Objects Analysis Threads Design

15-214

toad

Spring 2012

School of Computer Science

institute for SOFTWARE RESEARCH

Principles of Software Construction: Objects, Design, and Concurrency

Objects (continued)

Jonathan Aldrich Charlie Garrod

Announcements

- Homework 0 is out
  - Due Tuesday at 11:59pm
- Moving between sections
  - If you have a conflict, it's best to change sections officially in the course registration system
  - If all non-conflicting sections are full, you may attend others, but priority goes to those who are registered
    - **Others please wait to take a seat until the section begins**
- Waitlists
  - There is room in section A. Room in other sections may open up.
  - If you cannot attend section A, email us. We will give you access to SVN so you can do the first assignment
  - No extra late days for waitlisted students! Show you care about the class by doing the work.

Key object concepts

- **Inside an object**
  - **Kinds of members: Fields, Methods, Constructors**
  - **Visibility from the outside: hiding the members**
  - **The keyword *this***
- Interfaces and the management of expectations
  - Java interfaces
  - Introduction to types
- Objects and the heap
  - Method dispatch
- Objects and identity
  - Equals vs. ==
- Class
  - Defining the object template
  - Diagrams can show relationships among classes
  - A class can have its own *static* fields and methods
- Objects and mutability
  - Abstract mutability and implementation mutability

Review: Points and Rectangles

```
class Point {
    int x, y;
    int getX() { return x; } // a method; getY() is similar
    Point(int px, int py) { x = px; y = py; }  // constructor for creating the object
}
class Rectangle {
    Point origin;
    int width, height;
    Point getOrigin() { return origin; }
    int getWidth() { return width; }
    void draw() {
            drawLine(origin.getX(), origin.getY(),        // first line
                    origin.getX()+width, origin.getY());
            … // more lines here
    }
    Rectangle(Point o, int w, int h) {
            origin = o; width = w; height = h;
    }
}
```

Example: Points and Rectangles

```
class Point {
    int x, y;
    int getX() { return x; } // a method; getY() is similar
    Point(int px, int py) { x = px; y = py; }  // constructor for creating the object
}
class Rectangle {
    Point origin;
    int width, height;
    Point getOrigin() { return origin; }
    int getWidth() { return width; }
    void draw() {



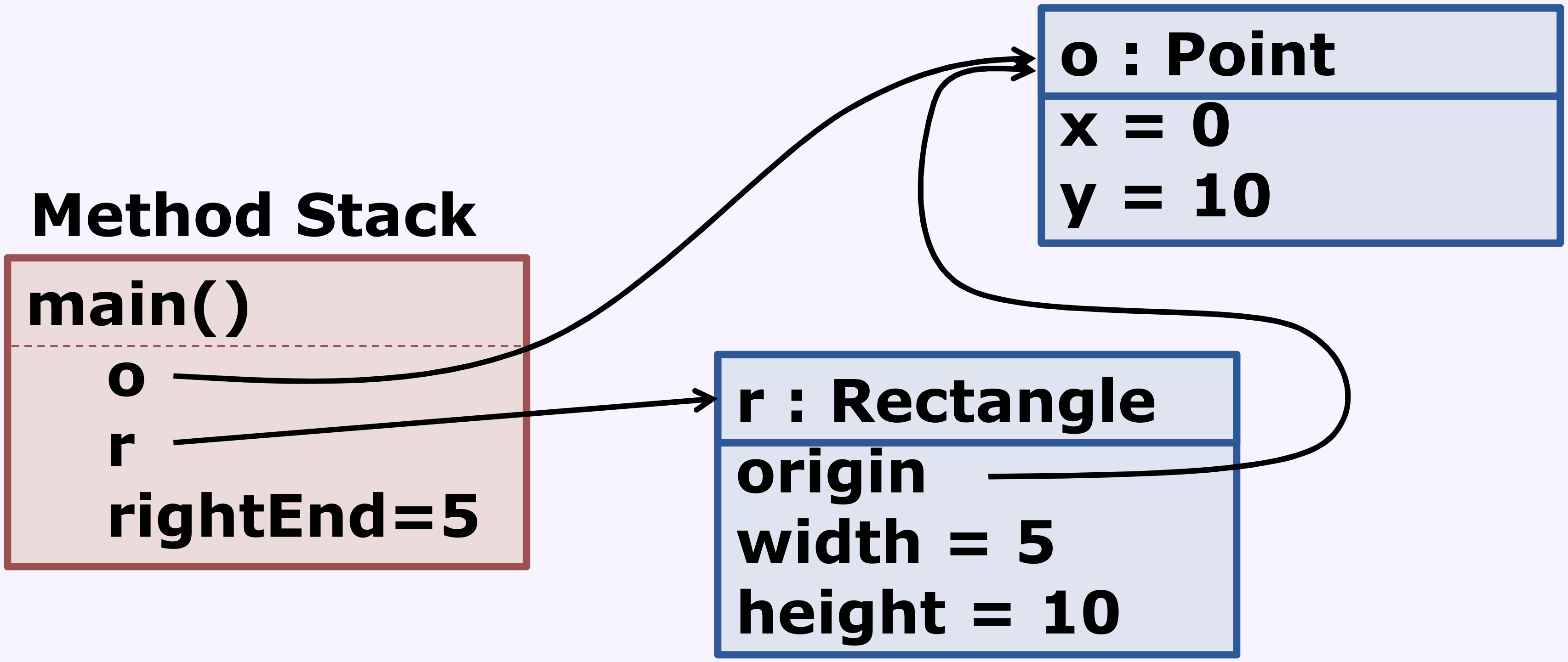
    }
    R

    }
}
```

Some Client Code

```
Point o = new Point(0, 10); // allocates memory, calls ctor
Rectangle r = new Rectangle(o, 5, 10);
r.draw();
int rightEnd = r.getOrigin().getX() + r.getWidth(); // 5
```

What's really going on?



