Marmalade

A Music Creation Language

Savvas Petridis	(sdp2137)	Language Guru
Uzo Amuzie	(ua2144)	Tester
Cathy Jin	(ckj2111)	System Architect
Raphael Norwitz	(rsn2117)	Manager

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Introduction:

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Marmalade is a very readable musical programming language. Similar languages and libraries use clunky object-oriented syntax and require language-specific knowledge, thereby preventing users from composing right away. We wanted to create a tool that would minimize the distance from one's conception of a musical idea to actually writing and playing it. So we tossed aside classes and anything else that seemed unnecessary and left the bare bones: integers, notes, time signatures, instruments, functions, lists, and lists of lists.

Why Marmalade?

This list structure, along with intuitive operators, simple function syntax, clear control flow, and a spartan standard library, gives the composer the freedom to write what they want without compromise. Marmalade breaks a musical piece into four discrete building blocks: notes, measures, phrases, and songs. The user must define and combine notes to form measures, then combine these measures into phrases to be played simultaneously. This bottom-up approach encourages the user to think about his composition as discrete pieces to be arranged and rearranged.

Marmalade can suit any user from those who only seek to use Marmalade's core features and create songs, to those who'd like to create as well as experiment with their pieces by defining complicated functions to transform them. Perhaps the most enticing feature of Marmalade is its low learning curve. One can easily define a series of measures, turn them into phrases and combine them into a song. While doing so, one can define and redefine the time signature at the measure level, instruments at the phrase level, and tempo at the song level to tweak the song to his or her particular liking. And in a few minutes a song has been created, played, and outputted as a midi file!

Language Tutorial:
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Running the compiler and executing a program:
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Steps to run the compiler:

1. $ make
2. $ ./make_java.sh
3. $ ./marmac name.marm executable_name
4. $ ./executable_name

It's that easy!

marmac is a bash script which calls an executable named 'marmalade' created by our compiler (marmalade.ml). It takes in two arguments: a marmalade file and the name of the executable to be created.

→ Sample programs are available in the "marmalade_sample_programs" directory

Language Reference Manual:
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Lexical Conventions:
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Comments:

Comments are ignored by the compiler and have no effect on the behavior of programs. There are is only one style of comments in Marmalade: multi-line.

Multi-line comments are initiated with a slash and star character '/*' and terminated with a star and slash character '*/'. the compiler ignores all content between the indicators. This type of comment does not nest.

```
/*  this is a comment  */
```

Whitespace:

Whitespace consists of any sequence of blank and tab characters. Whitespace is used to separate tokens and format programs. All whitespace is ignored by the marmalade compiler. As a result, indentations are not significant in Marmalade.

Tokens:

In Marmalade, a token is a string of one or more characters consisting of letters, digits, or underscores. Marmalade has 3 kinds of tokens:

1. Identifiers
2. Keywords
3. Operators

Identifier Tokens:

An identifier consists of a sequence of letters and digits. An identifier must start with a letter. A new valid identifier cannot be the same as reserved keywords or pitch literals (see Keywords and Literals). An identifier has no strict limit on length and can be composed of the following characters:

```
a b c d e f g h i j k l m n o p q r s t u v w x y z
A B C D E F G H I J K L M N O P Q R S T U V W X Y Z
0 1 2 3 4 5 6 7 8 9 _
```

Keywords:

funk	Function declaration
return	Function return keyword
if	Conditional Expression
else	Conditional Expression
while	Conditional Expression
and	Boolean AND
or	Boolean OR
int	Integer data type
int_list	Integer list data type
string	String data type
str_list	String list data type
measure	Measure data type
phrase	Phrase data type
song	Song data type
timesig	Time signature data type
play	Standard library function to play data types
print	Standard library function to print data types
output_midi	Standard library function to write data type to a .midi file

Operator tokens:

<table>
<tr><td>+</td><td>-</td><td>*</td><td>/</td><td>=</td><td>$</td></tr>
<tr><td>[]</td><td>&</td><td>|</td><td>==</td><td>!=</td><td>! <</td></tr>
<tr><td><=</td><td>></td><td>>=</td><td>.</td><td>:</td><td></td></tr>
</table>

These will be detailed in the ‘Operator Usage’ section.

Data Types:

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Integer:

An integer declaration consists of the ‘int’ declaration, a variable name, an assignment operator and an optional sign and any number of operators. Any arithmetic operators can be applied to integers as in any other programming language.

Example Declarations:

- `int i = 5;`
- `int i = -5;`

String:

A string declaration consists of the ‘string’ declaration, a variable name, an assignment operator, followed by a string defined in quotes. The string can contain any of the following characters:

letter → [‘a’ - ’z’   ‘A’ - ’Z’]
digit → [‘0’ - ‘9’]
symbols → '_' | ' ' | '.' | ',' | '!' | '$' | ':' | ';' | '(' | ')' | '[' | ']' | '{' |'}' | '&' | '#' | '@' | '?' | '<' | '>' | '+' | '=' | '-'

Example Declarations:

- `string s = “string”;`
- `string s = “Hello World!”;`

Note:

A note consists of the ‘note’ declaration, a positive integer, a period and a character indicating the note value. The positive integer represents the specific note to be played and the type indicates the note value. For example:

44 → C4 (the 4th C on a piano)

The character after the period represents the note value, or length that the note is played.

*.s	→	sixteenth note
*.e	→	eighth note
*.q	→	quarter note
*.h	→	half note
*.w	→	whole note

Example Declarations:

- `note n_0 = 44.s`
- `note n_1 = 44.e;`
- `note n_2 = 44.q;`
- `note n_3 = 54.h;`
- `note n_4 = 68.w;`

Time-Signature:

A time-signature consists of the ‘timesig’ declaration and two integers indicating how a sets of notes should be played. The time signature should be separated by a colon to indicate the numerator and denominator.

Example Declaration:

- `timesig t_sig_0 = $(4:4);`
- `timesig t_sig_1 = $(6:8);`

Instrument:

An instrument is a set of capital letters which indicate what set of sounds a given set of notes will map to.

See the appendix for the full list of instruments that can be used in Marmalade.

Tempo:

The tempo of a song is defined as the speed that a passage of music should be played. In the case of this language, tempo must be a positive integer that can only be applied to a song. Examples can be found in the Song section.

Lists:

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In Marmalade, lists are the only container for storing sets of data. Lists are of variable length. The lists below are list types defined in this language. See '**Operator Usage**' for more specifics.

Integer List:

An integer list declaration consists of the 'int_list' declaration, a variable name, an assignment operator, followed by a list of integers or variable names representing integers.

Example Declarations:

- `int_list i = [42, 47, 54, 19, 22];`
- `int_list i = [0];`
- `int_list i = [];`

String List:

A string list declaration consists of the 'str_list' declaration, a variable name, an assignment operator, followed by a list of strings or variable names containing strings.

Example Declarations:

- `str_list s = ["marmalade", "language", "plt"];`
- `str_list s = ["Hello World!"];`
- `str_list s = [];`

Measure:

Lists of notes in Marmalade are treated as measures. Given a list of notes:

```
measure m_0 = $() [44.q, 64.h, 89.q];
```

If the user would like to add a time signature, he defines it between the parentheses following the $ symbol. If nothing is typed between these parentheses the time-signature is automatically inferred to be 4/4. Thus '$()' represents the default time signature of a measure.

Here is an example with a time signature (6/8) included by the user:

```
measure m_1 = $(6:8)  [42.e, 36.q, 50.h];
```

If notes are predefined, a measure can also be declared as such:

```
note n1 = 44.q;
```

```
note n2 = 55.q;
measure m_1 = $(3:4) [n1, n2];
```

Phrases:

A Phrase is a list of measures to be played in succession from first to the last element. Each phrase is associated with an instrument. For instance:

```
ph_0 = $$() [m_0, m_1]; /* m_0 and m_1 are measures defined above */
```

The '$$()' indicates that the user opted to not specify an instrument for the phrase, and so the default instrument, piano, will be used. (Note: the default symbol of the phrase has one more '$' than the default symbol of the measure).

The user can also input his own instrument:

```
ph_1 = $(GUITAR) [m_0, m_1];
```

which would make ph_1 the same set of notes with the same time signature as ph_0 played by a guitar instead of a piano.

If the measures are not predefined, a phrase can also be declared as below:

```
ph_0 = $$() [ $(6:8)[44.q, 64.h, 89.q], $(3:4) [36.q, 50.h]];
```

As mentioned in the introduction, the programmer should note that a phrase does not need to represent all the notes being played by a given instrument at a given time. Rather it is more analogous to the left hand of a piano, which can play at the same time as the right hand.

Songs:

A song is a list of phrases to be played concurrently. An example of a song could be:

```
song_0 = $$$() [ph_0, ph_1];
```

This song will play phrases ph_0 and ph_1 simultaneously. '$$$()' represents the default tempo (beats per minute) a song is set to, which is 60 bpm. (Note: the default symbol here has one more '$' than the phrase default symbol, and two more '$' than the measure default symbol).

Of course the user can set one himself as well:

```
song_1 = $(120) [ph_0, ph_1];
```

As demonstrated above, phrases can also be declared directly to create a song. For example:

```
song_1 = $(120) [[
            $(PIANO) [ $(6:8)[64.h, 89.q], $(3:4) [36.q, 50.h]],
            $$() [ $(6:8)[44.q, 64.h, 89.q], $(3:4) [36.q, 50.h]
        ]];
```

Operator Usage:

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Arithmetic Operators	*Description*	*Example*
+	Addition	`x + 3`
-	Subtraction	`x - 2`
*	Multiplication	`5 * x`
/	Division	`12 / x`

Arithmetic operators are listed in increasing precedence, addition and subtraction having the least and multiplication and division having the most. Also, addition and subtraction can be applied to notes. For example:

```
45.q + 5        /* this expression has the value: 50.q */
```

Assignment Operator	*Description*	*Example*
=	Assigns value from left hand side to right hand side	`int a = 5`

List Operator	*Description*	*Example*
&	Access Element	`list&1`

```
List Operator Example:
      m_1 = $() [35.q, 35.h];
      n_1 = m_1&1; /* n_1 == 35.q */
```

Precedence of Operations :

ASSIGNMENT, LAST ELEMENT INSERTION **(lowest)**

ACCESS LIST ELEMENT
TIMES, DIVISION
PLUS, MINUS **(highest)**

Logical Operator	*Description*	*Example*
and	AND	`A and B`
or	OR	`A or B`
==	EQUALS	`A == B`
!=	NOT EQUAL	`A != B`

```
A or B
/* If A or B is not 0, the entire expression is evaluated to be 1. */

A and B
/* If A and B are both not 0, then the expression is 1, otherwise 0 */

A == B
/* If A has the same value as B, then A == B is 1 */

A != B
/* If A does not have the same value as B, then A != B is 1 */
```

Definition Operator	*Description*	*Example*
$	Define time signature, instrument, and tempo. Also indicates a function call returns something.	Instrument: $(GUITAR) Time Signature: $(4:4) Tempo: $(120)
[]	Define list	[35.q, 46.h, 42.q]
()	Define funk list (application shown later in funktions)	(play(), print(), play())

Reserved Words:

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Functions:

funk

The keyword ‘funk’ is used to indicate the beginning of a function. For more detailed usage of functions, see the ‘Funktions’ section.

return

The keyword ‘return’ is used only in functions to signify a return value from the function. This keyword can only return one object, since a function can only return one object. A function must have a return value, or else an error will be thrown. For examples of use, see the ‘Funktions’ section.

Control Flow:

if else

‘if’ must be followed by an expression that evaluates to a boolean in parentheses and the body following must be contained in braces, such as:

```
if ( /* boolean expression here */) {
        /* body */
}
```

An ‘if’ block can stand alone, but ‘else’ must be accompanied by at least an ‘if’.

```
if ( /* boolean expression here */) {
        /* if body */
}
else {
        /* else body */
}
```

while

The keyword ‘while’ is implemented similarly to how ‘if’. The expression following ‘while’ must evaluate to a boolean expression. For example:

```
while ( i < 5 ) {
        /* body */
}
```

Standard Library:

play

The ‘play’ keyword will allow a user to play any set of notes once the code is run. This includes a single note or any list object containing a series of notes. ‘play’ only takes in one argument. Notice that the measure it’s playing is in a list and how play is surrounded by parentheses; function application will be discussed in the functions section.

```
m_2 = $() [25.q, 26.q];
(play()) [m_2];         /* play m_2 */
```

print

The ‘print’ keyword will be able to print a string literal or any defined data type in the language. It will print out to the standard output in a way that is readable to the user, and only takes in one argument, which is the argument directly after the keyword. The usage of this keyword is similar to that of the ‘play’ keyword.

```
(print()) [“hello world!”]; /* print ‘hello world!’ */
```

write

The ‘write’ keyword performs almost the same as ‘play’ but will output a midi file, called ‘out.mid’.

```
m_2 = [25.q, 26.q];
(write()) [m_2]; /* writes m_2 to a .midi file */
```

length_measure

The ‘length_measure’ keyword represents a function that can only be applied to measures and will return the length of the measure’s note list.

```
int m_len = $length_measure(m); /* the $ signifies that the function is
returning a value */

/* m has type measure */
```

length_phrase

The ‘length_phrase’ keyword represents a function that can only be applied to phrases and will return the length of the phrase’s measure list.

```
int p_len = $length_phrase(ph); /* ph has type phrase */
```

length_song

The ‘length_song’ keyword represents a function that can only be applied to songs and will return the length of the song’s phrase list.

```
int s_len = $length_measure(song); /* song has type song */
```

length_int_list

The ‘length_int_list’ keyword represents a function that can only be applied to int_lists and will return the length of the int_list.

```
int il_len = $length_measure(inli); /* inli has type int_list */
```

length_string_list

The ‘length_string_list’ keyword represents a function that can only be applied to string_lists and will return the length of the string_list.

```
int strl_len = $length_measure(strl); /* strl has type string_list */
```

evaluate_note

The ‘evaluate_note’ keyword represents a function that can only be applied to a note. It creates a new copy of the note the function was applied to.

evaluate_measure

The ‘evaluate_measure’ keyword represents a function that can only be applied to a measure. It creates a new copy of the measure the function was applied to.

evaluate_phrase

The ‘evaluate_phrase’ keyword represents a function that can only be applied to a phrase. It creates a new copy of the phrase the function was applied to.

evaluate_song

The ‘evaluate_song’ keyword represents a function that can only be applied to a song. It creates a new copy of the song the function was applied to.

