Regular Expressions

Genome 559: Introduction to Statistical and Computational Genomics

Elhanan Borenstein

A quick review

- Arguments and return values:
  - Returning multiple values from a function:
    `return [sum, prod]`
  - Pass-by-reference vs. pass-by-value
  - Default Arguments
    `def printMulti(text, n=3):`
  - Keyword Arguments
    `runBlast("my_f.txt", matrix="PAM40")`
- **Modules:**
  - A file containing a set of related functions
  - Easy to create and use your own modules
  - First import it: `import utils …`
  - Then use dot notation: `utils.makeDict()`

utils.py

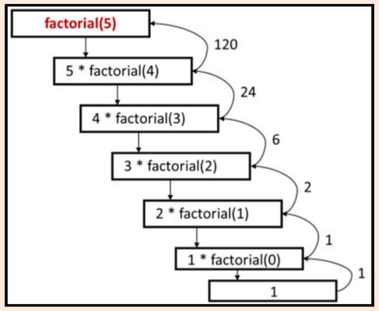
```
# This function makes a dictionary
def makeDict(fileName):
   myFile = open(fileName, "r")
   myDict = {}
   for line in myFile:
      fields = line.strip().split("\t")
      myDict[fields[0]] = float(fields[1])
   myFile.close()
   return myDict

# This function reads a 2D matrix
def makeMatrix(fileName):
    < ... >
```

my_prog.py

```
import utils
import sys

Dict1 = utils.makeDict(sys.argv[1])
Dict2 = utils.makeDict(sys.argv[2])

Mtrx = utils.makeMatrix("blsm.txt")


…
```

A quick review – cont’

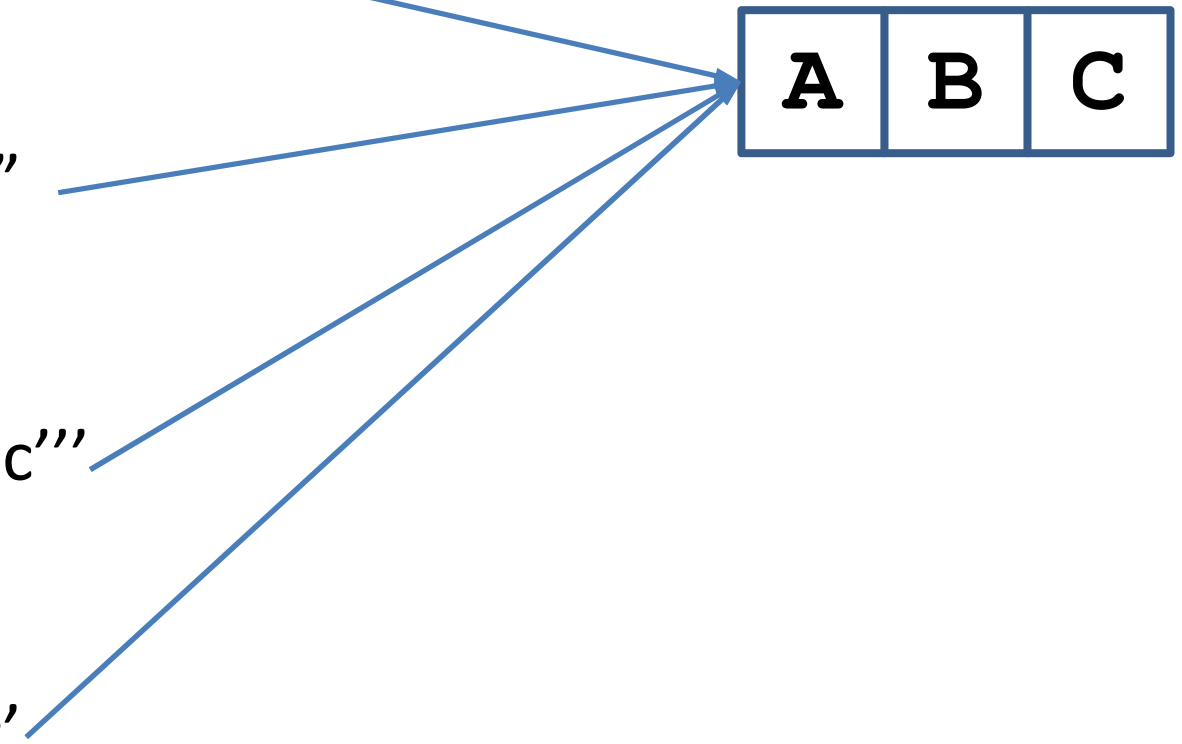
- **Recursion:**
  - A function that calls itself
  - Divide and conquer algorithms



