CS323 Lab 5

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Outline

- Bison introduction
- Revisit shift-reduce parsing
- Bison tutorial
- Bison assignment

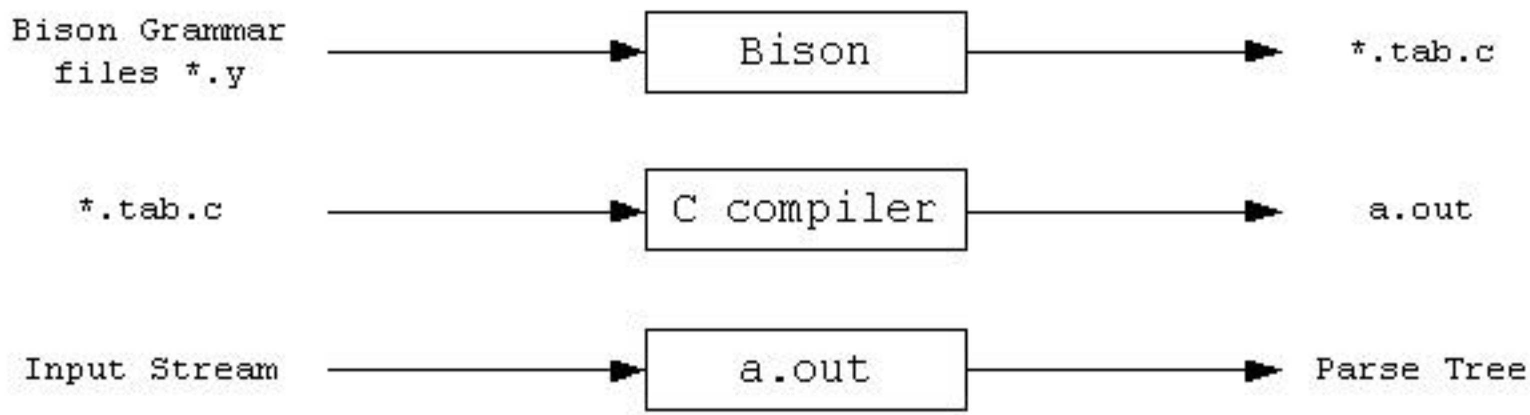
The Parser Generator Bison

- Bison generates a parser, which accepts the input token stream from Flex, to do syntax analysis, according to the specified CFG.

- Bison的前身为基于Unix的Yacc(Yet another compiler compiler)。Yacc的发布时间比Lex还要早，其采用的语法分析技术的理论基础早在20世纪50年代就已经由Knuth逐步建立了起来，而Yacc本身则是贝尔实验室的S.C. Johnson基于这些理论在1975年到1978年写成的。

- 到了1985年，当时在UC Berkeley的一个研究生Bob Corbett在BSD下重写了Yacc，取名为Bison (美洲野牛，yak牦牛的近亲)，后来GNU Project接管了这个项目，为其增加了许多新的特性，于是就有了我们今天所用的GNU Bison。

Input/Output of Bison (Yacc)



Structure of YACC Source Programs

- **Declarations (声明)**
  - Ordinary C declarations
  - Grammar tokens
- **Translation rules (翻译规则)**
  - Rule = a production + semantic action
- **Supporting C routines (辅助性C语言例程)**
  - Directly copied to `y.tab.c`
  - Can be invoked in the semantic actions
  - Other procedures such as error recovery routines may be provided

```
declarations
%%
translation rules
%%
supporting C routines
```

Translation Rules

$$
\begin{array}{llll}
\langle \text{head} \rangle & : & \langle \text{body} \rangle_1 & \{\ \langle \text{semantic action} \rangle_1\ \} \\
 & | & \langle \text{body} \rangle_2 & \{\ \langle \text{semantic action} \rangle_2\ \} \\
 & & \cdots & \\
 & | & \langle \text{body} \rangle_n & \{\ \langle \text{semantic action} \rangle_n\ \} \\
 & \boxed{;} & &
\end{array}
$$

