The Pragmatic Programmers

The Definitive ANTLR 4 Reference

Terence Parr

Edited by Susannah Davidson Pfalzer

CHAPTER 3

A Starter ANTLR Project

For our first project, let's build a grammar for a tiny subset of C or one of its derivatives like Java. In particular, let's recognize integers in, possibly nested, curly braces like {1, 2, 3} and {1, {2, 3}, 4}. These constructs could be int array or struct initializers. A grammar for this syntax would come in handy in a variety of situations. For one, we could use it to build a source code refactoring tool for C that converted integer arrays to byte arrays if all of the initialized values fit within a byte. We could also use this grammar to convert initialized Java short arrays to strings. For example, we could transform the following:

```
static short[] data = {1,2,3};
```

into the following equivalent string with Unicode constants:

```
static String data = "\u0001\u0002\u0003"; // Java char are unsigned short
```

where Unicode character specifiers, such as \u0001, use four hexadecimal digits representing a 16-bit character value, that is, a short.

The reason we might want to do this translation is to overcome a limitation in the Java .class file format. A Java class file stores array initializers as a sequence of explicit array-element initializers, equivalent to data[0]=1; data[1]=2; data[2]=3;, instead of a compact block of packed bytes.[1] Because Java limits the size of initialization methods, it limits the size of the arrays we can initialize. In contrast, a Java class file stores a string as a contiguous sequence of shorts. Converting array initializers to strings results in a more compact class file and avoids Java's initialization method size limit.

By working through this starter example, you'll learn a bit of ANTLR grammar syntax, what ANTLR generates from a grammar, how to incorporate the

1. To learn more about this topic, check out the slides from my JVM Language Summit presentation: http://parrt.cs.usfca.edu/doc/impl-parsers-in-java.pdf.

generated parser into a Java application, and how to build a translator with a parse-tree listener.

3.1 The ANTLR Tool, Runtime, and Generated Code

To get started, let's peek inside ANTLR's jar. There are two key ANTLR components: the ANTLR tool itself and the ANTLR runtime (parse-time) API. When we say "run ANTLR on a grammar," we're talking about running the ANTLR tool, class org.antlr.v4.Tool. Running ANTLR generates code (a parser and a lexer) that recognizes sentences in the language described by the grammar. A lexer breaks up an input stream of characters into tokens and passes them to a parser that checks the syntax. The runtime is a library of classes and methods needed by that generated code such as Parser, Lexer, and Token. First we run ANTLR on a grammar and then compile the generated code against the runtime classes in the jar. Ultimately, the compiled application runs in conjunction with the runtime classes.

The first step to building a language application is to create a grammar that describes a language's syntactic rules (the set of valid sentences). We'll learn how to write grammars in Chapter 5, *Designing Grammars*,on page 59, but for the moment, here's a grammar that'll do what we want:

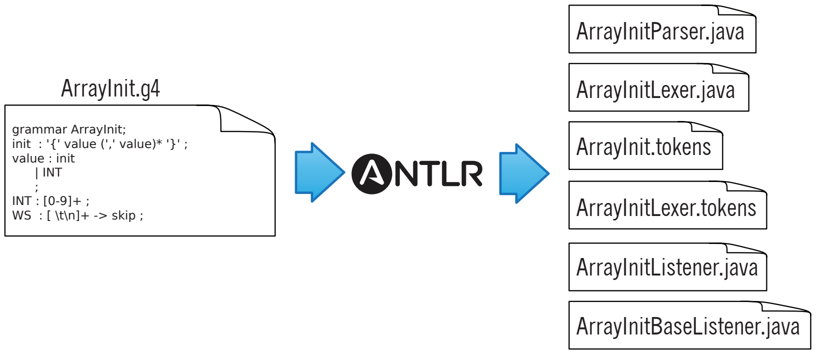
starter/ArrayInit.g4

```
/** Grammars always start with a grammar header. This grammar is called
 *  ArrayInit and must match the filename: ArrayInit.g4
 */
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
```

Let's put grammar file ArrayInit.g4 in its own directory, such as /tmp/array (by cutting and pasting or downloading the source code from the book website). Then, we can run ANTLR (the tool) on the grammar file.

```
$ cd /tmp/array
$ antlr4 ArrayInit.g4  # Generate parser and lexer using antlr4 alias
```

From grammar ArrayInit.g4, ANTLR generates lots of files that we'd normally have to write by hand.



At this point, we're just trying to get the gist of the development process, so here's a quick description of the generated files:

ArrayInitParser.java This file contains the parser class definition specific to grammar ArrayInit that recognizes our array language syntax.

```
public class ArrayInitParser extends Parser { ... }
```

It contains a method for each rule in the grammar as well as some support code.

ArrayInitLexer.java ANTLR automatically extracts a separate parser and lexer specification from our grammar. This file contains the lexer class definition, which ANTLR generated by analyzing the lexical rules INT and WS as well as the grammar literals '{', ',', and '}'. Recall that the lexer tokenizes the input, breaking it up into vocabulary symbols. Here's the class outline:

```
public class ArrayInitLexer extends Lexer { ... }
```

ArrayInit.tokens ANTLR assigns a token type number to each token we define and stores these values in this file. It's needed when we split a large grammar into multiple smaller grammars so that ANTLR can synchronize all the token type numbers. See *Importing Grammars*,on page 38.

