EDAN20
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

Short term:

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

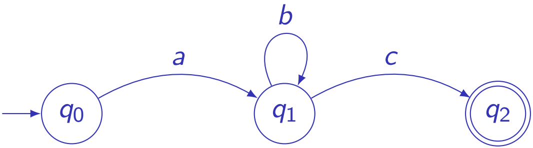
Longer term:

- Semantic processing
- Information and knowledge extraction from text
- Question answering

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
start(q0).
```

```
% The final states
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

Constant regular expressions:

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

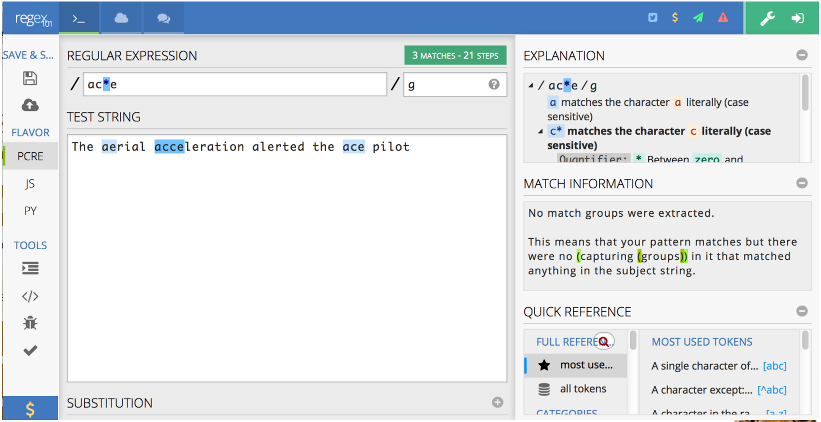
The automaton above is described by the regex `ab*c`

`grep 'ab*c' myFile1 myFile2`

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

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 alerted the ace 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	

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’>]
```

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.

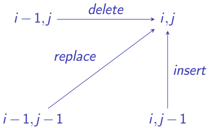
- Given a word in a text not in the dictionary, the spell checker generates all the transformations of this word.
- If we allow only one edit operation on a source string of length n, and if we consider an alphabet of 26 unaccented letters,
  - the deletion will generate n new strings;
  - the insertion, $(n+1) \times 26$ 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

a	b	Source
c	b	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*

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

Let us align

a	b	Source
c	b	Destination

b	2		
c	1		
Start	0	1	2
	Start	a	b

Distance between *ab* and *cb*

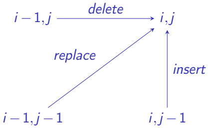
$$\begin{tikzcd} i-1,j \arrow[r, "\mathit{delete}"] & i,j \\ i-1,j-1 \arrow[ur, "\mathit{replace}"] & i,j-1 \arrow[u, "\mathit{insert}"'] \end{tikzcd}$$

Let us align

a	b	Source
c	b	Destination

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

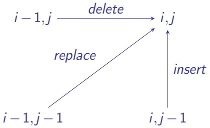
Distance between *ab* and *cb*



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

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])
```

Prolog Code

```
% edit_operation carries out one edit operation
% between a source string and a target string.
edit_operation([Char | Source], [Char | Target], Source,
    Target, ident, 0).
edit_operation([SChar | Source], [TChar | Target], Source,
    Target, sub(SChar,TChar), 2) :-
  SChar \= TChar.
edit_operation([SChar | Source], Target, Source, Target,
    del(SChar), 1).
edit_operation(Source, [TChar | Target], Source, Target,
    ins(TChar), 1).
```

Prolog Code

```
% edit_distance(+Source, +Target, -Edits, ?Cost).
edit_distance(Source, Target, Edits, Cost) :-
  edit_distance(Source, Target, Edits, 0, Cost).

edit_distance([], [], [], Cost, Cost).
edit_distance(Source, Target, [EditOp | Edits], Cost,
    FinalCost) :-
  edit_operation(Source, Target, NewSource, NewTarget,
    EditOp, CostOp),
  Cost1 is Cost + CostOp,
  edit_distance(NewSource, NewTarget, Edits, Cost1,
    FinalCost).
```

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
| | | | | | | |
l i n e ε a g e</td><td>l a n g u ε a g e
| | | | | | | | |
l i n ε ε e a g e</td></tr>
</table>