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Arrays

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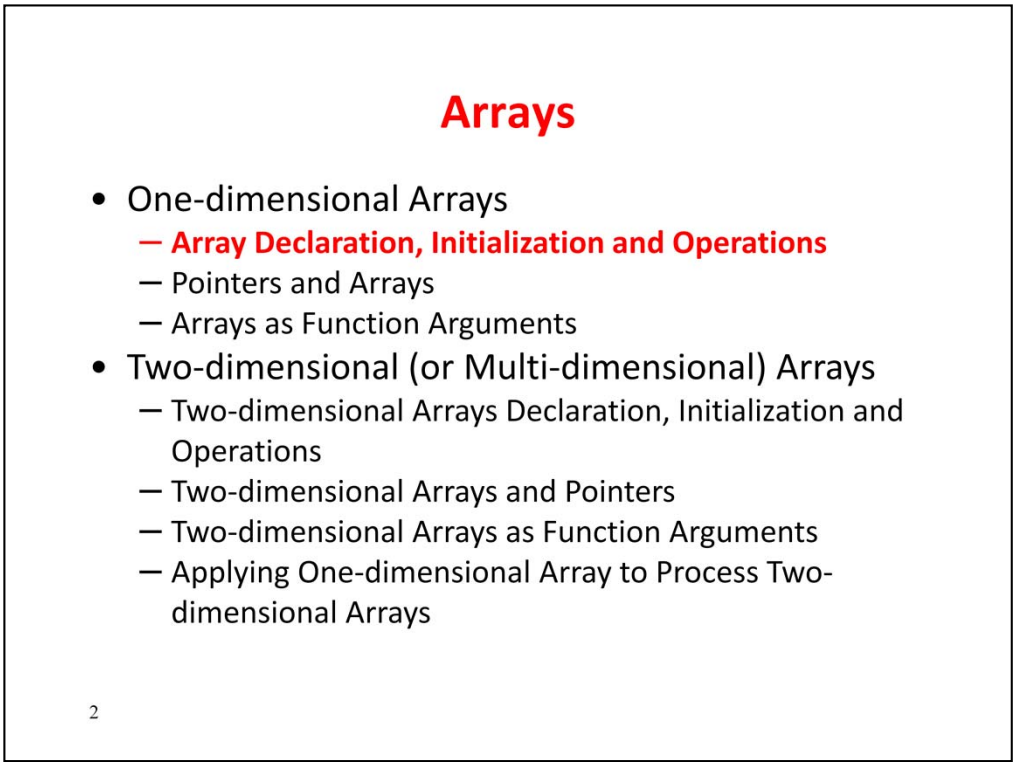
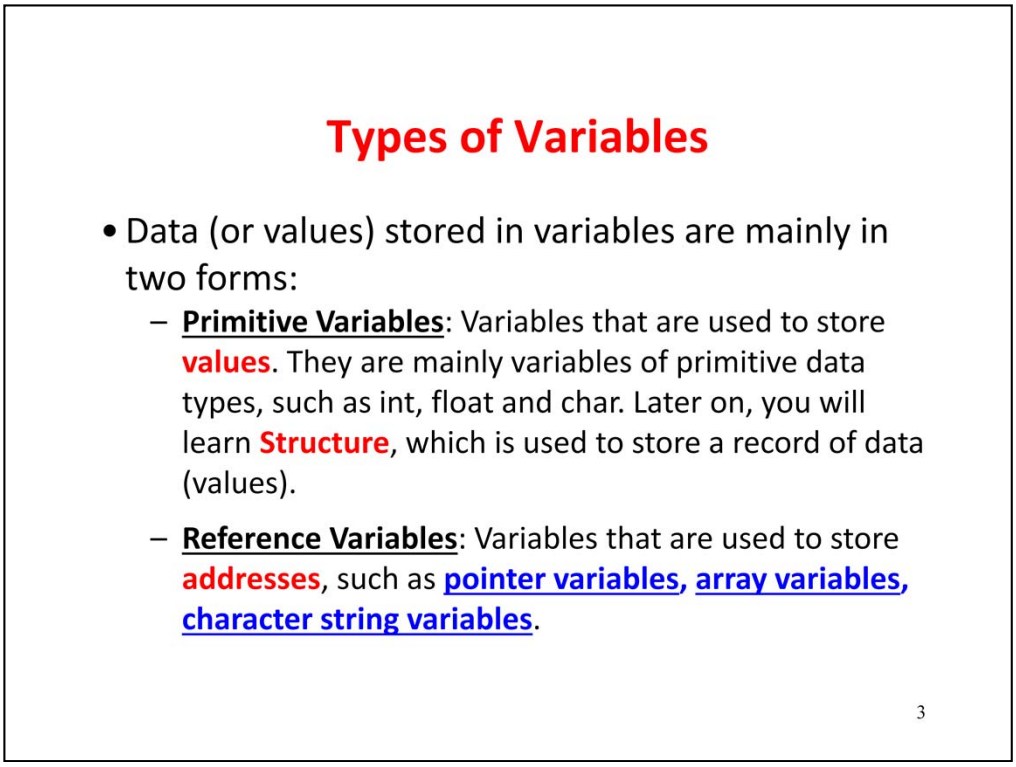
Why Learning Arrays?

1. Most programming languages provide array data structure as built-in data structure.
2. An array is a list of values with the **same** data type. If not using array, you will need to define many variables instead of just **one** array variable.
3. Python provides the **list** structure, two major differences from array:
   - Arrays have only limited operations while lists have a large number of operations;
   - Size of arrays cannot be changed while lists can grow and shrink.



Arrays – One-dimensional Arrays

1. In the previous lectures, we have discussed the various data types such as **char**, **int**, **float**, etc. When we define a variable of one of these types, the computer will reserve a memory location for the variable. Only one value is stored for each variable at any one time.
2. However, there are applications which require storing related data items under one variable name. For example, if we have different items with similar nature, such as examination marks for the programming course, we might need to declare different variables such as mark1, mark2, etc. to represent the mark for each student. This is quite cumbersome if the number of students is very large.
3. Instead, we can declare a variable called **mark** as an array, and each element of the array can be used to store the mark for each student. In arrays, we can use a single **variable** to collect a **group** of data items of the ***same data type***.
4. In this lecture, we introduce this important topic on data structure that can be used to organize and store related data items. *Arrays* are used to store related data items of the same data type.
5. In arrays, we can categorize them as one-dimensional arrays and two-dimensional (or multi-dimensional) arrays. In this lecture, we focus on discussing one-dimensional arrays and two-dimensional arrays.
6. Here, we discuss array declaration, initialization and operations in one-dimensional arrays.



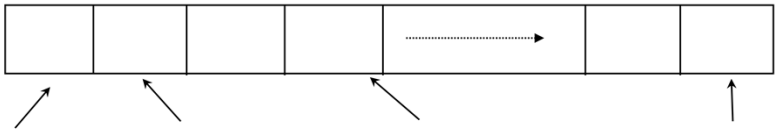
Types of Variables

1. As discussed before, there are mainly two types of variables: primitive type variables and reference (pointer) variables.
2. **Primitive variable** is of data type such as **int**, **float**, **char**, etc. which stores the data directly in its memory.
3. **Reference variable** such as pointer variable is used to store the **address**, from which the actual data is stored. Apart from pointer variables, arrays and strings are also reference variables. The content stored in an array variable is an address, not the actual data.

What is an Array?

- An **array** is a **list of values** with the **same data type**. Each value is stored at a specific, numbered position in the array.
- An array uses an **integer** called **index** to reference an element in the array.
- The **size** of an array is **fixed** once it is created. Could the size be created dynamically? Yes by using malloc(), you will learn that later.
- Index always starts with **0 (zero)**.

Array of size 12



1st element index=**0**

2nd element index=1

Nth element index=N-1

12th element index=**11**

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What is an Array?

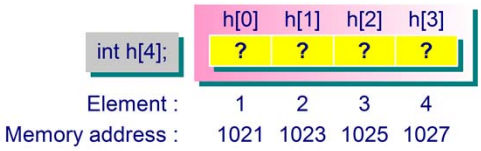
1. An array is a list of values with the same (one) data type. Each value is stored at a specific, numbered position in the array.
2. An array uses an integer called index to reference an element in the array.
3. The size of an array is fixed once it is created.
4. The index always starts with 0 (zero) and the last element will have an index of length minus 1.

Array Declaration

- Declaration of arrays **without initialization**:

```
float sales[365];        /*array of 365 floats */
char name[12];           /*array of 12 characters*/
int states[50];          /*array of 50 integers*/
int *pointers[5];        /* array of 5 pointers to integers */
```

- When an array is declared, some **consecutive memory** locations are allocated by the compiler for the whole array (**2 or 4** bytes for an integer depending on machine)



- The size of array must be integer constant or constant expression in declaration:

```
e.g.   char name[i];          // i variable  ==> illegal
       int states[i*6];       // i variable  ==> illegal
```

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Array Declaration

1. The syntax for an array declaration is **type_specifier array_name[array_size];**
2. For example, the declaration **char name[12];** defines an array of 12 elements, each element of the array stores data of type **char**.
3. The elements are stored sequentially in memory. Each memory location in an array is accessed by a relative address called an *index* (or *subscript*).
4. Arrays can be declared without initialization:

```
float sales[365];   /* array of 365 floats */
int states[50];     /* array of 50 integers */
int *pointers[5];   /* array of 5 pointers to integers */
```

5. When an array is declared, **consecutive memory locations** for the number of elements specified in the array are allocated by the compiler for the whole array. The total number of bytes of storage allocated to an array will depend on the size of the array and the type of data items. For example, in an older system, it uses 2 bytes to store an integer, the declaration for the array: **int h[4];** will result in a total of 8 bytes allocated for the array.
6. An integer constant or constant expression must be used to declare the size of the array. Variables or expressions containing a variable cannot be used for the declaration of the size of the array. The following declarations are illegal:

```
char name[i];      /* where i is a variable */
```

int states[i*6];

The size of memory required can be calculated using the following equation:

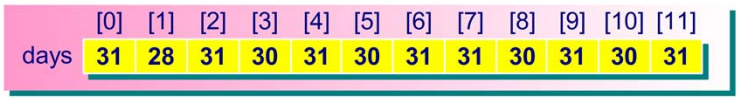
total_memory = sizeof(type_specifier)*array_size;

where **sizeof** operator gives the size of the specified data type and **array_size** is the total number of elements specified in the array.

Initialization of Arrays

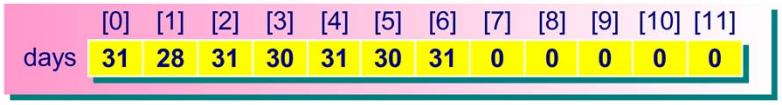
- **Initialize array** variables at declaration:

```
int days[12]={31,28,31,30,31,30,31,31,30,31,30,31};
```



- **Partial array initialization**: E.g. (initialize first 7 elements)

```
int days[12]={31,28,31,30,31,30,31};
/* remaining elements are initialized to zero */
```



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Array Initialization

1. After an array has been declared, it must be initialized. Arrays can be initialized at compile time after declaring them. The format for initializing an array is

   type_specifier array_name[array_size]={list_of_values};

2. The following statement initializes an array **days** with 12 data items:

   int days[12]={31,28,31,30,31,30,31,31,30,31,30,31};

3. An array can also be declared and initialized partially in which the number of elements in the list **{}** is less than the number of array elements. In the given example, only the first 7 elements of the array are initialized: **int days[12]={31,28,31,30,31,30,31};** After the first 7 array elements are initialized, the remaining array elements will be initialized to 0.

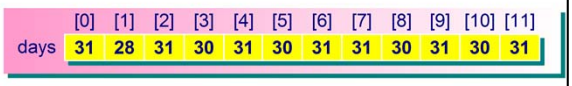
In addition, an array can also be declared and initialized without explicitly indicating the array size. The following declaration is valid:

int days[]={31,28,31,30,31,30,31}; /* an array of 7 elements */

In this declaration, it declares **days** as an array of 7 elements as there are 7 elements in the list.

Operations on Arrays

- **Accessing** array elements:




```
sales[0] = 143.50;
if (sales[23] == 50.0) ...        // using array index
```

- **Subscripting**: The element indices range from **0** to **n-1** where n is the declared size of the array.

```
char name[12];
name[12] = 'c';        // index out of range – common error
```

- Working on array values:

```
(1) days[1]= 29;                    OK ??
(2) days[2] = days[2] + 4;          OK ??
(3) days[3] = days[2] + days[3];    OK ??
(4) days[1]= {2,3,4,5,6};           OK ?? => NOT OK!!
```

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Operations on Arrays

1. We can access array elements and perform operations on the array elements. The following array variable **sales** is declared as an array of 365 floating point numbers:

   float sales[365]; /* array of 365 floats */

2. Values can be assigned into each array element using indexes: **sales[0]=143.50;**
3. The array can also be used in conditional expressions and looping constructs as follows:

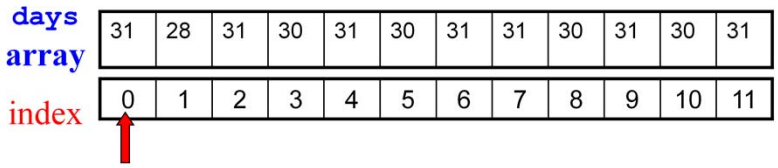
   if (sales[23]==50.0) {...}

   while (sales[364]!= 0.0) {...}

4. The elements are indexed from **0** to **n-1** where **n** is the declared size of the array. Therefore, if **char name[12];** then the following statement: **name[12]='c';** is invalid since the array elements can only range from **name[0]** to **name[11]**.
5. It is a common mistake to specify an index that is one value more than the largest valid index.
6. In the examples given, statement (4) **days[1]={2,3,4,5,6};** is invalid when a list of values is assigned to an array index location.

Traversing an Array – Using Array Index

- One of the **most common actions** in dealing with arrays is to examine every array element in order to perform an operation or assignment.
- This action is also known as **traversing** an array.
- Example:
  - Traverse the **days[ ]** array to display every element's content:



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Traversing an Array – Using Array Index

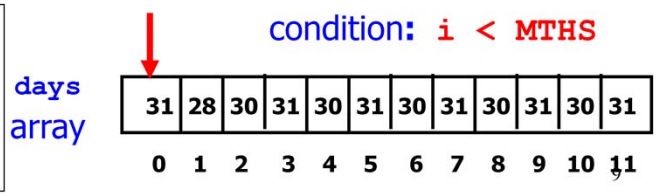
1. One of the most common actions in dealing with arrays is to examine every array element in order to perform an operation or assignment. This action is also known as traversing an array.
2. Since array elements can be accessed individually, the most efficient way of manipulating array elements is to use a **for** or **while** loop. The loop control variable is used as the index for the array. Thus, each element of the array can be accessed as the value of the loop control variable changes when the loop is executed. Also note that array values are printed using the corresponding indexes.
3. This is illustrated in this example on using the array **days[]**.

Example 1: Printing Values

```
#include <stdio.h>
#define MTHS 12              /* define a constant */
int main( )
{
    int i;
    int days[MTHS] = {31,28,31,30,31,30,31,31,30,31,30,31};
    /* print the number of days in each month */
    for (i = 0 ;  i < MTHS ;  i++ )
        printf("Month %d has %d days\n", i+1, days[i]);
    return 0;
}
```

Output

```
Month 1 has 31 days.
Month 2 has 28 days.
...
Month 12 has 31 days.
```



Traversing an Array – Printing Values

1. In the program, the array **days** is first initialized using a list of integers.
2. After that, a **for** loop is used as the control construct to print each element of the **days** array. It traverses from index 0 to 11 and executes the **printf()** statement.

Note that the number in the list should match the size of the array in array initialization. However, if the list is shorter than the size of the array, then the remaining elements are initialized to 0.

