Lecture 20

Operators and Abstraction

Announcements for Today

Two Weeks Out!

- **Prelim, Nov 21st at 7:30**
  - Same rooms as last time
  - Day after A6 is due
- **Material up to Nov. 12**
  - Study guide this weekend
  - Recursion + Loops + Classes
- **Conflict with Prelim?**
  - Prelim 2 Conflict on CMS
  - SDS students must submit!

Assignments

- A4 graded by Saturday
  - Will cover survey next week
- A5 also graded by Saturday
  - Returned via Gradescope
  - Similar policies to A2
- Need to be working on A6
  - Finish `Image` this weekend
  - Finish `Filter` by next Thurs
  - Best way to study for exam

Case Study: Fractions

- Want to add a new *type*
  - Values are fractions: ½, ¾
  - Operations are standard multiply, divide, etc.
  - **Example**: ½*¾ = ⅜
- Can do this with a class
  - Values are fraction objects
  - Operations are methods
- **Example**: frac1.py

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # INSTANCE ATTRIBUTES:
    # _numerator:    an int
    # _denominator: an int > 0

    def __init__(self,n=0,d=1):
        """Init: makes a Fraction"""
        self._numerator = n
        self._denominator = d
```

Case Study: Fractions

- Want to add a new ***type***
  - Values are fractions: ½ , ¾
  - Opera
    multi
  - **Exan**
- Can do
  - Values are fraction objects
  - Operations are methods
- **Example**: frac1.py

Reminder: Hide attributes, use **getters/setters**

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # INSTANCE ATTRIBUTES:
    # _numerator:    an int
    # _denominator: an int > 0

    def __init__(self,n=0,d=1):
        """Init: makes a Fraction"""
        self._numerator = n
        self._denominator = d
```

Problem: Doing Math is Unwieldy

What We Want	What We Get

$\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}\right)*\frac{5}{4}$	`>>> p = Fraction(1,2)`
	`>>> q = Fraction(1,3)`
	`>>> r = Fraction(1,4)`
	`>>> s = Fraction(5,4)`
	`>>> (p.add(q.add(r))).mult(s)`

This is confusing!

Problem: Doing Math is Unwieldy

What We Want

$$\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}\right)*\frac{5}{4}$$

Why not use the standard Python math operations?

What We Get

```
>>> p = Fraction(1,2)
>>> q = Fraction(1,3)
>>> r = Fraction(1,4)
>>> s = Fraction(5,4)
>>> (p.add(q.add(r))).mult(s)
```

This is confusing!

Special Methods in Python

- Have seen three so far
  - `__init__` for initializer
  - `__str__` for str()
  - `__repr__` for repr()
- Start/end with 2 underscores
  - This is standard in Python
  - Used in all special methods
  - Also for special attributes
- We can **overload operators**
  - Give new meaning to +, *, -

```
class Point3(object):
    """Instances are points in 3D space"""
    …

    def __init__(self,x=0,y=0,z=0):
        """Initializer: makes new Point3"""
        …

    def __str__(self,q):
        """Returns: string with contents"""
        …

    def __repr__(self,q):
        """Returns: unambiguous string"""
        …
```

Operator Overloading

- Many operators in Python a special symbols
  - +, -, /, *, ** for mathematics
  - ==, !=, <, > for comparisons
- The meaning of these symbols depends on type
  - 1 + 2 vs 'Hello' + 'World'
  - 1 < 2 vs 'Hello' < 'World'
- Our new type might want to use these symbols
  - We *overload* them to support our new type

Returning to Fractions

What We Want

$$\left(\frac{1}{2}+\frac{1}{3}+\frac{1}{4}\right)*\frac{5}{4}$$

Why not use the standard Python math operations?

