Programming Assignment #1. Flex & Bison Exercise

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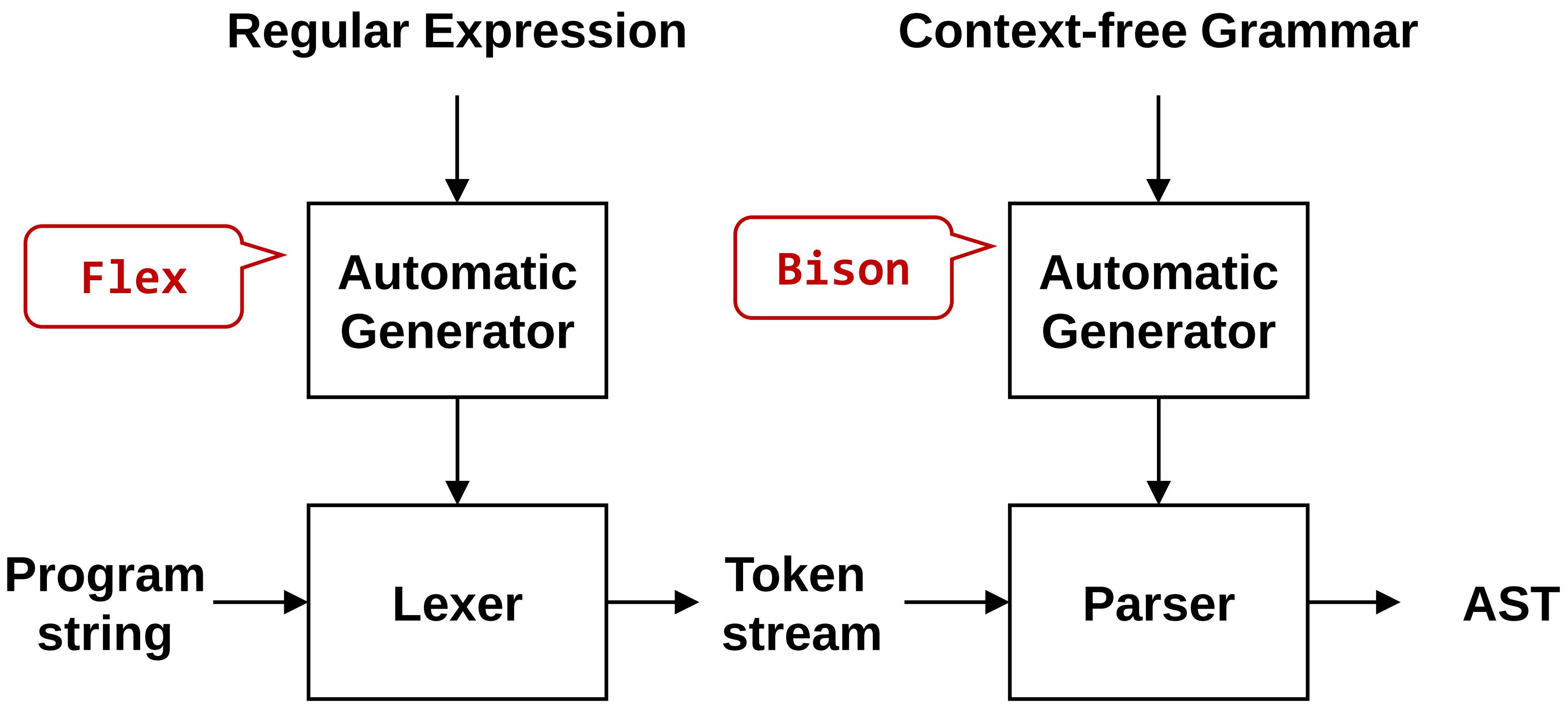
General Information

- **Check "HW #1" in *Assignment* tab of *Cyber Campus***
  - Skeleton code (`HW1.tgz`) is attached in the post
  - Deadline: **10/16** Mon. 23:59
  - Submission will be accepted in that post, too
  - Late submission deadline: **10/18** Wed. 23:59 **(-20% penalty)**
  - Delay penalty is applied uniformly **(not problem by problem)**
- **Please read the instructions in this slide carefully**
  - This slide is step-by-step tutorial for `Flex` and `Bison`
  - It also contains important submission guidelines
    - If you do not follow the guidelines, you will get penalty

Remind: Cheating Policy

- **Cheating (code copy) is strictly forbidden in this course**
  - Read the orientation slide once more
- **Don’t ask for solutions in the online community**
  - TA will regularly monitor the communities
- **Sharing your code with others is as bad as copying**
  - Your cooperation is needed to manage this course successfully

Automatic Front-End Generation



`Flex/Bison` vs. `Lex/Yacc`?

