Language Technology
http://cs.lth.se/edan20/
Chapter 2: Corpus Processing Tools

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Corpora

A corpus is a collection of texts (written or spoken) or speech
Corpora are balanced from different sources: news, novels, etc.

	English	French	German
Most frequent words in a collection of contemporary running texts	*the*	*de*	*der*
	of	*le* (article)	*die*
	to	*la* (article)	*und*
	in	*et*	*in*
	and	*les*	*des*
Most frequent words in Genesis	*and*	*et*	*und*
	the	*de*	*die*
	of	*la*	*der*
	his	*à*	*da*
	he	*il*	*er*

Characteristics of Current Corpora

Big: The Bank of English (Collins and U Birmingham) has more than 500 million words

Available in many languages

Easy to collect: The web is the largest corpus ever built and within the reach of a mouse click

Parallel: same text in two languages: English/French (Canadian Hansards), European parliament (23 languages)

Annotated with part-of-speech or manually parsed (treebanks):

- Characteristics/`N` of/`PREP` Current/`ADJ` Corpora/`N`
- (`NP` (`NP` Characteristics) (`PP` of (`NP` Current Corpora)))

Lexicography

Writing dictionaries

Dictionaries for language learners should be build on real usage

- *They're just trying to score* **brownie points** *with politicians*
- *The boss is pleased – that's another* **brownie point**

Bank of English: *brownie point* (6 occs) *brownie points* (76 occs)

Extensive use of corpora to:

- Find **concordances** and cite real examples
- Extract **collocations** and describe frequent pairs of words

Concordances

A word and its context:

Language	Concordances
English	`s beginning of miracles did Je`
	`n they saw the miracles which`
	`n can do these miracles that t`
	`ain the second miracle that Je`
	`e they saw his miracles which`
French	`le premier des miracles que fi`
	`i dirent: Quel miracle nous mo`
	`om, voyant les miracles qu'il`
	`peut faire ces miracles que tu`
	`s ne voyez des miracles et des`

Collocations

Word preferences: Words that occur together

	English	**French**	**German**
You say	*Strong tea*	*Thé fort*	*Schmales Gesicht*
	Powerful computer	*Ordinateur puissant*	*Enge Kleidung*
You don't say	*Strong computer*	*Thé puissant*	*Schmale Kleidung*
	Powerful tea	*Ordinateur fort*	*Enges Gesicht*

Word Preferences

Strong w			Powerful w		
strong w	*powerful w*	*w*	*strong w*	*powerful w*	*w*
161	0	showing	1	32	than
175	2	support	1	32	figure
106	0	defense	3	31	minority
...					

Corpora as Knowledge Sources

Traditional use:

- Describe usage more accurately
- Assess tools: part-of-speech taggers, parsers.
- Learn statistical/machine-learning models for speech recognition, taggers, parsers
- Derive automatically patterns from annotated or unannotated corpora

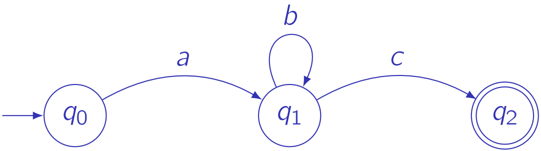
Now:

- Semantic processing
- Information and knowledge extraction
- Question answering from textual sources

Finite-State Automata

A flexible to tool to search and process text

A FSA accepts and generates strings, here *ac*, *abc*, *abbc*, *abbbc*, *abbbbbbbbbbbbc*, etc.



FSA

Mathematically defined by

- Q a finite number of states;
- Σ a finite set of symbols or characters: the input alphabet;
- q_0 a start state,
- F a set of final states $F \subseteq Q$
- δ a transition function $Q \times \Sigma \rightarrow Q$ where $\delta(q, i)$ returns the state where the automaton moves when it is in state q and consumes the input symbol i.

