Regular Expressions

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(based on original notes by Ewan Klein)

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Overview

Goals:

- a basic idea of the formal background for REs
- an ability to write small Python programs that do useful things with REs

Motivation

Task: To search for strings using (partially specified) patterns

Why:

- validate data fields (dates, email addresses, URLs)
- filter text (spam, disallowed web sites)
- identify particular strings in a text (token boundaries for tokenization)
- convert the output of one processing component into the format required for a second component (`rabbit_NN` → `<word pos=''NN''>rabbit</word>`)

The Basic Idea

- Regular expressions form a language for expressing patterns.
- The language can be stated as a formal algebra.
- Recognizers for RE can be efficiently implemented.
- 'Regular expression' also a term for a pattern that is constructed using the language.
- Every pattern specifies a set of strings.
- Text string: a sequence of letters, numerals, spaces, tabs, punctuation, ...

Initital Examples

	Pattern	Matches
concatenation	**abc**	abc
disjunction	**a** | **b**	a, b
	(**a** | **bb**) **d**	ad, bbd
closure	**a***	ϵ, a, aa, aaa, aaaa, ...
	c(**a** | **bb**)*	c, ca, cbb, cabb, caa, cbbbb, ...

Two Types of RE

Literals Every normal text character is an RE, and denotes itself.

Metacharacters Special characters which allow you to specify various sets of strings.

Example—Kleene star (*)

- **a** denotes *a*
- **a*** denotes ϵ (empty string), *a*, *aa*, *aaa*, . . .

Preliminaries: Operations on Sets of Strings

Let Σ be a finite set of symbols and let Σ^* be the set of all strings (including the empty string) over Σ. Suppose L, L_1, L_2 are subsets of Σ^*.

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- The *Kleene closure* of L, denoted L^*, is the set of strings constructed by concatenating any number of strings from L. L^* contains ϵ, the empty string.
- The *positive closure* of L, denoted L^+, is the same as L^* but without ϵ.

Examples

Let $L_1 = \{a, b\}$ and $L_2 = \{c\}$. Then

- $L_1 \cup L_2 = \{a, b, c\}$
- $L_1 L_2 = \{ac, bc\}$
- $\{a, b\}^* = \{\epsilon, a, b, aa, bb, ab, ba, \ldots\}$
- $\{a, b\}^+ = \{a, b, aa, bb, ab, ba, \ldots\}$

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Formal Definition of Regular Expressions

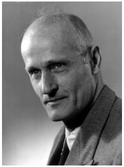
Regular expressions over a finite alphabet Σ:

1. ϵ is a regular expression and denotes the set $\{\epsilon\}$.
2. For each *a* in Σ, a is a regular expression and denotes the set $\{\mathbf{a}\}$.
3. If *r* and *s* are regular expressions denoting the sets *R* and *S* respectively, then
   - $(r \mid s)$ is a regular expression denoting $R \cup S$.
   - (rs) is a regular expression denoting RS.
   - (r^*) is a regular expression denoting R^*.

Recognizers

- A recognizer for a language is a program that takes as input a string x and answers "yes" if x is a sentence of the language and "no" otherwise.
- We can think of this program as a machine which only emits two possible responses to its input.

Finite State Automata



- A Finite State Automaton (FSA) is an abstract finite machine.
- Regular expressions can be viewed as a way to describe a Finite State Automaton (FSA)
- Kleene's theorem (1956): FSA and RE describe the same languages:
  - Any regular expression can be implemented as an FSA.
  - Any FSA can be described by a regular expression.
- Regular languages are those that can be recognized by FSAs (or characterized by a regular expression).

Metacharacters

NB. Different sets of metacharacters and notations used by different 'host languages' (e.g., Unix grep, GNU emacs, Perl, Java, Python, etc.). Cf. Jurafsky & Martin, Appendix A)

Disjunction: |

Wild card: .

Optionality: ?

