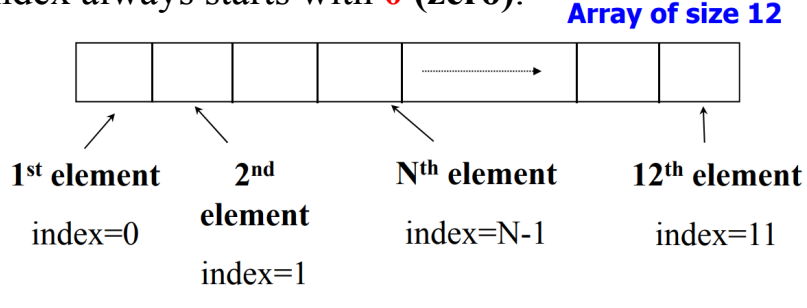
CS100
Introduction to Programming

Lecture 7. Arrays

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**.
- Index always starts with **0** **(zero)**.

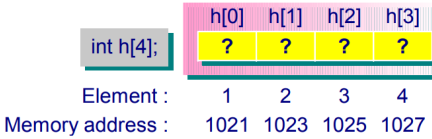


Array Declaration

- 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 a for the whole array (assu

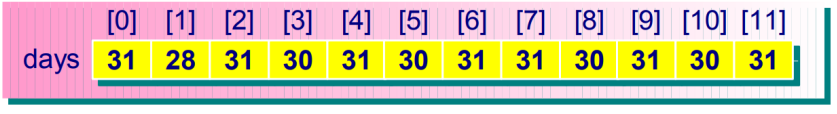


- The size of an array must be an integer constant or

Initialization of Arrays

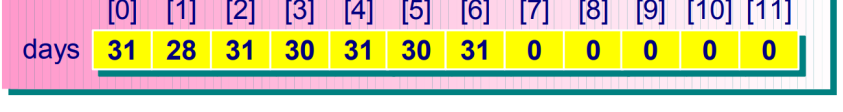
- Initialize array variables at declaration:

```
#define MTHS 12        /* define a constant */
int days[MTHS]={31,28,31,30,31,30,31,31,30,31,30,31};
```



- Partial array initialization, e.g. to initialize the first 7 elements:

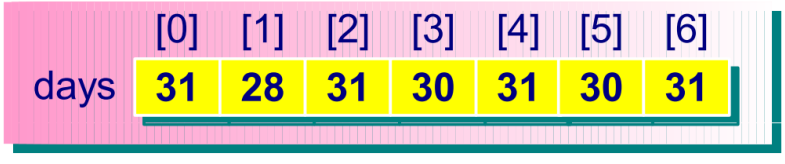
```
#define MTHS 12
int days[MTHS] = {31, 28, 31, 30, 31, 30, 31};
    /* remaining elements are initialized to 0 */
```



Initialization of Arrays

- Omitting the size in array initialization:

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



Operations on Arrays

- Accessing array elements:

```
sales[0] = 143.50;
if (sales[23] == 50.0) …
```

- **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’;    // error: index out of range
```

- Working on array values:

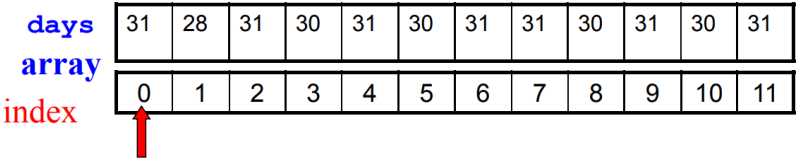
```
days[1] = 20;              // valid
days[2] = days[2] + 4;          // valid
```

Traversing an Array

- One of the most common actions in dealing with arrays is to examine every array element in order to perform an operation.

- This action is also known as **traversing** an array.

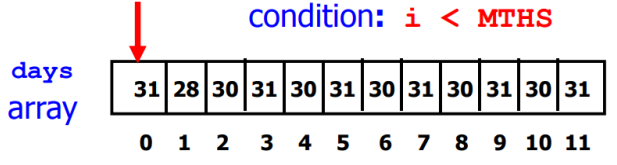
- Example:
  - Traverse the days[] array to display every element's content:



Traversing an Array – print values

```
#include <stdio.h>
#define MTHS 12   // define a constant
int main(void)
{
   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 – search for a value

