

Functional Bus Description Language

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Abstract

This document is the official specification of the Functional Bus Description Language. Its primary purpose is to define the syntax and semantics of the language. Functional Bus Description Language is a domain-specific language for bus and register management. Its main characteristic is the paradigm shift from the register-centric approach to the functionality-centric approach. In the register-centric approach, the user defines registers and then manually lays out the data into the registers. In the functionality-centric approach, the user defines the functionality of the data, and the registers, module hierarchy, and access codes are later automatically inferred. By defining the functionality of the data placed in the registers, it is possible to generate more code, increase code robustness, improve system design readability, and shorten the implementation process.

keywords: bus interface, code maintenance, computer languages, control interface, design automation, design verification, documentation generation, electronic design automation, EDA, electronic systems, Functional Bus Description Language, FBDL, hardware design, hardware description language, HDL, hierarchical register description, memory, programming, register addressing, register synthesis, software generation, system management

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Glossary

Not all terms defined in the glossary list are used in the specification. Some of them are formally defined because they are helpful when discussing, for example, compiler implementation.

call register

The call register term is used to refer to the proc register with the associated call pulse signal. When the call register is written, the call pulse is generated.

data

The data term is used to refer to the content of the registers. Unless it is used in the context of internal data types of the language.

downstream

The downstream is a stream from the requester to the provider.

exit register

The exit register term is used to refer to the proc register with the associated exit pulse signal. When the exit register is read, the exit pulse is generated.

functionality

The functionality is the functionality of given data. It can be seen as a type of the data. In case of functionalities encapsulating other functionalities, such as bus, block, proc or downstream, the functionality is used to denote a broader context of encapsulated data.

gap

The gap term is used to refer to unused bits within a register.

gateway

The gateway term is used to refer to the overall configuration of the logic placed in the FPGA to make it behave according to the desired description. The term is not formally defined anywhere, however it is used to unburden the firmware term. IEEE Std 610.12-1990 also mentions that the firmware term is too overloaded and confusing.

generator

The generator term is used to refer to the part of a compiler directly responsible for the target code generation based on registerification results.

information

The information term is used to refer to the metadata on the functionality data. The metadata describes where the data is located, for example bit masks and register addresses, and how to access the data.

means

The means term is used to refer to the automatically generated method or data that shall be used by the requester to request particular functionality. A means in particular programming language is usually a function, method or procedure that shall be called or class, dictionary, map or structure containing information on how to access particular functionality.

provider

The provider is the system component containing the generated registers and providing described functionalities.

pure call register

The term pure call register is used to refer to the call register containing no proc returns.

pure exit register

The term pure exit register is used to refer to the exit register containing no proc params.

registerification

The registerification is the process of placing data of functionalities into the registers. The process includes assigning data bit masks, register addresses as well as block addresses and masks. The term is new in the field and is coined in the specification.

requester

The requester is the system component accessing the generated registers and requesting described functionalities.

strobe register

The strobe register term is used to refer to the streamregister with the associated strobe pulse signal. When the strobe register is written (downstream), or read (upstream) the strobe pulse is generated.

target

The target term is used to refer to the transpilation target. For example, a target can be a requester Python code allowing to access functionalities of the provider in an asynchronous fashion. A VHDL code providing description of the functionality registers and exposing AXI compliant interface is a valid provider target. A JSON file describing registerification results is for example a valid documentation target. The target depends on several factors, but the most important ones are programming/description language, synchronous or asynchronous access interface, bus type, dynamic or static address map reloading. Each target has its recipient. It is either provider, requester or documentation.

upstream

The upstream is a stream from the provider to the requester.

1 Overview

1.1 Scope

This document specifies the syntax and semantics of the Functional Bus Description Language (FBDL).

1.2 Purpose

This document is intended for the implementers of tools supporting the language and for users of the language. The focus is on defining the valid language constructs, their meanings and implications for the hardware and software that is specified or configured, how compliant tools are required to behave, and how to use the language.

1.3 Motivation

Describing and managing registers can be a tedious and error-prone task. The information about registers is utilized by software, hardware, and verification engineers. Typically a specification of the registers is designed by the hardware designer or system architect. During the design and implementation phases, it changes multiple times due to different reasons such as bugs, requirement changes, technical limitations, or user feedback. A simple change in a single register may imply adjustments in both hardware and software. These adjustments cost money and time.

Several formal and informal tools exist to address issues related to register management. However, they all share the same concept of describing registers at a very low level. That is, the user has to implicitly define the layout of the registers. For example, in the case of a register containing multiple statuses, it's the user responsibility to specify the bit position for every status.

The FBDL is different in this term. The user specifies the functionalities that must be provided by the data stored in the registers. The register layout is automatically generated based on the functional requirements. Such an approach increases the amount of automatically generated hardware description and software code and decreases the amount of code requiring manual implementation compared to the register-centric approach. Not only the register masks, addresses, and single read and write functions can be generated, but complete custom functions with optimized access methods. This, in turn, leads to shorter design iterations and fewer bugs.

1.4 Word usage

The terms “must”, “must not”, “required”, “shall”, “shall not”, “should”, “should not”, “recommended”, “may”, and “optional” in this document are to be interpreted as described in the IETF Best Practices Document 14, RFC 2119.1.

1.5 Syntactic description

The formal syntax of the FBDL is described by means of context-free syntax using a simple variant of the Backus-Naur Form (BNF). In particular:

- a) Lowercase words in constant-width font, some containing embedded underscores, are used to denote syntactic categories, for example:

`single_import_statement`

Whenever the name of a syntactic category is used, apart from the syntax rules themselves, underscores are replaced with spaces thus, “single import statement” would appear in the narrative description when referring to the syntactic category.

- b) Boldface words are used to denote keywords, for example:

mask

Keywords shall be used only in those places indicated by the syntax.

