Microcontrollers

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Outline

- Microcontroller basics
- Development cycle

- Atmel AVR
  - Overview
  - AT Mega 328

- Most common embedded features
  - Digital I/O, ADC, PWM, Timers, Interrupts, WDT
  - Serial interfaces: USART, SPI, TWI

- Arduino
- Examples

Microcontroller basics

- Small computer on a single integrated circuit
- Designed for embedded applications
- Used when a single main functionality is required

- uC = processor core + memory + programmable I/O peripherals
- Low cost
- Low power consumption
- Reduced clock frequency (tens or hundreds of MHz)
- Industrial environment & consumer goods

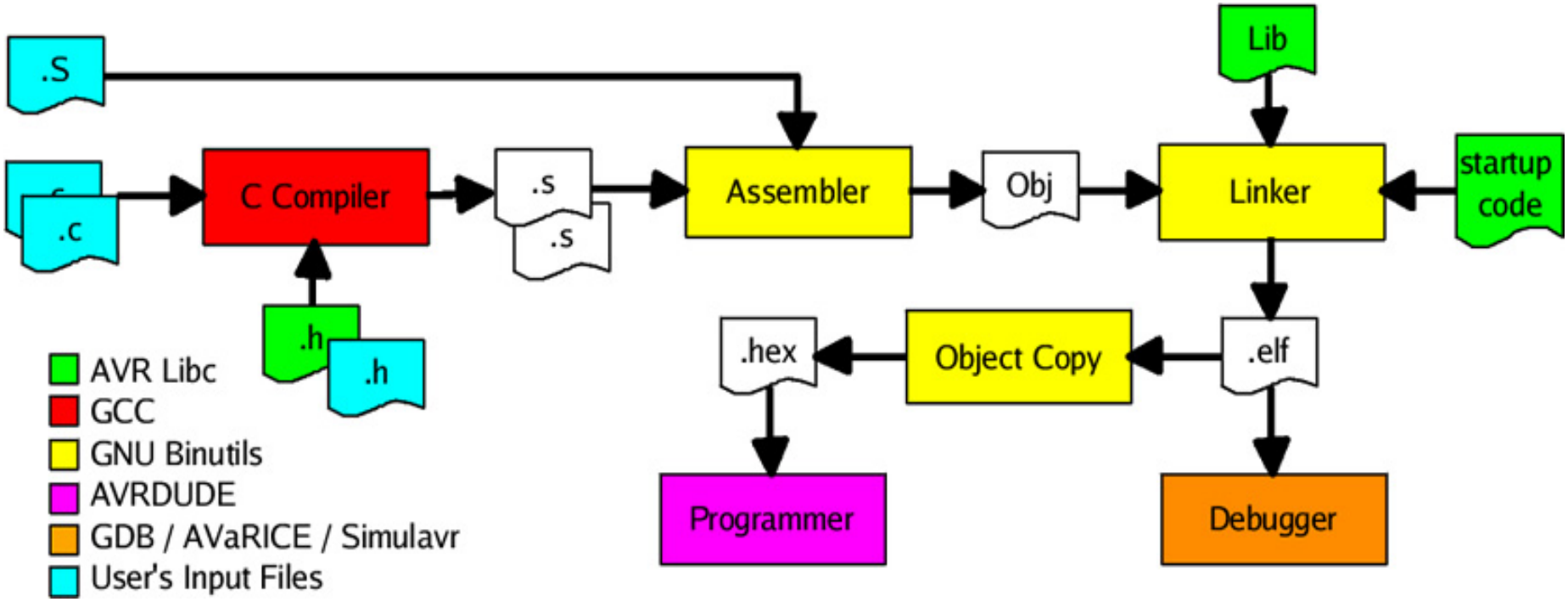
Microcontroller basics

Most common structures inside a uC:

- CPU (uC core); 8, 16, 32, 64 bits
- Volatile memory (RAM) + non-volatile (Flash, EEPROM)
- Digital I/O ports
- Serial interfaces (USART, SPI, I2C, CAN, RS485)
- Timers, PWM, WDT
- ADC
- Programming and debugging support

* some uC have separate busses for data and instructions. E.g. the Atmel AVR uC has 16bit instructions but 8 bit registers

Development cycle (AVR)



C
```
pinMode(4, OUTPUT);
digitalWrite(4, HIGH);
```

ASM
```
ldi r16, 0xFF
out DDRB, r16
sbi PortB, 4
```

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Atmel AVR Family

- The most used 8bit microcontrollers:
  - AVR family from Atmel
  - PIC family from Microchip

- Atmel AVR Family
  - 8-bit microcontrollers
  - RISC (Reduced Complexity Instruction Set Computer)
  - Same AVR core in all devices
  - One instruction per external clock
  - Launched in 1996
  - 4 categories (Tiny AVR, megaAVR, XMEGA, Application Specific AVR)

Atmel AVR Family

- **Tiny AVR**
  - 1-8 kB program memory
  - 8-32 pins
  - Limited set of peripherals

