QChecker: Detecting Bugs in Quantum Programs via Static Analysis

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Abstract—Static analysis is the process of analyzing software code without executing the software. It can help find bugs and potential problems in software that may only appear at runtime. Although many static analysis tools have been developed for classical software, due to the nature of quantum programs, these existing tools are unsuitable for analyzing quantum programs. This paper presents QChecker, a static analysis tool that supports finding bugs in quantum programs in Qiskit. QChecker consists of two main modules: a module for extracting program information based on abstract syntax tree (AST), and a module for detecting bugs based on patterns. We evaluate the performance of QChecker using the Bugs4Q benchmark. The evaluation results show that QChecker can effectively detect various bugs in quantum programs.

Index Terms—quantum programming, static analysis, software testing, program debugging, Qiskit

I. INTRODUCTION

Quantum computing has been applied to many cuttingedge areas, such as quantum machine learning [4, 9], big data analysis [24], and molecular simulations [14] due to its unique promising advantage over classical computing. Quantum programming is designing and constructing executable quantum programs to achieve a specific computational result. With the rapidly growing complexity of quantum programs, it is decisive to alleviate the efforts in programming such quantum programs. Several quantum programming languages are available for quantum programmers, such as Qiskit [2], Sliq [5], Cirq [12], Quipper [13], and Q# [27], allowing researchers and developers to implement and experiment with various quantum computing techniques quickly.

Given the importance and wide application of quantum programming, ensuring the correctness of quantum programs is crucial for quantum software development. However, recent empirical studies [7, 23, 35, 36] have shown that the current quantum program development process is still error-prone. While debugging and testing quantum programs has gained significant attention [3, 11, 15, 17, 19, 20], the existing debugging and testing techniques often require dynamic execution of the underlying quantum programs are executed on quantum computers and simulators available on the cloud, the existing debugging and testing techniques can be cumbersome and expensive.

In classical software development practice, static analysis techniques have been widely used to detect various types of bugs in classical programs due to their advantages in speed and cost [10, 16, 25, 26, 30]. However, detecting bugs in quantum programs via static analysis can be challenging. Since quantum computation logic is expressed in quantum circuits, and the states of quantum registers are measured probabilistically, static analysis tools designed for classical programs struggle to detect mistakes in quantum programs.

To bridge the gap, we present QChecker, a static analysis tool designed for detecting bugs in quantum programs, especially for Qiskit. The approach addresses the challenge above by first distilling a set of common bug patterns summarized from real quantum bugs in previous studies [35, 36] and then constructing eight detectors for detecting these bug patterns in quantum programs. The whole process is non-trivial since the distilled bug patterns must carefully consider the domainspecific constraints of quantum computing to be accurate and effective.

We evaluate QChecker on Bugs4Q [36], a realistic benchmark consisting of 42 real-world buggy quantum programs. Experimental results show that QChecker can efficiently detect bugs in quantum programs. Furthermore, we discuss the extendability of QChercker for other Python-based quantum programming languages.

In summary, this work makes the following contributions:

- We present the first bug detection tool dedicated to quantum programs in Qiskit. Using static analysis techniques, QChecker can generate diagnostic messages that assist developers in pinpointing potential bugs in their programs quickly.
- We implement QChecker and evaluate its effectiveness and performance in a real-world Bugs4Q benchmark. The results show that QChecker can effectively detect various types of bugs in quantum programs.

The rest of the paper is organized as follows. Section II provides some basics of quantum programming. Section III describes our QChecker approach for static analysis of quantum programs. Section IV presents the performance of QChecker on Bugs4Q. Section V reviews our threats of validity. Section VI discusses related work, and Section VII finally concludes this paper.

II. BACKGROUND

We briefly introduce the background information on programming in Qiskit and the basic concepts of qubits.

