PYTHON CLASSES and INHERITANCE

(download slides and .py files from Stellar to follow along!)

6.0001 LECTURE 8

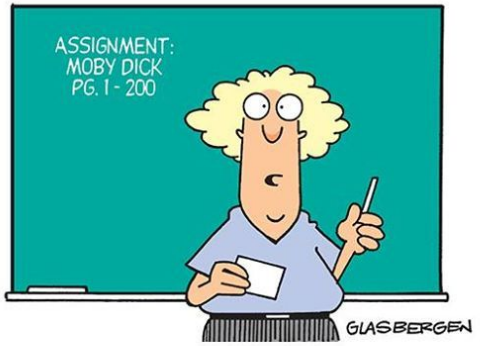
LAST TIME

- Abstract data types using classes
- `Coordinate` example
- `Fraction` example

TODAY

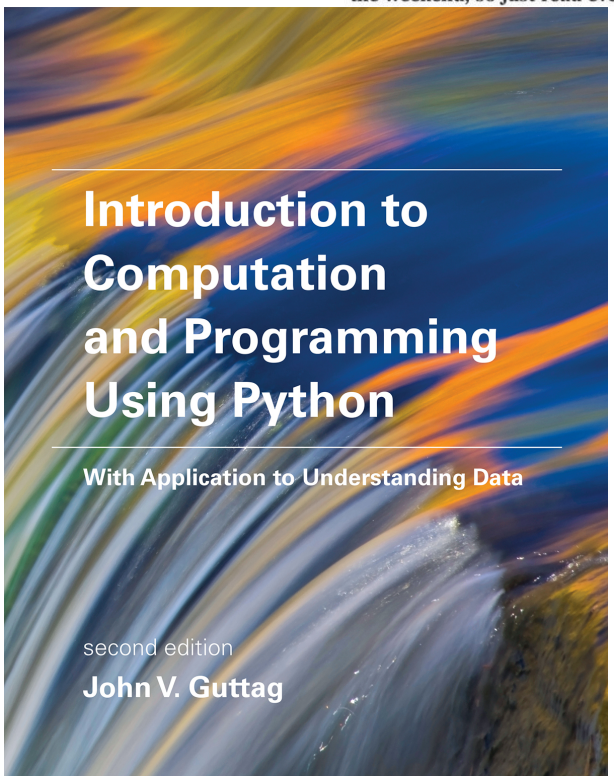
- Review classes
- More details on classes, class variables
- Inheritance and hierarchies of classes

Assigned Reading



"I don't like to give a lot of homework over the weekend, so just read every other word."

- Today
  - 8.2
  - 9.1 – 9.2
- Next lecture
  - 9.3



https://mitpress.mit.edu/sites/default/files/Guttag_errata_revised_083117.pdf

Why objects (or structured types)?

- Example: manipulate Geometric circles, point in circle test

Why objects (or structured types)?

- Example: manipulate Geometric circles

```
class Circle(object):
    def __init__(self, center, radius):
        self.center = center
        self.radius = radius
    def __str__(self):
        return "circle: "+str(self.center)+", "+str(self.radius)
    def is_inside(self, point):
        return point.distance(self.center)<self.radius
```

- Note that we can use our own classes (Coordinate) in the creation of new classes

Why objects (or structured types)?

- Example: manipulate Geometric circles
  - Without structured type:

Why objects and structured types?

- Example: manipulate Geometric circles
  - Without structured type:
    is_in_circle(x_c, y_c, r, x_p, y_p)
  - Lots of parameters, hard to read
  - We could try to package info into lists, but we would have to remember which index corresponds to coordinates vs. radius

THE POWER OF OBJECT ORIENTED PROGRAMMING

- **Bundle together objects** that share
  - common attributes and
  - procedures that operate on those attributes
- Use **abstraction** to make a distinction between how to implement an object versus how to use an object
- Build **layers** of object abstractions that inherit behaviors from other classes of objects
- Create our **own classes of objects** on top of Python's basic classes (and on top of our own classes)

Another instance of a virtuous cycle – just as defining procedures lets us create new procedures and treat as if built-in, we can create classes and treat as if built in to Python

IMPLEMENTING THE CLASS vs USING THE CLASS

- Write code from two different perspectives

Implementing a new object type with a class

- **Define** the class
- Define **data attributes** (WHAT IS the object)
- Define **methods** (HOW TO use the object)

Using the new object type in code

- Create **instances** of the object type
- Do **operations** with them

Class captures common properties and behaviors	Instances have specific values for attributes

CLASS DEFINITION OF AN OBJECT TYPE vs INSTANCE OF A CLASS

- Class name is the **type**

```
class Coordinate(object)
```

- Class is defined generically
  - Use `self` to refer to some instance while defining class

```
(self.x – self.y)**2
```

  - `self` is a parameter to methods in class definition

- Class defines data and methods **common across all instances**

- Instance is **one specific object**

```
coord = Coordinate(1,2)
```

- Data attribute values vary between instances

```
c1 = Coordinate(1,2)
c2 = Coordinate(3,4)
```