DO NOT miss it

- The first head in the list of rules is taken as the start symbol of the grammar
- A semantic action is a sequence of C statements
  - `$$` is a Bison's internal variable that holds the semantic value of the left-hand side of a production rule (i.e., the whole construct)
  - `$i` holds the semantic value of *i*th grammar symbol of the body
- A semantic action is performed when we apply the associated production for reduction (归约， the reverse of rewrite)
  - Most of the time, the purpose of an action is to compute the semantic value of the whole construct from the semantic values of its parts, i.e., compute `$$` using `$i`'s

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Bottom-Up Parsing

- The parser generated by Bison performs bottom-up parsing in shift-reduce style

- Shift-reduce parsing (移入-归约分析) is a general style of bottom-up parsing (using a stack to hold grammar symbols). Two basic actions:
  - **Shift:** Move an input symbol onto the stack
  - **Reduce:** Replace a string at the stack top with a non-terminal that can produce the string (the reverse of a rewrite step in a derivation)

Shift-Reduce Parsing Example

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

STACK	INPUT	ACTION
\$	$\mathbf{id}_1 * \mathbf{id}_2\ \$$	shift

$$E \rightarrow E + T \mid T$$
$$T \rightarrow T * F \mid F$$
$$F \rightarrow (E) \mid \mathbf{id}$$

$\mathbf{id} * \mathbf{id}$

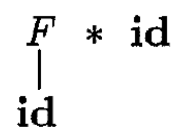
Initially, the tree only contains leaf nodes

Shift-Reduce Parsing Example

$$E \rightarrow E + T \mid T$$
$$T \rightarrow T * F \mid F$$
$$F \rightarrow (E) \mid \mathbf{id}$$

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

STACK	INPUT	ACTION
$\$$	$\mathbf{id}_1 * \mathbf{id}_2 \,\$$	shift
$\$\, \mathbf{id}_1$	$* \mathbf{id}_2 \,\$$	reduce by $F \rightarrow \mathbf{id}$



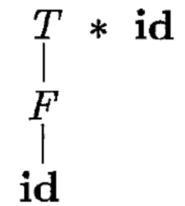
Tree "grows" when reduction happens

Shift-Reduce Parsing Example

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

$$E \to E + T \mid T$$
$$T \to T * F \mid F$$
$$F \to (E) \mid \mathbf{id}$$

STACK	INPUT	ACTION
$\$$	$\mathbf{id}_1 * \mathbf{id}_2 \$$	shift
$\$ \mathbf{id}_1$	$* \mathbf{id}_2 \$$	reduce by $F \to \mathbf{id}$
$\$ F$	$* \mathbf{id}_2 \$$	reduce by $T \to F$



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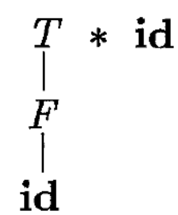
$\$\, T$	$* \mathbf{id}_2 \$$	shift



Tree does not change when shift happens

Shift-Reduce Parsing Example

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

$$E \rightarrow E + T \mid T$$
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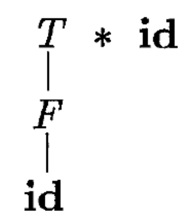
$\$ F$	$* \mathbf{id}_2 \$$	reduce by $T \rightarrow F$
$\$ T$	$* \mathbf{id}_2 \$$	shift
$\$ T *$	$\mathbf{id}_2 \$$	shift



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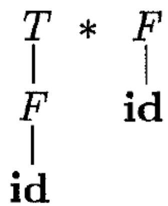
$\$\ T *$	$\mathbf{id}_2 \$$	shift
$\$\ T * \mathbf{id}_2$	$\$$	reduce by $F \rightarrow \mathbf{id}$



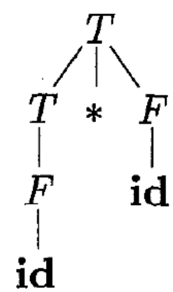
Tree "grows" when reduction happens

Shift-Reduce Parsing Example

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

$$E \rightarrow E + T \mid T$$
$$T \rightarrow T * F \mid F$$
$$F \rightarrow (E) \mid \mathbf{id}$$

