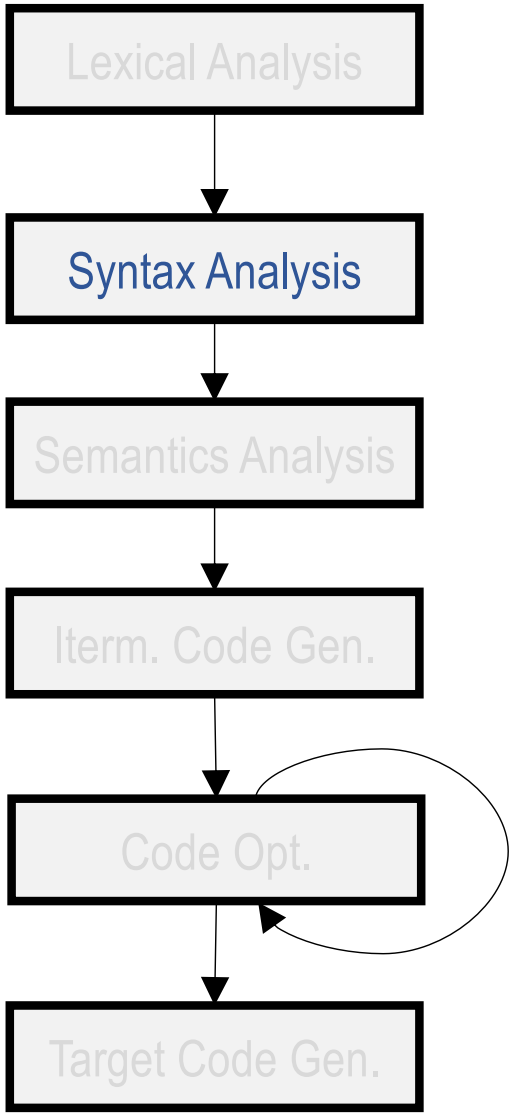
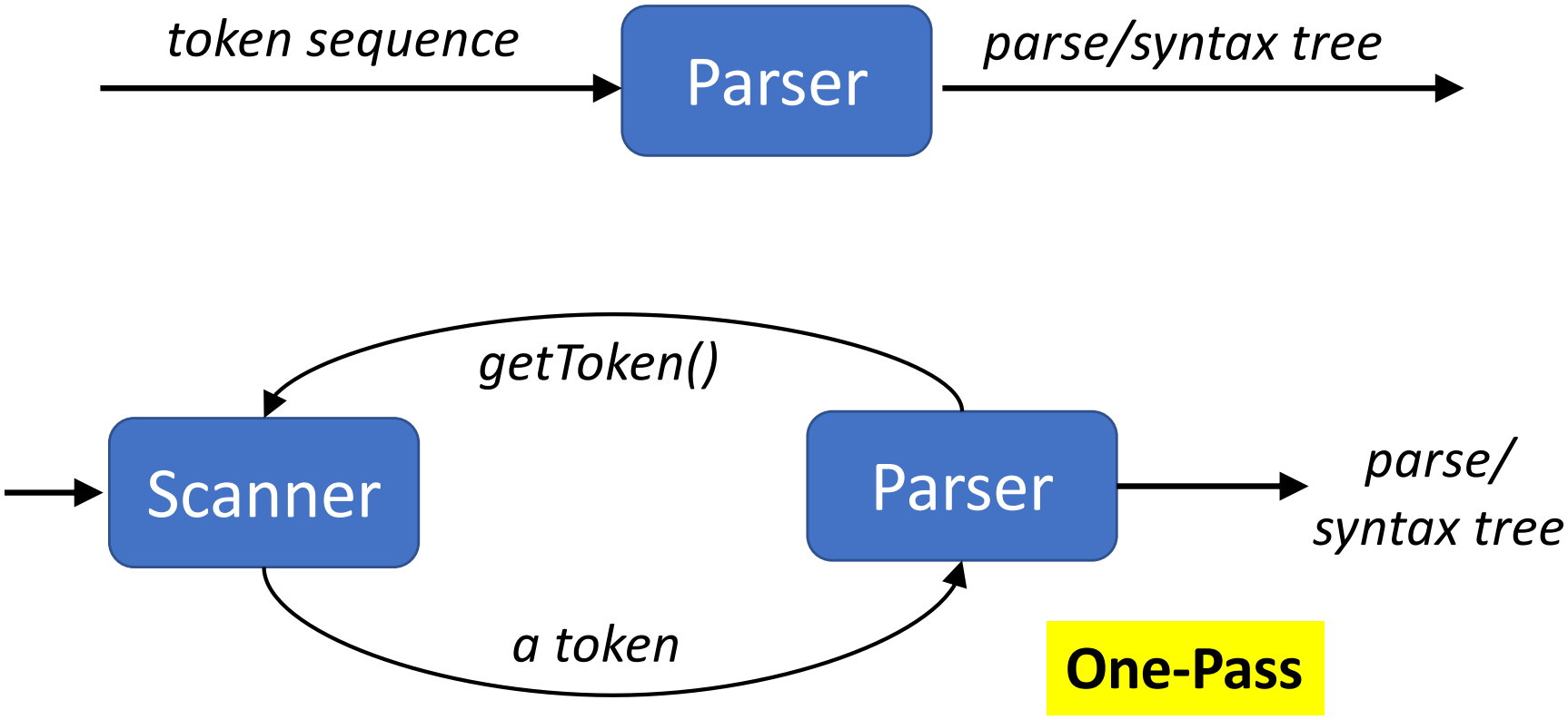
Syntax Analysis

