# Programming Abstractions

CS106B

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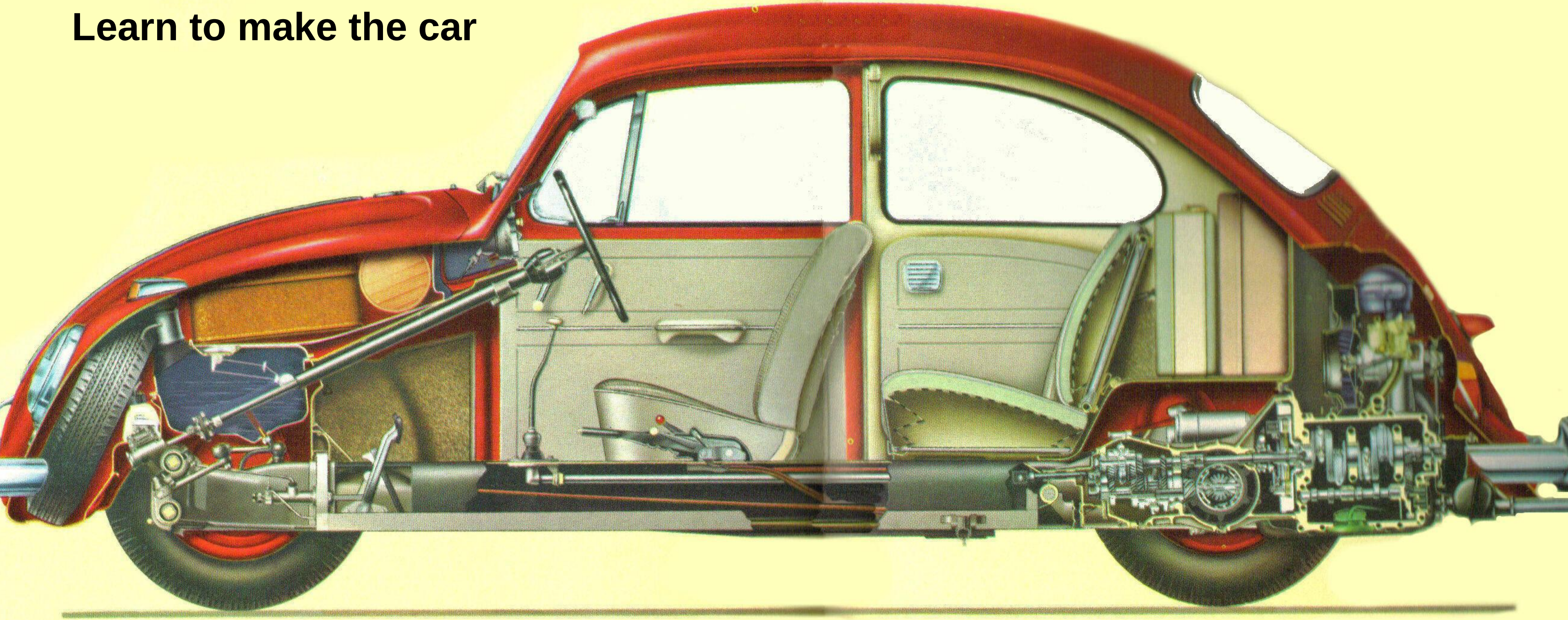
# Topics du Jour:

- **Make your own classes! (cont.)**
  - Last time we did a BankAccount class (pretty basic)
  - This time we will do something more like the classes you have used from the Stanford libraries
- **Arrays in C++**
  - In order to implement our version of a Vector (we're calling it ArrayList), we will need an array

# CS106B Weeks 1-3: Learn to use the car

# CS106B Weeks 4-8:
# Learn to make the car



# Relevant: Trailer to “The Love Bug (Herbie)” (1968)

https://www.youtube.com/watch?v=ay3GgrYEa1M

# Arrays in C++

(we will need one for our ArrayList class)

# Arrays (11.3)

```
type* name = new type[length];
```

- A **dynamically allocated** array.
- The variable that refers to the array is a **pointer**.
- The memory allocated for the array must be manually released, or else the program will have a **memory leak**.  (>_<)

- Another array creation syntax that we will not use:

  ```
  type name[length];
  ```

  - A fixed array; initialized at declaration; can never be resized.
  - Stored in a different place in memory; the first syntax uses the *heap* and the second uses the *stack*.  *(discussed later)*

