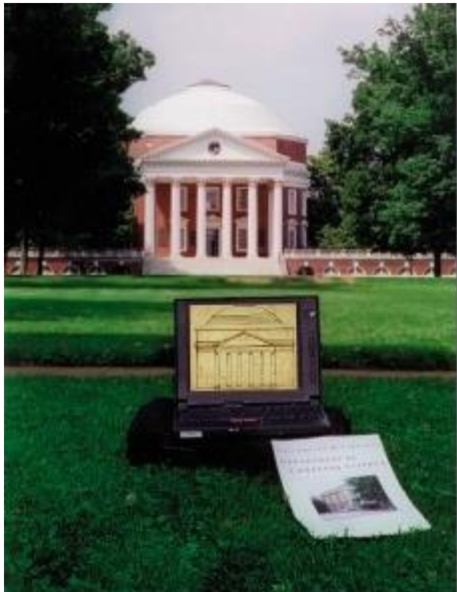


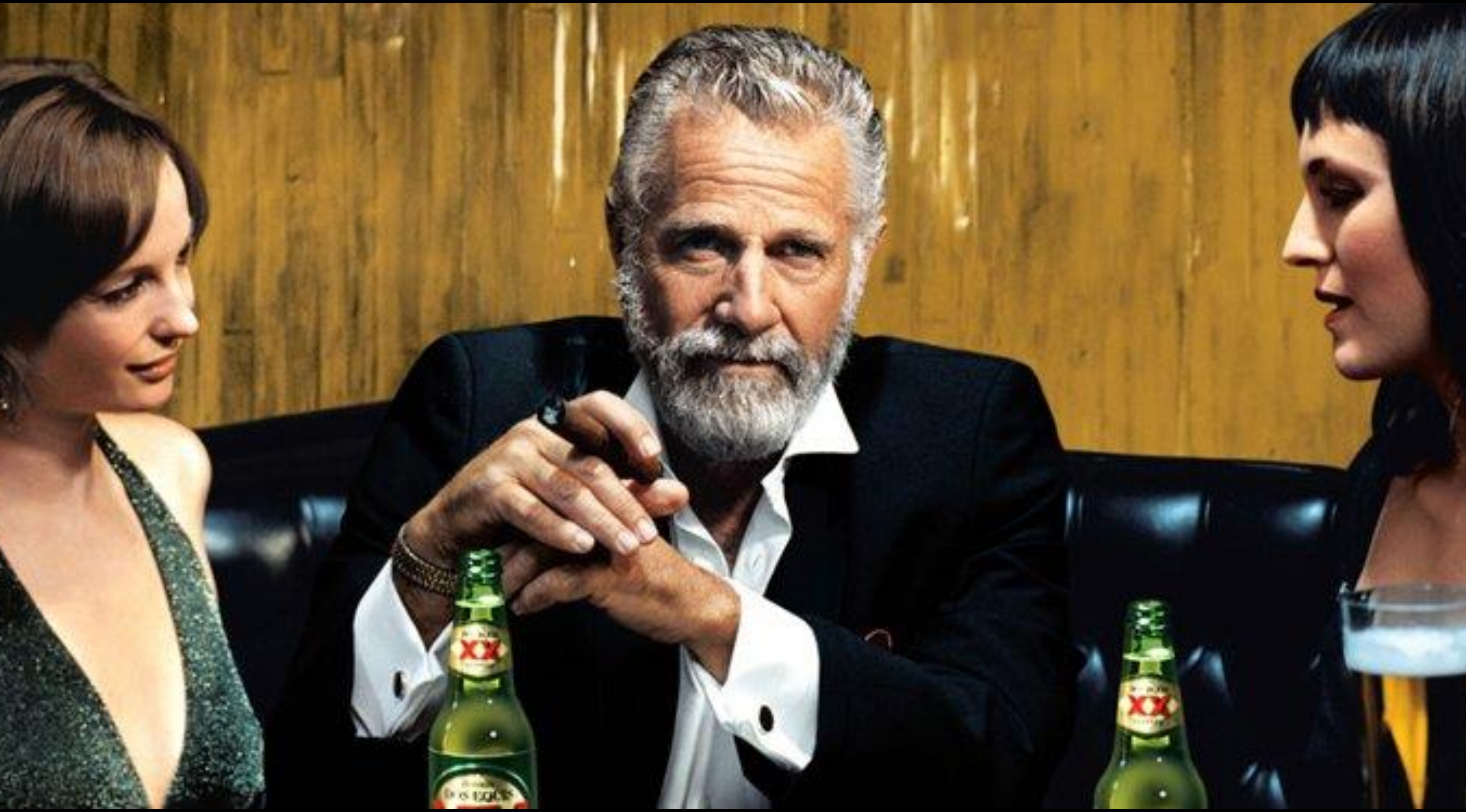
Life
Career Advice

Gabriel Robins

University of Virginia

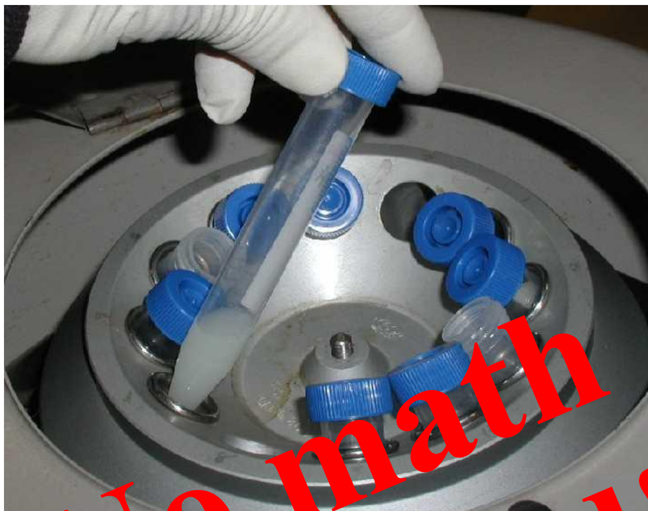
www.cs.virginia.edu/robins

The Most Interesting Man in the World: on Careers

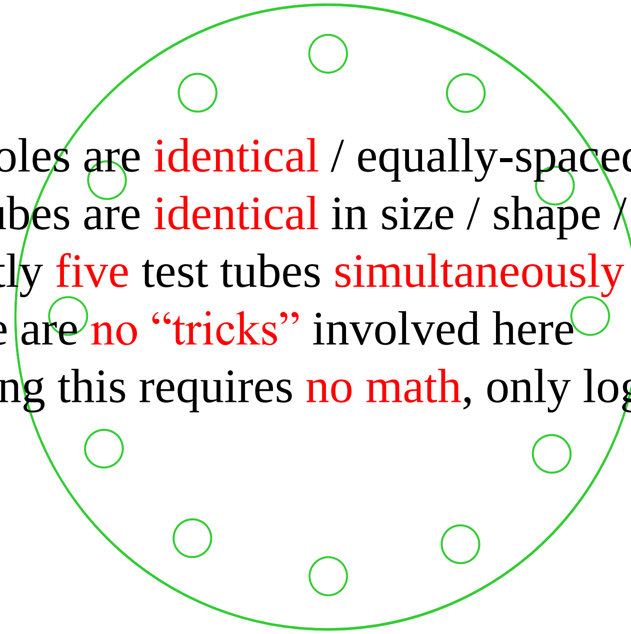


“Find out what it is in life you don’t do well,
and then don’t do that thing.”

Problem: Can 5 test tubes be spun simultaneously in a 12-hole centrifuge in a balanced way?

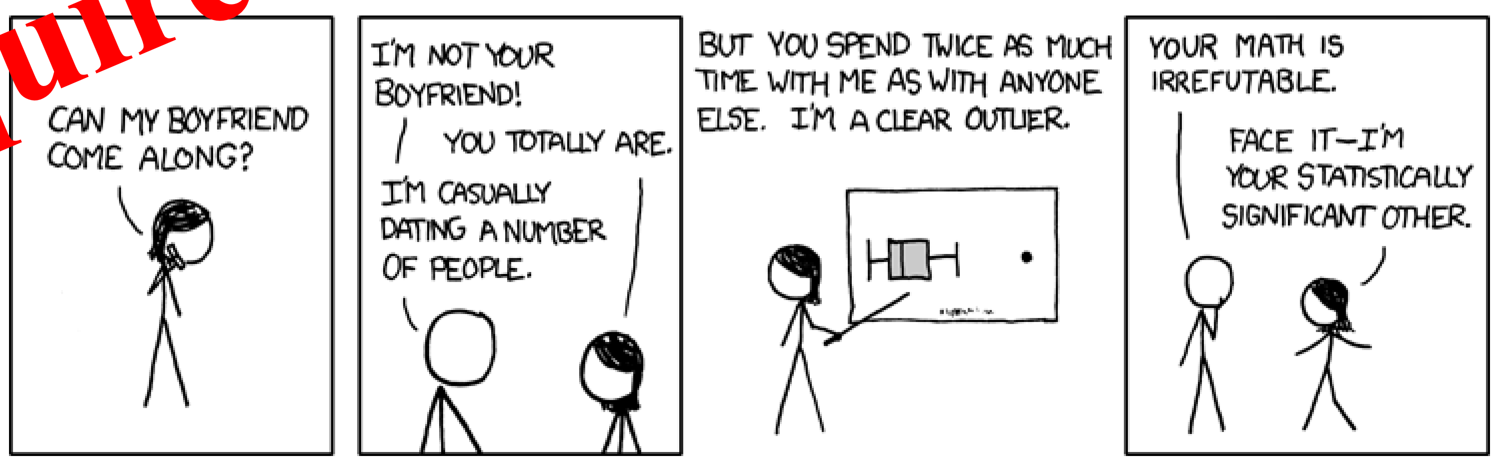


No math required!



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



Q: $1 + 2 + 3 + 4 + \ldots + (n-1) + n = ?$

Proof by picture

Q: $(1/4) + (1/4)^2 + (1/4)^3 + (1/4)^4 + \ldots = ?$

Q: Solve for X:

$$X^{X^{X^{X^{\cdot^{\cdot^{\cdot}}}}}} = 2$$

No math required!

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

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?

Supply & demand

Proactive!

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

Life-long

Take the Initiative

Why not as a grad student / postdoc:

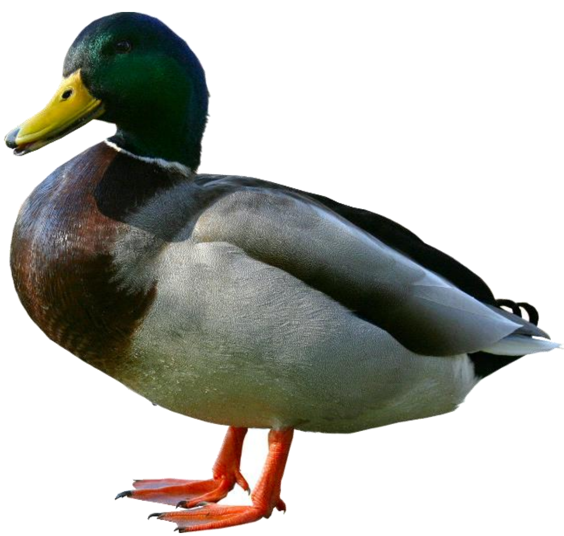
- Teach courses?
- Write grant proposals?
- Mentor students?
- Serve on committees?

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

Leadership!

The "Duck Test":

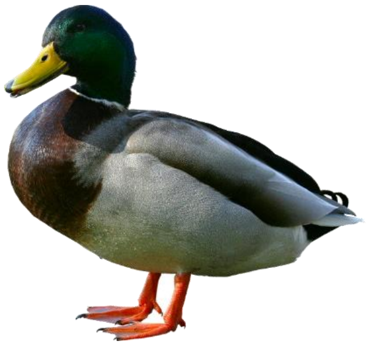
If it looks like a duck,
swims like a duck,
and quacks like a duck,
then it ~~probably~~ is a duck.

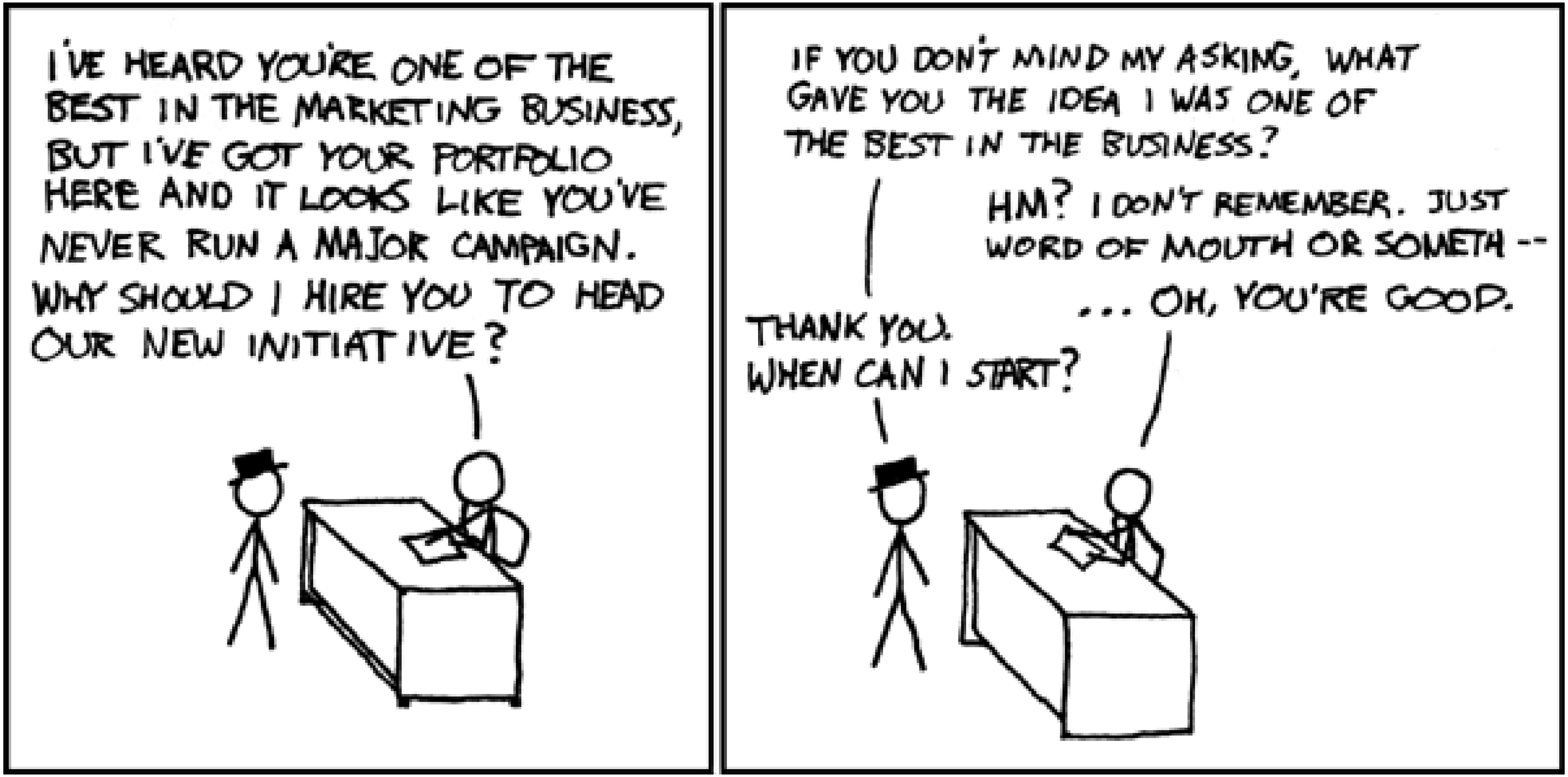


Start behaving in line with your goals!

Subliminal Impressions

- Subtle but powerful!
- Know more about other people's field than they know about your field!





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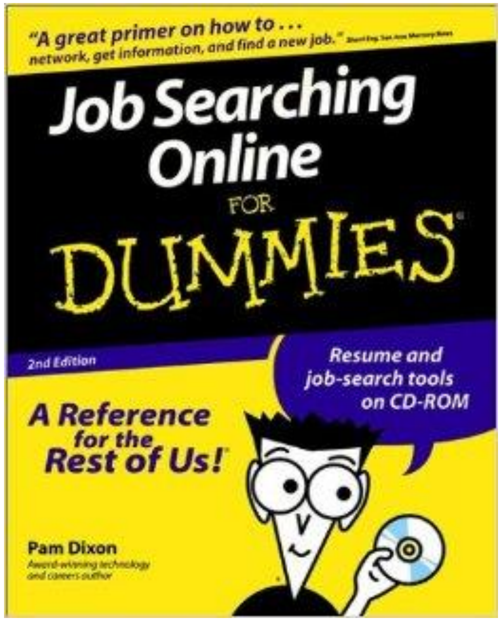

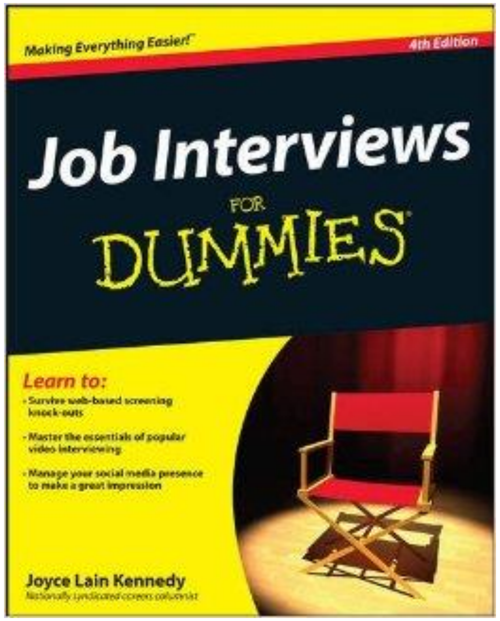

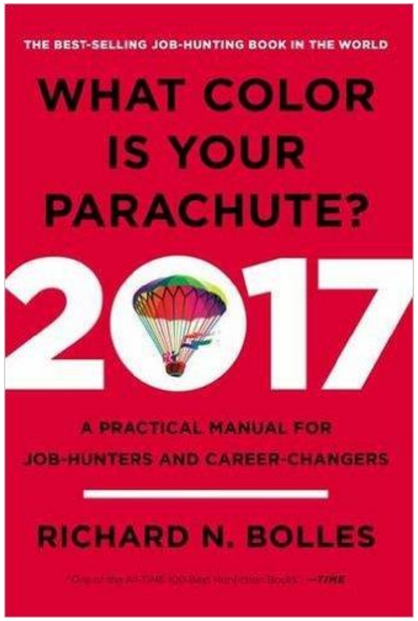

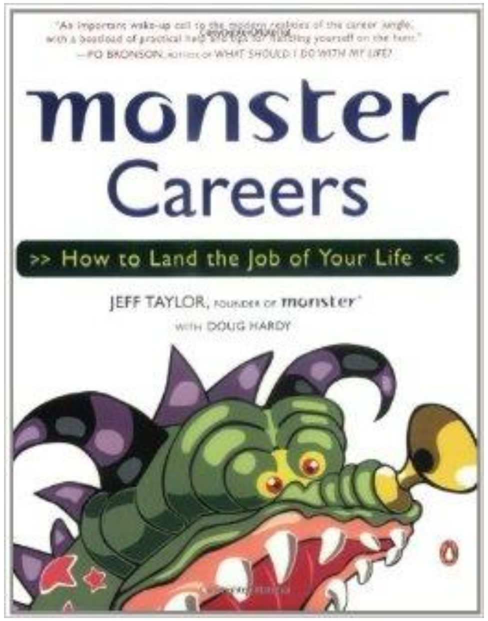

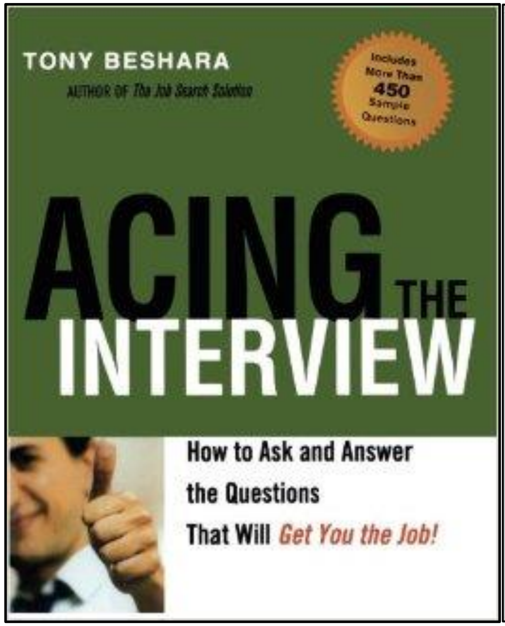

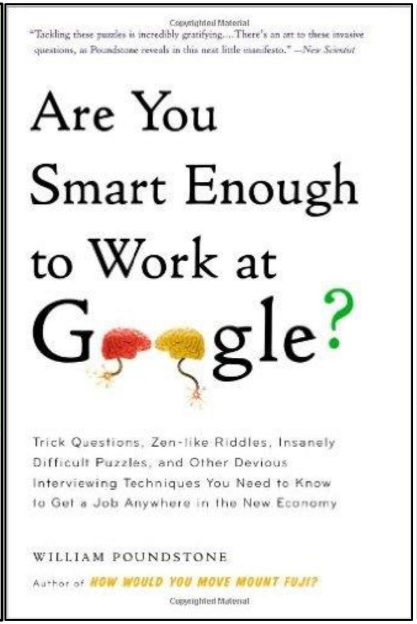

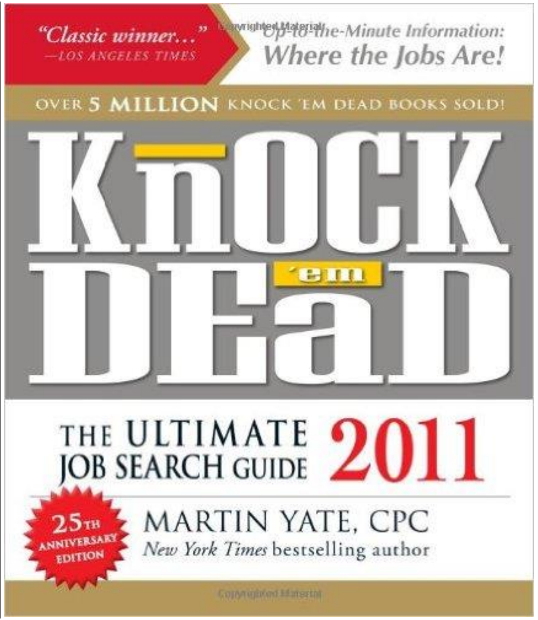

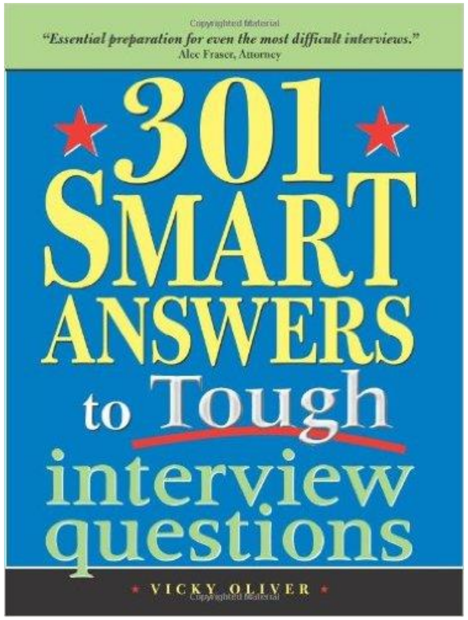

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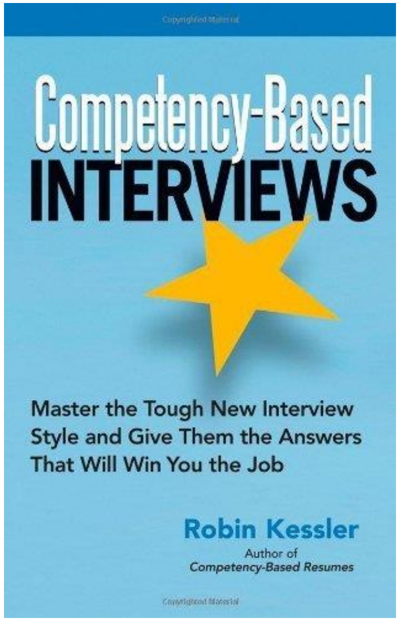

