Classes: programmer-defined types

Sometimes we use a collection of variables to represent a specific object

**Example:** we used a tuple of tuples to represent a matrix

**Example:** representing state of a board game
   List of players, piece positions, etc.

**Example:** representing a statistical model
   Want to support methods for estimation, data generation, etc.

**Important point:** these data structures quickly become very complicated, and we want a way to encapsulate them. This is a core motivation (but hardly the only one) for **object-oriented programming**.
Classes encapsulate data types

**Example:** I want to represent a point in 2-dimensional space $\mathbb{R}^2$

**Option 1:** just represent a point by a 2-tuple
Classes encapsulate data types

**Example:** I want to represent a point in 2-dimensional space $\mathbb{R}^2$.

**Option 1:** just represent a point by a 2-tuple

**Option 2:** make a point **class**, so that we have a whole new data type. Additional good reasons for this will become apparent shortly!
Classes encapsulate data types

Example: I want to represent a point in 2-dimensional space $\mathbb{R}^2$

Option 1: just represent a point by a 2-tuple

Option 2: make a point class, so that we have a whole new data type

Additional good reasons for this will become apparent shortly!

```
1 class Point:
2     '''Represents a 2-d point.'''
```

```
1 print(Point)
```

Credit: Running example adapted from A. B. Downey, *Think Python*
Classes encapsulate data types

Example: I want to represent a point in 2-dimensional space $\mathbb{R}^2$

Option 1: just represent a point by a 2-tuple

Option 2: make a point class, so that we have a whole new data type

Additional good reasons for this will become apparent shortly!

```
1 class Point:
2     '''Represents a 2-d point.'''
```

Class definition creates a class object, `Point`.

Credit: Running example adapted from A. B. Downey, *Think Python*
Creating an object: Instantiation

This defines a class `Point`, and from here on we can create new variables of type `Point`.  

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p
<__main__.Point at 0x10669b940>
```
Creating an object: Instantiation

Creating a new object is called **instantiation**. Here we are creating an instance `p` of the class `Point`.

Indeed, `p` is of type `Point`.

**Note**: An instance is an individual object from a given class. In general, the terms **object** and **instance** are interchangeable: an object is an instantiation of a class.
Assigning Attributes

This dot notation should look familiar. Here, we are assigning values to attributes \( x \) and \( y \) of the object \( p \). This both creates the attributes, and assigns their values.

Once the attributes are created, we can access them, again with dot notation.
Assigning Attributes

This dot notation should look familiar. Here, we are assigning values to attributes $x$ and $y$ of the object $p$. This both creates the attributes, and assigns their values.

Once the attributes are created, we can access them, again with dot notation.

Attempting to access an attribute that an object doesn’t have is an error.
Thinking about Attributes: Object Diagrams

At this point, `p` is just an object with no attributes.

```python
class Point:
    '''Represents a 2-d point.''

p = Point()

p.x = 3.0

p.y = 4.0
```
After these two lines, `p` has attributes `x` and `y`.

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p.x = 3.0
p.y = 4.0
```
Thinking about Attributes: Object Diagrams

After these two lines, `p` has attributes `x` and `y`.

So dot notation `p.x`, essentially says, look inside the object `p` and find the attribute `x`. 

```python
class Point:
    '''Represents a 2-d point.'''

p = Point()
p.x = 3.0
p.y = 4.0
```
Nesting Objects

Objects can have other objects as their attributes. We often call the attribute object `embedded`.
Nesting Objects

Both of these blocks of code create equivalent Rectangle objects.

Note here that instead of creating a point and then embedding it, we embed a Point object and then populate its attributes.
Objects are mutable

```python
pl = Point(); pl.x = 3.0; pl.y = 4.0
r1 = Rectangle()
r1.corner = pl
r1.height = 5.0; r1.width = 12.0
r1.height = 2*r1.height

def shift_rectangle(rec, dx, dy):
    rec.corner.x = rec.corner.x + dx
    rec.corner.y = rec.corner.y + dy

shift_rectangle(r1, 2, 3)
(r1.corner.x, r1.corner.y)
```

If my `Rectangle` object were immutable, this line would be an error, because I'm making an assignment.

