On to Python 3...

“Hello, World”

- C

```
#include <stdio.h>

int main(int argc, char ** argv)
{
   printf("Hello, World!\n");
}
```

- Java

```
public class Hello
{
   public static void main(String argv[])
   {
      System.out.println("Hello, World!");
   }
}
```

- now in Python

```
print("Hello, World!")
```

Printing an Array

```c
void print_array(char* a[], int len)
{
   int i;
   for (i = 0; i < len; i++)
   {
      printf("%s\n", a[i]);
   }
}
```

C

has to specify `len`,
and only for one type (`char*`)

Python

```python
for element in list:
    print(element)
```

only indentations
no { ... } blocks!

```
for ... in ... :
    ...
```

no C-style for-loops!

~~`for (i = 0; i < 10; i++)`~~

or even simpler:

```python
print(list)
```

Reversing an Array

```
static int[] reverse_array(int a[])
{
   int [] temp = new int[ a.length ];
   for (int i = 0; i < len; i++)
   {
      temp [i] = a [a.length - i - 1];
   }
   return temp;
}
```

Java

Python

```
def rev(a):
   if a == []:
      return []
   else:
      return rev(a[1:]) + [a[0]]
```

def ...(...):
...

no need to specify argument and return types!
python will figure it out.
(dynamically typed)

`a` without `a[0]`

singleton list

or even simpler:

`a.reverse()` ⟵ built-in list-processing function; *in-place*

Quick-sort

```java
public void sort(int low, int high)
{
    if (low >= high) return;
    int p = partition(low, high);
    sort(low, p);
    sort(p + 1, high);
}

void swap(int i, int j)
{
    int temp = a[i];
    a[i] = a[j];
    a[j] = temp;
}
```

```java
int partition(int low, int high)
{
    int pivot = a[low];
    int i = low - 1;
    int j = high + 1;
    while (i < j)
    {
        i++; while (a[i] < pivot) i++;
        j--; while (a[j] > pivot) j--;
        if (i < j) swap(i, j);
    }
    return j;
}
```

Java

Python

```python
def sort(a):
    if a == []:
        return []
    else:
        pivot = a[0]
        left  = [x for x in a if x < pivot ]
        right = [x for x in a[1:] if x >= pivot]
        return  sort(left)  + [pivot] +  sort(right)
```

$$\{x \mid x \in a,\ x < pivot\}$$

smaller semantic-gap!

how about `return [sort(left)] + [pivot] + [sort(right)]` *got an error??*

Python is...

- a scripting language (strong in text-processing)
  - interpreted, like Perl, but much more elegant
- a very high-level language (closer to human semantics)
  - almost like pseudo-code!
- procedural (like C, Pascal, Basic, and many more)
- but also object-oriented (like C++ and Java)
- and even functional! (like ML/OCaml, LISP/Scheme, Haskell, etc.)
- from today, you should use Python for everything
  - not just for scripting, but for serious coding!

Let’s take a closer look...

Python Interpreter

- Three ways to run a Python program

1. Interactive

    - like DrJava

```
>>> for i in range(5):
...     print(i, end=' ')
...
0 1 2 3 4
```

2. (default) save to a file, say, `foo.py`

    - in command-line: `python3 foo.py`

3. add a special line pointing to the default interpreter

    - add `#!/usr/bin/env python3` to the top of `foo.py`
    - make `foo.py` executable (`chmod +x foo.py`)
    - in the command-line: `./foo.py`

Switching to Python3

- starting from this term, we'll be using Python 3!
  - many libraries have dropped or will drop support of Python2
  - Python 3.x is not backward compatible with Python 2.x
  - you can use `python3` on school machine "`flip`"
    - you can ssh to `access.engr.oregonstate.edu` from home
  - or you can install Python 3 on your own mac/windows
    - anaconda is highly recommended (esp. for deep learning)

```
<flip1:~> python3
Python 3.4.5 (default, Dec 11 2017, 14:22:24)
[GCC 4.8.5 20150623 (Red Hat 4.8.5-16)] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>>

[<lhuang@Mac OS X:~>] which python3
/anaconda3/bin/python3
```

