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Inherent Ambiguity of Minimal Linear Grammars

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We give an example of minimal linear language, all of whose minimal linear grammars are ambiguous; this language is not ambiguous in the class of linear context-free languages.

Parikh has shown that there are context-free languages which are inherently ambiguous; he gave an example of context-free language (in fact linear), all of whose context-free grammars are ambiguous. Chomsky conjectured that there are languages inherently ambiguous relative to a class of grammars A, but not ambiguous in a class B, with $A \subset B$. We give here such a type of language where A is the class of minimal linear grammars, and B the class of linear grammars.

According to Chomsky and Schützenberger, a minimal linear language is generated by a context-free grammar of the particular form:

$$\left| \begin{array}{l} \{S \to f_i S g_i : \quad 1 \leqq i \leqq N\} \\ S \to c \end{array} \right|$$

Our example is the language

$$L = \{a^m c a^n : m \geqq n \geqq 0\}$$

It is a minimal linear language, since the following grammar generates it:

$$\left| \begin{array}{l} S \to aSa \\ S \to aS \\ S \to c \end{array} \right| \tag{1}$$

We show that any minimal linear grammar G which generates L is ambiguous.

It follows from the definition that any such G that can generate L is of the form:

$$\left| \begin{array}{l} \{S \to a^{p_i} S a^{q_i} : \quad 1 \leqq i \leqq N\} \\ S \to c \end{array} \right| \tag{2}$$

We have $p_i \geqq q_i$. Otherwise (2) would generate sentences of the type $a^m ca^n$ with $n > m$ which are not in L. We have, then, the three following types of rules:

$$\text{(i)} \qquad S \to a^{p_k} S \qquad p_k > 0$$

$$\text{(ii)} \qquad S \to a^{p_j} S a^{q_j} \qquad p_j \geqq q_j > 0$$

$$\text{(iii)} \qquad S \to c$$

The grammars (2), so constrained, generate sentences of the form: $a^m ca^n$, $m \geqq n \geqq 0$; in particular, they have to generate the sentences ac and aca. This entails that one of the rules of type (i) must be $S \to aS$ and one of the rules of type (ii) must be $S \to aSa$.

Then any grammar G has in fact the form:

$$\left| \begin{array}{l} S \to aSa \\ S \to aS \\ S \to c \\ \{S \to a^{p_j} S a^{q_j} : \quad p_j \geqq q_j \geqq 1\} \end{array} \right| \tag{3}$$

The effect of the rules $\{S \to a^{p_j} S a^{q_j} : p_j \geqq q_j \geqq 1\}$ can be obtained from q_j applications of the rule $S \to aSa$ and $p_j - q_j$ applications of the rule $S \to aS$. Suppressing these rules in (3) decreases the degree of ambiguity of sentences of L; so the grammar (1) is the minimal linear grammar which generates L with a minimum of ambiguity.

A particular sentence $a^m ca^n$ is generated by n applications of rule $S \to aSa$, $m - n$ applications of rule $S \to aS$, and at the end of the derivation, by application of rule $S \to c$; the ambiguity of a sentence results from the order in which rules $S \to aSa$ and $S \to aS$ are applied. The degree of ambiguity of the sentence $a^m ca^n$ is then $\binom{m}{n}$; it is not bounded when the length of the sentence increases.

The language L is not inherently ambiguous in the class of linear grammars: the following grammar generates it unambiguously:

$$\left| \begin{array}{l} S \to aSa \\ S \to aT \\ T \to aT \\ S \to c \\ T \to c \end{array} \right|$$

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