Scattered Context Grammars

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Modern Formal Language Theory, 2007

Scattered Context Grammar

Scattered Context Grammar

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

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

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

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

Propagating Scattered Context Grammar

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

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

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

Example I

Example

Propagating scattered context grammar

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

with

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

Example of derivation

$$S \Rightarrow ABC \Rightarrow aAbBcC \Rightarrow aaAbbBccC \Rightarrow aaabbbccc$$

Generated language

$$L(G) = \{a^n b^n c^n \; : \; n \geq 1\}$$

Example II

Example

Propagating scattered context grammar

$$G = (\{S, W, X, Y, Z, A, a\}, \{a\}, P, S),$$

where

$$\begin{aligned} P = \{ & 1 : (S) \to (a), \\ & 2 : (S) \to (aa), \\ & 3 : (S) \to (WAXY), \\ & 4 : (W, A, X, Y) \to (a, W, X, AAY), \\ & 5 : (W, X, Y) \to (a, W, AXY), \\ & 6 : (W, X, Y) \to (Z, Z, a), \\ & 7 : (Z, A, Z) \to (Z, a, Z), \\ & 8 : (Z, Z) \to (a, a)\} \end{aligned}$$

$$L = \{a^{2^n} : n \geq 0\}$$

$$\begin{aligned} S & \Rightarrow WAXY & [3] \\ & \Rightarrow aWXA^2Y & [4] \\ & \Rightarrow a^2WAA^2XY & [5] \\ & \Rightarrow a^3WAAXA^2Y & [4] \\ & \Rightarrow a^4WAXA^4Y & [4] \\ & \Rightarrow a^5WXA^6Y & [4] \\ & \Rightarrow a^6WA^7XY & [5] \\ & \Rightarrow a^6ZA^7Za & [6] \\ & \Rightarrow^7 a^{13}ZZa & [7^7] \\ & \Rightarrow a^{16} & [8] \end{aligned}$$

Production length

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

Definitions

nonterminal complexity is the number of nonterminals in G

degree of context-sensitivity $\text{dcs}(G)$ is the number of context-sensitive productions in G

maximum context sensitivity $\text{mcs}(G)$ is the greatest number in

$$\{\text{len}(p_i) - 1 \,:\, 1 \leq i \leq |P|\}$$

overall context sensitivity $\text{ocs}(G)$ is the sum of all members in

$$\{\text{len}(p_i) - 1 \,:\, 1 \leq i \leq |P|\}$$

Reduction – Results I

Lemma

There exists a scattered context grammar G such that G defines a non-context-free language and $\mathrm{dcs}(G) = \mathrm{mcs}(G) = \mathrm{ocs}(G) = 1$.

Proof

Consider a scattered context grammar

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

with

$$\begin{aligned} P = \{&(S) \to (AC), \\ &(A) \to (aAbB), \\ &(A) \to (\varepsilon), \\ &(C) \to (cCD), \\ &(C) \to (\varepsilon), \\ &(B, D) \to (\varepsilon, \varepsilon)\} \end{aligned}$$

$$L(G) = \{a^n b^n c^n \ : \ n \geq 0\}$$

$$\mathrm{dcs}(G) = \mathrm{mcs}(G) = \mathrm{ocs}(G) = 1$$

Reduction – Results II

Theorem

There are context-sensitive languages which cannot be described by a scattered context grammar $G = (V, T, P, S)$ *satisfying* $|V - T| = 1$.

Theorem

Every recursively enumerable language is generated by a scattered context grammar $G = (V, T, P, S)$ *satisfying*

$$|V - T| = 3,\ \mathrm{dcs}(G) = \infty,\ \mathrm{mcs}(G) = \infty,\ \mathrm{ocs}(G) = \infty.$$

Theorem

Every recursively enumerable language is generated by a scattered context grammar $G = (V, T, P, S)$ *satisfying*

$$|V - T| = 5,\ \mathrm{dcs}(G) = 2,\ \mathrm{mcs}(G) = 3,\ \mathrm{ocs}(G) = 6.$$

Reduction – Results III

Theorem

Every recursively enumerable language is generated by a scattered context grammar $G = (V, T, P, S)$ satisfying

$$|V - T| = 8,\ \mathrm{dcs}(G) = 6,\ \mathrm{mcs}(G) = 1,\ \mathrm{ocs}(G) = 6.$$

