Lists

['Demo']

Working with Lists

```
>>> digits = [1, 8, 2, 8]          >>> digits = [2//2, 2+2+2+2, 2, 2*2*2]
```

The number of elements

```
>>> len(digits)
4
```

An element selected by its index

```
>>> digits[3]                      >>> getitem(digits, 3)
8                                  8
```

Concatenation and repetition

```
>>> [2, 7] + digits * 2            >>> add([2, 7], mul(digits, 2))
[2, 7, 1, 8, 2, 8, 1, 8, 2, 8]     [2, 7, 1, 8, 2, 8, 1, 8, 2, 8]
```

Nested lists

```
>>> pairs = [[10, 20], [30, 40]]
>>> pairs[1]
[30, 40]
>>> pairs[1][0]
30
```

Containers

Containers

Built-in operators for testing whether an element appears in a compound value

```
>>> digits = [1, 8, 2, 8]
>>> 1 in digits
True
>>> 8 in digits
True
>>> 5 not in digits
True
>>> not(5 in digits)
True
```

(Demo)

For Statements

(Demo)

Sequence Iteration

```
def count(s, value):
    total = 0
    for element in s:
        if element == value:
            total = total + 1
    return total
```

Name bound in the first frame of the current environment (not a new frame)

For Statement Execution Procedure

```
for <name> in <expression>:
    <suite>
```

1. Evaluate the header <expression>, which must yield an iterable value (a sequence)
2. For each element in that sequence, in order:
   - A. Bind <name> to that element in the current frame
   - B. Execute the <suite>

Sequence Unpacking in For Statements

A sequence of fixed-length sequences

```
>>> pairs = [[1, 2], [2, 2], [3, 2], [4, 4]]
>>> same_count = 0
```

A name for each element in a fixed-length sequence

Each name is bound to a value, as in multiple assignment

```
>>> for x, y in pairs:
...     if x == y:
...         same_count = same_count + 1
>>> same_count
2
```

Ranges

The Range Type

A range is a sequence of consecutive integers.*

..., -5, -4, -3, -2, -1, 0, 1, 2, 3, 4, 5, ...

range(-2, 2)

Length: ending value - starting value

Element selection: starting value + index

(Demo)

```
>>> list(range(-2, 2))
[-2, -1, 0, 1]
>>> list(range(4))
[0, 1, 2, 3]
```

List constructor

Range with a 0 starting value

* Ranges can actually represent more general integer sequences.

List Comprehensions

```
>>> letters = ['a', 'b', 'c', 'd', 'e', 'f', 'm', 'n', 'o', 'p']
>>> [letters[i] for i in [3, 4, 6, 8]]
['d', 'e', 'm', 'o']
```

List Comprehensions

[<map exp> for <name> in <iter exp> if <filter exp>]

Short version: [<map exp> for <name> in <iter exp>]

A combined expression that evaluates to a list using this evaluation procedure:

1. Add a new frame with the current frame as its parent
2. Create an empty *result list* that is the value of the expression
3. For each element in the iterable value of <iter exp>:
   - A. Bind <name> to that element in the new frame from step 1
   - B. If <filter exp> evaluates to a true value, then add the value of <map exp> to the result list

Strings

Strings are an Abstraction

Representing data:

```
'200'      '1.2e-5'      'False'      '[1, 2]'
```

Representing language:

```
"""And, as imagination bodies forth
The forms of things unknown, the poet's pen
Turns them to shapes, and gives to airy nothing
A local habitation and a name.
"""
```

Representing programs:

```
'curry = lambda f: lambda x: lambda y: f(x, y)'
```

(Demo)

String Literals Have Three Forms

```
>>> 'I am string!'
'I am string!'

>>> "I've got an apostrophe"
"I've got an apostrophe"

>>> '您好'
'您好'

>>> """The Zen of Python
claims, Readability counts.
Read more: import this."""
'The Zen of Python\nclaims, Readability counts.\nRead more: import this.'
```

Single-quoted and double-quoted strings are equivalent

A backslash "escapes" the following character

"Line feed" character represents a new line

Dictionaries

```
{'Dem': 0}
```

Limitations on Dictionaries

Dictionaries are **unordered** collections of key-value pairs

Dictionary keys do have two restrictions:

- A key of a dictionary **cannot be** a list or a dictionary (or any *mutable type*)
- Two **keys cannot be equal**; There can be at most one value for a given key

This first restriction is tied to Python's underlying implementation of dictionaries

The second restriction is part of the dictionary abstraction

If you want to associate multiple values with a key, store them all in a sequence value

Data Abstraction

Data Abstraction

- Compound values combine other values together
  - A date: a year, a month, and a day
  - A geographic position: latitude and longitude
- Data abstraction lets us manipulate compound values as units
- Isolate two parts of any program that uses data:
  - How data are represented (as parts)
  - How data are manipulated (as units)
- Data abstraction: A methodology by which functions enforce an abstraction barrier between ***representation*** and ***use***

All Programmers

Great Programmers

Rational Numbers

$$\frac{\text{numerator}}{\text{denominator}}$$

Exact representation of fractions

A pair of integers

As soon as division occurs, the exact representation may be lost! (Demo)

Assume we can compose and decompose rational numbers:

Constructor
- `rational(n, d)` returns a rational number x

Selectors
- `numer(x)` returns the numerator of x
- `denom(x)` returns the denominator of x