Example 2: Searching for a Value

```
#include <stdio.h>
#define SIZE 5          /* define a constant */
int main ( )
{
    char myChar[SIZE] = {'b', 'a', 'c', 'k', 's'};
    int i;
    char searchChar;
    // Reading in user's input to search
    printf("Enter a char to search: ");
    scanf("%c", &searchChar);
    // Traverse myChar array and output character if found
    for  (i = 0;    i < SIZE;    i++) {
        if (myChar[i] == searchChar){
            printf ("Found %c at index %d", myChar[i], i);
            break;     //break out of the loop
        }
    }
10  return 0;
}
```

Output

```
Enter a char to search: a
Found a at index 1
```

Traversing an Array – Searching for a Value

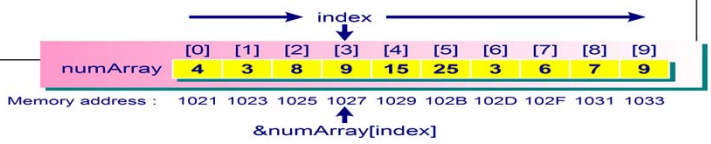
1. When working with arrays, it may be necessary to search for the presence of a particular element. The element that needs to be found is called a *search key*.
2. In the program, the array **myChar** is first initialized using a list of characters. The user can then enter the target character to search. The program will then traverse the array to find the index position of the target character.
3. The program searches for the search key from the array **myChar** and returns the corresponding index position if found. In the program, the target character is firstly read from the user. Then, the character values stored in the array are checked one by one using a **for** loop. If the character value of the checked item is the same as the target character, the corresponding index position is then printed on the screen. And the **break** statement is executed to exit the loop.
4. This **linear search algorithm** compares each element of the array with the search key until a match is found or the end of the array is reached. The program uses linear search by comparing each element of the array with the target character. On average, the linear search algorithm requires to compare the search key with half of the elements stored in an array. Linear search is sufficient for small arrays. However, it is inefficient for large and sorted arrays. Therefore, a more efficient technique such as binary search should be used for large arrays.

Example 3: Finding the Maximum Value

```
#include <stdio.h>
int main( )
{
    int index, max, numArray[10];
    max = -1; printf("Enter 10 numbers: \n");
    for (index = 0; index < 10; index++)
        scanf("%d", &numArray[index]);
    // Find maximum from array data
    for (index = 0;  index < 10;  index++) {
        if (numArray[index] > max)
            max = numArray[index];
    }
    printf("The max value is %d.\n", max);
    return 0;
}
```

This example shows how to find the largest value in an array of numbers.

Output
Enter 10 numbers:
4 3 8 9 15 25 3 6 7 9
The max value is 25.



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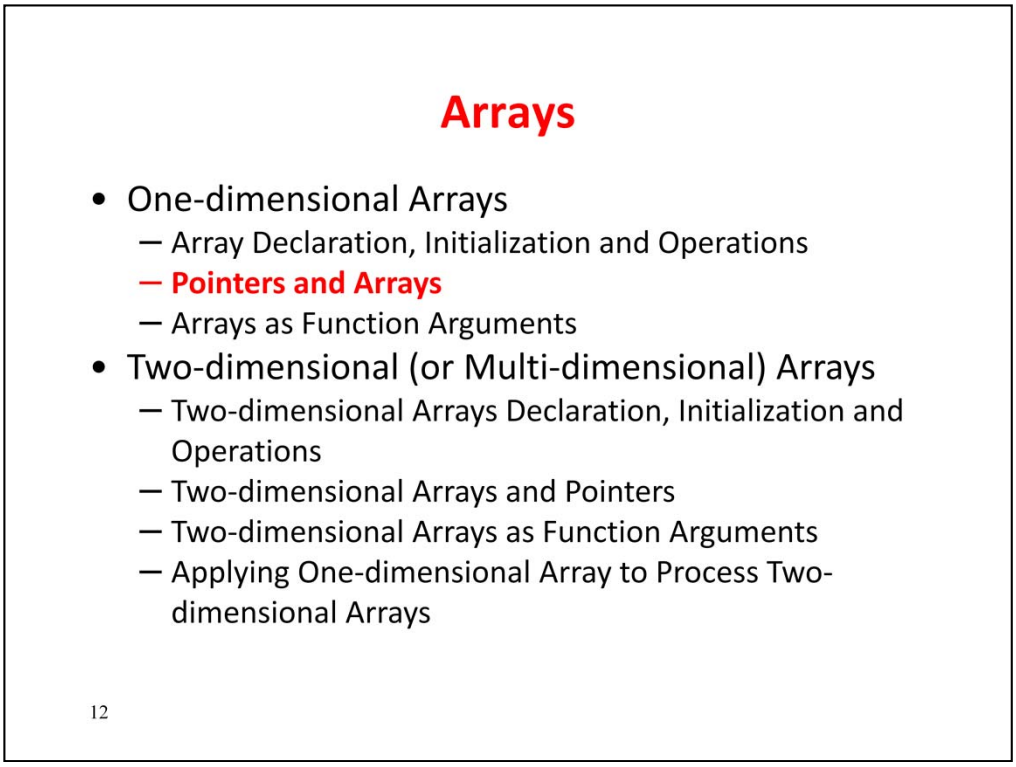
Traversing an Array – Finding the Maximum Value

1. The program finds the maximum non-negative value in an array. The value for each item in an array is read from the user and stored in the array. Then, the array is traversed element by element in order to find the maximum value in the array.
2. In the program, the value for each item in an array is firstly read from the user and stored in the array. The value –**1** is assigned to the variable **max,** which is defined as the current maximum.
3. Then, the items in the array are checked one by one using a **for** loop. If the value of the next item is larger than the current maximum, it becomes the current maximum. If the value of the next item is less than the current maximum, the current value of **max** is retained. The maximum value in the array is then printed on the screen.



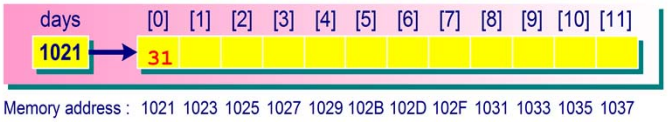
Arrays – One-dimensional Arrays

1. Here, we discuss pointers and arrays.

Pointer Constants

- The **array name** is actually a ***pointer constant***:
- An integer can be represented by 4 bytes (or 2 bytes – in older machines (as in this illustration)) and the array **days** begins at memory location 1021.

e.g. int **days**[12]; // **days – pointer constant**



days[0] = 31; /* days[0] contains the value assigned to it */

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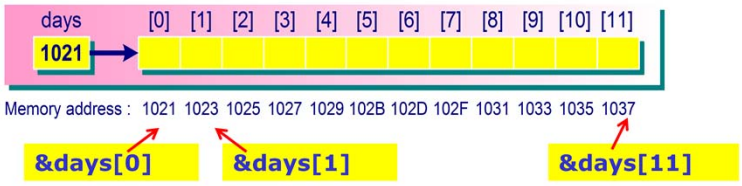
Pointer Constants

1. There is a strong relationship between pointers and arrays. The array name is actually a pointer constant.
2. When the array **days[]** is declared: **int days[12];** a *pointer constant* with the same name as the array is also created.
3. The pointer constant points to the first element of the array. Therefore, the array name by itself, **days**, is actually containing the address (or pointer) of the first element of the array.
4. Assume an integer is represented by 2 bytes (in older machines) and the array **days** begins at memory location 1021.
5. In this array declaration, the array consists of 12 elements. The value stored at **days** is 1021, which corresponds to the address of the first element of the array.

Pointer Constants (Cont'd.)

- Address of an array element:



&days[0] - is the **address** of the **1st** element [i.e. 1021]
&days[1] - is the **address** of the **2nd** element [i.e. 1023]
&days[i] - is the **address** of the **(i+1)th** element

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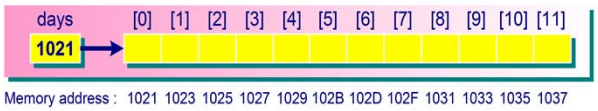
Pointer Constants

1. Note that to access the address of an array element, we can use the address operator.
2. For example, for the array **days[]**, **&days[0]** is the address of the 1st element; **&days[1]** is the address of the 2st element; and **&days[i]** is the address of the (i+1)th element.
3. The address of an array element is important when performing pointer arithmetic with array.

Pointer Constants (Cont'd.)

- **days** - is the **address (or pointer)** of the **1st element of the array**



- What have you observed?
  - Array variable **days** – contains a pointer constant (i.e. 1021) (the value cannot be changed)
  - Array index **days[0]**, days[1], etc. – contains the array value at that index location
  - Array element address **&days[0] (i.e. 1021)**, &days[1], etc. - days[0] has the address of 1021, days[1] has the address of 1023, etc.
- Goal – to be able to use the pointer **days** for accessing each array element. How to do that?

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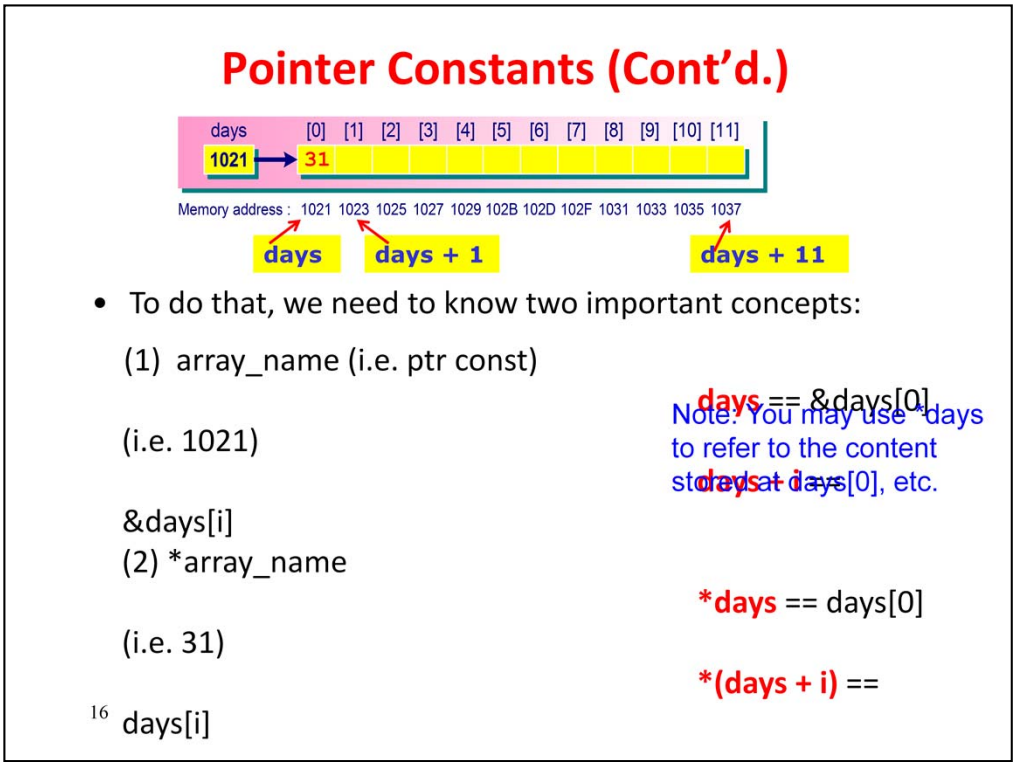
Pointer Constants

1. The array name by itself, **days**, is the address (or pointer) of the 1st element of the array.
2. What have you observed?
   - The array variable **days** contains a pointer constant (i.e. 1021) (i.e. the value cannot be changed)
   - The array index **days[0]**, days[1], etc. contains the array value at that index location.
   - The array element address is **&days[0] (i.e. 1021)**, &days[1], etc. That is, days[0] has the address of 1021, days[1] has the address of 1023, etc.
3. The goal is to use the pointer constant **days** for accessing each array element.



Pointer Constants

1. The array name **days** is a pointer constant.
2. Since the array name is the pointer to the first element of the array, we have

   days == &days[0]

   days+1 == &days[1]

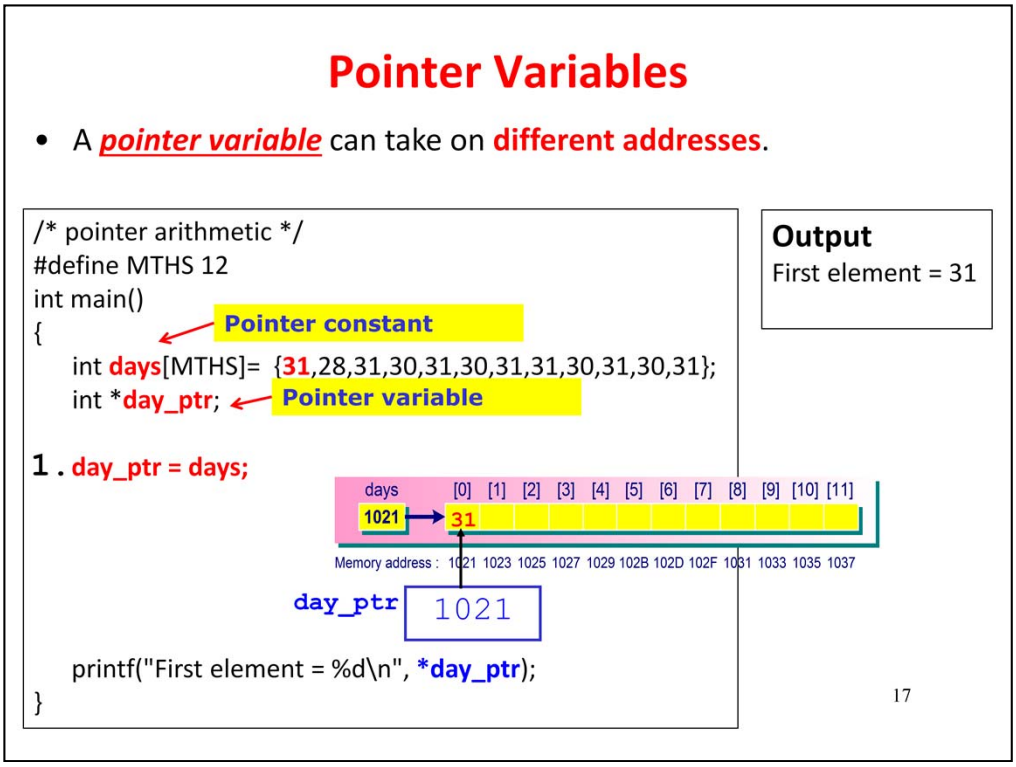
   days+i == &days[i]
3. Therefore, there are two ways to retrieve the content of the element of the arrays. For example, if we want to get the value of the first element, we can use either

   days[0] // using index notation or

   ***days // using pointer notation**
4. For example, we can write ***(days+1)** to access the array element **days[1]**. Similarly, ***(days+2)** is used to access array element **days[2]**, etc.
5. However, it is important to note that the array name is a **pointer constant**, not a pointer variable. It means that the value stored in **days** cannot be changed by any statements. As such, the following assignment statements are invalid:

   days += 5; and

   days++;



Pointer Variables

1. A pointer variable can take on different addresses.
2. In the program, we declare an array variable **days**[] of 12 elements and initialized it with values: int **days**[MTHS]= {31,28,31,30,31,30,31,31,30,31,30,31}; where **days** is a pointer constant which is declared as an array of 12 elements.
3. Then, we declare an integer pointer variable **day_ptr**: int ***day_ptr**;
4. The statement **day_ptr = days;** assigns the value 1021 from the array variable **days** to the pointer variable **day_ptr**. This causes the pointer variable to point to the first element of the array.
5. After that, we can use the pointer variable **day_ptr** to access each element of the array.

Pointer Variables (Cont'd.)

- A ***pointer variable*** can take on **different addresses**.

