Designing Data Types

Outline

APIs

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APIs should provide to clients just the methods they need and no others

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The API should be the only point of dependence between client and implementation — this is called modular programming

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In Python, lists are mutable, whereas and strings and tuples are immutable

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Duck typing leads to simpler and more flexible client code and puts the focus on operations rather than the type

A disadvantage of duck typing is that it is difficult to know precisely what the contract is between the client and the implementation — the API simply does not carry this information

Overloading

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To call a built-in function, Python internally calls the corresponding special method instead

To overload an operator or built-in function, we include an implementation of the corresponding special method with our own code

Overloading

Special methods for arithmetic operators

Client Operation	Special Method	Description
`x + y`	`__add__(self, y)`	sum of x and y
`x - y`	`__sub__(self, y)`	difference of x and y
`x * y`	`__mul__(self, y)`	product of x and y
`x ** y`	`__pow__(self, y)`	x to the power y
`x / y`	`__div__(self, y)`	quotient of x and y
`x // y`	`__floordiv__(self, y)`	floored quotient of x and y
`x % y`	`__mod__(self, y)`	remainder when dividing x by y
`+x`	`__pos__(self)`	x
`-x`	`__neg__(self)`	arithmetic negation of x

Overloading

Overloading

Special methods for comparison operators

Client Operation	Special Method	Description
`x == y`	`__eq__(self, y)`	are x and y equal?
`x != y`	`__ne__(self, y)`	are x and y not equal?
`x < y`	`__lt__(self, y)`	is x less than y?
`x <= y`	`__le__(self, y)`	is x less than or equal to y?
`x > y`	`__gt__(self, y)`	is x greater than y?
`x >= y`	`__ge__(self, y)`	is x greater than or equal to y?

Overloading

Overloading

Special methods for built-in functions

Client Operation	Special Method	Description
`len(x)`	`__len__(self)`	length of x
`float(x)`	`__float__(self)`	float equivalent of x
`int(x)`	`__int__(self)`	integer equivalent of x
`str(x)`	`__str__(self)`	string representation of x
`abs(x)`	`__abs__(self)`	absolute value of x
`hash(x)`	`__hash__(self)`	integer hash code for x
`iter(x)`	`__iter__(self)`	iterator for x

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For example, the following function evaluates the Riemann integral (ie, the area under the curve) of a real-valued function $f()$ in the interval (a, b), using the rectangle rule with n rectangles

```python
def integrate(f, a, b, n = 1000):
    total = 0.0
    dt = 1.0 * (b - a) / n
    for i in range(n):
        total += dt * f(a + (i + 0.5) * dt)
    return total
```

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    return total
```

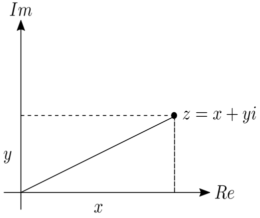
The following statement uses the above function to compute the area under the curve $f(x) = x^2$ in the interval $(0, 1)$

```
area = integrate(lambda x : x * x, 0, 1)
```

Examples

Examples

A complex number z in the cartesian form is expressed as $z = x + yi$, where x (the real part) and y (the imaginary part) are real numbers and $i = \sqrt{-1}$



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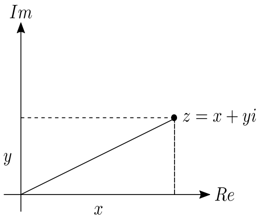

Complex arithmetic

- Conjugate: $(x + yi)^{\star} = x - yi$
- Addition: $(x + yi) + (v + wi) = (x + v) + (y + w)i$
- Multiplication: $(x + yi) \times (v + wi) = (xv - yw) + (yv + xw)i$
- Magnitude: $|x + yi| = \sqrt{x^2 + y^2}$

Examples

Examples

A data type `Complex` for representing complex numbers

Complex	
`Complex(x, y)`	a new complex object c with value $x + yi$
`c.re()`	real part of c
`c.im()`	imaginary part of c
`c.conjugate()`	conjugate of c
`c + d`	sum of c and d
`c * d`	product of c and d
`c == d`	are c and d equal?
`abs(c)`	magnitude of c
`str(c)`	string representation of c

Examples

Examples

complex.py