(Chapters 3-5)



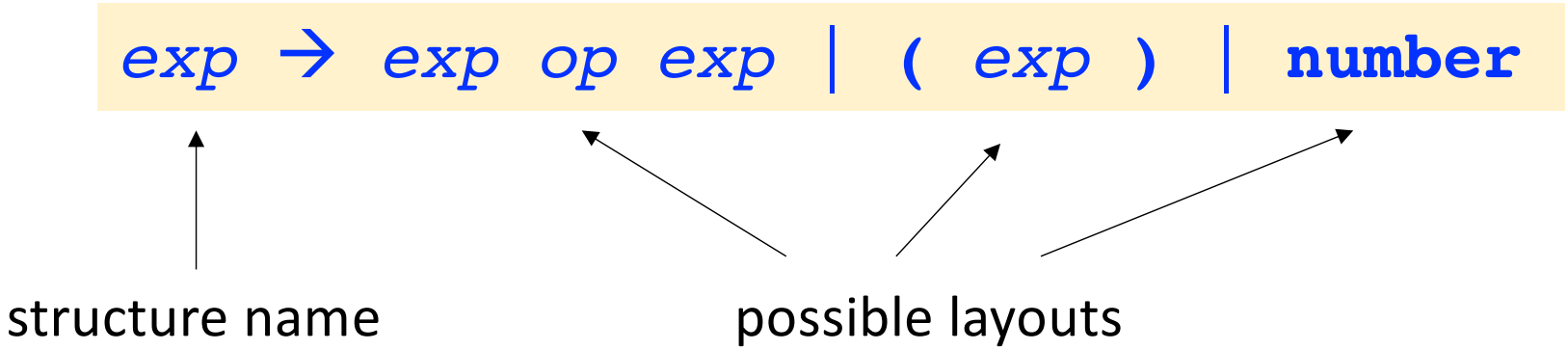
Parsing

- Determine the syntax (structure) of a program based on the token sequence; Typically, parser drives scanner



Context-Free Grammars

- A Rule in BNF
  - left-hand side (**LHS**) defines the name of a structure (**nonterminal**)
  - right-hand side (**RHS**) gives its possible layouts (sequence of **terminals** & **nonterminals**)



Context-Free Grammars

- Derivation
  - a sequence of replacements of structure names by layouts on RHS, starting from the ***start nonterminal***

Start Nonterminal

exp ⇒ *exp op exp*
⇒ *exp op number*
⇒ *number op number*
⇒ *number * number*

a legal token string with terminals only

(1) *exp* → *exp op exp*
(2) *exp* → (*exp*)
(3) *exp* → **number**
(4) *op* → +
(5) *op* → -
(6) *op* → *

CFG

Context-Free Grammars

- Derivation
  - **Leftmost derivation**: the leftmost nonterminal is replaced in each step

```
exp ⇒ exp op exp
    ⇒ ( exp ) op exp
    ⇒ ( exp op exp ) op exp
    ⇒ ( number op exp ) op exp
    ⇒ ( number - exp ) op exp
    ⇒ ( number – number ) op exp
    ⇒ ( number – number ) * exp
    ⇒ ( number – number ) * number
```

```
(1) exp → exp op exp
(2) exp → ( exp )
(3) exp → number
(4) op → +
(5) op → -
(6) op → *
```

CFG

Context-Free Grammars

- Derivation
  - **Rightmost derivation**: the rightmost nonterminal is replaced in each step

```
exp ⇒ exp op exp
    ⇒ exp op number
    ⇒ exp * number
    ⇒ ( exp ) * number
    ⇒ ( exp op exp ) * number
    ⇒ ( exp op number ) * number
    ⇒ ( exp – number ) * number
    ⇒ ( number – number ) * number
```

```
(1) exp → exp op exp
(2) exp → ( exp )
(3) exp → number
(4) op → +
(5) op → -
(6) op → *
```

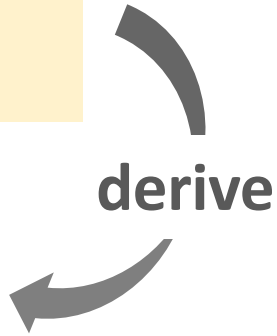
CFG

Context-Free Grammars

- Language
  - the set of *token strings* obtained from ***all possible derivations*** is the ***language*** defined by the CFG

$$\mathbf{L(G) = \{\ s \mid exp \Rightarrow^* s\}}$$

```
exp → exp op exp | ( exp ) | number
op → + | - | *
```

