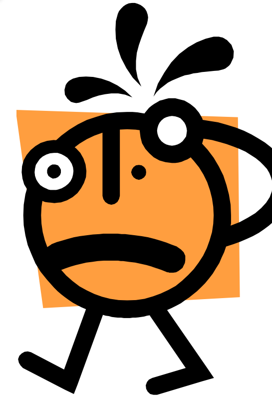
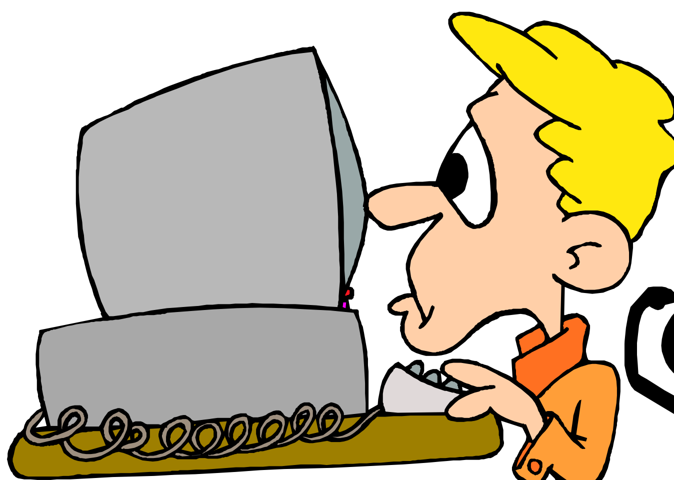
CS 1
Introduction to Computer Programming



Lecture 24: December 5, 2012

Advanced topics, part 2



Last time

- Advanced topics, lecture 1
  - recursion
  - first-class functions
  - **`lambda`** expressions
  - higher-order functions
    - **`map`**, **`filter`**, **`reduce`**

Today

- Advanced topics, lecture 2
  - command-line arguments
  - list comprehensions
  - iterators
  - generators
- Course wrap-up

Admin notes

- This is the last lecture! ☹
  - or maybe ☺?
- The final will be ready by Friday
  - due Friday, December 14th at 9 AM

Admin notes

- There is a course feedback form online
- I'd really appreciate it if you'd fill it out!
- Also, there is the "official" course feedback form (TQFR) which I would also ask you fill out
- Reason for two forms: mine is far more detailed!

Command-line arguments

- Most of the time, we've been running programs in one of two ways:
  1. importing a module directly into WingIDE and running it there
  2. running it from the terminal command line
- However, this is a very limited way of running programs
- Sometimes we need to pass information to the program at the moment we run it

Command-line arguments

- Example: We are writing a program called `capitalize.py` that will
  - take a text file
  - create a new file which has the same contents as the original file, but capitalized
- How do we write this program so that it works from the command line?

Command-line arguments

- Given what we know now, we would probably write it using `raw_input` to get the name of the original file and the name of the file we want to write, *e.g.*

```
% python capitalize.py
Name of input file: infile.txt
Name of output file: outfile.txt
```

- and the program would read from the input file `infile.txt` and write capitalized text to the output file `outfile.txt`

Command-line arguments

- An alternative (and simpler) approach is to make the names of the input and output file into *command-line arguments*:

```
% python capitalize.py infile.txt outfile.txt
```

- and the program will work the same way, without the calls to **`raw_input`**

Command-line arguments

command-line

```
% python capitalize.py infile.txt outfile.txt
```

- This entire line (which runs **`python`** on the program file **`capitalize.py`**) is called a *command-line*
  - *i.e.* a line containing a command
- The command-line is a feature of the terminal's command interpreter, *not* of Python
- However, Python can access the command-line from inside a Python program

Command-line arguments

command

`% python capitalize.py infile.txt outfile.txt`

- The command part can be viewed as just `python` or Python and the program that Python runs (`capitalize.py`)
  - we will consider the command to be the latter (`python capitalize.py`)

Command-line arguments

command-line arguments

```
% python capitalize.py infile.txt outfile.txt
```

- Anything that comes after the command are the *command-line arguments*, *i.e.* the arguments to the command
  - analogous to the arguments to a function, where the command is like a function call given to the Unix terminal
- Here, the command-line arguments are:
  - `infile.txt`
  - `outfile.txt`

Command-line arguments

```
% python capitalize.py infile.txt outfile.txt
```

- Writing programs to use command-line arguments is usually simpler than using `raw_input` if all you need to do is give some initial information to the program
  - here, names of files to work on
- But how do we actually use command-line arguments from inside the program?

