TDD55: Compilers and Interpreters

Lesson 3

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Schedule

1. Formal languages and automata theory
2. Formal languages and automata theory, Flex
3. Bison and intermediate code generation
4. Exam preparation
5. Exam preparation

Laboratory assignments

- Goal: Get some practical experience in compiler construction
- 4 assignments to complete in 4x2 sessions → non-scheduled time required
  1. Attribute Grammars and Top-Down parsing
  2. Scanner Specification
  3. Parser Generators
  4. Intermediate Code Generation

Handing in and deadline

- Demonstrate during scheduled sessions
- Then, hand in code and answers to any questions in the assignment via e-mail. One e-mail per group, subject: TDDD55: Lab n. From your LiU-email.
- Deadline: 21^{st} December

Skeleton

Copy to your home directory using:

```
cp -r ~TDDD55/lab .
```

- ~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

Lab 1

- Some grammar rules given:
- Rewrite the grammar to LL(1)
- Add attribute rules to the grammar
- Implement the LL(1) grammar and the attributes in a C++-class named Parser. Parser shall contain a method Parse() which returns the value of a single statement in the language.

Lab 2

- Finish a scanner specification in Flex (scanner.l) by adding rules for comments, identifiers, integers and reals.

Lab 3

- Finish a parser specification in Bison (parser.y) by adding rules for expressions, conditions, function definitions, etc.
- You also need to add error productions.
- More details in lesson 3.

Lab 4

- Generate intermediate code from a parse tree.
- Finish a generator for intermediate code by adding rules for some language statements.
- More details in lesson 3.

Bison

Purpose of a parser

- Accept tokens from a scanner and verify the syntactic correctness of the program
  - Uses formal grammar for specifying the language
- Along the way, it derives information about the program and stores it as an abstract syntax tree (AST)
- The AST 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 up, hence the name.

LR Parsing

- A specific bottom-up technique
- LR = left-to-right scan, reversed rightmost derivation
- Probably the most common and popular technique
- yacc, bison and many other parser generation tools utilize LR parsing
- Great for machines, harder for humans

Pros and Cons of LR Parsing

- Advantages
  - Accepts a wide range of grammars/languages
  - Well suited for automatic parser generation
  - Very fast
  - Generally easy to maintain
- Disadvantages
  - Error handling can be tricky
  - Difficult to use manually

Bison

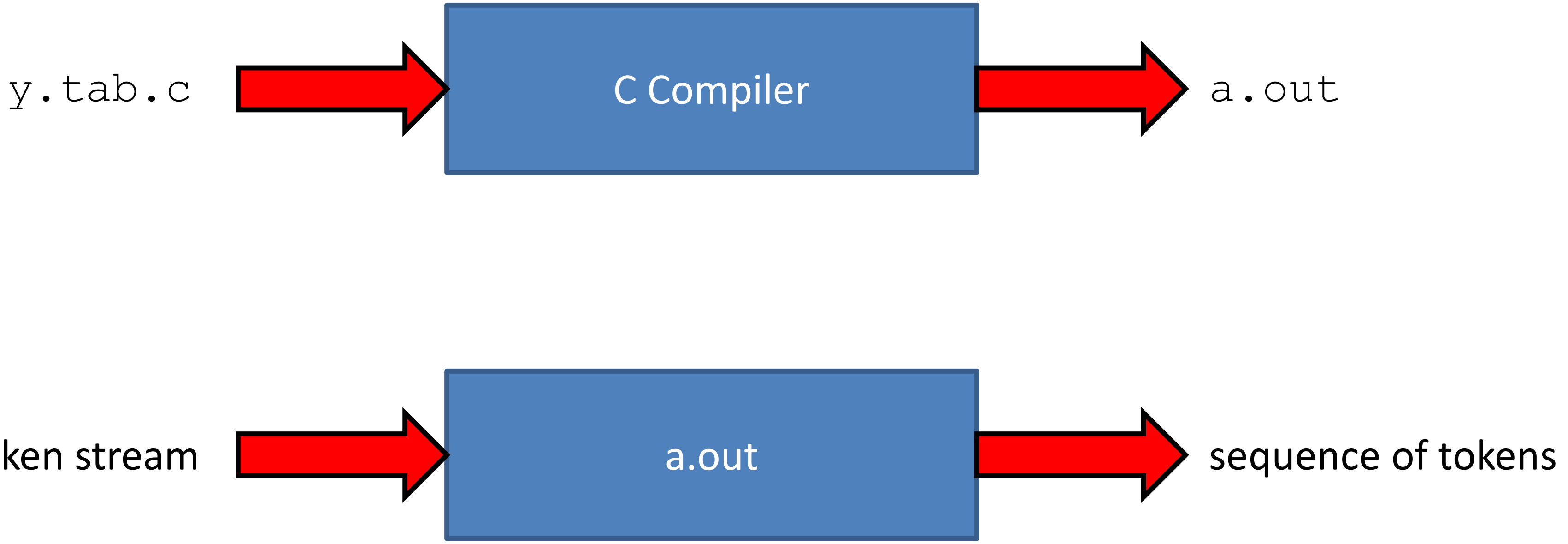
- Bison is a general-purpose parser generator that converts a grammar description of a context-free grammar into a C-program to parse the grammar
- Similar idea to flex

