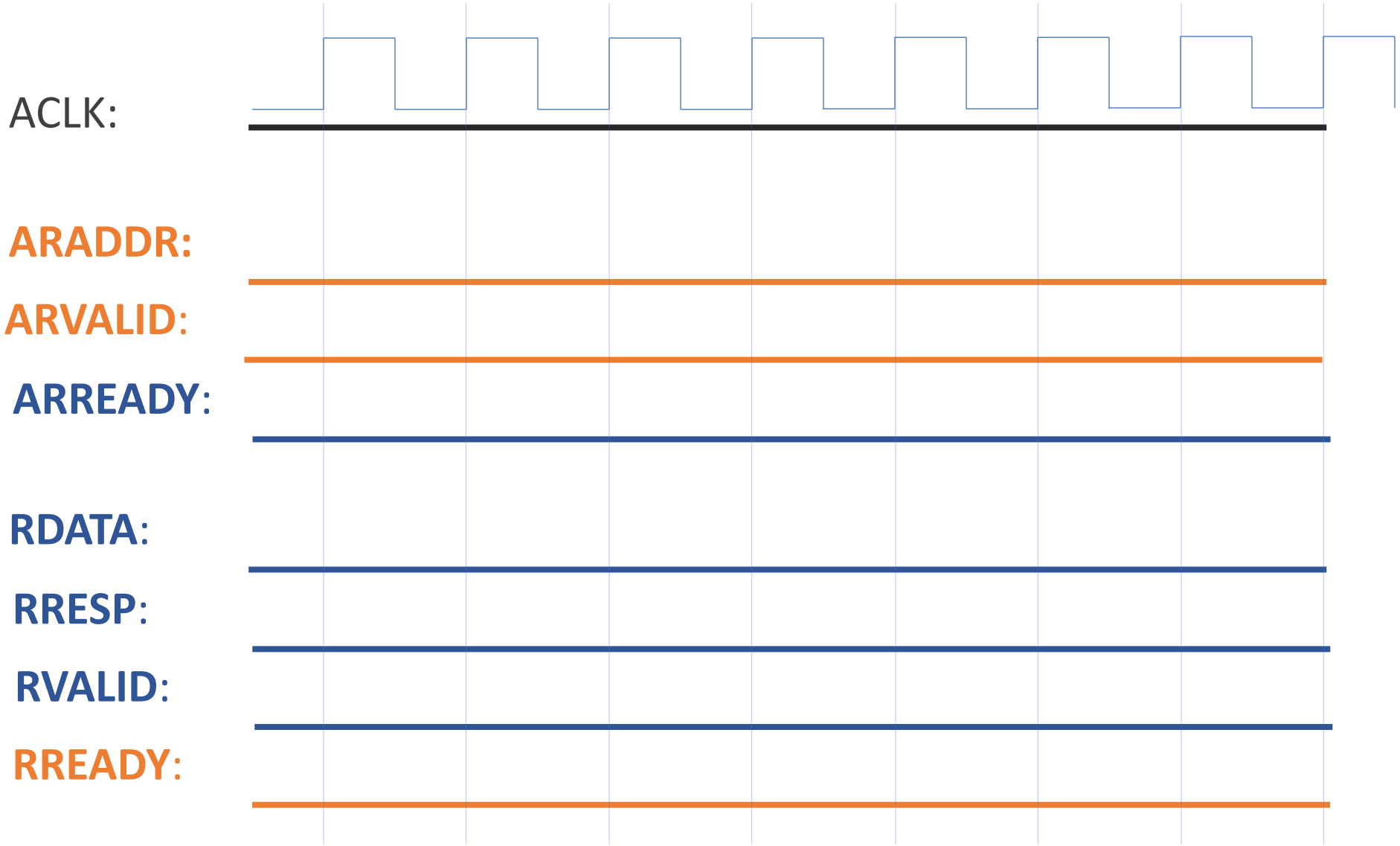
RRESP[1:0] BRESP[1:0]	Response
0b00	OKAY
0b01	EXOKAY
0b10	SLVERR
0b11	DECERR

