The Abel Prize Laureate 2014

Yakov G. Sinai

Princeton University, USA, and Landau Institute for
Theoretical Physics, Russian Academy of Sciences

www.abelprize.no

Yakov G. Sinai receives the Abel Prize for 2014

"for his fundamental contributions to dynamical systems, ergodic theory, and mathematical physics"

Citation

The Norwegian Academy of Science and Letters has decided to award the Abel Prize for 2014 to

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Ever since the time of Newton, differential equations have been used by mathematicians, scientists and engineers to explain natural phenomena and to predict how they evolve. Many equations incorporate stochastic terms to model unknown, seemingly random, factors acting upon that evolution. The range of modern applications of deterministic and stochastic evolution equations encompasses such diverse issues as planetary motion, ocean currents, physiological cycles, population dynamics, and electrical networks, to name just a few. Some of these phenomena can be foreseen with great accuracy, while others seem to evolve in a chaotic, unpredictable way. Now it has become clear that order and chaos are intimately connected: we may find chaotic behavior in deterministic systems, and conversely, the statistical analysis of chaotic systems may lead to definite predictions.

Yakov Sinai made fundamental contributions in this broad domain, discovering surprising connections between order and chaos and developing the use of probability and measure theory in the study of dynamical systems. His achievements include seminal works in ergodic theory, which studies the tendency of a system to explore all of its available states according to certain time statistics; and statistical mechanics, which explores the behavior of systems composed of a very large number of particles, such as molecules in a gas.

Sinai's first remarkable contribution, inspired by Kolmogorov, was to develop an invariant of dynamical systems. This invariant has become known as the Kolmogorov–Sinai entropy, and it has become a central notion for studying the complexity of a system through a measure-theoretical description of its trajectories. It has led to very important advances in the classification of dynamical systems.

Sinai has been at the forefront of ergodic theory. He proved the first ergodicity theorems for scattering billiards in the style of Boltzmann, work he continued with Bunimovich and Chernov. He constructed Markov partitions for systems defined by iterations of Anosov diffeomorphisms, which led to a series of outstanding works showing the power of symbolic dynamics to describe various classes of mixing systems.

With Ruelle and Bowen, Sinai discovered the notion of SRB measures: a rather general and distinguished invariant measure for dissipative systems with chaotic behavior. This versatile notion has been very useful in the qualitative study of some archetypal dynamical systems as well as in the attempts to tackle real-life complex chaotic behavior such as turbulence.

Sinai's other pioneering works in mathematical physics include: random walks in a random environment (Sinai's walks), phase transitions (Pirogov–Sinai theory), one-dimensional turbulence (the statistical shock structure of the stochastic Burgers equation, by E–Khanin–Mazel–Sinai), the renormalization group theory (Bleher–Sinai), and the spectrum of discrete Schrödinger operators.

Sinai has trained and influenced a generation of leading specialists in his research fields. Much of his research has become a standard toolbox for mathematical physicists. His works had and continue to have a broad and profound impact on mathematics and physics, as well as on the ever-fruitful interaction of these two fields.

Photo: Princeton University, Department of Mathematics

Biography

Yakov G. Sinai was born on 21 September 1935 in Moscow, Russia. Both of his parents, Gregory Sinai and Nadezda Kagan, were microbiologists with research careers. His grandfather, the mathematician Benjamin Fedorovich Kagan, was head of the Department of Differential Geometry at Moscow State University. Kagan had great influence on his grandson. He retired from his chair at Moscow State University in 1952, the year in which his grandson Yakov Grigorevich entered the Faculty of Mechanics and Mathematics.

Yakov Sinai received his B.S. (1957), his Ph.D. (1960), and his doctorate (1963) from Moscow State University. His advisor was the prominent Andrey Kolmogorov. Sinai was a Scientific Researcher at the Laboratory of Probabilistic and Statistical Methods at Moscow State University from 1960 to 1971. In 1971 he became a Professor at Moscow State University and a Senior Researcher at the Landau Institute of Theoretical Physics, Russian Academy of Sciences. Since 1993 he has been a Professor of Mathematics at Princeton University, USA, but has concurrently kept his position at the Landau Institute of Theoretical Physics. The Landau Institute was founded in 1964 and is located in Chernogolovka, some 40 kilometers northeast of Moscow; it is at the heart of a scientific network in the tradition of the Landau school.

