CSc 120
Introduction to Computer Programming II

Adapted from slides by
Dr. Saumya Debray

03: Basics of Object-Oriented Programming
Programming paradigms

• Procedural programming:
  – programs are decomposed into procedures (functions) that manipulate a collection of data structures

• Object-oriented programming
  – programs are composed of interacting entities (objects) that encapsulate data and code
What is an object?

To human beings, an object is:
"A tangible and/or visible thing; or
(a computer, a chair, a noise)

Something that may be apprehended intellectually; or
(the intersection of two sets, a disagreement)

Something towards which thought or action is directed"
(the procedure of planting a tree)

-Grady Booch
Objects

- Object-oriented programming models properties of, and interactions between, entities in the world
Objects

• Objects have state and behavior
  – the state of an object can influence its behavior
  – the behavior of an object can change its state

• State:
  – all the properties of an object and the values of those properties

• Behavior:
  how an object acts and reacts, in terms of changes in state and interaction with other objects

Object: An entity that combines state and behavior
EXERCISE

Consider an ipod:

• State (properties):
  – What properties does an ipod have?

• Behavior (operations):
  – What does an ipod do?
  – What operations could we define for an ipod?
The Class concept

• Class:
  A set of objects having the same behavior and underlying structure

• A class is a template for defining a new type of object

An object is an instance of a class.
Blueprint analogy

iPod blueprint

state:
current song
volume
battery life

behavior:
power on/off
change station/song
change volume
choose random song

used to create instances of an iPod

iPod #1
state:
song = "1,000,000 Miles"
volume = 17
battery life = 2.5 hrs

behavior:
power on/off
change station/song
change volume
choose random song

iPod #2
state:
song = "Letting You"
volume = 9
battery life = 3.41 hrs

behavior:
power on/off
change station/song
change volume
choose random song

iPod #3
state:
song = "Discipline"
volume = 24
battery life = 1.8 hrs

behavior:
power on/off
change station/song
change volume
choose random song
Classes

- In Python, that blueprint is expressed by a class definition

- A class describes the state and behavior of similar objects

- The attributes of a class represent the state of an instance

- The methods of a class describe the behavior
Example: a set of students at UA

<table>
<thead>
<tr>
<th>Name</th>
<th>ID</th>
<th>Major</th>
<th>Year</th>
<th>Grades</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alice</td>
<td>012</td>
<td>CS</td>
<td>Freshman</td>
<td>CSC 110: B; CSC 120: A</td>
</tr>
<tr>
<td>Bob</td>
<td>025</td>
<td>Physics</td>
<td>Junior</td>
<td>GEO 215: B; Phys 120: C; GEO 325: A</td>
</tr>
<tr>
<td>Charlie</td>
<td>101</td>
<td>Music</td>
<td>Senior</td>
<td>MUS 210: B; MUS 423: A; CSC 110: B</td>
</tr>
</tbody>
</table>
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Object-oriented representation

```
Name | Alice
ID   | 012
Major| CS
Year | Freshman
Grades| ... 

Name | Bob
ID   | 025
Major| Physics
Year | Junior
Grades| ... 

Name | Charlie
ID   | 101
Major| Music
Year | Senior
Grades| ... 
```
Example: a set of students at UA

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Example: a set of students at UA

Attributes or Instance variables

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Example: a set of students at UA

Class

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Instances of the class
Objects

• An object consists of:
  – a state
    o given by the values of its attributes or instance variables
  – a set of behaviors
    o given by its methods (e.g., accessing/modifying its instance variables)

• An object models an entity in a real or virtual world or system
Example: Student object

instance variables
• name
• id
• major
• year
• grades

methods:
• get_name(), set_name()
• get_id(), set_id()
• get_major(), set_major()
• get_year(), set_year()
• get_grades(), add_grade()
• update_grade()
• compute_GPA()

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Classes

• A class describes the state and behaviors of a set of similar objects
  – state: given by instance variables
  – behaviors: given by the methods of the class

• These objects are instances of the class
class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def get_name(self):
        return self._name

...
Example: Student class

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def get_name(self):
        return self._name

    ...

The keyword class defines a class
Example: Student class

class Student:
    def __init__(self, name, id):
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        self._id = id

    def get_name(self):
        return self._name

...
class Student:
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Example: Student class

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...
Example: Student class

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def get_name(self):
        return self._name

    ...

instance variables
    _name
    _id

These refer to attributes of the object being referred to, and so are written
    self._name
    self._id
Example: using the Student class

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id
    def get_name(self):
        return self._name
...

