TDDD55- Compilers and Interpreters
Lesson 3

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1. Grammars and Top-Down Parsing

- Some grammar rules are given
- Your task:
  - Rewrite the grammar (eliminate left recursion, etc.)
  - Add attributes and attribute rules to the grammar
  - Implement your grammar in a C++ class named **Parser**. The **Parser** class should contain a method named **Parse** that returns the value of a single statement in the language.

2. Scanner Specification

- Finish a scanner specification given in a *scanner.l* flex file, by adding rules for C and C++ style comments, identifiers, integers, and floating point numbers.

3. Parser Generators

- Finish a parser specification given in a *parser.y* bison file, by adding rules for expressions, conditions and function definitions, ... You also need to augment the grammar with error productions.

4. Intermediate Code Generation

- The purpose of this assignment to learn about how abstract syntax trees can be translated into intermediate code.
- You are to finish a generator for intermediate code by adding rules for some language statements.

Laboratory Skeleton

- ~TDDD55
  - /lab
    - /doc
      - Documentation for the assignments.
    - /lab1
      - Contains all the necessary files to complete the first assignment
    - /lab2
      - Contains all the necessary files to complete the second assignment
    - /lab3-4
      - Contains all the necessary files to complete assignment three and four

Bison – Parser Generator

Purpose of a Parser

- The parser accepts tokens from the scanner and verifies the syntactic correctness of the program.
  - Syntactic correctness is judged by verification against a formal grammar which specifies the language to be recognized.
- Along the way, it also derives information about the program and builds a fundamental data structure known as parse tree or abstract syntax tree (ast).
- The abstract syntax tree is an internal representation of the program and augments the symbol table.

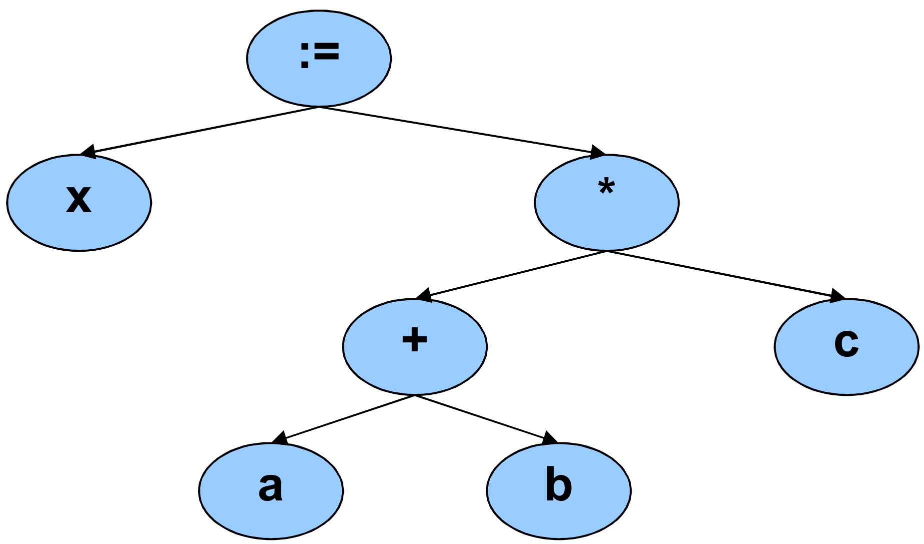
Bottom-Up Parsing

- Recognize the components of a program and then combine them to form more complex constructs until a whole program is recognized.

- The parse tree is then built from the bottom and up, hence the name.

Bottom-Up Parsing(2)

X := (a + b) * c;



LR Parsing

- A Specific bottom-up parsing technique
  - LR stands for Left to right scan, Rightmost derivation.
  - Probably the most common & popular parsing technique.
  - yacc, bison, and many other parser generation tools utilize LR parsing.
  - Great for machines, not so great for humans

Pros and Cons of LR parsing

- Advantages of LR:
  - Accepts a wide range of grammars/languages
  - Well suited for automatic parser generation
  - Very fast
  - Generally easy to maintain

- Disadvantages of LR:
  - Error handling can be tricky
  - Difficult to use manually

