LANGUAGE PROCESSORS

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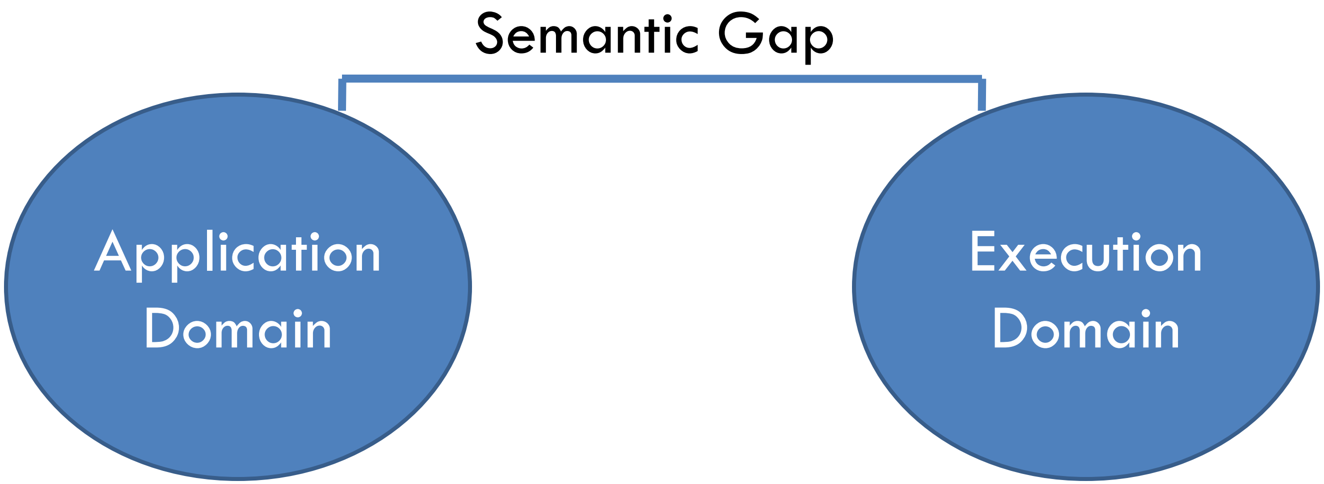
Introduction

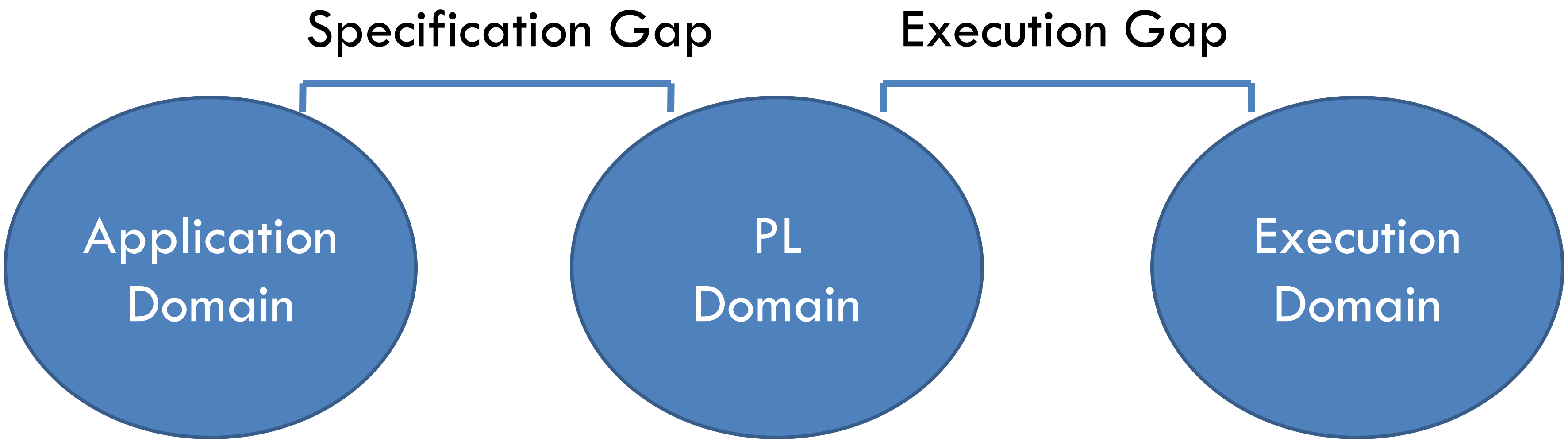
- Language Processing activities arise due to the differences between the manner in which a software designer describes ***the ideas concerning the behavior of a software*** and the manner in which ***these ideas are implemented in a computer system.***
- The designer expresses the ideas in terms related to the ***application domain*** of the software. To implement these ideas, their description has to be interpreted in terms related to the ***execution domain.***

Semantic Gap



- Semantic Gap has many consequences
  - Large development time
  - Large development effort
  - Poor quality of software

Specification and Execution Gaps



- The software engineering steps aimed at the use of a PL can be grouped into
  - Specification, design and coding steps
  - PL implementation steps

Specification and Execution Gaps

- Specification Gap
  - It is the semantic gap between two specifications of the same task.
- Execution Gap
  - It is the gap between the semantics of programs (that perform the same task) written in different programming languages.

