

Lecture #17: Abstraction Support: Exceptions, Operators, Properties

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Failed preconditions

- Part of the contract between the implementor and client is the set of *preconditions* under which a function, method, etc. is supposed to operate.
- Example:

```
class Rational:
    def __init__(self, x, y):
        """The rational number x/y. Assumes that x and y
        are ints and y != 0."""
```
- Here, "x and y are ints and y!=0" is a precondition on the client.
- So what happens when the precondition is not met?

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Programmer Errors

- Python has preconditions of its own.
- E.g., type rules on operations: `3 + (2, 1)` is invalid.
- What happens when we (programmers) violate these preconditions?

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Outside Events

- Some operations may entail the possibility of errors caused by the data or the environment in which a program runs.
- I/O over a network is a common example: connections go down; data is corrupted.
- User input is another major source of error: we may ask to read an integer numeral, and be handed something non-numeric.
- Again, what happens when such errors occur?

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Possible Responses

- One approach is to take the point of view that when a precondition is violated, all bets are off and the implementor is free to do anything.
 - Corresponds to a logical axiom: $\text{False} \Rightarrow \text{True}$.
 - But not a particularly helpful or safe approach.
- One can adopt a convention in which erroneous operations return special error values.
 - Feasible in Python, but less so in languages that require specific types on return values.
 - Used in the C library, but can't be used for non-integer-returning functions.
 - Error prone (too easy to ignore errors).
 - Cluttered (reader is forced to wade through a lot of error-handling code, a distraction from the main algorithm).
- Numerous programming languages, including Python, support a general notion of *exceptional condition* or *exception* with supporting syntax and semantics that separate error handling from main program logic.

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Exceptions

- An *exception mechanism* is a control structure that
 - Halts execution at one point in a program (called *raising* or *throwing* an exception).
 - Resumes execution at some other, previously designated point in the program (called *catching* or *handling* an exception).
- In Python, the *raise* statement throws exceptions, and *try* statements catch them:

```
def f0(...):
    try:
        g0(...)          # 1. Call of g...
        OTHER STUFF      # Skipped
    except:
        handle oops      # 3. Handle problem
...
def g1(...): # Eventually called by g0, possibly many calls down
    if detectError():
        raise Oops       # 2. Raise exception
    MORE                 # Skipped
```

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Communicating the Reason

- Normally, the handler would like to know the reason for an exception.
- "Reason," being a noun, suggests we use objects, which is what Python does.
- Python defines the class `BaseException`. It or any subclass of it may convey information to a handler. We'll call these *exception classes*.

- `BaseException` carries arbitrary information as if declared:

```
class BaseException:
    def __init__(self, *args):
        self.args = args
    ...
```

- The `raise` statement then packages up and sends information to a handler:

```
raise ValueError("x must be positive", x, y)
raise ValueError      # Short for raise ValueError()
e = ValueError("exceptions are just objects!")
raise e               # So this works, too
```

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Handlers

- A function indicates that something is wrong; it is the client (caller) that decides what to do about it.
- The `try` statement allows one to provide one or more handlers for a set of statements, with selection based on the type of exception object thrown.

`try:`

assorted statements

```
except ValueError:
    print("Something was wrong with the arguments")
except EnvironmentError: # Also catches subtypes IOError, OSError
    print("The operating system is telling us something")
except:                  # Some other exception
    print("Something wrong")
```

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Retrieving the Exception

- So far, we've just looked at exception *types*.
- To get at the exception objects, use a bit more syntax:

```
try:
    assorted statements
except ValueError as exc:
    print("Something was wrong with the arguments: {0}".format(exc))
```

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Cleaning Up and Reraising

- Sometimes we catch an exception in order to clean things up before the real handler takes over.

```
inp = open(aFile)
try:
    Assorted processing
    inp.close()
except:
    inp.close()
    raise      # Reraise the same exception
```

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Finally Clauses

- More generally, we can clean things up regardless of how we leave the `try` statement:

```
for i in range(100):
    try:
        setTimer(10) # Set time limit
        if found(i):
            break
        longComputationThatMightTimeOut()
    finally:
        cancelTimer()
        # Continue with 'break' or with exception
```

- This fragment will always cancel the timer, whether the loop ends because of `break` or a timeout exception.
- After which, it carries on whatever caused the `try` to stop.

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Standard Exceptions

- See the Python library for a complete rundown.
- We'll often encounter `ValueError` (inappropriate values), `AttributeError` (`x.foo`, where there is no `foo` in `x`), `TypeError`, `OSError` (bad system call), `IOError` (such as nonexistent files).
- Other exceptions are not errors, but are used because `raise` is a convenient way to achieve some effect:
 - `StopIteration`: see last lecture.
 - `SystemExit`: Results from `sys.exit(n)`, which is intended to end a program.

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Example: Implementing Iterators

- An **iterator** is an abstraction device for hiding the representation of a collection of values.

- The **for** statement is actually a generic control construct with the following meaning (well, Python adds a few more bells and whistles):

```
for x in C:
    S
```

MEANS

```
tmp_iter = C.__iter__()
try:
    while True:
        x = tmp_iter.__next__()
        S
except StopIteration:
    pass
```

- The `__next__` method can use the `raise StopIteration` statement to cause the loop to exit.
- Types that implement `__iter__` are called **iterable**, and those that implement `__next__` are **iterators**.
- The builtin functions `iter(x)` and `next(x)` are defined to call `x.__iter__()` and `x.__next__()`.

