Trinity College Dublin
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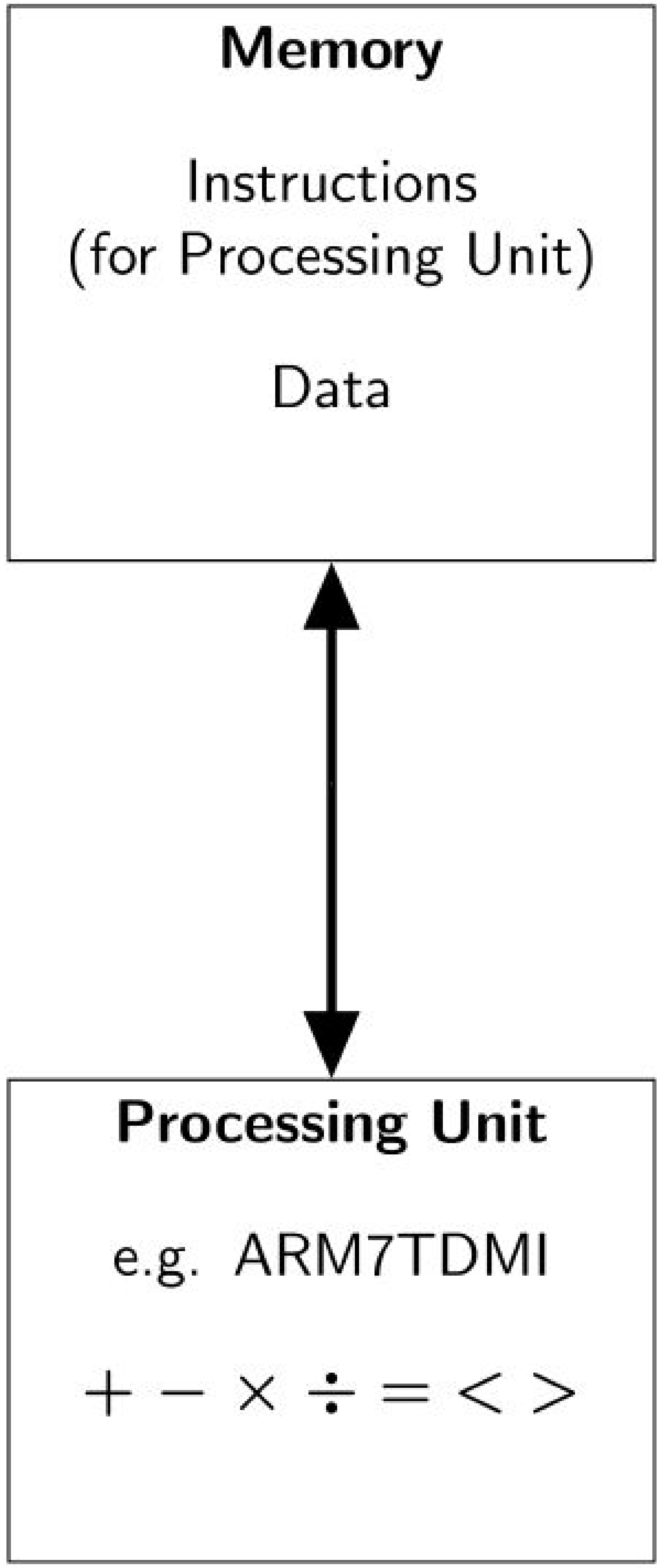
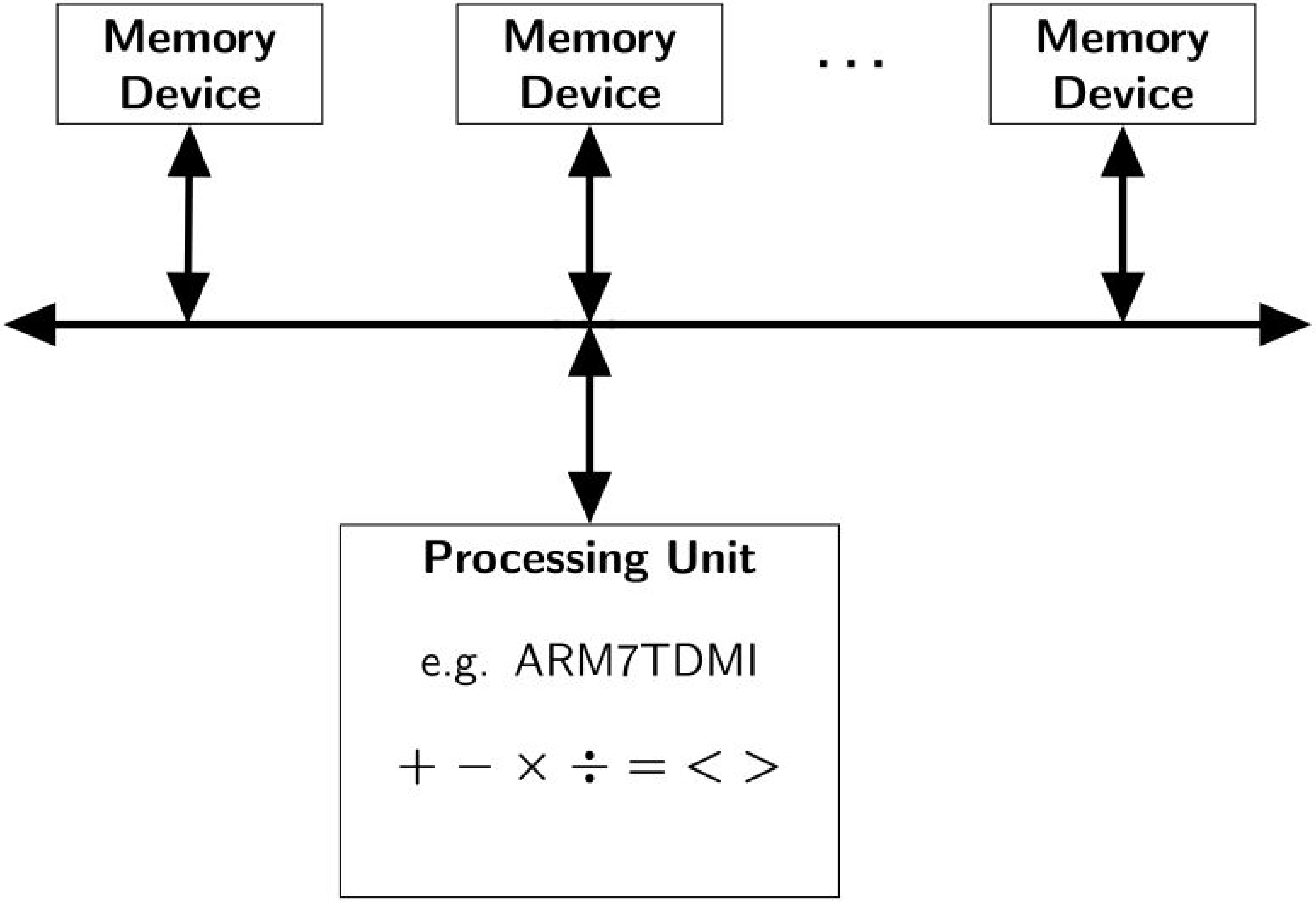
05 – Memory-Mapped I/O

