

Grigori Perelman

Grigori Yakovlevich Perelman (Russian: Григорий Яковлевич Перельман, IPA: [grɨˈɡorʲɪj ˈjakəvlʲɪvʲɪtɕ pʲɪrʲɪlʲˈman] (ⓘ)listen); born 13 June 1966) is a Russian mathematician. He has made contributions to Riemannian geometry and geometric topology. In 1994, Perelman proved the soul conjecture. In 2003, he proved Thurston's geometrization conjecture. The proof was confirmed in 2006. This consequently solved in the affirmative the Poincaré conjecture.

In August 2006, Perelman was offered the Fields Medal^[1] for "his contributions to geometry and his revolutionary insights into the analytical and geometric structure of the Ricci flow", but he declined the award, stating: "I'm not interested in money or fame; I don't want to be on display like an animal in a zoo."^[2] On 22 December 2006, the scientific journal *Science* recognized Perelman's proof of the Poincaré conjecture as the scientific "Breakthrough of the Year", the first such recognition in the area of mathematics.^[3]

On 18 March 2010, it was announced that he had met the criteria to receive the first Clay Millennium Prize^[4] for resolution of the Poincaré conjecture. On 1 July 2010, he rejected the prize of one million dollars, saying that he considered the decision of the board of CMI and the award very unfair and that his contribution to solving the Poincaré conjecture was no greater than that of Richard S. Hamilton, the mathematician who pioneered the Ricci flow with the aim of attacking the conjecture.^{[5][6]} He had previously rejected the prestigious prize of the European Mathematical Society, in 1996.^[7]

Contents

- Early life and education
- Soul conjecture
- Geometrization and Poincaré conjectures

Grigori Perelman



Grigori Perelman in 1993

Born	13 June 1966 <div>Leningrad, Soviet Union</div>
Nationality	Russian
Citizenship	Russia
Alma mater	Leningrad State University (PhD 1990)
Known for	Riemannian geometry <div>Geometric topology</div> <div>Proof of the soul conjecture</div> <div>Proof of the Poincaré conjecture</div>
Awards	Saint Petersburg

<div> <div>Problem</div> <div>Perelman's proof</div> <div>Verification</div> </div> <div> <div>Fields Medal and Millennium Prize</div> <div>Possible withdrawal from mathematics</div> <div>Perelman and the media</div> <div>Bibliography</div> <div>See also</div> <div>Notes</div> <div>References</div> <div>Further reading</div> <div>External links</div> </div>	<div> <div>Mathematical Society Prize (1991), accepted</div> <div>EMS Prize (1996), declined</div> <div>Fields Medal (2006), declined</div> <div>Millennium Prize (2010), declined</div> </div>
	<div>Scientific career</div>
	<div> <div>Fields</div> <div>Mathematics</div> </div>
	<div> <div>Thesis</div> <div><i>Saddle Surfaces in Euclidean Spaces</i> (1990)</div> </div>
	<div> <div>Doctoral advisor</div> <div>Aleksandr Aleksandrov</div> <div>Yuri Burago</div> </div>

Early life and education

Grigori Yakovlevich Perelman was born in Leningrad, Soviet Union (now Saint Petersburg, Russia) on 13 June 1966, to Russian-Jewish parents^{[8][9][10]} Yakov (who now lives in Israel)^[8] and Lyubov (who still lives in Saint Petersburg with Grigori).^[8] Grigori's mother Lyubov gave up graduate work in mathematics to raise him. Grigori's mathematical talent became apparent at the age of ten, and his mother enrolled him in Sergei Rukshin's after-school mathematics training program.^[11]

His mathematical education continued at the Leningrad Secondary School #239, a specialized school with advanced mathematics and physics programs. Grigori excelled in all subjects except physical education.^[12] In 1982, as a member of the Soviet Union team competing in the International Mathematical Olympiad, an international competition for high school students, he won a gold medal, achieving a perfect score.^[13] He continued as a student of The School of Mathematics and Mechanics at the Leningrad State University, without admission examinations and enrolled to the university.