- Every recursion must have two key features:
  1. There are one or more ***base cases*** for which no recursion is applied.
  2. All recursion chains eventually end up at one of the base cases.
- Examples:
  - Factorial, string reversal
  - **Binary search**
  - Traversing trees
  - **Merge sort**
- Recursion vs. iteration

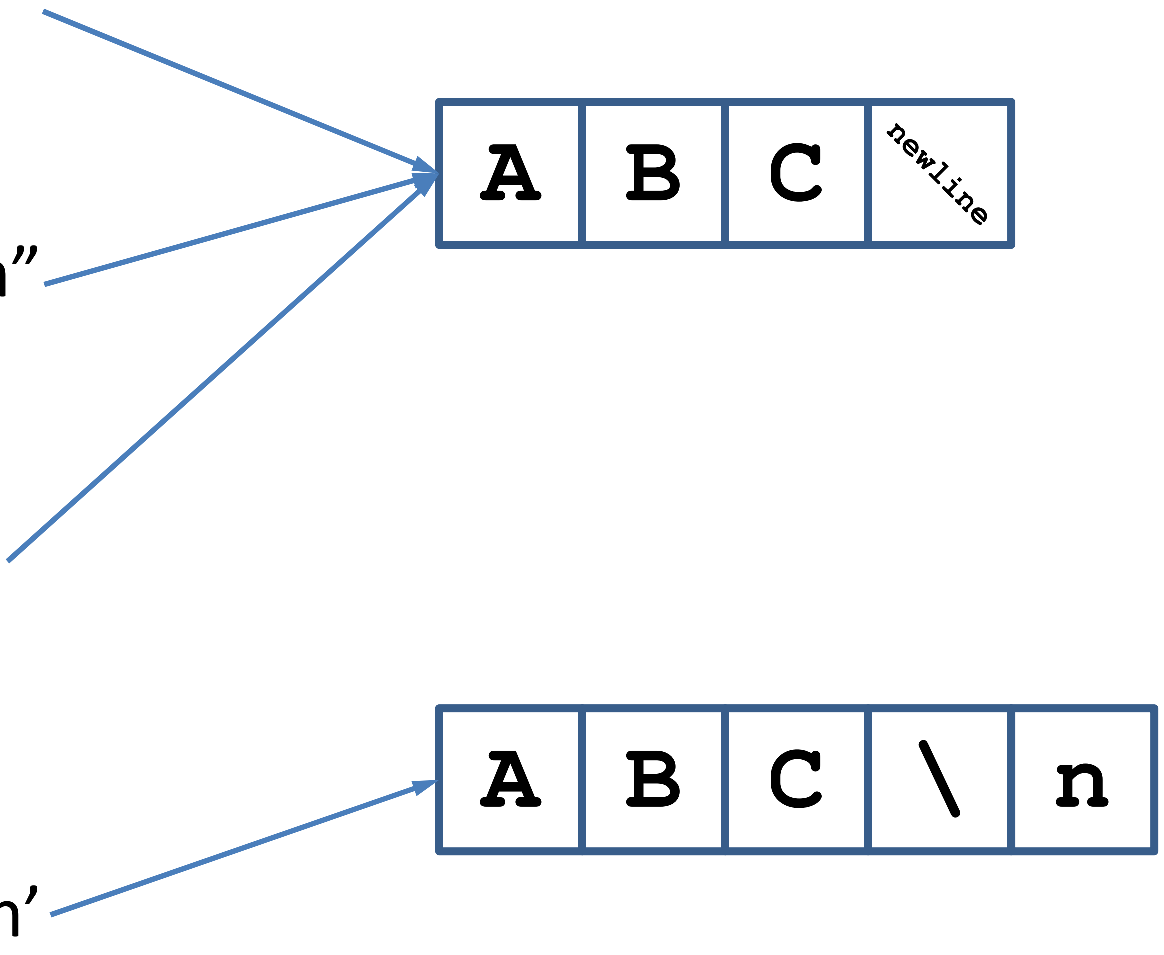
Strings

- ‘abc’
- “abc”
- “’’ abc’’’
- r’abc’



Newlines are a bit more complicated

- ‘abc\n’
- “abc\n”
- “’abc
  ’’’
- r’abc\n’



Why so many?