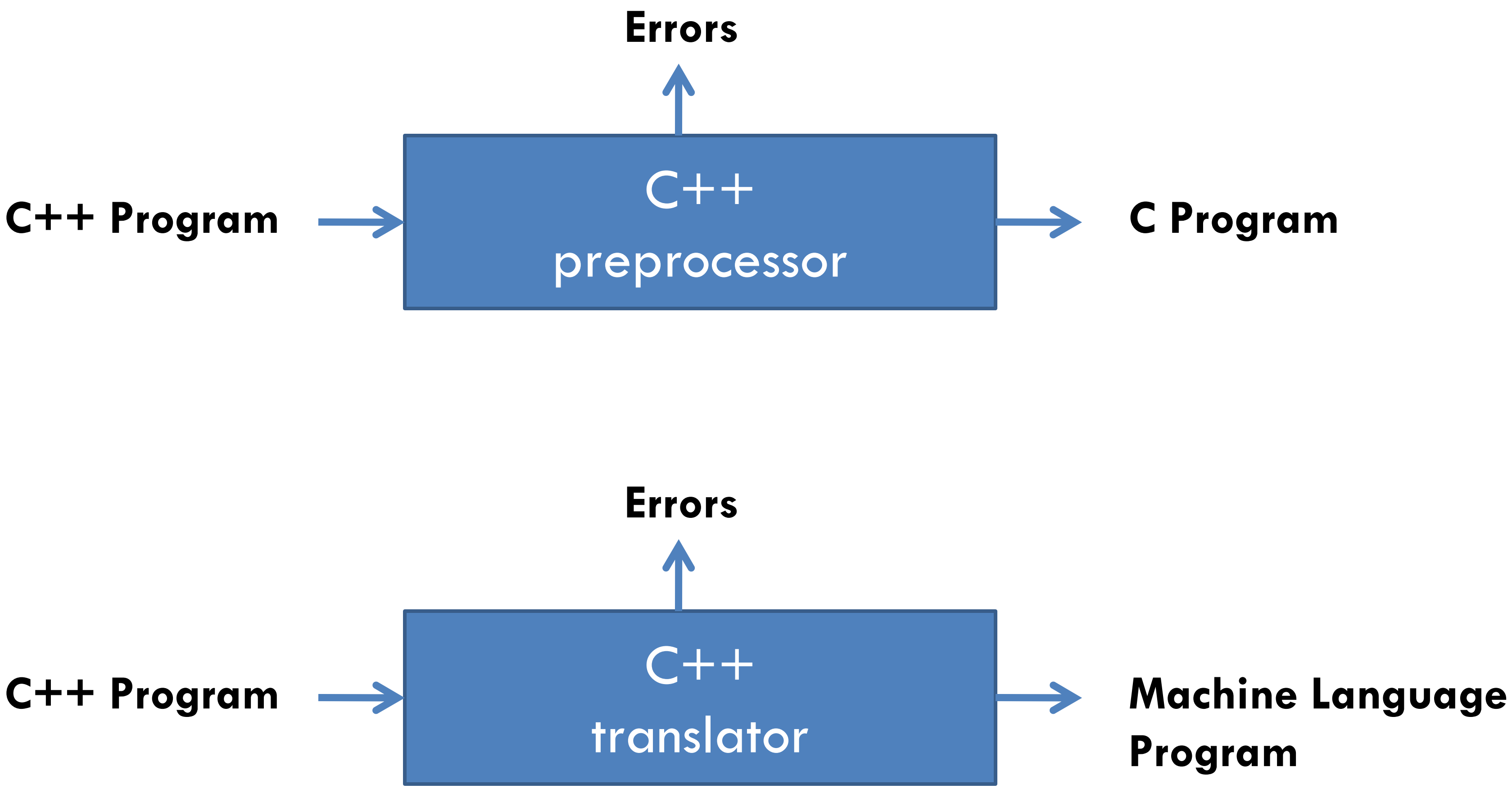
Language Processors

- "*A language processor is a software which bridges a specification or execution gap*".
- The program form input to a language processor as the *source program* and to its output as the *target program*.
- The languages in which these programs are written are called *source language* and *target language*, respectively.

Types of Language Processors

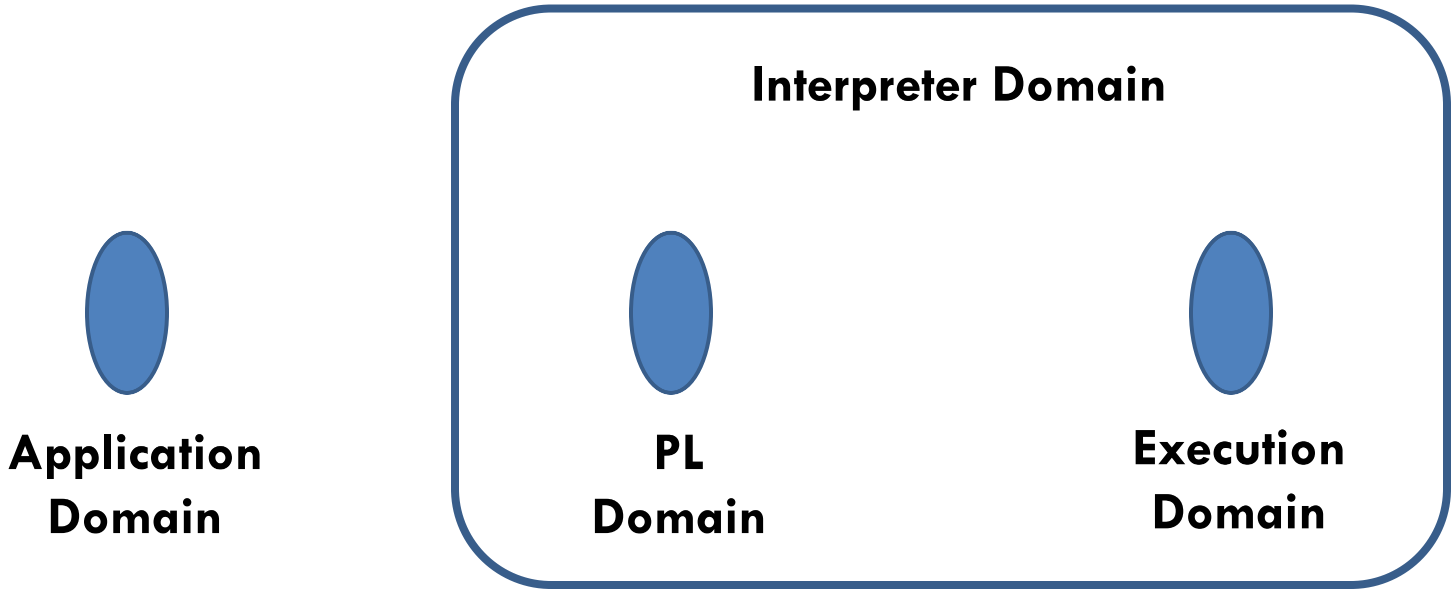
- A ***language translator*** bridges an execution gap to the machine language (or assembly language) of a computer system. E.g. Assembler, Compiler.
- A ***detranslator*** bridges the same execution gap as the language translator, but in the reverse direction.
- A ***preprocessor*** is a language processor which bridges an execution gap but is not a language translator.
- A ***language migrator*** bridges the specification gap between two PLs.

