

# Interrupts (II)

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# External Interrupts

- The external interrupts are triggered by the INT7:0 pins.
  - If enabled, the interrupts will trigger even if the INT7:0 are configured as outputs
    - This feature provides a way of generating a software interrupt.
  - Can be triggered by a falling or rising edge or a logic level
    - Specified in External Interrupt Control Register
      - EICRA (for INT3:0)
      - EICRB (for INT7:4)



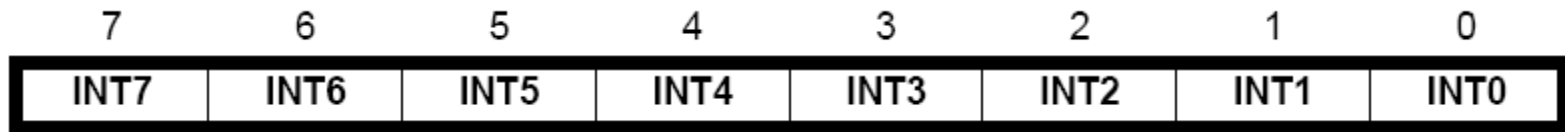
# External Interrupts (cont.)

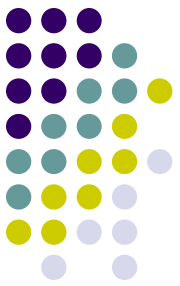
- To enable an interrupt, two bits must be set
  - I bit in SREG
  - INTx bit in EIMSK
- To activate an interrupt, the following must be met:
  - The interrupt must be enabled
  - The associated external pin must have a designed signal asserted.



# EIMSK

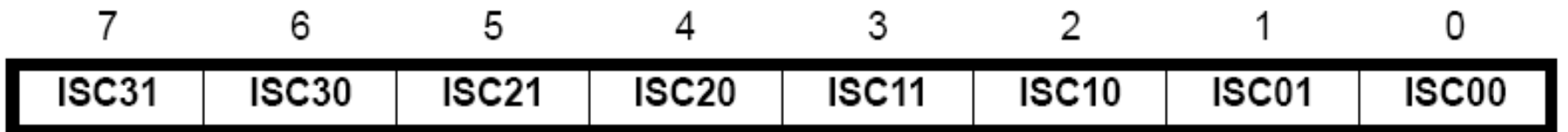
- External Interrupt Mask Register
  - A bit is set to enable the related interrupt





# EICRA

- External Interrupt Control Register A
  - For INT0-3
  - Defines the type of signals that activates the external Interrupt
    - on rising or falling edge or level sensed.

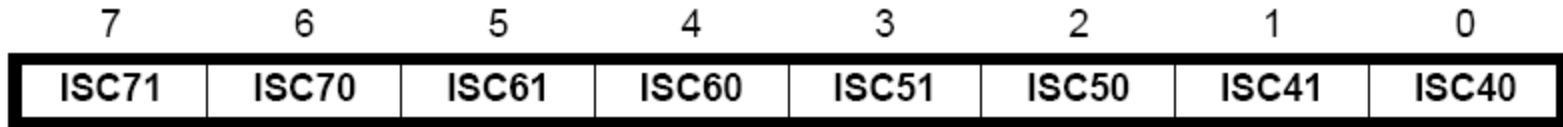


ISCn1	ISCn0	Description
0	0	The low level of INTn generates an interrupt request.
0	1	Reserved
1	0	The falling edge of INTn generates asynchronously an interrupt request.
1	1	The rising edge of INTn generates asynchronously an interrupt request.



# EICRB

- External Interrupt Control Register B
  - For INT4-7
  - Defines the type of signals that activates the External Interrupt
    - on rising or falling edge or level sensed.

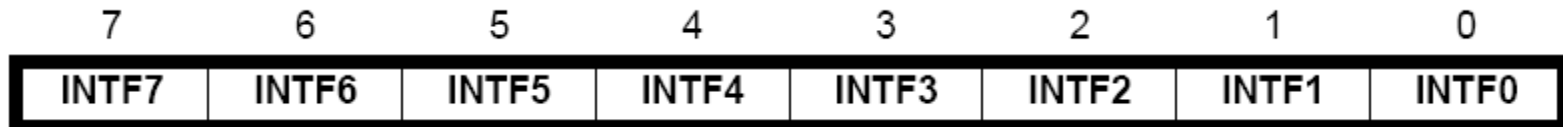


ISCn1	ISCn0	Description
0	0	The low level of INTn generates an interrupt request.
0	1	Any logical change on INTn generates an interrupt request
1	0	The falling edge between two samples of INTn generates an interrupt request.
1	1	The rising edge between two samples of INTn generates an interrupt request.