During 1997-1998 Yakov Sinai was Thomas Jones Professor at Princeton University and in 2005 he was Moore Distinguished Scholar at the California Institute of Technology in Pasadena, California.

Yakov Sinai is one of the most influential mathematicians of the twentieth century. He has achieved numerous groundbreaking results in the theory of dynamical systems, in mathematical physics and in probability theory. Many mathematical results are named after him, including Kolmogorov–Sinai entropy, Sinai's billiards, Sinai's random walk, Sinai-Ruelle-Bowen measures, and Pirogov-Sinai theory. Sinai is highly respected in both physics and mathematics communities as the major architect of the most bridges connecting the world of deterministic (dynamical) systems with the world of probabilistic (stochastic) systems. Perhaps it is only to be expected that he is the author of an article titled "Mathematicians and Physicists = Cats and Dogs?"[1]

During the past half-century Yakov Sinai has written more than 250 research papers and a number of books. Sinai and his wife Elena B. Vul, a mathematician and physicist, have also written a number of joint papers. Yakov Sinai has supervised more than 50 Ph.D. students.

1 *Bulletin (New Series) of the American Mathematical Society*, Vol 43, Number 4, October 2006, pages 563–565.

The deep contributions made by Sinai early in his career led to his being invited to lecture at the International Congress of Mathematicians in Stockholm in 1962. Sinai has since been an invited speaker at several important international conferences and has given many prestigious lectures worldwide. He has spoken four times at the International Congress of Mathematicians. He was a plenary speaker at the 1st Latin American Congress in Mathematics in 2000. In 2001 he was appointed Chairman of the Fields Medal Committee of International Mathematical Union, which decided on the awards of the Fields Medals at the Congress in Beijing in the following year.

Awards and honours

Yakov Sinai has received many distinguished international awards. In 2013 he was awarded the Leroy P. Steele Prize for Lifetime Achievement from the American Mathematical Society. Other awards include the Wolf Prize in Mathematics (1997), the Nemmers Prize in Mathematics (2002), the Henri Poincaré Prize from the International Association of Mathematical Physics (2009) and the Dobrushin International Prize from the Institute of Information Transmission of the Russian Academy of Sciences (2009). Among his many recognitions are the Boltzmann Gold Medal from the Commission on Statistical Physics of the International Union of Pure and Applied Physics (1986) and the Dirac Medal from the Abdus Salam International Centre for Theoretical Physics in Trieste (1992).

Many mathematical societies and academies have elected Sinai to membership or honorary membership: the American Academy of Arts and Sciences (1983), the Russian Academy of Sciences (1991), the London Mathematical Society (1992), the Hungarian Academy of Sciences (1993), the United States National Academy of Sciences (1999), the Brazilian Academy of Sciences (2000), the Academia Europaea (2008), the Polish Academy of Sciences (2009) and the Royal Society of London (2009).

He has received honorary degrees from Warsaw University (1993), Budapest University of Science and Technology (2002), the Hebrew University in Jerusalem (2005), and Warwick University (2010).

Professor Sinai is also respected as a teacher at Princeton. In the words of a former student, "It's quite inspirational to be in his class … People feel an immediate urge to participate – there is a radiance which comes from him and inspires us."[2] He is also known for his persistence in the face of obstacles, be they bureaucratic or theoretical, a trait which has served him well throughout the years.

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For his 70th birthday in 2005 a special issue of the Moscow Mathematical Journal was dedicated to Sinai: "Yakov Sinai is one of the greatest mathematicians of our time. The list of international prizes awarded to him as a sign of recognition of his scientific contributions is extremely long, and the list of his fundamental results is even longer. His permanent interest in mathematics and his exceptional scientific enthusiasm inspire several generations of scientists all over the world. His mere presence at a seminar or at a conference makes scientific life brighter and more exciting."

2 Dennis Kosygin, as quoted in *The Daily Princetonian*, Dec. 3, 1996, pp. 1,7, on the occasion of the awarding of the Wolf Prize.

