Dynamical interaction at the least decoherence, from local measurement and classical communication

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Objectives, motivations

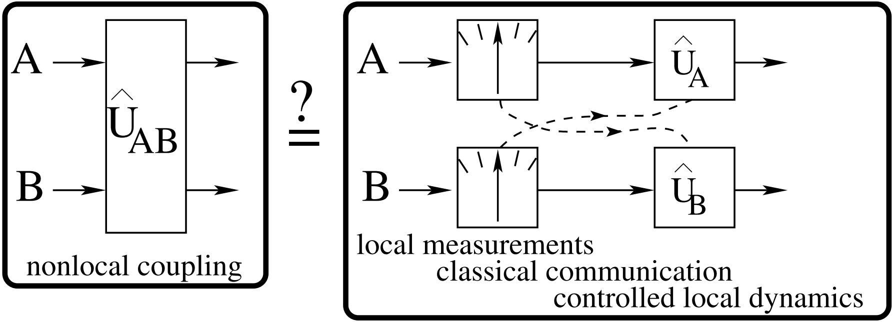
Diósi & Tilloy: *On GKLS dynamics for local operations and classical communication* 2017 OpenSys.Inf.Dyn. 24, 1740020.

Holger: *Simulation of interaction Hamiltonians by quantum feedback* 2005 J.Opt. B7, S208.

- What kind of non-local coupling can one construct via LOCC?
- How much is the price to pay in local decoherence (in noise)?
- Is there a natural concept to define the minimum price?

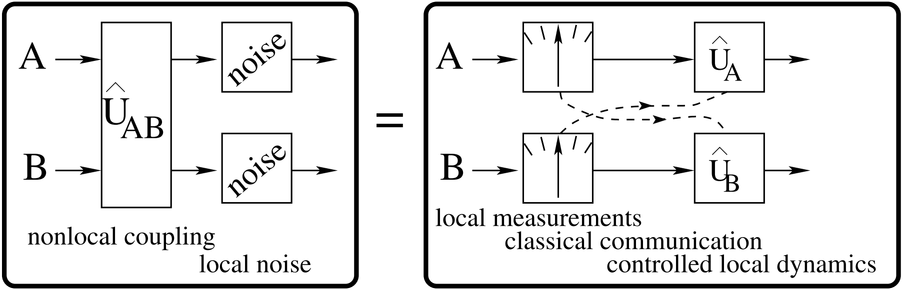
Motivations from a particular field: semiclassical gravity
D. 1990, 2011
D. & Tilloy 2016, 2017
Kafri, Taylor & Milburn 2014, 2015
Altamirano, Corona-Ugalde, Mann & Zych 2016

NonLocal-Unitary is not LOCC



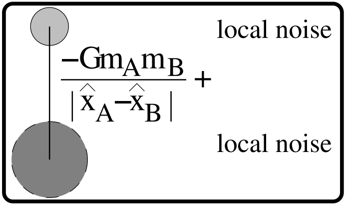
Can not be $=$, of course.

Compromise: NonLocal-Unitary+Noise can be LOCC



Then you may wish to minimize the noise.

A particular motivation: keep gravity non-quantum



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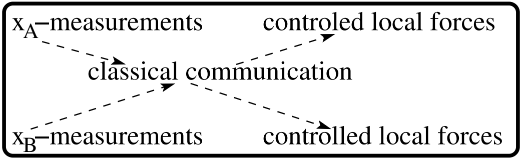

Nonlocal unitary $\hat{U}_{AB}=e^{-i\hat{A}\otimes\hat{B}}$+noise via LOCC

Alice and Bob, respectively,

- measure local observables $\hat{A}$ and $\hat{B}$,
- exchange measurement outcomes A and B classically,
- apply local unitaries $e^{-i\hat{A}B}$ and $e^{-iA\hat{B}}$.