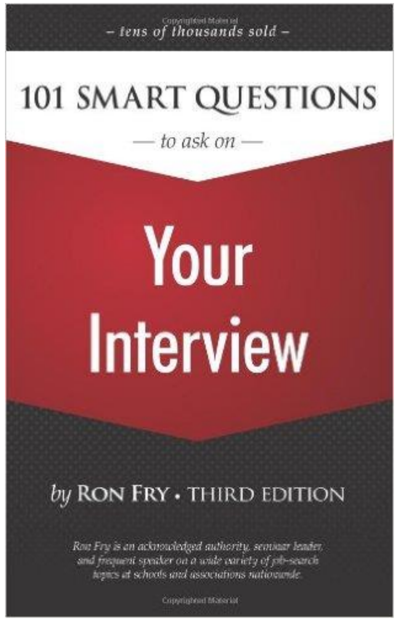

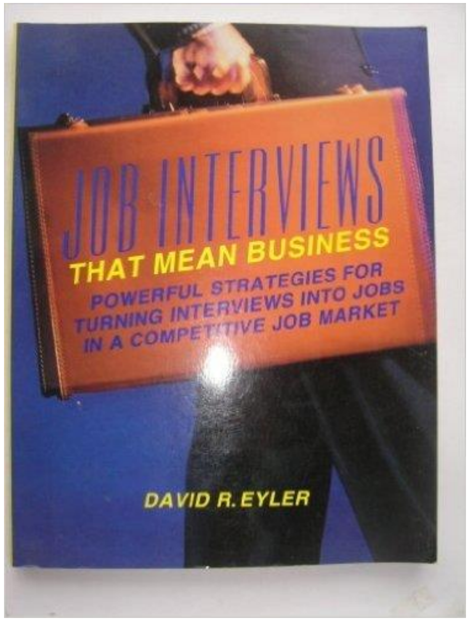

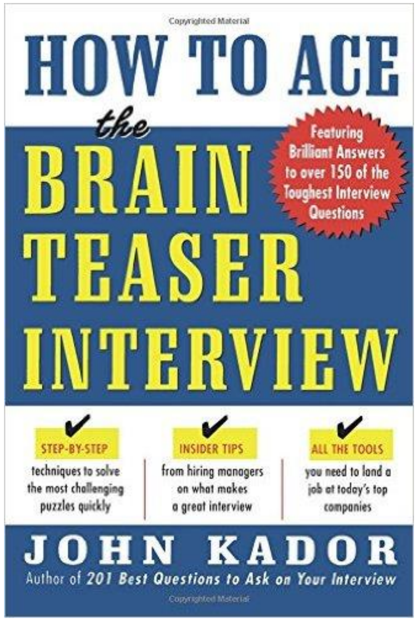

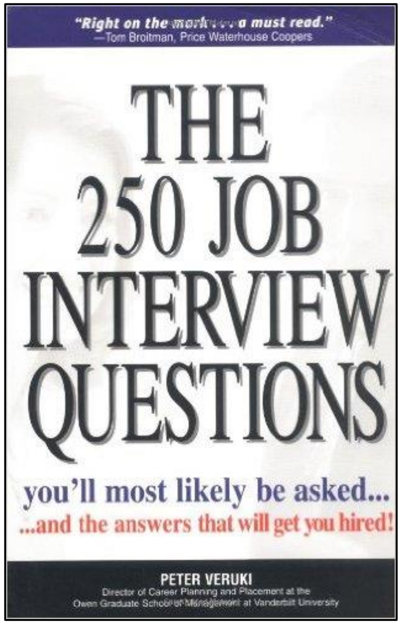

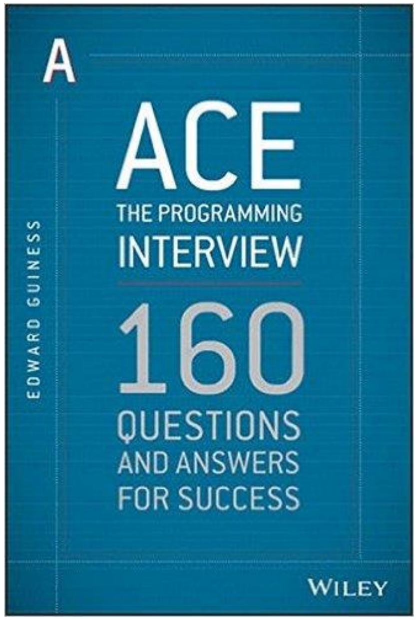

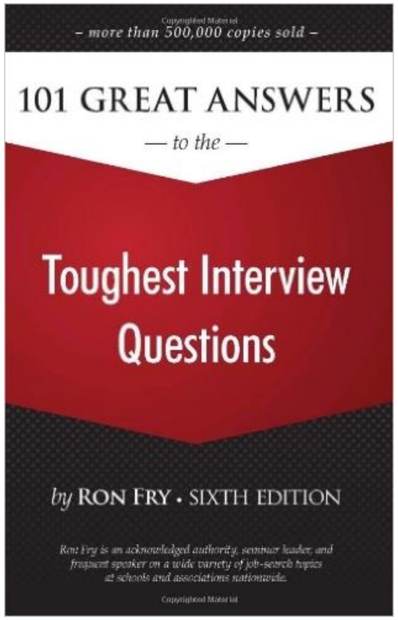

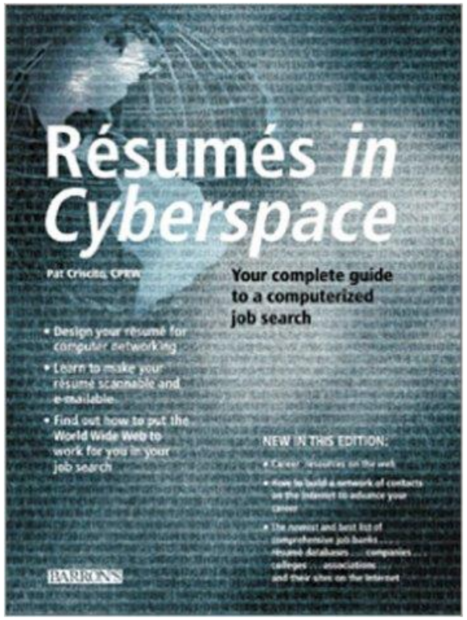

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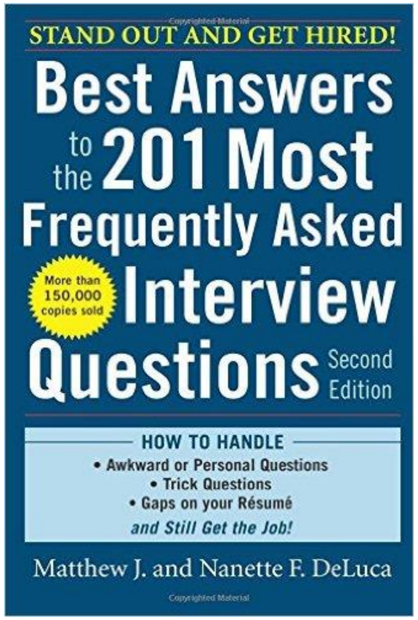

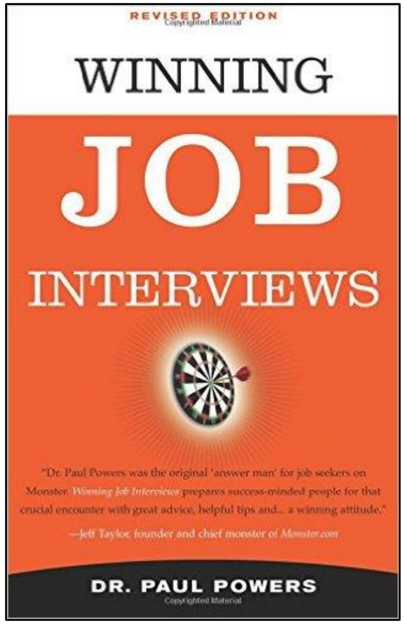

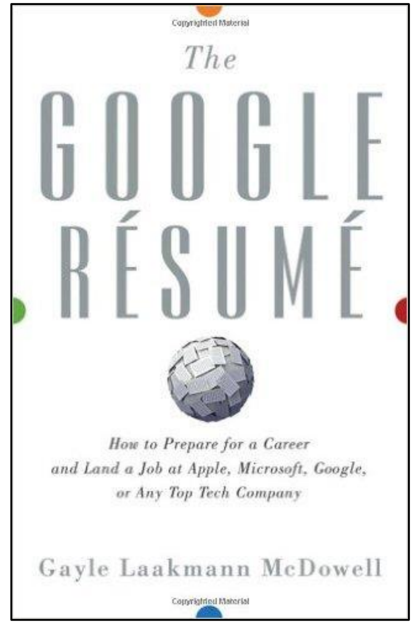

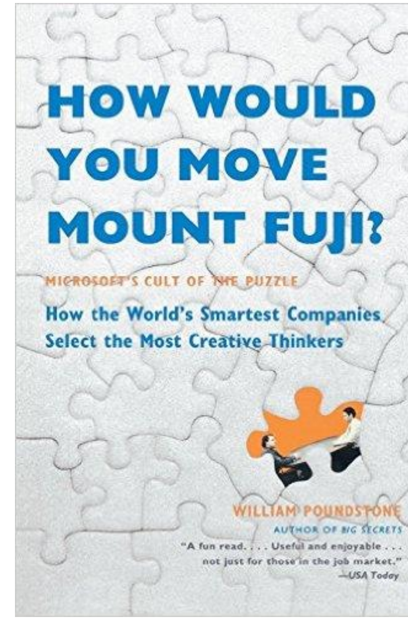

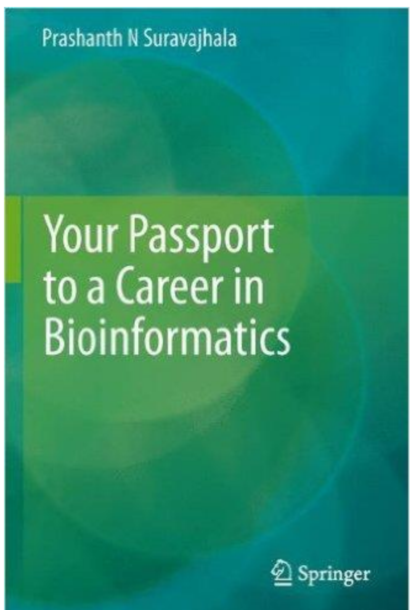

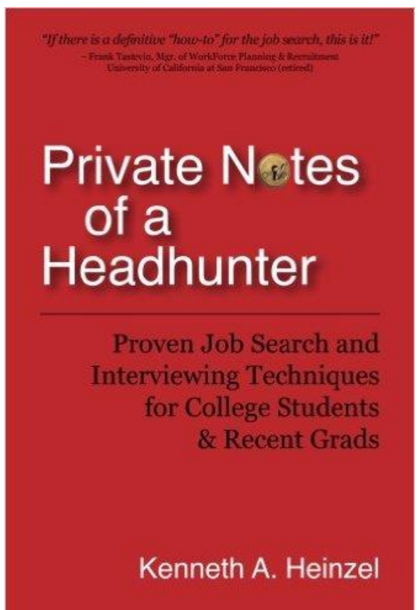

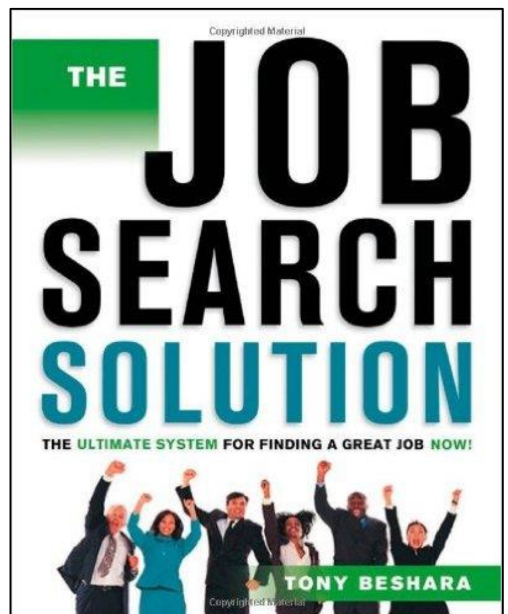

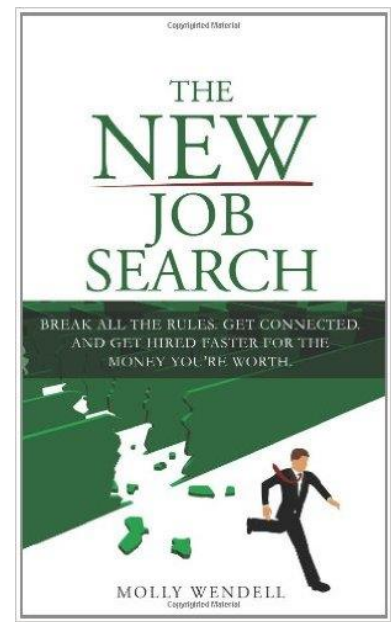

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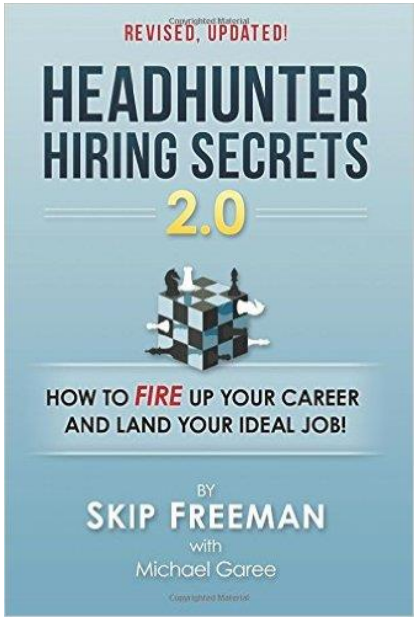

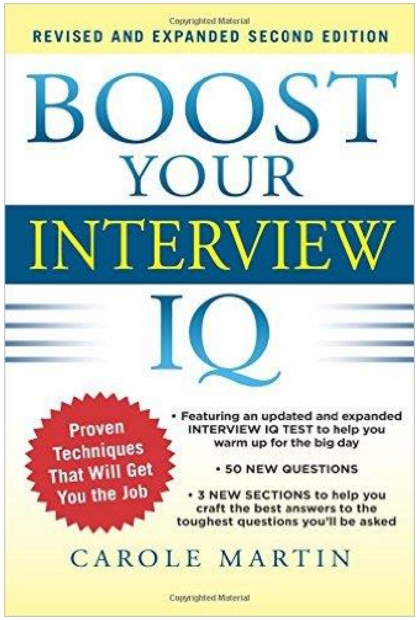

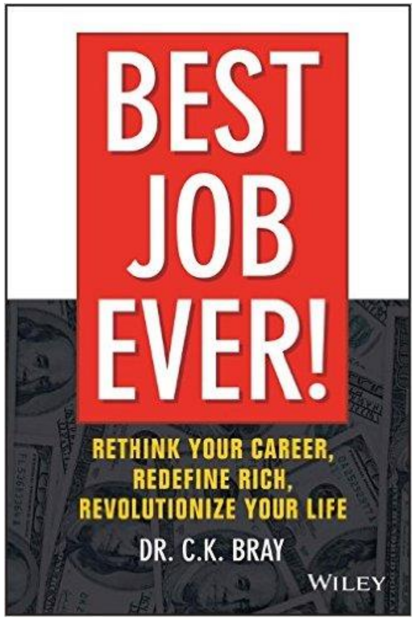

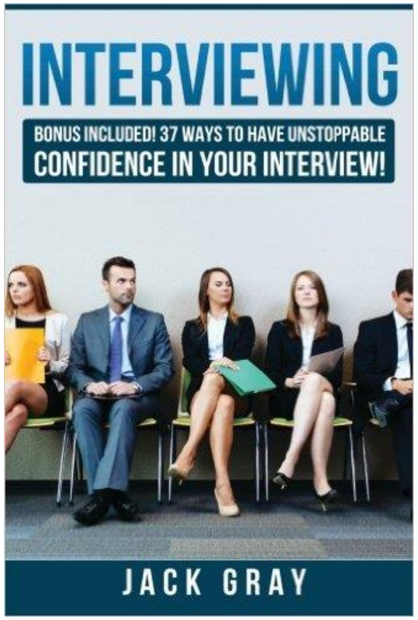

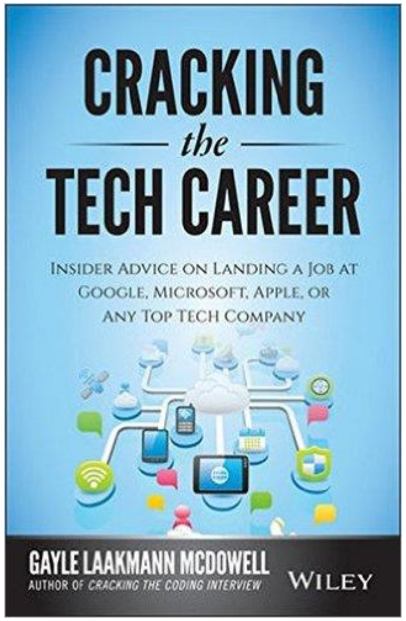

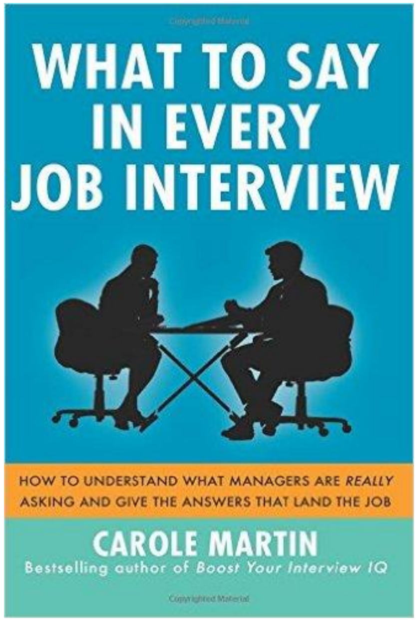

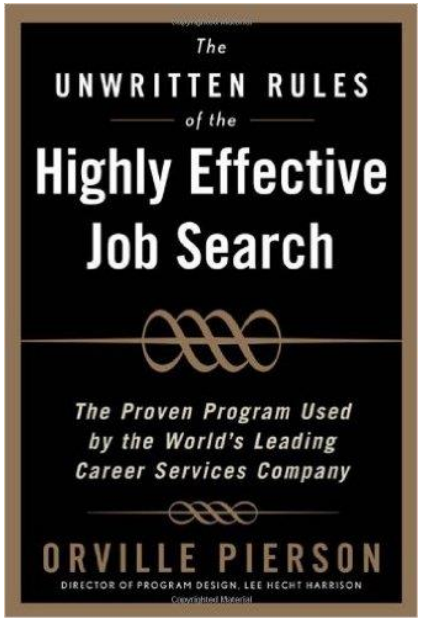

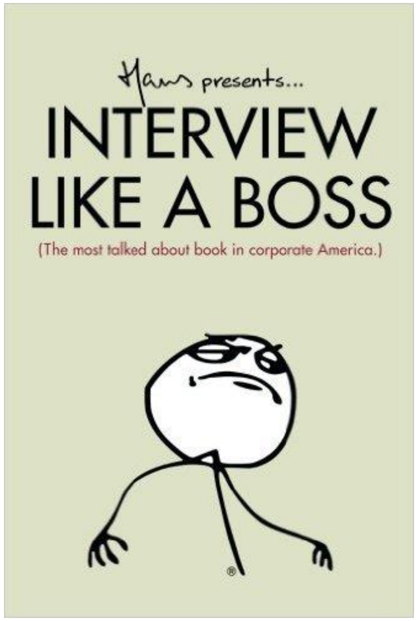

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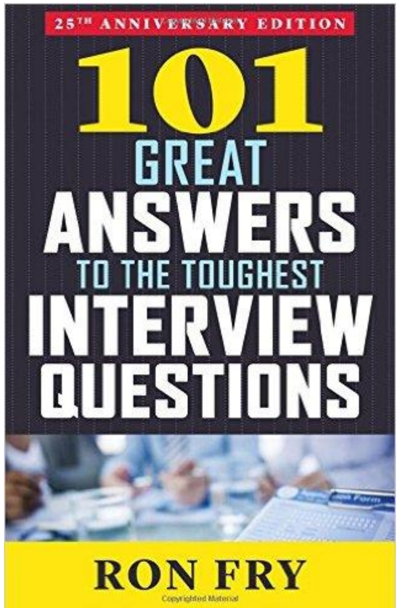

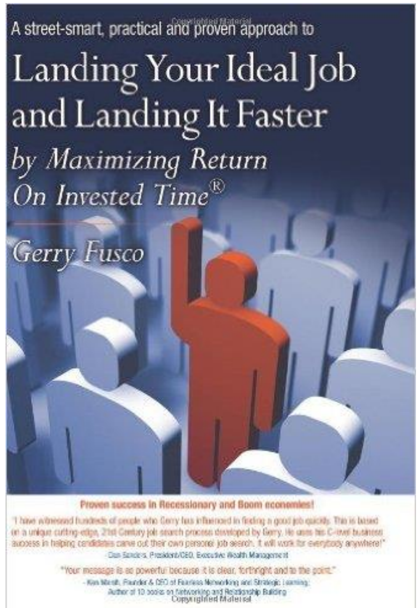

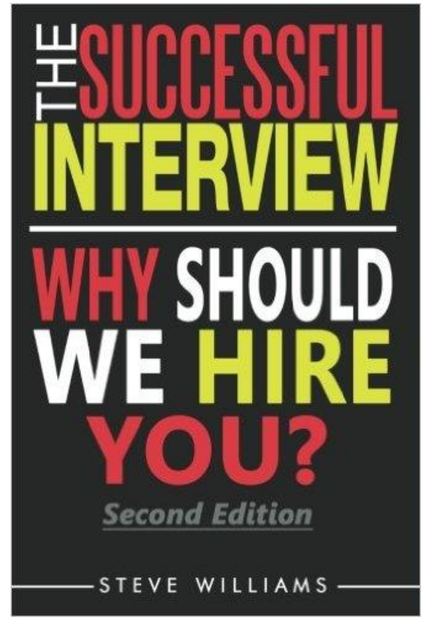

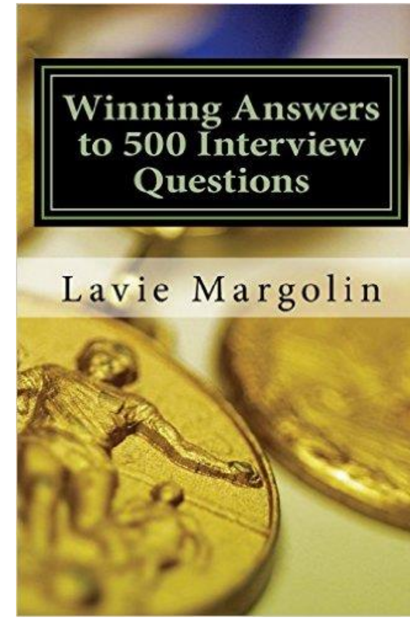

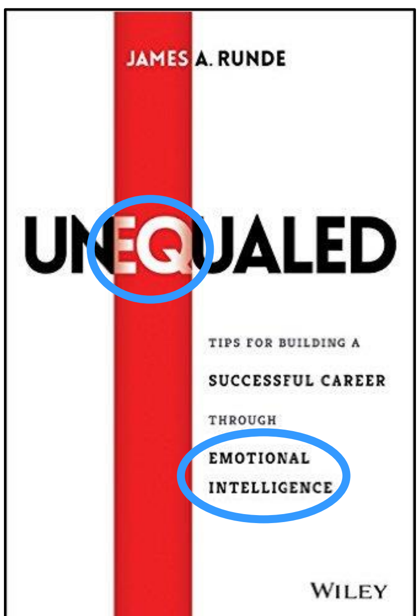

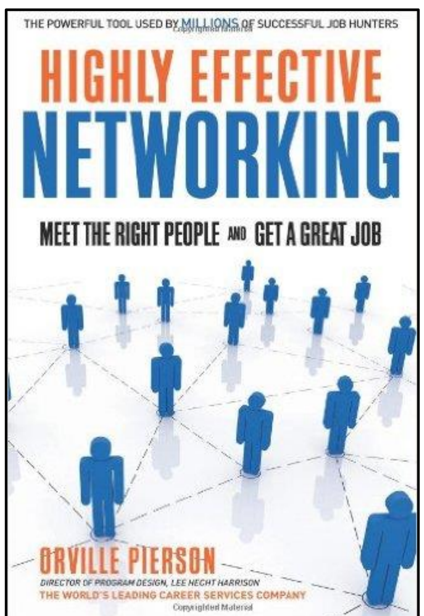

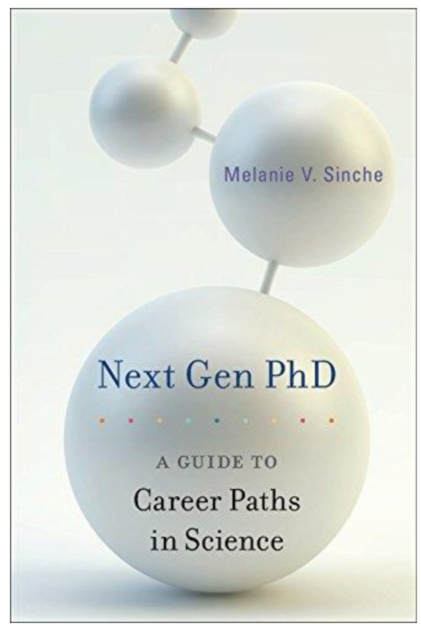

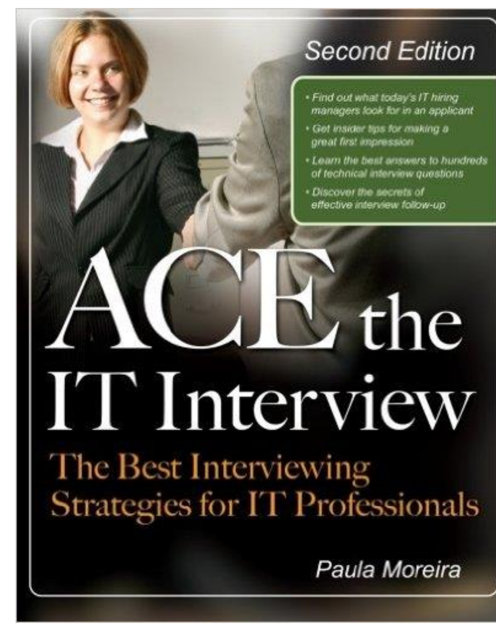

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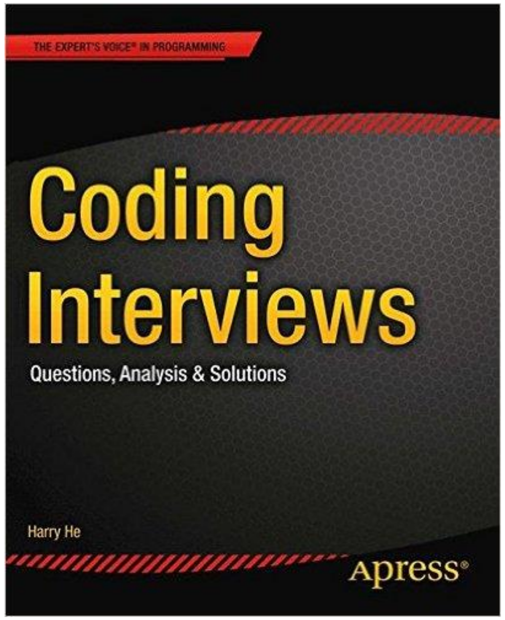

