Pointers

Bilal Khalid Dar
bilal.khalid@nu.edu.pk

Department of Computer Science,
National University of Computer & Emerging Sciences,
Islamabad Campus

C++ Memory Models

- **C++ leaves memory management** mostly **up to the programmer:**

  ve++: write **programs** that **use memory very efficiently**

  Ve--: write **programs** that **waste memory** or **do not work at all**

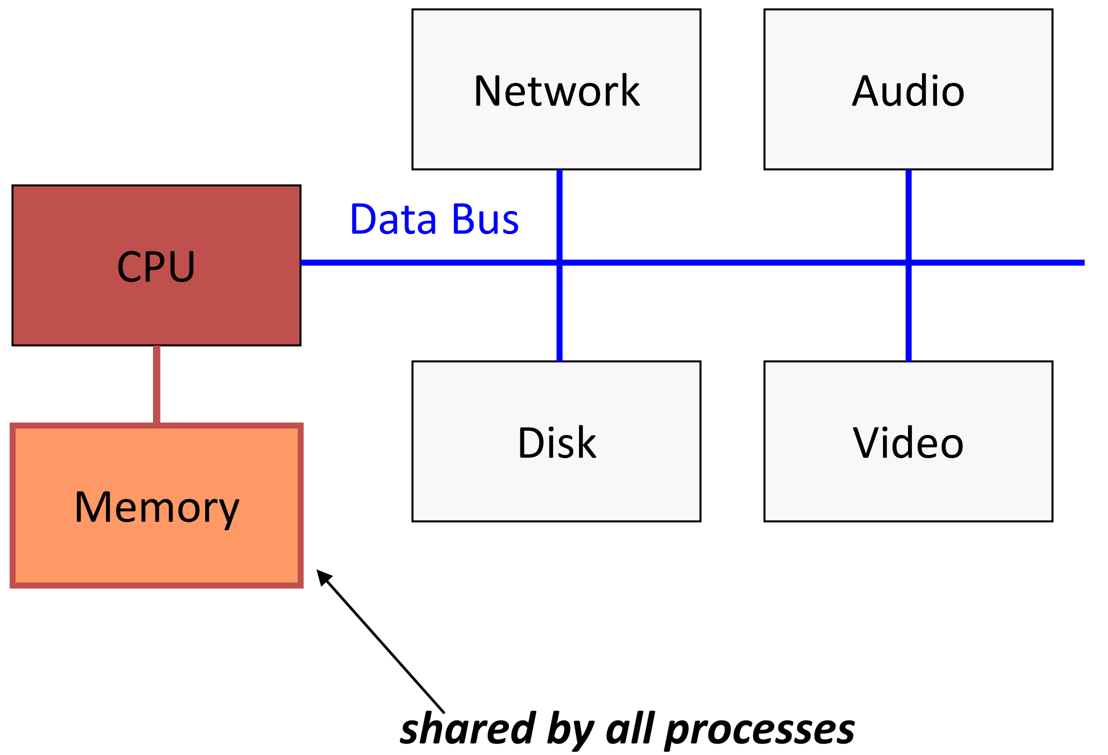
- **For efficient program working**, we need **good understanding** of the **memory models**

C++ Memory Models

- **Common errors** caused by **poor memory management**:
  - **Using** a **variable before** it has been **initialized**
  - **Allocating memory** for storage and **not deleting it**
  - **Using** a **value** after it **has been deleted**

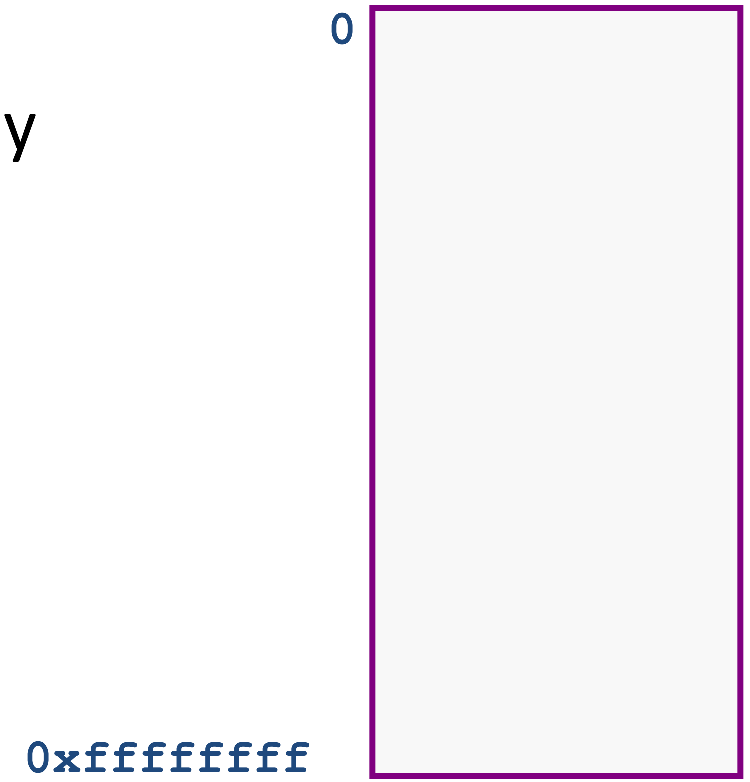
- **What are the solutions?**
  - ....

Main Memory


Network
Audio
Data Bus
CPU
Disk
Video
Memory
shared by all processes

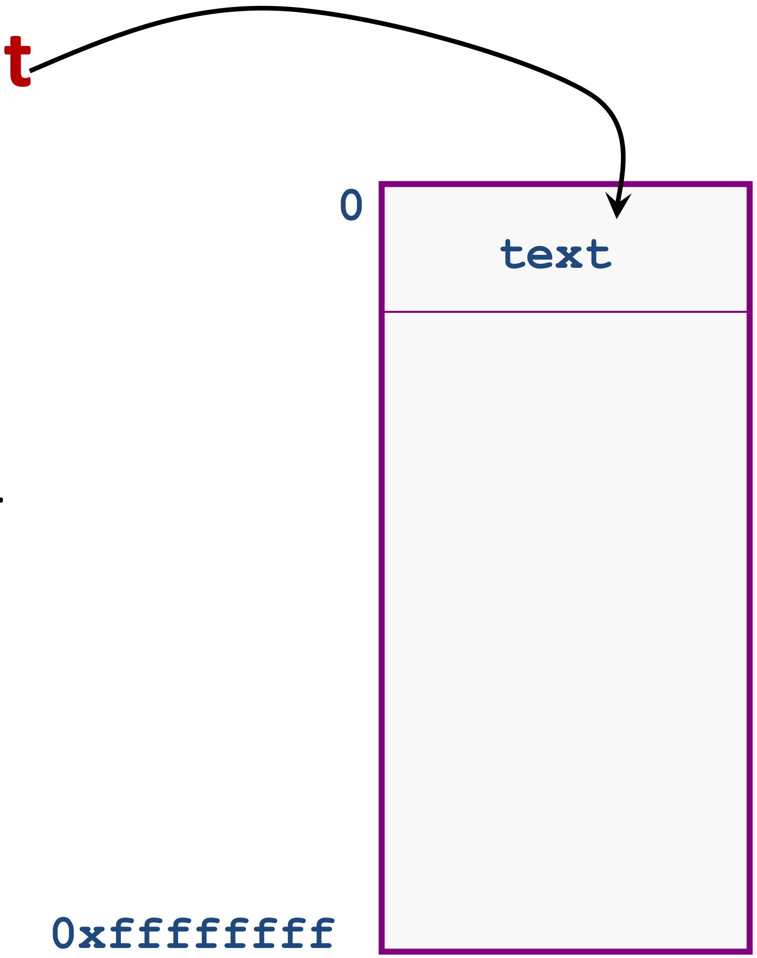
Virtual Memory
(How a CPU see’s a Process?)

- **Continuous memory space for all process:**
  - **Set of locations** as **needed** by a **process**



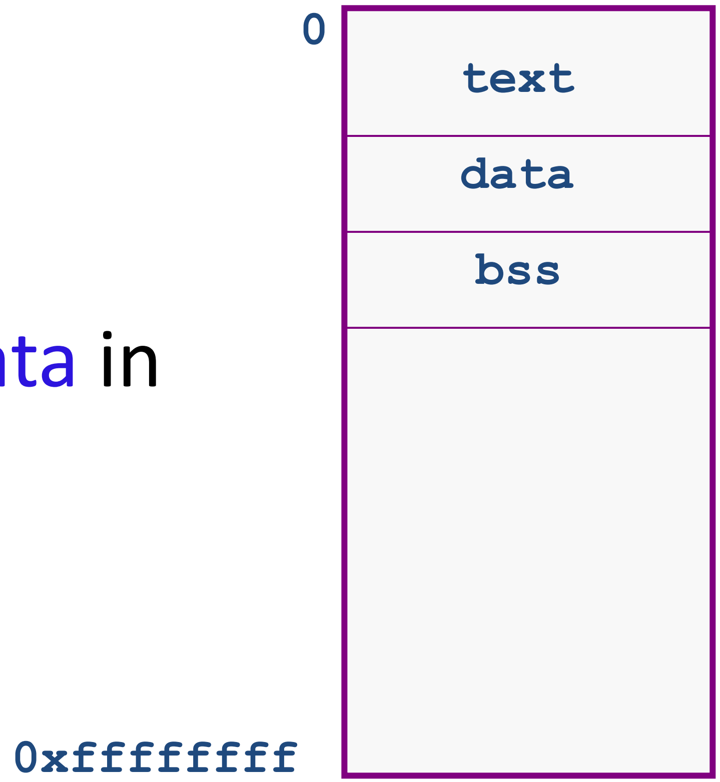
Organization of Virtual Memory: .text

- **Program code** and **constant**
  - binary form
  - loaded libraries
  - code instructions
  - space calculated at compile-time



