Probing quantum dynamics using correlators

Many-body dynamics tutorial

Journal club

3 February 2026

Maarten Stroeks

Article

Observation of constructive interference at the edge of quantum ergodicity

https://doi.org/10.1038/s41586-025-09526-6

Received: 3 November 2024

Accepted: 13 August 2025

Published online: 22 October 2025

Open access

Check for updates

Google Quantum AI and Collaborators*

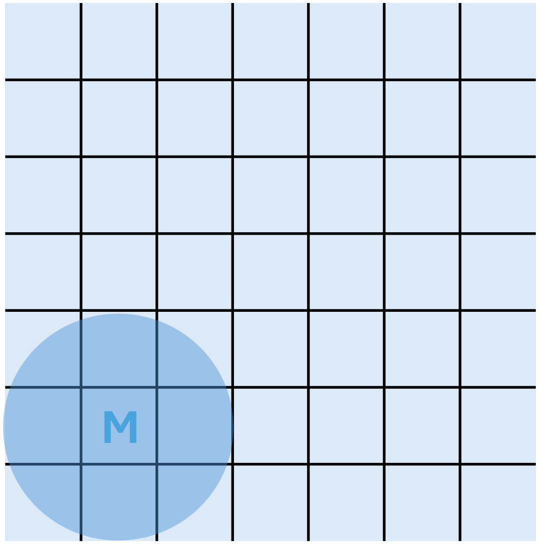
The dynamics of quantum many-body systems is characterized by quantum observables that are reconstructed from correlation functions at separate points in space and time[1–3]. In dynamics with fast entanglement generation, however, quantum observables generally become insensitive to the details of the underlying dynamics at long times due to the effects of scrambling. To circumvent this limitation and enable access to relevant dynamics in experimental systems, repeated time-reversal protocols have been successfully implemented[4]. Here we experimentally measure the second-order out-of-time-order correlators (OTOC$^{(2)}$)[5–18] on a superconducting quantum processor and find that they remain sensitive to the underlying dynamics at long timescales. Furthermore, OTOC$^{(2)}$ manifests quantum correlations in a highly entangled quantum many-body system that are inaccessible without time-reversal techniques. This is demonstrated through an experimental protocol that randomizes the phases of Pauli strings in the Heisenberg picture by inserting Pauli operators during quantum evolution. The measured values of OTOC$^{(2)}$ are substantially changed by the protocol, thereby revealing constructive interference between Pauli strings that form large loops in the configuration space. The observed interference mechanism also endows OTOC$^{(2)}$ with high degrees of classical simulation complexity. These results, combined with the capability of OTOC$^{(2)}$ in unravelling useful details of quantum dynamics, as shown through an example of Hamiltonian learning, indicate a viable path to practical quantum advantage.

What correlators are practically relevant and "too hard" to measure classically?

TOC

(time-ordered correlator)

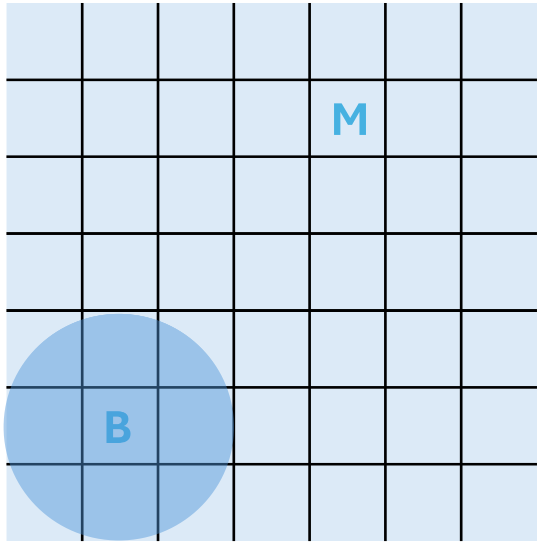
$$C^{(1)}(t) = \langle\psi|\, U(t)^{\dagger}\, M\, U(t)\, M\, |\psi\rangle$$



