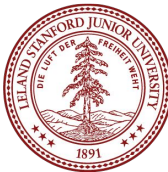


Console Programs and Vectors

What is the first thing that comes to your mind when you think of the phrase "data structure"?



Last Week...

(Answering Survey Questions!)

Python vs. Java vs. C++

What are the best C++ libraries
to know?

What are the best C++ libraries to know?

Trip's List:
strlib.h
The ADT .h files
simpio.h (for A1, A2)

Roadmap

C++ basics

User/client

vectors + grids

stacks + queues

sets + maps

Object-Oriented
Programming

Implementation

arrays

dynamic memory
management

linked data structures

real-world
algorithms

Life after CS106B!

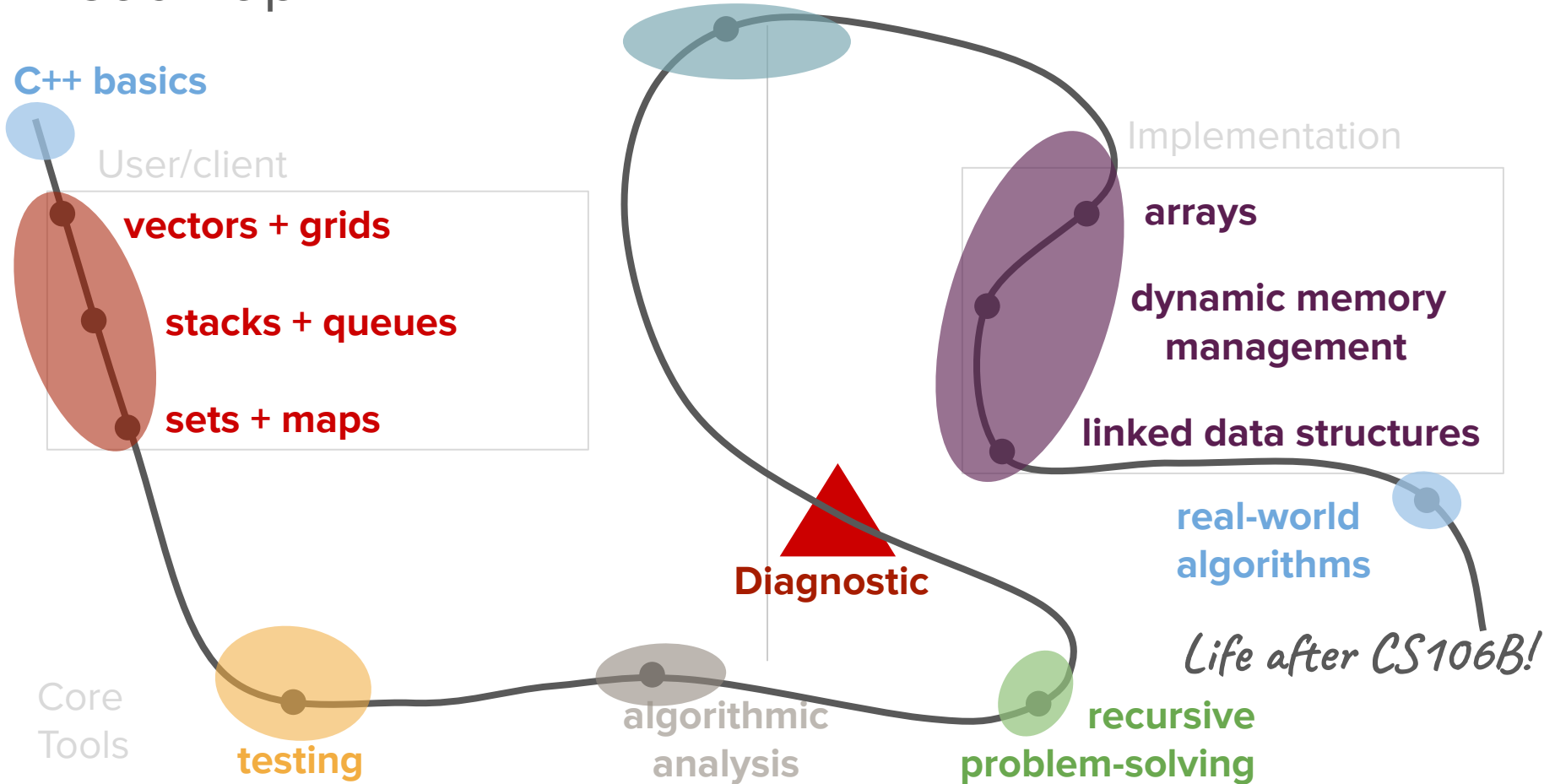
Core
Tools

testing

algorithmic
analysis

recursive
problem-solving

Diagnostic



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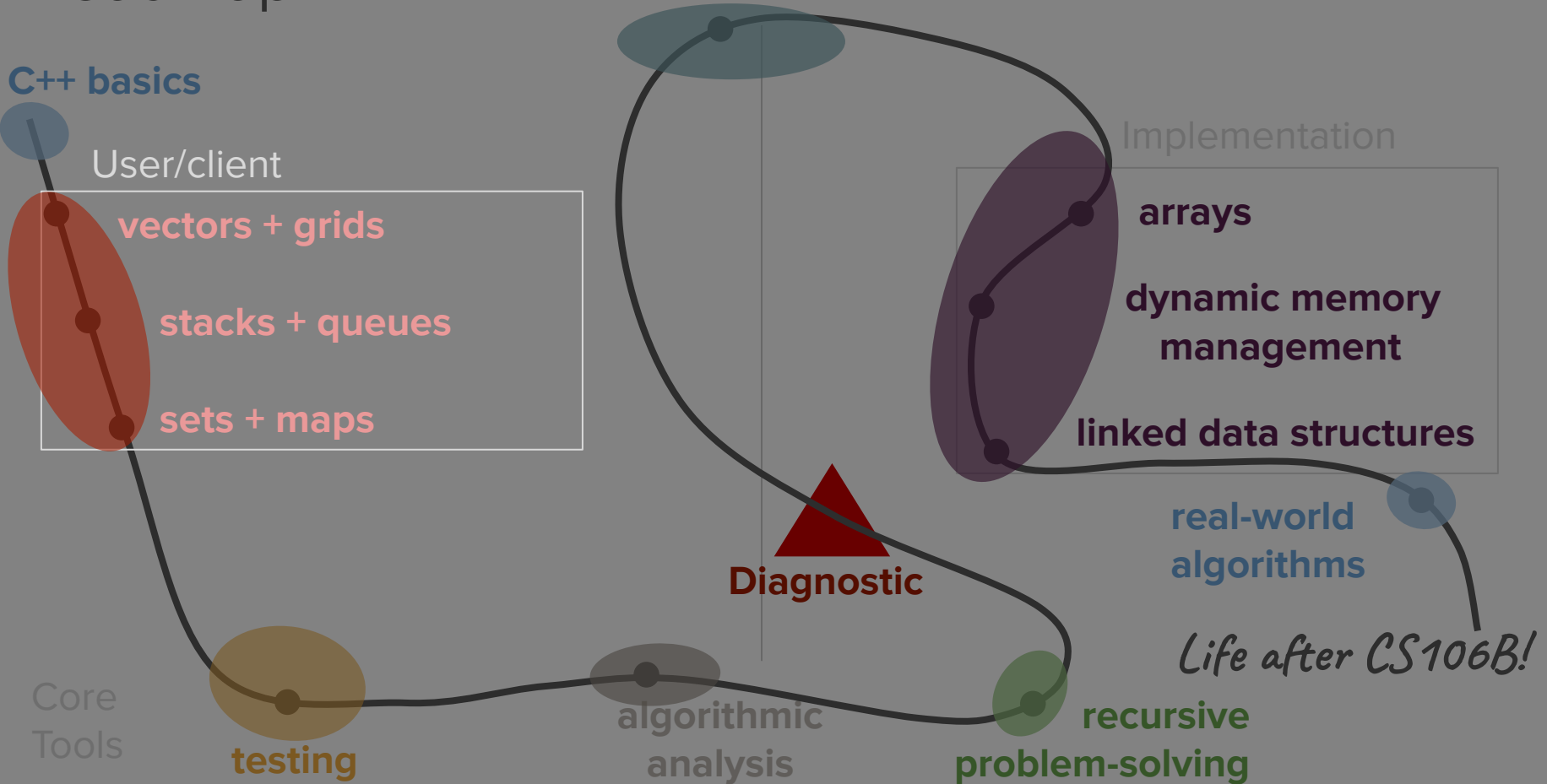
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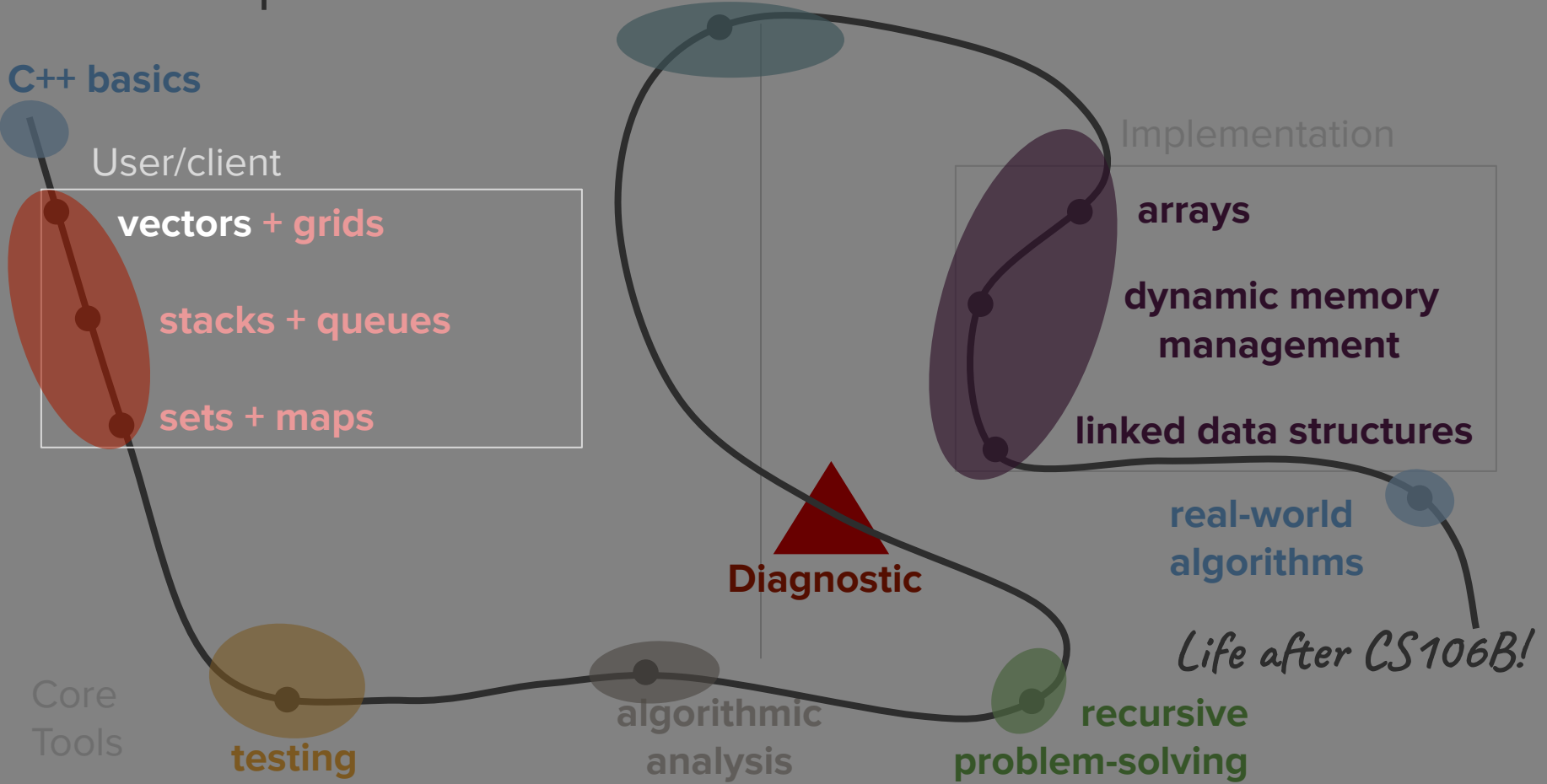
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Today's questions

How do we build programs that interact with users?

