Data Abstraction

Outline

Abstract Data Type (ADT)

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Example

☰ `dsa.Counter implements java.lang.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 `true` if this counter and `other` have the same tally, and `false` otherwise
`String toString()`	returns a string representation of this counter
`int compareTo(Counter other)`	returns a comparison of this counter with `other` by their tally

Abstract Data Type (ADT)

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Salient features of an ADT:

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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

Using an ADT

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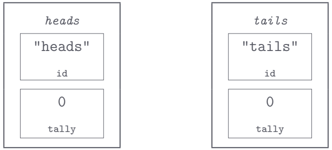
Example

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



Using an ADT

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

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Example

```
for (int i = 0; i < 100; i++) {
    if (StdRandom.bernoulli(0.5)) {
        heads.increment();
    } else {
        tails.increment();
    }
}
```

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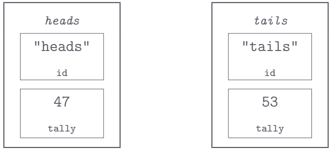
A method, invoked as `[<object>.]<name>(<argument1>, <argument2>, ...)`, operates on data-type values

Example

```
for (int i = 0; i < 100; i++) {
    if (StdRandom.bernoulli(0.5)) {
        heads.increment();
    } else {
        tails.increment();
    }
}
```

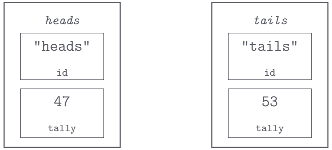


Using an ADT

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

Example

```
for (int i = 0; i < 100; i++) {
    if (StdRandom.bernoulli(0.5)) {
        heads.increment();
    } else {
        tails.increment();
    }
}
```



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StdOut.println(heads.tally());
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```

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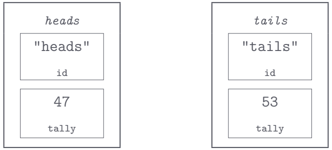
Example

```
for (int i = 0; i < 100; i++) {
    if (StdRandom.bernoulli(0.5)) {
        heads.increment();
    } else {
        tails.increment();
    }
}
```



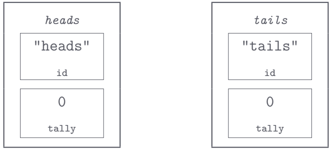
```
StdOut.println(heads.tally());
StdOut.println(tails.tally());
```

```
47
53
```

Using an ADT

Using an ADT

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



Using an ADT

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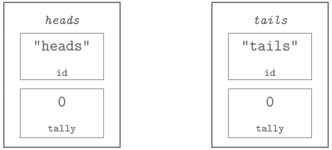
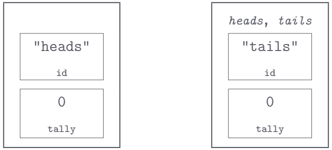


Aliasing

```
heads = tails;
```



Using an ADT

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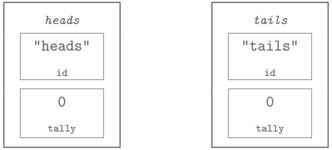

Aliasing

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heads = tails;
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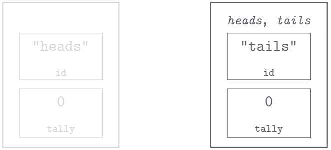

Using an ADT

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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

```
String x = "Hello, World";
String y = "Hello, World";
String z = "Cogito, ergo sum";
StdOut.println("x == x? " + (x == x));
StdOut.println("x == y? " + (x == y));
StdOut.println("x == z? " + (x == z));
StdOut.println("x.equals(x)? " + x.equals(x));
StdOut.println("x.equals(y)? " + x.equals(y));
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`

Example

```
String x = "Hello, World";
String y = "Hello, World";
String z = "Cogito, ergo sum";
StdOut.println("x == x? " + (x == x));
StdOut.println("x == y? " + (x == y));
StdOut.println("x == z? " + (x == z));
StdOut.println("x.equals(x)? " + x.equals(x));
StdOut.println("x.equals(y)? " + x.equals(y));
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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```
>_ ~/workspace/dsaj/programs