Some Client Code

```
Point o = new Point(0, 10); // allocates memory, calls ctor
Rectangle r = new Rectangle(o, 5, 10);
r.draw();
int rightEnd = r.getOrigin().getX() + r.getWidth(); // 5
```

Anatomy of a Method Call

r.setX(5)

The **receiver**, an implicit argument, called **this** inside the method

The method **name**. Identifies which method to use, of all the methods the receiver's class defines

Method **arguments**, just like function arguments

The keyword **this** refers to the “receiver”

```
class Point {
   int x, y;
   int getX() { return x; }
   Point(int px, int py) { x = px; y = py; }
}
```

can also be written in this way:

```
class Point {
   int x, y;
   int getX() { return this.x; }
   Point(int x, int y) { this.x = x; this.y = y; }
}
```

Controlling access by client code

```
class Point {
    private int x, y;
    public int getX() { return x; } // a method; getY() is similar
    public Point(int px, int py) { x = px; y = py; }  // constructor for creating the object
}
class Rectangle {
    private Point origin;
    private int width, height;
    public Point getOrigin() { return origin; }
    public int getWidth() { return width; }
    public void draw() {
            drawLine(origin.getX(), origin.getY(),         // first line
                    origin.getX()+width, origin.getY());
            … // more lines here
    }
    public Rectangle(Point o, int w, int h) {
            origin = o; width = w; height = h;
    }
}
```

Hiding interior state

```
class Point
    private i
    public in
    public Po
}
class Recta
    private P
    private int width, height;
    public Point getOrigin() { return origin; }
    public in
    public v
            c

            .
    }
    public R
            c
    }
}
```

Some Client Code

```
Point o = new Point(0, 10); // allocates memory, calls ctor
Rectangle r = new Rectangle(o, 5, 10);
r.draw();
int rightEnd = r.getOrigin().getX() + r.getWidth(); // 5
```

Client Code that will *not* work in this version

```
Point o = new Point(0, 10); // allocates memory, calls ctor
Rectangle r = new Rectangle(o, 5, 10);
r.draw();
int rightEnd = r.origin.x + r.width; //  trying to "look inside"
```

Hiding interior state

```
class Point
    private i
    public in
    public Po
}
class Recta
    private
    private int width, height;
    public Point getOrigin() { return origin; }
    public int getWidth() { return width; }
    public void draw() {
            drawLine(origin.getX(), origin.getY(),        // first line
                    origin.getX()+width, origin.getY());
            … // more lines here
    }
    public Rectangle(Point o, int w, int h) {
            origin = o; width = w; height = h;
    }
}
```

Discussion:

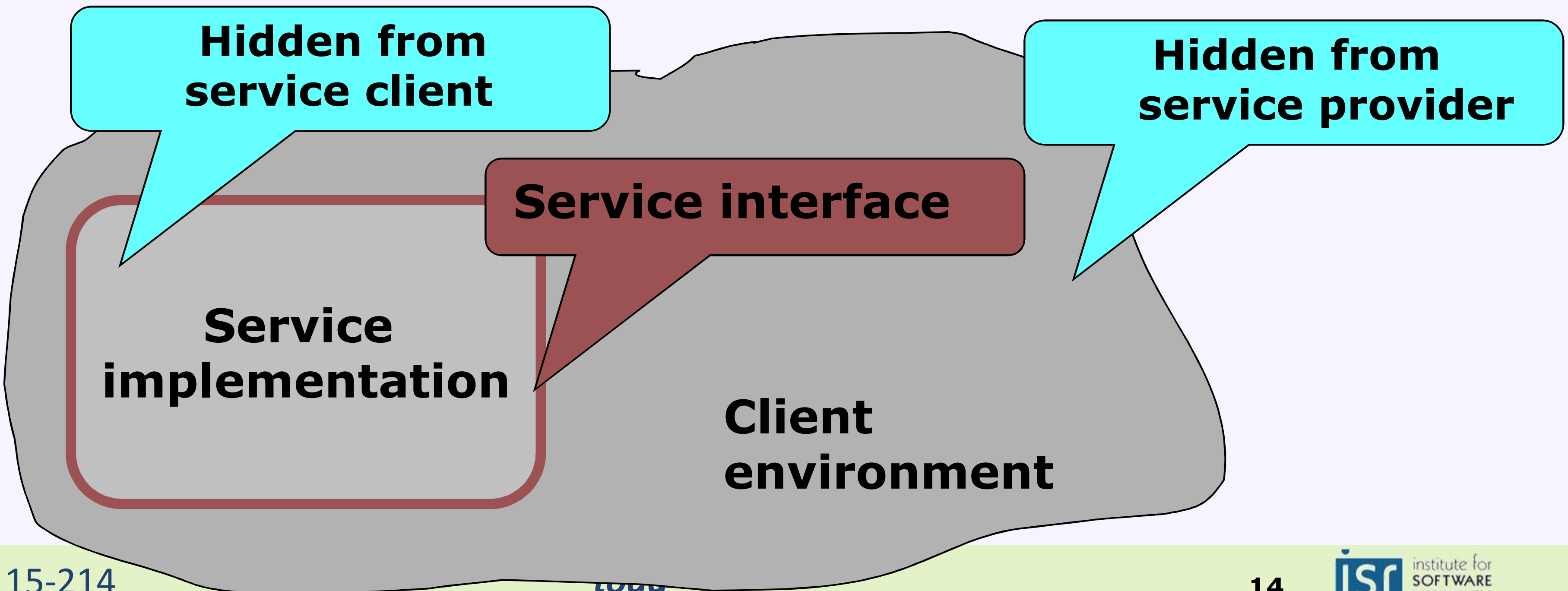
- ***What are the benefits of* private *fields?***
- ***Methods can also be private – why is this useful?***

Key object concepts

- Inside an object
  - Kinds of members: Fields, Methods, Constructors
  - Visibility from the outside: hiding the members
  - The keyword *this*
- **Interfaces and the management of expectations**
  - **Java interfaces**
  - **Introduction to types**
- Objects and the heap
  - Method Dispatch
- Objects and identity
  - Equals vs. ==
- Class
  - Defining the object template
  - Diagrams can show relationships among classes
  - A class can have its own *static* fields and methods
- Objects and mutability
  - Abstract mutability and implementation mutability

Contracts and Clients

- Contract of service provider and client
  - Interface specification
  - Functionality and correctness expectations
  - Performance expectations
  - Hiding of respective implementation details



Java **interfaces** and **classes**

Object-orientation

1. Organize program functionality around kinds of abstract "objects"
   - For each object kind, offer a specific set of operations on the objects
   - Objects are otherwise opaque
     - Details of representation are hidden
   - "Messages to the receiving object"
2. Distinguish *interface* from *class*
   - **Interface**: expectations
   - **Class**: delivery on expectations (the implementation)
3. Explicitly represent the taxonomy of object types
   - This is the "inheritance hierarchy"
     - A **square** is a **shape**

Functional Lists of Integers

- Some operations we **expect** to see:
  - **create** a new list
    - empty, or by adding an integer to an existing list
  - return the **size** of the list
  - **get** the *i*th integer in the list
  - **concatenate** two lists into a new list
- Key questions
  - How to **implement** the lists?
    - Many options
      - Arrays, linked lists, etc
    - How to hide the details of this choice from client code?
      - Why do this?
  - How to state **expectations**?
    - A variable **v** can reference a list of integers

