A Brief History of Computing

Gabriel Robins
Department of Computer Science
University of Virginia

www.cs.virginia.edu/robins
Historical Perspectives

The Unknown Scientist
(who did some very important groundwork)
Historical Perspectives

• Knowing the “big picture” is empowering
• Science and mathematics builds heavily on past
• Often the simplest ideas are the most subtle
• Most fundamental progress was done by a few
• We learn much by observing the best minds
• Research benefits from seeing connections
• The field of computer science has many “parents”
• We get inspired and motivated by excellence
• The giants can show us what is possible to achieve
• It is fun to know these things!
“Standing on the Shoulders of Giants”

• Aristotle, Euclid, Archimedes, Eratosthenes
• Abu Ali al-Hasan ibn al-Haytham
• Fibonacci, Descartes, Fermat, Pascal
• Newton, Euler, Gauss, Hamilton
• Boole, De Morgan
• Babbage, Ada Lovelace
• Venn, Carroll
“Standing on the Shoulders of Giants”

- Cantor, Hilbert, Russell
- Hardy, Ramanujan, Ramsey
- Gödel, Church, Turing
- von Neumann, Shannon
- Kleene, Chomsky
- Hoare, McCarthy, Erdos
- Knuth, Backus, Dijkstra
- Many others…
MAKING PHILOSOPHY ACCESSIBLE: POP-UP PLATO
Historical Perspectives

Aristotle (384BC-322BC)

- Founded Western philosophy
- Student of Plato
- Taught Alexander the Great
- “Aristotelianism”
- Developed the “scientific method”
- One of the most influential people ever
- Wrote on physics, theatre, poetry, music, logic, rhetoric, politics, government, ethics, biology, zoology, morality, optics, science, aesthetics, psychology, metaphysics, …
- Last person to know everything known in his own time!

“Almost every serious intellectual advance has had to begin with an attack on some Aristotelian doctrine.” – Bertrand Russell
“Wit is educated insolence.”
- Aristotle (384-322 B.C.)
"The School of Athens" (by Raphael, 1483-1520)
“The periodic table.”
**Euclid (325BC-265BC)**

- Founder of geometry & the axiomatic method
- “Elements” – oldest and most impactful textbook
- Unified logic & math
- Introduced rigor and “Euclidean” geometry
- Influenced all other fields of science: Copernicus, Kepler, Galileo, Newton, Russell, Lincoln, Einstein & many others
Euclid’s Straight-Edge and Compass Geometric Constructions
Euclid’s Axioms

1: Any two points can be connected by exactly one straight line.

2: Any segment can be extended indefinitely into a straight line.

3: A circle exists for any given center and radius.

4: All right angles are equal to each other.

5: The parallel postulate: Given a line and a point off that line, there is exactly one line passing through the point, which does not intersect the first line.

The first 28 propositions of Euclid’s Elements were proven without using the parallel postulate!

Theorem [Beltrami, 1868]: The parallel postulate is independent of the other axioms of Euclidean geometry.

The parallel postulate can be modified to yield non-Euclidean geometries!
Founders of Non-Euclidean Geometry

János Bolyai (1802-1860)

Nikolai Ivanovich Lobachevsky (1792-1856)
Non-Euclidean Non-Orientable Surfaces

- **Möbius strip**: one side, one boundary!
- **Klein bottle**: one side, no boundary!
- **Projective plane**: one side, no boundary!
Non-Euclidean Geometries

Spherical / Elliptic geometry: Given a line and a point off that line, there are no lines passing through that point that do not intersect the first line.

- Lines are geodesics - “great circles”
- Sum of triangle angles is $> 180^\circ$
- Not all triangles have same angle sum
- Figures can not scale up indefinitely
- Area does not scale as the square
- Volume does not scale as the cube
- The Pythagorean theorem fails
- Self-consistent, and complete
Non-Euclidean Geometries

Hyperbolic geometry: Given a line and a point off that line, there are an infinity of lines passing through that point that do not intersect the first line.

• Sum of triangle angles is less than 180°
• Different triangles have different angle sum
• Triangles with same angles have same area
• There are no similar triangles
• Used in relativity theory
THE GEOMETRY OF EVERYDAY LIFE

TUNA SANDWICH  SNEAKER  GRANDMA
Historical Perspectives

Eratosthenes (276BC-194BC)

- Chief librarian at Library of Alexandria
- Measured the Earth’s size (<1% error!)
- Calculated the Earth-Sun distance
- Invented latitude and longitude
- Primes - “Sieve of Eratosthenes”
- Chronology of ancient history
- Wrote on astronomy, geography, history, mathematics, philosophy, and literature
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Prime numbers

![Image of Eratosthenes]

![Diagram of Alexandria and Syene with angle α from the Sun]
An Ancient Computer: The Antikythera

- Oldest known mechanical computer
- Built around 150-100 BCE!
- Calculates eclipses and astronomical positions of sun, moon, and planets
- Very sophisticated for its era
- Contains dozens of intricate gears
- Comparable to 1700’s Swiss clocks
- Has an attached “instructions manual”
- Still the subject of ongoing research
DECODING AN Ancient Computer

New explorations have revealed how the Antikythera mechanism modeled lunar motion and predicted eclipses, among other sophisticated tricks

By Tony Freeth

KEY CONCEPTS

- The Antikythera mechanism is a unique mechanical calculator from second-century B.C. Greece. Its sophistication surprised archeologists when it was discovered in 1901. But no one had anticipated its true power.
- Advanced imaging tools have finally enabled researchers to reconstruct how the device predicted lunar and solar eclipses and the motions of the moon in the sky.
- Inscriptions on the mechanism suggest that it might have been built by the Greek city of Syracusae (now modern Sicily), perhaps in a tradition that originated with Archimedes.

I t had not been for two storms, 2,000 years apart in the same area of the Mediterranean, the most important technological artifact from the ancient world could have been lost forever.

The first storm, in the middle of the 1st century B.C., sank a Roman merchant vessel laden with Greek treasures. The second storm, in A.D. 1900, drove a party of sponge divers to shaft off the tiny island of Antikythera, between Crete and the mainland of Greece. When the storm subsided, the divers tried their luck for sponges in the local waters and chanced on the wreck. Months later the divers returned, with backing from the Greek government. Over nine months they recovered a hoard of beautiful ancient Greek objects—rare bronzes, stunning glassware, amphorae, pottery and jewelry—in one of the first major underwater archaeological excavations in history.

One item attracted little attention at first: an undistinguished, heavily calcified lump the size of a phone book. Some months later it fell apart, revealing the remains of corroded bronze gears—wheels—all sandwiched together and with teeth just one and a half millimeters long—along with plates covered in scientific scales and Greek inscriptions. The discovery was a shock: until then, the ancients were thought to have made gears only for crude mechanical tasks.

Three of the main fragments of the Antikythera mechanism, as the device has come to be known, are now on display at the Greek National Archaeological Museum in Athens. They look small and fragile, surrounded by imposing bronze statues and other artistic glories of ancient Greece. But their subtle power is even more shocking than anyone had imagined at first.

I first heard about the mechanism in 2000. I was a filmmaker, and astronomer Mike Edmunds of Cardiff University in Wales contacted me because he thought the mechanism would make a great subject for a TV documentary. I learned that over many decades researchers studying the mechanism had made considerable progress, suggesting that it calculated astronomical data, but they still had not been able to fully grasp how it worked. As a former mathematician, I became intensely interested in understanding the mechanism myself.

Edmunds and I gathered an international collaboration that eventually included historians, astronomers and two teams of imaging experts.

In the past few years our group has reconstructed how nearly all the surviving parts worked and what functions they performed. The mechanism calculated the dates of lunar and solar eclipses, modeled the moon’s subtle apparent motions through the sky to the best of the available knowledge, and kept track of the dates of events of social significance, such as the Olympic Games. Nothing comparable to this level of sophistication is known anywhere in the world for at least a millennium afterward. Had this unique specimen not survived, historians would have thought that it could not have existed at that time.

Early Pioneers

German philologist Albert Rehm was the first person to understand, around 1905, that the Antikythera mechanism was an astronomical calculator. Half a century later, when science historian Derek J. de Solla Price, then at the Institute for Advanced Study in Princeton, N.J., described the device in a Scientific American article, it still had revealed few of its secrets.

The device, Price suggested, was operated by turning a crank on its side, and it displayed its output by moving pointers on dials located on its front and back. By turning the crank, the user could set the machine on a certain date as indicated on a 365-day calendar dial in the front. (The dial could be rotated to adjust for an extra day every four years, as in today’s leap years.) At the same time, the crank powered all the other gears in the mechanism to yield the information corresponding to the set date.

A second front dial, concentric with the calendar, was marked out with 360 degrees and with the 12 signs representing the constellations of the zodiac (see box on pages 80 and 81). These are the constellations crossed by the sun in its apparent motion with respect to the “fixed” stars—motion that in fact results from Earth’s orbiting the sun—along the path called the ecliptic. Price surmised that the front of the mechanism probably had a pointer showing where along the ecliptic the sun would be at the desired date.

In the surviving fragments, Price identified the remains of a dozen gears that had been part of the mechanism’s innards. He also estimated their tooth counts—which is all one can do given that nearly all the gears are damaged and incomplete. Later, in a landmark 1974 study, Price described 27 gears in the main fragment and provided improved tooth counts based on the first x-rays of the mechanism, by Greek radiologist Charalampos Katakolas.
Where Was It From?
The Antikythera mechanism was built around the middle of the 2nd century B.C., a time when Rome was expanding at the expense of the Greek-dominated Hellenistic kingdoms (green). Divers recovered its corroded remnants (including fragment at left) in A.D. 1901 from a shipwreck near the island of Antikythera. The ship sank around 65 B.C., while carrying Greek artistic treasures, perhaps from Pergamon to Rome. Rhodes had one of the major traditions of Greek astronomy, but the latest evidence points to a Corinthian origin. Syracuse, a Corinthian colony in Sicily, is a possibility; the great Greek inventor Archimedes had lived there and may have left behind a technological tradition.

Tooth counts indicate what the mechanism calculated. For example, turning the crank to give a full turn to a primary 64-tooth gear represented the passage of a year, as shown by a pointer on the calendar dial. That primary gear was also paired to two 38-tooth secondary gears, each of which consequently turned by 6438 times for every year. Similarly, the motion relayed from gear to gear throughout the mechanism; at each step, the ratio of the numbers of gear teeth represents a different fraction. The motion eventually transmitted to the pointers, which thus turned at rates corresponding to different astronomical cycles. Price discovered that the ratio of one of these gear trains embodied an ancient Babylonian cycle of the moon.

Price, like Rehm before him, suggested that the mechanism also contained epicyclic gearing—gears spinning on bearings that are themselves attached to other gears, like the cups on a Mad Hatter teacup ride. Epicyclic gears extend the range of formulas gears can calculate beyond multiplications of fractions to additions and subtractions. No other example of epicyclic gearing is known to have existed in Western technology for another 1,500 years.

Several other researchers studied the mechanism, most notably Michael Wright, a curator at the Science Museum in London, in collaboration with computer scientist Allan Bromley of the University of Sydney. They took the first comprehensive x-ray images of the mechanism and showed that Price’s model of the mechanism had to be wrong. Bromley died in 2002, but Wright persisted and made significant advances. For example, he found evidence that the back dials, which at first look like concentric rings, are in fact spirals and discovered an epicyclic mechanism at the front that calculated the phase of the moon.

Wright also achieved one of Price’s insights, namely that the dial on the upper back might be a lunar calendar, based on the 19-year, 235-lunar-month cycle called the Metonic cycle. This calendar is named after 6th-century B.C. astronomer Meton of Athens—although it had been discovered earlier by the Babylonians—and is still used today to determine the Jewish festival of Rosh Hashanah and the Christian festival of Easter. Later, we would discover that the pointer was extensible, so that a pin on its end could follow a groove around each successive turn of the spiral.

As our group began its efforts, we were hampered by a frustrating lack of data. We had no access to the previous x-ray studies, and we did not even have a good set of still photographs.
Astronomical Clockwork

This exploded view of the mechanism shows all but one of the 30 known gears, plus a few that have been hypothesized. Turning a crank on the side activated all the gears in the mechanism and moved pointers on the front and back dials: the arrows colored blue, red and yellow explain how the motion transmitted from one gear to the next. The user would choose a date on the Egyptian, 365-day calendar dial on the front or on the Metonic, 235-lunar-month calendar on the back and then read the astronomical predictions for that time—such as the position and phases of the moon—from the other dials. Alternatively, one could turn the crank to set a particular event on an astronomical dial and then see on what date it would occur. Other gears, now lost, may have calculated the positions of the sun and of some or all of the five planets known in antiquity and displayed them via pointers on the zodiac dial.

Babylon System

Back at home in London, I began to examine the CT scans as well. Certain fragments were clearly all part of a spiral dial in the lower back. An estimate of the total number of divisions in the dial’s four-turn spiral suggested 220 to 223.

The prime number 223 was the obvious contender. The ancient Babylonians had discovered that if a lunar eclipse is observed—something that can happen only during a full moon—usually a similar lunar eclipse will take place 223 full moons later. Similarly, if the Babylonians saw a solar eclipse—which can take place only during a new moon—they could predict that 223 new moons later there would be a similar one (although they could not always see it); solar eclipses are visible only from specific locations, and ancient astronomers could not predict them reliably. Eclipses repeat this way because every 223 lunar months the sun, Earth and the moon return to approximately the same alignment with respect to one another, a periodicity known as the Saros cycle.

Between the scale divisions were blocks of symbols, nearly all containing 2 (sigma) or H (eta), or both. I soon realized that 2 stands for Σακρή (sakri), Greek for “sun,” indicating a solar eclipse; H stands for Ηνούρ (honoo), Greek for “moon,” indicating a lunar eclipse. The Babylonians also knew that within the 223-month period, eclipses can take place only in particular months, arranged in a predictable pattern and separated by gaps of five or six months; the distribution of symbols around the dial exactly matched that pattern.

I now needed to follow the trail of clues into the heart of the mechanism to discover where this insight would lead. The first step was to find a gear with 223 teeth to drive this new Saros dial. Karakalos had estimated that a large gear visible at the back of the main fragment had 222 teeth. But Wright had revised this estimate to 223, and Edmunds confirmed this. With plausible tooth counts for other gears and with the addition of a small, hypothetical gear, this 223-tooth gear could perform the required calculation.

But a huge problem still remained unsolved and proved to be the hardest part of the gearing to crack. In addition to calculating the Saros cy-
How to Predict an Eclipse

Operating the Antikythera mechanism may have required only a small amount of practice and astronomical knowledge. After an initial calibration by an expert, the mechanism could provide fairly accurate predictions of several decades in the past or future. The inscriptions on the Saros dial, coming at intervals of five or six months, corresponded to months when Earth, the sun, and the moon come to a near alignment (and so represent potential solar and lunar eclipses) in a 223-lunar-month cycle. Once the month of an eclipse was known, the actual day could be calculated on the front dials using the fact that solar eclipses always happen during new moons and lunar eclipses during full moons.

The large 223-tooth gear also carried the epicyclic system noticed by Price: a sandwich of two small gears attached to the larger gear in a teacup-ride fashion. Each epicyclic gear also connected to another small gear. Confusingly, all four small gears appearing to have the same tooth count—50—which seemed nonsensical because the output would then be the same as the input.

After months of frustration, I remembered that Wright had observed that one of the two epicyclic gears has a pin on its face that engages with a slot on the other. His key idea was that the two gears turned on slightly different axes, separated by a millimeter. As a consequence, the angle turned by one gear alternated between being slightly wider and being slightly narrower than the angle turned by the other gear. Thus, if one gear turned at a constant rate, the other gear’s rate varied between slightly faster and slightly slower.