STACK	INPUT	ACTION
$\$$	$\mathbf{id}_1 * \mathbf{id}_2\,\$$	shift
$\$\,\mathbf{id}_1$	$* \mathbf{id}_2\,\$$	reduce by $F \rightarrow \mathbf{id}$
$\$\,F$	$* \mathbf{id}_2\,\$$	reduce by $T \rightarrow F$
$\$\,T$	$* \mathbf{id}_2\,\$$	shift
$\$\,T *$	$\mathbf{id}_2\,\$$	shift
$\$\,T * \mathbf{id}_2$	$\$$	reduce by $F \rightarrow \mathbf{id}$
$\$\,T * F$	$\$$	reduce by $T \rightarrow T * F$



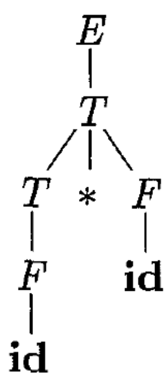
Tree "grows" when reduction happens

Shift-Reduce Parsing Example

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

$$E \rightarrow E + T \mid T$$
$$T \rightarrow T * F \mid F$$
$$F \rightarrow (E) \mid \mathbf{id}$$

STACK	INPUT	ACTION
$\$$	$\mathbf{id}_1 * \mathbf{id}_2 \$$	shift
$\$ \mathbf{id}_1$	$* \mathbf{id}_2 \$$	reduce by $F \rightarrow \mathbf{id}$
$\$ F$	$* \mathbf{id}_2 \$$	reduce by $T \rightarrow F$
$\$ T$	$* \mathbf{id}_2 \$$	shift
$\$ T *$	$\mathbf{id}_2 \$$	shift
$\$ T * \mathbf{id}_2$	$\$$	reduce by $F \rightarrow \mathbf{id}$
$\$ T * F$	$\$$	reduce by $T \rightarrow T * F$
$\$ T$	$\$$	reduce by $E \rightarrow T$



Tree "grows" when reduction happens

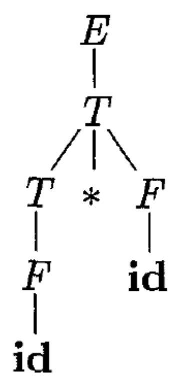
Shift-Reduce Parsing Example

Parsing steps on input $\mathbf{id}_1 * \mathbf{id}_2$

$$
\begin{aligned}
E &\rightarrow E + T \mid T \\
T &\rightarrow T * F \mid F \\
F &\rightarrow (E) \mid \mathbf{id}
\end{aligned}
$$

STACK	INPUT	ACTION
$\$$	$\mathbf{id}_1 * \mathbf{id}_2 \$$	shift
$\$ \mathbf{id}_1$	$* \mathbf{id}_2 \$$	reduce by $F \rightarrow \mathbf{id}$
$\$ F$	$* \mathbf{id}_2 \$$	reduce by $T \rightarrow F$
$\$ T$	$* \mathbf{id}_2 \$$	shift
$\$ T *$	$\mathbf{id}_2 \$$	shift
$\$ T * \mathbf{id}_2$	$\$$	reduce by $F \rightarrow \mathbf{id}$
$\$ T * F$	$\$$	reduce by $T \rightarrow T * F$
$\$ T$	$\$$	reduce by $E \rightarrow T$
$\$ E$	$\$$	accept

Success!!!