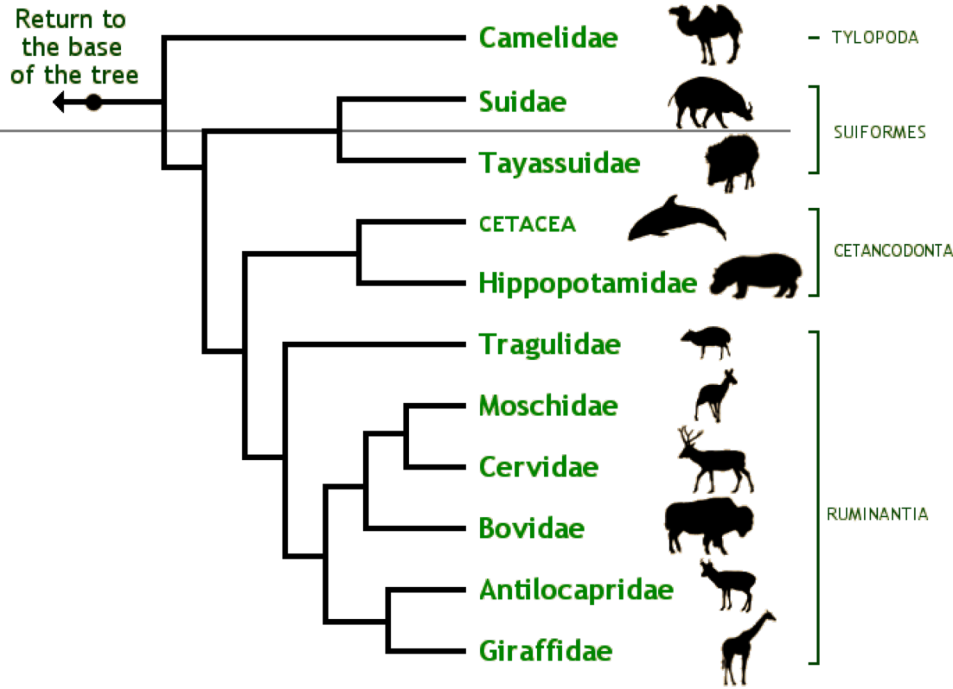
  - `c1` and `c2` have different data attribute values `c1.x` and `c2.x` because they are different objects

- Instance has the **structure of the class**

Classes & Instances

Classes (~type)
are similar to species

- define a “template”
- can be
  hierarchically organized



Instances (a.k.a. members)
are similar to individuals

CREATING INSTANCES (Recap)

- Usually when creating an instance of an object type, we will want to provide some initial values for the internal data. To do this, define an `__init__` method:

```
class Coordinate(object):
    def __init__(self, x, y):
        self.x = x
        self.y = y
```

Method is another name for a procedural attribute, or a procedure that "belongs" to this class

CREATING INSTANCES (Recap)

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class Coordinate(object):
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```

When calling a method of an object, Python always passes the instance as the first argument. By convention, we use `self` as the name of the first argument of methods.

CREATING INSTANCES (Recap)

- Usually when creating an instance of a type, we will want to provide some initial values for the internal data. To do this, define an `__init__` method:

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class Coordinate(object):
    def __init__(self, x, y):
        self.x = x
        self.y = y
```

When calling a method of an object, Python always passes the instance as the first argument. By convention, we use `self` as the name of the first argument of methods.

- The "." operator accesses an attribute of an object, so `__init__` defines two attributes for new object: `x` and `y`.

CREATING INSTANCES (Recap)

- Usually when creating an instance of a type, we will want to provide some initial values for the internal data. To do this, define an `__init__` method:

```
class Coordinate(object):
    def __init__(self, x, y):
        self.x = x
        self.y = y

c = Coordinate(3,4)
origin = Coordinate(0,0)
print(c.x, origin.x)
```

The expression `classname(values…)` creates a new object of type classname and then calls its `__init__` method with the new object and `values…` as the arguments. When the method is finished executing, Python returns the initialized object as the value.

Note that don't provide argument for self, Python does this automatically

Getters and setters

- For good encapsulation and abstraction, it is often advised to not presume how internal data is encoded
  - You should not use directly coord.x = 1.0 from outside the class
  - Instead, implement getters and setters
  - Coordinate.set_x
  - Coordinate.get_x

Motivation for getters and setters (aka accessors)

- Information hiding, abstraction
- Adding validation
- Support undo, history tracking
- Debugging insertion point
- Separate control of get vs. set
- Later in this lecture, with inheritance: change semantics for child class

- For fans of controversy, there are counter arguments

PYTHON NOT GREAT AT INFORMATION HIDING

- Allows you to **access data** from outside class definition in an instance

```
print(p.x)
```

- Allows you to **write to data** from outside class definition to an instance

```
p.x = 2
```

- Allows you to **create data attributes** for an instance from outside class definition

```
a.new_field = ”whatever"
```

- It’s usually considered **NOT GOOD STYLE** to do any of these!

Example of encapsulation and data hiding

- Credit card class that stores operation history

Default argument

- For any function, including class function attribute

```
def f(x, y=1):
    return x+y
print(f(1, 4))
print(f(2))
```

- When argument is not provided, use default
- Can only be done at end of argument list
- Kind of similar to default arguments of range(::)

Default argument examples

- def f(x, y, debug_mode_on=False)
- def f(x, y, z=0.0)
- Class Person(object):
  def __init__(first_name, last_name, title="")
- def sqrt(x, precision=1e-6)
- Def save_jpeg(image, quality=80)

Careful

- Careful with mutable default arguments (lists, dictionaries)
  - DON'T MUTATE THEM
- They get created only once

