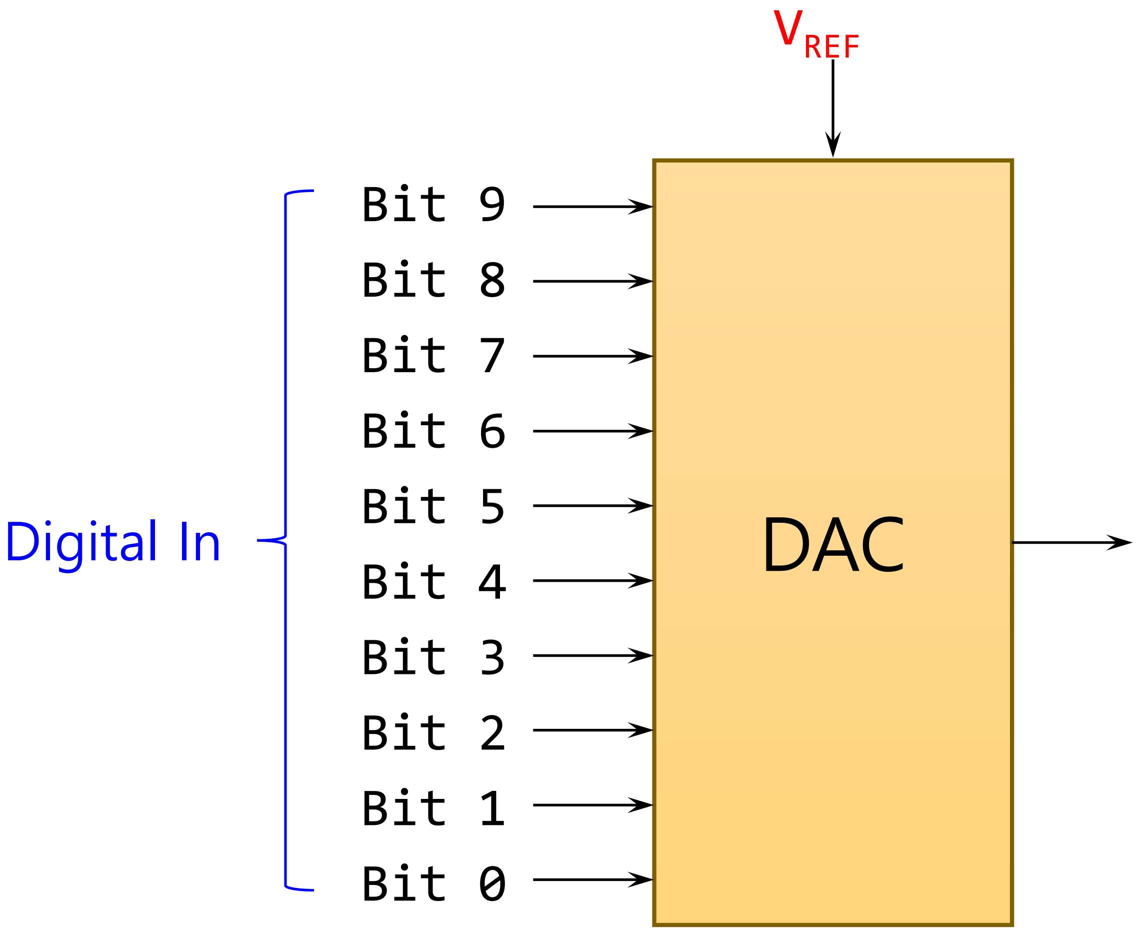
ADC

Analog-to-Digital Converter

ATmega328PB ADC Features

- 10-bit Resolution
- 13 – 260 µs Conversion Time
- Up to 76.9 kSPS (Up to 15 kSPS at Maximum Resolution)
- 6 Multiplexed Single Ended Input Channels
- 2 Additional Multiplexed Single Ended Input Channels (TQFP and QFN/MLF Package only)
- Temperature Sensor Input Channel
- 0 - V_{CC} ADC Input Voltage Range
- Selectable 1.1V ADC Reference Voltage
- Free Running or Single Conversion Mode
- Interrupt on ADC Conversion Complete
- Sleep Mode Noise Canceler

