Abstract Syntax Trees

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Parsing and Syntax Trees

Parsing decides if the program is part of the language.
Not that useful: we want more than a yes/no answer.
Like most, ANTLR parsers can include actions: pieces of code that run when a rule is matched.
Top-down parsers: actions executed during parsing rules.
Bottom-up parsers: actions executed when rule is "reduced."

Actions

In a top-down parser, actions are executed during the matching routines.
Actions can appear anywhere within a rule: before, during, or after a match.

```
rule { /* before */ }
  : A { /* during */ } B
  | C D { /* after */ } ;
```

Bottom-up parsers restricted to running actions only after a rule has matched.

Implementing Actions

Nice thing about top-down parsing: grammar is essentially imperative.
Action code simply interleaved with rule-matching.
Easy to understand what happens when.

```
public final int expr() { // What ANTLR builds
  int r;
  int a; r=0;
  r=mexpr();
  while ((LA(1)==PLUS)) { // ( ) *
    match(PLUS); // "+
    a=mexpr(); // a=mexpr
    r += a;
  } // { r += a; }
  match(Token.EOF_TYPE);
  return r;
}
```

Actions

Usually, actions build a data structure that represents the program.
Separates parsing from translation.
Makes modification easier by minimizing interactions.
Allows parts of the program to be analyzed in different orders.

What To Build?

Typically, an Abstract Syntax Tree that represents the program.
Represents the syntax of the program almost exactly, but easier for later passes to deal with.
Punctuation, whitespace, other irrelevant details omitted.

```
class CalcParser extends Parser;
expr returns [int r] { int a; r=0; }
  : r=mexpr ("+" a=mexpr { r += a; })* EOF ;
```

```
atom returns [int r] { r=0; }
  : i:INT { r = Integer.parseInt(i.getText()); } ;
```

```
```

Implementing Actions

```
```
Abstract vs. Concrete Trees

Like scanning and parsing, objective is to discard irrelevant details. E.g., comma-separated lists are nice syntactically, but later stages probably just want lists. AST structure almost a direct translation of the grammar.

Concrete Parse Tree

Abstract Syntax Tree

Example of AST structure

Typical AST Operations

Create a new node; Append a subtree as a child.

Comment on Generic ASTs

Is this general-purpose structure too general? Not very object-oriented: whole program represented with one type. Alternative: Heterogeneous ASTs: one class per object.

class BinOp {
    int operator; Expr left, right;
    void typeCheck() { ... };
    void constantProp() { ... };
    void buildThreeAddr() { ... };
};

Analyses spread out across class files. Classes become littered with analysis code, additional annotations.

Heterogeneous ASTs

Advantage: avoid switch statements when walking tree. Disadvantage: each analysis requires another method.

class BinOp {
    int operator; Expr left, right;
    void typeCheck() { ... };
    void constantProp() { ... };
    void buildThreeAddr() { ... };
};

Implementing ASTs

Most general implementation: ASTs are n-ary trees. Each node holds a token and pointers to its first child and next sibling.

ANTLR offers a compromise: It can automatically generate tree-walking code. It generates the big switch statement. Each analysis can have its own file. Still have to modify each analysis if the AST changes. Choose the AST structure carefully.
The Obvious Way to Build ASTs

class ASTNode {
    ASTNode( Token t ) { ... }
    void appendChild( ASTNode c ) { ... }
    void appendSibling( ASTNode c ) { ... }
}

stmt returns [ASTNode n] :
    'if' p=expr 'then' t=stmt 'else' e=stmt { n = new ASTNode(new Token("IF"));
    n.appendChild(p);
    n.appendChild(t);
    n.appendChild(e); } ;

The Obvious Way

Putting code in actions that builds ASTs is traditional and works just fine.
But it's tedious.
Fortunately, ANTLR can automate this process.

Building an AST Automatically with ANTLR

class TigerParser extends Parser;
options {
    buildAST=true;
}

By default, each matched token becomes an AST node.
Each matched token or rule is made a sibling of the AST for the rule.
After a token, ^ makes the node a root of a subtree.
After a token, ! prevents an AST node from being built.