Major Differences b/w 2.x and 3.x

- print(...)
- lazy by default: range vs. xrange, zip vs. itertools.izip, map vs. itertools.imap, dict.items vs. dict.iteritems
- division: / vs. //
- we'll discuss others along the way

Basic Python Syntax

Numbers and Strings

- like Java, Python has built-in (atomic) types
  - numbers (`int`, `float`), `bool`, `string`, `list`, etc.
  - numeric operators: `+ - * / ** %`

```
>>> a = 5
>>> b = 3
>>> type (5)
<type 'int'>
>>> a += 4
>>> a
9
```

no `i++` or `++i`

```
>>> 5/2
2.5
>>> 5/2.
2.5
>>> 5 // 2
2
```

```
>>> s = “hey”
>>> s + “ guys”
'hey guys'
>>> len(s)
3
>>> s[0]
'h'
>>> s[-1]
'y'
```

Assignments and Comparisons

```
>>> a = b = 0
>>> a
0
>>> b
0

>>> a, b = 3, 5
>>> a + b
8
>>> (a, b) = (3, 5)
>>> a + b
>>> 8
>>> a, b = b, a
(swap)
```

```
>>> a = b = 0
>>> a == b
True
>>> type (3 == 5)
<type 'bool'>
>>> "my" == 'my'
True

>>> (1, 2) == (1, 2)
True

>>> 1, 2 == 1, 2
???
(1, False, 2)

>>> (1, 2) == 1, 2
???
```

`for` loops and `range()`

- `for` always iterates through a list or sequence

```
>>> sum = 0
>>> for i in range(10):
...     sum += i
...
>>> print(sum)
45

>>> for word in ["welcome", "to", "python"]:
...     print(word, end=' ')
...
welcome to python

>>> range(5), range(4,6), range(1,7,2)
([0, 1, 2, 3, 4], [4, 5], [1, 3, 5])
```

Java 1.5

```
foreach (String word : words)
    System.out.println(word)
```

`while` loops

- very similar to `while` in Java and C
  - but be careful
    - `in` behaves differently in `for` and `while`
  - `break` statement, same as in Java/C

```
>>> a, b = 0, 1
>>> while b <= 5:
...         print(b)
...         a, b = b, a+b
...
1
1
2
3
5
```

simultaneous assignment

fibonacci series

Conditionals

```
>>> if x < 10 and x >= 0:
...     print(x, "is a digit")
...
>>> False and False or True
True
>>> not True
False
```

```
>>> if 4 > 5:
...     print("foo")
... else:
...     print("bar")
...
bar
```

```
>>> print(“foo” if 4 > 5 else “bar”)
...
>>> bar
```

conditional expr since Python 2.5

C/Java `printf( (4>5)? ”foo” : “bar”);`

if … elif … else

```
>>> a = "foo"
>>> if a in ["blue", "yellow", "red"]:
...     print(a + " is a color")
... else:
...     if a in ["US", "China"]:
...         print(a + " is a country")
...     else:
...         print("I don't know what", a, "is!")
...
I don't know what foo is!
```

```
>>> if a in …:
...     print …
... elif a in …:
...     print …
... else:
...     print …
```

C/Java

```
switch (a) {
    case "blue":
    case "yellow":
    case "red":
        print ...; break;
    case "US":
    case "China":
        print ...; break;
    else:
        print ...;
}
```

`break`, `continue` and `else`

- `break` and `continue` borrowed from C/Java
- special `else` in loops
  - when loop terminated *normally* (i.e., not by `break`)
  - very handy in testing a set of properties

```
>>> for n in range(2, 10):
...     for x in range(2, n):
...         if n % x == 0:
...             break
...     else:
...         print(n, end=' ')
...
```

prime numbers

```
for (n=2; n<10; n++) {
   good = true;
   for (x=2; x<n; x++)
      if (n % x == 0) {
         good = false;
         break;
      }
   if (good)
      printf("%d ", n);
}
```

C/Java

```
|| func(n)
if (x==n)
```

Defining a Function `def`

- no type declarations needed! wow!
  - Python will figure it out at run-time
    - you get a run-time error for type violation
      - well, Python does not have a compile-error at all

```
>>> def fact(n):
...     if n == 0:
...         return 1
...     else:
...         return n * fact(n-1)
...
>>> fact(4)
24
```