OTOC

(out-of-time-order correlator)

$$C^{(2k)}(t) = \langle\psi|\, [\, U(t)^{\dagger}\, B\, U(t)\, M\,]^{2\boldsymbol{k}}\, |\psi\rangle$$



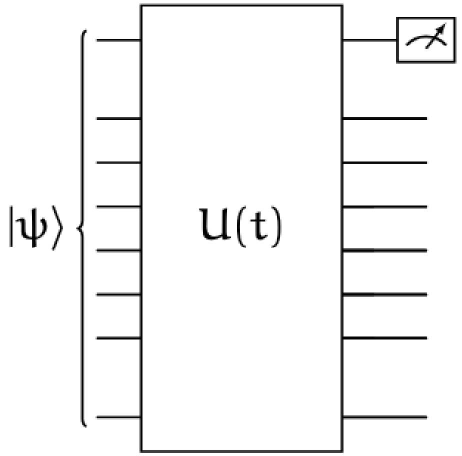
B and M are single-qubit Pauli's.

Measuring TOCs and OTOCs

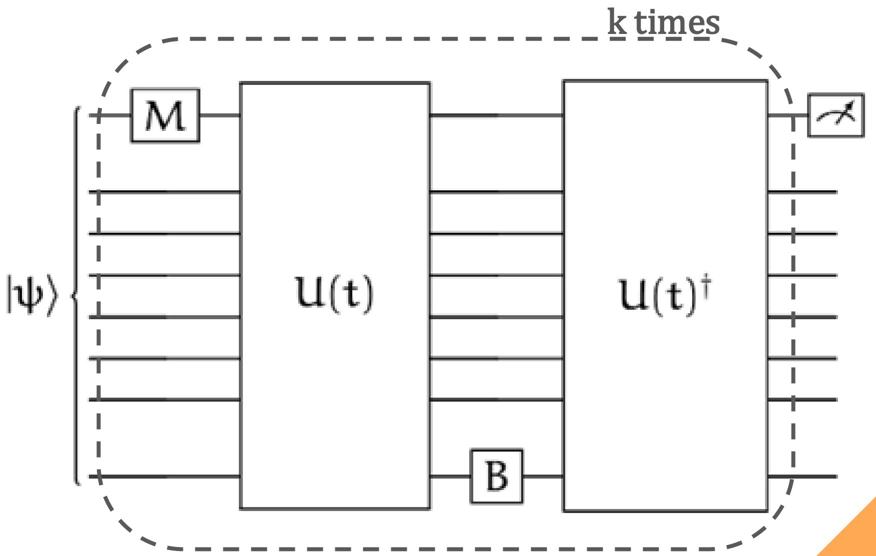
Trick: take $|\psi\rangle$ to be an eigenstate of M.

Then, estimate **Hermitian** observable.

$$C^{(1)}(t) = \langle\psi|\, U(t)^\dagger\, M\, U(t)\, M\, |\psi\rangle$$



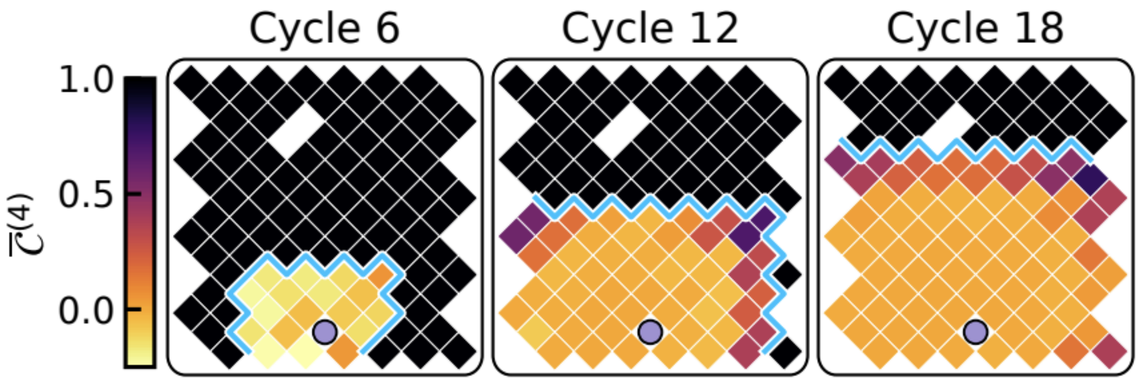
$$C^{(2k)}(t) = \langle\psi|\, [\, U(t)^\dagger\, B\, U(t)\, M\,]^{2k}\, |\psi\rangle$$