Language Processors - Examples



Interpreters

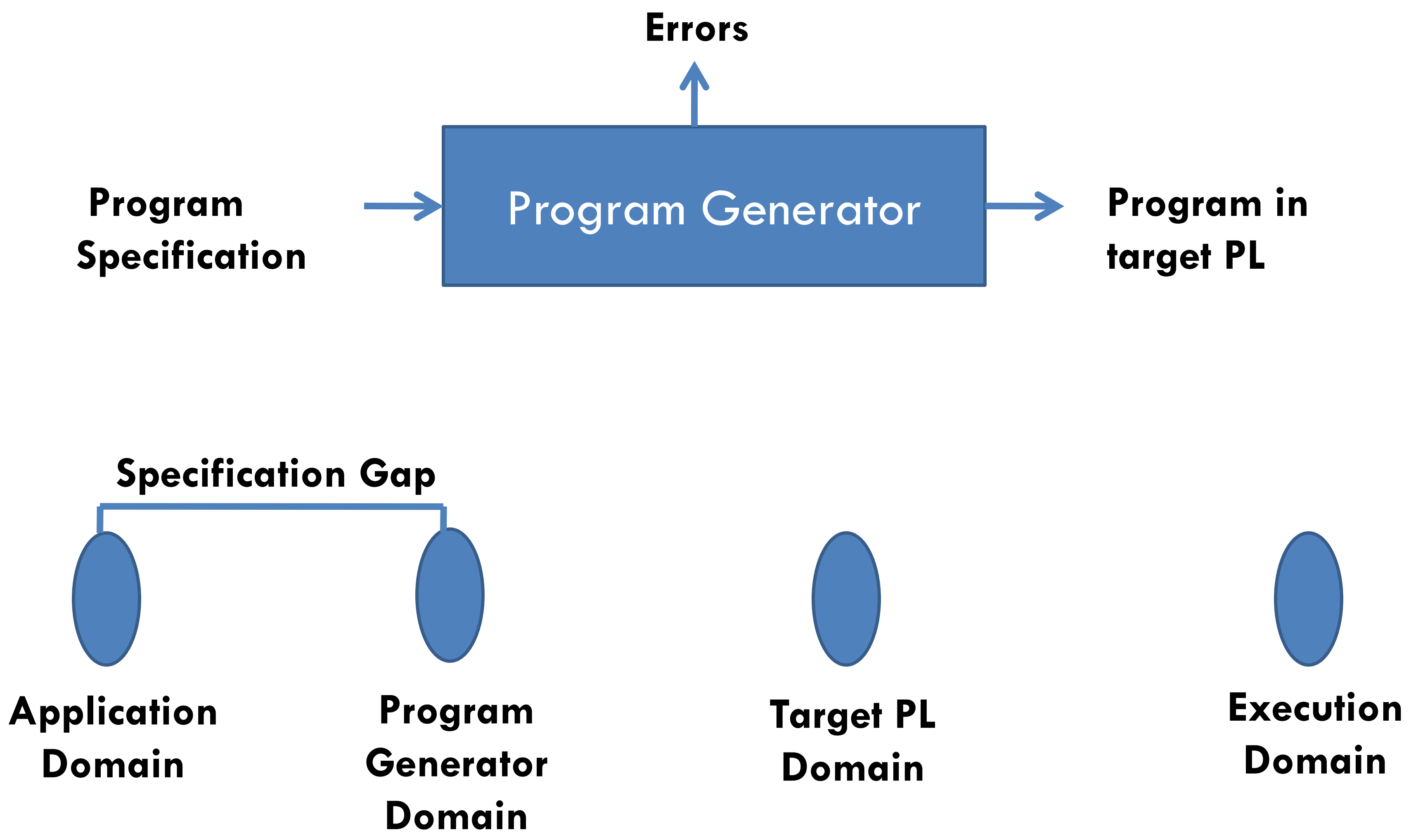
- An **interpreter** is a language processor which bridges an execution gap without generating a machine language program.
- An interpreter is a <u>language translator</u> according to classification.



Language Processing Activities

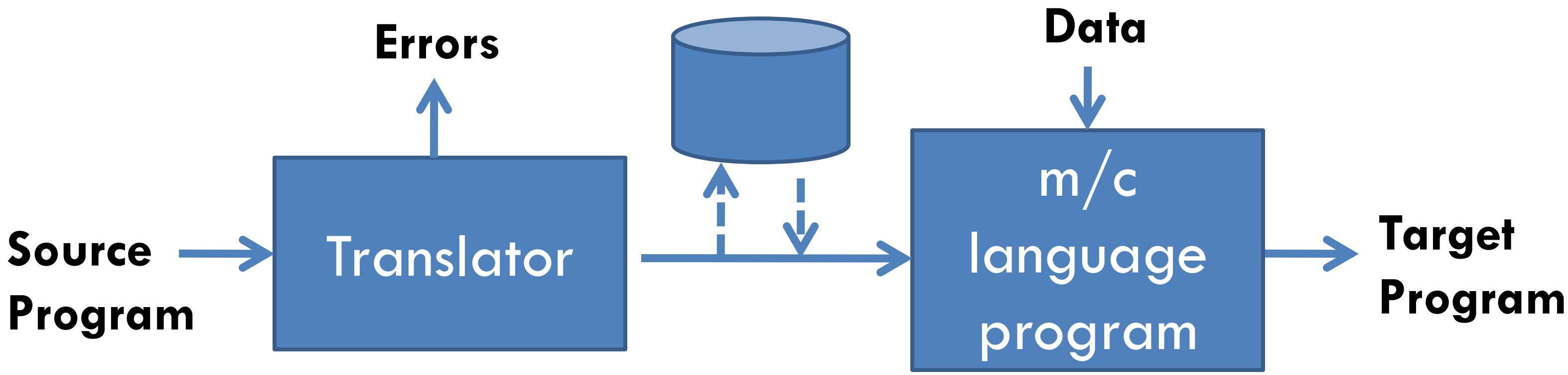
- Program Generation Activities
- Program Execution Activities

Program Generation



Program Execution

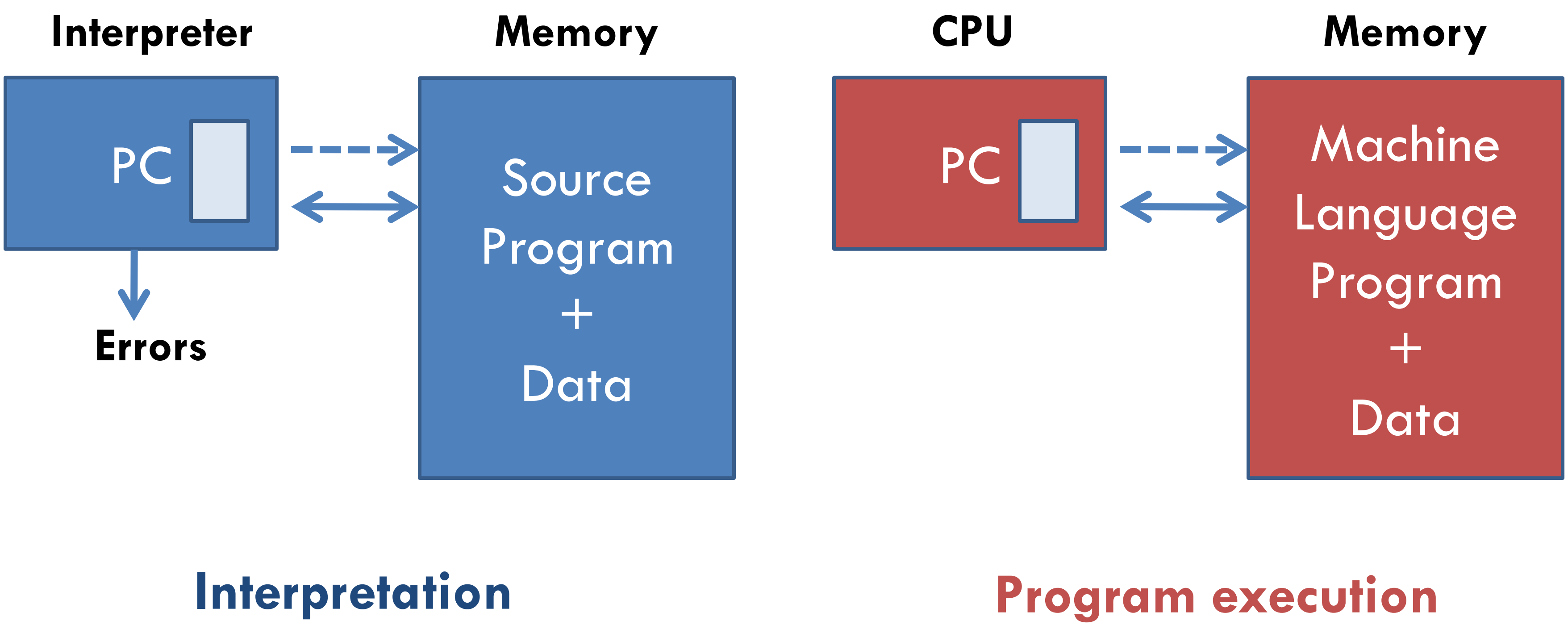
- Two popular models for program execution are translation and interpretation.
- **Program translation**