# EIFR

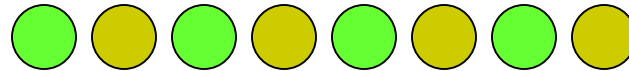
- Interrupt flag register
  - A bit is set when an event-triggered interrupt is enabled and the related event on the related INT pin happens.
    - Event-triggered interrupt: signal edge activated.





# Example 1

- Design a system, where the state of LEDs toggles under the control of the user.







# Example 1 (solution)

- Use an external interrupt
  - Connect the external interrupt pin to a push button
  - When the button pressed, the interrupt is generated
- In the assembly code
  - Set up the interrupt
    - Set up the interrupt vector
    - Enable the interrupt
  - Write a service routine for this interrupt
    - Change the display pattern
    - Write the pattern to the port connected to the LEDs



# Code for Example 1

```
.include "m2560def.inc"

.def    temp = r16
.def    output = r17
.def    count = r18
.equ    PATTERN = 0b01010101

                                ; set up interrupt vectors
                                jmp RESET
.org    INT0addr
                                jmp EXT_INT0

RESET:
    ldi temp, low(RAMEND)        ; initialize stack
    out SPL, temp
    ldi temp, high(RAMEND)
    out SPH, temp

    ser temp                    ; set Port C as output
    out DDRC, temp
    out PORTC, temp
    ldi output, PATTERN

                                ; continued
```

# Code for Example 1



```
; continued
    ldi temp, (2 << ISC00)    ; set INT0 as falling-
    sts EICRA, temp          ; edge triggered interrupt

    in temp, EIMSK           ; enable INT0
    ori temp, (1<<INT0)
    out EIMSK, temp

    sei                       ; enable Global Interrupt
    jmp main

EXT_INT0:
    push temp                ; save register
    in temp, SREG            ; save SREG
    push temp

    com output               ; flip the pattern
    out PORTC, output
    inc count

    pop temp                 ; restore SREG
    out SREG, temp
    pop temp                 ; restore register
    reti
```

# Code for Example 1



```
; continued  
  
; main - does nothing but increment a counter  
main:  
    clr count  
    clr temp  
loop:  
    inc temp           ; a dummy task in main  
    rjmp loop
```



