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using & building

PYTHON SET PRACTICE

Learn great API design ideas from Python's set types.

PYCON CLEVELAND 2019

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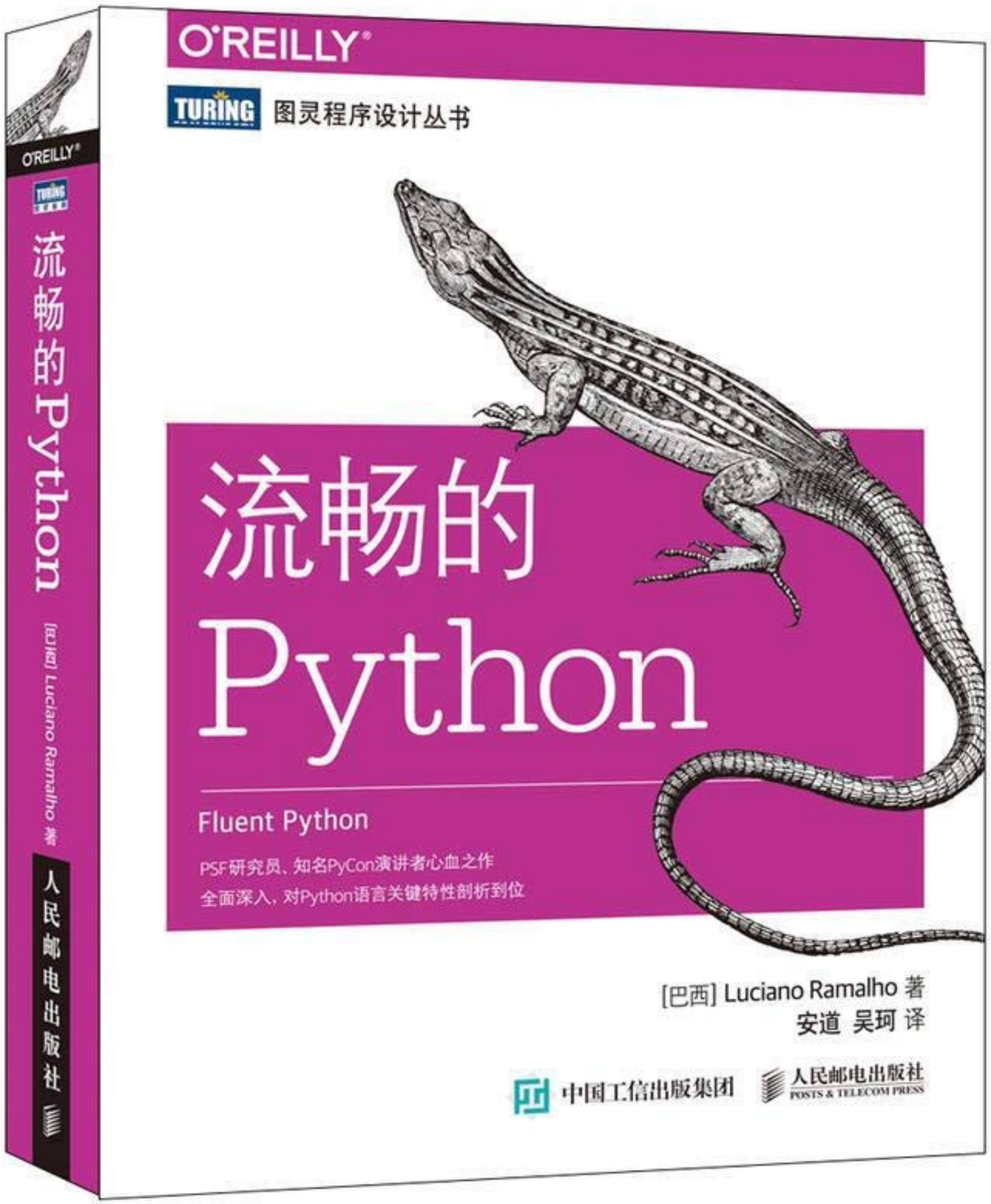
@standupdev

FLUENT PYTHON



Available in 9 languages:

- English
- Portuguese
- Russian
- Polish
- Japanese
- Korean
- Chinese (traditional)
- Chinese (simplified)

2nd ed: I'm working on it!

AGENDA

Motivation

Overview of Python Sets

Learning from the set API

The __magic__ behind a set class

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MOTIVATION

Some common use cases for sets

CASE STUDY #1

display product if all words in the query appear in the product description.

HAND-ROLLED SOLUTION #1

I've written code like this in Go, which lacks built-in sets:

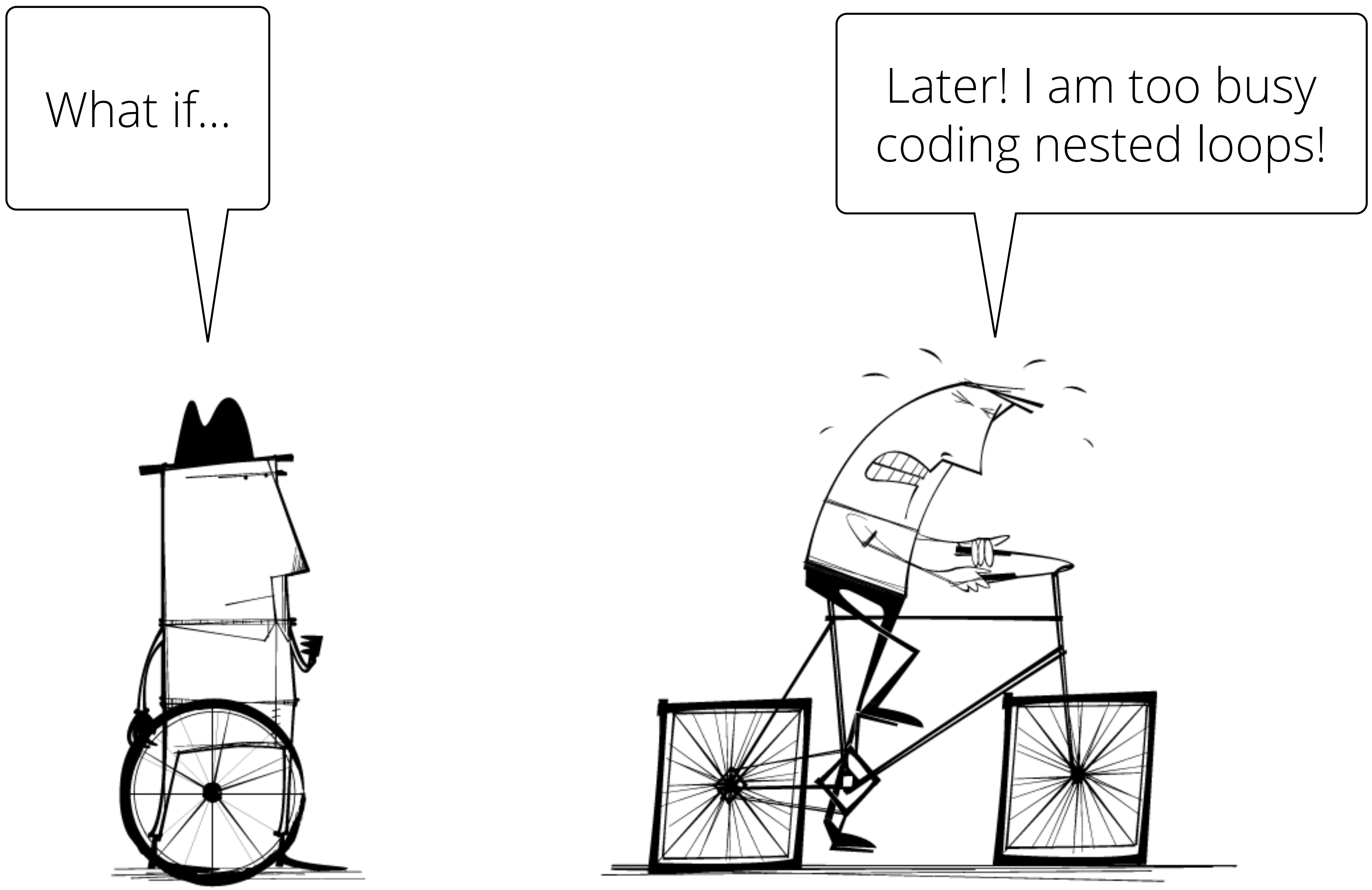
```go
func ContainsAll(slice, subslice []string) bool {
    for _, needle := range subslice {
        found := false
        for _, elem := range slice {
            if needle == elem {
                found = true
                break
            }
        }
        if !found {
            return false
        }
    }
    return true
}
```

