Building Java Programs
Chapter 11

Java Collections Framework

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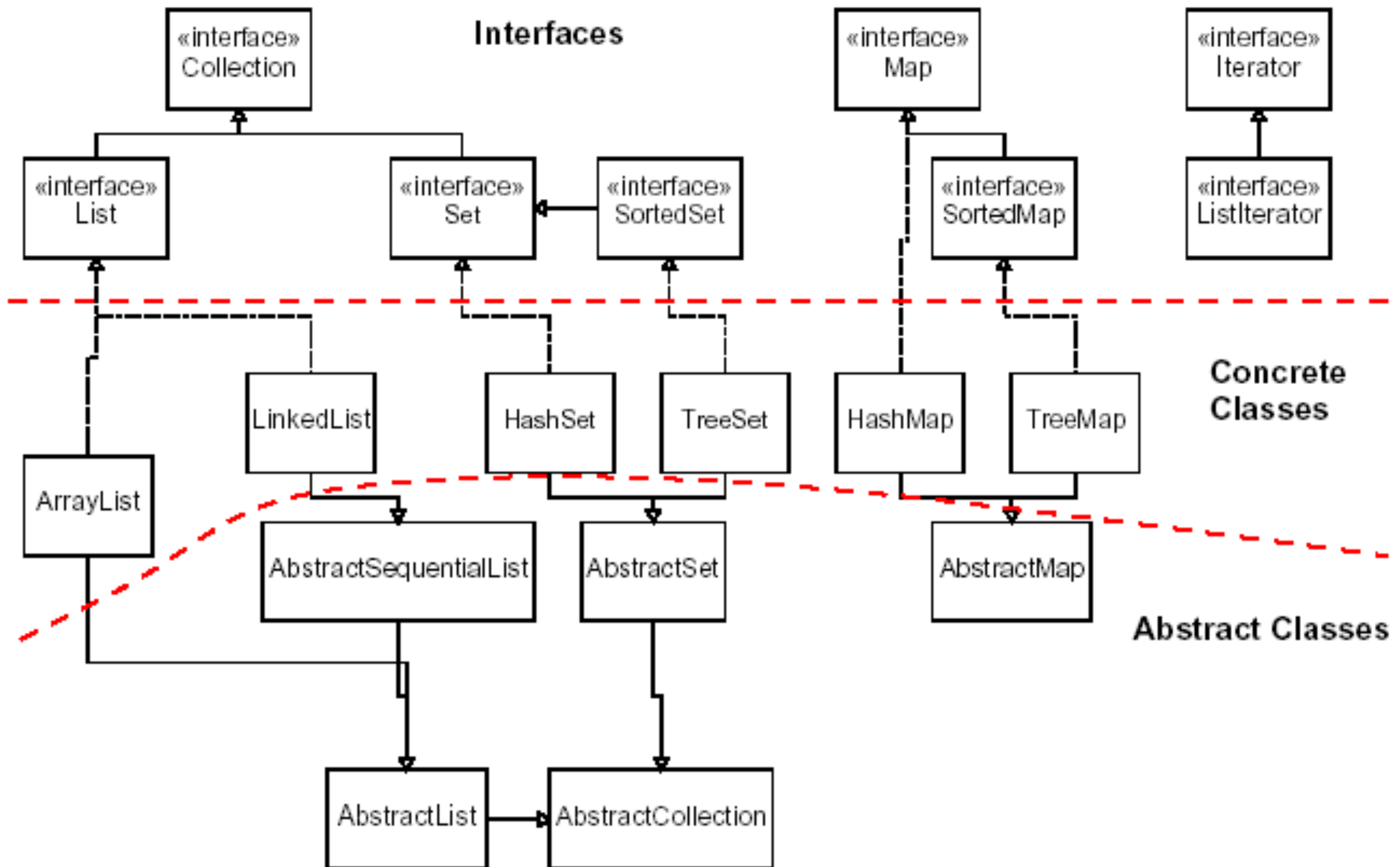
Java collections framework



Exercise

- Write a program that counts the number of unique words in a large text file (say, *Moby Dick* or the King James Bible).
  - Store the words in a collection and report the # of unique words.
  - Once you've created this collection, allow the user to search it to see whether various words appear in the text file.
- What collection is appropriate for this problem?

