CS 228: Introduction to Data Structures
Lecture 6

Example (Continued). Recall Wednesday's two `Point` objects.

```
Point p = new Point(1, 2);
Point q = new Point(3, 4);
```

If we now write:

```
p = q;
```

The object that p referenced before the statement (the `Point` with coordinates (1,2)) is now unreferenced — it becomes "garbage". Unreferenced objects are eventually ***garbage collected***.

Object Types versus Primitive Types

The next table compares object types and primitive types.

	Object types	Primitive types
Contains a	reference	built-in
How defined?	class definition	9, 42.5, ‘h’, `false`
How created?	“new”	default (usually zero)
How used?	method	operators: +, -, *, etc
Testing equality	`equals()` (override)	==

The last row deserves further explanation . . .

Equality and the `equals()` Method

The operation “`x == y`” determines whether variables x and y have the same values. When x and y are of the same primitive type, this corresponds to the usual notion of equality testing. For instance, suppose `i` and j are `int` variables and we set `i = 2`. Then, if we set `j = 3`, `i == j` is false and if we set `j = 2`, `i == j` is true.

When p and q are of object types, however, “p == q” determines whether variables p and q ***reference*** the same object. It does not determine whether the objects are “the same”. For instance, suppose we execute the following statements.

```
Point p = new Point(1, 2);
Point q = new Point(1, 2);
```

Intuitively, p and q are “the same”; however, `p == q` is false, because p and q reference different objects.

In Java, the notion of equality testing is captured by the `equals()` method. The default implementation of `equals()` in `java.lang.Object` just compares object references. Thus, if we used this default implementation, `p.equals(q)` would be false; i.e., no different than if we used `p == q`. If we want `p.equals(q)` to return `true` if and only if the x and y coordinates of p and q match (the usual notion of “sameness” of `Point` objects), we need to ***override*** the default implementation of `equals()`[1].

[1]The Java `Point` class (`java.awt.Point`) implements `equals()` exactly as we want it: Points are equal only if they have the same coordinates.

The code below — which should be inserted within the body of the `Point` class — illustrates the standard way to override `equals()`.

```
@Override
public boolean equals(Object obj)
{
  if (obj == null ||
      obj.getClass() != this.getClass())
  {
    return false;
  }

  Point other = (Point) obj;
  return x == other.x && y == other.y;
}
```

Note that `obj`, the method argument, must be an `Object`, not a `Point`, because the signature of `equals()` in `java.lang.Object` is

```
boolean equals(Object obj)
```

and, to override a method, we must match its signature.

Our implementation of `equals()` first verifies that `obj` is not `null` and that it is also a `Point` object (if the other object is not a `Point`, we should not attempt to examine its coordinates). After verifying that `obj` is indeed a `Point`, we need to downcast `obj` to the `Point` type, to let the compiler know that we can access the instance variables `x` and `y`.[2]

Note. Some textbook authors and developers use the `instanceof` operator in the `equals()` method to test if objects are of the same class:

```
    if (!(obj instanceof Point))
       return false;
```

We will not do that here; instead, we will always test for class equality using `getClass()`. The reason is that `instanceof` does not work correctly when inheritance is involved; in fact it will be incorrect for subtypes of `Point`. To fully understand the issues, you need to understand the formal definition of `equals()`. We provide this formal definition next, for the benefit of the mathematically inclined — we will not cover it in class.

[2] Note that we can access the instance variables `x` and `y`, because `equals()` is defined within the body of the `Point` class.

Formal Definition of `equals()`. The Java documentation[3] specifies that `equals()` implements an *equivalence relation* on non-null object references. That is, it satisfies the following properties.

- **Reflexivity:** for any non-null reference value `x`, `x.equals(x)` should return `true`.
- **Symmetry:** for any non-null reference values `x` and `y`, `x.equals(y)` should return `true` if and only if `y.equals(x)` returns `true`.
- **Transitivity:** for any non-null reference values `x`, y, and `z`, if `x.equals(y)` returns `true` and `y.equals(z)` returns true, then `x.equals(z)` should return `true`.
- **Consistency:** for any non-null reference values `x` and `y`, multiple invocations of `x.equals(y)` consistently return `true` or consistently return `false`, provided no information used in `equals` comparisons on the objects is modified.
- **Nothing equals null except null:** For any non-null reference value `x`, `x.equals(null)` should return `false`.

