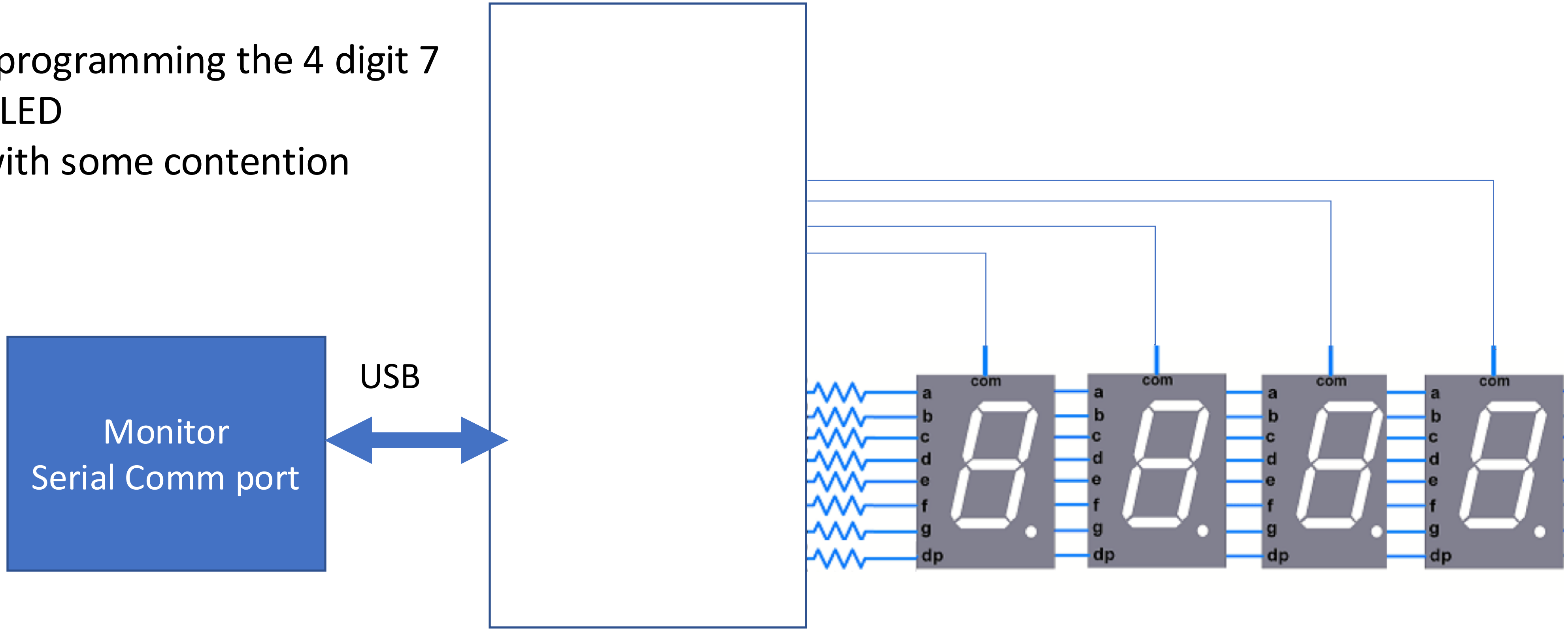
8.6 Retinal Persistence and the 4 digit, 7-segment LED.

ECE-231
Prof. McLaughlin

Let’s build a four digit ring counter (0000 – 9999) that displays digits on a serial monitor and on the 4-digit 7-segment display.

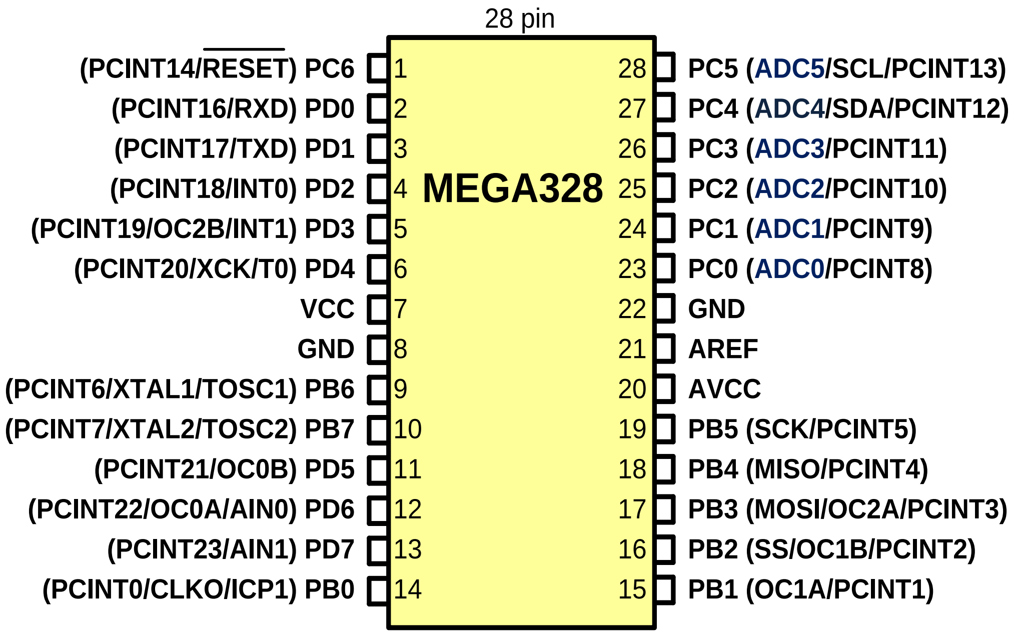
Topics:

- sending digits to serial monitor via UART
- wiring & programming the 4 digit 7 segment LED
- dealing with some contention issues



Sending digits to serial monitor via UART:

write a program that implements a 4 digit ring counter (0-9999, then repeat), sending the count via UART to the serial monitor.



28 pin

MEGA328

(PCINT14/$\overline{\text{RESET}}$) PC6 1

(PCINT16/RXD) PD0 2

(PCINT17/TXD) PD1 3

(PCINT18/INT0) PD2 4

(PCINT19/OC2B/INT1) PD3 5

(PCINT20/XCK/T0) PD4 6

VCC 7

GND 8

(PCINT6/XTAL1/TOSC1) PB6 9

(PCINT7/XTAL2/TOSC2) PB7 10

(PCINT21/OC0B) PD5 11

(PCINT22/OC0A/AIN0) PD6 12

(PCINT23/AIN1) PD7 13

(PCINT0/CLKO/ICP1) PB0 14

28 PC5 (ADC5/SCL/PCINT13)

27 PC4 (ADC4/SDA/PCINT12)

26 PC3 (ADC3/PCINT11)

25 PC2 (ADC2/PCINT10)

24 PC1 (ADC1/PCINT9)

23 PC0 (ADC0/PCINT8)

22 GND

21 AREF

20 AVCC

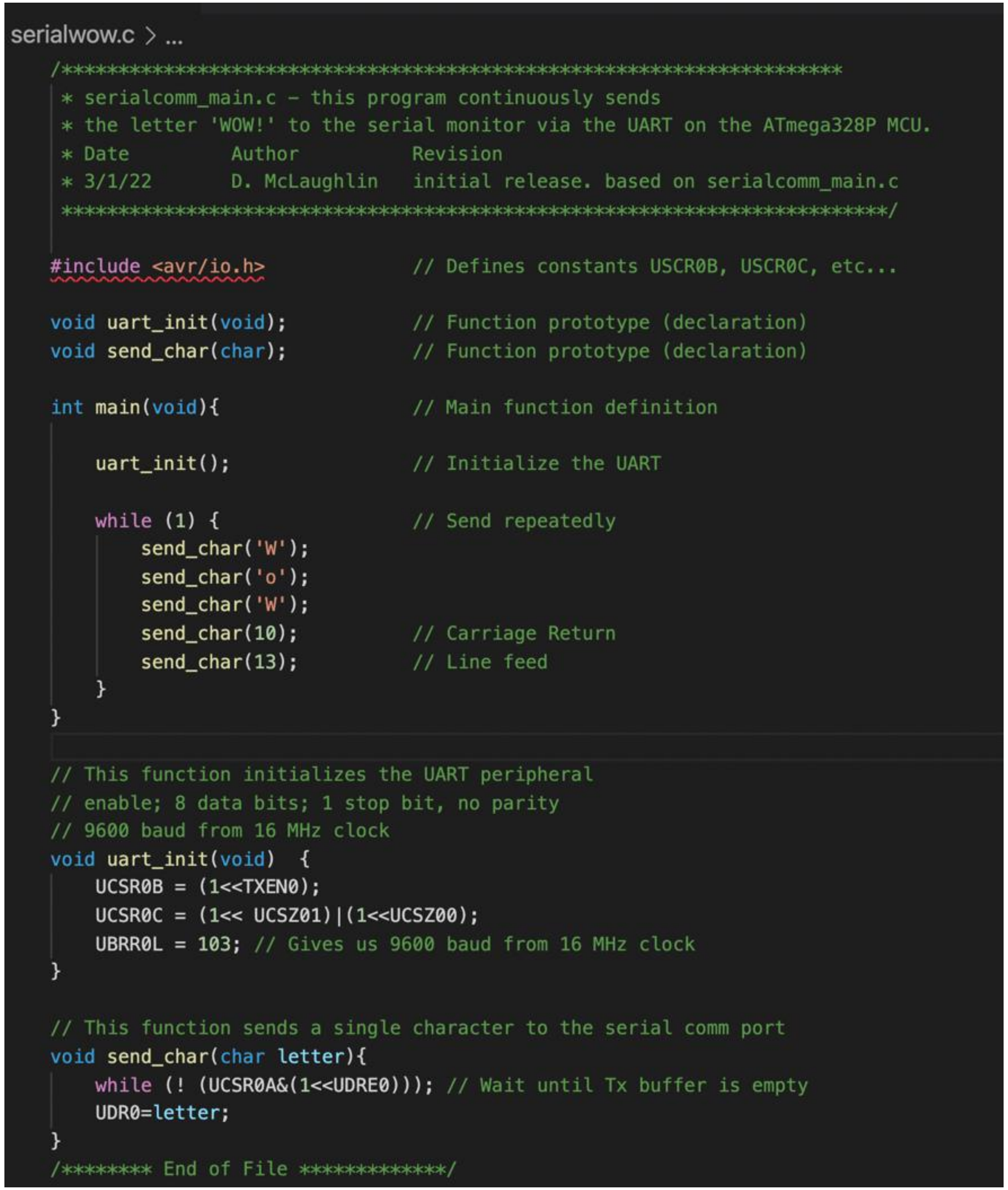
19 PB5 (SCK/PCINT5)

18 PB4 (MISO/PCINT4)

17 PB3 (MOSI/OC2A/PCINT3)

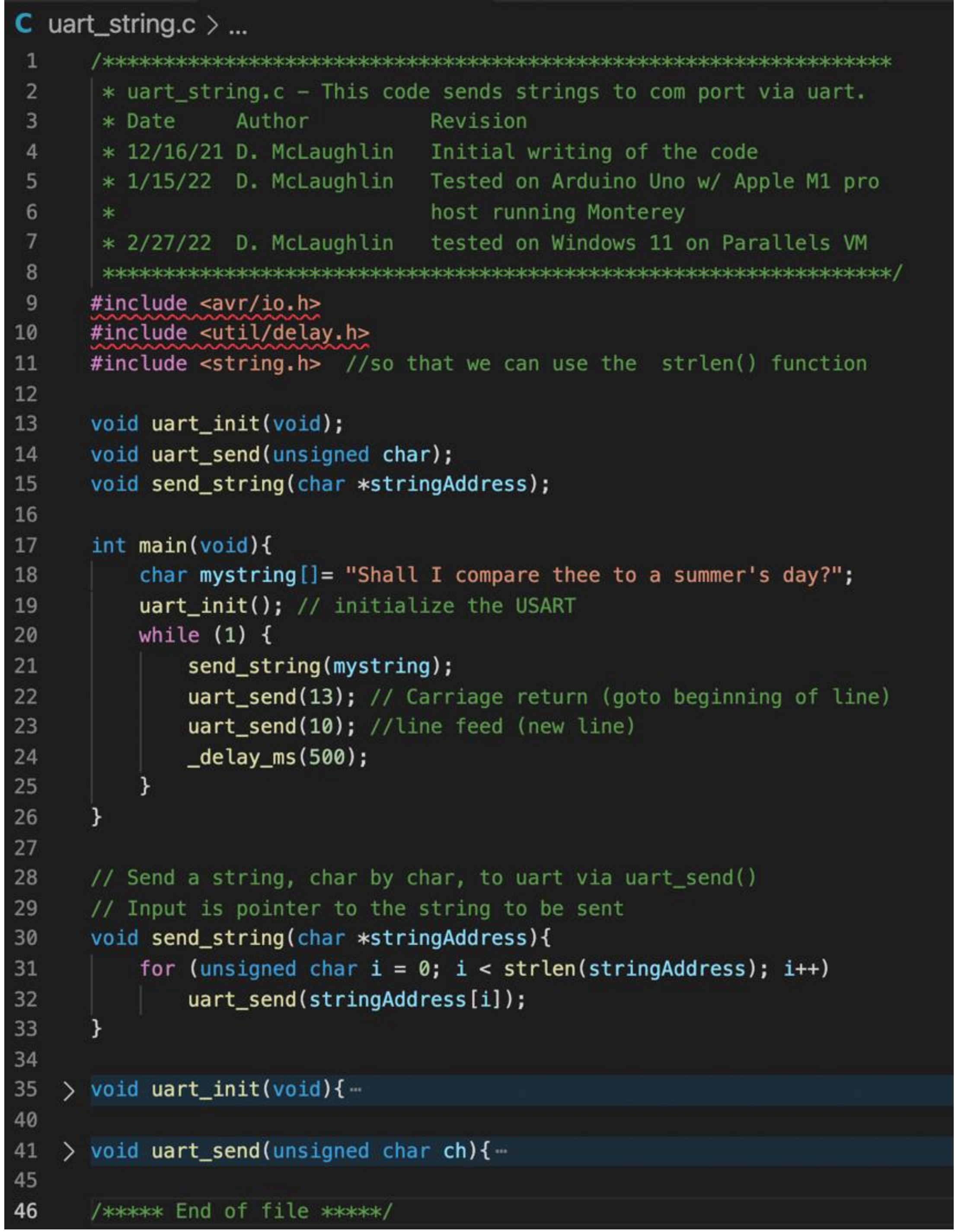
16 PB2 (SS/OC1B/PCINT2)

15 PB1 (OC1A/PCINT1)



serialwow.c > ...

```c
/**********************************************************************
 * serialcomm_main.c - this program continuously sends
 * the letter 'WOW!' to the serial monitor via the UART on the ATmega328P MCU.
 * Date         Author          Revision
 * 3/1/22       D. McLaughlin   initial release. based on serialcomm_main.c
 **********************************************************************/

#include <avr/io.h>             // Defines constants USCR0B, USCR0C, etc...

void uart_init(void);           // Function prototype (declaration)
void send_char(char);           // Function prototype (declaration)

int main(void){                 // Main function definition

    uart_init();                // Initialize the UART

    while (1) {                 // Send repeatedly
        send_char('W');
        send_char('o');
        send_char('W');
        send_char(10);          // Carriage Return
        send_char(13);          // Line feed
    }
}

// This function initializes the UART peripheral
// enable; 8 data bits; 1 stop bit, no parity
// 9600 baud from 16 MHz clock
void uart_init(void)  {
    UCSR0B = (1<<TXEN0);
    UCSR0C = (1<< UCSZ01)|(1<<UCSZ00);
    UBRR0L = 103; // Gives us 9600 baud from 16 MHz clock
}

// This function sends a single character to the serial comm port
void send_char(char letter){
    while (! (UCSR0A&(1<<UDRE0))); // Wait until Tx buffer is empty
    UDR0=letter;
}
/******** End of File *************/
```



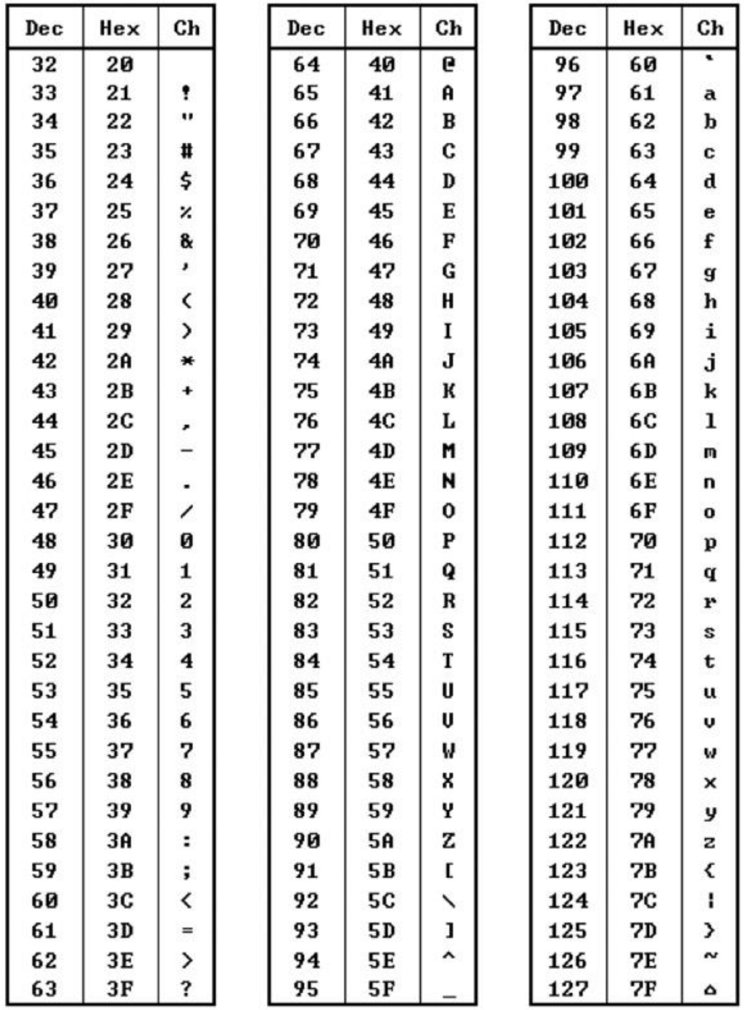
C uart_string.c > ...

```c
/*********************************************************************
 * uart_string.c - This code sends strings to com port via uart.
 * Date     Author          Revision
 * 12/16/21 D. McLaughlin   Initial writing of the code
 * 1/15/22  D. McLaughlin   Tested on Arduino Uno w/ Apple M1 pro
 *                          host running Monterey
 * 2/27/22  D. McLaughlin   tested on Windows 11 on Parallels VM
 *********************************************************************/
#include <avr/io.h>
#include <util/delay.h>
#include <string.h>  //so that we can use the  strlen() function

void uart_init(void);
void uart_send(unsigned char);
void send_string(char *stringAddress);

int main(void){
    char mystring[]= "Shall I compare thee to a summer's day?";
    uart_init(); // initialize the USART
    while (1) {
        send_string(mystring);
        uart_send(13); // Carriage return (goto beginning of line)
        uart_send(10); //line feed (new line)
        _delay_ms(500);
    }
}

// Send a string, char by char, to uart via uart_send()
// Input is pointer to the string to be sent
void send_string(char *stringAddress){
    for (unsigned char i = 0; i < strlen(stringAddress); i++)
        uart_send(stringAddress[i]);
}

void uart_init(void){⋯

void uart_send(unsigned char ch){⋯

/***** End of file *****/
```

we are making use of 3 user-defined functions:
uart_init() uart_send() send_string()

Send (transmit) the string: “Wow!”