Empirical analysis

Running a program and measuring its performance

`System.currentTimeMillis()`

– Returns an integer representing the number of milliseconds that have passed since 12:00am, January 1, 1970.
  - The result is returned as a value of type `long`, which is like `int` but with a larger numeric range (64 bits vs. 32).

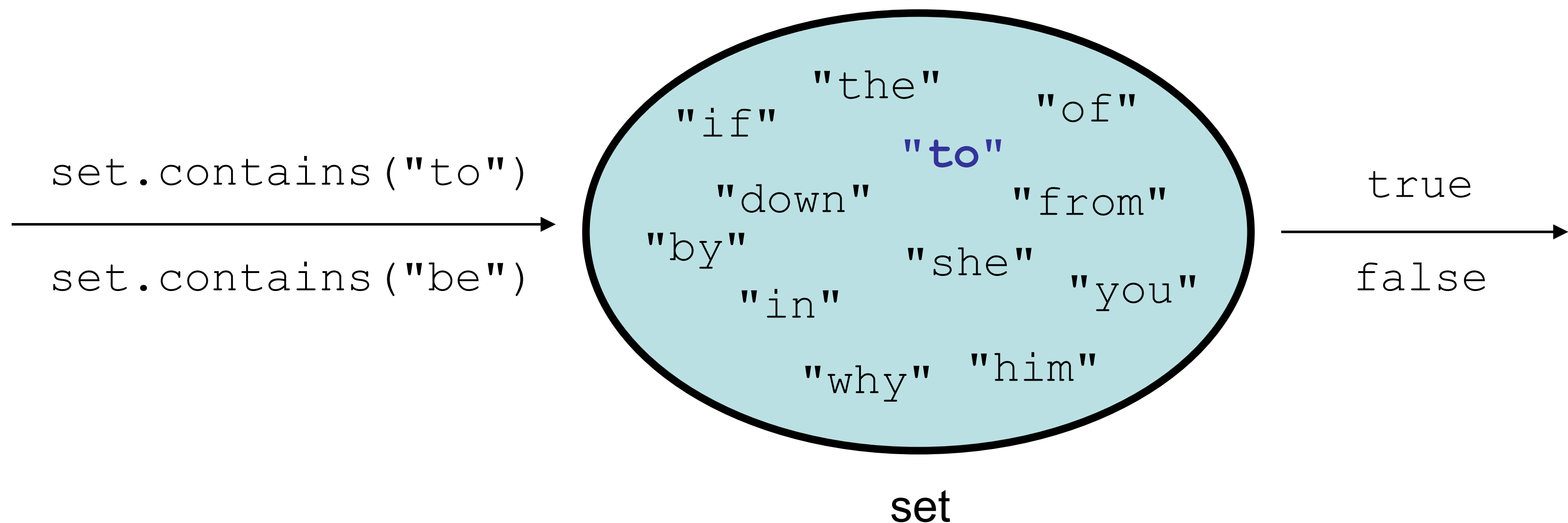
– Can be called twice to see how many milliseconds have elapsed between two points in a program.

- How much time does it take to store *Moby Dick* into a `List`?

Sets (11.2)

- **set**: A collection of unique values (no duplicates allowed) that can perform the following operations efficiently:
  - add, remove, search (contains)

  - We don't think of a set as having indexes; we just add things to the set in general and don't worry about order



`Set` implementation

- in Java, sets are represented by `Set` interface in `java.util`
- `Set` is implemented by `HashSet` and `TreeSet` classes
  - `HashSet`: implemented using a "hash table" array;
    very fast: **O(1)** for all operations
    elements are stored in unpredictable order
  - `TreeSet`: implemented using a "binary search tree";
    pretty fast: **O(log N)** for all operations
    elements are stored in sorted order
  - `LinkedHashSet`: **O(1)** but stores in order of insertion