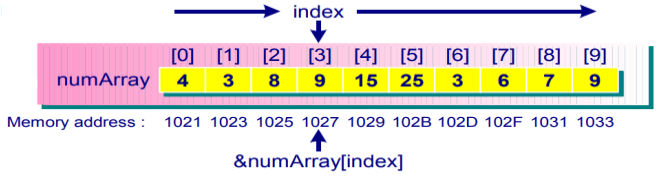
```
#include <stdio.h>
#define SIZE 5   // define a constant
int main(void)
{
  char myChar[SIZE] = {'b', 'a', 'c', 'k', 's'};
  // Reading in user's input to search
  printf("Enter a char to search: ");
  char searchChar;
  scanf("%c", &searchChar);
  /* Traverse myChar array and output the index of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

Output:
Enter a char to search: ***a***
Found a at index 1

Traversing an Array – find maximum value

```
/* This example shows how to find the largest value in an array of
numbers. */
#include <stdio.h>
int main(void)
{
  int i, max, numArray[10];
  max = -1;
  printf("Enter 10 numbers: \n");
  for (i = 0; i < 10; i++)
    scanf("%d", &numArray[index]);
  for (i = 0; i < 10; i++) {
    if (numArray[i] > max)
      max = numArray[i];
  }
  printf("The max value is %d.\n", max);
  return 0;
}
```

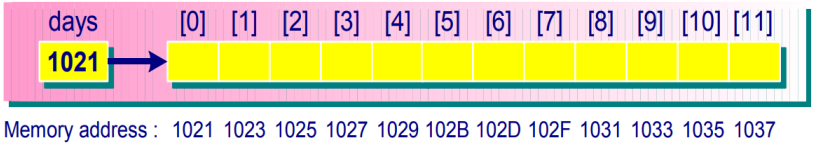
Output:
Enter 10 numbers:
4 3 8 9 15 25 3 6 7 9
The max value is 25.



Pointers and Arrays

- The array name is really a **pointer constant**:

  e.g. int days[12];



- If an integer is represented by 2 bytes and the array **days** begins at memory location **1021**, the above figure shows the layout of the array.

- Address of an array element: e.g. int h[5];

  &h[0] is the address of the 1st element

  &h[i] is the address of the (i+1)-th element

Pointers and Arrays

- Thus, **days**, the array name by itself, is really the **address (or pointer)** of the 1st element of the array, e.g. when using the array of int days[12], the following expressions are all true:

```
days == &days[0]
*days == days[0]
days + 1 == &days[1]
*(days + 1) == days[1]
```

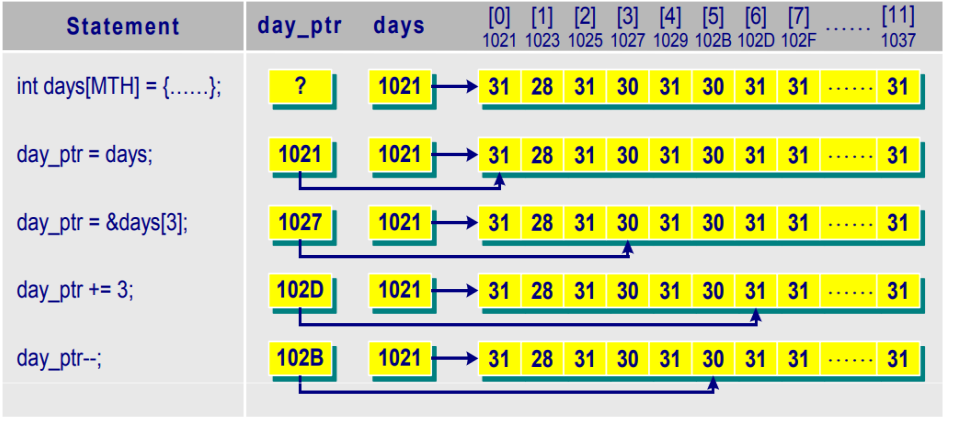
- You cannot change the value of the array name, because it is a **pointer constant**, **not a pointer variable**:

Pointers and Arrays

A ***pointer variable*** can take on different addresses, but an array cannot:

```
/* pointer arithmetic */
#define MTHS 12
int main(void)
{
  int days[MTHS] = {31,28,31,30,31,30,31,31,30,31,30,31};
  int *day_ptr;
  day_ptr = days;        /* points to the first element */
  day_ptr = &days[3];    /* points to the fourth element */
  day_ptr += 3;          /* points to the seventh element */
  day_ptr--;             /* points to the sixth element */
  return 0;
}
```

Pointers and Arrays



Pointer – Finding Maximum Number

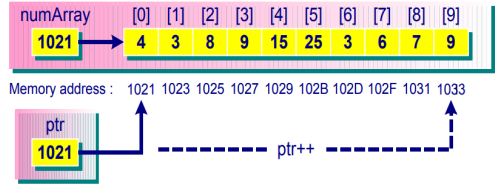
```
#include <stdio.h>
int main(void)
{
  int i, max, numArray[10];
  printf("Enter 10 numbers: \n");
  for (i = 0; i < 10; i++)
     scanf("%d", numArray + i);

  max = *numArray;
  for (i = 1; i < 10; i++) {
     if (*(numArray + i) > max)
        max = *(numArray + i);
  }
  printf("The max value is %d.\n", max);
  return 0;
}
```

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

Pointer – Finding Maximum Number

```
#include <stdio.h>
int main(void) {
   int i, max, numArray[10];
   int *ptr;
   ptr = numArray;
   printf("Enter 10 numbers: \n");
   for (i = 0; i < 10; i++)
      scanf("%d", ptr++);
   ptr = numArray;
   max = *ptr;
   for (i = 1; i < 10; i++) {  // find the max
      if (*ptr > max)
         max = *ptr;
      ptr++;
   }
   printf("max is %d.\n", max);
   return 0;
}
```

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



Arrays as Function Arguments

- Any dimensional array can be passed as a function argument, e.g.

fn(table); /* call a function */

where **fn()** is a function and **table** is a 1-D array.

- An array is passed **by reference** to a function. This means that the **address** of the first element of the array is passed to the function.

Arrays as Function Arguments

```
void fn(int table[], int n)
{
  ……
}
```

```
void fn(int
table[TABLESIZE])
{
  ……
}
```

```
void fn(int *table, int n)
{
  ……
}
```

- The prototype of the function becomes
  void fn(int table[], int n); or
  void fn(int table[TABLESIZE]); or
  void fn(int *table, int n);

Passing an Array as a Function Argument

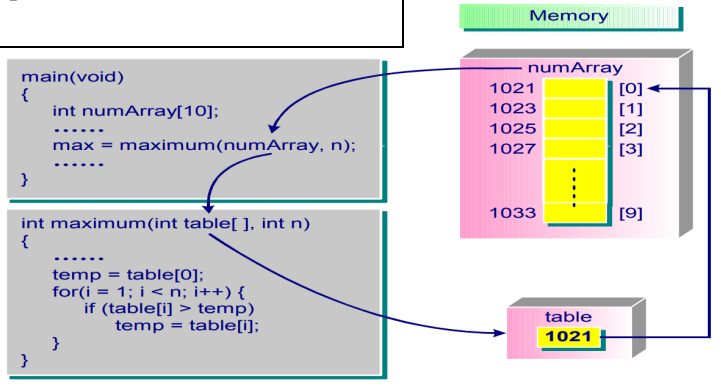
```
#include <stdio.h>

int maximum(int table[], int n);

int main(void)
{
  int max, i, n;
  int numArray[10];
  printf("Enter the number of values:");
  scanf("%d", &n);
  printf("Enter %d values: ", n);
  for (i = 0; i < n; i++)
     scanf("%d", &numArray[i]);
  max = maximum(numArray, n);
  printf("The max value is %d.\n", max);
  return 0;
}
```

Output:

Enter the number of values: ***5***
Enter 5 values: ***1 2 3 4 5***
The max value is 5.