# Timer/Counters

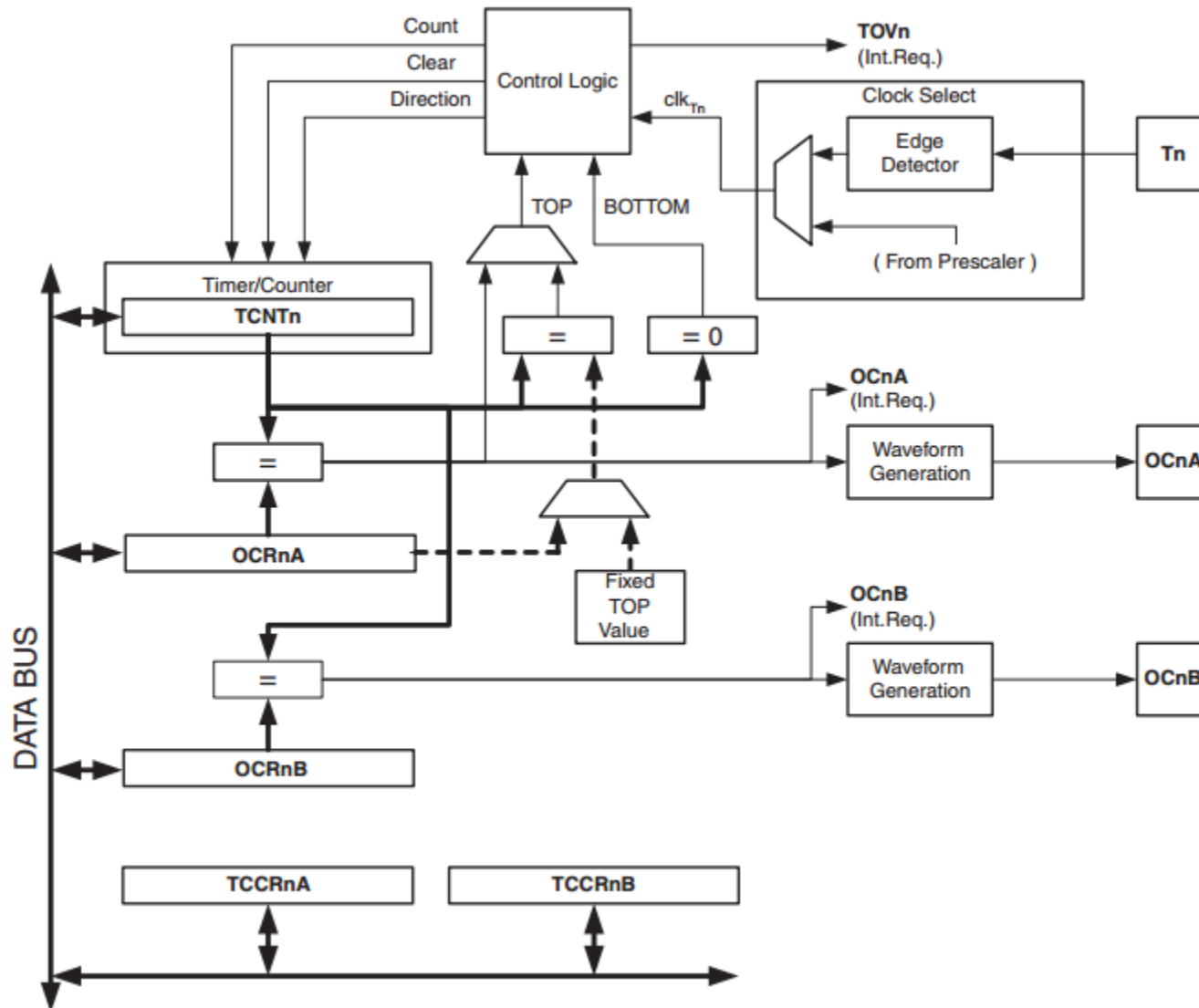
- Simply binary counters
- Used in two different modes:
  - Timer
    - Counting time periods
  - Counter
    - Counting the events or pulse or something of this nature
- Can be used to
  - Measure time periods, speed, frequency
  - Generate PWM signals
  - Schedule real-time tasks
  - etc.



# Timer/Counters in AVR

- In AVR, there are 8-bit and 16-bit timer/counters.
  - Timer 0 and Timer 2: 8-bit
  - Timer 1,3-5 16-bit

# 8-bit Timer/Counter Block Diagram





# 8-bit Timer/Counter

- The counter can be initialized with
  - 0 (controlled by *reset*)
  - a number (controlled by *count signal*)
- Can count up or down
  - controlled by *direction signal*
- Those controlled signals are generated by hardware control logic
  - The control logic is further controlled by programmer by
    - Writing control bits into TCCRnA/TCCRnB
- Output
  - Overflow interrupt request bit
  - Output Compare interrupt request bit
  - OCn bit: Output Compare bit for waveform generation





# TIMSK0

- Timer/Counter Interrupt Mask Register
  - Set TOIE0 (and I-bit in SREG) to enable the Overflow Interrupt
  - Set OCIE0(A/B) (and I bit in SREG) to enable Compare Match Interrupt

Bit	7	6	5	4	3	2	1	0	
(0x6E)	–	–	–	–	–	OCIE0B	OCIE0A	TOIE0	TIMSK0
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Control bits for timer/counter0



# TIFR0

- Timer/Counter Interrupt Flag Register
  - OCF0(A/B) bit is set when a Compare Match between the counter and the data in OCR0(A/B) (Output Compare Registers).
  - When  $(I=1) \& \& (OCIE0(A/B)=1) \& \& (OCF0(A/B)=1)$ , the related Timer/Counter Compare Match Interrupt is executed.
  - OCF0(A/B) bit is cleared by hardware when the related interrupt is handled or can be cleared by writing a logic 0 to the flag

Bit	7	6	5	4	3	2	1	0	
0x15 (0x35)	-	-	-	-	-	OCF0B	OCF0A	TOV0	TIFR0
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Interrupt control bits for timer/counter0



