بسم الله الرحمن الرحیم

طراحی سیستمهای ریزپردازنده

برنامه نویسی به زبان C

دانشکده مهندسی برق

دانشگاه صنعتی شاهرود

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۱۴۰۰

چرا C ؟

- زبان C یک زبان برنامه نویسی سطح بالا است و نسبت به زبان ماشین و اسمبلی قابل فهم تر است.

- برنامه نویسی سطح پایین را پشتیبانی می کند، بوسیله آن به تمام اجزای سخت افزاری میکروکنترلر ها دسترسی داریم.

- کتابخانه‌های متنوع: تغییر نوع داده، ورودی / خروجی استاندارد، محاسبات اعداد صحیح بزرگ و اعشاری

- مجموعه دستورات AVR به گونه‌ای طراحی شده که کامپایلرهای C را به خوبی پشتیبانی کنند. کدهای C به صورت بهینه به زبان اسمبلی تبدیل می شود

ابزارهای در دسترس

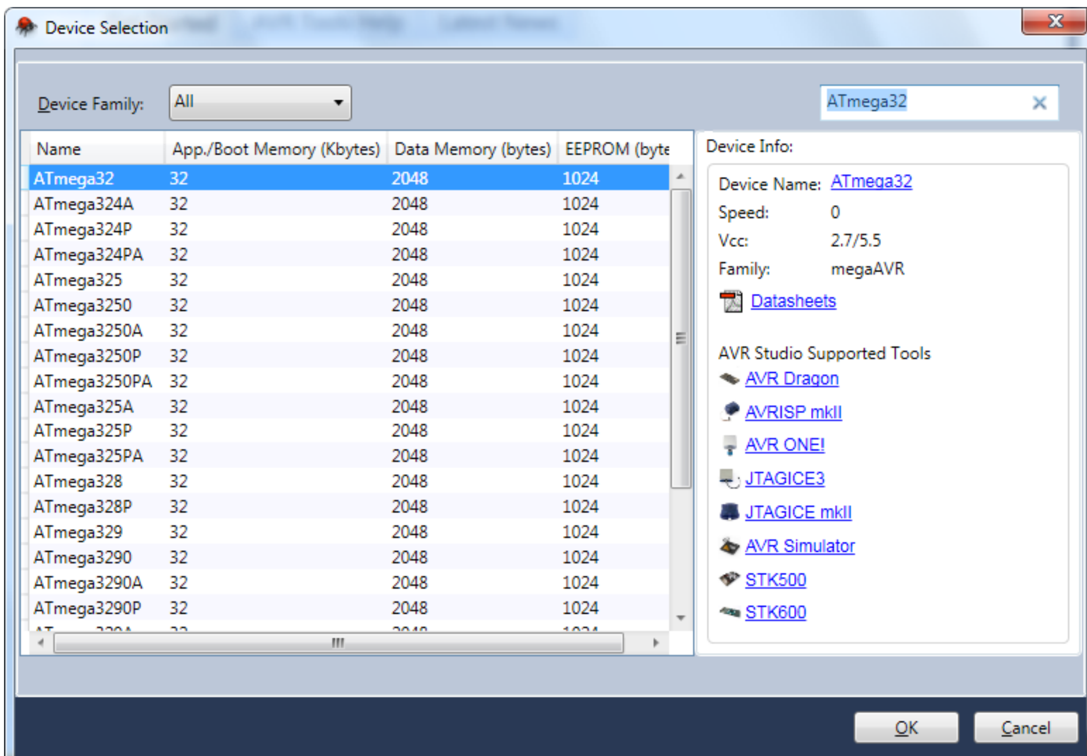
- اتمل استودیو
  - یک محیط توسعه یکپارچه برای میکروهای AVR
  - شامل ویرایشگر، اسمبلر، شبیه ساز و کامپایلر
  - امکان نوشتن مستقیم فایل هگز تولید شده روی میکرو
  - رایگان و قابل دانلود از آدرس زیر
    - microchip.com/mplab/avr-support/atmel-studio-7

ابزارهای در دسترس

- Code Vision AVR 3.34
  - ویزاردهای ساده و متنوع
  - کتابخانه های متنوع
  - تا حدی ساده تر از اتمل استودیو
  - عدم وجود دیباگر
  - رایگان نیست