The final parse tree

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A Parser That Performs Calculation

- When processing arithmetic expressions, lexical anlayzer will recognize the following types of tokens: INT, ADD, SUB, MUL, DIV
  - When analyzing the input string "3 + 6 / 2", the lexer will output this string of tokens: INT ADD INT DIV INT
- After lexical analysis, the parser will check if the string of tokens produced by lexer has a valid structure or not according to the synatatic specification described by the following context-free grammar

```
Calc -> Exp
Exp -> Factor | Exp ADD Factor | Exp SUB Factor
Factor -> Term | Factor MUL Term | Factor DIV Term
Term -> INT
```

*Red for non-terminals, Blue for terminals, Calc is the start symbol

Valid and Invalid Inputs

Valid input expressions:

- 3
- 3 + 5 * 4
- 3 + 6 / 2
- 3 + 2 – 1
- …

Invalid input expressions:

- -3
- 3 + 5 *
- …

Flex/Bison Code for Calculator

lex.l

```
%{
    #include "syntax.tab.h"
    #include "stdlib.h"
%}
%%
[0-9]+ { yylval = atoi(yytext); return INT; }
"+" { return ADD; }
"-" { return SUB; }
"*" { return MUL; }
"/" { return DIV; }
[ \n\r\t] {}
. { fprintf(stderr, "unknown symbol: %s\n", yytext);
    exit(1); }
```

syntax.y

```
%{
    #include "lex.yy.c"
    void yyerror(const char*);
%}
%token INT
%token ADD SUB MUL DIV
%%
Calc: /* to allow empty input */
    | Exp { printf("= %d\n", $1); }
    ;
Exp: Factor
    | Exp ADD Factor { $$ = $1 + $3; }
    | Exp SUB Factor { $$ = $1 - $3; }
    ;
Factor: Term
    | Factor MUL Term { $$ = $1 * $3; }
    | Factor DIV Term { $$ = $1 / $3; }
Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse(); // will invoke yylex()
}
```

yylval:

- Flex internal variable that is used to store the attribute of a recognized token
- Its data type is YYSTYPE (int by default)*
- After storing values to `yylval` in Flex code, the values will be propagated to Bison (i.e., the syntax anlayzer part) and can be retrieved using `$n`

*Can be customized by putting command like `#define YYSTYPE char*` at the beginning of .l and .y files.

A Further Look at Semantic Actions

syntax.y

```
%{
    #include "lex.yy.c"
    void yyerror(const char*);
%}
%token INT
%token ADD SUB MUL DIV
%%
Calc: /* to allow empty input */
    | Exp { printf("= %d\n", $1); }
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Exp: Factor
    | Exp ADD Factor { $$ = $1 + $3; }
    | Exp SUB Factor { $$ = $1 - $3; }
    ;
Factor: Term
    | Factor MUL Term { $$ = $1 * $3; }
    | Factor DIV Term { $$ = $1 / $3; }
Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

When appyling this rule for reduction, the semantic analysis is successful (i.e., the start symbol calc can generate the input expression), we output the calculation result.

A Further Look at Semantic Actions

syntax.y

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    ;
Factor: Term
    | Factor MUL Term { $$ = $1 * $3; }
    | Factor DIV Term { $$ = $1 / $3; }
Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

Intermediate calculation of semantic values of a language construct represented by the head symbol

A Further Look at Semantic Actions

syntax.y

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    #include "lex.yy.c"
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    ;
Factor: Term
    | Factor MUL Term { $$ = $1 * $3; }
    | Factor DIV Term { $$ = $1 / $3; }
Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

Although no action is specified, Bison will still propagate the attribute of the only symbol `INT` to the head `Term`

Same as writing: `{$$ = $1;}`

Illustrative Example

syntax.y

```
%{
    #include "lex.yy.c"
    void yyerror(const char*);
%}
%token INT
%token ADD SUB MUL DIV
%%
Calc: /* to allow empty input */
    | Exp { printf("= %d\n", $1); }
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Exp: Factor
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    ;
Factor: Term
    | Factor MUL Term { $$ = $1 * $3; }
    | Factor DIV Term { $$ = $1 / $3; }
Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

Input: 3 + 5
Token string: INT ADD INT

3 INT

Illustrative Example

syntax.y

```
%{
    #include "lex.yy.c"
    void yyerror(const char*);
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%token INT
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Calc: /* to allow empty input */
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void yyerror(const char *s) {
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Input: 3 + 5
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3 Term

3 INT

Illustrative Example

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void yyerror(const char *s) {
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int main() {
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```

Input: 3 + 5

Token string: INT ADD INT

3 Factor

3 Term

3 INT

Illustrative Example

