Entanglement-induced provable and robust quantum learning advantages

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Motivation

Can we find practical and provable quantum advantage in **classical** ML tasks?

(Most applications are classical, not quantum!)

Known obstacles:

1. Hard to unconditionally prove lower bounds.
2. More expressive QML models are harder to train.
3. Data-loading overheads lead to dequantization.
4. NISQ devices limit heuristic exploration.

Our work:

A machine learning task demonstrating
noise-tolerant unconditional linear quantum advantage in
representation power, inference speed, and training efficiency!

Our work:

practically relevant: seq-seq translation

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exp. improve SOTA $\Omega(\log n)$

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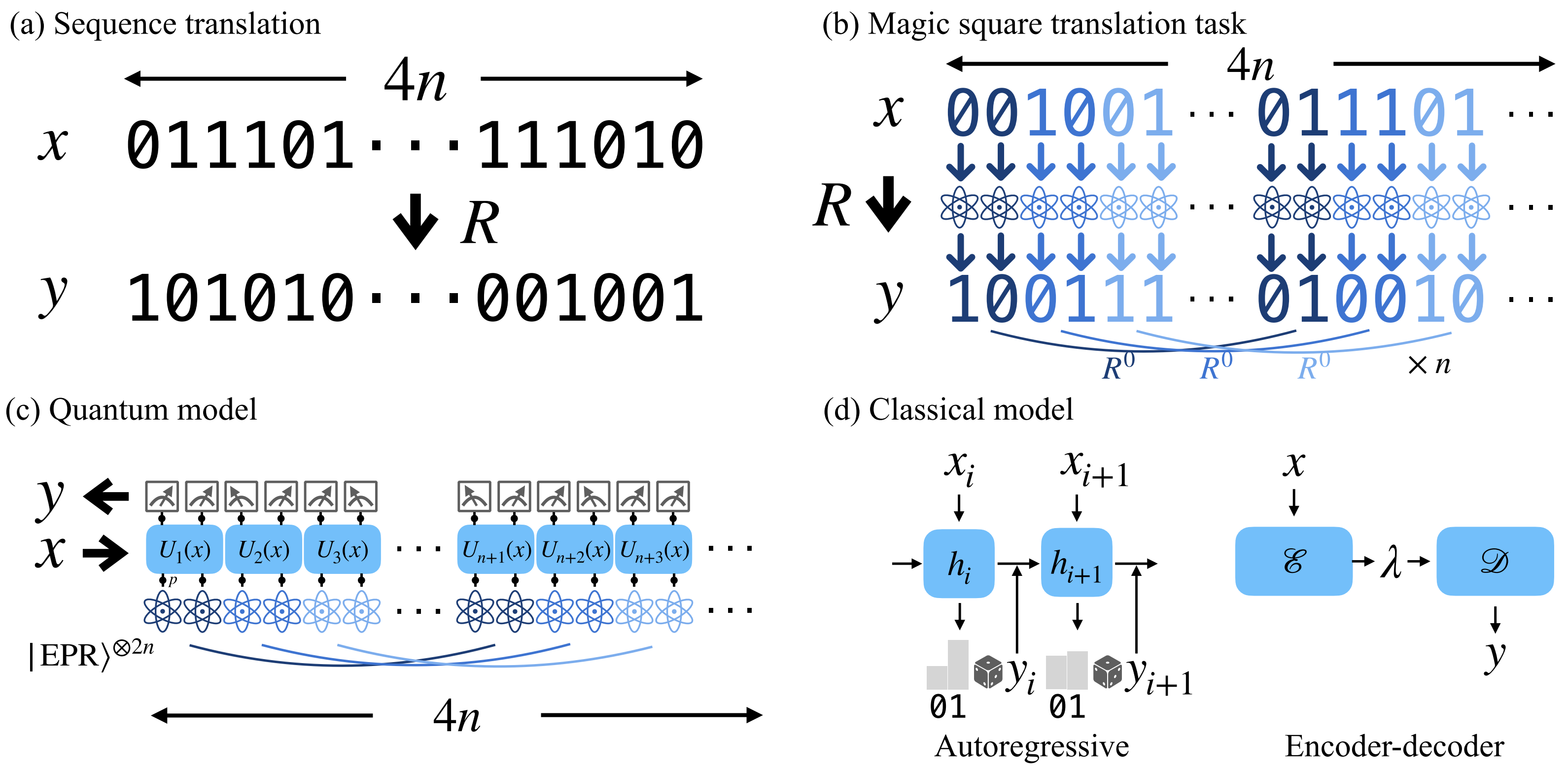
fewer parameters
faster inference & train
smaller sample size

