Compilation with Dynamic Grammars

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1 Abstract

Glossa is both a multi-language source to source compiler and, by extension, a framework for creating compilers. Ideally, Glossa converts any programming language **A** to any programming language **B**, such that the output in **B** is indistinguishable from code written by a native **B** programmer, in the same way that the output from Google Translate would ideally look as if it were written by a native speaker. If given an adequate description of each language's grammar, one language can be converted to another if the languages are *isomorphic*. If two languages are not *isomorphic*, one can still be converted to another if the non-isomorphisms are solved through an AST transformation.

Additionally, Glossa should provide a famework for creating programming languages. This is done using the translation interface, where syntax of a new language is described with files, and the language is translated either to machine code, or another programming language which will later be compiled.

2 Introduction

Many codebases have become unmanagable: they either use two many programming languages, or outdated programming languages, making them obsolete. Modern software needs to be written in a modern language. However, code should not be ported by hand, as this wastes the developers time, which could be spent on more important tasks.

Glossa translates any programming language to any other programming language. Since Glossa was created to be capable of translating many different programming languages, it provides a dynamic framework for easily modifying syntax of input and output languages. In addition to letting Glossa translate existing languages, this functionality makes implementing new programming

languages very simple.

Ultimately, modifiable syntax leads to better programming languages. Programming paradigms are implemented in syntax, and paradigms determine code. For example, strong, statically typed languages are used to build robust, scalable back-end software. Fluid, dynamically typed languages are used in scripting and front-end development.

If a language can be changed quickly and easily, then different styles can easily be experimented with, improving the chance of finding an optimal style. (i.e. A question like "What if C++ used indentation-delimiting instead of braces?" can be tested in an hour or so. If someone were to test this, they would likely find that indentation delimiting was clearer than brace delimiting..)

Since each programming language has its own compiler, there is some redundancy in each implementation. Essentially, Glossa abstracts the parts of a compiler that don't depend on which language is being compiled, and reads in rules for each language. Because of this, Glossa allows simple implementations of programming languages, which means that Glossa can easily become capable of translating many different languages with ease. For example, the lexer for a C++ compiler and a Java compiler would be extremely similar, since both languages use braces, semicolons, and parentheses in the same way. Even two programming languages that don't have similar syntax have similar parts of their compiler. For example, a lexer seperates text based on a list of delimiter-strings, which vary with each programming language. The string seperation function, however, is the same for every lexer, and would be redundant across multiple compilers. The same concept applies to Parsers and Generators, etc.. (Parsers read tokens and produce an AST, Generators use an AST to generate code)

If programming languages could be compiled with a framework, this redun-

dancy would go away, and programming language researchers would be able to focus on the language itself, as opposed to its compiler.

3 Methods

3.1 Compilation

Traditionally, a compiler takes a single high-level programming language, and converts it into machine instructions in the following steps:

1. Lexer: Code is lexed (seperated into tokens and tagged as keywords, punctuators, literals, etc...)
2. Parser: Tokens are parsed to build an Abstract Syntax Tree (symbolic code representation)
3. Transformer: The AST is optimized (i.e. unreachable code is removed, some loops are unrolled, much more..)
4. Generator: Machine instructions are generated from AST.

Glossa does exactly the same, but, instead of using hardcoded functions, Glossa creates a Lexer, Parser, Transformer and Generator during the compilation phase by reading in descriptions of the languages being translated.

Assuming conversion from **A** to **B**, as in the Abstract, Glossa creates the Lexer, Parser, and Transformer based on **A**, and the Generator based on **B**. As one would expect, this means that Glossa uses four types of descriptor files:

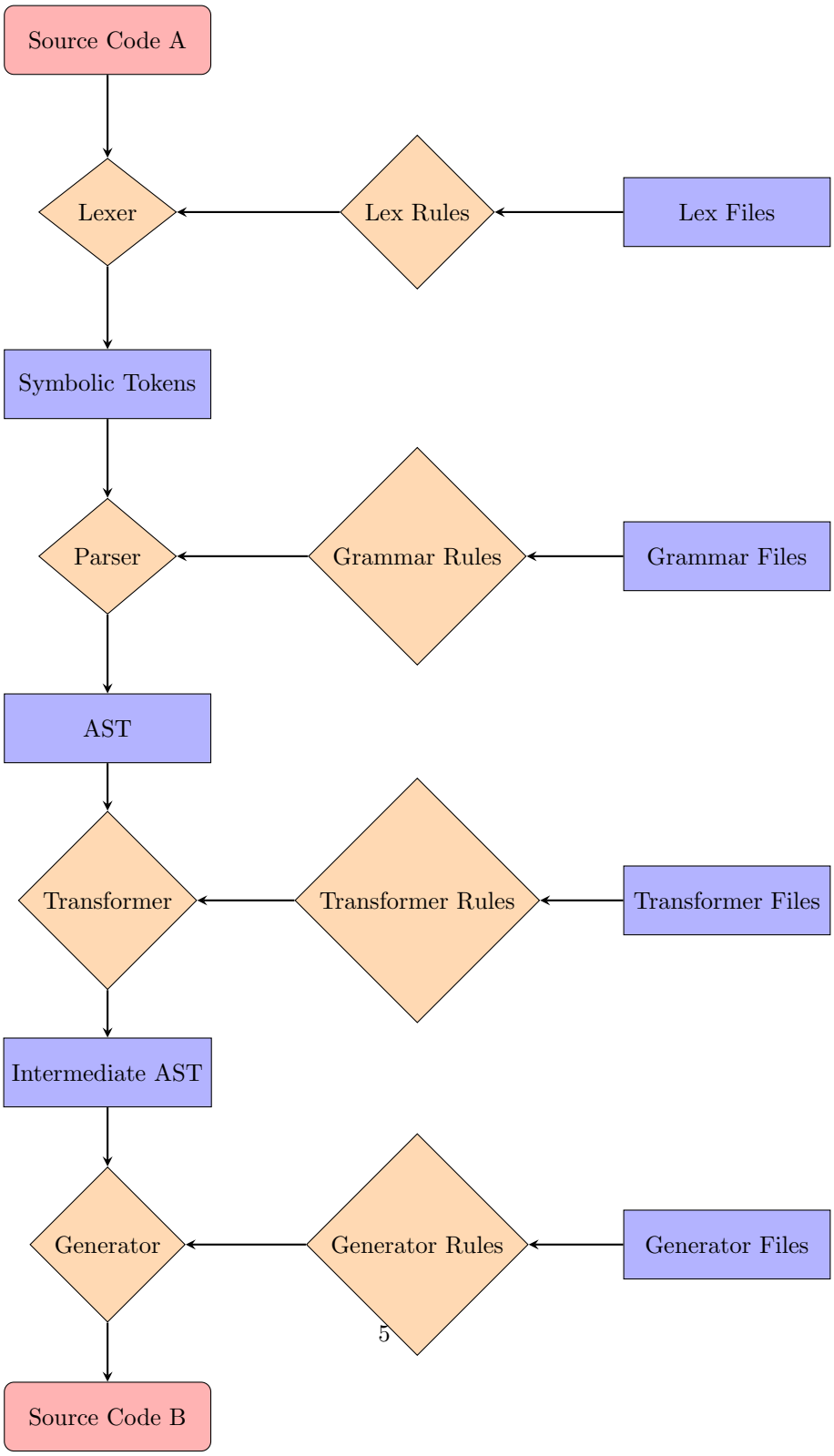
1. *lex files*: A list of strings that constitute atomic types like string literals, operators, and keywords in language **A**
2. *grammar files*: A description of a parser for each grammar element in language **A**

3. *constructor files*: A description of a generator for each grammar element in language **B**

4. *transformer files*: A description of transformations for each grammar element in language **A**.

The next page has a diagram of compilation in Glossa, utilizing these four file types to create the Lexer, Parser, Transformer, and Generator.

Compilation in Glossa



3.2 Lex Files

Lex files are the most straightforward of all of the descriptor files in Glossa.

A language's lex directory contains the following files:

```
comment_delimiters  logicaloperators  operators
punctuators  string_delimiters  whitespace
```

The files

```
logicaloperators operators punctuators string_delimiters
```

are each just lists of strings

The

```
comment_delimiters
```

file is a two-line file of the form:

```
#
"""
```

In General:

```
Single line comment delim
Multi line comment delim
```

An example whitespace file:

```
indent  false
space   false
newline false
```

Where each line is the name of a whitespace element, and a boolean indicating if the token should be kept when the language is lexed.

3.3 Grammar Files

Parsing converts a list of tokens to an AST.