```
def append_to(element, to=[]):
    to.append(element)
    return to

my_list = append_to(12)
print(my_list)

my_other_list = append_to(42)
print(my_other_list)
```

CREDIT CARD example

- Operations
  - spend(amount)
  - pay_bill(amount)
  - monthly_update: apply interest rate
- data:
  - balance, rate
- Initialize with:
  - yearly rate in %, set balance to zero

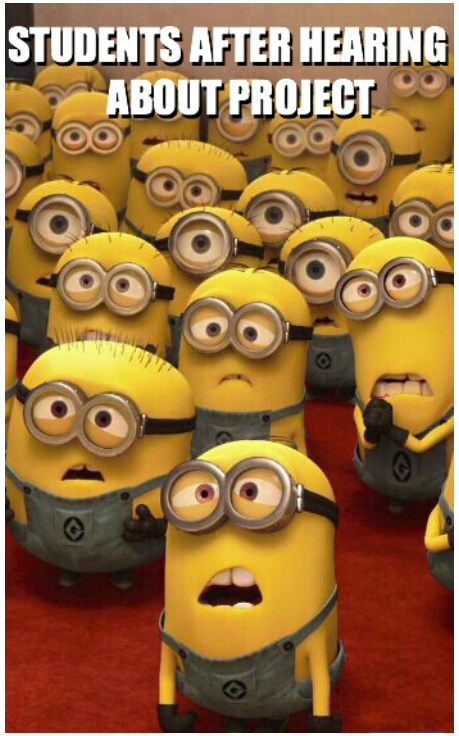
CREDIT CARD Class

```
class CreditCard(object):
    def __init__(self, yearly_rate_in_percent):
        self.balance = 0
        self.yearly_rate_in_percent = yearly_rate_in_percent

    def get_balance(self):
        return self.balance

    def spend(self, amount):
        self.balance += amount

    def pay_bill(self, amount):
        self.balance -= amount

    def monthly_update(self):
        interests = self.get_balance()*self.yearly_rate_in_percent/12.0/100.0
        self.balance += interests

    def __str__(self):
        return "amount due: "+str(self.get_balance())
```

```
#alternative that stores the monthly multiplier
# follows the same specifications
#  example of abstraction where internal representation
# can be changed without affecting external behavior

class CreditCard(object):
    def __init__(self, yearly_rate_in_percent):
        self.balance = 0
        self.monthly_interests_fraction = yearly_rate_in_percent/12.0/100.0

    def get_balance(self):
        return self.balance

    def spend(self, amount):
        self.balance += amount

    def pay_bill(self, amount):
        self.balance -= amount

    def monthly_update(self):
        interests = self.get_balance()*self.monthly_interests_fraction
        self.balance += interests

    def __str__(self):
        return "amount due: "+str(self.get_balance())
```

```
#alternative that stores a list of operations
# follows the same specifications
class CreditCard(object):
    def __init__(self, yearly_rate_in_percent):
        self.operations = []
        self.monthly_interests_fraction = yearly_rate_in_percent/12.0/100.0

    def get_balance(self):
        return sum(self.operations)

    def spend(self, amount):
        self.operations.append(amount)

    def pay_bill(self, amount):
        self.operations.append(-amount)

    def monthly_update(self):
        interests = self.get_balance()*self.monthly_interests_fraction
        self.operations.append(interests)

    def __str__(self):
        return "amount due: "+str(self.get_balance())
```

5 Minute Break



INHERITANCE

- Idea: “extend” a class with new/different capability
  - Reuse code from parent class in child class
  - Create sets of classes with similar capabilities
- Motivating examples
  - Checking account class
    gets extended into saving account class
  - Credit card card extends to reward card
  - Drawable class
    gets extended into various shapes (point, line, circle)
  - Clickable User Interface element
    parent of buttons, windows, text field
  - Output stream gets extended into file, print

REWARDS CARD

- Credit card
- Reward card
  - same as credit card
  - but also accumulates miles each time we spend money
    - add more behavior/information (miles)
    - augments the behavior of the credit card “spend” operator

HOW TO INHERIT

- Define parent class

```
class CreditCard(object):
```

HOW TO INHERIT

- Define parent class

```
class CreditCard(object):
```

Define child class:

```
class RewardCard(CreditCard):
```

Automatically inherits all data and function attributes of parent

Can be extended with

new data attributes

new function attributes

Modification of existing behavior
(function overloading)

CONSTRUCTOR

- We still need to initialize balance (or operations) and monthly_interests_fraction (or yearly)
- We could copy-paste the code from CreditCard
  - but it would be dirty and make the code harder to maintain
- Solution: call the parent function in the child function
  - using syntax:
    `ParentClass.function(self, ...)`

CONSTRUCTOR

```
class RewardCard(CreditCard):
    def __init__(self, yearly_rate_in_percent, miles_per_dollar):
        CreditCard.__init__(self, yearly_rate_in_percent)
        self.miles_per_dollar = miles_per_dollar
        self.miles = 0
```

- Note that here we use self in the call
  - yes, Python can be confusing
- Notice the dot notation after CreditCard?
  - Yes, classes are objects too!

NEW DATA ATTRIBUTE

- Parent class