- c) A production consists of a left-hand side, the symbol “::=” (which is read as can be replaced by), and a right-hand side. The left-hand side of a production is always a syntactic category, the right-hand side is a replacement rule. The meaning of a production is a textual-replacement rule. Any occurrence of the left-hand side may be replaced by an instance of the right-hand side.
- d) A vertical bar (|) separates alternative items on the right-hand side of a production unless it occurs immediately after an opening brace, in which case it stands for itself, for example:

```
decimal_digit ::= zero_digit | non_zero_decimal_digit  
choices ::= choice { | choice }
```

In the first instance, an occurrence of decimal digit can be replaced by either zero digit or non zero decimal digit. In the second case, “choices” can be replaced by a list of “choice”, separated by vertical bars, see item f) for the meaning of braces.
- e) Square brackets [] enclose optional items on the right-hand side of a production. Note, however, sometimes square brackets in the right-hand side of the production are part of the syntax. In such cases bold font is used.
- f) Braces { } enclose a repeated item or items on the right-hand side of a production. The items may appear zero or more times.
- g) The term *declared identifier* is used for any occurrence of an identifier that already denotes some declared item (declared by a user or by specification, for example, built-in function name).

2 References

The following referenced documents are indispensable for the application of this document (i.e., they must be understood and used, so each referenced document is cited in the text and its relationship to this document is explained). For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments or corrigenda) applies.

- IETF Best Practices Document 14, RFC 2119,
- IETF UTF-8, a transformation format of ISO 10646, RFC 3629,
- IEEE Std 754TM–2019, IEEE Standard for Floating-Point Arithmetic.

3 Concepts

The core concept behind the FBDL is based on the fact that if there is a system part with the registers that can be accessed, then there is at least one more system part accessing these registers. The part accessing the registers is called the *requester*. The part containing the registers is called the *provider*, as it provides functions via particular functionalities.

The code generated from the FBDL description can be conceptually divided into two parts, the requester part and the provider part. The requester code usually refers to the generated software or firmware implemented in typical programming languages such as: Ada, C, C++, Go, Java, Python, Rust etc. The provider code usually refers to the generated gateway or hardware implemented in hardware description languages or frameworks such as: VHDL, SystemVerilog, SystemC, Bluespec, PipelineC, MyHDL, Chisel etc. However, implementing the provider, for example as a firmware, using the C language and a microcontroller is practically doable and valid.

The description of functionalities shall be placed in files with the `.fdb` extension. By default, the bus named `Main` is the entry point for the description used for the code generation. A compiler is free to support a parameter for changing the name of the main bus.

```
description ::=
    import_statement |
    constant_definition |
    type_definition |
    instantiation
```

3.1 Properties

Each data in the FBDL description has associated functionality and each functionality has associated properties. Properties allow the configuration of functionalities. Each property must have a concrete type. The default value of each property is specified in the round brackets () in the functionality subsections. If the default value is `bus width`, then the default value equals the actual value of the bus width property. If the default value is `uninitialized`, then it shall be represented as the uninitialized meta value at the provider side. If the target language for the provider code does not have a concept of uninitialized value, then values such as `0`, `Null`, `None`, `nil` etc. shall be used.

Each property either defines or declares functionality feature or behavior. Definitive properties specify the desired behavior of the automatically generated code. They specify elements directly managed by the FBDL. Examples of definitive properties include `atomic` or `width` properties. Declarative properties describe the behavior of external elements that automatically generated code only interacts with. Declarative properties are required to generate valid logic, and it is the user's responsibility to make sure their values match the behavior of external components. Examples of declarative properties include `access` or `in-trigger` properties.

```
property_assignment ::= property_identifier = expression

property_assignments ::=
    property_assignments
    { ; property_assignment }
    newline

semicolon_and_property_assignments ::= ; property_assignments
```

```
property_identifier ::=
    access | add-enable | atomic | byte-write-enable | clear | delay |
    enable-init-value | enable-reset-value | groups | init-value |
    in-trigger | masters | out-trigger | range | read-latency |
    read-value | reset | reset-value | size | width
```

3.2 Instantiation

A functionality can be instantiated in a single line or in multiple lines.

```
instantiation ::= single_line_instantiation | multi_line_instantiation
single_line_instantiation ::=
    identifier
    [ array_marker ]
    declared_identifier | qualified_identifier
    [ argument_list ]
    newline | semicolon_and_property_assignments
multi_line_instantiation ::=
    identifier
    [ array_marker ]
    declared_identifier | qualified_identifier
    [ argument_list ]
    functionality_body
array_marker ::= [ expression ]
functionality_body ::=
    newline
    indent
    { constant_definition | type_definition | property_assignments | instantiation }
    dedent
```

The following code shows examples of single line instantiations:

```
C config
C config; width = 8
M [8]mask; atomic = false; width = 128; init-value = 0
err error_t(48); atomic = false
```

The following code shows examples of multi line instantiations:

```
My_Config config
    width = 96
    atomic = false
My_Irq irq
    add-enable = true
    in-trigger = "Edge"
```

3.3 Addressing

The FBDL specification does not impose byte or word addressing. There is also no property allowing to switch between these two addressing modes. The addressing mode handling is completely left to the particular compiler implementation. If the compiler has a monolithic structure (no distinction between the compiler frontend and backend), then it is probably the best decision to use the addressing mode used by the target bus (for example, byte addressing for AXI or word addressing for Wishbone). Another option is providing a compiler flag or parameter to specify the addressing mode during the compiler call. However, in the case of a compiler frontend implementation, it is recommended to use word addressing with a word width equal to the bus width. As it is not known whether the compiler

backend will use the word or byte addressing, using the word addressing in the compiler frontend is usually a more straightforward approach, as the byte addresses are word addresses multiplied by the number of bytes in the single word.

3.4 Positive logic

The FBDL uses only positive logic. An active level in positive logic is a high level (binary 1), and an active edge is a rising edge (transition from the low level to the high level, from binary 0 to binary 1). It does not mean that FBDL cannot be used with external components using negative logic. To connect external negative logic components to the generated FBDL positive logic components, one shall negate the signals at the interface connection level. Supporting both positive and negative logic would unnecessarily complex the language and would create a second way for solving the same problem making the set of possible solutions non-orthogonal.

