COMP3048: Lecture 5

Syntactic Analysis: Parser Generators

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This Lecture

- Parser generators (“compiler compilers”)
- The parser generator Happy
- A TXL parser written using Happy
- A TXL interpreter written using Happy

Parser Generators (1)

- Constructing parsers by hand can be very tedious and time consuming.
- This is true in particular for LR(k) and LALR parsers: constructing the corresponding DFAs is extremely laborious.
- E.g., this simple grammar (from the prev. lect.)

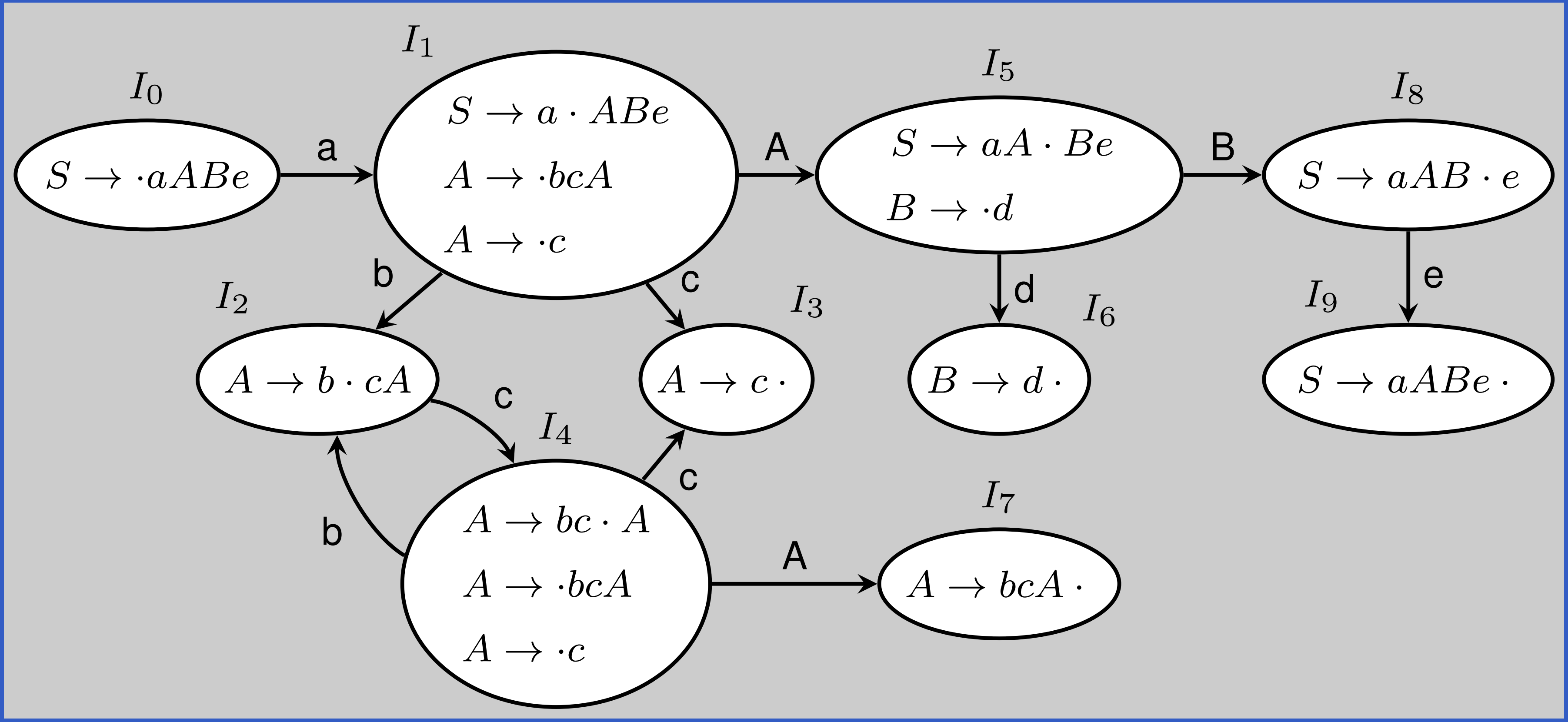
$$
\begin{array}{rcl}
S & \rightarrow & aABe \\
A & \rightarrow & bcA \mid c \\
B & \rightarrow & d
\end{array}
$$

gives rise to a 10 state LR(0) DFA!

Parser Generators (2)

An LR(0) DFA recognizing viable prefixes for

$$S \to aABe \qquad A \to bcA \mid c \qquad B \to d$$



Parser Generators (3)

- ***Parser construction*** is in many ways a very ***mechanical*** process. Why not write a program to do the hard work for us?
- A ***Parser Generator*** (or "compiler compiler") takes a grammar as input and outputs a parser (a program) for that grammar.
- The input grammar is augmented with ***"semantic actions"***: code fragments that get invoked when a derivation step is performed.
- The semantic actions typically construct an AST or interpret the program being parsed.

