Smart Software Project

Lecture: Week 4

ATmega2560 MCU

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Today

- Review from the last lecture
  - Analog vs. Digital, PWM
  - ATmega 2560
- Midterm: 2pm - 4:30pm, Mon Apr 11
- ATmega2560 microcontroller (MCU) architecture
  - CPU, Memory, I/O ports
- Announcement

Project Proposal Submission

- Project proposal per team
  - Due: 5pm on April 22, Friday
  - What to submit:
    - 1) Report hardcopy (printed report)
    - 2) Report softcopy (report file submission to Cyber Campus)
  - Where to submit:
    - HW box at "HyungJune Lee" in front of Asan 221-1
  - Language: English or Korean
  - Start discussing what your team will do with your team partner

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Project Proposal

- Project name (in English)
- Project statement
  - Goals of your project
- Project description
  - What will your project be doing?
  - Key functions
- Contributions of your work to research or industry
- Related work
  - Any existing previous works (at least two) similar to your project
  - What's similar and different?
- System overview & architecture
  - Block diagram of main blocks
  - What each block is doing
  - How each block is connected to other blocks, i.e., interface
    - Any message is exchanging between blocks? e.g., request/reply, data, etc?

Project Proposal

- Development environment
  - Arduino Mega 2560-based SmartCAR (or others if any, e.g., Android device)
  - Androx Studio IDE (or others if any)
  - What kind of sensors are to be used in your project
  - Other information from the connection to Android device or other devices? (location, Internet, etc.)
- Verification procedure
  - How can you test if your project works properly as designed
  - Test cases
- What do you anticipate will be the easiest part of your project?
- What do you anticipate will be the most difficult part of your project?
- Detailed time plan
- References

Evaluation criteria

- Format requirement
  - 5 points
- Creativity
  - 5 points
- Clarity
  - 5 points
- Concreteness (of software architecture)
  - 5 points
- Implementability
  - 5 points

- Total score: 25 points

Class Schedule

Week	Lecture Contents	Lab Contents
Week 1	Course introduction	Arduino introduction: platform & programming environment
Week 2	Embedded system overview & source management in collaborative repository (using GitHub)	Lab 1: Arduino Mega 2560 board & SmartCAR platform
Week 3	ATmega2560 Micro-controller (MCU): architecture & I/O ports, Analog vs. Digital, Pulse Width Modulation	Lab 2: SmartCAR LED control
Week 4	Analog vs. Digital & Pulse Width Modulation	Lab 3: SmartCAR motor control (Due: HW on creating project repository using GitHub)
Week 5	ATmega2560 MCU: memory, I/O ports, UART	Lab 4: SmartCAR control via Android Bluetooth
Week 6	ATmega2560 UART control & Bluetooth communication between Arduino platform and Android device	Lab 5: SmartCAR control through your own customized Android app (Due: Project proposal)
Week 7	Midterm exam	
Week 8	ATmega2560 Timer, Interrupts & Ultrasonic sensors	Lab 6: SmartCAR ultrasonic sensing
Week 9	Infrared sensors & Buzzer	Lab 7: SmartCAR infrared sensing
Week 10	Acquiring location information from Android device & line tracing	Lab 8: Implementation of line tracer
Week 11	Gyroscope, accelerometer, and compass sensors	Lab 9: Using gyroscope, accelerometer, and compass sensors
Week 12	Project	Team meeting (for progress check)
Week 13	Project	Team meeting (for progress check)
Week 14	Course wrap-up & next steps	
Week 15	Project presentation & demo I (Due: source code, presentation slides, & poster slide)	Project presentation & demo II
Week 16	Final week (no final exam)	

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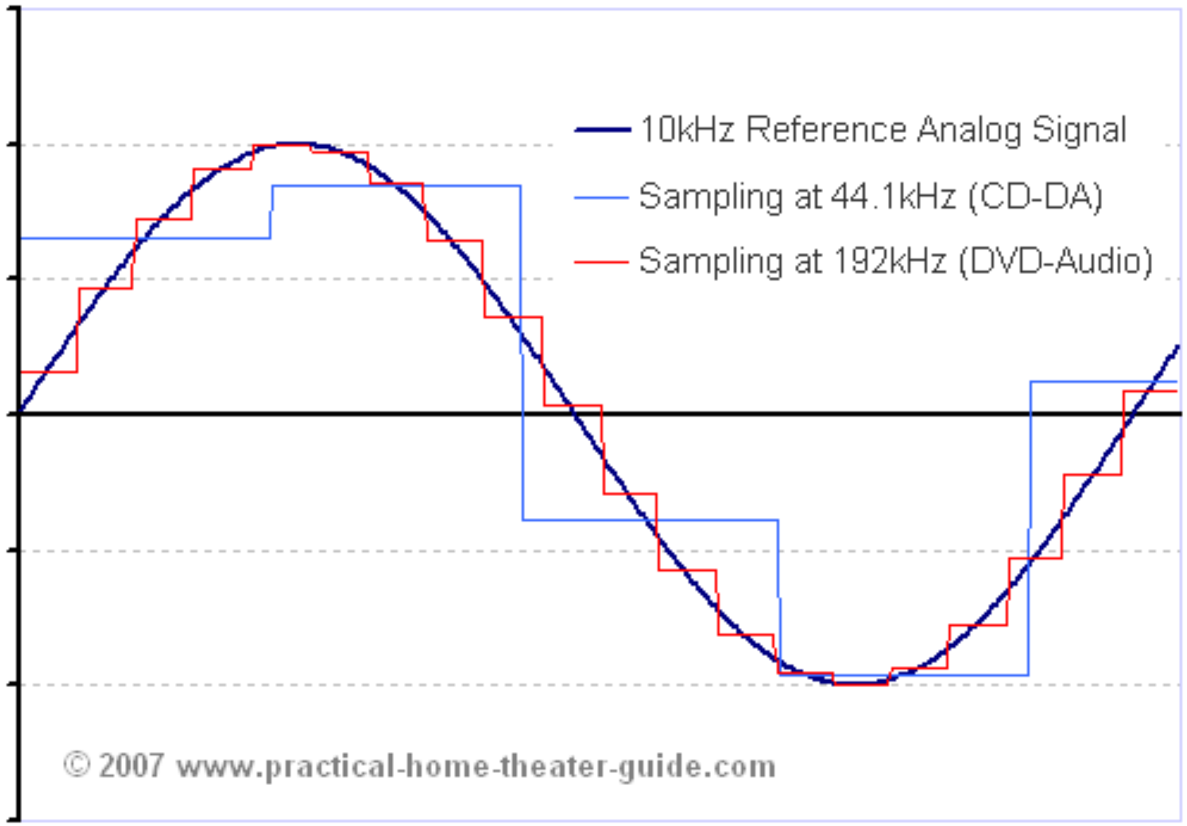
Analog vs. Digital

