CO321 : Embedded Systems

Programming AVR microcontrollers

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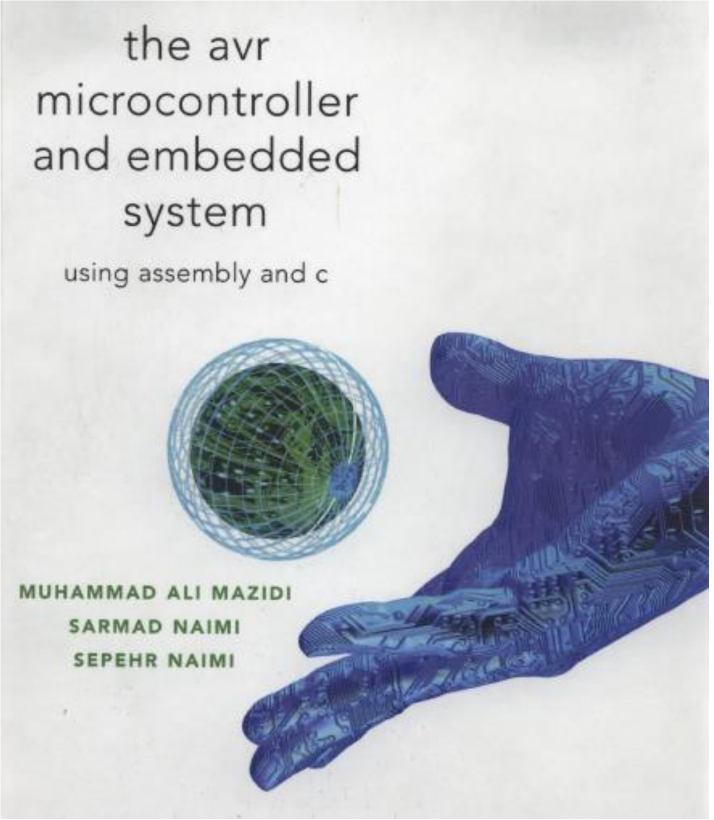
Outline

- Introduction to AVR microcontroller
- AVR architecture
- AVR programming in C
- AVR pin description and flashing

Reference :

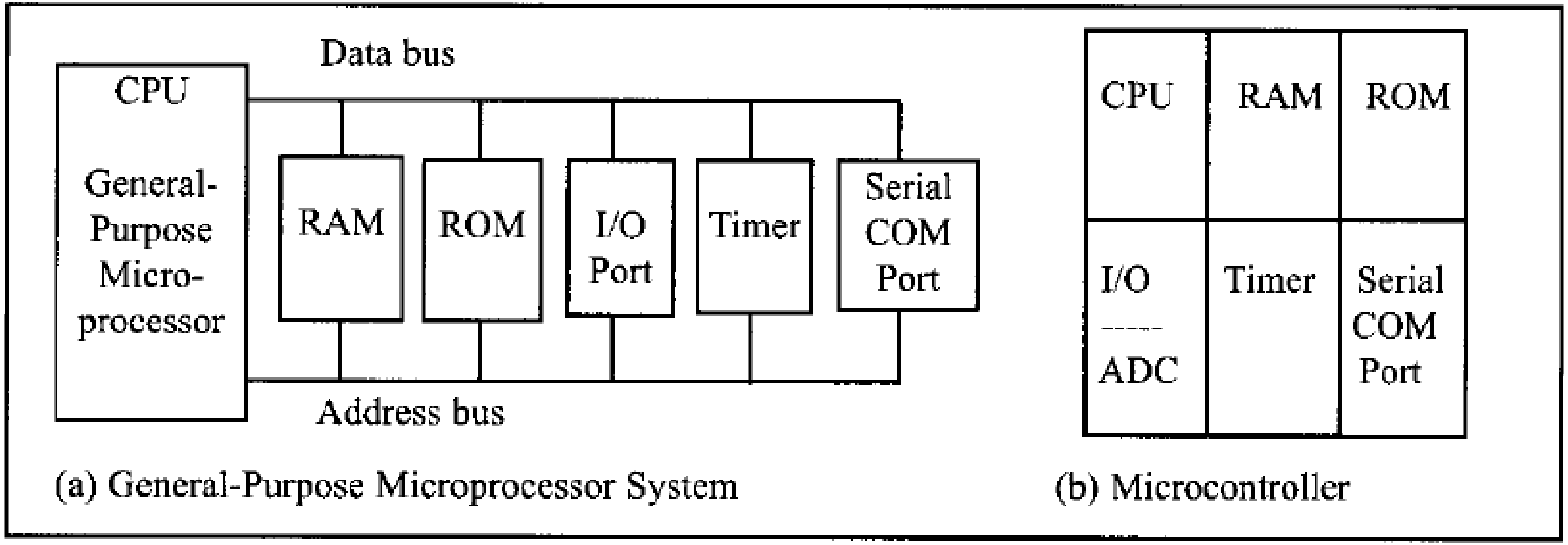
The AVR microcontroller and embedded systems using assembly and C

chapter 1,2,7,8



Introduction to AVR microcontroller

Microcontroller vs microprocessor



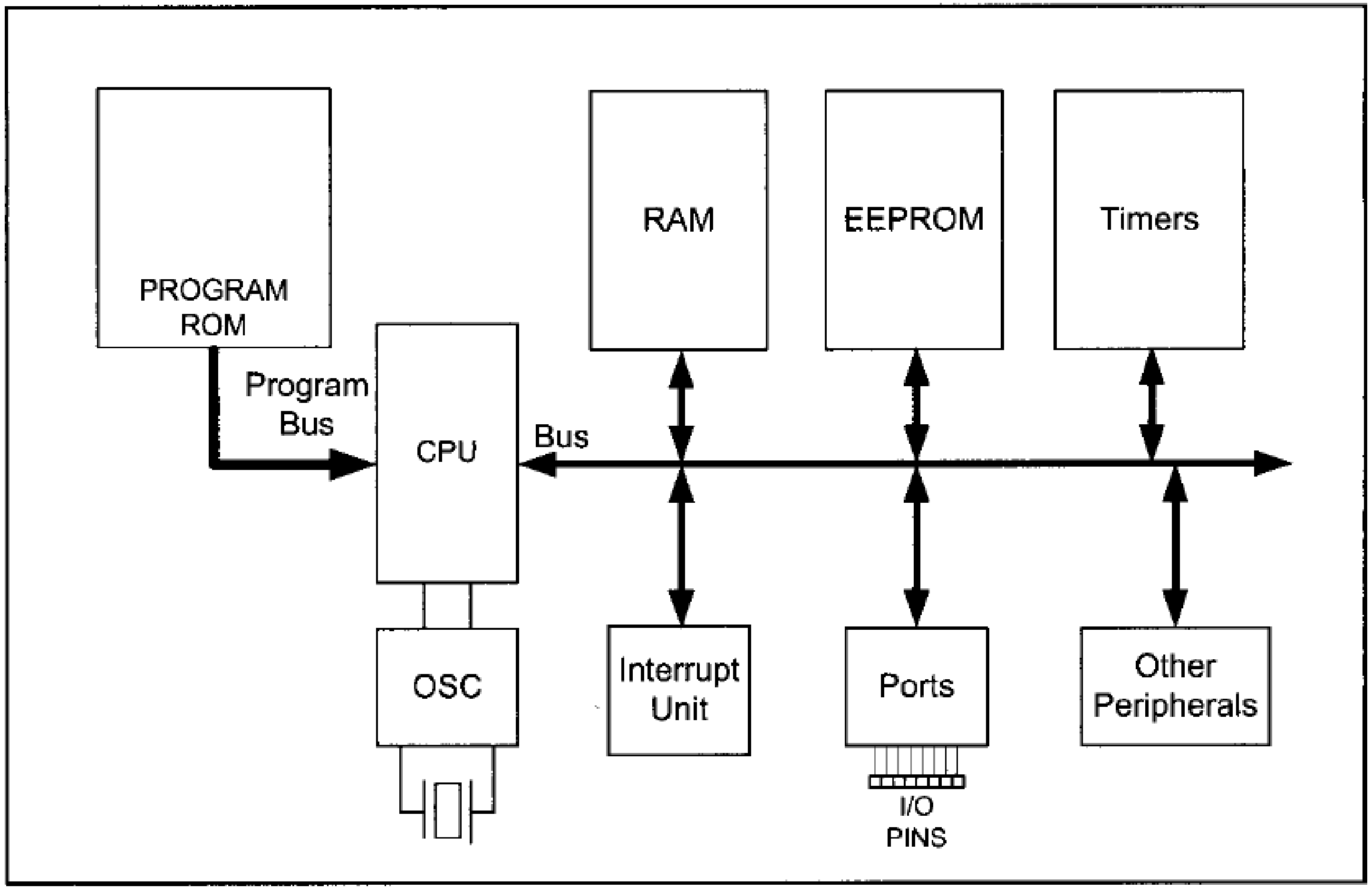
(a) General-Purpose Microprocessor System

(b) Microcontroller

Different microcontrollers

- Microchip PIC
- Atmel AVR
- Zilog Z8
- Freescale Semiconductors (Formerly Motorola)
- Intel 8051

A simplified view of an AVR microcontroller



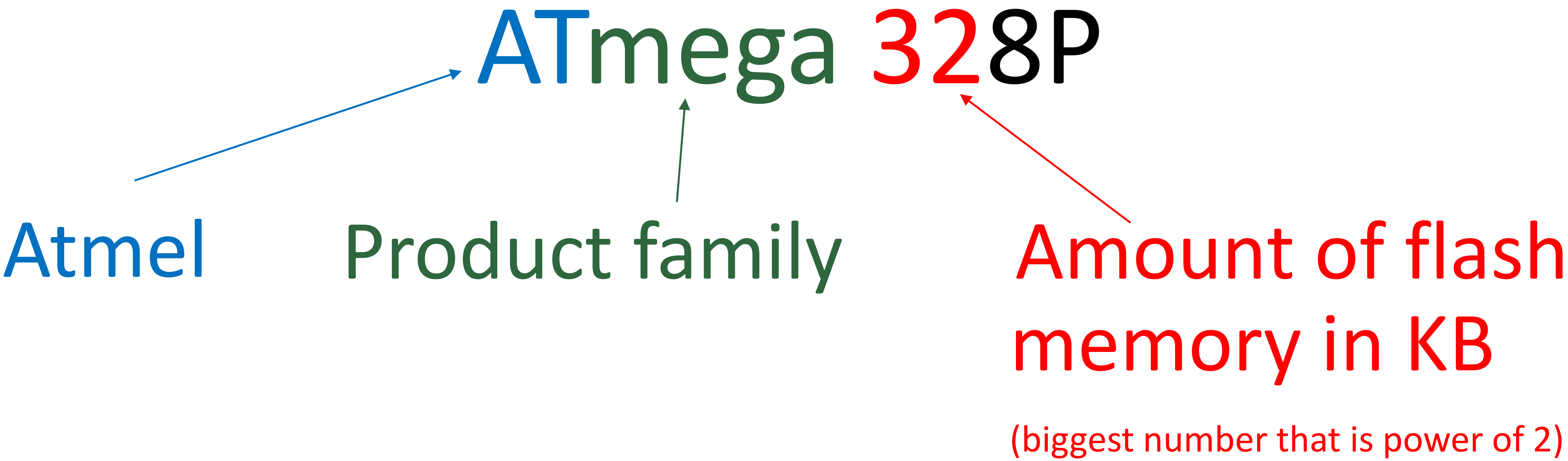
Harvard architecture :