HAND-ROLLED SOLUTION #2

More readable, but still inefficient:

```go
func Contains(slice []string, needle string) bool {
    for _, elem := range slice {
        if needle == elem {
            return true
        }
    }
    return false
}

func ContainsAll(slice, subslice []string) bool {
    for _, needle := range subslice {
        if !Contains(slice, needle) {
            return false
        }
    }
    return true
}
```

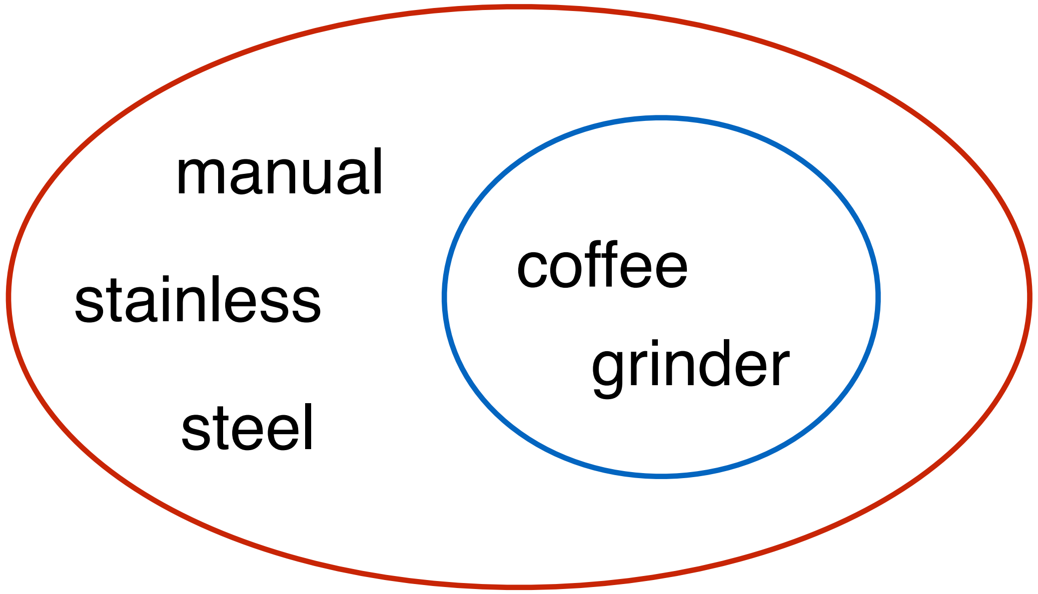


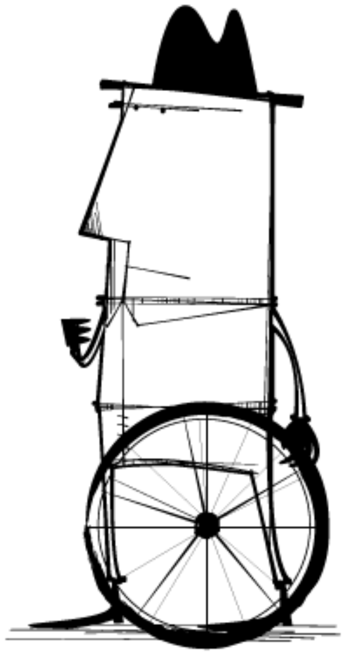
www.workcompass.com/

CASO DE USO #1

www.workcompass.com/

display product if all words in the query appear in the product description.



