

Data Abstraction

Outline

- ➊ Abstract Data Type (ADT)
- ➋ Using an ADT
- ➌ Examples of ADTs
- ➍ Defining an ADT
- ➎ Error Handling

Abstract Data Type (ADT)

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An abstract data type (ADT) is one whose representation is hidden from the program that uses the ADT

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Example

☰ Counter implements Comparable<Counter>

| | |
|------------------------------|--|
| Counter(String id) | constructs a counter given its id |
| void increment() | increments this counter by 1 |
| int tally() | returns the current value of this counter |
| void reset() | resets this counter to zero |
| boolean equals(Object other) | returns <code>true</code> if this counter and <code>other</code> have the same tally, and <code>false</code> otherwise |
| String toString() | returns a string representation of this counter |
| int compareTo(Counter other) | returns a comparison of this counter with <code>other</code> by their tally |

Abstract Data Type (ADT)

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- ↪ Some entries (called methods) lack the `static` keyword and operate on data-type values

Abstract Data Type (ADT)

Salient features of an ADT:

- ~> Some entries (called constructors) have the same name as the class and no return type
- ~> Some entries (called methods) lack the `static` keyword and operate on data-type values
- ~> Some methods such as `equals()`, `hashCode()`, and `toString()` are inherited from the parent `java.lang.Object` class and overridden in the ADT

Using an ADT

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An object is an entity that can take on a data-type value

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Creating an object

```
<type> <name> = new <type>(<argument1>, <argument2>, ...);
```

Using an ADT

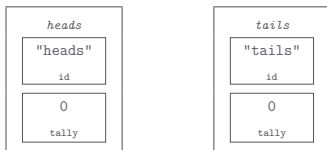
An object is an entity that can take on a data-type value

Creating an object

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<type> <name> = new <type>(<argument1>, <argument2>, ...);
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Example

```
1 Counter heads = new Counter("heads");  
2 Counter tails = new Counter("tails");
```



Using an ADT

```
using namespace std;
using namespace ADT;

int main()
{
    // Create a stack
    Stack s;

    // Push 10, 20, 30, 40, 50
    s.Push(10);
    s.Push(20);
    s.Push(30);
    s.Push(40);
    s.Push(50);

    // Print the stack
    cout << "Stack elements: ";
    while (!s.IsEmpty())
    {
        cout << s.Top() << " ";
        s.Pop();
    }
    cout << endl;

    // Create a queue
    Queue q;

    // Enqueue 10, 20, 30, 40, 50
    q.Enqueue(10);
    q.Enqueue(20);
    q.Enqueue(30);
    q.Enqueue(40);
    q.Enqueue(50);

    // Print the queue
    cout << "Queue elements: ";
    while (!q.IsEmpty())
    {
        cout << q.Front() << " ";
        q.Dequeue();
    }
    cout << endl;

    return 0;
}
```

Using an ADT

A method, invoked as `[<object>].<name>(<argument1>, <argument2>, ...)`, operates on data-type values

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Example

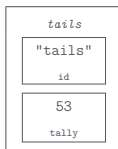
```
1  for (int i = 0; i < 100; i++) {  
2      if (StdRandom.bernoulli(0.5)) {  
3          heads.increment();  
4      } else {  
5          tails.increment();  
6      }  
7  }
```

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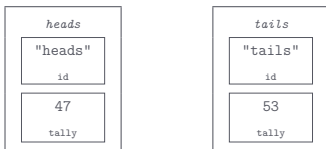


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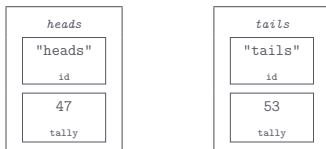
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1  StdOut.println(heads.tally());  
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Example

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1  for (int i = 0; i < 100; i++) {  
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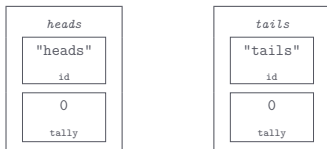
```
1  StdOut.println(heads.tally());  
2  StdOut.println(tails.tally());
```

```
47  
53
```

Using an ADT

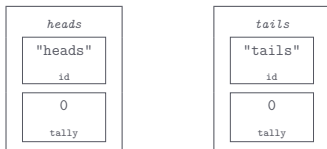
Using an ADT

```
1 Counter heads = new Counter("heads");  
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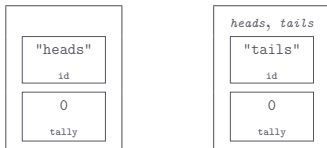
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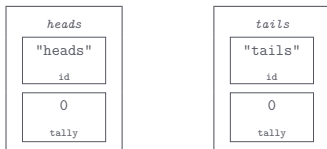
Aliasing

```
heads = tails;
```



Using an ADT

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Using an ADT

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Two objects `x` and `y` must be compared for equality as `x.equals(y)` and not as `x == y`

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Example

```
1 String x = "Hello, World";  
2 String y = "Hello, World";  
3 String z = "Cogito, ergo sum";  
4 StdOut.println("x == x? " + (x == x));  
5 StdOut.println("x == y? " + (x == y));  
6 StdOut.println("x == z? " + (x == z));  
7 StdOut.println("x.equals(x)? " + x.equals(x));  
8 StdOut.println("x.equals(y)? " + x.equals(y));  
9 StdOut.println("x.equals(z)? " + x.equals(z));
```

Using an ADT

Two objects `x` and `y` must be compared for equality as `x.equals(y)` and not as `x == y`

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```
1 String x = "Hello, World";
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3 String z = "Cogito, ergo sum";
4 StdOut.println("x == x? " + (x == x));
5 StdOut.println("x == y? " + (x == y));
6 StdOut.println("x == z? " + (x == z));
7 StdOut.println("x.equals(x)? " + x.equals(x));
8 StdOut.println("x.equals(y)? " + x.equals(y));
9 StdOut.println("x.equals(z)? " + x.equals(z));
```

```
x == x? true
x == y? false
x == z? false
x.equals(x)? true
x.equals(y)? true
x.equals(z)? false
```

Using an ADT

Using an ADT

Program: `Flips.java`

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↪ Command-line input: n (int)

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↪ Standard output: number of heads, tails, and the difference from n coin flips

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```
>_ ~/workspace/dsa/programs
```

```
$ _
```

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```

```
$ java Flips 1000000
```

Using an ADT

Program: `Flips.java`

↪ Command-line input: n (int)

↪ Standard output: number of heads, tails, and the difference from n coin flips

```
>_ ~/workspace/dsa/programs
```

```
$ java Flips 1000000
499771 Heads
500229 Tails
delta: 458
$ _
```

Using an ADT

Using an ADT

Flips.java

```
1 import dsa.Counter;
2 import stdlib.Stdout;
3 import stdlib.StdRandom;
4
5 public class Flips {
6     public static void main(String[] args) {
7         int n = Integer.parseInt(args[0]);
8         Counter heads = new Counter("Heads");
9         Counter tails = new Counter("Tails");
10        for (int i = 0; i < n; i++) {
11            if (StdRandom.bernoulli(0.5)) {
12                heads.increment();
13            } else {
14                tails.increment();
15            }
16        }
17        StdOut.println(heads);
18        StdOut.println(tails);
19        StdOut.println("delta: " + Math.abs(heads.tally() - tails.tally()));
20    }
21 }
```

Using an ADT