Separate bus for instruction memory and data memory

AVR families

Family	Description
Classic (AT90Sxxxx)	Original AVR chip which is outdated now
Mega (ATmegaxxxx)	More than 120 instructions and lot of peripherals and hence suitable for most designs
Tiny (ATtinyxxxx)	Lesser instructions and smaller packages for low cost and low power applications
Special purpose	Considered a subset of other groups with special capabilities such as USB controller, Ethernet controller, LCD controller, etc…

Product naming scheme



ATmega 328P

Atmel

Product family

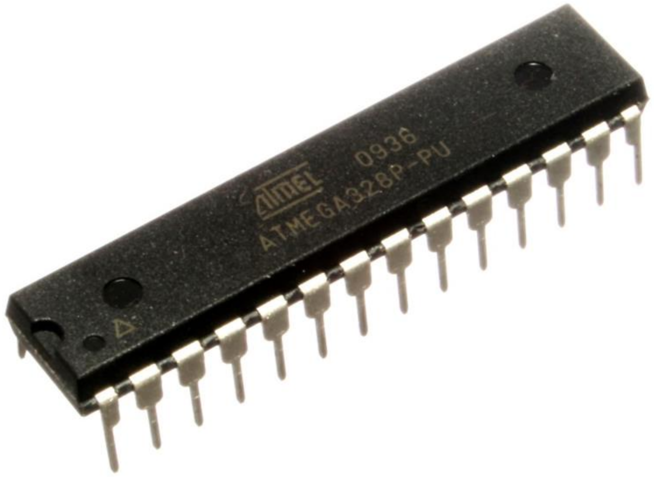
Amount of flash memory in KB

(biggest number that is power of 2)

There are some exceptions as well

ATmega328P

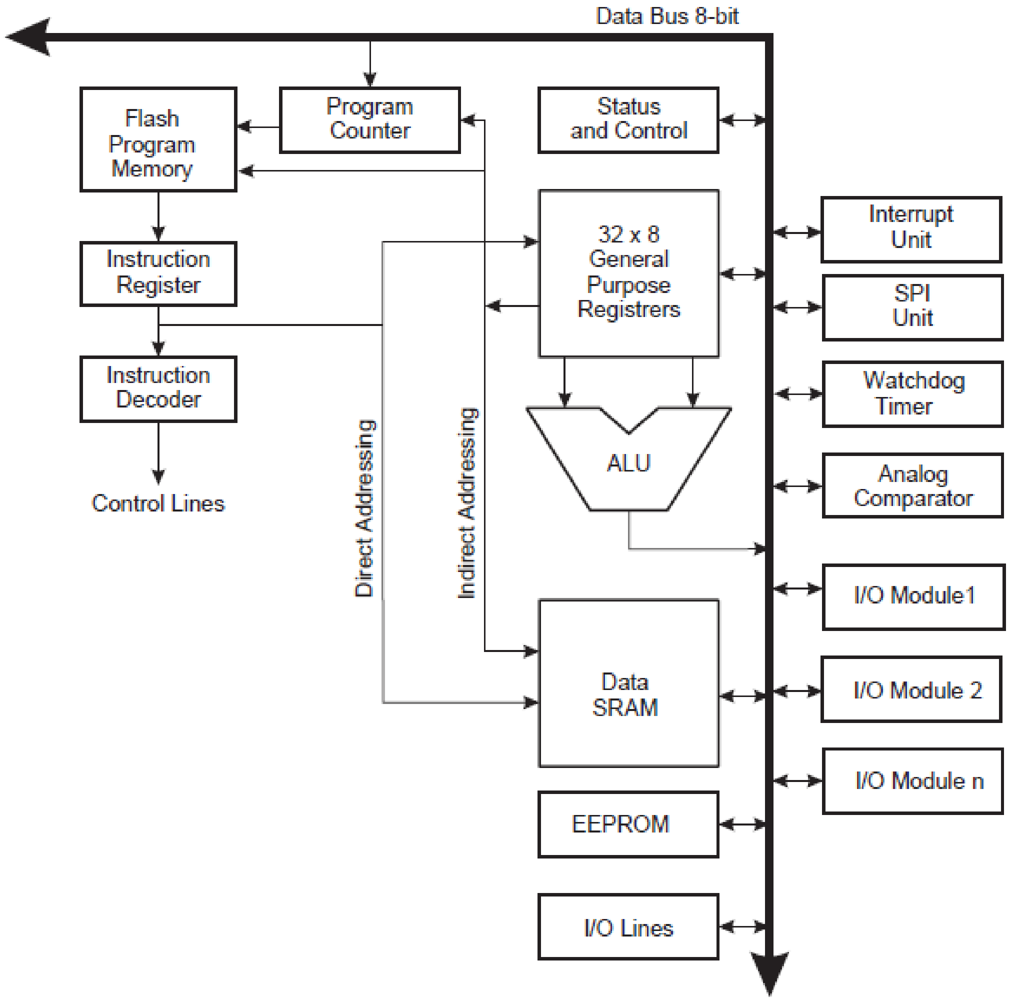
For our labs we use **ATmega328P** chip which is the microcontroller found on Arduino Uno.



Datasheet :
http://www.atmel.com/images/atmel-8271-8-bit-avr-microcontroller-atmega48a-48pa-88a-88pa-168a-168pa-328-328p_datasheet_complete.pdf

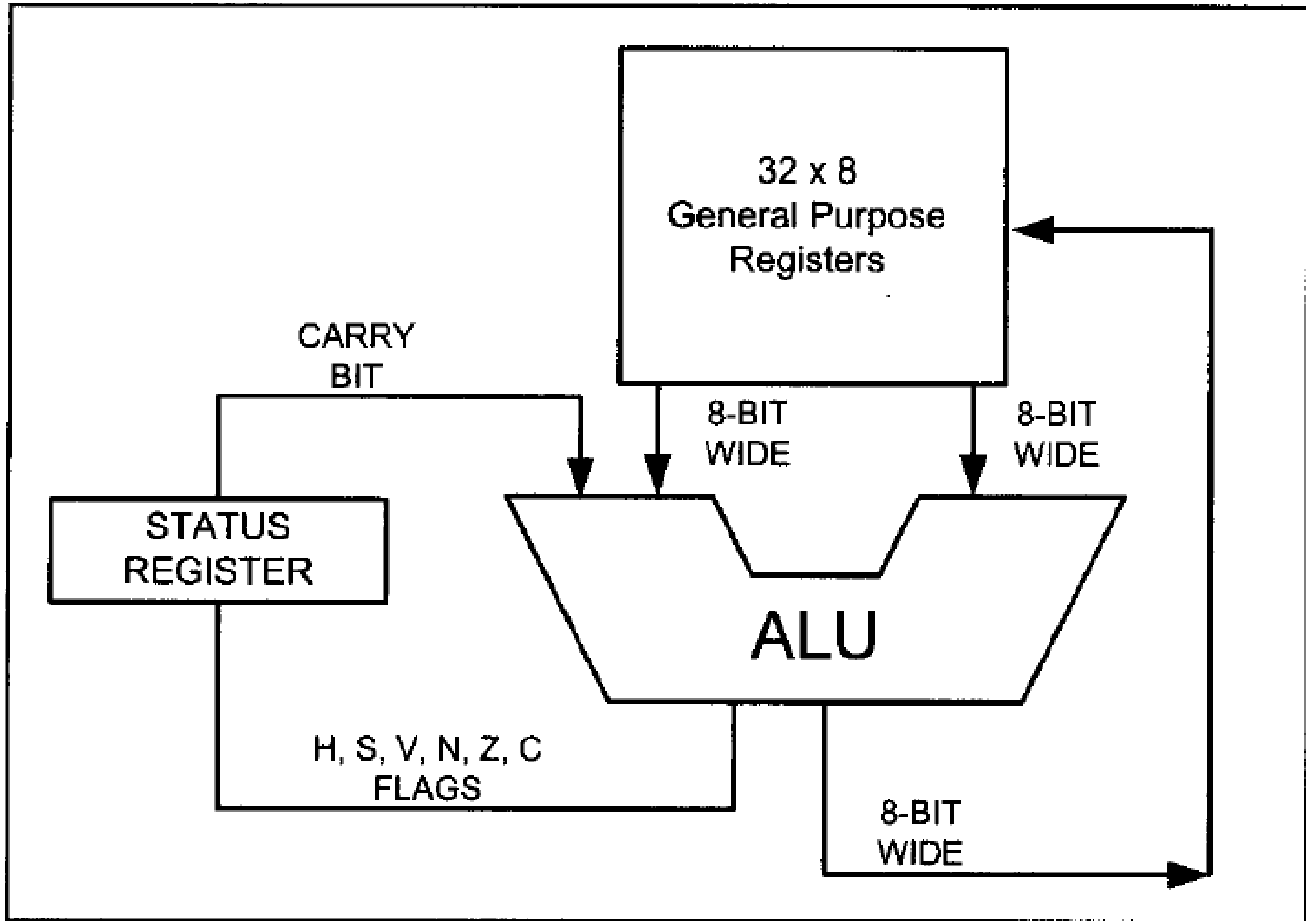
8 bit processor, 131 instructions, 32 general purpose registers
32KB FLASH, 2KB SRAM, 1KB EEPROM
3 timers, 10 bit ADC, USART, SPI and many other peripherals

ATmega328P block diagram



AVR architecture

AVR CPU core

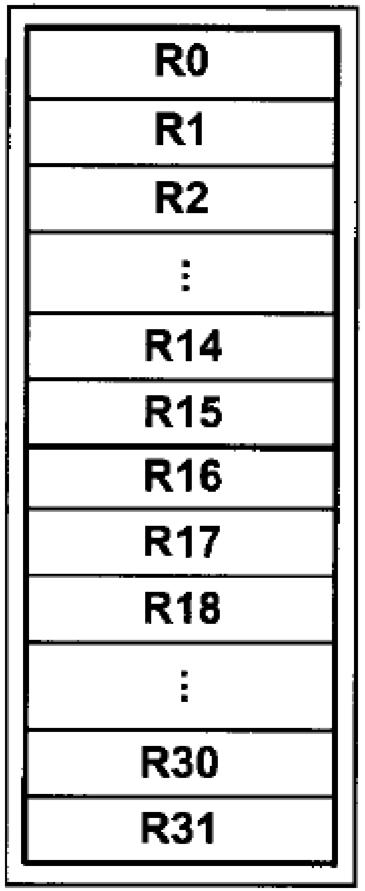

32 x 8
General Purpose
Registers
CARRY
BIT
8-BIT
WIDE
8-BIT
WIDE
STATUS
REGISTER
ALU
H, S, V, N, Z, C
FLAGS
8-BIT
WIDE

General Purpose Registers (GPRs)

- 32 GPRs
- All are 8-bit
- Located at lowest memory addresses
- Can be used by any arithmetic or logical instruction
- GPR in AVR are the same as the accumulator in other microprocessors

