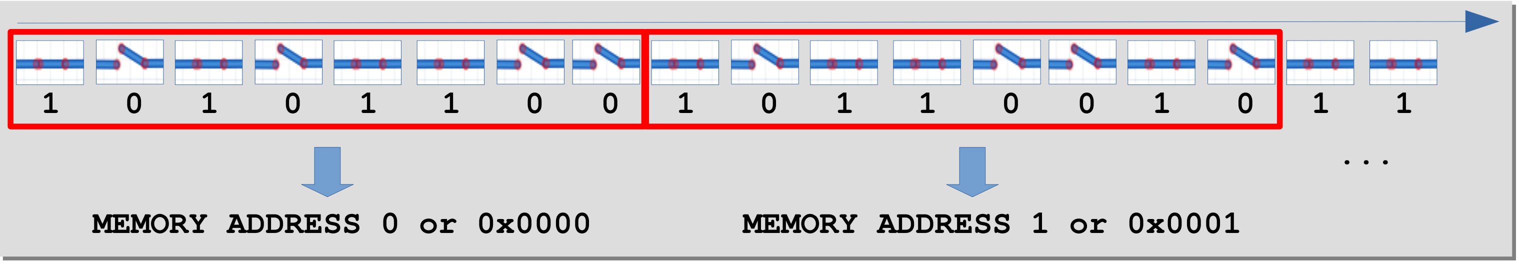
ATMEGA328/Arduino Uno - MEMORY ADDRESS

https://github.com/teaksoon/lmaewapm

MEMORY - A Long Sequence of ON/OFF "switches" or BITs represented by 1 or 0

MEMORY ADDRESS - LOCATION of a SINGLE MEMORY BLOCK of 8-BITS



One MEMORY ADDRESS = One BYTE (8-BIT)

MEMORY ADDRESS Starts from 0, increase by one for next MEMORY ADDRESS
(MEMORY ADDRESS = 0, MEMORY ADDRESS = 1, ...)

Very often we see MEMORY ADDRESS coded in Hexadecimal number format

Example:

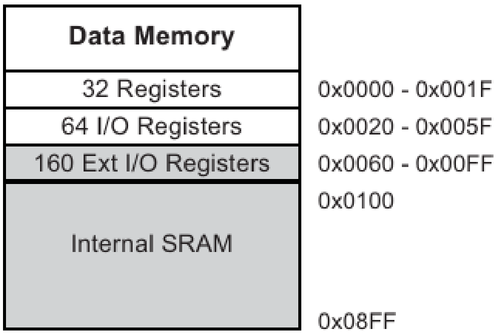
```
MEMORY ADDRESS 0     is often coded as 0x0000 in Hexadecimal format
MEMORY ADDRESS 1     is often coded as 0x0001 in Hexadecimal format
MEMORY ADDRESS 2298  is often coded as 0x08FA in Hexadecimal format
MEMORY ADDRESS 65535 is often coded as 0xFFFF in Hexadecimal format
```

The Hexadecimal number format contains letters like ABCDEF (sometimes can scare off beginners). Do not worry, they are just numbers. IF you do not like the Hexadecimal numbers you can also use the Decimal number, they are the same.

There are many hex-decimal-binary conversion tools available online. We can use them to do the conversion for us (if not, we can do manual conversion, which will take abit of time)

Figure 7-2. Data Memory Map

**ATMEGA328P
2048-BYTE SRAM**



According to the **ATMEGA328P micro-controller datasheet** above, The MEMORY ADDRESS does not start from the WORKING MEMORY(SRAM) alone, the MEMORY ADDRESS also includes those from the CPU MEMORY(REGISTERS)

For the ATMEGA328P micro-controller, the MEMORY ADDRESS is stored in a 16-BIT number. The maximum MEMORY ADDRESS for a 16-BIT Number is 0xFFFF(65535). If we look at the datasheet above, Maximum MEMORY ADDRESS for ATMEGA328P (2048-BYTE SRAM + CPU MEMORY) is just 0x08FF(2303), so a 16-BIT Number is way more than enough

For micro-controllers with big MEMORY, instead of 16-BIT, they will use either 32-BIT or 64-BIT numbers for their MEMORY ADDRESS

When we **Declare a Variable**, each datatype will **"Reserve" a different number of BITs from our MEMORY** for our Variable

