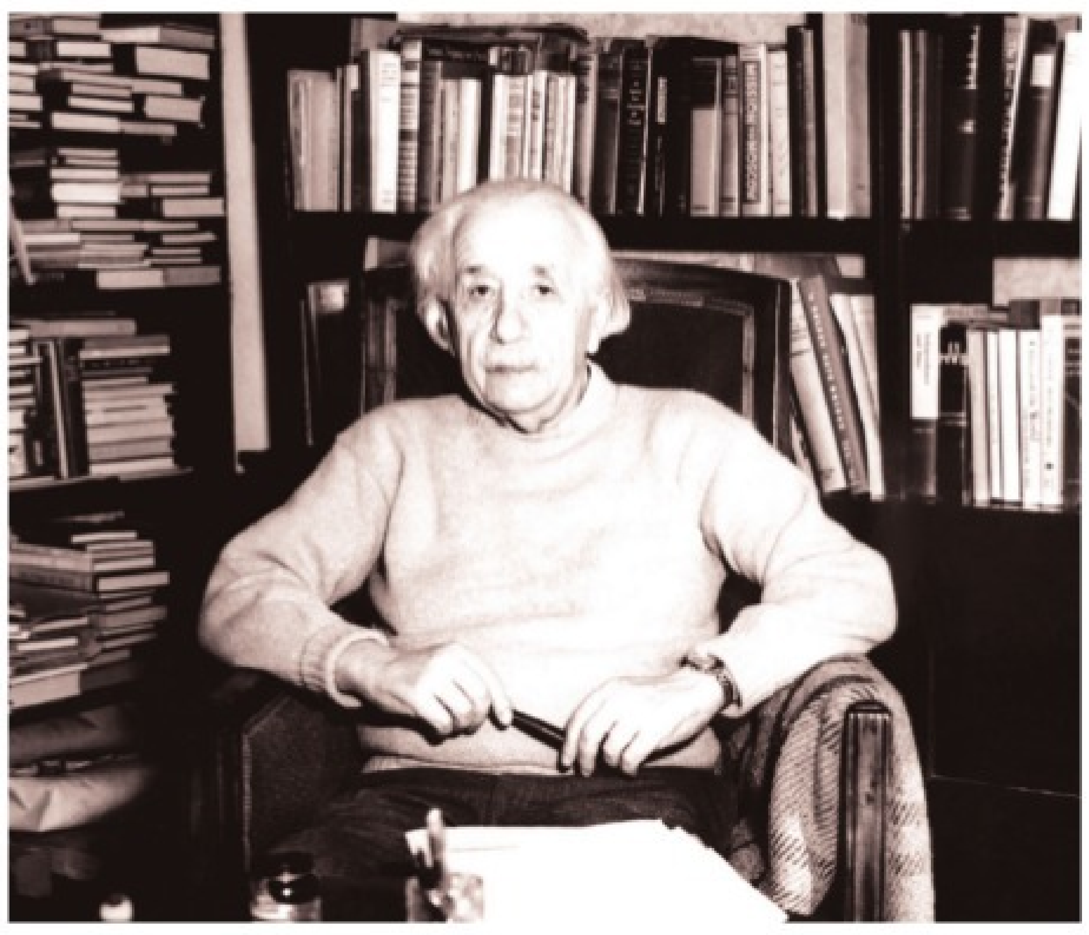
Relativity for everybody

Albert Einstein's popular description, written in 1917, is still the best for the layperson



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Close on the heels of detecting gravity waves in 2014 comes the picture that has been taken of a Black Hole in 2019. Both are dramatic realisations of what Albert Einstein's General Theory of Relativity predicted. The two events fall on either side of 2015, the centenary year of the publication of the theory, marking a century of debate, discussion and marvel at this epochal insight into the nature of things.

The first part of the theory, the Special Theory published in 1905, deals with differences in the way the world looks at high velocities and the equivalence of mass and energy. The discoveries, with effects at the scale of the atom, were revolutionary and led to quantum mechanics, the transistor, the laser, atomic power and most of the physics of the 20th century.