Since objects are mutable, I can change attributes of an object inside a function and those changes remain in the object in the `__main__` namespace.
Functions can return objects. Note that this function is implicitly assuming that \texttt{rdouble} has the attributes \texttt{corner}, \texttt{height} and \texttt{width}. We will see how to do this soon.

The function creates a \textit{new} \texttt{Rectangle} and returns it. Note that it doesn’t change the attributes of its argument.
Copying and Aliasing

Recall that aliasing is when two or more variables have the same referent i.e., when two variables are identical

Aliasing can often cause unexpected problems

**Solution:** make copy of object; variables equivalent, but not identical

```python
pl = Point(); pl.x = 3.0; pl.y = 4.0
import copy
p2 = copy.copy(pl)
p1 is p2
```

The `copy` module provides functions for copying objects. `p2` is a copy of `p1`, so they should not be identical...
Copying and Aliasing

Recall that aliasing is when two or more variables have the same referent, i.e., when two variables are identical.

Aliasing can often cause unexpected problems.

**Solution:** make copy of object; variables equivalent, but not identical.

```python
pl = Point(); pl.x = 3.0; pl.y = 4.0
import copy
p2 = copy.copy(pl)
pl is p2
False
pl == p2
False
```

The `copy` module provides functions for copying objects. `p2` is a copy of `pl`, so they should not be identical...

...but they should be equivalent.
Copying and Aliasing

Recall that aliasing is when two or more variables have the same referent, i.e., when two variables are identical.

Aliasing can often cause unexpected problems.

**Solution:** make **copy** of object; variables equivalent, but not identical.

```python
1 pl = Point(); pl.x = 3.0; pl.y = 4.0
2 import copy
3 p2 = copy.copy(pl)
4 pl is p2
False
```

Hey, those were supposed to be equivalent! What’s up with that? **Answer:** by default, for programmer-defined types, `==` and `is` are the same. It’s up to you, the programmer, to tell Python how to tell if two objects are equivalent, by defining a method `object.__eq__`. We’ll come back to this.

Documentation for the `copy` module: https://docs.python.org/3/library/copy.html
Here we construct a Rectangle, and then copy it. Expected behavior is that mutable attributes should not be identical, and yet...

...evidently our copied objects still have attributes that are identical.
By default, `copy.copy` only copies the "top level" of attributes. This is a problem if, for example, we have a method like `shift_rectangle` that changes the `corner` attribute. Calling `shift_rectangle(r1)` would also change the `corner` attribute of `r2`.
Copying and Aliasing

```python
pl = Point(); pl.x = 3.0; pl.y = 4.0
r1 = Rectangle()
r1.corner = pl
r1.height = 5.0; r1.width = 12.0
r2 = copy.deepcopy(r1)
```

`copy.deepcopy` is a recursive version of `copy.copy`. So it recursively makes copies of all attributes, and their attributes, and so on.

Now when we test for identity we get the expected behavior. Python has created a copy of `r1.corner`.

`copy.deepcopy` documentation explains how the copying operation is carried out:

https://docs.python.org/3/library/copy.html#copy.deepcopy

We often refer to `copy.copy` as a shallow copy in contrast to `copy.deepcopy`.
Pure functions vs modifiers

A **pure function** is a function that returns an object ...and **does not** modify any of its arguments

A **modifier** is a function that changes attributes of one or more of its arguments

```python
def double_sides(r):
    rdouble = Rectangle()
    rdouble.corner = r.corner
    rdouble.height = 2*r.height
    rdouble.width = 2*r.width
    return(rdouble)
```

double_sides is a pure function. It creates a new object and returns it, without changing the attributes of its argument r.

```python
def shift_rectangle(rec, dx, dy):
    rec.corner.x = rec.corner.x + dx
    rec.corner.y = rec.corner.y + dy
```

shift_rectangle changes the attributes of its argument rec, so it is a modifier. We say that the function has side effects, in that it causes changes outside its scope.

Pure functions vs modifiers

Why should one prefer one over the other?

