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Incremental Learning of Quantum Generative Adversarial Network

Czech Technical University in Prague, Faculty of Information Technology, Department of Computer Science

Bc. Artem Kandaurov
Supervisor: Ing. Ivo Petr, Ph.D.

Preparing generic quantum state problem and existing solutions

- Superposition and entanglement
- Quantum computer operates with quantum registers
- Loading classical data into quantum registers

$$|\Psi\rangle = \sum_{j=0}^{2^n-1} \sqrt{P(b_j)}\,|b_j\rangle$$

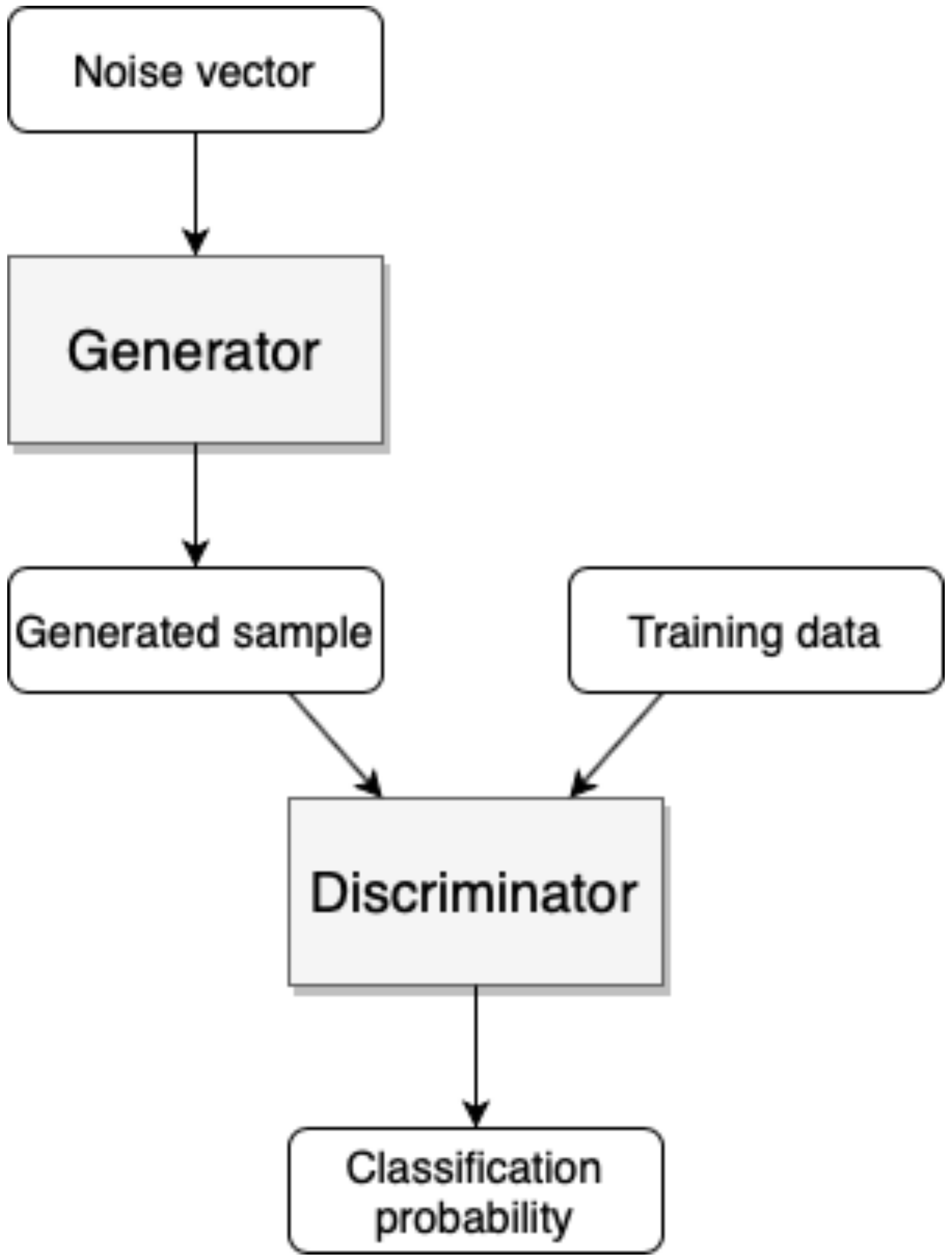
- Loading particular generic state in n qubits requires $O(2^n)$ gates
- Approximation

Generative Adversarial Network

Principles

- Introduced by Ian J. Goodfellow et al.
- Generator creates fake examples
- Discriminator labels real and fake samples
- Generator and discriminator are neural networks
- Adversarial learning as a minimax game

$$\min_{\theta_g}(\max_{\theta_d}(\mathbb{E}_{x\sim p_{real}}[\log D_{\theta_d}(x)] + \mathbb{E}_{z\sim p_{prior}}[\log(1 - D_{\theta_d}(G_{\theta_g}(z)))]))$$



