ANTLR4 Basics

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What's that?

ANTLR v.4 is a powerful parser generator that you can use to read, process, execute, or translate structured text or binary files.

From a grammar as a formal language description, ANTLR generates a parser for that language that can automatically build parse trees. ANTLR also automatically generates tree walkers that you can use to visit the nodes of those trees to execute application-specific code.

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How can I get it?

- Download last complete jar from `http://www.antlr.org/download.html`
- Put it in an appropriate folder, e.g. `/usr/local/lib`
- The jar contains:
  - all dependencies necessary to run the ANTLR tool
  - the runtime library needed to compile and execute recognizers generated by ANTLR
  - a sophisticated tree layout support library: `http://code.google.com/p/treelayout`
  - a template engine useful for generating code and other structured text: `http://www.stringtemplate.org`

How can I install it?

- Set the CLASSPATH environment variable to include "." and the jar:

  ```
  > export
  CLASSPATH=".:/usr/local/bin/antlr-4.7.1-complete.jar:$CLASSPATH"
  ```

- You can do it every time you start a session in a shell or you can edit the `.bash_profile` file
- To run the ANTLR4 Tool:

  ```
  > java -jar /usr/local/lib/antlr-4.0-complete.jar
  ```

  or directly:

  ```
  > java org.antlr.v4.Tool
  ```

- To save typing:

  ```
  > alias antlr4='java -jar /usr/local/lib/antlr-4.0-complete.jar'
  ```

How should I use it?

File Hello.g4

```
grammar Hello; // Define a grammar called Hello
r :  ’hello’ ID ; // Match the word ’hello’ followed by an identifier
ID : [a-z]+ ; // Match lower-case identifiers
WS : [\t \r \n]+ -> skip ; // skip spaces, tabs, newlines, \r (Windows)
```

```
> antlr4 Hello.g4
```

produces:

```
Hello.g4 HelloLexer.java HelloParser.java
Hello.tokens HelloLexer.tokens
HelloBaseListener.java HelloListener.java
```

Then:

```
> javac *.java
```

Testing Hello

- ANTLR4 generates an executable recognizer embodied by `HelloParser.java` and `HelloLexer.java`
- There is not (yet) a main program to trigger language recognition
- ANTLR4 provides a a flexible testing tool in the runtime library called `TestRig`
- `> alias grun='java org.antlr.v4.runtime.misc.TestRig'`
- The test rig takes:
    - a grammar name
    - a starting rule name
    - various options for the desired output

Testing Hello

```
> grun Hello r -tokens  # start the TestRig on grammar Hello at rule r
hello parrt             # input for the recognizer that you type
<eof>                   # type ctrl+D on Unix or ctrl+Z on Windows}\\
```

Outputs a detailed description of the tokens:

```
[@0,0:4=’hello’,<1>,1:0]
[@1,6:10=’parrt’,<2>,1:6]
[@2,12:11=’<EOF>’,<-1>,2:0]
```

Testing Hello

```
> grun Hello r -tree
hello parrt
<eof>
```

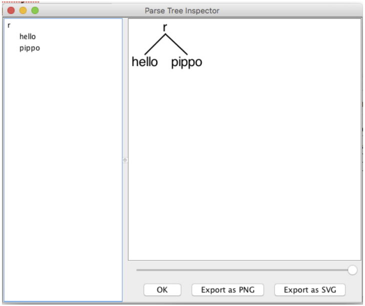
Outputs the parse tree in LISP-style text:

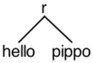
```
(r hello parrt)
```

Testing Hello

```
> grun Hello r -gui
hello pippo
<eof>
```

Opens a graphical representation of the parse tree:

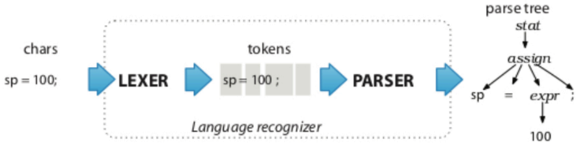




Compiler Phases in ANTLR4

Phases

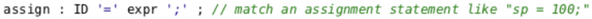
ANTLR4 follows the usual conceptual structure of a generic compiler that we have seen in this course



