Python
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Basic Structure

Python is an interpreted language (like Perl).
Programs are in files with the .py extension.
Programs should start with a “#!/” line:

    #!/usr/bin/env python

Programs are executed from top to bottom.

Advanced: it’s strongly dynamically typed (values have a fixed type, but variables can change type on the fly.)

Most unusual syntax: indenting and newlines are important.

Unlike Go, there are no {} characters to indicate the start and end of a block. That is done through indenting.
The command “python” will start an interactive python session:

```
$ python
[GCC 4.2.1 (Apple Inc. build 5646)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
>>> 
```

You can enter any python commands here.

The most important one is help(x), which will show you detailed help on function (or type or class) x.

Use Ctrl-D or quit() to exit.
iPython Notebooks
#!/usr/bin/env python

import sys
import seq

def remove_gap(s):
    return s.replace('-', '')

S1 = seq.read_fasta(sys.argv[1])
S2 = seq.read_fasta(sys.argv[2])

print sys.argv[1]
print sys.argv[2]

SD1 = dict((s.name, s) for s in S1)
SD2 = dict((s.name, s) for s in S2)

assert len(SD1) == len(SD2)

for s in SD1.itervalues():
    if s.seq != SD2[s.name].seq:
        print 'DISAGREE:', s.name
        print s.seq
        print SD2[s.name].seq

    if s.seq == SD2[s.name].seq:
        print 'AGREE:', s.name
Example 2

A function that takes 1 parameter

```python
def random_order(n):
    """Create random mapping between \([n]\) and \([n]\)"""
    import random
    R = range(n)
    random.shuffle(R)
    return dict(enumerate(R))
```

"""Docstring""" that documents what the function does.

Load the "random" library.

R = [0, 1, 2, 3, ..., n-1]
The list R is randomly shuffled to be something like [7, 8, 10, n-1, ..., 4]

Turns shuffled list into a list of pairs:
[(0, 7), (1, 8), (2, 10), ...]

Turns list of pairs [(i,j)] into a mapping from i \rightarrow j
Built-in Python Data Types

Main Idea: Sequences
Built-in Basic Data Types

\texttt{str} = string (delimit with ‘xyz’ or “xyz”)
  >>> str(10)
  '10'

\texttt{int} = arbitrary-sized integer (see also \texttt{long})
  >>> 7**73
  49221735352184872959961855190338177606846542622561400857262407L

\texttt{float} = floating point number
  >>> 1/2
  0
  >>> 1.0/2
  0.5

\texttt{bool} = True or False
  >>> bool(10)
  True
  >>> bool(0)
  False
Collection Data Types

**list** = mutable list
>>> ['a','b',10,10,7]
['a', 'b', 10, 10, 7]

**tuple** = frozen list (can’t change)
>>> ('a','b',10, 10,7)
('a', 'b', 10, 10, 7)

**dict** = dictionary, aka hash
>>> {'a':7, 'b':10, 13:2}
{'a': 7, 'b': 10, 13: 2}

**set** = mutable set of elements
>>> set(['a','b','b',10])
set(['a', 10, 'b'])

**frozenset** = frozen set of elements
>>> frozenset(['a','b','b',10])
frozenset(['a', 10, 'b'])
Collections

Can contain items of different type.

Can nest them: 
[(1, 2), (3, 4), [5, 6, 7, 8], {'a': 2}]

Sets do not preserve order.

Dictionary keys must be constant, but can be frozenset or tuples:

```python
>>> A = {}
>>> A[(1,2)] = 10
>>> A[frozenset([2,2,2,2])] = 13
>>> A
{(1, 2): 10, frozenset([2]): 13}
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
TypeError: unhashable type: 'list'
```
Slicing Lists and Strings

Can extract subranges from lists and strings:

```
s = “abcdef”
s[0] == “a”
s[2:] == “cdef”
s[-1] == “f”
```

Note: range i:j gives characters i, i+1,..., j-1.