Pure functions
  Are often easier to debug and verify (i.e., check correctness)
  Common in *functional programming*

Modifiers
  Often faster and more efficient
  Common in *object-oriented programming*
Modifiers vs Methods

A modifier is a **function** that changes attributes of its arguments.

A **method** is *like* a function, but it is provided by an object.

```
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''
    def print_time(self):
        print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))

t = Time()
t.hours=12; t.mins=34; t.secs=56
t.print_time()
```

Credit: Running example adapted from A. B. Downey, *Think Python*
More on Methods

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

    def print_time(self):
        print("%.2d:%.2d:%.2d" % (self.hours, self mins, self.secs))

    def time_to_int(self):
        return(self.secs + 60*self.mins + 3600*self.hours)

    def int_to_time(seconds):
        '''Convert a number of seconds to a Time object.''
        t = Time()
        (minutes, t.secs) = divmod(seconds, 60)
        (hrs, t.mins) = divmod(minutes, 60)
        t.hours = hrs % 24 #military time!
        return t

    t = int_to_time(1337)
t.time_to_int()
```

*int_to_time* is a pure function that creates and returns a new *Time* object.

*Time.time_to_int* is a method, but it is still a pure function in that it has no side effects.
I cropped out `time_to_int` and `print_time` for space.

Two different versions of the same operation. One is a pure function (pure method?), that does not change attributes of the caller. The second method is a modifier.

The modifier method does indeed change the attributes of the caller.

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

def increment_pure(self, seconds):
    '''Return new Time object representing this time incremented by the given number of seconds.'''
    t = Time()
    t = int_to_time(self.time_to_int() + seconds)
    return t

def increment_modifier(self, seconds):
    '''Increment this time by the given number of seconds.'''
    (mins, self.secs) = divmod(self.secs+seconds, 60)
    (hours, self.mins) = divmod(self.mins+mins, 60)
    self.hours = (self.hours + hours)%24

t1 = int_to_time(1234)
t1.increment_modifier(1111)
t1.time_to_int()```
More on Modifiers

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

def time_to_int(self):
    return(self.secs + 60*self.mins + 3600*self.hours)

def print_time(self):
    print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))

def incrementPure(self, seconds):
    '''Return new Time object representing this time
    incremented by the given number of seconds.'''
    t = Time()
    t = int_to_time(self.time_to_int() + seconds)
    return t

t1[incrementPure](100, 200)
```

Here’s an error you may encounter. How the heck did `incrementPure` get 3 arguments?!
More on Modifiers

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''
    def time_to_int(self):
        return(self.secs + 60*self.mins + 3600*self.hours)
    def print_time(self):
        print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))
    def increment_pure(self, seconds):
        '''Return new Time object representing this time
        incremented by the given number of seconds.''
        t = Time()
        t = int_to_time(t.time_to_int() + seconds)
        return t

tl.increment_pure(100, 200)
```

Here's an error you may encounter. How the heck did `increment_pure` get 3 arguments?!

```
TypeError
Traceback (most recent call last)
<ipython-input-55-1d8fb5e5c628> in <module>()
    14     return t
    15 ---> 16 tl.increment_pure(100, 200)

TypeError: increment_pure() takes 2 positional arguments but 3 were given
```

Answer: the caller is considered an argument (because of `self`)!
Recap: Objects, so far

So far: creating classes, attributes, methods

Next steps:
- How to implement operators (+, *, string conversion, etc)
- More complicated methods
- Inheritance

We will not come anywhere near covering OOP in its entirety
- My goal is only to make sure you see the general concepts
- Take a software engineering course to learn the deeper principles of OOP
Creating objects: the `__init__` method

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

def __init__(self, hours=0, mins=0, secs=0):
    self.hours = hours
    self.mins = mins
    self secs = secs

def print_time(self):
    print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self secs))

t = Time(); t.print_time()
00:00:00

t = Time(10); t.print_time()
10:00:00

t = Time(10, 20); t.print_time()
10:20:00
```

`__init__` is a special method that gets called when we instantiate an object. This one takes four arguments.