CS1022 – Introduction to Computing II

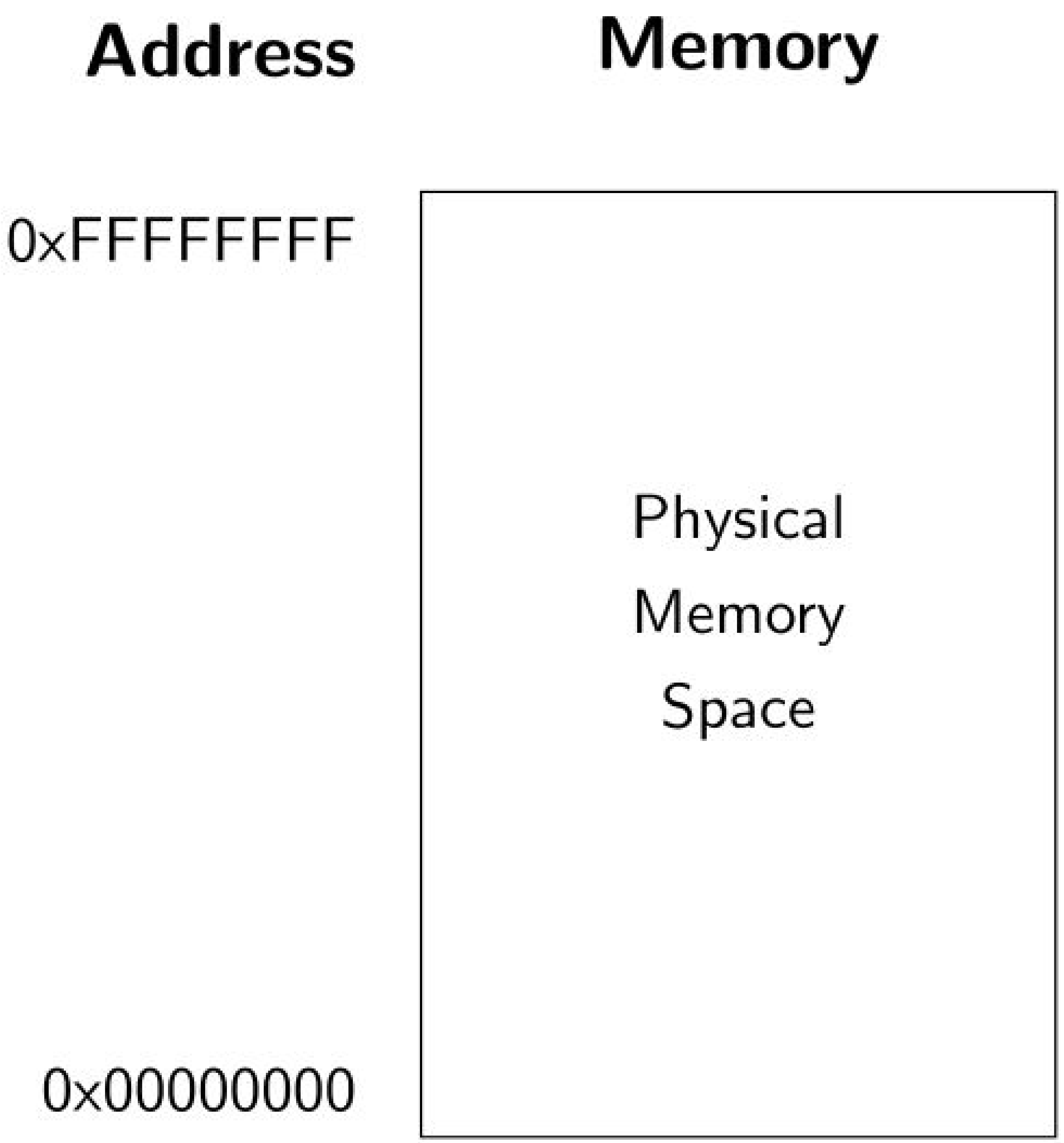
Dr Adam Taylor/ adam.taylor@tcd.ie
School of Computer Science and Statistics