Other Expressions:

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All expressions are made up of a sequence of variables, operators, & string literals.

Variables

All variables are of type string literal or one of the defined data types in the language. Variables must begin with a letter and can contain any combination of letters, digits, or the underscore '_'.

Scope:

The scope of all variables is contained to the the area limited between the outermost level of braces in which a variable is defined. For example, in the transpose function the scope of i is from lines 1-6 and the scope of m_1 is from lines 2-5. Local variables cannot be defined in a function however, so 'i' and 'm_1' exist outside the transpose function.

```
1	funk transpose(int i, measure m_1) {
2		m_1 = [40.h];
3		while (i < 5) {
4			/* body */
5		}
6	}
```

If there is a program with no outer braces, then the scope of the variable exists within the entire program. Scope will be fleshed out in more detail in the Funktions section.

Boolean Expressions:

Boolean expressions are defined as any expression that returns true or false. There is no boolean data type in our language. There must be a boolean expression using an operator like 'and', 'or', and '<' between the parentheses of an if statement or while loop. So the while loop displayed below does not compile:

```
int i = 0;
while (i) {
	/* body */
}
```

Funktions:

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Very Important: Local variables cannot be declared within the body of a function, if block, or while block.

This is the reason why function transpose_measure_w has so many arguments; the variables it takes in are all the variables being used within the function. For this reason, there is function ‘transpose_measure’ which takes in the two crucial arguments, then calls ‘transpose_measure_w’ with all of the necessary arguments.

```
/* This function transposes a measure by some value steps */

      funk measure measure transpose_measure_w(measure m, int steps, int
      counter, int j, note k, measure l)
      {
            j = $length_measure(m); /* standard library function */
            counter = 0;
            l = $evaluate_measure(m); /* standard library function */


            while(counter < j)
            {
                  k = l&counter; /* access l element at position counter */
                  l&counter = k + n; /* put new value at position counter in
                  l */
                  counter = counter + 1;
            }

            return l;
      }

      funk measure measure transpose_measure(measure m, int steps)
      {
            return $transpose_measure_w(m, steps, 0, 0, 44.q, $() [55.h]);
      }

      /* keyword funk indicates following code block is a function */
      /* the function is scoped with curly brackets */
```

All functions need to have an implicit parameter, which can either be a measure, phrase, or song. The first ‘measure’ following ‘funk’ indicates that the only implicit parameter this function takes is a measure. The second ‘measure’ indicates the return type, which in this case is a measure. The string after the return type is the name of the function: ‘transpose_measure_w’. The list in the parentheses after the name of the function are **all** the variables used within the function, as none can be declared within.

Applying multiple functions:

```
/* m_1 is a phrase */
```

```
(play(), play(), play()) [m_1, $transpose_measure(m_1, 3),
$transpose_measure(m_1,5)];
```

Functions that do not return anything can be placed in a list and applied to a list of arguments. In the example above, the first ‘play’ is applied to m_1, the second play is applied to the return value of $transpose_measure(m_1, 3), and the third play is applied to the return value of $transpose_measure(m_1,5).

```
(print(), play()) [“hello”, m_1];
```

```
/* this prints ‘hello’ and plays measure m_1 */
```

Project Plan:

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Specification

We used our weekly meetings in the first half of the semester to shell out our Language Proposal and Language Reference Manual. We often encountered issues adding features exactly as defined in our original LRM (i.e. static vs dynamic type system), so we had to update it as we went along.

Development

The development Marmalade's compiler began with implementing the features defined in the original Proposal and LRM in Marmalade's parser and scanner. The project was source-controlled through a git repository, and only the main branch was used, so as to prevent unnecessary merges conflicts. After creating a scanner, parser, and abstract syntax tree, we then created an initial java generator for Hello World. Afterwards we implemented a symbol table as well as an SAST to for semantic analysis. Then, we made a more robust java generator, using the verified objects from the SAST. Once the complete front-to-back progress was compiling marmalade tests and into Java executables, we added features one-by-one through the architecture, wrote tests for that feature, and ran our test suite to verify the functionality of the feature.

Testing

The tester script (run_tests.sh) was inspired by the MicroC version and was added around the Hello World stage of the project, so that tests could be added in. Every time a new feature was implemented, new tests were added to verify that the feature was working.

Programming Style Guide

Generally, we conformed to these general style conventions:

- Indentation → 4 spaces (or 8 for small branches)
- Characters/Line → Max 100

Roles and Responsibilities

Cathy Jin → System Architect
Savvas Petridis → Language Guru
Uzo Amuzie → Tester
Raphael Norwitz → Manager

Development Environment

Text Editor	→	Sublime Text 2/3
Development Machines	→	Mac OS X, ArchLinux Virtual Machine
Compiler Environment	→	OCaml 4.02.03
Automatic Build (OCaml)	→	Make
Testing Environment	→	Shell Scripts
Version Control	→	Github/git

Project Log

Our git commit log can be found here:
→ https://github.com/savvaspetridis/marmalade/commits/master

Our team meeting log can be found here:
→ https://docs.google.com/document/d/12bon_RbHgjMtegHVUVaJE5TC7hQV3rASFgyrxrVgQ3Y

Architectural Design:

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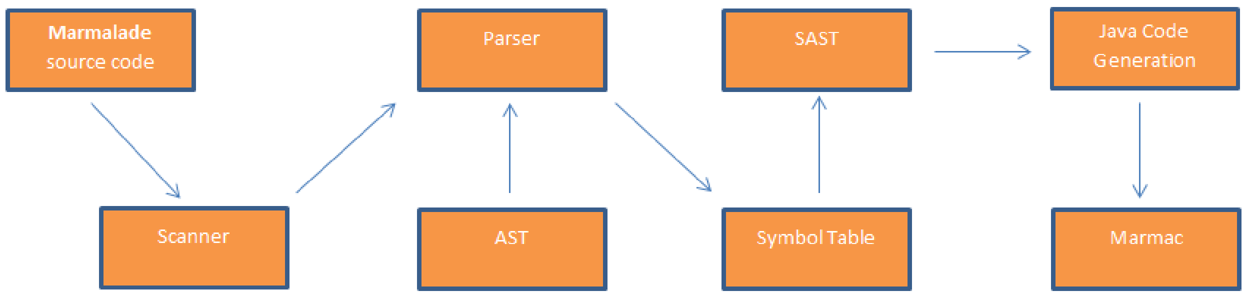

Scanner

The Scanner is passed an input marmalade (.marm) source file and converts the file to a tokenized output. It discards all whitespace and comments and raises an error if any invalid character sequences are encountered (e.g. invalid identifier or escape sequence).

Parser

The Parser is passed the tokenized stream from the scanner. It matches the tokens to a grammar defining the marmalade language. (This is the language structure defined in AST.) Syntax errors in the marmalade code will be identified during parsing, resulting in a raised exception.

Abstract Syntax Tree (AST)

The AST defines the rules and structure for the marmalade language in a Context Free Grammar (CFG). This includes all primitive types and things like variables, blocks, and funktions. This is the intermediate phase of a marmalade program, after being parsed but before being semantically checked.

Symbol Table

Using an approach adapted from corgi, we used the block ids set by the parser and translated these block ids into scope ids. The symbol table is a string map of declared variables and funktions. The symbol table is also used to enforce unique funktion and variables names within each scope (i.e. declaring “int swag” twice in the same scope) and to verify that each variable and funktion is visible within the current scope.

Semantically-checked Abstract Syntax Tree (SAST)

A SAST is generated at this stage with the data types from the AST but with additional information of the type attached. Through the construction of the SAST, the additional typing information allows us to check for type compatibility. Additionally, we check to make sure that funktion calls and return types of the funktions match the funktion declarations that we parsed. Any type mismatches or semantic errors will be reported during this step.

Java Generation

After doing research into music libraries developed for several different languages, we settled on using jMusic since it had some of the functionality most similar to what we were looking to implement in Marmalade. Although we were able to use certain functionalities in jMusic, a custom library (implemented as marmalade.jar in the project) was created to help create common functions for different objects.

Marmac

Marmac is an all-purpose shell script utility that (1) streamlines marmalade environment setup, (2) compiles marmalade source compilation to down to .JAVA and binary .CLASS files, and (3) creates a new shell script -- given the same base name as the marmalade source -- that will run the JAVA executable upon its own execution. A vital piece of marmac is loading the location of the jMusic JAR dependency to your CLASSPATH variable in your local file system, enabling jMusic library calls to be made in Generated Java Code.

Testing Plan:

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Script & Regression Testing

Our test script and testing infrastructure was adapted from MicroC. We developed a shell script that automated testing from a directory named "tests" that contained both unit tests written in marmalade source code, as well as target ".out" files with the expected standard output from each respective marmalade test. Source files were ran from the "tests" directory and their output (.java, .class, .out files) was sourced to a "testdir" directory that was timestamped. We also enabled automatic regression testing by adding an automated archival feature where each time the test script was run, all "testdir" directories from previous runs were automatically sourced to a "previous_tests" directory, with the most recently time-stamped "test_output" directory remained in the project's TLD. This allowed for our file system to remain clean and for previous test results to be easily referenced.

Issues Faced

Slightly inconsistent jMusic standard output: Our test suite adopted a MicroC like process where we utilize the “diff” utility to compare the output generated when marm source is compiled and run versus expected output pre-populated in a separate .out file.

```
[ua2144@uzo marmalade]$ ./test_note_play
jMusic Play: Playing score One note score using JavaSound General MIDI soundbank.
jMusic Play: Waiting for the end of One note score.
[ua2144@uzo marmalade]$
[ua2144@uzo marmalade]$
[ua2144@uzo marmalade]$ ./test_note_play
jMusic Play: Playing score One note score using JavaSound General MIDI soundbank.
jMusic Play: Waiting for the end of One note score.
jMusic MidiSynth: Stopped JavaSound MIDI playback
```

The “test_note_play” test has a corresponding “test_note_play.out” file that contains the stdout in green. The orange output is the typical/expected output, but once every now and then, the stdout in yellow is generated, which makes the test “fail”. This has popped up on occasion for tests with the format “test_<musicStructure>_play*”

Testing MIDI Creation: It was a challenge to add tests for the “write” library funktion call directly to the structure of test suite because of the .MIDI files generated by write. Upon Instructor/TA suggestion, time was spent looking for an alternate to the “diff” tool for .MIDI files but no useful solution was found. Instead, .MIDI files generated were compared to samples with “diff” straight from the command line (byte code was compared). They were also physically played and compared back-to-back as an informal sanity check.

Deprecated Tests: We made major adjustment to our language features in the last few weeks. We moved the test suite to “tests_deprecated ”and populated a new “tests” folder with relevant unit tests.

Lessons Learned:

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Uzo Amuzie (Tester)

All in all, I was glad to hear Professor Edwards say, "oh, that's cool," as anticlimactic as that sounds. This was a long semester that reaped a lot of lessons learned. For one, our group would've benefitted greatly from maintaining our early regularity with team meetings. As the semester unravelled, there was a bit of reluctance to keep our regular meeting time for fear of not accomplishing much in meetings, but we recently learned that the more time we spend together, the better. Even if it is to go over the concepts from lecture or the project plan/structure together and ensure that everyone was on the same page. Open and honest communication was a huge factor as well.

Personally, I wish I would have spoken up more and asked questions (to the TA team, professor, and my teammates) as soon as I was confused or didn't understand a concept. Often times, I had an idea of what I thought I needed to do, only to find out there were corners that I didn't cover. Developing good relationships early on with teammates will help to mitigate the feeling of apprehension of asking of help or clarification.

I'd advise heavily considering 3 things before taking PLT: (1) your potential group, (2) your potential semesterly workload, and (3) your learning/working/communication style. I noticed that most people had their groups set up on/before the first day of class, so strongly consider -- even plan ahead for -- taking this class with a cohort of friends you've gone through some CS classes with, if possible. Think twice about taking 3 (or even 2) heavy programming classes in the same semester. And lastly, know thyself.

Cathy Jin (System Architect)

Some of the biggest challenges we faced were organizing a semester-long group project efficiently, both in terms of working as a group and working on the code. Although we started off at the beginning of the semester meeting regularly, we weren't able to continue this pattern. Even though we thought meeting as a group took up more of everyone's time and sometime seemed like a fruitless use of time, I think meeting up in person would have put more responsibility on people and forced us to talk about and work on the project more consistently.

Something else that was a challenge was planning our work around the language better. We spent a lot of time thinking about interesting features to implement and how they would function within our language, but by the end we realized we should have focused on some of the more basic features first before trying to get other ones to work.

Even though I think we were able to turn in a reasonably cool project, having better time management skills as a team and better communication and accountability for work would have given us the chance to implement a few more features.

Savvas Petridis (Language Guru)

In the end, PLT was a positive experience. It was an incredible opportunity to build a significant piece of software from the bottom up in a semester. The process of deciding what kind of language we wanted to make and what tools we were going to use to actually implement the language was very insightful. I learned to maintain my reservations and not jump into programming without a clear idea of what I wanted to do. We started off with high expectations and an idea for a music creation language that was more clever than the one we actually implemented. But, this is to be expected. In the end we scrapped a few of the more complicated ideas and built a particularly solid, easy-to-read music language.