# Initialized?

```
type* name = new type[length];   // uninitialized
type* name = new type[length](); // initialize to 0
```

- If `()` are written after the array `[]`, it will set all array elements to their default zero-equivalent value for the data type. *(slower)*
- If no `()` are written, the elements are uninitialized, so whatever garbage values were stored in that memory beforehand will be your elements.

```
int* a = new int[3];
cout << a[0];              // 2395876
cout << a[1];              // -197630894

int* a2 = new int[3]();
cout << a[0];              // 0
cout << a[1];              // 0
```

# How a Vector works

Inside a Vector is an **array** storing the elements you have added.

- Typically the array is larger than the data added so far, so that it has some extra slots in which to put new elements later.
  - When we say `size`, we mean the number of items currently stored, and we say `capacity` to refer to the total space.

```
Vector<int> v;
v.add(42);
v.add(-5);
v.add(17);
```

| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
|---|---|---|---|---|---|---|---|---|---|---|
| *value* | 0 42 | 0 -5 | 0 17 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |

`size` 3 `capacity` 10

# Implementing our ArrayList

Making our own container class!

# Exercise

Let's write a class that implements a growable array of integers.

- We'll call it `ArrayList`. It will be very similar to the C++ `Vector`.

- its behavior:
  - `add(`***`value`***`)` `insert(`***`index, value`***`)`
  - `get(`***`index`***`),` `set(`***`index, value`***`)`
  - `size(),` `isEmpty()`
  - `remove(`***`index`***`)`
  - `indexOf(`***`value`***`),` `contains(`***`value`***`)`
  - `toString()`

  ...

- We'll start with an array of **length (**`capacity`**) 10** by default, and grow it as needed.

# ArrayList.h

```
#ifndef _arraylist_h
#define _arraylist_h
#include <string>
using namespace std;

class ArrayList {
public:
    ArrayList();
    void add(int value);
    void clear();
    int get(int index) const;
    void insert(int index, int value);
    bool isEmpty() const;
    void remove(int index);
    void set(int index, int value);
    int size() const;
    string toString() const;

private:
    int* myElements;   // array of elements
    int myCapacity;    // length of array
    int mySize;        // number of elements added
};

#endif
```

# Implementing add (bug)

```
// in ArrayList.cpp
// BUG
// Socrative: what is the bug in this code?
void ArrayList::add(int value) {
    myElements[mySize] = value;
}
```

# Implementing add

How do you append to the end of a list?    `list.add(42);`

- place the new value in slot number `size`
- increment `size`

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| *value* | 3 | 8 | 9 | 7 | 5 | 12 | 0 | 0 | 0 | 0 |
| `size` | 6 | | `capacity` | | 10 | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| *value* | 3 | 8 | 9 | 7 | 5 | 12 | 42 | 0 | 0 | 0 |
| `size` | 7 | | `capacity` | | 10 | | | | | |

# Implementing `insert`

How do you insert in the middle of a list? `list.insert(3, 42);`

- shift elements right to make room for the new element
- increment `size`

| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
|---|---|---|---|---|---|---|---|---|---|---|
| *value* | 3 | 8 | 9 | 7 | 5 | 12 | 0 | 0 | 0 | 0 |
| *size* | 6 | *capacity* | 10 | | | | | | | |

myElements[6] =
myElements[5]

| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
|---|---|---|---|---|---|---|---|---|---|---|
| *value* | 3 | 8 | 9 | **42** | 7 | 5 | 12 | 0 | 0 | 0 |
| *size* | **7** | *capacity* | 10 | | | | | | | |

**Q:** In which direction should our array-shifting loop traverse?

**A.** left-to-right [✓ **B.** right-to-left] **C.** either is fine

# insert solution

```
// in ArrayList.cpp
void ArrayList::insert(int index, int value) {
    // shift right to make room
    for (int i = mySize; i > index; i--) {
        myElements[i] = myElements[i - 1];
    }
    myElements[index] = value;
    mySize++;
}
```

# Implementing `clear`

How do you clear the list? `list.clear();`

- change `size` to 0
- do we need to zero out all the data?

