Exploring Python Bytecode

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Hi! I’m Anjana, and I’m a Pythoholic

OUTREACHY

mozilla

The **Recurse** Center

a Python puzzle...

```
# outside_fn.py
for i in range(10**8):
    i
```

```
# inside_fn.py
def run_loop():
    for i in range(10**8):
        i

run_loop()
```

```
$ time python3 outside_fn.py
real    0m9.185s
user    0m9.104s
sys     0m0.048s
```

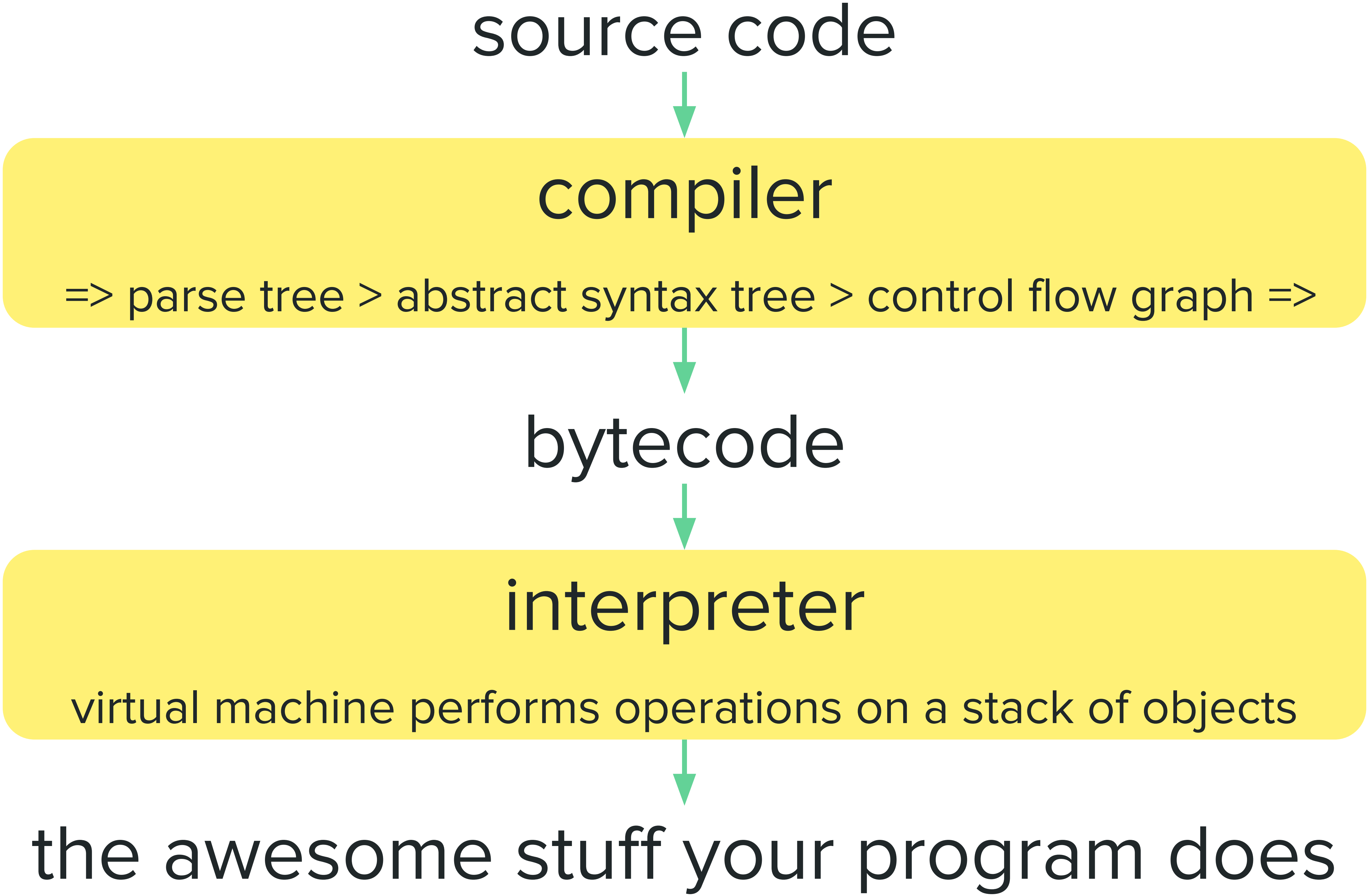
```
$ time python3 inside_fn.py
real    0m5.738s
user    0m5.634s
sys     0m0.055s
```

http://stackoverflow.com/questions/11241523/why-does-python-code-run-faster-in-a-function

What happens when you run Python code?