- A program must be translated before it can be executed.
- The translated program may be saved in a file. The saved program may be executed repeatedly.
- A program must be retranslated following modifications.

Program Execution

- **Program interpretation**



Fundamentals of Language Processing

Language Processing = *Analysis of SP + Synthesis of TP*

Collection of LP components engaged in analysis a source program as the analysis phase and components engaged in synthesizing a target program constitute the synthesis phase.

Analysis Phase

- The specification consists of three components:
  - ***Lexical rules*** which govern the formation of valid lexical units in the source language.
  - ***Syntax rules*** which govern the formation of valid statements in the source language.
  - ***Semantic rules*** which associate meaning with valid statements of the language.

- Consider the following example:

percent_profit = (profit * 100) / cost_price;

Lexical units identifies =, * and / operators, 100 as constant, and the remaining strings as identifiers.

Syntax analysis identifies the statement as an assignment statement with percent_profit as the left hand side and (profit * 100) / cost_price as the expression on the right hand side.

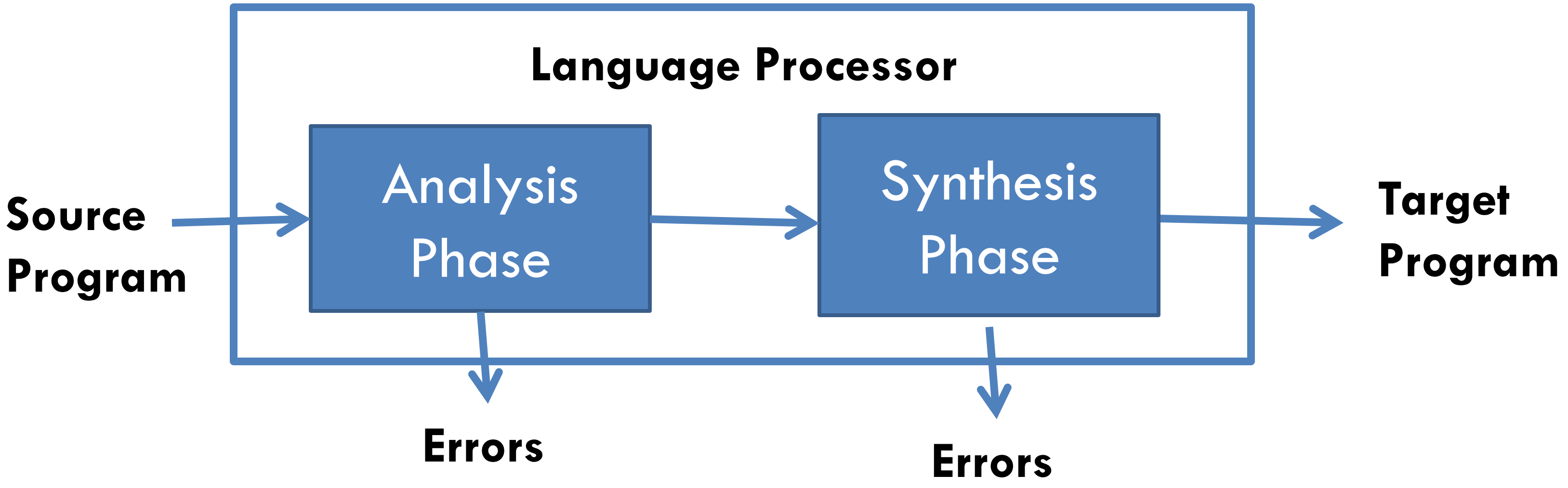
Semantic analysis determines the meaning of the statement to be the assignment of profit X 100 / cost_price to percent_profit.

Synthesis Phase

- The synthesis phase is concerned with the construction of target language statements which have the same meaning as a source statement.
- It performs two main activities:
  - Creation of data structures in the target program (**memory allocation**)
  - Generation of target code (**code generation**)
- Example

```
                        MOVER   AREG, PROFIT
                        MULT    AREG, 100
                        DIV     AREG, COST_PRICE
                        MOVEM   AREG, PERCENT_PROFIT
                        ...
PERCENT_PROFIT          DW      1
PROFIT                  DW      1
COST_PRICE              DW      1
```

Phases and Passes of LP



- Analysis of source statements can not be immediately followed by synthesis of equivalent target statements due to following reasons:
  - Forward References
  - Issues concerning memory requirements and organization of a LP

Lexical Analysis (Scanning)

- It identifies the lexical units in a source statements. It then classifies the units into different lexical classes, e.g. id's, constants, reserved id's, etc. and enters them into different tables.
- It builds a descriptor, called ***token***, for each lexical unit. A token contains two fields – *class code* and *number in class*.
- class code identifies the class to which a lexical unit belongs. number in class is the entry number of the lexical unit in the relevant table.
- We depict a token as Code # no, e.g. Id # 10

Lexical Analysis (Scanning) - Example

i : integer;

a, b : real;

a := b + i;

	Symbol	Type	Length	Address
1	**i**	**int**		
2	**a**	**real**		
3	**b**	**real**		
4	**i ***	**real**		
5	**temp**	**real**		

Note that int i first needed to be converted into real, that is why 4th entry is added into the table.

