Lecture Set #11: 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

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

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!!

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

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`

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;`

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`

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];
}
```

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

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

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

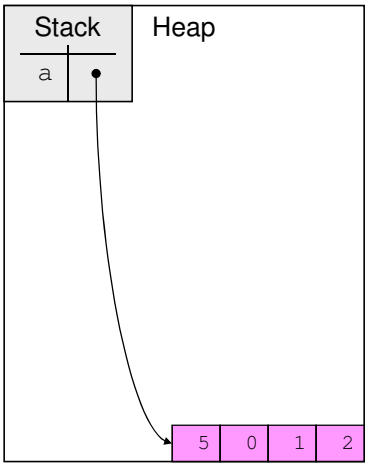
Array Initializers

- Arrays may be initialized at declaration time!

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

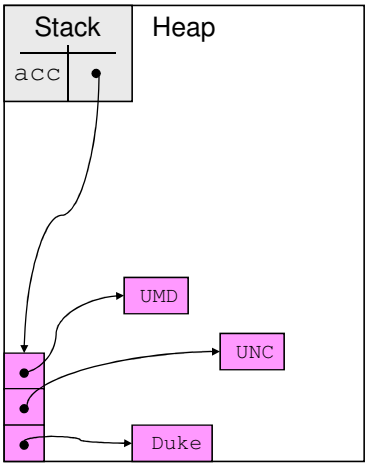
- Java:
  - counts elements (here, 4);
  - creates correct size of array
  - copies elements into array
  - returns reference to array

See Array Example 3



Arrays of Objects

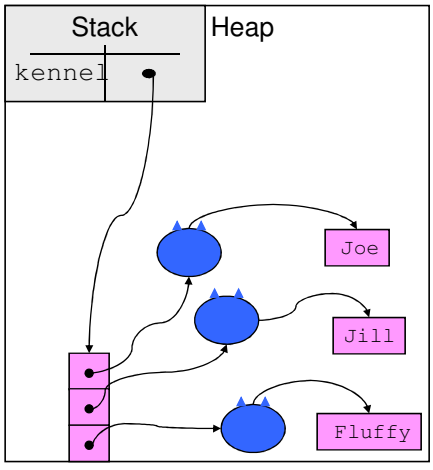
- Class types can also be base types of arrays
  - e.g.
    `String[] acc = new String[3];`
  - Array cells store references to objects
- Array initializers can also be used
  `String[] acc = {"UMD", "UNC", "Duke"};`



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")
};
```



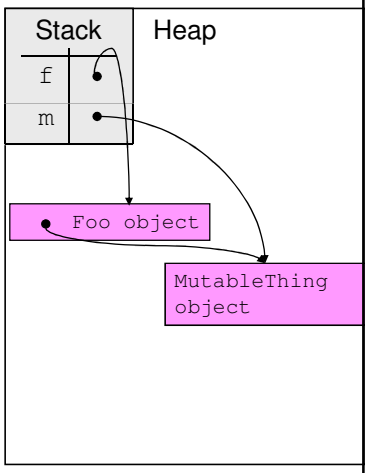
Privacy Leaks

```
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

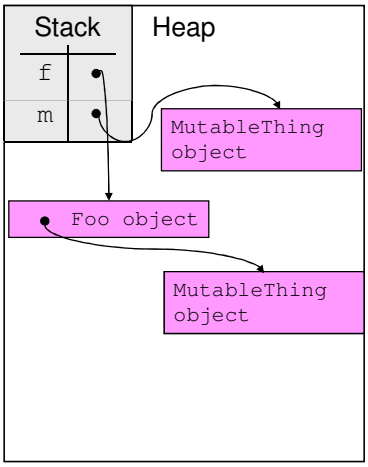


Fixing Privacy Leaks

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

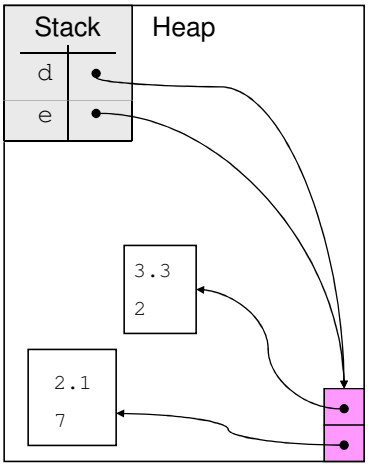
```
MutableThing getQ(){
    return new MutableThing(q);
}
```

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



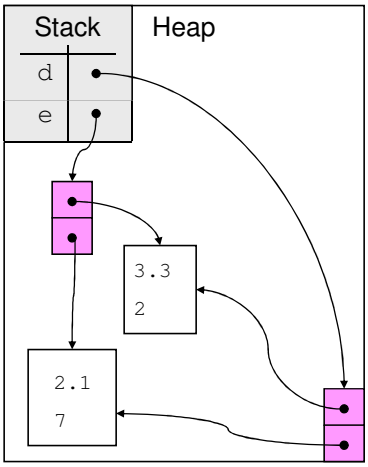
Reference Copying

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

Person[] e = d;
```



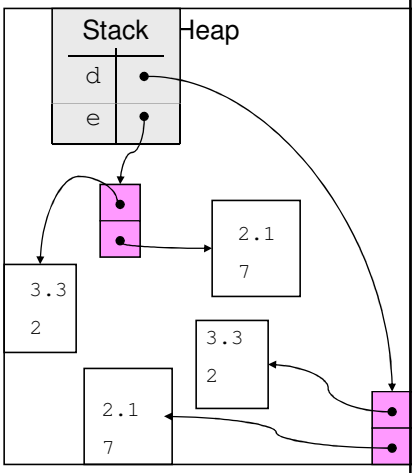
Shallow Copying

```
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];
}
```



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]);
}
```



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");
```

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.