Parser Generators (4)

Consider an LR shift-reduce parser:

- Some of the actions when parsing $abccde$:

State	Stack (γ)	Input (w)	Move
...	...	...	...
I_5	aA	de	Shift
I_6	aAd	e	Reduce by $B \to d$
I_8	aAB	e	Shift
I_9	$aABe$	ϵ	Reduce by $S \to aABe$
	S	ϵ	Done

- A ***reduction*** corresponds to a derivation step in the grammar (an LR parser performs a rightmost derivation in reverse).

Parser Generators (5)

- At a reduction, the terminals and non-terminals of the RHS of the production (the ***handle***) are on the parse stack, associated with ***semantic information*** or ***semantic value***; e.g., the corresponding AST fragments, expression values.
- Think of the RHS symbols as ***variables*** bound to the the semantic value resulting from a successful derivation for that symbol.
- Construction of AST, evaluation of expressions, etc. proceeds in ***bottom-up*** order.

Parser Generators (6)

Some examples of parser generators:

- Yacc ("Yet Another Compiler Compiler"): A classic UNIX LALR parser generator for C.
  `http://dinosaur.compilertools.net/`
- Bison: GNU project parser generator, a free Yacc replacement, for C and C++.
- Happy: a parser generator for Haskell, similar to Yacc and Bison.
  `http://www.haskell.org/happy/`
- Cup: LALR parser generator for Java.

Parser Generators (7)

- ANTLR: LL(k) (recursive descent) parser generator and other translator-oriented tools for Java, C#, C++. http://www.antlr.org/
- Many more compiler tools for Java here: http://catalog.compilertools.net/java.html
- And a general catalogue of compiler tools: http://catalog.compilertools.net/

Happy Parser for TXL (1)

We are going to develop a TXL parser using Happy. The TXL CFG:

$$
\begin{array}{lcl}
TXLProgram & \rightarrow & Exp \\
Exp & \rightarrow & AddExp \\
AddExp & \rightarrow & MulExp \\
 & | & AddExp \; \mathbf{+} \; MulExp \\
 & | & AddExp \; \mathbf{-} \; MulExp
\end{array}
$$

Note: ***Left-recursive!*** (To impart associativity.)
LR parsers have no problems with left- or right-recursion (except right recursion uses more stack).

Happy Parser for TXL (2)

The TXL CFG continued:

$$
\begin{array}{lcl}
\mathit{MulExp} & \rightarrow & \mathit{PrimExp} \\
 & | & \mathit{MulExp}\ \texttt{*}\ \mathit{PrimExp} \\
 & | & \mathit{MulExp}\ \texttt{/}\ \mathit{PrimExp} \\
\mathit{PrimExp} & \rightarrow & \underline{\mathit{IntegerLiteral}} \\
 & | & \underline{\mathit{Identifier}} \\
 & | & \texttt{(}\ \mathit{Exp}\ \texttt{)} \\
 & | & \texttt{let}\ \underline{\mathit{Identifier}}\ \texttt{=}\ \mathit{Exp}\ \texttt{in}\ \mathit{Exp}
\end{array}
$$

Happy Parser for TXL (3)

Haskell datatype for tokens:

```
data Token = T_Int Int
           | T_Id Id
           | T_Plus
           | T_Minus
           | T_Times
           | T_Divide
           | T_LeftPar
           | T_RightPar
           | T_Equal
           | T_Let
           | T_In
```

Happy Parser for TXL (4)

Haskell datatypes for AST:

```
data BinOp = Plus | Minus | Times | Divide

data Exp = LitInt   Int
         | Var      Id
         | BinOpApp BinOp Exp Exp
         | Let      Id Exp Exp
```

Happy Parser for TXL (5)

A simple Happy parser specification:

```
{ Module Header }
%name ParserFunctionName
%tokentype { TokenTypeName }

%token
Specification of Terminal Symbols
%%
Grammar productions with semantic actions

{ Further Haskell Code }
```

Happy Parser for TXL (6)

The terminal symbol specification specifies terminals to be used in productions and relates them to Haskell constructors for the tokens:

```
%token
    int         { T_Int $$ }
    ident       { T_Id $$ }
    '+'         { T_Plus }
    '-'         { T_Minus }
    ...
    '='         { T_Equal }
    let         { T_Let }
    in          { T_In }
```

Happy Parser for TXL (7)

- The code fragment between curly braces is a Haskell ***pattern*** that is matched against the actual tokens returned by the parsing function.
- If this pattern contains the special variable `$$`, then the corresponding part of the matched token becomes the semantic value. Examples: `T_Int $$`, `T_Id $$`
- Otherwise the entire token becomes the semantic value. Examples: `T_Plus`, `T_In`
- The semantic values of different terminal symbols may thus have different types.