نحوه ایجاد پروژه در اتمل استودیو

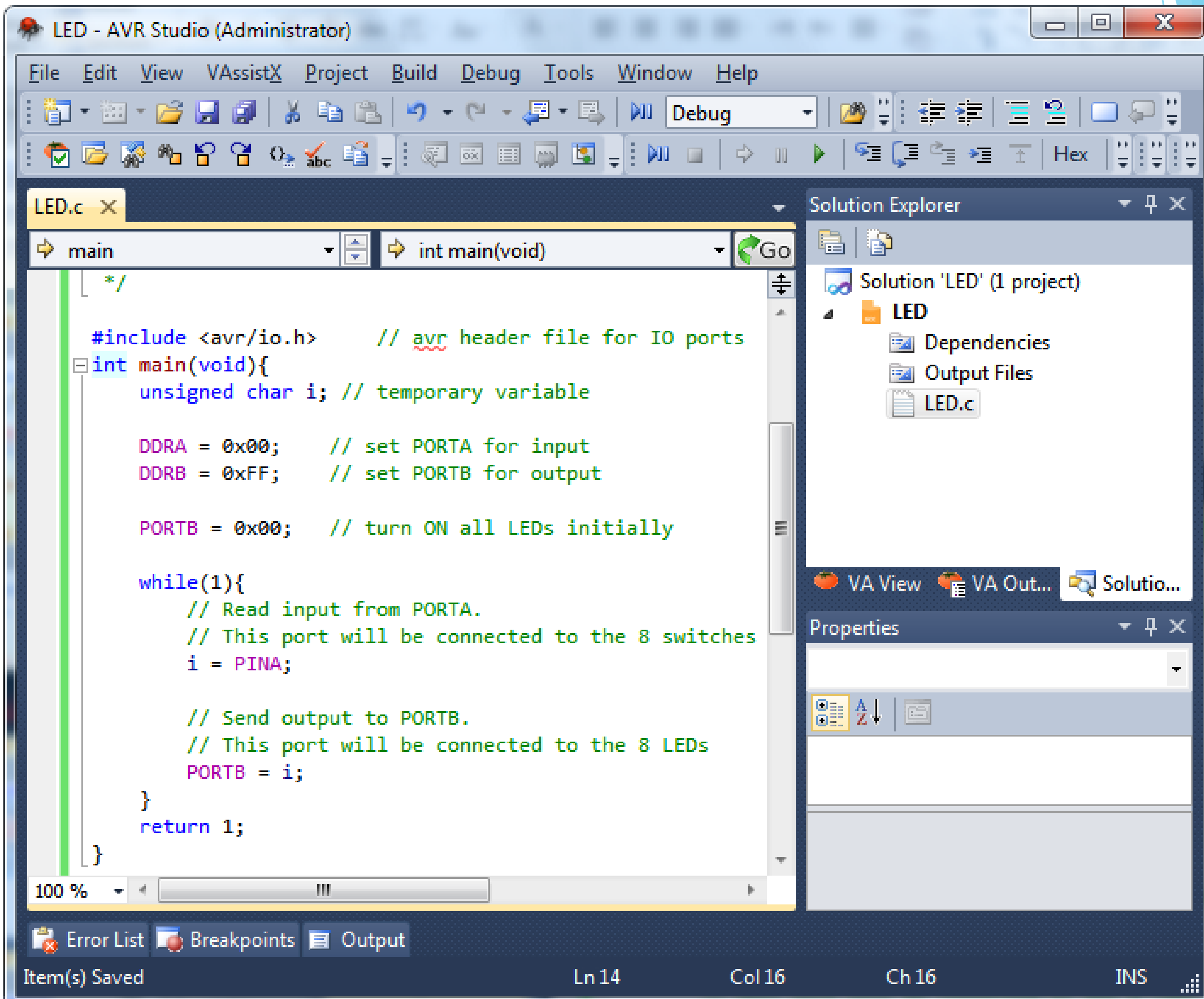
- New Project ➔ AVR GCC ➔ C Executable Project
  - اسم معناداری برای پروژه انتخاب کنید:
    - ☑ Traffic-Light, DC-Motor-Speed-Control, Homework2-LED
    - ☒ Asdf, test1, ttt, my project, unknown, untitled, salehi2
- Select destination AVR e.g. ATmega32 ➔ OK



نحوه ایجاد پروژه در اتمل استودیو - ادامه

- گام دوم: کد برنامه را وارد کنید
- گام سوم: کامپایل و تولید فایل هگز
  - خطاهای احتمالی را اصلاح کنید
- گام چهارم (اختیاری): شبیه سازی در پروتئوس
- گام پنجم: برنامه ریزی فایل هگز روی میکرو با استفاده از دستگاه برنامه ریز

