

Lecture Set #12: Arrays

This lecture set:

- Intro to arrays
- Copying arrays and making arrays bigger
- Array lengths and out-of-bounds indexing
- Passing arrays and array elements to a function
- Privacy Leaks
- Different levels of copy



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Data Structures and Arrays

- **Data structures:** mechanisms for storing data in a structured way
- We have seen simple data structures implemented as classes:
 - Rational.java
 - Rational number data stored as numerator / denominator pair
- **Arrays** are a very useful data structure provided by Java and other programming languages
 - Array: sequence of variables of the same type
 - homogeneous data structure
 - size (quantity) fixed when space is allocated
 - ordered
 - Individual elements of sequence can be referenced/updated/etc.
 - Arrays are objects (hence allocated on heap) with a reference on the stack
 - Like other objects, "instance variables" of array = cells in array are assigned default values (0 / null / etc.) when array created

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Array Indexing

- Java provides a special syntax for uniformly accessing cells in an array
 - Declaration of a:

```
int[] a;
```
 - Allocation of space for array named a:

```
a = new int[5];
```

 - This creates five int variables "named": a[0], a[1], a[2], a[3], a[4]
 - To modify contents of cell #2 to 6 and cell #1 to 74:

```
a[2] = 6;
a[1] = 74;
```
 - To use the contents of cell #2 and cell #1 :

```
System.out.println("value = " + (a[1]-a[2]));
```
- This access mechanism to the individual elements is called **array indexing**
 - In Java / C / C++, array cells are indexed beginning at 0 and going up to n-1 (n is number of cells)
 - Beware: start at 0! and end at one less than the size!!

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Square Brackets: [] and length



- Three uses in Java:
 - Array variable declaration
`int[] a;`
 - Array object creation
`new int[10];`
 - Array indexing
`a[0]`
- array also has `a.length` holds the amount of space currently allocated for that array

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Alternate Declaration Syntax



- To maintain consistency with C / C++, following declaration of array variables also possible
`int grade[];`
Compare to Java standard:
`int[] grade;`
- Java standard generally preferred
 - "type" emphasizes array status
- Alternative syntax sometimes handy:
`int grade[], i, gpa[];`
 - Declares two arrays of base type `int`: `grade, gpa`
 - Declares a single `int` variable: `i`

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Summary of Arrays



- Arrays are:
 - Sequences of cells holding values of the same type ("base type")
 - Objects (hence created using `new`)
- To define an array variable:
`int[] a; // an array with base type int`
- To create an array object:
`a = new int[10];`
 - Creates an array of 10 cells
 - The base type is `int`
- To access individual array cells: use indexing
 - `a[0], a[1], ..., a[9]`
 - Cells are just like variables:
 - They may be read: `x = a[3];`
 - They may be written: `a[2] = 7;`

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A Common Programming Idiom



- To process all elements in array `a...`
- Do following:

```
for (int i = 0; i < a.length; i++){
    ...process the one element at a[i]...
}
```
- Use fresh loop counter to avoid overwriting another variable of same name elsewhere
- Remember: Use `i < a.length`, not `i <= a.length`

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Copying Arrays



- Does the following copy `a` into `b`?

```
int[] a = new int[5];
int[] b = a;
```

No: `a, b` are aliases
- How to make a copy? For now, use loop:

```
int[] a = new int[5];
int[] b = new int[a.length];
for (int i = 0; i < a.length; i++){
    b[i] = a[i];
}
```

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Making Arrays Bigger



- Suppose we want to make an array bigger by adding an element.
- Does the following work?

```
int[] a = new int[5];
a.length++;
```
- No!
 - We get the following:

```
Exception in thread "main" java.lang.Error:
  Unresolved compilation problem:
    The final field array.length cannot be assigned
    at Sample.main(Sample.java:15)
```
 - `a.length` is immutable
 - No assignment is allowed

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To Make an Array Bigger...

- Create a new larger array object
- Copy old array contents into new object
- Assign address of new object to variable

```
int[] a = new int[5];
{
    int[] temp = new int[a.length + 1];
    for (int i = 0; i < a.length; i++){
        temp[i] = a[i];
    }
    a = temp;
}
```

- New variable temp created to hold copy
- New block created to ensure temp does not interfere with another variable of the same name
- Previous contents of a become garbage

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Arrays As Arguments

- Arrays = objects
- Array variables = references
- Array cells = variables of the base type (references or primitives depending on what that base type is)
- Both can be used as arguments to methods
 - Array cells: passed just like the variables of that base type
 - Array arguments: passed just like objects
 - Reference to array is passed in
 - If the method expects an array of doubles, an array of doubles **of any size** can be passed
 - **Promotion does not apply.** You cannot pass an int array when an array of doubles is expected

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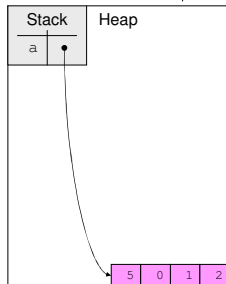
Array Initializers

- Arrays may be initialized at declaration time!

```
int[] a = {5,0,1,2};
```

- Java:
 - counts elements (here, 4);
 - creates correct size of array
 - copies elements into array
 - returns reference to array