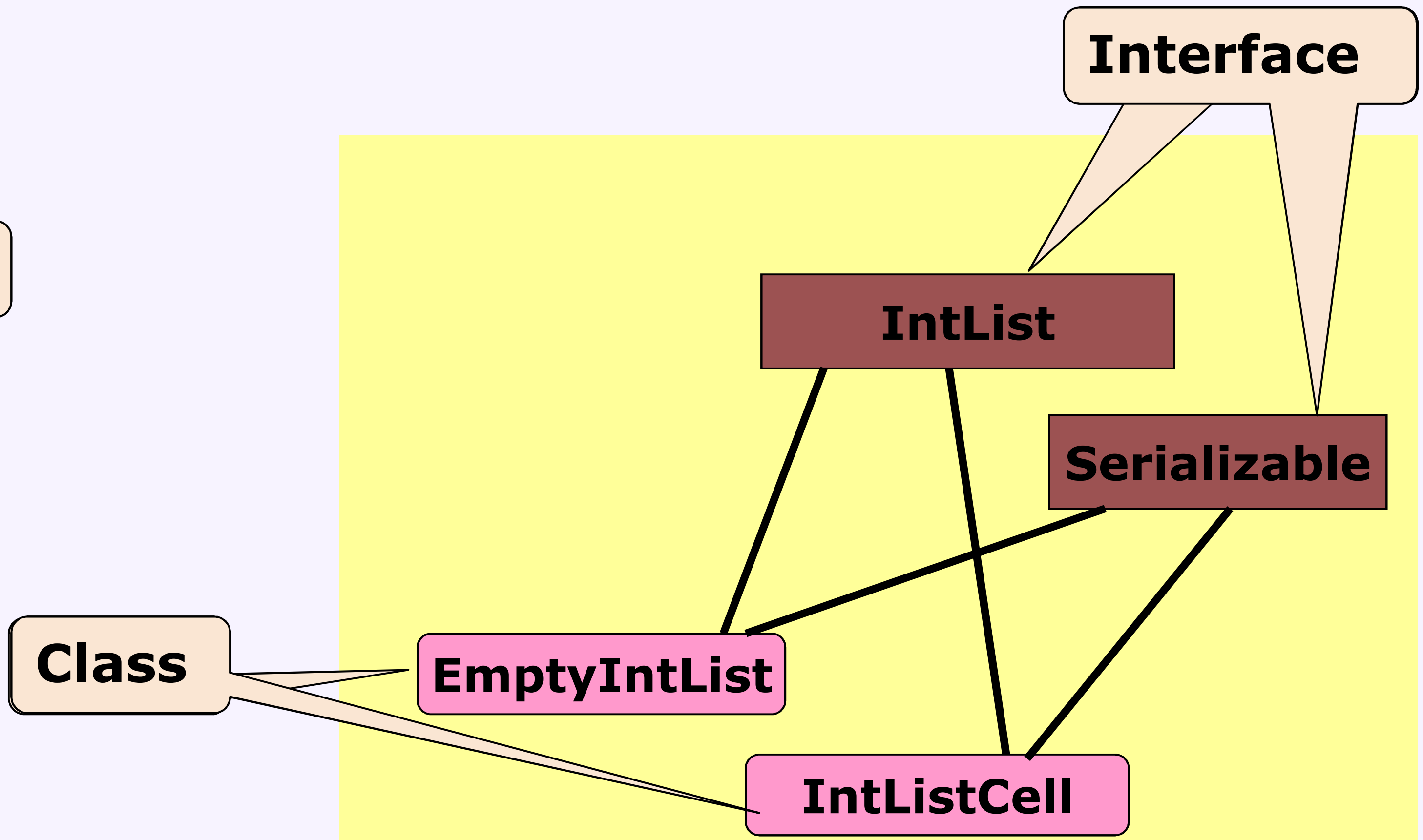
Interfaces, Types, Classes

- Two ways to put a new empty list into a variable

```
IntList         l = new EmptyIntList();
EmptyIntList al = new EmptyIntList();
```

Class

Type



Interfaces – stating **expectations**

- The IntList interface

```
public interface IntList {
    int size();
    int get(int n);
    IntList concatenate(IntList otherList);
    String toString();
}
```

- The declaration for **v** ensures that any object referenced by v will have implementations of the methods **size**, **get**, **concatenate**, and **toString**

```
Intlist v = …
```

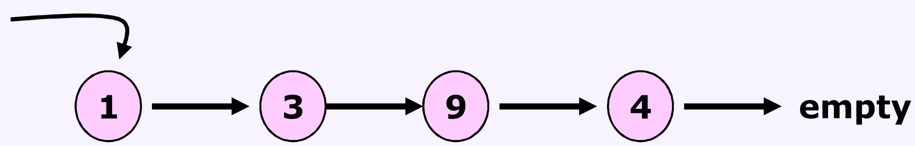
```
int len = v.size();
int third = v.get(2);
System.out.println (v.toString());
```

Implementing lists

- Two options (among many):
  - Arrays

1	3	7	5	11	13	6	42

  - Linked lists



• Operations:	**Array**	**List**
▪ **create** a new **empty** list	const	const
▪ return the **size** of the list	const	linear
▪ return the *i*th integer in the list	*?*	*?*
▪ **create** a list by adding to the **front**	*?*	*?*
▪ concatenate two lists into a new list	*?*	*?*

Implementation of interfaces

- Classes can *implement* one or more interfaces.

public class IntListCell implements IntList, Cloneable {…}

- **Semantics**
  - **Must provide code** for all methods in the interface(s)
- **Best practices**
  - Define an interface whenever there may be **multiple implementations** of a concept
  - Variables should have **interface type**, not class type

```
int addList(ArrayList list) { …  // no!
int addList(List list) { …       // yes!
```

An inductive definition

- *The size of a list L is*
  - *0* *if L is the empty list*
  - *1 + size of the tail of L* *otherwise*

Implementing Size

```
public class EmptyIntList implements IntList {
      public int size() {
            return 0; }
   . . .
}
```

Base case

```
public class IntListCell implements IntList {
      public int size() {
            return 1 + next.size(); }
   . . .
}
```

Inductive case

List Representation (BROKEN!)

```
public class EmptyIntList implements IntList {
   public int size() {
      return 0;
   }
   . . .
}
```

Base case

```
public class IntListCell implements IntList {
   private int value;
   private IntListCell next;

   public int size() {
      return 1 + next.size();
   }
   . . .
}
```

Type is wrong! May be a cell or an empty list!

Inductive case

List Representation (FIXED!)

```
public class EmptyIntList implements IntList {
   public int size() {
      return 0;
   }
   . . .
}
```

Base case

```
public class IntListCell implements IntList {
   private int value;
   private IntList next;

   public int size() {
      return 1 + next.size();
   }
   . . .
}
```

Interface type provides needed flexibility.