$ _
```

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/dsaj/programs

$ 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/dsaj/programs

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

Using an ADT

Using an ADT

Flips.java

```java
import dsa.Counter;
import stdlib.StdOut;
import stdlib.StdRandom;

public class Flips {
    public static void main(String[] args) {
        int n = Integer.parseInt(args[0]);
        Counter heads = new Counter("Heads");
        Counter tails = new Counter("Tails");
        for (int i = 0; i < n; i++) {
            if (StdRandom.bernoulli(0.5)) {
                heads.increment();
            } else {
                tails.increment();
            }
        }
        StdOut.println(heads);
        StdOut.println(tails);
        StdOut.println("delta: " + Math.abs(heads.tally() - tails.tally()));
    }
}
```

Using an ADT

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Program: `FlipsMax.java`

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>_ ~/workspace/dsaj/programs

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Program: `FlipsMax.java`

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```
>_ ~/workspace/dsaj/programs

$ java FlipsMax 1000000
500371 Heads wins
$ _
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Program: `FlipsMax.java`

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```
>_ ~/workspace/dsaj/programs

$ java FlipsMax 1000000
500371 Heads wins
$ java FlipsMax 1000000
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Using an ADT

Program: `FlipsMax.java`

- Command-line input: n (int)
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```
>_ ~/workspace/dsaj/programs

$ java FlipsMax 1000000
500371 Heads wins
$ java FlipsMax 1000000
500776 Tails wins
$ _
```

Using an ADT

Program: `FlipsMax.java`

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```
>_ ~/workspace/dsaj/programs

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

Using an ADT

Program: `FlipsMax.java`

- Command-line input: *n* (int)
- Standard output: the winner from *n* coin flips

```
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$ java FlipsMax 1000000
500371 Heads wins
$ java FlipsMax 1000000
500776 Tails wins
$ java FlipsMax 1000000
500995 Tails wins
$ _
```

Using an ADT

Using an ADT

FlipsMax.java

```java
import dsa.Counter;
import stdlib.StdOut;
import stdlib.StdRandom;

public class FlipsMax {
    public static void main(String[] args) {
        int n = Integer.parseInt(args[0]);
        Counter heads = new Counter("Heads");
        Counter tails = new Counter("Tails");
        for (int i = 0; i < n; i++) {
            if (StdRandom.bernoulli(0.5)) {
                heads.increment();
            } else {
                tails.increment();
            }
        }
        if (heads.equals(tails)) {
            StdOut.println("Tie");
        } else {
            StdOut.println(max(heads, tails) + " wins");
        }
    }

    private static Counter max(Counter x, Counter y) {
        if (x.tally() > y.tally()) {
            return x;
        }
        return y;
    }
}
```

Using an ADT

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Program: `Rolls.java`

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- Command-line input: n (int)

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Program: `Rolls.java`

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```
>_ ~/workspace/dsaj/programs

$ java Rolls 1000000
```

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Program: `Rolls.java`

- Command-line input: *n* (int)
- Standard output: frequencies of face values from rolling *n* 6-sided dice

```
>_ ~/workspace/dsaj/programs

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

Using an ADT

Using an ADT

Rolls.java

```java
import dsa.Counter;
import stdlib.StdOut;
import stdlib.StdRandom;

public class Rolls {
    public static void main(String[] args) {
        int n = Integer.parseInt(args[0]);
        int SIDES = 6;
        Counter[] rolls = new Counter[SIDES + 1];
        for (int i = 1; i <= SIDES; i++) {
            rolls[i] = new Counter(i + "s");
        }
        for (int j = 0; j < n; j++) {
            int result = StdRandom.uniform(1, SIDES + 1);
            rolls[result].increment();
        }
        for (int i = 1; i <= SIDES; i++) {
            StdOut.println(rolls[i]);
        }
    }
}
```

Examples of ADTs

Examples of ADTs

stdlib.In	
`In(String name)`	constructs an input stream from a file with the given name
`boolean isEmpty()`	returns `true` if this input stream is empty, and `false` otherwise
`double readDouble()`	reads and returns the next double from this input stream

