ANTLR 4

- Homepage: http://www.antlr4.org
- The Definitive ANTLR 4 Reference: http://pragprog.com/book/tpantlr2/the-definitive-antlr-4-reference

MEET ANTLR

- ANTLR is written in Java - so installing it is a matter of downloading the latest jar, such as antlr-4.0-complete.jar

- For syntax diagrams of grammar rules, syntax highlighting of ANTLR 4 grammars, etc, use the ANTLRWorks 2 or ANTRLWorks 2 Netbeans plugin. http://tunnelvisionlabs.com/products/demo/antlrworks

What is ANTLR?

ANTLR (ANother Tool for Language Recognition) is a powerful parser generator for translating structured text.

- ☑ It's widely used to build language related tools.
- ☑ From a grammar, ANTLR generates a parser that can build and walk parse trees.

- Terence Parr is the maniac behind ANTLR and has been working on language tools since 1989. He is a professor of computer science at the University of San Francisco.
- Twitter search uses for example ANTLR for query parsing.

Getting Started

Create aliases for the ANTLR Tool, and TestRig.

```
$ alias antlr4='java -jar /usr/local/lib/antlr-4.0-complete.jar'
$ alias grun='java org.antlr.v4.runtime.misc.TestRig'
```

A First Example

Hello.g4

```
// Define a grammar called Hello
grammar Hello;
r  : 'hello' ID ;           // match keyword hello followed by an identifier
ID : [a-z]+ ;               // match lower-case identifiers
WS : [ \t\r\n]+ -> skip ; // skip spaces, tabs, newlines
```

Then run ANTLR the tool on it:

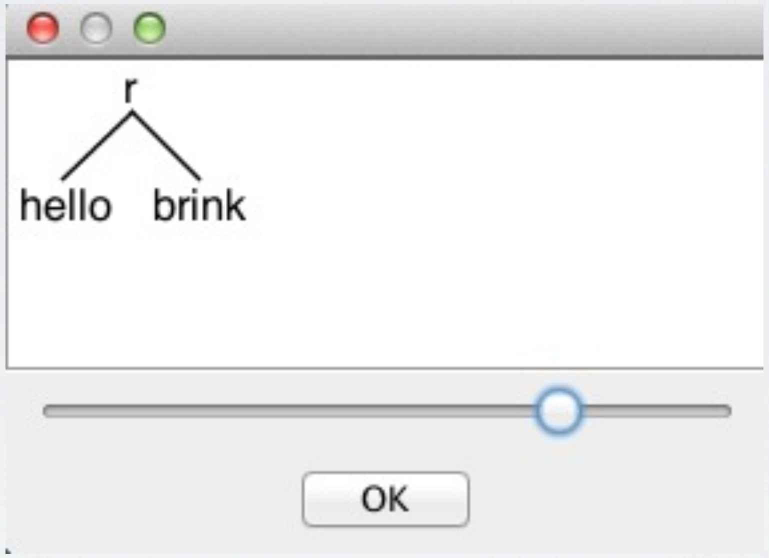
```
$ antlr4 Hello.g4
$ javac Hello*.java
```

Now test it:

```
$ grun Hello r -tree
hello brink
^D
(r hello brink)
```

```
$ grun Hello r -gui
hello brink
^D
```

This pops up a dialog box showing that rule r matched keyword hello followed by the identifier brink.

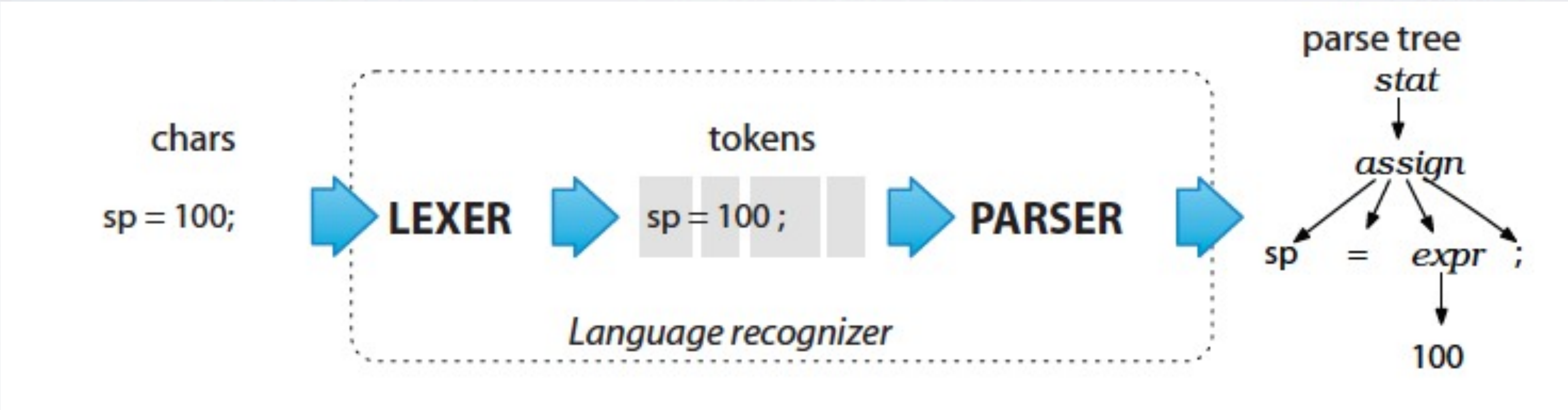


THE BIG PICTURE

Tokenizing:

- The process of grouping characters into words or symbols (tokens) is called lexical analysis or simply tokenizing.
- We call a program that tokenizes the input a lexer.
- The lexer group related tokens into token classes, or token types, such as INT, ID, FLOAT, etc.
- Tokens consist of at least two pieces of information: the token type and the text matched for that token by the lexer.

- The parser feeds off of the tokens to recognize the sentence structure.
- By default, ANTLR-generated parsers build a parse tree that records how the parse recognized the input sentence.



- By producing a parse tree, a parser delivers a handy data structure to be used by the rest of the language translation application.
- Trees are easy to process in subsequent steps and are well understood by programmers.
- Better yet, the parser can generate parse trees automatically.

- The ANTLR tool generates recursive-descent parsers from grammar rules.
- Recursive-descent parsers are really just a collection of recursive methods, one per rule.
- The descent term refers to the fact that parsing begins at the root of a parse tree and proceeds toward the leaves (tokens).

☑ To get an idea of what recursive-descent parsers look like, next some (slightly cleaned up) methods that ANTLR generates from grammar rules:

```
assign : ID '=' expr ';' ; // match an assignment statement like "sp = 100;"

// assign : ID '=' expr ';' ;
void assign() { // method generated from rule assign
   match(ID); // compare ID to current input symbol then consume
   match('=');
   expr(); // match an expression by calling expr()
   match(';');
}
```

```
/** Match any kind of statement starting at the current input position */
stat: assign // First alternative ('|' is alternative separator)
     | ifstat // Second alternative
     | whilestat
      ...
     ;
```

The parser will generate:

```
void stat() {
    switch ( «current input token» ) {
        CASE ID : assign(); break;
        CASE IF : ifstat(); break; // IF is token type for keyword 'if'
        CASE WHILE : whilestat(); break;
        ...
        default : «raise no viable alternative exception»
    }
}
```

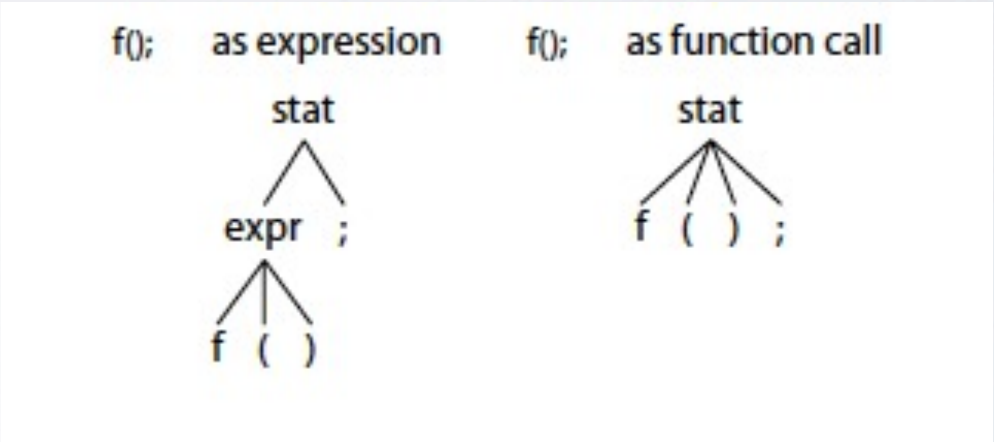
In the example on the previous slide:

- Method stat() has to make a parsing decision or prediction by examining the next input token.
- Parsing decisions predict which alternative will be successful.
- In this case, seeing a WHILE keyword predicts the third alternative of rule().
- A lookahead token is any token that the parser sniffs before matching and consuming it.
- Sometimes, the parser needs lots of lookahead tokens to predict which alternative will succeed. ANTLR silently handles all of this for you.

Ambiguous Grammars

```
stat: ID '=' expr ';' // match an assignment; can match "f();"
    | ID '=' expr ';' // oops! an exact duplicate of previous alternative
    ;
expr: INT ;
```

```
stat: expr ';' // expression statement
   | ID '(' ')' ';' // function call statement
   ;
expr: ID '(' ')'
    | INT
    ;
```



ANTLR resolves the ambiguity by choosing the first alternative involved in the decision.

- ☑ Ambiguities can occur in the lexer as well as the parser.