See Array Example 3

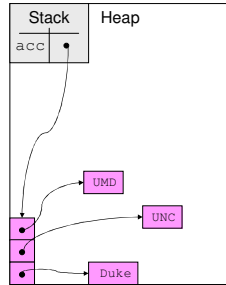


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Arrays of Objects

- **Class types** can also be base types of arrays
 - e.g.
`String[] acc = new String[3];`
 - Array cells store references to objects
- Array initializers can also be used
`String[] acc = {"UMD", "UNC", "Duke"};`



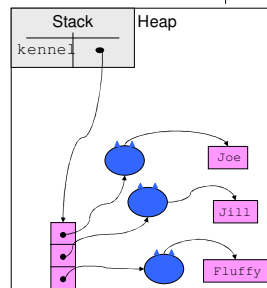
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Arrays of Objects (continued)

- More complicated example than strings:
Cat objects
- Expressions can also appear in initializers

```
Cat[] kennel = {  
    new Cat("Joe"),  
    new Cat("Jill"),  
    new Cat("Fluffy")  
};
```



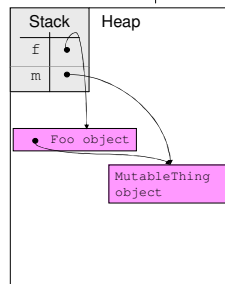
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Privacy Leaks

```
public class MutableThing {  
    ...  
    public void mutateMe() {...};  
}  
public class Foo {  
    private MutableThing q  
        = new MutableThing();  
    ...  
    public MutableThing getQ(){  
        return q;  
    }  
}
```

- Consider following code
`Foo f = new Foo();
MutableThing m = f.getQ();
m.mutateMe();`
- After this executes, what happens?
- This phenomenon is called a **privacy leak**
 - Private instance variables can be modified outside class
 - Behavior is due to aliasing



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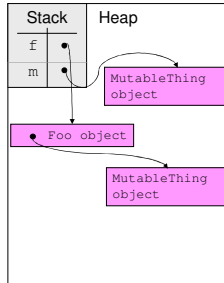
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Fixing Privacy Leaks

- Return **copies** of objects referenced by instance variables
- To fix `getQ` method in `Foo`:

```
MutableThing getQ(){
    return new MutableThing(q);
}
```

 - This returns a copy of `q`
 - Changes made to this copy will not affect original



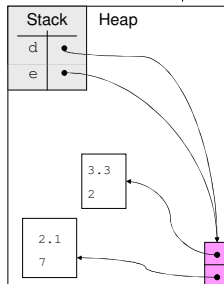
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Reference Copying

```
Person[] d = {
    new Person(2.1, 7, ...),
    new Person(3.3, 2, ...)
};

Person[] e = d;
```



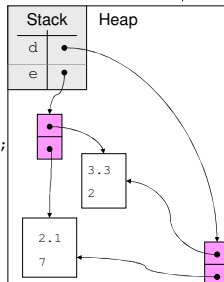
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Shallow Copying

```
Person[] d = {
    new Person(2.1, 7, ...),
    new Person(3.3, 2, ...)
};

Person[] e = new Person[d.length];
for (int i=0; i < d.length, i++){
    e[i] = d[i];
}
```



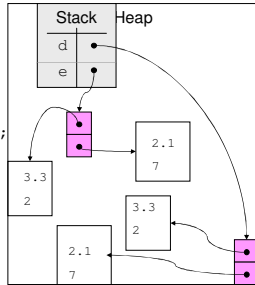
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Deep Copying

```
Person[] d = {
    new Person(2.1, 7, ...),
    new Person(3.3, 2, ...)
};
```

```
Person[] e = new Person[d.length];
for (int i=0; i<d.length; i++) {
    e[i] = new Person(d[i]);
}
```



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Three Ways of Copying

CDCollector contains an array of CD's;
ReCDCollector contains an array of rewritableCD's;

- **Reference copy**

```
public ReCD[] getCDsReferenceCopy() {
    return myFavorites;
}
```

- **Shallow copy**

```
public ReCD[] getCDsShallowCopy() {
    ReCD[] copy = new ReCD[myFavorites.length];
    for (int i = 0; i < copy.length; i++)
        copy[i] = myFavorites[i];
    return copy;
}
```

- **Deep copy**

```
public ReCD[] getCDsDeepCopy() {
    ReCD[] copy = new ReCD[myFavorites.length];
    for (int i = 0; i < copy.length; i++)
        copy[i] = new ReCD(myFavorites[i]);
    return copy;
}
```

```
ReCDCollectionOwner p =
    new RECD...;
ReCD[] a = p.getCD...();
a[0] = otherCDalreadycreated;
a[0].rewrite("other", "name");
```

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When To Use What Kind of Copying?

- Reference copying is usually a bad idea (not always but realize what you are doing)
- Deep copying provides maximal protection against aliasing (but takes a lot of time and space if it was not necessary)
- Storage space and time used
 - Reference: least
 - Shallow: middle
 - Deep: most
- If the class is mutable, aliasing is something to be avoided and you must have true copies to prevent privacy leaks and modifications outside.
- If you know the class is immutable, aliasing doesn't hurt but neither does making true copies (except wasted space and time).
- If storage is an issue, aliasing problems may be worth coping with but must be well documented.

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