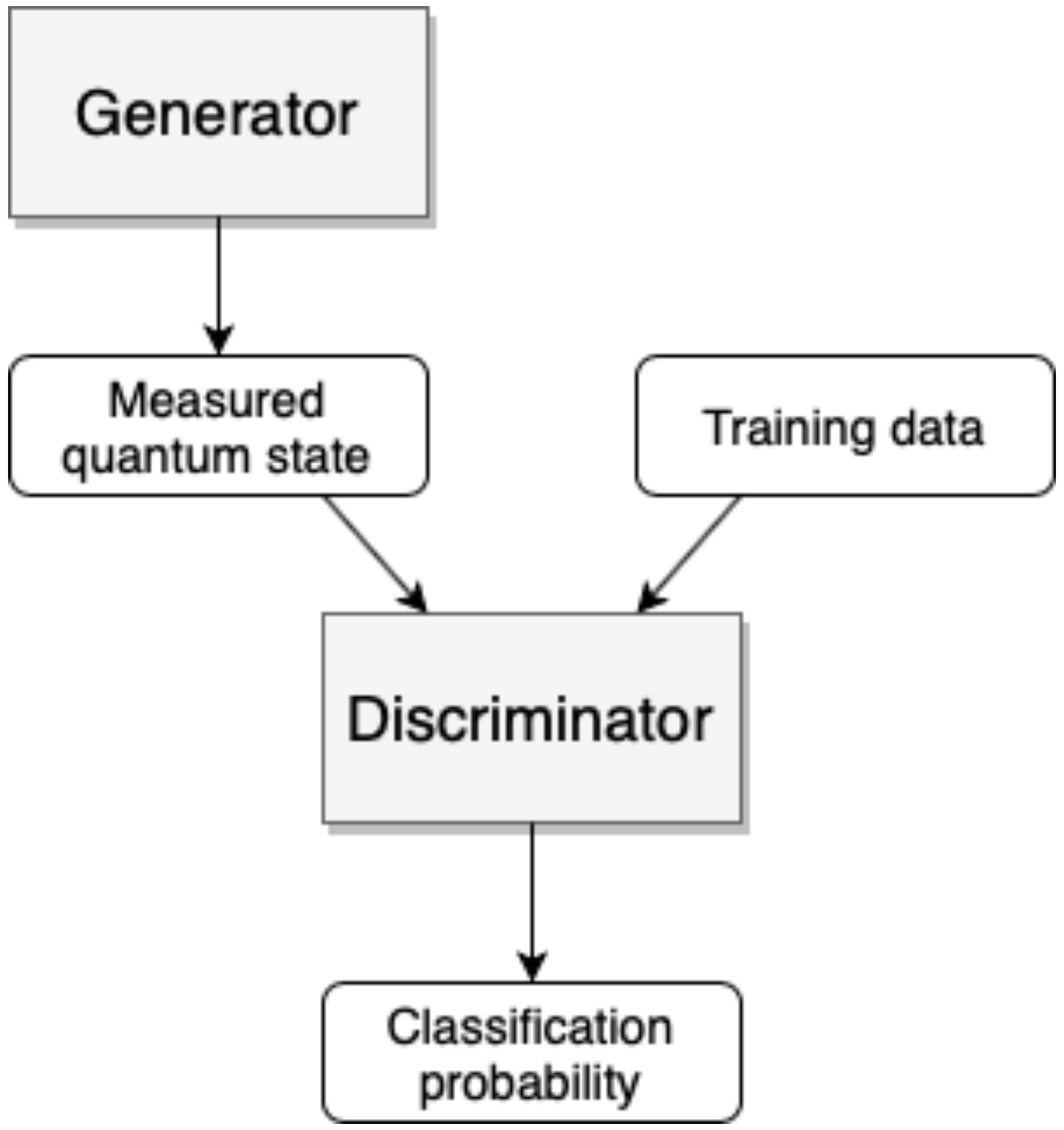
Quantum Generative Adversarial Network

Principles

- Introduced by Seth Lloyd et al.
- Quantum generator and classical discriminator
- More natural than classical GAN
- Loss functions

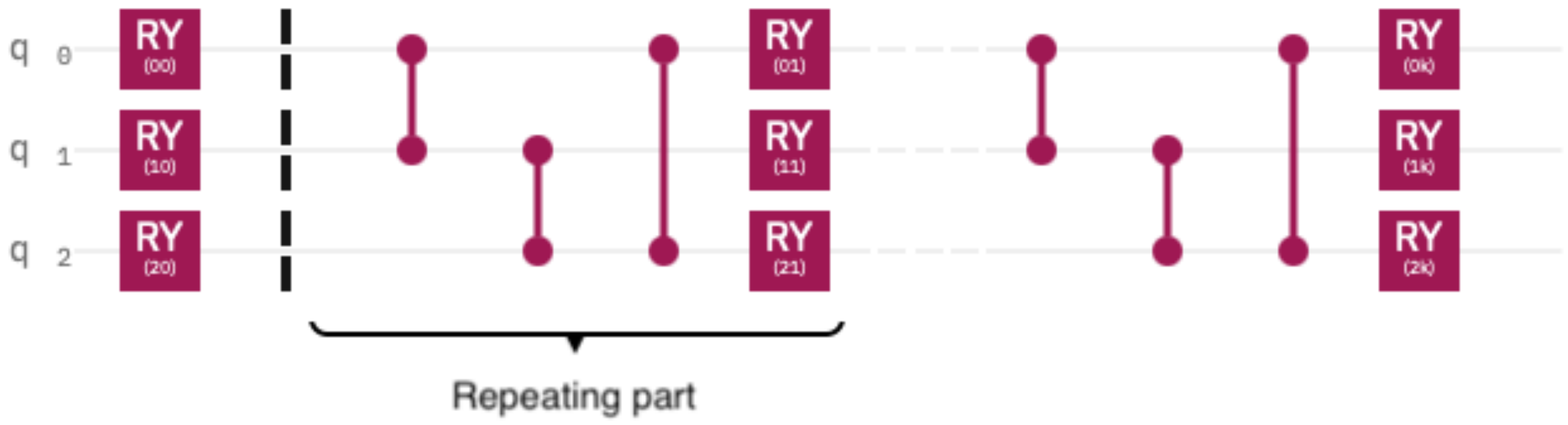
$$L_G(\theta_g, \theta_d) = -\mathbb{E}_{g\sim G_{\theta_g}}[\log(D_{\theta_d}(g))]$$

$$L_D(\theta_g, \theta_d) = \mathbb{E}_{x\sim p_{real}}[\log D_{\theta_d}(x)] + \mathbb{E}_{g\sim G_{\theta_g}}[\log(1 - D_{\theta_d}(g))]$$