How do we store / structure data using abstractions in code?

Today's topics

1. Review (strings, testing, and SimpleTest)
2. Console Programs
3. Abstract Data Types
 - a. Vectors
4. Pass by reference

Review

(strings, testing and SimpleTest)

SimpleTest

How does SimpleTest work?

main.cpp

```
#include "testing/SimpleTest.h"
```

```
#include "testing-examples.h"
```

```
int main()
```

```
{
```

```
    if (runSimpleTests(SELECTED_TESTS)) {
```

```
        return 0;
```

```
    }
```

```
    return 0;
```

```
}
```



```
SELECTED_TESTS  
ALL_TESTS
```

How does SimpleTest work?

main.cpp

```
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int main()
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    if (runSimpleTests(SELECTED_TESTS)) {
        return 0;
    }

    return 0;
}
```

testing-examples.cpp

```
#include "testing/SimpleTest.h"

int factorial (int num);

int factorial (int num) {
    /* Implementation here */
}

PROVIDED_TEST("Some provided tests.") {
    EXPECT_EQUAL(factorial(1), 1);
    EXPECT_EQUAL(factorial(2), 2);
    EXPECT_EQUAL(factorial(3), 6);
    EXPECT_EQUAL(factorial(4), 24);
}

STUDENT_TEST("student wrote this test") {
    // student tests go here!
}
```

How does SimpleTest work?

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```

How do we solve
interesting problems
with strings?

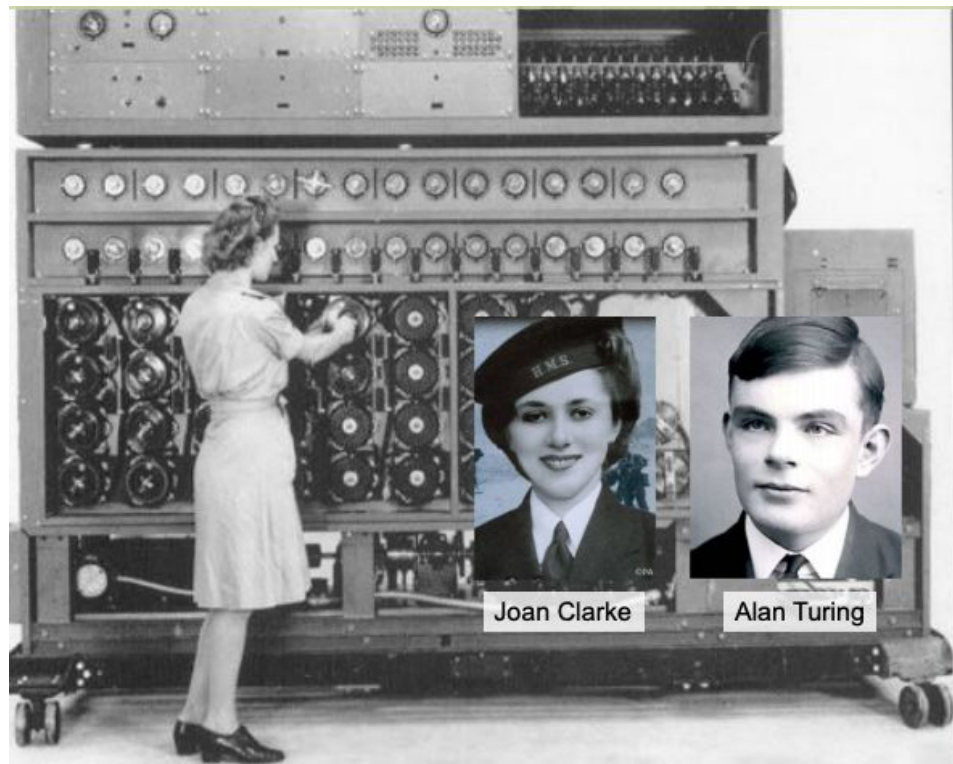
Real-life problems involving strings

- Encryption and decryption

```
string encrypted = 'Jvkpun pz mbu';
```

```
string decrypted = 'Coding is fun';
```

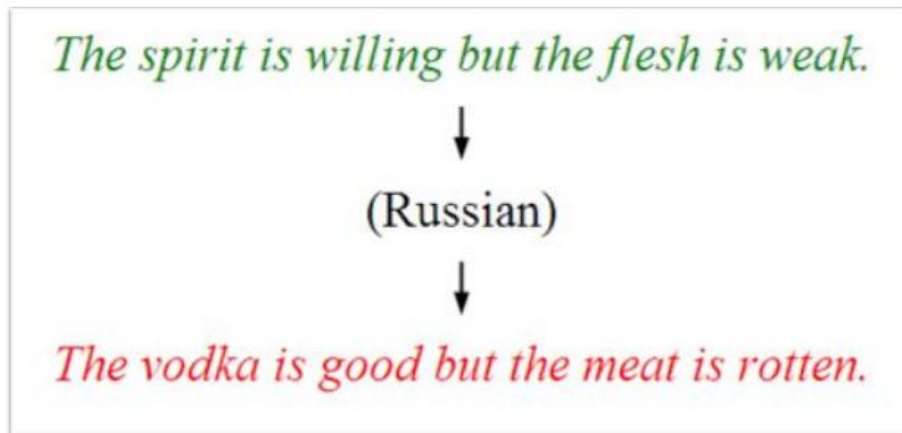
Bonus: What cipher is this?



Real-life problems involving strings

- Encryption and decryption
- Language translation

```
string input = "¿Dónde está la  
biblioteca?";  
  
string output = "Where is the  
library?";
```



**This result cost billions of dollars (adjusted for inflation)*

Real-life problems involving strings

- Encryption and decryption
- Language translation
- DNA Analysis

```
string input = "ATGCCGATGTGC";
```

```
output = gene analysis,
```

```
homology score, etc.
```



```
AGGTCAGTCAGATTTACCCCTGGCTCA  
TGTTCGTACAACCAATTTAGGTGAGT  
TTCGGAAAGACTCCCTGGTACCATCC  
CCGGGGCTTGGAAATTTACGGGTCAGA  
ACCAATCGTAACATATGAGAGCCACT  
ATAATAGGGGAGGGTTCATTTCCGTCG  
CTAACTTTGCTTAATACCCGACCACC  
CCACCCTGGCATTATAGTACCCCGAA  
CGTAGAGCCAGATGTATGCAATGCC  
GTAAGATCTCCAAAAGGTCGACGAT  
AGTGGGTACTTTGGATACCATCATTG  
ATCCGCTGATTGCTGGTTAATTCGTA  
TCCCGGTTTCAAGTTTCAGACACTAG  
CCTAGGGGGCGTCCGACTGCCGACCATA  
TCAAATAGGGTATCCGGGAGGTTTCATT  
TGGCACCCGTCCGTC AACGGTGTGCG  
GCCGCAGCTACCTCGAAAGTCATAGC  
CCTGATCGTCCATTACCCGGGATGTGT  
GCCGGAGGGTCAACACAGGTAACCTC  
CTAACCGCTCCCCATCCCATCCGAGA  
TTTTTAGAAATGTTTGTAGAATGGG  
TCGAGGGGTCCTTCGTTACCCATGGC  
AGTTCGCAGTATTGACAAAACGAGCAT  
CCAGGAATTCGGATGCCGATCGCTCG  
ACACCTTTGTCCAATAACAAAAGTAA  
TGTGAAAGTTTTACCTAGATGGTGGT
```

Real-life problems involving strings

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ATAATAGGGGAGGGTTCATTTCCGTCG  
CTAACTTTGCTTAATACCCGACCACC  
CCACCCTGGCATTATAGTACCCCGAA  
CGTAGAGCCAGATGTATGCAATGCC  
GTAAGATCTCCAAAAGGTCGACGAT  
AGTGGGTACTTTGGATACCATCATTG  
ATCCGCTGATTGCTGGTTAATTCGTA  
TCCCGGTTTCAAGTTTCAGACACTAG  
CCTAGGGGGCGTCCGACTGCCGACCATA  
TCAAATAGGGTATCCGGGAGGTTTCATT  
TGGCACCCGTCCGTC AACGGTGTGCG  
GCCGCAGCTACCTCGAAAGTCATAGC  
CCTGATCGTCCATTACCCGGGATGTGT  
GCCGGAGGGTCAACACAGGTAACCTC  
CTAACCGCTCCCCATCCCATCCGAGA  
TTTTTAGAAATGTTTGTAGAATGGG  
TCGAGGGGTCCTTCGTTACCCATGGC  
AGTTCGCAGTATTGACAAAACGAGCAT  
CCAGGAATTCGGATGCCGATCGCTG  
ACACCTTTGTCCAATAACAAAGTAA  
TGTGAAAGTTTTACCTAGATGGTGGT
```

Generating DNA Complement Sequences

- In biology, you might have learned that the fundamental unit of DNA is a nucleotide, or base.
- The four possible bases for DNA are Guanine (G), Cytosine (C), Adenine (A), and Thymine (T).
- These nucleotides form “base pairs” that make up complementary strands of DNA (which create its double-helix structure).
- A pairs with T, and G pairs with C.



Generating DNA Complement Sequences

We want to write a function with the prototype