- Think about music stored on a CD: an analog signal captured on digital media
  - Sampling (with sampling rate)
  - Discretization (with discretization level)



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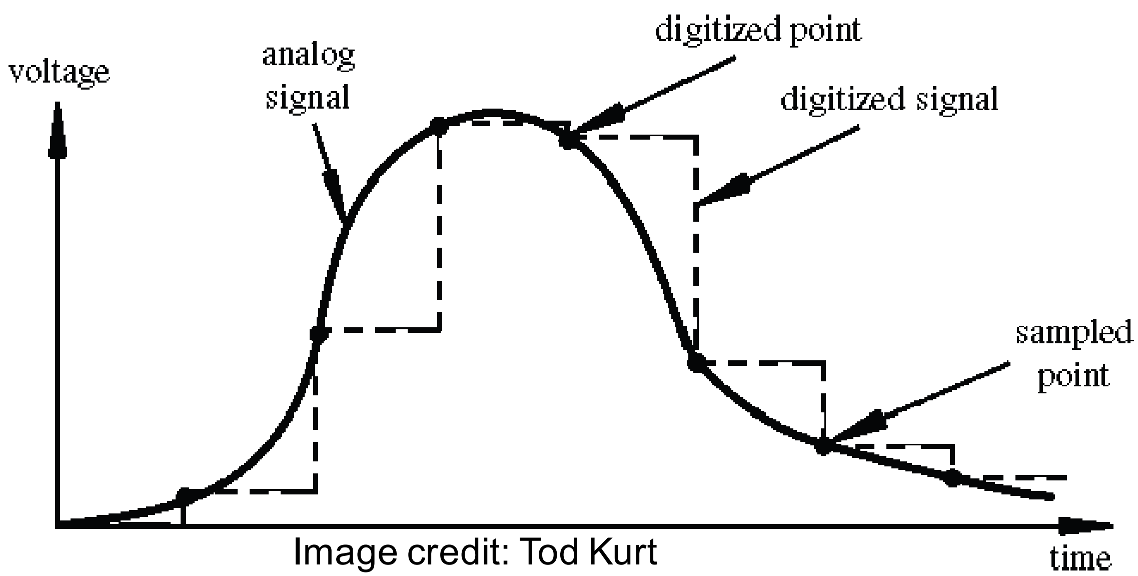
Arduino Analog Input



- *Resolution*: the number of different voltage levels (i.e., *states*) used to discretize an input signal
- Resolution values range from 256 states (8 bits) to 4,294,967,296 states (32 bits)
- The Arduino uses 1024 states (10 bits)
- Smallest measurable voltage change is 5V/1024 or 4.8 mV
- Maximum sample rate is 10,000 times a second

Analog Output

- Can a digital device produce analog output?

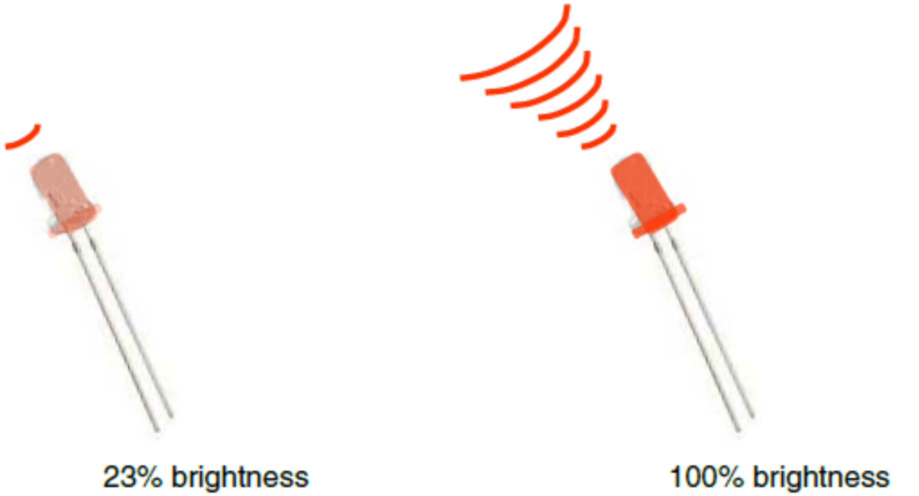


Image from *Theory and Practice of Tangible User Interfaces* at UC Berkley

- Analog output can be simulated using pulse width modulation (PWM)

Pulse Width Modulation

- Can't use digital pins to directly supply say 2.5V, but can pulse the output on and off really fast to produce the same effect

- On-off pulsing happens so quickly, the connected output device "sees" the result as a reduction in the voltage