If we supply fewer than three arguments to `__init__`, it defaults the extras, assigning from left to right until it runs out of arguments.

**Note:** arguments that are not keyword arguments are called **positional arguments**.
Creating objects: the `__init__` method

```python
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

def __init__(self, hours=0, mins=0, secs=0):
    self.hours = hours
    self mins = mins
    self secs = secs

def print_time(self):
    print("%.2d:%.2d:%.2d" % (self.hours, self.mins, self.secs))

t = Time(); t.print_time()
00:00:00

t = Time(10); t.print_time()
10:00:00

t = Time(10, 20); t.print_time()
10:20:00
```

**Important point:** notice how much cleaner this is than creating an object and then assigning attributes like we did earlier. Defining an `__init__` method also lets us ensure that there are certain attributes that are **always** populated in an object. This avoids the risk of an `AttributeError` sneaking up on us later. **Best practice** is to create all of the attributes that an object is going to have at initialization. Once again, Python allows you to do something, but it’s best never to do it!
While we’re on the subject...

Useful functions to know for debugging purposes: `vars` and `getattr`

`vars` returns a dictionary keyed on attribute names, values are attribute values.

```
1 for attr in vars(tl):
2     print(attr, getattr(tl, attr))
```

hours 11
mins 15
secs 10

This is a useful pattern for debugging. Downey recommends encapsulating it in a function like `print_attrs(obj)`. I think this is a bit extreme. You should be using test cases and sanity checks to debug rather than examining the contents of objects.
Objects to strings: the \_\_str\_\_ method

```
class Time:
    """Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs"

    def __init__(self, hours=0, mins=0, secs=0):
        self.hours = hours
        self.mins = mins
        self secs = secs

    def __str__(self):
        return "%.2d:%.2d:%.2d" % (self.hours, self.mins, self secs)

  t = Time(10,20,30)
  print(t)
```

From the documentation: \texttt{str(object)} returns \texttt{object.__str__()}, which is the “informal” or nicely printable string representation of \texttt{object}. For string objects, this is the string itself. If \texttt{object} does not have a \texttt{__str__()} method, then \texttt{str()} falls back to returning \texttt{repr(object)}.

https://docs.python.org/3.5/library/stdtypes.html#str
Overloading operators
We can get other operators (+, *, /, comparisons, etc) by defining special functions

```
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

    def time_to_int(self):
        return (self.secs + 60*self.mins + 3600*self.hours)

    def __add__(self, other):
        '''Add other to this time, return result.'''
        s = self.time_to_int() + other.time_to_int()
        return (int_to_time(s))

t1 = Time(11,15,10); t2 = Time(1,5,1)
print(t1+t2)
```

Defining the `__add__` operator lets us use + with `Time` objects. This is called overloading the + operator. All operators in Python have special names like this. More information: https://docs.python.org/3/reference/datamodel.html#specialnames
Type-based dispatch

```python
class Time:
    '''Represents time on a 24 hour clock. Attributes: int hours, int mins, int secs'''

def __add__(self, other):
    '''Add other to this time, return result.'''
    if isinstance(other, Time):
        s = self.time_to_int() + other.time_to_int()
        return(int_to_time(s))
    elif isinstance(other, int):
        s = self.time_to_int() + other
        return(int_to_time(s))
    else:
        raise TypeError('Invalid type.')
```

`isinstance` returns True iff its first argument is of the type given by its second argument.

Depending on the type of `other`, our method behaves differently. This is called **type-based dispatch**. This is in keeping with Python’s general approach of always trying to do something sensible with inputs.
Our + operator isn’t commutative! This is because int + Time causes Python to call the int.__add__ operator, which doesn’t know how to add a Time to an int. We have to define a Time.__radd__ operator for this to work.
class Time:
    '''Represents time on a 24 hour clock.
    Attributes: int hours, int mins, int secs'''

def __add__(self, other):
    '''Add other to this time, return result.'''
    if isinstance(other, Time):
        s = self.time_to_int() + other.time_to_int()
        return int_to_time(s)
    elif isinstance(other, int):
        s = self.time_to_int() + other
        return int_to_time(s)
    else:
        raise TypeError('Invalid type."

t1 = Time(11,15,10)
print(60 + t1)

Our + operator isn't commutative! This is because int + Time causes Python to call the int.__add__ operator, which doesn't know how to add a Time to an int. We have to define a Time.__radd__ operator for this to work.

