Lecture 20

Operators and Abstraction

Announcements for Today

Reading

- **Prelim, Nov 8th 5:15 or 7:30**
  - Same break-up as last time
  - But will swap times assigned
- **Material up to November 1**
  - Review posted this weekend
  - Recursion + Loops + Classes
- **Conflict with Prelim time?**
  - Prelim 2 Conflict on CMS
  - SDS students must submit!
  - **LAST DAY TO SUBMIT**

Assignments

- A4 graded by tomorrow
  - Will cover survey next week
- A5 to be graded Saturday
  - Returned via Gradescope
  - Similar policies to A2
- Need to be working on A6
  - Should have Dataset done
  - Cluster finished by Sunday
  - 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:    top        [int]
        _denominator: bottom [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
  - **Exam**
- 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:   top      [int]
      _denominator: bottom [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

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

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!

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)`

Why not use the standard Python math operations?

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 attributes:
        _numerator:    top        [int]
        _denominator: bottom [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 attributes:
        _numerator:   top      [int]
        _denominator: bottom [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
```

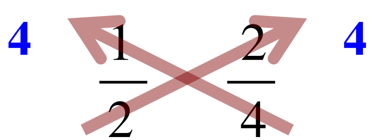
Python converts to

```
>>> 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

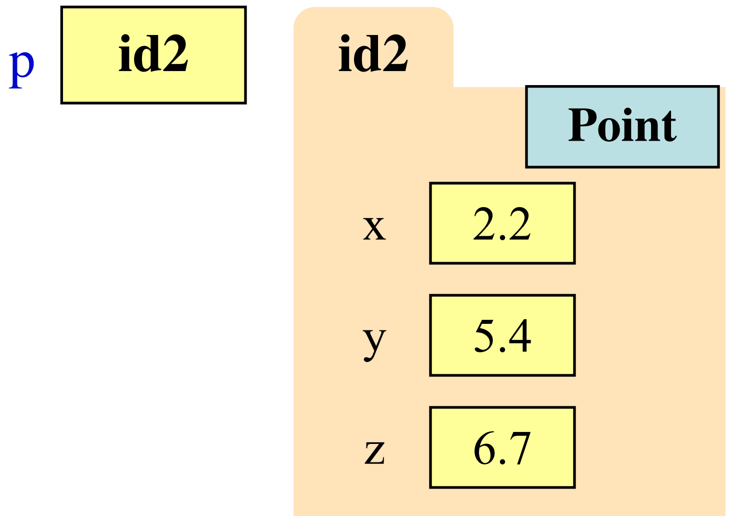


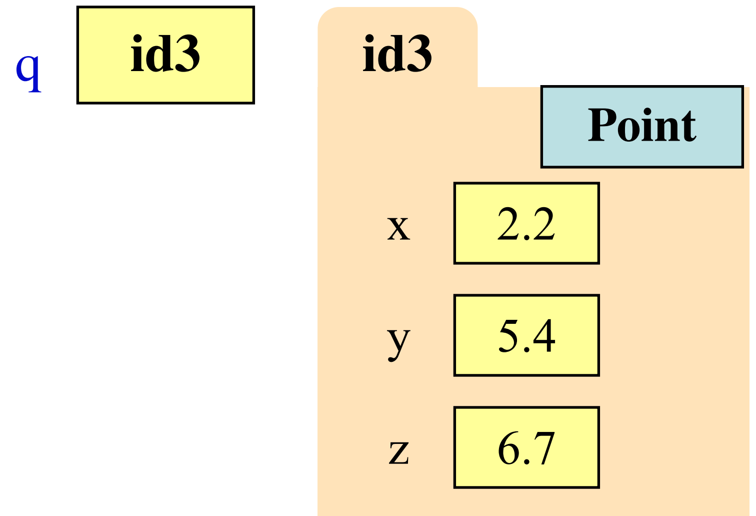

```
class Fraction(object):
    """Instance attributes:
        _numerator:   top         [int]
        _denominator: bottom [int > 0]"""

    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):
    """Instances represent a Fraction
     Attributes:
        _numerator: [int]
