Programming Principles in Python (CSCI 503/490)

Object-Oriented Programming

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Modules and Packages

- Python allows you to import code from other files, even your own
- A **module** is a collection of definitions
- A **package** is an organized collection of modules
- Modules can be
  - a separate python file
  - a separate C library that is written to be used with Python
  - a built-in module contained in the interpreter
  - a module installed by the user (via conda or pip)
- All types use the same import syntax

[RealPython]

What is the purpose of having modules or packages?

- Code reuse: makes life easier because others have written solutions to various problems
- Generally forces an organization of code that works together
- Standardizes interfaces; easier maintenance
- Encourages robustness, testing code

- This does take time so don't always create a module or package
  - If you're going to use a method once, it's not worth putting it in a module
  - If you're using the same methods over and over in (especially in different projects), a module or package makes sense

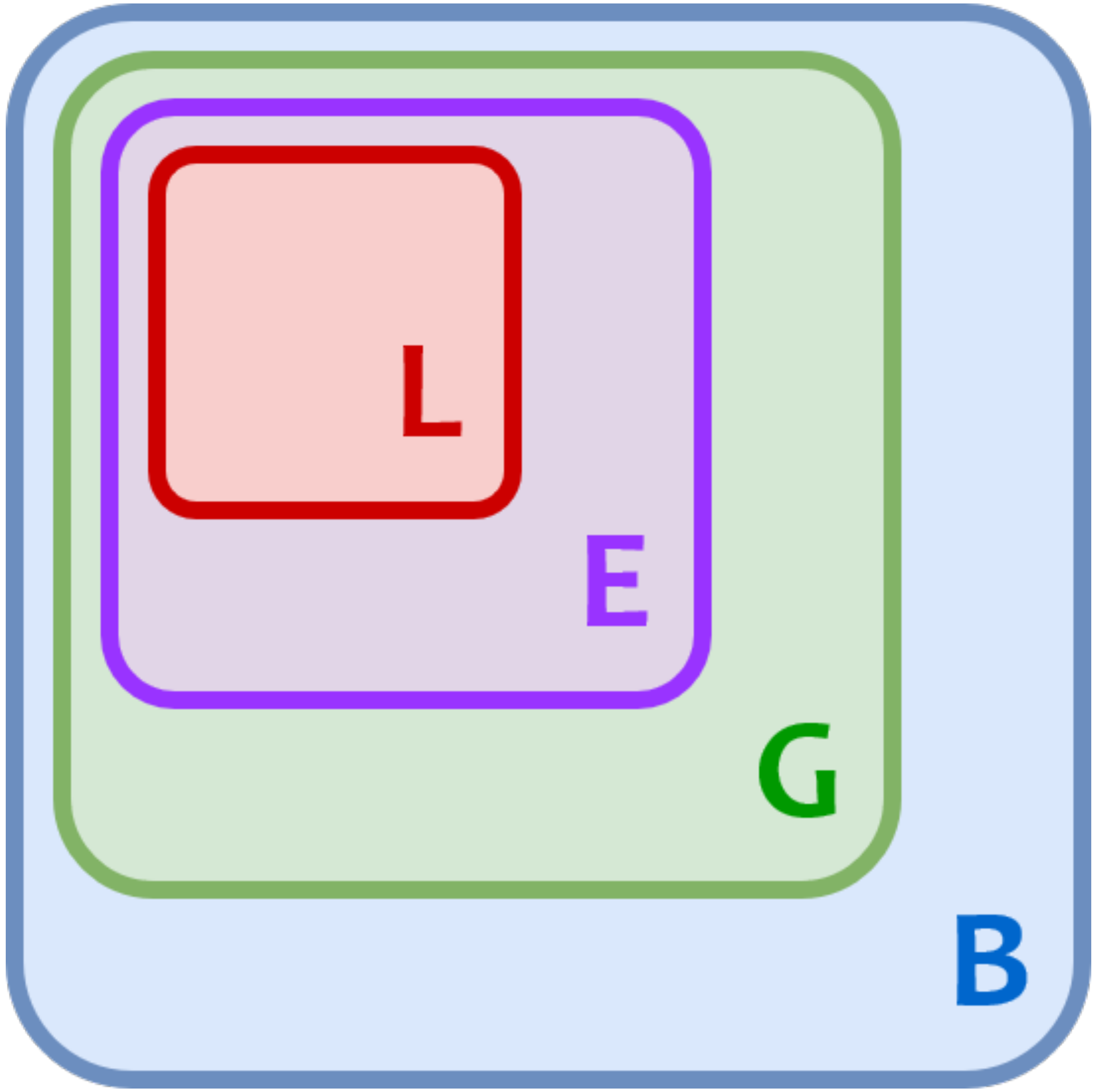
Importing modules

- `import <module>`
- `import <module> as <another-identifier>`
- `from <module> import <identifer-list>`
- `from <module> import <identifer> as <another-identifier>, …`

- `import` imports from the top, `from … import` imports "inner" names
- Need to use the qualified names when using import (`foo.bar.mymethod`)
- as clause **renames** the imported name