```
%{
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%%
void yyerror(const char *s) {
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int main() {
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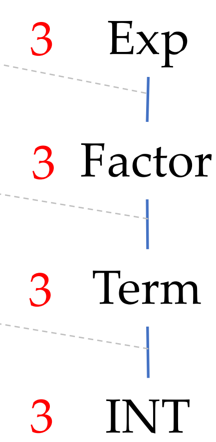
```

syntax.y

Input: 3 + 5

Token string: INT ADD INT



Illustrative Example

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Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

syntax.y

Input: 3 + 5
Token string: INT ADD INT

3 Exp ADD

3 Factor

3 Term

3 INT

Illustrative Example

syntax.y

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    #include "lex.yy.c"
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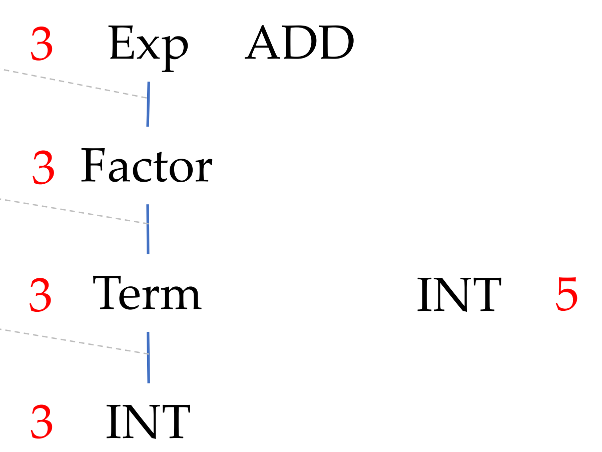
Input: 3 + 5
Token string: INT ADD INT



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}
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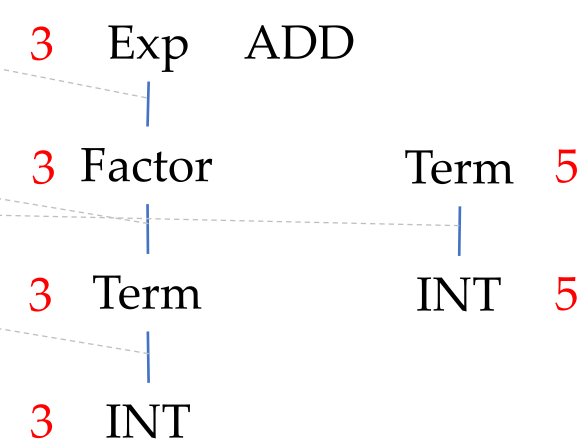
Token string: INT ADD INT



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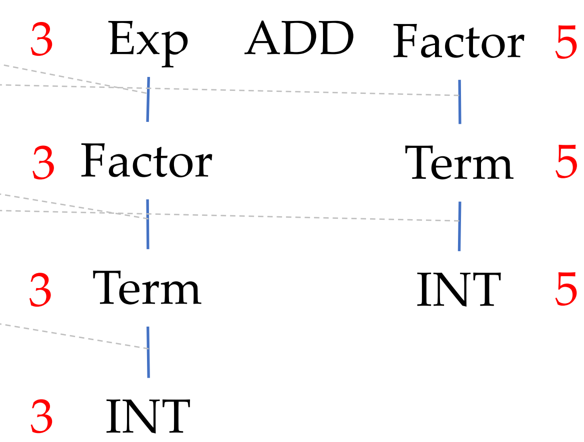
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

Input: 3 + 5
Token string: INT ADD INT



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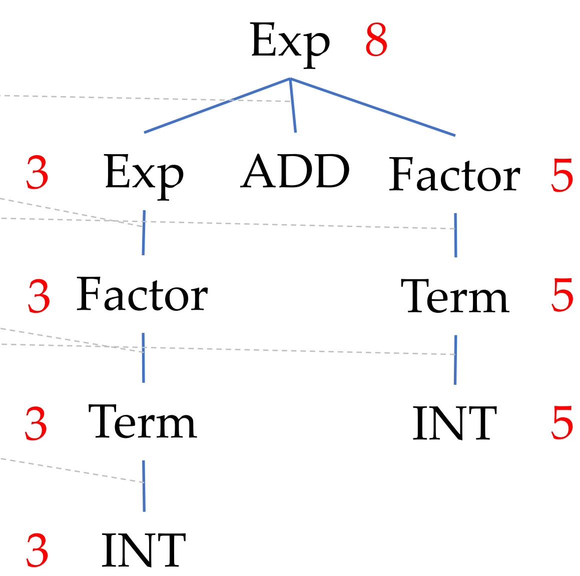
}
```

