Correlation as a Resource

The role of redundant correlated records in the emergence of Objective Classical Reality

Vishal Johnson[1,2,†] Ashmeet Singh[3] Torsten Enßlin[1,2]

November 26, 2025

[1]Max-Planck-Institut für Astrophysik, Garching [2]Ludwig-Maximilians-Universität, München [3]Whitman College, Walla Walla

[†]vishal@mpa-garching.mpg.de

Quantum25

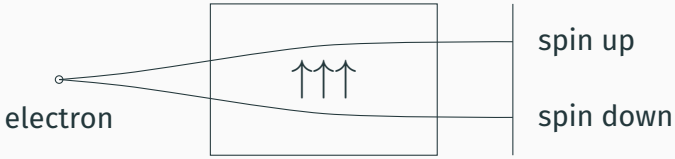
LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

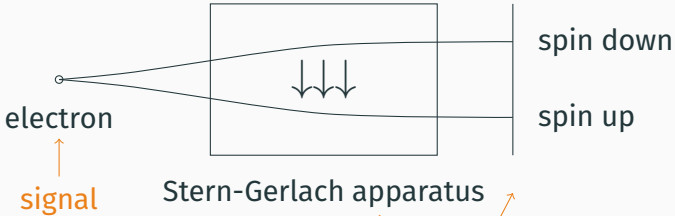
MAX-PLANCK-INSTITUT FÜR ASTROPHYSIK

preliminary version: abs/2212.03829

Motivation

Motivation: Stern Gerlach





Objective Classical Reality

Definition (Objective Classical Reality[1])
The state of a signal s exists objectively if multiple observers (o_α) can probe the signal independently and without disturbing it.

jointly called perceiver

[1] *Horodecki, R., Korbicz, J. K., and Horodecki, P. Phys. Rev. A. Mar. 2015.*

No-go Theorem

not all true:

1. unitary quantum mechanics holds universally ✓
2. for $|\phi\rangle \in \Phi \subseteq \mathcal{H}_\mathsf{p}$

$$\mathcal{U}^{\text{meas}}_{\mathsf{s}\to\mathsf{p}}|\psi\rangle_\mathsf{s}|\phi\rangle_\mathsf{p} = \sum \mathbb{\Pi}_m|\psi\rangle_\mathsf{s}|\mathcal{P}_{m\phi}\rangle_\mathsf{p} \text{ (objective classical reality) } ✓ \tag{1}$$

3. measurement outcomes distinguishable: ✓

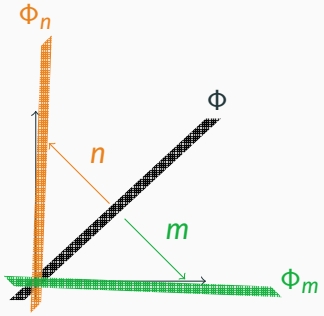
$$\langle\mathcal{P}_{m\chi}|\mathcal{P}_{n\phi}\rangle = \delta_{mn}\langle\mathcal{P}_{m\chi}|\mathcal{P}_{m\phi}\rangle \tag{2}$$

4. finite dimensional Hilbert spaces ✓
5. arbitrary initial state (Φ=$\mathcal{H}_\mathsf{p}$) ✗

No-go Theorem: Simple Argument

outcome m subspace: $\Phi_m = \{|\mathcal{P}_{m\phi}\rangle \forall |\phi\rangle \in \Phi\}$

$m \neq n \implies \Phi_m \perp \Phi_n$



$\implies \Phi \subset \mathcal{H}_\mathrm{p}$

Qudit Measurement Procedure

Correlated Perceiver

signal: $\mathcal{H}_\mathrm{s} = \mathbb{C}^d$

perceiver: $\mathcal{H}_\mathrm{p} = (\mathbb{C}^d)^{\otimes \mathrm{N}}$

$$\mathbb{C}^d \sim \Phi \ni |\phi\rangle_\mathrm{p} = \sum_l \phi_l |l\rangle_{\mathrm{p}_1} |l\rangle_{\mathrm{p}_2} \dots |l\rangle_{\mathrm{p}_\mathrm{N}} \tag{3}$$

Transferring Correlation (Imprint)

$$\mathcal{I}_{\mathrm{a}\to\mathrm{b}}|m\rangle_{\mathrm{a}}|n\rangle_{\mathrm{b}} = |m\rangle_{\mathrm{a}}|n+m\rangle_{\mathrm{b}}$$
$$\mathcal{I}^{-1}_{\mathrm{a}\to\mathrm{b}}|m\rangle_{\mathrm{a}}|n\rangle_{\mathrm{b}} = |m\rangle_{\mathrm{a}}|n-m\rangle_{\mathrm{b}} \tag{4}$$

