Homework 2:
Parser and Lexer

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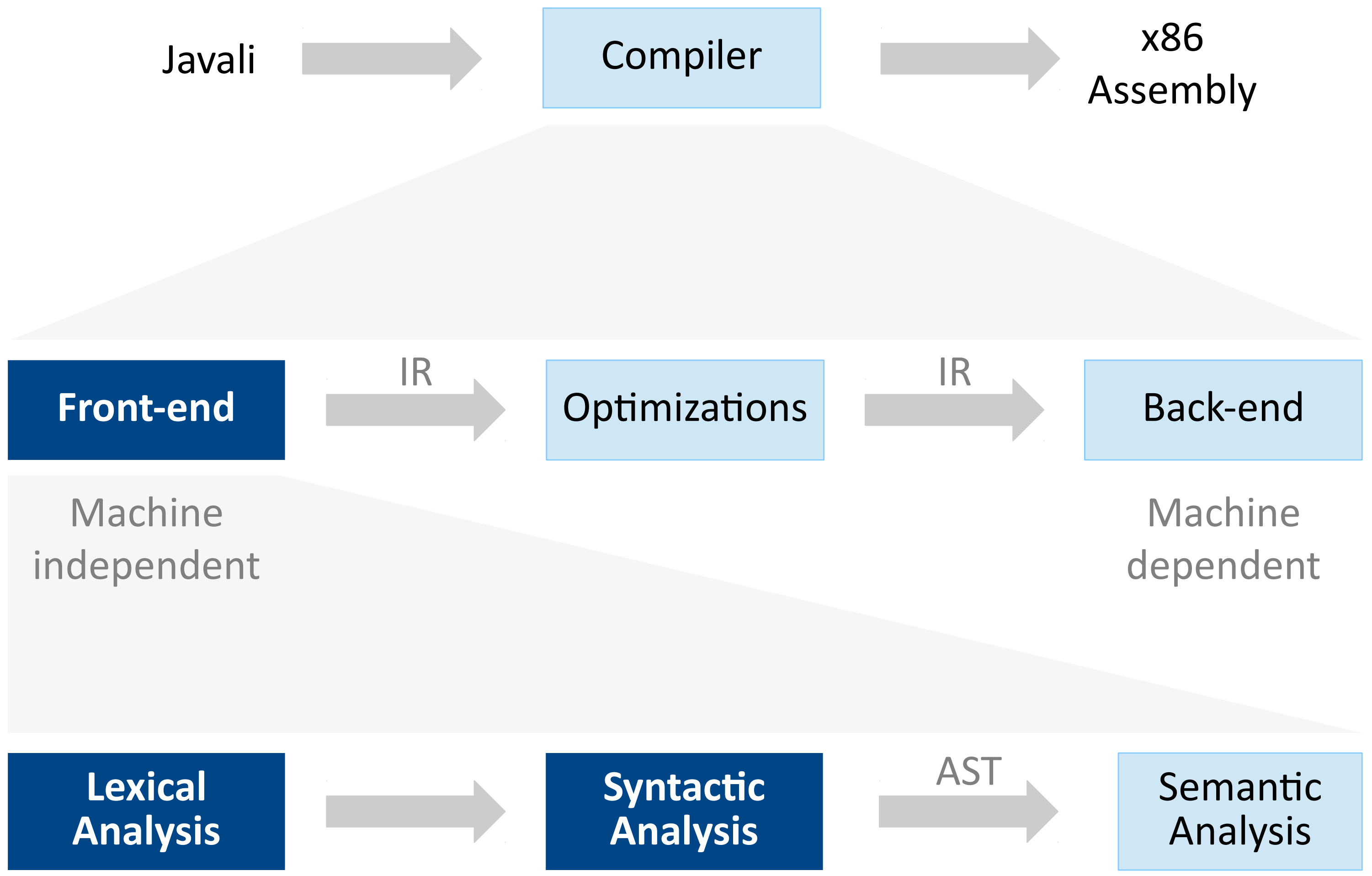
Compiler Design – 08.10.2015