Theorem

Every recursively enumerable language is generated by a scattered context grammar $G = (V, T, P, S)$ satisfying

$$|V - T| = 4,\ \mathrm{dcs}(G) = 4,\ \mathrm{mcs}(G) = 5,\ \mathrm{ocs}(G) = 20.$$

Economical Transformations

Context-Free and Context-Sensitive Productions

For a scattered context production p, if $\text{len}(p)$

$= 1$ then the production is context-free

≥ 2 then the production is context-sensitive

Theorem

Let $H = (M, T, R, S)$ be a phrase-structure grammar in Kuroda normal form. Then, there exists a scattered context grammar, $G = (V, T, P, E)$, that satisfies

1. $L(G) = L(H)$,
2. $|M| = |V| + 5$,
3. *P contains 4 new context productions,*
4. *P contains 1 new context-free production.*

Leftmost Derivations

Leftmost Derivation Step

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

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

where $A_i \notin \mathrm{alph}(u_i)$ for all $1 \leq i \leq n$, we write

$$u \ {}_{lm}\!\Rightarrow v \ [(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n)]$$

Theorem

Every context-sensitive language can be generated by a propagating scattered context grammar which uses only leftmost derivations.

Extended Propagating Scattered Context Grammar

An extended propagating scattered context grammar is a scattered context grammar

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

in which every

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

satisfies $|x_1 \ldots x_n| \geq n$

Theorem

Every context-sensitive language can be generated by an extended propagating scattered context grammar.

Unordered Scattered Context Grammar

Unordered Scattered Context Grammar

- scattered context grammar in which the order of context-free productions in a scattered context production is unimportant
- for $(A_1, \ldots, A_n) \rightarrow (x_1, \ldots, x_n) \in P$, a permuation $\pi : \{1, \ldots, n\} \rightarrow \{1, \ldots, n\}$, and

$$\begin{aligned} u &= u_1 A_{\pi(1)} \ldots u_n A_{\pi(n)} u_{n+1} \\ v &= u_1 x_{\pi(1)} \ldots u_n x_{\pi(n)} u_{n+1} \end{aligned}$$

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

Generative Power

- $\mathscr{L}(USC) = \mathscr{L}(P, \varepsilon)$
- $\mathscr{L}(PUSC) = \mathscr{L}(P) \subset \mathscr{L}(PSC)$

Open Problems

Open Problem

Are propagating scattered context grammars powerful enough to characterize all context-sensitive languages?

Open Problem

Can every recursively enumerable language be described by a scattered context grammar containing only two nonterminals?

Bibliography I

H. Fernau.
Scattered context grammars with regulation.
Annals of Bucharest University, Mathematics-Informatics Series, 45(1):41–49, 1996.

J. Gonczarowski and M. K. Warmuth.
Scattered versus context-sensitive rewriting.
Acta Informatica, 27:81–95, 1989.

S. Greibach and J. Hopcroft.
Scattered context grammars.
Journal of Computer and System Sciences, 3:233–247, 1969.

T. Masopust.
Regulated Formal Models and Their Reductions.
PhD thesis, Faculty of Information Technology, Brno University of Technology, Brno, Czech Republic, 2007.

Bibliography II

A. Meduna.
Economical transformation of phrase-structure grammars to scattered context grammars.
Acta Cybernetica, 13:225–242, 1998.

A. Meduna.
Generative power of three-nonterminal scattered context grammars.
Theoretical Computer Science, 246:276–284, 2000.

A. Meduna and J. Techet.
Maximal and minimal scattered context rewriting.
In *FCT 2007 Proceedings*, volume 2007, pages 412–423, Budapest, 2007. Springer Verlag.

Bibliography III

J. Techet.
A note on scattered context grammars with non-context-free components.
In *MEMICS 2007 Proceedings*, pages 225–232, Znojmo, 2007. Ing. Zdenek Novotny, CSc.

Gy. Vaszil.
On the descriptional complexity of some rewriting mechanisms regulated by context conditions.
Theoretical Computer Science, 330:361–373, 2005.

V. Virkkunen.
On scattered context grammars.
Acta Universitatis Ouluensis, Series A, Mathematica 6:75–82, 1973.