```
int maximum(int table[], int n)
{
  int i, temp;
  temp = table[0];
  for (i = 1; i < n; i++)
    if (table[i] > temp)
      temp = table[i];
  return temp;
}
```

Passing an Array as a Function Argument



Multidimensional Arrays

- Declared as consecutive pairs of brackets.
- E.g. A 2-dimensional array, or a 3-element array of 5-element arrays:

  int x[3][5];

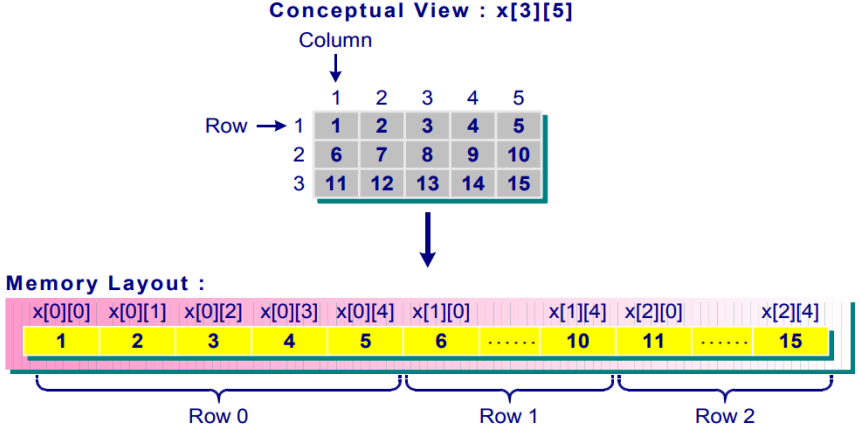
- E.g. A 3-dimensional array, or a 3-element array of 4-element arrays of 5-element arrays:

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

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

Multidimensional Arrays

	Column 0	Column 1	Column 2	Column 3	Column 4
Row 0	x[0][0]	x[0][1]	x[0][2]	x[0][3]	x[0][4]
Row 1	x[1][0]	x[1][1]	x[1][2]	x[1][3]	x[1][4]
Row 2	x[2][0]	x[2][1]	x[2][2]	x[2][3]	x[2][4]



Initializing Multidimensional Arrays

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

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

or

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

- Partial initialization (other cells are set to 0):

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

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

or

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

Initializing Multi-dimensional Arrays

- You can omit the outermost dimension because compiler can figure that out, e.g.

```
int arr[][3][2] = {
    { {1, 1}, {0, 0}, {1, 1} },
    { {0, 0}, {1, 2}, {0, 1} }
};
```

gives a [2][3][2] dimensioned array.

- The following is not correct. Why?

```
int wrong_arr[][] = {1, 2, 3, 4};
```

Operations on Multidimensional Arrays

```
#include <stdio.h>
int main(void)
{
  int array[3][3] = {
        {5, 10, 15},
        {10, 20, 30},
        {20, 40, 60}
     };
  int row, column, sum;
  /* sum of rows */
  for (row = 0; row < 3; row++) {
     sum = 0;
     for (column = 0; column < 3; column++)
        sum += array[row][column];
     printf("The sum of elements in row %d is %d\n",          row + 1,
sum);
  }
```

Code continues in next slide …

Operations on Multidimensional Arrays

```
  /* sum of columns */
  for (column = 0; column < 3; column++) {
     sum = 0;
     for (row = 0; row < 3; row++)
        sum += array[row][column];
     printf("The sum of elements in column %d is %d\n",
column + 1, sum);
  }
  return 0;
}
```

Output:

```
The sum of elements in row 1 is 30
The sum of elements in row 2 is 60
The sum of elements in row 3 is 120
The sum of elements in column 1 is 35
The sum of elements in column 2 is 70
The sum of elements in column 3 is 105
```

Multidimensional Arrays and Pointers

- Multidimensional arrays are also stored sequentially in memory, e.g.

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

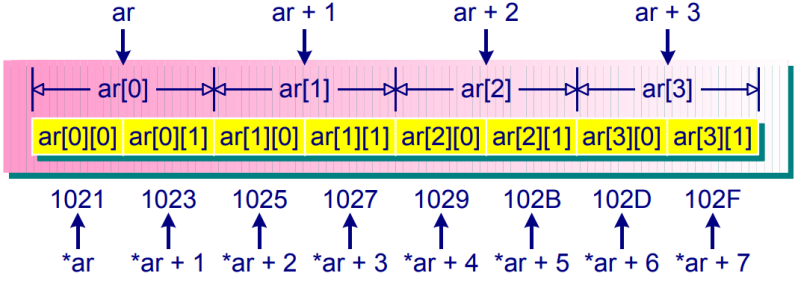
- **ar** is the address of the 1st element of the array. In this case, the 1st element is an array of 2 integers. Thus, ar is the address of a two-int-sized object.