Grammars and Parsers in ANTLR4

Grammar Definitions

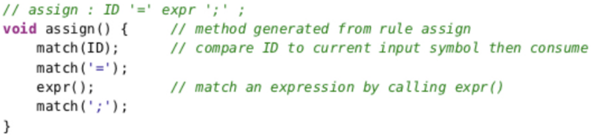
Rules defines non-terminal symbols starting with lower-case letters



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

Grammar Implementation

ANTLR4 essentially creates a Recursive Descent Parser for the given grammar

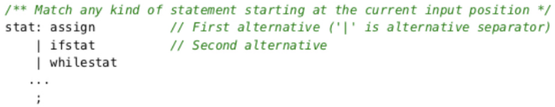


```
// assign : ID '=' expr ';' ;
void assign() {      // method generated from rule assign
    match(ID);       // compare ID to current input symbol then consume
    match('=');
    expr();          // match an expression by calling expr()
    match(';');
}
```

Lookaheads

Lookaheads

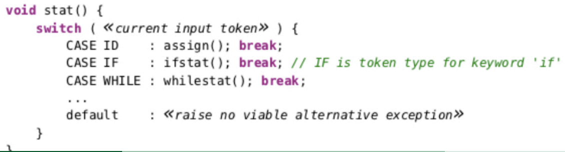
ANTLR4 autonomously decide how many lookaheads are needed to take parsing decision (even the whole text!)



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

Left Recursion

ANTLR4 accepts left recursive grammars and handles them transparently!

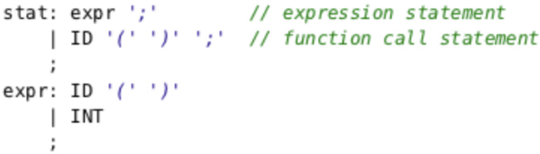


```
void stat() {
    switch ( «current input token» ) {
        CASE ID    : assign(); break;
        CASE IF    : ifstat(); break; // IF is token type for keyword 'if'
        CASE WHILE : whilestat(); break;
        ...
        default    : «raise no viable alternative exception»
    }
}
```

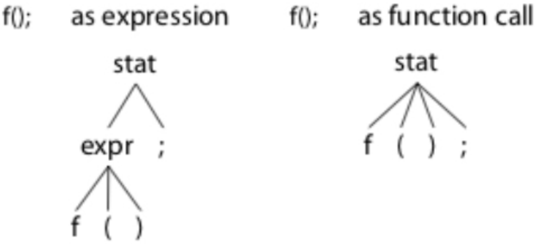
Ambiguity

Ambiguity

ANTLR4 accepts ambiguous grammars, but it cannot decide alone on which parse tree to generate for ambiguous sentences



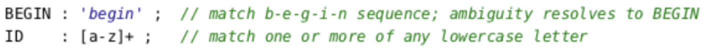
```
stat: expr ';'          // expression statement
    | ID '(' ')' ';'    // function call statement
    ;
expr: ID '(' ')'
    | INT
    ;
```



Ambiguity

- ANTLR4 will create, for an ambiguous sentence, the first parse tree that can be generated
- The order in which the rules are written in the .g4 file matters!
- In case of multiple choices the first rule is applied
- In case of fail, backtrack!

This resolves also possible ambiguities in LEXER (rules defining symbols starting with upper-case letters):



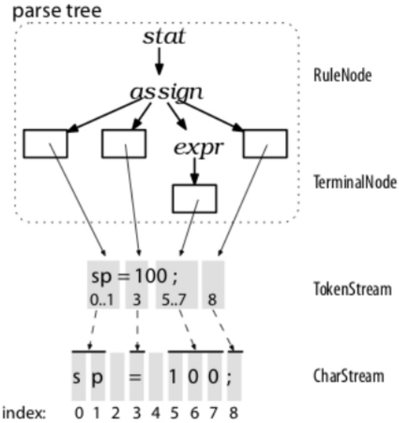
```
BEGIN : 'begin' ;  // match b-e-g-i-n sequence; ambiguity resolves to BEGIN
ID    : [a-z]+ ;   // match one or more of any lowercase letter
```

