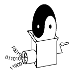

CS 412
Introduction to Compilers

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Lecture 8: Parser generators and abstract syntax trees

LR(1) parsing

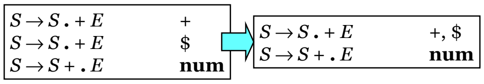
- As much power as possible out of 1 look-ahead symbol parsing table
- LR(1) grammar = recognizable by a shift/reduce parser with 1 look-ahead.
- LR(1) item = LR(0) item + look-ahead symbols possibly following production

LR(0): $\boxed{S \rightarrow \ .S + E}$

LR(1): $\boxed{S \rightarrow \ .S + E \qquad +}$

LR(1) state

- LR(1) state = set of LR(1) items
- LR(1) item = LR(0) item + set of look-ahead symbols
- No two items in state have same production + dot configuration



$S \rightarrow S\,.+E$ +
$S \rightarrow S\,.+E$ \$
$S \rightarrow S+.E$ **num**

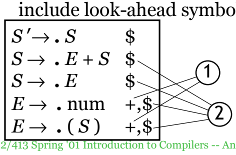
$S \rightarrow S\,.+E$ +, \$
$S \rightarrow S+.E$ **num**

LR(1) closure

Consider $\boxed{A \rightarrow \beta\,.\,C\,\delta \quad \lambda}$

Closure formed just as for LR(0) *except*

1. Look-ahead symbols include characters following the non-terminal symbol to the right of dot: FIRST(δ)
2. If non-terminal symbol may produce last symbol of production (δ is nullable), look-ahead symbols include look-ahead symbols of production (λ)



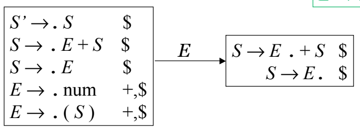
$S' \rightarrow .S$ \$
$S \rightarrow \ .E+S$ \$
$S \rightarrow \ .E$ \$
$E \rightarrow \ .$num +,\$
$E \rightarrow \ .(S)$ +,\$

$S \rightarrow \ E+S \mid E$
$E \rightarrow$ num $\mid (S)$

LR(1) DFA construction

- Given LR(1) state, for each symbol (terminal or non-terminal) following a dot, construct a state with dot shifted across symbol, perform closure

$S \rightarrow \ E+S \mid E$
$E \rightarrow$ **num** $\mid (S)$



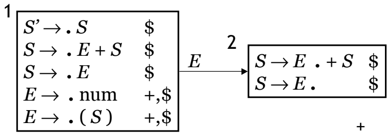
$S' \rightarrow .S$ \$
$S \rightarrow \ .E+S$ \$
$S \rightarrow \ .E$ \$
$E \rightarrow \ .$num +,\$
$E \rightarrow \ .(S)$ +,\$

$S \rightarrow E\ .+S$ \$
$S \rightarrow E.$ \$

LR(1) example

Reductions unambiguous if:
look-aheads are disjoint,
not to right of any dot in state

$S \rightarrow \ E+S \mid E$
$E \rightarrow$ **num** $\mid (S)$



$S' \rightarrow .S$ \$
$S \rightarrow \ .E+S$ \$
$S \rightarrow \ .E$ \$
$E \rightarrow \ .$num +,\$
$E \rightarrow \ .(S)$ +,\$

$S \rightarrow E\ .+S$ \$
$S \rightarrow E.$ \$

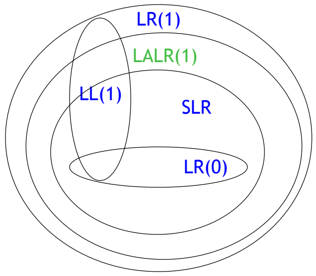
	+	$	E
1			2
2	s3	S→E	

LALR grammars

- Problem with LR(1): too many states
- LALR(1) (Look-Ahead LR)
  - Merge any two LR(1) states whose items are identical except look-ahead
  - Results in smaller parser tables—works extremely well in practice
  - Usual technology for automatic parser generators

$$\boxed{\begin{array}{ll} S \rightarrow id\,.\, & + \\ S \rightarrow E\,.\, & \$ \end{array}} + \boxed{\begin{array}{ll} S \rightarrow id\,.\, & \$ \\ S \rightarrow E\,.\, & + \end{array}} = ?$$

Classification of Grammars



How are parsers written?