ASCII Codes:



Dec	Hex	Ch	Dec	Hex	Ch	Dec	Hex	Ch
32	20		64	40	@	96	60	`
33	21	!	65	41	A	97	61	a
34	22	"	66	42	B	98	62	b
35	23	#	67	43	C	99	63	c
36	24	$	68	44	D	100	64	d
37	25	%	69	45	E	101	65	e
38	26	&	70	46	F	102	66	f
39	27	'	71	47	G	103	67	g
40	28	(	72	48	H	104	68	h
41	29	)	73	49	I	105	69	i
42	2A	*	74	4A	J	106	6A	j
43	2B	+	75	4B	K	107	6B	k
44	2C	,	76	4C	L	108	6C	l
45	2D	-	77	4D	M	109	6D	m
46	2E	.	78	4E	N	110	6E	n
47	2F	/	79	4F	O	111	6F	o
48	30	0	80	50	P	112	70	p
49	31	1	81	51	Q	113	71	q
50	32	2	82	52	R	114	72	r
51	33	3	83	53	S	115	73	s
52	34	4	84	54	T	116	74	t
53	35	5	85	55	U	117	75	u
54	36	6	86	56	V	118	76	v
55	37	7	87	57	W	119	77	w
56	38	8	88	58	X	120	78	x
57	39	9	89	59	Y	121	79	y
58	3A	:	90	5A	Z	122	7A	z
59	3B	;	91	5B	[	123	7B	{
60	3C	<	92	5C	\	124	7C	¦
61	3D	=	93	5D	]	125	7D	}
62	3E	>	94	5E	^	126	7E	~
63	3F	?	95	5F	_	127	7F	⌂

```
uart_send(‘W’);
uart_send(‘o’);
uart_send(’w’);
uart_send(‘!’);
```

or

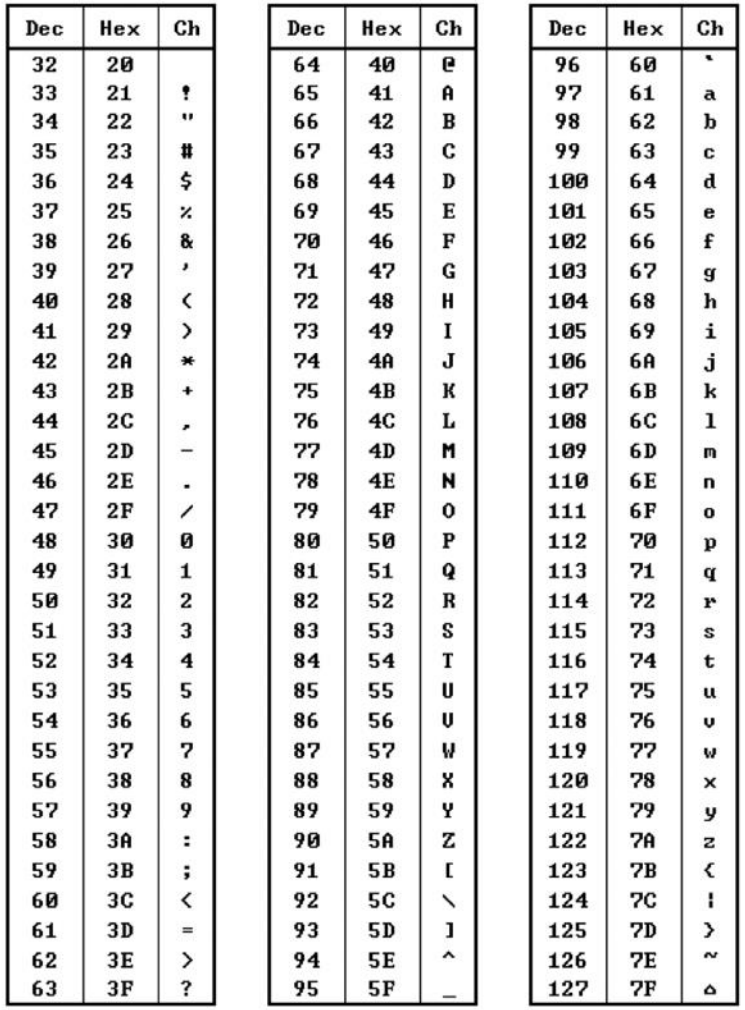
```
uart_send(87);
uart_send(111);
uart_send(119);
uart_send(33);
```

or

```
send_string(“Wow!”)
```

we are making use of 3 user-defined functions:
uart_init() uart_send() send_string()

ASCII Codes:



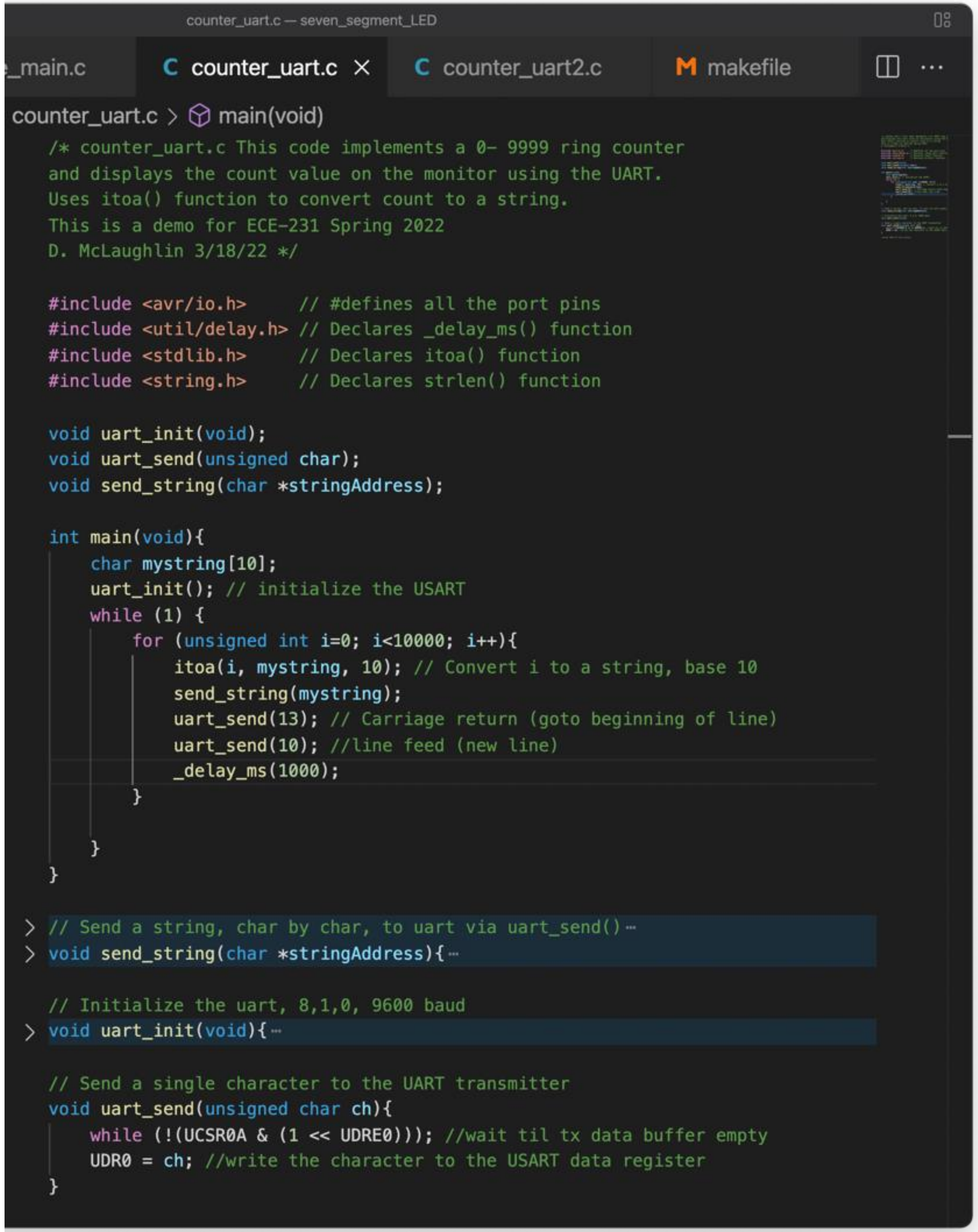
Dec	Hex	Ch	Dec	Hex	Ch	Dec	Hex	Ch
32	20		64	40	@	96	60	`
33	21	!	65	41	A	97	61	a
34	22	"	66	42	B	98	62	b
35	23	#	67	43	C	99	63	c
36	24	$	68	44	D	100	64	d
37	25	%	69	45	E	101	65	e
38	26	&	70	46	F	102	66	f
39	27	'	71	47	G	103	67	g
40	28	(	72	48	H	104	68	h
41	29	)	73	49	I	105	69	i
42	2A	*	74	4A	J	106	6A	j
43	2B	+	75	4B	K	107	6B	k
44	2C	,	76	4C	L	108	6C	l
45	2D	-	77	4D	M	109	6D	m
46	2E	.	78	4E	N	110	6E	n
47	2F	/	79	4F	O	111	6F	o
48	30	0	80	50	P	112	70	p
49	31	1	81	51	Q	113	71	q
50	32	2	82	52	R	114	72	r
51	33	3	83	53	S	115	73	s
52	34	4	84	54	T	116	74	t
53	35	5	85	55	U	117	75	u
54	36	6	86	56	V	118	76	v
55	37	7	87	57	W	119	77	w
56	38	8	88	58	X	120	78	x
57	39	9	89	59	Y	121	79	y
58	3A	:	90	5A	Z	122	7A	z
59	3B	;	91	5B	[	123	7B	{
60	3C	<	92	5C	\	124	7C	¦
61	3D	=	93	5D	]	125	7D	}
62	3E	>	94	5E	^	126	7E	~
63	3F	?	95	5F	_	127	7F	⌂

6 ways to transmit the letter G

```
uart_send(‘G’);
uart_send(71);
uart_send(0x47);
uart_send(6+65);
uart_send(6+’A’);
send_string(“G”);        // strings in “ “
```

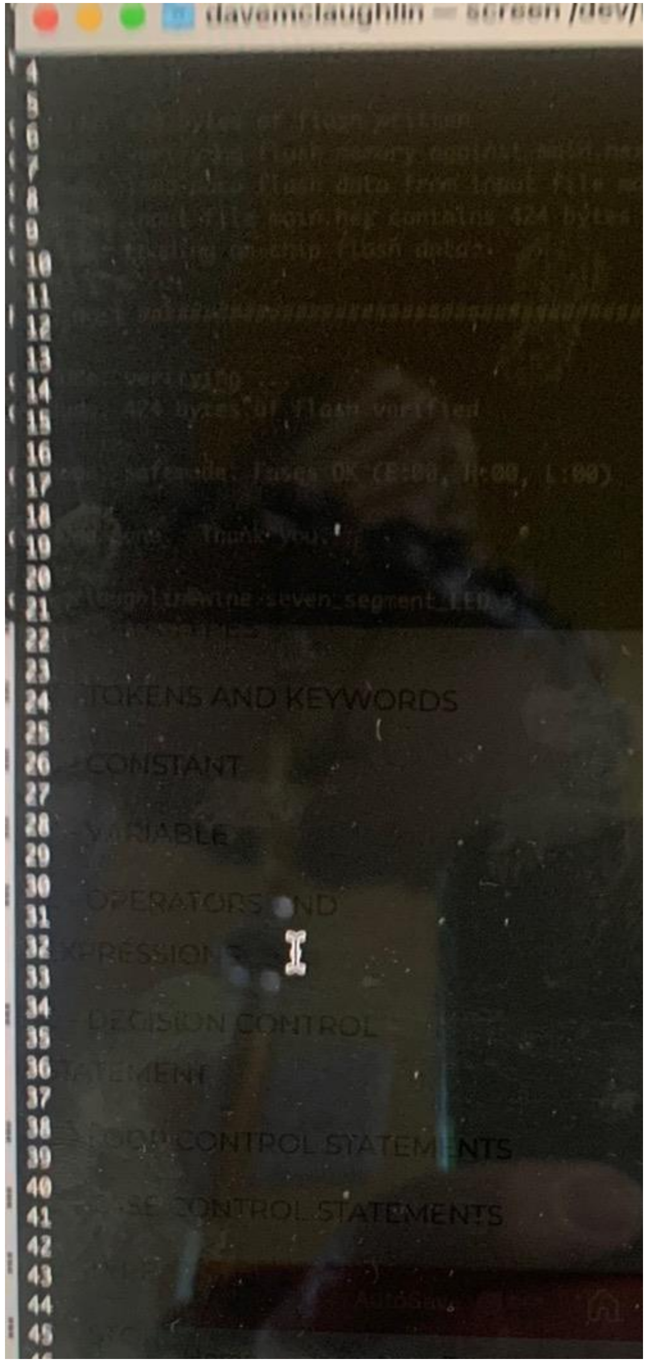
6 ways to transmit the number 4

```
uart_send(‘4’);
uart_send(52);
uart_send(0x34);
uart_send(4+48);
uart_send(4+’0’);
send_string(“4”);
```



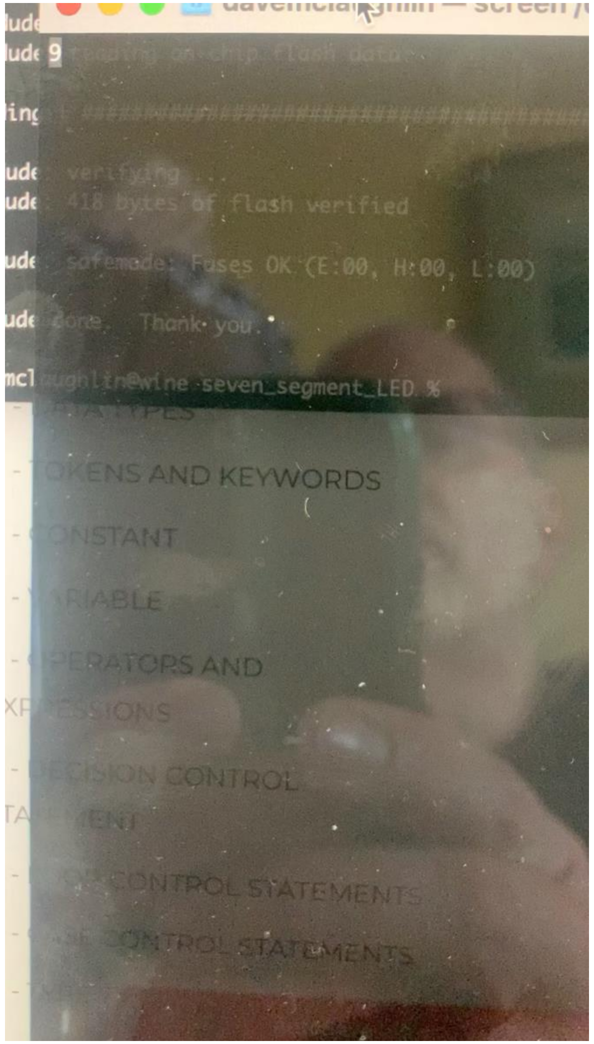
counter_uart.c — seven_segment_LED
_main.c
counter_uart.c
counter_uart2.c
makefile
counter_uart.c > main(void)

```c
/* counter_uart.c This code implements a 0- 9999 ring counter
and displays the count value on the monitor using the UART.
Uses itoa() function to convert count to a string.
This is a demo for ECE-231 Spring 2022
D. McLaughlin 3/18/22 */

#include <avr/io.h>     // #defines all the port pins
#include <util/delay.h> // Declares _delay_ms() function
#include <stdlib.h>     // Declares itoa() function
#include <string.h>     // Declares strlen() function

void uart_init(void);
void uart_send(unsigned char);
void send_string(char *stringAddress);

int main(void){
    char mystring[10];
    uart_init(); // initialize the USART
    while (1) {
        for (unsigned int i=0; i<10000; i++){
            itoa(i, mystring, 10); // Convert i to a string, base 10
            send_string(mystring);
            uart_send(13); // Carriage return (goto beginning of line)
            uart_send(10); //line feed (new line)
            _delay_ms(1000);
        }

    }
}

// Send a string, char by char, to uart via uart_send()…
void send_string(char *stringAddress){…

// Initialize the uart, 8,1,0, 9600 baud
void uart_init(void){…

// Send a single character to the UART transmitter
void uart_send(unsigned char ch){
    while (!(UCSR0A & (1 << UDRE0))); //wait til tx data buffer empty
    UDR0 = ch; //write the character to the USART data register
}
```

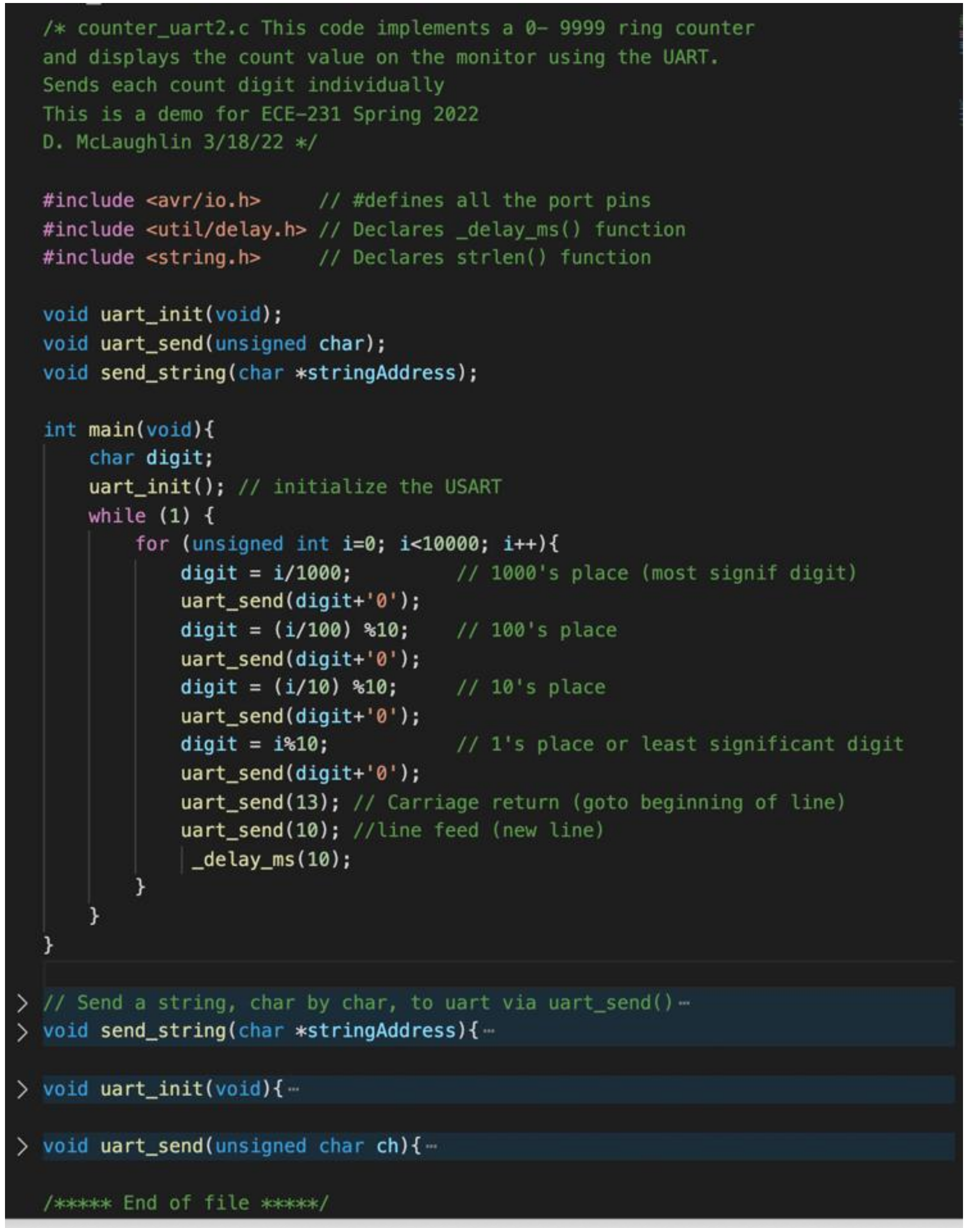


```
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
32
33
34
35
36
37
38
39
40
41
42
43
44
45
```

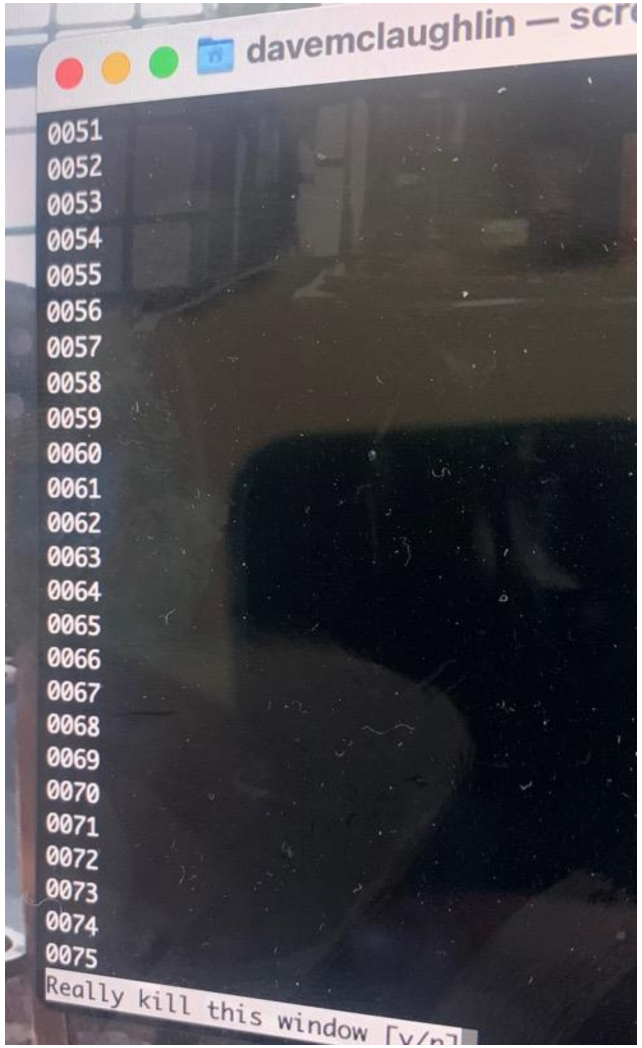
commenting out the usart_send(10); line



```
9

 verifying ...
 418 bytes of flash verified

 safemode: Fuses OK (E:00, H:00, L:00)

 done.  Thank you.

mclaughlin@wine seven_segment_LED %
```