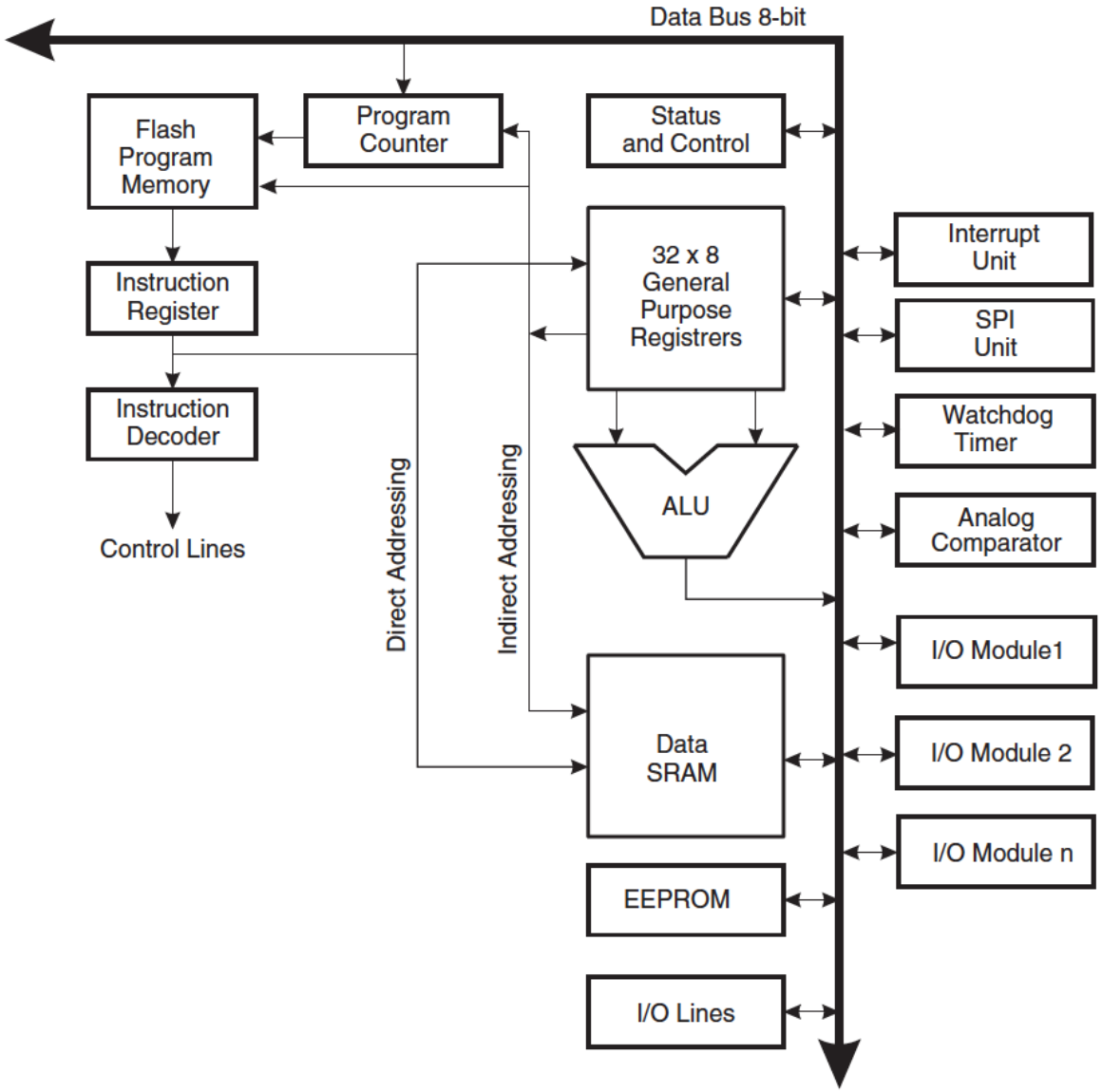
- **megaAVR**
  - 4-256 kB program memory
  - 28-100 pins
  - Extended set of peripherals and instructions

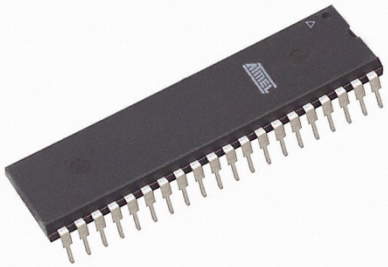
- **XMEGA**
  - 16-256 kB program memory
  - 44-100 pins
  - Extended interfaces (e.g. DMA, event system, cryptography)

- **Application Specific AVR**
  - megaAVR with special functions (e.g. LCD, USB, CAN controllers)