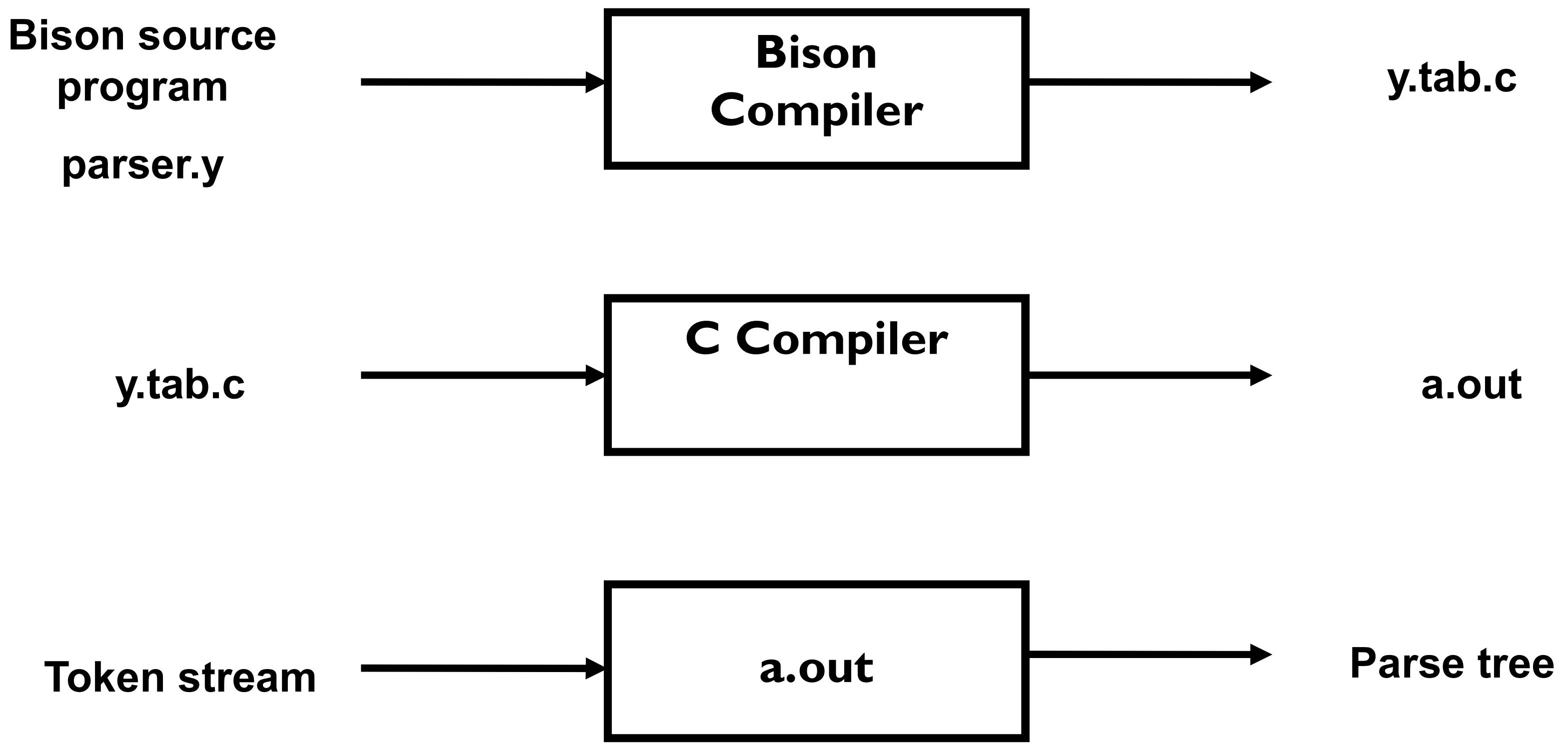
Bison

- **Bison** is a general-purpose parser generator that converts a grammar description of a context-free grammar into a **C** program to parse that grammar
- Similar idea to flex

Bison (2)

- Input: a specification file containing mainly the grammar definition
- Output: a C source file containing the parser
- The entry point is the function int yyparse();
  - yyparse reads tokens by calling yylex and parses until
    - end of file to be parsed, or
    - unrecoverable syntax error occurs
  - returns 0 for success and 1 for failure

Bison Usage



Bison source program
parser.y
Bison Compiler
y.tab.c
y.tab.c
C Compiler
a.out
Token stream
a.out
Parse tree

