MULTIVERSEJAVA

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MULTIVERSEJAVA<TEMPORAL>

by

Vishal Sharma

A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Computer Science

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UTAH STATE UNIVERSITY
Logan, Utah
2014
ABSTRACT

MultiverseJava<Temporal>

by

Vishal Sharma, Master of Science
Utah State University, 2014

Major Professor: Dr. Curtis Dyreson
Department: Computer Science

Sequenced semantics, which was first proposed in the context of temporal databases, is the semantics for the evaluation of a program on values annotated with time metadata. The time metadata records when each value is “live” (is valid or has existence). Sequenced semantics stipulates that a computation on values annotated with temporal metadata must be equivalent to, in effect, running the computation at every time point with only the values alive at that time. Sequenced semantics is challenging to program because it is more than just a re-interpretation of the run-time behavior of a program; for instance, a sequenced “if-else” statement may need to evaluate both the “true” and “false” branches, in different time slices of the computation.

This thesis introduces MultiverseJava. MultiverseJava supports sequenced semantics for time stamped values in a Java program. Programmers currently have to resort to ad hoc methods to implement sequenced semantics in Java programs; hence, a better approach is needed. We show how MultiverseJava can be implemented using a MultiverseJava to Java translation. The translation layer weaves support for computing with the timestamped values into a Java program. This thesis describes the MultiverseJava architecture, the layer, semantic templates, and experiments to quantify the cost of MultiverseJava.

(109 pages)
PUBLIC ABSTRACT

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Vishal Sharma

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To my mother and Jasmin...
ACKNOWLEDGMENTS

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Vishal Sharma
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CHAPTER 1
INTRODUCTION

The context of this research is the fertile nexus between programming languages (PLs) and databases (DBs). Historically, PLs have made a tremendous impact on DBs. The application of object-oriented ideas to DBs in the 1990s led to the development of object-oriented and object-relational DBs [1]. The 1990s were also when research in Datalog peaked [2]. Datalog combined logic programming with DBs and greatly advanced query optimization techniques, especially for recursive queries [3]. Currently, concepts from functional PLs are finding a home in the analysis of Big Data using Map/Reduce; Map and Reduce are well-known higher-order functions [4]. First-class support for functional motifs has also contributed to integrating PLs and DB query languages using systems like LINQ [5].

DBs, in contrast, have not had a significant impact on PLs. PLs have been extended in various ways to interface with databases through embedded languages and APIs, and there was a brief flurry of interest in persistent object-oriented languages. But no new PL paradigm or methodology has emerged from DBs, even though many programs manipulate data from DBs. DBs too often have been perceived by the PL community as a black box, where all that is needed in a PL is a way to put data into and extract data from the box.

Previous research in the PL/DB nexus has overlooked one aspect of data that we envision could have an important impact on PLs: metadata. Metadata in a DB context is often simplified to mean the schema or organization of the data [6]. But more broadly, metadata includes data that annotates and extends the meaning of data [7]. It is the broader sense that we will use metadata in this thesis. Many different kinds of metadata exist: temporal, security, privacy, reliability, quality, lineage, and measures of incompleteness (e.g., probability).

When a value is extracted from a DB black box into a PL, it is usually stripped of its metadata, since a PL can only compute with an unannotated value. Consider for instance the following simple
code snippet from a Java program.

```java
... int x;
... if (x < 3) x = 1;
else x = 0;
...
```

After the evaluation of the `if` the value of variable `x` is either 0 or 1 (exclusive, one or the other but not both). But now assume that initially the value of `x` is pulled out of a temporal database and annotated with time metadata such that at time `t_1` it is 2, but at time `t_2` it is 9. When annotated with time metadata, the `if` condition is `true` at time `t_1` and `false` at time `t_2`. (The value is `undefined` or `non-existent` at all times other than `t_1` or `t_2`.) Both branches of the `if` should be evaluated in different time slices, and after evaluation `x` should be both 1 (at time `t_1`) and 0 (at time `t_2`) (and `undefined` at other times).

In this thesis we focus on temporal metadata as an example of how a PL can be changed to provide better support for data with metadata, but more generally our technique is applicable to programming with a diverse panoply of “interesting values” that emerge from databases which store data annotated with metadata.

1.1 Background

1.1.1 The Multiverse\(\langle X\rangle\) Paradigm

In a multiverse programming paradigm a program is evaluated in multiple program universes, where each program universe is described by an intersection of metadata. The multiverse paradigm is novel, and can best be explained by contrasting the multiverse paradigm with the non-multiverse or universe programming paradigm, with which all programmers are familiar since it is how programs are normally evaluated. In the universe paradigm, there is only one program universe, which we will call the default universe. The default universe does not have explicit metadata, instead,
it has implicit metadata and all values have exactly the same metadata. Since all values share the same metadata in the default universe, the metadata can be entirely ignored in program evaluation. For example, suppose that values are annotated with temporal metadata. The temporal metadata describes when each value exists. In the default universe a value always exists, hence, it implicitly is annotated with “all of time.” (Or it could be assumed to exist only at the current time and be annotated with the time now.) The annotation is irrelevant to computation since all the metadata is the same, hence all computation is carried out in a single programming universe. But when values are annotated with different metadata more than one programming universe emerges. For temporal metadata, if two values are annotated with different times, then the metadata describes different program universes. In some universe one or both of the values may not exist.

The multiverse paradigm is parameterized by $X$, which is a list of metadata domains. In general a domain is a set of metadata values and an “intersection” function to compute the metadata common to a set of metadata values. Example domains include temporal, security, and privacy. For a temporal domain a metadata value is a set of times and the intersection function computes temporal intersection. Times can be represented compactly using temporal periods [8], e.g., the set of times from $t_a$ through (including) time $t_e$ can be represented as $[t_a, t_e]$. The temporal overlaps constructor computes the intersection of a set of periods. For a security domain, the metadata would be levels of security in a partial order, and the intersection operation would be least upper bound (LUB).

In this thesis we will focus on a single domain: time. Our goal is to provide better support for programmers of user-defined functions (UDFs) in temporal databases. Hence this thesis is titled MultiverseJava<Temporal>. The next three sections give a background of temporal databases and UDFs.

### 1.1.2 Temporal Databases

A temporal database is a database that provides special support for time. The temporal database community has recognized three primary kinds of time: transaction, valid, and user-defined time [8]. Transaction time is the time at which a fact is “live” in a system usually the time between when it
is created and deleted. *Valid time* is the real-world time of a fact. Both valid and transaction time are kinds of *metadata*, that is, they are data *about* a fact. In contrast, *user-defined time* is a time value within a data structure, i.e., user-defined time is field that happens to be a time value. As an example consider the fact that Joe was born in 1978, is employed at the ACME company from 2010 through 2012, and that this fact was created in the DBMS in 2011. One way to model the fact of Joe’s employment is with a user-defined time for his date of birth (1978), a valid time interval of [2010-2012] representing the real-world time of his employment, and a transaction time interval of [2011-<i>until changed</i>] (since the fact is current and has not yet been deleted, it lives in the database “<i>until changed</i>” [9]).

1.1.3 Sequenced Semantics

Time data can in general be treated as other kinds of data, but time metadata requires special handling. This is because the time metadata modifies the data, restricting its use in some contexts. In particular, a common semantics for time metadata is *sequenced semantics* [10]. Sequenced semantics defines the correctness criteria for the efficient evaluation of temporal programs and prevents, in effect, facts from different slices of a data collection being incorrectly mixed. An example of sequenced semantics is sketched in Figure 1.1. In the figure, a Java program is to be evaluated on a *temporal* relation. A temporal relation is a bag of tuples where each tuple has some number of “Data” attribute values annotated with “Time” (metadata) timestamps. The timestamp records the lifetime of the value in a temporal dimension. For example a *temporal period* [11] timestamp, \([t_b, t_e]\), records that the lifetime is from time \(t_b\) to time \(t_e\) (inclusive). The evaluation of a Java program on a temporal relation obeys sequenced semantics if, logically, it yields the same *result* as slicing the relation at each time point, evaluating each slice using the Java program, and then coalescing or recombining the slices into a single temporal relation with time metadata. As relations can be enormous, the slice-based evaluation strategy is infeasible in practice since a large number of slices (one for every time point) would need to be created and evaluated. Sequenced semantics ensures the correct and efficient processing of temporal relations, without computing each slice individually.
1.1.4 Passing values to Java

It is common for a database query to call a user-defined function (UDF). A user-defined function is an arbitrary piece of Java (or other language) code that is invoked during evaluation of a program. It is invoked for every value in a column, and the result of the function is substituted for the value. UDFs are a common part of database query languages, e.g., they can be invoked from SQL and XQuery queries. The problem is that a temporal value has temporal metadata that is ignored by the UDF, that is, the UDF is not evaluated using sequenced semantics. In this thesis, we show how to rewrite a UDF in Java to obey sequenced semantics.

1.2 What Is MultiverseJava?

MultiverseJava is Java with support for the multiverse programming paradigm. We implement MultiverseJava with a MultiverseJava to Java translator and a library of metadata-sensitive tools. In this section we briefly describe MultiverseJava from a programmer’s perspective.

1.2.1 The @multiverse Annotation

In MultiverseJava, the annotation @multiverse on a language construct (values, expressions or statements) indicates that the construct should be evaluated using the multiverse paradigm. As an example consider two variables x and y in the following code:
...  
@multiverse
int x;
...
int y;
...

The code represents that $x_f i$ is a multiverse int and $y$ is a non-multiverse int variable. Because $x$ is multiverse it can have different values in different multiverses. As shown in Figure 1.2 $x$ has three different values at three different times where data in the shaded box is the value of $x$ and the time for which the value is valid is in brackets. $x$ has value 3 from Jan 14 – Feb 20, 4 from Feb 21 – Apr 1, and 5 from Apr 2 – now. It can also be viewed as a table with a value and time stamp as shown below:

<table>
<thead>
<tr>
<th>Value</th>
<th>timestamp(start, end)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3</td>
<td>(Jan 14, Feb 20)</td>
</tr>
<tr>
<td>4</td>
<td>(Feb 21, Apr 1)</td>
</tr>
<tr>
<td>5</td>
<td>(Apr 2, now)</td>
</tr>
</tbody>
</table>

Figure 1.2 also represents value and metadata of $y$ (which is a non-multiverse integer) in a multiverse environment.
1.2.2 Multiverse Computation

Computation is a process of following an algorithm to produce definite outputs. In this section, we will see how the multiverse way of computing is different from the traditional way of computing. Figure 1.3 depicts the traditional way of computing where the given expressions are given below:

```plaintext
... 
x = y * z; 
... 
```

Notice that $x$ is calculated by multiplying $y$, which is 7, and $z$, which is 4, yielding 28. Figure 1.4 shows the multiverse way of computation. Below is the code representation of Figure 1.4.

```plaintext
... 
@multiverse
int y
@multiverse
int z
@multiverse
x = y * z;
... 
```

Operations on multiverse values are performed on the time they both are “live”. In the above example for calculating the value of $x$ which is the product of $y$ and $z$ we calculate the temporal intersection between $y$ and $z$ and multiply the associated values. In this case Jan 14 - Feb 20 and Apr 2 - now are when $x$ and $y$ intersect. The result is calculated by multiplying the values
from both $y$ and $z$, which is $3 \times 10$ at time Jan 14 - Feb 20 and $5 \times 20$ at time Apr 2 - now. Notice that value 4 from $y$ is omitted in the result since the time associated with it does not intersect with any time from $z$. There is no multiverse in which $y$ with value 4 is alive with a $z$ value.

1.2.3 Multiverse Flow of Control

Traditionally, computation is in a single universe (single execution flow), but computation on values annotated with metadata has multiple flows. Figure 1.5 and Figure 1.6 show the flow of control of an if statement in the universe and multiverse paradigm. Figure 1.5 depicts that control starts from if and executes the condition. If the condition evaluates to true it executes the then branch otherwise it executes else branch. In this case the value of $y$ is assumed to be less than 10 so it executes the else branch only. In a MultiverseJava paradigm, both are potentially executed. As shown in Figure 1.6, in some universe the condition may evaluate to true. For instance if $y$ is 23 from Jun 3 - Apr 5, then the then branch should be executed. But there may be some universe in which the condition evaluates to false and the else branch is executed. Potentially, both the true and false branches are executed.
1.2.4 Promoting a Universe to a Multiverse construct

A universe construct is promoted to a multiverse construct by adding default metadata. Figure 1.7 describes an operation between a non-multiversed int and a multiversed int. In this case the non-multiversed value $z$ is considered to be “all time” and it is multiplied to all of the values of $y$ because each time interval in $y$ will intersect all time of $z$. So the result is multiplication of all values of $y$ with the value of $z$.

1.2.5 Demoting a Multiverse to a Universe construct

A multiverse construct is demoted to a universe construct by stripping its metadata. Figure 1.8 describes an operation between two non-multiversed int and the result is stored in a multiversed int. In this case the non-multiversed values $z$ and $y$ are multiplied. So the result is 30 which is multiplication of 3 and 10. Multiversed int $x$ is converted to a universe construct and assigned the value 30.
Figure 1.7: Computation between Multiverse and Non-Multiverse

Figure 1.8: Degrading Multiverse to non-Multiverse
CHAPTER 2

TEMPLATES FOR JAVA STATEMENTS

The Multiverse paradigm changes the semantics or meaning of each statements. This section gives the denotational semantics for MultiverseJava<Temporal>. After giving the semantics we show how the templates are used with an example.

2.1 Denotational Semantics

Assume that the state, \( T = [T_s, T_r] \), consists of variables

- \( T_s \) - stack of Time variables, and
- \( T_r \) - a (sequenced) variable that holds the return value.

We define the following “macros”.

