

String-Partitioning Systems and An Infinite Hierarchy

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Motivation

inspiration and special characteristics

Inspiration:

- another rewriting mechanisms
- models with properties of both automata and grammars
- generative power of such devices?
- different and common properties?

Definition

string partitioning system and it's configuration

SPS is a quadruple $M = (Q, \Sigma, s, R)$

- Q is a finite set of states
- Σ is an alphabet, $\# \in \Sigma$ called *bounder*
- $s \in Q$ is a start state
- R is finite set of rules of the form:
 $p_i\# \rightarrow qx \in R$, where $p, q \in Q, i \in I, x \in \Sigma^*$.

Configuration of SPS

- is string $c \in Q\Sigma^*$

Definition

derivation step and derived language

Derivation step from $pu\#v$ to $quxv$, where

- $p, q \in Q, u, v, x \in \Sigma^*$
- $\text{occur}(u, \#) = n - 1$
- by using $p_n\# \rightarrow qx \in R$

is $pu\#v \Rightarrow quxv$ $[p_n\# \rightarrow qx]$ in M

Language derived by M , $L(M)$:

- $L(M) = \{w \mid s\# \Rightarrow^* qw, q \in Q, w \in (\Sigma - \{\#\})^*\}$

Simple example of SPS

generation of language $a^n b^n c^n$

$M = (\{s, p, q, f\}, \{a, b, c, \#\}, s, R)$, where R contains:

- | | |
|--------------------------------|------------------------------|
| 1. $s_1\# \rightarrow p\#\#$ | 4. $p_1\# \rightarrow f\ ab$ |
| 2. $p_1\# \rightarrow q\ a\#b$ | 5. $f_1\# \rightarrow f\ c$ |
| 3. $q_2\# \rightarrow p\ \#c$ | |

Example (derivation of string $aaabbbccc$)

$s\# \Rightarrow p\#\#[1] \Rightarrow qa\#b\#[2] \Rightarrow pa\#b\#c [3] \Rightarrow$
 $qaa\#bb\#c [2] \Rightarrow paa\#bb\#cc [3] \Rightarrow faaabbb\#cc [4] \Rightarrow$
 $faaabbbccc [5].$

$L(M) = \{a^n b^n c^n \mid n \geq 1\}, \quad \text{with } \text{Ind}(M) = 2$

Definition

finite index of used formal models

Finite index of grammar?

- max. number of N 's in sentential form w
- achievable sent. form - $S \Rightarrow^* w$
- leading to string x : $w \in x, x \in \Sigma^*$
- in the most economical derivation

Finite index of SPS?

- max.number of $\#$'s in sentential form

Definition

finite index of used formal models

Index of a language:

- equal to index of grammar/SPS

Family of languages of finite index k

- $\mathcal{L}_k(X)$

Family of all languages of finite index

- $\mathcal{L}_{fin}(X) = \bigcup_{i \geq 1} \mathcal{L}_i(X)$

Definition

programmed grammars

Programmed grammar (PG) – $G = (V, T, P, S)$

- V is a total alphabet
- $T \subseteq V$ is an alphabet of terminals
- $S \in (V - T)$ is the start symbol
- P is a finite set of rules of the form $p: A \rightarrow v, g(p)$
 - $p: A \rightarrow v$ is a context free rule labeled by p
 - $g(p)$ - set of rule labels associated with rule p (following set)
 - after p -application a rule labeled by a label from $g(p)$ has to be applied

Generative power of programmed grammars

Programmed grammars:

- $\mathcal{L}(CF) \subset \mathcal{L}(PG) \subset \mathcal{L}(PG_{ac}) \subset \mathcal{L}(CS) \subset \mathcal{L}(\lambda PG_{ac}) = \mathcal{L}(RE)$
- $\mathcal{L}(CF) \subset \mathcal{L}(PG) \subset \mathcal{L}(\lambda PG) \subset \mathcal{L}(RE)$

Programmed grammars of index k :

- $\mathcal{L}_{fin}(PG) = \mathcal{L}_{fin}(\lambda PG) = \mathcal{L}_{fin}(PG_{ac}) = \mathcal{L}_{fin}(\lambda PG_{ac})$
- $\mathcal{L}(CF) - \mathcal{L}_{fin}(PG) \neq \emptyset$
 $\Rightarrow \mathcal{L}_{fin}(PG)$ is incomparable towards $\mathcal{L}(CF)$