برنامه نمونه – تغییر وضعیت LEDها با فشرده شدن سوئیچها

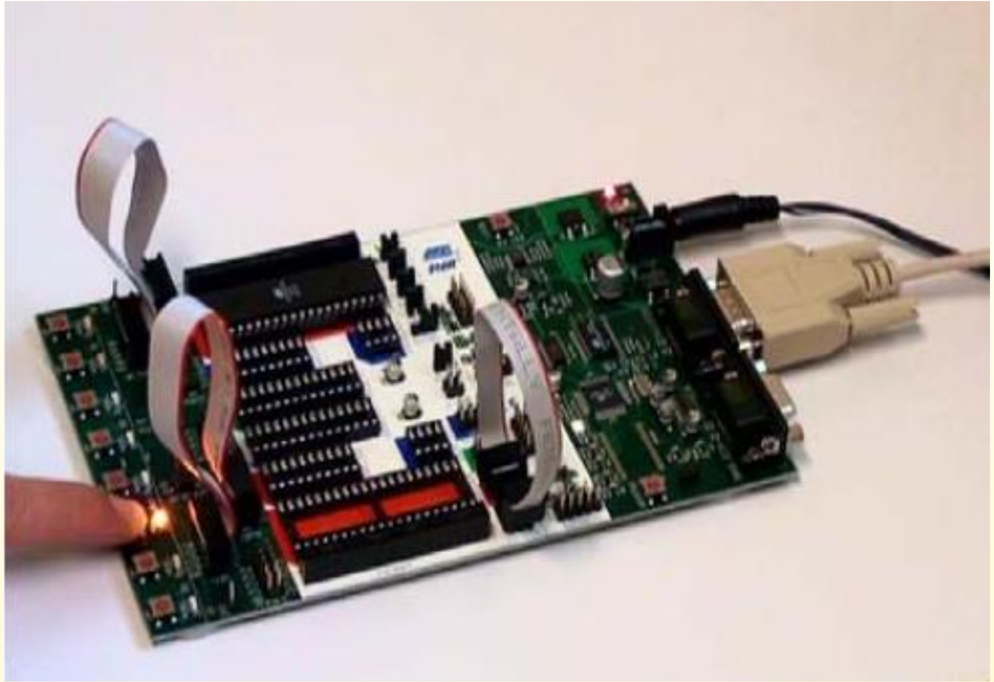


Toggle 8 LEDs using 8 switches

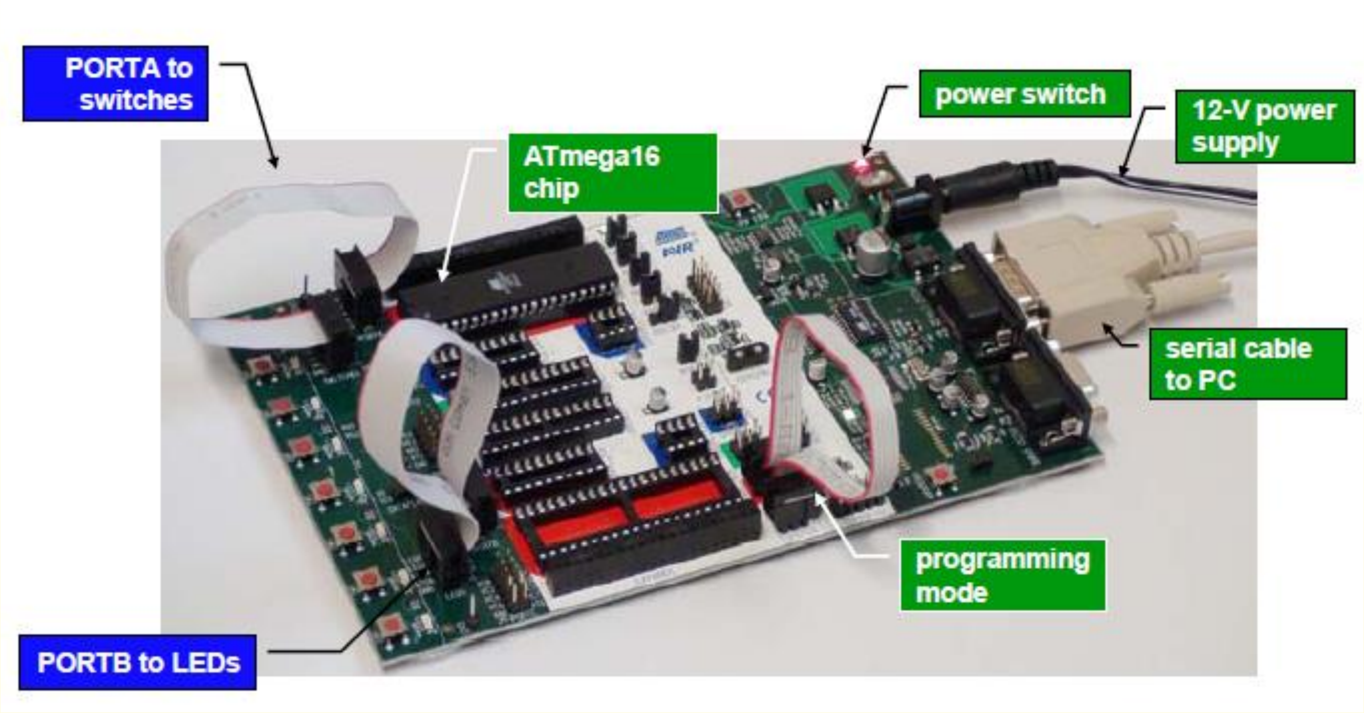
```
#include <avr/io.h>     // avr header file for IO ports
int main(void){
    unsigned char i; // temporary variable
    DDRA = 0x00;    // set PORTA for input (8 switches)
    DDRB = 0xFF;    // set PORTB for output (8 LEDs)
    PORTB = 0x00;   // turn ON all LEDs initially

    while(1){
        // Read input from PORTA (switches).
        i = PINA;
        // Send output to PORTB (LEDs).
        PORTB = i;
    }
    return 1;
}
```

Result on STK500



STK500



Hardware setup for LED sample program.
Connections to PORTA & PORTB are only for this example.

Digital IO in ATmega32

- **ATmega32 has four 8-bit digital IO ports:**
  - PORT A,
  - PORT B,
  - PORT C, and
  - PORT D.

- **Each port has 8 data pins.**
- **Every port is bi-directional.**
- **Each of the 8 pins can be individually configured as**
  - input (receiving data into microcontroller), or
  - output (sending data from microcontroller).

PORT names

- To access registers
  - PORTx to access port register
  - PINx to access port input register
  - DDRx to access data direction registers
  - x could be A,B,C or D

- To access special bit of registers
  - There is no standard method
  - Each compiler has its own syntax
  - **Use bitwise operators which works everywhere**
  - **To make pin5 as output and left others unchanged:**
    - **DDRC = DDRC | 0x10; //(00010000)**

I/O Ports

- 3 I/O registers per port, bitwise configuration
  - **DDRx**: **D**ata **D**irection **R**egister (1: out, 0: in)
    - Every pin can be configured as input or output
  - **PINx**: Port Input (**Read Only**)
    - DDR=0xFF → PORTx (with 1 clk latency)
    - DDR=0x00 → input data
  - **PORTx**:
    - **DDR = 0xFF → output data**
    - DDR = 0x00 → floating or pullup resistor (next slide)