Happy Parser for TXL (5)

The grammar productions are written in BNF, with an additional semantic action defining the semantic value for each production:

```
add_exp
   : mul_exp                  {$1}
   | add_exp '+' mul_exp {BinOpApp Plus $1 $3}
   | add_exp '-' mul_exp {BinOpApp Minus $1 $3}
mul_exp
   : prim_exp                  {$1}
   | mul_exp '*' prim_exp {BinOpApp Times $1 $3}
   | mul_exp '/' prim_exp {BinOpApp Divide $1 $3}
```

Happy Parser for TXL (6)

It is also possible to add type annotations:

```
add_exp :: { Exp }
add_exp
   : mul_exp                   {$1}
   | add_exp '+' mul_exp {BinOpApp Plus $1 $3}
   | add_exp '-' mul_exp {BinOpApp Minus $1 $3}
```

Most useful when semantic values are of different types.
See `HappyTXL.y` for the complete example.

Shift/Red. and Red./Red. Conflicts (1)

Context-free grammars are often initially ambiguous. Consider the grammar fragment:

$$\begin{array}{lcl} \mathit{Cmd} & \rightarrow & \ldots \\ & | & \texttt{if}\ \mathit{Exp}\ \texttt{then}\ \mathit{Cmd} \\ & | & \texttt{if}\ \mathit{Exp}\ \texttt{then}\ \mathit{Cmd}\ \texttt{else}\ \mathit{Cmd} \end{array}$$

According to this grammar, a program fragment

$\texttt{if}\ e_1\ \texttt{then}\ \texttt{if}\ e_2\ \texttt{then}\ c_1\ \texttt{else}\ c_2$

can be parsed in two ways, with very different meanings (the “dangling else” problem):

$\texttt{if}\ e_1\ \texttt{then}\ (\texttt{if}\ e_2\ \texttt{then}\ c_1)\ \texttt{else}\ c_2$

$\texttt{if}\ e_1\ \texttt{then}\ (\texttt{if}\ e_2\ \texttt{then}\ c_1\ \texttt{else}\ c_2)$

Shift/Red. and Red./Red. Conflicts (2)

In LR-parsing, ambiguous grammars lead to ***shift/reduce*** and ***reduce/reduce*** conflicts:

- shift/reduce: some states have mixed complete and incomplete items:

$$\begin{array}{rcl} A & \rightarrow & a\cdot \\ A & \rightarrow & a\cdot b \end{array}$$

Should parser shift or reduce?

Shift/Red. and Red./Red. Conflicts (3)

- reduce/reduce: some states have more than one complete item:

$$\begin{aligned} A &\rightarrow a\cdot \\ B &\rightarrow a\cdot \end{aligned}$$

Reduce, but by which production?

Shift/Red. and Red./Red. Conflicts (4)

- Shift/reduce conflicts often resolved by opting for shifting:
  - Typically the default option (e.g. Yacc, Bison, Happy)
  - Usually gives the desired result; e.g., resolves the dangling else problem in a natural way.
- Reduce/reduce conflicts are worse as no reason to pick one production over another: grammar has to be manually disambiguated.

Precedence and Associativity

Happy (like e.g. Yacc and Bison) allows operator precedence and associativity to be explicitly specified to disambiguate a grammar:

```
%left '+' '-'
%left '*' '/'
exp : exp '+' exp { BinOpApp Plus $1 $3 }
    | exp '-' exp { BinOpApp Minus $1 $3 }
    | exp '*' exp { BinOpApp Times $1 $3 }
    | exp '/' exp { BinOpApp Divide $1 $3 }
    ...
```

See `HappyTXL2.y` for further details.

A TXL Interpreter (1)

The semantic actions do not have to construct an AST. An alternative is to ***interpret*** the code being parsed. Basic idea:

```
exp :: { Int }
exp
  : exp '+' exp {$1 + $3}
  | exp '-' exp {$1 - $3}
  ...
```

But TXL has a `let`-construct . . .
What about TXL VARIABLES??? E.g.:
`let x = 3 in x + x`, semantic value of `x`?

A TXL Interpreter (2)

One way:

- Each semantic action returns a ***function*** of type

  ```
  Env -> Int
  ```

  where (for example)

  ```
  Type Env = Id -> Int
  ```

- The semantic action for evaluating a composite expression passes on the environment. E.g. semantic action for +:

  ```
  | exp '+' exp
  { \env -> $1 env + $3 env }
  ```

A TXL Interpreter (3)

- The semantic action for a variable looks up the variable value in the environment:

```
| ident { \env -> env $1 }
```

- The semantic action for `let` extends the argument environment and evaluates the body in the extended environment:

```
| let ident '=' exp in exp
{\env -> let v = $4 env
         in $6 (\i -> if i == $2
                      then v
                      else env i)}
```

A TXL Interpreter (4)

- A program gets evaluated by applying the overall result function to the empty environment:

  ```
  (\_ -> error "undefined variable")
  ```

See `HappyTXLInterpreter.y` for further details.