

Normal Forms of Type-0, Type-1, and Type-2 Grammars

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Chomsky Normal Form of Type-2 Grammars

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A type-2 grammar $G = (N, T, P, S)$ is in **Chomsky normal form** if every production $p \in P$ has one of these forms:

1 $A \rightarrow BC$

2 $A \rightarrow a$

where $A, B, C \in N$ and $a \in T$.

Theorem

For every type-2 grammar $G = (N, T, P, S)$, there is an equivalent type-2 grammar $H = (M, T, R, S)$ in Chomsky normal form.

Greibach Normal Form of Type-2 Grammars

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A type-2 grammar $G = (N, T, P, S)$ is in **Greibach normal form** if every production $p \in P$ satisfies

$$A \rightarrow aB_1 \dots B_n$$

where $A \in N$, $a \in T$, and $B_1, \dots, B_n \in N$ for some $n \geq 0$.

Two-Standard Greibach Normal Form

Greibach normal form is in two-standard form if $n \leq 2$.

Theorem

For every type-2 grammar $G = (N, T, P, S)$, there is an equivalent type-2 grammar $H = (M, T, R, S)$ in two-standard Greibach normal form.

Kuroda Normal Form of Type-0 Grammars

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A type-0 grammar $G = (N, T, P, S)$ is in **Kuroda normal form** if every production $p \in P$ has one of these forms:

1 $AB \rightarrow CD$

2 $A \rightarrow BC$

3 $A \rightarrow a$

4 $A \rightarrow \varepsilon$

where $A, B, C, D \in N$ and $a \in T$.

Theorem

For every type-0 grammar $G = (N, T, P, S)$, there is an equivalent type-0 grammar $H = (M, T, R, S)$ in Kuroda normal form.

Kuroda Normal Form Proof I

Let $G = (N, T, P, S)$ be a type-0 grammar. Transform G to $H = (M, T, R, S)$ in Kuroda normal form as follows:

- 0
 - $M := N$
 - If $p \in P$ satisfies Kuroda normal form, move p from P to R
- 1
 - In every $p \in P$, replace each $a \in T$ with nonterminal a'
 - Move every production that satisfies Kuroda normal form from P to R
 - Add $a' \rightarrow a$ to R and a' to M
- 2
 - In P , replace every

$$A_1 \dots A_m \rightarrow B_1 \dots B_n$$

where $n < m$ with

$$A_1 \dots A_m \rightarrow B_1 \dots B_n C \dots C,$$

where C is a new nonterminal and $|C \dots C| = m - n$

- Add C to M
- Add $C \rightarrow \varepsilon$ to R
- Move every production that satisfies Kuroda normal form from P to R
($A_1 A_2 \rightarrow B_1 C$)

Kuroda Normal Form Proof II

- 3 ■ In P , replace $A \rightarrow B$ with

$$A \rightarrow BC \text{ and } C \rightarrow \varepsilon,$$

where C is a new symbol

- Move $A \rightarrow BC, C \rightarrow \varepsilon$ to R
- Add C to M

- 4 ■ If $A \rightarrow B_1 \dots B_n \in P$ with $3 \leq n$, add

$$\begin{aligned} A &\rightarrow B_1 \langle B_2 \dots B_n \rangle \\ \langle B_2 \dots B_n \rangle &\rightarrow B_2 \langle B_3 \dots B_n \rangle \\ &\vdots \\ \langle B_{n-2} \dots B_n \rangle &\rightarrow B_{n-2} \langle B_{n-1} B_n \rangle \\ \langle B_{n-1} B_n \rangle &\rightarrow B_{n-1} B_n \end{aligned}$$

to R

- Add $\langle B_2 \dots B_n \rangle, \dots, \langle B_{n-1} B_n \rangle$ to M
- Remove $A \rightarrow B_1 \dots B_n$ from P

Kuroda Normal Form Proof III

- 5 ■ For every

$$A_1 \dots A_m \rightarrow B_1 \dots B_n \in P$$

with $2 \leq m$ and $3 \leq n$, add

$$A_1 A_2 \rightarrow B_1 C \text{ to } R$$

and C to M (C is a new symbol)

- If $|B_2 \dots B_n| \leq 2$, add

$$CA_3 \dots A_m \rightarrow B_2 \dots B_n \text{ to } R,$$

otherwise, add

$$CA_3 \dots A_m \rightarrow B_2 \dots B_n \text{ to } P$$

- Remove $A_1 \dots A_m \rightarrow B_1 \dots B_n$ from P
■ Repeat 5 until $P = \emptyset$

Kuroda Normal Form of Type-1 Grammars

Theorem

*For every type-1 grammar G , there is an equivalent type-1 grammar H in **Kuroda normal form**; that is, H has every production in one of these forms:*

1 $AB \rightarrow CD$

2 $A \rightarrow BC$

3 $A \rightarrow a$

where $A, B, C, D \in N$ and $a \in T$.

Theorem

*For every type-0 grammar G , there is an equivalent type-0 grammar H in **Penttonen normal form**; that is, H is in Kuroda normal form and, in addition, every production $AB \rightarrow CD$ satisfies $A = C$.*

Theorem

*For every type-1 grammar G , there is an equivalent type-1 grammar H in **Penttonen normal form**; that is, H is in Kuroda normal form and, in addition, every production $AB \rightarrow CD$ satisfies $A = C$.*

First Geffert Normal Form for Type-0 Grammars

First Geffert Normal Form for Type-0 Grammars

A type-0 grammar

$$G = (\{S, A, B, C\}, T, P \cup \{ABC \rightarrow \varepsilon\}, S)$$

is in the **first Geffert normal form** if every production $p \in P$ has one of these forms:

1 $S \rightarrow uSa,$

2 $S \rightarrow uSv,$

3 $S \rightarrow uv,$

where $u \in \{A, AB\}^*$, $a \in T$, and $v \in \{BC, C\}^*$.

Theorem

For every type-0 grammar $G = (N, T, P, S)$, there is an equivalent type-0 grammar H in the first Geffert normal form.

Second Geffert Normal Form for Type-0 Grammars

Second Geffert Normal Form for Type-0 Grammars

A type-0 grammar

$$G = (\{S, A, B, C, D\}, T, P \cup \{AB \rightarrow \varepsilon, CD \rightarrow \varepsilon\}, S)$$

is in the **second Geffert normal form** if every production $p \in P$ has one of these forms:

1 $S \rightarrow uSa,$

2 $S \rightarrow uSv,$

3 $S \rightarrow uv,$

where $u \in \{A, C\}^*$, $a \in T$, and $v \in \{B, D\}^*$.

Theorem

For every type-0 grammar $G = (N, T, P, S)$, there is an equivalent type-0 grammar H in the second Geffert normal form.

Third Geffert Normal Form for Type-0 Grammars

Third Geffert Normal Form for Type-0 Grammars

A type-0 grammar

$$G = (\{S, A, B\}, T, P \cup \{ABBBBA \rightarrow \varepsilon\}, S)$$

is in the **third Geffert normal form** if every production $p \in P$ has one of these forms:

1 $S \rightarrow uSa,$

2 $S \rightarrow uSv,$

3 $S \rightarrow uv,$

where $u \in \{AB, ABB\}^*$, $a \in T$, and $v \in \{BBA, BA\}^*$.

Theorem

For every type-0 grammar $G = (N, T, P, S)$, there is an equivalent type-0 grammar H in the third Geffert normal form.



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