Command-line arguments

- Inside our program, we would have:

```
import sys
if len(sys.argv) != 3:
    print >> sys.stderr, \
     'Not enough arguments!'
    sys.exit(1)
infile = open(sys.argv[1], 'r')
outfile = open(sys.argv[2], 'w')
# Then do the rest of the program
```

Command-line arguments

- The **`sys`** module contains functions to help us work with the external "system" that a Python program runs on
- We need to understand:
  - **`sys.argv`** (command-line argument list)
  - **`sys.exit`** (function to exit the program)

`sys.exit`

- `sys.exit` is basically the same as the `quit` function; it exits the program immediately
  - could just as well use `quit` here
- Normally, we give it an integer argument indicating whether or not the program exited successfully
  - `0` means "everything went well"
  - a nonzero value means "an error happened"
- Here, we give it the value `1`, meaning that an error happened

`sys.exit`

- The value we pass as an argument to `sys.exit` is "the return value of the entire program"
- Normally, we don't care about this, but the operating system can use this in various ways

`sys.argv`

- `sys.argv` is where the command-line arguments are stored every time a Python program runs
- It is a list of strings
- Each command-line argument (separated by spaces) is a separate string in the list
- The first item in the list is the name of the program
- The rest are the command-line arguments

sys.argv

- When we run this Python program from the command-line:

```
% python capitalize.py infile.txt outfile.txt
```

- Then `sys.argv` in the program is:

```
['capitalize.py', 'infile.txt', 'outfile.txt']
```

- `sys.argv[0]` is the name of the program (`capitalize.py`, without `python`)
  - normally don't need this
- Rest of `sys.argv` are the command-line arguments, which we do need

`sys.argv`

- Usually, we only need `sys.argv[0]` if something goes wrong
- It's good practice to print a *usage message* informing the user that they called the program incorrectly
  - *e.g.* didn't specify the input or output filenames
- as well as how to call the program correctly
- This code might look like this (next slide)

sys.argv

usage message

```
import sys
usage = 'usage: python %s input_file output_file'
if len(sys.argv) != 3:
    print >> sys.stderr, usage % sys.argv[0]
    sys.exit(1)
infile = open(sys.argv[1], 'r')
outfile = open(sys.argv[2], 'w')
# rest of program...
```

sys.argv

- If an incorrect number of command-line arguments are given, you will see this:

```
% python capitalize.py
usage: python capitalize.py input_file output_file
```

- This tells you how the program is supposed to be used, so you can use it correctly next time

New topic!

List comprehensions

- Python has a very general way of creating lists that have particular properties called *list comprehensions*
- The idea: you declare what kind of values you want your list to contain, and Python makes it for you

List comprehensions

- List comprehensions have three components:
  - The values from which our list elements are built
  - The values we don't want in our list
  - How we combine the good values to create the list elements
- This is easier to show than to describe
  - so let's see some examples!

List comprehensions

- Simple list comprehension:

```
>>> [2 * x for x in range(5)]
[0, 2, 4, 6, 8]
```

- A list comprehension is some Python code (with a particular structure) inside list brackets
- Here, we have only two of the three components:
  - where the values come from (`for x in range(5)`)
  - how to compute the list elements (`2 * x`)

List comprehensions

```
[2 * x for x in range(5)]
```

- The values come from here
- We are looking at values `x` that are taken from the list `range(5)` (*i.e.* `[0, 1, 2, 3, 4]`)
- So the value of `x` is `0`, then `1`, then `2`, then `3`, then `4`

List comprehensions

```
[2 * x for x in range(5)]
```

- The list elements are computed from `x` using the expression `2 * x`
- So the value of `2 * x` is `0`, then `2`, then `4`, then `6`, then `8`
- These values are collected together to give the final list: `[0, 2, 4, 6, 8]`