Parsing will attempt to identify remaining tokens with high-level statement types, which in turn use lower-level grammar types:

```
statement: ‘@statement a | b | c‘
```

Where a might be:

```
a: ‘@val d | e‘
```

A single grammar files defines a potential identification of tokens, producing a tagged dictionary of symbols if the tokens are identified successfully:

The simplest non-trivial grammar file is likely the assignment statement:

```
assignment: ‘@lval identifier **‘ ‘@op ’=’‘ ‘@rval boolexpression | expression‘
```

In plain english this reads: *”Parse an identifier, and save it to the symbol dictionary as ‘lval‘, then parse an equals operator, and save it to ‘op‘, lastly, parse a boolean expression or normal expression and save it to ‘rval‘”*

In general, a grammar element is defined like the following:

```
name: ‘first_element‘ ‘second_element‘ .. ‘last_element‘
or
name: ‘option_a‘ | ‘option_b‘ ..  | ‘option_c‘
```

Where each element is a parser of the form:

an optional ”@name” tag, which saves the result of the parser to the symbol dictionary under ”name” Either:

```
- A subtype parser (i.e ‘’=’‘),
- A subtype-type parser (i.e. ‘identifier self‘)
- A type parser (i.e. ‘identifier **‘)
- A link to another grammar element (i.e. ‘value‘)
```

So, the following are all examples of valid parsers:

```
‘@val value‘          // Link to value type, saved as "val"
‘identifier self‘     // Identifier "self", discarded
‘@name identifier **‘ // Any identifier saved as "name"
```

However, these parsers can be prefixed with the following keywords to change their meaning:

```
!           : discard the parse result of this parser
anyOf a b   : parse either a or b, keeping the result of the first successful parser.
    (alternatively written a | b)
*/many      : parse the parser several times until it fails
many1       : parse the parser several times, requiring it to parse successfully
                at least once.
optional    : make a parser optional
inOrder a b : run several parsers in order
sep a b     : parse bs seperated by as (i.e. sep , value)
```

Some examples of more sophisticated parsers:

```
‘@statement import_from | main | ... ‘
‘@val identifier ** | string | literal ** | ’None’ | ’True’ | ’False’‘
‘@val vector | functioncall | elementaccess | memberaccess | basevalue | parenexpr‘
‘@args optional sep ’,’ expression‘
```

So, fully formed grammar elements (for Python) look like:

```
main: ’if’ ’__name__’ ’==’ ‘literal string‘ ’:’ ‘@body *statement‘ ’end’


function: ’def’ ‘@identifier identifier **‘
    ’(’ ‘@args optional sep ’,’ identifier **‘ ’)’ ’:’
```

```
    ‘@body *statement‘ ’end’

pass: ’pass’

return: ’return’ ‘@expression expression‘

assignment: ‘@lval identifier **‘ ‘@op ’=’‘ ‘@rval boolexpression | expression‘
```

3.4 Constructors

Constructor files describe how to build generalized syntax features. Mostly, they look like code in the output language, but with the elements replaced with tags from the symbol dictionary. i.e. an assignment statement in c++

```
auto $lval$ $op$ $rval$
```

will generate

```
auto x = 42
```

However, if we wish to reassign to a variable, the auto type declaration needs to be left off, so we might redefine the constructor file as:

```
branch defined lval
$lval$ $op$ $rval$
elsebranch
auto $lval$ $op$ $rval$
end
```

Where ”defined lval” checks if lval is part of the namespace How does lval get inserted into the namespace in the first place? Constructor files must define which values will be put into the namespace, so our full constructor file would start with: Additionally, c++ has both header and source files in generation, but assignment statements look the same for each. Our full constructor file

looks like:

```
defines
lval

header
branch defined lval
$lval$ $op$ $rval$
elsebranch
auto $lval$ $op$ $rval$
end

source
branch defined lval
$lval$ $op$ $rval$
elsebranch
auto $lval$ $op$ $rval$
end
```

Where "header" and "source" are defined in the special cpp/constructors/file file, which outlines which filetypes c++ will construct

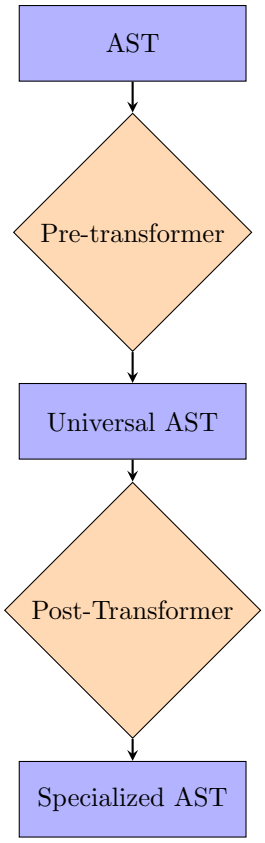
3.5 Transformer Files

AST Transformations solve non-isomorphisms, making language conversions more flexible by reducing language-to-language dependencies. Essentially, languages with a specialized feature set convert their language features to generalized ones (i.e. Haskell pattern matching might become a series of conditional checks on the arguments of a function). (Initial AST ->Universal AST) Then, if the output language does not contain some features in the Universal Feature

Set, then it represents the same concept in its native form. (Universal AST ->Specialized AST).