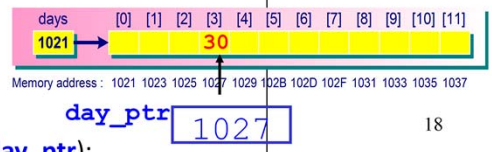
```
/* pointer arithmetic */
#define MTHS 12
int main()
{
    int days[MTHS]= {31,28,31,30,31,30,31,31,30,31,30,31};
    int *day_ptr;
    day_ptr = days;

    printf("First element = %d\n", *day_ptr);

2 . day_ptr = &days[3];  /* points to the fourth element */

    printf("Fourth element = %d\n", *day_ptr);
```

Pointer constant

Pointer variable

Output

First element = 31
Fourth element = 30



day_ptr 1027

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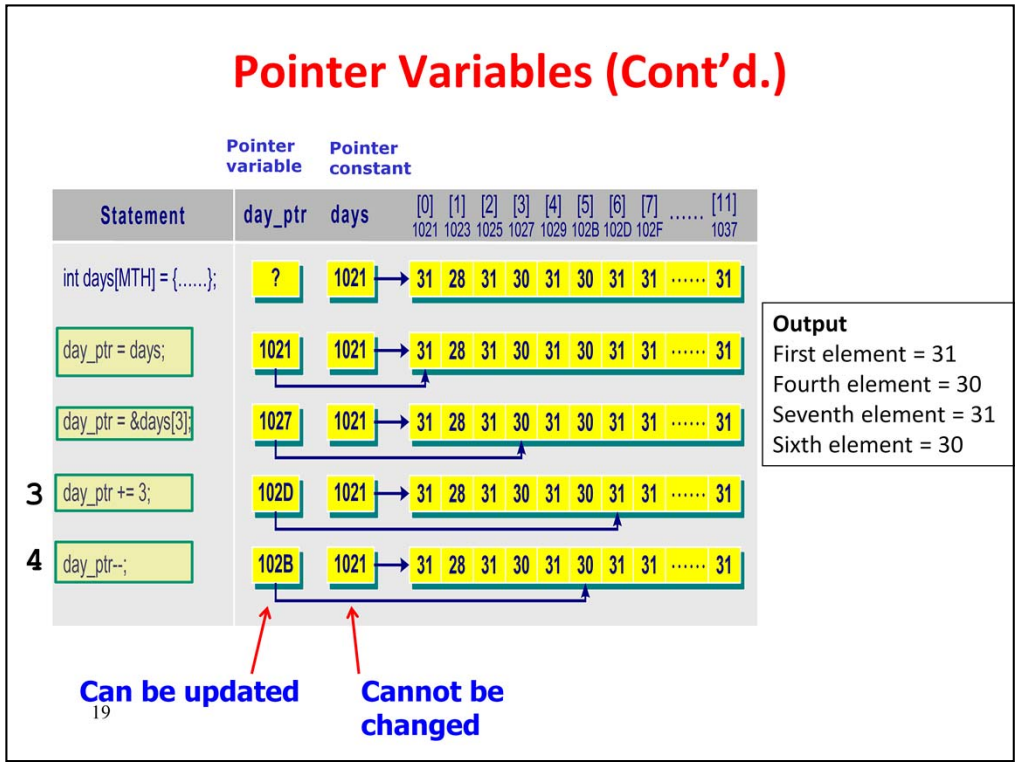
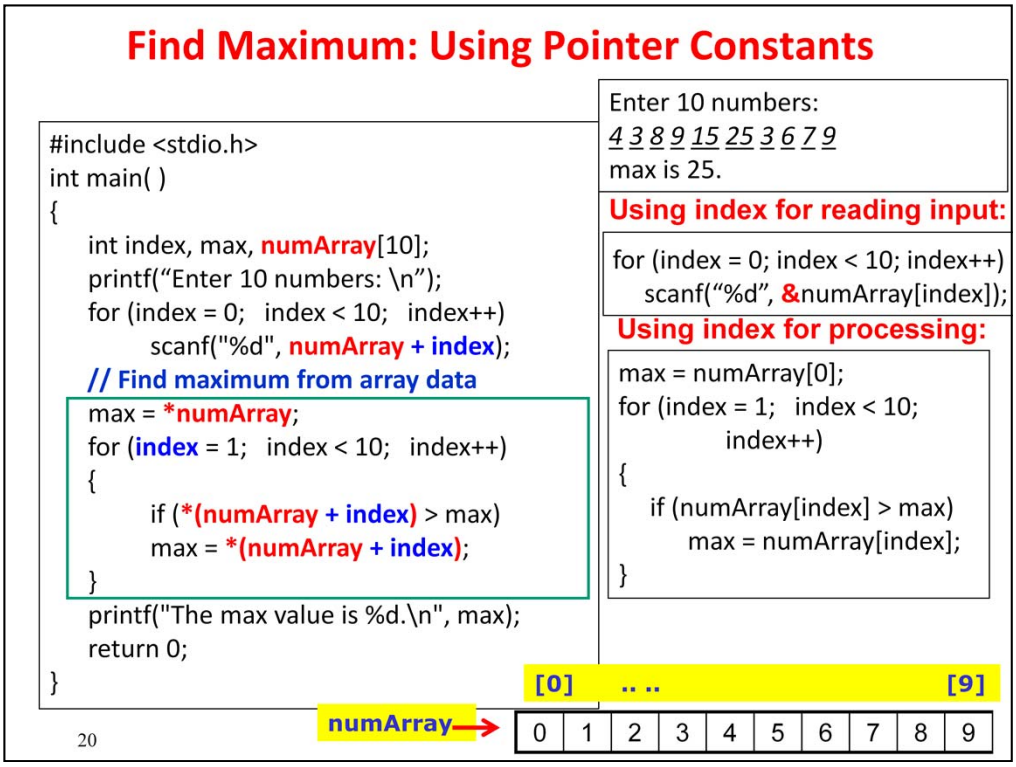
Pointer Variables

1. The statement **day_ptr = &days[3];** assigns the address of **days[3]** to the **day_ptr**. It updates the **day_ptr** to point to the fourth element of the array.
2. The value stored in **day_ptr** becomes 1027.



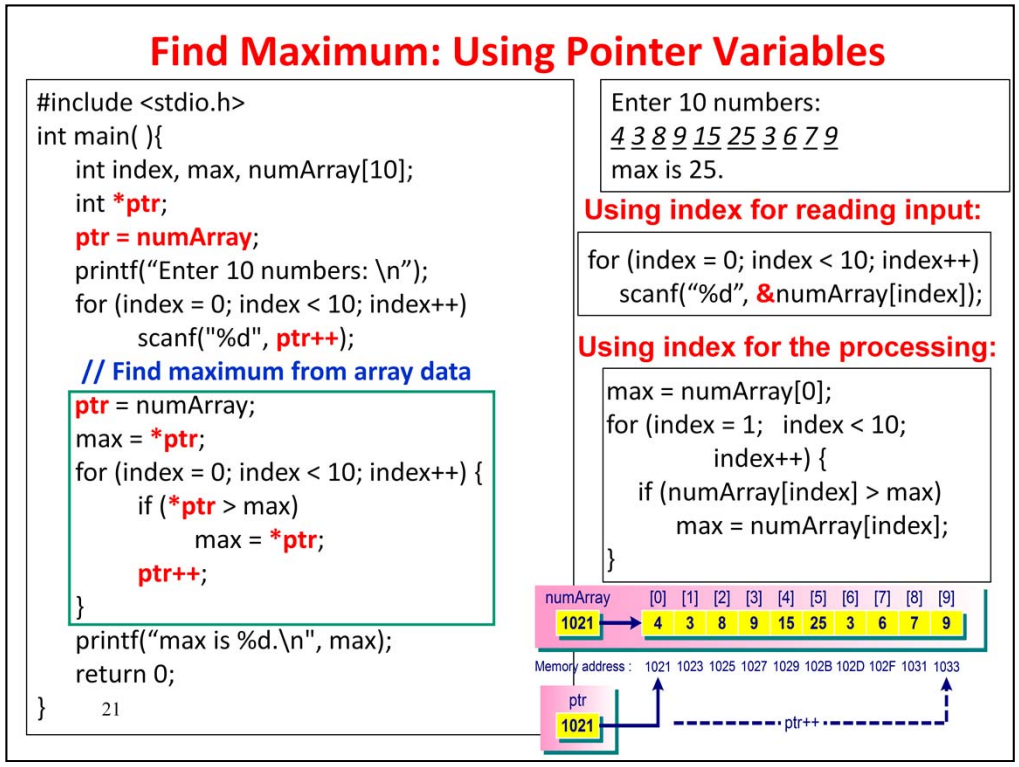
Pointer Variables

1. We can add an integer value of 3 to the pointer variable **day_ptr** as follows: **day_ptr += 3;** The **day_ptr** will move forward three elements.
2. The **day_ptr** contains the value of 102D, which is the address of the seventh element of the array **days[6]**.
3. The pointer variable can also be decremented as **day_ptr--;** The **day_ptr** moves back one element in the array. It points to the sixth element of the array **days[5]**.
4. When we perform pointer arithmetic, it is carried out according to the size of the data object that the pointer refers to. If **day_ptr** is declared as a pointer variable of type **int**, then every two bytes (assuming that **int** takes 2 bytes) will be added for every increment of one.
5. Therefore, after assigning the array variable to the pointer variable, we can either use the array variable **days** to access each element of the array, or we can use the pointer variable **day_ptr** to access each element. As such, there are two possible ways to process an array: (1) use the array variable directly, or (2) use a pointer variable and assign the array variable to the pointer variable.
6. However, note that the array variable **days** cannot be changed as it is a pointer constant.



Find Maximum: Using Pointer Constants

1. In this program, it shows the use of array variable (i.e. pointer constant) to access each element of the array to find the maximum number from an array.
2. The program first reads in 10 integers from the user and stores them into the array variable **numArray**. The **numArray** is the address of the first element of the array, and **numArray+index** is the address of element **numArray[index]**.
3. In addition, you may also use the array notation such as **numArray[index]** to access directly each element of the array. Note that the address operator (**&**) is needed in the **scanf()** statement.
4. The **for** loop accesses each element of the array, and compares it with **max** in order to determine the maximum value. The maximum value is then assigned to **max**. ***(numArray+index)** is the value of the element **numArray[index]**.
5. Moreover, you may also use the array notation such as **numArray[index]** to access directly each element of the array.



Find Maximum: Using Pointer Variables

1. The previous program uses the pointer constant **numArray** to access all the elements of the array.
2. Another way to access the elements of an array is to use a pointer variable. This program gives an example using a pointer variable to find the maximum element of the array.
3. To achieve this, it is important to assign **numArray** to **ptr**: **ptr = numArray;** After that, we can read in the array data via the pointer variable **ptr**.
4. In the first **for** loop, we use **scanf()** to read in user input. We increment the **ptr** as **ptr++;** to access each element of the array in order to store the input integer into the corresponding index location of the array. The first input will be stored at index location **numArray[0]**, after increasing the pointer **ptr** by 1, the next input integer will be stored at location **numArray[1]**, etc.
5. To find the maximum value stored in the array, we also use a **for** loop. In the second **for** loop, it traverses each element in the array using the pointer variable **ptr**. The value stored at the location of the array is referred to as ***ptr**. The content of each element of the array is compared with the current maximum value. After executing the loop, the maximum value in the array is determined. And the variable **max** will store the maximum value.

Arrays and Pointers – Key Points

- Array is declared as **pointer constant**: In this case, we cannot change the base pointer address.
  - Example: int **numArray**[10];
  - Generally, we can use the **index notation** to access each element of the array, e.g. numArray[0] refers to the first element.
  - We can also use the pointer constant to access each element of the array, e.g. ***(numArray+1)** refers to **numArray[1]**, etc.
- In addition, we can also declare **pointer variables** to access the array.
  - Example: declare a pointer variable and assign the array to the pointer variable:

    int ***ptr**;

    ptr = numArray;
  - Then we can use the pointer notation to access each element of the array, e.g. ***ptr** refers to the first element of the array **numArray[0]**, etc.

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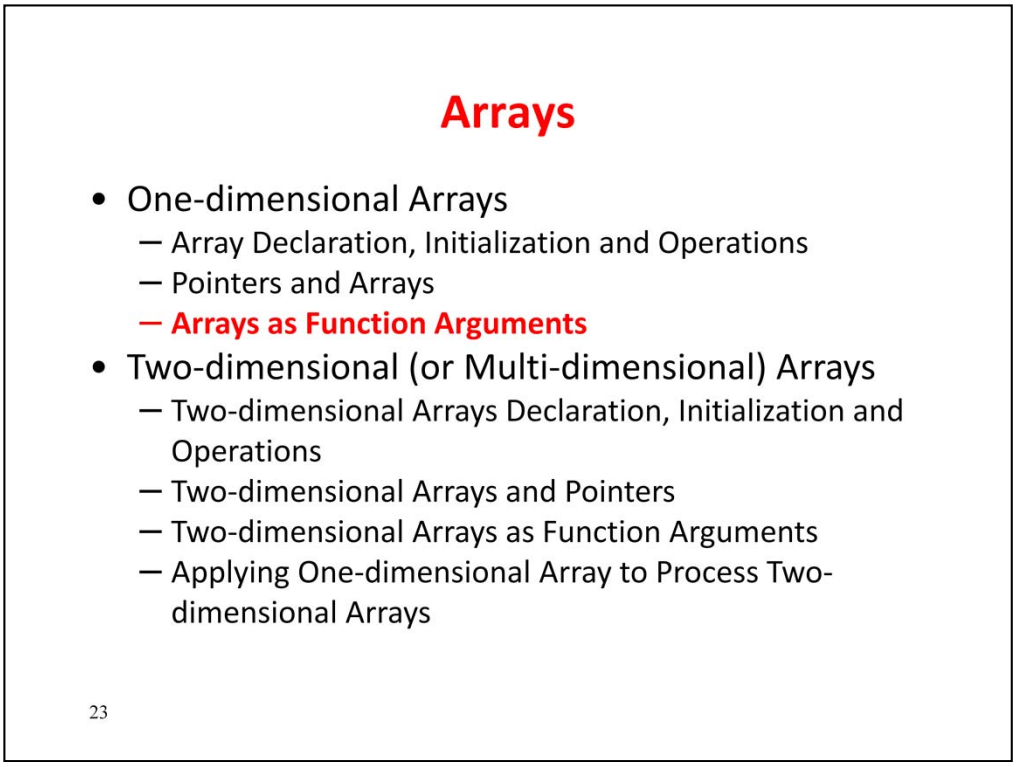
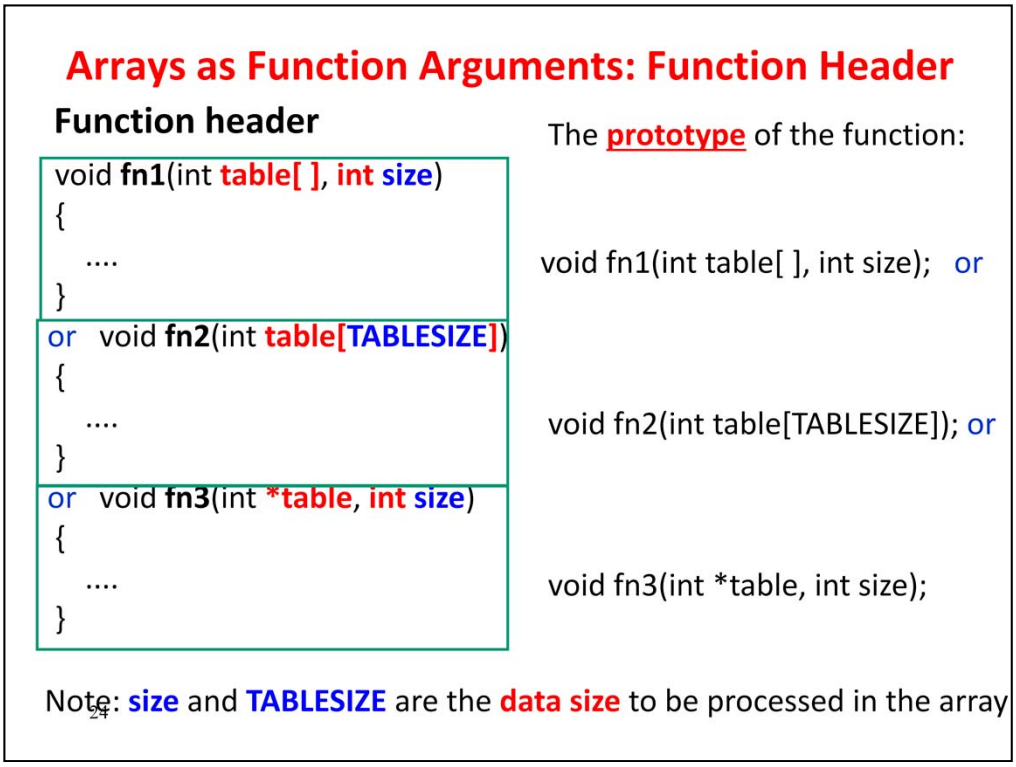
Arrays and Pointers – Key Points

1. Array is declared as pointer constant. For pointer constant declaration, e.g. int **numArray**[10]; We can use the **index notation** to access each element of the array, e.g. numArray[0] refers to the first element. We also can the pointer constant to access each element of the array, e.g. ***(numArray+1)** refers to **numArray[1]**, etc.
2. However, the base pointer address stored in the array variable cannot be changed.
3. In addition, we can also use pointer variable (e.g. int ***ptr**;) to access an array. After declaring a pointer variable, we can assign the pointer variable with the array address, i.e. **ptr = numArray**; we can then use the pointer variable to access each element of the array.
4. As such, both the use of array notation and pointer variable can be adopted for accessing individual elements of an array:
   - Using array index notation: e.g. **numArray[index]**
   - Using pointer constant: e.g. ***(numArray+index)**
   - Using pointer variable: e.g. ***ptr**
5. However, the use of pointer variable will be more efficient than the array notation, and it is also more convenient when working with strings.



