Trace decreasing semigroup for an open quantum system interacting with a repeatedly measured ancilla

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Talk is based on

R. Grimaudo, A. Messina, A. Sergi, N.V. Vitanov, S.N. Filippov. Two-qubit entanglement generation through non-Hermitian Hamiltonians induced by repeated measurements on an ancilla. Entropy 22, 1184 (2020)

E-print arXiv:2009.10004 [quant-ph]

and

I. A. Luchnikov, S. N. Filippov. Quantum evolution in the stroboscopic limit of repeated measurements. Phys. Rev. A 95, 022113 (2017)

E-print arXiv:1609.05501 [quant-ph]

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Non-Hermitian Hamiltonian

$$\varrho(t) = \frac{\rho(t)}{\mathrm{Tr}\left[\rho(t)\right]} = \frac{e^{-iH_{\mathrm{eff}}t}\rho(0)e^{iH_{\mathrm{eff}}^{\dagger}t}}{\mathrm{Tr}\left[e^{-iH_{\mathrm{eff}}t}\rho(0)e^{iH_{\mathrm{eff}}^{\dagger}t}\right]}$$

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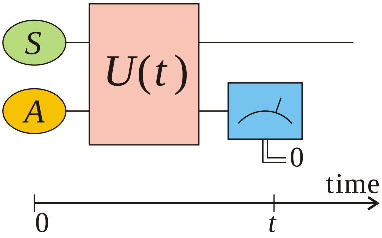
$$\frac{d}{dt}\varrho(t) = -\frac{i}{\hbar}\left[H_0, \varrho(t)\right] - \frac{1}{\hbar}\left\{\Gamma, \varrho(t)\right\} + \frac{2}{\hbar}\mathrm{Tr}\left[\Gamma\varrho(t)\right]\varrho(t)$$

$$\rho_S(0) \longrightarrow \rho_S^c(t) = \langle 0_A|\ U(t)\ \left[\rho_S(0) \otimes |0_A\rangle\langle 0_A|\right]\ U^\dagger(t)\ |0_A\rangle$$
$$= K(t)\rho_S(0)K^\dagger(t),$$

$$K(t) = \langle 0_A|\,U(t)\,|0_A\rangle$$



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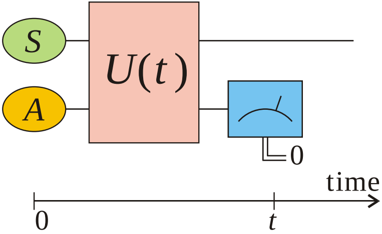
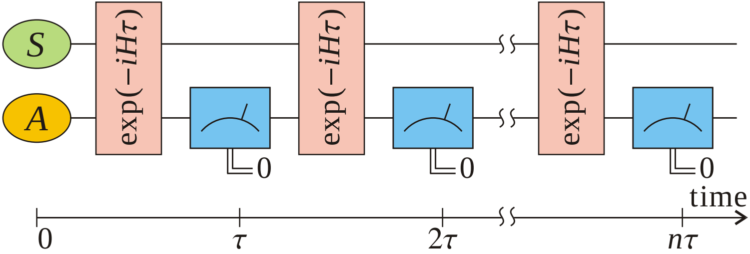


$$p_{\rho_S(0)}(t) = \mathrm{tr}\rho_S^c(t), \qquad \varrho_S^c(t) = \rho_S^c(t)/\mathrm{tr}\rho_S^c(t) = \rho_S^c(t)/p_0(t)$$