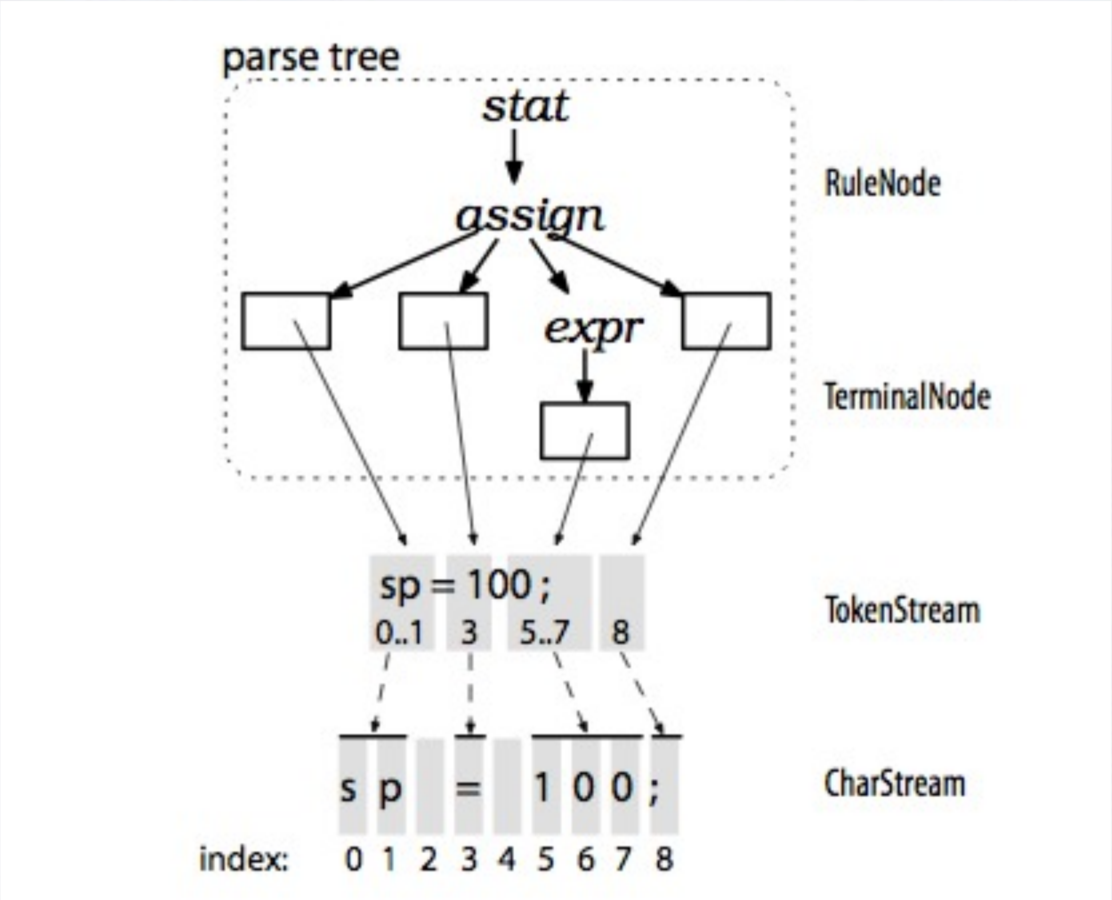
- ☑ ANTLR resolves lexical ambiguities by matching the input string to the rule specified first in the grammar.

```
BEGIN : 'begin' ; // match b-e-g-i-n sequence; ambiguity resolves to BEGIN

ID : [a-z]+ ; // match one or more of any lowercase letter
```