syntax.y

Input: 3 + 5

Token string: INT ADD INT

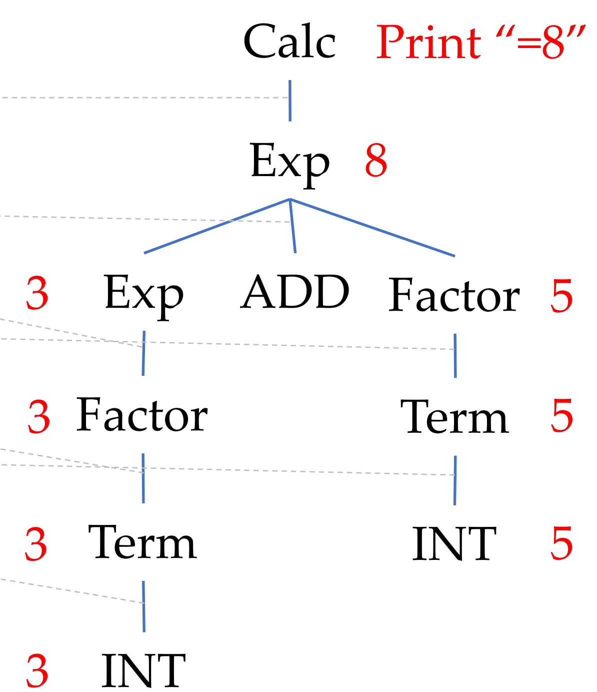


Illustrative Example

syntax.y

```
%{
    #include "lex.yy.c"
    void yyerror(const char*);
%}
%token INT
%token ADD SUB MUL DIV
%%
Calc: /* to allow empty input */
    | Exp { printf("= %d\n", $1); }
    ;
Exp: Factor
    | Exp ADD Factor { $$ = $1 + $3; }
    | Exp SUB Factor { $$ = $1 - $3; }
    ;
Factor: Term
    | Factor MUL Term { $$ = $1 * $3; }
    | Factor DIV Term { $$ = $1 / $3; }
Term: INT
    ;
%%
void yyerror(const char *s) {
    fprintf(stderr, "%s\n", s);
}
int main() {
    yyparse();
}
```

Input: 3 + 5
Token string: INT ADD INT



Compile the Example

- Compile the Bison code into C code: a header file and an implementation file
  - `bison -d syntax.y` (why it is compilable without lex.yy.c?)
  - The command produces `syntax.tab.h` and `syntax.tab.c`
- Compile the flex source code
  - `flex lex.l`
  - The command produce `lex.yy.c`
- Putting things together
  - `gcc syntax.tab.c -lfl -ly -o calc.out`
  - The options `-lfl` and `-ly` tell gcc to include Flex and Bison libraries

The code is available at `lab5/calc`. We provide a build target calc to facilitate the compilation.