- **‘** vs “ lets you put the other kind inside a string. Very Useful.
- **‘’’** lets you run across multiple lines.
- All 3 let you include and show *invisible* characters (using \n, \t, etc.)
- **r’…’** (*raw strings*) do not support invisible character, but avoid problems with backslash. Will become useful very soon.

```
open(’C:\new\text.dat’) vs.
open(’C:\\new\\text.dat’) vs.
open(r’C:\new\text.dat’)
```

String operations

- As you recall, the string data type supports a verity of operations:

```
>>> my_str = 'tea for too`
>>> print my_str.replace('too','two')
'tea for two'

>>> print my_str.upper()
TEA FOR TOO

>>> my_str.split(` `)
[`tea’, `for’, `too’]

>>> print my_str.find(“o")
5
>>> print my_str.count(“o")
3
```

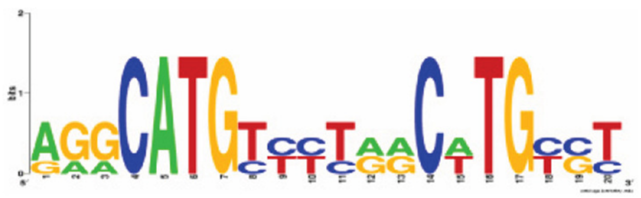
But …

- What if we want to do more complex things?
  - Get rid of all punctuation marks
  - Find all dates in a long text and convert them to a specific format
  - Delete duplicated words
  - Find **all** email addresses in a long text
  - Find everything that “looks” like a gene name in some output file
  - Split a string whenever a certain word (rather than a certain character) occurs
  - Find DNA motifs in a Fasta file

Well …

- We can always write a program that does that …

```
# assume we have a genome sequence in string variable myDNA
for index in range(0,len(myDNA)-20) :
    if (myDNA[index] == "A" or myDNA[index] == "G") and
       (myDNA[index+1] == "A" or myDNA[index+1] == "G") and
       (myDNA[index+2] == "A" or myDNA[index+2] == "G") and
       (myDNA[index+3] == "C") and
       (myDNA[index+4] == "A") and
       # and on and on!
       …
       (myDNA[index+19] == "C" or myDNA[index+19] == "T") :
            print "Match found at ",index
            break

6
```



Regular expressions

- Regular expressions (a.k.a. RE, regexp, regexes, regex) are a highly specialized **text-matching tool.**
- Regex can be viewed as a tiny programming language embedded in Python and made available through the **re** module.
- They are extremely useful in searching and modifying (long) string
- *http://docs.python.org/library/re.html*

Not only in Python

- REs are very widespread:
  - Unix utility “grep”
  - Perl
  - TextWrangler
  - TextPad
  - Python

- So, … learning the “RE language” would serve you in many different environments as well.

Do you absolutely need regexes?

- No, everything they do, you could do yourself!

- BUT … pattern-matching is:
  - Widely used (especially in bioinf applications)!
  - Tedious to program!
  - Error-prone!

- RE give you a flexible, systematic, compact, and automatic way to do it.
  (In truth, it’s still somewhat error-prone, but in a different way).

Regexe vs. Python

- The regular expression language is relatively small and restricted
  - Not all possible string processing tasks can be done using regular expressions.
  - Some tasks can be done with RE, but the expressions turn out to be **extremely** complicated.
- In these cases, you may be better off writing a Python code to do the processing:
  - Python code may take longer to write
  - It will be slower than an elaborate regular expression
  - But … it will also probably be more understandable.

Let’s get to it:
How do regexes work?

