RWTH AACHEN UNIVERSITY
Chair of Computer Science 2
Software Modeling and Verification

Master Thesis Proposal

Title tbd

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1 Introduction

- Short intro into QC
  - What is QC
  - Why is it important
  - What can it be used for

2 Motivation

- Classical control flow vs quantum control flow [YYF12]
- *Intro quantum control flow*

With the emergence of quantum computing, many quantum languages were introduced. Most languages focus on a lower level representation of quantum circuits. An example would be the popular Open Quantum Assembly Language (QASM)[CBSG17]. QASM consists mainly of quantum and classical gates that can be manipulated by predefined and composite gates as well as limited (classical) if-statements. There are also languages with a focus on high level interactions, e.g. Tower[ChMi22] which contains data structures in superposition, and Silq [BBGV20] which allows for automatic uncomputing of registers. What all these languages have in common is the restriction to quantum data while using only classical control flow. Although quantum control flow was defined by Ying et al. [YYF12] over 10 years ago, only very few languages have incorporated the principle. One example is the functional programming language proposed by Altenkirch et al. [AlGr05] where `if°` is used to define the Hadamar gate. Only recently was the Quantum Control Machine (QCM) with quantum control flow at its core proposed by Yuan et al. [YVC24].

The QCMs syntax and logic are both heavily influenced by classical assembly languages. The language consists of quantum registers, gate, swap and get-bit operations[1], simple numeric operations on registers, and, finally, jump instructions. The jump instructions range from simple to conditional to indirect and are used to enable quantum control flow. *Limitations ...*

[1]The gate operations are limited to the Hadaram and NOT gates.

- bounded by reversibility and synchronicity
  - what is reversibility, why is it needed
  - what is synchronicity, why is it needed
- based on classical assembly languages (jumps, registers, ...)
- Issues with qcm
- very unreadable
- can be reduced to basics

3 Concept

- Language features: qif-else, bounded loops, (boolean eval)
- Translation to quasm
- overall (more) realistic for NISQ
- Further (compliler optimizations)
- Example grammar

Bibliography

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[CBSG17] Andrew W. Cross, Lev S. Bishop, John A. Smolin, and Jay M. Gambetta. Open quantum assembly language.

[ChMi22] Charles Yuan and Michael Carbin. Tower: Data structures in quantum superposition, 2022.

[YVC24] Charles Yuan, Agnes Villanyi, and Michael Carbin. Quantum control machine: The limits of control flow in quantum programming. *Proceedings of the ACM on Programming Languages*, 8(OOPSLA1):1–28, 2024.

[YYF12] Mingsheng Ying, Nengkun Yu, and Yuan Feng. Defining quantum control flow.

```
grammar Luie;

parse
 : block EOF
 ;

block
 : (definition | statement)*
 ;

definition
 : 'qubit' IDENTIFIER ';'
 ;

statement
 : GATE IDENTIFIER ';'
 | qifStatement
 ;

qifStatement
 : ifStat elseStat? END
 ;

ifStat
 : IF IDENTIFIER DO block
 ;

elseStat
 : ELSE DO block
 ;

GATE
 : XGATE
 | ZGATE
 | HGATE
 ;

XGATE : 'x';
ZGATE : 'z';
HGATE : 'h';

IF       : 'qif';
ELSE     : 'else';
DO       : 'do';
END       : 'end';

IDENTIFIER
 : [a-zA-Z_] [a-zA-Z_0-9]*
 ;
```

```
50
51      COMMENT
52       : ( '//' ~[\r\n]* | '/*' .*? '*/'
             ) -> skip
53       ;
54
55      SPACE
56       : [ \t\r\n\u000C] -> skip
57       ;
```