How Python* Works

Built-in data structures

Compiling and Interpreting Python

**The CPython implementation; there are others*

Multiple Implementations

CPython: Python implemented in C

(What we have been using)

Jython: Python implemented in Java

- Uses Java classes in place of Python libraries

Iron Python: Python implemented in C#

- Runs on Microsoft CLR / .net framework

PyPy: Python in Python

- Originally a just-in-time translator; now Python -> C

...

CPython Implementation

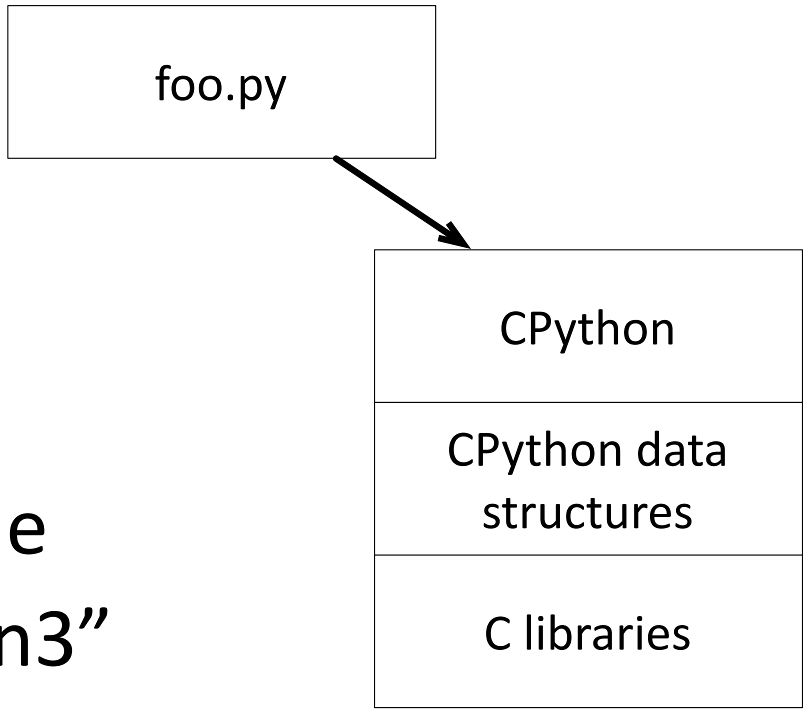
Caveats:

Some simplifications

Some guesswork

(there was more guesswork before I found Laurent Luce's blog: http://www.laurentluce.com/)

