Unrestricted (Phase Structure) Grammars

• Unrestricted grammars permits productions of the form:
  \[ \alpha \to \beta \]

• \( \alpha \) is a string of terminals and nonterminals with at least one nonterminal and is not \( \varepsilon \).

• \( \beta \) is a string of terminals and nonterminals.

• Unrestricted grammars are also called type 0 grammars.

• Type 0 grammars is equivalent to TM. Namely, any language defined by some type 0 grammar if and only if there exists a TM accepting it.
Example of Type 0 Grammar

S->ACaB
Ca->aaC
CB->DB
CB->E
aD->Da
AD->AC
aΕ >Ea
AE->ε

This grammar defines the language a^i, i is a positive power of 2.
Context-Sensitive Grammars

• context-sensitive grammars permits productions of the from:
  \[ \alpha \rightarrow \beta \]
• \( \alpha \) is a string of terminals and nonterminals with at least one nonterminal and is not \( \varepsilon \).
• \( \beta \) is a string of terminals and nonterminals.
• \( \beta \) is at least as long as \( \alpha \).
• Context-Sensitive grammars are also called type 1 grammars.
Example of Context-Sensitive Grammars

S->aSBA
S->abA
AB->BA
bB->bb
bA->ba
aA->aa

This grammar defines the language $a^n b^n a^n$, which is not context free language.
Linear Bounded Automata (LBA)

• A linear bounded automaton (LBA) is a nondeterministic TM satisfying the following two conditions.
  – its input alphabet includes two special symbols # and $, the left and right endmarkers, respectively.
  – the LBA has no moves left from # or right from $, nor may it print another symbol over # or $.
• LBA is equivalent to context-sensitive grammars.
Chomsky Hierarchy

• Type 0 grammars (unrestricted grammars)
  – TM
  – Recursive Enumerable Languages
• Type 1 grammars (context-sensitive grammars)
  – LBM
  – context-sensitive languages (a^n b^n a^n)
• Type 2 grammars (context-free grammars)
  – PDA
  – context-free languages (a^n b^n)
• Type 3 grammars (regular grammars)
  – FA
  – regular languages
Chomsky Hierarchy

- Type 0 grammars (unrestricted grammars)
  - Recursive enumerable languages
  - Recursive languages
- Type 1 grammars (context-sensitive grammars)
- Type 2 grammars (context-free grammars)
  - context-free language (wcw^R)
  - deterministic context-free languages (a^n b^n)
- Type 3 grammars (regular grammars)
LR grammars

- Languages defined by LR(0) grammars could be parsed from left to right without lookahead of symbols on the input.
- A LR(0) grammar is a deterministic context-free grammar, but a deterministic context-free grammar may not a LR(0) grammar.
- Languages defined by LR(k) grammars could be parsed from left to right with a lookahead of k symbols on the input.
- LR(k) grammar is equivalent to deterministic context-free grammar.