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Quantum-Inspired Ising Framework for Cholera Transmission Dynamics

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Key Insight: Epidemic intensity can be interpreted as interaction strength and correlation structure in an Ising-type quantum-inspired system.

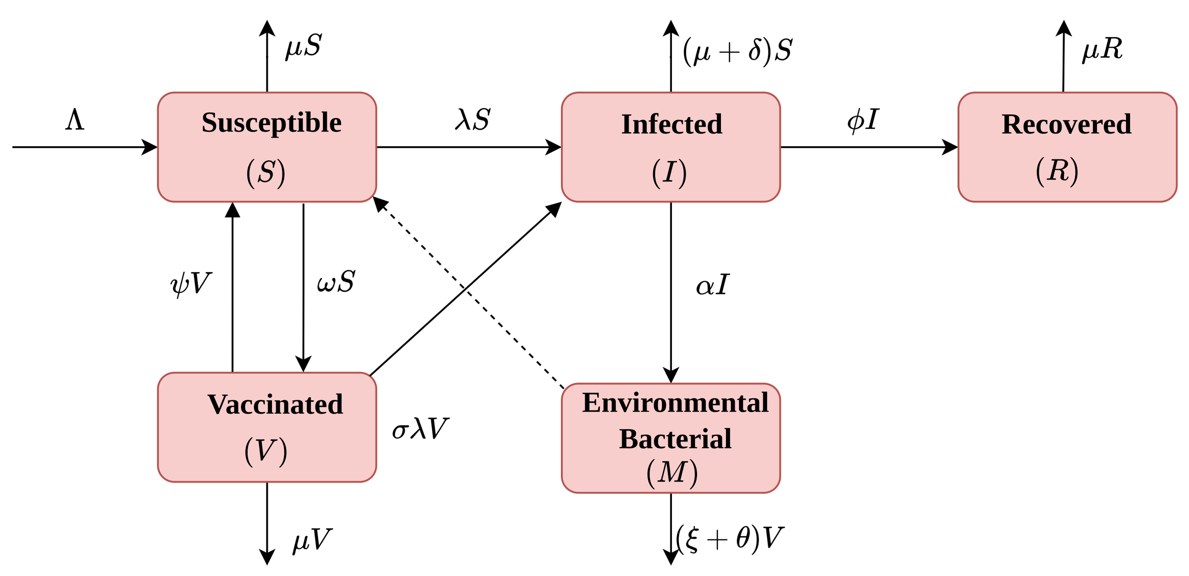
Motivation

Cholera transmission is driven by nonlinear interactions between infected individuals and environmental bacterial reservoirs.

- Classical models describe epidemic evolution.
- Interaction structure is usually implicit.
- We propose a quantum-inspired Ising mapping.

Goal: represent epidemic intensity through coupling and correlation.

From epidemic model to Ising coupling



Classical Model

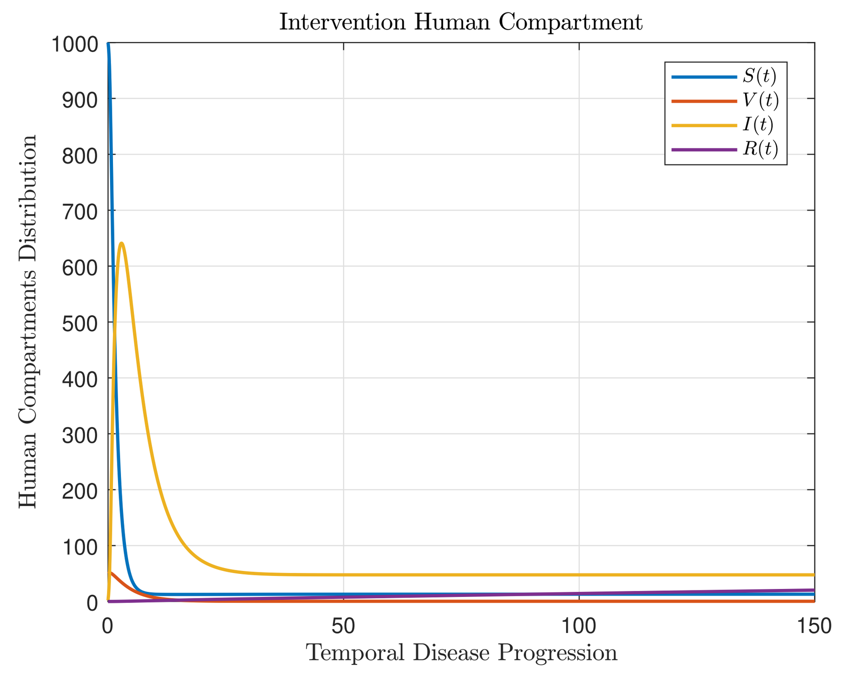
We model the coupling between infected individuals $I(t)$ and environmental bacteria $M(t)$.