CPython is a program



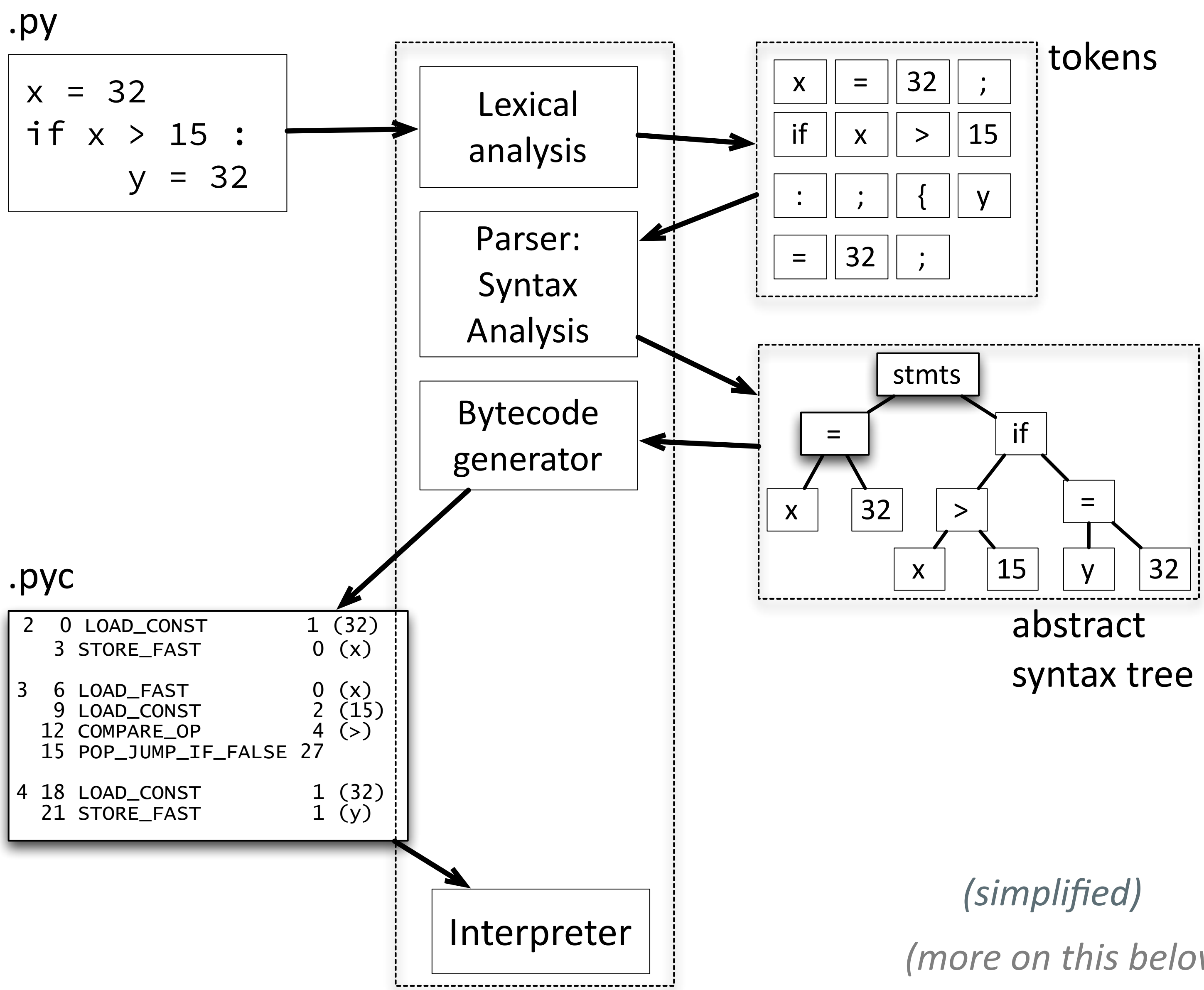
CPython is written in C

Compiled into machine code

named “python” or “python3”

Every Python data type is implemented by a C data structure in CPython

The Python Compiler/Interpreter



```
x = 32
if x > 15 :
    y = 32
```

```
2   0 LOAD_CONST          1 (32)
    3 STORE_FAST          0 (x)

3   6 LOAD_FAST           0 (x)
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   12 COMPARE_OP          4 (>)
   15 POP_JUMP_IF_FALSE  27

4  18 LOAD_CONST          1 (32)
   21 STORE_FAST          1 (y)
```
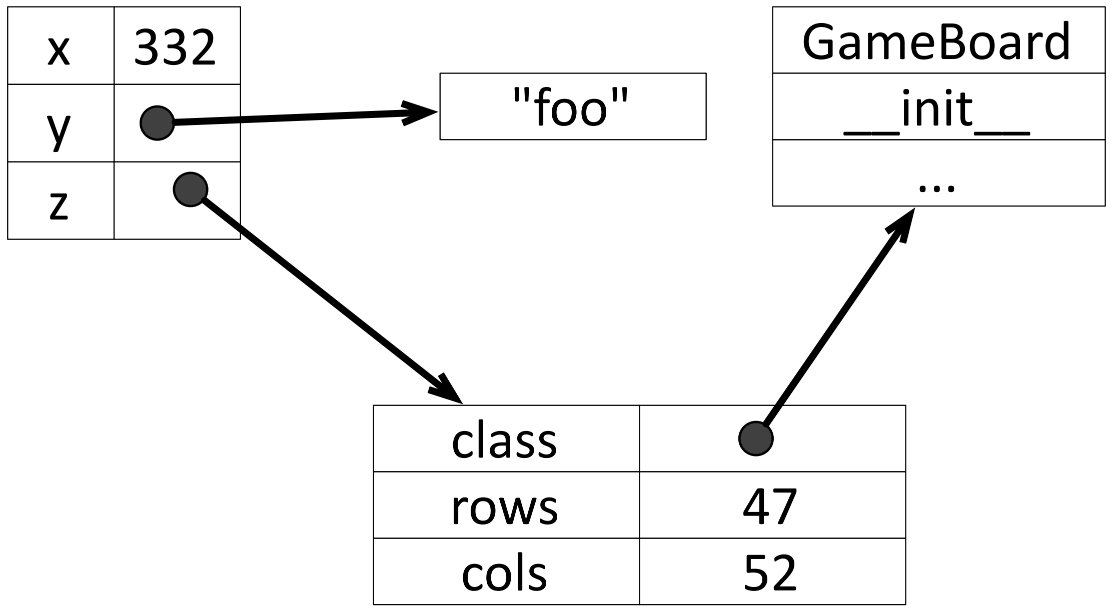

