Lecture 18

Using Classes Effectively

Announcements for Today

Assignments

- A4 is due tonight!
  - Survey is still open
- A5 to be posted tonight
  - Short written assignment
  - Due next Thursday
- A6 to be posted Sunday
  - Due a **day before** prelim
  - Designed to take two weeks
  - So get started on it early

Reading

- Chapter 17 for today
- Chapter 18 for Tuesday
- But only follow loosely

Recall: The __init__ Method

two underscores

w = Worker('Obama', 1234, None)

Called by the constructor

```
def __init__(self, n, s, b):
    """Initializer: creates a Worker

    Has last name n, SSN s, and boss b

    Precondition: n a string,
    s an int in range 0..999999999,
    b either a Worker or None.   """
    self.lname = n
    self.ssn  = s
    self.boss = b
```

id8

Worker

lname	'White'
ssn	1234
boss	None

Recall: The __init__ Method

w = Worker('Obama', 1234, None)

```
def __init__(self, n, s, b):
    """Initializer: creates a Worker

    Has last name n, SSN s, and boss b

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    s an int in range 0..999999999,
    b either a Worker or None.   """
    self.lname = n
    self.ssn  = s
    self.boss = b
```

Are there other special methods that we can use?

Example: Converting Values to Strings

str() Function

- **Usage**: str(<expression>)
  - Evaluates the expression
  - Converts it into a string
- How does it convert?
  - str(2) → '2'
  - str(True) → 'True'
  - str('True') → 'True'
  - str(Point3()) → '(0.0,0.0,0.0)'

repr() Function

- **Usage**: repr(<expression>)
  - Evaluates the expression
  - Converts it into a string
- How does it convert?
  - repr(2) → '2'
  - repr(True) → 'True'
  - repr('True') → "'True'"
  - repr(Point3()) →
    "<class 'Point3'> (0.0,0.0,0.0)"

Example: Converting Values to Strings

str() Function

- **Usage**: str(<expression>)
  - Evaluates the expression
  - Converts it into a string
- How does it con...

  > What type is this value?

  - str(2) → '2'
  - str(True) → 'True...
  - str('True') → 'True'
  - str(Point3()) → '(0.0,0.0,0.0)'

repr() Function

- > repr() is for *unambigious* representation

  How does it co...

  > The value's type is clear

  - repr(2) → '2'...
  - repr(True) → ...
  - repr('True') → "'True'"
  - repr(Point3()) →
    "<class 'Point3'> (0.0,0.0,0.0)"

What Does **str()** Do On Objects?

- Does **NOT** display contents

  ```
  >>> p = Point3(1,2,3)
  >>> str(p)
  '<Point3 object at 0x1007a90>'
  ```

- Must add a special method
  - __str__ for str()
  - __repr__ for repr()

- Could get away with just one
  - repr() requires __repr__
  - str() can use __repr__ (if __str__ is not there)

```python
class Point3(object):
    """Class for points in 3d space"""
    ...
    def __str__(self):
        """Returns: string with contents"""
        return '('+str(self.x) + ',' +
                    str(self.y) + ',' +
                    str(self.z) + ')'

    def __repr__(self):
        """Returns: unambiguous string"""
        return str(self.__class__)+
                    str(self)
```

What Does **str()** Do On Objects?

- Does **NOT** display contents

  >>> p = Point3(1,2,3)

  >>> str(p)

  '<Point3 object at 0x1007a90>'

- Must add a special method

  - __str__ for str()

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        """Returns: string with contents"""
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                    str(self.y) + ',' +
                    str(self.z) + ')'