Inductive case

List Constructors

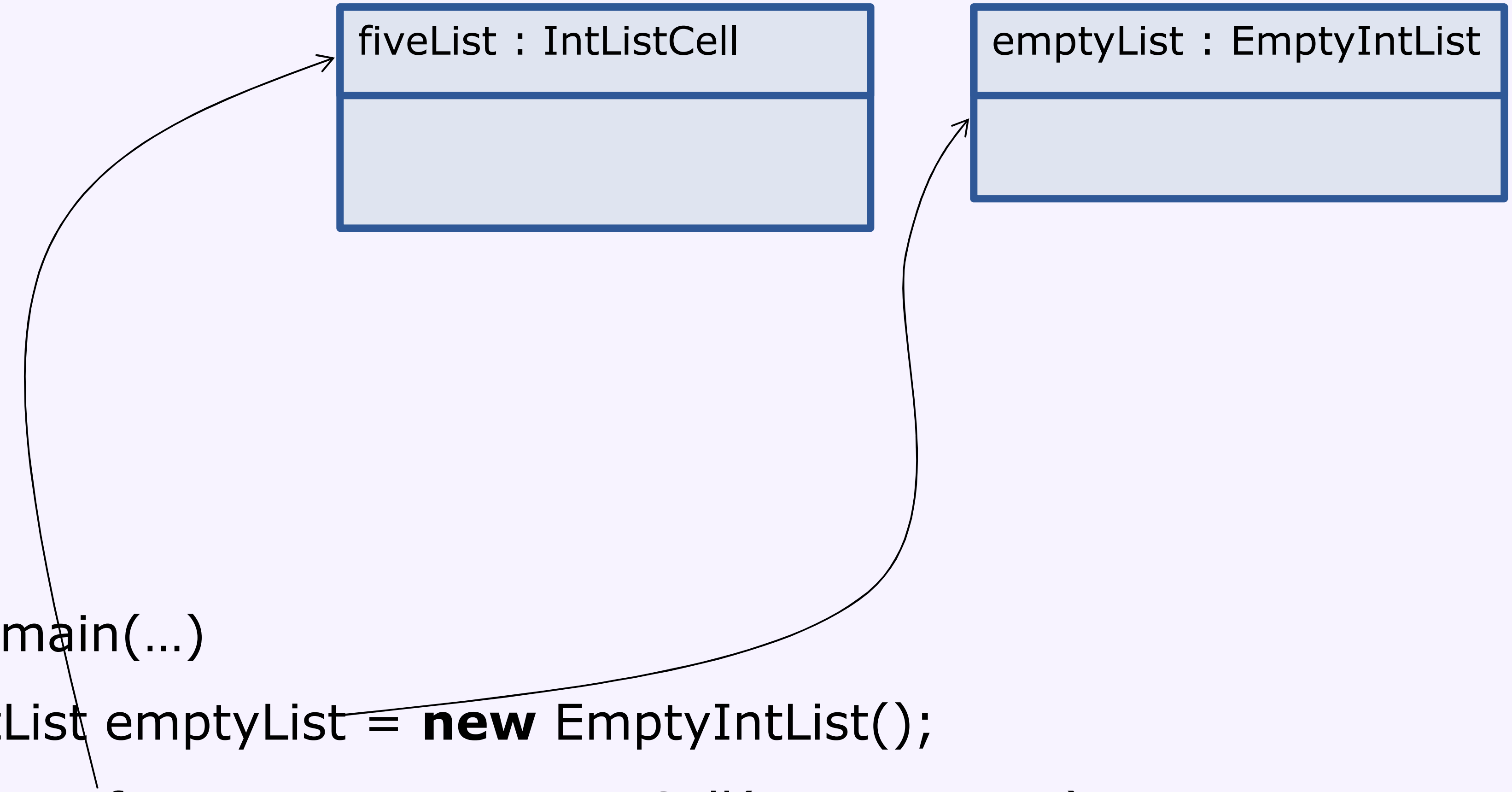
```
public class EmptyIntList implements IntList {
   public EmptyIntList() {
      // nothing to initialize
   }
   . . .
}

public class IntListCell implements IntList {
   public IntListCell(int val, IntList next) {
      this.value = val;
      this.next = next;
   }

   private int value;
   private IntList next;
   . . .
}
```

Java gives us this **default constructor** for free if we don't define any constructors.

Some Client Code

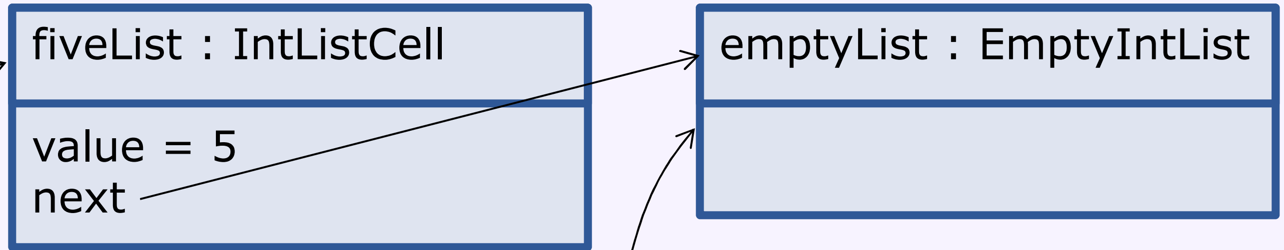


In main(…)

IntList emptyList = **new** EmptyIntList();

IntList fiveList = **new** IntListCell(5, emptyList);

Some Client Code




```
public IntListCell(int value, IntList next) {
      // value is 5, next is emptyList
      this.value = value; // this is fiveList
      this.next = next;
   }
```

In main(...)

IntList emptyList = **new** EmptyIntList();

IntList fiveList = **new** IntListCell(5, emptyList);

