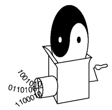

CS 4120
Introduction to Compilers

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Lecture 7: LR parsing and parser generators

11 Sep 09

Shift-reduce parsing

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

derivation	stack	input stream	action
(1+2+(3+4))+5 ←		(1+2+(3+4))+5	*shift*
(1+2+(3+4))+5 ←	(	1+2+(3+4))+5	*shift*
(1+2+(3+4))+5 ←	(1	+2+(3+4))+5	*reduce* E→num
(E+2+(3+4))+5 ←	(E	+2+(3+4))+5	*reduce* S → E
(S+2+(3+4))+5 ←	(S	+2+(3+4))+5	*shift*
(S+2+(3+4))+5 ←	(S+	2+(3+4))+5	*shift*
(S+2+(3+4))+5 ←	(S+2	+(3+4))+5	*reduce* E→num
(S+E+(3+4))+5 ←	(S+E	+(3+4))+5	*reduce* S→ S+E
(S+(3+4))+5 ←	(S	+(3+4))+5	*shift*
(S+(3+4))+5 ←	(S+	(3+4))+5	*shift*
(S+(3+4))+5 ←	(S+(	3+4))+5	*shift*
(S+(3+4))+5 ←	(S+(3	+4))+5	*reduce* E→num

LR(0) states

- A state is a set of *items* keeping track of progress on possible upcoming reductions
- An *LR(0) item* is a production from the language with a separator "." somewhere in the RHS of the production

state: $E \rightarrow \textbf{num} \, .$
item: $E \rightarrow (\, . \, S \,)$

- Stuff before "." is already on stack (beginnings of possible γ's to be reduced)
- Stuff after "." : what we might see next
- The prefixes α represented by state itself

LR(k) parsing

- As much power as possible out of parsing table with k look-ahead symbols
- 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): $S \rightarrow \, . \, S + E$

LR(1): $S \rightarrow \, . \, S + E \quad +$

Remaining input will reduce to S + E + ...

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 closure of item $A \rightarrow \beta \,.\, C\delta \quad \lambda$

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

1. Lookahead 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), lookahead symbols include lookahead symbols of production (λ)

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

1

2

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

LR(1) construction

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

1

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

—E→

2

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

	+	\$	E
1			2
2	s3	$S \rightarrow E$	

Know what to do if:
- reduce look-aheads distinct
- not to right of any dot

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 for look-ahead
  - Results in smaller parser tables—works extremely well in practice
  - The usual technology for automatic parser generators

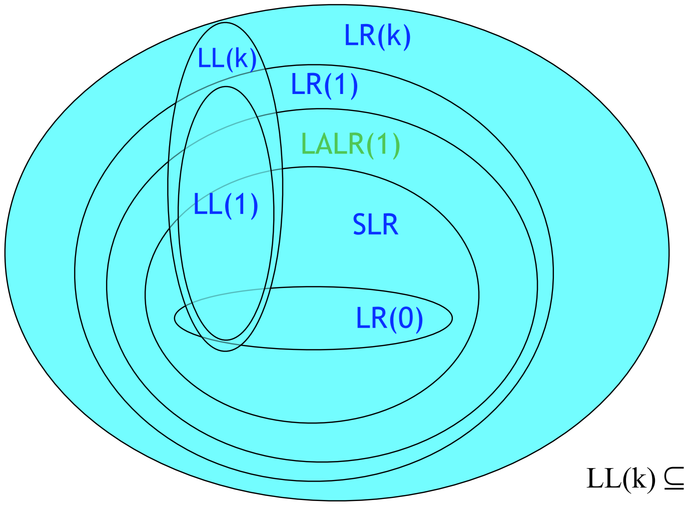
$S \rightarrow id \,.$	+
$S \rightarrow E \,.$	\$

\+

$S \rightarrow id \,.$	\$
$S \rightarrow E \,.$	+

= ?

Classification of Grammars



LL(k) ⊆ LR(k)

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, or LL(k), e.g. ANTLR
- 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!