(simplified)

(more on this below)

Everything is an object

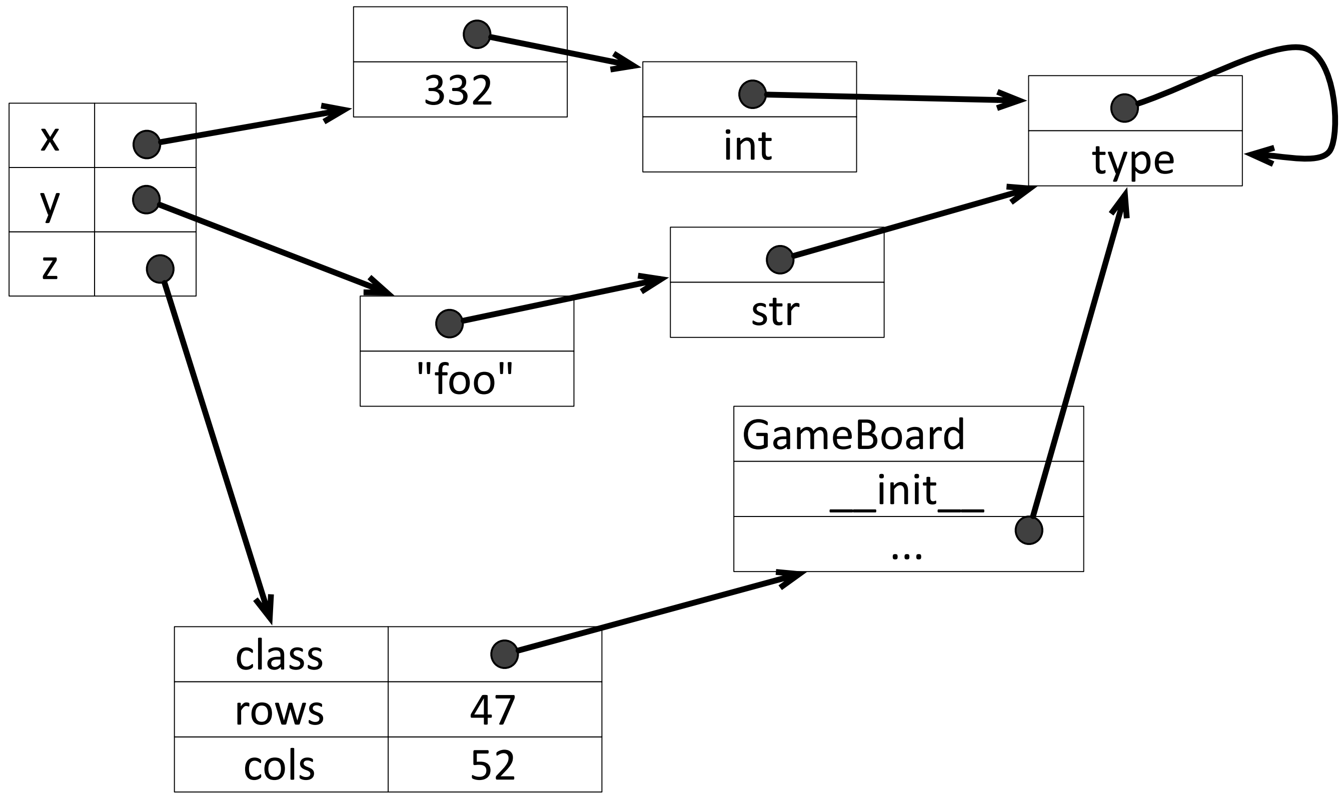
I've been ~~lying~~ oversimplifying a little in drawing diagrams likes this ...



Everything is an object

I've been ~~lying~~ oversimplifying a little in drawing diagrams ... because reality gets a little messy.

(I'm still omitting some details, and getting others wrong.)



