Augmented Transition Networks

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Outline

- **Introduction**

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Augmented Transition Networks

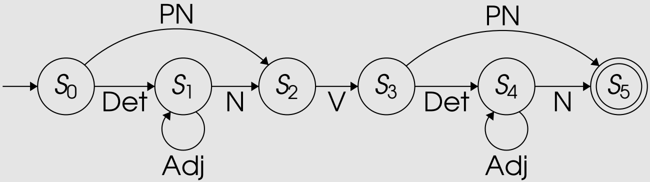
Augmented Transition Networks (ATN)

- One of the formal description of NL.
- One of the earliest implementations of a system for parsing natural languages.
- Work as finite state machines.

Augmented Transition Networks

Definition

- Non-deterministic finite state acceptor (NDA) - quadruple (Q, δ, q_0, F) over alphabet X.
  For a simple fragment of English can be constructed in following way:



- where:
  - X . . . input vocabulary
  - C . . . category vocabulary, made up of grammatical categories of NL (NP – noun phrase, VP – verb phrase, V - verb)
  - function $CAT : X \to C$, such that $CAT(x)$ is the defined category of x.

Example

Example

For example if

$$X = (dog, John, Mary, the, a, loves, saw, white)$$

and C is:

$$C = \mathrm{N}, \mathrm{Det}, \mathrm{V}, \mathrm{Adj}, \mathrm{PN}$$

Using the CAT function we define the following relationships:

- CAT(dog) = N

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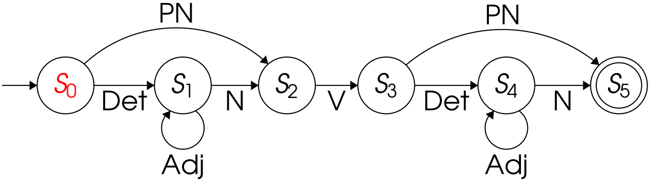

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- S_0 . . . initial state

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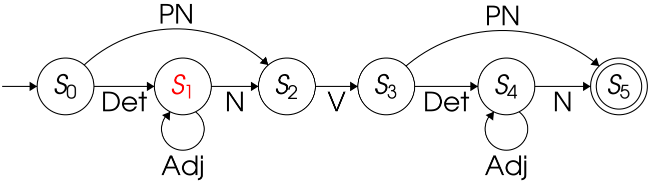

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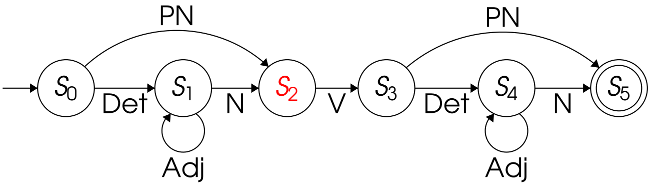

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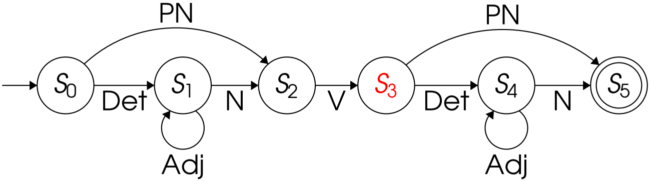

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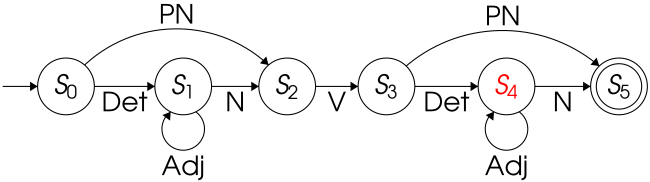

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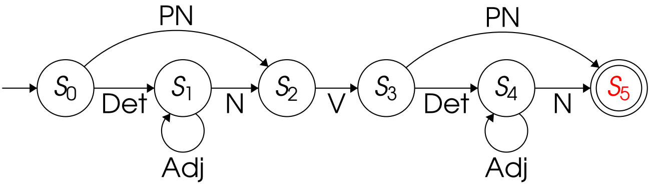

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- S_4 . . . the state in which is legal for the next word to be adjective or the noun of the next NP.
- S_5 . . . completion state and also $F = S_5$