Examples of ADTs

stdlib.In	
`In(String name)`	constructs an input stream from a file with the given name
`boolean isEmpty()`	returns `true` if this input stream is empty, and `false` otherwise
`double readDouble()`	reads and returns the next double from this input stream

stdlib.Out	
`Out(String name)`	constructs an output stream from a file with the given name
`void println(Object x)`	prints an object and a newline to this output stream
`void print(Object x)`	prints an object to this output stream
`void printf(String fmt, Object... args)`	prints `args` to this output stream using format string `fmt`

Examples of ADTs

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`java.lang.String`	
`String()`	creates an empty string
`int length()`	returns the length of the string
`char charAt(int i)`	returns the character in the string at index `i`
`String substring(int i, int j)`	returns a substring of the string from index `i` (inclusive) to index `j` (exclusive)

Examples of ADTs

java.lang.String

`String()`	creates an empty string
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`char charAt(int i)`	returns the character in the string at index `i`
`String substring(int i, int j)`	returns a substring of the string from index `i` (inclusive) to index `j` (exclusive)

Example

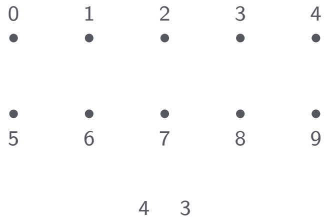
```java
public static boolean isPalindrome(String s) {
    int n = s.length();
    if (n < 2) {
        return true;
    }
    return s.charAt(0) == s.charAt(n - 1) && isPalindrome(s.substring(1, n - 1));
}
```

Examples of ADTs

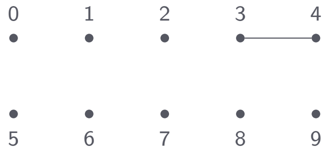
Examples of ADTs

0
1
2
3
4
5
6
7
8
9

Examples of ADTs

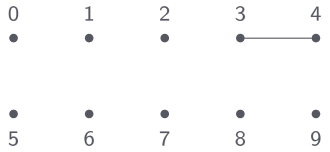


Examples of ADTs



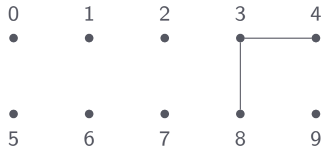
4 3

Examples of ADTs



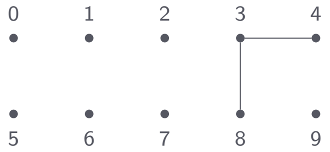
3 8

Examples of ADTs



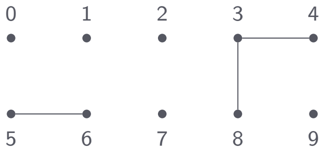
3 8

Examples of ADTs



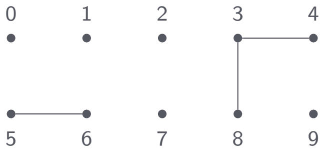
6 5

Examples of ADTs



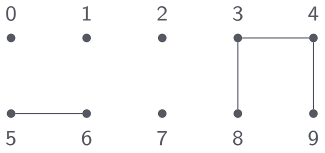
6 5

Examples of ADTs



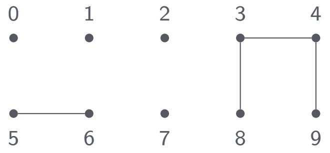
9 4

Examples of ADTs



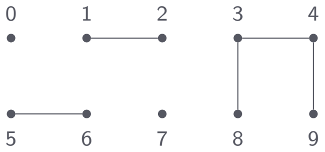
9 4

Examples of ADTs



2 1

Examples of ADTs



2 1

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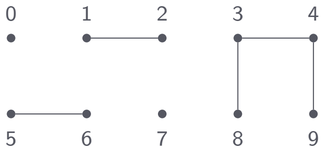
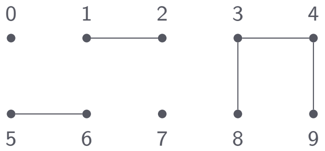