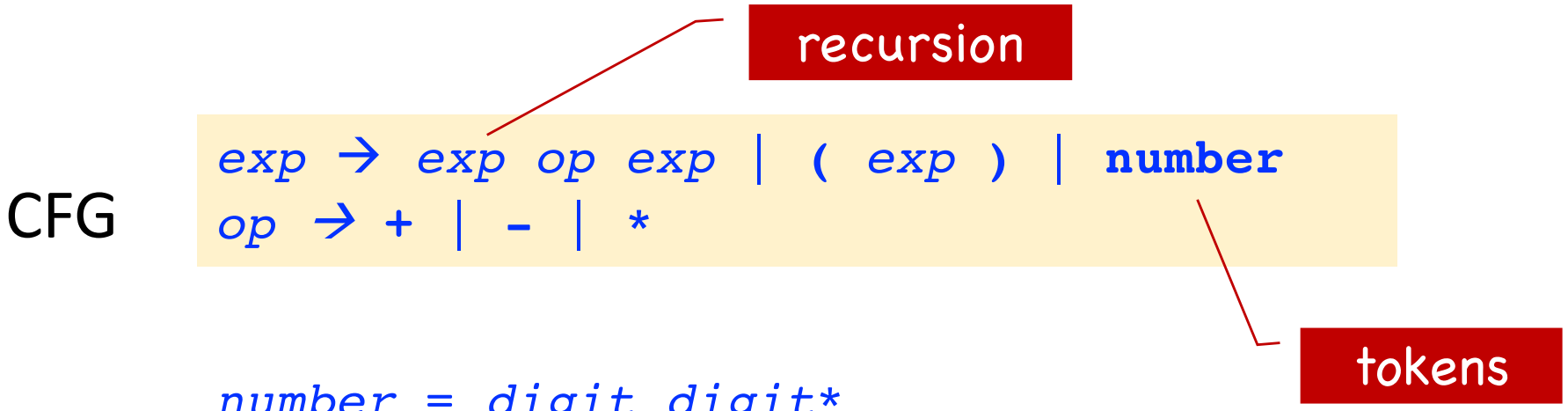


(number - number) * number

a legal token string

Context-Free Grammars

- Comparison to Regex
  - both use alternation, concatenation, and name
  - no repetition "*", but recursion ("→" instead of "=")
  - more powerful (balanced parentheses S → (S) S | ε)
  - terminals are tokens



Context-Free Grammars

- Example
  - Nested if-statments in a C-like form

```
statement → if-stmt | other
if-stmt → if ( exp ) statement
          | if ( exp ) statement else statement
exp → 0 | 1
```

```
other
if (0) other
if (1) other
if (0) other else other
if (0) if (0) other
...
```

Context-Free Grammars

- Example
  - A sequence of statements

```
;
s;
s;s;
s;s;s;
...
```

stmt_sequence → *stmt* **;** *stmt-sequence* | *stmt* **;**
stmt → **s** | **ε**

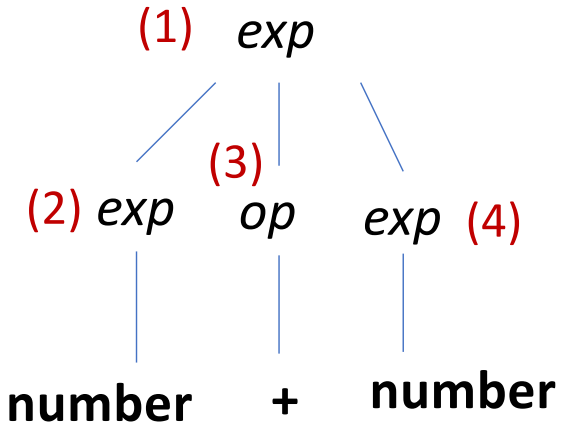
Parse/Syntax Tree

Parse Tree

- A labeled tree corresponding to a derivation
  - **Internal nodes**: nonterminals
  - **Leaf nodes:** terminals
  - **Children – parent relation**: a derivation step

(1) *exp* ⇒ *exp op exp*
(2) ⇒ **number** *op exp*
(3) ⇒ **number + *exp***
(4) ⇒ **number + number**

Leftmost Derivation

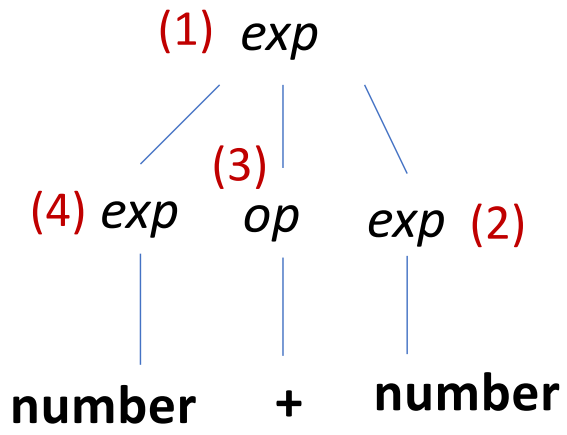


Parse Tree

- A labeled tree corresponding to a derivation
  - **Internal nodes**: nonterminals
  - **Leaf nodes:** terminals
  - **Children – parent relation**: a derivation step

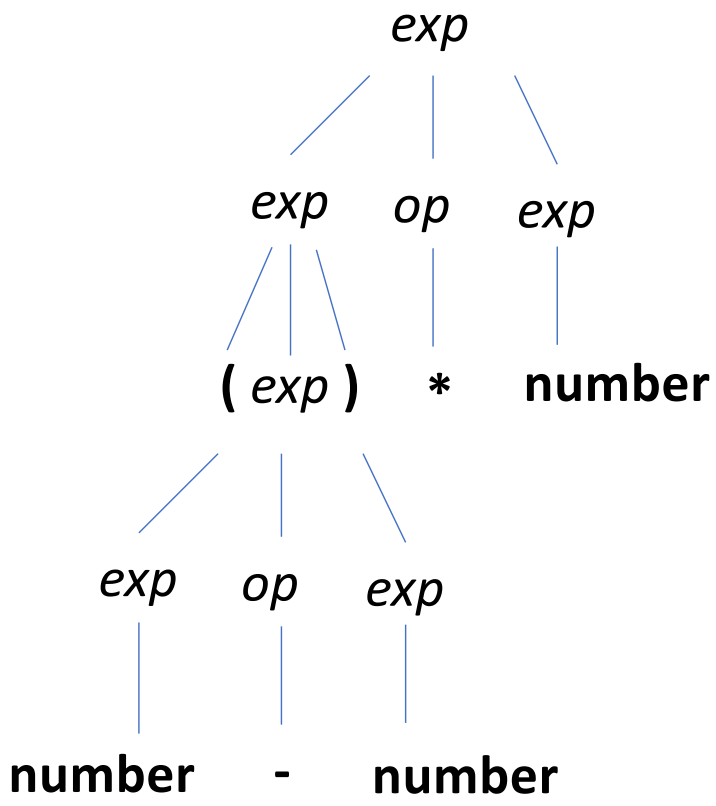
(1) *exp* ⇒ *exp op exp*
(2) ⇒ *exp op* **number**
(3) ⇒ *exp* **+ number**
(4) ⇒ **number + number**