Operator Overloading

- Python has methods that correspond to built-in ops
  - `__add__` corresponds to +
  - `__mul__` corresponds to *
  - `__eq__` corresponds to ==
  - Not implemented by default
- To overload operators you implement these methods

Operator Overloading: Multiplication

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0

    def __mul__(self,q):
        """Returns: Product of self, q
        Makes a new Fraction; does not
        modify contents of self or q
        Precondition: q a Fraction"""
        assert type(q) == Fraction
        top= self._numerator*q._numerator
        bot= self._denominator*q._denominator
        return Fraction(top,bot)
```

```
>>> p = Fraction(1,2)
>>> q = Fraction(3,4)
>>> r = p*q
```

Python converts to

```
>>> r = p.__mul__(q)
```

Operator overloading uses method in object on left.

Operator Overloading: Addition

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0

    def __add__(self,q):
        """Returns: Sum of self, q
        Makes a new Fraction
        Precondition: q a Fraction"""
        assert type(q) == Fraction
        bot= self._denominator*q._denominator
        top= (self._numerator*q._denominator+
              self._denominator*q._numerator)
        return Fraction(top,bot)
```

```
>>> p = Fraction(1,2)
>>> q = Fraction(3,4)
>>> r = p+q
```

Python converts to

```
>>> r = p.__add__(q)
```

Operator overloading uses method in object on left.

Comparing Objects for Equality

- Earlier in course, we saw == compare object contents
  - This is not the default
  - **Default**: folder names
- Must implement __eq__
  - Operator overloading!
  - Not limited to simple attribute comparison
  - **Ex**: cross multiplying

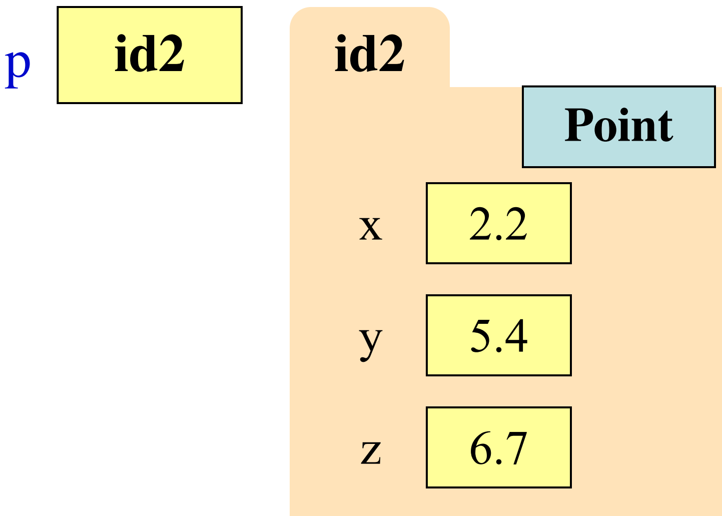
4 $\frac{1}{2}$ $\frac{2}{4}$ **4**

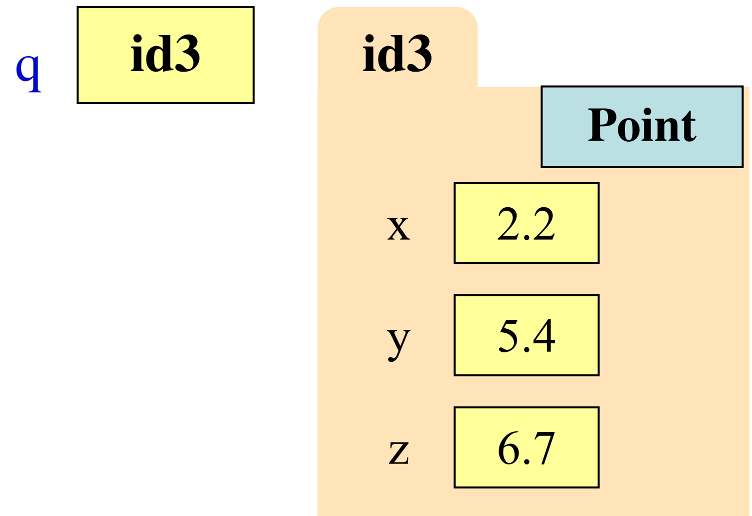
```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0

    def __eq__(self,q):
        """Returns: True if self, q equal,
        False if not, or q not a Fraction"""
        if type(q) != Fraction:
            return False
        left = self._numerator*q._denominator
        rght = self._denominator*q._numerator
        return left == rght
```

is Versus ==

- `p is q` evaluates to `False`
  - Compares folder names
  - Cannot change this
- `p == q` evaluates to `True`
  - But only because method `__eq__` compares contents