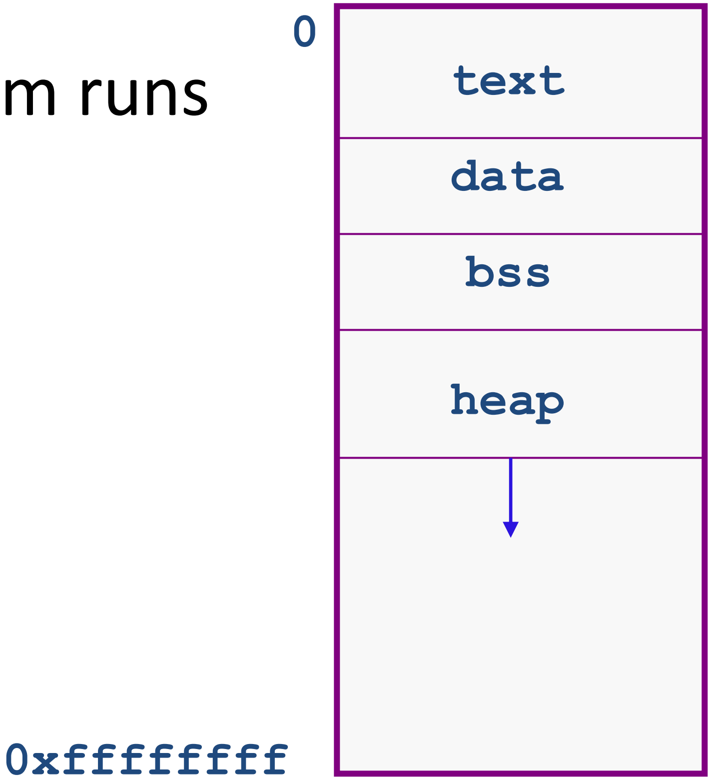
Organization of Virtual Memory: .data

- **Data**: initialized global data in the program
  - Ex: int size = 100;
- **BSS**: un-initialized global data in the program
  - Ex: int length;



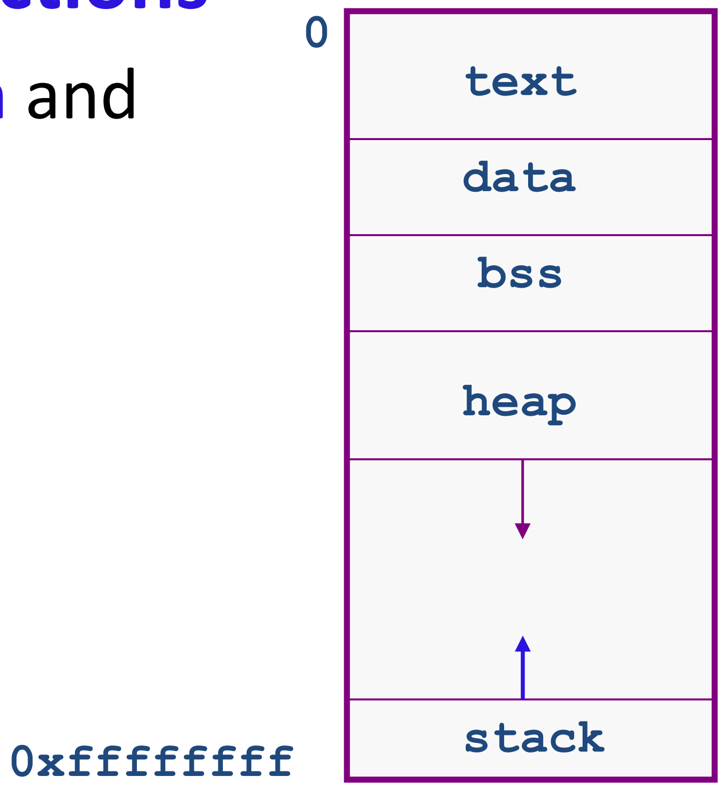
Organization of Virtual Memory: heap

- **Heap**: **dynamically-allocated spaces**
  - Ex: **new**, **delete**
  - **dynamically grows** as program runs



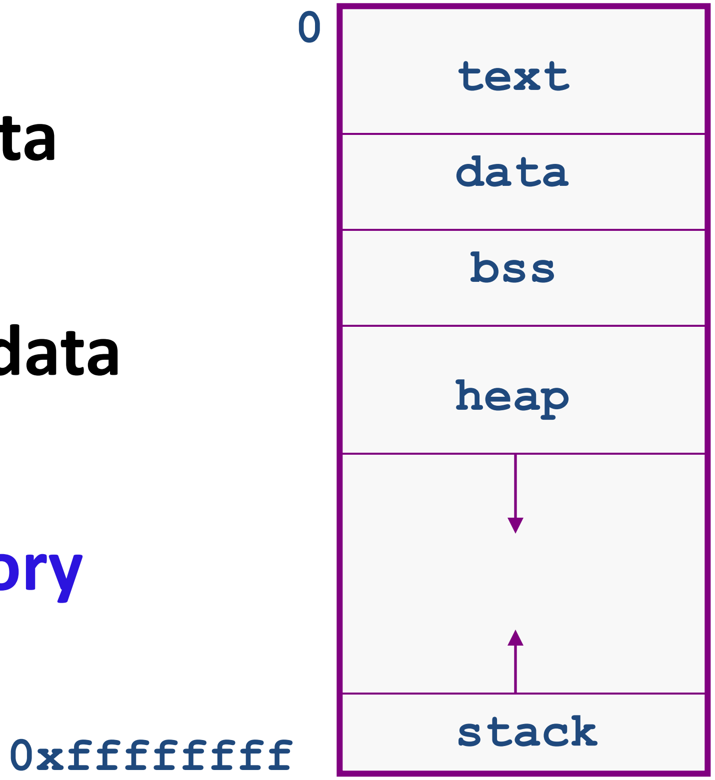
Organization of Virtual Memory: stack

- **Stack**: local variables in **functions**
  - **support function call/return** and **recursive functions**
  - **grow** to **low address**



Summary: Process Address Space

- **text**: program text/code
- **data**: initialized globals & static data
- **bss**: un-initialized globals & static data
- **heap**: dynamically managed memory
- **stack**: function's local variables

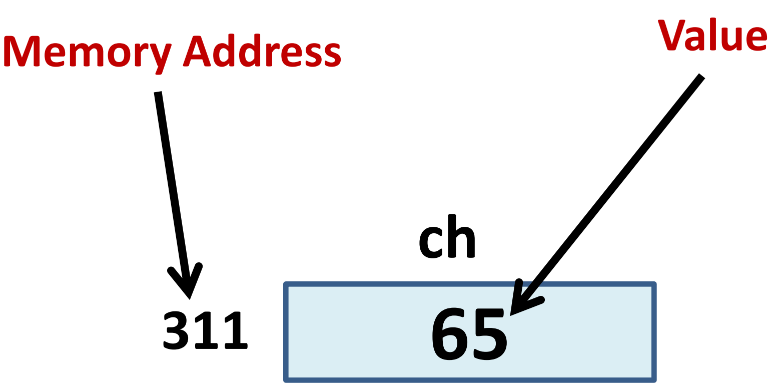


Introduction to Pointers

- When we **declare** a **variable,** some **memory** is **allocated** for it.

- Thus, we have **two properties** for any **variable**:
  1. Its **Address**
  2. and its **Data value**

E.g.,   char ch = ‘A’;



Introduction to Pointers

- **How to get** the **memory-address** of a **variable**?

- Address of a variable can be accessed through the referencing operator "**&**"
  - Example: **&i** ➔ will return **memory location** where the data value for "**i**" is stored.

- A **pointer is a variable,** that **stores** an **address**.

Introduction to Pointers

- We can declare pointers as follows:

Type* <variable Name>;

  - Example:

int* P;

- creates a ***pointer variable*** named **"P"**, that will ***store address*** (memory location) of some **int type** variable.