Data structures in CPython

For every built-in object type in Python ...

integer, string, dict, set, etc

... there is a CPython data structure implemented in C

(and compiled to machine language)

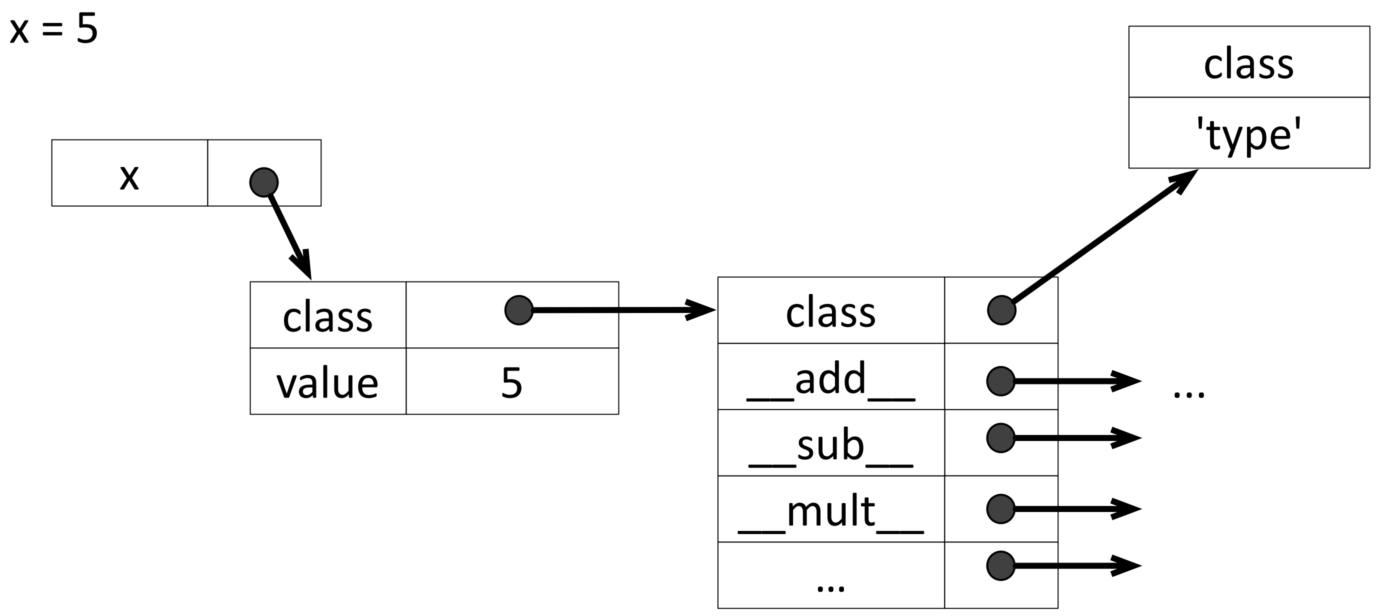
Integer

Even integers are objects, with methods (!)

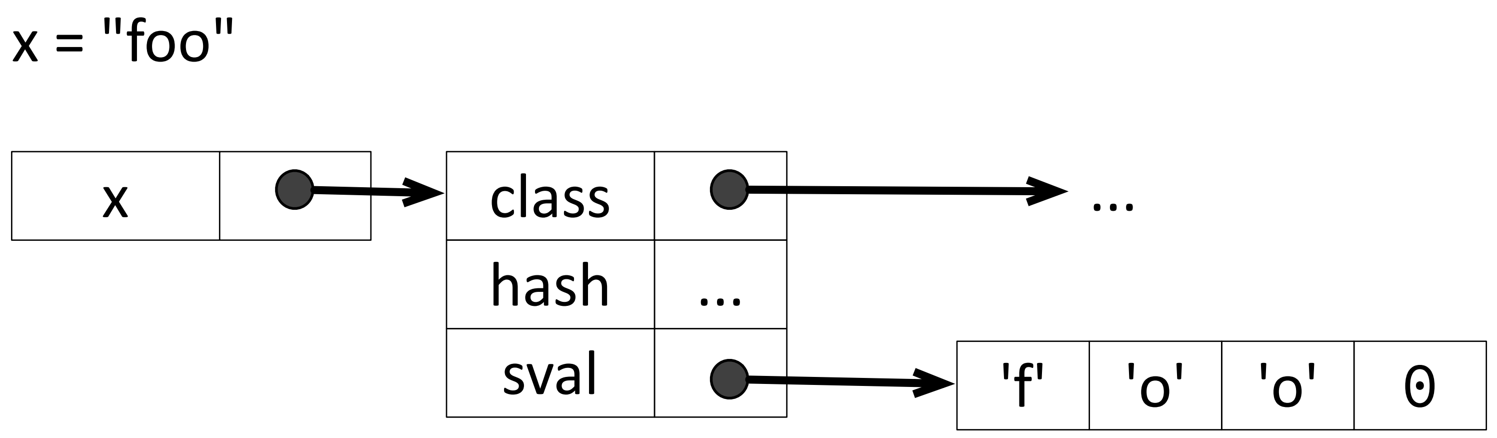
x + y is actually a method call to

`x.__add__(y)`

(Lots of cute tricks to make this reasonably fast)



