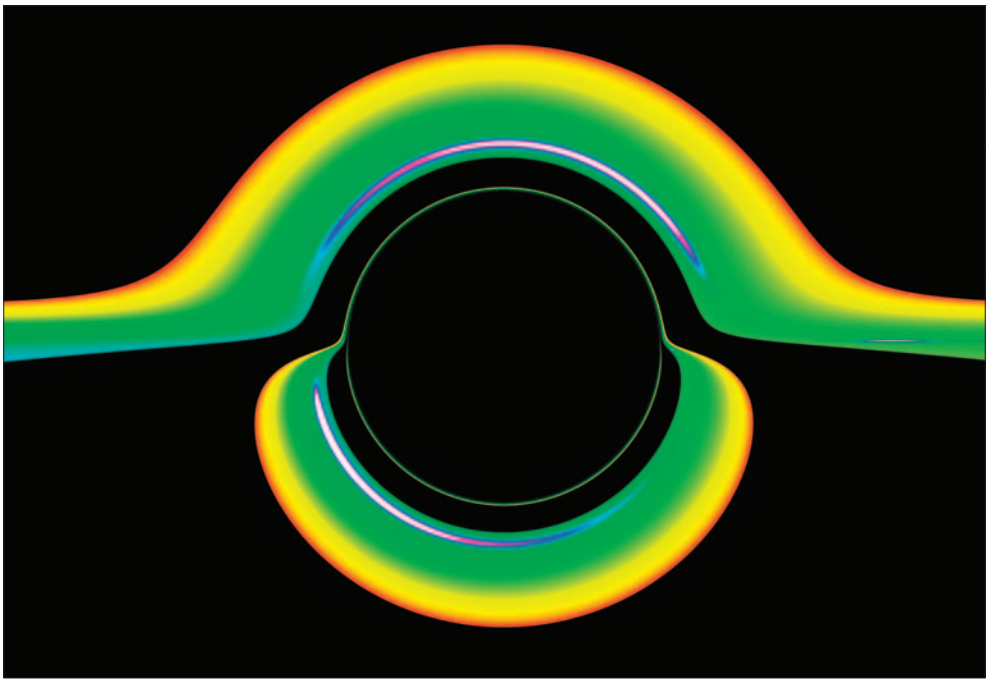
John Preskill

Wars of the holographic world



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Battle of wits
Information loss in black holes has been a source of controversy.

The Black Hole War: My Battle with Stephen Hawking to Make the World Safe for Quantum Mechanics
Leonard Susskind
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In the popular imagination, the iconic American theoretical physicist is Richard Feynman, in all his safe-cracking, bongo-thumping, woman-chasing glory. I suspect that many physicists, if asked to name a living colleague who best captures the spirit of Feynman, would give the same answer as me: Leonard Susskind. As far as I know, Susskind does not crack safes, thump bongos, or chase women, yet he shares Feynman's brash cockiness (which in Susskind's case is leavened by occasional redeeming flashes of self-deprecation) and Feynman's gift for spinning fascinating anecdotes. If you are having a group of physicists over for dinner and want to be sure to have a good time, invite Susskind.

Like Feynman, Susskind is a born teacher who longs to connect with his audience and often succeeds. Best of all, Susskind channels Feynman's uncanny intuition, and can penetrate to the heart of a deep scientific puzzle. These estimable qualities are on display in Susskind's impressive new book, *The Black Hole War*.

I should make some disclaimers. I have known and admired Susskind for 30 years, and his publications and our many discussions have strongly influenced my scientific development. To give but one example, his elegant 1979 paper on "technicolor", which proposed a new model of how symmetries of elementary particles are broken, persuaded me to abandon the fruitful work I was doing on phase transitions in the very early universe to focus full-bore on technicolor, which became the topic of my PhD dissertation.

Yet by the summer of 1980, Lenny, his T-shirt still soaked from a just-completed jog, stood in my office at Harvard loudly insisting that his earlier ideas about technicolor were deeply flawed and should be rejected. I resisted for many months before concluding that Susskind was probably right about having been wrong. It was an unforgettable lesson in scientific integrity.

During the 1990s I had some memorable discussions with Susskind about the quantum physics of black holes. So I was more than a little curious to see how well his version of the evolution of the subject in *The Black Hole War* would match my own recollections, especially given that three of the central events in his narrative are conferences we both attended: at Aspen in 1992, Santa Barbara in 1993 and Cambridge in 1994.