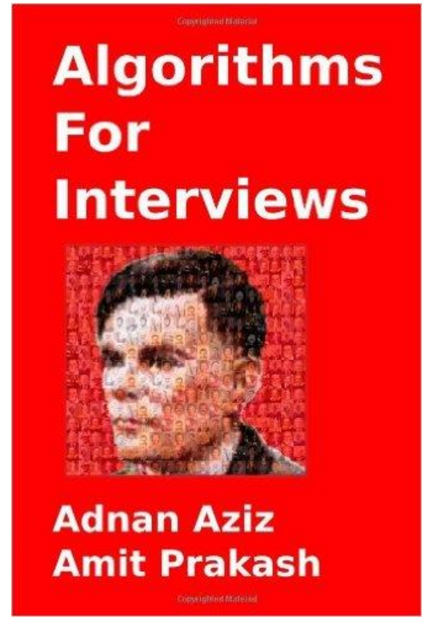

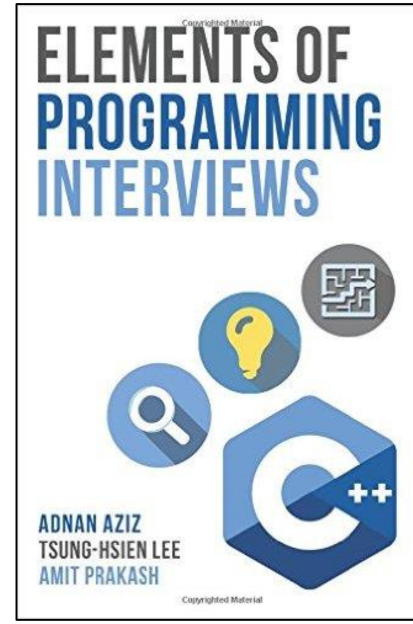

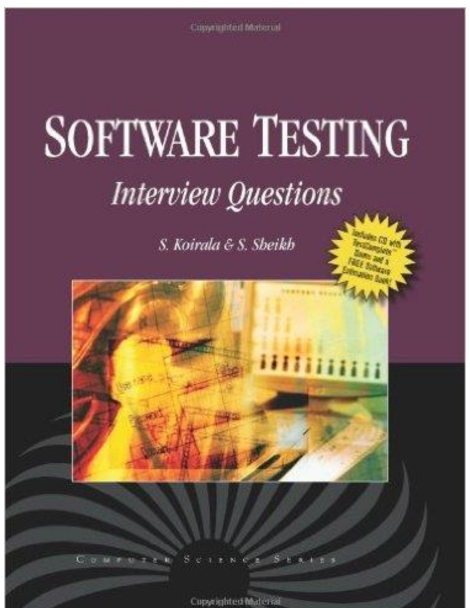

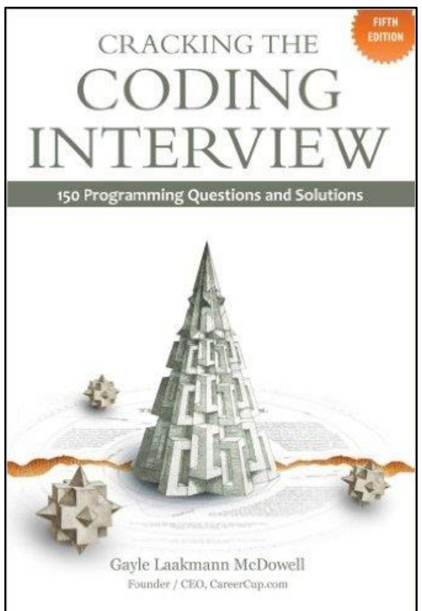

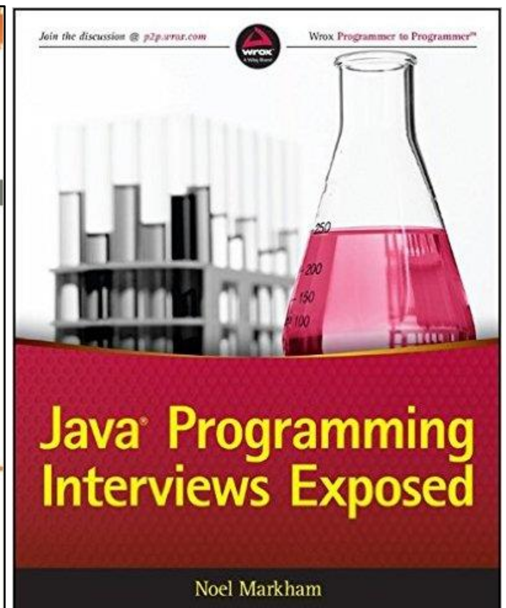

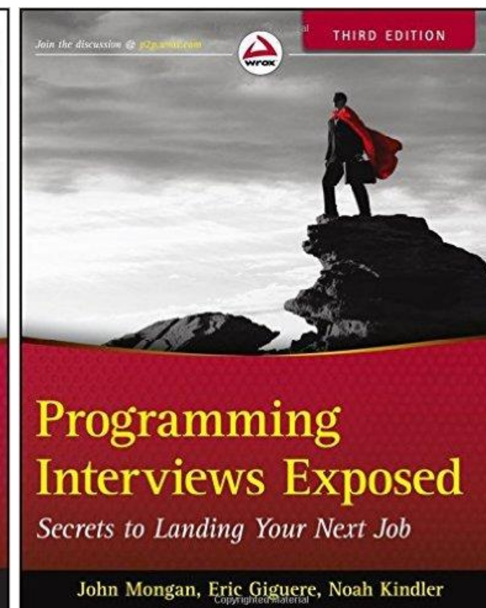

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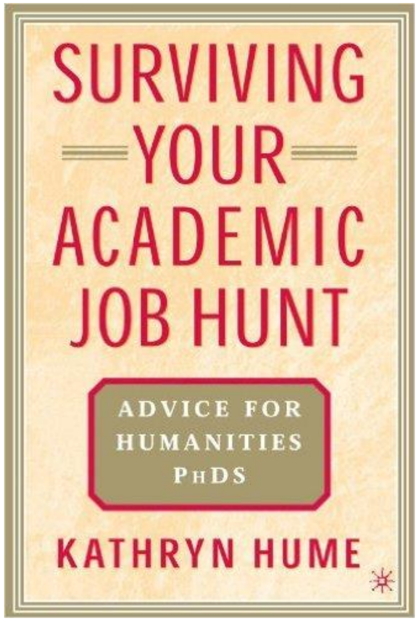

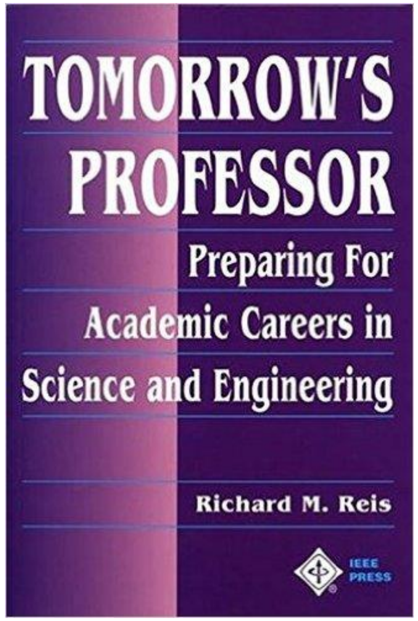

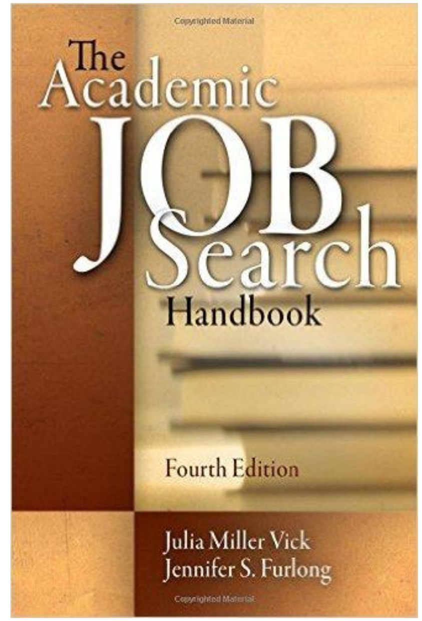

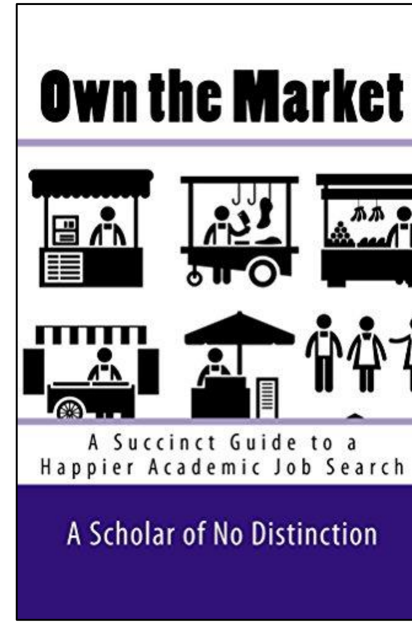

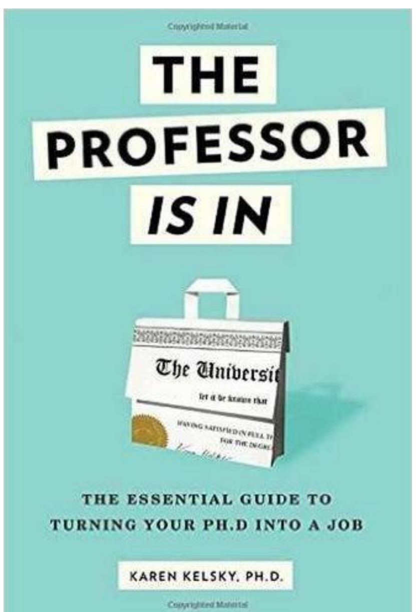

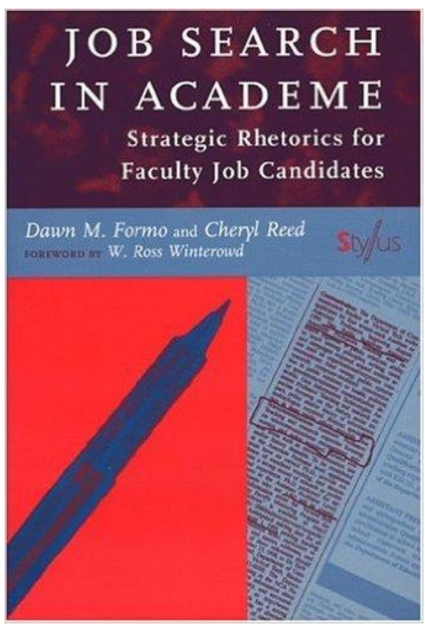

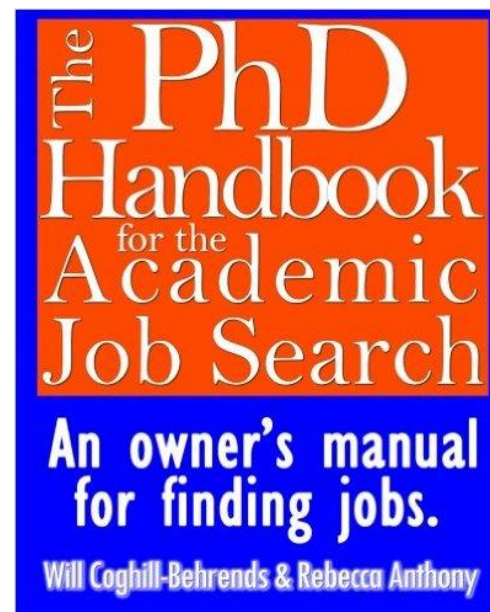

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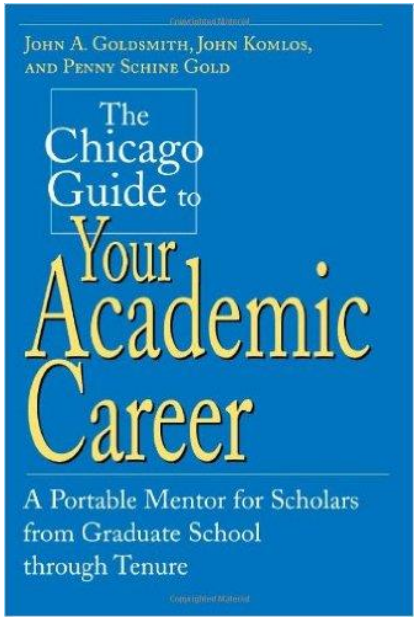
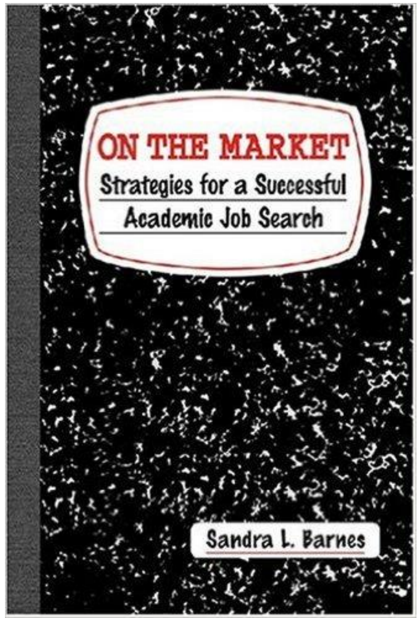
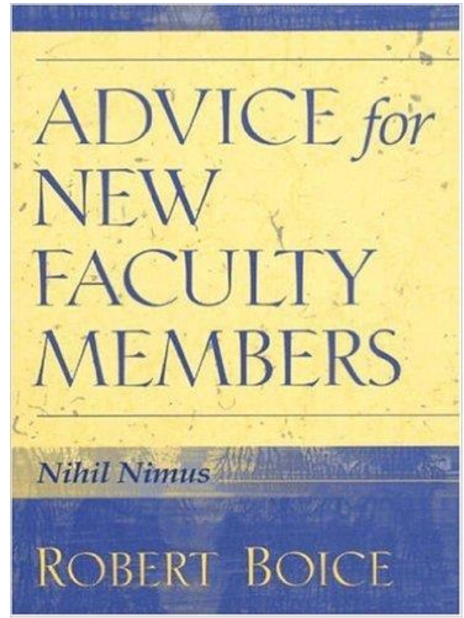
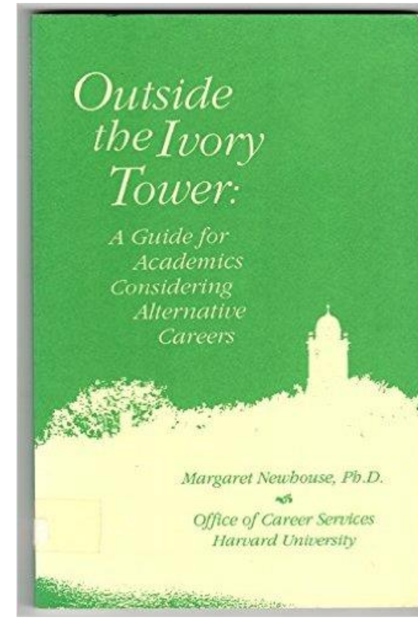
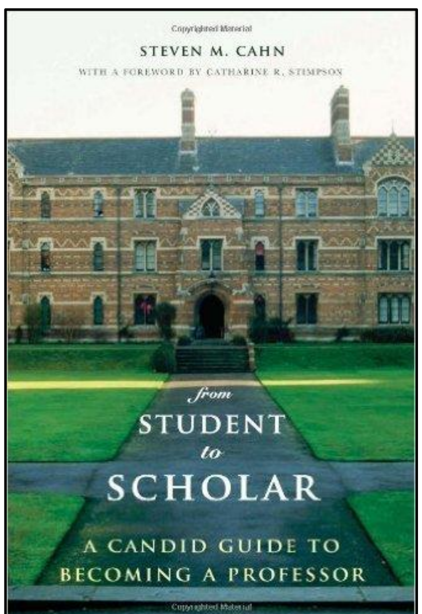
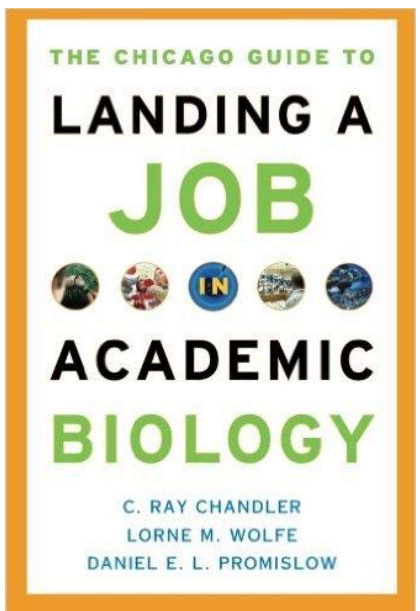


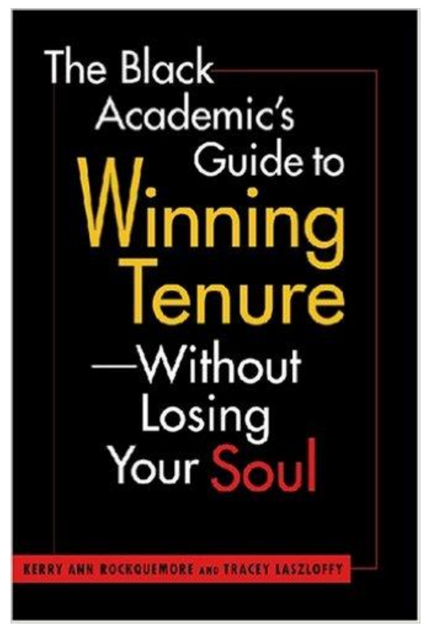


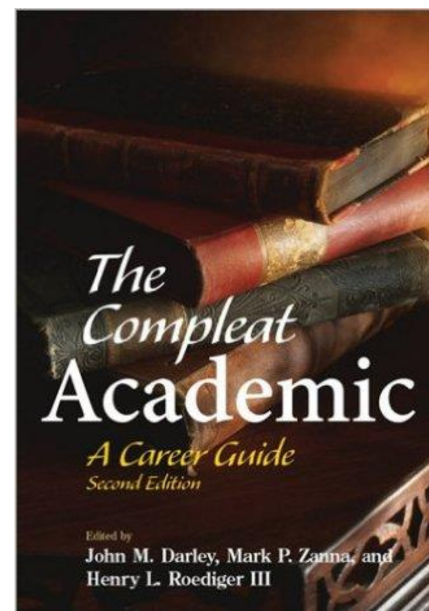




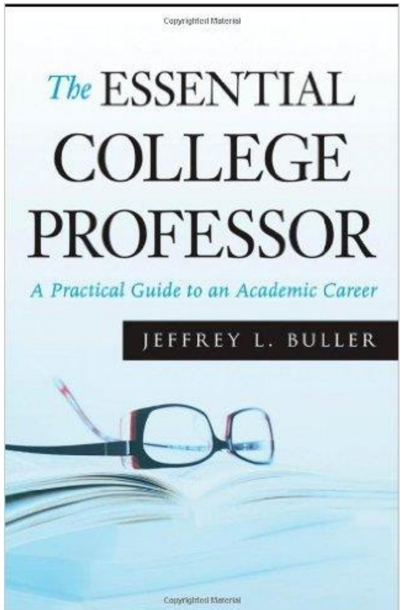


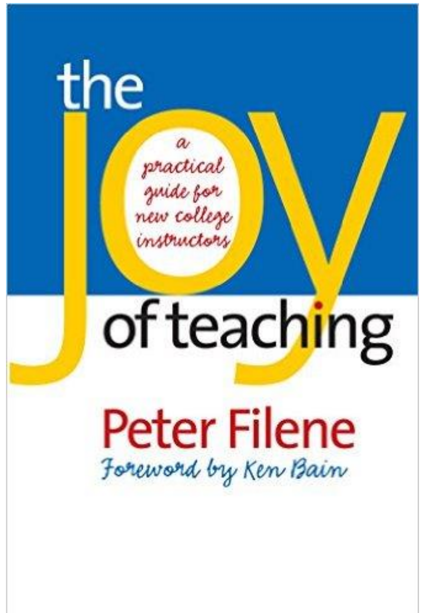


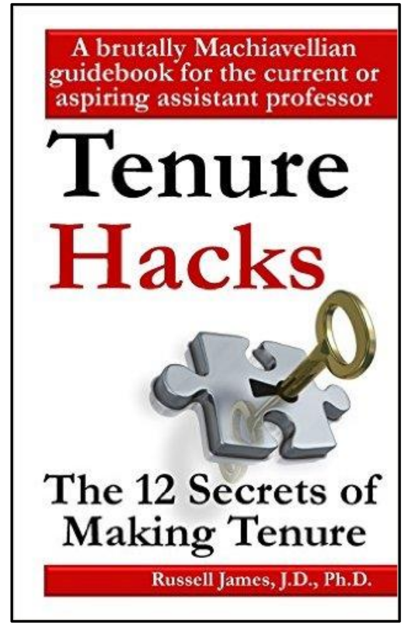


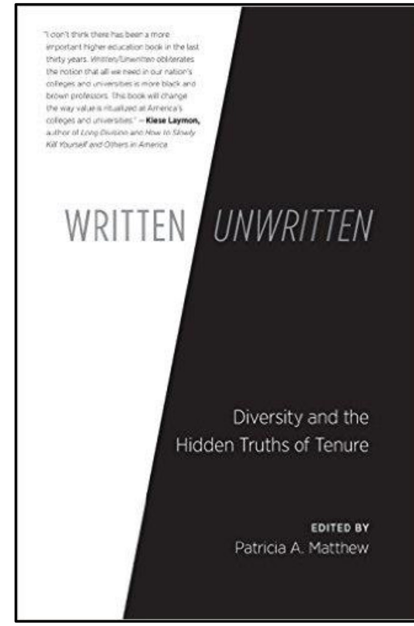


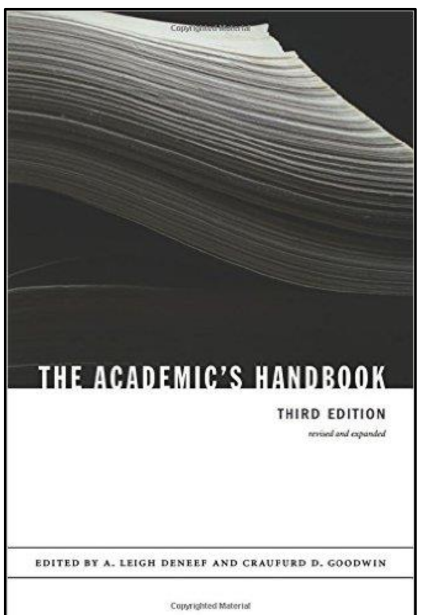
Prepare and Train!