```
string complement (string dnaStrand)
```

which takes in a strand of DNA as a string and returns its complement as a string.

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The function can assume that **all** of the base pairs of the input string are valid DNA base pairs— that is, the string consists only of the following characters: `'a'` , `'A'` , `'g'` , `'G'` , `'t'` , `'T'` , `'c'` , `'C'`

Your Task (`instructions.txt`)

- We've provided a buggy implementation of `complement` for you on the course website under today's lecture. We've also provided some tests, but all of the tests currently pass, so they haven't yet unearthed the bug in the code.
- Introduce yourself to the person sitting next to you and do the following:
 - Write at least one additional test that uncovers the bug in the provided implementation.
 - Fix the bug and confirm that your new test passes.
 - Make sure to add a more accurate name to the `STUDENT_TEST` identifier in the code. Discuss with your group what other tests/groups of tests you might add if you had more time to make the code more robust.

Happy Testing! (5 min)

(QT Project available on course website under the 6/27 lecture!)

DNA Exercise Recap

- What sort of test cases were not being covered?
 - Inputs with lowercase letters!
 - Example of a test that you could have added to surface an error
 - `STUDENT_TEST ("DNA strand with lowercase letter") {
 EXPECT_EQUAL(complement("aTg"), "TAC");
}`

DNA Exercise Recap

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 - `STUDENT_TEST ("DNA strand with lowercase letter") {
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- How do you fix the bug?
 - Need to do conversion of the characters in the string to uppercase!
 - Could add `ch = toupper(ch)` as the first line inside the for loop
 - Could convert the whole string to uppercase before starting the loop
 - Less optimal: check all 8 cases with if statements (for upper and lower case bases)

DNA Exercise Recap

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- Could add `ch = toupper(ch)` as the first line inside the for loop
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*Style tip: Minimize the number of  
hardcoded checks/conditional statements!*

How do we build programs  
that interact with users?

How do we build programs  
that interact with users?

*Console programs!*

## *Definition*

### **Console program**

A program that uses the interactive terminal (console) as a communication boundary with the user.



*An abstraction  
for the user!*

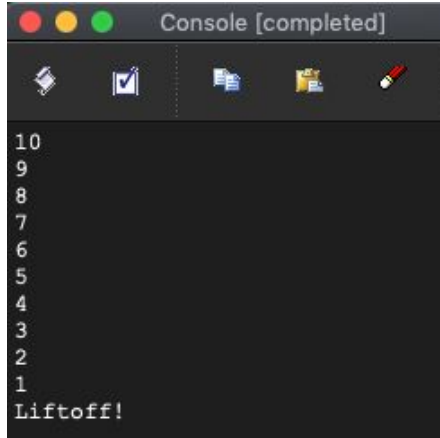
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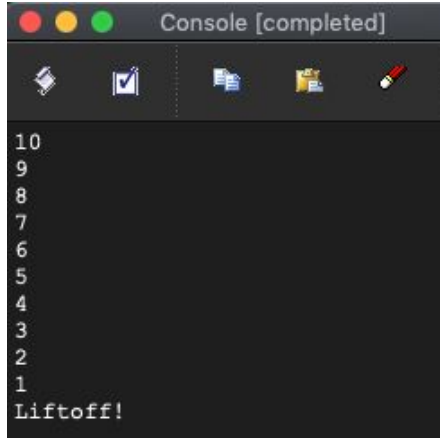


# Some example console programs

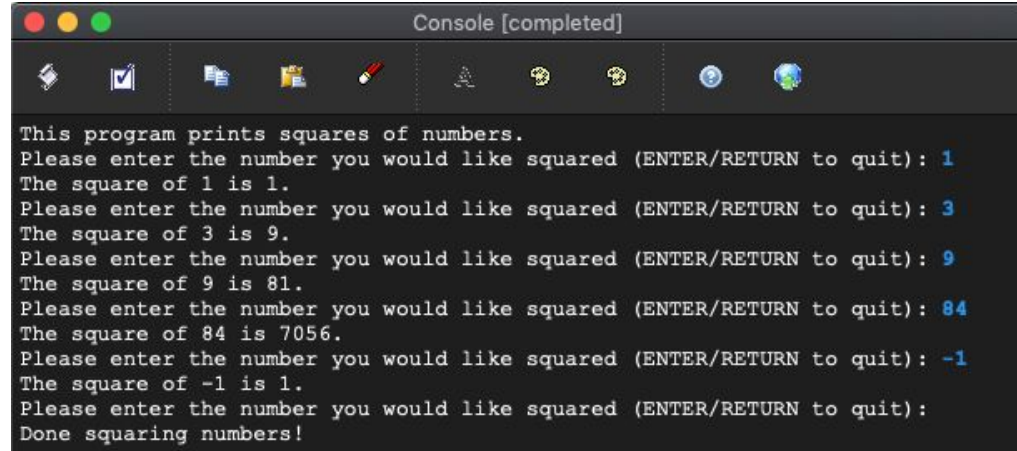


```
Console [completed]
10
9
8
7
6
5
4
3
2
1
Liftoff!
```

# Some example console programs

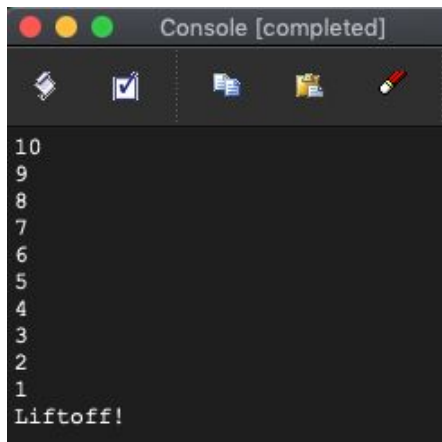


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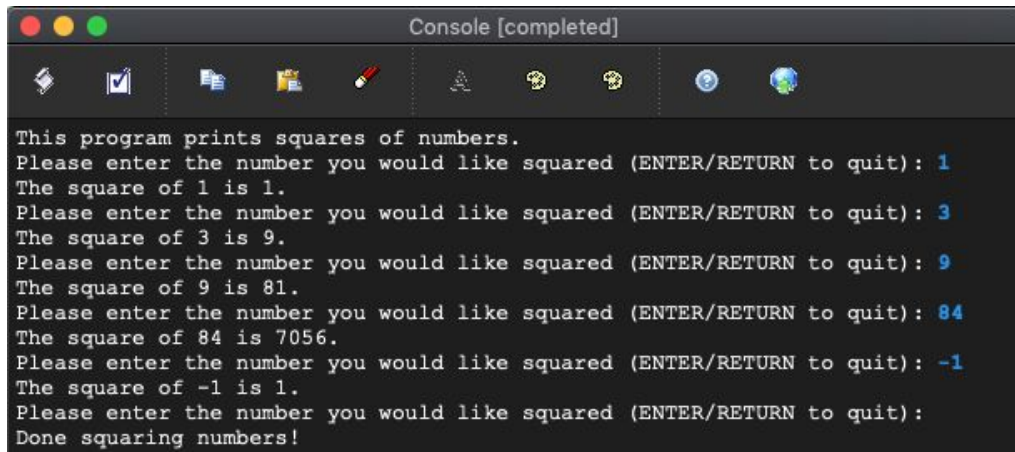


```
This program prints squares of numbers.
Please enter the number you would like squared (ENTER/RETURN to quit): 1
The square of 1 is 1.
Please enter the number you would like squared (ENTER/RETURN to quit): 3
The square of 3 is 9.
Please enter the number you would like squared (ENTER/RETURN to quit): 9
The square of 9 is 81.
Please enter the number you would like squared (ENTER/RETURN to quit): 84
The square of 84 is 7056.
Please enter the number you would like squared (ENTER/RETURN to quit): -1
The square of -1 is 1.
Please enter the number you would like squared (ENTER/RETURN to quit):
Done squaring numbers!
```

# Some example console programs



```
10
9
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The square of 84 is 7056.
Please enter the number you would like squared (ENTER/RETURN to quit): -1
The square of -1 is 1.
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Done squaring numbers!
```



