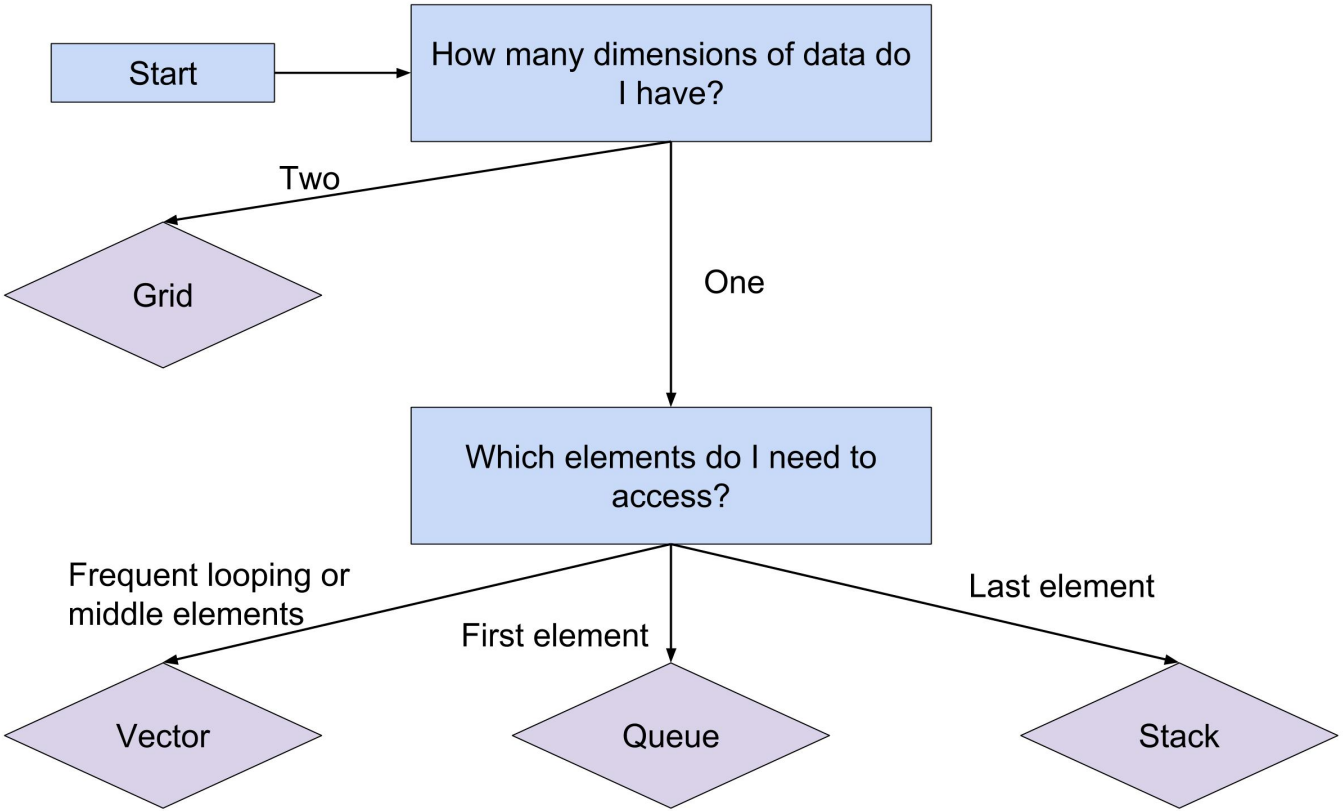
CS 106B, Lecture 7
Sets and Maps

ADTs So Far

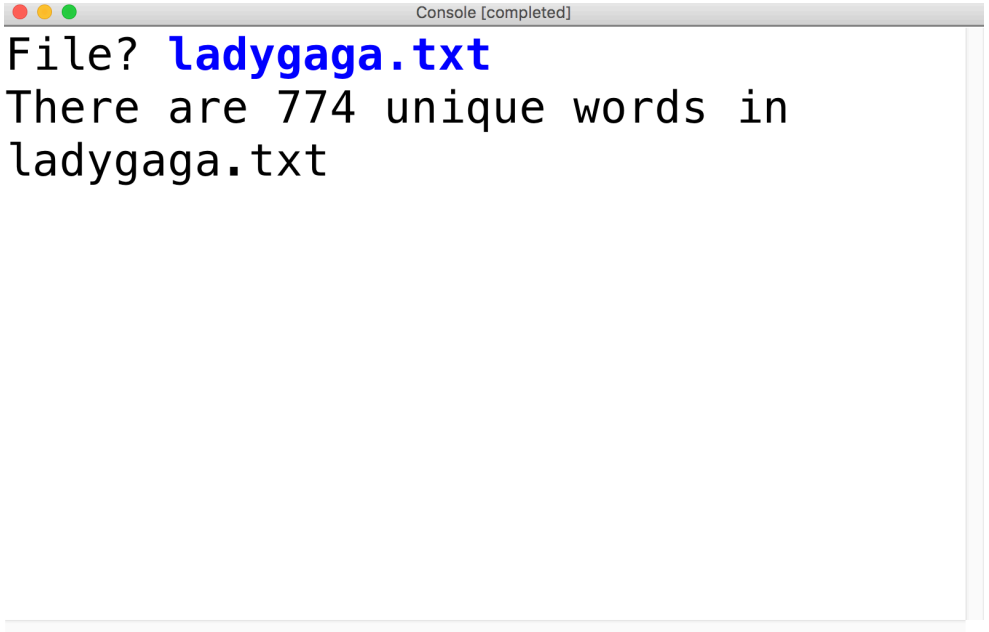

Start
How many dimensions of data do I have?
Two
Grid
One
Which elements do I need to access?
Frequent looping or middle elements
First element
Last element
Vector
Queue
Stack