Always use `(x is None)` **not** `(x == None)`

Structure of a Proper Python Class

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0

    def getNumerator(self):
        """Returns: Numerator of Fraction"""
    …
    def __init__(self,n=0,d=1):
        """Initializer: makes a Fraction"""
    …
    def __add__(self,q):
        """Returns: Sum of self, q"""
    …
    def normalize(self):
        """Puts Fraction in reduced form"""
    …
```

Docstring describing class
Attributes are all **hidden**

Getters and Setters.

Initializer for the class.
Defaults for parameters.

Python operator overloading

Normal method definitions

Recall: Overloading Multiplication

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0

    def __mul__(self,q):
        """Returns: Product of self, q
        Makes a new Fraction; does not
        modify contents of self or q
        Precondition: q a Fraction"""
        assert type(q) == Fraction
        top = self._numerator*q._numerator
        bot= self._denominator*q._denominator
        return Fraction(top,bot)
```

```
>>> p = Fraction(1,2)
>>> q = 2 # an int
>>> r = p*q
```

Python converts to

```
>>> r = p.__mul__(q) # ERROR
```

Can only multiply fractions.
But ints “make sense” too.

Solution: Look at Argument Type

- Overloading use **left** type
  - p*q => p.__mul__(q)
  - Done for us automatically
  - Looks in class definition
- What about type on **right**?
  - Have to handle ourselves
- Can implement with ifs
  - Write helper for each type
  - Check type in method
  - Send to appropriate helper

```
class Fraction(object):
    …
    def __mul__(self,q):
        """Returns: Product of self, q
        Precondition: q a Fraction or int"""
        if type(q) == Fraction:
            return self._mulFrac(q)
        elif type(q) == int:
            return self._mulInt(q)
     …
    def _mulInt(self,q): # Hidden method
        return Fraction(self._numerator*q,
                        self._denominator)
```

A Better Multiplication

```
class Fraction(object):
    …
    def __mul__(self,q):
        """Returns: Product of self, q
        Precondition: q a Fraction or int"""
        if type(q) == Fraction:
            return self._mulFrac(q)
        elif type(q) == int:
            return self._mulInt(q)
    …
    def _mulInt(self,q): # Hidden method
        return Fraction(self._numerator*q,
                        self._denominator)
```

```
>>> p = Fraction(1,2)
>>> q = 2 # an int
>>> r = p*q
```

Python converts to

```
>>> r = p.__mul__(q) # OK!
```

See frac3.py for a full example of this method

What Do We Get This Time?

```
class Fraction(object):
    …
    def __mul__(self,q):
        """Returns: Product of self, q
        Precondition: q a Fraction or int"""
        if type(q) == Fraction:
            return self._mulFrac(q)
        elif type(q) == int:
            return self._mulInt(q)
    …
    def _mulInt(self,q): # Hidden method
        return Fraction(self._numerator*q,
                        self._denominator)
```

```
>>> p = Fraction(1,2)
>>> q = 2 # an int
>>> r = q*p
```

A: Fraction(2,2)
B: Fraction(1,1)
C: Fraction(2,4)
D: Error
E: I don't know

What Do We Get This Time?

```
class Fraction(object):
    …
    def __mul__(self,q):
        """Returns: Product of self, q
        Precondition: q a Fraction or int"""
        if type(q) == Fraction:
            return self._mulFrac(q)
        elif type(q) == int:
            return self._mulInt(q)
    …
    def _mulInt(self,q): # Hidden method
        return Fraction(self._numerator*q,
                        self._denominator)
```

```
>>> p = Fraction(1,2)
>>> q = 2 # an int
>>> r = q*p
```

Meaning determined by left.
Variable q stores an **int**.

