Universal scaling of quenched correlators in CFT

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Outline

- Introduction: define, motivate and review recent results on quantum quenches
- Response of CFT correlators to quantum quenches: 1pt and 2pt functions
- Open questions

Introduction

- Quenching a quantum system means introducing a time-dependent parameter into the Hamiltonian, e.g. external field or time-dependent coupling.

- It is generally a very challenging problem to understand dynamical behavior following QQ. In the many-body context there are a number of reasons why these scenarios are worth

  a) Quenches across quantum phase transitions, e.g. Kibble-Zurek scaling (How the correlations behave? Do they decay or remain finite at late times? At what rate?)

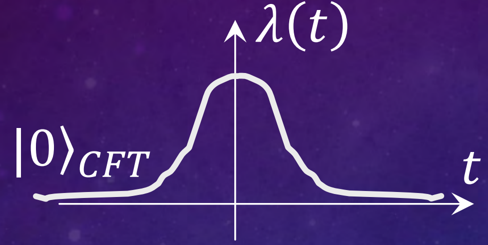
  b) Thermalization: Does the full, closed system serve as a good heat bath for itself, so that subsystems can be described by statistical ensemble?

  c) Following the evolution of nearly isolated system have become available in the lab

  d) Adiabatic quantum computation (do not know much)

Introduction

- Focus of the talk: quenches which involve critical/conformal point at the initial or both initial and final stages of the quench.



$$H = H_{CFT} + \lambda(t) \int d^{d-1}\vec{x}\, O_\Delta(t,\vec{x})$$

- Tractable regimes and tools are extremely limited in QFT (2D CFTs [Calabrese, Cardy], free QFTs or O(N) vector models in sudden quench approximation [Cardy, Sotiriadis])
- Strongly coupled regime via holography [Buchel, Lehner, Myers, van Niekerk] found

$$E \sim \frac{\lambda_0^2}{\delta t^{2\Delta - d}}\,,\ \langle O_\Delta \rangle \sim \frac{\lambda_0}{\delta t^{2\Delta - d}} \text{ for } \delta t \to 0$$

- [Das, Galante, Myers] confirmed this universal scaling for free fields with mass having time-dependent hyperbolic profile.

The upshot: there is a universal regime that sudden quench approximation missed!
smooth but fast and sudden QQ are two distinct protocoles

Quenched CFT

1. Universal scaling of correlation functions in a generic quenched CFT?
2. Late time impact of quenches?

To answer first question one has to identify the relevant hierarchy of scales

$$\delta \ll \delta t \ll L \quad where \quad \lambda \sim L^{\Delta-d}$$

$$H = H_{CFT} + \lambda(t) \int d^{d-1}\vec{x}\, O_\Delta(t,\vec{x})$$

In this regime it is tempting to employ the conformal perturbation theory + KS. However, one has to impose restriction on typical temporal intervals and distances in the correlation functions to ensure we are close to the fixed point

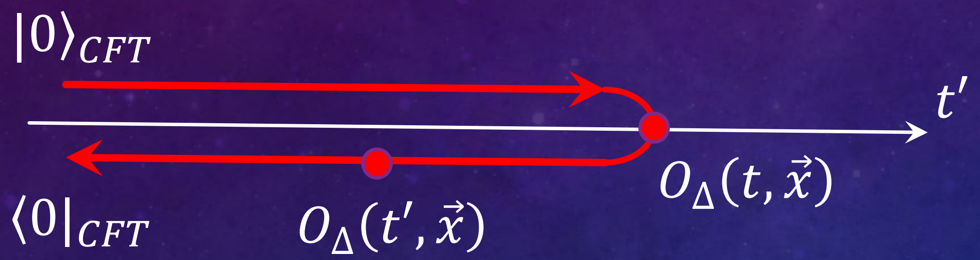
$$T, R \ll L$$

Hence `late times' are defined by: $\delta t \ll T \ll L$

Quenched CFT

The idea of calculation using 1pt function

$$\langle O_\Delta(t,\vec{x})\rangle = \langle 0|O_\Delta(t,\vec{x})|0\rangle - i\int_{-\infty}^{t} dt'\,\lambda(t')\int d^{d-1}\vec{y}\langle 0|[O_\Delta(t,\vec{x}),O_\Delta(t',\vec{y})]|0\rangle + O(\lambda^2)$$