Fibonacci Revisited

```
>>> a, b = 0, 1
>>> while b <= 5:
...         print(b)
...         a, b = b, a+b
...
1
1
2
3
5
```

```
def fib(n):
    if n <= 1:
        return n
    else:
        return fib (n-1) + fib (n-2)
```

conceptually cleaner, but much slower!

```
>>> fib(5)
5
>>> fib(6)
8
```

Default Values

```
>>> def add(a, L=[]):
...     return L + [a]
...
>>> add(1)
[1]

>>> add(1,1)
error!

>>> add(add(1))
[[1]]

>>> add(add(1), add(1))
???
[1, [1]]
```

lists are heterogenous!

Approaches to Typing

- ✓ strongly typed: types are strictly enforced. no implicit type conversion
- – weakly typed: not strictly enforced
- – statically typed: type-checking done at compile-time
- ✓ dynamically typed: types are inferred at runtime

	weak	strong
static	C, C++	Java, Pascal
dynamic	Perl, VB	Python, OCaml

Lists

heterogeneous variable-sized array

```
a = [1,'python', [2,'4']]
```

Basic List Operations

- length, subscript, and slicing

```
>>> a = [1,'python', [2,'4']]
>>> len(a)
3
>>> a[2][1]
'4'
>>> a[3]
IndexError!
>>> a[-2]
'python'
>>> a[1:2]
['python']
```

```
>>> a[0:3:2]
[1, [2, '4']]

>>> a[:-1]
[1, 'python']

>>> a[0:3:]
[1, 'python', [2, '4']]

>>> a[0::2]
[1, [2, '4']]

>>> a[::]
[1, 'python', [2, '4']]

>>> a[:]
[1, 'python', [2, '4']]
```

+, extend, +=, append

- extend (+=) and append mutates the list!

```
>>> a = [1,'python', [2,'4']]
>>> a + [2]
[1, 'python', [2, '4'], 2]
>>> a.extend([2, 3])
>>> a
[1, 'python', [2, '4'], 2, 3]
```

same as `a += [2, 3]`

```
>>> a.append('5')
>>> a
[1, 'python', [2, '4'], 2, 3, '5']
>>> a[2].append('xtra')
>>> a
[1, 'python', [2, '4', 'xtra'], 2, 3, '5']
```

Comparison and Reference

- as in Java, comparing built-in types is by value
  - by contrast, comparing objects is by reference

```
>>> [1, '2'] == [1, '2']
True
>>> a = b = [1, '2']
>>> a == b
True
>>> a is b
True
>>> b [1] = 5
>>> a
[1, 5]
>>> a = 4
>>> b
[1, 5]
>>> a is b
>>> False
```

```
>>> c = b [:]
>>> c
[1, 5]
>>> c == b
True
>>> c is b
False
```

slicing gets a shallow copy

```
>>> b[:0] = [2]
>>> b
[2, 1, 5]
>>> b[1:3]=[]
>>> b
[2]
```

insertion

deletion

```
>>> a = b
>>> b += [1]
>>> a is b
True
```

a += b means **a.extend(b)** NOT **a = a + b** !!

List Comprehension

```
>>> a = [1, 5, 2, 3, 4 , 6]
>>> [x*2 for x in a]
[2, 10, 4, 6, 8, 12]

>>> [x for x in a if \
... len( [y for y in a if y < x] ) == 3 ]
[4]
```

4th smallest element

```
>>> a = range(2,10)
>>> [x*x for x in a if \
... [y for y in a if y < x and (x % y == 0)] == [] ]
???
[4, 9, 25, 49]
```

square of prime numbers

List Comprehensions

```
>>> vec = [2, 4, 6]
>>> [[x,x**2] for x in vec]
[[2, 4], [4, 16], [6, 36]]

>>> [x, x**2 for x in vec]
SyntaxError: invalid syntax

>>> [(x, x**2) for x in vec]
[(2, 4), (4, 16), (6, 36)]

>>> vec1 = [2, 4, 6]
>>> vec2 = [4, 3, -9]
>>> [x*y for x in vec1 for y in vec2]
[8, 6, -18, 16, 12, -36, 24, 18, -54]
```

(cross product)

```
>>> [x+y for x in vec1 for y in vec2]
[6, 5, -7, 8, 7, -5, 10, 9, -3]

>>> [vec1[i]*vec2[i] for i in range(len(vec1))]
[8, 12, -54]
```

should use zip instead!