Valentine Day Special!
It’s all about finding a great match

Finding a good match

- **Using this RE tiny language, you can specify <u>patterns</u> that you want to <u>match</u>**

- You can then ask ***match*** questions such as:
  - "Does this string match this pattern?"
  - "Is there a match to this pattern anywhere in this string?"
  - "What are all the matches to this pattern in this string?"

- You can also use REs to **modify** a string
  - **Replace** parts of a string (sub) that match the pattern with something else
  - Break stings into smaller pieces (split) wherever this pattern is matched

A simple example

- Consider the following example:

```
>>> import re
>>> re.findall(r'\bf[a-z]*', 'which foot or hand fell fastest')

['foot', 'fell', 'fastest']
```

This RE means: A word that starts with ‘f’ followed by any number of alphabetical characters

- Note the *re.* prefix – findall is a function in the re module
- findall:
  - Format: `findall(<regexe>, <string>)`
  - Returns a list of all non-overlapping substrings that matches the regexe.
- REs are provided as strings.

Remember:
It’s all about matching

Regular expressions are patterns;
they “match” sequences of characters

Basic RE matching

- Most letters and numbers match themselves
  - For example, the regular expression `test` will match the string **test** exactly
  - Normally case sensitive

```
>>> re.findall(r'test', "Tests are testers' best testimonials")
['test', 'test']
```

- Most punctuation marks have special meanings!
  - Metacharacters: `. ^ $ * + ? { [ ] \ | ( )`
  - needs to be escaped by backslash (e.g., "\\." instead of ".") to get non-special behavior
  - Therefore, "raw" string literals (r'C:\new.txt') are generally recommended for regexes (unless you double your backslashes judiciously)

Sets

- **Square brackets** mean that any of the listed characters will do (matching one of several alternatives)
  - `[abc]` means either ”a” , ”b” , or “c”
- You can also give a range:
  - `[a-d]` means ”a”, ”b”, ”c”, or ”d”
- Negation: caret means ***not***
  - `[^a-d]` means anything but a, b, c or d
  - `[^5]` means anything but 5
- Metacharacters are not active inside sets.
  - `[ak$]` will match “a”, “k”, or “$”. Normally, “$” is a metacharacter. Inside a set it’s stripped of its special nature.

Predefined sets

- `\d` matches any decimal digit (equivalent to `[0-9]`).
- `\D` matches any non-digit character (equivalent to `[^0-9]`).
- `\s` matches any whitespace character (equivalent to `[ \t\n\r\f\v]`).
- `\S` matches any non-whitespace character (equivalent to `[^ \t\n\r\f\v]`).
- `\w` matches any alphanumeric character (equivalent to `[a-zA-Z0-9_]`).
- `\W` matches any non-alphanumeric character (equivalent to the class `[^a-zA-Z0-9_]`.

Note the pairs.
Easy to remember!

Matching boundaries

- `^` matches the beginning of the string
- `$` matches the end of the string

- `\b` matches a word boundary
- `\B` matches position that is not a word boundary

(A word boundary is a position that changes from a word character to a non-word character, or vice versa).

For example, `\bcat` will match **`catalyst`** but not **`location`**

Wildcards

- `.` matches **any** character (except newline)
- If you really mean "." you must use a backslash

- WARNING:
  - backslash is special in Python strings
  - It's special again in RE
  - This means you need too many backslashes
  - Use "raw strings" to make things simpler

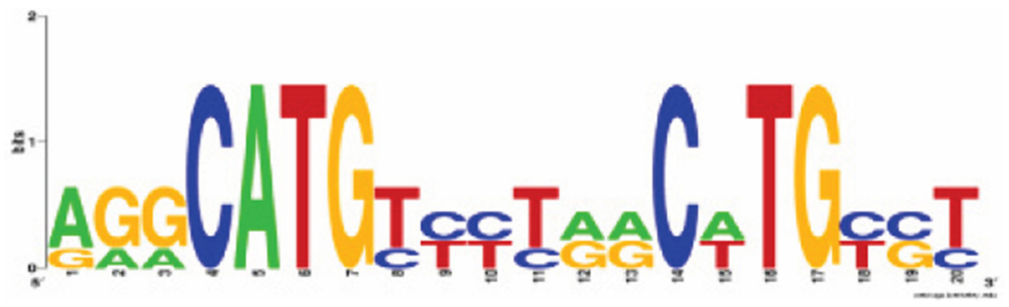
- What does this RE means: `r'\d\.\d'`?