Quantum Variational Circuit

- Parametrizing schemes: **RX, RY, RZ**
- Entanglement schemes: **CZ, CNOT**



Quantum Generative Adversarial Networks for learning and loading random distributions

- Introduced by Christa Zoufal et al.
- Quantum variational circuit should represent a probability distribution
- Underlying process is defined implicitly with a training dataset
- Loading requires $O(poly(n))$ gates
- Implementation is a part of Qiskit
- Training time is still the issue

Incremental learning of Quantum Generative Adversarial Network

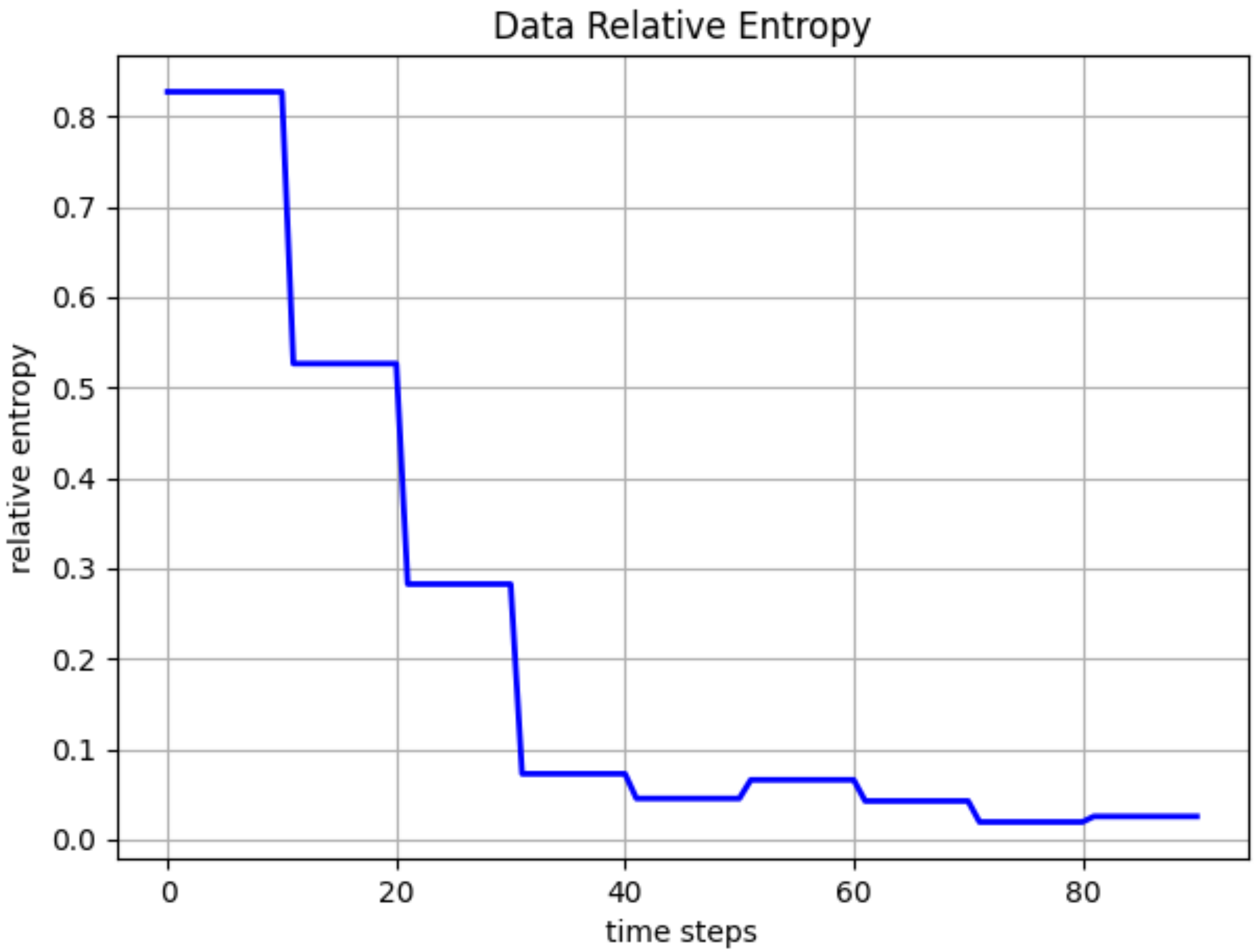
- Complete dataset availability assumption and data streams
- Extension of the original algorithm
- Stationary underlying processes learning
- Non-stationary underlying processes learning
- Possible application in quantum finances
- Code availability

Stationary process learning test case definition

- Number of qubits: 2
- Generator's distribution: Uniform
- Target distribution: Log-normal with $\mu = 1, \sigma = 1$
- Data stack limit: Unlimited
- Data source: Batch per 10 time steps

