Quantum Singularities in Holographic Models

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Albert Einstein's Theory of Relativity predicts existence of black holes: extremely massive objects surrounded by incredibly strong gravitational field. Their gravity is so strong that everything, including light, gets captured and inevitably heads towards certain doom at singularity: a point where gravitational field becomes infinitely strong. While for decades black holes were merely mathematical concepts, recent advancements in astronomy combined with observations of gravitational waves lead to the only possible conclusion: black holes are real. And this fact makes a serious problem, known as the "information paradox", even more serious. In nineteen-seventies Stephen Hawking shocked the scientific world by predicting that black holes are not black, as they radiate their mass and energy away. After some finite time a lonesome black hole should completely disappear, leaving nothing but thermal radiation propagating through space and time. A problem here is that any objects thrown into a black hole re-emerge as thermal radiation carrying no information whatsoever. This violates a sacred rule of quantum mechanics called "unitarity": a quantum version of classical determinism.

Throughout the years thousands of papers have been written about the information paradox, brining us closer not only to its resolution, but also uncovering fascinating facts about the nature of gravity, quantum mechanics and our universe. Nevertheless, despite the effort, the ultimate goal has not been reached. This proposal aims at approaching the paradox from a new perspective. Recent developments in the field suggest that there exist some elusive interactions between the interior and the exterior of a black hole. What I want to propose is that the relation between the two sides of a black hole resembles the relation between two sides of a mirror. But unlike a familiar mirror, a black hole looks like an extremely bumpy mirror that scrambles and distorts the reflection beyond recognition. To resolve the paradox means to figure out how to unscramble the image and what kind of a mirror would produce it.

I believe that the answer rests in a combination of cosmology and holography. Holographic duality is an extremely powerful tool discovered in 1997 by Juan Maldacena. Just like famous wave-particle duality states that one object, say an electron, can be described as a wave or a particle, holographic duality tells us that a black hole can be described in an alternative language that does not even include gravity. This makes many questions about black holes much simpler to deal with. When it comes to cosmology, what I mean here is the fact that the interior of a black hole resembles an evolving universe. It is not our universe, though (fortunately!). Our universe is an expanding cosmology: it expands in all directions, while the interior of a black hole represents a crunching cosmology: it expands in some directions but contracts in others. Nevertheless, there also exist holographic methods for cosmologies and they can be applied to crunching cosmologies. This is the essence of the proposed approach to the old problem: one can use holography for both sides of the "mirror". In this way we should be able to learn what kind of a mirror we are dealing with here. Or, what is the fundamental structure of black holes and what is the mechanism responsible for the information paradox.