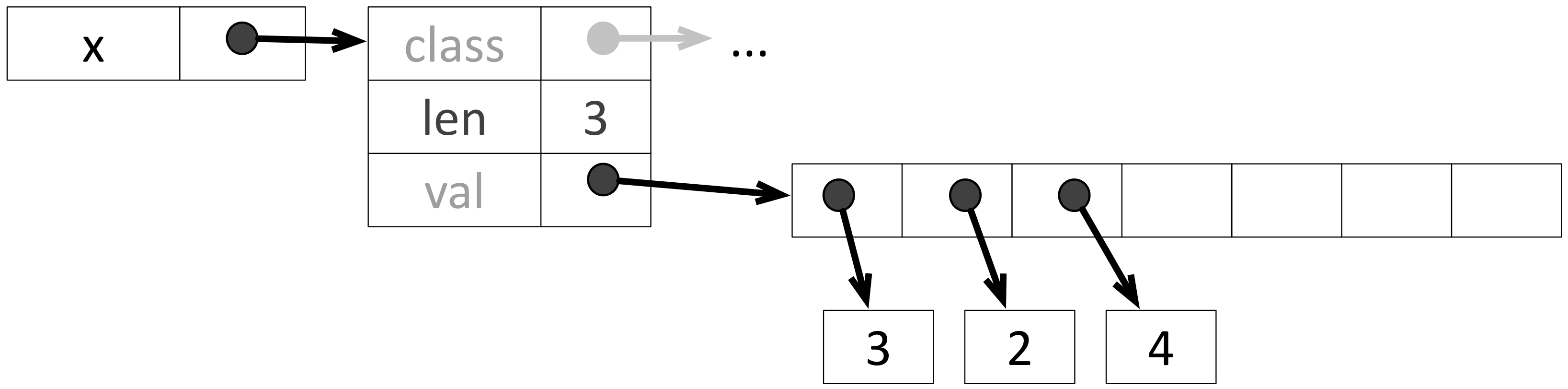
Strings in CPython



String value refers to an array of characters, ending with a nul (zero byte), as in the C language.

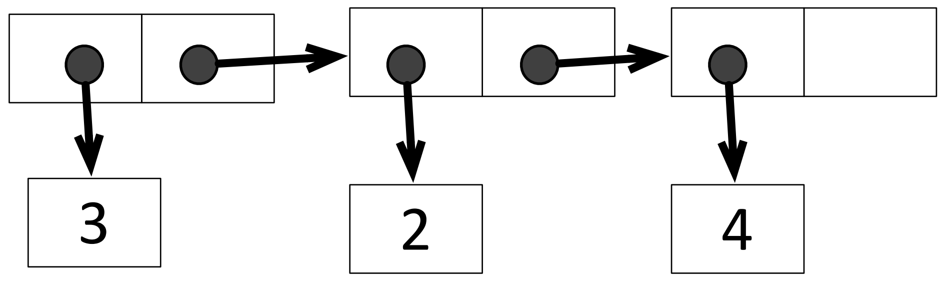
Lists in CPython

x = [3, 2, 4]

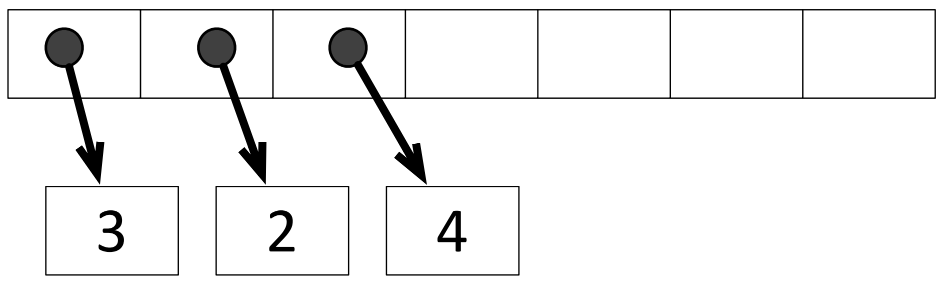


References an array longer than the current list length, so that x.append(7) will be fast. Re-allocates an array when necessary.