- \( t_t \) - Time variable on the top of the stack, i.e., \( t_t = T_s.\text{peek}() \)
- \( T \circ t \) - establish \( t \) as the current time variable, i.e., \( T_s.\text{push}(t) \) to start parsing a construct and \( T_s.\text{pop}() \) after parsing.
- \( T \circ \bot \) - establish loop boundary, \( \bot \), when parsing
- \( \varphi(t, X) \) - multiverse:Boolean constructor, e.g. \( \text{new multiverse:Boolean}(t, X) \)

Non-multiverse

\([@\text{nonmultiverse } X](T) \equiv X\]

Note that in the semantics, to reduce clutter, we use the annotation \( @\text{nonmultiverse} \) to switch to a universe programming paradigm, other than the annotation \( @\text{multiverse} \) to turn on the multiverse paradigm. This is syntactic sugar.
Constant
\[ \text{[constant]}(T) \equiv \text{constant} \]

Identifier
\[ \text{[var]}(T) \equiv \text{var} \]

Assignment
\[ \text{[V=E]}(T) \equiv \text{[V]}(T).\text{assign}(t_t, \text{[E]}(T)) \]

Right-associative binary operation
\[ \text{[E_1 \ op \ E_2]}(T) \equiv \text{[E_1]}(T).\text{op}(t_t, \text{[E_2]}(T)) \]

Left-associative binary operation
\[ \text{[E_1 \ op \ E_2]}(T) \equiv \text{[E_2]}(T).\text{op}(t_t, \text{[E_1]}(T)) \]

Unary operation
\[ \text{[\ op \ E]}(T) \equiv \text{[E]}(T).\text{op}(t_t) \]

Ternary (conditional) operation
\[ \text{[ ( C ) ? E_1 : E_2]}(T) \equiv \]
\[ \quad // C \ may \ have \ side \ effects, \ execute \ only \ once \]
\[ \quad // \ Allocate \ variables \ to \ collect \ the \ time \ of \ C \]
\[ \quad \text{private static Time } t_1 = \text{null}; \]
\[ \quad \text{private static Time } t_2 = \text{null}; \]
\[ \quad // \ Build \ a \ function \ to \ store \ the \ true \ and \ false \ times \]
\[ \quad \text{private Boolean } F() \ { \}
\[ \quad \quad \text{TimePair } t_c = \text{\var(t_t, [C](T)).getWhen();} \]
\[ t_1 = t_c . \text{whenTrue}(); \]
\[ t_2 = t_c . \text{whenFalse}(); \]
\[ \text{return true; } \]
\}

// Evaluate alternatives at \textit{true} and \textit{false} times

// \( F \) executed for side effects, expression returns a sequenced type
\[
(F) \circ [E_1](T \circ t_1). \text{temporalUnion}([E_2](T \circ t_2))
\]

(*) Note that \( F, t_1, \) and \( t_2 \) are generated names

\textbf{If}
\[
[\text{if (} C ) S_1 [\text{else } S_2]](T) \equiv
\]
\{

// Capture time of \( C \)
\text{TimePair} t_c = \varphi(t_t, [C](T)) . \text{getWhen}();

// Evaluate true branch at times \( C \) is true
\text{Time} t = Q . \text{whenTrue}();
\text{if (!t.empty()}) [S_1](T \circ t)

// Evaluate false branch at times \( C \) is false
\text{t} = t_c . \text{whenFalse}();
\text{if (!t.empty()}) [S_2](T \circ t)
\}

(*) Note that \( t, \) and \( t_c \) are generated names

\textbf{While}
\[
[\text{while} ( C ) \text{ do } S](T) \equiv
\]
\text{while (true) do } 
\{
\text{TimePair} t_c = [C](T) . \text{getWhen}();
\text{Time} t = t_c . \text{whenTrue}();
if (t.empty()) break;

[S](T □ t)

Break (from loop)

[break](T) ≡

// Remove current time, \( t_t \), from times in loop on stack
// For every \( t_i \) on the stack before the first \( \bot \)
\( t_i \).subtractTime(\( t_t \));

Continue (in loop)

[continue](T) ≡

// Set current time (top of TimeStack) to empty
\( t_t = \) new Time(null);

Return

[return V](T) ≡

// Add to multiversed return value
\( T_r = T_r . merge([V](T)) \);

// Remove current time, \( t_t \), from times in function on stack
// For every \( t_i \) on the stack
\( t_i \).subtractTime(\( t_t \));

GOTO

[GOTO L; ... L: ...](T) ≡

{
    Allocate a variable to accumulate the “GOTO” time
    Time \( t = \) new Time(null);
...  
// Replace GOTO by setting current time to null  
\[t_t = \text{new \ Time(null)};\]  
...  
// Replace L, merge GOTO time with current time  
\[L:\]  
\[t_t . \text{union}(t);\]  
\[t = \text{new \ Time(null)};\]  
...  
}

Try-catch (only partially multiversed)

// Java does not support “resume” exception-handling semantics,  
// exceptions resume after end of block, hence can’t be fully sequenced  
\[[\text{try} \{ S_1 ; \ldots ; S_n \} \ \text{catch} \ E](T) \equiv \]  
\[[\text{try} \{ [S_1](T) \} \ \text{catch} \ E \]  
...  
\[\text{try} \{ [S_n](T) \} \ \text{catch} \ E\]

Sequencing
\[[S_1 ; S_2](T) \equiv \]  
\[[S_1](T);\]  
\[[S_n](T);\]

Do
\[[\text{do} \ S \ \text{while} \ (C)](T) \equiv \]  
\{  
  \[\text{Time} \ t = t_t;\]  
\}
do {
    \([S](T \circ \bot \circ t)\)
    TimePair \(t_c = \llbracket C \rrbracket(T).timePair()\)
    if (\(t_c\).whenTrue().empty()) break;
} while (true);
}

For
\[ \llbracket I \rrbracket(T) \equiv \llbracket I \rrbracket(T) \]
while (true) do {
    TimePair \(t_c = \llbracket C \rrbracket(T).getTime();\)
    Time \(t = t_c\).whenTrue();
    if (\(t\).empty()) break;
    \([S](T \circ \bot \circ t)\)
    \([K](T \circ \bot \circ t)\)
}

For each
\( \llbracket \text{for } (T V : C) \rrbracket(T) \equiv \) \text{multiverse.}\(T V;\)
while (true) do {
    TimePair \(t_c = \varphi(t_c, \llbracket C \rrbracket(T)).getTime();\)
    Time \(t = t_c\).whenTrue();
    if (\(t\).empty()) break;
    \([S](T \circ \bot \circ t)\)
    \([K](T \circ \bot \circ t)\)
}
Method call

\[ \text{[obj.method} (E_1, \ldots, E_n)](T) \equiv \]
\[ \text{obj.method}(t, [E_1](T), \ldots, [E_n](T)) \]

Method def

\[ \text{[modifiers } N (\ldots, Y_i P_i, \ldots) \{ S \}](T) \equiv \]
\[ \text{modifiers } N(\text{Time } t, \ldots, [Y_i P_i](T \circ t), \ldots) \]

Formal param

\[ [Y P](T) \equiv \]
\[ [Y](T) P \]

Type

\[ [Y](T) \equiv \text{multiverse}.Y \]

Class def

\[ \text{[class } N \{ S \}](T) \equiv \]
\[ \text{class } N \text{ extends Multiverse } \{ [S](T) \} \]

Package def

\[ [\text{package } N](T) \equiv \text{package multiverse}.N \]
```java
int test=0;
if (test==1)
{
    test+=10;
}
else
{
    while(test>10)
    {
        test++;
        break;
    }
}
```

Figure 2.1: Example Java code

2.2 Example of template translation

This section depicts usage of denotational semantics with an example. The code given in Figure 2.1 is in the universe programming paradigm. The user adds @multiverse annotations to convert the program to the multiverse paradigm.

Note in Figure 2.3: lines with // are clarifying comments. Comments ( // ) are not part of the actual code translation.
/**
* Input
**/
@multiverse
int test=0;
@multiverse
if (test==1)
{
    test+=10;
}
else
{
    @multiverse
    while(test>10)
    {
        test++;
        @multiverse
        break;
    }
}

Figure 2.2: A programmer annotates the code in Figure 2.1 to use the multiverse programming paradigm
/**
 * Output
 **/
// int test=0;
sequenced.Integer test = new sequenced.Integer(timeMap, 0);

// if (test==1)
TimeMapPair tp21 = (test.equal(allTime, 1).timeMapPair();
TimeMap tTrue22 = tp21.trueTimeMap();
if (tTrue22.notEmpty())
{
    // test+=10;
    test.plusAssign(tTrue22, 10);
}

// else
TimeMap tFalse23 = tp21.falseTimeMap();
if (tFalse23.notEmpty())
{
    // while(test>10)
    while (true)
    {
        TimeMapPair tp24 = (test.greaterThan(tFalse23, 10).timeMapPair();
        TimeMap tTrue25 = tp24.trueTimeMap();
        if (tTrue25.empty())
        {
            break;
        }
        // test++;
        test.increment(tTrue25, 12);
        // break;
        tp21.subtractTime(tTrue25);
        tpAllTime.subtractTime(tTrue25);
    }
}

Figure 2.3: Translation of the code in Figure 2.2 to Java.
CHAPTER 3

ARCHITECTURE OF MUTIVERSEJAVA

This section describes architecture of MultiverseJava and the layer built over the Java parser. It also explains how the Java grammar modifications are performed using ANTLRWorks.

3.1 Multiversed Architecture

The Multiverse architecture is shown in Figure 3.1. A sample program in `program.mvjava` is input to our Multiverse Java translator which converts the program to a Java program and the final output is passed to the Java compiler. The architecture of the translation is shown in Figure 3.1.

- Input code is converted to character stream `CharStream`.
- `CharStream` is passed to `JavaLexer`.
- Result is converted to tokens of `TokenRewriteStream`. `TokenRewriteStream` is used to modify tokens to produce Multiverse Java version.
- `tokens` are passed to Java parser which generates Parser Tree followed by Abstract Syntax Tree. This is the `modification stage` where we use `TokenRewriteStream` to modify the given input.
- Finally we print out the modified code.

Details about the MultiverseJava translator using ANTLRWorks are given in section 3.3.

3.2 Classes Description

Code generation using ANTLRWorks was the first step, the next step is to build classes for multiverse package. This requires each expression to be rewritten and this is the stage where we provide
Temporal support/operation in the code. All the operations will be based on time that annotated a value.

Assuming \( y \) and \( f \) are multiverse integers Figure 3.2 is the list of few operations on \( \text{int} \). The method name written on right are equivalent to the operations used on the left. In the function call \( \text{timeMap} \) is the time variable which represents the time for which this operation will be executed. The evaluation in the methods will be based on \( \text{timeMap} \), by finding the intersection of times from metadata associated with operands and \( \text{timeMap} \). The final piece is the second operand of the expression.
3.3 Parsing with ANTLRWorks

In our approach to modify Java we are using annotations in the input and based on the annotations we modify the source to multiverse code. During translation the code annotations are removed as the abstract syntax tree is built. We perform all the code modifications before the abstract syntax tree is built. To perform this task we use ANTLRWorks 1.5.2 and Java grammer which are open source.

ANTLRWorks is a tool for writing the grammer of a programming languages. The main purpose of ANTLRWorks is to make grammer of programming language more accessible so that it can be improved and easily maintained. ANTLR based Java.g contains the Java grammer which
generates Java parser Tree and modified Java.g is the translating layer over source/input code.

Parsing of source code starts with conversion of source code to character stream. The character stream is passed to the Java lexer which converts the stream to tokens. The TokenRewriteStream is used to store tokens and we perform all the modification required on tokens using the TokenRewriteStream as shown in Figure 3.4. The TokenRewriteStream is a class library present in ANTLRWorks and it is useful in dumping out the input stream after performing some augmentation or manipulations. We can use this to insert, delete, remove, replace, convert to string etc. on input stream. This is very efficient because all operations are lazily performed which makes sure that the data is not moving around all the time. We can also imagine this as insert, delete, modifying a node in a LinkedList, where the data is not moved just the pointers are manipulated. Figure 3.4 represents an operation result = x + ( y * z ) in the universe programming paradigm and its equivalent outcome in the multiverse paradigm. Below code snippet is used to perform actions shown in Figure 3.4

```java
tokens.replace($ASSIGN, ".assign(");
tokens.replace($ADD, ".add(");
tokens.replace($STAR, ".multiply(");
```

Individual operations are converted to their respective method call and the result is given below:

```java
result.assign(..., x.add(..., y.multiply(..., z)));
```

NOTE: “...” represents time variable as explained in previous section.

Rewritten tokens are then passed to the parser. A Java Parser Tree is generated followed by Abstract Syntax tree and then the final code.
result = x + (y * z)

result :=
  +
    result
    x
    *
      y
      z
  
  .add(
    x
    multiply(
      y
      z
    ))

Figure 3.4: ANTLRWorks Java grammar modification
CHAPTER 4

OBJECT-ORIENTED CHALLENGES

This chapter describes several Object Oriented challenges faced during building library for giving support for temporal operations.

1. Number of libraries in Java: Java built-in library is enormous. Building support for all of them is a really challenging task. It will require a lot of code to be rewritten. Moreover it can also degrade the performance.

2. Multiverse Classes and Objects: Currently we have translation layer only for primitive data types (int, byte, long, short, char, boolean, long, float, double) of Java but building support for User-Defined Classes is a challenging task because of OO concepts used in User-Defined classes viz. Polymorphism, Inheritance etc.
CHAPTER 5

CONCLUSION AND FUTURE WORK

This thesis introduces *MultiverseJava*. *MultiverseJava* supports sequenced semantics for timestamped values in a Java program. We show how *MultiverseJava* can be implemented using a *MultiverseJava* to Java translation. The translation layer weaves support for computing with the timestamped values into a Java program. This thesis describes the *MultiverseJava* architecture, the layer, semantic templates, and experiments to quantify the cost of *MultiverseJava*.

Currently we use *time* as metadata. In future, *Security* and *privacy* can be used as metadata. Building a debudding tool to debug code generated using translation can be very helpful. This paradigm can be adapted in other programming languages. Applying multiverse semantics to Javascript will be lot less challenging compared to Java because of duck typing. It will allow us to overcome several object oriented challenges we are currently facing in Java.

Currently we have to define all statements using annotations. In future, using fewer annotations to infer others.
REFERENCES


[8] Curtis Dyreson, Fabio Grandi, Wolfgang Käfer, Nick Kline, Nikos Lorentzos, Yannis Mitsopoulos, Angelo Montanari, Daniel Nonen, Elisa Peressi, Barbara Pernici, John F. Roddick, Nandlal L. Sarda, Maria Rita Scalas, Arie Segev, Richard Thomas Snodgrass, Mike D. Soo,


An ANTLRv3 capable Java 1.5 grammar for building ASTs.

