A Stitch in Quantum Time

Rodolfo Gambini and Jorge Pullin are unpicking the threads of spacetime's fabric to understand both time and quantum gravity.

by ANIL ANANTHASWAMY

FQXi Collaboration: Rodolfo Gambini & Jorge Pullin

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They make for an odd couple. Jorge Pullin is an outgoing go-getter, while Rodolfo Gambini, 15 years his senior, is shy and circumspect and a deliberate thinker. But together are they proving that when you're butting heads against the very nature of space and time, two heads are better than one.

For nearly two decades now, Gambini and Pullin have been tackling one of the greatest problems facing modern physics: reconciling gravity with quantum mechanics. Whether it's slicing and dicing the fabric of space, or messing with the very meaning of time, they have been laying the stepping stones for physicists to bring gravity in line with the other fundamental forces of nature.

Collaboration may turn out to be the only way forward when it comes to uniting general relativity and quantum mechanics, both pillars of modern physics. The former may have been the work of a lone genius—that now celebrated clerk who revolutionized our understanding of reality from a Swiss patent office. The latter, however, was hardly a one-person effort. Instead, quantum mechanics emerged out of a massive collaborative effort between theorists and experimenters.

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While each theory is successful in its own domain, general relativity and quantum mechanics fail to work together when confronted with realms that overlap, such as when immense gravitational forces are concentrated within microscopic volumes of spacetime. It's a problem that cannot be wished away when dealing with the very beginnings of the universe, or when studying black holes. "The fact that these two theories don't seem to work well together seems like a very attractive, open problem in physics at the fundamental level," says Pullin.

JORGE PULLIN
Embarking on the road to quantum gravity

Delicate Balance

Attractive it may be, but so far the problem has proved quite intractable. It's little wonder then that physicists are pooling resources—even if they live on different continents, like Pullin, who is based at Louisiana State University in Baton Rouge, and Gambini, who is at Uruguay's University of the Republic in Montevideo.

Pullin and Gambini make perfect partners—despite their geographic separation—because their contrasting styles complement each other. Pullin works with "incredible breadth and incredible speed," says their colleague Abhay Ashtekar, at Penn State. Gambini on the other hand, has always impressed Ashtekar with his ability to think of "deep, elegant solutions."

"If you do things in too much of a hurry, then the contribution is not lasting. And if you are too slow, and want to solve every problem, everything is slow, and you don't leave an impact," says Ashtekar. "A nice delicate balance between the two is really what is needed. I think they have an extremely good collaboration."

Ashtekar should know, for he inadvertently brought the pair together while he was working towards a theory of quantum gravity. By 1986, Ashtekar had taken a big step towards quantizing gravity—rewriting Einstein's equations in a form that resembled those used to describe interactions in particle physics.

JORGE PULLIN
Louisiana State University

His work led to the development of *loop quantum gravity*, with Lee Smolin of the Perimeter Institute in Waterloo, Ontario, and Carlo Rovelli, of the University of the Mediterranean in Marseille, France.

Quantum Threads

In loop quantum gravity theory, spacetime isn't the smooth fabric that Einstein envisioned. Instead, if you zoom down to scales of 10^{-33} cm, the fabric turns out to be woven of quantum threads. Ashtekar, Smolin, and Rovelli soon realized that they needed new mathematics to work with these threads. Luckily, Gambini and his colleague Antoni Trias had developed mathematical techniques that Ashtekar believed could do just the job.

So, in 1991, Ashtekar invited Gambini to Syracuse University, inNew York, where he was based at the time. It was there that Gambini met Pullin, then a young post-doc from Argentina. The two immediately gelled. "I'm a rather shy person and I used to speak very little. But it was very easy to interact with Jorge," says Gambini. "We were very enthusiastic about the possibilities of applying my techniques. That was the starting point of our collaboration."

Since then, Gambini and Pullin have concentrated on working with the quantum version of Einstein's equations. This has proved a challenge, but they have borrowed a trick from particle physics to tackle it. To describe the interactions of quarks and gluons, particle physicists break the smooth fabric of spacetime into a lattice, or a patchwork. It's far easier to work with equations for each small bit and then stitch them back together, than to attack the entire fabric as a whole. So Gambini and Pullin chopped up spacetime in a similar manner, in an effort to get a grip on quantum gravity.

But when you're playing with general relativity, nothing is ever that simple, and the physicists soon hit a problem. One of the tenets of Einstein's relativity is that physics looks the same to all observers—nobody is special. But as soon as you introduce a lattice, you define a preferred set of observers. "The physics is not the same for an observer who is moving with respect to the lattice compared with one that is fixed [on the lattice]," says Pullin. This created a significant headache for the researchers. "When you put the theory in the lattice, the equations turn out to be inconsistent," Pullin explains.

The duo's persistence, though, has brought them closer to their goal. They can't wipe out the problem entirely, but they have found ways of defining the theory on a lattice, so that they get close to the answers that you would expect from general relativity when you make the lattice very small. The essential property that physics looks the same to all observers is restored.

Having overcome problems with chopping up space, Gambini and Pullin bumped into another rather prickly concept: that of time. Their aim is to describe how a system evolves using quantum Einstein's equations. But while Einstein famously taught us that time is relative, and there are no absolute clocks, quantum mechanics is built on the notion that time is absolute. So before going any further, the physicists had to get a handle on what makes time tick.