Semantic Analysis and Code Generation

- ANTLR4 permits the definition of Syntax Directed Translation Schemes
- However, the main and preferred way to implement actions associated to parsing is through walking or visiting the generated parse tree
- This has a lot of advantages in modularity and re-usability

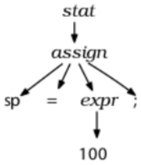
ANTLR4 Java Classes

- ANTLR4 creates by default Java code for a given .g4 file
- Some ANTLR4 classes are `CharStream, Lexer, Token, Parser` and `ParseTree`

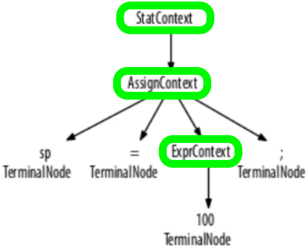


ANTLR4 Java Classes for Rules

- ANTLR4 creates specific subclasses for each symbol
- This facilitates accessing to the subtrees



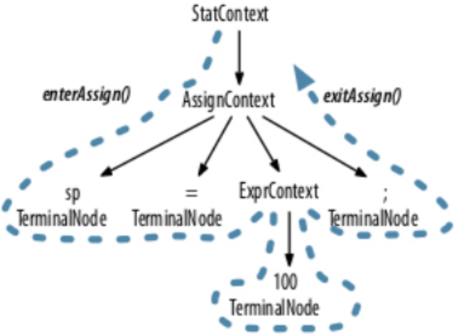
Parse tree



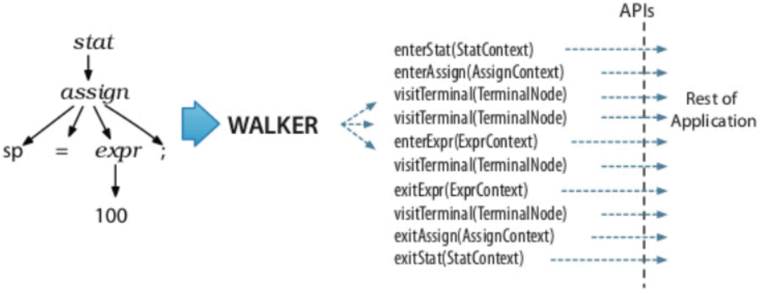
Parse tree node class names

Run-time tree walking

- By default ANTLR4 generates a parse tree *listener* interface
- This responds to events triggered by the built-in tree walker
- The built-in tree walker performs a dept-first left-to-right visit of the parse tree
- For each node rule `name` two methods `enterName()` and `exitName()` are created:

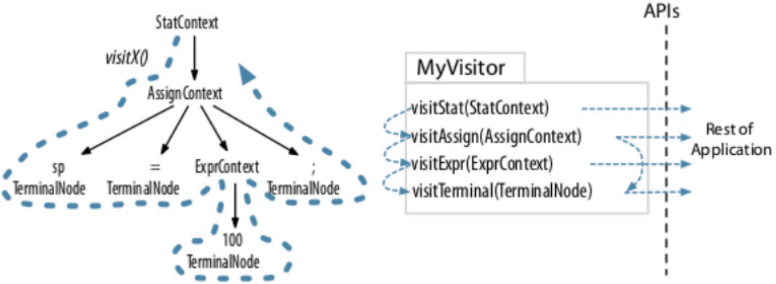


Run-time tree walking


stat
assign
sp
=
expr
;
100
WALKER
APIs
enterStat(StatContext)
enterAssign(AssignContext)
visitTerminal(TerminalNode)
visitTerminal(TerminalNode)
enterExpr(ExprContext)
visitTerminal(TerminalNode)
exitExpr(ExprContext)
visitTerminal(TerminalNode)
exitAssign(AssignContext)
exitStat(StatContext)
Rest of
Application