```
class CreditCard(object):
    def __init__(self, yearly_rate_in_percent):
        self.balance = 0
        self.yearly_rate_in_percent = yearly_rate_in_percent
```

- Child class:

```
class RewardCard(CreditCard):
    def __init__(self, yearly_rate_in_percent, miles_per_dollar):
        CreditCard.__init__(self, yearly_rate_in_percent)
        self.miles_per_dollar = miles_per_dollar
        self.miles = 0
```

RewardCard has all attributes of credit card (balance, yearly_rate_in_percent)

It has two extra one: miles, miles_per_dollar

NEW BEHAVIOR

```
def get_miles(self):
    return self.miles
```

MODIFIED BEHAVIOR

- Change spend to increment miles
- In this case, call parent version of spend to preserve parent behavior
- Augment with extra behavior

```
def spend(self, amount):
    CreditCard.spend(self, amount)
    self.miles += amount * self.miles_per_dollar
```

SUBSTITUTION PRINCIPLE

```
def spend(self, amount):
    CreditCard.spend(self, amount)
    self.miles += amount * self.miles_per_dollar
```

- When modifying a method,
  make sure that code that works correctly with the parent method still works with the modified child

How does it work?

- When using dot notation (data, function)
  - E.g. card.spend()
- Python tries to find it at level of child class
- If it can't, it looks for it in parent class
  - Potentially recursively if the parent has a parent
- Note: if you want to augment the old behavior, you have to call it explicitly (here CreditCard.spend())

```
def spend(self, amount):
    CreditCard.spend(self, amount)
    self.miles += amount * self.miles_per_dollar
```

Good abstraction

```
class RewardCard(CreditCard):
    def __init__(self, yearly_rate_in_percent, miles_per_dollar):
        CreditCard.__init__(self, yearly_rate_in_percent)
        self.miles_per_dollar = miles_per_dollar
        self.miles = 0
    def spend(self, amount):
        CreditCard.spend(self, amount)
        self.miles += amount * self.miles_per_dollar
    def get_miles(self):
        return self.miles
    def __str__(self):
        return CreditCard.__str__(self)+"; reward "+str(self.get_miles())+" miles"
```

Our RewardClass still works if we change the implementation of CreditCard

- balance vs. operations
- yearly vs. monthly rate

POLYMORPHISM

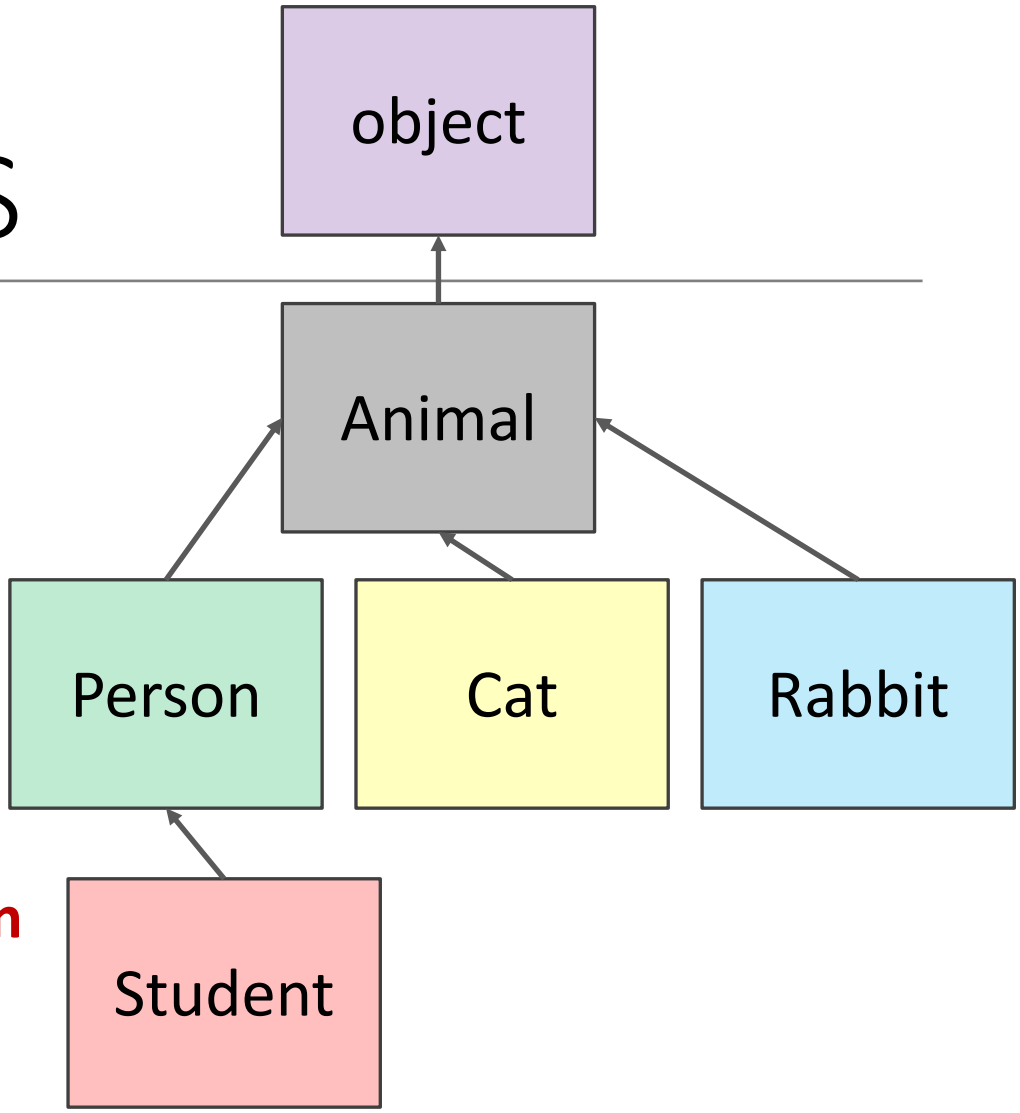
- Functions like spend are called polymorphic
- They can function on different datatypes

Questions?

HIERARCHIES

HIERARCHIES

- **Parent class** (superclass)
- **Child class** (subclass)
  - **Inherits** all data and behaviors of parent class
  - **Add** more **information**
  - **Add** more **behaviors**
  - **Override** behavior



Class variables

- So far we have used instance variables
  - Each object instance has a different value for the data attribute
- New:
  class variables are shared for all members of a class
  - But not across parents and children
  - Declared inside class definition but not in __init__

Example of class variables