Today's Topics

- Sets (no duplicates allowed!)
  - Lexicons
- Maps (map a key to a value)

CountUniqueWords

- One basic statistic about a text is the number of unique words it has
  - Linguists and computer scientists frequently start analysis with the number of unique words
  - Good indication of vocabulary
- Problem: how can we determine the number of unique words in a file?

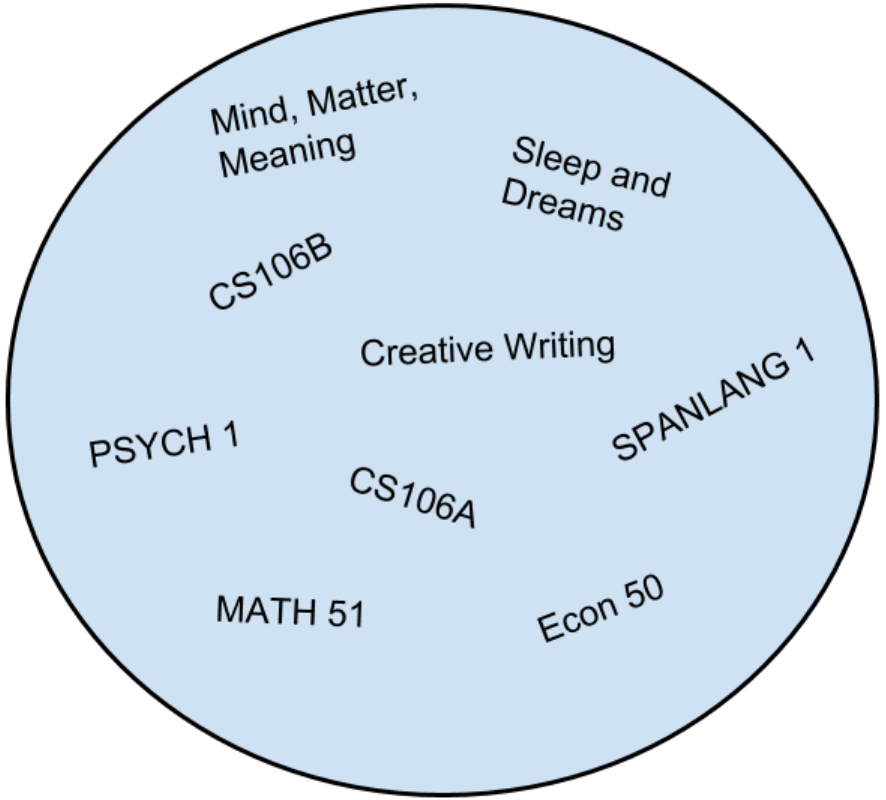


Today's Topics

- Sets (no duplicates allowed!)
  - Lexicons
- Maps (map a key to a value)

Sets

- Only answers question of membership
  - **No duplicates**
- Operations
  - `contains(`*`elem`*`)`
  - `add(`*`elem`*`)`
  - `remove(`*`elem`*`)`
- Comparison to `Vector`
  - Does not maintain insertion order
  - No duplicates
  - Really fast at finding membership



Stanford C++ sets (5.5)

- `Set`: implemented using a linked structure called a *binary tree*.
  - pretty fast; elements are stored in **sorted order**
  - values must have a < operation

- `HashSet`: implemented using a special array called a *hash table*.
  - *very* fast; elements are stored in **unpredictable order**
  - values must have a `hashCode` function *(provided for most standard types)*
    - variant: `LinkedHashSet` *(slightly slower, but remembers insertion order)*

How to choose: Do you need the elements to be in sorted order?

- If so: Use `Set`.
- If not: Use `HashSet` for the performance boost.

Looping over Sets

- Sets don't have indices, so we use a for-each loop
- Iterates in sorted order (alphabetical order for strings)
- Can't edit while we iterate

```
Set<string> friends;
friends.add("Leland");
friends.add("Kate");

// prints in alphabetical order
for (string myFriend : friends) {
      cout << "Hi, " << myFriend << endl;
      cout << "Let's get dinner." << endl;
}
```

Looping over a set

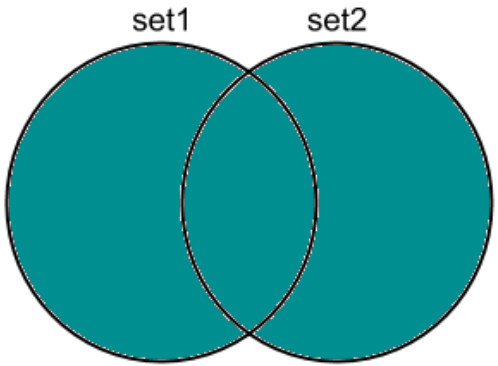
```
// forward iteration with for-each loop (read-only)
for (type name : collection) {
    statements;
}
```