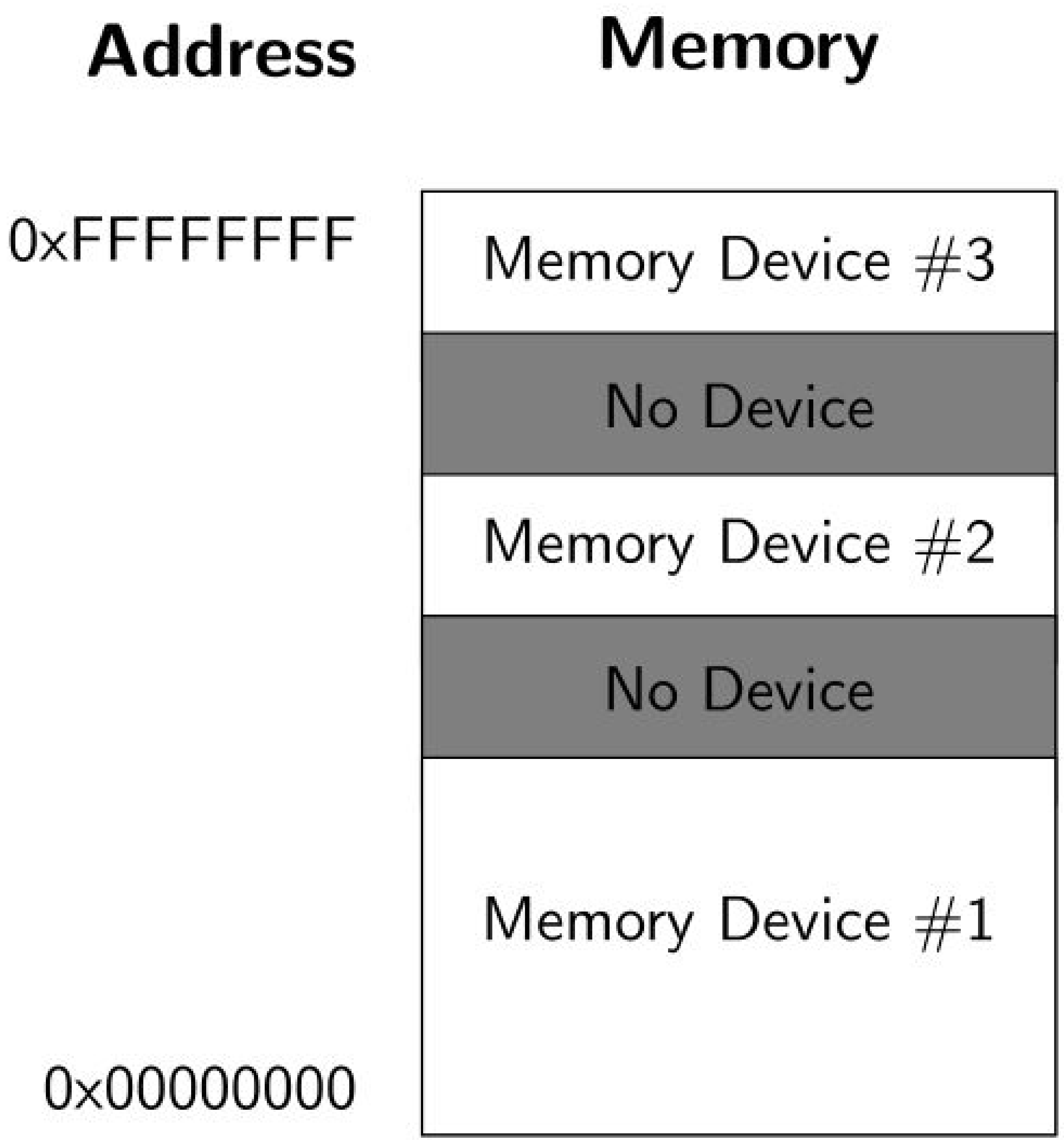
Simple Model of a Microprocessor





Address Space and Memory Map





NXP LPC2468

LPC2468 Development Board

On-Chip Flash (Read-Only) Memory (512KB)

On-Chip RAM
(64KB + 16KB for Ethernet + 16KB = 96KB)

Off-Chip RAM (32MB)

4GB address space (32 bit addresses)

Each memory device is mapped into a region of the address space

Memory accesses (loads/stores) are directed to the device that is mapped into the address being accessed

Address	Memory
0xFFFFFFFF	. . .
0xA1FFFFFF – 0xA0000000	External SDRAM 32MB
	. . .
0x81FFFFFF – 0x81000000	External NAND Flash 32MB
0x80FFFFFF – 0x80000000	External NOR Flash 4MB
	. . .
0x7FE03FFF – 0x7FE00000	Internal SRAM Ethernet 16KB
	. . .
0x7FD03FFF – 0x7FD00000	Internal SRAM USB 16KB
	. . .
0x4000FFFF – 0x40000000	Internal SRAM 64KB
	. . .
0x0007FFFF – 0x00000000	Internal Flash Memory 512KB