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

$E \rightarrow E + E\,\bullet$	$+$
$E \rightarrow E\,\bullet + E$	$+,\$$

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

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

⇩

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

Conflicts w/o precedence

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

$$E \rightarrow E\,.+E\,...$$
$$E \rightarrow E \times E\,.\;+$$

$$E \rightarrow E + E\,.\;\times$$
$$E \rightarrow E\,.\times E\;...$$

Predecence in CUP

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

$$E \rightarrow E\,.+E\,...$$
$$E \rightarrow E \times E\,.\;+$$

$$E \rightarrow E + E\,.\;\times$$
$$E \rightarrow E\,.\times E\;...$$

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

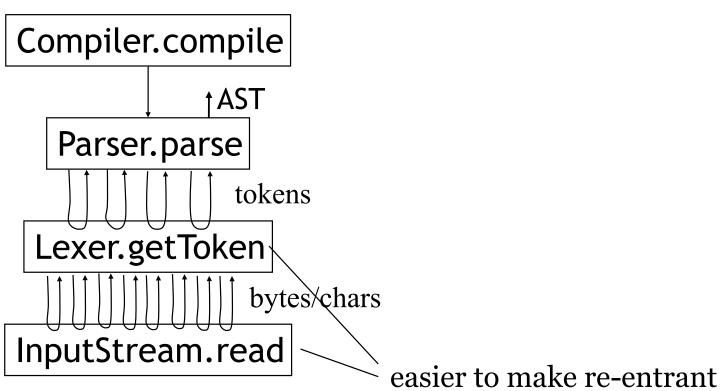
Summary

- 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

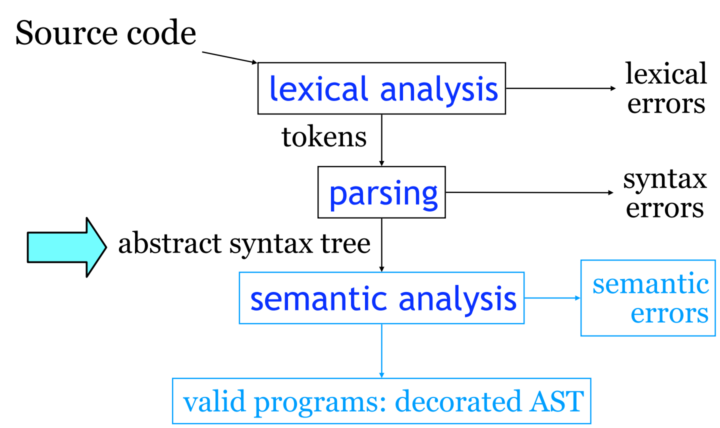
Compiler 'main program'

```
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

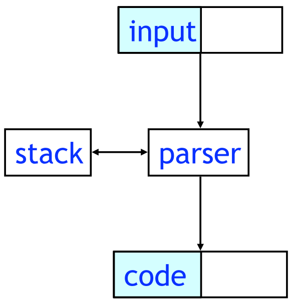


Semantic Analysis



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 (e.g., recursion)
- bad code!

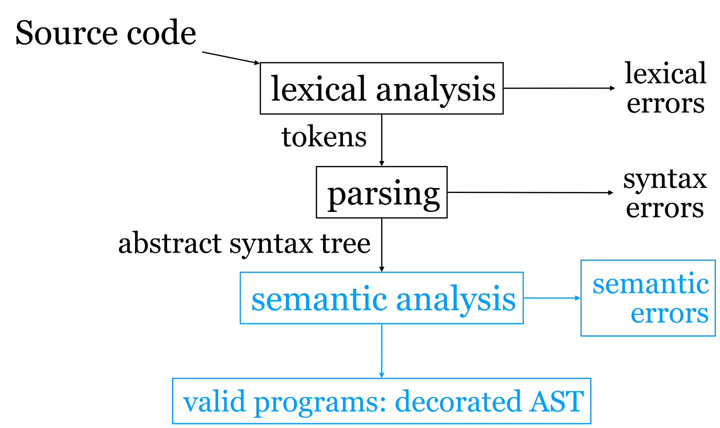
AST

- **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

Outline

- Abstract syntax trees
- Type checking
- Symbol tables
- Using symbol tables for analysis

Semantic Analysis



Building the AST bottom-up

- Semantic actions are attached to grammar statements
- E.g. CUP: Java statement attached to each production