(dot product)

Strings

sequence of characters

Basic String Operations

- join, split, strip
- upper(), lower()

```
>>> s = " this is  a  python course. \n"
>>> words = s.split()
>>> words
['this', 'is', 'a', 'python', 'course.']
>>> s.strip()
'this is  a  python course.'
>>> " ".join(words)
'this is a python course.'
>>> "; ".join(words).split("; ")
['this', 'is', 'a', 'python', 'course.']
>>> s.upper()
' THIS IS  A  PYTHON COURSE. \n'
```

http://docs.python.org/lib/string-methods.html

Basic Search/Replace in String

```
>>> "this is a course".find("is")
2
>>> "this is a course".find("is a")
5
>>> "this is a course".find("is at")
-1
```

```
>>> "this is a course".replace("is", "was")
'thwas was a course'
>>> "this is a course".replace(" is", " was")
'this was a course'
>>> "this is a course".replace("was", "were")
'this is a course'
```

these operations are much faster than regexps!

String Formatting

```
>>> print(“%.2f%%” % 97.2363)
97.24%

>>> s = '%s has %03d quote types.' % ("Python", 2)
>>> print(s)
Python has 002 quote types.
```

Sequence Types

- list, tuple, str; buffer, xrange, unicode

```
>>> lists = [[]] * 3
>>> lists
[[], [], []]
```

```
>>> lists[0].append(3)
>>> lists
[[3], [3], [3]]
```

the tricky *

```
>>> [1, 2] * 3
[1, 2, 1, 2, 1, 2]

>>> [] * 3
[]

>>> [[]] * 3
[[], [], []]

>>> a = [3]
>>> b = a * 3
>>> b
[3, 3, 3]

>>> a[0] = 4
>>> b
[3, 3, 3]
```

```
>>> a = [[3]]
>>> b = a * 3
>>> b
[[3], [3], [3]]

>>> a[0][0] = 4
[[4], [4], [4]]

>>> a[0] = 5
>>> b
[[4], [4], [4]]

>>> a = [3]
>>> b = [a] * 3
>>> b
[[3], [3], [3]]
```

```
>>> a[0] = 4
>>> b
[[4], [4], [4]]

>>> b[1] = 5
>>> b
[[4], 5, [4]]

>>> b[0] += [2]
[[4, 2], 5, [4, 2]]

>>> " " * 3
"   "

>>> "_ " * 3
"_ _ _ "
```

Pythonic Styles

- do not write ... when you can write ...

`for key in d.keys():`	`for key in d:`
`if d.has_key(key):`	`if key in d:`

`i = 0`
`for x in a:`
`    ...`
`    i += 1`
	`for i, x in enumerate(a):`

`a[0:len(a) - i]`	`a[:-i]`
`for line in \` `    sys.stdin.readlines():`	`for line in sys.stdin:`

`for x in a:`
`    print(x, end=' ')`
`print`
	`print(" ".join(map(str, a)))`

`s = ""`
`for i in range(lev):`
`    s += " "`
`print(s)`
	`print(" " * lev)`

Tuples

immutable lists

Tuples and Equality

- caveat: singleton tuple

```
a += (1,2)  # new copy
a += [1,2]  # in-place
```

- `==`, `is`, `is not`

```
>>> (1, 'a')
(1, 'a')
>>> (1)
1
>>> [1]
[1]
>>> (1,)
(1,)
>>> [1,]
[1]
>>> (5) + (6)
11
>>> (5,)+ (6,)
(5, 6)
```

```
>>> 1, 2 == 1, 2
(1, False, 2)
>>> (1, 2) == (1, 2)
True
>>> (1, 2) is (1, 2)
False
>>> "ab" is "ab"
True
>>> [1] is [1]
False
>>> 1 is 1
True
>>> True is True
True
```