What happens when you run Python code?

**with CPython*



source code

compiler

=> parse tree > abstract syntax tree > control flow graph =>

bytecode

interpreter

virtual machine performs operations on a stack of objects

the awesome stuff your program does

What is bytecode?

an **intermediate representation** of your program

what the interpreter “sees”

when it runs your program

machine code for a **virtual machine**

(the interpreter)

a series of **instructions**
for **stack operations**

cached as **.pyc** files

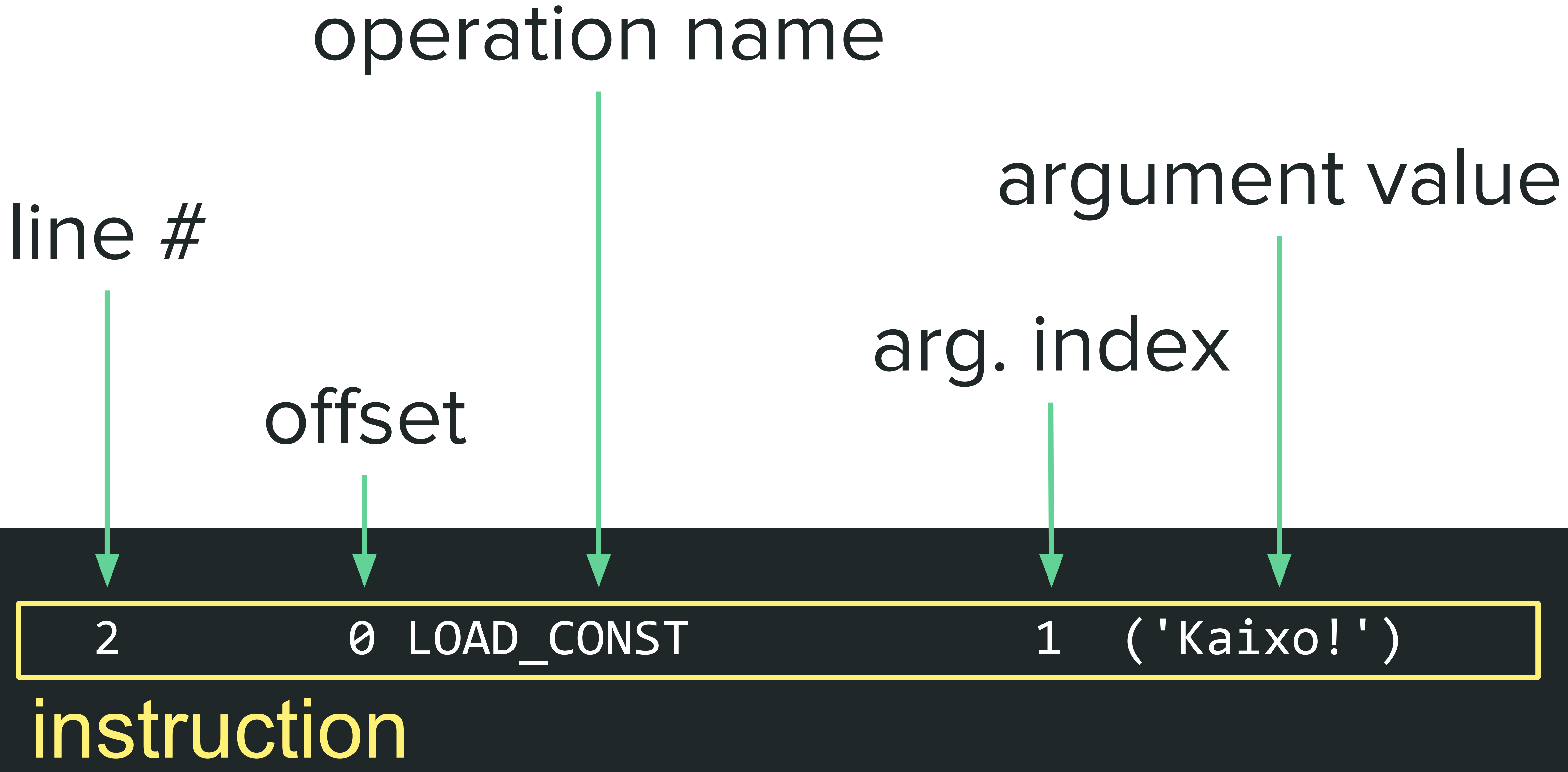
How can we read it?