For range i:j

- if i is omitted, it’s assumed to be 0.
- if j is omitted, it’s assumed to be len + 1.

Assignment works for lists (but not strings or tuples):

```
L[2:4] = [7,8,9,10] → [1, 2, 7, 8, 9, 10, 5]
```
For Loops

For loops always loop over a sequence.

Collections are sequences.

```
for x in [1,2,3,4]:
    print x

for key in {'a':10,'b':100}:
    print key

for i in set([1,2,3,2]):
    print i
```

Generate sequences:

```
range(100) = [0,1,2,...,99]
range(10,50) = [10,11,...,49]
range(10,20,2) = [10, 12, 14, 16, 18]
```

for i in range(32):
    print 2**i
def prim_mst(G):
    for u in G.nodes():
        G.node[u]["distto"] = float("inf")  # key stores the Prim key
        G.node[u]["heap"] = None  # heap = pointer to node's HeapItem
    parent = {}

    heap = makeheap([])
    v = G.nodes()[0]

    # go through vertices in order of closest to current tree
    while v != None:
        G.node[v]["distto"] = float("-inf")  # v now in the tree

        # update the estimated distance to each of v's neighbors
        for w in G.neighbors(v):
            # if new length is smaller that old length, update
            if G[v][w]["length"] < G.node[w]["distto"]:
                # closest tree node to w is v
                G.node[w]["distto"] = G[v][w]["length"]
                parent[w] = v

                # add to heap or decrease key if already in heap
                hi = G.node[w]["heap"]
                if hi is None:
                    G.node[w]["heap"] = heapinsert(G.node[w]["distto"], w, heap)
                else:
                    heap_decreasekey(hi, G.node[w]["distto"], heap)

        # get the next vertex closest to the tree
        v = deletemin(heap)
        v = v.item if v is not None else None
    return parent
List Comprehensions

Can construct lists from rules:

\[
L = [i**2 + j**2 \text{ for } i \text{ in } \text{range}(10) \\
    \text{ for } j \text{ in } \text{range}(10) \\
    \text{ if } i \geq j]
\]

>>> L
[1, 4, 5, 9, 10, 13, 16, 17, 20, 25, 25, 26, 29, 34, 41, 36, 37, 40, 45, 52, 61, 49, 50, 53, 58, 65, 74, 85, 64, 65, 68, 73, 80, 89, 100, 113, 81, 82, 85, 90, 97, 106, 117, 130, 145]

>>> set(L)
set([1, 130, 4, 5, 9, 10, 13, 16, 17, 20, 25, 26, 29, 34, 36, 37, 40, 41, 45, 49, 50, 52, 53, 58, 61, 64, 65, 68, 73, 74, 80, 81, 82, 85, 89, 90, 97, 100, 145, 106, 113, 117])

General syntax: \([ \text{EXPR for ... if ... for ... if }]\)

L = []
for i in range(10):
    for j in range(10):
        if i >= j:
            L.append(i**2 + j**2)
Generators

Often it is wasteful to create a list in memory:

```python
for i in range(2**20):
    print i
```
First creates a list of \( \approx 1 \) million items, then iterates through it.

```python
for i in xrange(2**20):
    print i
```
Creates a generator for the list and iterates through it.

Generators are rules that generate a sequence:

```python
(i**2 + j**2 for i in range(10)
    for j in range(10)
    if i >= j)
```

Generator has same syntax as list comprehension, but will only create an item as you iterate through it.