    def __repr__(self):
        """Returns: unambiguous string"""
        return str(self.__class__)+
                str(self)
```

Gives the class name

__repr__ using __str__ as helper

Designing Types

- **Type**: set of values and the operations on them
  - ▪ int: (**set**: integers; **ops**: +, −, *, //, …)
  - ▪ Time (**set**: times of day; **ops**: time span, before/after, …)
  - ▪ Worker (**set**: all possible workers; **ops**: hire, pay, promote, …)
  - ▪ Rectangle (**set**: all axis-aligned rectangles in 2D;
            ops: contains, intersect, …)

- To define a class, think of a *real type* you want to make
  - ▪ Python gives you the tools, but does not do it for you
  - ▪ Physically, any object can take on any value
  - ▪ Discipline is required to get what you want

Making a Class into a Type

1. Think about what values you want in the set

   ▪ What are the attributes? What values can they have?

2. Think about what operations you want

   ▪ This often influences the previous question

- To make (1) precise: write a *class invariant*

   ▪ Statement we promise to keep true **after every method call**

- To make (2) precise: write *method specifications*

   ▪ Statement of what method does/what it expects (preconditions)

- Write your code to make these statements true!

Planning out a Class

```python
class Time(object):
    """Class to represent times of day.

    Inv: hour is an int in 0..23
    Inv: min is an int in 0..59"""


    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""


    def increment(self, hours, mins):
        """Move time hours and mins
        into the future.
        Pre: hours int >= 0; mins in 0..59"""


    def isPM(self):
        """Returns: True if noon or later."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Time instance.

Method Specification

States what the method does.

Gives preconditions stating what is assumed true of the arguments.

Planning out a Class

```python
class Rectangle(object):
    """Class to represent rectangular region

    Inv: t (top edge) is a float
    Inv: l (left edge) is a float
    Inv: b (bottom edge) is a float
    Inv: r (right edge) is a float
    Additional Inv: l <= r and b <= t."""

    def __init__(self, t, l, b, r):
        """The rectangle [l, r] x [t, b]
        Pre: args are floats; l <= r; b <= t"""

    def area(self):
        """Return: area of the rectangle."""

    def intersection(self, other):
        """Return: new Rectangle describing
           intersection of self with other."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Rectangle instance.

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Planning out a Class

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    Additional Inv: l <= r and b <= t."""

    def __init__(self, t, l, b, r):
        """The rectangle [l, r] x [t, b
        Pre: args are floats; l <= r;

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        """Return: area of the rectangle."""

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           intersection of self with other."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Rectangle instance.

Special invariant **relating** attributes to each other

Method Specification

States what the method does.

Gives preconditions stating what is assumed true of the arguments.

Planning out a Class

```python
class Hand(object):
    """Instances represent a hand in cards.

    Inv: cards is a list of Card objects.
    This list is sorted according to the
    ordering defined by the Card class."""

    def __init__(self, deck, n):
        """Draw a hand of n cards.
        Pre: deck is a list of >= n cards"""

    def isFullHouse(self):
        """Return: True if this hand is a full
        house; False otherwise"""

    def discard(self, k):
        """Discard the k-th card."""
```

Class Invariant

States what attributes are present and what values they can have.

A statement that will always be true of any Rectangle instance.

Method Specification

States what the method does.

Gives preconditions stating what is assumed true of the arguments.

Implementing a Class

- All that remains is to fill in the methods. (All?!)

- When **implementing methods**:
  1. Assume preconditions are true
  2. Assume class invariant is true to start
  3. Ensure method specification is fulfilled
  4. Ensure class invariant is true when done

- Later, when **using the class**:
  - When calling methods, ensure preconditions are true
  - If attributes are altered, ensure class invariant is true

Implementing an Initializer

```python
def __init__(self, hour, min):
    """The time hour:min.
    Pre: hour in 0..23; min in 0..59"""
```

This is true to start

```python
self.hour = hour
self.min = min
```

You put code here

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This should be true at the end

Implementing a Method

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This is true to start

```
def increment(self, hours, mins):
    """Move this time <hours> hours
    and <mins> minutes into the future.
    Pre: hours [int] >= 0; mins in 0..59"""
```

What we are supposed to accomplish

This is also true to start

```
self.min  = self.min + mins
self.hour = self.hour + hours
```

?

You put code here

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This should be true at the end

Implementing a Method

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

```python
def increment(self, hours, mins):
    """Move this time <hours> hours
    and <mins> minutes into the future.
    Pre: hours [int] >= 0; mins in 0..59"""
```

What we are supposed to accomplish

This is also true to start