- **FPSLIC (AVR up to 50MHz with FPGA 5K-40K gates)**

Atmel AT Mega Block Diagram





```
ldi r16, 5
out UBRR, r16
```

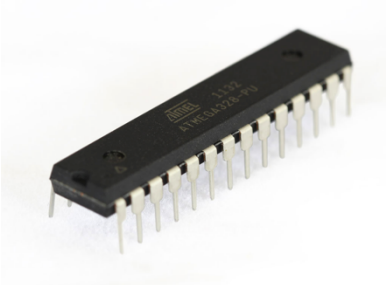
Atmel AT Mega Instruction Set

~130 instructions: arithmetic, transfer, jump, branch, call, bit & others

Mnemonics	Operands	Description	Operation	Flags	#Clocks
ARITHMETIC AND LOGIC INSTRUCTIONS					
ADD	Rd, Rr	Add two Registers	Rd ← Rd + Rr	Z,C,N,V,H	1
ADC	Rd, Rr	Add with Carry two Registers	Rd ← Rd + Rr + C	Z,C,N,V,H	1
ADIW	Rdl,K	Add Immediate to Word	Rdh:Rdl ← Rdh:Rdl + K	Z,C,N,V,S	2
SUB	Rd, Rr	Subtract two Registers	Rd ← Rd - Rr	Z,C,N,V,H	1
SUBI	Rd, K	Subtract Constant from Register	Rd ← Rd - K	Z,C,N,V,H	1
SBC	Rd, Rr	Subtract with Carry two Registers	Rd ← Rd - Rr - C	Z,C,N,V,H	1
SBCI	Rd, K	Subtract with Carry Constant from Reg.	Rd ← Rd - K - C	Z,C,N,V,H	1
SBIW	Rdl,K	Subtract Immediate from Word	Rdh:Rdl ← Rdh:Rdl - K	Z,C,N,V,S	2
AND	Rd, Rr	Logical AND Registers	Rd ← Rd • Rr	Z,N,V	1
ANDI	Rd, K	Logical AND Register and Constant	Rd ← Rd • K	Z,N,V	1
OR	Rd, Rr	Logical OR Registers	Rd ← Rd v Rr	Z,N,V	1
ORI	Rd, K	Logical OR Register and Constant	Rd ← Rd v K	Z,N,V	1
EOR	Rd, Rr	Exclusive OR Registers	Rd ← Rd ⊕ Rr	Z,N,V	1
COM	Rd	One's Complement	Rd ← 0xFF – Rd	Z,C,N,V	1
NEG	Rd	Two's Complement	Rd ← 0x00 – Rd	Z,C,N,V,H	1
SBR	Rd,K	Set Bit(s) in Register	Rd ← Rd v K	Z,N,V	1
CBR	Rd,K	Clear Bit(s) in Register	Rd ← Rd • (0xFF - K)	Z,N,V	1
INC	Rd	Increment	Rd ← Rd + 1	Z,N,V	1
DEC	Rd	Decrement	Rd ← Rd – 1	Z,N,V	1
TST	Rd	Test for Zero or Minus	Rd ← Rd • Rd	Z,N,V	1
CLR	Rd	Clear Register	Rd ← Rd ⊕ Rd	Z,N,V	1
SER	Rd	Set Register	Rd ← 0xFF	None	1
MUL	Rd, Rr	Multiply Unsigned	R1:R0 ← Rd x Rr	Z,C	2
MULS	Rd, Rr	Multiply Signed	R1:R0 ← Rd x Rr	Z,C	2

Atmel AT Mega 328

- High performance, low power, 8-bit uC
- 32 kB Flash (maximum program size)
- 2kB EEPROM
- 2kB RAM
- Max 20MHz, 1.8-5.5 V
- 6 x PWM
- 6 x ADC channels, 10 bits resolution
- 23 I/O pins
- 3 timers: 2x8 bits, 1x16 bits
- Serial interfaces: 1xUSART, 1xSPI, 1xTWI/I2C
- Power consumption: 0.6mA/MHz



Atmel AT Mega 328

	(PCINT14/RESET) PC6	1	28	PC5 (ADC5/SCL/PCINT13)	A5
D0	(PCINT16/RXD) PD0	2	27	PC4 (ADC4/SDA/PCINT12)	A4
D1	(PCINT17/TXD) PD1	3	26	PC3 (ADC3/PCINT11)	A3
D2	(PCINT18/INT0) PD2	4	25	PC2 (ADC2/PCINT10)	A2
D3	(PCINT19/OC2B/INT1) PD3	5	24	PC1 (ADC1/PCINT9)	A1
D4	(PCINT20/XCK/T0) PD4	6	23	PC0 (ADC0/PCINT8)	A0
	VCC	7	22	GND	
	GND	8	21	AREF	
	(PCINT6/XTAL1/TOSC1) PB6	9	20	AVCC	
	(PCINT7/XTAL2/TOSC2) PB7	10	19	PB5 (SCK/PCINT5)	D13
D5	(PCINT21/OC0B/T1) PD5	11	18	PB4 (MISO/PCINT4)	D12
D6	(PCINT22/OC0A/AIN0) PD6	12	17	PB3 (MOSI/OC2A/PCINT3)	D11
D7	(PCINT23/AIN1) PD7	13	16	PB2 (SS/OC1B/PCINT2)	D10
D8	(PCINT0/CLKO/ICP1) PB0	14	15	PB1 (OC1A/PCINT1)	D9