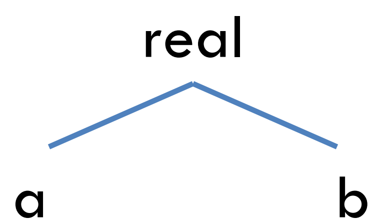
Addition of entry 3 and 4, gives entry 5 (temp), which is value b + (i *).

The statement a := b+i; is represented as the string of tokens

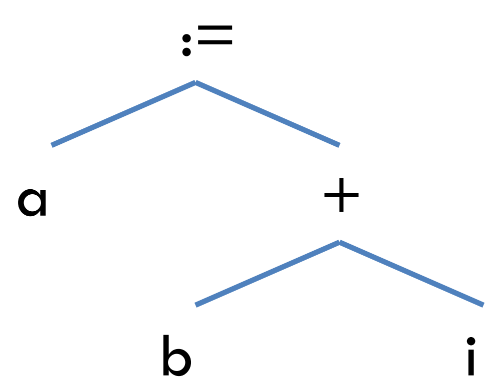
Id#2	Op#5	Id#3	Op#3	Id#1	Op#10

Syntax Analysis (Parsing)

- It processes the string of tokens built by lexical analysis to determine the ***statement class***, e.g. assignment statement, if statement etc.
- It then builds an IC which represents the structure of a statement. The IC is passed to semantic analysis to determine the meaning of the statement.



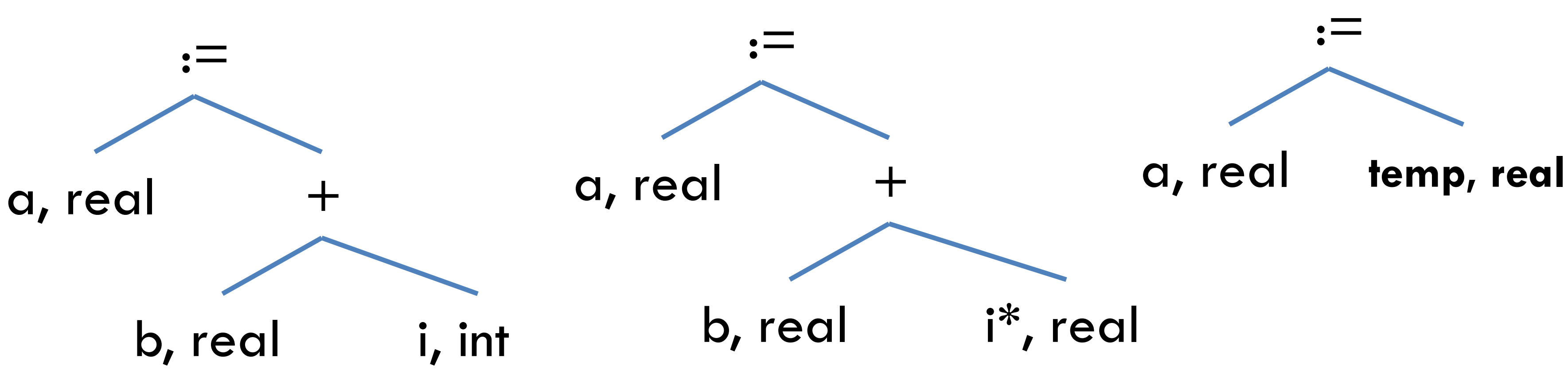
a, b : real



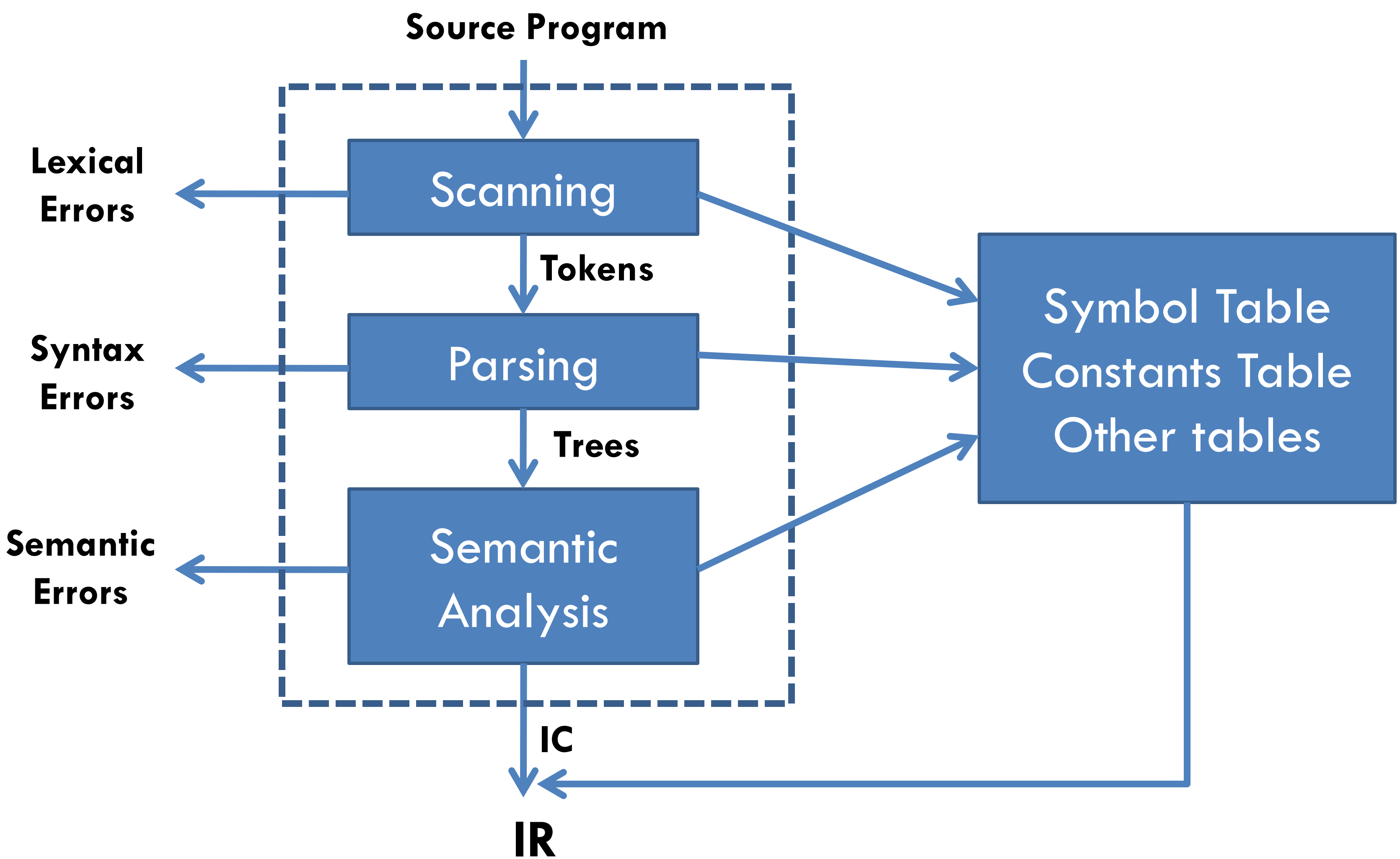
a := b + i

Semantic Analysis

- It identifies the sequence of actions necessary to implement the meaning of a source statement.
- It determines the meaning of a sub tree in the IC, it adds information to a table or adds an action to the sequence of actions. The analysis ends when the tree has been completely processed.