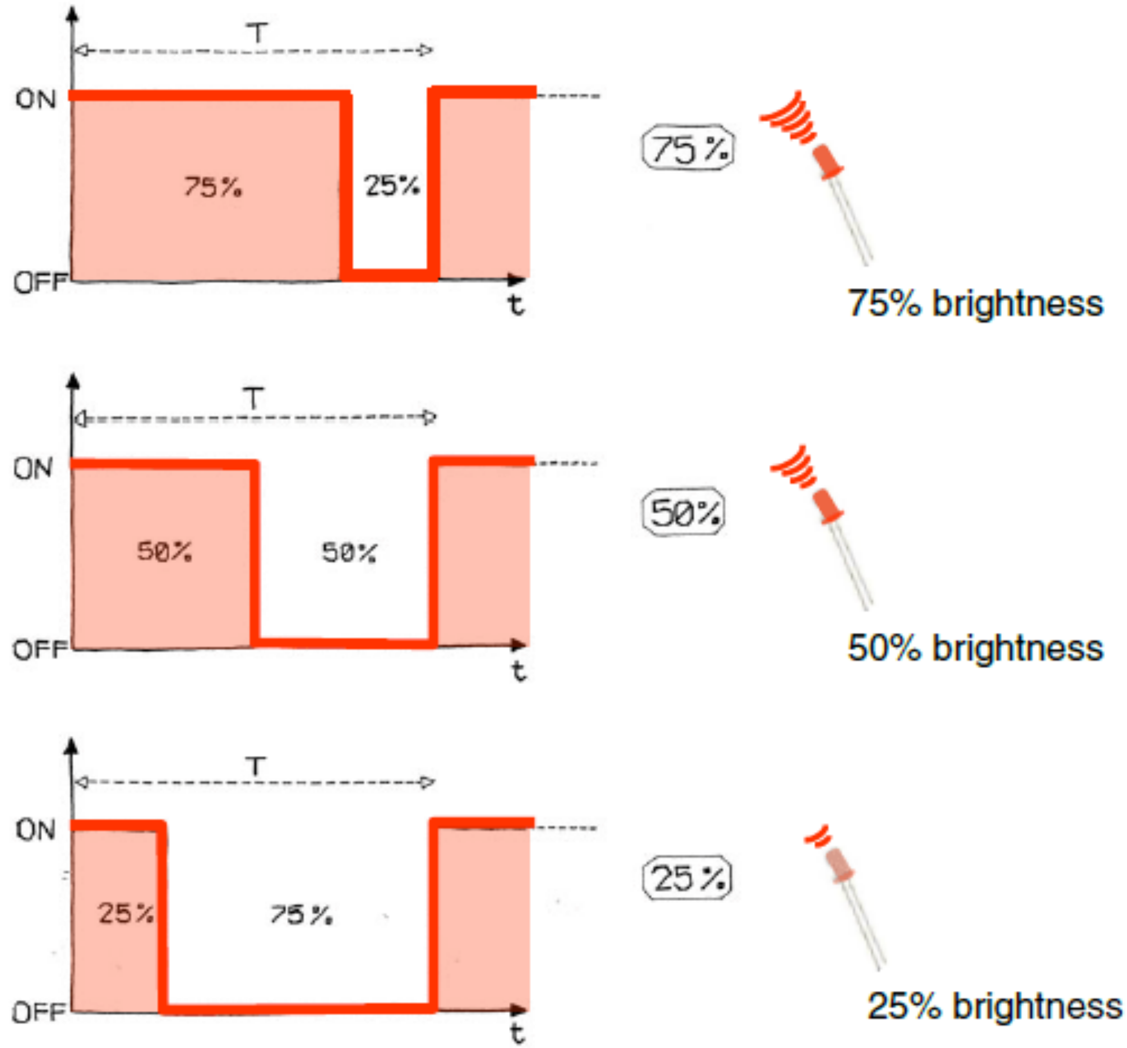


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Image from *Theory and Practice of Tangible User Interfaces* at UC Berkeley