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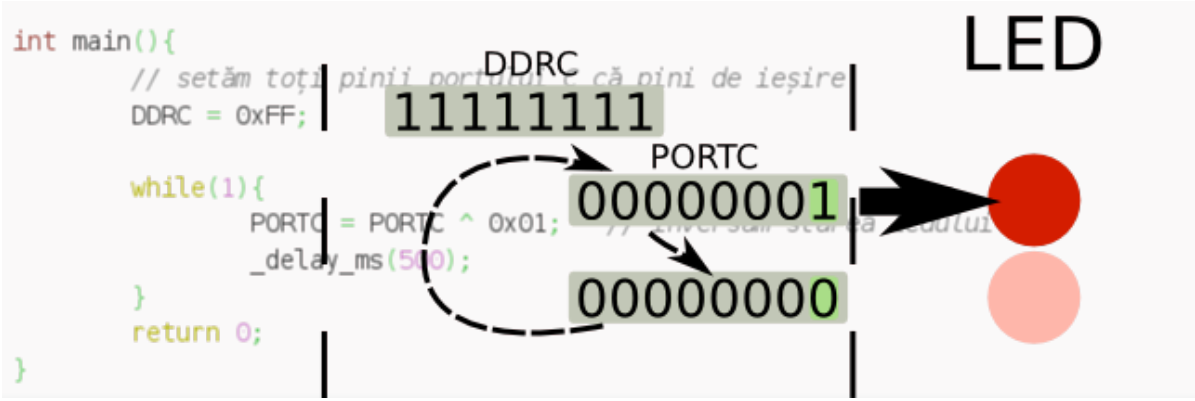
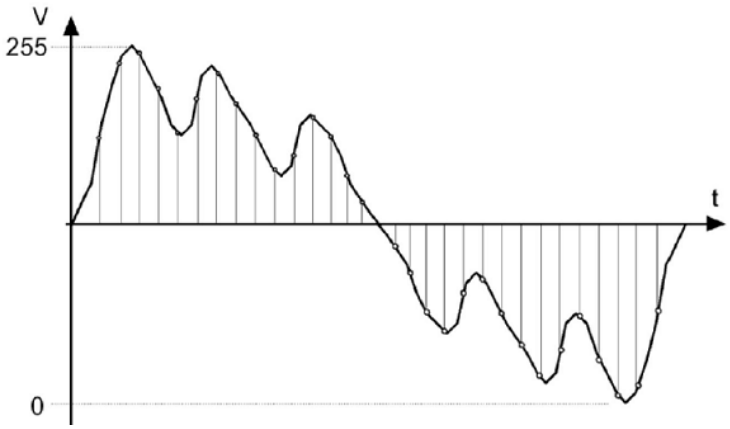
Digital I/O

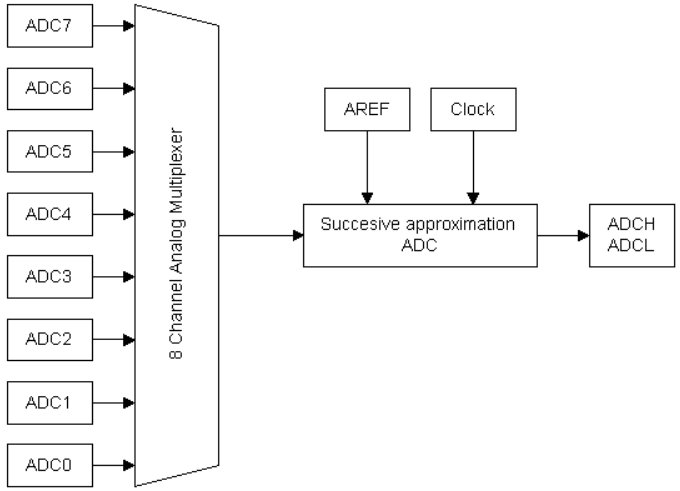
- 0V = 0, 5V = 1
- Reading/setting the (digital) voltage level of a pin
- 3 important registers for each I/O port:
  - DDR (Data Direction Register)
  - PORT (writing)
  - PIN (reading)
- Usage: LEDs, push buttons, relay switches etc.



ADC

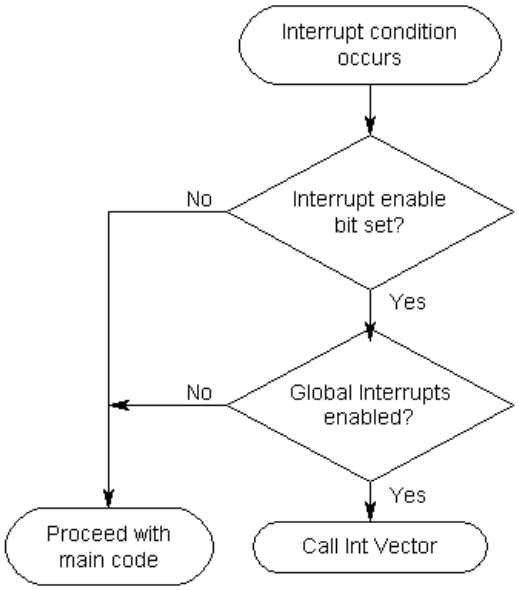
- Most important characteristics:
  - resolution
    - 10bits ADC, 0-5V range -> (5V – 0V) / 1024 = 4.8 mV
  - sampling rate
    - Nyquist: minimum twice the frequency of the measured signal
    - AVR: 50-200kHz
- Usage: sensors, potentiometers etc.