FSA in Prolog

```
% The start state         % The final states
start(q0).                 final(q2).

transition(q0, a, q1).
transition(q1, b, q1).
transition(q1, c, q2).

accept(Symbols) :-
  start(StartState),
  accept(Symbols, StartState).

accept([], State) :-
  final(State).
accept([Symbol | Symbols], State) :-
  transition(State, Symbol, NextState),
  accept(Symbols, NextState).
```

FSA with OpenFst

OpenFst (`http://openfst.org`) is a comprehensive library to build and process transducers.
OpenFst represents automata in a tabular format
The first transition is represented by the line:

```
0 1 a
```

and the whole automaton by (`fsa1.fst`):

```
0 1 a
1 1 b
1 2 c
2
```

FSA with OpenFst (II)

OpenFst only accepts numbers and we need to provide it with a conversion table, where we encode the symbols as integers (`symbols.txt`):

```
<epsilon> 0
a 1
b 2
c 3
```

OpenFst compiles the text files into a binary format (`fsa1.bin`):

```
$ fstcompile --isymbols=symbols.txt --osymbols=symbols.txt \
  --acceptor fsa1.fst fsa1.bin
```

FSA with OpenFst (III)

Inputs, *abbc* or *abbcb*, are entered as linear chain automata:

The sequence *abbc* in file `input1.fst`

```
0 1 a
1 2 b
2 3 b
3 4 c
4
```

The sequence *abbcb* in `input2.fst`

```
0 1 a
1 2 b
2 3 b
3 4 c
4 5 b
5
```

```
$ fstcompose input1.bin fsa1.bin | fstprint --acceptor \
 --isymbols=symbols.txt
0 1 a
1 2 b
2 3 b
3 4 c
4
```

Regular Expressions

Regexes are equivalent to FSA and generally easier to use

1. Constant regular expressions:

Pattern	String
`regular`	*A section on regular expressions*
`the`	*The book of the life*

2. Metacharacters like $*$, where the automaton above is described by the regex `ab*c`

   `$ grep 'ab*c' myFile1 myFile2`

While `grep` was the first regex tool, most programming languages adopt the Perl syntax

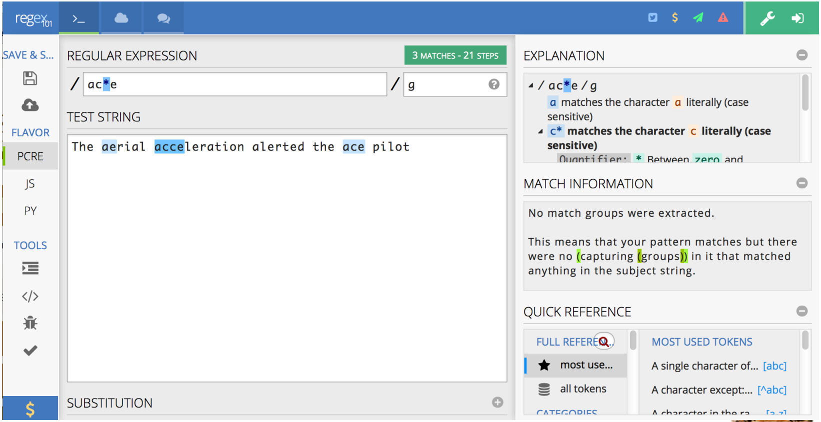
Main Regex Operations

The two main regex operations are match and substitute.
They are often abridged using the Perl regex notations where:

- The `m/regex/` construct denotes a match operation with the regular expression `regex`.
- The `s/regex/replacement/` construct is a substitution operation. This statement matches the first occurrence of `regex` and replaces it by the `replacement` string. If we want to replace all the occurrences of a pattern, we use the g modifier, where g stands for globally: `s/regex/replacement/g`.

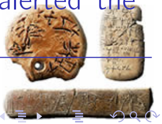
regex101.com

regex101.com: A site to experiment and test regular expressions.