One MEMORY ADDRESS stores One BYTE (8-BIT) of DATA

Each "char" Variable is 8-BIT (1-BYTE)
– Means, each "char" Variable will occupy One(1) MEMORY ADDRESS
Each "int" Variable is 16-BIT (2-BYTE)
– Means, each "int" Variable will occupy Two(2) MEMORY ADDRESS
Each "long" Variable is 32-BIT (4-BYTE)
– Means, each "long" Variable will occupy Four(4) MEMORY ADDRESS

The **MEMORY ADDRESS** is the LOCATION of One(1) BYTE of DATA. If the Variable **occupy multiple MEMORY ADDRESS**, the **MEMORY ADDRESS** will be the **first MEMORY ADDRESS** from the multiple MEMORY ADDRESS

Arduino IDE|Save PROGRAM as: **c_variable_memory_address**
Enter codes below and upload. Use the Serial Monitor to see results

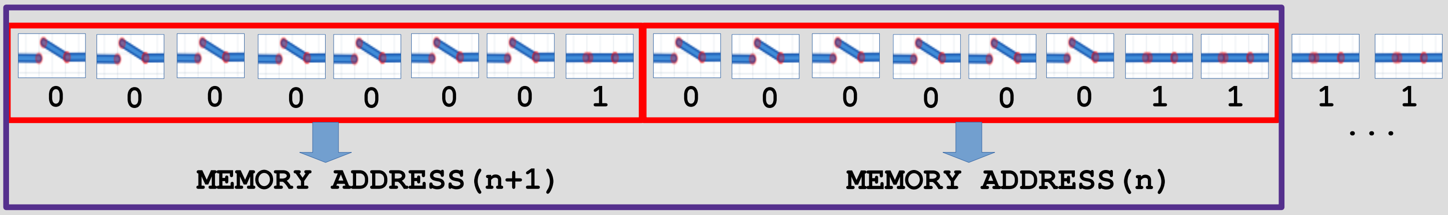
```
void setup() {
  Serial.begin(9600);Serial.print("\n\nSerial Monitor(9600)...");

  int var_name;
  Serial.print("\n\nNumber of BITs in int Variable = ");
  Serial.print(sizeof(var_name)*8);
  Serial.print("\nThe Starting MEMORY ADDRESS of int Variable = ");
  Serial.print((unsigned int) &var_name); // get MEMORY ADDRESS

  var_name = 259; // change DATA in MEMORY
  Serial.print("\n\nRetrieved DATA from MEMORY = ");
  Serial.print(var_name); // read data from MEMORY

  Serial.print("\nThe BITs in the MEMORY = ");
  for (int i=15; i>=0; i--) {
    Serial.print((var_name >> i) & 1);Serial.print(" ");
  }
  Serial.print(" ( int occupies Two(2) MEMORY ADDRESS )");
}
void loop(){}
```

int var_name; – an int Variable "var_name" is Declared

&var_name   – To get the MEMORY address from var_name Variable
var_name = 259 – To change DATA in var_name Variable MEMORY to 259
var_name   – To retrieve DATA from var_name Variable MEMORY

int var_name;
– var_name will occupy Two(2) MEMORY ADDRESS(n) and MEMORY ADDRESS(n+1)

var_name = 259;
– the int value 259 in decimal will change the DATA in Two(2) MEMORY ADDRESS to 0000000100000011



MEMORY ADDRESS(n)   – store 00000011
MEMORY ADDRESS(n+1) – store 00000001

In order to manipulate DATA in the SRAM MEMORY, we normally use Variables. After we Declare our Variable, we only need to specify the Variable Name to retrieve and change DATA in the reserved SRAM MEMORY

The C-Language have something called "Pointers"

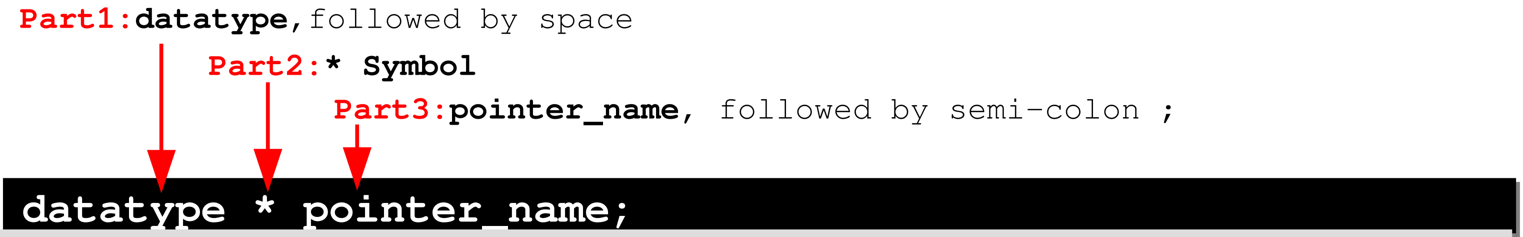
The C-Language Pointers allows C-Langauge to manipulate the MEMORY directly without using Variables