```
ar == &ar[0]       *ar == ar[0]
ar + 1 == &ar[1]   *(ar + 1) == ar[1]
ar + 2 == &ar[2]   *(ar + 2) == ar[2]
ar + 3 == &ar[3]   *(ar + 3) == ar[3]
```

Multidimensional Arrays and Pointers

- **ar[0]** is an array of 2 integers; ar[0] is the address of an int-sized object.

ar[0] == &ar[0][0]	*ar[0] == ar[0][0]
ar[1] == &ar[1][0]	*ar[1] == ar[1][0]
ar[2] == &ar[2][0]	*ar[2] == ar[2][0]
ar[3] == &ar[3][0]	*ar[3] == ar[3][0]



Multidimensional Arrays and Pointers

- Adding 1 to a pointer or address yields a value larger **by the size of the referred-to object**.

  E.g. **ar** has the same address value as **ar[0]**, but **ar+1** (1025) is different from **ar[0]+1** (1023)

- Dereferencing a pointer or an address (apply ***operator**) yields the value represented by the referred-to object. For example:

  *(ar[0]) == the value stored in ar[0][0].

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

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

- In general,

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

Multidimensional Arrays as Function Arguments

- The definition of a function with a 2-D array as the argument is:

```
void fn(int ar2[2][4])          or      void fn(int ar2[][4])
{                                       {
    …                                       …
}                                       }
/* the first dimension can be excluded */
```

- In the above definition, the **first dimension can be excluded** because the C compiler needs the information of all but the first dimension.

Multidimensional Arrays as Function Arguments

- For example, the assignment operation

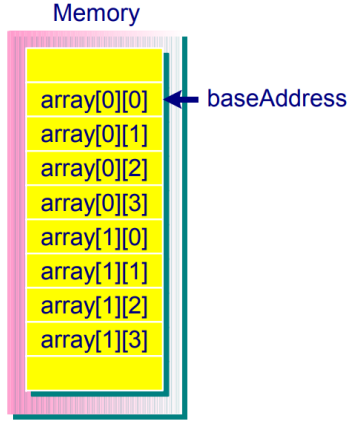
  ar2[1][3] = 100;

  requests the compiler to compute the address of **ar2[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 us redefine **ar2** as

Multidimensional Arrays as Function Arguments

- The **baseAddress** is the address pointing to the beginning of **ar2**. Because **D1** is not needed in computing the address, one can omit the first dimension value in defining a function which takes arrays as its formal arguments.



- The prototype of the function becomes

void fn(int **ar2[2][4]**); or

void fn(int **ar2[][4]**);

Passing 2-D Array as Function Arguments

```
#include <stdio.h>
int sum_rows(int ar[][3]);
int sum_columns(int ar[][3]);
int main(void)
{
  int array[3][3] = {
        {5, 10, 15},
        {10, 20, 30},
        {20, 40, 60}
     };
  int total_row, total_column;
  total_row = sum_rows(array);
  total_column = sum_columns(array);
  printf("The sum of all elements in rows is %d\n",                    total_row);
  printf("The sum of all elements in columns is %d\n",                 total_column);
  return 0;
}
```

Output:

The sum of all elements in rows is 210
The sum of all elements in columns is 210

Passing 2-D Array as Function Arguments

```
int sum_rows(int ar[][3]) {
  int row, column;
  int sum = 0;
  for (row = 0; row < 3; row++) {
    for (column = 0; column < 3; column++)
      sum += ar[row][column];
  }
  return sum;
}