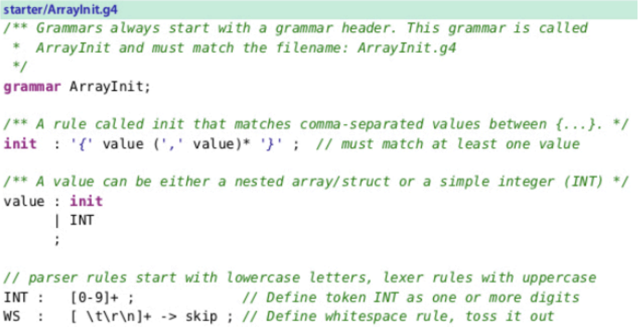
Run-time tree visitors

- We can also decide a particular order in which the tree is visited, different from the standard one
- Call ANTLR4 with `-visitor` option
- It generates a visit method for each rule name
- Inside the code we have to make explicit calls to the other visit methods



Starter Project

- Let's create the first application
- We want to parse integer lists inside possibly nested curly braces: `{1, 2, 3}` or `{1, {2, 3}, 4 }`
- We want to produce corresponding strings of Unicode characters
- E.g., `{1, 2, 3}` is translated to `"\u0001\u0002\u0003"`

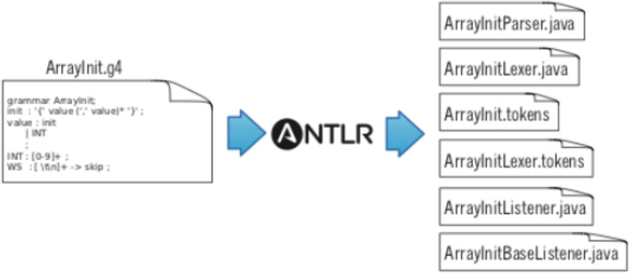


starter/ArrayInit.g4

```
/** 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
```

Starter Project

- Let’s run ANTLR4 and produce the stub code:



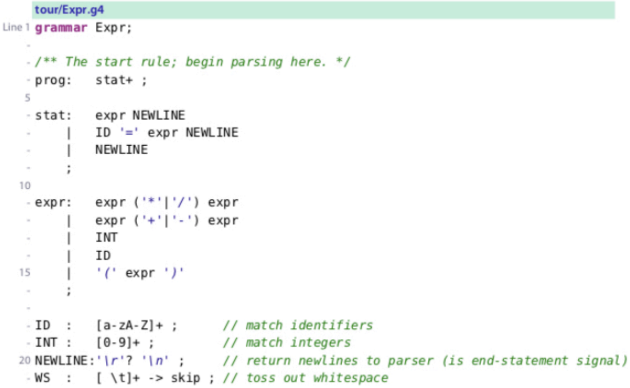
```
grammar ArrayInit;
init : '{' value (',' value)* '}' ;
value : init
      | INT
      ;
INT : [0-9]+ ;
WS  : [ \t\n]+ -> skip ;
```

Starter Project

- Analyse the code
- Create simple Test class
- Create a subclass to define actions at enter and exit of the rules
- Create a class for realising the translation

Expressions Project

- Let’s create an ANTLR4 project for a desk calculator
- It will parse sequences of expressions and will print the corresponding value

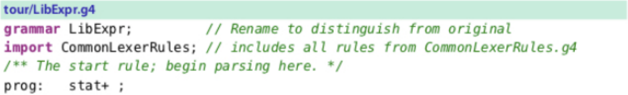


tour/Expr.g4

```
grammar Expr;

/** The start rule; begin parsing here. */
prog:   stat+ ;

stat:   expr NEWLINE
    |   ID '=' expr NEWLINE
    |   NEWLINE
    ;

expr:   expr ('*'|'/') expr
    |   expr ('+'|'-') expr
    |   INT
    |   ID
    |   '(' expr ')'
    ;

ID  :   [a-zA-Z]+ ;      // match identifiers
INT :   [0-9]+ ;         // match integers
NEWLINE:'\r'? '\n' ;     // return newlines to parser (is end-statement signal)
WS  :   [ \t]+ -> skip ; // toss out whitespace
```