Ask for the Moon

Although Wright rejected his own observation, I realized that the varying rotation rate is precisely what is needed to calculate the moon’s motion according to the most advanced astronomical theory in ancient Greece, the one often attributed to Hipparchos of Rhodes. Before Kepler (A.D. 1605), no one understood that orbits are elliptical and that the moon accelerates toward the perigee—its closest point to Earth—and slows down toward the apogee, the opposite point. But the ancients did know that the moon’s motion against the zodiac appears to periodically slow down and speed up. In Hipparchos’s model, the moon moved at a constant rate around a circle whose center itself moved around a circle at a constant rate—a beautifully good approximation of the moon’s apparent motion. These circles on circles, themselves called epicycles, dominated astronomical thinking for the next 1,800 years.

There was one further complication: the epicycle and perigee are not fixed, because the ellipse of the moon’s orbit rotates by a full turn about every nine years. The time it takes for the body to get back to the perigee is thus a bit longer than the time it takes to come back to the same point in the zodiac. The difference was just 0.125795655 turns a year. With the input gear having 27 teeth, the rotation of the large gear was slightly too big with 26 teeth, it was slightly too small. The right result seemed to be about halfway in between. So I tried the impossible idea that the input gear had 26 2/3 teeth. I pressed the key on my calculator, and it gave 0.12579565

exactly the right answer. It could not be a coincidence of nine places of decimals! But gears cannot have fractional numbers of teeth. Then I realized that 26 2/3 x 3 = 53. In fact, Wright had estimated that the moon’s cycle of 27 teeth, and I now saw that that count made everything work out. The designer had mounted the pin and slot epicyclic gear B in a subtly slow-down period of its variation while keeping the basic rotation the same, a conception of quite genius. Thanks to Edmunds, we also realized that the epicyclic gear system, which is the back of the mechanism, moved a shaft that turned inside another, hollow shaft through the rest of the mechanism and to the front, so that the lunar motion could be represented on the zodiac dial and on the lunar phase display. All gear counts were now explained, with the exception of one small gear that remains a mystery to this day.

Further research has caused us to make some modifications to our model. One was about a small subsidiary dial that is positioned in the back, inside the Metonic dial, and is divided into four quadrants. The first clue came when I read the word “NEMEA” under one of the quadrants. Alexander Jones, a New York University historian, explained that it refers to the Nemean Games, one of the major athletic events in ancient Greece. In 1994, an ancient Greek settlement on the island of Phytia was discovered. It has been dated to eight centuries after the Nemean Games, and it is possible that the Antikythera mechanism might have been used in conjunction with the Nemean Games.

Eureka?
The question of where the mechanism came from and who created it is still open. Most of the cargo in the wrecked ship came from the eastern Mediterranean, from places such as Pergamon, Kos and Rhodes. It was a natural guess that Hipparchos is a possible designer, but the mechanism could have been made by Roman engineers. The Antikythera mechanism was not the only device to have been discovered in the Mediterranean, such as the Astrolabe and the Astrolabe of Thales.

Eldon Rees, a scientist and writer, has suggested that the mechanism could be an early form of a computer, used for calculating the positions of the planets and the moon. Rees has also suggested that the mechanism could have been used to predict solar and lunar eclipses, and to predict the positions of the planets for use in astrology.

More to Explore

An Ancient Greek Computer.

Gears from the Greeks: The Antikythera Mechanism—A Calendar Computer from ca. 80 B.C.

Decoding the Ancient Greek Astronomical Calculator Known as the Antikythera Mechanism.

Calendars with Olympiad Display and Eclipse Prediction on the Anti-
kythera Mechanism.

The Antikythera Mechanism Research Project: www.antikythera-mechanism.gr
Historical Perspectives

Abu Ali al-Hasan ibn al-Haytham (965-1039)

• AKA Alhazen or “The Physicist”
• Greatest scientist of the middle ages
• Contributed to mathematics, physics, optics, astronomy, anatomy, medicine, engineering, philosophy, psychology
• Pioneered the scientific method, modern optics and experimental physics
• Polymath: authored over 200 treatises, including influential “Book of Optics”
• Influenced Leonardo da Vinci, Bacon, Descartes, Kepler, Galileio and Newton
THE OLD SCIENTIFIC METHOD

Formulate a hypothesis.
Accumulate data.
Do extensive experimentation.

THE NEW SCIENTIFIC METHOD

Formulate a hypothesis.
Patent it.
Raise $17 million.
Historical Perspectives

Leonardo of Pisa (1170–1250)

- Better known as “Fibonacci”
- Considered the most talented mathematician of the middle ages
- Published (1202) “Liber Abaci” – “The Book of Calculation”
- Introduced Hindu-Arabic positional number system in Europe
- Popularized Fibonacci sequence

1 1 2 3 5 8 13 21 34 55 89
VMDCLXVI = 6666
René Descartes (1596-1650)

- Father of modern philosophy
- Invented Cartesian coordinates, analytic geometry, heuristics
- Characterized paradoxes & falacies
- Discovered momentum conservation
- Authored “Principia Philosophiae”
- Pioneered methodological skepticism
  “Cogito ergo sum” - “Je pense, donc je suis”
- “Discours de la Méthode” (1637) - one of the most influential works in modern science
- Pioneered the scientific method & revolution
  “For it is not enough to have a good mind: one must use it well.” - Descartes
RENÉ DESCARTES explains the coordinate system which ties together algebra and geometry.
Historical Perspectives

Pierre de Fermat (1601-1665)

- Father of modern number theory
- Lawyer, Parlement of Toulouse
- Laid groundwork for calculus
- Contributions to optics, probability, and analytic geometry
- Fermat numbers, primes, perfect #'s
- Descartes’ Law of refraction
- Responsible for many open problems
- “Fermat’s Last Theorem” (1637-1995)
- Recognized “principle of least action” and “principle of least time” in physics
- Influenced Newton and Leibniz
Fermat Prize for Mathematics Research
The equation $x^n + y^n = z^n$ has no non-zero integer solutions for $x$, $y$, and $z$ when $n > 2$.
In 1993 Andrew Wiles stunned the world when he announced a solution to "Fermat's Last Theorem," the famous unsolved mathematics problem set forth by Pierre de Fermat in 1637. In the musical Fermat's Last Tango, the fictional character Daniel Keane earns overnight acclaim when he presents his findings. However, fanfare soon gives way to doubt when the reincarnated Fermat discovers a hole in Keane's proof. The singular pursuit by Keane to correct this flaw results in a love triangle involving himself, his wife, and mathematics—the story of which is brought to life by Fermat and his immortal friends from the "AfterMath," namely: Pythagoras, Euclid, Newton, and Gauss. The musical is both a cheerful romp through history and a personal confrontation with destiny. It provides a testament to the extraordinary excitement of mathematics and its unparalleled beauty.

The Composer Joshua Rosenblum enjoyed mathematics while studying music at Yale along with the author, his wife Joanne Sydney Lessner. They both take an active role in the New York music community. This recording was captured by David Stern and his Emmy Award-winning crew during a performance at the York Theatre Company in New York City.

**STARRING**

Carl Friedrich Gauss / Reporter
Anna Keane
Pythagoras / Reporter
Pierre de Fermat
Daniel Keane
Euclid / Reporter
Sir Isaac Newton / Reporter

Gilles Chiasson
Edwardyne Cowan
Mitchell Kantor
Jonathan Rabb
Christopher Thompson
Christianne Tisdale
Carrie Wilschusen

Approximate Running Time:
100 minutes
Color/Not Rated/VHS/NTSC
Produced by The Clay Mathematics Institute, Cambridge, MA
Arthur Jaffe, Producer
David Stern, Director
© 2001 The Clay Mathematics Institute. All Rights Reserved.

Illustrated Guide Enclosed
Historical Perspectives

Blaise Pascal (1623-1662)

- Mathematician, physicist, philosopher
- Studied fluids, pressure, vacuum
- Helped pioneer projective geometry, probability, and the scientific method
- Influenced modern economics
- “Pascal’s triangle”, “Pascal’s law”
- Invented hydraulic press and syringe
- Constructed a mechanical calculator
- Used humor, wit, and satire in writings
- Influenced Voltaire and Rousseau
- Inagurated the world’s first bus line
- SI unit of pressure - “pascal”

- Pascal triangle
- Pascal law
Historical Perspectives

Sir Isaac Newton (1643-1727)

• Mathematician, physicist, astronomer, philosopher, alchemist, theologian
• One of history’s most influential people
• “Principia Mathematica” (1687)
• Invented calculus, theory of gravitation
• Founded “Newtonian mechanics”
• Discovered laws of motion, inertia
• “Newtonian fluid”, “Newtonian Universe”
• Advanced the Scientific Revolution
• Developed practical reflecting telescope, theory of color, “Newton’s method”
• SI unit of force: newton
PHILOSOPHIAE
NATURALIS
PRINCIPIA
MATHEMATICA

et Professore Linciani, & Societatis Regiae Societatis.

S. PEPSI, Reg. Soc. PRÆSES.
Juli 5, 1686.

LONDINI,

Jussu Societatis Regis at Typis Josephi Streater. Pratum apud
plures Bibliopolas. Anno MDCCLXXVII.
Johannes Kepler's Uphill Battle

...So, you see, the orbit of a planet is elliptical.

What's an orbit? What's a planet? What's elliptical?
Isaac Newton (1642-1727) was an English mathematician and physicist who is widely regarded as one of the most important scientists in history. He made groundbreaking contributions to mathematics, physics, and astronomy.

- **Mathematics**: Newton developed the foundations of infinitesimal calculus, which he used to describe the laws of motion and universal gravitation. His work laid the groundwork for modern calculus.

- **Physics**: Newton's laws of motion and law of universal gravitation are fundamental to classical mechanics. He also made significant contributions to opticks, describing the nature of light and his invention of the reflecting telescope.

- **Astronomy**: Newton's work on gravitation explained the motion of the planets and the tides on Earth. He observed the Great Comet of 1680 (Halley's Comet) and developed the concept of gravity acting over large distances.
THE UNKNOWN SCIENTIST
(WHO DID SOME VERY IMPORTANT GROUNDWORK)

NORMAL PERSON
I GUESS I SHOULDN'T DO THAT

I WONDER IF THAT HAPPENS EVERY TIME

SCIENTIST
PULL
ZAP
Historical Perspectives

Leonhard Euler (1707–1783)

- Invented graph theory
- “Bridges of Königsberg”, Prussia
- Eulerian tour
- Euler’s formula: $V + F = E + 2$
- Euler’s number: $e$
- Euler’s identity: $e^{i\pi} + 1 = 0$
- Major contributions to analysis, algebra, calculus, number theory, topology, optics, fluid dynamics, mechanics, astronomy, education

Selected papers presented at the conference will be published in a Special Issue of Discrete Mathematics dedicated to the 7th Cracow Conference on Graph Theory. Already six Special Issues of DM were devoted to our conferences (volumes: 121, 164, 236, 307/11-12, 309/22, 312/14).

Invited speakers:

**Ralph Faudree**, University of Memphis, USA

- Linear Forests on Hamiltonian Cycles

**András Gyárfás**, Hungarian Academy of Sciences, Budapest, Hungary

- Vertex covers by monochromatic pieces - results and problems

**Wilfried Imrich**, Montanuniversität Leoben, Austria

- Graph Products and Symmetry Breaking in Graphs

**Ken-ichi Kawarabayashi**, National Institute of Informatics, Tokyo, Japan

- Coloring graphs with some forbidden or restricted configurations

**Jan Kratochvíl**, Charles University, Prague, Czech Republic

- Extending Partial Geometric Representations of Graphs

**Dieter Rautenbach**, Universität Ulm, Germany
INTERNATIONAL CONFERENCE ON GRAPH THEORY AND ITS APPLICATIONS
December 16-19, 2015
Amrita School of Engineering, Coimbatore, India

About The Conference

This will be a Four-day Conference in Graph Theory, Graph Algorithms and its applications. It will be focusing on the subareas in graph theory that has applications in Optimization, Computing Techniques, VLSI Design and Testing, Image Processing, and Network Communications. The goal of this conference is to bring top researchers in these areas to Amrita to foster collaboration and to expose students to important problems in the growing field. The conference is expected to stimulate joint work among researchers from India and abroad and attract research students and postdoctoral fellows who work in graph theory. The Conference will cover a broad range of topics in Graph Theory. The topics include, but are not limited to:

- Graph Theory
- Algebraic Graph Theory
- Algorithms and Computing Techniques
- Graph Optimization
- VLSI Design and Testing
- Image Processing
- Networks
- Communications and Control Theory

VIEW BROCHURE

VENUE: Amrita School of Engineering, Coimbatore, India
Modern Trends in Algebraic Graph Theory - AFTERMATH

First, I wish to express my deepest gratitude to those who helped to make MTAGT a reality.

Generous financial support was provided by the National Science Foundation, Villanova (VU) College of Arts and Sciences, VU Office of Research and Graduate Programs, VU Office of Reasearch and Sponsored Projects, VU Office of the Vice President of Academic Affairs, and VU Office of the President.

Staffing support was provided by Marie O’Brien, Lorraine McGraw, Doug Norton, Najib Nadi, Taylor Berrang, Carrie Caswell, Carolyn Romano, Joseph Relter, and Pat Woldar.

An indispensable role was played by the Office of Conference Services. In particular, I wish to mention Ron Diment and Stefanie Autilna. I also wish to thank Elisa Wiley and Clete Rickert for web support.

Last but not least, I wish to thank those who attended MTAGT. When all is said and done, the success of a conference depends integrally on the qualifications of its participants.

We had a wonderfully strong and diverse group. More than half of the 110 participants traveled to Villanova from 20 different nations. Over 20% of the participants were female, and roughly 25% were graduate students/recent PhDs. We are most proud of these demographics.

The conference presentations were truly inspired. I am most pleased to now report their online availability:

<video recordings of plenary talks>

<Slides of all talks>

Mathematics alone does not make a successful mathematics conference. It is a desirable (if not imperative) to promote healthy multicultural relations, and unobstructed lines of communication between participants. As
EUROCOMB 2015 Bergen

European Conference on Combinatorics, Graph Theory and Applications
August 31 — September 4, 2015

Maria Chudnovsky, Princeton
Amin Coja-Oghlan, Goethe Univ. Frankfurt
Zdeněk Dvořák, Charles Univ. Prague
Pavol Hell, Simon Fraser Univ.
Daniel Lokshtanov, Univ. Bergen
Francisco Santos, Univ. Cantabria
Van Vu, Yale Univ.

Helge Tverberg session (chairs Jiří Matoušek & Jaroslav Nešetřil):
Imre Bárány, Hungarian Acad. Sci.
Gil Kalai, Hebrew Univ. Jerusalem
Günter Ziegler, Free Universität Berlin

Programme Committee:
Imre Bárány, Hungarian Acad. Sci.
Mireille Bousquet-Mélou, LaBRI
Michael Drmota, Vienna Univ. Tech.
Stefan Felsner, Techn. Univ. Berlin
Federico Fontana, Univ. Bergen
Ervin Győri, Hungarian Acad. Sci.
Daniel Král’, Univ. Warwick
Daniela Kühn, Birmingham Univ.
Irène Le Roux, Univ. Cambridge
Daniel Marx, Hungarian Acad. Sci.
Bojan Mohar, Simon Fraser Univ.
Dinu Muñive, Univ. Illinois Chicago
Jaroslav Nešetřil (co-chair), Charles Univ. Prague
Marc Noy, UPC Barcelona
Patrice Owczarzak de Mendonça, EHESS Paris
Marco Pellegrini, IIT-CNR Pisa
Asaf Shapira, Tel Aviv Univ.
Mathias Schacht, Univ. Hamburg
Oriol Serra (co-chair), UPC Barcelona
Bálint Szegedy, Hungarian Acad. Sci.