OTOC measurements

$$C^{(2k)}(t) = \langle\psi|\,[\,U(t)^{\dagger}\,B\,U(t)\,M\,]^{2k}\,|\psi\rangle$$

$C^{(2k)}(t)$ is 1 for small times and then decays for larger times.



So, we can measure TOCs and OTOCs, but when are they interesting?

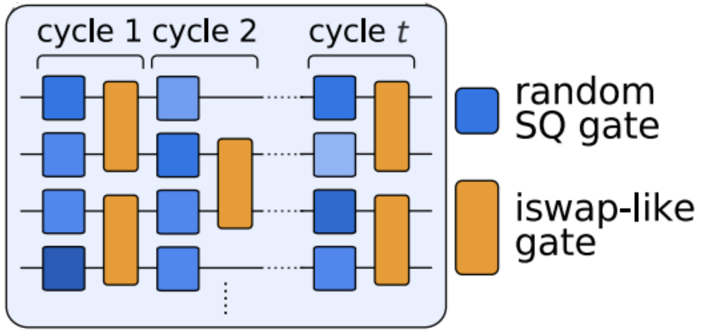
Let's focus only on TOC, OTOC $^{(1)}$ and OTOC $^{(2)}$.

	TOC	OTOC $^{(1)}$	OTOC $^{(2)}$
Measurable	✓	✓	✓
Verifiable		✓	✓
Classically hard			✓

Importantly, we want to compute quantities that are not just verifiable and classically hard, but also *practically relevant.*

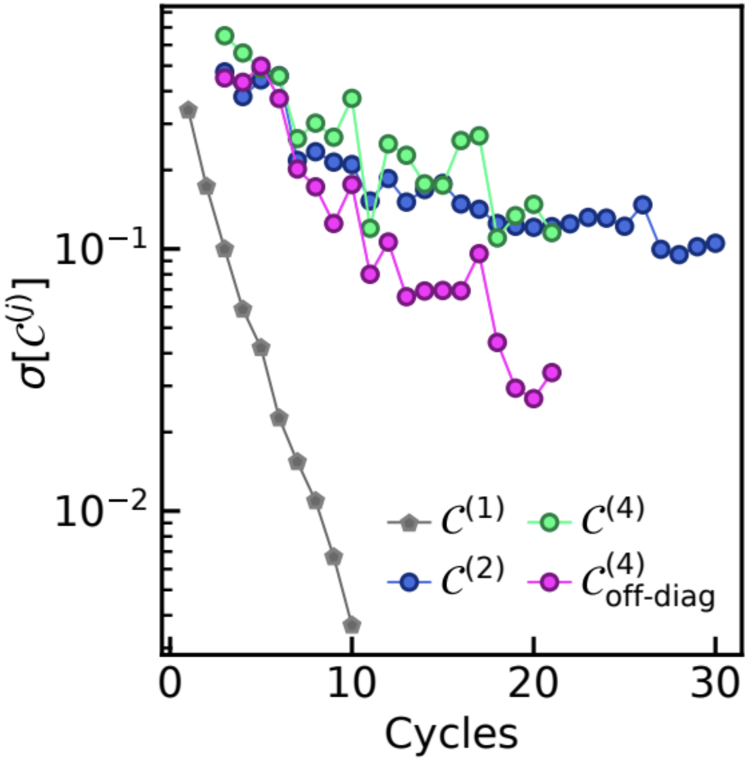
OTOCs are sensitive to details of dynamics

Take $U(t)$ to be a product of fixed 2-qubit gates and randomly chosen 1-qubit gates.



