Quantum Model Checking Isn't Evil

It Is Mandatory For Quantum Robots

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June 28, 2015

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Acknowledgment

Dott. Francesco Stefanni, University of Verona

Soon-to-be Dr. Prateek Tandon, who initiated the formation of this reading group on quantum robotics.

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Background Information

- Designs of Quantum Robots must be verified, tested, and validated
- Formally verify these designs via quantum model checking
- Carry out quantum model checking on invariants of quantum automata.
- Extend this to verify safety properties for reversible automata
- Extend this to verify ω-properties for reversible Büchi automata

Problem Statement

- Verify functional correctness of quantum systems.
- Input: Description of system behavior
  - i.e., specifications based on quantum automata
- Input: Functional properties in linear temporal logic (LTL)
  - LTL invariants of quantum automata-based model
- Output: Boolean flag indicating correct/incorrect system behavior/functionality.

Milestones in Model Checking (2)

- CounterExample-Guided Abstraction Refinement (CEGAR). Clarke, E., Grumberg, O., Jha, S., Lu, Y., and Veith, H. Counterexample-guided abstraction refinement. In Proceedings of the 12th International Conference on Computer Aided Verification (CAV 2000) (Chicago, IL, July 15?19 2000), vol. 1855 of Lecture Notes in Computer Science, Springer-Verlag Berlin Heidelberg, pp. 154?169.
- Property Directed Reachability (PDR), or Incremental Construction of Inductive Clauses for Indubitable Correctness (IC3). See `http://theory.stanford.edu/~arbrad/`.

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Additional Formal Verification Techniques for Quantum Robots (1)

- Reachability analysis:
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    - Possible solution: Quantum partially-observable Markov decision processes (QMDPs)
    - Reference: Shenggang Ying and Mingsheng Ying, "Reachability Analysis of Quantum Markov Decision Processes," *arXiv*, Cornell University, Ithaca, NY, July 9, 2014. Available online from *arXiv* as Version 2 at: `http://arxiv.org/abs/1406.6146v2`; May 30, 2015 was the last accessed date.
- Quantum Equivalence Checking:
    - Given 2 models of a quantum robot, determine if they are functionally equivalent.
    - Use quantum information decision diagrams (QuIDD), global-phase equivalence, and relative-phase equivalence (Viamontes et al., 2009).
    - Ditto for tensor calculus, dynamic tensor products, partial

Additional Formal Verification Techniques for Quantum Robots (2)

- SMT-based quantum formal verification:
  - Use SMT solver (decision procedure for satisfiability modulo theories) as reasoning engine for formal verification
  - Use reasoning/computational engine for hybrid model checking and theorem proving or model checking and equivalence checking
  - Use fragments of 1st-order logic, such as differential dynamic logics, for hybrid systems verification; see work by Prof. André Platzer at `http://symbolaris.com/`.
  - Get the quantum logic equivalent of these.
  - References:

1. Platzer, A. Logical Analysis of Hybrid Systems: Proving Theorems for Complex Dynamics. Springer- Verlag Berlin Heidelberg, Heidelberg, Germany, 2010.

Additional Formal Verification Techniques for Quantum Robots (3)

- Exploit equivalence of maximum satisfiability (Max-SAT), pseudo-boolean optimization (PBO) , and wighted PBO:
  1. Use meta-algorithms via algorithmic portfolio optimization to select the "best" or set of good solutions (Max-SAT, Max-SMT, PBO, or Weighted PBO).
  2. Engineer quantum logic variant/equivalent.
  3. Turn numerical models in the time domain to algebraic models in the frequency domain, via transform methods (e.g., Fourier transform, Laplace transform, and z-transform) and approximations via parameterization and (quasi-) linearization
  4. The meta-algorithms enable us to plug-and-play (or plug-and-pray) components for quantum formal verification.

Additional Formal Verification Techniques for Quantum Robots (4)

- Use Quantum Model Order Reduction for Approximation:
  1. Quantum Model Order Reduction approximates components of quantum robots as continuous-time dynamical systems.
  2. Reference: [1] Viamontes, G. F., Markov, I. L., and Hayes, J. P. Quantum Circuit Simulation. Springer Science+Business Media, B.V., Dordrecht, The Netherlands, 2009.