Bison Specification File

- A Bison specification is composed of 4 parts.

```
%{
    /* C declarations */
%}
    /* Bison declarations */

%%

    /* Grammar rules */

%%

    /* Additional C code */
```

1.1. C Declarations

- Contains macro definitions and declarations of functions and variables that are used in the actions in the grammar rules
- Copied to the beginning of the parser file so that they precede the definition of yyparse
- Use #include to get the declarations from a header file. If C declarations isn’t needed, then the %{ and %} delimiters can be omitted

1.2. Bison Declarations

- Contains:
  - declarations that define terminal and non-terminal symbols
  - Data types of semantic values of various symbols
  - specify precedence

Bison Specification File

- A Bison specification is composed of 4 parts.

```
%{
    /* C declarations */
%}
    /* Bison declarations */

%%

    /* Grammar rules */

%%

    /* Additional C code */
```

2. Grammar Rules

- Contains one or more Bison grammar rules

- Example:
  - expression : expression ‘+’ term { $$ = $1 + $3; } ;

- There must always be at least one grammar rule, and the first %% (which precedes the grammar rules) may never be omitted even if it is the first thing in the file.

Bison Specification File

- A Bison specification is composed of 4 parts.

```
%{
    /* C declarations */
%}
    /* Bison declarations */

%%

    /* Grammar rules */

%%

    /* Additional C code */
```

3. Additional C Code

- Copied verbatim to the end of the parser file, just as the C declarations section is copied to the beginning.
- This is the most convenient place to put anything that should be in the parser file but isn't needed before the definition of yyparse().
- The definitions of yylex() and yyerror() often go here.

Bison Example 1 – Parsing simple mathematical expressions

```
%{
#include <ctype.h> /* standard C declarations here */
double int yylex();
}%
%token DIGIT /* bison declarations */
%%
/* Grammar rules */
line : expr '\n'            {  printf { "%d\n", $1 };  };
expr : expr '+' term        {  $$ = $1 + $3;  }
       | term               {  $$ = $1;  } ;
term : term '*' factor      {  $$ = $1 * $3;  }
       | factor             {  $$ = $1;  } ;
factor : '(' expr ')'       {  $$ = $2;  }
          | DIGIT ;
```

Bison Example 1 (cont)

```
%%
/* Additional C code */

int yylex () {
   /* A really simple lexical analyzer */
   int c = getchar ();
   if ( isdigit (c) ) {
      yylval = c - ’0’ ;
      return DIGIT;
   }
   return c;
}
```

Bison Example 2 – Mid-Rules

```
thing: A { printf("seen an A"); } B ;

The same as:

thing: A fakename B ;
fakename: /* empty */ { printf("seen an A"); } ;
```

Bison Example 3 – Simple Calculator

```
%{
#define YYSTYPE double
#include <math.h>
%}

/* BISON Declarations  */
%token NUM
/*introduce precedence and associativity */
%left '-' '+'
%left '*' '/‘
%right '^'    /* exponentiation        */

%%
```

Bison Example 3 (cont)

```
input:    /* empty string */
        | input line ;
line:     '\n'
        | expr '\n'  { printf ("\t%.10g\n", $1); };
expr :      NUM                     { $$ = $1;       }
        | expr '+' expr             { $$ = $1 + $3;   }
        | expr '-' expr             { $$ = $1 - $3;   }
        | expr '*' expr             { $$ = $1 * $3;   }
        | expr '/' expr             { $$ = $1 / $3;   }
        | expr '^' expr             { $$ = pow ($1, $3); }
        | '(' expr ')‘              { $$ = $2;  }
;
%%
```

Syntax Errors

- Error productions can be added to the specification
- They help the compiler to recover from syntax errors and to continue to parse
- In order for the error productions to work we need at least one valid token after the error symbol
- Example:
  - functionCall : ID '(' paramList ')'

    | ID '(' error ')'
- Recover from syntax errors by discarding tokens until it reaches the valid token.

Using Bison With Flex

- Bison and flex are designed to work together
- Bison produces a driver program called yylex()
  - #include “lex.yy.c” in the last part of bison specification
  - this gives the program yylex access to bisons’ token names

Using Bison with Flex (2)

- Thus, do the following:
  - flex scanner.l
  - bison parser.y
  - cc y.tab.c -ly -ll
- This will produce an a.out which is a parser with an integrated scanner included

Laboratory Assignment 3

Parser Generation

- Finnish a parser specification given in a *parser.y* bison file, by adding rules for expressions, conditions and function definitions, ...