- creating a new Student object:
  s = Student('Dennis', 543)

- invoking a method:
  name = s.get_name()
Method invocation

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def get_name(self):
        return self._name

...

a = Student(“Sally”, 202)  # create a Student object
a.get_name()  # invoke a method

Think of "self" as an alias to the current object when the method is called.
class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def get_name(self):
        return self._name

1. Write a method get_id that returns a Student object's id.

2. Create a Student object with name 'Harry' and id 342.
Example: using the Student class

def main():
    infile = get_input_file()
    student_list = []
    for line in infile:
        (name, id, major, year) = parse_student_info(line)
        student = Student(name, id)
        student_list.append(student)
        student.set_major(major)
        student.set_year(year)
    ...

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id
    def get_name(self):
        return self._name
    ...

Example: using the Student class

def main():
    infile = get_input_file()
    student_list = []
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        (name, id, major, year) = parse_student_info(line)
        student = Student(name, id)
        student_list.append(student)
        student.set_major(major)
        student.set_year(year)
    ...

    create a new Student object

class Student:
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        student = Student(name, id)
        student_list.append(student)
        student.set_major(major)
        student.set_year(year)
        ...

    ...

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id
    def get_name(self):
        return self._name
    ...

create a new Student object
add this student to the list of students
set other attributes
Example: A tally counter

Has a name.
Starts a counter at zero.
Increments the counter on a click.

Suppose we want to define a class for a Counter:

• Data: ???
  – *what data might we want to associate with a Counter?*

• Methods: ???
  – *what methods are required for Counter objects?*
Example: A tally counter

class Counter:
    def __init__(self, name):
        self._name = name
        self._count = 0

def click(self):
    self._count += 1

def count(self):
    return self._count
EXERCISE 3

Add a reset() method that will set the count to zero.

class Counter:
    def __init__(self, name):
        self._name = name
        self._count = 0

    def click(self):
        self._count += 1

    ....
EXERCISE 4

Add a get_reset_count() method that returns the number of times the counter has been reset.

class Counter:
    def __init__(self, name):
        self._name = name
        self._count = 0

def click(self):
    self._count += 1
    ....
Printing out objects

In general, the Python system doesn't know how to print user-defined objects — inconvenient

Ideally, each object (or class) should be able to determine how it is printed

```python
>>> class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

>>> s1 = Student('Pat', '623')
>>> print(s1)
<_main_.Student object at 0x10238b9e8>
>>> ```
Printing out objects: `__str__()`

```python
>>> class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def __str__(self):
        return "Student_" + self._name + ":" + str(self._id)

>>> s1 = Student('Pat', '623')
>>> print(s1)
Student_Pat:623
```
EXERCISE 5

Write a `__str__` method for `Counter`.

class Counter:
    def __init__(self, name):
        self._name = name
        self._count = 0

    def click(self):
        self._count += 1

    ....
Example: Point class

class Point:
    def __init__(self, x, y):
        self._x = x
        self._y = y

Methods:
    - what methods might we want to associate with point objects?
      - change a point object's position by a given amount
      - compute its distance from the origin (0,0)
EXERCISE 6 & 7

Write a method `translate` that changes a Point's location by a given dx, dy amount.

Write a method `distance_from_origin` that returns the distance between a Point and the origin, (0,0).

Use the formula:

\[
\sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2}
\]
import math
class Point:
    def __init__(self, x, y):
        self._x = x
        self._y = y
    def translate(self, dx, dy):
        self._x = self._x + dx
        self._y = self._y + dy
    def distance_from_origin(self):
        return math.sqrt(self._x**2 + self._y **2)
Special methods: `__repr__`

- Returns a string
  - the "official" string representation of the object
  - must look like a valid Python expression

- `__repr__(obj)`:
  - If possible, this string should look like an expression that, when evaluated (using `eval()`), would create `obj`
EXERCISE

Write a `__repr__` method for Counter.

class Counter:
    def __init__(self, name):
        self._name = name
        self._count = 0

    def click(self):
        self._count += 1

    ....
Special methods: `__repr__`

- Returns a string
  - the "official" string representation of the object
  - must look like a valid Python expression

- `__repr__(obj)`:
  - If possible, this string should look like an expression that, when evaluated (using `eval()`), would create `obj`
  - otherwise, should provide a useful description for `obj`:

  `<...some useful information...>`

  angle brackets
Special methods: `__repr__`

Example:

<table>
<thead>
<tr>
<th>class:</th>
<th>Student</th>
</tr>
</thead>
<tbody>
<tr>
<td>attributes:</td>
<td>name</td>
</tr>
<tr>
<td></td>
<td>id</td>
</tr>
<tr>
<td></td>
<td>major</td>
</tr>
<tr>
<td></td>
<td>grades</td>
</tr>
</tbody>
</table>

