CSE 143

Dynamic Memory In Classes

[Chapter 4, p 156-157]

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Remember Class Vector?

```
class Vector {
public:
   Vector ( );
   bool  isEmpty( );
   int   length ( );
   void  vectorInsert (int newPosition, Item newItem);
   Item  vectorDelete (int position);
   Item  vectorRetrieve (int position);
   ...
   }
```

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Many Ways to Implement

- Version 1: With Fixed length arrays
  - Very efficient to access individual elements
  - Limited in size, flexibility
- Version 2: With a linked list (later)
  - Very flexible in size
  - Inefficient to access individual elements
    - Have to chase pointers down the list
- Here's a third way:
  - Use an array (for efficient access)
  - Make the array itself "dynamic"
    - Able to grow as needed

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Vector Implementation

```
class Vector {
   public:
     // constructors and other methods, as before
   private:
     Item *Items;  // items[0..capacity] is space allocated for
                   // this vector
     int  size;    // items are stored in Items[0..size-1]
     int capacity; //current maximum array size

     // might need additional private helper functions

};
```

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Draw the picture!

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Vector Constructor

```
Vector::Vector() {
     // set up private variables
     capacity = DEFAULT_CAPACITY;
     size = 0;
     // allocate memory
     items = new Item[capacity];
     // what goes here?
}
```

Except for this, the public methods can be the same as for the fixed array implementation.

Exception: insert needs to insure there is room to add a new item.

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Useful Private Functions

```
class Vector {
  public:
    // constructors and other methods
  private:
    // data members here...
    // ensure the Vector can hold at least n elements
    void ensureCapacity(int n);
    // set size of the Vector to n elements
    void growArray(int n);
};
```

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ensureCapacity( )

```
// ensure that Vector can hold at least n
// elements
void Vector::ensureCapacity(int n) {
    // return if existing capacity is ok
    if (capacity >= n)
      return;
    // out of space: double capacity
    int newCapacity = capacity * 2;
    if (newCapacity < n)
      newCapacity = n;
    // grow the array
    growArray(newCapacity);
}
```

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growArray( )

```
// Set size of vector to newCapicity
void Vector::growArray(int newCapacity) {
   Item *newItems = new Item[newCapacity];
   assert(newItems != NULL);
   for (int i = 0; i < size; ++i)
     newItems[i] = items[i];
...
   items = newItems;
   capacity = newCapacity;

}
```

Have we forgotten anything?

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Now insert is easy!

```
// insert newItem at newPosition in Vector
void Vector::vectorInsert(int newPosition,
                          Item newItem) {
    // make room
    ensureCapacity(size+1);
    // shift data over
    for (int i=size; i > newPosition; --i)
      items[i] = items[i-1];
    // store the item
    size++;
    items[newPosition] = newItem;
}
```

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Issues with Dynamic Memory

- Using dyanamic memory in classes raises issues
- Familiar dangers:
  - Dangling pointers, Uninitialized pointers, Memory leaks, etc.
- Some new complications
  - Many of them arise when objects are copied
    - Copied automatically when passed as params, etc.
    - Copied explicitly by programmer
  - Other dangers when objects are deleted
    - Explictly deleted, or just go out of scope
  - C++ has some special features to help the situation

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Innocence Destroyed (I)

// assume Item == int
Vector v1, v2;
v1.insert(0, 30);
v1.insert(1, 4);
v2 = v1;
v2.delete(0);

- //Draw the picture and weep!

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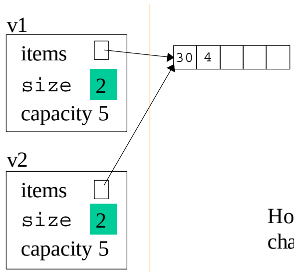
After v2=v1, Before v2.delete



How does v2.delete change the picture?

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Innocence Destroyed (II)

void add42 (Vector v) { //add 42 to front of vector
v.insert(0, 42); }

//code in main
Vector v1;
v1.insert(0, 0);
add42(v1);

- v1 passed by value, so no harm done -- right??
- Draw the picture and weep!