Interrupts

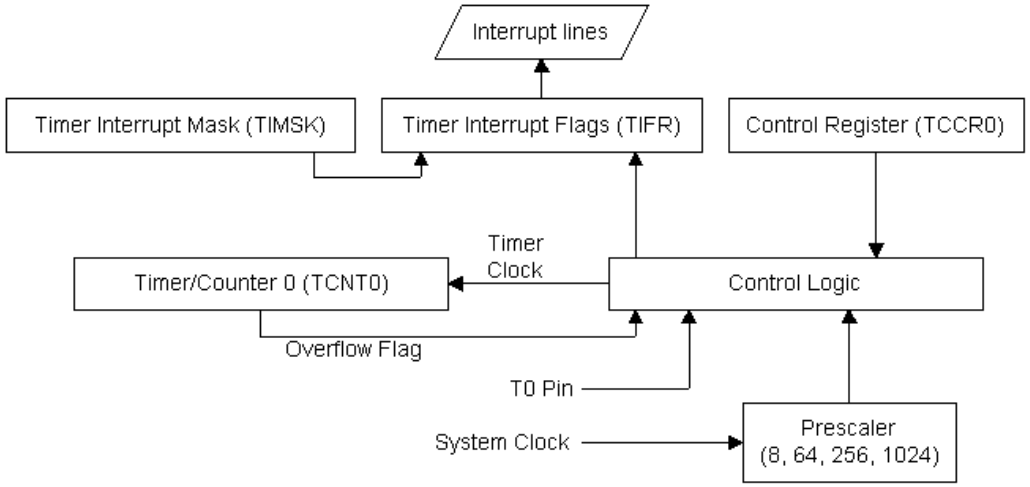
- Used to interrupt the normal program flow
  - INT0, INT1, timers, USART etc.
- External vs. internal
- Usage: handle events




```
Address  Labels Code                    Comments
0x0000          jmp    RESET            ; Reset Handler
0x0002          jmp    EXT_INT0         ; IRQ0 Handler
0x0004          jmp    EXT_INT1         ; IRQ1 Handler
0x0006          jmp    PCINT0           ; PCINT0 Handler
0x0008          jmp    PCINT1           ; PCINT1 Handler
0x000A          jmp    PCINT2           ; PCINT2 Handler
0x000C          jmp    WDT              ; Watchdog Timer Handler
0x000E          jmp    TIM2_COMPA       ; Timer2 Compare A Handler
0x0010          jmp    TIM2_COMPB       ; Timer2 Compare B Handler
0x0012          jmp    TIM2_OVF         ; Timer2 Overflow Handler
0x0014          jmp    TIM1_CAPT        ; Timer1 Capture Handler
0x0016          jmp    TIM1_COMPA       ; Timer1 Compare A Handler
0x0018          jmp    TIM1_COMPB       ; Timer1 Compare B Handler
```