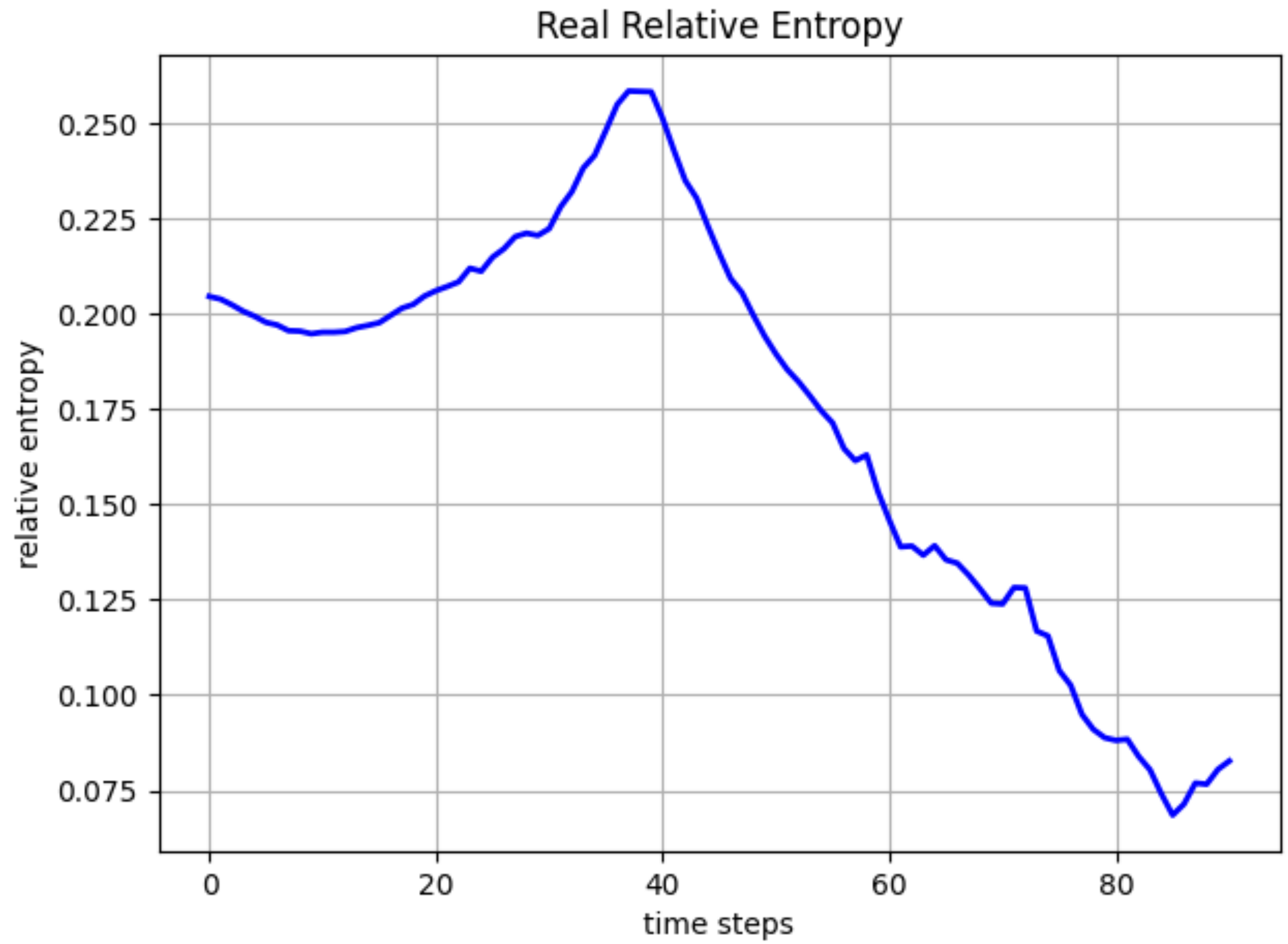
Stationary process learning

Relative entropy between *available* and *unknown* dataset



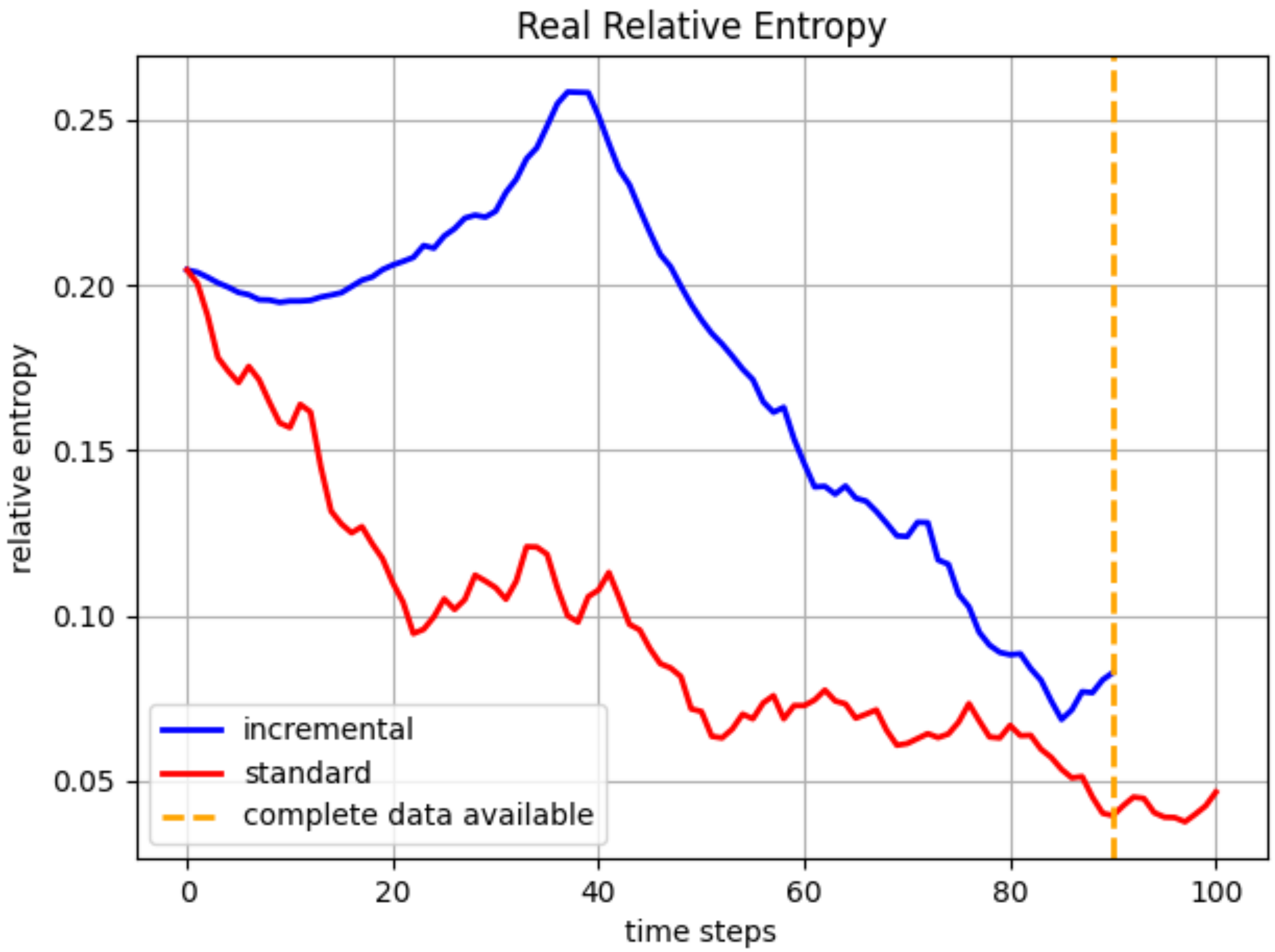
Stationary process learning

Relative entropy between *trained* and *unknown wanted* state



Stationary process learning

Real relative entropy comparison