```python
import math
import stdio

class Complex:
    def __init__(self, re=0.0, im=0.0):
        self._re = re
        self._im = im

    def re(self):
        return self._re

    def im(self):
        return self._im

    def conjugate(self):
        return Complex(self._re, -self._im)

    def __add__(self, other):
        re = self._re + other._re
        im = self._im + other._im
        return Complex(re, im)

    def __mul__(self, other):
        re = self._re * other._re - self._im * other._im
        im = self._re * other._im + self._im * other._re
        return Complex(re, im)

    def __abs__(self):
        return math.sqrt(self._re * self._re + self._im * self._im)

    def __eq__(self, other):
        return self._re == other._re and self._im == other._im

    def __str__(self):
        SUFFIX = 'i'
```

Examples

complex.py

```python
        if self._im == 0:
            return str(self._re)
        elif self._re == 0:
            return str(self._im) + SUFFIX
        elif self._im < 0:
            return str(self._re) + ' - ' + str(-self._im) + SUFFIX
        else:
            return str(self._re) + ' + ' + str(self._im) + SUFFIX

def _main():
    a = Complex(5.0, -6.0)
    b = Complex(3.0, 4.0)
    stdio.writeln("a       = " + str(a))
    stdio.writeln("b       = " + str(b))
    stdio.writeln("conj(a) = " + str((a.conjugate())))
    stdio.writeln("a + b   = " + str(a + b))
    stdio.writeln("a * b   = " + str(a * b))
    stdio.writeln("|b|     = " + str(abs(b)))

if __name__ == '__main__':
    _main()
```

Examples

Examples

Program: `mandelbrot.py`

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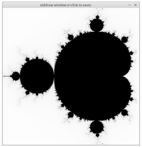
```
>_ ~/workspace/ipp/programs

$ python3 mandelbrot.py -0.5 0 2
```



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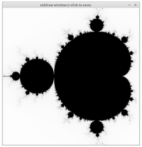
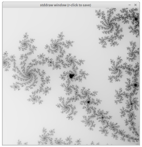



```
>_ ~/workspace/ipp/programs
$ python3 mandelbrot.py 0.1015 -0.633 .01
```



Examples

Examples

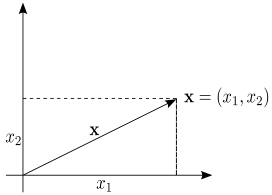
mandelbrot.py

```
from color import Color
from complex import Complex
from picture import Picture
import stddraw
import sys

def main():
    xc = float(sys.argv[1])
    yc = float(sys.argv[2])
    size = float(sys.argv[3])
    N = 512
    ITERATIONS = 255
    picture = Picture(N, N)
    for col in range(N):
        for row in range(N):
            x0 = xc - size / 2 + size * col / N
            y0 = yc - size / 2 + size * row / N
            z0 = Complex(x0, y0)
            gray = ITERATIONS - _mandel(z0, ITERATIONS)
            color = Color(gray, gray, gray)
            picture.set(col, N - 1 - row, color)
    stddraw.setCanvasSize(N, N)
    stddraw.picture(picture)
    stddraw.show()

def _mandel(z0, iterations):
    z = z0
    for i in range(iterations):
        if abs(z) > 2.0:
            return i
        z = z * z + z0
    return iterations

if __name__ == '__main__':
    main()
```

Examples

Examples

A spatial vector is an abstract entity that has a magnitude and a direction



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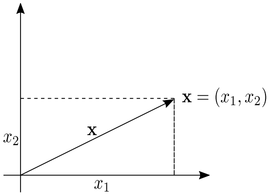

Vector operations, assuming $\mathbf{x} = (x_1, x_2, \dots, x_n)$, $\mathbf{y} = (y_1, y_2, \dots, y_n)$, and $\alpha \in \mathbb{R}$

- Addition: $\mathbf{x} + \mathbf{y} = (x_1 + y_1, x_2 + y_2, \dots, x_n + y_n)$
- Subtraction: $\mathbf{x} - \mathbf{y} = (x_1 - y_1, x_2 - y_2, \dots, x_n - y_n)$
- Scalar product: $\alpha\mathbf{x} = (\alpha x_1, \alpha x_2, \dots, \alpha x_n)$
- Dot product: $\mathbf{x} \cdot \mathbf{y} = x_1 y_1 + x_2 y_2 + \dots + x_n y_n$
- Magnitude: $|\mathbf{x}| = (x_1^2 + x_2^2 + \dots + x_n^2)^{1/2}$
- Direction: $\mathbf{x}/|\mathbf{x}| = (x_1/|\mathbf{x}|, x_2/|\mathbf{x}|, \dots, x_n/|\mathbf{x}|)$

Examples

Examples

A data type `Vector` for spatial vectors

Vector	
`Vector(a)`	a new vector v with Cartesian coordinates taken from the list a
`v[i]`	ith Cartesian coordinates of v
`v + w`	sum of v and w
`v - w`	difference of v and w
`v.dot(w)`	dot product of v and w
`v.scale(alpha)`	scalar product of float α and v
`v.direction()`	unit vector in the same direction as v
`abs(v)`	magnitude of v
`len(v)`	length of v
`str(v)`	string representation of v

Examples

Examples

vector.py