There were challenges of course, the primary one being team management. We would meet and perhaps only two to three of us would actually be thinking about the project at once. We needed to define more concrete roles and really hold people accountable for their work and define a strict set of deadlines. Because of this, we never really had a good testing system during the entire semester, which of course hurts our project.
A big piece of advice for other teams is to really be careful with who you take. Be sure to choose reliable workers. Finally, my last piece of advice is to get the core details of your language hammered out first before attempting to add any fancy functions. We wasted a great deal of time on parts of our language that made it 'cool'. We should have really nailed down a robust testing system and solidified our language.

Raphael Norwitz (Manager)

Overall this was a terrific experience. Building a substantial piece of software from the ground up is not something you'll get to do all that often and though it's really daunting and potentially horrible if you push it off till the last minute, you'll really get out what you put in. Expect to have mixed feelings throughout the process, especially before you start generating code. Were I to have written this a few days ago, before I started coding in Marmalade, I may have voiced different sentiments.

Given that our goal was to create something that would allow people to quickly and efficiently write readable code that played music, I'd absolutely call Marmalade a success. The way we break music down into discrete interchangeable parts removes the inherent clunky-ness associated with writing music in a typical object oriented language and the way we evaluate functions via lists allows the user to perform many more operations in a tiny fraction of the code, which when you're doing something as involved as writing music is a blessing. We did have to scrap two of our biggest features at the last minute, but in retrospect they weren't critical to the core functionality of the language. To that end, were I to do it again I would start off focusing more on the actual structure of the language, rather than what Edwards calls 'syntactic sugar'. Our decisions to make Marmalade almost script like, so a user can just start coding and in two or three lines produce a useable program, ended up being a really cool, but if we had a different purpose in mind this may not have worked out so nicely.

In terms of general advice, there's a lot of finicky stuff you'll have to do but if you're resourceful and aren't scared to ask help from Edwards and the TA's (provided you're not wasting their time) you'll be fine. Though OCaml looks completely intractable to begin with, if you go to Edwards with specific questions, he'll really clear things up. One thing we as a group could have done better is get an understanding of the bigger picture before diving in and writing a parser. Had I spent a good 10-15 hours at the beginning of the semester looking at other projects and making sure I at least had a sense of what each of the files were doing, it would have saved us the chore of rewriting the parser. On the other hand, I think the way we looked closely at three different languages, Corgi , Sheets and Fry (all from Fall 2014), each of which had a few features we wanted to emulate but which were otherwise very different, worked really well. The case studies gave us a wide view of different implementations which helped us implement some of our more unorthodox features.

Maybe the most valuable thing I got out of this class was experiencing firsthand the difficulties that come with trying to manage people in the context of a sizable project. An accommodating, hands-off leader may work when you have an all around solid team, but in the grand scheme of PLT those are rare. Don't assume your teammates' code works just because they say it works, or they show you it working on their machine or in a specific case. Look at their code and if you see something fishy, be vocal about it and don't be scared to threaten and go to Edwards if there's repeated misbehavior. Though Marmalade feels like such an excellent project now, I recognize that there's a high likelihood there are fixable bugs because our test suite isn't comprehensive. This would not have been the case had I been more forceful and proactive.

As a manager, I also learned how judicious one needs to be in delegating work. Especially if you've worked something out in your head, make sure you understand exactly how it'll churn out code on the other end before dumping it on a teammate. Much of one of my teammates time was spent building a complicated function to parse expressions which was a million times more complicated than it needed to be, and made code generation on the front end totally impossible. Though mistakes happen, this one could easily have been avoided and hopefully this mistake will finally teach me to plan rigorously before I code.
All complaints aside though, I'm extremely happy with the end result and I've gained so much experience and programmatic maturity that I'd unquestionably do it again, irrespective of the team.

Appendix

Appendix:

--

Instrument List:

--

The following instruments can be applied in Marmalade:

AC_GUITAR	FRENCH_HORN	POLYSYNTH
ACCORDION	GLOCK	RECORDER
AGOGO	GUITAR	REED_ORGAN
ALTO	HARMONICA	SAXOPHONE
ALTO_SAX	HARP	SITAR
BAGPIPE	HARPSICHORD	STEELDRUM
BANJO	HONKYTONK	STRINGS
BARITONE_SAX	HONK	TOM_TOMS
BASSOON	HORN	TROMBONE
BELLS	JAZZ_GUITAR	TRUMPET
BRASS	JAZZ_ORGAN	TUBA
CELLO	KALIMBA	VIBRAPHONE
CHOIR	MARIMBA	VIOLA
CHURCH_ORGAN	MUSIC_BOX	VIOLIN
CLARINET	OBOE	VOICE
CYMBAL	OOH	WHISTLE
DOUBLE_BASS	ORGAN	WOODBLOCKS
DRUM	PAN_FLUTE	XYLOPHONE
ECHO	PHONE	
ELECTRIC_BASS	PIANO	
ELECTRIC_GUITAR	PICCOLO	
FIDDLE	PIPE_ORGAN	
FLUTE	PIPES	

Marmac and marmalade.ml:

```
#!/bin/bash

# run the marmalade compiler
./marmalade $2 < $1

# compile the java source
javac -classpath ./javaclasses/jMusic1.6.4.jar:./javaclasses/
    marmalade.jar:. $2.java

# create a Bash script which runs the java program and set the
    privilages so it's accessable
STR=$'#!/bin/bash\njava -classpath ./javaclasses/jMusic1.6.4.jar:./
    javaclasses/marmalade.jar:. '
echo "$STR$2" > ./$2
chmod 755 ./$2
```

Listing 1: marmac

```
(*
 * Compiler for Marmalade
 *)

open Printf

let _ =
  let lexbuf = Lexing.from_channel stdin in
  let program = Parser.program Scanner.token lexbuf in
  let env = Table.create_table program in
  let sast_pgm = Sast.confirm_semantics program env in
  let compiled_program = (*Compile.to_java program Sys.argv.(1)*)
    Javagen.gen_pgm sast_pgm Sys.argv.(1)
     let file = open_out (Sys.argv.(1) ^ ".java") in
      fprintf file "%s" compiled_program;
```

Listing 2: marmalade.ml

Scanner:

```
{ open Parser }

let digit = ['0'-'9']
let letter = ['a'-'z' 'A'-'Z']

rule token = parse
    [' ' '\t' '\r' '\n'] { token lexbuf } (* Whitespace *)
|    "/*"         { comment lexbuf }
|    '('          { LPAREN }
|    ')'          { RPAREN }
|    '{'          { LBRACE }
|    '}'          { RBRACE }
|    '['          { LBRACK }
|    ']'          { RBRACK }
|    ';'          { SEMI }
|    ','          { COMMA }
|    '+'          { PLUS }
|    '-'          { MINUS }
|    '*'          { TIMES }
|    '/'          { DIVIDE }
|    '='          { ASSIGN }
```

```
|   "=="          { EQ }
|   "!="          { NEQ }
|   '<'           { LT }
|   "<="          { LEQ }
|   '>'           { GT }
|   ">="          { GEQ }
|   '-'           { DASH }
|   "<<"          { APPEND }
|   '!'           { NOT }
|   "if"          { IF }
|   "else"        { ELSE }
|   "elif"        { ELIF }
|   "and"         { AND }
|   "or"          { OR }
|   '.'           { PERIOD }
|   ':'           { COLON }
|   "return"      { RETURN }
|   "while"       { WHILE }
|   "funk"        { FUNK }
|   "int"       { INT }
|   "note"      { NOTE}
| "int_list"    { INTLIST }
| "str_list"    { STRL}
|   "string"    { STRING }
| "measure"     { MEASURE }
| "phrase"      { PHRASE }
| "song"        { SONG }
| "list"        { LIST }
| "timesig"     { TIMESIG }
| "instr"       { INSTR }
| "tempo"       { TEMPO }
| '@'           { AT }
| '&'           { INDEX }
| '$'          { DOLLAR }
|   '.' (('s'|'e'|'q'|'h'|'w') as lxm) { NOTE_TYPE(lxm) }
|    (digit)+ as lxm { INT_LIT(int_of_string lxm) }
|   '"' ((letter | digit | '_' | ' ' | '.' | ',' |'!' | '$' | ':' |
    ';' |'(' | ')' | '[' | ']' | '{' |'}' | '&' | '&' | '#' | '@'
  | '?' | '<' | '>' | '+' | '=' | '-' )* as lxm) '"' {
  STRING_LIT(lxm) }
|   (letter | digit | '_')+ as lxm  { ID(lxm) }
| ''' ((letter | digit | ' ') as lxm) ''' { BOUND(lxm) }
|   (letter)+ as lxm { INSTRUMENT(lxm) }
|   eof         { EOF }
|   _ as char { raise (Failure("Error: Illegal character: " ^ Char.
    escaped char)) }

and comment = parse
    "*/"          { token lexbuf }
|   _             { comment lexbuf }
```

Listing 3: scanner.mll

Parser:

```
%{ open Ast

let scope_id = ref 1

let inc_block_id (u:unit) =
    let x = scope_id.contents in
    scope_id := x + 1; x
```

```
%}

%token LPAREN RPAREN LBRACE RBRACE LBRACK RBRACK
%token SEMI COMMA PLUS MINUS TIMES
%token <char> BOUND
%token INT NOTE STRING MEASURE PHRASE SONG LIST TIMESIG INSTR TEMPO
    INTLIST STRL
%token DIVIDE ASSIGN EQ NEQ LT LEQ
%token GT GEQ DASH APPEND NOT
%token <char> NOTE_TYPE
%token IF ELSE ELIF AND OR
%token PERIOD COLON
%token RETURN WHILE
%token FUNK AT DOLLAR INDEX
%token <int> INT_LIT
%token <string> STRING_LIT ID INSTRUMENT
%token EOF

%nonassoc ELSE
%nonassoc NOELSE
%right ASSIGN
%left OR
%left AND
%left EQ NEQ
%left LT GT LEQ GEQ
%left PLUS MINUS
%left TIMES DIVIDE
%right NOT

%start program
%type <Ast.program> program

%%
program:
    /* nothing */  {{stmts = []; funcs = []} }
    /* List is built backwards */
|   program fdecl {{ stmts = $1.stmts; funcs = $2 :: $1.funcs }}
| program stmt {{stmts = $2 :: $1.stmts; funcs = $1.funcs}}

/* Function Declaration */

fdecl:
   t_dec_l ID LPAREN arguments RPAREN LBRACE stmt_list RBRACE
     {{ ret_type = List.hd (List.rev $1);
      f_type = List.tl (List.rev $1);
        fname = $2;
      args = $4;
      body = {locals = $4; statements = List.rev $7; block_id =
    inc_block_id ()}
   }}

t_dec_l:
      FUNK  { [] }
    | t_dec_l type_dec { $2 :: $1 }

/* Argument list creator for Function Declarations */

arguments:
  /* nothing */ { [] }
  | arg_list    { List.rev $1 }

/* Argument list */
```

```

arg_list:
  fvmod { [$1] }
  | arg_list COMMA fvmod { $3 :: $1 }

fvmod:
  INT ID {($2, false, Int)}
  | STRING ID {($2, false, String)}
  | NOTE ID {($2, false, Note)}
  | SONG ID {($2, true, Song)}
  | MEASURE ID {($2, true, Measurepoo)}
  | INTLIST ID {($2, true, Intlist)}
  | STRL ID {($2, true, Stringlist)}
  | PHRASE ID {($2, true, Phrase)}
    | TIMESIG ID {($2, false, TimeSig)}
    | INSTR ID {($2, false, Instr)}
    | TEMPO ID {($2, false, Tempo)}

/* a stmt can be an expression, variable modification, a
    conditional stmt, or return */

stmt:
  expr SEMI { Expr($1) }
| vmod SEMI   { VarDecl($1) }
| conditional_stmt { $1 }
|   RETURN expr SEMI { Return($2)}

/* all type declarations */

type_dec:
  INT    {Int}
| NOTE   {Note}
| MEASURE {Measurepoo}
| PHRASE  {Phrase}
| SONG   {Song}
| STRING  {String}
|    LIST  {List}
| INTLIST {Intlist}
| STRL  {Stringlist}
|    TIMESIG {TimeSig}
|    INSTR    {Instr}
|    TEMPO    {Tempo}

conditional_stmt:
  IF LPAREN expr RPAREN block %prec NOELSE { If($3, $5, {locals =
    []; statements = []; block_id = inc_block_id ()}) }
|   IF LPAREN expr RPAREN block ELSE block { If($3, $5, $7) }
| WHILE LPAREN expr RPAREN block { While($3, $5) }

block:
  LBRACE stmt_list RBRACE { {locals = []; statements = List.rev $2;
     block_id = inc_block_id ()} }

stmt_list:
    /* nothing */  { [] }
    | stmt_list stmt { $2 :: $1 }

vmod:
| type_dec ID ASSIGN expr {Assign($1, $2, $4)}
| ID ASSIGN expr {Update($1, $3)}
| list_index ASSIGN expr { Index_Update($1, $3) }