```
Console [Completed]
File Edit Options Help
What is your first name? Trip
What is your favorite food? Oreos
Hello, Trip, it is nice to meet you!
You like Oreos? Gosh, that's so 2009.
```

How do we get  
information from the  
user?

How do we get  
information from the  
user?

*The interactive terminal (console)  
and the `getLine()` function!*

The console and the `getLine()` function

# The console and the `getline()` function

- The console is the text-output area that we have already seen when using `cout` to display information. In addition to displaying text, the console can also solicit text from a user.



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- The function will then wait while the user types in text into the console.
- After the user submits their answer by hitting the “Enter/Return” key, the function returns the value that the user typed into the console.

NOT to be mistaken  
with `getline()`  
(lowercase 'l') in the  
cpp standard library!

# The console and the `getline()` function

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Console Programs

Demo

# Console program summary

- Use `getline(prompt)` to read in information from the user.
  - Make sure to convert the data to the correct type
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# Console program summary

- Use `getline(prompt)` to read in information from the user.
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  - You can also use functions from [simpio.h](#) to get data of other types
- Use a `while` loop to enable multiple runs of your program.
  - `while(true)` paired with `break` is a powerful construct
- Console programs should *not* be run with SimpleTest
  - Doesn't make sense to write tests using SimpleTest because they don't have neatly defined "output" to compare against



# Announcements

# Announcements (I)

- Section (actually) starts this week! Initial section assignments should have been posted last night / this morning. Please check [cs198.stanford.edu](https://cs198.stanford.edu) to find your section time and location.
  - Section attendance and engaged participation are a part of your grade, so make sure to attend!
  - If you did not yet sign up for section, please do so now on the 198 website!
- Assignment 1 is out and is due this Friday at 11:59pm PDT.
  - The YEAH session will take at 5:15PM in Hewlett 101. It will also be recorded and posted on Canvas, but you won't be able to ask live questions that way :(
- C++ survey results
  - Check out [the Ed post](#) we made that answers all of your questions from the C++ survey!
- When emailing instructors, please email Kylie and Jenny together!

# Announcements (II)

- As a reminder, if you contract COVID, please email Trip as well as [cs198lair@gmail.com](mailto:cs198lair@gmail.com) with proof of your positive infection (screenshot of color test / rapid test works fine).
  - **An important update:** due to some policy updates from our administrators, minors who have COVID will not be able to attend LaIR virtually. If you are a minor and contract COVID, Trip will work with you to ensure that you have the appropriate extensions to complete the assignment.
- Please do not post blocks of your own code on Ed
  - Code is for LaIR or OH – we want to maximize public / conceptual posts so that we can learn as a community!
- On the flipside, please come to LaIR!
  - Check out the [LaIR schedule on the course website!](#)

How do we structure data using  
abstractions in code?

# Abstract Data Types

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- These ADTs give us certain guarantees about the organization and properties of our data, without our having to worry about managing the underlying details
- While we specifically study implementations of ADTs from the Stanford C++ libraries, these principles transcend language boundaries
  - We will do our best to point out comparisons to Java and Python along the way.
  - We will not be learning how to use the standard C++ (STL) data structures. If you're interested in learning more about these, check out the [CS106L course materials](#).

# Vectors

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 *A collection of function prototypes that allows for code sharing and reuse.*

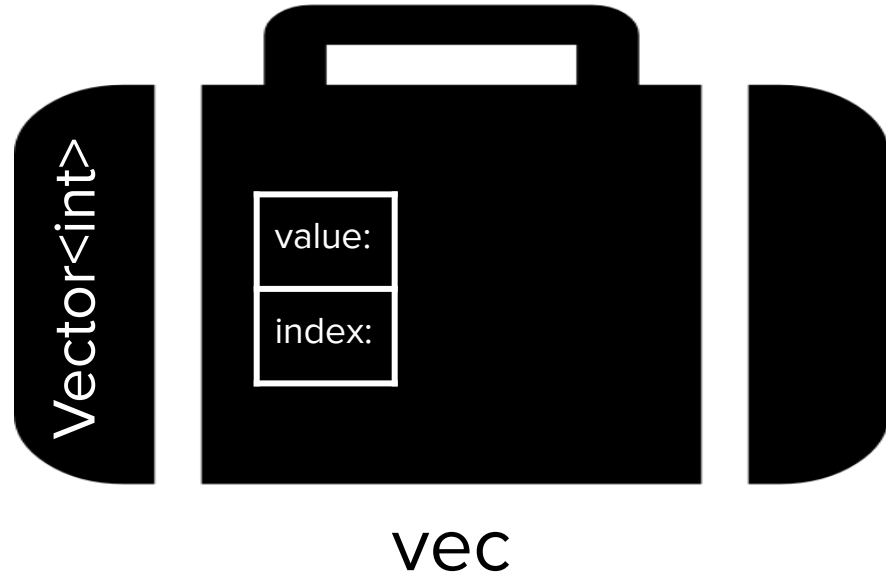
# Basic Vector Operations: Creation

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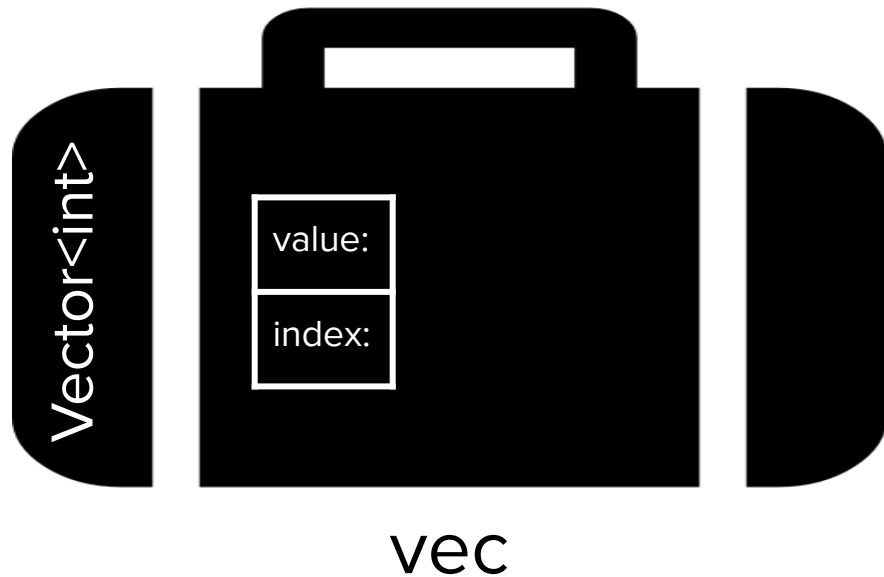


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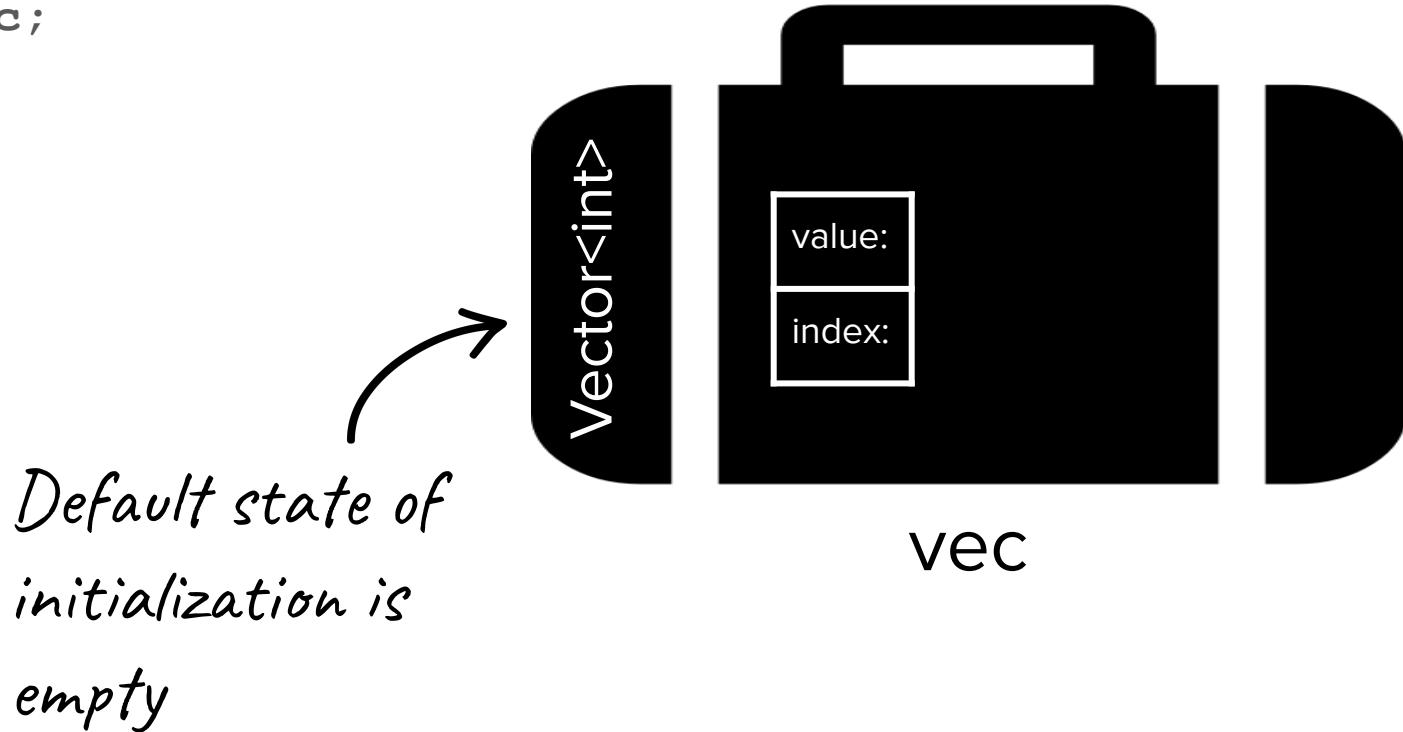


*Must specify the  
type of values  
that will be held  
at creation time.*



# Basic Vector Operations: Creation

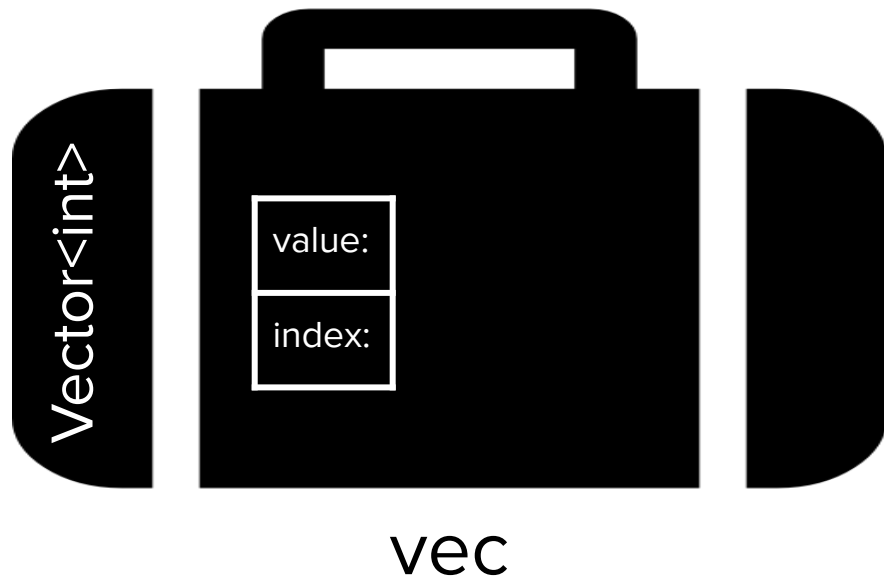
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Vector<int> vec;
```