3.5 Domain-specific language

The FBDL is a domain-specific language with its own syntax. Some of the register-centric tools are built on top of standard file formats or markup languages such as JSON, TOML, XML or YAML. Such an approach allows for fast prototyping and has a lower entry threshold. However, it becomes a burden when more conceptually advanced features, for example parametrization, have to be supported. The description quickly begins to gain in volume, and the overall feeling is it is needlessly verbose. What is more, having its own adjusted language syntax allows for more informative compiler error messages.

4 Lexical elements

FBDL has following types of lexical tokens:

- comment,
- identifier,
- indent,
- keyword,
- literal,
- newline.

4.1 Comments

There is only a single type of comment, a *single-line comment*. A single-line comment starts with the '#' character and extends up to the end of the line. A single-line comment can appear on any line of an FBDL file and may contain any character, including glyphs and special characters. The presence or absence of comments has no influence on whether a description is legal or illegal. Their sole purpose is to enlighten the human reader.

4.1.1 Documentation comments

Documentation comments are comments that appear immediately before constant definitions, type definitions, and functionality instantiations with no intervening newlines. The following code shows examples of documentation comments:

```
# Number of receivers
const RECEIVERS_COUNT = 7
Main bus
  # Data receivers
  Receivers [RECEIVERS_COUNT]block
    # 0 disable receiver, 1 enable receiver
    Enable config; width = 1
    # Number of frames in the buffer
    Frame_Count status
    # Documentation comments can consist of
    # multiple single-line comments.
    Read_Frame proc
      data [4]return; width = 8
```

4.2 Identifiers

Identifiers are used as names. An identifier shall start with a letter.

```
uppercase_letter ::=
  A | B | C | D | E | F | G | H | I | J | K | L | M |
  N | O | P | R | S | T | U | V | W | X | Y | Z

lowercase_letter ::=
  a | b | c | d | e | f | g | h | i | j | k | l | m |
  n | o | p | r | s | t | u | v | w | x | y | z

letter ::= uppercase_letter | lowercase_letter
letter_or_digit ::= letter | decimal_digit
identifier ::= letter { underscore | letter_or_digit }
```

The following code contains some valid and invalid identifiers:

```
const C_20 = 20 # Valid
const _C20 = 20 # Invalid
Main bus
  cfg1 config # Valid
  lcfg config # Invalid
```

4.2.1 Declared identifier

Declared identifier is used for any occurrence of an identifier that already denotes some declared item.

`declared_identifier ::= letter { underscore | letter_or_digit }`

4.2.2 Qualified identifier

The qualified identifier is used to reference a symbol from foreign package.

`qualified_identifier ::= declared_identifier.declared_identifier`

The first declared identifier denotes the package, and the second one denotes the symbol from this package.

4.3 Indent

The indentation has semantics meaning in the FBDL. The indent sequence consists of two space characters (U+0020). It is hard to express the indent and dedent using BNF. Ident is the increase of the indentation level, and dedent is the decrease of the indentation level. In the following code the indent happens in the lines number 2, 5 and 7, and the dedent happens in the line number 4. What is more, double dedent happens at the EOF. The number of indents always equals the number of dedents in the syntactically and semantically correct file.

```
1: type cfg_t config
2:   atomic = false
3:   width = 64
4: Main bus
5:   C cfg_t
6:   blk block
7:     C cfg_t
8:     S status
```

Not only the indent alignment is important, but also its level. In the following code the first type definition is correct, as the indent level for the definition body is increased by one. The second type definition is incorrect, even though the indent within the definition body is aligned, as the indent level is increased by two.

```
# Valid indent
type cfg1_t config
  atomic = false
  width = 8
# Invalid indent, indent increased by two
type cfg2_t config
  atomic = false
  width = 8
```

4.4 Keywords

FBDL has following keywords: **atomic**, **block**, **bus**, **clear**, **config**, **const**, **false**, **import**, **init-value**, **irq**, **mask**, **memory**, **param**, **proc**, **range**, **reset**, **read-value**, **reset-value**, **return**, **static**, **stream**, **true**, **type**, **in-trigger**, **out-trigger**.

Keywords can be used as identifiers with one exception. Keywords denoting built-in types (functionalities) cannot be used as identifiers for custom types.

4.5 Literals

4.5.1 Bool literals

`bool_literal ::= false | true`

4.5.2 Number literals

`underscore ::= _`

`zero_digit ::= 0`

`non_zero_decimal_digit ::= 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9`

`decimal_digit ::= zero_digit | non_zero_decimal_digit`

`binary_base ::= 0B | 0b`

`binary_digit ::= 0 | 1`

`octal_base ::= 00 | 0o`

`octal_digit ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7`

`hex_base ::= 0X | 0x`

`hex_digit ::= 0 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9
| A | a | B | b | C | c | D | d | E | e | F | f`

4.5.3 Integer literals

`integer_literal ::= binary_literal | octal_literal | decimal_literal | hex_literal`

`binary_literal ::= binary_base binary_digit { [underscore] binary_digit }`

`octal_literal ::= octal_base octal_digit { [underscore] octal_digit }`

`decimal_literal ::= non_zero_decimal_digit { [underscore] decimal_digit }`

`hex_literal ::= hex_base hex_digit { [underscore] hex_digit }`

4.5.4 Real literals

The real literals shall be represented as described by IEEE Std 754, an IEEE standard for double-precision floating-point numbers.

Real numbers can be specified in either decimal notation (for example, 17.83) or in scientific notation (for example, 13e8, which indicates 13 multiplied by 10 to the eighth power). Real numbers expressed with a decimal point shall have at least one digit on each side of the decimal point.

4.5.5 String literals

A string literal is a sequence of zero or more UTF-8 characters enclosed by double quotes (“”).

`string_literal ::= "{UTF-8 character}"`

4.5.6 Bit string literals

A bit string literal is a sequence of zero or more digit or meta value characters enclosed by double quotes (“”) and preceded by a base specifier. The meta value characters are supported because of hardware description languages, that also have a concept of metalogical values.