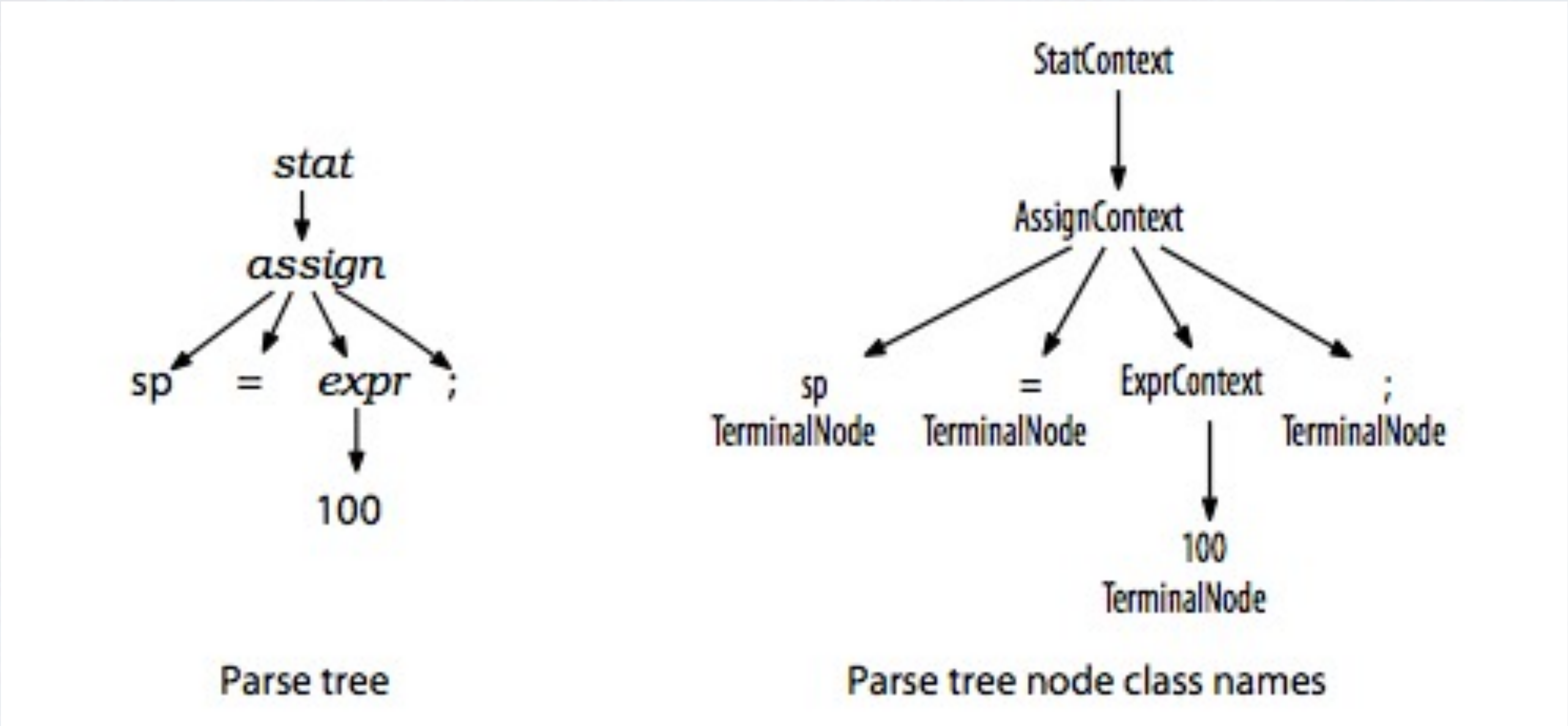
Building Language Applications Using Parse Trees

Lexers process characters and pass tokens to the parser, which in turn checks syntax and creates a parse tree.

The corresponding ANTLR classes are CharStream, Lexer, Token, Parser, and ParseTree. The "pipe" connecting the lexer and parser is called a TokenStream.



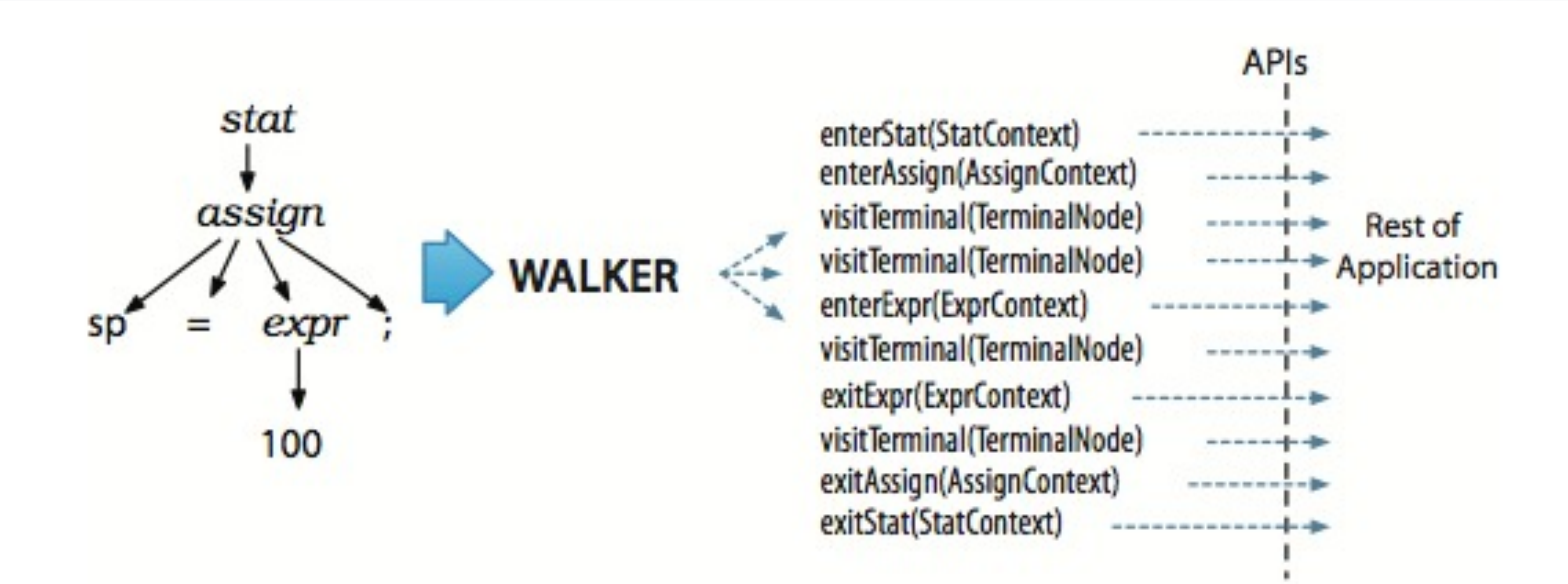
- ANTLR uses context objects which knows the start and stop tokens for a recognized phrase and provides access to all of the elements of that phrase.
- For example, AssignContext provides methods ID() and expr() to access the identifier node and expression subtree.