Metacharacters

Chars	Descriptions	Examples
*	Matches any number of occurrences of the previous character – zero or more	ac*e matches strings ae, ace, acce, accce, etc. as in "The aerial acceleration alerted the ace pilot"
?	Matches at most one occurrence of the previous character – zero or one	ac?e matches ae and ace as in "The aerial acceleration alerted the ace pilot"
+	Matches one or more occurrences of the previous character	ac+e matches ace, acce, accce, etc. as in as in "The aerial acceleration alerted the ace pilot"



Metacharacters

Chars	Descriptions	Examples
`{n}`	Matches exactly *n* occurrences of the previous character	`ac{2}e` matches `acce` as in "The aerial acceleration alerted the ace pilot"
`{n,}`	Matches *n* or more occurrences of the previous character	`ac{2,}e` matches `acce`, `accce`, etc.
`{n,m}`	Matches from *n* to *m* occurrences of the previous character	`ac{2,4}e` matches `acce`, `accce`, and `acccce`.

Literal values of metacharacters must be quoted using \

The Dot Metacharacter

The dot `.` is a metacharacter that matches one occurrence of any character except a new line

`a.e` matches the strings *ale* and *ace* in:

> *The aerial acceleration <u>ale</u>rted the <u>ace</u> pilot*

as well as *age*, *ape*, *are*, *ate*, *awe*, *axe*, or *aae*, *aAe*, *abe*, *aBe*, *a1e*, etc.

`.*` matches any string of characters until we encounter a new line.

The Longest Match

The previous slide does not tell about the match strategy.

Consider the string *aabbc* and the regular expression `a+b*`

By default the match engine is greedy: It matches as early and as many characters as possible and the result is `aabb`

Sometimes a problem. Consider the regular expression `<b>.*</b>` and the phrase

> *They match as early and as many characters as they can.*

It is possible to use a lazy strategy with the `*?` metacharacter instead: `<b>.*?</b>` and have the result:

> *They match as early and as many characters as they can.*

Character Classes

`[...]` matches any character contained in the list.

`[^...]` matches any character not contained in the list.

`[abc]` means one occurrence of either `a`, `b`, or `c`

`[^abc]` means one occurrence of any character that is not an `a`, `b`, or `c`,

`[ABCDEFGHIJKLMNOPQRSTUVWXYZ]` one upper-case unaccented letter

`[0123456789]` means one digit.

`[0123456789]+\.[0123456789]+` matches decimal numbers.

`[Cc]omputer [Ss]cience` matches `Computer Science`, `computer Science`, `Computer science`, `computer science`.

Predefined Character Classes

Expr.	Description	Example
`\d`	Any digit. Equivalent to `[0-9]`	`A\dC` matches A0C, A1C, A2C, A3C etc.
`\D`	Any nondigit. Equivalent to `[^0-9]`	
`\w`	Any word character: letter, digit, or underscore. Equivalent to `[a-zA-Z0-9_]`	`1\w2` matches 1a2, 1A2, 1b2, 1B2, etc
`\W`	Any nonword character. Equivalent to `[^\w]`	
`\s`	Any white space character: space, tabulation, new line, form feed, etc.	
`\S`	Any nonwhite space character. Equivalent to `[^\s]`	

Nonprintable Symbols or Positions

Char.	Description	Example
`^`	Matches the start of a line	`^ab*c` matches ac, abc, abbc, etc. when they are located at the beginning of a new line
`$`	Matches the end of a line	`ab?c$` matches ac and abc when they are located at the end of a line
`\b`	Matches word boundaries	`\babc` matches `abcd` but not `dabc` `bcd\b` matches `abcd` but not `abcde`
`\n`	Matches a new line	`a\nb` matches a b
`\t`	Matches a tabulation	

```
egrep '^[aeiou]*$' myFile
```

Union and Boolean Operators

Union denoted `|`: `a|b` means either `a` or `b`.

Expression `a|bc` matches the strings `a` and `bc` and `(a|b)c` matches `ac` and `bc`,

Order of precedence:

1. Closure and other repetition operator (highest)
2. Concatenation, line and word boundaries
3. Union (lowest)

`abc*` is the set `ab`, `abc`, `abcc`, `abccc`, etc.

`(abc)*` corresponds to `abc`, `abcabc`, `abcabcabc`, etc.