Namespaces

- Namespace is basically a dictionary with names and their values
- Accessing namespaces
  - `__builtins__`, `globals()`, `locals()`
- Examine contents of a namespace: `dir(<namespace>)`
- Python checks for a name in the sequence: local, enclosing, global, builtins
- To access names in outer scopes, use `global` (global) and `nonlocal` (enclosing) declarations



[RealPython]

Import Conventions

- Avoid wildcard imports like: `from math import *`
- Imports should be on separate lines
  - ```
    import sys
    import os
    ```
- Sometimes, a conditional import is required
  - ```
    if sys.version_info >= [3,7]:
        OrderedDict = dict
    else:
        from collections import OrderedDict
    ```
- Absolute imports best but relative imports allowed (`import .submodule`)
- Import abbreviations: `import pandas as pd; import numpy as np`

Reloading a Module?

- If you re-import a module, what happens?
  - ```
    import my_module
    my_module.SECRET_NUMBER # 42
    ```
  - Change the definition of `SECRET_NUMBER` to `14`
  - ```
    import my_module
    my_module.SECRET_NUMBER # Still 42!
    ```
- Modules are **cached** so they are not reloaded on each import call
- Can reload a module via `importlib.reload(<module>)`
- Be careful because **dependencies** will persist! (Order matters)

Python Packages

- A package is basically a collection of modules in a directory subtree
- Structures a module namespace by allowing dotted names
- Example:

```
- test_pkg/
      __init__.py
      foo.py
      bar.py
      baz/
          fun.py
```

- For packages that are to be executed as scripts, `__main__.py` can also be added

Finding Packages

- Python Package Index (PyPI) is the standard repository (https://pypi.org) and pip (pip installs packages) is the official python package installer
  - Types of distribution: source (sdist) and wheels (binaries)
  - Each package can specify dependencies
  - Creating a PyPI package requires adding some metadata
- Anaconda is a package index, conda is a package manager
  - conda is language-agnostic (not only Python)
  - solves dependencies
  - conda deals with non-Python dependencies
  - has different channels: default, conda-forge (community-led)

Installing Packages

- `pip install <package-name>`
- `conda install <package-name>`
- In Jupyter use:
  - `%pip install <package-name>`
  - `%conda install <package-name>`
- Arguments can be multiple packages
- Be careful! Security exploits using package installation and dependencies (e.g. Alex Birsan)

Environments

- Both pip and conda support environments
  - venv
  - conda env
- Newer tools like uv and pixi also support environments
- Idea is that you can create different environments for different work
  - environment for cs503
  - environment for research
  - environment for each project

Assignment 4

- Assignment covers strings and files
- Reading & writing data to files
- Dealing with string formatting
- Due today

Assignment 5

- Scripts, modules, packages
- Command-line program
- Out soon

Object-Oriented Programming

Object-Oriented Programming Concepts

- ?

Object-Oriented Programming Concepts

- Abstraction: simplify, hide implementation details, don't repeat yourself
- Encapsulation: represent an entity fully, keep attributes and methods together
- Inheritance: reuse (don't reinvent the wheel), specialization
- Polymorphism: methods are handled by a single interface with different implementations (overriding)

Object-Oriented Programming Concepts

- **Abstraction**: simplify, hide implementation details, don't repeat yourself
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Vehicle Example

- Suppose we are implementing a city simulation, and want to model vehicles driving on the road
- How do we represent a vehicle?
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Vehicle Example

- Suppose we are implementing a city simulation, and want to model vehicles driving on the road
- How do we represent a vehicle?
  - Information (attributes): make, model, year, color, num_doors, engine_type, mileage, acceleration, top_speed, braking_speed
  - Methods (actions): compute_estimated_value(), drive(num_seconds, acceleration), turn_left(), turn_right(), change_lane(dir), brake(), check_collision(other_vehicle)

Other Entities

- Road, Person, Building, ParkingLot
- Some of these interact with a Vehicle, some don't
- We want to store information associated with entities in a structured way
  - Building probably won't store anything about cars
  - Road should not store each car's make/model
  - …but we may have an association where a Road object keeps track of the cars currently driving on it

Object-Oriented Design

- There is a lot more than can be said about how to best define classes and the relationship between different classes
- It's not easy to do this well!
- Software Engineering
- Entity Relationship (ER) Diagrams
- Difference between Object-Oriented Model and ER Model

Class vs. Instance

- A **class** is a blueprint for creating instances
  - e.g. Vehicle
- An **instance** is an single object created from a class
  - e.g. 2000 Red Toyota Camry
  - Each object has its own attributes
  - Instance methods produce results unique to each particular instance