Qudit Measurement Procedure

$$
\begin{aligned}
|\psi\rangle_{\mathrm{s}}|\phi\rangle_{\mathrm{p}} = \sum \psi_m \phi_l \; & |m\rangle_{\mathrm{s}}|l\rangle_{\mathrm{p_1}}|l\rangle_{\mathrm{p_2}} \dots |l\rangle_{\mathrm{p_N}} \\
& \Big\downarrow \mathcal{I}_{\mathrm{s}\to\mathrm{p_1}} \\
& |m\rangle_{\mathrm{s}}|l+m\rangle_{\mathrm{p_1}}|l\rangle_{\mathrm{p_2}} \dots |l\rangle_{\mathrm{p_N}} \\
& \Big\downarrow \mathcal{I}^{-1}_{\mathrm{p_2}\to\mathrm{p_1}} \\
& |m\rangle_{\mathrm{s}}|l+m-l\rangle_{\mathrm{p_1}}|l\rangle_{\mathrm{p_2}} \dots |l\rangle_{\mathrm{p_N}} \\
\hookrightarrow \Big(\sum \psi_m |m\rangle_{\mathrm{s}}|m\rangle_{\mathrm{p_1}} \Big) & \Big(\sum \phi_l |l\rangle_{\mathrm{p_2}} \dots |l\rangle_{\mathrm{p_N}} \Big)
\end{aligned}
\tag{5}
$$

repeating:

$$
\Big(\sum \psi_m |m\rangle_{\mathrm{s}}|m\rangle_{\mathrm{p_1}} \dots |m\rangle_{\mathrm{p_K}} \Big) \Big(\sum \phi_l |l\rangle_{\mathrm{p_{K+1}}} \dots |l\rangle_{\mathrm{p_N}} \Big) \tag{6}
$$

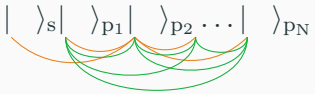
correlation is a resource!

Numerical Results

Correlation Proxy

pairwise correlations : level of agreement of measurement outcomes

$$C_\alpha : \sum \text{pairwise correlations with qudit } \alpha$$
$$C_\mathsf{p} : \sum_{\alpha \in \mathsf{per}} C_\alpha \tag{7}$$

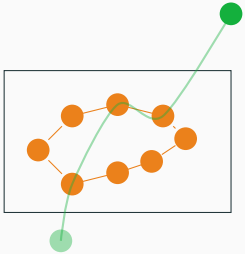


compare initial C_p with final C_s!

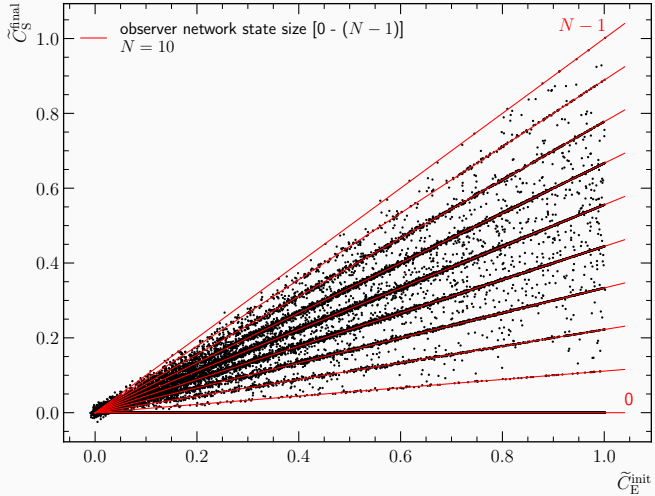
Simulation Procedure

$\mathcal{H}_s = \mathbb{C}^2$

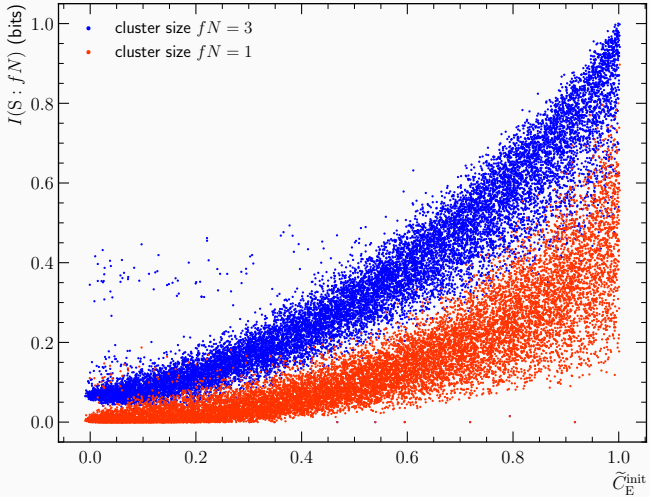
$\mathcal{H}_p = (\mathbb{C}^2)^{\otimes N}$



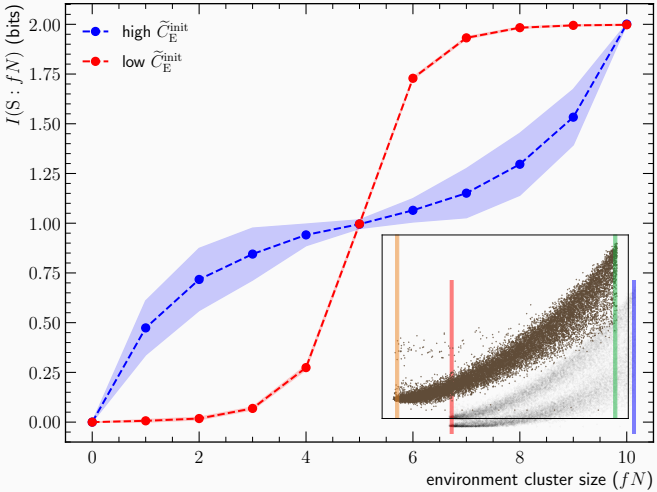
Simulation Results: C_S vs C_P



Simulation Results: mutual information vs $-C_P$



Simulation Results: mutual information plateau?



Summary

Summarising

- special initial state for perceiver
- correlation is a resource
- simulations confirm hypothesis
- how did correlation emerge?
- experimental confirmation?

Thanks! Any Questions?