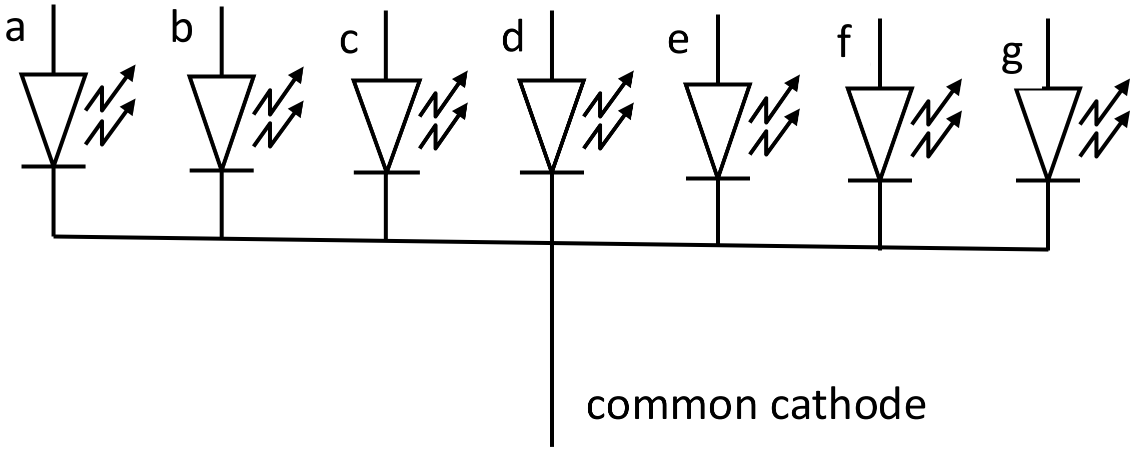


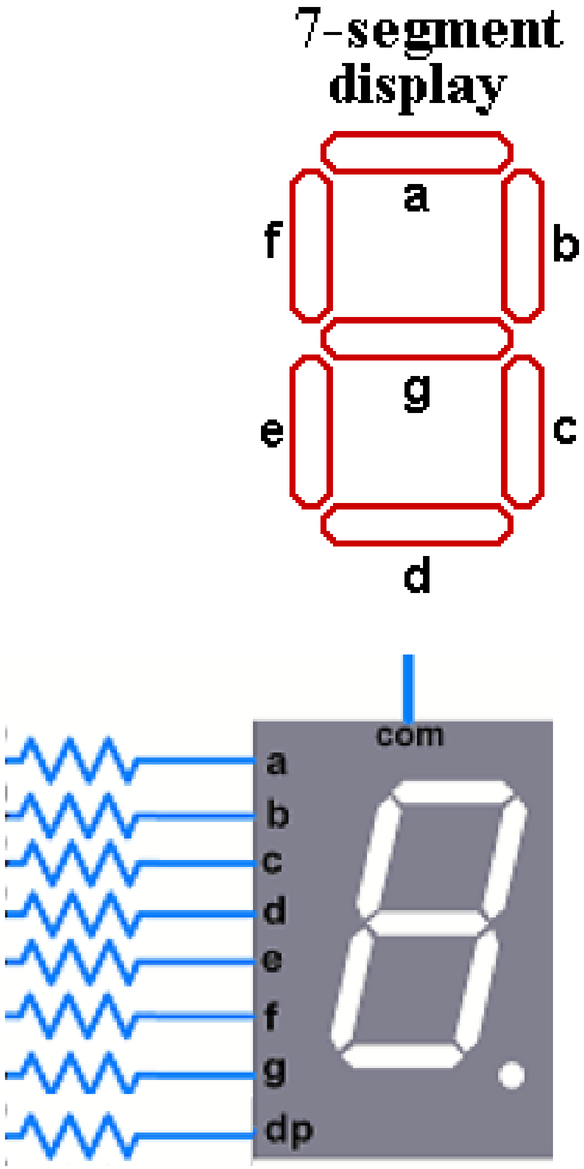
```
/* counter_uart2.c This code implements a 0- 9999 ring counter
and displays the count value on the monitor using the UART.
Sends each count digit individually
This is a demo for ECE-231 Spring 2022
D. McLaughlin 3/18/22 */

#include <avr/io.h>     // #defines all the port pins
#include <util/delay.h> // Declares _delay_ms() function
#include <string.h>     // Declares strlen() function

void uart_init(void);
void uart_send(unsigned char);
void send_string(char *stringAddress);

int main(void){
    char digit;
    uart_init(); // initialize the USART
    while (1) {
        for (unsigned int i=0; i<10000; i++){
            digit = i/1000;         // 1000's place (most signif digit)
            uart_send(digit+'0');
            digit = (i/100) %10;    // 100's place
            uart_send(digit+'0');
            digit = (i/10) %10;     // 10's place
            uart_send(digit+'0');
            digit = i%10;           // 1's place or least significant digit
            uart_send(digit+'0');
            uart_send(13); // Carriage return (goto beginning of line)
            uart_send(10); //line feed (new line)
             _delay_ms(10);
        }
    }
}

> // Send a string, char by char, to uart via uart_send()⋯
> void send_string(char *stringAddress){⋯

> void uart_init(void){⋯

> void uart_send(unsigned char ch){⋯

/***** End of file *****/
```



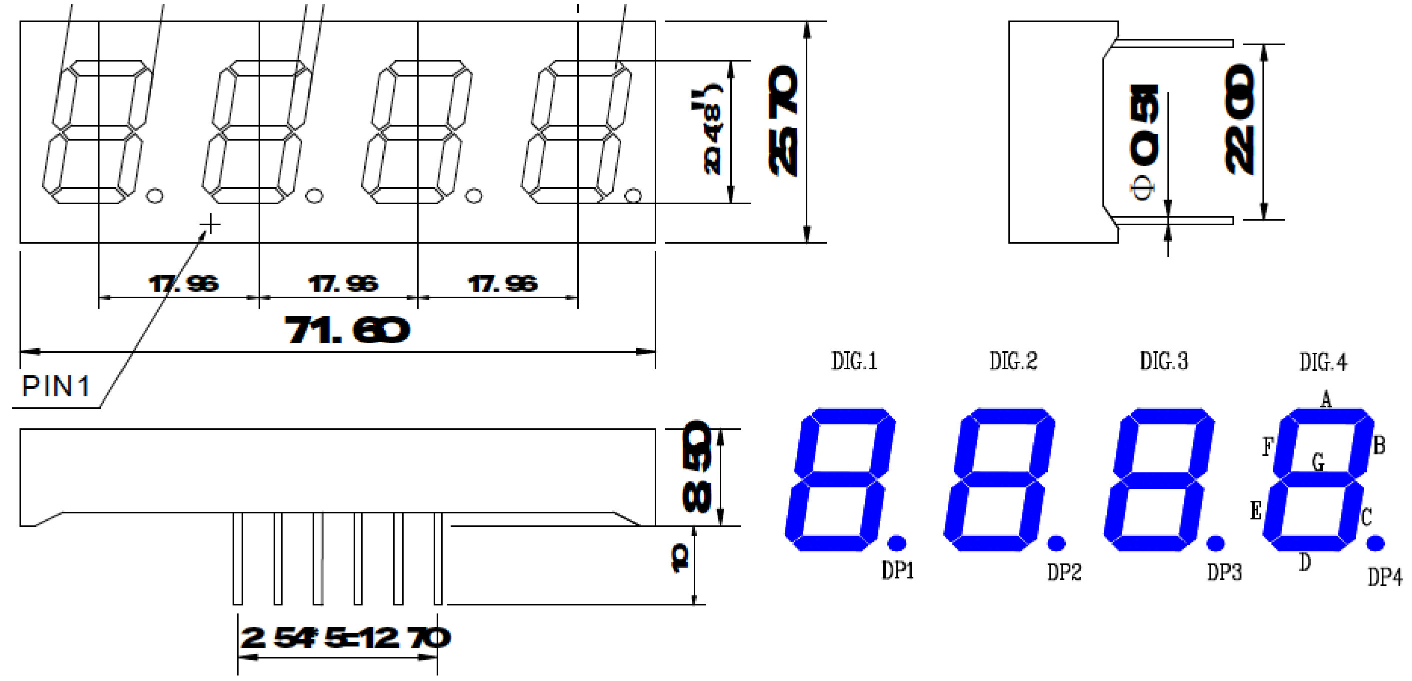
```
0051
0052
0053
0054
0055
0056
0057
0058
0059
0060
0061
0062
0063
0064
0065
0066
0067
0068
0069
0070
0071
0072
0073
0074
0075
Really kill this window [y/n]
```

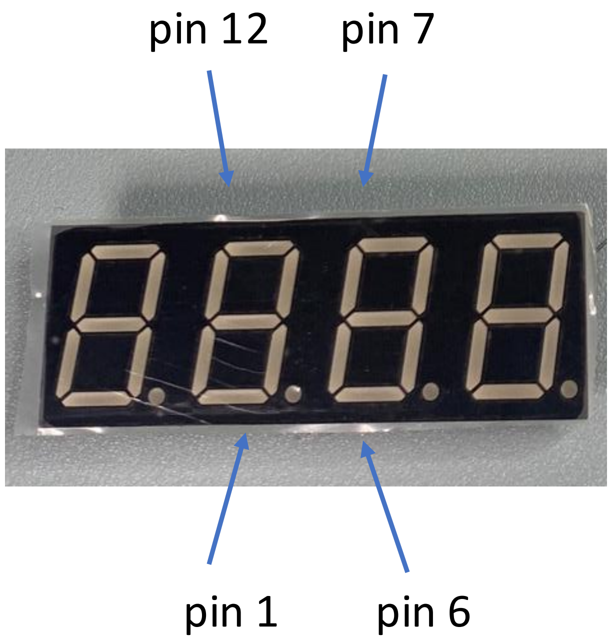
Common Cathode 7 Segment LED

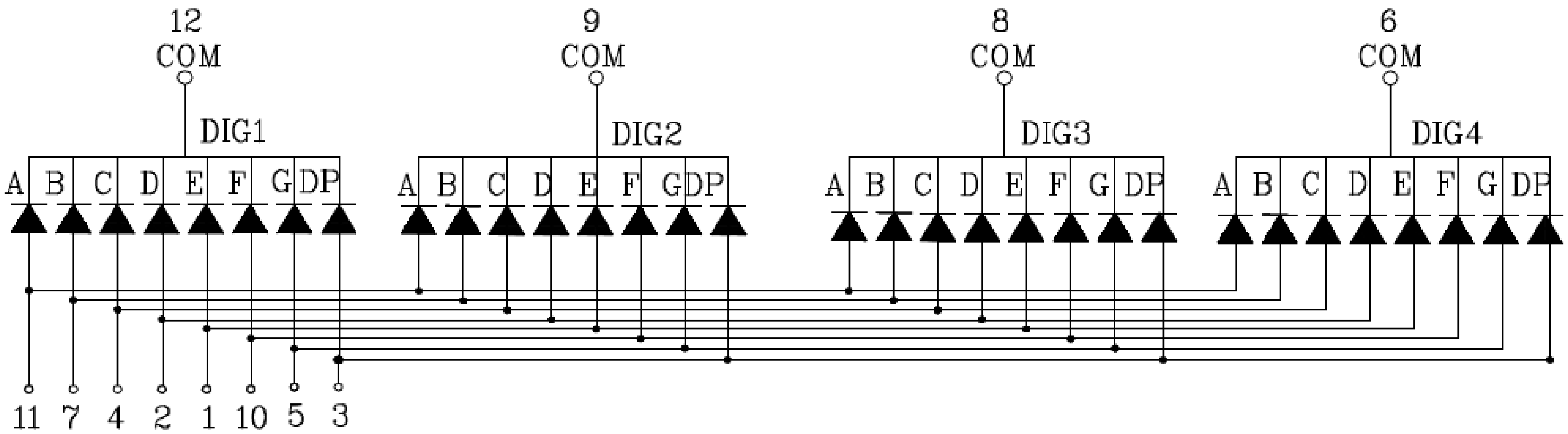




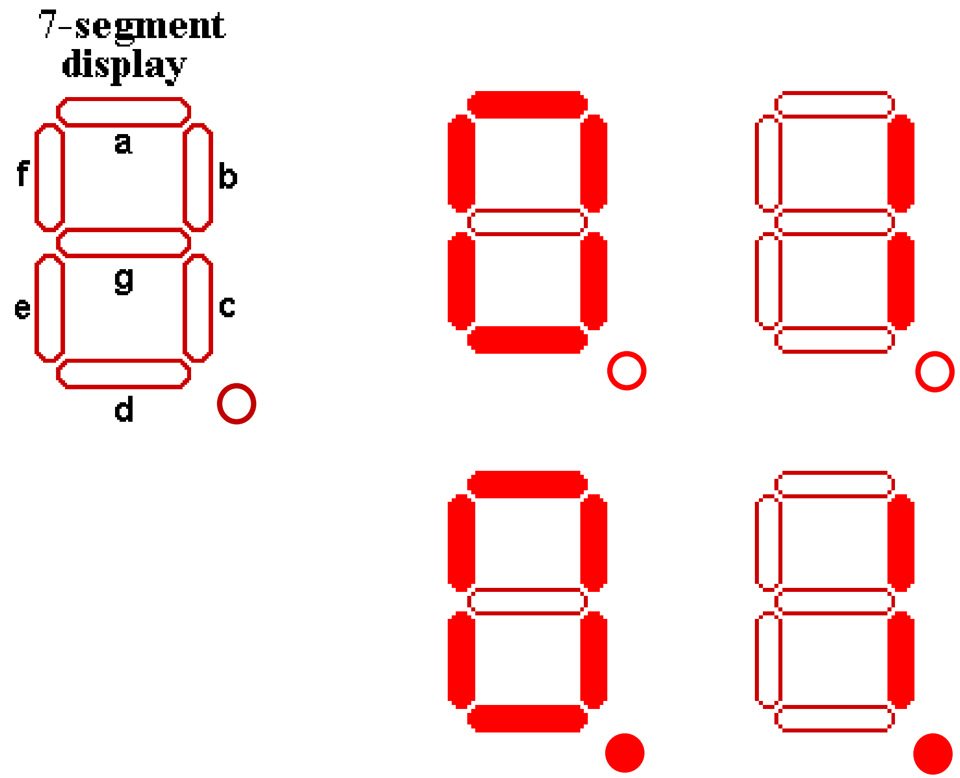
some also have a decimal point as an 8th segment

