

QLang: Qubit Language

(Reference Manual)

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1 Introduction

2 Lexical conventions

There are five kinds of tokens: identifiers, keywords, constants, expression operators, and other separators. There are six kinds of tokens: identifiers, keywords, constants, strings, expression operators, and other separators. If the input stream has been parsed into tokens up to a given character, the next token is taken to include the longest string of characters which could possibly constitute a token.

Rephrase:
that's plagia-
rism

2.1 Character set

QLang supports a subset of ASCII; that is, allowed characters are `a-zA-Z0-9@#,-_ ; () [] { } < > = + / | *`, as well as tabulations `\t`, spaces, and line returns `\n` and `\r`.

2.2 Comments

Comments start with a `#` sign, which then extends until the next carriage return. Multiline comments are not supported.

2.3 Identifier (names)

An identifier is an arbitrarily long sequence of alphabetic and numeric characters, where `_` is included as “alphabetic”. It must start with a lowercase or uppercase letter, i.e. one of `a-zA-Z`.

The language is case-sensitive: `hullabaloo` and `hullABaLoo` are considered as different.

2.4 Keywords

The following identifiers are reserved for keywords, and no one shall use them because it's forbidden and uncool.

```
pi e
int float comp rvect cvect mat
true false
if elif else
def for from to by while break
or and xor
not re im norm isunit trans det adj conj sin cos tan
```

2.5 Constants

There are three sorts of constants in the language, namely *integer*, *complex* and *identifier* constants. The first are comprised of any sequence of integers of the form `0|([1-9][0-9]*)` (recall that integers are non-negative), and have type `int`. The second are of type `com` and have the form `R|R+Ri|Ri` where `R` consists of a (i) sign, (ii) an integer part followed by (iii) a point, (iv) a decimal part, then (v) either a `e` or a `E` followed by an exponent part, possibly signed. (i) and (v) are optional, and either (ii) or (iv) can be missing as well. In more detail, `R` is

defined as $[+-]\{0,1\}(((A.B*|.B+)([eE][+-]?B+)?)|A[eE][+-]?B+)$ and $A=0|([1-9]B*)$, $B=0|[1-9]$ (that is, R matches a real number such as 2.78e5, 1.5E-1 or 10.25). Finally, the identifier constants are a subset of the reserved keywords, and include:

check this paragraph.

e the base of natural logarithm $e = \sum_{k=0}^{\infty} \frac{1}{k!}$. Equivalent to `exp(1)`; has type `com`.

Pi the constant π . Has type `com`.

true represents the Boolean value `true`. Stored internally as `int 1`.

false represents the Boolean value `false`. Stored internally as `int 0`.

3 Syntax notation

4 What's in a Name?

5 Objects and lvalues

6 Conversions

7 Expressions

7.1 Operator Precedence

Operator Type	Operator	Associativity
Unary	not re im norm unit trans det adj conj sin cos tan	Right
Binary	* / % + - @ eq lt gt leq geq or and xor	Left (except ^ which is Right)
Assignment	=	Left

The remaining major subsections of this section describe the groups of expression operators, while the minor subsections describe the individual operators within a group.

7.2 Primary Expressions

7.2.1 identifier

Identifiers are primary expressions. All identifiers have an associated type that is given to them upon declaration (e.g. `float ident;` declares an identifier named `ident` that is of type `float`).

7.2.2 constant

Constants are primary expressions. As discussed above, constants are integers, floats, complex numbers, qubits, and matrices. All constants have an associated type that are predetermined by the QLang language (e.g. integers are of type `int`).

7.2.3 (expression)

Parenthesized expressions are primary expressions. The type and value of a parenthesized expression is the same as the type and value of the expression without parenthesis. Parentheses allow expressions to be evaluated in a desired precedence. Parenthesized expressions are evaluated relative to each other starting with the expression that is nested the most deeply and ending with the expression that is nested the least deeply (i.e. the shallowest).