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Problem: Reconstruct the range class

- Want `Range(1, 10)` to give us something that behaves like a Python range, so that this loop prints 1-9:

```
for x in Range(1, 10):
    print(x)
```

```
class Range:
    def __init__(self, low, high):
        self._low = low
        self._high = high
    def __iter__(self):
        return RangeIter(self)

class RangeIter:
    def __init__(self, limits):
        self._bound = limits._high
        self._next = limits._low
    def __next__(self):
        if self._next >= self._bound:
            raise StopIteration
        else:
            self._next += 1
            return self._next-1
```

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Summary

- Exceptions are a way of returning information from a function "out of band," and allowing programmers to clearly separate error handling from normal cases.
- In effect, specifying possible exceptions is therefore part of the interface.
- Usually, the specification is implicit: one assumes that violation of a precondition might cause an exception.
- When a particular exception indicates something that might normally arise (e.g., bad user input), it will often be mentioned explicitly in the documentation of a function.
- Finally, `raise` and `try` may be used purely as normal control structures. By convention, the exceptions used in this case don't end in "Error."

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Back To Rationals

- Before, we implemented rational numbers as functions. The "standard" way is to use a class.
- There are a few interesting problems along the way, at least if you want to make something that meets our natural expectations.
- Python has defined a whole bunch of library classes to capture different kinds of number (see `numbers` and `fractions`), but we're going to build our own here.

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Some Basics

- We'd like rational numbers, with the usual arithmetic.
- Furthermore, we'd like to integrate rationals with other numeric types, especially `int` and `float`.
- So, let's start with the constructor:

```
class rational:
    def __init__(self, number=0, denom=1):
        if type(number) is not int or type(denom) is not int:
            raise TypeError("numerator or denominator not int")
        if denom == 0:
            raise ZeroDivisionError("denominator is 0")
        d = gcd(number,denom)
        self._numerator, self._denom = number // d, denom // d
```

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Arithmetic

- Would be nice to use normal syntax, such as `a+b` for rationals.
- But we know how to do that from early lectures:

```
def __add__(self, y):
    return rational(self._numerator * y._denom + self._denom * y._numerator,
                    self._denom * y._denom)
```

- What do we do if `y` is an `int`?
- One solution: **Coercion**:

```
def __add__(self, y):
    y = rational._coerceToRational(y)
    return rational(self._numerator * y._denom + self._denom * y._numerator,
                    self._denom * y._denom)
```

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Coercion

- In programming languages, *coercion* refers to conversions between types or representations that preserve abstract values.

```
@staticmethod    # Why is this appropriate?
def _coerceToRational(y):
    if type(y) is rational:
        return y
    else:
        return ?
```

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Type Dispatching

- But now what about `3 + rational(1,2)`? Ints don't know about rationals.
- This is a general problem with object-oriented languages. I call it "worship of the first parameter." It's the type of the first parameter (or that left of the dot) that controls what method gets called.
- Others use the phrase "the expression problem," because it arises in the context of arithmetic-expression-like things.
- There are various ways that languages have dealt with this.
- The brute-force solution is to introduce *multimethods* as a language feature (functions chosen on the basis of all parameters' types.)
- Or one can build something like this explicitly:

```
_add_dispatch_table = { (rational, int): _addri,
                        (int, rational): _addir, ...}

def __add__(self, y):
    _add_dispatch_table[(type(self), type(y))](self, y)
```

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A Python Approach

- The dispatch-table requires a lot of cooperation among types.
- Python uses a different approach that allows extensibility without having to change existing numeric types.
- The expression `x+y` first tries `x._add_(y)`.
- If that throws the exception `NotImplementedError`, it next tries `y._radd_(x)`.
- The `__add__` functions for standard numeric types observe this, and throw `NotImplementedError` if they can't handle their right operands.
- So, in `rational`:

```
def __radd__(self, y):
    return rational._coerceToRational(y).__add__(x)
```

- And now:

```
>>> 3 + rational(1,2)
7/2
```

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Syntax for Accessors

- Our previous implementation of rational numbers had functions for accessing the numerator and denominator, which now might look like this:

```
def numer(self):
    """My numerator in lowest terms."""
    return self._numer

def denom(self):
    """My denominator in lowest terms."""
    return self._denom
```

- It would be more convenient to be able to write simply `x.numer` and `x.denom`, but so far, the only way we know to allow this has problems:
 - The attributes are assignable, which we don't want if rationals are to be immutable.
 - We are forced to implement them as instance variables; the implementation has no opportunity to do any calculations to produce the values.
- That is, the syntax *exposes too much about the implementation*.

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Properties

- To help class implementors control syntax, Python provides an egregiously general mechanism known as *descriptors*.
- An attribute of a class that is set to a descriptor object behaves differently from usual when selected.
- Descriptors, in their full details, are wonders to behold, so we'll stick with simple uses.
- If we define

```
def numer0(self): return self._numer
numer = property(numer0) # numer is now a descriptor
```

Then fetching a value `x.numer` (i.e., without parentheses) is translated to `x.numer0()`.

- Can't assign to it, any more than you can assign to any function call.

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Properties (contd.)

- The usual shorthand for writing this is to use `property` as a *decorator*:

```
@property
def numer(self): return self._numer
```

where the '@' syntax is defined to be equivalent to

```
def numer(self): return self._numer
numer = property(numer) # Redefinition.
```

- Actually, the builtin `property` function is even more general. As an example:

```
class RestrictedInt:
    """If R is RestrictedInt(L, U), then assign R.x = V first checks
    that L <= V <= U and then causes R.x to be V."""
    def __init__(self, low, high):
        self._low, self._high, self._x = low, high, low
    def _getx(self): return self._x
    def _setx(self, val):
        assert self._low <= val <= self._high
        self._x = val
    x = property(_getx, _setx)
```

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