int sum_columns(int ar[][3]) {
  int row, column;
  int sum = 0;
  for (column = 0; column < 3; column++) {
    for (row = 0; row < 3; row++)
      sum += ar[row][column];
  }
  return sum;
}
```

Processing 2-D Arrays as 1-D Arrays

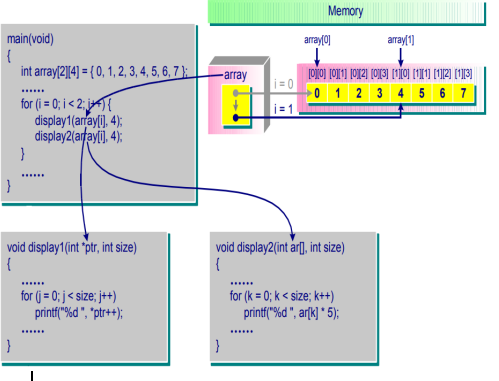
```
#include <stdio.h>
void display1(int *ptr, int size);
void display2(int ar[], int size);
void display3(int ar[][4], int size);

int main(void)
{
  int array[2][4] = {0,1,2,3,4,5,6,7};
  int i;

  for (i = 0; i < 2; i++) {
     display1(array[i], 4);
     display2(array[i], 4);
  }
  display3(array, 2);
  display1(array, 8);
  display2(array, 8);
  return 0;
}
```

Output:

```
Display1 result: 0 1 2 3
Display2 result: 0 5 10 15
Display1 result: 4 5 6 7
Display2 result: 20 25 30 35
Display3 result: 0 10 20 30 40 50 60 70
Display1 result: 0 1 2 3 4 5 6 7
Display2 result: 0 5 10 15 20 25 30 35
```

```
void display1(int *ptr, int size)
{
  int j;
  printf("Display1 result: ");
  for (j=0; j < size; j++)
     printf("%d ", *ptr++);
  putchar('\n');
}
void display2(int ar[], int size)
{
  int k;
  printf("Display2 result: ");
  for (k=0; k < size; k++)
     printf("%d ", ar[k]*5);
  putchar('\n');
}
void display3(int ar[][4], int size)
{
  int i,j;
  printf("Display3 result: ");
  for (i=0; i < size; j++)
     for (j=0; j < 4; j++)
        printf("%d ", ar[i][j]*10);
  putchar('\n');
}
```

Processing 2-D Arrays as 1-D



Passing Array as Pointer Argument

- Passing 1D array as pointer

```
void display(int *ptr, int size)
{
  int i;
  printf("Display result: ");
  for (i=0; i < size; i++)
     printf("%d ", *ptr++);
     //printf("%d ", ptr[i]);
  putchar('\n');
}
```

```
#include <stdio.h>
void display(int *ptr, int size);

int main(void)
{
  int array[8] = {0,1,2,3,4,5,6,7};
  display(array, 8);
 //display(&array[0], 8);
  return 0;
}
```

Passing Array as Pointer Argument

- Passing 2D static array as pointer

```
void display(int *ptr,
  int size1, int size2)
{
  int i, j;
  printf("Display result: ");
  for (i=0; i < size1; i++)
      for (j=0; j < size2; j++)
        printf("%d ", ptr[size2*i+j]);
  putchar('\n');
}
```

```
void display(int **ptr,
  int size1, int size2)
{
  int i, j;
  printf("Display result: ");
  for (i=0; i < size1; i++)
      for (j=0; j < size2; j++)
        printf("%d ", *((int *)ptr+size2*i+j));
  putchar('\n');
}
```

```
#include <stdio.h>
void display(int *ptr, int size1, int size2);
void display(int **ptr, int size1, int size2);

int main(void)
{
  int array[2][4] = {{0,1,2,3},{4,5,6,7}};
  display((int *)array, 2, 4);
  // display((int **)array, 2, 4);
  return 0;
}
```

The sizeof Operator and Array

```
#include <stdio.h>

int main(void)
{
   int ar2[2][4];
   printf("Array size is %d",
          sizeof(ar2) / sizeof(ar2[0][0]));
   return 0;
}
```

Output:
Array size is 8

The sizeof Operator and Array

- sizeof(operand) is an operator which gives the size (how many bytes) of its operand. Its syntax is

  sizeof (**operand**) or

  sizeof operand

- The **operand** can be:

  int, float, …., complexDataTypeName, variableName, arrayName

```
#include <stdio.h>
#define SIZE 5
int item[SIZE] = {1, 2, 3, 4, 5};
void main(void)
{
  total = sum(item, SIZE);
  printf("Size of item = %d\n", sizeof(item));
}
```

The sizeof Operator and Array