```
using namespace std;
using namespace ADT;

int main()
{
    // Create a stack
    Stack s;

    // Push 10, 20, 30, 40, 50
    s.Push(10);
    s.Push(20);
    s.Push(30);
    s.Push(40);
    s.Push(50);

    // Print the stack
    cout << "Stack elements: ";
    while (!s.IsEmpty())
    {
        cout << s.Top() << " ";
        s.Pop();
    }
    cout << endl;

    // Create a queue
    Queue q;

    // Enqueue 10, 20, 30, 40, 50
    q.Enqueue(10);
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    // Print the queue
    cout << "Queue elements: ";
    while (!q.IsEmpty())
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        cout << q.Front() << " ";
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    return 0;
}
```

Using an ADT

Program: `FlipsMax.java`

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>_ ~/workspace/dsa/programs
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```
>_ ~/workspace/dsa/programs
```

```
$ java FlipsMax 1000000
500371 Heads wins
$ _
```

Using an ADT

Program: FlipsMax.java

↪ Command-line input: n (int)

↪ Standard output: the winner from n coin flips

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>_ ~/workspace/dsa/programs
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Program: FlipsMax.java

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>_ ~/workspace/dsa/programs
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$ java FlipsMax 1000000
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500776 Tails wins
$ _
```

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```

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```

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500776 Tails wins
$ java FlipsMax 1000000
500995 Tails wins
$ _
```


Using an ADT

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FlipsMax.java

```
1 import dsa.Counter;
2 import stdlib.Stdout;
3 import stdlib.StdRandom;
4
5 public class FlipsMax {
6     public static void main(String[] args) {
7         int n = Integer.parseInt(args[0]);
8         Counter heads = new Counter("Heads");
9         Counter tails = new Counter("Tails");
10        for (int i = 0; i < n; i++) {
11            if (StdRandom.bernoulli(0.5)) {
12                heads.increment();
13            } else {
14                tails.increment();
15            }
16        }
17        if (heads.equals(tails)) {
18            StdOut.println("Tie");
19        } else {
20            StdOut.println(max(heads, tails) + " wins");
21        }
22    }
23
24    private static Counter max(Counter x, Counter y) {
25        if (x.tally() > y.tally()) {
26            return x;
27        }
28        return y;
29    }
30 }
```

Using an ADT

```
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int main()
{
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    // Print the stack
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    // Create a queue
    Queue q;

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    // Print the queue
    cout << "Queue elements: ";
    while (!q.IsEmpty())
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        q.Dequeue();
    }
    cout << endl;

    return 0;
}
```

Using an ADT

Program: `Rolls.java`

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Program: `Rolls.java`

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```
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```

```
$ java Rolls 1000000
```


Using an ADT

Program: `Rolls.java`

~> Command-line input: n (int)

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```
>_ ~/workspace/dsa/programs
```

```
$ java Rolls 1000000
166923 1s
166543 2s
166528 3s
166373 4s
166517 5s
167116 6s
$ _
```

Using an ADT

Using an ADT

Rolls.java

```
1 import dsa.Counter;
2 import stdlib.Stdout;
3 import stdlib.StdRandom;
4
5 public class Rolls {
6     public static void main(String[] args) {
7         int n = Integer.parseInt(args[0]);
8         int SIDES = 6;
9         Counter[] rolls = new Counter[SIDES + 1];
10        for (int i = 1; i <= SIDES; i++) {
11            rolls[i] = new Counter(i + "s");
12        }
13        for (int j = 0; j < n; j++) {
14            int result = StdRandom.uniform(1, SIDES + 1);
15            rolls[result].increment();
16        }
17        for (int i = 1; i <= SIDES; i++) {
18            StdOut.println(rolls[i]);
19        }
20    }
```

Examples of ADTs

Stacks and Queues

Priority Queues

Hash Tables

Graphs

Binary Trees

Heaps

Disjoint Sets

Union-Find

Segment Trees

Interval Trees

Dynamic Programming

Examples of ADTs

| Type | Description |
|---|--|
| <code>java.lang.Integer</code> | wraps a primitive <code>int</code> |
| <code>java.lang.Double</code> | wraps a primitive <code>double</code> |
| <code>java.lang.String</code> | represents a sequence of characters |
| <code>java.util.NoSuchElementException</code> | used to indicate that the requested element does not exist |
| <code>dsa.Stopwatch</code> | represents a stopwatch |
| <code>dsa.WeightedQuickUnionUF</code> | represents the union-find data structure |

Examples of ADTs · String

☰ java.lang.String

| | |
|---|---|
| <code>String()</code> | creates an empty string |
| <code>int length()</code> | returns the length of the string |
| <code>char charAt(int i)</code> | returns the character in the string at index <code>i</code> |
| <code>String substring(int i, int j)</code> | returns a substring of the string from index <code>i</code> (inclusive) to index <code>j</code> (exclusive) |

Examples of ADTs · String

☰ java.lang.String

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|--------------------------------|---|
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Example