Automatic AST Construction

Running

class CalcParser extends Parser;
options { buildAST=true; }
expr : mexpr ('+' mexpr) * EOF ;
mexpr : atom (' * ' atom) * ;
atom : INT ;
on
2*3+4*5+6

AST Construction with Annotations

Running

class CalcParser extends Parser;
options { buildAST=true; }
expr : mexpr ('+' ! mexpr) * EOF ! ;
mexpr : atom (' * ' ! atom) * ;
atom : INT ;
on
2*3+4*5+6

drawbacks of ASTs

Sequences of Things

Comma-separated lists are common
int gcd(int a, int b, int c)
args : "(" ( arg (""," arg) )? "")" ;
A concrete parse tree:

Choosing AST Structure

designing an AST structure

Sequences of Things

Better to choose a simpler structure for the tree.
Punctuation irrelevant; build a simple list.
int gcd(int a, int b, int c)
args : "(" ( arg (""," ! arg) )? "")" !
    { #args = #([ARGS], args); } ;
What's going on here?

args : "(! ( arg ("! arg )? "!)"!
   #args = #([ARGS], args); } ;
Rule generates a sequence of arg nodes.
Node generation suppressed for punctuation (paren, commas).
Action uses ANTLR's terse syntax for building trees.
( #args = #([ARGS], args) ; ) ;
"set the args tree to a new tree whose root is a node of
type ARGS and whose child is the old args tree"

Removing Unnecessary Punctuation

Punctuation makes the syntax readable, unambiguous.
Information represented by structure of the AST
Things typically omitted from an AST
- Parentheses
  - Grouping and precedence/associativity overrides
- Separators (commas, semicolons)
Mark divisions between phrases
- Extra keywords
  - while-do, if-then-else (one is enough)

How Many Types of Tokens?

Since each token is a type plus some text, there is some
choice.
Generally, want each "different" construct to have a
different token type.
Different types make sense when each needs different
analysis.
Arithmetic operators usually not that different.
For the assignment, you need to build a node of type
"BINOP" for every binary operator.

Walking ASTs

ANTLR can build "tree parsers" as easily as token parsers.
Much simpler: tree structure is already resolved.
Simple recursive walk on the tree.
Matches are sufficient, not exact.
(Cheaper to implement.)
#( A B ) also matches the larger tree
#( A #(B C) D )

Walking ASTs with ANTLR

class CalcParser extends Parser
expr : mexpr ("+" mexpr)* ;
mexpr : atom ("*" mexpr)* ;
atom : INT | "(" expr ")" ;
class CalcWalker extends TreeParser
expr returns [int r]
{ int a,b; r=0; }
   #: "+" a=expr b=expr { r = a + b; }
   | ":*" a=expr b=expr { r = a * b; }
   | :INT { r = parseInt(i.getText()); }
   ;
This walker only has one rule: grammar had three.
Fine: only structure of tree matters.

Walking ASTs with ANTLR

The highlighted line says
Match a tree #( ... )
With the token "+" at the root
With two children matched by expr
(Store their results in a and b)
When this is matched, assign a + b to the result r.
Comments on walking ASTs

Tree grammars may seem to be ambiguous. Does not matter: tree structure already known. Unlike proper parsers, tree parsers have only one token of lookahead. Must be possible to make a decision locally. Has impact on choice of AST structure.

Optional clauses can cause trouble. Place them at the end.

```
stmt
   : #("if" expr stmt (stmt)?) // OK
   | #("do" (stmt)? expr) // Bad
   ;
```

First rule works: can easily decide if there is another child. Second rule does not: not enough lookahead.

Lists of undefined length can also cause trouble

```
funcdef
   : #("func" ID (arg)* stmt)
   ;
```

Does not work because the tree walker does not look ahead. Solution: use a subtree

```
funcdef
   : #("func" #$args (arg)* stmt)
   ;
```

The placeholder resolves the problem.