[3] http://docs.oracle.com/javase/8/docs/api/java/lang/Object.html#equals(java.lang.Object)

Exercise: Which of these properties imply that we should use `getClass()` instead of `instanceof()` in `equals()`?

`equals()` and the `String` class

Suppose we do the following.

```
String s = "hurley";
String t = "HURLEY".toLowerCase();
```

Now strings `s` and `t` contain the same characters, but they ***are not*** the same object.

```
System.out.println(s == t);        // false
```

As you probably saw in ComS 227, the proper way to test if two strings are the same (i.e., contain the same characters), is to use the `equals()` method.

```
System.out.println(s.equals(t));   // true
```

This behaves as you would expect, because the implementors of Java have done some work for you: the `String` class overrides `equals()` to check whether the characters are the same.

Another Example

The same pattern we used for the `Point` class to override `equals()` for other classes. Here is an `equals()` method for the Bee class:

```
@Override
public boolean equals(Object o)
{
    if (o == null ||
        o.getClass() != getClass())
    {
        return false;
    }

    // typecast o to Bee so that we can
    // compare data members
    Bee b = (Bee) o;

    // Compare the data members and return
    // accordingly
    return b.size == size
```

```
                   && (b.color == color ||
                   b.color != null &&
                   b.color.equals(color))
                  && (b.swarm == swarm ||
                   b.swarm != null &&
                   b.swarm.equals(swarm));
}
```

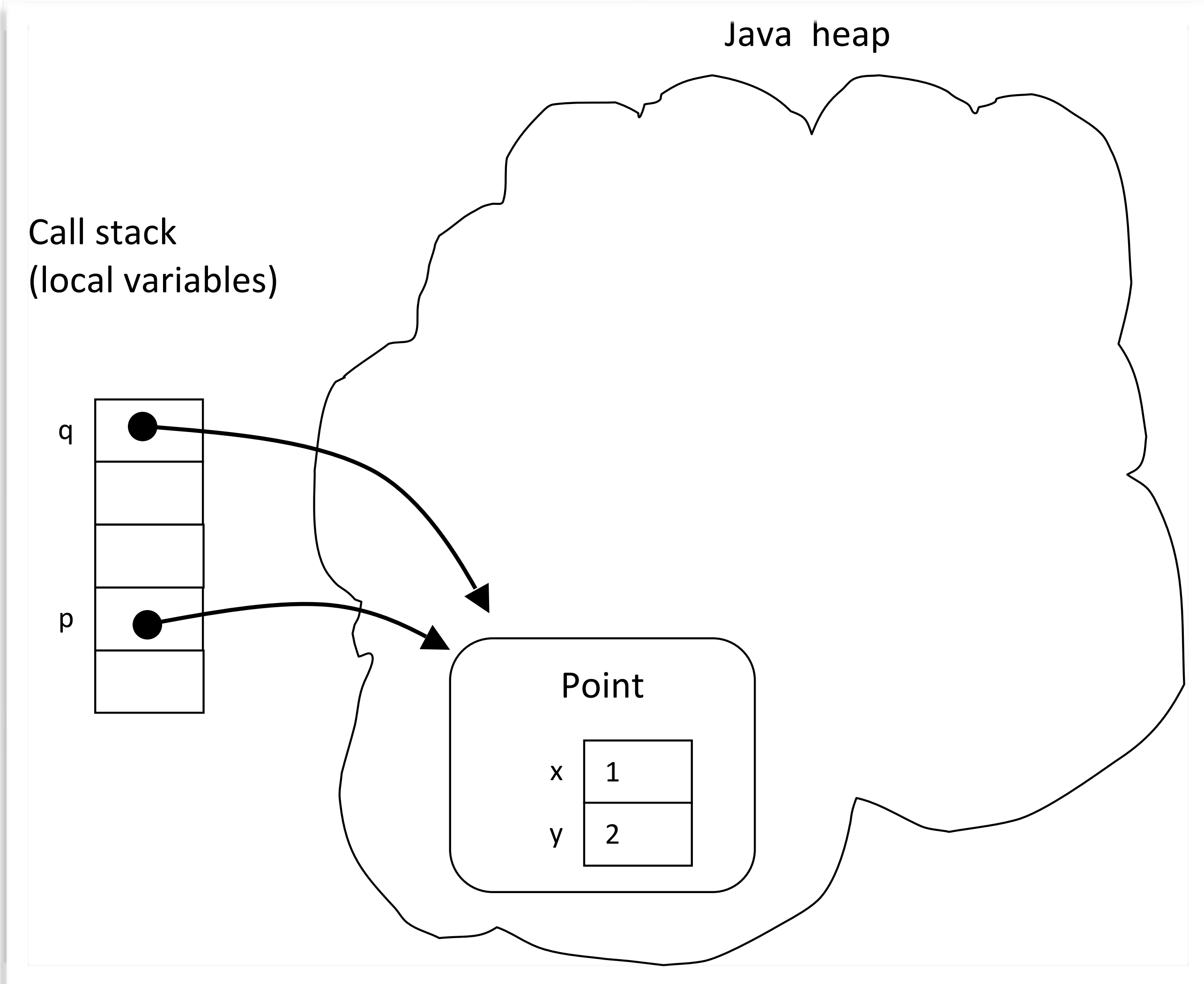
Note how `equals()` calls itself. Of course, this (recursive) call is to the `equals()` method for the `String` class (which we assume is implemented).
By inheritance, the same implementation can be used by any subclass of Bee, unless it is overridden by the subclass.