- **`Flex` (<u>`F`</u>ast <u>`Lex`</u>) is rewritten version of `Lex`**
  - Also, the license is more permissive
- **Similarly, `Bison` is rewritten version of `Yacc`**
- **We will use `Flex` and `Bison` for this assignment**
- **In most Linux systems, `Lex/Yacc` are automatically redirected to `Flex/Bison`**
  - Still, many people just call them **`Lex`** and **`Yacc`**

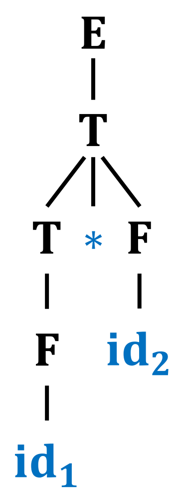
`Bison`: LALR Parsing

- **`Bison` generates an LALR parser for the provided CFG**
- **Recall that LALR is one kind of *bottom-up* parsing**
- **Although we have not learned the details of bottom-up (and LALR) parsing, we can still use `Bison`**
  - All you have to know is how to deal with CFG
  - But after finishing the ***Syntax Analysis*** chapter, you will better understand what is internally going on

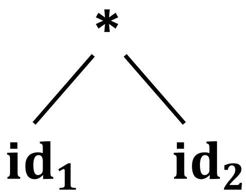
Goal of This Assignment

- **Of course, the first goal is learning how to use `Flex` and `Bison` to generate front-end code**
- **Another important topic to cover is constructing AST**
  - In ***Syntax Analysis*** chapter, we focused on **parse tree**
  - However, **AST** is more concise and desirable form
  - Our `Bison`-generated parser will construct AST *on the fly*

Parse tree of $\mathbf{id_1} * \mathbf{id_2}$



Abstract syntax tree (AST) form



Our Source Language

- **We are going to write a front-end for simple numeric expression language**
  - Initialize variables with values (optional)
  - Initialization is followed by a single numeric expression
- **Our lexer/parser must be able to handle programs below**
  - Also, we will compute the value denoted by the expression

```
x=1, y=2, z=3;
x + y * z
```

7

```
 ;
(8 - 2) / 3
```

2

```
var_1 = 10;
-2 * var_1
```

-20

Skeleton Code

- **Copy HW1.tgz into CSPRO server and decompress it**
  - Don't decompress-and-copy; copy-and-decompress
  - This course will use [cspro**5**.sogang.ac.kr](cspro5.sogang.ac.kr) **(don't miss the "5")**
- **`src/`: Source files you have to work with**
- **`Makefile`: Type `make` to build the whole project**
  - Internally redirects to **`src/Makefile`**
- **`testcase/`: Sample test cases and their answers**
- **`check.py`: Script for self-grading with test cases**
- **`config`: Used by the grading script (you don't have to care)**

```
jason@ubuntu:~$ tar -xzf HW1.tgz
jason@ubuntu:~$ ls HW1
check.py  config  Makefile  src  testcase
```

Src Directory Structure

- **First, you must understand the provided code**
  - Once you know what is going on, this HW is not much hard
  - You only have to write or fix about 50+ lines of code
- **`prog.l` : Input file for `Lex/Flex` (*RegEx* + α)**
- **`prog.y` : Input file for `Yacc/Bison` (CFG + α)**
- **`ast.*` and `varlist.*` : C header and source files to help the implementation of our front-end**
- **`Makefile`: The top-level `Makefile` redirects to this one**

```
jason@ubuntu:~/CSE4120-Lab/HW1$ cd src
jason@ubuntu:~/CSE4120-Lab/HW1/src$ ls
ast.c   ast.h   Makefile   prog.l   prog.y   varlist.c   varlist.h
```

Structure of `.l` and `.y` File

- **Both `Lex` file (`.l`) and `Yacc` file (`.y`) have the following structure**

```
%{
```

