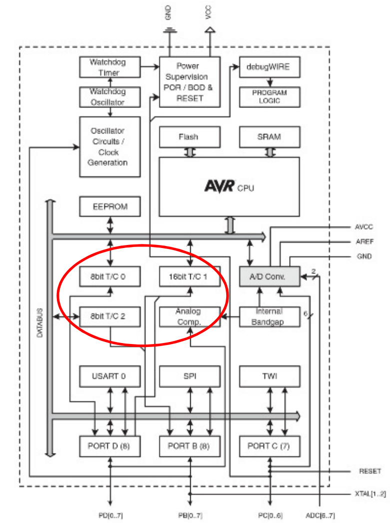
Unit C – Timers and Counters

Counter/Timers Overview

ATmega328P has two 8-bit and one 16-bit counter/timers.

- Can count at some rate up to a value, generate an interrupt and start over counting from 0.
- Useful for performing operations at specific time intervals.
- Can be used for other tasks such as pulse-width modulation or counting external events.



Counter/Timers Overview

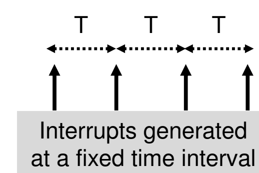
But we already have delay() functions … why do we need timers?

- Delay functions tie up the processor while executing.
- Better to let a timer measure the delay, and generate an interrupt when complete.
- We can do other useful work while we are waiting for time to elapse!

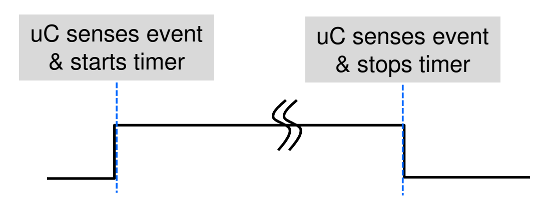
```
while(1)
{
  lcd_moveto(0,0);
  lcd_stringout("hello");
  _delay_ms(500);
}
// is "hello" printed
// every 500 ms?
```


Use of Timers

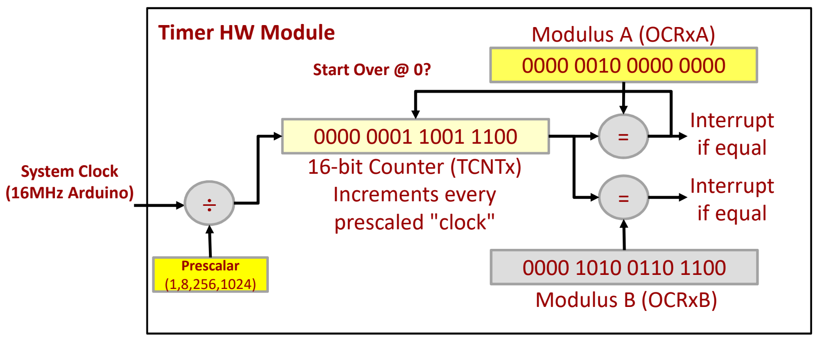
- Use 1: Generate an interrupt at a regular interval
  - Great for fixed time periods



- Use 2: Use HW timer to measure time duration
  - Great for measuring unknown timer intervals



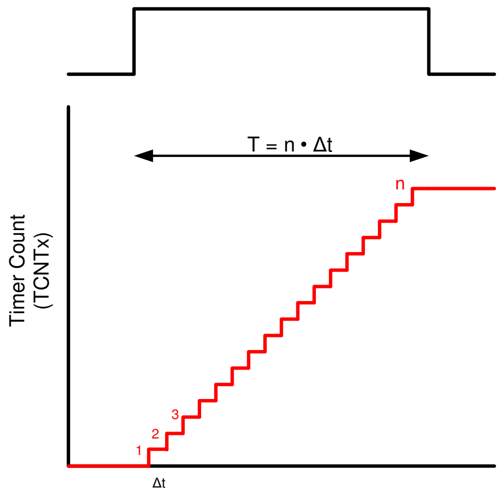
General Overview of Timer HW



We'll just use the modulus A register so you can ignore B for our class

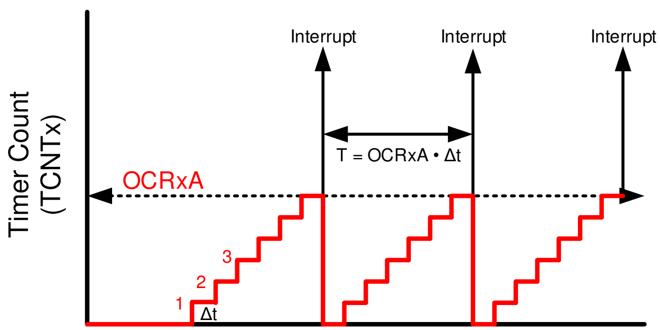
Duration Timer

- Timer can be configured to count at a certain rate (Δt)
- Start/stop the timer when the microcontroller senses the start/stop of an event
- The count value, n, can determine the duration of the event: T = n•Δt