Note that there's also the tree grammar 'JavaTreeParser.g' that can be fed with this grammar's output.

Please report any detected errors or even suggestions regarding this grammar to
dieter [D O T] habelitz [A T] habelitz [D O T] com
with the subject jsom grammar: [your subject note]

To generate a parser based on this grammar you'll need ANTLRv3, which you can get from 'http://www.antlr.org'.

This grammar is published under the ...

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http://www.habelitz.com

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* LIMITED TO, PROCUREMENT OF SUBSTITUTE GOODS OR SERVICES; LOSS OF USE,
DATA,
* OR PROFITS; OR BUSINESS INTERRUPTION) HOWEVER CAUSED AND ON ANY
THEORY OF
* LIABILITY, WHETHER IN CONTRACT, STRICT LIABILITY, OR TORT (INCLUDING
* NEGLIGENCE OR OTHERWISE) ARISING IN ANY WAY OUT OF THE USE OF THIS
SOFTWARE,
* EVEN IF ADVISED OF THE POSSIBILITY OF SUCH DAMAGE.
*
*/

grammar Java;

options {
  backtrack = true;
  memoize = true;
  output = AST;
  ASTLabelType = CommonTree;
}

tokens {
  // operators and other special chars
  AND = '&';
AND_ASSIGN = '&&=' ;
ASSIGN = '=' ;
AT = '@' ;
BIT_SHIFT_RIGHT = '>>>' ;
BIT_SHIFT_RIGHT_ASSIGN = '>>>>=' ;
COLON = ':' ;
COMMA = ',' ;
DEC = '−−' ;
DIV = '/' ;
DIV.Assign = '/=' ;
DOT = '.' ;
DOTSTAR = '.*' ;
ELLIPSIS = '... ' ;
EQUAL = '== ' ;
GREATER_OR_EQUAL = '>= ' ;
GREATER_THAN = '>' ;
INC = '++ ' ;
LBRACK = '[' ;
LCURLY = '{' ;
LESS_OR_EQUAL = '<= ' ;
LESS_THAN = '< ' ;
LOGICAL_AND = '&&' ;
LOGICAL_NOT = '!' ;
LOGICAL_OR = '|| ' ;
LPAREN = '(' ;
MINUS = '−' ;
MINUS_ASSIGN = '−=' ;
MOD = '%' ;
MOD_ASSIGN = '%=' ;
NOT = '˜ ' ;
NOT_EQUAL = '!= ' ;
OR = '|' ;
OR_ASSIGN = '|=' ;
PLUS = '+' ;
PLUS_ASSIGN = '+=' ;
QUESTION = '?' ;
RBRACK = ']' ;
RCURLY = '}' ;
RPAREN = ')' ;
SEMI = ';' ;
SHIFT_LEFT = '<<' ;
SHIFT_LEFT_ASSIGN = '<<=' ;
SHIFT_RIGHT = '>>' ;
SHIFT_RIGHT_ASSIGN = '>>=' ;
<table>
<thead>
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<th>Keyword</th>
<th>Value</th>
</tr>
</thead>
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</tr>
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<td>ASSERT</td>
<td>'assert'</td>
</tr>
<tr>
<td>BOOLEAN</td>
<td>'boolean'</td>
</tr>
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<td>'break'</td>
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<td>'byte'</td>
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<td>'case'</td>
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<td>'continue'</td>
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</tr>
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<td>'do'</td>
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<td>'double'</td>
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<td>'native'</td>
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<td>NULL</td>
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<td>'private'</td>
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<td>PROTECTED</td>
<td>'protected'</td>
</tr>
<tr>
<td>PUBLIC</td>
<td>'public'</td>
</tr>
<tr>
<td>RETURN</td>
<td>'return'</td>
</tr>
<tr>
<td>SHORT</td>
<td>'short'</td>
</tr>
</tbody>
</table>
161 STATIC = 'static';
162 STRICTFP = 'strictfp';
163 SUPER = 'super';
164 SWITCH = 'switch';
165 SYNCHRONIZED = 'synchronized';
166 THIS = 'this';
167 THROW = 'throw';
168 THROWS = 'throws';
169 TRANSIENT = 'transient';
170 TRUE = 'true';
171 TRY = 'try';
172 VOID = 'void';
173 VOLATILE = 'volatile';
174 WHILE = 'while';
175
176 // tokens for imaginary nodes
177
178 ANNOTATION_INIT_ARRAY_ELEMENT;
179 ANNOTATION_INIT_BLOCK;
180 ANNOTATION_INIT_DEFAULT_KEY;
181 ANNOTATION_INIT_KEY_LIST;
182 ANNOTATION_LIST;
183 ANNOTATION_METHOD_DECL;
184 ANNOTATION_SCOPE;
185 ANNOTATION_TOP_LEVEL_SCOPE;
186 ARGUMENT_LIST;
187 ARRAY_DECLARATOR;
188 ARRAY_DECLARATOR_LIST;
189 ARRAY_ELEMENT_ACCESS;
190 ARRAY_INITIALIZER;
191 BLOCK_SCOPE;
192 CAST_EXPR;
193 CATCH_CLAUSE_LIST;
194 CLASS_CONSTRUCTOR_CALL;
195 CLASS_INSTANCE_INITIALIZER;
196 CLASS_STATIC_INITIALIZER;
197 CLASS_TOP_LEVEL_SCOPE;
198 CONSTRUCTOR_DECL;
199 ENUM_TOP_LEVEL_SCOPE;
200 EXPRESSION;
201 EXTENDS_BOUND_LIST;
202 EXTENDS_CLAUSE;
203 FORCONDITION;
204 FOREACH;
FOR_INIT;
FOR_UPDATE;
FORMAL_PARAM_LIST;
FORMAL_PARAM_STD_DECL;
FORMAL_PARAM_VARARGS_DECL;
FUNCTION_METHOD_DECL;
GENERIC_TYPE_ARG_LIST;
GENERIC_TYPE_PARAM_LIST;
INTERFACE_TOP_LEVEL_SCOPE;
IMPLEMENTS_CLAUSE;
LABELED_STATEMENT;
LOCAL_MODIFIER_LIST;
JAVA_SOURCE;
METHOD_CALL;
MODIFIER_LIST;
PARENTESIZED_EXPR;
POST_DEC;
POST_INC;
PRE_DEC;
PRE_INC;
QUALIFIED_TYPE_IDENT;
STATIC_ARRAY_CREATOR;
SUPER_CONSTRUCTOR_CALL;
SWITCH_BLOCK_LABEL_LIST;
THIS_CONSTRUCTOR_CALL;
THROWS_CLAUSE;
TYPE;
UNARY_MINUS;
UNARY_PLUS;
VAR_DECLARATION;
VAR_DECLARATOR;
VAR_DECLARATOR_LIST;
VOID_METHOD_DECL;

@header {
   package sequencedjava.grammar;
}

@members {
   private boolean mMessageCollectionEnabled = false;
   private boolean mHasErrors = false;
}
```java
private List<String> mMessages;

TokenRewriteStream tokens;

Boolean isSequence = false;
Boolean temp = false;
String ident = "";
Boolean forStart = false;
Boolean forBlock = false;
String relationalOperator = "";
SymbolTable st = new SymbolTable();
String opr = "";
Boolean doIt;
String doDont = "";

public void setTokenStream(TokenRewriteStream input) {
    // super.setTreeNodeStream(input);
    tokens = input;
}

Stack<String> timeMapStack = new Stack<String>();
Stack<String> timeMapPairStack = new Stack<String>();
TimeMap allTime = new TimeMap();
Boolean sequencedIf = false;
Boolean ifSeqStatement = false;
String ifcondition = "";
int count = 0;
Boolean sequencedElse = false;
Boolean seqIf = false;

String forcondition = "";
Boolean whileBlock = false;
Boolean doWhile = false;
Boolean doPara = false;
Boolean switchCase = false;
Stack<String> cases = new Stack<String>();
    Stack<String> statements = new Stack<String>();
    Boolean isBreak = false;
    Boolean leftCurly = false;
    Boolean rightCurly = false;
    Boolean breakTrue = false;
    Boolean methodBlock = false;
```
Iterator x;
String returnType = "void";
Boolean sequencedReturn = false;
Boolean methodCall = false;
// variable for operation identification

final int and = 1;
final int and_assign = 2;
final int assign = 3;
final int bit_shift_right = 4;
final int bit_shift_right_assign = 5;
final int dec = 6;
final int div = 7;
final int div_assign = 8;
final int equal = 9;
final int greater_or_equal = 10;
final int greater_than = 11;
final int inc = 12;
final int less_or_equal = 13;
final int less_than = 14;
final int logical_and = 15;
final int logical_not = 16;
final int logical_or = 17;
final int minus = 18;
final int minus_assign = 19;
final int mod = 20;
final int mod_assign = 21;
final int not = 22;
final int not_equal = 23;
final int or = 24;
final int or_assign = 25;
final int plus = 26;
final int plus_assign = 27;
final int shift_left = 28;
final int shift_left_assign = 29;
final int shift_right = 30;
final int shift_right_assign = 31;
final int star = 32;
final int star_assign = 33;
final int xor = 34;
final int xor_assign = 35;

/**
* Switches error message collection on or off.
* The standard destination for parser error messages is <code>System.err</code>.
* However, if <code>true</code> gets passed to this method this default
* behaviour will be switched off and all error messages will be collected
* instead of written to anywhere.
* The default value is <code>false</code>.
* @param pNewState <code>true</code> if error messages should be collected.
 */

public void enableErrorMessageCollection(boolean pNewState) {
    mMessageCollectionEnabled = pNewState;
    if (mMessages == null && mMessageCollectionEnabled) {
        mMessages = new ArrayList<String>();
    }
}

/**
 * Collects an error message or passes the error message to <code>
 * super.emitErrorMessage(...) </code>.
 * The actual behaviour depends on whether collecting error
 * messages has been enabled or not.
 * @param pMessage The error message.
 */

@Override
public void emitErrorMessage(String pMessage) {
    if (mMessageCollectionEnabled) {
        mMessages.add(pMessage);
    } else {
        super.emitErrorMessage(pMessage);
    }
}

/**
 * Returns collected error messages.
 */
40

* @return A list holding collected error messages or `<code>null</code>` if collecting error messages hasn't been enabled. Of course, this list may be empty if no error message has been emitted.

*/

public List<String> getMessages() {
    return mMessages;
}

/**
* Tells if parsing a Java source has caused any error messages.
* @return `<code>true</code>` if parsing a Java source has caused at least one error message.
*/

public boolean hasErrors() {
    return mHasErrors;
}

@lexer::header {
    package sequencedjava.grammar;
}

@lexer::members {
    /**
     * Determines if whitespaces and comments should be preserved or thrown away.
     * If `<code>true</code>` whitespaces and comments will be preserved within the hidden channel, otherwise the appropriate tokens will be skipped. This is a 'little bit' expensive, of course. If only one of the two behaviours is needed forever the lexer part of the grammar should be changed by replacing the 'if–else' stuff within the appropriate lexer grammar actions.
     */
    public boolean preserveWhitespacesAndComments = true;
}

/*
@rulecatch
{
  catch (RecognitionException re) { throw re; }
}

// Starting point for parsing a Java file.
javaSource : compilationUnit
  -> "(JAVA_SOURCE compilationUnit)
  ;
compilationUnit :
  {
    st.enterScope();
    timeMapStack.push("allTime");
    timeMapPairStack.push("tpAllTime");
  }
annotationList
packageDeclaration?
importDeclaration*
typeDeclsl*
  {
    // System.out.println("last timeMapStack "+timeMapStack.peek());
    // System.out.println("last timeMapPairStack "+timeMapPairStack.peek());
    timeMapPairStack.pop();
    timeMapStack.pop();
    st.exitScope();
  }

;
typeDeclaration
  : modifierList!
    ( classTypeDeclaration [ $modifierList . tree ]
      | interfaceTypeDeclaration [ $modifierList . tree ]
      | enumTypeDeclaration [ $modifierList . tree ]
      | annotationTypeDeclaration [ $modifierList . tree ]
    )
  ;

classTypeDeclaration [ CommonTree modifiers ]
  : CLASS IDENT genericTypeParameterList? classExtendsClause?
    implementsClause? classBody
      -> "(CLASS { $modifiers } IDENT genericTypeParameterList?
        classExtendsClause? implementsClause? classBody)"
  ;

classExtendsClause
  : EXTENDS type
    -> "(EXTENDS_CLAUSE[$EXTENDS, "EXTENDS_CLAUSE"] type)
  ;

interfaceExtendsClause
  : EXTENDS typeList
    -> "(EXTENDS_CLAUSE[$EXTENDS, "EXTENDS_CLAUSE"] typeList)
  ;

implementsClause
  : IMPLEMENTS typeList
    -> "(IMPLEMENTES_CLAUSE[$IMPLEMENTES, "IMPLEMENTES_CLAUSE"]
      typeList)
  ;

genericTypeParameterList
  : LESS_THAN genericTypeParameter (COMMA genericTypeParameter)*
    genericTypeListClosing
      -> "(GENERIC_TYPE_PARAM_LIST[$LESS_THAN, "GENERIC_TYPE_PARAM_LIST"]
        genericTypeParameter+)
  ;
genericTypeListClosing  // This 'trick' is fairly dirty — if there's some
time a better solution should
   // be found to resolve the problem with nested
generic type parameter lists
   // (i.e. <T1 extends AnyType<T2>> for generic
type parameters or <T1<T2>> for
generic type arguments etc).
   :
   | GREATER_THAN
   | SHIFT_RIGHT
   | BIT_SHIFT_RIGHT
   | // nothing
   :
genericTypeParameter
   :
   INT bound?
   -> "(IDENT bound?)
   :
   bound
   :
   EXTENDS type (AND type)*
   -> "([EXTENDS_BOUND_LIST[$EXTENDS, "EXTENDS_BOUND_LIST"] type+)
   :
enumTypeDeclaration[CommonTree modifiers]
   :
   ENUM IDENT implementsClause? enumBody
   -> "([ENUM {$modifiers} IDENT implementsClause? enumBody)
   :
enumBody
   :
   SLCURLY {st.enterScope();} enumScopeDeclarations {st.exitScope();}
   CRCURLY
   -> "([ENUM.TOP_LEVEL_SCOPE[$SLCURLY, "ENUM.TOP_LEVEL_SCOPE"]
   enumScopeDeclarations)
   :
enumScopeDeclarations
   :
enumConstants (COMMA!)? enumClassScopeDeclarations?
   :
enumClassScopeDeclarations
   :
   SEMI classScopeDeclarations
   -> "([CLASS.TOP_LEVEL_SCOPE[$SEMI, "CLASS.TOP_LEVEL_SCOPE"]
   classScopeDeclarations*)
   ;
enumConstants
    : enumConstant (COMMA! enumConstant)+
    ;