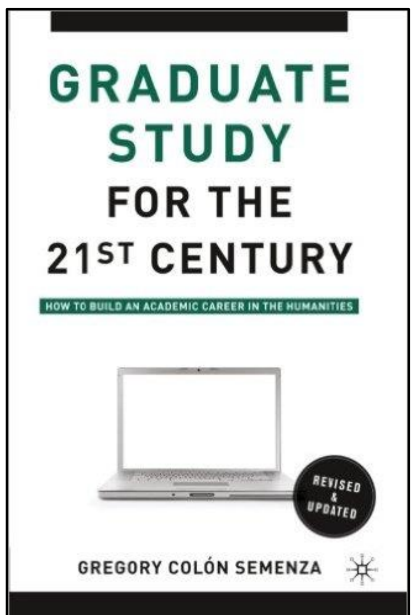


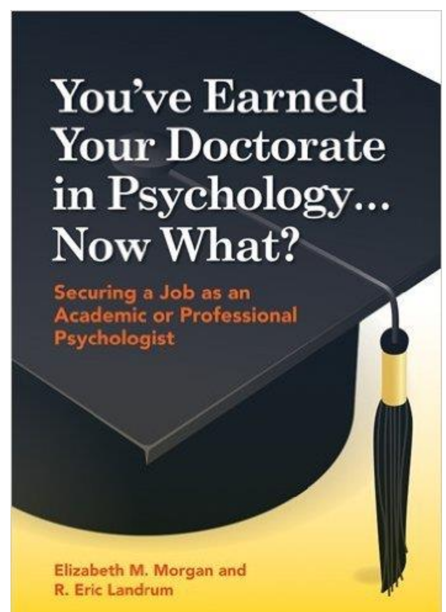


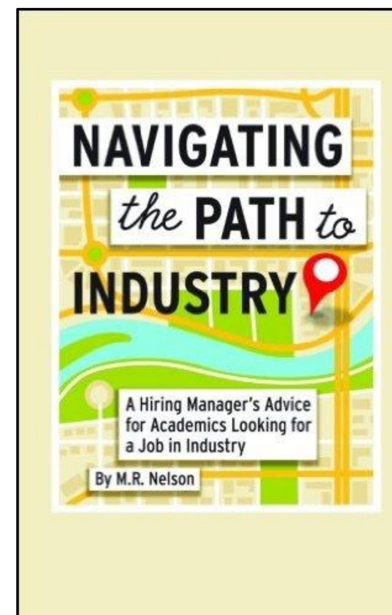












Prepare and Train!

- These books are available at:

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

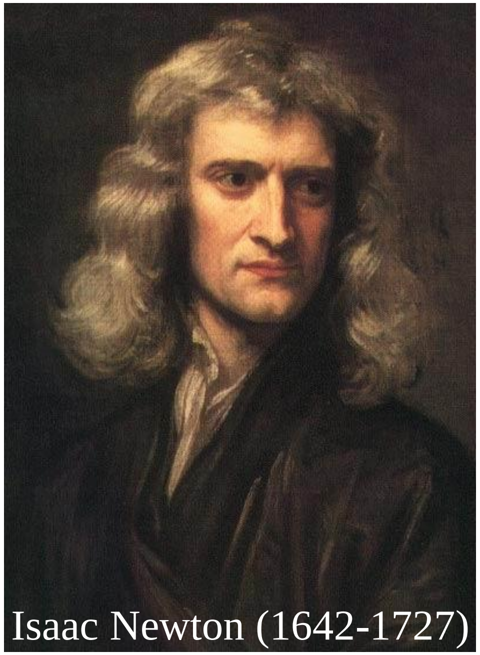
- Q: How can you identify the best books?
- Cultivate intellectual curiosity!
- Acquire broad knowledge
- Become a deep thinker
- Drink from the "fire hose"
- Impress your colleagues!

"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


Ada Lovelace (1815-1852)


Isaac Newton (1642-1727)


Euclid (300 BC)

“Stand on the Shoulders of Giants”

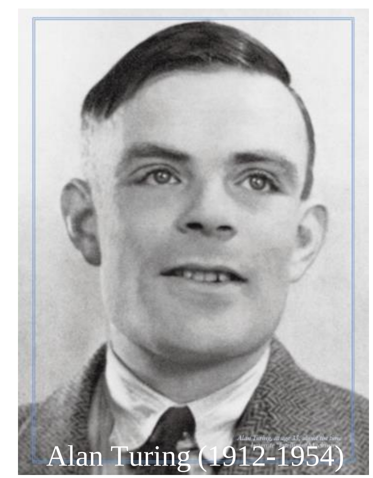
- Hilbert, Russell, Shakespeare
- Bohr, Curie, Ramanujan
- Gödel, Church, Turing
- von Neumann, Shannon
- Kleene, Feynman, Chomsky
- McCarthy, Erdos, Sagan
- Knuth, Dijkstra, Hawking
- Gates, Jobs, Musk

And many others…


Bertrand Russell (1872-1970)

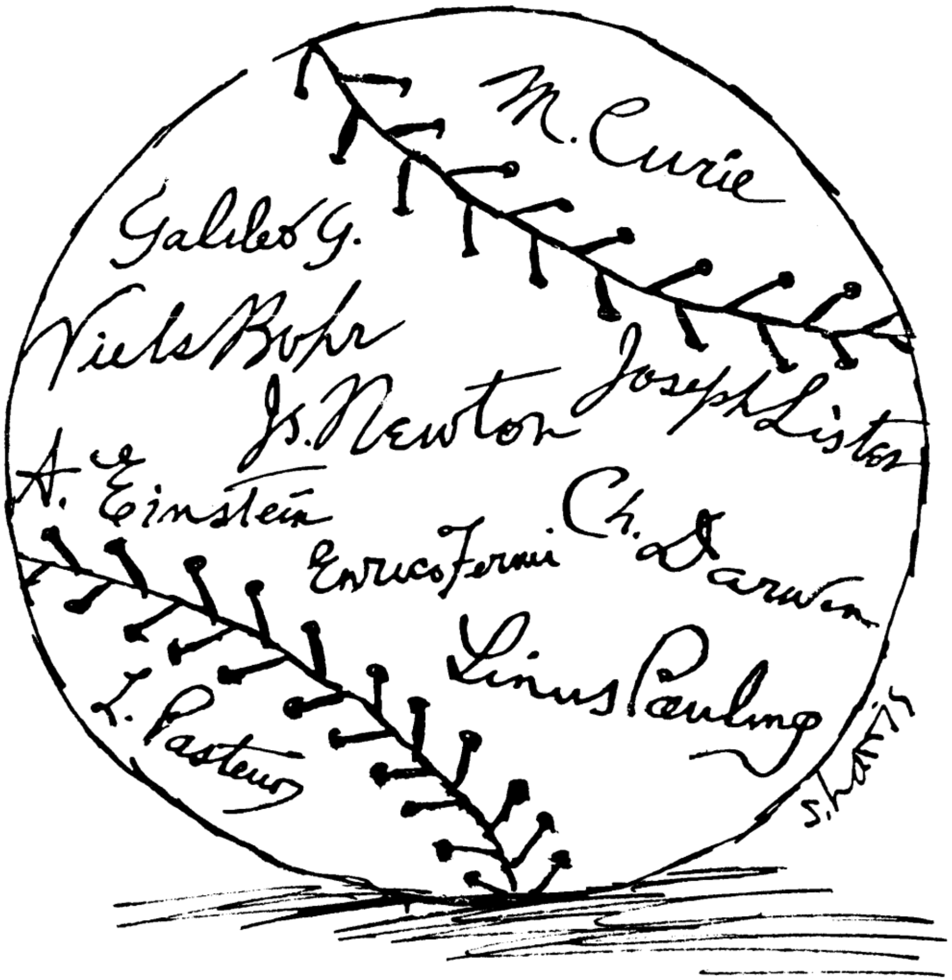

David Hilbert (1862-1943)


Kurt Gödel (1906-1978)


Alan Turing (1912-1954)

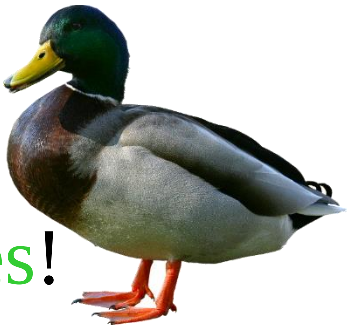
Alan Turing (1912-1954)

Know your Science Superstars!



Goal: Be able to talk at length about each one!

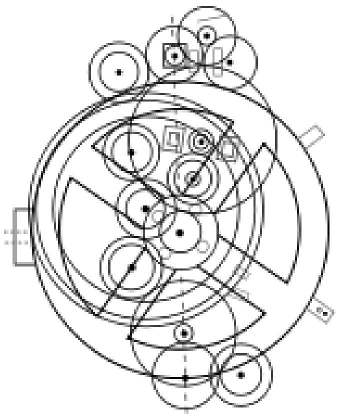
Broadly explore lots of cool ideas & technologies!

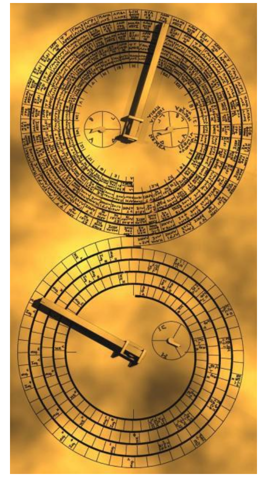


“The School of Athens”
by Raphael (1483-1520)

An Ancient Computer: The Antikythera

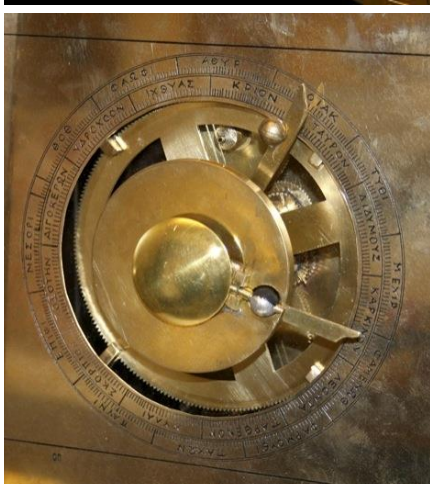
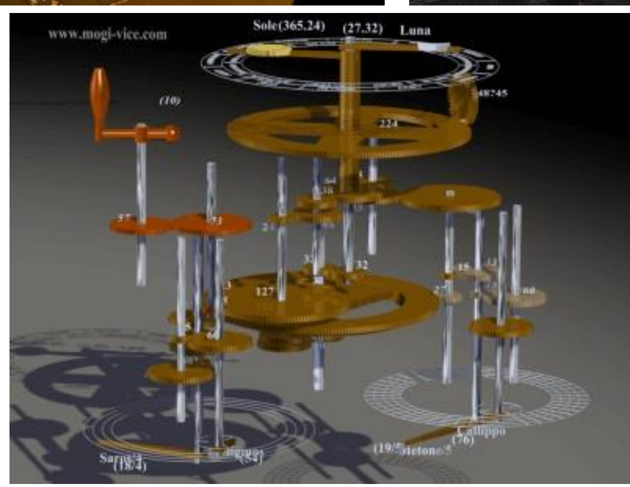
- Oldest known mechanical computer
- Built around 150-100 BCE !
- Calculates eclipses and astronomical positions of sun, moon, and planets
- Very sophisticated for its era
- Contains dozens of intricate gears
- Comparable to 1700's Swiss clocks
- Has an attached "instructions manual"
- Still the subject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










www.mogi-vice.com
Sole(365.24)
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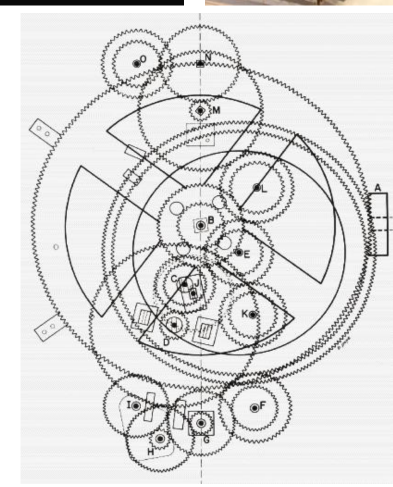
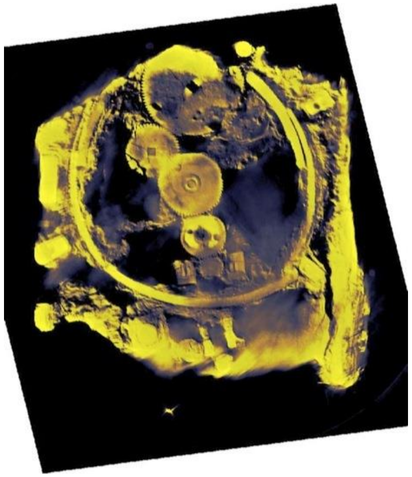
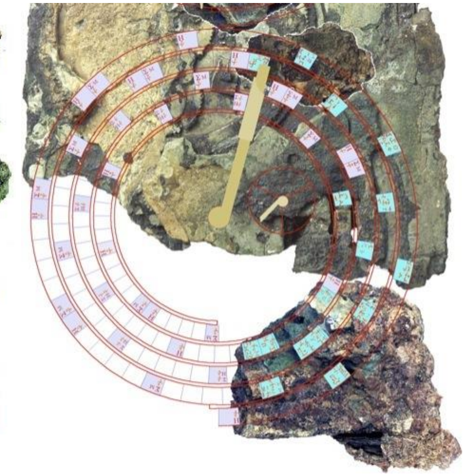
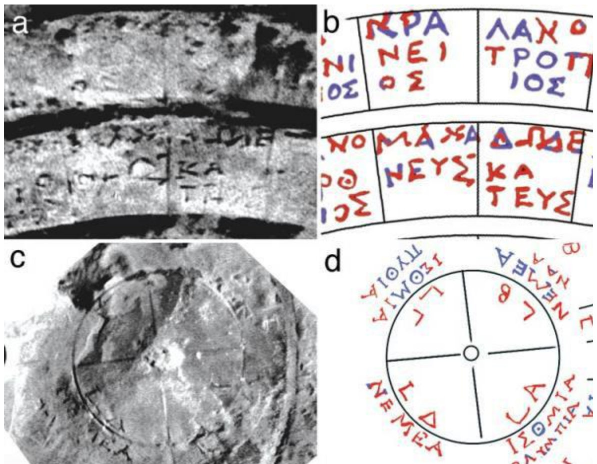
Luna
Calippo
(76)






© Antikythera Mechanism Research Project

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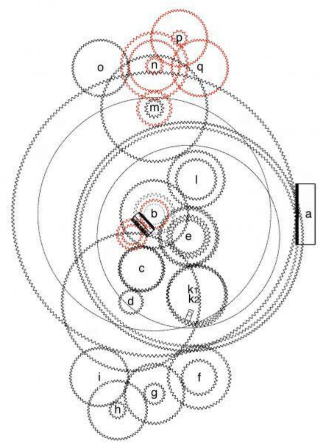

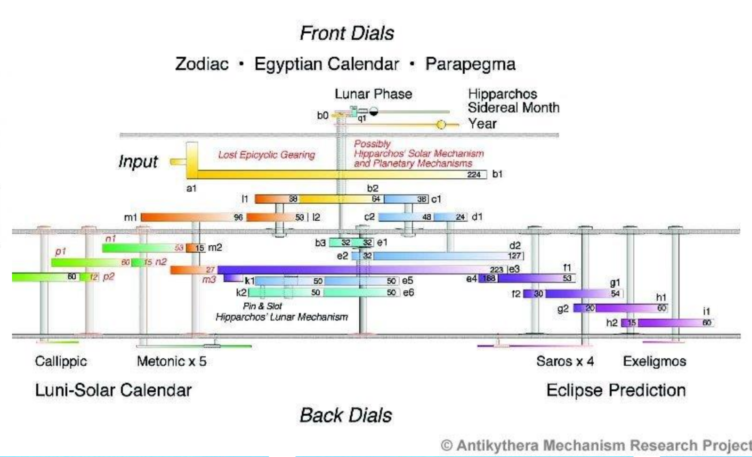
Front Dials
Zodiac • Egyptian Calendar • Parapegma
Lunar Phase
Hipparchos
Sidereal Month
Year
Input
Lost Epicyclic Gearing
Possibly Hipparchos' Solar Mechanism and Planetary Mechanisms
Pin & Slot
Hipparchos' Lunar Mechanism
Callippic
Metonic x 5
Saros x 4
Exeligmos
Luni-Solar Calendar
Eclipse Prediction
Back Dials
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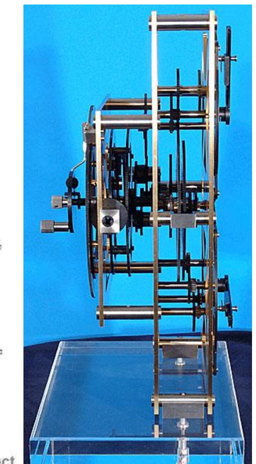
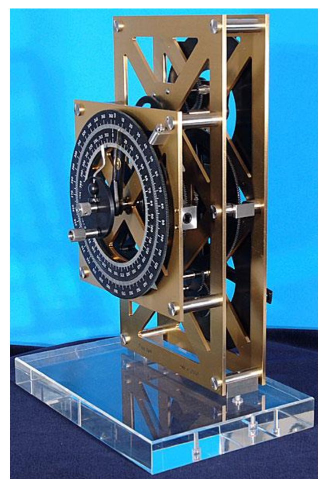
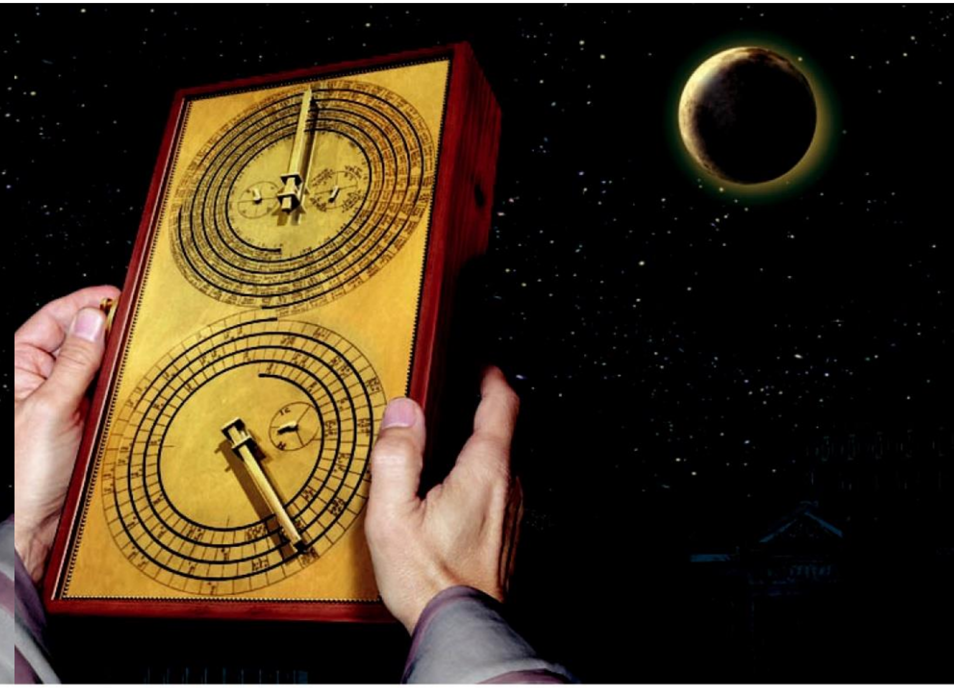




DECODING AN *Ancient Computer*

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

By Tony Freeth



ANCIENT GREEKS knew how to calculate the recurring patterns of lunar eclipses thanks to observations made for centuries by the Babylonians. The Antikythera mechanism would have done those calculations for them—or perhaps for the wealthy Romans who could afford to own it. The depiction here is based on a theoretical reconstruction by the author and his collaborators.

KEY CONCEPTS

- The Antikythera mechanism is a unique mechanical calculator from second-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 motion 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 Archimedes.

—*The Editors*

If it 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 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 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 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 Charalambos Karakalos.

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[THE PLACES]

The Greek and Roman worlds, circa 145 B.C.

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, which had been 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 64/38 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 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-rays 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 adopted 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 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 Zafeiropoulou at the museum. She had been to the basement storage 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 Malzbender, assembled a mysterious-looking dome about five feet across and covered in electronic flashbulbs that provided lighting from a range 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 reflectance 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 Yanis Bitsakis, also at the University of Athens, and Agamemnon Tselikas of the Center for History and Palaeography be-

Historians would have thought that SOMETHING SO COMPLEX *could not have existed at the time.*

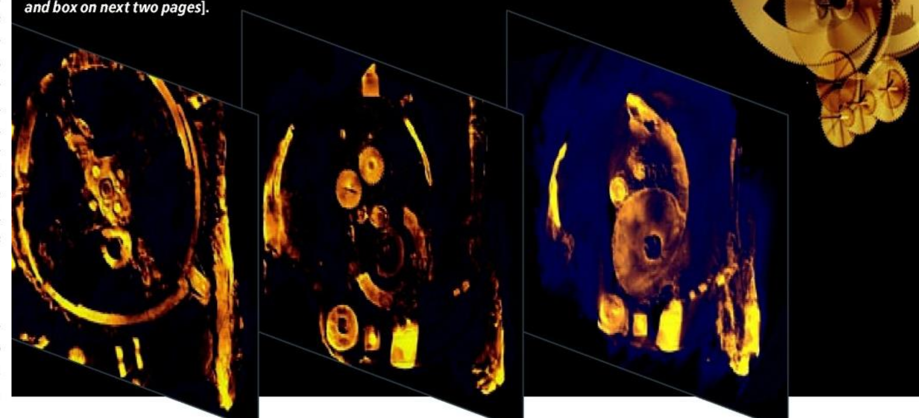
[THE AUTHOR]

Tony Freeth's academic background is in mathematics and mathematical logic (in which he holds a Ph.D.). His award-winning career as a filmmaker culminated in a series of documentaries about increasing crop yields in sub-Saharan Africa, featuring the late Nobel Peace Prize Laureate Norman Borlaug. Since 2000 Freeth has returned to an academic focus with research on the Antikythera mechanism. He is managing director of the film and television production company Images First, and he is now developing a film on the mechanism.

[THE RECONSTRUCTION]

Anatomy of a Relic

Computed tomography—a 3-D mapping obtained from multiple x-ray shots—enabled the author and his colleagues to get inside views of the Antikythera mechanism's remnants. For example, a CT scan can be used to virtually slice up an object (*below, slices of main fragment*). The information helped the team see how the surviving gears connected and estimate their tooth counts, which determined what calculations they performed. The team could then reconstruct most of the device [*see model at right and box on next two pages*].



gan 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.

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 225.

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 Σ (*sigma*) or *H* (*eta*), or both. I soon realized that Σ stands for Σεληνη (*selene*), Greek for "moon," indicating a lunar eclipse; *H* stands for Ηλιοσ (*helios*), 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.

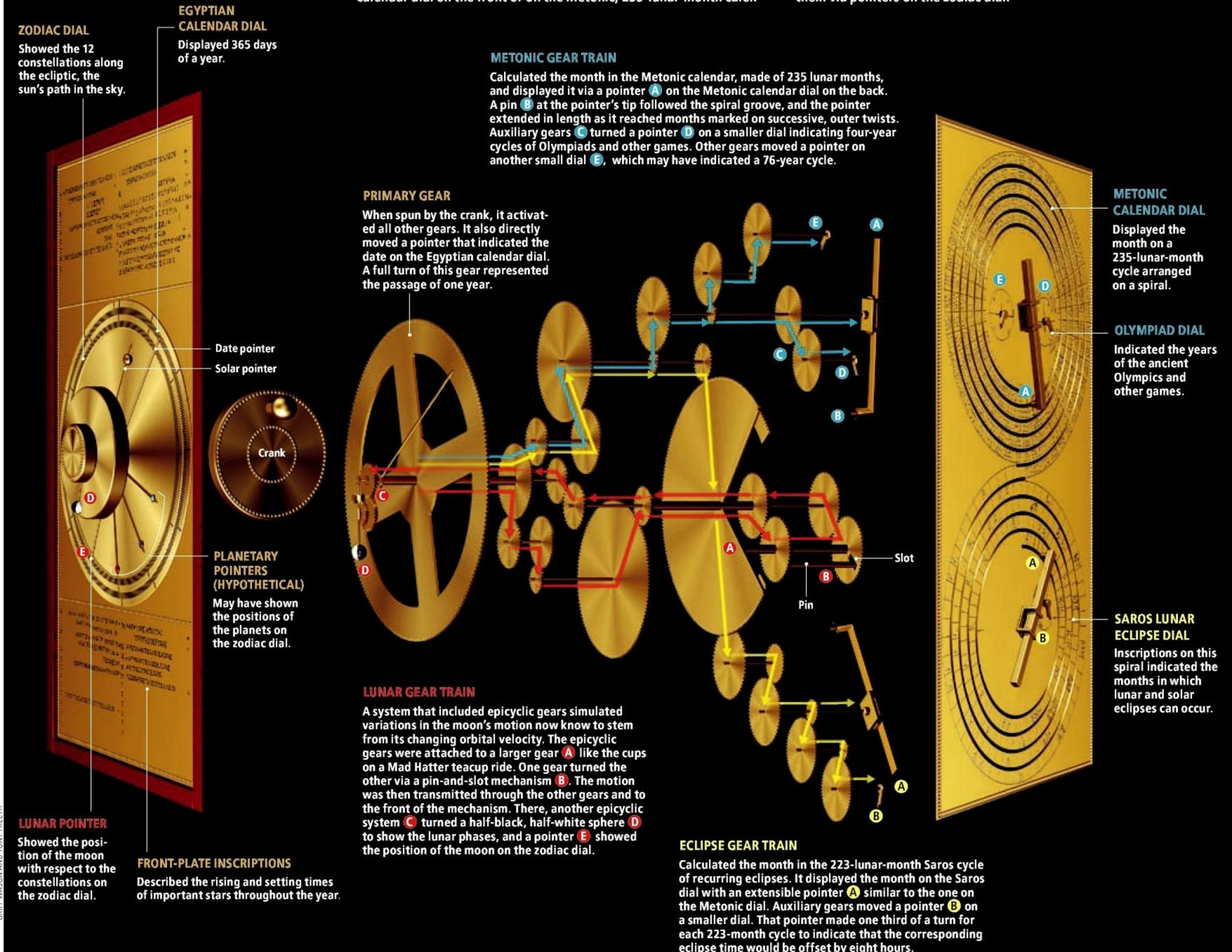
I now needed to follow the trail of clues into the heart of the mechanism to discover where this new insight would lead. The first step was to find a gear with 223 teeth to drive this new Saros dial. Karakalos had estimated that a large gear visible at the back of the main fragment had 222 teeth. But 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 cy-

[INSIDE THE ANTIKYTHERA MECHANISM]

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.



