

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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