CS412/CS413

Introduction to Compilers
Tim Teitelbaum

Lecture 11: Syntax-Directed Definitions
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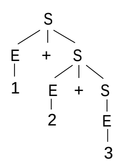
Parsing Techniques

- LL parsing
  - Computes a Leftmost derivation
  - Determines the derivation top-down
  - LL parsing table indicates which production to use for expanding the leftmost non-terminal
- LR parsing
  - Computes a Rightmost derivation
  - Determines 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

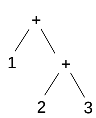
AST Review

- 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

Parse Tree



AST

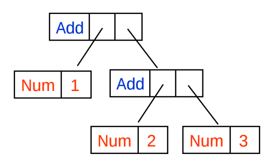


AST Data Structures

```
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; }
}
```



AST Construction

- LL/LR parsing techniques implicitly walk the parse tree during parsing
  - LL parsing: Parse tree is implicitly represented by the sequence of applied derivation steps (preorder)
  - LR parsing: Parse tree is implicitly represented by the sequence of applied reductions (endorder)
- The AST is implicitly defined by the parse tree
- We want to explicitly construct the AST during parsing:
  - add code in the parser to explicitly build the AST

LL AST Construction

- LL parsing: extend procedures for nonterminals
- Example:

$S \to ES'$
$S' \to \varepsilon \mid + S$
$E \to$ num | (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();
  }
}
```

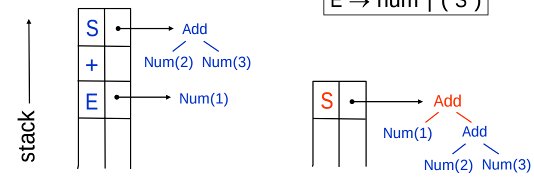
LR AST Construction

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

LR AST Construction, ctd.

- Example

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



Before reduction
$S \to E+S$

After reduction
$S \to E+S$

Issues

- 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 = actions written in C
  - CUP = actions written in Java
- The actions can access the parser stack!
  - Parser generators extend the stack of states (corresponding to RHS symbols) symbols with entries for user-defined structures (e.g., parse trees)
- The action code should be able to refer to the states (corresponding to the RHS grammar symbols) in the production
  - Need a naming scheme...

Naming Scheme

- Need 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:
  - Name RHS nonterminal occurrences using distinct, user-defined labels:

    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 during parsing

non terminal Expr expr;

(Expr: User-defined type for semantic 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

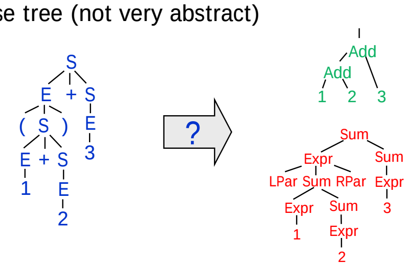
E → num | (E) | E+E | E*E

- Parser stack stores value of each symbol

Stack	Value	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 → E+E | E*E | -E | (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

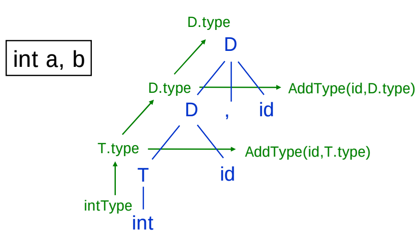
- Can use syntax-directed definitions to perform semantic checks during parsing
  - E.g., type-checking
- Benefit = efficiency
  - One single compiler pass for multiple tasks
- Disadvantage = unstructured code
  - Mixes parsing and semantic checking phases
  - Perform checks while AST is changing
  -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

Type Declaration Example

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

Propagation of Values

- Propagate type attributes while building the AST



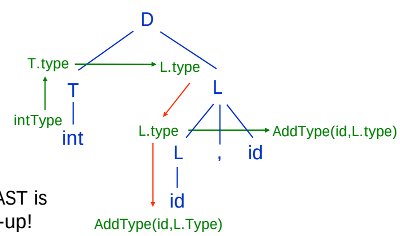
Another Example

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

Propagation of Values

- Propagate values both bottom-up and top-down

int a, b

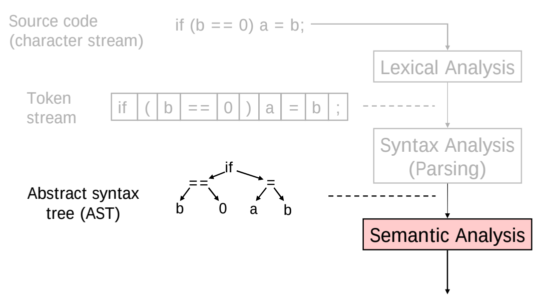


- LR parsing: AST is built bottom-up!

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 more flexible and less error-prone
  - It is better when efficiency is not a critical issue

Where We Are



Visitor Methodology for AST Traversal

- Visitor pattern: useful OO programming pattern that separates data structure definition (e.g., the AST) from code that traverses the structure (e.g., the name resolution code and the type checking code).
- Define a Visitor interface for all traversals of the AST
- Extend each AST class with a method that accepts any Visitor
- Code each traversal as a separate class that implements the Visitor interface

AST Data Structure