DAC (Digital to Analog Converter)



$$V_{OUT} = V_{REF} \times \frac{Digital\ In}{1024}$$

Successive Approximation ADC

DAC = Digital-to-Analog converter

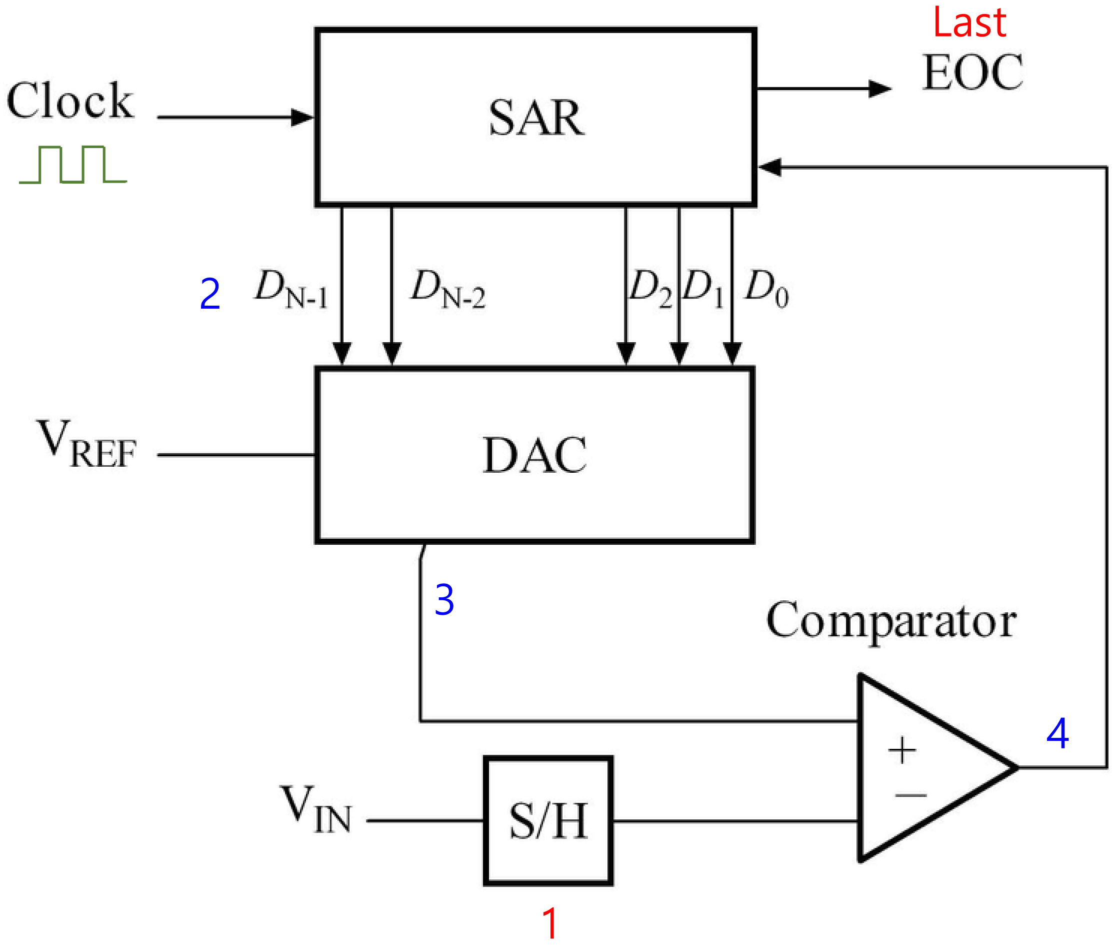
EOC = end of conversion

SAR = successive approximation register

S/H = sample and hold circuit

V_{IN} = input voltage

V_{REF} = reference voltage



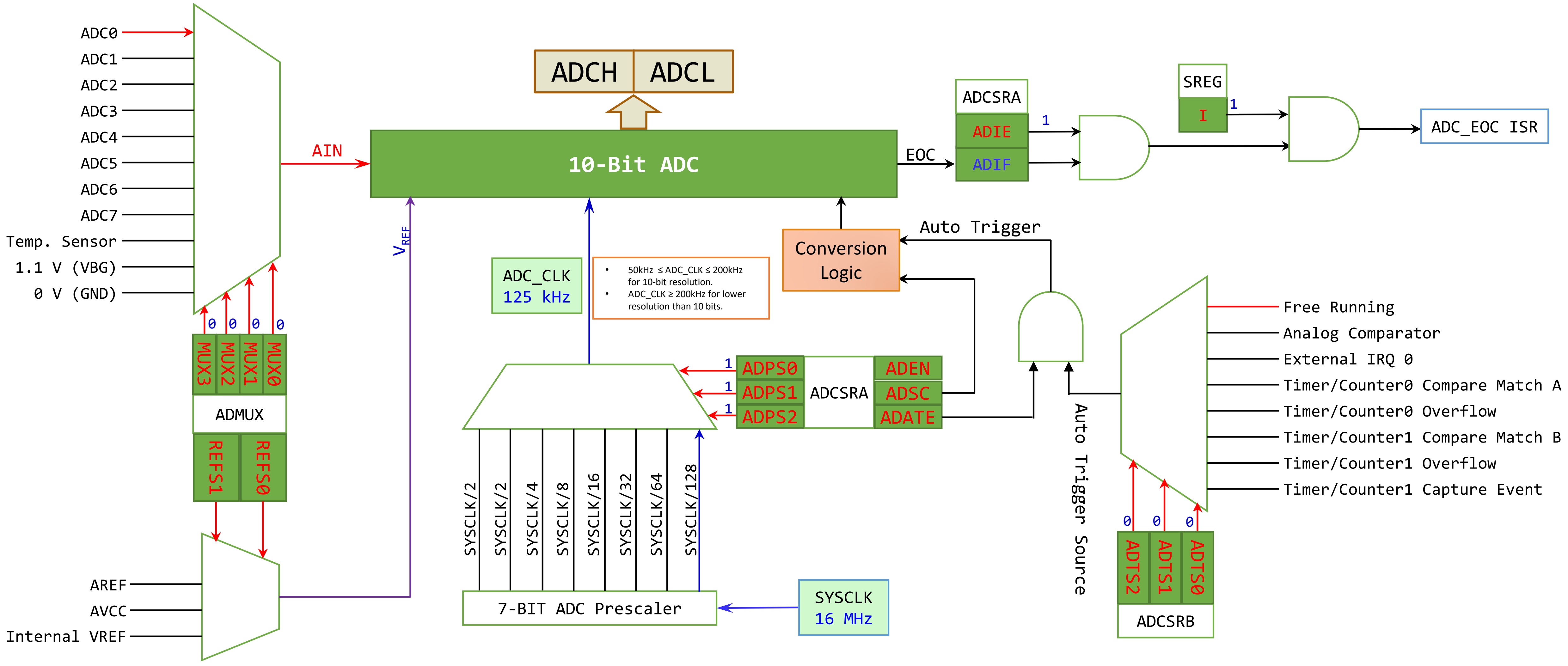
ATmega328PB ADC Conversion Results

- For single ended conversion, the result is

$$ADC_{out} = \frac{V_{IN}}{V_{REF}} \times 1024$$

  where V_{IN} is the voltage on the selected input pin, and V_{REF} the selected voltage reference.
- `0x000` (`0b0000000000`): represents analog ground.
- `0x3FF` (`0b1111111111`): represents the selected reference voltage minus one LSB.