Simple solution:
def __radd__(self, other):
    return self.__add__(other)

TypeError: unsupported operand type(s) for +: 'int' and 'Time'
Polymorphism

Type-based dispatch is useful, but tedious

Better: write functions that work for many types

Examples:

String functions often work on tuples
int functions often work on floats or complex

Functions that work for many types are called **polymorphic**. Polymorphism is useful because it allows code reuse.
Interface and Implementation

Key distinction in object-oriented programming
  Interface is the set of methods supplied by a class
  Implementation is how the methods are actually carried out

Important point: ability to change implementation without affecting interface

Example: our Time class was represented by hour, minutes and seconds
  Could have equivalently represented as seconds since midnight
  In either case, we can write all the same methods (addition, conversion, etc)
Interface and Implementation

Key distinction in object-oriented programming
   Interface is the set of methods supplied by a class
   Implementation is how the methods are actually carried out

Important point: ability to change implementation without affecting interface

Example: our Time class was represented by hour, minutes and seconds
   Could have equivalently represented as seconds since midnight
   In either case, we can write all the same methods (addition, conversion, etc)

Certain implementations make certain operations easier than others.
Example: comparing two times in our hours, minutes, seconds representation is complicated, but if Time were represented as seconds since midnight, comparison becomes trivial. On the other hand, printing hh:mm:ss representation of a Time is complicated if our implementation is seconds since midnight.
Inheritance

Inheritance is perhaps the most useful feature of object-oriented programming.

Inheritance allows us to create new Classes from old ones.

Our running example for this will follow Downey’s chapter 18.

Objects are playing cards, hands and decks.

Assumes some knowledge of Poker [https://en.wikipedia.org/wiki/Poker](https://en.wikipedia.org/wiki/Poker)

- 52 cards in a deck
- 4 suits: Spades > Hearts > Diamonds > Clubs
- 13 ranks: Ace, 2, 3, 4, 5, 6, 7, 8, 9, 10, Jack, Queen, King
Creating our class

A card is specified by its suit and rank, so those will be the attributes of the card class. The default card will be the two of clubs.

```python
class Card:
    '''Represents a playing card'''
    def __init__(self,suit=0,rank=2):
        self.suit = suit
        self.rank = rank
```

We will encode suits and ranks by numbers, rather than strings. This will make comparison easier.

<table>
<thead>
<tr>
<th>Suit encoding</th>
<th>0 : Clubs</th>
<th>1 : Diamonds</th>
<th>2 : Hearts</th>
<th>3 : Spades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rank encoding</td>
<td>0 : None</td>
<td>1 : Ace</td>
<td>2 : 2</td>
<td>3 : 3</td>
</tr>
<tr>
<td></td>
<td>10 : 10</td>
<td>11 : Jack</td>
<td>12 : Queen</td>
<td>13 : King</td>
</tr>
</tbody>
</table>

This stage of choosing how you will represent objects (and what objects to represent) is often the most important part of the coding process. It’s well worth your time to carefully plan and design your objects, how they will be represented and what methods they will support.
Creating our class

Variables defined in a class but outside any method are called **class attributes**. They are shared across all instances of the class.

**Instance attributes** are assigned to a specific object (e.g., `rank` and `suit`). Both class and instance attributes are accessed via dot notation.

Here we use instance attributes to index into class attributes.
Creating our class

Variables defined in a class but outside any method are called **class attributes**. They are shared across all instances of the class.

Instance attributes are assigned to a specific object (e.g., `rank` and `suit`). Both class and instance attributes are accessed via dot notation.

Here we use instance attributes to index into class attributes.

We've chosen to order cards based on rank and then suit, with aces low. So a jack is bigger than a ten, regardless of the suit of either one. Downey orders by suit first, then rank.