Functions

```
function : funcnamedecl parameters ‘:’ type variables functions block ‘;’
{
    // Set the return type of the function
    // Set the function body
    // Set current function to point to the parent again
} ;

funcnamedecl : FUNCTION id
{
    // Check if the function is already defined, report error if so
    // Create a new function information and set its parent to current function
    // Link the newly created function information to the current function
    // Set the new function information to be the current function
}  ;
```

Expressions

- For precedence and associativity you can factorize the rules for expressions …
- Or specify precedence and associativy at the top of the Bison specification file, in the Bison Declarations section. Read more about this in the Bison reference.

Expressions (2)

- Example with factoring:

```
expression : expression '+' term
{
 // If any of the sub-expressions is NULL, set $$ to NULL
// Create a new Plus node and return in $$
//IntegerToReal casting might be needed
}
|
...
```

Laboratory Assignment 4

Intermediate code

Intermediate Code

- Closer to machine code, but not machine specific
- Can handle temporary variables.
- Means higher portability, intermediate code can easier be expanded to assembly code.
- Offers the possibility of performing code optimizations such as register allocation.

Intermediate Code

- Why do we use intermediate languages?
- Retargeting - build a compiler for a new machine by attaching a new code generator to an existing front-end and middle-part
- Optimization - reuse intermediate code optimizers in compilers for different languages and different machines
- Code generation - for different source languages can be combined

Intermediate Languages

- Infix notation
- Postfix notation
- Three address code
  - Triples
  - Quadruples

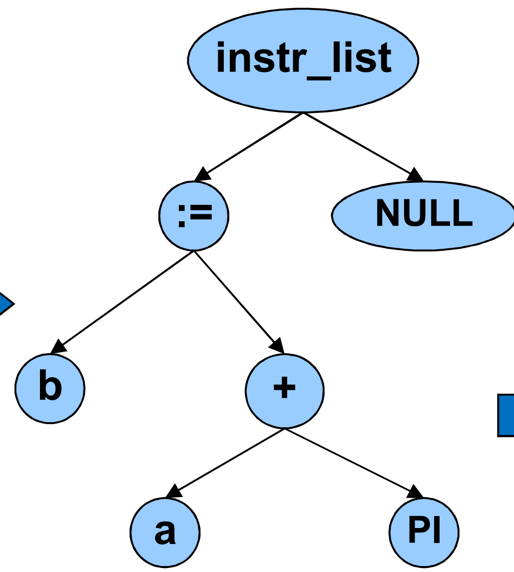
Quadruples

- You will use quadruples as intermediate language where an instruction has four fields:

operator	operand1	operand2	result

Generation of Intermediate Code

```
program example;
const
   PI = 3.14159;
var
   a : real;
   b : real;
begin
   b := a + PI;
end.
```



q_rplus	A	PI	$1
q_rassign	$1	-	B
q_labl	4	-	-

Quadruples

(A + B) * (C + D) - E

operator	operand1	operand2	result
+	A	B	T1
+	C	D	T2
*	T1	T2	T3
-	T3	E	T4

Intermediate Code Generation

- The purpose of this assignment is to learn how abstract syntax trees can be translated into intermediate code.
- You are to finish a generator for intermediate code (quadruples) by adding rules for some language constructs.
- You will work in the file *codegen.cc*.

Binary Operations

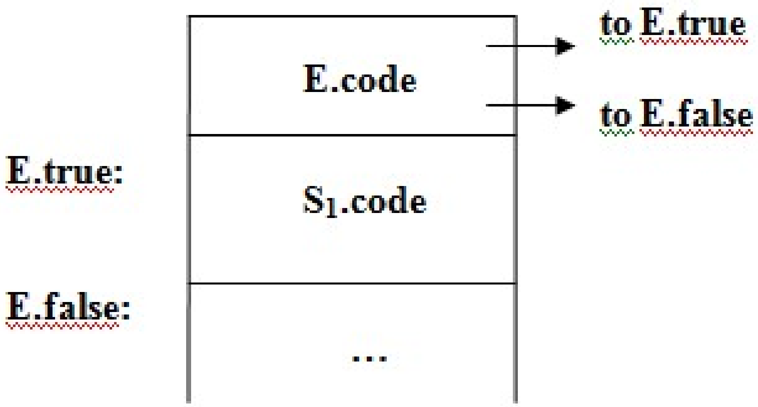
- In function *BinaryGenerateCode*:
  - Generate code for left expression and right expression.
  - Generate either a *realop* or *intop* quadruple
    - Type of the result is the same as the type of the operands
    - You can use *currentFunction->TemporaryVariable*