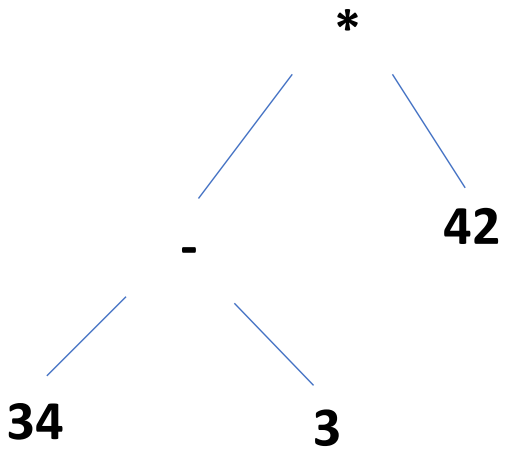
Rightmost Derivation



Parse Tree

- **Issue:** match derivation well, but not in a concise form





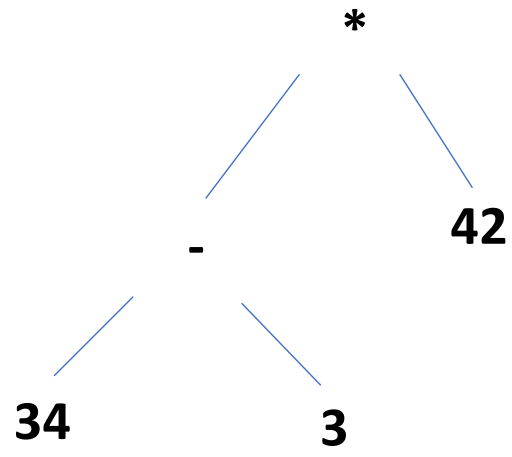
Abstract Syntax Tree (AST)

- a.k.a. Syntax Tree
  - abstract syntactic structure (may miss some syntax details)
  - token sequence may NOT be recoverable from the AST
  - still contains all necessary info for translation

```
(34 – 3) * 42
```

```
((34 – 3)) * 42
```

```
((34 – 3) * 42)
```



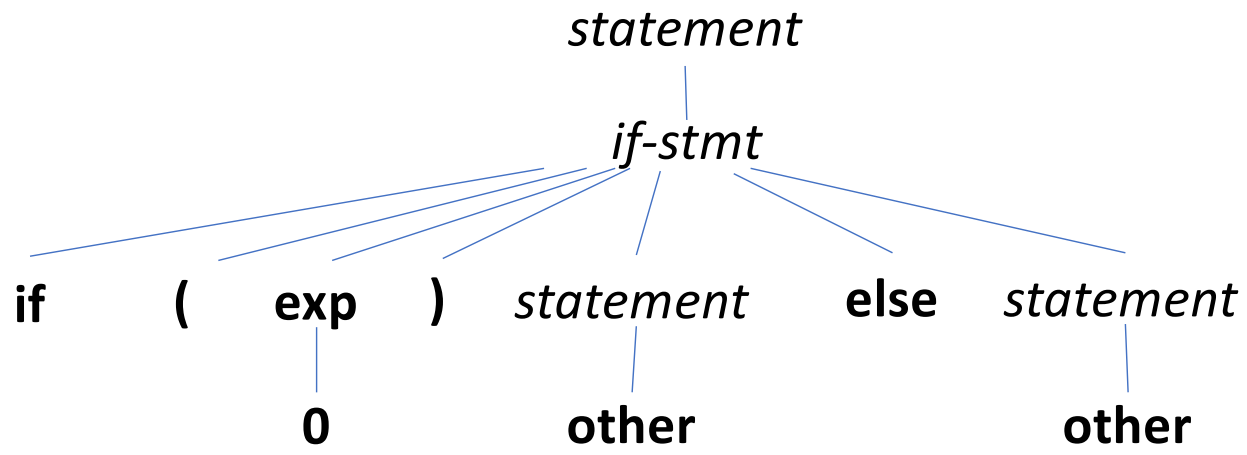
Abstract Syntax Tree (AST)

- 2nd Example

```
if (0) other else other
```

```
statement → if-stmt | other
if-stmt → if ( exp ) statement
        | if ( exp ) statement else statement
exp → 0 | 1
```

Parse Tree



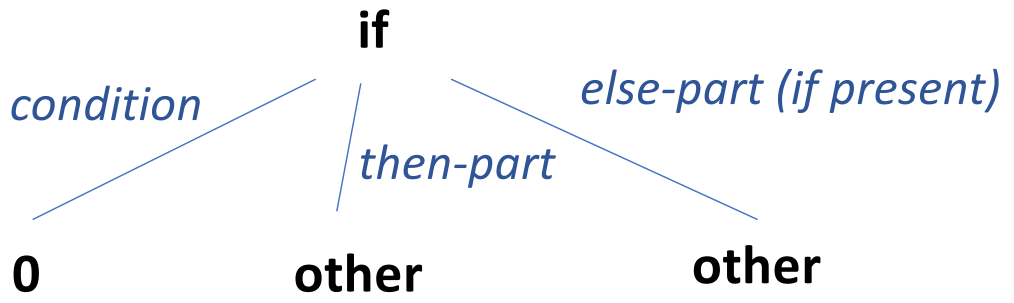
Abstract Syntax Tree (AST)