List comprehensions

- List comprehensions thus provide a very compact way of creating lists with particular properties
- We can also specify which of the values we *don't* want in the list by including an `if` statement inside the list comprehension

List comprehensions

```
>>> [2 * x for x in range(5) if x % 2 == 0]
[0, 4, 8]
```

- This says:
  - take all elements `x` from the list `range(5)`
  - but only `if x % 2 == 0` *i.e.* `x` is even *i.e.* `x` is either `0`, `2`, or `4`
  - and use those `x` values to compute `2 * x`
- So the result is `[0, 4, 8]`

List comprehensions

- Another way to look at list comprehensions:

```
[2 * x for x in range(5) if x % 2 == 0]
```

- means the same thing as:

```
result = []
for x in range(5):
    if x % 2 == 0:
        result.append(2 * x)
```

- where `result` will have the final list value

List comprehensions

- You can have more than one "value generator" in a list comprehension:

```
>>> [(x, y) for x in range(3) \
            for y in [True, False]]
[(0, True), (0, False),
 (1, True), (1, False),
 (2, True), (2, False)]
```

More examples

- Create a list of all the pairs **`(x, y)`** where **`x`** and **`y`** are positive and **`x + y == 5`**

```
>>> [(x, y) for x in range(6) \
            for y in range(6) \
            if x + y == 5]
[(0, 5), (1, 4), (2, 3), (3, 2), (4, 1), (5, 0)]
```

More examples

- Create a list of all numbers between 2 and 100 which are not divisible by 2, 3, 5, or 7:

```
>>> [n for n in range(2, 101) \
        if n % 2 != 0 \
        if n % 3 != 0 \
        if n % 5 != 0 \
        if n % 7 != 0]
[11, 13, 17, 19, 23, 29, 31, 37, 41, 43, 47, 53,
 59, 61, 67, 71, 73, 79, 83, 89, 97]
```

- (all prime numbers between 8 and 100)

`map` and `filter`

- Note that list comprehensions can also be used instead of **`map`** and **`filter`**:

```
>>> map(lambda x: x ** 2, [1, 2, 3, 4, 5])
[1, 4, 9, 16, 25]
>>> [x ** 2 for x in [1, 2, 3, 4, 5]]
[1, 4, 9, 16, 25]
>>> filter(lambda x: x % 2 == 0, [1, 3, 4, 6, 7])
[4, 6]
>>> [x for x in [1, 3, 4, 6, 7] if x % 2 == 0]
[4, 6]
```

List comprehensions

- List comprehensions are very convenient, but not an essential feature of Python
- They don't allow you to do anything you couldn't do before
- They often *do* allow you to create a list with particular values much more concisely than you could have done it before
- Use them as you see fit

Interlude

- A classic clip!

Iterators

- We've seen that a lot of data types can be looped over inside a `for` loop:
  - lists (by list elements)
  - strings (by characters)
  - dictionaries (by keys)
  - files (by lines in the file)
- What if we have our own special data type that we want to loop over?
- What if we want to loop over a standard data type in a non-standard way?

Iterators

- What we need is a way of saying "this is how we can loop over this data type in this particular way"
- In Python, we handle this problem by creating an object called an *iterator*
  - *i.e.* "something that we can loop over in a `for` loop"
- Many data types already have iterators built-in to them, but we can define new ones as well

Iterators

- An iterator is a special kind of Python object that can be used in a `for` loop:

```
for <item> in <iterator>:
    # do something with <item>
```

Iterators

- Any Python object can be an iterator if it contains two methods:
- `__iter__`
  - This returns the object itself
- `next`
  - This returns the "next thing" in the object
  - If there is no "next thing", this raises the `StopIteration` exception
- *Any* object that contains these two methods can be looped over in a `for` loop

`__iter__`

- The `__iter__` method may seem useless, and it is for iterator objects
- However, non-iterator objects (those that do not have a `next` method) can also define `__iter__` to return an iterator object that iterates over the non-iterator object
- Example: a list object has the `__iter__` method but not the `next` method
- Calling the `__iter__` method on the list returns an iterator over the list elements