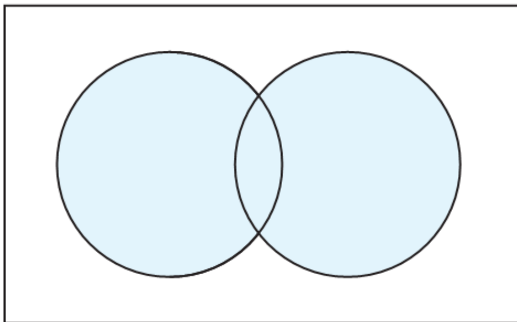
`Set` methods

```
List<String> list = new ArrayList<String>();
...
Set<Integer> set = new TreeSet<Integer>();      // empty
Set<String> set2 = new HashSet<String>(list);
```

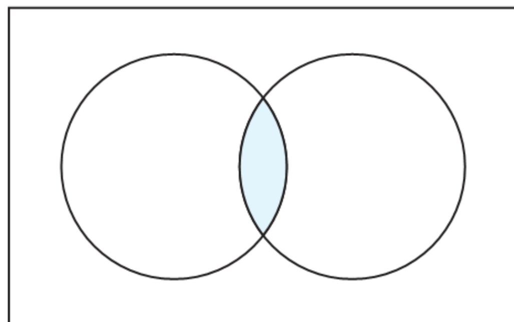
– can construct an empty set, or one based on a given collection

`add(`**value**`)`	adds the given value to the set
`contains(`**value**`)`	returns `true` if the given value is found in this set
`remove(`**value**`)`	removes the given value from the set
`clear()`	removes all elements of the set
`size()`	returns the number of elements in list
`isEmpty()`	returns `true` if the set's size is 0
`toString()`	returns a string such as `"[3, 42, -7, 15]"`

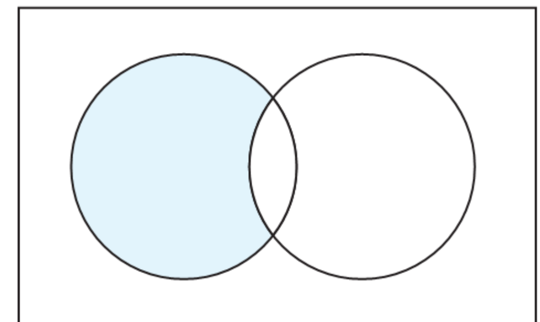
Set operations



addAll



retainAll



removeAll

`addAll(`**collection**`)`	adds all elements from the given collection to this set
`containsAll(`**coll**`)`	returns `true` if this set contains every element from given set
`equals(`**set**`)`	returns `true` if given other set contains the same elements
`iterator()`	returns an object used to examine set's contents *(seen later)*
`removeAll(`**coll**`)`	removes all elements in the given collection from this set
`retainAll(`**coll**`)`	removes elements *not* found in given collection from this set
`toArray()`	returns an array of the elements in this set

Sets and ordering

- `HashSet` : elements are stored in an unpredictable order

```
Set<String> names = new HashSet<String>();
names.add("Jake");
names.add("Robert");
names.add("Marisa");
names.add("Kasey");
System.out.println(names);
// [Kasey, Robert, Jake, Marisa]
```

- `TreeSet` : elements are stored in their "natural" sorted order

```
Set<String> names = new TreeSet<String>();
...
// [Jake, Kasey, Marisa, Robert]
```

- `LinkedHashSet` : elements stored in order of insertion

```
Set<String> names = new LinkedHashSet<String>();
...
// [Jake, Robert, Marisa, Kasey]
```

The "for each" loop (7.1)

```
for (type name : collection) {
    statements;
}
```

- Provides a clean syntax for looping over the elements of a `Set`, `List`, array, or other collection

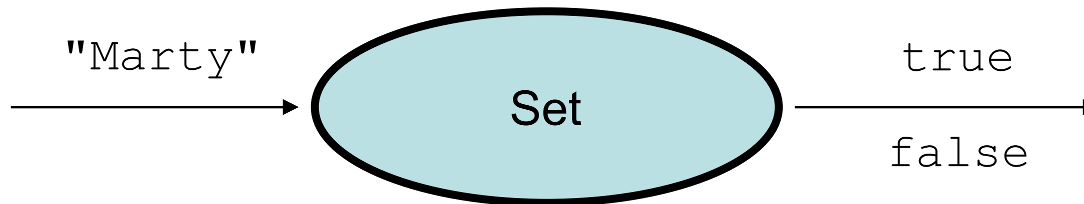
```
Set<Double> grades = new HashSet<Double>();
...

for (double grade : grades) {
    System.out.println("Student's grade: " + grade);
}
```