The only thing you can do with generators is iterate through them.
Generators and other sequences can be passed to functions that create new generators:

```python
G = (i**2 + j**2 for i in xrange(10) for j in xrange(10) if i >= j)
for i in sorted(G):
    print i

s = "abcd"
for c in reversed(s):
    print c

L = ["a", "b", "c", "d"]
for (i, c) in enumerate(L):
    print i, c

Q = ["e", "f", "g", "h"]
for (a,b) in zip(Q, L):
    print a, b
```

G is a saved generator
sorted(G) returns the same sequence as G, but sorted

s → (‘d’, ‘c’, ‘b’, ‘a’)

L → ((0, “a”), (1, “b”), (2, “c”), (3, “d”))

((“e”, “a”), (“f”, “b”), (“g”, “c”), (“h”, “d”))
Organizing Code
Functions

Functions can be defined using the syntax:

```python
def name(a, b, c=True, d=2*10):
   BODY
```

The syntax “= EXPR” after a parameter gives the parameter’s default value.

Functions can be called using:

```python
name(10,20, False)
name(10, b=20, d=32)
name(b=10, a=20)
```

Values can be returned from functions using the `return` statement:

```python
def sum(S):
   s = 0.0
   for i in S: s = s + i
   return s
```
Comments

Comments start with # and go until the end of the line:

```plaintext
# this is a comment
```

Strings can be placed as comments as first statement in a file or a function:

```python
def bandwidth(M):
    "Compute the Bandwidth of M"
    return max(abs(i-j) for i in xrange(len(M))
                for j in xrange(i,len(M)) if M[i,j] != 0)
```

Strings surrounded by """xxx"""" or ‘’’xxx’’’ can span multiple lines.
Packages

Code can be imported from other files and standard packages using `import`:

```python
import NAME
from NAME import id1, id2, id3 ...
from NAME import *
```

For example:

```python
import math
print math.log(10)
from math import log
print log(10)
```

`import` will search your current directory, the standard python directories, and directories in your PYTHONPATH environment variable.
A class represents a user defined type. Classes can have functions and variables associated with them. Classes are instantiated into objects.

```
class Species:
    def __init__(self, name):
        self.name = name
    def species_name(self):
        return self.name

Ce = Species("C. elegans")
Hs = Species("H. sapiens")
print Ce.name, Hs.name
print Ce.species_name(), Hs.species_name()
```

Special function called `__init__` is the constructor that says how to build an instance of the class. All functions in a class take a “self” parameter that represents the object. New instance of Species created with name = “C. elegans”
Classes

Objects made from classes can be used anywhere other variables can be used:

```
L = [Hs, Ce, Hs]

Strange = Species(Hs)  # Syntactically correct!
```

Fields can be added to objects on the fly:

```
Hs.size = 10
print Hs.size
print Ce.size  # Error! “size” field only exists in the Hs object.
```
class TreeNode:
    """Represents a node in the tree to be drawn"""

    def __init__(self, parent=None, name='', **options):
        self.name, self.parent = name, parent
        self.children = []
        self.length = 0.0

        if parent != None: parent.children.append(self)
        if "default_len" in options:
            self.length = options["default_len"]
```python
class HeapItem(object):
    """Represents an item in the heap""
    def __init__(self, key, item):
        self.key = key
        self.item = item
        self.pos = None

def makeheap(S):
    """Create a heap from set S, which should be a list of pairs (key, item).""
    heap = list(HeapItem(k,i) for k,i in S)
    for pos in xrange(len(heap)-1, -1, -1):
        siftdown(heap[pos], pos, heap)
    return heap

def findmin(heap):
    """Return element with smallest key, or None if heap is empty""
    return heap[0] if len(heap) > 0 else None

def deletemin(heap):
    """Delete the smallest item""
    if len(heap) == 0: return None
    i = heap[0]
    last = heap[-1]
    del heap[-1]
    if len(heap) > 0:
        siftdown(last, 0, heap)
    return i

def heapinsert(key, item, heap):
    """Insert an item into the heap""
    heap.append(None)
    hi = HeapItem(key, item)
    siftup(hi, len(heap)-1, heap)
    return hi

def siftup(hi, pos, heap):
    """Move hi up in heap until its parent is smaller than hi.key""
    p = parent(pos)
    while p is not None and heap[p].key > hi.key:
        heap[pos] = heap[p]
        heap[pos].pos = pos
        pos = p
        p = parent(p)
    heap[pos] = hi
    hi.pos = pos

def siftdown(hi, pos, heap):
    """Move hi down in heap until its smallest child is bigger than hi's key""
    c = minchild(pos, heap)
    while c != None and heap[c].key < hi.key:
        heap[pos] = heap[c]
        heap[pos].pos = pos
        pos = c
        c = minchild(c, heap)
    heap[pos] = hi
    hi.pos = pos

def heap_decreasekey(hi, newkey, heap):
    """Decrease the key of hi to newkey""
    hi.key = newkey
    siftup(hi, hi.pos, heap)
```

