CS 106B, Lecture 5
Stacks and Big O

reading:

Programming Abstractions in C++, Chapter 4-5

Plan for Today

- Analyzing algorithms using **Big O** analysis
  - Understand what makes an algorithm "good" and how to compare algorithms
- Another type of collection: the **Stack**

Big O

Big O Intuition

- Lots of different ways to solve a problem; which is best?
- Measure algorithmic **efficiency**
  - how many resources (time? memory? etc.) does the program use
  - We'll focus on time
- Idea: algorithms are better if they take less time
- Problem: amount of time a program takes is variable
  - Depends on what computer you're using, what other programs are running, if your laptop is plugged in…

Big O

- Idea: assume each statement of code takes some unit of time
  - for the purposes of this class, that unit doesn't matter
- We can count the number of units of time and get the runtime
- Sometimes, the number of statements depends on the input – we'll say the input size is N

Big O

```
statement1;                             // runtime = 1

for (int i = 1; i <= N; i++) {          // runtime = N^2
    for (int j = 1; j <= N; j++) {      // runtime = N
        statement2;
    }
}

for (int i = 1; i <= N; i++) {          // runtime = 3N
    statement3;
    statement4;
    statement5;
}                                       // total = N^2 + 3N + 1
```

Big O

- The actual constant doesn't matter (remember that we haven't even specified how much a unit of time is) – so we get rid of the constants: $N^2 + 3N + 1 \rightarrow N^2 + N + 1$
- Only the biggest power of N matters: $N^2 + N + 1 \rightarrow N^2$
  - The biggest term grows so much faster than the other terms that the runtime of that term "dominates"
  - Another way to think about it: $N^2 + N + 1 < 2N^2$ when N is big, and we already said we don't care about constants
- We would then say the code snippet has **$O(N^2)$ runtime**

Finding Big O

- Work from the innermost indented code out
- Realize that some code statements are more costly than others
  - It takes $O(N^2)$ time to call a function with runtime $O(N^2)$, even though calling that function is only one line of code
- Nested code multiplies
- Code at the same indentation level adds

What is the Big O?

```
int sum = 0;
for (int i = 1; i < 100000; i++) {
    for (int j = 1; j <= i; j++;) {
        for (int k = 1; k <= N; k++) {
            sum++;
        }
     }
}
Vector<int> v;
for (int x = 1; x <= N; x += 2) {
    v.insert(0, x);
}
cout << v << endl;
```

Complexity Classes

- complexity class: A category of algorithmic efficiency based on the algorithm's relationship to the input size "N".

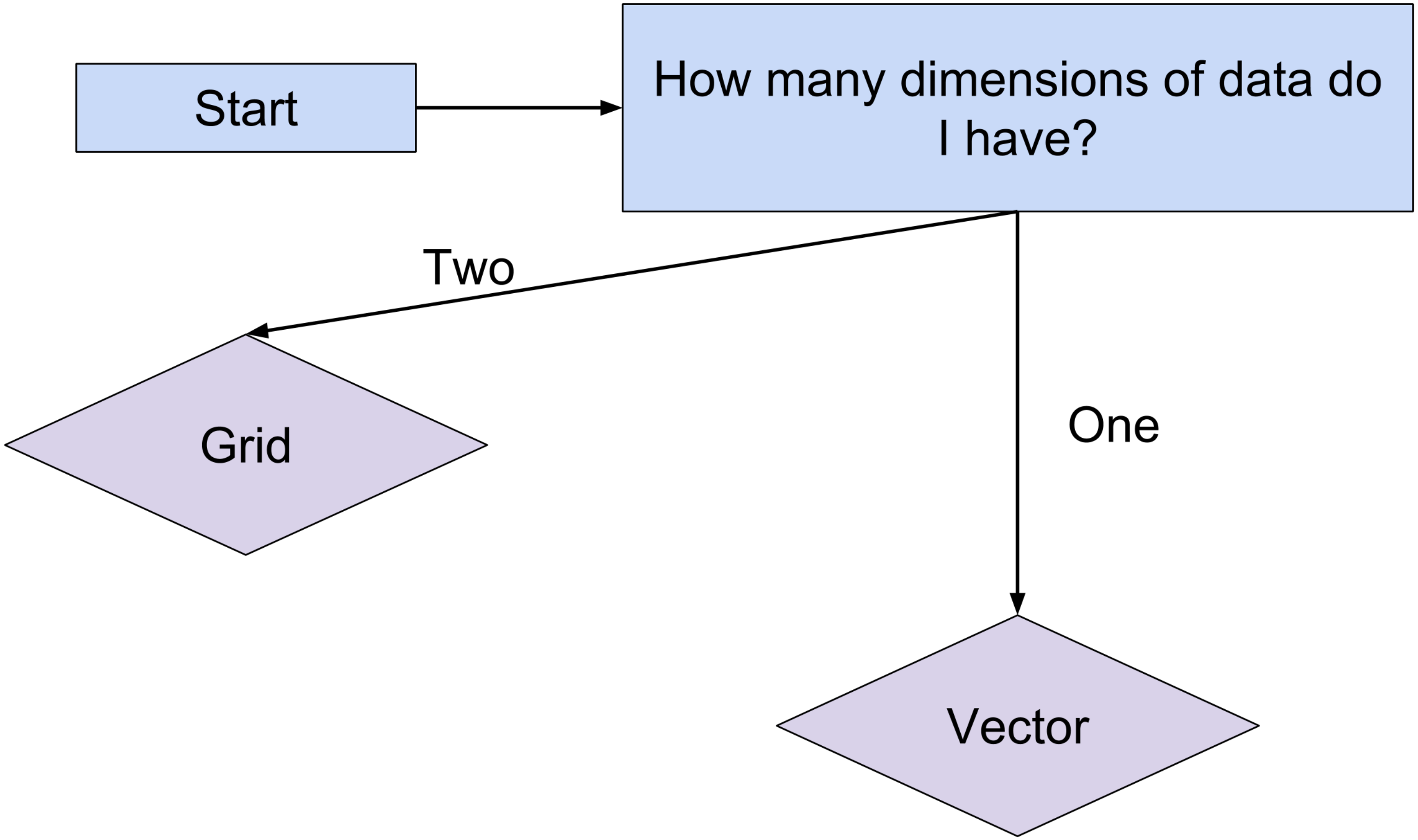
Class	Big-Oh	If you double N, ...	Example
constant	$O(1)$	unchanged	10ms
logarithmic	$O(\log_2 N)$	increases slightly	175ms
linear	$O(N)$	doubles	3.2 sec
log-linear	$O(N \log_2 N)$	slightly more than doubles	11 sec
quadratic	$O(N^2)$	quadruples	1 min 42 sec
quad-linear	$O(N^2 \log_2 N)$	slightly more than quadruple	8 min
cubic	$O(N^3)$	multiplies by 8	55 min
...	...	...	...
exponential	$O(2^N)$	multiplies drastically	$5 * 10^{61}$ years
factorial	$O(N!)$	multiplies drastically	10^{200} years