Memory Mapping Example

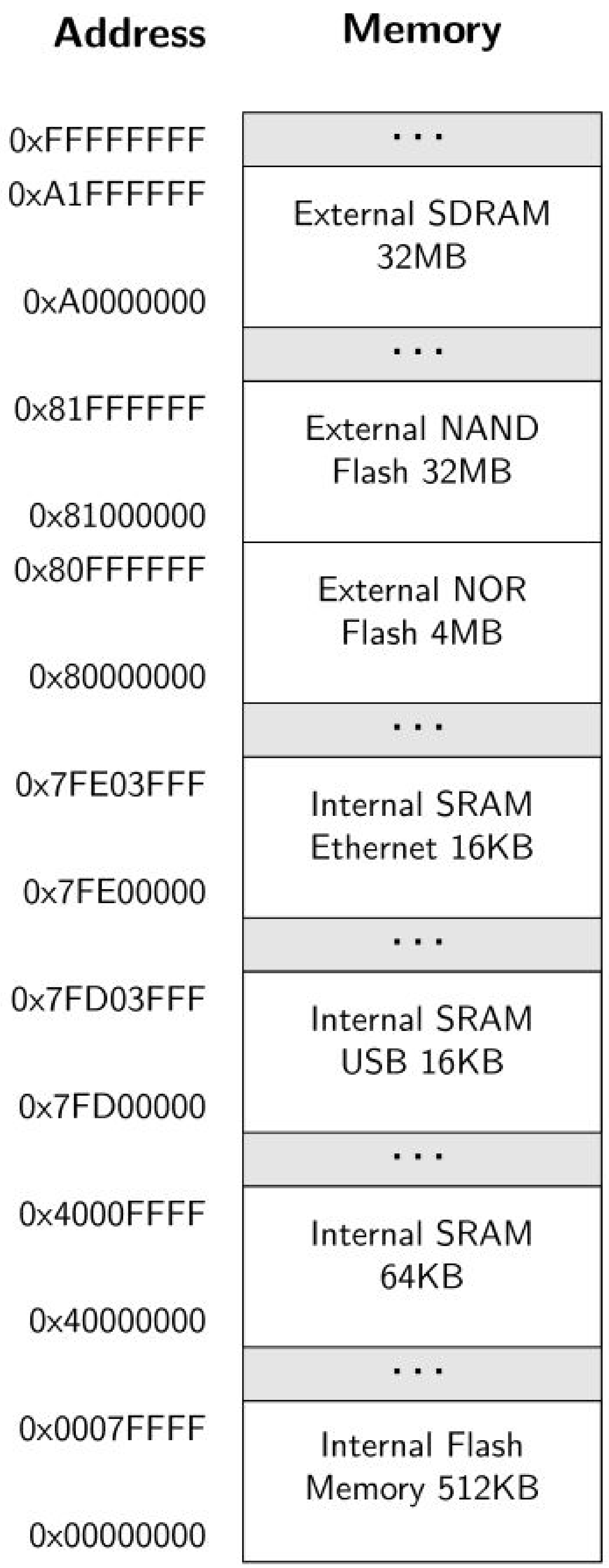
512KB Internal Flash Memory

- 512KB = 524288 bytes = 2^{19} bytes
- Address range: 0 … 527287_{10} = 0x00000 … 0x7FFFF
- Device required 19-bit addresses

Choose address 0x00000000 as device base address

- Mapped into processor address space 0x00000000 … 0x0007FFFF

Similarly for Internal SRAM, External SDRAM, …



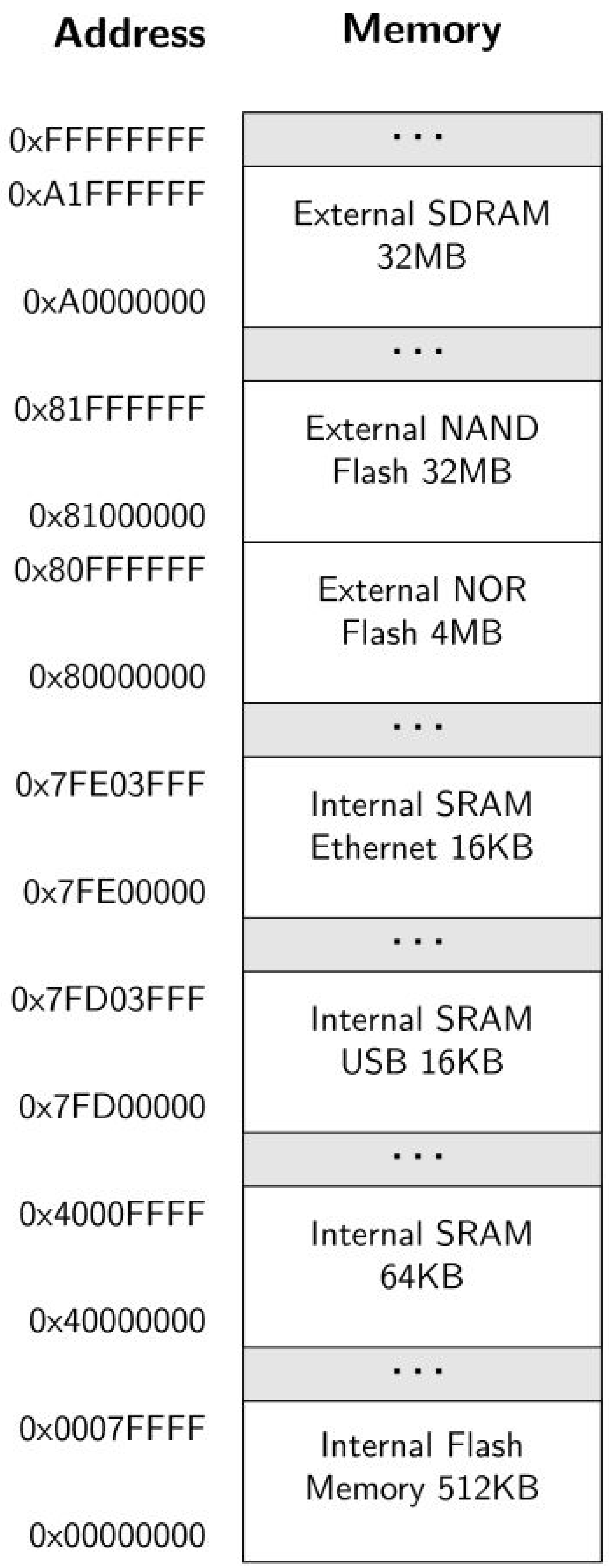
Memory Mapping Example

64KB Internal SRAM

- 64KB = 65536 bytes = 2^{16} bytes
- Address range: 0 … 65535_{10} = 0x0000 … 0xFFFF
- Device required 19-bit addresses