# TIFR0 (cont.)

- Timer/Counter Interrupt Flag Register
  - TOV0 bit is set when an overflow occurs in the counter.
    - When  $(I=1) \& \& (TOIE0=1) \& \& (TOV0=1)$ , the related Timer/Counter Overflow Interrupt is executed.
    - In PWM mode, this bit is set when the counter changes counting direction at 0x00
  - OCF0(A/B) bit is cleared by hardware when the related interrupt is handled or can be cleared by writing a logic 0 to the flag

Bit	7	6	5	4	3	2	1	0	
0x15 (0x35)	-	-	-	-	-	OCF0B	OCF0A	TOV0	TIFR0
Read/Write	R	R	R	R	R	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

Interrupt control bits for timer/counter0



# TCCR0A/B

- Timer Counter Control Register
  - For Timer/Counter0
  - Similar registers for other timers

Bit	7	6	5	4	3	2	1	0	
0x24 (0x44)	<b>COM0A1</b>	<b>COM0A0</b>	<b>COM0B1</b>	<b>COM0B0</b>	–	–	<b>WGM01</b>	<b>WGM00</b>	<b>TCCR0A</b>
Read/Write	R/W	R/W	R/W	R/W	R	R	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	
Bit	7	6	5	4	3	2	1	0	
0x25 (0x45)	<b>FOC0A</b>	<b>FOC0B</b>	–	–	<b>WGM02</b>	<b>CS02</b>	<b>CS01</b>	<b>CS00</b>	<b>TCCR0B</b>
Read/Write	W	W	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

# TCCR0 Bit Description



- COM0xn/WGM0n/FOC0
  - Control the mode of operation
    - The behavior of the Timer/Counter and the output, is defined by the combination of the Waveform Generation mode (WGM02:00) and Compare Output mode (COM0x1:0) bits.
    - The simplest mode of operation is the Normal Mode (WGM02:00 = 00). In this mode the counting direction is always up. The counter rolls over when it passes its maximum 8-bit value (TOP = 0xFF) and then restarts from the bottom (0x00).
- Refer to Mega2560 Data Sheet (pages 118~194) for details.



# TCCR0 Bit Description (cont.)

- Bit 2:0 in TCCR0B

**Table 16-9.** Clock Select Bit Description

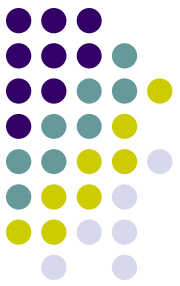
CS02	CS01	CS00	Description
0	0	0	No clock source (Timer/Counter stopped)
0	0	1	$clk_{I/O}$ /(No prescaling)
0	1	0	$clk_{I/O}/8$ (From prescaler)
0	1	1	$clk_{I/O}/64$ (From prescaler)
1	0	0	$clk_{I/O}/256$ (From prescaler)
1	0	1	$clk_{I/O}/1024$ (From prescaler)
1	1	0	External clock source on T0 pin. Clock on falling edge
1	1	1	External clock source on T0 pin. Clock on rising edge

Bit	7	6	5	4	3	2	1	0	
0x25 (0x45)	FOC0A	FOC0B	–	–	WGM02	CS02	CS01	CS00	TCCR0B
Read/Write	W	W	R	R	R/W	R/W	R/W	R/W	
Initial Value	0	0	0	0	0	0	0	0	

# Example 2



- Implement a scheduler that can execute a task every one second.

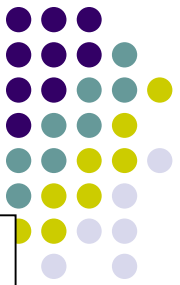


# Example 2 (solution)

- Use Timer0 to count the time
  - Let's set Timer0 prescaler to 8
    - The time-out for the setting should be
      - $256 * (\text{clock period}) = 256 * 8 / (16 \text{ MHz})$   
 $= 128 \text{ us}$ 
        - Namely, we can set the Timer0 overflow interrupt that is to occur every 128 us.
        - Note,  $\text{Clk}_{\text{tos}} = 1/16 \text{ MHz}$  (obtained from the data sheet)
      - For one second, there are
        - $1000000 / 128 = \sim 7812$  interrupts
- In code,
  - Set Timer0 interrupt to occur every 128 microseconds
  - Use a counter to count to 7812 interrupts for counting 1 second
  - To observe the 1 second time period, toggle an LED every second.