Example usage by add instruction :

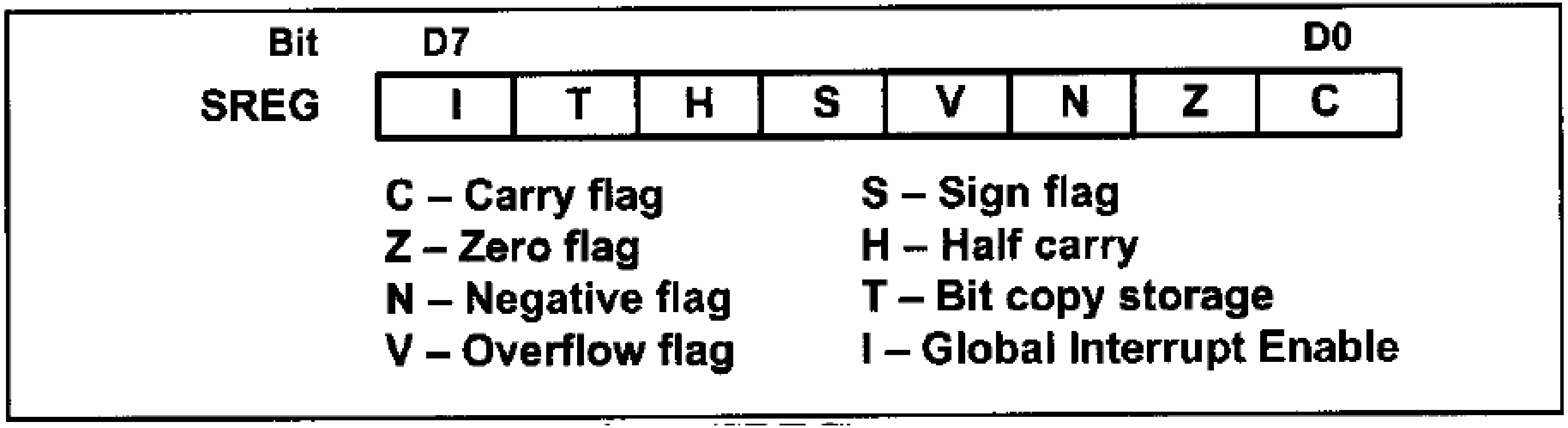
ADD R16,R17 ; R16=R16+R17



R0
R1
R2
⋮
R14
R15
R16
R17
R18
⋮
R30
R31

Status Register (SReg)

- This is the flag register in AVR
- 8-bit register
- Corresponding flags in status register are set by the execution of arithmetic or logical instructions



Bit	D7							D0
SREG	I	T	H	S	V	N	Z	C

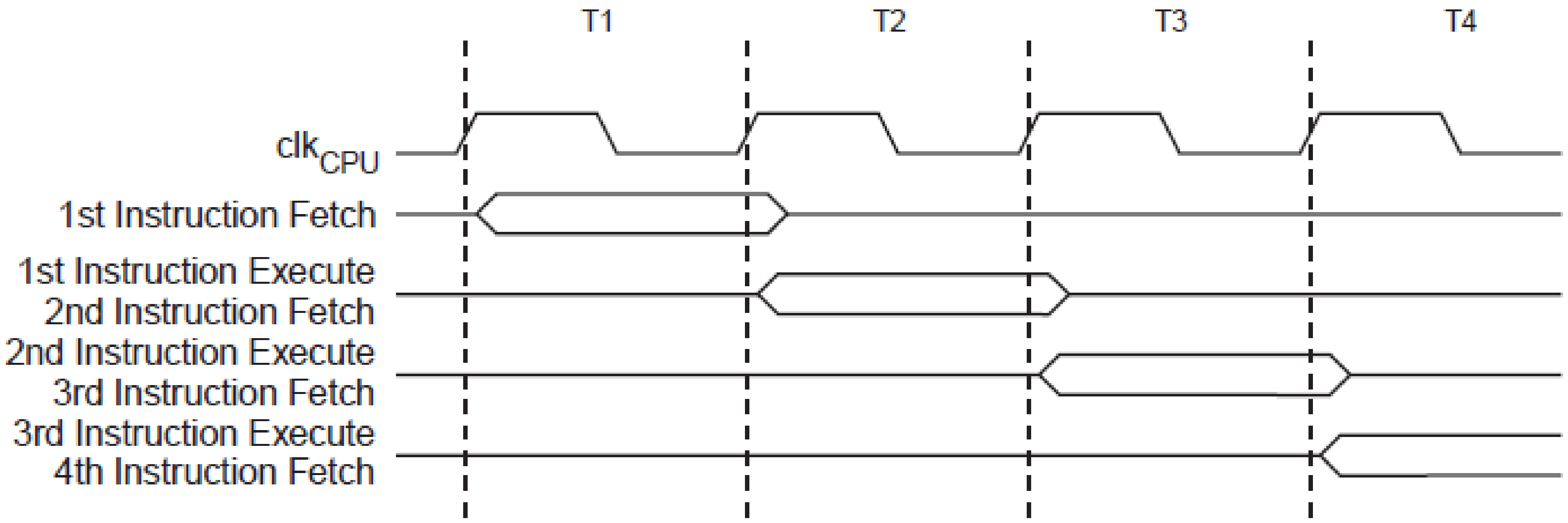
C – Carry flag
Z – Zero flag
N – Negative flag
V – Overflow flag

S – Sign flag
H – Half carry
T – Bit copy storage
I – Global Interrupt Enable

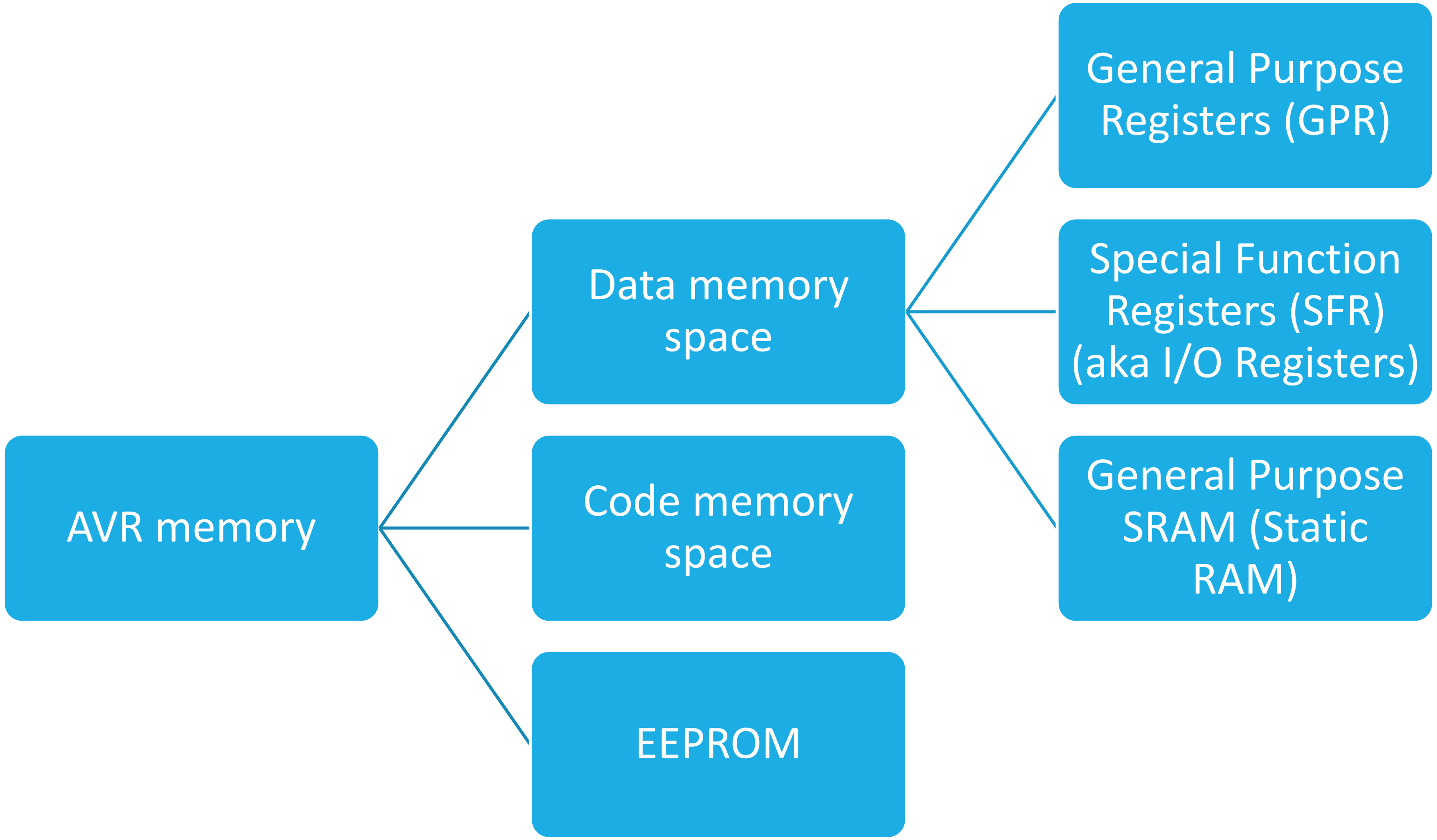
Instruction set architecture

- AVR is RISC
- Most instructions take single clock cycle
- 2 stage pipeline

The Parallel Instruction Fetches and Instruction Executions



AVR memory architecture



AVR memory

Data memory space

Code memory space

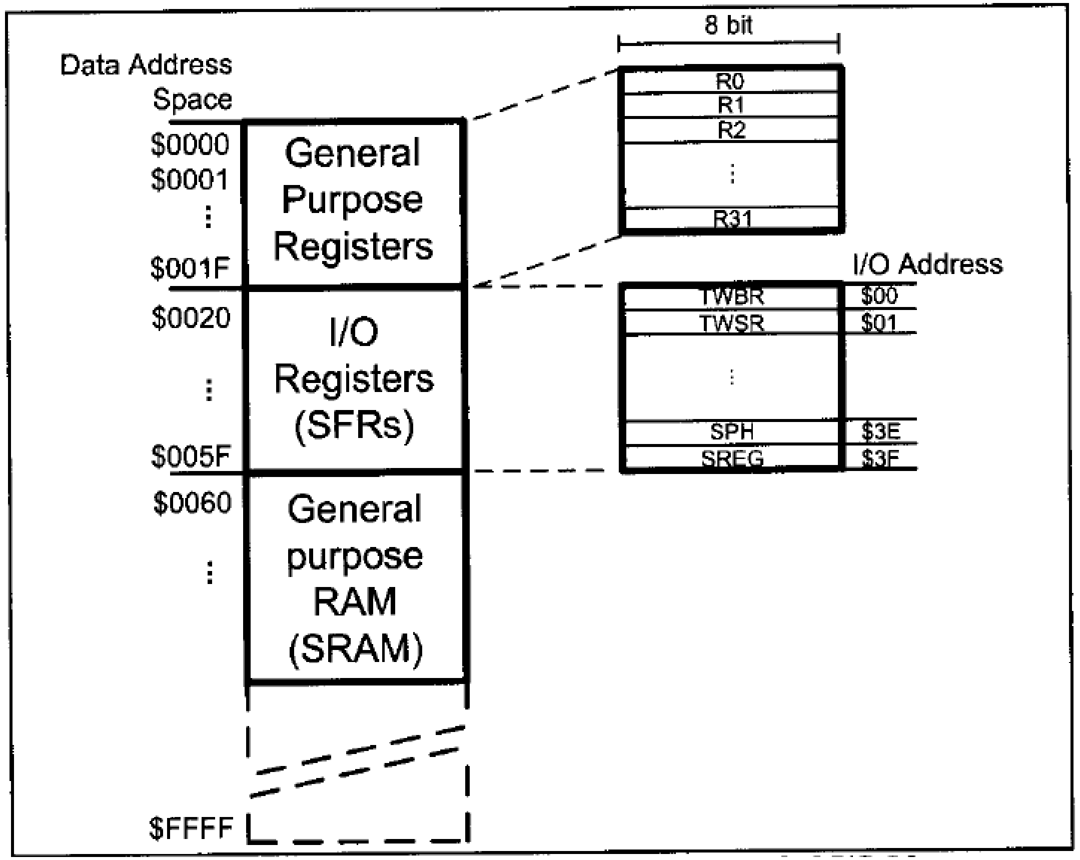
EEPROM

General Purpose Registers (GPR)