Choose address 0x40000000 as device base address

- Mapped into processor address space 0x40000000 … 0x4000FFFF



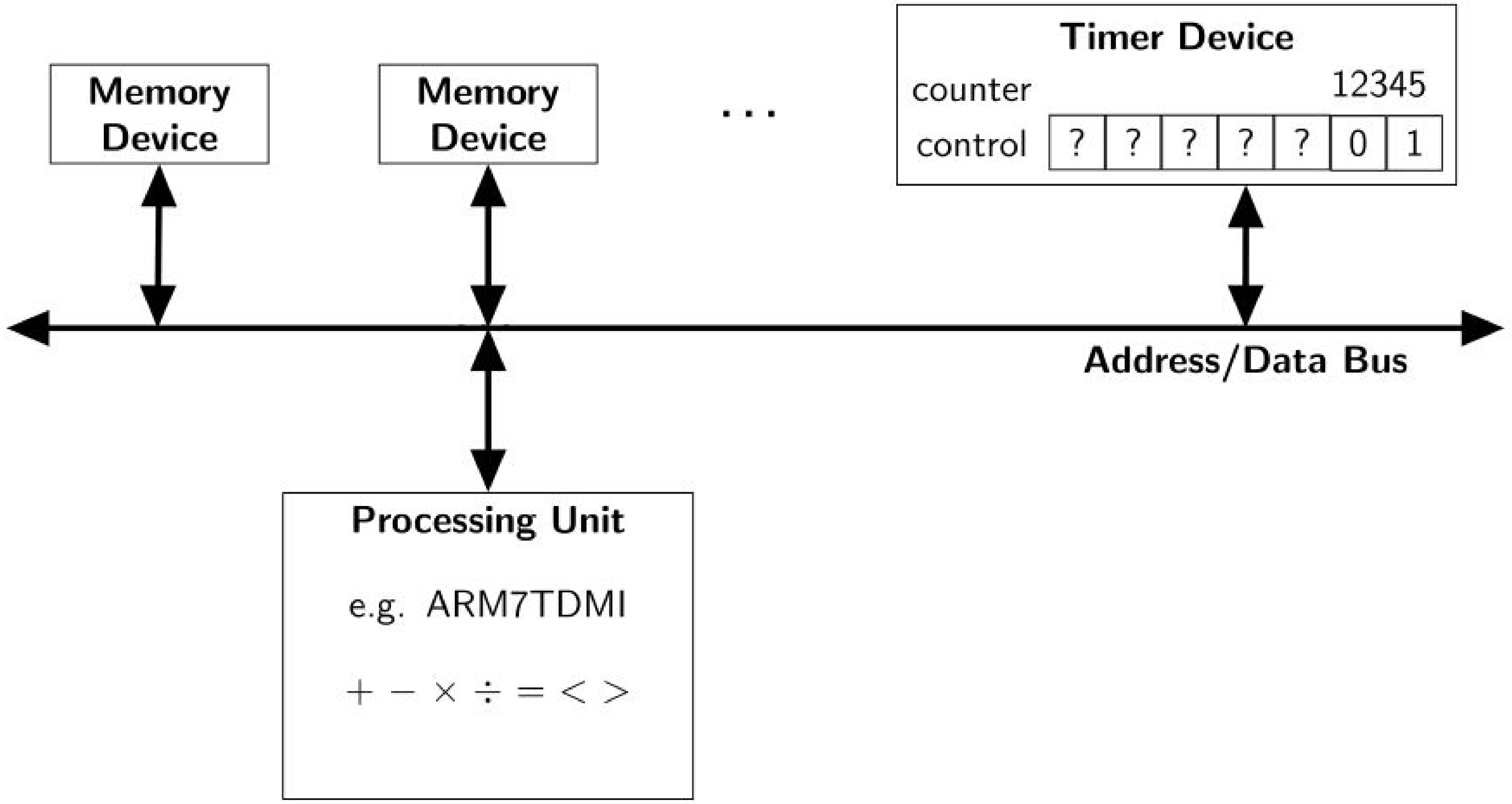
Other Non-memory Devices?

How do we communicate with non-memory devices external to the microprocessor?

Consider a fictional timer device that can measure elapsed time

- Fictional timer has two internal registers
- Control Register, 8-bits, bit 0 = start/stop, bit 1 = reset
- Counter Register, 32-bits, contains elapsed time

Map device registers into the memory space (just like other “normal” memory devices)



Other Non-memory Devices?