```
1 public static boolean isPalindrome(String s) {
2     int n = s.length();
3     if (n == 0) {
4         return true;
5     }
6     return s.charAt(0) == s.charAt(n - 1) && isPalindrome(s.substring(1, n - 1));
7 }
```


Examples of ADTs · Union-find

Union-find is a data structure that supports two operations:

• **Union**: Merge two sets into one.

• **Find**: Determine which set an element belongs to.

Union-find is used in many algorithms, including:

• Kruskal's algorithm for finding the minimum spanning tree.

• The algorithm for finding connected components in a graph.

• The algorithm for finding the number of connected components in a graph.

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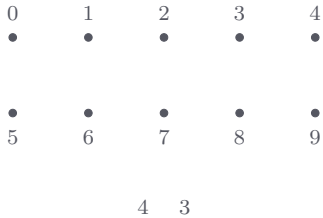
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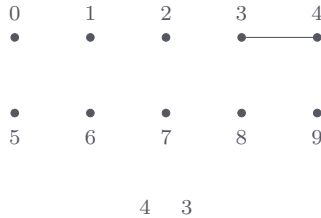
Examples of ADTs · Union-find



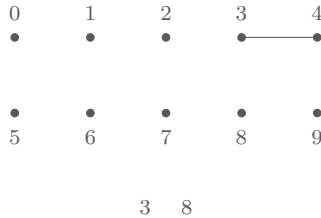
Examples of ADTs · Union-find



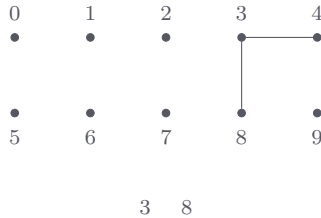
Examples of ADTs · Union-find



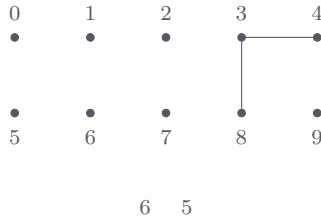
Examples of ADTs · Union-find



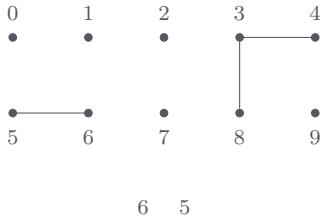
Examples of ADTs · Union-find



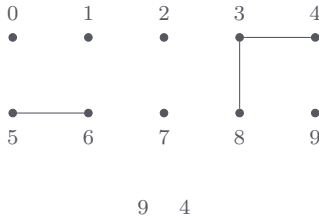
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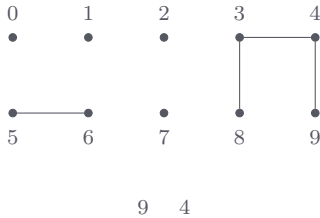
Examples of ADTs · Union-find



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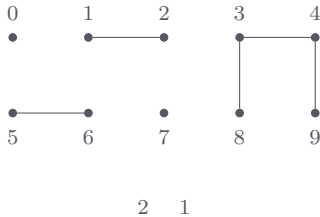


Examples of ADTs · Union-find

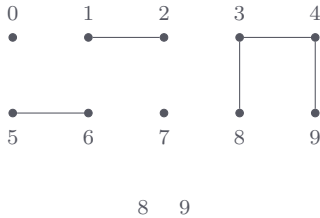


2 1

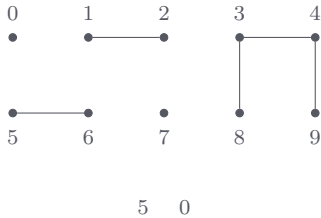
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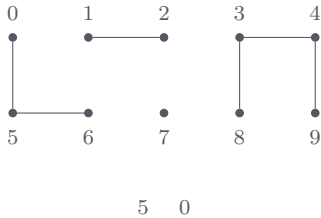
Examples of ADTs · Union-find



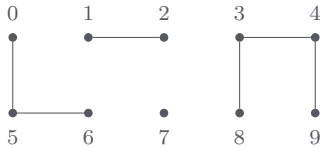
Examples of ADTs · Union-find



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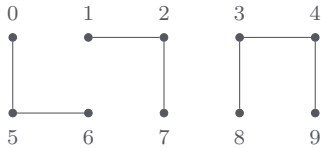


Examples of ADTs · Union-find



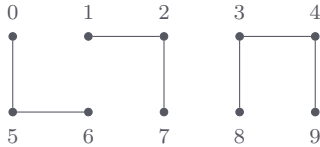
7 2

Examples of ADTs · Union-find



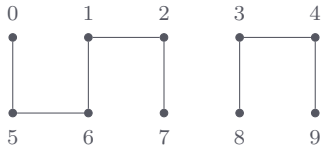
7 2

Examples of ADTs · Union-find



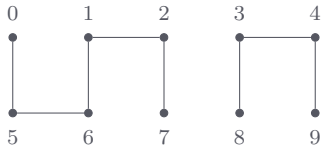
6 1

Examples of ADTs · Union-find



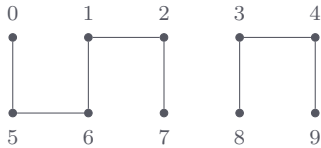
6 1

Examples of ADTs · Union-find



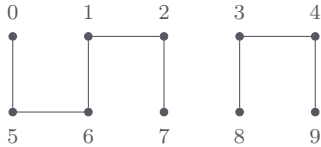
1 0

Examples of ADTs · Union-find



6 7

Examples of ADTs · Union-find



Examples of ADTs · Union-find

Union-find is a data structure that supports two operations:

• **Union**: Merge two sets into one.

• **Find**: Determine the set an element belongs to.

Union-find is used in many algorithms, including:

• Kruskal's algorithm for finding the minimum spanning tree.

• The algorithm for finding the connected components of a graph.

Union-find is a simple data structure, but it is very powerful.

It is a good example of how a simple data structure can be used to solve a wide range of problems.

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Examples of ADTs · Union-find

☰ WeightedQuickUnionUF implements UF

| | |
|--|---|
| <code>WeightedQuickUnionUF(int n)</code> | constructs an empty union-find data structure with n sites |
| <code>int find(int p)</code> | returns the canonical site of the component containing site p |
| <code>int count()</code> | returns the number of components |
| <code>boolean connected(int p, int q)</code> | returns <code>true</code> if sites p and q belong to the same component, and <code>false</code> otherwise |
| <code>void union(int p, int q)</code> | connects sites p and q |

Examples of ADTs · Union-find

Union-find is a data structure that supports two operations:

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↪ Standard input: n (int) and a sequence of pairs of integers representing sites

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- ↪ Standard output: number of components left after merging the sites that are in different components

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```
>_ ~/workspace/dsa/programs
```

```
$ _
```

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```

```
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```

```
10
4 3
3 8
6 5
9 4
2 1
8 9
5 0
7 2
6 1
1 0
6 7
$ _
```

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10
```

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```
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```
6 5
```

```
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```

```
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```

```
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```

```
5 0
```

```
7 2
```

```
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```
6 7
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```
$ java Components < ../data/tinyUF.txt
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- ↪ Standard input: n (int) and a sequence of pairs of integers representing sites
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```
$ cat ../data/tinyUF.txt
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```

```
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```
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```
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```
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```

```
7 2
```

```
6 1
```

```
1 0
```

```
6 7
```

```
$ java Components < ../data/tinyUF.txt
```

```
2 components
```

```
$ _
```

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Union-find is used in many algorithms, including:

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• The algorithm for finding the connected components of a graph.

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Union-find is a simple data structure, but it is very powerful.

It can be implemented in many ways, and it can be optimized.

Union-find is a good example of a simple data structure that can be used to solve many problems.

Union-find is a good example of a data structure that is easy to understand and use.

Union-find is a good example of a data structure that is efficient and effective.

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Components.java

```
1 import dsa.WeightedQuickUnionUF;
2 import stdlib.StdIn;
3 import stdlib.StdOut;
4
5 public class Components {
6     public static void main(String[] args) {
7         int n = StdIn.readInt();
8         WeightedQuickUnionUF uf = new WeightedQuickUnionUF(n);
9         while (!StdIn.isEmpty()) {
10             int p = StdIn.readInt();
11             int q = StdIn.readInt();
12             uf.union(p, q);
13         }
14         StdOut.println(uf.count() + " components");
15     }
16 }
```

Defining an ADT

Defining an ADT

Program.java

```
1  [package dsa;]
2
3  // Import statements.
4  ...
5
6  // Class definition.
7  public class Program [implements <name>] {
8      // Field declarations.
9      ...
10
11     // Constructor definitions.
12     ...
13
14     // Method definitions.
15     ...
16
17     // Function definitions.
18     ...
19
20     // Inner class definitions.
21     ...
22 }
```

Defining an ADT

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Field declaration statement

```
private|public [static] <type> <name>;
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Fields are accessed as [`<target>`].`<name>`, where `<target>` is an object name for an instance field and a library name for a `static` field

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Examples:

↪ Instance fields `String id` and `int count` in `Counter`

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Examples:

↪ Instance fields `String id` and `int count` in `Counter`

↪ Static field `double PI` in `Math`

Defining an ADT

Defining an ADT

Constructor definition

```
1 private|public <name>(<parameter1>, <parameter2>, ...) {  
2     <statement>  
3     ...  
4 }
```

where <name> is the name of the ADT

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```
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where `<name>` is the name of the ADT

Example

✏ Counter.java