Python

Match: m/regex/

```
import regex as re

line = 'The aerial acceleration alerted the ace pilot'
match = re.search('ab*c', line)
match       # <regex.Match object; span=(11, 13), match='ac'>
match.group() # ac
```

The `re.search()` function stops at the first match.

Python

Use findall() or finditer() to return all the matches

Match: m/regex/g

```
match_list = re.findall('ab*c', line)   # ['ac', 'ac']
```

Match: m/regex/g

```
match_iter = re.finditer('ab*c', line)
list(match_iter)
        # [<regex.Match object; span=(11, 13), match='ac'>,
        #  <regex.Match object; span=(36, 38), match='ac'>]
```

Match Modifiers

Flags that modifies the match operation. These flags are equivalent to Perl's `m/regex/modifiers`.

- Case insensitive: `i`. The instruction `m/regex/i`. In Python, this corresponds to the flag: `re.I`.
- Multiple lines: `m` (`re.M` in Python). `m/regex/m`.
- Single line: `s` (`re.S` in Python). The `/s` modifier makes a dot in the instruction `m/regex/s` match any character, including new lines.

In Python, the modifiers (called flags) are specified as a sequence separated by vertical bars: |.

Python

Match: m/regex/modifiers

```
text = sys.stdin.read()
match = re.search('^ab*c', text, re.I | re.M) # m/^ab*c/im
if match:
    print('-> ' + match.group())
```

Python

Substitute: s/regex/replacement/g

```
for line in sys.stdin:
    if re.search('ab+c', line):
        print("Old: " + line, end='')
        # Replaces all the occurrences
        line = re.sub('ab+c', 'ABC', line)   # s/ab+c/ABC/g
        print("New: " + line, end='')
```

Substitute: s/regex/replacement/

If we just want to replace the first occurrence, we use this statement instead:

```
        # Replaces the first occurrence
        line = re.sub('ab+c', 'ABC', line, 1) # s/ab+c/ABC/
```

Python

Back references

The instruction `m/(.)\1\1/` matches sequences of three identical characters:

```
line = 'abbbcdeeef'
match = re.search(r'(.)\1\1', line)
match.group(1)                   # 'b'
```

We need to use a raw string and the `r` prefix to encode the regex in `search()`, otherwise `\1` would be interpreted as an octal number

Substitutions

```
s/(.)\1\1/***/g
```

```
re.sub(r'(.)\1\1', '***', 'abbbcdeeef')  # 'a***cd***f'
```

Python

Multiple back references

Python can create as many buffers as we need: \1, \2, \3, etc.
Outside the regular expression, the \<digit> reference is returned by `group(<digit>)`: `match_object.group(1)`, `match_object.group(2)`, `match_object.group(3)`, etc.

Multiple back references

```
m/\$ *([0-9]+)\.?([0-9]*)/

price = "We'll buy it for $72.40"
match = re.search('\$ *([0-9]+)\.?([0-9]*)', price)
match.group()              # '$72.40' The entire match
match.group(1)             # '72' The first group
match.group(2)             # '40' The second group
```

Python

Substitutions

```
s/\$ *([0-9]+)\.?([0-9]*)/\1 dollars and \2 cents/g

price = "We'll buy it for $72.40"
re.sub('\$ *([0-9]+)\.?([0-9]*)',
       r'\1 dollars and \2 cents', price)
   # We'll buy it for 72 dollars and 40 cents
```

Python

Match objects

- `match_object.group()` or `match_object.group(0)` return the entire match;
- `match_object.group(n)` returns the nth parenthetized subgroup.