Analysis Phase (Front end)



Synthesis Phase (Back end)

- It performs memory allocation and code generation.

- **Memory Allocation**
  - The memory requirement of an identifier is computed from its type, length and dimensionality and memory is allocated to it.
  - The address of the memory area is entered in the symbol table.

	Symbol	Type	Length	Address
1	i	int		2000
2	a	real		2001
3	b	Real		2002

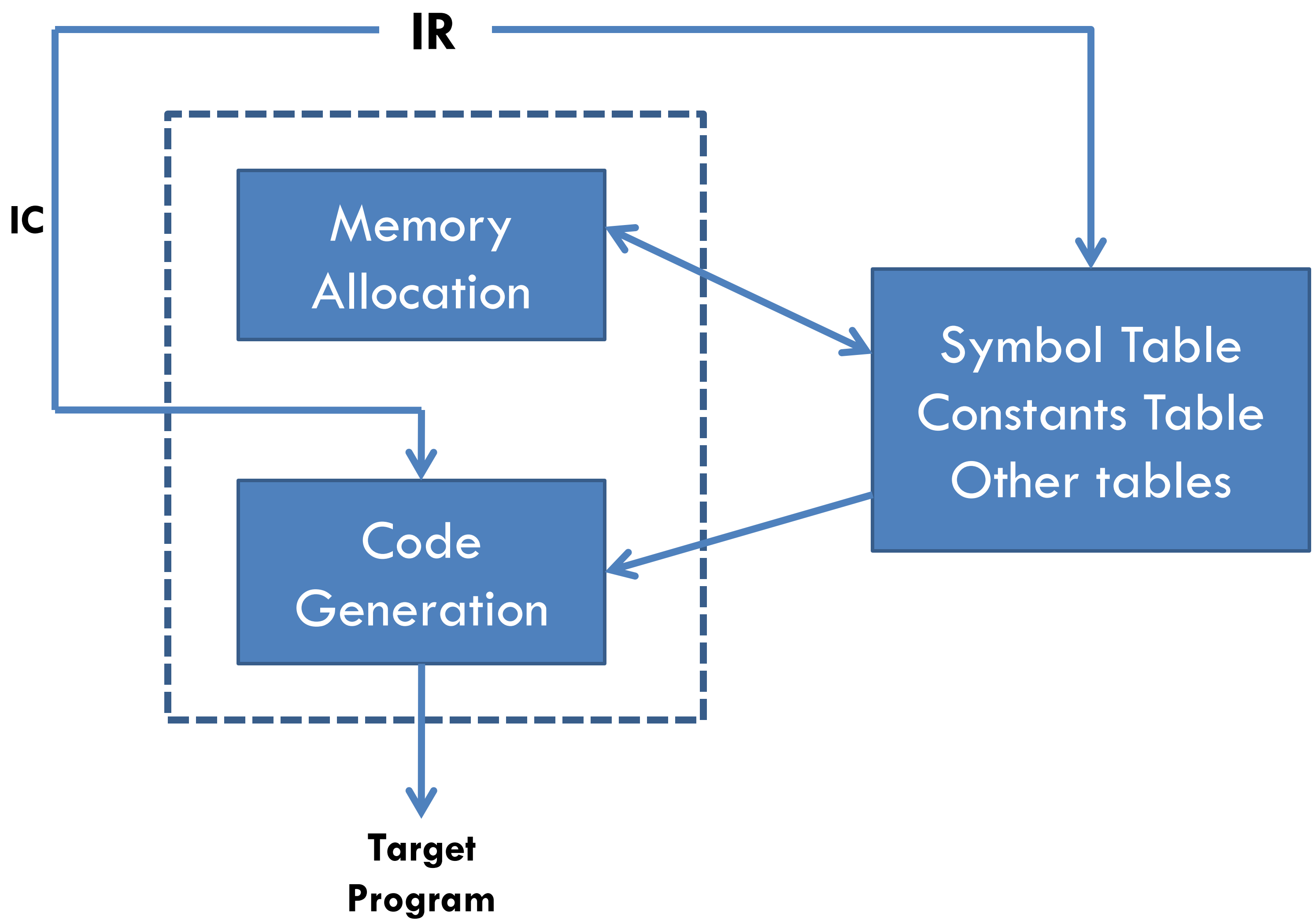
Synthesis Phase (Back end)

Code Generation

- It uses knowledge of the target architecture, viz. knowledge of instructions and addressing modes in the target computer, to select the appropriate instructions.
- The synthesis phase may decide to hold the values of i* and temp in machine registers and may generate the assembly code.
- a := b + i;

```
CONV_R      AREG, I
ADD_R       AREG, B
MOVEM       AREG, A
```

Synthesis Phase (Back end)



Fundamentals of Language Specification

- PL Grammars
  - The lexical and syntactic features of a programming language are specified by its grammar.
  - A language L can be considered to be a collection of valid sentences.
  - Each sentence can be looked upon as a sequence of words, and each word as a sequence of letters or graphic symbols acceptable in L.
  - A language specified in this manner is known as a *formal language*.

Alphabet

- The alphabet of L, denoted by the Greek symbol ∑ is the collection of symbols in its character set.
- We use lower case letters a, b, c, etc. to denote symbols in ∑
- A symbol in the alphabet is known as a ***terminal symbol*** (T) of L.
- The alphabet can be represented using mathematical notation of a set, e.g.

∑ = { a, b, …, z, 0, 1, …, 9 }

where {, “,”, } are called *meta symbols*.

String

- A string is a finite sequence of symbols.
- We represent strings by Greek symbols α, β, γ, etc. Thus α= axy is a string over $\sum$
- The length of a string is the number of symbols in it.
- Absence of any symbol is also a string, null string ε.
- Example

$$\alpha = ab, \beta = axy$$

$$\alpha\beta = \alpha.\beta = abaxy \text{ [concatenation]}$$

Nonterminal symbols

- A Nonterminal symbol (NT) is the name of a syntax category of a language, e.g. noun, verb, etc.
- An NT is written as a single capital letter, or as a name enclosed between <…>, e.g. A or <Noun>.
- It is a set of symbols not in ∑ that represents intermediate states in the generation process.