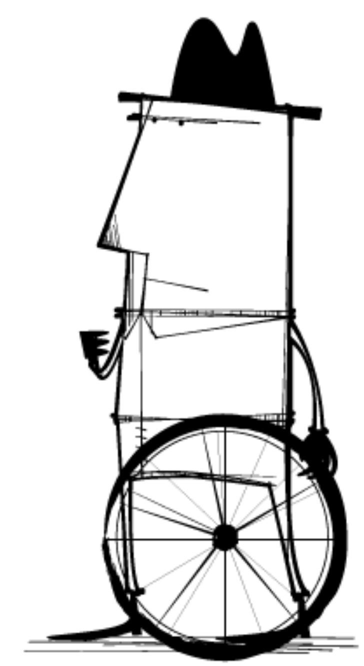


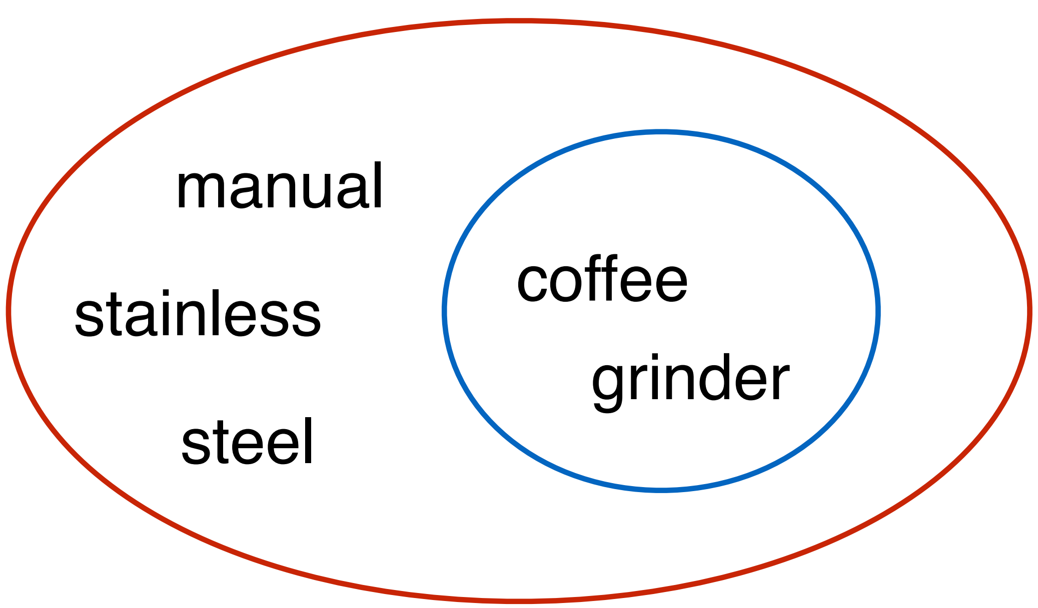
CASO DE USO #1

www.workcompass.com/

display product if all words in the query appear in the product description.

$$Q \subset D$$



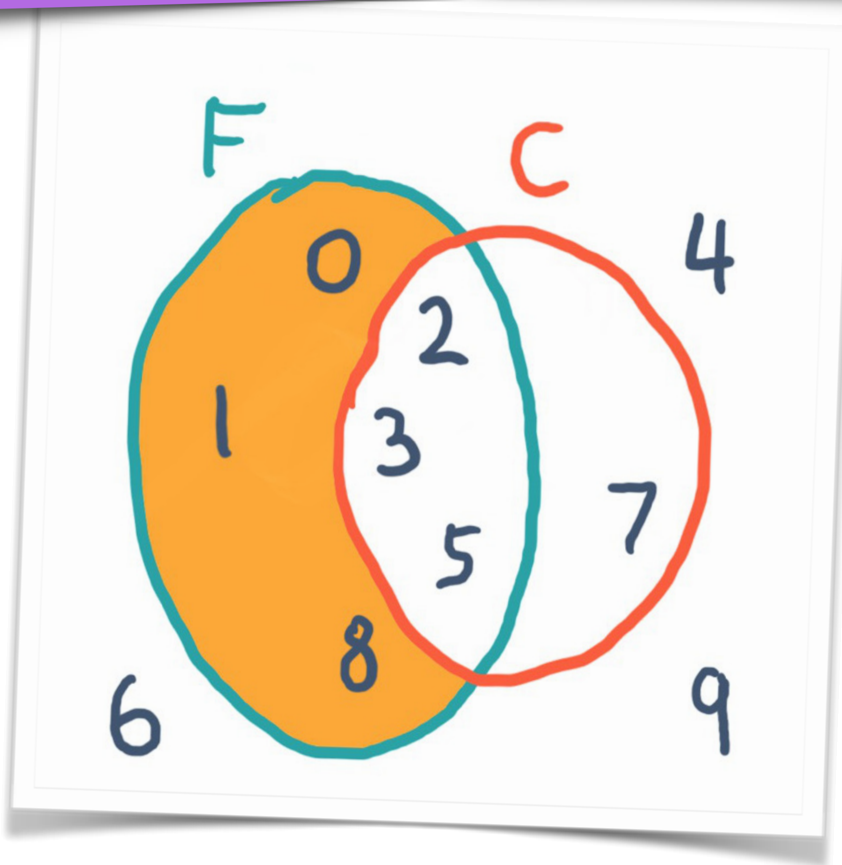


CASO DE USO #2

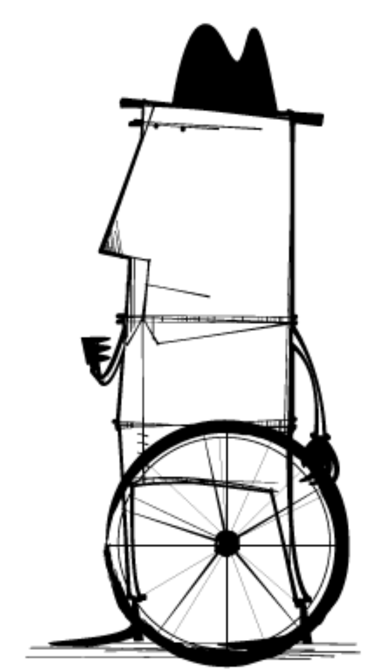
Mark all products previously favorited, except those already in the shopping cart.

CASO DE USO #2

Mark all products previously favorited, except those already in the shopping cart.



$$F \setminus C$$



LOGIC AND SETS

A close relationship

Nobody has yet discovered a branch of mathematics that has successfully resisted formalization into set theory.