In addition, the `match_object.groups()` returns a tuple with all the groups and the `match_object.string` instance variable contains the input string.

```
price = "We’ll buy it for $72.40"
match = re.search(’\$ *([0-9]+)\.?([0-9]*)’, price)
match.string                # We’ll buy it for $72.40
match.groups()              # (’72’, ’40’)
```

Python

Match objects

We extract the indices of the matched substrings with the functions:

```
match_object.start([group])
match_object.end([group])

line = """Tell me, O muse, of that ingenious hero
  who travelled far and wide after he had sacked
  the famous town of Troy."""

match = re.search(',.*,', line, re.S)
line[0:match.start()]                 # 'Tell me'
line[match.start():match.end()]    # ', O muse,'
line[match.end():]    # 'of that ingenious hero
         #  who travelled far and wide after he had sacked
         #  the famous town of Troy.'
```

A Regex to Find Concordances

To print concordances, we need to write a regex that matches the pattern as well as a left and right context.
For instance *Nils Holgersson* with a context of 15 characters:

```
.{0,15}Nils Holgersson.{0,15}
```

Ideally, we would pass `pattern` and `width` as parameters:

```
pattern = 'Nils Holgersson'
width = 15
'.{0,width}pattern.{0,width}'
```

format()

`str.format()` provides variable substitutions as in:

```
begin = 'my'
'{} string {}'.format(begin, 'is empty')
                                     # 'my string is empty'
```

`format()` has many options like reordering the arguments through indices:

```
begin = 'my'
'{1} string {0}'.format('is empty', begin)
                                     # 'my string is empty'
```

If the input string contains braces, we escape them by doubling them: `{{` for a literal `{` and `}}` for `}`.

```
('.{{0,{width}}}{pattern}.{{0,{width}}}'
 .format(pattern=pattern, width=width))
```

Concordances in Python

```
[file_name, pattern, width] = sys.argv[1:]
try:
    text = open(file_name).read()
except:
    print('Could not open file', file_name)
    exit(0)

# spaces match tabs and newlines
pattern = re.sub(' ', '\\s+', pattern)
# Replaces newlines with spaces in the text
text = re.sub('\s+', ' ', text)
concordance = ('(.{{0,{width}}}{pattern}.{{0,{width}}})'
               .format(pattern=pattern, width=width))
for match in re.finditer(concordance, text):
    print(match.group(1))
```

Approximate String Matching

A set of edit operations that transforms a source string into a target string: copy, substitution, insertion, deletion, reversal (or transposition).
Edits for *acress* from Kernighan et al. (1990).

Typo	Correction	Source	Target	Position	Operation
acress	actress	–	t	2	Deletion
acress	cress	a	–	0	Insertion
acress	caress	ac	ca	0	Transposition
acress	access	r	c	2	Substitution
acress	across	e	o	3	Substitution
acress	acres	s	–	4	Insertion
acress	acres	s	–	5	Insertion

Building a Spell Checker

Spell checkers use a dictionary and a set of transformations to suggest corrections to misspelled words in a text.
Dictionaries are collected from well-written texts: novels, newspapers, etc.

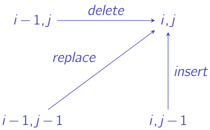
- Given a word in a text not in the dictionary, the spell checker generates all the transformations of this word.
- If we allow only one edit operation on a source string of length n, and if we consider an alphabet of 26 unaccented letters,
  - the deletion will generate n new strings;
  - the insertion, $(n+1) \times 26$ strings;
  - the substitution, $n \times 25$; and
  - the transposition, $n-1$ new strings.
- The spell checker keeps the transformations that are in the dictionary and orders them by frequency to suggest the correct word.

For an implementation, see `http://norvig.com/spell-correct.html`

Building a Spell Checker

```
freq('acres') = 36.
freq('caress') = 3.
freq('cress') = false.
freq('actress') = 7.
freq('access') = 56.
freq('across') = 222.
```

Distance between *ab* and *cb*



Edit distances measure the similarity between strings.

Let us align $\frac{\text{a} \quad \text{b} \quad \text{Source}}{\text{c} \quad \text{b} \quad \text{Destination}}$

b	2		
c	1		
Start	0	1	2
	Start	a	b

Minimum Edit Distance

We compute the minimum edit distance using a matrix where the value at position (i,j) is defined by the recursive formula:

$$edit\_distance(i,j) = \min \begin{pmatrix} edit\_distance(i-1,j) + del\_cost \\ edit\_distance(i-1,j-1) + subst\_cost \\ edit\_distance(i,j-1) + ins\_cost \end{pmatrix}.$$

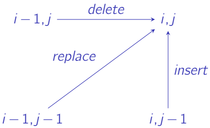
where $edit\_distance(i,0) = i$ and $edit\_distance(0,j) = j$.