# Basic Vector Operations: Adding Elements

```
Vector<int> vec;
```

```
vec.add(4);
```

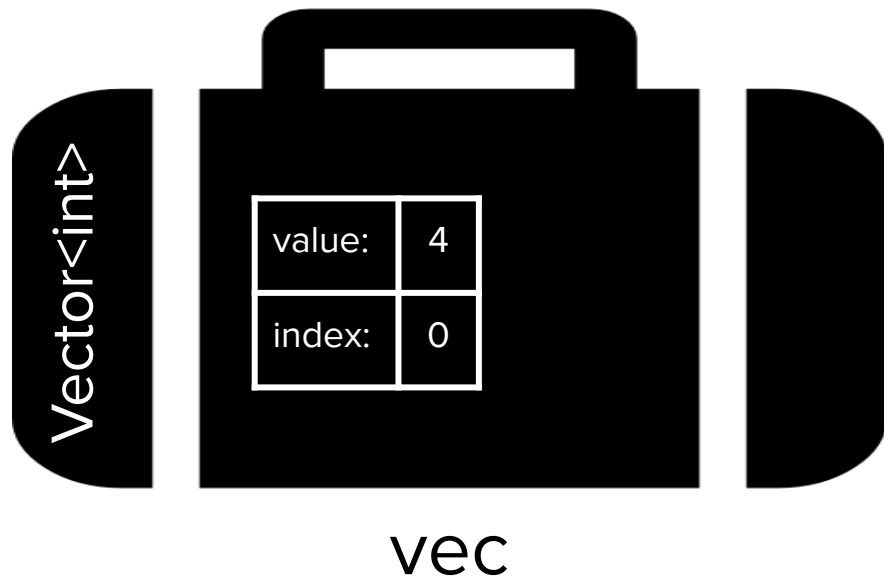




# Basic Vector Operations: Adding Elements

```
Vector<int> vec;
```

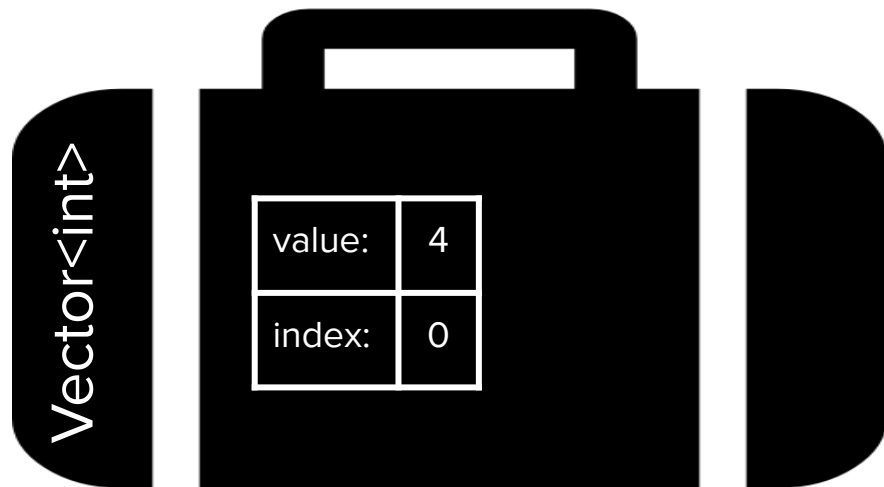
```
vec.add(4);
```



# Basic Vector Operations: Adding Elements

```
Vector<int> vec;
```

```
vec.add(4);
```



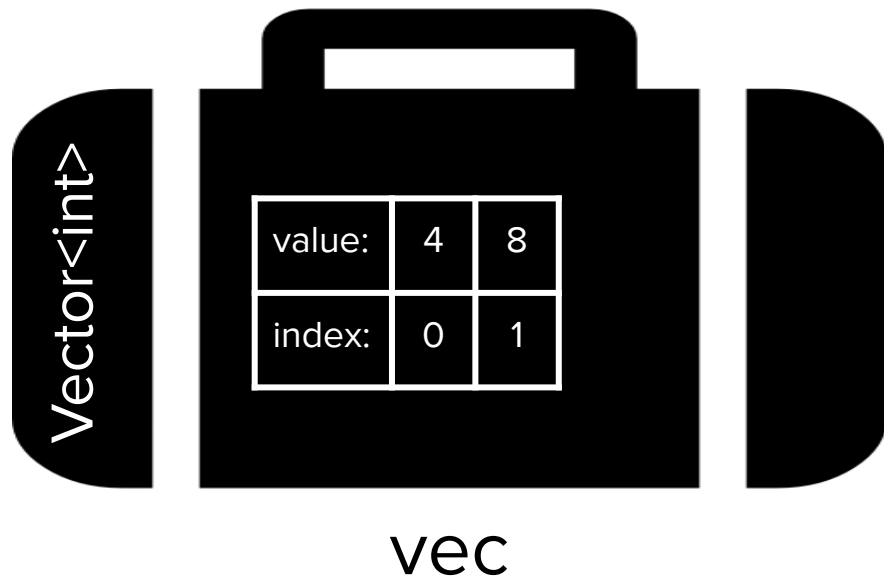
*Note: indexing `vec`  
starts at 0*

# Basic Vector Operations: Adding Elements

```
Vector<int> vec;
```

```
vec.add(4);
```

```
vec.add(8);
```



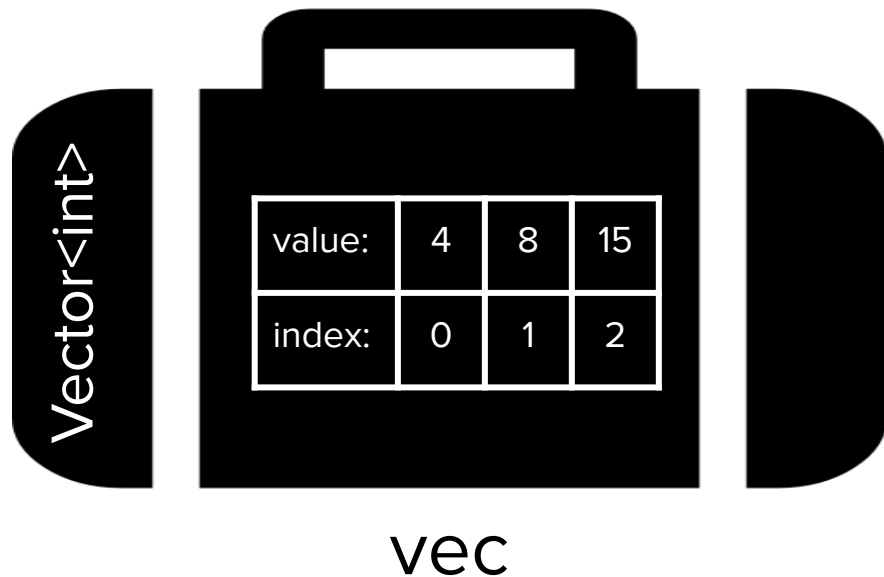
# Basic Vector Operations: Adding Elements

```
Vector<int> vec;
```

```
vec.add(4);
```

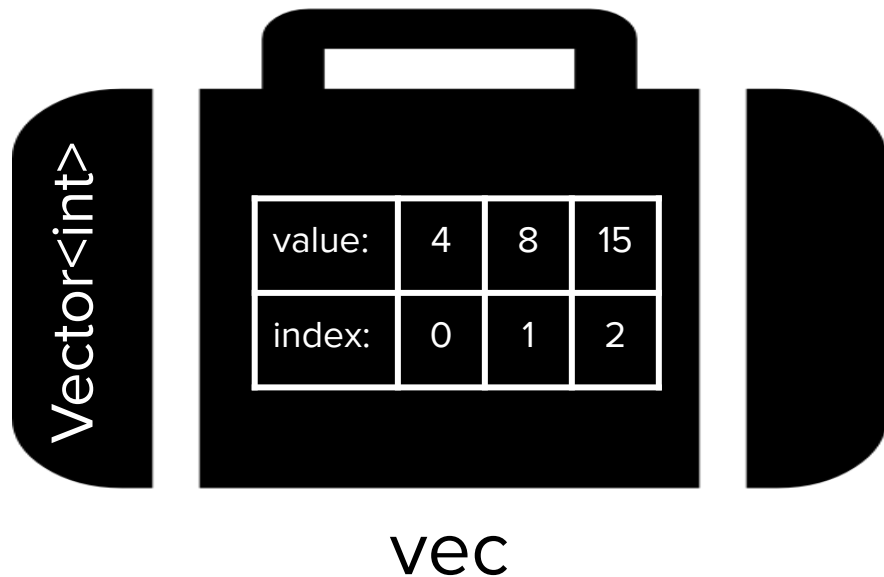
```
vec.add(8);
```

```
vec.add(15);
```