**Python Code to for a d-Heap**
Python Code to for a d-Heap

```python
def parent(pos):
    """Return the position of the parent of pos""
    if pos == 0: return None
    return int(math.ceil(pos / ARITY) - 1)

def children(pos, heap):
    """Return a list of children of pos""
    return xrange(ARITY * pos + 1, min(ARITY * (pos + 1) + 1, len(heap)))

def minchild(pos, heap):
    """Return the child of pos with the smallest key""
    minpos = minkey = None
    for c in children(pos, heap):
        if minkey == None or heap[c].key < minkey:
            minkey, minpos = heap[c].key, c
    return minpos
```
Other Statements
Reading Files

"with" statement sets up a context. The main use is to open an file and ensure, no matter what happens, the file will be closed.

```python
with open(filename) as inp:
    for line in inp:
        line = line.strip()
        s = line.split()
        ...
```

Input file is a sequence of lines & we can iterate over the lines using a for loop.

the strip() function removes whitespace from the start and end of the string.

split() converts the string into a list of words.
Print

print expr1, expr2, ..., exprK

will output the result of converting the given expressions into strings.

Expressions will be separated by a space, and a newline will be printed at the end.

>>> print 10, 20, "cat", 2*100-5
 10 20 cat 195

End with a comma to omit the newline at the end and to smartly separate items with spaces:

>>> for a in (1,2,3,4): print "item=", a,
item= 1 item= 2 item= 3 item= 4

Output to a file with the (strange) syntax:

    print >>F, expr1, expr2, ..., exprK

where F is an open file object.
Math Operators

\[ x + y; \quad x - y; \quad x \times y \]: addition, subtraction, and multiplication

\[ x / y \]: type-preserving division (if \( x \) and \( y \) are both integers, the result will be an integer)

\[ x // y \]: integer division (floor(float(x)/y))

\[ x \mod y \]: remainder of \( x / y \)

\[ x^{**}y \]: \( x \) raised to the \( y \)th power

\[ \text{abs}(x) \]: absolute value of \( x \)

\[ \text{round}(x) \]: round \( x \) to nearest integer

\[ \text{sum}(SEQ) \]: sum of items in the sequence

\[ \text{max}(SEQ) \]: largest item in the sequence

\[ \text{min}(SEQ) \]: smallest item in the sequence

floor, ceil, log, exp, sin, cos, sqrt, factorial, and others available in the built-in “math” package.
Boolean Expressions

Comparison operators are: ==  <  >  <=  >=  !=  in  is

>>> 1 == 2
False
>>> 1 > 2
False
>>> 1 <= 2
True
>>> 1 != 2
True
>>> "a" in "aeiou"
True
>>> 7 in [7,8,9]
True

Boolean operators are: and or not

"a" in "aeiou" and "z" not in "aeiou"

1 < i < 128 and i*j == 100
If Statements

if 2 in xrange(-3,10,2):
    print “YES”

if “abc” in “abcde”:
    print “YES”
else:
    print “NO”

if s == “Whitman”:
    print “Leaves of Grass”
elif s == “Poe”:
    print “The Raven”
elif s == “Hawthorne”
    print “The House of Seven Gables”
else:
    print “Author unknown”

Syntax: if EXPR:

“else” block executed if the if-EXPR is False.