- sets have no indexes; can't use normal `for` loop with index `[i]`
- `Set` iterates in sorted order; `HashSet` in unpredictable order

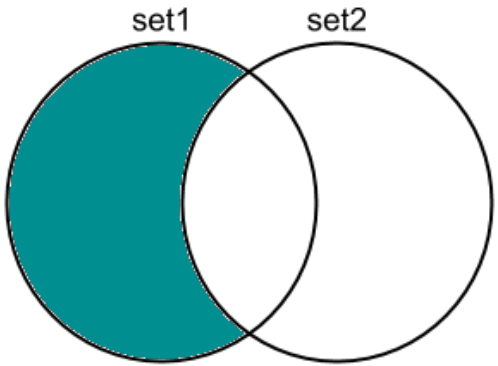
~~
```
for (int i = 0; i < set.size(); i++) {
    do something with set[i];          // does not compile
}
```
~~

it is
that doesn't work

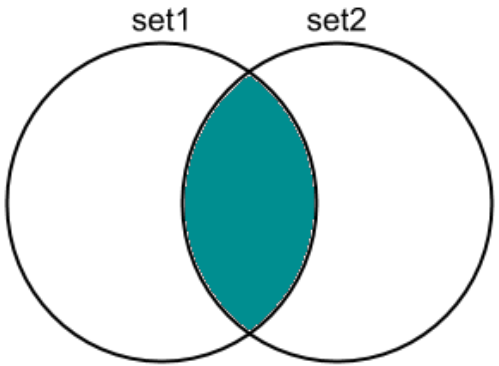
Good Operations to Know



Union: set1 + set2



Difference: set1 - set2



Intersection: set1 * set2

Sets – Method List

`s.add(value)`	O(log N)	Adds an element to this set, if it was not already there
`s.clear()`	O(N)	Removes all elements from this set
`s.contains(value)`	O(log N)	Returns **`true`** if ***value*** is in this set
`s.equals(set)`	O(N)	Returns **`true`** if the two sets contain the same elements
`s.first()`	O(log N)	Returns the first value in the set in order
`s.isEmpty()`	O(1)	Returns **`true`** if the set contains no elements
`s.isSubsetOf(s2)`	O(N)	Returns **`true`** if all the elements in the set are also in ***s2***
`s.remove(value)`	O(log N)	Removes an element from this set
`s.size()`	O(1)	Returns the number of elements in this set
`s.toString()`	O(N)	Converts the set to a printable string representation

Set members

```
#include "set.h"
#include "hashset.h"
```

Member	Set	HashSet	Description
`s.add(value);`	O(log *N*)	**O(1)**	adds given value to set
`s.clear();`	O(*N*)	O(*N*)	removes all elements of set
`s.contains(value)`	O(log *N*)	**O(1)**	`true` if given value is found
`s.isEmpty()`	O(1)	O(1)	`true` if set contains no elements
`s.isSubsetOf(set)`	O(*N* log *N*)	O(*N*)	`true` if *set* contains all of this one
`s.remove(value);`	O(log *N*)	**O(1)**	removes given value from set
`s.size()`	O(1)	O(1)	number of elements in set
`s.toString()`	O(*N*)	O(*N*)	e.g `"{3, 42, -7, 15}"`
`ostr << s`	O(*N*)	O(*N*)	print set to stream

Set operators

`s1 == s2`	`true` if the sets contain exactly the same elements
`s1 != s2`	`true` if the sets don't contain the same elements
`s1 + s2`	returns the **union** of s1 and s2 (elements from either)
`s1 += s2;`	sets s1 to the union of s1 and s2 (or adds a value to s1)
`s1 * s2`	returns **intersection** of s1 and s2 (elements in both)
`s1 *= s2;`	sets s1 to the intersection of s1 and s2
`s1 - s2`	returns **difference** of s1, s2 (elements in s1 but not s2)
`s1 -= s2;`	sets s1 to the difference of s1 and s2 (or removes a value from s1)

```
Set<string> set;
set += "Jess";
set += "Alex";
Set<string> set2 {"a", "b", "c"};   // initializer list
...
```

and differences using operators

Set exercise

isHappyNumber

- Write a function **isHappyNumber** that returns whether a given integer is "happy". An integer is "happy" if repeatedly summing the squares of its digits eventually leads to the number 1.
  - Examples:

139 is happy:	4 is unhappy:
$1^2+3^2+9^2 = 91$	$4^2 = 16$
$9^2+1^2 = 82$	$1^2+6^2 = 37$
$8^2+2^2 = 68$	$3^2+7^2 = 58$
$6^2+8^2 = 100$	$5^2+8^2 = 89$
$1^2+0^2+0^2 = 1$	$8^2+9^2 = 145$

$1^2+4^2+5^2 = 42$

$4^2+2^2 = 20$

$2^2+0^2 = 4$

that doesn't work there okay
all right um

  - How can this problem be solved using a set?