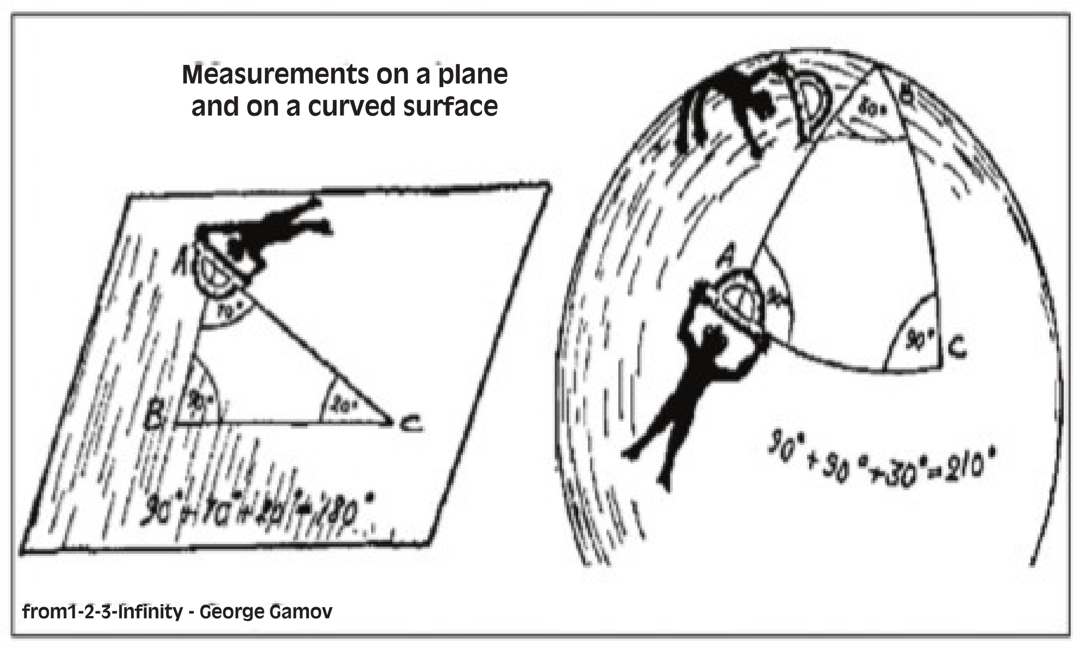
The second part, the General Theory, looks at gravitation and effects at the scale of the cosmos, things that are not seen in everyday life. But the General Theory, which has been verified with breathtaking accuracy, is an undeniable part of nature and has to guide the quest to understand her laws.

Sensitive to both the importance and the specialised nature of the discoveries, Einstein himself resolved to put out a clear and simple, but rigorous exposition of the Theories for the benefit of readers who were not professional scientists. The result was his "booklet", as he called it, *Relativity: The Special and the General Theory (A popular account)* published in German in the spring of 1917. And in the spirit of the centenary, the Princeton University Press, with the Hebrew University of Jerusalem, has brought out a paperback reprint of the 1960 translation, including the appendices that were later added, and a "Reading Companion" of commentaries, notes on other translations and memorabilia.

The book itself is just 132 pages, spread over 32 chapters. Does that sound like many chapters? Yes, Einstein splits his Relativity primer into bite-sized portions, one of the chapters, in fact, is just one page long. And with simplicity and clarity, he introduces just the essentials to grasp the line of thinking, with the least use of mathematics. "To those readers," as he says in the preface, "who, from a general scientific and philosophical point of view, are interested in the theory, but who are not conversant with the mathematical apparatus of theoretical physics."

Einstein first introduces the traditional idea that if observation platforms are moving at a uniform speed with respect to each other, speeds in one platform could be translated to speeds in the other platform by adding or subtracting the relative speed of the platforms. No observer can hence tell that she is on a platform that is "at rest" or moving uniformly, because the laws of physics are the same for any pair of observers in uniform relative motion. And this invariance, Einstein puts down as the Principle of Relativity.