Copying and Cloning

If we execute these two statements

```
Point p = new Point(1, 2);
Point q = p;
```

the result is this:



The second assignment does not make a copy of the `Point` object, it just assigns the reference. That is, q is now an ***alias*** for p. This is potentially dangerous, since any changes we make through q affect p as well, which might not be what we want.

In order to make an actual copy of an object, we have to implement a special method to do so. Two common options are to

- write a ***copy constructor*** or

- write a cloning method.

We will illustrate these approaches using the `Point` class.

Copy Constructors

A copy constructor initializes the object under construction ("`this`" object) using the values from an existing one:

```
  public Point(Point existing)
  {
    this.x = existing.x;
    this.y = existing.y;
  }
```

Usage:

```
Point p = new Point(1, 2);
q = new Point(p);
```

Cloning

A cloning method returns a ***new*** object from the values in `this` object. Here is an an ad-hoc cloning method for the `Point` class.

```
  public Point makeClone()
  {
    Point copy = new Point();
    copy.x = this.x;
    copy.y = this.y;
    return copy;
  }
```

Usage:

```
Point p = new Point(1, 2);
q = p.makeClone();
```

Another option is to override Java's `Object.clone()` method. For this, you either have to explicitly declare that your class implements the `Cloneable` interface or some superclass of your class must implement `Cloneable`. Thus, the declaration for Point would be

```
public class Point implements Cloneable{…}
```

We will see how to override `clone()` next time.

Overriding the `clone()` Method

An alternative to writing our own (ad hoc cloning) method is to override Java's `Object.clone()` method. The default implementation of `clone()` creates a field-by-field copy — that is, a ***shallow copy*** — of its argument. Since shallow copying is not always appropriate, Java intentionally disables `clone()`, by declaring it as `protected`, not `public` — so you have to call it from the subclass using `super` — and by having it throw a `CloneNotSupportedException` when called.
To override `clone()`, you either have to explicitly declare that your class implements `Cloneable` or some superclass of your class must implement `Cloneable`.
Thus, the declaration for Point would be

```
public class Point implements Cloneable{…}
```

Your public `clone` method can then call the protected `clone` method to create a shallow copy, if that suffices. For the `Point` class, a shallow copy is enough. The code is:

```
@Override
public Object clone()
{
  Point copy = null;
  try
  {
    // super.clone() creates copies of
    // all fields
    copy = (Point) super.clone();
  }
  catch (CloneNotSupportedException e)
  {
    // Should never happen unless there's
    // a programming error
  }
  return copy;
}
```

Usage:

```
Point p = new Point(1, 2);
q = (Point) p.clone();
```

Shallow versus Deep Copying

A shallow copy suffices for `Point`, because both of its fields, `x` and `y`, are primitive. In general, though, an object may contain references to other objects. In this case, to get a completely independent copy, you have to recursively copy/clone the objects the object references — this is called a ***deep copy***.