`meta_character ::= - | U | W | X | Z`

The meta characters have following meaning:

- ‘-’ - don’t care,
- ‘U’ - uninitialized,
- ‘W’ - weak unknown,
- ‘X’ - unknown,
- ‘Z’ - high-impedance state.

`binary_or_meta ::= binary_digit | meta_character`

`octal_or_meta ::= octal_digit | meta_character`

`hex_or_meta ::= hex_digit | meta_character`

There are three types of bit string literals: binary bit string literal, octal bit string literal and hex bit string literal.

`bit_string_literal ::=`
`binary_bit_string_literal |`
`octal_bit_string_literal |`
`hex_bit_string_literal`

`binary_bit_string_base = B | b`

`binary_bit_string_literal = binary_bit_string_base "{binary_or_meta}"`

`octal_bit_string_base = 0 | o`

`octal_bit_string_literal = octal_bit_string_base "{octal_or_meta}"`

`hex_bit_string_base = X | x`

`hex_bit_string_literal = hex_bit_string_base "{hex_or_meta}"`

If meta value is present in a bit string literal, then it is expanded to the proper width depending on the bit string base. For example, following equations are true:

`o"XW" = b"XXXWWW"`
`x"U-" = b"UUUU----"`

4.5.7 Time literals

A time literal is a sequence of integer literal and a time unit.

`time_unit ::= ns | us | ms | s`

`time_literal ::= integer_literal time_unit`

Time literals are used to create values of time data type, required for example by the delay property.

5 Data types

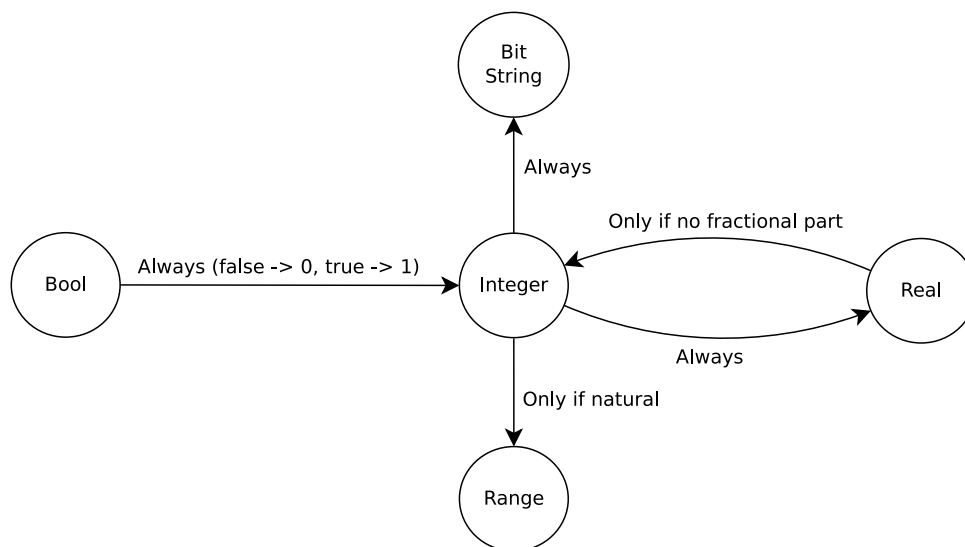
There are 7 data types in FBDL:

- bit string,
- bool,
- integer,
- range,
- real,
- string,
- time.

Types are implicit and are not declared. The type of the value evaluated from an expression must be checked before any assignment or comparison. If there is a type mismatch that can be resolved with implicit rules, then it shall be resolved. In case of a type mismatch that cannot be resolved, an error must be reported by the compiler.

Conversion from bool to integer in expressions is implicit. Conversion from integer to real in expressions is implicit. Conversion from integer to range can be implicit if the integer value is natural. Conversion from real to integer can be implicit if there is no fractional part. If fractional part is present, then conversion from real to integer must be explicit and must be done by calling any function returning integer type, for example `ceil()`, `floor()`.

The below picture presents a graph of possible implicit conversions between different data types.



5.1 Bit string

The value of the bit string type is used for all ***-value** properties. It might be created explicitly using the bit string literal or it might be converted implicitly from the value of integer type. The only way to create a bit string value containing meta values is to explicitly use the bit string literal.

The below table presents unary negation operation results applied to possible bit string data type values.

Bit string unary bitwise negation	
In Value	Out Value
0	1
1	0
-	-
U	U
W	W
X	X

Below tables present binary operation results applied to possible bit string data type values.

Bit string binary bitwise and (&) resolution							
Operands	0	1	-	U	W	X	Z
0	0	0	0	U	0	X	0
1	0	1	1	U	1	X	1
-	0	1	-	U	W	X	Z
U	U	U	U	U	U	U	U
W	0	1	X	U	W	X	W
X	X	X	X	U	X	X	X
Z	0	1	X	U	W	X	Z

Bit string binary bitwise or () resolution							
Operands	0	1	-	U	W	X	Z
0	0	1	0	U	0	X	0
1	1	1	1	U	1	X	1
-	0	1	-	U	W	X	Z
U	U	U	U	U	U	U	U
W	0	1	X	U	W	X	W
X	X	X	X	U	X	X	X
Z	0	1	X	U	W	X	Z

Bit string binary bitwise xor (^) resolution							
Operands	0	1	-	U	W	X	Z
0	0	1	0	U	0	X	0
1	1	0	1	U	1	X	1
-	0	1	-	U	W	X	Z
U	U	U	U	U	U	U	U
W	0	1	X	U	W	X	W
X	X	X	X	U	X	X	X
Z	0	1	X	U	W	X	Z

5.2 Bool

The value of the bool type can be created explicitly using `true` or `false` literals. The value of the bool type shall be implicitly converted to the value of the integer type in places where the value of the integer type is required. The boolean `false` value shall be converted to the integer value 0. The boolean `true` value shall be converted to the integer value 1. In the following example, the value of `I1` evaluates to 1, and the value of `I2` evaluates to 2.

```
const B0 = false
const B1 = true
const I1 = B0 + B1
const I2 = B1 + B1
```

The bool - integer conversion is asymmetric. Implicit conversion of a value of the integer type to a value of the bool type is forbidden. This is because values of the bool type are often used to count the number of elements or to arbitrarily enable/disable an element generation. However, a value of the integer type appearing in a place where a value of the bool type is required is usually a sign of a mistake. To convert a value of the integer type to a value of the bool type the built-in `bool()` function must be called.