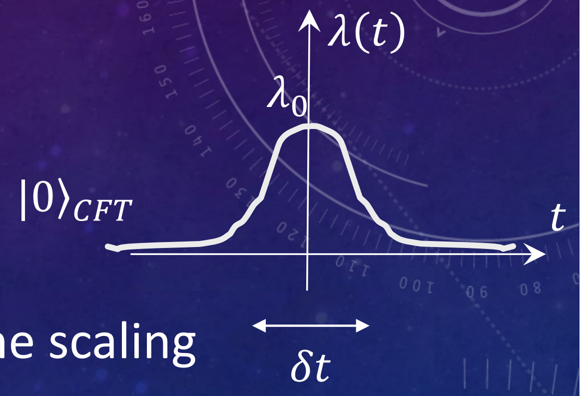


In general, Lorentzian correlators with certain ordering of operators are obtained by analytic continuation from Euclidean correlators using appropriate $i\varepsilon$ prescription, e.g., the above vev of the commutator is encoded in Euclidean 2p function, and the final answer is:

Quenched CFT

$$H = H_{CFT} + \lambda(t) \int d^{d-1}\vec{x}\, O_\Delta(t,\vec{x})$$

$$\langle O_\Delta(t,\vec{x})\rangle = \frac{-2\pi^{\frac{d+1}{2}}}{\Gamma(\Delta)\Gamma\left(\frac{d}{2}-\Delta+\frac{1}{2}\right)} \int_{-\infty}^{t} dt' \frac{\lambda(t')}{(t-t')^{2\Delta-d+1}} + O(\lambda^2)$$



- For $t \in \delta t$ we recover the universal scaling $\langle O_\Delta\rangle \sim \frac{\lambda_0}{\delta t^{2\Delta-d}}$
- For certain $\Delta = \frac{d+n}{2}, n \in even\ \mathbb{Z}_+$ there is a log enhancement to the scaling
- For late times $\langle O_\Delta\rangle$ decays, but not all 1pt decay at late times. For example,
- One can use Ward identity $\frac{d}{dt}\langle T_{00}\rangle = -\frac{d\lambda}{dt}\langle O_\Delta\rangle$ to calculate energy pumped into the system during the quench $E \sim \frac{\lambda_0^2}{\delta t^{2\Delta-d}}$
- 1st order vanishes for $\langle O_{\Delta_0}\rangle$ with $\Delta_0 \neq \Delta$, but 2nd order can be evaluated and the same conclusions hold.

Quenched CFT

Similarly, using KS, conformal perturbation theory and analytically continuing Euclidean 3pt functions, one can study $\langle O_{\Delta_1}(t_1,\vec{x}_1) O_{\Delta_2}(t_2,\vec{x}_2)\rangle$. For example,

$$\langle O_{\Delta_1}(t,\vec{x}) O_{\Delta_2}(t,0\,)\rangle \sim \frac{C}{|\vec{x}|^{2\Delta_1}}\frac{\lambda_0}{\delta t^{\Delta+\Delta_2-\Delta_1-d}} + (1 \leftrightarrow 2) \quad \text{for } |\vec{x}| \gg \delta t\,, \quad t \in \delta t\,,$$

$$\langle O_{\Delta_1}(t,0\,) O_{\Delta_2}(0,0\,)\rangle \sim \frac{C}{t^{2\Delta_1}}\frac{\lambda_0}{\delta t^{\Delta+\Delta_2-\Delta_1-d}} \quad \text{for } t \gg \delta t \text{ (late times)}$$

- These results can be understood in terms of appropriate OPE
- For certain range of conformal dimensions the limit $\delta t \to 0$ is singular thus for fast but smooth quenches the correlation is amplified at late times

Open questions

- How to explore very late times $L \ll T$?
- Universal behavior at late times? For example, it has been shown holographically that EE of a spatial region exhibits the following universal scaling after the quench [Liu, Suh]

$$\Delta S_{EE} = \begin{cases} \frac{\pi}{d-1} \mathcal{E} A_{\Sigma} t^2 , & for \quad \delta t \ll t \ll L \\ v_E \, s_{eq} A_{\Sigma} t , & for \quad L \ll t \end{cases}$$

- Is there \`overlap' between EE result and universal scaling of correlators that emerges in the limit of fast but smooth quenches?

Thank you !