Classes and Instances in Python

- Class Definition:
  - ```
    class Vehicle:
        def __init__(self, make, model, year, color):
            self.make = make
            self.model = model
            self.year = year
            self.color = color

        def age(self):
            return 2024 - self.year
    ```
- Instances:
  - `car1 = Vehicle('Toyota', 'Camry', 2000, 'red')`
  - `car2 = Vehicle('Dodge', 'Caravan', 2015, 'gray')`
    ```

Constructor

- How an object is created and initialized
  - ```
    def __init__(self, make, model, year, color):
        self.make = make
        self.model = model
        self.year = year
        self.color = color
    ```
- `__init__` denotes the **constructor**
  - Not required, but usually should have one
  - All initialization should be done by the constructor
  - There is only **one** constructor allowed
  - Can add defaults to the constructor (`year=2021, color='gray'`)
    ```

Instance Attributes

- Where information about an object is stored
  - ```
    def __init__(self, make, model, year, color):
        self.make = make
        self.model = model
        self.year = year
        self.color = color
    ```
- `self` is the current object
- `self.make`, `self.model`, `self.year`, `self.color` are **instance attributes**
- There is **no declaration** required for instance attributes like in Java or C++
  - Can be created in any instance method…
  - …but good OOP design means they should be initialized in the constructor
    ```

Instance Methods

- Define actions for instances

```
- def age(self):
      return 2024 - self.year
```

- Like constructors, have `self` as first argument
- `self` will be the object calling the method
- Have access to instance attributes and methods via `self`
- Otherwise works like a normal function
- Can also **modify** instances in instance methods:

```
- def set_age(self, age):
      self.year = 2024 - age
```

Creating and Using Instances

- Creating instances:
  - Constructor expressions specify the name of the class to instantiate and specify any arguments to the constructor (not including `self`)
  - Returns new object
  - `car1 = Vehicle('Honda', 'Accord', 2009, 'red')`
  - `car2 = Vehicle('Dodge', 'Caravan', 2015, 'gray')`
- Calling an instance method
  - `car1.age()`
  - `car1.set_age(20)`
  - Note `self` is not passed explicitly, it's `car1` (instance before the dot)

Used Objects Many Times Before

- Everything in Python is an object!
  - `my_list = list()`
  - `my_list.append(3)`
  - `num = int('64')`
  - `name = "Gerald"`
  - `name.upper()`

Visibility

- In some languages, encapsulation allows certain attributes and methods to be hidden from those using an instance
- public (visible/available) vs. private (internal only)
- Python does not have visibility descriptors, but rather conventions (PEP8)
  - Attributes & methods with a leading underscore (_) are intended as private
  - Others are public
  - You can still access private names if you want but generally **shouldn't**:
    - `print(car1._color_hex)`
  - Double underscores leads to **name mangling**: `self.__internal_vin` is stored at `self._Vehicle__internal_vin`

Representation methods

- Printing objects:
  - `print(car1) # <__main__.Vehicle object at 0x7efc087c6b20>`
- "Dunder-methods": `__init__`
- Two for representing objects:
  - `__str__`: human-readable
  - `__repr__`: official, machine-readable
-
```
>>> now = datetime.datetime.now()
>>> now.__str__()
'2020-12-27 22:28:00.324317'
>>> now.__repr__()
'datetime.datetime(2020, 12, 27, 22, 28, 0, 324317)'
```

[https://www.journaldev.com/22460/python-str-repr-functions]

Representation methods

- Car example:
  - ```
    class Vehicle:
        …
        def __str__(self):
            return f'{self.year} {self.make} {self.model}'
    ```
- Don't call `print` in this method! Return a string
- When using, don't call directly, use `str` or `repr`
  - `str(car1)`
- `print` internally calls `__str__`
  - `print(car1)`
    ```

Other Dunder Methods

- `__eq__(<other>)`: return `True` if two objects are equal
- `__lt__(<other>)`: return `True` if object < other
- Collections:
  - `__len__()`: return number of items
  - `__contains__(item)`: return `True` if collection contains `item`
  - `__iter__(): returns iterator`
- Sequence + dict
  - `__getitem__(index)`: return item at `index` (which could be a key)
- + More

Properties

- Common pattern is getters and setters:
  - ```
    def age(self):
        return 2024 - self.year
    ```
  - ```
    def set_age(self, age):
        self.year = 2024 - age
    ```
- In some sense, this is no different than year except that we don't want to store `age` separate from `year` (they should be linked)
- Properties allow transformations and checks but are accessed like attributes
- ```
  @property
  def age(self):
      return 2024 - self.year
  ```
- `car1.age # 15`
  ```

Properties

- Can also define setters
- Syntax is a bit strange, want to link the two: `@<property-name>.setter`
- Method has the same name as the property: How?
- Decorators (`@<decorator-name>`) do some magic
- ```
  @property
  def age(self):
      return 2024 - self.year
  ```
- ```
  @age.setter
  def age(self, age):
      self.year = 2024 - age
  ```
- `car1.age = 15`

Properties

- Add validity checks!
- First car was 1885 so let's not allow ages greater than that (or negative ages)
-
```
@age.setter
def age(self, age):
    if age < 0 or age > 2024 - 1885:
        print("Invalid age, will not set")
    else:
        self.year = 2024 - age
```
- Better: raise exception (later)