Can we observe these random choices in our correlators?

Yes!



So, OTOCs are practically relevant, but what about computing them classically?

Towards a quantum advantage

↓

Measuring large interference loops

Infinite temperature, for simplicity.

$$C^{(2k)}(t) = \mathrm{Tr}\left(\left[\,U(t)^\dagger\, B\, U(t)\, M\,\right]^{2k}\right)/2^N$$

$$U(t)^\dagger\, B\, U(t) = \sum_{n=1}^{4^N} b_n(t) P_n$$

$$M P_n M = \pm P_n$$

$$C^{(2k)}(t) = \sum_{\alpha_1,\ldots,\alpha_{2k}} c_{\alpha_1,\ldots,\alpha_{2k}} \mathrm{Tr}\left(P_{\alpha_1} P_{\alpha_2} \ldots P_{\alpha_{2k}}\right)$$

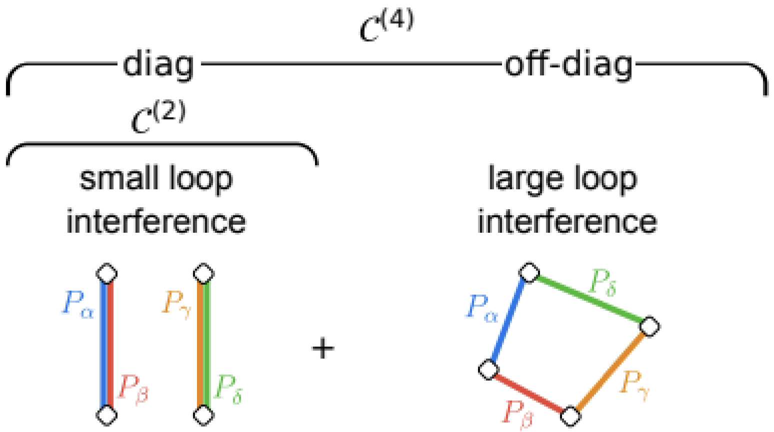
Measuring large interference loops

↓

Isolating *off-diagonal* contributions

Only non-zero for $P_{\alpha_1}P_{\alpha_2}P_{\alpha_3}P_{\alpha_4} = \pm I$.

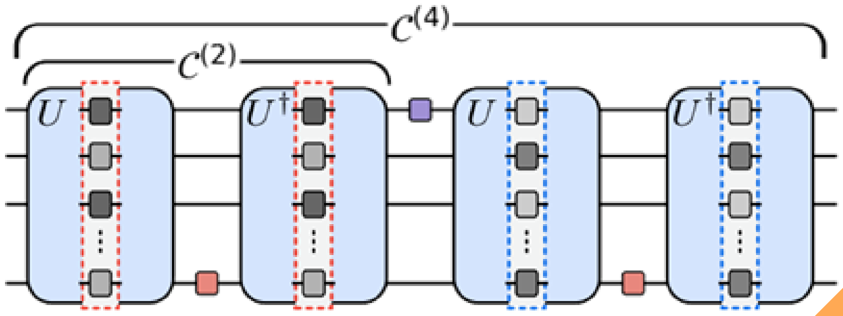
$$C^{(4)}(t) = \sum_{\alpha_1,\dots,\alpha_4} c_{\alpha_1,\dots,\alpha_4} \mathrm{Tr}\left(P_{\alpha_1}P_{\alpha_2}P_{\alpha_3}P_{\alpha_4}\right).$$



Not there for $C^{(4)}(t)$.