Structs

- C++ has an entity called a *structure* (**struct**).
  - Like a lightweight class; a collection of data and behavior.
  - By default, member variables and methods are public.

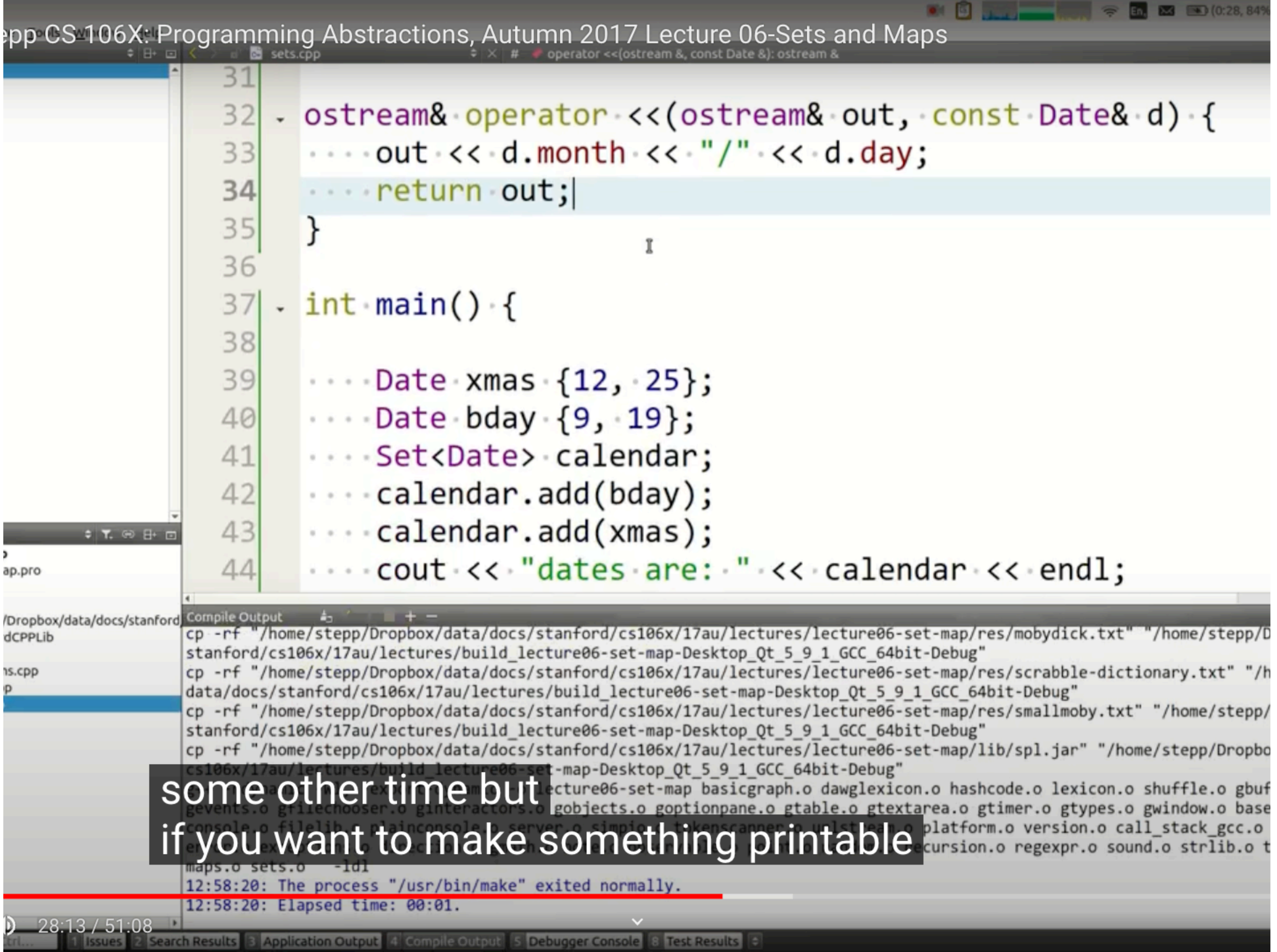
```
struct Date {           // declaring a struct type
    int month;
    int day;            // members of each Date structure
};
...

Date today;             // construct structure instances
today.month = 7;
today.day = 13;

Date xmas {12, 25};     // initialize on one line
```

no methods but just two instance variables

Set/HashSet of structs

- By default, our libs can't store your struct in a `Set` or `HashSet`.
  - To be in a `Set`, your struct needs to be sortable using a **< operator**.
  - To be in a `HashSet`, you need **==**, **!=**, and a **hashCode** function.
    - We will talk about these ideas in much more detail later.

```
// operator overloading; define < operation on dates
// (required in order to put Date in a Set)
bool operator <(const Date& d1, const Date& d2) {
    return d1.month < d2.month
        || (d1.month == d2.month && d1.day < d2.day);
}

// converts a Date into an integer key
// (required in order to put Date in a HashSet)
int hashCode(const Date& date) {
    return date.month * 100 + date.day;
}
```



some other time but
if you want to make something printable

Today's Topics

- Sets (no duplicates allowed!)
  - Lexicons
- Maps (map a key to a value)

