Principles and Applications of Microcontrollers

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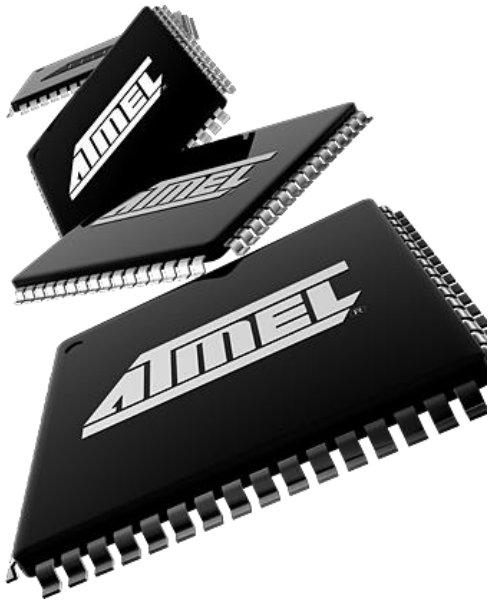
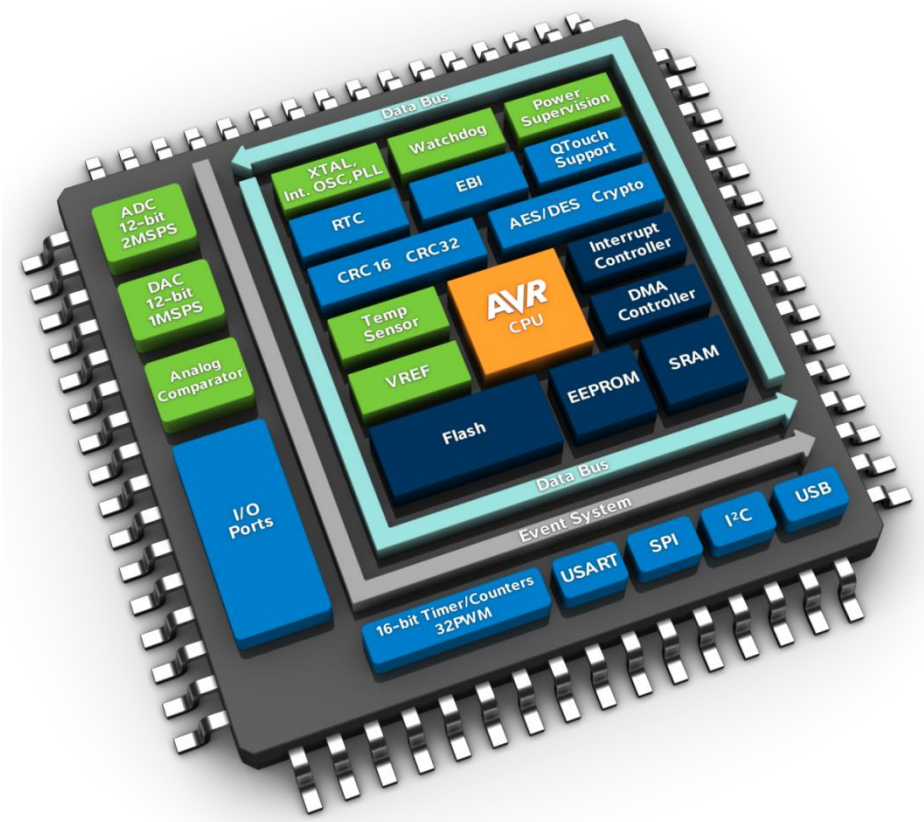
Today:

- AVR CPU
- Assembly introduction

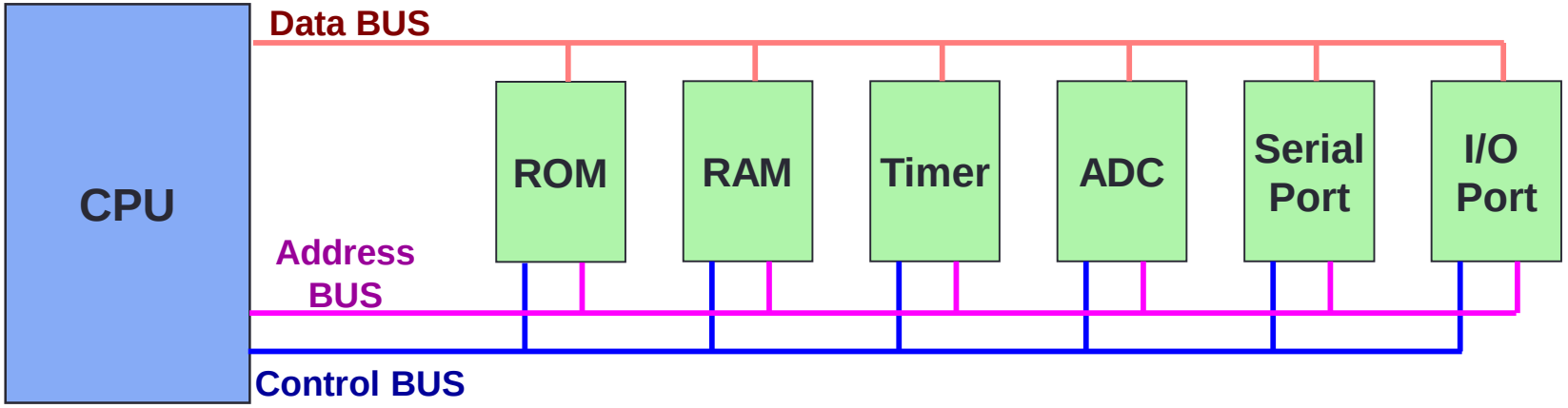


Outline

- AVR CPU architecture
- How computers work
- Assembly
  - Instruction in CPU
  - Accessing I/O
- I/O programming
- Getting started



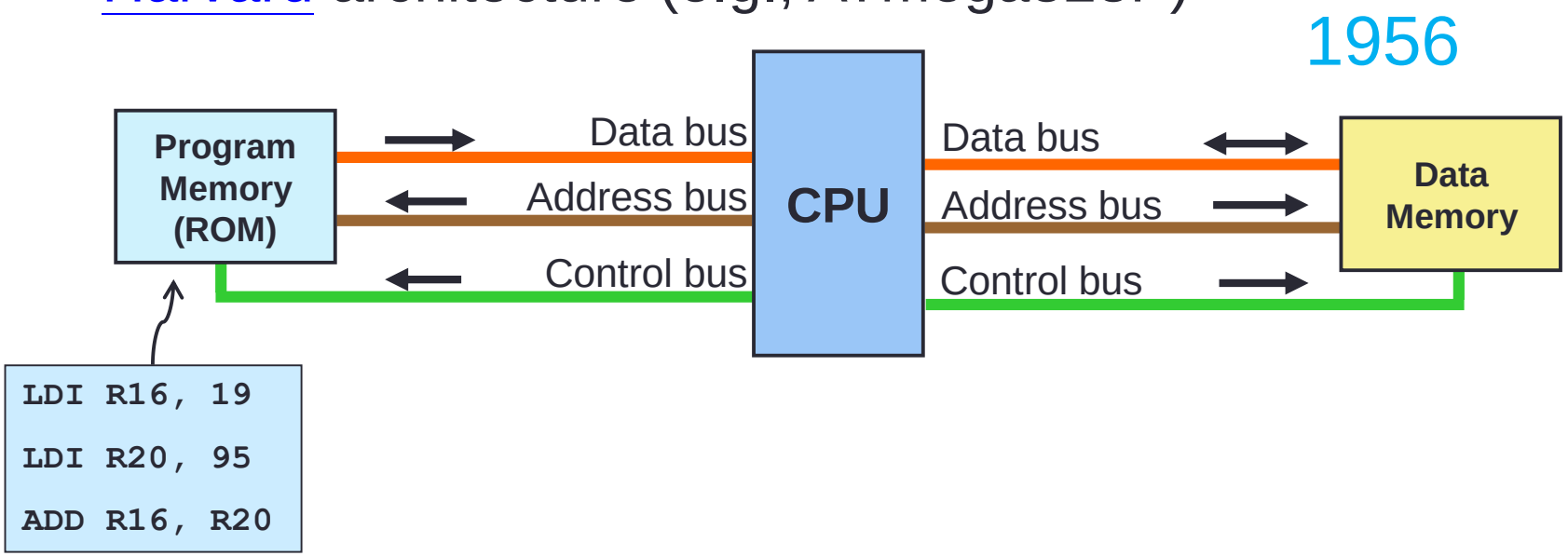
Microcontroller Structure



- We have talked about the peripherals (e.g., I/O, Timer, ADC, Serial)
- It's time to focus on program you wrote and the CPU
- Where is the program stored?

