2017 Levi L. Conant Prize

David H. Bailey

Jonathan Borwein

Andrew Mattingly

Glenn Wightwick

David H. Bailey, Jonathan Borwein, Andrew Mattingly, and Glenn Wightwick were awarded the 2017 Levi L. Conant Prize at the 123rd Annual Meeting of the AMS in Atlanta, Georgia, in January 2017 for their article "The computation of previously inaccessible digits of π^2 and Catalan's constant," published in the *Notices of the American Mathematical Society* in 2013.

Citation

This fascinating article will delight any mathematician who has ever been intrigued by the mysteries of the digits of π. The reader is first taken on a historical journey from Archimedes to the computer age with many interesting anecdotes along the way. For example, "Isaac Newton devised an arcsine-like scheme to compute digits of π and… sheepishly acknowledged 'I am ashamed to tell you to how many figures I carried these computations, having no other business at the time.' Newton wrote these words during the plague year 1666, when, ensconced in a country estate, he devised the fundamentals of calculus and the laws of motion and gravitation."

The remarkable "BBP" formula, discovered by the first author along with Peter Borwein and Simon Plouffe, allows one to calculate binary or hexadecimal digits of π beginning with the nth digit without first calculating any of the preceding $n-1$ digits. We are led through an elementary proof of the BBP formula but also learn about the nonconventional search that originally led to this formula, along with similar formulas for Catalan's constant and π^2.

Most intriguing are the insights into the age-old question of whether the digits of π are truly randomly distributed. A real number α is said to be b-normal, where b is a positive integer, if every string of base b digits appears in the base b expansion of α with the expected limiting frequency. The first two authors and Richard Crandall observed that the normality of real numbers such as π that admit BBP formulas can be reduced to proving the equidistribution in (0,1) of a related recursively defined sequence. In particular, we are shown an explicit sequence x_n in (0,1) such that $16x_n$ appears to produce exactly the hexadecimal expansion of π, with an explicit minuscule bound on any possible errors. If this sequence can be proven to be randomly distributed, it will follow that π is 16-normal.

Computations of digits of π have practical applications: running paired computations of π provides a strenuous integrity test of computer hardware and software. Well beyond such applications, however, few mathematical objects have piqued the public interest as powerfully as π. Next π Day, we can amaze our friends by reciting the sequence of ten digits of π starting from position 17,387,594,880, namely 0123456789!

We are saddened that the second author, a frequent contributor to the *Notices*, did not live to receive this prize. Borwein's creative work and beautiful expositions will be sorely missed.

Biographical Sketch: David H. Bailey

David H. Bailey received his PhD in mathematics from Stanford University in 1976 and in his subsequent career worked at the NASA Ames Research Center and then at the Lawrence Berkeley National Laboratory. He recently retired from the Berkeley Lab but continues as a research associate with the University of California Davis, Department of

Computer Science. His published work includes over two hundred papers in experimental mathematics, computational number theory, parallel computing, high-precision computing, fast Fourier transforms, and mathematical finance. Perhaps his best-known paper, coauthored with Peter Borwein and Simon Plouffe, describes a new formula for π, discovered by a computer program, that permits one to directly calculate binary digits of π, beginning at an arbitrary starting position, without needing to calculate any of the preceding digits. Bailey operates several blogs and writes articles on mathematics, computing, and science for the *Huffington Post* and the *Conversation*. He has previously received the Chauvenet and Merten Hesse Prizes from the Mathematical Association of America, the Sidney Fernbach Award from the IEEE Computer Society, and the Gordon Bell Prize from the Association of Computing Machinery.

Response from David H. Bailey

I am truly honored to be a co-recipient of this year's Levi L. Conant Prize. It is remarkable how the number π, after more than two millennia, continues to amaze, delight, and inspire the general public and professional mathematicians alike. We have learned so much, and yet there is so much more that we still do not know, such as the age-old question of whether and why the digits of π are normal—whether given a positive integer b, every m-long string of base b digits appears in the base b expansion of π with the limiting frequency $1/b^m$. We do not know the answer to this question even for $b = 2$ and $m = 1$, let alone for all m or all b. Computationally exploring questions such as this is a delight and opens an avenue for mathematicians to work hand-in-hand with computer scientists, such as our coauthors Andrew Mattingly and Glenn Wightwick, to make significant contributions. With new theoretical results, combined with ever-more-powerful computer tools, we can look forward to uncovering additional interesting facts about π in the years to come.

This article was the brainchild of our coauthor Jonathan M. Borwein, who sadly passed away on August 2, 2016, in what can only be described as a monumental loss to the world mathematical community. My own career was deeply intertwined with Jon's, dating back to 1985 when I read a paper by Jon and his brother Peter on their new nth-order convergent algorithms for π. Since then Jon and I have collaborated on five books and more than eighty papers, encompassing a large fraction of my career, and so I owe him a deep debt of gratitude for his inspiration and support. Jon's fascination with π, as well as his delight in bringing the excitement of new findings on π to the general public, was matched only by his indefatigable energy in pursuing a wide range of mathematical research, ranging from optimization and experimental mathematics to biomedical imaging and mathematical finance, using state-of-the-art computer tools to discover and understand new results. For decades to come we will be mining his enormous published corpus (over five hundred papers and twenty-eight books) for insights and inspiration.