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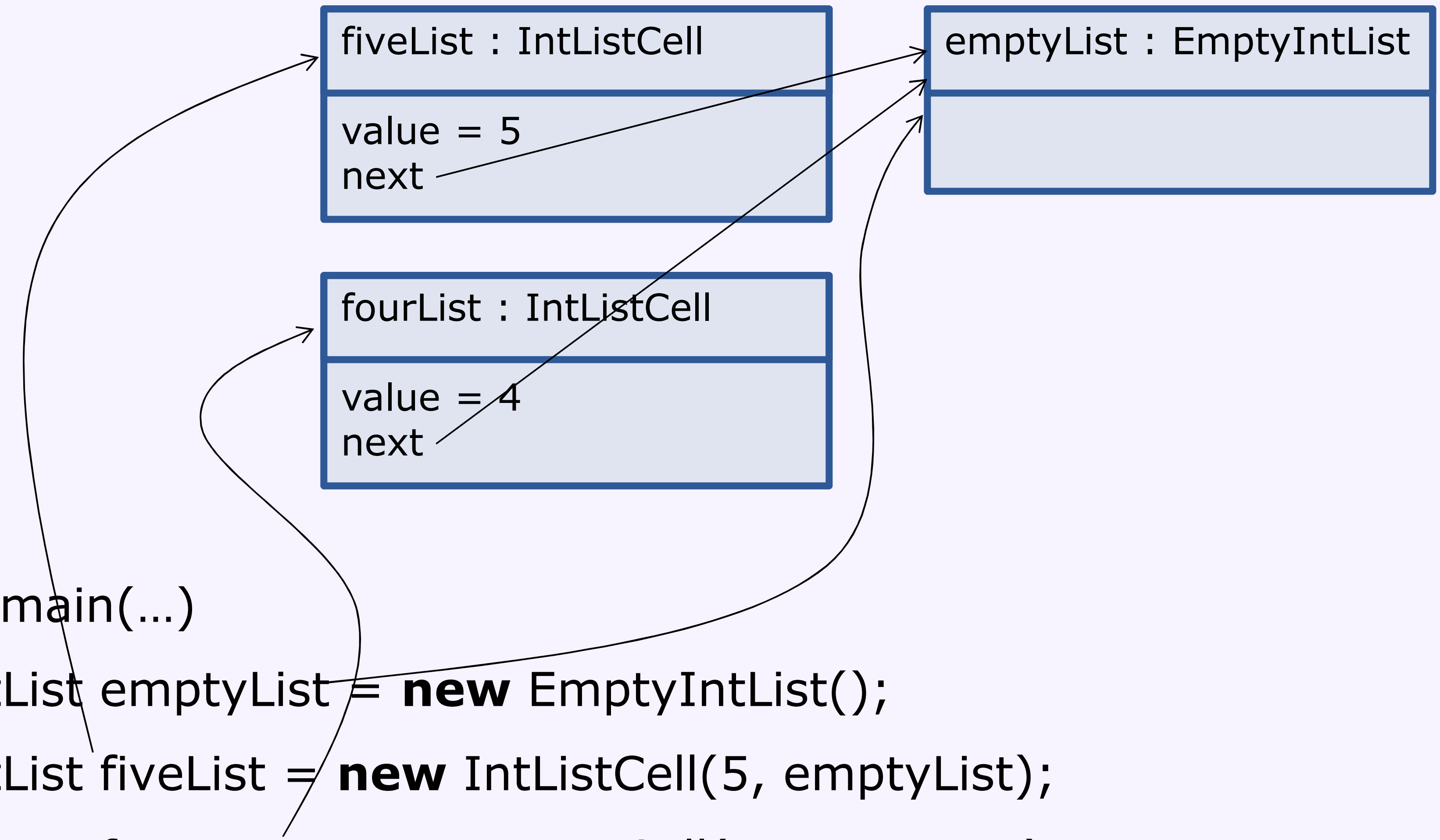


In main(…)

```
IntList emptyList = new EmptyIntList();
IntList fiveList = new IntListCell(5, emptyList);
IntList fourList = new IntListCell(4, emptyList);
IntList fourFive = fourList.concatenate(fiveList); // what happens?
```

Implementing Concatenate

```
public class EmptyIntList implements IntList {
      public IntList concatenate(IntList other) {
            return other; }
   . . .
}
```

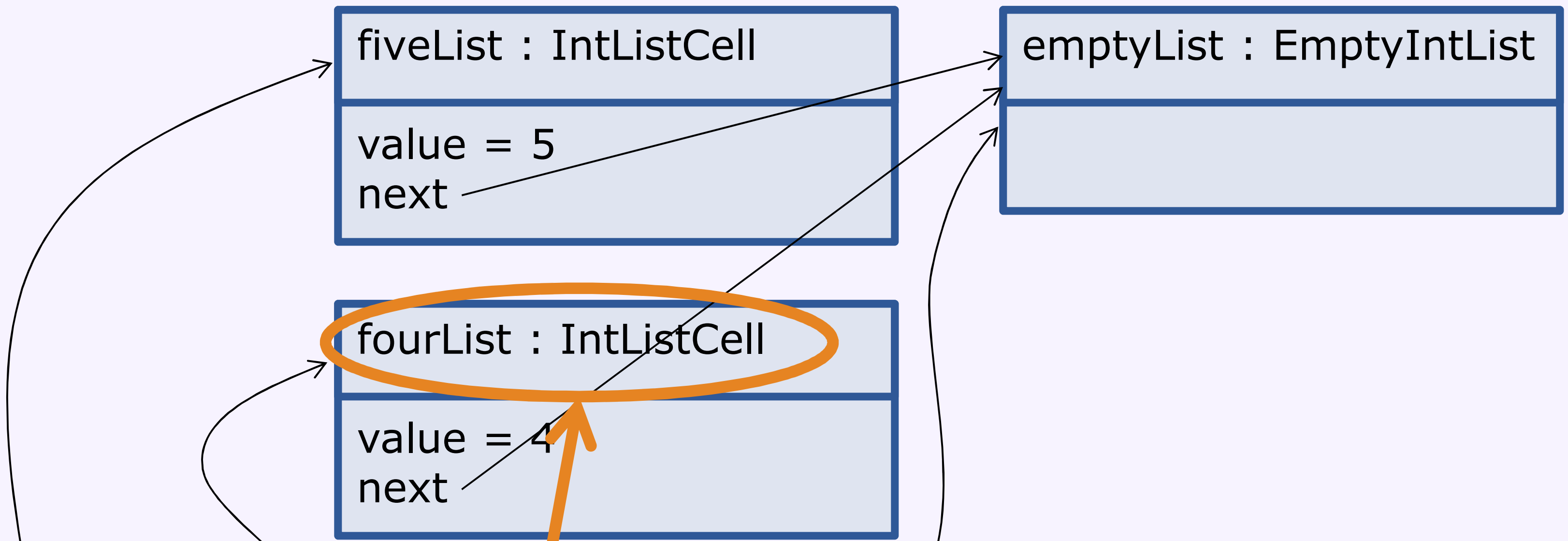
Base case

```
public class IntListCell implements IntList {
      public IntList concatenate(IntList other) {
            IntList newNext = next.concatenate(other);
            return new IntListCell(value, newNext); }
   . . .
}
```

Inductive case

Two concatenate methods – which do we use?