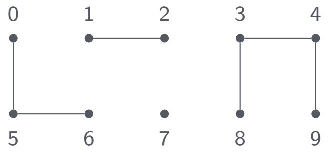
8 9

Examples of ADTs



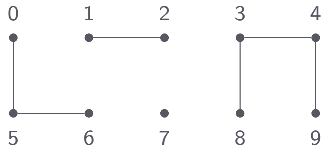
5 0

Examples of ADTs



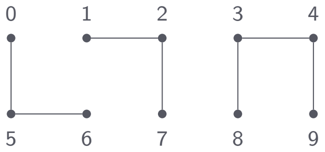
5 0

Examples of ADTs



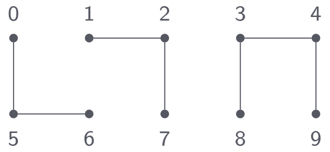
7 2

Examples of ADTs



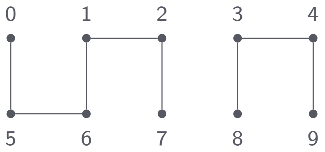
7 2

Examples of ADTs



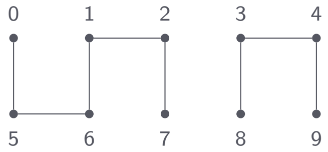
6 1

Examples of ADTs



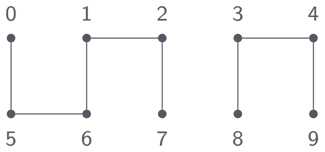
6 1

Examples of ADTs



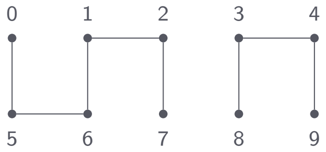
1 0

Examples of ADTs



6 7

Examples of ADTs



Examples of ADTs

Examples of ADTs

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

Examples of ADTs

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Program: `Components.java`

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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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Program: `Components.java`

- Standard input: *n* (int) and a sequence of pairs of integers representing sites
- Standard output: number of components left after merging the sites that are in different components

```
>_ ~/workspace/dsaj/programs

$ _
```

Examples of ADTs

Program: `Components.java`

- Standard input: n (int) and a sequence of pairs of integers representing sites
- Standard output: number of components left after merging the sites that are in different components

```
>_ ~/workspace/dsaj/programs

$ cat ../data/tinyUF.txt
```

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```
>_ ~/workspace/dsaj/programs

$ cat ../data/tinyUF.txt
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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- Standard output: number of components left after merging the sites that are in different components

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>_ ~/workspace/dsaj/programs

$ cat ../data/tinyUF.txt
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3 8
6 5
9 4
2 1
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7 2
6 1
1 0
6 7
$ java Components < ../data/tinyUF.txt
```

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

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>_ ~/workspace/dsaj/programs

$ cat ../data/tinyUF.txt
10
4 3
3 8
6 5
9 4
2 1
8 9
5 0
7 2
6 1
1 0
6 7
$ java Components < ../data/tinyUF.txt
2 components
$ _
```

Examples of ADTs

Examples of ADTs

Components.java

```java
import dsa.WeightedQuickUnionUF;
import stdlib.StdIn;
import stdlib.StdOut;

public class Components {
    public static void main(String[] args) {
        int n = StdIn.readInt();
        WeightedQuickUnionUF uf = new WeightedQuickUnionUF(n);
        while (!StdIn.isEmpty()) {
            int p = StdIn.readInt();
            int q = StdIn.readInt();
            uf.union(p, q);
        }
        StdOut.println(uf.count() + " components");
    }
}
```

Defining an ADT

Defining an ADT

Program.java

```
[package dsa;]

// Import statements.
...

// Class definition.
public class Program [implements <name>] {
    // Field declarations.
    ...

    // Constructor definitions.
    ...

    // Method definitions.
    ...

    // Function definitions.
    ...

    // Inner class definitions.
    ...
}
```

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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Defining an ADT

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Example:

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

Defining an ADT

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private|public [static] <type> <name>;
```

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

Example:

- Instance fields `String id` and `int count` in `Counter`
- Static field `double PI` in `Math`

Defining an ADT

Defining an ADT

Constructor definition

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

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

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Example (`Counter.java`)