$$\lambda(t) = \frac{\beta_1 M(t)}{k + M(t)} + \beta_2 I(t)$$

- environmental transmission: $\frac{\beta_1 M(t)}{k+M(t)}$,
- direct human transmission: $\beta_2 I(t)$.

Limitation: the nonlinear force of infection does not explicitly express interaction strength.

Dynamics of human compartments



Quantum-Inspired Mapping

The epidemic variables are mapped to two interacting qubits:

$$I(t) \to q_0, \qquad M(t) \to q_1.$$

The effective reproduction measure is

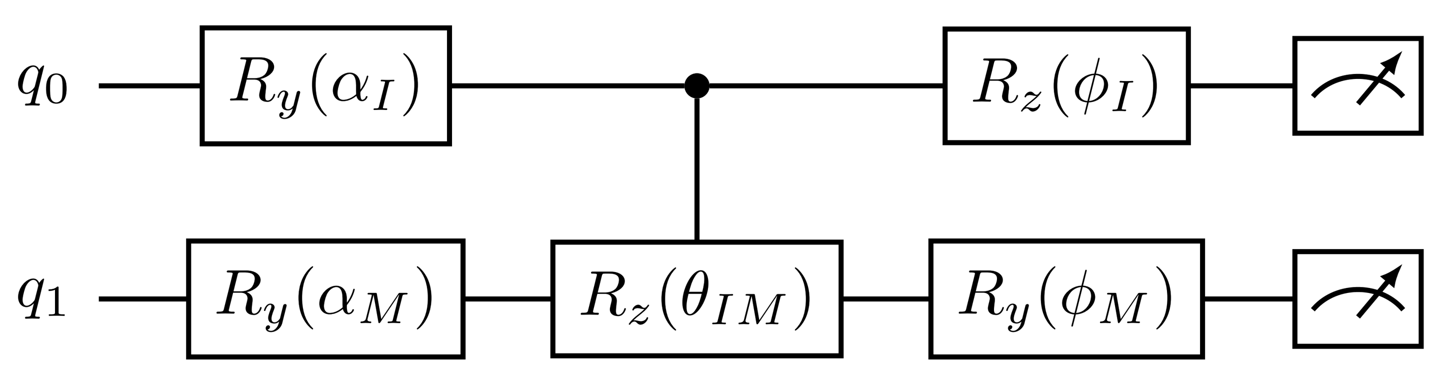
$$\mathcal{R}_{\text{eff}}(t) = \mathcal{R}_h(t) + \mathcal{R}_e(t)$$

The Ising coupling is defined as

$$J(t) = J_{\max} \frac{\mathcal{R}_{\text{eff}}(t)}{1 + \mathcal{R}_{\text{eff}}(t)}$$

Interpretation: higher epidemic intensity corresponds to stronger coupling.