7.2.4 primary-expression[expression]

Primary expressions followed by expressions in brackets are primary expressions. Such primary expressions represent indexing into an array, where the primary expression is the array and the expression in brackets is the index. Because indices must be of type int, the expression in brackets must evaluate to an int. The evaluation of the overall primary expression should give the value associated with the given index of the array.

7.2.5 primary-expression(expression-list)

Primary expressions followed by a parenthesized expression list are primary expressions. The expression list is mandatory and must consist of one or more expressions separated by commas. Such primary expressions can be used in the declaration of functions or function calls. If being used in function declarations, they must be preceded by the correct function declaration syntax and each expression in the expression list must evaluate to a type followed by an identifier. If being used in function calls each expression in the expression list must evaluate to an identifier.

7.3 Unary Operators

7.3.1 not expression

The result is the negative of the expression. The type of the expression must be int or float. The result has the same type as the expression.

7.3.2 re expression

The result is the real component of the expression. The type of the expression must be comp. The result has the same type as the expression (it is a complex number with 0 imaginary component).

7.3.3 im expression

The result is the imaginary component of the expression. The type of the expression must be comp. The result has the same type as the expression (it is a complex number with 0 real component).

7.3.4 norm expression

The result is the norm of the expression. The type of the expression must be mat. The result has type int if the expression is an integer matrix, type float if the expression is a float matrix, and type comp if the expression is a complex number matrix.

7.3.5 isunit expression

The result is a boolean indicating if it is true or false that the expression is a unit matrix. The type of the expression must be mat.

7.3.6 trans expression

The result is the transpose of the expression. The type of the expression must be mat. The result has the same type as the expression.

7.3.7 det expression

The result is the determinant of the expression. The type of the expression must be mat. The result has type int if the expression is an integer matrix, type float if the expression was a float matrix, and type comp if the expression was a complex number matrix.

7.3.8 adj expression

The result is the adjugate of the expression. The type of the expression must be mat. The result has the same type as the expression.

7.3.9 conj expression

The result is the complex conjugate of the expression. The type of the expression must be comp or mat. The result has type mat. The result has the same type as the expression.

7.3.10 sin expression

The result is the evaluation of the trigonometric function sine on the expression. The type of the expression must be int, float, or comp. The result has type float if the expression is of type int or float and type comp if the expression is of type comp.

7.3.11 cos expression

The result is the evaluation of the trigonometric function cosine on the expression. The type of the expression must be int, float, or comp. The result has type float if the expression is of type int or float and type comp if the expression is of type comp.

7.3.12 tan expression

The result is the evaluation of the trigonometric function tangent on the expression. The type of the expression must be int, float, or comp. The result has type float if the expression is of type int or float and type comp if the expression is of type comp.

7.4 Binary Operators

7.4.1 $\text{expression} \wedge \text{expression}$

The result is the exponentiation of the first expression by the second expression. The types of the expressions must be of type int, float, or comp. If the expressions are of the same type, the result has the same type as the expressions. Otherwise, if at least one expression is a comp, the result is of type comp; if neither expressions are comp, but at least one is float, the result is of type float.

7.4.2 $\text{expression} * \text{expression}$

The result is the product of the expressions. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$.

7.4.3 $\text{expression} / \text{expression}$

The result is the quotient of the expressions, where the first expression is the dividend and the second is the divisor. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$. Integer division is rounded towards 0 and truncated.

7.4.4 $\text{expression} \% \text{expression}$

The result is the remainder of the division of the expressions, where the first expression is the dividend and the second is the divisor. The sign of the dividend and the divisor are ignored, so the result returned is always the remainder of the absolute value of the dividend divided by the absolute value of the divisor. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$.

7.4.5 $\text{expression} + \text{expression}$

The result is the sum of the expressions. The types of the expressions must be of type int, float, comp, or qubit. Otherwise, if at least one expression is a comp, the result is of type comp; if neither expressions are comp, but at least one is float, the result is of type float. Qubits are special and can only be summed with each other.

