CSCI-1200 Data Structures — Fall 2014
Lecture 6 — Pointers & Dynamic Memory

Test 1 will be held Monday, February 15th, 2014 from 6-7:50pm

- Test 1 will be held **Monday, Sept 15th, 2014 from 6-7:50pm**,
  - Lab sections 1-5 will be in DCC 308.
  - Lab sections 6-7 will be in DCC 324.
- Contact the professor by email **TODAY** to arrange for extra time accommodations.

Review from Lecture 5

- Pointer variables, arrays, pointer arithmetic and dereferencing, character arrays, and calling conventions.

Today's Lecture — Pointers and Dynamic Memory

- Arrays and pointers, different types of memory, dynamic allocation of arrays, and examples.

6.1 Three Types of Memory

- Automatic memory: memory allocation inside a function when you create a variable. This allocates space for local variables in functions (on the *stack*) and deallocates it when variables go out of scope. For example:

```
int x;
double y;
```

- Static memory: variables allocated statically (with the keyword `static`). They are are not eliminated when they go out of scope. They retain their values, but are only accessible within the scope where they are defined.

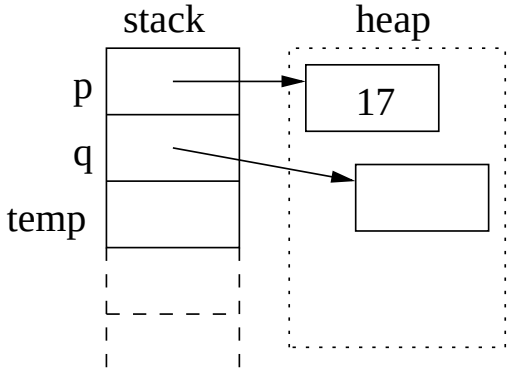
```
static int counter;
```

- Dynamic memory: explicitly allocated (on the *heap*) as needed. This is our focus for today.

6.2 Dynamic Memory

- Dynamic memory is:
  - created using the `new` operator,
  - accessed through pointers, and
  - removed through the `delete` operator.
- Here's a simple example involving dynamic allocation of integers:

```
int * p = new int;
*p = 17;
cout << *p << endl;
int * q;
q = new int;
*q = *p;
*p = 27;
cout << *p << " " << *q << endl;
int * temp = q;
q = p;
p = temp;
cout << *p << " " << *q << endl;
delete p;
delete q;
```



- The expression `new int` asks the system for a new chunk of memory that is large enough to hold an integer and returns the address of that memory. Therefore, the statement `int * p = new int;` allocates memory from the heap and stores its address in the pointer variable `p`.
- The statement `delete p;` takes the integer memory pointed by `p` and returns it to the system for re-use.

- This memory is allocated from and returned to a special area of memory called the *heap*. By contrast, local variables and function parameters are placed on the *stack* as discussed last lecture.
- In between the `new` and `delete` statements, the memory is treated just like memory for an ordinary variable, except the only way to access it is through pointers. Hence, the manipulation of pointer variables and values is similar to the examples covered in Lecture 5 except that there is no explicitly named variable for that memory other than the pointer variable.
- Dynamic allocation of primitives like ints and doubles is not very interesting or significant. What's more important is dynamic allocation of arrays and objects.

6.3 Exercise

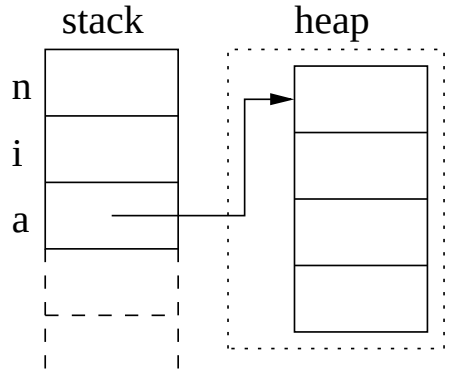
- What's the output of the following code? Be sure to draw a picture to help you figure it out.

```
double * p = new double;
*p = 35.1;
double * q = p;
cout << *p << " " << *q << endl;
p = new double;
*p = 27.1;
cout << *p << " " << *q << endl;
*q = 12.5;
cout << *p << " " << *q << endl;
delete p;
delete q;
```

6.4 Dynamic Allocation of Arrays

- Declaring the size of an array at compile time doesn't offer much flexibility. Instead we can *dynamically* allocate an array based on data. This gets us part-way toward the behavior of the standard library vector class. Here's an example:

```
int main() {
  std::cout << "Enter the size of the array: ";
  int n,i;
  std::cin >> n;
  double *a = new double[n];
  for (i=0; i<n; ++i)   { a[i] = sqrt(i); }
  for (i=0; i<n; ++i) {
    if ( double(int(a[i])) == a[i] )
      std::cout << i << " is a perfect square " << std::endl;
  }
  delete [] a;
  return 0;
}
```