Lexicons

- Set where the only type is string
- Can do everything a Set does
- Also answers the question – do any words start with this prefix?
  - `lexicon.containsPrefix(prefix)`
- Used to store dictionaries
- We'll talk about lexicons more later

Stanford Lexicon (5.6)

```
#include "lexicon.h"
```

- A set of words optimized for dictionary and prefix lookups

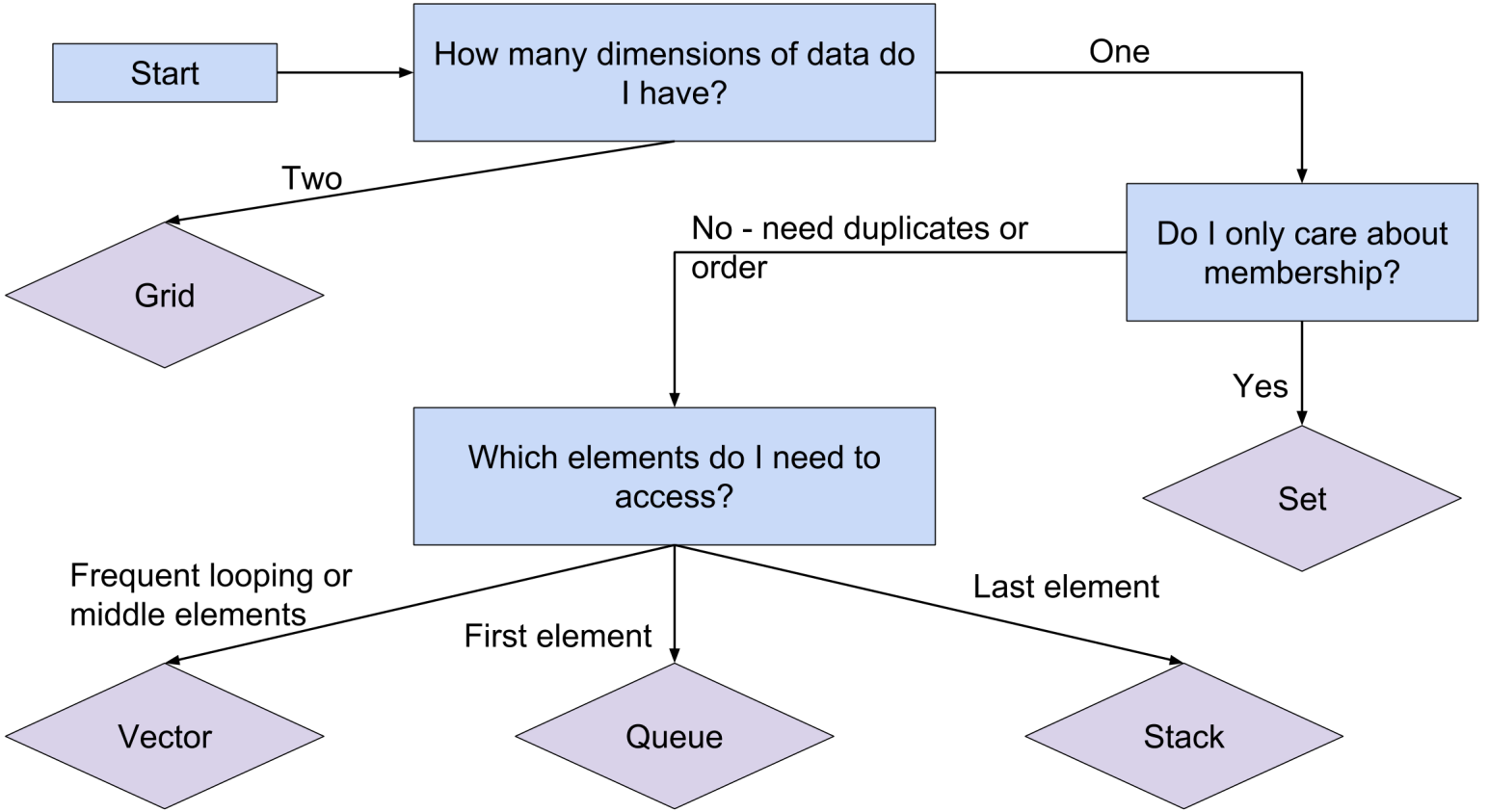
Member	Big-Oh	Description
`Lexicon name;` `Lexicon name("file");`	O(*N*len*)	create empty lexicon or read from file
`L.add(word);`	O(*len*)	adds the given word to lexicon
`L.addWordsFromFile("f");`	O(*N*len*)	adds all words from input file (one per line)
`L.clear();`	O(*N*len*)	removes all elements of lexicon
`L.contains("word")`	O(*len*)	`true` if word is found in lexicon
`L.containsPrefix("str")`	O(*len*)	`true` if `s` is the start of any word in lexicon
`L.isEmpty()`	O(1)	`true` if lexicon contains no words
`L.remove("word");`	O(*len*)	removes word from lexicon, if present
`L.removePrefix("str");`	O(*len*)	removes all words that start with prefix
`L.size()`	O(1)	number of elements in lexicon
`L.toString()`	O(*N*)	e.g. `{"arm", "cot", "zebra"}`