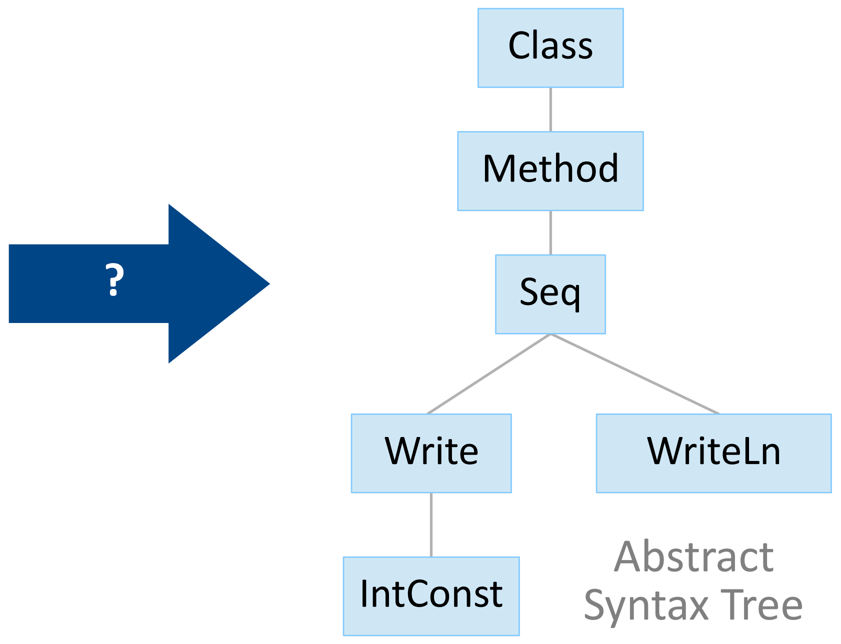
Compiler phases



Homework 2

```
class Main {
    void main() {
        write(222);
        writeln();
    }
}
```