```
int sum(int a[], int n)
{
  int i;
  int s = 0;
  printf("Size of a = %d\n", sizeof(a));
  for (i=0; i < n; i++)
     s += a[i];
  return s;
}
```

Output:
Size of a = 4
Size of item = 20

Applying ***sizeof*** to an **array name** yields the array size

BUT

Applying ***sizeof*** to a **pointer variable** yields the size of the pointer

Size of a Pointer

- **What is the size of a pointer?**
  - Always fixed size for pointer of any type
  - OS System dependent
    - Old system: 32bit (4 bytes); can only access 4G memory
    - System nowadays: 64bit (8 bytes); can access very large

```
#include <stdio.h>

void main(void)
{
  float a=10.0; float *p_a=&a;
  int b=5; int *p_b=&b;
  printf("Size of a = %d\n", sizeof(p_a));
  printf("Size of b = %d\n", sizeof(p_b));
}
```

Dynamically Allocated Array

- **Static v.s. dynamic array**
  - Whether the size of the array can be dynamically changed during execution

```
float A[10];


#define SIZE 10
float A[SIZE]


const int SIZE=10;
float A[SIZE];
```

Examples of declaring static array

```
int SIZE=10;
float A[SIZE];
```

How about the dynamic array size?

Dynamically Allocated 1D Array

- **How to achieve dynamic array?**
  - Using pointers
  - With dynamic memory allocation function

```
int main()
{
  int size=10;
  float *pArray=NULL;
  pArray=(float *)malloc(sizeof(float)*size);
  memset(pArray,0,sizeof(float)*size);
  /*access the array*/
  free(pArray);

  return 0;
}
```

Dynamically Allocated 1D Array

- **Access array elements**
  - The allocated array pointer can be taken as the normal array

```
int main()
{
  …
  /*access the array*/
  for(int i=0;i<size;i++)
     pArray[i]=float(i);
   //*(pArray+i)=float(i);
  …

  return 0;
}
```

Dynamically Allocated 2D Array

- **Dynamically allocating 2D array**
  - Using double pointer indexing

```
int main()
{
   int size1=10, size2=8;
   float **pArray=NULL;
   pArray=(float **)malloc(sizeof(float *)*size1);
   for(int i=0;i<size1;i++)
       pArray[i]=(float *)malloc(sizeof(float)*size2);

   /*access the array*/

   for(int i=0;i<size1;i++)
      free(pArray[i]);
   free(pArray);

   return 0;
}
```

Out-of-Bound Array Access

- **What is out-of-bound array access?**
  - The array index is out of the allowable range
  - The range is specified when array is created

```
int main()
{
  int size=10;
  float *pArray=NULL;
  pArray=(float *)malloc(sizeof(float)*size);

  /*access the array*/
  for(int i=0;i<20;i++)
   pArray[i]=float(i);

  free(pArray);
  return 0;
}
```

Memory Leak

- **What is the potential problem for dynamic memory allocation?**
  - The memory may not be released (freed)
  - Completely depend on programmer's design

- **Memory leak**
  - Memory which is no longer needed is not released
  - They can exhaust available system memory as an application runs

Memory Leak

- Example

```
int main()
{
  int size=10;
  float *pArray=NULL;
  pArray=(float *)malloc(sizeof(float)*size);

  /*access the array*/
  for(int i=0;i<size;i++)
   pArray[i]=float(i);

  return 0;
}
```

Memory Leak

- Example

```
float* CreateArray(int size)
{
  return (float *)malloc(sizeof(float)*size);
}

int main()
{
  float* pArray=CreateArray(10);

  /*access the array*/
  for(int i=0;i<10;i++)
   pArray[i]=float(i);

  return 0;
}
```

Dangling Pointer

- **Pointers that do not point to a valid object of the appropriate type**
  - Usually a pointer which points to a dynamically allocated array which has been freed

```
float* InitArray(int size)
{
  float* pArray=(float *)
       malloc(sizeof(float)*size);
  for(int i=0;i<size;i++)
   pArray[i]=0

  free(pArray);

  return pArray;
}
```

```
int main()
{
  float* pArray=InitArray(10);

  /*access the array*/
  for(int i=0;i<10;i++)
   pArray[i]=float(i);

  return 0;
}
```