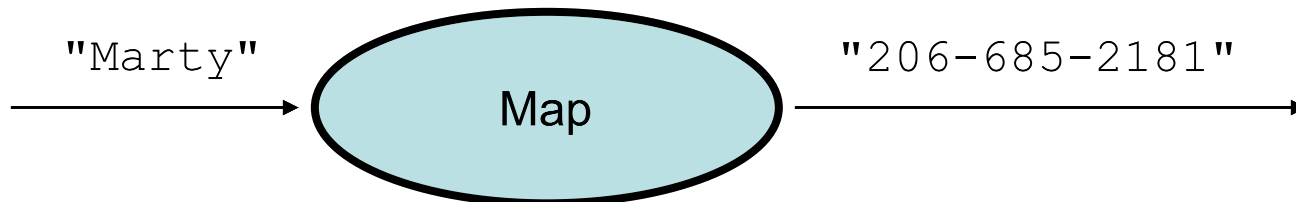
  - needed because sets have no indexes; can't `get` element `i`

Maps vs. sets

- A set is like a map from elements to `boolean` values.
  - *Set: Is "Marty" found in the set? (true/false)*



  - *Map: What is "Marty" 's phone number?*



`keySet` and `values`

- `keySet` method returns a `Set` of all keys in the map
  - can loop over the keys in a foreach loop
  - can get each key's associated value by calling `get` on the map

```
Map<String, Integer> ages = new TreeMap<String, Integer>();
ages.put("Marty", 19);
ages.put("Geneva", 2);  // ages.keySet() returns Set<String>
ages.put("Vicki", 57);
for (String name : ages.keySet()) {              // Geneva -> 2
    int age = ages.get(age);                     // Marty -> 19
    System.out.println(name + " -> " + age);     // Vicki -> 57
}
```

- `values` method returns a collection of all values in the map
  - can loop over the values in a foreach loop
  - no easy way to get from a value to its associated key(s)

Problem: opposite mapping

- It is legal to have a map of sets, a list of lists, etc.
- Suppose we want to keep track of each TA's GPA by name.

```
Map<String, Double> taGpa = new HashMap<String, Double>();
taGpa.put("Jared", 3.6);
taGpa.put("Alyssa", 4.0);
taGpa.put("Steve", 2.9);
taGpa.put("Stef", 3.6);
taGpa.put("Rob", 2.9);
...
System.out.println("Jared's GPA is " +
                   taGpa.get("Jared"));    // 3.6
```

- This doesn't let us easily ask which TAs got a given GPA.
  - How would we structure a map for that?

Reversing a map

- We can reverse the mapping to be from GPAs to names.

```
Map<Double, String> taGpa = new HashMap<Double, String>();
taGpa.put(3.6, "Jared");
taGpa.put(4.0, "Alyssa");
taGpa.put(2.9, "Steve");
taGpa.put(3.6, "Stef");
taGpa.put(2.9, "Rob");
...
System.out.println("Who got a 3.6? " +
                   taGpa.get(3.6));   // ???
```

- What's wrong with this solution?
  - More than one TA can have the same GPA.
  - The map will store only the last mapping we add.

Proper map reversal

- Really each GPA maps to a *collection* of people.

```
Map<Double, Set<String>> taGpa =
        new HashMap<Double, Set<String>>();
taGpa.put(3.6, new TreeSet<String>());
taGpa.get(3.6).add("Jared");
taGpa.put(4.0, new TreeSet<String>());
taGpa.get(4.0).add("Alyssa");
taGpa.put(2.9, new TreeSet<String>());
taGpa.get(2.9).add("Steve");
taGpa.get(3.6).add("Stef");
taGpa.get(2.9).add("Rob");
...
System.out.println("Who got a 3.6? " +
                   taGpa.get(3.6));   // [Jared, Stef]
```

– must be careful to initialize the set for a given GPA before adding

Exercises

- Modify the word count program to print every word that appeared in the book at least 1000 times, in sorted order from least to most occurrences.