Importing grammars

- ANTLR4 permits to import grammars
- Very useful for modularity

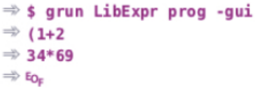


tour/LibExpr.g4

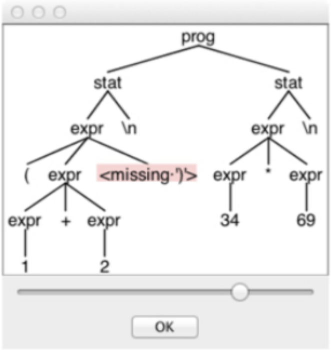
```
grammar LibExpr;         // Rename to distinguish from original
import CommonLexerRules; // includes all rules from CommonLexerRules.g4
/** The start rule; begin parsing here. */
prog:   stat+ ;
```

Handling Errors

- ANTLR4 automatically handles errors
- The standard behaviour can be customised (advanced topic)

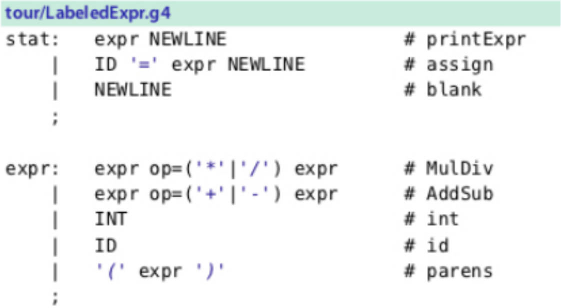


```
⇒ $ grun LibExpr prog -gui
⇒ (1+2
⇒ 34*69
⇒ EOF
```



Rule labeling

- When rules have alternatives it is better to give names to them

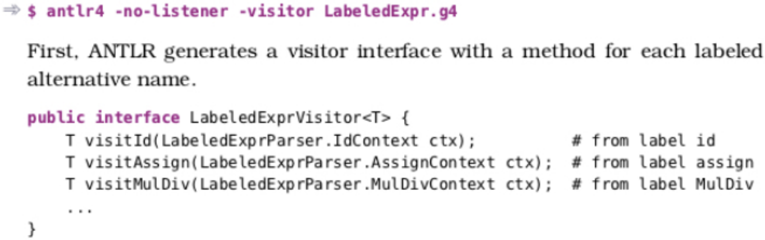


tour/LabeledExpr.g4

```
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
    ;
```

Calculator Implementation with Visitor

- Let’s implement the calculator using the Visitor Pattern



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

First, ANTLR generates a visitor interface with a method for each labeled alternative name.

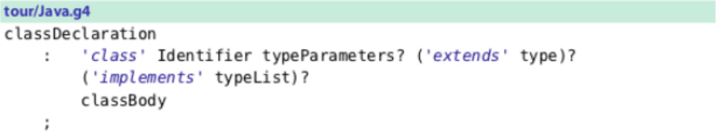
```
public interface LabeledExprVisitor<T> {
    T visitId(LabeledExprParser.IdContext ctx);         # from label id
    T visitAssign(LabeledExprParser.AssignContext ctx); # from label assign
    T visitMulDiv(LabeledExprParser.MulDivContext ctx); # from label MulDiv
    ...
}
```

Calculator Implementation with Visitor

- Subclass `LabeledExprBaseVisitor<T>` with `T` as `Integer`
- Redefine the behaviour of the visit methods
- Create a class with a main that creates a visitor object and visits a parse tree
- See Code...

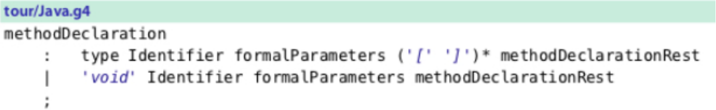
Translator from Java classes to Java interfaces

- Let’s implement a translator that can parse Java files!
- We are given a Java grammar specification `Java.g4`
- The translator has to transform the code of a Java class into a code for a Java interface containing the same methods without implementation
- Any comment appearing within the method signature must be retained



tour/Java.g4

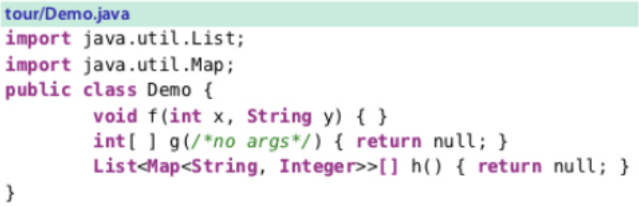
```
classDeclaration
    :   'class' Identifier typeParameters? ('extends' type)?
        ('implements' typeList)?
        classBody
    ;
```



tour/Java.g4

```
methodDeclaration
    :   type Identifier formalParameters ('[' ']')* methodDeclarationRest
    |   'void' Identifier formalParameters methodDeclarationRest
    ;
```