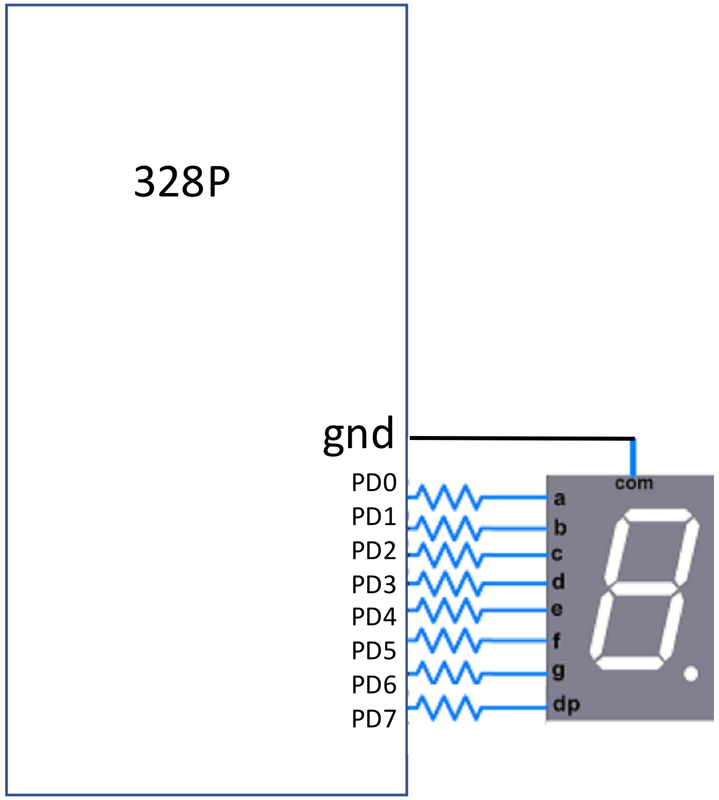






Datasheet: https://www.sparkfun.com/products/11409



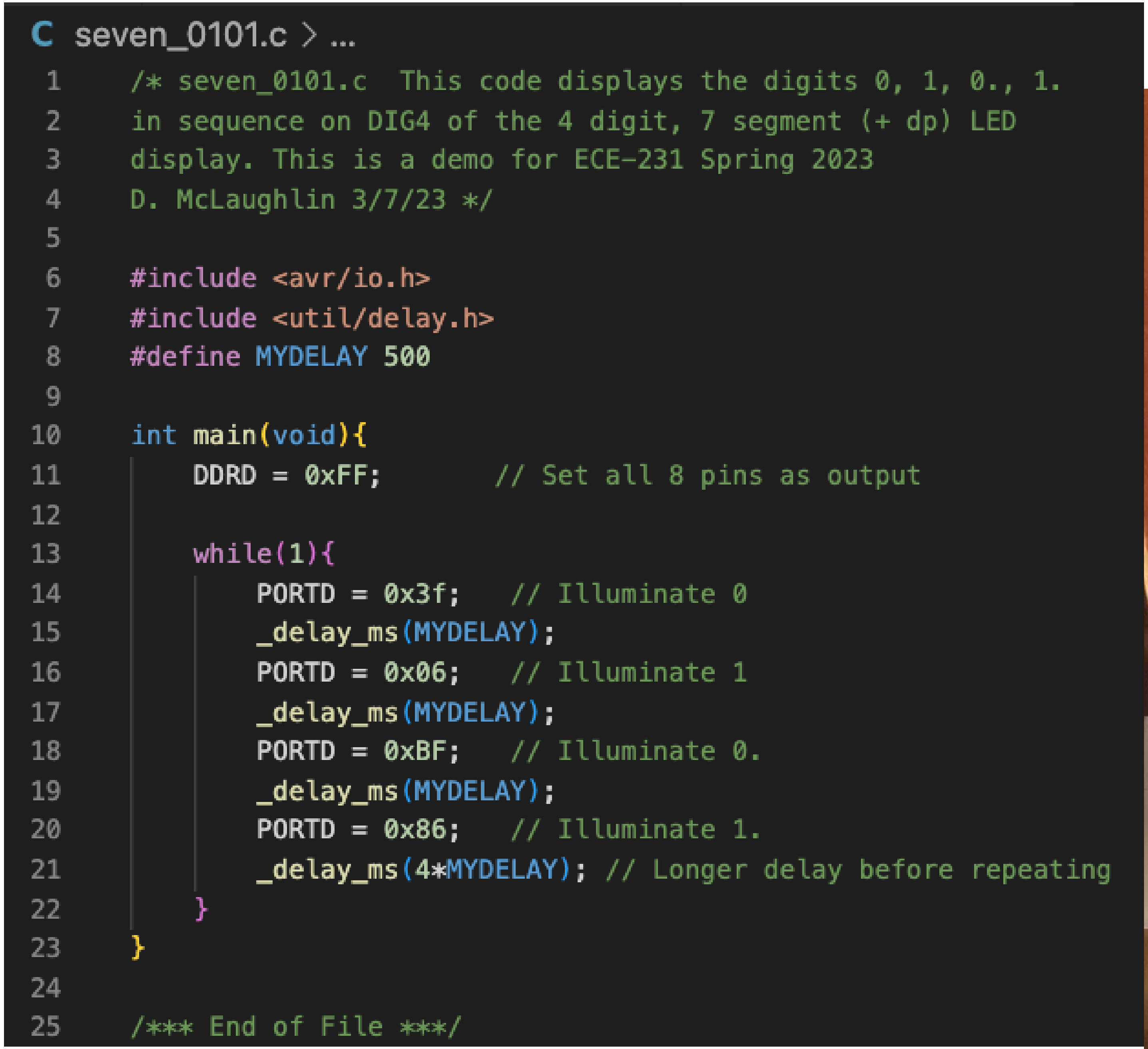


Common Cathode 7 Segment LED

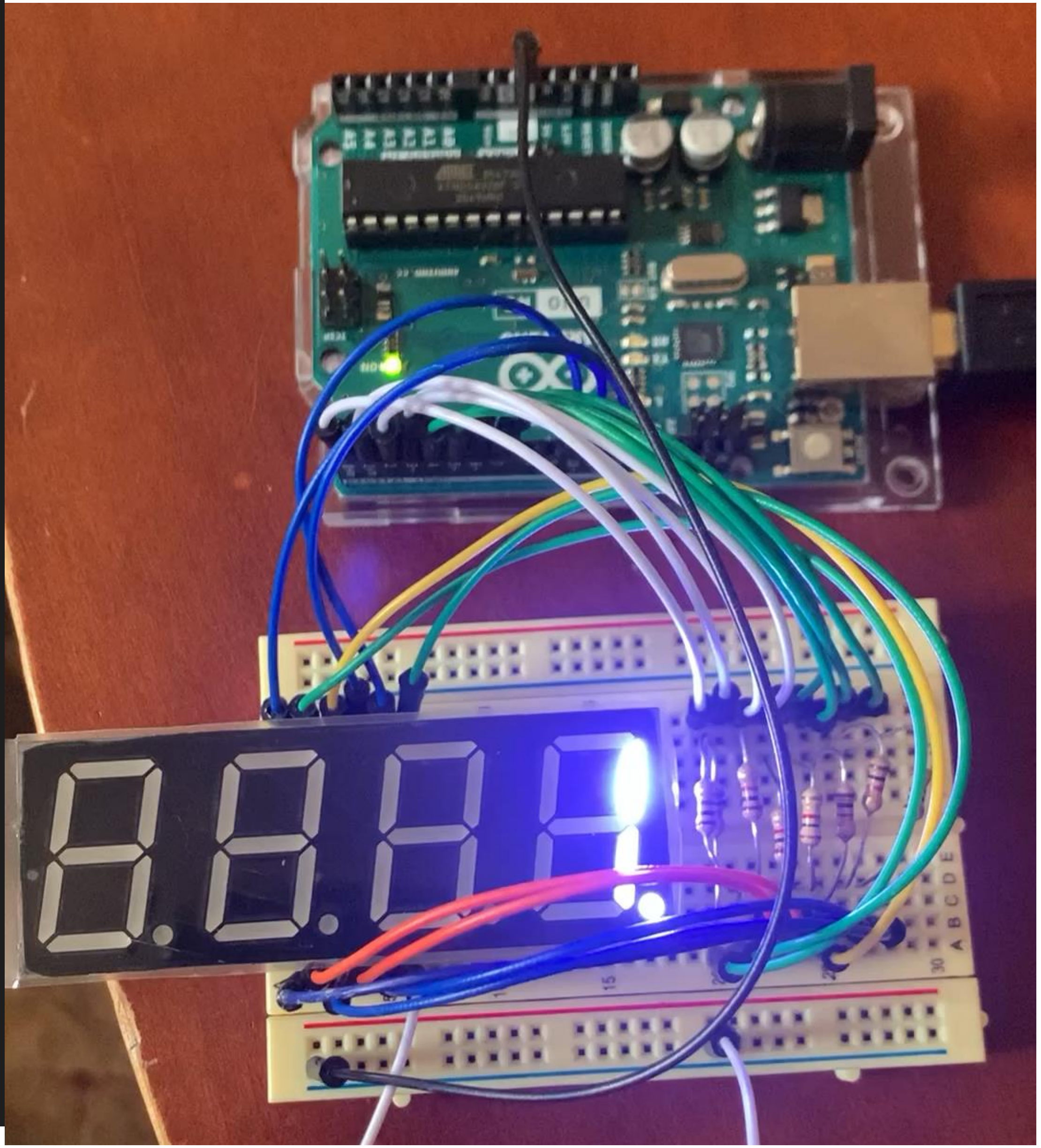
	dp	g	f	e	d	c	b	a		
	PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0	Binary	Hex
0	0	0	1	1	1	1	1	1	0011 1111	0x3F
1	0	0	0	0	0	1	1	0	0000 0110	0x06

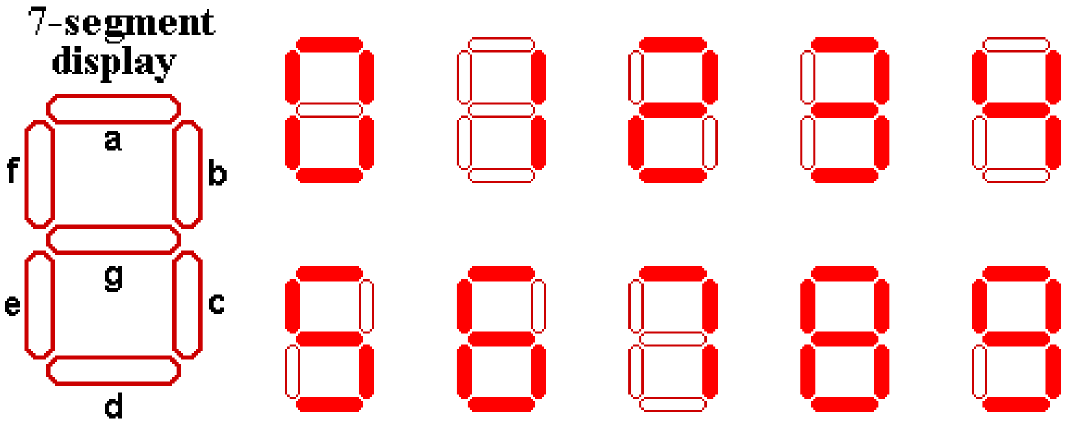
	dp	g	f	e	d	c	b	a		
	PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0	Binary	Hex
0.	1	0	1	1	1	1	1	1	1011 1111	0xBF
1.	1	0	0	0	0	1	1	0	1000 0110	0x86

note: these slides use ABCDEFG and abcdefg interchangably

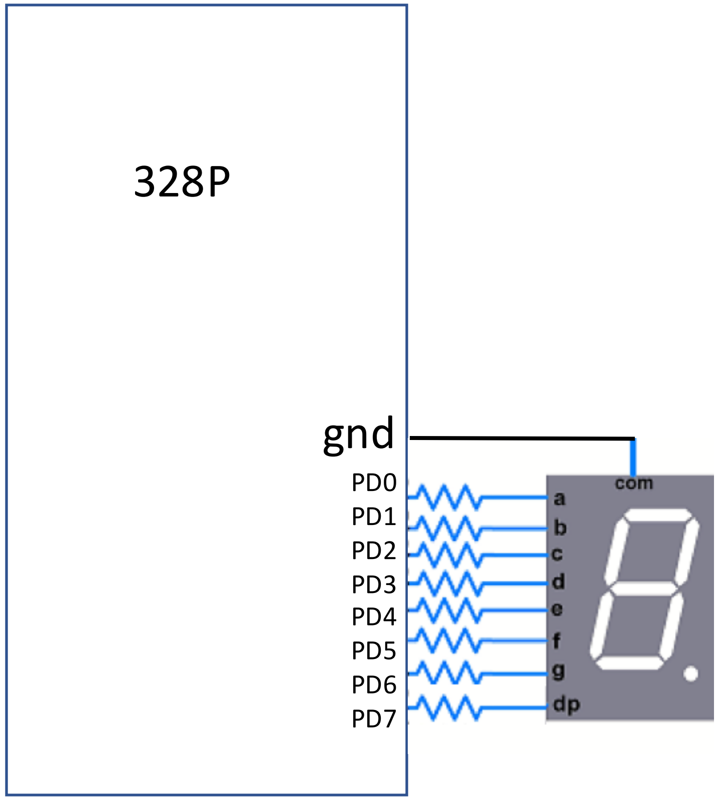


```c
/* seven_0101.c  This code displays the digits 0, 1, 0., 1.
in sequence on DIG4 of the 4 digit, 7 segment (+ dp) LED
display. This is a demo for ECE-231 Spring 2023
D. McLaughlin 3/7/23 */

#include <avr/io.h>
#include <util/delay.h>
#define MYDELAY 500

int main(void){
    DDRD = 0xFF;        // Set all 8 pins as output

    while(1){
        PORTD = 0x3f;   // Illuminate 0
        _delay_ms(MYDELAY);
        PORTD = 0x06;   // Illuminate 1
        _delay_ms(MYDELAY);
        PORTD = 0xBF;   // Illuminate 0.
        _delay_ms(MYDELAY);
        PORTD = 0x86;   // Illuminate 1.
        _delay_ms(4*MYDELAY); // Longer delay before repeating
    }
}

/*** End of File ***/
```

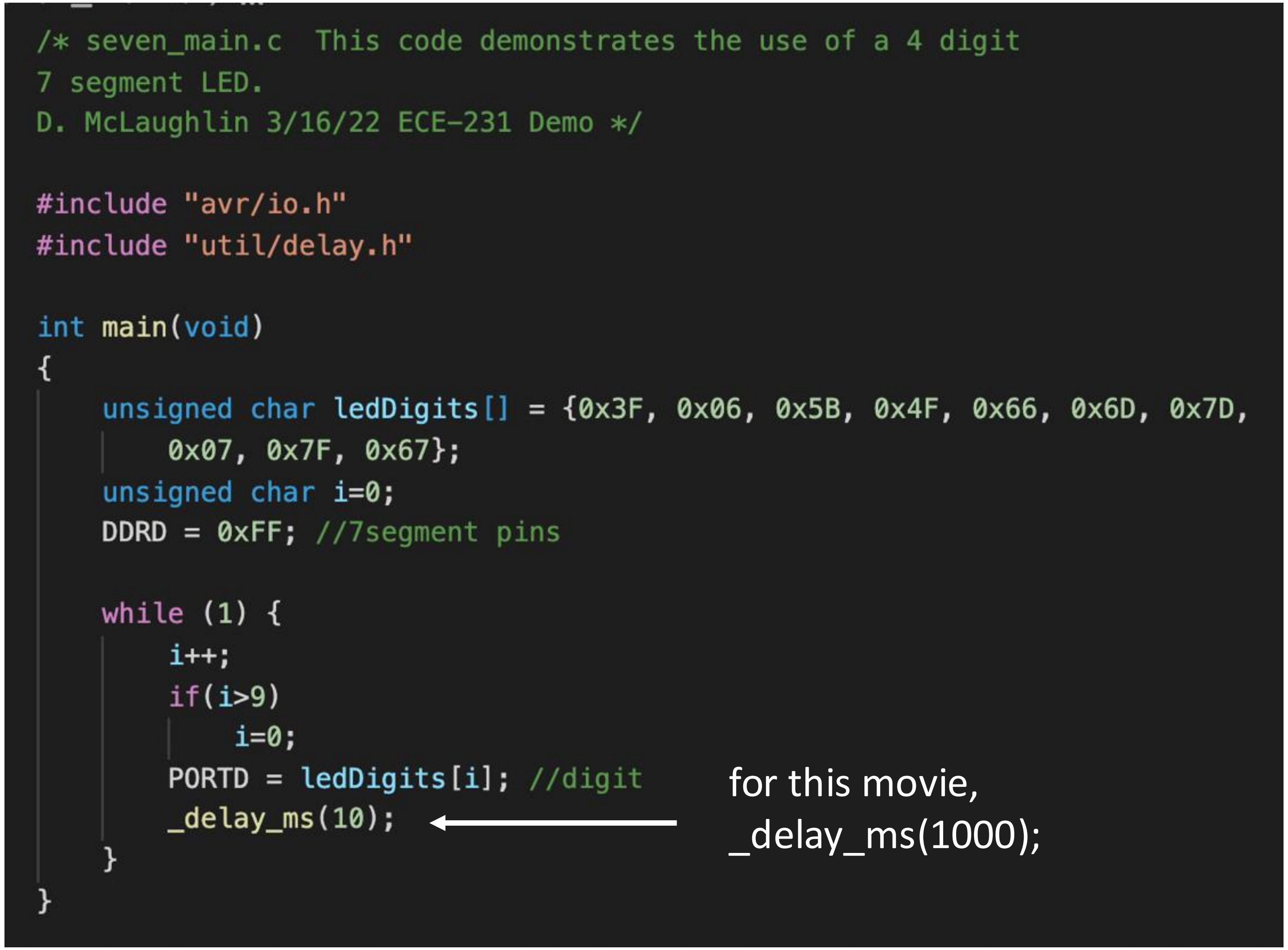




	dp	g	f	e	d	c	b	a		
	PD7	PD6	PD5	PD4	PD3	PD2	PD1	PD0	Binary	Hex
0	0	0	1	1	1	1	1	1	0011 1111	0x3F
1	0	0	0	0	0	1	1	0	0000 0110	0x06
2	0	1	0	1	1	0	1	1	0101 1011	0x5B
3	0	1	0	0	1	1	1	1	0100 1111	0x4F
4										
5	0	1	1	0	1	1	0	1	0110 1101	0x6D
6										
7										
8										
9	0	1	1	0	1	1	1	1	0110 1111	0x6F

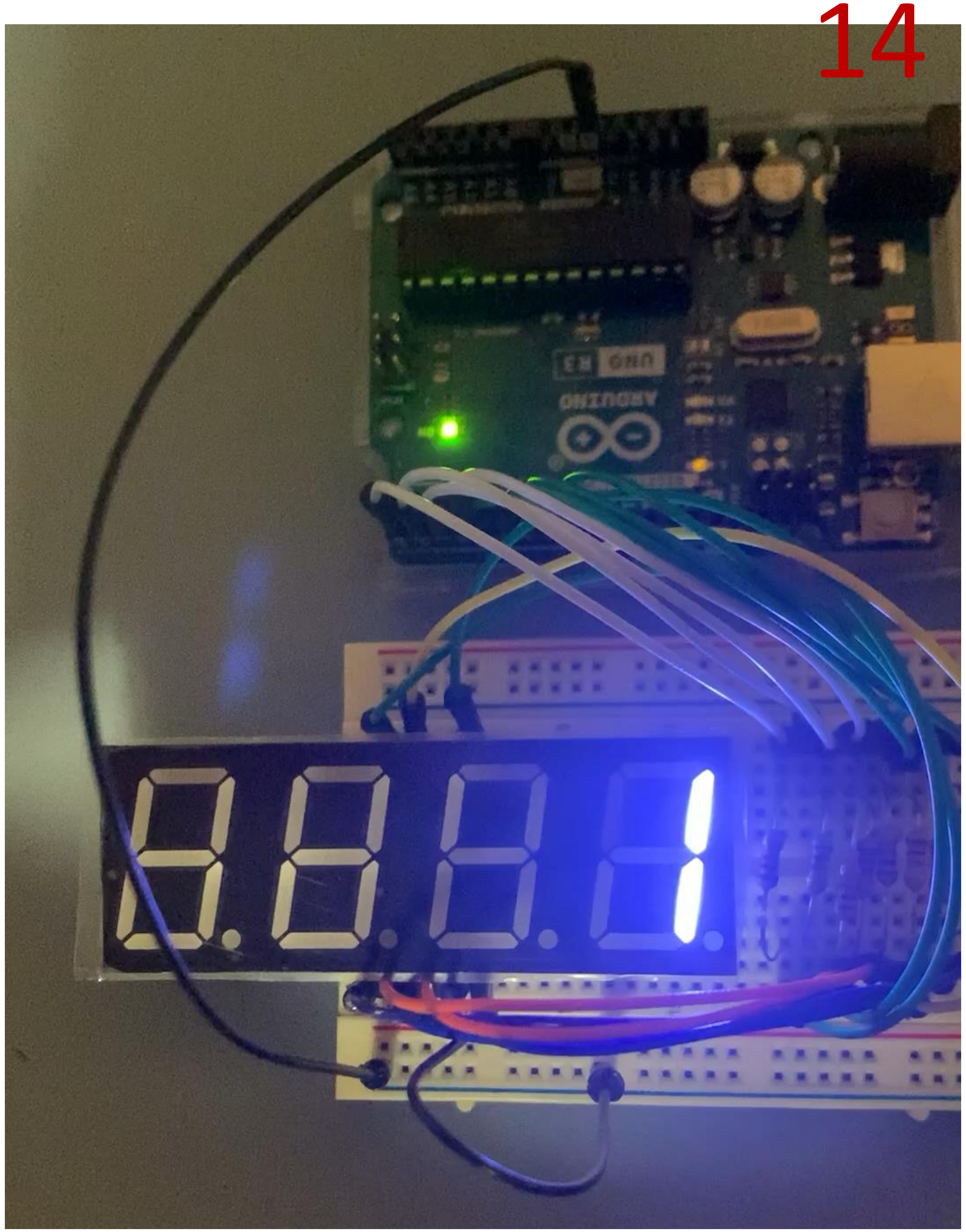


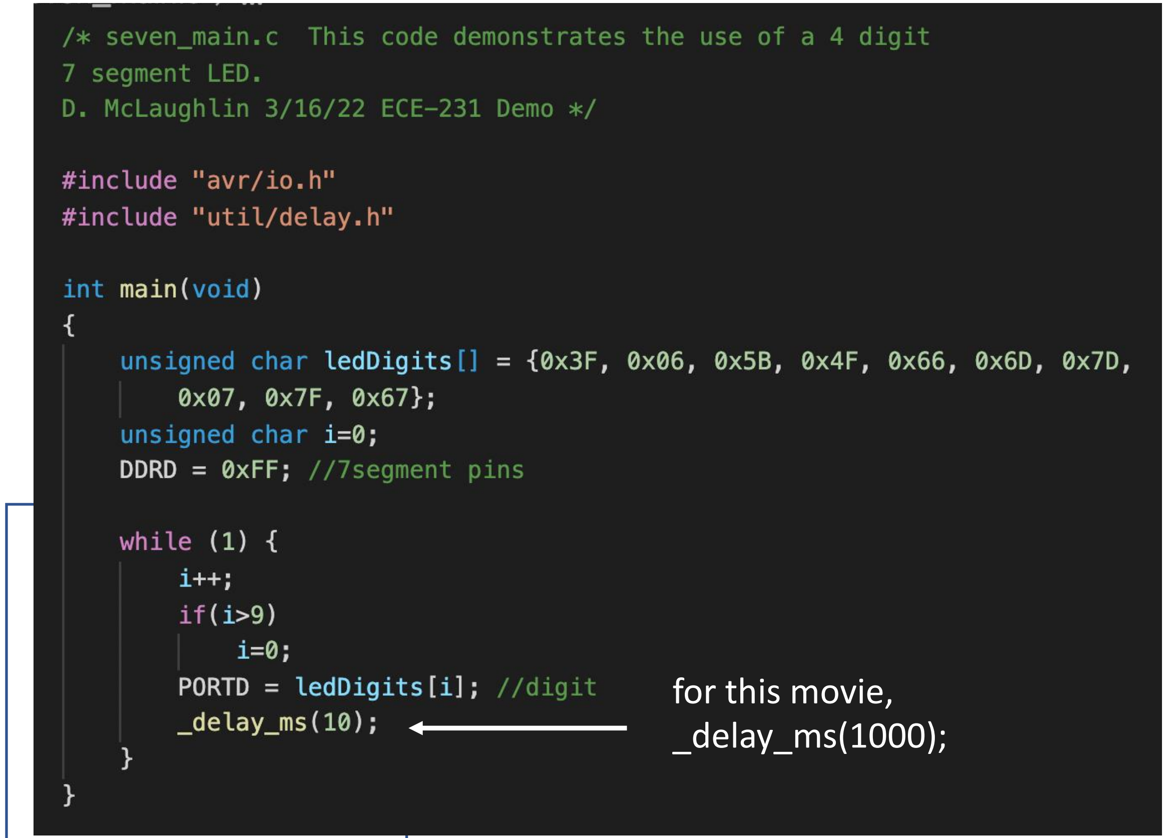
Common Cathode 7 Segment LED



```
/* seven_main.c  This code demonstrates the use of a 4 digit
7 segment LED.
D. McLaughlin 3/16/22 ECE-231 Demo */

#include "avr/io.h"
#include "util/delay.h"

int main(void)
{
    unsigned char ledDigits[] = {0x3F, 0x06, 0x5B, 0x4F, 0x66, 0x6D, 0x7D,
        0x07, 0x7F, 0x67};
    unsigned char i=0;
    DDRD = 0xFF; //7segment pins

    while (1) {
        i++;
        if(i>9)
            i=0;
        PORTD = ledDigits[i]; //digit
        _delay_ms(10);
    }
}
```

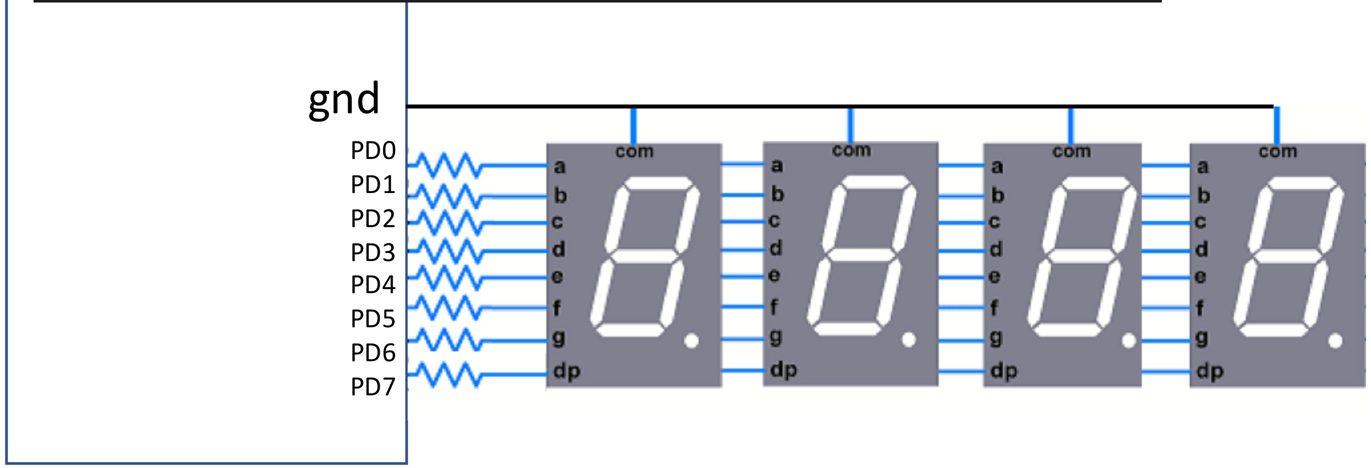
for this movie,
_delay_ms(1000);