7.4.6 $\text{expression} - \text{expression}$

The result is the difference of the first and second expressions. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$.

7.4.7 $\text{expression} @ \text{expression}$

The result is the tensor product of the first and second expressions. The The expressions must be of type of mat. The result has the same type as the expression.

7.4.8 $\text{expression} \text{ eq } \text{expression}$

The result is a boolean indicating if it is true or false that the two expression are structurally equivalent. The type of the expressions must be the same.

7.4.9 expression lt expression

The result is a boolean indicating if it is true or false that the first expression is less than the second. The type of the expressions must be int, float, or comp and must be the same.

7.4.10 expression gt expression

The result is a boolean indicating if it is true or false that the first expression is greater than the second. The type of the expressions must be int, float, or comp and must be the same.

7.4.11 expression leq expression

The result is a boolean indicating if it is true or false that the first expression is less than or equal to the second. The type of the expressions must be int, float, or comp and must be the same.

7.4.12 expression geq expression

The result is a boolean indicating if it is true or false that the first expression is greater than or equal to the second. The type of the expressions must be int, float, or comp and must be the same.

7.4.13 expression or expression

The result is a boolean indicating the logical *or* of the expressions. The type of the expressions must be int or float and must be the same. In the expressions, 0 is considered false and all other values are considered true.

7.4.14 expression and expression

The result is a boolean indicating the logical *and* of the expressions. The type of the expressions must be int or float and must be the same. In the expressions, 0 is considered false and all other values are considered true.

7.4.15 expression xor expression

The result is a boolean indicating the logical *xor* of the expressions. The type of the expressions must be int, float and must be the same. In the expressions, 0 is considered false and all other values are considered true.

7.5 Assignment Operators

Assignment operators have left associativity

7.5.1 lvalue = expression

The result is the assignment of the expression to the lvalue. The lvalue must have been previously declared. The type of the expression must be of the same that the lvalue was declared as. Recall, lvalues can be declared as int, float, comp, mat, and qubit.

8 Declarations

Declarations are used within functions to specify how to interpret each identifier. Declarations have the form

declaration:
type-specifier declarator-list

8.1 Type Specifiers

There are four main type specifiers

type-specifier:
int
float
com
mat

8.2 Declarator List

The declarator-list field of a declaration is a comma-separated sequence of declarators.

declarator-list:
declarator
declarator , declarator-list

Declarators refer to a certain object. That object is of the type indicated by the type-specifier in the declaration. Declarators have the syntax

declarator:
identifier
declarator ()
declarator [constant-expression]
(declarator)

The grouping in this definition is the same as in expressions.

8.3 Meaning of Declarators

Each expression that has the same form as a declarator is a call to create an object of the specified type. Each declarator has one identifier. Each identifier is of the type indicated by the specifier.

If declarator D has the form

D ()

then the contained identifier has the type "function returning ...", where "..." is the type which the identifier would have had if the declarator had been D.

If a declarator has the form

$$D[\textit{constant-expression}]$$

or

$$D[]$$

then it is a declarator whose identifier is of type "array". In the first case, the constant-expression is an expression whose value is determinable at compile time. The type of that constant-expression is int. In the second case, the constant expression 1 is used.

An array may be constructed from one of the basic types, or from another array.

Parentheses in declarators do not alter the type of the contained identifier, but rather the binding of the individual components of the declarator.

Not all possibilities of the above syntax are actually allowed. There are certain further restrictions. There are no array of functions.

9 Statements

10 Scope rules

11 Constant expressions

Operator Type	Operator	Associativity
Unary	not re im norm unit trans det adj conj sin cos tan	Right
Binary	* / % + - @ eq lt gt leq geq or and xor	Left (except ^ which is Right)
Assignment	=	Left

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11.1 Primary Expressions

11.1.1 identifier

Identifiers are primary expressions. All identifiers have an associated type that is given to them upon declaration (e.g. float ident; declares an identifier named ident that is of type float).