GRIFF WASON AND TONY FREETH

cle, 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 teacup-ride fashion. Each epicyclic gear also connected to another small gear. Confusingly, all four small gears appeared 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 about 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 kept varying 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 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. 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 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 it 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 ½ teeth. I pressed the key on my calculator, and it gave 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.

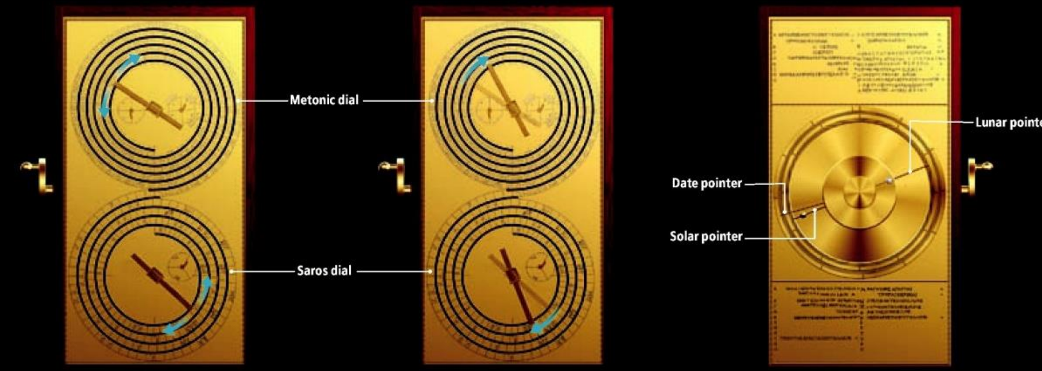
Then I realized that 26 ½ × 2 = 53. In fact, Wright had estimated a crucial gear to have 53 teeth, and I now saw that that count made everything work out. The designer had mounted the pin and slot epicyclically to subtly slow down the period of its variation while keeping the basic rotation the same, a conception of pure genius. Thanks to Edmunds, we also realized that the epicyclic gearing 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. Eventually we found, engraved round the four sectors of the dial, most of "*ISTHMIA*," for games at Corinth, "*PYTHIA*," for games at Delphi, "*NAA*," for minor games at Dodona, and "*OLYMPIA*," for the most important games of the Greek world, the Olympics. All games took place every two or four years. Previously we had considered the mechanism to be purely an instrument of mathematical astronomy, but the Olympiad dial—as we named it—gave it an entirely unexpected social function.

[A USER'S MANUAL]

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-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.



RESET DATE
Begin by turning the crank to set the current month and year on the Metonic calendar. The lower pointer will turn to the corresponding month on the Saros (*eclipse*) dial.

FIND ECLIPSE MONTH
Turn the crank to move time forward until the pointer on the Saros dial points to an eclipse inscription. The inscription will indicate month and time of the day (but not the day) of an eclipse and whether it will be solar or lunar.

CALCULATE DAY
Adjust the crank until the lunar and solar pointers are aligned (*for a solar eclipse*) or at 180 degrees (*for a lunar eclipse*). The Egyptian calendar pointer will move correspondingly and indicate the day of the eclipse.

DATA BY X-TEK SYSTEMS, SOFTWARE BY VOLUME GRAPHICS, © 2005 ANTIKYTHERA MECHANISM RESEARCH PROJECT

GRIFF WASON AND TONY FREETH

Twenty-nine of the 30 surviving gears calculate cycles of the sun and the moon. But our studies of the inscriptions at the front of the mechanism have also yielded a trove of information on the risings and settings of significant stars and of the planets. Moreover, on the "primary" gearwheel at the front of the mechanism remnants of bearings stand witness to a lost epicyclic system that could well have modeled the back-and-forth motions of the planets along the ecliptic (as well as the anomalies in the sun's own motion). All these clues strongly support the inclusion of the sun and of at least some of the five planets known in ancient times—Mercury, Venus, Mars, Jupiter and Saturn.

Wright built a model of the mechanism with epicyclic systems for all five planets. But his ingenious layout does not agree with all the evidence. With its 40 extra gears, it may also be too complex to match the brilliant simplicity of the rest of the mechanism. The ultimate answer may still lie 50 meters down on the ocean floor.

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 Greek world, from places such as Pergamon, Kos and Rhodes. It was a natural guess that Hipparchos or another Rhodian astronomer built the mechanism. But text hidden between the 235 monthly scale divisions of the Metonic calendar contradicts this view. Some of the month names were used only in specific locations in the ancient Greek world and suggest a Corinthian origin. If the mechanism was from Corinth itself, it was almost certainly made before Corinth was completely devastated by the Romans in 146 B.C. Perhaps more likely is that it was made to be used in one of the Corinthian colonies in northwestern Greece or Sicily.

Sicily suggests a remarkable possibility. The island's city of Syracuse was home to Archimedes, the greatest scientist of antiquity. In the first century B.C. Roman statesman Cicero tells how in 212 Archimedes was killed at the siege of Syracuse and how the victorious Roman general, Marcellus, took away with him only one piece of plunder—an astronomical instrument made by Archimedes. Was that the Antikythera mechanism? We believe not, because it appears to have been made many decades after Archimedes died. But it could have been constructed in a tradition of instrument making that originated with the eureka man himself.

Many questions about the Antikythera mechanism remain unanswered—perhaps the greatest being why this powerful technology seems to have been so little exploited in its own era and in succeeding centuries.

In *Scientific American*, Price wrote:

> *It is a bit frightening to know that just before the fall of their great civilization the ancient Greeks had come so close to our age, not only in their thought, but also in their scientific technology.*

Our discoveries have shown that the Antikythera mechanism was even closer to our world than Price had conceived. ■

➡ MORE TO EXPLORE

An Ancient Greek Computer. Derek J. de Solla Price in *Scientific American*, Vol. 200, No. 6, pages 60–67; June 1959.

Gears from the Greeks: The Antikythera Mechanism—A Calendar Computer from ca. 80 B.C. Derek de Solla Price in *Transactions of the American Philosophical Society*, New Series, Vol. 64, No. 7, pages 1–70; 1974.

Decoding the Ancient Greek Astronomical Calculator Known as the Antikythera Mechanism. Tony Freeth et al. in *Nature*, Vol. 444, pages 587–591; November 30, 2006.

Calendars with Olympiad Display and Eclipse Prediction on the Antikythera Mechanism. Tony Freeth, Alexander Jones, John M. Steele and Yanis Bitsakis in *Nature*, Vol. 454, pages 614–617; July 31, 2008.

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

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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-)

Peserverance!

Good Insights

"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)

Occam's razor!

More quotes: www.cs.virginia.edu/robins/quotes.html

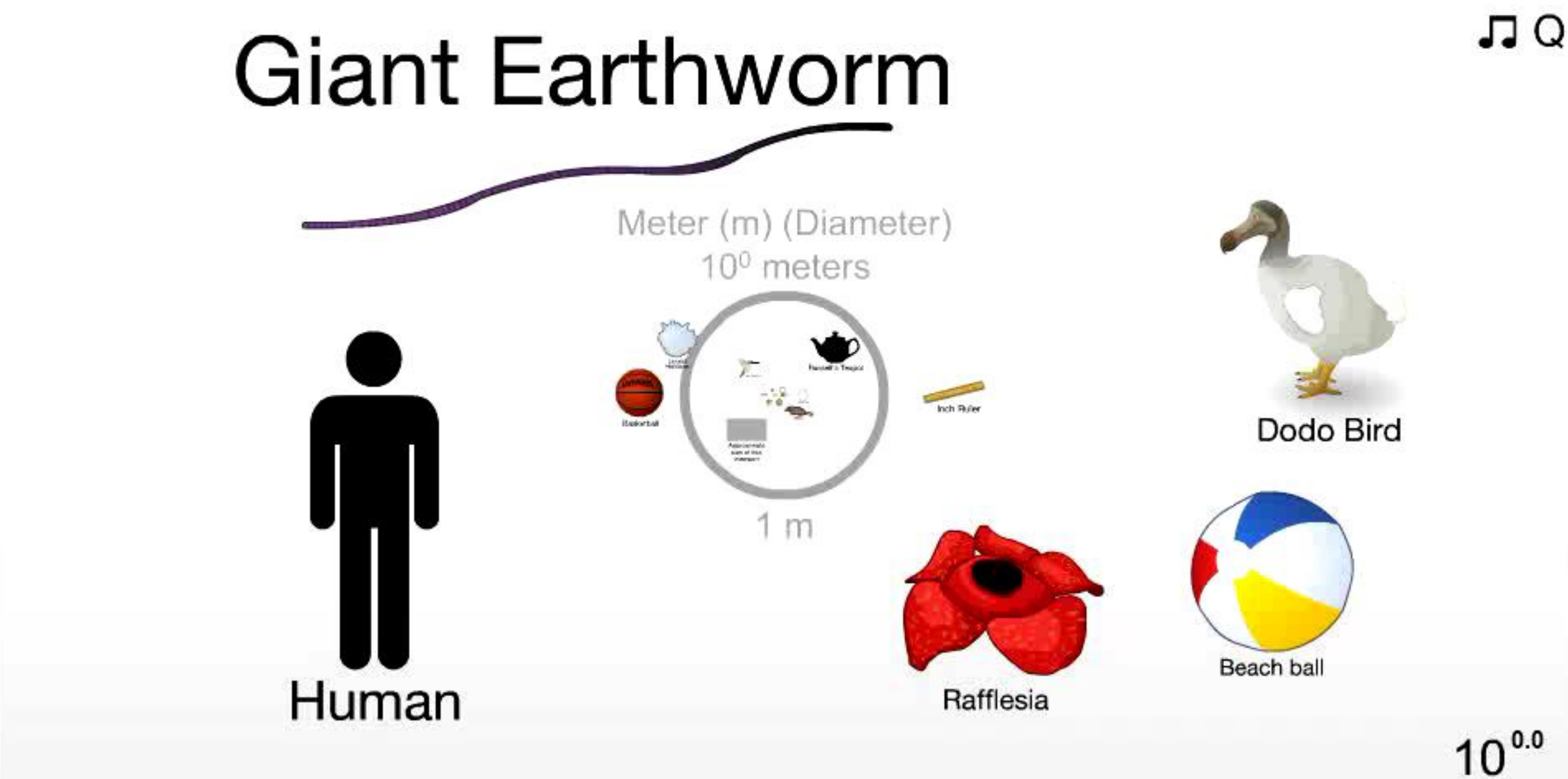
Watch these Videos

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

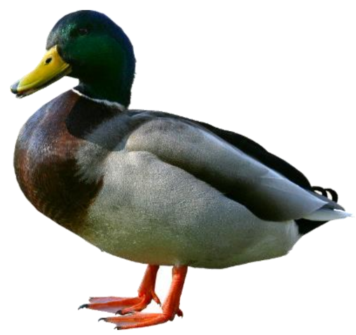


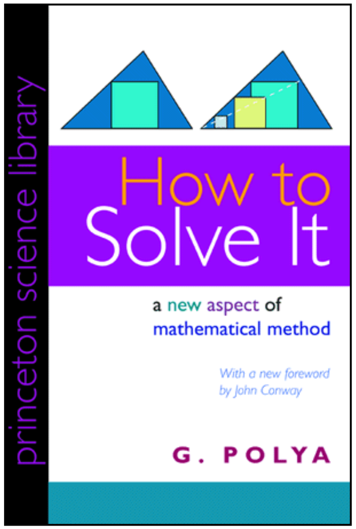
- 10^{-24} to 10^{26} meters $\Rightarrow$ 50 orders of magnitude!

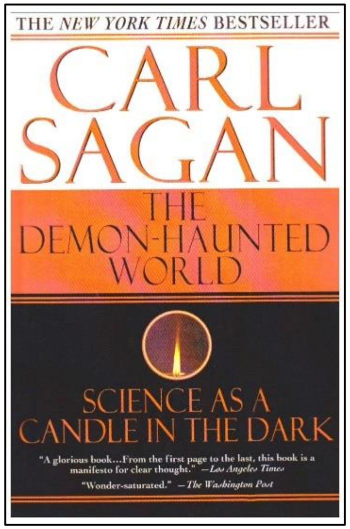
More Great Reads

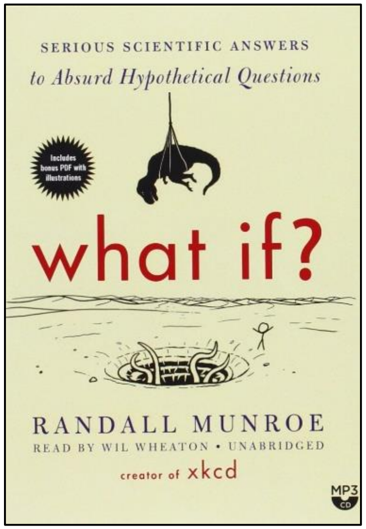
www.cs.virginia.edu/robins/CS_readings.html

- You and Your Research, Richard Hamming, 1986
- "How to Solve It", Polya, 1957
- "The Demon-Haunted World", Sagan, 2009
- "What If", Munroe, 2014
- The Pattern Behind Self-Deception, Shermer TED talk, 2010



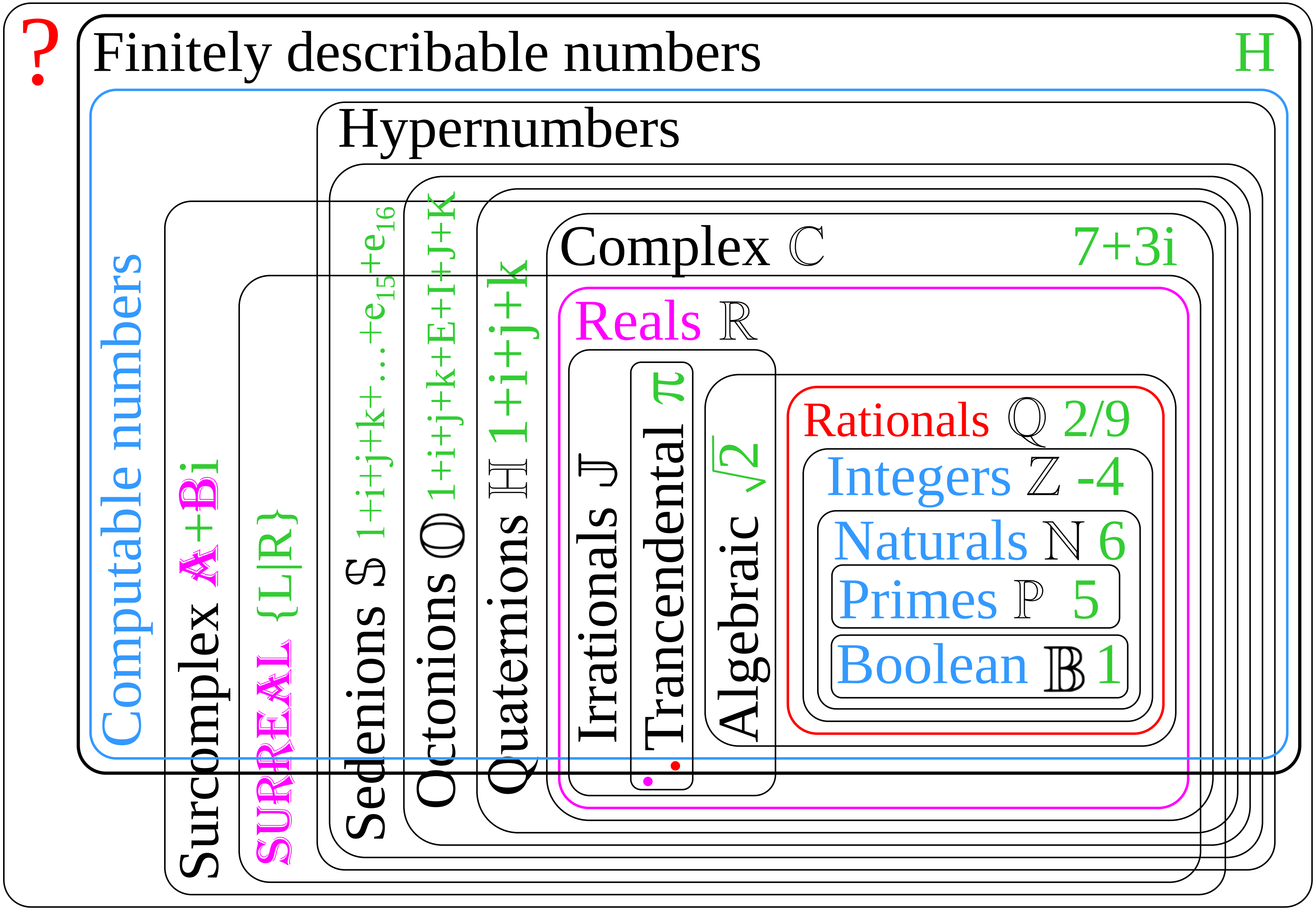






Michael Shermer

Cool Fact: Generalized Numbers



Theorem: some real numbers are not finitely describable!

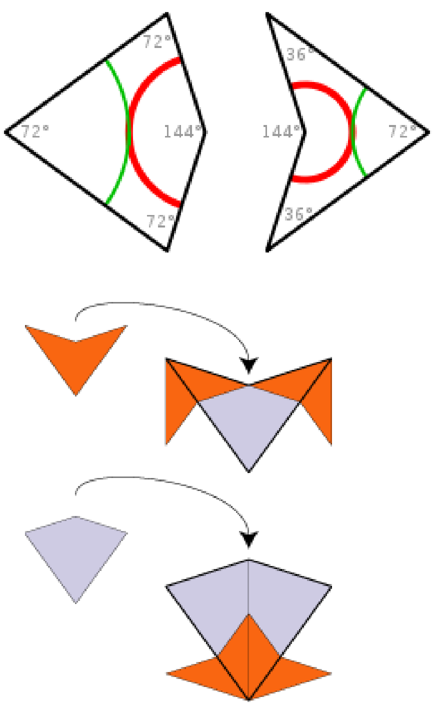
Theorem: some finitely describable real numbers are not computable!

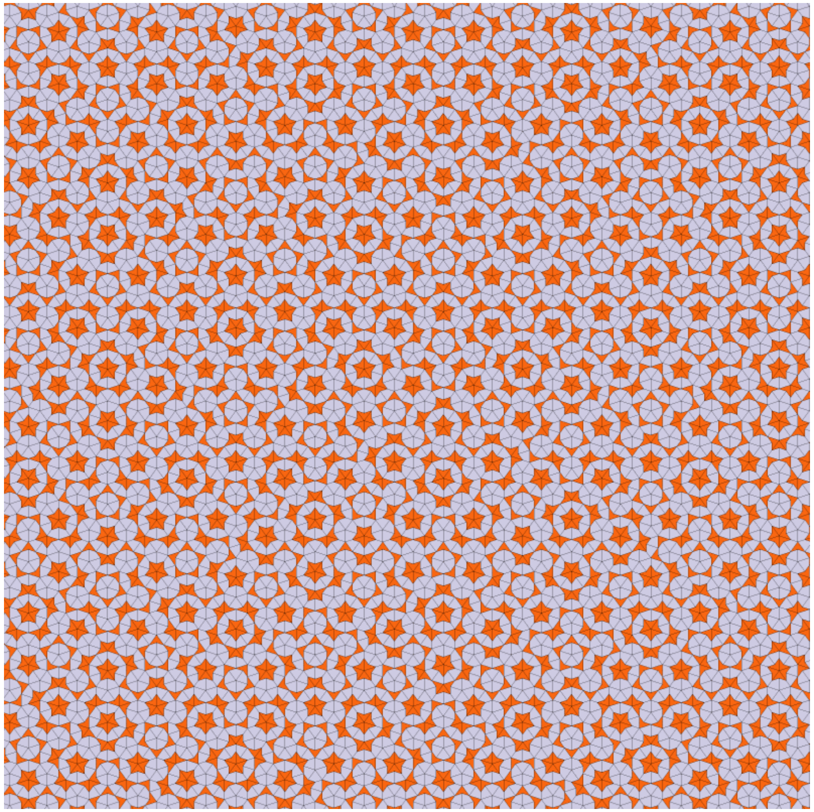
Cool Fact: Aperiodic Tilings

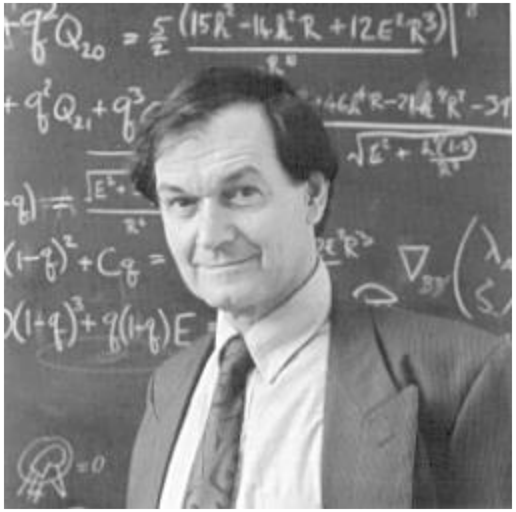
Goal: tile the entire plane without overlaps, non-periodically

- 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





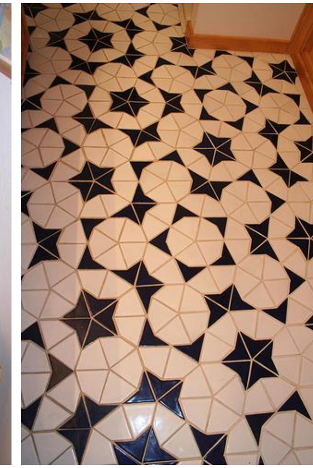


Open question:

∃ a single-tile 2D aperiodic tiling?