```

```
expr:
app_gen  {$1}
| list_index {$1}
| arith {$1}
| add_on_expr {$1}


list_index:
    ID INDEX INT_LIT { Index($1, IntLit($3)) }
 |  ID INDEX ID {Index($1, Id($3))}

add_on_expr:
    DOLLAR LPAREN RPAREN reg_list { Measure($4, TimeSig(4, 4))}
| DOLLAR DOLLAR LPAREN RPAREN reg_list  { Phrase( $5, Instr("PIANO")) }
| DOLLAR DOLLAR DOLLAR LPAREN RPAREN reg_list { Song($6, Tempo(60))}
|   DOLLAR LPAREN INT_LIT COLON INT_LIT RPAREN reg_list { Measure($7, TimeSig($3, $5)) }
|   DOLLAR LPAREN ID RPAREN reg_list { Phrase( $5, Instr($3))  }
|   DOLLAR LPAREN INT_LIT RPAREN reg_list { Song( $5, Tempo($3)) }

/* beginning of chain of expressions, ordered by precedence */

arith:
  l_OR { $1 }

primary_expr:
    ID              { Id($1) }
| literal     { $1 }
| LPAREN expr RPAREN { $2 }

bound_list:
      {[]}
| bound_list BOUND DASH BOUND {(Ranges($2, $4) :: $1)}

literal:
  INT_LIT {IntLit($1)}
| note      {$1}
|   STRING_LIT {String_Lit($1)}
| DOLLAR function_invocation { $2 }

/* multiplication */

mul_expr:
  primary_expr /*lit*/    { $1 }
| mul_expr TIMES primary_expr { Binop($1, Times,$3) }
|   mul_expr DIVIDE primary_expr { Binop($1, Divide, $3) }

/* addition */

add_expr:
  mul_expr { $1 }
| primary_expr PLUS mul_expr  { Binop($1, Plus, $3) }
|   primary_expr MINUS mul_expr { Binop($1, Minus, $3) }

/* <, <=, >, >= */

r_expr:
  add_expr    { $1 }
|   r_expr LT r_expr    { Binop($1, Less, $3) }
|   r_expr LEQ r_expr   { Binop($1, Leq, $3) }
```

```
|    r_expr GT r_expr     { Binop($1, Greater, $3) }
|    r_expr GEQ r_expr    { Binop($1, Geq, $3) }

/* equal and not equal */

eq_exp:
  r_expr { $1 }
|    eq_exp EQ eq_exp     { Binop($1, Equal, $3) }
|    eq_exp NEQ eq_exp    { Binop($1, Neq, $3) }

/* logical And */

l_AND:
  eq_exp { $1 }
| l_AND AND l_AND    { Binop($1, And, $3) }

/* logical Or */

l_OR:
  l_AND { $1 }
|    l_AND OR l_OR    { Binop($1, Or, $3) }

/* app_gen creates lists, as well as lists of functions for
    application */

app_gen:
| funk reg_list {FuncList($1, $2)}
|    reg_list  {BasicList($1)}

/* parenthesis contain the list of functions to be applied */

funk:
  LPAREN f_arithmetics RPAREN {$2}

/* make list of function_invocations */

f_arithmetics:
  f_arithmetics COMMA function_invocation {$3 :: $1}
|    function_invocation {[$1]}

/* ID and arguments of function in list */

function_invocation:
  ID LPAREN funk_args RPAREN {FunkCall($1, List.rev $3)}
| ID LPAREN RPAREN {FunkCall($1, [])}

/* make list of function arguments */

funk_args:
  funk_args COMMA arithmeticID_arg {$3 :: $1}
| arithmeticID_arg {[$1]}

/* arguments can be many expressions: another list, addition expr,
    logical expr, etc */

arithmeticID_arg:
    list_index {$1}
    | app_gen {$1}
    | arith {$1}
    | add_on_expr { $1 }
    | function_invocation { $1 }

```

```
reg_list:
  LBRACK funk_args RBRACK {List.rev $2}

note:
  INT_LIT NOTE_TYPE {Note($1, $2)}
```

Listing 4: parser.mly

Abstract Syntax Tree:

```
(*
 * Marmalade Abstract Syntax Tree
 *)

type op = Plus | Minus | Times | Divide | Equal | Neq | Less | Leq | Greater | Geq | And | Or

type declare_type = Int | Note | String | Song | Phrase | Measurepoo | TimeSig |
Instr | Tempo | List | Intlist | Stringlist | Wild | Null_Type | Default | SongArr

type char_pair = Ranges of char * char

type var = string * bool * declare_type

type range = int * int

type expr =
  IntLit of int
  | Id of string
  | String_Lit of string
  | Note of int * char
    | TimeSig of int * int
    | Instr of string
    | Tempo of int
    | Index of string * expr
    | Default
    | Msk_list of expr * expr
    | Measure of expr list * expr (* list of notes, and its time signature *)
    | Phrase of expr list * expr (* list of measures and an instrument *)
    | Song of expr list * expr (* list of phrases and a BPM *)
  | Binop of expr * op * expr
  | BasicList of expr list
  | FuncList of expr list * expr list
    | FunkCall of string * expr list

and special_exp = {ids: string list; bounds: char_pair list list}

type vmod =
  Assign of declare_type * string * expr  (* declare a new variable with its type *)
  | Update of string * expr (* reassign a value to a previously declared variable *)
  | Index_Update of expr * expr

type stmt =
  Expr of expr
  | VarDecl of vmod
  | If of expr * block * block
```

```
  | While of expr * block
  | Return of expr
  | Fdecl of fdecl
  | Null_Type
  | None

(* each block has a list of variables, statments, and an id *)

and block = {
  locals: var list;
  statements: stmt list;
  block_id: int
}

(* function declaration *)

and fdecl = {
    fname : string;
    ret_type : declare_type;
    f_type : declare_type list;
    args : var list;
    body : block;
}

type scope_var_decl = string * bool * declare_type * int

type scope_func_decl = string * declare_type * declare_type list *
    declare_type list * int

type decl =
    Func_Decl of scope_func_decl
  | Var_Decl of scope_var_decl

type program = {stmts: stmt list; funcs: fdecl list}
```

Listing 5: ast.ml

Symbol Evaluation Table:

```

(*
 * table.ml of marmalade
 * Creates table for checking SAST
 *)

open Ast

module StrMap = Map.Make(String)

let table_env (table,_) = table
let scope_env (_,scope) = scope
let type_of_funct_args (_,_,p_type) = p_type

let over_scope = Array.make 1000 0

let rec map func lst env =
  match lst with
      [] -> env
    | head :: tail ->
      let new_env = func head env in
        map func tail new_env

```

```

let name_scope_str (name:string) env =
  name ^ "_" ^ (string_of_int (scope_env env))

let rec get_scope name env =
    if StrMap.mem (name_scope_str name env) (fst env) then (snd env)
    else if (snd env) = 0 then raise(Failure("Error: Symbol " ^ name ^ " not declared. " ^ string_of_int (snd env)))
    else get_scope name (fst env, over_scope.(snd env))

let rec get_decl name env =
  let key = name_scope_str name env in
  if StrMap.mem key (fst env) then StrMap.find key (fst env)
  else
    if (snd env) = 0 then raise (Failure("Error: Symbol " ^ name ^ " not declared in current scope" ^ string_of_int (snd env) ^ "."))
      else get_decl name ((fst env), over_scope.(snd env))

let insert_symb (name:string) (decl:decl) env =
  let key = name_scope_str name env in
    if StrMap.mem key (table_env env)
    then raise(Failure("Error: Symbol " ^ name ^ " declared twice in same scope."))
    else ((StrMap.add key decl (table_env env)), (scope_env env))

let insert_var var env =
  let (name, p_type) = var in
  let is_implicit_array =
    (match p_type with
      (Int | Note | String | TimeSig | Instr | Tempo) -> false
      | _ -> true) in insert_symb name (Var_Decl(name, is_implicit_array, p_type, (scope_env env))) env

let insert_astvar var env =
  let (name, arr_b, typ) = var in
  insert_var (name, typ) env

(* insert stmt - matches first, then inserts *)

let rec insert_stmt stmt env =
  (match stmt with
  Expr(exp) -> env
  | If(e, bl_1, bl_2) -> let env_1 = insert_code_block bl_1 Wild env in insert_code_block bl_2 Wild env_1
  | While(e, bl) -> insert_code_block bl Wild env
  | Fdecl(fdec) -> insert_funk fdec env
  | VarDecl(chan) -> (match chan with
    Assign(typ, id, blah) -> insert_var (id, typ) env
    | Update(str, exr) ->  env
    | Index_Update(_, _) -> env)
  | _ ->  env )

(* insert contents of a block of code *)

and insert_code_block block return_tp env =
  let (table, scope) = env in
  let id = block.block_id in
  let env = map insert_astvar block.locals (table, id) in
  let env = map insert_stmt block.statements env in
  over_scope.(id) <- scope;
```

```
  ((table_env env), scope)

(* insert contents of a function into the table *)

and insert_funk func env =
  let (table, scope) = env in
  let arg_names = List.map type_of_funct_args func.args in
  let env = insert_symb func.fname (Func_Decl(func.fname, func.ret_type, func.f_type, arg_names, scope)) env in
  insert_code_block func.body (func.ret_type) ((table_env env), scope)

(* initialize start_env *)

let start_env =
  let table = StrMap.add "print_0" (Func_Decl("print", Null_Type, [Int; Note;
    String; Song; Phrase; Measurepoo; TimeSig; Instr; Tempo; List ; Intlist ; Stringlist; Wild], [], 0)) StrMap.empty in
    let table = StrMap.add "evaluate_note_0" (Func_Decl("evaluate_note", Note, [Int; Note;
    String; Song; Phrase; Measurepoo; TimeSig; Instr; Tempo; List ; Intlist ; Stringlist; Wild], [Note], 0)) table in
     let table = StrMap.add "evaluate_measure_0" (Func_Decl("evaluate_measure", Measurepoo, [Int; Note;
    String; Song; Phrase; Measurepoo; TimeSig; Instr; Tempo; List ; Intlist ; Stringlist; Wild], [Measurepoo], 0)) table in
    let table = StrMap.add "evaluate_phrase_0" (Func_Decl("evaluate_phrase", Phrase, [Int; Note;
    String; Song; Phrase; Measurepoo; TimeSig; Instr; Tempo; List ; Intlist ; Stringlist; Wild], [Phrase], 0)) table in
    let table = StrMap.add "evaluate_song_0" (Func_Decl("evaluate_song", Song, [Int; Note;
    String; Song; Phrase; Measurepoo; TimeSig; Instr; Tempo; List ; Intlist ; Stringlist; Wild], [Song], 0)) table in
    let table = StrMap.add "length_note_0" (Func_Decl("length_mnote", Int, [Measurepoo; Note; Phrase; Song; Intlist; Stringlist], [Note], 0)) table in
    let table = StrMap.add "length_measure_0" (Func_Decl("length_measure", Int, [Measurepoo; Note; Phrase; Song; Intlist; Stringlist], [Measurepoo], 0)) table in
    let table = StrMap.add "length_phrase_0" (Func_Decl("length_phrase", Int, [Measurepoo; Note; Phrase; Song; Intlist; Stringlist], [Phrase], 0)) table in
    let table = StrMap.add "length_song_0" (Func_Decl("length_measure", Int, [Measurepoo; Note; Phrase; Song; Intlist; Stringlist], [Song], 0)) table in
    let table = StrMap.add "length_int_list_0" (Func_Decl("length_int_list", Int, [Measurepoo; Note; Phrase; Song; Intlist ; Stringlist], [Intlist], 0)) table in
    let table = StrMap.add "length_string_list_0" (Func_Decl("length_string_list", Int, [Measurepoo; Note; Phrase; Song; Intlist; Stringlist], [Stringlist], 0)) table in
  let table = StrMap.add "play_0"  (Func_Decl("play", Null_Type, [Note; String; Song; Phrase; Measurepoo; Wild], [], 0)) table in
  let table = StrMap.add "write_0" (Func_Decl("write", Null_Type, [Note; String; Song; Phrase; Measurepoo], [], 0)) table in
  let table = StrMap.add "main_0" (Func_Decl("main", Null_Type, [], [], 0)) table in
  (table, 0)

(* main function in this file -- initiates table, inserts
```

```
    statements and funks *)

let create_table p =
  let env = start_env in
  let env =  map insert_stmt (List.rev p.stmts) env in
  let env = map insert_funk (List.rev p.funcs) env in
  let () = Printf.printf "// Symbol Table Created" in
    env
```