Comparison

- between the same type: "lexicographical"
- between different types: arbitrary
- `cmp()`: three-way <, >, ==
  - C: `strcmp(s, t)`, Java: `a.compareTo(b)`

```
>>> (1, 'ab') < (1, 'ac')
True
>>> (1, ) < (1, 'ac')
True
>>> [1] < [1, 'ac']
True
>>> 1 < True
False
>>> True < 1
False
```

```
>>> [1] < [1, 2] < [1, 3]
True
>>> [1] == [1,] == [1.0]
True
>>> cmp ( (1, ), (1, 2) )
-1
>>> cmp ( (1, ), (1, ) )
0
>>> cmp ( (1, 2), (1, ) )
1
```

enumerate

```
>>> words = ['this', 'is', 'python']
>>> i = 0
>>> for word in words:
...     i += 1
...     print(i, word)
...
1 this
2 is
3 python

>>> for i, word in enumerate(words):
...     print(i+1, word)
...
```

- how to enumerate two lists/tuples simultaneously?

zip and _

```
>>> a = [1, 2]
>>> b = ['a', 'b']

>>> list(zip (a,b))
[(1, 'a'), (2, 'b')]

>>> list(zip(a,b,a))
[(1, 'a', 1), (2, 'b', 2)]
```

```
>>> list(zip ([1], b))
[(1, 'a')]
```

```
>>> a = ['p', 'q']; b = [[2, 3], [5, 6]]
>>> for i, (x, [_, y]) in enumerate(zip(a, b)):
...     print(i, x, y)
...
0 p 3
1 q 6
```

zip and list comprehensions

```
>>> vec1 = [2, 4, 6]
>>> vec2 = [4, 3, -9]
>>> [(x, y) for x in vec1 for y in vec2]
[(2, 4), (2, 3), (2, -9), (4, 4), (4, 3), (4, -9), (6, 4),
(6, 3), (6, -9)]

>>> [(vec1[i], vec2[i]) for i in range(len(vec1))]
[(2, 4), (4, 3), (6, -9)]

>>> sum([vec1[i]*vec2[i] for i in range(len(vec1))]
-34

>>> sum(x*y for (x,y) in zip(vec1, vec2))
-34

>>> sum(v[0]*v[1] for v in zip(vec1, vec2))
-34
```

how to implement zip?

binary zip: easy

```
>>> def myzip(a,b):
...     if a == [] or b == []:
...             return []
...     return [(a[0], b[0])] + myzip(a[1:], b[1:])
...
```

```
>>> myzip([1,2], ['a','b'])
[(1, 'a'), (2, 'b')]
>>> myzip([1,2], ['b'])
[(1, 'b')]
```

how to deal with arbitrarily many arguments?

Dictionaries

(heterogeneous) hash maps

Constructing Dicts

- key : value pairs

```
>>> d = {'a': 1, 'b': 2, 'c': 1}
>>> d['b']
2
>>> d['b'] = 3
>>> d['b']
3
>>> d['e']
KeyError!
>>> d.has_key('a')
True
>>> 'a' in d
True
>>> d.keys()
['a', 'c', 'b']
>>> d.values()
[1, 1, 3]
```

Other Constructions

- zipping, list comprehension, keyword argument
- dump to a list of tuples

```
>>> d = {'a': 1, 'b': 2, 'c': 1}
>>> keys = ['b', 'c', 'a']
>>> values = [2,  1,   1 ]
>>> e = dict (zip (keys, values))
>>> d == e
True
>>> d.items()
[('a', 1), ('c', 1), ('b', 2)]

>>> f = dict( [(x, x**2) for x in values] )
>>> f
{1: 1, 2: 4}

>>> g = dict(a=1, b=2, c=1)
>>> g == d
True
```

default values

- counting frequencies

```
>>> def incr(d, key):
...     if key not in d:
...             d[key] = 1
...     else:
...             d[key] += 1
...
```

```
>>> def incr(d, key):
...     d[key] = d.get(key, 0) + 1
...

>>> incr(d, 'z')
>>> d
{'a': 1, 'c': 1, 'b': 2, 'z': 1}
>>> incr(d, 'b')
>>> d
{'a': 1, 'c': 1, 'b': 3, 'z': 1}
```

defaultdict

- best feature introduced in Python 2.5

```
>>> from collections import defaultdict
>>> d = defaultdict(int)
>>> d['a']
0
>>> d['b'] += 1
>>> d
{'a': 0, 'b': 1}

>>> d = defaultdict(list)
>>> d['b'] += [1]
>>> d
{'b': [1]}

>>> d = defaultdict(lambda : <expr>)
```