```
1 ...  
2 public Counter(String id) {  
3     this.id = id;  
4     count = 0;  
5 }  
6 ...
```

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Within a constructor, `this` is a reference to the object being constructed

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If an ADT has no explicit constructors, `javac` implicitly provides an empty constructor

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Method definition

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1 private|public <type> <name>(<parameter1>, <parameter2>, ...) {  
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Example

✏ Counter.java

```
1 ...  
2     public void increment() {  
3         count++;  
4     }  
5  
6     public int tally() {  
7         return count;  
8     }  
9     ...
```

Defining an ADT

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```

Within a method, `this` is a reference to the object on which the method was invoked

Defining an ADT · Interface

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An interface provides a formal mechanism for describing an ADT's API and supporting different implementations of that API

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```
1 public class Elephant implements Animal {  
2     public String sound() {  
3         return "trumpet";  
4     }  
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1 public class Tiger implements Animal {  
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4     }  
5 }
```

```
1 Animal elephant = new Elephant();  
2 Animal tiger = new Tiger();  
3 StdOut.println("An elephant's " + elephant.sound() + "!");  
4 StdOut.println("A tiger's " + tiger.sound() + "!");
```

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5 }
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1 Animal elephant = new Elephant();  
2 Animal tiger = new Tiger();  
3 StdOut.println("An elephant's " + elephant.sound() + "!");  
4 StdOut.println("A tiger's " + tiger.sound() + "!");
```

```
An elephant's trumpet!  
A tiger's roar!
```

Defining an ADT · Comparison Interfaces

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☰ *java.lang.Comparable*

`int compareTo(Type other)` returns a comparison of this object with `other`

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☰ *java.lang.Comparable*

`int compareTo(Type other)` returns a comparison of this object with `other`

☰ *java.util.Comparator*

`int compare(Type v, Type w)` returns a comparison of object `v` with object `w`

Defining an ADT · Comparable ADT

Comparable ADT: `Comparable` interface

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Defining an ADT · Comparable ADT

ComparableADT.java

```
1  import java.util.Comparator;
2
3  public class ComparableADT implements Comparable<ComparableADT> {
4      ...
5      // Natural ordering.
6      public int compareTo(ComparableADT other) {
7          ...
8      }
9
10     public static Comparator<ComparableADT> aOrder() {
11         return new AOrder();
12     }
13
14     public static Comparator<ComparableADT> bOrder() {
15         return new BOrder();
16     }
17
18     // Alternate ordering 1.
19     private static class AOrder implements Comparator<ComparableADT> {
20         ...
21         public int compare(ComparableADT v, ComparableADT w) {
22             ...
23         }
24     }
25
26     // Alternate ordering 2.
27     private static class BOrder implements Comparator<ComparableADT> {
28         ...
29         public int compare(ComparableADT v, ComparableADT w) {
30             ...
31         }
32     }
33     ...
34 }
```

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Defining an ADT · Comparable ADT

☰ Counter implements Comparable<Counter>

| | |
|------------------------------|--|
| Counter(String id) | constructs a counter given its id |
| void increment() | increments this counter by 1 |
| int tally() | returns the current value of this counter |
| void reset() | resets this counter to zero |
| boolean equals(Object other) | returns <code>true</code> if this counter and <code>other</code> have the same tally, and <code>false</code> otherwise |
| String toString() | returns a string representation of this counter |
| int compareTo(Counter other) | returns a comparison of this counter with <code>other</code> by their tally |

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Program: `Counter.java`

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↪ Command-line input: n (int), *trials* (int)

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Program: `Counter.java`

↪ Command-line input: n (int), $trials$ (int)

↪ Standard output: frequencies obtained from $trials$ random draws of numbers from the interval $[0, n)$

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```

```
$ _
```


Defining an ADT · Comparable ADT

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```
>_ ~/workspace/dsa/programs
```

```
$ java dsa.Counter 2 1000
```

Defining an ADT · Comparable ADT

Program: `Counter.java`

↪ Command-line input: n (int), $trials$ (int)

↪ Standard output: frequencies obtained from $trials$ random draws of numbers from the interval $[0, n)$

```
>_ ~/workspace/dsa/programs  
  
$ java dsa.Counter 2 1000  
501 counter 0  
499 counter 1  
$ _
```

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Defining an ADT · Comparable ADT

Counter.java

```
1 package dsa;
2
3 import stdlib.StdOut;
4 import stdlib.StdRandom;
5
6 public class Counter implements Comparable<Counter> {
7     private String id;
8     private int count;
9
10    public Counter(String id) {
11        this.id = id;
12        count = 0;
13    }
14
15    public void increment() {
16        count++;
17    }
18
19    public int tally() {
20        return count;
21    }
22
23    public void reset() {
24        count = 0;
25    }
26
27    public boolean equals(Object other) {
28        if (other == null) {
29            return false;
30        }
31        if (other == this) {
32            return true;
33        }
34        if (other.getClass() != this.getClass()) {
35            return false;
```

Defining an ADT · Comparable ADT

Counter.java

```
36     }
37     Counter a = this, b = (Counter) other;
38     return a.count == b.count;
39 }
40
41 public String toString() {
42     return count + " " + id;
43 }
44
45 public int compareTo(Counter other) {
46     return this.count - other.count;
47 }
48
49 public static void main(String[] args) {
50     int n = Integer.parseInt(args[0]);
51     int trials = Integer.parseInt(args[1]);
52     Counter[] hits = new Counter[n];
53     for (int i = 0; i < n; i++) {
54         hits[i] = new Counter("counter " + i);
55     }
56     for (int t = 0; t < trials; t++) {
57         hits[StdRandom.uniform(n)].increment();
58     }
59     for (int i = 0; i < n; i++) {
60         StdOut.println(hits[i]);
61     }
62 }
63 }
```

Defining an ADT · Comparable ADT

Comparable ADT: `Comparable` interface

Comparable ADT: `Comparable` interface

Comparable ADT: `Comparable` interface

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Defining an ADT · Comparable ADT

Transaction implements Comparable<Transaction>

| | |
|--|---|
| Transaction(String name, Date date, double amount) | constructs a transaction from a name, date, and amount |
| Transaction(String s) | constructs a transaction from a string s of the form “name date amount” |
| String name() | returns the name of the person involved in this transaction |
| Date date() | returns the date of this transaction |
| double amount() | returns the amount of this transaction |
| int hashCode() | returns a hash code for this transaction |
| String toString() | returns a string representation of this transaction |
| int compareTo(Transaction other) | returns a comparison of this transaction with other by amount |
| static Comparator<Transaction> nameOrder() | returns a comparator for comparing two transactions by name |
| static Comparator<Transaction> dateOrder() | returns a comparator for comparing two transactions by date |
| static Comparator<Transaction> amountOrder() | returns a comparator for comparing two transactions by amount |

Defining an ADT · Comparable ADT

Comparable ADT: `Comparable` interface and `Comparable` class

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Defining an ADT · Comparable ADT

Program: `Transaction.java`

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↪ Standard output: four transactions (one per line) in different orders

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```
>_ ~/workspace/dsa/programs
```

```
$ _
```

Defining an ADT · Comparable ADT

Program: `Transaction.java`

↪ Standard output: four transactions (one per line) in different orders