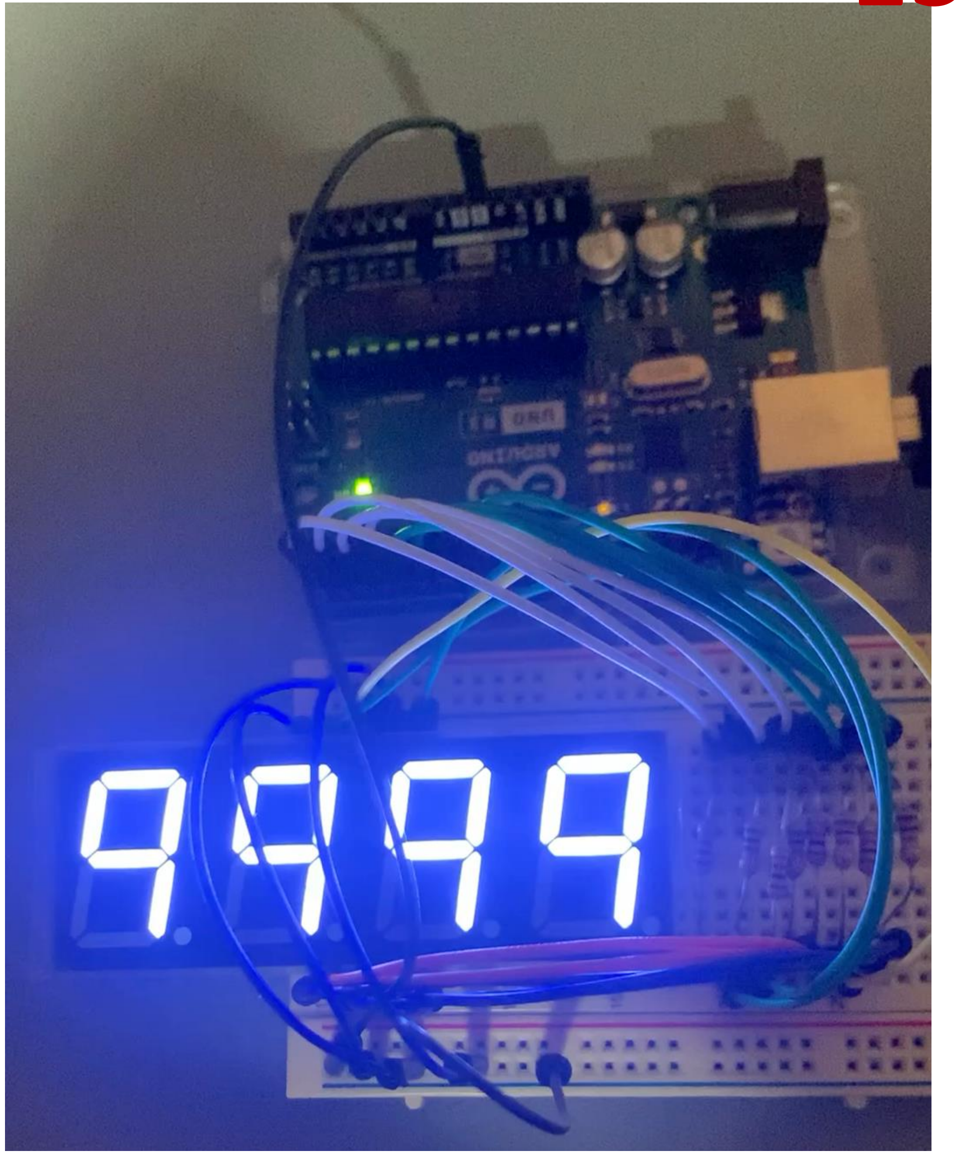


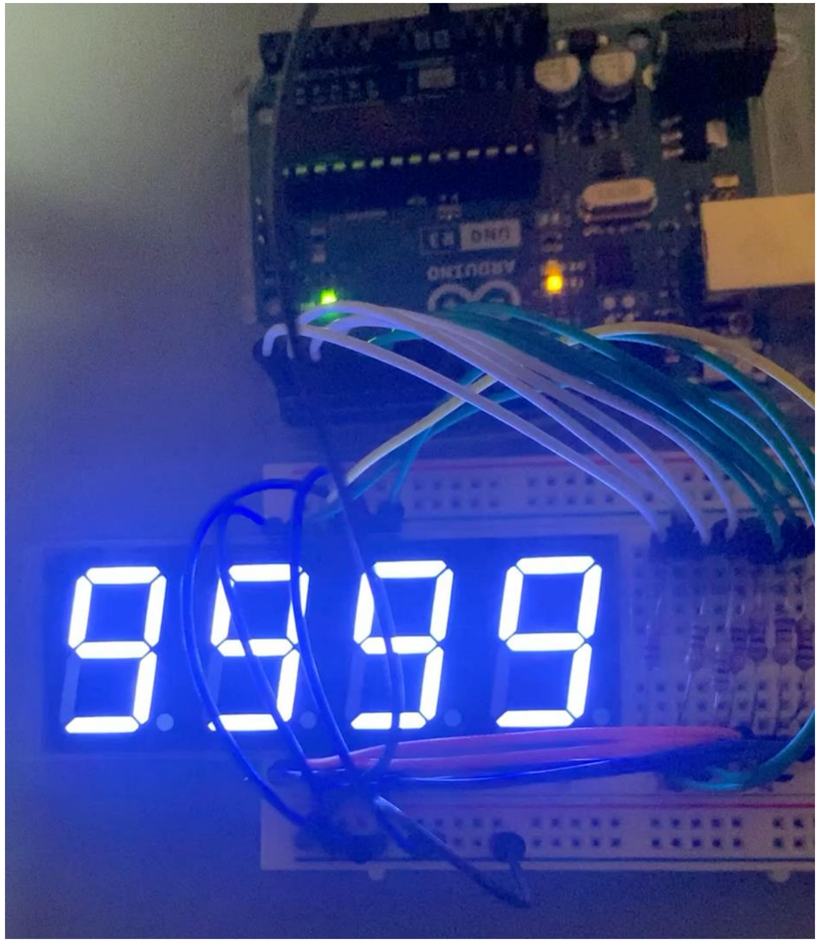


```
/* seven_main.c  This code demonstrates the use of a 4 digit
7 segment LED.
D. McLaughlin 3/16/22 ECE-231 Demo */

#include "avr/io.h"
#include "util/delay.h"

int main(void)
{
    unsigned char ledDigits[] = {0x3F, 0x06, 0x5B, 0x4F, 0x66, 0x6D, 0x7D,
        0x07, 0x7F, 0x67};
    unsigned char i=0;
    DDRD = 0xFF; //7segment pins

    while (1) {
        i++;
        if(i>9)
            i=0;
        PORTD = ledDigits[i]; //digit
        _delay_ms(10);
    }
}
```

for this movie,
_delay_ms(1000);

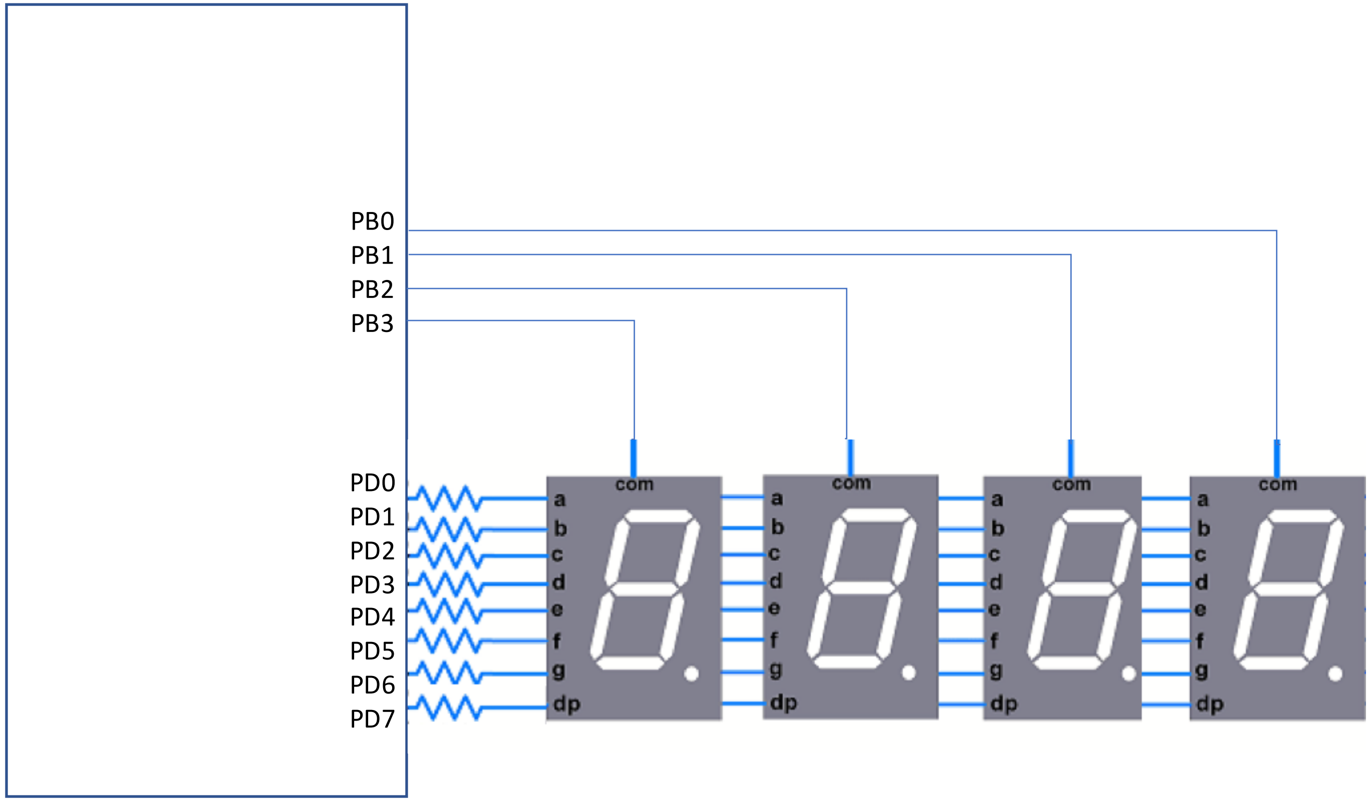


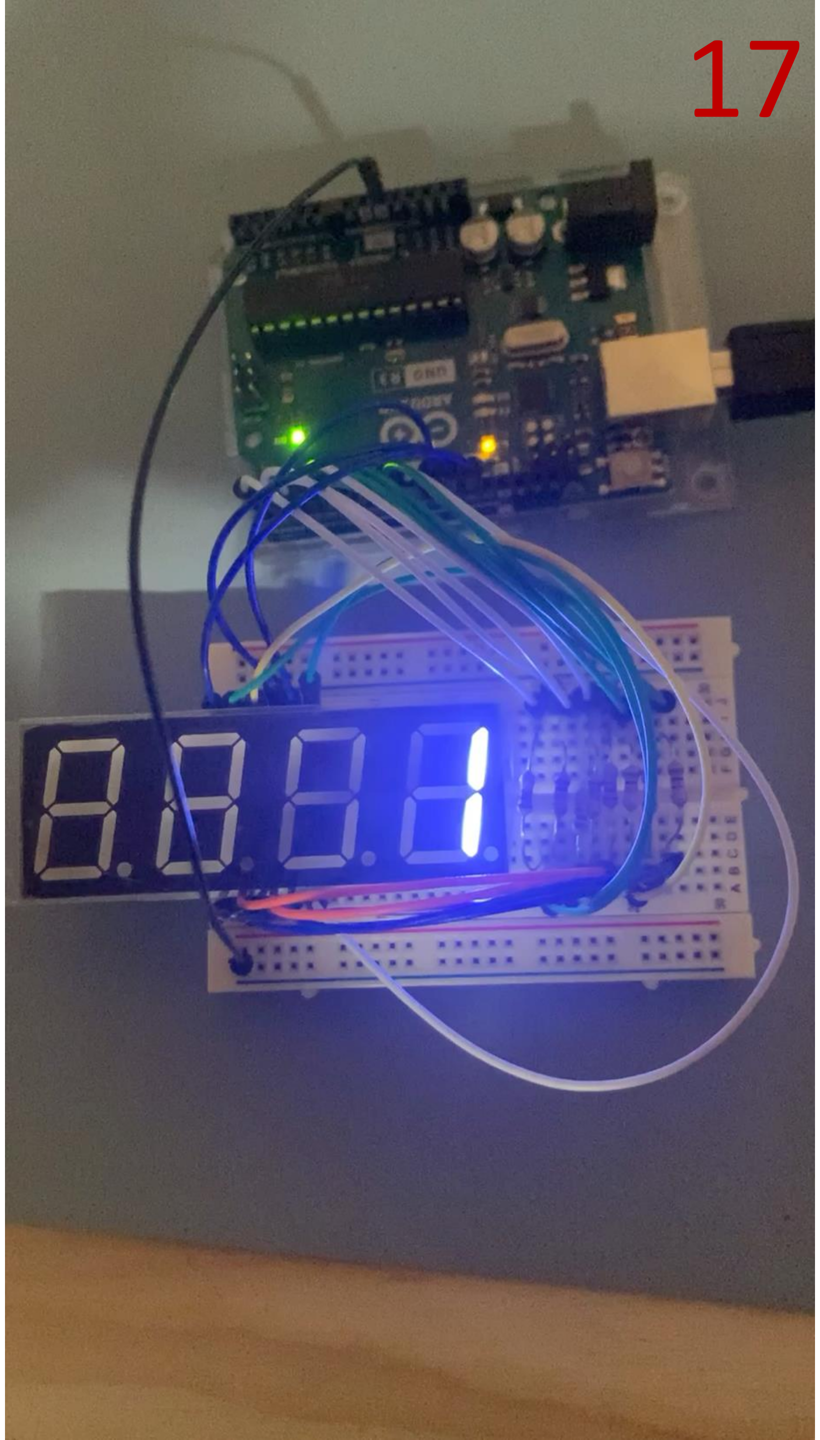




Retinal Persistence

The com pin for each digit connected to PB0-PB4. When these pins are low, the digit will glow. Code (not shown) sequences through PB0 – PB1 – PB2 – PB3 to sequence through the digits.



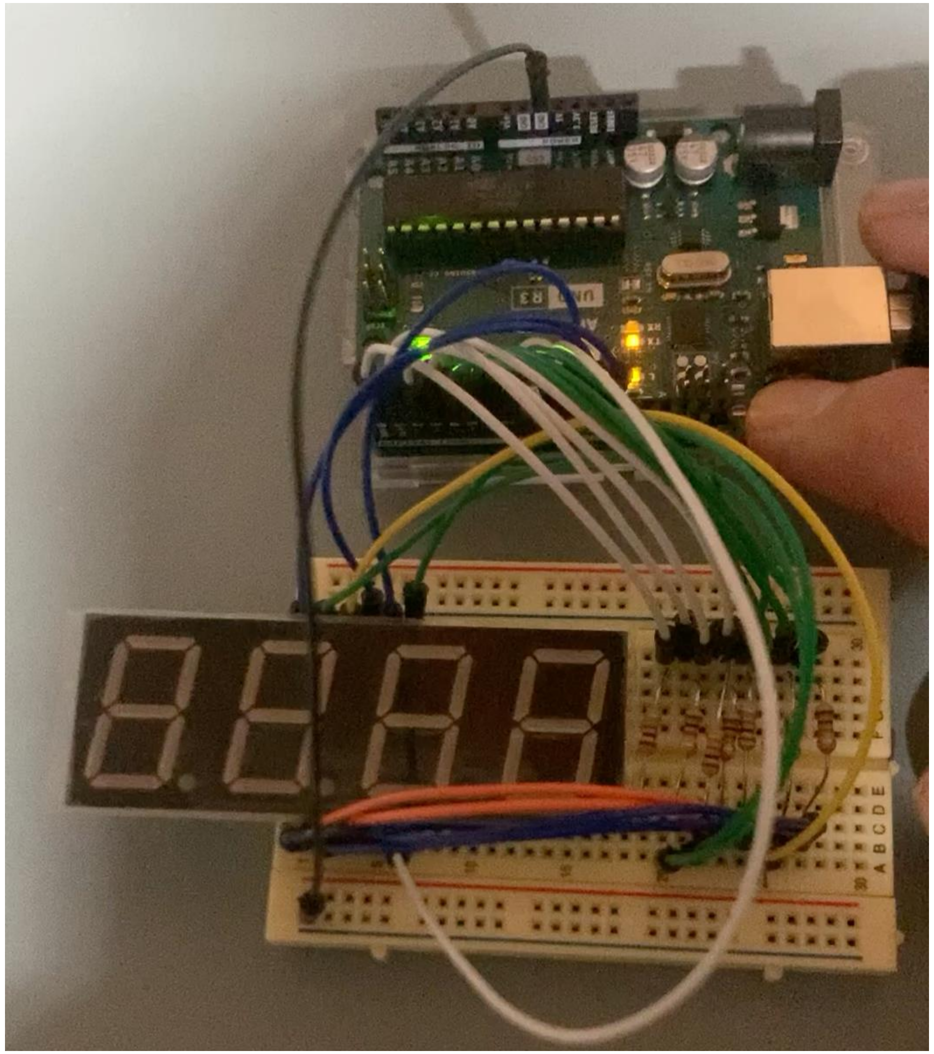


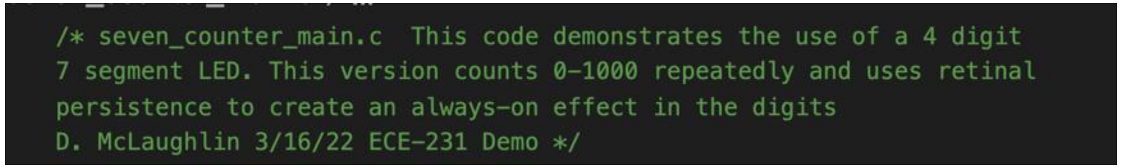
retinal persistence: repeatedly illuminate digits with update faster than 1/30 sec = 0.033 sec = 33 msec

pseudocode:

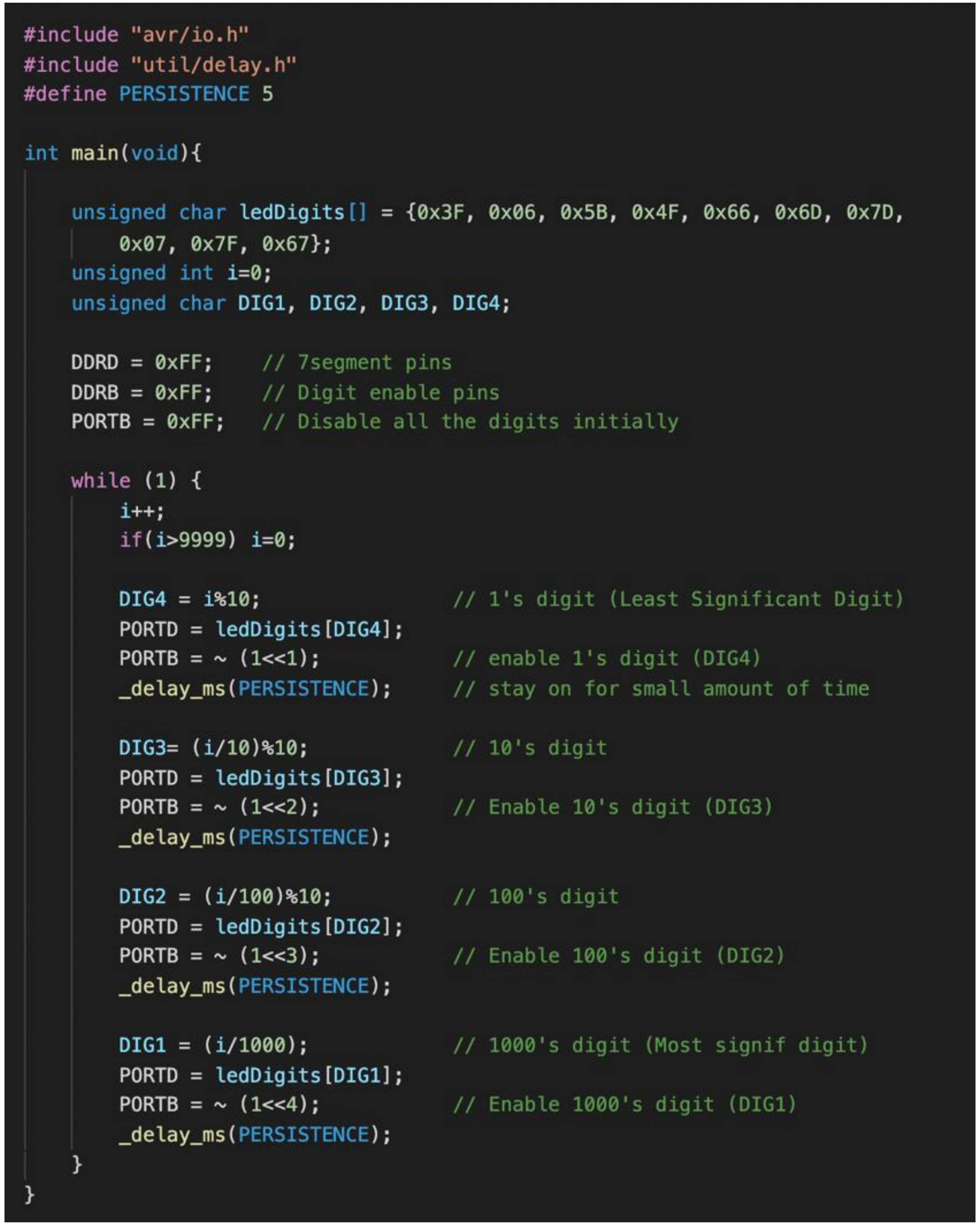
```
increment counter (0-9999)

illuminate 1's digit
wait 5 ms

illuminate 10's digit
wait 5 ms

illuminate 100's digit
wait 5 ms

illuminate 1000's digit
wait 5 ms

repeat
```

this loop
repeatedly
illuminate
each digit
every 20 msec

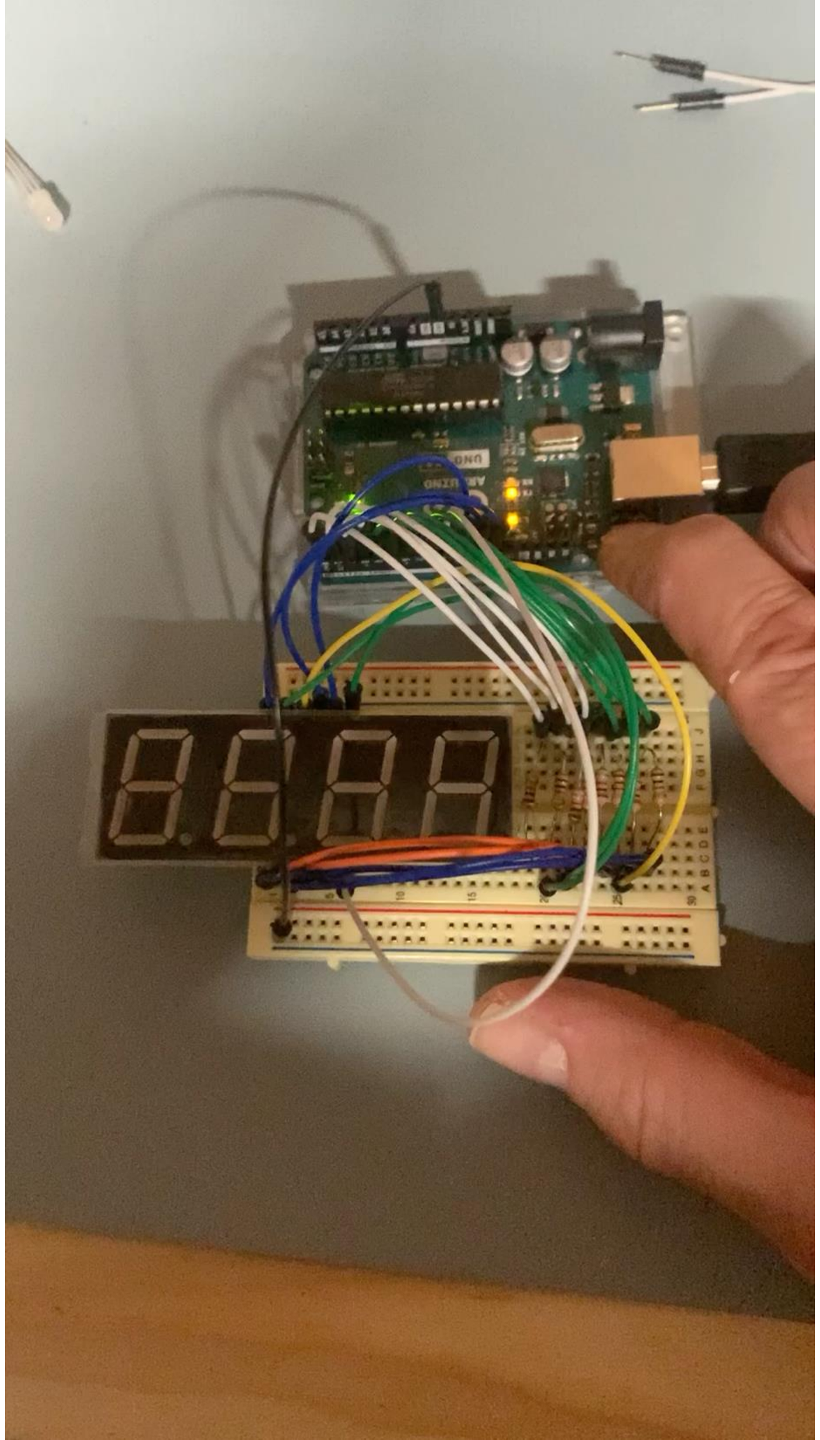


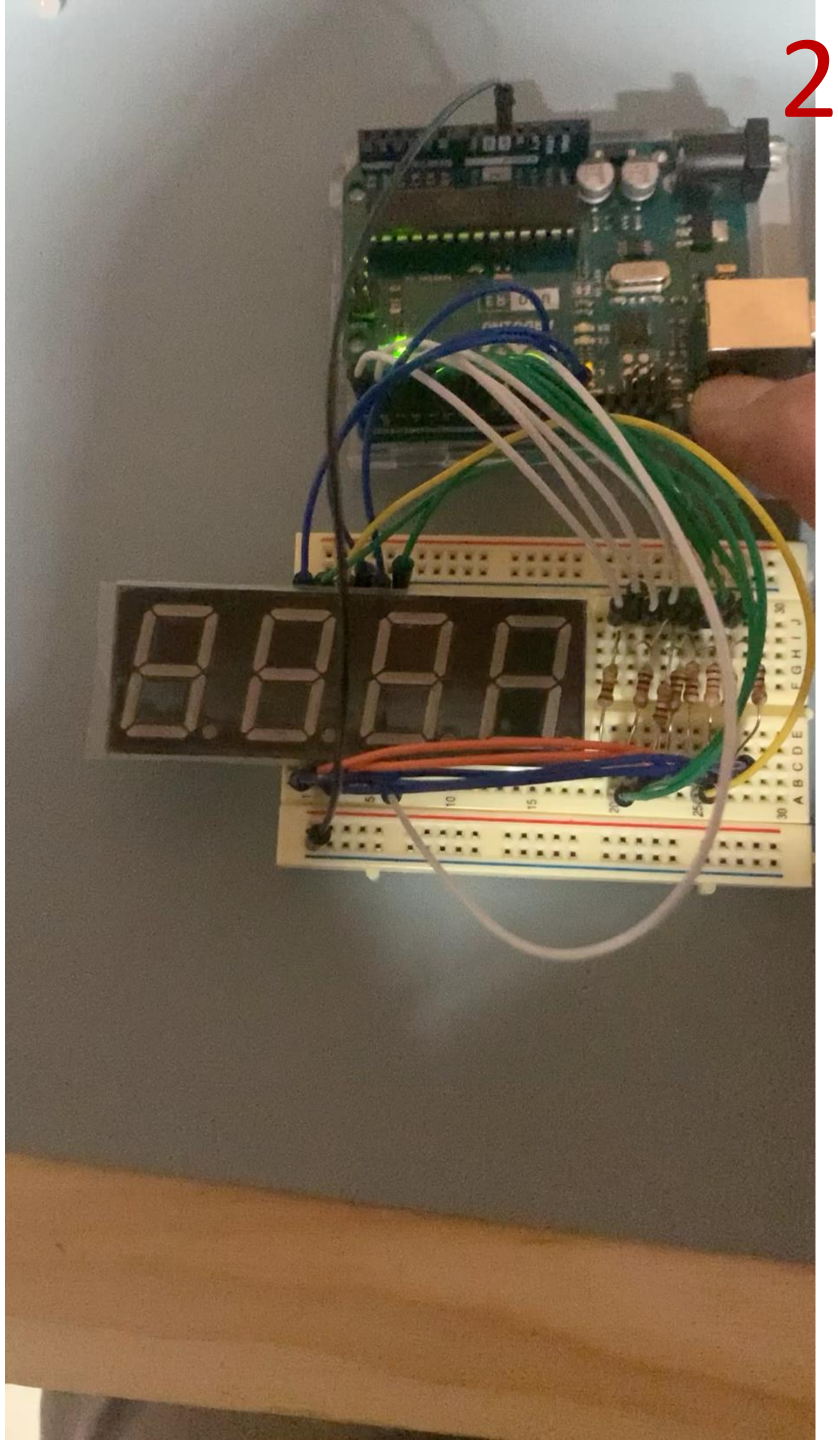


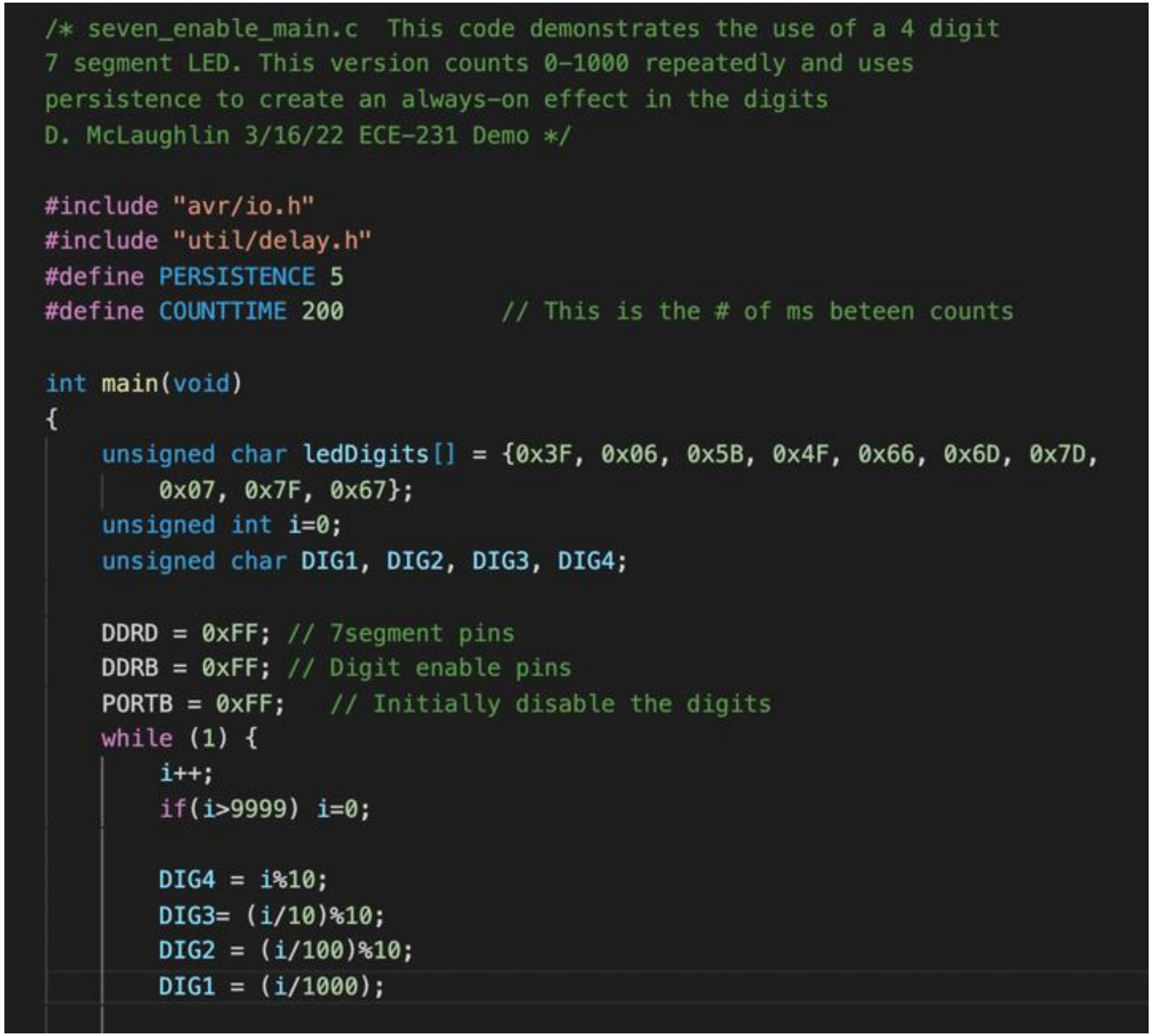
```
/* seven_counter_main.c  This code demonstrates the use of a 4 digit
7 segment LED. This version counts 0-1000 repeatedly and uses retinal
persistence to create an always-on effect in the digits
D. McLaughlin 3/16/22 ECE-231 Demo */
```



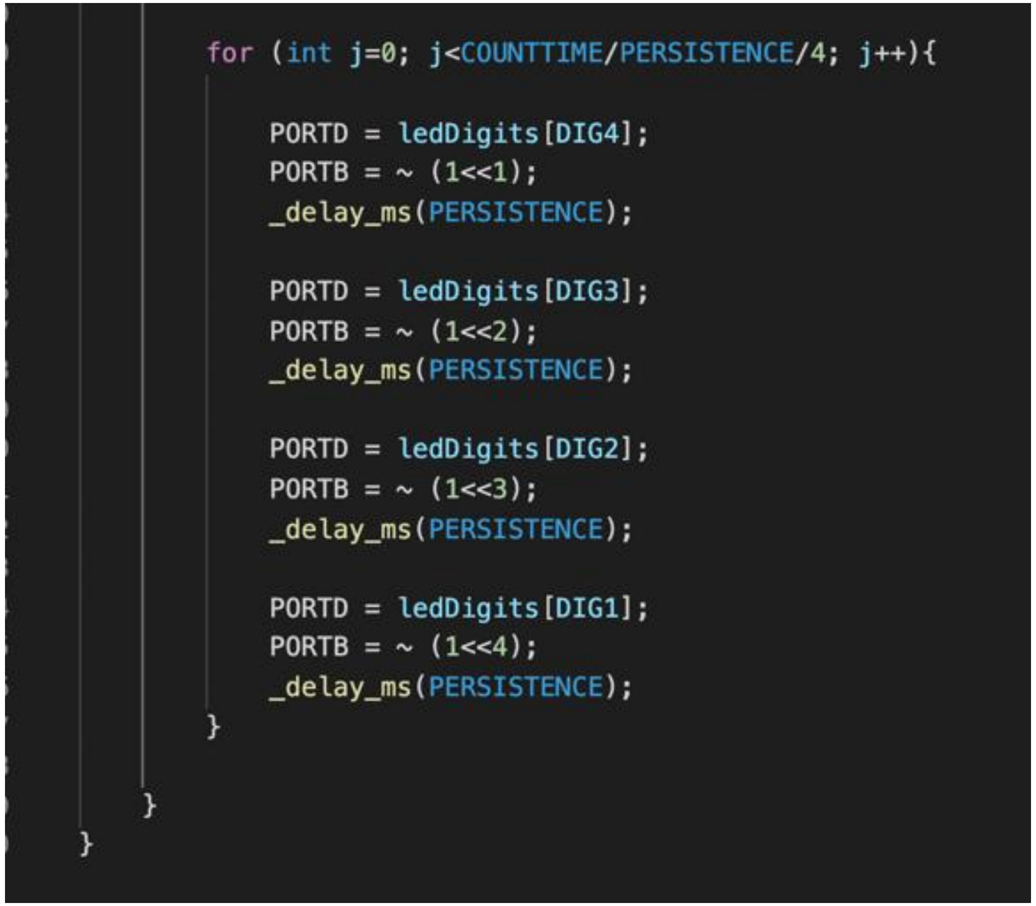
```
#include "avr/io.h"
#include "util/delay.h"
#define PERSISTENCE 5

int main(void){

    unsigned char ledDigits[] = {0x3F, 0x06, 0x5B, 0x4F, 0x66, 0x6D, 0x7D,
        0x07, 0x7F, 0x67};
    unsigned int i=0;
    unsigned char DIG1, DIG2, DIG3, DIG4;

    DDRD = 0xFF;    // 7segment pins
    DDRB = 0xFF;    // Digit enable pins
    PORTB = 0xFF;   // Disable all the digits initially

    while (1) {
        i++;
        if(i>9999) i=0;

        DIG4 = i%10;                // 1's digit (Least Significant Digit)
        PORTD = ledDigits[DIG4];
        PORTB = ~ (1<<1);           // enable 1's digit (DIG4)
        _delay_ms(PERSISTENCE);     // stay on for small amount of time

        DIG3= (i/10)%10;            // 10's digit
        PORTD = ledDigits[DIG3];
        PORTB = ~ (1<<2);           // Enable 10's digit (DIG3)
        _delay_ms(PERSISTENCE);

        DIG2 = (i/100)%10;          // 100's digit
        PORTD = ledDigits[DIG2];
        PORTB = ~ (1<<3);           // Enable 100's digit (DIG2)
        _delay_ms(PERSISTENCE);

        DIG1 = (i/1000);            // 1000's digit (Most signif digit)
        PORTD = ledDigits[DIG1];
        PORTB = ~ (1<<4);           // Enable 1000's digit (DIG1)
        _delay_ms(PERSISTENCE);
    }
}
```





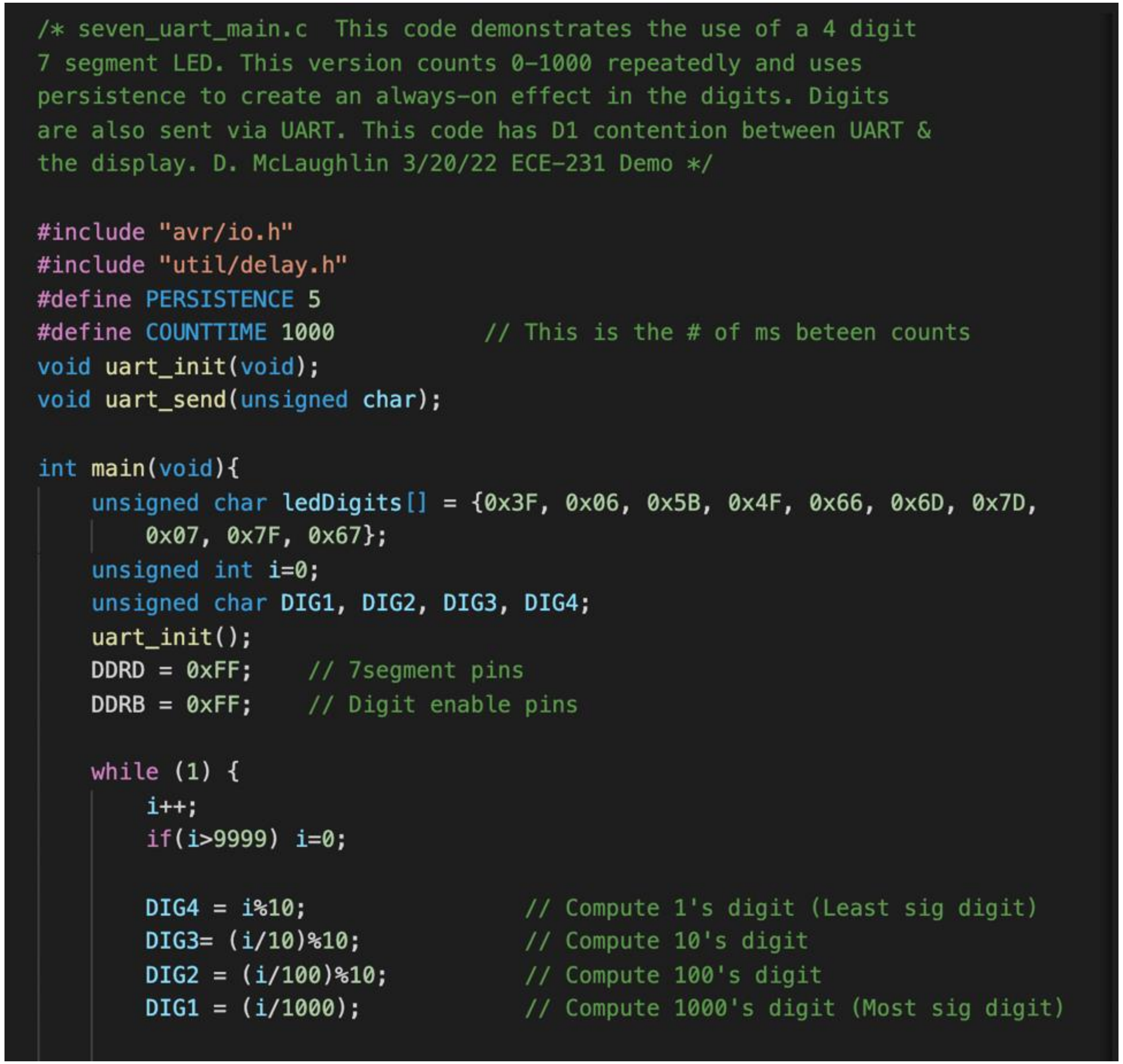


```
/* seven_enable_main.c  This code demonstrates the use of a 4 digit
7 segment LED. This version counts 0-1000 repeatedly and uses
persistence to create an always-on effect in the digits
D. McLaughlin 3/16/22 ECE-231 Demo */

#include "avr/io.h"
#include "util/delay.h"
#define PERSISTENCE 5
#define COUNTTIME 200           // This is the # of ms beteen counts

int main(void)
{
    unsigned char ledDigits[] = {0x3F, 0x06, 0x5B, 0x4F, 0x66, 0x6D, 0x7D,
        0x07, 0x7F, 0x67};
    unsigned int i=0;
    unsigned char DIG1, DIG2, DIG3, DIG4;

    DDRD = 0xFF; // 7segment pins
    DDRB = 0xFF; // Digit enable pins
    PORTB = 0xFF;   // Initially disable the digits
    while (1) {
        i++;
        if(i>9999) i=0;

        DIG4 = i%10;
        DIG3= (i/10)%10;
        DIG2 = (i/100)%10;
        DIG1 = (i/1000);
```