Intuition

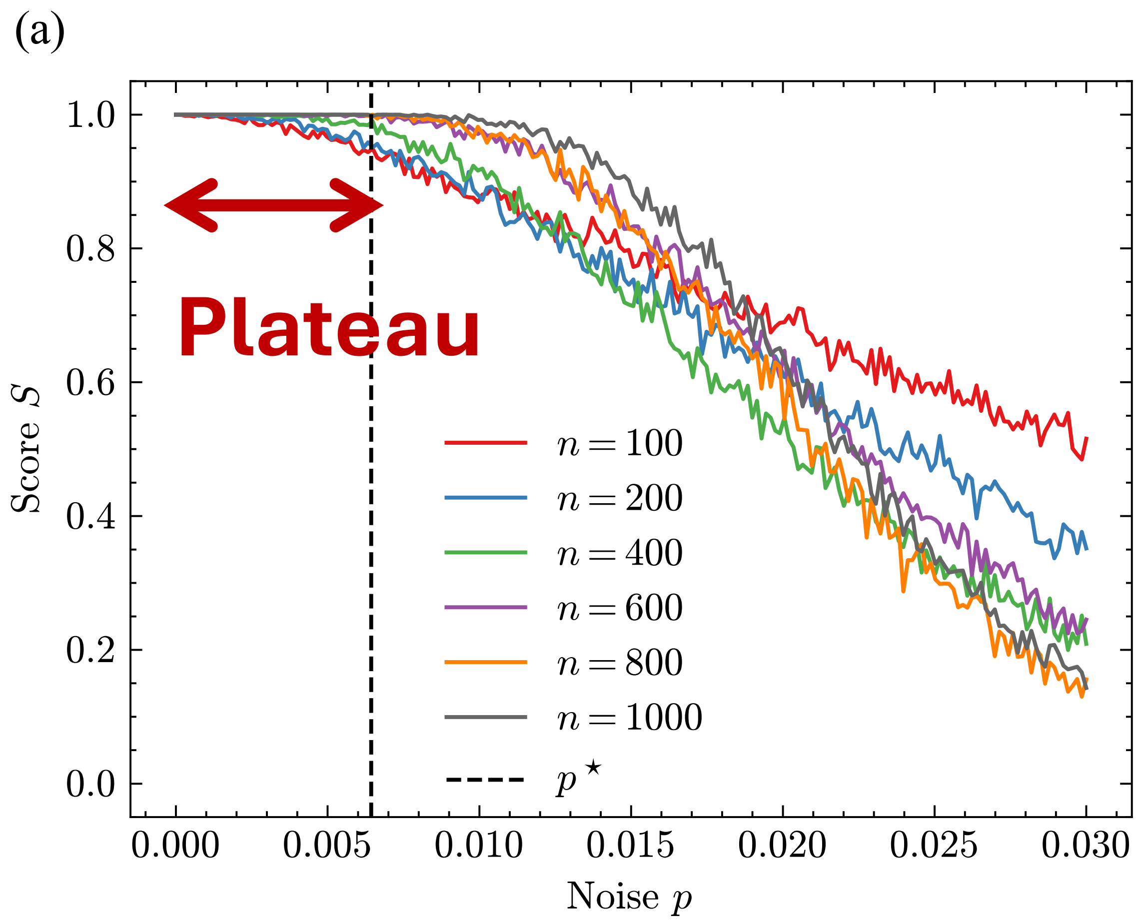
Pseudo-telepathy: entanglement reduces communication complexity of seq. transl. tasks

