

Legend Of Bluespec

kr469

October 2021

Contents

1	Introduction	2
1.1	Reality	2
1.2	Solution	2
2	Preparation	4
2.1	Understanding Bluespec	4
2.1.1	Rules	4
2.1.2	Modules and interfaces	5
2.1.3	Types	5
2.1.4	Typeclasses	5
2.2	Creating a grammar	5
2.2.1	Why grammar is needed ?	5
2.2.2	What grammar is needed ?	5
2.2.3	Where to find this grammar ?	5
2.2.4	Technical aspects	6
3	Implementation	7
3.1	Reading packages	7
3.1.1	Bluetcl	7
3.2	Parsing	7
3.2.1	Understanding abstract syntax tree (AST)	8
3.2.2	Organizing data and functionality	8
3.3	Building the top level module	8
3.3.1	Resolving types	8
3.3.2	Provisos explained (intuition)	8
3.4	Synthesizing	9

Chapter 1

Introduction

Making hardware is hard, and similarly to other problems in computer science, we make it easier by adding layers of abstraction. There are many layers involved in making hardware from that abstract transistors to gates to logical operations to functions to modules to chips to multi-chip modules to whole devices. The layer this project focuses on is going from modules to chips(TODO: this probably need renaming). At this layer we already have code for modules like memory, CPU-cores, interconnects and so on. Now what we need is an ability to compose them in such a way that they create a whole device. On a paper this should be a simple task but in reality it's a lot more complicated.

1.1 Reality

Creating custom hardware is getting more expensive both in terms of money but also in terms of man-hours needed to create it. This creates barriers to entry for new players, and also reinforces strong positions of already adopted standards. Two monoliths that I will focus on are language Verilog and design software Intel Quartus Prime(IQP). In my work I will work with Bluespec language that can be compiled down to Verilog.

Market share and justification for focusing entirely on comparisons with Intel Quartus Prime

It's a bit difficult to accurately judge market share of IQP, but It is produced by one of the biggest chip manufacturer and designer in the world, and it's also used by Qualcomm according to HG Insights. Using Google trends tool we can see that while in recent years(since 2016) competitor Xilinx Vivado has overtaken, IQP in interest at the global scale, in most developed countries like US, Europe, and parts of Asia. There is roughly 50/50 split between IQP and Vivado. My personal observations suggest that Xilinx Vivado has been more popular in India which is a large country that is currently developing rapidly. Therefore, while I'm going to assume that IQP is still one of two biggest hardware design platforms, and it's fair to not investigate Xilinx's software during evaluation(TODO: check if this has changed).

My project will try to tackle a subset of functionality provided by a tool called Platform Designer that is a part of Intel Quartus Prime package. Platform Designer is a GUI tool for connecting modules, it is capable of saving and loading designs, from proprietary plain text file format. Unfortunately, those files are not exactly what one might call "Human readable" as they have a tendency to be megabytes long(millions of characters). This tool also have some other pains that will be explained later.

1.2 Solution

During my project I will try to create an alternative file format that is much simpler and allows for editing by a human. To do this I will harness power of types in Bluespec language. My tool will be able to operate

on Bluespec packages, but thanks to other tools that allow for interoperability of Bluespec and Verilog, it should be still technically possible to use my tool with wider Verilog ecosystem.

Chapter 2

Preparation

2.1 Understanding Bluespec

To begin working with Bluespec we first need to understand the language.

2.1.1 Rules

In Bluespec all computation is done in form of rules. Each cycle we will take a subset of all rules that we are going to execute in this cycle, rule is fired (executed) in cycle only if it's ready (or will be ready) and it's not conflicting with other rules (If this happens compiler must issue a warning, and picks arbitrary rule to fire from subset of conflicting rules). Each rule can fire at most one time per cycle. For rule to be ready to fire it needs it's implicit and explicit conditions to be true. Rule can be fired in a cycle even if it's not ready at the start of cycle, for example if you add item on an empty queue and then pop can happen in same cycle.