Productions

- A production, also called a rewriting rule, is a rule of the grammar.
- It has the form

A nonterminal symbol ::= String of Ts and NTs

↓ L.H.S. ↓ R.H.S.

e.g. <article> ::= a | an | the

<Noun> ::= boy | apple

<Noun Phrase> ::= <article> <Noun>

Derivation, Reduction and Parse Trees

- A grammar G is used for two purposes, to generate valid strings of L_G and to 'recognize' valid strings of L_G.
- The derivation operation helps to generate valid strings while the reduction operation helps to recognize valid strings.
- A parse tree is used to depict the syntactic structure of a valid string as it emerges during a sequence of derivations or reductions.

Derivation

- Let production P_1 of grammar G be of the form

  P_1 : A::= α

  and let β be a string such that β = γAθ, then replacement of A by α in string β constitutes a derivation according to production P_1.
- Example

  <Sentence> ::= <Noun Phrase><Verb Phrase>

  <Noun Phrase> ::= <Article> <Noun>

  <Verb Phrase> ::= <Verb><Noun Phrase>

  <Article> ::= a | an | the

  <Noun> ::= boy | apple

  <Verb> ::= ate

Derivation

- The following strings are ***sentential forms*** of LG.

  <Noun Phrase> <Verb Phrase>

  the boy <Verb Phrase>

  <Noun Phrase> ate <Noun Phrase>

  the boy ate <Noun Phrase>

  sentential forms

  the boy ate an apple ← **sentence**

Reduction

Let production P_1 of grammar G be of the form

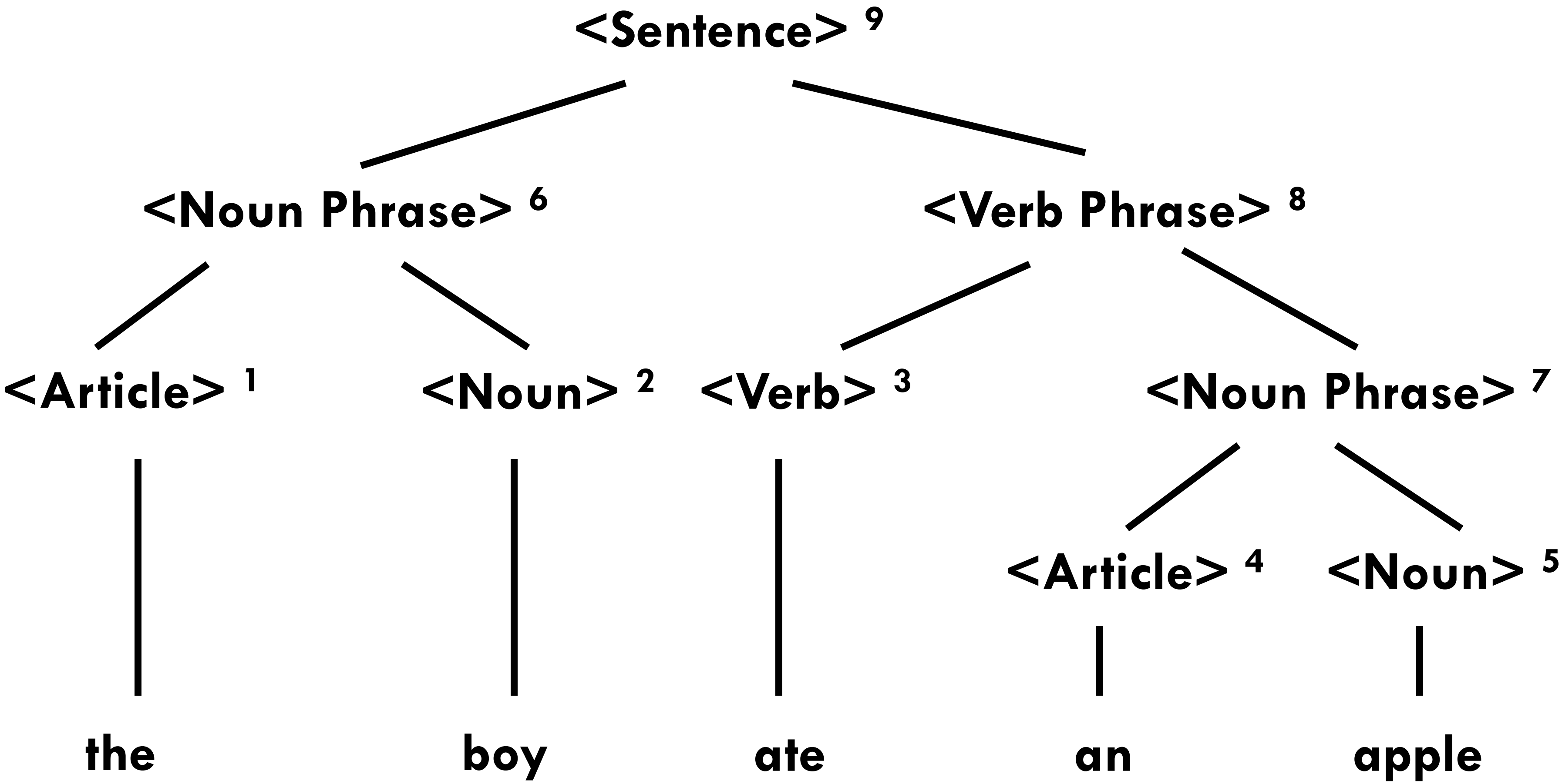
$P_1 : A ::= \alpha$

and let σ be a string such that $\sigma = \gamma A \theta$, then replacement of α by A in string σ constitutes a reduction according to production P_1.

Step	String
0	the boy ate an apple
1	<Article> boy ate an apple
2	<Article> <Noun> ate an apple
3	<Article> <Noun> <Verb> an apple
4	<Article> <Noun> <Verb> <Article> apple
5	<Article> <Noun> <Verb> <Article> <Noun>
6	<Noun Phrase> <Verb> <Article> <Noun>
7	<Noun Phrase> <Verb> <Noun Phrase>
8	<Noun Phrase> <Verb Phrase>
9	<Sentence>

Parse Trees

- A sequence of derivations or reductions reveals the syntactic structure of a string with respect to G, in the form of a parse tree.



Classification of Grammars

- Type-0 grammar (Phrase Structure Grammar)

  $\alpha ::= \beta$, where both can be strings of Ts and NTs.

  But it is not relevant to specification of Prog. Lang.
- Type-1 grammar (Context Sensitive Grammar)

  $\alpha A \beta ::= \alpha \pi \beta$,

  But it is not relevant to specification of Prog. Lang.
- **Type-2 grammar (Context Free Grammar)**

  $A ::= \pi$, which can be applied independent of its context.