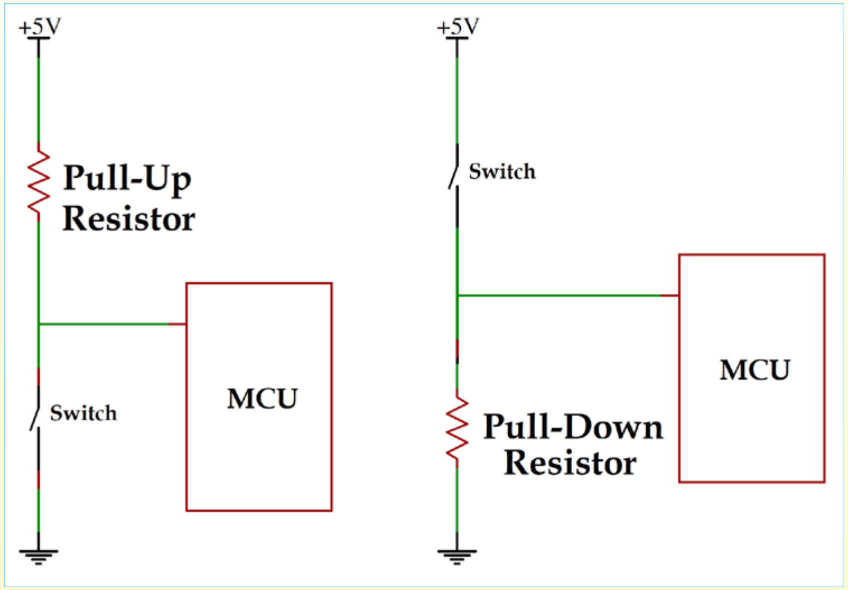
DDRx

PINx

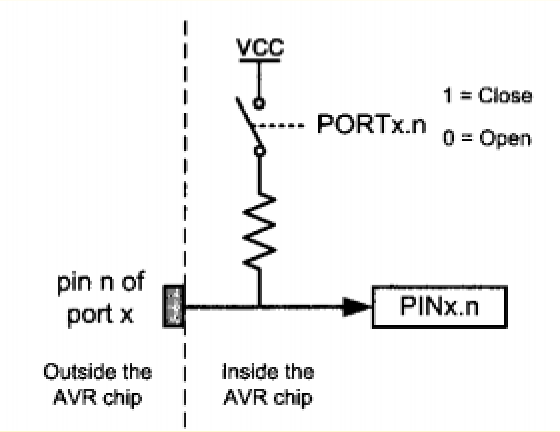
PORTx

ثبات PORTX

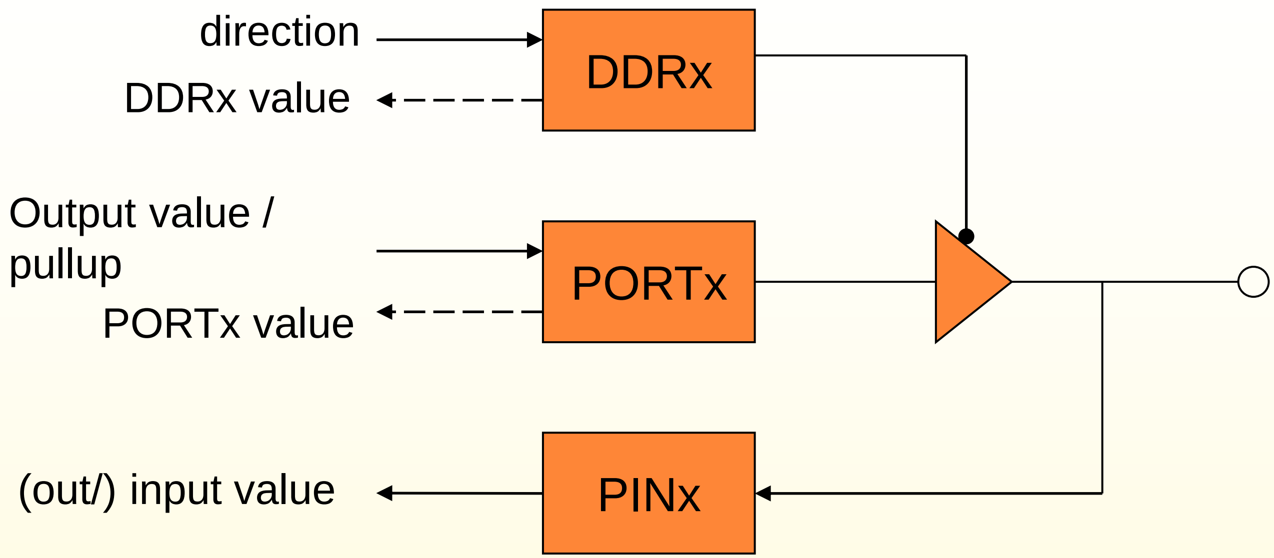
- **PORTx:**
  - **DDR = 0xFF ➔ output data**
  - DDR = 0x00 ➔ floating or pullup resistor
    - If PORTxn is written logic one when the pin is configured as an input pin, the pull-up resistor is activated



Pullup Resistor in AVR



I/O ports (simple view)



DDxn	PORTxn	PUD (in SFIOR)	I/O	Pull-up	Comment
0	0	X	Input	No	Tri-state (Hi-Z)
0	1	0	Input	Yes	Pxn will source current if ext. pulled low.
0	1	1	Input	No	Tri-state (Hi-Z)
1	0	X	Output	No	Output Low (Sink)
1	1	X	Output	No	Output High (Source)

