Lecture #9: Abstractions and Objects

Data Abstraction

- Functions are abstractions that represent computations and actions.
- In the old days, one described programs as hierarchies of actions: *procedural decomposition*.
- Starting in the 1970's, emphasis moved to the data that the functions operate on.
- An *abstract data type (ADT)* represents some kind of thing and the operations upon it.
- Instances of the type are often generically called *objects*.
- We can usefully organize our programs around the abstract data types in them.
- For each type, we define an *interface* that describes for users ("clients") of that type of data what operations are available.
- Typically, the interface consists of functions.
- The collection of specifications (syntactic and semantic—see lecture #6) constitute a specification of the type.
- We call ADTs *abstract* because clients ideally need not know internals.

Functions as Data Abstractions (I)

- Functions can serve as objects.
- In the path-finding example, the `blocked` argument was a function.
- But it essentially represented data: the set of places that were blocked.

Rational Numbers

- The book uses “rational number” as an example of an ADT:

```
def make_rat(n, d):
    """The rational number n/d, assuming n, d are integers, d!=0"""

def add_rat(x, y):
    """The sum of rational numbers x and y."""

def mul_rat(x, y):
    """The product of rational numbers x and y."""

def numer(r):
    """The numerator of rational number r."""

def denom(r):
    """The denominator of rational number r."""
```

- These definitions pretend that `x`, `y`, and `r` really are rational numbers.
- But from this point of view, `numer` and `denom` are problematic. Why?

A Better Specification

- Problem is that "the numerator (denominator) of r" is not well-defined for a rational number.
- If `make_rat` really produced rational numbers, then `make_rat(2, 4)` and `make_rat(1, 2)` ought to be identical. So should `make_rat(1, -1)` and `make_rat(-1, 1)`.
- So a better specification would be

```
def numer(r):
    """The numerator of rational number r in lowest terms."""

def denom(r):
    """The denominator of rational number r in lowest terms.
    Always positive."""
```

Representation as Functions (I)

- We have a tool that can implement this specification now: functions.

```
from math import gcd  # Need Python3.5 actually.

def make_rat(n, d):
    """The rational number n/d, assuming n, d are integers, d!=0"""
    g = gcd(n, d) if d > 0 else -gcd(n, d)
    n //= g; d //= g
    return lambda which: n if which == 0 else d

def numer(r):
    """The numerator of rational number r."""
    return ?________

def denom(r):
    """The denominator of rational number r."""
    return ?________
```

Representation as Functions (II)

- Rational numbers represented as functions that take a single argument and reveal one of their local variables.

```
from math import gcd
def make_rat(n, d):
    """The rational number n/d, assuming n, d are integers, d!=0"""
    g = gcd(n, d) if d > 0 else -gcd(n, d)
    n //= g; d //= g
    return lambda flag: n if flag == 0 else d
def numer(r):
    """The numerator of rational number r."""
    return r(0)
def denom(r):
    """The denominator of rational number r."""
    return r(1)

def add_rat(x, y):
    """The sum of rational numbers x and y."""
    return ?________
def mul_rat(x, y):
    """The product of rational numbers x and y."""
    return ?________
```

Representation as Functions (III)

- One possibility:

```
from math import gcd

def make_rat(n, d):
    """The rational number n/d, assuming n, d are integers, d!=0"""
    g = gcd(n, d) if d > 0 else -gcd(n, d)
    n //= g; d //= g
    return lambda flag: n if flag == 0 else d
...
def add_rat(x, y):
    n0, n1, d0, d1 = x(0), y(0), x(1), y(1)
    n, d = n0 * d1 + n1 * d0, d0 * d1
    g = gcd(n, d) if d > 0 else -gcd(n, d)
    n //= g; d //= g
    return lambda flag: n if flag == 0 else d

def mul_rat(x, y):
    """The product of rational numbers x and y."""
    return ?________
```

- Comments?

