Career Advice

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The Most Interesting Man in the World: on Careers

“Find out what it is in life you don’t do well, and then don’t do that thing.”
Problem: Can 5 test tubes be spun simultaneously in a 12-hole centrifuge in a balanced way?

Notes:
- All holes are identical / equally-spaced
- All tubes are identical in size / shape / weight / density
- Exactly five test tubes simultaneously
- There are no “tricks” involved here
- Solving this requires no math, only logic / rationality

No math required!
Q: \[ 1 + 2 + 3 + 4 + \ldots + (n-1) + n = ? \]

Q: \[ \left(\frac{1}{4}\right) + \left(\frac{1}{4}\right)^2 + \left(\frac{1}{4}\right)^3 + \left(\frac{1}{4}\right)^4 + \ldots = ? \]

Q: Solve for X:

\[ X^X^X^X^\ldots = 2 \]

Q: How can a new guest be accommodated in a full infinite hotel?

“Mr. Osborne, may I be excused? My brain is full.”
This Talk Gives Meta-Advice!

- Focus on the analogies
- Abstract and generalize the advice
- Don’t take things too literally
- Find the metaphors

“Wax on, wax off…”
The Dating Analogy

• Job searching and dating have a lot in common!

   “Political correctness is tyranny with manners.”
   - Charlton Heston (1924-2008)

• What makes you a more attractive job candidate?
• How can you generate more employer interest?
• Cultivate your confidence and humor
• Leverage the underlying psychology
• Develop meta-strategies:
  Q: Why also apply for jobs you don’t want?
  Q: How to start a “bidding war” over you?
  Q: How can you bootstrap new interviews?
  Q: How to easily get a pay raise or promotion?
More Career Advice

• Make it a “life calling”, not just a job
• Job search in not an application – it’s a campaign!
• Use meta-strategies!
• Watch lots of TED talks
• Read Scientific American and Science News, etc.
• Multitask & leverage

Passive... Proactive!

Wax on

Wax off

Life-long
Take the Initiative

Why not as a grad student / postdoc:
• Teach courses?
• Write grant proposals?
• Mentor students?
• Serve on committees?

Doing what you don’t have to do is much more impressive than just doing what you must!

The “Duck Test”:
If it looks like a duck,
swims like a duck,
and quacks like a duck,
then it probably is a duck.

Start behaving in line with your goals!
Subliminal Impressions

• Subtle but powerful!
• Know more about other people’s field than they know about your field!

I’ve heard you’re one of the best in the marketing business, but I’ve got your portfolio here and it looks like you’ve never run a major campaign. Why should I hire you to head our new initiative?

If you don’t mind my asking, what gave you the idea I was one of the best in the business?

HM? I don’t remember. Just word of mouth or someth... oh, you’re good.

Thank you. When can I start?
Prepare and Train!
Prepare and Train!
Prepare and Train!

- Stand Out and Get Hired! Best Answers to the 201 Most Frequently Asked Interview Questions, Second Edition
- Winning Job Interviews
- Google Résumé: How to Prepare for a Career and Land a Job at Apple, Microsoft, Google, or Any Top Tech Company
- How Would You Move Mount Fuji?
- Your Passport to a Career in Bioinformatics
- Private Notes of a Headhunter
- The Job Search Solution: The Ultimate System for Finding a Great Job Now!
- The New Job Search
Prepare and Train!

- Headhunter Hiring Secrets 2.0: How to Fire Up Your Career and Land Your Ideal Job
  - By Skip Freeman with Michael Goree

- Boost Your Interview IQ
  - Proven Techniques That Will Get You the Job
  - By Carole Martin

- Best Job Ever!
  - Rethink Your Career, Redefine Rich, Revolutionize Your Life
  - By Dr. C.K. Bray

- Interviewing: Bonus Included! 37 Ways to Have Unstoppable Confidence in Your Interview!
  - By Jack Gray

- Cracking the Tech Career
  - Insider Advice on Landing a Job at Google, Microsoft, Apple, or Any Top Tech Company
  - By Gayle Laakmann McDowell

- What to Say in Every Job Interview
  - By Carole Martin

- The Unwritten Rules of the Highly Effective Job Search
  - The Proven Program Used by the World's Leading Career Services Company
  - By Orville Pierson

- [Meme: Interview Like a Boss]
  - By [Unknown Author]
Prepare and Train!
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Prepare and Train!
Prepare and Train!

- The Chicago Guide to Your Academic Career
- On the Market: Strategies for a Successful Academic Job Search
- Advice for New Faculty Members
- Outside the Ivory Tower: A Guide for Academics Considering Alternative Careers
- The Chicago Guide to Landing a Job in Academic Biology
- The Black Academic’s Guide to Winning Tenure—Without Losing Your Soul
Prepare and Train!
Prepare and Train!