How it works

Bison generates a C source file, y.tab.c

How it works

y.tab.c is compiled and linked with required libraries to produce an executable, which is the parser



Bison specifications

Bison specifications are divided into 4 parts

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

  /* Grammar rules */

%%

  /* Additional C code */
```

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 aren’t needed, then the %{ and %} can be omitted

Bison declarations

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

Bison specifications

Bison specifications are divided into 4 parts

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

  /* Grammar rules */

%%

  /* Additional C code */
```

Grammar rules

- Contains one or more Bison grammar rules, and nothing else.
- Example:
  - expression : expression ‘+’ expression { $$ = $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 specifications

Bison specifications are divided into 4 parts

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

  /* Grammar rules */

%%

  /* Additional C code */
```

Additional C code

- Copied verbatim to the end of the parser file, just as the C declarations are 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
- For example, yylex() and yyerror() often go here

Example 1

```
%{
#include <ctype.h>
#define YYSTYPE double
int yylex();
%}
%token DIGIT
%%
line : expr '\n'      { printf("%d\n", $1); };
expr : expr '+' term { $$ = $1 + $3; }
     | term           { $$ = $1; };
term : term '*' fact { $$ = $1 * $3; }
     | fact           { $$ = $1; };
fact : '(' expr ')'  { $$ = $2; }
     | DIGIT;
```

Example 1 (cont)

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

Example 2

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

Same as

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

Example 3

```
%{
#define YYSTYPE double
#include <math.h>
%}
%token NUM
%left '-' '+'
%left '*' '/'
%right '^'
```

Example 3 (cont)

```
%%
input : /* empty string */ | input line;
line  : '\n'
      | expr '\n'     { printf("\t%.10f\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 ')'  { $$ = $1; };
%%
```

Syntax Errors

- Error productions can be added
- 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
- Flex produces a driver program called yylex()
  - #include "lex.yy.c" in the last part of bison specification
  - this gives the program yylex access to bison's token names

Using Bison with Flex

- 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 included scanner

Assignment 3

Parser generators

Parser Generators

- Finish a parser specification given in *parser.y* 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 and conditions

- For precedence and associativity you can factorize the rules…
- or specify precedence and associativity at the top of the Bison specification file. Read more about this in the Bison reference.

Expressions - Example

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

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

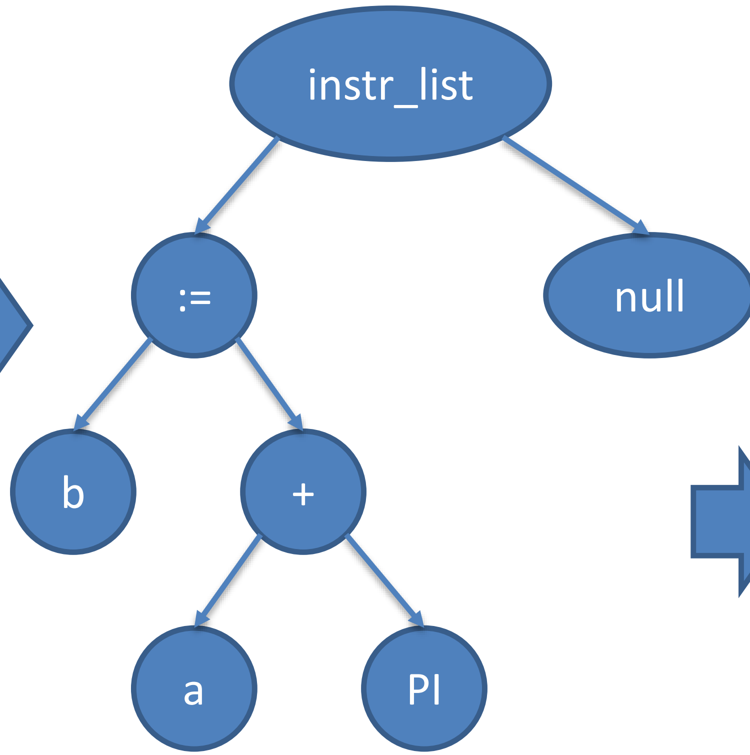
Quadruples

- We use quadruples as an intermediate language.
- An instruction has four fields:

operator	operand1	operand2	result

Generation