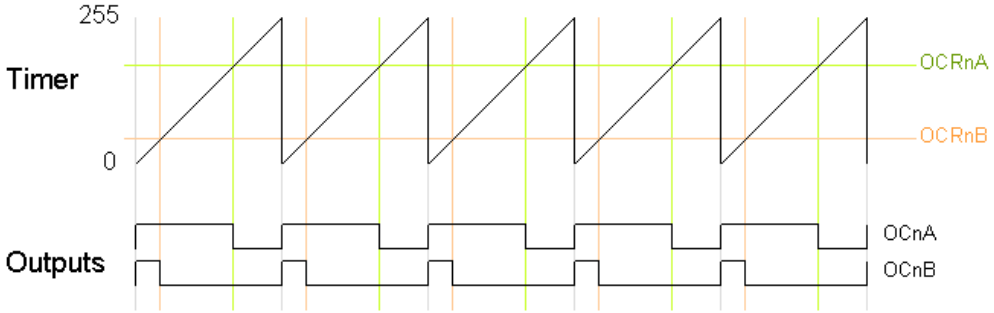
Timers

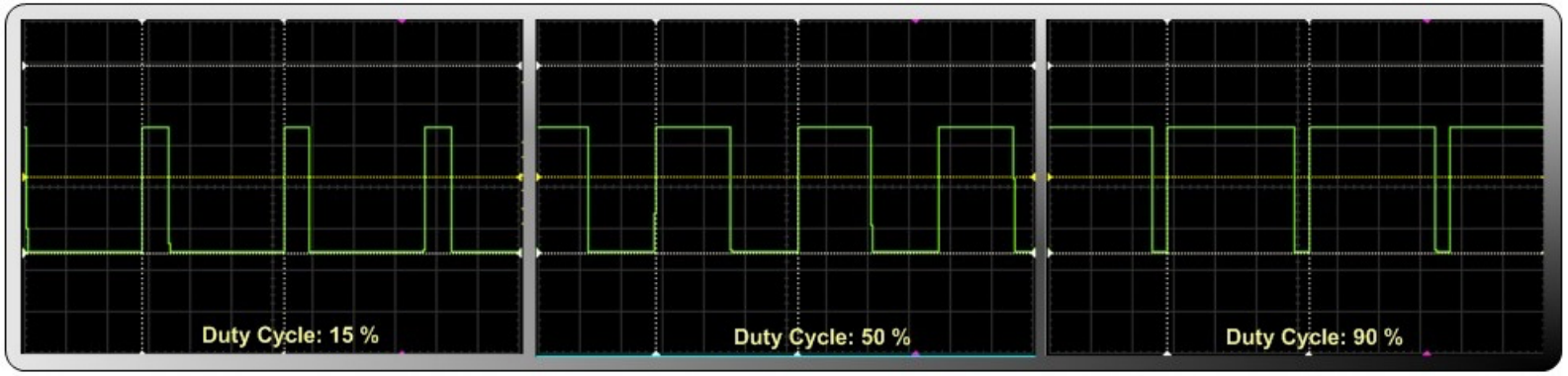
- Counters connected to some clock signal
- Modes
  - normal: counts up and trigger the overflow interrupt
  - output compare: compare value with OCRA
  - input capture: measure the time between 2 edges on the ICP pin
  - PWM



PWM

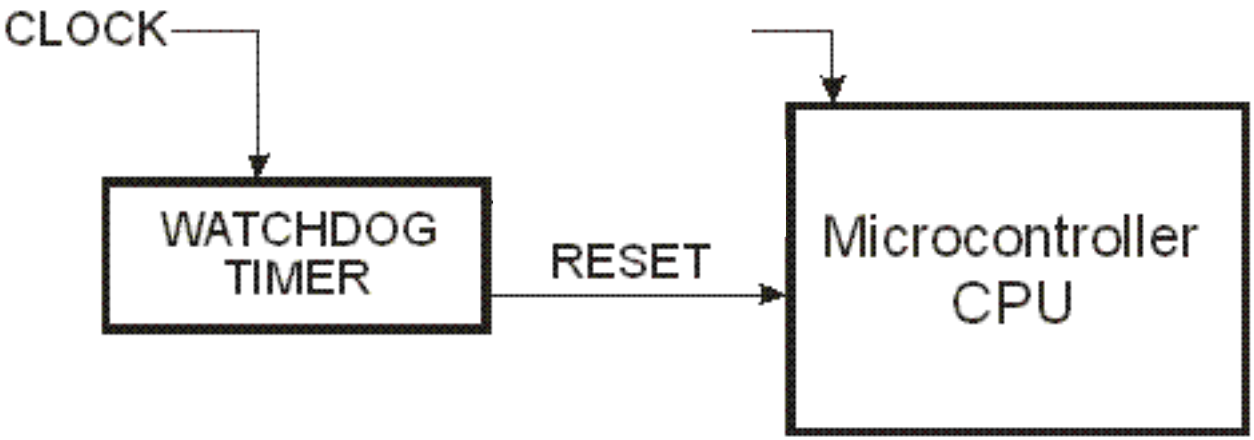
- Used to control analog circuits from the digital domain
- Fast PWM, Phase Correct PWM, Phase and Freq. Correct PWM
- Usage: leds, electrical motors