- Embed non-local games into a translation task.
- Score = winning probability
- $O(1)$ q model + $\leq 0.64\%$ noise
$\Rightarrow 1 - 2^{-\Omega(n)}$ score
- $o(n)$ classical model
$\Rightarrow \leq 2^{-\Omega(n)}$ score
Clifford simulation $O(n^3)$
- MLE training in $O(1)$ time



Numerics & Ion trap

- Noise tolerance
- Exponential separation in score
- Classical models suffer from q advantage + overfitting



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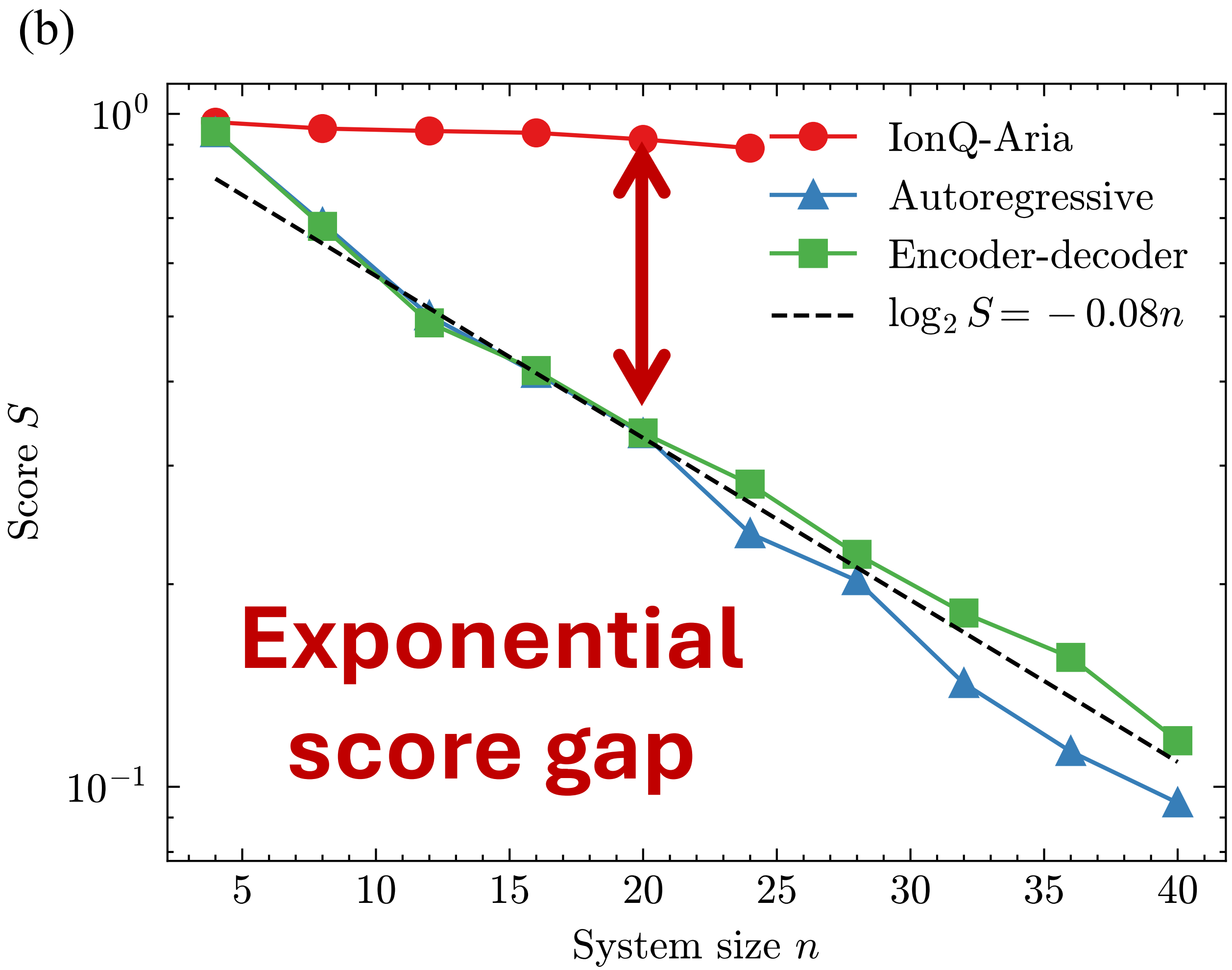