S
A
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exp(−iHτ)
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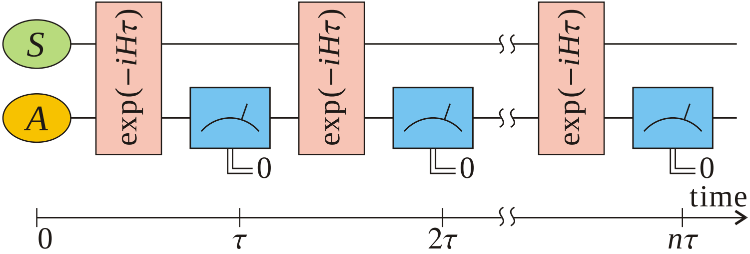
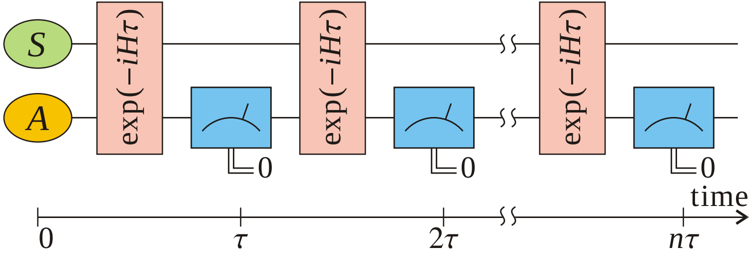


$$\rho_S(0) \longrightarrow \rho_S^c(n\tau) = K^n(\tau)\rho_S(0)\left(K^n(\tau)\right)^\dagger$$



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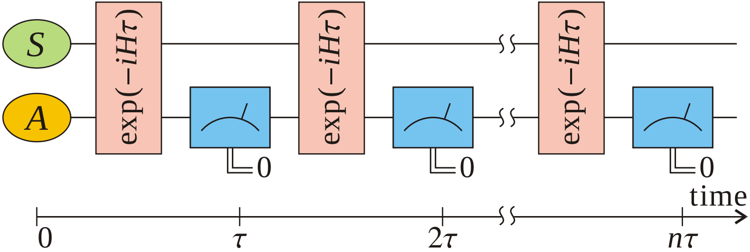

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$$K(\tau) = \langle 0_A|\exp(-iH\tau)|0_A\rangle$$

$$\begin{aligned} K(\tau) &= \langle 0_A| \left(I_{S+A} - i\tau H - \frac{\tau^2}{2} H^2 + o_{S+A}(\tau^2) \right) |0_A\rangle \\ &= I_S - i\tau \langle 0_A|H|0_A\rangle - \frac{\tau^2}{2} \langle 0_A|H^2|0_A\rangle + o_S(\tau^2) \\ &= \exp\left(-i\tau H_0^{\mathrm{S}} - \frac{\tau^2}{2} \Gamma_{\mathrm{S}} + o_S(\tau^2) \right), \end{aligned}$$

$\lim_{\tau \to 0} \|o(\tau^2)\|/\tau^2 = 0$

$H_0^{\mathrm{S}} = (H_0^{\mathrm{S}})^\dagger = \langle 0_A|H|0_A\rangle$

$\Gamma_{\mathrm{S}} = \Gamma_{\mathrm{S}}^\dagger = \langle 0_A|H^2|0_A\rangle - (H_0^{\mathrm{S}})^2 = \langle 0_A|H|1_A\rangle \langle 1_A|H|0_A\rangle \geq 0$

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$$\frac{dp(t)}{dt} = \frac{d\,\mathrm{tr}[\rho_S^c(t)]}{dt} = -\tau\mathrm{tr}[\Gamma_{\mathrm{S}}\rho_S^c(t)] \leq 0$$

$$\varrho_S^c(t) = \frac{\rho_S^c(t)}{\mathrm{tr}[\rho_S^c(t)]} = \frac{K^n(t)\rho_S(0)(K^n)^\dagger(t)}{\mathrm{tr}[K^n(t)\rho_S(0)(K^n)^\dagger(t)]} = \frac{e^{-iH_{\mathrm{eff}}t}\rho_S(0)e^{+iH_{\mathrm{eff}}^\dagger t}}{\mathrm{tr}[e^{-iH_{\mathrm{eff}}t}\rho_S(0)e^{+iH_{\mathrm{eff}}^\dagger t}]}$$

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$$i\frac{d|\psi_S(t)\rangle}{dt} = \left(H_0^{\mathrm{S}} - \frac{i\tau}{2}\Gamma_{\mathrm{S}}\right)|\psi_S(t)\rangle + \frac{i\tau}{2}\langle\psi_S(t)|\Gamma_{\mathrm{S}}|\psi_S(t)\rangle\,|\psi_S(t)\rangle$$