Repetitions

- Allows you to specify that a portion of the RE must/can be repeated a certain number of times.
- ***** : The previous character can repeat 0 or more times
  - `ca*t` matches ”ct”, ”cat”, ”caat”, ”caaat” etc.
- **+** : The previous character can repeat 1 or more times
  - `ca+t` matches ”cat”, ”caat” etc. but not ”ct”
- Braces provide a more detailed way to indicate repeats
  - `A{1,3}` means at least one and no more than three A’s
  - `A{4,4}` means exactly four A’s

A quick example

- Remember this PSSM:



```
re.findall(r'[AG]{3,3}CATG[TC]{4,4}[AG]{2,2}C[AT]TG[CT][CG][TC]', myDNA)
```

More examples

```
>>> re.sub('\d', 'x', 'a_b - 12')
'a_b - xx'
>>> re.sub('\D', 'x', 'a_b - 12')
'xxxxxx12'
>>> re.sub('\s', 'x', 'a_b - 12')
'a_bx-x12'
>>> re.sub('\S', 'x', 'a_b - 12')
'xxx x xx'
>>> re.sub('\w', 'x', 'a_b - 12')
'xxx - xx'
>>> re.sub('\W', 'x', 'a_b - 12')
'a_bxxx12`
>>> re.sub('^', 'x', 'a_b - 12')
'xa_b - 12'
>>> re.sub('$', 'x', 'a_b - 12')
'a_b - 12x'
>>> re.sub('\b', 'x', 'a_b - 12')
'a_b - 12'
>>> re.sub('\\b', 'x', 'a_b - 12')
'xa_bx - x12x'
>>> re.sub(r'\b', 'x', 'a_b - 12')
'xa_bx - x12x'
>>> re.sub('\B', 'x', 'a_b - 12')
'ax_xb x-x 1x2'
```

RE Semantics

- If R, S are regexes:
  - RS matches the concatenation of strings matched by R, S individually
  - R|S matches the union (either R or S)

- Parentheses can be used for grouping
  - `(abc)+` matches ‘abc’, ‘abcabc’, ‘abcabcabc’, etc.
  - `this|that` matches ‘this’ and ‘that’, but not ‘thisthat’.

Conflicts?

- Check this example:

```
>>> import re
>>> mystring = "This contains 2 files, hw3.py and uppercase.py."
>>> all_matches = re.findall(r'.+\.py', mystring)
>>> print all_matches
```

- What do you think all_matchs contains?

```
[' This contains 2 files, hw3.py and uppercase.py']
```

What happened?

Matching is **greedy**

```
>>> import re
>>> mystring = "This contains 2 files, hw3.py and uppercase.py."
>>> all_matches = re.findall(r'.+\.py', mystring)
>>> print all_matches
[' This contains 2 files, hw3.py and uppercase.py']
```

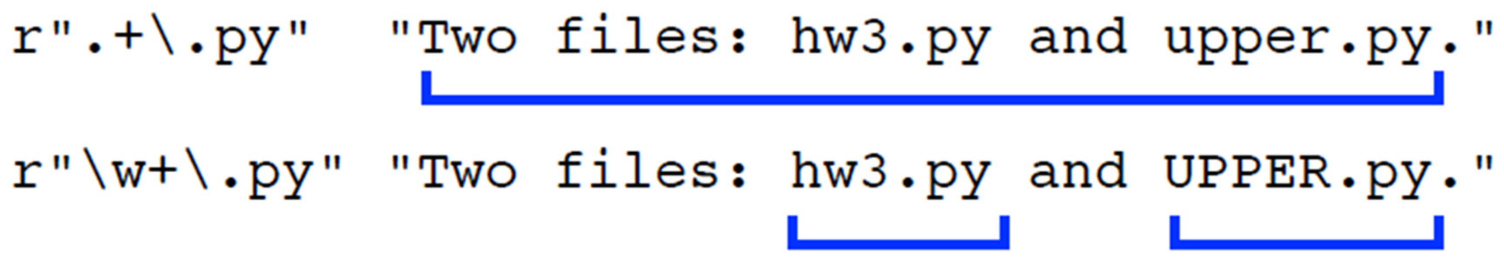
- Our RE matches "*hw3.py*"
- Unfortunately …
  - It also matches: "This contains 2 files, hw3.py"
  - And it even matches: "This contains 2 files, hw3.py and uppercase.py"
- **Python will choose the longest match!**
- Solution:
  - Break my text first into words (not an ideal solution)
  - I could specify that no spaces are allowed in my match