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| *value* | 3 | 8 | 9 | 7 | 5 | 12 | 0 | 0 | 0 | 0 |
| `size` | 6 | | `capacity` | | 10 | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| *value* | 3 | 8 | 9 | 7 | 5 | 12 | 0 | 0 | 0 | 0 |
| `size` | 0 | | `capacity` | | 10 | | | | | |

# Other members

Let's implement the following member functions in our list:

- `size()` - Returns the number of elements in the list.
- `get(`***`index`***`)` - Returns the value at a given index.
- `set(`***`index`***`, `***`value`***`)` - Changes the value at the given index.
- `isEmpty()` - Returns `true` if list contains no elements.
  - (Why bother to write this if we already have a `size` function?)

- `toString()` - String of the list such as `"{4, 1, 5}"`.
- `operator <<` - Make the list printable to `cout`

# Other members code

```
// in ArrayList.cpp
int ArrayList::get(int index) {
    return myElements[index];
}

void ArrayList::set(int index, int value) {
    myElements[index] = value;
}

int ArrayList::size() {
    return mySize;
}

bool ArrayList::isEmpty() {
    return mySize == 0;
}
```

# Other members code

```
// in ArrayList.cpp
ostream& operator <<(ostream& out, const ArrayList& list) {
    out << "{";
    if (!list.isEmpty()) {
        out << list.get(0);
        for (int i = 1; i < list.size(); i++) {
            out << ", " << list.get(i);
        }
    }
    out << "}";
    return out;
}

string ArrayList::toString() const {
    ostringstream out;
    out << *this;
    return out.str();
}
```

# Implementing remove

How do you remove an element from a list? `list.remove(2);`

- shift elements left to cover the deleted element
- decrement *size*

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| *value* | 3 | 8 | **9** | 7 | 5 | 12 | 0 | 0 | 0 | 0 |
| *size* | 6 | *capacity* | 10 | | | | | | | |

| | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
| *value* | 3 | 8 | 7 | 5 | 12 | 0 | 0 | 0 | 0 | 0 |
| *size* | **5** | *capacity* | 10 | | | | | | | |

**Q:** In which direction should our array-shifting loop traverse?

[✓ **A.** left-to-right] **B.** right-to-left **C.** either is fine

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# remove solution

```
// in ArrayList.cpp
void ArrayList::remove(int index) {
    // shift left to cover up the slot
    for (int i = index; i < mySize; i++) {
        myElements[i] = myElements[i + 1];
    }
    ~~myElements[mySize - 1] = 0;~~
    mySize--;
}
```

# Freeing array memory

```
delete[] name;
```

- Releases the memory associated with the given array.
- Must be done for all arrays created with `new`
  - Or else the program has a *memory leak*. (No garbage collector like Java)
  - Leaked memory will be released when the program exits, but for long-running programs, memory leaks are bad and will eventually exhaust your RAM.

```
int* a = new int[3];
a[0] = 42;
a[1] = -5;
a[2] = 17;
for (int i = 0; i < 3; i++) {
    cout << i << ": " << a[i] << endl;
}
...
delete[] a;
```

# Destructor (12.3)

```
// ClassName.h                 // ClassName.cpp
~ClassName();                  ClassName::~ClassName() { ...
```

**destructor**: Called when the object is deleted by the program.

(when the object goes out of `{}` scope;  opposite of a constructor)

- Useful if your object needs to do anything important as it dies:
  - saving any temporary resources inside the object
  - freeing any dynamically allocated memory used by the object's members
  - ...

- Does our `ArrayList` need a destructor?  If so, what should it do?

# Destructor solution

```
// in ArrayList.cpp
void ArrayList::~ArrayList() {
    delete[] myElements;
}
```

# Running out of space

myElements[size] = value;
my

What if the client wants to add more than 10 elements?

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 |
|---|---|---|---|---|---|---|---|---|---|---|
| value | 3 | 8 | 9 | 7 | 5 | 12 | 4 | 8 | 1 | 6 |
| size | 10 | capacity | 10 | | | | | | | |

- `list.add(75);     // add an 11th element`

| index | 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17 | 18 | 19 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| value | 3 | 8 | 9 | 7 | 5 | 12 | 4 | 8 | 1 | 6 | **75** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| size | **11** | capacity | | | **20** | | | | | | | | | | | | | | | |

- Answer: **Resize the array** to one twice as large.
  - Make sure to *free the memory* used by the old array!