5.3 Integer

The integer data type is always signed integer and must be at least 64 bits wide.

5.4 Range

The range data type is used to assign value to the `range` property. It consists of left and right bounds, both expressed as expressions, separated by the colon character. The range data type can be created solely using the range expression. There is no range literal.

```
range_expression ::= expression : expression
```

5.5 Real

The real data type is 64 bits IEEE 754 double precision floating-point type.

5.6 String

The string data type can only be created explicitly using a string literal. The string data type is only used for setting values of some properties, for example `access`.

5.7 Time

The time data type is only used for assigning value to the properties expressed in time. The value of time type can be created explicitly using the time literal. Values of time type can be added regardless of their time units. Values of the time type can also be multiplied by values of the integer type. All of the below property assignments are valid.

```
delay = 1 s + 1 ms + 1 us + 1 ns
delay = 5 * 60 s # Sleep for 5 minutes.
delay = 10 ms * 4 + 7 * 8 us
```

6 Expressions

An expression is a formula that defines the computation of a value by applying operators and functions to operands.

```
expression ::=
  bool_literal |
  integer_literal |
  real_literal |
  string_literal |
  bit_string_literal |
  time_literal |
  declared_identifier |
  qualified_identifier |
  unary_operation |
  binary_operation |
  function_call |
  subscript |
  parenthesized_expression |
  range_expression |
  expression_list
```

The function call is used to call one of built-in functions.

```
function_call ::= declared_identifier( [ expression { , expression } ] )
```

The subscript is used to refer to a particular element from the expression list.

```
subscript ::= declared_identifier[ expression ]
```

The parenthesized expression may be used to explicitly set order of operations.

```
parenthesized_expression ::= ( expression )
```

The expression list may be used to create a list of expressions.

```
expression_list ::= [ [ expression { , expression } ] ]
```

6.1 Operators

6.1.1 Unary Operators

```
unary_operation ::= unary_operator expression
```

```
unary_operator ::= unary_arithmetic_operator | unary_bitwise_operator
```

```
unary_arithmetic_operator ::= -
```

```
unary_bitwise_operator ::= !
```

FBDL unary operators

Token	Operation	Operand Type	Result Type
-	Opposite	Integer Real	Integer Real
!	Negation	Bit string Integer	Bit string Integer

6.1.2 Binary Operators

```
binary_operation ::= expression binary_operator expression
```

```

binary_operator ::=
  binary_arithmetic_operator |
  binary_bitwise_operator |
  binary_comparison_operator |
  binary_logical_operator |
  binary_range_operator

binary_arithmetic_operator ::= + | - | * | / | % | **
binary_bitwise_operator ::= << | >>
binary_comparison_operator ::= == | != | < | <= | > | >=
binary_logical_operator ::= && | ||
binary_range_operator ::= :

```

FBDL binary arithmetic operators

Token	Operation	Left Operand Type	Right Operand Type	Result Type
+	Addition	Integer	Integer	Integer
		Integer	Real	Real
		Real	Integer	Real
		Real	Real	Real
		Time	Time	Time
-	Subtraction	Integer	Integer	Integer
		Integer	Real	Real
		Real	Integer	Real
		Real	Real	Real
*	Multiplication	Integer	Integer	Integer
		Integer	Real	Real
		Real	Integer	Real
		Real	Real	Real
		Integer	Time	Time
/	Division	Time	Integer	Time
		Integer	Integer	Real
		Integer	Real	Real
		Real	Integer	Real
%	Remainder	Real	Real	Real
		Integer	Integer	Integer
		Integer	Integer	Integer
		Integer	Integer	Integer
**	Exponentiation	Integer	Integer	Integer
		Integer	Real	Real
		Real	Integer	Real
		Real	Real	Real

FBDL binary bitwise operators

Token	Operation	Left Operand Type	Right Operand Type	Result Type
<<	Left Shift	Integer	Integer	Integer
>>	Right Shift	Integer	Integer	Integer
&	And	Bit String Integer	Bit String Integer	Bit String Integer
	Or	Bit String Integer	Bit String Integer	Bit String Integer
^	Xor	Bit String Integer	Bit String Integer	Bit String Integer

FBDL binary comparison operators

Token	Operation	Left Operand Type	Right Operand Type	Result Type
==	Equality	Integer	Integer	Bool
		Integer	Real	Bool
		Real	Integer	Bool
		Real	Real	Bool
!=	Nonequality	Integer	Integer	Bool
		Integer	Real	Bool
		Real	Integer	Bool
		Real	Real	Bool
<	Less Than	Integer	Integer	Bool
		Integer	Real	Bool
		Real	Integer	Bool
		Real	Real	Bool
<=	Less Than or Equal	Integer	Integer	Bool
		Integer	Real	Bool
		Real	Integer	Bool
		Real	Real	Bool
>	Greater Than	Integer	Integer	Bool
		Integer	Real	Bool
		Real	Integer	Bool
		Real	Real	Bool
>=	Greater Than or Equal	Integer	Integer	Bool
		Integer	Real	Bool
		Real	Integer	Bool
		Real	Real	Bool

FBDL binary logical operators

Token	Operation	Left Operand Type	Right Operand Type	Result Type
&&	Short-circuiting logical AND	Bool	Bool	Bool
	Short-circuiting logical OR	Bool	Bool	Bool

FBDL binary range operator

Token	Operation	Left Operand Type	Right Operand Type	Result Type
:	Range	Integer	Integer	Range

The bool data type is not valid operand type for the most of the binary operations. However, as there is the rule for implicit conversion from the bool data type to the integer data type, all operations accepting the integer operands work also for the bool operands.