Listing 6: table.ml

Semantic Analysis:

```
(*
 * Semantic analysis for Marmalade
 *
 *)

open Ast

let fst_of_three (t, _, _) = t
let snd_of_three (_, t, _) = t
let thrd_of_three (_, _, t) = t

(* verified expressions *)

type s_expr =
  S_Int_Lit of int * declare_type
  | S_Id of string * declare_type
  | S_String_Lit of string * declare_type
  | S_Note of int * char * declare_type
  | S_Measure of s_expr list * s_expr * declare_type (* S_Note list
    , S_TimeSig, declare_type *)
  | S_Phrase of s_expr list * s_expr * declare_type  (* S_Measure
    list, S_Instr, declare_type *)
  | S_Song of s_expr list  * s_expr * declare_type   (* S_Phrase
    list, *)
    | S_TimeSig of int * int * declare_type        (* ex: ((4:4),
    TimeSig) *)
    | S_Instr of string * declare_type           (* ex: (BASS,
    Instr) *)
    | S_Tempo of int * declare_type             (* ex: (120, Tempo)
    *)
    | S_Binop of s_expr * op * s_expr * declare_type
  | S_Call of string * s_expr * s_expr list * declare_type list *
    declare_type
  | S_Index of string * s_expr * declare_type
  | S_Arr of s_expr list * declare_type
  | S_Db_Arr of s_expr * s_expr
  | S_Call_lst of s_expr list
  | S_Noexpr                       (* Default - No value *)

(* verified statemnets *)

type s_stmt =
  S_CodeBlock of s_block
  | S_expr of s_expr
  | S_Assign of string * s_expr * declare_type
  | S_Arr_Assign of string * s_expr * s_expr * declare_type
  | S_Return of s_expr
  | S_If of s_expr * s_stmt * s_stmt (* stmts of type D_CodeBlock
    *)
```

```
  | S_For of s_stmt * s_stmt * s_stmt * s_block (* stmts of type D_Assign | D_Noexpr * D_Expr of type bool * D_Assign | D_Noexpr *)
  | S_While of s_expr * s_block
  | S_Append_Assign of declare_type * string * s_expr list
  | S_Index_Update of string * s_expr * s_expr * declare_type


and s_block = {
  s_locals : scope_var_decl list;
  s_statements: s_stmt list;
  s_block_id: int;
}

(* verified function declaration *)

type s_func = {
  s_fname : string;
  s_ret_type : declare_type; (* Changed from types for comparison error in confirm_stmt *)
    s_f_type : declare_type list;
    s_formals : scope_var_decl list;
  s_fblock : s_block;
}

type s_program = {
  s_gvars: scope_var_decl list;
  s_pfuncs: s_func list;
}

let rec get_range l (a:char) b =
  let lower = Char.code a in
  let upper = Char.code b in
  if lower = upper then
    a :: l
  else
    get_range (a :: l) (Char.chr (lower+1)) b

let get_dt fdc = match fdc with
  | Func_Decl(_, dt, it, _, den) -> (dt, it, den)
  | Var_Decl(_, _, dt, den) -> (dt, [dt], den)

(* returns string of the primitive type *)

let string_of_prim_type = function
  | Int -> "int"
  | String -> "string"
  | Note -> "note"
  | Measurepoo -> "measure"
  | Phrase -> "phrase"
  | Song -> "song"
  | TimeSig -> "timesig"
  | Instr -> "instr"
  | Tempo -> "tempo"
  | Intlist -> "int_list"
  | Stringlist -> "str_list"
  | Null_Type -> "null"


(* returns type of expr *)

let rec type_of_expr here = match here with
```

```
  S_Int_Lit(_,t) -> t
  | S_String_Lit(_,t) -> t
  | S_Id(_,t) -> t
  | S_Note(_,_,t) -> t
  | S_TimeSig(_,_,t) -> t
  | S_Instr(_,t) -> t
  | S_Tempo(_,t) -> t
  | S_Measure(_, _, t) -> t
  | S_Phrase(_, _, t) -> t
  | S_Song( _, _, t) -> t
  | S_Binop(_,_,_,t) -> t
  | S_Arr (_, t) -> let tpe = (match t with
      Int -> Intlist
      | String -> Stringlist
      | Note -> Measurepoo
      | Measurepoo -> Phrase
      | Phrase -> Song) in tpe
  | S_Call (_, _, _, _, t) -> t
  | S_Index (_, _, t) -> let tpe = (match t with
        Intlist -> Int
        | Stringlist -> String
        | Measurepoo -> let hack = S_Note(5, 'a', Note) in
            let bs = (match hack with S_Note(i, d, k) -> k) in
                bs
        | Phrase -> Measurepoo
        | Song -> Phrase) in tpe
  | S_Db_Arr(_, ar) -> let b = type_of_expr ar in b
  | S_Noexpr -> Null_Type
  | _ -> raise(Failure("Error: Could not match type in type_of_expr
    ."))


let rec map_to_list_env func lst env =
  match lst with
      [] -> []
    | head :: tail ->
      let r = func head env in
        r :: map_to_list_env func tail env

let rec traverse_main func lst =
  match lst with
    [] -> []
    | head :: tail ->
      let r = func head in
      r :: traverse_main func tail

let drop_funk li =
  match li with
    Expr(v) ->          Expr(v)
    | VarDecl(v) ->       VarDecl(v)
    | If(exp_1, blk, exp_2) ->  If(exp_1, blk, exp_2)
    | While(exp, blk) ->    While(exp, blk)
    | _ ->             Null_Type

let confirm_var var env =
  let decl = Table.get_decl (fst_of_three var) env in
  match decl with
    Func_Decl(f) -> raise(Failure("Error: symbol is not a variable"
    ))
    | Var_Decl(v) ->  let (vname, varray, vtype, id) = v in
      (vname, varray, vtype, id)

```

```
let confirm_func_decl name env =
  let decl = Table.get_decl name env in
  match decl with
    Func_Decl(f) -> name
    | _ -> raise(Failure("Error: id " ^ name ^ " not a function"))

let confirm_id_get_type id env =
  let decl = Table.get_decl id env in
  match decl with
    Var_Decl(v) -> let (_, _, t, _) = v in t
    | _ -> raise(Failure("Error: id " ^ id ^ " not a variable."))

(* get variables *)

let get_vars li =
  (match li with
    VarDecl(v) ->
      (match v with
        Assign(dt, iden, v) ->
          (match dt with
            Int -> (iden, false, dt)
            | Note -> (iden, false, dt)
            | Measurepoo -> (iden, false, dt)
            | String -> (iden, false, dt)
                        | TimeSig -> (iden, false, dt)
                        | Instr -> (iden, false, dt)
                        | Tempo -> (iden, false, dt)
                        | _ -> (iden, true, dt))
        | Update(iden, v) -> ("", false, Wild)
        | Index_Update(expr_1, expr_2) -> ("", false, Wild))
    | _ ->  ("", false, Wild))

(* confirm correct format of a binary operation *)

let confirm_binop l r op =
  let tl = type_of_expr l in
  let tr = type_of_expr r in
  match op with
    Plus | Minus | Times | Divide  -> (match (tl, tr) with
      Int, Int -> Int
      | Note, Int -> Note
      | _, _ -> raise(Failure("Error: Cannot apply + - * / op to
    types " ^ string_of_prim_type tl ^ " + " ^ string_of_prim_type
    tr)))
    | Equal | Neq -> if tl = tr then Int else (match(tl, tr) with
      _, _ -> raise(Failure("Error: Cannot apply == !=  op to types
     " ^ string_of_prim_type tl ^ " + " ^ string_of_prim_type tr)))
    | Less | Greater | Leq | Geq-> (match (tl, tr) with
      Int, Int -> Int
      | Note, Int -> Int
      | Note, Note -> Int
      | _, _ -> raise(Failure("Error: Cannot apply < > <= >=  op to
     types " ^ string_of_prim_type tl ^ " + " ^ string_of_prim_type
     tr)))
    | And | Or -> (match (tl, tr) with
      Int, Int-> Int
      | _, _ -> raise(Failure("Error: Cannot apply && ||  op to
    types " ^ string_of_prim_type tl ^ " + " ^ string_of_prim_type
    tr)))

(* map function to list *)

```

```
let rec map1 lst func env boo =
  match lst with
    [] -> []
    | head :: tail ->
      let ret = func head env boo in
        ret :: map1 tail func env boo

(* map function to 2d list *)

let rec map2 lst func env boo =
  match lst with
    [] -> []
    | head :: tail ->
      let ret = map1 head func env boo in
        ret :: map2 tail func env boo

(* map function to 3d list *)

let rec map3 lst func env boo =
  match lst with
    [] -> []
    | head :: tail ->
      let ret = map2 head func env boo in
        ret :: map3 tail func env boo

(* convert AST expressions into SAST expressions *)

let rec confirm_expr ex env boo =
  match ex with
  IntLit(i)        -> S_Int_Lit(i, Int)
  | Id(st)       -> S_Id(st, confirm_id_get_type st env)
  | String_Lit(st)  -> S_String_Lit(st, String)
  | Note(ct, nt)    -> S_Note(ct, nt, Note)
  | Measure(nt_list, time) -> let new_time = confirm_expr time env true in
                 let s_note_list = map1 nt_list confirm_expr env true in
                 S_Measure(s_note_list, new_time, Measurepoo)
  | Phrase(m_l, inst) -> let verified_list = map1 m_l confirm_expr env boo in
                S_Phrase( verified_list, confirm_expr inst env boo, Phrase)
  | Song(s_l, tempo) -> S_Song(map1 s_l confirm_expr env boo, confirm_expr tempo env boo, Song)
    | TimeSig(num, den) -> S_TimeSig(num, den, TimeSig)
    | Instr(st)          -> S_Instr(st, Instr)
    | Tempo(i)           -> S_Tempo(i, Tempo)
    | Index(str, i)      ->
            let st = get_id_type str env in
            let rl_int = (match i with IntLit(v) -> S_Int_Lit(v, Int)
              | Id(nme) -> S_Id(nme, Int)) in
            S_Index(str, rl_int, st)
  | Binop(lft, op, rgt) ->
    let l = confirm_expr lft env false in
    let r = confirm_expr rgt env false in
    let tp = confirm_binop l r op in
    let lt = type_of_expr l in
    let rt = type_of_expr r in
    if lt = rt then S_Binop(l, op, r, tp)
    else (match (lt,rt) with
    Note, Int -> S_Binop(l, op, r, Note)
```

```
    | _ -> raise(Failure("Error: Illegal operation on illegal pair of types " ^ string_of_prim_type lt ^ " and " ^ string_of_prim_type rt)) )
  | BasicList(li) ->
    let (it, ty) = check_arr li env in
    S_Arr(it, ty)
  | FuncList(li, fl) ->
    let mapval fu (arg:expr) = (* for array to be created *)
      let (nme, ag) =
        (match fu with
        FunkCall(i, e) -> (i, e)
        | _ -> raise(Failure("Error: Specified string in FuncList is not a valid function."))) in
      let fn_decl = Table.get_decl nme env in
      let (dt, it, de) = get_dt fn_decl in
      let typ = (match arg with
        IntLit(i) -> Int
        | Note(_, _) -> Note
        | String_Lit(_) -> String
        | Id(st) -> let v_decl = Table.get_decl st env in
          let (t_st, _, _) = get_dt v_decl in
          t_st
        | FunkCall(id, args) -> let f_decl = Table.get_decl id env in
          let (ty_funk, _, _ ) = get_dt f_decl in ty_funk
                | Index(id, place) -> let var_dec = Table.get_decl id env in
                    let (t_obj, _, _) = get_dt var_dec in t_obj
                 | Measure(_, _) -> Measurepoo
                 | Phrase(_, _) -> Phrase
                 | Song(_, _) -> Song
                 | _ -> raise(Failure("A function cannot be called on this type."))
        ) in
      let verify_type_and_vars tok =
        let nwvar =  check_ex_list tok env in
        let nwtp = check_call_and_type nme nwvar env in
        nwvar in
      let verify_mod_expr tok = confirm_expr tok env false in
      let ags = verify_type_and_vars ag in
      let i_arg = verify_mod_expr arg in
      if List.mem typ it then
      (match dt with
      Null_Type ->
        i_arg
      | _ ->  S_Call(nme, i_arg, ags, it, dt))
      else  raise(Failure("Error: Illegal function call " ^ nme ^ " on argument ")) in
    let mapcall fu (arg:expr) = (* for void calls to be executed before*)
      let (nme, ag) =
        (match fu with
        FunkCall(i, e) -> (i, e)
        | _ -> raise(Failure("Error: Specified string in FuncList is not a valid function."))) in
      let fn_decl = Table.get_decl nme env in
      let (dt, it, de) = get_dt fn_decl in
      let typ = (match arg with
        IntLit(i) -> Int
        | Note(_, _) -> Note
        | String_Lit(_) -> String
        | Id(st) -> let v_decl = Table.get_decl st env in
```

```
          let (t_st, _, _) = get_dt v_decl in
          t_st
        | Default -> Wild
        | FunkCall(nme, arg_vals) -> Wild
                | Index(id, place) -> let var_dec = Table.get_decl id env in
                  let (t_obj, _, _) = get_dt var_dec in t_obj
                | Measure(_, _) -> Measurepoo
                | Phrase(_, _) -> Phrase
                | Song(_, _) -> Song
                | _ -> raise(Failure("A function cannot be called on this type."))

        ) in
      let verify_type_and_vars tok =
        let nwvar =  check_ex_list tok env in
        let nwtp = check_call_and_type nme nwvar env in
        nwvar in
      let verify_mod_expr tok = confirm_expr tok env false in
      let ags = verify_type_and_vars ag in
      let i_arg = verify_mod_expr arg in
      if List.mem typ it then
      (match dt with
      Null_Type ->
        S_Call(nme, i_arg, ags, it, dt)
      | _ -> S_Noexpr)
      else  raise(Failure("Error: Illegal function call " ^ nme ^ " on an argument.")) in
    let l_calls =  List.map2 mapval li fl in
    let r_calls = List.map2 mapcall (List.rev li) fl in
    let (it, ty) = check_arr fl env in
    let ret = (match boo with
       true -> S_Db_Arr(S_Call_lst(r_calls), S_Arr(l_calls, ty))
      | false -> S_Db_Arr(S_Call_lst(r_calls), S_Noexpr)
      ) in ret
  | FunkCall(i, lis) ->
    let arg_var = check_ex_list lis env in
    let rt_typ = check_call_and_type i arg_var env in
    let decl_f = Table.get_decl i env in
    let (implicit_parm_type, explicit_param_types, arg_types) = get_dt decl_f in
    S_Call(i, (confirm_expr Default env false), arg_var, explicit_param_types, rt_typ)
  | Default -> S_Noexpr

and check_arr arr env =
  match arr with
  [] -> ([], Null_Type) (* Empty *)
  | head :: tail ->
    let verified_head = confirm_expr head env false in
    let head_type = type_of_expr verified_head in
      let rec verify_list_and_type l t e = match l with
        [] -> ([], t)
        | hd :: tl ->
          let ve = confirm_expr hd e false in
          let te = type_of_expr ve in
          (ve :: (fst (verify_list_and_type tl te e)), t) in
    (verified_head :: (fst (verify_list_and_type tail head_type env)), head_type)

and check_ex_list (lst: expr list) env =
  match lst with
```

```
  [] -> []
  | head :: tail -> confirm_expr head env false :: check_ex_list tail env


(* confirm correct function calls *)

and check_call_and_type name vargs env =
  let decl = Table.get_decl name env in (* function name in symbol table *)
  let fdecl = match decl with
    Func_Decl(f) -> f                        (* check if it is a function *)
    | _ -> raise(Failure ("Error: " ^ name ^ " is not a function.")) in
  if name = "print" then Int (* note returns wrong type *)
  else if name = "write" then Wild (* note returns wrong type *)
  else if name = "play" then Wild (* note returns wrong type *)
  else if name = "evaluate" then Wild
  else
    let (_,rtype, _, params,_) = fdecl in
    if (List.length params) = (List.length vargs) then
      let arg_types = List.map type_of_expr vargs in
      if params = arg_types then rtype
      else raise(Failure("Error: Argument types in " ^ name ^ " call do not match formal parameters."))
    else raise(Failure("Error: Function " ^ name ^ " takes " ^ string_of_int (List.length params) ^ " arguments, called with " ^ string_of_int (List.length vargs)))

(* get the type of an id of a variable *)

and get_id_type den env =
  let mark = Table.get_decl den env in
  let var = match mark with
  Var_Decl(sk) -> sk
  | _ -> raise(Failure ("Error: " ^ den ^ " is not a variable.")) in
  let  (_, _, tp, _)  = var in
  tp

(* convert AST statements into SAST statements *)

let rec confirm_stmt stmt ret_type env =
  (match stmt with
  Return(e) ->
    let verified_expr = confirm_expr e env false in
    S_Return(verified_expr)
  | Expr(e) ->
    let verified_expr = confirm_expr e env false in
    S_expr(verified_expr)
  | VarDecl(mo) ->  (match mo with
      Assign(typ, id, e) -> (* Verify that id is compatible type to e *)
      let ve = confirm_expr e env true in
      let eid_type = type_of_expr ve in
      if typ = eid_type
        then S_Assign(id, ve, typ)
      else raise(Failure("Error: Return type does not match* " ^ string_of_prim_type eid_type ^ " " ^ string_of_prim_type typ ^ "."))
      | Update(st, ex) ->
```

```
        let vid_type = get_id_type st env in
        let de = confirm_expr ex env true in
        let de_tp = type_of_expr de in
        if de_tp = vid_type then S_Assign(st, de, de_tp)
        else raise(Failure("Attempting to assign variable name " ^ st ^ " to value of type " ^ string_of_prim_type de_tp ^ "
          when " ^ st ^ " is already defined as a variable of type " ^ string_of_prim_type vid_type ^ "."))
      | Index_Update(expr_1, expr_2) -> let type_1 = (match expr_1 with
            Index(str, exp) -> let typ_known = Table.get_decl str env in
              let (plz, typ, den) = get_dt typ_known in plz
              | _ -> raise(Failure("Error in matching index type"))) in
            let iden = (match expr_1 with
            Index(str, exp) -> str) in
            let idx = (match expr_1 with
            Index(str, exp) -> exp) in
            let v_exp1 = confirm_expr idx env false in
            let v_exp2 = confirm_expr expr_2 env false in
            S_Index_Update(iden, v_exp1, v_exp2, type_1))
  | If(e, b1, b2) ->
    let verified_expr = confirm_expr e env false in
    if (type_of_expr verified_expr) = Int then
      let vb1 = confirm_block b1 ret_type (fst env, b1.block_id) in
      let vb2 = confirm_block b2 ret_type (fst env, b2.block_id) in
      S_If(verified_expr, S_CodeBlock(vb1), S_CodeBlock(vb2))
    else raise(Failure("Error: Condition in IF statement must be a boolean expression."))
  | While(condition, block) ->
    let vc = confirm_expr condition env false in
    let vt = type_of_expr vc in
    if vt = Int then
      let vb = confirm_block block ret_type (fst env, block.block_id) in
      S_While(vc, vb)
    else raise(Failure("Error: Condition in WHILE statement must be boolean expression."))
  | _ -> raise(Failure("Error: Can't map to statement.")))

(* iterates through a list of statements and confirms them *)

and confirm_stmt_list stmt_list ret_type env =
  match stmt_list with
      [] -> []
    | head :: tail -> (confirm_stmt head ret_type env) :: (confirm_stmt_list tail ret_type env)

(* function to confirm a block --> confirms each variable and statement *)

and confirm_block block ret_type env =
  let verified_vars = map_to_list_env confirm_var block.locals (fst env, block.block_id) in
  let verified_stmts = confirm_stmt_list block.statements ret_type env in
  { s_locals = verified_vars; s_statements = verified_stmts; s_block_id = block.block_id }

(* goes through each fun, verifies block, arguments, and finally the declaration *)
```

```
let confirm_func func env =
  let verified_block = confirm_block func.body func.ret_type (fst
    env, func.body.block_id) in
  let verified_args = map_to_list_env confirm_var func.args (fst
    env, func.body.block_id) in
  let verified_func_decl = confirm_func_decl func.fname env in
    { s_f_type = func.f_type; s_fname = verified_func_decl;
    s_ret_type = func.ret_type; s_formals = verified_args; s_fblock
     = verified_block }

(* SAST begins here - first function called: confirm_semantics *)

let confirm_semantics program env =
  let main_stmts = traverse_main drop_funk (program.stmts) in
  let main_vars = traverse_main get_vars main_stmts in
  let g_var_val = List.filter (fun x -> x <> ("", false, Wild))
    main_vars in
  let verified_gvar_list = map_to_list_env confirm_var g_var_val
    env in
  let main_func = confirm_func ({fname = "main"; ret_type =
    Null_Type; f_type = []; args = []; body = {locals = [];
    statements = List.rev main_stmts; block_id = 0}}) env in
  let verified_func_list = main_func :: map_to_list_env
    confirm_func program.funcs env in
  let () = prerr_endline "// Passed semantic checking \n" in
    { s_pfuncs = List.rev verified_func_list; s_gvars = List.rev
    verified_gvar_list}
```