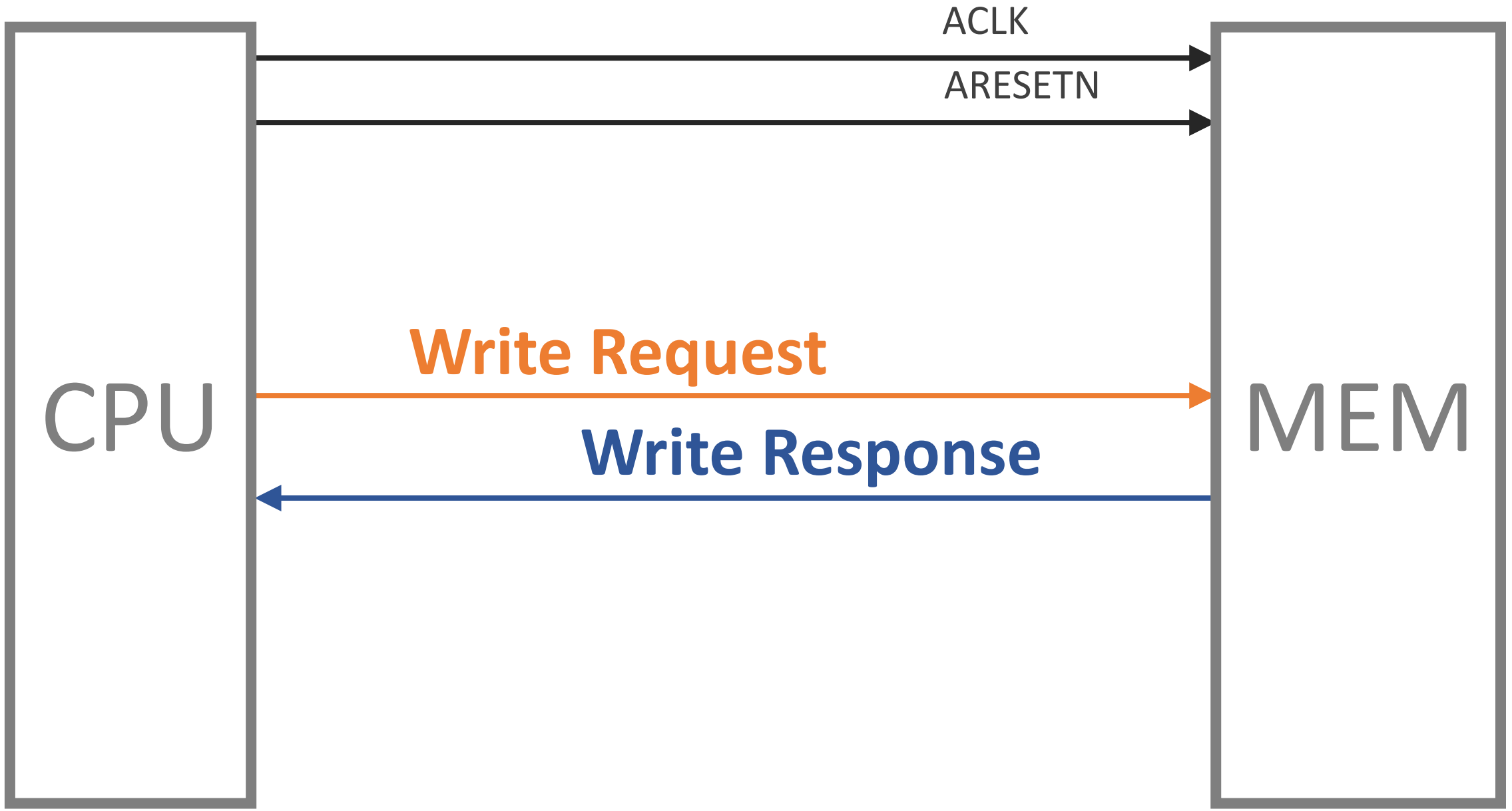
- Mostly used to send error codes back to CPU