- 2nd Example

```
if (0) other else other
```

```
statement → if-stmt | other
if-stmt → if ( exp ) statement
          | if ( exp ) statement else statement
exp → 0 | 1
```

AST



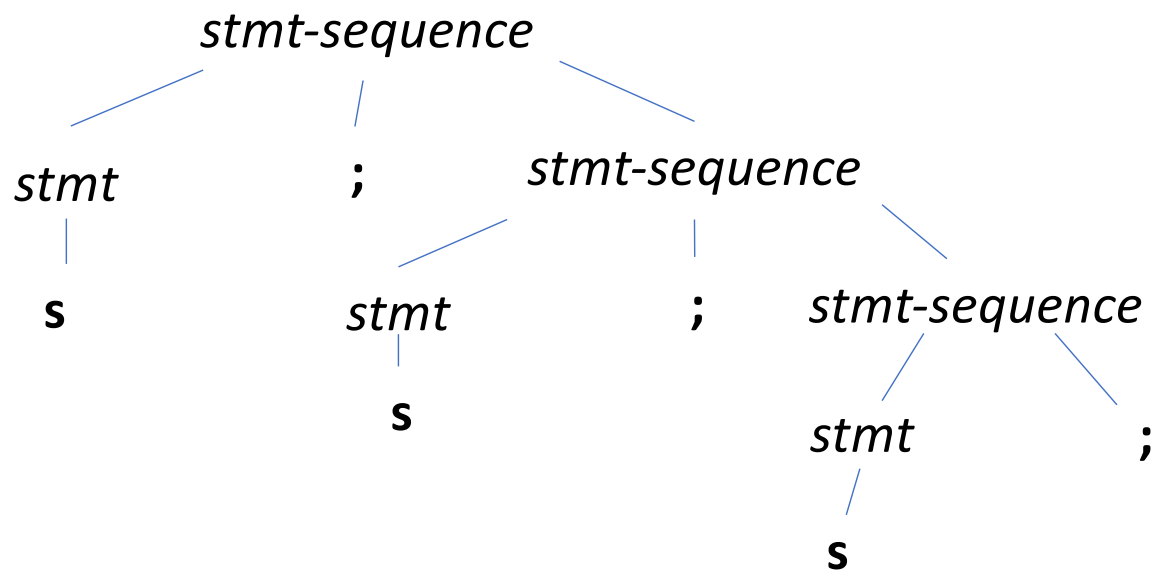
Abstract Syntax Tree (AST)

- 3rd Example

```
s;s;s;
```

stmt_sequence → *stmt;* *stmt-sequence* | *stmt;*
stmt → **s** | ε

Parse Tree

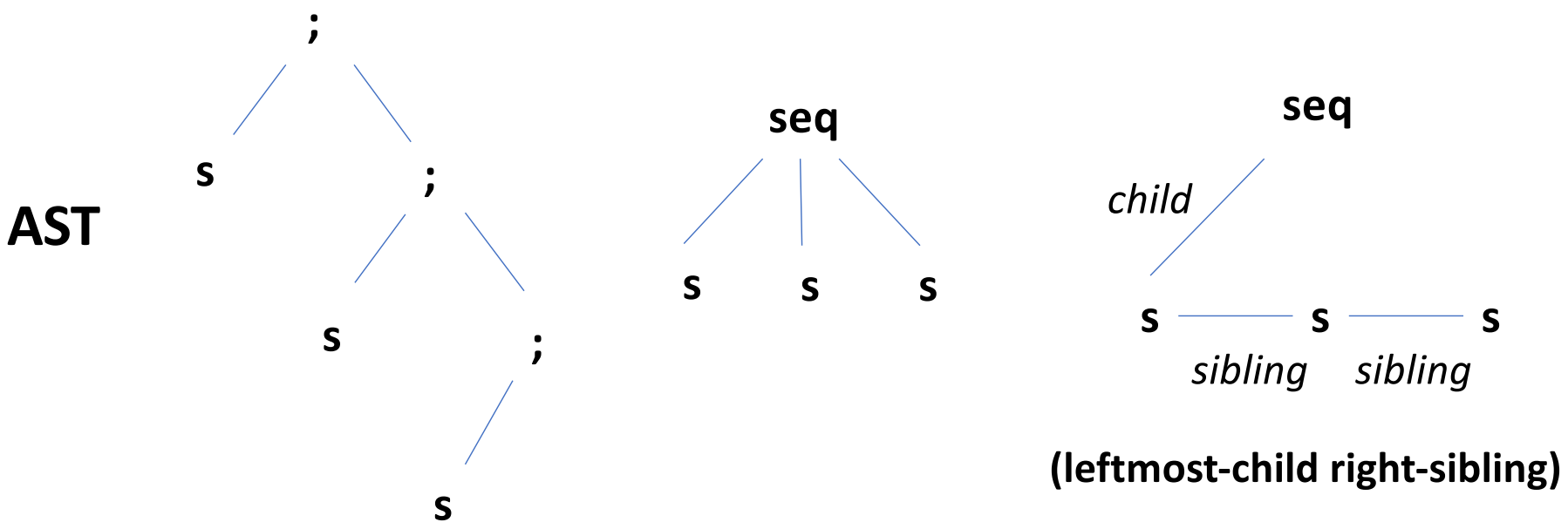


Abstract Syntax Tree (AST)