Read Only Memory (ROM)

- Harvard architecture (e.g., ATmega328P)

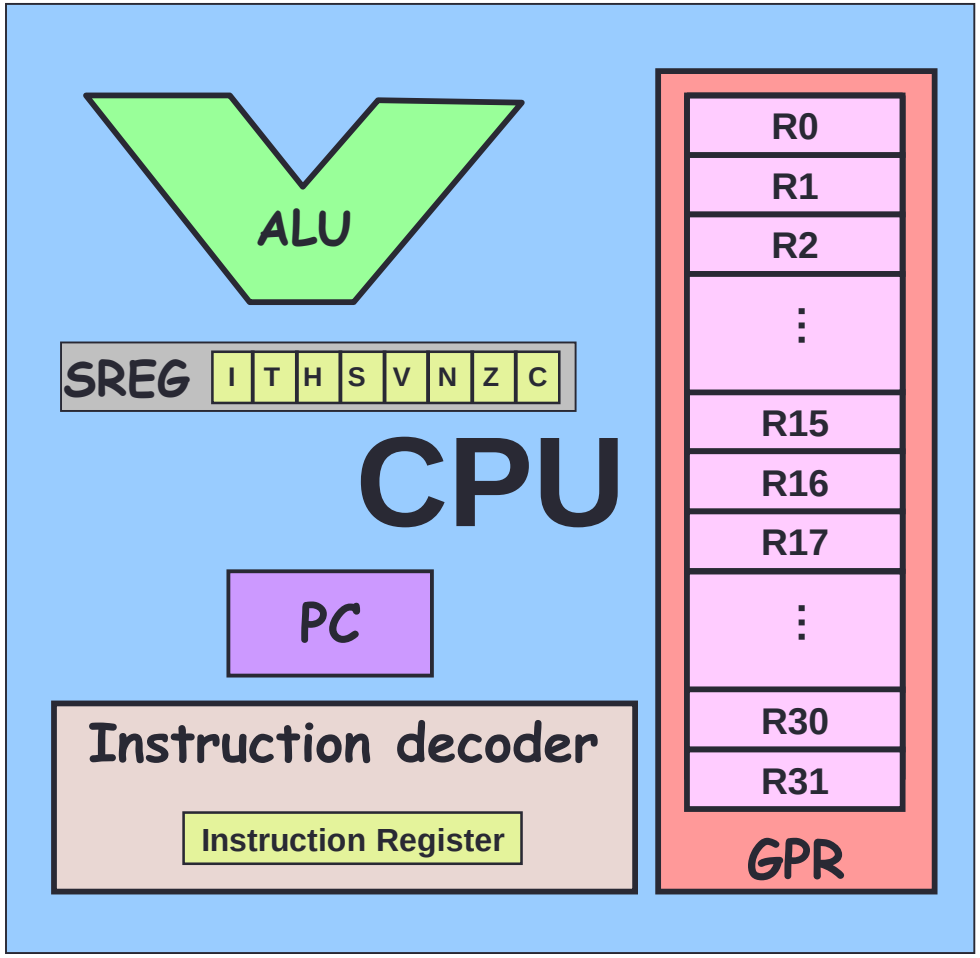


FLASH ROM	EEPROM	SRAM
32K Bytes	1K Bytes	2K Bytes

AVR's CPU

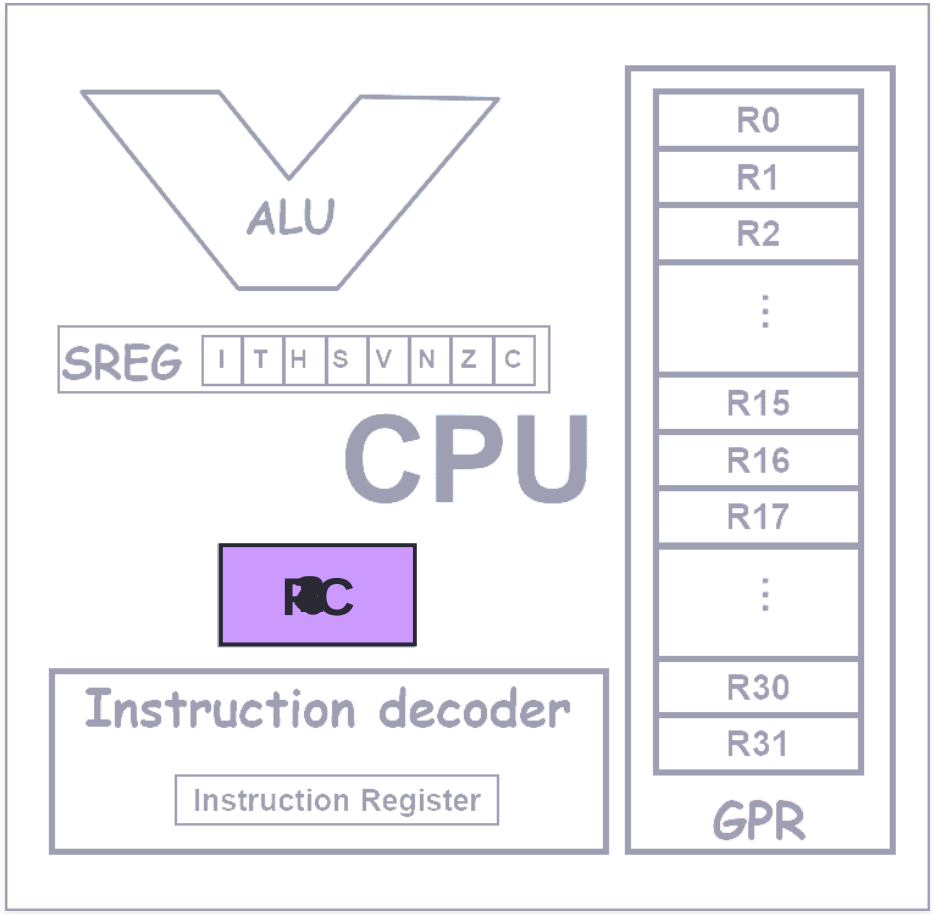
1. Program counter (PC)
2. General purpose registers (GPR) × 32
3. Arithmetic logic unit (ALU)
4. Instruction decoder
5. Status register (SREG)

