

Not So local

A principle of physics is that what happens here, stays here: “local” events do not influence events far away. Steven Giddings is not so sure.



by TOM SIEGFRIED

FQXi Awardee: Steven Giddings, University of California, Santa Barbara

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Physics and politics have a lot in common. Both are complicated. Both deal with laws. And just as all politics are local, as the old saying goes, physics is supposed to be all local, too. In fact, this notion of “locality” has occupied a prominent place in the foundations of physics ever since Einstein developed his theory of relativity more than a century ago.

Abandoning locality looks kind of bad. But the other things that happen with the other alternatives look even worse.

- Steven Giddings

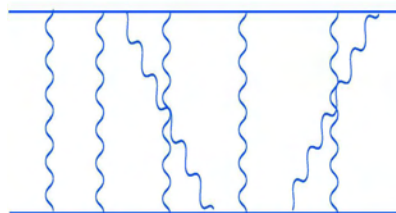
“The basic idea is that events that take place here and now are independent of events that take place far away,” says physicist and FQXi Awardee Steven Giddings of the University of California, Santa Barbara. Events here on Earth, for instance, should proceed without concern for anything happening in, say, the Andromeda galaxy. And nothing happening here bothers any Andromedans.

“There’s no way that an event here can influence an event in the other galaxy until light has had time to travel from here to there,” says Giddings. “That’s the basic idea of locality. It really has been one of the cornerstones of basic physics throughout the 20th century.”

It’s that very cornerstone that Giddings would like to extract and examine to see whether it really does belong in physics’ foundation. Rather than supporting the edifice of physical theory, locality may be an impediment to completing the ultimate theoretical structure.

Mountains, Black Holes, And Other Big Things Under Small Scrutiny

While he occasionally spends his time challenging gravity by scaling mountains – he has climbed peaks and cliffs in Europe, New Zealand, and across most of the western United States – Giddings mostly ponders gravity from the other side, especially how it operates at tiny distances, smaller than the width of an atom. In that microworld, gravity meets quantum mechanics, the math that rules the behavior of atoms and their building blocks. It is not a happy encounter, though. For decades, physicists have tried to merge the math of quantum physics with Einstein’s theory of gravity. But the math refuses to mesh, suggesting to some that Einstein’s gravity and quantum mechanics can’t both be completely correct.



GRAVITON EXCHANGE A Feynman diagram representing gravitational interactions of two very high energy particles; a collision at sufficiently close range is expected to form a black hole, and possibly exhibit nonlocal behavior.

Giddings is especially intrigued by one acute paradox involving the cosmic vacuum cleaners known as black holes, whose voracious gravity swallows up any matter that passes inside their gravitational horizons.



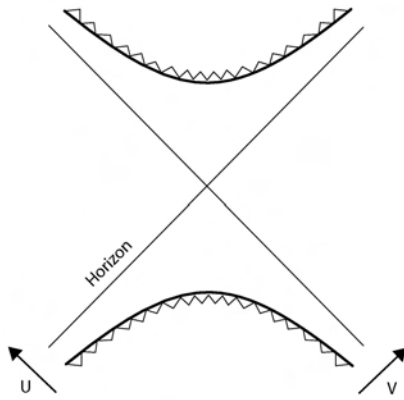
LOOKING AT NONLOCALITY
Steven Giddings

Originally, physicists believed anything swallowed by a black hole was trapped forever — even light would remain imprisoned by the hole’s overwhelming gravity. But in the 1970s, the British physicist Stephen Hawking showed that black holes must evaporate, spitting out the swallowed matter — but only after the matter has been crushed and digested into random radiation. Eventually (although in this case “eventually” can mean billions of years) the black hole goes poof, disappearing completely.

Therein lies the conflict. Quantum math requires the preservation of all the information about the structure of the original matter eaten by the black hole. But the black hole regurgitates randomness and then disappears, apparently shredding the original information. Something is amiss, perhaps requiring a revision in the basic laws of physics. Giddings suspects that the problem lies in the assumption of locality.