PWM Duty Cycle

Output voltage = (on_time / cycle_time) * 5V

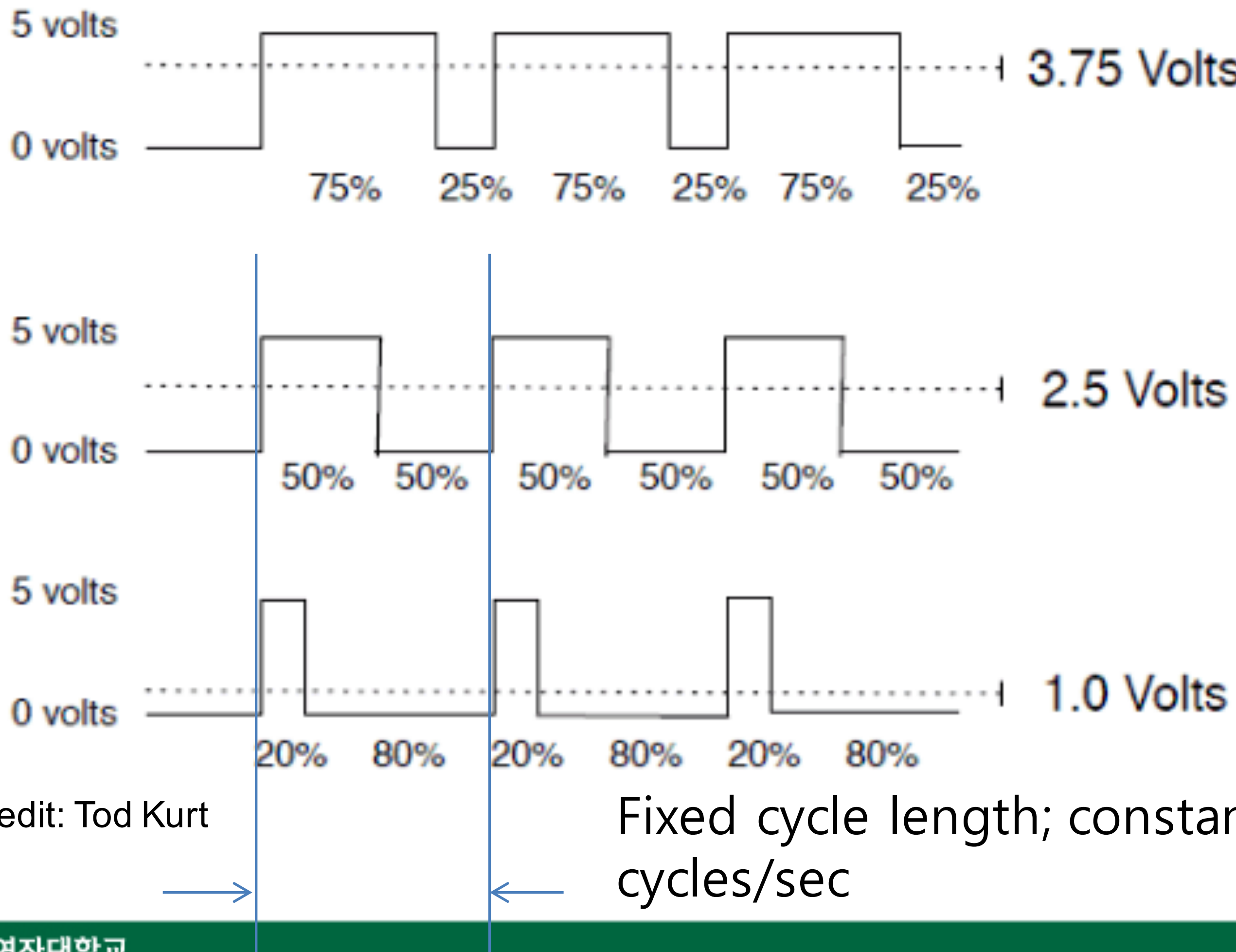


Image credit: Tod Kurt

Fixed cycle length; constant number of cycles/sec

Microprocessor vs. Microcontroller

- Microprocessor
  - Single chip semi-conductor device
  - But not a complete computer
  - Contains ALU, PC, timing & control units, registers
- Microcontroller
  - Functional computer **system-on-chip**
  - Contains microprocessor, memory, and programmable input/output peripherals
    - RAM, EEPROM
    - Timer, parallel I/O
    - ADC, DAC

What is ATmega2560?

- One of AVR 8-bit RISC **microcontrollers** by Atmel
- The acronym **AVR** has been reported to stand for
  - Advanced Virtual RISC and also for the chip's designers: Alf-Egil Bogen and Vegard Wollan who designed the basic architecture at the Norwegian Institute of Technology

- RISC stands for **reduced instruction set computer**

  : CPU design with a reduced instruction set as well as a simpler set of instructions (like for example PIC and AVR)

RISC vs. CISC

- RISC - Reduced Instruction Set Computer
  - The instruction set is small, and most instructions complete in one cycle (100 or less instruction types, smaller range of addressing modes).
  - Multiply & Divide performed using add/subtract & shift

RISC vs. CISC

- CISC - Complex Instruction Set Computer
  - The instruction set is large, and offers great variety of instructions (100 or more instruction types, many addressing modes).
  - Few instructions complete in one cycle
  - Typically includes multiply & divide operations that may take many cycles to complete.

Von Neumann vs. Harvard

- Von Neumann Architecture
  - The computer follows a step-by-step program that governs its operation.
  - The program is stored as data
  - No distinction between data and instructions.

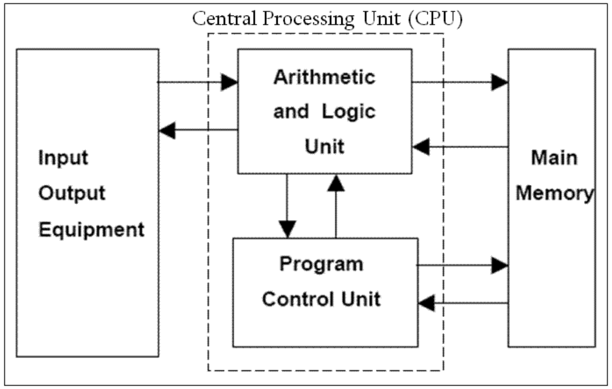
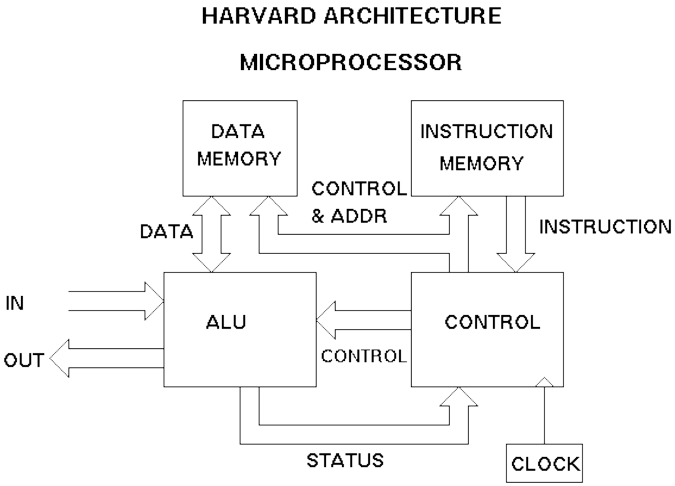


