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A Note on Grammars with Regular Restrictions

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A context-free ε-free grammar with regular restrictions is a context-free ε-free grammar G over which a context-free rule r or G is applicable on a string x only if $x \in \gamma(r)$ where $\gamma(r)$ is a regular set. It is known from [1] that the context-free ε-free grammars with regular restrictions are as powerful as Chomsky's grammars of the type 0. It is shown, that the same result holds for the grammars, for which the condition $x \in \gamma(r)$ is replaced by the condition $x \in \gamma$ where γ is a regular set associated with the whole grammar (i.e. independent on the rule r to be applied).

A context-free grammar with regular restrictions [1] is a quituple $G = (V, U, R, \Phi, S)$, where $G' = (V, U, R, S)$ is a context-free grammar and $\Phi = \{\gamma(r) \mid r \text{ is a rule of } G', \gamma(r) \text{ is a regular set}\}$. A context-free grammar $G = (V, U, R, \Phi, S)$ with regular restrictions is a context-free ε-free grammar with regular restrictions if $G' = (V, U, R, S)$ is a context-free ε-free grammar.

Let G be a context-free (ε-free) grammar with regular restrictions. For $x, y \in (V \cup U)^*$ we write $x \Rightarrow_G y$ if there is a rule $r = (u, v) \in R$, $x = x_1ux_2$, $y = x_1vx_2$ and $x \in \gamma(r)$. $\Rightarrow_G^*$ is a transitive and reflexive closure of $\Rightarrow_G$.

Friš proved in [1] and [2], that contex-free ε-free grammars with regular restrictions (ε-CFRR grammars for short) are as powerful as Chomsky type 1 (context-sensitive) grammars, i.e. to each context sensitive grammar G there is a ε-CFRR grammar G_1 such that $L(G_1) = L(G_2)$ and vice versa to each ε-CFRR grammar G_2 there is a context sensitive grammar G_1 such that $L(G_2) = L(G_1)$.

Denote $T_1 = \{A \mid A = L(G) \text{ for a context-sensitive grammar } G\}$, $T^{rest} = \{A \mid A = L(G), G \text{ is a } \varepsilon\text{-CFRR grammar}\}$. A grammar is context-free ε-free with weak regular restriction (ε-CFWRR grammar for short) if it is a ε-CFRR grammar $G = (V, U, R, \Phi, S)$ where $\Phi = \{\gamma\}$ i.e. $\gamma(r_1) = \gamma(r_2)$ for each two rules r_1, r_2 of G. Let $T'^{rest} = \{A \mid A = L(G), G \text{ is a } \varepsilon\text{-CFWRR grammar}\}$.

As noted above $T_1 = T^{rest}$. We shall prove the following result.

Theorem. $T_1 = T'^{rest}$.

Proof. As it obviously holds $T'^{\text{rest}} \subset T^{\text{rest}} = T_1$ it suffices to prove that $T'^{\text{rest}} \supset$ $\supset T_1$.

Let $G = (V, U, R, S)$ be a context sensitive grammar. Without loss of generality we can assume that all the rules $r \in R$ are of the form $r = (h_1 A h_2, h_1 \omega h_2)$ where A is a nonterminal symbol.

Let $G' = (W, U, P, \Phi, S)$ be a ε-CFWRR grammar of the following properties. $W_1 = \{\uparrow_r \mid \uparrow_r$ is a new symbol for each $r \in R\}$, $W = W_1 \cup V$. Let further $P = P_1 \cup P_2$ where

$$P_1 = \{\bar{r} \mid \bar{r} = (A, \uparrow_r),\ r = (h_1 A h_2, h_1 \omega h_2) \in R\}\,,$$

$$P_2 = \{\bar{\bar{r}} \mid \bar{\bar{r}} = (\uparrow_r, \omega),\ r = (h_1 A h_2, h_1 \omega h_2) \in R\}\,.$$

Finally $\Phi = \{\gamma\}$ where

$$\gamma = (V \cup U)^* \cup \bigcup_{\substack{r \in R \\ r = (h_1 A h_2, h_1 \omega h_2)}} (V \cup U)^* \, h_1 \uparrow_r h_2 (V \cup U)^*$$

From this construction it follows that if $D = (w_0, w_1, \ldots, w_n)$, $w_0 \in (V \cup U)^*$, $w_n \in U^*$ is a derivation over G' then in D a rule $\bar{r}$ from P_1 is applied on w_0 (the rules from P_2 are not applicable). On w_1 the rules from P_1 and the rule $\bar{\bar{r}}$ from P_2 can be applied. If a rule q from P_1 were applied on w_1 then a string w_2' with two occurrences of symbols from W_1 would be obtained. But w_2' does not belong to γ. It must be therefore $w_2' = w_n$ which violates the assumption $w_n \in U^*$. Therefore on w_1 the rule $\bar{\bar{r}}$ must be applied. It follows $w_2 \in (U \cup V)^*$, $w_0 \Rightarrow_G w_2$. From it follows that if $(S, \ldots,$ $\ldots, w_n)$ is a derivation over G then $n = 2j$, $S \Rightarrow_G w_2 \Rightarrow_G w_4 \ldots \Rightarrow_G w_n$ and $L(G') \subset$ $\subset L(G)$. Because the reverse inclusion is obvious the proof is complete.

It is worth of mention that from the equality of generative powers of the type 1 grammars and the ε-CFRR grammars it does not follow that the grammars with regular restrictions (and even with context-free restriction) are not worth of study. One reason for it is that context-free grammars with regular restriction could generate non context-free languages (such as Algol 60) in a more "natural" way than context sensitive languages. For such grammars phrase markers seems to have almost no reasonable meaning. One reason for is discussed in [4]. One says that a derivation $(w_0, w_1, \ldots, w_n)$ over a Chomsky grammar G has the property H_k, $k \geqq 1$, if each w_j can be expressed in the form $w_j = w_{j1} w_{j2} \ldots w_{js_j}$ where the length $|w_{ji}|$ of w_{ji} is not greater than k and for each $h \leqq j$ and $i \leqq s_j$ there is $w_{h\Theta_h(i,j)}$ such that $w_{h\Theta_h(,ij)} \Rightarrow$ $\Rightarrow_G^* w_{ji}$. It is clear that each derivation over a context-free grammar has the property H_1. It is shown in [4] that the set $L_k(G) = \{x \mid$ there is a derivation $(S, \ldots, x)$ over G of the property $H_k\}$ is a context-free set for every Chomsky type 0 grammar and every $k \geqq 1$.

It follows that in the case that $L(G)$ is a set which is not context-free then to each k there is an $x \in L(G)$ such that every derivation D of x from the initial symbol contains a member m having a nonterminal substring y of the lengths greater then k. Moreover

D has the property that in the subderivation D' of x from m all the parts of y are dependent, i.e. the subderivation from arbitrary part of y cannot be separated from the subderivations in another parts of y. This fact can hardly be reflected in phrase markers, but phrase markers are fundamental for the syntactical analysis.

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