- Write a program that reads a list of TA names and quarters' experience, then prints the quarters in increasing order of how many TAs have that much experience, along with their names.

```
Allison 5
Alyssa 8
Brian 1
Kasey 5
...
```

```
1 qtr: [Brian]
2 qtr: ...
5 qtr: [Allison, Kasey]
```

Iterators

reading: 11.1; 15.3; 16.5

Examining sets and maps

- elements of Java `Set`s and `Map`s can't be accessed by index
  - must use a "foreach" loop:

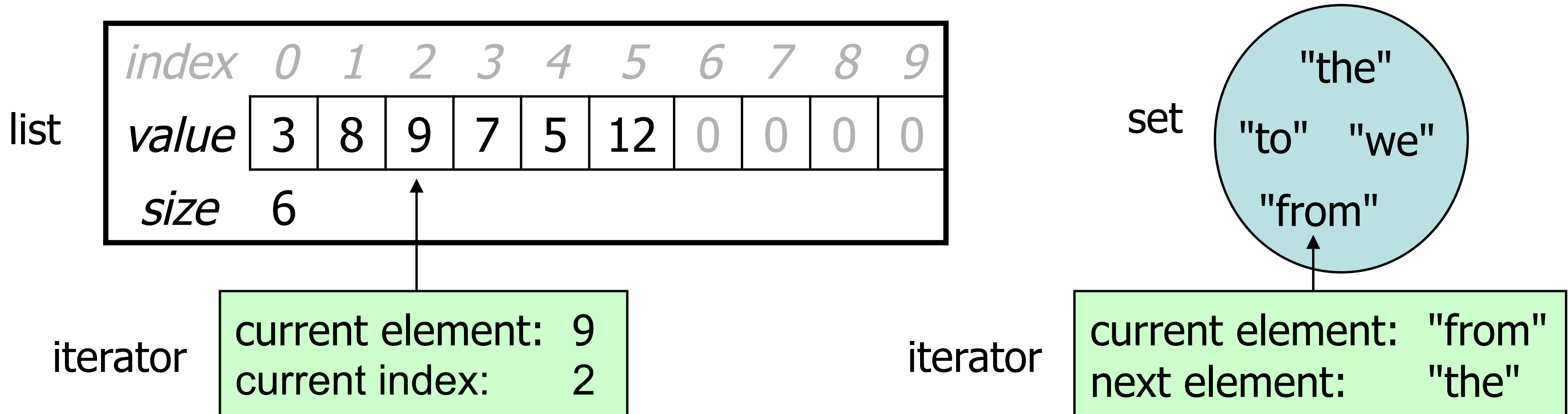
```
Set<Integer> scores = new HashSet<Integer>();
for (int score : scores) {
    System.out.println("The score is " + score);
}
```

  - Problem: foreach is read-only; cannot modify set while looping

```
for (int score : scores) {
    if (score < 60) {
    // throws a ConcurrentModificationException
        scores.remove(score);
    }
}
```

Iterators (11.1)

- **iterator**: An object that allows a client to traverse the elements of any collection.
  - Remembers a position, and lets you:
    - get the element at that position
    - advance to the next position
    - remove the element at that position



`Iterator` methods

`hasNext()`	returns `true` if there are more elements to examine
`next()`	returns the next element from the collection (throws a `NoSuchElementException` if there are none left to examine)
`remove()`	removes the last value returned by `next()` (throws an `IllegalStateException` if you haven't called `next()` yet)

- `Iterator` interface in `java.util`
  - every collection has an `iterator()` method that returns an iterator over its elements

```
Set<String> set = new HashSet<String>();
...
Iterator<String> itr = set.iterator();
...
```

Iterator example

```
Set<Integer> scores = new TreeSet<Integer>();
scores.add(94);
scores.add(38);    // Kim
scores.add(87);
scores.add(43);    // Marty
scores.add(72);
...

Iterator<Integer> itr = scores.iterator();
while (itr.hasNext()) {
    int score = itr.next();

    System.out.println("The score is " + score);

    // eliminate any failing grades
    if (score < 60) {
        itr.remove();
    }
}
System.out.println(scores);  // [72, 87, 94]
```