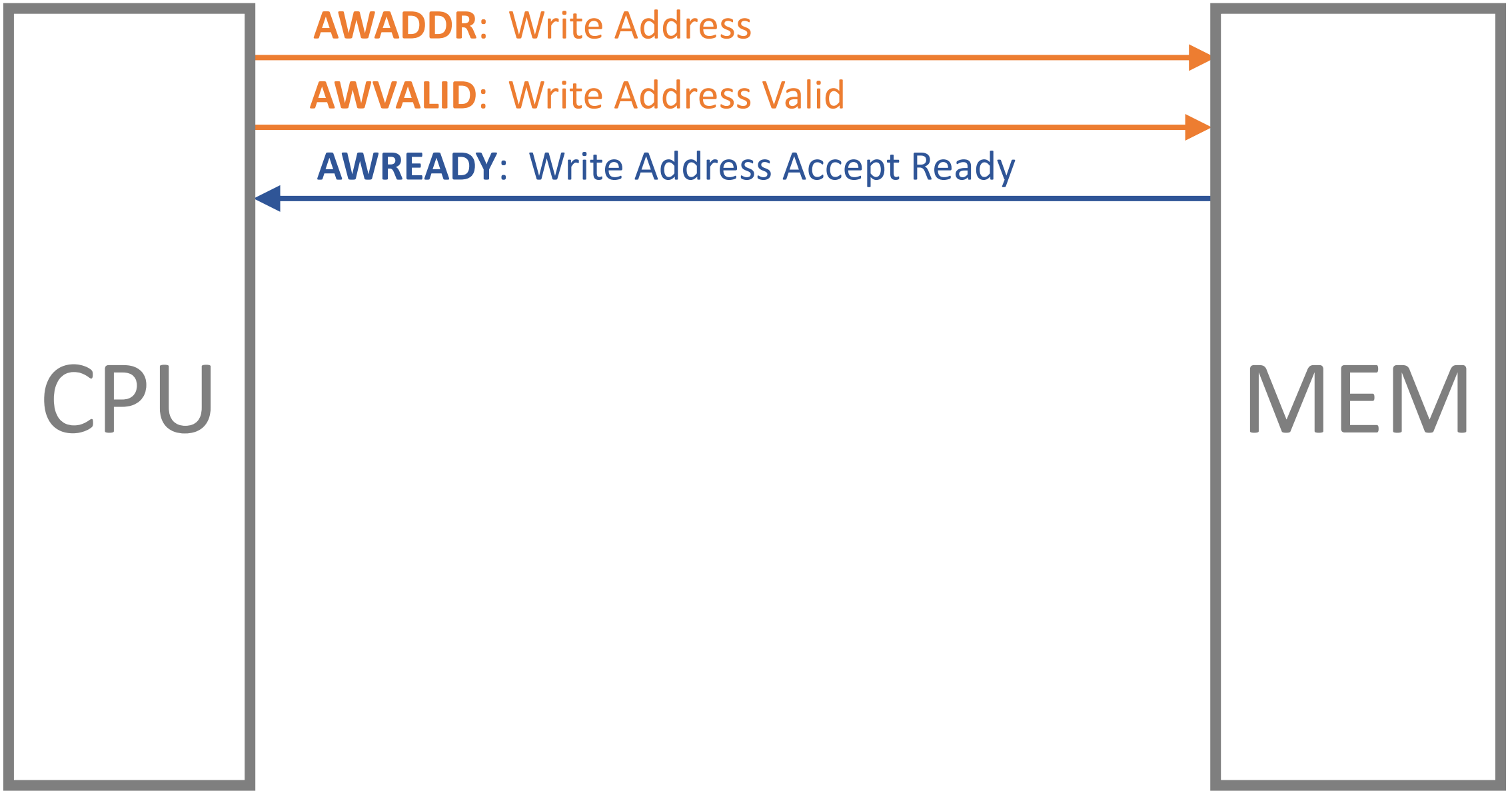
- We'll always just use 0b00

Load 0x1234, response: 0xabcd

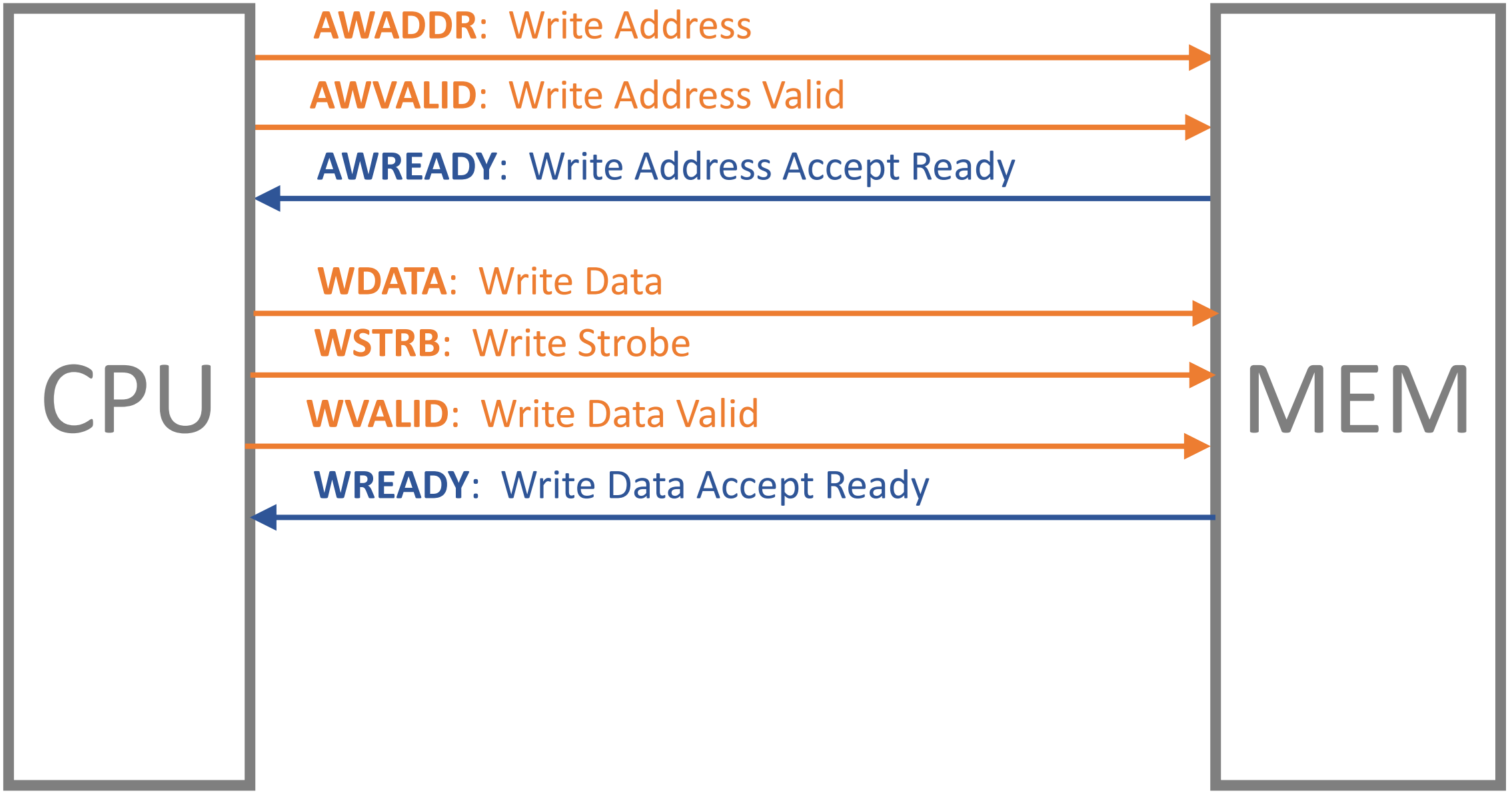
assume ARESETN = 1




ACLK
ARESETN
CPU
Write Request
Write Response
MEM



ACLK and ARESETN not shown



ACLK and ARESETN not shown

Q: How do you send a 1-byte (8-bit) value on a 32-bit bus?