  CFGs are ideally suited for PL specifications.
- Type-3 grammar (Linear or Regular Grammar)

  $A ::= t\ B \mid t$ OR $A ::= B\ t \mid t$

  Nesting of constructs or matching of parentheses cannot be specified using such productions.

Ambiguity in Grammatic Specification

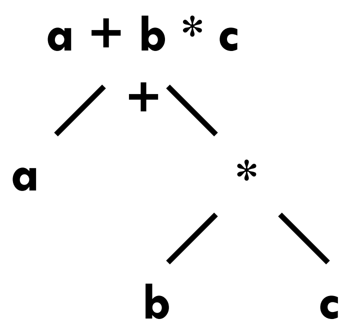
- It implies the possibility of different interpretation of a source string.
- Existence of ambiguity at the level of the syntactic structure of a string would mean that more than one parse tree can be built for the string. So string can have more than one meaning associated with it.

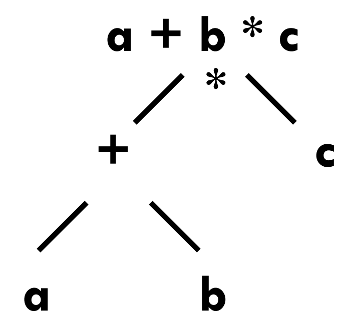
Ambiguous Grammar

E → id | E + E | E * E

Id → a | b | c

Assume source string is a + b * c





Eliminating Ambiguity – An Example

Unambiguous Grammar

E → E + T | T

T → T * F | F

F → F ^ P | P

P → id

id → a | b | c

a + b * c

⇒ **id + id * id**

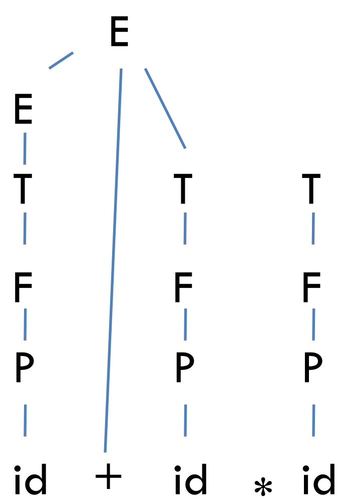
⇒ **P + P * P**

⇒ **F + P * P**

⇒ **T + F * F**

⇒ **E + T * T**

⇒ **E * T (?? Ambiguous)**



a + b * c

⇒ **id + id * id**

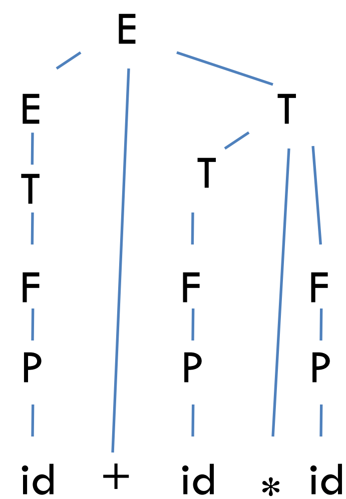
⇒ **P + P * P**

⇒ **F + F * P**

⇒ **T + T * F**

⇒ **E + T**

⇒ **E (Unambiguous)**



GTU Examples

- List out the unambiguous production rules (grammar) for arithmetic expression containing +, –, *, / and ^ (exponent).

  E → E + T | E – T | T

  T → T * F | T / F | F

  F → F ^ P | P

  P → (E) | <id>

  Derive string <id> – <id> * <id> ^ <id> + <id>

E → E + T

→ E – T + T

→ T – T + T

→ F – T + T

→ P – T + T

→ <id> – T + T

→ <id> – T * F + T

→ <id> – F * F + T

→ <id> – P * F + T

→ <id> – <id> * F + T

→ <id> – <id> * F ^ P + T

→ <id> – <id> * P ^ P + T

→ <id> – <id> * <id> ^ P + T

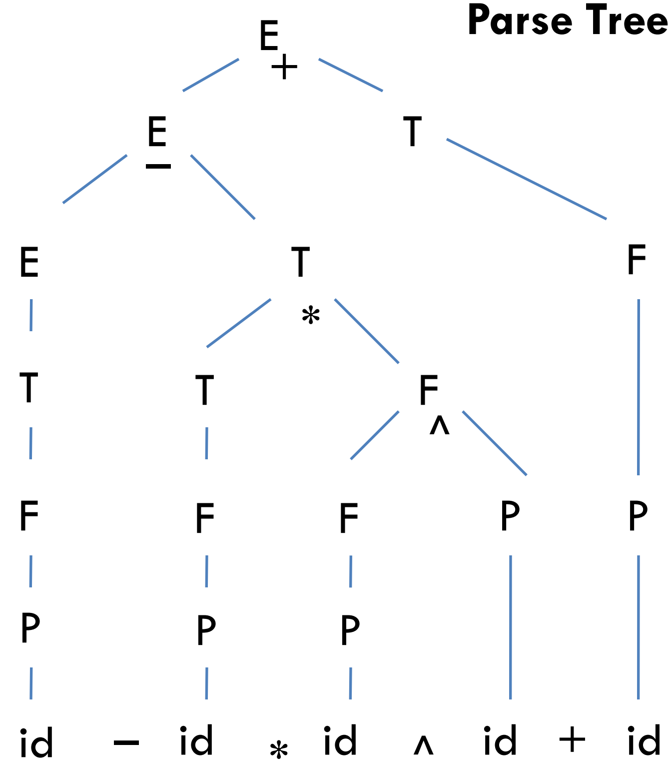
→ <id> – <id> * <id> ^ <id> + T

→ <id> – <id> * <id> ^ <id> + F

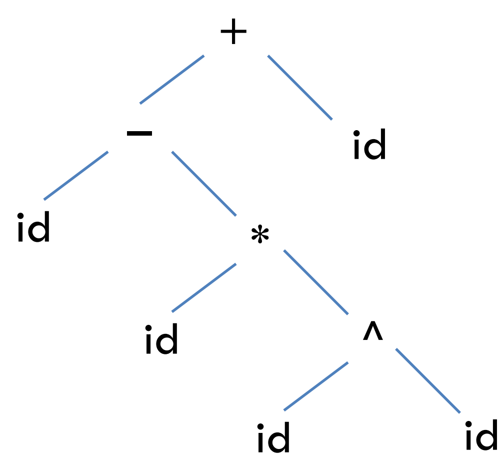
→ <id> – <id> * <id> ^ <id> + P

→ <id> – <id> * <id> ^ <id> + <id>

Parse Tree



Abstract Syntax Tree



Another Example

- Consider the following grammar:

$$S \rightarrow a\ S\ b\ S \mid b\ S\ a\ S \mid \varepsilon$$

Derive the string ***abab.*** Draw corresponding parse tree. Are these rules ambiguous ? Justify.

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