Thomas Forster

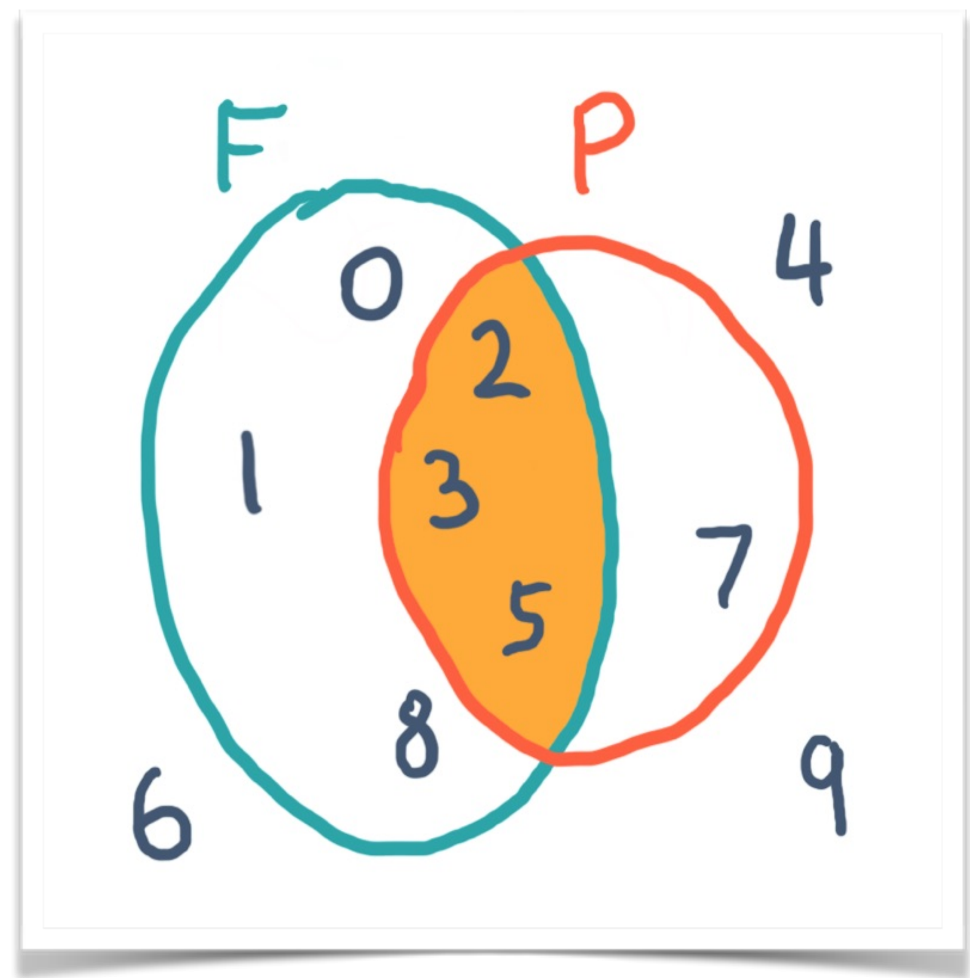
Logic Induction and Sets, p. 167

LOGIC CONJUNCTION IS INTERSECTION

x belongs to the intersection of A with B.

is the same as:

x belongs to A and
x also belongs to B.



Math notation:

$$x \in (A \cap B) \iff (x \in A) \wedge (x \in B)$$

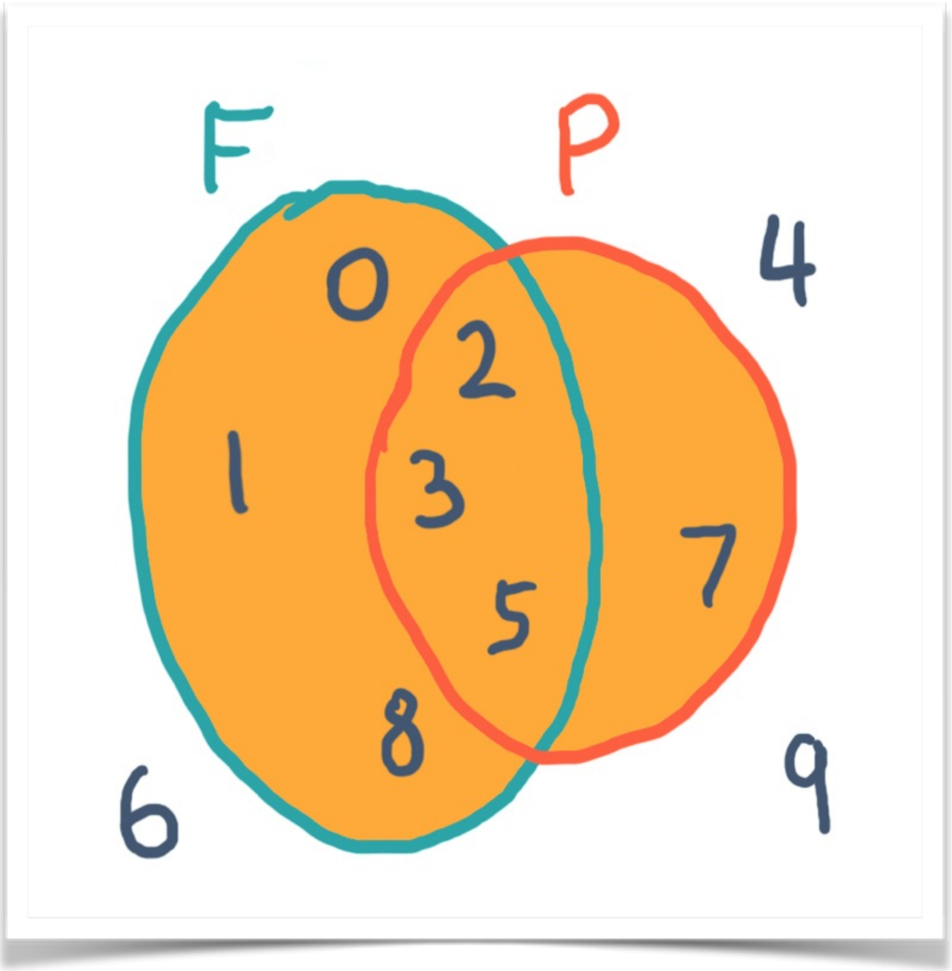
In computing: **AND**

LOGIC DISJUNCTION: UNION

x belongs to the union of A and B.

is the same as:

x belongs to A or
x belongs to B.



Math notation:

$$x \in (A \cup B) \iff (x \in A) \vee (x \in B)$$

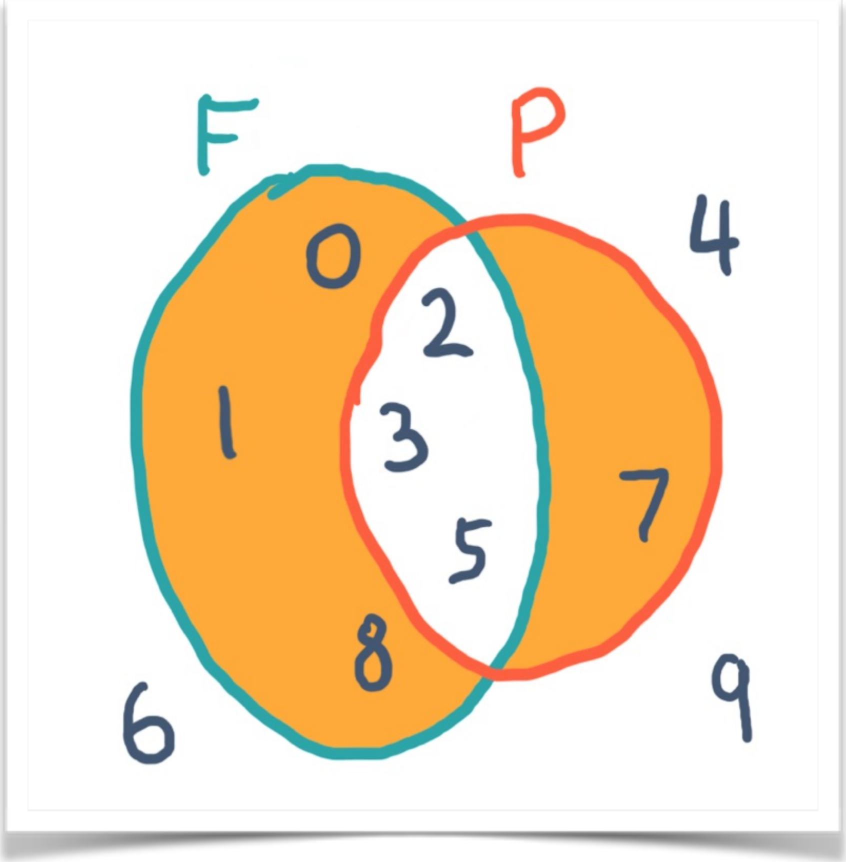
In computing: **OR**

SYMMETRIC DIFFERENCE

x belongs to A or
x belongs to B but
does not belong to both

Is the same as:

x belongs to the union of A with B
less the intersection of A with B.