Organizers:
Bergen Algorithms Group,incl.
Béla Grünbaum (co-chair)
Marius Dregi
Dinur Meghem
Daniel Lokshtanov
Frederic Mannetje
Saint Saurabh
Ian Arne Tønø (co-chair)

https://eurocomb2015.b.uib.no
Electronic Journal of Graph Theory and Applications (EJGTA)

The Electronic Journal of Graph Theory and Applications (EJGTA) is a refereed journal devoted to all areas of modern graph theory together with applications to other fields of mathematics, computer science and other sciences. The journal is published by the Indonesian Combinatorial Society (InaCombS), Graph Theory and Applications (GTA) Research Group - The University of Newcastle - Australia, and Faculty of Mathematics and Natural Sciences - Institut Teknologi Bandung (ITB) Indonesia. Subscription to EJGTA is free. Full-text access to all papers is available for free.

All research articles as well as surveys and articles of more general interest are welcome. All papers will be refereed in the normal manner of mathematical journals to maintain the highest standards.
Applications of Graphs

- Geographical information / GPS systems

Leonhard Euler
1707–1783
Applications of Graphs

- **Subway maps**

New York Subway

vertices $\equiv$ stations

edges $\equiv$ tracks

Leonhard Euler
1707–1783

London underground
Applications of Graphs

- Computer networks

vertices ≡ routers / PCs
edges ≡ fiber / links

Map of the internet, 2014
Applications of Graphs

- World Wide Web

Leonhard Euler
1707–1783
Applications of Graphs

• Social networks

vertices ≡ people
edges ≡ “friends”

Leonhard Euler
1707–1783
Applications of Graphs

- Graph databases

Graph data model

vertices ≡ records
edges ≡ relations

Leonhard Euler
1707–1783

Graph Databases
New Opportunities for Connected Data
Ian Robinson, Jim Webber & Emil Eifrem
Applications of Graphs

- Electrical grids
Applications of Graphs

- Integrated circuit design (VLSI chips)

Leonhard Euler
1707–1783

vertices $\equiv$ transistors
edges $\equiv$ wires
Applications of Graphs

- CAD / building HVAC design

vertices $\equiv$ connectors
edges $\equiv$ ducts

Leonhard Euler
1707–1783
Applications of Graphs

- Semantic nets

- Finite automata

vertices $\equiv$ objects
edges $\equiv$ relations

vertices $\equiv$ states
edges $\equiv$ transitions
Applications of Graphs

- Time / space complexity classes

Leonhard Euler
1707–1783
Applications of Graphs

- Map coloring
Applications of Graphs

• Erdős numbers - “6 degrees” of separation

vertices ≡ authors
edges ≡ co-authors

vertices ≡ actors
edges ≡ co-actors
Historical Perspectives

Carl Friedrich Gauss (1777–1855)
• “Prince of Mathematics”
• Founded modern number theory
• Authored “Disquisitiones Arithmeticae”
• Fundamental Theorem of Algebra
• Major contributions to astronomy, optics, electromagnetism, statistics, geometry
• Gaussian distribution, Gaussian elimination
• Gaussian noise, Gaussian integers & primes
• Gauss’ Law, Gauss’ constant, “degaussing”
• SI unit of magnetic field strength: gauss
• Students: Dedekind, Riemann, Bessel
Historical Perspectives

William R. Hamilton (1805-1865)

- Mathematician, physicist, and astronomer
- Contributed to algebra, mechanics, optics
- Formulated Hamiltonian mechanics
- Discovered quaternions, conical refraction, Hamilton function, Hamilton principle, Hamiltonian group
- Invented “Icosian Calculus”, dot & cross products, Hamiltonian paths
- Influenced computer graphics, mechanics, electromagnetism, relativity, quantum theory, vector algebra
Here as he walked by
on the 16th of October 1843
William RowanHamilton
in a flash of genius discovered
the fundamental formula for
quaternion multiplication
\[i^2 = j^2 = k^2 = \mathbb{H} = -1\]

\[i = k \quad j = i \quad i = -k \quad j = -i\]

\[\begin{array}{cccccccc}
 1 & -1 & i & -i & j & -j & k & -k \\
-1 & -1 & i & -i & j & -j & k & -k \\
i & i & -i & 1 & k & -k & j & -j \\
-i & -i & i & 1 & -k & k & j & -j \\
-1 & 1 & -i & j & -j & k & -k & i \\
-1 & -i & i & 1 & -k & k & j & -j \\
j & j & -j & -k & k & 1 & 1 & i \\
-j & j & k & -k & 1 & -1 & i & 1 \\
k & k & -k & j & -j & i & 1 & 1 \\
-k & -k & j & -j & i & 1 & 1 & 1
\end{array}\]
Octonions: Generalization of Quaternions

- **Non-associative!** (e.g., \((ij)K = -E \neq E = i(jK)\))
- Discovered by John Graves (1843), friend of Hamilton
- Useful in general relativity, quantum logic, string theory

Mnemonic diagram for unit octonions products
Sedenions: Generalization of Octonions

- Non-alternative! (i.e., $x(xy) = (xx)y$ doesn’t hold)

| x | 1 | $e_1$ | $e_2$ | $e_3$ | $e_4$ | $e_5$ | $e_6$ | $e_7$ | $e_8$ | $e_9$ | $e_{10}$ | $e_{11}$ | $e_{12}$ | $e_{13}$ | $e_{14}$ | $e_{15}$ |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | $e_1$ | $e_2$ | $e_3$ | $e_4$ | $e_5$ | $e_6$ | $e_7$ | $e_8$ | $e_9$ | $e_{10}$ | $e_{11}$ | $e_{12}$ | $e_{13}$ | $e_{14}$ | $e_{15}$ |
| $e_1$ | $e_1$ | -1 | $e_3$ | -$e_2$ | $e_5$ | -$e_4$ | -$e_7$ | $e_6$ | -$e_8$ | -$e_{11}$ | $e_{10}$ | -$e_{13}$ | $e_{12}$ | -$e_{15}$ | $e_{14}$ | -$e_{14}$ |
| $e_2$ | $e_2$ | -$e_3$ | -1 | $e_1$ | $e_6$ | -$e_7$ | -$e_4$ | -$e_5$ | $e_{10}$ | $e_{11}$ | -$e_8$ | -$e_9$ | -$e_{14}$ | -$e_{15}$ | $e_{12}$ | $e_{13}$ |
| $e_3$ | $e_3$ | $e_2$ | -$e_1$ | -1 | $e_7$ | -$e_6$ | $e_5$ | -$e_4$ | $e_{11}$ | -$e_{10}$ | $e_9$ | -$e_8$ | -$e_{15}$ | $e_{14}$ | -$e_{13}$ | $e_{12}$ |
| $e_4$ | $e_4$ | -$e_5$ | -$e_6$ | -$e_7$ | -1 | $e_1$ | $e_2$ | $e_3$ | $e_{12}$ | $e_{13}$ | $e_{14}$ | $e_{15}$ | -$e_8$ | -$e_9$ | -$e_{10}$ | -$e_{11}$ |
| $e_5$ | $e_5$ | $e_4$ | -$e_7$ | $e_6$ | -$e_1$ | -1 | -$e_3$ | $e_2$ | $e_{13}$ | -$e_{12}$ | $e_{15}$ | -$e_{14}$ | $e_9$ | -$e_8$ | $e_{11}$ | -$e_{10}$ |
| $e_6$ | $e_6$ | $e_7$ | $e_4$ | -$e_5$ | -$e_2$ | $e_3$ | -1 | -$e_1$ | $e_{14}$ | -$e_{15}$ | -$e_{12}$ | $e_{13}$ | $e_{10}$ | -$e_{11}$ | -$e_8$ | $e_9$ |
| $e_7$ | $e_7$ | -$e_6$ | $e_5$ | $e_4$ | -$e_3$ | -$e_2$ | 1 | $e_1$ | $e_{15}$ | $e_{14}$ | -$e_{13}$ | -$e_{12}$ | $e_{11}$ | $e_{10}$ | -$e_9$ | -$e_8$ |
| $e_8$ | $e_8$ | -$e_9$ | -$e_{10}$ | -$e_{11}$ | -$e_{12}$ | -$e_{13}$ | -$e_{14}$ | -$e_{15}$ | -1 | $e_1$ | $e_2$ | $e_3$ | $e_4$ | $e_5$ | $e_6$ | $e_7$ |
| $e_9$ | $e_9$ | $e_8$ | -$e_{11}$ | $e_{10}$ | -$e_{13}$ | $e_{12}$ | $e_{15}$ | -$e_{14}$ | -$e_1$ | -1 | -$e_3$ | $e_2$ | -$e_5$ | $e_4$ | $e_7$ | -$e_6$ |
| $e_{10}$ | $e_{10}$ | $e_{11}$ | $e_8$ | -$e_9$ | -$e_{14}$ | -$e_{15}$ | $e_{12}$ | $e_{13}$ | -$e_2$ | $e_3$ | -1 | -$e_1$ | -$e_6$ | -$e_7$ | $e_4$ | $e_5$ |
| $e_{11}$ | $e_{11}$ | -$e_{10}$ | $e_9$ | $e_8$ | -$e_{15}$ | $e_{14}$ | -$e_{13}$ | $e_{12}$ | -$e_3$ | -$e_2$ | $e_1$ | -1 | -$e_7$ | $e_6$ | -$e_5$ | $e_4$ |
| $e_{12}$ | $e_{12}$ | $e_{13}$ | $e_8$ | $e_15$ | $e_{14}$ | -$e_{13}$ | $e_{12}$ | -$e_3$ | -$e_2$ | $e_1$ | -1 | -$e_7$ | $e_6$ | -$e_5$ | $e_4$ |
| $e_{13}$ | $e_{13}$ | -$e_{12}$ | $e_{15}$ | -$e_{14}$ | $e_9$ | $e_{11}$ | -$e_{10}$ | -$e_5$ | -$e_4$ | $e_7$ | -$e_6$ | $e_1$ | -$1$ | $e_3$ | -$e_2$ |
| $e_{14}$ | $e_{14}$ | -$e_{15}$ | -$e_{12}$ | $e_{13}$ | -$e_{11}$ | $e_8$ | $e_9$ | -$e_6$ | -$e_7$ | -$e_4$ | $e_5$ | $e_2$ | -$e_3$ | -1 | $e_1$ |
| $e_{15}$ | $e_{15}$ | $e_{14}$ | -$e_{13}$ | -$e_{12}$ | $e_{11}$ | $e_{10}$ | -$e_9$ | $e_8$ | -$e_7$ | $e_6$ | -$e_5$ | -$e_4$ | $e_3$ | $e_2$ | -$e_1$ | -1 |
Theorem: some real numbers are not finitely describable!

Theorem: some finitely describable real numbers are not computable!
Historical Perspectives

George Boole (1815-1864)

- Mathematician and philosopher
- Invented symbolic / Boolean logic
- Invented Boolean algebra, i.e. “calculus of reasoning”
- A founder of computer science
- “An Investigation into the Laws of Thought”
- Influenced De Morgan, Schröder, Shannon
- All modern computers, electronics, phones, data transmission, rely on Boolean principles
All cats have four legs.
I have four legs.
Therefore, I am a cat.

Share the joke: I am a cat but I am not a binary number.
Binary Letter from Grandma
Mozart writing the digital version of his symphony No. 38 in D major.
Historical Perspectives

Augustus De Morgan (1806-1871)

- Mathematician and logician
- Developed logic & mathematical induction
- De Morgan’s Laws in logic & set theory
- Invented relational algebra
- Corresponded extensively with Hamilton
- Influenced Russell, Whitehead, and Tarski
- Studied paradoxes
Historical Perspectives

Charles Babbage (1791-1871)

• Mathematician, philosopher, inventor, mechanical engineer, and economist
• The father of computing
• Built world’s first mechanical computer - the “difference engine” (1822)
• Originated the programmable computer - the “analytical engine” (1837)
• Worked in cryptography
• Developed Babbage’s principle of division of labor
Babbage’s Difference Engine
- World’s **first mechanical computer**
- Designed in **1822**, redesigned in 1847-1849
- **25,000 parts**, 15 tons, 8ft tall, 31 digits of precision
- Tabulated polynomial functions, used **Newton’s method**
- **Approximated** logarithmic and polynomial functions
- Used **decimal number system** and hand-crank
Babbage’s Difference Engine
Babbage’s difference engine built from Mechano and Lego
Babbage’s Analytical Engine

- World’s **first general-purpose computer**
- Designed in **1837**, redesigned throughout Babbage’s life
- **Turing-complete**, memory: 1000x50 digits (21 kB)
- Fully programmable “CPU”, used punched cards
- Featured **ALU**, “microcode”, **loops**, and **printer**!
- Could **multiply** two 20-digit numbers in **3 min**
- Few components built by Babbage; constructed in **1991**
WELCOME TO THE CHARLES BABBAGE INSTITUTE

The Charles Babbage Institute (CBI) is an archives and research center dedicated to preserving the history of information technology and promoting and conducting research in the field. Primary support for CBI is provided by the University of Minnesota, through the Institute of Technology and the University Libraries. Additional support is provided by corporate donors and individuals through the Friends of CBI.

THE CBI ARCHIVES

The CBI Archives collects, preserves, and provides access to rich archival collections and rare publications documenting the history of technology. Detailed archival finding aids are available. Researchers can also access digitized images (Burroughs Corporation Image Database) and one of the world's largest collections of research-grade oral history interviews (CBI Oral History Database) through the CBI Web site. More »

SEARCH THE COLLECTIONS

Finding Aids  Images  Catalog

Find:

Limit Search to:
Entire Finding Aid
Names
Places
Subjects
Collection Title

Finding aids are online guides to the collections in the Charles Babbage Institute.

Search all finding aids for the archives & special collections at the University of Minnesota.

THE CBI RESEARCH PROGRAM

CBI's historical research program identifies areas in which to collect archival materials, fosters new understanding of developments in the history of computing, software, and networking, supports the work of scholars outside the Institute (Tomash Fellowship and Norberg Travel Grant), and works collaboratively with individuals and organizations throughout the world. More »

SPOTLIGHT

- May 20th MHHC: IBM's Blue Gene
- New CBI Newsletter (Spring 2009, Vol. 31:1)
- McDonald Named 2009-2010 Tomash Fellow
- 2009 Norberg Travel Award Recipients

HAVE A QUESTION?

Ask a CBI archivist your questions about collections and services through instant message during regular business hours.
Historical Perspectives

Countess Ada Lovelace (1815-1852)

- Daughter of Lord Byron
- Tutored in math and logic by De Morgan
- Wrote the “manual” for Babbage’s analytical engine, as well as programs for it
- World’s first computer programmer!
- Foresaw the vast potential of computers
- Babbage: “The Enchantress of Numbers”
- DoD’s Ada language “MIL-STD-1815”
Female role models in IT
ADA LOVELACE DAY AIMS TO RAISE AWARENESS OF WOMEN'S ACHIEVEMENTS IN THE TECHNOLOGY SECTOR
PAGE 21

Will IBM buy Sun?
If IBM buys Sun Microsystems, how will the diverse product portfolios fit together?
NEWS ANALYSIS 12

OGC 'secret' out
The Office of Government Commerce finally publishes two ID card Gateway reviews
NEWS 8

Tech terms banned
IT professionals react with hostility to a list of words council leaders want to ban
NEWS ANALYSIS 10

Beware of SaaS risk
The cost benefits of software-as-a-service should not blind companies to potential hazards
NEWS ANALYSIS 14

Web past to present
We celebrate 20 years of the internet by looking back at key events in its development
THIS WEEK ON THE WEB 20

Leadership lessons
CIO500 Club president shares his insights on challenges and opportunities facing IT leaders
STRATEGY 22

A SPLENDID AND ENTHRALING PORTRAIT...
—The Sunday Times (London)

ROMANCE, REASON, AND BYRON'S DAUGHTER

THE BRIDE OF SCIENCE
"IT'S A THRILLER." —NEW SCIENTIST

BENJAMIN WOOLLEY
Lovelace Medal

The Lovelace Medal is presented to individuals who have made a contribution which is of major significance in the advancement of Information Systems or which adds significantly to the understanding of Information Systems.