```python
    self.min  = self.min + mins
    self.hour = (self.hour + hours +
                      self.min // 60)
    self.min  = self.min % 60
    self.hour = self.hour % 24
```

You put code here

Inv: hour is an int in 0..23
Inv: min is an int in 0..59

This should be true at the end

Object Oriented Design

Interface

- How the code fits together
  - interface btw programmers
  - interface btw parts of an app
- Given by **specifications**
  - Class spec and invariants
  - Method specs and preconds
  - Interface is **ALL of these**

Implementation

- What the code actually does
  - when create an object
  - when call a method
- Given by method **definitions**
  - Must meet specifications
  - Must not violate invariants
  - But otherwise flexible

Important concept for making
large software systems

Implementing a Class

- All that remains is to fill in the methods. (All?!)

- When **implementing methods**:
    1. Assume preconditions are true
    2. Assume class invariant is true to start
    3. Ensure method specification is fulfilled
    4. Ensure class invariant is true when done

- Later, when **using the class**:

    ▪ When calling methods, ensure preconditions are true

    ▪ If attributes are altered, ensure class invariant is true

Recall: Enforce Preconditions with assert

```
def anglicize(n):
    """Returns: the anglicization of int n.

    Precondition: n an int, 0 < n < 1,000,000"""
    assert type(n) == int, str(n)+' is not an int'
    assert 0 < n and n < 1000000, repr(n)+' is out of range'
    # Implement method here...
```

Check (part of)
the precondition

(Optional) Error message
when precondition violated

Enforce Method Preconditions with **assert**

```python
class Time(object):
    """Class to represent times of day."""
```

Inv: hour is an int in 0..23
Inv: min is an int in 0..59"""

```python
    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""
        assert type(hour) == int
        assert 0 <= hour and hour < 24
        assert type(min) == int
        assert 0 <= min and min < 60
```

Initializer creates/initializes all of the instance attributes.

Asserts in initializer guarantee the initial values satisfy the invariant.

```python
    def increment(self, hours, mins):
        """Move this time <hours> hours
        and <mins> minutes into the future.
        Pre: hours is int >= 0; mins in 0..59"""
        assert type(hour) == int
        assert type (min) == int
        assert hour >= 0
        assert 0 <= min and min < 60
```
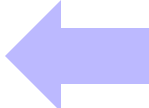
Asserts in other methods enforce the method preconditions.

Hiding Methods From Access

- Hidden methods
  - start with an **underscore**
  - do not show up in help()
  - are meant to be **internal** (e.g. helper methods)
- But they are **not restricted**
  - You can still access them
  - But this is bad practice!
  - Like a precond violation
- Can do same for attributes
  - Underscore makes it hidden
  - Only used inside of methods

```python
class Time(object):
    """Class to represent times of day.

    Inv: hour is an int in 0..23
    Inv: min is an int in 0..59"""

    def _is_minute(self,m):
        """Return: True if m valid minute"""
        return (type(m) == int and
                m >= 0 and m < 60)

    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""
        assert self._is_minute(m)
        ...
```

Helper

Hiding Methods From Access

- Hidden methods
  - start with an **underscore**
  - do not show up in help()
  - are meant to be **internal** (e.g. helper methods)
- But they are **not restricted**
  - You can still access them
  - But this is bad practice!
  - Like a precond violation
- Can do same for attributes

Will come back to this

```
class Time(object):
    """Class to represent times of day.

    Inv: hour is an int in 0..23
         min is an int in 0..59"""


    def _is_minute(self,m):
        """Return: True if m valid minute"""
        return (type(m) == int and
                m >= 0 and m < 60)


    def __init__(self, hour, min):
        """The time hour:min.
        Pre: hour in 0..23; min in 0..59"""
        assert self._is_minute(m)
        ...
```

HIDDEN

Helper

Enforcing Invariants

```python
class Time(object):
    """Class to repr times of day.

    Inv: hour is an int in 0..23
    Inv: min is an int in 0..59
    """
```

Invariants: Properties that are always true.

- These are just comments!