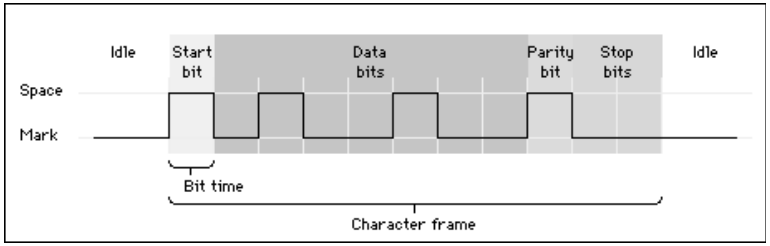
WDT

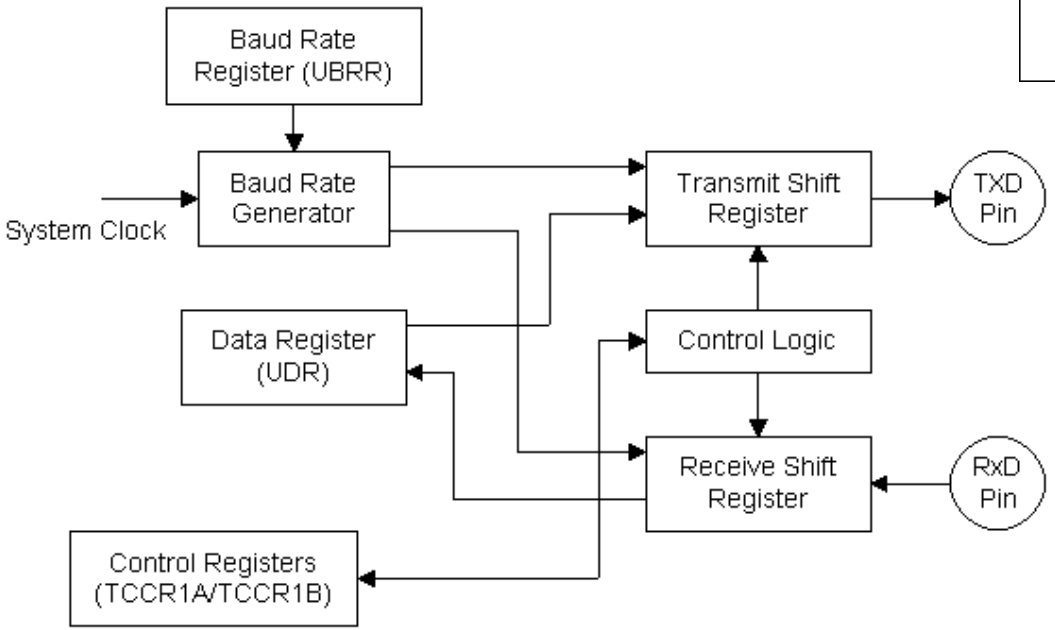
- Watchdog Timer
- Counter clocked by a separate on-chip oscilator
- When WDT overflows the uC receives a reset signal
- Usage: to make the device robust and fault-tolerant



Serial communication: USART

- Universal Synchronous-Asynchronous Receiver Transmitter
- Very used communication peripheral
- 5-9 data bits, 1-2 stop bits, parity

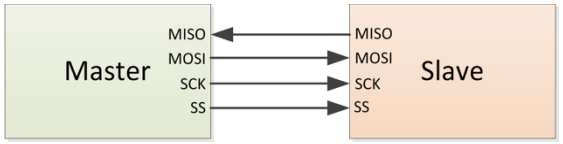


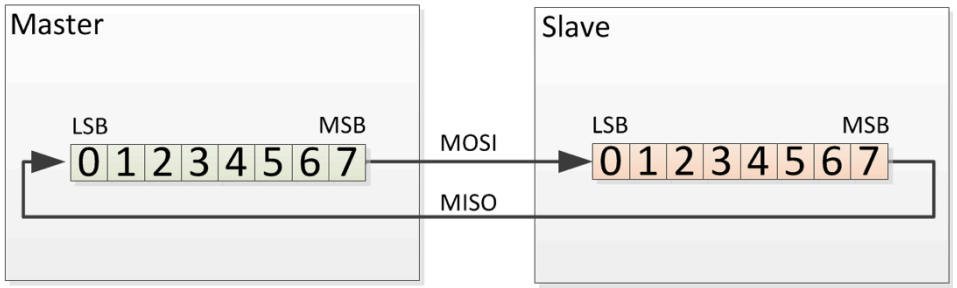


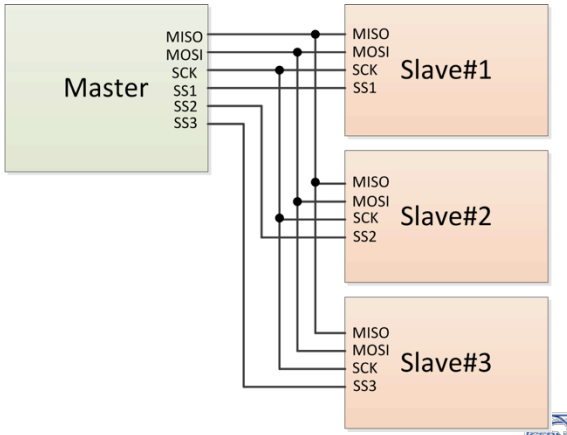

```
setup_uart:
ldi r16, 5
out UBRR, r16

ldi r16, 0b00011000
out UCR, r16

ret
```

Serial communication: SPI

- One master device, one or more slaves
- MISO, MOSI, SCK and SS' pins
- Registers: SPDR, SPSR
- Usage: SD cards, ADC, other uC, ISP Programming