After his PhD in 1990, Perelman began work at the Leningrad Department of Steklov Institute of Mathematics of the USSR Academy of Sciences, where his advisors were Aleksandr Aleksandrov and Yuri Burago. In the late 1980s and early 1990s, with a strong recommendation from the geometer Mikhail Gromov,^[14] Perelman obtained research positions at several universities in the United States.

In 1991 Perelman won the Young Mathematician Prize of the St. Petersburg Mathematical Society for his work on Aleksandrov's spaces of curvature bounded from below.^[15] In 1992, he was invited to spend a semester each at the Courant Institute in New York University and Stony Brook University where he began work on manifolds with lower bounds on Ricci curvature. From there, he accepted a two-year Miller Research Fellowship at the University of California, Berkeley in 1993. After having proved the soul conjecture in 1994, he was offered jobs at several top universities in the US, including Princeton and Stanford, but he rejected them all and returned to the Steklov Institute in Saint Petersburg in the summer of 1995 for a research-only position.^[11]

Soul conjecture

Cheeger and Gromoll's **soul conjecture** states:

Suppose (M, g) is complete, connected and non-compact with sectional curvature $K \geq 0$, and there exists a point in M where the sectional curvature (in all sectional directions) is strictly positive. Then the soul of M is a point; equivalently M is diffeomorphic to \mathbf{R}^n .

Perelman proved the conjecture by establishing that in the general case $K \geq 0$, Sharafutdinov's retraction $P : M \rightarrow S$ is a submersion.

Geometrization and Poincaré conjectures

Until late 2002, Perelman was best known for his work in comparison theorems in Riemannian geometry. Among his notable achievements was a short and elegant proof of the soul conjecture.

Problem

The Poincaré conjecture, proposed by French mathematician Henri Poincaré in 1904, was one of the key problems in topology. Any loop on a 3-sphere—as exemplified by the set of points at a distance of 1 from the origin in four-dimensional Euclidean space—can be contracted into a point. The Poincaré conjecture asserts that any closed three-dimensional manifold, such that any loop can be contracted into a point, is topologically a 3-sphere. The analogous result has been known to be true in dimensions greater than or equal to five since 1960 as in the work of Stephen Smale. The four-dimensional case resisted longer, finally being solved in 1982 by Michael Freedman. But the case of three-manifolds turned out to be the hardest of them all. Roughly speaking, this is because in topologically manipulating a three-manifold there are too few dimensions to move "problematic regions" out of the way without interfering with something else. The most fundamental contribution to the three-dimensional case had been produced by Richard S. Hamilton. The role of Perelman was to complete the Hamilton program.

Perelman's proof

In November 2002, Perelman posted the first of a series of eprints to the arXiv, in which he claimed to have outlined a proof of the geometrization conjecture, of which the Poincaré conjecture is a particular case.^{[16][17][18]}

Perelman modified Richard S. Hamilton's program for a proof of the conjecture. The central idea is the notion of the Ricci flow. Hamilton's fundamental idea is to formulate a "dynamical process" in which a given three-manifold is geometrically distorted such that this distortion process is governed by a differential equation analogous to the heat equation. The heat equation (which much earlier motivated Riemann to state his Riemann hypothesis on the zeros of the zeta function) describes the behavior of scalar quantities such as temperature. It ensures that concentrations of elevated temperature will spread out until a uniform temperature is achieved throughout an object. Similarly, the Ricci flow describes the behavior of a tensorial quantity, the Ricci curvature tensor. Hamilton's hope was that under the Ricci flow concentrations of large curvature will spread out until a uniform curvature is achieved over the entire three-manifold. If so, if one starts with any three-manifold and lets the Ricci flow occur, then one should, in principle, eventually obtain a kind of "normal form". According to William Thurston this normal form must take one of a small number of possibilities, each having a different kind of geometry, called Thurston model geometries.

This is similar to formulating a dynamical process that gradually "perturbs" a given square matrix and that is guaranteed to result after a finite time in its rational canonical form.

Hamilton's idea attracted a great deal of attention, but no one could prove that the process would not be impeded by developing "singularities", until Perelman's eprints sketched a procedure for overcoming these obstacles. According to Perelman, a modification of the standard Ricci flow, called *Ricci flow with surgery*, can systematically excise singular regions as they develop, in a controlled way.