```
abstract class Expr { ... }
class Add extends Expr { ...
    Expr e1, e2
    }
class Num extends Expr { ...
    int value
    }
class Id extends Expr { ...
    String name
    }
```


Visitor Interface

```
interface Visitor {
   void visit(Add e);
   void visit(Num e);
   void visit(Id e);
}
```

Accept methods

```
abstract class Expr { ...
    abstract public void accept(Visitor v);
}
class Add extends Expr { ...
    public void accept(Visitor v) {
        v.visit(this); }
}
class Num extends Expr { ...
    public void accept(Visitor v) {
        v.visit(this); }
}
class Id extends Expr { ...
    public void accept(Visitor v) {
        v.visit(this); }
}
```

The declared type of **this** is the subclass it which it occurs.

Overload resolution of
v.visit(**this**);
invokes appropriate visit function in the Visitor.

Visitor Methods

- For each kind of traversal, implement the Visitor interface, e.g.,

```
class PostfixOutputVisitor implements Visitor {
    void visit(Add e) {
        e.e1.accept(this); e.e2.accept(this); System.out.print( "+" );
    }
    void visit(Num e) {
        System.out.print(value);
    }
    void visit(Id e) {
        System.out.print(id);
    }
}
```

Dispatch to e'.accept in the visit methods eliminates case analysis on AST subclasses

- To traverse expression e:

```
PostfixOutputVisitor v = new PostfixOutputVisitor();
e.accept(v);
```


Inherited and Synthesized Information

- So far, OK for traversal and action w/o communication of values
- But we need a way to pass information
  - Down the AST (inherited)
  - Up the AST (synthesized)
- To pass information down the AST
  - add parameter to visit functions
- To pass information up the AST
  - add return value to visit functions

Visitor Interface (2)

```
interface Visitor {
  Object visit(Add e, Object inh);
  Object visit(Num e, Object inh);
  Object visit(Id e, Object inh);
}
```


Accept methods (2)

```
abstract class Expr { ...
    abstract public Object accept(Visitor v, Object inh);
}
class Add extends Expr { ...
    public Object accept(Visitor v, Object inh) {
        return v.visit(this, inh); }
}
class Num extends Expr { ...
    public Object accept(Visitor v, Object inh) {
        return v.visit(this, inh);
    }
class Id extends Expr { ...
    public Object accept(Visitor v, Object inh) {
        return v.visit(this, inh); }
    }
}
```


Visitor Methods (2)

- For kind of traversal, implement the Visitor interface, e.g.,

```
class EvaluationVisitor implements Visitor {
    Object visit(Add e, Object inh) {
        int left = (int) e.e1.accept(this, inh);
        int right = (int) e.e2.accept(this, inh);
        return left+right;
    }
    Object visit(Num e, Object inh) {
        return value;
    }
    Object visit(Id e, Object inh) {
        return Lookup(id, (SymbolTable)inh);
    }
}
```

- To traverse expression e:

```
EvaluationVisitor v = new EvaluationVisitor ();
e.accept(v, EmptyTable());
```

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 that traverse the AST