Programming Abstractions

CS106B

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Today's Topics

Abstract Data Types

- What is an ADT?
- Vector ADT
- Grid ADT
- *Next time:* Stack, Queue ADTs

- Announcements:
  - Section begins this week!
  - Assignment 1 out, due a week from Tuesday (Jan 20)
    - *Do not use STL classes like vector, map, etc. for assignment 1 (or ever in this class).*
    - *We also strongly recommend against using any Stanford library ADTs this time (except as directed).*
    - *We carefully design these assignments to exercise certain skills learned in the class up to the date the assignment is released, so trust us, (a) you don't need them, (b) if you think you need them then you are missing a nice clean solution that takes a different approach.*
    - *Think about topics we did cover in week 1, such as strings, and look for <string> and "strlib.h" functions that may be helpful.*

ADTs

ADTs = “Abstract Data Types”

- **Language-independent models of common containers**
  - In other words, we try to focus on the aspects of the ADT that transcend whether we happen to be using it in C++, Java, Python, or some other language
- ADTs encompass both the nature of the data and ways of accessing it
- ADTs form a rich **vocabulary** of **nouns** (nature of the data) and **verbs** (ways of accessing it), often drawing on analogies to make their use intuitive
  - Skillful ADT use gives code added readability!

Types of ADTs

- When we say the "nature of the data," we mean questions like:
  - Is the data **ordered** in some way?
    - Could/should you be able to say about the data that this element is the "first" one, and this other piece is the "tenth" one?
  - Is the data **paired or matched** in some way?
    - Could/should you be able to say about the data that this element A goes with element B (not D), and this element C goes with element D (not B)?
- When we say "ways of accessing it," we mean questions like:
  - Is it important to be **able to add and remove data** during the course of use, or do we assume we have the whole collection from the beginning?
  - Is it important to be able to **search for <u>any</u> piece of data** in the collection, or is it enough to always take the first available one?

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  - Is the data **paired or matched** in some way?
    - Could/should you be able to say about the data that this element A goes with element B (not D), and this element C goes with element D (not B)?
- When we say "ways of accessing it," we mean questions like:
  - Is it important to be **able to add and remove data** during the course of use, or do we assume we have the whole version from the beginning?
  - Is it important to be able to **search for <u>any</u> piece of data** in the collection, or is it enough to always take the first available one?

We'll talk about ADTs in this category today and Wednesday.

We'll talk about ADTs in this category on Friday.

Vector:
Our First ADT!

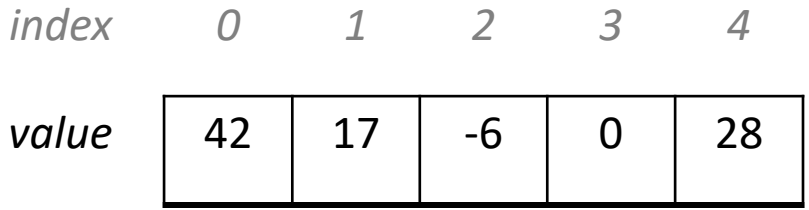
Vector ADT

- ADT abstraction similar to an array or list
- You're probably thinking, "Hey, there was something like that in the language I studied before!"
  - This shouldn't be a surprise—remember that ADTs are defined as conceptual abstractions that are language-independent
- We will use **Stanford** library `Vector.h`
  - (there is also an STL `<vector>`, which will not use—watch out for capitalization!)

Stanford Library Vector

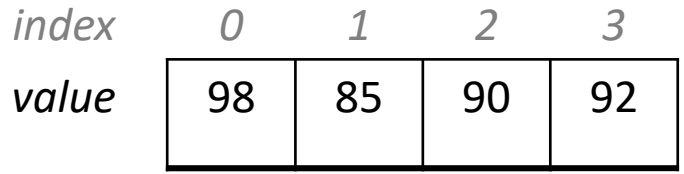
- We declare one like this:
  - `#include "vector.h"   // note quotes to mean Stanford version`
  - `Vector<string> lines; // note uppercase V here`
- This <> syntax is called **template** syntax
  - In C++, template containers must be **homogenous** (*all items the same type*)
  - The type goes in the < > after the class name Vector

```
// Example: initialize a vector containing 5 integers
Vector<int> nums {42, 17, -6,  0, 28};
```