It was known that singularities (including those that, roughly speaking, occur after the flow has continued for an infinite amount of time) must occur in many cases. However, any singularity that develops in a finite time is essentially a "pinching" along certain spheres corresponding to the prime decomposition of the 3-manifold. Furthermore, any "infinite time" singularities result from certain collapsing pieces of the JSJ decomposition. Perelman's work proves this claim and thus proves the geometrization conjecture.

Verification

Perelman's work was checked relatively quickly. In April 2003, Perelman visited the Massachusetts Institute of Technology, Princeton University, Stony Brook University, Columbia University and New York University to give a short series of lectures on his work.

On 25 May 2006, Bruce Kleiner and John Lott, both of the University of Michigan, posted a paper on arXiv that fills in the details of Perelman's proof of the Geometrization conjecture.^[19] John Lott said in ICM2006, "It has taken us some time to examine Perelman's work. This is partly due to the originality of Perelman's work and partly to the technical sophistication of his arguments. All indications are that his arguments are correct."

In June 2006, the *Asian Journal of Mathematics* published a paper by Zhu Xiping of Sun Yat-sen University in China and Huai-Dong Cao of Lehigh University in Pennsylvania, giving a complete description of Perelman's proof of the Poincaré and the geometrization conjectures. The June 2006 paper claimed: "This proof should be considered as the crowning achievement of the Hamilton–Perelman theory of Ricci flow."^[20] Even more boldly, in the introduction of the paper the authors state that they "give the first written account of a complete proof of the Poincaré conjecture and the geometrization conjecture of Thurston." Asked about the paper, Perelman said the pair had not contributed anything original, and had simply reworked his proof because they "did not quite understand the argument".^[21]

In November 2006, Cao and Zhu published an erratum disclosing that they had failed to cite properly the previous work of Kleiner and Lott published in 2003. In the same issue, the *AJM* editorial board issued an apology for what it called "incautions" in the Cao–Zhu paper.^[22]

On December 3, 2006, Cao and Zhu retracted the original version of their paper, which was titled "A Complete Proof of the Poincaré and Geometrization Conjectures — Application of the Hamilton–Perelman Theory of the Ricci Flow"^[23] and posted a revised version, renamed, more modestly, "Hamilton–Perelman's Proof of the Poincaré Conjecture and the Geometrization Conjecture".^[24] Rather than the grand claim of the original abstract, "we give a complete proof", suggesting the proof is by the authors, the revised abstract states: "we give a detailed exposition of a complete proof". The authors also removed the phrase "crowning achievement" from the abstract.

In July 2006, John Morgan of Columbia University and Gang Tian of the Massachusetts Institute of Technology posted a paper on arXiv titled, "Ricci Flow and the Poincaré Conjecture". In this paper, they provide a detailed version of Perelman's proof of the Poincaré conjecture.^[25] On 24 August 2006, Morgan delivered a lecture at the ICM in Madrid on the Poincaré conjecture.^[26] This was followed up with the paper on arXiv, "Completion of the Proof of the Geometrization Conjecture" on 24 September 2008.^[27]

Fields Medal and Millennium Prize

In May 2006, a committee of nine mathematicians voted to award Perelman a Fields Medal for his work on the Poincaré conjecture.^[21] However, Perelman declined to accept the prize. Sir John Ball, president of the International Mathematical Union, approached Perelman in Saint Petersburg in June 2006 to persuade him to accept the prize. After 10 hours of attempted persuasion over two days, Ball gave up. Two weeks later, Perelman summed up the conversation as follows: "He proposed to me three alternatives: accept and come; accept and don't

come, and we will send you the medal later; third, I don't accept the prize. From the very beginning, I told him I have chosen the third one ... [the prize] was completely irrelevant for me. Everybody understood that if the proof is correct, then no other recognition is needed."^[21] "I'm not interested in money or fame,' he is quoted to have said at the time. 'I don't want to be on display like an animal in a zoo. I'm not a hero of mathematics. I'm not even that successful; that is why I don't want to have everybody looking at me.'"^[28] Nevertheless, on 22 August 2006, Perelman was publicly offered the medal at the International Congress of Mathematicians in Madrid "for his contributions to geometry and his revolutionary insights into the analytical and geometric structure of the Ricci flow".^[29] He did not attend the ceremony, and declined to accept the medal, making him the only person to decline this prestigious prize.^{[7][30]}