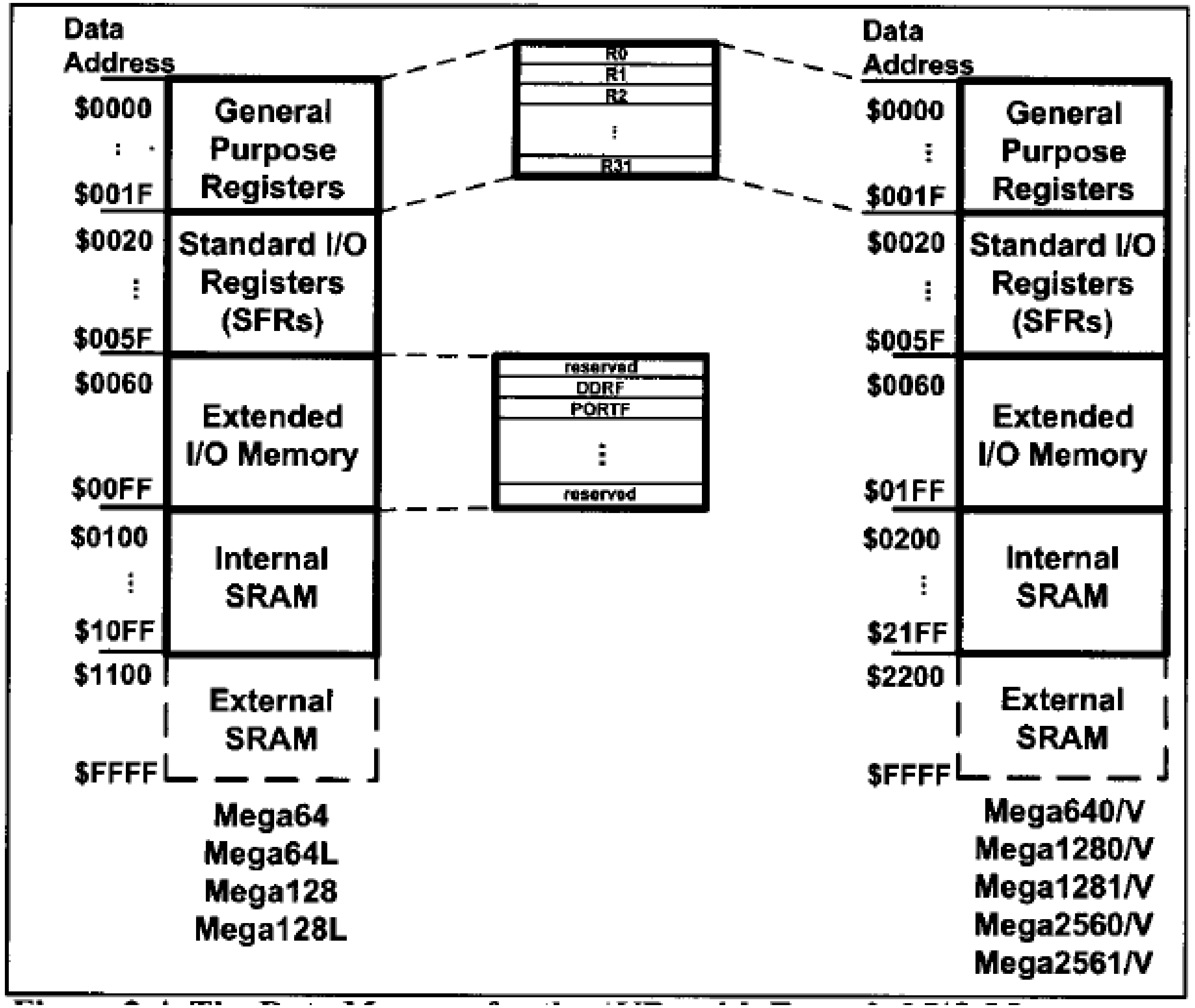
Special Function Registers (SFR) (aka I/O Registers)

General Purpose SRAM (Static RAM)

AVR Data Memory

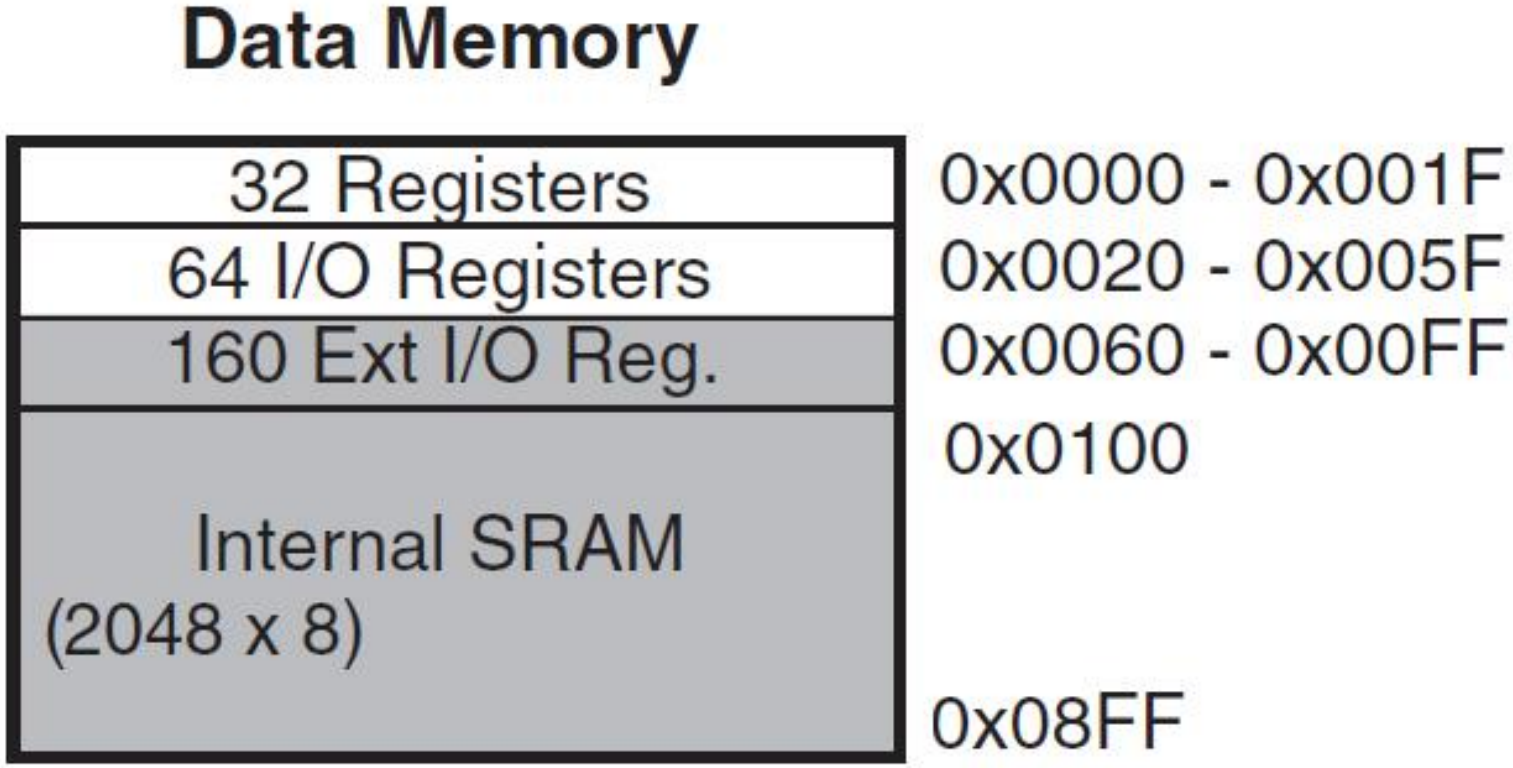


Without extended I/O



With extended I/O

Data memory in 328P



Data Memory

32 Registers	0x0000 - 0x001F
64 I/O Registers	0x0020 - 0x005F
160 Ext I/O Reg.	0x0060 - 0x00FF
Internal SRAM (2048 x 8)	0x0100 0x08FF

Data memory

GPR

- 32 bytes of data memory space from 00-FF in memory space (already discussed)

I/O memory (SFR)

- Dedicated for specific functions such as status register, timers, serial communication, I/O ports, ADC and so on
- I/O memory is made up of 8-bit registers

SRAM

- Used for storing data and parameters
- Called the scratch pad
- Each location is 8-bit wide

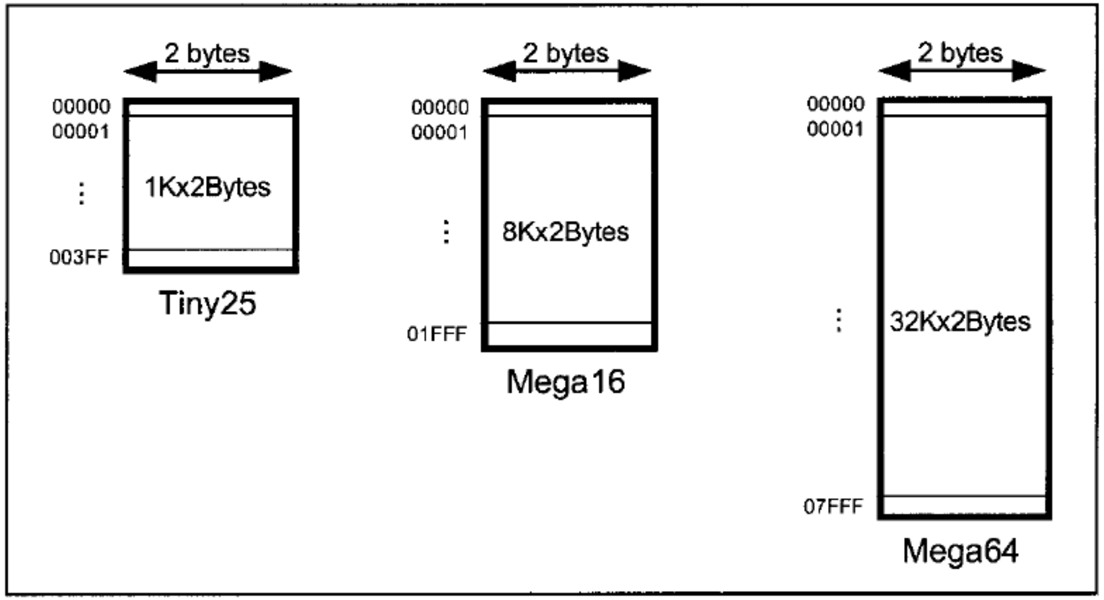
EEPROM

Used for storing data that are rarely changed or should not lost when power is off