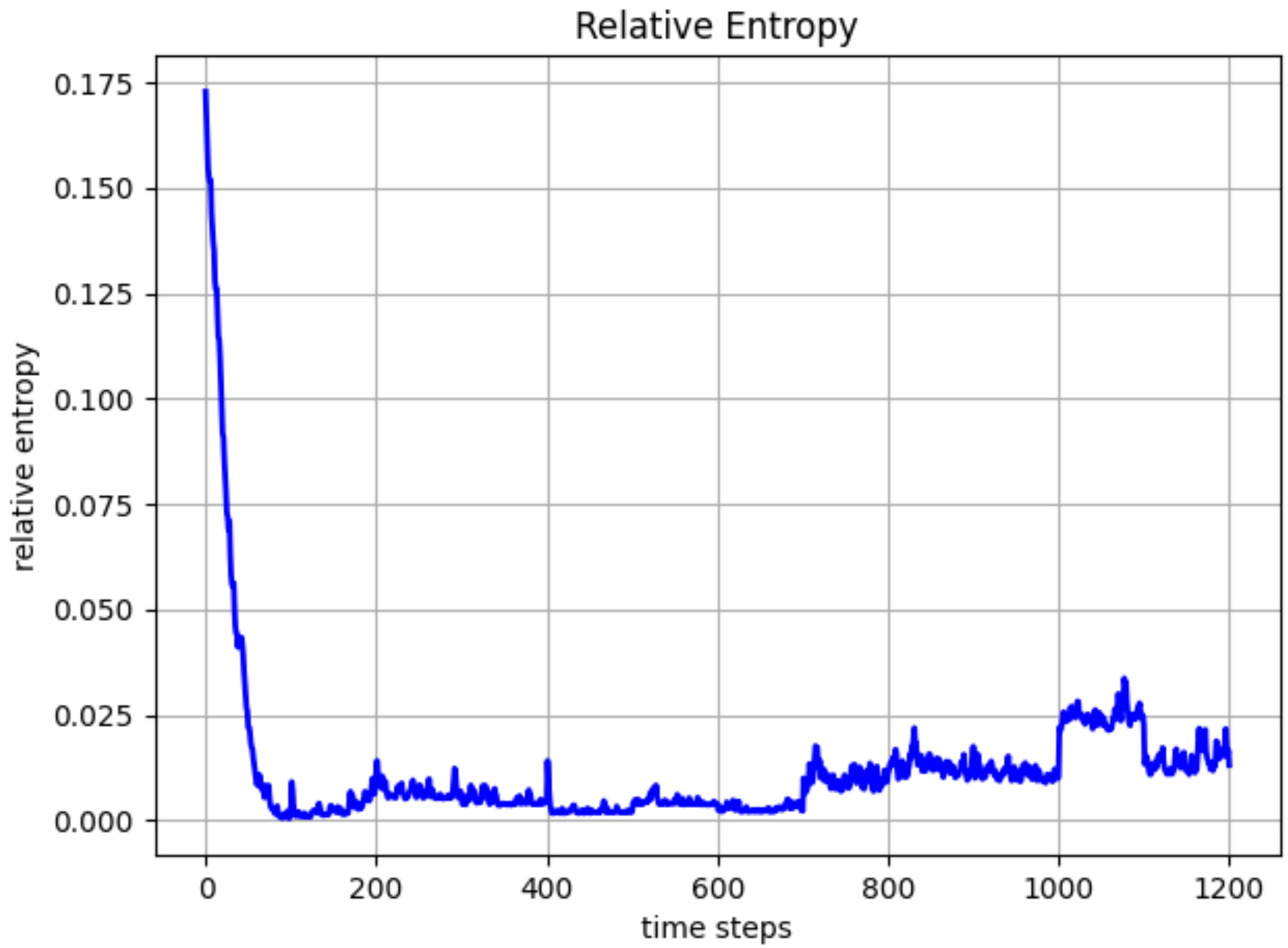


Non-stationary process learning test case definition

- Number of qubits: 2
- Generator's distribution: Uniform
- Initial distribution: Log-normal with $\mu = 1, \sigma = 1$
- Target distribution: Log-normal with $\mu = 2, \sigma = 1$
- Data stack limit: 10 batches
- Data source: Batch per 100 time steps

