QDB: From Quantum Algorithms Towards Correct Quantum Programs

Yipeng Huang, Margaret Martonosi

Detailed debugging effort across quantum algorithms

Semantic gap
- Need languages, abstractions...
Tools gap
- Need optimizing compilers, simulators, debuggers...
Infrastructure gap
- Need more abundant, more reliable qubits...
Educational gap
- Need researchers, college curricula, K-12 pipeline...

Where possible, validate across quantum languages

Superposition underlies power, but precludes ‘printf’

Huge state space limits simulation to ‘toy’ problems

Teams now racing towards accurate and more qubits

Quantum chemistry algorithms
- Calculating molecule properties from first principles
- Use quantum mechanical system to simulate quantum mechanics!
- Near term: needs few qubits, needs no error correction

Shor’s integer factorization quantum algorithm
- Factors large integers in polynomial time!
- (known best classical algorithms take exponential time)
- Distant future: needs many qubits, needs error correction

We cannot pause a quantum computer and “printf debug”, because measurement collapses state.

0 ⊗ |0 = power, but precludes ‘printf’

Towards Correct Quantum Programs

Motivation: Race to practical quantum computation

Huge state space limits

Bug type 1: classical input parameters

\[ a \text{, the algorithm iteration} \begin{array}{c|c|c|c|c} \hline k & 0 & 1 & 2 & 3 \\ \hline a & 7 & 4 & 1 & 1 \\ \hline a^{-1} & 13 & 4 & 1 & 1 \\ \hline \end{array} \]

Bug type 2: quantum initial values

Bug type 3: coding up basic operations

Bug type 4A: iterating operations

Bug type 4B: recursing operations

Bug type 4C: mirroring operations

Bug type 5: qubit garbage collection

Classifier quantum programming bugs, pair with defenses, debugging and assertions

Defense 1: algorithm progress assertions

Defense 2: pre-condition assertions

Defense 3: support for modules and unit tests

Defense 4A: support for numeric data types

Defense 4B: support for controlled operations

Defense 4C: support for reversible compute

Defense 5: post-condition assertions

Classify quantum programming bugs, pair with defenses, debugging and assertions

Bug type 1: mistake in quantum initial values

Bug type 2: mistake in coding basic operations

Bug type 3: mistake in quantum initial values

Bug type 4A: mistake in coding basic operations

Bug type 4B: mistake in recursing operations

Bug type 4C: mistake in mirroring operations

Bug type 5: mistake in qubit garbage collection

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