Program memory

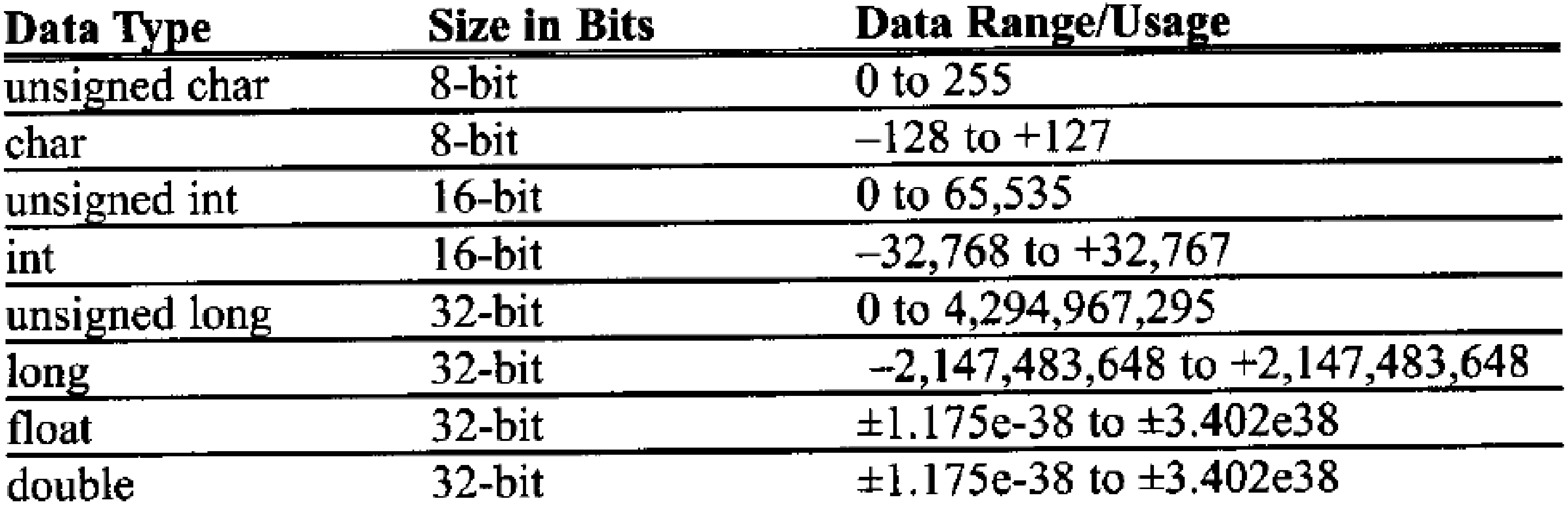
- Stores the program code
- Made up of flash memory
- Each memory location is 2-bytes wide

Atmega 328P has 32KB of Flash memory



AVR programming in C

Datatypes in AVR C

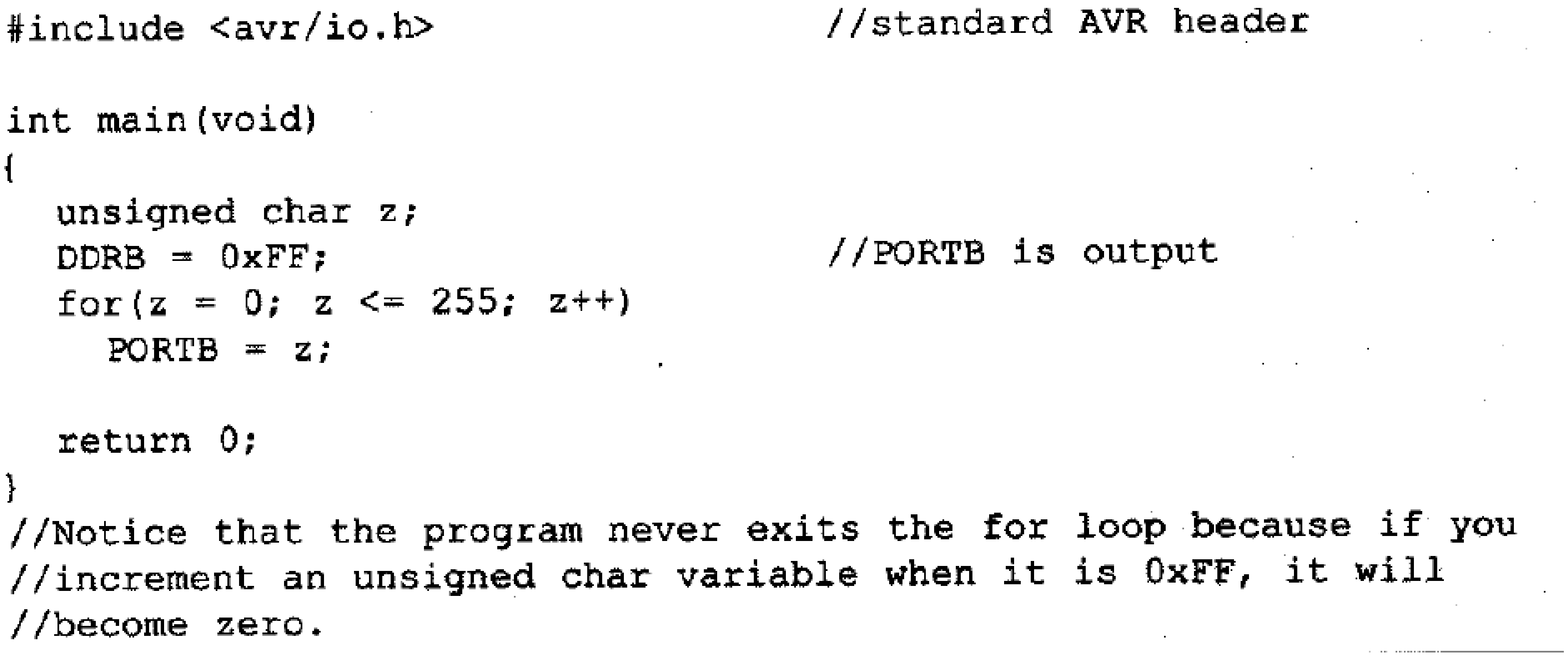


Data Type	Size in Bits	Data Range/Usage
unsigned char	8-bit	0 to 255
char	8-bit	–128 to +127
unsigned int	16-bit	0 to 65,535
int	16-bit	–32,768 to +32,767
unsigned long	32-bit	0 to 4,294,967,295
long	32-bit	–2,147,483,648 to +2,147,483,648
float	32-bit	±1.175e-38 to ±3.402e38
double	32-bit	±1.175e-38 to ±3.402e38

Memory in a microcontroller is limited. Hence use the suitable data type.

Example 1

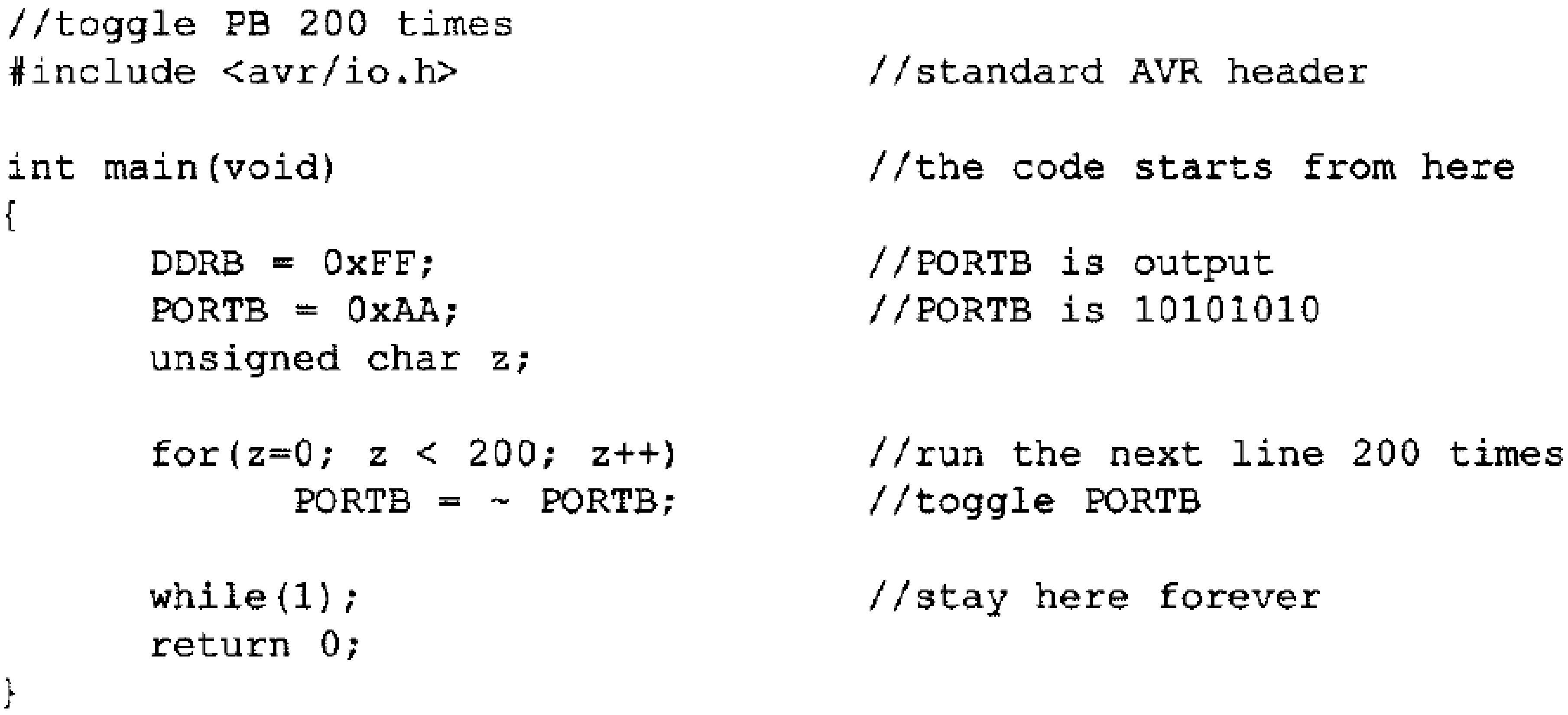
Write an AVR C program to send values 00-FF to Port B.



```
#include <avr/io.h>                      //standard AVR header

int main(void)
{
  unsigned char z;
  DDRB = 0xFF;                           //PORTB is output
  for(z = 0; z <= 255; z++)
    PORTB = z;

  return 0;
}
//Notice that the program never exits the for loop because if you
//increment an unsigned char variable when it is 0xFF, it will
//become zero.
```