Figure : General structure of Von Neumann Architecture

- Harvard Architecture
  - Separate data and address spaces
  - The program is stored in its own address space

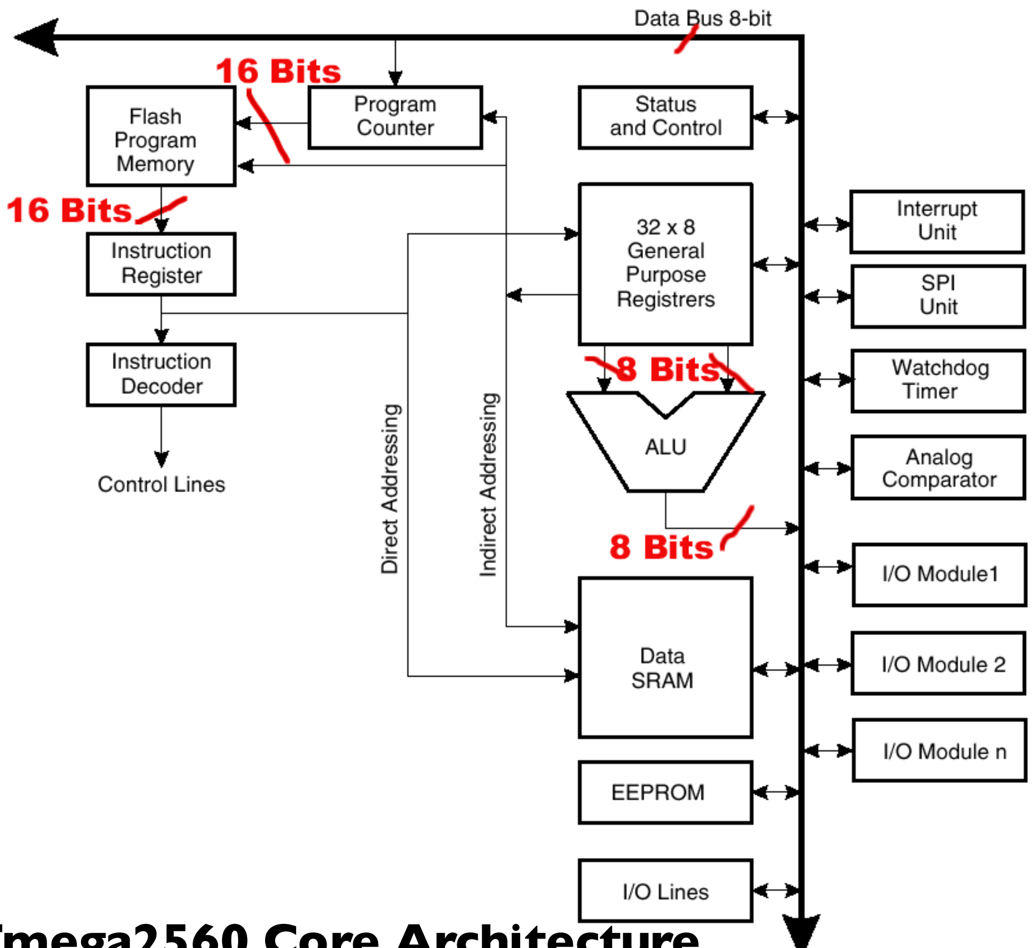


AVR 8-Bit RISC High Performance

- True single cycle execution
  - single-clock-cycle-per-instruction execution
  - PIC microcontrollers take 4 clock cycles per instruction
- One MIPS (mega instructions per second) per MHz
  - up to 20 MHz clock
- 32 x 8 bit general purpose registers
  - provide flexibility and performance when using high level languages
  - prevents access to RAM
- Harvard architecture
  - separate bus for program and data memory

ATmega2560 CPU Architecture

Figure 3. Block Diagram of the AVR Architecture



Mega2560 CPU Core

- Seperate Instruction and Data Memories (Harvard)
- all 32 General Purpose Registers connected to ALU
- I/O Modules connected to Data Bus and accessible via Special Function Registers

ATmega2560 Core Architecture

Data Memory Map

Figure 8-2. Data Memory Map

Address (HEX)	
0 - 1F	32 Registers
20 - 5F	64 I/O Registers
60 - 1FF	416 External I/O Registers
200	Internal SRAM (8192 × 8)
21FF	
2200	External SRAM (0 - 64K × 8)
FFFF	