11.1.2 constant

Constants are primary expressions. As discussed above, constants are integers, floats, complex numbers, qubits, and matrices. All constants have an associated type that are predetermined by

the QLang language (e.g. integers are of type `int`).

11.1.3 (expression)

Parenthesized expressions are primary expressions. The type and value of a parenthesized expression is the same as the type and value of the expression without parenthesis. Parentheses allow expressions to be evaluated in a desired precedence. Parenthesized expressions are evaluated relative to each other starting with the expression that is nested the most deeply and ending with the expression that is nested the least deeply (i.e. the shallowest).

11.1.4 primary-expression[expression]

Primary expressions followed by expressions in brackets are primary expressions. Such primary expressions represent indexing into an array, where the primary expression is the array and the expression in brackets is the index. Because indices must be of type `int`, the expression in brackets must evaluate to an `int`. The evaluation of the overall primary expression should give the value associated with the given index of the array.

11.1.5 primary-expression(expression-list)

Primary expressions followed by a parenthesized expression list are primary expressions. The expression list is mandatory and must consist of one or more expressions separated by commas. Such primary expressions can be used in the declaration of functions or function calls. If being used in function declarations, they must be preceded by the correct function declaration syntax and each expression in the expression list must evaluate to a type followed by an identifier. If being used in function calls each expression in the expression list must evaluate to an identifier.

11.2 Unary Operators

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The result is the negative of the expression. The type of the expression must be `int` or `float`. The result has the same type as the expression.

11.2.2 re expression

The result is the real component of the expression. The type of the expression must be `comp`. The result has the same type as the expression (it is a complex number with 0 imaginary component).

11.2.3 im expression

The result is the imaginary component of the expression. The type of the expression must be `comp`. The result has the same type as the expression (it is a complex number with 0 real component).

11.2.4 norm expression

The result is the norm of the expression. The type of the expression must be `mat`. The result has type `int` if the expression is an integer matrix, type `float` if the expression is a float matrix, and type `comp` if the expression is a complex number matrix.

11.2.5 isunit expression

The result is a boolean indicating if it is true or false that the expression is a unit matrix. The type of the expression must be mat.

11.2.6 trans expression

The result is the transpose of the expression. The type of the expression must be mat. The result has the same type as the expression.

11.2.7 det expression

The result is the determinant of the expression. The type of the expression must be mat. The result has type int if the expression is an integer matrix, type float if the expression was a float matrix, and type comp if the expression was a complex number matrix.

11.2.8 adj expression

The result is the adjugate of the expression. The type of the expression must be mat. The result has the same type as the expression.

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The result is the complex conjugate of the expression. The type of the expression must be comp or mat. The result has type mat. The result has the same type as the expression.

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The result is the evaluation of the trigonometric function cosine on the expression. The type of the expression must be int, float, or comp. The result has type float if the expression is of type int or float and type comp if the expression is of type comp.

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11.3 Binary Operators

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11.3.2 $\text{expression} * \text{expression}$

The result is the product of the expressions. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$.

11.3.3 $\text{expression} / \text{expression}$

The result is the quotient of the expressions, where the first expression is the dividend and the second is the divisor. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$. Integer division is rounded towards 0 and truncated.

11.3.4 $\text{expression} \% \text{expression}$

The result is the remainder of the division of the expressions, where the first expression is the dividend and the second is the divisor. The sign of the dividend and the divisor are ignored, so the result returned is always the remainder of the absolute value of the dividend divided by the absolute value of the divisor. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$.

11.3.5 $\text{expression} + \text{expression}$

The result is the sum of the expressions. The types of the expressions must be of type int, float, comp, or qubit. Otherwise, if at least one expression is a comp, the result is of type comp; if neither expressions are comp, but at least one is float, the result is of type float. Qubits are special and can only be summed with each other.