enumConstant
    : annotationList IDENT^ arguments? classBody?
    ;

interfaceTypeDeclaration [CommonTree modifiers]
    : INTERFACE IDENT genericTypeParameterList? interfaceExtendsClause
        ? interfaceBody
    "(INTERFACE \{$modifiers\} IDENT genericTypeParameterList? interfaceExtendsClause? interfaceBody)"
    ;

typeList
    : type (COMMA! type)*
    ;

classBody
    : LCURLY {st.enterScope();} classScopeDeclarations* {st.exitScope ();}RCURLY
    "(CLASS_TOP_LEVEL_SCOPE[SLCURYL, "CLASS_TOP_LEVEL_SCOPE"]
        classScopeDeclarations *)"
    ;

interfaceBody
    : LCURLY {st.enterScope();} interfaceScopeDeclarations* {st.
        exitScope ();}RCURLY
    "(INTERFACE_TOP_LEVEL_SCOPE[SLCURYL, "CLASS_TOP_LEVEL_SCOPE"
        ] interfaceScopeDeclarations *)"
    ;

classScopeDeclarations
    : block -> "(CLASS_INSTANCE_INITIALIZER block)
        | STATIC block -> "(CLASS_STATIC_INITIALIZER[SSTATIC, "
            CLASS_STATIC_INITIALIZER"] block)
        | modifierList
            ( genericTypeParameterList?
                ( q=type {if(isSequence) returnType=$q.text;} IDENT
                    formalParameterList arrayDeclaratorList? throwsClause? (block | SEI)"
interfaceScopeDeclarations

: modifierList

| ( genericTypeParameterList?

  | ( type IDENT formalParameterList arrayDeclaratorList? 

    throwsClause? SEMI

    -> "(FUNCTION_METHOD_DECL modifierList 

       genericTypeParameterList? type IDENT 

       formalParameterList arrayDeclaratorList? 

       throwsClause? block)"

  | VOID IDENT formalParameterList throwsClause? (block | 

    SEMI)

  | "(VOID_METHOD_DECL modifierList 

     genericTypeParameterList? IDENT formalParameterList 

     throwsClause? block)"

  | id=IDENT formalParameterList throwsClause? block

  | "(CONSTRUCTOR DECL[ $id , "CONSTRUCTOR DECL"] 

     modifierList genericTypeParameterList? 

     formalParameterList throwsClause? block)"

  )

| type classFieldDeclaratorList SEMI

| (VAR_DECLARATION modifierList type 

   classFieldDeclaratorList)

| type declaration

| SEMI!

| ;

| ;
classFieldDeclaratorList
: q=classFieldDeclarator (COMMA classFieldDeclarator)∗
→ "(VAR_DECLARATOR_LIST classFieldDeclarator+)
;

classFieldDeclarator
: variableDeclaratorId (ASSIGN variableInitializer)?
→ "(VAR_DECLARATOR variableDeclaratorId variableInitializer?)
;

interfaceFieldDeclaratorList
: interfaceFieldDeclarator (COMMA interfaceFieldDeclarator)∗
→ "(VAR_DECLARATOR_LIST interfaceFieldDeclarator+)
;

interfaceFieldDeclarator
: variableDeclaratorId ASSIGN variableInitializer
→ "(VAR_DECLARATOR variableDeclaratorId variableInitializer)
;

variableDeclaratorId
: q=IDENT" { 
  if(isSequence)
  {
    st.addId($q.text,true);
    isSequence = false;
  }

  }  
else
  {
    st.addId($q.text,false);
  }
} arrayDeclaratorList?
;

variableInitializer
: arrayInitializer
  | expression
  ;

arrayDeclarator
: LBRACK RBRACK
→ "(ARRAY DECLARATOR)
;
arrayDeclaraorList
: arrayDeclarator+
-> "(ARRAY_DECLARATOR_LIST arrayDeclarator+)"
;

arrayInitializer
: LCURLY variableInitializer (COMMA variableInitializer)* COMMA?
? RCURLY
-> "(ARRAY_INITIALIZER [SL CURLY, "ARRAY_INITIALIZER"]
  variableInitializer*)"
;

throwsClause
: THROWS qualifiedIdentList
-> "(THROWS_CLAUSE [STHROWS, "THROWS_CLAUSE"]
  qualifiedIdentList )"
;

modifierList
: modifier*
-> "(MODIFIER_LIST modifier*)"
;

modifier
: PUBLIC
| PROTECTED
| PRIVATE
| STATIC
| ABSTRACT
| NATIVE
| SYNCHRONIZED
| TRANSIENT
| VOLATILE
| STRICTFP
| localModifier
;

localModifierList
: localModifier*
-> "(LOCAL_MODIFIER_LIST localModifier*)"
;

localModifier

type
  : simpleType
  | objectType
  ;

simpleType // including static arrays of simple type elements
  : primitiveType arrayDeclaratorList?
    -> "(TYPE primitiveType arrayDeclaratorList?)"
  ;

objectType // including static arrays of object type reference elements
  : qualifiedTypeIdent arrayDeclaratorList?
    -> "(TYPE qualifiedTypeIdent arrayDeclaratorList?)"
  ;

objectTypeSimplified
  : qualifiedTypeIdentSimplified arrayDeclaratorList?
    -> "(TYPE qualifiedTypeIdentSimplified arrayDeclaratorList?)"
  ;

qualifiedTypeIdent
  : typeIdent (DOT typeIdent)*
    -> "(QUALIFIED_TYPE_IDENT typeIdent+)
  ;

qualifiedTypeIdentSimplified
  : typeIdentSimplified (DOT typeIdentSimplified)*
    -> "(QUALIFIED_TYPE_IDENT typeIdentSimplified+)
  ;

typeIdent
  : IDENT^
    {
      if (isSequence)
        {
            tokens.replace(SIDENT, "sequenced."+SIDENT.text);
            isSequence = false;
            ident = "sequenced."+SIDENT.text;
        }
    }
  ;
genericTypeArgumentList?

; typIdentSimplified

: IDENT* genericTypeArgumentListSimplified?

;

primitiveType

: BOOLEAN

{

    if (isSequence)

    {

        tokens.replace($BOOLEAN, "sequenced.Boolean");

        ident = "sequenced.Boolean";

    }

}

|

CHAR

{

    if (isSequence)

    {

        tokens.replace($CHAR, "sequenced.Char");

        ident = "sequenced.Char";

    }

}

|

BYTE

{

    if (isSequence)

    {

        tokens.replace($BYTE, "sequenced.Byte");

        ident = "sequenced.Byte";

    }

}

|

SHORT

{

    if (isSequence)

    {

        tokens.replace($SHORT, "sequenced.Short");

        ident = "sequenced.Short";

    }

}

|

INT

{

    if (isSequence)

    {

        tokens.replace($INT, "sequenced.Integer");

    }
ident = "sequenced.Integer";
}

| LONG
{
    if (isSequence)
    {
        tokens.replace($LONG, "sequenced.Long");
        ident = "sequenced.Long";
    }
    }

| FLOAT
{
    if (isSequence)
    {
        tokens.replace($FLOAT, "sequenced.Float");
        ident = "sequenced.Float";
    }
    }

| DOUBLE
{
    if (isSequence)
    {
        tokens.replace($DOUBLE, "sequenced.Double");
        ident = "sequenced.Double";
    }
    }

;
(EXTENDS | SUPER)^ type

genericTypeArgumentListSimplified

genericTypeArgumentSimplified

LESS_THAN genericTypeArgumentSimplified (COMMA
genericTypeArgumentSimplified)* genericTypeListClosing

"(GENERIC_TYPE_ARG_LIST [LESS_THAN, "GENERIC_TYPE_ARG_LIST"]
genericTypeArgumentSimplified+)

type

| QUESTION

qualifiedIdentList

qualifiedIdentifier (COMMA! qualifiedIdentifier)*

LPAREN

if (isSequence)
{
    tokens.insertAfter(SLPAREN, "TimeMap timeMap.");
    isSequence = false;
    methodBlock = true;
}

// Contains at least one standard argument declaration and
optionally a variable argument declaration.

formalParameterStandardDecl (COMMA
    formalParameterStandardDecl)* (COMMA
    formalParameterVarArgDecl)?

"(FORMAL_PARAM_LIST [SLPAREN, "FORMAL_PARAM_LIST"]
    formalParameterStandardDecl+ formalParameterVarArgDecl?)

// Contains a variable argument declaration only.

| formalParameterVarArgDecl

"(FORMAL_PARAM_LIST [SLPAREN, "FORMAL_PARAM_LIST"]
    formalParameterVarArgDecl)

// Contains nothing.

| "(FORMAL_PARAM_LIST [SLPAREN, "FORMAL_PARAM_LIST"])

)}
formalParameterStandardDecl
  : localModifierList type variableDeclaratorId
  \rightarrow "(FORMAL_PARAM_STD_DECL localModifierList type
  variableDeclaratorId)
  ;

formalParameterVarArgDecl
  : localModifierList type ELLIPSIS variableDeclaratorId
  \rightarrow "(FORMAL_PARAM_VARARGDECL localModifierList type
  variableDeclaratorId)
  ;

qualifiedIdentifier
  : ( i=IDENT { 
    if (isSequence)
    {
      st.addId($i.text, true);
      //isSequence=false;
    }
    else
    {
      st.addId($i.text, false);
    }
  } \rightarrow IDENT
  )
  ( DOT ident=IDENT \rightarrow "(DOT $qualifiedIdentifier $ident)
  )*
  ;

// ANNOTATIONS

annotationList
  : annotation*
  \rightarrow "(ANNOTATION_LIST annotation*)
  ;

annotation
  : AT" q=qualifiedIdentifier z=annotationInit?
  {
    //System.out.println("IN ");
    if ($q.text.equals("Sequence"))
```java
{ 
  isSequence = true;
  temp = true;
  // System.out.println("IN ");
  if ($z.text != null)
    tokens.replace($AT.getTokenIndex(),
                  $z.stop.getTokenIndex(), ",");
  else
    tokens.replace($AT.getTokenIndex(),
                  $q.stop.getTokenIndex(), ",");

  // System.out.println("OUT ");
}

;   
annotationInit
  :  LPAREN annotationInitializers RPAREN 
     -> "(ANNOTATION_INIT_BLOCK[SLPAREN, "ANNOTATION_INIT_BLOCK"]
                      annotationInitializers)
     ;

annotationInitializers
  :  annotationInitializer (COMMA annotationInitializer)*
     -> "(ANNOTATION_INIT_KEY_LIST annotationInitializer+)
     | annotationElementValue // implicit initialization of the
                       annotation field 'value'
     -> "(ANNOTATION_INIT_DEFAULT_KEY annotationElementValue)
     ;

annotationInitializer
  :  IDENT^ ASSIGN! annotationElementValue
     ;

annotationElementValue
  :  annotationElementValueExpression
     | annotation
     | annotationElementValueArrayInitializer
     ;

annotationElementValueExpression
  :  conditionalExpression
     -> "(EXPR conditionalExpression)"
     ;
```
annotationElementValueArrayInitializer
    :   LCURLY (annotationElementValue (COMMA annotationElementValue)*)?
        (COMMA)? RCURLY
    -> "(ANNOTATION_INIT_ARRAY_ELEMENT[$LCURLY, "ANNOTATION_ELEM_VALUE_ARRAY_INIT"]
        annotationElementValue*)"
    ;

annotationTypeDeclaration[CommonTree modifiers]
    :   AT INTERFACE IDENT annotationBody
    -> "(AT {$modifiers} IDENT annotationBody)
    ;

annotationBody
    :   LCURLY annotationScopeDeclarations* RCURLY
    -> "(ANNOTATION_TOP_LEVEL_SCOPE[$LCURLY, "CLASS_TOP_LEVEL_SCOPE"
        ] annotationScopeDeclarations*)"
    ;

annotationScopeDeclarations
    :   modifierList type
        ( IDENT LPAREN RPAREN annotationDefaultValue? SEMI
    -> "(ANNOTATION_METHOD_DECL modifierList type IDENT
        annotationDefaultValue?)
    |   classFieldDeclaratorList SEMI
    -> "(VAR_DECLARATION modifierList type
        classFieldDeclaratorList)
    )
    |   typeDeclaration
    ;

annotationDefaultValue
    :   DEFAULT annotationElementValue
    ;

// STATEMENTS / BLOCKS

block
    :   LCURLY
        {
            st.enterScope();
            if(leftCurly)
            {

tokens.replace($LCURLY,"";}

// code to insert for Sequenced for Loop
if (forBlock)
{
timeMapPairStack.push("tp"+count);
count++;
timeMapStack.push("tTrue"+count);
count++;

tokens.insertAfter($LCURLY,\"n \t i f ("+timeMapStack.peek()+".empty()) break;\")
tokens.insertAfter($LCURLY,\"n \t TimeMap "+timeMapStack.peek()
+" = "+timeMapPairStack.peek()+".trueTimeMap();\")
tokens.insertAfter($LCURLY,\"n \t TimeMapPair "+
timeMapPairStack.peek()+" = "+forcondition+.timeMapPair();\")
forBlock = false;
}

// code to insert in sequenced while block
if (whileBlock)
{
timeMapPairStack.push("tp"+count);
count++;
timeMapStack.push("tTrue"+count);
count++;

tokens.insertAfter($LCURLY,\"n \t i f ("+timeMapStack.peek()+".empty()) break;\")
tokens.insertAfter($LCURLY,\"n \t TimeMap "+timeMapStack.peek()
+" = "+timeMapPairStack.peek()+".trueTimeMap();\")
tokens.insertAfter($LCURLY,\"n \t TimeMapPair "+
timeMapPairStack.peek()+" = "+forcondition+.timeMapPair();\")
//whileBlock = false;
}

if (methodBlock & & !("void".equals(returnType)))
{
tokens.insertAfter($LCURLY,\"n"+returnType+" ret1 = new "+
returnType+"("+timeMapPairStack.peek()+");\")
;
methodBlock = false;
returnType = "void";
}