General I/O Port Configuration

PUD: **P**ull-**U**p **D**isable

WDx: **W**rite **DDR**x

RDx: **R**ead **D**DRx

WPx: **W**rite **P**ORTx

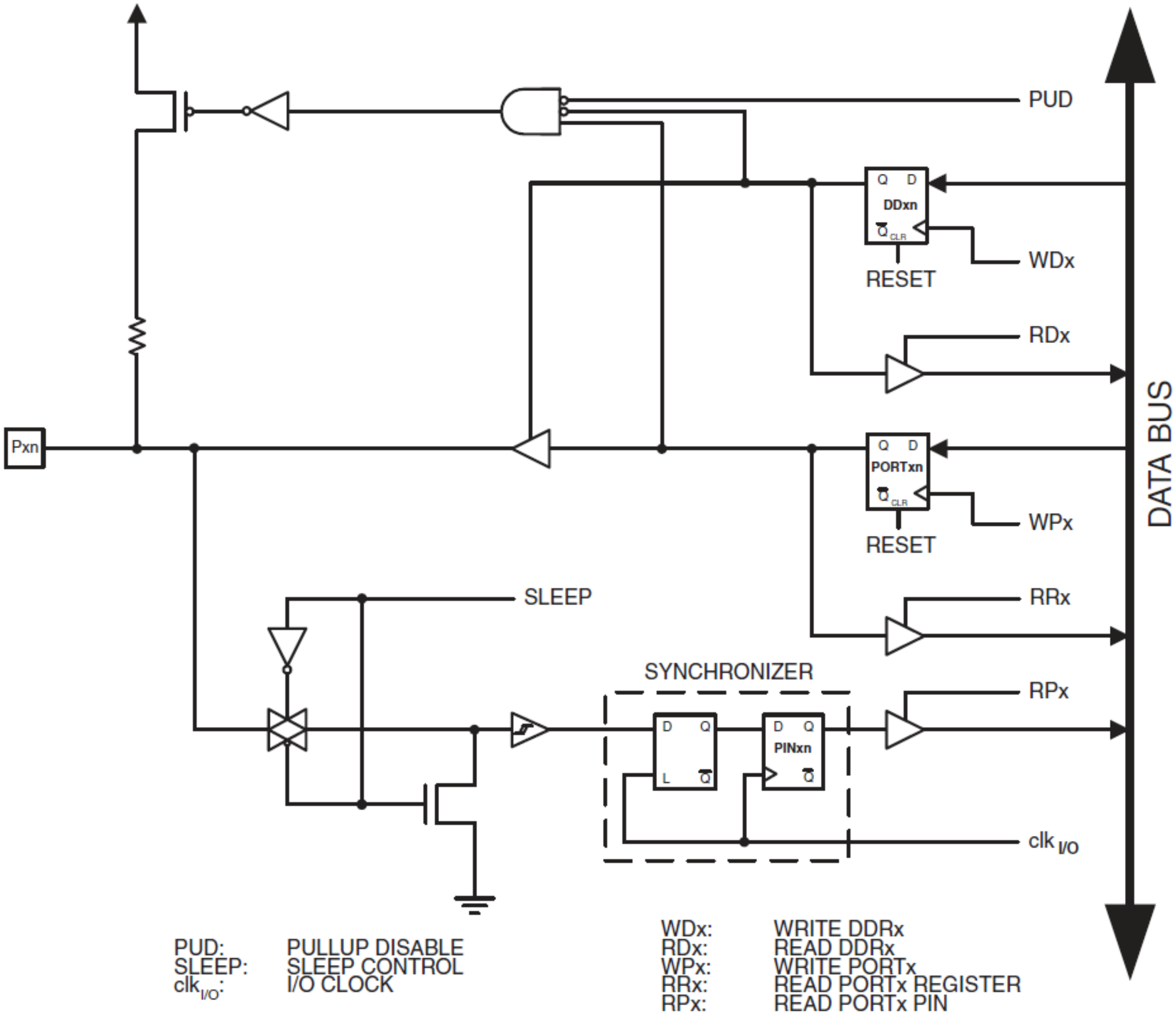
RRx: **R**ead PORTx **R**egister

RPx: **R**ead **P**INx

Note:

WPx, WDx, RRx, RPx, and RDx are common to all pins within the same port. $clk_{I/O}$, SLEEP, and PUD are common to all ports.

These are internal to AVR and we don't have access to them and never use them except PUD (SFIOR D2)



Examples

- To set Port A pins 0 to 3 for input, pins 4 to 7 for output, we write C code:

```
DDRA = 0b11110000; // configure pins
```

- To write a binary 0 to output pin 6, binary 1 to other pins of Port A, we write C code:

```
PORTA = 0b10111111; // write output
```

- To read the input pins of Port A, we write C code:

```
unsigned char temp; // temporary variable
temp = PINA;     // read input
```

SFR Definition

- Where do the C names PINA, PORTA, DDRA come from?
- <avr/iom32.h>
  - .\AVR Studio 5.0\AVR ToolChain\avr\include\avr\iom32.h

```
/* Port D */
#define PIND    _SFR_IO8(0x10)
#define DDRD    _SFR_IO8(0x11)
#define PORTD   _SFR_IO8(0x12)
```

- Where does iom32.h come from?
- <avr/io.h>

```
#if defined (__AVR_ATmega32__)
#include <avr/iom32.h>
```