```
program ex;
const
   PI = 3.1415;
var
   a : real;
   b : real;
begin
   b := a + PI;
end
```



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

Quadruples

$$\boxed{(A+B)*(C+D)-E}$$

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 machine code.
- You are to finis a generator for intermediate code (quadruples) by adding rules for some language constructs.
- You will work in *codegen.cc.*

Binary Operations

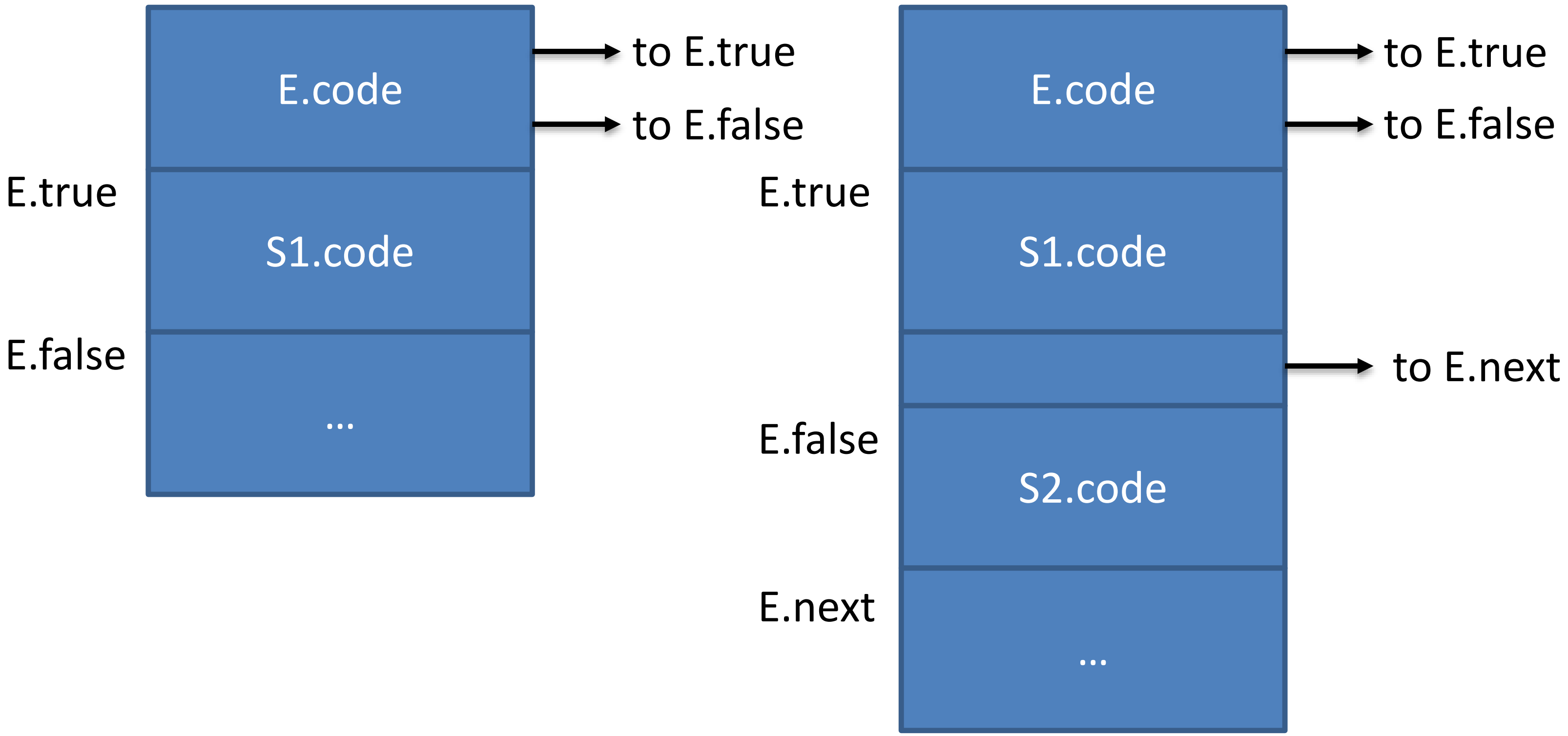
- Create code for left expression and right expression
- Generate either a realop or intop quad
  - Type of the result is the same as the type of the operands
  - You can use currentFunction->TemporaryVariable

Array References

- The absolute address is computed as follows:
  - absAddr = baseAddr + arrayTypeSize*index
- Generate code for the index expression
- You must then compute the absolute address
  - You will have to create several temporary variables
  - Create a quad for loading the size of the type to a temporary
  - Then generate iadd and imul quads
  - Finally generate either a istore or rstore quad

If Statement

- S -> if E then S1
- S -> if E then S1 else S2



While Statement

- S -> while E do S1