- 3rd Example

```
s;s;s;
```

stmt_sequence → *stmt;* *stmt-sequence* | *stmt;*
stmt → **s** | ε



Ambiguous Grammar

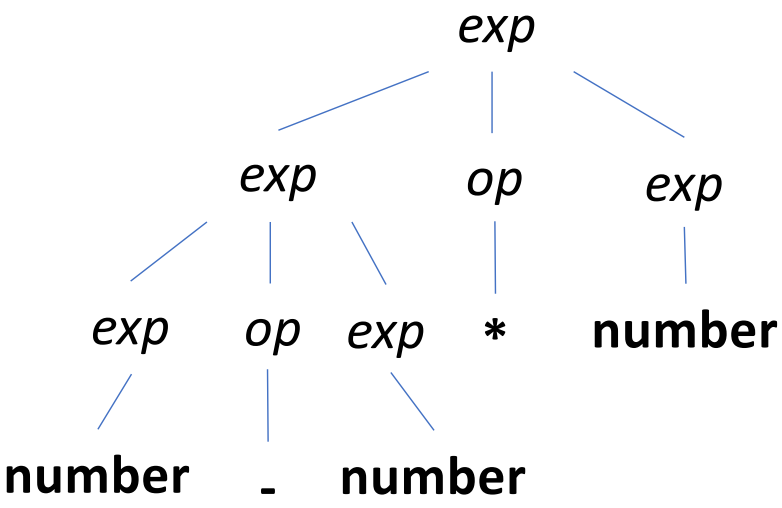
Ambiguous Grammar

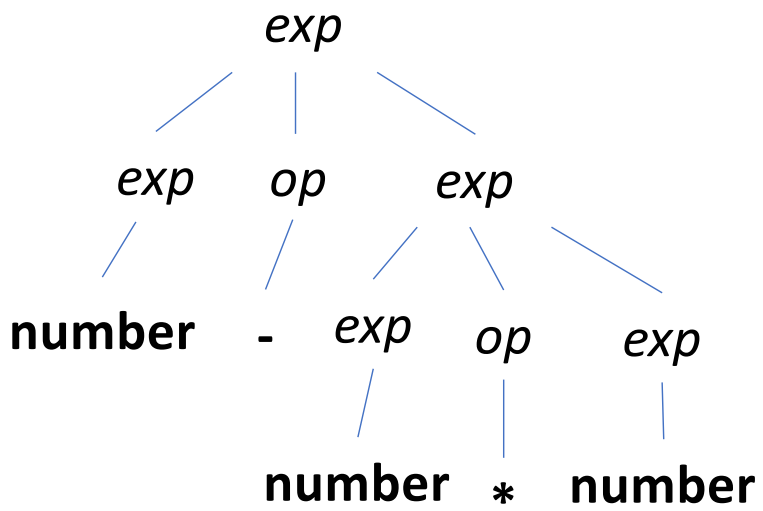
- A grammar allowing a string to have

  more than one parse tree

```
exp → exp op exp | ( exp ) | number
op → + | - | * | /
```

```
34 – 3 * 42
```





Ambiguous Grammar

- A grammar allowing a string to have

  more than one parse tree

```
exp → exp op exp | ( exp ) | number
op → + | - | * | /
```

```
34 – 3 * 42
```

Ambiguous Grammar

- Problem – multiple leftmost / multiple rightmost derivations

```
exp → exp op exp | ( exp ) | number
op → + | - | * | /
```

```
34 – 3 * 42
```

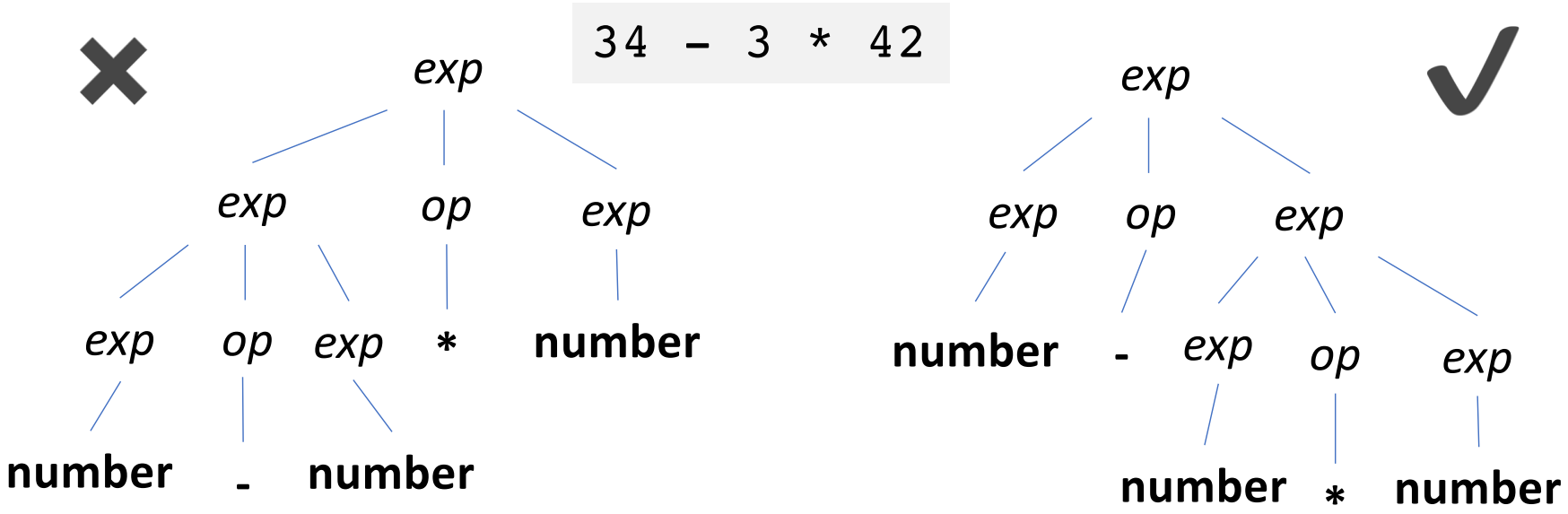
```
exp ⇒ exp op exp
    ⇒ exp op exp op exp
    ⇒ number op exp op exp
    ⇒ number – exp op exp
    ⇒ number – number op exp
    ⇒ number – number * exp
    ⇒ number – number * number
```

```
exp ⇒ exp op exp
    ⇒ number op exp
    ⇒ number – exp
    ⇒ number – exp op exp
    ⇒ number – number op exp
    ⇒ number – number * exp
    ⇒ number – number * number
```