Example 2

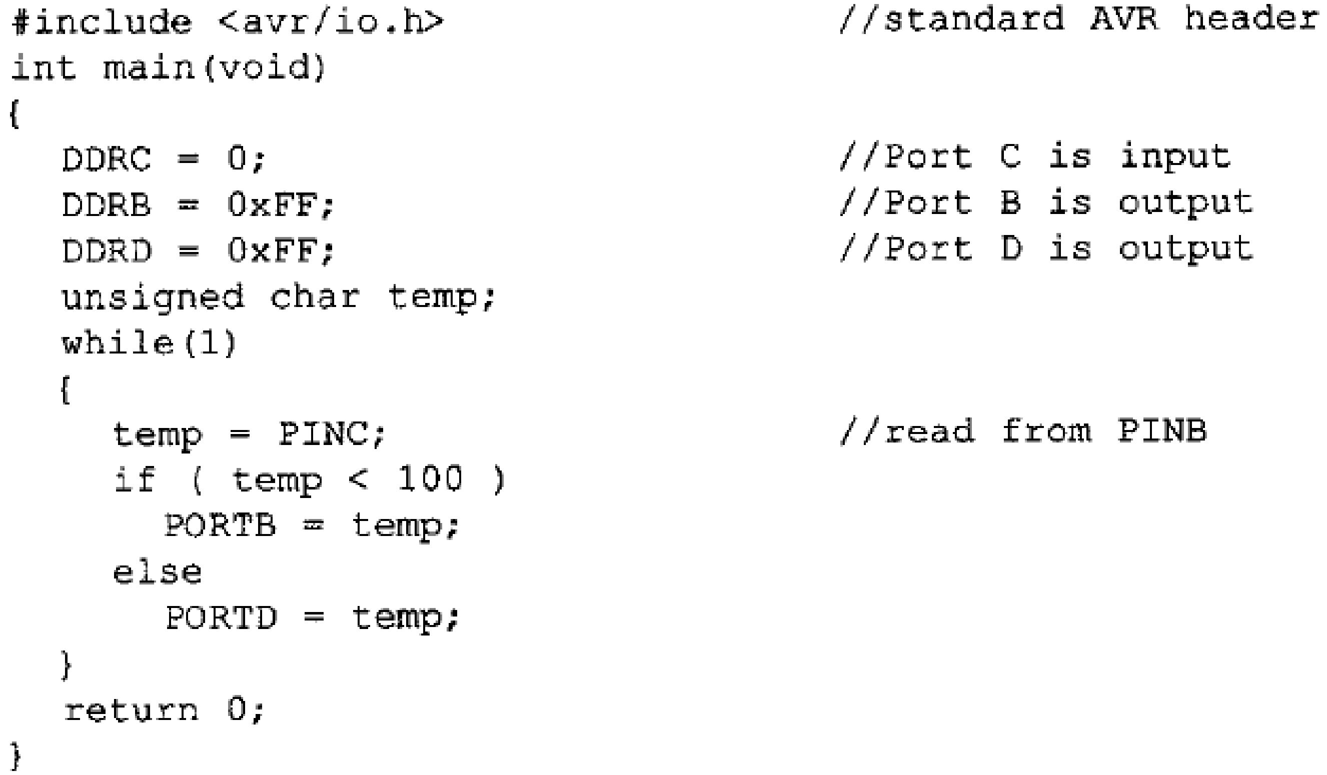
Write an AVR C program to toggle all the bits of Port B 200 times.



```
//toggle PB 200 times
#include <avr/io.h>                     //standard AVR header

int main(void)                          //the code starts from here
{
      DDRB = 0xFF;                      //PORTB is output
      PORTB = 0xAA;                     //PORTB is 10101010
      unsigned char z;

      for(z=0; z < 200; z++)            //run the next line 200 times
            PORTB = ~ PORTB;            //toggle PORTB

      while(1);                         //stay here forever
      return 0;
}
```

Example 3

Write an AVR C program to get a byte of data from Port C. If it is less than 100, send it to Port B, otherwise send it to Port D.



```
#include <avr/io.h>                    //standard AVR header
int main(void)
{
  DDRC = 0;                            //Port C is input
  DDRB = 0xFF;                         //Port B is output
  DDRD = 0xFF;                         //Port D is output
  unsigned char temp;
  while(1)
  {
    temp = PINC;                       //read from PINB
    if ( temp < 100 )
      PORTB = temp;
    else
      PORTD = temp;
  }
  return 0;
}
```

Setting a single bit

Set only bit 4 of Port B without disturbing other pins of Port B.

Method 1 : PORTB = PORTB | 0b00010000

Method 2 : PORTB = PORTB | 16

Method 3 : PORTB = PORTB | 0x10

Method 4 : PORTB = PORTB | (1<<4)

Next slides are only demonstrated via method 4 but any method is usable.

Clearing a single bit

Clear only bit 4 of Port B without disturbing other pins of Port B.

```
PORTB = PORTB & ~(1<<4)
```

Toggling a single bit

Toggle only bit 4 of Port B without disturbing other pins of Port B.

```
PORTB = PORTB ^ (1<<4)
```

Checking a single bit

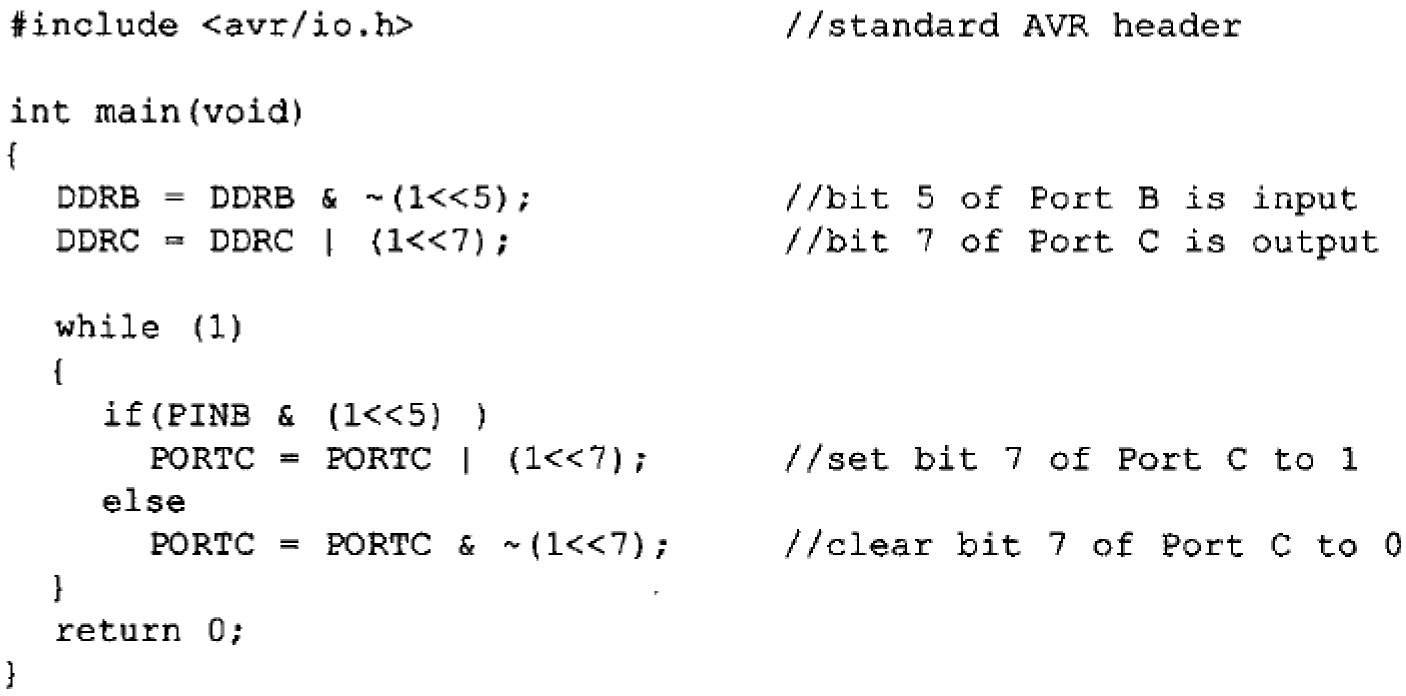
Check if bit 4 of Port B is set to 1.

Method 1 : if ((PORTB >> 4) & 1){……….}

Method 2 : if (PORTB & (1<<4)) {……….}

Example

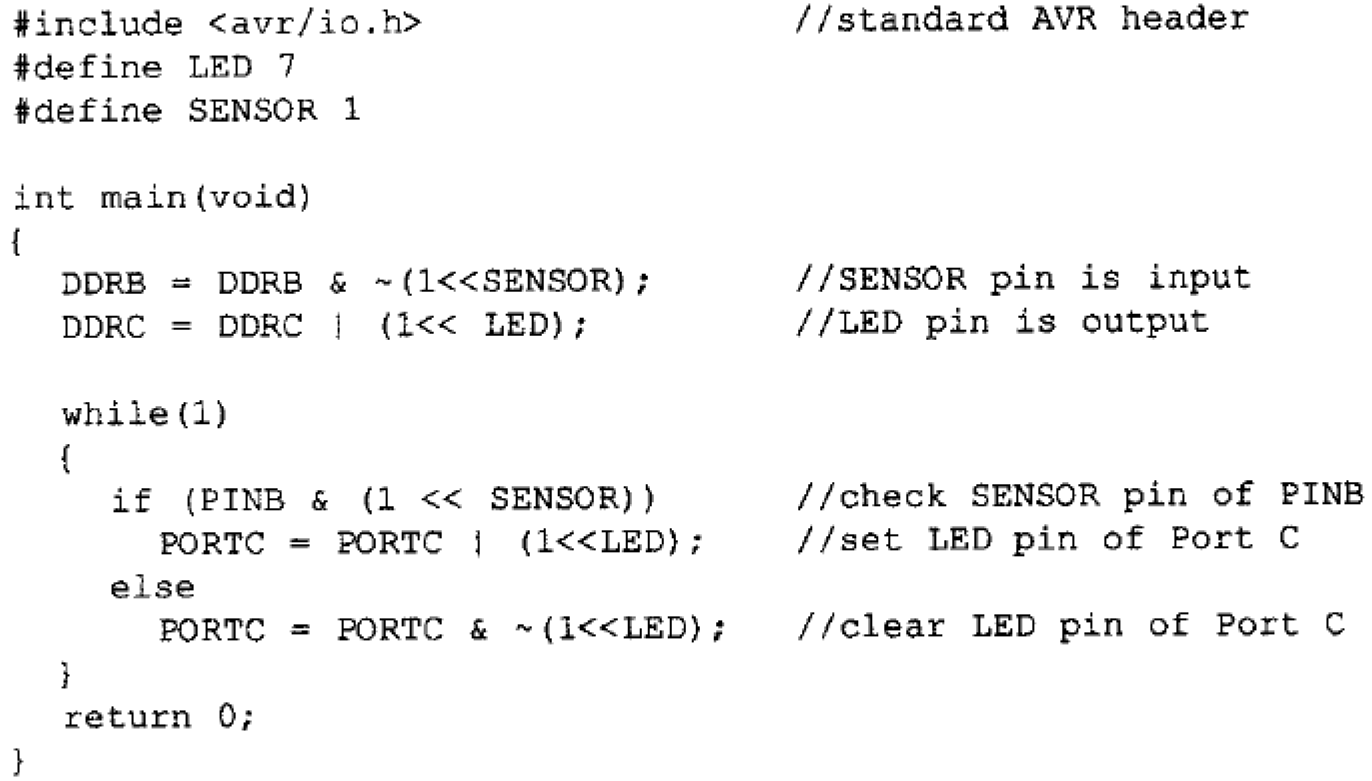
Write an AVR C program to get the status of bit 5 of port B and send it to pin 7 of port C continuously.



```
#include <avr/io.h>                    //standard AVR header

int main(void)
{
   DDRB = DDRB & ~(1<<5);              //bit 5 of Port B is input
   DDRC = DDRC | (1<<7);               //bit 7 of Port C is output

   while (1)
   {
      if(PINB & (1<<5) )
         PORTC = PORTC | (1<<7);       //set bit 7 of Port C to 1
      else
         PORTC = PORTC & ~(1<<7);      //clear bit 7 of Port C to 0
   }
   return 0;
}
```