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```
simulator = Aer.get_backend("qasm_simulator")
```

```
qreg = QuantumRegister(3)
creg = ClassicalRegister(3)
circuit = QuantumCircuit(qreg, creg)
circuit.h(0)
circuit.h(2)
circuit.cx(0, 1)
circuit.measure([0,1,2], [0,1,2])
```

job = execute(circuit, simulator, shots=1000)
result = job.result()
counts = result.get_counts(circuit)
print(counts)



A. Qiskit

Qiskit [2] is one of the most widely used open-source frameworks for quantum computing, allowing us to create algorithms for quantum computers. As a Python package, it provides tools for creating and manipulating quantum programs and running on prototype quantum devices and simulators and can use built-in modules for noise characterization and circuit optimization to reduce the impact of noise. Qiskit also provides a library of quantum algorithms for machine learning, optimization, and chemistry.

In Qiskit, a program is defined by a quantum object data structure that contains configuration information and the experiment sequences. The object can be used to get status information and retrieve results [22]. Figure 1 shows a simple Qiskit program that illustrates the entire workflow of a quantum program. The function Aer.get_backend('qasm_simulator') returns a backend object for the given backend name (gasm_simulator). The backend class is an interface to the simulator, and the actual name of Aer for this class is AerProvider. After the experimental design is completed, the instructions are run through the execute method. The shots of the simulation, which means the number of times the circuit is run, is set to 1000 while the default is 1024. When outputting the results of a measurement, the method job.result() is used to retrieve the measurement results. We can access the counts via the method get_counts(circuit), which gives the experiment's aggregate outcomes.

B. Basic Properties of Qubits

In this subsection, we use Qiskit as an example to explain the characteristics of quantum bit (*qubit* for short) and the necessary execution process of a complete quantum program.

The basic unit of information in quantum computing is the qubit. As shown in Figure 1, qreg = QuantumRegister(3) means assigning a quantum register of three qubits, and the value of each qubit is $|0\rangle$ by default. So the initial value of these three qubits is $|000\rangle$. Next, let the first and third qubits pass through the H (Hadamard) gate, as shown by circuit.h(0) and circuit.h(2). In this way, the unique property *superposition* of qubits is realized, which

means the qubit contains the states of $|0\rangle$ and $|1\rangle$. There is also an *entanglement* of qubit properties that only multiple qubits can achieve. The code in the sample program is circuit.cx(0, 1). That is to say, the first qubit is entangled with the second qubit through a CNOT (Controlled-NOT) gate operation. We measure the first qubit, and its output is 0 for 50 percent probability and 1 for 50 percent probability. After that, measuring the second qubit is 100 percent the same as the first measurement result. Since the third qubit is not related to the first two qubits, the last qubit's measurement result is still taken with 0 for 50 percent probability and 1 for 50 percent probability. The measurement statement of qubits shown in Figure 1 is circuit.measure([0,1,2], [0, 1, 2]). Measurement can lead to the collapse of a quantum superposition state to a classical state. There are many kinds of quantum measurements, and the projection measurement of a single qubit is used here. That is, each qubit is projected onto a state space consisting of base vectors $|0\rangle$ or $|1\rangle$. In this program, the final output is a three-bit array.

III. THE QCHECKER TOOL

In this section, we introduce the construction of QChecker, which is developed based on Python. As illustrated in Figure 2, QChecker first performs a thorough information extraction of the quantum programs based on their ASTs. The corresponding operations are in the module Ast_Operator. The information mainly includes the variable assign operations and function calls, which will be further stored in QP_Attribute and QP_Operation. Then QChecker transmits the extracted information to the bug detectors. The bug detectors can detect various bug patterns, as shown in Table I. Finally, QChecker generates bug detection reports, including the buggy programs, line numbers, and bug descriptions.

A. Information Extraction

The previous static analysis tools inspire us (e.g., PyLint [28]) that using AST for program information extraction is effective and efficient. However, different from classical static analysis tools, the AST_Operator in QChecker has the ability to extract information specific to the semantics and the function of quantum programs. Taking the program shown in Figure 1 as an example, we apply a structured parsing to each quantum program file, i.e., generating the AST. We adopt two modules named QP_Attribute and QP_Operation to store the AST information of all the variables and function calls, respectively. In addition, QChecker also supports handling complex syntax and data structures such as dictionaries, lists, function definitions, loops, and conditional branches. The purpose of this design is that the structured AST-based information extraction can help QChecker trace the relationship between each variable and function call. For example, a variable may be modified multiple times, or its name may be changed when passed as an argument inside a function. Nevertheless, we can still trace back the initial value of the variables in the program. We plot instances of QP_Attribute and QP_Operation in Figures 3 and 4, respectively.



Fig. 2. The structure of QChecker.