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So, just what is time? It's essentially being able to tell the change in one observable quantity with respect to changes in another—making up a clock tick. In classical physics, the clock is external to the system being studied. But if

RODOLFO GAMBINI
University of the Republic in Montevideo

you're considering situations near the origin of the universe, or close to black holes, you are not going to have any handy clocks nearby. You won't even find objects or variables that could behave like classical clocks and rulers, says Pullin. Instead, you'll be forced to use some of the variables of the system you are studying, to measure the rest of the system.

Time Warp

It's certainly not ideal. But using real clocks instead of idealized external clocks that tick away at an absolute rate has interesting implications. One is that you must sacrifice *unitarity*—a property which preserves the pristine nature of a quantum system. According to quantum mechanics, systems can exist in pure states, or as a *superposition* of many different states. If you use real clocks, which change as the quantum system evolves, then unitarity is lost and a pure state will evolve into a superposition of states.

If this loss of unitarity is confirmed experimentally, it will be a boost for Gambini and Pullin's theory. But it will be tough to see the effect in the lab. "You need to have a coherent superposition of at least a million atoms," says Gambini. "The technology does not allow that kind of superposition, so we are still far from having a direct verification of this effect."

In the meantime, Thomas Thiemann of the Max Planck Institute for Gravitational Physics in Golm, Germany, says that Gambini and Pullin should regard their partnership as a success. "They are in very close collaboration all the time, although they are in different physical locations," he says. "[That] requires a lot of self-discipline and extra effort."

So how do Gambini and Pullin pull it off? To start with, they meet many times a year. Pullin travels to Uruguay or Gambini comes to the US, for they need face-to-face interactions to work on what Ashtekar describes as "deep questions."

"This is not something that happens by email or by phone," says Pullin. "You have to be there together. Typically we start with Gambini trying to explain something to me, and it gets all very confusing, and very unsettling, and eventually things settle down."

> Both of us know that in some sense, our research is better because of the other person.
> - *Rodolfo Gambini*

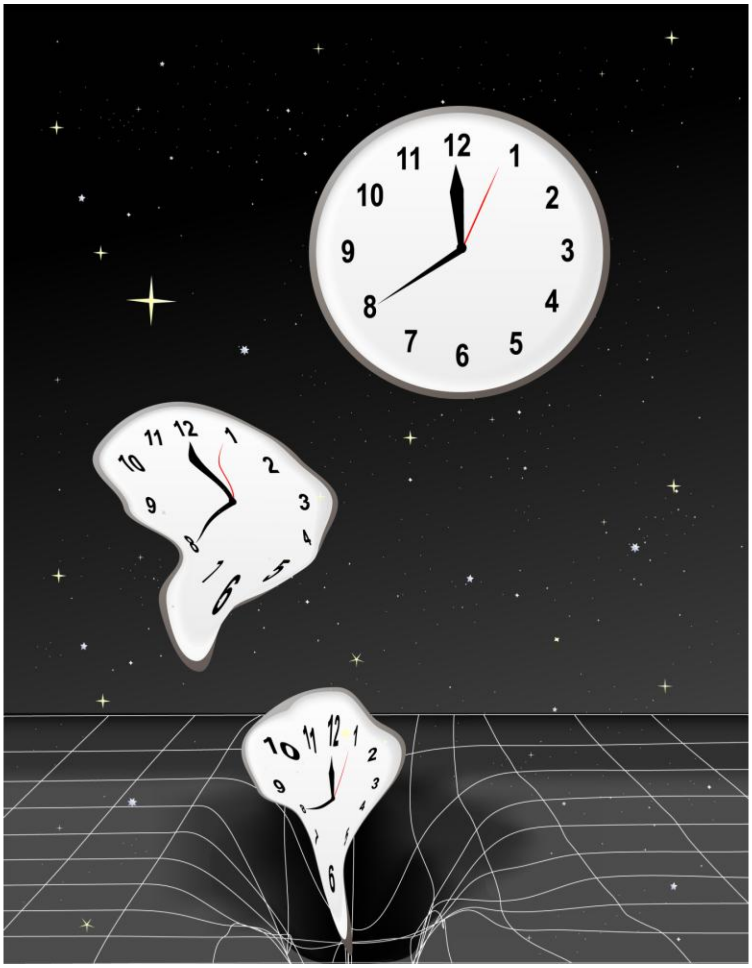
Part of it comes down to their friendship and the pleasure of working with each other. "I enjoy immensely discussing physics with Gambini," says Pullin. "He is very quick and intuitive."

Meeting in person also helps to clear up confusion, when ideas get muddied. "[Gambini] tends to have a very convoluted way of thinking, and by discussing things with him usually things get much more streamlined," Pullin adds. "It is only through challenging discussions and questioning that it finally fleshes out."

Do these discussions ever turn into full-blown arguments? "Yes, it always gets heated," says Gambini, laughing.

But it never gets personal. "You are aggressively pushing ideas, not people. It's clear that one is challenging the idea, not the person," says Pullin.

That demands understanding and mutual respect. "Both need to have a very clear understanding of what the other person is giving to the collaboration," says Gambini. "Both of us know that in some sense, our research is better because of the other person."



TIME FLIES near a black hole
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