```
>_ ~/workspace/dsa/programs
```

```
$ java dsa.Transaction
```

Defining an ADT · Comparable ADT

Program: Transaction.java

↪ Standard output: four transactions (one per line) in different orders

```
>_ ~/workspace/dsa/programs
```

```
$ java dsa.Transaction
```

```
Unsorted:
```

| | | |
|----------|-----------|---------|
| Turing | 6/17/1990 | 644.08 |
| Tarjan | 3/26/2002 | 4121.85 |
| Knuth | 6/14/1999 | 288.34 |
| Dijkstra | 8/22/2007 | 2678.40 |

```
Sorted by name:
```

| | | |
|----------|-----------|---------|
| Dijkstra | 8/22/2007 | 2678.40 |
| Knuth | 6/14/1999 | 288.34 |
| Tarjan | 3/26/2002 | 4121.85 |
| Turing | 6/17/1990 | 644.08 |

```
Sorted by date:
```

| | | |
|----------|-----------|---------|
| Turing | 6/17/1990 | 644.08 |
| Knuth | 6/14/1999 | 288.34 |
| Tarjan | 3/26/2002 | 4121.85 |
| Dijkstra | 8/22/2007 | 2678.40 |

```
Sorted by amount:
```

| | | |
|----------|-----------|---------|
| Knuth | 6/14/1999 | 288.34 |
| Turing | 6/17/1990 | 644.08 |
| Dijkstra | 8/22/2007 | 2678.40 |
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```
$ _
```

Defining an ADT · Comparable ADT

Comparable ADT: `Comparable` interface and `Comparable` class

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Comparable ADT: `Comparable` interface and `Comparable` class

Defining an ADT · Comparable ADT

Transaction.java

```
1 package dsa;
2
3 import java.util.Arrays;
4 import java.util.Comparator;
5
6 import stdlib.StdOut;
7
8 public class Transaction implements Comparable<Transaction> {
9     private String name;
10    private Date date;
11    private double amount;
12
13    public Transaction(String name, Date date, double amount) {
14        this.name = name;
15        this.date = date;
16        this.amount = amount;
17    }
18
19    public Transaction(String s) {
20        String[] a = s.split("\\s+");
21        name = a[0];
22        date = new Date(a[1]);
23        amount = Double.parseDouble(a[2]);
24    }
25
26    public String name() {
27        return name;
28    }
29
30    public Date date() {
31        return date;
32    }
33
34    public double amount() {
35        return amount;
```

Defining an ADT · Comparable ADT

Transaction.java

```
36     }
37
38     public int hashCode() {
39         int hash = 1;
40         hash = 31 * hash + name.hashCode();
41         hash = 31 * hash + date.hashCode();
42         hash = 31 * hash + ((Double) amount).hashCode();
43         return hash;
44     }
45
46     public String toString() {
47         return String.format("%-10s %10s %8.2f", name, date, amount);
48     }
49
50     public int compareTo(Transaction other) {
51         return Double.compare(this.amount, other.amount);
52     }
53
54     public static Comparator<Transaction> nameOrder() {
55         return new NameOrder();
56     }
57
58     public static Comparator<Transaction> dateOrder() {
59         return new DateOrder();
60     }
61
62     public static Comparator<Transaction> amountOrder() {
63         return new AmountOrder();
64     }
65
66     private static class NameOrder implements Comparator<Transaction> {
67         public int compare(Transaction v, Transaction w) {
68             return v.name.compareTo(w.name);
69         }
70     }
```


Defining an ADT · Comparable ADT

Transaction.java

```
71 private static class DateOrder implements Comparator<Transaction> {
72     public int compare(Transaction v, Transaction w) {
73         return v.date.compareTo(w.date);
74     }
75 }
76
77
78 private static class AmountOrder implements Comparator<Transaction> {
79     public int compare(Transaction v, Transaction w) {
80         return Double.compare(v.amount, w.amount);
81     }
82 }
83
84 public static void main(String[] args) {
85     Transaction[] transactions = new Transaction[4];
86     transactions[0] = new Transaction("Turing 6/17/1990 644.08");
87     transactions[1] = new Transaction("Tarjan 3/26/2002 4121.85");
88     transactions[2] = new Transaction("Knuth 6/14/1999 288.34");
89     transactions[3] = new Transaction("Dijkstra 8/22/2007 2678.40");
90     StdOut.println("Unsorted:");
91     for (Transaction transaction : transactions) {
92         StdOut.println(transaction);
93     }
94     StdOut.println();
95     StdOut.println("Sorted by name:");
96     Arrays.sort(transactions, new NameOrder());
97     for (Transaction transaction : transactions) {
98         StdOut.println(transaction);
99     }
100     StdOut.println();
101     StdOut.println("Sorted by date:");
102     Arrays.sort(transactions, new DateOrder());
103     for (Transaction transaction : transactions) {
104         StdOut.println(transaction);
105     }
```

Defining an ADT · Comparable ADT

Transaction.java

```
106     StdOut.println();
107     StdOut.println("Sorted by amount:");
108     Arrays.sort(transactions, new AmountOrder());
109     for (Transaction transaction : transactions) {
110         StdOut.println(transaction);
111     }
112 }
113 }
```

Defining an ADT · Iteration Interfaces

Defining an ADT · Iteration Interfaces


 *java.lang.Iterable*

`Iterator<Type> iterator()` returns an iterator over a collection of items of type `Type`

Defining an ADT · Iteration Interfaces

 *java.lang.Iterable*

| | |
|--|--|
| <code>Iterator<Type> iterator()</code> | returns an iterator over a collection of items of type <code>Type</code> |
|--|--|

 *java.util.Iterator*

| | |
|--------------------------------|--|
| <code>boolean hasNext()</code> | returns <code>true</code> if the iterator has more items, and <code>false</code> otherwise |
|--------------------------------|--|

| | |
|--------------------------|---------------------------------------|
| <code>Type next()</code> | returns the next item in the iterator |
|--------------------------|---------------------------------------|

| | |
|----------------------------|---------------|
| <code>void remove()</code> | not supported |
|----------------------------|---------------|

Defining an ADT · Iterable ADT

```
def __iter__(self):
    """Return an iterator over the elements of the list"""
    return _ListIterator(self._data)

def __getitem__(self, index):
    """Return the element at the given index"""
    return self._data[index]

def __len__(self):
    """Return the number of elements in the list"""
    return len(self._data)

def __str__(self):
    """Return a string representation of the list"""
    return str(self._data)

def __repr__(self):
    """Return a string representation of the list"""
    return repr(self._data)
```

Defining an ADT · Iterable ADT

An `Iterable` object `o` can be iterated over using the for-each statement

```
1 for (Type item : o) {  
2     <statement>  
3     ...  
4 }
```

Defining an ADT · Iterable ADT

An `Iterable` object `o` can be iterated over using the for-each statement

```
1  for (Type item : o) {  
2      <statement>  
3      ...  
4  }
```

which is equivalent to

```
1  Iterator iter = o.iterator();  
2  while (iter.hasNext()) {  
3      Type item = iter.next();  
4      <statement>  
5      ...  
6  }
```


Defining an ADT · Iterable ADT

An `Iterable` object `o` can be iterated over using the for-each statement

```
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5      ...  
6  }
```