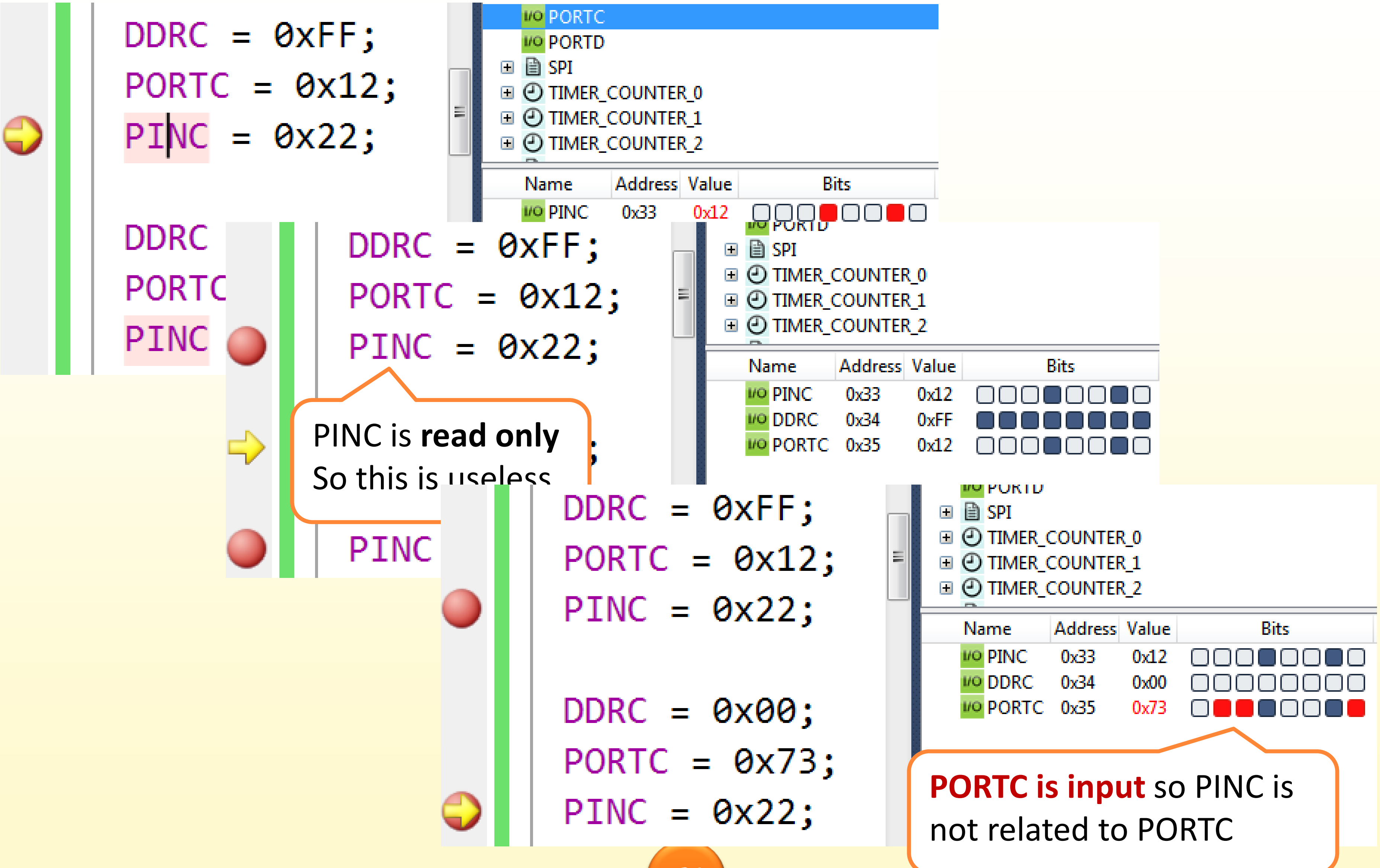
AVR header file

- To access all AVR microcontroller registers, your program must include the header file <io.h>
  - ❑ `#include <avr/io.h>`

- Depending on which device selected in your project, file ‘io.h’ will automatically redirect to a specific header file.

- **Example**
  - ❑ For ATmega32, the specific header file is `<avr/iom32.h>`
  - The header file lists the C names for all registers in ATmega32, and their memory locations.
  - We always use the C names in our code.

I/O Ports



DDRC = 0xFF;
PORTC = 0x12;
PINC = 0x22;
PORTC
PORTD
SPI
TIMER_COUNTER_0
TIMER_COUNTER_1
TIMER_COUNTER_2
Name Address Value Bits
PINC 0x33 0x12
DDRC 0x34 0xFF
PORTC 0x35 0x12
PINC is **read only**
So this is useless
DDRC = 0x00;
PORTC = 0x73;
PINC = 0x22;
PINC 0x33 0x12
DDRC 0x34 0x00
PORTC 0x35 0x73
PORTC is input so PINC is not related to PORTC

Review of C Programming

- Most students in this class learnt C programming in their first year.
- Is it learned or passed?
- Here, we review briefly major aspects of the C programming language.
  - Structure of a C program
  - Data types and operators
  - Flow control in C
  - C functions
- In all lectures, C code examples will be used extensively.

Structure of a C program

- A C program typically has two main sections.
- include section: to insert header files.
- main() section: code that runs when the program starts.
- In the example below, <avr/io.h> is a header file that contains all register definitions for the AVR microcontroller.

```c
#include <avr/io.h>  // avr header file for IO ports
int main(void){
    unsigned char i;  // temporary variable
    DDRA = 0x00;      // set PORTA for input
    DDRB = 0xFF;      // set PORTB for output
    PORTB = 0x00;     // turn ON all LEDs initially
    while(1){
       // Read input from PORTA (switches).
       i = PINA;
       // Send output to PORTB (LEDS).
       PORTB = i;
    }
    return 1;
}
```

C Comments

- Comments are text that the compiler ignores.
- For a single-line comment, use double back slashes

```
DDRA = 0x00; // set PORTA for input
```

- For a multi-line comment, use the pair /* and */

```
/* File: led.c
Description: Simple C program for the ATMEL
AVR(ATmega32 chip)
It lets user turn on LEDs by pressing the switches
on the STK500 board
Author:  (1390/12/11)
*/
```

- Always use comments to make program easy to understand.

C statements and blocks

C Statements

- C statements control the program flow.
- They consist of keywords, expressions and other statements.
- A statement ends with semicolon (;) .
- `DDRB = 0xFF; // set PORTB for output`

C Blocks

- A C block is a group of statements enclosed by braces {}.
- Usually, a C block is run depending on some logical conditions.

```
while (1){
// Read input from PORTA - switches
i = PINA;
// Send output to PORTB - LEDs
PORTB = i;
}
```

Data types and operators

- The main data types in C are

```
char: 8-bit integer
int: 16-bit integer
long int: 32-bit integer
float: 32-bit floating point
```

- The above data types can be modified by keyword unsigned

```
char a; // a value range -128, …, 0, …, 127
unsigned char b; // b value range 0, 1, 2, …, 255
unsigned long int c; // c value range 0,…, 2^32 – 1
unsigned float f;// illegal. float is always signed
```

- Some examples of variable assignment

```
a = 0xA0; // a stores hexadecimal value of A0
b = '1'; // b stores ASCII code of character '1'
c = 2000ul; // c stores an unsigned long 2000
```

C Operators

- C has a rich set of operators
  - Arithmetic operators
  - Relational operators
  - Logical operators
  - Bit-wise operators
  - Data access operators
  - Miscellaneous operators

