Chapter 13

Arrays of Objects

13.1 The Road Ahead

In the next three chapters we will develop programs to work with playing cards and decks of cards. Before we dive in, here is an outline of the steps:

1. In this chapter we'll define a `Card` class and write methods that work with `Cards` and arrays of `Cards`.

2. In Chapter 14 we will create a `Deck` class and write methods that operate on `Decks`.

3. In Chapter 15 I will present object-oriented programming (OOP) and we will transform the `Card` and `Deck` classes into a more OOP style.

I think that way of proceeding makes the road smoother; the drawback is that we will see several versions of the same code, which can be confusing. If it helps, you can download the code for each chapter as you go along. The code for this chapter is here: `http://thinkapjava.com/code/Card1.java`.

13.2 `Card` objects

If you are not familiar with common playing cards, now would be a good time to get a deck, or else this chapter might not make much sense. Or read `http://en.wikipedia.org/wiki/Playing_card`.

There are 52 cards in a deck; each belongs to one of four suits and one of 13 ranks. The suits are Spades, Hearts, Diamonds and Clubs (in descending order in Bridge). The ranks are Ace, 2, 3, 4, 5, 6, 7, 8, 9, 10, Jack, Queen and King. Depending on what game you are playing, the Ace may be considered higher than King or lower than 2.

If we want to define a new object to represent a playing card, it is pretty obvious what the instance variables should be: `rank` and `suit`. It is not as obvious what type the instance variables should be. One possibility is `String`s, containing things like `"Spade"` for suits and `"Queen"` for ranks. One problem with this implementation is that it would not be easy to compare cards to see which had higher rank or suit.

An alternative is to use integers to **encode** the ranks and suits. By "encode" I do not mean what some people think, which is to encrypt or translate into a secret code. What a computer scientist means by "encode" is something like "define a mapping between a sequence of numbers and the things I want to represent." For example,

Spades	$\mapsto$	3
Hearts	$\mapsto$	2
Diamonds	$\mapsto$	1
Clubs	$\mapsto$	0

The obvious feature of this mapping is that the suits map to integers in order, so we can compare suits by comparing integers. The mapping for ranks is fairly obvious; each of the numerical ranks maps to the corresponding integer, and for face cards:

Jack	$\mapsto$	11
Queen	$\mapsto$	12
King	$\mapsto$	13

The reason I am using mathematical notation for these mappings is that they are not part of the program. They are part of the program design, but they never appear explicitly in the code. The class definition for the `Card` type looks like this:

```
class Card
{
    int suit, rank;
    public Card() {
        this.suit = 0;  this.rank = 0;
    }

    public Card(int suit, int rank) {
        this.suit = suit;  this.rank = rank;
    }
}
```

As usual, I provide two constructors: one takes a parameter for each instance variable; the other takes no parameters.

To create an object that represents the 3 of Clubs, we invoke `new`:

```
    Card threeOfClubs = new Card(0, 3);
```

The first argument, `0` represents the suit Clubs.

13.3 The `printCard` method

When you create a new class, the first step is to declare the instance variables and write constructors. The second step is to write the standard methods that every object should have, including one that prints the object, and one or two that compare objects. Let's start with `printCard`.

To print `Card` objects in a way that humans can read easily, we want to map the integer codes onto words. A natural way to do that is with an array of `String`s. You can create an array of `String`s the same way you create an array of primitive types:

```
    String[] suits = new String[4];
```

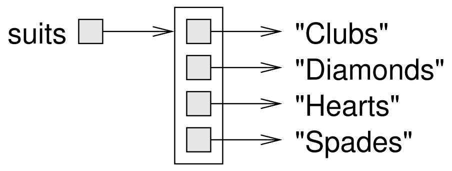
Then we can set the values of the elements of the array.

```
    suits[0] = "Clubs";
    suits[1] = "Diamonds";
    suits[2] = "Hearts";
    suits[3] = "Spades";
```

Creating an array and initializing the elements is such a common operation that Java provides a special syntax for it:

```
    String[] suits = { "Clubs", "Diamonds", "Hearts", "Spades" };
```

This statement is equivalent to the separate declaration, allocation, and assignment. The state diagram of this array looks like:



The elements of the array are *references* to the `String`s, rather than `String`s themselves.