# Basic Vector Operations: Creating + Adding Together

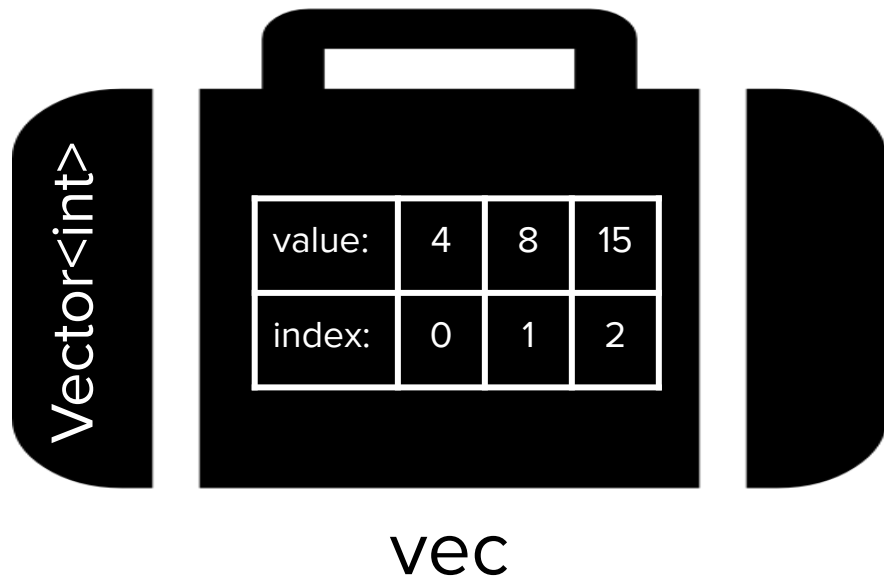
```
Vector<int> vec = {4, 8, 15};
```



# Basic Vector Operations: Accessing Elements

```
Vector<int> vec = {4, 8, 15};
```

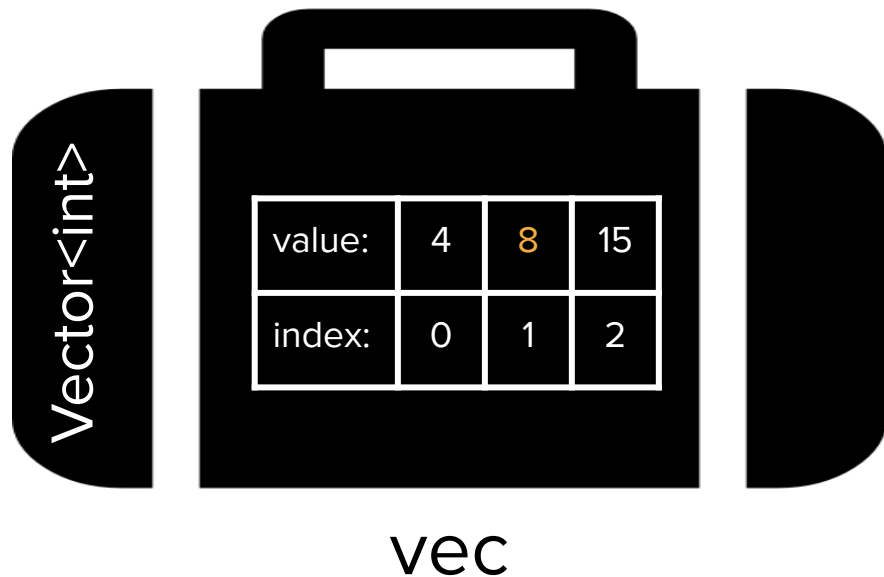
```
cout << vec[1] << endl;
```



# Basic Vector Operations: Accessing Elements

```
Vector<int> vec = {4, 8, 15};
```

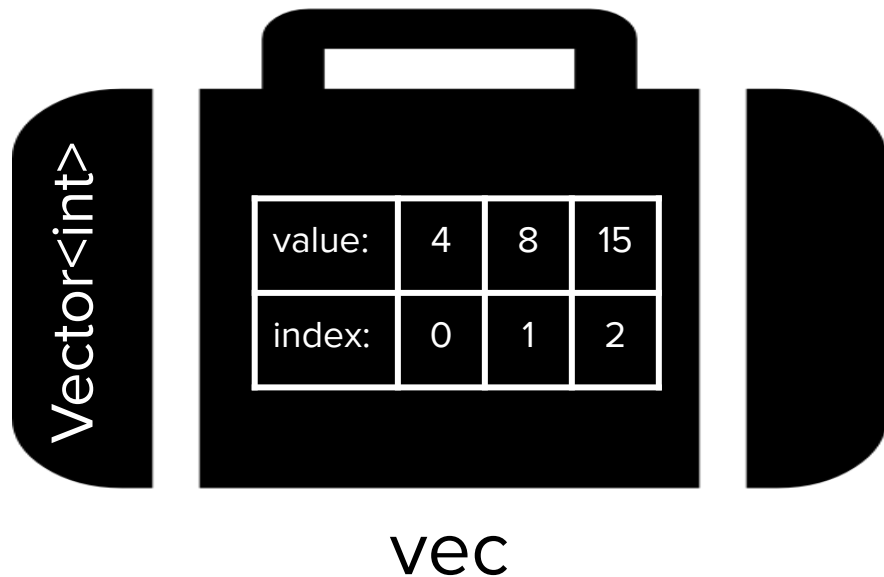
```
cout << vec[1] << endl;
```



# Basic Vector Operations: Accessing Elements

```
Vector<int> vec = {4, 8, 15};
```

```
cout << vec[3] << endl;
```





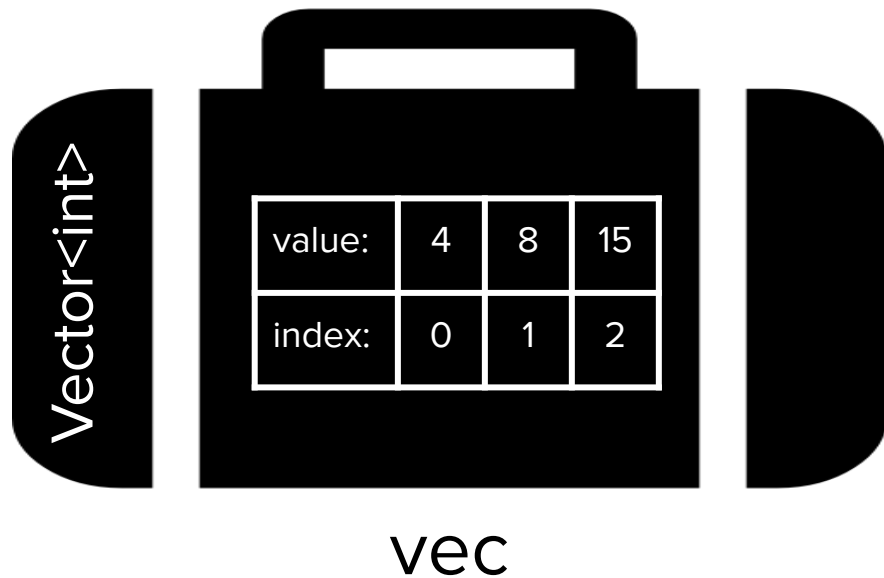
# Basic Vector Operations: Accessing Elements

```
Vector<int> vec = {4, 8, 15};
```

```
cout << vec[3] << endl;
```

**Poll: What will be the output of the above code snippet?**

**[PollEv.com/tripmaster419](https://PollEv.com/tripmaster419)**



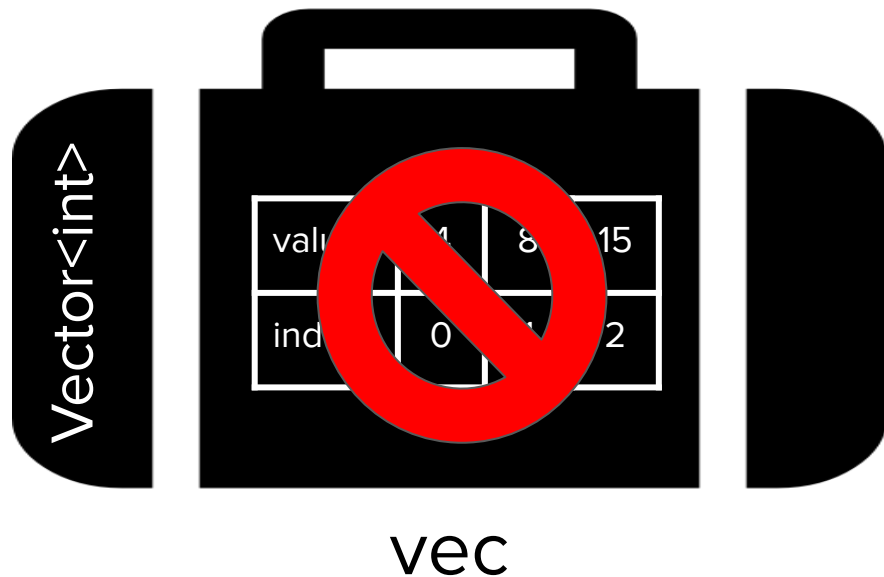
# Basic Vector Operations: Accessing Elements

```
Vector<int> vec = {4, 8, 15};
```

```
cout << vec[3] << endl;
```

```
// this will throw an error!
```

```
// takeaway: Vector does
bounds checking and will not
allow you to access elements
that are out of bounds
```

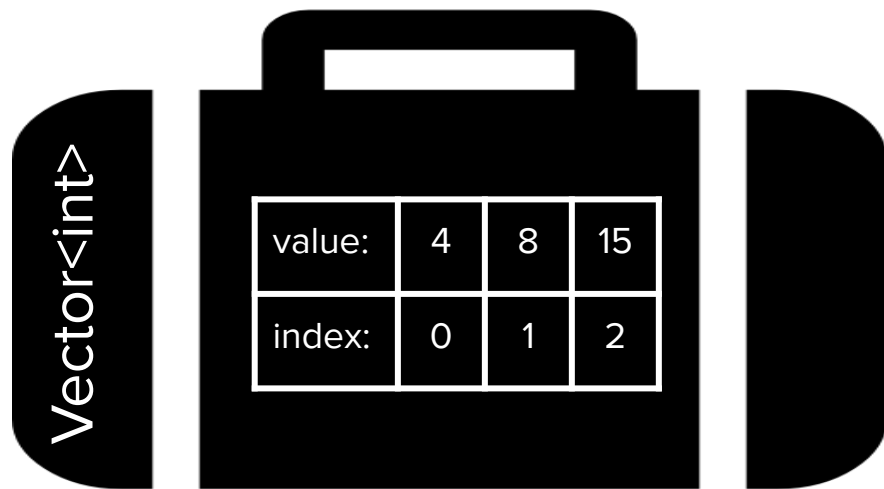


# Basic Vector Operations: Removing Elements

```
Vector<int> vec = {4, 8, 15};
```

```
cout << vec[1] << endl;
```

```
vec.remove(0);
```



`vec`

# Basic Vector Operations: Removing Elements

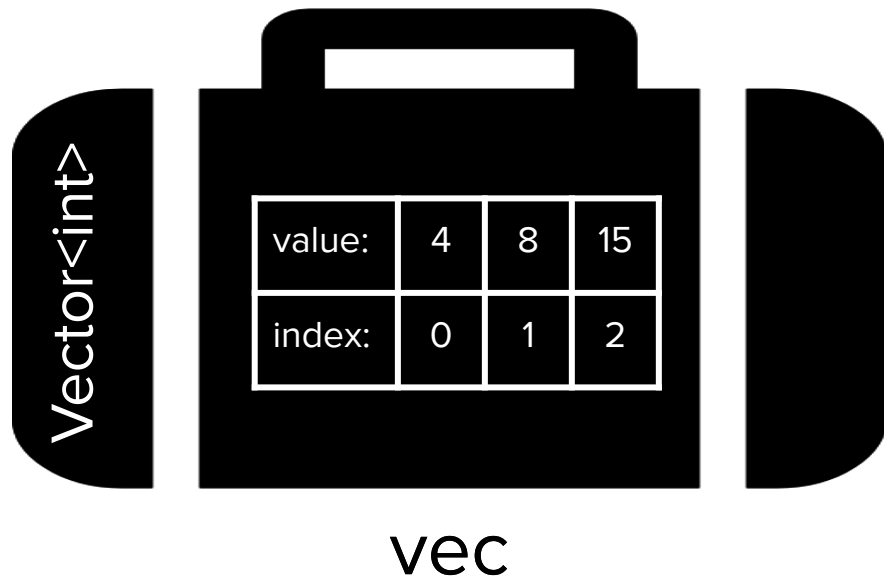
```
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```

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```

```
vec.remove(0);
```



Specify the *index*  
to remove at



# Basic Vector Operations: Removing Elements

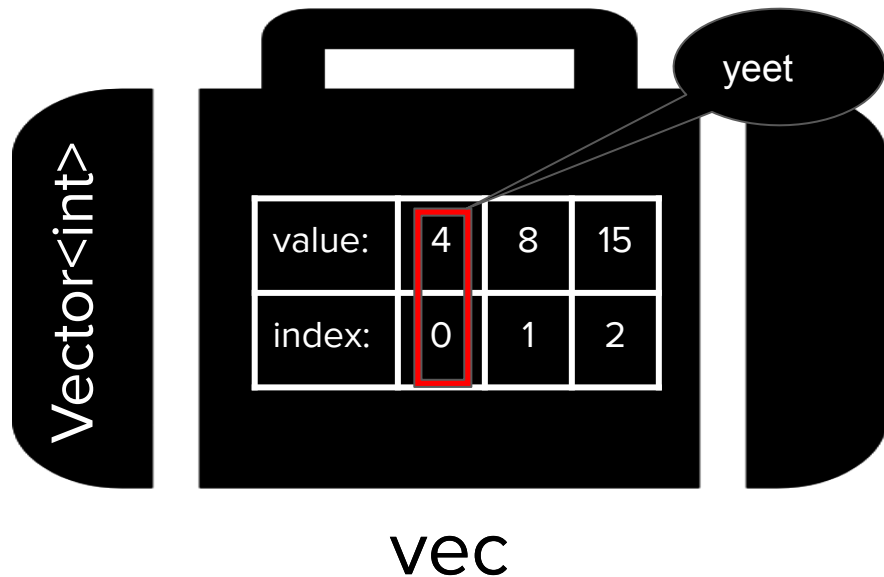
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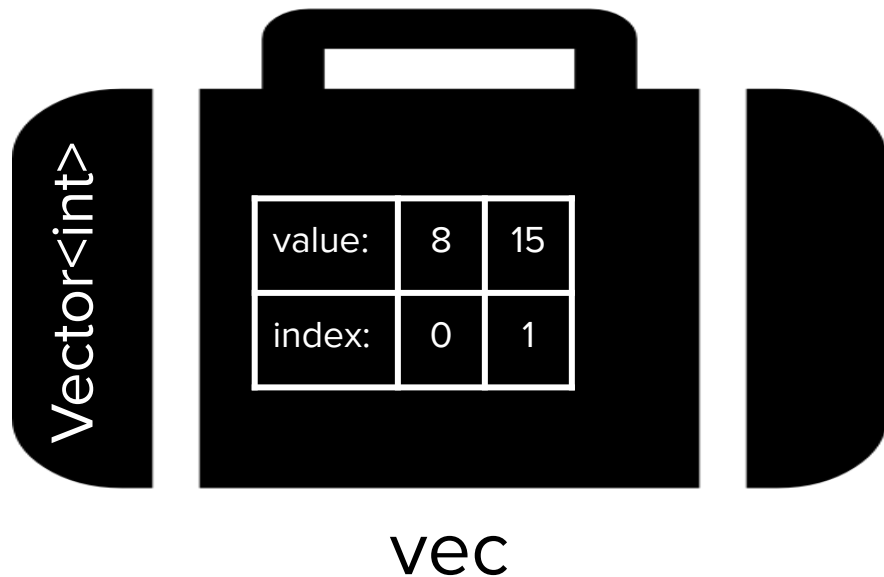


# Basic Vector Operations: Removing Elements