Sets

identity maps, unordered collection

Sets

- [] for lists, () for tuples, {} for dicts, and {} for sets (2.7)
- construction from lists, tuples, dicts (keys), and strs
- in, not in, add, remove

```
>>> a = {1, 2}
a
>> set([1, 2])
>>> a = set((1,2))
>>> a
set([1, 2])
>>> b = set([1,2])
>>> a == b
True
>>> c = set({1:'a', 2:'b'})
>>> c
set([1, 2])
```

```
>>> type({})
'dict'  # not set!
```

```
>>> a = set()
>>> 1 in a
False
>>> a.add(1)
>>> a.add('b')
>>> a
set([1, 'b'])
>>> a.remove(1)
>>> a
set(['b'])
```

Set Operations

- union, intersection, difference, is_subset, etc..

demo

```
>>> a = set('abracadabra')
>>> b = set('alacazam')
>>> a
set(['a', 'r', 'b', 'c', 'd'])
>>> a - b
set(['r', 'd', 'b'])
>>> a | b
set(['a', 'c', 'r', 'd', 'b', 'm', 'z', 'l'])
>>> a & b
set(['a', 'c'])
>>> a ^ b
set(['r', 'd', 'b', 'm', 'z', 'l'])
>>> a |= b
>>> a
set(['a', 'c', 'b', 'd', 'm', 'l', 'r', 'z'])
```

set and frozenset type

Basic `import` and I/O

`import` and I/O

- similar to `import` in Java
- File I/O much easier than Java

demo

```
import sys
for line in sys.stdin:
   print(line.split())
```

or

```
from sys import *
for line in stdin:
   print(line.split())
```

```
import System;
```

Java

```
import System.*;
```

```
>>> f = open("my.in", "rt")
>>> g = open("my.out", "wt")
>>> for line in f:
...     print(line, file=f)
... g.close()
```

file copy

to read a line:

```
line = f.readline()
```

to read all the lines:

```
lines = f.readlines()
```

note this comma!

`import` and `__main__`

- multiple source files (modules)
  - C: `#include "my.h"`
  - Java: `import My`
- demo
- handy for debugging

foo.py

demo

```
def pp(a):
   print(" ".join(a))

if __name__ == "__main__":
   from sys import *
   a = stdin.readline()
   pp (a.split())
```

```
>>> import foo
>>> pp([1,2,3])
1 2 3
```

interactive

Quiz

- Palindromes

  `abcba`

  - read in a string from standard input, and print `True` if it is a palindrome, print `False` if otherwise

```
def palindrome(s):
    if  len(s) <= 1 :
        return True
    return  s[0] == s[-1]  and palindrome(  s[1:-1]  )

if __name__ == '__main__':

    import sys
    s = sys.stdin.readline().__strip()
    print(palindrome(s))
```

Functional Programming

map and filter

- intuition: function as data
- we have already seen functional programming a lot!
  - list comprehension, custom comparison function

```
map(f, a)

filter(p, a)
```

```
[ f(x) for x in a ]

[ x for x in a if p(x) ]
```

```
map(f, filter(p, a))
```

```
[ f(x) for x in a if p(x) ]
```