Math notation:

$$x \in (A \; \Delta \; B) \iff (x \in A) \veebar (x \in B)$$

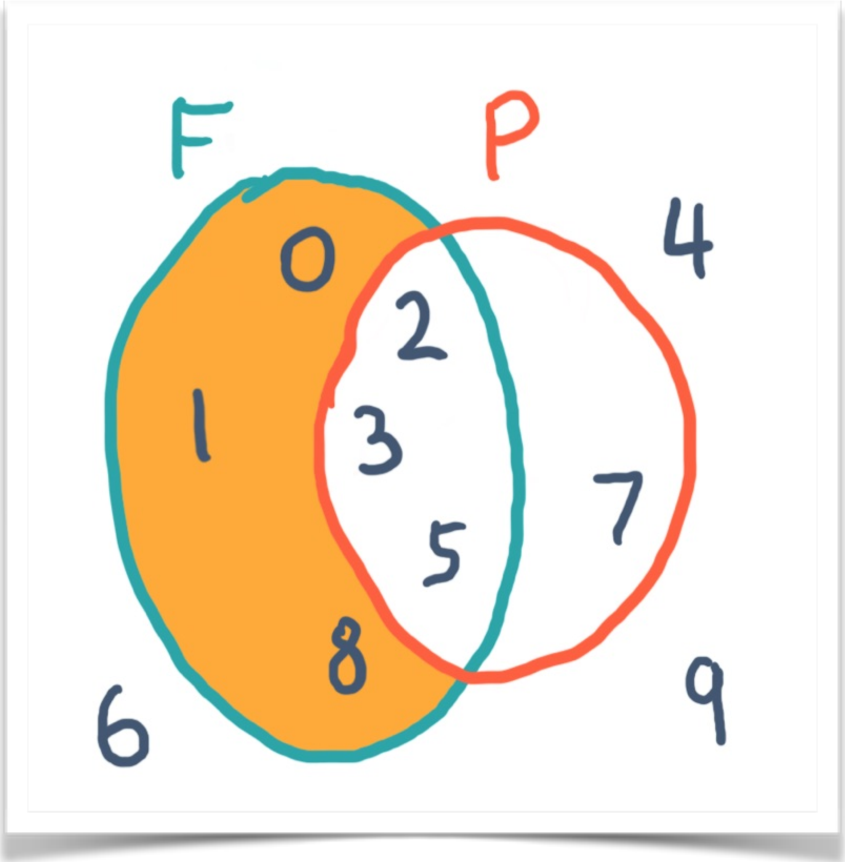
In computing: **XOR**

DIFFERENCE

x belongs to A but
does not belong to B.

is the same as:

elements of A minus elements of B



Math notation:

$$x \in (A \setminus B) \iff (x \in A) \land (x \notin B)$$

SETS IN SEVERAL LANGUAGES

SETS IN SEVERAL STANDARD LIBRARIES

Some languages/platform APIs that implement sets in their standard libraries

Java	Set interface: < 10 methods; 8 implementations
Python	set, frozenset: > 10 methods and operators
.Net (C# etc.)	ISet interface: > 10 methods; 2 implementations
JavaScript (ES6)	Set: < 10 methods
Ruby	Set: > 10 methods and operators

Python, .Net and Ruby offer rich set APIs

SETS IN PYTHON

The built-in types

BUILDING A SET FROM A SERIES OF NUMBERS

Using a set comprehension:

In [1]:
```python
def fibonacci(stop):
    a, b = 0, 1
    while a < stop:
        yield a
        a, b = b, a + b
```

In [2]:
```python
f = {n for n in fibonacci(10)}
f
```

Out[2]:
```
{0, 1, 2, 3, 5, 8}
```

ANOTHER SET, FOR THE EXAMPLES

In [3]:

```python
def primes(stop):
    '''Yields the sequence of prime numbers via
    m = {}  # map composite integers to primes 
    q = 2   # first integer to test for primali
    while q < stop:
        if q not in m:
            yield q          # not marked composi
            m[q*q] = [q]     # first multiple of 
        else:
            for p in m[q]: # move each witness 
                m.setdefault(p+q,[]).append(p)
            del m[q]         # no longer need m[q
        q += 1
```

In [4]:

```python
p = {n for n in primes(10)}
p
```

Out[4]: {2, 3, 5, 7}

ELEMENT CONTAINMENT: THE IN OPERATOR

O(1) in sets, because they use a hash table to hold elements.

Implemented by the __contains__ special method:

```
In [6]: 1 in f
Out[6]: True

In [7]: 1 in p
Out[7]: False
```

FUNDAMENTAL SET OPERATIONS

In [8]:
```
f & p
```
Out[8]: {2, 3, 5}

Intersection

In [9]:
```
f | p
```
Out[9]: {0, 1, 2, 3, 5, 7, 8}

Union

In [10]:
```
f ^ p
```
Out[10]: {0, 1, 7, 8}

Symmetric difference
(a.k.a. XOR)

In [11]:
```
f - p
```
Out[11]: {0, 1, 8}

Difference

In [12]:
```
p - f
```
Out[12]: {7}

SET COMPARISONS

Subset and superset testing.

In math: ⊂, ⊆, ⊃, ⊇.

In [13]:
```
f >= p
```
Out[13]: False

In [14]:
```
p >= f
```
Out[14]: False

In [15]:
```
f >= {1, 2, 3}
```
Out[15]: True

In [16]:
```
p >= {1, 2, 3}
```
Out[16]: False

DE MORGAN'S LAW: #1

In [17]:
```python
e = {n for n in range(10) if n % 2 == 0}
e
```
Out[17]: `{0, 2, 4, 6, 8}`

In [18]:
```python
p & e
```
Out[18]: `{2}`

In [19]:
```python
f - (p & e)
```
Out[19]: `{0, 1, 3, 5, 8}`

In [20]:
```python
f - (p & e) == (f - p) | (f - e)
```
Out[20]: `True`

DE MORGAN'S LAW: #2

```
In [21]: p | e
Out[21]: {0, 2, 3, 4, 5, 6, 7, 8}

In [22]: f - (p | e)
Out[22]: {1}

In [23]: f - (p | e) == (f - p) & (f - e)
Out[23]: True
```

SET METHODS

Going beyond what operators can do.

SET OPERATORS AND METHODS (1)

Table 3-2. Mathematical set operations: these methods either produce a new set or update the target set in place, if it's mutable

Math symbol	Python operator	Method	Description
S ∩ Z	`s & z`	`s.__and__(z)`	Intersection of s and z
	`z & s`	`s.__rand__(z)`	Reversed & operator
		`s.intersection(it, …)`	Intersection of s and all sets built from iterables `it`, etc.
	`s &= z`	`s.__iand__(z)`	s updated with intersection of s and z
		`s.intersection_update(it, …)`	s updated with intersection of s and all sets built from iterables `it`, etc.
S ∪ Z	`s | z`	`s.__or__(z)`	Union of s and z
	`z | s`	`s.__ror__(z)`	Reversed |
		`s.union(it, …)`	Union of s and all sets built from iterables `it`, etc.
	`s |= z`	`s.__ior__(z)`	s updated with union of s and z
		`s.update(it, …)`	s updated with union of s and all sets built from iterables `it`, etc.