The C-Language Pointers only needs MEMORY ADDRESS(a number), meaning the entire MEMORY is now exposed to the C-Language. There is nothing we can do to stop the C-Language Pointers from retrieving or changing DATA anywhere in the MEMORY. This is not just for micro-controllers, it also applies to the regular Computers. Just imagine, even when we are typing half-way, it also involves MEMORY and if C-Language knows the MEMORY ADDRESS, even our key-strokes can be "hijacked" by the Pointers

This thing can be used for good or bad. The Point is, it is very powerful

To use Pointers, we need to make a "Pointer Variable" first

Declare a "Pointer Variable" (declaration is similar to a Normal Variable)
Part1:datatype
Part2:* Symbol
Part3:pointer_name



Part1:datatype,followed by space

Part2:* Symbol

Part3:pointer_name, followed by semi-colon ;

```
datatype * pointer_name;
```

Once "Pointer Variable" is Declared like the above, we can start using the Pointer Variable. We can do the following with the Pointer Variable,

1. Assign MEMORY ADRESSS (a 16-BIT number) into the Pointer Variable

2. Use Pointer Variable to Retrieve or Change DATA in the PHYSICAL MEMORY based on the MEMORY ADDRESS in the Pointer Variable

Each Pointer Variable can only store ONE MEMORY ADDRESS

1. Assign MEMORY ADRESSS (a 16-BIT number) into the Pointer Variable

```
int var_name;  // Normal Variable Declaration
int *ptr_name; // Pointer Variable Declaration

ptr_name = &var_name; // "var_name" Normal Variable MEMORY ADDRESS

ptr_name = 2298; // direct MEMORY ADDRESS assignment, ADDRESS LOCATION 2298
```

2. Use Pointer Variable to Retrieve or Change DATA in the PHYSICAL MEMORY based on the MEMORY ADDRESS in the Pointer Variable

```
int *ptr_name;

ptr_name = 2298; // direct MEMORY ADDRESS assignment, ADDRESS LOCATION 2298

*ptr_name = 259; // Change int DATA Starting MEMORY ADDRESS 2298

*ptr_name; // Retrieve int DATA Starting MEMORY ADDRESS 2298
```

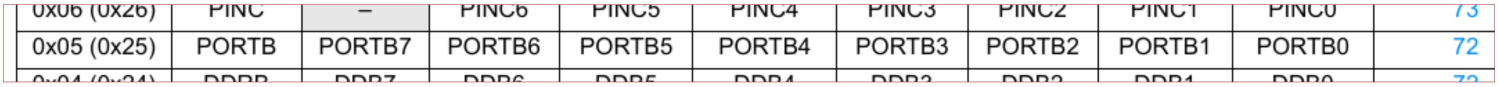
Arduino IDE|Save PROGRAM as: **c_variable_pointer**
Enter codes below and upload. Use the Serial Monitor to see results

```
void setup() {
  Serial.begin(9600);Serial.print("\n\nSerial Monitor(9600)...");

  int var_name = 259;  // DATA in a normal Variable

  int *ptr_int;
  ptr_int = &var_name; // get MEMORY ADDRESS from normal Variable

  Serial.print("\n\nMEMORY ADDRESS in Pointer Variable = ");
  Serial.print((unsigned int) ptr_int);
  Serial.print("\nDATA retrieved from MEMORY using Pointer = ");
  Serial.print(*ptr_int);
  Serial.print("\nThe BITs in the MEMORY = ");
  for (int i=15; i>=0; i--) {
    Serial.print((*ptr_int >> i) & 1);Serial.print(" ");
  }
  Serial.print(" ( int occupies Two(2) MEMORY ADDRESS ) ");

  Serial.print("\n\nChange DATA in MEMORY using Pointer ");
  Serial.print("*ptr_int = 258;");
  *ptr_int = 258;

  Serial.print("\n\nMEMORY ADDRESS in Pointer Variable = ");
  Serial.print((unsigned int) ptr_int);
  Serial.print("\nDATA retrieved from MEMORY using Pointer = ");
  Serial.print(*ptr_int);
  Serial.print("\nThe BITs in the MEMORY = ");
  for (int i=15; i>=0; i--) {
    Serial.print((*ptr_int >> i) & 1);Serial.print(" ");
  }
  Serial.print(" ( int occupies Two(2) MEMORY ADDRESS ) ");

  // 8-BIT Pointer Variable to access individual MEMORY ADDRESS
  // - each MEMORY ADDRESSS is 8-BIT
  char *ptr_char;
  ptr_char = (unsigned int) &var_name; // MEMORY ADDRESS(n) from Variable

  Serial.print("\n\nBITs in individual MEMORY ADDRESS( ");
  Serial.print((unsigned int) ptr_char); Serial.print(" ) = ");
  for (int i=8; i>=0; i--) {
    Serial.print((*ptr_char >> i) & 1);Serial.print(" ");
  }
  ptr_char = ptr_char+1; // Next MEMORY ADDRESS(n+1)
  Serial.print("\nBITs in individual MEMORY ADDRESS( ");
  Serial.print((unsigned int) ptr_char);Serial.print(" ) = ");
  for (int i=8; i>=0; i--) {
    Serial.print((*ptr_char >> i) & 1);Serial.print(" ");
  }
}
void loop(){}
```