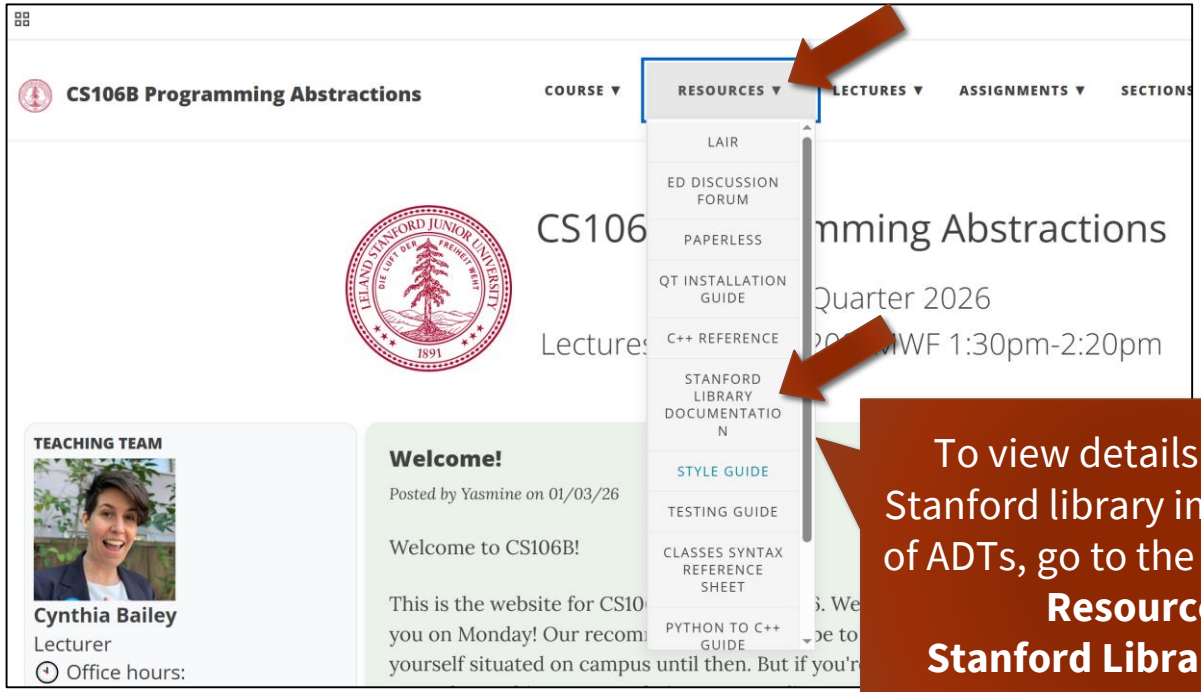
Vector

- Examples of declaring a Vector:
  - `Vector<int> pset3Scores;`
  - `Vector<double> measurementsData;`
  - `Vector<string> names;`



- Examples of using a Vector:
  - `pset3Scores.add(98);`
  - `pset3Scores.add(85);`
  - `pset3Scores.add(92);`
  - `cout << pset3Scores[0] << endl; // prints 98`
  - `cout << pset3Scores[pset3Scores.size() - 1] << endl; // prints 92`
  - `pset3Scores.insert(2, 90);`
  - `cout << pset3Scores[2] << " " << pset3Scores[3] << endl; // prints 90 92`

Pro Tip: Read the documentation



To view details of any of our Stanford library implementations of ADTs, go to the course website: **Resources** tab, **Stanford Library Reference**

Vector Performance

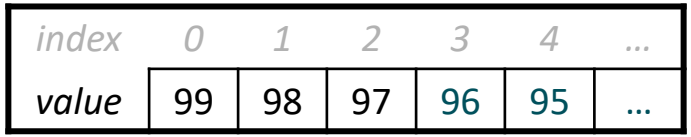
A LITTLE PEEK AT HOW VECTORS WORK BEHIND THE SCENES

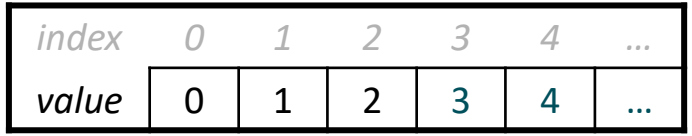
Your turn: Vector performance

- **Warm-up question:** what do the contents of the vectors look like at the end of each of OPTION 1 and at the end of OPTION 2. *(As shown,* v *starts out empty in both cases.)*

```
Vector<int> v;
for (int i = 0; i < 100; i++) {
    v.insert(0, i); // OPTION 1
}
```

```
Vector<int> v;
for (int i = 0; i < 100; i++) {
    v.add(i); // OPTION 2
}
```