Example: The `IntVector` Class

An `IntVector` has a *dimension* `dim` and an array `coords` of coordinates. Its class definition begins like this (the code is posted on BB).

```
public class IntVector implements Cloneable
{
   private int dim;

   private int[] coords;
```

The constructor is

```
   public IntVector(int dimension)
   {
      if (dimension <= 0)
```

```
        throw
          new IllegalArgumentException();
      dim = dimension;
      coords = new int[dim];
   }
```

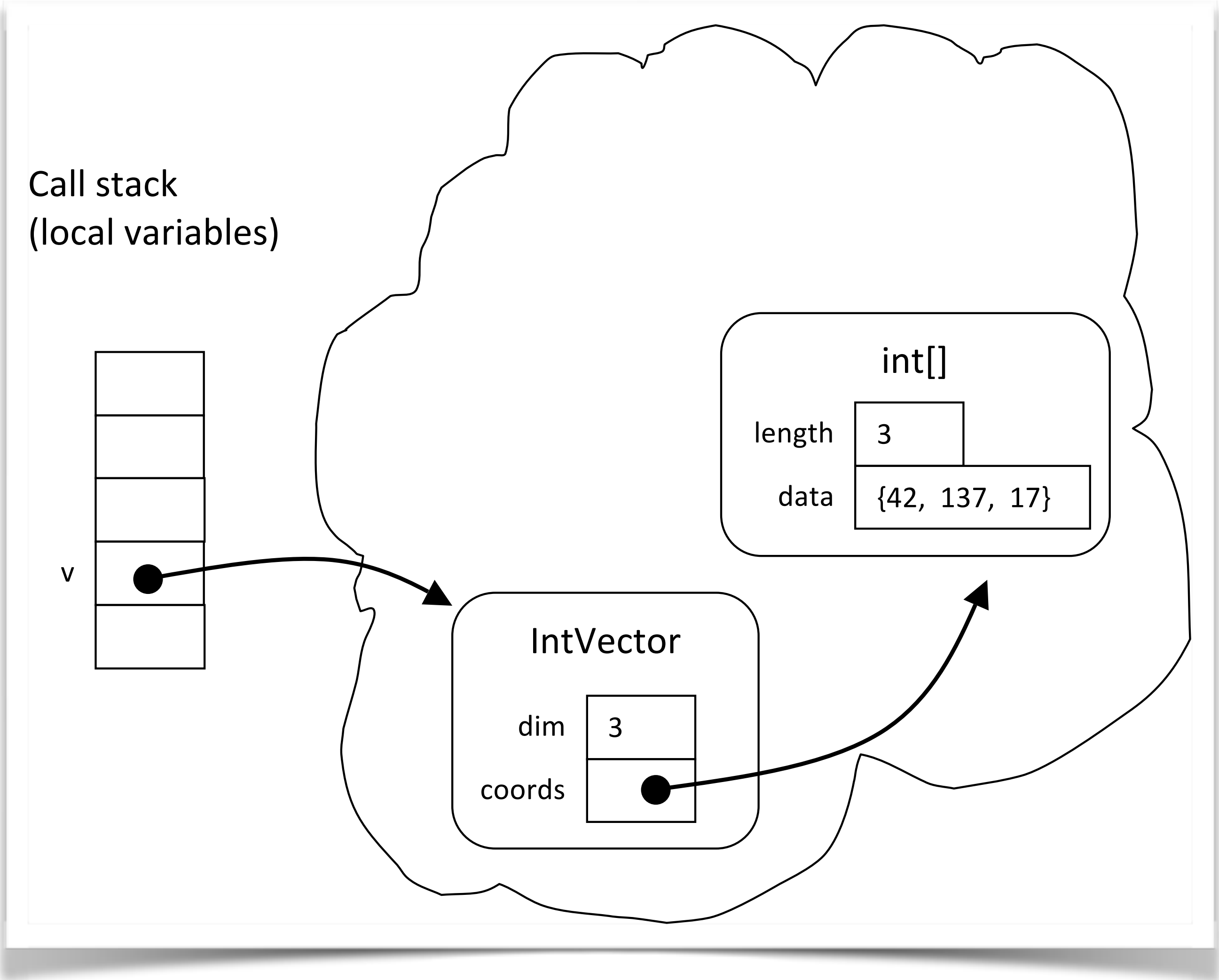
Here is the setter.

```
   public void set(int index, int value)
   {
      coords[index] = value;
   }
```