- These books are available at: www.cs.virginia.edu/robins/CS_readings.html
- Q: How can you identify the best books?
- Cultivate **intellectual curiosity**!
- Acquire **broad knowledge**
- Become a **deep thinker**
- Drink from the **“fire hose”**
- Impress your colleagues!

“Le Penseur”
Auguste Rodin, 1902
Musée Rodin, Paris
“Stand on the Shoulders of Giants”

- Aristotle, **Plato**, Socrates, **Euclid**, Archimedes
- al-Hasan, Fibonacci, **da Vinci**, Galileo
- **Newton**, Descartes, Fermat, Pascal
- **Euler**, Gauss, Hamilton, **Darwin**
- **Boole**, De Morgan, Babbage, Lovelace
- **Venn**, Carroll, Cantor
- **Einstein**, Tesla, Edison
“Stand on the Shoulders of Giants”

• Hilbert, Russell, Shakespeare
• Bohr, Curie, Ramanujan
• Gödel, Church, Turing
• von Neumann, Shannon
• Kleene, Feynman, Chomsky
• McCarthy, Erdos, Sagan
• Knuth, Dijkstra, Hawking
• Gates, Jobs, Musk

And many others…
"BENEDICT CUMBERBATCH IS OUTSTANDING"

"THE BEST BRITISH FILM OF THE YEAR"

"AN INSTANT CLASSIC"

"A SUPERB THRILLER"

THE IMITATION GAME

BASED ON THE INCREDIBLE TRUE STORY

IN CINEMAS NOVEMBER 14

Alan Turing (1912-1954)
Know your Science Superstars!

Goal: Be able to talk at length about each one! Broadly explore lots of cool ideas & technologies!
“The School of Athens” by Raphael (1483-1520)
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 2nd-century B.C. Greece.
- Its sophistication surprised archaeologists 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 in the Greek city of Syracuse (now in modern Sicily), perhaps in a tradition that originated with the 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 shelter 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 gearwheels—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 staters 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 of comparable technological 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 and 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 Charalambos Karakalos.
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 6,438 times for every year. Similarly, the motion of a helical gear was transmitted 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 ratios 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 three-dimensional x-ray of the mechanism and showed that Price's model of the mechanism had been 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 adopted some 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 fifth-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.

BladeRunner in Athens

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.

Two images in a science magazine—x-rays of a goldfish and an enhanced photograph of a Babylonian clay tablet—suggested to me new ways to get better data.

We asked Hewlett-Packard in California to perform state-of-the-art photographic imaging and X-Tek Systems in the U.K. to do three-dimensional x-ray imaging. After four years of careful diplomacy, John Seiradakis of the Aristotle University of Thessaloniki and Xenophon Moussas of the University of Athens obtained the required permissions, and we arranged for the imaging teams to bring their tools to Athens, a necessary step because the Antikythera mechanism is too fragile to travel.

Meanwhile we had a totally unexpected call from Mary Zafeiriopoulos at the museum. She said she'd been looking at an ancient vessel and found boxes of bits labeled “Antikythera.” Might we be interested? Of course we were interested. We now had a total of 82 fragments, up from about 20.

The HP team, led by Tom Malakoudis, assembled a mysterious-looking dome about five feet across and covered in electronic flashbulbs with a glass and quartz dome of different angles. The team exploited a technique from the computer gaming industry, called polynomial texture mapping, to enhance surface details. Inscriptions Price had found difficult to read were now clearly legible, and fine details could be enhanced on the computer screen by controlling the reflection of the surface and the angle of the lighting. The inscriptions are essentially an instruction manual written on the outer plates.

A month later local police had to clear the streets in central Athens so that a truck carrying the BladeRunner, X-Tek’s eight-ton x-ray machine, could gain access to the museum. The BladeRunner performs computed tomography similar to a hospital’s CT scan, but with finer detail. X-Tek’s Roger Hadland and his group had specially modified it with enough x-ray power to penetrate the fragments of the Antikythera mechanism. The resulting 3-D reconstruction was wonderful: whereas Price could see only a puzzle of overlapping gears, we could now isolate layers inside the fragment and see all the fine details of the gear teeth.

Unexpectedly, the x-rays revealed more than 2,000 new text characters that had been hidden deep inside the fragments. (We have now identified and interpreted a total of 3,000 characters out of perhaps 15,000 that existed originally.) In Athens, Moussas and Yannis Bisaktis, also at the University of Athens, and Agamemnon Tsilakis of the Center for History and Palaeography, have begun to translate these characters. The team has discovered that the mechanism is more than a calendar. It could track the time of the sun, the moon and the planets, and even predict eclipses. The Antikythera was a wonder of its time.
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.