Announcements

- Assignment 1 due **Thursday at 5PM**
- Shreya will be guest-presenting tomorrow!
- No class on July 4th – if you have section, either attend a Thursday or Friday section or watch the videoed section and email your SL a summary
  - No LaIR either
- **SCPD Exam Form Typo**: final exam is on August 18 NOT August 25; please check your Stanford email/Piazza for details (only SCPD students who did not indicate they'd take the exam on August 18 were emailed)

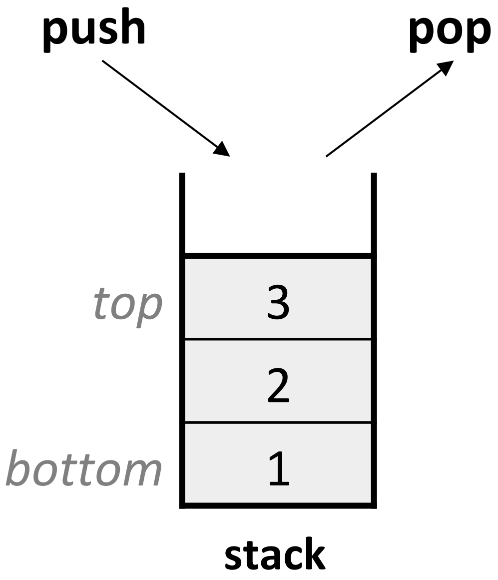
Stacks

ADTs – the Story so Far



A new ADT: the Stack

- A specialized data structure that only allows a user to add, access, and remove the **last** element
  - **"Last In, First Out"**
  - Super fast (O(1)) for these operations
    - Built directly into the hardware
- Main operations:
  - **`push(value)`**: add an element to the end of the stack
  - **`pop()`**: remove and return the last element in the stack
  - **`peek()`**: return (but do not remove) the last element in the stack



"Stacked" examples

- Real life
  - Pancakes
  - Clothes
  - Plates in the dining hall
- In computer science
  - Function calls
  - Keeping track of edits to undo or pages visited on a website to go back to (you'll implement this in assignment 5)

source: https://c2.staticflickr.com/8/7583/15638298618_104af94267_b.jpg

Stack Syntax

```
#include "stack.h"

Stack<int> nums;
nums.push(1);
nums.push(3);
nums.push(5);
cout << nums.peek() << endl; // 5
cout << nums << endl; // {1, 3, 5}
nums.pop(); // nums = {1, 3}
```

`s.isEmpty()`	O(1)	returns `true` if stack has no elements
`s.peek()`	O(1)	returns **top** value without removing it; throws an error if stack is empty
`s.pop()`	O(1)	removes **top** value and returns it; throws an error if stack is empty
`s.push(value);`	O(1)	places given value on **top** of stack
`s.size()`	O(1)	returns number of elements in stack

Stack limitations/idioms

- You cannot access a stack's elements by index.

```
Stack<int> s;
...
for (int i = 0; i < s.size(); i++) {
    do something with s[i];          // does not compile
}
```

- Instead, you pull elements out of the stack one at a time.
- **common idiom: Pop each element until the stack is empty.**

```
// process (and empty!) an entire stack
while (!s.isEmpty()) {
    do something with s.pop();
}
```

Sentence Reversal

- Goal: print the words of a sentence in reverse order
  - "Hello my name is Inigo Montoya" -> "Montoya Inigo is name my Hello"
  - "Inconceivable" -> "Inconceivable"
- Assume characters are only letters and spaces
- How could we use a `Stack`?

Sentence Reversal Solution

```
void printSentenceReverse(const string &sentence) {
    Stack<string> wordStack;
    for (char c : sentence) {
        if (c == SPACE) {
            wordStack.push(word);
            word = ""; // reset
        } else {
            word += c;
        }
    }
    if (word != "") {
        wordStack.push(word);
    }
    cout << " New sentence: ";
    while (!wordStack.isEmpty()) {
        word = wordStack.pop();
        cout << word << SPACE;
    }
    cout << endl;
}
```

ADTs – the Story so Far