Edit Operations

$$\begin{tikzcd} i-1,j \arrow[r, "delete"] & i,j \\ i-1,j-1 \arrow[ur, "replace"] & i,j-1 \arrow[u, "insert"'] \end{tikzcd}$$

Usually, $del\_cost = ins\_cost = 1$
$subst\_cost = 2$ if $source(i) \neq target(j)$
$subst\_cost = 0$ if $source(i) = target(j)$.

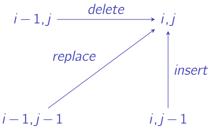
Distance between *ab* and *cb*



Let us align $\frac{\text{a} \quad \text{b} \quad \text{Source}}{\text{c} \quad \text{b} \quad \text{Destination}}$

b	2		
c	1		
Start	0	1	2
	Start	a	b

Distance between *ab* and *cb*

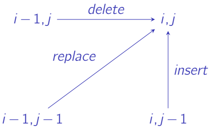


Let us align

a	b	Source
c	b	Destination

b	2		
c	1	2	
Start	0	1	2
	Start	a	b

Distance between *ab* and *cb*

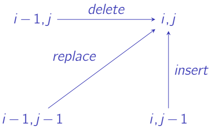


Let us align

a	b	Source
c	b	Destination

b	2	3	
c	1	2	3
Start	0	1	2
	Start	a	b

Distance between *ab* and *cb*



Let us align

a	b	Source
c	b	Destination

b	2	3	**2**
c	1	2	3
Start	0	1	2
	Start	a	b

Distance between *language* and *lineage*

e	7								
g	6								
a	5								
e	4								
n	3								
i	2								
l	1								
Start	0	1	2	3	4	5	6	7	8
	Start	l	a	n	g	u	a	g	e

Distance between *language* and *lineage*

e	7	6	5						
g	6	5	4						
a	5	4	3						
e	4	3	4						
n	3	2	3						
i	2	1	2	3	4	5	6	7	8
l	1	0	1	2	3	4	5	6	7
Start	0	1	2	3	4	5	6	7	8
	Start	l	a	n	g	u	a	g	e

Distance between *language* and *lineage*

e	7	6	5	6	5	6	7	6	**5**
g	6	5	4	5	4	5	6	5	6
a	5	4	3	4	5	6	5	6	7
e	4	3	4	3	4	5	6	7	6
n	3	2	3	2	3	4	5	6	7
i	2	1	2	3	4	5	6	7	8
l	1	0	1	2	3	4	5	6	7
Start	0	1	2	3	4	5	6	7	8
	Start	l	a	n	g	u	a	g	e

Python Code

```
[source, target] = sys.argv[1:]

length_s = len(source) + 1
length_t = len(target) + 1

# Initialize first row and column
table = [None] * length_s

for i in range(length_s):
    table[i] = [None] * length_t
    table[i][0] = i
for j in range(length_t):
    table[0][j] = j
```

Python Code

```
# Fills the table. Start index of rows and columns is 1
for i in range(1, length_s):
    for j in range(1, length_t):
        # Is it a copy or a substitution?
        cost = 0 if source[i - 1] == target[j - 1] else 2
        # Computes the minimum
        minimum = table[i - 1][j - 1] + cost
        if minimum > table[i][j - 1] + 1:
            minimum = table[i][j - 1] + 1
        if minimum > table[i - 1][j] + 1:
            minimum = table[i - 1][j] + 1
        table[i][j] = minimum

print('Minimum distance: ', table[length_s - 1][length_t - 1])
```

Distance between *language* and *lineage*

<table>
<tr><th></th><th>First alignment</th><th>Third alignment</th></tr>
<tr><td>Without epsilon symbols</td><td>l a n g u a g e
| | | | / / /
l i n e a g e</td><td>l a n g u a g e
| | | / / /
l i n e a g e</td></tr>
<tr><td>With epsilon symbols</td><td>l a n g u a g e
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