Alternative List Data Structures

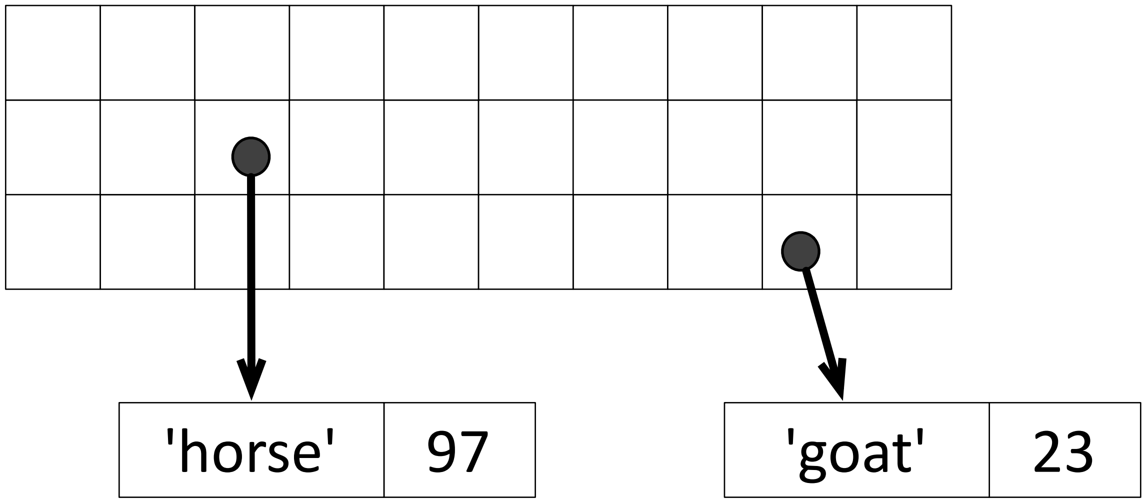


Fast insert, delete from either end; slow to find lis[99] (like List in Java)



Fast insert, delete only at end; fast to find or change lis[99] (like Vector in Java)

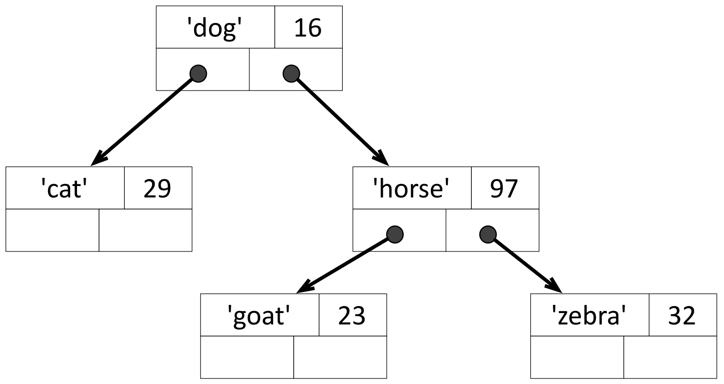
Dictionaries are "hash tables"



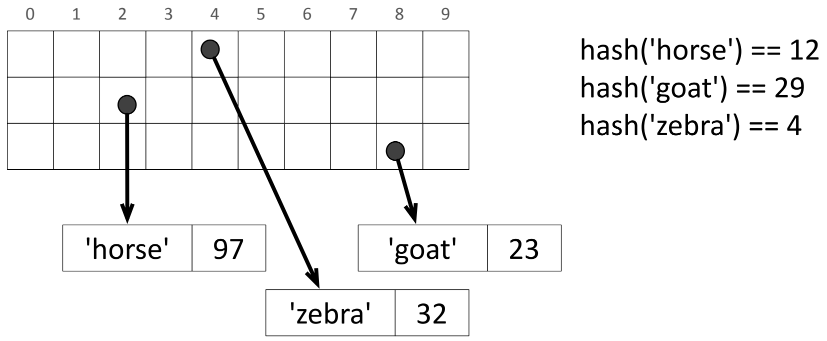
hash('horse') == 12
hash('goat') == 29

Pseudo-random but deterministic "scatter storage" based on a "hash function"

Ways to implement dictionaries



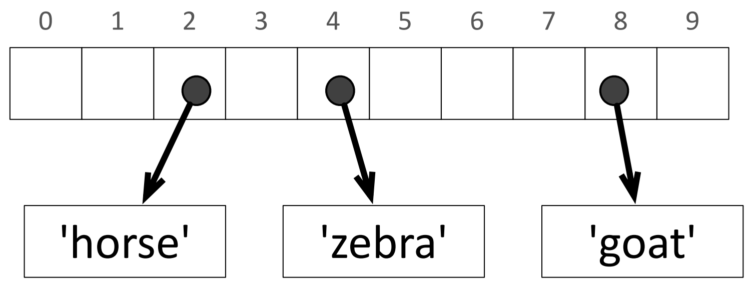
Search tree: Like binary search, but "go left" or "go right" depending on comparison. Database files use a version of this.
Complication: keeping the tree "balanced."



