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PROGRAMMING TECHNIQUES

Week 2: Pointers and Dynamic Memory (1)

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- Pointers and Dynamic Memory
  - What are pointers
  - Why dynamically allocate memory
  - How to dynamically allocate memory
  - What about deallocation?
  - Walk through pointer exercises
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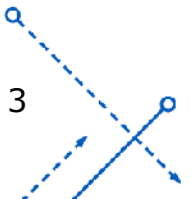
Pointers

- In C++, a pointer is just a different kind of variable.
- This type of variable *points to another variable or object*
  - (i.e., it is used to store the memory address of another variable or an object).
  - Such pointers must first be defined and then initialized.
  - Then, they can be manipulated.

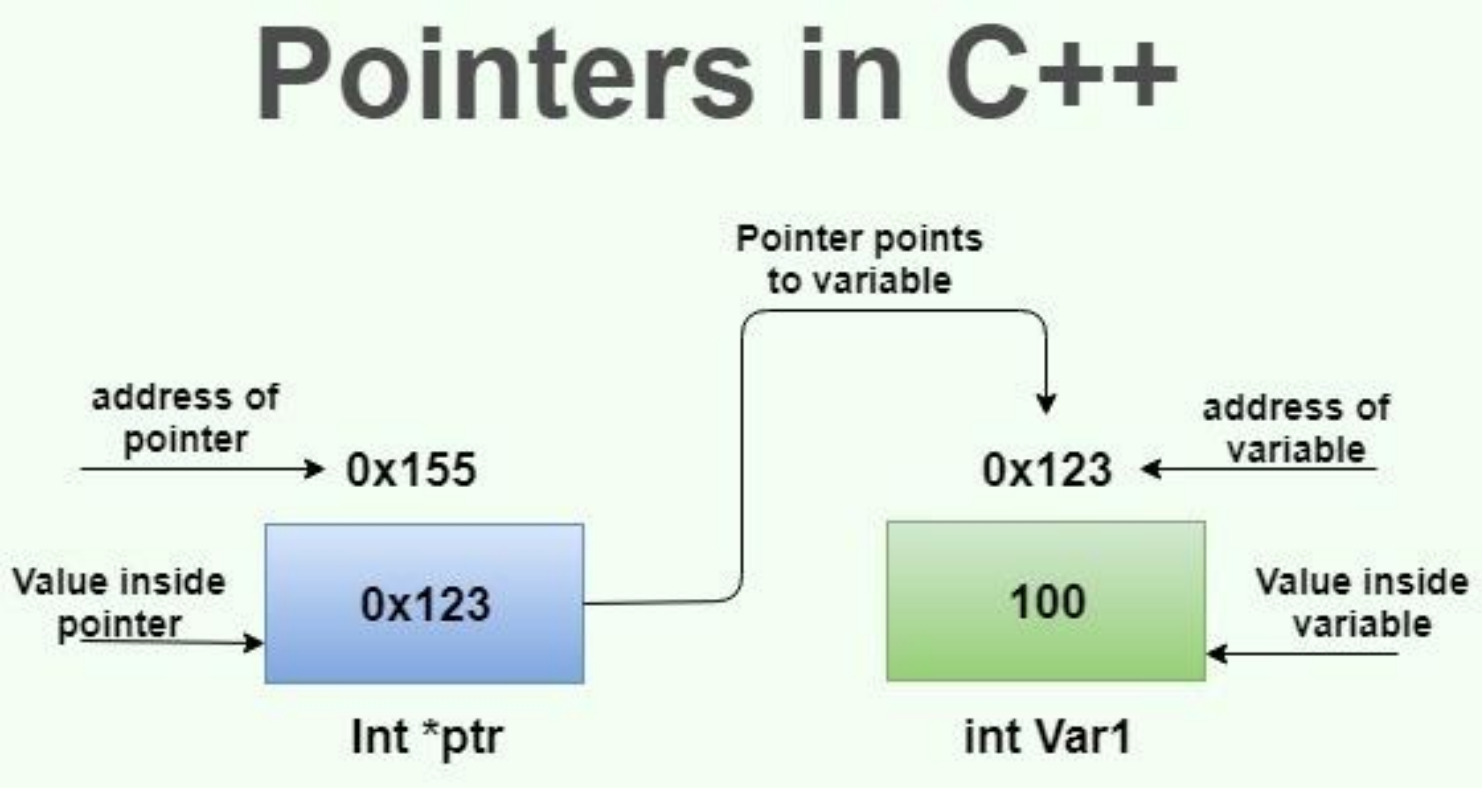


Memory Address in C++

- In the pass-by-reference examples, the & operator is used to create a reference variable. (i.e., to get the memory address of a variable)
- Memory address of a variable is the location where the variable is stored on the computer.
- Example:

```
int main()
{
   int a = 50;
   cout << a;  //Outputs 50
   cout << &a; //Outputs 0x000000ecf8eff834
}
```

Pointers

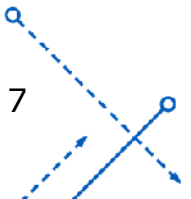

Pointers in C++
Pointer points to variable
address of pointer
0x155
address of variable
0x123
Value inside pointer
0x123
100
Value inside variable
Int *ptr
int Var1

Pointers

- A pointer variable is simply a new type of variable.
  - Instead of holding an int, float, char, or some object's data....it holds ***an address***.
  - A pointer variable is assigned memory.
  - The contents of the memory location is some address of another “variable”.
  - Therefore, the value of a pointer is a memory location.

Pointers

- We can have pointers to (one or more)
  - integers
  - floating point types
  - characters