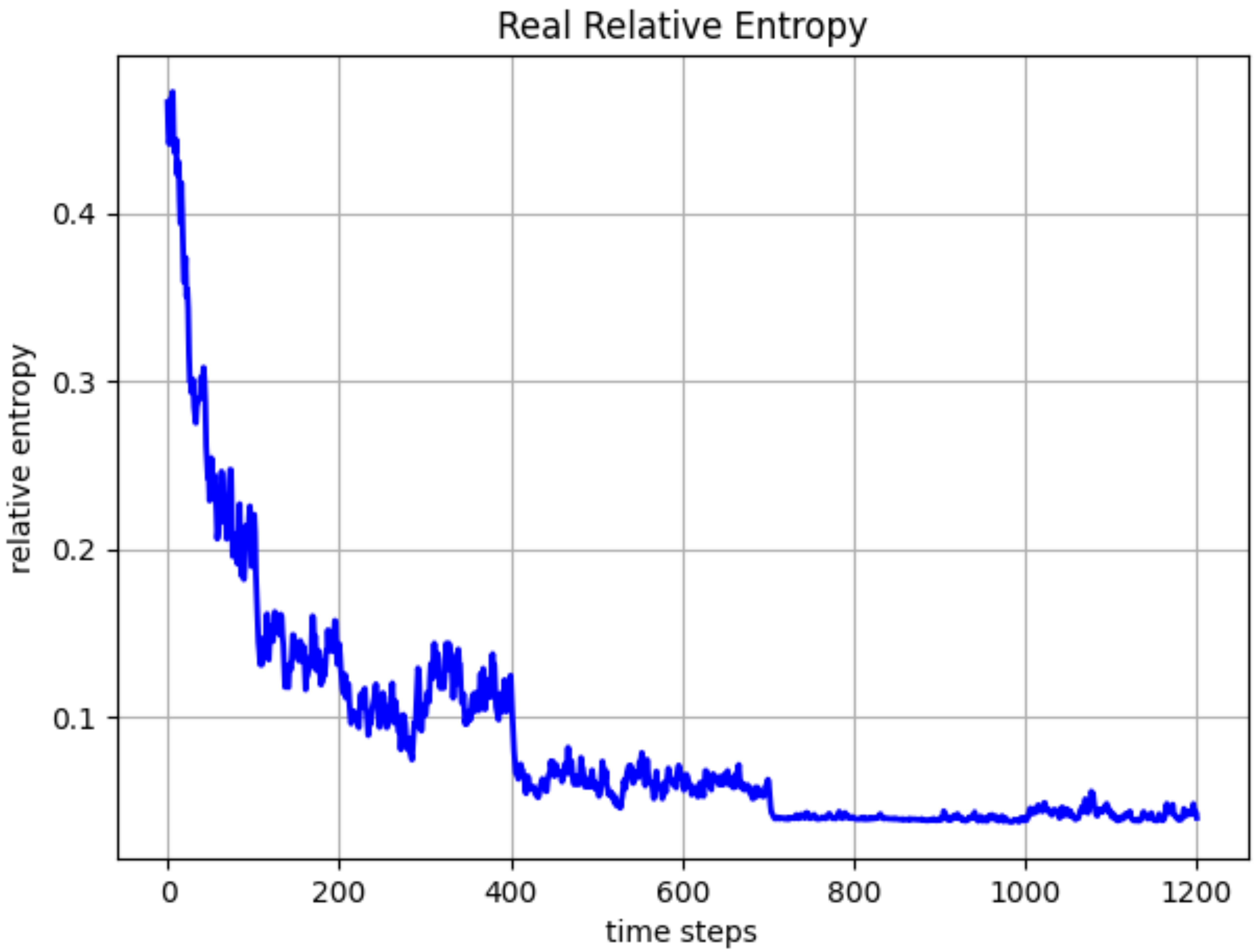
Non-stationary process learning

Relative entropy between *trained* and *wanted* state



Non-stationary process learning

Relative entropy between *trained* and *unknown wanted end* state

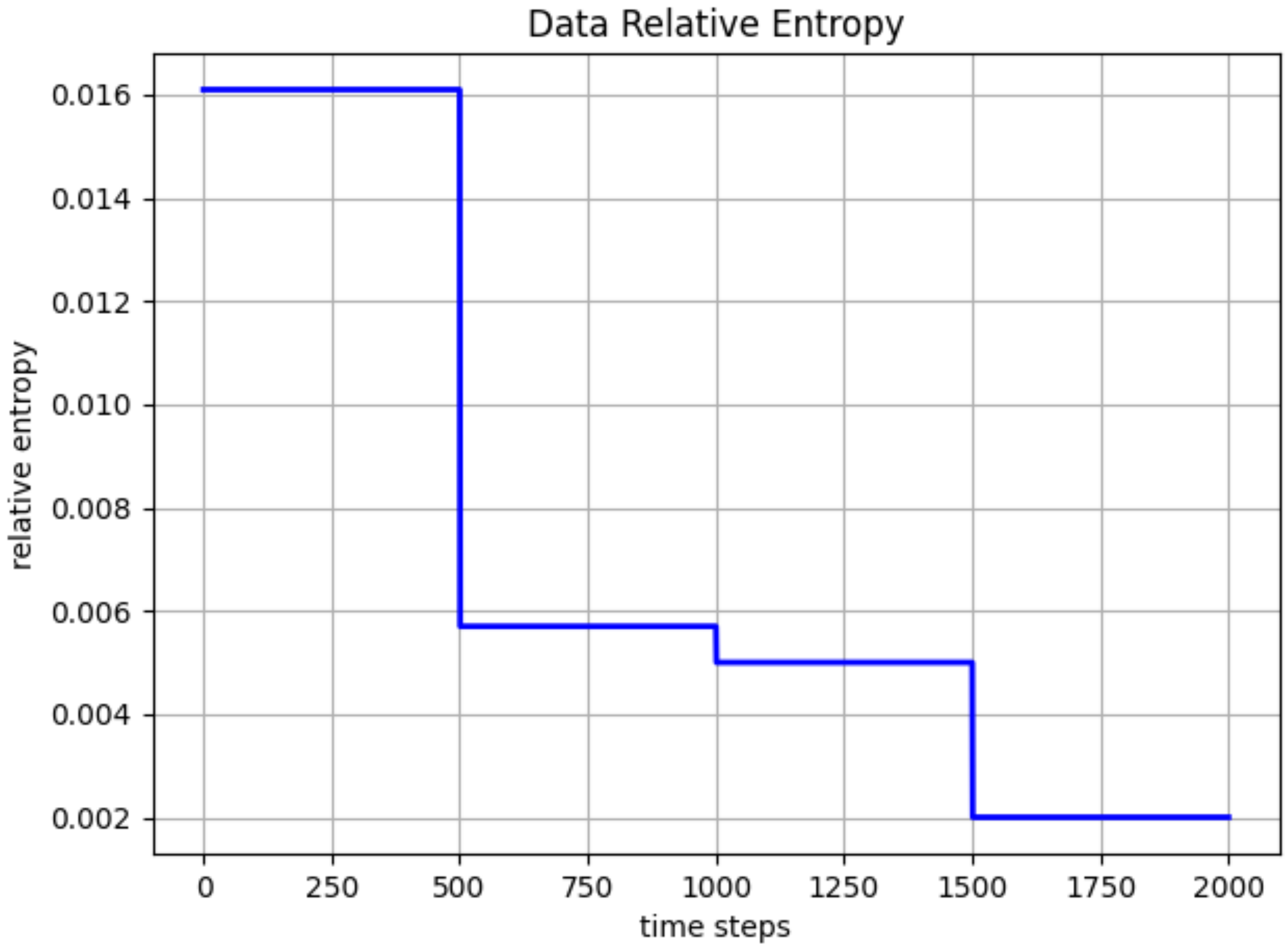


Stationary process learning with noisy simulator test case definition