Inclusion of C header files and declaration of C variables (already done for you)

```
%}
```

Declaration (we will see what to declare)

```
%%
```

Definition (we will see what to define)

```
%%
```

If needed, more functions like **`main()`** can be defined here (already done for you)

Getting Started: My First `.y` File

- **We will start with a simple CFG (not the complete one)**
  - Caution: the code below is **NOT** the skeleton code
- **First, declare tokens and start symbol in `prog.y`**
- **Then, define the production rules of CFG in `prog.y`**

Simplified CFG

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

```
%token NUM ID PLUS MULT
%start Exp

%%

Exp:
 Term
 | Exp PLUS Term
;
...
```

Getting Started: Run `Bison`

- **Now run "`bison -d prog.y`" on the completed `Yacc` file**
  - It may seem awkward to generate a parser even before a lexer is prepared, but this is totally fine
- **It will generate `prog.tab.c` and `prog.tab.h`**
  - **`prog.tab.c`** is the generated parser code
  - **`prog.tab.h`** will be included by **`prog.l`** to use token declaration

The first part of **`prog.l`** file (continued in the next page)

```
%{
#include "prog.tab.h"
%}

...
```

Getting Started: My First `.l` File

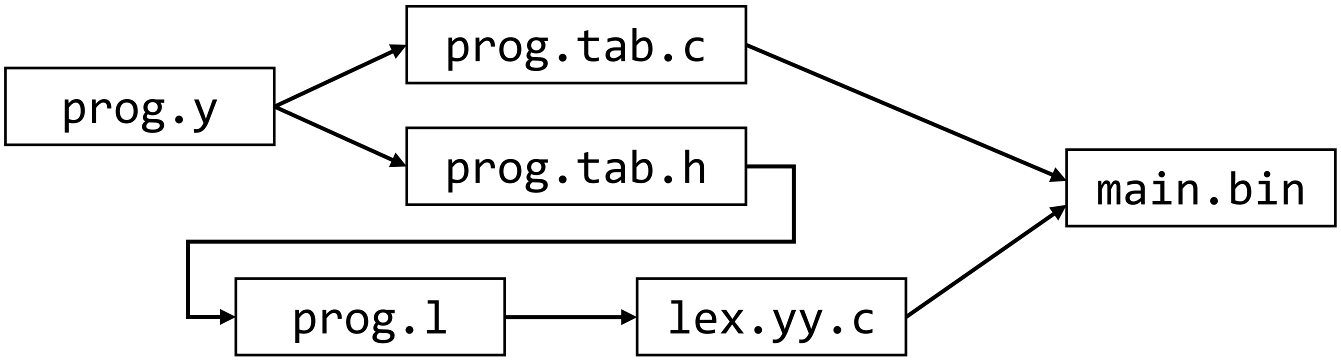
- **Now, define the *RegEx* for each token in `prog.l`**
  - Notation is slightly different from the ***Lexical Analysis*** Chapter
  - We specify in C which token to return for each *RegEx* pattern
    - If the code snippet doesn't return anything, token is skipped
  - We can declare some patterns (**`dig`**, **`let`**) to remove duplication

```
dig [0-9]
let [A-Za-z]

%%

"+"                         { return PLUS; }
"*"                         { return MULT; }
{dig}+                      { return NUM; }
({let}|_)({let}|{dig}|_)*   { return ID; }
[ \t\n]+                    { /* Skip (do nothing) */ }
```

Putting Things Together

- **Now run "`flex prog.l`" on the completed `Lex` file**
  - It will generate the lexer code in **`lex.yy.c`** file
- **Finally, compile the generated code with `gcc`**
  - A simple **`Makefile`** will look like this

```
../main.bin: prog.y prog.l
	bison -d prog.y
	flex prog.l
	gcc -o ../main.bin prog.tab.c lex.yy.c
```