Array References

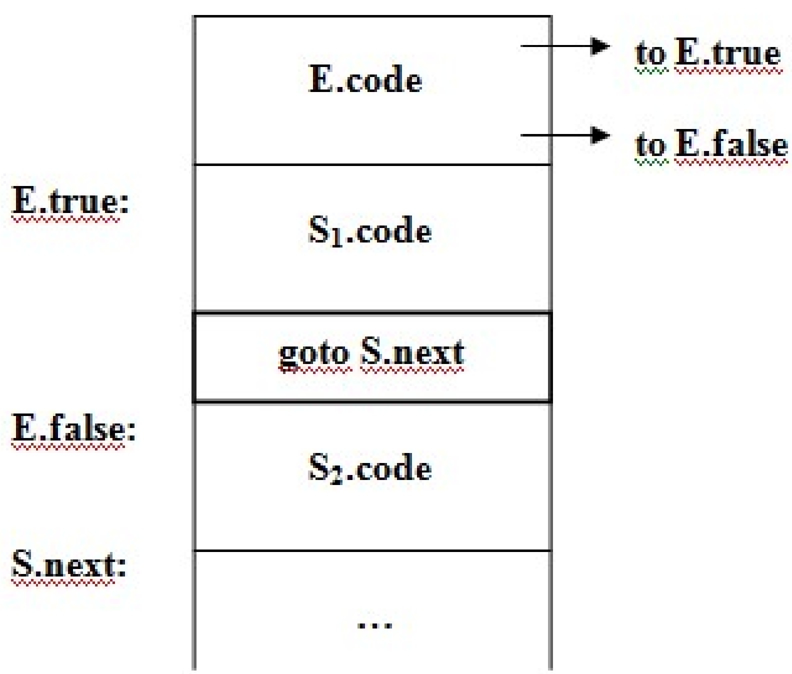
- The absolute address is computed as follows:
  - *absAdr = baseAdr + arrayTypeSize * index*
- Generate code for the index expression
- You must then compute the absolute address
  - You will have to create several temporary variables (of integer type) for intermediate storage
  - Generate a quadruple *iaddr* with *id* variable as input for getting the base address
  - Create a quadruple for loading the size of the type in question to a temporary variable
  - Then generate *imul* and *iadd* quadruples
  - Finally generate either a *istore* or *rstore* quadruple

If Statement

- **S → if E then S_1**
- **S → if E then S_1 else S_2**



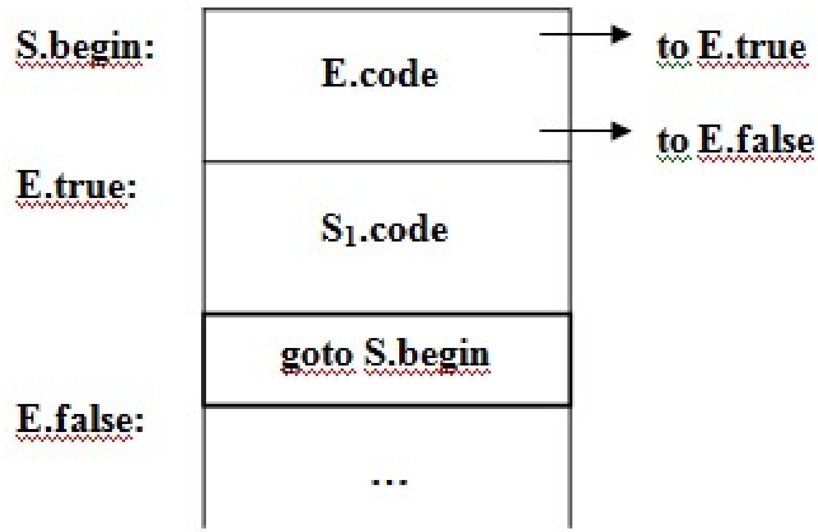
if - then



if – then - else

WHILE Statement

- **S → while E do S_1**



while - do