The address of Operator &

- The **&** operator can be used to **determine** the **address of** a **variable**, which can be assigned to a **pointer variable**
  - Examples:

Dereferencing Operator *

- C++ uses the * **operator** in yet another way with pointers
  - "The variable values pointed to by p" → ***p**
  - Here the * is the **dereferencing operator**

    p is said to be dereferenced

```
int v1=99;
int* p= &v1;
cout<<" P points to the value: "<<*p;
```

Dereferencing Pointer Example

```
int v1 = 0;
int* p1 = &v1;
*p1 = 42;
cout << v1 << endl;
cout << *p1 << endl;
```

v1 and *p1 now refer to the same variable

Output:

```
42
42
```

Pointer Assignment and Dereferencing

- **Assignment operator** (**=**) is used to assign value of one **pointer** to another

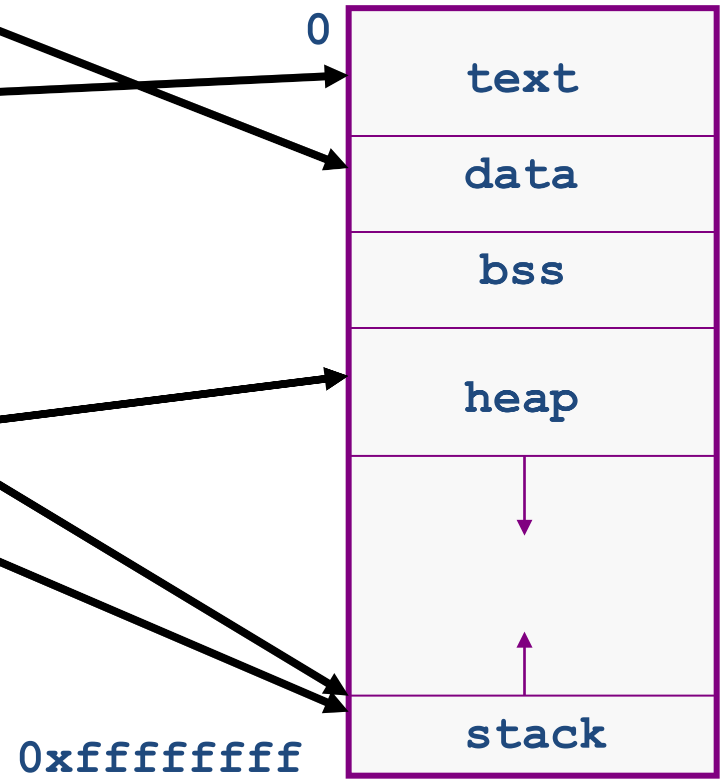
- **Pointer stores addresses** so **p1=p2** copies **an address value** into another pointer

```
int v1 = 55;
int* p1 = &v1;
int* p2;
p2=p1;
cout << *p1 << endl;
cout << *p2 << endl;
```

```
Output:

      55
      55
```

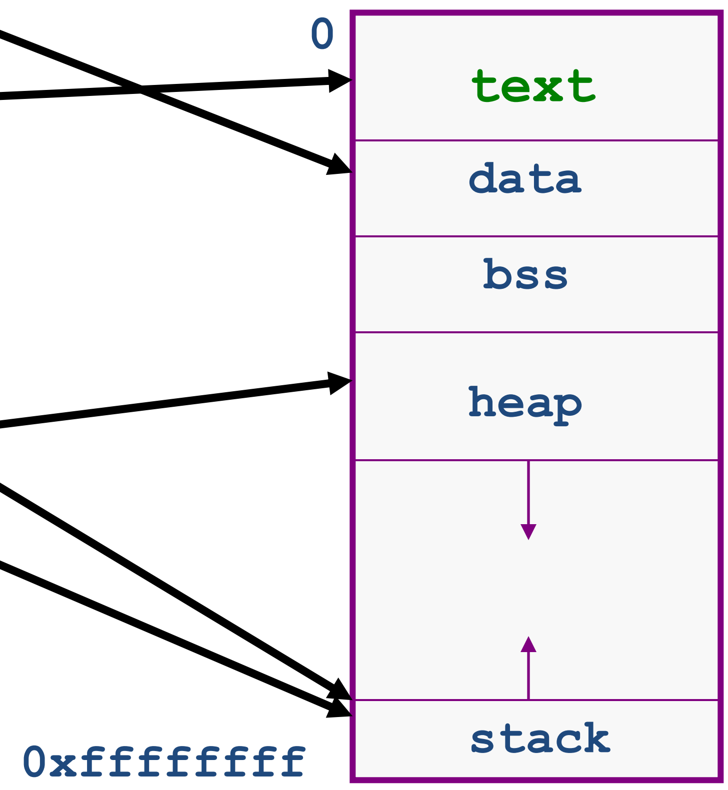
Example

```
char *string = "hello";

const int iSize=8;

char* f(int x)
{
  char *p;

  p = new char[iSize];

  return p;
}
```



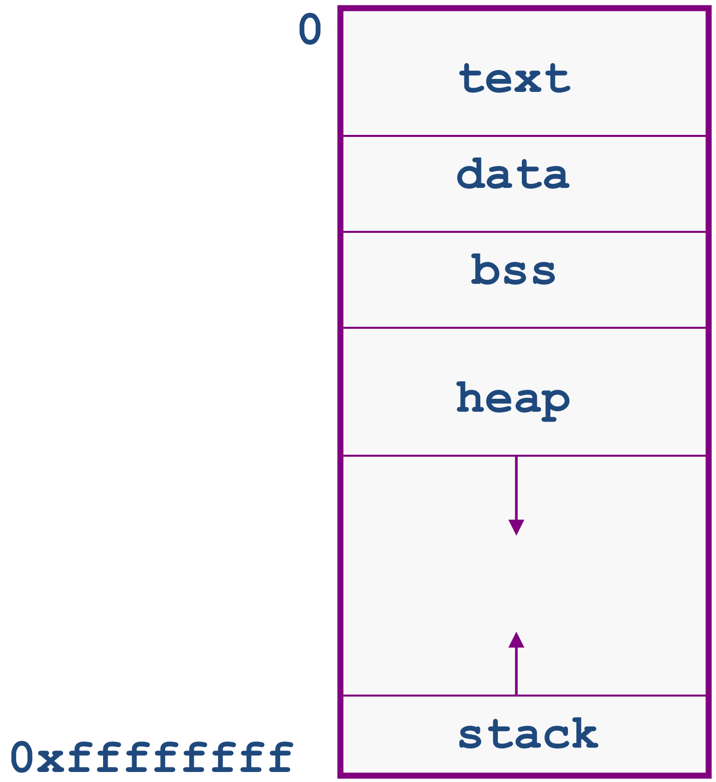
Example

```
char *string = "hello";

const int iSize=8;

char* f(int x)
{
  char *p;

  p = new char[iSize];

  return p;
}
```



Variable Lifetime

- **text:**
  - program startup
  - program finish
- **data, bss:**
  - program startup
  - program finish
- **heap:**
  - dynamically allocated
  - de-allocated (free)
- **stack:**
  - function call
  - function return



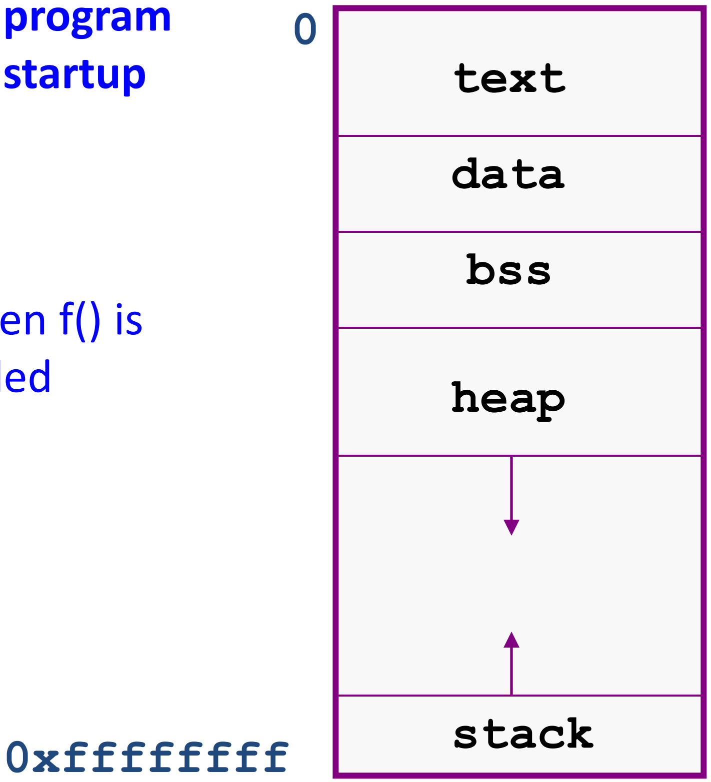
Example

```
char *string = "hello";

const int iSize=8;

char *f (int x)
{
  char *p;

  p = new char[iSize];

  return p;
}
```

program startup

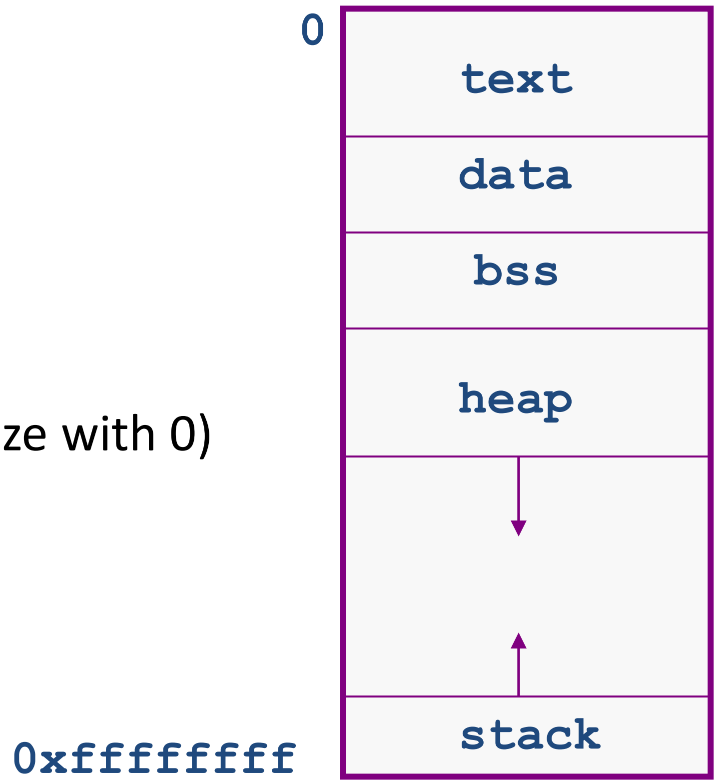
when f() is called

live after allocation; till ***delete*** or **program finish**



Variable Initialization

- **text:**
  - **Read-only (once; e.g., constants)**
- **data**
  - **on program startup**
- **bss:**
  - **un-initialized** (though some systems initialize with 0)
- **heap:**
  - **un-initialized**
- **stack:**
  - **un-initialized**



Dynamic Memory Allocation

- Used when space requirements are unknown at compile time
- Most of the time the amount of space required is unknown at compile time
- Dynamic Memory Allocation (DMA):-
  – With Dynamic memory allocation we can allocate/deletes memory (elements of an array) at runtime or execution time.