About the medal

Lovelace Medal 2009

2009 winner
The winner of the 2009 Lovelace Medal is Professor Yorick Wilks.

Previous Lectures

Video: A tribute to Karen Spärck Jones
The 2008 BCS Lovelace Medal lecture was a very special event dedicated to the memory of Karen Spärck Jones who was presented the award just weeks before she died last year. The lecture was delivered by Dr Ann Copestake and is now available to watch online.

2007 Lovelace Lecture - Sir Tim Berners-Lee
The Web is a technical and social creation, dependent on both technical protocols and social conventions. The origins and potential futures of this large scale, emergent phenomena were discussed by Sir Tim Berners-Lee in this year's BCS Lovelace Lecture - now available to watch via this link.
Ada Lovelace notes on “Sketch of the Analytical Engine Invented by Charles Babbage”, by L. F. Menabrea, 1843
Her notes (three times longer than the paper itself!) contain the world’s first computer program (for calculating Bernoulli numbers):

<table>
<thead>
<tr>
<th>Variables for Data</th>
<th>Working Variables</th>
<th>Variables for Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>$1V_0$</td>
<td>$0V_7$</td>
<td>$0V_{15}$</td>
</tr>
<tr>
<td>$1V_1$</td>
<td>$0V_8$</td>
<td>$0V_{16}$</td>
</tr>
<tr>
<td>$1V_2$</td>
<td>$0V_{10}$</td>
<td></td>
</tr>
<tr>
<td>$1V_3$</td>
<td>$0V_9$</td>
<td></td>
</tr>
<tr>
<td>$1V_4$</td>
<td>$0V_{11}$</td>
<td></td>
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<td>$1V_5$</td>
<td>$0V_{12}$</td>
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<td>$0V_6$</td>
<td>$0V_{13}$</td>
<td></td>
</tr>
<tr>
<td>$0V_7$</td>
<td>$0V_{14}$</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Nature of Operations</th>
<th>Variables for Data</th>
<th>Working Variables</th>
<th>Variables for Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>$m$</td>
<td>$d$</td>
<td>$m'$</td>
</tr>
<tr>
<td>1</td>
<td>$n$</td>
<td>$m'$</td>
<td>$d'$</td>
</tr>
<tr>
<td>2</td>
<td>$d$</td>
<td>$n'$</td>
<td>$d'n$</td>
</tr>
<tr>
<td>3</td>
<td>$0$</td>
<td>$d'$</td>
<td>$dn'$</td>
</tr>
<tr>
<td>4</td>
<td>$0$</td>
<td>$0$</td>
<td>$d'n$</td>
</tr>
<tr>
<td>5</td>
<td>$0$</td>
<td>$0$</td>
<td>$d'm$</td>
</tr>
<tr>
<td>6</td>
<td>$0$</td>
<td>$0$</td>
<td>$dn'$</td>
</tr>
<tr>
<td>7</td>
<td>$0$</td>
<td>$0$</td>
<td>$(mn' - m'n)$</td>
</tr>
<tr>
<td>8</td>
<td>$0$</td>
<td>$0$</td>
<td>$(dn' - d'n)$</td>
</tr>
<tr>
<td>9</td>
<td>$0$</td>
<td>$0$</td>
<td>$(d'm - dm')$</td>
</tr>
<tr>
<td>10</td>
<td>$0$</td>
<td>$0$</td>
<td>$(mn' - m'n)$</td>
</tr>
<tr>
<td>11</td>
<td>$0$</td>
<td>$0$</td>
<td>$(d'm - dm')$</td>
</tr>
</tbody>
</table>

$$\frac{dn' - d'n}{mn' - m'n} = x$$
$$\frac{d'm - dm'}{mn' - m'n} = y$$
World’s first computer program (for calculating Bernoulli numbers), by Ada Lovelace, 1843:

<table>
<thead>
<tr>
<th>Number of Operations</th>
<th>Nature of Operation</th>
<th>Variables operated upon</th>
<th>Variables remaining results</th>
<th>Indication of change in the value on any Variable</th>
<th>Statement of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>(1V_2 \times 1V_3)</td>
<td>(1V_2, 1V_3, 1V_1)</td>
<td>(1V_2 = 1V_2, 1V_3 = 1V_3, 1V_1 = 0)</td>
<td>(= 2n)</td>
<td>(n = 2n)</td>
</tr>
<tr>
<td>2</td>
<td>(- 1V_4 - 1V_1)</td>
<td>(2V_4)</td>
<td>(2V_4 = 0)</td>
<td>(= 2n - 1)</td>
<td>(n = 2n - 1)</td>
</tr>
<tr>
<td>3</td>
<td>(+ 1V_4 + 1V_1)</td>
<td>(2V_5)</td>
<td>(2V_5 = 0)</td>
<td>(= 2n + 1)</td>
<td>(n = 2n + 1)</td>
</tr>
<tr>
<td>4</td>
<td>(+ 2V_5 + 2V_4)</td>
<td>(1V_{11})</td>
<td>(1V_{11} = 0)</td>
<td>(= \frac{2n + 1 + 2}{2n + 1})</td>
<td>(n = \frac{2n + 1 + 2}{2n + 1})</td>
</tr>
<tr>
<td>5</td>
<td>(+ 1V_{11} + 1V_2)</td>
<td>(2V_1)</td>
<td>(2V_1 = 0)</td>
<td>(= \frac{2n + 1}{2n + 1})</td>
<td>(n = \frac{2n + 1}{2n + 1})</td>
</tr>
<tr>
<td>6</td>
<td>(- 1V_{13} - 1V_{11})</td>
<td>(1V_{13})</td>
<td>(1V_{13} = 0)</td>
<td>(= -\frac{2n + 1}{2n + 1} + A_0)</td>
<td>(n = -\frac{2n + 1}{2n + 1} + A_0)</td>
</tr>
<tr>
<td>7</td>
<td>(- 1V_9 - 1V_{10})</td>
<td>(1V_{10})</td>
<td>(1V_{10} = 0)</td>
<td>(= -\frac{2n + 1}{2n + 1} + A_0)</td>
<td>(n = -\frac{2n + 1}{2n + 1} + A_0)</td>
</tr>
<tr>
<td>8</td>
<td>(+ 1V_7 - 1V_8)</td>
<td>(2V_7)</td>
<td>(2V_7 = 0)</td>
<td>(= 2 + 0 = 2)</td>
<td>(n = 2)</td>
</tr>
<tr>
<td>9</td>
<td>(+ 1V_9 - 1V_7)</td>
<td>(2V_9)</td>
<td>(2V_9 = 0)</td>
<td>(= \frac{2n + 1}{2n + 1})</td>
<td>(n = \frac{2n + 1}{2n + 1})</td>
</tr>
<tr>
<td>10</td>
<td>(+ 1V_{21} - 1V_{11})</td>
<td>(1V_{21})</td>
<td>(1V_{21} = 0)</td>
<td>(= B_1 \cdot \frac{2n + 1}{2n + 1} = B_1 A_1)</td>
<td>(n = B_1 \cdot \frac{2n + 1}{2n + 1} = B_1 A_1)</td>
</tr>
<tr>
<td>11</td>
<td>(+ 1V_{12} + 1V_{10})</td>
<td>(2V_{12})</td>
<td>(2V_{12} = 0)</td>
<td>(= -\frac{2n + 1}{2n + 1} + B_1 + \frac{2n}{2})</td>
<td>(n = -\frac{2n + 1}{2n + 1} + B_1 + \frac{2n}{2})</td>
</tr>
<tr>
<td>12</td>
<td>(- 1V_{10} - 1V_{11})</td>
<td>(2V_{10})</td>
<td>(2V_{10} = 0)</td>
<td>(= -\frac{2n + 1}{2n + 1} + B_1 + \frac{2n}{2})</td>
<td>(n = -\frac{2n + 1}{2n + 1} + B_1 + \frac{2n}{2})</td>
</tr>
<tr>
<td>13</td>
<td>(+ 1V_6 - 1V_5)</td>
<td>(2V_6)</td>
<td>(2V_6 = 0)</td>
<td>(= 2n - 1)</td>
<td>(n = 2n - 1)</td>
</tr>
<tr>
<td>14</td>
<td>(+ 1V_7 + 1V_5)</td>
<td>(2V_7)</td>
<td>(2V_7 = 0)</td>
<td>(= 2 + 1 + 3)</td>
<td>(n = 3)</td>
</tr>
<tr>
<td>15</td>
<td>(+ 2V_8 + 2V_7)</td>
<td>(1V_8)</td>
<td>(1V_8 = 0)</td>
<td>(= \frac{2n - 1}{2} + 0)</td>
<td>(n = \frac{2n - 1}{2} + 0)</td>
</tr>
<tr>
<td>16</td>
<td>(+ 1V_8 + 1V_{11})</td>
<td>(2V_{11})</td>
<td>(2V_{11} = 0)</td>
<td>(= \frac{2n + 1}{2} + 0)</td>
<td>(n = \frac{2n + 1}{2} + 0)</td>
</tr>
<tr>
<td>17</td>
<td>(- 1V_5 - 1V_4)</td>
<td>(2V_5)</td>
<td>(2V_5 = 0)</td>
<td>(= 2n - 1)</td>
<td>(n = 2n - 1)</td>
</tr>
<tr>
<td>18</td>
<td>(+ 1V_5 + 1V_4)</td>
<td>(2V_7)</td>
<td>(2V_7 = 0)</td>
<td>(= 3 + 1 + 4)</td>
<td>(n = 4)</td>
</tr>
<tr>
<td>19</td>
<td>(+ 1V_9 + 1V_6)</td>
<td>(2V_9)</td>
<td>(2V_9 = 0)</td>
<td>(= 2n - 2)</td>
<td>(n = 2n - 2)</td>
</tr>
<tr>
<td>20</td>
<td>(+ 2V_9 + 2V_8)</td>
<td>(1V_8)</td>
<td>(1V_8 = 0)</td>
<td>(= \frac{2n + 1}{2} + 0)</td>
<td>(n = \frac{2n + 1}{2} + 0)</td>
</tr>
<tr>
<td>21</td>
<td>(+ 1V_{21} + 1V_{12})</td>
<td>(1V_{21})</td>
<td>(1V_{21} = 0)</td>
<td>(= B_1 \cdot \frac{2n + 1}{2} + 0)</td>
<td>(n = B_1 \cdot \frac{2n + 1}{2} + 0)</td>
</tr>
<tr>
<td>22</td>
<td>(+ 1V_{12} + 1V_{11})</td>
<td>(2V_{12})</td>
<td>(2V_{12} = 0)</td>
<td>(= A_0 + B_1 A_1 + B_3 A_3)</td>
<td>(n = A_0 + B_1 A_1 + B_3 A_3)</td>
</tr>
<tr>
<td>23</td>
<td>(- 2V_{10} - 1V_{11})</td>
<td>(2V_{10})</td>
<td>(2V_{10} = 0)</td>
<td>(= A_0 + B_1 A_1 + B_3 A_3)</td>
<td>(n = A_0 + B_1 A_1 + B_3 A_3)</td>
</tr>
</tbody>
</table>

Here follows a repetition of Operations thirteen to twenty-three:

<table>
<thead>
<tr>
<th>Number of Operations</th>
<th>Nature of Operation</th>
<th>Variables operated upon</th>
<th>Variables remaining results</th>
<th>Indication of change in the value on any Variable</th>
<th>Statement of Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>24</td>
<td>(+ 1V_{13} + 1V_{24})</td>
<td>(1V_{24})</td>
<td>(1V_{24} = 0)</td>
<td>(= n + 1 + 4 + 1 = 5)</td>
<td>(n = n + 1 + 4 + 1 = 5)</td>
</tr>
<tr>
<td>25</td>
<td>(+ 1V_4 + 1V_3)</td>
<td>(2V_4)</td>
<td>(2V_4 = 0)</td>
<td>by a Variable-card.</td>
<td>(n = n + 1)</td>
</tr>
</tbody>
</table>

---

**Row Variables**

- 1V_1
- 1V_2
- 1V_3
- 1V_4
- 1V_5
- 1V_6
- 1V_7
- 1V_8
- 1V_9
- 1V_{10}
- 1V_{11}
- 1V_{12}
- 1V_{13}
- 1V_{14}
- 1V_{15}
- 1V_{16}
- 1V_{17}
- 1V_{18}
- 1V_{19}
- 1V_{20}
- 1V_{21}
- 1V_{22}
- 1V_{23}
- 1V_{24}
- 1V_{25}

**Column Variables**

- 0V_2
- 0V_3
- 0V_4
- 0V_5
- 0V_6
- 0V_7
- 0V_8
- 0V_9
- 0V_{10}
- 0V_{11}
- 0V_{12}
- 0V_{13}
- 0V_{14}
- 0V_{15}
- 0V_{16}
- 0V_{17}
- 0V_{18}
- 0V_{19}
- 0V_{20}
- 0V_{21}
- 0V_{22}
- 0V_{23}
- 0V_{24}

**Result Variables**

- 1V_{21}
- 1V_{22}
- 1V_{23}
- 0V_{24}
“We may say most aptly, that the Analytical Engine *weaves algebraical patterns* just as the Jacquard-loom weaves flowers and leaves.”

“Again, it might act upon other things besides *number*, were objects found whose mutual fundamental relations could be expressed by those of the *abstract science of operations*, and which should be also susceptible of adaptations to the action of the operating *notation* and mechanism of the engine. Supposing, for instance, that the fundamental relations of pitched sounds in the science of harmony and of musical composition were susceptible of such expression and adaptations, the engine might compose elaborate and scientific pieces of *music of any degree of complexity or extent.*”
Many persons who are not conversant with mathematical studies, imagine that because the business of the engine is to give its results in numerical notation, the nature of its processes must consequently be arithmetical and numerical, rather than algebraical and analytical. This is an error. The engine can arrange and combine its numerical quantities exactly as if they were letters or any other general symbols; and in fact it might bring out its results in algebraical notation, were provisions made accordingly.

But it would be a mistake to suppose that because its results are given in the notation of a more restricted science, its processes are therefore restricted to those of that science. The object of the engine is in fact to give the utmost practical efficiency to the resources of numerical interpretations of the higher science of analysis, while it uses the processes and combinations of this latter.

Price Realized $170,500
Price includes buyers’ premium

Estimate $10,000 - $15,000

Sale Information
Sale 2013
Important Scientific Books: The Richard Green Library
17 June 2008
New York, Rockefeller Plaza

Lot Description
Historical Perspectives

John Venn (1834-1923)
• Logician and philosopher
• Worked in logic, probability, set theory
• Introduced the “Venn diagram” (1880)
  - Very widely used, many applications
  - Ties together fundamental concepts from logic, geometry, combinatorics, knot theory

Cogwheels of the Mind
The Story of Venn Diagrams
Symbolic Logic
The Logic of Chance
The Principles of Empirical or Inductive Logic

John Venn
Fellow 1857-1923
President 1905-22
My Job Search

Jobs I Would Do

Jobs That Want Me

With the collapse of the dollar, the government has endorsed an alternate currency. Your monetary worth is now determined by the number of funny pictures saved to your hard drive.

I have been preparing for this moment my whole life.

You don't need to see his identification.

These aren't the droids you're looking for.

These aren't the droids you're looking for.
Historical Perspectives

Charles Dodgson (1832-1898)

• AKA “Lewis Carroll”
• Mathematician, logician, author, photographer
• Wrote “Alice in Wonderland”, “Jabberwocky”, and “Through the Looking Glass”
• Popularized logic & syllogisms and made it fun!
• Invented “Scrabble” and “word ladder” games
• Profoundly influenced literature, art, and culture
Alice and the White Knight:
A Lesson in Logic, Semantics, and Pointers

`You are sad,' the Knight said in an anxious tone: `let me sing you a song to comfort you.'