AVR Register File

- The Register File
  - 32 8-bit registers

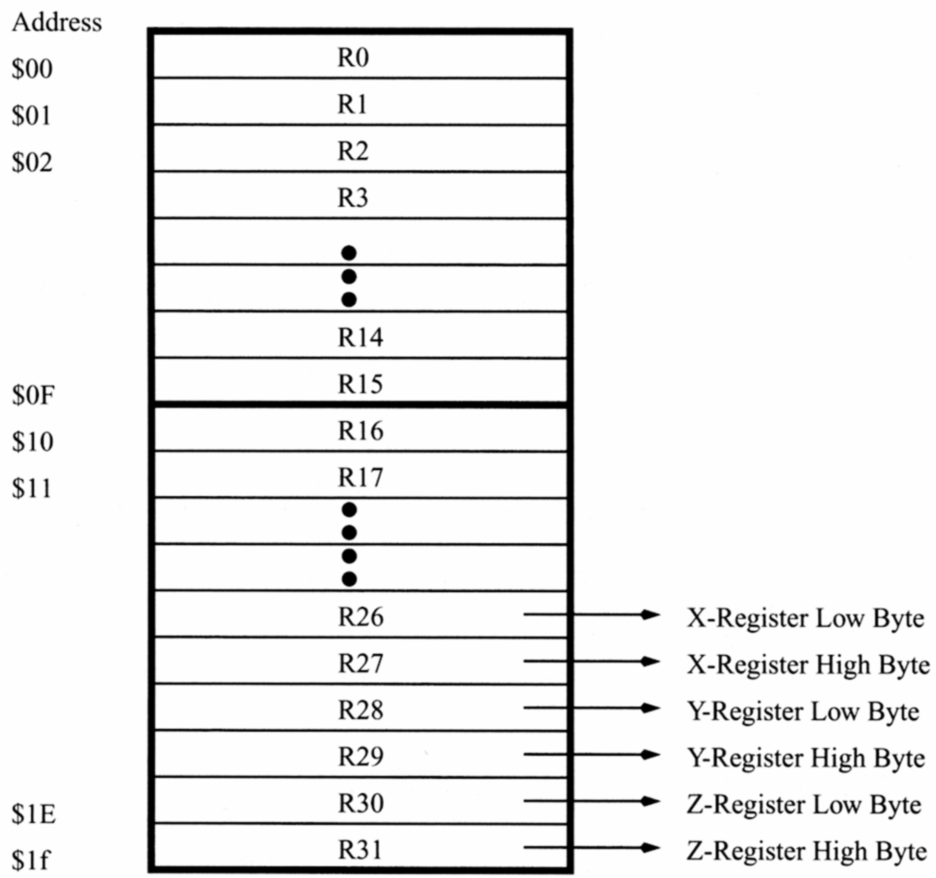


FIGURE 3.4 AVR register file.

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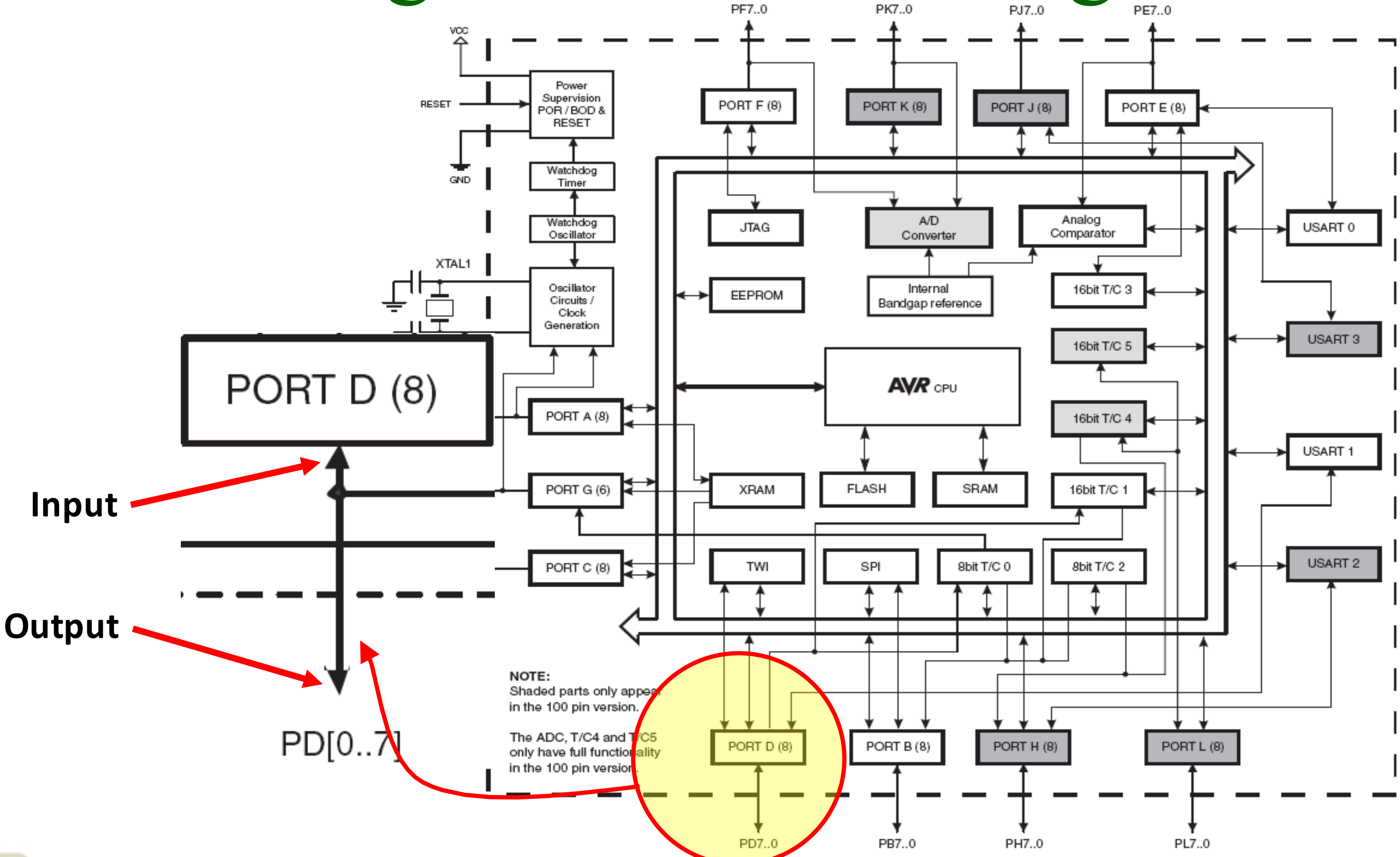
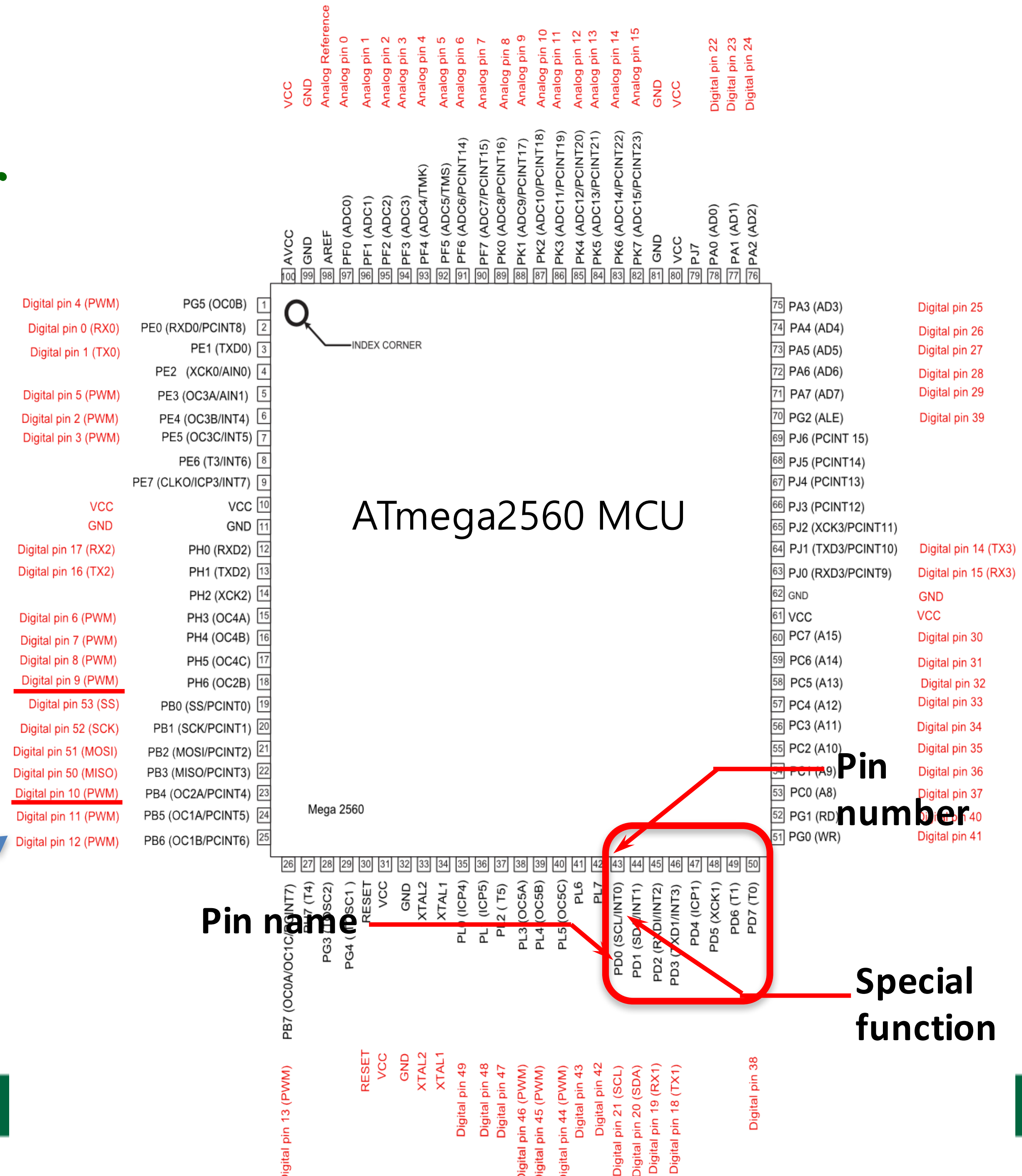
I/O Memory Registers