B: Fraction(1,1)
C: Fraction(2,4)
D: Error **CORRECT**
E: I don’t know

The Python Data Model

Note: Slicing is done exclusively with the following three methods. A call like

```
a[1:2] = b
```

is translated to

http://docs.python.org/3/reference/datamodel.html

```
a[slice(1, 2, None)] = b
```

and so forth. Missing slice items are always filled in with `None`.

`object.__getitem__`(*self, key*)

Called to implement evaluation of `self[key]`. For sequence types, the accepted keys should be integers and slice objects. Note that the special interpretation of negative indexes (if the class wishes to emulate a sequence type) is up to the `__getitem__()` method. If *key* is of an inappropriate type, `TypeError` may be raised; if of a value outside the set of indexes for the sequence (after any special interpretation of negative values), `IndexError` should be raised. For mapping types, if *key* is missing (not in the container), `KeyError` should be raised.

Note: `for` loops expect that an `IndexError` will be raised for illegal indexes to allow proper detection of the end of the sequence.

`object.__missing__`(*self, key*)

Called by `dict.__getitem__()` to implement `self[key]` for dict subclasses when key is not in the dictionary.

`object.__setitem__`(*self, key, value*)

Called to implement assignment to `self[key]`. Same note as for `__getitem__()`. This should only be implemented for mappings if the objects support changes to the values for keys, or if new keys can be added, or for sequences if elements can be replaced. The same exceptions should be raised for improper *key* values as for the `__getitem__()` method.

`object.__delitem__`(*self, key*)

Called to implement deletion of `self[key]`. Same note as for `__getitem__()`. This should only be implemented for mappings if the objects support removal of keys, or for sequences if elements can be removed from the sequence. The same exceptions should be raised for improper *key* values as for the `__getitem__()` method.

We Have Come Full Circle

- On the first day, saw that a **type** is both
  - a set of *values*, and
  - the *operations* on them
- In Python, **all values are objects**
  - Everything has a folder in the heap
  - Just ignore it for immutable, basic types
- In Python, **all operations are methods**
  - Each operator has a double-underscore helper
  - Looks at type of object on left to process

Advanced Topic Warning!

The following will not be on the exam

If you ask “Will this be on the Exam”

we will be 

Properties: Invisible Setters and Getters

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0
    @property
    def numerator(self):
        """Numerator value of Fraction
        Invariant: must be an int"""
        return self._numerator

    @numerator.setter
    def numerator(self,value):
        assert type(value) == int
        self._numerator = value
```

```
>>> p = Fraction(1,2)
>>> x = p.numerator
```

Python converts to

```
>>> x = p.numerator()
```

```
>>> p.numerator = 2
```

Python converts to

```
>>> p.numerator(2)
```

Properties: Invisible Setters and Getters

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0
    @property
    def numerator(self):
        """Numerator value of Fraction
        Invariant: must be an int"""
        return self._numerator

    @numerator.setter
    def numerator(self,value):
        assert type(value) == int
        self._numerator = value
```

Decorator specifies that next method is **getter** for property of the same name as method

Docstring describing property

Property uses **hidden** attribute.

Decorator specifies that next method is the **setter** for property whose name is numerator.

Properties: Invisible Setters and Getters

```
class Fraction(object):
    """Instance is a fraction n/d"""
    # _numerator:    an int
    # _denominator:  an int > 0
    @property
    def numerator(self):
        """Numerator value of Fraction
        Invariant: must be an int"""
        return self._numerator

    @numerator.setter
    def numerator(self,value):
        assert type(value) == int
        self._numerator = value
```

Goal: Data Encapsulation
Protecting your data from other, "clumsy" users.

Only the **getter** is required!

If no **setter**, then the attribute is "immutable".

Replace **Attributes** w/ **Properties**
(Users cannot tell difference)