The Entropy of a Dynamical System

Arne B. Sletsjøe

In 1948 the American mathematician Claude E. Shannon published an article entitled "A Mathematical Theory of Communication". His idea was to use the formalism of mathematics to describe communication as a phenomenon. The purpose of all communication is to convey a message, but how this is done is the messenger's choice. Some will express themselves using numerous words or characters; others prefer to be briefer. The content of the information is the same, but the information density may vary. An example is the so-called SMS language. When sending an SMS message it is common to try to minimize the number of characters. The sentence "I love You" consists of 10 characters, while "I <3 U" consists of only 6, but the content of the two messages is the same. Shannon introduced the notion of entropy to measure the density of information. To what extent does the next character in the message provide us with more information? High Shannon entropy means that each new character provides new information; low Shannon entropy indicates that the next character just confirms something we already know.

Towards the end of the 1950s, the Russian mathematician Andrey Kolmogorov held a seminar series on dynamical systems at Moscow University. A question often raised in the seminar concerned the possibility of deciding structural similarity between different dynamical systems. A young seminar participant, Yakov Sinai, presented an affirmative answer, introducing the concept of entropy of a dynamical system.

A dynamical system is a description of a physical system and its evolution over time. The system has many phases and all phases are represented in the phase space of the system. A path in the phase space describes the dynamics of the dynamical system.

A dynamical system may be deterministic. In a deterministic system no randomness is involved in the development of future states of the system. A swinging pendulum describes a deterministic system. Fixing the position and the speed, the laws of physics will determine the motion of the pendulum. When throwing a dice, we have the other extreme; a stochastic system. The future is completely uncertain, the last toss of the dice has no influence on the next.

In general, we can get a good overview of what happens in a dynamical system in the short term. However, when analyzed in the long term, dynamical systems are difficult to understand and predict. The problem of weather forecasting illustrates this phenomenon; the weather condition, described by air pressure, temperature, wind, humidity, etc. is a phase of a dynamical system. A weather forecast for the next ten minutes is much more reliable than a weather forecast for the next ten days.

Yakov Sinai was the first to come up with a mathematical foundation for quantifying the complexity of a given dynamical system. Inspired by Shannon's entropy in information theory, and in the framework of Kolmogorov's Moscow seminar, Sinai introduced the concept of entropy for so-called measure-preserving dynamical systems, today known as Kolmogorov–Sinai-entropy. This entropy turned out to be a strong and far-reaching invariant of dynamical systems.

The Kolmogorov–Sinai-entropy provides a rich generalization of Shannon entropy. In information theory a message is an infinite sequence of symbols, corresponding to a phase in the framework of dynamical systems. The shift operator, switching the sequence one step, gives the dynamics of the system. Entropy measures to what extent we are able to predict the next step in the sequence.

Another example concerns a container filled with gas. The phase space of this physical system represents phases of the gas, i.e. the position and the momentum of every single gas molecule, and the laws of nature determine the dynamics. Again, the degree of complexity and chaotic behaviour of the gas molecules will be the ingredients in the concept of entropy.

Summing up, The Kolmogorov–Sinai-entropy measures unpredictability of a dynamical system. The higher unpredictability, the higher entropy. This fits nicely with Shannon entropy, where unpredictability of the next character is equivalent to new information. It also fits with the concept of entropy in thermodynamics, where disorder increases the entropy, and disorder and unpredictability are closely related.

Kolmogorov–Sinai-entropy has strongly influenced our understanding of the complexity of dynamical systems. Even though the formal definition is not that complicated, the concept has shown its strength through the highly adequate answers to central problems in the classification of dynamical systems.

About the Abel Prize

The Abel Prize is an international award for outstanding scientific work in the field of mathematics, including mathematical aspects of computer science, mathematical physics, probability, numerical analysis, scientific computing, statistics, and also applications of mathematics in the sciences. The Norwegian Academy of Science and Letters awards the Abel Prize based upon recommendations from the Abel Committee. The Prize is named after the exceptional Norwegian mathematician Niels Henrik Abel (1802–1829). According to the statutes of the Abel Prize, the objective is both to award the annual Abel Prize, and to contribute towards raising the status of mathematics in society and stimulating the interest of children and young people in mathematics. The prize carries a cash award of 6 million NOK (about 750,000 Euro or about 1 million USD) and was first awarded in 2003. Among initiatives supported are the Abel Symposium, the International Mathematical Union's Commission for Developing Countries, the Abel Conference at the Institute for Mathematics and its Applications in Minnesota, and The Bernt Michael Holmboe Memorial Prize for excellence in teaching mathematics in Norway. In addition, national mathematical contests, and various other projects and activities are supported in order to stimulate interest in mathematics among children and youth.

