

# Inheritance

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October 23, 2018

The language feature most often associated with object-oriented programming is **inheritance**. Inheritance is the ability to define a new class that is a modified version of an existing class. In this chapter I demonstrate inheritance using classes that represent playing cards, decks of cards, and poker hands.

If you don't play poker, you can read about it at <http://en.wikipedia.org/wiki/Poker>, but you don't have to; I'll tell you what you need to know for the exercises.

Code examples from this chapter are available from <http://thinkpython2.com/code/Card.py>.

## 1 Card objects

There are fifty-two cards in a deck, each of which belongs to one of four suits and one of thirteen 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 the game that you are playing, an Ace may be higher than King or lower than 2.

If we want to define a new object to represent a playing card, it is obvious what the attributes should be: rank and suit. It is not as obvious what type the attributes should be. One possibility is to use strings containing words 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 a higher rank or suit.

An alternative is to use integers to **encode** the ranks and suits. In this context, “encode” means that we are going to define a mapping between numbers and suits, or between numbers and ranks. This kind of encoding is not meant to be a secret (that would be “encryption”).

For example, this table shows the suits and the corresponding integer codes:

Spades	↦	3
Hearts	↦	2
Diamonds	↦	1
Clubs	↦	0

This code makes it easy to compare cards; because higher suits map to higher numbers, we can compare suits by comparing their codes.

The mapping for ranks is fairly obvious; each of the numerical ranks maps to the corresponding integer, and for face cards:

Jack	↦	11
Queen	↦	12
King	↦	13

I am using the  $\mapsto$  symbol to make it clear that these mappings are not part of the Python program. They are part of the program design, but they don't appear explicitly in the code.

The class definition for Card looks like this:

```
class Card:
    """Represents a standard playing card."""

    def __init__(self, suit=0, rank=2):
        self.suit = suit
        self.rank = rank
```

As usual, the init method takes an optional parameter for each attribute. The default card is the 2 of Clubs.

To create a Card, you call Card with the suit and rank of the card you want.

```
queen_of_diamonds = Card(1, 12)
```

## 2 Class attributes

In order to print Card objects in a way that people can easily read, we need a mapping from the integer codes to the corresponding ranks and suits. A natural way to do that is with lists of strings. We assign these lists to **class attributes**:

```
# inside class Card:

suit_names = ['Clubs', 'Diamonds', 'Hearts', 'Spades']
rank_names = [None, 'Ace', '2', '3', '4', '5', '6', '7',
              '8', '9', '10', 'Jack', 'Queen', 'King']

def __str__(self):
    return '%s of %s' % (Card.rank_names[self.rank],
                        Card.suit_names[self.suit])
```

Variables like suit\_names and rank\_names, which are defined inside a class but outside of any method, are called class attributes because they are associated with the class object Card.

This term distinguishes them from variables like suit and rank, which are called **instance attributes** because they are associated with a particular instance.

Both kinds of attribute are accessed using dot notation. For example, in \_\_str\_\_, self is a Card object, and self.rank is its rank. Similarly, Card is a class object, and Card.rank\_names is a list of strings associated with the class.

Every card has its own suit and rank, but there is only one copy of suit\_names and rank\_names.

Putting it all together, the expression Card.rank\_names[self.rank] means “use the attribute rank from the object self as an index into the list rank\_names from the class Card, and select the appropriate string.”

The first element of rank\_names is None because there is no card with rank zero. By including None as a place-keeper, we get a mapping with the nice property that the index 2 maps to the string '2', and so on. To avoid this tweak, we could have used a dictionary instead of a list.

With the methods we have so far, we can create and print cards:

```
>>> card1 = Card(2, 11)
>>> print(card1)
Jack of Hearts
```

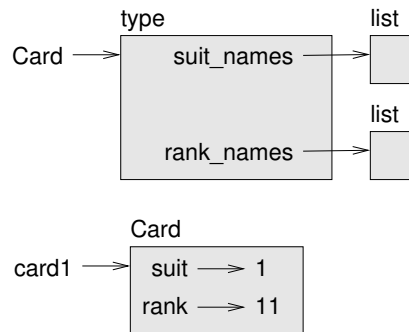


Figure 1: Object diagram.

Figure 1 is a diagram of the `Card` class object and one `Card` instance. `Card` is a class object; its type is `type`. `card1` is an instance of `Card`, so its type is `Card`. To save space, I didn't draw the contents of `suit_names` and `rank_names`.