- Number of qubits: 2
- Generator's distribution: Uniform
- Target distribution: Log-normal with $\mu = 1, \sigma = 1$
- Data stack limit: Unlimited
- Data source: Batch per 500 time steps

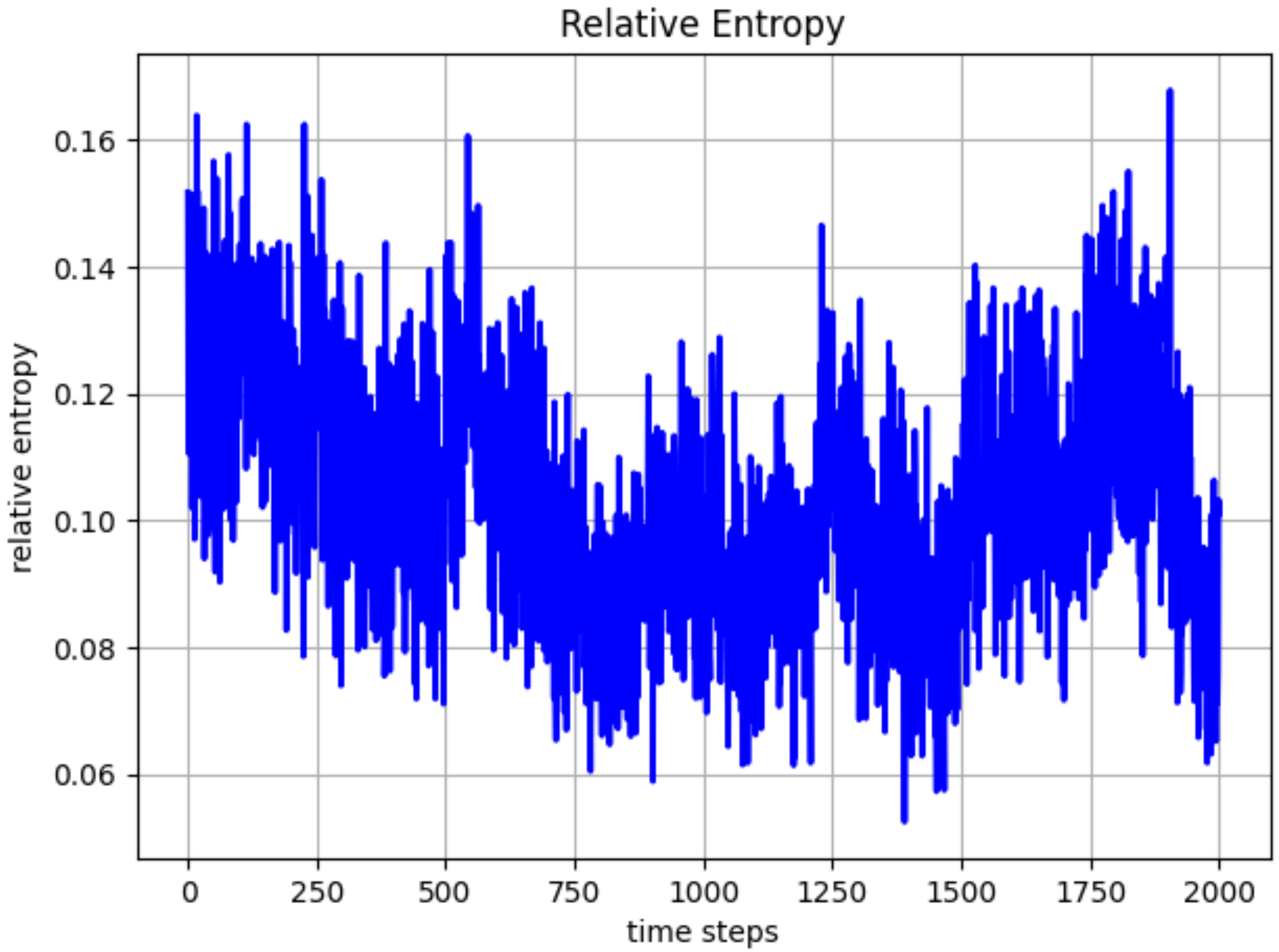
Stationary process learning with noisy simulator