Now the front-end runs, but…

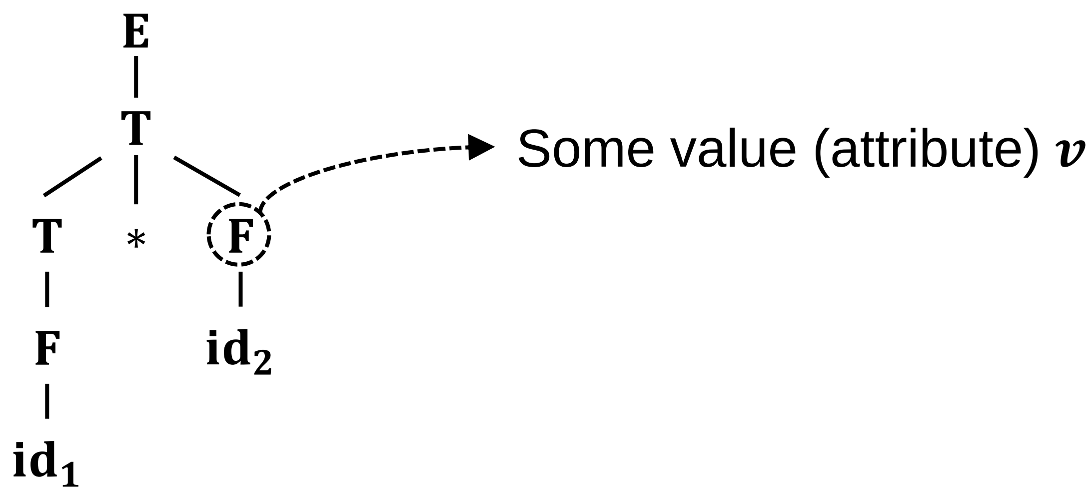
- The compiled `main.bin` will accept valid numeric expression and reject invalid ones
- But it does not do anything interesting
- Let's fix our front-end to construct AST and evaluate the value of numeric expression

```
$ cat tc-1
7 + 3 * 4
$ ./main.bin tc-1
$ cat tc-2
7 + 3 * + 4
$ ./main.bin tc-2
error: syntax error
```

Adding Values and Actions

- **The key idea is to associate some value (a.k.a. attribute) with each node of parse tree**
- **We also define appropriate actions for each CFG rule**
  - Each action is executed when the rule is applied
- **These actions compute value (attribute) for each node**

(Parse tree)



Values for Terminal Symbol (Token)

- **We must store the value of a token to `yylval`**
  - `NUM` token must be associated with an integer
  - `ID` token must be associated with a string (pointer)
- **`yytext` is the string that just has been matched by lexer**

prog.y

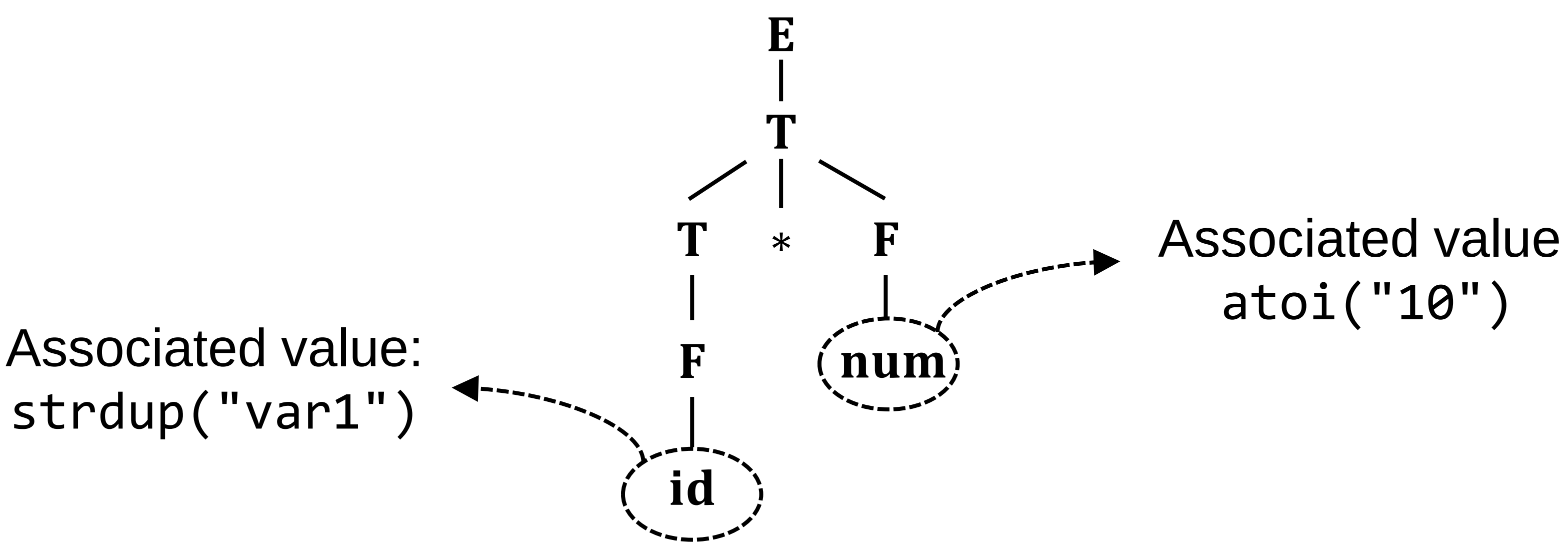
```
%union {
    int n;
    char *s;
}
%token <n> NUM
%token <s> ID
%token PLUS MULT
...
%%
...
```