A better version

- This will work:

```
>>> import re
>>> mystring = "This contains 2 files, hw3.py and uppercase.py."
>>> all_matches = re.findall(r’ [^ ]+\.py’, mystring)
>>> print all_matches
```

```
[’hw3.py’,’uppercase.py’]
```



```
r".+\.py"   "Two files: hw3.py and upper.py."
r"\w+\.py" "Two files: hw3.py and UPPER.py."
```

Code like a pro …

TIP OF THE DAY

- Suppose you are not sure:
  - … whether the format you are using for a certain command is the correct one
  - or … whether range(4) returns 0 to 4 or 0 to 3
  - or … whether string has a method “reverse”
  - or … whether you are allowed to break inside a nested loop
  - or … whether your code is correct

What should you do?

Code like a pro …

TIP OF THE DAY

- **JUST RUN IT!!!**
- Don’t be afraid:
  - Running a bugged code will not harm your computer!
  - (it also should not hurt your self-esteem)
  - It doesn’t cost anything
  - It will be faster (and more accurate) than you trying to “think it through”
  - In many cases, the error message or output will be extremely informative

“The freedom to run experiments is the most precious luxury of computational biologists”

Nanahle Nietsnerob

Sample problem #1

- Download the course webpage (e.g., use the “save as” option). Write a program that reads this webpage text and scan for all the email addresses in it.
- An email address usually follows these guidelines:
  - Upper or lower case letters or digits
  - Starting with a letter
  - Followed by a the “@” symbol
  - Followed by a string of alphanumeric characters. No spaces are allowed
  - Followed by a the dot “.” symbol
  - Followed by a domain extension. Assume domain extensions are always 3 alphanumeric characters long (e.g., “com”, “edu”, “net”.

Solution #1

```
import sys
import re

file_name = sys.argv[1]
file = open(file_name,"r")
text = file.read()

addresses = re.findall(r'[a-zA-Z]\w*@\w+\.\w{3,3}', text)
print addresses
```

What's missing

```
[`jht@uw.edu', `elbo@uw.edu']
```

Sample problem #2

1. Download and save warandpeace.txt. Write a program to read it line-by-line. Use re.findall to check whether the current line contains one or more “proper” names ending in “...ski”. If so, print these names:

```
['Bolkonski']
['Bolkonski']
['Bolkonski']
['Bolkonski']
['Volkonski']
['Volkonski']
['Volkonski']
```

2. Now, instead of printing these names for each line, insert them into a dictionary and just print all the “...ski” names that appear in the text at the end of your program (preferably sorted):

```
Aski
Bitski
Bolkonski
Borovitski
Bronnitski
Czartoryski
Golukhovski
Gruzinski
```

Solution #2.1

```
import sys
import re

file_name = sys.argv[1]
file = open(file_name,"r")

names_dict = {} # A dictionary for storing all names
for line in file:
    names = re.findall(r'\w+ski', line)
    if len(names) > 0:
        print names

file.close()
```

Solution #2.2

```
import sys
import re

file_name = sys.argv[1]
file = open(file_name,"r")

names_dict = {} # A dictionary for storing all names
for line in file:
    names = re.findall(r'\w+ski', line)
    for name in names:
        names_dict[name] = 1

file.close()

name_list = names_dict.keys()
name_list.sort()

for name in name_list:
    print name
```

Challenge problem

- "Translate" War and Peace to Pig Latin.
- The rules of translations are as follows:
  - If a word starts with a consonant: move it to the end and append "ay"
  - Else, for words that starts with a vowel, keep as is, but add "zay" at the end
  - Examples:
    - beast → eastbay
    - dough → oughday
    - happy → appyhay
    - another→ anotherzay
    - if→ ifzay