Note: All registers are 8-bit word length



Program Counter

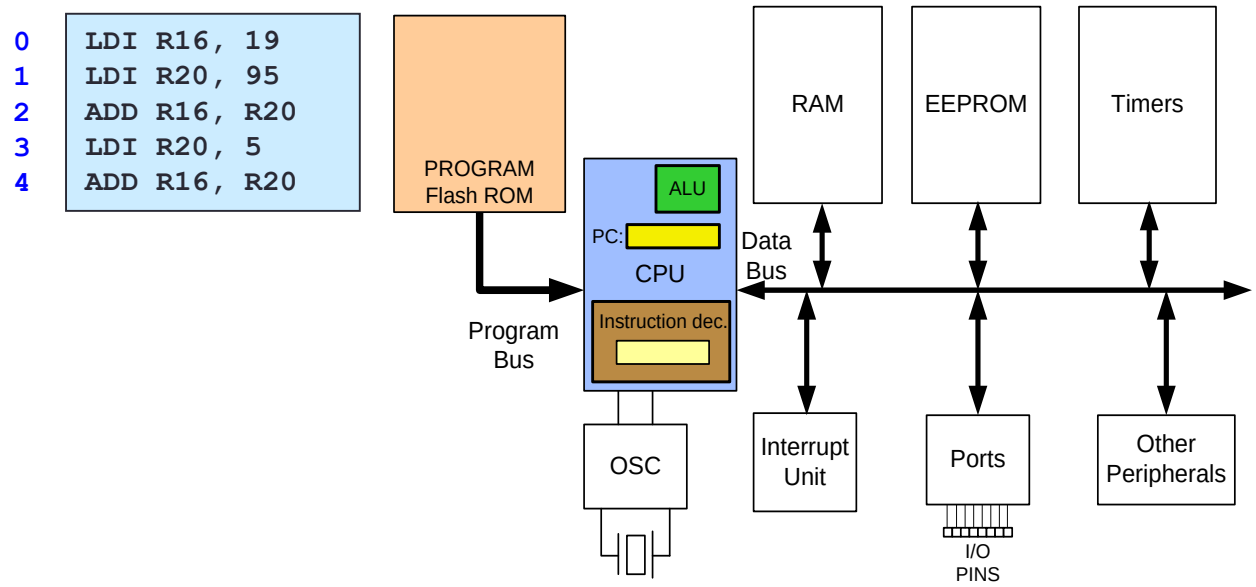
- A pointer to the address of the program ROM



Flash ROM	Address
`LDI R16, 19`	0
`LDI R20, 95`	1
`ADD R16, R20`	2
`LDI R20, 5`	3
`ADD R16, R20`	4

Program Execution Process

1. “Fetch” the machine code at the program counter
2. Program counter +=1
3. Execute the fetched machine code



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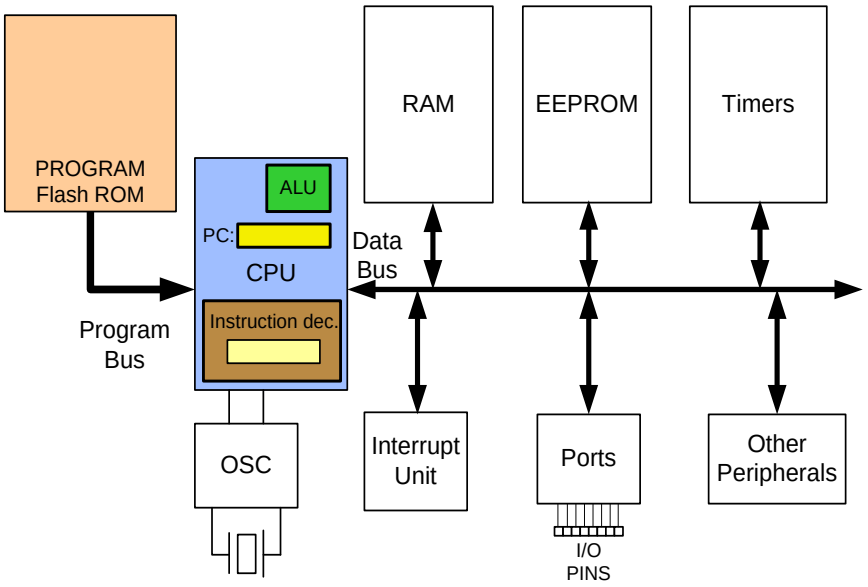
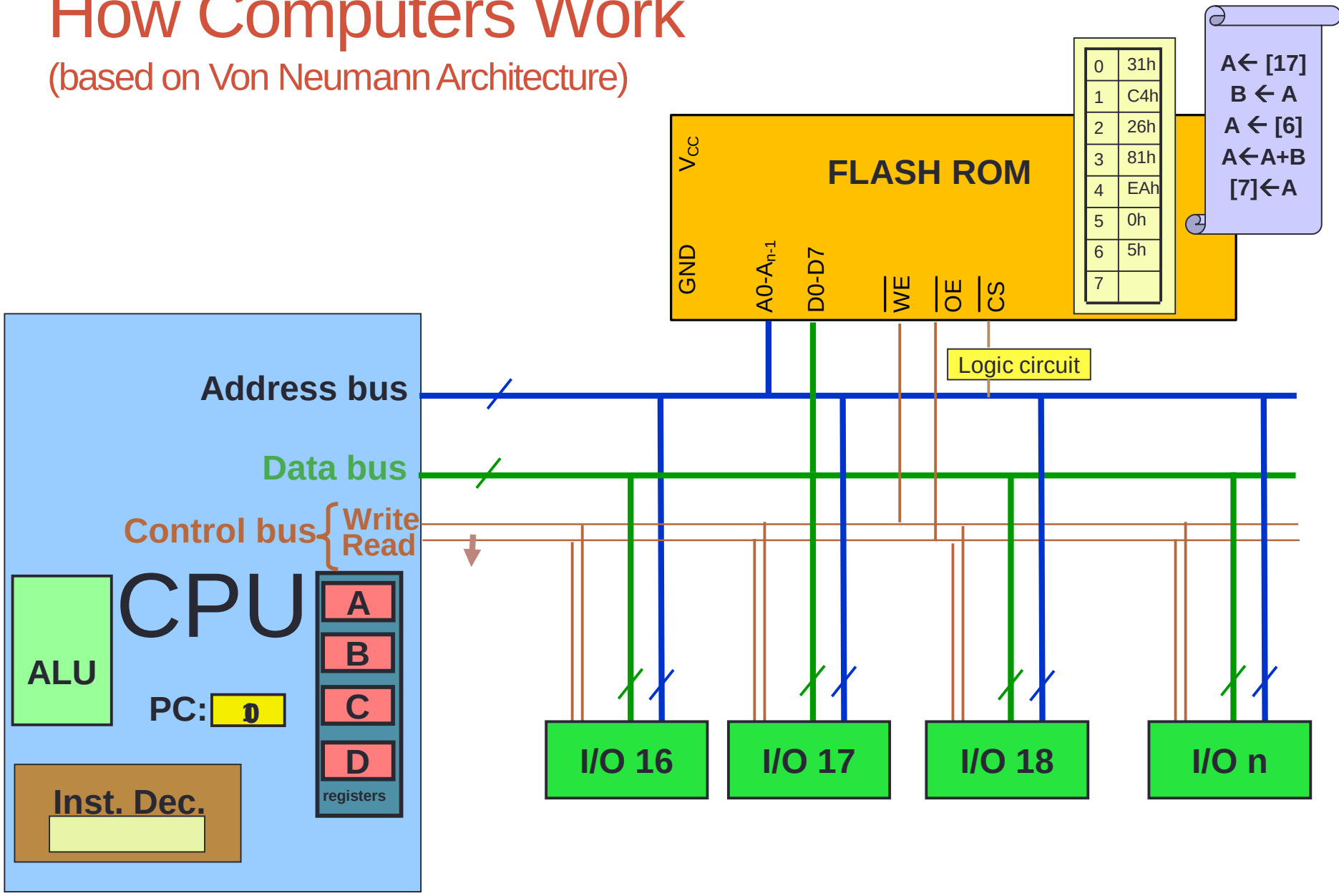


How Computers Work

(based on Von Neumann Architecture)