- **SREG**: Status Register
- **SP**: Stack Pointer Register
- **GIMSK**: General Interrupt Mask Register
- **GIFR**: General Interrupt Flag Register
- **MCUCR**: MCU General Control Register
- **MCUSR**: MCU Status Register
- **TCNTO**: Timer/Counter 0 Register
- **TCCR0A**: Timer/Counter 0 Control Register A
- **TCCR0B**: Timer/Counter 0 Control Register B
- **OCR0A**: Timer/Counter 0 Output Compare Register A
- **OCR0B**: Timer/Counter 0 Output Compare Register B
- **TIMSK0**: Timer/Counter 0 Interrupt Mask Register
- **TIFR0**: Timer/Counter 0 Interrupt Flag Register
- **EEAR**: EEPROM Address Register
- **EEDR**: EEPROM Data Register
- **EECR**: EEPROM Control Register
- **PORTB**: PortB Data Register
- **DDRB**: PortB Data Direction Register
- **PINB**: Input Pins on PortB
- **PORTD**: PortD Data Register
- **DDRD**: PortD Data Direction Register
- **PIND**: Input Pins on PortD
- **SPI** I/O Data Register
- **SPI** Status Register
- **SPI** Control Register
- **UART** I/O Data Register
- **UART** Status Register
- **UART** Control Register
- **UART** Baud Rate Register
- **ACSR**: Analog Comparator Control and Status Register

ATmega2560 Block Diagram



Atmega2560 Microcontroller Pin Mapping to Arduino Board



Arduino ADK Board Pin Mapping

PORT Pin and Register Details

PORTD – The Port D Data Register

Bit	7	6	5	4	3	2	1	0	
0x0B (0x2B)	PORTD7	PORTD6	PORTD5	PORTD4	PORTD3	PORTD2	PORTD1	PORTD0	PORTD
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

DDRD – The Port D Data Direction Register

Bit	7	6	5	4	3	2	1	0	
0x0A (0x2A)	DDD7	DDD6	DDD5	DDD4	DDD3	DDD2	DDD1	DDD0	DDRD
Read/Write	R/W	R/W	R/W	R/W	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