For example: Haskell's Pre-transformer might convert a parsed *Data* element into a universal structure like a class. (Haskell's special data type is not in the Universal Feature set, but a class is.) Then, if the output is in a language that doesn't support classes, i.e. C, then C's Post-transformer would convert the class to struct-function-collections, creating the specialized AST, which would be compilable in C.

Dual-AST transform



Each element of the AST is MultiSymbol, which is a tag (string), and a string dictionary of symbols. Each of these symbols can be either another MultiSymbol, or an atom like a literal, operator, or identifier. To transform an AST element, the tag can be changed, or elements within the dictionary can be manipulated.

A transformer file is just a series of these transformations:

```
createreg [name]
// Copy an element from global multisymbol table to a key in a register's multisymbol table
transfer(-append) [reg-name] [global-key] [reg-key]
// Move the multisymbol from a register to the destination key in the multisymbol table.
// If a destination_reg is specified, this table is the table of a register.
// Otherwise, it is the global multisymbol table
pushback(-override) [reg-name] [destination] (optional)[destination_reg]
// Prefix for performing an operation on a register
reg [name] {command (any of below)}

// The following also work with operations on the table of the current multisymbol
// In add and append, type might be "identifier" or "literal"
//                                and value might be "x" or "2"
// I.e to add an identifier foo under the key "name",
//   use the command (add name identifier foo)
// Add overwrites a key, append adds onto it.
add    [key] [type] [value]
append [key] [type] [value]
// Move deletes the source key, copy does not.
copy(-append) [key1] [key2]
move(-append) [key1] [key2]
```

```
// Change the tag of the register
retag newtag
// Delete a key from the multisymbol table
delete [key]
```

Which can be surrounded by control flow, in the same way that constructor files can:

```
branch defined identifier
move identifier old_identifier
add name identifier f
elsebranch
add name identifier f
end
```

(This AST transform renames the syntax element to f, saving the old name to the key "old_identifier"

3.6 Inheritance Lists

Languages can inherit from other programming languages. Currently, only the Parser for a particular language is inherited. Inheritance is defined in a special file, ./languages/lang_name/inherits, which is simply a list of language IDs to inherit from. As with class constructs in programming, it is safer to only inherit from a single parent. However, heirarchical inheritance is possible. For example, Auta inherits from Python3, which inherits from Python_core.

4 Applications

Glossa has two core applications: Translation of code, and programming language design.

4.1 Translation

Because Glossa dynamically reads in language descriptions, it can support a large number of programming languages both as inputs and outputs. When given adequate description files, Glossa is potentially as capable as a specialized compiler or interpreter. Several examples of translations done with Glossa are shown in the Appendix.

Even though translation works very well, there are still several limitations to keep in mind: Retention of readability is not always guaranteed, especially if there are many non-isomorphisms that need to be solved. Code that uses libraries is harder to translate: It requires either a foreign function interface to be written, or the library to be translated alongside the software. Translation of the library depends on access to the library's source code, which isn't always available.

4.2 Language Design

Since Glossa uses dynamic language descriptions, languages can easily be created or modified by changing their descriptor files. This functionality encourages language experimentation. Glossa also allows languages to inherit from existing languages. For example, descriptions for C++ might inherit from C, and only overwrite or add features.

Language design in Glossa is not affected in the same way that Translation is. The only possible limitation is the descriptor file interface. The success of an implemented language depends on how well it has been described. If description is straightforward, then language creation will be as well.

Since Glossa ships with constructor files (Currently for Python3 and C++), a new language only has to provide grammar, lex and (optional) transformer files.

For example, adding a function to a particular programming language takes a single line:

```
function: 'def' `@name identifier **` '(' `@args sep ',' identifier **` ')' ':' `@body *stat
```

To change this Python style function to one in Haskell:

```
function: `@name identifier **` `@args sep SPACE identifier **` '=' `@body return` 'end'
```

Since these two parsers define the same fields (name, args, body), they would be compiled in identical ways.

For reference, the CPython interpreter uses a Python grammar file, which is around 130 lines (counting whitespace). A grammar file for a similar language would be a similar size. While each line requires some careful thought, a new programming language could be implemented in a matter of hours. Alternatively, an existing language could be modified in the same way that the above function syntax was changed from Python style to Haskell style.