Arrays – One-dimensional Arrays

1. Here, we discuss using arrays as function arguments.



Arrays as Function Arguments: Function Header [Overview]

1. There are three ways to define a function with a one-dimensional array as the argument.
2. The first way is to define the function as **void function1(int table[], int size)** where **table** is an array and **size** is an integer. The data type of the array is specified, and empty square brackets follow the array name. The integer **size** is used to indicate the size of the array.
3. Another way is to define the function as **void function2(int table[TABLESIZE])** where the parameter list includes an array only. The array size **TABLESIZE** is also specified in the square brackets of the array **table**.
4. The third way is to define the function as **void function3(int *table, int size)** where **table** is a pointer of type **int**, and **size** is an integer.

The function prototypes of the functions are given below:

void function1(int table[], int size);

or **void function2(int table[TABLESIZE]);**

or **void function3(int *table, int size);**

Arrays as Function Arguments: Calling the Function

- Any dimensional array can be passed as a function argument, e.g. we can **call the function**:

```
fn1(table, n);      /* calling a function */
```

where **fn1()** is a function and **table** is an one-dimensional array, and **n** is the size of the array **table**.

- An **array table** is passed in using **call by reference** to a function.
- This means the **address** of the **first element** of the array is passed to the function.

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Arrays as Function Arguments: Calling the Function

1. We can use an array in a function's body. We may also use an array as a function argument. An array consists of a number of elements. We may access individual element, or pass an element to a function.
2. An array can also be passed to a function as an argument, e.g., **function1(table, n);** where **function1()** is a function and **table** is an one-dimensional array.
3. When we pass an array as a function argument, the array is passed using **call by reference** to the function. This means that the address of the first element of the array is passed to the function. Since the function has the address of the array, any changes to the array are made to the original array. There is no local copy of the array to be maintained in the function. This is mainly due to efficiency as arrays can be quite large and thereby taking a considerably large storage space if a local copy is stored.

Array as a Function Argument: Maximum

```
#include <stdio.h>
int maximum(int table[ ], int n);
int main( )
{
    int max, index, n;
    int numArray[10];   // Using index for input
    printf("Enter the number of values: ");
    scanf("%d", &n);
    printf("Enter %d values: ", n);
    for (index = 0; index < n; index++)
        scanf("%d", &numArray[index]);

    // find maximum          // Calling the function
    max = maximum(numArray, n);
    printf("The maximum value is %d\n", max);

    return 0 ;
}
```

Output

```
Enter the number of values:  10
Enter 10 values: 0 1 2 3 4 5 6 7 8 9
The maximum value is 9
```

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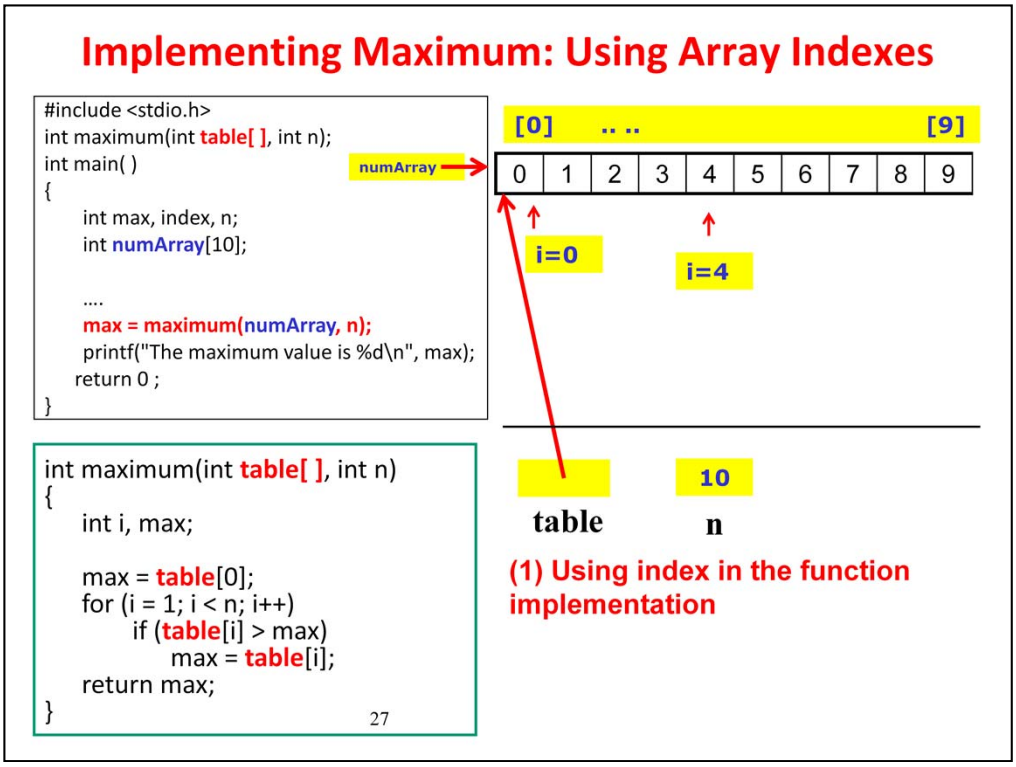
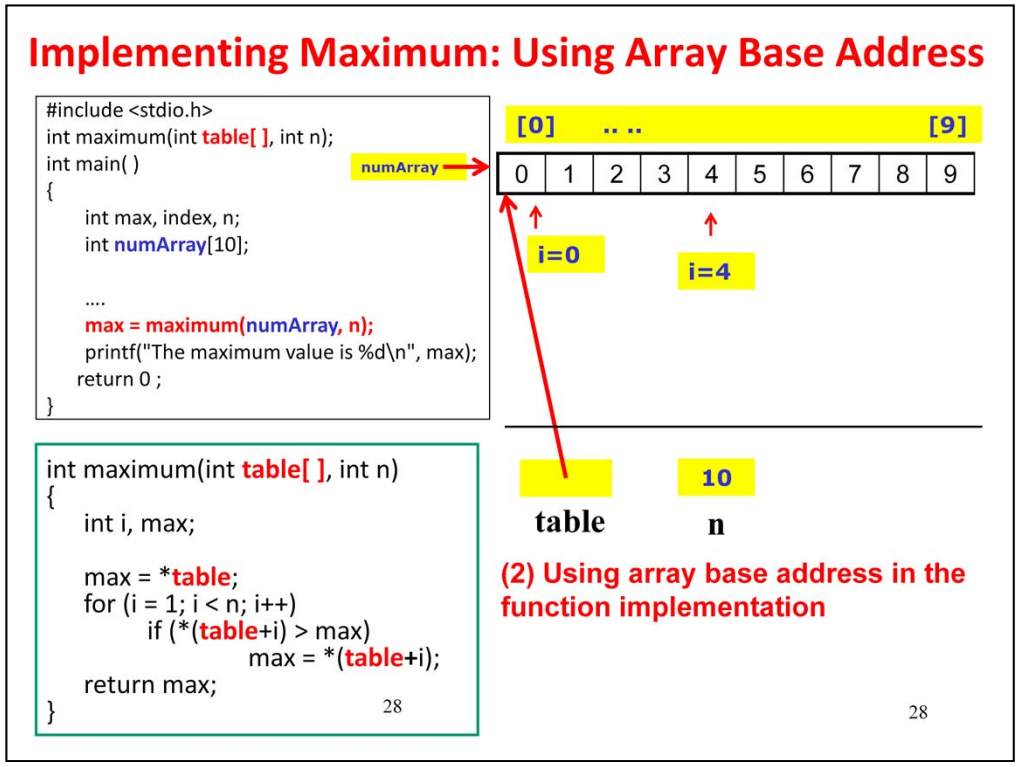
Arrays as Function Arguments: Maximum

1. In the program, the **main()** function calls the function **maximum()** to compute the maximum value in an array. When the function **maximum()** is called, it passes an array as the function argument.
2. The function **maximum()** determines the maximum value stored in the array. Apart from the array argument **numArray**, the number of elements stored in the array is also passed as an integer argument **n**.



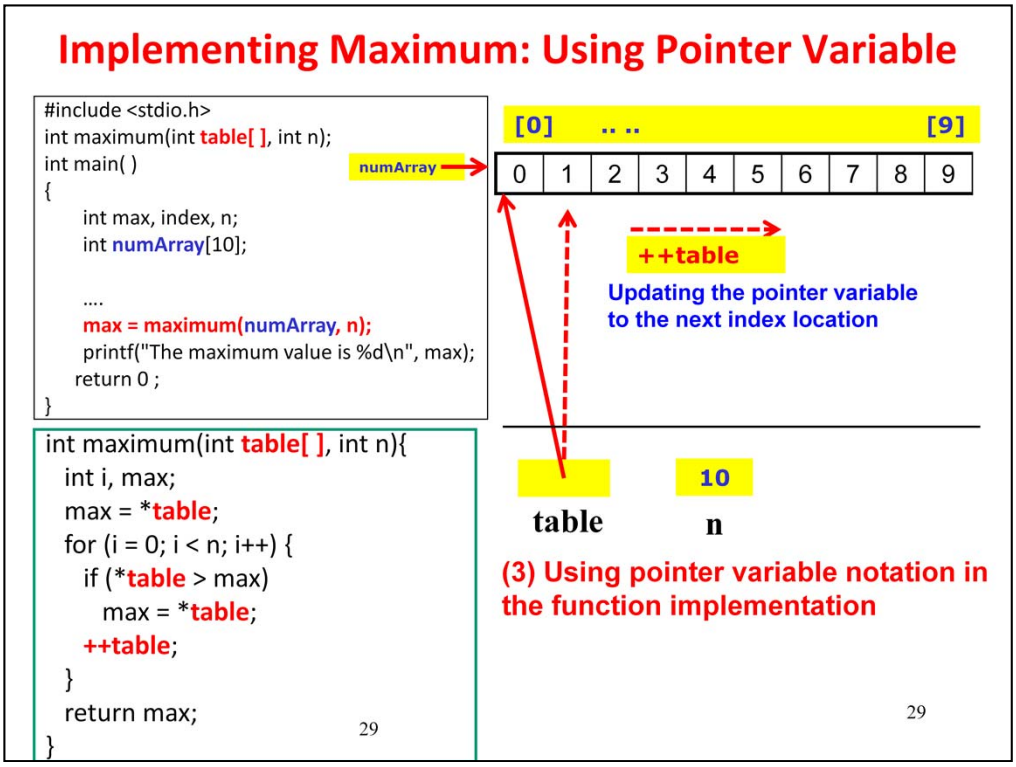
Implementing Maximum: Using Array Indexes

1. The implementation of the function **maximum()** uses **array indexes**. It has two parameters: **table** and **n**.
2. The array is traversed element by element using indexing with **table[i]**, where **i** is the index from 0 to **n**-1, in order to find the maximum number.
3. At the end of the function, the maximum number stored in **max** is passed back to the calling function.



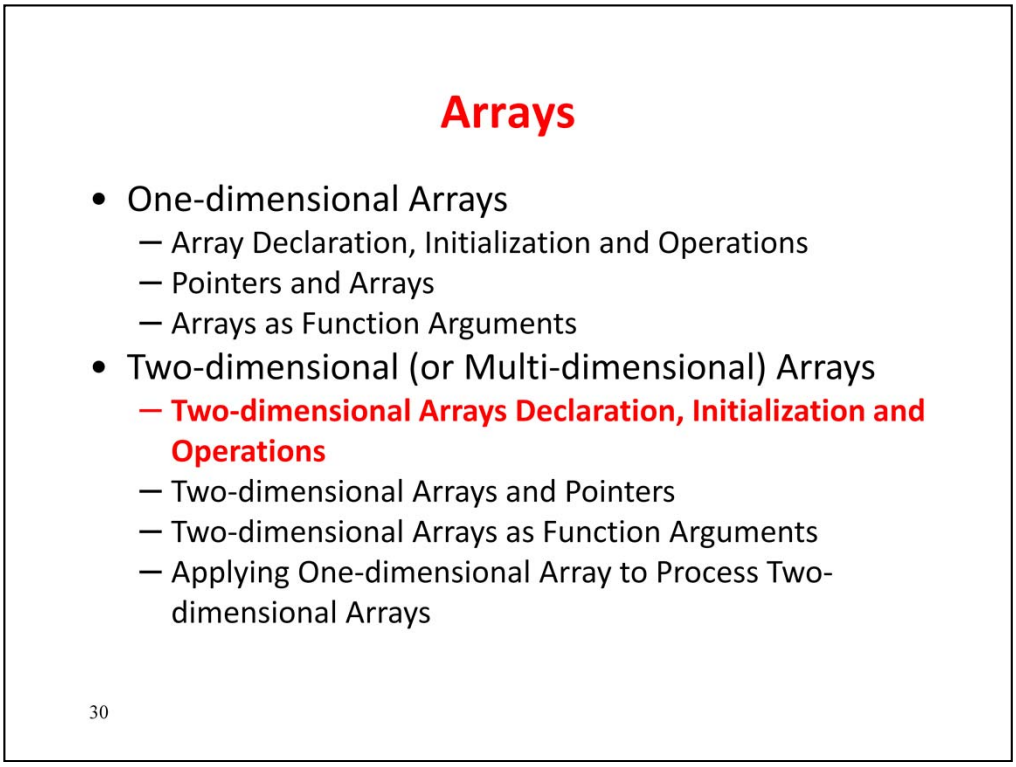
Implementing Maximum: Using Array Base Address

1. The implementation of the function **maximum()** uses array base address.
2. As shown, the base address of the array **table** is used. When traversing the array, the array element is accessed via ***(table+i)**, where **i** is the index from 0 to **n**-1.
3. The maximum number is then determined at the end of the loop.



Implementing Maximum: Using Pointer Variable

1. The implementation of the function **maximum()** uses pointer variable notation.
2. In this version of implementation, the array **table** is used as a pointer variable. When traversing the array, the array element is accessed via ***table**, and the variable **table** is incremented by 1 using **table++** in order to access each element of the array.
3. The maximum number is then determined at the end of the loop.



Arrays - Two-dimensional Arrays

1. We have discussed one-dimensional arrays in which only a single index (or subscript) is needed to access a specific element of the array.
2. The number of indexes that are used to access a specific element in an array is called the *dimension* of the array.
3. Arrays that have more than one dimension are called multi-dimensional arrays.
4. Here, we focus mainly on two-dimensional arrays. We may use two-dimensional arrays to represent data stored in tabular form. Two-dimensional arrays are particularly useful for matrix manipulation.
5. We first discuss two-dimensional array declaration, initialization and operations.

Two-dimensional (or Multi-dimensional) Arrays Declaration

- Declared as **consecutive** pairs of brackets.
- E.g. **2-dimensional**; 3-element array of 5-element arrays :

  int x[3][5];

- E.g. **3-dimensional**; 3-element array of 4-element arrays of 5-element arrays

  char x[3][4][5];

- ANSI C standard requires a minimum of **6 dimensions** to be supported.