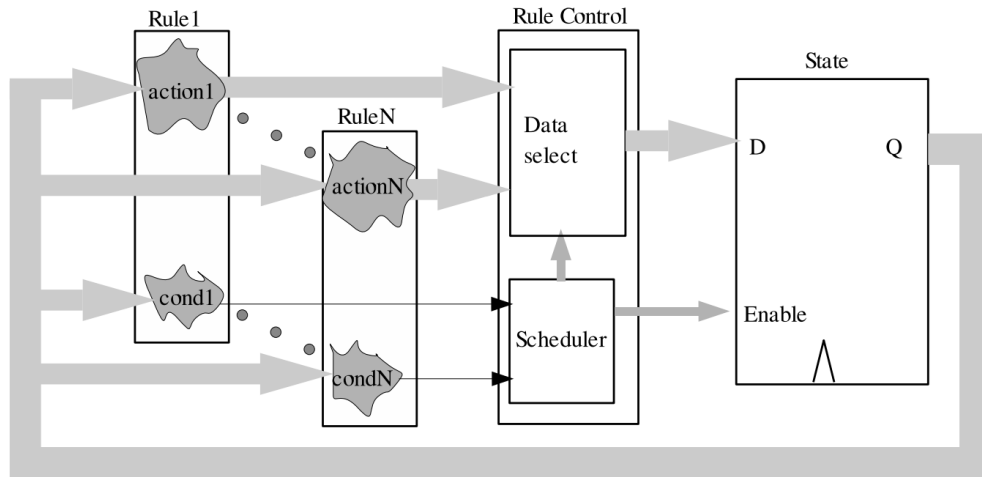


Figure 1: A general scheme for mapping an N-rule system into clocked synchronous hardware.

(TODO: add reference to the bsv reference document from which this image was taken)

TODO: piece of Bluespec with module using fifo and other rule explaining types of conditions.

2.1.2 Modules and interfaces

Module is something (TODO: I have no Idea how to call it). Modules don't have types, instead they implement some interface. This means that you can have multiple different modules that implement the same interface, this makes interoperability much easier. Interfaces are made up out of two things:

- Methods - that allow for interaction with the module.
- Subinterfaces - That allow for more generalization, for example you need to connect one more thing you don't need to change an interface used by other modules, you can just create a new interface that contains two subinterfaces and pass them accordingly.

2.1.3 Types

Welp, there is a ton of them.

2.1.4 Typeclasses

Types classes in Bluespec are used to group types for which specific functions are implemented. TODO:

2.2 Creating a grammar

2.2.1 Why grammar is needed ?

I had effectively 3 choices for a language to write this grammar in:

- Haskell - This would require me to directly tap into compiler for information about modules and ect. in packages, and I would also need to learn Haskell effectively from scratch. I hope that I don't need to explain why learning Haskell while trying to understand compiler of another language is a bad idea.
- Tcl (pronounced "tickle") - This language is used as a scripting language in both Inter and Xilinx tools, I will be reading packages using Tcl scripts provided by the creators of the Bluespec compiler (BSC), but my understanding is that those scripts are just handy wrappers for some Haskell code. This is also foreign language to me with minimal presence, and negligible learning resources.
- Python - Firstly this is a language I have experience working with, secondly it's widely supported, and there is extensive tooling for it. It's flexible typing system allows for rapid experimenting.

I have chosen Python for this project as I didn't want to dabble in the BSC as I was advised that this is dangerous for part II project as compilers are overwhelmingly complex and difficult to understand. This meant that I will need to parse output of Bluetcl (compiler script for inspecting packages), and to do this I'm going to need grammar.

2.2.2 What grammar is needed ?

Bluetcl produces many, outputs but two of them that we are going to focus on are: descriptions of functions and descriptions of types. To simplify parsing of those I will have one grammar capable of parsing both outputs at the same time, as some grammar structures are reused in both outputs.