```
    public Counter(String id) {
        this.id = id;
        count = 0;
    }
```

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

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```
    public Counter(String id) {
        this.id = id;
        count = 0;
    }
```

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

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

Defining an ADT

Defining an ADT

Method definition

```
private|public void|<type> <name>(<parameter1>, <parameter2>, ...) {
    <statement>
    ...
}
```

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Method definition

```
private|public void|<type> <name>(<parameter1>, <parameter2>, ...) {
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    ...
}
```

Example (`Counter.java`)

```
    public void increment() {
        count++;
    }

    public int tally() {
        return count;
    }
```

Defining an ADT

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```
private|public void|<type> <name>(<parameter1>, <parameter2>, ...) {
    <statement>
    ...
}
```

Example (`Counter.java`)

```
    public void increment() {
        count++;
    }

    public int tally() {
        return count;
    }
```

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

Defining an ADT

Defining an ADT

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

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Example

```
public interface Animal {
    public String sound();
}
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```java
public interface Animal {
    public String sound();
}
```

```java
public class Elephant implements Animal {
    public String sound() {
        return "trumpet";
    }
}
```

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Example

```
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```

```
public class Elephant implements Animal {
    public String sound() {
        return "trumpet";
    }
}
```

```
public class Tiger implements Animal {
    public String sound() {
        return "roar";
    }
}
```

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        return "trumpet";
    }
}
```

```
public class Tiger implements Animal {
    public String sound() {
        return "roar";
    }
}
```

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

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Example

```
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}
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}
```

```
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    public String sound() {
        return "roar";
    }
}
```

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

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

Defining an ADT

Defining an ADT

Comparison interfaces

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

Defining an ADT

ComparableADT.java

```java
import java.util.Comparator;

public class ComparableADT implements Comparable<ComparableADT> {
    ...
    // Natural ordering.
    public int compareTo(ComparableADT other) {
        ...
    }

    public static Comparator<ComparableADT> aOrder() {
        return new AOrder();
    }

    public static Comparator<ComparableADT> bOrder() {
        return new BOrder();
    }

    // Alternate ordering 1.
    private static class AOrder implements Comparator<ComparableADT> {
        ...
        public int compare(ComparableADT v, ComparableADT w) {
            ...
        }
    }

    // Alternate ordering 2.
    private static class BOrder implements Comparator<ComparableADT> {
        ...
        public int compare(ComparableADT v, ComparableADT w) {
            ...
        }
    }
    ...
}
```

Defining an ADT

Defining an ADT

dsa.Counter implements java.lang.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 `true` if this counter and `other` have the same tally, and `false` otherwise
`String toString()`	returns a string representation of this counter
`int compareTo(Counter other)`	returns a comparison of this counter with `other` by their tally

Defining an ADT

Defining an ADT

Program: `Counter.java`

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

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

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```
>_ ~/workspace/dsaj/programs

$ _
```

Defining an 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/dsaj/programs

$ java dsa.Counter 2 1000
```

Defining an 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/dsaj/programs
```

```
$ java dsa.Counter 2 1000
501 counter 0
499 counter 1
$ _
```

Defining an ADT

Defining an ADT

Counter.java

```java
package dsa;

import stdlib.StdOut;
import stdlib.StdRandom;

public class Counter implements Comparable<Counter> {
    private String id;
    private int count;

    public Counter(String id) {
        this.id = id;
        count = 0;
    }

    public void increment() {
        count++;
    }

    public int tally() {
        return count;
    }

    public void reset() {
        count = 0;
    }

    public boolean equals(Object other) {
        if (other == null) {
            return false;
        }
        if (other == this) {
            return true;
        }
        if (other.getClass() != this.getClass()) {
            return false;
```

Defining an ADT

Counter.java

```
        }
        Counter a = this, b = (Counter) other;
        return a.count == b.count;
    }

    public String toString() {
        return count + " " + id;
    }

    public int compareTo(Counter other) {
        return this.count - other.count;
    }

    public static void main(String[] args) {
        int n = Integer.parseInt(args[0]);
        int trials = Integer.parseInt(args[1]);
        Counter[] hits = new Counter[n];
        for (int i = 0; i < n; i++) {
            hits[i] = new Counter("counter " + i);
        }
        for (int t = 0; t < trials; t++) {
            hits[StdRandom.uniform(n)].increment();
        }
        for (int i = 0; i < n; i++) {
            StdOut.println(hits[i]);
        }
    }
}
```