- A: WSTB: Write Strobe

What is WSTRB?

The **WSTRB[n:0]** signals when HIGH, specify the byte lanes of the data bus that contain valid information. There is one write strobe for each eight bits of the write data bus, therefore **WSTRB[n]** corresponds to **WDATA[(8n)+7: (8n)]**

What is WSTRB here?

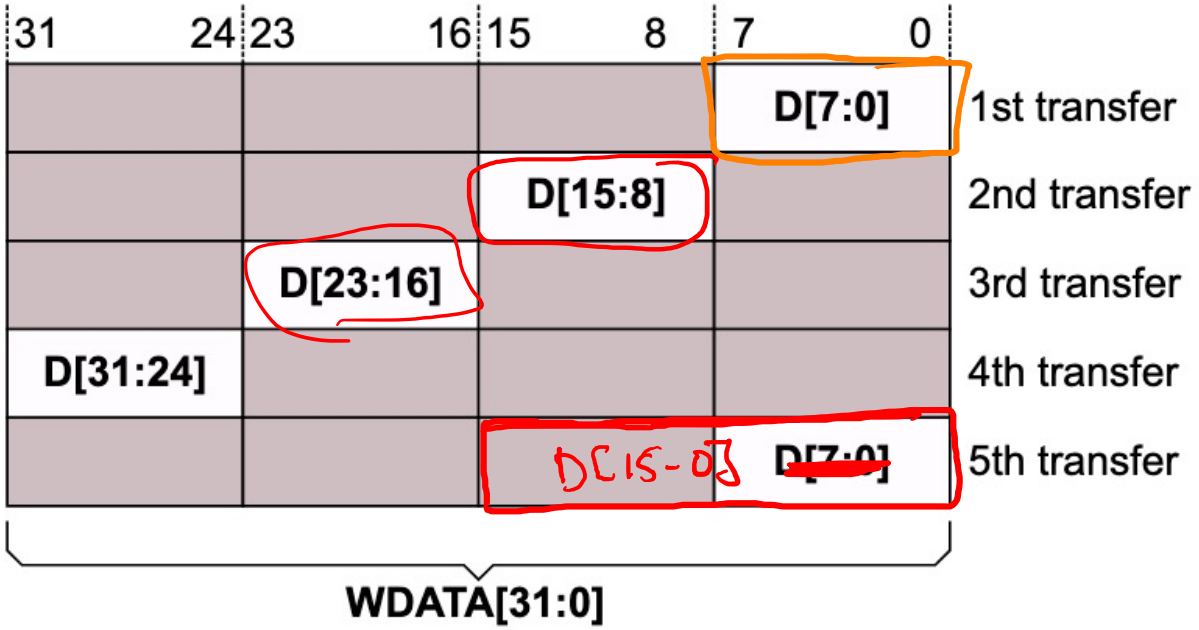


Figure A3-8 Narrow transfer example with 8-bit transfers

MSB LSB

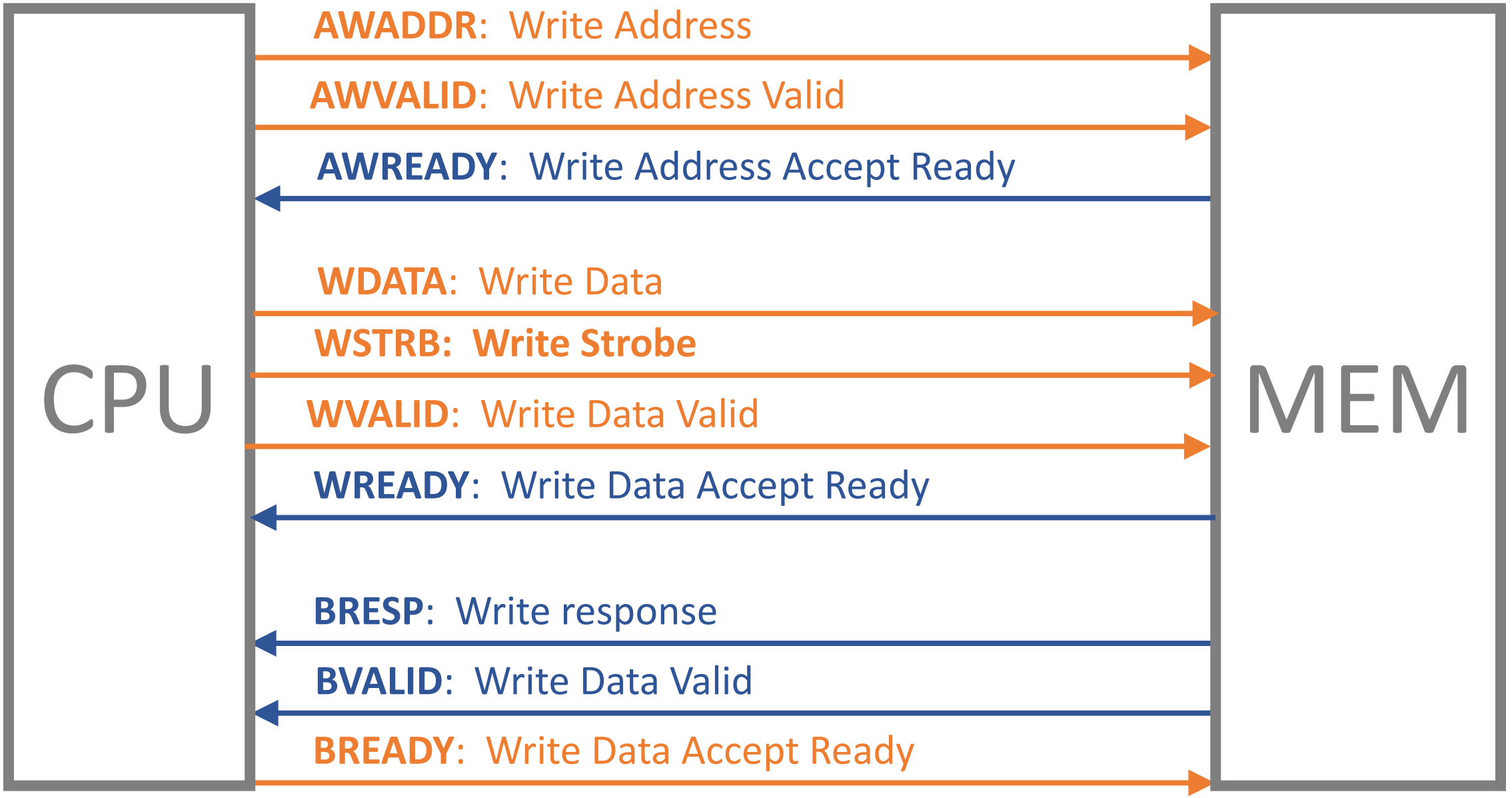
WSTRB = 0001 = 0x1

= 0010 = 0x2

= 0100 = 0x4

= 1000 = 0x8

= 0011 = 0x3



ACLK and ARESETN not shown

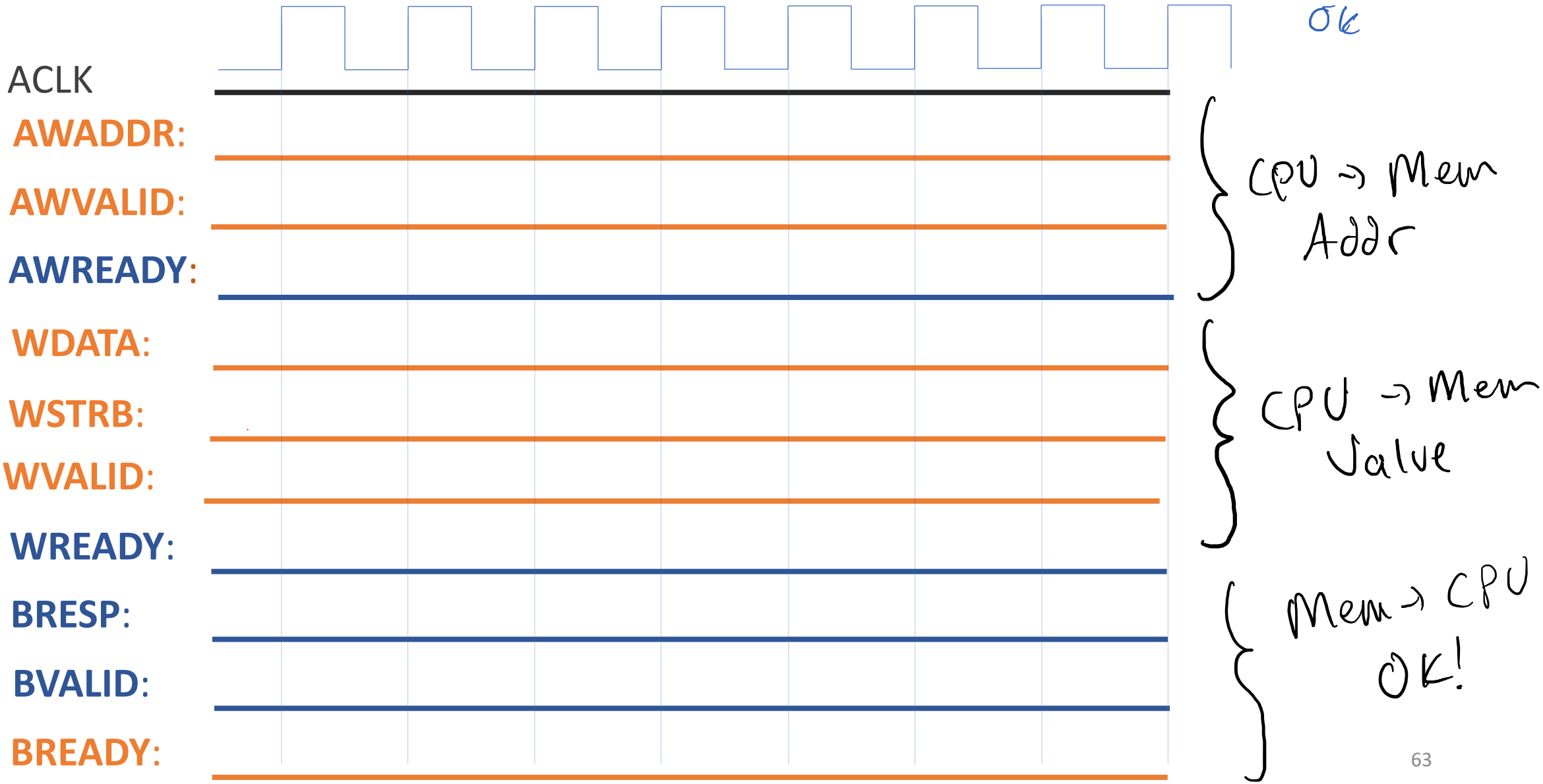
BRESP is just like RRESP