ATmega328PB ADC Block Diagram



ATmega328P ADC Clock

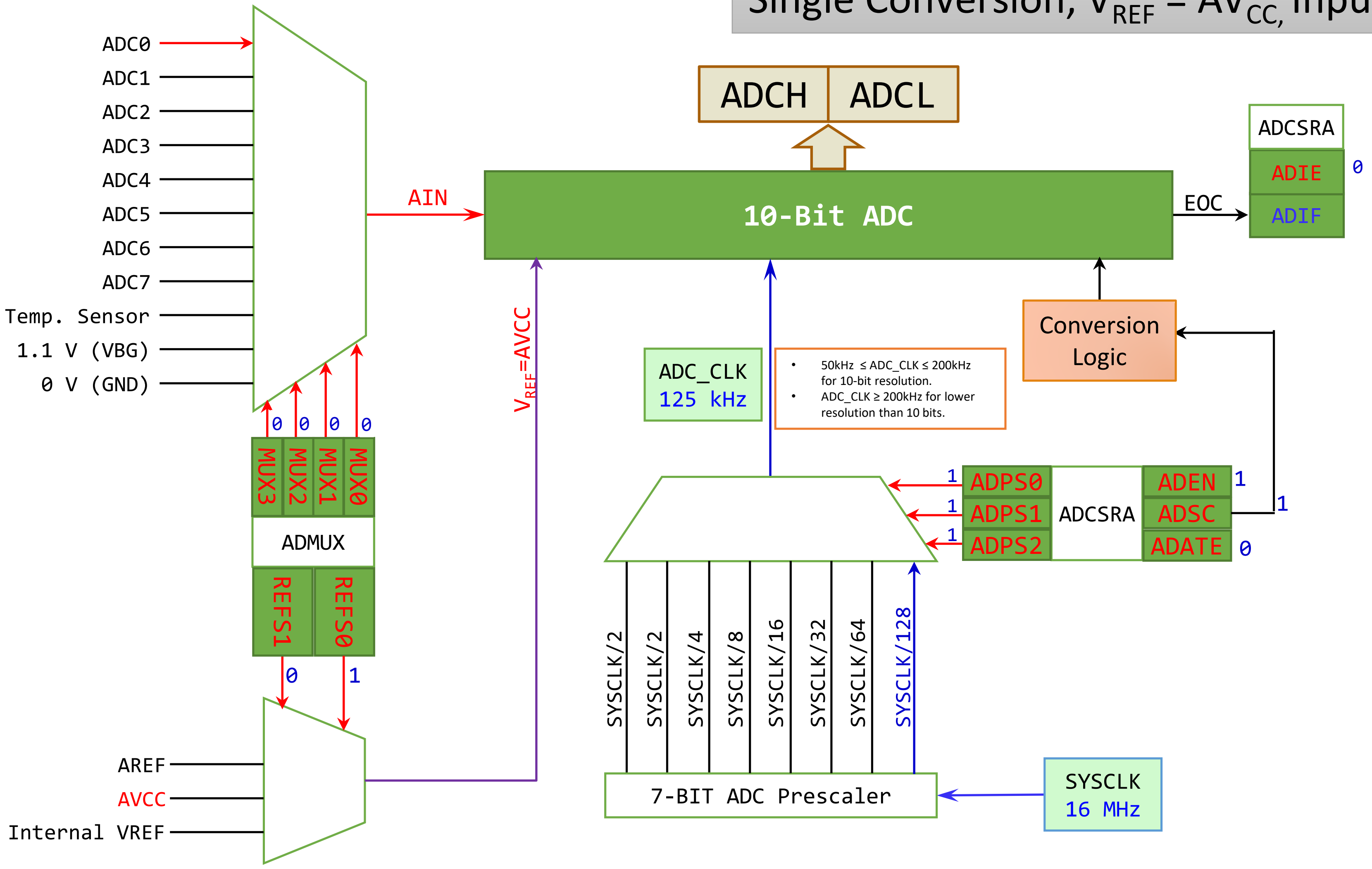
- ADC Clock
  - By default, the successive approximation circuitry requires an input clock frequency between 50kHz and 200kHz to get maximum resolution.
  - If a lower resolution than 10 bits is needed, the input clock frequency to the ADC can be higher than 200kHz to get a higher sample rate.

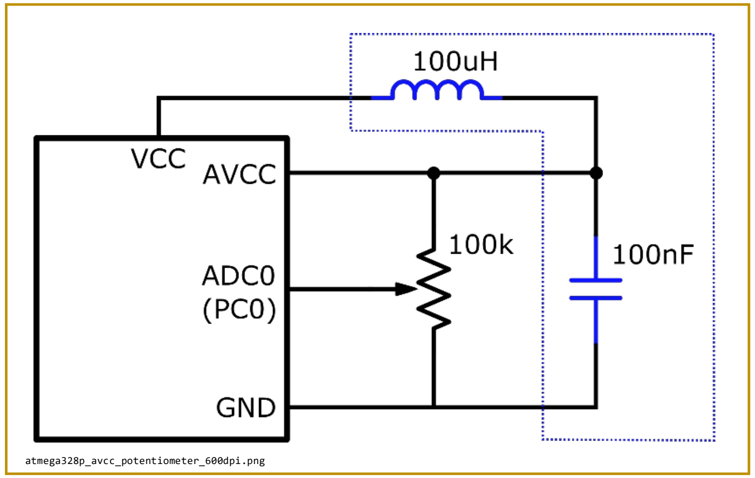
- ADC Conversion Time

Condition	Sample & Hold (Cycles from Start of Conversion)	Conversion Time (Cycles)
First conversion	13.5	25
Normal conversions, single ended	1.5	13
Auto Triggered conversions	2	13.5

ATmega328PB ADC Example 1 (Polling, Single Channel) (1)

Single Conversion, V_{REF} = AV_{CC}, Input Channel: ADC0, Non-interrupt





ATmega328PB ADC Example 1 (Polling, Single Channel) (2)