Your turn: Vector performance

- Compare how many times we write a number into one "box" of the Vector, in these two codes. Write can be the original write, or because it had to move over one place. *(As shown,* v *starts out empty in both cases)*

```
Vector<int> v;
for (int i = 0; i < 100; i++) {
    v.insert(0, i); // OPTION 1
}
```

```
Vector<int> v;
for (int i = 0; i < 100; i++) {
    v.add(i); // OPTION 2
}
```

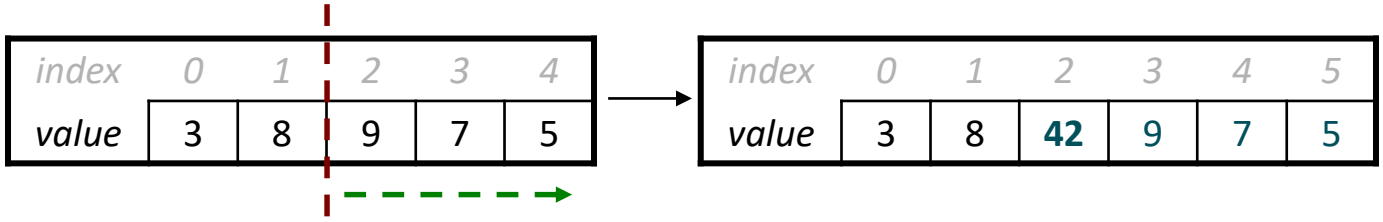
A. They both write in a box about the same number of times
B. One writes about 2x as many times as the other
C. One writes about 5x as many times as the other
D. Something else!

Answer now on pollev.com/cs106b !

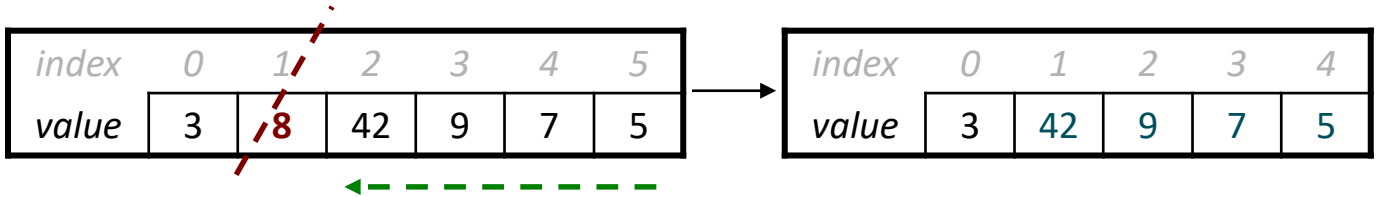
Since B and C don't say *which* option writes more than the other, if you pick one of those, be sure to address that in your group discussion!

Performance Warning Vector insert/remove

- **`v.insert(2, 42)`**
  - shift elements right to make room for the new element



- **`v.remove(1)`**
  - shift elements left to cover the space left by the removed element



- **These operations are slower the more elements they need to shift**

Your turn: Vector performance

- **Answer: (D) Something else! (about 50x)**
  - In addition to analyzing the code and predicting number of writes needed, we can also time the code using our Stanford 106B test system.
  - **Check the code bundle for class today for runnable version!**

```
void runInsert(int size)
{
    Vector<int> v;
    for (int i = 0; i < size; i++) {
        v.insert(0, i);
    }
}

void runAdd(int size)
{
    Vector<int> v;
    for (int i = 0; i < size; i++) {
        v.add(i);
    }
}
```

```
/* * * * * * Test Cases * * * * * */
PROVIDED_TEST("Timing comparison")
{
    int size = 500000;
    TIME_OPERATION(size, runInsert(size));
    TIME_OPERATION(size, runAdd(size));
}
```

Your turn: Vector performance

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  - In addition to analyzing the code and predicting number of writes needed, we can also time the code using our Stanford 106B test system.
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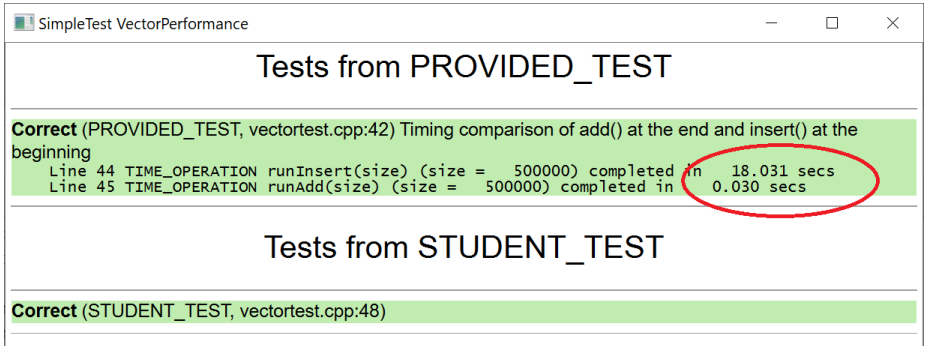
```
void runInsert(int size)
{
    Vector<int> v;
    for (int i = 0; i < size; i++) {
        v.insert(0, i);
    }
}

void runAdd(int size)
{
    Vector<int> v;
    for (int i = 0; i < size; i++) {
        v.add(i);
    }
}
```

```
/* * * * * * Test Cases * * * * * */
PROVIDED_TEST("Timing comparison")
{
    int size = 500000;
    TIME_OPERATION(size, runInsert(size));
    TIME_OPERATION(size, runAdd(size));
}
```



