CSC 222: Object-Oriented Programming
Spring 2012

Searching and sorting

- sequential search
- algorithm analysis: big-Oh, rate-of-growth
- binary search
- insertion sort, selection sort

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Searching a list

suppose you have a list, and want to find a particular item, e.g.,

- lookup a word in a dictionary
- find a number in the phone book
- locate a student's exam from a pile

searching is a common task in computing

- searching a database
- checking a login password
- lookup the value assigned to a variable in memory

if the items in the list are unordered (e.g., added at random)

- desired item is equally likely to be at any point in the list
- need to systematically search through the list, check each entry until found

➔ sequential search

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Sequential search

sequential search traverses the list from beginning to end

- check each entry in the list
- if matches the desired entry, then FOUND (return its index)
- if traverse entire list and no match, then NOT FOUND (return -1)

recall: the `ArrayList` class has an `indexOf` method

```
/**
 * Performs sequential search on the array field named items
 *   @param desired item to be searched for
 *   @returns index where desired first occurs, -1 if not found
 */
public int indexOf(Object desired) {
    for(int k=0; k < items.length; k++) {
        if (desired.equals(items[k])) {
            return k;
        }
    }
    return -1;
}
```

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How efficient is sequential search?

for this algorithm, the dominant factor in execution time is checking an item

- the number of checks will determine efficiency

in the worst case:

- the item you are looking for is in the last position of the list (or not found)
- requires traversing and checking every item in the list

- if 100 or 1,000 entries → NO BIG DEAL
- if 10,000 or 100,000 entries → NOTICEABLE

in the average case?

in the best case?

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Big-Oh notation

- to represent an algorithm's performance in relation to the size of the problem, computer scientists use *Big-Oh* notation
  - an algorithm is O(N) if the number of operations required to solve a problem is proportional to the size of the problem
  - sequential search on a list of N items requires *roughly* N checks (+ other constants)
    ➔ O(N)

- for an O(N) algorithm, doubling the size of the problem requires double the amount of work (in the worst case)
  - if it takes 1 second to search a list of 1,000 items, then
    it takes 2 seconds to search a list of 2,000 items
    it takes 4 seconds to search a list of 4,000 items
    it takes 8 seconds to search a list of 8,000 items
    . . .

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Searching an ordered list

- when the list is unordered, can't do any better than sequential search
  - but, if the list is ordered, a better alternative exists

- e.g., when looking up a word in the dictionary or name in the phone book
  - can take ordering knowledge into account
  - pick a spot – if too far in the list, then go backward; if not far enough, go forward

- binary search algorithm
  - check midpoint of the list
  - if desired item is found there, then DONE
  - if the item at midpoint comes after the desired item in the ordering scheme, then repeat the process on the left half
  - if the item at midpoint comes before the desired item in the ordering scheme, then repeat the process on the right half

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Binary search

the `Collections` utility class contains a `binarySearch` method

- takes a `List` of `Comparable` items and the desired item
  - `List` is an interface that specifies basic list operations (`ArrayList` implements)
  - `Comparable` is an interface that requires `compareTo` method (`String` implements)

more on interfaces later

```
/**
 * Performs binary search on a sorted list.
 *   @param items sorted list of Comparable items
 *   @param desired item to be searched for
 *   @returns index where desired first occurs, -(insertion point)-1 if not found
 */
public static <T extends Comparable<? super T>> int
                                binarySearch(List<T> items, Comparable desired) {
    int left = 0;                      // initialize range where desired could be
    int right = items.length-1;

    while (left <= right) {
        int mid = (left+right)/2;      // get midpoint value and compare
        int comparison = desired.compareTo(items[mid]);

        if (comparison == 0) {         // if desired at midpoint, then DONE
            return mid;
        }
        else if (comparison < 0) {     // if less than midpoint, focus on left half
            right = mid-1;
        }
        else {                         // otherwise, focus on right half
            left = mid + 1;
        }
    }
    return /* CLASS EXERCISE */ ;      // if reduce to empty range, NOT FOUND
}
```