Periodic Interrupt Timer

- Timer can be configured to count at a certain rate (Δt) and an upper bound (aka modulus count / OCRxA register)
- Start the timer and whenever its value reaches the upper bound an interrupt will be generated
  - Can be configured to immediately restart the count at 0 and repeat



Periodic Interrupt Timer Steps

To use the counter to generate interrupts at a fixed interval:

- Decide how long an interval is required between interrupts (1 sec, 50 ms, etc.) for your application
- Determine a counter frequency (time period), and a counter modulus (max period)that will make the counter take that long to count from 0 to the modulus value.
- Configure registers.
- Write an ISR.
- Start the timer.

Counter/Timer Registers

- Bad News: Lots of register bits to deal with

Register								
Control Register A (TCCR1A)	COM1A1	COM1A0	COM1B1	COM1B0			WGM11	WGM10
Control Register B (TCCR1B)	ICNC1	ICES1		WGM13	WGM12	CS12	CS11	CS10
Control Register C (TCCR1C)	FOC1A	FOC1B						
Timer/Counter Register (TCNT1H & TCNT1L)	TCNT1[15:8]							
	TCNT1[7:0]							
Output Compare Register A (OCR1AH & OCR1AL)	OCR1A[15:8]							
	OCR1A[7:0]							
Output Compare Register B (OCR1BH & OCR1BL)	OCR1B[15:8]							
	OCR1B[7:0]							
Input Capture Register (ICR1H & ICR1L)	ICR115:8]							
	ICR1[7:0]							
Interrupt Mask Register (TIMSK1)			ICIE1			OCIE1B	OCIE1A	TOIE1
Interrupt Flag Register (TIFR1)			ICF1			OCF1B	OCF1A	TOV1

Counter/Timer Registers

- Good News: Can ignore most for simple timing

Register								
Control Register B (TCCR1B)				WGM13	WGM12	CS12	CS11	CS10
Output Compare Register A (OCR1AH & OCR1AL)	OCR1A[15:8]							
	OCR1A[7:0]							
Interrupt Mask Register (TIMSK1)							OCIE1A	

Computing the Desired Cycle Delay

- **Primary step**: calculate how many processor clock cycles are required for your desired delay
  - Desired clock cycles (aka "modulus") = clock frequency × desired delay time
  - Arduino UNO clock is fixed at 16 MHz
- Example: 0.25 second delay with a 16 MHz clock
  - Desired clock cycles = 16,000,000 c/s × 0.25s = 4,000,000 cycles
  - The Arduino timer starts at 0, so we will set the max count to 3,999,999
    - 4,000,000-1 = 3,999,999
- Problem: The desired value you calculate must fit in at most a 16-bit register (i.e. max 65,535)
  - If the number is bigger than 65,535 then a prescalar must be used to reduce the clock frequency to the counter from 16MHz to something slower

Calculating the Prescalar

- The counter prescalar divides the processor clock down to a lower frequency so the counter is counting slower.
- Can divide the processor clock by four different powers of two: 8, 64, 256, or 1024.
- Try prescalar options until the cycle count fits in 16-bits
  - 4,000,000 / 8 = 500,000 ← too big
  - 4,000,000 / 64 = 62,500 ← OK
  - 4,000,000 / 256 = 15,625 ← OK
  - 4,000,000 / 1024 = 3906.25 ← OK, but not an integer
- In this example, either of the last three could work but since we can only store integers in our timer count registers the last one would not yield exactly 0.25s (more like 0.249984s)

Counter/Timer Initialization 1

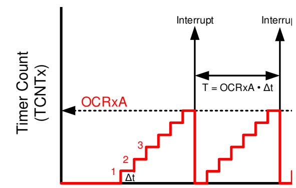
- Set the mode for "Clear Timer on Compare" (CTC)
  - WGM13 = 0, WGM12 = 1
  - This tells the hardware to start over at 0 once the counter is reaches your desired value
- Enable "Output Compare A Match Interrupt"
  - OCIE1A = 1
- Load the 16-bit counter modulus into OCR1A
  - This is the value the counter will count up to and then generate an interrupt.
  - The counter then clears to zero and starts counting up again.
  - In C, the register can be accessed as...
    - A 16-bit value "OCR1A"
    - Or as two eight bit values "OCR1AH" and OCR1AL".

```
// Set to CTC mode
TCCR1B |= (1 << WGM12);

// Enable Timer Interrupt
TIMSK1 |= (1 << OCIE1A);

// Load the MAX count
// Assuming prescalar=256
//  counting to 15625 =
//  0.25s w/ 16 MHz clock
OCR1A = 15625;
```