```
Vector<int> vec = {4, 8, 15};
```

```
cout << vec[1] << endl;
```

```
vec.remove(0);
```



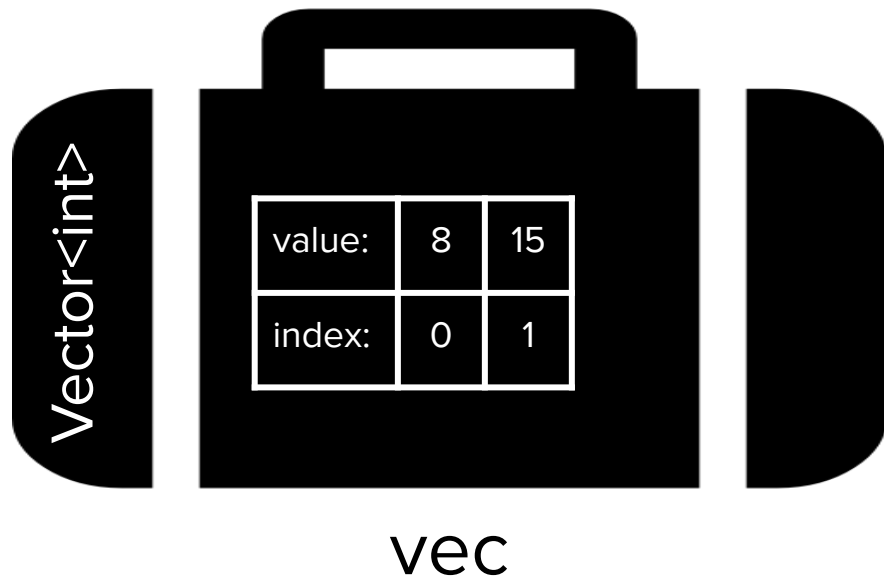
# Basic Vector Operations: Number of Elements

```
Vector<int> vec = {4, 8, 15};
```

```
cout << vec[1] << endl;
```

```
vec.remove(0);
```

```
cout << vec.size() << endl;
```



# Basic Vector Operations: Number of Elements

```
Vector<int> vec = {4, 8, 15};

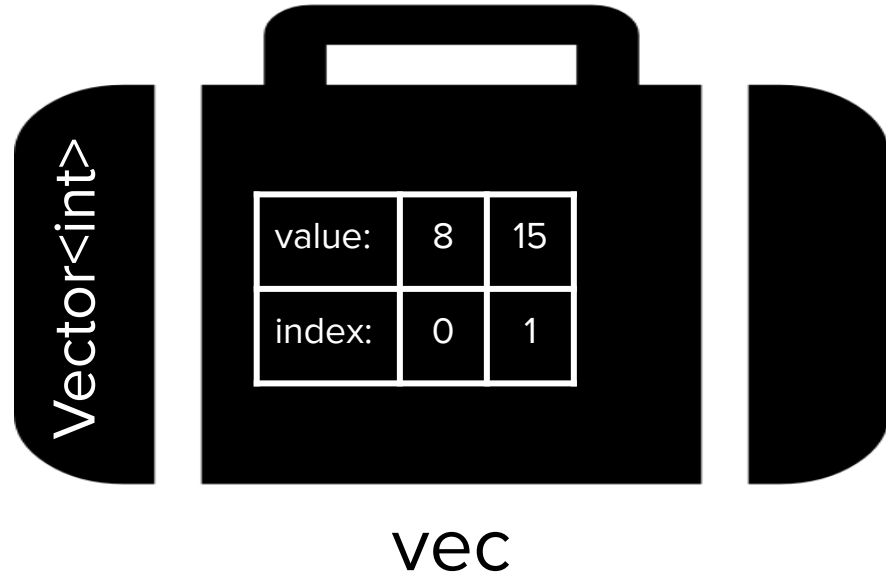
cout << vec[1] << endl;

vec.remove(0);

cout << vec.size() << endl;
```

**Output:**

**2**





# Traversing a Vector

- Method 1: Traditional for loop

```
Vector<int> vec = {1, 0, 6};
for (int i = 0; i < vec.size(); i++) {
 cout << vec[i] << endl;
}
```

# Traversing a Vector

- Method 1: Traditional for loop

```
Vector<int> vec = {1, 0, 6};
for (int i = 0; i < vec.size(); i++) {
 cout << vec[i] << endl;
}
```

**Output:**

1

0

6

# Traversing a Vector

- Method 1: Traditional for loop

```
Vector<int> vec = {1, 0, 6};
for (int i = 0; i < vec.size(); i++) {
 cout << vec[i] << endl;
}
```

- Method 2: for-each loop

```
Vector<int> vec = {1, 0, 6};
for (int num: vec) {
 cout << num << endl;
}
```

**Output:**

1

0

6

# Vector Functions

```
#include "vector.h"
```

- The following functions are part of the Vector collection, and can be useful:
  - `vec.size()`: Returns the number of elements in the vector.
  - `vec.isEmpty()`: Returns true if the vector is empty, false otherwise.
  - `vec[i]`: Selects the *i*th element of the vector.
  - `vec.add(value)`: Adds a new element to the end of the vector.
  - `vec.insert(index, value)`: Inserts the value before the specified index, and moves the values after it up by one index.
  - `vec.remove(index)`: Removes the element at the specified index, and moves the rest of the elements down by one index.
  - `vec.clear()`: Removes all elements from the vector.
  - `vec.sort()`: Sorts the elements in the list in increasing order.
- For the exhaustive list, check out the [Stanford Vector class](#) documentation

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- For the exhaustive list, check out the [Stanford Vector class](#) documentation

# A vector example

[demo + attendance ticket]

# Eliminating Negativity

- Consider the following task: Given a Vector of integers, write a function that eliminates negativity from the vector by changing the sign of all negative values to turn them into their positive equivalents

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```
void eliminateNegativity(Vector<int> v){
 for (int i = 0; i < v.size(); i++){
 if (v[i] < 0){
 v[i] = -1 * v[i];
 }
 }
}

int main(){
 Vector<int> nums = {1, -4, 18, -11};
 eliminateNegativity(nums);
 cout << nums << endl;
}
```



# Eliminating Negativity

- Consider the following task: Given a Vector of integers, write a function that eliminates negativity from the vector by changing the sign of all negative values to turn them into their positive equivalents
- **Attendance ticket: What is the output of the code snippet? Please discuss with a partner!**
- <https://tinyurl.com/cs106blec4>

```
void eliminateNegativity(Vector<int> v){
 for (int i = 0; i < v.size(); i++){
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 eliminateNegativity(nums);
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# Attendance ticket:

<https://tinyurl.com/cs106blec4>

Please don't send this link to students who are not here. It's on your honor!

# Eliminating Negativity

- Consider the following task: Given a Vector of integers, write a function that eliminates negativity from the vector by changing the sign of all negative values to turn them into their positive equivalents
- Result: The vector is passed by value, so a copy is modified, and no changes persist.

```
void eliminateNegativity(Vector<int> v){
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```

# Eliminating Negativity

- Consider the following task: Given a Vector of integers, write a function that eliminates negative values from the vector by changing them to their positive equivalent.
- Result: The vector is modified in place, so a copy is not needed. Changes persist.

```
void eliminateNegativity(Vector<int> v){
 for (int i = 0; i < v.size(); i++){
 if (v[i] < 0){
 v[i] = -1 * v[i];
 }
 }
}
```

*So how do we allow functions to modify vectors?*

```
int> nums = {1, -4, 18, -11};
eliminateNegativity(nums);
cout << endl;
```

# Pass by reference

(i.e. How do we efficiently and effectively handle data structures in functions?)

## Definition

### **pass by value**

When a parameter is passed into a function, the new variable *stores a copy* of the passed in value in memory

## Definition

### **pass by reference**

When a parameter is passed into a function, the new variable stores a *reference* to the passed in value, which allows you to directly edit the original value

# What exactly is a reference?

- Regular variables look like this:

We will think of a variable as a **named container** storing a value.

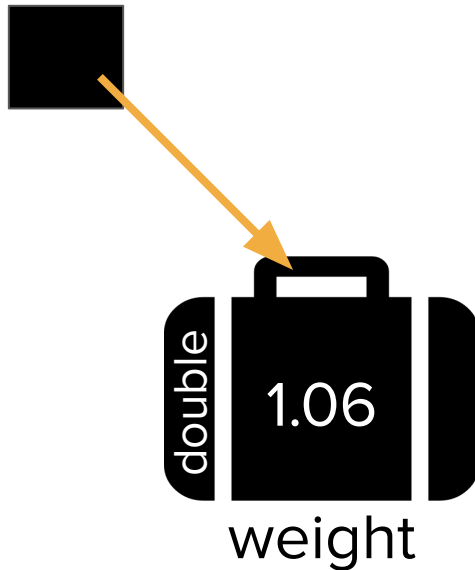




# What exactly is a reference?

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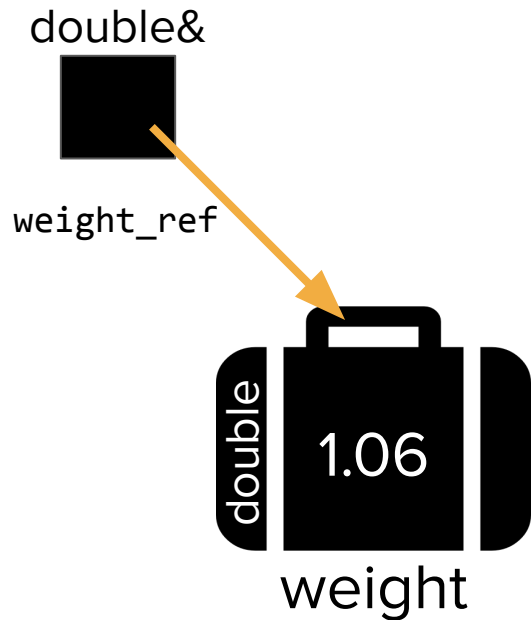
We will think of a reference as a box that just refers to an existing variable.