Now we need another array of `String`s to decode the ranks:

```
    String[] ranks = { "narf", "Ace", "2", "3", "4", "5", "6",
                 "7", "8", "9", "10", "Jack", "Queen", "King" };
```

The reason for the `"narf"` is to act as a place-keeper for the zeroeth element of the array, which is never used (or shouldn't be). The only valid ranks are 1–13. To avoid this wasted element, we could have started at 0, but the mapping is more natural if we encode 2 as 2, and 3 as 3, etc.

Using these arrays, we can select the appropriate `String`s by using the `suit` and `rank` as indices. In the method `printCard`,

```
public static void printCard(Card c) {
    String[] suits = { "Clubs", "Diamonds", "Hearts", "Spades" };
    String[] ranks = { "narf", "Ace", "2", "3", "4", "5", "6",
                 "7", "8", "9", "10", "Jack", "Queen", "King" };

    System.out.println(ranks[c.rank] + " of " + suits[c.suit]);
}
```

the expression `suits[c.suit]` means "use the instance variable `suit` from the object `c` as an index into the array named `suits`, and select the appropriate string." The output of this code

```
    Card card = new Card(1, 11);
    printCard(card);
```

is `Jack of Diamonds`.

13.4 The sameCard method

The word "same" is one of those things that occur in natural language that seem perfectly clear until you give it some thought, and then you realize there is more to it than you expected.

For example, if I say "Chris and I have the same car," I mean that his car and mine are the same make and model, but they are two different cars. If I say "Chris and I have the same mother," I mean that his mother and mine are one person. So the idea of "sameness" is different depending on the context.

When you talk about objects, there is a similar ambiguity. For example, if two `Card`s are the same, does that mean they contain the same data (rank and suit), or they are actually the same `Card` object?

To see if two references refer to the same object, we use the `==` operator. For example:

```
Card card1 = new Card(1, 11);
Card card2 = card1;

if (card1 == card2) {
    System.out.println("card1 and card2 are identical.");
}
```

References to the same object are **identical**. References to objects with same data are **equivalent**.

To check equivalence, it is common to write a method with a name like `sameCard`.

```
public static boolean sameCard(Card c1, Card c2) {
    return(c1.suit == c2.suit && c1.rank == c2.rank);
}
```

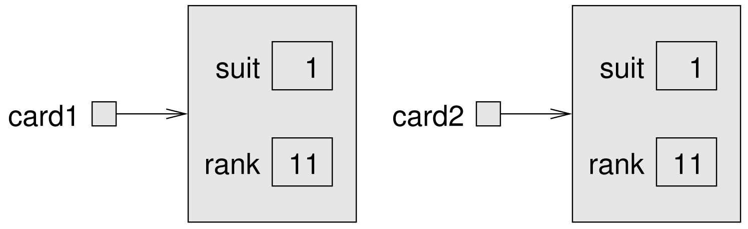
Here is an example that creates two objects with the same data, and uses `sameCard` to see if they are equivalent:

```
Card card1 = new Card(1, 11);
Card card2 = new Card(1, 11);

if (sameCard(card1, card2)) {
    System.out.println("card1 and card2 are equivalent.");
    }
```

If references are identical, they are also equivalent, but if they are equivalent, they are not necessarily identical.

In this case, `card1` and `card2` are equivalent but not identical, so the state diagram looks like this:



What does it look like when `card1` and `card2` are identical?

In Section 8.10 I said that you should not use the `==` operator on `String`s because it does not do what you expect. Instead of comparing the contents of the `String` (equivalence), it checks whether the two `String`s are the same object (identity).

13.5 The `compareCard` method

For primitive types, the conditional operators compare values and determine when one is greater or less than another. These operators (`<` and `>` and the others) don't work for object types. For `String`s Java provides a `compareTo` method. For `Card`s we have to write our own, which we will call `compareCard`. Later, we will use this method to sort a deck of cards.

Some sets are completely ordered, which means that you can compare any two elements and tell which is bigger. Integers and floating-point numbers are totally ordered. Some sets are unordered, which means that there is no meaningful way to say that one element is bigger than another. Fruits are unordered, which is why we cannot compare apples and oranges. In Java, the `boolean` type is unordered; we cannot say that `true` is greater than `false`.