```python
import math
import stdarray
import stdio

class Vector:
    def __init__(self, a):
        self._n = len(a)
        self._coords = a[:]

    def __getitem__(self, i):
        return self._coords[i]

    def __add__(self, other):
        result = stdarray.create1D(self._n, 0)
        for i in range(self._n):
            result[i] = self._coords[i] + other._coords[i]
        return Vector(result)

    def __sub__(self, other):
        result = stdarray.create1D(self._n, 0)
        for i in range(self._n):
            result[i] = self._coords[i] - other._coords[i]
        return Vector(result)

    def dot(self, other):
        result = 0
        for i in range(self._n):
            result += self._coords[i] * other._coords[i]
        return result

    def scale(self, alpha):
        result = stdarray.create1D(self._n, 0)
        for i in range(self._n):
            result[i] = alpha * self._coords[i]
        return Vector(result)
```

Examples

vector.py

```python

    def direction(self):
        return self.scale(1.0 / abs(self))

    def __abs__(self):
        return math.sqrt(self.dot(self))

    def dimension(self):
        return self._n

    def __str__(self):
        return str(self._coords)

def _main():
    xCoords = [1.0, 2.0, 3.0, 4.0]
    yCoords = [5.0, 2.0, 4.0, 1.0]
    x = Vector(xCoords)
    y = Vector(yCoords)
    stdio.writeln('x       = ' + str(x))
    stdio.writeln('y       = ' + str(y))
    stdio.writeln('x + y   = ' + str(x + y))
    stdio.writeln('x - y   = ' + str(x - y))
    stdio.writeln('x dot y = ' + str(x.dot(y)))
    stdio.writeln('10x     = ' + str(x.scale(10.0)))
    stdio.writeln('xhat    = ' + str(x.direction()))
    stdio.writeln('|x|     = ' + str(abs(x)))
    stdio.writeln('ydim    = ' + str(y.dimension()))

if __name__ == '__main__':
    _main()
```

Examples

Examples

A data type `Sketch` for compactly representing the content of a document

Sketch	
`Sketch(text, k, d)`	a new sketch *s* built from the string *text* using *k*-grams and dimension *d*
`s.similarTo(t)`	similarity measure between sketches *s* and *t* (a float between 0.0 and 1.0)
`str(s)`	string representation of *s*

Examples

Examples

sketch.py

```python
from vector import Vector
import stdarray
import stdio
import sys

class Sketch:
    def __init__(self, text, k, d):
        freq = stdarray.create1D(d, 0)
        for i in range(len(text) - k + 1):
            kgram = text[i:i + k]
            h = hash(kgram)
            freq[abs(h % d)] += 1
        vector = Vector(freq)
        self._sketch = vector.direction()

    def similarTo(self, other):
        return self._sketch.dot(other._sketch)

    def __str__(self):
        return str(self._sketch)

def _main():
    k = int(sys.argv[1])
    d = int(sys.argv[2])
    text = stdio.readAll()
    sketch = Sketch(text, k, d)
    stdio.writeln(sketch)

if __name__ == '__main__':
    _main()
```

Examples

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Program: `comparedocuments.py`

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- Command-line input: k (int), d (int), and *path* (str)

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- Command-line input: k (int), d (int), and *path* (str)
- Standard input: a document list
- Standard output: computes d-dimensional profiles based on k-gram frequencies for all those documents under the *path* directory, and writes a matrix of similarity measures between all pairs of documents

Examples

Program: `comparedocuments.py`

- Command-line input: *k* (int), *d* (int), and *path* (str)
- Standard input: a document list
- Standard output: computes *d*-dimensional profiles based on *k*-gram frequencies for all those documents under the *path* directory, and writes a matrix of similarity measures between all pairs of documents

