CSCI 262
Data Structures

14 – Dynamically Allocated Memory

OUTLINE

Dynamic Allocation: Linked Lists

In a previous lecture, we said:

Where do nodes come from…?

Don't worry about *where* just yet, but here's *how* we do it:

```
node* ptr = new node;
```

Declare a pointer variable (of type pointer to node) — Create (*dynamically allocate*) a node object.

new is a C++ keyword. You can't use it as a variable name, etc.

This Lecture

We'll return to the topic of dynamic allocation of objects.

We're going to cover some other stuff first, though.

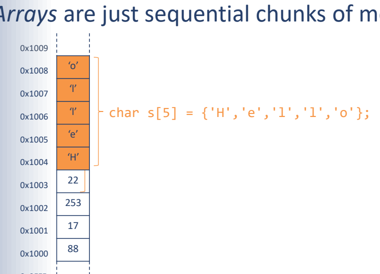
Here's the outline for today:

- Pointers and arrays
- Pointer arithmetic
- Dynamic array allocation
- Dynamic object allocation

POINTERS AND ARRAYS

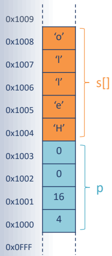
Arrays

Arrays are just sequential chunks of memory:



Arrays and Pointers

Array *variables* are secretly pointers:

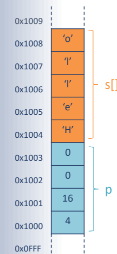



```
char s[5] = {'H','e','l','l','o'};
char *p = s;

cout << *p << endl; // prints 'H'
cout << *s << endl; // also prints 'H'
```


Arrays and Pointers

Pointers are also secretly array variables:




```
char s[5] = {'H','e','l','l','o'};
char *p = s;

for (int j = 0; j < 5; j++) {
    cout << p[j] << endl;
}
```

To the compiler:

```
p[j] == *(p + j)
```


POINTER ARITHMETIC

Pointer Arithmetic: `char`

Suppose:

```
char s[] = {'H','e','l','l','o'};
char* p = s;
```

We've stated that:

```
p[j] == *(p + j)
```

Another way to look at it is:

```
p[j] == s[j] when p == s
```

Thus:

`p[0]=='H'`, `p[1]=='e'`, `p[2]=='l'`, etc.

Pointer Arithmetic: `int`

Now, suppose we have:

```
int arr[] = {42, 17, 33, 6};
int* q = arr;
```

It can be demonstrated that:

```
q[j] == *(q + j) == arr[j]
```

This implies that:

```
q[1] == *(q + 1) == arr[1] == 17
```

Then `q + 1` *is not simply* 1 byte address beyond q, but must be 4 bytes beyond q.

Pointer Arithmetic

- Pointer arithmetic depends on *type*
  - `char* p` → `p++` advances by 1 byte
  - `int* q` → `q++` advances by 4 bytes (size of int)
- You can add or subtract:
  - `q--` → go back 4 bytes
  - `q + 3` → q plus 12 bytes
- Just keep in mind the array/pointer equivalence:

```
    sometype* ptr;
    *(ptr + k) == ptr[k]
```

i.e.

```
    (ptr + k) == &(p[k])        // k * sizeof(sometype)
                                // bytes after ptr
```

Miscellaneous

POINTER NOTES

C-style Strings

In C, strings are simply arrays of char:
```
char *s = "Hello!";      // valid in C; for C++ add const
```

This array has size *7*, not 6: the last entry stores byte value 0, or '\0':

'H'	'e'	'l'	'l'	'o'	'!'	'\0'

Without this value, there's no way to detect the end of a string!
With it, though, we can do:
```
for (char* p = s; *p != '\0'; p++) { … }
```

String *literals* in C++ are still stored this way, but convert to the string type:
```
string foo = "Hello";
     or
string("Hello")
```


Pointers and Reference Parameters

Reference parameters are not pointers!
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If you have a function
```
void foo(int &x) { … }
```

Inside foo, you cannot do
```
*x = 10;   // incorrect!
```
You just do
```
x = 10;    // correct
```

Sources of confusion:
- & denotes a reference parameter
- & also used as address-of operator
- References use pointers "under the covers"

DYNAMIC ARRAY ALLOCATION

Array Limitations in C++

Standard C++ does not let you do this*:

```
int sz;
cout << "What size do you need?" << endl;
cin >> sz;
int arr[sz];  // compiler error
…
```

*Strangely, later versions of C do allow this. Confusingly, so does g++ (some versions).

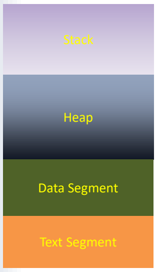
Dynamic Array Allocation

So what if you know you'll need an array, but not the size (at compile time)?

```
int sz;
cout << "What size do you need?" << endl;
cin >> sz;
int *arr = new int[sz];
…
```

Note that **new** gives us a *pointer* to our memory.