NOTE: In this example PROGRAM:
*ptr_int - manipulating the DATA stored in the PHYSICAL MEMORY
ptr_int - manipulating the MEMORY ADDRESS stored in the Pointer Variable

Lets do something “nasty”. Here, we bypass everything and go straight to the MEMORY ADDRESS 0x25 with our Pointer Variable (dont worry, the MEMORY ADDRESS 0x25 is safe to play with, some are not). We can do something worse by retrieving or changing a MEMORY LOCATION that we should not

From the ATMEGA328P Datasheet below, it says 0x25 is the MEMORY ADDRESS for PORTB(confirmed harmless). We are going to change the BIT at position PORTB5 with our Pointer Variable(that BIT controls the Arduino Uno Pin-13)



0x06 (0x26)	PINC	–	PINC6	PINC5	PINC4	PINC3	PINC2	PINC1	PINC0	73
0x05 (0x25)	PORTB	PORTB7	PORTB6	PORTB5	PORTB4	PORTB3	PORTB2	PORTB1	PORTB0	72

Arduino IDE|Save PROGRAM as: **c_variable_pointer_direct**
Enter codes below and upload. Watch the LED on the Arduino Uno board

```
char *ptr_char;

void setup() {
  pinMode(13,OUTPUT);
  ptr_char = (unsigned int) 0x25; // MEMORY ADDRESS 0x25
}
void loop(){
  *ptr_char = *ptr_char | (1<<5);
  delay(250);
  *ptr_char = *ptr_char & ~(1<<5);
  delay(250);
}
```

We can also go “stealth”. In the example above we can clearly see 0x25 in our code. What if, we do not want people to know that we are accessing 0x25. Lets make another PROGRAM(below). I am not encouraging “hacking” with Pointers. For micro-controllers, this is not an issue because we only have one PROGRAM running and we can also make the micro-controller chip unable to load new PROGRAM. However for the regular Computers, this kind of thing can become a big problem(just imagine). Anyway, lets get back on-track. The purpose of this example is to show a **simple Pointer Variable math**

Arduino IDE|Save PROGRAM as: **c_variable_pointer_math**
Enter codes below and upload. Watch the LED on the Arduino Uno board

```
char *ptr_char;

void setup() {
  ptr_char  = (unsigned int) 0x00; // Start from 0x00
  ptr_char  = ptr_char+36; // Add Decimal 36 to Pointer Variable (Hex 0x24)
  *ptr_char = *ptr_char | (1<<5);
  ptr_char  = ptr_char+1;  // Add Decimal  1 to Pointer Variable (Hex 0x25)
}
void loop(){
  *ptr_char = *ptr_char | (1<<5);
  delay(250);
  *ptr_char = *ptr_char & ~(1<<5);
  delay(250);
}
```

- If the **datatype of Pointer Variable is 1-BYTE**, MEMORY **ADDRESS** will **increase by 1** when we add 1 to the Pointer Variable name
- If the **datatype of Pointer Variable is 2-BYTE**, MEMORY **ADDRESS** will **increase by 2** when we add 1 to the Pointer Variable name
- If the **datatype of Pointer Variable is 4-BYTE**, MEMORY **ADDRESS** will **increase by 4** when we add 1 to the Pointer Variable name