  ```
  >>> t = Time(2,30)
  >>> t.hour = 'Hello'
  ```

- How do we prevent this?

- **Idea**: Restrict direct access
  - Only access via methods
  - Use asserts to enforce them

- **Example**:

```python
def getHour(self):
    """Returns: the hour"""
    return self.hour


def setHour (self,value):
    """Sets hour to value"""
    assert type(value) == int
    assert value >= 0 and value < 24
    self.numerator = value
```

Data Encapsulation

- **Idea**: Force the user to only use methods
- Do not allow direct access of attributes

Setter Method

- Used to change an attribute
- Replaces all assignment statements to the attribute
- **Bad**:

  ```
  >>> t.hour = 5
  ```

- **Good**:

  ```
  >>> t.setHour(5)
  ```

Getter Method

- Used to access an attribute
- Replaces all usage of attribute in an expression
- **Bad**:

  ```
  >>> x = 3*t.hour
  ```

- **Good**:

  ```
  >>> x = 3*t.getHour()
  ```

Data Encapsulation

```
class Time(object):
    """Class to repr times of day. """


    def getHour (self):
        """Returns: hour attribute"""
        return self._hour


    def setHour(self, h):
        """ Sets hour to h
        Pre: h is an int in 0..23"""
        assert type(h) == int
        assert 0 <= h and h < 24
        self._hour = d
```

Getter

Setter

NO ATTRIBUTES in class specification

Method specifications describe the attributes

Setter precondition is same as the **invariant**

Data Encapsulation

```python
class Time(object):
    """Class to repr times of day. """


    def getHour (self):
        """Returns: hour attribute"""
        return self._hour


    def setHour(self):
        """ Sets ho...
        Pre: h is a...
        assert type(h) == int
        assert 0 <= h and h < 24
        self._hour = d
```

Getter

Setter

Hidden attribute user should **NOT** know about

NO ATTRIBUTES in class specification

Method specifications describe the attributes

precondition is same as the **invariant**

Encapsulation and Specifications

```
class Time(object):
    """Class to represent times of day. """
```

No attributes in class spec

```
    ### Hidden attributes
    # Att _hour: hour of the day
    # Inv: _hour is an int in 0..23
    # Att _min: minute of the hour
    # Inv: _min is an int in 0..59
```

These comments make it part of the **class invariant** but not part of the (public) **interface**

These comments do not go in help()

Encapsulation and Specifications

```
class Time(object):
    """Class to represent times of day. """
```

No attributes in class spec

```
    ### Hidden attributes
    # Att _h
    # Inv: _h
    # Att _min: minute of the hour
    # Inv: _min is an int in 0..59
```

New style for 2019!

The_ comments _ part of the _ **invariant** but not part of the (public) **interface**

These comments do not go in `help()`

Class Invariant vs Interface

Class Invariant

- List attributes that are present
  - Both hidden AND unhidden
  - Lists the invariants of each
- For the **implementer**
  - Guide for the initializer
  - Guide for method definitions

Interface

- Describes what is accessible
  - Unhidden methods/attribs
  - What is visible in help()
- For user/**other programmers**
  - Enough to create an object
  - Enough to call the methods

Previous years of CS1110 confused these two topics

Mutable vs. Immutable Attributes

Mutable

- Can change value directly
  - If class invariant met
  - **Example:** turtle.color
- Has both getters and setters
  - Setters allow you to change
  - Enforce invariants w/ asserts

Immutable

- Can't change value directly
  - May change "behind scenes"
  - **Example:** turtle.x
- Has only a getter
  - No setter means no change
  - Getter allows limited access

May ask you to differentiate on the exam

Mutable vs. Immutable Attributes

Mutable

- Can change value directly

  - If class invariant met

  - **Example:** turtle.color

- Has both getters and setters

  - Setters allow

  - Enforce invar

> **Where?** Next week.

Immutable

- Can't change value directly

  - May change "behind scenes"

  - **Example:** turtle.x

- Has only a getter

  - No setter means no change

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May ask you to differentiate on the exam

Exercise: Design a (2D) Circle

- What are the **attributes**?

  - What is the bare minimum we need?

  - What are some extras we might want?

  - What are the invariants?

- What are the **methods**?

  - With just the one circle?

  - With more than one circle?