A Note on Scattered Context Grammars with Non-Context-Free Components

Jiří Techet Tomáš Masopust Alexander Meduna

Department of Information Systems
Faculty of Information Technology
Brno University of Technology
Božetěchova 2, Brno 61266, Czech Republic

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Scattered Context Grammar

Scattered Context Grammar (SC Grammar)

G = (V, T, P, S), where

V is a finite alphabet

T is a set of terminals, $T \subset V$

S is the start symbol, $S \in V - T$

P is a finite set of productions of the form

$$(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n),$$

where $A_1, \ldots, A_n \in V - T$, $x_1, \ldots, x_n \in V^*$

Propagating Scattered Context Grammar (PSC Grammar)

- each $(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n)$ satisfies $x_1, \ldots, x_n \in V^+$

SC Grammar—Derivation Step

Derivation Step

For $(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n) \in P$ and

$$u = u_1 A_1 \ldots u_n A_n u_{n+1}$$
$$v = u_1 x_1 \ldots u_n x_n u_{n+1}$$

we write $u \Rightarrow v\ [(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n)]$

Generated Language

$L(G) = \{x \in T^* : S \Rightarrow^* x\}$

Generative Power

- $\mathscr{L}(SC) = \mathscr{L}(RE)$
- $\mathscr{L}(CF) \subset \mathscr{L}(PSC) \subseteq \mathscr{L}(CS)$

SC Grammar—Example

Production Length

- $\text{len}((A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n)) = |A_1 \ldots A_n| = n$

Example

SC grammar $G = (\{A, B, C, S, a, b, c\}, \{a, b, c\}, P, S)$ with

$$
\begin{aligned}
P = \{&(S) \rightarrow (ABC), \\
&(A, B, C) \rightarrow (aA, bB, cC), \\
&(A, B, C) \rightarrow (\varepsilon, \varepsilon, \varepsilon)\}
\end{aligned}
$$

$S \Rightarrow ABC \Rightarrow aAbBcC \Rightarrow aaAbbBccC \Rightarrow aabbcc$
$L(G) = \{a^n b^n c^n \ : \ n \geq 0\}$

Linear Scattered Context Grammars

Linear Scattered Context Grammar

- scattered context grammar $G = (V, T, P, S)$
- P is a finite set of productions of the following two forms:
  1. $(S) \rightarrow (x_1 A_1 \dots x_k A_k x_{k+1})$, where $A_i \in (V - T) - \{S\}$, $x_i \in T^*$ for all $1 \leq i \leq k$, for some $k \geq 1$,
  2. $(A_1, \dots, A_k) \rightarrow (z_1, \dots, z_k)$, where $A_i \in (V - T) - \{S\}$, and either
     - $z_i = x_i B_i y_i$, where $x_i, y_i \in T^*$, $B_i \in (V - T) - \{S\}$, or
     - $z_i \in T^*$

     for all $1 \leq i \leq k$, for some $k \geq 1$

Degree n of Linear Scattered Context Grammar

- $(S) \rightarrow (x_1 A_1 \dots x_n A_n x_{n+1}) \in P$ satisfies $n \geq m$ for all $(S) \rightarrow (y_1 A_1 \dots y_m A_m y_{m+1}) \in P$
- for each $p \in P$, $\text{len}(p)$ is constant for every grammar ($\text{len}(p)$ does not depend on the degree)

Right-Linear Scattered Context Grammars

Right-Linear Scattered Context Grammar

- linear scattered context grammar $G = (V, T, P, S)$
- P is a finite set of productions of the following two forms:
  1. $(S) \rightarrow (x_1 A_1 \dots x_k A_k)$, where $A_i \in (V - T) - \{S\}$, $x_i \in T^*$ for all $1 \leq i \leq k$, for some $k \geq 1$,
  2. $(A_1, \dots, A_k) \rightarrow (z_1, \dots, z_k)$, where $A_i \in (V - T) - \{S\}$, and either
     - $z_i = x_i B_i$, where $x_i \in T^*$, $B_i \in (V - T) - \{S\}$, or
     - $z_i \in T^*$

     for all $1 \leq i \leq k$, for some $k \geq 1$

Language Families

- $\mathscr{L}(SC, LIN, n)$ – linear scattered context grammars of degree n
- $\mathscr{L}(SC, RLIN, n)$ – right-linear scattered context grammars of degree n

Main Results I

Theorem
For each $n \geq 1$,

$$\begin{aligned} \mathscr{L}(SC, LIN, n) &\subset \mathscr{L}(SC, LIN, n+1), \\ \mathscr{L}(SC, RLIN, n) &\subset \mathscr{L}(SC, RLIN, n+1), \\ \mathscr{L}(SC, RLIN, n) &\subset \mathscr{L}(SC, LIN, n). \end{aligned}$$

- $\mathscr{L}(SC, LIN) = \bigcup_{n=1}^{\infty} \mathscr{L}(SC, LIN, n)$
- $\mathscr{L}(SC, RLIN) = \bigcup_{n=1}^{\infty} \mathscr{L}(SC, RLIN, n)$

Theorem

$$\begin{aligned} \mathscr{L}(SC, LIN) &\subset \mathscr{L}(PSC),\ \mathscr{L}(CF) - \mathscr{L}(SC, LIN) \neq \emptyset, \\ \mathscr{L}(SC, RLIN) &\subset \mathscr{L}(PSC),\ \mathscr{L}(CF) - \mathscr{L}(SC, RLIN) \neq \emptyset, \\ \mathscr{L}(SC, RLIN) &\subset \mathscr{L}(SC, LIN). \end{aligned}$$

Main Results II

Theorem (Positive Closure Properties)

Each family $\mathscr{L}(SC, LIN, n)$ and $\mathscr{L}(SC, RLIN, n)$, where $n \geq 1$, is closed under union, reversal, homomorphism, inverse homomorphism, substitution with regular languages, concatenation with regular languages, intersection with regular languages, left and right quotient by regular languages. $\mathscr{L}(SC, LIN)$ and $\mathscr{L}(SC, RLIN)$ are closed under concatenation.

Theorem (Negative Closure Properties)

Each family $\mathscr{L}(SC, LIN, n)$, where $n \geq 1$, is not closed under concatenation with linear languages. Each family $\mathscr{L}(SC, RLIN, n)$, where $n \geq 1$, is not closed under concatenation with $\mathscr{L}(SC, RLIN, 2)$. $\mathscr{L}(SC, LIN)$ and $\mathscr{L}(SC, LIN)$ are not closed under intersection, complement and Kleene star. $\mathscr{L}(SC, LIN)$ is not closed under substitution with linear languages. $\mathscr{L}(SC, RLIN)$ is not closed under substitution with $\mathscr{L}(SC, RLIN, 2)$.

Conclusion and Open Problems

- The proof of the previous theorems is based on the proof of the equivalence of (right) linear sattered context grammars and (right) linear simple matrix grammars
- We may want to know what is the power of scattered context grammars with context-sensitive and unrestricted components; clearly:
  - $\mathscr{L}(SC, CS) = \mathscr{L}(CS)$
  - $\mathscr{L}(SC, RE) = \mathscr{L}(RE)$
- Concerning the power of scattered context grammars, there remains the original open problem:

$$\mathscr{L}(CS) - \mathscr{L}(PSC) \stackrel{?}{=} \emptyset$$