`__iter__` and `next`

```
>>> lst = [1, 2, 3]
>>> i = lst.__iter__()
>>> i
<listiterator object at 0x100496a90>
>>> i.next()
1
>>> i.next()
2
>>> i.next()
3
>>> i.next()
StopIteration
```

`__iter__` and `next`

- Iterators explain why so many different data structures (lists, strings, dictionaries, files) can work correctly in `for` loops
- When you see this code:

```
for item in object: ...
```

- What Python is really doing is using `object.__iter__()` instead of `object` to get an iterator over the object and calling the `next` method on the iterator to get `item` every time the loop body is executed

Examples of iterators

- Looping over a list starts at the beginning of a list and continues to the end
- What if we want to start at the end of a list and continue back to the beginning?
- We don't want to alter the list, so using the `reverse` method is out
- Let's define an iterator class to do this for us

Examples of iterators

```
class ReverseListIterator:
    def __init__(self, lst):
        if type(lst) is not list:
            raise TypeError('need a list argument')
        self.lst = lst[:]   # copy the list
    def __iter__(self):
        return self
    def next(self):
        if self.lst == []:  # no more items
            raise StopIteration
        return self.lst.pop()
```

Examples of iterators

- The `ReverseListIterator` class stores a copy of a list
- Every time it's asked for a new element (when the `next` method is called) it pops an element off the end of the list using the `pop` method on lists
- If there are no more elements in the list, the `StopIteration` exception is raised
- Let's see how we would use this

Examples of iterators

```
>>> li = ReverseListIterator([1, 2, 3, 4, 5])
>>> for i in li:
...     print i
5
4
3
2
1
```

- We have just extended what the `for` loop can do to handle our new iterator class
  - cool!

Examples of iterators

- In fact, the **`ReverseListIterator`** class is useful enough that Python provides a built-in function called **`reversed`** which creates an iterator just like this:

```
>>> for i in reversed([1, 2, 3, 4, 5]):
...     print i
5
4
3
2
1
```

Examples of iterators

- Another example: iterating over a file character-by-character
- Recall: using a file in a `for` loop iterates over the file line-by-line
  - usually what we want, but not always
- Let's define a file iterator class to allow us to iterate over files by characters

Examples of iterators

```
class FileCharIterator:
    def __init__(self, file):
        self.file = file
        self.current = []
    def __iter__(self):
        return self
    def next(self):
        if self.current == []:
            nextline = self.file.readline()
            if nextline == '':
                raise StopIteration
            self.current = list(nextline)
        return self.current.pop(0) # return first char
```

Examples of iterators

- The `__init__` method stores a file object in the iterator and stores a "current line" field called `current` that is initially the empty list
  - `current` will hold the current line of the file, as a list of characters
- The `__iter__` method just returns the iterator object itself
- The `next` method is where all the action is
  - so let's look at it again

Examples of iterators

```
class FileCharIterator:
    # ... stuff left out ...
    def next(self):
        if self.current == []:  # no more characters
            # Try to get another line from the file.
            nextline = self.file.readline()
            if nextline == '':   # end of file
                raise StopIteration
            # Convert the line to a list of characters
            self.current = list(nextline)
        # Remove (pop) the first character from current
        # and return it.
        return self.current.pop(0)
```

Examples of iterators

- Using the new iterator:

```
f = open('foo.txt', 'r')
fi = FileCharIterator(f)
for char in fi:
    print char
# Prints every character of the file,
# on a separate line
```

Last topic!

Generators

- We take it for granted that when we return from a function, we are done with that call to the function
- But what if it was possible to return from a function "temporarily", so we could "pick up where we left off" later?
- Python has this feature: it's called a `generator`
  - because it "generates" values for us

Generators and `yield`

- *The idea*: instead of using **`return`** to return from a function, use the new keyword **`yield`**
- When you **`yield`** a result, you are saying "here is the result you wanted, but I'm ready to keep going whenever you want more results"
- A generator is basically an iterator which is constructed automatically from a function

Generator example

```
def fib():
    (a, b) = (0, 1)
    while True:
        yield a
        (a, b) = (b, a + b)
```

- This is a function that returns a generator object (because of the `yield` statement)
- The generator will generate all fibonacci numbers (0, 1, 1, 2, 3, 5, 8, 13, ...) in order
  - forever!