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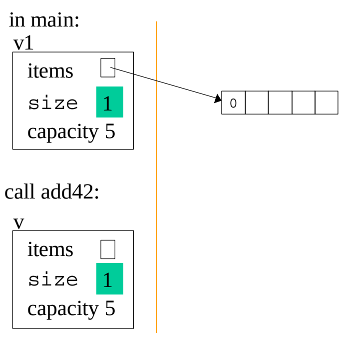
After v1.insert(0,0)



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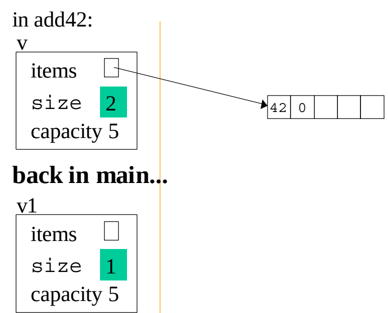
After v.insert(0, 42);...



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Innocence Destroyed (III)

```
void MyFunction () {
   Vector tempVector; //local variable
   // build a temporary vector for whatever reason
   ...
   }
```

- When a function exits
  - local variables are automatically destroyed
  - so having a local Vector is no problem -- right?
- Draw the picture and weep!

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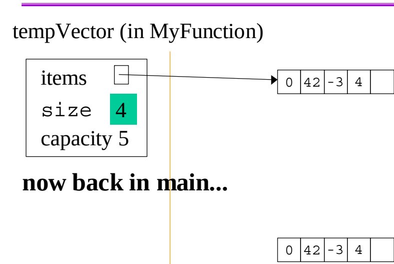
Local variable goes away...



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The Culprit: "Shallow Copy"

- For structs and classes, all and only the member variables are copied
- When there's dynamic memory, that's not enough
  - Example: the `items` pointer value is copied, so the copy points to the same place
  - Can lead to surprises and bugs
- Solution: need a concept of "deep copy"

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More copy problems

- The problem with deep vs. shallow copying can also appear in these contexts:
  - Initialization in a variable declaration:

```
SomeClass f1;
SomeClass f2 = f1;
```

  - Passing a copy of an actual to a formal parameter (*pass-by-value*)
  - Returning an instance as the value of a function:

```
return someIntVector;
Why? because a function returns a new, temporary object
```

- By default, C++ performs such initializations using shallow copy semantics.

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Needed: Deep Copy

- A "deep copy" should make a complete new copy, including new dynamic memory
- A way to make the deep copy happen *automatically* when appropriate
  - Vector v1 = v2;
  - v1 = v2;
  - func1(v1);
  - return v1;
- PS: this won't solve the problem of cleaning up dynamic memory used by local variables
  - We'll get back to that

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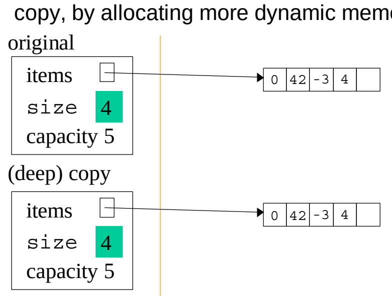
"Deep copy"

- A deep copy makes a completely independent copy, by allocating more dynamic memory



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Deep copy for Vector

- Initialize the new vector to empty.
- For each element in the vector
  - add it to the new vector
- Could be a client function
  - *void copyVector (Vector &orig, Vector &newVec);*
  - use member functions like length, retrieve, insert, etc.
- Could be a public or private member function
  - void Vector::copy (Vector &orig);
  - copies from orig to current vector
  - use private data directly

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Making It Automatic

- Problem with copyVector: *must be called explicitly*
- We need it to happen *automatically* in certain cases
- Solution: C++ allows a "Copy Constructor"
  - Will be called automatically in certain cases where an object must be initialized from an existing object
- Compiler recognizes it as a constructor with a special parameter list: *(classname &)*
  - or *(const classname &)*

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Copy Constructor for listClass

class Vector {
public:
    Vector ( );
    Vector(Vector &);
...
}

- Compiler recognizes this as a copy constructor
- Will call automatically when
  - passing arguments by value
  - initializing variable with = in a variable declaration
  - copying a return value

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Inside the Constructor

- It's just a function, it can do anything!
- But... what you normally write is a deep copy
- For our Vector copy constructor:
  - could call a previously defined copyVector function
  - could build the new copy directly
- If you don't define your own copy constructor, the compiler generates a default copy constructor
  - Does a *shallow* copy