Defining an ADT

Defining an ADT

dsa.Transaction implements java.lang.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

Defining an ADT

Defining an ADT

Program: `Transaction.java`

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

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```
>_ ~/workspace/dsaj/programs

$ _
```

Defining an ADT

Program: `Transaction.java`

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

```
>_ ~/workspace/dsaj/programs

$ java dsa.Transaction
```

Defining an ADT

Program: `Transaction.java`

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

```
>_ ~/workspace/dsaj/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
Tarjan      3/26/2002  4121.85
$ _
```

Defining an ADT

Defining an ADT

Transaction.java

```
package dsa;

import java.util.Arrays;
import java.util.Comparator;

import stdlib.StdOut;

public class Transaction implements Comparable<Transaction> {
    private String name;
    private Date date;
    private double amount;

    public Transaction(String name, Date date, double amount) {
        this.name = name;
        this.date = date;
        this.amount = amount;
    }

    public Transaction(String s) {
        String[] a = s.split("\s+");
        name = a[0];
        date = new Date(a[1]);
        amount = Double.parseDouble(a[2]);
    }

    public String name() {
        return name;
    }

    public Date date() {
        return date;
    }

    public double amount() {
        return amount;
```

Defining an ADT

Transaction.java

```
    }

    public int hashCode() {
        int hash = 1;
        hash = 31 * hash + name.hashCode();
        hash = 31 * hash + date.hashCode();
        hash = 31 * hash + ((Double) amount).hashCode();
        return hash;
    }

    public String toString() {
        return String.format("%-10s %10s %8.2f", name, date, amount);
    }

    public int compareTo(Transaction other) {
        return Double.compare(this.amount, other.amount);
    }

    public static Comparator<Transaction> nameOrder() {
        return new NameOrder();
    }

    public static Comparator<Transaction> dateOrder() {
        return new DateOrder();
    }

    private static class NameOrder implements Comparator<Transaction> {
        public int compare(Transaction v, Transaction w) {
            return v.name.compareTo(w.name);
        }
    }

    private static class DateOrder implements Comparator<Transaction> {
        public int compare(Transaction v, Transaction w) {
            return v.date.compareTo(w.date);
```

Defining an ADT

Transaction.java

```
        }
    }

    public static void main(String[] args) {
        Transaction[] transactions = new Transaction[4];
        transactions[0] = new Transaction("Turing   6/17/1990  644.08");
        transactions[1] = new Transaction("Tarjan   3/26/2002 4121.85");
        transactions[2] = new Transaction("Knuth    6/14/1999  288.34");
        transactions[3] = new Transaction("Dijkstra 8/22/2007 2678.40");
        StdOut.println("Unsorted:");
        for (int i = 0; i < transactions.length; i++) {
            StdOut.println(transactions[i]);
        }
        StdOut.println();
        StdOut.println("Sorted by name:");
        Arrays.sort(transactions, Transaction.nameOrder());
        for (int i = 0; i < transactions.length; i++) {
            StdOut.println(transactions[i]);
        }
        StdOut.println();
        StdOut.println("Sorted by date:");
        Arrays.sort(transactions, Transaction.dateOrder());
        for (int i = 0; i < transactions.length; i++) {
            StdOut.println(transactions[i]);
        }
        StdOut.println();
        StdOut.println("Sorted by amount:");
        Arrays.sort(transactions);
        for (int i = 0; i < transactions.length; i++) {
            StdOut.println(transactions[i]);
        }
    }
}
```

Defining an ADT

Defining an ADT

Iteration interfaces

java.lang.Iterable

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

java.util.Iterator

`boolean hasNext()`	returns `true` if the iterator has more items, and `false` otherwise
`Type next()`	returns the next item in the iterator

Defining an ADT

Defining an ADT

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