- The expression `new double[n]` asks the system to *dynamically* allocate enough consecutive memory to hold n double's (usually $8n$ bytes).
  - What's crucially important is that `n` is a variable. Therefore, its value and, as a result, the size of the array are not known until the program is executed and the the memory must be allocated dynamically.
  - The address of the start of the allocated memory is assigned to the pointer variable `a`.
- After this, `a` is treated as though it is an array. For example: `a[i] = sqrt( i );`
  In fact, the expression `a[i]` is exactly equivalent to the pointer arithmetic and dereferencing expression `*(a+i)` which we have seen several times before.
- After we are done using the array, the line: `delete [] a;` releases the memory allocated for the entire array. Without the `[]`, only the first double would be released.
  - Since the program is ending, releasing the memory is not a major concern. However, to demonstrate that you understand memory allocation & deallocation, you should *always* delete dynamically allocated memory in this course, even if the program is terminating.
  - In more substantial programs it is ABSOLUTELY CRUCIAL. If we forget to release memory repeatedly the program can be said to have a *memory leak*. Long-running programs with memory leaks will eventually run out of memory and crash.

6.5 Exercises

1. Write code to dynamically allocate an array of `n` integers, point to this array using the integer pointer variable `a`, and then read n values into the array from the stream `cin`.

2. Now, suppose we wanted to write code to double the size of array `a` without losing the values. This requires some work: First allocate an array of size `2*n`, pointed to by integer pointer variable *temp* (which will become `a`). Then copy the `n` values of `a` into the first `n` locations of array `temp`. Finally delete array `a` and assign `temp` to `a`.

   Why don't you need to delete `temp`?

   Note: The code for part 2 of the exercise is very similar to what happens inside the `resize` member function of vectors!

6.6 Dynamic Allocation: Arrays of Class Objects

- We can dynamically allocate arrays of class objects. The default constructor (the constructor that takes no arguments) must be defined in order to allocate an array of objects.

```
class Foo {
public:
  Foo();
  double value() const { return a*b; }
private:
  int a;
  double b;
};

Foo::Foo() {
  static int counter = 1;
  a = counter;
  b = 100.0;
  counter++;
}

int main() {
  int n;
  std::cin >> n;
  Foo *things = new Foo[n];
  std::cout << "size of int: " << sizeof(int) << std::endl;
  std::cout << "size of double: " << sizeof(double) << std::endl;
  std::cout << "size of foo object: " << sizeof(Foo) << std::endl;
  for (Foo* i = things; i < things+n; i++)
    std::cout << "Foo stored at: " << i << " has value " << i->value() << std::endl;
  delete [] things;
}
```

```
size of int: 4
size of double: 8
size of foo object: 16
Foo stored at: 0x104800890 has value 100
Foo stored at: 0x1048008a0 has value 200
Foo stored at: 0x1048008b0 has value 300
Foo stored at: 0x1048008c0 has value 400
...
```

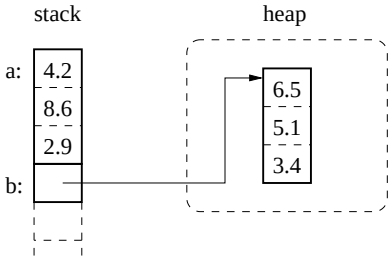
6.7 Diagramming Memory Exercises

- Draw a diagram of the *heap* and *stack* memory for each segment of code below. Use a "?" to indicate that the value of the memory is uninitialized. Indicate whether there are any errors or memory leaks during execution of this code.

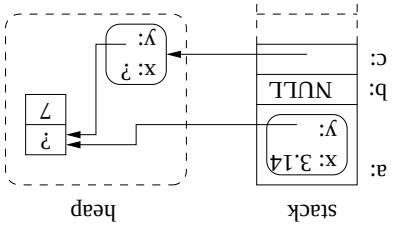
```
class Foo {
public:
  double x;
  int* y;
};
Foo a;
a.x = 3.14159;
Foo *b = new Foo;
(*b).y = new int[2];
Foo *c = b;
a.y = b->y;
c->y[1] = 7;
b = NULL;
```

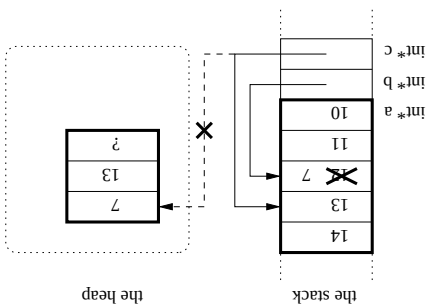
```
int a[5] = { 10, 11, 12, 13, 14 };
int *b = a + 2;
*b = 7;
int *c = new int[3];
c[0] = b[0];
c[1] = b[1];
c = &(a[3]);
```

- Write code to produce this diagram:



6.8 Solutions to Diagramming Memory Exercises






```
double a[3];
double *b = new double[3];
a[0] = 4.2;
a[1] = 8.6;
a[2] = 2.9;
b[0] = 6.5;
b[1] = 5.1;
b[2] = 3.4;
```

There is a memory leak of
3 ints in this program.