Listing 7: sast.ml

Java Generator:

```

(* Java generator for Marmalade *)


open Ast
open Sast

(* rewrite AST types as the actual java types in the file. *)

let write_type = function
    | Int -> "j_int"
    | String -> "j_string"
    | Note -> "j_note"
    | Measurepoo -> "j_measure"
    | Phrase -> "j_phrase"
    | Song -> "j_song"
    | TimeSig -> "TimeSig"
    | Instr -> "int"
    | Tempo -> "int"
    | Intlist -> "j_intlist"
    | Stringlist -> "j_stringlist"
    | _ -> raise(Failure "Error: Type string of PD_Tuple or
    Null_Type being generated")

(* rewrite operations to their actual expressions in java. *)

let write_op_primitive op e1 e2 =
    match op with
    Plus -> "new j_int(j_int.add(" ^ e1 ^ ", " ^ e2 ^ "))"
```

```
    | Minus -> "new j_int(j_int.sub(" ^ e1 ^ ", " ^ e2 ^ "))"
    | Times -> "new j_int(j_int.mult(" ^ e1 ^ ", " ^ e2 ^ "))"
    | Divide -> "new j_int(j_int.divide(" ^ e1 ^ ", " ^ e2 ^ "))"
    | Equal -> "j_int.eq(" ^ e1 ^ ", " ^ e2 ^ ")"
    | Neq -> "j_int.neq(" ^ e1 ^ ", " ^ e2 ^ ")"
    | Less -> "j_int.lt(" ^ e1 ^ ", " ^ e2 ^ ")"
    | Leq -> "j_int.leq(" ^ e1 ^ ", " ^ e2 ^ ")"
    | Greater -> "j_int.gt(" ^ e1 ^ ", " ^ e2 ^ ")"
    | Geq -> "j_int.geq(" ^ e1 ^ ", " ^ e2 ^ ")"
    | And -> "(" ^ e1 ^ ") && (" ^ e2 ^ ")"
    | Or -> "(" ^ e1 ^ ") || (" ^ e2 ^ ")"
    | _ -> raise (Failure "Error: and/or begin applied to a java primitive")

(* notes map to values in jmusic *)

let write_rhythm dr =
    match dr with
    's' -> "0.125"  (* sixteenth note maps to 0.125 *)
    | 'e' -> "0.25" (* eigth note maps to 0.25 *)
    | 'q' -> "0.5"
    | 'h' -> "1.0"
    | 'w' -> "2.0"

(* get type of expression *)

let rec get_typeof_dexpr = function
     S_Int_Lit(intLit, t) -> t
    | S_String_Lit(strLit, t) -> t
    | S_Id (str, t) -> t
    | S_Arr(dexpr_list, t) -> t
    | S_Binop (dexpr1, op, dexpr2, t) -> t
    | S_Noexpr -> Null_Type
    | S_Call(str, _, dexpr_list, _, t) -> t

(* write actual java compare expression *)

let write_op_compares e1 op e2 =
    match op with
    Equal -> "(" ^ e1 ^ ").equals(" ^ e2 ^ ")"
    | Less ->  "(" ^ e1 ^ ").compareTo(" ^ e2 ^ ")" ^ " < 0"
    | Leq -> "(" ^ e1 ^ ").compareTo(" ^ e2 ^ ")" ^ " <= 0"
    | Greater -> "(" ^ e1 ^ ").compareTo(" ^ e2 ^ ")" ^ " > 0"
    | Geq -> "(" ^ e1 ^ ").compareTo(" ^ e2 ^ ")" ^ " >= 0"
    | Neq -> "(" ^ e1 ^ ").compareTo(" ^ e2 ^ ")" ^ " != 0"
    | _ -> raise (Failure("Error: Not a comparator operation."))

(* convert marmalade's sast expressions into java expressions *)

let rec write_expr = function
    S_Int_Lit(intLit, t) -> "(new j_int(" ^ string_of_int intLit ^ "))"
    | S_String_Lit(strLit, t) -> "(new j_string(\"" ^ strLit ^ "\"))"
    | S_Id (str, yt) -> str
    | S_Arr(dexpr_list, t) -> write_array_expr dexpr_list t
    | S_Binop (dexpr1, op, dexpr2, t) -> write_binop_expr dexpr1 op dexpr2 t
    | S_Db_Arr(call, mark) -> (
            match mark with
            S_Arr(l_one, l_two) ->   write_expr call
            | S_Noexpr -> write_expr call)
```

```
    | S_Measure(s_note_list, s_time, typ) -> "new j_measure(new
    j_note[] {" ^ (String.concat ", " (List.map write_expr
    s_note_list)) ^ "}, new TimeSig (" ^ write_expr s_time ^ "))"
    | S_Phrase(s_measure_list, s_instr, typ) -> "new j_phrase(new
    j_measure[] {" ^ (String.concat ", " (List.map write_expr
    s_measure_list)) ^ "}, " ^ write_expr s_instr ^ ")"
    | S_Song(s_phrase_list, s_tempo, typ) -> "new j_song(new
    j_phrase[] {" ^ (String.concat ", " (List.map write_expr
    s_phrase_list)) ^ "}, " ^ write_expr s_tempo ^ ")"
    | S_Noexpr -> ""
    | S_Note(i, ch, tp) -> "new j_note(" ^ string_of_int i ^ ", " ^
     write_rhythm ch ^ ")"
    | S_TimeSig(i, i_2, tp) -> string_of_int i ^ ", " ^
    string_of_int i_2
    | S_Instr(str, tp) -> str
    | S_Tempo(i, tp) -> string_of_int i
    | S_Index(str, i, tp) -> str ^ ".get(" ^ write_expr i ^ ")"
  | S_Call(str, exp, dexpr_list,t_ret, t_send) -> (match str with
                "print" -> "System.out.println("  ^ write_expr exp
     ^ ");\n"
             | "play" -> write_expr exp ^ ".play();\n"
           | "write" -> "Write.midi(" ^ write_expr exp ^ ".getObj
    (), \"out.mid\");\n"
           | "evaluate_measure" -> "new j_measure(" ^ String.
    concat "" (List.map write_expr dexpr_list) ^ ") "
                        | "evaluate_phrase" -> "new j_phrase(" ^
    String.concat "" (List.map write_expr dexpr_list) ^ ") "
                        | "evaluate_song" -> "new j_song(" ^ String
    .concat "" (List.map write_expr dexpr_list) ^ ") "
                        | "evaluate_note" -> "new j_note(" ^ String
    .concat "" (List.map write_expr dexpr_list) ^ ") "
                        | "length_measure" -> "new j_int(" ^ String
    .concat "" (List.map write_expr dexpr_list) ^ ".length())"
                        | "length_phrase" -> "new j_int(" ^ String.
    concat "" (List.map write_expr dexpr_list) ^ ".length())"
                        | "length_song" -> "new j_int(" ^ String.
    concat "" (List.map write_expr dexpr_list) ^ ".length())"
                        | "length_int_list" -> "new j_int(" ^
    String.concat "" (List.map write_expr dexpr_list) ^ ".length())
    "

                        | "length_string_list" -> "new j_int(" ^
    String.concat "" (List.map write_expr dexpr_list) ^ ".length())
    "

           | _ -> ( match exp with
                S_Noexpr -> str ^ "(" ^ String.concat "," (List
    .map write_expr dexpr_list) ^ ")"
              | _ -> write_expr exp ^ "." ^ str ^ "(" ^ String.
    concat "," (List.map write_expr dexpr_list) ^ ");/n")
             )
  | S_Call_lst(s) -> String.concat "" (List.map write_expr s)
  | _ -> raise(Failure("Error: Not a valid expression."))


(* this function matches to each kind of s_stmt, calling the
    function write_expr to write each of them in Java. *)

and write_stmt d vg = (match d with
      S_CodeBlock(dblock) -> write_block dblock vg
    | S_expr(dexpr) -> write_expr dexpr ^ ";"
    | S_Assign (name, dexpr, t) -> (match vg with
        true -> (
        match dexpr with
```

```
        S_Db_Arr(a1, a2) -> write_expr (S_Db_Arr(a1, a2)) ^ write_assign name a2 t true ^ ";\n"
        | _ -> write_assign name dexpr t true ^ ";\n" )
        | false -> (match dexpr with
        S_Db_Arr(a1, a2) -> write_expr (S_Db_Arr(a1, a2)) ^ write_assign name a2 t false ^ ";\n"
        | _ -> write_assign name dexpr t false ^ ";\n" ) )
    | S_Return(dexpr) -> "return " ^ write_expr dexpr ^ ";\n"
    | S_If(dexpr, dstmt1, dstmt2) -> "if(" ^ write_expr dexpr ^ ")" ^ write_stmt dstmt1 vg ^ "else" ^ write_stmt dstmt2 vg
    | S_While(dexpr, dblock) -> "while(" ^ write_expr dexpr ^ ")" ^ write_block dblock vg (* check true *)
    | S_Index_Update(nme, expr_1, expr_2, typ) ->
    (match typ with

        (* jMusic syntax for setting a note, measure, and part ( which is the same as a phrase in marmalade) *)
        Measurepoo -> nme ^ ".set_Note(" ^ write_expr expr_2 ^ "," ^ write_expr expr_1 ^ ");\n"
        | Phrase -> nme ^ ".set_Measure( " ^ write_expr expr_1 ^ ", " ^ write_expr expr_2 ^ ");\n"
        | Song -> nme ^ ".set_Part( " ^ write_expr expr_1 ^ ", " ^ write_expr expr_2 ^ ");\n" )
    | _ -> raise(Failure(" is not a valid statement")))

and write_stmt_true d = write_stmt d true

and write_stmt_false d = write_stmt d false

(* function that matches the expression on each side of the binop, then writes it *)

and write_binop_expr expr1 op expr2 t =
    let e1 = write_expr expr1 and e2 = write_expr expr2 in
        let write_binop_expr_help e1 op e2 =
            match t with
                Int -> (match op with
                    (Plus | Minus | Times | Divide | Equal | Neq | Less | Leq | Greater | Geq | And | Or) ->
                    write_op_primitive op e1 e2)
              | String -> (match op with
                    Plus -> "new j_string(j_string.add(" ^ e1 ^ ", " ^ e2 ^
                    "))"
                    | (Equal | Less | Leq | Greater | Geq) -> write_op_compares e1 op e2
                    | _ -> raise(Failure(write_op_primitive op e1 e2 ^ " is not a supported operation for String_Type")))
              | Note -> (match op with (Plus | Minus | Divide | Times) -> "new j_note( " ^ write_op_primitive op e1 e2 ^ ", " ^ e1 ^ ".getLength() )"
                        | _ -> raise(Failure("Error: Cannot add to note.")) )
              | _ -> raise(Failure("Error: " ^ write_op_primitive op e1 e2 ^ " is not a supported operation for " ^ write_type t ^ "."))
        in write_binop_expr_help e1 op e2

(* writes an array expression *)

and write_array_expr dexpr_list t =
      match t with
```

```
        Int -> "new j_intlist (new j_int[] {" ^ String.concat "," (* if Int, then write an int list *)
              (List.map write_expr dexpr_list) ^ "})"
        | String -> "new j_stringlist (new j_string[] {" ^ String.concat "," (* if String, then write a string list *)
        (List.map write_expr dexpr_list) ^ "})"
        | _ -> "new " ^ write_type t ^ " []" ^ " {" ^ String.concat "," (List.map write_expr dexpr_list) ^ "}"

(* helper function to apply java toString function *)

and tostring_str dexpr =
    let t = get_typeof_dexpr dexpr in
    match t with
         Int -> write_expr dexpr
        | String -> write_expr dexpr
        | _ -> "(" ^ write_expr dexpr ^ ").toString()"

and write_scope_var_decl_func svd =
    let (n, b, t, _) = svd in
        write_type t ^ " " ^ n

and write_scope_var_decl svd =
    write_scope_var_decl_func svd ^ ";\n"

and write_global_scope_var_decl gsvd =
    "static " ^ write_scope_var_decl_func gsvd ^ ";\n"

(* write assign expression in java *)

and write_assign name dexpr t vg =
    match vg with

    true -> (match t with
      String | Instr | Tempo | Intlist | Stringlist -> name ^ " = " ^ write_expr dexpr
    | Int | Note | TimeSig | Measurepoo | Phrase | Song  -> name ^ " = " ^ "(" ^ write_expr dexpr ^ ")"
    | _ -> raise(Failure("Error: " ^ write_type t ^ " is not a valid assign_type.")))
    | false -> (match t with
      String | Instr | Tempo | Intlist | Stringlist -> write_type t ^ " " ^ name ^ " = " ^ write_expr dexpr
    | _ -> raise(Failure("Error: " ^ write_type t ^ " is not a valid assign_type.")))

and write_block dblock vg =
    match vg with
    true -> "{\n" ^ String.concat "\n" (List.map write_stmt_true dblock.s_statements ) ^ "\n}"
    | false -> "{\n" ^ String.concat "\n" (List.map write_scope_var_decl dblock.s_locals) ^ String.concat "\n" (List.map write_stmt_false dblock.s_statements ) ^ "\n}"


(* include necessary java lines -> main *)

let write_func_wrapper x str =
    String.concat "\n"
    (let write_func dfunc =
        match (dfunc.s_fname, str) with
        ("main", String) -> "public static void main(String[] args)
```

```
    " ^ write_block dfunc.s_fblock true
    | (_, _) -> (String.concat "\n" (let match_type ftype =
        match ftype with
        str -> "static " ^ write_type dfunc.s_ret_type ^ " " ^
        dfunc.s_fname ^ "(" ^ String.concat "," (List.map
    write_scope_var_decl_func
        dfunc.s_formals) ^ ")" ^ write_block dfunc.s_fblock true
        | _ -> "" in
        List.map match_type dfunc.s_f_type)) in
    List.map write_func x)

(* Below is necessary java placed into the file *)

let gen_pgm pgm name =
    "import java.util.Arrays;\n" ^
    "import java.util.ArrayList;\n" ^
    "import jm.JMC;\n" ^
    "import jm.music.data.*;\n" ^
    "import jm.util.*;\n" ^
    "import marmalade.*;\n" ^
    "import jm.midi.event.TimeSig;\n" ^


    "public class " ^ name ^ " implements JMC{\n" ^ String.concat "
    \n" (List.map write_global_scope_var_decl pgm.s_gvars) ^
     (write_func_wrapper pgm.s_pfuncs String) ^
    "\n\n" ^

    "public static class j_int extends m_Int {\n" ^
    "public j_int(int n) {\n" ^
    "super(n);\n}\n" ^
     "public j_int(j_int n) {\n" ^
     "super(n);\n}" ^
     (write_func_wrapper pgm.s_pfuncs Int) ^
     "\n}\n\n" ^

     "public static class j_intlist extends m_Int_List {\n" ^
     "public j_intlist(j_int[] j) {\n" ^
     "super(j);\n}" ^
     "public j_int get(int i) {\n" ^
     "return new j_int(getList()[i]);\n}" ^
     (write_func_wrapper pgm.s_pfuncs Intlist) ^
     "\n}\n\n" ^


     "public static class j_string extends m_String {\n" ^
     "public j_string(j_string x) {\n" ^
     "super(x);\n}" ^
     "public j_string(String x) {\n" ^
     "super(x);\n}" ^
     (write_func_wrapper pgm.s_pfuncs String) ^
     "\n}\n\n" ^


     "public static class j_stringlist extends m_String_List {\n" ^
     "public j_stringlist(j_string[] j) {\n" ^
     "super(j);\n}" ^
     "public j_string get(int i) {\n" ^
     "return new j_string(getList()[i]);\n}" ^
     (write_func_wrapper pgm.s_pfuncs Stringlist) ^
     "\n}\n\n" ^