The set of playing cards is partially ordered, which means that sometimes we can compare cards and sometimes not. For example, I know that the 3 of Clubs is higher than the 2 of Clubs, and the 3 of Diamonds is higher than the 3 of Clubs. But which is better, the 3 of Clubs or the 2 of Diamonds? One has a higher rank, but the other has a higher suit.

To make cards comparable, we have to decide which is more important, rank or suit. The choice is arbitrary, but when you buy a new deck of cards, it comes sorted with all the Clubs together, followed by all the Diamonds, and so on. So let's say that suit is more important.

With that decided, we can write `compareCard`. It takes two `Card`s as parameters and returns 1 if the first card wins, -1 if the second card wins, and 0 if they are equivalent.

First we compare suits:

```
    if (c1.suit > c2.suit) return 1;
    if (c1.suit < c2.suit) return -1;
```

If neither statement is true, the suits must be equal, and we have to compare ranks:

```
    if (c1.rank > c2.rank) return 1;
    if (c1.rank < c2.rank) return -1;
```

If neither of these is true, the ranks must be equal, so we return `0`.

13.6 Arrays of cards

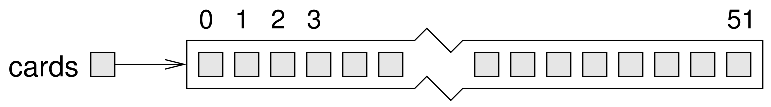
By now we have seen several examples of composition (the ability to combine language features in a variety of arrangements). One of the first examples we saw was using a method invocation as part of an expression. Another example is the nested structure of statements: you can put an `if` statement within a `while` loop, or within another `if` statement, etc.

Having seen this pattern, and having learned about arrays and objects, you should not be surprised to learn that you can make arrays of objects. And you can define objects with arrays as instance variables; you can make arrays that contain arrays; you can define objects that contain objects, and so on. In the next two chapters we will see examples of these combinations using `Card` objects.

This example creates an array of 52 cards:

```
Card[] cards = new Card[52];
```

Here is the state diagram for this object:



The array contains *references* to objects; it does not contain the `Card` objects themselves. The elements are initialized to `null`. You can access the elements of the array in the usual way:

```
if (cards[0] == null) {
    System.out.println("No cards yet!");
}
```

But if you try to access the instance variables of the non-existent `Card`s, you get a `NullPointerException`.

```
cards[0].rank;                // NullPointerException
```

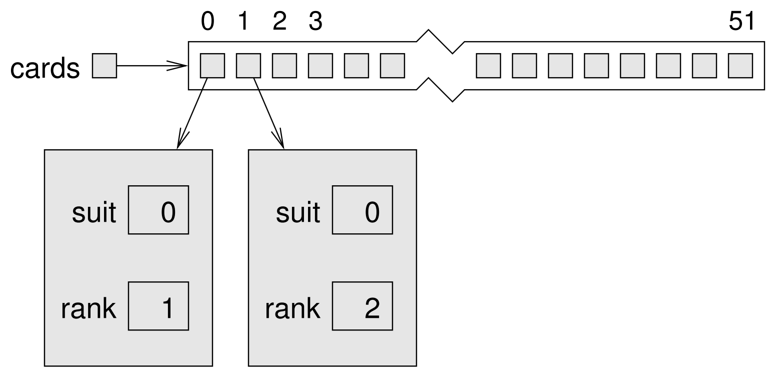
But that is the correct syntax for accessing the `rank` of the "zeroeth" card in the deck. This is another example of composition, combining the syntax for accessing an element of an array and an instance variable of an object.

The easiest way to populate the deck with `Card` objects is to write nested for loops (i.e., one loop inside the body of another):

```
int index = 0;
for (int suit = 0; suit <= 3; suit++) {
    for (int rank = 1; rank <= 13; rank++) {
        cards[index] = new Card(suit, rank);
        index++;
    }
}
```

The outer loop enumerates the suits from 0 to 3. For each suit, the inner loop enumerates the ranks from 1 to 13. Since the outer loop runs 4 times, and the inner loop runs 13 times, the body is executed is 52 times.