Text

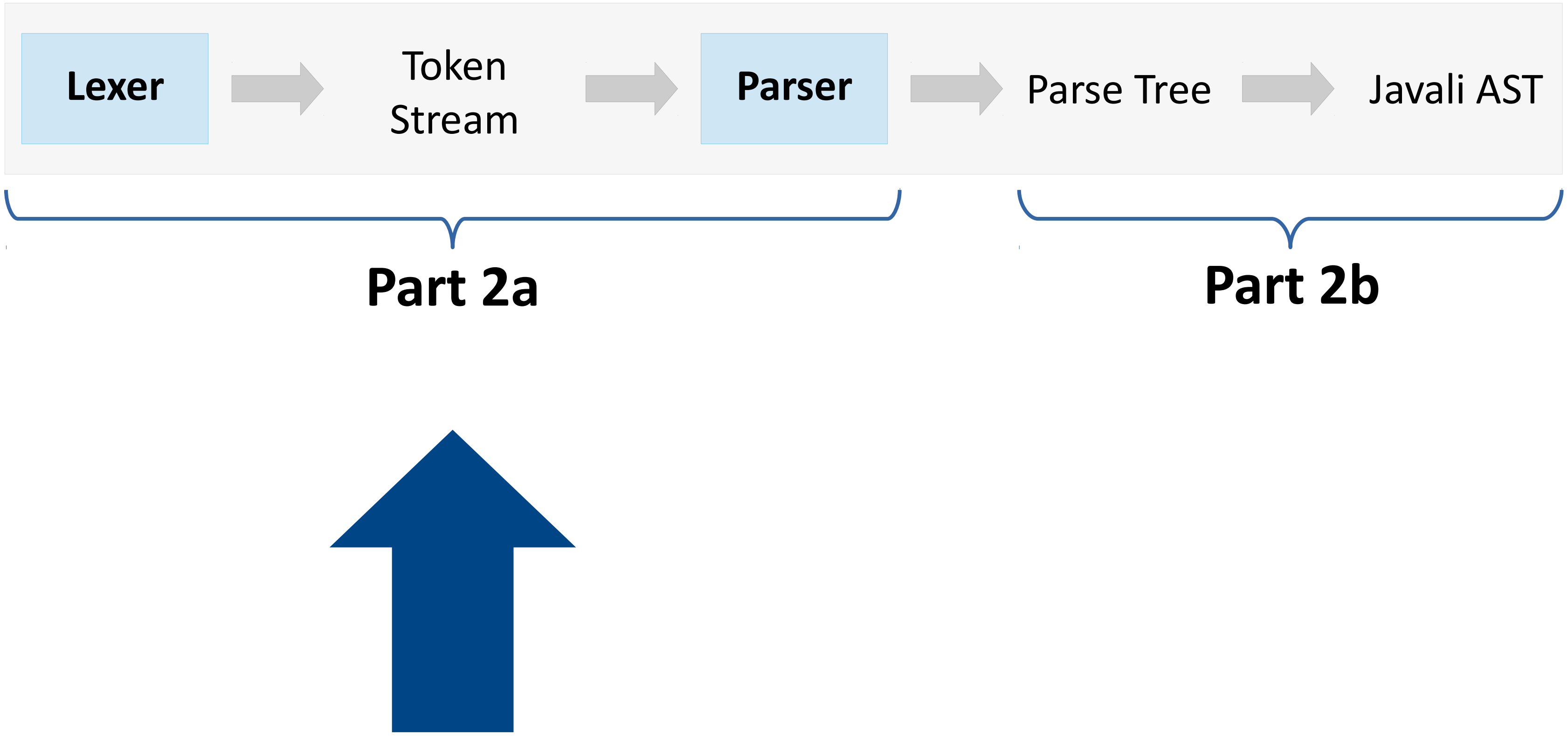


Abstract Syntax Tree

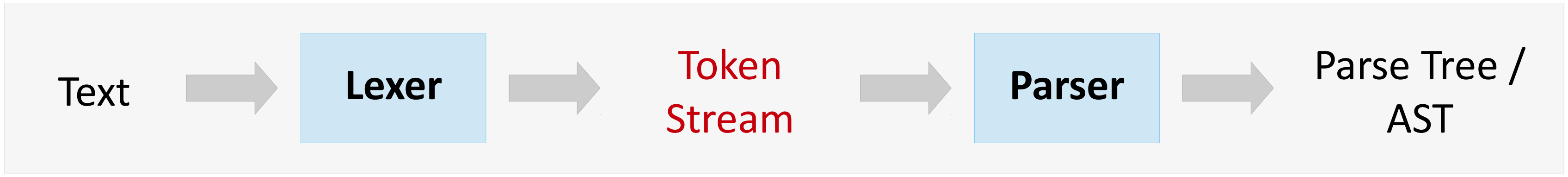
How do we…

- check if a program follows the syntax of Javali?
- extract meaning / structure?

Homework 2


Lexer
Token Stream
Parser
Parse Tree
Javali AST
Part 2a
Part 2b

Lexical Analysis



Lexer

- Read input character by character
- Recognize character groups → tokens

Token

- Sequence of characters with a **collective meaning**
  → grammar terminals
- E.g. constants, identifiers, keywords, …

Lexical Analysis

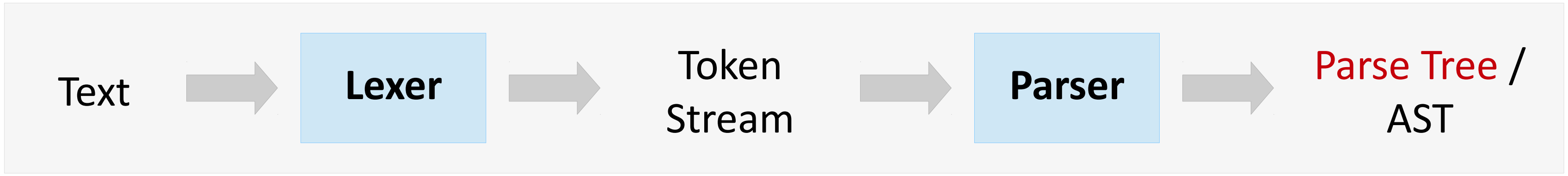
```
class Main {
    void main() {
        write(222);
        writeln();
    }
}
```

```
ID   : [a-zA-Z]+ ;
NUM  : [0-9]+ ;
MISC : [{()};] ;
WS   : ('\n'|' ') → skip ;
```

Token stream:

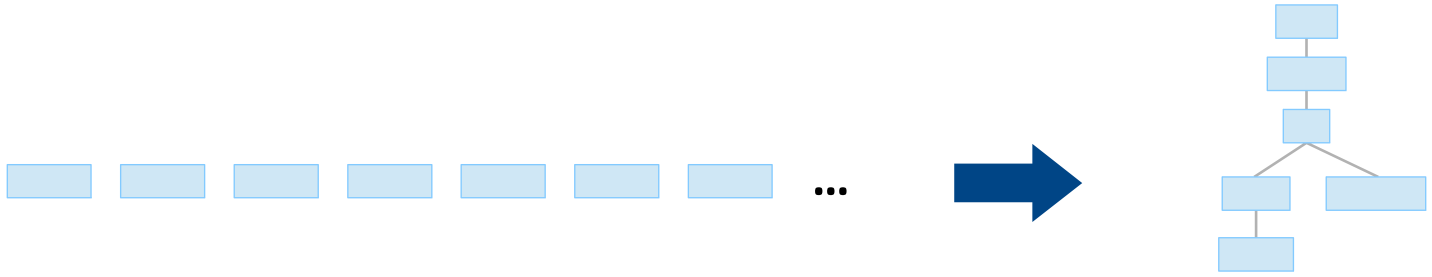
ID: *class* **ID**: *Main* **MISC**: *{* **ID**: *void* **ID**: *main* **MISC**: *(* **MISC**: *)* **…**

Syntactic Analysis



Parser

- **Check** if token stream follows the grammar
- Group tokens hierarchically (**extract structure**)
  → Parse Tree / Abstract Syntax Tree



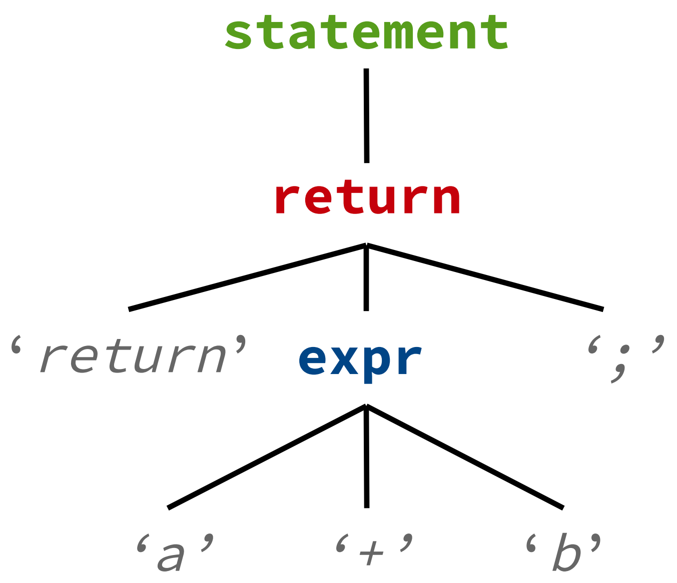
TOP-DOWN PARSER

Top-down parsers

Grammar in Extended Backus-Naur Form (EBNF):

```
statement:
        return
      | assign

return:
     'return' expr ';'

assign:
     ID '=' expr ';'

expr: ID '+' ID
```

return a + b ;



Implementation

Grammar in Extended Backus-Naur Form (EBNF):

```
statement:
      return
    | assign

return:
    ‘return’ expr ‘;’

assign:
    ID ‘=’ expr ‘;’

expr: ID ‘+’ ID
```

```
void statement() {
    return();
    assign();
}

void return() {
    match(‘return’);
    expr();
    match(‘;’);
}

void expr() {
    match(ID);
    match(‘+’);
    match(ID);
}
```

How to deal with alternatives?

Lookahead

Grammar in Extended Backus-Naur Form (EBNF):

```
statement:
        return
     |  assign

return:
     'return' expr ';'

assign:
    ID '=' expr ';'

expr: ID '+' ID
```

```
void statement() {
    if (next() is 'return') {
      return();
    } else if (next() is ID) {
      assign();
    }
}
```

LL(1)

ANTLR

http://www.antlr4.org/

(or HW2 fragment)

ANTLR

Token
specifications
+
Grammar

→ ANTLR →

MyLexer.java
MyParser.java

Top-down parser generator

- ALL(*) adaptive, arbitrary lookahead
- handles any non-left-recursive context-free grammar

ANTLR – Grammar description

Start rule matching end-of-file

Lower-case initial: Parser

Literals → Tokens

Upper-case initial: Lexer

```
/*  This is an example */
grammar Example;

/* Parser rules = Non-terminals */
program :
    statement* EOF ;


statement :
        assignment  ';'
      | expression  ';'
      ;


/* Lexer rules = Terminals */
Identifier : Letter (Letter | Digit)* ;
Letter : '\u0024' | '\u0041'..'\u005a';
```