6.2 Functions

The FBDL does not allow defining custom functions for value computations. However, FBDL has following built-in functions:

abs(x integer|real) integer|real

The abs function returns the absolute value of x.

bool(x integer) bool

The bool function returns a value of the bool type converted from a value x of the integer type. If x equals 0, then the false is returned. In all other cases the true is returned.

ceil(x real) integer

The ceil function returns the least integer value greater than or equal to x.

floor(x real) integer

The floor function returns the greatest integer value less than or equal to x.

log2(x real) integer|real

The log2 function returns the binary logarithm of x.

log10(x real) integer|real

The log10 function returns the decimal logarithm of x.

log(x, b real) integer|real

The log function returns the logarithm of x to the base b.

u2(x, w integer) integer

The u2 function returns two's complement representation of x as an integer assuming width w. For example, u2(-1, 8) returns 255.

7 Functionalities

Functionalities are the core part of the FBDL. They define the capabilities of the provider. Each functionality is distinct and unambiguously defines the provider behavior and the interface that must be generated for the requester. There are following 14 functionalities:

1. blackbox,
2. block,
3. bus,
4. config,
5. group,
6. irq,
7. mask,
8. memory,
9. param,
10. proc,
11. return,
12. static,
13. status,
14. stream.

Sections of this chapter describe all available functionalities. Functionality properties are defined in the following notation.

property-name expected value type (default value) {kind}

Due to implicit data type conversion rules, some properties accept more than one data type. For example, the range property expects a value of the range data type. However, as there is a rule for implicit conversion from the integer type to the range type, the “range = 5” assignment is also valid.

The property kind indicates whether the property is a definitive or a declarative property as described in Section 3.1.

7.1 Blackbox

The blackbox functionality is used to incorporate blocks implemented manually or generated by external tools. For example, a user may want to explicitly manage some particular registers’ layouts. In such a case, a register-centric tool might be used, and the generated block can be incorporated into the wrapping functionality-centric description using the blackbox functionality.

The blackbox functionality has following properties:

size integer (obligatory) [definitive]

The size property defines size of the blackbox in the number of words with width equal to the width property value of the block in which blackbox is defined.

The code generated for the requester should not provide any means for accessing the blackbox. The code generated for the provider must provide a means to connect the blackbox to the remaining part of the bus generated by an FBDL compiler.

7.2 Block

The block functionality is used to logically group or encapsulate functionalities. The block is usually used to separate functionalities related to particular peripherals such as UART, I2C transceivers, timers, ADCs, DACs etc. The block might also be used to limit the access for particular provider to only a subset of functionalities.

The block functionality has following properties:

masters integer (1) {definitive}

The masters property defines the number of block masters.

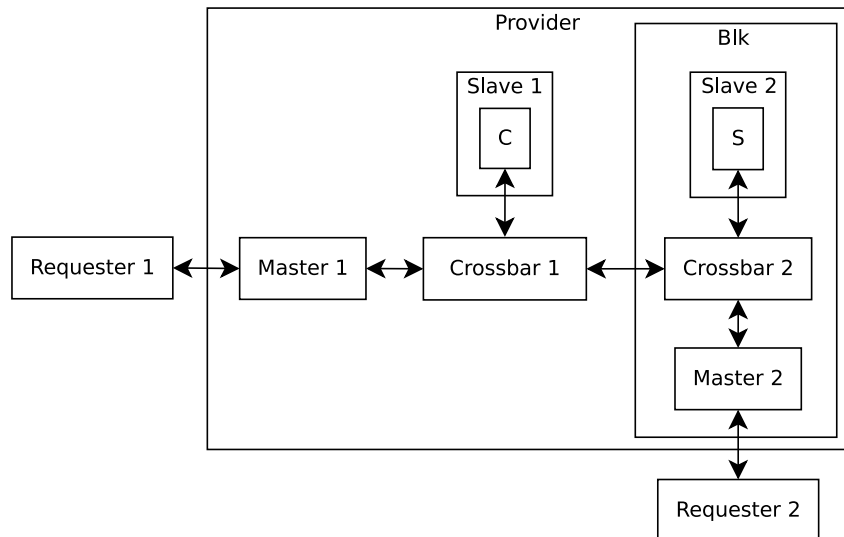
reset string (None) {definitive}

The reset property defines the block reset type. By default the block has no reset. Valid values of the reset property are "Sync" for synchronous reset and "Async" for asynchronous reset.

The following example presents how to limit the scope of access for particular requester.

```
Main bus
  C config
  Blk block
    masters = 2
    S status
```

The logical connection of the system components may look as follows:



The requester number 1 can access both config C and status S. However, the requester number 2 can access only the status S.

7.3 Bus

The bus functionality represents the bus structure. Every valid description must have at least one bus instantiated, as the bus is the entry point for the description used for the code generation.

The bus functionality has following properties:

masters integer (1) {definitive}

The masters property defines the number of bus masters.

reset string (None) {definitive}

The reset property defines the bus reset type. By default the bus has no reset. Valid values of the reset property are "Sync" for synchronous reset and "Async" for asynchronous reset.

width integer (32) {definitive}

The width property defines the bus data width.

The bus address width is not explicitly set, as it implies from the address space size required to pack all functionalities included in the bus description.

7.4 Config

The config functionality represents configuration data. The configuration data is data that is automatically read by the provider from its registers. As the config is automatically read by the provider, there is no need for an additional signal associated with the config, indicating the config write by the requester. By default, a config can be written and read by the requester.