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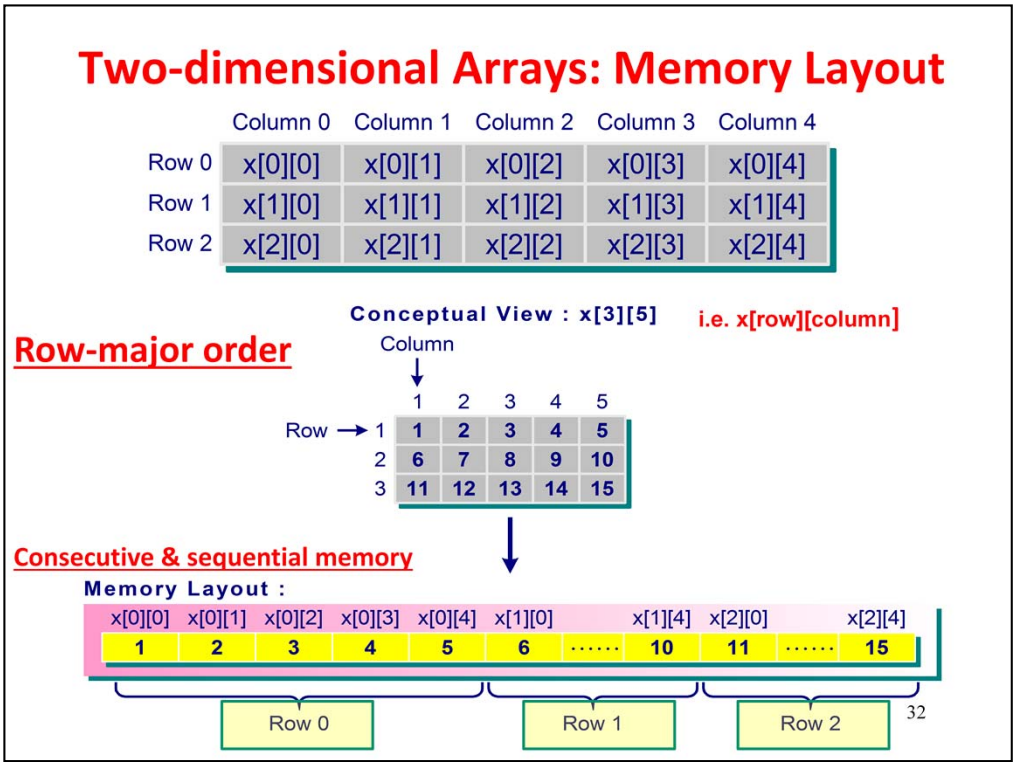
Two-dimensional (Multi-dimensional) Arrays Declaration

1. A two-dimensional array can be declared as

   int x[3][5]; /* 3-element array of 5-element arrays */

2. Two indexes are needed to access each element of the array.
3. Similarly, a three-dimensional array can be declared as **char x[3][4][5];** Three indexes are used to access a specific element of the array. ANSI C standard supports arrays with a minimum of 6 dimensions.



Two-dimensional Arrays: Memory Layout

1. The statement **int x[3][5];** declares a two-dimensional array **x[][]** of type **int** having three rows and five columns. The compiler will set aside the memory for storing the elements of the array.
2. The two-dimensional array can also be viewed as a table made up of rows and columns. For example, the array **x[3][5]** can be represented as a table. The array consists of three rows and five columns.
3. The array name and two indexes are used to represent each individual element of the array. The first index is used for the row, and the second index is used for column ordering. For example, **x[0][0]** represents the first row and first column, and **x[1][0]** represents the second row and first column, and **x[1][3]** represents second row and fourth column, etc.
4. A two-dimensional array is stored in ***row-major*** order in the memory.
5. Note that the memory storage of the two-dimensional array **x[3][5]** is consecutive and sequential.

Initializing Two-dimensional Arrays

- **Initializing** multidimensional arrays: enclose each row in braces.

```
int x[2][2] = {  { 1, 2},    /* 1st row */
                 { 6, 7}  }; /* 2nd row */
```

or

```
int x[2][2] = { 1, 2, 6, 7};
```

- **Partial** initialization:

```
int exam[3][3] = {{1,2}, {4}, {5,7}};
int exam[3][3] = { 1,2,4,5,7 };
          i.e. = { {1,2,4}, {5,7}};
```

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Initializing Two-dimensional Arrays

1. For the initialization of two-dimensional arrays, each row of data is enclosed in braces:

```
int x[2][2] = { {1,2},          /* first row */
              {6,7}    };       /* second row */
```

2. The data in the first interior set of braces is assigned to the first row of the array, the data in the second interior set goes to the second row, etc. If the size of the list in the first row is less than the array size of the first row, then the remaining elements of the row are initialized to zero. If there are too many data, then it will be an error.
3. Since the inner braces are optional, a two-dimensional array can be initialized as

```
int x[2][2] = { 1,2,6,7 };
```

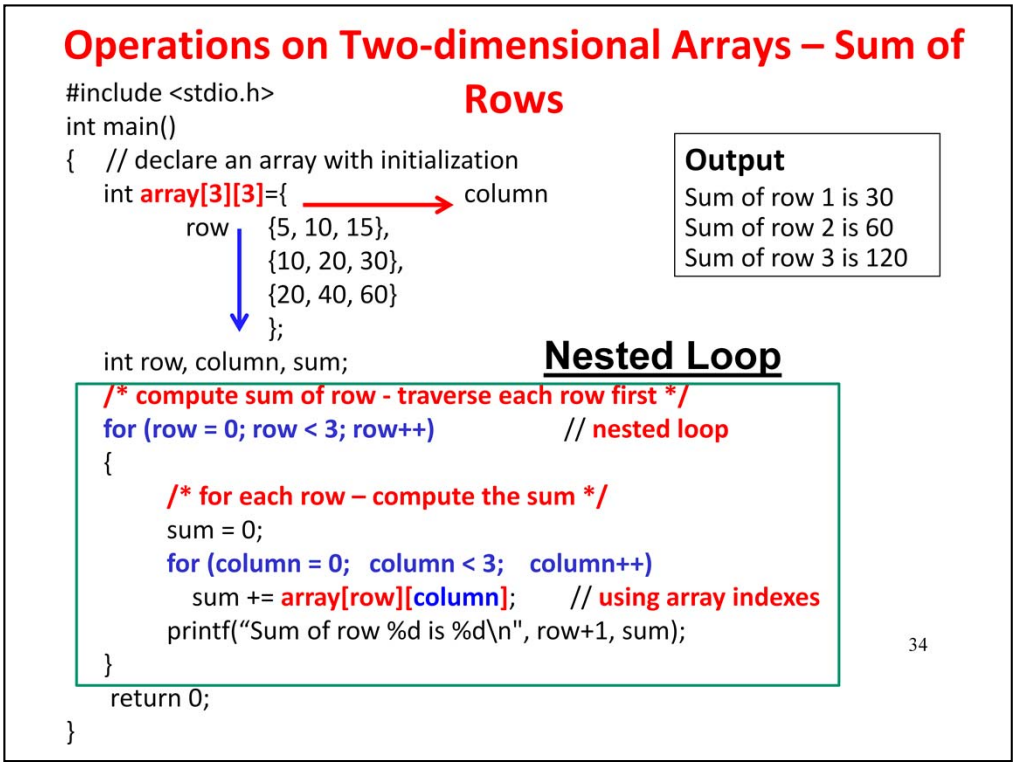
4. An array can also be initialized partially, for example, **int exam[3][3] = { {1,2}, {4}, {5,7} };** This statement initializes the first two elements in the first row, the first element in the second row, and the first two elements in the third row. All elements that are not initialized are set to zero by default.
5. For the following statement, **int exam[3][3] = { 1,2,4,5,7 };** the two-dimensional array will be initialized as

```
int exam[3][3] = { {1,2,4}, {5,7} };
```

If the number of rows and columns are not specified in the declaration statement, the compiler will determine the size of the array based on information about the initialization of the array. For example, the following statement

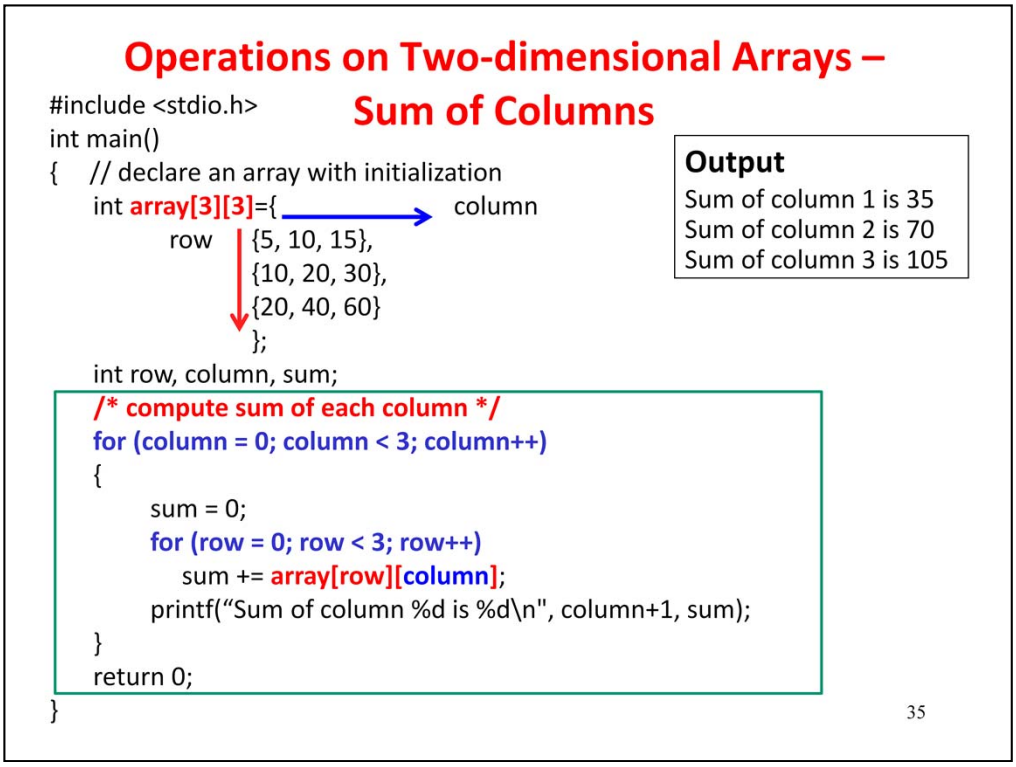
```
int array[][] = {   {1,2},
                    {6,7}     };
```

will create an array having two rows and two columns. The array is also initialized according to the values specified in the initialization of the array.



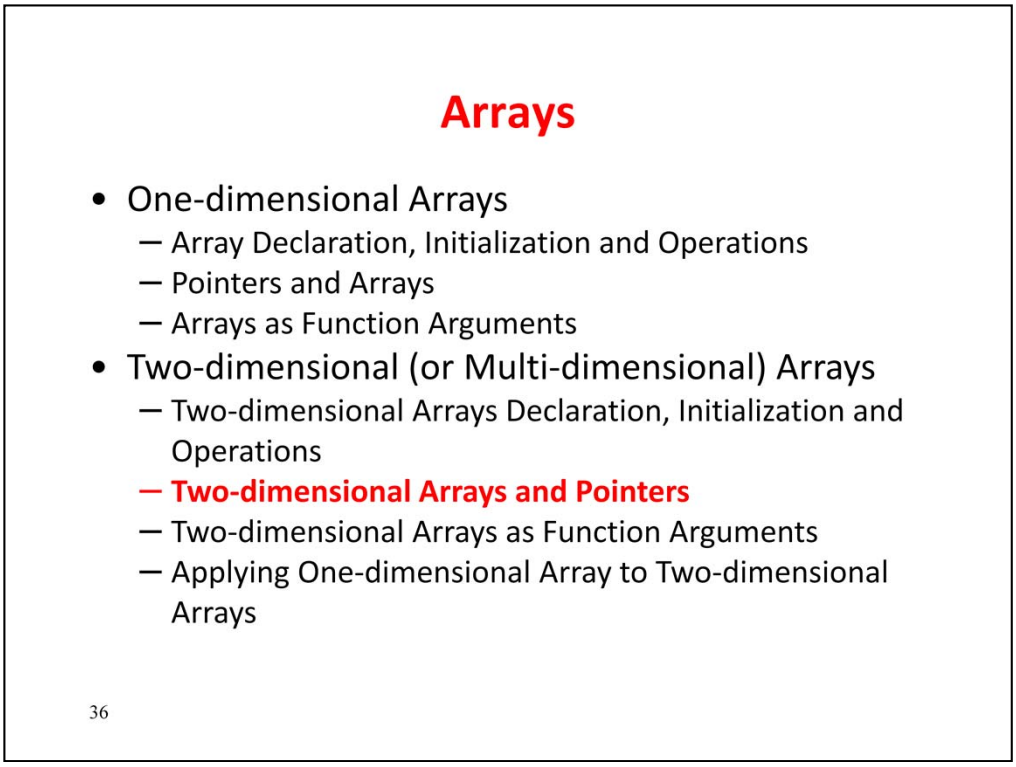
Operations on Two-dimensional Arrays – Sum of Rows

1. The program determines the sum of rows of two-dimensional arrays. It uses indexes to traverse each element of the two-dimensional **array**.
2. In the program, the array is first initialized. When accessing two-dimensional arrays using indexes, we use an index variable **row** to refer to the row number and another index variable **column** to refer to the column number.
3. A nested **for** loop is used to access the individual elements of the array.
4. To process the sum of rows, we use the index variable **row** as the outer **for** loop. Then, it traverses each element of each row with another **for** loop and add them up to give the sum of rows.
5. Note that the first dimension of an array is row and the second dimension is column. It is row-major.



Operations on Two-dimensional Arrays – Sum of Columns

1. The program determines the sum of columns of two-dimensional arrays. It uses indexes to traverse each element of the two-dimensional **array**. In the program, the array is first initialized.
2. To process the sum of columns, a nested **for** loop is used. We use the index variable **column** as the outer **for** loop. Then, it traverses each element of each column with another **for** loop and add them up to give the sum of columns.
3. Again note that the first dimension of an array is row and the second dimension is column. It is row-major.



Arrays - Two-dimensional Arrays

1. Here, we discuss two-dimensional arrays and pointers.

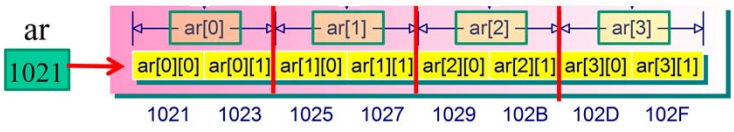
Two-dimensional Arrays and Pointers

- Two-dimensional arrays - stored sequentially in memory.

```
int ar[4][2];        /* ar is an array of 4 elements;
                        each element is an array of 2 ints */
```

or

```
int ar[4][2] = {
                  {1, 2},
                  {3, 4},
                  {5, 6},
                  {7, 8}
                };
```



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Two-dimensional Arrays and Pointers

1. Consider the following two-dimensional array:

   int ar[4][2]; /* ar is an array of 4 elements; */

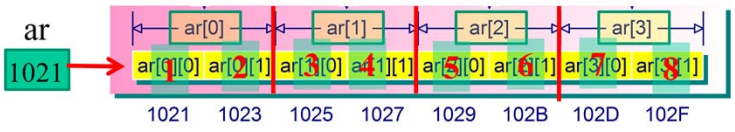
   /* each element is an array of 2 integers */

2. Where the array variable **ar** is the address of the first element of the array.

Two-dimensional Arrays and Pointers (Cont'd.)

- Two-dimensional arrays - stored sequentially in memory.

```
int ar[4][2];        /* ar is an array of 4 elements;
                        each element is an array of 2 ints */
or  int ar[4][2] = {
                      {1, 2},
                      {3, 4},
                      {5, 6},
                      {7, 8}
                    };
```



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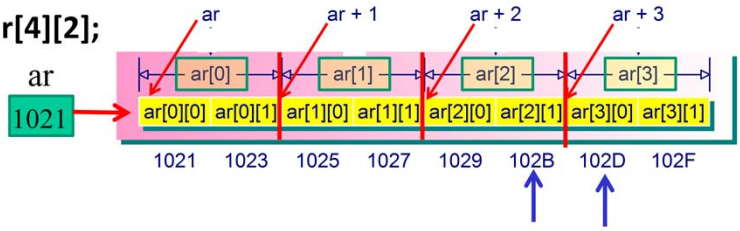
Two-dimensional Arrays and Pointers

1. The memory of the two-dimensional array is organized in a sequential manner.
2. The values of the two-dimensional arrays are stored sequentially in the memory.