Arrays are iterable, and thus can be iterated using the for-each statement

Defining an ADT · Iterable ADT

An `Iterable` object `o` can be iterated over using the for-each statement

```
1 for (Type item : o) {  
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3     ...  
4 }
```

which is equivalent to

```
1 Iterator iter = o.iterator();  
2 while (iter.hasNext()) {  
3     Type item = iter.next();  
4     <statement>  
5     ...  
6 }
```

Arrays are iterable, and thus can be iterated using the for-each statement

Example

```
1 String[] dow = {"Sun", "Mon", "Tue", "Wed", "Thu", "Fri", "Sat"};  
2 for (String s : dow) {  
3     StdOut.println(s);  
4 }
```

Defining an ADT · Iterable ADT

Defining an ADT · Iterable ADT

✎ IterableADT.java

```
1 import java.util.Iterator;
2
3 public class IterableADT implements Iterable<Type> {
4     ...
5     public Iterator<Type> iterator() {
6         return new AnIterator();
7     }
8
9     private class AnIterator implements Iterator<Type> {
10         ...
11         public boolean hasNext() {
12             ...
13         }
14
15         public Type next() {
16             ...
17         }
18
19         public void remove() {
20             throw new UnsupportedOperationException();
21         }
22     }
23     ...
24 }
```

Defining an ADT · Iterable ADT

```
def __iter__(self):
    """Return an iterator over the elements of the list"""
    return _ListIterator(self._data)

def __getitem__(self, index):
    """Return the element at the given index"""
    return self._data[index]

def __len__(self):
    """Return the number of elements in the list"""
    return len(self._data)

def __str__(self):
    """Return a string representation of the list"""
    return str(self._data)

def __repr__(self):
    """Return a string representation of the list"""
    return repr(self._data)

def __eq__(self, other):
    """Return True if the list is equal to the other list"""
    return self._data == other._data

def __neq__(self, other):
    """Return True if the list is not equal to the other list"""
    return self._data != other._data

def __lt__(self, other):
    """Return True if the list is less than the other list"""
    return self._data < other._data

def __gt__(self, other):
    """Return True if the list is greater than the other list"""
    return self._data > other._data

def __le__(self, other):
    """Return True if the list is less than or equal to the other list"""
    return self._data <= other._data

def __ge__(self, other):
    """Return True if the list is greater than or equal to the other list"""
    return self._data >= other._data
```

Defining an ADT · Iterable ADT

Program: `Words.java`

Defining an ADT · Iterable ADT

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↪ Command-line input: *sentence* (String)

Defining an ADT · Iterable ADT

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↪ Standard output: the words in *sentence*, one per line

Defining an ADT · Iterable ADT

Program: `Words.java`

↪ Command-line input: *sentence* (String)

↪ Standard output: the words in *sentence*, one per line

```
>_ ~/workspace/dsa/programs
```

```
$ _
```

Defining an ADT · Iterable ADT

Program: `Words.java`

↪ Command-line input: *sentence* (String)

↪ Standard output: the words in *sentence*, one per line

```
> ~/workspace/dsa/programs
```

```
$ java Words "it was the best of times it was the worst of times"
```

Defining an ADT · Iterable ADT

Program: Words.java

↪ Command-line input: *sentence* (String)

↪ Standard output: the words in *sentence*, one per line

```
> ~/workspace/dsa/programs
```

```
$ java Words "it was the best of times it was the worst of times"
it
was
the
best
of
times
it
was
the
worst
of
times
$ _
```

Defining an ADT · Iterable ADT

```
def __iter__(self):
    """Return an iterator over the elements of the list"""
    return ListIterator(self)

class ListIterator:
    """Iterator over the elements of the list"""
    def __init__(self, list):
        self._list = list
        self._index = 0

    def __next__(self):
        """Return the next element in the list"""
        if self._index < len(self._list):
            element = self._list[self._index]
            self._index += 1
            return element
        else:
            raise StopIteration
```

Defining an ADT · Iterable ADT

Words.java

```
1  import java.util.Iterator;
2
3  import stdlib.Stdout;
4
5  public class Words implements Iterable<String> {
6      private String sentence;
7
8      public Words(String sentence) {
9          this.sentence = sentence;
10     }
11
12     public Iterator<String> iterator() {
13         return new WordsIterator();
14     }
15
16     private class WordsIterator implements Iterator<String> {
17         private String[] words;
18         private int i;
19
20         public WordsIterator() {
21             words = sentence.split("\\s+");
22             i = 0;
23         }
24
25         public boolean hasNext() {
26             return i < words.length;
27         }
28
29         public String next() {
30             return words[i++];
31         }
32
33         public void remove() {
34             throw new UnsupportedOperationException();
35         }
36     }
37 }
```

Defining an ADT · Iterable ADT

Words.java

```
36     }
37
38     public static void main(String[] args) {
39         String sentence = args[0];
40         Words words = new Words(sentence);
41         for (String word : words) {
42             StdOut.println(word);
43         }
44     }
45 }
```

Error Handling

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Errors (aka exceptions) are disruptive events that occur while a program is running

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Examples: `ArrayIndexOutOfBoundsException` and `NullPointerException`

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Throwing an exception

```
throw new <exception>(<message>);
```

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Errors (aka exceptions) are disruptive events that occur while a program is running