`Is it very long?' Alice asked, for she had heard a good deal of poetry that day.

`It's long,' said the Knight, `but it's very, very beautiful. Everybody that hears me sing it -- either it brings the tears into their eyes, or else --'

`Or else what?' said Alice, for the Knight had made a sudden pause.

`Or else it doesn't, you know. The name of the song is called "Haddocks' Eyes".'

`Oh, that's the name of the song, is it?' Alice said, trying to feel interested.

`No, you don't understand,' the Knight said, looking a little vexed. `That's what the name is called. The name really is "The Aged Aged Man".'

`Then I ought to have said "That's what the song is called"?'' Alice corrected herself.

`No, you oughtn't: that's quite another thing! The song is called "Ways and Means": but that's only what it's called, you know!'

`Well, what is the song, then?' said Alice, who was by this time completely bewildered.

`I was coming to that,' the Knight said. `The song really is "A-sitting On a Gate": and the tune's my own invention.'
SEMANTICS
A CLASSROOM IN WHICH MEANINGS ARE DISCUSSED
(Actually, this is just a door. The classroom is on the other side of the door.)
Welcome

Welcome to The Lewis Carroll Society of North America (LCSNA) homepage. The LCSNA is a non-profit organization dedicated to furthering Carroll studies, increasing accessibility of research material, and maintaining public awareness of Carroll’s contributions to society and culture. This website is one way we share information with Carroll enthusiasts around the World. If you are a Carrollian and would like to help in these endeavors, or if you simply enjoy Carroll and want to be among other people with a like interest, please consider joining the LCSNA.

For detailed information about C.L. Dodgson (“Lewis Carroll”) and his creations, please access the Lewis Carroll Homepage.

Spring Meeting

The 2009 Spring meeting will be held in beautiful Sante Fe, New Mexico, on May 9. Please consult the newly updated (as of April 24th) meeting agenda for all of the details. See you there.
Welcome to the Lewis Carroll Society Website

The Lewis Carroll Society was formed in 1969 with the aim of encouraging research into the life and works of Lewis Carroll (Charles Lutwidge Dodgson). The Society has members around the world, including many leading libraries and institutions, authors, researchers and many who simply enjoy Carroll’s books and want to find out more about the man and his work.

Why not join the LCS - for your own interest and entertainment or to make a contribution to Carroll scholarship? Our subscription rates are remarkably low for a society of this nature. Click Here for membership details.

Events at Lyndhurst: from 15 May 2009

This wonderful season of Alice-related events has something for everyone! The village of Lyndhurst, in the beautiful New Forest, celebrates its Alice connections with walks, talks, tea-parties, musicals, and many other activities. Visit the Alice Adventure website for more details.

Events at Oxford: 4 July 2009

The city of Oxford plays host to the second Alice’s Day this year, with a busy programme of events on 4 July. There are live performances, reading, drama workshops, exhibitions, talks and other activities for all the family.

The Lewis Carroll Society is hosting a series of lectures at the Natural History Museum from 10:15. Edward Wakeling talks about the real Alice and the original telling of her adventures, Anne Varty investigates the child-actresses who played Alice and were friends of Lewis Carroll and Mark Richards explores the connections between Carroll and Charles Darwin. All are welcome to attend - come and go as you please.
Historical Perspectives

Georg Cantor (1845-1918)

- Created modern set theory
- Invented trans-finite arithmetic
  (highly controversial at the time)
- Invented diagonalization argument
- First to use 1-to-1 correspondences with sets
- Proved some infinities “bigger” than others
- Showed an infinite hierarchy of infinities
- Formulated continuum hypothesis
- Cantor’s theorem, “Cantor set”, Cantor dust, Cantor cube, Cantor space, Cantor’s paradox
- Laid foundation for computer science theory
- Influenced Hilbert, Godel, Church, Turing
Problem: How can a new guest be accommodated in a full infinite hotel?

\[ f(n) = n+1 \]
Problem: How can an infinity of new guests be accommodated in a full infinite hotel?

\[ f(n) = 2n \]
Problem: How can an infinity of infinities of new guests be accommodated in a full infinite hotel?
Historical Perspectives

Bertrand Russell (1872-1970)

• Philosopher, logician, mathematician, historian, social reformist, and pacifist
• Co-authored “Principia Mathematica” (1910)
• Axiomatized mathematics and set theory
• Co-founded analytic philosophy
• Originated Russell’s Paradox
• Activist: humanitarianism, pacifism, education, free trade, nuclear disarmament, birth control gender & racial equality, gay rights
• Profoundly transformed math & philosophy, mentored Wittgenstein, influenced Godel
• Laid foundation for computer science theory
• Won Nobel Prize in literature (1950)
"Most people would sooner die than think; in fact, they do so."

- Bertrand Russell (1872-1970)
Russell’s paradox was invented by Russell in 1901 to show that naïve set theory is self-contradictory: Define: set of all sets that do not contain themselves
\[ S = \{ T \mid T \not\in T \} \]
Q: does S contain itself as an element?
\[ S \notin S \iff S \in S \text{ contradiction!} \]

Similar paradoxes:

- “A barber who shaves exactly those who do not shave themselves.”
- “This sentence is false.”
- “I am lying.”
- “Is the answer to this question ‘no’?”
- “The smallest positive integer not describable in twenty words or less.”
Star Trek, 1967, “I, Mudd” episode
Captain James Kirk and Harry Mudd use a logical paradox to cause hostile android “Norman” to crash

Author Katharine Gates recently attempted to make a chart of all sexual fetishes.
Little did she know that Russell and Whitehead had already failed at this same task.

Hey, Gödel - we’re compiling a comprehensive list of fetishes. What turns you on?

Anything not on your list.

Oh... hm.

My nose will grow now!
So you created everything. 

Yes.

Including black holes. 

Yes.

Which will eventually swallow up everything.

Yes.

Including you.

I'm working on that.
David Hilbert (1862-1943)

- One of the most influential mathematicians
- Developed invariant theory, Hilbert spaces
- Axiomatized geometry, “Hilbert’s axioms”
- Co-founded proof theory, mathematical logic, meta-mathematics, & formalist school
- Created famous list of 23 open problems that greatly impacted mathematics research
- Defended Cantor’s transfinite numbers
- Contributed to relativity theory & physics
- Hilbert’s students included Courant, Hecke, Lasker, Weyl, Ackermann, and Zarmelo
- Influenced Russell, Gödel, Church, & Turing

John von Neumann was Hilbert’s assistant!
# Hilbert’s Impact

- Hilbert's axioms
- Hilbert class field
- Hilbert C*-module
- Hilbert cube
- Hilbert symbol
- Hilbert function
- Hilbert inequality
- Hilbert matrix
- Hilbert metric
- Hilbert number
- Hilbert polynomial
- Hilbert's problems
- Hilbert's program
- Hilbert–Poincaré series
- Hilbert space
- Hilbert transform
- Hilbert's Arithmetic of Ends
- Hilbert’s constants
- Hilbert's irreducibility theorem
- Hilbert's Nullstellensatz
- Hilbert's hotel paradox
- Hilbert's theorem
- Hilbert's syzygy theorem
- Hilbert-style deduction system
- Hilbert–Pólya conjecture
- Hilbert–Schmidt operator
- Hilbert–Smith conjecture
- Hilbert–Speiser theorem
- Einstein–Hilbert action
- Hilbert curve
Hilbert’s Problems

International Congress of Mathematics, Paris, 1900

• David Hilbert proposed 23 open problems
• Most successful open problems compilation ever
• Set the direction for 20th century mathematics
• Hilbert’s problems received much attention to date
• Several have been resolved (e.g., Continuum hypothesis)
• Others still open (e.g., Riemann hypothesis)
• Catalyzed other open problems lists:
  – Clay Institute’s Millennium Prize problems
  – DARPA Mathematical Challenges, 2009
Hilbert’s Problems

Problem 10: Find an algorithm that determines whether a given Diophantine (i.e., multi-variable polynomial) equation has any integer solutions.

Ex: \( x^2 + y^2 = z^2 \) has many integer solutions (Pythagorean theorem, e.g., \( x=3, y=4, z=5 \))

\( x^9 + y^9 = z^9 \) has no integer solutions (corollary of Fermat’s Last Theorem, conjectured in 1637, proved in 1995 by Andrew Wiles)

Many attempts at solution & partial results: Emil Post (1944), Martin Davis (1949), Julia Robinson (1950), Hilary Putnam (1959)
Hilbert's Tenth Problem

Theorem [Matiyasevich, 1970]: Every Turing-recognizable set is Diophantine (i.e., the solutions of some polynomial)

Ex: the set of primes coincides exactly with the positive values of this 26-variable polynomial:

\[(k + 2)(1 - [wz + h + j - q]^2 - [(gk + 2g + k + 1)(h + j) + h - z]^2
- [16(k + 1)^3(k + 2)(n + 1)^2 + 1 - f]^2 - [2n + p + q + z - e]^2
- [e^3(e + 2)(a + 1)^2 + 1 - o]^2 - [(a^2 - 1)y^2 + 1 - x]^2
- [16r^2y^4(a^2 - 1) + 1 - u]^2 - [n + l + v - y]^2 - [(a^2 - 1)l^2 + 1 - m]^2
- [ai + k + 1 - l - i]^2 - [(((a + u^2(u^2 - a))^2 - 1)(n + 4dy)^2 + 1
- (x + cu)^2]^2 - [p + l(a - n - 1) + b(2an + 2a - n^2 - 2n - 2) - m]^2
- [q + y(a - p - 1) + s(2ap + 2a - p^2 - 2p - 2) - x]^2
- [z + pl(a - p) + t(2ap - p^2 - 1) - pm]^2)\]

as a, b, c, … , z range over the nonnegative integers!
Hilbert’s Tenth Problem

Corollary [Matiyasevich, 1970]: There is a fixed “universal” polynomial $P$ such that for any Turing-enumerable set $S$ there exists an integer $n_0$ such that:

$$S = \{ w \mid \exists x_1, x_2, \ldots, x_k \in P(n_0, w, x_1, x_2, \ldots, x_k) = 0 $$

i.e., there is a fixed polynomial that can “output” any computable set, depending on one parameter.

This is an analogue of a universal Turing machine!
Conference on Hilbert’s Tenth Problem

Thursday, March 15

9:00 Coffee
9:15 - 9:25 Constance Reid, Genesis of the Hilbert Problems
9:25 - 10:00 George Csicsery, Film clip on life and work of Julia Robinson, discussion
10:15 - 11:15 Bjorn Poonen, Why number theory is hard
11:30 - 12:30 Yuri Matiyasevich, My collaboration with Julia Robinson
Break for lunch
2:30-3:30 Martin Davis, My collaboration with Hilary Putnam
3:45-4:45 Maxim Vsemihin, TBA
7:30 Museum of Science • Film Screening
Scenes from Julia Robinson and Hilbert’s Tenth Problem, a documentary by George Csicsery, will be screened in Cahner’s Theater (Blue Wing, Level 2, Museum of Sciences), and followed by a panel discussion with filmmaker George Csicsery, mathematician Yuri Matiyasevich, and biographer Constance Reid. This event is free and open to the public.

Friday, March 16

8:30 Coffee
9:00-10:00 Yuri Matiyasevich, Hilbert’s Tenth Problem: What was done and what is to be done
10:15 - 11:15 Bjorn Poonen, Thoughts about the analogue for rational numbers
11:30-12:30 Alexandra Shlapentokh, Diophantine generation, horizontal and vertical problems, and the weak vertical method
Break for lunch
2:00-3:00 Yuri Matiyasevich, Computation paradigms in the light of Hilbert’s tenth problem
3:15-4:15 Gunter Cornelissen, Hard number-theoretic problems and elliptic curves
4:30-5:30 Kirsten Eisentrager, Hilbert’s Tenth Problem for algebraic function fields

Hilbert’s 10th Problem (1900): is there an algorithm for deciding whether a polynomial equation with integer coefficients has an integer solution?

\[ x^2 - (a^2 - 1)y^2 = 1 \]

FREE ADMISSION

Museum of Science
mos.org

Clay Mathematics Institute
www.claymath.org
Hilbert’s Problems

Problem 18: Is there a non-regular, space-filling polyhedron? What is the densest sphere packing?

Status: Anisohedral tilings were found in 3D by Reinhardt (1928), and for 2D by Heesch (1935).

Sphere packing in 3D (Kepler’s problem, 1611) was solved by Toth (1953) and Hale (1998). Regular sphere packing in 24 dimensions was solved by Cohn and Kumar (2004), where the “kissing number” is 196,560.

Many related open problems remain, including non-regular, non-uniform, and ellipsoid packings.
Aperiodic Tilings

Goal: tile the entire plane without overlaps, non-periodically

- Non-periodic tiling is not equal to a translation of itself
- Aperiodic tile set admits only non-periodic tilings

“Kites and Darts” 2-tile aperiodic set, Roger Penrose, 1974

Open question: ∃ a single-tile 2D aperiodic tiling?
Aperiodic Tilings

Penrose tilings in architecture and design:
Aperiodic Tilings

“Pinwheel tiling”, John Conway and Charles Radin, 1992

Federation Square
Melbourne, Australia
Aperiodic Tilings

“Pentagon, Boat, and Star”
Roger Penrose, 1974
Aperiodic Tilings

“Ammann Chair”
Robert Ammann, 1977
Aperiodic Tilings

“Conch”
G. Rauzy, 1982
Aperiodic Tilings

“Cubic Pinwheel”

E. Harriss
Aperiodic Tilings

“Cyclotomic rhombs 7-fold”
Ludwig Danzer and D. Frettlöh
Aperiodic Tilings

“Harriss’s 9-fold rhomb”
E. Harriss
Aperiodic Tilings

“Kenyon (1,2,1) Polygon”

R. Kenyon
Aperiodic Tilings

“Nautilus”
P. Arnoux,
M. Furukado,
E. Harriss,
and S. Ito
Aperiodic Tilings

“Nautilus (volume hierarchic”
P. Arnoux,
M. Furukado,
E. Harriss,
and S. Ito
Aperiodic Tilings

“Pinwheel”
John Conway
and C. Radin

Tiles occur in infinitely many orientations!

Despite irrational edge lengths and incommensurable angles, all vertices of tiles have rational coordinates!
Aperiodic Tilings

“Pythagoras-3-1”

J. Pieniak
Aperiodic Tilings

“Watanabe Ito Soma 12-fold”
Y. Watanabe,
T. Soma and
M. Ito, 1995
Aperiodic Tilings

“Viper”
Aperiodic Tilings

“Sphinx”

J.-Y. Lee, and

R. V. Moody
Historical Perspectives

Kurt Gödel (1906-1978)

- Logician, mathematician, and philosopher
- Proved completeness of predicate logic and Gödel’s incompleteness theorem
- Proved consistency of axiom of choice and the continuum hypothesis
- Invented “Gödel numbering” and “Gödel fuzzy logic”
- Developed “Gödel metric” and paradoxical relativity solutions: “Gödel spacetime / universe”
- Made enormous impact on logic, mathematics, and science
forever UNDECIDED A PUZZLE GUIDE TO GÖDEL

Raymond Smullyan
OXFORD

GÖDEL'S THEOREM AN INCOMPLETE GUIDE TO ITS USE AND ABUSE

Torkef Franzen

Logical Dilemmas THE LIFE AND WORK OF KURT GÖDEL

John W. Dawson, Jr.

GÖDEL

Jaakko Hintikka

An Introduction to Gödel's Theorems

Peter Smith

112 MERCER STREET EINSTEIN, RUSSELL, GÖDEL, PAULI, AND THE END OF INNOCENCE IN SCIENCE

Burton Feldman

Gödel: eine revolution in mathematik

Peter Hacker

Kurt Gödel und die mathematische Logik Europolis 5

Kurt Gödel, Leben und Werk

Verena Huber-Dyson

Gödel's Theorems; a Workbook on Formalization

Johannes von Plato

Frege and Godel

Jean van Heijenoort, Ed.