```
>_ ~/workspace/ipp/programs

$ cat ../data/documents.txt
constitution.txt
tomsawyer.txt
huckfinn.txt
tale.txt
prejudice.txt
actg.txt
djia.csv
$ python3 comparedocuments.py 5 10000 ../data < ../data/documents.txt
        cons    toms    huck    tale    prej    actg    djia
cons    1.00    0.66    0.60    0.67    0.64    0.11    0.18
toms    0.66    1.00    0.93    0.92    0.88    0.15    0.23
huck    0.60    0.93    1.00    0.84    0.81    0.13    0.21
tale    0.67    0.92    0.84    1.00    0.87    0.14    0.21
prej    0.64    0.88    0.81    0.87    1.00    0.15    0.24
actg    0.11    0.15    0.13    0.14    0.15    1.00    0.12
djia    0.18    0.23    0.21    0.21    0.24    0.12    1.00
```

Examples

Examples

comparedocuments.py

```python
from instream import InStream
from sketch import Sketch
import stdarray
import stdio
import sys

def main():
    k = int(sys.argv[1])
    d = int(sys.argv[2])
    path = sys.argv[3]
    filenames = stdio.readAllStrings()
    n = len(filenames)
    sketches = stdarray.create1D(n, None)
    for i in range(n):
        inStream = InStream(path + '/' + filenames[i])
        text = inStream.readAll()
        sketches[i] = Sketch(text, k, d)
    stdio.write('    ')
    for filename in filenames:
        stdio.writef('%8.4s', filename)
    stdio.writeln()
    for i in range(n):
        stdio.writef('%.4s', filenames[i])
        for j in range(n):
            stdio.writef('%8.2f', sketches[i].similarTo(sketches[j]))
        stdio.writeln()

if __name__ == '__main__':
    main()
```

Examples

Examples

A data type `Counter` for counting

Counter	
`Counter(id, maxCount)`	a new counter *c* named *id*, with maximum value *maxCount*
`c.increment()`	increment *c*, unless its value is *maxCount*
`c.tally()`	value of *c*
`c.reset()`	reset value of *c*
`c < d`	is *c* less than *d*?
`c == d`	are *c* and *d* equal?
`str(c)`	string representation of *c*

Examples

Examples

counter.py

```python
import stdarray
import stdio
import stdrandom
import sys

class Counter:
    def __init__(self, id):
        self._id = id
        self._count = 0

    def increment(self):
        self._count += 1

    def tally(self):
        return self._count

    def reset(self):
        self._count = 0

    def __lt__(self, other):
        return self._count < other._count

    def __eq__(self, other):
        return self._count == other._count

    def __str__(self):
        return str(self._count) + ' ' + self._id

def _main():
    n = int(sys.argv[1])
    trials = int(sys.argv[2])
    counters = stdarray.create1D(n, None)
    for i in range(n):
        counters[i] = Counter('counter ' + str(i))
    for i in range(trials):
```

Examples

counter.py

```
        counters[stdrandom.uniformInt(0, n)].increment()
    for counter in sorted(counters):
        stdio.writeln(counter)

if __name__ == '__main__':
    _main()
```

Examples

Examples

```
>_ ~/workspace/ipp/programs
```

```
$ python3 counter.py 6 10000
1620 counter 0
1629 counter 3
1653 counter 2
1686 counter 1
1686 counter 4
1726 counter 5
```

Examples

Examples

A comparable data type `Country` that represents a country by its name, capital, and population

Country	
`Country(name, capital, population)`	constructs a country c given its name, capital, and population
`c < d`	is the country c less than country d by name?
`c == d`	is the country c equal to country d by population?
`str(c)`	string representation of c

Examples

Examples

country.py

```
import stdarray
import stdio

class Country:
    def __init__(self, name, capital, population):
        self._name = name
        self._capital = capital
        self._population = population

    def __lt__(self, other):
        return self._name < other._name

    def __eq__(self, other):
        return self._name == other._name

    def __str__(self):
        return self._name + ' (' + self._capital + '): ' + str(self._population)

def _main():
    countries = stdarray.create1D(5, None)
    countries[0] = Country('United States', 'Washington, D.C.', 329334246)
    countries[1] = Country('Pakistan', 'Islamabad', 218719520)
    countries[2] = Country('India', 'New Delhi', 1358989650)
    countries[3] = Country('China', 'Beijing', 1401463880)
    countries[4] = Country('Indonesia', 'Jakarta', 266911900)
    stdio.writeln('Unsorted:')
    for country in countries:
        stdio.writeln(country)
    stdio.writeln()
    stdio.writeln('Sorted by name:')
    for country in sorted(countries):
        stdio.writeln(country)
    stdio.writeln()
    stdio.writeln('Sorted by capital:')
    for country in sorted(countries, key=lambda country: country._capital):
```

Examples

Examples

country.py