```

```
"public static class j_note extends m_Note {\n" ^
"public j_note(Note n) {\n" ^
"super(n);\n}" ^
"public j_note(int pitch, double length) {\n" ^
"super(pitch, length);\n}" ^
"public j_note(j_int pitch, double length) {\n" ^
"super(pitch, length);\n}" ^
(write_func_wrapper pgm.s_pfuncs Note) ^
"\n}\n\n" ^


"public static class j_measure extends Measure {\n\n" ^
"public j_measure(j_note[] m, TimeSig n) {\n" ^
"  super(m, n);\n}" ^
"public j_measure(Phrase p) {\n" ^
"  super(p);\n}" ^
"public j_measure(j_measure l) \n
{\n    super(l.getObj()); \n}\n"^
"public j_note get(int i) {\n" ^
"  Note n = getObj().getNote(i);\n     j_note m = new j_note(n
);\n     return m;\n}" ^
"public j_note get(j_int i) {\n" ^
"  Note n = getObj().getNote(i.get());\n   j_note m = new
j_note(n);\n     return m;\n}" ^
"public void set_Note(j_note i, j_int k){
   this.p.setNote(i.getObj(), k.get());\n
}\n" ^
"public void set_Note(j_note i, int k){
   this.p.setNote(i.getObj(), k);
}\n" ^
(write_func_wrapper pgm.s_pfuncs Measurepoo) ^
"\n}\n" ^


"public static class j_phrase extends
m_Phrase {\n" ^
"  public j_phrase(Part p) {\n" ^
"super(p);\n}" ^
"  public j_phrase(j_measure[] m, int n) {\n" ^
"super(m, n);\n}" ^
"  public j_phrase(j_measure[] m, j_int n) {\n" ^
"super(m, n);\n}\n" ^
"public j_phrase(j_phrase l) \n
{\n    super(l.getObj()); \n}\n" ^
"  public j_measure get(int i) {\n" ^
"Phrase p = getObj().getPhrase(i);\n" ^
"  return (new j_measure(p));\n}" ^
"public j_measure get(j_int i) {\n" ^
"  Phrase p = getObj().getPhrase(i.get());\n" ^
"return (new j_measure(p));\n}" ^

"public void set_Measure(j_int idx, j_measure n_measure)\n
{\n
   this.set_Measure(idx.get(), (Measure) n_measure); \n
}\n" ^

"public void set_Measure(int idx, j_measure n_measure)\n
{\n
   this.set_Measure(idx, (Measure) n_measure); \n
}\n" ^
```

```
    (write_func_wrapper pgm.s_pfuncs Phrase) ^
    "\n}\n" ^

    "public static class j_song
    extends Song {\n" ^
    "public j_song(j_phrase[] m, int n) {\n" ^
    "  super(m, n);\n}" ^
    "public j_song(j_phrase[] m, j_int n) {\n" ^
    "  super(m, n);\n}\n" ^
    "public j_song(j_song l) \n
    {\n   super(l); \n}\n" ^
    "public j_phrase get(int i) {\n" ^
    "  Part s = getObj().getPart(i);\n" ^
    "return (new j_phrase(s));\n}" ^

    "public j_phrase get(j_int i) {\n" ^
    "Part s = getObj().getPart(i.get());\n
    return (new j_phrase(s));\n}" ^

   "public void set_Part(j_int idx, j_phrase n_phrase)\n
    {\n
       this.set_Part(idx.get(), (m_Phrase) n_phrase); \n
   }\n" ^

   "public void set_Part(int idx, j_phrase n_phrase)\n
    {\n
       this.set_Part(idx, (m_Phrase) n_phrase); \n
   }\n" ^

    (write_func_wrapper pgm.s_pfuncs Song) ^
    "\n}\n}\n"
```

Listing 8: javagen.ml

Script to Test Java:

```
# make_java.sh
cd javaclasses
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_Int.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_Int_List.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_String.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_String_List.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_Note.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/Measure.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_Phrase.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/Song.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/m_Tempo.java
javac -cp ./jMusic1.6.4.jar:./ marmalade/Tester.java
jar cvf marmalade.jar marmalade/*.class
java -cp ./jMusic1.6.4.jar:./ marmalade/Tester
cd ..
```

Listing 9: script to make java

Script to Run Test Suite:

```
#!/bin/bash

# run_tests.sh

# Based on MicroC Regression Test Suite Script (microc/testall.sh)
```

```
# 0 stdin
# 1 stdout
# 2 stderr


MARMALADE="./marmac"
    #marmac depends on "marmalade" compiler

# Set time limit for all operations
ulimit -t 30

globallog=tests.log
rm -f $globallog
error=0
globalerror=0

keep=0

Usage() {
    echo "Usage: run_tests.sh [options] [.marm files]"
    echo "-k    Keep intermediate files"
    echo "-h    Print this help"
    exit 1
}

SignalError() {
    if [ $error -eq 0 ] ; then
  echo "FAILED"
  error=1
    fi
    echo "  $1"
}

# Compare <outfile> <reffile> <difffile>
# Compares the outfile with reffile.  Differences, if any, written to difffile
Compare() {
    generatedfiles="$generatedfiles $3"
    echo diff -b $1 $2 ">" $3 1>&2
    cat $1 >&2
    diff -b "$1" "$2" > "$3" 2>&1 || {
  SignalError "$1 differs"
  echo "FAILED $1 differs from $2" 1>&2
    }
}

# Run <args>
# Report the command, run it, and report any errors
Run() {
    echo $* 1>&2
    eval $* || {
  SignalError "$1 failed on $*"
  return 1
    }
}

Check() {
    # $1    name of basename file    (i.e. test_arith_add1)
    # $2    name of testdir          (i.e. testdir_2015-11-24_061339)

```

```
    error=0
    basename=`echo $1 | sed 's/.*\\///
                            s/.marm//'`
    reffile=`echo $1 | sed 's/.marm$//'`
    basedir="`echo $1 | sed 's/\/[^\/]*$//'`/."

    echo -n "$basename..."

    echo 1>&2
    echo "###### Testing $basename" 1>&2

    generatedfiles=""


    # GENERATE .java .class <outfile>.t.out .t.diff FILES

    generatedfiles="$2/${basename}.t.out"
    Run "$MARMALADE" "$1" "${basename}"
    ./${basename} &> "./$2/${basename}.t.out"
    mv "${basename}" "$2/${basename}"
    mv "${basename}.java" "$2/${basename}.java"
    mv "${basename}.class" "$2/${basename}.class"
    mv *.class "$2/"

    Compare $2/${basename}.t.out ${reffile}.out $2/${basename}.t.
    diff

    echo

    generatedfiles="$generatedfiles $2/${basename}.t.out $2/${
    reffile}.out $2${basename}.t.diff"
    generatedfiles="$generatedfiles $2/${basename} $2/${basename}.
    java $2/${basename}.class"


    # Report the status and clean up the generated files

    if [ $error -eq 0 ] ; then
  if [ $keep -eq 0 ] ; then
     # rm -f $generatedfiles
       echo ""
  fi
  echo "OK"
  echo "###### SUCCESS" 1>&2
    else
  echo "###### FAILED" 1>&2
  globalerror=$error
    fi
}



#BEGINNING OF SCRIPT
#BEGINNING OF SCRIPT
#BEGINNING OF SCRIPT

while getopts kdpsh c; do
    case $c in
  k) # Keep intermediate files
      keep=1
      ;;
  h) # Help
```

```
        Usage
        ;;
    esac
done

shift `expr $OPTIND - 1`

if [ $# -ge 1 ]
then
    files=$@
else
    files="tests/fail_* tests/test_*"
    # files="tests/fail_*.marm tests/test_*.marm"
fi



# AUTO ARCHIVE TEST FILES
if [ -d "testing_archive" ]; then
    mv testdir_* testing_archive/
else
    mkdir "testing_archive"
fi


# CREATE NEW TEST DIR FOR INTERMEDIATE FILES
date=`date +%F_%H%M%S`
testdir="testdir_${date}"
mkdir "$testdir"


for file in $files
do
    case $file in
    *.out)
        ;;
  *test_*)
        Check $file $testdir 2>> $globallog
        ;;
  *fail_*)
        CheckFail $file $testdir 2>> $globallog
        ;;
  *)
        echo "unknown file type $file"
        globalerror=1
        ;;
    esac
done


exit $globalerror
```