Differences between Static and Dynamic Memory Allocation

- **Dynamically allocated memory** is kept on the **memory heap** (also known as the **free store**)

- **Dynamically allocated memory cannot have a "name"**, it must be referred to

- ***Declarations*** are used to statically allocate memory,
  - the ***new*** **operator** is used to **dynamically allocate memory**

Dynamic Memory Allocation

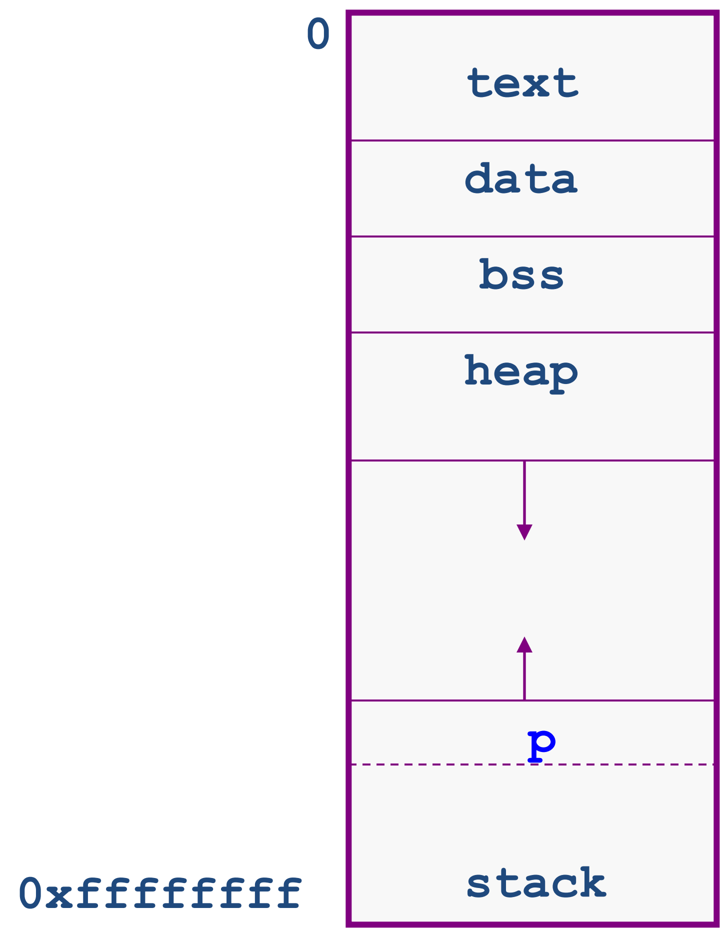
- **Heap management in C++ is explicit:**

```
ptr = new data-type;
//allocte memory for one element

ptr = new data-type [ size ];
//allocte memory for fixed number of element
```

```
delete ptr;
//deallocte memory for one element

delete[] ptr;
//deallocte memory for array
```

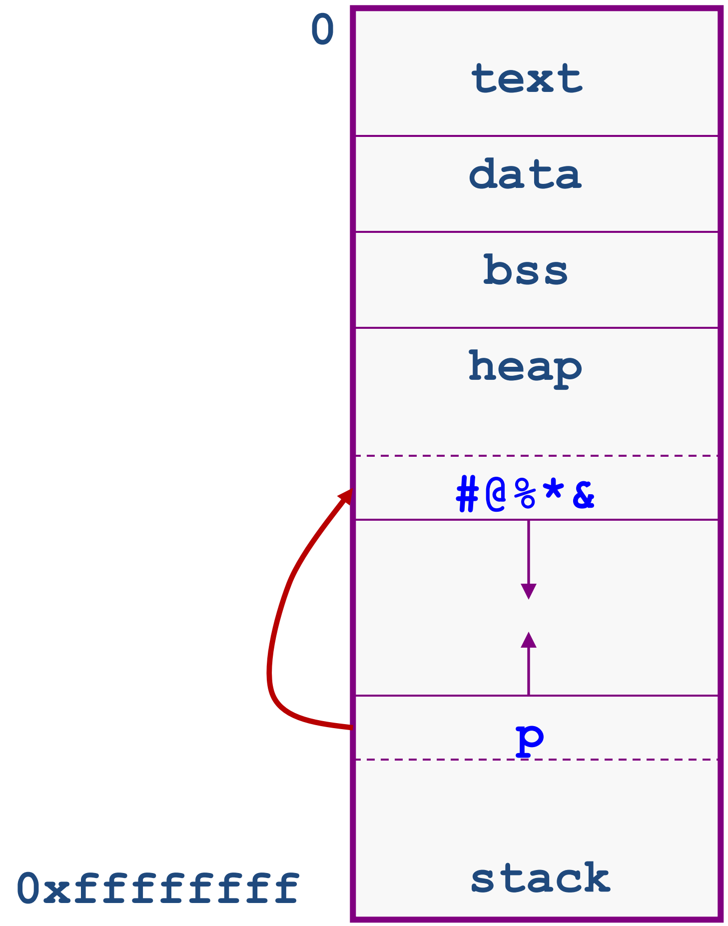
Example

```
int main()
{
  int *p;

  p = new int;

  return 0;
}
```



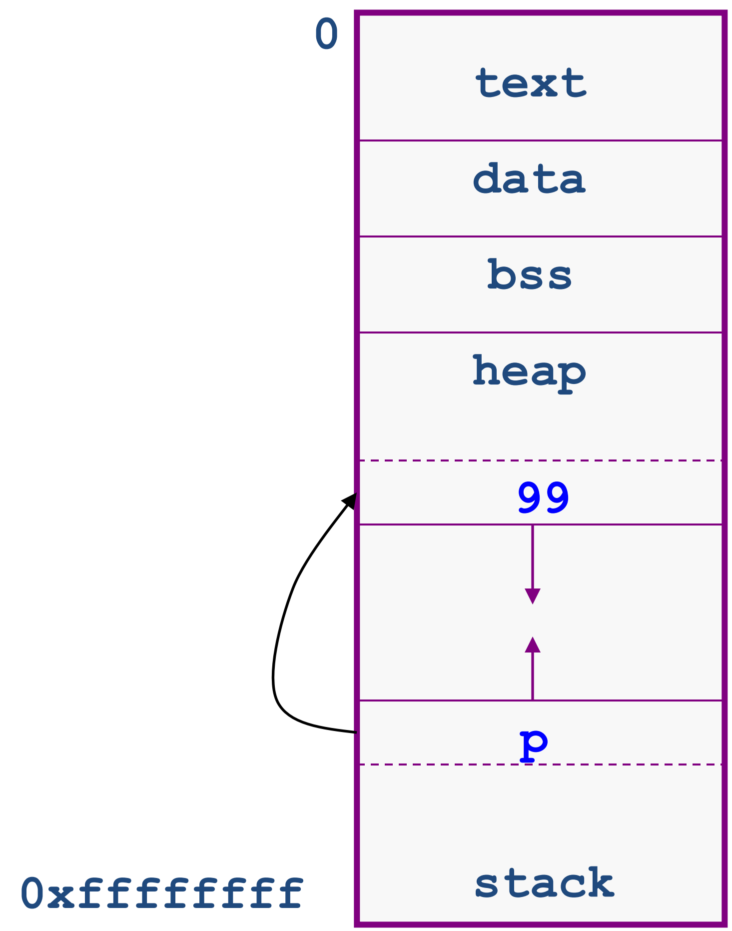
Example

```
int main()
{
  int *p;

  p = new int;


  return 0;
}
```