```
class Animal(object):
    #class variables will be shared by all instances
    species = ""
    counter = 0
            #class variable will be shared by all instances
    def __init__(self, name, age):
        self.age = age
        self.name = name
        #increment counter to count all amimals
        Animal.counter += 1
    def __str__(self):
        return self.species+" "+str(self.name)+":"+str(self.age)
```

```
class Rabbit(Animal):
    species = "Rabbit"
    #insert here whatever it is rabbits do

class Fox(Animal):
    species = "Fox"
    #insert here whatever it is foxes do
```

INSTANCE VARIABLES vs CLASS VARIABLES

- we have seen **instance variables** so far in code
- specific to an instance
- created for **each instance**, belongs to an instance
- used the generic variable name self within the class definition

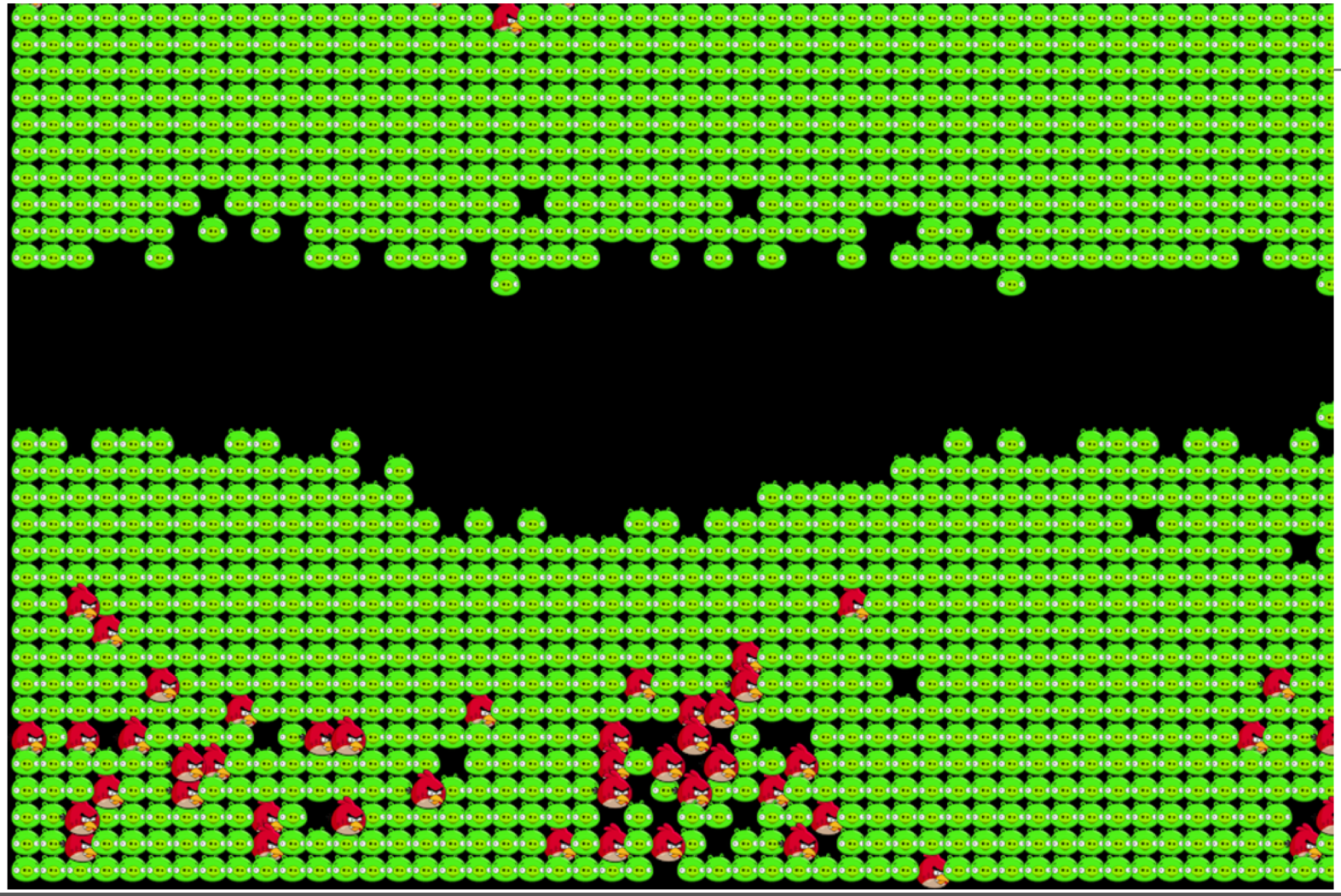
```
self.variable_name
```

- introduce **class variables** that belong to the class
- defined inside class but outside any class methods, outside `__init__`
- **shared** among all objects/instances of that class

THE POWER OF OBJECT ORIENTED PROGRAMMING

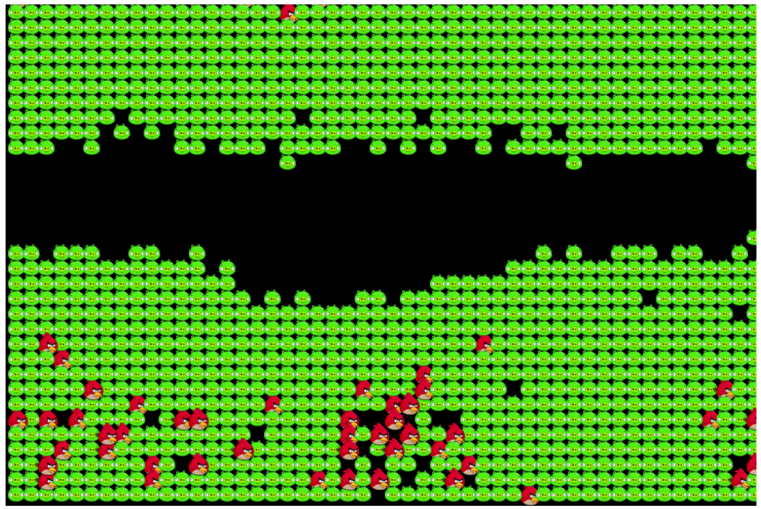
- **Bundle together objects** that share
  - common attributes and
  - procedures that operate on those attributes
- Use **abstraction** to make a distinction between how to implement an object versus how to use an object
- Build **layers** of object abstractions that inherit behaviors from other classes of objects