# What exactly is a reference?

- References look like this:

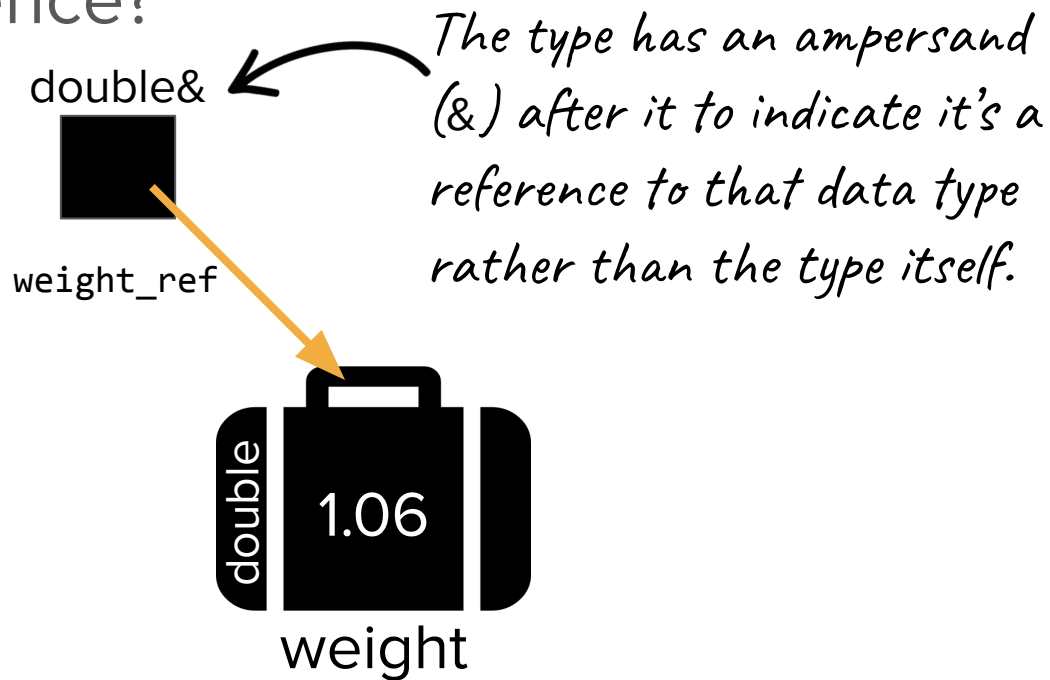
References have **names** and **types**, just like regular variables.



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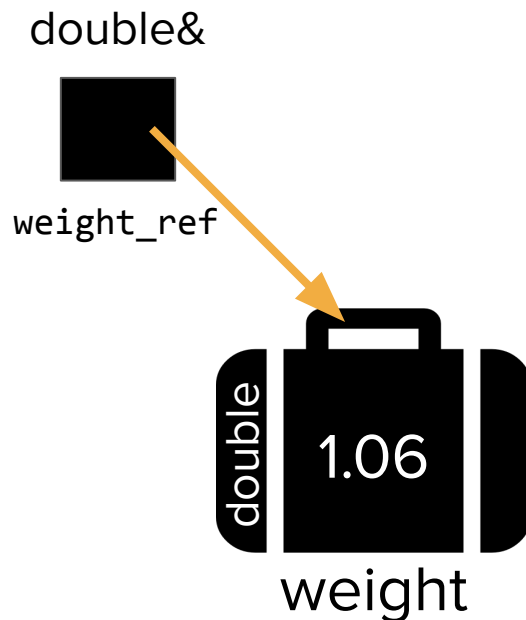
# What exactly is a reference?

- References look like this:

Here's what this would look like in code:

```
void tripleWeight(double& weight_ref) {
 weight_ref *= 3; // triple the weight
}

int main() {
 double weight = 1.06;
 tripleWeight(weight);
 cout << weight << endl; //prints 3.18
}
```



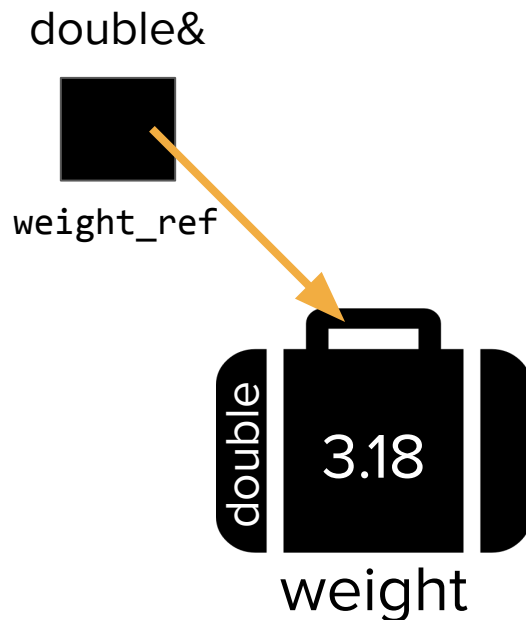
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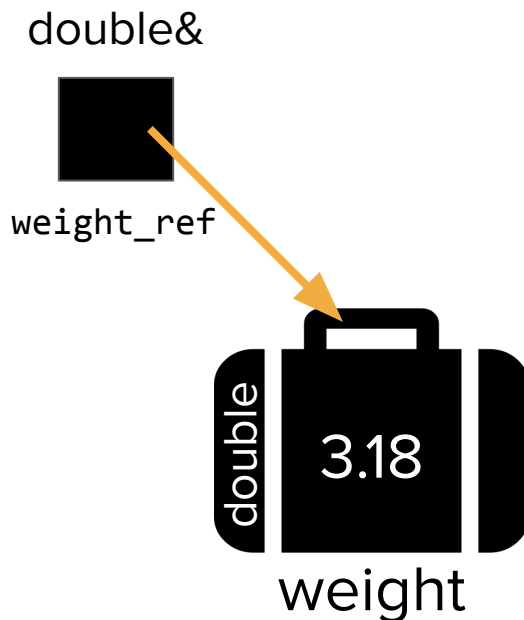
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 double weight = 1.06;
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}
```



*But we don't usually write code this way...*

# When we use references

- To allow helper functions to edit data structures in other functions

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  - But why don't we just return a copy of the data structure?



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  - Passing data structures by reference makes your code more efficient!

# When we use references

- To allow helper functions to edit data structures in other functions
  - But why don't we just return a copy of the data structure?
- To avoid making new copies of large data structures in memory
  - Passing data structures by reference makes your code more efficient!
- References also provide a workaround for **multiple return values**
  - Your function can both have a return value and also directly edit a Vector object passed in as a parameter. This makes it as if your function is returning both the vector and the actual return value!

# When we use references

- To allow helper functions to edit data structures in other functions
  - But why don't we just return a copy of the data structure?
- To avoid making new copies of large data structures in memory
  - Passing data structures by reference makes your code more efficient!
- References also provide a workaround for **multiple return values**
  - Your function can take in multiple pieces of information by reference and modify them all. In this way you can "return" both a modified Vector and some auxiliary piece of information about how the structure was modified. This makes it as if your function is returning two updated pieces of information to the function that called it!

# Revisiting eliminateNegativity

[demo]

# When we *don't* use references

- If we always used references, functions would all be able to edit one another's variables, and scoping would get confusing!
  - This would also make bugs much more likely. Unexpected and unintended changes to variables could persist across functions.

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- Note: You can't provide a literal as an argument if you are passing a parameter by reference.

```
void tripleWeight(double& weight_ref);
...
tripleWeight(1.06);
```

← *Don't do this!*  
*Compiler error!*

# When we *don't* use references

- If we always used references, functions would all be able to edit one another's variables, and scoping would get confusing!
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What's next?

# Roadmap

## Object-Oriented Programming

C++ basics

User/client

vectors + grids

stacks + queues

sets + maps

Implementation

arrays

dynamic memory management

linked data structures

real-world algorithms

*Life after CS106B!*

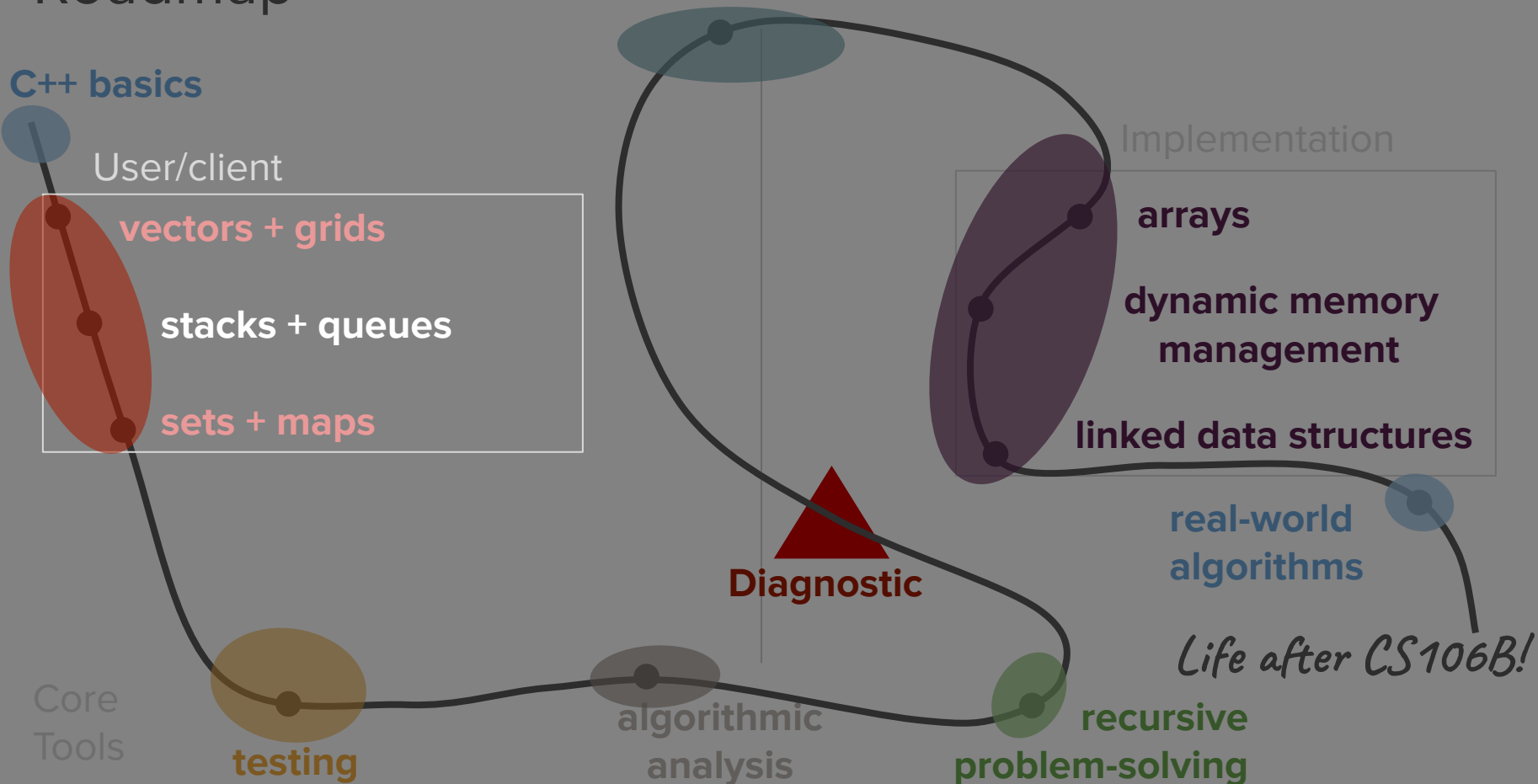
Core Tools

testing

algorithmic analysis

recursive problem-solving

Diagnostic



# Stacks and Queues