Quantification: * and +

Choice: **[Mm] [0123456789]**

Ranges: **[a-z] [0-9]**

Negation: **[^Mm]** (only when '^' occurs immediately after '[')

Special Backslash Sequences

- Standard escape sequences
  `\t`: tab
  `\n`: newline
- Abbreviatory forms

`\d`: digit (i.e., numeral)	`\D`: non-digit
`\s`: 'whitespace' ([`\t\n`])	`\S`: non-whitespace
`\w`: 'alphanumeric' ([a-zA-Z0-9])	`\W`: non-alphanumeric

- `\` is a general escape character; e.g., `\.` is not a wildcard, but matches a period, `.`
- If you want to use `\` in a string, it has to be escaped: `\\`

Anchors

(Also: zero-width characters)

- Anchors don't match strings in the text, instead
- they match positions in the text.

  `^`: matches beginning of line (or text)

  `$`: matches end of line (or text)

  `\b`: matches word boundary (i.e., a location with `\w` on one side but not the other)

Wildcard

```
>>> from nltk_lite.utilities import re_show
>>> s = '''BP has agreed to sell
... it's petrochemicals unit for $5.1bn.'''
>>> re_show('...', s)
{BP }{has}{ ag}{ree}{d t}{o s}{ell}
{it'}{s p}{etr}{och}{emi}{cal}{s u}{nit}{ fo}{r $}{5.1}{bn.
```

Wildcard

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>>> re_show('...', s)
{BP }{has}{ ag}{ree}{d t}{o s}{ell}
{it'}{s p}{etr}{och}{emi}{cal}{s u}{nit}{ fo}{r $}{5.1}{bn.

>>> re_show('.a..', s)
BP {has }agreed to sell
it's petrochemi{cals} unit for $5.1bn.
```

Wildcards with Quantifiers

```
>>> re_show('s.*l', s)
BP ha{s agreed to sell}
it'{s petrochemical}s unit for $5.1bn.
```

Wildcards with Quantifiers

```
>>> re_show('s.*l', s)
BP ha{s agreed to sell}
it'{s petrochemical}s unit for $5.1bn.

>>> re_show('B.*P', s)
{BP} has agreed to sell
it's petrochemicals unit for $5.1bn.
```

Wildcards with Quantifiers

```
>>> re_show('s.*l', s)
BP ha{s agreed to sell}
it'{s petrochemical}s unit for $5.1bn.

>>> re_show('B.*P', s)
{BP} has agreed to sell
it's petrochemicals unit for $5.1bn.

>>> re_show('B.+P', s)
BP has agreed to sell
it's petrochemicals unit for $5.1bn.
```

Disjunction

```
>>> re_show('has|it', s)
BP {has} agreed to sell
{it}'s petrochemicals un{it} for $5.1bn.
```

Disjunction

```
>>> re_show('has|it', s)
BP {has} agreed to sell
{it}'s petrochemicals un{it} for $5.1bn.

>>> re_show('has | it', s)
BP {has }agreed to sell
it's petrochemicals unit for $5.1bn.
```

Disjunction

```
>>> re_show('has|it', s)
BP {has} agreed to sell
{it}'s petrochemicals un{it} for $5.1bn.

>>> re_show('has | it', s)
BP {has }agreed to sell
it's petrochemicals unit for $5.1bn.

>>> re_show('(e|l)+', s)
BP has agr{ee}d to s{ell}
it's p{e}troch{e}mica{l}s unit for $5.1bn.
```

Zero Width Characters

```
>>> re_show('l', s)
BP has agreed to se{l}{l}
it's petrochemica{l}s unit for $5.1bn.
```

Zero Width Characters

```
>>> re_show('l', s)
BP has agreed to se{l}{l}
it's petrochemica{l}s unit for $5.1bn.

>>> re_show('l$', s)
BP has agreed to sel{l}
it's petrochemicals unit for $5.1bn.
```

Zero Width Characters

```
>>> re_show('l', s)
BP has agreed to se{l}{l}
it's petrochemica{l}s unit for $5.1bn.