  - structures
  - objects of a class
- Each represents a different type of pointer



Pointers

- We define a pointer to an integer by:

```
int* ptr;  //same as int *ptr;
```

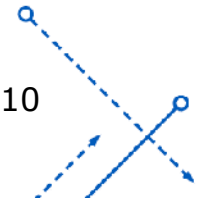
- Read this variable definition from *right to left:*
  - ptr is a pointer (that is what the * means) to an integer.
  - this means ptr can contain the address of some other integer

Pointers

- At this point, you may be wondering why pointers are necessary.
- They are essential for allowing us to use data structures that grow and shrink as the program is running.
  - after midterm time we will learn how to do this...with *linked lists*
    - We are no longer stuck with a fixed size array throughout the lifetime of our program.

Pointers

- But first,
  - we will learn that pointers can be used to allow us to set the size of an array at run-time versus fixing it at compilation time;
  - if an object is a list of names...then the size of that list can be determined dynamically while the program is running.
  - This cannot be accomplished in a user friendly way with simple arrays!



Defining Pointers

- So, what are the data types for the following variables?

```
int* ptr1, obj1;    //watch out!
char* ptr2, *ptr3;
float obj2, *ptr4;
```

- What are their initial values (if local variables)?

-- yes, garbage --

Defining Pointers

- The best initial value for a pointer is
  - zero (address zero),
  - also known as `NULL` (this is a #define constant in the iostream library for the value zero!)
  - The following accomplish the same thing:

```
int *ptr1 = NULL;
int *ptr2 = 0;
int *ptr3 (0);
```

Defining Pointers

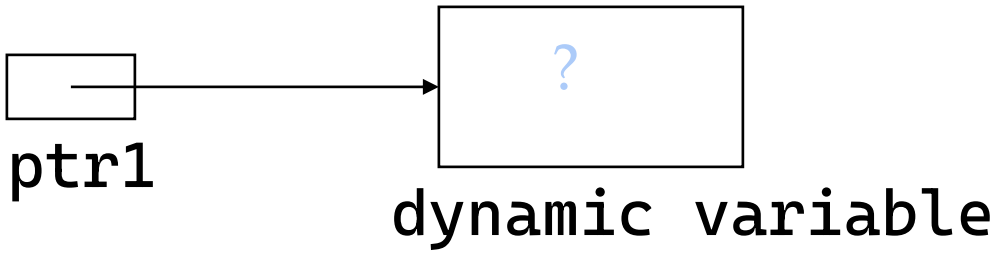
- You can also initialize or assign the address of some other variable to a pointer,
  - using the address-of operator

```
int variable;
int *ptr1 = &variable;
```