Now that we've defined the `__eq__` operator, we can check for equivalence correctly.
Define a new object representing a deck of cards. A standard deck of playing cards is 52 cards, four suits, 13 ranks per suit, etc.

Represent cards in the deck via a list. To populate the list, just use a nested for-loop to iterate over suits and ranks.

String representation of a deck will just be the cards in the deck, in order, one per line. Note that this produces a single string, but it includes newline characters.

There’s another 45 or so more strings down there...
Providing additional methods

```python
import random

class Deck:
    ''''Represents a deck of cards''''

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

    def add_card(self, c):
        self.cards.append(c)

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

One method for dealing a card off the “top” of the deck, and one method for adding a card back to the “top” of the deck.

Note: methods like this that are really just wrappers around other existing methods are often called **veneer** or **thin methods**.

After shuffling, the cards are not in the same order as they were on initialization.
Let’s take stock

We have:
- a class that represents playing cards (and some basic methods)
- a class that represents a deck of cards (and some basic methods)

Now, the next logical thing we want is a class for representing a hand of cards
So we can actually represent a game of poker, hearts, bridge, etc.

The naïve approach would be to create a new class Hand from scratch
But a more graceful solution is to use inheritance

Key observation: a hand is a lot like a deck (it’s a collection of cards)
...of course, a hand is also different from a deck in some ways...
Inheritance

This syntax means that the class `Hand` inherits from the class `Deck`. Inheritance means that `Hand` has all the same methods and class attributes as `Deck` does.

We say that the child class `Hand` inherits from the parent class `Deck`. 
Inheritance

This syntax means that the class `Hand` **inherits** from the class `Deck`. Inheritance means that `Hand` has all the same methods and class attributes as `Deck` does.

So, for example, `Hand` has `__init__` and `shuffle` methods, and they are identical to those in `Deck`. Of course, we quickly see that the `__init__` inherited from `Deck` isn’t quite what we want for `Hand`. A hand of cards isn’t usually the entire deck...

So we already see the ways in which inheritance can be useful, but we also see immediately that there’s no free lunch here. We will have to **override** the `__init__` function inherited from `Deck`.

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

h = Hand()
h.shuffle()
print(h)
```
Inheritance: methods and overriding

```python
class Hand(Deck):
    '''Represents a hand of cards'''

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

Redefining the `__init__` method overrides the one inherited from `Deck`. 
Inheritance: methods and overriding

```python
class Hand(Deck):
    '''Represents a hand of cards'''

def __init__(self, label=' '):
    self.cards = list()
    self.label = label

h = Hand('new hand')
d = Deck(); d.shuffle()
h.add_card(d.pop_card())
print(h)
```

Redefining the `__init__` method overrides the one inherited from `Deck`.

Now, when we initialize a `Hand` object, it starts out empty.

Simple way to deal a single card from the deck to the hand: pop a card off of the deck, add it to the hand.
Encapsulate this pattern in a method supplied by `Deck`, and we have a method that deals cards to a hand.

The `move_cards` method is supplied by `Deck` but it modifies both the caller and the `Hand` object in the first argument.

Note: `Hand` also inherits the `move_cards` method from `Deck`, so we have a way to move cards from one hand to another (e.g., as at the beginning of a round of hearts)
Inheritance: pros and cons

Pros:
- Makes for simple, fast program development
- Enables code reuse
- Often reflects some natural structure of the problem

Cons:
- Can make debugging challenging (e.g., where did this method come from?)
- Code gets spread across multiple classes
- Can accidentally override (or forget to override) a method
A Final Note on OOP

Object-oriented programming is ubiquitous in software development
  Useful when designing large systems with many interacting parts
As a statistician, most systems you build are… not so complex
  (At least not in the sense of requiring lots of interacting subsystems)

We’ve only scratched the surface of OOP
  Not covered: factories, multiple inheritance, abstract classes…
  Take a software engineering course to learn more about this

In my opinion, OOP isn’t especially useful for data scientists, anyway.
  This isn’t to say that objects aren’t useful, only OOP as a paradigm
Understanding functional programming is far more important (next lecture)