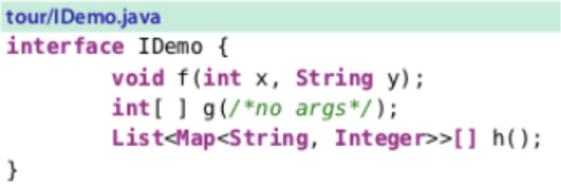
Translator from Java classes to Java interfaces



tour/Demo.java

```java
import java.util.List;
import java.util.Map;
public class Demo {
        void f(int x, String y) { }
        int[ ] g(/*no args*/) { return null; }
        List<Map<String, Integer>>[] h() { return null; }
}
```

must produce (see code):

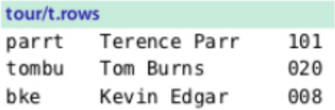


tour/IDemo.java

```java
interface IDemo {
        void f(int x, String y);
        int[ ] g(/*no args*/);
        List<Map<String, Integer>>[] h();
}
```

Implementing an SDT in ANTLR4

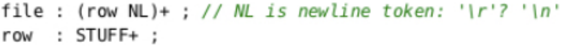
- Let's implement a translator that parses a csv text file with tab as separator
- We want to select the data values of a particular column



tour/t.rows

```
parrt   Terence Parr    101
tombu   Tom Burns       020
bke     Kevin Edgar     008
```

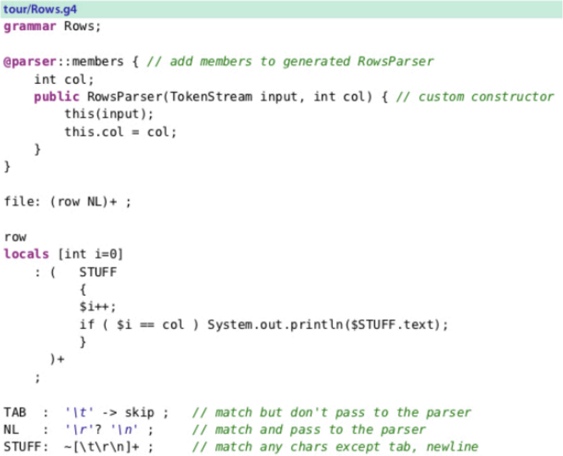
Base grammar:



```
file : (row NL)+ ; // NL is newline token: '\r'? '\n'
row  : STUFF+ ;
```

Implementing an SDT in ANTLR4

- Enriched grammar with code

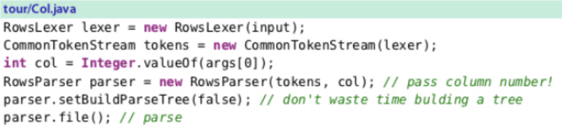


tour/Rows.g4

```
grammar Rows;

@parser::members { // add members to generated RowsParser
    int col;
    public RowsParser(TokenStream input, int col) { // custom constructor
        this(input);
        this.col = col;
    }
}

file: (row NL)+ ;

row
locals [int i=0]
    : (   STUFF
          {
          $i++;
          if ( $i == col ) System.out.println($STUFF.text);
          }
      )+
    ;

TAB  :  '\t' -> skip ;    // match but don't pass to the parser
NL   :  '\r'? '\n' ;      // match and pass to the parser
STUFF:  ~[\t\r\n]+ ;      // match any chars except tab, newline
```

Implementing an SDT in ANTLR4

- Running the parser (see code)



tour/Col.java

```java
RowsLexer lexer = new RowsLexer(input);
CommonTokenStream tokens = new CommonTokenStream(lexer);
int col = Integer.valueOf(args[0]);
RowsParser parser = new RowsParser(tokens, col); // pass column number!
parser.setBuildParseTree(false); // don't waste time bulding a tree
parser.file(); // parse
```