prog.l

```
"+"     { return PLUS; }
"*"     { return MULT; }
{dig}+ {
    yylval.n = atoi(yytext);
    return NUM;
}
({let}|_)({let}|{dig}|_)*   {
    yylval.s = strdup(yytext);
    return ID;
}
```

Terminal’s Value: Example

- **Assume that the input string is `var1 * 10`**
  - At token level, represented as **id** $*$ **num**
  - Value of **`yytext`** is `"var1"` for **id** token, `"10"` for **num** token
- **The values of terminal symbols are illustrated below**
- **Now, how to compute values for non-terminals (E, T, F)?**



Values for Non-terminal Symbol

- **Example: Actions for the rules F → num and F → id**
  - **`$$`** is the value of ***LHS*** symbol, **`$n`** is the value of ***RHS*** symbols

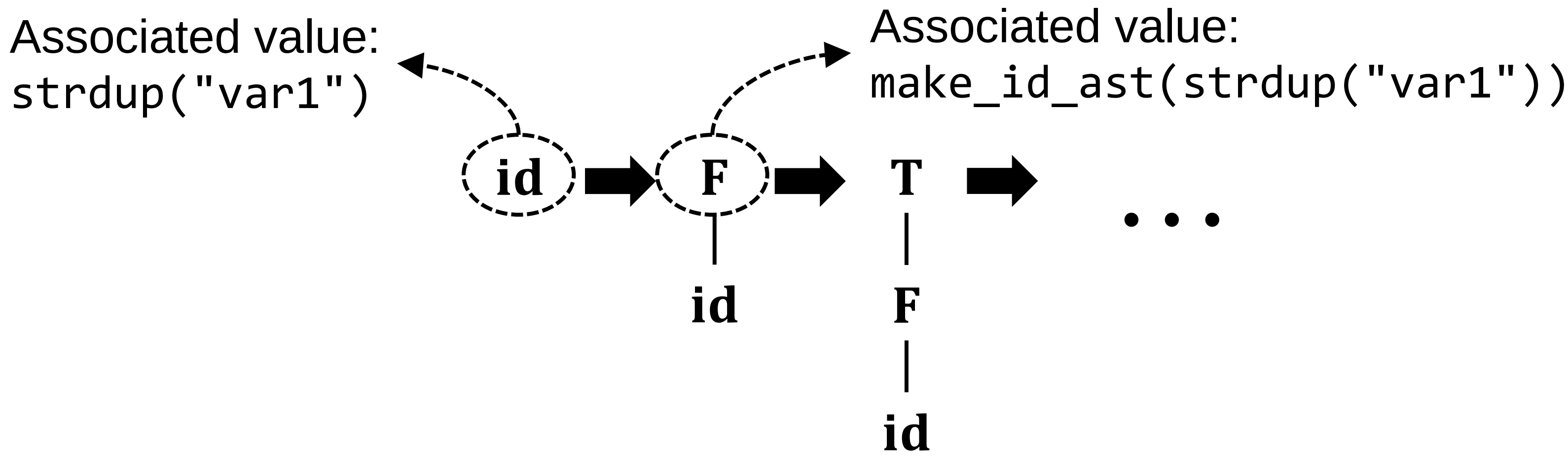
```
%union {
    int n;
    char *s;
    struct AST *a;
}
...
%type <a> Fact

%%
...
Fact:
 NUM    { $$ = make_num_ast($1); }
 | ID   { $$ = make_id_ast($1); }
;
```