Except that in the case of light, the speed (in vacuum) is always 3,00,000 kms a second, regardless of the speed of the emitter or receiver, which contradicts the Principle. As the constancy of the speed of light had been derived based on the principles of electromagnetism by HA Lorentz, there seemed to be a case to let go the Principle, although there was no evidence to the contrary.



from1-2-3-Infinity - George Gamov

This is when the Special Theory of Relativity enters, to use the work of Lorentz to reinterpret the nature of space and time, which resolves the apparent contradiction — the speed light stays the same in both the platforms in relative motion, but lengths and time intervals contract when measured in moving frames of reference.

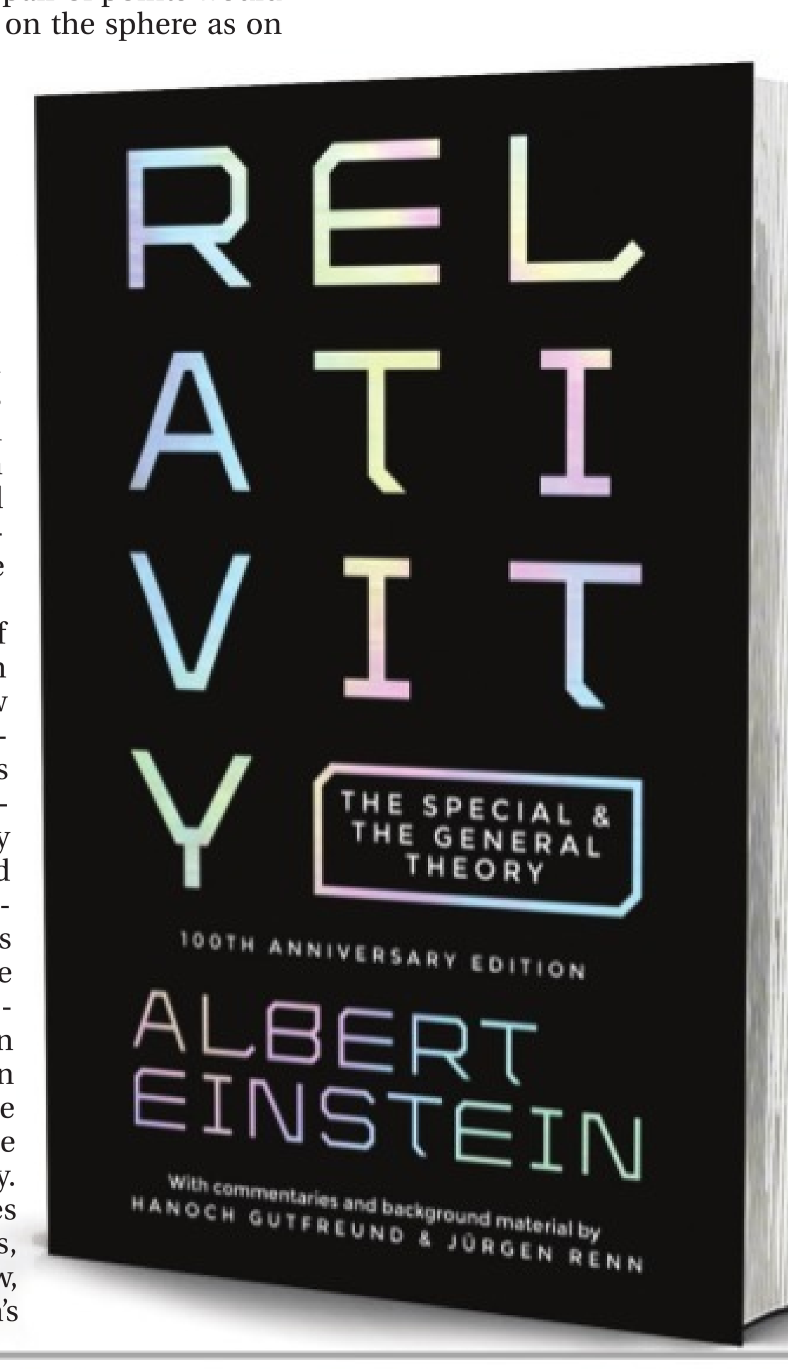
And another consequence of this reinterpretation is that energy of motion of a particle depends not just on its rest mass and speed, but on the mass and a factor that grows with the speed. As this factor is the square of the speed, divided by the square of the speed of light, the increase in the mass is negligible except at very high speeds. This expression for the energy, however, gives a relationship for the intrinsic energy of a particle at rest, the well known $E=mc^2$ formula.