Example

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The preceding state diagram corresponds to the following transition function:

- $\delta(S_0, \text{Det}) = \{S_1\}$
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The language accepted by the NDA:

$$L = \{\text{PN} \cup \text{Det Adj} * \text{N}\}.\{\text{V}\}.\{\text{PN} \cup \text{Det Adj} * \text{N}\}$$

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Example of accepted sentences:

1. *John loves Mary.*
2. *The white cat saw Mary.*
3. *Mary loves a cat.*

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Recursive Transition Network

Problems of NDA formalism

NDA model is unsatisfying:

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- FSM fails to capture a significant generalization in the structure of the language.
- Any kind of movement dependencies are impossible to capture.

Recursive Transition Network (RTN)

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- Recursivity – for recognizing *A* we call *B* which calls *C* etc. until we come to a transition which calls *A*-recognizer again.

Restructuralization of the NDA

Example

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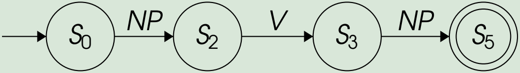
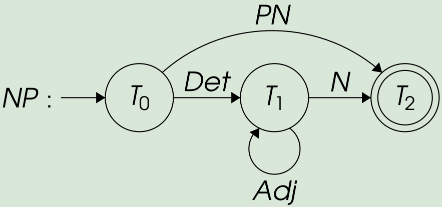
The first RTN:



and the second RTN:



Recursive Transition Network

Definition

A recursive transition network R is given by the following data:

1. X is a finite set of *terminal* symbols (eg. words of natural language).
2. C is a finite set of *categories*.
3. CAT is a map $X \to C$.
4. V is a set of *nonterminal* symbols.
5. $S \in V$ is the *start* symbol.

Recursive Transition Network

Recursive Transition Network

- For each $v \in V$, there is a NDA $M_V = \{Q_V, q_v, \delta_V, F_V\}$, where $q_V \in Q_V, F_V \subset Q_V$, and $\delta_V : Q_V \times (C \cup V) \rightarrow 2^Q$
- We associate each $v \in V$ with an acceptance set T_V defined recursively as follows:
  - A string w is in T_V just in case it can be partitioned into a sequence $w_1 w_2 \ldots w_n$ such that either $CAT(w_j) = a_j \in C_j$ or $w_j \in T_{a_j}$ for $a_j \in V$ and such that

$$\delta_v^*(q_V, a_1 a_2 \ldots a_n) \in F_V.$$

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- It means that a string is accepted by M_V with the transitions from states q to q' in M_V either made with a single x with $CAT(x) = c$ such that $q' \in \delta_V(q, c)$ or by a substring w' which is accepted by some M_u for which $q' \in \delta_V(q, u)$.
- The language $L(R)$ accepted by R is just T_S, the acceptance set for the start symbol S.

Recursive Transition Network

Theorem

For every recursive transition network R there is a pushdown automaton (PDA) $P(R)$ which accepts the same language.

Recursive Transition Network

Problems of RTN model

- There is no way to relate *wh*-sentence with its indicative form.
- Some local independencies are impossible to express (subject-verb agreement).

Solution

- RTN can be extended by adding registers to the model.
- Register may hold arbitrary information about input vocabulary.
- Resulting systems are called augmented transition network (ATN).

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Augmented Transition Network

Consider two cases involving agreement

- the subject and verb of a sentence
- the determiner and main noun of an NP.

With the RTN (without register) - there is no way to ensure that sentences like the following are prevented from being accepted as a part of the language.

1. ☹The *boys is* mischievous.
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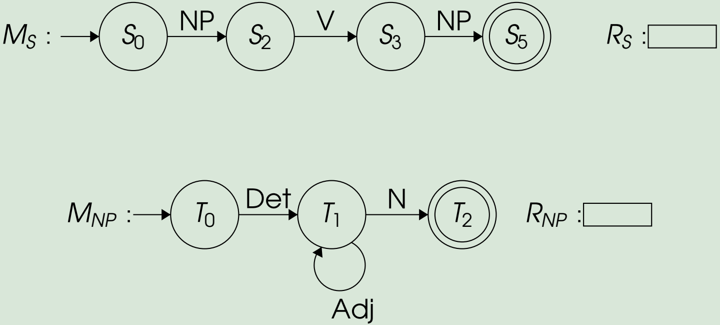
We need to check the number of the subject NP in some way and make the verb transition conditional on the verb agreeing with this NP feature. The following two conditions hold:

Condition I.: If the NP is singular then V must be singular.
Condition II.: If the NP is plural then V must be plural.