Single Conversion, V_{REF} = AV_{CC}, Input Channel: ADC0, Non-interrupt

```c
/* adc_single_channel_manual_trig.c
 * Convert single channel (ADC0) manually */

#include <stdio.h>
#include <avr/io.h>

void uart_init(void);

int main(void)
{
    unsigned int adc_data;

    uart_init();                              // 9,600 bps, 8-data, 1 stop

    ADMUX  = 0b01000000;                      // Vref=AVCC, convert ADC0.
    ADCSRA = (1 << ADEN) | (0b111 << ADPS0);  // Enable ADC. ADC_CLK=16MHz/128=125kHz.

    while (1)
    {
        ADCSRA |= (1 << ADSC);                // Start ADC
        while ((ADCSRA & (1 << ADIF)) == 0)   // Wait for End of Conversion
            ;
        ADCSRA |= (1 << ADIF);                // Clear ADIF

        adc_data = ADCW;                      // Read 10-bit ADC result
        printf("ADC result=%u\n", adc_data);  // display the result
    }
}
```

```c
/* usart.c */

#define F_CPU 16000000UL
#define UART_BAUD_RATE 9600UL
#define DIVISOR (((F_CPU / (UART_BAUD_RATE * 16UL))) - 1)

#include <stdio.h>
#include <avr/io.h>

int uart_putchar(char ch, FILE *stream);

FILE uart_str = FDEV_SETUP_STREAM(uart_putchar, NULL, _FDEV_SETUP_RW);

void uart_init(void)
{
    UCSR0B |= (1 << RXEN0) | (1 << TXEN0);    // enable TX and RX
    UCSR0C |= (1 << UCSZ00) | (1 << UCSZ01);  // 8-bit word
    UBRR0 = DIVISOR;

    stdout = &uart_str;
}

int uart_putchar(char ch, FILE *stream)
{
    while ((UCSR0A & (1 << UDRE0)) == 0);

    UDR0 = ch;
    return 0;
}
```

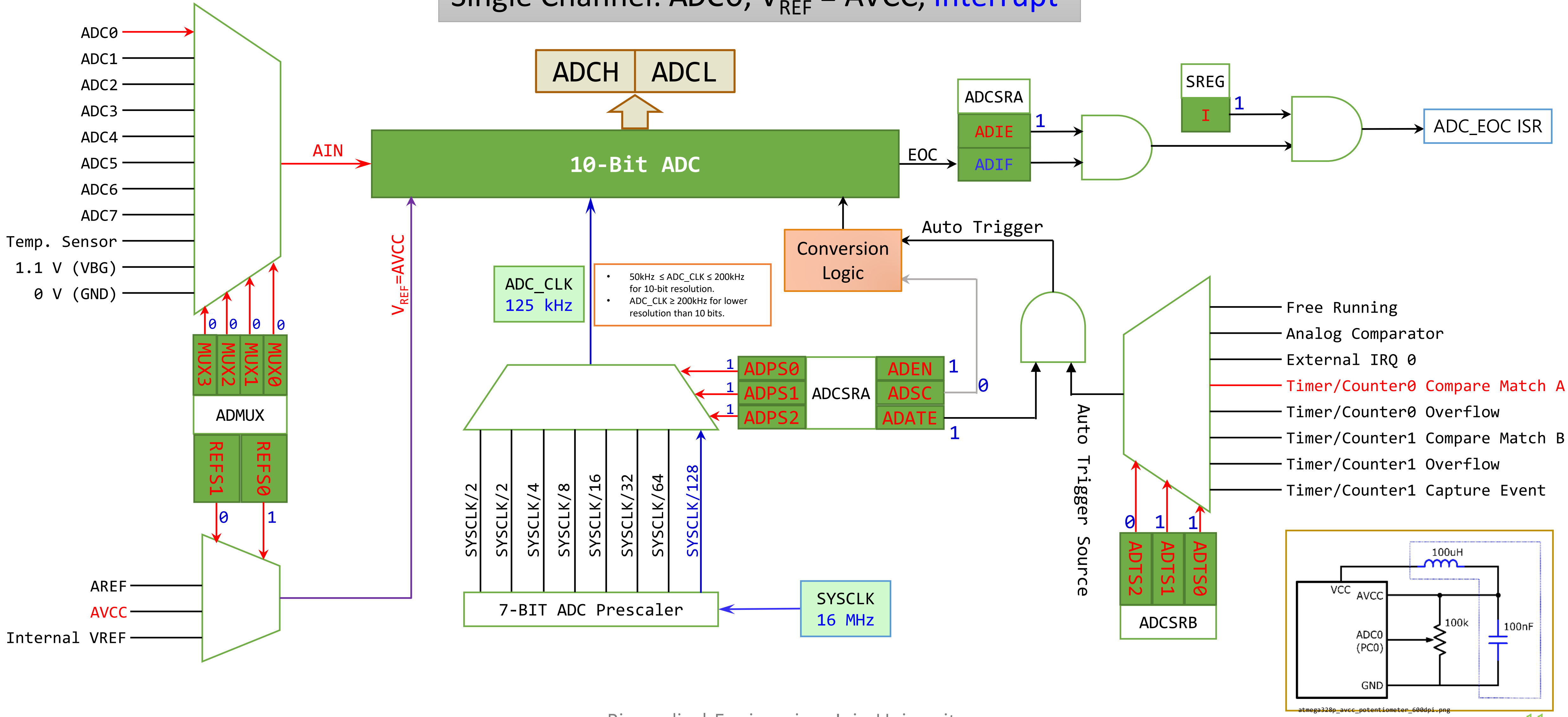
ATmega328PB ADC Example 2 (Interrupt, Single Channel) (1)