2.2.3 Where to find this grammar ?

Unfortunately this grammar is not documented anywhere, so I needed to reverse engineer it. This grammar might not be perfect and might not cover every input, but if created carefully to allow for as much flexibility as possible, and use of large body of test input in from of standard library during creation of it we should be exposed to enough examples to be able to parse decently large subset of future inputs. Here are other reasons to justify this approach:

- Heaps' law suggests that number of unique words in given body of text is proportional to roughly square root of number of words in the text. I think it's fair to assume that something similar will be true if we consider number of unique grammar rules.
- This grammar while different from grammar of Bluespec language maps subset of Bluespec grammar, so we can supplement our deductions with cases that we expect to arise.
- We don't need to understand everything to just connect modules, and because at the module level, things need to be less abstract as they need to be synthesizable, we don't expect highly exotic things to appear in higher level modules.
- This approach is probably the best way for me anyway.

2.2.4 Technical aspects

This is EBNF grammar, I parse it using Lark library for Python, and I'm using Earley parser, as it is capable of arbitrary length lookahead. Grammar I created contains roughly 90 rules, and I won't include all of them here, but I will show few examples to give a feel of what is happening.

Parsing position TODO maybe find a better example with shorter line

```
tcl_position: "{" "position" "{" tcl_path NUMBER NUMBER [{" "Library" identifier_u "}"] "}" "}"
// todo check paths with spaces
tcl_path: ["%/" /(((["{1,2})|(\w+)) / ["/" /(((["."] | (["."]|(\w+)))/)* "." /\w+/

----- Text to parse -----
{position {%/Libraries/Connectable.bs 25 1 {Library Connectable}}}
```

```
▼ tcl_position
  ▼ tcl_path
    Libraries
    Connectable
    bs
    25
    1
  ▼ identifier_u
    Connectable
```

A nice feature supported by Lark is ability to have regular expressions in the grammar, I'm mentioning this as is effectively having parser in side of parser. A handy tool for debugging and creating grammar was this website: <https://www.lark-parser.org/ide/>, it can run parser online, and show output tree.

Chapter 3

Implementation

3.1 Reading packages

3.1.1 Bluetcl

As mentioned before, bluetcl is a tool written in bash that starts Tcl terminal and sets up environment to use certain Tcl commands thanks to which one can inspect packages. To interact with this tool I have written a script using Pexpect library. This script works by creating subprocess of bluetcl, and exposes functions that allow for performing queries. Core of this script is a function called `call` that takes as input a string that is a command and returns output of stripped of warnings or raises an exception if error occurred (for example in case where package was not found). To remove warnings I make some assumptions.

- I only use fixed set of commands.
- For those commands important output about is always on the last line. (this was checked empirically)
- Output of a command is always followed by `%` a character that never occurs in the rest of the output and marks the end of the output.

Thanks to them I don't need sophisticated system for parsing error, and or warnings. I can just make a quick search for error, and if needed forward this to user otherwise drop all warnings.

In total this script allows me for:

- Initialize subprocess
- Add folder to search path of bluetcl
- Load package (bluetcl takes care of loading dependencies)
- Get list of loaded packages
- List functions in package
- List types in package
- Get information about types and function in the package

3.2 Parsing

Output of bluetcl is text, and I need it in some better organized form, so I can parse it. I decided to use Lark library for parsing, and I'm using Earley parser. At this step I encountered first major difficulty that is total lack of documentation on form bluetcl output. I decided to reverse engineer it, and I'm using this website: <https://www.lark-parser.org/ide/> to debug and create grammar, it can run parser online, and show

output tree. To aid myself in this process I consulted Bluespec reference guide. While bluetcl output was undocumented it still needed to map to features of Bluespec. In total, I produced grammar with roughly 80 non-terminals.