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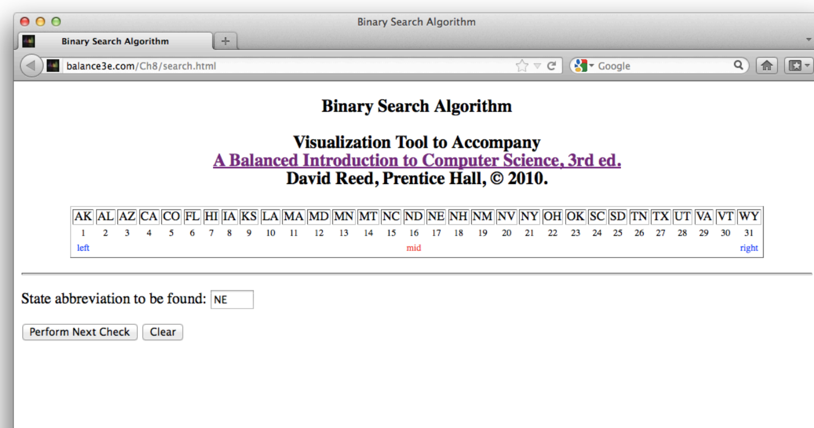
Visualizing binary search

note: each check reduces the range in which the item can be found by half

- see http://balance3e.com/Ch8/search.html for demo



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How efficient is binary search?

again, the dominant factor in execution time is checking an item

- the number of checks will determine efficiency

in the worst case:

- the item you are looking for is in the first or last position of the list (or not found)

start with N items in list

after 1st check, reduced to N/2 items to search
after 2nd check, reduced to N/4 items to search
after 3rd check, reduced to N/8 items to search
. . .
after $\log_2$ N checks, reduced to 1 item to search

in the average case?

in the best case?

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Big-Oh notation

an algorithm is O(log N) if the number of operations required to solve a problem is proportional to the logarithm of the size of the problem

binary search on a list of N items requires *roughly* $\log_2$ N checks (+ other constants)
➔ O(log N)

for an O(log N) algorithm, doubling the size of the problem adds only a constant amount of work

- if it takes 1 second to search a list of 1,000 items, then
  searching a list of 2,000 items will take time to check midpoint + 1 second
  searching a list of 4,000 items will take time for 2 checks + 1 second
  searching a list of 8,000 items will take time for 3 checks + 1 second
  . . .

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Comparison: searching a phone book

Number of entries in phone book	Number of checks performed by sequential search	Number of checks performed by binary search
100	100	7
200	200	8
400	400	9
800	800	10
1,600	1,600	11
…	…	…
10,000	10,000	14
20,000	20,000	15
40,000	40,000	16
…	…	…
1,000,000	1,000,000	20

to search a phone book of the United States (~310 million) using binary search?

to search a phone book of the world (7 billion) using binary search?

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Dictionary w/ binary search

reconsider the Dictionary class
- load the 117K `dictionary.txt` & perform several searches

modify Dictionary to utilize binary search
- import the `Collections` utility class

```
import java.util.Collections;
```

- modify the `contains` method so that it uses `Collections.binarySearch`

```
return (Collections.binarySearch(this.dict, desiredWord) >= 0);
```

compare performance
- is it noticeably faster when performing searches?

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Dictionary revisited

binary search works as long as the list of words is sorted

- `dictionary.txt` is sorted, so can load the dictionary and do searches
- to ensure correct behavior, must also make sure that add methods maintain sorting

```
public class Dictionary {
  private ArrayList<String> words;

  . . .

  public boolean addWord(String newWord) {
    int index = Collections.binarySearch(this.words, newWord.toLowerCase())
    this.words.add(Math.abs(index)-1, newWord.toLowerCase());
    return true;
  }

  public boolean addWordNoDupes(String newWord) {
    int index = Collections.binarySearch(this.words, newWord.toLowerCase());
    if (index < 0) {
      this.words.add(Math.abs(index)-1, newWord.toLowerCase());
      return true;
    }
    return false;
  }

  public boolean findWord(String desiredWord) {
    return (Collections.binarySearch(this.words, desiredWord.toLowerCase()) >= 0);
  }
}
```

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In the worst case…

suppose words are added in reverse order: "zoo", "moo", "foo", "boo"

zoo				

to add "moo", must first shift "zoo" one spot to the right

moo	zoo			

to add "foo", must first shift "moo" and "zoo" each one spot to the right

foo	moo	zoo		

to add "boo", must first shift "foo", "moo" and "zoo" each one spot to the right

boo	foo	moo	zoo	

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Worst case (in general)

if inserting N items in reverse order

- 1st item inserted directly
- 2nd item requires 1 shift, 1 insertion
- 3rd item requires 2 shifts, 1 insertion
- . . .
- Nth item requires N-1 shifts, 1 insertion