Table A3-4 RRESP and BRESP encoding

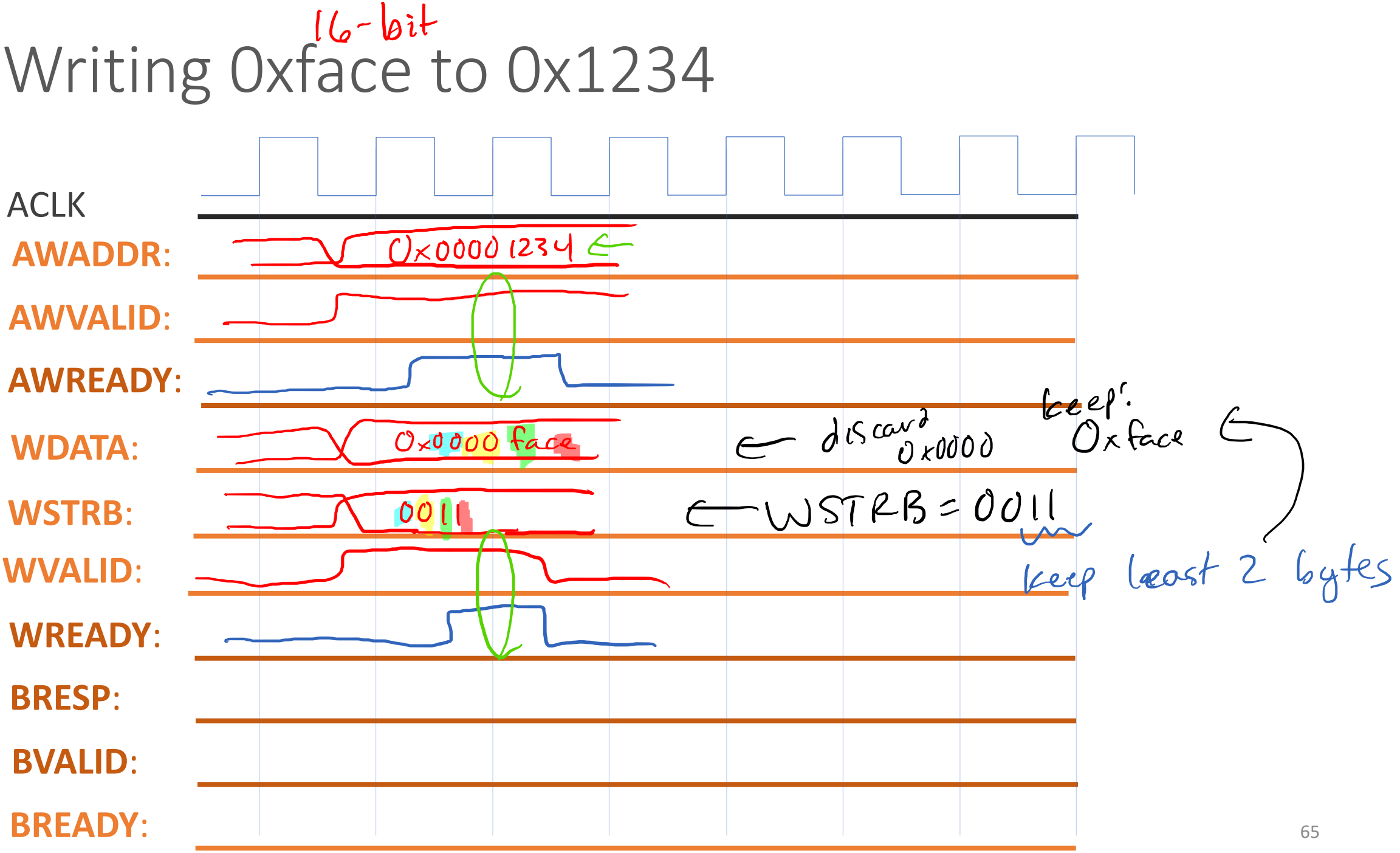
RRESP[1:0] BRESP[1:0]	Response
0b00	OKAY
0b01	EXOKAY
0b10	SLVERR
0b11	DECERR

- Mostly used to send error codes back to CPU
- We'll always just use 0b00

Writing 0xdeadbeef to 0x1234



Writing 0xface to 0x1234



References

- https://www.youtube.com/watch?v=okiTzvihHRA
- https://web.eecs.umich.edu/~prabal/teaching/eecs373/
- https://en.wikipedia.org/wiki/File:Computer_system_bus.svg
- https://www.realdigital.org/doc/a9fee931f7a172423e1ba73f66ca4081

07: MMIO Buses

Engr 315: Hardware / Software Codesign

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