>>> re_show('l$', s)
BP has agreed to sel{l}
it's petrochemicals unit for $5.1bn.

>>> re_show('i', s)
BP has agreed to sell
{i}t's petrochem{i}cals un{i}t for $5.1bn.
```

Zero Width Characters

```
>>> re_show('l', s)
BP has agreed to se{l}{l}
it's petrochemica{l}s unit for $5.1bn.

>>> re_show('l$', s)
BP has agreed to sel{l}
it's petrochemicals unit for $5.1bn.

>>> re_show('i', s)
BP has agreed to sell
{i}t's petrochem{i}cals un{i}t for $5.1bn.

>>> re_show('^i', s)
BP has agreed to sell
{i}t's petrochemicals unit for $5.1bn.
```

Escaping Special Characters

```
>>> re_show('.', s)
{B}{P}{ }{h}{a}{s}{ }{a}{g}{r}{e}{e}{d}...
```

Escaping Special Characters

```
>>> re_show('.', s)
{B}{P}{ }{h}{a}{s}{ }{a}{g}{r}{e}{e}{d}...

>>> re_show('\.', s)
BP has agreed to sell
it's petrochemicals unit for $5{.}1bn{.}
```

Escaping Special Characters

```
>>> re_show('.', s)
{B}{P}{ }{h}{a}{s}{ }{a}{g}{r}{e}{e}{d}...

>>> re_show('\.', s)
BP has agreed to sell
it's petrochemicals unit for $5{.}1bn{.}

>>> re_show('$', s)
BP has agreed to sell{}
it's petrochemicals unit for $5.1bn.{}
```

Escaping Special Characters

```
>>> re_show('.', s)
{B}{P}{ }{h}{a}{s}{ }{a}{g}{r}{e}{e}{d}...

>>> re_show('\.', s)
BP has agreed to sell
it's petrochemicals unit for $5{.}1bn{.}

>>> re_show('$', s)
BP has agreed to sell{}
it's petrochemicals unit for $5.1bn.{}

>>> re_show('\$', s)
BP has agreed to sell
it's petrochemicals unit for {$}5.1bn.
```

Metacharacters and Negated Ranges

```
>>> re_show('\w',s)
{B}{P} {h}{a}{s} {a}{g}{r}{e}{e}{d} ...
```

Metacharacters and Negated Ranges

```
>>> re_show('\w',s)
{B}{P} {h}{a}{s} {a}{g}{r}{e}{e}{d} ...

>>> re_show('\d',s)
BP has agreed to sell
it's petrochemicals unit for ${5}.{1}bn.
```

Metacharacters and Negated Ranges

```
>>> re_show('\w',s)
{B}{P} {h}{a}{s} {a}{g}{r}{e}{e}{d} ...

>>> re_show('\d',s)
BP has agreed to sell
it's petrochemicals unit for ${5}.{1}bn.

>>> re_show('[^a-z\s]',s)
{B}{P} has agreed to sell
it{'}s petrochemicals unit for {$}{5}{.}{1}bn{.}
```

Metacharacters and Negated Ranges

```
>>> re_show('\w',s)
{B}{P} {h}{a}{s} {a}{g}{r}{e}{e}{d} ...

>>> re_show('\d',s)
BP has agreed to sell
it's petrochemicals unit for ${5}.{1}bn.

>>> re_show('[^a-z\s]',s)
{B}{P} has agreed to sell
it{'}s petrochemicals unit for {$}{5}{.}{1}bn{.}

>>> re_show('[^\w]',s)
BP{ }has{ }agreed{ }to{ }sell{
}it{'}s{ }petrochemicals{ }unit{ }for{ }{$}5{.}1bn{.}
```

Using REs in Python, 1

- Usually best to compile the RE into a PatternObject; more efficient, and it can be re-used.