Generator example

- Let's see how we can use it:

```
>>> gen = fib()
>>> gen
<generator object at 0x5c6a30>
>>> gen.next()
0
>>> gen.next()
1
>>> gen.next()
1
>>> gen.next()
2
```

Generator example

- Let's print the first ten fibonacci numbers:

```
>>> gen = fib()
>>> for i, e in enumerate(gen):
...     if i >= 10:
...         break
...     print e
0
1
1
2
3
5 ...
```

Generator example 2

- Let's create a generator which will generate all *prime numbers*
- A prime number is an integer >= 2 which is only divisible by itself or 1
- We'll use the generator to print out all primes < 100

Generator example 2

```
def primes():
    prev = []     # previously-seen primes
    i = 2
    while True:   # infinite loop!
        prime = True  # assume i is prime
        for p in prev:
            if i % p == 0:  # i is not a prime
                prime = False
                break
        if prime:
            prev.append(i)
            yield i
        i += 1  # try the next integer
```

Generator example 2

- Using the primes generator to generate all primes below 100:

```
>>> gen = primes()
>>> for p in gen:
...     if p >= 100:
...         break
...     print p
```

Generator example 2

- This prints:

```
2
3
5
7
11
13
17
19
23
29
...
```

Python

- Iterators and generators are two of the coolest features of Python
- Python has many more features than I could cover in this course
- The online documentation is excellent! Get familiar with it!

Python 3.x

- The version of Python we have been using is version `2.7.3`
- The most recent version is version `3.3.0`
- Versions `3.0` and up have quite a few (mostly non-essential) differences from the version we have been using
- Everything you need to know about this is on the Python website: **`www.python.org`**

Wrapping up

Where to go from here

- There are several courses you can take after CS 1
- CS 2 will teach more about algorithms, data structures, and give you practice with larger programming projects and application areas
  - using Java (I think)
- CS 11 will teach you specific languages
  - C, C++, Java, Erlang, Ocaml, Haskell, whatever!
  - taught by Donnie and me

Where to go from here

- CS 4 will be a more abstract/theoretical course focussing on the big ideas of computer programming
- It will use the *Scheme* and *Ocaml* languages and will be significantly harder than CS 1
  - good for hard-core programmer types and/or current or future CS majors
- It will be awesome!
  - Oh yeah, I'm teaching that too ☺

Finally...

- I hope you enjoyed the course!
  - and learned a lot!
- If you've done well,
- if you really like programming,
- if you think you'd like teaching...

I want YOU to be a CS 1 TA!

CS 1 TAs

- If you're interested, email me
- No rush, but no later than Spring term
- Lots of work
  - but good money (~$30/hour currently)
  - and GREAT teaching experience!
- Probably 3-4 open slots at least

And…

- Thanks for letting me teach you!
- One final clip...

[End]

Code summary

```
class ReverseListIterator:
    def __init__(self, lst):
        if type(lst) is not list:
            raise TypeError('need a list argument')
        self.lst = lst[:]   # copy the list
    def __iter__(self):
        return self
    def next(self):
        if self.lst == []:  # no more items
            raise StopIteration
        return self.lst.pop()
```

Code summary

```
class FileCharIterator:
    # ... stuff left out ...
    def next(self):
        if self.current == []:  # no more characters
            # Try to get another line from the file.
            nextline = self.file.readline()
            if nextline == '':   # end of file
                raise StopIteration
            # Convert the line to a list of characters
            self.current = list(nextline)
        # Remove the first character from current and
        # return it.
        return self.current.pop(0)
```

Code summary

```
def fib():
    (a, b) = (0, 1)
    while True:
        yield a
        (a, b) = (b, a + b)
```

Code summary

```
def primes():
    prev = []  # previously-seen primes
    i = 2
    while True:
        prime = True  # assume i is prime
        for p in prev:
            if i % p == 0:  # i is not a prime
                prime = False
                break
        if prime:
            prev.append(i)
            yield i
        i += 1  # try the next integer
```