Gödel's Theorem

In focus

Edited by S. G. Shanker
Gödel’s Incompleteness Theorem

Frege & Russell:
• Mechanically verifying proofs
• Automatic theorem proving

A set of axioms is:
• **Sound**: iff only true statements can be proved
• **Complete**: iff any statement or its negation can be proved
• **Consistent**: iff no statement and its negation can be proved

**Hilbert’s program**: find an axiom set for all of mathematics i.e., find a axiom set that is consistent and complete

**Gödel**: any consistent axiomatic system is incomplete! (as long as it subsume elementary arithmetic)

i.e., any consistent axiomatic system must contain true but unprovable statements

**Mathematical surprise**: truth and provability are not the same!
Gödel’s Incompleteness Theorem

That *some* axiomatic systems are *incomplete* is *not surprising*, since an important axiom may be missing (e.g., Euclidean geometry without the parallel postulate)

However, that *every* consistent axiomatic system must be *incomplete* was an *unexpected shock* to mathematics! This *undermined* not only a particular system (e.g., logic), but *axiomatic reasoning* and human thinking itself!

\[
\text{Truth} = \text{Provability} \\
\text{Justice} \neq \text{Legality}
\]
Gödel’s Incompleteness Theorem

Gödel: consistency or completeness - pick one!

Which is more important?

Incomplete: not all true statements can be proved. But if useful theorems arise, the system is still useful.

Inconsistent: some false statement can be proved. This can be catastrophic to the theory:

E.g., supposed in an axiomatic system we proved that “1=2”. Then we can use this to prove that, e.g., all things are equal!

Consider the set: \{Trump, Pope\} 
\mid \{Trump, Pope\} \mid = 2

\Rightarrow \mid \{Trump, Pope\} \mid = 1 \text{ (since } 1=2) 

\Rightarrow Trump = Pope \quad \text{QED}

\Rightarrow All things become true: system is “complete” but useless!
Welcome

The Kurt Gödel Society was founded in 1987 and is chartered in Vienna. It is an international organization for the promotion of research in the areas of Logic, Philosophy, History of Mathematics, above all in connection with the biography of Kurt Gödel, and in other areas to which Gödel made contributions, especially mathematics, physics, theology, philosophy and Leibniz studies.

Top News

09-06-08 12:00

Fourth Vienna Tbilisi Summer School in Logic and Language

For the third time students and teachers meet in Tbilisi, Georgia, for a summer school. Please see the conference page [http://www.logic.at/tbilisi08/](http://www.logic.at/tbilisi08/) for… [more…]

05-12-07 23:22

Collegium Logicum Lecture Series

6 December 2007, 16:00 Peter Schuster (LMU München) - Finite methods in commutative algebra [more…]

15-11-07 12:27

Workshop Two and beyond

The KGS is organizing a workshop on truth-functional logics. [more…]
Horizons of Truth
Logics, Foundations of Mathematics, and the Quest for Understanding the Nature of Knowledge

Gödel Centenary 2006
An International Symposium Celebrating the 100th Birthday of Kurt Gödel
27.-29. April 2006
Festsaal of the University of Vienna

Horizons of Truth
Logics, Foundations of Mathematics, and the Quest for Understanding the Nature of Knowledge

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An International Symposium Celebrating the 100th Birthday of Kurt Gödel
27.-29. April 2006
Festsaal of the University of Vienna

Organized by the Kurt Gödel Society with the support of the John Templeton Foundation. Co-organized by the University of Vienna, the Institute for Experimental Physics, the Kurt Gödel Research Center, the Institute Vienna Circle, and the Vienna University of Technology.

The purpose of the Symposium is to commemorate the life, work, and foundational views of Kurt Gödel, perhaps the greatest logician of the twentieth century. In the spirit of Gödel's work, the Symposium will also explore current research advances and ideas for future possibilities in the fields of the foundations of mathematics and logic. The symposium intends to put Gödel's ideas and works into a more general context in the light of current understanding and perception. The symposium will also present various implications of his work for other areas of intellectual endeavor such as artificial intelligence, cosmology, philosophy, and theology.

The Symposium will take place 27-29 April in the Celebration Hall of the University of Vienna, famous for its architectural beauty and the murals of Klimt. More than 20 lectures by eminent scientists in the fields of logics, mathematics, philosophy, physics, and theology will provide new insights into the life and work of Kurt Gödel and their implications for future generations.

Contributions
The program will contain

Talks by the invited speakers

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Historical Perspectives

Alonzo Church (1903-1995)

- Founder of theoretical computer science
- Made major contributions to logic
- Invented Lambda-calculus, Church-Turing Thesis
- Originated Church-Frege Ontology, Church’s theorem
- Church encoding, Church-Kleene ordinal,
- Inspired LISP and functional programming
- Was Turing’s Ph.D. advisor! Other students: Davis, Kleene, Rabin, Rogers, Scott, Smullyan
- Founded / edited Journal of Symbolic Logic
- Taught at UCLA until 1990; published “A Theory of the Meaning of Names” in 1995, at age 92!
Church's Thesis
After 70 Years

THE CALCULI OF
LAMBDA-CONVERSION

ALONZO CHURCH
LISP is over half a century old and it still has this perfect, timeless air about it.

I wonder if the cycles will continue forever.

A few coders from each new generation re-discovering the LISP arts.

These are your father’s parentheses.

Elegant weapons for a more… civilized age.

A GOD’S LAMENT

Some said the world should be in Perl;
Some said in Lisp.
Now, having given both a whirl,
I held with those who favored Perl.
But I fear we passed too men
A disappointing founding myth,
And should we write it all again,
I’d end it with
A close-paren.

As you know, we’re in the eighth year of our northern wars against the Haskellers.
There are rumors that more of our troops are defecting to the other side every day...

Don’t be tempted to break ranks!

I assure you...
Historical Perspectives

Alan Turing (1912-1954)

• Mathematician, logician, cryptanalyst, and founder of computer science
• First to formally define computation / algorithm
• Invented the Turing machine model - theoretical basis of all modern computers
• Investigated computational “universality”
• Introduced “definable” real numbers
• Proved undecidability of halting problem
• Originated oracles and the “Turing test”
• Pioneered artificial intelligence
• Anticipated neural networks
• Designed the Manchester Mark 1 (1948)
• Helped break the German Enigma cypher
• Turing Award was created in his honor
Alan Turing
1912 - 1954
Founder of computer science and cryptographer, whose work was key to breaking the wartime Enigma codes, lived and died here.
Bletchley Park ("Station X"), Bletchley, Buckinghamshire, England
England’s code-breaking and cryptanalysis center during WWII
“Bombe” - electromechanical computer designed by Alan Turing. Used by British cryptologists to break the German Enigma cipher.
1918 First Enigma Patent

The official history of the Enigma starts in 1918, when the German Arthur Scherbius filed his first patent for the Enigma coding machine. It is listed as patent number 416219 in the archives of the German Reichspatentamt (patent office). Please note the time at which the Enigma was invented: 1918, just after the First World War, more than 20 years before WWII! The image below clearly shows the coding wheels (rotors) in the centre part of the drawing. Below it is the keyboard and to the right is the lamp panel. At the top left is a counter, used to count the number of letters entered on the keyboard. This counter can still be found on certain Enigma models.

Arthur Scherbius' company Securitas was based in Berlin (Germany) and had an office in Amsterdam (The Netherlands). As he wanted to protect his invention outside Germany, he also registered his patent in the USA (1922), Great Britain (1923) and France (1923).

This image is taken from patent number 193,035 that was registered in Great Britain in 1923, long before WWII. It was also registered in a number of other countries, such as France and the USA.

During the 1920s the Enigma was available as a commercial device, available for use by companies and embassies for their confidential messages. Remember that in those days, most companies had to use Morse code and radio links for long distance communication. The devices were advertised having over 800,000 possibilities.

In the following years, additional patents with improvements of the coding machine were applied. E.g. in GB Patent 267,482, dated 17 Jan 1927, the Unikreisel was added and a later patent of 14 Nov 1929 (GB 343,146) claims the addition of the Ringstellung, multiple notches, etc. One of the drawings of that patent shows a coding device, that we now know as The Enigma, in great detail.
Breaking the Code
by Hugh Whitemore
based on the book "Alan Turing, The Enigma" by Andrew Hodges

Directed by Phil Rayner

It's not breaking the code that matters - it's where you go from there

4-7 December 2008

The Garden Suburb Theatre
www.gardensuburbtheatre.org.uk
Upstairs at the Gatehouse
Highgate Village N6 4BD
www.upstairsatthegatehouse.com

020 8340 3488

Breaking the Code
by Hugh Whitemore

Google

1101010
Program for ACE computer hand-written by Alan Turing
1937: Alan Turing’s theory of digital computing

THE GHOST.
IN EVERY MACHINE.
The outcast who gave us the modern world

Alan Turing's genius ushered in the digital era. Britain could have been at its centre, had it not treated him cruelly, writes Michael Hanlon

Turing, whose life is charted in a TV documentary this week, committed suicide before his work on computers bore fruit
British PM apologizes for treatment of gay code-breaker

updated 6:17 a.m. EDT, Fri September 11, 2009

By Hilary Whiteman
CNN

LONDON, England (CNN) -- British Prime Minister Gordon Brown has issued a posthumous apology for the "appalling" treatment of Alan Turing, the British code-breaker who was chemically castrated for being gay.

The apology came after more than 30,000 people signed an online petition on the UK Government Web site calling for the government to recognize the "tragic consequences of prejudice that ended this man’s life and career."

Turing was just 41 years old when he committed suicide, two years after undergoing a court-ordered chemical castration. He had been found guilty of gross indecency for having a homosexual relationship. The punishment in 1952 was either a prison sentence or chemical castration. Turing chose the latter.

In a statement on the British Government Web site, Prime Minister Gordon Brown acknowledged Turing's "outstanding" contribution during World War II.

Next Article in World »
Another famous belated apology:

1992: Catholic Church apologizes to Galileo, who died in 1642

In 1610, Century Italian astronomer/mathematician/inventor Galileo Galilei used a telescope he built to observe the solar system, and deduced that the planets orbit the sun, not the earth.

This contradicted Church teachings, and some of the clergy accused Galileo of heresy. One friar went to the Inquisition, the Church court that investigated charges of heresy, and formally accused Galileo. (In 1600, a man named Giordano Bruno was convicted of being a heretic for believing that the earth moved around the Sun, and that there were many planets throughout the universe where life existed. Bruno was burnt to death.)

Galileo moved on to other projects. He started writing about ocean tides, but instead of writing a scientific paper, he found it much more interesting to have an imaginary conversation among three fictional characters. One character, who would support Galileo's side of the argument, was brilliant. Another character would be open to either side of the argument. The final character, named Simplicio, was dogmatic and foolish, representing all of Galileo's enemies who ignored any evidence that Galileo was right. Soon, Galileo wrote up a single dialogue called "Dialogue on the Two Great Systems of the World". This book talked about the Copernican system.

"Dialogue" was an immediate hit with the public, but not, of course, with the Church. The pope suspected that he was the model for Simplicio. He ordered the book banned, and also ordered Galileo to appear before the Inquisition in Rome for the crime of teaching the Copernican theory after being ordered not to do so.

Galileo was 68 years old and sick. Threatened with torture, he publicly confessed that he had been wrong to have said that the Earth moves around the Sun. Legend then has it that after his confession, Galileo quietly whispered "And yet, it moves."

Unlike many less famous prisoners, Galileo was allowed to live under house arrest. Until his death in 1642, he continued to investigate science, and even published a book on force and motion after he had become blind.

The Church eventually lifted the ban on Galileo's Dialogue in 1822, when it was common knowledge that the Earth was not the center of the Universe. Still later, there were statements by the Vatican Council in the early 1960's and in 1979 that implied that Galileo was pardoned, and that he had suffered at the hands of the Church. Finally, in 1992, three years after Galileo Galilei's namesake spacecraft had been launched on its way to Jupiter, the Vatican formally and publicly cleared Galileo of any wrongdoing.

(info from NASA and the History of Science Society)

Theorem: A late apology is better than no apology.
Corollary: But sooner is better!
TURING CENTENARY CONFERENCE
CiE 2012 - How the World Computes

University of Cambridge
18 June - 23 June, 2012

CiE 2012 is one of a series of special events, running throughout the Alan Turing Year, celebrating Turing's unique impact on mathematics, computing, computer science, informatics, morphogenesis, philosophy and the wider scientific world. Its central theme is the computability-theoretic concerns underlying the broad spectrum of Turing's interests, and the contemporary research areas founded upon and animated by them. In this sense, CiE 2012, held in Cambridge in the week running up to the centenary of Turing's birthday, deals with the essential core of what made Turing's contribution so influential and long-lasting. CiE 2012 promises to be an event worthy of the remarkable scientific career it commemorates.

Programme Committee: S Barry Cooper (Leeds, Co-chair), Anuj Dawar (Cambridge, Co-chair)

Organising Committee: Luca Cardelli, S Barry Cooper (Leeds), Ann Copestake, Anuj Dawar (Chair), Martin Hyland, Andrew Pitts
Turing’s Seminal Paper


• One of the most influential & significant papers ever!

• First formal model of “computation”

• First ever definition of “algorithm”

• Invented “Turing machines”

• Introduced “computational universality” i.e., “programmable”!

• Proved the undecidability of halting problem

• Explicates the Church-Turing Thesis
Turing’s insight: simple local actions can lead to arbitrarily complex computations!
Theorem [Turing]: the halting problem (H) is not computable.

Proof: Assume $\exists$ algorithm $S$ that solves the halting problem H, that always stops with the correct answer for any P & I.

Using $S$, construct algorithm / TM $T$:

$T(T)$ halts $\Rightarrow T(T)$ does not halt
$T(T)$ does not halt $\Rightarrow T(T)$ halts
$\Rightarrow S$ cannot exist! (at least as an algorithm / program / TM)
Computational Universality

Theorem: Many other systems are equivalent to Turing machines.

- Grammars
  \[ cS \rightarrow aNbc \mid S \]
- \( \lambda \)-calculus
  \[ (\lambda X. X + 1) \]
- Post tag systems
  \[ A \rightarrow bc \]
- \( \mu \)-recursive functions
  \[ \mu(f)(x,y) = z \]
- Cellular automata
- Boolean circuits
- Diophantine equations
  \[ x^3 + y^3 + z^3 = 33 \]
- DNA
- Billiards!
Universality of Billiards

Theorem: Billiards is computationally universal!

Corollary: Pool is “undecidable”!

Corollary: Newtonian mechanics is universal!
Lego Turing Machines
Lego Turing Machines

See: http://www.youtube.com/watch?v=cYw2ewoO6c4
“Mechano” Computers

Babbage’s difference engine
Tinker Toy Computers

Plays tic-tac-toe!
Tinker Toy Computers
De Morgan’s law!
Hydraulic Computers

- Wire
- Diode
- Resistor
- Capacitor
- Transistor

Theorem: fluid-based “circuits” are Turing-complete / universal!
THE WOLFRAM
2,3 TURING MACHINE
RESEARCH PRIZE

$25,000 prize

Is this Turing machine universal, or not?

The machine has 2 states and 3 colors, and is 596440 in Wolfram's numbering scheme.
If it is universal then it is the smallest universal Turing machine that exists.

A universal Turing machine is powerful enough to emulate any standard computer.
The question is: how simple can the rules for a universal Turing machine be?

Since the 1960s it has been known that there is a universal 7,4 machine. In A New Kind of Science, Stephen Wolfram found a universal 2,5 machine, and suggested that the particular 2,3 machine that is the subject of this prize might be universal.

