Syntax-Directed Definitions

Organization

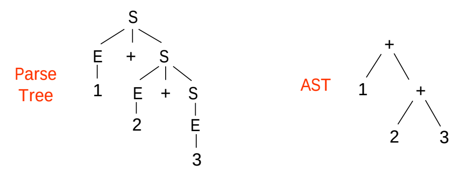
- Building an AST
  - Top-down parsing
  - Bottom-up parsing
  - Making YACC, CUP build ASTs
- AST class definitions
  - Exploiting type-checking features of OO languages
- Writing AST visitors
  - Separate AST code from visitor code for better modularity

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
- 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

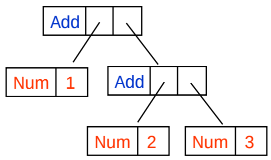


AST Data Structures

```
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; }
}
```



AST Construction

- LL/LR parsing implicitly walks parse tree during parsing
  - LL parsing: Parse tree implicitly represented by sequence of derivation steps (preorder)
  - LR parsing: Parse tree implicitly represented by sequence of reductions (endorder)
- The AST is implicitly defined by parse tree
- Want to explicitly construct AST during parsing:
  - add code to parser to build it

LL AST Construction

- LL parsing: extend procedures for nonterminals
- Example:

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

```
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();
  }
}
```

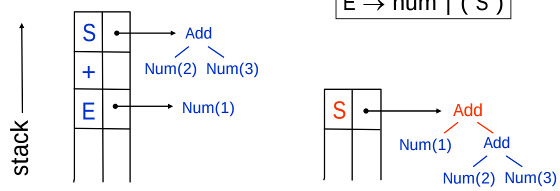

LR AST Construction

- LR parsing
  - Need to add code for explicit AST construction
- AST construction mechanism for LR Parsing
  - With each symbol X on stack, also store AST sub-tree for X on stack
  - When parser performs reduce operation for $A \rightarrow \beta$, create AST subtree for A from AST fragments on stack for β, pop $|\beta|$ subtrees from stack, push subtree for β.

LR AST Construction, ctd.

- Example

S → E+S | S
E → num | (S)



Before reduction
S → E+S

After reduction
S → 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 → E+S { 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 need 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

$$E \rightarrow E_1 + E_2$$

- Distinguish the nonterminal on the LHS

$$E_0 \rightarrow E + E$$

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 (an interpreter):

```
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 (an interpreter):

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


Building the AST

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

User-defined type for semantic objects on the stack

Nonterminal name

```
non terminal Expr expr;

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

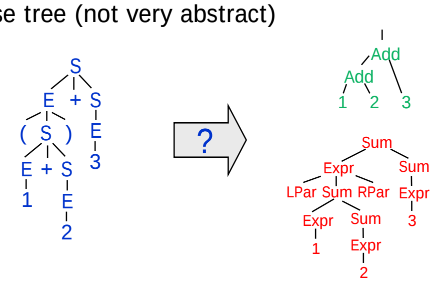
E → num | (E) | E+E | E*E

- Parser stack stores value of each symbol

		(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 tree node for every node in parse tree (not very abstract)



AST Design

- Do not use 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

- Use subclassing to solve problem
  - Use abstract class for each “interesting” set of nonterminals (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)...}
```

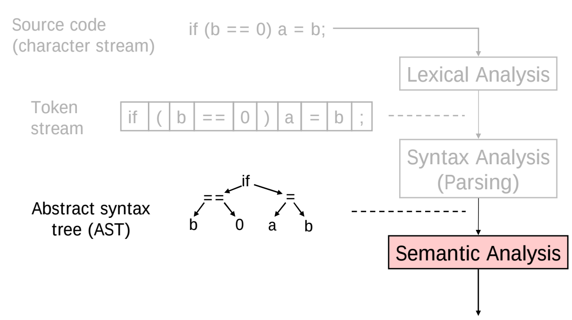

Other Syntax-Directed Definitions

- Can use syntax-directed definitions to perform semantic checks during parsing
  - E.g., type-checking
- Benefit = efficiency
  - One 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

Structured Approach

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

Where We Are



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;


  }
```


Could add AST computation to class, but...

```
abstract class Expr {
  ...; /* state variables for visitA */

  }
class Add extends Expr { ...
  Expr e1, e2;
  void visitA(){ ...; visitA(this.e1); ...; visitA(this.e2); ...}

  }
class Num extends Expr { ...
  int value;
  void visitA(){...}

  }
class Id extends Expr { ...
  String name;
  void visitA(){...}

  }
```


Undesirable Approach to AST Computation

```
abstract class Expr {
  ...; /* state variables for visitA */
  ...; /* state variables for visitB */
  }
class Add extends Expr { ...
  Expr e1, e2;
  void visitA(){ ...; visitA(this.e1); ...; visitA(this.e2); ...}
  void visitB(){ ...; visitB(this.e2); ...; visitB(this.e1); ...}
  }
class Num extends Expr { ...
  int value;
  void visitA(){...}
  void visitB(){...}
  }
class Id extends Expr { ...
  String name;
  void visitA(){...}
  void visitB(){...}
  }
```


Visitor Methodology for AST Traversal

- Visitor pattern: separate data structure definition (e.g., AST) from algorithms that traverse the structure (e.g., name resolution code, type checking code, etc.).
- Define Visitor interface for all AST traversals
- Extend each AST class with a method that accepts any Visitor (by calling it back)
- Code each traversal as a separate class that implements the Visitor interface

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 in which it occurs.

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

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(e.value);
    }
    void visit(Id e) {
        System.out.print(e.id);
    }
}
```

Dynamic dispatch e'.accept invokes accept method of appropriate AST subclass and 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 each 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, but better not to
- Separate AST construction from semantic checks or other actions that traverse the AST