11.3.6 $\text{expression} - \text{expression}$

The result is the difference of the first and second expressions. The type considerations are the same as they are for $\text{expression} \wedge \text{expression}$.

11.3.7 $\text{expression} @ \text{expression}$

The result is the tensor product of the first and second expressions. The The expressions must be of type of mat. The result has the same type as the expression.

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The result is a boolean indicating if it is true or false that the two expression are structurally equivalent. The type of the expressions must be the same.

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11.3.15 expression xor expression

The result is a boolean indicating the logical *xor* of the expressions. The type of the expressions must be int, float and must be the same. In the expressions, 0 is considered false and all other values are considered true.

11.4 Assignment Operators

Assignment operators have left associativity

11.4.1 lvalue = expression

The result is the assignment of the expression to the lvalue. The lvalue must have been previously declared. The type of the expression must be of the same that the lvalue was declared as. Recall, lvalues can be declared as int, float, comp, mat, and qubit.

12 Examples

We present some examples that illustrates the use of Qlang in solving quantum computing problems.

12.1 Solving Quantum Computation Problem

12.1.1 Problem1

Evaluate the following expressions: a. $(H \otimes X)|00\rangle$ b. $\langle 101|000\rangle$ c. $\langle 01|H \otimes H|01\rangle$

```
def pseudo = evaluate () {
    qubit mat0 = |00>;
    mat HX = H @ X
    pseudo = HX * mat0;
}
```

12.1.2 Problem 2

Find the matrix corresponding to the quantum circuit:

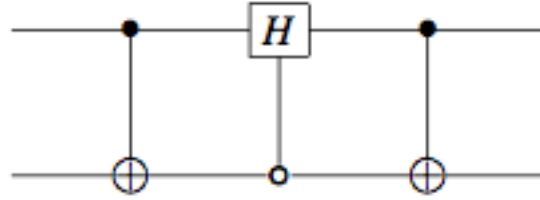


Figure 1: Quantum Circuit implementing series of control gates

```
def circuitMat = findMatrix () {
    qubit mat0=|00>;
    qubit mat1=|01>;
    qubit mat2=|10>;
    qubit mat3=|11>;

    CNOT = [1,0,0,0;0,1,0,0;0,0,0,1;0,0,1,0]
    HNOT = [1/sqrt(2),0,0,1/sqrt(2);0,1,0,0;1/sqrt(2),0,1,-1/sqrt(2);0,0,0,0]
    allGates = CNOT * HNOT * CNOT

    circuitMat =[allGates*mat0:allGates*mat1:allGates*mat2:allGates*mat3]
}
```

12.1.3 Problem 3

Consider the circuit and show the probabilities of outcome 0 and 1.

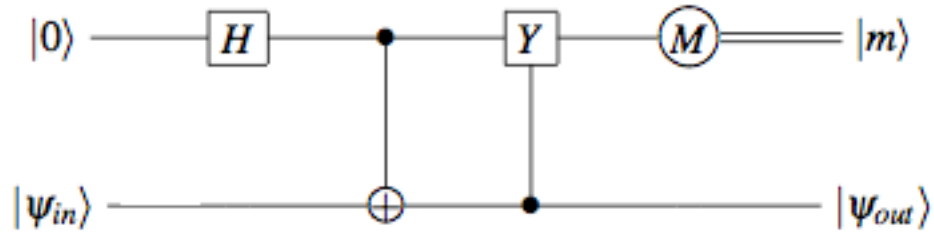


Figure 2: Quantum Circuit

12.2 Deutsch Jozsa Algorithm

```
def outcome = deutschJozsa(qubit in , mat U){

    mat qubitInput;
    qubitInput = in @ |1>;
    input = (H @ H)*input;
    input = U * input;
    input = (H @ I)*input;
    input=(in*Adj(in)@ I)*input;

    if (input == 0){
        outcome = 0;
    }
    else{
        outcome = 1;
    }
}
```