Examples: `ArrayIndexOutOfBoundsException` and `NullPointerException`

Throwing an exception

```
throw new <exception>(<message>);
```

Example

```
throw new IllegalArgumentException("x must be positive");
```

Error Handling

| | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | | |
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185 | 186 | 187 | 188 | 189 | 190 | 191 | 192 | 193 | 194 | 195 | 196 | 197 | 198 | 199 | 200 | 201 | 202 | 203 | 204 | 205 | 206 | 207 | 208 | 209 | 210 | 211 | 212 | 213 | 214 | 215 | 216 | 217 | 218 | 219 | 220 | 221 | 222 | 223 | 224 | 225 | 226 | 227 | 228 | 229 | 230 | 231 | 232 | 233 | 234 | 235 | 236 | 237 | 238 | 239 | 240 | 241 | 242 | 243 | 244 | 245 | 246 | 247 | 248 | 249 | 250 | 251 | 252 | 253 | 254 | 255 | 256 | 257 | 258 | 259 | 260 | 261 | 262 | 263 | 264 | 265 | 266 | 267 | 268 | 269 | 270 | 271 | 272 | 273 | 274 | 275 | 276 | 277 | 278 | 279 | 280 | 281 | 282 | 283 | 284 | 285 | 286 | 287 | 288 | 289 | 290 | 291 | 292 | 293 | 294 | 295 | 296 | 297 | 298 | 299 | 300 | 301 | 302 | 303 | 304 | 305 | 306 | 307 | 308 | 309 | 310 | 311 | 312 | 313 | 314 | 315 | 316 | 317 | 318 | 319 | 320 | 321 | 322 | 323 | 324 | 325 | 326 | 327 | 328 | 329 | 330 | 331 | 332 | 333 | 334 | 335 | 336 | 337 | 338 | 339 | 340 | 341 | 342 | 343 | 344 | 345 | 346 | 347 | 348 | 349 | 350 | 351 | 352 | 353 | 354 | 355 | 356 | 357 | 358 | 359 | 360 | 361 | 362 | 363 | 364 | 365 | 366 | 367 | 368 | 369 | 370 | 371 | 372 | 373 | 374 | 375 | 376 | 377 | 378 | 379 | 380 | 381 | 382 | 383 | 384 | 385 | 386 | 387 | 388 | 389 | 390 | 391 | 392 | 393 | 394 | 395 | 396 | 397 | 398 | 399 | 400 | 401 | 402 | 403 | 404 | 405 | 406 | 407 | 408 | 409 | 410 | 411 | 412 | 413 | 414 | 415 | 416 | 417 | 418 | 419 | 420 | 421 | 422 | 423 | 424 | 425 | 426 | 427 | 428 | 429 | 430 | 431 | 432 | 433 | 434 | 435 | 436 | 437 | 438 | 439 | 440 | 441 | 442 | 443 | 444 | 445 | 446 | 447 | 448 | 449 | 450 | 451 | 452 | 453 | 454 | 455 | 456 | 457 | 458 | 459 | 460 | 461 | 462 | 463 | 464 | 465 | 466 | 467 | 468 | 469 | 470 | 471 | 472 | 473 | 474 | 475 | 476 | 477 | 478 | 479 | 480 | 481 | 482 | 483 | 484 | 485 | 486 | 487 | 488 | 489 | 490 | 491 | 492 | 493 | 494 | 495 | 496 | 497 | 498 | 499 | 500 | 501 | 502 | 503 | 504 | 505 | 506 | 507 | 508 | 509 | 510 | 511 | 512 | 513 | 514 | 515 | 516 | 517 | 518 | 519 | 520 | 521 | 522 | 523 | 524 | 525 | 526 | 527 | 528 | 529 | 530 | 531 | 532 | 533 | 534 | 535 | 536 | 537 | 538 | 539 | 540 | 541 | 542 | 543 | 544 | 545 | 546 | 547 | 548 | 549 | 550 | 551 | 552 | 553 | 554 | 555 | 556 | 557 | 558 | 559 | 560 | 561 | 562 | 563 | 564 | 565 | 566 | 567 | 568 | 569 | 570 | 571 | 572 | 573 | 574 | 575 | 576 | 577 | 578 | 579 | 580 | 581 | 582 | 583 | 584 | 585 | 586 | 587 | 588 | 589 | 590 | 591 | 592 | 593 | 594 | 595 | 596 | 597 | 598 | 599 | 600 | 601 | 602 | 603 | 604 | 605 | 606 | 607 | 608 | 609 | 610 | 611 | 612 | 613 | 614 | 615 | 616 | 617 | 618 | 619 | 620 | 621 | 622 | 623 | 624 | 625 | 626 | 627 | 628 | 629 | 630 | 631 | 632 | 633 | 634 | 635 | 636 | 637 | 638 | 639 | 640 | 641 | 642 | 643 | 644 | 645 | 646 | 647 | 648 | 649 | 650 | 651 | 652 | 653 | 654 | 655 | 656 | 657 | 658 | 659 | 660 | 661 | 662 | 663 | 664 | 665 | 666 | 667 | 668 | 669 | 670 | 671 | 672 | 673 | 674 | 675 | 676 | 677 | 678 | 679 | 680 | 681 | 682 | 683 | 684 | 685 | 686 | 687 | 688 | 689 | 690 | 691 | 692 | 693 | 694 | 695 | 696 | 697 | 698 | 699 | 700 | 701 | 702 | 703 | 704 | 705 | 706 | 707 | 708 | 709 | 710 | 711 | 712 | 713 | 714 | 715 | 716 | 717 | 718 | 719 | 720 | 721 | 722 | 723 | 724 | 725 | 726 | 727 | 728 | 729 | 730 | 731 | 732 | 733 | 734 | 735 | 736 | 737 | 738 | 739 | 740 | 741 | 742 | 743 | 744 | 745 | 746 | 747 | 748 | 749 | 750 | 751 | 752 | 753 | 754 | 755 | 756 | 757 | 758 | 759 | 760 | 761 | 762 | 763 | 764 | 765 | 766 | 767 | 768 | 769 | 770 | 771 | 772 | 773 | 774 | 775 | 776 | 777 | 778 | 779 | 780 | 781 | 782 | 783 | 784 | 785 | 786 | 787 | 788 | 789 | 790 | 791 | 792 | 793 | 794 | 795 | 796 | 797 | 798 | 799 | 800 | 801 | 802 | 803 | 804 | 805 | 806 | 807 | 808 | 809 | 810 | 811 | 812 | 813 | 814 | 815 | 816 | 817 | 818 | 819 | 820 | 821 | 822 | 823 | 824 | 825 | 826 | 827 | 828 | 829 | 830 | 831 | 832 | 833 | 834 | 835 | 836 | 837 | 838 | 839 | 840 | 841 | 842 | 843 | 844 | 845 | 846 | 847 | 848 | 849 | 850 | 851 | 852 | 853 | 854 | 855 | 856 | 857 | 858 | 859 | 860 | 861 | 862 | 863 | 864 | 865 | 866 | 867 | 868 | 869 | 870 | 871 | 872 | 873 | 874 | 875 | 876 | 877 | 878 | 879 | 880 | 881 | 882 | 883 | 884 | 885 | 886 | 887 | 888 | 889 | 890 | 891 | 892 | 893 | 894 | 895 | 896 | 897 | 898 | 899 | 900 | 901 | 902 | 903 | 904 | 905 | 906 | 907 | 908 | 909 | 910 | 911 | 912 | 913 | 914 | 915 | 916 | 917 | 918 | 919 | 920 | 921 | 922 | 923 | 924 | 925 | 926 | 927 | 928 | 929 | 930 | 931 | 932 | 933 | 934 | 935 | 936 | 937 | 938 | 939 | 940 | 941 | 942 | 943 | 944 | 945 | 946 | 947 | 948 | 949 | 950 | 951 | 952 | 953 | 954 | 955 | 956 | 957 | 958 | 959 | 960 | 961 | 962 | 963 | 964 | 965 | 966 | 967 | 968 | 969 | 970 | 971 | 972 | 973 | 974 | 975 | 976 | 977 | 978 | 979 | 980 | 981 | 982 | 983 | 984 | 985 | 986 | 987 | 988 | 989 | 990 | 991 | 992 | 993 | 994 | 995 | 996 | 997 | 998 | 999 | 1000 | 1001 | 1002 | 1003 | 1004 | 1005 | 1006 | 1007 | 1008 | 1009 | 1010 | 1011 | 1012 | 1013 | 1014 | 1015 | 1016 | 1017 | 1018 | 1019 | 1020 | 1021 | 1022 | 1023 | 1024 | 1025 | 1026 | 1027 | 1028 | 1029 | 1030 | 1031 | 1032 | 1033 | 1034 | 1035 | 1036 | 1037 | 1038 | 1039 | 1040 | 1041 | 1042 | 1043 | 1044 | 1045 | 1046 | 1047 | 1048 | 1049 | 1050 | 1051 | 1052 | 1053 | 1054 | 1055 | 1056 | 1057 | 1058 | 1059 | 1060 | 1061 | 1062 | 1063 | 1064 | 1065 | 1066 | 1067 | 1068 | 1069 | 1070 | 1071 | 1072 | 1073 | 1074 | 1075 | 1076 | 1077 | 1078 | 1079 | 1080 | 1081 | 1082 | 1083 | 1084 | 1085 | 1086 | 1087 | 1088 | 1089 | 1090 | 1091 | 1092 | 1093 | 1094 | 1095 | 1096 | 1097 | 1098 | 1099 | 1100 | 1101 | 1102 | 1103 | 1104 | 1105 | 1106 | 1107 | 1108 | 1109 | 1110 | 1111 | 1112 | 1113 | 1114 | 1115 | 1116 | 1117 | 1118 | 1119 | 1120 | 1121 | 1122 | 1123 | 1124 | 1125 | 1126 | 1127 | 1128 | 1129 | 1130 | 1131 | 1132 | 1133 | 1134 | 1135 | 1136 | 1137 | 1138 | 1139 | 1140 | 1141 | 1142 | 1143 | 1144 | 1145 | 1146 | 1147 | 1148 | 1149 | 1150 | 1151 | 1152 | 1153 | 1154 | 1155 | 1156 | 1157 | 1158 | 1159 | 1160 | 1161 | 1162 | 1163 | 1164 | 1165 | 1166 | 1167 | 1168 | 1169 | 1170 | 1171 | 1172 | 1173 | 1174 | 1175 | 1176 | 1177 | 1178 | 1179 | 1180 | 1181 | 1182 | 1183 | 1184 | 1185 | 1186 | 1187 | 1188 | 1189 | 1190 | 1191 | 1192 | 1193 | 1194 | 1195 | 1196 | 1197 | 1198 | 1199 | 1200 | 1201 | 1202 | 1203 | 1204 | 1205 | 1206 | 1207 | 1208 | 1209 | 1210 | 1211 | 1212 | 1213 | 1214 | 1215 | 1216 | 1217 | 1218 | 1219 | 1220 | 1221 | 1222 | 1223 | 1224 | 1225 | 1226 | 1227 | 1228 | 1229 | 1230 | 1231 | 1232 | 1233 | 1234 | 1235 | 1236 | 1237 | 1238 | 1239 | 1240 | 1241 | 1242 | 1243 | 1244 | 1245 | 1246 | 1247 | 1248 | 1249 | 1250 | 1251 | 1252 | 1253 | 1254 | 1255 | 1256 | 1257 | 1258 | 1259 | 1260 | 1261 | 1262 | 1263 | 1264 | 1265 | 1266 | 1267 | 1268 | 1269 | 1270 | 1271 | 1272 | 1273 | 1274 | 1275 | 1276 | 1277 | 1278 | 1279 | 1280 | 1281 | 1282 | 1283 | 1284 | 1285 | 1286 | 1287 | 1288 | 1289 | 1290 | 1291 | 1292 | 1293 | 1294 | 1295 | 1296 | 1297 | 1298 | 1299 | 1300 | 1301 | 1302 | 1303 | 1304 | 1305 | 1306 | 1307 | 1308 | 1309 | 1310 | 1311 | 1312 | 1313 | 1314 | 1315 | 1316 | 1317 | 1318 | 1319 | 1320 | 1321 | 1322 | 1323 | 1324 | 1325 | 1326 | 1327 | 1328 | 1329 | 1330 | 1331 | 1332 | 1333 | 1334 | 1335 | 1336 | 1337 | 1338 | 1339 | 1340 | 1341 | 1342 | 1343 | 1344 | 1345 | 1346 | 1347 | 1348 | 1349 | 1350 | 1351 | 1352 | 1353 | 1354 | 1355 | 1356 | 1357 | 1358 | 1359 | 1360 | 1361 | 1362 | 1363 | 1364 | 1365 | 1366 | 1367 | 1368 | 1369 | 1370 | 1371 | 1372 | 1373 | 1374 | 1375 | 1376 | 1377 | 1378 | 1379 | 1380 | 1381 | 1382 | 1383 | 1384 | 1385 | 1386 | 1387 | 1388 | 1389 | 1390 | 1391 | 1392 | 1393 | 1394 | 1395 | 1396 | 1397 | 1398 | 1399 | 1400 | 1401 | 1402 | 1403 | 1404 | 1405 | 1406 | 1407 | 1408 | 1409 | 1410 | 1411 | 1412 | 1413 | 1414 | 1415 | 1416 | 1417 | 1418 | 1419 | 1420 | 1421 | 1422 | 1423 | 1424 | 1425 | 1426 | 1427 | 1428 | 1429 | 1430 | 1431 | 1432 | 1433 | 1434 | 1435 | 1436 | 1437 | 1438 | 1439 | 1440 | 1441 | 1442 | 1443 | 1444 | 1445 | 1446 | 1447 | 1448 | 1449 | 1450 | 1451 | 1452 | 1453 | 1454 | 1455 | 1456 | 1457 | 1458 | 1459 | 1460 | 1461 | 1462 | 1463 | 1464 | 1465 | 1466 | 1467 | 1468 | 1469 | 1470 | 1471 | 1472 | 1473 | 1474 | 1475 | 1476 | 1477 | 1478 | 1479 | 1480 | 1481 | 1482 | 1483 | 1484 | 1485 | 1486 | 1487 | 1488 | 1489 | 1490 | 1491 | 1492 |
|---|---|---|---|---|---|---|---|---|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-----|-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Error Handling