I was gratified to be described as a "wiry man" in Susskind's account of a lunch-table conversation at the Santa Barbara conference, which may have been a better description of my physique in 1993 than it is today. Generally, my impression is that Susskind's colourful stories about his interactions with colleagues are honestly reported, take only excusable dramatic licence and only rarely veer toward self-aggrandizement.

Physicists love paradoxes, because a deeply vexing paradox can expose in stark relief where our understanding of the laws of physics is deficient, and point the way towards pathbreaking new insights. No paradox has stirred more passionate debate among physicists in recent decades than the "black-hole information-loss paradox" – the theme of *The Black Hole War*. Classical gravitation theory states that nothing can escape from a black hole; however, Stephen Hawking discovered in the mid-1970s that black holes actually emit radiation due to quantum effects. This emission is very weak for a large black hole, but it gets stronger and stronger as an evaporating black hole gets smaller and smaller, until, if we wait long enough, the black hole eventually explodes and disappears.

But Hawking also argued that the emitted radiation is featureless, devoid of any information about what the black hole swallowed to attain its initial mass. Thus, Hawking asserted, the formation and subsequent complete evaporation of a black hole is a truly *irreversible* process, in which some information about the past state of the universe is permanently erased.

While physicists are accustomed to the idea that information can become inaccessible in practice, the claim that information can be irretrievably lost in principle was highly inflammatory. What seemed paradoxical was that, by following the accepted laws of physics to an apparently unassailable conclusion, Hawking had overturned a tenet at the heart of quantum mechanics. This precipitated a crisis, and although awareness of the crisis spread only gradually, by 1990 there was widespread appreciation among physicists that information loss in black-hole evaporation is a deep and important problem.

After an engaging introductory explanation of some of the relevant features of black holes and quantum physics, *The Black Hole War* recounts Susskind's own 20-year struggle to pinpoint flaws in Hawking's reasoning and, as he puts it, "make the world

safe for quantum mechanics". He spices his account with tongue-in-cheek military metaphors (not just the book's title, but also chapter headings such as "The Dutch resistance," "Skirmish at Aspen," and "The battle of Santa Barbara"), which, though a bit forced, are just about witty enough to be forgiven. I trust that most readers will recognize that disagreements among theoretical physicists are not really so hostile as perhaps the bellicose language implies.

The pivotal event in the saga occurred in 1994, when Susskind, elucidating ideas originated by Dutch physicist Gerard 't Hooft, formulated the "holographic principle". This outlandishly unintuitive idea suggests that our 3D world is illusory, in that all of the information residing deep inside a 3D volume can actually be encoded on its 2D surface. An important implication is that when information seems to tumble into a black hole, it actually remains accessible outside the black hole's surface.

Susskind goes on to explain the subsequent developments in string theory that allowed this outrageous proposal to gain wide acceptance.

Is the black-hole war really finished? Perhaps not

This is the most ambitious part of the book: five chapters that build toward an explanation of how string theorists learned to count the microscopic quantum states of black holes, and to construct explicit models of quantum gravity that exhibit the holographic duality between 3D and 2D descriptions of the same phenomenon.

When it applies, this duality has great power, because it connects the evaporating black hole with a complementary physical system in which conservation of information is manifest. Finally, in 2004, Hawking concluded that information is really conserved after all, and Susskind's defence of quantum mechanics was vindicated.

Is the black-hole war really finished? Perhaps not. First, the case for string theory as a description of nature is far from airtight. Second, even if string theory is correct, so far the holographic principle can be justified only in mathematical models that are far from realistic. Third, even with holographic models one hungers for deeper insight into the meaning of holography, and a better grasp of where Hawking's argument failed. The battle to achieve a wholly satisfying reconciliation of quantum theory with gravitation is still very much a work in progress.

The Black Hole War succeeds on two levels: as an engaging memoir by a skilled story teller; and as a compelling introduction to some elusive but captivating scientific ideas. Though some other stars in the theoretical physics firmament make enjoyable cameo appearances (Feynman, Hawking and 't Hooft among others), this is really a story with two protagonists: Susskind and the black hole. Fortunately, both characters are engrossing enough to keep the pages turning late into the night.

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