Iterator example 2

```
Map<String, Integer> scores = new TreeMap<String, Integer>();
scores.put("Kim", 38);
scores.put("Lisa", 94);
scores.put("Roy", 87);
scores.put("Marty", 43);
scores.put("Marisa", 72);
...

Iterator<String> itr = scores.keySet().iterator();
while (itr.hasNext()) {
    String name = itr.next();
    int score = scores.get(name);
    System.out.println(name + " got " + score);

    // eliminate any failing students
    if (score < 60) {
        itr.remove();     // removes name and score
    }
}
System.out.println(scores);  // {Lisa=94, Marisa=72, Roy=87}
```

Exercise

- Modify the Book Search program from last lecture to eliminate any words that are plural or all-uppercase from the collection.

- Modify the TA quarters experience program so that it eliminates any TAs with 3 quarters or fewer of experience.

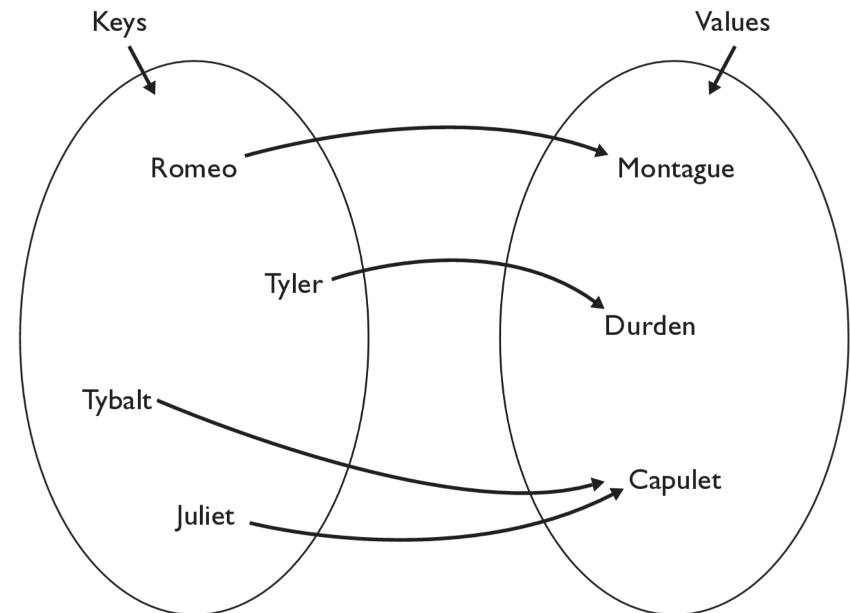
Exercise

- Write a program to count the occurrences of each word in a large text file (e.g. *Moby Dick* or the King James Bible).
  - Allow the user to type a word and report how many times that word appeared in the book.
  - Report all words that appeared in the book at least 500 times, in alphabetical order.
- How will we store the data to solve this problem?

The Map ADT

- **map**: Holds a set of unique *keys* and a collection of *values*, where each key is associated with one value.
  - a.k.a. "dictionary", "associative array", "hash"

- basic map operations:
  - **put**(*key*, *value*): Adds a mapping from a key to a value.
  - **get**(*key*): Retrieves the value mapped to the key.
  - **remove**(*key*): Removes the given key and its mapped value.



`myMap.get("Juliet")` returns `"Capulet"`

Maps and tallying

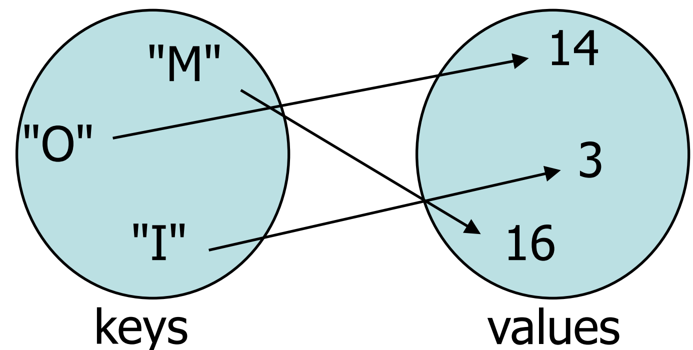
- a map can be thought of as generalization of a tallying array
  - the "index" (key) doesn't have to be an `int`
- recall previous tallying examples from CSE 142
  - count digits: `22092310907`

index	0	1	2	3	4	5	6	7	8	9
value	3	1	3	0	0	0	0	1	0	2

```
// (M)cCain, (O)bama, (I)ndependent
```