- Create our **own classes of objects** on top of Python's basic classes

Predator-Prey Simulation



PREDATOR/PREY SIMULATION

- Animals move on discrete grids
- Reproduce at given rates by parthenogenesis
- Predators need to eat preys to survive



Predator-Prey OOP

- Animals
  - **Behavior**: move, reproduce, eat
  - Maintain **information**: location, time without eating
  - Many instances of the same class
  - Hierarchy: Animal
    - Prey
    - Predator
  - share properties/behavior, differ in others

LOOK AT CODE

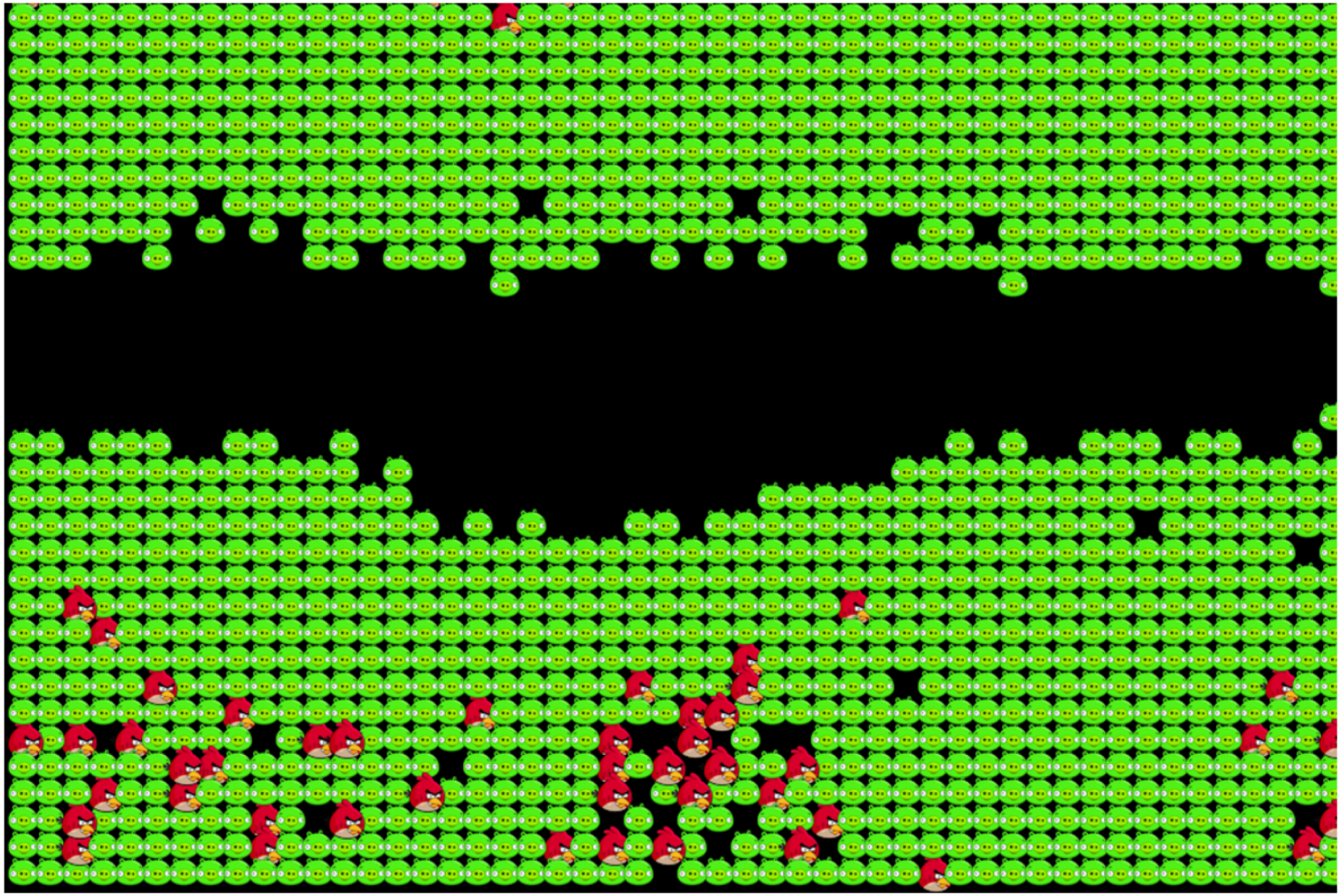
```
class Animal:
    baseProbaToReproduce=0.0
    def __init__(self, x, y, world):
        self.x=x
        self.y=y
        self.world=world
        world.addAnimal(self)
        self.dead=False
    def simulate(self): pass;
    def reproduce(self, x, y): pass
    def die(self):
        self.world.setCell(self.x, self.y, None)
        self.dead=True
        self.world.listOfAnimals.remove(self)
    def move(self, x, y):
        self.world.setCell(self.x, self.y, None)
        self.x=x
        self.y=y
        self.world.setCell(x, y, self)
    def moveAndReproduceProba(self, x, y):
        oldX, oldY=self.x, self.y
        self.move(x,y)
        LFriends=self.world.neighborsOfType(self.x, self.y, type(self))
        if rnd.random()<self.baseProbaToReproduce*len(LFriends):
            offspring=self.reproduce(oldX, oldY)
```