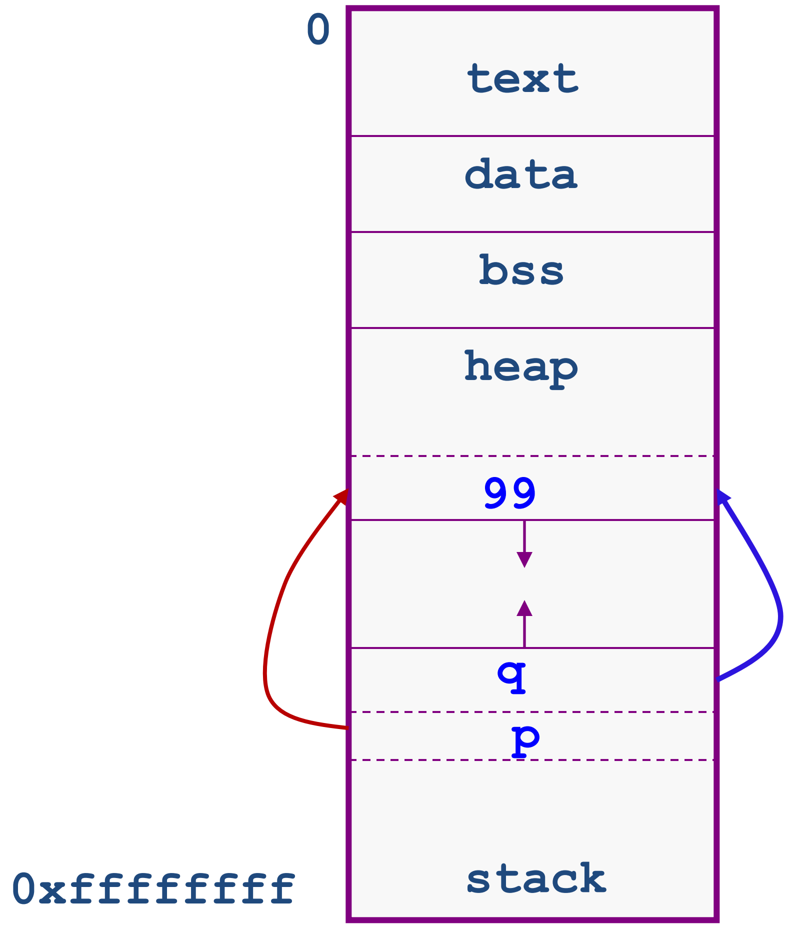
Example

```
int main()
{
  int *p;

  p = new int;
  *p = 99;

  return 0;
}
```



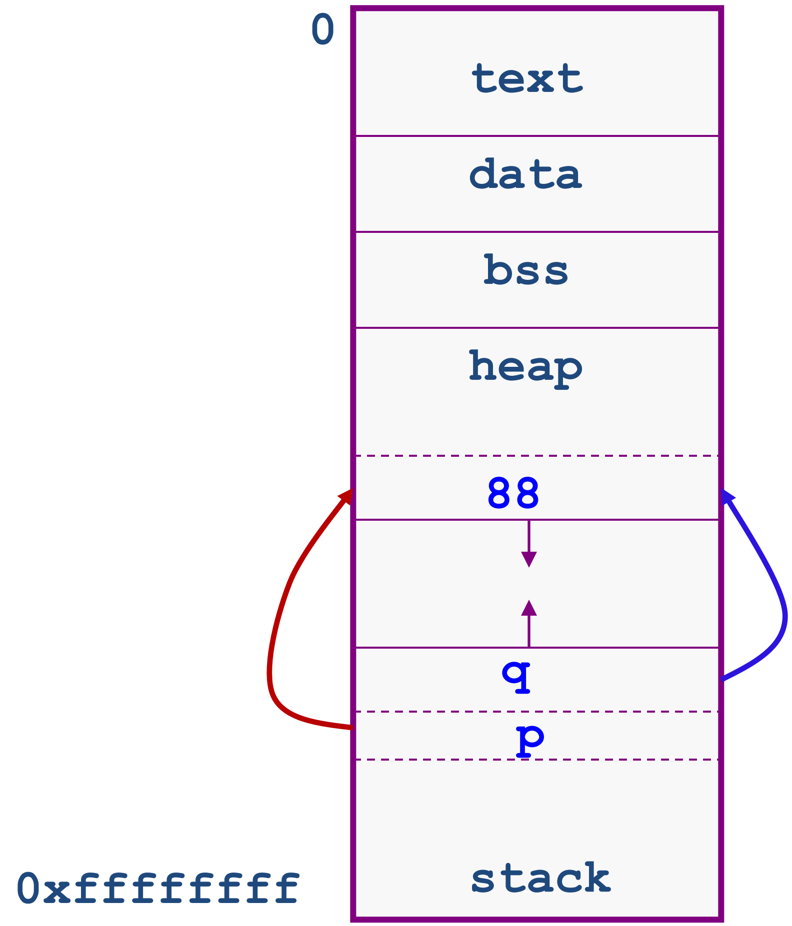
Aliasing

```
int main()
{
   int *p, *q;

   p = new int;
  *p = 99;
   q = p;

   return 0;
}
```



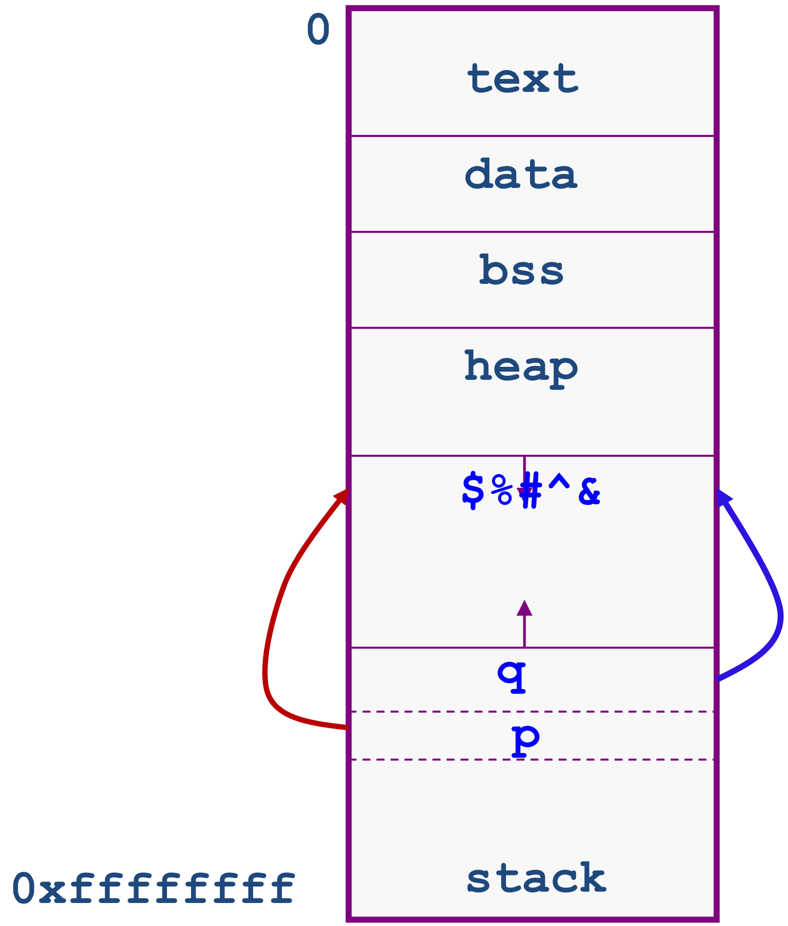
Aliasing

```
int main()
{
   int *p, *q;

   p = new int;
   *p = 99;
   q = p;

   *q = 88;

   return 0;
}
```



Aliasing

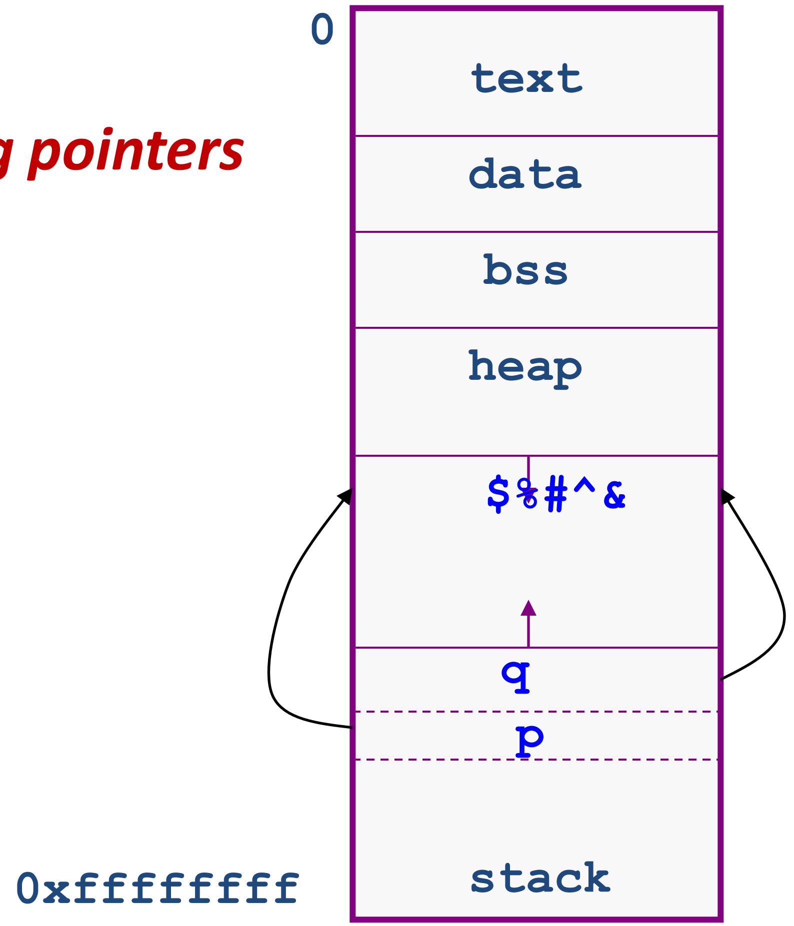
```
int main()
{
   int *p, *q;

   p = new int;
   *p = 99;
   q = p;

   *q = 88;

   delete q;

   return 0;
}
```



Dangling Pointers

```
int main()
{
   int *p, *q;

   p = new int;
   *p = 99;
   q = p;

   *q = 88;

   delete q;

   *p = 77;

   return 0;
}
```

P and q are dangling pointers
WHY?