  - count votes: `"MOOOOOOMMMMMOOOOOOMOMMIMOMMIMOMMIO"`

key	"M"	"O"	"I"
value	16	14	3



`Map` implementation

- in Java, maps are represented by `Map` interface in `java.util`

- `Map` is implemented by the `HashMap` and `TreeMap` classes
  - `HashMap`: implemented using an array called a "hash table"; extremely fast: **O(1)** ; keys are stored in unpredictable order
  - `TreeMap`: implemented as a linked "binary tree" structure; very fast: **O(log N)** ; keys are stored in sorted order

  - A map requires 2 type parameters: one for keys, one for values.

```
// maps from String keys to Integer values
Map<String, Integer> votes = new HashMap<String, Integer>();
```

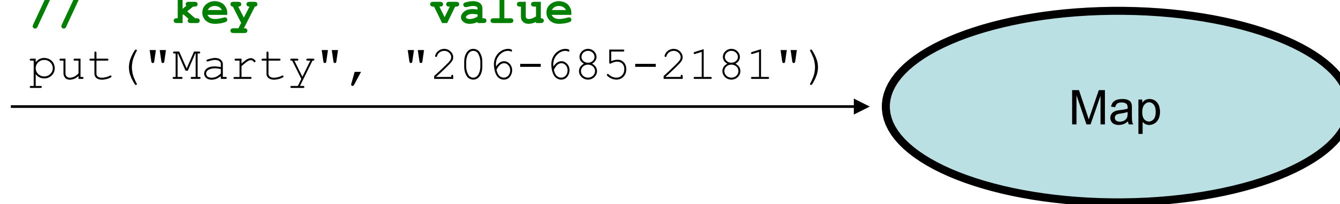
`Map` methods

`put(`**key**`, `**value**`)`	adds a mapping from the given key to the given value; if the key already exists, replaces its value with the given one
`get(`**key**`)`	returns the value mapped to the given key (`null` if not found)
`containsKey(`**key**`)`	returns `true` if the map contains a mapping for the given key
`remove(`**key**`)`	removes any existing mapping for the given key
`clear()`	removes all key/value pairs from the map
`size()`	returns the number of key/value pairs in the map
`isEmpty()`	returns `true` if the map's size is 0
`toString()`	returns a string such as `"{a=90, d=60, c=70}"`

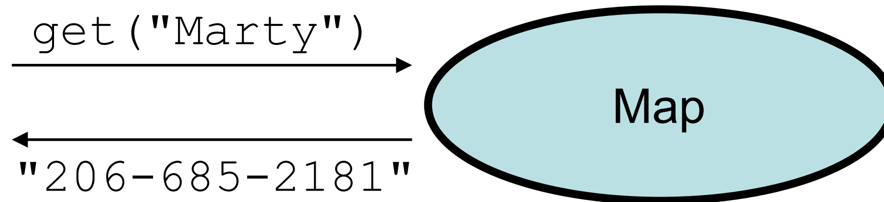
`keySet()`	returns a set of all keys in the map
`values()`	returns a collection of all values in the map
`putAll(`**map**`)`	adds all key/value pairs from the given map to this map
`equals(`**map**`)`	returns `true` if given map has the same mappings as this one

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).