Control Register B (TCCR1B)		WGM13	WGM12	CS12	CS11	CS10
Output Compare Register A (OCR1AH & OCR1AL)	OCR1A[15:8] / OCR1A[7:0]					
Interrupt Mask Register (TIMSK1)					OCIE1A	

Counter/Timer Initialization 2

- Select the prescalar value with bits: CS12, CS11, CS10 in TCCR1B reg.
  - 000 = stop ⟸ Timer starts when prescaler set to non-zero
  - 001 = clock/1
  - 010 = clock/8
  - 011 = clock/64
  - 100 = clock/256
  - 101 = clock/1024
- Enable global interrupts




```
// Set to CTC mode
TCCR1B |= (1 << WGM12);

// Enable Timer Interrupt
TIMSK1 |= (1 << OCIE1A);

// Load the MAX count
// Assuming prescalar=256
//  counting to 15625 =
//  0.25s w/ 16 MHz clock
OCR1A = 15625;

// Set prescalar = 256
//  and start counter
TCCR1B |= (1 << CS12);

// Enable interrupts
sei();
```

Control Register B (TCCR1B)		WGM13	WGM12	CS12	CS11	CS10
Output Compare Register A (OCR1AH & OCR1AL)	OCR1A[15:8] / OCR1A[7:0]					
Interrupt Mask Register (TIMSK1)					OCIE1A	

Counter/Timer Initialization 3

- Make sure you have an appropriate ISR function defined
  - Using name ISR(TIMER1_COMPA_vect)

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

volatile unsigned cnt = 0;
void init_timer1(unsigned short m)
{
  TCCR1B |= (1 << WGM12);
  TIMSK1 |= (1 << OCIE1A);
  OCR1A = m;
  TCCR1B |= (1 << CS12);
}
int main()
{
  init_timer1(15625);

  sei()

  while(){
    // do something w/ cnt
  }
  return 0;
}

ISR(TIMER1_COMPA_vect){
  // increments every 0.25s
  cnt++;
}
```

Control Register B (TCCR1B)		WGM13	WGM12	CS12	CS11	CS10
Output Compare Register A (OCR1AH & OCR1AL)	OCR1A[15:8] / OCR1A[7:0]					
Interrupt Mask Register (TIMSK1)					OCIE1A	

8-bit Counter/Timers

- The other two counters are similar but only 8-bits.
- Same principle: find the count modulus that fits in an 8-bit value.

Control Register A (TCCR0A)	COM0A1	COM0A0	COM0B1	COM0B0			WGM01	WGM00
Control Register B (TCCR0B)	FOC0A	FOC0B			WGM02	CS02	CS01	CS00
Timer/Counter Register (TCNT0)	TCNT0[7:0]							
Output Compare Register A (OCR0A)	OCR0A[7:0]							
Output Compare Register B (OCR0B)	OCR0B[7:0]							
Interrupt Mask Register (TIMSK0)						OCIE0B	OCIE0A	TOIE0
Interrupt Flag Register (TIFR0)						OCF0B	OCF0A	TOV0

8-bit Timers (Timer 0 & Timer 2)

- Timer0 (Timer2) of the Arduino only have an 8-bit timer and max count value (thus we can only count up to 255)
- Set WGM01 (WGM21) bit to CTC
- Enable interrupt via OCIE0A (OCIE2A) bit in TIMSK0 (TIMSK2) register
- Load the OCR0A (OCR2A) Register
- Start timer when desired by setting appropriate prescalar

CS0[2:0]	Prescalar
000	Timer off
010	Clk / 8
011	Clk / 64
100	Clk / 256
101	Clk / 1024

WGM?1, WGM?0	Meaning
00	Normal (Counter)
01	Phase Correct PWM
10	**CTC (Timer)**
11	Fast PWM (Top=255, Thresh=OCRx)

COM0 A1	COM0 A0	COM0 B1	COM0 B0	-	-	WGM 01	WGM 00

TCCR0A Reg. (TCCR2A)
Timer/Counter0 Control Register

FOC 0A	FOC 0B	-	-	WGM 02	CS02	CS01	CS00

TCCR0B Reg. (TCCR2B)
Timer/Counter0 Control Register

Bit 7					OCIE0 B	OCIE0 A	TOIE0

TIMSK0 Reg (TIMSK2)
Timer0 Interrupt Mask Register

Bit 7							Bit 0

OCR0A Reg (OCR2A)
Max/Modulo count value for TMR0 (2)

8-bit Timers can only count up to 255. Be sure to select a prescalar such that your OCR value will fit in 8-bits.

ISR Names

- In CTC mode, an "Output Compare A Match Interrupt" will vector to an ISR with these names:
  - ISR(TIMER0_COMPA_vect) { } /* 8-bit Timer 0 */
  - ISR(TIMER1_COMPA_vect) { } /* 16-bit Timer 1 */
  - ISR(TIMER2_COMPA_vect) { } /* 8-bit Timer 2 */