Programming Languages

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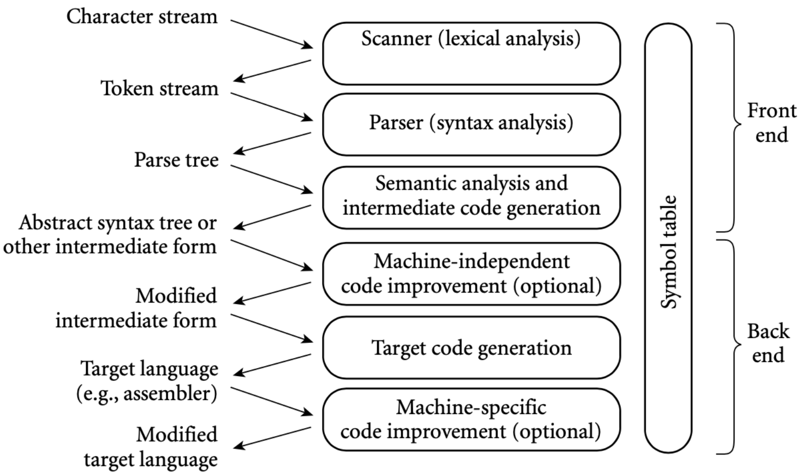
February 6-10, 2023

Most Important Steps in Compilation



Lexical Analysis

Lexical analysis produces a "token stream" in which the progam is reduced to a sequence of token types, each with its identifying number and the actual string (in the program) corresponding to it.

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  – "$\leq$" or "while" to describe an operator or reserved word,
- or a $<$ *rule* $>$
  – a rule $<$ *unsigned int* $>$ example: "a sequence of one or more digits";
  – a rule $<$ *identifier* $>$ example: "a letter followed by a sequence of zero or more letters or digits."

Typical Tokens in Programming Languages

- *Operators and Punctuation*
  - `+ - * / ( )  [ ] ; :  ::  < <= == = != !  ...!`
- *Keywords*
  - `if while for goto return switch void ...`
- *Identifiers* (variables)
- *Integer constants*
  - Other constants (string, floating point, boolean, ...), etc.

Lexical Complications

- Most modern languages are free-form
  - Layout doesn't matter
  - White space separates tokens
- Alternatives
  - Haskell, Python - indentation and layout can imply grouping

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- Grammars are often specified in BNF notation ("Backus Naur Form"):

```
<item1> ::= valid replacements for <item1>
<item2> ::= valid replacements for <item2>
```

Alternative Notations

- There are several syntax notations for productions in common use; all mean the same thing. E.g.:

```
ifStmt ::= if ( expr ) statement
ifStmt → if ( expr ) statement
<ifStmt> ::= if ( <expr> ) <statement>
```

Example: Grammar for Pigese (or Pigish?)

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```
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```
variable → rule1 | rule2 | rule3 | ...
```

You can also write each rule on a separate line

Grammars (Context-free Grammars): EXAMPLE

Grammar

A, B, and C are non-terminals.
0, 1, and 2 are terminals.
The start symbol is A.
The rules are:

- $A \rightarrow 0A|1C|2B|0$
- $B \rightarrow 0B|1A|2C|1$
- $C \rightarrow 0C|1B|2A|2$

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Can 1112202 be parsed?
Can 00102 be parsed?
Can 2121 be parsed?

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Consider:

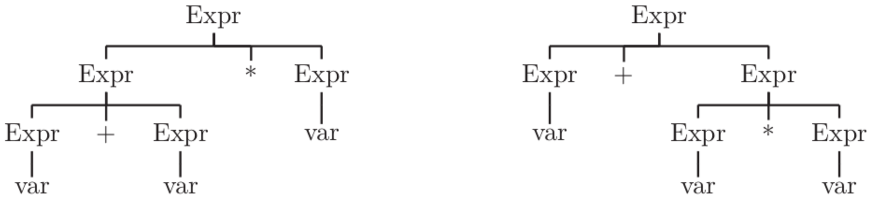
1. $S \rightarrow ASB$
2. $S \rightarrow \epsilon$
3. $A \rightarrow a$
4. $B \rightarrow b$

Ambiguity

Consider:

1. Expr $\rightarrow$ Expr $+$ Expr
2. Expr $\rightarrow$ Expr * Expr
3. Expr $\rightarrow$ (Expr)
4. Expr $\rightarrow$ var
5. Expr $\rightarrow$ const

There are two different derivation trees for the string var+var*var



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- We need unambiguous grammars for parsing
  - The derivation determines the shape of the parse tree/ abstract syntax tree, which in turn determines meaning.
- If a grammar can be made unambiguous at all, it is usually made unambiguous through **layering**.
  – Have exactly one way to build each piece of the string.
  – Have exactly one way of combining those pieces back together.

Resolving Ambiguity

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- *With grammar*: If you can re-design the language, can avoid the problem entirely, e.g., create an `end` to match closest `if`
- *With tools*: Most parser tools can cope with ambiguous grammars.
  - Typically one can specify operator precedence and associativity.
  - Allows simpler, ambiguous grammar with fewer non-terminals as basis for generated parser, without creating problems.

Activity 7: Grammar Ambiguity

Determine if the grammar is ambiguous

Regular Expressions used for Scanning

- Defined over some alphabet $\sum$.
  - For programming languages, alphabet is usually ASCII or Unicode.
- If `re` is a regular expression, `L(re)` is the language (set of strings) generated by `re`.

Fundamentals of Regular Expressions (REs)

- These are the basic building blocks that other REs are built from.

re	*L*(*re*)	Notes
a	{ a }	Singleton set, for each symbol a in the alphabet Σ
ε	{ ε }	Empty string
∅	{ }	Empty language

Operations on REs

re	*L*(*re*)	Notes
rs	L(r)L(s)	Concatenation – r followed by s
r|s	L(r) ∪ L(s)	Combination (union) – r or s
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- Precedence: (R), R*, $R_1 R_2$, $R_1|R_2$ (lowest).
- Parenthesis can be used to group REs as needed.

Examples

re	Meaning
+	single + character
!	single ! character
!=	2 character sequence "!="
xyzzy	5 character sequence "xyzzy"
(1|0)*	Zero or more binary digits
(1|0)(1|0)*	Binary constant (possible leading 0s)
0|1(1|0)*	Binary constant without extra leading 0s, i.e, 0 or starts with 1 (| has lowest precedence)

Abbreviations on REs

- There are common abbreviations used for convenience.

Abbr.	Meaning	Notes
r+	(rr*)	1 or more occurrences
r?	(r | ε)	0 or 1 occurrence
[a-z]	(a|b|...|z)	1 character in given range
[abxyz]	(a|b|x|y|z)	1 of the given characters

Example

- Possible syntax for numeric constants
  ```
  digit ::= [0-9]
  digits ::= digit +
  number ::= digits ( .  digits )?
  ([eE] (+ | -)?  digits )?
  ```
- Notice that this allows (unnecessary) leading 0s, e.g., 00045.6. (0, or 0.14 would be necessary 0s).

Example

- **Possible syntax for numeric constants**

```
digit ::= [0-9]
nonzero_digit ::= [1-9]
digits ::= digit +
number ::= (0 | nonzero_digit digits?)
( . digits )?
([eE] (+ | -)? digits )?
```

RE Practice:

https://regexone.com/