Biographical Sketch: Andrew Mattingly

Andrew Mattingly holds a bachelor of science degree with honours in applied mathematics and meteorology from Monash University (Melbourne, Australia) and a master of science in astronomy from Swinburne University (Melbourne, Australia). He is employed as a software architect with IBM Australia. While he specializes in IBM's mainframe systems, he has experience with distributed and supercomputing environments, in particular, IBM's Blue Gene supercomputer. Andrew also operates a remote optical observatory in outback Australia for the benefit of astronomy students at Wheaton College in Massachusetts.

Response from Andrew Mattingly

I am very honoured to receive the Levi L. Conant Prize in the company of my esteemed coauthors. I am grateful to Glenn Wightwick for inviting me to participate in the Pi Day project that led to our winning paper. This collaboration with Glenn, David H. Bailey, and the late Jon Borwein led to many subsequent collaborations in experimental mathematics, awakening my enthusiasm for mathematics that, apart from brief encounters in the course of my astronomical pursuits, had lain dormant for decades while I pursued a career in computer software. I very much appreciate the guidance and patience offered by Jon and David during the preparation of this paper, as we wrangled the IBM Blue Gene into producing the desired numerical results.

Biographical Sketch: Glenn Wightwick

Glenn Wightwick is the deputy vice chancellor and vice president (research) at the University of Technology Sydney (UTS), where he is responsible for research activity and research policy development, postgraduate education, industry liaison, intellectual property, and commercialization. Prior to joining UTS, he worked for IBM for over twenty-seven years in a number of roles related to high-performance and scientific computing. He led the establishment of IBM research and development laboratories in Australia, as director of IBM Research–Australia and director of IBM Australia Development Laboratory and also held the position of chief technologist for IBM Australia. He was appointed an IBM distinguished engineer in 2003 and elected to the IBM Academy of Technology in 2000.

Glenn Wightwick is recognized as a leader in developing Australia's information technology industrial research and development base and as a significant contributor to innovation across the nation. He has a distinguished industrial research and development track record. A fellow of the Australian Academy of Technological Sciences and Engineering, Wightwick has also served on the Australian Research Council (ARC) College of Experts and the Board of National ICT Australia and has led national bodies and committees such as the NSW Digital Economy Industry Taskforce. He has a bachelor of science from Monash University.

FROM THE AMS SECRETARY

Response from Glenn Wightwick

I am absolutely delighted and deeply honoured to receive the 2017 Levi L. Conant Prize along with my collaborators David H. Bailey, Jonathan Borwein, and Andrew Mattingly for our paper in the *Notices of the AMS*. The computations associated with this research work were undertaken on an IBM Blue Gene supercomputer and were partly motivated by a public event at the University of Technology Sydney (where I now work) to celebrate international Pi Day in 2011. Even though I am not a practicing mathematician, the opportunity to contribute to a large computation involving π connects me back to some of my first interactions with computers at school in 1976. I was fortunate then to have access to DEC PDP-11/750 and an Apple and used them to compute π using various algorithms, including a Monte Carlo method which revealed (rather painfully!) fundamental limitations in the underlying pseudorandom number generator. This began a lifelong love of computation, and I have been very fortunate to work on numerical weather models, seismic processing algorithms, computational chemistry problems, and bioinformatics. I would very much like to acknowledge my coauthors on this paper and the many colleagues over the years whom I have interacted with. In particular, I would like to acknowledge Lance Leslie, who taught me everything I know about numeric weather prediction. Finally, I was deeply saddened by the passing of Jonathan Borwein in August 2016. He was one of the world's experts in π, and he will be sadly missed by many inside and outside the mathematical community.

About the Prize

The Levi L. Conant Prize is awarded annually to recognize an outstanding expository paper published in either the *Notices of the AMS* or the *Bulletin of the AMS* in the preceding five years.

Established in 2001, the prize honors the memory of Levi L. Conant (1857–1916), who was a mathematician at Worcester Polytechnic Institute. The prize carries a cash award of US$1,000.

The Conant Prize is awarded by the AMS Council acting on the recommendation of a selection committee. For the 2017 prize, the selection committee consisted of the following individuals:

- John C. Baez
- Carolyn Gordon (Chair)
- Serge L. Tabachnikov

The complete list of recipients of the Conant Prize follows.

2001 Carl Pomerance
2002 Elliott Lieb, Jakob Yngvason
2003 Nicholas Katz, Peter Sarnak
2004 Noam D. Elkies
2005 Allen Knutson, Terence Tao
2006 Ronald M. Solomon
2007 Jeffrey Weeks
2008 J. Brian Conrey, Shlomo Hoory, Nathan Linial, Avi Wigderson
2009 John W. Morgan
2010 Bryna Kra
2011 David Vogan
2012 Persi Diaconis
2013 John Baez, John Huerta
2014 Alex Kontorovich
2015 Jeffrey C. Lagarias, Chuanming Zong
2016 Daniel Rothman
2017 David H. Bailey, Jonathan Borwein, Andrew Mattingly, Glenn Wightwick

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