Example

A door sensor is connected to the Port B pin 1, and an LED is connected to Port C pin 7. Write an AVR C program to monitor the door sensor and, when it opens, turn on the LED.



```
#include <avr/io.h>                     //standard AVR header
#define LED 7
#define SENSOR 1

int main(void)
{
  DDRB = DDRB & ~(1<<SENSOR);           //SENSOR pin is input
  DDRC = DDRC | (1<< LED);              //LED pin is output

  while(1)
  {
    if (PINB & (1 << SENSOR))           //check SENSOR pin of PINB
      PORTC = PORTC | (1<<LED);         //set LED pin of Port C
    else
      PORTC = PORTC & ~(1<<LED);        //clear LED pin of Port C
  }
  return 0;
}
```

Changing multiple bits

Set only bit 4 and bit 7 of Port B without disturbing other pins of Port B.

```
PORTB = PORTB | ((1<<7)|(1<<4))
```

AVR pin description and flashing

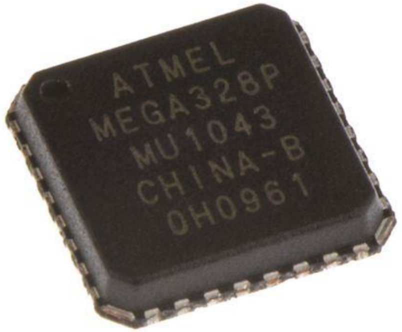
Different package types

ATmega microcontrollers come in different packages

- DIP (Dual in-line package)
- MLF (Micro Lead Frame Package)
- QFP (Quad Flat Package)

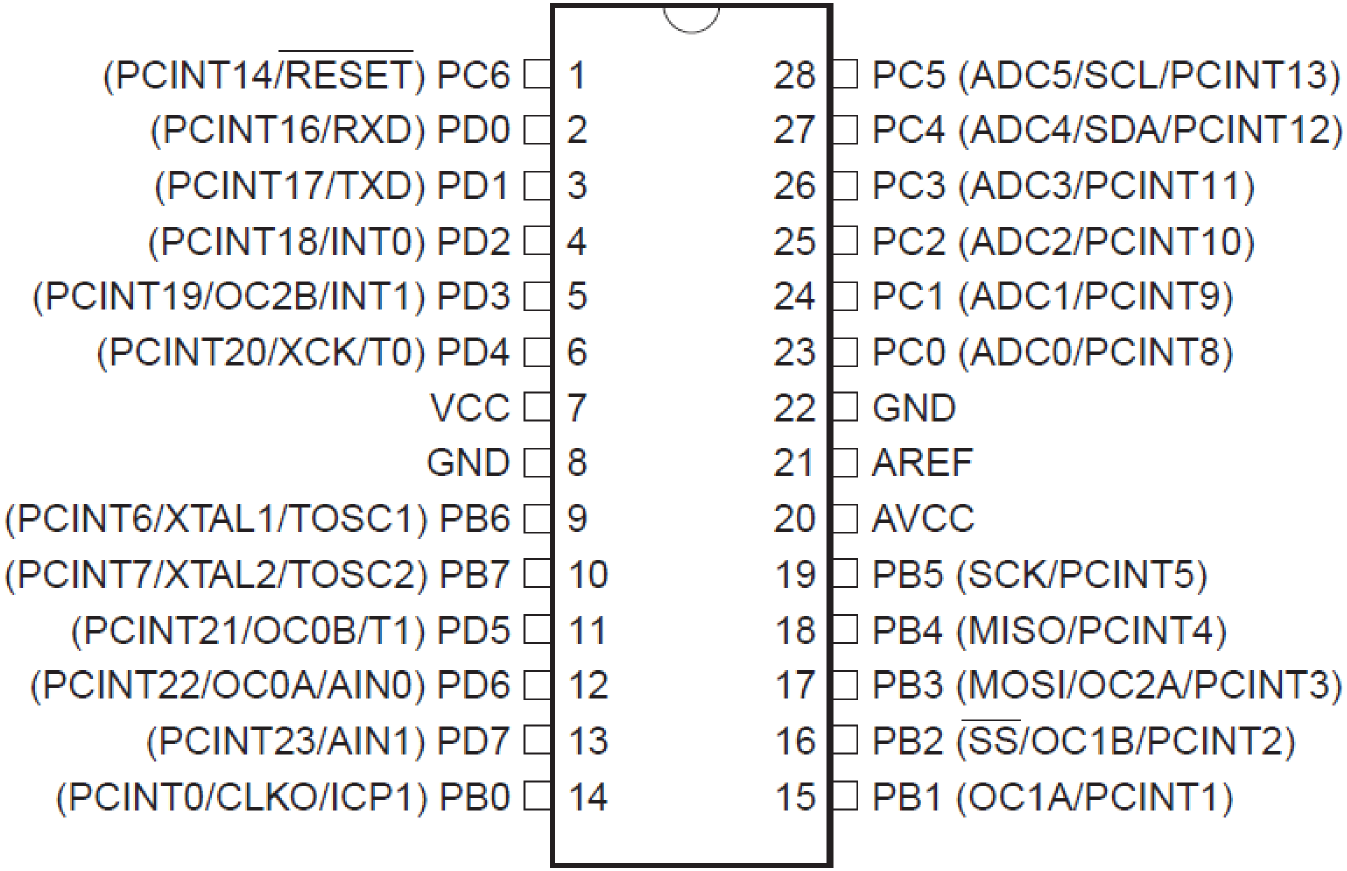
DIP

QPF



MLF

Atmel 328P DIP

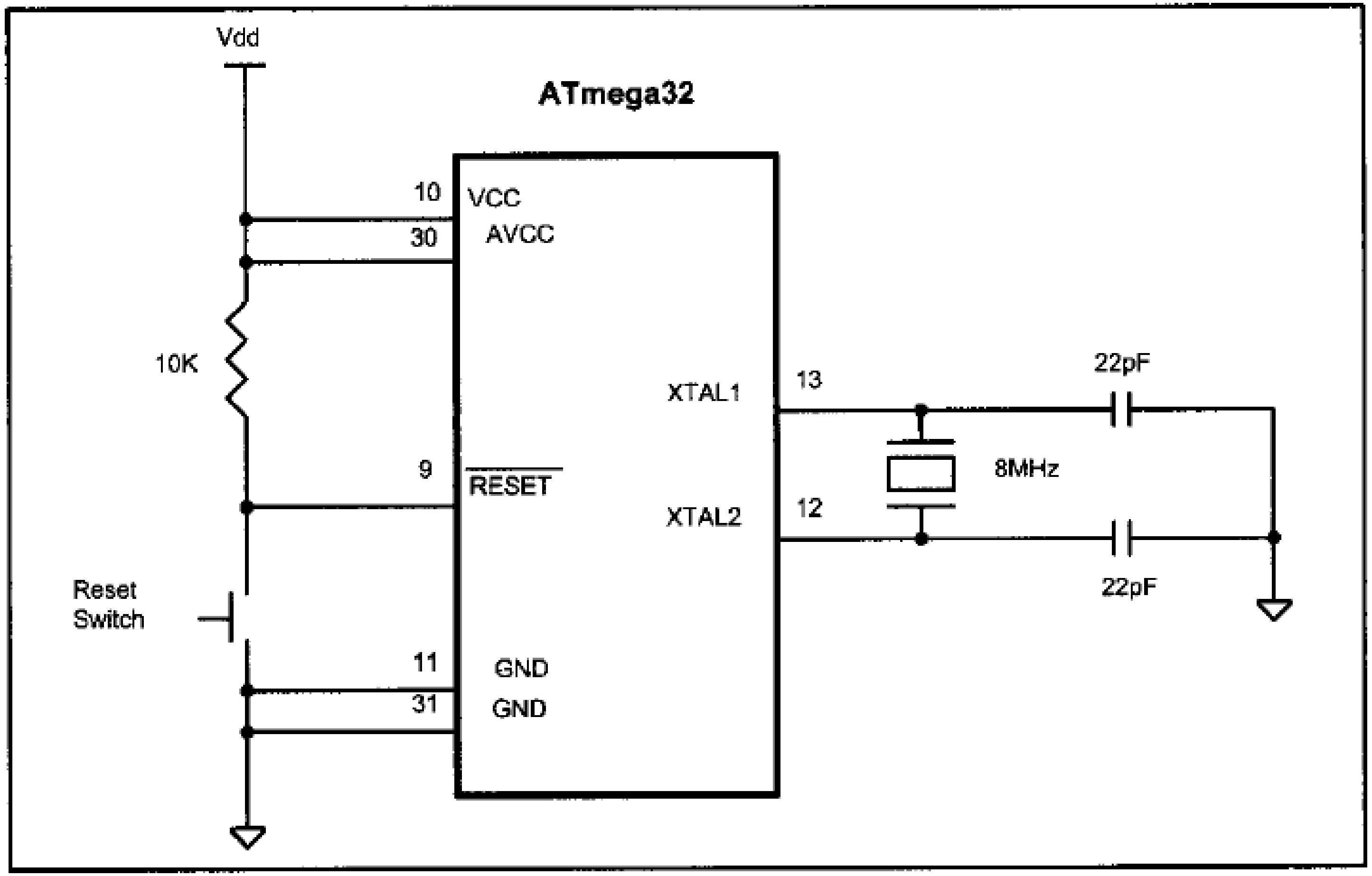


(PCINT14/$\overline{\text{RESET}}$) PC6 1 — 28 PC5 (ADC5/SCL/PCINT13)
(PCINT16/RXD) PD0 2 — 27 PC4 (ADC4/SDA/PCINT12)
(PCINT17/TXD) PD1 3 — 26 PC3 (ADC3/PCINT11)
(PCINT18/INT0) PD2 4 — 25 PC2 (ADC2/PCINT10)
(PCINT19/OC2B/INT1) PD3 5 — 24 PC1 (ADC1/PCINT9)
(PCINT20/XCK/T0) PD4 6 — 23 PC0 (ADC0/PCINT8)
VCC 7 — 22 GND
GND 8 — 21 AREF
(PCINT6/XTAL1/TOSC1) PB6 9 — 20 AVCC
(PCINT7/XTAL2/TOSC2) PB7 10 — 19 PB5 (SCK/PCINT5)
(PCINT21/OC0B/T1) PD5 11 — 18 PB4 (MISO/PCINT4)
(PCINT22/OC0A/AIN0) PD6 12 — 17 PB3 (MOSI/OC2A/PCINT3)
(PCINT23/AIN1) PD7 13 — 16 PB2 ($\overline{\text{SS}}$/OC1B/PCINT2)
(PCINT0/CLKO/ICP1) PB0 14 — 15 PB1 (OC1A/PCINT1)