ANTLR – Operators

Extended Backus-Naur Form (**EBNF**)

```
program :
    statement* EOF;

statement :
    assignment ';'
  | expression ';'
  ;

method :
    type name
        '(' params? ')'
  ;
```

EBNF operators	
`x | y | z`	(ordered) alternative
`x?`	at most once (optional)
`x*`	0 .. n times
`x+`	1 .. n times
`[charset]`	one of the chars, e.g.: `[a-zA-Z]`
`'x'..'y'`	characters in range

$\left.\begin{matrix} \\ \\ \end{matrix}\right\}$ lexer-only

Demo 1

ANTLR – Troubleshooting

ANTLR does not warn about **ambiguous** rules

- resolves ambiguity at runtime
  → requires lots of testing

ANTLR does not handle indirect **left-recursion**

- direct left-recursion supported

ANTLR – Lexer ambiguity

What if some input is matched by multiple lexer rules?

```
parserRule : 'enum' parserRule ;

fragment
Letter : [a-z] ;

Identifier : Letter+ ;
```

document order

creates implicit lexer rule
T123 : *'enum'*

fragment enforces that the rule never produces a token, but can be used in other lexer rules (e.g., *a*)

can never match *enum*, but
e.g., *enums*

Lexer decides based on:

1. rule with the longest match first
2. literal tokens before all regular Lexer rules
3. document order
4. **fragment** rules never match on their own

ANTLR – Parser ambiguity

```
stmt: 'if' expr 'then' stmt 'else' stmt      (1)
    | 'if' expr 'then' stmt                  (2)
    | ID '=' expr ;
```

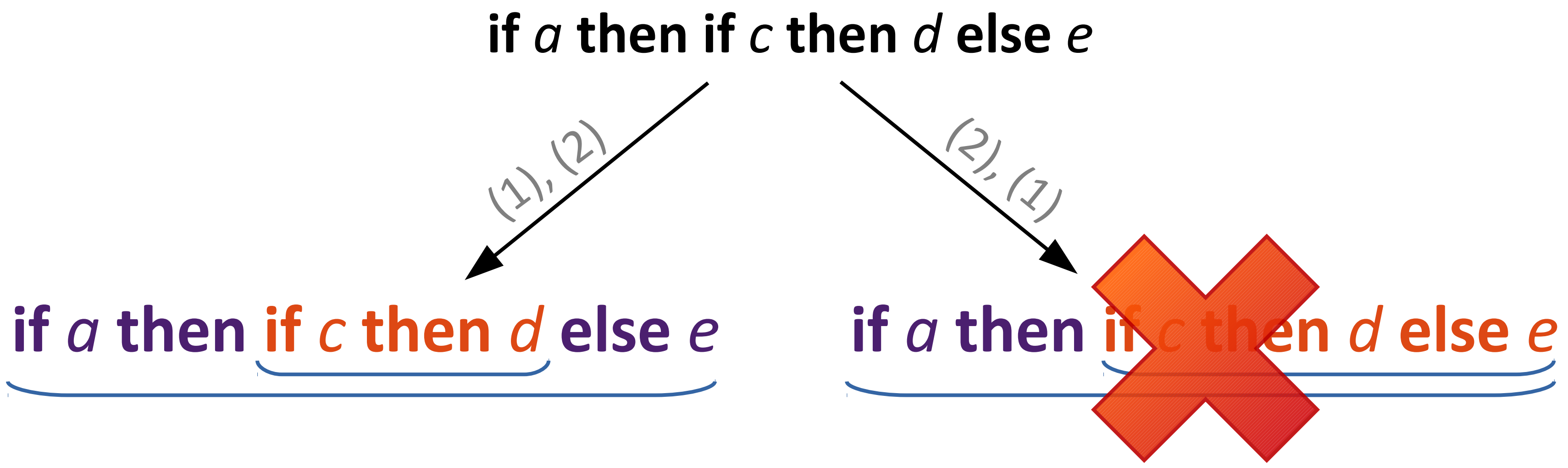
$$\begin{tikzcd}[column sep=small]
 & \textbf{if } a \textbf{ then if } c \textbf{ then } d \textbf{ else } e \arrow[dl, "{(1), (2)}"'] \arrow[dr, "{(2), (1)}"] & \\
\underbrace{\textbf{if } a \textbf{ then } \underbrace{\textbf{if } c \textbf{ then } d} \textbf{ else } e} & & \underbrace{\textbf{if } a \textbf{ then } \underbrace{\textbf{if } c \textbf{ then } d \textbf{ else } e}}
\end{tikzcd}$$

Ambiguous since there exist more than one parse trees for the same input.