Run the Calculator

- In the runs below, we use pipes* to pass the output of the first command to be the input of the second command

```
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab4/calc$ echo "3" | ./calc.out
= 3
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab4/calc$ echo "3+5*4" | ./calc.out
= 23
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab4/calc$ echo "3+6/2" | ./calc.out
= 6
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab4/calc$ echo "3+ 2-1" | ./calc.out
= 4
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab4/calc$ echo "-3" | ./calc.out
syntax error
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab4/calc$ echo "3+5*" | ./calc.out
syntax error
```

* https://linuxhint.com/what-is-pipe-in-linux/

Lab Exercise 1

- Modify the `lex.l` and `syntax.y` to support parentheses

```
Calc -> Exp
Exp -> Factor | Exp ADD Factor | Exp SUB Factor
Factor -> Term | Factor MUL Term | Factor DIV Term
Term -> LP Exp RP | INT
```

*Red for non-terminals, Blue for terminals, Calc is the start symbol

```
liu@liu-VirtualBox:~/Desktop/CS323-2022F-Private/lab4-sol/calc$ echo "(1+1)*3" | ./calc.out
= 6
liu@liu-VirtualBox:~/Desktop/CS323-2022F-Private/lab4-sol/calc$ echo "(2*4)*(3-3)" | ./calc.out
= 0
liu@liu-VirtualBox:~/Desktop/CS323-2022F-Private/lab4-sol/calc$ echo "((2*4)*(3*3-3))" | ./calc.out
= 48
liu@liu-VirtualBox:~/Desktop/CS323-2022F-Private/lab4-sol/calc$ echo "((2*4)*(3*3-3)" | ./calc.out
syntax error
```

Outline

- Bison tutorial
- Revisit shift-reduce parsing
- Bison tutorial
- Bison assignment

Validate IP Address (leetcode #468)

- Use Bison and Flex to complete the following task:
  - Given a string *queryIP*, output "IPv4" if *queryIP* is a valid IPv4 address, "IPv6" if *queryIP* is a valid IPv6 address or "Invalid" otherwise

- A valid IPv4 address is an IP in the form of "$x_1.x_2.x_3.x_4$":
  - Each x_i is a decimal integer in the range [0, 255]
  - x_i cannot contain leading zeros
  - Examples: 192.168.0.1 (valid), 192.168.01.1 (invalid), 192.168@1.1 (invalid)

Validate IP Address (leetcode #468)

- A valid IPv6 address is an IP in the form "x_1:x_2:x_3:x_4:x_5:x_6:x_7:x_8":
  - The length of each x_i is in the range [1, 4]
  - x_i is a hexadecimal string which may contain digits, lowercase English letter ('a' to 'f') and upper-case English letters ('A' to 'F')
  - Valid examples:
    - `2001:0db8:85a3:0000:0000:8a2e:0370:7334`
    - `2001:db8:85a3:0:0:8A2E:0370:7334`
  - Invalid examples:
    - `2001:0db8:85a3::8A2E:037j:7334`
    - `02001:0db8:85a3:0000:0000:8a2e:0370:7334`

More instructions

- Clone the `lab5/ipaddr` directory
- The `lex.l` file is provided to recognize x strings (but does not check its validity), the dot and colon in IP addresses. Please use it as is.
- Complete the `syntax.y` file and providing production rules, semantic actions, as well as necessary supporting functions
- You may use the build target `ip` to get the executable `ip.out`
- Please finish the assignment before this Sunday (10:00 PM)

Test Inputs and Sample Outputs

```
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "192.168.0.1" | ./ip.out
IPv4
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "192.168.01.1" | ./ip.out
Invalid
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "192.168@1.1" | ./ip.out
Invalid
```

```
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "2001:0db8:85a3:0000:0000:8a2e:0370:7334" | ./ip.out
IPv6
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "2001:db8:85a3:0:0:8A2E:0370:7334" | ./ip.out
IPv6
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "2001:0db8:85a3::8A2E:037j:7334" | ./ip.out
Invalid
liu@liu-VirtualBox:~/Desktop/CS323-2022F/lab5/ipaddr$ echo "02001:0db8:85a3:0000:0000:8a2e:0370:7334" | ./ip.out
Invalid
```

Project Phase 1 Reminder

- Please get familiar with SPL language specification and start the implementation if you haven't done so.
- Submission deadline: 10:00 PM, Oct 29.
- Each team only needs to make one submission on Blackboard.