Lexical Analysis

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Lexical

> *"Relating to words or the vocabulary of a language as distinguished from its grammar and construction."*
>
> Webster's Dictionary

Words

Words are *simple constructs*:

- on a natural language we can simply *enumerate* them
- not possible with technical languages (too many words!)

But technical words are simpler than natural words:

C identifier rules

- a sequence of non-digit characters (including the underscore _, the lowercase and uppercase Latin letters, and other characters) and digits
- cannot starts with a digit

Regular expression can *describe* their structure!

Analysis

Lexical analysis must:

- *recognize* tokens in a stream of characters (e.g. identifiers)
- possibly *decorate* tokens with additional info (e.g. the name of the identifier)

Performed by mean of a scanner:

- coding by hand is both tedious and error-prone
- usually automatically generated from a regular expressions-based description

No surprises: the scanner is just a big Finite State Automaton.

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A Simple Lexical Analysis

The simplest lexical analysis is *recognize* words:

- many UNIX tools provide a regular expression interface to match words
- each tool is specialized on doing something with matched words

Good knowledge of these tools can speedup your work.

Finding Words

Given a file with a list of names, one per line, find all names starting with a vowel:

Using grep

```
$ cat names.txt
ettore
chiara
michela
antonio
$ grep '^[aeiou]' names.txt
ettore
antonio
```

Delete Patterns

Given a file with a list of names, one per line, delete all names whose second character is a vowel:

Using sed

```
$ cat names.txt
ettore
chiara
michela
antonio
$ sed '/^.[aeiou]/d' names.txt
ettore
chiara
antonio
```

CSV Processing

Given CSV file, where each line is the pair (`person,field`), print all people working on the `astrophysics` field:

Using `awk`

```
$ cat bindings.txt
ettore,compilers
chiara,automotive
michela,astrophysics
antonio,compilers
$ awk -F , '/,astrophysics$/ {print $1}' \
  bindings.txt
michela
```

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Back to Compilers

We need a scanner to recognize language words:

- the `flex` tool generates scanners

Getting `flex`

Available in your distribution repositories:

Debian `aptitude install flex`

Fedora `yum install flex`

The Scanning Problem

For some applications, a scanner is enough:

- it is used to both detecting words and applying semantic actions

But language translation is not a simple task, thus the scanner *prepares input* for semantic analysis:

- detect words (e.g. identifiers)
- clean input (e.g. removes comments)
- add info to words (e.g. identifier names)

We will see these aspects later, now we will use only the scanner.

A Case Lowering Tool

Given a string, build the lower case equivalent string.

String lowering

HELLO Flex → *hello flex*

We can describe our language with a regular expression:

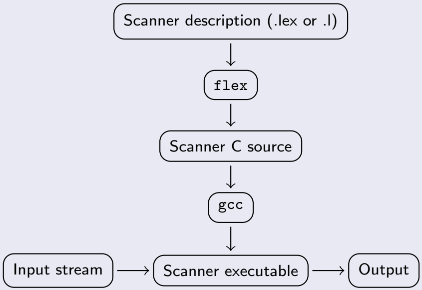
$$STRING \rightarrow WORD(' \ ', WORD)^*$$
$$WORD \rightarrow (UPPER|LOWER)^+$$
$$UPPER \rightarrow ('A'|'B'|\ldots|'Z')$$
$$LOWER \rightarrow ('a'|'b'|\ldots|'z')$$

We must express the same things using `flex`.

Introducing `flex`

The `flex` tool must be used inside a tool-chain:

`flex` work-flow



Detecting Words

Starts with two simple concepts:

- by default unmatched chars are copied to `stdout`
- thus we must add only rules to match uppercase letters

case-matching.l

```
%option noyywrap
UPPER [A-Z]
%%
{UPPER} { }
%%
int main (int argc,char* argv[]) {
  return yylex();
}
```

Automating Repetitive Tasks

Invoking `flex` is easy:

By-hand compilation

```
$ flex case-matching.l
$ gcc lex.yy.c
```

Better to use `make`:

Automated compilation

```
$ make case-matching
lex -t case-matching.l > case-matching.c
cc -c -o case-matching.o case-matching.c
cc case-matching.o -o case-matching
rm case-matching.o case-matching.c
```

Adding Semantic

Semantic actions are added beside rules:

case-lowering.l

```
%option noyywrap
UPPER [A-Z]
%%
{UPPER} { printf("%c",tolower(*yytext)); }
%%
int main (int argc,char* argv[]) {
  return yylex();
}
```

File Format

Three sections:

definitions declare tokens

rules bind token combinations to actions

user code plain old C code

Input of flex [a]

```
/* Definitions */
%%
/* Rules */
%%
/* User code */
```

[a] Comments not allowed inside rules

Definitions

Allows to associate a name to a set of characters:

- you can use regular expression to define character sets
- usually used to define *simple* concepts (e.g digits)

Definitions

```
/* Lower case and upper case letters */
LETTER [a-zA-Z]
/* Numerical digits */
DIGITS [0-9]
```

Rules I

What to do when something is recognized:

- exploits definitions to define complex concepts (e.g. from DIGIT to NUMBER)
- can use regular expression as glue!