“A number of people have come to the conclusion that there is likely some-

thing wrong with locality,” he says. “There have been several indications that we should question it.”



KRUSKAL DIAGRAM A Space-time picture of a black hole geometry; zig-zag lines represent the singularity. An outstanding puzzle is how quantum effects modify this picture.

Gravity, Locality, Strings, Oh My!

One of those indications is the nature of gravity itself, viewed in Einstein’s theory as a warping of space and time. On small scales, where gravity meets quantum physics, space and time fluctuate, making the notion of distance fuzzy and thereby confusing the very meaning of locality.

A further hint involves the well-known conundrum of the observer’s role in quantum physics. In a quantum experiment, the outcome can depend on what an experimenter chooses to observe. But observers, Giddings point out, are also governed by quantum physics. In fact, a full quantum description of the observation process might require locality to be just an approximate notion, because it is impossible to precisely localize the observers themselves.

Another indication comes from studies of string theory, a popular attempt to reconcile gravity and quantum mechanics. String theory seems able to meld the

two theories into a mathematical marriage, tied together by the notion that nature’s basic particles are like tiny bits of string. Strings vibrating in different modes correspond to various subatomic particles, much as different vibrations of violin strings correspond to distinct musical notes.

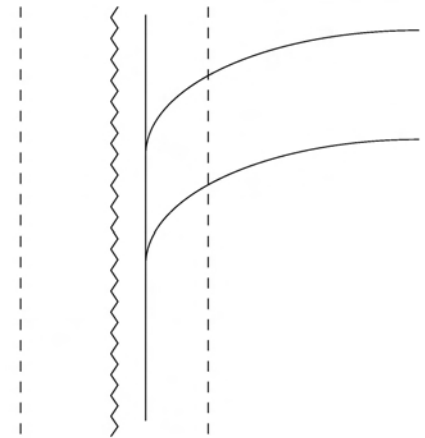
String theory also implies that non-local ideas may be needed to reach the ultimate understanding of gravity. Physicists believe that the surface area of a black hole is proportional to the amount of information it has swallowed. And string theory math links the physics within a volume of space — a non-local relationship called “holography.” If holography holds for black holes, it could be a key part of the solution of the black hole information problem.

If physicists could resolve the black hole information paradox by rejecting locality that could lead to a novel approach to all of physics, recasting its overall picture in much the way that quantum mechanics redrew the canvas of classical physics.

In fact, the information paradox strikes Giddings as similar to a critical problem afflicting physics a century ago. Experiments showed that atoms consisted mostly of empty space, with a dense nucleus in the core surrounded by electrons at a distance. Classical physics demanded that the electrons fall quickly into the nucleus, crushing the atom out of existence. Quantum mechanics rescued atoms from that fate, but only at the expense of doing away with cherished ideas about how particles move through space.

Doing away with locality could, in a similar way, change the way physicists think about space and time. Locality will remain a good approximation for describing most things in physics, but relaxing its grip at a fundamental level could profoundly alter the picture that physicists have drawn of space and time in

the inner world of the atom, perhaps solving some longstanding mysteries and offering a deeper glimpse into reality’s ultimate nature.



SPATIAL SLICES A representation of constant time slices in a black hole geometry, relevant for discussion of Hawking’s arguments for information loss in black hole evaporation.

“Unifying gravity and quantum mechanics presents theoretical physics with deep conceptual challenges,” says physicist James Hartle, Giddings’ colleague at UC-Santa Barbara. “The FQXi program led by Steve Giddings is an ambitious effort to directly confront the conceptual challenges relating to the likely non-locality of quantum gravity.” Giddings’ work, Hartle says, “could be an important guide to the shape of the final theory.”

Removing locality from the foundations of physics would no doubt require dramatic rethinking about how the world works. But the problems facing physics today run so deep that nothing less than an earthshaking change, of one sort or another, will be able to solve them.

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