Entanglement structure and UV regularization in cMERA

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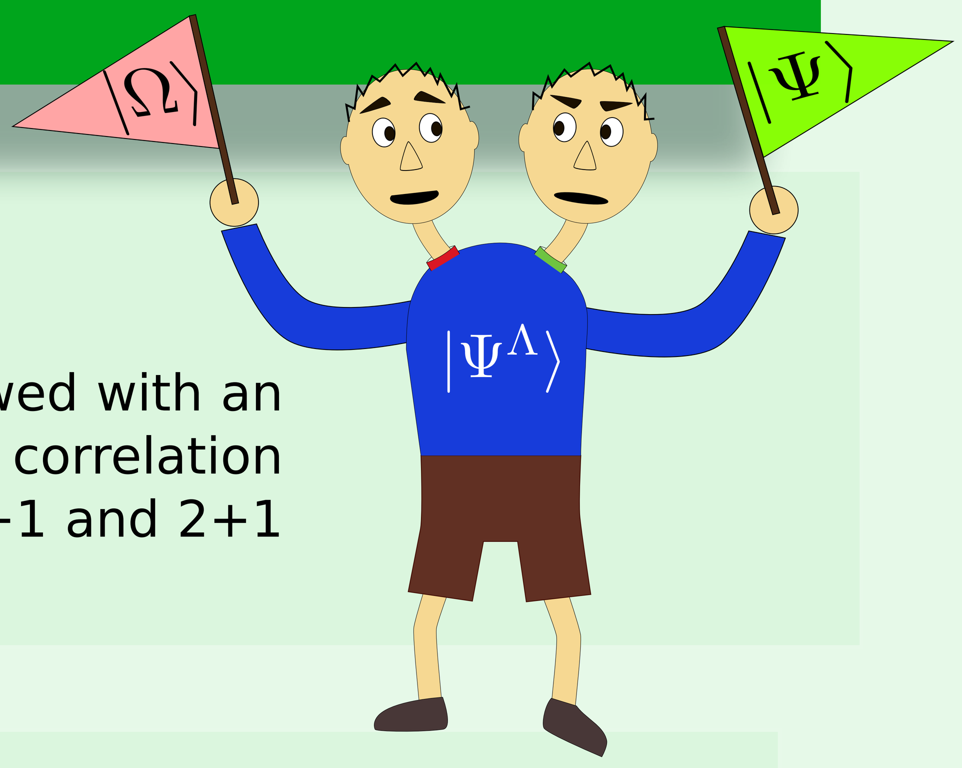
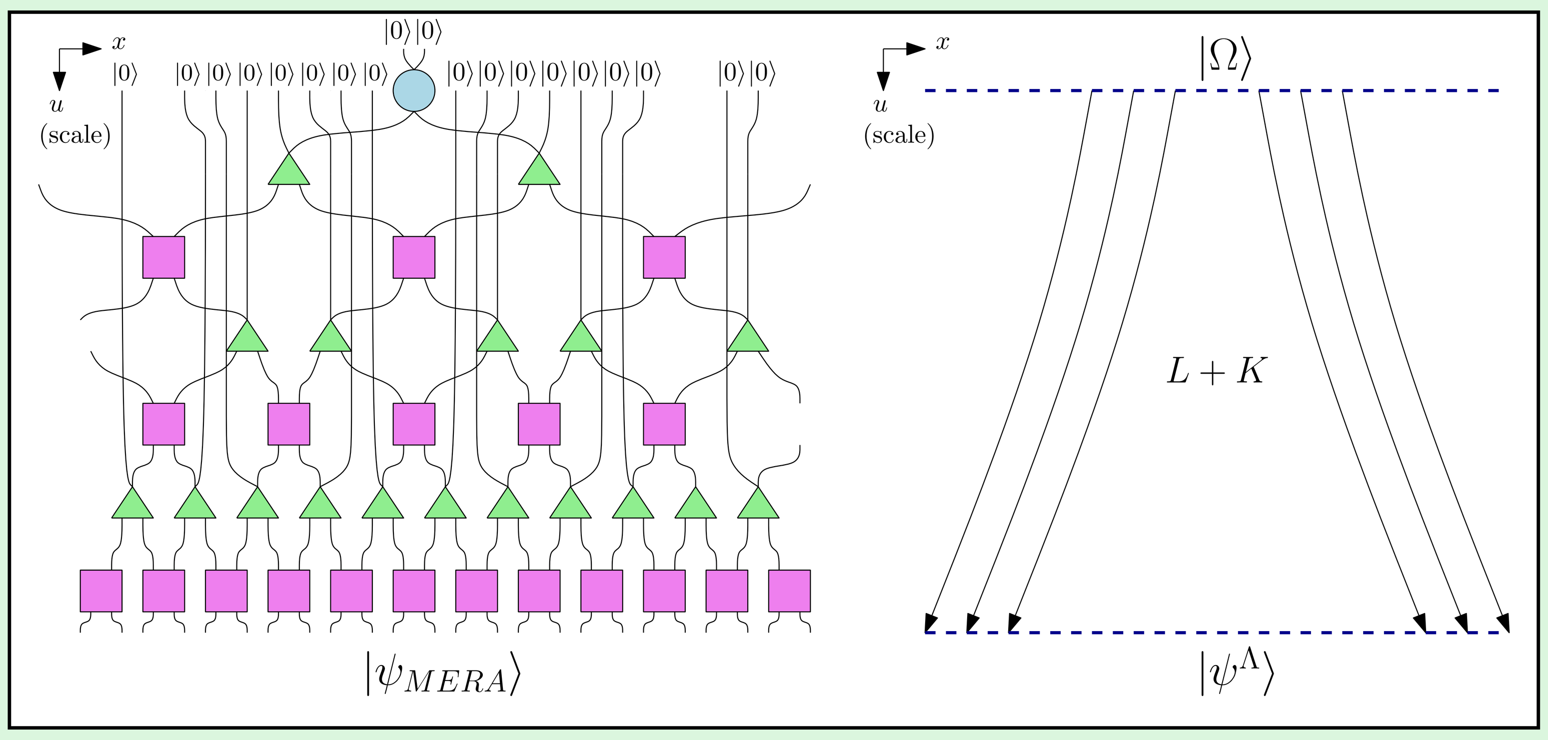