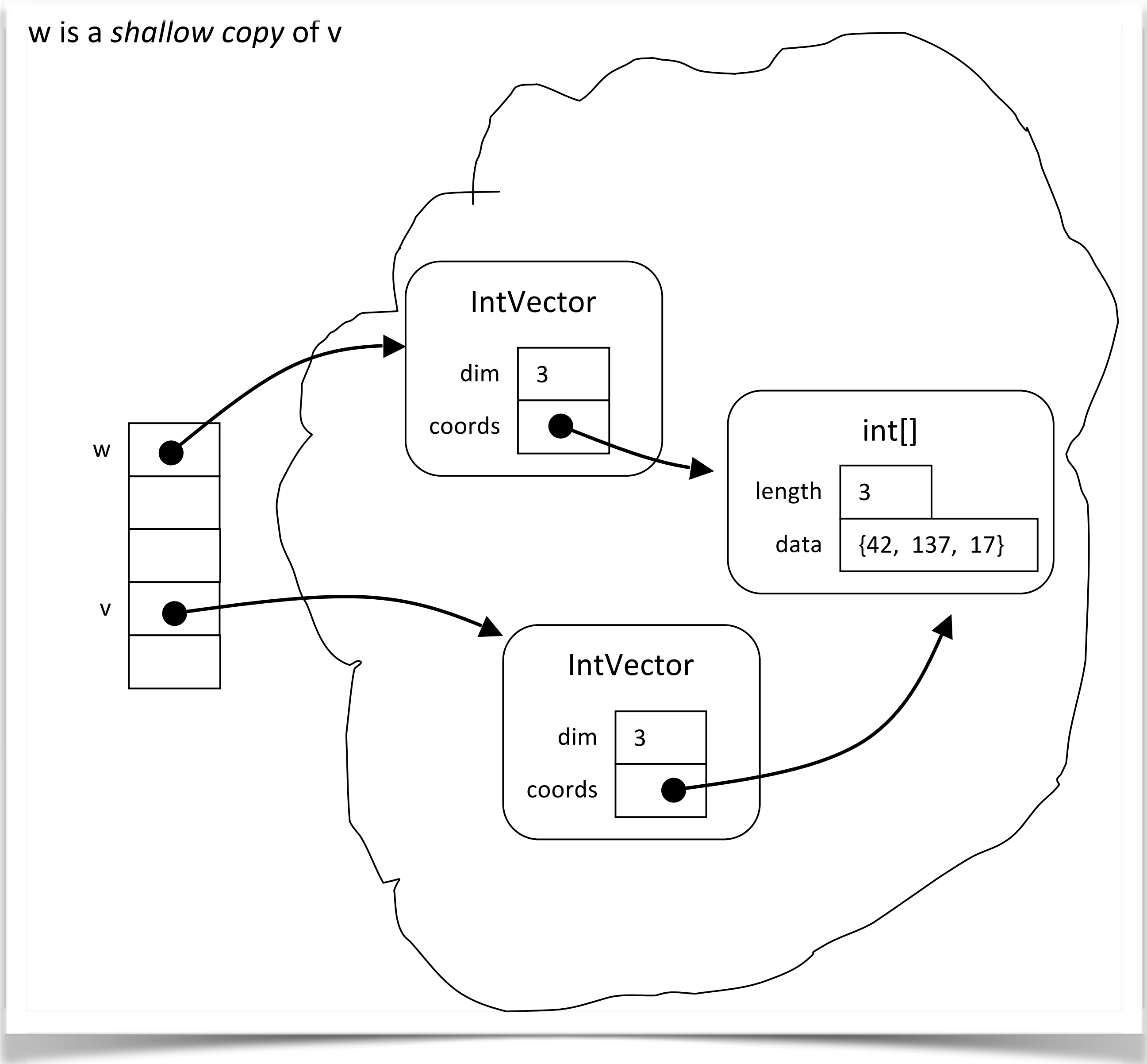
Now, suppose we execute the statements below:

```
IntVector v = new IntVector(3);
v.set(0, 42);
v.set(1, 137);
v.set(2, 17);
```