### 3 Comparing cards

For built-in types, there are relational operators (`<`, `>`, `==`, etc.) that compare values and determine when one is greater than, less than, or equal to another. For programmer-defined types, we can override the behavior of the built-in operators by providing a method named `__lt__`, which stands for "less than".

`__lt__` takes two parameters, `self` and `other`, and returns `True` if `self` is strictly less than `other`.

The correct ordering for cards is not obvious. For example, which is better, the 3 of Clubs or the 2 of Diamonds? One has a higher rank, but the other has a higher suit. In order to compare cards, you have to decide whether rank or suit is more important.

The answer might depend on what game you are playing, but to keep things simple, we'll make the arbitrary choice that suit is more important, so all of the Spades outrank all of the Diamonds, and so on.

With that decided, we can write `__lt__`:

```
# inside class Card:

def __lt__(self, other):
    # check the suits
    if self.suit < other.suit: return True
    if self.suit > other.suit: return False

    # suits are the same... check ranks
    return self.rank < other.rank
```

You can write this more concisely using tuple comparison:

```
# inside class Card:

def __lt__(self, other):
    t1 = self.suit, self.rank
    t2 = other.suit, other.rank
    return t1 < t2
```

As an exercise, write an `__lt__` method for `Time` objects. You can use tuple comparison, but you also might consider comparing integers.

## 4 Decks

Now that we have `Cards`, the next step is to define `Decks`. Since a deck is made up of cards, it is natural for each `Deck` to contain a list of cards as an attribute.

The following is a class definition for `Deck`. The `init` method creates the attribute `cards` and generates the standard set of fifty-two cards:

```
class Deck:

    def __init__(self):
        self.cards = []
        for suit in range(4):
            for rank in range(1, 14):
                card = Card(suit, rank)
                self.cards.append(card)
```

The easiest way to populate the deck is with a nested loop. The outer loop enumerates the suits from 0 to 3. The inner loop enumerates the ranks from 1 to 13. Each iteration creates a new `Card` with the current suit and rank, and appends it to `self.cards`.

## 5 Printing the deck

Here is a `__str__` method for `Deck`:

```
#inside class Deck:

    def __str__(self):
        res = []
        for card in self.cards:
            res.append(str(card))
        return '\n'.join(res)
```

This method demonstrates an efficient way to accumulate a large string: building a list of strings and then using the string method `join`. The built-in function `str` invokes the `__str__` method on each card and returns the string representation.

Since we invoke `join` on a newline character, the cards are separated by newlines. Here's what the result looks like:

```
>>> deck = Deck()
>>> print(deck)
Ace of Clubs
2 of Clubs
3 of Clubs
...
10 of Spades
Jack of Spades
Queen of Spades
King of Spades
```

Even though the result appears on 52 lines, it is one long string that contains newlines.

## 6 Add, remove, shuffle and sort

To deal cards, we would like a method that removes a card from the deck and returns it. The list method `pop` provides a convenient way to do that:

```
#inside class Deck:

    def pop_card(self):
        return self.cards.pop()
```

Since `pop` removes the *last* card in the list, we are dealing from the bottom of the deck.

To add a card, we can use the list method `append`:

```
#inside class Deck:

    def add_card(self, card):
        self.cards.append(card)
```

A method like this that uses another method without doing much work is sometimes called a **veneer**. The metaphor comes from woodworking, where a veneer is a thin layer of good quality wood glued to the surface of a cheaper piece of wood to improve the appearance.

In this case `add_card` is a “thin” method that expresses a list operation in terms appropriate for decks. It improves the appearance, or interface, of the implementation.

As another example, we can write a `Deck` method named `shuffle` using the function `shuffle` from the `random` module:

```
# inside class Deck:

    def shuffle(self):
        random.shuffle(self.cards)
```

Don’t forget to import `random`.

As an exercise, write a `Deck` method named `sort` that uses the list method `sort` to sort the cards in a `Deck`. `sort` uses the `__lt__` method we defined to determine the order.

## 7 Inheritance

Inheritance is the ability to define a new class that is a modified version of an existing class. As an example, let’s say we want a class to represent a “hand”, that is, the cards held by one player. A hand is similar to a deck: both are made up of a collection of cards, and both require operations like adding and removing cards.

A hand is also different from a deck; there are operations we want for hands that don’t make sense for a deck. For example, in poker we might compare two hands to see which one wins. In bridge, we might compute a score for a hand in order to make a bid.