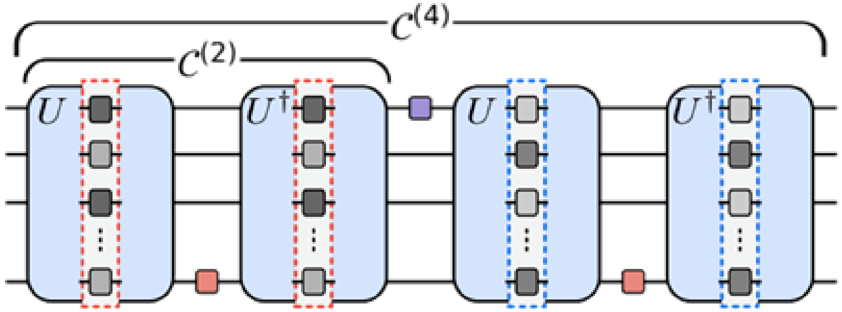
$C^{(4)}(t)_{\text{off-diag}}$ equals

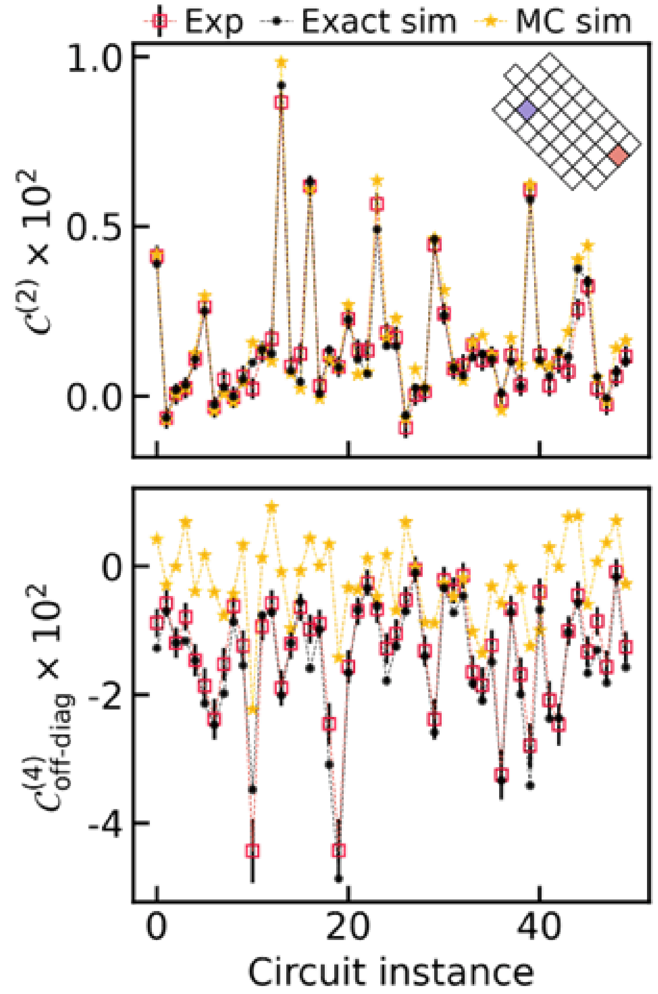
$$C^{(4)}(t) - \mathbb{E}_{\text{random Pauli's}}\left(C^{(4)}(t)\right).$$



Meausuring large interference loops

$C^{(4)}(t)_{\text{off-diag}}$ equals
$C^{(4)}(t) - \mathbb{E}_{\text{random Pauli's}}\left(C^{(4)}(t)\right)$.





Some discussion points:

1. Do you need a **large** quantum computer to measure relevant OTOCs?

2. Can the sensitivity of OTOC $^{(2)}$ be observerd for **any** type of many-body dynamics?

3. Can the **in**sensitivity of TOCs be observerd for general many-body dynamics?

Probing quantum dynamics using correlators

Many-body dynamics tutorial

Journal club

3 February 2026

Maarten Stroeks