Listing 10: script to run test suite

Makefile:

```
# Makefile for marmalade compiler

OBJS = ast.cmo table.cmo sast.cmo parser.cmo scanner.cmo javagen.cmo marmalade.cmo

TESTS = \

YACC = ocamlyacc

marmalade : $(OBJS)
	ocamlc -o marmalade $(OBJS)


scanner.ml : scanner.mll
	ocamllex scanner.mll

parser.ml parser.mli : parser.mly
	$(YACC) parser.mly

%.cmo : %.ml
	ocamlc -c $<

%.cmi : %.mli
	ocamlc -c $<

.PHONY : clean
clean :
	rm -f marmalade parser.ml parser.mli scanner.ml \
	   *.cmo *.cmi *.out *.diff


ast.cmo:
ast.cmx:

sast.cmo: ast.cmo
sast.cmx: ast.cmx

javagen.cmo: ast.cmo
javagen.cmx: bytecode.cmx ast.cmx
marmalade.cmo: scanner.cmo parser.cmi compile.cmo
marmalade.cmx: scanner.cmx parser.cmx compile.cmx
parser.cmo: ast.cmo parser.cmi
parser.cmx: ast.cmx parser.cmi
scanner.cmo: parser.cmi
scanner.cmx: parser.cmx
parser.cmi: ast.cmo
```

Listing 1: Makefile for marmalade

Programs:

```
/* gcd and Fibinnaci algorithm */

/*
fibinacci number algorithm
*/

/* recursive algorithm for calulating nth fibinacci number */
funk int int fib(int n, int val_1, int val_2)
```

```
{

  if(n <= 2 or n <= 0){
    return 1;
  }

  else{

    val_1 = $fib(n-1, 0, 0);

    val_2 = $fib(n-2, 0, 0);

    n = val_1 + val_2;

    return n;
  }

}

/* gcd algorthim */

funk int int gcd(int a, int b){

  while(a != b){
    if (a > b) {
      a = a- b;
      }
    else
    {
      b = b - a;
    }
  }

  return a;
}


/* prints the gcd and factorial */

(print(), print()) [gcd(30, 90), fib(10, 0, 0)];
```

Listing 2: a function implementing and testing gcd and fibinacci algorithms

```
/* 99 bottles of beer in marmalade */

int offset = 0;
int current_bottle = 99;
int next_bottle = 98;

while(offset < 98)
{
  current_bottle = current_bottle - 1;
  next_bottle = next_bottle - 1;

  (print(), print()) [ current_bottle, " bottles of beer on the
    wall " ];
  (print(), print()) [ current_bottle, " bottles of beer. Take one
    down, pass it around "];
  (print(), print()) [ next_bottle, " bottles of beer on the wall."
    ]
  offset = offset + 1;

```

```
}
```

Listing 3: script that prints 99 bottles of beer

```
/* 99 bottles of beer */

measure t_1 = $(6:8) [67.e, 67.e, 67.e, 62.e, 62.e, 62.e];
measure t_2 = $(6:8) [67.e, 67.e, 67.e, 67.h];
measure t_3 = $(6:8) [69.e, 69.e, 69.e, 64.e, 64.e, 64.e];
measure t_4 = $(6:8) [69.h, 0.e, 0.e, 67.e];
measure t_5 = $(6:8) [65.e, 65.e, 65.e, 62.e, 62.e, 62.e];
measure t_6 = $(6:8) [65.e, 65.e, 65.e, 65.e, 65.e, 64.e];
measure t_7 = $(6:8) [62.e, 62.e, 62.e, 62.e, 64.e, 65.e];
measure t_8 = $(6:8) [67.e, 67.e, 67.e, 67.h];

phrase ph1 = $(HARP) [t_1, t_2, t_3, t_4, t_5, t_6, t_7, t_8];
phrase ph2 = $(HARP) [t_2, t_3, t_4, t_5, t_6, t_7, t_8];

song s1 = $(60) [ph1];

(print(), play())

int offset = 0;


while(offset < 30)
{
  offset = offset + 15;
  (print(), play(), print(), play()) ["Original song:", s1, "
    Transposed song", $transpose_song(s1, offset)];

}

while(offset < 60)
{

  offset = offset + 15;
  (print(), play(), print(), play()) ["Piano:", $(PIANO) [t_1, t_2,
     t_3, t_4, t_5, t_6, t_7, t_8], "Harp:", ph2];

}




funk song song transpose_song_w(song s, int n, int counter, int j,
    phrase k, song g)
{
  j = $length_song(s);
  counter = 0;
  g = $evaluate_song(s);

  while(counter < j)
  {
    k = s&counter;
    g&counter = $transpose_phrase(k, n);
    counter = counter + 1;
  }

  return g;
}

funk song song transpose_song(song s, int n)
```

```
{
  return $transpose_song_w(s, n, 0, 0, $$() [$() [44.q]], $$$() [$$
    () [$() [44.q]]]);
}

funk phrase phrase transpose_phrase_w(phrase p, int n, int counter,
     int j, measure k, phrase h){
  j = $length_phrase(p);
  counter = 0;
  h = $evaluate_phrase(p);

  while(counter < j)
  {
    k = p&counter;
    h&counter = $transpose_measure(k, n);
    counter = counter + 1;
  }

  return h;
}

funk phrase phrase transpose_phrase(phrase p, int n)
{
  return $transpose_phrase_w(p, n, 0, 0, $() [44.q], $$() [$() [44.
    h]]);
}

funk measure measure transpose_measure_w(measure m, int n, int
    counter, int j, note k, measure l)
{
  j = $length_measure(m);
  counter = 0;
  l = $evaluate_measure(m);


  while(counter < j)
  {
    k = l&counter;
    l&counter = k + n;
    counter = counter + 1;
  }

  return l;
}

funk measure measure transpose_measure(measure m, int n)
{
  return $transpose_measure_w(m, n, 0, 0, 44.q, $() [55.h]);
}
```

Listing 4: script that implements transpose methods for all musical objects and uses it to play 99 bottles of beer transposed in different ways

```
/* Reptilia.marm */

measure a_1 = $(4:4) [47.e, 47.e, 47.e, 47.e, 47.e, 47.e, 47.e, 47.
    e];
measure a_2 = $(4:4) [47.e, 47.e, 47.e, 47.e, 47.e, 47.e, 47.e, 47.
    e];
measure a_3 = $(4:4) [52.e, 52.e, 52.e, 52.e, 52.e, 52.e, 52.e, 52.
    e];
measure a_4 = $(4:4) [52.e, 52.e, 52.e, 52.e, 52.e, 52.e, 52.e, 52.
    e];
```

```

measure r_1 = $(4:4) [0.e, 0.e, 0.e, 0.e, 0.e, 0.e, 0.e, 0.e];

measure b_1 = $(4:4) [50.e, 50.e, 50.e, 50.e, 50.e, 50.e, 50.e, 50.e];
measure b_2 = $(4:4) [50.e, 50.e, 50.e, 50.e, 50.e, 50.e, 50.e, 50.e];
measure b_3 = $(4:4) [55.e, 55.e, 55.e, 55.e, 55.e, 55.e, 55.e, 55.e];
measure b_4 = $(4:4) [55.e, 55.e, 55.e, 55.e, 55.e, 55.e, 55.e, 55.e];

measure r_2 = $(4:4) [0.e, 0.e, 0.e, 0.e, 0.e, 0.e, 0.e, 0.e];

measure c_1 = $(4:4) [62.e, 62.e, 0.e, 62.e, 59.e, 0.e, 57.e, 0.e];
measure c_2 = $(4:4) [62.e, 62.e, 0.e, 62.e, 59.e, 0.e, 57.e, 0.e];
measure c_3 = $(4:4) [56.e, 56.e, 0.e, 56.e, 59.e, 0.e, 62.e, 0.e];
measure c_4 = $(4:4) [56.e, 56.e, 0.e, 56.e, 59.e, 0.e, 62.e, 0.e];

measure r_3 = $(4:4) [0.e, 0.e, 0.e, 0.e, 0.e, 0.e, 0.e, 0.e];

phrase ph_01 = $(BASS) [ a_1, a_2, a_3, a_4, r_1, r_1, r_1, r_1, a_1, a_2, a_3, a_4, r_1, r_1, r_1, r_1 ];
phrase ph_10 = $(BASS) [ r_1, r_1, r_1, r_1, a_1, a_2, a_3, a_4, r_1, r_1, r_1, r_1, a_1, a_2, a_3, a_4 ];
phrase ph_02 = $(BASS) [ r_2, r_2, r_2, r_2, b_1, b_2, b_3, b_4, r_2, r_2, r_2, r_2, b_1, b_2, b_3, b_4 ];
phrase ph_11 = $(PIANO)[ c_1, c_2, c_3, c_4, r_3, r_3, r_3, r_3, c_1, c_2, c_3, c_4, r_3, r_3, r_3, r_3 ];
phrase ph_22 = $(PIANO)[ r_3, r_3, r_3, r_3, c_1, c_2, c_3, c_4, r_3, r_3, r_3, r_3, c_1, c_2, c_3, c_4 ];

song reptilia = $(80) [ph_01, ph_10, ph_02, ph_11, ph_22];

(play()) [reptilia];
```

Listing 5: script which plays Reptilia by the Strokes

```

/* Script which plays a remix of Clocks by Coldplay */

measure c_1 = $(4:4) [63.e, 70.e, 66.e, 63.e, 70.e, 66.e, 63.e, 70.e];
measure c_2 = $(4:4) [62.e, 70.e, 65.e, 62.e, 70.e, 65.e, 62.e, 70.e];
measure c_3 = $(4:4) [62.e, 70.e, 65.e, 62.e, 70.e, 65.e, 62.e, 70.e];
measure c_4 = $(4:4) [60.e, 69.e, 65.e, 60.e, 69.e, 65.e, 60.e, 69.e];


measure b_1 = $(4:4) [48.e, 48.e, 48.e, 48.e, 48.e, 48.e, 48.e, 48.e];
measure b_2 = $(4:4) [67.e, 67.e, 67.e, 67.e, 67.e, 67.e, 67.e, 67.e];

measure t_1 = $(4:4) [63.h, 70.h];
measure t_2 = $(4:4) [62.h, 70.h];
measure t_3 = $(4:4) [60.h, 69.h];



measure s_1 = $(4:4) [63.w];
```

```
measure s_2 = $(4:4) [62.w];
measure s_3 = $(4:4) [60.w];

measure w_1 = $(4:4) [60.s, 60.s, 60.s, 60.s, 60.s, 60.s, 60.s, 60.s, 60.q, 60.q];

measure rest_1 = $(4:4) [0.w];


phrase ph_1_0 = $(PIANO)     [ c_1, c_2, c_3, c_4, rest_1, rest_1, rest_1, rest_1, c_1, c_2, c_3, c_4, rest_1, rest_1, rest_1, rest_1 ];
phrase ph_2_0 = $(BASS)      [ b_1, b_2, b_1, b_2, rest_1, rest_1, rest_1, rest_1, b_1, b_2, b_1, b_2, rest_1, rest_1, rest_1, rest_1 ];
phrase ph_3_0 = $(TIMPANI)   [ t_1, t_2, t_2, t_3, rest_1, rest_1, rest_1, rest_1, t_1, t_2, t_2, t_3, rest_1, rest_1, rest_1, rest_1 ];
phrase ph_4_0 = $(TENOR_SAX)[ s_1, s_2, s_2, s_3, rest_1, rest_1, rest_1, rest_1, s_1, s_2, s_2, s_3, rest_1, rest_1, rest_1, rest_1 ];
phrase ph_5_0 = $(PIPES)     [ w_1, w_1, w_1, w_1, rest_1, rest_1, rest_1, rest_1, w_1, w_1, w_1, w_1, rest_1, rest_1, rest_1, rest_1 ];

phrase ph_1_1 = $(PIANO)     [ rest_1, rest_1, rest_1, rest_1, c_1, c_2, c_3, c_4, rest_1, rest_1, rest_1, rest_1, c_1, c_2, c_3, c_4 ];
phrase ph_2_1 = $(BASS)      [ rest_1, rest_1, rest_1, rest_1, b_1, b_2, b_1, b_2, rest_1, rest_1, rest_1, rest_1, b_1, b_2, b_1, b_2 ];
phrase ph_3_1 = $(TIMPANI)   [ rest_1, rest_1, rest_1, rest_1, t_1, t_2, t_2, t_3, rest_1, rest_1, rest_1, rest_1, t_1, t_2, t_2, t_3 ];
phrase ph_5_1 = $(PIPES)     [ rest_1, rest_1, rest_1, rest_1, w_1, w_1, w_1, w_1, rest_1, rest_1, rest_1, rest_1, w_1, w_1, w_1, w_1 ];

song clocks = $(80) [ph_1_0, ph_2_0, ph_3_0, ph_4_0, ph_5_0, ph_1_1, ph_2_1, ph_3_1, ph_5_1 ];

(play()) [clocks];
```

Listing 6: script which plays Clocks