Two leftmost derivations

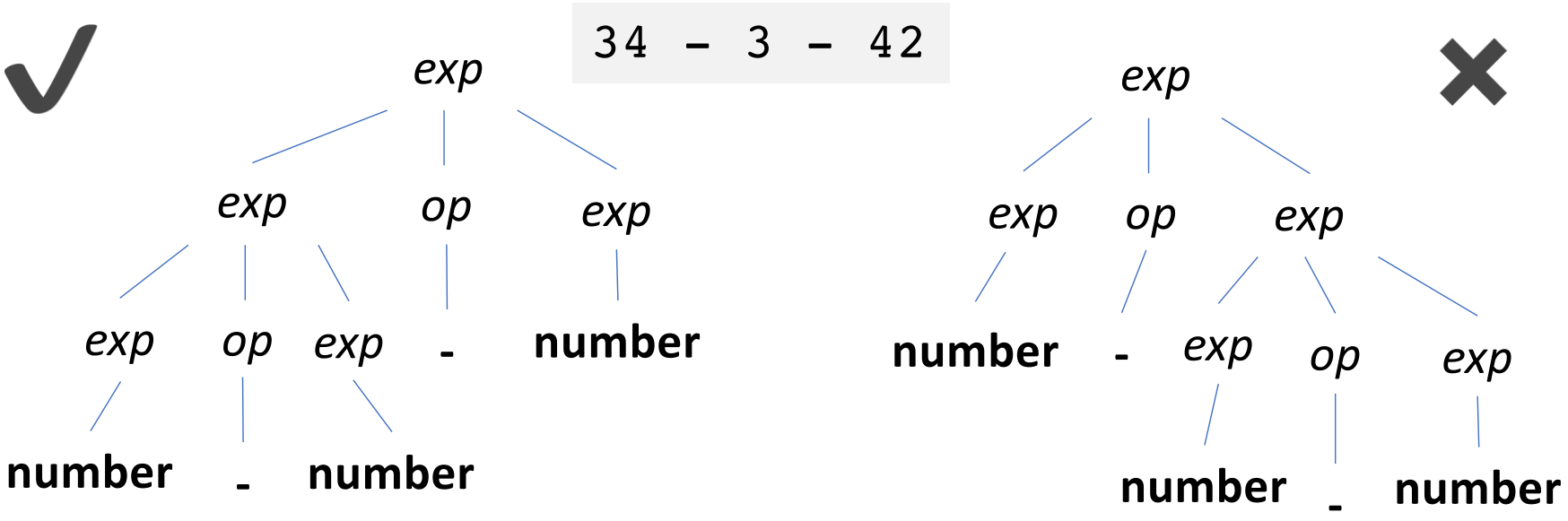
Ambiguous Grammar

- **Disambiguation rule needed** → * has **precedence** over –



Ambiguous Grammar

- **Disambiguation rule needed** → **–** is **left associative**: left to right calculation



Ambiguous Grammar

- **Add disambiguation rules to grammars**

`*` **and** `/` have **precedence** over `–` and `+`

`–` and `/` are **left associative**

```
exp → exp op exp | ( exp ) | number
op → + | - | * | /
```

Ambiguous Grammar

Precedence Rules

Rewrite the grammar

group operators of same precedence;

write a different production rule for each precedence group

```
exp → exp op exp | ( exp ) | number
op → + | - | * | /
```

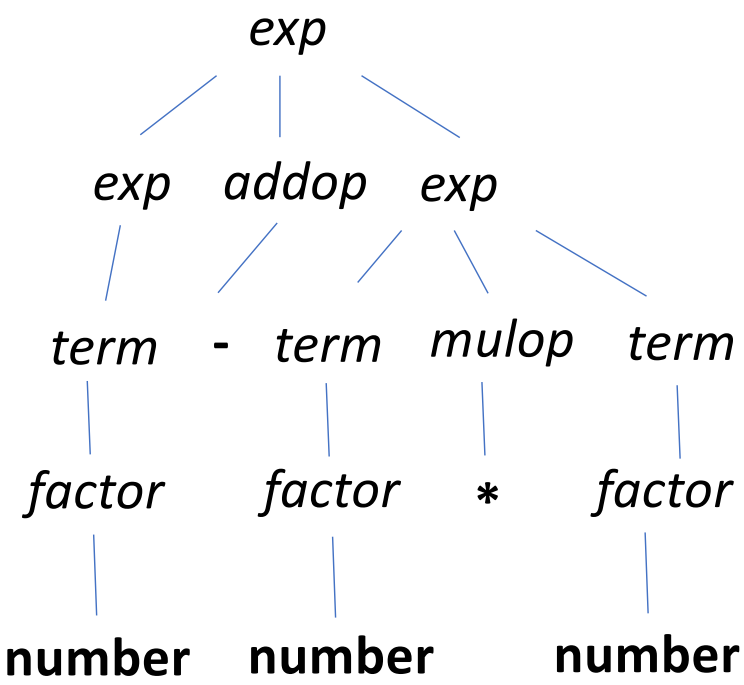
```
exp → exp addop exp | term
addop → + | -
term → term mulop term | factor
mulop → * | /
factor → ( exp ) | number
```