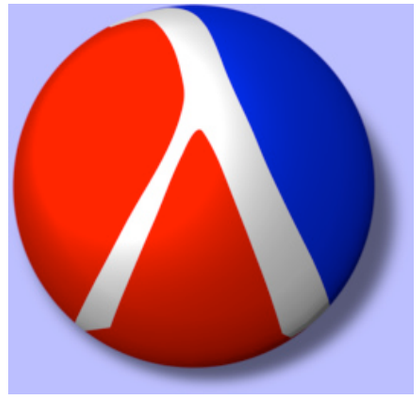
```
>>> map(int, ['1','2'])
[1, 2]
>>> " ".join(map(str, [1,2]))
1 2
```

```
>>> def is_even(x):
...     return x % 2 == 0
...
>>> filter(is_even, [-1, 0])
[0]
```

demo

lambda

- map/filter in one line for custom functions?
  - "anonymous inline function"
- borrowed from LISP, Scheme, ML, OCaml



```
>>> f = lambda x: x*2
>>> f(1)
2
>>> map (lambda x: x**2, [1, 2])
[1, 4]
>>> filter (lambda x: x > 0, [-1, 1])
[1]
>>> g = lambda x,y : x+y
>>> g(5,6)
11
>>> map (lambda (x,y): x+y, [(1,2), (3,4)])
[3, 7]
```

demo

more on lambda

```
>>> f = lambda : "good!"
>>> f
<function <lambda> at 0x381730>
>>> f()
'good!'
```

lazy evaluation

```
>>> a = [5, 1, 2, 6, 4]
>>> a.sort(lambda x,y : y - x)
>>> a
[6, 5, 4, 2, 1]
```

custom comparison

```
>>> a = defaultdict(lambda : 5)
>>> a[1]
5
>>> a = defaultdict(lambda : defaultdict(int))
>>> a[1]['b']
0
```

demo

Basic Sorting

```
>>> a = [5, 2, 3, 1, 4]
>>> a.sort()
>>> print(a)
[1, 2, 3, 4, 5]

>>> a = [5, 2, 3, 1, 4]
>>> a.sort(reverse=True)
>>> a
[5, 4, 3, 2, 1]

>>> a = [5, 2, 3, 1, 4]
>>> a.sort()
>>> a.reverse()
>>> a
[5, 4, 3, 2, 1]
```

sort() is in-place,
but sorted() returns new copy

```
>>> a = [5, 2, 3, 1, 4]
>>> sorted(a)
[1, 2, 3, 4, 5]
>>> a
[5, 2, 3, 1, 4]
```

Built-in and custom cmp

```
>>> a = [5, 2, 3, 1, 4]
>>> def mycmp(a, b):
        return b-a

>>> sorted(a, mycmp)
[5, 4, 3, 2, 1]

>>> sorted(a, lambda x,y: y-x)
[5, 4, 3, 2, 1]
```

demo

```
>>> a = list(zip([1,2,3], [6,4,5]))
>>> a.sort(lambda (_,y1), (__, y2): y1-y2)
>>> a
[(2, 4), (3, 5), (1, 6)]
>>> a.sort(lambda (_,y1), (_, y2): y1-y2)
SyntaxError: duplicate argument '_' in function definition
```

Sorting by Keys or Key mappings

```
>>> a = "This is a test string from Andrew".split()
>>> a.sort(key=str.lower)
>>> a
['a', 'Andrew', 'from', 'is', 'string', 'test', 'This']

>>> import operator
>>> L = [('c', 2), ('d', 1), ('a', 4), ('b', 3), ('b', 1)]
```

```
>>> L.sort(key=operator.itemgetter(1))
>>> L
[('d', 1), ('b', 1), ('c', 2), ('b', 3), ('a', 4)]

>>> sorted(L, key=operator.itemgetter(1, 0))
[('b', 1), ('d', 1), ('c', 2), ('b', 3), ('a', 4)]

>>> operator.itemgetter(1,0)((1, 2, 3))
(2, 1)
```

demo

sort by two keys

lambda for key mappings

- you can use lambda for both custom cmp and key map

```
>>> a = "This is a test string from Andrew".split()
>>> a.sort(lambda x, y: cmp(x.lower(), y.lower()))
>>> a
['a', 'Andrew', 'from', 'is', 'string', 'test', 'This']

>>> a.sort(key=lambda x: x.lower())
```

```
>>> L = [('c', 2), ('d', 1), ('a', 4), ('b', 3), ('b', 1)]

>>> L.sort(key=lambda (_, y): y)
>>> L
[('d', 1), ('b', 1), ('c', 2), ('b', 3), ('a', 4)]

>>> sorted(L, key=lambda (x, y): (y, x))
[('b', 1), ('d', 1), ('c', 2), ('b', 3), ('a', 4)]
```