Relative entropy between *available* and *unknown* dataset



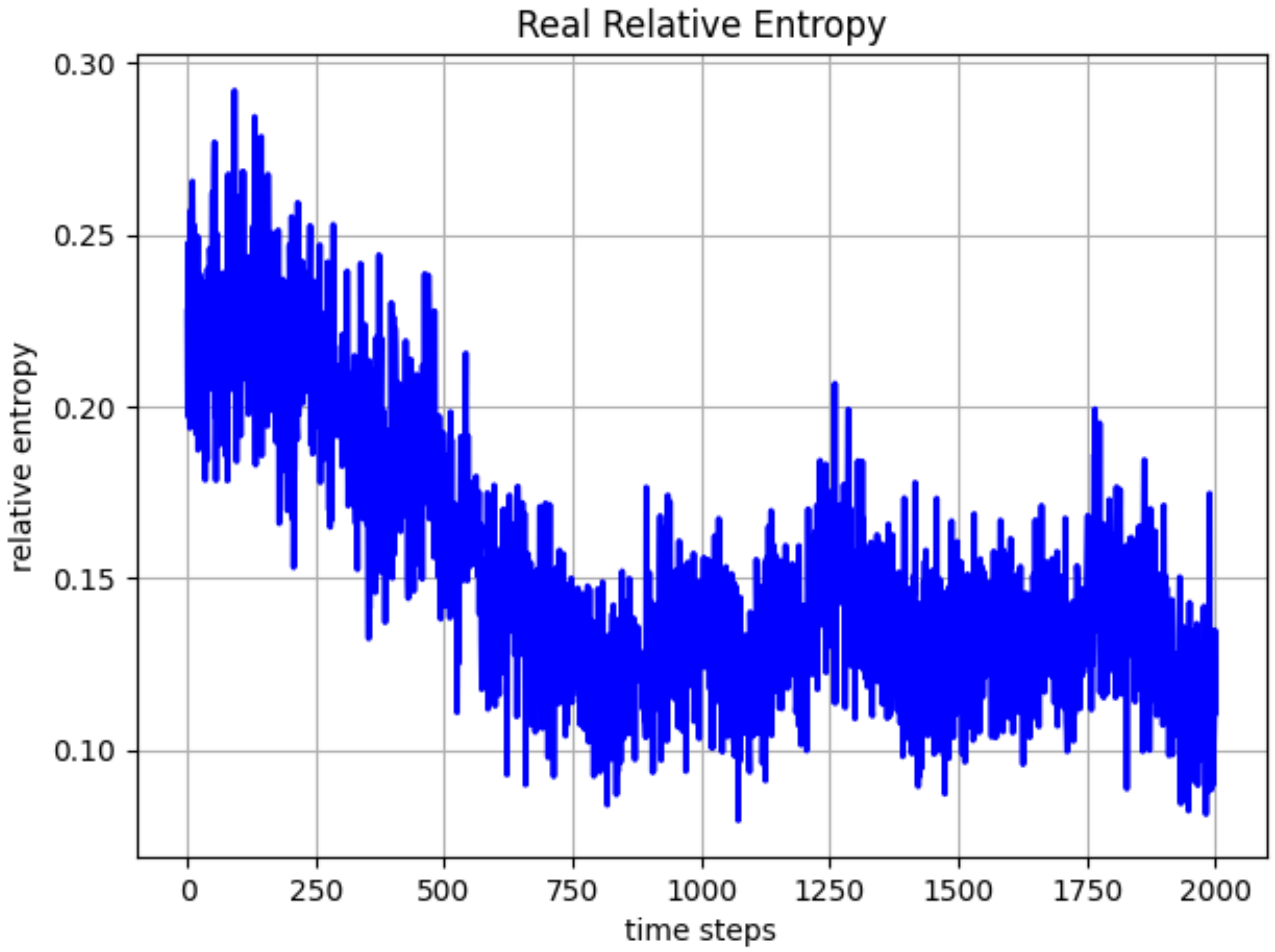
Stationary process learning with noisy simulator

Relative entropy between *trained* and *wanted* state



Stationary process learning with noisy simulator

Relative entropy between *trained* and *unknown wanted* state



References

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- Lloyd, S.; Weedbrook, C. Quantum generative adversarial learning. *Physical review letters*, volume 121, no. 4, 2018: p. 040502.
- Zoufal, C.; Lucchi, A.; et al. Quantum generative adversarial networks for learning and loading random distributions. *npj Quantum Information*, volume 5, no. 1, 2019: pp. 1–9.