ANTLR – Parser ambiguity

```
stmt: 'if' expr 'then' stmt 'else' stmt      (1)
    | 'if' expr 'then' stmt                  (2)
    | ID '=' expr ;
```

At decision points, if more than one alternative match a given input, follow **document order**.


if *a* **then if** *c* **then** *d* **else** *e*
(1), (2)
(2), (1)
if *a* **then if** *c* **then** *d* **else** *e*
if *a* **then if** *c* **then** *d* **else** *e*

ANTLR – Parser ambiguity

```
stmt: 'if' expr 'then' stmt 'else' stmt    (1)
    | 'if' expr 'then' stmt                (2)
    | ID '=' expr ;
```

At decision points, if more than one alternative match a given input, follow **document order**.

Solution

```
stmt: 'if' expr 'then' stmt
    | 'if' expr 'then' stmt 'else' stmt
    | ID '=' expr ;
```

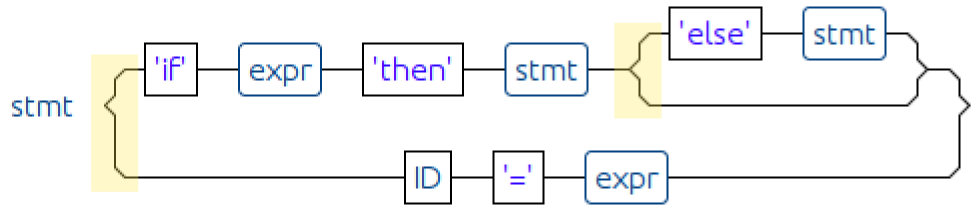
ANTLR – Parser ambiguity

At **decision points**, if more than one alternative match a given input, follow **document order**.

Alternative solution:

```
stmt: 'if' expr 'then' stmt ('else' stmt)?
    | ID '=' expr ;
```

(…)? → (…|)



Sub-rules introduce additional decision points.

ANTLR – Left-recursion

Without: *"a, b, c"*

```
list : LETTER (',' LETTER)*;
```

✓

Direct:

```
list : list ',' LETTER
     | LETTER ;
```

✓

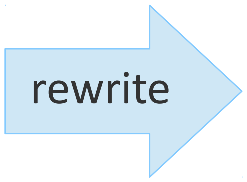
Indirect:

```
list : LETTER
     | longlist ;

longlist : list ',' LETTER;
```

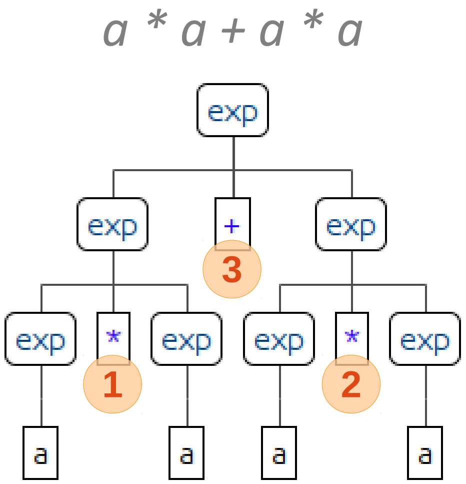
✗

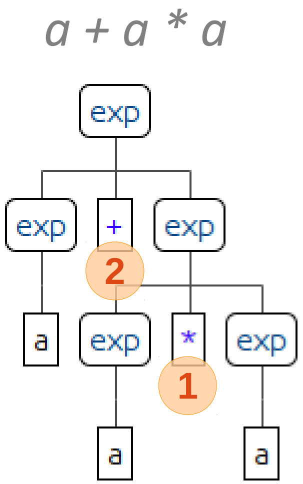
ANTLR – Direct left-recursion

```
exp :  exp  '*'  exp
     |  exp  '+'  exp
     | ID ;
```