```
('simulator', 'Aer.get_backend("qasm_simulator")')
('qreg', 'QuantumRegister(3)')
('creg', 'ClassicalRegister(3)')
('circuit', 'QuantumCircuit(qreg,creg)')
('job', 'execute(circuit,simulator,shots=1000)')
('result', 'job.result()')
('counts', 'result.get_counts(circuit)')
```



- **QP_Attribute**: The AST structure of a variable includes its variable name, variable value (which can come from a constant, another variable, or the result of a function calculation), type, and location (line of code). As shown in Figure 3, The QP_Attribute module is designed in a key-value manner. The keys are variable names which can be the indices for the variable values.
- **QP_Operation**: The AST structure of a function call contains a list of its arguments, the type and value of each argument, its position, and other information. As shown in Figure 4, The <code>QP_Operation</code> module is a list that contains all the function calls in the quantum program file. In detail, each function call can be further divided into function call names, arguments, and values. This information is stored in a more comprehensive table from QChecker, which uses the function call strings in <code>QP_Operation</code> as the index.

These two modules contain all the information of a quantum program and make it more straightforward for further bug detection. Moreover, users can directly obtain the above information through QChecker based on the API we released. It is worth mentioning that those programs containing basic syntax errors (e.g., python indentation errors, unrecognized operators, undefined variables and functions, etc.) will not be processed by QChecker. Instead, they will be prompted as syntax errors and thus be excluded from the static checking.

```
'Aer.get_backend("qasm_simulator")'
'QuantumRegister(3)'
'ClassicalRegister(3)'
'QuantumCircuit(qreg,creg)'
'circuit.h(0)'
'circuit.h(2)'
'circuit.cx(0,1)'
'circuit.measure([0,1,2],[0,1,2])'
'execute(circuit,simulator,shots=1000)'
'job.result()'
'result.get_counts(circuit)'
'print(counts)'
```

Fig. 4. Program information extracted by QP_Operation.

B. Bug Pattern Detectors

Bug patterns are erroneous code idioms or bad coding practices that have been proven to fail time and time again, which are usually caused by the misunderstanding of a programming language's features, the use of erroneous design patterns, or simple mistakes sharing common behaviors. Previous work has identified some bug patterns for the Qiskit programming language [35, 36]. In this work, we refined these bug patterns and built eight detectors to detect them. Table I shows the name of detectors and descriptions of bug patterns. We briefly describe each detector as follows.

1) Incorrect uses of quantum gates (IG): This detector mainly checks if quantum gates are called correctly. It determines whether a gate is recognized by Qiskit and whether it has been defined. In addition, the compliance of a custom gate and a three-qubit gate with the specification would also be checked.

2) Measurement related issue (MI): Incorrect measurement means not only the improper use of measure operation that cause bugs but also the wrong operation after measurement. As shown in Figure 5, the user wants to achieve a quantum teleportation program. The measured qubits are used as control qubits to entangle with other qubits. This detector mainly acts after the measure method is called. It iterates through the

 TABLE I

 BUG PATTERNS THAT EACH DETECTOR IS RESPONSIBLE FOR.

Detector Name	Bug patterns Descriptions					
	- Gates are not among the backend's basis gates.					
IG	- Handle custom multi-qubit gates.					
	- Random gate is not defined.					
MI	- Ignoring the effects of measurement.					
	- Number of qubits larger than the registers defined.					
IS	- The insufficient number of qubits.					
	- Insufficient length of classical registers.					
	- Instruction not in basis gates.					
PE	- Incorrect parameters in gates.					
	- Using classical bits for entanglement.					
	- Same physical qubit used in one operation.					
	- Not giving lists for coupling_map.					
	- Unrecognized parameters.					
СМ	- Quantum circuit interaction error.					
	- Create redundant classical registers.					
	- The wrong command was used.					
	- Object call error.					
CE	- Import error.					
	- Backend error.					
	- Translating error.					
QE	- Issue with new from_qasm_str() method.					
DO	- Method has been deprecated.					