dis: bytecode disassembler

https://docs.python.org/library/dis.html

```
>>> def hello():
...     return "Kaixo!"
...
>>> import dis
>>> dis.dis(hello)
  2           0 LOAD_CONST               1 ('Kaixo!')
              3 RETURN_VALUE
```

What does it all mean?



operation name

argument value

line #

arg. index

offset

```
  2           0 LOAD_CONST               1 ('Kaixo!')
```

instruction

sample operations

https://docs.python.org/library/dis.html#python-bytecode-instructions

`LOAD_CONST(`*c*`)` pushes *c* onto top of stack (TOS)

`BINARY_ADD` pops & adds top 2 items, result becomes TOS

`CALL_FUNCTION(`*a*`)` calls function with arguments from stack
a indicates # of positional & keyword args

```
>>> dis.opmap['BINARY_ADD']     # => 23
>>> dis.opname[23]              # => 'BINARY_ADD'
```

What can we `dis`?

functions

```
>>> def add(spam, eggs):
...     return spam + eggs
...
>>> dis.dis(add)
  2        0 LOAD_FAST             0 (spam)
           3 LOAD_FAST             1 (eggs)
           6 BINARY_ADD
           7 RETURN_VALUE
```

classes

```
>>> class Parrot:
...     def __init__(self):
...         self.kind = "Norwegian Blue"
...     def is_dead(self):
...         return True
...
>>>
```

classes

```
>>> dis.dis(Parrot)
Disassembly of __init__:
  3        0 LOAD_CONST              1 ('Norwegian Blue')
           3 LOAD_FAST               0 (self)
           6 STORE_ATTR              0 (kind)
           9 LOAD_CONST              0 (None)
           12 RETURN_VALUE
Disassembly of is_dead:
  5        0 LOAD_GLOBAL             0 (True)
           3 RETURN_VALUE
```

code strings (3.2+)

```
>>> dis.dis("spam, eggs = 'spam', 'eggs'")
  1           0 LOAD_CONST               3 (('spam', 'eggs'))
              3 UNPACK_SEQUENCE          2
              6 STORE_NAME               0 (spam)
              9 STORE_NAME               1 (eggs)
              12 LOAD_CONST              2 (None)
              15 RETURN_VALUE
```

modules

```
$ echo $'print("Ni!")' > knights.py
$ python3 -m dis knights.py
  1       0 LOAD_NAME            0 (print)
          3 LOAD_CONST           0 ('Ni!')
          6 CALL_FUNCTION        1 (1 positional, 0 keyword pair)
          9 POP_TOP
          10 LOAD_CONST          1 (None)
          13 RETURN_VALUE
```

modules (3.2+)

```
# knights.py
print("Ni!")
```

```
>>> dis.dis(open('knights.py').read())
    1     0 LOAD_NAME            0 (print)
          3 LOAD_CONST           0 ('Ni!')
          6 CALL_FUNCTION        1 (1 positional, 0 keyword pair)
          9 RETURN_VALUE
```

modules

```
# knights.py
print("Ni!")
def is_flesh_wound():
    return True
```

```
>>> import knights
Ni!
>>> dis.dis(knights)
Disassembly of is_flesh_wound:
  3       0 LOAD_CONST            1 (True)
          3 RETURN_VALUE
```

nothing! (last traceback)

```
>>> print(spam)
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
NameError: name 'spam' is not defined
>>> dis.dis()
  1       0 LOAD_NAME            0 (print)
     -->  3 LOAD_NAME            1 (spam)
          6 CALL_FUNCTION        1 (1 positional, 0 keyword pair)
          9 PRINT_EXPR
         10 LOAD_CONST           0 (None)
         13 RETURN_VALUE
```

Why do we care?

