CS412/413

Introduction to Compilers
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Lecture 10: Syntax-Directed Definitions
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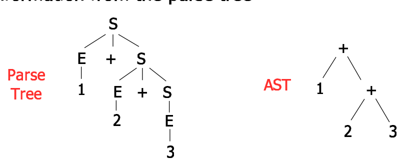
Parsing Techniques

- LL parsing
  - Computes a Leftmost derivation
  - Builds the derivation top-down
  - LL parsing table indicates which production to use for expanding the rightmost non-terminal
- LR parsing
  - Computes a Rightmost derivation
  - Builds the derivation bottom-up
  - Uses a set of LR states and a stack of symbols
  - LR parsing table indicates, for each state, what action to perform (shift/reduce) and what state to go to next
- Use these techniques to construct an AST

AST Review

- Derivation = sequence of applied productions
  $S \rightarrow E + S \rightarrow 1 + S \rightarrow 1 + E \rightarrow 1 + 2$
- Parse tree = graph representation of a derivation
  - Doesn't capture the order of applying the productions
- Abstract Syntax Tree (AST) discards unnecessary information from the parse tree

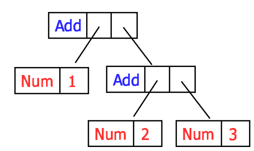


AST Data Structures

```
abstract class Expr { }

class Add extends Expr {
    Expr left, right;
    Add(Expr L, Expr R) {
        left = L; right = R;
    }
}

class Num extends Expr {
    int value;
    Num (int v) { value = v); }
}
```



Implicit AST Construction

- LL/LR parsing techniques implicitly build the AST
- The parse tree is captured in the derivation
  - LL parsing: AST is implicitly represented by the sequence of applied productions
  - LR parsing: AST is implicitly represented by the sequence of applied reductions
- We want to explicitly construct the AST during the parsing phase:
  - add code in the parser to explicitly build the AST

AST Construction

- LL parsing: extend procedures for nonterminals
- Example:

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

```
void parse_S() {
  switch (token) {
    case num: case '(':
      parse_E();
      parse_S'();
      return;
    default:
      throw new ParseError();
  }
}
```

```
Expr parse_S() {
  switch (token) {
    case num: case '(':
      Expr left = parse_E();
      Expr right = parse_S'();
      if (right == null) return left;
      else return new Add(left, right);
    default: throw new ParseError();
  }
}
```

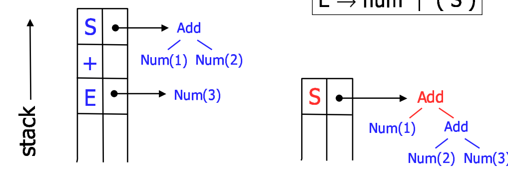
AST Construction

- LR parsing
  - We need again to add code for explicit AST construction
- AST construction mechanism for LR Parsing
  - Store parts of the tree on the stack
  - For each nonterminal symbol X on stack, also store the sub-tree rooted at X on stack
  - Whenever the parser performs a reduce operation for a production $X \to \gamma$, create an AST node for X

AST Construction for LR Parsing

- Example

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



Before reduction $S \to E + S$

After reduction $S \to E + S$

Problems

- Unstructured code: mixed parsing code with AST construction code
- Automatic parser generators
  - The generated parser needs to contain AST construction code
  - How to construct a customized AST data structure using an automatic parser generator?
- May want to perform other actions concurrently with the parsing phase
  - E.g. semantic checks
  - This can reduce the number of compiler passes

Syntax-Directed Definition

- Solution: syntax-directed definition
  - Extends each grammar production with an associated semantic action (code):

$$S \to E + S \quad \{ \text{ action } \}$$

  - The parser generator adds these actions into the generated parser
  - Each action is executed when the corresponding production is reduced

Semantic Actions

- Actions = code in a programming language
  - Same language as the automatically generated parser
- Examples:
  - Yacc = write actions in C
  - CUP = write actions in Java
- The actions access the parser stack!
  - Parser generators extend the stack of symbols with entries for user-defined structures (e.g. parse trees)
- The action code should be able to refer to the grammar symbols in the production
  - Need a naming scheme…

Naming Scheme

- Need special names for grammar symbols to use in the semantic action code
- Need to refer to multiple occurrences of the same nonterminal symbol

$$E \to E_1 + E_2$$

- Distinguish the nonterminal on the LHS

$$E_0 \to E + E$$

Naming Scheme: CUP

- CUP:
  - Rename nonterminals using distinct, user-defined names:

    expr ::= expr:e1 PLUS expr:e2
  - Use keyword RESULT for LHS nonterminal
- CUP Example:

```
expr ::= expr:e1 PLUS expr:e2
      {:  RESULT = e1 + e2;  :}
```