Dangling Pointers

- The **delete operator does not delete the pointer**, it takes the **memory being pointed** to and **returns** it **to the heap**

- It **does not even change the contents** of the **pointer**

- Since the memory **being pointed to is no longer available** (and **may even be given to another application**), such a **pointer is said to be dangling**

Avoiding a Dangling Pointer

- **For Variables:**

```
delete v1;
v1 = NULL;
```

- **For Arrays:**

```
delete[ ] arr;
arr = NULL;
```

Returning Memory to the Heap

- **Remember:**
  - Return **memory to the heap before *undangling* the pointer**

- What's Wrong with the Following:

```
ptr = NULL;
delete ptr;
```

Memory Leaking

```
int main()
{

   int *p;

   p = new int;

   // make the above space unreachable; How?
   p = new int;


   // even worse…; WHY?
   while (1)
      p = new int;

   return 0;
}
```

Memory Leaking

```
void f ( )
{
    int *p;
    p = new int;

    return;
}



int main ( )
{
    f ( );
    return 0;
}
```

Memory Leaks

- Memory ***leaks*** when it is **allocated from the heap** using the **new** operator but **not returned to the heap** using the **delete** **operator**

Memory Leaking and Dangling Pointers

- **Dangling pointers** and **memory leaking** are **evil sources of bugs**:
  - **hard to debug**
    - may appear after a long time of run
    - may far from the bug point
  - **hard to prevent**
- ***What should be the good programming practices while using Pointers?***

Pointers Data-Type

- **Question:**

Why is it important to declare the type of the variable that a pointer points to?

Aren’t **all memory addresses of the same length**?

Pointers Type

- **Answer:**
  - **All memory addresses are of the same length**,
    - However, with **operation "p++"** where **"p"** is a **pointer** → the **compiler needs to know** the **data type** of the **variable "p"** (**to jump at next memory location**)
    - Examples:
      - If "p" is a **character-pointer** then "p++" will increment "p" by **one byte** **(next location)**
      - if "p" is an **integer-pointer** its value on "p++" would be incremented by **4 bytes** **(next loc.)**

Null Address

- Like a **local variable**, a **pointer** is assigned a **random value (i.e., address)** if not initialized
- **0** is a **pointer constant** that represents the **empty** or **Null address**
- **Should be used to avoid dangling pointers**
  - **Cannot Dereference a Pointer whose value is Null:**

```
int *ptr = 0; OR int *ptr=NULL;

cout << *ptr << endl; // ERROR: ptr
                      // does not point to
                      // a valid address
```

Relationship Between Pointers and Arrays

- **Arrays** and **pointers** are **closely related**
  - **Array name** is **like** <u>**constant pointer**</u>
  - ***All arrays elements are placed in the consecutive locations***.
    - **Example:-** **int List [10];** ***List is the start address of array***

  - **Pointers can do array subscripting operations** We can access array elements using pointers.
    - **Example:-** **int value = List [2];** **//value assignment**

      int* p = List; **//address assignment**

Relationship Between Pointers and Arrays (Cont.)

Effect:-

- **List is an address, no need for &**
- The **bPtr pointer** will contain the **address of the first element** of **array List**.
- Element **List[2]** can be accessed by ***(bPtr + 2)**

Relationship between Arrays and Pointers

- **Arrays** and **pointers** are ***closely related***:

```
void main()
{
  int numbers[]={10,20,30,40,50};
  cout<<numbers[0]<<endl;
  cout<<numbers<<endl;
  cout<<*numbers<<endl;
  cout<<*(numbers+1);
}
```

10

Address e.g., &34234

10

20

Arrays and Pointers

Array name is the **starting address** of the **array**

- Let `int A[25];`
  `int *p; int i, j;`
- Let `p = A;`
- Then `p` points to `A[0]`
  `p + i` points to `A[i]`
  `&A[j] == p+j`
  `*(p+j)` is the same as `A[j]`

Arrays and Pointers

Expression	Assuming p is a pointer to a…	… and the size of *p is…	Value added to the pointer
p+1	char	1	1
p+1	short	2	2
p+1	int	4	4
p+1	double	8	8
p+2	char	1	2
p+2	short	2	4
p+2	int	4	8
p+2	double	8	16

Pointer Arithmetic

Only two types of arithmetic operations allowed:

1) **Addition :** only **integers** can be added
2) **Subtraction:** only **integers** be subtracted

Which of the following are valid/invalid?

I. pointer + integer (ptr+1)
II. integer + pointer (1+ptr)
III. pointer + pointer (ptr + ptr)
IV. pointer – integer (ptr – 1)
V. integer – pointer (1 – ptr)
VI. pointer – pointer (ptr – ptr)
VII. compare pointer to pointer (ptr == ptr)
VIII. compare pointer to integer (1 == ptr)
IX. compare pointer to 0 (ptr == 0)
X. compare pointer to NULL (ptr == NULL)

Comparing Pointers

- If one address comes before another address in memory, the ***first address*** is considered ***less than*** the ***second address.***

- Two pointer variables can be compared using C++ relational operators: **<**, **>**, **<=**, **>=**, **==**

- In an array, elements are stored in consecutive memory locations, E.g., *address of* **Arr[2]** *will be smaller than the address of* **Arr[3]** *etc.*

Void Pointer

- **`void*`** is a **pointer** to **no type** at all:
  - ***Any pointer type*** *may be* ***assigned*** *to* ***void ****

```
int iVar=5;
float fVar=4.3;
char cVar='Z';
int* p1;
void* vp2;
p1 = &iVar; // Allowed
p1 = &fvar; // Not Allowed
P1 = &cVar; // Not Allowed
vp2 = &fvar; // Allowed
vp2 = &cVar; // Allowed
vp2 = &iVar; // Allowed
```

This is a great advantage… So, What are the limitations/challenges?

Accessing 1-Demensional Array Using Pointers

- We know, **Array name** denotes the **memory address** of its first slot.
  - Example:

```
int List [ 50 ];
int *Pointer;
Pointer = List;
```

- Other slots of the **Array (List [50])** can be accessed using by performing **Arithmetic operations** on **Pointer**.
- For example the address of **(element 4th)** can be accessed using:-

```
int *Value = Pointer + 3;
```

- The value of **(element 4th)** can be accessed using:-

```
int Value = *(Pointer + 3);
```

Address	Data
980	Element 0
982	Element 1
984	Element 2
986	Element 3
988	Element 4
990	Element 5
992	Element 6
994	Element 7
996	Element 8
...	
...	
998	Element 49

Accessing 1-Demensional Array

```
….
….
    int List [ 50 ];
    int *Pointer;
    Pointer = List; // Address of first Element

    int *ptr;
    ptr = Pointer + 3; // Address of 4th Element
    *ptr = 293; // 293 value store at 4th element
    address

}
```

Address	Data
980	Element 0
982	Element 1
984	Element 2
986	293
988	Element 4
990	Element 5
992	Element 6
994	Element 7
996	Element 8
…	
…	
998	Element 49

Accessing 1-Demensional Array

We can access all element of List [50] using Pointers and for loop combinations.

```
...
...
    int List [ 50 ];
    int *Pointer;
    Pointer = List;
    for ( int i = 0; i < 50; i++ )
    {
        cout << *Pointer;
        Pointer++; // Address of next element
    }
```

Address	Data
980	Element 0
982	Element 1
984	Element 2
986	Element 3
988	Element 4
990	Element 5
992	Element 6
994	Element 7
996	Element 8
...	
...	
998	Element 49

This is Equivalent to

```
    for ( int loop = 0; loop < 50; loop++ )
        cout <<  Array [ loop ] ;
```

Accessing 2-Demensional Array

- Note that the statements

```
int *Pointer;
Pointer = &List [3];
```

- represents that we are accessing the address of 4th slot.

- In 2-Demensional array the statements

```
int List[ 5 ][ 6 ];
int *Pointer;
Pointer = &List [3];
```

Represents that we are accessing the address of 4th row

- or ***the address the 4th row and 1st column.***

Address	Data
980	Element 0
982	Element 1
984	Element 2
986	Element 3
988	Element 4
990	Element 5
992	Element 6
994	Element 7
996	Element 8
…	
…	
998	Element 50

Accessing 2-Demensional Array

- int List [9] [6];
- int *ptr;
- ptr = &List [3];

- To access the address of **4^{th} row 2^{nd} column**:
  - **ptr++;** // address of 4^{th} row 2^{nd} column
  - (**faster than normal array accessing** **Why?**)
  - Equivalent to **List [3][1] ;**

Column

Row	0	1	2	3	4	5
0	300	302	304	306	308	310
1	312	314	316	318	320	322
2	324	326	328	330	332	334
3	336	338	340	342	344	346
4	348	350	352	354	356	358
5	360	362	364	366	368	370
6	372	374	376	378	380	382
7	384	386	388	390	392	394
8	396	398	400	402	404	406

Memory address

Accessing 2-Demensional Array

- We know **computer can perform only one operation at any time** (**remember fetch-decode-execute cycle**).