Goal

Because of the way they are built, cMERA approximations to QFT states [1] are expected to be endowed with an intrinsic UV momentum cutoff Λ. In this work we look for evidence of this cutoff by studying the correlation structure and entanglement entropy profile of a variety of cMERA states whose target theories are 1+1 and 2+1 dimensional free CFTs.

1. cMERA



cMERA states provide ansätze for QFT states built by an **entangling evolution in scale**:

$$|\Psi^\Lambda\rangle := U(0,-\infty)|\Omega\rangle \qquad U(u_1,u_2) = e^{i(u_2-u_1)(L+K)}$$

$|\Omega\rangle$ is an initial product state devoid of entanglement.

L is the generator of scale transformations.

K is the **entangler**. It has a built-in length scale $1/\Lambda$ and contains the variational parameters of the ansatz.

Optimized cMERA states have proved themselves useful at representing CFTs accurately enough to allow for the recovery of **conformal data** [2].

2. Gaussian cMERA

We work with Gaussian states which can be characterized by a set of linear constraints parameterized by a single function:

Bosons (scalar field)

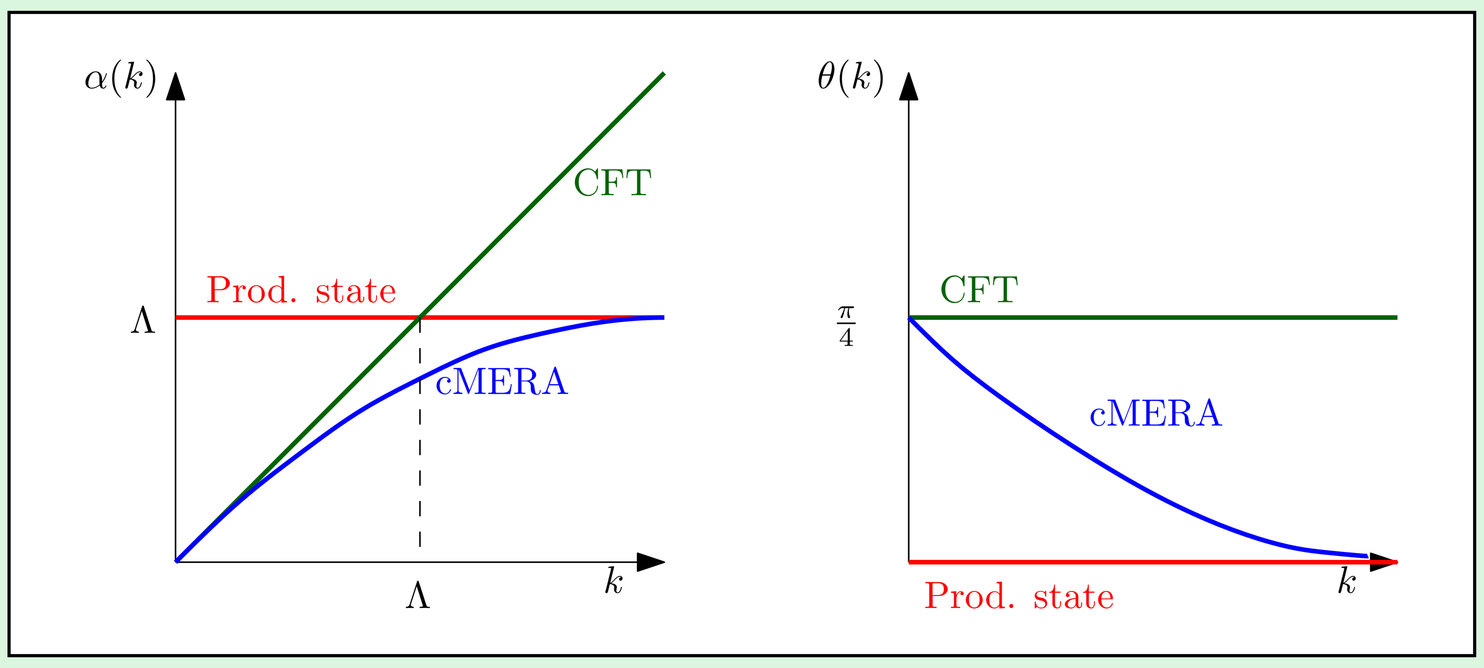
$$a(\vec{k})|\Psi\rangle = 0$$

$$a(\vec{k}) = \sqrt{\frac{\alpha(\vec{k})}{2}}\phi(\vec{k}) + i\sqrt{\frac{1}{2\alpha(\vec{k})}}\pi(\vec{k})$$

Fermions (2n component spinor)

$$\tilde{\psi}_i(\vec{k})|\Psi\rangle = 0 \qquad i = 1,\ldots,n$$
$$\tilde{\psi}_j^\dagger(\vec{k})|\Psi\rangle = 0 \qquad j = n+1,\ldots,2n$$

$$\tilde{\psi}(\vec{k}) = e^{\theta(\vec{k})\vec{\gamma}\cdot\hat{k}}\psi(\vec{k})$$

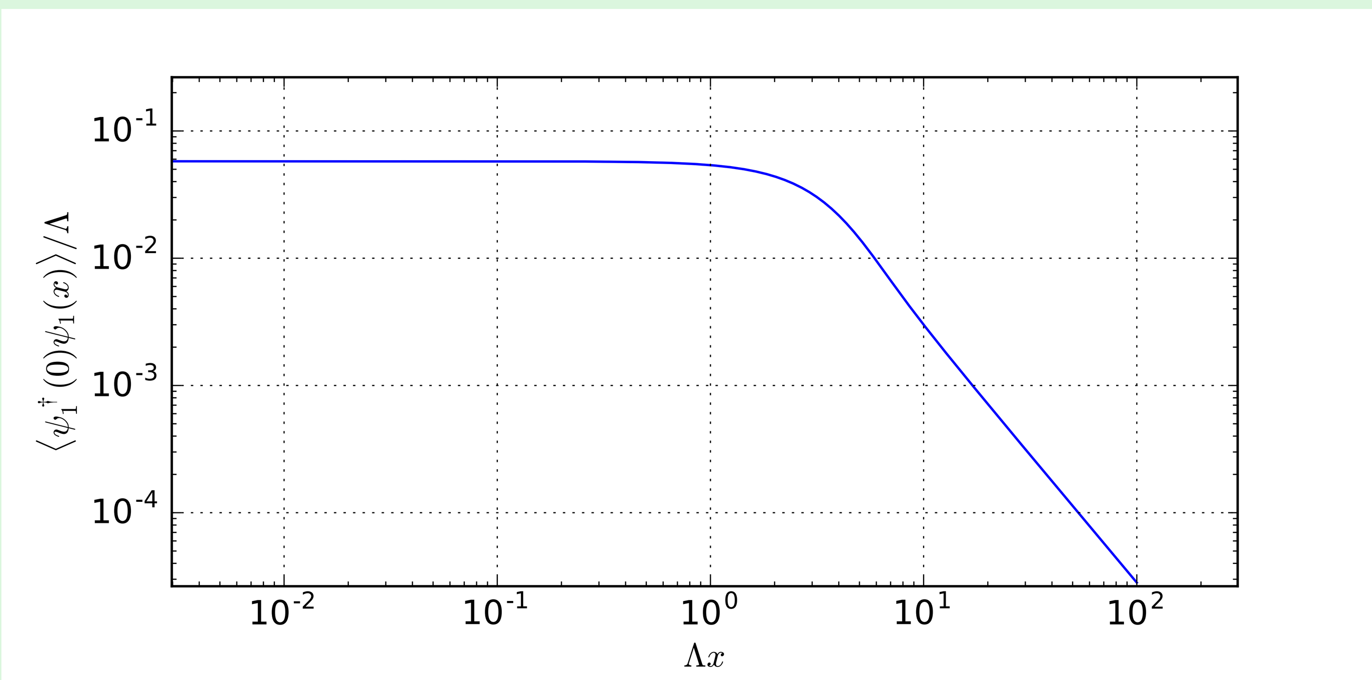


cMERA states are defined by constraints that **interpolate** between those of the target state $|\Psi\rangle$ (at smaller momenta / longer distances) and those of the initial product state $|\Omega\rangle$ (at larger momenta / shorter distances)!