Two-dimensional Arrays and Pointers (Cont'd.)

int ar[4][2];



- After some calculations (omitted here - please refer to the slides at the end of this lecture, and TEL video lecture for the details), we will get the general formula for using pointer to access each element of a 2-D array **ar** with row=**m**, column=n, as follows:

  ar[m][n] == *(*(ar + m) + n)

  e.g. **ar[2][1]** = *(*(ar + **2**) + **1**) [m=2, n=1]
  ar[3][0] = *(*(ar + **3**) + **0**) [m=3, n=0]

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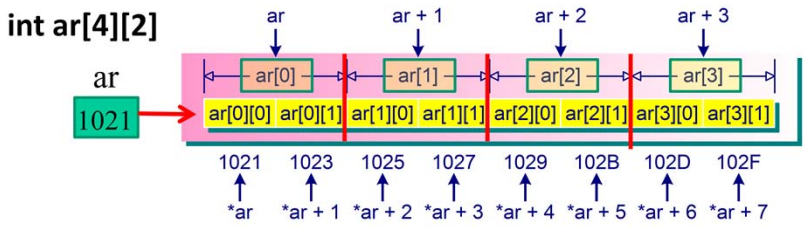
Two-dimensional Arrays and Pointers

1. After some calculations using **double** dereferencing as shown above, we can represent each individual element of a two-dimensional array as **ar[m][n] == *(*(ar+m)+n)**, where **m** is the index associated with **ar**, and **n** is the index associated with the sub-array **ar[m]**.
2. This can be interpreted as follows: First, dereferencing ***(ar+m)** to get the address of the inner array of **ar** according to the row number **m**. Then, by adding the column number **n** to ***(ar+m)**, i.e. ***(ar+m)+n**, it becomes the address of the element of **ar[m][n]**. Applying the * operator to that address gives the content at that address location, i.e. the array element content.
3. Note that you are not required to remember the calculation on deriving the general formula.

Two-dimensional Arrays and Pointers (Cont'd.)



Two ways to access two-dimensional Array:

- Using indexes (easy and simple): e.g. ar[m][n]
- Using pointers and the general formula for 2D array:

  ar[m][n] == *(*(ar + m) + n)

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Two-dimensional Arrays and Pointers

1. There are two ways to access each element of the array :
   a) Using the index approach: **ar[m][n]** with indexes **m** and **n**; or
   b) Using the general formula: ***(*(ar+m)+n)** for **ar[m][n]**.

Processing Two-dimensional Arrays: Example

```
#include <stdio.h>
int main() {
  int ar[3][3]= {
    {5, 10, 15},
    {10, 20, 30},
    {20, 40, 60}
  };
  int index, i, j;
    // (1) using indexes
  for (i=0; i<3; i++)
    for (j=0; j<3; j++)
      printf("%d ", ar[i][j]);
  printf("\n");
    // (2) using the general formula
  for (i=0; i<3; i++)
    for (j=0; j<3; j++)
      printf("%d ", *(*(ar+i)+j));
  return 0;
}
```

Output

```
5 10 15 10 20 30 20 40 60
5 10 15 10 20 30 20 40 60
```

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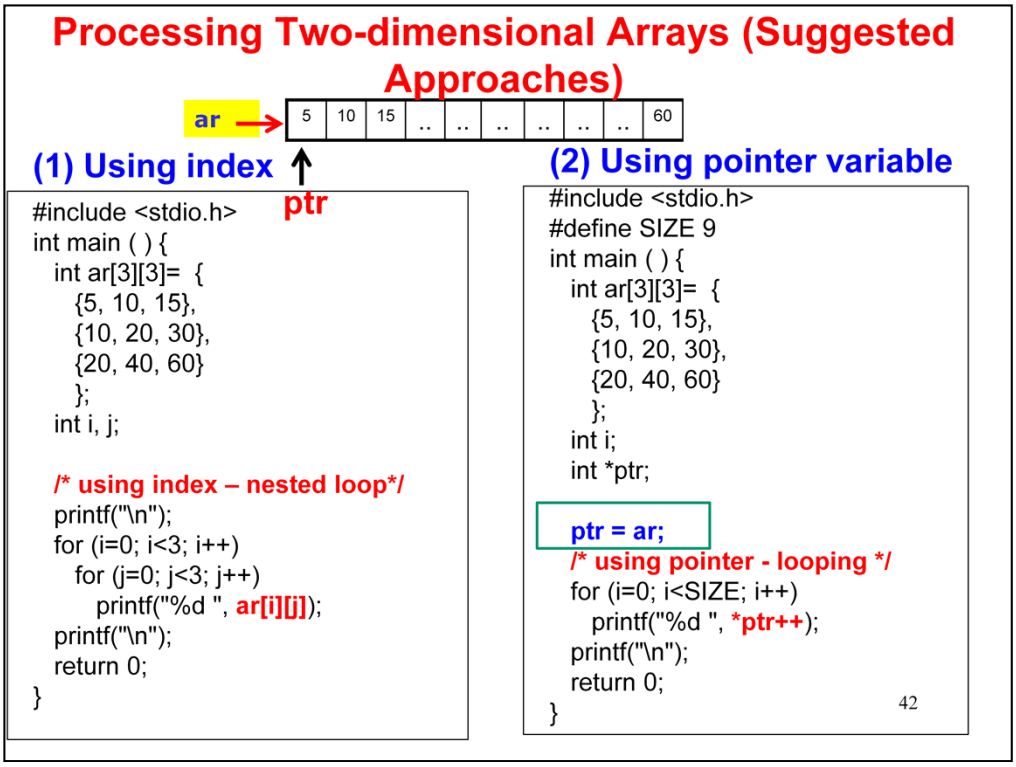
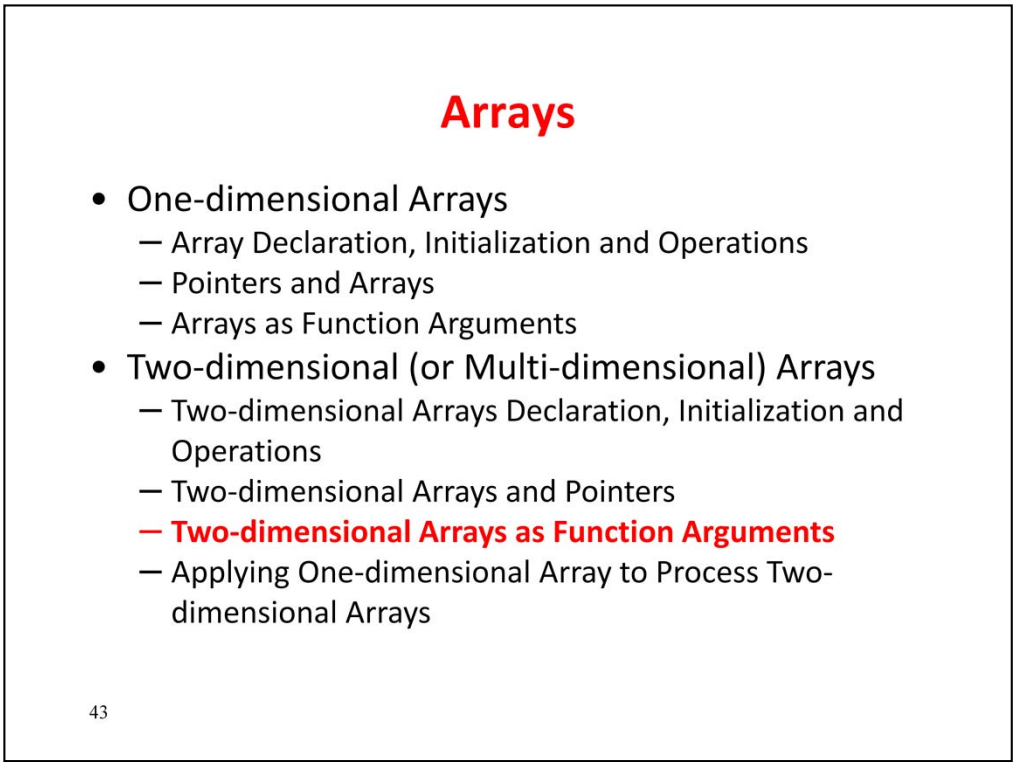
Processing Two-dimensional Arrays: Example

1. The program aims to print the value of each array element in a two-dimensional array.
2. In the program, it first initializes each array element of the array **ar[3][3]**.
3. There are two ways to access each element of the array with a nested **for** loop:
    a) Using the index approach or
    b) Using the general formula



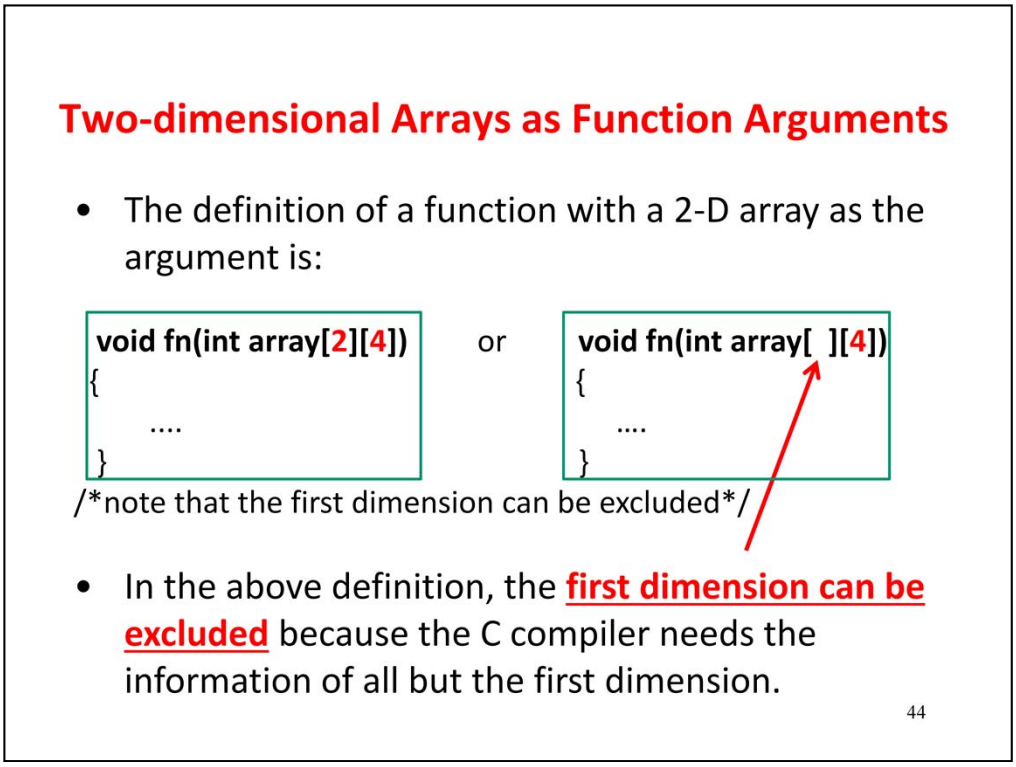
Processing Two-dimensional Arrays: Suggested Approaches

1. For processing two-dimensional arrays, you may use array index or pointer variable for processing each element of the array.
2. When using the index approach, indexes are used to access each individual element of a two-dimensional array.
3. When using pointer variable approach, a pointer variable is declared and assigned with the array value. It is then used to traverse each element of a two-dimensional array by incrementing the pointer variable to access the content of each element of the array.



Arrays - Two-dimensional Arrays

1. Here, we discuss using two-dimensional arrays as function arguments.



Two-dimensional Arrays as Function Arguments

1. The individual element of a two-dimensional array can be passed as an argument to a function. This can be done by specifying the array name with the corresponding row number and column number.
2. If an entire two-dimensional array is to be passed as an argument to a function, this can be done in a similar manner to a one-dimensional array.
3. The definition of a function with a two-dimensional array argument is given as follows:

   void function(int array[2][4]) or

   void function(int array[][4])
4. Note that the first dimension of the array can be omitted in the function definition.

Why the First Dimension can be Omitted?

- For example, the assignment operation

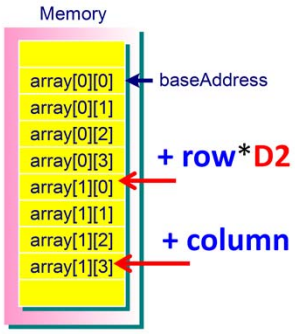
  array[1][3] = 100;

  requests the compiler to compute the address of array[1][3] and then place 100 to that address.
- In order to compute the address, the dimension information must be given to the compiler.
- Let's redefine array (i.e. **int array[2][4]**) as

  int array[D1][D2]; // D1=2, D2=4

  The address of array[1][3] is computed as

  baseAddress + **row** * **D2** + **column**
  ==> baseAddress + **1** * **4** + **3**
  ==> baseAddress + 7
  The **baseAddress** is the address pointing to the beginning of array.



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Why the First Dimension can be Omitted?

1. The first dimension (i.e. the row information) of an array can be excluded in the function definition because C compiler can determine the first dimension automatically. However, the number of columns must be specified.
2. For example, the assignment statement **array[1][3] = 100;** requests the compiler to compute the address of **array[1][3]** and then places a value of 100 to that address. In order to compute the address, the dimension information must be given to the compiler. Let us redefine **array** as: **int array[D1][D2];**
3. The address of **array[1][3]** is computed as:

   baseAddress + row * D2 + column

   => baseAddress + 1 * 4 + 3

   => baseAddress + 7

   where the baseAddress is the address pointing to the beginning of **array**.
4. Note that **D1** is not needed in computing the address.

Why the First Dimension can be Omitted? (Cont'd.)

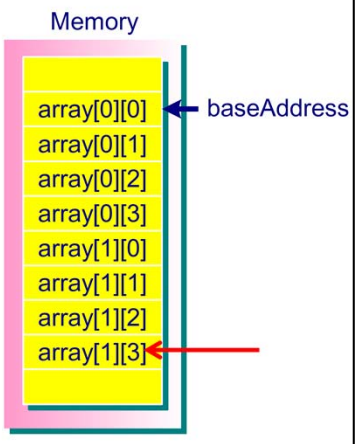
- Since **D1** is **not needed in computing the address**, we can omit the first dimension value in defining a function which takes arrays as its formal arguments.

- Therefore, the prototype of the function could be:

  void fn(int **array[2][4]**);

  or

  void fn(int **array[ ][4]**);



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Why the First Dimension can be Omitted?

1. Since D1 is not needed in computing the address, we can omit the value of the first dimension of an array in defining a function, which takes arrays as its formal arguments.
2. Therefore, the function prototype of the function **function()** can be

   void function(int array[2][4]); or

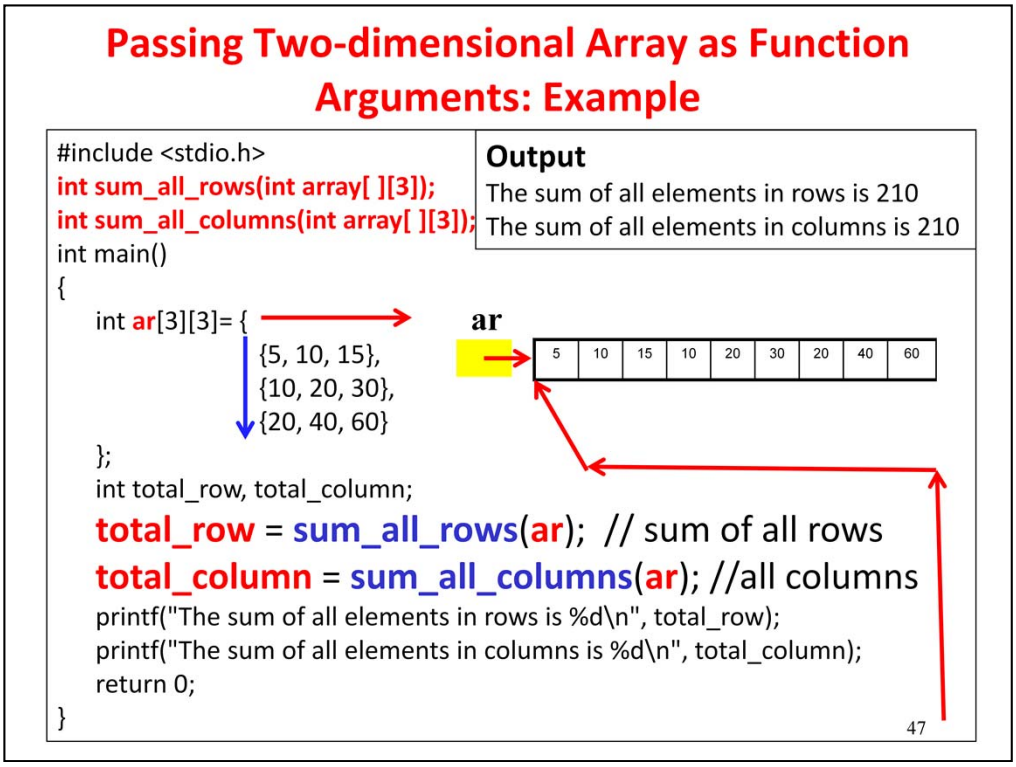
   void function(int array[][4]);

In the **main()** function, it calls **function()** as follows:

```
int table[2][4];
....
function(table);
```

Similar to one-dimensional array, the name of the array **table** is specified as the argument without any subscripts in the function call.