/* if (doWhile) */
{

timeMapPairStack.push("tp" + count);
count++;
timeMapStack.push("tTrue" + count);
count++;

tokens.insertAfter(SLCURLY, "\n \t if (" + timeMapStack.peek() + ".empty()) break; ");
tokens.insertAfter(SLCURLY, "\n \t TimeMap" + timeMapStack.peek() + " = " + timeMapPairStack.peek() + ".trueTimeMap() ; ");
tokens.insertAfter(SLCURLY, "\n \t TimeMapPair" + timeMapPairStack.peek() + " = " + forcondition + ".timeMapPair() ; ");
} */

blockStatement* { s.exitScope(); } RCURLY

{  
  if (doPara)
  {
    tokens.replace(SRCURLY, "");
doPara = false;
  }
  
  if (rightCurly)
  {
    tokens.replace(SRCURLY, "");  
  }
  }

-> "(BLOCK_SCOPE[SLCURLY, "BLOCK_SCOPE"] blockStatement*)

; : localVariableDeclaration SEMI!
| typeDeclaration
| q=statement
;

localVariableDeclaration
    : localModifierList type classFieldDeclaratorList
    -> "(VAR DECLARATION localModifierList type
classFieldDeclaratorList)

statement
    : block
    | annotation statement
    | ASSERT expr1=expression
    ( COLON expr2=expression SEMI
    -> "(ASSERT $expr1

    $expr2)
    | SEMI

    -> "(ASSERT $expr1)
    )
    | IF
    { if(isSequence)
    { sequencedIf = true;
    }
    }
    q=parenthesizedExpression
    {
    ifCondition = Sq.text;
    if(sequencedIf)
    {
    timeMapPairStack.push("tp"+count);
    count++;
    timeMapStack.push("tTrue"+count);
    count++;
    tokens.replace(Sq.start getTokenIndex(),Sq.stop.
    getTokenIndex(),"("+timeMapStack.peek() +" notEmpty")(")");
    tokens.insertBefore(SIF,"\t TimeMap "+timeMapStack.peek() +
    " = "+timeMapPairStack.peek()+" trueTimeMap () ;\n")
    tokens.insertBefore(SIF,"TimeMapPair "+timeMapPairStack.
    peek() +" = "+ifCondition+" timeMapPair () ;\n")
    }
1073     // sequencedIf = false;
1074     sequencedElse = true;
1075     seqIf = true;
1076     // timeMapStack.pop();
1077  }
1078  }
1079  ifStat = statement  { if (sequencedIf) {timeMapStack.pop();} }
1080  ( ELSE
1081  {
1082     if (sequencedElse)
1083     {
1084       timeMapStack.push("tFalse"+count);
1085       count++;
1086       tokens.replace($ELSE,"\t if ("+timeMapStack.peek()
1087       +".notEmpty())");
1088       tokens.insertBefore($ELSE,"\t TimeMap "+timeMapStack.
1089       peek() +" = "+timeMapPairStack.peek()+".falseTimeMap
1090       ()\n"};
1091     sequencedElse = false;
1092     }
1093     elseStat = statement
1094  }
1095  {
1096    // remove the timemap and timeMapPair
1097    timeMapStack.pop();
1098    if (seqIf)
1099    {
1100      // System.out.println("In seqIf "+timeMapPairStack.peek())
1101      timeMapPairStack.pop();
1102      seqIf = false;
1103      sequencedIf = false;
1104      sequencedElse = false;
1105    }
1106  }
1107  }
1108 }  -> ^(IF parenthesizedExpression
1109     $ifStat $elseStat)
if (seqIf)
{
    //System.out.println("In seqIf "+timeMapPairStack.peek());
    timeMapPairStack.pop();
    seqIf = false;
    sequencedElse = false;
    sequencedIf = false;
}

   -> ^((IF parenthesizedExpression ifStat)

   | FOR {
        if (isSequence)
        {
            forBlock=true;
            forStart = true;
        }
        }

LPAREN
    ( forInit SEI z=forCondition
    {
        if (forStart)
        {
            //System.out.println("for condition "+$z.text);
            forCondition = $z.text;
            tokens.replace($z.start.getTokenIndex(),$z.stop.
                getTokenIndex()+1,";");
            forStart = false;
        }
    }

SEMI forUpdater RPAREN statement

    {
        // POPPING timeMap and TimeMapPair
        timeMapPairStack.pop();
        timeMapStack.pop();
    }

   -> ^(FOR forInit forCondition forUpdater statement)

    | localModifierList type IDENT COLON expression RPAREN statement
      -> ^(FOR_EACH[FOR, "FOR_EACH"]
          localModifierList type IDENT expression statement)
60

WHILE
{
  if (isSequence)
  {
    whileBlock=true; //forStart = true;
  }
}
q=parenthesizedExpression
{
  if (whileBlock)
  {
    forcondition = $q$.text;
    tokens.replace($q$.start.getTokenIndex(),$q$.stop.get getTokenIndex(),"(true)");
  }
}
statement
{
  // POPPING timeMap and TimeMapPair
  if (whileBlock)
  {
    //System.out.println("In while "+timeMapPairStack.peek());
    if (breakTrue == false)
    {
      timeMapPairStack.pop();
    }
    timeMapStack.pop();
    whileBlock = false;
    breakTrue = false;
  }
}

DO
{
  if (isSequence)
  {
    doWhile = true;
    doPara = true;
  
  
-> (WHILE parenthesizedExpression statement)
// tokens.insertBefore($DO, 
" t TimeMap " + timeMapStack.peek() + 
" TimeMapPairStack.peek() + " falseTimeMap();\n");
}

}  

statement WHILE q=parenthesizedExpression
{
  if (doWhile)
  {

    // code
    timeMapPairStack.push("tp"+count);
    count++;
    timeMapStack.push("tTrue"+count);
    count++;

    tokens.insertBefore($WHILE, 
" t TimeMap " timeMapStack.peek() + 
" TimeMapPairStack.peek() + " trueTimeMap();\n" );
    tokens.insertBefore($WHILE, 
" TimeMapPair " timeMapPairStack.peek() + 
" $q . text + " timeMap();\n" );
    tokens.replace($q . start . getTokenIndex(),$q . stop .
getTokenIndex(), 
" (true) ");

doWhile = false;
}

}

SEMI {timeMapStack.pop();
    timeMapPairStack.pop();}

-> "(DO statement parenthesizedExpression)
| TRY block (catches finallyClause? | finallyClause)
    -> "(TRY block catches? finallyClause?)
| SWITCH
{
  if (isSequence)
  {
    switchCase = true;
    doPara = true;
    leftCurly = true;
    rightCurly = true;
  }
  tokens.replace($SWITCH,"" );
}
q=parenthesizedExpression {tokens.replace($q.start.getTokenIndex(), $q.stop.getTokenIndex(),""};  }

switchBlockLabels
{
    st.exitScope();
    cases.removeAllElements();
    statements.removeAllElements();
    switchCase = false;
    doPara = false;
    leftCurly = false;
    rightCurly = false;
}
RCURLY {tokens.replace($SRCURLY,"");}  (SWITCH parenthesizedExpression switchBlockLabels)
| SYNCHRONIZED parenthesizedExpression block
   -> "(SYNCHRONIZED parenthesizedExpression block)
| RETURN {
if(isSequence)
{
    sequencedReturn = true;
    isSequence = false;
}
}
q=expression?
{
    if (sequencedReturn)
    {
        tokens.replace($RETURN,"ret1=merge("+$q.text+";\n";
        String temp = timeMapStack.peek();
tokens.insertAfter($RETURN,temp+" = new Time(null);");
        //tokens.replace($RETURN,"";
tokens.replace($q.start.getTokenIndex(),$q.stop.getTokenIndex(),"");
        sequencedReturn = false;
    }
}
}
<"RETURN expression ?")

THROW expression SEMI

expression)

{isBreak = true; } BREAK

if (isSequence)

{ String temp = timeMapStack.peek();
timeMapPairStack.pop();
breakTrue = true;

x = timeMapPairStack.iterator();

while (x.hasNext())

{ tokens.insertAfter "$BREAK,$next() +" . subtractTime(" +temp +") ; \n ");

} tokens.replace "$BREAK," ;

isSequence = false;

}

IDENT? SEMI

IDENT ?)

CONTINUE

if (isSequence)

{ String temp = timeMapStack.peek();
tokens.replace "$CONTINUE,$temp+" = new Time (null); "");

isSequence = false;

}

IDENT? SEMI

IDENT COLON statement

IDENT COLON statement)

LabeledStatement IDENT statement)

expression SEMI!

SEMI
catches : catchClause+ => "(CATCH_CLAUSE_LIST catchClause+)"
;

catchClause : CATCH* LPAREN! formalParameter StandardDecl RPAREN! block
;

finallyClause : FINALLY block => block
;

switchBlockLabels : switchCaseLabels switchDefaultLabel? switchCaseLabels
    => "(SWITCH_BLOCK_LABELLIST switchCaseLabels
        switchDefaultLabel? switchCaseLabels)"
;

switchCaseLabels
    : switchCaseLabel+
    ;

switchCaseLabel
    : CASE* z=expression COLON! q=blockStatement* //System.out.println(isBreak);
    {
        //System.out.println(switchCase+"in case labels "+isBreak);
        if (switchCase)
        {
            cases.push($z.text);
            statements.push($q.text);
            //System.out.println("in case labels "+isBreak);
            tokens.replace($z.start.getTokenIndex(),$q.stop.getTokenIndex(),"");
            tokens.replace($CASE,"");
            if (isBreak == true) {
                String code = "";
            }
```java
int size = cases.size();

for (int i = 0; i < size; i++) {
    code = statements.pop() + "\n" + code;
    //System.out.println("if(" + cases.pop() + ")\n" + code + ");
    tokens.insertBefore(SCASE,"if(" + cases.pop() + ")\n{" + code + "}\n");
}
isBreak = false;
}
}

switchDefaultLabel
    : DEFAULT COLON! blockStatement*
    ;

forInit
    :
    localVariableDeclaration  -> "(FOR_INIT
        localVariableDeclaration)
    | expressionList  -> "(FOR_INIT expressionList)
    |                    -> "(FOR_INIT)
    ;

forCondition
    :

    q=expression?  /<*System.out.println("forcon "+Sq.text);*/-> "(FOR_CONDITION expression?)
    ;

forUpdater
    : q=expressionList? //{*System.out.println("expressionList "+Sq.
            text);}-> "(FOR_UPDATE expressionList)
    ;

// EXPRESSIONS
```
parenthesizedExpression
  : LPAREN expression RPAREN
  -> "(PARENTESIZED_EXPR[SLPAREN, "PARENTESIZED_EXPR"] expression )
  ;

expressionList
  : q=expression
     {
      if(isSequence)
      {
        tokens.insertBefore($q.start,"TimeMap timeMap,");
        //temp.pop();
        isSequence = false;
      }
    }
  (COMMA! expression)* ;

expression
  : q=assignmentExpression  // {System.out.println("expression "+Sq.text);} 
  -> "(EXPR assignmentExpression )
  ;

assignmentExpression returns [Boolean isSeq]
  : {$isSeq=false; doDont="";}
    q = conditionalExpression  {$isSeq=$q.isSeq; } {
      // replace i=0 -> 0 to new sequenced.Integer( timeMap,0)
      if(!ident.equals(""))
      {
        String t = Sq.text;
        tokens.replace(Sq.start getTokenIndex(), Sq.
        stop.getTokenIndex(),"new "+ident+"("
        timeMap,"+Sq.text+")") ;
        ident = "";
      }
    }
  ( ( ASSIGN
  { 
    opr = "ASSIGN";  // assign
    if($q.isSeq)
tokens.replace($ASSIGN.getTokenIndex(), ".assign(
  "+timeMapStack.peek()+".+assign+",")
$seq = true;
doDont="dontDo";
}

PLUS_ASSIGN
{
  opr = "PLUS_ASSIGN"; // plusAssign()
  if ($seq)
    tokens.replace($PLUS_ASSIGN.getTokenIndex(), ".
      plusAssign("+timeMapStack.peek()+".+plus_assign+",")
$seq = true;
doDont="dontDo";
}

MINUS_ASSIGN
{
  opr = "MINUS_ASSIGN"; // minusAssign()
  if ($seq)
    tokens.replace($MINUS_ASSIGN.getTokenIndex(), ".
      minusAssign("+timeMapStack.peek()+".+minus_assign+",")
$seq = true;
doDont="dontDo";
}

STAR_ASSIGN
{
  opr = "STAR_ASSIGN"; // starAssign()
  if ($seq)
    tokens.replace($STAR_ASSIGN.getTokenIndex(), ".
      starAssign("+timeMapStack.peek()+".+star_assign+",")
$seq = true;
doDont="dontDo";
}

DIV_ASSIGN

opr = "$DIV\_ASSIGN"; // divideAssign()
if ($q.isSeq)
{

tokens.replaceAll($DIV\_ASSIGN.getTokIndex(), ".
divideAssign("+timeMapStack.peek()+","+ 
div\_assign+","));

$isSeq = true;
doDont = "dontDo";
}

| AND\_ASSIGN
opr = "$AND\_ASSIGN"; // andAssign()
if ($q.isSeq)
{

tokens.replaceAll($AND\_ASSIGN.getTokIndex(), ".
andAssign("+timeMapStack.peek()+","+ 
and\_assign+","));

=isSeq = true;
doDont = "dontDo";
}

| OR\_ASSIGN
opr = "$OR\_ASSIGN"; // orAssign()
if ($q.isSeq)
{

tokens.replaceAll($OR\_ASSIGN.getTokIndex(), ".
orAssign("+timeMapStack.peek()+","+or\_assign 
+","));

=isSeq = true;
doDont = "dontDo";
}

| XOR\_ASSIGN
opr = "$XOR\_ASSIGN"; // xorAssign()
if ($q.isSeq)
{

tokens.replaceAll($XOR\_ASSIGN.getTokIndex(), ".
xorAssign("+timeMapStack.peek()+","+ 
xor\_assign+","));