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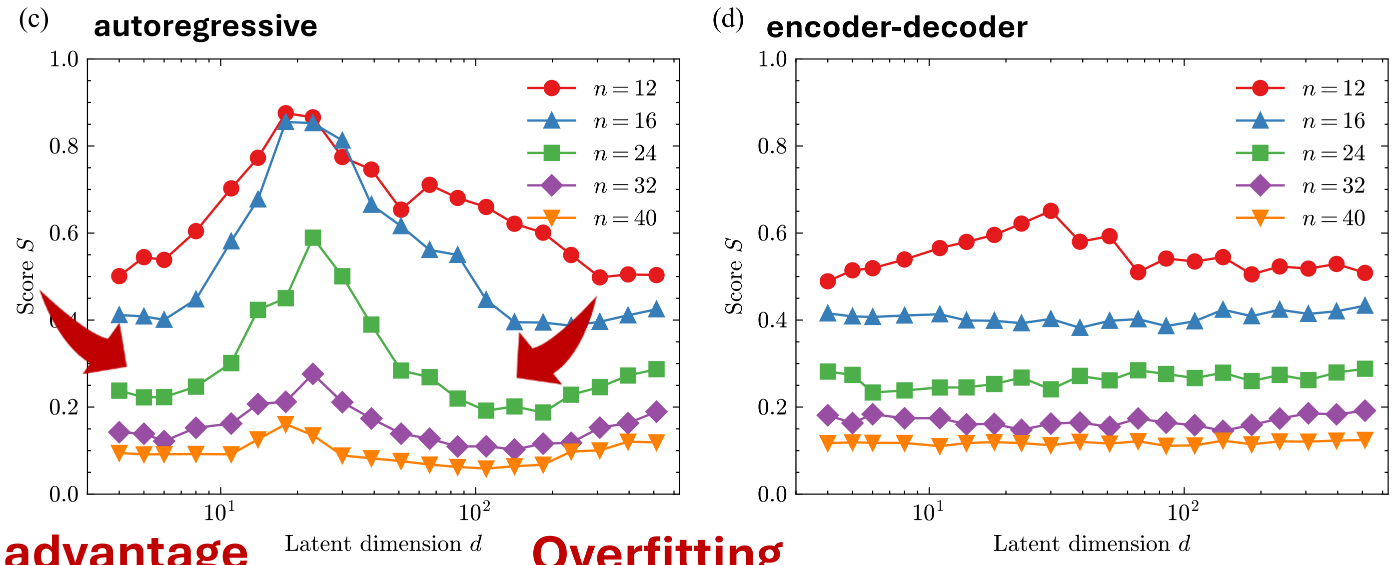

q. advantage

≪

Overfitting

≫ #

Conclusions & Future directions

A quantum advantage in ML

- provable w/o conjectures
- tolerate $O(1)$ depolarize noise
- quantum $O(1)$ vs classical $\Omega(n)$
  exp. improve SOTA, $\Omega(\log n)$
- fewer parameters
  faster inference & train
  smaller sample size

visible on small size!
(q. advantage + overfit)

? boost advantage w/
many-body Bell inequalities?

? against more general classical
models?

? non-locality in real-world?
e.g., natural language?