Lexicon example

```
#include "lexicon.h"
...

// read file into a dictionary lexicon
Lexicon dictionary;
dictionary.addWordsFromFile("dict.txt");

// look up words/prefixes in the dictionary
string word = getLine("type a word: ");
if (dictionary.contains(word)) {
    cout << "That word is in the dictionary!" << endl;
} else if (dictionary.containsPrefix(word)) {
    cout << "Some words start with " << word << endl;
}
```

print the words in sorted order
yep uh okay

ADTs Expanded

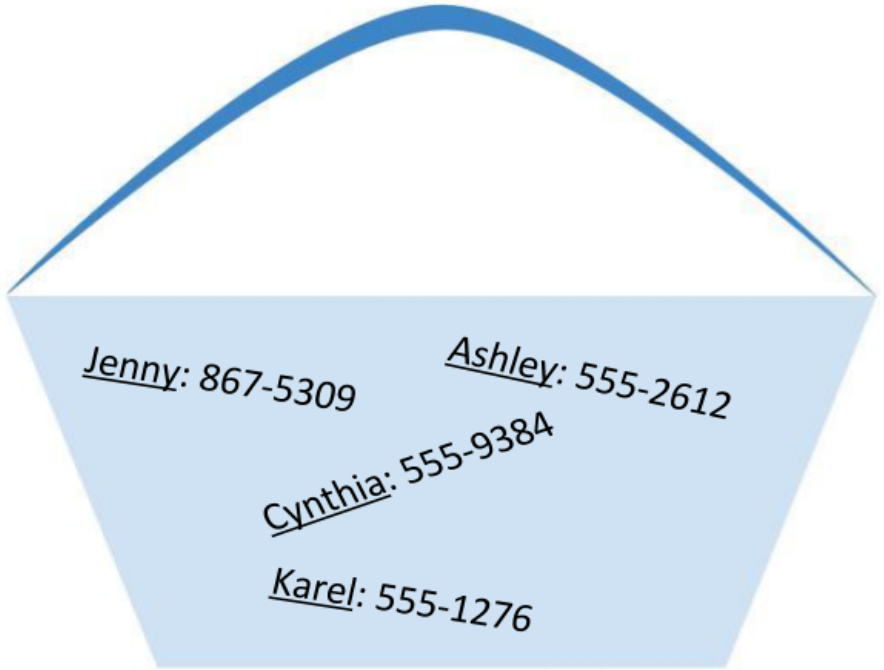


Today's Topics

- Sets (no duplicates allowed!)
  - Lexicons
- Maps (map a key to a value)

Maps

- Stores **pairs** of information
  - First half of the pair is called a **key**, and the second half is the associated **value**
  - Find a value by looking up its associated key
  - Keys must be unique (just like elements in a Set!)
- Comparison with Vector
  - Vectors look up elements by *index*, Maps look them up by *key*
  - Need to declare two types (for the key and the value)
  - Ordered by key, not index



Map Syntax

- *map*.put(*key*, *value*)
  - *map*[*key*] = *value*
  - Adds the key if it wasn't already in the map
  - Otherwise edits its value
- *map*.get(*key*)
  - *map*[*key*]
    - This alternate syntax will create a key with the **default** value in the map
- *map*.remove(*key*)
  - No effect if the key isn't in the map

Map Example: Dictionary

```
ifstream file;
promptUserForFile(file, "Where is your dictionary?");
Map<string, string> dictionary;
string word;

while (getline(file, word)) {
        string definition;
        getline(file, definition);
        dictionary[word] = definition;
}

while (true) {
        string query = getLine("Word to look up?");
        if (dictionary.containsKey(query)) {
                cout << "The definition is " << dictionary[query] << endl;
        } else {
                cout << "I don't know that word!" << endl;
        }
}
```

Looping over Maps

- Maps also don’t have indices, so we use a for-each loop over the keys
- Iterates in sorted order over the keys
- Can’t edit the keys while we iterate (can edit values)

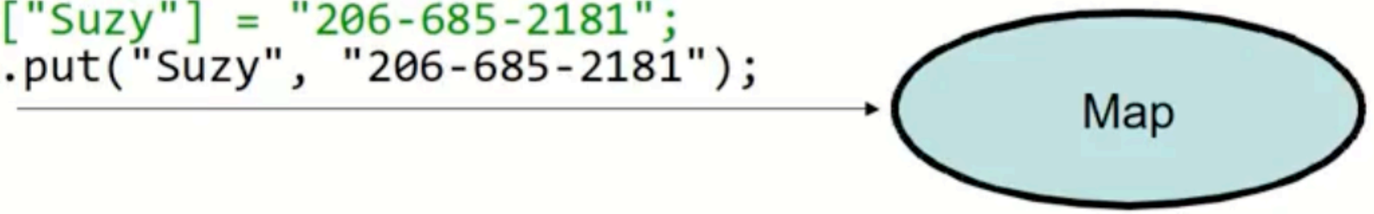
```
Map<string, int> phonebook;
phonebook["Tyler"] = 5551234;
phonebook["Kate"] = 5559876;

// prints in alphabetical order
for (string name: phonebook) {
        int phoneNumber = phonebook[name];
        cout << "I’m going to call " << name;
        cout << " at " << phoneNumber << endl;
}
```

Using maps

- A map allows you to get from one half of a pair to the other.
  - Remembers one piece of information about every index (key).