He had previously rejected a prestigious prize from the European Mathematical Society.^[7]

On 18 March 2010, Perelman was awarded a Millennium Prize for solving the problem.^[31] On June 8, 2010, he did not attend a ceremony in his honor at the Institut Océanographique, Paris to accept his \$1 million prize.^[32] According to Interfax, Perelman refused to accept the Millennium prize in July 2010. He considered the decision of the Clay Institute unfair for not sharing the prize with Richard S. Hamilton,^[5] and stated that "the main reason is my disagreement with the organized mathematical community. I don't like their decisions, I consider them unjust."^[6]

The Clay Institute subsequently used Perelman's prize money to fund the "Poincaré Chair", a temporary position for young promising mathematicians at the Paris Institut Henri Poincaré.^[33]

Possible withdrawal from mathematics

Perelman quit his job at the Steklov Institute in December 2005.^[34] His friends are said to have stated that he currently finds mathematics a painful topic to discuss; some even say that he has abandoned mathematics entirely.^[35]

Perelman is quoted in an article in *The New Yorker* saying that he is disappointed with the ethical standards of the field of mathematics. The article implies that Perelman refers particularly to the efforts of Fields medalist Shing-Tung Yau to downplay Perelman's role in the proof and play up the work of Cao and Zhu. Perelman added, "I can't say I'm outraged. Other people do worse. Of course, there are many mathematicians who are more or less honest. But almost all of them are conformists. They are more or less honest, but they tolerate those who are not honest."^[21] He has also said that "It is not people who break ethical standards who are regarded as aliens. It is people like me who are isolated."^[21]

This, combined with the possibility of being awarded a Fields medal, led him to quit professional mathematics. He has said that "As long as I was not conspicuous, I had a choice. Either to make some ugly thing or, if I didn't do this kind of thing, to be treated as a pet. Now, when I become a very conspicuous person, I cannot stay a pet and say nothing. That is why I had to quit." (*The New Yorker* authors explained Perelman's reference to "some ugly thing" as "a fuss" on Perelman's part about the ethical breaches he perceived.)^[36]

It is uncertain whether his resignation from Steklov and subsequent seclusion mean that he has ceased to practice mathematics. Fellow countryman and mathematician Yakov Eliashberg said that, in 2007, Perelman confided to him that he was working on other things but it was too premature to talk about it. He is said to have been interested in the past in the Navier–Stokes equations and the problem of their existence and smoothness.^[37]

In 2014, Russian media reported that Perelman was working in the field of nanotechnology in Sweden.^[38] However, shortly afterwards, he was spotted again in his native hometown, Saint Petersburg.^[38]

Perelman and the media

Perelman has avoided journalists and other members of the media. Masha Gessen, the author of *Perfect Rigour: A Genius and the Mathematical Breakthrough of the Century*, a book about him, was unable to meet him.^[39]

A Russian documentary about Perelman in which his work is discussed by several leading mathematicians including Mikhail Gromov was released in 2011 under the title "Иноходец. Урок Перельмана," "Maverick: Perelman's Lesson."

In April 2011, Aleksandr Zabrovsky, producer of "President-Film" studio, claimed to have held an interview with Perelman and agreed to shoot a film about him, under the tentative title *The Formula of the Universe*.^[40] Zabrovsky says that in the interview,^[41] Perelman explained why he rejected the one million dollar prize.^[40] A number of journalists^{[42][43][44]} believe that Zabrovky's interview is most likely a fake, pointing to contradictions in statements supposedly made by Perelman.

The writer Brett Forrest briefly interacted with Perelman in 2012.^{[45][46]} Perelman refuses to talk to journalists. One who managed to reach him on his mobile was told: "You are disturbing me. I am picking mushrooms."^[47]

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See also

- Homology sphere
- "Manifold Destiny" (On *The New Yorker* article)

- Uniformization theorem
- Asteroid 50033 Perelman

Notes

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