```
non terminal Expr expr; …
expr ::= expr:e1 PLUS expr:e2
     {: RESULT = new Add(e1,e2); :}
```

grammar production

semantic action

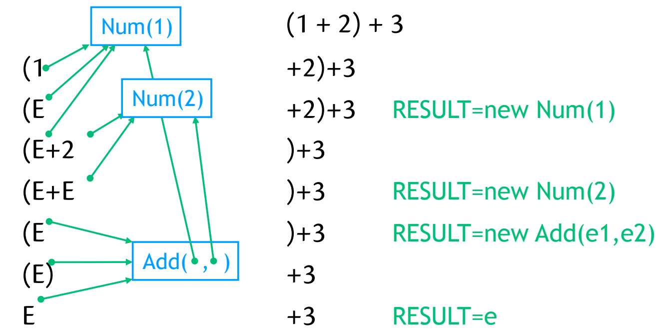
- *Semantic action* executed when parser reduces a production
- Variable RESULT is *value* of non-terminal symbol being reduced (in yacc: $$)
- AST is built bottom-up along with parsing

Actions in S-R parser

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

```
non terminal Expr expr; …
expr ::= expr:e1 PLUS expr:e2
     {: RESULT = new Add(e1,e2); :}
```

- Parser stack stores value of each non-terminal

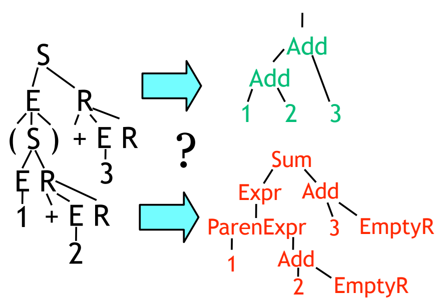


How not to design an AST

- Introduce a tree node for every node in parse tree
  - not very abstract
  - creates a lot of useless nodes to be dealt with later

$$S \rightarrow E\,R$$
$$R \rightarrow \varepsilon \mid + E\,R$$
$$E \rightarrow \mathrm{num} \mid (S)$$

(1 + 2) + 3



How not to design the AST, part II

- Simple(minded) approach: have one class AST_node
- E.g. need information for if, while, +, *, ID, NUM

```
class AST_node {
    int node_type;
    AST_node[ ] children;
    String name; int value; …etc…
}
```

- Problem: must have fields for every different kind of node with attributes
- Not extensible, Java type checking no help

Using class hierarchy

- Can use subclassing to solve problem
  - write *abstract* class for each "interesting" non-terminal in grammar
  - write non-abstract subclass for (almost) every prod'n

$$E \rightarrow E + E \mid E * E \mid -E \mid (E)$$

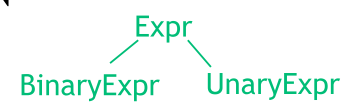
```
abstract class Expr { … } // E
class Add extends Expr { Expr left, right; … }
class Mult extends Expr { Expr left, right; … }
// or: class BinExpr extends Expr { Oper o; Expr l, r;  }
class Negate extends Expr { Expr e; …}
```


Creating the AST

non terminal Expr expr; …

"RESULT has type Expr in all semantic actions for expr"

```
expr ::= expr:e1 PLUS expr:e2
    {: RESULT = new BinaryExpr(plus, e1, e2); :}
| expr:e1 TIMES expr:e2
    {: RESULT = new BinaryExpr(times, e1, e2); :}
| MINUS expr:e
    {: RESULT = new UnaryExpr(negate, e); :}
| LPAREN expr:e RPAREN
    {: RESULT = e; :}
```



plus, times, negate: Oper

Another Example

expr ::= *num* | (*expr*) | *expr* + *expr* | **id**

stmt ::= *expr* ; | *if* (*expr*) *stmt* |
if (expr) *stmt* else *stmt* | **id** = *expr* ; | ;

```
abstract class Expr { … }
class Num extends Expr { Num(int value) … }
class Add extends Expr { Add(Expr e1, Expr e2) … }
class Id extends Expr { Id(String name) … }
abstract class Stmt { … }
class If extends Stmt { If(Expr cond, Stmt s1, Stmt s2) }
class EmptyStmt extends Stmt { EmptyStmt() … }
class Assign extends Stmt { Assign(String id, Expr e)…}
```


And…top-down

- parse_X method for each non-terminal X
- Return type is abstract class for X

```
Stmt parseStmt() {
  switch (next_token) {
    case IF: eat(IF); eat(LPAREN);
      Expr e = parseExpr;
      eat(RPAREN);
      Stmt s2, s1 = parseStmt();
      if (next_token == ELSE) { eat(ELSE);
                                s2 = parseStmt(); }
      else s2 = new EmptyStmt();
      return new IfStmt(e, s1, s2); }
    case ID: …
```