Aperiodic Tilings in Real Life

Penrose tilings in architecture and design:

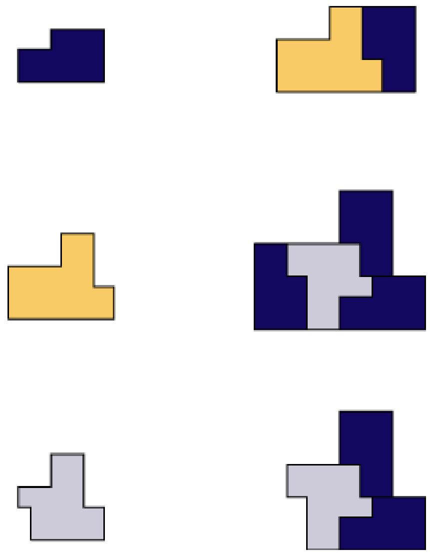

Aperiodic tilings also occur in nature (e.g., quasi-crystals)

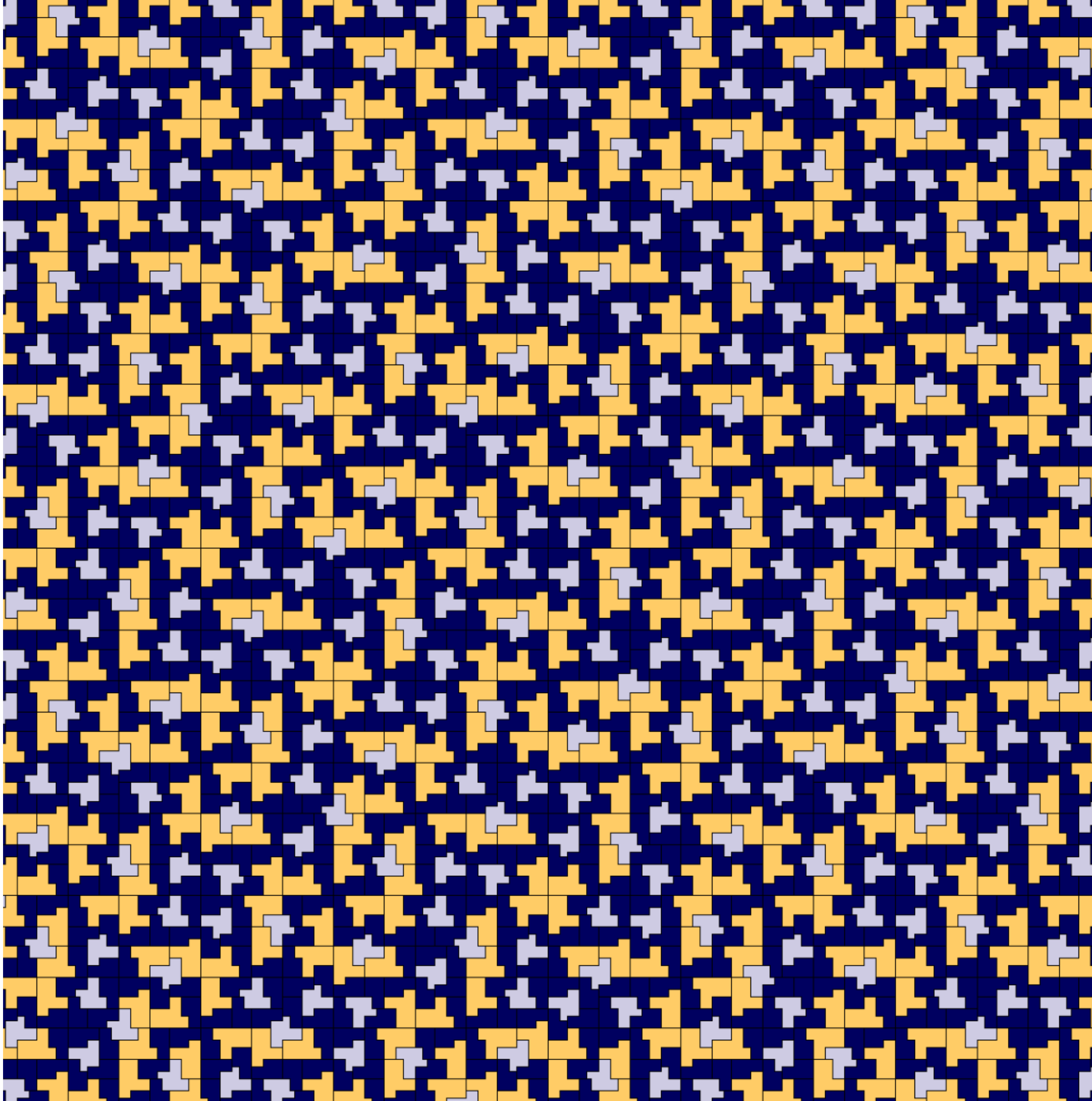
Aperiodic Tilings

"Ammann A3"

Robert Ammann,

1977

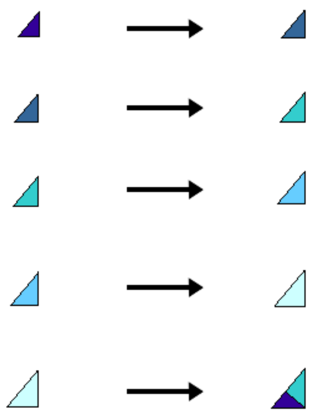


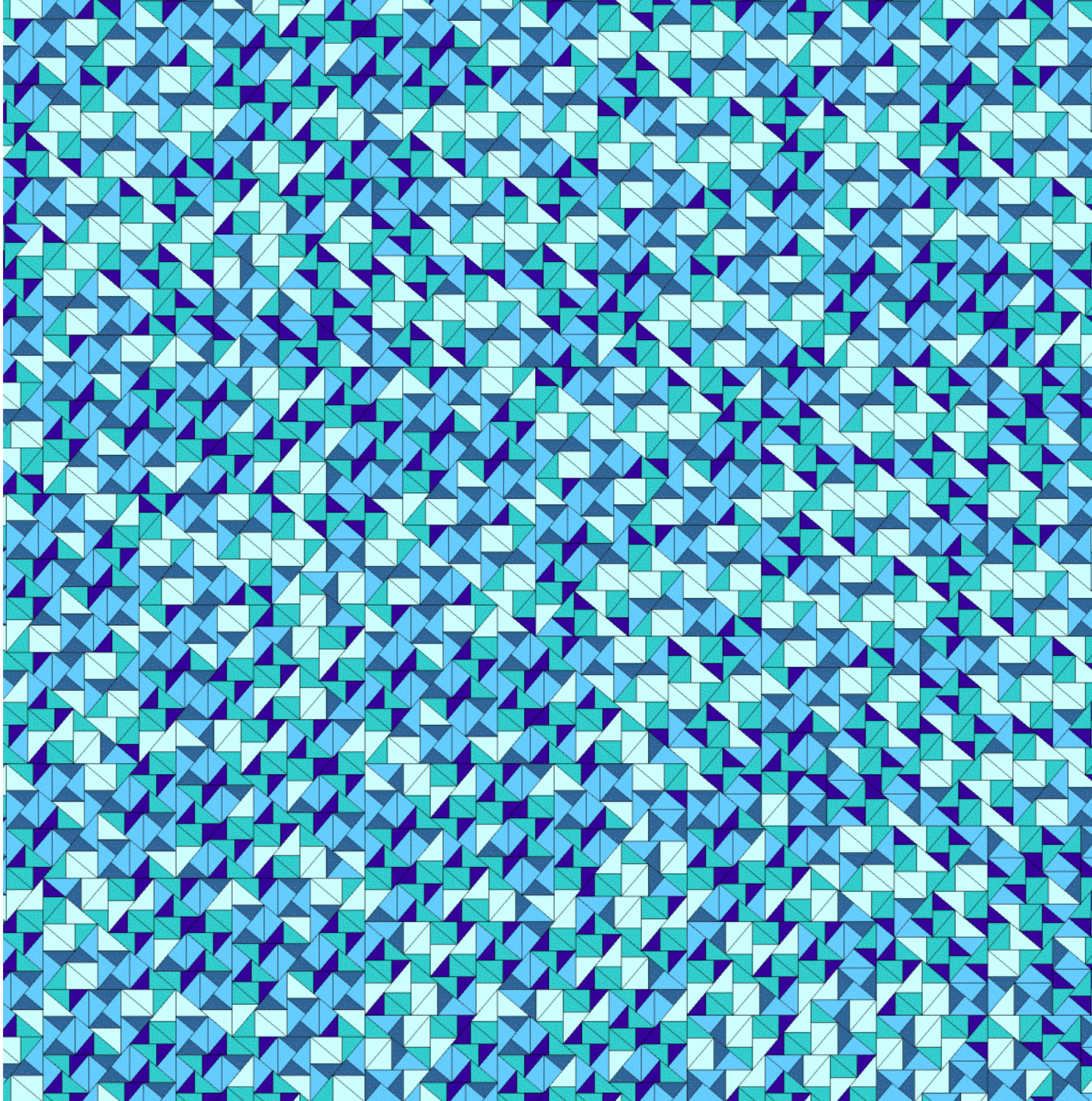


Aperiodic Tilings

"Pythagoras-3-1"

J. Pieniak





Aperiodic Tilings

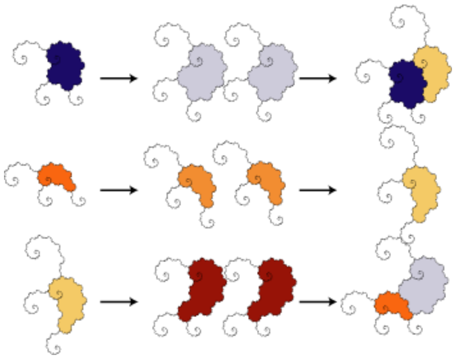
"Nautilus (volume hierarchic"

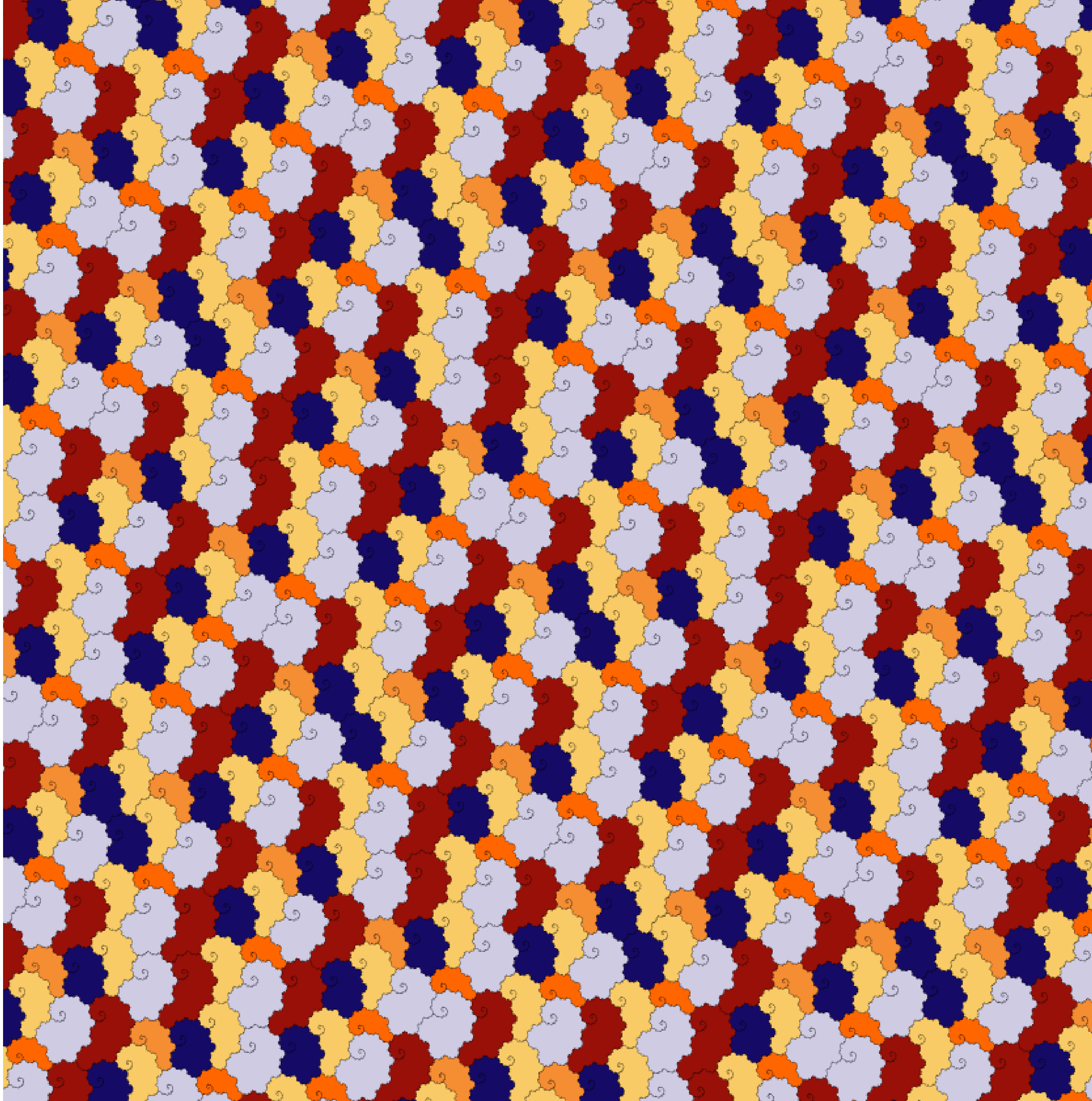
P. Arnoux,

M. Furukado,

E. Harriss,

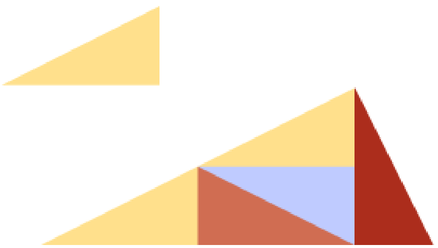
and S. Ito

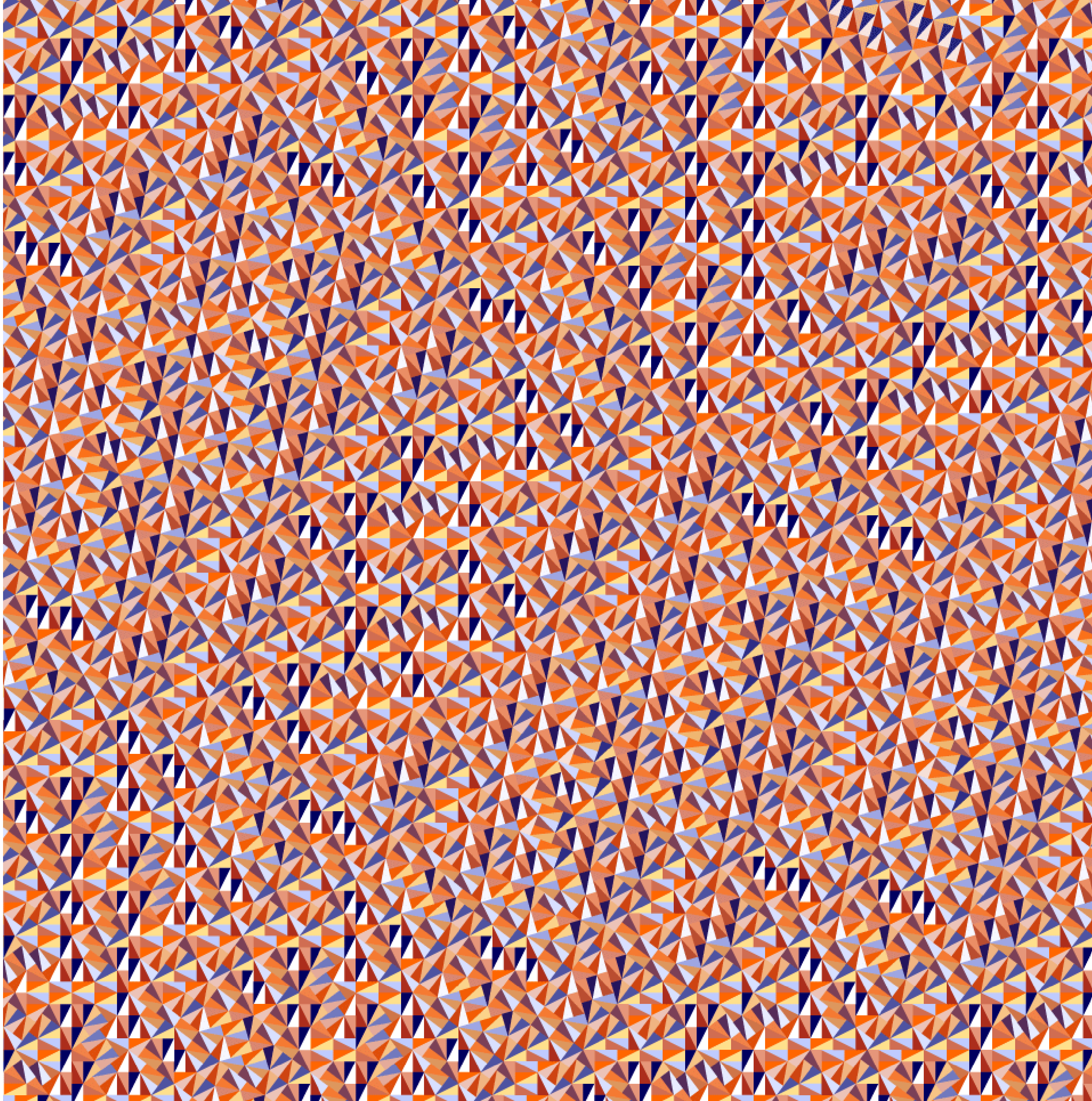




Aperiodic Tilings

"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

NEW SCIENTIST

SCIENCE

Bathroom tiling to drive you mad

Ian Stewart

AN AMERICAN mathematician has come up with what is probably the strangest way ever of covering a floor or wall with tiles. The set of tiles which has been devised by Charles Radin of the University of Texas at Austin can only be assembled in a highly complex way (*Annals of Mathematics*, vol 109, p 661).

The usual way of assembling tiles is in a periodic pattern, one that starts with a basic unit, which is repeated at regularly spaced intervals. However, more complex patterns of tiling are perfectly possible and the subject of aperiodic tilings was created by the philosopher Hao Wang in 1961. Wang was studying the existence or otherwise of certain "decision procedures" in mathematical logic—ways of working out in advance whether certain problems have solutions—when he came to the surprising conclusion that the problem could be reformulated in terms of tiles.

Choose a finite collection of shapes and call them prototiles. A tiling is then a way to assemble perfect copies of those prototiles so that they cover the entire infinite plane without any gaps or overlaps. Wang discovered that he could design prototiles that corresponded to various logical statements, in such a way that the rules for fitting prototiles together corresponded exactly to the rules of logical deduction. So, in effect, a tiling pattern corresponded to a logical proof. This new viewpoint led Wang to ask whether there existed a set of prototiles that could tile the plane, but could not tile it periodically.

Tiling a plane aperiodically turns out to be easy. It can be done with a single domino-shaped prototile. First, however, it is necessary to tile the plane with squares. Then each square is divided into two dominos by splitting it in half in either the vertical or horizontal direction. If the pattern of verticals and horizontals is aperiodic, so too is the tiling: the easiest method is to vary the directions randomly. However, dominos can also tile the plane periodically—for example, by making all splits point the same way.

Wang wanted something much more subtle: a set of prototiles that produced only aperiodic tilings. Such a set of tiles was found in 1966 by his student Robert Berger. The best known of such sets are the Penrose tilings, introduced by Roger Penrose of the University of Oxford in 1977; these produce tilings with fivefold "almost" symmetries.

Radin notes that: "All published examples . . . have the feature that in every tiling each prototile only appears in finitely many orientations." For instance, dominos can be laid down horizontally or vertically but not oriented at any other angle; and Penrose tiles rotate only through multiples of an angle of 36°. This means that if the set of prototiles is expanded so that it includes a copy of each prototile in each orientation, then the new prototiles can tile the whole plane without being rotated. Only translations of these "oriented prototiles" are then needed.

Radin's new discovery is a set of prototiles that are forced to appear in an infinite number of orientations. Because periodic tilings involve only a finite number of directions—the ones in the basic repeating unit—Radin's tilings are necessarily aperiodic.

His starting point is an idea thought up by John Horton Conway of Princeton University in New Jersey. Begin with a "half-domino" prototile, a right triangle of sides 1 and 2 units (whose hypotenuse is 5 units). This can be surrounded by four copies of itself in order to create a triangle of the same shape, but larger and rotated through an angle (see Figure). The process can be thought of as defining a "level-l" tiling of part of the plane with five triangular tiles. The construction can now be repeated, surrounding the level-1 set of five tiles with four copies of those sets to make an even larger and further rotated triangle that is composed of 25 of the original prototiles: this is known as the level-2 tiling.

Continuing this "expansion" process indefinitely from each level to the next leads to a strange, random-looking tiling of the infinite plane by half-dominos (see Figure), called the Conway tiling. Because the angle of rotation at each stage does not exactly divide into an integer number of full turns, the half-domino appears in an infinite number of different orientations throughout the plane.

However, this particular prototile can also tile the plane periodically. This can be done if two half-dominos are stuck together to make a domino and the plane is tiled periodically with those. To eliminate these periodic possibilities, Radin modifies the construction so that certain features of the Conway tiling, in particular its hierarchical structure into levels, cannot be avoided.

The essential idea is an old one: the edges of prototiles can be "labelled" with marks or symbols, with the extra rule that adjacent tiles must have matching labels along their common edges. This produces a larger set of labelled prototiles with more restrictive tiling rules. The point is that the labels can be realised by making notches in the edges of one tile and adding protruding lugs to match them in the adjacent tile. By using a different shaped notch/lug pair for each symbol used as a label, we can convert labelled prototiles into ordinary ones of more complicated shapes.

It is, of course, easier to think about simple shapes that have labelled edges, and this is the way in which Radin proceeds. His prototiles are labelled half-dominos, and he invents a complicated range of different labels whose matching rules cleverly force the appearance of the same structure as the Conway tiling.

It is astonishing that such a simple shape as half a domino can have such curious implications, and it shows that even in today's complex world mathematics can still advance by looking at a simple idea in a new way. □

World's most complex tiling? Surround a triangular "half-domino" by four more. Then simply repeat . . .

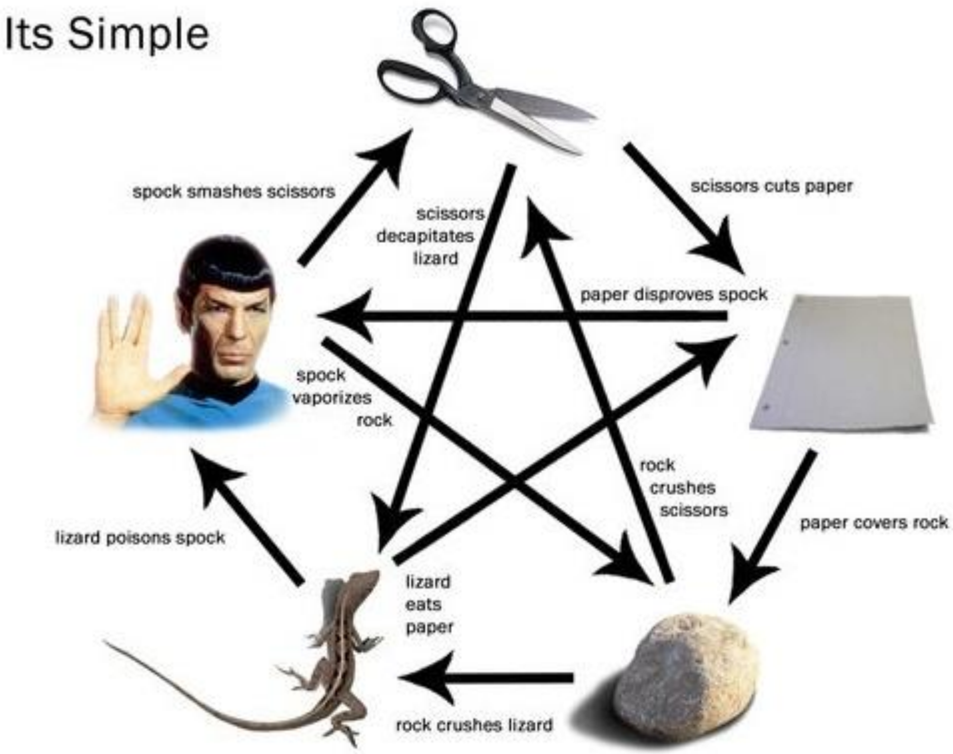
14

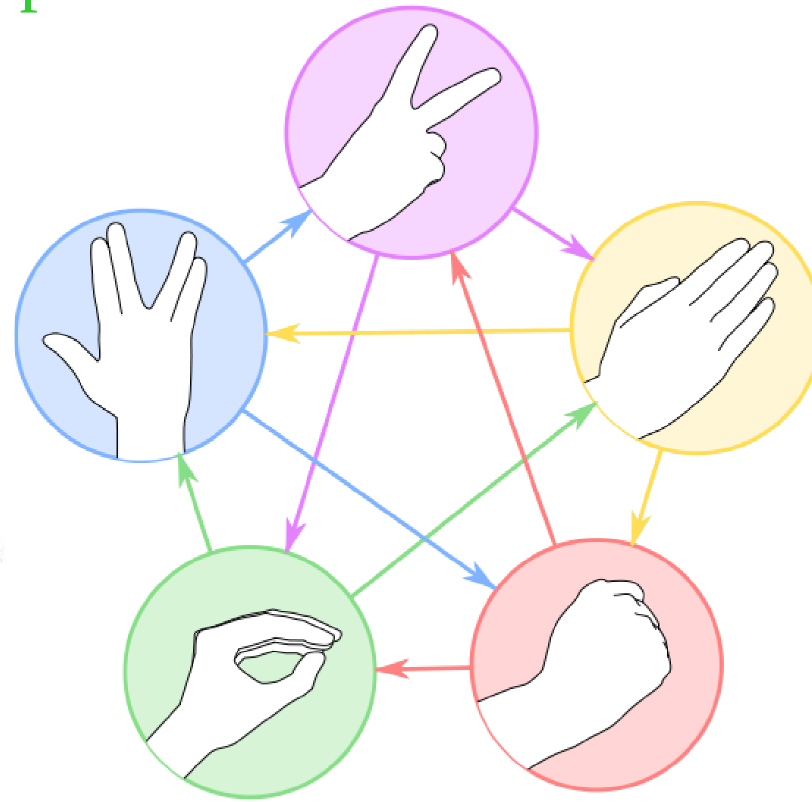
24 September 1994

Federation Square
Melbourne, Australia

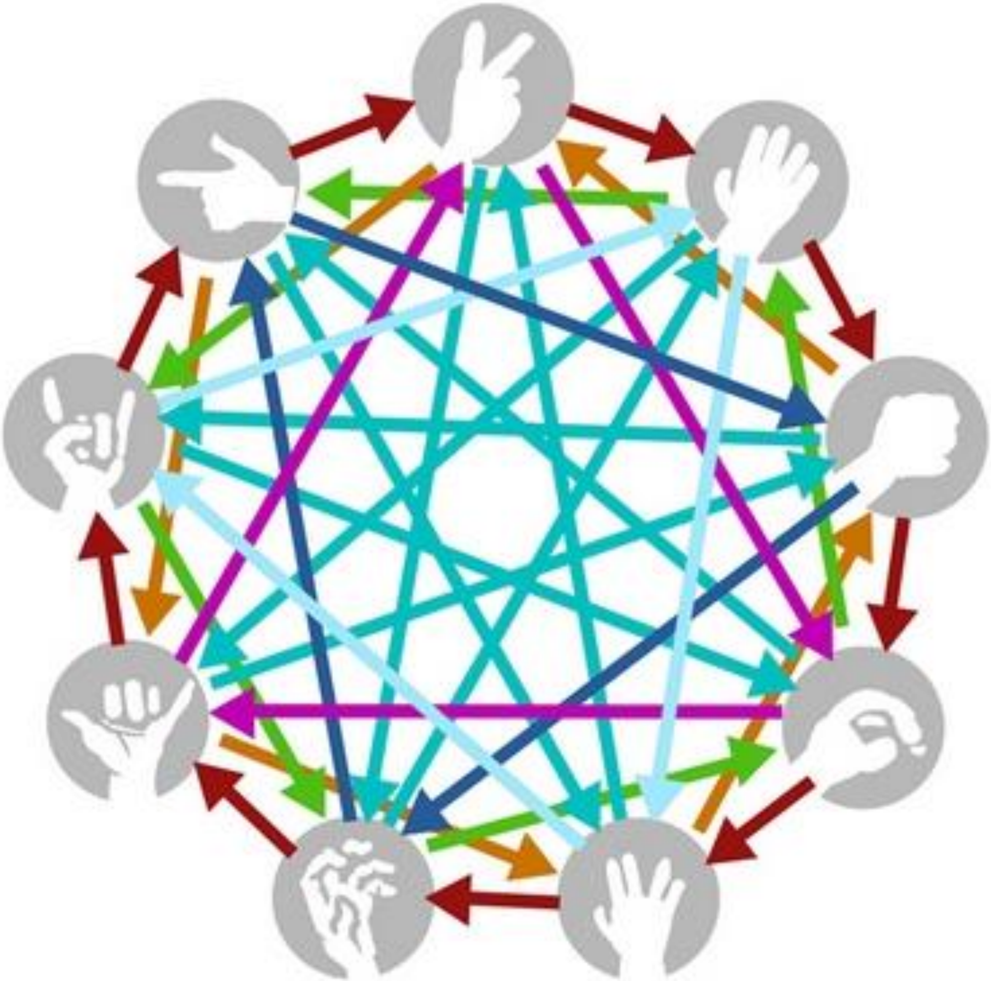
Cool Fact: Generalized Rock-Paper-Scissors