  - Later, we can supply only the key and get back the related value:
    Allows us to ask: *What is Marty's phone number?*



Exercise solution

```
// read file into a map of [word --> number of occurrences]
Map<String, Integer> wordCount = new HashMap<String, Integer>();
Scanner input = new Scanner(new File("mobydick.txt"));
while (input.hasNext()) {
    String word = input.next();
    if (wordCount.containsKey(word)) {
        // seen this word before; increase count by 1
        int count = wordCount.get(word);
        wordCount.put(word, count + 1);
    } else {
        // never seen this word before
        wordCount.put(word, 1);
    }
}

Scanner console = new Scanner(System.in);
System.out.print("Word to search for? ");
String word = console.next();
System.out.println("appears " + wordCount.get(word) + " times.");
```

keySet and values

- `keySet` method returns a set of all keys in the map
  - can loop over the keys in a foreach loop
  - can get each key's associated value by calling `get` on the map

```
Map<String, Integer> ages = new HashMap<String, Integer>();
ages.put("Marty", 19);
ages.put("Geneva", 2);
ages.put("Vicki", 57);
for (String name : ages.keySet()) {                 // Geneva -> 2
    int age = ages.get(age);                        // Marty -> 19
    System.out.println(name + " -> " + age);        // Vicki -> 57
}
```

- `values` method returns a collection of all values in the map
  - can loop over the values in a foreach loop
  - there is no easy way to get from a value to its associated key(s)

Languages and Grammars

Languages and grammars

- (formal) **language**: A set of words or symbols.

- **grammar**: A description of a language that describes which sequences of symbols are allowed in that language.
  - describes language *syntax* (rules) but not *semantics* (meaning)
  - can be used to generate strings from a language, or to determine whether a given string belongs to a given language

Backus-Naur (BNF)

- **Backus-Naur Form (BNF)**: A syntax for describing language grammars in terms of transformation *rules*, of the form:

  <**symbol**> ::= <**expression**> | <**expression**> ... | <**expression**>

  - **terminal**: A fundamental symbol of the language.
  - **non-terminal**: A high-level symbol describing language syntax, which can be transformed into other non-terminal or terminal symbol(s) based on the rules of the grammar.

  - developed by two Turing-award-winning computer scientists in 1960 to describe their new ALGOL programming language

An example BNF grammar

```
<s>::=<n> <v>
<n>::=Marty | Victoria | Stuart | Jessica
<v>::=cried | slept | belched
```

- Some sentences that could be generated from this grammar:

```
Marty slept
Jessica belched
Stuart cried
```

BNF grammar version 2

```
<s>::=<np> <v>
<np>::=<pn> | <dp> <n>
<pn>::=Marty | Victoria | Stuart | Jessica
<dp>::=a | the
<n>::=ball | hamster | carrot | computer
<v>::=cried | slept | belched
```

- Some sentences that could be generated from this grammar:

```
the carrot cried
Jessica belched
a computer slept
```

BNF grammar version 3

```
<s>::=<np> <v>
<np>::=<pn> | <dp> <adj> <n>
<pn>::=Marty | Victoria | Stuart | Jessica
<dp>::=a | the
<adj>::=silly | invisible | loud | romantic
<n>::=ball | hamster | carrot | computer
<v>::=cried | slept | belched
```

- Some sentences that could be generated from this grammar:

```
the invisible carrot cried
Jessica belched
a computer slept
a romantic ball belched
```

Grammars and recursion

```
<s>::=<np> <v>
<np>::=<pn> | <dp> <adjp> <n>
<pn>::=Marty | Victoria | Stuart | Jessica
<dp>::=a | the
<adjp>::=<adj> <adjp> | <adj>
<adj>::=silly | invisible | loud | romantic
<n>::=ball | hamster | carrot | computer
<v>::=cried | slept | belched
```

- Grammar rules can be defined *recursively*, so that the expansion of a symbol can contain that same symbol.
  - There must also be expressions that expand the symbol into something non-recursive, so that the recursion eventually ends.

Grammar, final version

```
<s>::=<np> <vp>
<np>::=<dp> <adjp> <n>|<pn>
<dp>::=the|a
<adjp>::=<adj>|<adj> <adjp>
<adj>::=big|fat|green|wonderful|faulty|subliminal
<n>::=dog|cat|man|university|father|mother|child
<pn>::=John|Jane|Sally|Spot|Fred|Elmo
<vp>::=<tv> <np>|<iv>
<tv>::=hit|honored|kissed|helped
<iv>::=died|collapsed|laughed|wept
```

- Could this grammar generate the following sentences?

```
Fred honored the green wonderful child
big Jane wept the fat man fat
```

- Generate a random sentence using this grammar.

Sentence generation