A grammar that implicitly assigns **priorities** to alternatives in document order





https://theantlrguy.atlassian.net/wiki/display/ANTLR4/Left-recursive+rules

Demo 2

Homework

$$\begin{tikzcd}
\textbf{Lexer} \arrow[r] & \text{Token Stream} \arrow[r] & \textbf{Parser} \arrow[r] & \text{Parse Tree} \arrow[r] & \text{Javali AST}
\end{tikzcd}$$

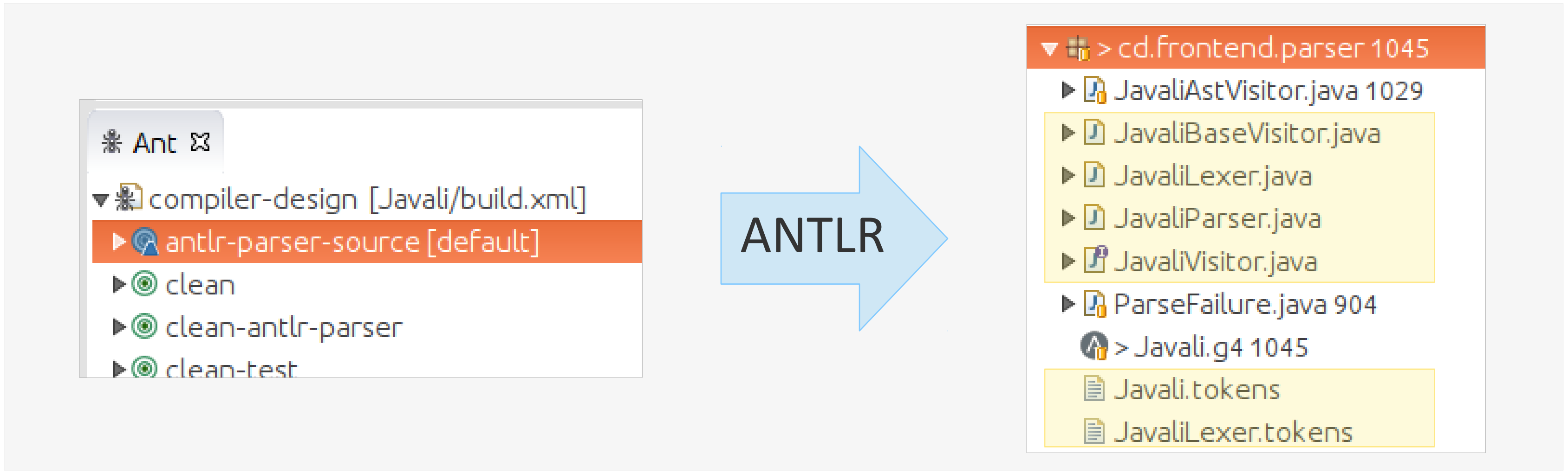
Part 2a

Parser grammar: Javali.g4

Part 2b

JavaliAstVisitor.java

Generated files



Javali***Lexer***/***Parser***.java

- the real thing

Javali(***Base***)***Visitor***.java

- base class for parse-tree visitor

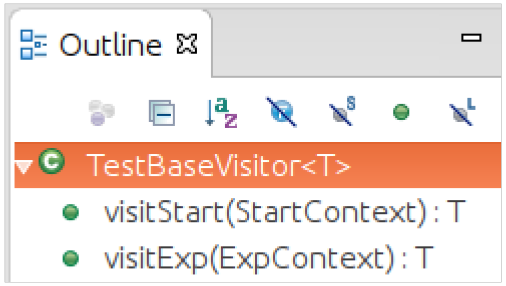
Javali(***Lexer***).tokens

- token → number mapping for debugging

Generated visitor

```
start : exp EOF
      ;

exp : exp '*' exp
    | exp '+' exp
    | ID
    ;
```