Parse-Tree Listeners and Visitors

- By default, ANTLR generates a parse-tree listener interface that responds to events triggered by the built-in tree walker.
- To walk a tree and trigger calls into a listener, ANTLR's runtime provides the class ParseTreeWalker.
- To make a language application, we write a ParseTreeListener.
- The beauty of the listener mechanism is that it's all automatic. We don't have to write a parse-tree walker, and our listener methods don't have to explicitly visit their children.

ParseTreeWalker call sequence

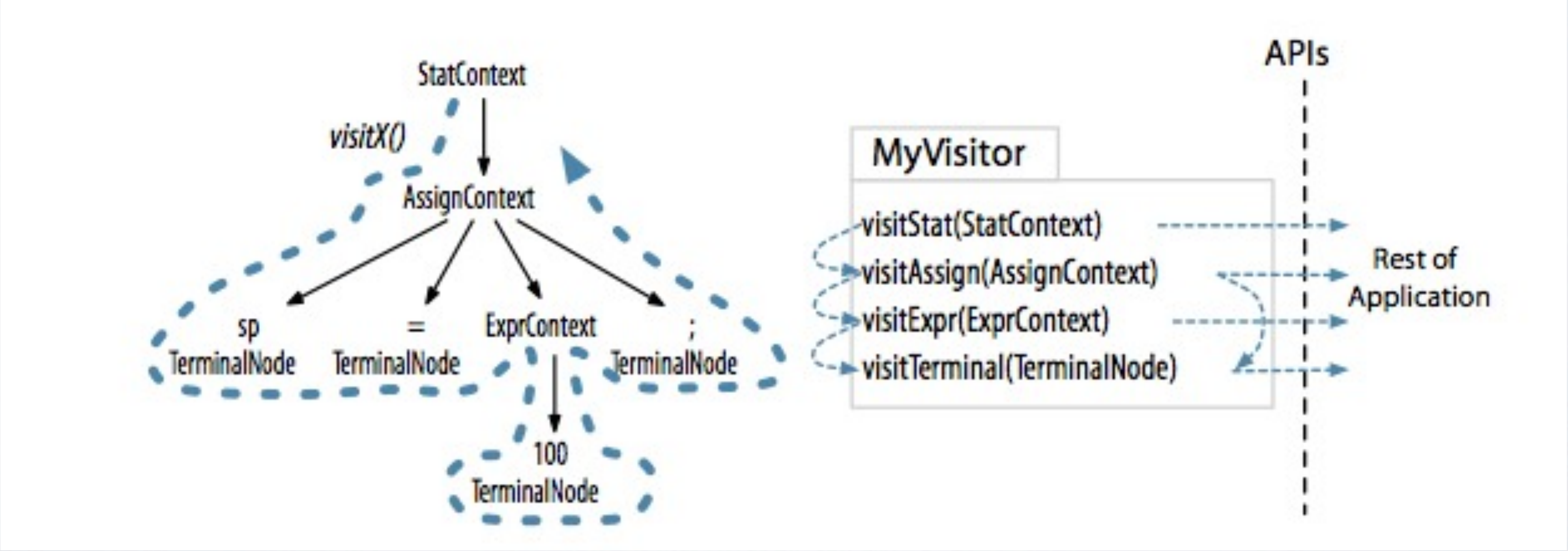


Parse-Tree Visitors

There are situations, however, where we want to control the walk itself, explicitly calling methods to visit children.

Option -visitor asks ANTLR to generate a visitor interface from a grammar with a visit method per rule.

```
ParseTree tree = ... ; // tree is result of parsing

MyVisitor v = new MyVisitor();
v.visit(tree);
```