```
>>> import re
>>> str = 'do you say hello or hullo?'
>>> helloRE = re.compile('h[eu]llo')
```

- The resulting PatternObject has a number of methods:

findall(s): returns a list of all matches of pattern in string s

search(s): searches for leftmost occurrence of pattern in string s

match(s): tries to match pattern at the beginning of string s

Using REs in Python, 2

- The PatternObject method findall returns a list:

```
>>> helloRE.findall(str)
['hello', 'hullo']
```

Using REs in Python, 2

- The PatternObject method `findall` returns a list:

```
>>> helloRE.findall(str)
['hello', 'hullo']
```

- The PatternObject method `search` (and `match`) returns a MatchObject or None.
- A MatchObject has a variety of methods, but is not a string.

```
>>> m = helloRE.search(str)
>>> m
<_sre.SRE_Match object at 0x47b138>
>>> m.group() # return matched substring (sort of!)
'hello'
>>> m.end() # index of end of target
16
```

Groups

- Groups in regular expressions are captured using parentheses.

```
>>> import re
>>> str = 'do you say hello or hullo?'
>>> reGRP = re.compile('(d.)(.*)(e..)')
>>> m = reGRP.search(str)
>>> m
<_sre.SRE_Match object at 0x64390>
>>> m.groups()
('do', ' you say h', 'ell')
```

Named Groups

- Name groups captured using (?P<name>):

```
FROM = re.compile("""
     ^From:              # Anchor to start of line
     \s*                 # maybe some spaces
     (?P<user>\w+)       # 'user': group of word characters
     @
     (?P<domain>         # the 'domain':
     \S+)                # some non-space characters
     \s                  # finally, a space character
     """,re.VERBOSE)
```

Named Groups (cont.)

```
from nltk_lite.corpus import twenty_newsgroups

for item in twenty_newsgroups.items('misc.forsale'):
    text = twenty_newsgroups.read(item)
    m = FROM.search(text)
    if m:
      print '%s is at %s' % \
      (m.group('user'), m.group('domain'))
```

```
kedz is at bigwpi.WPI.EDU
myoakam is at cis.ohio-state.edu
gt1706a is at prism.gatech.EDU
jvinson is at xsoft.xerox.com
hungjenc is at usc.edu
thouchin is at cs.umr.edu
kssimon is at silver.ucs.indiana.edu
```

Tokenization with Regular Expressions (1)

- The method `tokenize.regexp()` takes a string and a regular expression, and returns the list of substrings that match the RE

```
>>> from nltk_lite import tokenize
>>> s = "Hello.   Isn't this fun?"
>>> pat= r'\w+|[^\w\s]+'
>>> list(tokenize.regexp(s, pat))
['Hello', '.', 'Isn', "'", 't', 'this', 'fun', '?']
```

- This is a simple tokenizer that may break up things we want to keep as a single token:

```
>>> t = "That poster from the U.S.A. costs $22.50."
>>> list(tokenize.regexp(t, pat))
['That', 'poster', 'from', 'the', 'U', '.', 'S', '.',
'A', '.', 'costs', '$', '22', '.', '50', '.']
```

Tokenization with Regular Expressions (2)

- Add further components to the RE used in the tokenizer:

```
>>> import re
>>> pat2 = re.compile(r'''
...      \$?\d+(\.\d+)? # currency amounts (eg $22.50)
...    | ([A-Z]\.)+     # abbreviations (eg U.S.A.)
...    | \w+            # sequences of 'word' characters
...    | [^\w\s]+       # punctuation sequences
... ''', re.VERBOSE)
>>> list(tokenize.regexp(t, pat2))
['That', 'poster', 'from', 'the', 'U.S.A.', 'costs',
'$22.50', '.']
```

Reading

- Jurafsky & Martin, Chap 2
- NLTK Lite Tutorial: Regular Expressions available from `http://nltk.sourceforge.net/lite/doc/en/regexps.html`