“elif” blocks are tested in order if the first if is False and the first elif block that is True is run.
While Loops

while EXPR:
    BLOCK

will repeatedly execute BLOCK until EXPR is False.

**continue**: jump to the next iteration of the while or for loop.

**break**: exit out of the while or for loop.
Regular Expressions

```python
import re
S = "al capone abalone"
if re.search(r'one|all$', S):
    print "FOUND"

The results of the search can be saved:

```text
m = re.search(r'(one).*?(one)', S)
m.group(0) == "pone abalone"
m.group(1) == "pone"
m.group(2) == "lone"
m.start() == 5
m.end() == 17
```

re.sub performs substitutions:

```text
S2 = re.sub(r'[aeiou]', ' ', S, count=10)
```

Omit count to replace all.
S is unchanged.

re.findall finds all non-overlapping instances:

```text
re.findall(r'[aeiou]', S)
['a', 'a', 'o', 'e', 'a', 'a', 'o', 'e']
```
Regular Expressions 2

re.split divides the string at the pattern:

```python
>>> re.split(r'\[\s,\]*', "10 , 200,30 74")
['10', '200', '30', '74']
```

Regular expressions support:

- `^` $ : start, end of string
- `*` : repeat 0 or more times
- `+` : repeat 1 or more times
- `?` : occur 0 or 1 time
- `{m,n}` : occur between m and n times (inclusive)
- `[ ]` : character classes
- `|` : or
- `()` : grouping for later retrieval
- `
\number` : match contents of given group
- `\s` : matches space
- `\d` : matches digit
- `\w` : matches alphanumeric
Other Examples
def local_align(x, y, score=ScoreParam(-7, 10, -5)):
    """Do a local alignment between x and y""
    # create a zero-filled matrix
    A = make_matrix(len(x) + 1, len(y) + 1)

    best = 0
    optloc = (0,0)

    # fill in A in the right order
    for i in xrange(1, len(x)):
        for j in xrange(1, len(y)):

            # the local alignment recurrence rule:
            A[i][j] = max(
                A[i][j-1] + score.gap,
                A[i-1][j] + score.gap,
                A[i-1][j-1] + (score.match if x[i] == y[j] else score.mismatch),
                0
            )

            # track the cell with the largest score
            if A[i][j] >= best:
                best = A[i][j]
                optloc = (i,j)

    # return the opt score and the best location
    return best, optloc
def make_matrix(sizex, sizey):
    """Creates a sizex by sizey matrix filled with zeros."""
    return [[0]*sizey for i in xrange(sizex)]

class ScoreParam:
    """The parameters for an alignment scoring function"""
    def __init__(self, gap, match, mismatch):
        self.gap = gap
        self.match = match
        self.mismatch = mismatch
def build_suffix_trie(s):
    """Construct a suffix trie.""
    assert len(s) > 0
    # explicitly build the two-node suffix tree
    Root = SuffixNode()  # the root node
    Longest = SuffixNode(suffix_link = Root)
    Root.add_link(s[0], Longest)
    for c in s[1:]:
        Current = Longest; Previous = None
        while c not in Current.children:
            # create new node r1 with transition Current -c->r1
            r1 = SuffixNode()
            Current.add_link(c, r1)
            # if we came from some previous node, make that
            # node’s suffix link point here
            if Previous is not None:
                Previous.suffix_link = r1
            # walk down the suffix links
            Previous = r1
            Current = Current.suffix_link
        # make the last suffix link
        if Current is Root:
            Previous.suffix_link = Root
        else:
            Previous.suffix_link = Current.children[c]
        # move to the newly added child of the longest path
        # (which is the new longest path)
        Longest = Longest.children[c]
    return Root
Other Language Features

Exceptions:

```
try:
    ....
except ValueError:
    ....
```

Lambda functions:

Can define a function without a name that contains a single expression:

```
f = lambda a,b: a**2 + b
f(10,2)
L.sort(cmp=lambda a,b: cmp(a[0],b[0]))
```