- Thus to access List [3][1] element (**without pointer**) **two operations are involved:-**
  - **First to determine row List [3]**
  - **Second to determine column List[3][1]**

- But using pointer we can reach the element of 4^{th} row 2^{nd} column (directly) by **increment our pointer value (which is a single operation).**
  - **ptr+1; // 4^{th} row 2^{nd} column**
  - **ptr+2; // 4^{th} row 3^{rd} column**
  - **ptr+3; // 4^{th} row 4^{th} column**

Column

Row	0	1	2	3	4	5
0	300	302	304	306	308	310
1	312	314	316	318	320	322
2	324	326	328	330	332	334
3	336	338	340	342	344	346
4	348	350	352	354	356	358
5	360	362	364	366	368	370
6	372	374	376	378	380	382
7	384	386	388	390	392	394
8	396	398	400	402	404	406

Memory address

Differences between Static and Dynamic Memory Allocation

- **Dynamically allocated memory** is kept on the **memory heap** (also known as the **free store**)

- **Dynamically allocated memory** **cannot have a "name"**, it must be referred to

- ***Declarations*** are used to statically allocate memory,
  - the ***new*** **operator** is used to **dynamically allocate memory**

Returning Memory to the Heap

- **How Big is the Heap?**
  - **Most applications request memory** from the **heap** when they are running;
  - It is **possible** to **run out of memory** (you may even have gotten a message like "***Running Low On Virtual Memory***")
  - So, it is **important to return memory to the heap** when you no longer need it

Casting pointers

- **Pointers** have types, so you cannot just do

```
int *pi;   double *pd;
pd = pi;
```

- Even though they are both just integers, C++ not allows (**Error**)

Casting pointers

- C++ will let you change the type of a pointer with an **explicit cast**

```
int *pi; double *pd;
pd = (double*) pi;
```

Note: Values differenced after cast are undermined (difference of memory size)

Creating Dynamic 2D Arrays

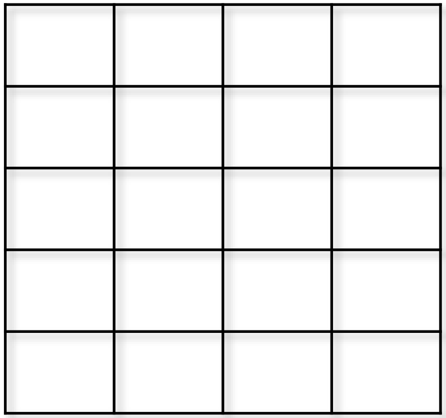
- **Two basic methods:**
  1. Using a <u>single Pointer</u>
  2. Using a <u>Array of Pointers</u>

Dynamic two dimensional arrays

1. Using a single Pointer

- Total elements in a 2D Array:
  - m * n (i.e., rows * cols)

5 rows * 4 columns
= 20 elements



Target Approach=
- allocate 20 elements using dynamic allocation
- Use a single pointer to point and access those items.

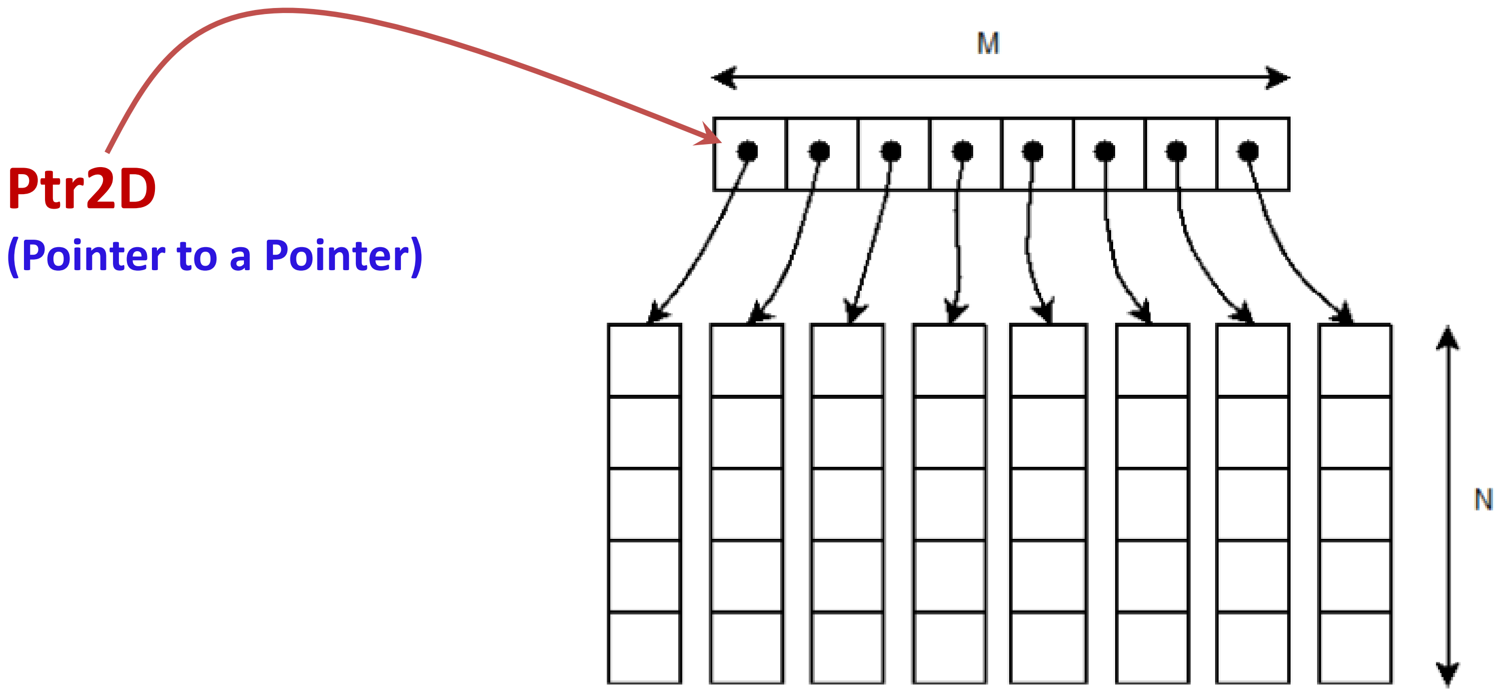
Dynamic 2D Arrays

```
#include <iostream>

// M x N matrix
#define M 4
#define N 5

// Dynamically Allocate Memory for 2D Array in C++
int main()
{
    // dynamically allocate memory of size M*N
    int* A = new int[M * N];

    // assign values to allocated memory
    for (int i = 0; i < M; i++)
        for (int j = 0; j < N; j++)
            *(A + i*N + j) = rand() % 100;

    // print the 2D array
    for (int i = 0; i < M; i++)
    {
        for (int j = 0; j < N; j++)
            std::cout << *(A + i*N + j) << " ";    // or (A + i*N)[j])

        std::cout << std::endl;
    }

    // deallocate memory
    delete[] A;

    return 0;
}
```

Dynamic 2D Array – Double Pointer

2. Using a Pointer that points to Array of Pointer

- Total elements in a 2D Array: M_rows * N_coulmns



Dynamic 2D Array – Double Pointer

```
int **dynamicArray = 0;

//memory allocated for elements of rows.


dynamicArray = new int *[ROWS] ;

//memory allocated for  elements of each column.


for( int i = 0 ; i < ROWS ; i++ )
dynamicArray[i] = new int[COLUMNS];

//free the allocated memory


for( int i = 0 ; i < ROWS ; i++ )
delete [] dynamicArray[i] ;
delete [] dynamicArray ;
```

```
#include <iostream>

// M x N matrix
#define M 4
#define N 5

// Dynamic Memory Allocation in C++ for 2D Array
int main()
{
    // dynamically create array of pointers of size M
    int** A = new int*[M];

    // dynamically allocate memory of size N for each row
    for (int i = 0; i < M; i++)
        A[i] = new int[N];

    // assign values to allocated memory
    for (int i = 0; i < M; i+
        for (int j = 0; j < N
            A[i][j] = rand()

    // print the 2D array
    for (int i = 0; i < M; i+
    {
        for (int j = 0; j < N; j++)
            std::cout <

        std::cout << s
    }

    // deallocate memo
    for (int i = 0; i
        delete[] A[i];

    delete[] A;

    return 0;
}
```

Can we vary size of each column in Dynamic 2D Array (using double pointer)

PP → start of array of pointers
*PP → First Address pointed by first row (sub array)
*(*PP) → First value of first array
(*PP)++ → Move to next address in the first array
PP++ → Move to Next row (second array address

Dynamic 2D Array

(Varying Row Size)

```
// Dynamically Allocate Memory for 2D Array in C++
int main()
{
    // dynamically create array of pointers of size M
    int** A = new int*[M];

    // dynamically allocate memory of size N for each row
    for (int i = 0; i < M; i++)
        A[i] = new int[N+i];

    // assign values to allocated memory
    for (int i = 0; i < M; i++)
        for (int j = 0; j < N+i; j++)
            A[i][j] = rand() % 100;

    // print the 2D array
    for (int i = 0; i < M; i++)
    {
        for (int j = 0; j < N+i; j++)
            std::cout << A[i][j] << " ";

        std::cout << std::endl;
    }

    // deallocate memory using delete[] operator
    for (int i = 0; i < M; i++)
        delete[] A[i];

    delete[] A;

    return 0;
}
```