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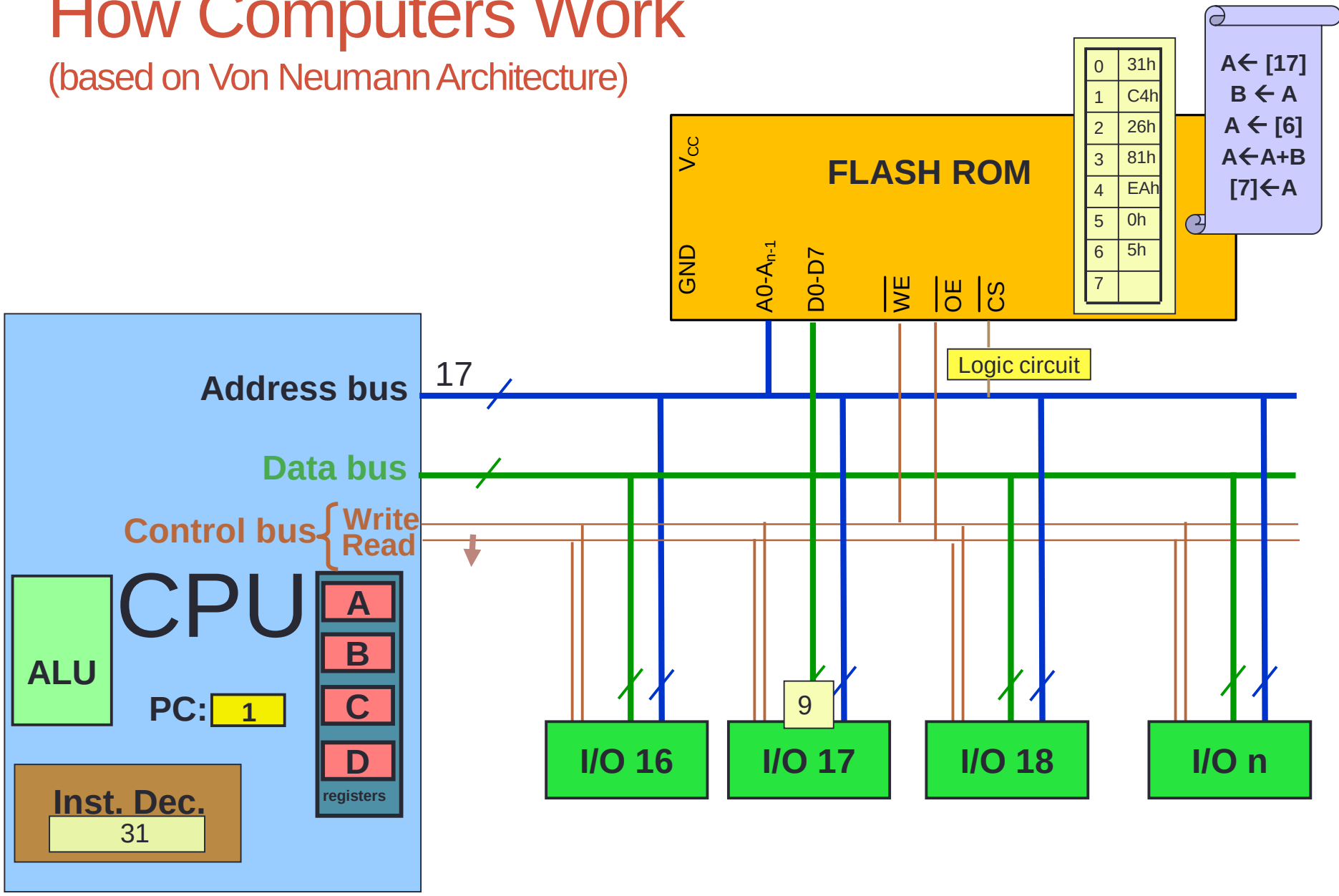

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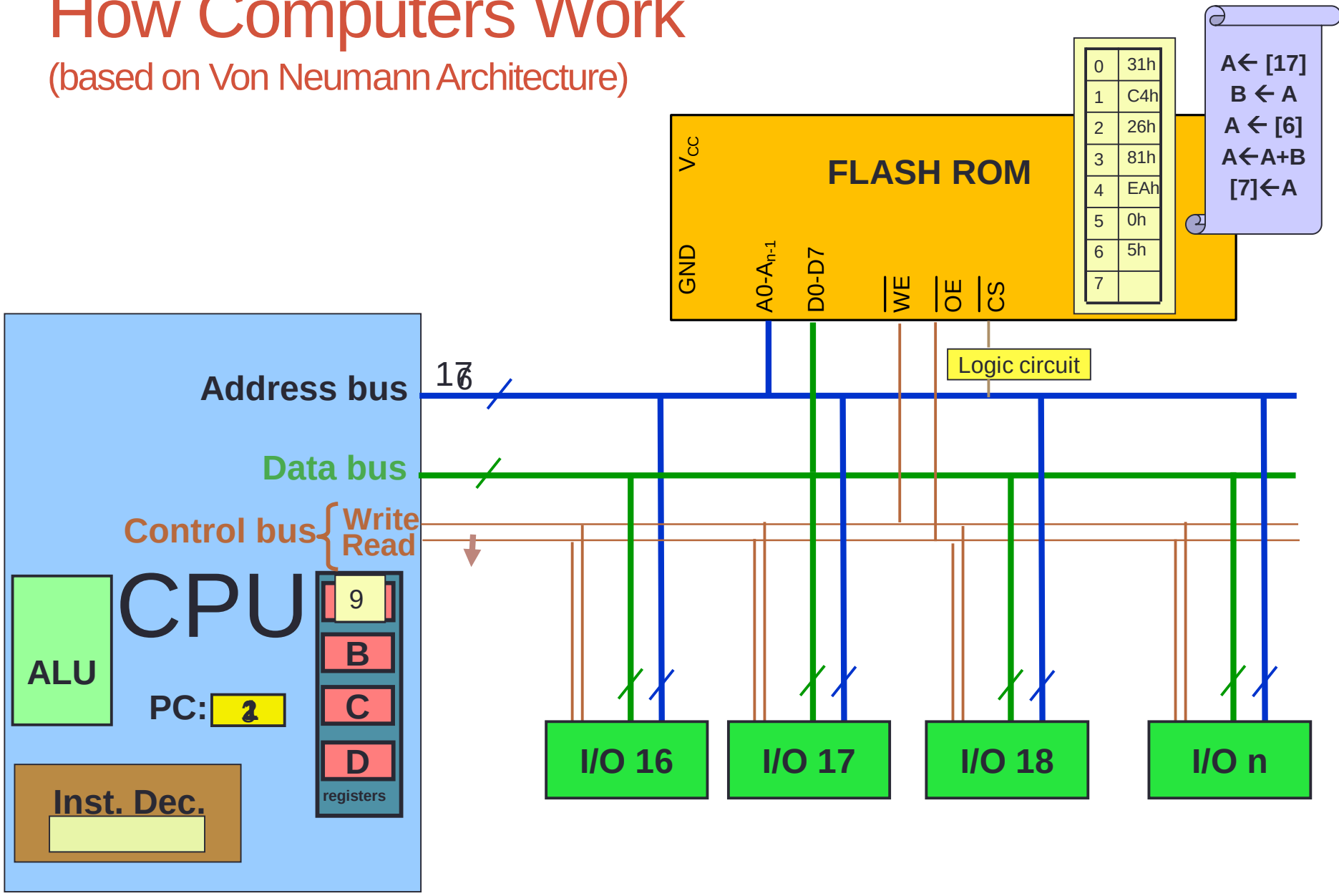