Decorate-Sort-Undecorate

```
>>> words = "This is a test string from Andrew.".split()

>>> deco = [ (word.lower(), i, word) for i, word in \
... enumerate(words) ]

>>> deco.sort()

>>> new_words = [ word for _, _, word in deco ]
```

demo

```
>>> print(new_words)
['a', 'Andrew.', 'from', 'is', 'string', 'test', 'This']
```

- Most General
- Faster than custom cmp (or custom key map) -- why?
- stable sort (by supplying index)

Sorting: Summary

- 3 ways: key mapping, custom cmp function, decoration
- decoration is most general, key mapping least general
- decoration is faster than key mapping & cmp function
  - decoration only needs O(n) key mappings
  - other two need O(nlogn) key mappings -- or $O(n^2)$ for insertsort
  - real difference when key mapping is slow
- decoration is stable

Memoized Recursion v1

- Fibonacci revisited

```
def fib(n):
    a, b = 1, 1
    for _ in range(n-1):
        a, b = b, a+b
    return b
```

```
def fib(n):
    if n <= 1:
        return n
    else:
        return fib (n-1) + fib (n-2)
```

```
fibs = {0:1, 1:1}
def fib(n):
    if n in fibs:
        return fibs[n]
    fibs[n] = fib(n-1) + fib(n-2)
    return fibs[n]
```

can we get rid of the global variable?

Memoized Recursion v2

- Fibonacci revisited

```
def fib(n):
    a, b = 1, 1
    for _ in range(n-1):
        a, b = b, a+b
    return b
```

```
def fib(n):
    if n <= 1:
        return n
    else:
        return fib (n-1) + fib (n-2)
```

```
def fib(n, fibs={0:1, 1:1}):
    if n not in fibs:
    fibs[n] = fib(n-1, fibs) + fib(n-2, fibs)
    return fibs[n]
```

Memoized Recursion v3

- Fibonacci revisited

```
def fib(n):
    a, b = 1, 1
    for _ in range(n-1):
        a, b = b, a+b
    return b
```

```
>>> fib(3)
1 {1: 1}
0 {0: 1, 1: 1}
2 {0: 1, 1: 1, 2: 2}
3 {0: 1, 1: 1, 2: 2, 3: 3}
3
>>> fib(2)
2
>>> print(fibs)
Error!
```

draw the tree!

```
def fib(n, fibs={0:1, 1:1}):
    if n not in fibs:
    fibs[n] = fib(n-1) + fib(n-2)
#       print(n, fibs)
    return fibs[n]
```

the `fibs` variable has a weird closure!! feature or bug?

most people think it's a bug, but Python inventor argues it's a feature.

Memoized Recursion v4

- Fibonacci revisited

```
def fib(n):
    a, b = 1, 1
    for _ in range(n-1):
        a, b = b, a+b
    return b
```

```
>>> fib(4)
{0: 1, 1: 1, 2: 2}
{0: 1, 1: 1, 2: 2, 3: 3}
{0: 1, 1: 1, 2: 2, 3: 3, 4: 5}
5
>>> fib(3)
{0: 1, 1: 1, 2: 2}
{0: 1, 1: 1, 2: 2, 3: 3}
3
```

```
def fib(n, fibs=None):
    if fibs is None:
        fibs = {0:1, 1:1}
    if n not in fibs:
    fibs[n] = fib(n-1, fibs) + fib(n-2, fibs)
#       print(n, fibs)
    return fibs[n]
```

this is so far the cleanest way to avoid this bug.

Mutable types are not hashable

- mutables: list, dict, set
- immutables: tuple, string, int, float, frozenset, ...
  - only recursively immutable objects are hashable
- your own class objects are hashable (but be careful...)

```
>>> {{1}: 2}
TypeError: unhashable type: 'set'

>>> {{1:2}: 2}
TypeError: unhashable type: 'dict'

>>> {frozenset([1]): 2}
{frozenset([1]): 2}

>>> {frozenset([1, [2]]): 2}
TypeError: unhashable type: 'list'
```