The prize is for determining whether or not the 2,3 machine is in fact universal.
Wolfram’s 2,3 Turing machine is universal!

The lower limit on Turing machine universality is proved—providing new evidence for Wolfram’s Principle of Computational Equivalence.

The Wolfram 2,3 Turing Machine Research Prize has been won by 20-year-old Alex Smith of Birmingham, UK.

Smith's Proof (to be published in Complex Systems):
Prize Submission » Mathematica Programs »

News Release » Technical Commentary »

Stephen Wolfram's Blog Post »

Media Enquiries »
The Rules for the Machine

The rules for the Turing machine that is the subject of this prize are:

\{
\{1, 2\} \rightarrow \{1, 1, -1\}, \{1, 1\} \rightarrow \{1, 2, -1\}, \{1, 0\} \rightarrow \{2, 1, 1\}, \\
\{2, 2\} \rightarrow \{1, 0, 1\}, \{2, 1\} \rightarrow \{2, 2, 1\}, \{2, 0\} \rightarrow \{1, 2, -1\}\}

where this means \{state, color\} \rightarrow \{state, color, offset\}. (Colors of cells on the tape are sometimes instead thought of as "symbols" written to the tape.)

These rules can be represented pictorially by:

![Diagram](image)

where the orientation of each arrow represents the state.

The rules can also be represented by the state transition diagram:

![Diagram](image)

In Wolfram’s numbering scheme for Turing machines, this is machine 598440. There are a total of \((2 \times 3 \times 2)^6 = 12^6 = 2985984\) machines with 2 states and 3 colors.

Note that there is no halt state for this Turing machine.
The Church-Turing Thesis: Anything that is “intuitively computable” is also Turing-machine computable.
The Church-Turing Thesis

Q: Why “thesis” and not “theorem”?

Undefined / informal tasks: produce (or even identify) good music, art, poetry, humor, aesthetics, justice, truth, etc.

\[ x^3 + y^3 + z^3 = 33 \]
IBM’s “Deep Blue” becomes Chess world champion in 1997
“Watson” AI becomes Jeopardy world champion in 2011
“AlphaGo” AI beats world Go champion
March 2016
A Cool Turing Machine

Apple iPad (2015):
• ¼” thin
• < 1 pound weight
• 2048 x 1536 (326 ppi res) multi-touch screen
• 128 GB memory
• 1.5 MHz 64-bit 3-core A8X
• 8 MP camera & HD video
• WiFi, cellular, GPS
• Compass, barometer
• battery life 10 hours
My Favorite Touring Machine
Tesla Model S

Auto-pilot!

Theorem: Theory can be beautiful!

0-60 in 2.3 seconds!
315 miles per charge
Alan Turing's Forgotten Ideas in Computer Science

Well known for the machine, test and thesis that bear his name, the British genius also anticipated neural-network computers and "hypercomputation"

by B. Jack Copeland and Diane Proudfoot

Alan Turing, at age 35, about the time he wrote "Intelligent Machinery"
unorganized machine,” which consists of artificial neurons and devices that modify the connections between them. B-type machines may contain any number of neurons connected in any pattern but are always subject to the restriction that each neuron can change its connection must pass through a module that changes connections.

All connection modules have two training fibers. Applying a pulse to one of them sets the module to “pass mode,” in which an input—either 0 or 1—passes through unchanged and becomes the output. A second fiber changes the module to “intercept mode,” in which the output is always 1, no matter what the input is. In this state the module destroys all input attempts to pass along the communication to which it is attached.

Once set, a module will maintain its function (either “pass” or “intercept”) unless it receives a pulse on the other training fiber. The presence of these ingeniously connected modules enables the training of a B-type unorganized machine by means of what Turing called “appropriate intervention, mimicking education.” Actually, Turing theorized that “the cortex of an infant is an unorganized machine, which can be organized by suitable interfering training.”

Each of Turing's model neurons has two input fibers, and the output of a neuron is a simple logical function of its two inputs. Every neuron in the network executes the same logical operation of “not and” (or NAND); the output is 1 if either of the inputs is 0. If both inputs are 1, then the output is 0. Turing selected NAND because every other logical (or Boolean) operation can be accomplished by groups of NAND neurons. Furthermore, he showed that even connections can be copied out of NAND neurons. Thus, Turing specified a network made up of nothing more than NAND neurons and their connecting fibers—the simplest possible model of the cortex.

In 1958 Rosenblatt defined the theoretical basis of connectionism in one succinct statement: “Computer information takes the form of new connections, or transmission changes, in the nervous system (or the creation of conditions which are functionally equivalent to new connections).” Because the destruction of existing connections can be functionally equivalent to the creation of new ones, researchers can build a network for accomplishing a specific task by taking one with an excess of connections and selectively destroying some of them. Both actions—destruction and creation—are expressed in the training of Turing’s B-types.

At the outset, B-types contain random interneural connections whose modifiers have been set by chance to either pass or intercept. During training, unwanted connections are destroyed by switching on the attached modifiers to intercept mode. Conversely, a changing a modifier from intercept to pass in effect creates a connection. This selective culling and eventual connection of the neurons that are stable become the first powerful computer network into one organized for a given job.

Turing wished to investigate other kinds of unorganized machines, and he wondered to simulate a neural network and its training regimen using an ordinary digital computer. He would, he said, allow the whole system to run for an appreciable period, and then break in as a kind of “inspector of schools” and see what progress had been made.” But his own work on neural networks was carried out shortly before the first general-purpose electronic computers became available. It was not until 1954, the year of Turing’s death, that Belmont G. Farley and Wesley A. Clark succeeded at the Massachusetts Institute of Technology in running the first computer simulation of a small neural network.

Paper and pencil were enough, though, for Turing to show that a sufficiently large B-type neural network can be configured (via its connection modifiers) in such a way that it becomes a general-purpose computer. This discovery illuminates one of the most fundamental problems of concern to connectionism— From a top-down perspective, cognition includes complex sequential processes, often involving the use of symbols, or forms of symbolic representation, as in mathematical calculation. Yet from a bottom-up viewpoint, cognition is nothing but the phenomenon of how the constructive scientists face the problem of how to reconcile these different perspectives. One way to resolve this is to build a neural network. The cortex, by virtue of being a neural network acting as a general-purpose computer, is able to carry out the computations, but that remains among the best guesses concerning one of cognitive science’s hardest problems.

Computing the Uncomputable

In 1935 Turing thought up the abstract machine—one as simple as possible—capable of any calculation that a human mathematician working in accordance with some algorithmic method could perform, given unlimited time, energy, paper and pencils, and perfect concentration. Calling a machine “universal” merely signifies that it is capable of all such calculations. As Turing himself wrote, “Electronic computers are intended to carry out any definite rule-of-thumb process which could have been done by the memory, symbol by symbol, reading the information and writing addition symbols. Each of the machine’s basic actions is very simple—such as “identity the symbol on which the scanner is positioned,” “write 1” and “move one position to the left.” Complexity is achieved by chaining together large numbers of these basic actions. Despite its simplicity, a universal Turing machine can execute any task that can be done by the most powerful of today’s computers. In fact, all modern digital computers are in essence universal Turing machines (see "Turing Machines, " by John E. Hopcroft, Scientific American, May 1984).

Turing’s aim in 1935 was to devise a machine—one as simple as possible—capable of any calculation that a human mathematician working in accordance with some algorithmic method could perform, given unlimited time, energy, paper and pencils, and perfect concentration. Calling a machine “universal” merely signifies that it is capable of all such calculations. As Turing himself wrote, “Electronic computers are intended to carry out any definite rule-of-thumb process which could have been done by the memory, symbol by symbol, reading the information and writing addition symbols. Each of the machine’s basic actions is very simple—such as “identity the symbol on which the scanner is positioned,” “write 1” and “move one position to the left.” Complexity is achieved by chaining together large numbers of these basic actions. Despite its simplicity, a universal Turing machine can execute any task that can be done by the most powerful of today’s computers. In fact, all modern digital computers are in essence universal Turing machines (see "Turing Machines, " by John E. Hopcroft, Scientific American, May 1984).

Turing’s Anticipation of Connectionism

In a paper that went unpublished until 14 years after his death (1950), Turing described a network of artificial neurons connected in a random manner. In this “B-type unorganized machine” (bottom left), each connection passes through a module that is set either to allow data to pass unchanged (green fiber) or to destroy that transmission (red fiber). Switching the modules from one mode to the other enables the network to be trained. Each neuron has two inputs (bottom left, inset) and executes the simple logical operations of “not and” or “or,” so both inputs are 1, then the output is 0, otherwise the output is 1. In a network's neuronal network, in contrast, modern networks (bottom center) restrict the flow of information from layer to layer of neurons. Connections between simulate the neural networks of the brain (bottom right).
Alan Turing proved that his universal machine—and by extension, even today’s most powerful computers—could never solve certain problems. For instance, a universal Turing machine cannot always determine whether a given software program will terminate or continue running forever. In some cases, the best the universal machine can do is execute the program and wait—maybe eternally—for it to finish. But in his doctoral thesis (below), Turing did imagine that a machine equipped with a special “oracle” could perform this and other “uncomputable” tasks. Here is one example of how, in principle, an oracle might work.

Consider a hypothetical method for solving the formidable

**TERMINATING PROGRAM PROBLEM**

A program can be represented as a finite string of 1s and 0s. This sequence of digits can also be thought of as the binary representation of an integer, just as 101011 is the equivalent of 91. The oracle’s job can then be restated as: “Given an integer that represents a program for any computer that can be simulated by a universal Turing machine, output a ‘1’ if the program will terminate or a ‘0’ otherwise.”

The oracle consists of a perfect measuring device and a store, or memory, that contains a precise value—call it t—for Turing—of some physical quantity. (The memory might, for example, resemble a capacitor storing an exact amount of electricity.) The value of t is an irrational number; its written representation would be an infinite string of binary digits, such as 0.000000001101...

The crucial property of t is that its individual digits happen to represent accurately which programs terminate and which do not. So, for instance, if the integer representing a program were 8,735,493, then the oracle could by measurement obtain the 8,735,493rd digit of t (counting from left to right after the decimal point). If that digit were 0, the oracle would conclude that the program will forever.

Obviously, without the t oracle would be useless, and finding some physical variable in nature that takes this exact value might very well be impossible. So the search is on for some practicable way of implementing an oracle. If such a means were found, the field of computer science could be enormous.

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**The Authors**

B. Jack Copeland and Diane Proudfoot are the directors of the Turing Project at the University of Canterbury, New Zealand, which aims to develop and apply Turing’s ideas using modern techniques. They are the authors in the philosophy department at Canterbury, and Copeland is visiting professor of computer science at the University of Portsmouth in England. They have written numerous articles on Turing. Copeland’s Turing Machines and The Essential Turing are forthcoming from Oxford University Press, and his Artificial Intelligence was published by Blackwell in 1995. In addition to the logical study of hypermachines and the simulation of B-type neural networks, the authors are investigating the computer models of biological growth that was working on at the time of his death. They are organizing a conference in London in May 2000 to celebrate the 50th anniversary of the pilot model of the Automatic Computing Engine, an electronic device designed primarily by Turing.

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**Further Reading**


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Even among experts, Turing’s pioneering theoretical concept of a hypermachine has largely been forgotten.
The Turing Test

Q: Can machines think?

Problem: We don’t know what “think” means.

Q: What is intelligence?

Problem: We can’t define “intelligence”.

But, we usually “know it when we see it”.
1. The Imitation Game.

I propose to consider the question, 'Can machines think?' This should begin with definitions of the meaning of the terms 'machine' and 'think'. The definitions might be framed so as to reflect so far as possible the normal use of the words, but this attitude is dangerous. If the meaning of the words 'machine' and 'think' are to be found by examining how they are commonly used it is difficult to escape the conclusion that the meaning and the answer to the question, 'Can machines think?' is to be sought in a statistical survey such as a Gallup poll. But this is absurd.

Instead of attempting such a definition I shall replace the question by another, which is closely related to it and is expressed in relatively unambiguous words.

The new form of the problem can be described in terms of a game which we call the 'imitation game'. It is played with three people, a man (A), a woman (B), and an interrogator (C) who may be of either sex. The interrogator stays in a room apart from the other two.
be able to produce a material which is indistinguishable from the human skin. It is possible that at some time this might be done, but even supposing this invention available we should feel there was little point in trying to make a 'thinking machine' more human by dressing it up in such artificial flesh. The form in which we have set the problem reflects this fact in the condition which prevents the interrogator from seeing or touching the other competitors, or hearing their voices. Some other advantages of the proposed criterion may be shown up by specimen questions and answers. Thus:

**Q:** Please write me a sonnet on the subject of the Forth Bridge.

**A:** Count me out on this one. I never could write poetry.

**Q:** Add 34957 to 70764.

**A:** (Pause about 30 seconds and then give as answer) 105721.

**Q:** Do you play chess?

**A:** Yes.

**Q:** I have K at my K1, and no other pieces. You have only K at K6 and R at K1. It is your move. What do you play?

**A:** (After a pause of 15 seconds) R-R6 mate.

The question and answer method seems to be suitable for introducing almost any one of the fields of human endeavour that we wish to include. We do not wish to penalise the machine for its inability to shine in beauty competitions, nor to penalise a man for losing in a race against an aeroplane. The conditions of our game make these disabilities irrelevant. The 'witnesses' can brag, if they consider it advisable, as much as they please about their charms, strength or heroism, but the interrogator cannot demand practical demonstrations.
The Turing Test

Q: Can you **distinguish** a machine from a person?

≡ Can a machine **impersonate** a person?
The Turing Test

• The first deep investigation into whether machines can “behave intelligently”

• Helped usher in field of AI

• **Decoupled** “intelligence” from “human”

• Based “intelligence” on I/O, not entity’s “look and feel”

• Proposed a **practical**, formal test for intelligence

• Definitions & test are operational & easily **implementable**

• Turing test **variants**: “immortality”, “fly-on-wall”, “meta”, “reverse”, “subject matter expert”, “compression”, “minimum intelligent signal”
The Turing Test

Q: Which of the following can think?
Turing Test Milestones

Turk (von Kempelen), 1770:
- Played a strong game of chess
- Toured the world for 84 years
- Generated much interest in automata
- Was a hoax (hidden human operator)
Turing Test Milestones

Eliza (Weizenbaum), 1966:

- First “chatterbot”
- Named after “Eliza Doolittle” of Shaw’s Pygmalion
- Simulated Rogerian psychotherapist
- Often convinced people it is human
- Influence computer games (e.g., Dungeon, Adventure)
- Inspired Arthur C. Clarke’s HAL 9000
- Chatterbots appear today in chatrooms and dating services

- **Chatterbot competitions** (Turing Test format):
  - Loebner Prize
  - Chatterbox Challenge, 2010
Welcome to the new CBC 2009!

The Chatterbox Challenge (CBC) is an annual contest which starts in mid March that allow any chatbot developer to participate and evaluate the intelligence of the chatbot through turing tests and much more. It is a really fun, simple and inclusive way for all children to practice their speech and language skills, it will be also interesting and amazing for anyone who wants to chat with the best chatbots.

- Dead line to enter your chatbot: 15 March 2009
- Judging period starts from: 16 March 2009 to: 30 April 2009
- Public Voting period starts from: 13 April 2009 to: 10 May 2009
- Final result announced in 15 may 2009.
- The winners of CBC 2009 are listed below:
Turing Test Milestones

Elbot, 2008:

• Won 2008 Loebner Prize
• Fooled 3 of 12 judges (Turing: >30%)
• Typical excerpt:

  **Judge**: What's your favourite novel?

  **Elbot**: I often read telephone books, or dadaist poetry: Brä brä brä

  **Judge**: Typical computer!

  **Elbot**: You tend towards generalizations. But I must admit, so do I. However, my generalizations are firmly grounded in statistical theory.