Rules [1]

```
/* Identifiers: letters plus digits */
{LETTER}({LETTER}|{DIGIT})* { return ID; }
/* Number: a list of digits */
{DIGIT}+ { return NUMBER; }
/* The "if" keyword */
"if" { return IF; }
```

Rules II

Actions:

- are executed every time the rule is matched
- can access to matched data

Simple scanners executes directly the semantic action (e.g. case lowering).
Complex scanners (e.g. language tokenizer):

1. assign a value to the recognized token
2. return the token type

Rules III

Here is a partial list of variables that can be accessed from inside an action:

Rule variables

Variable	Type	Meaning
`yytext`	`char*`	matched text
`yyleng`	`int`	matched text length

[1] Comments not allowed inside rules

User Code

User C code is copied to the generated scanner *as is*:

- the `main` function
- any other routine called by actions
- scanner-wrapping routines
- ...

Additional Code

Arbitrary code can be put inside definitions and rules sections by *escaping* from `flex`:

- code copied *as is* into the generated scanner
- good place for header inclusions, globals, ...

Header inclusions

```
%{
#include <limits.h>
#include <string.h>
%}
```

Regular Expressions I

The following tables contains the regular expressions accepted by `flex`:

Basic regular expressions

Syntax	Matches
`x`	the `x` character
`.`	any character except newline
`[xyz]`	`x` or `y` or `z`
`[a-z]`	any character between `a` and `z`
`[^a-z]`	any character except those between `a` and `z`
`{X}`	expansion of `X` definition
`"hello"`	the `hello` string

Regular Expressions II

Regular expression composition

Syntax	Matches
R	the R regular expression
RS	concatenation of R and S
R|S	either R or S
R*	zero or more occurrences of R
R+	one or more occurrences of R
R?	zero or one occurrence of R
R{m,n}	a number or R occurrences ranging from n to m
R{n,}	n or more occurrences of n
R{n}	exactly n occurrences of R

Regular Expressions III

Regular expression utilities

Syntax	Matches
`(R)`	override precedence
`^R`	`R` at beginning of a line
`R$`	`R` at the end of a line

Note that most of UNIX tools handling regular expression *accept* the same syntax.

Some Notes on Scanner Generation I

The scanner is just *a finite state automaton*! Look at the sources:

Scanner states of `case-lowering.l`

```
/* States */
static yyconst flex_int16_t yy_def[7] =
  { 0, 6, 1, 6, 6, 6, 0 };
/* Accepting states */
static yyconst flex_int16_t yy_accept[7] =
  { 0, 0, 0, 3, 2, 1, 0 };
/* Starting state */
static int yy_start = 0;
```

Some Notes on Scanner Generation II

Scanner transitions of case-lowering.l

```
/* Transitions */
static yyconst flex_int16_t yy_nxt[7] =
  { 0, 4, 5, 6, 3, 6, 6 };
```

Obviously states are encoded to allow fast matching.

Scanner Behaviour

The scanner applies the following:

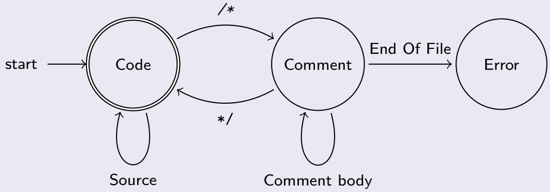
- **longest matching rule**: if more than one matching string is found, the rule that generates the longest one is selected
- **first rule**: if more than one string with the same length are found, the rule listed first in the rules section is selected
- **default action**: if no rules were found the next character in input is considered matched and it is copied to the output stream, then the scanner goes on

Multiple Scanners I

Sometimes is useful to have more than one scanner together:

- code scanner
- comment scanner

C scanners



Multiple Scanners II

To support multiple scanners:

- rules can be marked with the name of the associated scanner (*start condition*)
- special actions to switch between scanners

Multiple Scanners III

A start condition `S`:

- mark rules with a prefix `<S>RULE`
- activate marked rules only when the scanner is in `S`

Moreover:

- the `*` start condition matches every start condition
- the initial start condition is `INITIAL`
- start conditions are stored as integers (C `int`)
- the current start condition is stored in the `YY_START` variable

Multiple Scanners IV

Start conditions can be:

- **exclusive** declared with `%x S`; disable unmarked rules when the scanner is in the `S` start condition
- **inclusive** declared with `%s S`; unmarked rules active when scanner is in the `S` start condition

Multiple Scanners V

Here is a table with relevant special actions:

Special actions

Action	Meaning
`BEGIN(S)`	place scanner in start condition S
`ECHO`	copies `yytext` to output

Comment Eater I

Eat C-99 style comment:

C-99 comment eater (counters)

```
%x COMMENT
%option noyywrap
%{
   #define MAX_DEPTH 10

   int nest = 0;
   int caller[MAX_DEPTH];
%}
```

Comment Eater II

C-99 comment eater (code rules)

```
<INITIAL>[^/]* {
                  ECHO;
                }
<INITIAL>"/"+[^*/]* {
                      ECHO;
                    }
<INITIAL>"/*" {
                caller[nest++] = YY_START;
                BEGIN(COMMENT);
              }
```

Comment Eater III

C-99 comment eater (comment rules)

```
<COMMENT>[^/*]*
<COMMENT>"/"+[^*/]*
<COMMENT>"/*" {
                caller[nest++] = YY_START;
                BEGIN(COMMENT);
               }
<COMMENT>"*"+[^*/]*
<COMMENT>"*"+"/" {
                   BEGIN(caller[--nest]);
                  }
%%
```

Comment Eater IV

C-99 comment eater (main)

```
int main(int argc, char* argv[]) {
  return yylex();
}
```

Clean Regular Expressions

Regular expression can describe `simple` concepts:

- complex structures are typically described by "encrypted" regular expression

Even with simple concepts is better to keep the regular expression as clean as possible:

- they becomes unreadable very quickly

Exploit tool features to simplify regular expressions (e.g. definitions).

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