    Store pair ("Suzy", "206-685-2181").

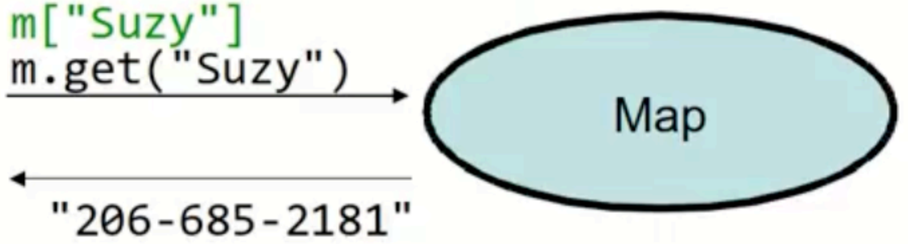
```
//      key           value
// m["Suzy"] = "206-685-2181";
   m.put("Suzy", "206-685-2181");
```



  - Later, we can supply only the key and get back the related value:

    What is Suzy's phone number?

```
// m["Suzy"]
   m.get("Suzy")
```



Map implementation

- in the Stanford C++ library, there are two map classes:
  - **`Map`**: implemented using a linked structure called a *binary search tree*.
    - pretty fast for all operations; keys are stored in **sorted order**
    - both kinds of maps implement exactly the same operations
    - the keys' type must be a comparable type with a < operation
  - **`HashMap`**: implemented using a special array called a *hash table*.
    - *very* fast, but keys are stored in unpredictable order
    - the keys' type must have a hashCode function (but most types have one)
- Requires 2 type parameters: one for keys, one for values.

```
// maps from string keys to integer values
Map<string, int> votes;
```

Map members

Member	Map	HashMap	Description
`m.clear();`	O(*N*)	O(*N*)	removes all key/value pairs
`m.containsKey(key)`	O(log *N*)	**O(1)**	`true` if map has a pair with given key
`m[key]` or `m.get(key)`	O(log *N*)	**O(1)**	returns value mapped to given key; if not found, **adds** it with a default value
`m.isEmpty()`	O(1)	O(1)	`true` if the map contains no pairs
`m.keys()`	O(*N*)	O(*N*)	a `Vector` copy of all keys in map
`m[key] = value;` or `m.put(key, value);`	O(log *N*)	**O(1)**	adds a key/value pair; if key already exists, **replaces** its value
`m.remove(key);`	O(log *N*)	**O(1)**	removes any pair for given key
`m.size()`	O(1)	O(1)	returns number of pairs in map
`m.toString()`	*O(N)*	*O(N)*	e.g. `"{a:90, d:60, c:70}"`
`m.values()`	O(*N*)	O(*N*)	a `Vector` copy of all values in map
`ostr << m`	O(*N*)	O(*N*)	prints map to stream

Word Count

- We've found the number of unique words in a file. Another statistic is how frequently each word is used.
- Given a text file and a user-inputted word, how frequently is that word used in the file?

```
to be or not to be
```