Some Client Code



In main(…)

```
IntList emptyList = new EmptyIntList();
IntList fiveList = new IntListCell(5, emptyList);
IntList fourList = new IntListCell(4, emptyList);
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```

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  - Visibility from the outside: hiding the members
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- Interfaces and the management of expectations
  - Java interfaces
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- **Objects and the heap**
  - **Method dispatch**
- Objects and identity
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Method dispatch (simplified)

Example:

```
IntList fourList = new IntListCell(4, emptyList);
IntList fourFive = fourList.concatenate(fiveList);
```

- Step 1 (compile time): determine what type to look in
  - Look at the static type (IntList) of the receiver (fourList)
- Step 2 (compile time): find the method in the class
  - Find the method in the class with the right name
    - Later: there may be more than one such method

      IntList concatenate(IntList otherList);

  - Keep the method only if it is *accessible*
    - e.g. remove private methods
  - Error if there is no such method

Method dispatch (simplified)

Example:

List fourList = **new** IntListCell(4, emptyList);

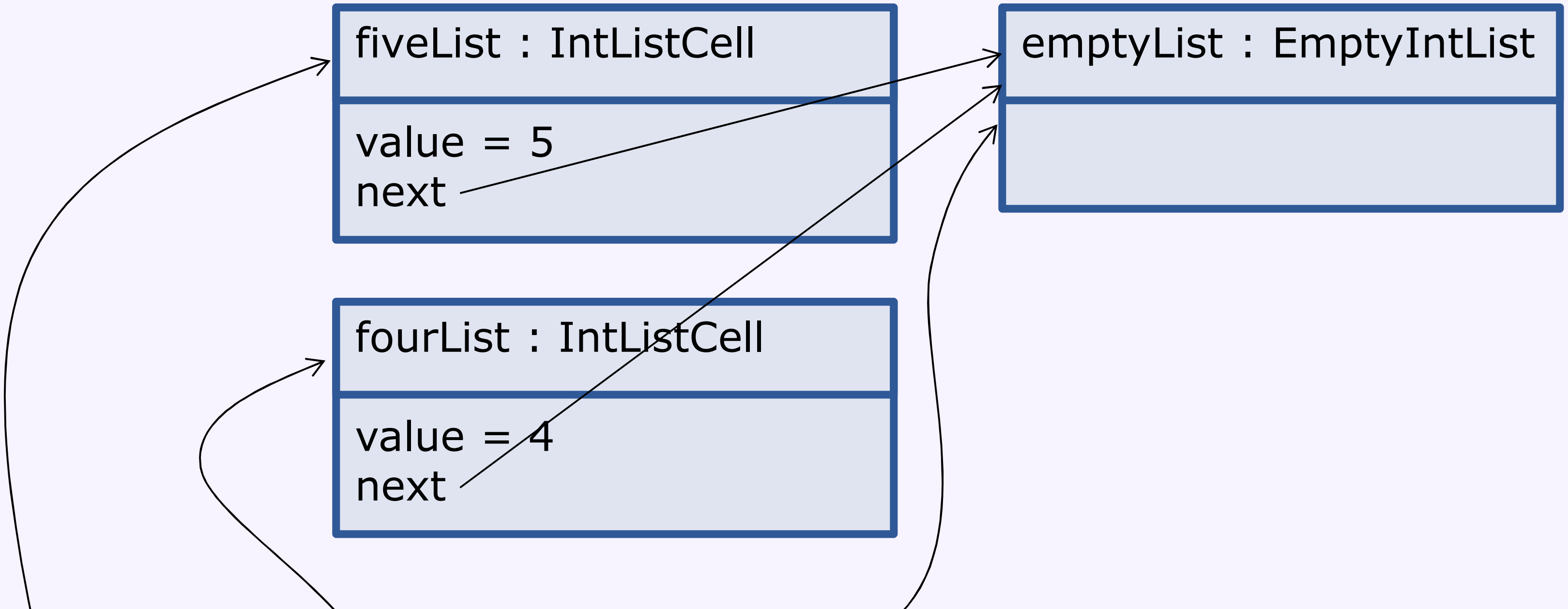
List fourFive = fourList.concatenate(fiveList);

- Step 3 (run time): Determine the run-time type of the receiver
  - Look at the object in the heap and get its class
- Step 4 (run time): Locate the method implementation to invoke
  - Look in the class for an implementation of the method we found statically (step 2)

```
public IntList concatenate(IntList other) {
        IntList newNext = next.concatenate(other);
        return new IntListCell(value, newNext); }
```

  - Invoke the method

Some Client Code

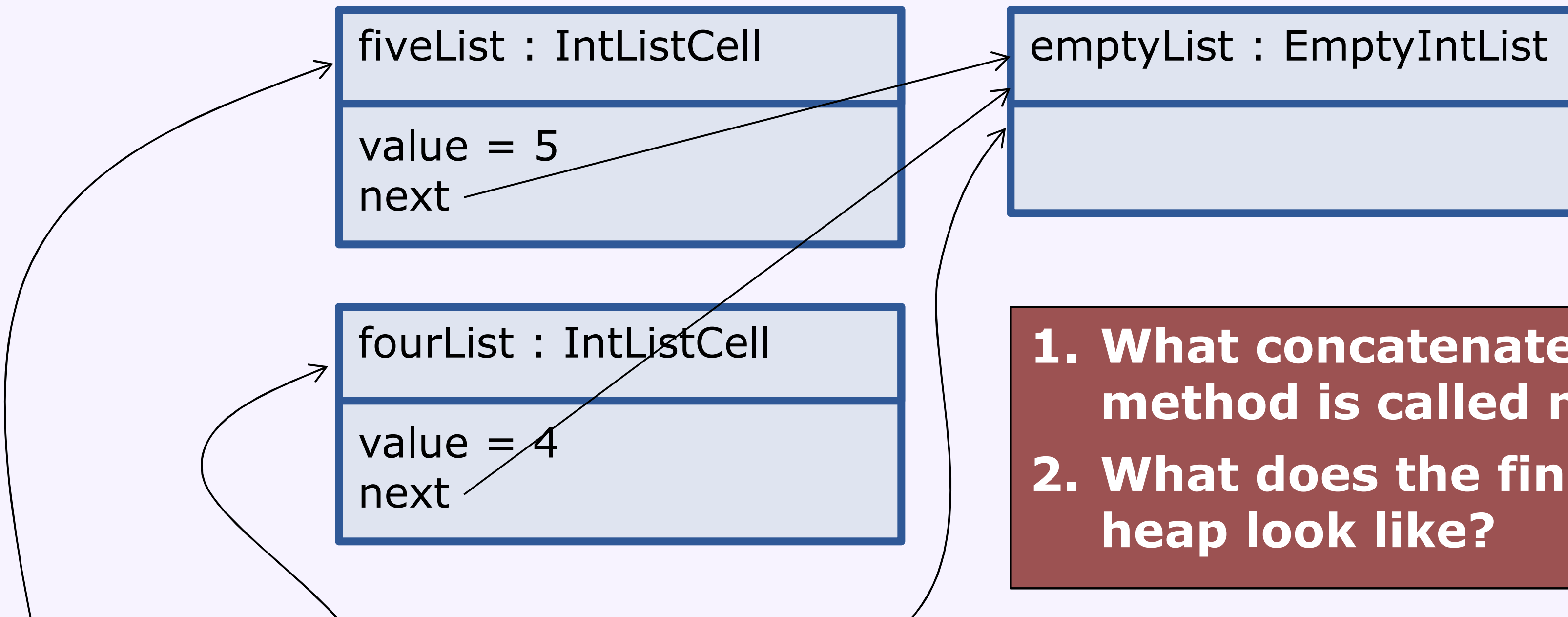



