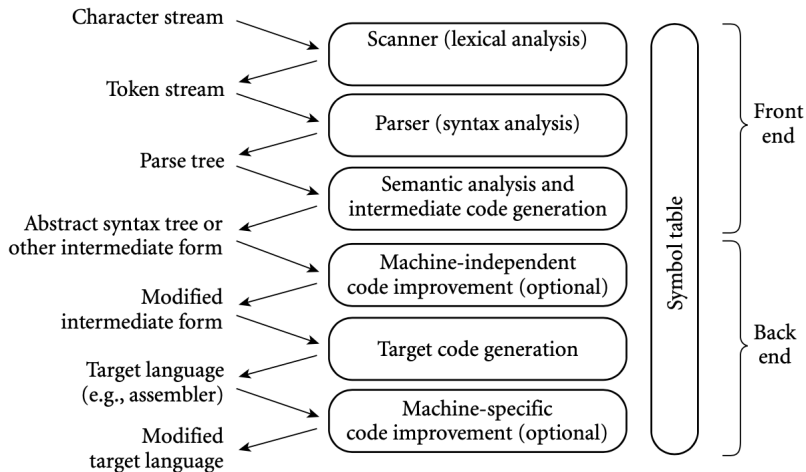# Programming Languages

Janyl Jumadinova

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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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- either a literal string
  - "$\leq$" 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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```
<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?)

- A formal grammar for a "pig language" could be:
  ```
  PigTalk ::= oink PigTalk (Rule 1)
            | oink!   (Rule 2)
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  1. `PigTalk ::= oink!    (Rule 2)`
  2. `PigTalk ::= oink PigTalk (Rule 1)`
     ```
              ::= oink oink!
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  1. `PigTalk ::= oink!   (Rule 2)`
  2. `PigTalk ::= oink PigTalk (Rule 1)`
     ```
             ::= oink oink!
     ```
  3. `PigTalk ::= oink PigTalk (Rule 1)`
     ```
             ::= oink oink PigTalk  (Rule 1)
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variable $\rightarrow$ rule1 | rule2 | rule3 | ...

You can also write each rule on a separate line (as in the book)

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:

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

https://itempool.com/jjumadinova/live

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Can 2011020 be parsed?

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Can 1112202 be parsed?

Can 00102 be parsed?

Can 2121 be parsed?

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
$\varnothing$	{ }	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/