Abstraction Violations and DRY

- Having created an abstraction (`make_rat`, `numer`, `denom`), use it:
  - Then, later changes of representation will affect less code.
  - Code will be clearer, since well-chosen names in the API make intent clear.

```
...

def add_rat(x, y):
    return make_rat(numer(x) * denom(y) + numer(y) * denom(x),
                    denom(x) * denom(y))

def mul_rat(x, y):
    """The product of rational numbers x and y."""
    return make_rat(numer(x) * numer(y), denom(x) * denom(y))
```

Objects in Python

- In Python 3, every value is a *reference to* an object.
- Varieties of object correspond (roughly) to *classes* (*types*).
- Each object has some set of *attributes*, accessible using dot notation, which are values:
  - `E.Attr`, where `E` is a simple expression and `Attr` is a name, means "the current value of the `Attr` attribute of the object referred to by the value of `E`."
- Among these attributes are those whose values are a kind of function known as a *method*.
- For historical reasons or notational clarity, there are often alternative ways to access attributes than dot notation:

x.__add__(y)	add(x, y) or x+y
L.__getitem__(k)	L[k]
x.__len__()	len(x)
x.__eq__(y)	x == y

Primitive Types: Numbers

- A *primitive type* is one that is built into a language, possibly with characteristics or syntax that cannot be written into user-defined types.
- In Python, numbers are such types: have their own literals and internal attributes that are not accessible to the programmer.
- Python distinguishes four types:
  - int: Integers.
  - bool: Limited integers restricted to two values equivalent to 0 and 1: `False` and `True`.
  - float: A subset of the rational numbers used to approximate real-valued quantities.
  - complex: A subset of the rational complex numbers used to approximate complex-valued quantities.

Primitive Types: Tuples

- *tuple* is another primitive type with special syntax.
- To create *construct* a tuple, use a sequence of expressions in parentheses:

```
()        # The tuple with no values
(1, 2)    # A pair: tuple with two items
(1, )     # A singleton tuple: use comma to distinguish from (1).
(1, "Hello", (3, 4)) # Any mix of values possible.
```

- When unambiguous, the parentheses are unnecessary:

```
x = 1, 2, 3          # Same as x = (1,2,3)
return True, 5       # Same as return (True, 5)
for i in 1, 2, 3:    # Same as for i in (1,2,3):
```

Tuples in Python (II)

- Basically, one can *select* values from a tuple and compare or print them, but little else.
- Select by item number:

```
x = (1, 7, 5)
print(x[1], x[2])  # Prints 7 and 5
from operator import getitem
print(getitem(x, 1), getitem(x, 2))       # Prints 7 and 5
print(x.__getitem__(1), x.__getitem__(2)) # Prints 7 and 5
```

- Or select by "unpacking" (syntactic sugar):

```
x = (1, (2, 3), 5)
a, b, c = x
print(b, c)          # Prints (2, 3) and 5
d, (e, f), g = x
print(e, g)          # Prints 2 and 5
```

- A useful way to return multiple things from a function.

A (More Conventional) Representation of Rational

- Yes, we *can* use functions to represent data, but it's not common practice.
- Quite a bit of overhead, both in space and time.
- So, let's use tuples instead:

```
from math import gcd

def make_rat(n, d):
    """The rational number n/d, assuming n, d are integers, d!=0"""
    g = gcd(n, d) if d > 0 else -gcd(n, d)
    return (n//g, d//g)

def numer(r):
    """The numerator of rational number r."""
    return r[0]

def denom(r):
    """The denominator of rational number r."""
    return r[1]
```

- What else changes (`add_rat, mul_rat`)?

Discussion

- But by using `numer` and `denom` in `add_rat` and `mul_rat` (slide 8), we have avoided having to touch them after this change in representation.
- The general lesson:

Try to confine each design decision in your program to as few places as possible.

Endnote

`math.gcd` was introduced into Python in version 3.5. In its absence, you can implement it yourself:

```
def gcd(a, b):
    if a == b == 0:
        return 1
    a, b = abs(a), abs(b)
    if a > b:
       a, b = b, a

    while a != 0 != b:
        a, b = b % a, a
    return b
```