I used `index` to keep track of where in the deck the next card should go. The following state diagram shows what the deck looks like after the first two cards have been allocated:



13.7 The printDeck method

When you work with arrays, it is convenient to have a method that prints the contents. We have seen the pattern for traversing an array several times, so the following method should be familiar:

```
    public static void printDeck(Card[] cards) {
        for (int i = 0; i < cards.length; i++) {
            printCard(cards[i]);
        }
    }
```

Since `cards` has type `Card[]`, an element of `cards` has type `Card`. So `cards[i]` is a legal argument for `printCard`.

13.8 Searching

The next method I'll write is `findCard`, which searches an array of `Card`s to see whether it contains a certain card. This method gives me a chance to demonstrate two algorithms: **linear search** and **bisection search**.

Linear search is pretty obvious; we traverse the deck and compare each card to the one we are looking for. If we find it we return the index where the card appears. If it is not in the deck, we return -1.

```
public static int findCard(Card[] cards, Card card) {
    for (int i = 0; i< cards.length; i++) {
        if (sameCard(cards[i], card)) {
            return i;
        }
    }
    return -1;
}
```

The arguments of `findCard` are `card` and `cards`. It might seem odd to have a variable with the same name as a type (the `card` variable has type `Card`). We can tell the difference because the variable begins with a lower-case letter.

The method returns as soon as it discovers the card, which means that we do not have to traverse the entire deck if we find the card we are looking for. If we get to the end of the loop, we know the card is not in the deck.

If the cards in the deck are not in order, there is no way to search faster than this. We have to look at every card because otherwise we can't be certain the card we want is not there.

But when you look for a word in a dictionary, you don't search linearly through every word, because the words are in alphabetical order. As a result, you probably use an algorithm similar to a bisection search:

1. Start in the middle somewhere.
2. Choose a word on the page and compare it to the word you are looking for.
3. If you find the word you are looking for, stop.
4. If the word you are looking for comes after the word on the page, flip to somewhere later in the dictionary and go to step 2.
5. If the word you are looking for comes before the word on the page, flip to somewhere earlier in the dictionary and go to step 2.

If you ever get to the point where there are two adjacent words on the page and your word comes between them, you can conclude that your word is not in the dictionary.

Getting back to the deck of cards, if we know the cards are in order, we can write a faster version of `findCard`. The best way to write a bisection search is with a recursive method, because bisection is naturally recursive.

The trick is to write a method called `findBisect` that takes two indices as parameters, `low` and `high`, indicating the segment of the array that should be searched (including both `low` and `high`).

1. To search the array, choose an index between `low` and `high` (call it `mid`) and compare it to the card you are looking for.
2. If you found it, stop.
3. If the card at `mid` is higher than your card, search the range from `low` to `mid-1`.
4. If the card at `mid` is lower than your card, search the range from `mid+1` to `high`.

Steps 3 and 4 look suspiciously like recursive invocations. Here's what this looks like translated into Java code:

```java
public static int findBisect(Card[] cards, Card card, int low, int high) {
    // TODO: need a base case
    int mid = (high + low) / 2;
    int comp = compareCard(cards[mid], card);

    if (comp == 0) {
        return mid;
    } else if (comp > 0) {
        return findBisect(cards, card, low, mid-1);
    } else {
        return findBisect(cards, card, mid+1, high);
    }
}
```

This code contains the kernel of a bisection search, but it is still missing an important piece, which is why I added a TODO comment. As written, the method recurses forever if the card is not in the deck. We need a base case to handle this condition.

If `high` is less than `low`, there are no cards between them, see we conclude that the card is not in the deck. If we handle that case, the method works correctly:

```
public static int findBisect(Card[] cards, Card card, int low, int high) {
    System.out.println(low + ", " + high);

    if (high < low) return -1;

    int mid = (high + low) / 2;
    int comp = compareCard(cards[mid], card);

    if (comp == 0) {
        return mid;
    } else if (comp > 0) {
        return findBisect(cards, card, low, mid-1);
    } else {
        return findBisect(cards, card, mid+1, high);
    }
}
```

I added a print statement so I can follow the sequence of recursive invocations. I tried out the following code:

```
    Card card1 = new Card(1, 11);
    System.out.println(findBisect(cards, card1, 0, 51));
```

And got the following output:

```
0, 51
0, 24
13, 24
19, 24
22, 24
23
```

Then I made up a card that is not in the deck (the 15 of Diamonds), and tried to find it. I got the following:

```
0, 51
0, 24
13, 24
13, 17
13, 14
13, 12
-1
```

These tests don't prove that this program is correct. In fact, no amount of testing can prove that a program is correct. On the other hand, by looking at a few cases and examining the code, you might be able to convince yourself.