# Example 3



```
; This program implements a timer that counts one second using  
; Timer0 interrupt
```

```
.include "m2560def.inc"
```

```
.equ PATTERN = 0b11110000
```

```
.def temp = r16
```

```
.def leds = r17
```

```
; The macro clears a word (2 bytes) in a memory  
; the parameter @0 is the memory address for that word
```

```
.macro clear
```

```
    ldi YL, low(@0)      ; load the memory address to Y
```

```
    ldi YH, high(@0)
```

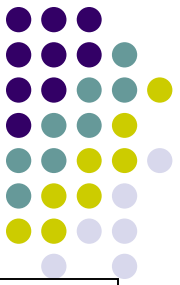
```
    clr temp
```

```
    st Y+, temp          ; clear the two bytes at @0 in SRAM
```

```
    st Y, temp
```

```
.endmacro
```

```
; continued
```



# Example 3

```
; continued
.dseg
SecondCounter:
    .byte 2           ; Two-byte counter for counting seconds.
TempCounter:
    .byte 2           ; Temporary counter. Used to determine
                    ; if one second has passed

.cseg
.org 0x0000
    jmp RESET
    jmp DEFAULT      ; No handling for IRQ0.
    jmp DEFAULT      ; No handling for IRQ1.
.org OVf0addr
    jmp Timer0OVf    ; Jump to the interrupt handler for
                    ; Timer0 overflow.

...
    jmp DEFAULT      ; default service for all other interrupts.
DEFAULT:  reti      ; no service
                    ; continued
```

# Example 3



```
; continued
```

```
RESET: ldi temp, high(RAMEND)
       out SPH, temp
       ldi temp, low(RAMEND)
       out SPL, temp
```

```
       ser temp
       out DDRC, temp
```

```
       rjmp main
```

```
; Initialize stack pointer
```

```
; set Port C as output
```

```
; continued
```

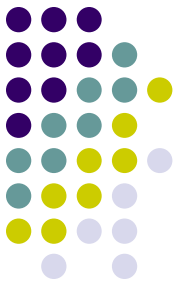


# Example 3

```
; continued

Timer0OVF:                ; interrupt subroutine to Timer0
    in temp, SREG
    push temp              ; Prologue starts.
    push YH                ; Save all conflict registers in the prologue.
    push YL
    push r25
    push r24              ; Prologue ends.
                          ; Load the value of the temporary counter.
    lds r24, TempCounter
    lds r25, TempCounter+1
    adiw r25:r24, 1       ; Increase the temporary counter by one.
                          ; continued
```

# Example 3



```

cpi r24, low(7812)           ; Check if (r25:r24) = 7812
ldi temp, high(7812)        ; 7812 = 106/128
cpc r25, temp
brne NotSecond
com leds
out PORTC, leds
clear TempCounter           ; Reset the temporary counter.
                             ; Load the value of the second counter.

lds r24, SecondCounter
lds r25, SecondCounter+1
adiw r25:r24, 1 ; Increase the second counter by one.
                ; continued
```

# Example 3



```
sts SecondCounter, r24
sts SecondCounter+1, r25
rjmp EndIF
```

NotSecond:

```
                ; Store the new value of the temporary counter.
```

```
sts TempCounter, r24
sts TempCounter+1, r25
```

EndIF:

```
pop r24          ; Epilogue starts;
pop r25          ; Restore all conflict registers from the stack.
pop YL
pop YH
pop temp
out SREG, temp
reti            ; Return from the interrupt.
                ; continued
```

# Example 3



```
main:
    ldi leds, 0xFF
    out PORTC, leds
    ldi leds, PATTERN
    clear TempCounter           ; Initialize the temporary counter to 0
    clear SecondCounter        ; Initialize the second counter to 0
    ldi temp, 0b00000000
    out TCCR0A, temp
    ldi temp, 0b00000010
    out TCCR0B, temp           ; Prescaling value=8
                                ; = 128 microseconds
    ldi temp, 1<<TOIE0        ; T/C0 interrupt enable
    sts TIMSK0, temp          ; Enable global interrupt
    sei
loop:  rjmp loop              ; loop forever
```



# Reading Material

- Chapter 8: Interrupts and Real-Time Events. Microcontrollers and Microcomputers by Fredrick M. Cady.
- Mega2560 Data Sheet.
  - External Interrupts.
  - Timer0





# Homework

1. What do you need to do to set up an Timer0 Output Compare Match Interrupt?

# Homework



2. Based on the Example 1 in this week lecture slides, implement a software interrupt such that when there is an overflow in the counter that counts the number of LED toggles, all LEDs are turned on.