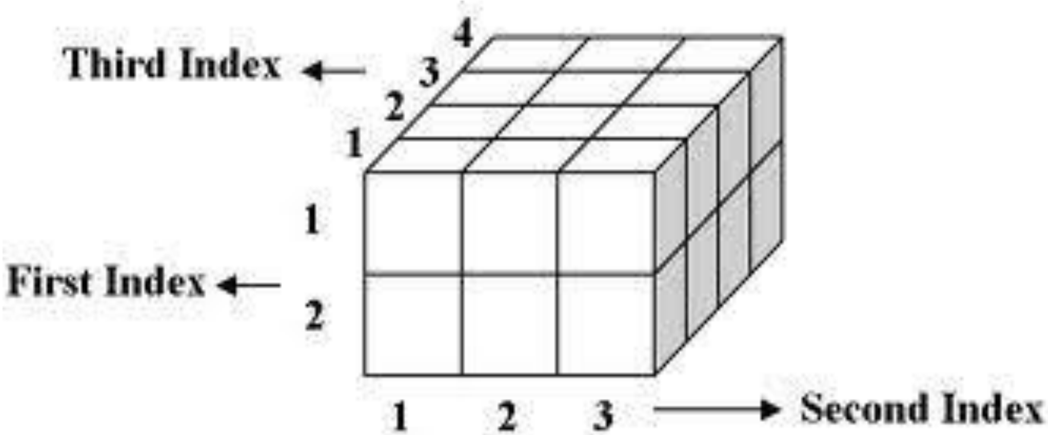
Output

```
83 86 77 15 93
35 86 92 49 21 62
27 90 59 63 26 40 26
72 36 11 68 67 29 82 30
```

Home Work

- Manipulating a 3D Array

1. Using a single pointer
2. Using a triple pointer



Three-dimensional array with twenty four elements

3D Array Using a single pointer

```cpp
#include <iostream>

// X x Y x Z matrix
#define X 2
#define Y 3
#define Z 4

// Dynamic Memory Allocation in C++ for 3D Array
int main()
{
    // dynamically allocate memory of size X*Y*Z
    int* A = new int[X * Y * Z];

    // assign values to allocated memory
    for (int i = 0; i < X; i++)
        for (int j = 0; j < Y; j++)
            for (int k = 0; k < Z; k++)
                *(A + i*Y*Z + j*Z + k) = rand() % 100;

    // print the 3D array
    for (int i = 0; i < X; i++)
    {
        for (int j = 0; j < Y; j++)
        {
            for (int k = 0; k < Z; k++)
                std::cout << *(A + i*Y*Z + j*Z + k) << " ";

            std::cout << std::endl;
        }
        std::cout << std::endl;
    }

    // deallocate memory
    delete[] A;

    return 0;
}
```

```
#include <iostream>

// X x Y x Z matrix
#define X 2
#define Y 3
#define Z 4

// Dynamically Allocate Memory for 3D Array in C++
int main()
{
    int*** A = new int**[X];

    for (int i = 0; i < X; i++)
    {
        A[i] = new int*[Y];

        for (int j = 0; j < Y; j++)
            A[i][j] = new int[Z];
    }

    // assign values to allocated memory
    for (int i = 0; i < X; i++)
        for (int j = 0; j < Y; j++)
            for (int k = 0; k < Z; k++)
                A[i][j][k] = rand() % 100;

    // print the 3D array
    for (int i = 0; i < X; i++)
    {
        for (int j = 0; j < Y; j++)
        {
            for (int k = 0; k < Z; k++)
                std::cout << A[i][j][k] << " ";

            std::cout << std::endl;
        }
        std::cout << std::endl;
    }

    // deallocate memory
    for (int i = 0; i < X; i++)
    {
        for (int j = 0; j < Y; j++)
            delete[] A[i][j];

        delete[] A[i];
    }

    delete[] A;

    return 0;
}
```

Constant Pointer

- A **constant pointer** is a **pointer** that is **constant**, such that we **cannot change** the **location** (**address**) to which the pointer points to:

```
char c = 'c';
char d = 'd';
char* const ptr1 = &c;
ptr1 = &d;  // Not Allowed
```

```
int* const ptrInt=&v1; //ptr is constant pointer to int
```

Pointer to Constant 1/2

- we **cannot** set a **non-const pointer** to a **const data-item**

```
const int value = 5; // value is const
int *ptr = &value; // compile error: cannot convert const int* to int*
*ptr = 6; // change value to 6
```

```
const int value = 5;
const int *ptr = &value; // this is okay,
*ptr = 6; // not allowed, we cannot change a const value
```

Pointer to Constant 2/2

- A **pointer** through which we **cannot change** the **value** of **variable** it **points** is known as a **pointer to constant**.
- These type of pointers **can change** the **address** they point to but **cannot change** the **value** kept at those address.

```
int var1 = 0;
const int* ptr = &var1;
*ptr = 1;  // Not Allowed
 cout<<*ptr;
```

char* and const

- `const char *ptr` : This is a pointer to a constant character. **You cannot change the value pointed by ptr, but you can change the pointer itself**. “const char *” is a (non-const) pointer to a const char.

- `char *const ptr` : This is a constant pointer to non-constant character. **You cannot change the pointer p, but can change the value pointed by ptr.**

- `const char * const ptr` : This is a constant pointer to constant character. **You can neither change the value pointed by ptr nor the pointer ptr.**

C-String and Char Pointer

- A **String:** is simply defined as **an array of characters**

  char* s;

  // **s** is the **address** of the **first character** (byte) of the **string**

- A **valid C string ends** with the **null character** **'\0'**

- **Direct initialization** char* <string Literal>;

```
char* s="FAST";
cout<<s<<sizeof(s);
cout<<++s<<sizeof(s);
```

char [ ] VS. char *

char A[20]="FAST";

1) A is an Array
2) A++; //invalid
3) sizeof(A) → 20 Characters or bytes
4) A and &A points to same memory address
5) A="PAKISTAN"; //invalid
A is an address, "PAKISTAN" is the start address where "PAKISTAN" string is stored in memory.
6) A[0]='p'; //Valid
7) A is stored in stack

char* P="FAST";

1) P is a pointer variable
2) P++; //Valid
3) Sizeof(P) → 8 bytes
4) P points to start address where characters are stored, and &P points to address of pointer variable.
5) P="PAKISTAN" //valid
6) P[0]='p'; //inValid
7) P is stored in Stack, "FAST" is stored in "Text" section (Read-only)

C-String and Char Pointer

```
int main()
   {
   char str1[] = "Defined as an array";
   char* str2 = "Defined as a pointer";

   cout << str1 << endl;    // display both strings
   cout << str2 << endl;

// str1++;                  // can't do this; str1 is a constant
   str2++;                  // this is OK, str2 is a pointer

   cout << str2 << endl;    // now str2 starts "efined..."
   return 0;
   }
```

C-String and Char Pointer - Example

```
// Copying string using Pointers

char* str1 = "Self-conquest is the greatest victory.";
char str2[80]; //empty string
char* src = str1;
char* dest = str2;

while( *src ) //until null character,
      *dest++ = *src++; //copy chars from src to dest

*dest = '\0'; //terminate dest

cout << str2 << endl; //display str2
```

Functions→ Pass by using Reference Pointer

- **Pass-by-reference with pointer** arguments
  - Use pointers as formal parameters and addresses as actual parameters

- **Pass address** of **argument** using **&** operator
  - **Arrays not passed with &** because array name already an address
  - Pointers variable are used inside function

Pass by Reference Pointers– Example1

```
void func(int  *num)
{
        cout<<"num = "<<*num<<endl;
        *num = 10;
        cout<<"num = "<<*num<<endl;
}

void main()
{
    int n = 5;
    cout<<"Before call: n = "<<n<<endl;
    func(&n);
    cout<<"After call: n = "<<n<<endl;
}
```

Pass by Reference Pointers– Example2

```
void compDouble(int* Ar)
{
      for(int i=0;i<10;i++)
      {      *Ar=(*Ar)*2;
              Ar++;
      }
}
void main()
{     int Arr[10]={0,1,2,3,4,5,6,7,8,9};
      compDouble(Arr);
      for(int i=0;i<10;i++)
            cout<<Arr[i]<<endl;
}
```

Pass by Reference Pointers– Example2

```
void compDouble(int* Ar)
{
      for(int i=0;i<10;i++)
      {      *Ar=(*Ar)*2;
              Ar++;
      }
}
void main()
{     int Arr[10]={0,1,2,3,4,5,6,7,8,9};
      compDouble(Arr);
      for(int i=0;i<10;i++)
            cout<<Arr[i]<<endl;
}
```

Questions (last lecture)

Address of character variable…

```
char c = 'd';
cout<<"\n Value: "<<c;  // value ‘d’
cout<<"\n Address: "<<&c;  //treated as char * start address onwards characters
cout<<"\n Address (casted) : "<<(int*)&c;   //prints as address value
*(int*)&c = 'e'; //assign new value at the casted address
cout<<"\n New Value: "<<c;  // value ‘e’
cout<<"\n Address (casted) : "<<(int*)&c;    //prints as address value
cout<<"\n Value (casted) : "<<*(int*)&c;    //prints as address value
```

```
Value: d
Address: d�頏�
Address (casted) : 0x7ffd84a0e8ef
New Value: e
Address (casted) : 0x7ffd84a0e8ef
Value (casted) : 101
```

<u>Reference Variable and a Pointer</u>

The main **difference between** C++ **Reference** vs **Pointer is** that one **is** referring to another **variable** while the latter **is** storing the address **of** a **variable**. ... An array **of pointers** can be created while an array **of references** cannot be created. A null value cannot be assigned to a **reference** but it can be assigned to a **pointer**.