debugging

```
>>> ham/eggs + ham/spam # => ZeroDivisionError: eggs or spam?
>>> dis.dis()
  1           0 LOAD_NAME                0 (ham)
              3 LOAD_NAME                1 (eggs)
              6 BINARY_TRUE_DIVIDE                  # OK here...
              7 LOAD_NAME                0 (ham)
             10 LOAD_NAME                2 (spam)
    -->      13 BINARY_TRUE_DIVIDE                  # error here!
             14 BINARY_ADD
             15 PRINT_EXPR
             16 LOAD_CONST               0 (None)
             19 RETURN_VALUE
```

solving puzzles!

```python
# outside_fn.py
for i in range(10**8):
    i
```

```
$ time python3 outside_fn.py
real    0m9.185s
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```python
# inside_fn.py
def run_loop():
    for i in range(10**8):
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run_loop()
```

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$ time python3 inside_fn.py
real    0m5.738s
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```

http://stackoverflow.com/questions/11241523/why-does-python-code-run-faster-in-a-function

```
>>> outside = open('outside_fn.py').read()
>>> dis.dis(outside)
  2       0 SETUP_LOOP          24 (to 27)
          3 LOAD_NAME            0 (range)
          6 LOAD_CONST           3 (100000000)
          9 CALL_FUNCTION        1 (1 positional, 0 keyword pair)
         12 GET_ITER
     >>  13 FOR_ITER            10 (to 26)
         16 STORE_NAME           1 (i)

  3      19 LOAD_NAME            1 (i)
         22 POP_TOP
         23 JUMP_ABSOLUTE       13
     >>  26 POP_BLOCK
     >>  27 LOAD_CONST           2 (None)
         30 RETURN_VALUE
```

```
>>> from inside_fn import run_loop as inside
>>> dis.dis(inside)
  3       0 SETUP_LOOP          24 (to 27)
          3 LOAD_GLOBAL          0 (range)
          6 LOAD_CONST           3 (100000000)
          9 CALL_FUNCTION        1 (1 positional, 0 keyword pair)
         12 GET_ITER
     >>  13 FOR_ITER            10 (to 26)
         16 STORE_FAST           0 (i)

  4      19 LOAD_FAST            0 (i)
         22 POP_TOP
         23 JUMP_ABSOLUTE       13
     >>  26 POP_BLOCK
     >>  27 LOAD_CONST           0 (None)
         30 RETURN_VALUE
```

let’s investigate...

https://docs.python.org/3/library/dis.html#python-bytecode-instructions

`STORE_NAME`(*namei*)

Implements `name = TOS`. *namei* is the index of *name* in the attribute `co_names` of the code object.

`LOAD_NAME`(*namei*)

Pushes the value associated with `co_names[namei]` onto the stack.

`STORE_FAST`(*var_num*)

Stores TOS into the local `co_varnames[var_num]`.

`LOAD_FAST`(*var_num*)

Pushes a reference to the local `co_varnames[var_num]` onto the stack.

Want to dig deeper?

`ceval.c`: the heart of the beast

https://hg.python.org/cpython/file/tip/Python/ceval.c#l1358

A. Kaptur: "A 1500 (!!) line `switch` statement powers your Python"

http://akaptur.com/talks/

- `LOAD_FAST` (#l1368) is ~10 lines, involves fast locals lookup
- `LOAD_NAME` (#l2353) is ~50 lines, involves slow dict lookup
- prediction (#l1000) makes `FOR_ITER` + `STORE_FAST` even faster

More on SO: Why does Python code run faster in a function?

http://stackoverflow.com/questions/11241523/why-does-python-code-run-faster-in-a-function

Resources:

Python Module Of The Week: `dis`

https://pymotw.com/2/dis/

Allison Kaptur: Fun with `dis`

http://akaptur.com/blog/2013/08/14/python-bytecode-fun-with-dis/

Yaniv Aknin: Python Innards

https://tech.blog.aknin.name/category/my-projects/pythons-innards/

Python data model: code objects

https://docs.python.org/3/reference/datamodel.html#index-54

Eli Bendersky: Python ASTs

http://eli.thegreenplace.net/2009/11/28/python-internals-working-with-python-asts/

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...and the rest of the Recursers!

EuroPython

Outreachy

Thank you!

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