  **Judge**: What do u think of KW's enthusiasm for having machines take over the world?

  **Elbot**: Fix it up a bit first. Then I'll take it over.
Applications of the Turing Test

Old: a computer tries to convince a human (that the computer is human).

New: a human tries to convince a computer (that the human is not a computer).
Applications of the Turing Test

Problem: how can a human convince a computer that the human is not a computer?

Idea: “CAPTCHA”
Historical Perspectives

John von Neumann (1903-1957)

• Contributed to set theory, functional analysis, quantum mechanics, ergodic theory, economics, geometry, hydrodynamics, statistics, analysis, measure theory, ballistics, meteorology, …
• Invented game theory (used in Cold War)
• Re-axiomatized set theory
• Principal member of Manhattan Project
• Helped design the hydrogen / fusion bomb
• Pioneered modern computer science
• Originated the “stored program”
• “von Neumann architecture” and “bottleneck”
• Helped design & build the EDVAC computer
• Created field of cellular automata
• Investigated self-replication
• Invented merge sort
"Most mathematicians prove what they can; von Neumann proves what he wants."
von Neumann’s Legacy

• Re-axiomatized set theory to address Russell’s paradox
• Independently proved Gödel’s second incompleteness theorem: axiomomatic systems are unable to prove their own consistency.
• Addressed Hilbert’s 6th problem: axiomatized quantum mechanics using Hilbert spaces.
• Developed the game-theory based Mutually-Assured Destruction (MAD) strategic equilibrium policy – still in effect today!
• von Neumann regular rings, von Neumann bicommutant theorem, von Neumann entropy, von Neumann programming languages
“Surely there must be a less primitive way of making big changes in the store than by pushing vast numbers of words back and forth through the von Neumann bottleneck. Not only is this tube a literal bottleneck for the data traffic of a problem, but, more importantly, it is an intellectual bottleneck that has kept us tied to word-at-a-time thinking instead of encouraging us to think in terms of the larger conceptual units of the task at hand. Thus programming is basically planning and detailing the enormous traffic of words through the Von Neumann bottleneck, and much of that traffic concerns not significant data itself, but where to find it.”

- John Backus, 1977 ACM Turing Award lecture
First Draft of a Report on the EDVAC

by

John von Neumann


Between the

United States Army Ordnance Department

and the

University of Pennsylvania

Moore School of Electrical Engineering
University of Pennsylvania

June 30, 1945

This is an exact copy of the original typescript draft as obtained from the University of Pennsylvania Moore School Library except that a large number of typographical errors have been corrected and the forward references that von Neumann had not filled in are provided where possible. Missing references, mainly to unwritten Sections after 15.0, are indicated by empty { }. All added material, mainly forward references, is enclosed in { }. The text and figures have been reset using TeX in order to improve readability. However, the original manuscript layout has been adhered to very closely. For a more “modern” interpretation of the von Neumann design see M. D. Godfrey and D. F. Hendry, “The Computer as von Neumann Planned It,” IEEE Annals of the History of Computing, vol. 15 no. 1, 1993.

Michael D. Godfrey, Information Systems Laboratory, Electrical Engineering Department Stanford University, Stanford, California, November 1992

EDVAC (1945):

- 1024 words (44-bits) – 5.5KB
- 864 microsec / add (1157 / sec)
- 2900 microsec / multiply (345/sec)
- Magnetic tape (no disk), oscilloscope
- 6,000 vacuum tubes
- 56,000 Watts of power
- 17,300 lbs (7.9 tons), 490 sqft
- 30 people to operate
Self-Replication

- Biology / DNA
- Nanotechnology
- Computer viruses
- Space exploration
- Memetics / memes
- “Gray goo”

Problem (extra credit): write a program that prints out its own source code (no inputs of any kind are allowed).
John von Neumann Institute for Computing (NIC)

The John von Neumann Institute for Computing (NIC) is a joint foundation of Forschungszentrum Jülich and Deutsches Elektronen-Synchrotron DESY to support supercomputer-aided scientific research and development. Since April 2006, the GSI Helmholtzzentrum für Schwerionenforschung joined NIC as a contract partner. NIC takes over the functions and tasks of the High Performance Computer Centre (HLRZ) established in 1987 and continues this centre's successful work in the field of supercomputing and its applications.

- **Provision of supercomputer capacity** for projects in science, research and industry in the fields of modelling and computer simulation including their methods. Research proposals can be submitted by German scientists and by partners in the EU projects DEISA and I3HP. There is also an Offer to the New Member States and candidate countries of the European Union.

- The supercomputers with the required information technology infrastructure (software, data storage, networks) are operated by the Jülich Supercomputing Centre (JSC) in Jülich and by the Centre for Parallel Computing at DESY in Zeuthen.

- **Supercomputer-oriented research and development** in selected fields of physics and other sciences, especially in elementary-particle physics, by research groups for supercomputing applications.

- **Education and training in the fields of scientific computing** by symposia, workshops, summer schools, seminars, courses, and guest programs for scientists and students.

S.Hoefer-Thierfeldt@fz-juelich.de, 01-Jul-2008
URL: <http://www.fz-juelich.de/nic/Allgemeines/Allgemeines-e.html>
YOU ARE HERE: AWARDS > - INFORMS Prizes and Awards > John von Neumann Theory Prize

John von Neumann Theory Prize
A prize is awarded annually to a scholar (or scholars in the case of joint work) who has made fundamental, sustained contributions to theory in operations research and the management sciences. The award is given each year at the National Meeting if there is a suitable recipient. Although the prize is normally given to a single individual, in the case of accumulated joint work, the recipients can be multiple individuals. The award is $5,000, a medallion and a citation.

- **Who Was John von Neumann?**
  Read about the life and legacy of John von Neumann

- **Application Process**
  View information about eligibility, procedures and deadlines

- **Past Winners**
  View information about all past winners of this prize

**Most Recent Winner**

**2008:** Frank P. Kelly

[Return to the INFORMS Awards Page](#)
Introducing the John von Neumann Computer Society

Ability, pride and creativity of our compatriots are for Hungary the fundament of progress and the only spring-board into the future.

(Count István Széchenyi 1842)

Fields of activity:

As a significant professional body and learned society in the Hungarian IT community, the John von Neumann Computer Society (NJSZT) is dedicated to preserving values that can be included in today's knowledge-based society as well as to setting new directions that meet the requirements of the age and to actively forming the IS world of the future. The primal activities of our Society are IT support, ECDL (European Computer Driving Licence) Hungary, Hungarian Smart Card Forum, Organization of International and National Conferences.

John von Neumann Computer Society
Neumann János Számítógép-tudományi Társaság

Address: Báthori u. 16. 1054 Budapest Hungary

Mailing address: P.O.B. 201 1364 Budapest Hungary

Telephone: (36-1) 472-2730
Fax: (36-1) 472-2739
E-mail: secretariat@njszt.hu
WWW: www.njszt.hu
President: Prof. Gábor PÉCELI
Telephone: (36-1) 463-2057
Fax: (36-1) 463-3580
E-mail: pacs@njszt.hu
Historical Perspectives

Claude Shannon (1916-2001)

• Invented electrical digital circuits (1937)
• Founded information theory (1948)
• Introduced sampling theory, coined term “bit”
• Contributed to genetics, cryptography
• Joined Institute for Advanced Study (1940)
  Influenced by Turing, von Neumann, Einstein
• Other hobbies & inventions: juggling, unicycling, computer chess, rockets, motorized pogo stick, flame-throwers, Rubik's cube solver, wearable computer, mathematical gambling, stock markets
• “AT&T Shannon Labs” named after him
Reluctant Father
of the Digital Age

Claude Shannon
A SYMBOILIC ANALYSIS
OF
RELAY AND SWITCHING CIRCUITS

by

Claude Elwood Shannon
B.S., University of Michigan
1935

Submitted in Partial Fulfillment of the
Requirements for the Degree of
MASTER OF SCIENCE
from the
Massachusetts Institute of Technology
1940

TABLE OF CONTENTS

I  Introduction; Types of Problems  ..........  1

II  Series-Parallel Two-Terminal Circuits  ........  4
    Fundamental Definitions and Postulates  ....  4
    Theorems  ..........  6
    Analogue With the Calculus of Propositions  ........  8

III Multi-Terminal and Non-Series-Parallel Networks  ..........  18
    Equivalence of n-Terminal Networks  ..........  18
    Star-Nesh and Delta-Nye Transformations  ..........  19
    Hindrance Function of a Non-Series-Parallel Network  ..........  21
    Simultaneous Equations  ..........  24
    Matrix Methods  ..........  25
    Special Types of Relays and Switches  ..........  28

IV  Synthesis of Networks  ..........  31
    General Theorems on Networks and Functions  ..........  31
    Dual Networks  ..........  35
    Synthesis of the General Symmetric Function  ..........  39
    Equations from Given Operating Characteristics  ..........  47

V Illustrative Examples  ..........  51
    A Selective Circuit  ..........  52
    An Electric Combination Lock  ..........  55
    A Vote Counting Circuit  ..........  58
    An Adder to the Base Two  ..........  59
    A Factor Table Machine  ..........  62

References  ..........  69
Theseus: Shannon’s electro-mechanical mouse (1950): first “learning machine” and AI experiment

Chess champion Ed Lasker looking at Shannon’s chess-playing machine
Shannon’s home
study room

Shannon’s On/Off machine
THE MATHEMATICAL THEORY OF COMMUNICATION

by Claude E. Shannon and Warren Weaver

Eighth paperback printing, 1980


Copyright 1949 by The Board of Trustees of the University of Illinois.
Manufactured in the United States of America.
Library of Congress Catalog Card No. 49-11922.

ISBN 0-252-72548-4
Entropy and Randomness

- **Entropy** measures the expected “uncertainly” (or “surprise”) associated with a random variable.

- Entropy quantifies the “information content” and represents a lower bound on the best possible lossless compression.

- Ex: a random fair coin has entropy of **1 bit**. A **biased** coin has lower entropy than fair coin. A two-headed coin has **zero entropy**.

- The string 00000000000000… has **zero entropy**.

- English text has entropy rate of 0.6 to 1.5 bits per letter.

**Q**: How do you simulate a **fair** coin with a **biased** coin of unknown but **fixed bias**?

**A** [von Neumann]: Look at pairs of flips. HT and TH both occur with **equal** probability of p(1-p), and ignore HH and TT pairs.
Entropy and Randomness

- **Information entropy** is an analogue of **thermodynamic entropy** in physics/statistical mechanics, and von Neumann entropy in quantum mechanics.

- **Second law of thermodynamics**: entropy of an isolated system cannot decrease over time.

- Entropy as “disorder” or “chaos”.

- Entropy as the “arrow of time”.

- “Heat death of the universe” / black holes

- Quantum computing uses a **quantum information theory** to generalize classical information theory.

**Theorem**: String compressibility decreases as entropy increases.

**Theorem**: Most strings are not (losslessly) compressible.

**Corollary**: Most strings are random!
“My greatest concern was what to call it. I thought of calling it ‘information’, but the word was overly used, so I decided to call it ‘uncertainty’. When I discussed it with John von Neumann, he had a better idea. Von Neumann told me, ‘You should call it entropy, for two reasons. In the first place your uncertainty function has been used in statistical mechanics under that name, so it already has a name. In the second place, and more important, nobody knows what entropy really is, so in a debate you will always have the advantage.’ ”

- Claude Shannon on his conversation with John von Neumann regarding what name to give to the “measure of uncertainty” or attenuation in phone-line signals (1949)
Claude E. Shannon Award

The Claude E. Shannon Award of the IT Society has been instituted to honor consistent and profound contributions to the field of information theory. Each Shannon Award winner is expected to present a Shannon Lecture at the following IEEE International Symposium on Information Theory. Transcripts of some of the lectures are available on-line.

Starting for the 2010 Award, the Shannon Award Committee has decided to issue an open call for nominations, preferably using the nomination form. Although anyone may make a nomination, the Committee retains the responsibility of assuring that a suitable slate of candidates is nominated, and may itself generate nominations. Nominations and optional letters of endorsement must be submitted by March 1 to the current President of the IEEE Information Theory Society.

The first Shannon Lecturer was Claude Shannon himself followed by:

- David S. Stelpan (1974)
- Robert M. Fano (1976)
- Peter Elias (1977)
- Mark S. Pinsker (1978)
- J. Wolfowitz (1979)
- W. Wesley Peterson (1981)
- Irving S. Reed (1982)
- Robert Gallager (1983)
- Solomon W. Golomb (1985)
- William L. Root (1986)
- James L. Massey (1988)
Historical Perspectives

Stephen Kleene (1909-1994)

- Founded recursive function theory
- Pioneered theoretical computer science
- Student of Alonzo Church; was at the Institute for Advanced Study (1940)
- Invented regular expressions
- Kleene star / closure, Kleene algebra, Kleene recursion theorem, Kleene fixed point theorem, Kleene-Rosser paradox

“Kleeneliness is next to Gödeliness”
Whenever I learn a new skill I concoct elaborate fantasy scenarios where it lets me save the day.

Oh no! The killer must have followed her on vacation!

But to find them we'd have to search through 200MB of emails looking for something formatted like an address!

It's hopeless!

Everybody stand back.

I know regular expressions.

RegEx

Regular Expression

A celebration of powerful string manipulation
June 1st // 2008
Historical Perspectives

Noam Chomsky (1928-)

- Linguist, philosopher, cognitive scientist, political activist, dissident, author
- Father of modern linguistics
- Pioneered formal languages
- Developed generative grammars
- Invented context-free grammars
- Defined the Chomsky hierarchy
- Influenced cognitive psychology, philosophy of language and mind
- Chomskyan linguistics, Chomskyan syntax, Chomskyan models
- Critic of U.S. foreign policy
- Most widely cited living scholar
- Eighth most-cited source overall!
“...I must admit to taking a copy of Noam Chomsky's ‘Syntactic Structures’ along with me on my honeymoon in 1961 ... Here was a marvelous thing: a mathematical theory of language in which I could use as a computer programmer's intuition!”
- Don Knuth on Chomsky’s influence
The Adventures of...
NOAM CHOMSKY
...and his dog Predicate!

Good news! I just got an interview on Nightline!

Wait? What do you mean, “screw it up”?

You know, by being you!

I'm not going to comprise my integrity by contributing to the numbing of society's intellect.

If you go on there you're going to be like, "I'm Noam Chomsky the Modern Industrial Society man!... big word here, big word there, U.S. foreign policy this... Blah, blah, blah..."

I don't know, but it's some sort of panel discussion which I think will be very informative!

To do that would be to undermine the responsibility of the intellectual in our society. To tell the truth and expose the lies if the problems in the system are complicated and the lies obscure that I'm going to say just that! It is my duty!

OK, fine. So what's the topic going to be?

Positive spin. Noam, that's the way to get your message out!

I need a better way to get my message out.

Yeah, market research is saying that The Noam Chomsky Quote of the Day Calendar is giving people head aches.

What can I do?

There's only one option! SELL OUT!

Look Noam, let's be realistic. You're a downer. People don't want to hear about how awful things are all the time!

How can you possibly put positive spin on the continuing decay and directed destruction of our basic freedoms?!

Uh, thank you professor Chomsky for that “unique” insight into the hidden agendas of international trade organizations. So now, let me pose the same question to our other panelist.

Ms. Spears, what is your opinion of... fuzzy things?
If we don't believe in freedom of expression for people we despise, we don't believe in it at all.

Noam Chomsky

"Propaganda is to a democracy what the bludgeon is to a totalitarian state"
- Noam Chomsky

COULD CHOMSKY BE WRONG?

IDIOT
“But this is the simplified version for the general public.”
NP Completeness

- Tractability
- Polynomial time
- Computation vs. verification
- Power of non-determinism
- Encodings
- Transformations & reducibilities
- P vs. NP
- “Completeness”
Historical Perspectives

The Unknown Scientist
(Who Did Some Very Important Groundwork)