```
qc = QuantumCircuit(3, 3)
qc.x(0)
qc.h(1)
qc.cx(1, 2)
qc.cx(0, 1)
qc.h(0)
qc.measure(0, 0)
qc.measure(1, 1)
qc.cx(1, 2) <- Problematic operation
qc.cz(0, 2) <- Problematic operation</pre>
```

Fig. 5. Example of Incorrect Mearsurement

operations following the measure statement and determines whether the measured qubit appears as a control qubit in the double-qubit gate operations.

3) Incorrect initial state (IS): This detector does not simply check whether the definitions of QuantumRegister and ClassicalRegister conform to the specification. It determines whether the initialization satisfies the entire quantum program's operation on qubits. Sometimes, the Qiskit program limits the number of qubits used when simulating quantum programs. Such as, after our validation, using Aer.get_backend('qasm_simulator') as backends supports less than 30 qubits for measure operation, while BasicAer.get_backend('qasm_simulator') supqreg = qk.QuantumRegister(7)

layout	= {qreg[0]:	12,	<-	Problematic	operation
	qreg[1]:	11,			
	qreg[2]:	13,			
	qreg[3]:	17,			
	qreg[4]:	14,			
	qreg[5]:	12,	<-	Problematic	operation
	qreg[6]:	6}			

Fig. 6. Example of parameters error

phase = Parameter('phase')

with pulse.build(FakeAlmaden()) as phase_test_sched:

pulse.shiftphase(<- Unrecognized
phase, pulse.drive_channel(0))</pre>

phase_test_sched.instructions



ports less than 24 qubits. In this case, the detector first checks the backend chosen by users and Identifies if the initialized qubits are out of limits. When the number of initialized qubits is set to n, the checker will keep track of the number of qubits called in the program.

4) Parameter error (PE): After a quantum gate is invoked, this detector is responsible for determining whether the parameters in the gate are correct, including the parameters that do not exist in multiple-qubit gates, and the wrong use of numeric types. However, some bug patterns are not easy to find. From Figure 6, we can see that the user wants to assign the qubits in the register to the physical qubits, both qreg[0] are qreg[5] assigned to the physical qubits 12. Therefore, the detector goes through the parameter values and checks for duplicate physical qubit occupancy.

5) Command misuse (CM): This detector could detect the wrong or improper use of commands. Sometimes, parameters are not recognized because the method name is miswritten. On the other hand, some methods can not recognize parameters and raise errors. As shown in Figure 7, attribute pulse.shiftphase() is not in module qiskit.phase. Some of the commands in Qiskit are difficult to detect. For example, there are more than two quantum circuits while the user wants to nest one circuit with the others: 1) Command to_gate() could be used to change the circuit into a combination of gates embedded in other circuits. 2) Command decompose() could be used to decompose the circuit for embedded operation automatically.

6) Call error (CE): This detector is responsible for call errors, including Python package calls, backend simulator calls, and translator calls. Besides, the detector can check for problems with parameter declarations. As shown in Figure 8, this error is not a duplicate call to PauliMeasurementBasis(). After running the code, we found that there was an error of *invalid qubits for ba*-