SET OPERATORS AND METHODS (2)

Differences:

$S \setminus Z$	`s - z`	`s.__sub__(z)`	Relative complement or difference between `s` and `z`
	`z - s`	`s.__rsub__(z)`	Reversed `-` operator
		`s.difference(it, …)`	Difference between `s` and all sets built from iterables `it`, etc.
	`s -= z`	`s.__isub__(z)`	`s` updated with difference between `s` and `z`
		`s.difference_update(it, …)`	`s` updated with difference between `s` and all sets built from iterables `it`, etc.
		`s.symmetric_difference(it)`	Complement of `s & set(it)`
$S \Delta Z$	`s ^ z`	`s.__xor__(z)`	Symmetric difference (the complement of the intersection `s & z`)
	`z ^ s`	`s.__rxor__(z)`	Reversed `^` operator
		`s.symmetric_difference_update(it, …)`	`s` updated with symmetric difference of `s` and all sets built from iterables `it`, etc.
	`s ^= z`	`s.__ixor__(z)`	`s` updated with symmetric difference of `s` and `z`

SET TESTS

All of these return a bool:

Table 3-3. Set comparison operators and methods that return a bool

Math symbol	Python operator	Method	Description
		`s.isdisjoint(z)`	`s` and `z` are disjoint (have no elements in common)
$e \in S$	`e in s`	`s.__contains__(e)`	Element `e` is a member of `s`
$S \subseteq Z$	`s <= z`	`s.__le__(z)`	`s` is a subset of the `z` set
		`s.issubset(it)`	`s` is a subset of the set built from the iterable `it`
$S \subset Z$	`s < z`	`s.__lt__(z)`	`s` is a proper subset of the `z` set
$S \supseteq Z$	`s >= z`	`s.__ge__(z)`	`s` is a superset of the `z` set
		`s.issuperset(it)`	`s` is a superset of the set built from the iterable `it`
$S \supset Z$	`s > z`	`s.__gt__(z)`	`s` is a proper superset of the `z` set

ADDITIONAL METHODS

These have nothing to do with math, and all to do with practical computing:

Table 3-4. Additional set methods

	set	frozenset	
`s.add(e)`	•		Add element `e` to `s`
`s.clear()`	•		Remove all elements of `s`
`s.copy()`	•	•	Shallow copy of `s`
`s.discard(e)`	•		Remove element `e` from `s` if it is present
`s.__iter__()`	•	•	Get iterator over `s`
`s.__len__()`	•	•	`len(s)`
`s.pop()`	•		Remove and return an element from `s`, raising `KeyError` if `s` is empty
`s.remove(e)`	•		Remove element `e` from `s`, raising `KeyError` if `e not in s`

ABSTRACT SET INTERFACES

These interfaces are all defined in collections.abc.

set and frozenset both implement Set

set also implements MutableSet

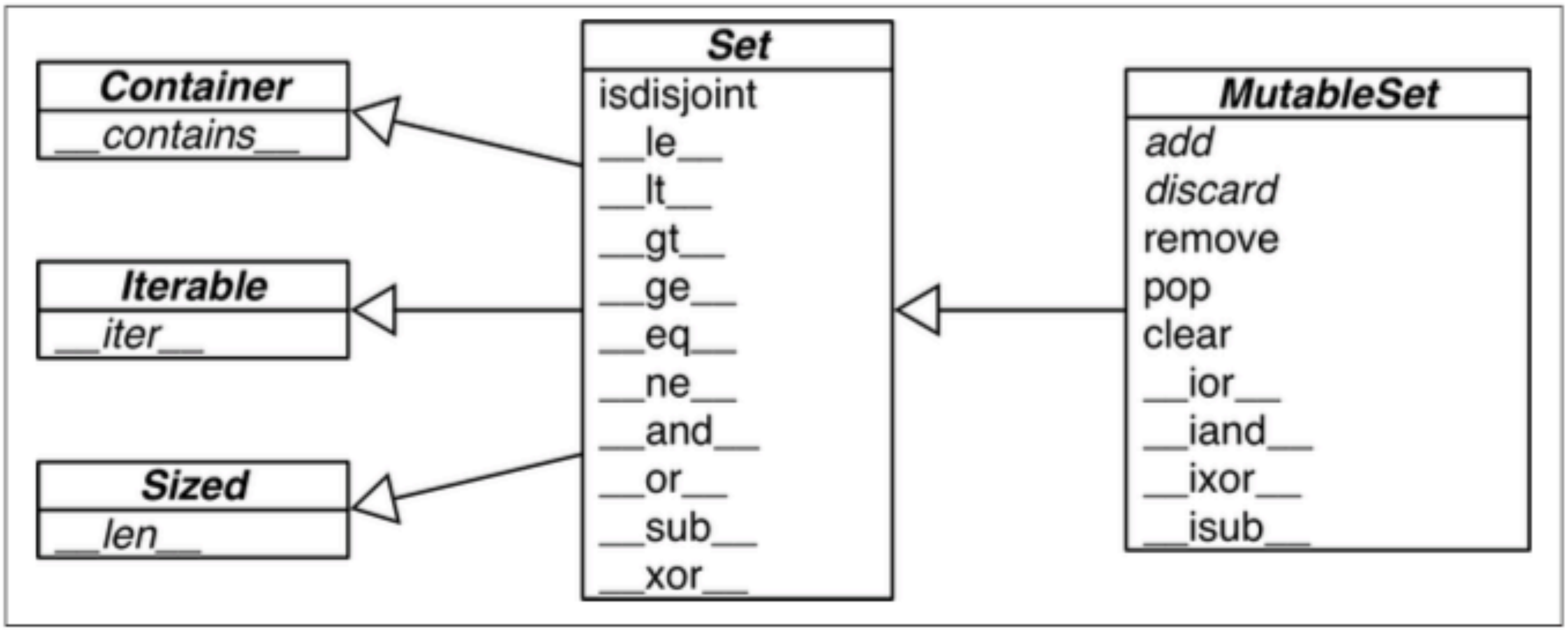


Figure 3-2. UML class diagram for MutableSet and its superclasses from collections.abc (names in italic are abstract classes and abstract methods; reverse operator methods omitted for brevity)

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OPERATOR OVERLOADING

Not as bad as they say

COMPARISON OPERATORS

Table 13-2. Rich comparison operators: reverse methods invoked when the initial method call returns NotImplemented