```
class IntListCell {
        public IntList concatenate(IntList other) {
                // this is fourList, other is fiveList
                IntList newNext = next.concatenate(other);
                return new IntListCell(value, newNext);
        }
```

List fourList = **new** IntListCell(4, emptyList);

List fourFive = fourList.concatenate(fiveList); ***// what happens?***

A Question for You!



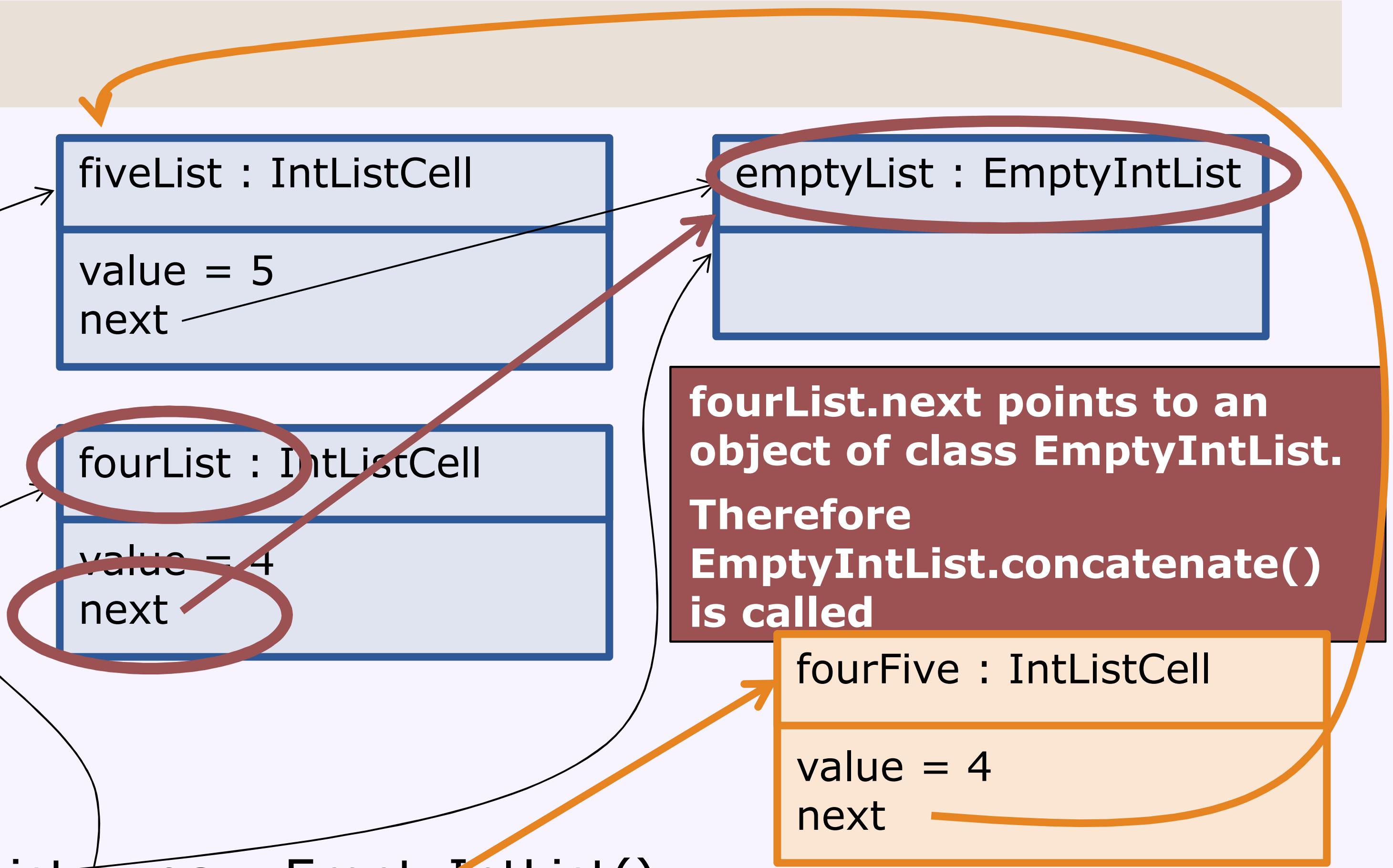
1. **What concatenate method is called next?**
2. **What does the final heap look like?**

```
class IntListCell {
        public IntList concatenate(IntList other) {
                // this is fourList, other is fiveList
                IntList newNext = next.concatenate(other);
                return new IntListCell(value, newNext);
        }
```

List fourList = **new** IntListCell(4, emptyList);

List fourFive = fourList.concatenate(fiveList); ***// what happens?***

Answers




```
In main(...)
List emptyList = new EmptyIntList();
List fiveList = new IntListCell(5, emptyList);
List fourList = new IntListCell(4, emptyList);
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Object identity vs. equality

- There are two notions of equality in OO
  - The *same object.* References are the same.
  - Possibly different objects, but equivalent content
    - From the client perspective!! The actual internals might be different

```
String s1 = new String (“abc”);
String s2 = new String (“abc”);
```

  - There are two string objects, s1 and s2.
    - The strings are are equivalent, but the references are different

```
if (s1 == s2) { same object } else { different objects }

if (s1.equals(s2)) { equivalent content } else { not}
```

Defined in the class String

  - An interesting wrinkle: *literals*

```
String s3 = “abc”;
String s4 = “abc”;
```

  - These are true: s3==s4. s3.equals(s2). s2 != s3.

Objects Analysis Threads Design

15-214

Principles of Software Construction: Objects, Design, and Concurrency

Exceptions

toad

Spring 2012

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Help! What do I do now?

```
int readFromFile(String file) {
        if (exists(file))
                return … // read the integer
        else
                // uh, oh!
}
int getValueFromList(int index) {
        if (index < 0)
                // uh, oh!
        else …
}
void transferFunds(int amount, Account to) {
        if (tooPoor())
                // uh, oh!
        else …
}
```

Exceptions

- Exceptions notify the caller of an operation of failure

- Benefits of exceptions
  - Provide high-level summary of error and stack trace
    - compare: core dumped in C

Throwing Exceptions

- Programmatically throwing exceptions
  - **throw new** ScaryException("reason we are scared");
  - For example: Java library code throws exceptions when I/O fails
- Exceptions thrown by the Java runtime
  - e.g. failed cast, null pointer dereference, array out of bounds, out of memory
- Semantics
  - Exception propagates from callee to caller
  - Until main() is reached, or the exception is caught

Exceptions

- Exceptions notify the caller of an operation of failure

- Benefits of exceptions
  - Provide high-level summary of error and stack trace
    - compare: core dumped in C
  - **Can't forget to handle common failure modes**
    - compare: using a flag or special return value
  - **Can optionally recover from failure**
    - compare: calling System.exit()