```
        stdio.writeln(country)
    stdio.writeln()
    stdio.writeln('Sorted by population:')
    for country in sorted(countries, key=lambda country: country._population):
        stdio.writeln(country)
    stdio.writeln()
    stdio.writeln('Reverse sorted by population:')
    for country in sorted(countries, key=lambda country: country._population, reverse=True):
        stdio.writeln(country)

if __name__ == '__main__':
    _main()
```

Examples

Examples

```
>_ ~/workspace/ipp/programs

$ python3 country.py
Unsorted:
United States (Washington, D.C.): 329334246
Pakistan (Islamabad): 218719520
India (New Delhi): 1358989650
China (Beijing): 1401463880
Indonesia (Jakarta): 266911900

Sorted by name:
China (Beijing): 1401463880
India (New Delhi): 1358989650
Indonesia (Jakarta): 266911900
Pakistan (Islamabad): 218719520
United States (Washington, D.C.): 329334246

Sorted by capital:
China (Beijing): 1401463880
Pakistan (Islamabad): 218719520
Indonesia (Jakarta): 266911900
India (New Delhi): 1358989650
United States (Washington, D.C.): 329334246

Sorted by population:
Pakistan (Islamabad): 218719520
Indonesia (Jakarta): 266911900
United States (Washington, D.C.): 329334246
India (New Delhi): 1358989650
China (Beijing): 1401463880

Reverse sorted by population:
China (Beijing): 1401463880
India (New Delhi): 1358989650
United States (Washington, D.C.): 329334246
Indonesia (Jakarta): 266911900
Pakistan (Islamabad): 218719520
```

Examples

Examples

An iterable `FibonacciSequence` data type for iterating over Fibonacci sequences

FibonacciSequence	
`FibonacciSequence(n)`	a new object *f* for iterating over the first *n* Fibonacci numbers
`iter(f)`	an iterable object *fiter* on *f*
`next(fiter)`	the next number in the Fibonacci sequence *fiter*

Examples

Examples

fibonaccisequence.py

```python
import stdio
import sys

class FibonacciSequence:
    def __init__(self, n):
        self._n = n
        self._a = 1
        self._b = 1
        self._count = 0

    def __iter__(self):
        return self

    def __next__(self):
        self._count += 1
        if self._count > self._n:
            raise StopIteration()
        if self._count <= 2:
            return 1
        temp = self._a
        self._a = self._b
        self._b += temp
        return self._b

def _main():
    n = int(sys.argv[1])
    for v in FibonacciSequence(n):
        stdio.writeln(v)

if __name__ == '__main__':
    _main()
```

Examples

Examples

```
>_ ~/workspace/ipp/programs

$ python3 fibonaccisequence.py 10
1
1
2
3
5
8
13
21
34
55
```

Exceptions

Exceptions

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We can raise our own exceptions as follows

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raise Exception('Error message here.')
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We can raise our own exceptions as follows

```
raise Exception('Error message here.')
```

We can handle exceptions using a try-except block

Exceptions

Exceptions

Program: `errorhandling.py`

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- Command-line input: x (float)

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Program: `errorhandling.py`

- Command-line input: x (float)
- Standard output: square root of x, reporting an error if x is not specified, is not a float, or is negative

```
>_ ~/workspace/ipp/programs

$ python3 errorhandling.py
x not specified
$ python3 errorhandling.py two
x must be a float
$ python3 errorhandling.py -2
x must be positive
$ python3 errorhandling.py 2
1.4142135623730951
```

Exceptions

Exceptions

errorhandling.py

```python
import math
import stdio
import sys

def main():
    try:
        x = float(sys.argv[1])
        result = _sqrt(x)
        stdio.writeln(result)
    except IndexError as e:
        stdio.writeln('x not specified')
    except ValueError as e:
        stdio.writeln('x must be a float')
    except Exception as e:
        stdio.writeln(e)
    finally:
        stdio.writeln('Done!')

def _sqrt(x):
    if x < 0:
        raise Exception('x must be positive')
    return math.sqrt(x)

if __name__ == '__main__':
    main()
```