Choose a base address for fictional timer

e.g. 0xE0004004

Map device registers to memory locations beginning at base address

control register: 0xE0004004

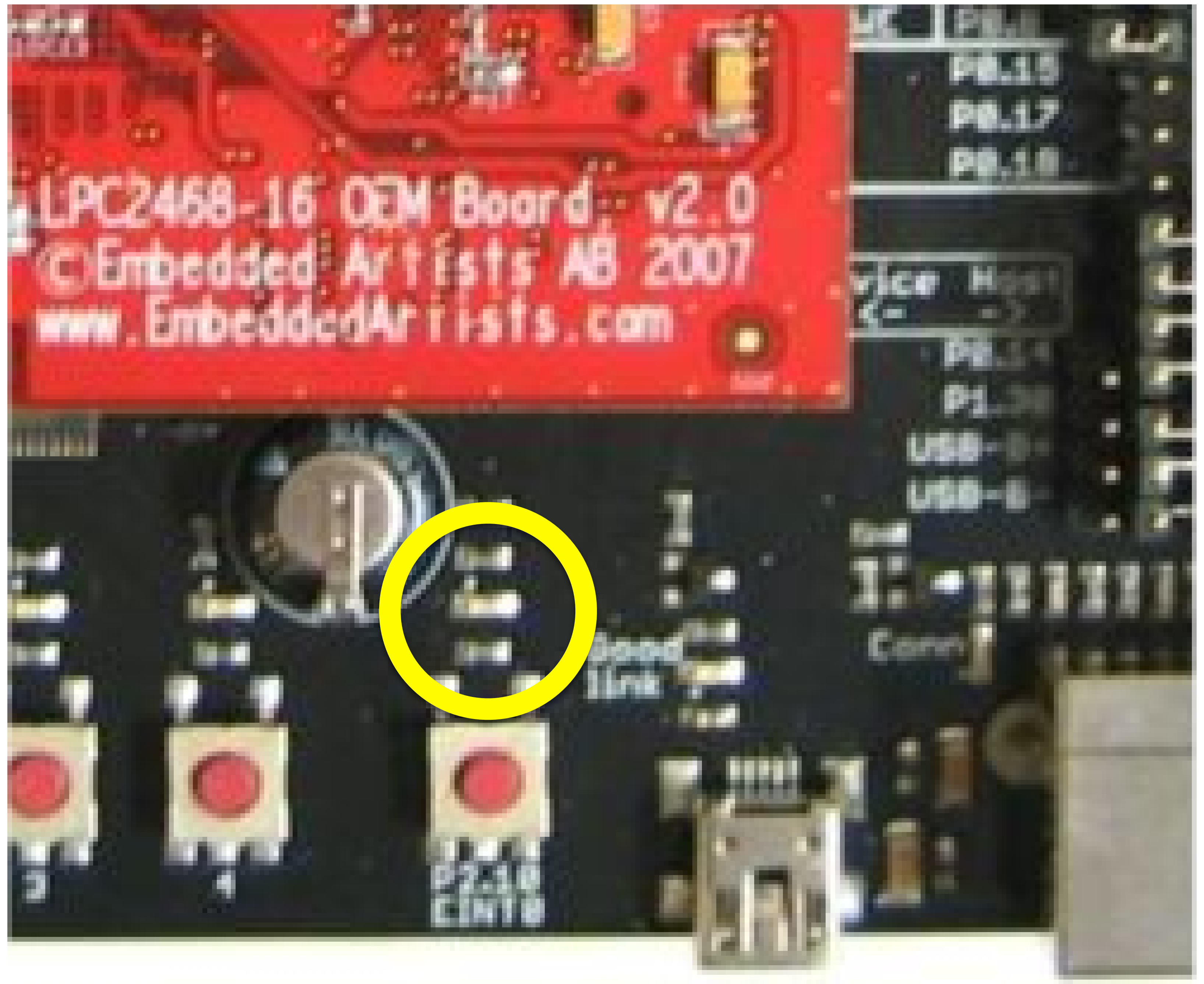
counter register: 0xE0004008

e.g. to reset timer

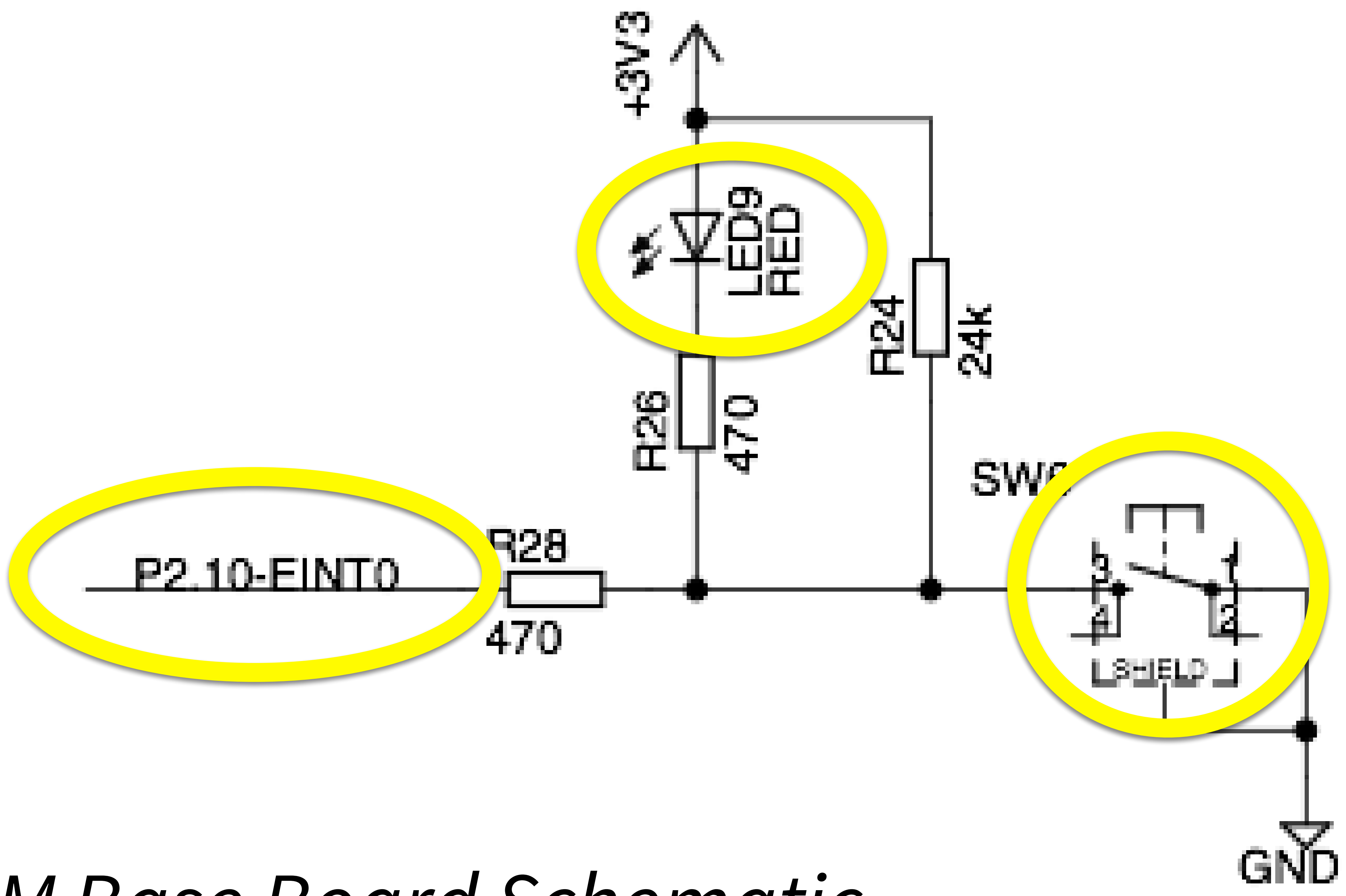
```
LDR R4, =0xE0004004
LDR R5, =2
STR R5, [R4]
```

I/O Example

Design and write an ARM Assembly Language program that will cause an LED to blink on and off repeatedly



Interrupt (P2.10) key



LPC2468 OEM Base Board Schematic

General Purpose I/O (GPIO)