The above discussion and definition of two-dimensional arrays can be generalized to the arrays of higher dimensions.



Passing Two-dimensional Array as Function Arguments: Example

1. The program determines the total sum of all the rows and the total sum of all the columns of a two-dimensional array. Two functions **sum_all_rows()** and **sum_all_columns()** are written to compute the total sums. Both functions take an array as its argument:

   int sum_all_rows(int array[][3])

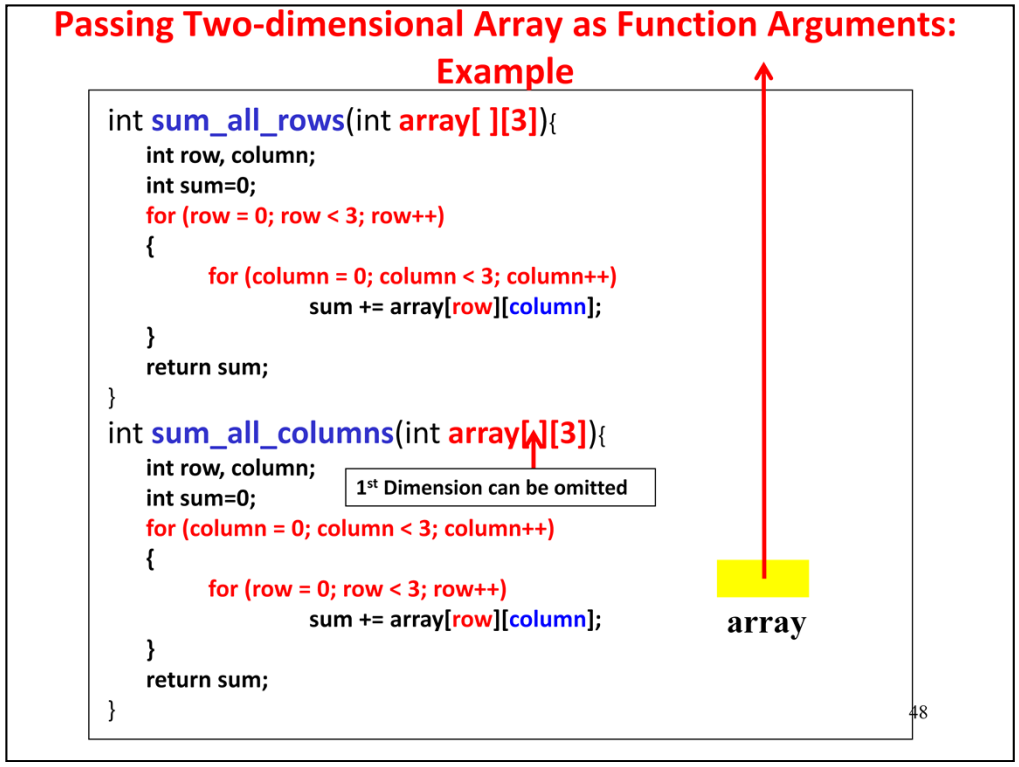
   int sum_all_columns(int array[][3])

2. Note that the first dimension of the array parameter in the function prototype can be omitted. When calling the functions, the name of the array is passed to the calling functions:

   total_row = sum_all_rows(ar);

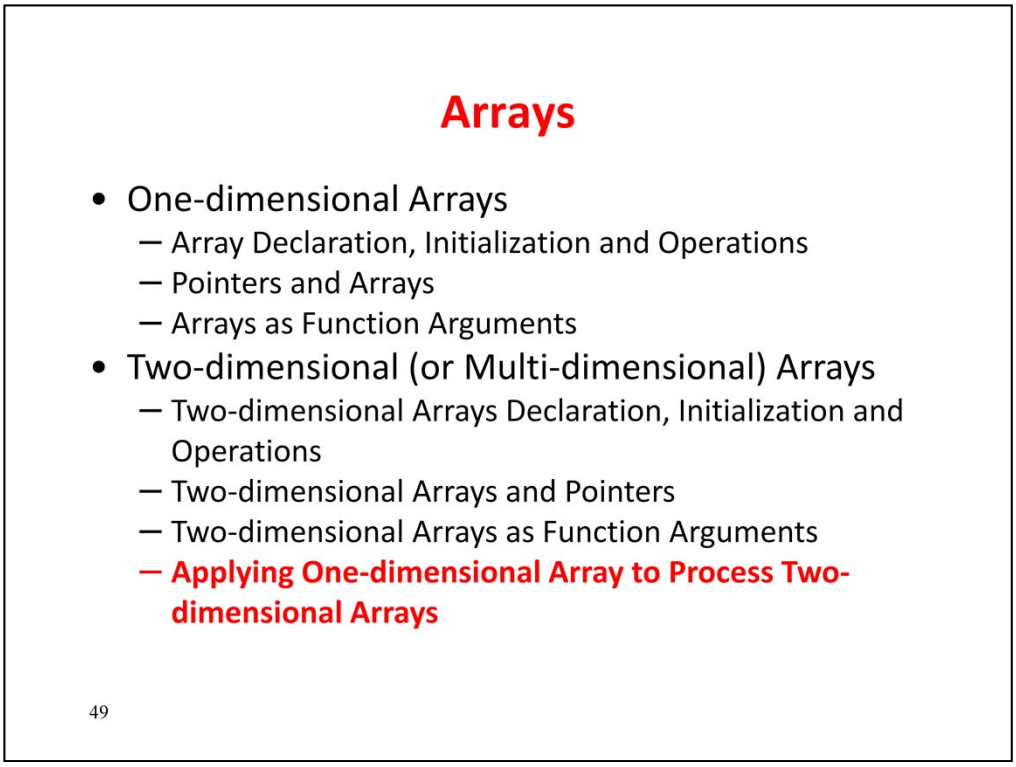
   total_column = sum_all_columns(ar);

3. The total values are computed in the two functions and placed in the two variables **total_row** and **total_column** respectively.



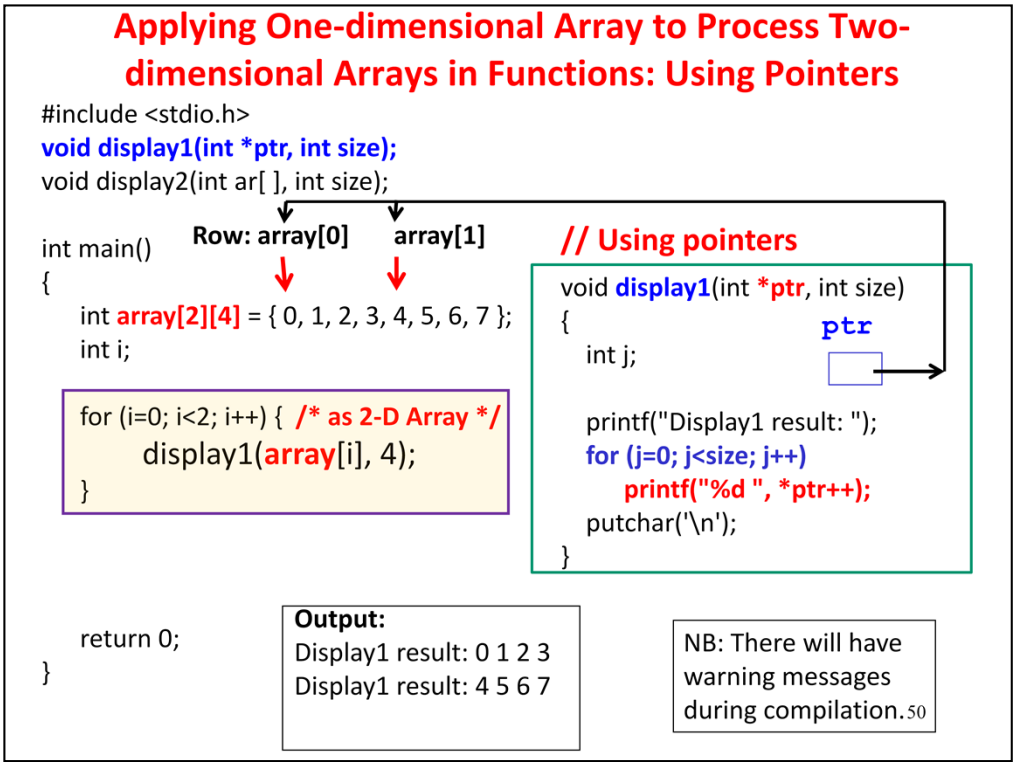
Passing Two-dimensional Array as Function Arguments: Example

1. Note that the first dimension of the array parameter **array** in the function **sum_all_rows()** can be omitted. A nested **for** loop is used to traverse the 2-dimensional array in order to compute the sum of all rows. The result **sum** is then returned to the calling **main()** function.
2. Similarly, the first dimension of the array parameter **array** in the function **sum_all_columns()** can be omitted. The function **sum_all_columns()** is implemented similarly to **sum_all_rows()**.



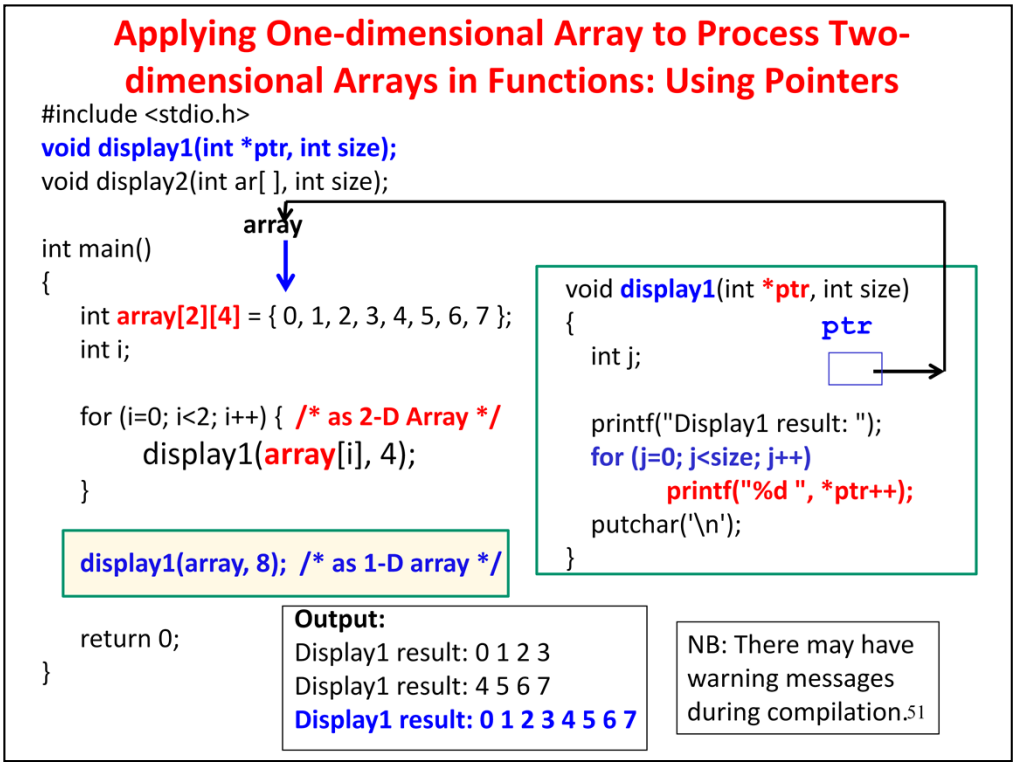
Arrays - Two-dimensional Arrays

1. Here, we discuss how to apply one-dimensional array to process two-dimensional arrays.



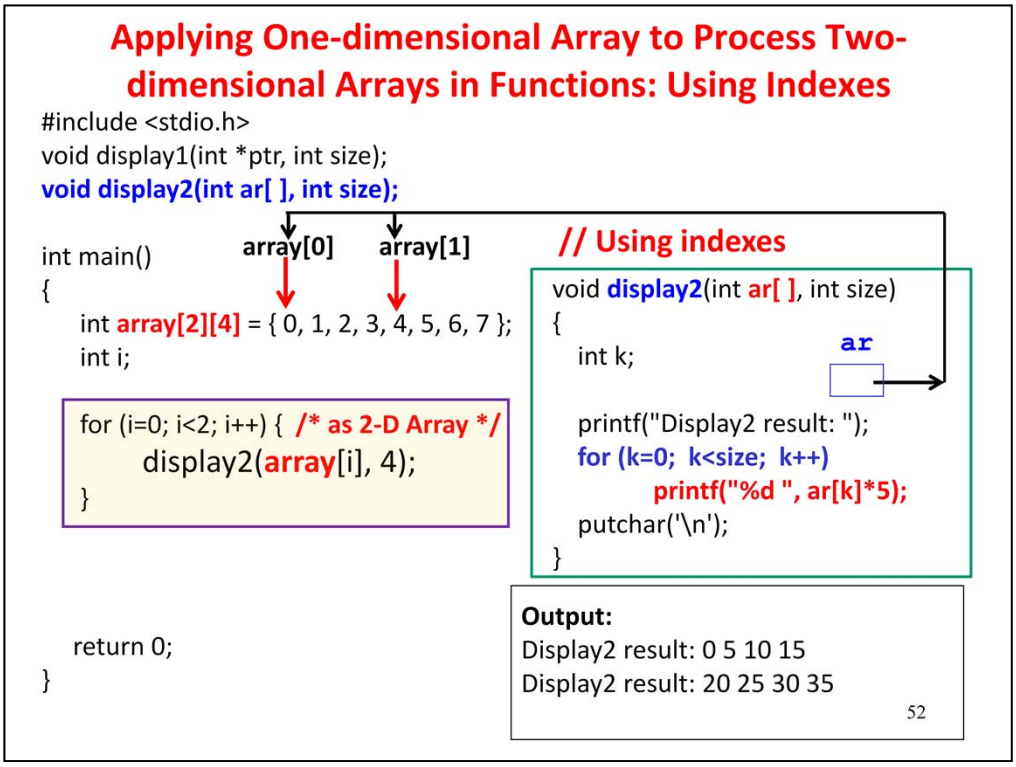
Applying One-dimensional Array to Process Two-dimensional Arrays – using Pointers

1. A function that is written for processing one-dimensional arrays can be used to deal with two-dimensional arrays.
2. In the program, **array** is an array of 2x4 integers. The function **display1()** is written to access the elements of the array with the specified **size** and prints the contents to the screen.
3. In **display1()**, it accepts a pointer variable and accesses the elements of the array using the pointer variable.
4. In the **for** loop of the **main()** function, when **i=0**, we pass **array[0]** to **display1()**. **array[0]** corresponds to the address of **array[0][0]** (i.e. **&array[0][0]**). The function then accesses the array starting from the location **array[0][0]**, and prints the 4 elements out to the display as specified in the function.
5. When **i=1**, **array[1]** is passed to **display1()**. Now, **array[1]** corresponds to the address of **array[1][0]** (i.e. **&array[1][0]**).
6. The function then accesses the 4 elements starting from **array[1][0]**, and print the contents of the 4 elements.