Your turn: Vector performance

- **Answer: (D) Something else! (about 50x)**
  - Number of times a number is written in a box:
    - OPTION 1:
      - First loop iteration: 1 write
      - Next loop iteration: 2 writes … continued…
      - Formula for sum of numbers 1 to N = (N * (N + 1)) / 2
      - *(don't worry if you don't know this formula, we only expected a ballpark estimate)*
      - 100 * (100 + 1) / 2 = 10,100 / 2 = **5,050 writes**
    - OPTION 2:
      - First loop iteration: 1 write
      - Next loop iteration: 1 write
      - … continued…
      - **= 100 writes**

Vector performance and parameter passing

- **Pro Tip:** always use pass-by-reference for containers like Vector (and Grid, which we'll see next) in this class!
  - For efficiency reasons—don't want to make a big copy every time with pass-by-value!

```
void printFirst(Vector<int>& input) {
    cout << input[0] << endl;
}

void printFirst100Times(Vector<int>& input) {
    for (int i = 0; i < input.size(); i++) {
        printFirst(input); // very expensive if not for &
    }
}
```

Grid container

ESSENTIALLY A MATRIX (LINEAR ALGEBRA FANS CELEBRATE NOW)

Grid

- ADT abstraction similar to an array of arrays (matrix)
- Many languages have a version of this
  - (remember, ADTs are conceptual abstractions that are language-independent)

- In C++ we declare one like this:

```
#include "grid.h"

Grid<int> chessboard(8, 8);
Grid<int> image(500, 1000);
Grid<double> realMatrix(10, 10);
```

Code Reading Exercise: Grids and loops and loop

```
void printMe(Grid<int>& grid, int row, int col) {
    for (int r = row - 1; r <= row + 1; r++) {
        for (int c = col - 1; c <= col + 1; c++) {
            if (grid.inBounds(r, c)) {
                cout << grid[r][c] << " ";
            }
        }
        cout << endl;
    }
}
```

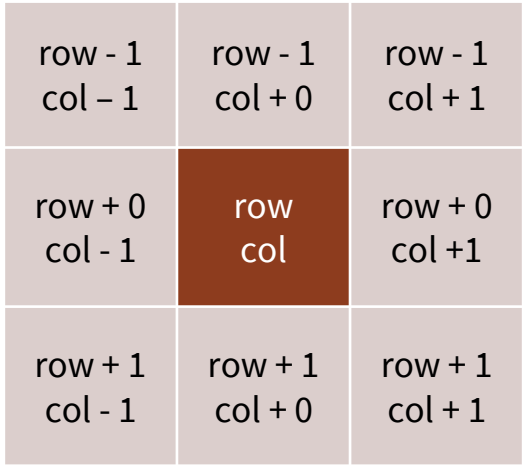
How many 0's does this print with input `row = 2, col = 3`?
(and grid as shown on right)

2	1	2	0	0
1	0	2	1	2
0	0	0	1	1
2	2	2	2	2
1	1	0	1	1

(A) None or 1
(B) 2 or 3
(C) 4 or 5
(D) 6 or 7

Handy loop idiom: iterating over "neighbors" in a Grid

```
void printNeighbors(Grid<int>& grid, int row, int col) {
    for (int r = row - 1; r <= row + 1; r++) {
        for (int c = col - 1; c <= col + 1; c++) {
            if (grid.inBounds(r, c)) {
                cout << grid[r][c] << " ";
            }
        }
        cout << endl;
    }
}
```



These nested for loops generate all the pairs in the cross product {-1,0,1} x {-1,0,1}, and we can add these as offsets to a (r,c) coordinate to generate all the neighbors (note: often want to test for and exclude the (0,0) offset, which is "myself" not a neighbor)