Many external LPC2468 pins have multiple uses

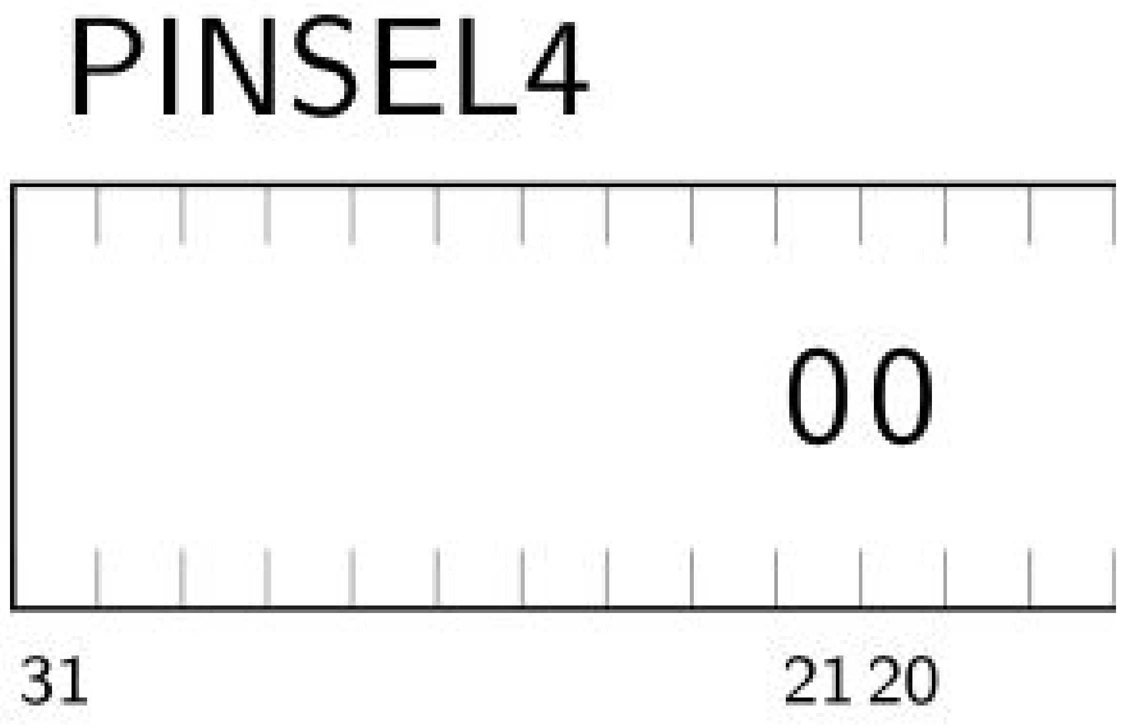
Configured by software at runtime using *Pin Connect Block* PINSELx and PINMODEx memory mapped registers

PINSELx defines pin function

Each 32-bit register controls 16 pins (2 bits to select one of $2^2 = 4$ possible functions for each physical pin)

Table 135. LPC2420/60/68/70/78 pin function select register 4 (PINSEL4 - address 0xE002 C010) bit description

PINSEL4	Pin name	Function when 00	Function when 01	Function when 10	Function when 11	Reset value
21:20	P2[10]	GPIO Port 2.10	$\overline{\text{EINT0}}$	Reserved	Reserved	00



LPC2468 User Manual
Chapter 9: LPC24xx Pin Connect

Table 135. LPC2420/60/68/70/78 pin function select register 4 (PINSEL4 - address 0xE002 C010) bit description

PINSEL4	Pin name	Function when 00	Function when 01	Function when 10	Function when 11	Reset value
1:0	P2[0]	GPIO Port 2.0	PWM1[1]	TXD1	TRACECLK[1]/ LCDPWR	00
3:2	P2[1]	GPIO Port 2.1	PWM1[2]	RXD1	PIPESTAT0[1]/ LCDLE	00
5:4	P2[2]	GPIO Port 2.2	PWM1[3]	CTS1	PIPESTAT1[1]/ LCDDCLK	00
7:6	P2[3]	GPIO Port 2.3	PWM1[4]	DCD1	PIPESTAT2[1]/ LCDFP	00
9:8	P2[4]	GPIO Port 2.4	PWM1[5]	DSR1	TRACESYNC[1]/ LCDENAB/ LCDM	00
11:10	P2[5]	GPIO Port 2.5	PWM1[6]	DTR1	TRACEPKT0[1]/ LCDLP	00
13:12	P2[6]	GPIO Port 2.6	PCAP1[0]	RI1	TRACEPKT1[1]/ LCDVD[0]/ LCDVD[4]	00
15:14	P2[7]	GPIO Port 2.7	RD2	RTS1	TRACEPKT2[1]/ LCDVD[1]/ LCDVD[5]	00
17:16	P2[8]	GPIO Port 2.8	TD2	TXD2	TRACEPKT3[1]/ LCDVD[2]/ LCDVD[6]	00
19:18	P2[9]	GPIO Port 2.9	$\overline{\text{USB\_CONNECT1}}$	RXD2	EXTIN0[1]/ LCDVD[3]/ LCDVD[7]	00
21:20	P2[10]	GPIO Port 2.10	$\overline{\text{EINT0}}$	Reserved	Reserved	00
23:22	P2[11]	GPIO Port 2.11	$\overline{\text{EINT1}}$/ LCDCLKIN	MCIDAT1	I2STX_CLK	00
25:24	P2[12]	GPIO Port 2.12	$\overline{\text{EINT2}}$/ LCDVD[4]/ LCDVD[3]/ LCDVD[8]/ LCDVD[8]/ LCDVD[18]	MCIDAT2	I2STX_WS	00
27:26	P2[13]	GPIO Port 2.13	$\overline{\text{EINT3}}$/ LCDVD[5]/ LCDVD[9]/ LCDVD[19]	MCIDAT3	I2STX_SDA	00
29:28	P2[14]	GPIO Port 2.14	$\overline{\text{CS2}}$	CAP2[0]	SDA1	00
31:30	P2[15]	GPIO Port 2.15	$\overline{\text{CS3}}$	CAP2[1]	SCL1	00