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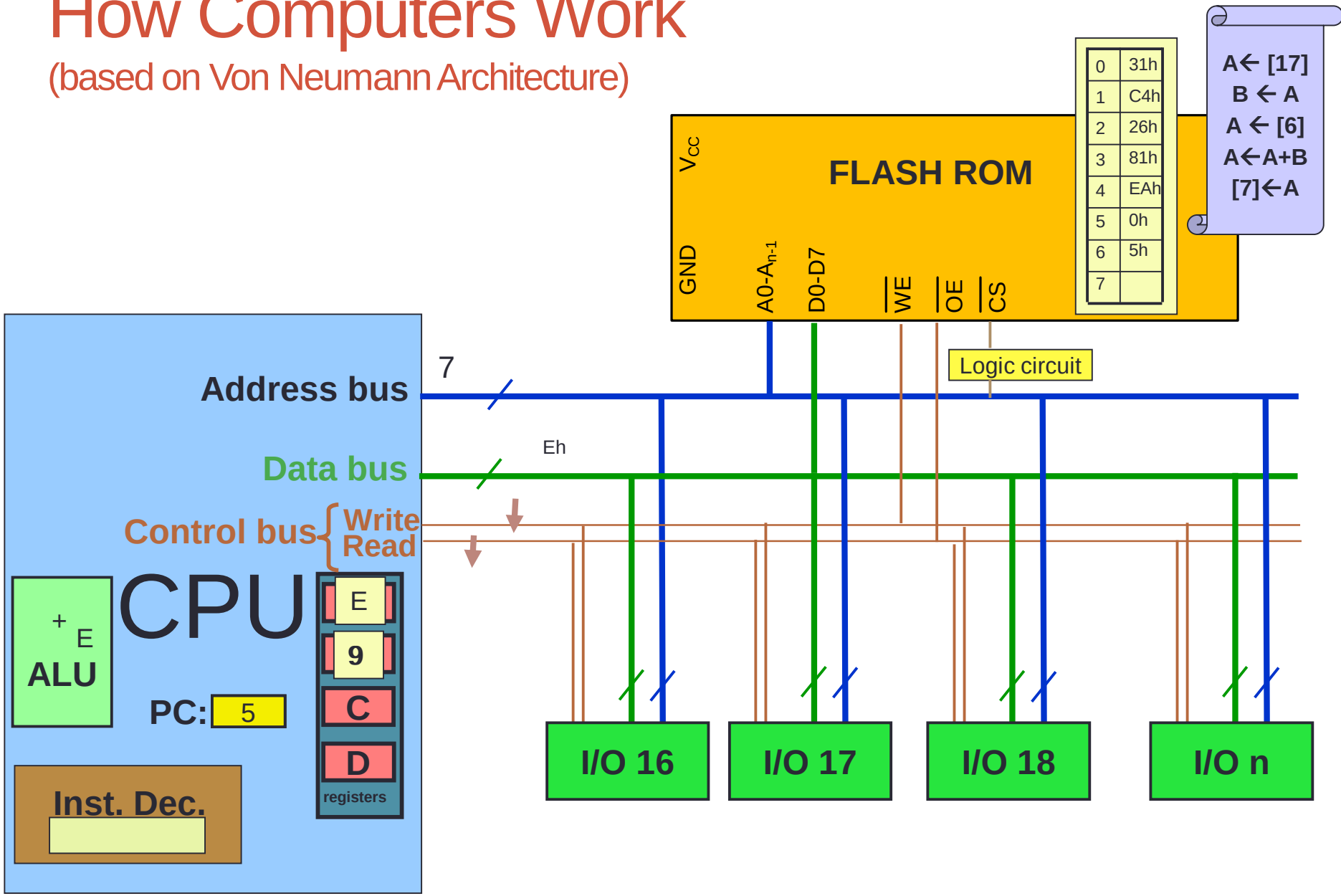

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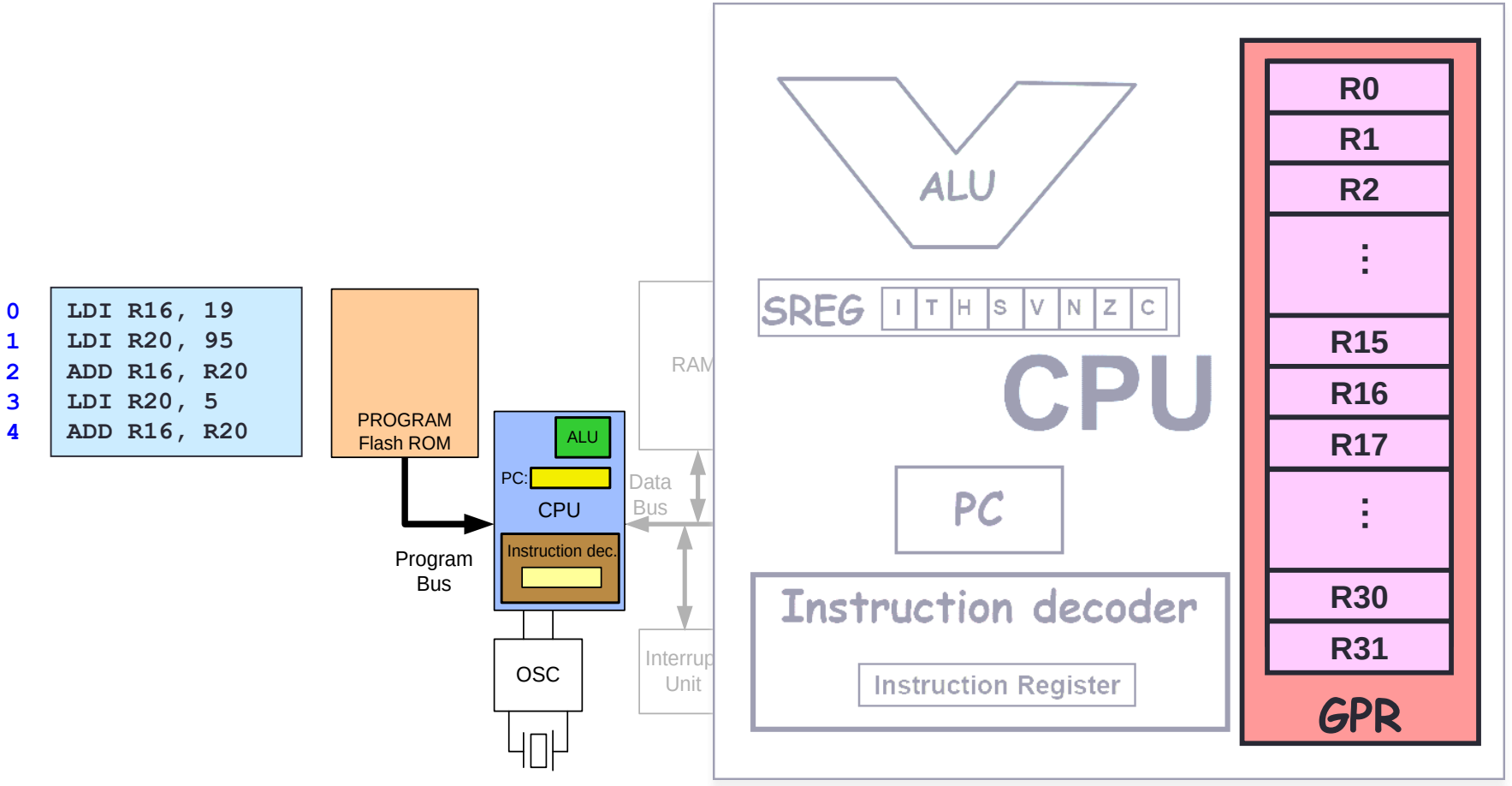
Let's Focus on CPU and ROM

- How do I assign a number to a GPR?



