Programming techniques

Week 1b: Pointers and Dynamic Memory

01/2024

Pointers and Dynamic Memory

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

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 nor an object).
  - Such pointers must first be defined and then initialized.
  - Then, they can be manipulated.

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

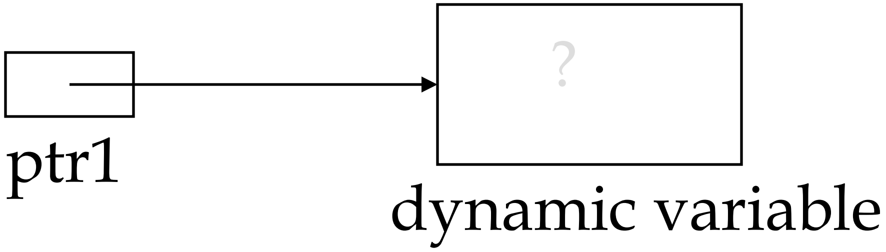
- You can also initialize or assign the address of some other variable to a pointer,
  - using the address-of operator

```
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

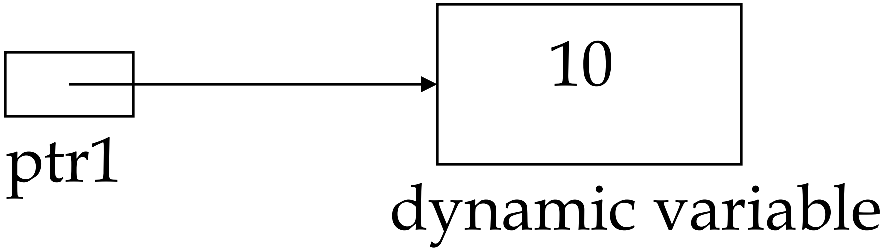
- Ok, so we have learned how to set up a pointer variable to point to another variable or to point to memory dynamically allocated.
- But, how do we access that memory to set or use its value?
- By **dereferencing** our pointer variable:

```
*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;
```

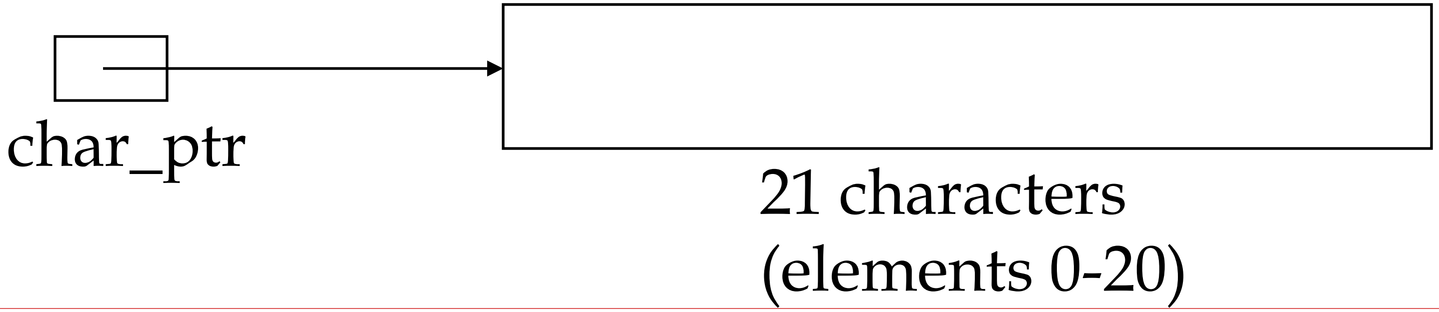
- For an array of integers we need a pointer to an int:

```
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

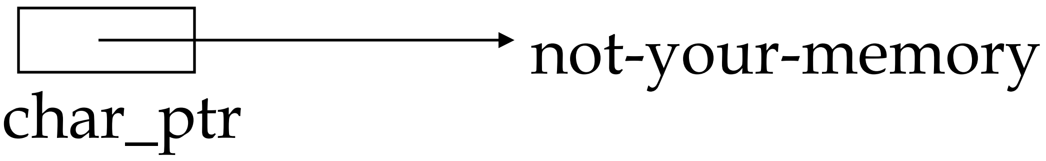
- Some interest thoughts:
  - the pointer diagram is identical to the pointer diagram for the statically allocated array discussed earlier!
  - therefore, we can access the elements in the exact same way we do for any array:

```
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
  - deallocating that array
  - writing a loop to set the values
  - 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!!!

For Next Time

- Next time we will discuss:
  - more about pointers
  - dynamically allocated memory