In this example PROGRAM: Pointer Variable datatype is char(1-BYTE), so we code “**ptr_char = ptr_char+1;**” MEMORY ADDRESS will be increased by 1

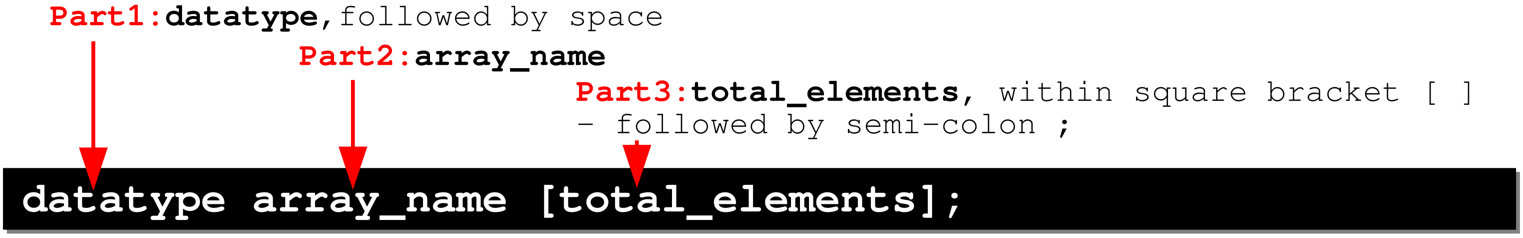
Array Variable is a Variable that has multiple Variables(elements) of the same datatype arranged in sequence in the MEMORY

Example:
If we declared int Array Variable with 3 elements, it means we will have 3 int Variables (3 elements) next to each other in the MEMORY. Each of the elements will have their own DATA and MEMORY ADDRESS, next to each other in sequence in the SRAM MEMORY

The Array Variable itself will also have a MEMORY ADDRESS, which is also the MEMORY ADDRESS of the first element in the Array Variable

To use an Array Variable, we need to Declare Array Variable first

Declare a "Array Variable" (like a Normal Variable)
Part1:datatype
Part2:array_name
Part3:total_elements (within a square bracket [] pair)



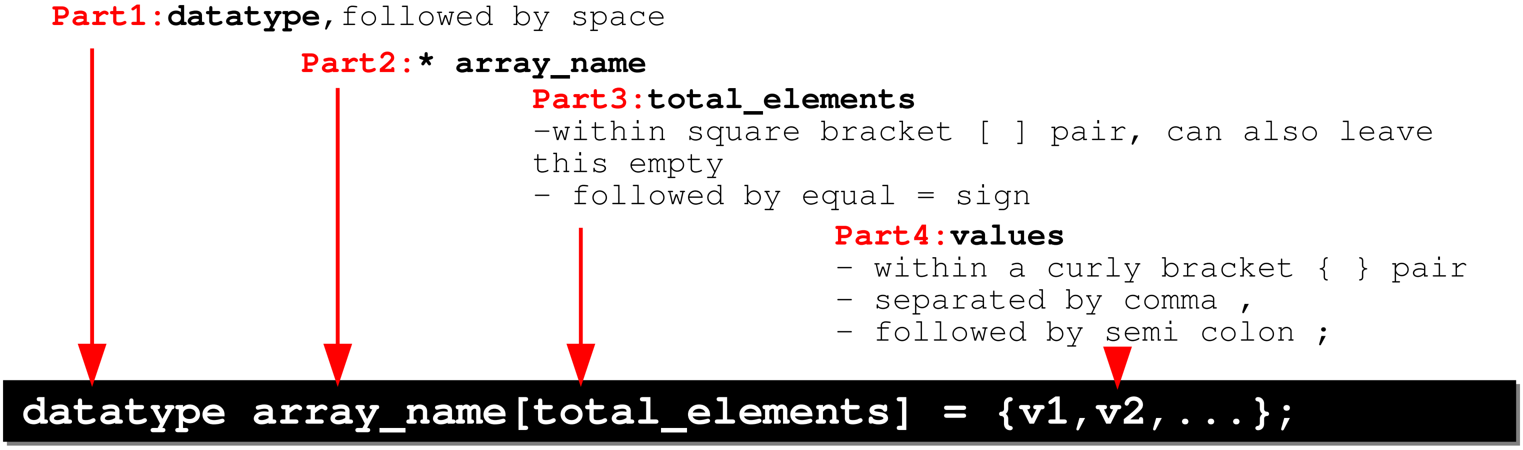
Part1:datatype,followed by space

Part2:array_name

Part3:total_elements, within square bracket [ ]
– followed by semi-colon ;

```
datatype array_name [total_elements];
```