The config functionality has following properties:

atomic bool (true) {definitive}

The atomic property defines whether an access to the config must be atomic. If atomic is true, then the provider must guarantee that any change of the config value, triggered by the requester write, is seen as an atomic change by the other modules of the provider. This is especially important when the config spans more than single register, as in case of single register write the change is always atomic.

init-value bit string (uninitialized) {definitive}

The init-value property defines the initial value of the config.

range range | [range] (None) {definitive}

The range property defines the range of valid values. Range bound values shall not be negative. This is because the FBDL makes no assumptions on the negative values encoding. To accomplish negative range checks functions such as `u2` must be explicitly called. For example, following assignment limits the possible range from -16 to -8: `range = u2(-8, 8):u2(-16, 8)`. The range property shall not be explicitly set if the width property is already set. If the range property is not set, then the actual range implies from the width property. The code generated for the provider is not required to check or report if the value provided for the config write is within the valid range. The recommended way is to implement compiler parameter allowing enabling/disabling range check generation.

read-value bit string (uninitialized) {definitive}

The read-value property defines the value returned by the provider on the config read. If the read-value is not set, then the provider must return the actual value of the config.

reset-value bit string (uninitialized) {definitive}

The reset-value property defines the value of the config after the reset. If the reset-value is set, but a bus or block containing the config is not resettable (`reset = None`), then the compiler shall report an error.

width integer (bus width) {definitive}

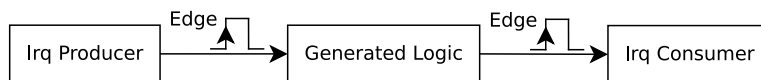
The width property defines the bit width of the config. The width property shall not be explicitly set if the range property is already set.

The code generated for the requester must provide means for writing and reading the config.

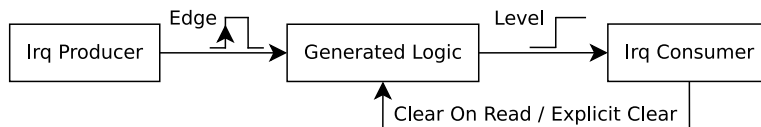
7.5 Irq

The irq functionality represents an interrupt handling. The irq functionality allows for automatic connection of the following interrupt producers (in-trigger) and consumers (out-trigger):

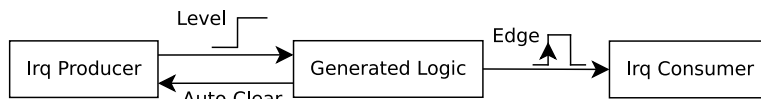
1. edge producer and edge sensitive consumer,



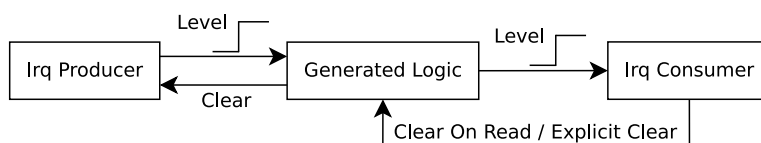
2. edge producer and level sensitive consumer,



3. level producer and edge sensitive consumer,



4. level producer and level sensitive consumer,



The irq functionality has following properties:

add-enable bool (false) {definitive}

The add-enable property defines whether an interrupt has associated enable bit in the interrupt enable register. The enable can be used to mask the interrupt.

clear string ("Explicit") {definitive}

The clear property defines how particular interrupt flag is cleared. The clear property is valid only in case of level-triggered interrupt consumer. If clear property is set for edge-triggered interrupt consumer a compiler shall report an error. Valid values are "Explicit" and "On Read". The "Explicit" clear requires compiler to generate a means that must be explicitly used to clear the interrupt flag. The "On Read" clear requires the provider to clear the interrupt flag on each interrupt flag read.

enable-init-value bit string (uninitialized) {definitive}

The enable-init-value property defines the initial value of the enable bit in the interrupt enable register. The value must not exceed one bit. If add-enable is false and enable-init-value is set, then a compiler must report an error.

enable-reset-value bit string (uninitialized) {definitive}

The enable-reset-value property defines the value of the enable bit in the interrupt enable register after the reset. The value must not exceed one bit. If add-enable is false and enable-reset-value is set, then a compiler must report an error. If the enable-reset-value is set, but a bus or block containing the irq is not resettable (reset = None), then the compiler shall report an error.

in-trigger string ("Level") {declarative}

The in-trigger property declares the interrupt producer type of trigger. Valid values are "Edge" and "Level". It is up to the user to make sure declared trigger is coherent with the actual producer behavior. A mismatch may lead to incorrect behavior.

out-trigger string ("Level") {declarative}

The out-trigger property declares the interrupt consumer type of trigger. Valid values are *"Edge"* and *"Level"*. It is up to the user to make sure declared trigger is coherent with the actual consumer requirement. A mismatch may lead to incorrect behavior.

7.6 Mask

The mask functionality represents a bit mask. The mask is data that is automatically read by the provider from its registers. By default, a mask can be written and read by the requester. The mask is very similar to the config. The difference is that the config is value-oriented, whereas the mask is bit-oriented. From the provider's perspective the mask and the config are the same. From the requester's perspective the code generated for interacting with the mask and the config is different.

The mask functionality has following properties:

atomic bool (true) {definitive}

The atomic property defines whether an access to the mask must be atomic. If atomic is true, then the provider must guarantee that any change of the mask value, triggered by the requester write, is seen as an atomic change by the other modules of the provider. This is especially important when the mask spans more than single register, as in case of single register write the change is always atomic.

init-value bit string (uninitialized) {definitive}

The init-value property defines the initial value of the mask.

read-value bit string (None) {definitive}

The read-value property defines the value returned by the provider on the mask read. If the read-value is not set, then the provider must return the actual value of the mask.

reset-value bit string (None) {definitive}

The reset-value property defines the value of the mask after the reset. If the reset-value is set, but a bus or block containing the mask is not resettable (reset = None), then the compiler shall report an error.

width integer (bus width) {definitive}

The width property defines the bit width of the mask.

The code generated for the requester must provide means for setting, clearing and updating particular bits of the mask. The updating includes setting, clearing and toggling. The set differs from the update set. The set sets particular bits and simultaneously clears all remaining bits. The update set sets particular bits and keeps the value of the remaining bits. The clear differs from the update clear in an analogous way. The toggle always works on provided bits leaving the remaining bits untouched.