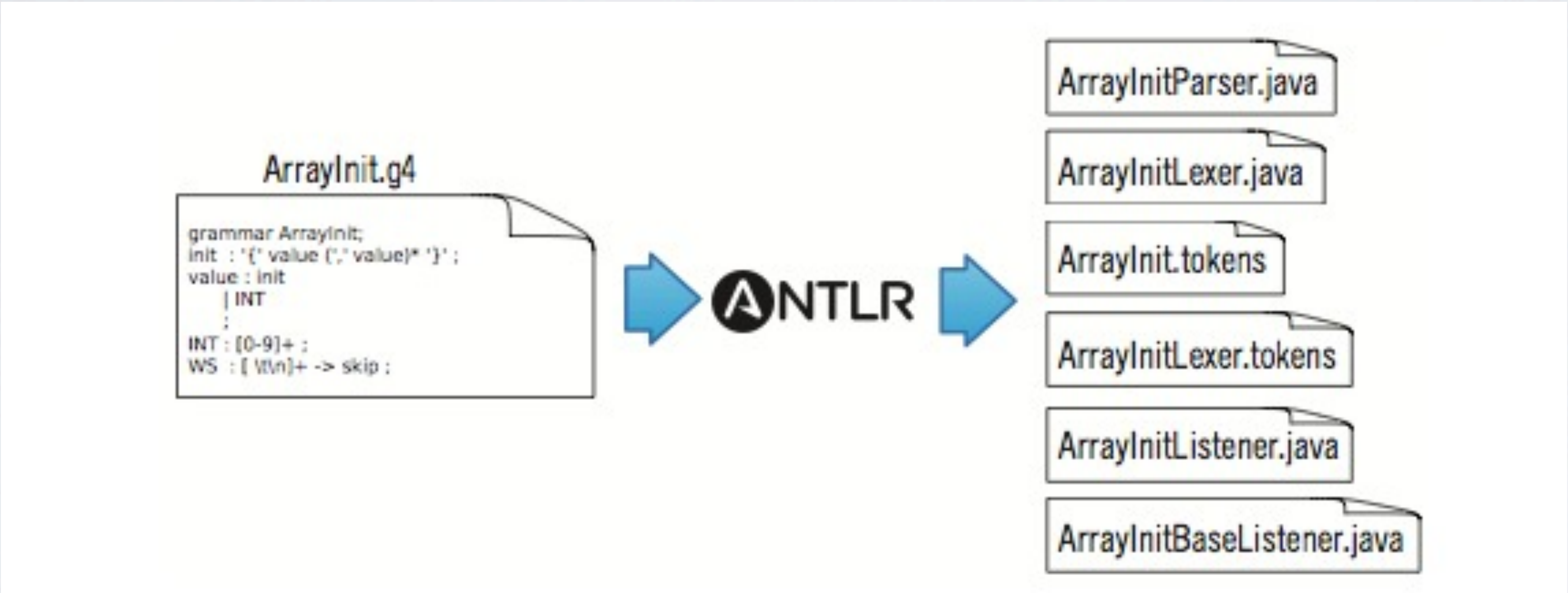


A STATER ANTLR PROJECT

- Let's build a grammar to recognize integers in, possibly nested, curly braces like {1, 2, 3} and {1, {2, 3}, 4}.

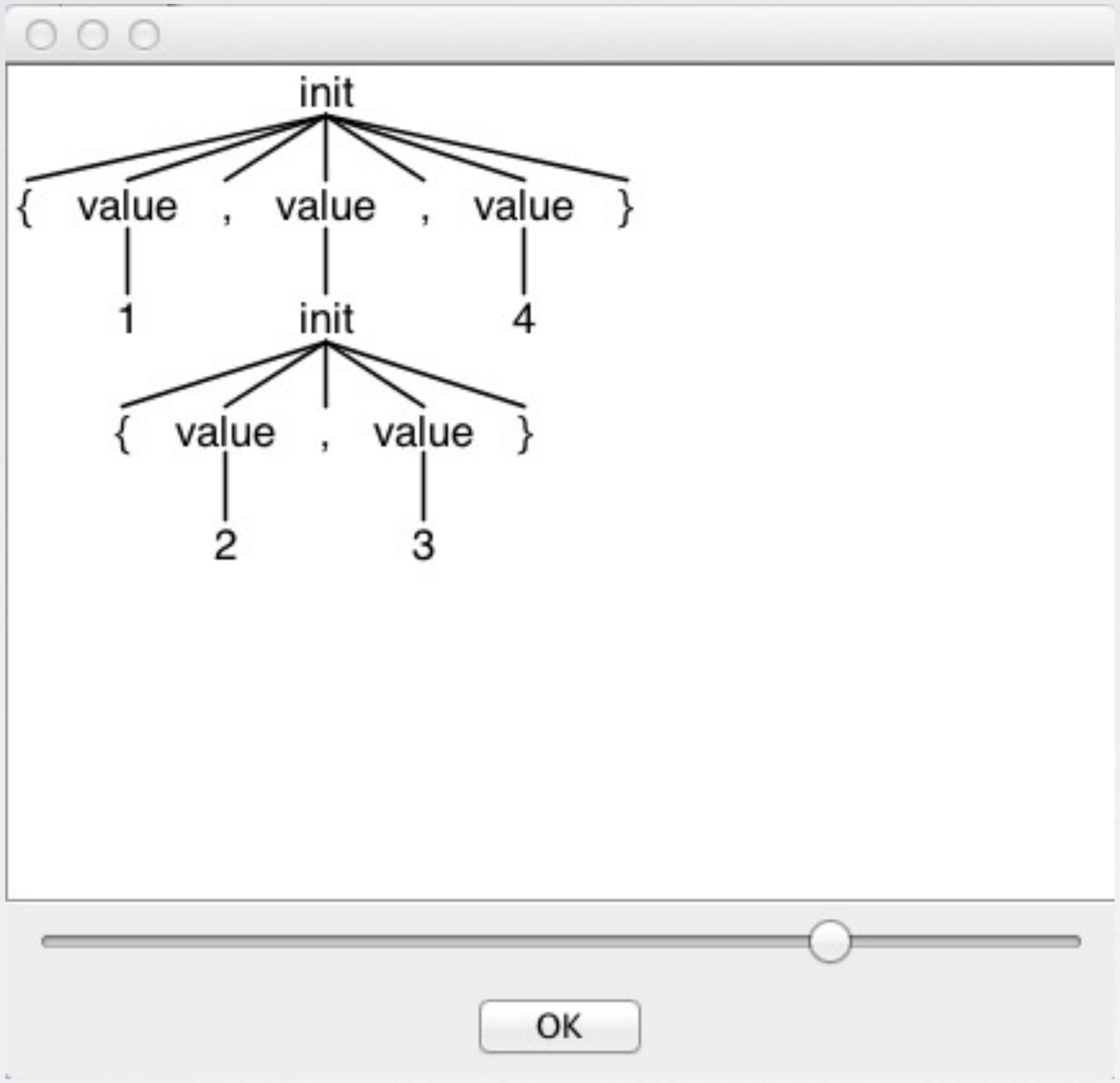
```
grammar ArrayInit;

/** A rule called init that matches comma-separated values between {...}. */

init : '{' value (',' value)* '}' ; // must match at least one value

/** A value can be either a nested array/struct or a simple integer (INT) */
value : init | INT;

// parser rules start with lowercase letters, lexer rules with uppercase
INT : [0-9]+ ;  // Define token INT as one or more digits
WS : [ \t\r\n]+ -> skip ;  // Define whitespace rule, toss it out
```