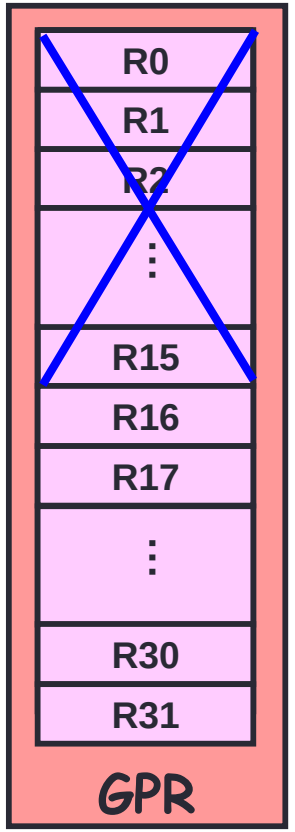
Instruction – LDI

- LDI (**L**oa**d** **I**mmediate) – loading values into the general purpose registers
- Syntax: **`LDI Rd, k`**

  where $16 \le d \le 31$, $0 \le k \le 255$

- Equivalent to: Rd = k in C language
- Example:
  - `LDI R16, 53` `;R16 = 53`
  - `LDI R23, $27` `;R23 = 0x27`
  - `LDI R30, 0x7F2` `;R30 = 0x7F2`

Is there any problem in the example?

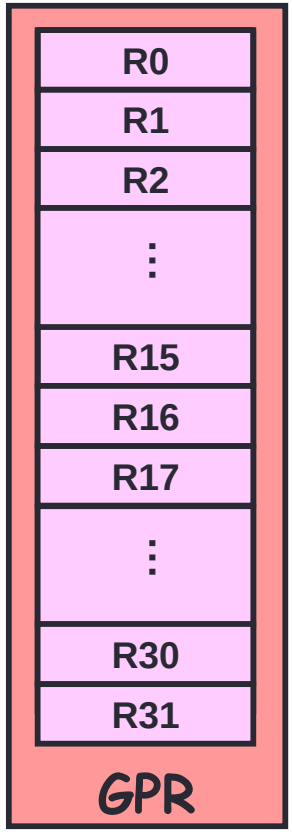


Instruction – ADD

- ADD – add and store values in the general purpose registers
- Syntax: **`ADD Rd, Rs`**

  where $0 \le d \le 31$, $0 \le s \le 31$

- Equivalent to: Rd = Rd + Rs in C language
- Example:
  - **`ADD R25, R9`** `;R25 = R25 + R9`
  - **`ADD R17, R30`** `;R17 = R17 + R30`



Sample Programs

- Write a program that calculates 19 + 95

```
LDI R16, 19   ;R16 = 19
LDI R20, 95   ;R20 = 95
ADD R16, R20  ;R16 = R16 + R20
```

- Write a program that calculates 19 + 95 + 5

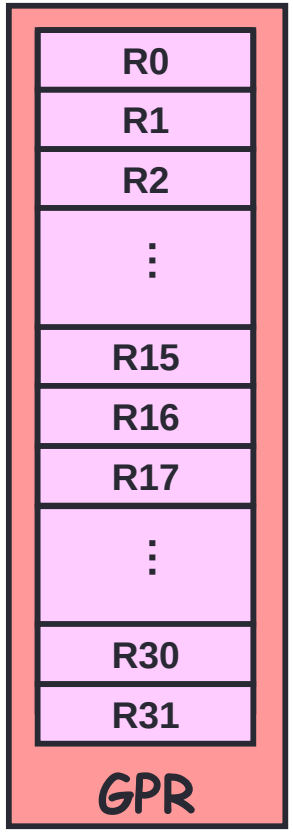
```
LDI R16, 19   ;R16 = 19
LDI R20, 95   ;R20 = 95
ADD R16, R20  ;R16 = R16 + R20
LDI R20, 5    ;R20 = 5
ADD R16, R20  ;R16 = R16 + R20
```

Instruction – SUB

- SUB – **sub**tract and store values in the general purpose registers
- Syntax: **`SUB Rd, Rs`**

  where $0 \le d \le 31$, $0 \le s \le 31$

- Equivalent to: Rd = Rd - Rs in C language
- Example:
  - **`SUB R25, R9`** `;R25 = R25 - R9`
  - **`SUB R17, R30`** `;R17 = R17 - R30`



Instruction – INC & DEC

- INC – **inc**rement the contents of a register by one
- Syntax: `INC Rd`
  where 0 ≤ d ≤ 31
- Equivalent to: Rd = Rd + 1 in C language

- DEC – **dec**rement the contents of a register by one
- Syntax: `DEC Rd`
  where 0 ≤ d ≤ 31
- Equivalent to: Rd = Rd - 1 in C language

- Example:
  - `INC R2 ;R2 = R2 + 1`

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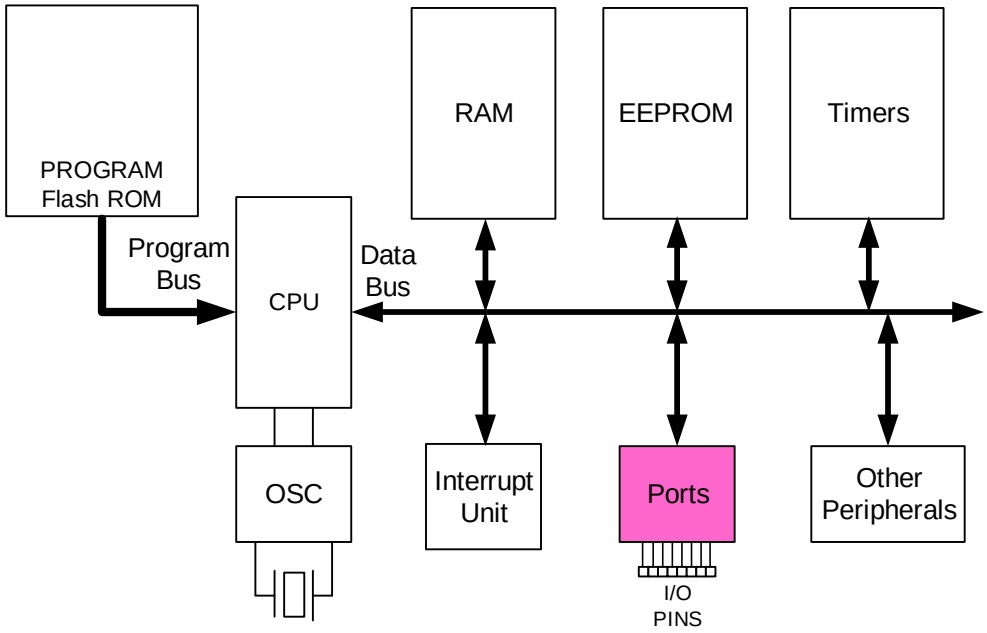
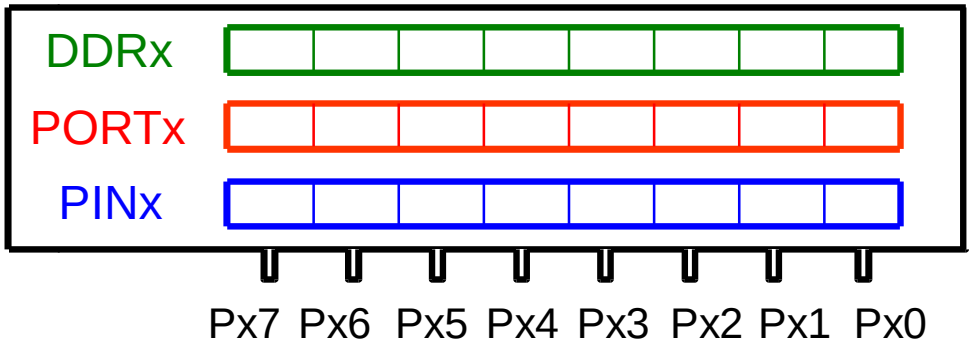
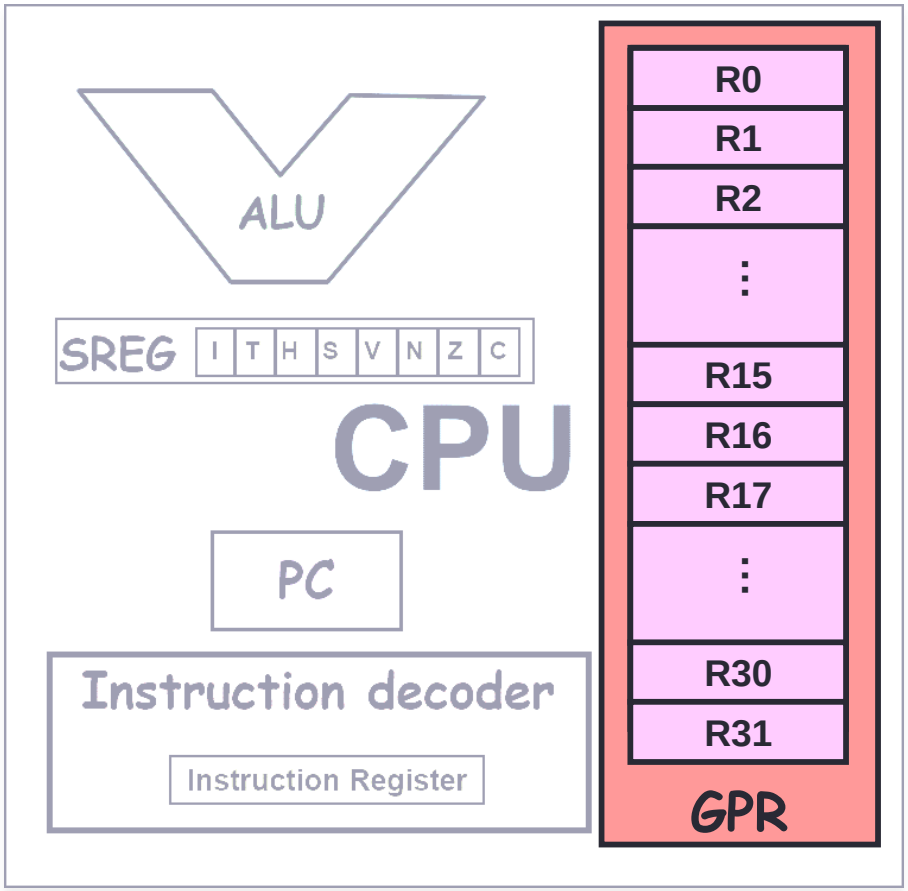