The number of recursive invocations is typically 6 or 7, so we only invoke `compareCard` 6 or 7 times, compared to up to 52 times if we did a linear search. In general, bisection is much faster than a linear search, and even more so for large arrays.

Two common errors in recursive programs are forgetting to include a base case and writing the recursive call so that the base case is never reached. Either error causes infinite recursion, which throws a `StackOverflowException`. (Think of a stack diagram for a recursive method that never ends.)

13.9 Decks and subdecks

Here is the prototype (see Section 8.5) of `findBisect`:

```
public static int findBisect(Card[] deck, Card card, int low, int high)
```

We can think of `cards`, `low`, and `high` as a single parameter that specifies a **subdeck**. This way of thinking is common, and is sometimes referred to as an **abstract parameter**. What I mean by "abstract" is something that is not literally part of the program text, but which describes the function of the program at a higher level.

For example, when you invoke a method and pass an array and the bounds `low` and `high`, there is nothing that prevents the invoked method from accessing parts of the array that are out of bounds. So you are not literally sending a subset of the deck; you are really sending the whole deck. But as long as the recipient plays by the rules, it makes sense to think of it abstractly as a subdeck.

This kind of thinking, in which a program takes on meaning beyond what is literally encoded, is an important part of thinking like a computer scientist. The word "abstract" gets used so often and in so many contexts that it comes to lose its meaning. Nevertheless, **abstraction** is a central idea in computer science (and many other fields).

A more general definition of "abstraction" is "The process of modeling a complex system with a simplified description to suppress unnecessary details while capturing relevant behavior."

13.10 Glossary

encode: To represent one set of values using another set of values, by constructing a mapping between them.

identity: Equality of references. Two references that point to the same object in memory.

equivalence: Equality of values. Two references that point to objects that contain the same data.

abstract parameter: A set of parameters that act together as a single parameter.

abstraction: The process of interpreting a program (or anything else) at a higher level than what is literally represented by the code.

13.11 Exercises

Exercise 13.1. Encapsulate the code in Section 13.5 in a method. Then modify it so that aces are ranked higher than Kings.

Exercise 13.2. Encapsulate the deck-building code of Section 13.6 in a method called `makeDeck` that takes no parameters and returns a fully-populated array of `Card`s.

Exercise 13.3. In Blackjack the object of the game is to get a collection of cards with a score of 21. The score for a hand is the sum of scores for all cards. The score for an aces is 1, for all face cards is ten, and for all other cards the score is the same as the rank. Example: the hand (Ace, 10, Jack, 3) has a total score of $1 + 10 + 10 + 3 = 24$.

Write a method called `handScore` that takes an array of cards as an argument and that returns the total score.

Exercise 13.4. In Poker a "flush" is a hand that contains five or more cards of the same suit. A hand can contain any number of cards.

1. Write a method called `suitHist` that takes an array of Cards as a parameter and that returns a histogram of the suits in the hand. Your solution should only traverse the array once.

2. Write a method called `hasFlush` that takes an array of Cards as a parameter and that returns `true` if the hand contains a flush, and `false` otherwise.

Exercise 13.5. Working with cards is more interesting if you can display them on the screen. If you haven't played with the graphics examples in Appendix A, you might want to do that now.

First download `http://thinkapjava.com/code/CardTable.java` and `http://thinkapjava.com/code/cardset.zip` into the same folder. Then unzip `cardset.zip`, which contains a `cardset-oxymoron` subfolder with all the card images. (Note the variable `cardset` in `CardTable.main` is the name of this folder.) Run `CardTable.java` and you should see images of a pack of cards laid out on a green table.

You can use this class as a starting place to implement your own card games.