Group	Infix operator	Forward method call	Reverse method call	Fall back
Equality	`a == b`	`a.__eq__(b)`	`b.__eq__(a)`	Return `id(a) == id(b)`
	`a != b`	`a.__ne__(b)`	`b.__ne__(a)`	Return `not (a == b)`
Ordering	`a > b`	`a.__gt__(b)`	`b.__lt__(a)`	Raise `TypeError`
	`a < b`	`a.__lt__(b)`	`b.__gt__(a)`	Raise `TypeError`
	`a >= b`	`a.__ge__(b)`	`b.__le__(a)`	Raise `TypeError`
	`a <= b`	`a.__le__(b)`	`b.__ge__(a)`	Raise `TypeError`

Table 13-1. Infix operator method names (the in-place operators are used for augmented assignment; comparison operators are in Table 13-2)

Operator	Forward	Reverse	In-place	Description
`+`	`__add__`	`__radd__`	`__iadd__`	Addition or concatenation
`-`	`__sub__`	`__rsub__`	`__isub__`	Subtraction
`*`	`__mul__`	`__rmul__`	`__imul__`	Multiplication or repetition
`/`	`__truediv__`	`__rtruediv__`	`__itruediv__`	True division
`//`	`__floordiv__`	`__rfloordiv__`	`__ifloordiv__`	Floor division
`%`	`__mod__`	`__rmod__`	`__imod__`	Modulo
`divmod()`	`__divmod__`	`__rdivmod__`	`__idivmod__`	Returns tuple of floor division quotient and modulo
`**`, `pow()`	`__pow__`	`__rpow__`	`__ipow__`	Exponentiation[a]
`@`	`__matmul__`	`__rmatmul__`	`__imatmul__`	Matrix multiplication[b]
`&`	`__and__`	`__rand__`	`__iand__`	Bitwise and
`|`	`__or__`	`__ror__`	`__ior__`	Bitwise or
`^`	`__xor__`	`__rxor__`	`__ixor__`	Bitwise xor
`<<`	`__lshift__`	`__rlshift__`	`__ilshift__`	Bitwise shift left
`>>`	`__rshift__`	`__rrshift__`	`__irshift__`	Bitwise shift right

[a] `pow` takes an optional third argument, `modulo`: `pow(a, b, modulo)`, also supported by the special methods when invoked directly (e.g., `a.__pow__(b, modulo)`).

[b] New in Python 3.5.

THE BEAUTY OF DOUBLE DISPATCH

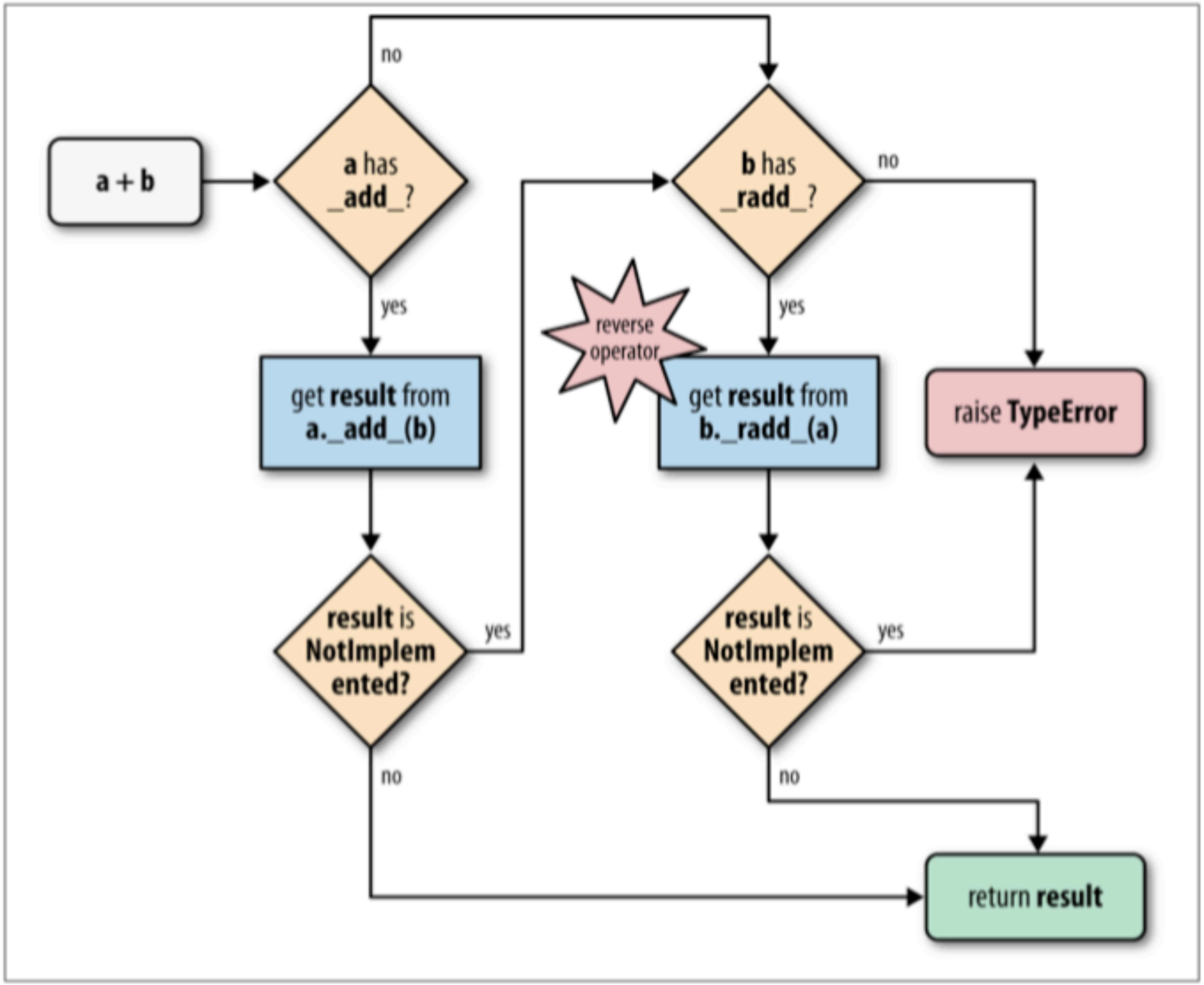

Figure 13-1. Flowchart for computing a + b with __add__ and __radd__

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EXAMPLE IMPLEMENTATION

A set for non-negative integers

UINTSET: A SET CLASS FOR NON-NEGATIVE INTEGERS

Inspired by the **intset** example in chapter 6 of *The Go Programming Language* by A. Donovan and B. Kernighan

An empty set is represented by zero.

A set of integers {**a**, **b**, **c**} is represented by **on** bits in an integer at offsets **a**, **b**, and **c**.