**Astronomical Clockwork**

**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 another 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 Σαλπίμα (salpin), Greek for “moon,” indicating a lunar eclipse; H stands for Ἑλώμα (helio), Greek for “sun,” indicating a solar 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 new 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 cycle to discover inscriptions that had been invisible to human eyes for more than 2,000 years. One translated as “… spiral subdivisions 235…”, confirming that the upper back dial was a spiral describing the Metonic calendar.
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 events 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 represented potential solar and lunar eclipses) in a 223-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.

Ask for the Moon

Although Wright rejected his own observation, he realized that the varying rotation rate is precisely what is needed to calculate the moon’s motion according to the most advanced astronomical theory of the second century B.C., 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. The ancients did know that the moon’s motion against the zodiac appears to periodically slow down and speed up. In Hipparchos’ model, the moon moved at a constant rate around the circle whose center itself moved around a circle at a constant rate—a fairly 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 apogee 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 0.112579655 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% teeth. I pressed the key on my calculator, and I gave it 0.112579655—exactly the right answer. It could not be a coincidence to nine places of decimals! But gears cannot have fractional numbers of teeth.

Then I realized that 26 2/3 x 2 = 53. In fact, Wright had estimated a crucial gear to have 53 teeth, and I knew that that count made everything work out. The designer had mounted the pin and slot epicycle B 9.228 days slowly down the period of its variation while keeping the basic rotation the same, a conception of pure genius.

Thanks to Edmunds, we also realized that the epicyclic gear system, which is in 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. Between 400 and 300 B.C., the four sides of the stadium were decorated with the four months of the year. The Saros and Metonic calendars are related to the ancient Greek calendar, which the ancient Greeks used. The year was divided into 12 months, each month was divided into 30 days, and each day was divided into 24 hours.

Eurekah?

The question of where the mechanism came from and who created it remains open. We do know that the ancient Greeks were familiar with the concept of time, and that they used it to measure the movements of the moon, sun, and planets. The ancient Greeks also knew that the moon has a cycle of phases, and that the phases are related to the position of the moon in its orbit around the Earth. They also knew that the moon has a cycle of eclipses, and that these eclipses are related to the position of the moon in its orbit around the Earth.

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Good Insights

“Try to **learn something about everything** and everything about something.”
- Thomas Huxley (1825-1895)

“It's kind of fun to do the **impossible**.”
- Walt Disney (1901-1966)

“Talent does what it can; **genius** does what it must.”
- Edward George Bulwer-Lytton (1803-1873)

“I have not **failed**. I've just found 10,000 ways that won't work.”
- Thomas Edison (1847-1931)

“If you are going through hell, **keep going**.”
- Sir Winston Churchill (1874-1965)

"First they ignore you, then they laugh at you, then they fight you, then you **win**." - Mahatma Gandhi (1869-1948)

“Ninety percent of success is just **showing up**.”
- Woody Allen (1935- )
“Argue for your limitations, and sure enough they're yours.”
- Richard Bach (1936- )

“We all agree that your theory is crazy, but is it crazy enough?”
- Niels Bohr (1885-1962)

“You can avoid reality, but you cannot avoid the consequences of avoiding reality.” - Ayn Rand (1905-1982)

“Make everything as simple as possible, but not simpler.”
- Albert Einstein (1879-1955)

"Moral indignation is jealousy with a halo."
- H. G. Wells (1866-1946)

“Wit is educated insolence.”
- Aristotle (384-322 BC)

Watch these Videos

www.cs.virginia.edu/robins/CS_readings.html

- **Last Lecture**, Randy Pausch, 2007
- **Time Management**, Randy Pausch, 2007
- **Powers of Ten**, Charles and Ray Eames, 1977
Understand the “Big Picture”

• “Scale of the Universe”, Cary and Michael Huang, 2012

- $10^{-24}$ to $10^{26}$ meters $\Rightarrow$ 50 orders of magnitude!
More Great Reads

www.cs.virginia.edu/robins/CS_readings.html

– You and Your Research, Richard Hamming, 1986
– “How to Solve It”, Polya, 1957
– “What If”, Munroe, 2014
– The Pattern Behind Self-Deception, Shermer TED talk, 2010
Cool Fact: **Generalized Numbers**

Theorem: **some** real numbers are not finitely describable!