3.2.1 Understanding abstract syntax tree (AST)

Given AST I needed to turn it into a more useful form. To do this I used **Transformer** class provided by Lark. The way it worked is that I created subclass of **Transformer** that implemented a function for each non-terminal / rule (Each non-terminal can have multiple rules and Lark allows for renaming individual of rules, this for example allows parsing different non-terminals using same function or parsing single non-terminal using different function depending on constructing rule). **Transformer** will then perform bottom up transformation of AST, and for each rule it will call respective member function, with parsed children as arguments. At the end of the transforming process I would have a list of objects that represented data from Bluetcl.

One of the bigger inconveniences I encounter is the fact that Lark passes parsed children, as a simple list. This doesn't provide information about what exactly is each child, this isn't a problem if rule contains fixed number of non-terminals, but otherwise I employ mix of length based inference, or I wrap data from children into tuples, to provide remove ambiguity.

What was quite useful at this stage is Python's type system flexibility, I was able to gradually build up system and add typing information only after I had firm understand what type something needs to be. For some things it wasn't imminently obvious, what is the best way to represent type, and what often happen is that I would shape type to needs of the functions using it and not other way.

3.2.2 Organizing data and functionality

I created a class called **TypeDatabase** it is basically a wrapper over previously mentioned functionality that manages organizing parsed output into separate dictionaries, like types, functions, type classes ect. It is also capable of loading and storing it's state to pickle file. This saves a lot of time as all this parsing and communication with bluetcl isn't particularly fast. TODO some break down of the speed.

3.3 Building the top level module

Building the top level module can be broken down into few operations.

- Instantiating new modules.
- Connecting modules using **mkConnection** function.
- Connecting modules using busses.
- Synthesizing Bluespec.

Those operations if implemented naively would be almost as simple as formatting a string. But If this was the only thing that this project provided I wouldn't need to go through all the trouble of parsing Bluespec grammar, and generally users would be better off just writing Bluespec code. My unique proposition is effectively running something similar to a language server, that will be capable of dynamically resolving types, and aiding user in the design process by providing possible connections, informing whether values passed to initialize module are correct, and informing about subinterfaces that can be found in the instantiated modules. At the basis of all those features will be type resolution, and to do it we first need to talk about do we do this.

3.3.1 Resolving types

3.3.2 Provisos explained (intuition)

On big feature of Bluespec typing is support for provisos. They create constraints on types that can be used with given function and give information about expected type of output of the function. This is similar

to how C++ has template types, but it is much more powerful. For example, we can have a polymorphic function from `Bit#(a)` to `Bit#(b)` and $a = b + 1$ where `Bit#(x)` a vector of x bits. To do something like this we would write a proviso `Add#(b,1,a)` which means that $b + 1$ must be equal to a .

System of provisos and typeclass work similarly to Prolog. We have variables that are lowercase names, we have values that are either strings or integers, and we have parametric types that are like compound terms. Typeclass instances are like rules and provisos attached to it are like predicates. To resolve types I do something I run Prolog style resolution.

Provisos explained (formally)

There are two types of provisos: Size Relationship provisos, and typeclass based provisos.

Mentioned above `Add` is one of Size Relationship provisos, other such provisos are `Mul` `Div` `Max` `Min` `Log`. Those provisos can't be nested, but we still can express complex arithmetic constraints, thanks to size relationship type functions. They essentially represent result of the operation on values on that were supplied. There are only 8 of them, and they are `TAdd` `TSub` `TDiv` `TMul` `TMax` `TMin` `TLog` `TExp`. To better explain this let's look at some simple example:

`Add#(TExp#(a),TMul#(a,8),c)` is a proviso that says that following equation on values must be satisfied $2^a + a * 8 = c$.

Of course, we can have multiple provisos that together create a set of equations.

Typeclass based provisos, allow us to either check if certain functions are defined for given type or to deuce something. For example `Bits#(a,b)` means that type `a` must be convertible to vector of b bits. This can be used to get the length in bits of given objects, on which we can later put constraints using Size Relationship provisos. In my project I will often check if there exists instance of the `Connectable#(a,b)` typeclass to check if function `mkConnection`(used to connect two interfaces together) is defined for given types.

3.4 Synthesizing

The goal of this project is to synthesize a