Allocating Memory

- Now the interesting stuff!
- You can allocate memory dynamically (as our programs are running)
  - and assign the address of this memory to a pointer variable.

```
int *ptr1 = new int;
```



`int *ptr1 = new int;`

- The diagram used is called a
  - pointer diagram
  - it helps to visualize what memory we have allocated and what our pointers are referencing
  - notice that the dynamic memory allocated is of size int in this case
  - and, its contents is uninitialized
  - new is an operator and supplies back an address of the memory set allocated

Dereferencing

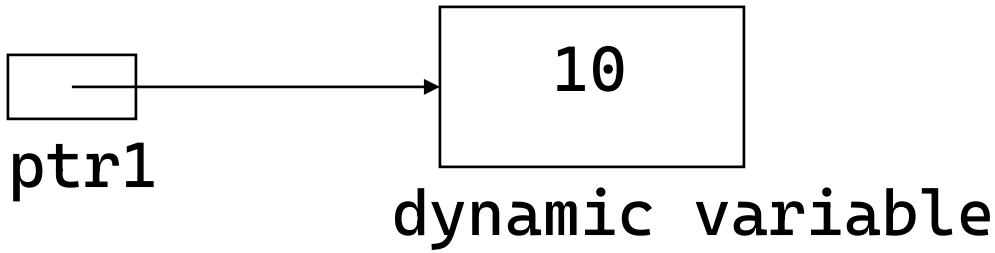
- Ok, so we have learned how to set up a pointer variable to point to another variable or to point to memory dynamically allocated.
- But, how do we access that memory to set or use its value?
- By **dereferencing** our pointer variable:

```
*ptr1 = 10;
```

Dereferencing

- Now a complete sequence:

```
int *ptr1;
ptr1 = new int;
*ptr1 = 10;
...
cout <<*ptr1;//displays 10
```



Deallocating

- Once done with dynamic memory,
  - we must deallocate it
  - C++ does not require systems to do “garbage collection” at the end of a program’s execution!
- We can do this using the delete operator:

```
delete ptr1;
```

this does not delete the pointer variable!

Deallocating

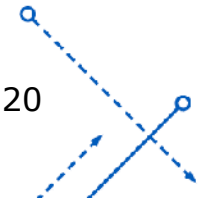
- Again:

  this does **not** delete the pointer variable!

- Instead, it deallocates the memory referenced by this pointer variable
  - It is a no-op if the pointer variable is NULL
  - It does not reset the pointer variable
  - It does not change the contents of memory
  - *Let's talk about the ramifications of this...*

Allocating Arrays

- But, you may be wondering:
  - Why allocate an integer at run time (dynamically) rather than at compile time (statically)?
- The answer is that we have now learned the mechanics of how to allocate memory for a single integer.
- Now, let's apply this to arrays!



Allocating Arrays

- By allocating arrays dynamically,
  - we can wait until run time to determine what size the array should be
  - the array is still “fixed size”...but at least we can wait until run time to fix that size
  - this means the size of a dynamically allocated array can be a variable!!