       _denominator: [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 attributes:
        _numerator    [int]:       top
        _denominator [int > 0]: bottom """

    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

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

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

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

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*)

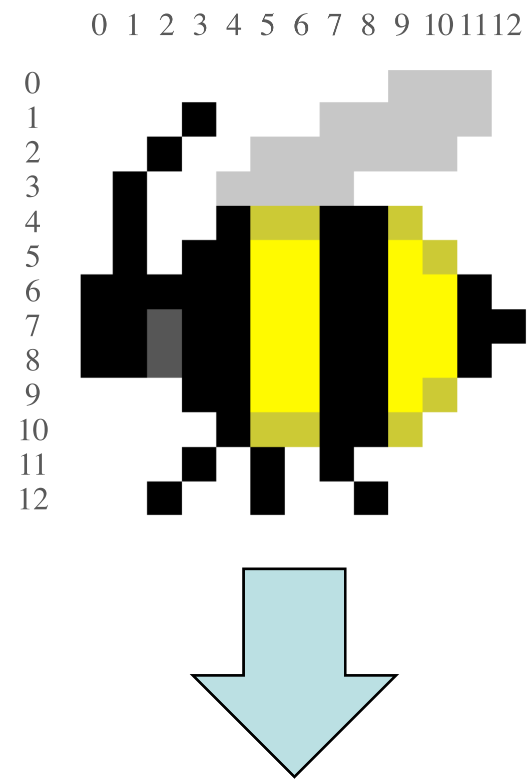
Called to implement assignment to `self[key]`. Same note as for `__getitem__()`. This should only be implemented for mappings if the objects support changes to the values for keys, or if new keys can be added, or for sequences if elements can be replaced. The same exceptions should be raised for improper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

Advanced Example: Pixels

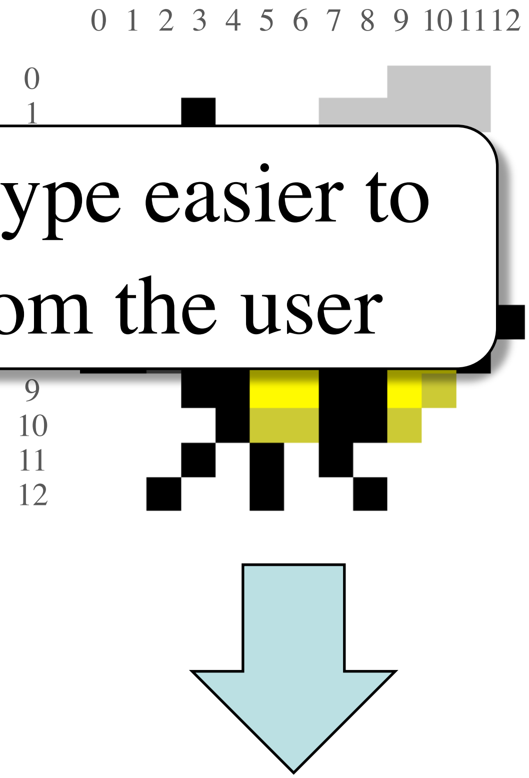
- Image is list of list of RGB
  - But this is really slow
  - **Faster**: byte buffer (???)
  - Beyond scope of course
- **Compromise**: Pixels class
  - Has byte buffer attribute
  - *Pretends* to be list of tuples
  - You can slice/iterate/etc…
- Uses data model to do this



[(255,255,255), (255,255,255), ...]

Advanced Example: Pixels

- Image is list of list of RGB
  - F
  - I
  - B
- **Compromise**: Pixels class
  - Has byte buffer attribute
  - *Pretends* to be list of tuples
  - You can slice/iterate/etc…
- Uses data model to **lie to you!**



(255,255,255), (255,255,255), …]

> **Abstraction**: Making a type easier to use by hiding details from the user

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 attributes:
        _numerator:   [int]
        _denominator: [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 attributes:
        _numerator:   [int]
        _denominator: [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 attributes:
        _numerator:   [int]
        _denominator: [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)