Review – I/O Registers

- Each port is associated with three 8-bit registers:
  - DDRx: data direction
  - PORTx: output
  - PINx: input

  where x = B, C, or D





Accessing I/O Registers – IN & OUT

- IN – load the reading from an I/O register to a GPR
- Syntax: **IN Rd, A**

  where 0 ≤ d ≤ 31, A is the name of an I/O register
- Example:
  - **IN R1,**
- OUT – sto
- Syntax: **OU**

  where 0 ≤
- Example:
  - **OUT DD**

Example: Write a program that adds the contents of the PINC to the contents of PIND and stores the result to PIND

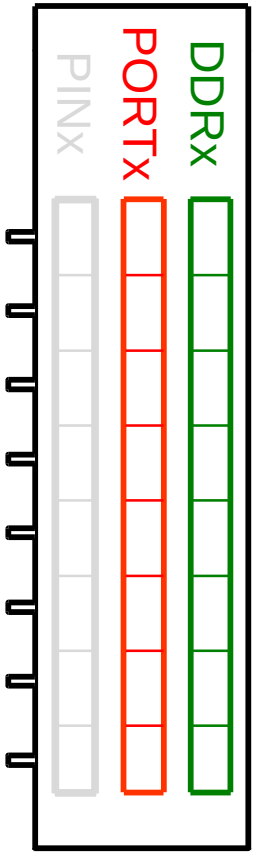
Solution:

```
IN R20, PINC   ;R20 = PINC
IN R21, PIND   ;R21 = PIND
ADD R20, R21   ;R20 = R20 + R21
OUT PIND, R20  ;PIND = R20
```

Note: IN and OUT only work for I/O registers

Review: Output Mode

- DDRx = 1
- PINx is NOT used
- PORTx contains the output voltages
  - 1: logic HIGH – 5V
  - 0: logic LOW – 0V



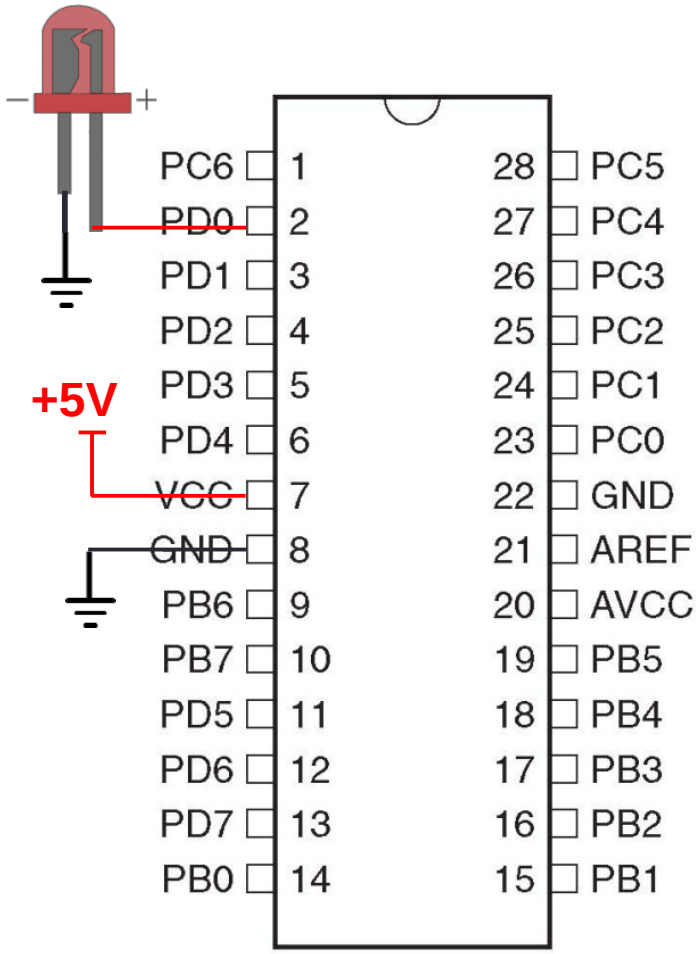
Example: Turn on An LED

- Turn on an LED connected to PD0
- Pseudo program code:

```
DDRD=0b00000001;

PORTD=0b00000001;
```

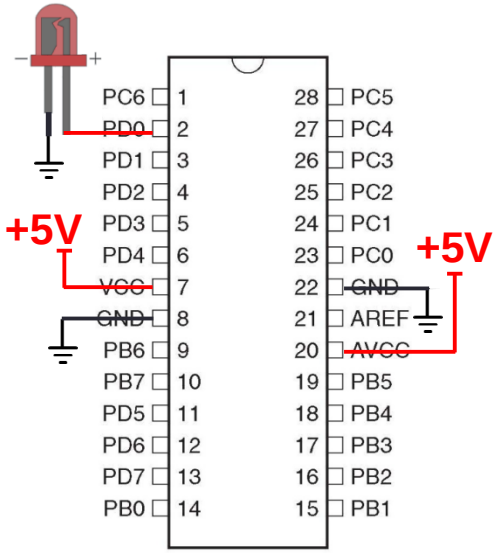
- Assembly program code:

```
LDI R20, 0b00000001

OUT DDRD, R20

OUT PORTD, R20
```