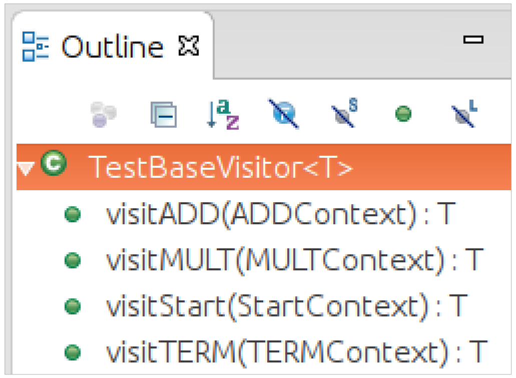
one method
per rule


Outline

TestBaseVisitor<T>
- visitStart(StartContext) : T
- visitExp(ExpContext) : T

```
start : exp EOF
      ;

exp : exp '*' exp # MULT
    | exp '+' exp # ADD
    | ID          # TERM
    ;
```

one method
per label / rule

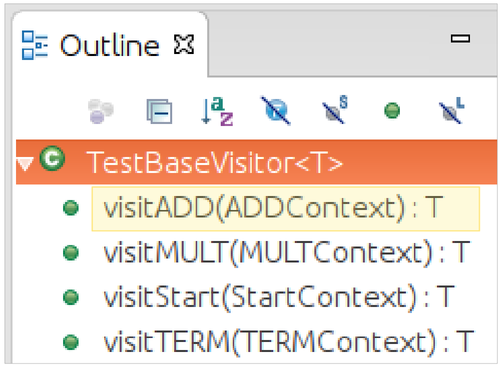

Outline

TestBaseVisitor<T>
- visitADD(ADDContext) : T
- visitMULT(MULTContext) : T
- visitStart(StartContext) : T
- visitTERM(TERMContext) : T

https://theantlrguy.atlassian.net/wiki/display/ANTLR4/Parser+Rules

Constructing the Javali AST

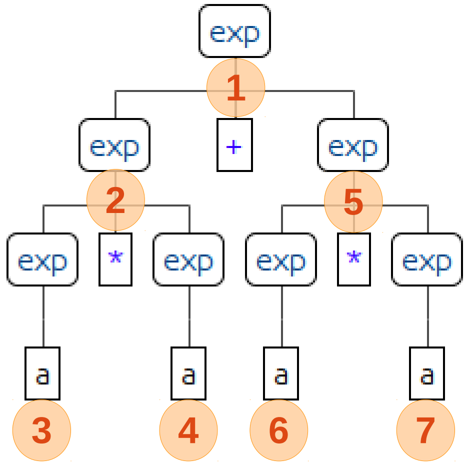
```
start : exp EOF
      ;

exp : exp '*' exp # MULT
    | exp '+' exp # ADD
    | ID          # TERM
    ;
```

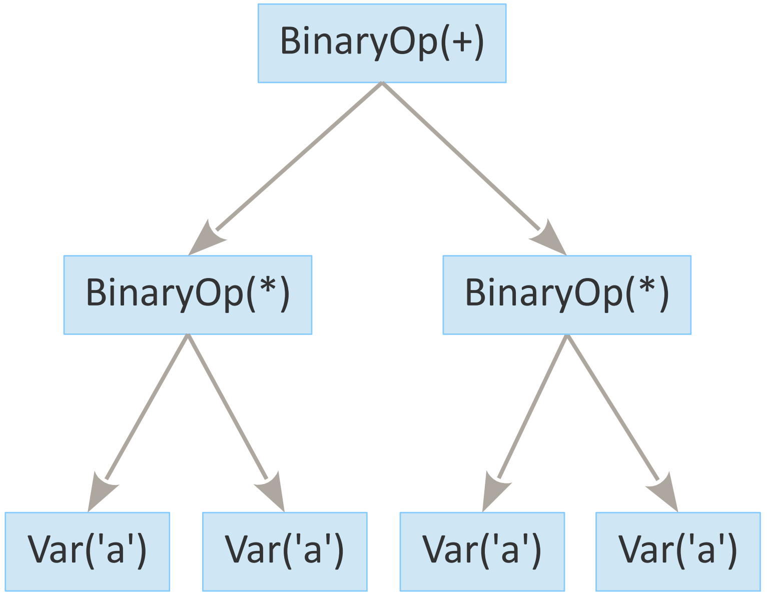


Outline

TestBaseVisitor<T>
- visitADD(ADDContext) : T
- visitMULT(MULTContext) : T
- visitStart(StartContext) : T
- visitTERM(TERMContext) : T

"a * a + a * a"





Demo 3

Notes

- You are not allowed to use **syntactic predicates**.
- Look on our website for more material.
- Due date is **October, 22th**