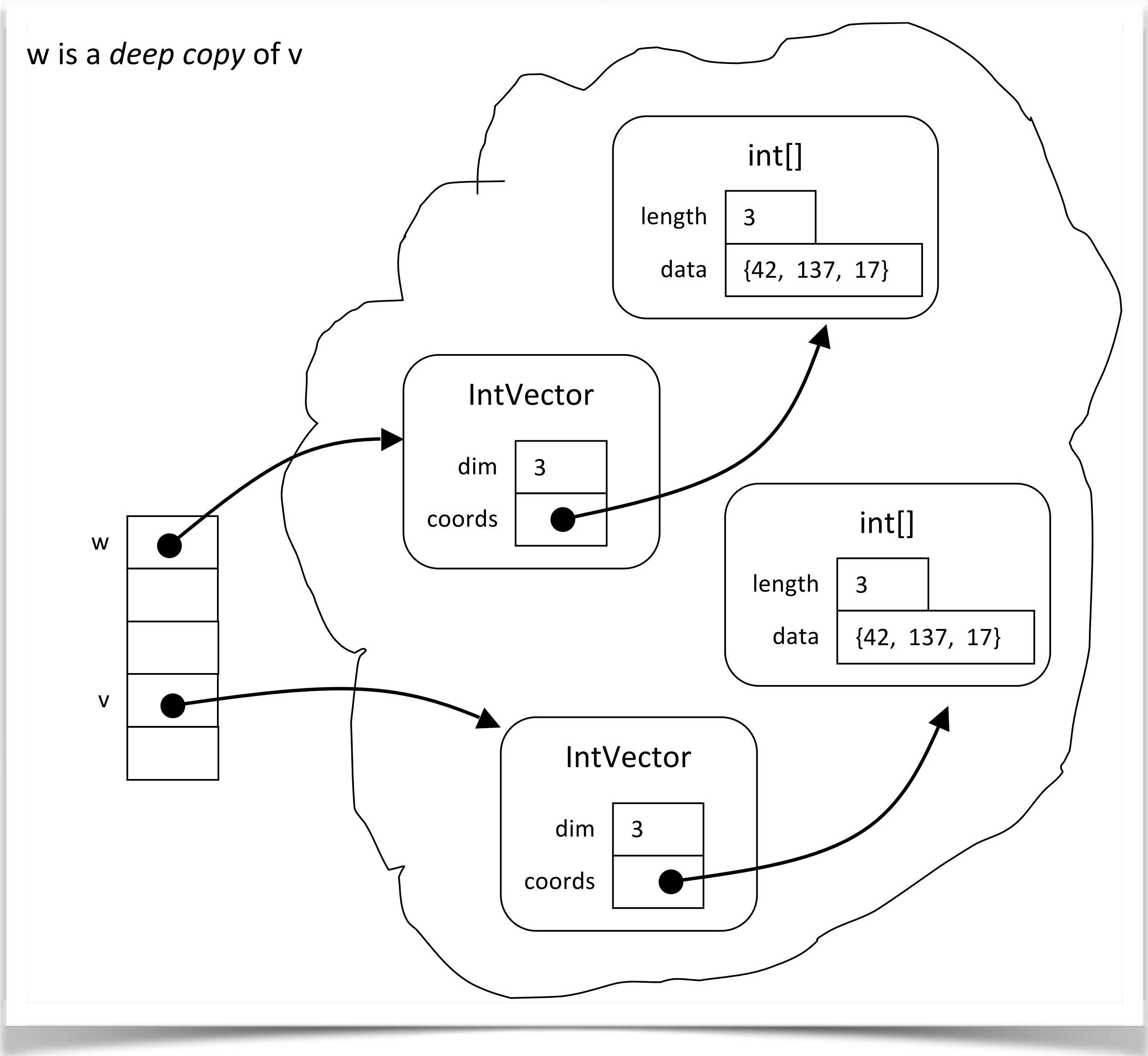
The result is:



Suppose `w` is a shallow copy of `v`; i.e., `w` is obtained by copying the fields of `w`. Since the `coords` field is a reference, we just copy the reference. Thus, the `coords` fields of `v` and `w` end up referring to the same array.



This can be dangerous, since any modification to the `coords` array through `w` also affects `v`. What we probably want is, in fact, a completely independent copy — a ***deep copy*** — of this array, like this:



A Copy Constructor for `IntVector`

Here is the code for a copy constructor that builds a deep copy of an `IntVector` object.

```
public IntVector(IntVector existing)
{
  dim = existing.dim;
  coords = new int[dim];

  for (int i = 0; i < dim; ++i)
  {
    coords[i] = existing.coords[i];
  }
}
```

Note that we could use `System.arraycopy()`[4] instead of the `for` loop.