The General Theory

While these are the considerations of platforms moving at uniform relative speeds, Einstein now considers a case where one platform is accelerated, or the relative speed continuously changes. An observer in the accelerated platform would experience a force, opposite to the direction of the acceleration and she would perceive all free objects to fall in its opposite direction, and the observer would have no way to distinguish the acceleration perceived from a force of gravity. Einstein goes on to show that there is, in fact, no difference and suggests extending the Principle of Relativity to the general case of accelerated or platforms in a gravitational field.

Here, the path of a ray of light, which is seen as straight in one platform, it turns out, would appear as curved, when seen in a platform that is accelerated, or which is the same thing in a gravitational field. Would this mean the Principle of Relativity does not hold in the general case? Einstein deals with this question by developing a new way of designating events, in terms of measures, like the distance and direction from a fixed point, and the time.

A usual way of locating a point on a plane surface is by taking its distance from a pair of perpendicular lines. The distance between two points shown like this can then be worked out. However, if the surface on which the two lines are drawn is not a plane, but say a sphere like the Earth, then the distance between a pair of points would not be the same on the sphere as on the plane. Using reasoning like this, and no mathematics, Einstein develops the idea of a curved space that corresponds to the presence of a gravitational field, and shows that the curved beam of light, in the gravitational field, is still moving at the same speed!



This line of thought then leads to a new system of dynamics that governs the cosmos, where there are very large masses and gravitational fields. This system is distinct from the Newtonian system that has been so impressive in describing the Solar System since the 17th century. When the masses are "low", that is, comparatively low, however, Einstein's system reduces to the same Newtonian way.

Newton's theory of gravity was hence an approximation that worked so well only while measurements were not accurate enough. The inverse square law that Newton proposed is also an approximation, and with Einstein's General Theory of Relativity, need not be proposed to fit facts, but appears naturally, in the low mass limit.

Einstein describes other cosmological inconsistencies in traditional cosmology, which the General Theory resolves. A particular success he describes is calculating the period of precession of the orbit of Mercury. Under Newtonian mechanics, the orbits of the planets are ellipses and these ellipses are fixed. And so they were found to be, for all the planets except Mercury, the planet closest to the Sun. Here the elliptical orbit itself is found to turn around, exceedingly slowly, just 43 seconds, or the 3,600th parts of a degree, every century. Newtonian mechanics was powerless to explain this. But Einstein, with the publication of the General Theory, showed that the orbits of all planets would turn around, and for Mercury, he calculated the speed to be exactly 43 seconds in a century!

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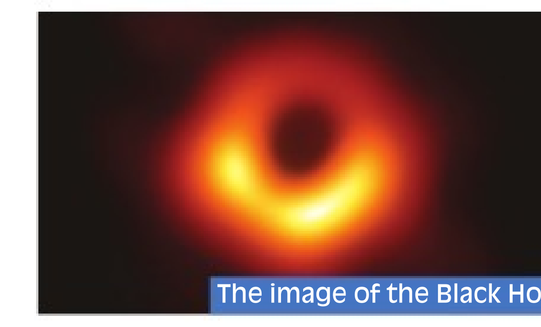
PLUS POINTS