Make an application which converts ADC0 analog input signal to 10-bit digital signal.

- V_{REF}: AVCC
- ADC Clock: 125 kHz
- Sampling rate: about 100 samples per second (SPS)
- ADC auto trigger signal: `Timer/Counter0 Compare Match A`

ATmega328PB ADC Example 2 (Interrupt, Single Channel) (2)

Single Channel: ADC0, V_{REF} = AVCC, Interrupt



ATmega328PB ADC Example 2 (Interrupt, Single Channel) (3)

Single Channel: ADC0, V_{REF} = AVCC, Interrupt

```c
/* adc_single_channel_TC0_trigger_interrupt.c
   Single channel(ADC0), Timer/Counter0 Compare Match trigger,
   End of Conversion Interrupt. */

#include <stdio.h>
#include <avr/io.h>
#include <avr/interrupt.h>

void uart_init(void);

unsigned int adc_data_raw;
volatile unsigned char eoc_flag;    // must be volatile

int main(void)
{
    unsigned int adc_data;

    uart_init();                    // 1Mbps

    ADMUX  = 0b01000000;            // Vref=AVCC, convert ADC0.
    ADCSRA = (1 << ADEN)            // Enable ADC.
           | (1 << ADATE)           // ADC Auto trigger.
           | (1 << ADIE)            // Enable ADC Interrupt.
           | (0b111 << ADPS0);      // ADC_CLK=125kHz.

    ADCSRB = (0b011 << ADTS0);      // ADC Auto Trig Src: TC0 Cmp Mat A
    TCCR0A = (0b10 << WGM00);           // Set TC0 to CTC mode: TOP=OCR0A
    TCCR0B = (0b101 << CS00);           // TC0 Prescale Ratio=1024 (15,625Hz)
    OCR0A  = 155;                       // ADC auto trig freq≈100Hz

    sei();

    while (1)
    {
        while (eoc_flag == 0);          // Wait for End of Conversion

        cli();                          // Disable ADC EOC interrupt
        adc_data = adc_data_raw;        // Read 10-bit ADC result
        sei();                          // Enable ADC EOC interrupt

        eoc_flag = 0;

        printf("ADC result=%u\n", adc_data);    // display the result
    }
}

ISR(ADC_vect)
{
    adc_data_raw = ADCW;     // Read 10-bit ADC result
    eoc_flag = 1;            // indicate that new ADC data available

    TIFR0 |= (1 << OCF0A);   // Clear OCF0A flag.
}
```