Ambiguous Grammar

- What is the parse tree with the new grammar?

```
34 - 3 * 42
```

```
exp → exp addop exp | term
addop → + | -
term → term mulop term | factor
mulop → * | /
factor → ( exp ) | number
```



Ambiguous Grammar

- Some ambiguity still exists due to associativity rules

```
34 - 3 - 42
```

```
exp → exp addop exp | term
addop → + | -
term → term mulop term | factor
mulop → * | /
factor → ( exp ) | number
```

recursion occuring on both sides

Ambiguous Grammar

- Associativity Constraints
  - **Rewrite the grammar**

    Replace one of the recurisons with the base case

```
exp → exp op exp | ( exp ) | number
op → + | - | * | /
```

```
exp → exp addop term | term
addop → + | -
term → term mulop factor | factor
mulop → * | /
factor → ( exp ) | number
```

Ambiguous Grammar

- Example parse tree for the new grammar

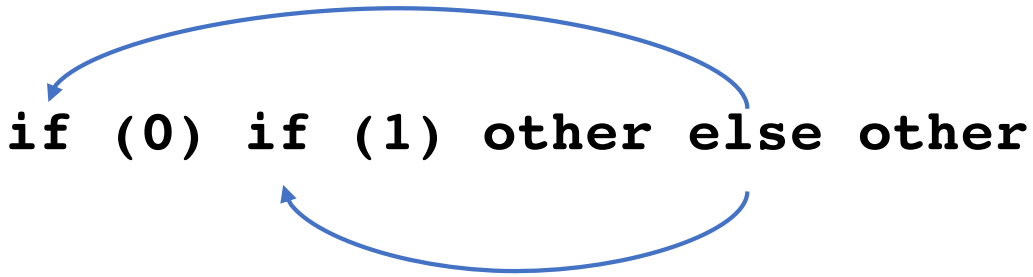
```
34 - 3 - 42
```

```
exp → exp addop term | term
addop → + | -
term → term mulop factor | factor
mulop → * | /
factor → ( exp ) | number
```

Ambiguous Grammar

- Revisit the if-statments

```
statement → if-stmt | other
if-stmt → if ( exp ) statement
          | if ( exp ) statement else statement
exp → 0 | 1
```

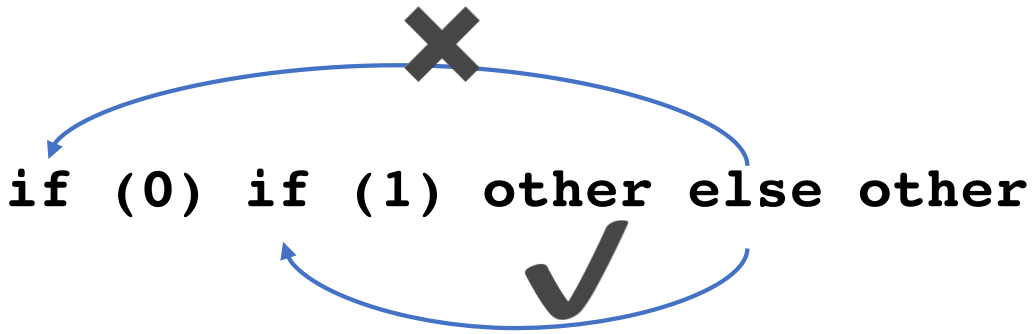


"Dangling Else" Problem

Ambiguous Grammar

- Revisit the if-statments

```
statement → if-stmt | other
if-stmt → if ( exp ) statement
          | if ( exp ) statement else statement
exp → 0 | 1
```



disambiguation rule: most closely nested rule

Ambiguous Grammar

- Revisit the if-statments

```
statement → if-stmt | other
if-stmt → if ( exp ) statement
          | if ( exp ) statement else statement
exp → 0 | 1
```

```
statement → matched-stmt | unmatched-stmt
matched-stmt → if (exp) matched-stmt else matched-stmt
             | other
unmatched-stmt → if (exp) statement
           | if (exp) matched-stmt else unmatched-stmt
exp → 0 | 1
```

Harder to write (often not used in practice)

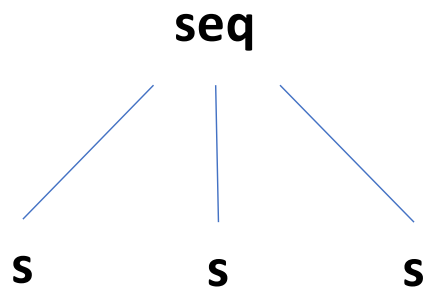
Ambiguous Grammar

- Harmless Ambiguity
  - ambiguous grammar may always produce unique AST

    (but may produce different parse trees)

```
stmt_sequence → stmt-sequence ; stmt-sequence | stmt ;
stmt → s | ε
```

```
s; s; s;
```



Ambiguous Grammar

- Harmless Ambiguity
  - even for ambiguous grammar producing different ASTs

```
34 + 3 + 42
```

Both carry the same semantics