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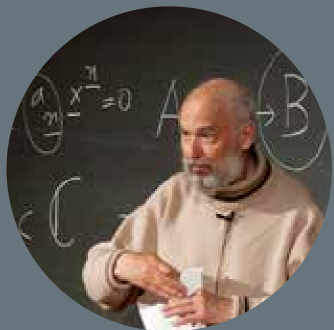
Call for nominations 2015:
The Norwegian Academy of Science and Letters hereby calls for nominations for the Abel Prize 2015, and invite you (or your society or institution) to nominate candidate(s). Nominations are confidential and a nomination should not be made known to the nominee.

Deadline for nominations for the Abel Prize 2015 is September 15, 2014. Please consult **www.abelprize.no** for more information

Welcome back in 2015:
Abel Prize Award Ceremony Tuesday May 19, 2015, University Aula, Oslo.



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The Abel Prize Laureates

2014
Yakov G. Sinai

"for his fundamental contributions to dynamical systems, ergodic theory, and mathematical physics."

2013
Pierre Deligne

"for seminal contributions to algebraic geometry and for their transformative impact on number theory, representation theory, and related fields."

2012
Endre Szemerédi

"for his fundamental contributions to dis crete mathematics and theoretical computer science, and in recognition of the profound and lasting impact of these contributions on additive number theory and ergodic theory."

2011
John Milnor

"for pioneering discoveries in topology, geometry and algebra."

2010
John Torrence Tate

"for his vast and lasting impact on the theory of numbers."

2009
Mikhail Leonidovich Gromov

"for his revolutionary contributions to geometry."

2008
John Griggs Thompson and Jacques Tits

"for their profound achievements in algebra and in particular for shaping modern group theory."

2007
Srinivasa S. R. Varadhan

"for his fundamental contributions to probability theory and in particular for creating a unified theory of large deviations."

2006
Lennart Carleson

"for his profound and seminal contributions to harmonic analysis and the theory of smooth dynamical systems."

2005
Peter D. Lax

"for his groundbreaking contributions to the theory and application of partial differential equations and to the computation of their solutions."

2004
Sir Michael Francis Atiyah and Isadore M. Singer

"for their discovery and proof of the index theorem, bringing together topology, geometry and analysis, and their outstand ing role in building new bridges between mathematics and theoretical physics."

2003
Jean-Pierre Serre

"for playing a key role in shaping the modern form of many parts of mathematics, including topology, algebraic geometry and number theory."

Programme
Abel Week 2014

May 19

Holmboe Prize Award Ceremony
The Minister of Education and Research presents the Bernt Michael Holmboe Memorial Prize for teachers of mathematics at Oslo Cathedral School

Wreath-laying ceremony
by the Abel Prize Laureate at the Abel Monument in the Palace Park

May 20

Abel Prize Award Ceremony
HRH The Crown Prince presents the Abel Prize in the University Aula, University of Oslo

Reception and interview with the Abel Laureate
Journalist Tonje Steinsland interviews the Abel Laureate at Det Norske Teatret

Abel Banquet at Akershus Castle in honour of the Abel Laureate
Hosted by the Norwegian Government (by invitation from the Norwegian Government)

May 21

The Abel Lectures
Laureate Lecture, Science Lecture, and other lectures in the field of the Laureate's work
Georg Sverdrups Hus, Aud. 1,
University of Oslo

The Abel Party
at The Norwegian Academy of Science and Letters

May 22

Laureate Lecture and events for schoolchildren in Stavanger
Programme at Vitenfabrikken in Sandnes, and Laureate lecture at the University of Stavanger

ABEL PRIZE 2014

The Norwegian Academy of Science and Letters

Press contact:
Anne-Marie Astad
a.m.astad@dnva.no
+47 22 12 10 92
+47 415 67 406

For other information:
Trine Gerlyng
abelprisen@dnva.no

Register online at: www.abelprize.no from mid-April, or contact abelprisen@dnva.no

Photo front page: Princeton University, Department of Mathematics