Declare a "Array Variable" (like a Normal Variable) with **Initial Values**
Part1:datatype
Part2:array_name
Part3:total_elements (within a square bracket [] pair)
Part4:values (within a curly bracket { } pair, separated by comma,)



Part1:datatype,followed by space

Part2:* array_name

Part3:total_elements
-within square bracket [ ] pair, can also leave this empty
– followed by equal = sign

Part4:values
– within a curly bracket { } pair
– separated by comma ,
– followed by semi colon ;

```
datatype array_name[total_elements] = {v1,v2,...};
```

```
datatype array_name[] = {v1,v2,...};
```

Once an Array Variable is Declared. We can Retrieve and Change DATA into the Array elements by using an a type of "ADDRESS" – index numbers. First element has an index of 0, second element, index of 1, third element, index of 2 and so on... Index number are contained inside a square bracket [ ] pair

```
int array_name[3]; // Declare an Array Variable with 3 int elements

array_name[0] = 10; // Change Array element at index 0, DATA to 10
array_name[0];      // Retrieve DATA from the Array element at index 0
```

This is a single Dimension Array, we can also make Multi-Dimension Array
We will do that in another topic

Arduino IDE|Save PROGRAM as: **c_variable_array**
Enter codes below and upload. Use the Serial Monitor to see results

```
void setup() {
  Serial.begin(9600);Serial.print("\n\nSerial Monitor(9600)...");

  int array_name[3]; // Declare Array with 3 elements
  Serial.print("\n\nArray Variable MEMORY ADDRESS = ");
  Serial.print((unsigned int) array_name);
  Serial.print("\nNumber of BITs in Array Variable = ");
  Serial.print(sizeof(array_name)*8);
  Serial.print("\nNumber of elements in Array Variable = ");
  Serial.print((sizeof(array_name)*8)/(sizeof(array_name[0])*8) );

  array_name[0] = 1;
  array_name[1] = 2;
  array_name[2] = 3;
  Serial.print("\n\nDATA in Array[0] = ");Serial.print(array_name[0]);
  Serial.print("\nDATA in Array[1] = ");  Serial.print(array_name[1]);
  Serial.print("\nDATA in Array[2] = ");  Serial.print(array_name[2]);

  Serial.print("\n\nRetrieve the BITs from int Array using int Pointer\n");
  int *ptr;

  ptr = array_name; // Starting ADDRESS
  // ptr = &array_name[0]; // this is the same as above

  Serial.print("\nStarting from ADDRESS ( ");
  Serial.print((unsigned int) ptr);Serial.print(" ) = ");
  for (int i=16; i>=0; i--) {
    Serial.print((*ptr >> i) & 1);Serial.print(" ");
  }
  ptr = ptr+1; // Move to next int ADDRESS
  Serial.print("\nStarting from ADDRESS ( ");
  Serial.print((unsigned int) ptr);Serial.print(" ) = ");
  for (int i=16; i>=0; i--) {
    Serial.print((*ptr >> i) & 1);Serial.print(" ");
  }
  ptr = ptr+1; // Move to next int ADDRESS
  Serial.print("\nStarting from ADDRESS ( ");
  Serial.print((unsigned int) ptr);Serial.print(" ) = ");
  for (int i=16; i>=0; i--) {
    Serial.print((*ptr >> i) & 1);Serial.print(" ");
  }
}
void loop(){}
```

In this example PROGRAM:
This Array Variable has 3 elements. Since we specify “int” datatype for the Array Variable, 16-BIT MEMORY will be “reserved” for each of the elements. So this Array Variable will “reserve” a total of 48-BITS of MEMORY in a sequence

Each Element will be referenced by an index number,
array_name[0] for first element,
array_name[1] for second element
array_name[2] for third element
Each element is similar to a normal int Variable

The Array Variable Name, “array_name” has the MEMORY ADDRESS of the first element “array_name[0]” in the Array Variable. The Code **array_name** and **&array_name[0]** will give us the same value(MEMORY ADDRESS)