=isSeq = true;
doDont="dontDo";

if (Sq.isSeq)
{
    tokens.replace($MOD_ASSIGN getTokenIndex(), ".modAssign("+timeMapStack.peek()+"."+
        mod_assign+".");
    $isSeq = true;
    doDont="dontDo";
}

opr = "SHIFT_LEFT_ASSIGN"; // .shiftLeftAssign()
if (Sq.isSeq)
{
    tokens.replace($SHIFT_LEFT_ASSIGN getTokenIndex(), ".shiftLeftAssign("+timeMapStack.peek()+"."+
        shift_left_assign+".");
    $isSeq = true;
    doDont="dontDo";
}

opr = "SHIFT_RIGHT_ASSIGN"; // .shiftRightAssign()
if (Sq.isSeq)
{
    tokens.replace($SHIFT_RIGHT_ASSIGN getTokenIndex(), ".shiftRightAssign("+timeMapStack.peek()+
        ","+shift_right_assign+".");
    $isSeq = true;
    doDont="dontDo";
}

opr = "BIT_SHIFT_RIGHT_ASSIGN"; // .bitShiftRightAssign()
if (Sq.isSeq)
{

tokens.replace($BIT_SHIFT_RIGHT_Assign.getPrecedence(),".bitShiftRightAssign("+
    timeMapStack.Peek()"+,"+
    bit_shift_right_assign+",";

$isSeq = true;
doDont="dontDo";
}

z=assignmentExpression

{ if($q.isSeq!=null && $z.isSeq!=null)
    {
        if($z.isSeq && (!doDont.equals("dontDo")))
            {
                if(opr.equals("ASSIGN"))
                    {
                        String t = $q.text;
tokens.replace($q.start.getTokenIndex(),$q.
                        stop.getTokenIndex(),$z.text);
tokens.replace($ASSIGN.getTokenIndex(),".
                        assign("+timeMapStack.peek()"+,"+assign+
                        ",");
                        //tokens.insertAfter($ASSIGN,"")
                        tokens.replace($z.start.getTokenIndex(),$z.
                        stop.getTokenIndex(),t);
                    }
                if(opr.equals("PLUS_ASSIGN"))
                    {
                        String t = $q.text;
tokens.replace($q.start.getTokenIndex(),$q.
                        stop.getTokenIndex(),$z.text);
tokens.replace($PLUS_ASSIGN.getTokenIndex(),
                        ",.plusAssign("+timeMapStack.peek()"+,"+
                        plus_assign+",");
                        //tokens.insertAfter($PLUS_ASSIGN,"")
                        tokens.replace($z.start.getTokenIndex(),$z.
                        stop.getTokenIndex(),t);
                    }
                if(opr.equals("MINUS_ASSIGN"))
                    {
                        String t = $q.text;
tokens.replace($q.start.getTokenIndex(),$q.
                        stop.getTokenIndex(),$z.text);
                    }}}}
tokens.replace($MINUS_ASSIGN getTokenIndex(),
    ".minusAssign("+timeMapStack.peek()+","+
    minus_assign+";
)
tokens.replace($z.start.getTokenIndex(),$z.
    stop.getTokenIndex(),t);
}
}
if (opr.equals("STAR_ASSIGN"))
{
    String t = $q.text;
tokens.replace($q.start.getTokenIndex(),$q.
    stop.getTokenIndex(),$z.text);
tokens.replace($STAR_ASSIGN getTokenIndex(),
    ".starAssign("+timeMapStack.peek()+","+
    star_assign+";
)
tokens.replace($z.start.getTokenIndex(),$z.
    stop.getTokenIndex(),t);
}
}
if (opr.equals("DIV_ASSIGN"))
{
    String t = $q.text;
tokens.replace($q.start.getTokenIndex(),$q.
    stop.getTokenIndex(),$z.text);
tokens.replace($DIV_ASSIGN getTokenIndex(),","+
    divAssign("+timeMapStack.peek()+","+
    div_assign+";
)
tokens.replace($z.start.getTokenIndex(),$z.
    stop getTokenIndex(),t);
}
if (opr.equals("AND_ASSIGN"))
{
    String t = $q.text;
tokens.replace($q.start.getTokenIndex(),$q.
    stop getTokenIndex(),$z.text);
tokens.replace($AND_ASSIGN getTokenIndex(),
    ".andAssign("+timeMapStack.peek()+","+
    and_assign+";
)
tokens.replace($z.start getTokenIndex(),$z.
    stop getTokenIndex(),t);
}
if (opr.equals("OR_ASSIGN"))
{
    String t = $q.text;
tokens.replace($q.start getTokenIndex(),$q.
    stop getTokenIndex(),$z.text);
tokens.replace($OR_ASSIGN, getTokenIndex(), "
orAssign("+timeMapStack.peek()\+","+
or_assign+",");
tokens.replace($z.start.getTokenIndex(), $z.stop.getTokenIndex(), t);
}
if (opr.equals("XOR_ASSIGN"))
{
  String t = $q.text;
tokens.replace($q.start.getTokenIndex(), $q.stop.getTokenIndex(), $z.text);
tokens.replace($XOR_ASSIGN, getTokenIndex(), 
  .xorAssign("+timeMapStack.peek()\+","+
xor_assign+","));
tokens.replace($z.start.getTokenIndex(), $z.stop.getTokenIndex(), t);
}
if (opr.equals("MOD_ASSIGN"))
{
  String t = $q.text;
tokens.replace($q.start.getTokenIndex(), $q.stop.getTokenIndex(), $z.text);
tokens.replace($MOD_ASSIGN, getTokenIndex(), 
  .modAssign("+timeMapStack.peek()\+","+
  mod_assign+","));
tokens.replace($z.start.getTokenIndex(), $z.stop.getTokenIndex(), t);
}
if (opr.equals("SHIFT_LEFT_ASSIGN"))
{
  String t = $q.text;
tokens.replace($q.start.getTokenIndex(), $q.stop.getTokenIndex(), $z.text);
tokens.replace($SHIFT_LEFT_ASSIGN, getTokenIndex(), 
  .shiftLeftAssign("+timeMapStack.peek()\+","+
  shift_left_assign+","));
tokens.replace($z.start.getTokenIndex(), $z.stop.getTokenIndex(), t);
}
if (opr.equals("SHIFT_RIGHT_ASSIGN"))
{
  String t = $q.text;
tokens.replace(Sq.start.getTokenIndex(), Sq.stop.getTokenIndex(), $z.text);
tokens.replace(SShift_Right_Assign, getTokenIndex(), ".shiftRightAssign("+timeMapStack.peek()+", "+shift_right_assign+");
tokens.replace(Sz.start.getTokenIndex(), Sz.stop.getTokenIndex(), t);
}
if (opr.equals("BIT_SHIFT_RIGHT_ASSIGN"))
{
    String t = Sq.text;
tokens.replace(Sq.start.getTokenIndex(), Sq.stop.getTokenIndex(), $z.text);
tokens.replace($BIT_SHIFT_RIGHT_ASSIGN, getTokenIndex(), ".bitShiftRightAssign("+timeMapStack.peek()+", "+bit_shift_right_assign+");
tokens.replace(Sz.start.getTokenIndex(), Sz.stop.getTokenIndex(), t);

    }
    $isSeq = true;
    }
    if ($z.isSeq || $q.isSeq)
    }
tokens.insertAfter($z.stop.getTokenIndex(), ")");
}

if ($e.isSeq != null && $e1.isSeq != null && $e2.isSeq != null)
{
    if ($e.isSeq == true)
    {
        tokens.replace($QUESTION, getTokenIndex(), ")");
tokens.replace($COLON, getTokenIndex(), ")");
        String t = $e.text+".conditional("+timeMapStack.peek()()+","+$e1.text+","+$e2.text+");
    }
}

conditionalExpression returns [Boolean isSeq]
{
    $isSeq=false; doDont=""; e=logicalOrExpression {$isSeq=$e.isSeq ;}(QUESTION e1=assignmentExpression COLON! e2= conditionalExpression )?

    { if ($e.isSeq!=null && $e1.isSeq!=null && $e2.isSeq!=null)
        {
            if ($e.isSeq==true)
            {
                tokens.replace($QUESTION, getTokenIndex(), ")");
tokens.replace($COLON, getTokenIndex(), ")");
                String t = $e.text+".conditional("+timeMapStack.peek()()+","+$e1.text+","+$e2.text+");
            }
        }
}

tokens.replace($e.start.getTokenIndex(),$e.stop.getTokenIndex(),$e.text+".conditional("+$e1.text+","+$e2.text+")");
tokens.replace($e.start.getTokenIndex(),$e2.stop.getTokenIndex(),t);
}
}
}

logicalOrExpression returns [Boolean isSeq]
{: {isSeq=false; doDont="";} q=logicalAndExpression {isSeq=q.isSeq;} (LOGICAL_OR^}

opr = "LOGICAL_OR"; // logicalOr()
if(q.isSeq!=null && q.isSeq)
{
tokens.replace(SLOGICAL_OR.getTokenIndex(),".
logicalOr("+timeMapStack.peek()+","+
logical_or+"",");
isSeq = true;
doDont="dontDo";
}

z=logicalAndExpression

if(q.isSeq!=null && z.isSeq!=null)
{
if(z.isSeq && (!doDont.equals("dontDo"))}

if(opr.equals("LOGICAL_OR"))
{
String t = q.text;
tokens.replace(q.start.getTokenIndex(),q.stop.getTokenIndex(),q.text);
tokens.replace(SLOGICAL_OR.getTokenIndex(),".
logicalOr("+timeMapStack.peek()+","+
logical_or+"",");
tokens.replace(z.start.getTokenIndex(),z.stop.getTokenIndex(),z.text);
isSeq = true;
}

if(q.isSeq || z.isSeq)
logicalAndExpression returns [Boolean isSeq]

```java
logicalAndExpression = {
    isSeq=false; doDont="";
} q=inclusiveOrExpression {
    isSeq=q.isSeq;
    \( \text{LOGICAL\_AND} \)
    opr = "LOGICAL\_AND"; // logicalAnd()
    if (q.isSeq)
        tokens.replace(SLOGICAL\_AND.getTokenIndex(), ".logicalAnd()
            logicalAnd("+timeMapStack.peek()+"," +
            logical\_and+","));
    isSeq = true;
    doDont="dontDo";
}

z=inclusiveOrExpression
```

```java
{  
    if (q.isSeq!=null && z.isSeq!=null)
        {
            if (z.isSeq && (!doDont.equals("dontDo")))
                {  
                    if (opr.equals("LOGICAL\_AND"))
                    {  
                        String t = q.text;
                        tokens.replace(q.start.getTokenIndex(),q.stop.getTokenIndex(),t);
                        tokens.replace(SLOGICAL\_AND.getTokenIndex(), ".logicalAnd()
                            logicalAnd("+timeMapStack.peek()+"," +
                            logical\_and+","));
                        tokens.replace(z.start.getTokenIndex(),z.stop.getTokenIndex(),t);
                        isSeq = true;
                    }
                    }
                }
        }
    else
        {  
            isSeq = true;
        }
    if (z.isSeq || z.isSeq)
        tokens.insertAfter(z.stop.getTokenIndex(),")");
```
inclusiveOrExpression returns [Boolean isSeq]
    : {isSeq=false ; doDont="";} q=inclusiveOrExpression {isSeq=Sq. isSeq;} (OR
    
    opr = "OR" ; // . or()
    if(Sq.isSeq)
    {
        tokens.replace(SQ.getTokenIndex()," . or("
    timeMapStack.peek()+" , "+or+", ");
        $isSeq = true;
        doDont="dontDo";
    }
    
    z=inclusiveOrExpression
    {
        if(Sq.isSeq!=null && $z.isSeq!=null)
        {
            if($z.isSeq & & (!doDont.equals("dontDo")))
            {
                if(opr.equals("OR"))
                {
                    String t = SQ.text;
                    tokens.replace(SQ.start.getTokenIndex(),SQ.
stop.getTokenIndex(),$z.text);
                    tokens.replace($OR.getTokenIndex()," . or("
    timeMapStack.peek()+" , "+or+", ");
                    tokens.replace($z.start.getTokenIndex(),$z.
stop.getTokenIndex(),t);
                    $isSeq = true;
                }
                
                isSeq = true;
            }
            
            if($z.isSeq || SQ.isSeq)
            tokens.insertBefore($z.stop.getTokenIndex()," ");
        }
    }
    
    }*)
    ;
    
exclusiveOrExpression returns [Boolean isSeq]
: {isSeq=false; doDont="";} q=andExpression {isSeq= Sq.isSeq;}

  XOR^*

  if (Sq.isSeq)

    
      opr = "XOR"; // xor()

    

  tokens.replace(XOR getTokenIndex(), " xor("+timeMapStack.peek()+","+xor","))

  isSeq = true;

  doDont=" dontDo ";

  }

  }

z=andExpression

  // System.out.println("$q.isSeq"+"+$z.isSeq");

  if ($q.isSeq!=null && $z.isSeq!=null)

    
      if ($z.isSeq && (!doDont.equals(" dontDo ")))

    

      if (opr.equals("XOR"))

    

      String t = Sq.text;

      tokens.replace(Sq.start getTokenIndex(), Sq.

 stop .getTokenIndex(), $z .text);

      tokens.replace(XOR getTokenIndex(), " xor("+timeMapStack.peek()+","+xor","));

      tokens.replace($z .start .getTokenIndex(), $z.

 stop .getTokenIndex(), t);

      isSeq = true;

    

    }

  isSeq = true;

  }

  if ($z.isSeq || $q.isSeq)

    tokens.insertAfter($z .stop .getTokenIndex(), "")