From the grammar ArrayInit.g4, ANTLR generates the following files:



- ☑ **ArrayInitParser.java** This file contains the parser class definition specific to grammar ArrayInit that recognizes our array language syntax.
- ☑ **ArrayInitLexer.java** ANTLR automatically extracts a separate parser and lexer specification from our grammar.
- ☑ **ArrayInit.tokens** ANTLR assigns a token type number to each token we define and stores these values in this file.
- ☑ **ArrayInitListener.java, ArrayInitBaseListener.java** By default, ANTLR parsers build a tree from the input. By walking that tree, a tree walker can fire "events" (callbacks) to a listener object that we provide.
- ☑ **ArrayInitListener** is the interface that describes the callbacks we can implement.
- ☑ **ArrayInitBaseListener** is a set of empty default implementations.

Brink-Van-der-Merwes-MacBook-Pro:antlr_crap brink$ grun ArrayInit init -gui
{1,{2,3},4}



Integrating a Generated Parser into a Java Program

```java
// import ANTLR's runtime libraries
import org.antlr.v4.runtime.*;

import org.antlr.v4.runtime.tree.*;

public class Test {
    public static void main(String[] args) throws Exception {
        // create a CharStream that reads from standard input
        ANTLRInputStream input = new ANTLRInputStream(System.in);
        // create a lexer that feeds off of input CharStream

        ArrayInitLexer lexer = new ArrayInitLexer(input);

        // create a buffer of tokens pulled from the lexer

        CommonTokenStream tokens = new CommonTokenStream(lexer);

        // create a parser that feeds off the tokens buffer

        ArrayInitParser parser = new ArrayInitParser(tokens);

        ParseTree tree = parser.init(); // begin parsing at init rule

        System.out.println(tree.toStringTree(parser)); // print LISP-style tree

    }
}
```

Building a Language Application using ArrayInitBaseListener

```
/** Convert short array inits like {1,2,3} to "\u0001\u0002\u0003" */
public class ShortToUnicodeString extends ArrayInitBaseListener {
    /** Translate { to " */
    @Override
    public void enterInit(ArrayInitParser.InitContext ctx) {System.out.print(' " '); }
    /** Translate } to " */
    @Override
    public void exitInit(ArrayInitParser.InitContext ctx) {System.out.print(' " '); }
    /** Convert short array inits like {1,2,3} to "\u0001\u0002\u0003" */
    @Override
    public void enterValue(ArrayInitParser.ValueContext ctx) {
        // Assumes no nested array initializers
        int value = Integer.valueOf(ctx.INT().getText());
        System.out.printf("\\u%04x", value); }
    }
}
```

Driver program for ArrayInitBaseListener

```
public class Translate {
    public static void main(String[] args) throws Exception {
        // create a CharStream that reads from standard input
        ANTLRInputStream input = new ANTLRInputStream(System.in);

        // create a lexer that feeds off of input CharStream
        ArrayInitLexer lexer = new ArrayInitLexer(input);

        // create a buffer of tokens pulled from the lexer
        CommonTokenStream tokens = new CommonTokenStream(lexer);

        // create a parser that feeds off the tokens buffer
        ArrayInitParser parser = new ArrayInitParser(tokens);
        ParseTree tree = parser.init(); // begin parsing at init rule

        // Create a generic parse tree walker that can trigger callbacks
        ParseTreeWalker walker = new ParseTreeWalker();

        // Walk the tree created during the parse, trigger callbacks
        walker.walk(new ShortToUnicodeString(), tree);
        System.out.println(); // print a \n after translation
    }
}
```