7.7 Memory

The memory functionality is used to directly connect and map an external memory to the generated bus address space. A memory can also be connected to the bus using the proc or stream functionality. However, using the memory functionality usually leads to greater throughput, but increases the size of the generated address space.

The memory functionality has following properties:

access string (*"Read Write"*) {definitive}

The access property declares the valid access permissions to the memory for the requester. Valid values of the access property are: *"Read Write"*, *"Read Only"*, *"Write Only"*.

byte-write-enable bool (false) {declarative}

The byte-write-enable property declares byte-enable writes, that update the memory on contents on a byte-to-byte basis. If the byte-write-enable property is explicitly set by a user, and a memory access is "*Read Only*", then a compiler shall report an error.

read-latency integer (obligatory if access supports read) {declarative}

The read-latency property declares the read latency in the number of clock cycles. It is required, if a memory supports read access, to correctly implement read logic.

size integer (obligatory) {declarative}

The size property declares the memory size. The size is in the number of memory words with width equal to the memory width property value.

width integer (bus width) {declarative}

The width property declares the memory data width.

The code generated for the requester must provide means for single read/write and block read/write transactions. Whether access means for vectored (scatter-gather) transactions are automatically generated is up to the compiler. If memory is read-only or write-only, then an unsupported write or read access code is recommended not to be generated.

7.8 Param

The param functionality is an inner functionality of the proc and stream functionalities. It represents a data fed to a procedure or streamed by a downstream.

The param functionality has following properties:

range range | [range] (None) {definitive}

The range property defines the range of valid values. The range property on param behaves exactly the same as the range property on config.

width integer (bus width) {definitive}

The width property defines the bit width of the param.

The following example presents the definition of a downstream with three parameters.

```
Sum_Reduce stream
  type param_t param; width = 16
  a param_t
  b param_t
  c param_t
```

7.9 Proc

The proc functionality represents a procedure called by the requester and carried out by the provider. The proc functionality might contain param and return functionalities. Params are procedure parameters and returns represent data returned from the procedure.

The proc has associated signals at the provider side, the call signal and the exit signal. The call signal must be driven active for one clock cycle after all registers storing the parameters have been written. The exit signal must be driven active for one clock cycle after all registers storing the returns have been read. An empty proc (proc without params and returns) by default has only the call signal. However, if an empty proc has the delay property set, then it has both the call signal and the exit signal. A proc having only parameters has by default only the call signal. However, if a proc having only parameters has the delay property set, then it also has the exit signal. A proc having only returns has by default

only the exit signal. However, if a proc having only returns has the delay property set, then it also has the call signal. The existence or absence of call and exit signals is summarized in the below table.

Proc call and exit signals occurrence

Delay Set	Empty	Only Params	Only Returns	Params & Returns
No	call	call	exit	call & exit
Yes	call & exit	call & exit	call & exit	call & exit

The proc functionality has following properties:

delay time (None) {definitive}

The delay property defines the time delay between parameters write end and returns read start.

The code generated for the requester must provide a mean for calling the procedure.

7.10 Return

The return functionality is an inner functionality of the proc and stream functionalities. It represents data returned by a procedure or streamed by an upstream.

The return functionality has following properties:

width integer (bus width) {definitive}

The width property defines the bit width of the return.

The following example presents the definition of a procedure returning four element byte array, and a single bit flag indicating whether the data is valid.

```
Read_Data proc
  data [4]return; width = 8
  valid return; width = 1
```

7.11 Static

The static functionality represents data, placed at the provider side, that shall never change.

The static functionality has following properties:

init-value bit string (obligatory) {definitive}

The init-value property defines the initial value of the static.

read-value bit string (None) {definitive}

The read-value property defines the value that must be returned by the provider on the static read after the first read. If the read-value property is set, then the actual value of the static can be read only once.

reset-value bit string (None) {definitive}

The reset-value property defines the value of the static after the reset. If the reset-value is set, but a bus or block containing the static is not resettable (reset = None), then the compiler shall report an error. If both read-value and reset-value properties are set, then the static can be read one more time after the reset.

width integer (bus width) {definitive}

The width property defines the bit width of the static.

The static functionality may be used for example for versioning, bus id, bus generation timestamp or for storing secrets, that shall be read only once. Example:

```
Secret static
width = 8
init-value = 0x13
read-value = 0xFF
```

7.12 Status

The status represents data that is produced by the provider and is only read by the requester.

The status functionality has following properties:

atomic bool (true) {definitive}

The atomic property defines whether an access to the status must be atomic. If atomic is true, then the provider must guarantee that any change of the status value is seen as an atomic change by the requester. This is especially important when a status spans more than single register, as in case of single register read the change is always atomic.

read-value bit string (None) {definitive}

The read-value property defines the value that must be returned by the provider on the status read after the first read. If the read-value property is set, then the actual value of the status can be read only once.

width integer (bus width) {definitive}

The width property defines the bit width of the status.

The code generated for the requester must provide a mean for reading the status.

7.13 Stream

The stream functionality represents a stream of data to a provider (downstream), or a stream of data from a provider (upstream). An empty stream (stream without any param or return) is always a downstream. It is useful for triggering cyclic action with constant time interval. A downstream must not have any return. An upstream shall not have any param, and must have at least one return.

The stream functionality is very similar to the proc functionality, but they are not the same. There are two main differences. The first one is that the stream must not contain both param and return. The second one is that the code for the stream, generated for the requester, shall take into account the fact that access to the stream is multiple and access to the proc is single. For example, let's consider the following bus description:

```
Main bus
P proc
p param
S stream
p param
```

The code generated for the requester, implemented in the C language, might include following function prototypes:

```
int Main_P(const uint32_t p);
int Main_S(const uint32_t * p, size_t count);
```

The stream has associated strobe signal at the provider side. The strobe signal must be driven active for one clock cycle after all registers storing the parameters of a downstream have been written. It also

must be driven active for one clock cycle after all registers storing the returns of an upstream have been read.

The stream functionality has following properties.

delay time (None) {definitive}

The delay property defines the time delay between writing/reading consecutive datasets for a downstream/upstream.