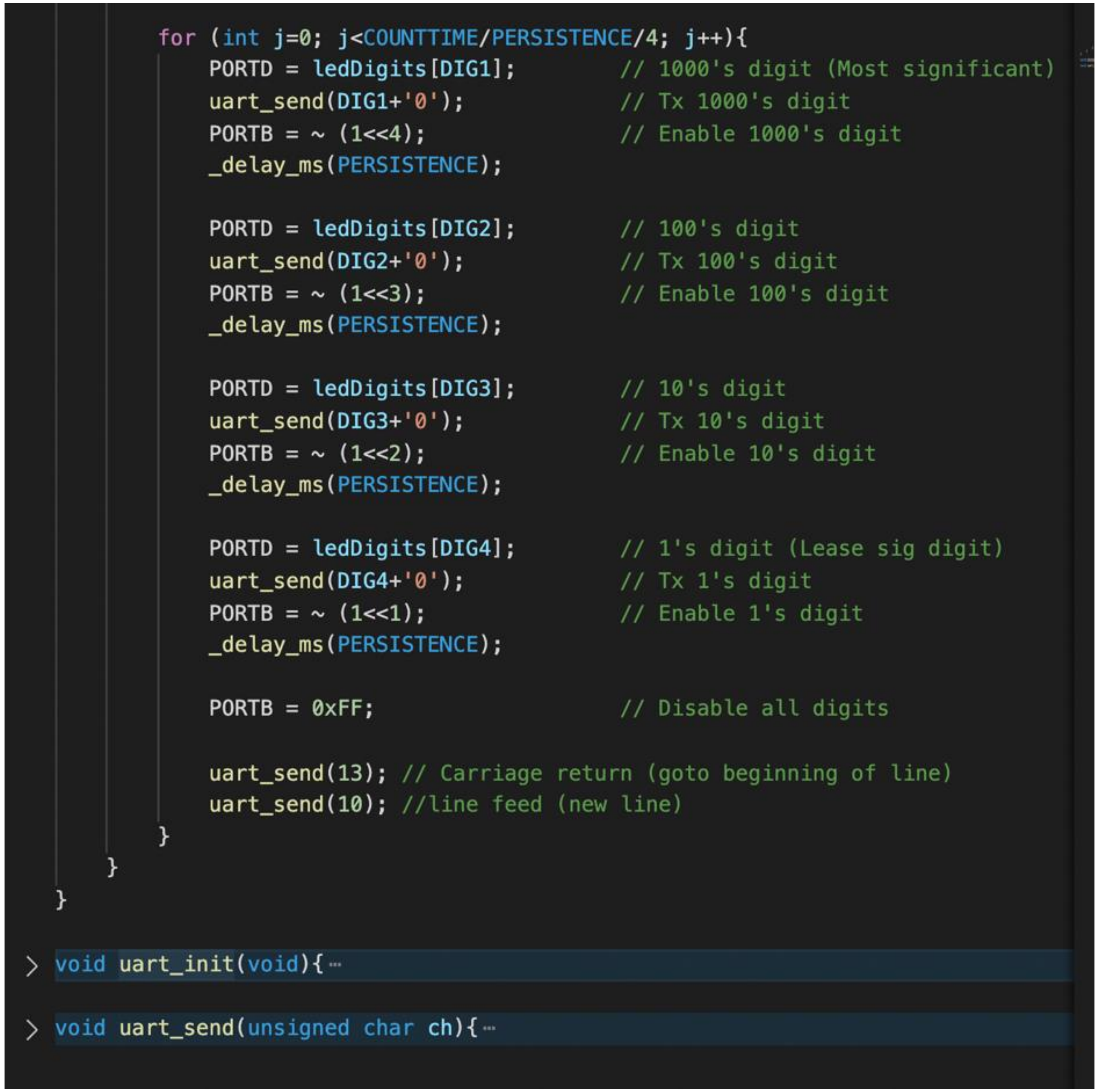


```
        for (int j=0; j<COUNTTIME/PERSISTENCE/4; j++){

            PORTD = ledDigits[DIG4];
            PORTB = ~ (1<<1);
            _delay_ms(PERSISTENCE);

            PORTD = ledDigits[DIG3];
            PORTB = ~ (1<<2);
            _delay_ms(PERSISTENCE);

            PORTD = ledDigits[DIG2];
            PORTB = ~ (1<<3);
            _delay_ms(PERSISTENCE);

            PORTD = ledDigits[DIG1];
            PORTB = ~ (1<<4);
            _delay_ms(PERSISTENCE);
        }

    }
}
```

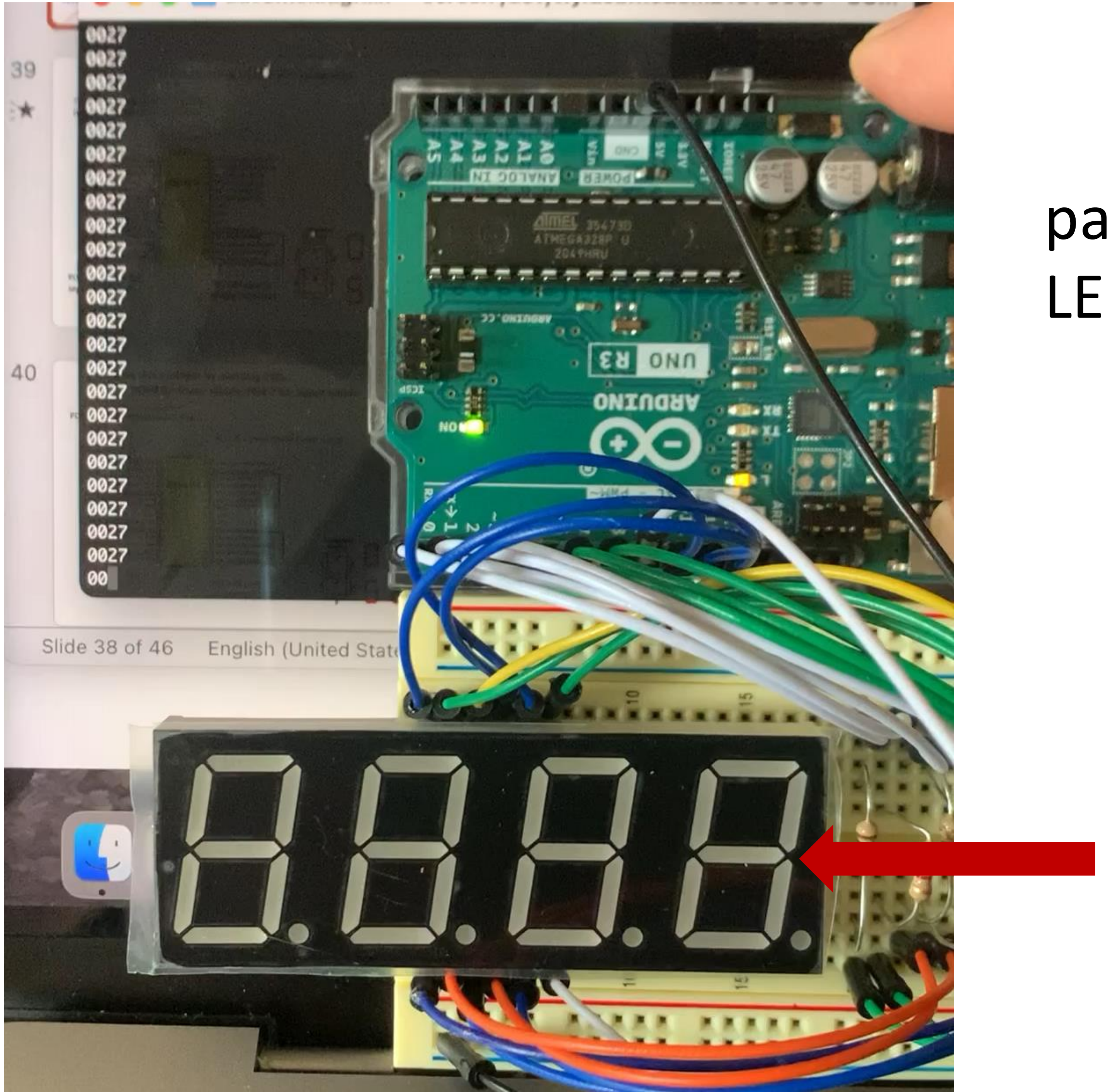
This code combines UART & 4 digit 7 segment display



```c
/* seven_uart_main.c  This code demonstrates the use of a 4 digit
7 segment LED. This version counts 0-1000 repeatedly and uses
persistence to create an always-on effect in the digits. Digits
are also sent via UART. This code has D1 contention between UART &
the display. D. McLaughlin 3/20/22 ECE-231 Demo */

#include "avr/io.h"
#include "util/delay.h"
#define PERSISTENCE 5
#define COUNTTIME 1000          // This is the # of ms beteen counts
void uart_init(void);
void uart_send(unsigned char);

int main(void){
    unsigned char ledDigits[] = {0x3F, 0x06, 0x5B, 0x4F, 0x66, 0x6D, 0x7D,
        0x07, 0x7F, 0x67};
    unsigned int i=0;
    unsigned char DIG1, DIG2, DIG3, DIG4;
    uart_init();
    DDRD = 0xFF;    // 7segment pins
    DDRB = 0xFF;    // Digit enable pins

    while (1) {
        i++;
        if(i>9999) i=0;

        DIG4 = i%10;                // Compute 1's digit (Least sig digit)
        DIG3= (i/10)%10;            // Compute 10's digit
        DIG2 = (i/100)%10;          // Compute 100's digit
        DIG1 = (i/1000);            // Compute 1000's digit (Most sig digit)
```



```c
        for (int j=0; j<COUNTTIME/PERSISTENCE/4; j++){
            PORTD = ledDigits[DIG1];        // 1000's digit (Most significant)
            uart_send(DIG1+'0');            // Tx 1000's digit
            PORTB = ~ (1<<4);               // Enable 1000's digit
            _delay_ms(PERSISTENCE);

            PORTD = ledDigits[DIG2];        // 100's digit
            uart_send(DIG2+'0');            // Tx 100's digit
            PORTB = ~ (1<<3);               // Enable 100's digit
            _delay_ms(PERSISTENCE);

            PORTD = ledDigits[DIG3];        // 10's digit
            uart_send(DIG3+'0');            // Tx 10's digit
            PORTB = ~ (1<<2);               // Enable 10's digit
            _delay_ms(PERSISTENCE);

            PORTD = ledDigits[DIG4];        // 1's digit (Lease sig digit)
            uart_send(DIG4+'0');            // Tx 1's digit
            PORTB = ~ (1<<1);               // Enable 1's digit
            _delay_ms(PERSISTENCE);

            PORTB = 0xFF;                   // Disable all digits

            uart_send(13); // Carriage return (goto beginning of line)
            uart_send(10); //line feed (new line)
        }
    }
}

> void uart_init(void){⋯

> void uart_send(unsigned char ch){⋯
```



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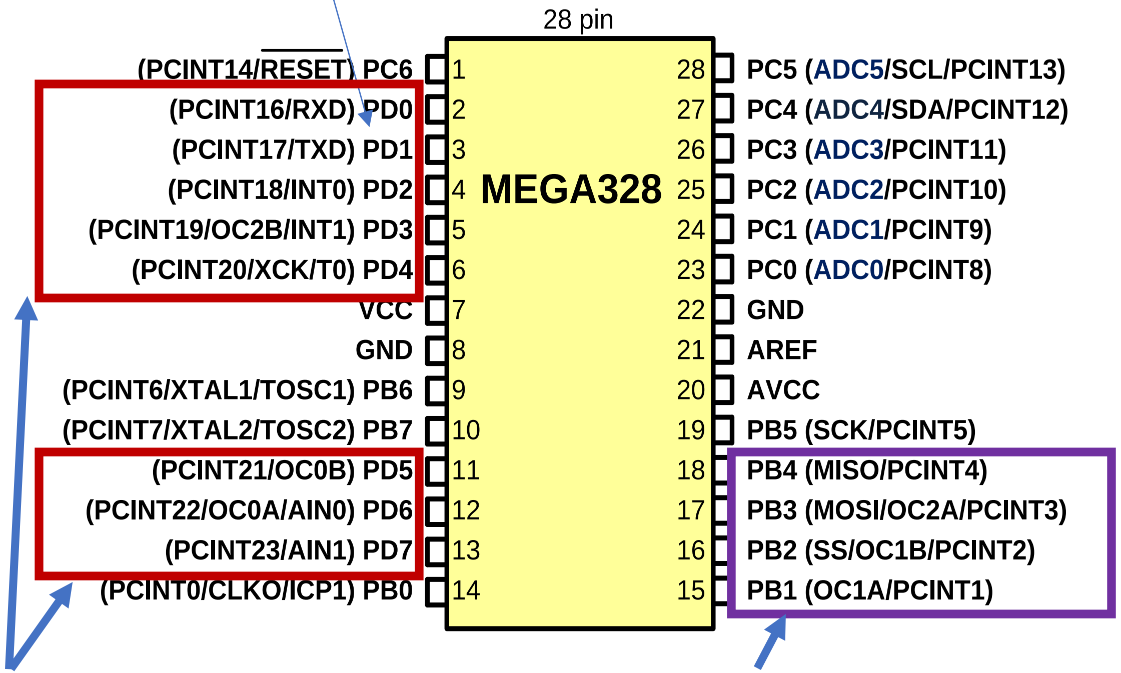
```

pay attention to LED segment b

GPIO PORTD & USART wire contention

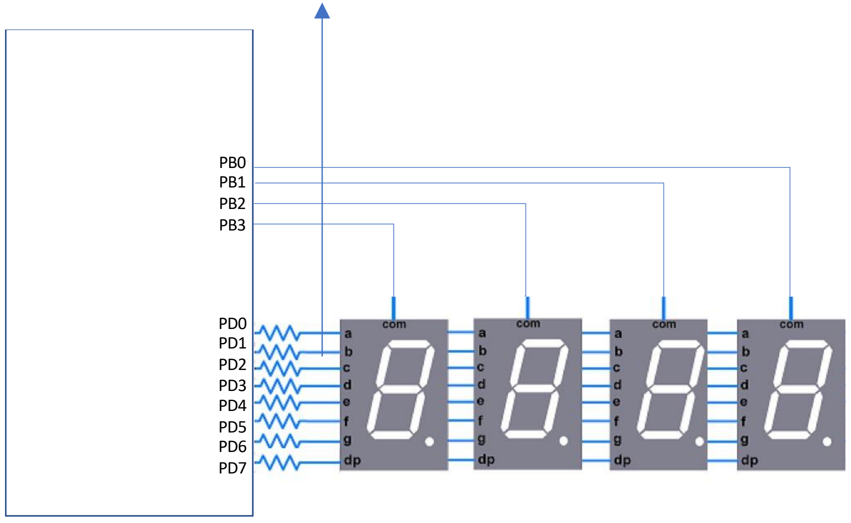
TXD (USART) uses same wire as PD1 (wired to segment b of the display)

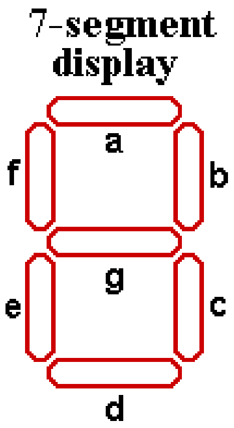


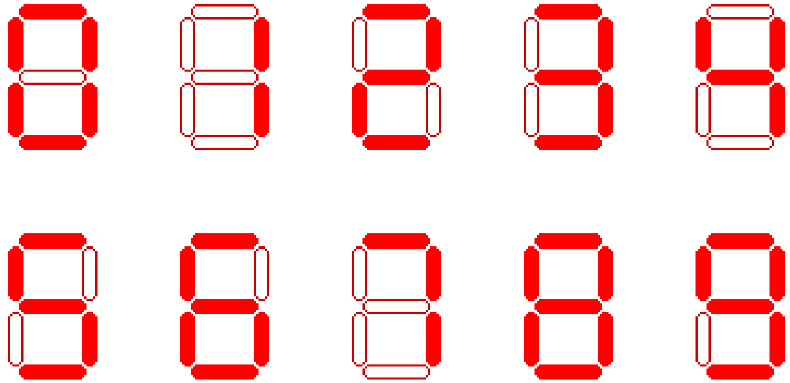
PD0-PD7 used to for segments a-g & dp

PB1-PB4 used to enable DIG1-DIG4

TXD from UART to UART/USB converter



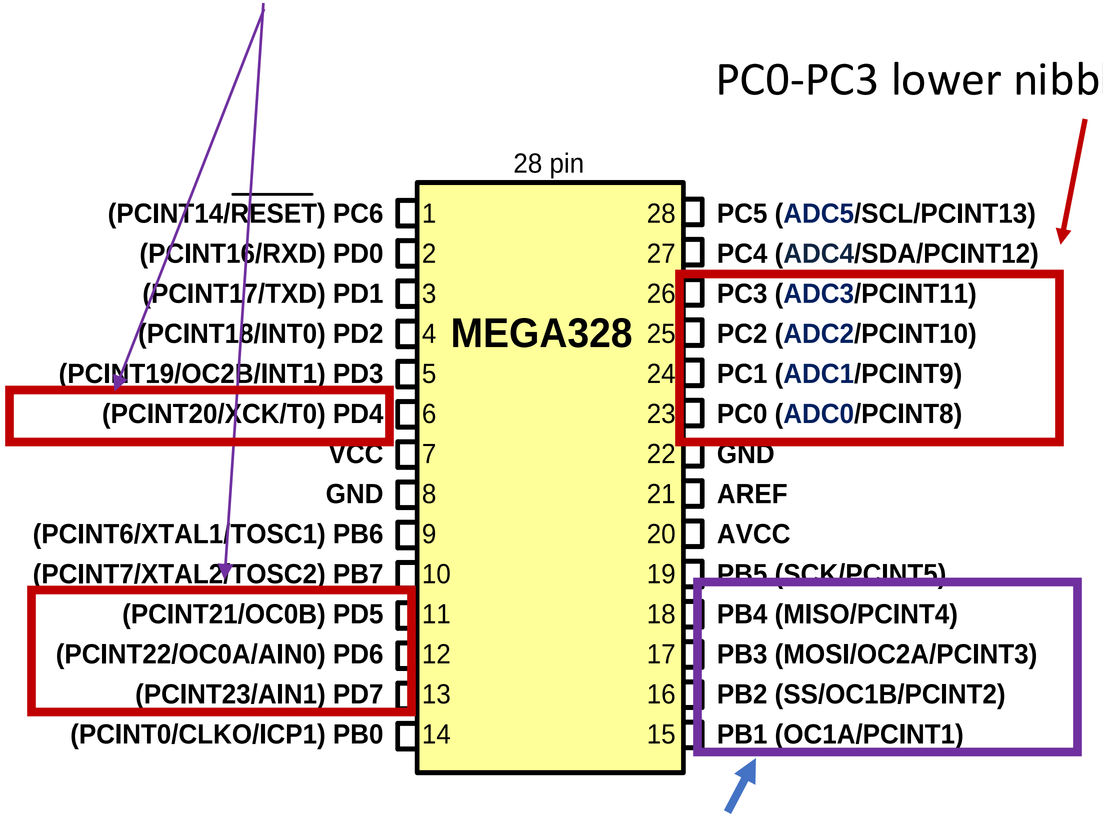




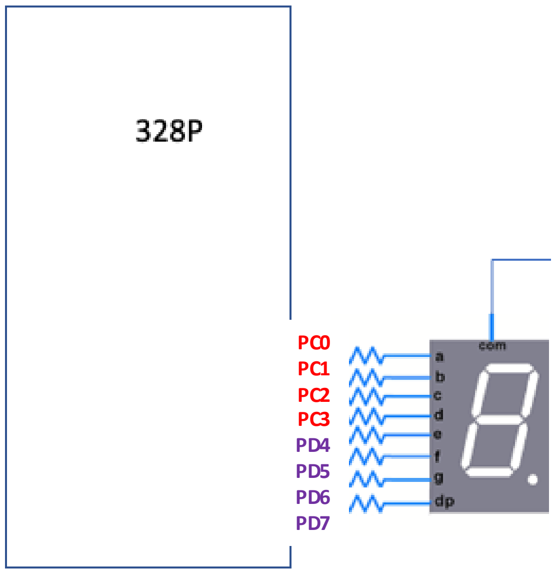
Solve this problem by avoiding PD0.
Use PC0-3 for lower nibble; PD4-7 for upper nibble

PD4-PD7 upper nibble (upper 4 bits)

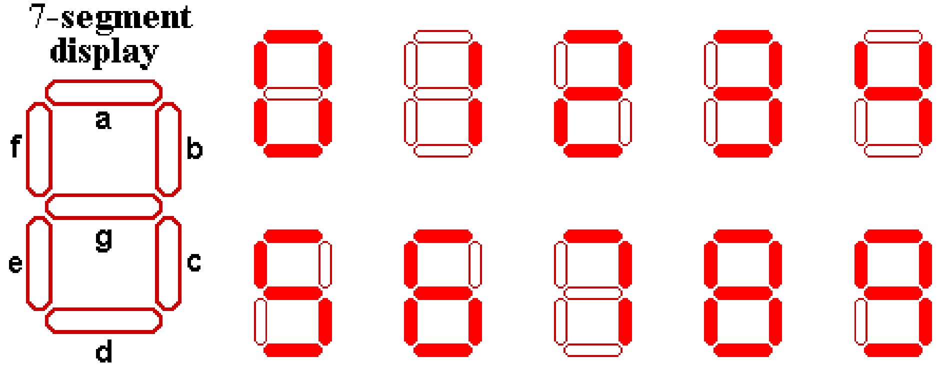
PC0-PC3 lower nibble (lower 4 bits)

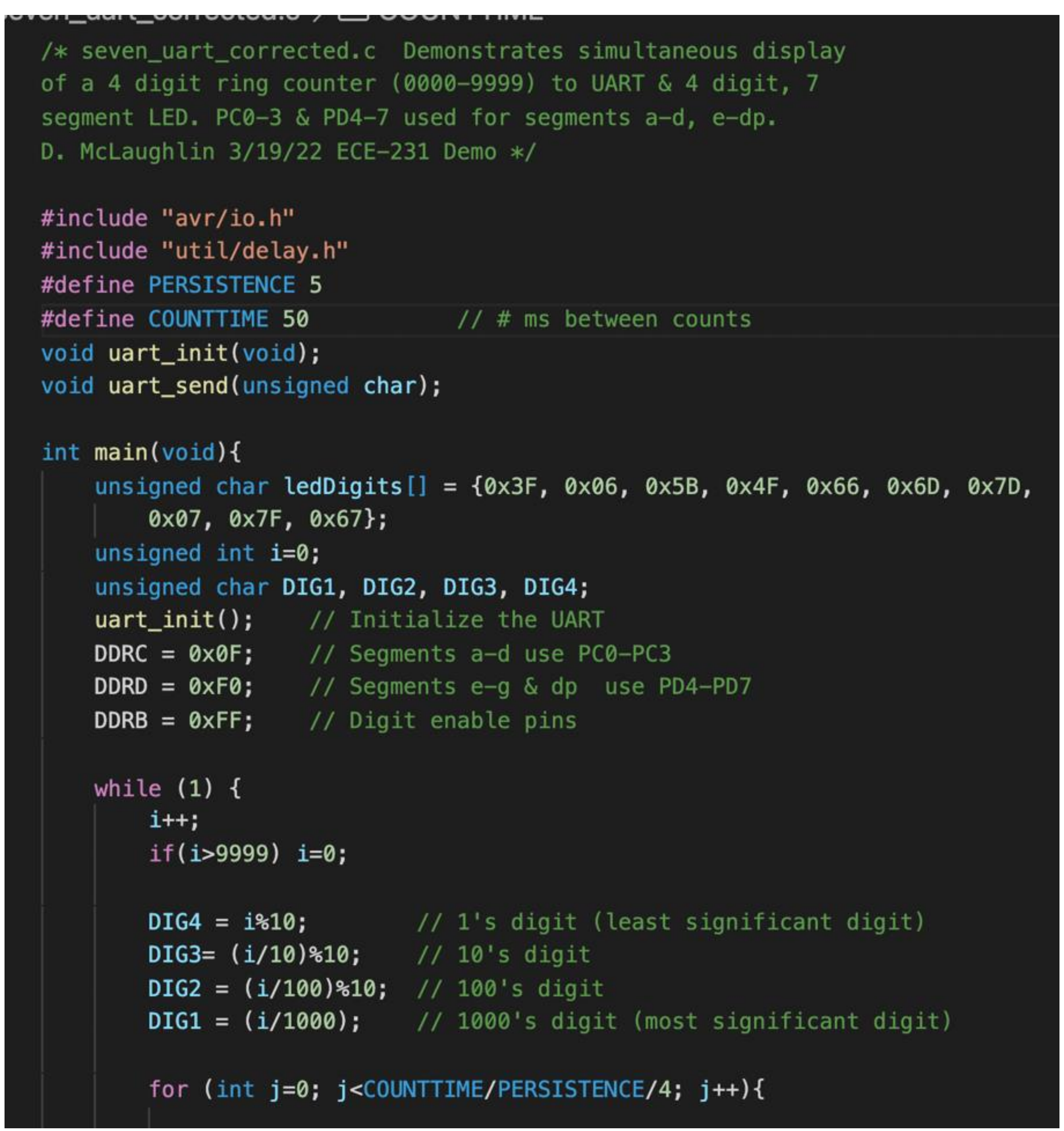


PB1-PB4 used to enable DIG1-DIG4



Common Cathode 7 Segment LED