Where Does Memory Come From?



The stack: local variables, function arguments, return values. Grows "down".

The heap: dynamically allocated memory (using **new**). Grows "up".

Global and static variables, constants.

Program code. Read only!

Data Segment/BSS

Global and static variables:

- Only ever one instance of them
- Get stored in their own special area
- Memory is pre-allocated, fixed in size

The Stack

- Holds "stack frames" aka "activation records"
- Each function call results in a new stack frame
- Each stack frame contains memory for:
  - Local variables declared in the function
  - Parameters passed into function
  - Return address for function
- When the function is exited, all of this memory is returned to the stack automatically.

The Heap

A big ol' chunk of memory!

- Get pieces of it ("allocate memory") using **`new`**
- Pieces stay allocated until explicitly released by use of **`delete`**

Heap memory has a lifetime ***independent of scope*** – it can be used after a function that created it returns. You can't do that with local variables!

Stack vs Heap

- Stack: *local* aka *automatic* variables and arrays:

```
int z;
foo f;
double darray[100];
```

Memory for these is allocated on the **stack** when they come into scope, is returned to the stack when they go out of scope (e.g., when function returns).

- Heap: dynamically allocated objects and arrays:

```
int* p = new int;
foo* fp = new foo;
double* dptr = new double[100];
```

All of these live on the **heap**. They will exist until explicitly deallocated by user code.

Dynamic Arrays

Allocate dynamic arrays using new:

```
double *darray = new double[1024];
```

Use the array pointer just like a regular array:

```
for (int j = 0; j < 1024; j++)
    darray[j] = 0.0;
```

Always clean up (*deallocate*) when you are done:

```
delete[] darray;
```

DYNAMIC OBJECT ALLOCATION

Pointers, Objects, and Dynamic Memory

Consider this simple class:

```
class student {
public:
    string name;

    student()         { ; }
    student(string n) { name = s; }

    void eat();
    void sleep();
  };
```


Creating New Objects: Stack

If we want to create a student *locally*:

```
student student1;
student student2("Kirk");
```

- These are created on the *stack*.
- They will vanish when exiting the current scope.

student1 is created using the default constructor:

```
student();
```

student2 is created using another constructor:

```
student(string s);
```


Creating New Objects: Heap

We can also create single objects *dynamically*:

Pointers!

```
student* sp1 = new student;
student* sp2 = new student("Picard");
```

These are created on the *heap*.

They will live forever unless deleted:

```
delete sp1;
delete sp2;
```

Note – no square brackets when calling delete on a single object.

Note, again, the two different constructors.

Working With Object Variables

Consider:

```
student  student1;
student* p = new student;
```

We know that we can do:

```
student1.name = "Sisko";
student1.eat();
```

What can we do with p?

Working with Object Pointers

We have:

```
student* p = new student;
```

We could just dereference (perfectly fine!)

```
(*p).name = "Janeway";
(*p).sleep();
```

Note that this won't work correctly:
`*p.name = "Janeway";`
The . has higher precedence than *

C++ gives us another operator we can use directly:

```
p->name = "Archer";
p->sleep();
```

The Destructor

The counterpart to the constructor:

- No return type
- Name is ~ followed by class name, e.g.,

```
~student();
```

- Never takes a parameter!

The destructor is called automatically when:

- A local (stack allocated) object goes out of scope
- delete is called on a dynamically allocated object

Arrays of Objects

We can also use new to create arrays of objects:

```
int n = 100;
student* arr = new student[n];
```

The **default constructor** is used to create *every* object in the array.

Now we can do, e.g.:

```
for (int i = 0; i < n; i++)
    arr[i].gpa = 4.0;
```

As with base types, we use delete[] on dynamically allocated arrays of objects:

```
delete[] arr;
```

The **destructor** is called on *every* object in the array.

WRAPPING UP

Dynamic Memory Don'ts

Never:

- Dereference a pointer which has not been set to valid memory (using new or &)
- Dereference a pointer to memory which has already been deallocated (a *dangling pointer*)
- Change or lose a pointer which is pointing to dynamically allocated memory (or you won't be able to deallocate – this causes a *memory leak*)
- Use `delete` on a pointer which isn't pointing to dynamically allocated memory (e.g., a dangling or NULL pointer)

Up Next

- Reading: Chapter 7
- Wednesday, March 13
  - ArrayList (how to implement a vector, part 1)
  - Reading: Chapter 13.1
- Friday, March 15
  - Lab 9 – TBD
  - Project 3 – Evil Hangman due
  - New assignment – TBD