5 Results

Glossa currently ships with the following translation examples:

1. Python3 ->C++
2. Python2 ->C++
3. Python2 ->Python3
4. FORTRAN ->C++
5. FORTRAN ->Python3

Support for the different versions of Python and C++ output are significantly developed, supporting 80-90% of the syntax for each language. However,

support for FORTRAN is more experimental, but 100% support would be trivial to add, since FORTRAN has very simple syntax. Glossa could currently support more complex input languages, like C++ or Haskell, but the description files would be more difficult to write.

For language design, Glossa is fully equipped. The only restriction is the time required to write description files.

5.1 Language Design

As discussed in the Applications section, dynamic grammars simplify language creation. For example, Glossa ships with an experimental language, Auta, which extends the Python3 programming language by adding common tasks, like download spreadsheets or sending emails, to the language's syntax:

```
every Tuesday:
    send_email(team_a, Meeting in room 1024 @ 2:00 )
every week:
    i = download_spreadsheet(weekly  income )
    out = calc_taxes(i)
    upload_spreadsheet(out)
```

Which would compile to several Google-API calls in Python, which would be much more complicated. Simplifying the API calls by building them into Auta's syntax allows a layperson to write simple scripts.

This is only an example of a DSL (Domain Specific Language), but a full language could easily be implemented using the exact same concepts. Autas grammar file is extremely brief (as it inherits syntax from Python3):

```
statement: ‘@val every‘
every: ’every’ ‘@count optional literal int‘ ‘@unit identifier **‘ ’:’ ‘@body *statement‘ ’e
```

Most of Auta's functionality is made possible by a 200 line Python library, which is imported by the output script. While Auta is only a proof of concept,

it was implemented in less than two hours, the majority of which was spent building the library.

6 Conclusion

Glossa shows that a multi-language source to source compiler is possible. Since description files are the only pre-requisite for translating a particular language, Glossa can theoretically translate any language, as long as a description is provided. While Glossa only supports a few different languages, it could easily support more if more description files were written. However, Glossa's interface would benefit from simplification, since writing description files is a hard task. Also, even in description files, there is some redundancy that could be eliminated. As the description file interface improves, Glossa will come closer to being an ideal multi-language source to source compiler.

While Glossa is useful at doing some automated translations, it is likely more useful for implementing new programming languages. Because of the generalizations (discarding of hard-coded rules) that Glossa makes, changing language definitions is trivial compared to the potential difficulty of modifying the source of a compiler. With Glossa, a new language can be implemented in a minimal amount of time, and then modified easily.

Glossa has accomplished far more than it originally set out to. As it matures, it will certainly be capable of doing industrial-level transformations, as well as implementing new programming languages with minimal effort.

7 Appendix

7.1 Original Python Code

```
def sort(array):
    less    = []
    equal   = []
    greater = []

    if len(array) <= 1:
        return array
    else:
        pivot = array[0]
        for x in array:
            if x < pivot:
                less.append(x)
            if x == pivot:
                equal.append(x)
            if x > pivot:
                greater.append(x)
        return sort(less) + equal + sort(greater)

def main():
    l = sort([3, 2, 12, 9, 4, 68, 17, 1, 2, 3, 4, 5, 6, 12, 9 , 8, 7, 6,5, 4, 743])

if __name__ == "__main__":
    main()
```

7.2 Generated C++ Code (Glossa)

```cpp
#include "../std/std.hpp"
template <typename T_array>
auto sort (T_array array)
{
    auto less = std::vector<Object>({});
    auto equal = std::vector<Object>({});
    auto greater = std::vector<Object>({});
    if (len(array) <= 1)
    {
        return array;
    }
    else
    {
        auto pivot = array[0];
        for (auto x : array)
        {
            if (x < pivot)
            {
                less.push_back(x);
            }
            if (x == pivot)
            {
                equal.push_back(x);
            }
            if (x > pivot)
            {
                greater.push_back(x);
            }
        };
        return sort(less) + equal + sort(greater);
    };
}
```

7.3 Generated C Code (Cython)

Generated code for Cython is much more complex, as it integrates with the Python FFI

For example, this snippet declares an empty array

```
 /* "main.py":6
*     Sorts an array of comparable values
*     """
*     less    = []            # <<<<<<<<<<<<<<
*     equal   = []
*     greater = []
*/
 __pyx_t_1 = PyList_New(0); if (unlikely(!__pyx_t_1)) {__pyx_filename = __pyx_f[0]; __pyx_lineno = 6; __pyx_clineno = __LINE__; g
 __Pyx_GOTREF(__pyx_t_1);
 __pyx_v_less = ((PyObject*)__pyx_t_1);
 __pyx_t_1 = 0;
```