Theorem: **some** finitely describable real numbers are not computable!
Cool Fact: Aperiodic Tilings

Goal: tile the entire plane without overlaps, non-periodically
• Non-periodic tiling is not equal to any translation of itself
• Q: Do non-periodic exist?

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

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

Penrose tilings in architecture and design:

Aperiodic tilings also occur in nature (e.g., quasi-crystals)
Aperiodic Tilings

“Ammann A3”
Robert Ammann, 1977
Aperiodic Tilings

“Pythagoras-3-1”

J. Pieniak
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 in Real Life

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

Federation Square
Melbourne, Australia
Cool Fact: **Generalized Rock-Paper-Scissors**

e.g. Rock-Paper-Scissors-Lizard-Spock

**Rules:** Scissors cuts Paper covers Rock crushes Lizard poisons Spock smashes Scissors decapitates Lizard eats Paper disproves Spock vaporizes Rock crushes Scissors
Scissors cuts paper.
Paper covers rock.
Rock crushes lizard.
Lizard poisons Spock.
Spock zaps wizard.
Wizard stuns Batman.
Batman scares Spider-Man.
Spider-Man disarms glock.
Glock breaks rock.
Rock interrupts wizard.
Wizard burns paper.
Paper disproves Spock.
Spock befuddles Spider-Man.
Spider-Man defeats lizard.
Lizard confuses Batman (because he looks like Killer Croc).
Batman dismantles scissors.
Scissors cut wizard.
Wizard transforms lizard.
Lizard eats paper.
Paper jams glock.
Glock kills Batman's mom.
Batman explodes rock.
Rock crushes scissors.
Scissors decapitates lizard.
Lizard is too small for glock.
Glock shoots Spock.
Spock vaporizes rock.
Rock knocks out Spider-Man.
Spider-Man rips paper.
Paper delays Batman.
Batman hangs Spock.
Spock smashes scissors.
Scissors cut Spider-Man.
Spider-Man annoys wizard.
Wizard melts glock.
Glock dents scissors.
Cool Fact: **Cantor Set**

Start with unit segment
- Remove (open) middle third
- **Repeat recursively** on all remaining segments
- Cantor set is all the **remaining points**

Total length removed: \( \frac{1}{3} + \frac{2}{9} + \frac{4}{27} + \frac{8}{81} + \ldots = 1 \)

Cantor set does not contain any intervals
Cantor set is **not empty** (since, e.g. interval endpoints remain)
An **uncountable number of non-endpoints** remain as well (e.g., \( \frac{1}{4} \))
Cantor set is **totally disconnected** (no nontrivial connected subsets)
Cantor set is **self-similar** with Hausdorff dimension of \( \log_3 2 = 1.585 \)
Cantor set is a **closed**, totally bounded, **compact**, complete metric space, with **uncountable** cardinality and lebesgue **measure zero**
Cantor dust (2D generalization): Cantor set crossed with itself

- Changed our conception of areas and volumes!
Cantor cube (3D): Cantor set crossed with itself three times
Explore lots of cool ideas!

Goal: Become a more effective problem solver!
Problem: Can 5 test tubes be spun simultaneously in a 12-hole centrifuge in a balanced way?

- What does “balanced” mean?
- Why are 3 test tubes balanced?
- Symmetry!
- Can you merge solutions?
- Superposition!
- Linearity! $f(x + y) = f(x) + f(y)$
- Can you spin 7 test tubes?
- Complementarity!
- Empirical testing…

No vector calculus / trig!
No equations!
Truth is guaranteed!
Fundamental principles exposed!
Easy to generalize!
High elegance / beauty!
Problem: $1 + 2 + 3 + 4 + … + 100 = ?$

Proof: Induction…

$$100 + 99 + 98 + … + 2 + 1 = \frac{100 \times 101}{2} = 5050$$
Problem: $(1/4) + (1/4)^2 + (1/4)^3 + (1/4)^4 + \ldots = \, ?$

Find a short, geometric, induction-free proof.

\[ \sum_{i=1}^{\infty} \frac{1}{4^i} = \frac{1}{3} \]
Problem: \( (1/8) + (1/8)^2 + (1/8)^3 + (1/8)^4 + \ldots = ? \)

Find a short, geometric, induction-free proof.

\[
\sum_{i=1}^{\infty} \frac{1}{8^i} = \frac{1}{7}
\]
Problem: Solve the following equation for $X$:

\[ \underbrace{X X X \cdots}_n = 2 \]

where the stack of exponentiated $x$’s extends forever.

This “power tower” converges for:

\[ 0.065988 \approx e^{-e} < X < e^{1/e} \approx 1.444668 \]

Generalization to complex numbers:
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?
Stay curious / be proactive!

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’?