  }

}

andExpression returns [Boolean isSeq]
(AND

```java
1799 : {isSeq=false; doDont="";} q=equalityExpression {isSeq=q.isSeq
1800 {
1801 {opr = "AND"; } (AND^
1802
1803 if(q.isSeq)
1804 {
1805 tokens.replace($AND.getTokenIndex(),". and("+timeMapStack.peek()+","+and+",");
1806 $isSeq = true;
1807 doDont="dontDo";
1808
1809
1810 }
1811 z=equalityExpression
1812 {
1813 $isSeq = z.isSeq;
1814 if(q.isSeq!=null & & z.isSeq!=null)
1815 {
1816 if(z.isSeq & & (!doDont.equals("dontDo")))
1817 {
1818 if(opr.equals("AND"))
1819 {
1820 String t = q.text;
1821 tokens.replace(Sq.start.getTokenIndex(),Sq.
1822 stop.getTokenIndex(),Sq.text);
1823 tokens.replace($AND.getTokenIndex(),". and("+timeMapStack.peek()+","+and+",");
1824 tokens.replace(z.start.getTokenIndex(),z.
1825 stop.getTokenIndex(),z.text);
1826 $isSeq = true;
1827 }
1828 if(q.isSeq || $isSeq)
1829 tokens.insertBefore($z.stop.getTokenIndex(),""");
1830 }
1831 }
1832 }
1833
equalityExpression returns [Boolean isSeq]
1834 : {isSeq=false; } q=instanceOfExpression {isSeq=q.isSeq;}
1835 ( ( {doDont="";} EQUAL^
opr = "EQUAL"; // .equal()

if (Sq.isSeq)
{
    tokens.replace(SEQUAL.getTokenIndex(),".equal("+timeMapStack.peek()+","+equal+");
    isSeq = true;
    doDont="dontDo";
}

| NOT_EQUAL^ | opr = "NOT_EQUAL"; // notEqual()

if (Sq.isSeq)
{
    tokens.replace(SNOT_EQUAL.getTokenIndex(),"."+_notEqual("+timeMapStack.peek()+","+_not_equal +"",");
    isSeq = true;
    doDont="dontDo";
}

z=instanceOfExpression

if (Sq.isSeq!=null & & Sz.isSeq!=null)
{
    if (Sz.isSeq & & (!doDont.equals("dontDo")))
    {
        if (opr.equals("EQUAL"))
        {
            String t = Sq.text;
            tokens.replace(Sq.start.getTokenIndex(),Sq.stop.getTokenIndex(),t);
            tokens.replace(SEQUAL.getTokenIndex(),"."+_equal("+timeMapStack.peek()+","+_equal+");
            tokens.replace(Sz.start.getTokenIndex(),Sz.stop.getTokenIndex(),t);
        }
    }
}
if (opr.equals("EQUAL"))
{
    String t = Sq.text;
    tokens.replace(Sq.start.getTokenIndex(),Sq.stop.getTokenIndex(),$z.text);
    tokens.replace($NOT_EQUAL getTokenIndex(),
    notEqual("+timeMapStack.peek()","+
    not_equal+",")
    tokens.replace($z.start.getTokenIndex(),$z.
    stop.getTokenIndex(),t);
}

$IsSeq = true;
}

if ($z.isSeq || $q.isSeq)
    tokens.insertAfter($z.stop.getTokenIndex(),"]")

/*
    INSTANCEOF instance returns [Boolean isSeq]

    $IsSeq=false; q=relationalExpression $isSeq=$q.isSeq: ( INSTANCEOF* z=type )?
    
    if ($z.text != null && $q.isSeq)
    tokens.replace($z.start.getTokenIndex(),$z.stop.
    getTokenIndex(),"sequenced."+$z.text);
*/

instanceOfExpression returns [Boolean isSeq]

    $IsSeq=false; q=relationalExpression $isSeq=$q.isSeq: ( INSTANCEOF* z=type )?
    
    if ($z.text != null && $q.isSeq)
    tokens.replace($z.start getTokenIndex(),$z.stop.
    getTokenIndex(),"sequenced."+$z.text);

// RELATIONAL EXPRESSION FOR for loop

// Relational expression for If else statement

relationalExpression returns [Boolean isSeq]

    $IsSeq=false;doDont=""; q=shiftExpression $isSeq=$q.isSeq:
    
    ( ( LESS_OR_EQUAL
    
    { opr = "LESS_OR_EQUAL"; // lessOrEqual ()
    */

if ($q.isSeq)
    {
tokens.replace($LESS_OR_EQUAL.getTokenIndex(),
  lessOrEqual("+timeMapStack.peek()+","+
  less_or_equal+",");

$isSeq = true;
doDont="dontDo";

if ($isSeq)
  opr = "GREATER_OR_EQUAL"; // greaterOrEqual()

if ($isSeq)
  opr = "LESS_THAN"; // lessThan()

if ($isSeq)
  opr = "GREATER_THAN"; // greaterThan()

if ($isSeq != null)
  if ($isSeq)
tokens.replace($GREATER_THAN, getTokenIndex(), ".
greaterThan("+timeMapStack.peek()+" 
"greater_than+",");

if ($isSeq == true)

doDont="dontDo";

}

}

}

z=shiftExpression

{

if ($q.isSeq != null & & $z.isSeq != null)

{

if ($z.isSeq & & (! doDont.equals("dontDo")))

{

if (opr.equals("LESS_OR_EQUAL"))

{

String t = $q.text;

tokens.replace($q.start getTokenIndex(), $q.
stop getTokenIndex(), $q.text);

tokens.replace($LESS_OR_EQUAL, getTokenIndex()
,".lessOrEqual("+timeMapStack.peek()+" 
"+less_or_equal+",");

tokens.replace($z.start getTokenIndex(), $z.
stop getTokenIndex(), t);

}

if (opr.equals("GREATER_OR_EQUAL"))

{

String t = $q.text;

tokens.replace($q.start getTokenIndex(), $q.
stop getTokenIndex(), $q.text);

tokens.replace($GREATER_OR_EQUAL, getTokenIndex()
,".greaterOrEqual("+timeMapStack.peek()+" 
"+greater_or_equal+",");

tokens.replace($z.start getTokenIndex(), $z.
stop getTokenIndex(), t);

}

if (opr.equals("LESS_THAN"))

{

String t = $q.text;

tokens.replace($q.start getTokenIndex(), $q.
stop getTokenIndex(), $q.text);
tokens.replace($LESS THAN, getTokenIndex(), ".
  lessThan("+timeMapStack.peek()","+ less_than+");
tokens.replace($z.start.getTokenIndex(),$z.
  stop.getTokenIndex(),t);
}
if(opr.equals("GREATER THAN"))
{
  String t=$q.text;
tokens.replace($q.start.getTokenIndex(),$q.
  stop.getTokenIndex(),$q.text);
tokens.replace($GREATER THAN,getTokenIndex(),
  ",.greaterThan("+timeMapStack.peek()","+ greater_than+");
tokens.replace($z.start.getTokenIndex(),$z.
  stop.getTokenIndex(),t);
}

$isSeq = true;
}
if($z.isSeq || $q.isSeq)
tokens.insertAfter($z.stop.getTokenIndex(),")");
}

shiftExpression returns [Boolean isSeq]
: {isSeq=false:doDont="";} q=additiveExpression {isSeq=$q.isSeq
  ;}
  ( (BIT_SHIFT_RIGHT^//.bitShiftRight())
  {
    opr = "BIT_SHIFT_RIGHT";
    if($q.isSeq!=$null)
      {
        if($q.isSeq)
        {
          tokens.replace($BIT_SHIFT_RIGHT,getTokenIndex(),
            ",.bitShiftRight("+timeMapStack.peek()","+ bit_shift_right+");
          $isSeq = true;
          doDont="dontDo";
        }
      }
    
  }
}
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| SHIFT_RIGHT^ //.shiftRight()
| opr = "SHIFT_RIGHT";
| if (Sq.isSeq != null) {
| | if (Sq.isSeq) {
| | tokens.replace($SHIFT_RIGHT.getTokenIndex(), ".shiftRight("+timeMapStack.peek()+","+shift_right+","));
| | $isSeq = true;
| | } doDont="dontDo";
| }
| } //.shiftLeft()
| opr = "SHIFT_LEFT";
| if (Sq.isSeq != null) {
| | if (Sq.isSeq) {
| | tokens.replace($SHIFT_LEFT.getTokenIndex(), ".shiftLeft("+timeMapStack.peek()+","+shift_left+",");
| | $isSeq = true;
| | } doDont="dontDo";
| }
| )
| z= additiveExpression
| }
| if (Sq.isSeq != null && $z.isSeq != null) {
| | if ($z.isSeq && (!doDont.equals("dontDo"))) {
| | if (opr.equals("BIT_SHIFT_RIGHT")) {
| | String t = Sq.text;
| | tokens.replace(Sq.start.getTokenIndex(), Sq.stop.getTokenIndex(), $z.text);
| | tokens.replace($BIT_SHIFT_RIGHT.getTokenIndex(), ".bitShiftRight("+}
timeMapStack.peek() + "," + bit.shift_right + " , " +

tokens.replace($z.start.getTokenIndex(), $z.
stop getTokenIndex(), t);

} if (opr.equals("SHIFT_RIGHT"))
{
  String t = Sq.text;
  tokens.replace($q.start.getTokenIndex(), Sq.
stop getTokenIndex(), $z.text);
  tokens.replace($SHIFT_RIGHT.getTokenIndex(), 
.shiftRight(" + timeMapStack.peek() + "," +
shift_right + ") ;
  tokens.replace($z.start.getTokenIndex(), $z.
stop getTokenIndex(), t);
}

if (opr.equals("SHIFT_LEFT"))
{
  String t = Sq.text;
  tokens.replace($q.start.getTokenIndex(), Sq.
stop getTokenIndex(), $z.text);
  tokens.replace($SHIFT_LEFT.getTokenIndex(), 
.shiftLeft(" + timeMapStack.peek() + "," +
shift_left + ") ;
  tokens.replace($z.start.getTokenIndex(), $z.
stop getTokenIndex(), t);

  $isSeq = true;
}

if ($z.isSeq || $q.isSeq)
  tokens.insertBefore($z.stop.getTokenIndex(), ");

$additiveExpression returns [Boolean isSeq]

: { $isSeq = false; doDont = ""; doIt = false; } q= multiplicativeExpression
  { $isSeq = $q.isSeq; }

( (PLUS

{ opr = "PLUS";
  if ($q.isSeq! = null)
  {

if ($q.isSeq)
{
    tokens.replace($PLUS.getTokenIndex(),".add("+ timeMapStack.peek()+","+plus+",");

    $isSeq = true;
    doDont="dontDo";
}

opr = "MINUS";

if ($q.isSeq)
{
    tokens.replace($MINUS.getTokenIndex(),".subtract("+ timeMapStack.peek()+","+minus+",");

    $isSeq = true;
    doDont="dontDo";
}

z=multiplicativeExpression

if ($q.isSeq!=null && $z.isSeq!=null)
{
    if ($z.isSeq && (!doDont.equals("dontDo")))
    {
        doIt = true;
        if (opr.equals("PLUS"))
        {
            String t = $q.text;
            tokens.replace($q.start.getTokenIndex(),$q.
                stop.getTokenIndex(),$z.text);
            tokens.replace($PLUS.getTokenIndex(),".add("+
                timeMapStack.peek()+","+plus+",");

            tokens.replace($z.start.getTokenIndex(),$z.
                stop.getTokenIndex(),t);
            $isSeq = true;
        }
        if (opr.equals("MINUS"))
        {
            String t = $q.text;
            tokens.replace($q.start.getTokenIndex(),$q.
                stop.getTokenIndex(),$z.text);
        }
    }
}
consumes |"-"| |"\star\"| |"/\"| |"%\"|

```java
tokens.replace($MINUS, getTokenIndex(), ". subtract("+timeMapStack.peek()+", "+minus +"), ");
tokens.replace($z.start.getTokenIndex(), $z.stop.getTokenIndex(), t);
}

sisSeq = true;
}

tokens.insertAfter($z.stop.getTokenIndex(), ");
}

#multiplicativeExpression returns [Boolean isSeq]

q = unaryExpression {
    isSeq = $q.isSeq;
}

(' | DIV | MOD)
```

```java
op = "STAR";
if ($q.isSeq)
{
    tokens.replace($STAR, getTokenIndex(), ". multiply("+timeMapStack.peek()+", "+star+"), ");
    isSeq = true;
    doDont="dontDo";
}

| DIV

op = "DIV";
if ($q.isSeq)
{
    tokens.replace($DIV, getTokenIndex(), ". divide("+timeMapStack.peek()+", "+div+"), ");
    isSeq = true;
    doDont="dontDo";
}