Pin descriptions

Pin	Description
VCC	Power supply pin. The typical voltage source is 5V
AVCC	Supply voltage pin for A/D converter. It should be connected even if A/D is not used
GND	Two pins used for ground
XTAL1 and XTAL2	To connect quartz crystal oscillator as the clock source
RESET	When LOW pulse is microcontroller will reset

Minimal connection for ATmega 32



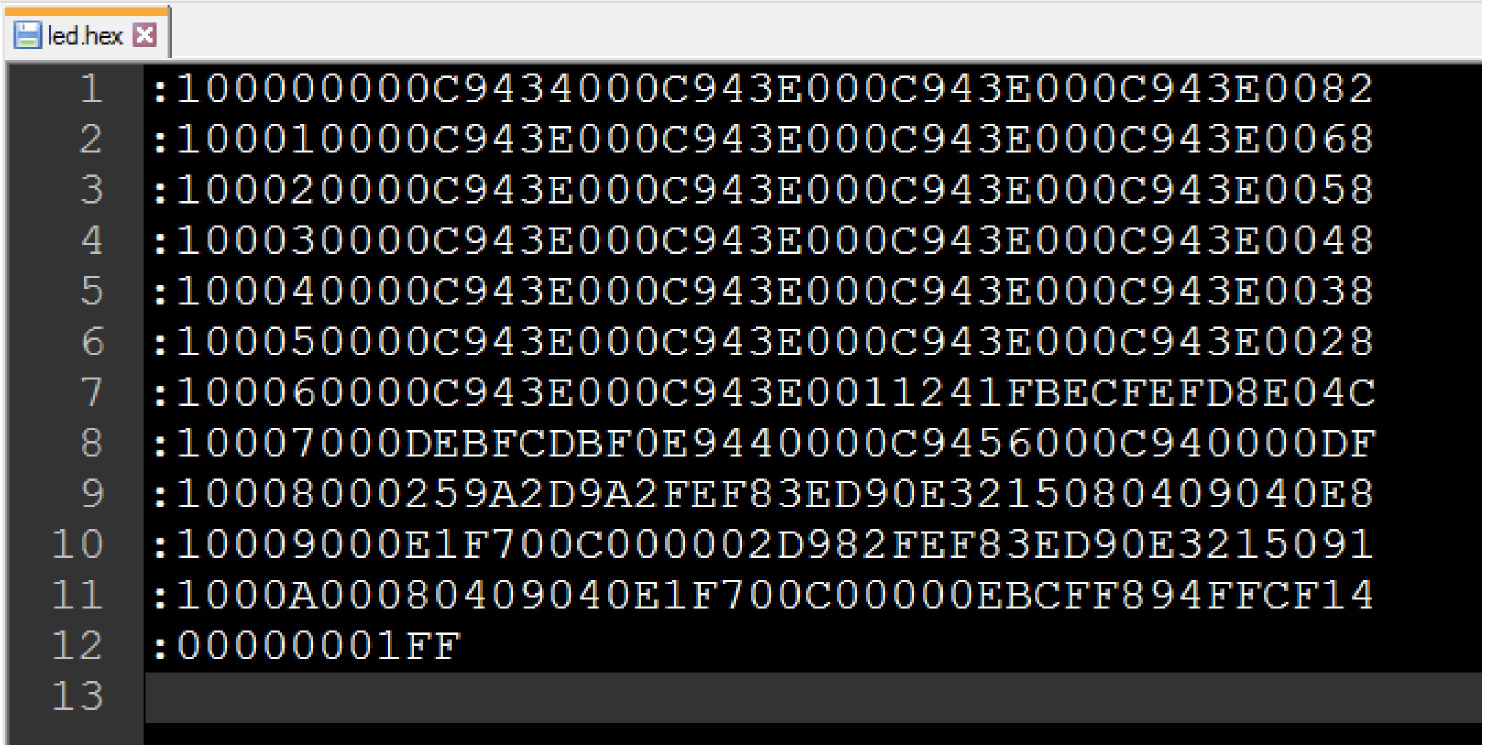
Ports

Port	Description
Port B (PB7:0)	8-bit bi-directional I/O port
Port C (PC5:0)	7-bit bi-directional I/O port
Port D (PD7:0)	8-bit bi-directional I/O port

Note that most pins have alternate functions which change depending on the configuration.

HEX files for AVR

Intel HEX is a widely used file format designed to standardize the loading (transferring) of executable machine code into a chip



```
:100000000C9434000C943E000C943E000C943E0082
:100010000C943E000C943E000C943E000C943E0068
:100020000C943E000C943E000C943E000C943E0058
:100030000C943E000C943E000C943E000C943E0048
:100040000C943E000C943E000C943E000C943E0038
:100050000C943E000C943E000C943E000C943E0028
:100060000C943E000C943E0011241FBECFEFD8E04C
:10007000DEBFCDBF0E9440000C9456000C940000DF
:10008000259A2D9A2FEF83ED90E3215080409040E8
:10009000E1F700C000002D982FEF83ED90E3215091
:1000A00080409040E1F700C00000EBCFF894FFCF14
:00000001FF
```

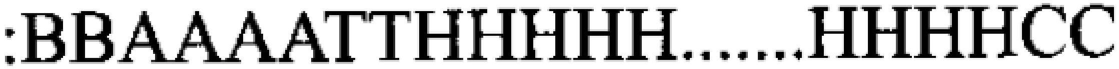
Intel HEX file

Since the programmer (loader) uses the HEX file to download opcode into Flash, following information are provided

- Number of bytes of information to be loaded
- Information to be loaded
- Starting address where information must be placed

Intel HEX file

Each line of HEX file has six parts



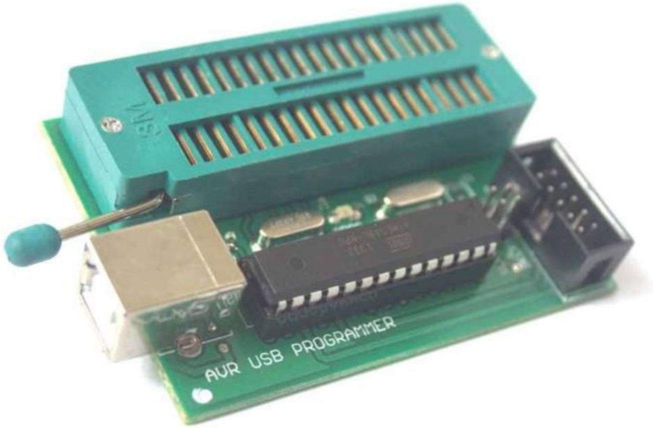
:BBAAAATTHHHHH......HHHHCC

- Each line starts with a ‘:’
- BB tells how many bytes are in the line (in hexadecimal)
- AAAA is the 16-bit address at which the loader should place the first byte
- TT is the type. 00 means there are more lines to come after this line, 01 means the last line
- HH…..H is the real information
- CC is the checksum for everything in the line

AVR programming

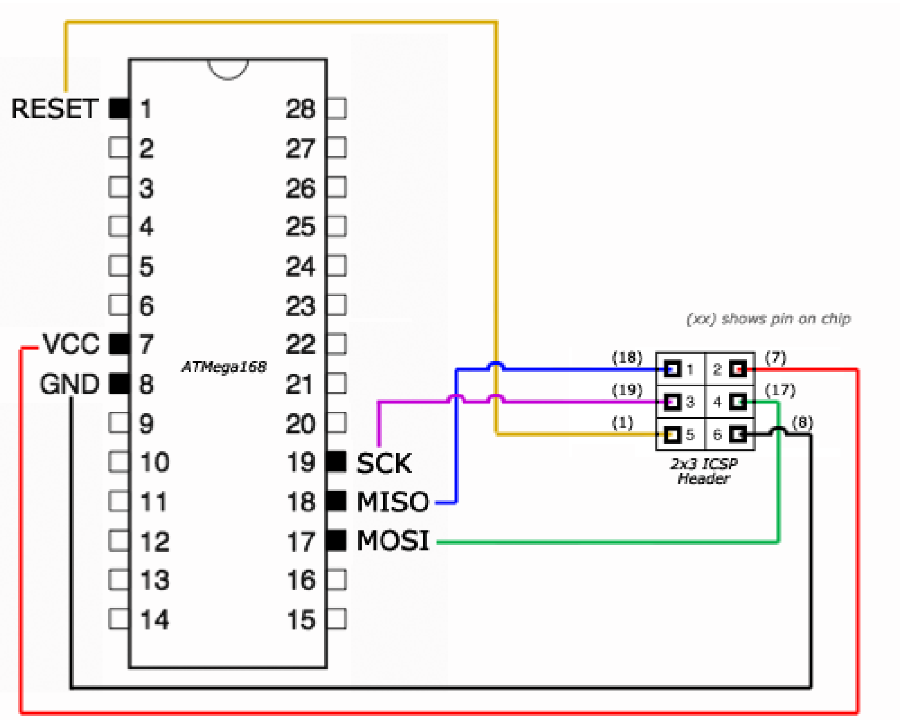
There are 3 ways to load a program to the flash memory

- Parallel programming
  - Chip is programmed before being inserted to the circuit or the chip is removed and reprogrammed
  - ZIF (Zero insertion force) sockets are used



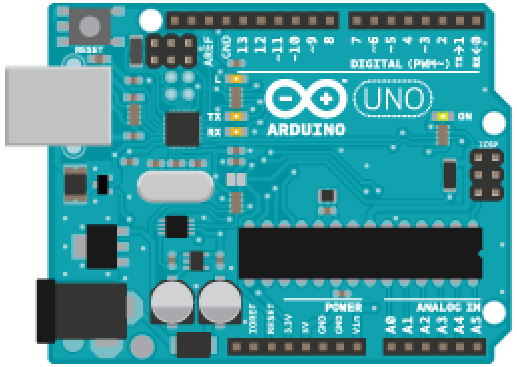
AVR programming

- ISP (In-circuit Serial Programming)
  - Chip is programmed while it is on the circuit



AVR programming

- Bootloader
  - A piece of code burned into microcontroller’s flash
  - It communicates with the user‘s board via serial port / USB/ network
  - Drawback : requires a communication port and program space on the microcontroller
  - Advantage : convenience
  - Arduino has bootloader
  - We use this method for programming



Thank you