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. This class makes it easy for us to override just the callbacks we're interested in. (See Section 7.2, *Implementing Applications with Parse-Tree Listeners*,on page 114.) ANTLR can also generate tree visitors for us with the -visitor command-line option. (See *Traversing Parse Trees with Visitors*,on page 121.)

We'll use the listener classes to translate short array initializers to String objects shortly (sorry about the pun), but first let's verify that our parser correctly matches some sample input.

ANTLR Grammars Are Stronger Than Regular Expressions

Those of you familiar with regular expressions[a] might be wondering if ANTLR is overkill for such a simple recognition problem. It turns out that we can't use regular expressions to recognize initializations because of nested initializers. Regular expressions have no memory in the sense that they can't remember what they matched earlier in the input. Because of that, they don't know how to match up left and right curlies. We'll get to this in more detail in *Pattern: Nested Phrase*,on page 67.

a. http://en.wikipedia.org/wiki/Regular_expression

3.2 Testing the Generated Parser

Once we've run ANTLR on our grammar, we need to compile the generated Java source code. We can do that by simply compiling everything in our /tmp/array directory.

```
$ cd /tmp/array
$ javac *.java     # Compile ANTLR-generated code
```

If you get a ClassNotFoundException error from the compiler, that means you probably haven't set the Java CLASSPATH correctly. On UNIX systems, you'll need to execute the following command (and likely add to your start-up script such as .bash_profile):

```
$ export CLASSPATH=".:/usr/local/lib/antlr-4.0-complete.jar:$CLASSPATH"
```

To test our grammar, we use the TestRig via alias grun that we saw in the previous chapter. Here's how to print out the tokens created by the lexer:

```
⇒ $ grun ArrayInit init -tokens
⇒ {99, 3, 451}
⇒ EOF
❮ [@0,0:0='{',<1>,1:0]
  [@1,1:2='99',<4>,1:1]
  [@2,3:3=',',<2>,1:3]
  [@3,5:5='3',<4>,1:5]
  [@4,6:6=',',<2>,1:6]
  [@5,8:10='451',<4>,1:8]
  [@6,11:11='}',<3>,1:11]
  [@7,13:12='<EOF>',<-1>,2:0]
```

After typing in array initializer {99, 3, 451}, we have to hit EOF[2] on a line by itself. By default, ANTLR loads the entire input before processing. (That's the most common case and the most efficient.)

Each line of the output represents a single token and shows everything we know about the token. For example, [@5,8:10='451',<4>,1:8] indicates that it's the token at index 5 (indexed from 0), goes from character position 8 to 10 (inclusive starting from 0), has text 451, has token type 4 (INT), is on line 1 (from 1), and is at character position 8 (starting from zero and counting tabs as a single character). Notice that there are no tokens for the space and newline characters. Rule WS in our grammar tosses them out because of the -> skip directive.

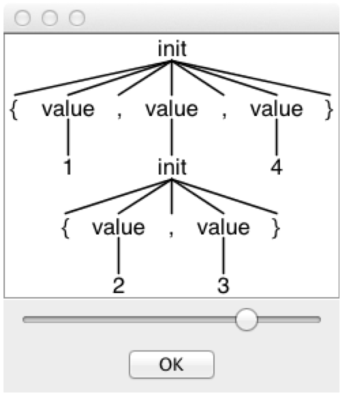
To learn more about how the parser recognized the input, we can ask for the parse tree with the -tree option.

```
⇒ $ grun ArrayInit init -tree
⇒ {99, 3, 451}
⇒ EOF
❮ (init { (value 99) , (value 3) , (value 451) })
```

Option -tree prints out the parse tree in LISP-like text form (*root children*). Or, we can use the -gui option to visualize the tree in a dialog box. Try it with a nested group of integers as input: {1,{2,3},4}.

```
⇒ $ grun ArrayInit init -gui
⇒ {1,{2,3},4}
⇒ EOF
```

Here's the parse tree dialog box that pops up:



2. The end-of-file character is Ctrl+D on Unix and Ctrl+Z on Windows.

In English, the parse tree says, “The input is an initializer with three values surrounded by curly braces. The first and third values are the integers 1 and 4. The second value is itself an initializer with two values surrounded by curly braces. Those values are integers 2 and 3.”

Those interior nodes, init and value, are really handy because they identify all of the various input elements by name. It’s kind of like identifying the verb and subject in an English sentence. The best part is that ANTLR creates that tree automatically for us based upon the rule names in our grammar. We’ll build a translator based on this grammar at the end of this chapter using a built-in tree walker to trigger callbacks like enterInit() and enterValue().

Now that we can run ANTLR on a grammar and test it, it’s time to think about how to call this parser from a Java application.