Augmented Transition Network: Example

Example

Example of what a register can contain and how this information is structured.



Augmented Transition Network: Example

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- singular,
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- neutral.

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Transition 2	$\delta_S(S_2, x) = S_3$ if $CAT(X) = v$ and the number of x agrees with that stored in R_S.
Transition 3	$\delta_S(S_3, w) = S_5$ if $w \in T_{NP}$.

Augmented Transition Network: Example

Example

Transitions for M_{NP}:

Transition 4. $\delta_{NP}(T_0, x) = T_1$ if $CAT(X) = Det$. In making the transition, $R_{NP} :=$ the number of x.

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Augmented Transition Network: Example

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Transitions for M_{NP}:

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- Transition 6. $\delta_{NP}(T_2, x) = T_1$ if $CAT(X) = N$ and the number of x agrees with that stored in R_{NP}.

Augmented Transition Network: Example

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Transition 6. $\delta_{NP}(T_2, x) = T_1$ if $CAT(X) = N$ and the number of x agrees with that stored in R_{NP}.

On exit from T_2, a string w in NP carries the number stored in R_{NP}

Long-distance Dependencies in ATN

Long-distance dependencies

How long-distance dependencies can be handled in an ATN formalism?
Note that neither FSAs nor RTNs were able to parse these sentences (including wh-movement).

1. *What does John love?*
2. *Who loves Mary?*

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With previous 6 transitions we are now unable to handle such sentences.
One of the possible solutions is to use global register.

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Global Register

We need some additional rules.

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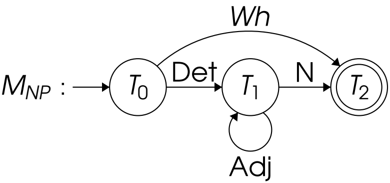
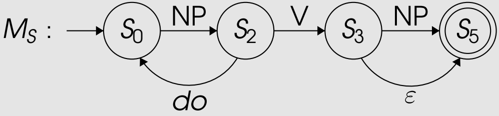
- eg. to parse previous sentences → modify ATN in the following way: we add global register R_{wh} which can be empty, hold *wh* or hold *do*.



We add new transitions to M_{NP}:

Transition 7. $\delta_{NP}(T_0, x) = T_2$ if $CAT(X) = Wh$ in making the transition, $R_{wh} := x$, and $R_{NP} := neutral$.

And to M_S we add these two new transitions:



Transition 8. $\delta_M(S_2, x) = S_0$ if $CAT(X) = do$ and $R_{wh} := wh$.
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Transition 9. $\delta_M(S_3, \varepsilon) = S_5$ if $R_{wh} := do$.

Global Register

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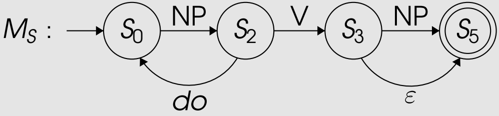

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Transition 9. $\delta_M(S_3, \varepsilon) = S_5$ if $R_{wh} := do$.

And to Transition 3 we add the condition $R_{wh} \neq do$

Transition 3 $\delta_S(S_3, w) = S_5$ if $w \in T_{NP}$, $R_{wh} \neq do$.

ATN: Conclusion

This structure accepts both previous sentences 1 and 2 and also sentence 4, but rejects 3 (which is not correct.)

1. What does John love?
2. Who loves Mary?
3. ☹Who likes?
4. Who likes who?

ATN: Conclusion

This structure accepts both previous sentences 1 and 2 and also sentence 4, but rejects 3 (which is not correct.)

1. What does John love?
2. Who loves Mary?
3. ☹Who likes?
4. Who likes who?

The ability to augment a transition with arbitrary tests and computation gives an ATN the computational power of **Turing machines**.

Theorem

For each Turing machine T, there is an ATN which accepts precisely the string accepted by T.

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Thank you for your attention!

End