Catching an exception

```
1  try {  
2      <statement>  
3      ...  
4  }  
5  catch (<exception> e) {  
6      <statement>  
7      ...  
8  }  
9  catch (<exception> e) {  
10     <statement>  
11     ...  
12 }  
13 ...  
14 finally {  
15     <statement>  
16     ...  
17 }  
18 <statement>  
19 ...
```

Error Handling

Error Handling

Program: `ErrorHandling.java`

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ _
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ _
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ java ErrorHandling two
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ java ErrorHandling two
x must be a double
Done!
$ _
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ java ErrorHandling two
x must be a double
Done!
$ java ErrorHandling -2
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ java ErrorHandling two
x must be a double
Done!
$ java ErrorHandling -2
x must be positive
Done!
$ -
```


Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ java ErrorHandling two
x must be a double
Done!
$ java ErrorHandling -2
x must be positive
Done!
$ java ErrorHandling 2
```

Error Handling

Program: `ErrorHandling.java`

↪ Command-line input: x (double)

↪ Standard output: the square root of x

```
>_ ~/workspace/dsa/programs
```

```
$ java ErrorHandling
x not specified
Done!
$ java ErrorHandling two
x must be a double
Done!
$ java ErrorHandling -2
x must be positive
Done!
$ java ErrorHandling 2
1.4142135623730951
Done!
$ -
```

Error Handling

Error Handling

ErrorHandling.java

```
1 import stdlib.Stdout;
2
3 public class ErrorHandling {
4     public static void main(String[] args) {
5         try {
6             double x = Double.parseDouble(args[0]);
7             double result = sqrt(x);
8             StdOut.println(result);
9         } catch (ArrayIndexOutOfBoundsException e) {
10             StdOut.println("x not specified");
11         } catch (NumberFormatException e) {
12             StdOut.println("x must be a double");
13         } catch (IllegalArgumentException e) {
14             StdOut.println(e.getMessage());
15         } finally {
16             StdOut.println("Done!");
17         }
18     }
19
20     private static double sqrt(double x) {
21         if (x < 0) {
22             throw new IllegalArgumentException("x must be positive");
23         }
24         return Math.sqrt(x);
25     }
26 }
```