Hash table: Fast on average, but potentially slow in the worst case because of "collisions" (equal hashes).
Compilers use this for variable names.
Complications: Handling collisions, expanding full tables.

Python sets are also hash tables

{ 'horse', 'goat', 'zebra' }



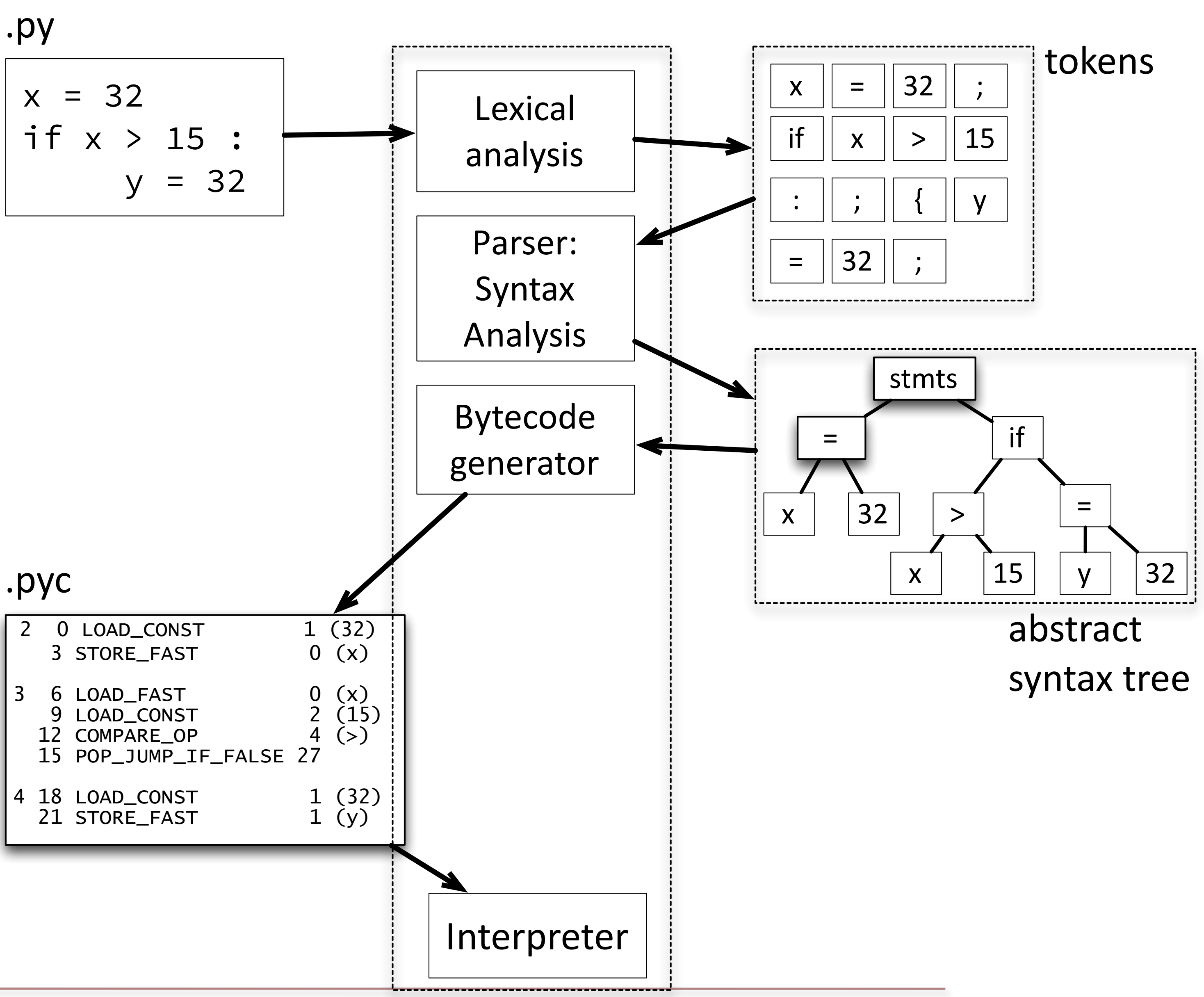
hash('horse') == 22 % 10 == 2
hash('goat') == 98 % 10 == 8
hash('zebra') == 34 % 10 == 4

Hash codes are actually large numbers; position is remainder when divided by table size.   The hash table is expanded (copied to a larger table) if it becomes 2/3 full.