```
class Prey(Animal):
    baseProbaToReproduce=2.0/8.0
    def reproduce(self, x, y):
        offspring=Prey(x, y, self.world)
    def simulate(self):
        if self.dead: return
        LFree=self.world.freeNeighbors(self.x, self.y)
        LFriends=self.world.neighborsOfType(self.x, self.y, Prey)
        if len(LFree)>0:
            i=rnd.randint(len(LFree))
            self.moveAndReproduceProba(LFree[i][0], LFree[i][1])
```

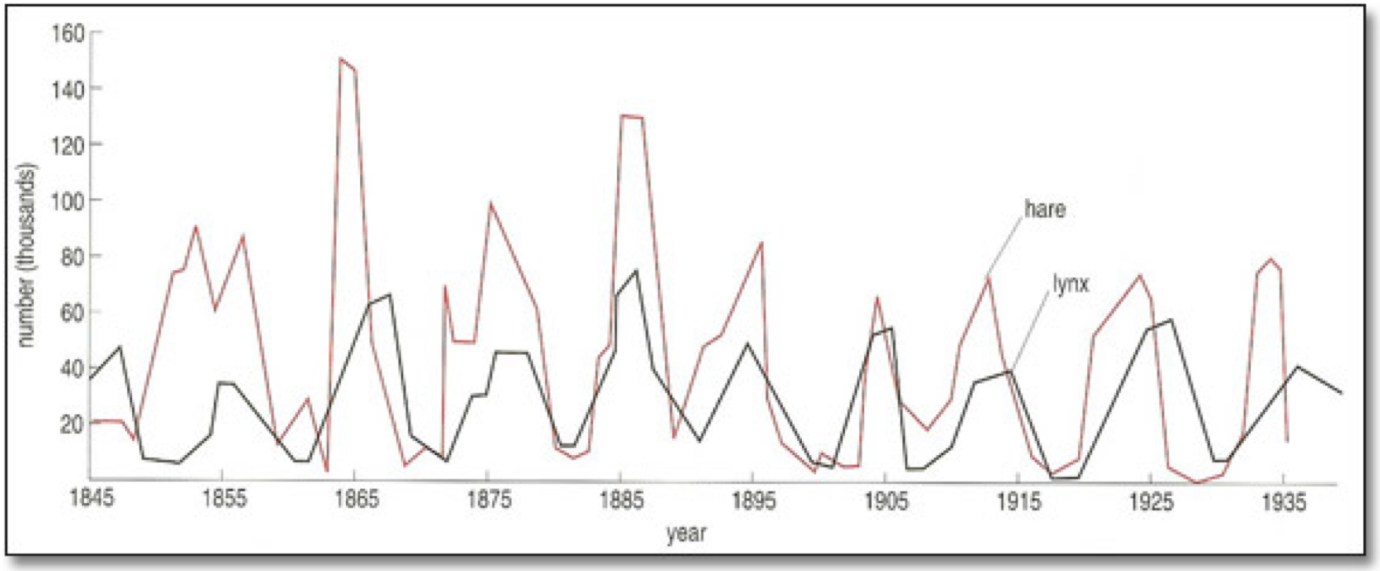
```
class Predator(Animal):
    baseProbaToReproduce=0.1/8.0
    baseProbaToCatchPrey=0.3
    maxTimeWithoutEating=5
    def __init__(self, x, y, world):
        Animal.__init__(self, x, y, world)
        self.timeWithoutEating=0
    def display(self):
        displayUtilities2.displayBird(self.x*scale, self.y*scale)
    def reproduce(self, x, y):
        offspring=Predator(x, y, self.world)
    def simulate(self):
        if self.dead: print('predator dead:'), self.dead
        if self.dead: return
        self.timeWithoutEating=self.timeWithoutEating+1
        L=self.world.listOfNeighbors(self.x, self.y)
        LFree=self.world.freeNeighbors(self.x, self.y)
        LFriends=self.world.neighborsOfType(self.x, self.y, Predator)
        LPrey=self.world.neighborsOfType(self.x, self.y, Prey)
        if rnd.random()< self.baseProbaToCatchPrey*len(LPrey): #eat a prey
            i=rnd.randint(len(LPrey))
            prey=self.world.cell(LPrey[i][0], LPrey[i][1])
            prey.die()
            self.moveAndReproduceProba(LPrey[i][0], LPrey[i][1])
            self.timeWithoutEating=0
            return
        if self.timeWithoutEating>self.maxTimeWithoutEating: #starvation
            self.die()
            return
        if len(LFree)>0:
            i=rnd.randint(len(LFree))
            self.moveAndReproduceProba(LFree[i][0], LFree[i][1])
```