```
seven_uart_corrected.c > COUNTTIME
/* seven_uart_corrected.c  Demonstrates simultaneous display
of a 4 digit ring counter (0000-9999) to UART & 4 digit, 7
segment LED. PC0-3 & PD4-7 used for segments a-d, e-dp.
D. McLaughlin 3/19/22 ECE-231 Demo */

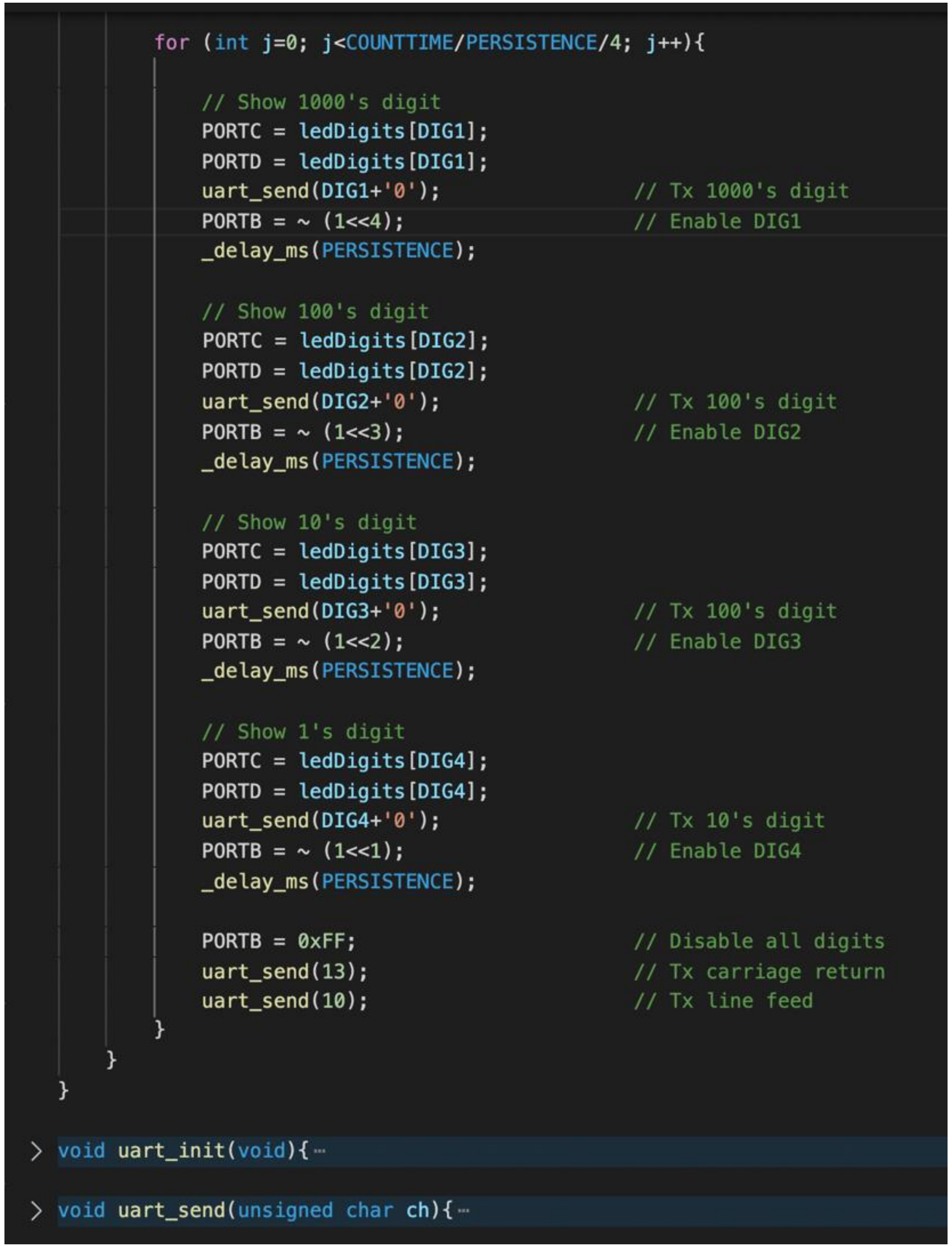
#include "avr/io.h"
#include "util/delay.h"
#define PERSISTENCE 5
#define COUNTTIME 50           // # ms between counts
void uart_init(void);
void uart_send(unsigned char);

int main(void){
    unsigned char ledDigits[] = {0x3F, 0x06, 0x5B, 0x4F, 0x66, 0x6D, 0x7D,
        0x07, 0x7F, 0x67};
    unsigned int i=0;
    unsigned char DIG1, DIG2, DIG3, DIG4;
    uart_init();    // Initialize the UART
    DDRC = 0x0F;    // Segments a-d use PC0-PC3
    DDRD = 0xF0;    // Segments e-g & dp  use PD4-PD7
    DDRB = 0xFF;    // Digit enable pins

    while (1) {
        i++;
        if(i>9999) i=0;

        DIG4 = i%10;        // 1's digit (least significant digit)
        DIG3= (i/10)%10;    // 10's digit
        DIG2 = (i/100)%10;  // 100's digit
        DIG1 = (i/1000);    // 1000's digit (most significant digit)

        for (int j=0; j<COUNTTIME/PERSISTENCE/4; j++){
```



```
            for (int j=0; j<COUNTTIME/PERSISTENCE/4; j++){

                // Show 1000's digit
                PORTC = ledDigits[DIG1];
                PORTD = ledDigits[DIG1];
                uart_send(DIG1+'0');                // Tx 1000's digit
                PORTB = ~ (1<<4);                   // Enable DIG1
                _delay_ms(PERSISTENCE);

                // Show 100's digit
                PORTC = ledDigits[DIG2];
                PORTD = ledDigits[DIG2];
                uart_send(DIG2+'0');                // Tx 100's digit
                PORTB = ~ (1<<3);                   // Enable DIG2
                _delay_ms(PERSISTENCE);

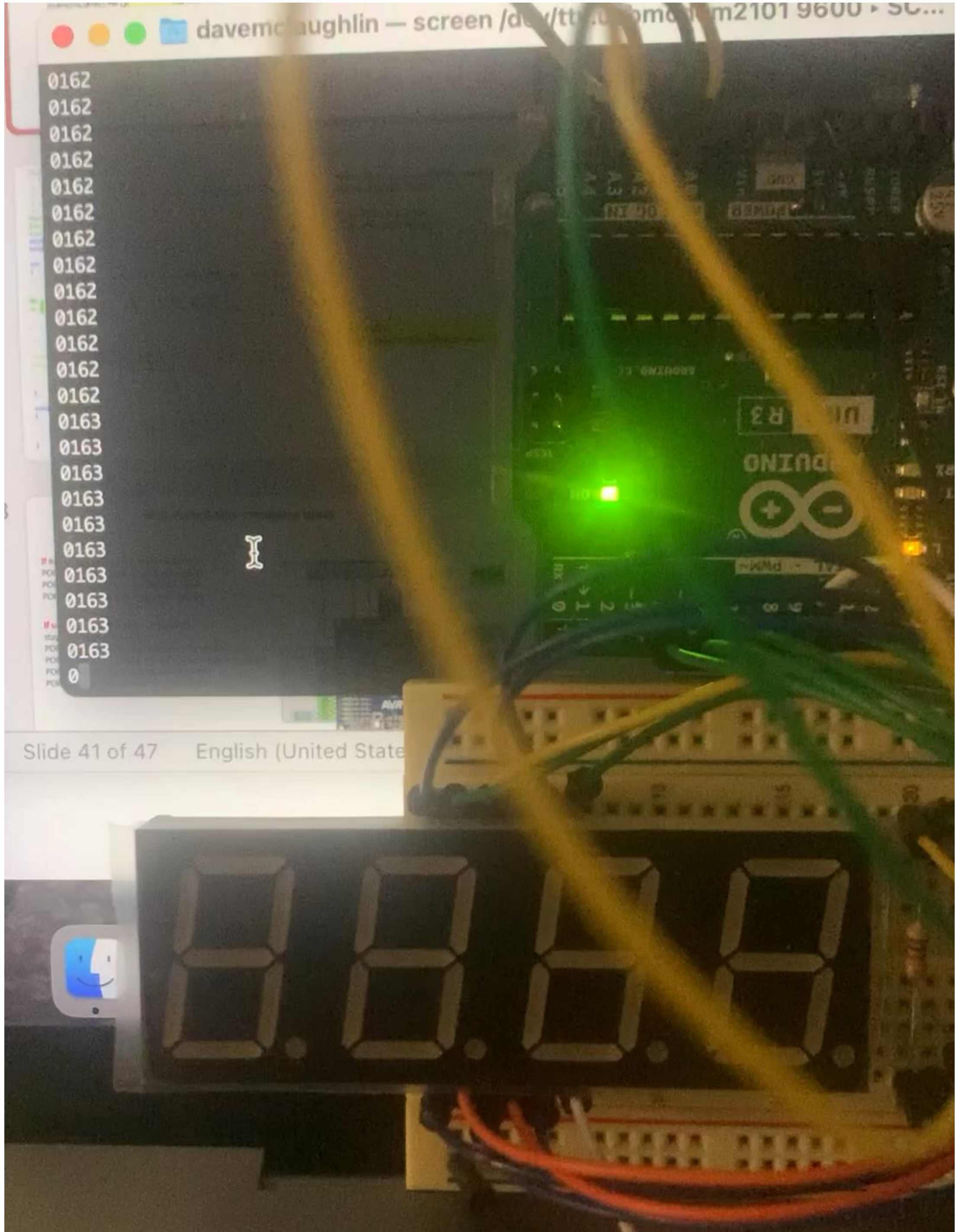
                // Show 10's digit
                PORTC = ledDigits[DIG3];
                PORTD = ledDigits[DIG3];
                uart_send(DIG3+'0');                // Tx 100's digit
                PORTB = ~ (1<<2);                   // Enable DIG3
                _delay_ms(PERSISTENCE);

                // Show 1's digit
                PORTC = ledDigits[DIG4];
                PORTD = ledDigits[DIG4];
                uart_send(DIG4+'0');                // Tx 10's digit
                PORTB = ~ (1<<1);                   // Enable DIG4
                _delay_ms(PERSISTENCE);

                PORTB = 0xFF;                       // Disable all digits
                uart_send(13);                      // Tx carriage return
                uart_send(10);                      // Tx line feed
            }
        }
    }

> void uart_init(void){…

> void uart_send(unsigned char ch){…
```



```
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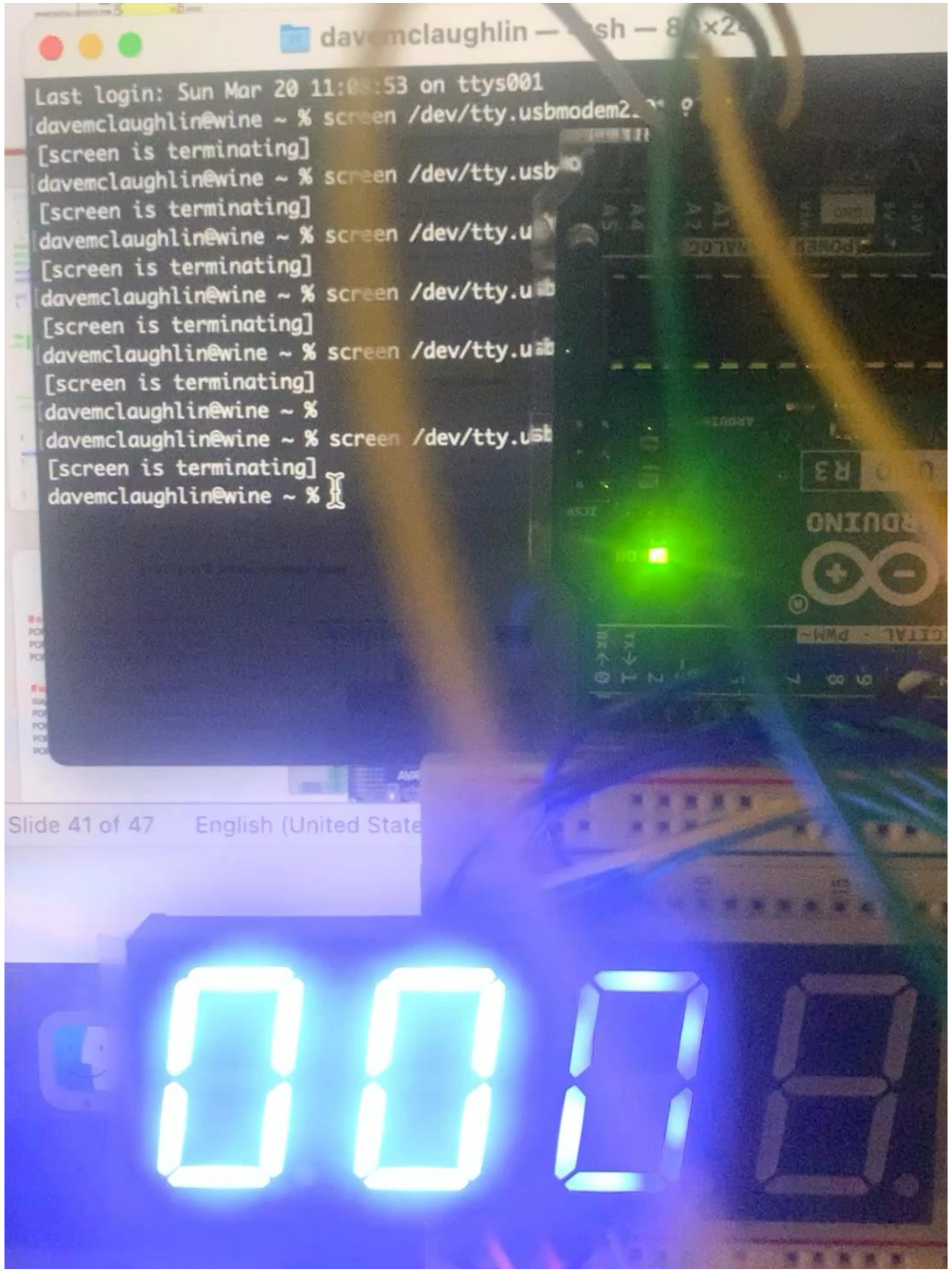

```
Last login: Sun Mar 20 11:0 :53 on ttys001
davemclaughlin@wine ~ % screen /dev/tty.usbmodem2
[screen is terminating]
davemclaughlin@wine ~ % screen /dev/tty.usb
[screen is terminating]
davemclaughlin@wine ~ % screen /dev/tty.u
[screen is terminating]
davemclaughlin@wine ~ % screen /dev/tty.u
[screen is terminating]
davemclaughlin@wine ~ % screen /dev/tty.u
[screen is terminating]
davemclaughlin@wine ~ %
davemclaughlin@wine ~ % screen /dev/tty.us
[screen is terminating]
davemclaughlin@wine ~ %
```