Naming Scheme: yacc

- Yacc:
  - Uses keywords: $1 refers to the first RHS symbol, $2 refers to the second RHS symbol, etc.
  - Keyword $$ refers to the LHS nonterminal
- Yacc Example:

```
expr ::= expr PLUS expr   { $$ = $1 + $3; }
```


Building the AST

- Use semantic actions to build the AST
- AST is built bottom-up along with parsing

non terminal Expr expr;

(Expr: User-defined type for objects on the stack; expr: Nonterminal name)

```
expr ::= NUM:i                  {: RESULT = new Num(i.val); :}
expr ::= expr:e1 PLUS expr:e2   {: RESULT = new Add(e1,e2); :}
expr ::= expr:e1 MULT expr:e2   {: RESULT = new Mul(e1,e2); :}
expr ::= LPAR expr:e RPAR       {: RESULT = e; :}
```


Example

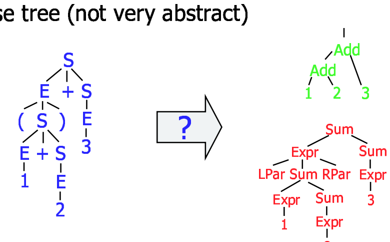
E → num | (E) | E + E | E * E

- Parser stack stores value of each non-terminal

Stack	Values	Input	Action
		(1+2)*3	
(1		+2)*3	
(E	Num(1)	+2)*3	RESULT=new Num(1)
(E+2		)*3	
(E+E	Num(2)	)*3	RESULT=new Num(2)
(E	Add(•,•)	)*3	RESULT=new Add(e1,e2)
(E)		*3	
E		*3	RESULT=e

AST Design

- Keep the AST abstract
- Do not introduce a tree node for every node in parse tree (not very abstract)



AST Design

- Do not use one single 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

Use Class Hierarchy

- Can use subclassing to solve problem
  - Use an abstract class for each "interesting" set of non-terminals in grammar (e.g. expressions)

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

```
abstract class Expr { … }
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 Minus extends Expr { Expr e; …}
```


Another Example

E ::= num | (E) | E + E | **id**
S ::= E ; | if (E) S |
  if (E) S else S | **id** = E ; | ;

```
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 IfS extends Stmt { IfS(Expr c, Stmt s1, Stmt s2) }
class EmptyS extends Stmt { EmptyS() … }
class AssignS extends Stmt { AssignS(String id, Expr e)…}
```


Other Syntax-Directed Definitions

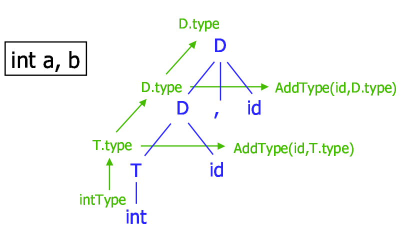
- Can use syntax-directed definitions to perform semantic checks during parsing
  - E.g. type-checking
- Benefit = efficiency
  - One single compiler pass for multiple tasks
- Disadvantage = unstructured code
  - Mixes parsing and semantic checking phases
  - Perform checks while AST is changing

Type Declaration Example

$D \rightarrow T$ id	{ AddType(id, T.type); D.type = T.type; }
$D \rightarrow D_1$, id	{ AddType(id, D_1.type); D.type = D_1.type; }
$T \rightarrow$ int	{ T.type = intType; }
$T \rightarrow$ float	{ T.type = floatType; }

Propagation of Values

- Propagate type attributes while building the AST



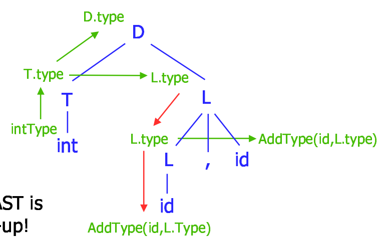
Another Example

$D \rightarrow T\ L$	{ AddType(id, T.type); D.type = T.type; L.type = D.type; }
$T \rightarrow$ int	{ T.type = intType; }
$T \rightarrow$ float	{ T.type = floatType; }
$L \rightarrow L_1$, id	{ AddType(id, L_1.type); ??? }
$L \rightarrow$ id	{ AddType(id, ???); }

Propagation of Values

- Propagate values both bottom-up and top-down

int a, b



- LR parsing: AST is built bottom-up!

Structured Approach

- Separate AST construction from semantic checking phase
- Traverse the AST and perform semantic checks (or other actions) only after the tree has been built and its structure is stable
- This approach is less error-prone
  - It is better when efficiency is not a critical issue

Summary

- Syntax-directed definitions attach semantic actions to grammar productions
- Easy to construct the AST using syntax-directed definitions
- Can use syntax-directed definitions to perform semantic checks
- Separate AST construction from semantic checks or other actions which traverse the AST