# CSC 427: Data Structures and Algorithm Analysis

# Fall 2007

## Inheritance and efficiency

- ArrayList → SortedArrayList
- tradeoffs with adding/searching
- timing code
- divide-and-conquer algorithms

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## Dictionary revisited

recall the Dictionary class from last week

- the ArrayList add method simply appends the item at the end → O(1)
- the ArrayList contains method performs sequential search → O(N)

this is OK if we are doing lots of adds and few searches

```
import java.util.List;
import java.util.ArrayList;
import java.util.Scanner;
import java.io.File;

public class Dictionary {
    private List<String> words;

    public Dictionary() {
        this.words = new ArrayList<String>();
    }

    public Dictionary(String filename) {
        this();

        try {
            Scanner infile = new Scanner(new File(filename));
            while (infile.hasNext()) {
                String nextWord = infile.next();
                this.words.add(nextWord.toLowerCase());
            }
        }
        catch (java.io.FileNotFoundException e) {
            System.out.println("FILE NOT FOUND");
        }
    }

    public void add(String newWord) {
        this.words.add(newWord.toLowerCase());
    }

    public void remove(String oldWord) {
        this.words.remove(oldWord.toLowerCase());
    }

    public boolean contains(String testWord) {
        return this.words.contains(testWord.toLowerCase());
    }
}
```

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## Timing dictionary searches

we can use the `java.util.Date` class to verify the O(N) efficiency

| dict. size | insert time |
|---|---|
| 38,621 | 460 msec |
| 77,242 | 760 msec |
| 144,484 | 1471 msec |

| dict. size | search time |
|---|---|
| 38,621 | 1.11 msec |
| 77,242 | 2.81 msec |
| 144,484 | 5.61 msec |

execution time roughly doubles as dictionary size doubles

```
import java.util.Scanner;
import java.io.File;
import java.util.Date;

public class DictionaryTimer {

  public static void main(String[] args) {
      System.out.println("Enter name of dictionary file:");
      Scanner input = new Scanner(System.in);
      String dictFile = input.next();

      Date start1 = new Date();
      Dictionary dict = new Dictionary(dictFile);
      Date end1 = new Date();

      System.out.println(end1.getTime()-start1.getTime());

      Date start2 = new Date();
      for (int i = 0; i < 100; i++) {
          dict.contains("zzyzyba");
      }
      Date end2 = new Date();

      System.out.println((end2.getTime()-start2.getTime())/100.0);
  }
}
```



## Sorting the list

if searches were common, then we might want to make use of binary search

- this requires sorting the words first, however

we could change the Dictionary class to do the sorting and searching

- a more general solution would be to extend the ArrayList class to SortedArrayList
- could then be used in any application that called for a sorted list

recall:

```
public class java.util.ArrayList<E> implements List<E> {
    public ArrayList() { … }
    public boolean add(E item) { … }
    public void add(int index, E item) { … }
    public E get(int index) { … }
    public E set(int index, E item) { … }
    public int indexOf(Object item) { … }
    public boolean contains(Object item) { … }
    public boolean remove(Object item) { … }
    public E remove(int index) { … }
    …
}
```

## SortedArrayList (v.1)

using inheritance, we only need to redefine what is new

- add method sorts after adding; indexOf uses binary search
- no additional fields required

- big-Oh for add?  big-Oh for indexOf?

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

public class SortedArrayList<E extends Comparable<? super E>> extends ArrayList<E> {
    public SortedArrayList() {
        super();
    }

    public boolean add(E item) {
        super.add(item);
        Collections.sort(this);
        return true;
    }

    public int indexOf(Object item) {
        return Collections.binarySearch(this, (E)item);
    }
}
```

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## SortedArrayList (v.2)

is this version any better?  when?

- big-Oh for add?
- big-Oh for indexOf?

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

public class SortedArrayList<E extends Comparable<? super E>> extends ArrayList<E> {
    public SortedArrayList() {
        super();
    }

    public boolean add(E item) {
        super.add(item);
        return true;
    }

    public int indexOf(Object item) {
        Collections.sort(this);
        return Collections.binarySearch(this, (E)item);
    }
}
```

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## SortedArrayList (v.3)

if insertions and searches are mixed, sorting for each insertion/search is extremely inefficient

- instead, could take the time to insert each item into its correct position
- big-Oh for add? big-Oh for indexOf?

