Asymmetric Gaussian Steering

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The term “steering” was introduced by Schrödinger in 1935 [1] as a description of the effect which has since become famous as the Einstein-Podolsky-Rosen (EPR) paradox [2]. In 2007 Wiseman *et al.* restated Schrödinger’s concept in the language of modern quantum information theory and related it mathematically to the inferred variance criteria used to demonstrate continuous-variable demonstrations of the EPR paradox. In their work, they raised the question of whether a bipartite state could exist where measurements performed on one half could affect the ensemble of possible states describing the other, but not vice-versa.

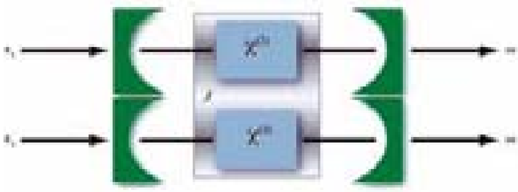

Figure 1: Schematic of the intracavity nonlinear coupler.

For the case of Gaussian measurements, which are normal for continuous-variable states, we answered this question in the affirmative. We showed that there are operating regimes of the intracavity nonlinear coupler where the standard EPR correlations give totally different results for each side, with the paradox being demonstrable by one party but not the other [4]. Measurements of the Duan-Simon criteria can tell us that the system is entangled, as shown in Fig. 2, but do not show this asymmetry.

To show this asymmetric steering, we define the inferred quadrature variances

$$\begin{aligned} V_{inf}(\hat{X}_i) &= V(\hat{X}_i) - \frac{[V(\hat{X}_i,\hat{X}_j)]^2}{V(\hat{X}_j)}, \\ V_{inf}(\hat{Y}_i) &= V(\hat{Y}_i) - \frac{[V(\hat{Y}_i,\hat{Y}_j)]^2}{V(\hat{Y}_j)}, \end{aligned}$$

with $V_{inf}(\hat{X}_i)V_{inf}(\hat{Y}_i) < 1$ showing that subsystem j can steer subsystem i. In a symmetric system, this would hold with the indices swapped, but for certain parameters we found

$$V_{inf}(\hat{X}_i)V_{inf}(\hat{Y}_i) < 1 \leq V_{inf}(\hat{X}_j)V_{inf}(\hat{Y}_j),$$

which is a demonstration of asymmetric Gaussian steering.

Fig. 2 shows a clear example of this, for the parameters $\gamma_1 = 1$, $\gamma_2 = 36$, $J = 5$, $\Delta_1 = 0.001J$, $\Delta_2 = 200\Delta_1$, $\epsilon_1 = 10^3$, $\epsilon_2 = 80\epsilon_1$, $\chi_1 = 10^{-8}$ and $\chi_2 = 10\chi_1$. The Δ_j and γ_j are respectively the cavity detunings and loss rates. The quadrature angles are $\theta = 9^0$ for EPR_{12} and 130^0 for EPR_{21}. We expect that this effect will have applications in quantum cryptography, communications and control. Future work will investigate whether asymmetric steering can exist for all possible measurements, rather than just Gaussian.

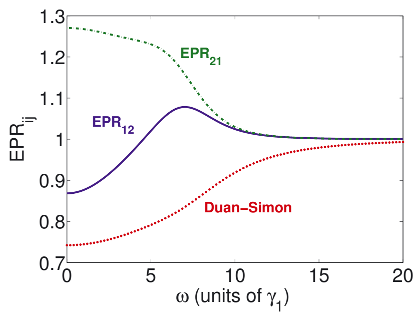

Figure 2: Output EPR and Duan-Simon correlations, showing a clear asymmetry in the EPR measurements.

References

[1] E. Schrödinger, Proc. Cambridge Philos. Soc. **31**, 555 (1935).
[2] A. Einstein, B. Podolsky, and N. Rosen, Phys. Rev. **47**, 777 (1935).
[3] H. M. Wiseman, S. J. Jones, and A. C. Doherty, Phys. Rev. Lett. **98**, 140402 (2007).
[4] S. L. W. Midgley, A. J. Ferris, and M. K. Olsen, Phys. Rev. **A**, 022101 (2010).