```
for (Type item : o) {
    <statement>
    ...
}
```

which is equivalent to

```
Iterator iter = o.iterator();
while (iter.hasNext()) {
    Type item = iter.next();
    <statement>
    ...
}
```

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

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    <statement>
    ...
}
```

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

Example

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

Defining an ADT

Defining an ADT

IterableADT.java

```java
import java.util.Iterator;

public class IterableADT implements Iterable<Type> {
    ...
    public Iterator<Type> iterator() {
        return new AnIterator();
    }

    private class AnIterator implements Iterator<Type> {
        ...
        public boolean hasNext() {
            ...
        }

        public Type next() {
            ...
        }
    }
    ...
}
```

Defining an ADT

Defining an ADT

Program: `Words.java`

Defining an ADT

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

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- Command-line input: *sentence* (String)
- Standard output: the words in *sentence*, one per line

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```
>_ ~/workspace/dsaj/programs

$ _
```

Defining an ADT

Program: `Words.java`

- Command-line input: *sentence* (String)
- Standard output: the words in *sentence*, one per line

```
>_ ~/workspace/dsaj/programs

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

Defining an ADT

Program: `Words.java`

- Command-line input: *sentence* (String)
- Standard output: the words in *sentence*, one per line

```
>_ ~/workspace/dsaj/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

Defining an ADT

Words.java

```java
import java.util.Iterator;

import stdlib.StdOut;

public class Words implements Iterable<String> {
    private String sentence;

    public Words(String sentence) {
        this.sentence = sentence;
    }

    public Iterator<String> iterator() {
        return new WordsIterator();
    }

    private class WordsIterator implements Iterator<String> {
        private String[] words;
        private int i;

        public WordsIterator() {
            words = sentence.split("\s+");
            i = 0;
        }

        public boolean hasNext() {
            return i < words.length;
        }

        public String next() {
            return words[i++];
        }
    }

    public static void main(String[] args) {
        String sentence = args[0];
```

Defining an ADT

Words.java

```
        Words words = new Words(sentence);
        for (String word : words) {
            StdOut.println(word);
        }
    }
}
```

Error Handling

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

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Example: `ArrayIndexOutOfBoundsException` and `NullPointerException`

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Throwing an exception

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

Error Handling

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

Example: `ArrayIndexOutOfBoundsException` and `NullPointerException`

Throwing an exception

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

Example

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

Error Handling

Error Handling

Catching an exception

```
try {
    <statement>
    ...
}
catch (<exception> e) {
    <statement>
    ...
}
catch (<exception> e) {
    <statement>
    ...
}
...
finally {
    <statement>
    ...
}
...
```

Error Handling

Error Handling

Program: `ErrorHandling.java`

Error Handling

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- Command-line input: x (double)

Error Handling

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- 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/dsaj/programs

$ _
```

Error Handling

Program: `ErrorHandling.java`

- Command-line input: x (double)
- Standard output: the square root of x

```
>_ ~/workspace/dsaj/programs

$ java ErrorHandling
```

Error Handling

Program: `ErrorHandling.java`

- Command-line input: x (double)
- Standard output: the square root of x

```
>_ ~/workspace/dsaj/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/dsaj/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/dsaj/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/dsaj/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/dsaj/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

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Done!
$ java ErrorHandling two
x must be a double
Done!
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x must be positive
Done!
$ java ErrorHandling 2
1.4142135623730951
Done!
$ _
```

Error Handling

Error Handling

ErrorHandling.java

```java
import stdlib.StdOut;

public class ErrorHandling {
    public static void main(String[] args) {
        try {
            double x = Double.parseDouble(args[0]);
            double result = sqrt(x);
            StdOut.println(result);
        } catch (ArrayIndexOutOfBoundsException e) {
            StdOut.println("x not specified");
        } catch (NumberFormatException e) {
            StdOut.println("x must be a double");
        } catch (IllegalArgumentException e) {
            StdOut.println(e.getMessage());
        } finally {
            StdOut.println("Done!");
        }
    }

    private static double sqrt(double x) {
        if (x < 0) {
            throw new IllegalArgumentException("x must be positve");
        }
        return Math.sqrt(x);
    }
}
```