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

public class SortedArrayList<E extends Comparable<? super E>> extends ArrayList<E> {
    public SortedArrayList() {
        super();
    }

    public boolean add(E item) {
        int i;
        for (i = 0; i < this.size(); i++) {
            if (item.compareTo(this.get(i)) < 0) {
                break;
            }
        }
        super.add(i, item);
        return true;
    }

    public int indexOf(Object item) {
        return Collections.binarySearch(this, (E)item);
    }
}
```



## Dictionary using SortedArrayList

note that repeated calls to add serve as insertion sort

| dict. size | insert time |
|---|---|
| 38,621 | 29.4 sec |
| 77,242 | 127.0 sec |
| 144,484 | 508.9 sec |

| dict. size | search time |
|---|---|
| 38,621 | 0.0 msec |
| 77,242 | 0.0 msec |
| 144,484 | 10.0 msec |

insertion time roughly quadruples as dictionary size doubles; search time is trivial

```
import java.util.Scanner;
import java.io.File;
import java.util.Date;

public class DictionaryTimer {

  public static void main(String[] args) {
      System.out.println("Enter name of dictionary file:");
      Scanner input = new Scanner(System.in);
      String dictFile = input.next();

      Date start1 = new Date();
      Dictionary dict = new Dictionary(dictFile);
      Date end1 = new Date();

      System.out.println(end1.getTime()-start1.getTime());

      Date start2 = new Date();
      for (int i = 0; i < 100; i++) {
          dict.contains("zzyzyba");
      }
      Date end2 = new Date();

      System.out.println((end2.getTime()-start2.getTime())/100.0);
  }
}
```

# SortedArrayList (v.4)

if adds tend to be done in groups (as in loading the dictionary)

- it might pay to perform lazy insertions & keep track of whether sorted
- big-Oh for add? big-Oh for indexOf?
- if desired, could still provide addInOrder method (as before)

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

public class SortedArrayList<E extends Comparable<? super E>> extends ArrayList<E> {
    private boolean isSorted;

    public SortedArrayList() {
        super();
        this.isSorted = true;
    }

    public boolean add(E item) {
        this.isSorted = false;
        return super.add(item);
    }

    public int indexOf(Object item) {
        if (!this.isSorted) {
            Collections.sort(this);
            this.isSorted = true;
        }
        return Collections.binarySearch(this, (E)item);
    }
}
```



# Timing dictihe lazy dictionaryonary searches

modify the Dictionary class to use the lazy SortedArrayList

| dict. size | insert time |
|---|---|
| 38,621 | 610 msec |
| 77,242 | 811 msec |
| 144,484 | 1382 msec |

| dict. size | 1st search |
|---|---|
| 38,621 | 0 msec |
| 77,242 | 50 msec |
| 144,484 | 110 msec |

| dict. size | search time |
|---|---|
| 38,621 | 0 msec |
| 77,242 | 0 msec |
| 144,484 | 0 msec |

```
import java.util.Scanner;
import java.io.File;
import java.util.Date;

public class DictionaryTimer {
  public static void main(String[] args) {
      System.out.println("Enter name of dictionary file:");
      Scanner input = new Scanner(System.in);
      String dictFile = input.next();

      Date start1 = new Date();
      Dictionary dict = new Dictionary(dictFile);
      Date end1 = new Date();
      System.out.println(end1.getTime()-start1.getTime());

      Date start2 = new Date();
      dict.contains("zzyzyba");
      Date end2 = new Date();

      System.out.println(end2.getTime()-start2.getTime());

      Date start3 = new Date();
      for (int i = 0; i < 100; i++) {
          dict.contains("zzyzyba");
      }
      Date end3 = new Date();

      System.out.println((end3.getTime()-start3.getTime())/100.0);
  }
}
```