```
circ = QuantumCircuit(1,1)
circ.x(0)
```

```
tomo = ProcessTomography(
    circuit=circ,
    measurement_basis=PauliMeasurementBasis(),
    measurement_qubits=None,
    preparation_basis=PauliMeasurementBasis(), <-
    preparation_qubits=None,
    basis_indices=None,
    qubits=None)</pre>
```



sis. The call of PauliMeasurementBasis() is invalid for preparation_basis. This types of bugs are hard to detect by QChecker, the detector can only judge one scenario now.

7) QASM error (QE): This detector detects problems with qasm_simulator as the backend or when building qasm programs with the Qiskit programming language.

8) *Discarded orders (DO):* This detector determines if a deprecated method is being called, and it comes into play when an old operation or variable type is discarded due to a version update.

C. Bug Detection

The bug patterns shown in Table I represent the general bugs in quantum programs. In addition to syntactic bugs, it also contains some faulty logic in some quantum-related operations. Based on the program information extraction modules (QP_Attribute and QP_Operation), as well as the detectors, we can perform a thorough static analysis for the quantum program files. To enable comprehensive and useful bug detection and benefit the debug process, we report the details of the buggy programs (code lines, content, etc.), bug types (patterns), and specific descriptions. We hope such information may help users improve the quality of quantum programs.

IV. EVALUATION

This section presents the empirical performance of QChecker. We evaluate QChecker on Bugs4Q [36], which contains 42 real-world buggy quantum programs in Qiskit. The experiments were conducted on a server with an Intel i9-10940X CPU, 128G RAM, running on Ubuntu 20.04 with Python 3.10 installed.

A. Metrics

We adopt *Precision, Recall,* and *F1-score* to evaluate the performance of QChecker. Specifically, for each bug *b* in Bugs4Q, we use the bug type in Bugs4Q as ground truth and apply QChecker to its source quantum program. If the detection result of QChecker matches the corresponding bug type in Bugs4Q, we call this *b* as *True Positive* (TP). Otherwise, this *b* is a *False Positive* (FP). *False Negative* (FN) is a ground-truth bug that can not be detected by QChecker. The *Precision* is calculated as TP/(TP+FP), *Recall* as TP/(TP+FN) and *F1-score* as $2 \times Precision \times Recall/(Precision + Recall)$.

B. Performance on Real-World Qiskit Programs

First of all, there are 42 Qiskit programs detected by QChecker, and 24 bugs were found. Figure 9 shows the empirical results produced by applying QChecker on Bugs4Q. Detector PE found 10 bugs, while CE and IS found 7 and 2 bugs, respectively. And other detectors found one bug in each. As we know, out of the 42 bugs in Bugs4Q, 22 bugs are output errors, i.e., the output of the program does not match the user's expectations. This condition makes Qchercker unable to detect these bugs. So we consider that the remaining number of bugs in Bugs4Q found by Qchecker is in line with expectations. Combining Table I with the results in Figure 9, we analyzed and derived two points about the performance of each detector:

- *The more cases the detectors can cover, the more bugs can be found.* As we made the detectors according to the relevance of the bug patterns, the number of cases covered by each detector may vary. Detector PE and CE can detect more cases than other detectors. And in fact, the two detectors made a better performance.
- The performance of detectors also depends on the type of errors made by the programmers. Considering the limited number of bugs in Bugs4Q, we believe that some detectors perform poorly because they cover cases that rarely occur. For example, detector IG, CM, and IS can detect more than one case while the results are barely satisfactory.

In addition, a detector that solves only one case does not indicate poor performance. Instead, with their increased functionality, these specialized detectors will realize their potential to detect bugs better.



Fig. 9. Distribution of bugs found by each detector.

The efficiency of QChecker on 42 Qiskit programs provided by Bugs4Q is shown in Table II. As illustrated in [21], executing a quantum program on simulators can easily consume more than 10^3 ms. As a result, QChecker demonstrates high efficiency by taking an average time of only 48.2 ms to complete detection on a single quantum program. To better represent this, we investigated the 42 quantum programs in

 TABLE II

 Performance of QChecker on Qiskit programs.

Performance	Prec.	Recall	F1-score	Avg. Time				
QChecker	0.625	0.882	0.731	48.2ms				
import cirq								
gubit = cirg.NamedOubit("mygubit")								

circuit = cirq.Circuit(cirq.H(qubit))
for i in range(10):
 result2 = cirq.measure(qubit, key='myqubit')
 print(result2)
print(circuit)
result = cirq.Simulator().simulate(circuit)
print(result2)

Fig. 10. An exapmle of Cirq program.

Bugs4Q. The average execution time for these programs was 2.14 seconds, while the average amount of code per program was 31 LOC. From Section II, we already know that obtaining the state of a qubit requires a large number of iterations of the output to obtain its probability distribution, which we consider to be the main cost of executing one program.

In summary, QChecker has the advantage of being efficient and relatively effective in execution, while the disadvantage is QChecker does not avoid the problem of false positives. As the number of qubits in future quantum programs increases, we believe it is necessary and effective to find bugs before program execution by means of static analysis.

C. Extendability of QChecker

We next discuss the extendability of QChecker. The example of a Cirq program and the corresponding detection result of QChecker are shown in Figures 10 and 11, respectively. After careful inspection of the results, we find that the information extraction part of QChecker can still function on other Pythonbased quantum languages (e.g., Cirq). The syntax difference between these quantum languages may cause the detectors designed for Qiskit fails to work, which leads to the lack of guaranteed performance.

In summary, the experimental results show that QChecker can successfully detect bugs in real-world Qiskit quantum programs, exhibiting the effectiveness of applying static analysis to quantum programs. Besides, the intermediate results indicate that the QChecker can correctly extract the QP_Attribute and QP_Operation information from the underlying Cirq program, indicating that the QChecker can be easily extended to common Python-based quantum programming languages.

V. TREATS TO VALIDITY

A. External Threats

Even for the most widely used Qiskit quantum programming language, there are still not enough buggy programs. Moreover, existing quantum programs are usually run on simulators rather than on actual quantum computers, which leads to the

```
('qubit', 'cirq.NamedQubit("myqubit")')
('circuit', 'cirq.Circuit(cirq.H(qubit))')
('result', 'cirq.Simulator().simulate(circuit)')
('result2', 'cirq.measure(qubit,key="myqubit")')
'cirg.NamedQubit("myqubit")'
'cirq.Circuit (cirq.H(qubit))'
'range(10)'
'print(circuit)'
'cirq.Simulator().simulate(circuit)'
'print("result:")'
print (result2)
'cirq.H(qubit)'
'cirq.measure(qubit, key="myqubit")',
print(result2)',
'cirq.Simulator()'
```

Fig. 11. A Cirq program detected by QChecker