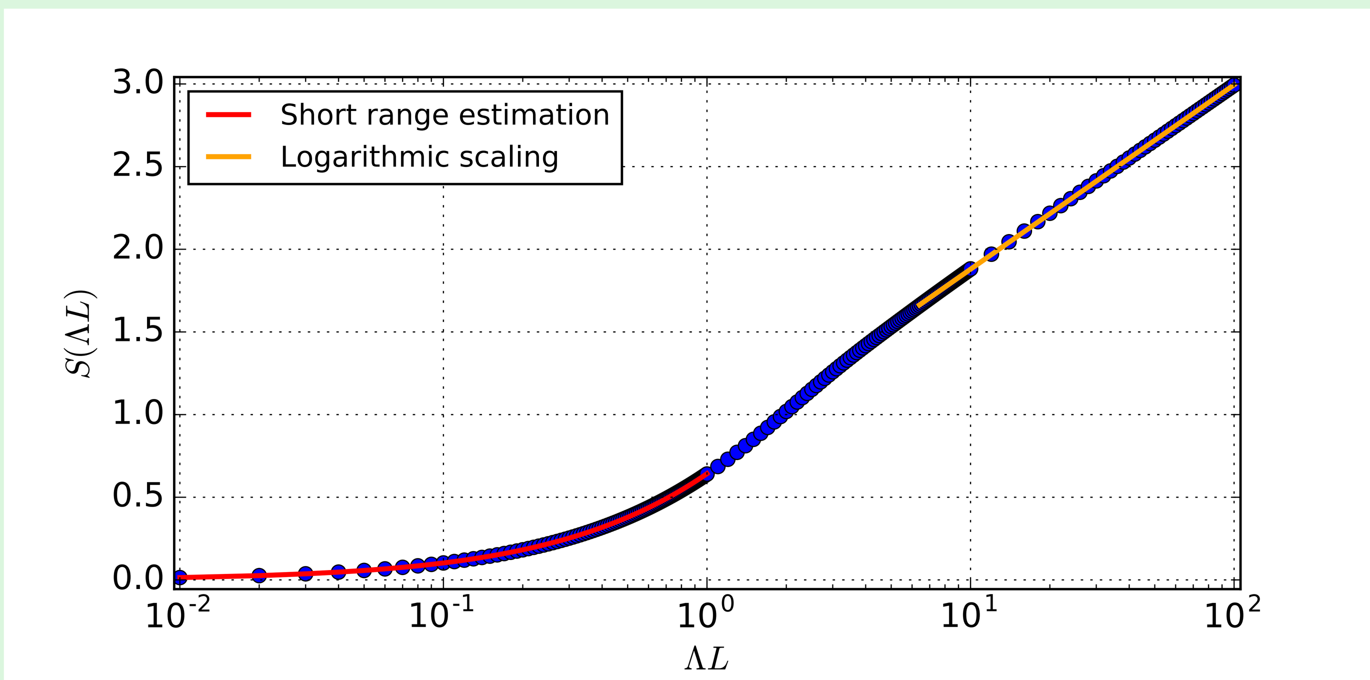
3. Results

In all studied theories, the structure of correlations displays two clearly differentiated regimes separated by the cutoff length scale $1/\Lambda$ [3]. Only at long length scales the CFT behaviour is recovered. We also observe that the entanglement entropy of spatial regions has a finite value, which is a strong hint at UV regularization. We present here as an example two plots from the 1+1 free Dirac fermion cMERA.

$\langle\psi_1^\dagger(0)\psi_1(x)\rangle$ two-point function



Entanglement entropy vs. length of the interval



At short distances, the correlator deviates from the CFT behaviour and goes to a constant. An onsite delta function is not represented on this plot.

At long distances, the correlator decays with a power law consistent with the scaling dimension obtained from the CFT.

For short intervals, the entropy scales differently than in the CFT, and grows like

$$S(L) \sim L - L\log L$$

For long intervals, we recover the CFT expression with the right central charge

$$S(L) \sim \frac{c}{3}\log L$$

References

[1] J. Haegeman, T.J. Osborne, H. Verschelde and F. Verstraete, *Entanglement renormalization for quantum fields*, Phys. Rev. Lett., 110, 100402 (2013)

[2] Q. Hu, G. Vidal, *Spacetime symmetries and conformal data in the continuous multi-scale renormalization ansatz*, arXiv: 1703.04798

[3] A. Franco-Rubio, G. Vidal, *Entanglement and correlations in the continuous multi-scale entanglement renormalization ansatz*, in preparation

Acknowledgements

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