## Divide & Conquer algorithms

recursive algorithms such as binary search and merge sort are known as *divide & conquer algorithms*

the divide & conquer approach tackles a complex problem by breaking into smaller pieces, solving each piece, and combining into an overall solution

- e.g., to binary search a list, check the midpoint then binary search the appropriate half of the list

divide & conquer is applicable when a problem can naturally be divided into independent pieces

- e.g., merge sort divided the list into halves, conquered (sorted) each half, then merged the results

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## Iterative vs. divide & conquer

many iterative algorithms can naturally be characterized as divide-and-conquer

- sequential search for X in list[0..N-1] =

| | |
|---|---|
| false | *if N == 0* |
| true | *if X == list[0]* |
| sequential search for X in list[1..N-1] | *otherwise* |

- sum of list[0..N-1] =

| | |
|---|---|
| 0 | *if N == 0* |
| list[0] + sum of list[1..N-1] | *otherwise* |

- number of occurrences of X in a list[0..N-1] =

| | |
|---|---|
| number of occurrences of X in list[1..N-1] | *if X != list[0]* |
| 1 + number of occurrences of X in list[1..N-1] | *if X == list[0]* |

interesting, but not very useful from a practical side (iteration is faster)

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# Euclid's algorithm

one of the oldest known algorithms is Euclid's algorithm for calculating the greatest common divisor (gcd) of two integers

- appeared in Euclid's *Elements* around 300 B.C., but may be even 200 years older
- defines the gcd of two numbers recursively, in terms of the gcd of smaller numbers

```
/** Calculates greatest common divisor of a and b
 *    @param a a positive integer
 *    @param b a positive integer (a >= b)
 *    @return the GCD of a and b
 */
public int gcd(int a, int b) {
    if (b == 0) {
        return a;
    }
    else {
        return gcd(b, a % b);
    }
}
```

| | |
|---|---|
| e.g.., gcd(32, 12) | = gcd(12, 8)<br>= gcd(8, 4)<br>= gcd(4, 0)<br>= 4 |
| e.g.., gcd(1024, 96) | = gcd(96, 64)<br>= gcd(64, 32)<br>= gcd(32, 0)<br>= 32 |
| e.g.., gcd(17, 5) | = gcd(5, 2)<br>= gcd(2, 1)<br>= gcd(1, 0)<br>= 1 |

if the larger number has N digits,

- Euclid's algorithm requires at most O(N) recursive calls
- however, each (a % b) requires O(N) steps

→O($N^2$)

*there is no known algorithm with better big-Oh (but is possible to reduce constants)*

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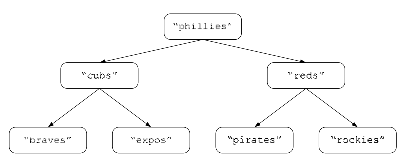
# Multidimensional divide & conquer

we will see later that divide & conquer is especially useful when manipulating multidimensional structures

- e.g., print values in a binary tree

```
public void traverse(TreeNode<String> root) {
    if (root != null) {
        traverse(root.getLeft());
        System.out.println(root.getValue());
        traverse(root.getRight());
    }
}
```




- e.g., find the distance of the closest pair of points in a space

1. LDist = distance of closest pair in left half
2. RDist = distance of closest pair in right half
3. LClose = set of points whose x-coord are within min(LDist,RDist) to the left of center
4. RClose = set of points whose x-coord are within min(LDist,RDist) to the right of center
5. answer = min(LDist, RDist, distance($LClose_i$,$RClose_j$))

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