If they used von Neumann detectors of precisions σ_A,σ_B, resp., the initial state $\hat{\rho}$ maps into $\mathcal{D}e^{-i\hat{A}\hat{B}}\hat{\rho}e^{i\hat{A}\hat{B}}$,

$$\mathcal{D}=\exp\left\{-\left(\frac{1}{8\sigma_A^2}+\frac{\sigma_B^2}{2}\right)\hat{A}_\Delta^2-\left(\frac{1}{8\sigma_B^2}+\frac{\sigma_A^2}{2}\right)\hat{B}_\Delta^2\right\}$$

Principle of least decoherence: $\left(\frac{1}{8\sigma_A^2}+\frac{\sigma_B^2}{2}\right)\left(\frac{1}{8\sigma_B^2}+\frac{\sigma_A^2}{2}\right)=\min$

$$\Rightarrow\ \sigma_A\sigma_B=\tfrac{1}{2}$$

For symmetry $A\Leftrightarrow B$, unique decoherence:

$$\mathcal{D}=\exp\left\{-\tfrac{1}{2}\hat{A}_\Delta^2-\tfrac{1}{2}\hat{B}_\Delta^2\right\}$$

$\hat{A}_\Delta\bullet=[\hat{A},\bullet]$, and similarly for $\hat{B}_\Delta$.

Nonlocal Hamiltonian $\hat{H}_{AB} = \hat{A} \otimes \hat{B}$+noise via LOCC

Alice and Bob, resp., repeat the modified protocol at rate $1/\Delta t$:

- measure $\hat{A}, \hat{B}$, with (squared) precisions
$$\sigma_A^2 = \gamma_A/\Delta t, \quad \sigma_B^2 = \gamma_B/\Delta t,$$
- exchange measurement outcomes A and B classsically,
- apply local unitaries $e^{-i\hat{A}B\Delta t}$ and $e^{-iA\hat{B}\Delta t}$.

In the *weak-measurement—time-continuous* limit $\Delta t \to 0$,
GKLS master eq. of LOCC structure:

$$\frac{d\hat{\rho}}{dt} = -i[\hat{A}\hat{B}, \hat{\rho}] - \left(\frac{\gamma_A}{8} + \frac{1}{2\gamma_B}\right)[\hat{A}, [\hat{A}, \hat{\rho}]] - \left(\frac{\gamma_B}{8} + \frac{1}{2\gamma_A}\right)[\hat{B}, [\hat{B}, \hat{\rho}]]$$

Principle of least decoherence $\Rightarrow$ $\gamma_A\gamma_B = 4$.
For symmetry $A \Leftrightarrow B$, unique decoherence:

$$\frac{d\hat{\rho}}{dt} = -i[\hat{A}\hat{B}, \hat{\rho}] - \frac{1}{2}[\hat{A}, [\hat{A}, \hat{\rho}]] - \frac{1}{2}[\hat{B}, [\hat{B}, \hat{\rho}]]$$

Pair-potential $V(\hat{x}_A - \hat{x}_B)$+noise via LOCC

In Fourier representation: $V(\hat{x}_A - \hat{x}_B) = \sum_k \hat{A}_k \hat{B}_k$.
Alice & Bob extends the LOCC protocol of $\hat{A}\hat{B}$ for sum of them:

$$\frac{d\hat{\rho}}{dt} = -i[\hat{H}_A + \hat{H}_B + V(\hat{x}_A - \hat{x}_B), \hat{\rho}] + \mathcal{D}_A\hat{\rho} + \mathcal{D}_B\hat{\rho}$$

Principle of least decoherence yields unique $\mathcal{D}_A, \mathcal{D}_B$:

$$\mathcal{D}_{A/B}\hat{\rho} = \iint \underbrace{V(x-y)}_{must\ \ be\ \ \pm-definite} \delta(x-\hat{x}_{A/B})\hat{\rho}\delta(y-\hat{x}_{A/B})dxdy - \underbrace{V(0)\hat{\rho}}_{div.for"1/r"}$$

$\mathcal{D}_{A/B}$: equivalent with local white-noise potentials as in

$$-i[V_A(\hat{x}_A, t) + V_B(\hat{x}_B, t), \hat{\rho}],$$

with correlations

$$\langle V_A(x,t)V_A(y,s)\rangle = \langle V_B(x,t)V_B(y,s)\rangle = \pm V(x-y)\delta(t-s)$$

Summary

- Any nonlocal dynamical can be approximated by LOCC.
- Price is pure dephasing.
- *Principle of least decoherence* yields best LOCC protocol.

LOCC protocols at the *Least Decoherence*:

- with von Neumann detectors - done
- with counters - to be done (consider CNOT-gate first)
- resulting GKLS master equation - done
- for pair-potential - done

Implications for semiclassical gravity:

- Ask me!