The Ghost in the Radiation: Robust Encodings of the Black Hole Interior (Invited Paper)

Isaac H. Kim
University of Sydney
Australia
isaac.kim@sydney.edu.au

Eugene Tang
California Institute of Technology
USA
eugene.tang@caltech.edu

John Preskill
California Institute of Technology
USA
preskill@caltech.edu

ABSTRACT

We reconsider the black hole firewall puzzle, emphasizing that quantum error-correction, computational complexity, and pseudorandomness are crucial concepts for understanding the black hole interior. We assume that the Hawking radiation emitted by an old black hole is pseudorandom, meaning that it cannot be distinguished from a perfectly thermal state by any efficient quantum computation acting on the radiation alone. We then infer the existence of a subspace of the radiation system which we interpret as an encoding of the black hole interior. This encoded interior is entangled with the late outgoing Hawking quanta emitted by the old black hole, and is inaccessible to computationally bounded observers who are outside the black hole. Specifically, efficient operations acting on the radiation, those with quantum computational complexity polynomial in the entropy of the remaining black hole, commute with a complete set of logical operators acting on the encoded interior, up to corrections which are exponentially small in the entropy. Thus, under our pseudorandomness assumption, the black hole interior is well protected from exterior observers as long as the remaining black hole is macroscopic. On the other hand, if the radiation is not pseudorandom, an exterior observer may be able to create a firewall by applying a polynomial-time quantum computation to the radiation.

CCS CONCEPTS

• **Theory of computation** → **Quantum complexity theory**; **Pseudorandomness and derandomization**; **Error-correcting codes**.

KEYWORDS

Quantum Gravity; Black Hole Information; Quantum Error-Correcting Code; Quantum Computational Complexity

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BIOGRAPHY OF THE SPEAKER JOHN PRESKILL

John Preskill is the Richard P. Feynman Professor of Theoretical Physics at the California Institute of Technology, and Director of the Institute for Quantum Information and Matter at Caltech. Preskill received his Ph.D. in physics in 1980 from Harvard, and joined the Caltech faculty in 1983. Preskill began his career in particle physics and cosmology, but now his main research area is quantum information science. He's interested in how to build and use quantum computers, and in how our deepening understanding of quantum information can illuminate issues in fundamental physics. You can follow him on Twitter @preskill.

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