# Resize solution

```
// in ArrayList.cpp
void ArrayList::checkResize() {
    if (mySize == myCapacity) {
        // create bigger array and copy data over
        int* bigger = new int[2 * capacity]();
        for (int i = 0; i < myCapacity; i++) {
            bigger[i] = myElements[i];
        }
        delete[] myElements;
        myElements = bigger;
        myCapacity *= 2;
    }
}
```

# Problem: size vs. capacity

What if the client accesses an element past the size?

```
list.get(7)
```

| *index* | *0* | *1* | *2* | *3* | *4* | *5* | *6* | *7* | *8* | *9* |
|---|---|---|---|---|---|---|---|---|---|---|
| *value* | 3 | 8 | 9 | 7 | 5 | 0 | 0 | 0 | 0 | 0 |
| *size* | 5 | *capacity* | 10 | | | | | | | |

- Currently the list allows this and returns 0.
  - Is this good or bad? What (if anything) should we do about it?

# Private helpers

```
// in ClassName.h file
private:
    returnType name(parameters);
```

a **private member** function can be called only by its own class

- your object can call the "helper" function, but clients cannot call it

```
void ArrayList::checkIndex(int i, int min, int max) {
    if (i < min || i > max) {
        throw "Index out of range";
    }
}
```

# Extra topic: Template classes

Something that Stanford library containers have that our ArrayList lacks.

# Template function (14.1-2)

```
template<typename T>
returntype name(parameters) {
    statements;
}
```

**Template**: A function or class that accepts a *type parameter(s)*.

- Allows you to write a function that can accept many types of data.
- Avoids redundancy when writing the same common operation on different types of data.

- Templates can appear on a single function, or on an entire class.

- FYI: Java has a similar mechanism called *generics*.

# Template func example

```
template<typename T>
T max(T a, T b) {
    if (a < b) { return b; }
    else       { return a; }
}
```

- The template is *instantiated* each time you use it with a new type.
  - The compiler actually generates a new version of the code each time.
  - The type you use must have an operator < to work in the above code.

```
int i    = max(17, 4);              // T = int
double d = max(3.1, 4.6);           // T = double
string s = max(string("hi"),        // T = string
               string("bye"));
```

# Template class (14.1-2)

**Template class**: A class that accepts a type parameter(s).

- In the header and cpp files, mark each class/function as templated.
- Replace occurrences of the previous type `int` with `T` in the code.

```
// ClassName.h
template<typename T>
class ClassName {
    ...
};

// ClassName.cpp
template<typename T>
type ClassName::name(parameters) {
    ...
}
```

# Recall: ArrayList.h

```
class ArrayList {
public:
    ArrayList();
    ~ArrayList();
    void add(int value);
    void clear();
    int get(int index) const;
    void insert(int index, int value);
    bool isEmpty() const;
    void remove(int index);
    void set(int index, int value) const;
    int size() const;
    string toString() const;
private:
    int* elements;
    int mysize;
    int capacity;
    void checkIndex(int index, int min, int max) const;
    void checkResize();
};
```

# Template ArrayList.h

```
template <typename T> class ArrayList {
public:
    ArrayList();
    ~ArrayList();
    void add(T value);
    void clear();
    T get(int index) const;
    void insert(int index, T value);
    bool isEmpty() const;
    void remove(int index);
    void set(int index, T value) const;
    int size() const;
    string toString() const;
private:
    T* elements;
    int mysize;
    int capacity;
    void checkIndex(int index, int min, int max) const;
    void checkResize();
};
```

# Template ArrayList.cpp

```
template <typename T>
ArrayList<T>::ArrayList() {
    myCapacity = 10;
    myElements = new T[myCapacity];
    mySize = 0;
}

template <typename T>
void ArrayList<T>::add(T value) {
    checkResize();
    myElements[mySize] = value;
    mySize++;
}

template <typename T>
T ArrayList<T>::get(int index) const {
    checkIndex(index, 0, mySize - 1);
    return myElements[index];
}

...
```

# Template .h and .cpp

Because of an odd quirk with C++ templates, the separation between .h header and .cpp implementation must be reduced.

- Either write all the bodies in the .h file (suggested),
- Or #include the .cpp at the end of .h file to join them together.

```
// ClassName.h
#ifndef _classname_h
#define _classname_h

template<typename T>
class ClassName {
    ...
};

#include "ClassName.cpp"
#endif   // _classname_h
```