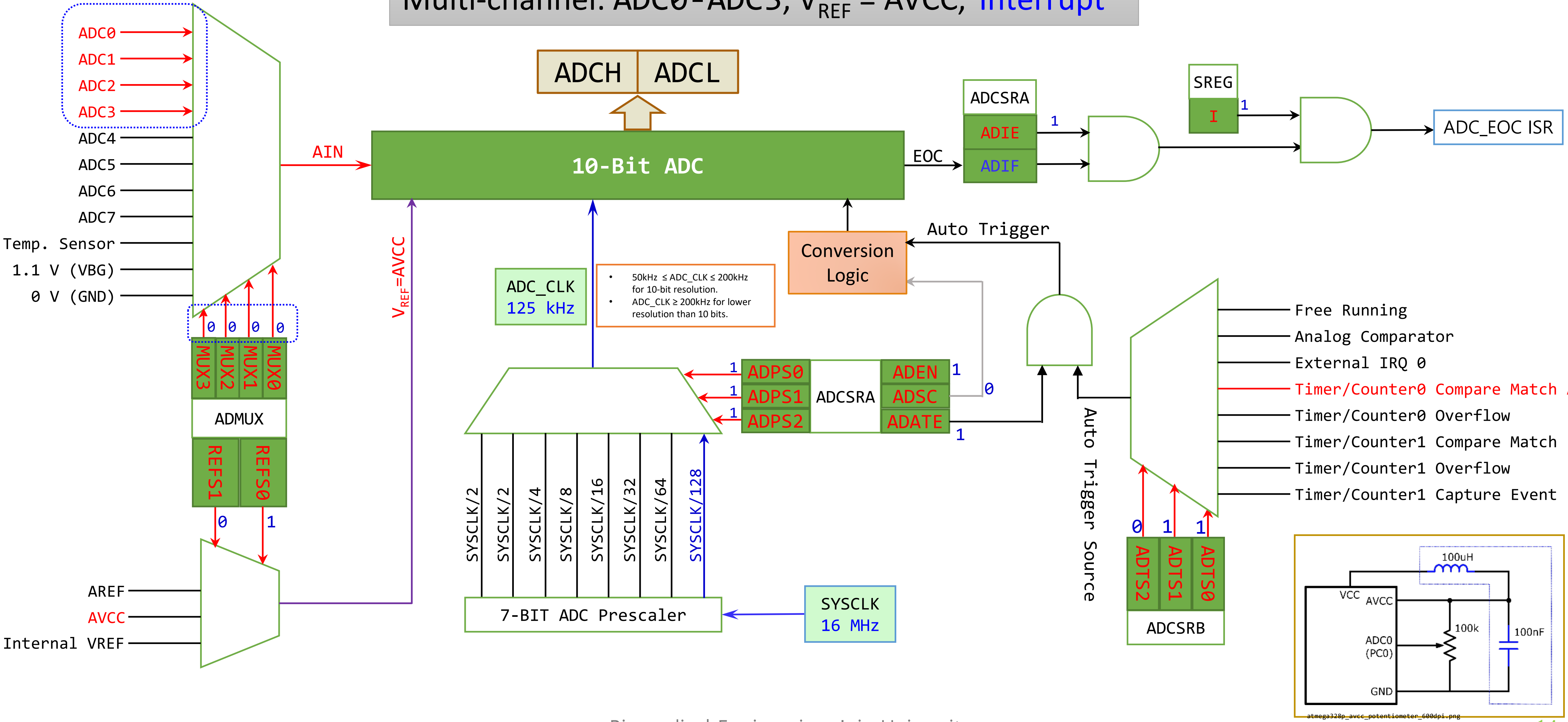
ATmega328PB ADC Example 3 (Interrupt, Multi-Channel) (1)

Make an application which converts `ADC0-ADC3` analog input signals to 10-bit digital signals.

- V_{REF}: AVCC
- ADC Clock: 125 kHz
- Sampling rate: about 25 samples per second (SPS) per channel
- ADC auto trigger signal: `Timer/Counter0 Compare Match A`

ATmega328PB ADC Example 3 (Interrupt, Multi-Channel) (2)

Multi-channel: ADC0-ADC3, V_{REF} = AVCC, Interrupt



ATmega328PB ADC Example 3 (Interrupt, Multi-Channel) (3)

Multi-channel: ADC0-ADC3, V_{REF} = AVCC, Interrupt

```c
/* Multi-channel(ADC0-ADC3), Timer/Counter0 Compare Match trigger,
   End of Conversion Interrupt. */

#define NUM_ADC_CH 4

#include <stdio.h>
#include <avr/io.h>
#include <avr/interrupt.h>

void uart_init(void);

unsigned int adc_data_raw[NUM_ADC_CH];
volatile unsigned char eoc_flag;        // must be volatile

int main(void)
{
    unsigned char i;
    unsigned int adc_data[NUM_ADC_CH];

    uart_init();                        // 1Mbps

    ADMUX  = (0b01 << REFS0);           // Vref=AVCC, convert ADC0.
    ADCSRA = (1 << ADEN)                // Enable ADC.
           | (1 << ADATE)               // ADC Auto trigger.
           | (1 << ADIE)                // Enable ADC Interrupt.
           | (0b111 << ADPS0);          // ADC_CLK=125kHz.

    ADCSRB = (0b011 << ADTS0);          // ADC Auto Trig Src: TC0 Cmp Mat A
    TCCR0A = (0b10 << WGM00);           // Set TC0 to CTC mode: TOP=OCR0A
    TCCR0B = (0b101 << CS00);           // TC0 Prescale Ratio=1024 (15,625Hz)
    OCR0A  = 155;                       // ADC auto trig freq≈100Hz
```