```
class World:
    def __init__(self, width, height):
        self.width=width
        self.height=height
        self.worldMap=[]
        for y in xrange(height):
            row=[]
            for x in xrange(width):
                row.append(None)
            self.worldMap.append(row)
        self.listOfAnimals=[]


    ....
```

SIMULATE



Lynx vs. hare



Differential equation: Lotka-Volterra

p://labspace.open.ac.uk/mod/oucontent/view.php?id=474950&printable=1
p://mathnathan.com/2010/12/predator-prey-model/

Other applications

Gang territories

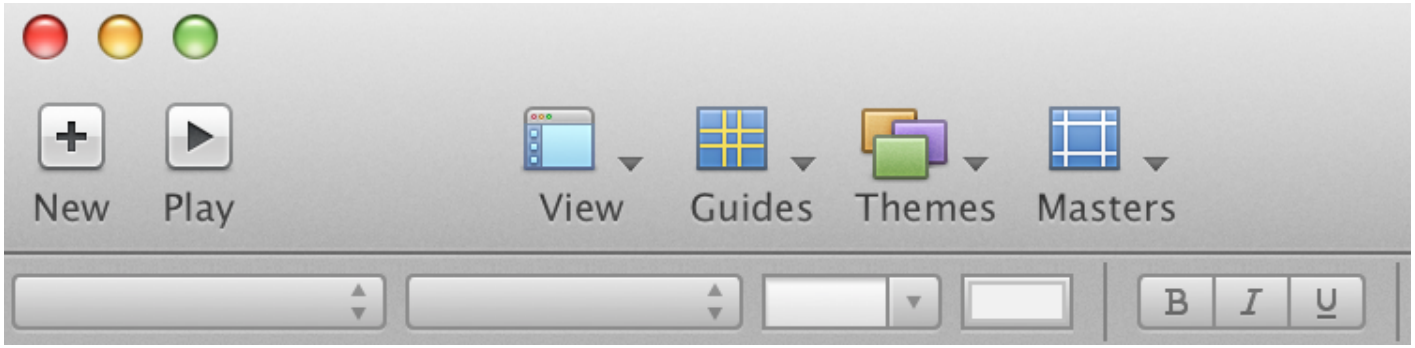
- http://www.scientificamerican.com/podcast/episode.cfm?id=predator-prey-equations-govern-gang-12-07-02

Stock market and bubbles

- http://www.catataxis.com/index.php/the-cultural-theory-of-risk/
- http://en.wikipedia.org/wiki/Competitive_Lotka%E2%80%93Volterra_equations

Object Oriented Programming (OOP) biggest successes

- Graphical User Interface
  - Many types of buttons/window/sliders
  - state: on/off, active or not, pushed or not
  - some behavior is similar
  - some differs



- Agent-based simulation, games

OBJECT ORIENTED PROGRAMMING LIMITATIONS

- Inheritance can create rigidity and complexity
- Changes to parent classes can still break a lot of things
- The world or your problem cannot always be decomposed into a hierarchy
- http://wiki.c2.com/?ArgumentsAgainstOop
- https://github.com/raganwald-deprecated/homoiconic/blob/master/2010/12/oop.md
- https://medium.com/@cscalfani/goodbye-object-oriented-programming-a59cda4c0e53
- https://cacm.acm.org/magazines/2010/9/98017-objects-never-well-hardly-ever/fulltext

IN THE END

- Structured types are good
- Object are useful
- Grouping things is useful. OOP is one way of grouping
- Polymorphism is great (but may not need inheritance)
- Inheritance is sometimes useful, sometimes dangerous, but it's also used a lot (e.g. for GUIs)