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



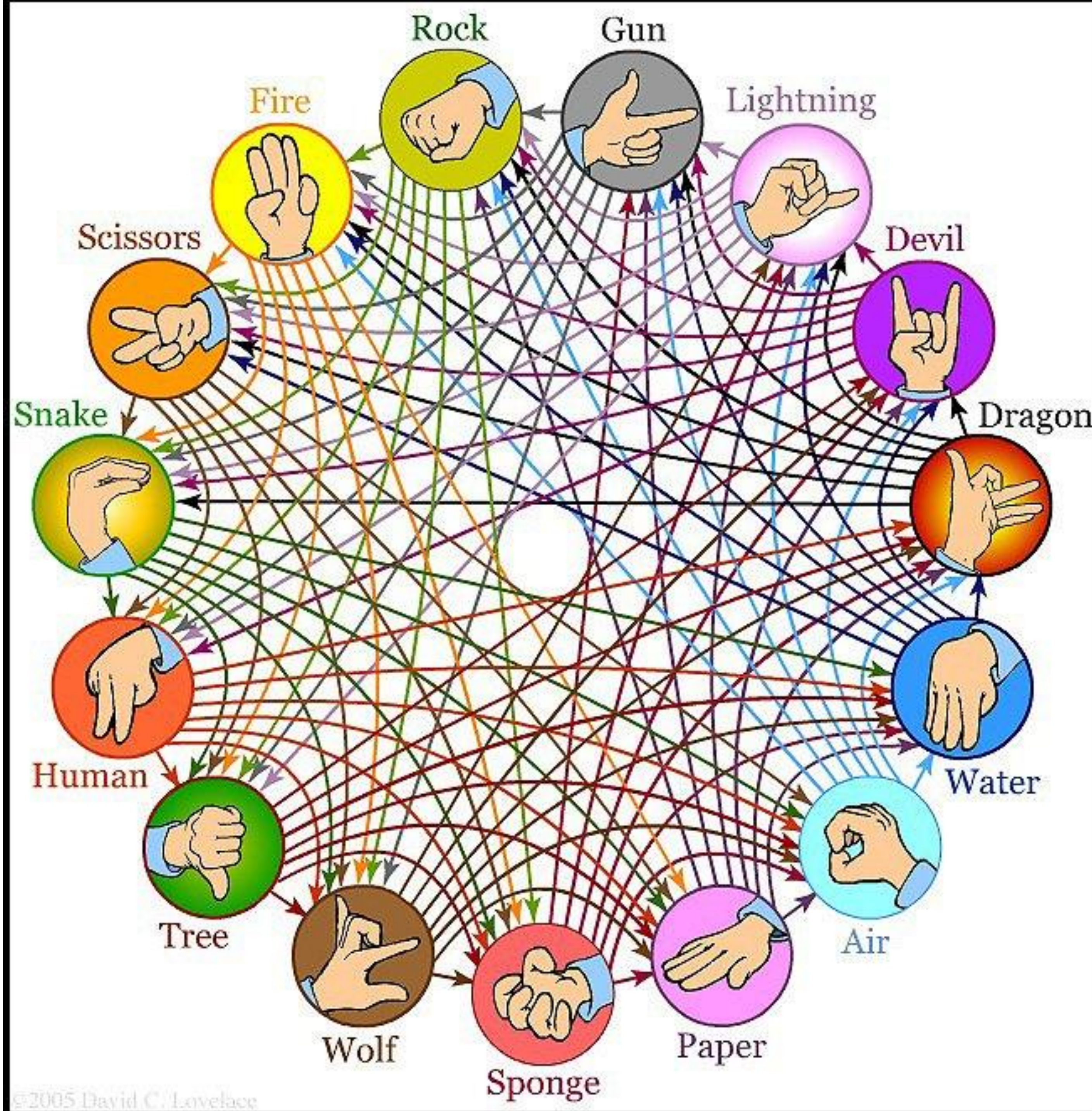


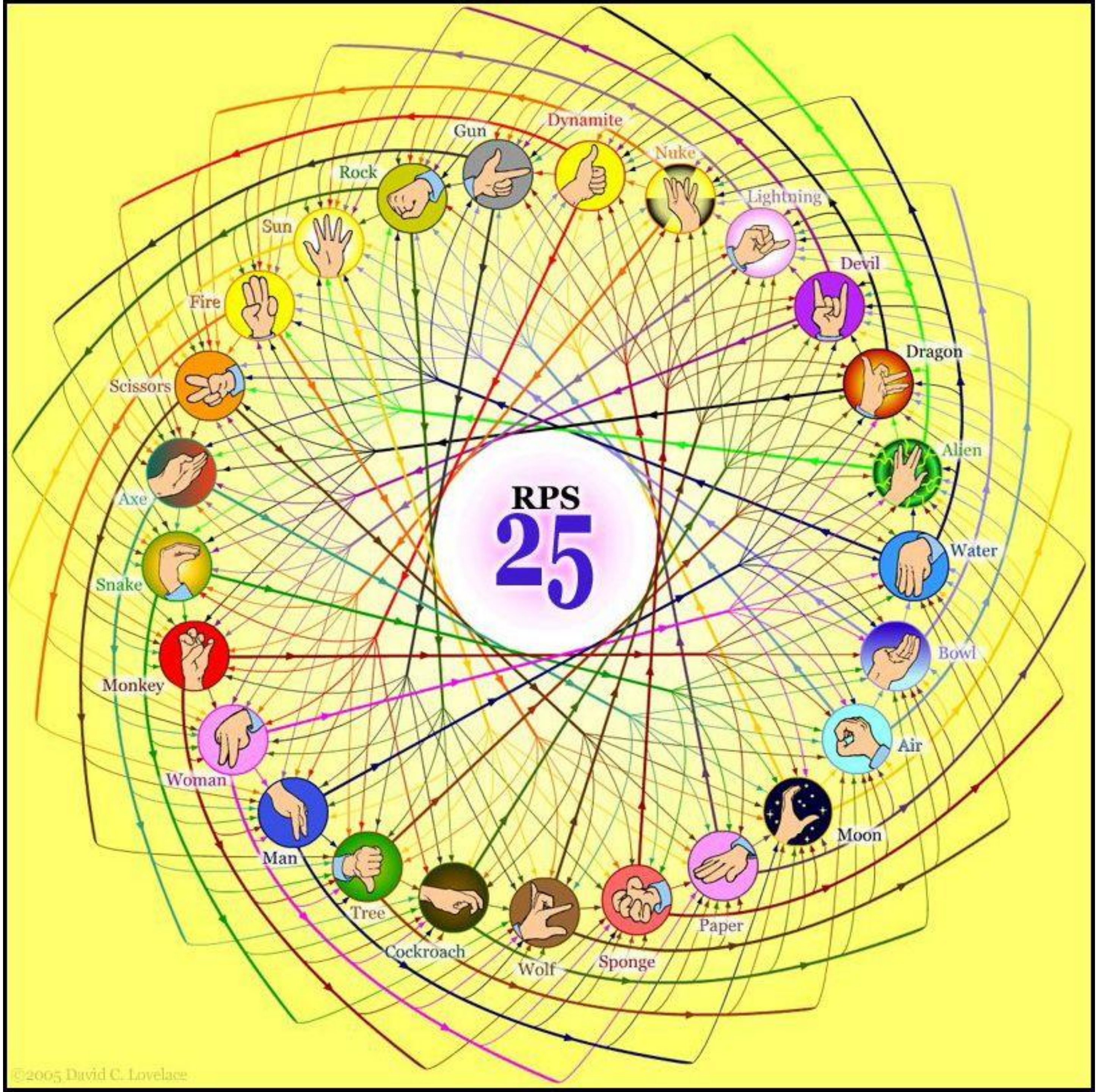
Rules: Scissors cuts Paper covers Rock crushes Lizard poisons Spock smashes Scissors decapitates Lizard eats Paper disproves Spock vaporizes Rock crushes Scissors



ROCK PAPER SCISSORS LIZARD SPOCK SPIDER-MAN BATMAN WIZARD GLOCK

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.


Rock
Gun
Fire
Lightning
Scissors
Devil
Snake
Dragon
Human
Water
Tree
Air
Wolf
Sponge
Paper
©2005 David C. Lovelace



RPS
25
Gun
Dynamite
Nuke
Lightning
Devil
Dragon
Alien
Water
Bowl
Air
Moon
Paper
Sponge
Wolf
Cockroach
Tree
Man
Woman
Monkey
Snake
Axe
Scissors
Fire
Sun
Rock
©2005 David C. Lovelace

GUN
- TARGETS ROCK
- SHOOTS AT SUN
- (GUN) FIRES
- DESTROYS SCISSORS
- CHIPS AXE
- SHOOTS SNAKE
- SHOOTS MONKEY
- SHOOTS WOMAN
- SHOOTS MAN
- TARGETS TREE
- SHOOTS COCKROACH
- SHOOTS WOLF

DYNAMITE
- OUTCLASSES GUN
- EXPLODES ROCK
- SMOKE BLOTS OUT SUN
- STARTS FIRE
- EXPLODES SCISSORS
- EXPLODES AXE
- EXPLODES SNAKE
- EXPLODES MONKEY
- EXPLODES WOMAN
- EXPLODES MAN
- EXPLODES TREE
- EXPLODES COCKROACH

NUKE
- OUTCLASSES DYNAMITE
- OUTCLASSES GUN
- INCINERATES ROCK
- HAS POWER OF SUN
- STARTS MASSIVE FIRE
- INCINERATES SCISSORS
- INCINERATES SNAKE
- INCINERATES AXE
- INCINERATES MONKEY
- INCINERATES WOMAN
- INCINERATES MAN
- INCINERATES TREE

LIGHTNING
- DEFUSES NUKE
- IGNITES DYNAMITE
- MELTS GUN
- SPLITS ROCK
- STORM BLOCKS SUN
- STARTS FIRE
- MELTS SCISSORS
- MELTS AXE
- STRIKES SNAKE
- STRIKES MONKEY
- STRIKES WOMAN
- STRIKES MAN

DEVIL
- CASTS LIGHTNING
- INSPIRES NUKE
- INSPIRES DYNAMITE
- INSPIRES GUN
- HURLS ROCK
- CURSES SUN
- BREATHES FIRE
- IMMUNE TO SCISSORS
- IMMUNE TO AXE
- EATS SNAKES
- ENRAGES MONKEY
- TEMPTS WOMAN

DRAGON
- COMMANDS DEVIL
- BREATHES LIGHTNING
- LIVED BEFORE NUKES
- FLOSSES WITH DYNAMITE
- IMMUNE TO GUN
- RESTS UPON ROCK
- BLOTS OUT SUN
- BREATHES FIRE
- IMMUNE TO SCISSORS
- IMMUNE TO AXE
- SPAWNS SNAKE
- CHARS MONKEY

ALIEN
- VAPORIZES DRAGON
- NON-BELIEVER IN DEVIL
- SHOOTS LIGHTNING
- DEFUSES NUKE
- DEFUSES DYNAMITE
- FORCE-FIELDS GUN
- VAPORIZES ROCK
- DESTROYS SUN
- FUSES FIRE
- FORCE-FIELDS SCISSORS
- FORCE-FIELDS AXE
- MUTATES SNAKE

WATER
- TOXIC TO ALIEN
- DROWNS DRAGON
- BLESSES DEVIL
- CONDUCTS LIGHTNING
- SHORT-CIRCUITS NUKE
- DOUSES DYNAMITE
- RUSTS GUN
- ERODES ROCK
- REFLECTS SUN
- PUTS OUT FIRE
- RUSTS SCISSORS
- RUSTS AXE

BOWL
- CONTAINS WATER
- SHAPES CRAFT OF ALIEN
- DROWNS DRAGON
- BLESSES DEVIL
- FOCUSES LIGHTNING
- ENCASES CORE OF NUKE
- SPLASHES DYNAMITE
- SPLASHES GUN
- ONCE MADE OF ROCK
- FOCUSES SUN
- SNUFFS OUT FIRE
- COVERS SCISSORS

AIR
- TIPS OVER BOWL
- EVAPORATES WATER
- CHOKES ALIEN
- FREEZES DRAGON
- CHOKES DEVIL
- CREATES LIGHTNING
- BLOWS ASTRAY NUKE
- BLOWS OUT DYNAMITE
- TARNISHES GUN
- ERODES ROCK
- COOLS HEAT OF SUN
- BLOWS OUT FIRE

MOON
- HAS NO AIR
- SHAPED LIKE BOWL
- HAS NO WATER
- HOUSES ALIEN
- SHINES ON DRAGON
- TERRIFIES DEVIL
- FAR ABOVE LIGHTNING
- TOO FAR FOR NUKE
- SUFFOCATES DYNAMITE
- MOONSHINE GUNFIGHT
- SHINES ON ROCK
- ECLIPSES SUN

PAPER
- (PAPER) MOON
- FANS AIR
- MACHE BOWL
- FLOATS ON WATER
- DISPROVES ALIEN
- REBUKES DRAGON
- REBUKES DEVIL
- DEFINES LIGHTNING
- DEFINES NUKE
- ENCASES DYNAMITE
- OUTLAWS GUN
- COVERS ROCK

SPONGE
- SOAKS PAPER
- LOOKS LIKE MOON
- USES AIR POCKETS
- CLEANS BOWL
- ABSORBS WATER
- INTRIGUES ALIEN
- CLEANSES DRAGON
- CLEANSES DEVIL
- CONDUCTS LIGHTNING
- CLEANS NUKE
- SOAKS DYNAMITE
- CLEANS GUN

WOLF
- CHEWS UP SPONGE
- CHEWS UP PAPER
- HOWLS AT MOON
- BREATHES AIR
- DRINKS FROM BOWL
- DRINKS WATER
- CHASES ALIEN
- OUTRUNS DRAGON
- BITES HEINY OF DEVIL
- OUTRUNS LIGHTNING
- "WOLF-2" LAUNCHES NUKE
- OUTRUNS DYNAMITE

COCKROACH
- SLEEPS IN FUR OF WOLF
- NESTS IN SPONGE
- NESTS BETWEEN PAPERS
- NOCTURNAL WITH MOON
- BREATHES AIR
- HIDES UNDER BOWL
- DRINKS WATER
- STOWS AWAY WITH ALIEN
- EATS EGGS OF DRAGON
- MAKES MEN DEVILS
- HIDES FROM LIGHTNING
- SURVIVES NUKE

TREE
- SHELTERS COCKROACH
- SHELTERS WOLF
- OUTLIVES SPONGE
- CREATES PAPER
- BLOCKS MOON
- PRODUCES AIR
- WOOD CREATES BOWL
- DRINKS WATER
- ENSNARES ALIEN SHIP
- SHELTERS DRAGON
- IMPRISONS DEVIL
- ATTRACTS LIGHTNING

MAN
- PLANTS TREE
- STEPS ON COCKROACH
- TAMES WOLF
- CLEANS WITH SPONGE
- WRITES PAPER
- TRAVELS TO MOON
- BREATHES AIR
- EATS FROM BOWL
- DRINKS WATER
- DISPROVES ALIEN
- SLAYS DRAGON
- EXORCISES DEVIL

WOMAN
- TEMPTS MAN
- PLANTS TREE
- STEPS ON COCKROACH
- TAMES WOLF
- CLEANS WITH SPONGE
- WRITES PAPER
- ALIGNS WITH MOON
- BREATHES AIR
- EATS FROM BOWL
- DRINKS WATER
- DISPROVES ALIEN
- SUBDUES DRAGON

MONKEY
- FLINGS POOP AT WOMAN
- FLINGS POOP AT MAN
- LIVES IN TREE
- EATS COCKROACH
- ENRAGES WOLF
- RIPS UP SPONGE
- RIPS UP PAPER
- SCREECHES AT MOON
- BREATHES AIR
- SMASHES BOWL
- DRINKS WATER
- INFURIATES ALIEN

SNAKE
- BITES MONKEY
- BITES WOMAN
- BITES MAN
- LIVES IN TREE
- EATS COCKROACH
- BITES WOLF
- SWALLOWS SPONGE
- NESTS IN PAPER
- NOCTURNAL WITH MOON
- BREATHES AIR
- SLEEPS IN BOWL
- DRINKS WATER

AXE
- CHOPS SNAKE
- CLEAVES MONKEY
- CLEAVES WOMAN
- CLEAVES MAN
- CHOPS DOWN TREE
- CHOPS COCKROACH
- CLEAVES WOLF
- CHOPS SPONGE
- SLICES PAPER
- REFLECTS MOON
- FLIES THROUGH AIR
- CHOPS BOWL

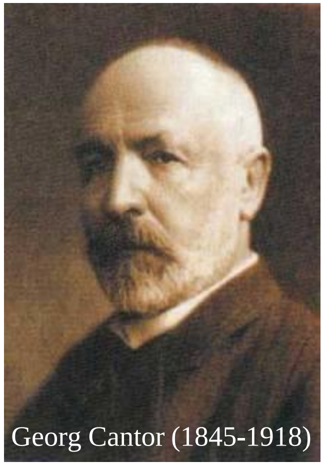
SCISSORS
- SHARPER THAN AXE
- STAB SNAKE
- STAB MONKEY
- CUT WOMEN'S HAIR
- CUT MAN'S HAIR
- CARVE TREE
- STAB COCKROACH
- CUT WOLF'S HAIR
- CUT UP SPONGE
- CUT PAPER
- REFLECT MOON
- SWISH THROUGH AIR

FIRE
- MELTS SCISSORS
- FORGES AXE
- BURNS SNAKE
- BURNS MONKEY
- BURNS WOMAN
- BURNS MAN
- BURNS DOWN TREE
- BURNS COCKROACH
- BURNS WOLF
- BURNS SPONGE
- BURNS PAPER
- CAMPFIRE BY MOONLIGHT

SUN
- MADE OF FIRE
- MELTS SCISSORS
- MELTS AXE
- WARMS SNAKE
- WARMS MONKEY
- WARMS WOMAN
- WARMS MAN
- FEEDS TREE
- WARMS COCKROACH
- WARMS WOLF
- DRIES UP SPONGE
- SHINES THROUGH PAPER

ROCK
- SHADES SUN
- POUNDS OUT FIRE
- SMASHES SCISSORS
- CHIPS AXE
- CRUSHES SNAKE
- CRUSHES MONKEY
- CRUSHES WOMAN
- CRUSHES MAN
- BLOCKS TREE ROOTS
- SQUISHES COCKROACH
- CRUSHES WOLF
- CRUSHES SPONGE

Cool Fact: Cantor Set



Georg Cantor (1845-1918)

Start with unit segment

- Remove (open) middle third
- Repeat recursively on all remaining segments
- Cantor set is all the remaining points

Total length removed: 1/3 + 2/9 + 4/27 + 8/81 + … = 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., 1/4)

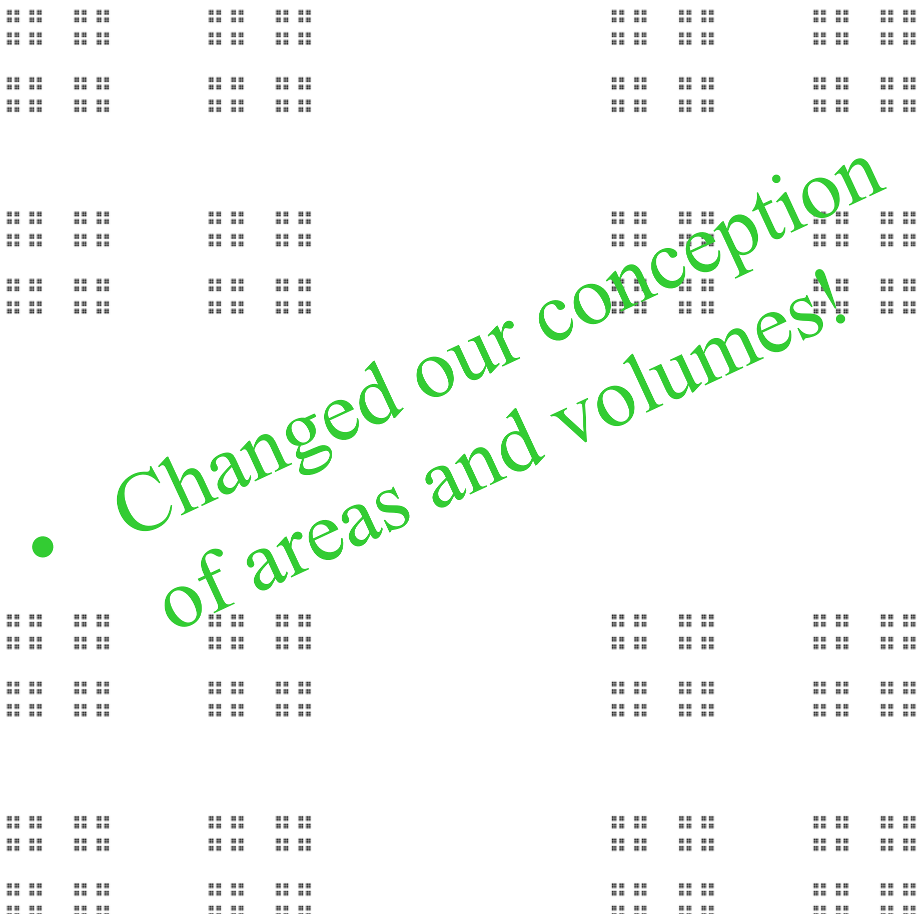
Cantor set is totally disconnected (no nontrivial connected subsets)