| MOD

op = "MOD";
```
if ($q.isSeq)
{
    tokens.replace($MOD.getTokenIndex(), ", modulus("+
timeMapStack.peek()\"\", \"+mod\", \"\")
    $isSeq = true;
    doDont="dontDo";
}
}
}
z=unaryExpression
{
    if ($q.isSeq!=null && $z.isSeq!=null)
    {
        if ($z.isSeq && (!doDont.equals("dontDo")))
        {
            if (opr.equals("STAR"))
            {
                String t = $q.text;
                tokens.replace($q.start.getTokenIndex(),$q.
stop.getTokenIndex(),$z.text);
                tokens.replace($STAR.getTokenIndex(), ",
multiply("+timeMapStack.peek()\"\", \"+star+
\"\")
                tokens.replace($z.start.getTokenIndex(),$z.
stop.getTokenIndex(),t);
            }
            if (opr.equals("DIV"))
            {
                String t = $q.text;
                tokens.replace($q.start.getTokenIndex(),$q.
stop.getTokenIndex(),$z.text);
                tokens.replace($DIV.getTokenIndex(), ", divide
("+timeMapStack.peek()\"\", \"+div\", \")
                tokens.replace($z.start.getTokenIndex(),$z.
stop.getTokenIndex(),t);
            }
            if (opr.equals("MOD"))
            {
                String t = $q.text;
                tokens.replace($q.start.getTokenIndex(),$q.
stop.getTokenIndex(),$z.text);
                tokens.replace($MOD.getTokenIndex(), ",
modulus("+timeMapStack.peek()\"\", \"+mod\", \\
\")
            }
tokens.replace($z.start.getTokenIndex(),$z.
stop.getTokenIndex(),t);
    
    $isSeq = true;
    
}  

if($z.isSeq || $q.isSeq)
    tokens.insertAfter($z.stop.getTokenIndex(),""");

$isSeq = true;
}

)*

unaryExpression returns [Boolean isSeq]
    : {$isSeq=false;}
    PLUS p=unaryExpression

    {
        if($p.isSeq)
        {
            tokens.insertAfter($PLUS.getTokenIndex()+1,".add("+ 
timeMapStack.peek()+", "+plus+)");
            tokens.replace($PLUS.getTokenIndex(),""");
            $isSeq = true;
        }
    }

    -> "(UNARY_PLUS[$PLUS, "UNARY_PLUS"] unaryExpression)

    | MINUS m=unaryExpression

    {
        if($m.isSeq)
        {
            tokens.insertAfter($MINUS.getTokenIndex()+1,".subtract(" +timeMapStack.peek()+", "+minus+");
            tokens.replace($MINUS.getTokenIndex(),""");
            $isSeq = true;
        }
    }

    -> "(UNARY_MINUS[$MINUS, "UNARY_MINUS"] unaryExpression)

    // prefix operations

    | INC i=postfixedExpression

    {
        if($i.isSeq)
        {
            tokens.insertAfter($INC.getTokenIndex()+1,".increment("+ 
timeMapStack.peek()+", "+inc+");
            tokens.replace($INC.getTokenIndex(),""");
        }
    }
$isSeq = true;

}  

}  

-> "(PRE_INC[$INC, "PRE_INC"] postfixedExpression)"

// prefix operations
| DEC d=postfixedExpression

{  
  if($d.isSeq)
  {
    tokens.insertAfter($DEC getTokenIndex()+1,".decrement("+timeMapStack.peek()+"."+dec+)");
    tokens.replace($DEC getTokenIndex()," ");
    $isSeq = true;
  }
  }

-> "(PRE_DEC[$DEC, "PRE_DEC"] postfixedExpression)"

| q=unaryExpressionNotPlusMinus

{  
  $isSeq = $q.isSeq;
  }

;

unaryExpressionNotPlusMinus returns [Boolean $isSeq]

: {$isSeq=false:} NOT n=unaryExpression

{  
  if($n.isSeq)
  {
    tokens.insertAfter($NOT getTokenIndex()+1,".not("+timeMapStack.peek()+"."+not+)");
    tokens.replace($NOT getTokenIndex()," ");
    $isSeq = true;
  }
  }

-> "(NOT unaryExpression)"

| LOGICAL_NOT ln=unaryExpression

{  
  if($ln.isSeq)
  {
    tokens.insertAfter($LOGICAL_NOT getTokenIndex()+1,".logicalNot("+timeMapStack.peek()+"."+logical_not+)");
    tokens.replace($LOGICAL_NOT getTokenIndex()," ");
    $isSeq = true;
  }
  }
postfixedExpression returns [Boolean isSeq]
   // At first resolve the primary expression ...
   : ( {isSeq=false;} q=primaryExpression
   {   $isSeq = $q.isSeq;
   } $isSeq = $q.isSeq;
   ) $isSeq = $q.isSeq;
   )
   -> primaryExpression
   )
   // ... and than the optional things that may follow a primary expression 0 or more times.
   ( outerDot=DOT
   ( ( genericTypeArgumentListSimplified? // Note: generic type arguments are only valid for method calls, i.e. if there
     ( )
     ( arguments
     /*{*
     if(isSequence)
     {   System.out.println(" abc ");
     methodCall = true;
     isSequence = false;
     }
    }*/
   )
   -> ^(DOT
   $postfixedExpression IDENT)
   )
   )
   ( arguments
   /*{
   if(isSequence)
   {   System.out.println(" abc ");
   methodCall = true;
   isSequence = false;
   }
    */
   )
   -> ^(METHOD_CALL
   $postfixedExpression
genericTypeArgumentListSimplified
? arguments)

| THIS -> ^(DOT $postfixedExpression THIS)
| Super=Super arguments -> ^(SUPER_CONSTRUCTOR_CALL[$Super, "SUPER_CONSTRUCTOR_CALL"] $postfixedExpression arguments)
| ( SUPER innerDot=DOT IDENT -> ^(innerDot ^(SouterDot $postfixedExpression SUPER) IDENT)
| arguments /*{
| if(isSequence)
| } System.out.println(" abc ");
| methodCall = true;
| isSequence = false;
| */
| (METHOD_CALL $postfixedExpression arguments)
| innerNewExpression -> ^(DOT $postfixedExpression innerNewExpression)
| LBRACK expression RBRACK -> ^(ARRAY_ELEMENT_ACCESS $postfixedExpression expression)
| )*
| // At the end there may follow a post increment/decrement.
| // Post fix increment
| ( INC
| )
| if($q.isSeq)
| { tokens.replace(SINC,".increment("+timeMapStack.peek (+", "+inc+")");
| }
| -> ^(POST_INC[$INC, "POST_INC"] $postfixedExpression)
| | DEC
| // Post fix decrement
| )
| if($q.isSeq)
tokens.replace($DEC, "decrement(" + timeMapStack.peek() + "+" + dec + ")");

-> "(POST_DEC[$DEC, "POST_DEC"] $postfixedExpression)"

primaryExpression returns [Boolean isSeq]
{ $isSeq = false; } parenthesizedExpression
| z=literal { $isSeq = $z.isSeq; }
| newExpression
| q=qualifiedIdentExpression
{ $isSeq = $q.isSeq; }
genericTypeArgumentListSimplified
| SUPER
  ( arguments
    -> "(
        SUPER_CONSTRUCTOR_CALL[$SUPER, "SUPER_CONSTRUCTOR_CALL"]
        genericTypeArgumentListSimplified arguments)
  )
| DOT IDENT arguments
    -> "(
        METHOD_CALL ^(DOT SUPER IDENT)
        genericTypeArgumentListSimplified arguments)

| q1=IDENT
{ System.out.println($q1.text);
  if (isSequence)
  {
    System.out.println("abc");
    methodCall = true;
    isSequence = false;
  }
}
arguments
-> "(METHOD_CALL IDENT
genericTypeArgumentListSimplified arguments)
| THIS arguments
  -> "(
      THIS_CONSTRUCTOR_CALL[$THIS, "THIS_CONSTRUCTOR_CALL"]
genericTypeArgumentListSimplified arguments)
| ( THIS
    -> THIS
)
qualifiedIdentExpression returns [Boolean isSeq]
   // The qualified identifier itself is the starting point for this rule.
   : ( { $isSeq = false; } q = qualifiedIdentifier { 
      boolean t = st.probe(q.text);
      // System.out.println(" sequenced check "+q.text + "+"+t);
      if (t)
      { 
      }
$isSeq = true;

}  

}  

} => qualifiedIdentifier

// And now comes the stuff that may follow the qualified identifier.

( arrayDeclarator => ^( 
arrayDeclarator $qualifiedIdentExpression)
)

+ 

( DOT CLASS => ^(DOT 

$qualifiedIdentExpression CLASS)
)

| {

if (isSequence)

{

System.out.println(" abc ");

methodCall = true;

isSequence = false;

}

} arguments

| outerDot=DOT

| CLASS => ^(DOT 

qualifiedIdentifier CLASS)

| genericTypeArgumentListSimplified

( Super=SUPER arguments => ^( 

SUPER_CONSTRUCTOR_CALL[$Super , 

SUPER_CONSTRUCTOR_CALL"] $qualifiedIdentExpression 

genericTypeArgumentListSimplified arguments)

| SUPER innerDot=DOT IDENT arguments

| IDENT arguments

/!* { if (isSequence) 

{

System.out.println(" abc ");

methodCall = true;

isSequence = false;
(METHOD_CALL ^{(DOT
qualifiedIdentifier IDENT)
genericTypeArgumentListSimplified
arguments)}
)
THIS
qualifiedIdentifier
THIS
SUPER arguments
SUPER_CONSTRUCTOR_CALL[$Super, "SUPER_CONSTRUCTOR_CALL"]
qualifiedIdentifier arguments
innerNewExpression
qualifiedIdentifier
innerNewExpression
) {isSequence = false:}
;
;
newExpression

NEW
(primitiveType
newArrayConstruction // new static array
of primitive type elements
)

(STATIC_ARRAY_CREATOR[$NEW, "STATIC_ARRAY_CREATOR"]
primitiveType
newArrayConstruction)

| genericTypeArgumentListSimplified?
qualifiedTypeIdentSimplified
(newArrayConstruction // new static array
of object type reference elements
)

(STATIC_ARRAY_CREATOR[$NEW, "STATIC_ARRAY_CREATOR"]
genericTypeArgumentListSimplified?
qualifiedTypeIdentSimplified
newArrayConstruction)

| arguments
classBody? // new object type
via constructor invocation

(CLASS_CONSTRUCTOR_CALL[$NEW, "STATIC_ARRAY_CREATOR"
] genericTypeArgumentListSimplified?
qualifiedTypeIdentSimplified
arguments
classBody?)
)
;
;
innerNewExpression // something like 'InnerType innerType = outer.new
InnerType();'

: NEW
genericTypeArgumentListSimplified?
IDENT
arguments
classBody
?
2470    -> "(CLASS_CONSTRUCTOR_CALL[$NEW, "STATIC_ARRAY_CREATOR"]
    genericTypeArgumentListSimplified? IDENT arguments classBody
    ?)
2471    ;
2472
2473  newArrayConstruction
2474    : arrayDeclaratorList arrayInitializer
2475    | LBRACK! expression RBRACK! (LBRACK! expression RBRACK!)*
2476               arrayDeclaratorList?
2477    ;
2478
2479  arguments
2480    : LPAREN
2481    {
2482      If (methodCall)
2483      {
2484        System.out.println("method call");
2485        tokens.insertAfter($LPAREN,timeMapStack.peek()+", ");
2486        methodCall = false;
2487      }
2488    }
2489    expressionList? RPAREN
2490    -> "(ARGUMENT_LIST[$LPAREN, "ARGUMENT_LIST"] expressionList?)
2491    ;
2492
2493  literal returns [Boolean isSeq]
2494    : {$isSeq=false} q= HEX_LITERAL
2495       {
2496      boolean t = st.probe($q.text);
2497      if (t)
2498        $isSeq = true;
2499    }
2500    | q= OCTAL_LITERAL
2501       {
2502      boolean t = st.probe($q.text);
2503      if (t)
2504        $isSeq = true;
2505    }
2506    | q= DECIMAL_LITERAL
2507       {
2508      boolean t = st.probe($q.text);
2509      if (t)
2510        $isSeq = true;
2511    }
2512    | q= FLOATING_POINT_LITERAL
2513       {
2514      boolean t = st.probe($q.text);
2515      if (t)
$isSeq = true;

<table>
<thead>
<tr>
<th>q = CHARACTER_LITERAL</th>
</tr>
</thead>
</table>
| boolean t = st.probe($q.text);
| if(t) $isSeq = true; |

<table>
<thead>
<tr>
<th>q = STRING_LITERAL</th>
</tr>
</thead>
</table>
| boolean t = st.probe($q.text);
| if(t) $isSeq = true; |

<table>
<thead>
<tr>
<th>q = TRUE</th>
</tr>
</thead>
</table>
| boolean t = st.probe($q.text);
| if(t) $isSeq = true; |

<table>
<thead>
<tr>
<th>q = FALSE</th>
</tr>
</thead>
</table>
| boolean t = st.probe($q.text);
| if(t) $isSeq = true; |

<table>
<thead>
<tr>
<th>q = NULL</th>
</tr>
</thead>
</table>
| boolean t = st.probe($q.text);
| if(t) $isSeq = true; |

// LEXER

HEX_LITERAL : '0' ("x" | "X") HEX_DIGIT+ INTEGER_TYPE_SUFFIX? ;

DECIMAL_LITERAL : ('0' | '1'..'9' '0'..'9') INTEGER_TYPE_SUFFIX? ;

OCTAL_LITERAL : '0' ('0'..'7')+ INTEGER_TYPE_SUFFIX? ;

fragment HEX_DIGIT : ('0'..'9'|'a'..'f'|'A'..'F') ;

fragment INTEGER_TYPE_SUFFIX : ('l'|'L') ;

FLOATING_POINT_LITERAL
\[
\begin{align*}
\text{IDENT} & : \ \text{JAVA_ID_START} \ (\text{JAVA_ID_PART})^* \\
\text{FLOAT_TYPE_SUFFIX} & : (\text{d} | \text{D}) \\
\text{EXPONENT} & : (\text{e} | \text{E}) \ (\text{+} | \text{−}) \ (0 \ldots 9)^+ \\
\text{ESCAPE_SEQUENCE} & : 'b' | 't' | 'n' | 'f' | 'r' | '\\' | '\n' | '\f' | '\r' | '\t' \\
\text{OCTAL_ESCAPE} & : '0' \ldots '7' | '0' \ldots '7' | '0' \ldots '7' \\
\text{UNICODE.Escape} & : 'u' \text{HEX_DIGIT} \text{HEX_DIGIT} \text{HEX_DIGIT} \text{HEX_DIGIT}
\end{align*}
\]
fragment
  JAVA_ID_START
  :  '\u0024'
  |  '\u0041'.. '\u005a'
  |  '\u005f'
  |  '\u0061'.. '\u007a'
  |  '\u00c0'.. '\u00d6'
  |  '\u00d8'.. '\u00f6'
  |  '\u00f8'.. '\u00ff'
  |  '\u0100'.. '\u1fff'
  |  '\u3040'.. '\u337f'
  |  '\u3400'.. '\u3d2d'
  |  '\u4e00'.. '\u9fff'
  |  '\uf900'.. '\ufaff'
  ;

fragment
  JAVA_ID_PART
  :  JAVA_ID_START
  |  '\u0030'.. '\u0039'
  ;

WS  :  ( ' ' | '\r' | '\t' | '\u000c' | '\n' )
  {
  if ( ! preserveWhitespacesAndComments ) {
    skip();
  } else {
    $channel = HIDDEN;
  }

COMMENT
  :  '/\*' ( options { greedy=false; } : . )* '/
  {
  if ( ! preserveWhitespacesAndComments ) {
    skip();
  } else {
    $channel = HIDDEN;
  }

  }
101

2643 ;
2644
2645 LINE_COMMENT
2646 : '//' ~ ('\n' | '\r')* '\r'? '\n'
2647 {
2648     if (!preserveWhiteSpacesAndComments) {
2649         skip();
2650     } else {
2651         $channel = HIDDEN;
2652     }
2653 }
2654 ;