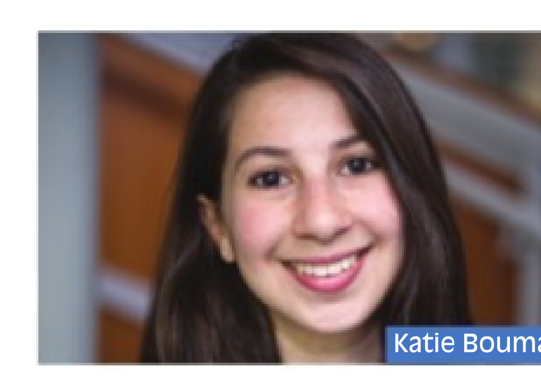
Scientist questioned


The image of the Black Hole

Katie Bouman, the scientist who became a hero after helping to create the famous first image of a Black Hole, has repeatedly looked to shine a light on the colleagues that she worked with to do it. Her new found fame has, however, led to a number of trolls suggesting she is receiving undue credit, and that more attention should be given to men.

Bouman has won praise from all over the world for her help in creating the image. In just about every discussion of the results, she has looked to highlight the work of the huge team of scientists who helped create it. Though Bouman worked on the algorithm that helped create the picture, she did so with a team and using data that came from astronomers who helped capture the radio signals that let the image be created in the first place.

"No one algorithm or person made this image, it required the amazing talent of a team of scientists from around the globe and years of hard work to develop the instrument, data processing, imaging methods, and analysis techniques that were necessary to pull off this seemingly impossible feat," she wrote on *Facebook* soon after the results were announced. Still the interest she has received has led to attacks from some people who believe she is receiving too much credit for the work. That is despite the fact she has never claimed to be responsible, and has highlighted her colleagues at every opportunity.


Katie Bouman

Numerous fake accounts have been set up in her name that suggest she has attempted to claim undue credit for the work and that others — usually men — should be getting attention instead. A common claim suggested that a man had actually written "850,000 of the 900,000 lines of code that were written in the historic black-hole image algorithm", for instance, and was passed around social media along with pictures of Bouman.

But Andrew Chael, the graduate student who has been repeatedly credited with doing that work, has tweeted that it a mischaracterisation of how the work was done and is a false understanding of what he himself did. "So apparently some (I hope very few) people online are using the fact that I am the primary developer of the (software library that helped created the image) to launch awful and sexist attacks on my colleague and friend Katie Bouman," he wrote. "Stop.


Andrew Chael

"While I wrote much of the code for one of these pipelines, Katie was a huge contributor to the software; it would have never worked without her contributions and the work of many others who wrote code, debugged, and figured out how to use the code on challenging EHT data. With a few others, Katie also developed the imaging framework that rigorously tested all three codes and shaped the entire paper.

"As a result, this is probably the most vetted image in the history of radio interferometry. I'm thrilled Katie is getting recognition for her work and that she's inspiring people as an example of women's leadership in science, technology, engineering and mathematics.

"I'm also thrilled she's pointing out that this was a team effort including contributions from many junior scientists, including many women junior scientists. Together, we all make each other's work better; the number of commits doesn't tell the full story of who was indispensable.

"So while I appreciate the congratulations on a result that I worked hard on for years, if you are congratulating me because you have a sexist vendetta against Katie, please go away and reconsider your priorities in life," he concluded, before committing to stick around on *Twitter* and continue to post about Black Holes, "space, being a gay astronomer, Ursula K Le Guin, architecture, and musicals".

The Independent

From another viewpoint

Empathy is the secret ingredient that makes cooperation — and civilisation — possible

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Human societies are so prosperous mostly because of how altruistic we are. Unlike other animals, people cooperate even with complete strangers. We share knowledge on *Wikipedia*, we show up to vote, and we work together to responsibly manage natural resources.

But where do these cooperative skills come from and why don't our selfish instincts overwhelm them? Using a branch of mathematics called evolutionary game theory to explore this feature of human societies, my collaborators and I found that empathy — a uniquely human capacity to take another person's perspective — might be responsible for sustaining such extraordinarily high levels of cooperation in modern societies.