Allocating Arrays

- First, let's remember what an array is:
  - the name of an array is **a constant address to the first element in the array**
  - So, saying `char name[21];`

    means that **`name`** is a constant pointer who's value is the *address of the first character* in a sequence of 21 characters

Allocating Arrays

- To dynamically allocate an array
  - we must define a pointer variable to contain an address of the element type
- For an array of characters we need a pointer to a char:

```
char *char_ptr;
```

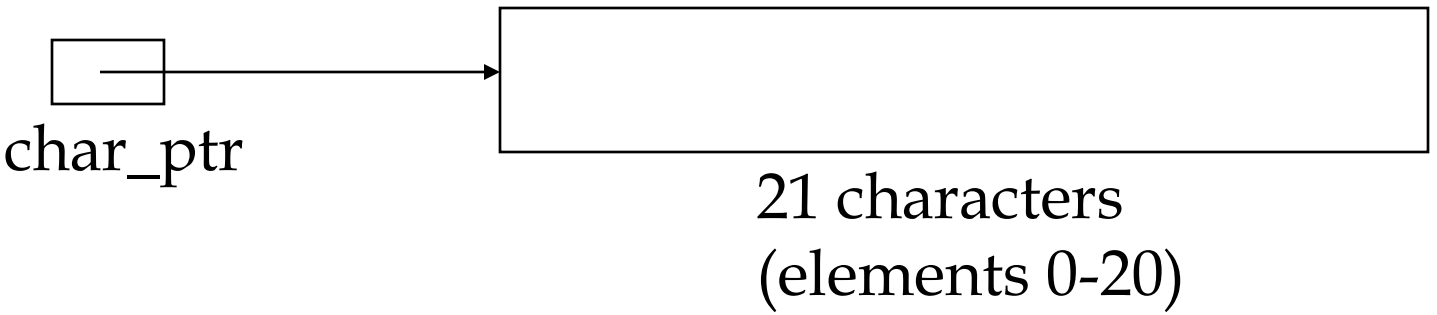
- For an array of integers we need a pointer to an int:

```
int *int_ptr;
```

Allocating Arrays

- Next, we can allocate memory and examine the pointer diagram:

```
int size = 21; //for example
char *char_ptr;
char_ptr = new char [size];
```



Allocating Arrays

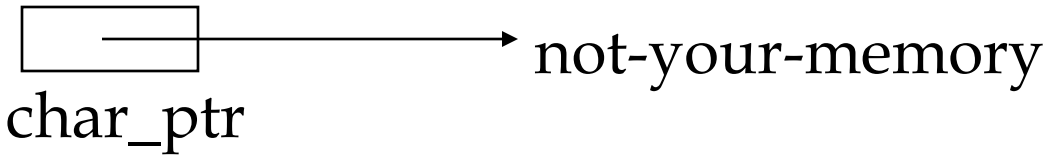
- Some interest thoughts:
  - the pointer diagram is identical to the pointer diagram for the statically allocated array discussed earlier!
  - therefore, we can access the elements in the exact same way we do for any array:

```
char_ptr[index] = 'a';     //or
cin.get(char_ptr,21,'\n');
```

Allocating Arrays

- The only difference is when we are finally done with the array,
  - we must deallocate the memory:

```
delete [] char_ptr;
```



It is best, after doing this to say: char_ptr = NULL;

Allocating Arrays

- One of the common errors we get
  - once allocating memory dynamically is a segmentation fault
  - it means you have accessed memory that is not yours,
    - you have dereferenced the null pointer,
    - you have stepped outside the array bounds,
    - or you are accessing memory that has already been deallocated

In Review

- On the board, let's walk through examples of the following:
  - allocating an array of integers dynamically
  - writing a loop to set the values
  - deallocating that array
  - now, allocate an array of video-structures dynamically
  - Show how you'd access the 3rd title

Pointer Arithmetic

- When we use the subscript operator,
  - pointer arithmetic is really happening
  - this means the following are equivalent:

    ```
    ptr1[3] == *(ptr1+3)
    ```

  - This means the subscript operator adds the value of the index to the starting address and then dereferences the quantity!!!

Exercises

1. How would you define a pointer variable, that can point to a float?
2. Would this change if you wanted the pointer to reference an array of floats?
3. Show how to dynamically allocate an array of 20 floats
4. Show two ways of accessing element 19