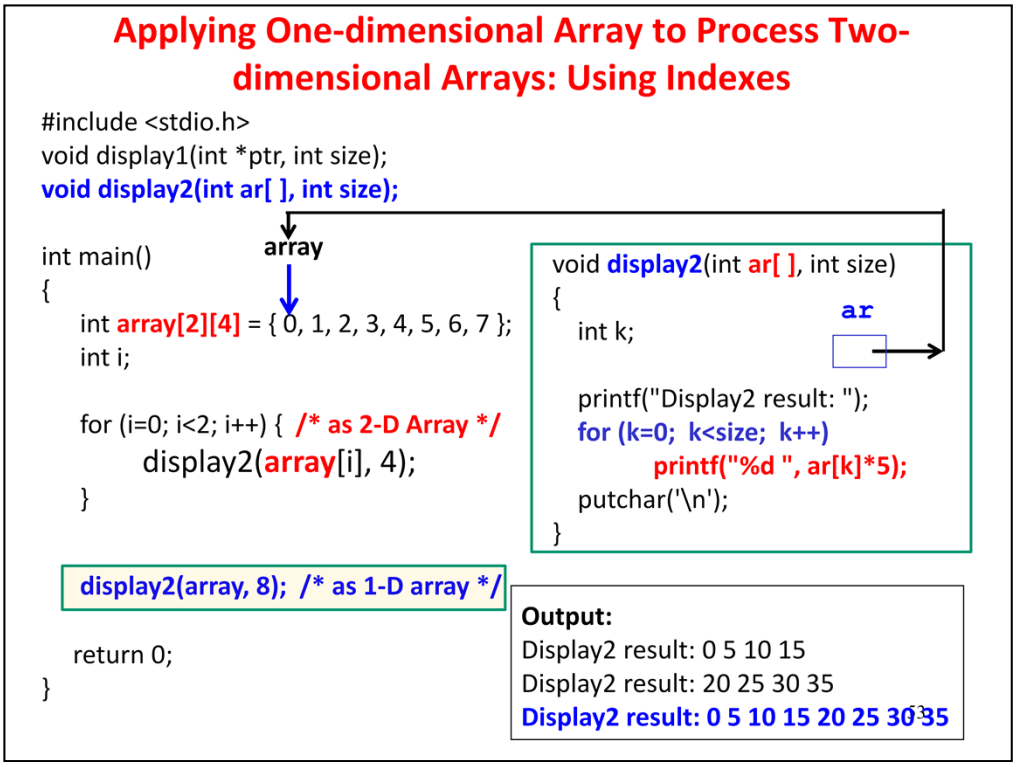
Applying One-dimensional Array to Process Two-dimensional Arrays – using Pointers

1. We can also view **array** as an array of 8 integers. When we pass **array** as an argument to the functions **display1()** with **display1(array, 8);** the pointer **ptr** in the function **display1()** is initialized to the address of **array[0][0]**. As a result, dereferencing the pointer variable ***ptr** corresponds to **array[0][0]**, while ***(ptr+1)** corresponds to **array[0][1]**.
2. Similarly, ***(ptr+4)** corresponds to **array[1][0]**, and so on.
3. Therefore, all the elements of the two-dimensional array can be accessed via the pointer variable **ptr** and printed to the screen.



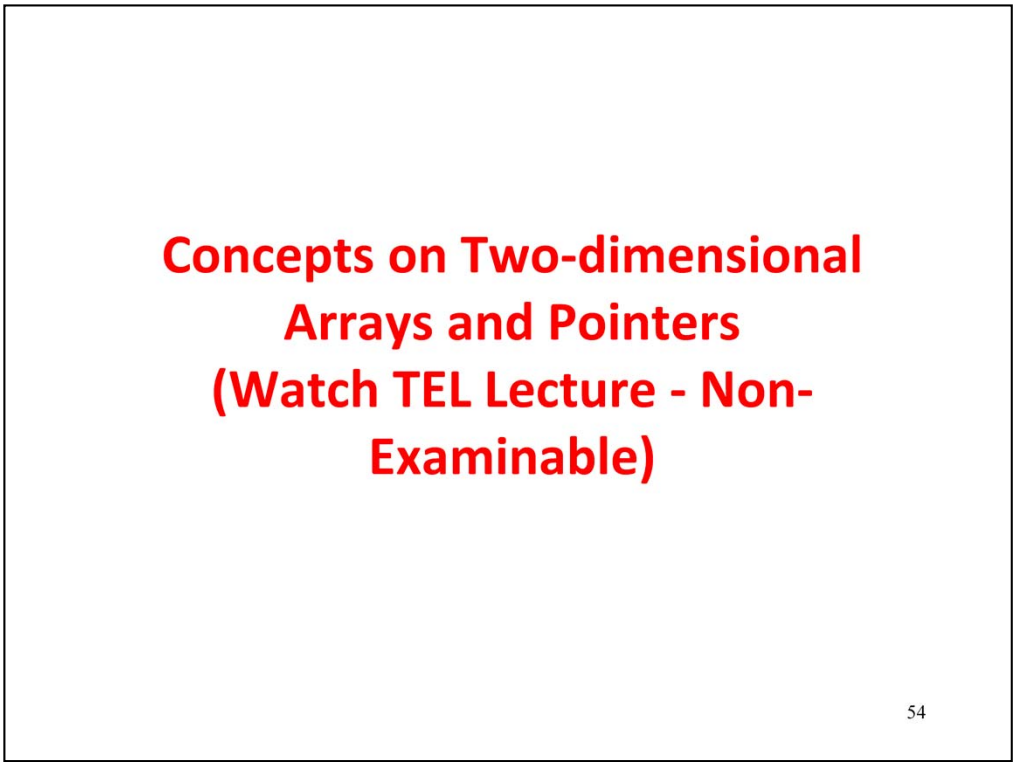
Applying One-dimensional Array to Process Two-dimensional Arrays – using Indexes

1. In the program, **array** is an array of 2x4 integers. The function **display2()** is written to access the elements of the array with the specified **size** and prints the contents to the screen.
2. In **display2()**, it accepts the array pointer and uses array index to access the elements of the array.
3. In the **for** loop of the **main()** function, when **i=0**, we pass **array[0]** to **display2()**. **array[0]** corresponds to the address of **array[0][0]** (i.e. **&array[0][0]**). The function then accesses the 4 elements of the array starting from the location **array[0][0]**, and prints the results to the display as specified in the function.
4. When **i=1**, **array[1]** is passed to **display2()**. Now, **array[1]** corresponds to the address of **array[1][0]** (i.e. **&array[1][0]**).
5. The function then accesses the 4 elements starting from **array[1][0]**, and prints the results according to the function.



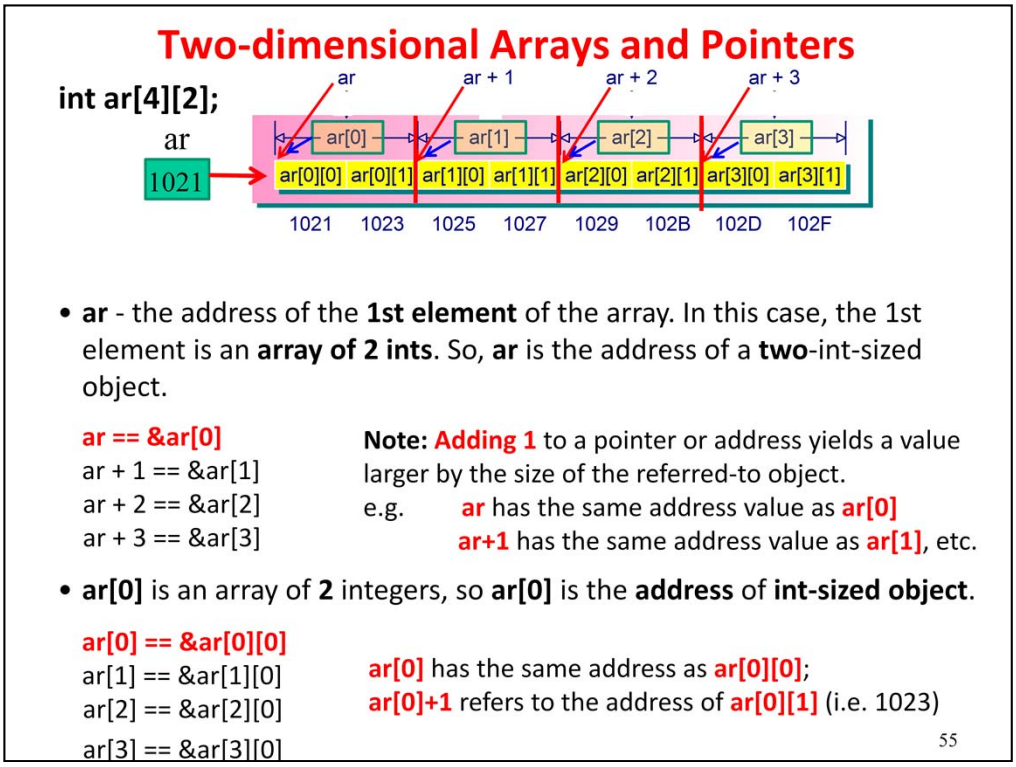
Applying One-dimensional Array to Process Two-dimensional Arrays – using Indexes

1. We can also view **array** as an array of 8 integers. When we pass **array** as an argument to the function **display2()** with **display2(array, 8);** the array **ar** in the function **display2()** is initialized to the address of **array[0][0]**. As a result, **ar[0]** corresponds to **array[0][0]**, while **ar[1]** in the function **display2()** corresponds to **array[0][1]**.
2. Similarly, **ar[4]** in the function **display2()** correspond to **ar[1][0]**, and so on.
3. Therefore, all the elements of the two-dimensional array can be accessed and printed to the screen.



Two-dimensional Arrays and Pointers - Concepts

1. Here, we discuss the concepts behind on using pointers for two-dimensional arrays.



Two-dimensional Arrays and Pointers

1. The memory layout of the two-dimensional array is shown with its associated pointers.
2. The first element is an array of 2 integers. **ar** is the address of a two-integer sized object.
3. Therefore, we have

   ar == &ar[0]

   ar + 1 == &ar[1]

   ar + 2 == &ar[2]

   ar + 3 == &ar[3]

4. **ar[0]** is an array of 2 integers, so **ar[0]** is the address of an integer sized object.
5. Therefore, we have

   ar[0] == &ar[0][0]

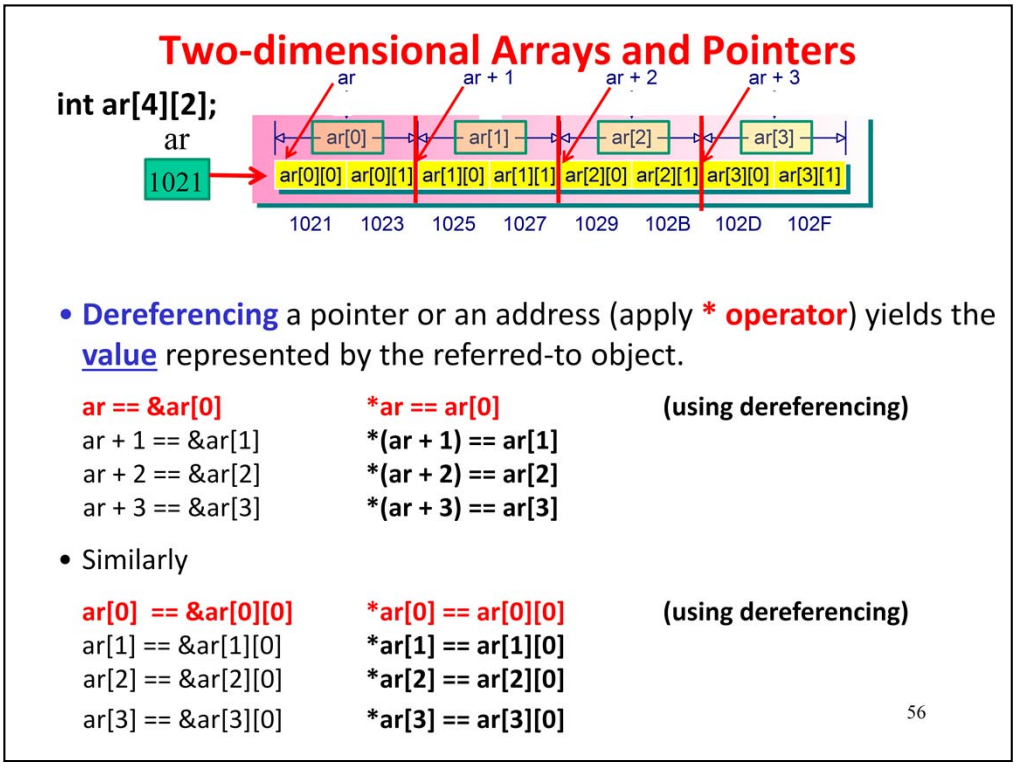
   ar[1] == &ar[1][0]

   ar[2] == &ar[2][0]

   ar[3] == &ar[3][0]

6. Note that adding 1 to a pointer or address yields a value larger by the size of the referred-to object. For example, although **ar** has the same address value as **ar[0]**, **ar+1** (i.e. 1025) is different from **ar[0]+1** (i.e. 1023). This is due to the fact that **ar** is a two-integer sized object.
7. On the other hand, **ar[0]** is an integer sized object. Adding 1 to **ar** increases by 4 bytes.

ar[0] refers to ***ar**, which is the address of an integer, adding 1 to it increases by 2 bytes.



Two-dimensional Arrays and Pointers

1. **Dereferencing** a pointer or an address (by applying the dereferencing ***operator**) yields the **value** represented by the referred-to object.

   ar == &ar[0], using dereferencing we have ***ar == ar[0]**

   ar + 1 == &ar[1], using dereferencing we have ***(ar + 1) == ar[1]**

   ar + 2 == &ar[2], using dereferencing we have ***(ar + 2) == ar[2]**

   ar + 3 == &ar[3], using dereferencing we have ***(ar + 3) == ar[3]**

2. Similarly, we have

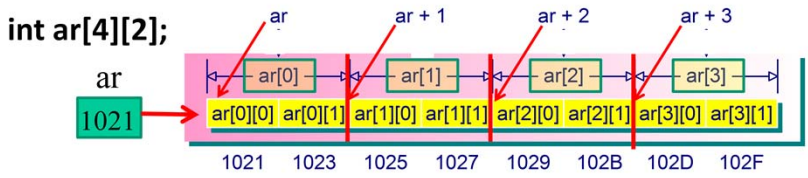
   ar[0] == &ar[0][0], using dereferencing we have ***ar[0] == ar[0][0]**

   ar[1] == &ar[1][0], using dereferencing we have ***ar[1] == ar[1][0]**

   ar[2] == &ar[2][0], using dereferencing we have ***ar[2] == ar[2][0]**

   ar[3] == &ar[3][0], using dereferencing we have ***ar[3] == ar[3][0]**

Two-dimensional Arrays and Pointers



- Therefore:
  - ***ar[0]** == the value stored in **ar[0][0]**.
  - ***ar** == the value of its first element, **ar[0]**.

  we have
  - ****ar** == the value of **ar[0][0]** (***double indirection***)

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Two-dimensional Arrays and Pointers

1. We can use the dereferencing operator * to dereference a pointer or an address to yield the value represented by the referred-to object:

   ***ar[0]** == the value stored in **ar[0][0]**

2. Since

   ***ar** == the value of its first element, **ar[0]**

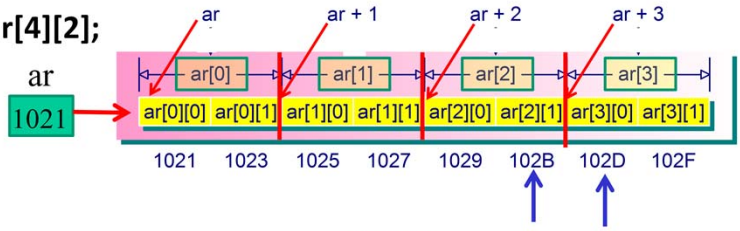
3. We have

   ****ar** == ***(ar[0]) == ar[0][0]**

4. This is called *double indirection*. Therefore, to obtain **ar[0][0]**, we can achieve it through ****ar** via double dereferencing.

Two-dimensional Arrays and Pointers

int ar[4][2];



- After some calculations using **double** dereferencing as shown above, we will get the general formula for using pointer to access each element of a 2-D array **ar** with row=**m**, column=n, as follows:

  ar[m][n] == *(*(ar + m) + n)

  e.g. **ar[2][1]** = *(*(ar + **2**) + **1**) [m=2, n=1]
  ar[3][0] = *(*(ar + **3**) + **0**) [m=3, n=0]

Note: you are not required to remember the calculation on deriving the general formula.

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Two-dimensional Arrays and Pointers

1. After some calculations using **double** dereferencing as shown above, we can represent each individual element of a two-dimensional array as **ar[m][n] == *(*(ar+m)+n)**, where **m** is the index associated with **ar**, and **n** is the index associated with the sub-array **ar[m]**.
2. This can be interpreted as follows: First, dereferencing ***(ar+m)** to get the address of the inner array of **ar** according to the row number **m**. Then, by adding the column number **n** to ***(ar+m)**, i.e. ***(ar+m)+n**, it becomes the address of the element of **ar[m][n]**. Applying the * operator to that address gives the content at that address location, i.e. the array element content.
3. Note that you are not required to remember the calculation on deriving the general formula.

Thank you !!!

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