Declare that non-terminal symbol **`Fact`** is associated with a **`AST*`**

`AST* make_num_ast(int n)` and **`AST* make_id_ast(char *s)`** are defined in **`ast.h/ast.c`** files

Non-terminal's Value: Example

- Again, assume input string `var1 * 10`
- Recall the bottom-up parsing process for this string
- In the first step that applies rule **F → id** reversely, its action `$$ = make_id_ast($1)` is performed
  - `$1` is the value associated with the first symbol in RHS (**id**)
  - Recall that we have previously set it with `strdup("var1")`



Now basic explanation is over

You must read the skeleton code and figure out what is going on (it will take some time)

Source Language: Lexer Spec

- **Translate the following descriptions into regular expressions in `prog.l` file**
  - Most parts are already done for you
- **Your lexer must recognize these symbols as distinct tokens: "`+`", "`-`", "`*`", "`/`", "`=`", "`(`", "`)`", "`,`", "`;`"**
- **Identifier token can start with any alphabet or _, and trailing characters can be alphabet, digit, or _**
- **Number token can be any decimal integer**
  - Does not include sign prefix
  - Therefore, string "-1523" must be recognized as two tokens

Source Language: Parser Spec

- **Context-free grammar for our source language**
  - $\mathbf{Program} \rightarrow \mathbf{;\ E} \mid \mathbf{Init\ ;\ E}$
  - $\mathbf{Init} \rightarrow \mathbf{id\ = num} \mid \mathbf{id\ = num,\ Init}$
  - $\mathbf{E} \rightarrow \mathbf{E + T} \mid \mathbf{E - T} \mid \mathbf{T}$
  - $\mathbf{T} \rightarrow \mathbf{T * F} \mid \mathbf{T\ /\ F} \mid \mathbf{F}$
  - $\mathbf{F} \rightarrow \mathbf{num} \mid \mathbf{id} \mid \mathbf{(\ E\ )} \mid \mathbf{-\ F}$
- **Specify this CFG in `prog.y`**
  - Some rules are already implemented for you
- **Symbol names do not have to exactly match with this**
  - The order of rules does not matter, too
- **Ask me if this CFG seems to have a problem or mistake**

Your Mission

- **Complete `prog.l` and `prog.y` according to the spec**
  - **But do not change** `main()` and `yyerror()` code in `prog.y`
- **You also have to implement some C functions in `ast.c` and `varlist.c` (functions marked with `"TODO"` comment)**
- **You will be asked to submit these four files**
- **Do not touch any other files**
  - Such as `Makefile` or header files (`ast.h` and `varlist.h`)

Self-Grading

- **Run `check.py` script to run your code with test inputs in `testcase/` directory**
  - Symbols in the result have the following meanings
    - **`'O'`**: Correct, **`'X'`**: Incorrect
    - **`'T'`**: Timeout, **`'E'`**: Runtime error, **`'C'`**: Compile error
  - In **`testcase/`** directory, **`tc-N`** (test input) and **`ans-N`** (expected output of **`tc-N`**) files are provided

```
jason@ubuntu:~/HW1$ ls
check.py  config  main.bin  Makefile  src  testcase
jason@ubuntu:~/HW1$ ./check.py
[*] Result: XXXX
```

Test Cases for Real Grading

- **During the real grading, I will use additional test cases**
- **So you are encouraged to run your own test cases**
- **Assumptions for test cases:**
  - All the variables that appear in the numeric expression are properly initialized (no uninitialized variable)
  - Each variable is initialized only once (no duplicate initialization)
  - I will not use invalid inputs as test cases
    - You don’t have to worry about reporting lexical/syntax errors

Submission Guideline

- **You should submit the following four files**
  - `prog.l`
  - `prog.y`
  - `ast.c`
  - `varlist.c`
- **Submission format**
  - Upload these files directly to *Cyber Campus* (**do not zip them**)
  - **Do not change the file name** (e.g., adding any prefix or suffix)
  - If your submission format is wrong, you will get **-20% penalty**