Source code:

`https://github.com/standupdev/uintset`

REPRESENTING SETS OF INTEGERS AS BIT PATTERNS

This set:

```
UintSet({13, 14, 22, 28, 38, 53, 64, 76, 94, 102, 107, 121,
136, 143, 150, 157, 169, 173, 187, 201, 213, 216, 234, 247,
257, 268, 283, 288, 290})
```

REPRESENTING SETS OF INTEGERS AS BIT PATTERNS

This set:

```
UintSet({13, 14, 22, 28, 38, 53, 64, 76, 94, 102, 107, 121,
136, 143, 150, 157, 169, 173, 187, 201, 213, 216, 234, 247,
257, 268, 283, 288, 290})
```

Is represented by this integer

```
2502158007702946921897431281681230116680925854234644385938703
363396454971897652283727872
```

REPRESENTING SETS OF INTEGERS AS BIT PATTERNS

This set:

```
UintSet({13, 14, 22, 28, 38, 53, 64, 76, 94, 102, 107, 121,
136, 143, 150, 157, 169, 173, 187, 201, 213, 216, 234, 247,
257, 268, 283, 288, 290})
```

Is represented by this integer

```
2502158007702946921897431281681230116680925854234644385938703
363396454971897652283727872
```

Which has this bit pattern:

```
1010000100000000000000100000000001000000000100000000000010000
0000000000000100100000000000100000000000001000000000000010001
0000000000010000001000000100000010000000000000010000000000000
1000010000000100000000000000000100000000000100000000001000000
00000000100000000010000010000000110000000000000
```

REPRESENTING SETS OF INTEGERS AS BIT PATTERNS

This set:

```
UintSet({290})
```

Is represented by this integer

```
1989292945639146568621528992587283360401824603189390869761855
907572637988050133502132224
```

Which has this bit pattern:

```
1000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000
0000000000000000000000000000000000000000000000000000000000000
00000000000000000000000000000000000000000000000
```

REPRESENTING SETS OF INTEGERS AS BIT PATTERNS (2)

`UintSet() → 0`

0

`UintSet({0}) → 1`

1

`UintSet({1}) → 2`

1	0

`UintSet({0, 1, 2, 4, 8}) → 279`

1	0	0	0	1	0	1	1	1

`UintSet({0, 1, 2, 3, 4, 5, 6, 7, 8, 9}) → 1023`

1	1	1	1	1	1	1	1	1	1

`UintSet({10}) → 1024`

1	0	0	0	0	0	0	0	0	0	0

`UintSet({0, 2, 4, 6, 8, 10, 12, 14, 16, 18}) → 349525`

1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1

`UintSet({1, 3, 5, 7, 9, 11, 13, 15, 17, 19}) → 699050`

1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0	1	0

DIVE INTO THE CODE

https://github.com/standupdev/uintset

CONCLUSION

KEY TAKEAWAYS

1. Set operations allow simpler, faster solutions for many tasks.

2. Python's set classes are lessons in idiomatic API design.

3. A set class provides good context for operator overloading.

THANK YOU! COME SEE ME AT THE EXPO ALL...

A deeper look at the code for **UintSet**

- Today, 11:30 at the JetBrains/PyCharm booth

Fluent Python book signing *—handing out free copies!*

- Today, 4:00 at the O'Reilly booth

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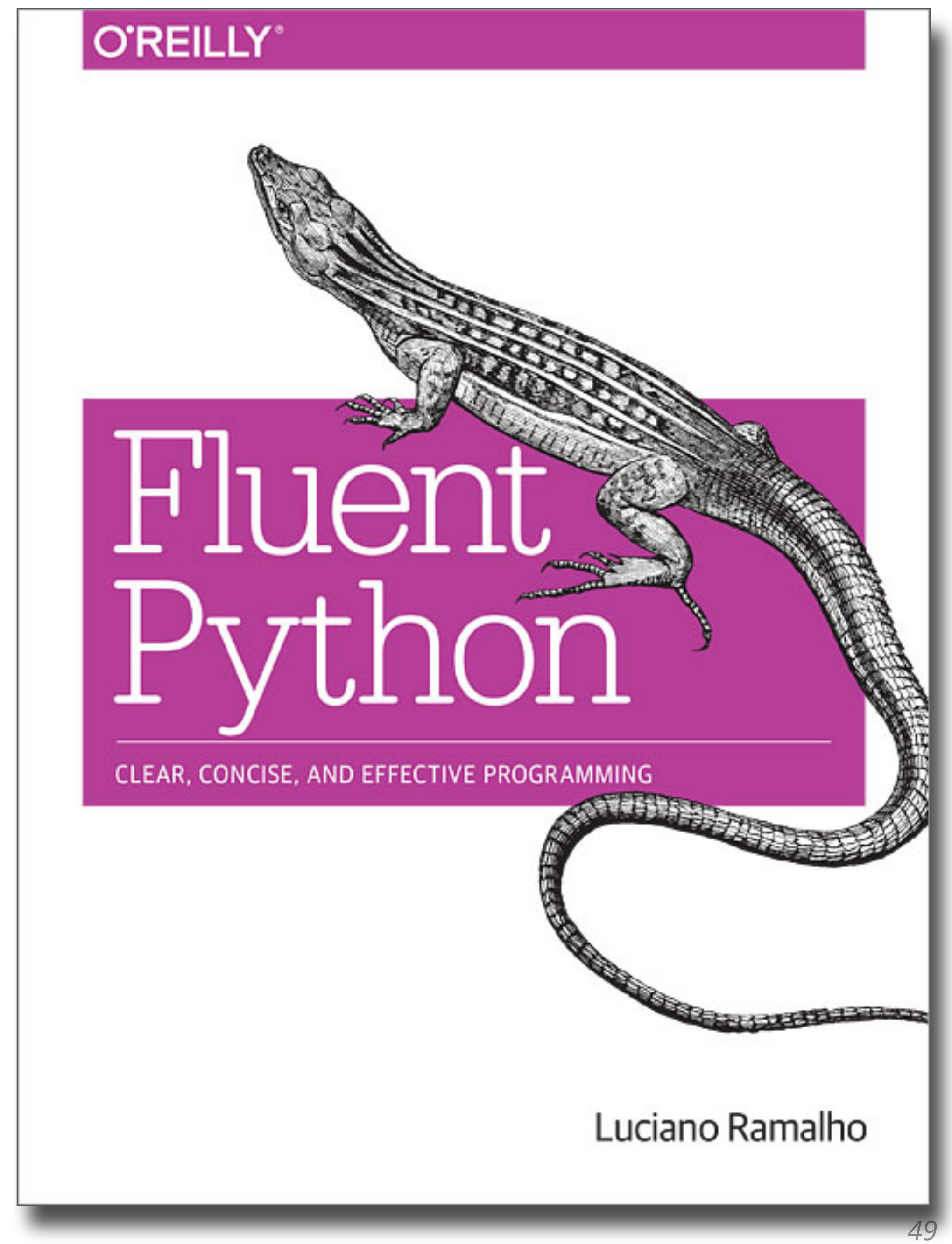

THANK YOU!

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