`clone()` for `IntVector`

By default, `Object.clone()` creates shallow copies. That is OK for `Point`, but not for `IntVector`. Here is how to make a deep copy.

[4] See http://docs.oracle.com/javase/8/docs/api/java/lang/System.html.

```java
@Override
public IntVector clone()
{
  try
  {
    IntVector copy
        = (IntVector) super.clone();

    // Object.clone() copies fields, now
    // make it into deep copy

    copy.coords = new int[dim];
    for (int i = 0; i < dim; ++i)
    {
      copy.coords[i] = coords[i];
    }
    return copy;
  }
  catch (CloneNotSupportedException e)
  {
    // should never happen...
    return null;
  }
}
```

Shallow versus Deep Comparison

The shallow versus deep issue also arises when implementing `equals()`. For example, `ArrayList`'s `equals()` method does a shallow comparison of two `ArrayLists`: they are "equal" if they have the same length and contain identical values in the same order. To implement `IntVector`'s `equals()` properly, we must do a deep comparison:

```
@Override
public boolean equals(Object obj)
{
  if (obj == null ||
        obj.getClass() !=
           this.getClass()) return false;
  IntVector other = (IntVector) obj;

  if (dim == other.dim)
  {
    // Check whether all coordinates are
    // the same
    for (int i = 0; i < dim; ++i)
    {
      if (coords[i] != other.coords[i])
      {
        return false;
      }
```

```
      }
      return true;
    }
    else
    {
      return false;
    }
  }
```

Note. For comparing the `int` arrays, you could also use the utility

```
Arrays.equals(coords, other.coords).
```

However, since the class `int[]` does not override `equals()`, the following will ***not*** work:

```
coords.equals(other.coords)
```

Comments on Overriding Methods

Notice that the return type in `IntVector.clone()` is `IntVector`, while the return type in `Point.clone()` is `Object`. Either way is correct. The potential advantage of the former is that we can avoid the cast we needed with `Point`.

Here are some additional things you can and cannot do when you override a method.

- You ***cannot*** change the method's name or parameter types.
- You ***can*** change the return type, as long as the new type is ***compatible*** with the original.
- You ***can*** change a method from protected to public, but you ***cannot*** make the access more restrictive.
- You ***can*** omit a `throws` declaration, but you ***cannot*** add a `throws` declaration.

`static` Fields and Methods

The keyword **`static`** in Java means "associated with the class as a whole, not with an instance". Fields and methods can be static.

A ***static field*** is a single variable shared by a whole class of objects; its value does not vary from object to object. Thus, static fields are also called ***class variables***. If we declare a field `static`, there is just one field for the whole class. One common use of static fields is to define constants, such as `Math.PI`, that are **`static`** and **`final`**. Here is another example.

Example. Suppose we want to keep track of the number of `Person` objects that we have constructed. It does not make sense for each object to have its own copy of this number: we would have to update every `Person`'s number whenever a new `Person` is created. It makes more sense to have a single variable, a static field, for the entire class that counts the number of people created thus far. The constructor increments this static field, called `numberOfPeople`, by one.

```
class Person {
  public static int numberOfPeople;
  public String name;
  public Person(String name) {
    this.name = name;
    numberOfPeople++;
  }
}
```

If we want to look at the variable `numberOfPeople` from another class, we write it in the usual notation, but we prefix it with the class name rather than the name of a specific object. For example,

```
  int kids = Person.numberOfPeople / 4;
```

The following works too, but has nothing to do with `joe` specifically.

```
  int kids = joe.numberOfPeople / 4;
```

Don't do this; it is bad (confusing) style.

A ***static method*** does not implicitly pass an object as a parameter — in contrast, for example, the call `p.foo(q)` implicitly passes p as a parameter to `foo`. Thus, a static method can be used without creating an instance of the class. One example is `Math.cos()`. Here's another one.

```
class Person {
  ...
  public static void printPopulation() {
    System.out.println(numberOfPeople);
  }
}
```

Now, we can call "`Person.printPopulation()`" from another class. We can also call "`joe.printPopulation()`", and it works, but it is bad style, and `joe` will NOT be passed along as "`this`".

The `main()` method is always `static`, because when we run a program, we are not passing it an object.

Important: In a `static` method, there is no "`this`"! Any attempt to reference "`this`" will cause a compile-time error.