3.3 Integrating a Generated Parser into a Java Program

Once we have a good start on a grammar, we can integrate the ANTLR-generated code into a larger application. In this section, we’ll look at a simple Java main() that invokes our initializer parser and prints out the parse tree like TestRig’s -tree option. Here’s a boilerplate Test.java file that embodies the overall recognizer data flow we saw in Section 2.1, *Let’s Get Meta!*,on page 9:

starter/Test.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
    }
}
```

The program uses a number of classes like CommonTokenStream and ParseTree from ANTLR's runtime library that we'll learn more about starting in Section 4.1, *Matching an Arithmetic Expression Language*,on page 34.

Here's how to compile everything and run Test:

```
⇒ $ javac ArrayInit*.java Test.java
⇒ $ java Test
⇒ {1,{2,3},4}
⇒ EOF
❮ (init { (value 1) , (value (init { (value 2) , (value 3) })) , (value 4) })
```

ANTLR parsers also automatically report and recover from syntax errors. For example, here's what happens if we enter an initializer that's missing the final curly brace:

```
⇒ $ java Test
⇒ {1,2
⇒ EOF
❮ line 2:0 missing '}' at '<EOF>'
  (init { (value 1) , (value 2) <missing '}'>)
```

At this point, we've seen how to run ANTLR on a grammar and integrate the generated parser into a trivial Java application. An application that merely checks syntax is not that impressive, though, so let's finish up by building a translator that converts short array initializers to String objects.

3.4 Building a Language Application

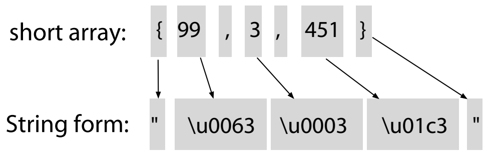
Continuing with our array initializer example, our next goal is to translate not just recognize initializers. For example, let's translate Java short arrays like {99 , 3 , 451 } to "\u0063\u0003\u01c3" where 63 is the hexadecimal representation of the 99 decimal.

To move beyond recognition, an application has to extract data from the parse tree. The easiest way to do that is to have ANTLR's built-in parse-tree walker trigger a bunch of callbacks as it performs a depth-first walk. As we saw earlier, ANTLR automatically generates a listener infrastructure for us. These listeners are like the callbacks on GUI widgets (for example, a button would notify us upon a button press) or like SAX events in an XML parser.

To write a program that reacts to the input, all we have to do is implement a few methods in a subclass of ArrayInitBaseListener. The basic strategy is to have each listener method print out a translated piece of the input when called to do so by the tree walker.

The beauty of the listener mechanism is that we don't have to do any tree walking ourselves. In fact, we don't even have to know that the runtime is walking a tree to call our methods. All we know is that our listener gets notified at the beginning and end of phrases associated with rules in the grammar. As we'll see in Section 7.2, *Implementing Applications with Parse-Tree Listeners*,on page 114, this approach reduces how much we have to learn about ANTLR—we're back in familiar programming language territory for anything but phrase recognition.

Starting a translation project means figuring out how to convert each input token or phrase to an output string. To do that, it's a good idea to manually translate a few representative samples in order to pick out the general phrase-to-phrase conversions. In this case, the translation is pretty straightforward.



In English, the translation is a series of "*X goes to Y*" rules.

1. Translate { to ".
2. Translate } to ".
3. Translate integers to four-digit hexadecimal strings prefixed with `\u`.

To code the translator, we need to write methods that print out the converted strings upon seeing the appropriate input token or phrase. The built-in tree walker triggers callbacks in a listener upon seeing the beginning and end of the various phrases. Here's a listener implementation for our translation rules:

starter/ShortToUnicodeString.java

```
/** 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('"');
    }
    /** Translate integers to 4-digit hexadecimal strings prefixed with \\u */
    @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);
    }
}
```

We don't need to override every enter/exit method; we do just the ones we care about. The only unfamiliar expression is ctx.INT(), which asks the context object for the integer INT token matched by that invocation of rule value. Context objects record everything that happens during the recognition of a rule.

The only thing left to do is to create a translator application derived from the Test boilerplate code shown earlier.

starter/Translate.java

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

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
    }
}
```

The only difference from the boilerplate code is the highlighted section that creates a tree walker and asks it to walk the tree returned from the parser. As the tree walker traverses, it triggers calls into our ShortToUnicodeString listener.

Please note: To focus our attention and to reduce bloat, the remainder of the book will typically show just the important or novel bits of code rather than entire files. If you're reading the electronic version of this book, you can always click the code snippet titles; the title bars are links to the full source code on the Web. You can also grab the full source code bundle on the book's website.[3]

Let's build the translator and try it on our sample input.

```
⇒ $ javac ArrayInit*.java Translate.java
⇒ $ java Translate
⇒ {99, 3, 451}
⇒ EOF
❮ "\u0063\u0003\u01c3"
```

It works! We've just built our first translator, without even touching the grammar. All we had to do was implement a few methods that printed the appropriate phrase translations. Moreover, we can generate completely different output simply by passing in a different listener. Listeners effectively isolate the language application from the grammar, making the grammar reusable for other applications.

In the next chapter, we'll take a whirlwind tour of ANTLR grammar notation and the key features that make ANTLR powerful and easy to use.

3. http://pragprog.com/titles/tpantlr2/source_code