Arithmetic Operators

Operator	Name	Example	Description
*	Multiplication	x * y	Multiply x times y
/	Division	x / y	Divide x by y
%	Modulo	x % y	Remainder of x divided by y
+	Addition	x + y	Add x and y
-	Subtraction	x – y	Subtract y from x
++	Increment	x++ ++x	Increment x by 1 after using it Increment x by 1 before using it
--	Decrement	x-- --x	Decrement x by 1 after using it Decrement x by 1 before using it
-	Negation	-x	Negate x

Relational operators

Operator	Name	Example	Description
>	Greater than	x > 5	1 if x is greater than 5, 0 otherwise
>=	Greater than or equal to	x >=5	1 is x is greater than or equal to 5, 0 otherwise
<	Less than	x < y	1 if x is smaller than y, 0 otherwise
<=	Less than or equal to	x <= y	1 is x is smaller than or equal to y, 0 otherwise
==	Equal to	x == y	1 is x is equal to y, 0 otherwise
!=	Not equal to	x != 4	1 is x is not equal to 4, 0 otherwise

Logical operators

- These operate on logical variables/constants.

Operator	Name	Example	Description
!	Logical NOT	!x	1 if x is 0, otherwise 0
&&	Logical AND	x && y	1 if both x and y are 1, otherwise 0
||	Logical OR	x || y	0 if both x and y are 0, otherwise 1

Bit-wise operators

➢ These operate on individual bits of a variable/constant.

Operator	Name	Example	Description
~	Bit-wise complement	**~x**	Toggle every bit from 0 to 1, or 1 to 0
&	Bitwise AND	**x & y**	Bitwise AND of x and y
|	Bitwise OR	**x | y**	Bitwise OR of x and y
^	Bitwise XOR	**x ^ y**	Bitwise XOR of x and y
<<	Shift left	**x << 3**	Shift bits in x three positions to the left
>>	Shift right	**x >> 1**	Shift bits in x one position to the right

Bitwise Operators - truth table

a	b	a&b	a|b	a^b	~a
0	0	0	0	0	1
0	1	0	1	1	1
1	0	0	1	1	0
1	1	1	1	0	0

Bitwise Operators - Examples

```
11010011
&
10001100
------------
10000000
```

```
11010011
|
10001100
------------
11011111
```

```
11010011
^
10001100
------------
01011111
```

```
~11010011
------------
  00101100
```

```
11010011>>3
------------
  00011010
```

```
11010011<<3
------------
  10011000
```

Setting Bits

- How can we set a bit on or off?
- Manipulations on bits are enabled by mask and bitwise operators.
- Bitwise OR of anything with 1 results in 1.
- Bitwise AND of anything with 0 results in 0.

Setting Bits

- For instance, how can we turn on the light in room #3?

```
char lights = 0x10;
char mask = 0x1;
mask <<= 2;
lights |= mask;
```

lights: 00000000

mask: 00000001

mask: 00000100

lights: 00000100

Setting Bits

- For instance, how can we turn off the light in room #3?

```
char lights = 0x27;
char mask = 0xfb;
lights &= mask;
```

lights: 00100111

mask: 11111011

lights: 00100011

Getting Bits

- How can we know if a bit is on or off?
- Manipulations on bits are enabled by mask and bitwise operators.
- Bitwise AND of anything with 1 results in the same value.

Getting Bits

- For instance, how can we check if the light in room #3 is turned on or off?

```
char lights = 0x27;
char mask = 0x1;
mask <<= 2;
if(lights & mask)
   puts("turned on");
else
   puts("turned off");
```

lights: 00100111

mask: 00000001

mask: 00000100

lights & mask: 00000100

Data-access operators

- These operate on arrays, structures or pointers.
- We'll learn more about these operators later.

Operator	Name	Example	Description
[]	Array element	x[2]	Third element of array x
.	Member selection	x.age	Field 'age' of structure variable x
->	Member selection	p->age	Field 'age' of structure pointer p
*	Indirection	*p	Content of memory location pointed by p
&	Address of	&x	Address of the memory location where variable x is stored

Miscellaneous operators

Operator	Name	Example	Description
()	Function	`_delay_ms(250)`	Call a function to create delay of 250ms
(type)	Type cast	`char x = 3;` `(int) x`	x is 8-bit integer x is converted to 16-bit integer
?	Conditional evaluation	`char x;` `y=(x>5)?10:20;`	This is equivalent to **if (x > 5)** **y = 10;** **else** **y = 20;**

Flow control in C

- By default, C statements are executed sequentially.
- To change the program flow, there are six types of statements
- if-else statement
- switch statement

Conditional

- while statement
- for statement
- do statement

Iterative

- goto statement

Should be avoided!

“if-else” statement

- **General syntax**

```
if (expression)
   statement_1;
else
   statement_2;
```

- **Example code**

```
char a, b, sum;
a = 4; b = -5;
sum = a + b;
if (sum < 0)
   printf(“sum is negative”);
else if (sum > 0)
   printf(“sum is positive”);
else
   printf(“sum is zero”);
```

“switch” statement

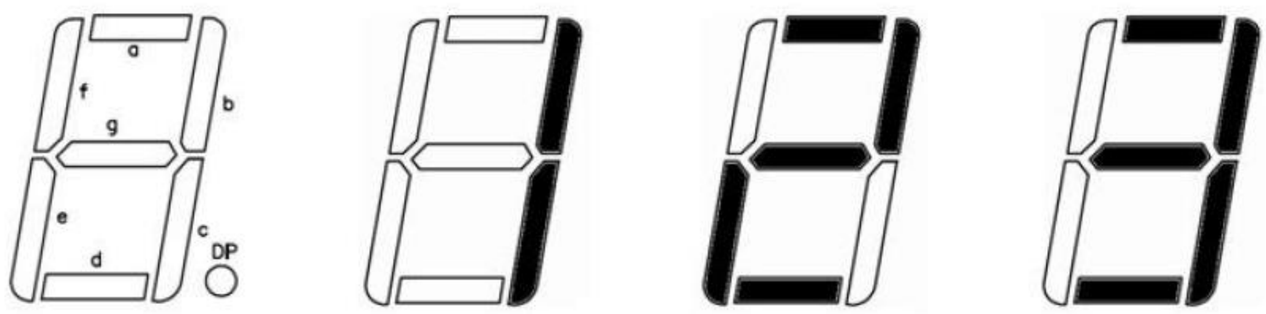
General syntax

```
switch (expression)
{
case constant_1:
  statement_1;
  break;
case constant_2:
  statement_2;
  break;
…
case constant_n:
  statement_n;
  break;
default:
  default_statement;
  break;
}
```

Use **break** to separate different cases.