Building a Calculator Using a Visitor

```
grammar LabeledExpr;

prog:   stat+ ;

stat:   expr NEWLINE                    # printExpr
    |   ID '=' expr NEWLINE             # assign
    |   NEWLINE                         # blank
    ;

expr:   expr op=('*'|'/') expr          # MulDiv
    |   expr op=('+'|'-') expr          # AddSub
    |   INT                             # int
    |   ID                              # id
    |   '(' expr ')'                    # parens
    ;

MUL :   '*' ; // assigns token name to '*' used above in grammar
DIV :   '/' ;
ADD :   '+' ;
SUB :   '-' ;
ID  :   [a-zA-Z]+ ;      // match identifiers
INT :   [0-9]+ ;         // match integers
```

Driver class: Calc.java

```java
LabeledExprLexer lexer = new LabeledExprLexer(input);

CommonTokenStream tokens = new CommonTokenStream(lexer);

LabeledExprParser parser = new LabeledExprParser(tokens);

ParseTree tree = parser.prog(); // parse

EvalVisitor eval = new EvalVisitor();

eval.visit(tree);
```

Use ANTLR to generate a visitor interface with a method for each labeled

```
$ antlr4 -no-listener -visitor LabeledExpr.g4
```

```
public interface LabeledExprVisitor<T> {
    T visitId(LabeledExprParser.IdContext ctx);
    T visitAssign(LabeledExprParser.AssignContext ctx);
    T visitMulDiv(LabeledExprParser.MulDivContext ctx);
    ...
}
```

To implement the calculator, we override the methods associated with statement and expression alternatives.

```java
import java.util.HashMap;
import java.util.Map;
public class EvalVisitor extends LabeledExprBaseVisitor<Integer> {
    /** "memory" for our calculator; variable/value pairs go here */
    Map<String, Integer> memory = new HashMap<String, Integer>();
   /** ID '=' expr NEWLINE */
    @Override
    public Integer visitAssign(LabeledExprParser.AssignContext ctx) {
        String id = ctx.ID().getText(); // id is left-hand side of '='
        int value = visit(ctx.expr());
        memory.put(id, value);
        return value;
    }
etc.
```

Building a Translator with a Listener

Imagine you want to build a tool that generates a Java interface file from the methods in a Java class definition.

Sample Input:

```
import java.util.List;

import java.util.Map;

public class Demo {

    void f(int x, String y) {...}

    int[ ] g( ) { return null; }

    List<Map<String, Integer>>[ ] h( ) { return null; }
}
```

Output:

```
interface IDemo {

    void f(int x, String y);

    int[ ] g( );

    List<Map<String, Integer>>[ ] h( );
}
```

- The key "interface" between the grammar and our listener object is called JavaListener, and ANTLR automatically generates it for us.
- It defines all of the methods that the class ParseTreeWalker from ANTLR's runtime can trigger as it traverses the parse tree.
- Here are the relevant methods from the generated listener interface:

```
public interface JavaListener extends ParseTreeListener {
   void enterClassDeclaration(JavaParser.ClassDeclarationContext ctx);
   void exitClassDeclaration(JavaParser.ClassDeclarationContext ctx);
   void enterMethodDeclaration(JavaParser.MethodDeclarationContext ctx);
   ...
}
```

- ☑ Listener methods are called by the ANTLR-provided walker object, whereas visitor methods must walk their children with explicit visit calls.
- ☑ Forgetting to invoke visit() on a node's children means those subtrees don't get visited.
- ☑ ANTLR generates a default implementation called JavaBaseListener. Our interface extractor can then subclass JavaBaseListener and override the methods of interest.

```java
public class ExtractInterfaceListener extends JavaBaseListener {
    JavaParser parser;
    public ExtractInterfaceListener(JavaParser parser) {this.parser = parser;}
    /** Listen to matches of classDeclaration */
    @Override
    public void enterClassDeclaration(JavaParser.ClassDeclarationContext ctx){
        System.out.println("interface I"+ctx.Identifier()+" {");
    }
    @Override
    public void exitClassDeclaration(JavaParser.ClassDeclarationContext ctx) {
        System.out.println("}");
    }

    /** Listen to matches of methodDeclaration */
    @Override
    public void enterMethodDeclaration(JavaParser.MethodDeclarationContext ctx)
    {
        // need parser to get tokens
        TokenStream tokens = parser.getTokenStream();
        String type = "void";
        if ( ctx.type()!=null ) {
            type = tokens.getText(ctx.type());
        }
        String args = tokens.getText(ctx.formalParameters());
        System.out.println("\t"+type+" "+ctx.Identifier()+args+";");
    }
}
```

Homework 6

Will be added on homepage tomorrow.

Due: 31 May