Social rules of cooperation

For decades scholars have thought that social norms and reputation can explain much altruistic behaviour. Humans are far more likely to be kind to individuals they see as "good," than they are to people of "bad" reputation. If everyone agrees that being altruistic toward other cooperators earns you a good reputation, cooperation will persist.

This universal understanding of whom we see as morally good and worthy of cooperation is a form of social norm — an invisible rule that guides social behaviour and promotes cooperation.

A common norm in human societies called "stern judging," for instance, rewards cooperators who refuse to help bad people, but many other norms are possible.

This idea that you help one person and someone else helps you is called the theory of indirect reciprocity. However, it's been built assuming that people always agree on each others' reputations as they change over time.

Moral reputations were presumed to be fully objective and publicly known. Imagine, for instance, an all-seeing institution monitoring people's behaviour and assigning reputations, like China's social credit system, in which people will be rewarded or sanctioned based on "social scores" calculated by the government.

But in most real-life communities, people often disagree about each others' reputations. A person who appears good to me might seem like a bad individual from my friend's perspective. My friend's judgment might be based on a different social norm or a different observation than mine. This is why reputations in real societies are relative — people have different opinions about what is good or bad.

Using biology-inspired evolutionary models, I set out to investigate what happens in a more realistic setting. Can cooperation evolve when there are disagreements about what is considered good or bad? To answer this question, I first worked with mathematical descriptions of large societies, in which people could choose between various types of cooperative and selfish behaviours based on how beneficial they were. Later I used computer models to simulate social interactions in much smaller societies that more closely resemble human communities.

The results of my modelling work were not encouraging — overall, moral relativity made societies less altruistic. Cooperation almost vanished under most social norms. This meant that most of what was known about social norms promoting human cooperation may have been false.

Evolution of empathy

To find out what was missing from the dominant theory of altruism, I teamed up with Joshua Plotkin, a theoretical biologist at the University of Pennsylvania, and Alex Stewart at the University of Houston, both experts in game theoretical approaches to human behaviour. We agreed that my pessimistic findings went against our intuition — most people do care about reputations and about the moral value of others' actions.

But we also knew that humans have a remarkable ability to empathetically include other people's views when deciding that a certain behaviour is morally good or bad. On some occasions, for instance, you might be tempted to judge an uncooperative person harshly, when you really shouldn't if from their own perspective, cooperation was not the right thing to do.

This is when my colleagues and I decided to modify our models to give individuals the capacity for empathy — that is, the ability to make their moral evaluations from the perspective of another person. We also wanted individuals in our model to be able to learn how to be empathetic, simply by observing and copying personality traits of more successful people.

When we incorporated this type of empathetic perspective-taking into our equations, cooperation rates skyrocketed; once again we observed altruism winning over selfish behaviour. Even initially uncooperative societies in which everyone judged each other based mostly on their own selfish perspectives, eventually discovered empathy — it became socially contagious and spread throughout the population. Empathy made our model societies altruistic again.

Moral psychologists have long suggested that empathy can act as social glue, increasing cohesiveness and cooperation of human societies. Empathetic perspective-taking starts developing in infancy, and at least some aspects of empathy are learned from parents and other members of the child's social network. But how humans evolved empathy in the first place remained a mystery.

It is incredibly difficult to build rigorous theories about concepts of moral psychology as complex as empathy or trust. Our study offers a new way of thinking about empathy, by incorporating it into the well-studied framework of evolutionary game theory. Other moral emotions like guilt and shame can potentially be studied in the same way.

I hope that the link between empathy and human cooperation we discovered can soon be tested experimentally. Perspective-taking skills are most important in communities where many different backgrounds, cultures and norms intersect; this is where different individuals will have diverging views on what actions are morally good or bad.

If the effect of empathy is as strong as our theory suggests, there could be ways to use our findings to promote large-scale cooperation in the long term — for instance, by designing nudges, interventions and policies that promote development of perspective-taking skills or at least encourage considering the views of those who are different.

The writer is Postdoctoral Researcher of Evolutionary Biology, University of Pennsylvania, US. This article first appeared on www.theconversation.com