“switch” statement – Example

Find the bit pattern to display a digit on the 7-segment LED



(a) 7 segments of the LED

Bit number:	7	6	5	4	3	2	1	0
Purpose:	***DP***	***g***	***f***	***e***	***d***	***c***	***b***	***a***

- **Bit pattern for digit ‘1’: 0 0 0 0 0 1 1 0**
- **Bit pattern for digit ‘2’: 0 1 0 1 1 0 1 1**

“switch” statement – Example

```
unsigned char digit = PINA;
unsigned char led_pattern;
switch (digit)
{
  case '0':
     led_pattern = 0b00111111;
     break;
  case '1':
     led_pattern = 0b00000110;
     break;
  case '2':
    led_pattern = 0b01011011;
     break;
    //you can complete more cases here...
  default:
     break;
}
PORTB = led_pattern; // send to PORTB and 7-segment LED
```

“while” statement

- ## General syntax

```
while (expression){
  statements;
}
```

- ## Example code: **Compute the sum of 1 + 2+ …+ 100**

```
int sum, i;
i = 1; sum = 0;
while (i <= 100){
  sum = sum + i;
  i = i + 1;
}
```

“for” statement

- **General syntax**

```
for (expression1; expression2; expression3)
{
  statements;
 }
```

- expression1 is run before the loop starts.
- expression2 is evaluated before each iteration.
- expression3 is run after each iteration.

- **Example code: Compute the sum of 1 + 2+ …+ 10**

```
int sum;
sum = 0;
for (int i = 1; i <= 10; i++){
  sum = sum + i;
}
```

“do” statement

- **General syntax**

```
do {
  statements;
} while (expression);
```

- **Example code:** compute the sum of 1 + 2 + … + 10

```
int sum, i;
i = 1; sum = 0;
do{
  sum = sum + i;
  i = i + 1;
} while (i <= 10);
```

“break” statement in loop

- The break statement inside a loop forces early termination of the loop.

- What is the value of sum after the following code is executed?

```
int sum, i;
i = 1; sum = 0;
while (i <= 10){
  sum = sum + i;
  i = i + 1;
  if (i > 5)
     break;
}
```

“continue” statement in loop

- The **continue** statement skips the subsequent statements in the code block and forces the execution of the next iteration.

- What is the value of **sum** after the following code is executed?

```
int sum, i;
i = 1; sum = 0;
while (i <= 10){
  i = i + 1;
  if (i < 5)
     continue;
  sum = sum + i;
}
```

C Arrays

- An array is a list of values that have the same data type.
- In C, array index starts from 0.
- An array can be one-dimensional, two-dimensional or more.

- This code example creates a 2-D array (multiplication table):

```
int a[8][10];
for (int i = 0; i < 8; i++)
  for (int j = 0; j < 10; j++)
    a[i][j]= i * j;
```

- An array can be initialized when it is declared:

```
int b[3] = {4, 1, 10};
unsigned char keypad_key[3][4] = {{'1', '4', '7', '*'},
                                  {'2', '5', '8', '0'},
                                  {'3', '6', '9', '#'}};
```

C functions

- C functions are sub-routines that can be called from the main program or other functions.
- A C function can have a list of parameters and produce a return value.
- Functions enable modular designs, code reuse, and hiding of complex implementation details.
- Let us study C functions through examples.

Functions – Example 1

Write a function to compute the factorial n! for a given n.

```
// factorial is the name of the custom function
// it accepts an input n of type int, and returns an output of type int
int factorial(int n){
   int prod = 1;
   for (int i = 1; i <=n; i++)
      prod = prod * i;
   return prod;    // return the result
}

int main(void){
   int n = 5;     // some example value of n
   int v;        // variable to storage result
   v = factorial(n); //call the function, store return value in v
   return 1;
}
```

Functions – Example 2

Write a function to compute the factorial n! for a given n.

```
// factorial is the name of the custom function
 // it accepts an input n of type int,
 // it stores output at memory location by int pointer p
 void factorial(int n, int* p){
   int prod = 1;
   for (int i = 1; i <=n; i++)
      prod = prod * i;
   *p = prod;// store output at memory location pointed by p
 }

 int main(void){
    int n = 5;     // some example value of n
    int v;         // variable to storage result
    factorial(n, &v); // call the function, store return value in v
 }
```

Guidelines on C coding and documentation

- Optimize the C code for efficiency and length.
- Delete unnecessary lines of code.
- The C code must be properly formatted.
- Use indentation to show the logical structure of the program.
- Use a blank or comment line to separate code sections.
- Use **meaningful variable** names and **function names**.
- Use comments concisely to explain code.
  - Specially cite the **purpose of the code, author name** and **date of generation**

Summary

- **What we learnt in this lecture:**
  - The tools and the steps for programming the Atmel AVR.
    - AVR Studio
    - Development Cycle for C Language
  - Basics about C programming.
  - Programming the digital I/O ports of Atmega32.

- **References:**
  - ATmega32 datasheet
  - Lecture notes of Dr. Lam Phung
    - University of Wollongong, Australia, 2011 (elec.uow.edu.au)