$(1 + 2 + 3 + \ldots + N\text{-}1) = N(N\text{-}1)/2 = (N^2 - N)/2$ shifts + N insertions

this approach is called "insertion sort"

- insertion sort builds a sorted list by repeatedly inserting items in correct order

since an insertion sort of N items can take roughly N^2 steps,
it is an $O(N^2)$ algorithm

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Timing the worst case

`System.currentTimeMillis` method accesses the system clock and returns the time (in milliseconds)

- we can use it to time repeated `add`s to a dictionary

```
public class TimeDictionary {
  public static int timeAdds(int numValues) {
    Dictionary dict = new Dictionary();

    long startTime = System.currentTimeMillis();
    for (int i = numValues; i > 0; i--) {
      String word = "0000000000" + i;
      dict.addWord(word.substring(word.length()-10));
    }
    long endTime = System.currentTimeMillis();

    return (int)(endTime-startTime);
  }
}
```

# items (N)	time in msec
5,000	15
10,000	49
20,000	162
40,000	651
80,000	2270
160,000	9168
320,000	36463

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$O(N^2)$ performance

as the problem size doubles, the time can quadruple

makes sense for an $O(N^2)$ algorithm

- if X items, then X^2 steps required
- if 2X items, then $(2X)^2 = 4X^2$ steps

QUESTION: why is the factor of 4 not realized immediately?

# items (N)	time in msec
5,000	15
10,000	49
20,000	162
40,000	651
80,000	2270
160,000	9168
320,000	36463

Big-Oh captures rate-of-growth behavior *in the long run*

- when determining Big-Oh, only the dominant factor is significant (in the long run)

cost = N(N-1)/2 shifts (+ N inserts + additional operations) → $O(N^2)$

N=1,000: 499,500 shifts + 1,000 inserts + … overhead cost is significant

N=100,000: 4,999,950,000 shifts + 100,000 inserts + … only N^2 factor is significant

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Best case for insertion sort

while insertion sort can require $\sim N^2$ steps in worst case, it can do much better

- BEST CASE: if items are added in order, then no shifting is required
- only requires N insertion steps, so O(N)
  → if double size, roughly double time

list size (N)	time in msec
40,000	32
80,000	79
160,000	194
320,000	400

on average, might expect to shift only half the time

- $(1 + 2 + \ldots + N-1)/2 = N(N-1)/4 = (N^2 - N)/4$ shifts, so still $O(N^2)$

→ would expect faster timings than worst case, but still quadratic growth

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Timing insertion sort (average case)

can use a `Random` object to pick random numbers and add to a String

list size (N)	time in msec
10,000	87
20,000	119
40,000	397
80,000	1420
160,000	5306
320,000	20442

```
import java.util.Random;

public class TimeDictionary {
  public static long timeAdds(int numValues) {
    Dictionary1 dict = new Dictionary1();
    Random randomizer = new Random();

    long startTime = System.currentTimeMillis();
    for (int i = 0; i < numValues; i++) {
      String word = "0000000000" +
                    randomizer.nextInt();
      dict.addWord(word.substring(word.length()-10));
    }
    long endTime = System.currentTimeMillis();

    return (endTime - startTime);
  }
}
```

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A more generic insertion sort

we can code insertion sort independent of the Dictionary class

- could use a temporary list for storing the sorted numbers, but not needed

- don't stress about `<T extends Comparable<? super T>>`
- specifies that the parameter must be an ArrayList of items that either implements or extends a class that implements the Comparable interface (???)
- more later, for now, it ensures the class has a `compareTo` method

```
public static <T extends Comparable<? super T>> void insertionSort(ArrayList<T> items) {
   for (int i = 1; i < items.size(); i++) {        // for each index i,
     T itemToPlace = items.get(i);                  //   save the value at index i
     int j = i;                                     //   starting at index i,
     while (j > 0 && itemToPlace.compareTo(items.get(j-1)) < 0) {
         items.set(j, items.get(j-1));              //     shift values to the right
         j--;                                       //     until find spot for the value
     }
     items.set(j, itemToPlace);                     //   store the value in its spot
   }
 }
```

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Other O(N^2) sorts

alternative algorithms exist for sorting a list of items

e.g., selection sort:

- find smallest item, swap into the 1st index
- find next smallest item, swap into the 2nd index
- find next smallest item, swap into the 3rd index
- . . .

```
public static <T extends Comparable<? super T>> void selectionSort(ArrayList<T> items) {
   for (int i = 0; i < items.size()-1; i++) {      // for each index i,
     int indexOfMin = i;                           //   find the ith smallest item
     for (int j = i+1; j < items.size(); j++) {
       if (items.get(j).compareTo(items.get(indexOfMin)) < 0) {
         indexOfMin = j;
       }
     }

     T temp = items.get(i);                        //   swap the ith smallest
     items.set(i, items.get(indexOfMin));          //   item into position i
     items.set(indexOfMin, temp);
   }
 }
```

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HW5: Hunt the Wumpus

you are to implement a text-based adventure game from the 70's

```
HUNT THE WUMPUS:  Your mission is to explore the maze of caves
and destroy all of the wumpi (without getting yourself killed).
To move to an adjacent cave, enter 'M' and the tunnel number.
To toss a grenade into a cave, enter 'T' and the tunnel number.

You are currently in The Fountainhead
    (1) unknown
    (2) unknown
    (3) unknown

What do you want to do? m 2

You are currently in The Silver Mirror
    (1) The Fountainhead
    (2) unknown
    (3) unknown

What do you want to do? m 3

You are currently in Shelob's Lair
    (1) The Silver Mirror
    (2) unknown
    (3) unknown
You smell an awful stench coming from somewhere nearby.

What do you want to do? t 2

Missed, dagnabit!
A startled wumpus charges into your cave... CHOMP CHOMP CHOMP
GAME OVER
```

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Cave class

you must implement a class that models a single cave

- each cave has a name & number, and is connected to three other caves via tunnels
- by default, caves are empty & unvisited (although these can be updated)

how do we represent the cave contents?

- we could store the contents as a string: "EMPTY", "WUMPUS", "BATS", "PIT"

```
Cave c = new Cave("Cavern of Doom", 0, 1, 2, 3);
c.setContents("WUMPUS");
```

- potential problems?

there are only 4 possible values for cave contents

- the trouble with using a String to represent these is no error checking

```
c.setContents("WUMPAS");    // perfectly legal, but ???
```

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Enumerated types

there is a better alternative for when there is a small, fixed number of values

- an enumerated type is a new type (class) whose value are explicitly enumerated

```
public enum CaveContents {
    EMPTY, WUMPUS, PIT, BATS
}
```

- note that these values are NOT Strings – they do not have quotes
- you specify a enumerated type value by ENUMTYPE.VALUE

```
c.setContents(CaveContents.WUMPUS);
```

since an enumerated type has a fixed number of values, any invalid input would be caught by the compiler

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CaveMaze

the CaveMaze class reads in & stores a maze of caves

- since the # of caves is set, simpler to use an array
- provided version only allows limited movement
- you must add functionality

```
20
 0  1  4  9 The Fountainhead
 1  0  2  5 The Rumpus Room
 2  1  3  6 Buford's Folly
 3  2  4  7 The Hall of Kings
 4  0  3 14 The Silver Mirror
 5  1  9 11 The Gallimaufry
 6  2  7 12 The Den of Iniquity
 7  3  6  8 The Findledelve
 8  7  3 13 The Page of the Deniers
 9  0  5 10 The Final Tally
10  9 11 14 Ess four
11  5 10 12 The Trillion
12  6 11 13 The Scrofula
13  8 12 18 Ephemeron
14  4 10 15 Shelob's Lair
15 15 16 19 The Lost Caverns of the Wyrm
16 15 17 19 The Lost Caverns of the Wyrm
17 16 17 18 The Lost Caverns of the Wyrm
18 13 17 19 The Lost Caverns of the Wyrm
19 15 16 17 The Lost Caverns of the Wyrm
```

```
public class CaveMaze {
  private Cave[] caves;
  private Cave currentCave;
  private boolean alive;

  public CaveMaze(String filename) throws java.io.FileNotFoundException {
      Scanner infile = new Scanner(new File(filename));

      int numCaves = infile.nextInt();
      this.caves = new Cave[numCaves];

      for (int i = 0; i < numCaves; i++) {
          int num1 = infile.nextInt();
          int num2 = infile.nextInt();
          int num3 = infile.nextInt();
          int num4 = infile.nextInt();
          String name = infile.nextLine().trim();
          this.caves[num1] = new Cave(name, num1, num2, num3, num4);
      }

      this.alive = true;
      this.currentCave = this.caves[0];
      this.currentCave.markAsVisited();
  }

  . . .
}
```

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