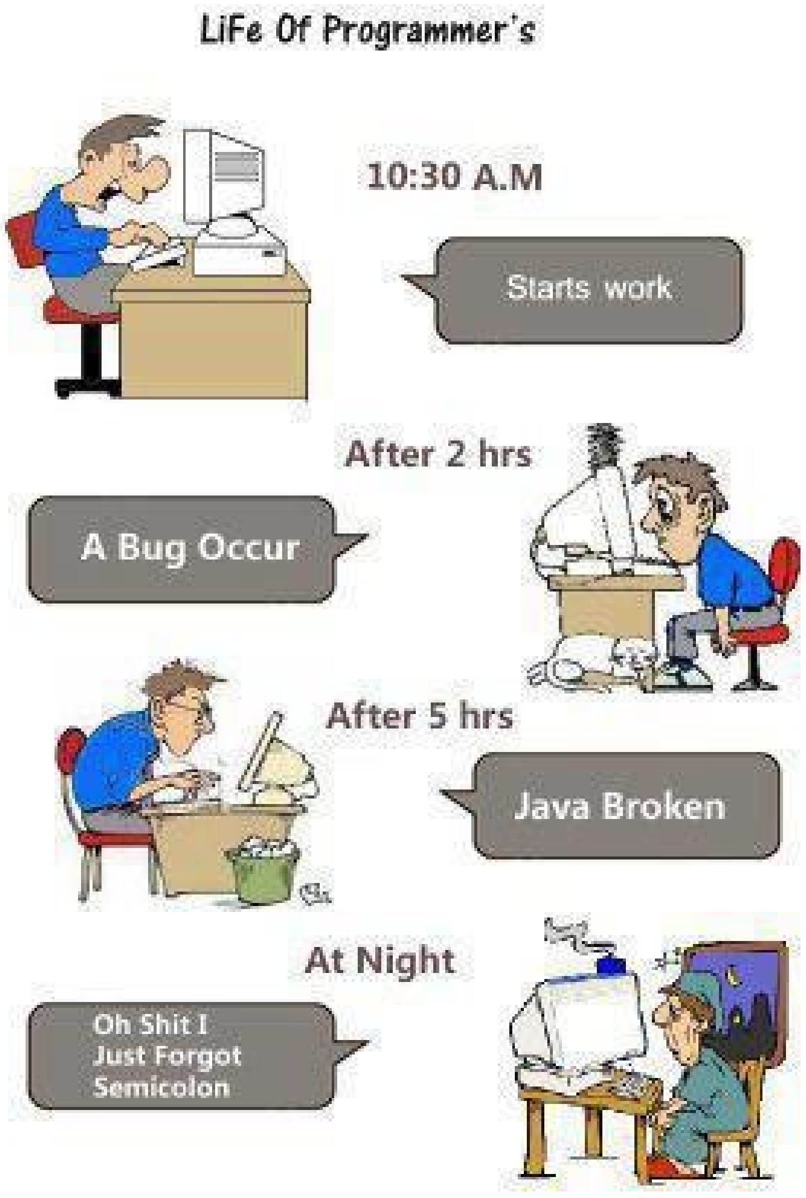
```c
    sei();                              // Enable global interrupt

    while (1)
    {
        while (eoc_flag == 0);          // Wait for End of Conversion

        cli();
        for (i=0; i<NUM_ADC_CH; i++)
            adc_data[i] = adc_data_raw[i];    // Read ADC result
        sei();
        eoc_flag = 0;
        printf("ADC0=%u, ADC1=%u, ADC2=%u, ADC3=%u\n", adc_data[0], adc_data[1],
                adc_data[2], adc_data[3]);    // display the result
    }
}

ISR(ADC_vect)
{
    unsigned char ch_num;

    ch_num = ADMUX & 0x0F;          // Extract current ADC channel number
    adc_data_raw[ch_num] = ADCW;    // Save result
    ch_num++;                       // Next ADC channel
    if (ch_num == NUM_ADC_CH)       // Last channel?
    {
        ch_num = 0;                 // Yes. Go to the 1st channel
        eoc_flag = 1;               // Indicate that new ADC data available
    }
    ADMUX = (0b01 << REFS0) | ch_num;   // Update next ADC channel number
    TIFR0 |= (1 << OCF0A);              // Clear OCF0A flag.
}
```


LiFe Of Programmer's
10:30 A.M
Starts work
After 2 hrs
A Bug Occur
After 5 hrs
Java Broken
At Night
Oh Shit I Just Forgot Semicolon

ADC
END