This relationship between classes—similar, but different—lends itself to inheritance. To define a new class that inherits from an existing class, you put the name of the existing class in parentheses:

```
class Hand(Deck):
    """Represents a hand of playing cards."""
```

This definition indicates that `Hand` inherits from `Deck`; that means we can use methods like `pop_card` and `add_card` for `Hands` as well as `Decks`.

When a new class inherits from an existing one, the existing one is called the **parent** and the new class is called the **child**.

In this example, `Hand` inherits `__init__` from `Deck`, but it doesn't really do what we want: instead of populating the hand with 52 new cards, the `init` method for `Hands` should initialize cards with an empty list.

If we provide an `init` method in the `Hand` class, it overrides the one in the `Deck` class:

```
# inside class Hand:

    def __init__(self, label=''):
        self.cards = []
        self.label = label
```

When you create a `Hand`, Python invokes this `init` method, not the one in `Deck`.

```
>>> hand = Hand('new hand')
>>> hand.cards
[]
>>> hand.label
'new hand'
```

The other methods are inherited from `Deck`, so we can use `pop_card` and `add_card` to deal a card:

```
>>> deck = Deck()
>>> card = deck.pop_card()
>>> hand.add_card(card)
>>> print(hand)
King of Spades
```

A natural next step is to encapsulate this code in a method called `move_cards`:

```
#inside class Deck:

    def move_cards(self, hand, num):
        for i in range(num):
            hand.add_card(self.pop_card())
```

`move_cards` takes two arguments, a `Hand` object and the number of cards to deal. It modifies both `self` and `hand`, and returns `None`.

In some games, cards are moved from one hand to another, or from a hand back to the deck. You can use `move_cards` for any of these operations: `self` can be either a `Deck` or a `Hand`, and `hand`, despite the name, can also be a `Deck`.

Inheritance is a useful feature. Some programs that would be repetitive without inheritance can be written more elegantly with it. Inheritance can facilitate code reuse, since you can customize the behavior of parent classes without having to modify them. In some cases, the inheritance structure reflects the natural structure of the problem, which makes the design easier to understand.

On the other hand, inheritance can make programs difficult to read. When a method is invoked, it is sometimes not clear where to find its definition. The relevant code may be spread across several modules. Also, many of the things that can be done using inheritance can be done as well or better without it.

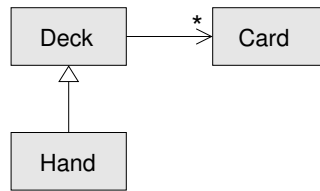


Figure 2: Class diagram.

## 8 Class diagrams

So far we have seen stack diagrams, which show the state of a program, and object diagrams, which show the attributes of an object and their values. These diagrams represent a snapshot in the execution of a program, so they change as the program runs.

They are also highly detailed; for some purposes, too detailed. A class diagram is a more abstract representation of the structure of a program. Instead of showing individual objects, it shows classes and the relationships between them.

There are several kinds of relationship between classes:

- Objects in one class might contain references to objects in another class. For example, each Rectangle contains a reference to a Point, and each Deck contains references to many Cards. This kind of relationship is called **HAS-A**, as in, “a Rectangle has a Point.”
- One class might inherit from another. This relationship is called **IS-A**, as in, “a Hand is a kind of a Deck.”
- One class might depend on another in the sense that objects in one class take objects in the second class as parameters, or use objects in the second class as part of a computation. This kind of relationship is called a **dependency**.

A **class diagram** is a graphical representation of these relationships. For example, Figure 2 shows the relationships between Card, Deck and Hand.

The arrow with a hollow triangle head represents an IS-A relationship; in this case it indicates that Hand inherits from Deck.

The standard arrow head represents a HAS-A relationship; in this case a Deck has references to Card objects.

The star (\*) near the arrow head is a **multiplicity**; it indicates how many Cards a Deck has. A multiplicity can be a simple number, like 52, a range, like 5..7 or a star, which indicates that a Deck can have any number of Cards.

There are no dependencies in this diagram. They would normally be shown with a dashed arrow. Or if there are a lot of dependencies, they are sometimes omitted.

A more detailed diagram might show that a Deck actually contains a *list* of Cards, but built-in types like list and dict are usually not included in class diagrams.

## 9 Debugging

Inheritance can make debugging difficult because when you invoke a method on an object, it might be hard to figure out which method will be invoked.

Suppose you are writing a function that works with Hand objects. You would like it to work with all kinds of Hands, like PokerHands, BridgeHands, etc. If you invoke a method

like `shuffle`, you might get the one defined in `Deck`, but if any of the subclasses override this method, you'll get that version instead. This behavior is usually a good thing, but it can be confusing.