```
eng = MainEngine()
qubits = eng.allocate_qureg(3)
H | qubits[0]
CX | (qubits[0], qubits[2])
eng.flush()
amplitudes = np.array(eng.backend.cheat()[1])
amplitudes = np.abs(amplitudes)
All(Measure) | qubits
```



small size of current quantum programs. As a result, the number of bug patterns can be a threat to validity. We have put much effort into collecting bugs from quantum programs and extracting as many bug patterns as possible from these collected bugs. However, due to the limitation of the current scale of development and application of quantum programs, we cannot include more bug patterns in QChecker. Therefore, we will continue to collect quantum programs and their bugs, enrich QChecker's detection capabilities, and continuously update the tool.

B. Internal Threats

QChecker is designed for Qiskit and can be extended to other Python-based quantum languages (e.g., Cirq) with slight modifications. However, it also has limitations. For instance, ProjectQ has overloaded the | operator, which will cause the information extractor fails to work. As shown in Figures 12 and 13, QChecker could not extract information from the underlying ProjectQ program, such as the H gate and CX gate. These limitations will be resolved with the extension of QChecker.

C. Verifiability

This threat concerns the possibility of replicating this research. we provide all the necessary details to help researchers replicate this work. The replication package is made publicly available at https://github.com/Z-928/QChecker.

VI. RELATED WORK

A large number of error detection techniques based on static analysis [10, 16, 25, 26, 30] have been developed in classical

```
'eng.allocate_qureg(3)'
'eng.flush()'
'np.array([1])'
'np.abs(amplitudes)'
'All(Measure)'
'eng.backend.cheat()']
```

Fig. 13. A ProjectQ program detected by QChecker.

software development. However, static analysis techniques for classical programs are difficult to apply directly to quantum programs due to the essential differences between quantum programs and classical programs.

Currently, static analysis techniques for quantum programs have emerged. Yu and Palsberg [34] proposed an abstract interpretation technique for quantum programs and used this technique to detect assertions to find errors in the programs. Xia and Zhao [32] proposed a practical static entanglement analysis technique to accurately analyze the entanglement information within and between modules in Q# quantum programs, which can help find errors related to entanglement in the programs. ScaffCC [18] is a scalable compiler framework for the quantum programming language Scaffold [1], which also supports entanglement analysis. ScaffCC explores dataflow analysis techniques to automatically track the entanglements within the code by annotating the output of the QASM-HL program, an intermediate representation of ScaffCC, to denote possibly entangled qubits. The analysis is conservative because it assumes that if two qubits interact, they are likely to have become entangled with each other. In contrast to these analysis methods, QChecker aims to find bugs in quantum programs based on bug patterns through static analysis.

Researchers have also extended Hoare logic to the quantum domain to support the formal verification of quantum programs [6, 8, 33, 29, 37]. Among them, Li *et al.* [37] introduced applied quantum Hoare logic (aQHL), which is a simplified version of quantum Hoare logic (QHL) [33], with particular emphasis on supporting debugging and testing of the quantum programs. aQHL simplified QHL through binding QHL to a particular class of pre- and postconditions (assertions), that is, projections, to reduce the complexity of quantum program verification and provide a convenient way used for debugging and testing quantum software. However, as we know, formal verification can be costly and difficult to scale up.

Another line of research is to develop debugging [17, 19] and testing [3, 11, 15, 20, 31] techniques for quantum programs, which are based on dynamic program analysis in principle. Although more accurate results can be obtained, the running cost of these techniques is relatively high compared to static analysis techniques due to the nature of quantum programs.

VII. CONCLUSION REMARKS

This paper has presented QChecker, a static analysis tool for quantum programs to enable effective and efficient potential bug detection of quantum programs. QChecker involves two AST-based program information extraction modules and comprehensive bug detectors which can detect various bug patterns. We applied QChecker to the Bugs4Q benchmark suite and evaluated its effectiveness. The results show that QChecker can detect various types of bugs in quantum programs. In the future, we plan to extend QChecker to detect more bug patterns of Qiskit programs and support bug detection of other common quantum programming languages such as Cirq and ProjectQ.

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