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$$H = \frac{1}{2}(H_{\text{eff}} + H_{\text{eff}}^\dagger) \otimes |0_A\rangle\langle 0_A| + \sqrt{cI + \frac{i}{\tau}(H_{\text{eff}} - H_{\text{eff}}^\dagger)} \otimes (|0_A\rangle\langle 1_A| + |1_A\rangle\langle 0_A|)$$

Example

$$
\begin{aligned}
H &= \gamma_{xy}(\sigma_1^x\sigma_2^x + \sigma_1^y\sigma_2^y) + \gamma_z\sigma_1^z\sigma_2^z + g_{xy}(\sigma_1^x\sigma_3^x + \sigma_1^y\sigma_3^y) \\
&\quad + g_z\sigma_1^z\sigma_3^z + g_{xy}(\sigma_2^x\sigma_3^x + \sigma_2^y\sigma_3^y) + g_z\sigma_2^z\sigma_3^z
\end{aligned}
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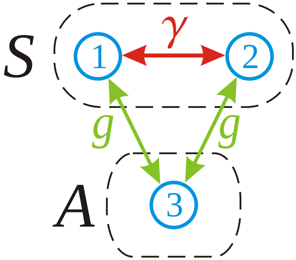

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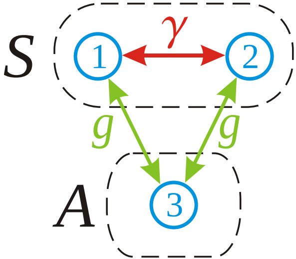

$$H_{\text{eff}} = \gamma_{xy}(\sigma_1^x\sigma_2^x + \sigma_1^y\sigma_2^y) + \gamma_z\sigma_1^z\sigma_2^z + g_z(\sigma_1^z + \sigma_2^z) - i\tau g_{xy}^2\,(2I_{12} + \sigma_1^x\sigma_2^x + \sigma_1^y\sigma_2^y - \sigma_1^z - \sigma_2^z)$$

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$$\mathcal{U}(t) = \begin{pmatrix} e^{-i(\gamma_z+2g_z)t/\hbar}\ e^{2\tau g_{xy}^2 t/\hbar} & 0 & 0 & 0 \\ 0 & \cos\alpha & -i\sin\alpha & 0 \\ 0 & -i\sin\alpha & \cos\alpha & 0 \\ 0 & 0 & 0 & e^{-i(\gamma_z-2g_z)t/\hbar}\ e^{-2\tau g_{xy}^2 t/\hbar} \end{pmatrix}$$

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$$\varrho_S^c(t) = \frac{\rho_S^c(t)}{\mathsf{Tr}\{\rho_S^c(t)\}} = \frac{\mathcal{U}(t)\rho_S(0)\mathcal{U}^\dagger(t)}{\mathsf{Tr}\{\mathcal{U}(t)\rho_S(0)\mathcal{U}^\dagger(t)\}}$$

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$$\varrho_S^c(t) = \frac{1}{|\cos(\alpha)|^2 + |\sin(\alpha)|^2} \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & |\cos\alpha|^2 & i\cos\alpha\sin\alpha^* & 0 \\ 0 & -i\cos\alpha^*\sin\alpha & |\sin\alpha|^2 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix}$$

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$$\varrho_S^c(t \to \infty) = \frac{1}{2} \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & -1 & 0 \\ 0 & -1 & 1 & 0 \\ 0 & 0 & 0 & 0 \end{pmatrix} = |\Psi^-\rangle\langle\Psi^-|, \qquad |\Psi^-\rangle = \frac{|01\rangle - |10\rangle}{\sqrt{2}}$$

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- Inverse problem (non-Hermitian Hamiltonian engineering) is resolved
- If S is a composed system, then some interesting effects like entanglement generation (entanglement stabilization) are predicted
- Hermitian Hamiltonian dynamics for $S + A \Longrightarrow$ map for S has Kraus rank $= 1$, so the conditional output states remain pure if they were pure in the beginning
- Open problem: What dynamics would be induced if the interaction between S and A is not unitary?