PIND – The Port D Input Pins Address

Bit	7	6	5	4	3	2	1	0	
0x09 (0x29)	PIND7	PIND6	PIND5	PIND4	PIND3	PIND2	PIND1	PIND0	PIND
Read/Write	R	R	R	R	R	R	R	R	
Initial Value	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	

Parallel I/O Ports

- Most general-purpose I/O devices
- Each I/O Port has 3 associated registers

1. DDRx (where “x” is A, B, C…)
    - Data Direction Register Port x
    - Determines which bits of the port are input and which are output

    DDRB = 0x02; /* sets the second lowest of port B to output” */

2. PORTx
    - Port Driver Register for write

    PORTB = 0x02; /* sets the second bit of port B and clears the others */

3. PINx
    - Port Pins Registers for read
    - Returns the status of all 8 port B pins.

    unsigned int x;
    x = PINB; /* Places the status of port B into variable x */

Input/Output Ports

- All ports initially set to input
  - DDRB = 0x00; /* by default */
- Must declare all output pins using DDRx (Data Direction Registry Port x)
- The default for input port pins is *floating*
  Can supply a pull-up resistor by writing logic 1 to the corresponding bit of the port driver register

  DDRA = 0xC0; /* upper 2 bits are output, lower 6 bits are input*/

  PORTA = 0x03; /enable internal pull-ups on lowest 2 bits*/
- Port pins in output mode are typically capable of sinking 20 mA, but source much less

Data Direction Register (DDR)

- If the bit is *zero* -> pin will be an *input*
  - Making a bit to be zero == '**clearing** the bit'
- If the bit is *one* -> pin will be an *output*
  - Making a bit to be one == '**setting** the bit'
- To change the data direction for a set of pins belonging to PORTx at the same time:
  1. Determine which bits need to be set and cleared in DDRx
  2. Store the binary number or its equivalent (in an alte rnate base, such as hex) into DDRx

Bitwise Operations

- Treat the value as an array of bits
- Bitwise operations are performed on pairs of corresponding bits

```
X = 0b0011, Y = 0b0110
Z = X | Y = 0b0111
Z = X & Y = 0b0001
Z = X ^ Y = 0b0101
Z = ~X = 0b1100
Z = X << 1 = 0b0110
Z = x >> 1 = 0b0001
```

Bit Masks

- Need to access a subset of the bits in a variable
  - Write or read
- Masks are bit sequences which identify the importa nt bits with a '1' value
- Ex. Set bits 3 and 5 or X, don't change other bits

  X = 01010101, mask = 0010100

  X = X | mask
- Ex. Clear bits 2 and 4

  mask = 11101011

  X = X & mask

Bit Assignment Macros

```
#define SET_BIT(p,n) ((p) |= (1 << (n)))
#define CLR_BIT(p,n) ((p) &= ~(1 << (n)))
```

- 1 << (n) and ~(1 << (n)) create the mask
  - Single 1 (0) shifted n times
- Macro doesn’t require memory access (on stack)

Example 1

- Make Arduino pin 10 (PB4) to be output
  - Arduino pin 10 connected to SmartCAR front LED

- Arduino approach

```
pinMode(10, OUTPUT);
```

- Alternative approach

```
DDRB = 0b00010000;

or

DDRB = 0x10;

or

DDRB |= (1<<PB4);
```

Example 2

- Make pins Arduino pins 0 and 1 (PE0 and PE1) inputs, and turn on initially (enabling pull-up R)

- Arduino approach

```
pinMode(0, INPUT);
pinMode(1, INPUT);
digitalWrite(0, HIGH);
digitalWrite(1, HIGH);
```

- Alternative approach

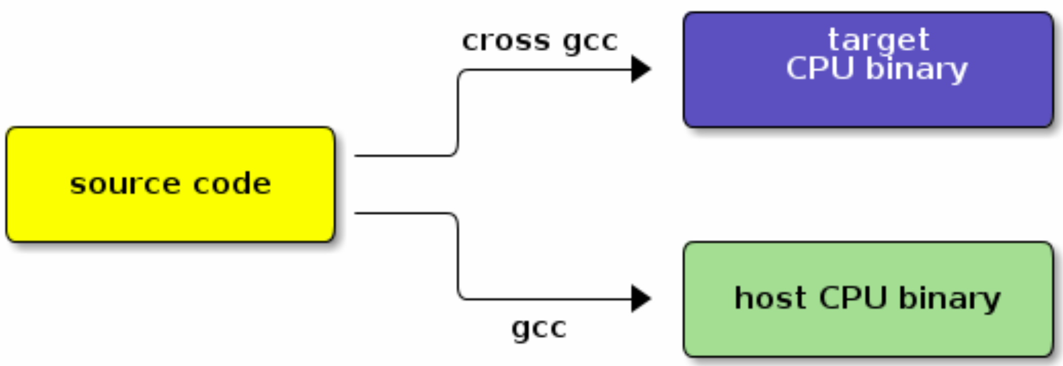
```
DDRE = 0; // all PORTE pins inputs
PORTE = 0b00000011;
or
PORTE = 0x03;

or better yet:
DDRE &= ~(1<<PE1 | 1<<PE0);
PORTE |= (1<<PE1 | 1<<PE0);
```

QUESTION)
WHAT IS CROSS-COMPILER IN EMBEDDED SYSTEM?

Cross-Compiler

- A compiler which generates code for a platform different from the one it executes on
  - Executes on host, generates code for target
- Generates an **object file (.o)**
- Contains machine instructions
- **References are virtual**
  - Absolute addresses are not yet available
  - Labels are used instead



Course Announcement

- For lab session, we will cover
  - SmartCAR Motor Control

- Next week, we will study on
  - ATmega2560 microcontroller (MCU) architecture
  - Timer & Interrupts