Any time you are unsure about the flow of execution through your program, the simplest solution is to add print statements at the beginning of the relevant methods. If `Deck.shuffle` prints a message that says something like `Running Deck.shuffle`, then as the program runs it traces the flow of execution.

As an alternative, you could use this function, which takes an object and a method name (as a string) and returns the class that provides the definition of the method:

```
def find_defining_class(obj, meth_name):
    for ty in type(obj).mro():
        if meth_name in ty.__dict__:
            return ty
```

Here's an example:

```
>>> hand = Hand()
>>> find_defining_class(hand, 'shuffle')
<class 'Card.Deck'>
```

So the `shuffle` method for this `Hand` is the one in `Deck`.

`find_defining_class` uses the `mro` method to get the list of class objects (types) that will be searched for methods. “MRO” stands for “method resolution order”, which is the sequence of classes Python searches to “resolve” a method name.

Here's a design suggestion: when you override a method, the interface of the new method should be the same as the old. It should take the same parameters, return the same type, and obey the same preconditions and postconditions. If you follow this rule, you will find that any function designed to work with an instance of a parent class, like a `Deck`, will also work with instances of child classes like a `Hand` and `PokerHand`.

If you violate this rule, which is called the “Liskov substitution principle”, your code will collapse like (sorry) a house of cards.

## 10 Data encapsulation

The previous chapters demonstrate a development plan we might call “object-oriented design”. We identified objects we needed—like `Point`, `Rectangle` and `Time`—and defined classes to represent them. In each case there is an obvious correspondence between the object and some entity in the real world (or at least a mathematical world).

But sometimes it is less obvious what objects you need and how they should interact. In that case you need a different development plan. In the same way that we discovered function interfaces by encapsulation and generalization, we can discover class interfaces by **data encapsulation**.

Markov analysis provides a good example. If you download my code from <http://thinkpython2.com/code/markov.py>, you'll see that it uses two global variables—`suffix_map` and `prefix`—that are read and written from several functions.

```
suffix_map = {}
prefix = ()
```



Because these variables are global, we can only run one analysis at a time. If we read two texts, their prefixes and suffixes would be added to the same data structures (which makes for some interesting generated text).

To run multiple analyses, and keep them separate, we can encapsulate the state of each analysis in an object. Here's what that looks like:

```
class Markov:
```

```
    def __init__(self):
        self.suffix_map = {}
        self.prefix = ()
```

Next, we transform the functions into methods. For example, here's `process_word`:

```
    def process_word(self, word, order=2):
        if len(self.prefix) < order:
            self.prefix += (word,)
            return

        try:
            self.suffix_map[self.prefix].append(word)
        except KeyError:
            # if there is no entry for this prefix, make one
            self.suffix_map[self.prefix] = [word]

        self.prefix = shift(self.prefix, word)
```

Transforming a program like this—changing the design without changing the behavior—is another example of refactoring.

This example suggests a development plan for designing objects and methods:

1. Start by writing functions that read and write global variables (when necessary).
2. Once you get the program working, look for associations between global variables and the functions that use them.
3. Encapsulate related variables as attributes of an object.
4. Transform the associated functions into methods of the new class.

As an exercise, download my Markov code from <http://thinkpython2.com/code/markov.py>, and follow the steps described above to encapsulate the global variables as attributes of a new class called `Markov`. Solution: <http://thinkpython2.com/code/Markov.py> (note the capital M).

## 11 Glossary

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

**class attribute:** An attribute associated with a class object. Class attributes are defined inside a class definition but outside any method.

**instance attribute:** An attribute associated with an instance of a class.

**veneer:** A method or function that provides a different interface to another function without doing much computation.

**inheritance:** The ability to define a new class that is a modified version of a previously defined class.

**parent class:** The class from which a child class inherits.

**child class:** A new class created by inheriting from an existing class; also called a “sub-class”.

**IS-A relationship:** A relationship between a child class and its parent class.

**HAS-A relationship:** A relationship between two classes where instances of one class contain references to instances of the other.

**dependency:** A relationship between two classes where instances of one class use instances of the other class, but do not store them as attributes.

**class diagram:** A diagram that shows the classes in a program and the relationships between them.

**multiplicity:** A notation in a class diagram that shows, for a HAS-A relationship, how many references there are to instances of another class.

**data encapsulation:** A program development plan that involves a prototype using global variables and a final version that makes the global variables into instance attributes.