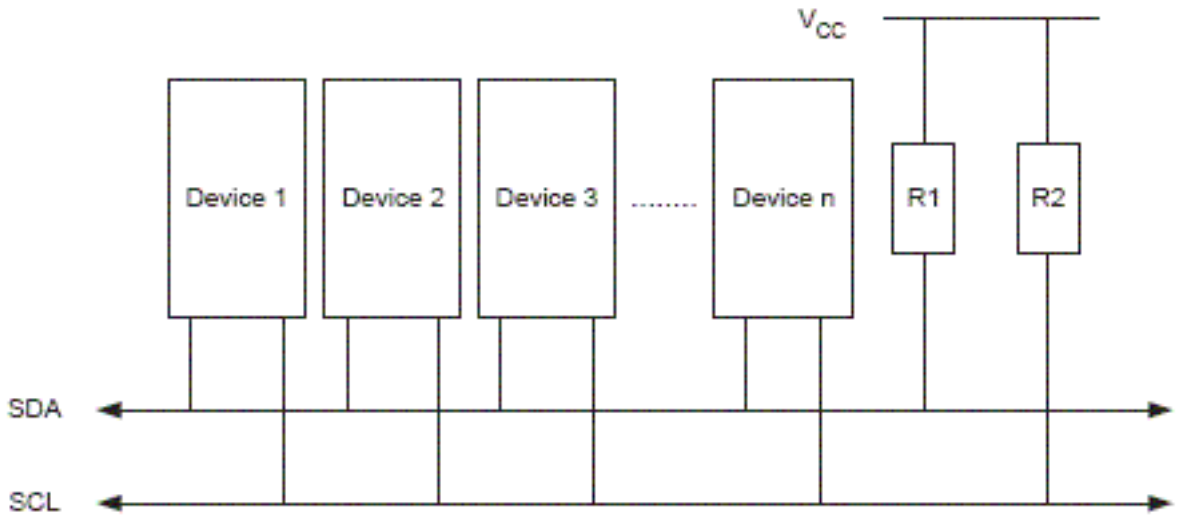






Serial communication: TWI, I2C

- 2 wire synchronous serial bus
- Connects up to 127 slaves to one or more masters
- Clock speed usually 100kHz or 400kHz
- Usage: sensors, eeprom



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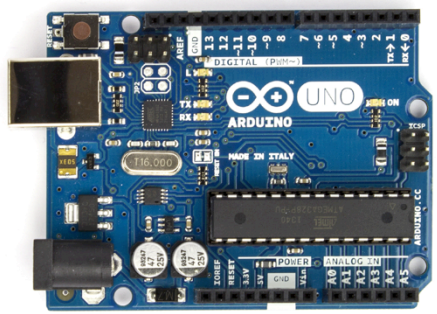
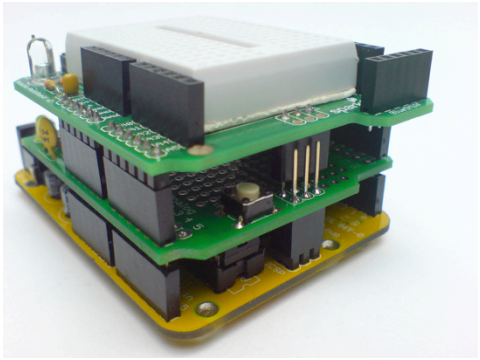
Arduino

- Open-source single-board microcontroller (8-bit AVR)
- + software (IDE & libraries)
- Introduced in 2005
- Inexpensive and easy to use
- (Stackable) shields





For Lab 10

- Arduino Uno, w/ Atmel AT Mega 328 uC

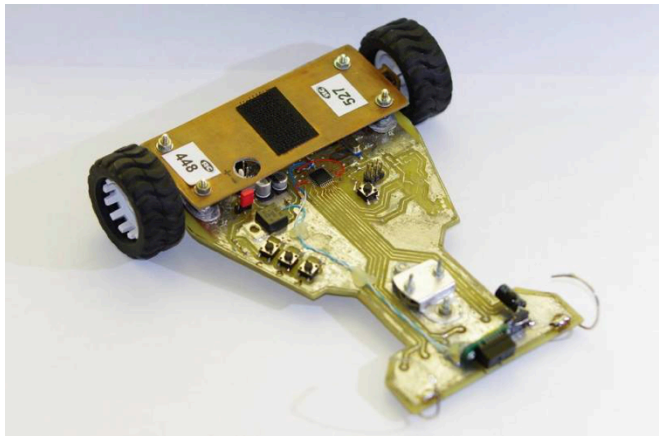
Usage

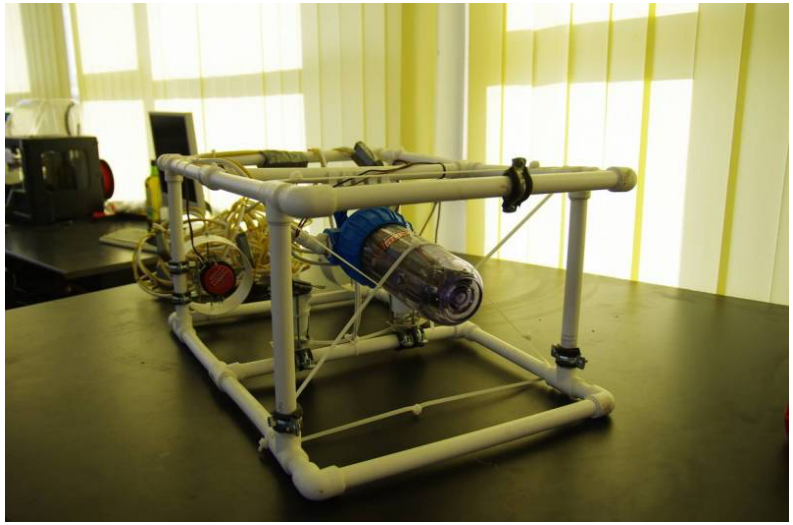
- Industrial products
- Everyday consumption products

- Aerospace
- Medical devices
- Toys

- Communication/ configuration (e.g. IPMI)
- Quads, drones

Examples





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