CSc 120
Introduction to Computer Programming II

Adapted from slides by
Dr. Saumya Debray

04: 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
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
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 alarm clock:

• State:
  - *what state does an alarm clock have?*

• Behavior:
  - *what does a clock do?*
  - *what operations could we define for a clock?*
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

---

**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

*used to create instances of an iPod*
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>
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<td>Music</td>
<td>Senior</td>
<td>MUS 210: B; MUS 423: A; CSC 110: B</td>
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Object-oriented representation

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<td>...</td>
<td>...</td>
<td>...</td>
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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

<table>
<thead>
<tr>
<th>Class</th>
<th>Name</th>
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<th>Major</th>
<th>Year</th>
<th>Grades</th>
</tr>
</thead>
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Grades: ...
Example: a set of students at UA

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Objects

• An object consists of:
  – a state
    o given by the values of its 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()

*methods:*
- like functions
- they look at and/or modify the instance variables of the object

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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
Example: Student class

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

    def get_name(self):
        return self._name

    ...

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indented `def`s define the methods of the class

the first non-indented line ends the class definition
Example: Student class

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

the first argument of each method (self) denotes the object being referred to

by convention this argument is written 'self' — this is recommended but not mandatory
class Student:
    def __init__(self, name, id):
        self._name = name
        self._id = id
    def get_name(self):
        return self._name
    ...

the `__init__(...)` method is special:

- called when an object is created (right after its creation)
- used to initialize the object's instance variables
- the initial values are supplied as arguments to `__init__(...)`
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()

Note: self (the object reference) is not explicitly specified when using the object
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
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Example: using the Student class

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        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
EXERCISE

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

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

    def get_name(self):
        return self._name
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

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

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

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

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

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**.
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()
    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:  
  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.
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 = ??

....
EXERCISE

Suppose we want to define a class for a *Point*:

• Data: ???
  – *what data might we want to associate with point objects?*

• Methods: ???
  – *what methods might we want to associate with point objects?*
EXERCISE

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:

\[ \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \]
Encapsulation

- **encapsulation**: Hiding implementation details of an object from the users of that object.
  - Encapsulation provides *abstraction*.
    - 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 (invariants).
  - Example: Only allow Points with non-negative coordinates.
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

† The Pythonic convention is that "_" at the beginning of an attribute name denotes that it is "private"
## Class attribute naming conventions

<table>
<thead>
<tr>
<th>Convention</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>One leading underscore <code>self._var1</code></td>
<td>Indicates that the attribute is &quot;not public&quot; and should only be accessed by the class's internals (convention; not enforced by Python)</td>
</tr>
<tr>
<td>One trailing underscore <code>self.var1_</code></td>
<td>Used to avoid conflicts with Python keywords, e.g., list_, class_, dict_</td>
</tr>
<tr>
<td>Two leading underscores <code>self.__var1</code></td>
<td>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></td>
</tr>
<tr>
<td>Two leading + trailing underscores <code>self.__var1__</code></td>
<td>Intended only for names that have special significance for Python, e.g., <code>__init__</code></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
## 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>
Printing out objects

>>> 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 + ":" + self._id

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

```python
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__()
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:

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 3.4.3 (default, Nov 17 2016, 01:08:31)
[GCC 4.8.4] on linux
Type "copyright", "credits" or "license()" for more information.

```python
>>> class Student:
    def \_\_init\_\_(self, name, id):
        self._name = name
        self._id = id
    def \_\_eq\_\_(self, other):
        return self._name == other._name \n        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
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><strong>eq</strong>()</td>
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<td><code>!=</code></td>
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<td><code>&lt;=</code></td>
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<td><strong>gt</strong>()</td>
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<tr>
<td><code>&gt;=</code></td>
<td><strong>ge</strong>()</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 s</td>
<td><code>len(s)</code></td>
<td><code>s.__len__()</code></td>
</tr>
<tr>
<td>whether the object s contains an item x</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__(), …
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)