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Look at the code:

```
Vector::Vector(Vector &other) { copy(other); }

// private member function: replace this Vector
// with a deep copy of other
void Vector::copy(Vector &other) {
      // set up private variables
      capacity = other.capacity;
      size = other.size;
      // allocate memory
      items = new Item[capacity];
      assert(items != NULL);
      // copy data
      for (int i = 0; i < size; ++i)
         items[i] = other.items[i];
}
```

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Technicalities of '='

Vector MyVector = YourVector;
is NOT THE SAME AS
Vector MyVector;
MyVector = YourVector;

- The difference in technical terms:
  - in the first case, the object is being created
  - in the second case, the object already exists
- To handle the latter case, we have to define an "overloaded assignment operator"
  - Syntax: **Vector & Vector::operator = (Vector &other);**
  - The code for this function could perform a deep copy.

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Detour: *this*

- A reserved word in C++
- Means "a pointer to the current object"
- Like a hidden parameter to member functions
  - int Vector::length(Vector *this) { ... }
  - only exists in member functions!
- Can use like any other pointer
  - Vector *vp = this;
  - if (vp == this) ...
  - return this->size;
  - this->capacity = this->capacity * 2;
  - this->length( )

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Overloaded operator =

Four important parts:

1. Test for same object:
   - `if (&other != this) { /* copy code */ }`
2. Delete old dynamically allocated data
   - call `cleanup()` function, or
   - directly: `delete [] items;`
3. Copy new data
   - `copy()`
4. Return a reference to the current object:
   - `return *this;`

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And the code...

```
Vector & Vector::operator=(Vector &other) {
   if (&other != this) {
      cleanup();
      copy(other);
   }
   return *this;
}
// private member function
void Vector::cleanup() {
   delete [] items;
}
```

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Next Problem: Cleanup

- When a local goes away, only the local memory is released
  - Dynamic memory stays allocated
  - results in a memory leak
    `unless there is another pointer to the data`
- One solution: write a function to delete the allocated dynamic memory
  - cleanup() function we used in operator =
  - For Vector, this would be simply `delete [] items;`
  - Drawback: you (or client) must remember to call the function

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C++ Solution: A "Destructor"

- Called automatically to de-construct the object
  - When it goes out of scope (e.g. end of function)
  - When *delete* operator used
- Can contain most any code
  - Normally it would contain code to release all dynamically allocated memory
- Special syntax identifies it:
  ~classname ( )
  - no return value
  - no arguments allowed
- The compiler-generated default destructor does nothing.

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Vector Destructor

```
Vector::~Vector()
{
  cleanup();
}
```

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Wise Advice

- When defining a class which uses dynamic memory, ALWAYS provide
  - a default constructor
  - a deep copy method
  - a copy constructor (calls the deep copy method)
  - an overloaded assignment operator (calls the deep copy)
  - a destructor
- It may seem like unnecessary work, but will save you (and your readers) from nasty surprises.

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Constructor Puzzle

- Assume the class Vector has all of the following defined: DC: default constructor; CC: copy constructor; op =: overloaded assignment operator; D: destructor
- On each line, say if DC, CC, op =, or D is called.

```
Vector  puzzlfunction (Vector & v1) {  //line 1
    Vector v2;                    //line 2
    Vector v3 = v1;               //line 3
    v2 = v1;                      //line 4
    v2.VectorInsert(1, 0);        //line 5
    Vector * v4;                  //line 6
    v4 = new Vector;              //line 7
    delete v4;                    //line 8
    printVector(v2);              //line 9
    return (v2);                  //line 10 (tricky)
}                                 // line 11
```

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More Wrinkles

- Classes within classes, i.e., member variables which are themselves classes
  - Have to know what order the constructors are called in

    `Answer: bottom up`
  - Have to know what order destructors are called in

    `Answer: top down`
  - Special syntax for calling non-default constructors of member variables within outer-level constructors

    `"member initializer list" in implementation`

    `trivial examples p.172, 173`
- Nothing is ever as simple as it seems in C++!

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Where We're Headed

- We know the C++ features for dynamic memory
- We know how to package ADTs that use dynamic memory
- Armed with this... we can begin to investigate a series of interesting and useful data structures and ADTs. For each one:
  - What the ADT is (abstractly)
  - How to implement (often more than one way)
  - Applications

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