Generative power and infinite hierarchy of string partitioning systems of finite index

infinite hierarchy for SPS

$$\mathcal{L}_k(\text{SPS}) \subset \mathcal{L}_{k+1}(\text{SPS}), \text{ for all } k \geq 1$$

① $\mathcal{L}_k(\text{PG}) \subset \mathcal{L}_{k+1}(\text{PG}), \text{ for all } k \geq 1$ (Gh. Păun, 1980)

② $\mathcal{L}_k(\text{SPS}) = \mathcal{L}_k(\text{PG})$

Theorem 2

$$\mathcal{L}_k(\text{SPS}) = \mathcal{L}_k(\text{PG}), \text{ for every } k \geq 1$$

Proof: 1) $\mathcal{L}_k(\text{PG}) \subseteq \mathcal{L}_k(\text{SPS})$ 2) $\mathcal{L}_k(\text{SPS}) \subseteq \mathcal{L}_k(\text{PG})$

Proof (basic idea)

first part: $PG_k \rightarrow SPS_k$

Conversion: $PG_k \rightarrow SPS_k$

- nonterminals represented by #s and information in state
- each state in SPS_k (2 components) of form:

$$\langle A_1 \dots A_j, q \rangle$$

$$A_1, \dots, A_j \in N_{PG_k}, \quad 0 \leq j \leq k, \quad q \in g(p)$$

- one symbol in $A_1 \dots A_k$ is marked for following rewriting
- q represents next rule to use
- bounders mark positions for former nonterminals

$$x_0 \textcolor{red}{A} x_1 \textcolor{red}{B} x_2$$

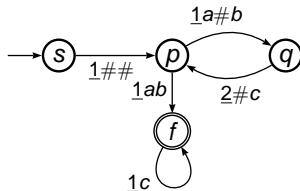


$$\langle \textcolor{red}{AB}, q \rangle x_0 \# x_1 \# x_2$$

Proof (demonstration)

second part: $SPS_k \rightarrow PG_k$

$SPS_2 M = (\{s, p, q, f\}, \{a, b, c, \#\}, s, R)$:



- 1 $s_1\# \rightarrow p\#\#$
- 2 $p_1\# \rightarrow q\ a\#b$
- 3 $q_2\# \rightarrow p\ \#c$
- 4 $p_1\# \rightarrow f\ ab$
- 5 $f_1\# \rightarrow f\ c$

How to construct PG's rule set based on SPS' rules?

basic idea will be presented..

Proof (demonstration)

second part: $SPS_k \rightarrow PG_k$

Conversion: $SPS_k \rightarrow PG_k$

- 1 every $A \in N$ is of form $\langle p, i, h \rangle$, $s := \langle s, 1, 1 \rangle$
- 2 every SPS_k 's rule $p_i \# \rightarrow qy$ simulate by sequence of steps (differs for every number of #s in configuration):

$$p \underline{a} \# b \# c \Rightarrow_{SPS} f \underline{aabb} \# c \quad [p_1 \# \rightarrow f ab]$$



a) **renumbering**

$$a \langle p, 1, 2 \rangle b \langle p, 2, 2 \rangle c \Rightarrow_{PG} a \langle f'', 1, 1 \rangle b \langle p, 2, 2 \rangle c \Rightarrow_{PG}$$

b) **rewriting**

$$a \langle \underline{f''}, 1, 1 \rangle b \langle f', 1, 1 \rangle c \Rightarrow_{PG} \underline{aabb} \langle f', 1, 1 \rangle c \Rightarrow_{PG}$$

c) **finalization**

$$\underline{aabb} \langle f, 1, 1 \rangle c$$

Modifications of SPS

another challenges...

SPS with finite index:

- deterministic variant
- accepting variant
- parallel variant

SPS without index limitation:

- generative power
- properties

References...



J. Dassow, Gh. Păun.

Regulated Rewriting in Formal Language Theory.

Springer, New York, 1989.



A. Meduna.

Automata and Languages, Theory and Applications.

Springer, London, 2000.



T. Kasai

A Hierarchy Between Context-Free and Context-Sensitive Languages.

Journal of Computer and System Sciences, vol. 4, 1970.