Instantaneous Noise-Based Logic

My Work in Progress

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Cheap(er), Small(er), and Fast(er)!!!

Is that possible? For real???

More Moore's Law,
Generalized Moore's Law,
More than Moore's Law

Continuum Noise-Based Logic (NBL):

- Deterministic
- Reduce error accumulation & propagation
- More energy efficient
- Greater circuit complexity

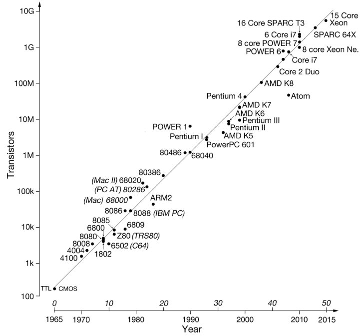

Figure: Semi-log Plot (log-lin type) of the number of transistors on a processor against time.

Instantaneous Noise-Based Logic (iNBL)

iNBL: no time averaging operations, with the exception of the output interfaces.

$\therefore$ NBL schemes without time averaging are instantaenous.

- Advantages over continuum NBL:
  - Performance (computational time complexity) speedup by 10-100 X.
  - Simpler, hence cheaper, circuit complexity.
- Examples of iNBL schemes:
  - noise-based brain logic scheme
  - bipolar random telegraph waves

Bipolar Random Telegraph Waves (bipolar RTW)

Bipolar random telegraph waves (RTW) is defined by the function `bipolar_rtw(n)`.

$$\texttt{bipolar\_rtw(n)} = \begin{cases} 1, & \texttt{random(n)} \geq 0.5, \\ -1, & \texttt{random(n)} < 0.5, \end{cases}$$
$$\forall n \in \{1, 2, 3, \dots\}(\text{or n} \in |\mathbb{Z}| > 0)$$

where n is the n^{th} time step in a bipolar logic signal, $\texttt{bipolar\_rtw(n)} \in \{1, -1\}$, that is generated from a (pseudo-) random noise generator.

References for Classical Reachability Analysis

(Yuan, 2006) Yuan, J., Pixley, C., and Aziz, A. Constrained-Based Verification. Springer Science+Business Media, Inc., New York, NY, 2006.

Problem Statement

- Models of concurrent and nondeterministic quantum systems need to be verified.
- Quantum Markov decision processes (qMDPs) can model such quantum systems.
- Question: How can we carry out reachability analysis on concurrent and nondeterministic quantum systems, modeled as qMDPs?
- Input: qMDP $\mathcal{M}$
- Input: state space $\mathcal{H}$, which is a Hilbert space
- Input: state space $B \in \mathcal{H}$
- Output: Scheduler $\mathfrak{S}$
- Output: Non-negative integer, n.

Shortcomings of Classical Reachability Analysis

- Classic Markov chains cannot capture concurrency.
- A Markov chain only allows one "choice" of action per state, which implies that all "rewards" of the Markov chain are the same.
- Cannot formalize behavior/functionality of quantum systems
    - Discrete state spaces of classical systems are finite or countably finite
    - Continuous state spaces of quantum systems cannot be addressed by discrete state spaces
    - State spaces of quantum systems are continuous, even for finite-dimensional quantum systems
    - Need to examine a finite number of representative elements (in an orthonormal basis) of the state space of a quantum system
    - Or, at most, examine countably infinitely many representative elements of this state space
    - Always preserve the linear algebraic structure of the representative elements [& linear-time properties]

Prior and Related Work

- Almost all previous work use model checking to verify quantum communication protocols
- Use quantum process algebra to verify quantum communication systems, including quantum error correction codes
- Use simulation tools for quantum systems to verify their behavior/functionality, especially their correctness and safety properties
- Quantum partially observable Markov decision processes (QOMDPs), which are introduced by (Barry, Barry, and Aaronson, 2014), only care about the reachability of a single state (i.e., goal state).:
  - The paper does not specifically address the reachability of invariant subspaces.
  - Goal-state reachability is undecidable for QOMDPs.

Invariant subspace: sounds like T: V–¿V something that transforms you into the same space

Design Decisions

- Quantum model checking framework for the formal verification of generic quantum engineering systems
  - Not just quantum communication systems
- Use a formal method based on modeling quantum systems with quantum automaton
  - Exploit similar work in quantum Markov chains, quantum dot automata, & quantum cellular automata
- Only consider linear-time properties of generic quantum systems
  - Describe these linear-time properties as infinite sequences of sets of atomic propositions, just like LTL model checking
- Extend this to verify safety properties for reversible automata
- Extend this to verify ω-properties for reversible Büchi automata
- Meet requirements for correctness, safety, & reliability

Key Contributions of (Ying 2014)

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Analysis on Decidability of Quantum Reachability Analysis In the Finite-Horizon

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Analysis on Decidability of Quantum Reachability Analysis In the Infinite-Horizon

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Analysis on Complexity of Quantum Reachability Analysis In the Finite-Horizon

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Analysis on Complexity of Quantum Reachability Analysis In the Infinite-Horizon

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Questions That I Have

- I assume that uncomputable problems are the same as undecidable problems (Barry, Barry, and Aaronson, 2014).
- From (Barry, Barry, and Aaronson, 2014), can QOMDPs be reduced to qMDPs?
- The authors mentioned that quantum systems can be modeled as qMDPs? Do such quantum systems include robots, which can be modeled as quantum dynamical systems? Or, is it restricted to quantum computer programs?
- What is the ortho-complement of a subspace?
- What does it mean for a measurement to be projective? What does it mean mathematically?
- Is "W" on page 2, right column, in the last paragraph ($w \in W$), a set of words "w"?
- $\otimes$, right column, in paragraph 1/2 on page 2

do Markov chains inherently model nondeterminism?

Are there extensions of Markov chains to capture/model concurrency?

Discussions

- (What do I think about this work?)
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Future Work

- Extensions of