Java library equivalents: hashmap, hashset

The Python Compiler/Interpreter

(simplified)



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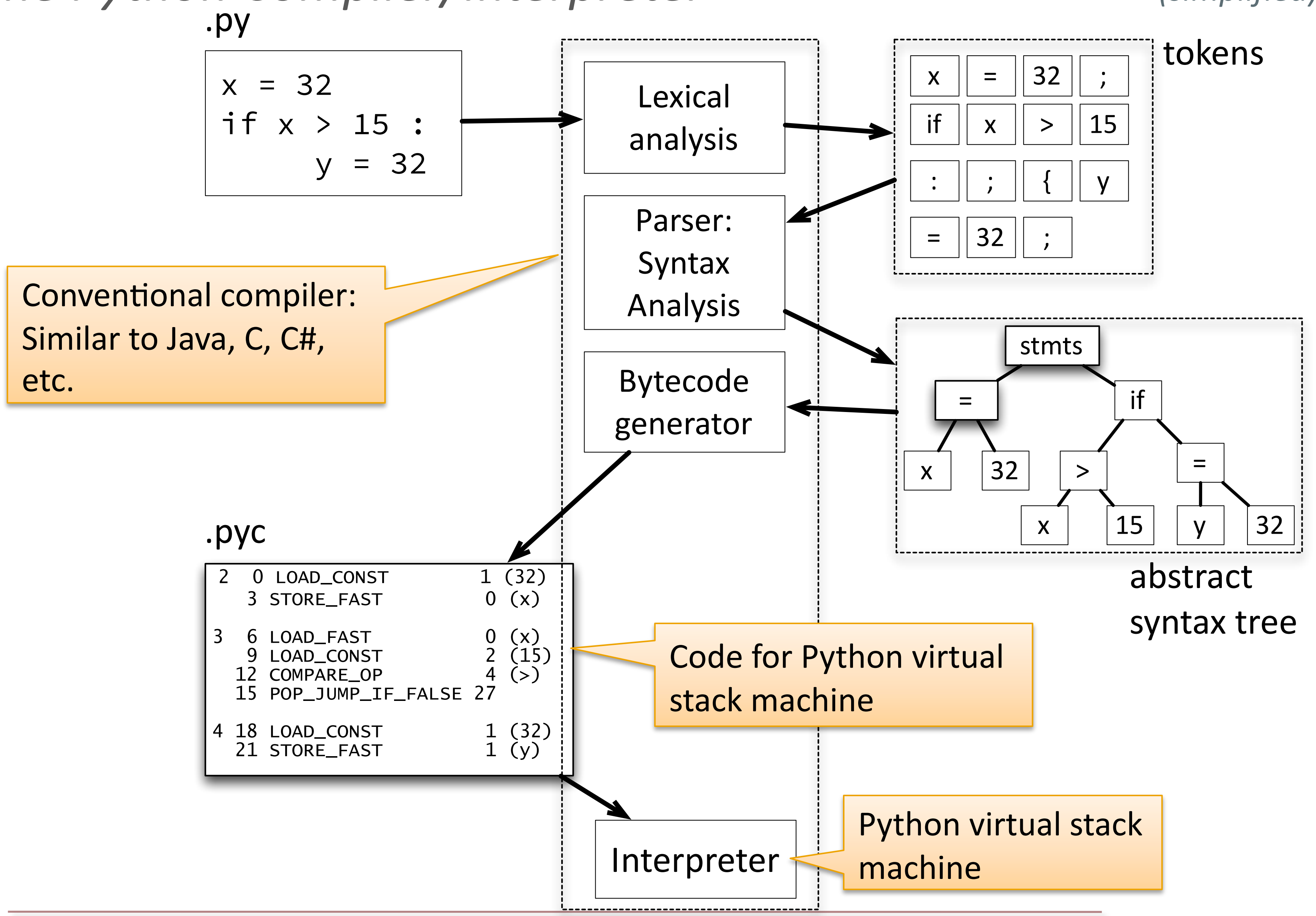

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Python vs. C, Java, etc.

CPython compiler generates byte code

- vs: C compiler generates machine code (the interpreter is the computer)
- vs: standard Java compiler generates byte code (also for a stack machine)
- vs. Dalek Java compiler (Android) generates byte code for a virtual register machine

Python values are all objects in the heap

- vs: C values can be in the stack or the heap, untagged
- vs: Java "primitive" values are in the stack and untagged; objects are in the heap and tagged

Compiled? Interpreted? Both!