T-(538|725)-MALV, Natural Language Processing
Finite-state automata

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Outline

1 Usage and definition

2 Types of automata

3 Operations
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1. Usage and definition
2. Types of automata
3. Operations
Usage

- We need to be able to search corpora for words or phrases.
- Search must extend beyond fixed strings.
  - For example, a word or its plural form, uppercase or lowercase letters, expressions containing numbers, etc.
- This is where finite-state automata (FSA) (and regular expressions) help
- FSA are flexible tools for processing and searching texts.
A device which accepts or rejects an input stream of tokens (i.e. strings).

Often called a recognizer.

Can also be used as a generator, i.e. a device which generates strings.

Very efficient in terms of speed and memory usage.

Very suitable for text searching.
An example of a FSA
Mathematical definition

An FSA consists of five components \((Q, \Sigma, q_0, F, \delta)\):

1. \(Q\) is a finite set of states, \(q_0, q_1 \ldots q_n\).
2. \(\Sigma\) is a finite set of input symbols.
3. \(q_0\) is the start state, \(q_0 \in Q\).
4. \(F\) is the set of final states, \(F \subseteq Q\).
5. \(\delta\) is the transition function \(Q \times \Sigma \rightarrow Q\). \(\delta(q, i)\) returns the state to which the automaton moves when it is in state \(q\) and consumes the input symbol \(i\).

Example: \(Q = \{q_0, q_1, q_2\}, \Sigma = \{a, b, c\}, F = \{q_2\}, \delta = \{\delta(q_0, a) = q_1, \delta(q_1, b) = q_1, \delta(q_1, c) = q_2\}\)
**Finite-state automaton (FSA)**

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**Mathematical definition**

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Finite-state automata: Two types

Deterministic Finite Automaton – DFA (í. Löggeng stöðuvél)

Given a state and an input, there is one single possible destination state.

Non-deterministic Finite Automaton – NFA (í. Brigðgeng stöðuvél)

- More than one path is possible from a state for an input.
- The path is not determined in advance.
- $\epsilon$ (the empty string) is an accepted input symbol.
- Example: Fig. 2.3 page 31.

An NFA can be converted to an equivalent DFA automatically.
Algorithm to simulate a DFA

- **Input:** a string $x$ ending with EOF. DFA, $D$, with start state $s_o$ and a set, $F$, of final states.
- **Output:** The answer “yes” if $D$ recognises $x$, otherwise “no”.

$s = s_o$
$c = \text{nextchar}();$
while ($c <> \text{EOF}$) {
    $s = \text{move}(s, c);$  // returns the state to which the automaton moves
    // from state $s$ on input $c$
    $c = \text{nextchar}();$
}
if $s \in F$ then return “yes”
else return “no”;

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FSA
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Operations on Finite-State Automata

Main operations

- Union (í. Sammengi)
- Concatenation (í. Samtenging)
- Iteration; “Kleene Closure” (í. Endurtekning)
### Union

- The union of two automata $A$ and $B$ accepts (or generates) all strings of $A$ and all strings of $B$.
- Denoted by $A \cup B$.
- Obtained by adding a new initial state with an $\epsilon$-transition to both $A$ and $B$. 
An example of a union

\[ A \cup B = \text{Union} \]
Operations on Finite-State Automata

Concatenation

- The concatenation of two automata $A$ and $B$ accepts (or generates) all the strings that are concatenations of two strings, the first one being accepted by $A$ and the second one by $B$.
- Denoted $AB$.
- Obtained by connecting all the final states of $A$ to the initial state of $B$ using an $\epsilon$-transition (See Fig. 2.8 page 34).
Operations on Finite-State Automata

**Iteration**

- The *closure* of an automaton $A$ accepts (or generates) the concatenations of any number of its strings and the empty string $\epsilon$.
- Denoted $A^*$. $A^* = \{\epsilon\} \cup A \cup AA \cup AAA \cup \ldots$
- Obtained by linking the final state of $A$ to its initial state using $\epsilon$-transition and adding a new initial state.
An example of a closure

Closure of $A = A^*$
Other common operations

- **Intersection** (í. Sniðmengi). The intersection of two automata $A \cap B$ accepts all the strings accepted both by $A$ and $B$.

- **Difference** (í. Mismunur). The difference of two automata $A - B$ accepts all the strings accepted by $A$ but not by $B$.

- **Complementation** (í. Uppbót?).
  - $\Sigma^*$ denotes the infinite set of all possible strings generated from the alphabet $\Sigma$.
  - The complementation of the automaton $A$ in $\Sigma^*$ accepts all the strings that are not accepted by $A$, i.e. $\hat{A} = \Sigma^* - A$. 
Transformations to optimize speed and memory requirements

- **$\epsilon$-removal.**
  - Transforms an initial automaton into an equivalent one without $\epsilon$-transitions.

- **Determination.**
  - Transforms an NFA to a DFA.

- **Minimisation.**
  - Constructs an equivalent automaton with as few states as possible.