Quantum circuit for infection-environment coupling



$$\theta_{IM} \propto \lambda(t) = \frac{\beta_1 M(t)}{k+M(t)} + \beta_2 I(t)$$

Interaction Dynamics

The quantum-inspired dynamics are governed by the time-dependent Ising Hamiltonian

$$H(t) = -J(t) \sum_{\langle i,j \rangle} \sigma_i^z \sigma_j^z.$$

The interaction is implemented using

$$R_{ZZ}(\theta_{IM}), \qquad \theta_{IM} \propto \lambda(t).$$

Key idea: Stronger coupling = higher epidemic intensity

Correlation Analysis

To characterize interaction dynamics, we evaluate the quantum correlation between the two subsystems.

$$C_{zz}(t) = \langle \psi(t) | \sigma_1^z \sigma_2^z | \psi(t) \rangle$$

where

$$|\psi(t)\rangle = e^{-iH(t)\Delta t} |\psi_0\rangle.$$

Interpretation:

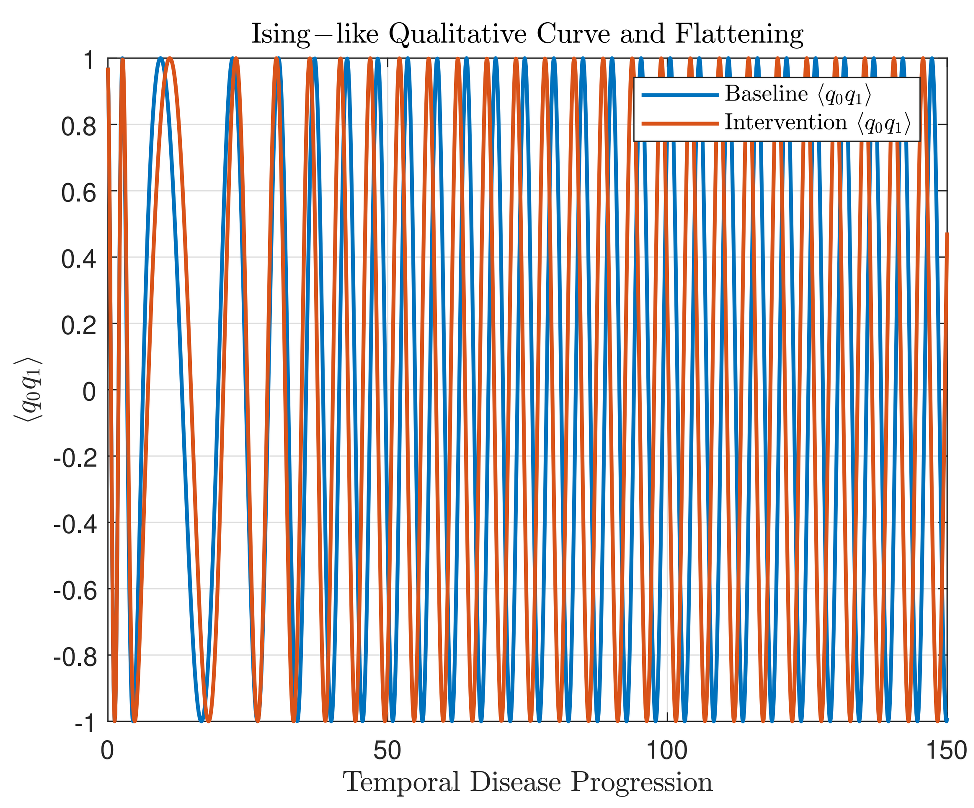
- Large $C_{zz}(t)$: strong interaction.
- Small $C_{zz}(t)$: controlled transmission.
- Changes in $C_{zz}(t)$: regime shifts.

Thus, epidemic regimes can be identified through correlation structure without changing the underlying classical model.

Results and Future Directions

Correlation reflects epidemic intensity under baseline and intervention scenarios.

Higher correlation = stronger transmission



Key findings:

- higher correlation indicates stronger transmission,
- lower correlation corresponds to controlled dynamics,
- intervention effects can be interpreted through coupling reduction.

Future work:

- quantum implementation,
- real-data validation,
- extension to multi-compartment models.

Acknowledgement. REFRESH – Research Excellence For Region Sustainability and High-tech Industries project number CZ.10.03.01/00/22_003/0000048 via the Operational Programme Just Transition.

Manuscript note. This poster is based on the manuscript *"A Quantum-Inspired Ising Framework for a Deterministic Cholera Model with Environmental Transmission, Umar Shafique, Marek Lampart, Ali Raza, Mathematical Modelling and Analysis"*, currently submitted.