```
def __str__(self):
    return "Student_" + self._name + ": " + self._id

def __repr__(self):
    return "< name :" + self._name + "+ ", id :" + self._id \ 
    + ", major: " + self._major \ 
    + ", grades: " + str(self._grades) + ">
```

`__str__(self)___
called by str(obj)`

`__repr__(self)___
called by repr(obj)`
`__repr__` vs. `__str__`

- `__str__` : aims to be *readable*
  - "unofficial" string representation of an object
  - used by the end user, e.g., for printing out the object
  - not intended to be unambiguous
    - E.g.: `str("3") == str(3)`

- `__repr__` : aims to be *unambiguous*
  - "official" string representation of an object
    - can contain detailed internal information about the object
  - used by the developer, e.g., for debugging or logging
  - used for "unofficial" representation if the class defines `__repr__()`, but not `__str__()`. 
EXERCISE

The "+" key on the keyboard is broken. Implement Counter using another means to keep track of the count.

class Counter:
    def __init__(self, name):
        self._name = name
        self._count = ???

    def click(self):
        self._count = ??

    def count(self):
        return ???
class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

def get_name(self):
    return self._name
Terminology

Provide the names of the items pointed to by the arrows.

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def get_name(self):
        return self._name

...
**Terminology**

*What happens at the arrow?*

class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

def get_name(self):
    return self._name

...?

a = Student(“Sally”, 202)
class Student : Initializing attributes

More initialization

class Student:
    def __init__(self, name, id, major, year):
        self._name = name
        self._id = id
        self._major = major
        self._year = year

... def main():
    ...
    student = Student(name, id, major, year)

Less initialization

class Student:
    def __init__(self):
        self._name = ''
        self._id = ''

... def main():
    ...
    student = Student()
    student.set_name(name)
    student.set_id(id)
...
class Student : Initializing attributes

More initialization

class Student:
    def __init__(self, name, id, major, year):
        self._name = name
        self._id = id
        self._major = major
        self._year = year
...

def main():

Typically, it's better to let each class handle its own internal details.

Avoid letting the outside world know about the internals of the class.

This is encapsulation.

---

Less initialization

class Student:
    def __init__(self):
        self._name = ''
        self._id = ''
    ...

def main():
    ...
    student = Student()
    student.set_name(name)
    student.set_id(id)
    ...

52
class Student: Initializing attributes

More initialization

class Student:
    def __init__(self, name, id, major, year):
        self._name = name
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        self._major = major
        self._year = year

...  
def main():

Less initialization

class Student:
    def __init__(self):  
        self._name = ''
        self._id = ''

...  
def main():
    ...  
    student = Student()
    student.set_name(name)
    student.set_id(id)
    ...  

If details have to be handled by the outside world, it increases the complexity of the program.

It makes it harder to change the implementation later.
class Student : Initializing attributes

More initialization

class Student:
    def __init__(self, name, id, major, year):
        self._name = name
        self._id = id
        self._major = major
        self._year = year

    ...

def main():
    ...

    student = Student(name, id, major, year)

A good class (like a good function) facilitates thinking abstractly.

Note to C programmers: Don't think of this as a struct with 4 fields.

This expression causes an instance of the class Student to be created.

The values used to set the attributes are provided as arguments.
Encapsulation

• **encapsulation**: Hiding implementation details of an object from the users of that object.
  
  – Encapsulation provides *abstraction*.
    
    o separates external view (behavior) from internal view (state)
  
  – Encapsulation protects the integrity of an object's data.
Benefits of encapsulation

• Provides abstraction between an object and users of the object.

• Protects an object from unwanted access by code outside the class.
  – A bank app forbids a client to change an Account's balance.

• Allows you to change the class implementation.
  – Point could be rewritten to use polar coordinates (radius $r$, angle $\theta$), but with the same methods.

• Allows you to constrain objects' state.
  – Example: Only allow Points with non-negative coordinates.
Public and private attributes

• Some languages allow the *visibility* of attributes to be
  – **public** : visible to all code
  or
  – **private** : visible only within the class†

• Our practice is to only use private attributes to enforce encapsulation

† Our *Pythonic* convention is that "_" at the beginning of an attribute name denotes that it is "private"

† [https://www.python.org/dev/peps/pep-0008/](https://www.python.org/dev/peps/pep-0008/)

† It is a signal to the user that they should not modify the instance variable.
# Class attribute naming conventions

<table>
<thead>
<tr>
<th>One leading underscore</th>
<th>Indicates that the attribute is &quot;not public&quot; and should only be accessed by the class's internals (convention; not enforced by Python)</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>self._var1</code></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>One trailing underscore</th>
<th>Used to avoid conflicts with Python keywords, e.g., list_, class_, dict_</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>self.var1_</code></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two leading underscores</th>
<th>Invokes <em>name mangling</em>: from outside the class to enforce private e.g., <code>self.__var1</code> appears to be at <code>YourClassName._YourClassName__var1</code></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>self.__var1</code></td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Two leading + trailing underscores</th>
<th>Intended only for names that have special significance for Python, e.g., <code>__init__</code></th>
</tr>
</thead>
<tbody>
<tr>
<td><code>self.__var1__</code></td>
<td></td>
</tr>
</tbody>
</table>
Classic methods styles

• getter and setter methods
  – used to access (getter methods) and modify (setter methods) a class's private variables

• helper methods
  – methods that help other methods perform their tasks
Example: getter

class BookData:
    def __init__(self, author, title, rating):
        self._author = author
        self._title = title
        self._rating = rating

    def get_author(self):
        return self._author

    def get_rating(self):
        return self._rating

.....
Example: setter

class Point:
    def __init__(self, x, y):
        self._x = x
        self._y = y

    ....

    def move_to(self, x, y):
        self._x = x
        self._y = y
# Methods vs. functions

<table>
<thead>
<tr>
<th>Functions</th>
<th>Methods</th>
</tr>
</thead>
<tbody>
<tr>
<td>• Not associated with any class or object</td>
<td>• Associated with a class or object</td>
</tr>
<tr>
<td>– invoked by name alone</td>
<td>– invoked by object.name</td>
</tr>
<tr>
<td>• Arguments passed explicitly</td>
<td>• The object for which it was called is passed implicitly</td>
</tr>
<tr>
<td>• Operates on data passed to it</td>
<td>• Can operate on data contained within the class</td>
</tr>
</tbody>
</table>
Special methods: __eq__

• When are two objects equal?
  – students (people): the name alone may not be enough
  – dictionaries, sets: order of elements unimportant
  – In general: depends on what the object denotes (i.e., its class)

• Python provides special methods __eq__() and __ne__() for this
  – a class can define its own __eq__() and __ne__() methods to define equality
Special methods: `__eq__`

Example:

```python
class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id

    def __eq__(self, other):
        return self._name == other._name \ 
        and self._id == other._id

...
Special methods: \_\_eq\_\_ 

```python
>>> class Student:
    def \_\_init\_\_(self, name, id):
        self._name = name
        self._id = id
    def \_\_eq\_\_(self, other):
        return self._name == other._name \ 
        and self._id == other._id

>>> s1 = Student('John', '123')
>>> s2 = Student('John', '456')
>>> s3 = Student('John', '123')

>>> s1 == s2
False
>>> s1 == s3
True
```

== on the objects calls the \_\_eq\_\_() method of the class
EXERCISE

Write an `__eq__` method for Point.

class Point:
    def __init__(self, x, y):
        self._x = x
        self._y = y

....
Special methods: rich comparison

`__eq__()` is an example of a *rich comparison* method:

<table>
<thead>
<tr>
<th>Comparison operator</th>
<th>Method called</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>==</code></td>
<td><code>__eq__()</code></td>
</tr>
<tr>
<td><code>!=</code></td>
<td><code>__ne__()</code></td>
</tr>
<tr>
<td><code>&lt;</code></td>
<td><code>__lt__()</code></td>
</tr>
<tr>
<td><code>&lt;=</code></td>
<td><code>__le__()</code></td>
</tr>
<tr>
<td><code>&gt;</code></td>
<td><code>__gt__()</code></td>
</tr>
<tr>
<td><code>&gt;=</code></td>
<td><code>__ge__()</code></td>
</tr>
</tbody>
</table>
Special methods: `__len__` `__contains__`

For a class that acts like a collection of items:

<table>
<thead>
<tr>
<th>You want…</th>
<th>You write…</th>
<th>And Python calls…</th>
</tr>
</thead>
<tbody>
<tr>
<td>the no. of items in the object <code>s</code></td>
<td><code>len(s)</code></td>
<td><code>s.__len__()</code></td>
</tr>
<tr>
<td>whether the object <code>s</code> contains an item <code>x</code></td>
<td><code>x in s</code></td>
<td><code>s.__contains__(x)</code></td>
</tr>
</tbody>
</table>
Summary: Class

- A class is a blueprint, or template, for the code and data associated with a collection of objects
  - the objects are *instances* of the class
Summary: Instance variables

• A variable associated with an object
  – specifies some property of that object
  – each object has its own copy of the instance variables
    o so updating one object's instance variables does not affect other objects

• Examples: Name, ID, Major, etc. of a student object
Summary: Methods

• Methods are pieces of code associated with a class (and instances of that class, i.e., objects)
  – they define the behaviors for these objects

• Examples:
  – getters: get_name(), get_id(), ...
  – setters: set_name(), set_id(), ...
  – special methods: __init__(), __str__(), ...

Object-oriented programming

Informally:

"Instead of a bit-grinding processor plundering data structures, we have a universe of well-behaved objects that courteously ask each other to carry out their various desires."

-Dan Ingalls