Catching Exceptions

```
try {
  dangerousOperation();
} catch (MildException e) {
  recover();
} catch (DeadlyException e) {
  revive();
}
```

Exceptions

- Exceptions notify the caller of an operation of failure

- Benefits of exceptions
  - Provide high-level summary of error and stack trace
    - compare: core dumped in C
  - Can't forget to handle common failure modes
    - compare: using a flag or special return value
  - Can optionally recover from failure
    - compare: calling System.exit()
  - **Can clean up on the way out**

Finally

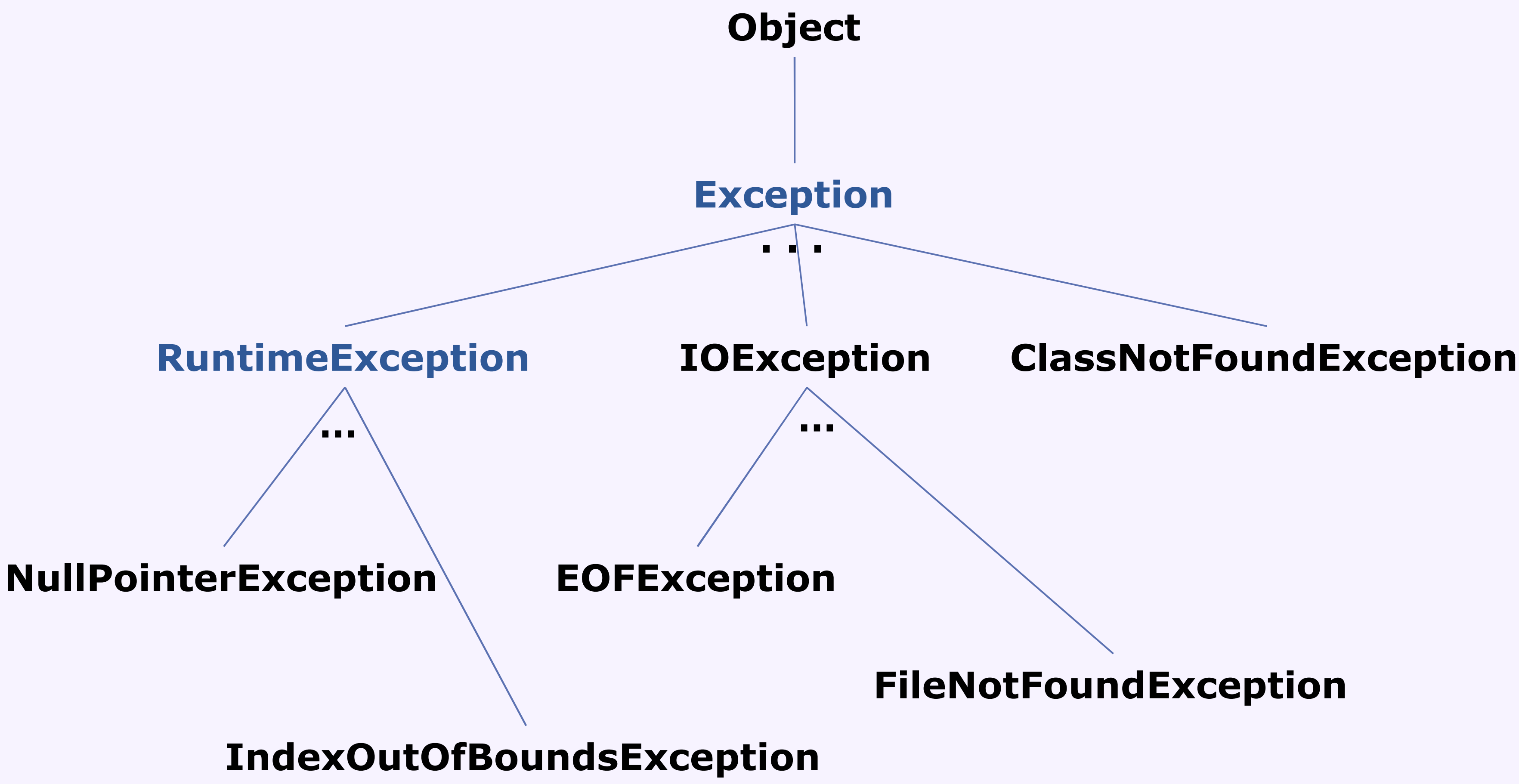
```
try {
  dangerousOperation();
} catch (MildException e) {
  recover();
} catch (DeadlyException e) {
  revive();
} finally {     // called on normal completion, any catch
  block,
  cleanup();   // or uncaught exception
}
```

Exceptions

- Exceptions notify the caller of an operation of failure

- Benefits of exceptions
  - Provide high-level summary of error and stack trace
    - compare: core dumped in C
  - Can’t forget to handle common failure modes
    - compare: using a flag or special return value
  - Can optionally recover from failure
    - compare: calling System.exit()
  - Can clean up on the way out
  - **Improve code structure**
    - Separates failure code from common-case code
    - Allows handling multiple failure type, and multiple failure locations, with one failure handler

The Exception Hierarchy



Checked and Unchecked Exceptions

- Unchecked exception
  - subclass of RuntimeException
  - indicates an error which is *highly unlikely* and/or *typically unrecoverable*
  - Examples: failed cast, null pointer dereference, array out of bounds, out of memory

- Checked exception
  - Subclass of Exception but not RuntimeException
  - Indicates an error that every caller should be aware of and explicitly decide to handle or pass on
  - Must declare in your method signature if your method might throw one!
    - whether directly or because you call anther method that does

void dangerousOperation() **throws** DeadlyException { … }

Guidelines for Exception Use

- Catch and handle all checked exceptions
  - Unless there is no good way to do so, in which case you should pass them on to your caller or throw a RuntimeException
- Use runtime exceptions for programming errors
  - If you receive bad input, throw a subclass of RuntimeException
- Other good practices
  - Do not swallow an exception without doing anything. At least print a stack trace! Better yet, try to recover.
  - When you throw an exception, provide an informative string to the constructor explaining the error

Toad's Take-Home Messages

- OOP – code is organized code around *kinds of things*
  - **Objects** correspond to things/concepts of interest
  - Objects embody:
    - State – held in **fields**, which hold or reference data
    - Actions – represented by **methods**, which describe operations on state
    - **Constructors** – how objects are created
  - A **class** is a family of similar objects
  - An **interface** states expectations for classes and their objects
- Objects reside in the **heap**
  - They are accessed by **reference**, which gives the objects **identity**
  - **Dispatch** is used to choose a method implementation based on the **class** of the **receiver**
  - Equivalence (**equals**) does not mean the same object (==)
- **Exceptions** are a structured way to manage failure