- Automatic parser generators: yacc, bison, CUP
- Accept LALR(1) grammar specification
  - *plus:* declarations of precedence, associativity
  - output: LR parser code (inc. parsing table)
- Some parser generators accept LL(1), e.g. **javacc** – less powerful
- Rest of this lecture: how to use parser generators
- Can we use parsers for programs other than compilers?

Associativity

$$S \rightarrow S + E \mid E$$
$$E \rightarrow \text{num} \mid (S)$$

⇩

$$E \rightarrow E + E \mid \text{num} \mid (E)$$

What happens if we run this grammar through LALR construction?

Conflict!

$$E \rightarrow E + E \mid \text{num} \mid (E)$$

$$\boxed{\begin{array}{ll} E \rightarrow E + E\,. & + \\ E \rightarrow E\,. + E & +,\$ \end{array}}$$

shift/reduce conflict

1+2+3
  ^

shift: 1+(2+3)
reduce: (1+2)+3

Grammar in CUP

```
non terminal E; terminal PLUS, LPAREN...
precedence left PLUS;
```

“When shifting + conflicts with reducing a production containing +, choose reduce”

```
E ::= E  PLUS  E
    |  LPAREN  E  RPAREN
    |  NUMBER ;
```

Precedence

- Also can handle operator precedence

$$E \to E + E \mid T$$
$$T \to T \times T \mid \text{num} \mid (\,E\,)$$

⇩

$$E \to E + E \mid E \times E$$
$$\mid \text{num} \mid (\,E\,)$$

Conflicts w/o precedence

$$E \to E + E \mid E \times E$$
$$\mid \text{num} \mid (\,E\,)$$

$E \to E\ .+E$ ...
$E \to E \times E\ .$ $+$

$E \to E + E\ .$ $\times$
$E \to E\ .\times E$ ...

Predecence in CUP

```
precedence left PLUS;
precedence left TIMES; // TIMES > PLUS
E ::= E PLUS E  |  E TIMES E  |  ...
```

$E \to E\ .+E$ ...
$E \to E \times E\ .$ $+$

$E \to E + E\ .$ $\times$
$E \to E\ .\times E$ ...

Rule: in conflict, choose **reduce** if production symbol higher precedence than shifted symbol; choose **shift** if vice-versa

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Summary

- Look-ahead information makes SLR(1), LALR(1), LR(1) grammars expressive
- Automatic parser generators support LALR(1)
- Precedence, associativity declarations simplify grammar writing
- Easiest and best way to read structured human-readable input

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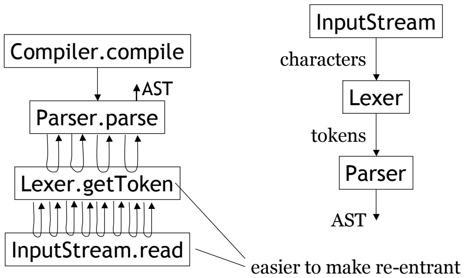
Compiler 'main program'

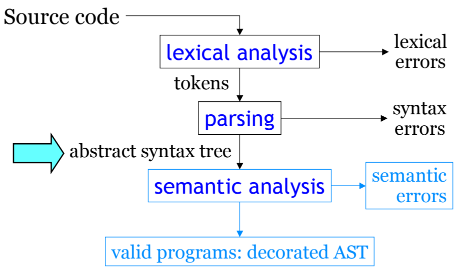
```
class Compiler {
   void compile() throws CompileError {
        Lexer l = new Lexer(input);
        Parser p = new Parser(l);
        AST tree = p.parse();
            // calls l.getToken() to read tokens
        if (typeCheck(tree))
            IR = genIntermediateCode(tree);
        IR.emitCode();
   }
}
```

Thread of Control



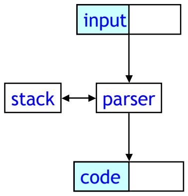
easier to make re-entrant

Semantic Analysis



Do we need an AST?

- Old-style compilers: semantic actions generate code during parsing!
- Especially for stack machine:



```
expr ::= expr PLUS expr
    {: emitCode(add); :}
```

Problems:

- hard to maintain
- limits language features
- bad code!

AST

- **A**bstract **S**yntax **T**ree is a tree representation of the program. Used for
  - semantic analysis (type checking)
  - some optimization (*e.g.* constant folding)
  - intermediate code generation (sometimes intermediate code = AST with somewhat different set of nodes)
- Compiler phases = recursive tree traversals
- Object-oriented languages convenient for defining AST nodes