Enable GPIO mode for Pin P2.10

Pin P2.10 possible functions

GPIO port P2.10

External interrupt source EINT0

Configured using bits 21:20 of PINSEL4

Set bits 21:20 to 00_2 for GPIO function

REMEMBER! Need to leave the other bits (0 … 19 and 22 … 31) of PINSEL4 unmodified

PINSEL4 address – 0xE002C010 (from LPC2468 User Manual)

Read-Modify-Write operation to set register value

```
; Enable P2.10 for GPIO
LDR R5, =PINSEL4          ; 0xE002C010
LDR R6, [R5]              ; Read current PINSEL4 value
BIC R6, #(0x3 << 20)      ; Modify to clear bits 21:20
STR R6, [R5]              ; Write new PINSEL4 value
```

Set Pin P2.10 for output

GPIO pins can be either inputs or outputs

Controlling LED = output

Direction (I/O) set using FIOxDIRy register

- Use FIO2DIR1 for P2.10
- Set bit 2 of FIO2DIR1 to 1 for output
- Refer to LPC2468 User Manual

```
; Set P2.10 for output
LDR R5, =FIO2DIR1
LDRB  R6, [R5]           ; Read FIO2DIR1
ORR R6, #(0x01 << 2)     ; Modify
STRB  R6, [R5]           ; Write FIO2DIR1
```

Repeatedly invert state of LED

Set output value (0/1) using bit 2 of FIO2PIN1 register

- Must not change other bits of FIO2PIN1

Read, Modify, Write again

- test if LED is on or off [READ]
- if it is off then turn it on, if it is on then turn it off [MODIFY]
- output new value [WRITE]

Naïve delay implemented using a counting loop

```
repeat                  ; while (forever) {
  LDR R4, =0x04         ;   setup bit mask for bit 2 of FIO2 (P2.10)
  LDR R5, =FIO2PIN1
  LDRB  R6, [R5]        ;   read FIO2PIN1
  AND R7, R6, R4        ;   only want to test bit 2 - mask other bits
  CMP R7, #0            ;   if (LED on)
  BNE elseoff           ;   {
  BIC R6, R6, R4        ;     clear bit 2 (turn LED off)
  B endif               ;   }
elseoff                 ;   else if 1, turn LED off {
  ORR R6, R6, R4        ;     set bit 2 (turn LED on)
endif                   ;   }
  STRB  R4, [R5]        ;   write RIO2PIN1

  ; delay
  LDR R4, =0x400000     ;   count = 0x400000
whDelay                 ;   while (count > 0)
  CMP R4, #0            ;   {
  BEQ eWhDelay          ;
  SUB R4, R4, #1        ;     count = count - 1
  B whDelay             ;   }
eWhDelay
  B repeat              ; }
```

DAC and Sound

Initialise the DAC (Digital analog converter) on Pin0.26 for AOUT

Write 10 to bits 20 and 21 of PINSEL1 to say we are using it for writing to AOUT

DAC is always on, so no more configuration to set it up

Now use PWM (pulse width modulation) to play a sound

DACR bits 6-15 are used to feed into the DAC, alternate 1023 and 0 at some frequency will play a square wave

Square Waves as Notes

LPC2468's peripheral clock (the one the DAC runs on) is 12MHz

This means every 1/12M seconds we can change pulse amplitude

Music (or any sound) is a pressure wave

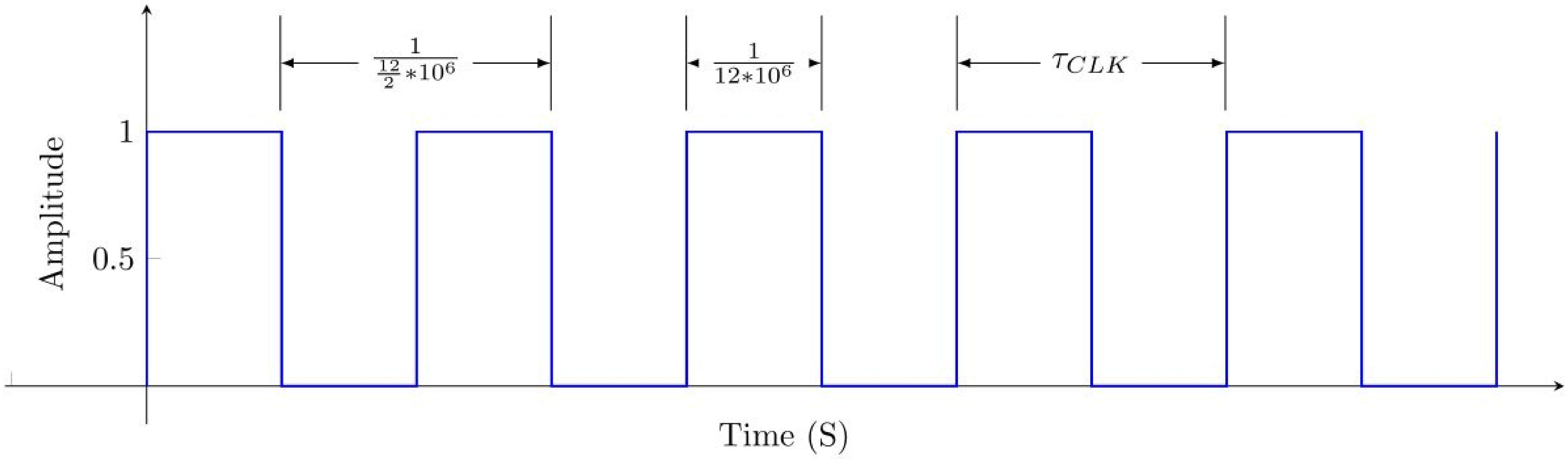
It takes two pulses for the buzzer to generate a pressure wave

C_4 (middle C)'s frequency is 261.626Hz (slower than LPC2468's CLK)

So we need to generate a pressure wave every n CLK cycles

Square Waves as Notes

Clock Frequency



Note C_4 from the DAC