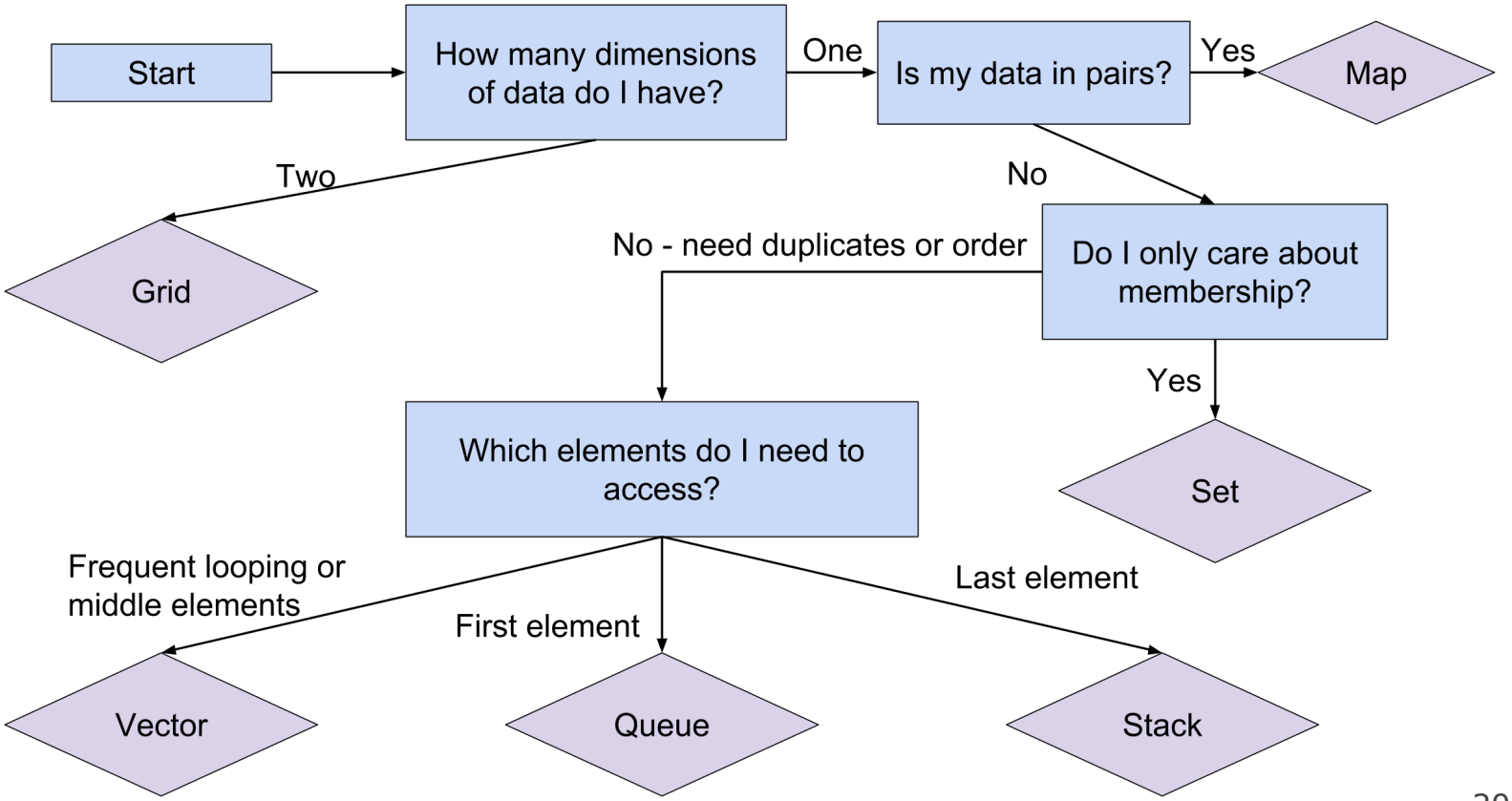
tiny.txt

```
File? tiny.txt

Word? to
"to" appears 2 times

Word? or
"or" appears 1 times
```

Solution

```
int main() {
    ifstream infile;
    promptUserForFile(infile, "File?");
    Map<string, int> map;
    string word;
    while (infile >> word) {
        map[word]++;
    }
    infile.close();

    string userWord = getLine("Enter a word (or enter to quit): ");
    while (userWord != "") {
        if (map.containsKey(userWord)) {
            cout << "\"" << userWord << "\"" << " appears " << map[userWord] << " times."
<< endl;
        }
        userWord = getLine("Enter a word (or enter to quit): ");
    }
    return 0;
}
```

ADT Soup


Start
How many dimensions of data do I have?
One
Is my data in pairs?
Yes
Map
Two
Grid
No
No - need duplicates or order
Do I only care about membership?
Yes
Set
Which elements do I need to access?
Frequent looping or middle elements
Vector
First element
Queue
Last element
Stack

Anagram exercise

- Write a program to find all **anagrams** of a word the user types.

```
Type a word [Enter to quit]: scared
Anagrams of scared:
cadres
cedars
sacred
scared
```

  - What is a good compound collection to use on this problem?

Nesting ADTs: Where2Eat

- Problem: we want to schedule a dinner with some group of our friends
- We have a text file with all our friends' dinner preferences
- Given a group of friends going to a dinner, where should we eat to maximize happiness?
  - We might not be able to find a place that makes everyone happy – such is life

```
Ashley
In n Out
Chipotle
Axe and Palm

Ketan
Chipotle
Bytes Cafe

Karel
Bytes Café
Forbes Cafe
```

- Which ADT(s) should we use?

Solution

```
int main() {
    ifstream file;
    file.open("restaurants.txt");
    Map<string, Set<string> > map;

    string myFriend;
    while (getline(file, myFriend)) {
        string restaurant;
        while (getline(file, restaurant) &&
restaurant != "") {
            map[myFriend] += restaurant;
        }
    }
    Set<string> guests;
    string guest = getLine("Enter a guest: ");
```

```
while (guest != "") {

        while (guest != "") {
            guests.add(guest);
            guest = getLine("Enter a guest: ");
        }
        cout << "Here are the acceptable
restaurants:" << endl;
        Set<string> restaurants;
        for (string guest : guests) {
            if (restaurants.isEmpty()) {
                restaurants = map[guest];
            } else {
                restaurants *= map[guest];
            }
        }
        for (string restaurant : restaurants) {
            cout << restaurant << endl;
        }
    }
    return 0;
}
```

Closing Remarks

- Sets/Maps do extend functionality past the vector unlike what we saw with stack/queue. If stack/queue didn't extend functionality, why do we care about them?

- Example counting words in books using a vector and vec.contains(…). Really slow. Now switch vector to set and goes much faster. Why?

- Stack/queue does NOT have for-each loop. That would violate our rule of only being able to see the "next" element.

Look Ahead

- Assignment 1 due **today at 5PM**
- Assignment 2 comes out today, due **Wednesday, July 10 at 5PM**