Rational Number Arithmetic

$$\frac{3}{2} * \frac{3}{5} = \frac{9}{10}$$

$$\frac{3}{2} + \frac{3}{5} = \frac{21}{10}$$

Example

$$\frac{nx}{dx} * \frac{ny}{dy} = \frac{nx*ny}{dx*dy}$$

$$\frac{nx}{dx} + \frac{ny}{dy} = \frac{nx*dy + ny*dx}{dx*dy}$$

General Form

Rational Number Arithmetic Implementation

```
def mul_rational(x, y):
    return rational(numer(x) * numer(y),
                    denom(x) * denom(y))

def add_rational(x, y):
    nx, dx = numer(x), denom(x)
    ny, dy = numer(y), denom(y)
    return rational(nx * dy + ny * dx, dx * dy)

def print_rational(x):
    print(numer(x), '/', denom(x))

def rationals_are_equal(x, y):
    return numer(x) * denom(y) == numer(y) * denom(x)
```

Constructor

Selectors

$$\frac{nx}{dx} * \frac{ny}{dy} = \frac{nx*ny}{dx*dy}$$

$$\frac{nx}{dx} + \frac{ny}{dy} = \frac{nx*dy + ny*dx}{dx*dy}$$

- `rational(n, d)` returns a rational number x
- `numer(x)` returns the numerator of x
- `denom(x)` returns the denominator of x

These functions implement an abstract representation for rational numbers

Pairs

Representing Pairs Using Lists

```
>>> pair = [1, 2]
>>> pair
[1, 2]
```

A list literal: Comma-separated expressions in brackets

```
>>> x, y = pair
>>> x
1
>>> y
2
```

"Unpacking" a list

```
>>> pair[0]
1
>>> pair[1]
2
```

Element selection using the selection operator

```
>>> from operator import getitem
>>> getitem(pair, 0)
1
>>> getitem(pair, 1)
2
```

Element selection function

Representing Rational Numbers

```
def rational(n, d):
    """Construct a rational number that represents N/D."""
    return [n, d]
```

Construct a list

```
def numer(x):
    """Return the numerator of rational number X."""
    return x[0]

def denom(x):
    """Return the denominator of rational number X."""
    return x[1]
```

Select item from a list

(Demo)

Reducing to Lowest Terms

Example:

$\frac{3}{2} * \frac{5}{3} = \frac{5}{2}$ $\qquad$ $\frac{2}{5} + \frac{1}{10} = \frac{1}{2}$

$\frac{15}{6} * \frac{1/3}{1/3} = \frac{5}{2}$ $\qquad$ $\frac{25}{50} * \frac{1/25}{1/25} = \frac{1}{2}$

```
from fractions import gcd
```

Greatest common divisor

```
def rational(n, d):
    """Construct a rational that represents n/d in lowest terms."""
    g = gcd(n, d)
    return [n//g, d//g]
```

(Demo)

Abstraction Barriers

Abstraction Barriers

Parts of the program that...	Treat rationals as...	Using...
Use rational numbers to perform computation	whole data values	add_rational, mul_rational rationals_are_equal, print_rational
Create rationals or implement rational operations	numerators and denominators	rational, numer, denom
Implement selectors and constructor for rationals	two-element lists	list literals and element selection

Implementation of lists

Violating Abstraction Barriers

Does not use constructors

Twice!

```
add_rational( [1, 2], [1, 4] )

def divide_rational(x, y):
    return [ x[0] * y[1], x[1] * y[0] ]
```

No selectors!

And no constructor!

Data Representations

What are Data?

- We need to guarantee that constructor and selector functions work together to specify the right behavior
- Behavior condition: If we construct rational number x from numerator n and denominator d, then numer(x)/denom(x) must equal n/d
- Data abstraction uses selectors and constructors to define behavior
- If behavior conditions are met, then the representation is valid

You can recognize an abstract data representation by its behavior

(Demo)

Rationals Implemented as Functions

```
def rational(n, d):
    def select(name):
        if name == 'n':
            return n
        elif name == 'd':
            return d
    return select
```

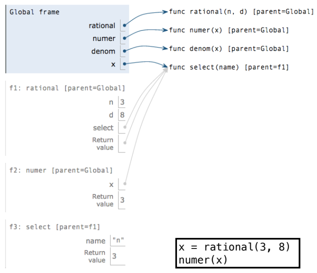
This function represents a rational number

Constructor is a higher-order function

```
def numer(x):
    return x('n')

def denom(x):
    return x('d')
```

Selector calls x



pythontutor.com/composingprograms.html#code=def%20rational%28n,%20d%29%3A%0A%20%20%20%20def%20select%28name%29%3A%0A%20%20%20%20%20%20%20%20if%20name%20%3D%3D%20'n'%3A%0A%20%20%20%20%20%20%20%20%20%20%20%20return%20n%0A%20%20%20%20%20%20%20%20elif%20name%20%3D%3D%20'd'%3A%0A%20%20%20%20%20%20%20%20%20%20%20%20return%20d%0A%20%20%20%20return%20select%0A%20%20%20%20%0Adef%20numer%28x%29%3A%0A%20%20%20%20return%20x%28'n'%29%0A%0Adef%20denom%28x%29%3A%0A%20%20%20%20return%20x%28'd'%29%0A%20%20%20%20%0Ax%20%3D%20rational%283,%208%29%0Anumer%28x%29&mode=display&origin=composingprograms.js&cumulative=true&py=3&rawInputLstJSON=[]&curInstr=0

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