Example: Flash An LED

- Flash the LED at PD0
- Program code:

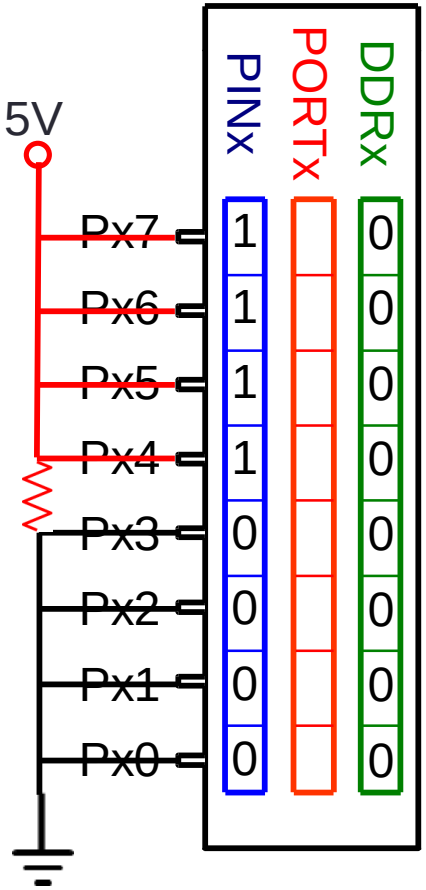



```
        LDI R20, 0b00000001
        LDI R21, 0b00000000
        OUT DDRD, R20
L1:     OUT PORTD, R20
        CALL DELAY
        OUT PORTD, R21
        CALL DELAY
        JMP L1
```

```
DELAY:LDI R17, 12
L2:   LDI R18, 0xFF
L3:   LDI R19, 0xFF
L4:   DEC R19
      BRNE L4
      DEC R18
      BRNE L3
      DEC R17
      BRNE L2
      RET
```

Review: Input Mode without Pull-up

- DDRx = 0
- PINx contains the input logic signal
  - 1: logic HIGH – 5V
  - 0: logic LOW – 0V
- PORTx is NOT used (if not considering pull-up)



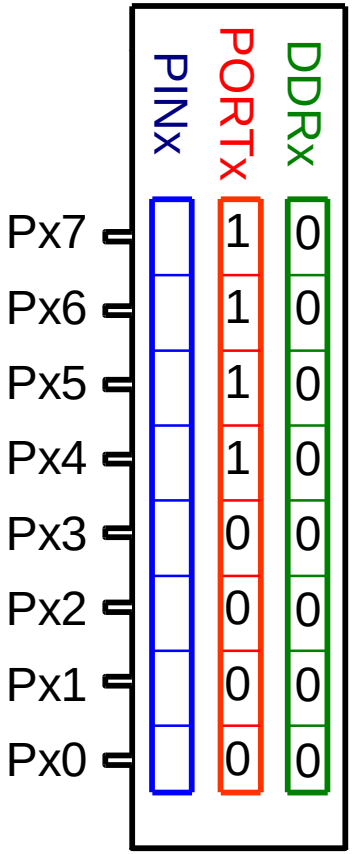
Example: Input Mode without Pull-up

- Make all the pins of Port B input
- Make all the pins of Port D output
- Send the reading from Port B to Port D, after adding a value 5 to it

```
LDI R16, 0x00     ;R16 = 00000000 (binary)
OUT DDRB, R16     ;make Port B an input port
LDI R16, 0xFF     ;R16 = 11111111 (binary)
OUT DDRD, R16     ;make Port D an output port
IN R16, PINB      ;read data from Port B to R16
LDI R17, 5
ADD R16, R17      ;add 5 to it
OUT PORTD, R16    ;send it to Port D
```

Review: Input Mode with Pull-up

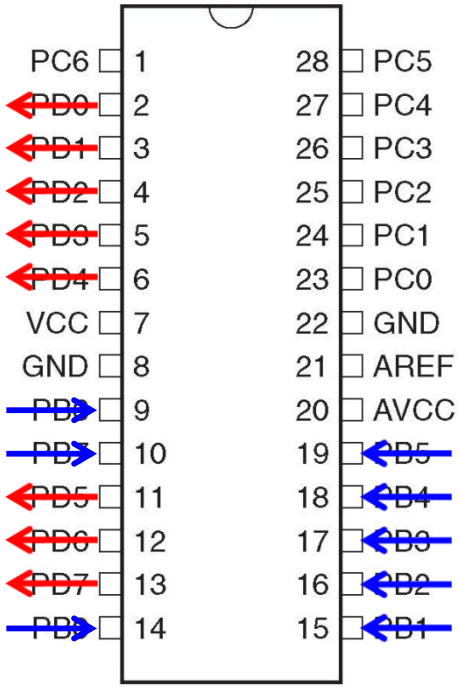
- DDRx = 0
- PORTx determines if pull-up resistors are connected or not
  - 1: pull-up ON
  - 0: pull-up OFF
- PINx contains the input logic signal
  - 1: logic HIGH – 5V
  - 0: logic LOW – 0V



Example: Input with Pull-up

- Read Port B and writes the readings to Port D, with pull-up enabled

```
    LDI   R20, 0x0    ;R20 = 00000000
    OUT   DDRB, R20   ;DDRB = R20
    LDI   R20, 0xFF   ;R20 = 11111111
    OUT   DDRD, R20   ;DDRD = R20
    OUT   PORTB, R20  ;pull-up enabled
    IN    R20, PINB   ;R20 = PINB
    OUT   PORTD, R20  ;PORTD = R20
```



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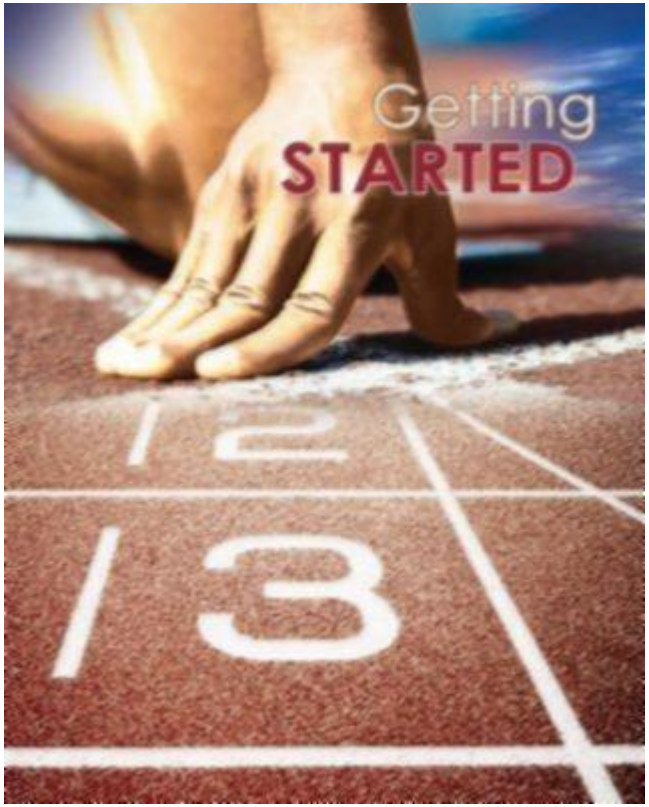

Reference

- ATmega328P data sheet
- AVR 8-bit instruction set
- AVR910: In-System Programming
- M. A. Mazidi, S. Naimi, and S. Naimi, *The AVR Microcontroller and Embedded Systems: Using Assembly and C*, Prentice Hall, 2010