Cantor set is self-similar with Hausdorff dimension of $\log_3 2 = 1.585$

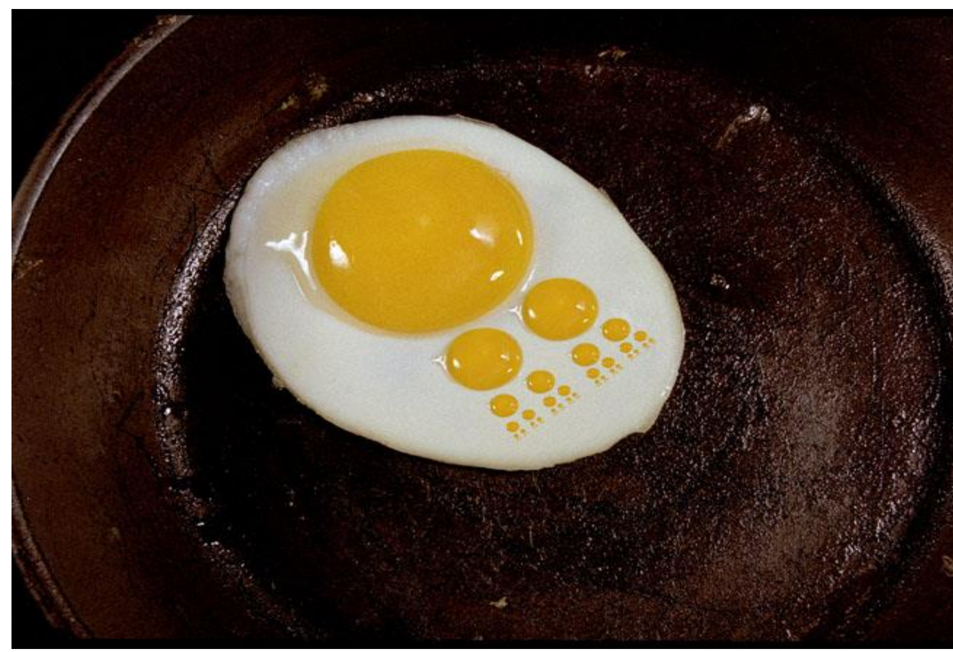
Cantor set is a closed, totally bounded, compact, complete metric space, with uncountable cardinality and lebesque measure zero

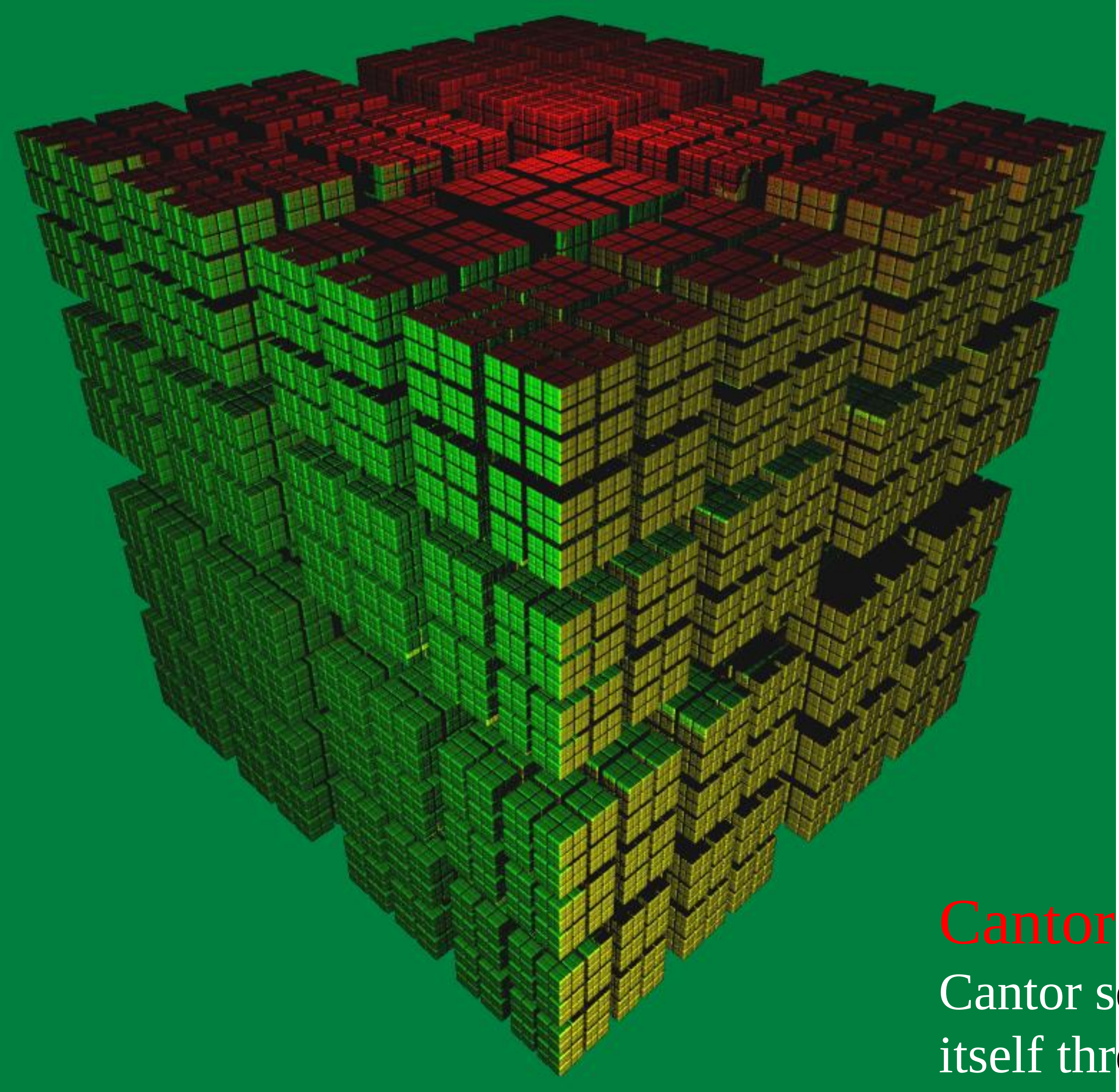
CANTOR

Cantor dust (2D generalization): Cantor set crossed with itself



- Changed our conception of areas and volumes!





Cantor cube (3D):

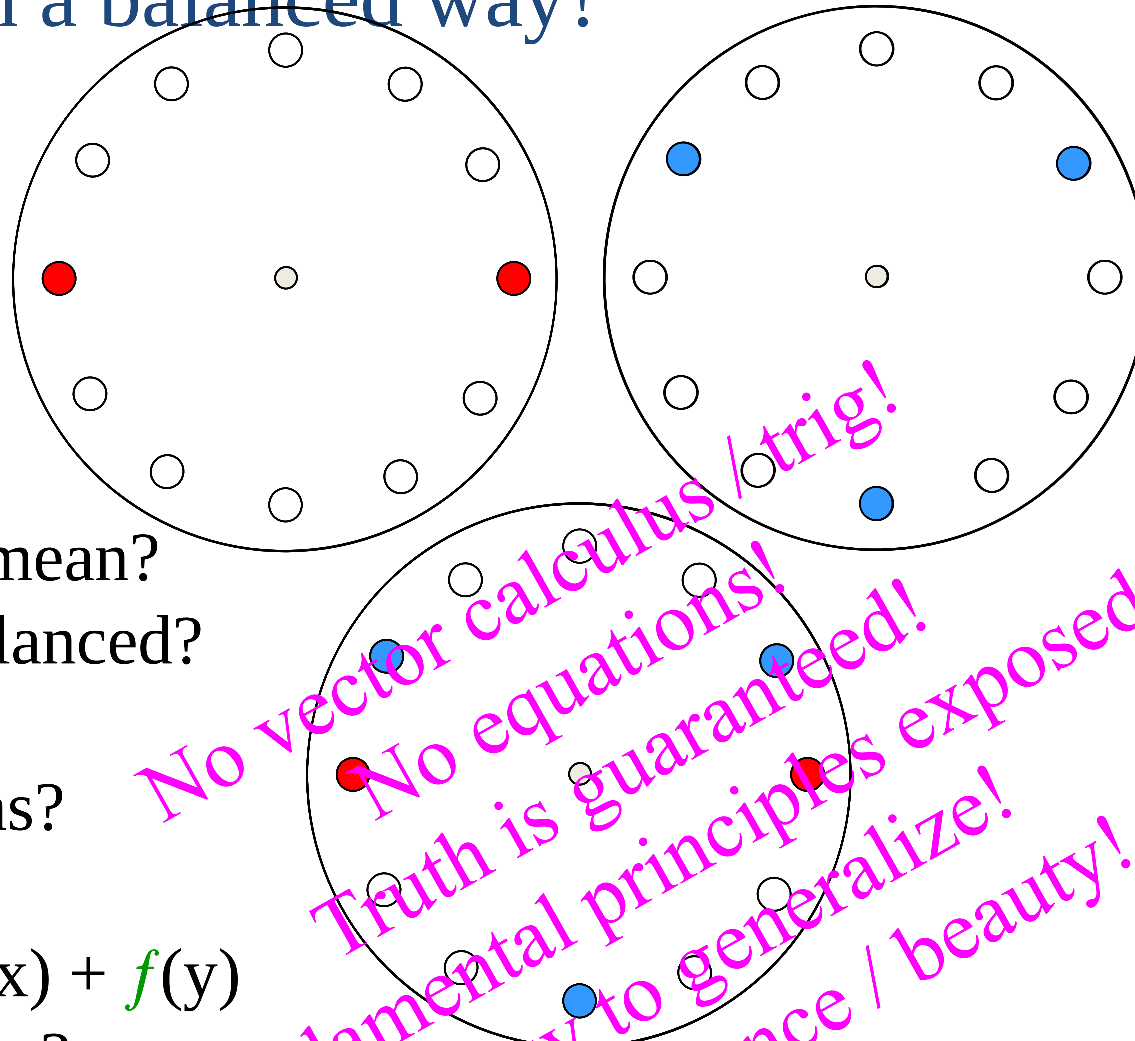
Cantor set crossed with itself three times

Explore lots of cool ideas!

Goal: Become a more effective problem solver!

Resourcefulness!

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 = ?

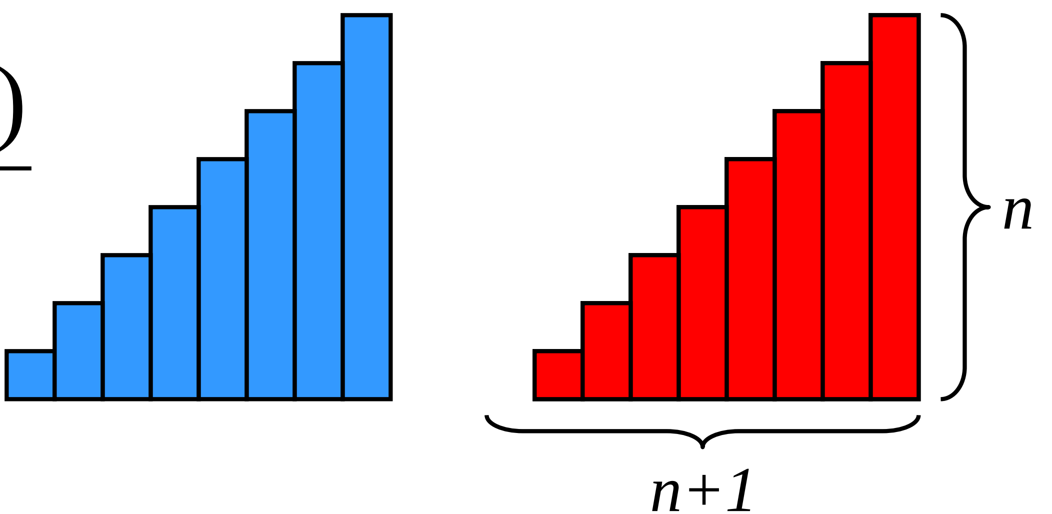
= (100*101)/2

= 5050

Proof: ~~Induction~~…

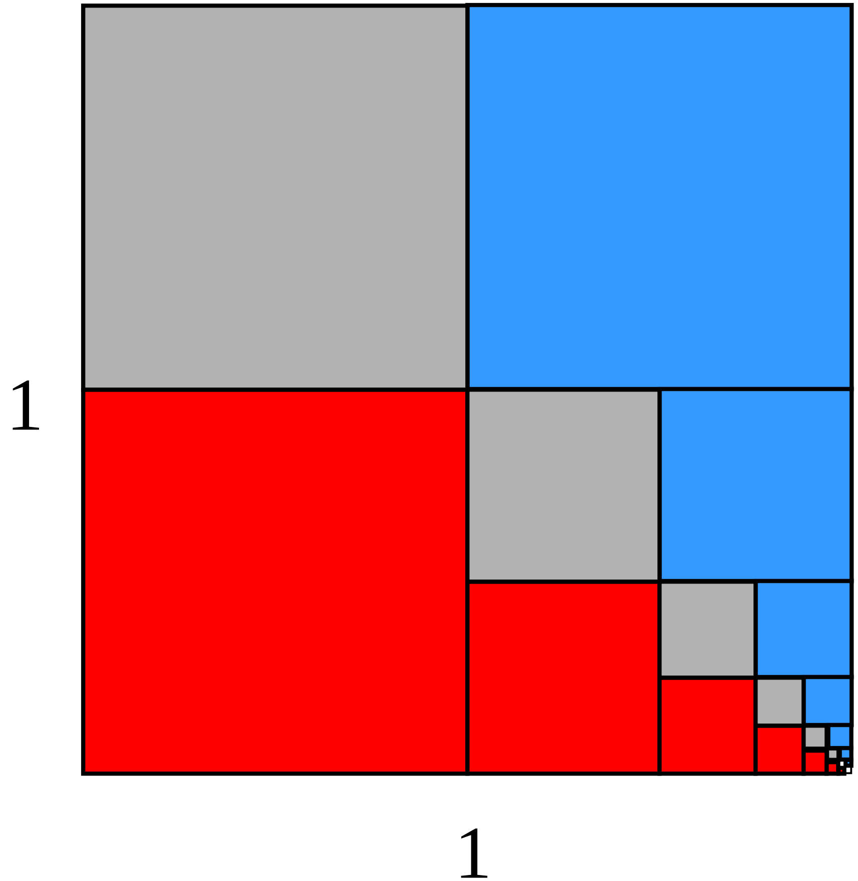
$$
\begin{array}{ccccccccccc}
1 & + & 2 & + & 3 & + & \ldots & + & 99 & + & 100 \\
100 & + & 99 & + & 98 & + & \ldots & + & 2 & + & 1 \\
\hline
101 & + & 101 & + & 101 & + & \ldots & + & 101 & + & 101
\end{array} = 100*101
$$

$$\sum_{i=1}^{n} i = \frac{n(n+1)}{2}$$



Problem: $(1/4) + (1/4)^2 + (1/4)^3 + (1/4)^4 + \ldots = ?$

Find a short, geometric, induction-free proof.

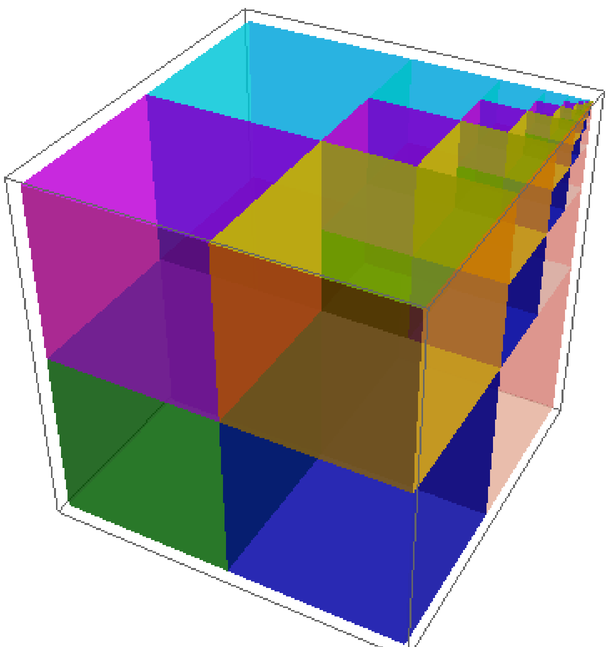


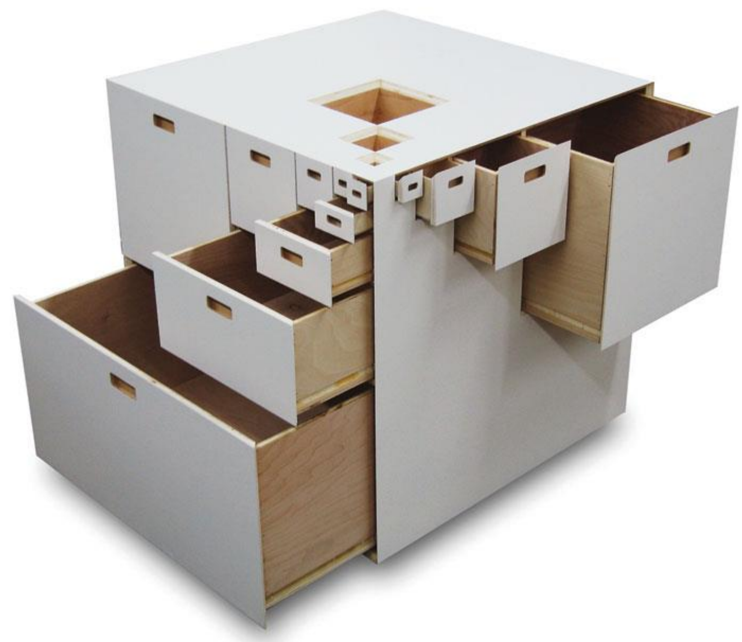
$$\sum_{i=1}^{\infty} \frac{1}{4^i} = \frac{1}{3}$$

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:

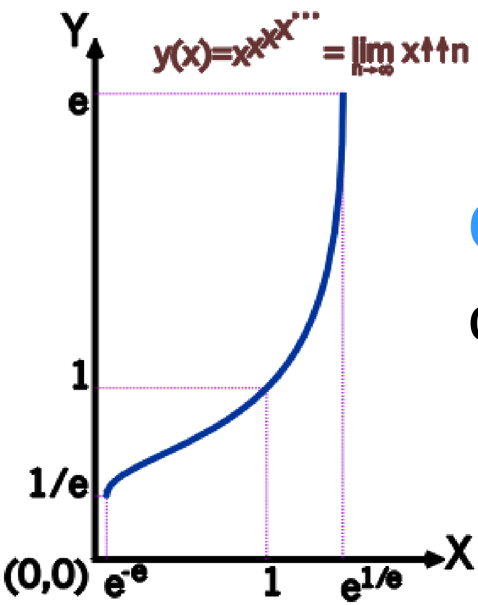
$$X^{X^{X^{X^{\cdot^{\cdot^{\cdot}}}}}} = 2 \quad \Rightarrow X^2=2 \quad \Rightarrow X=\sqrt{2}$$

$$X^{X^{X^{\cdot^{\cdot^{\cdot}}}}} = 2$$

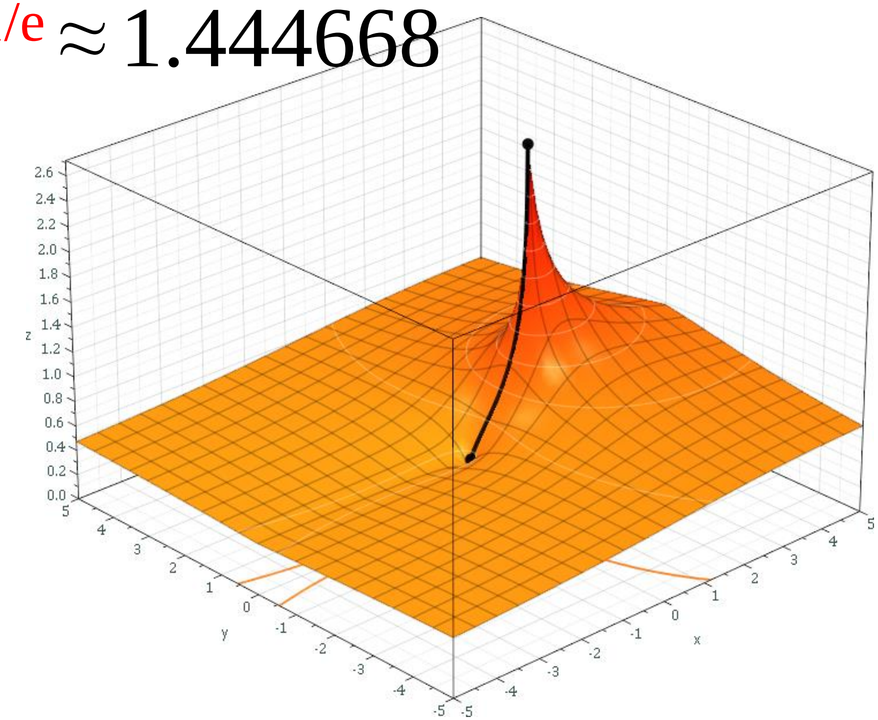
where the stack of exponentiated x's extends forever.

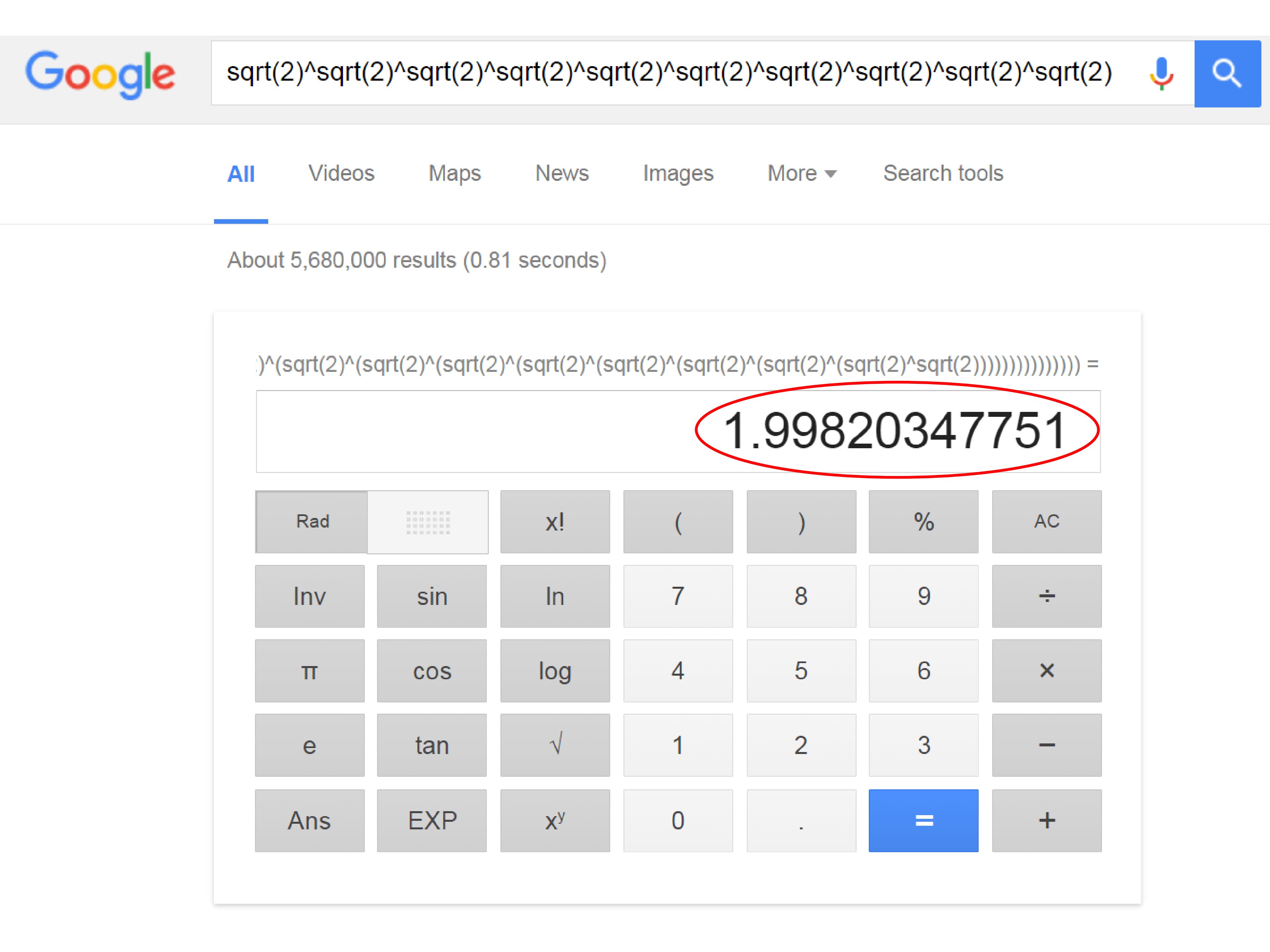
This "power tower" converges for:

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



Generalization to complex numbers:




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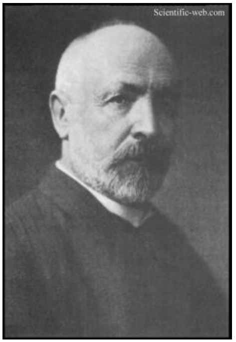
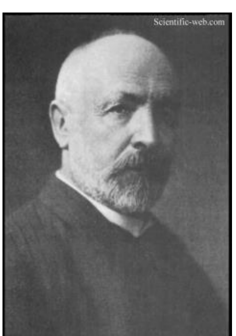
Problem: How can a new guest be accommodated in a full infinite hotel?

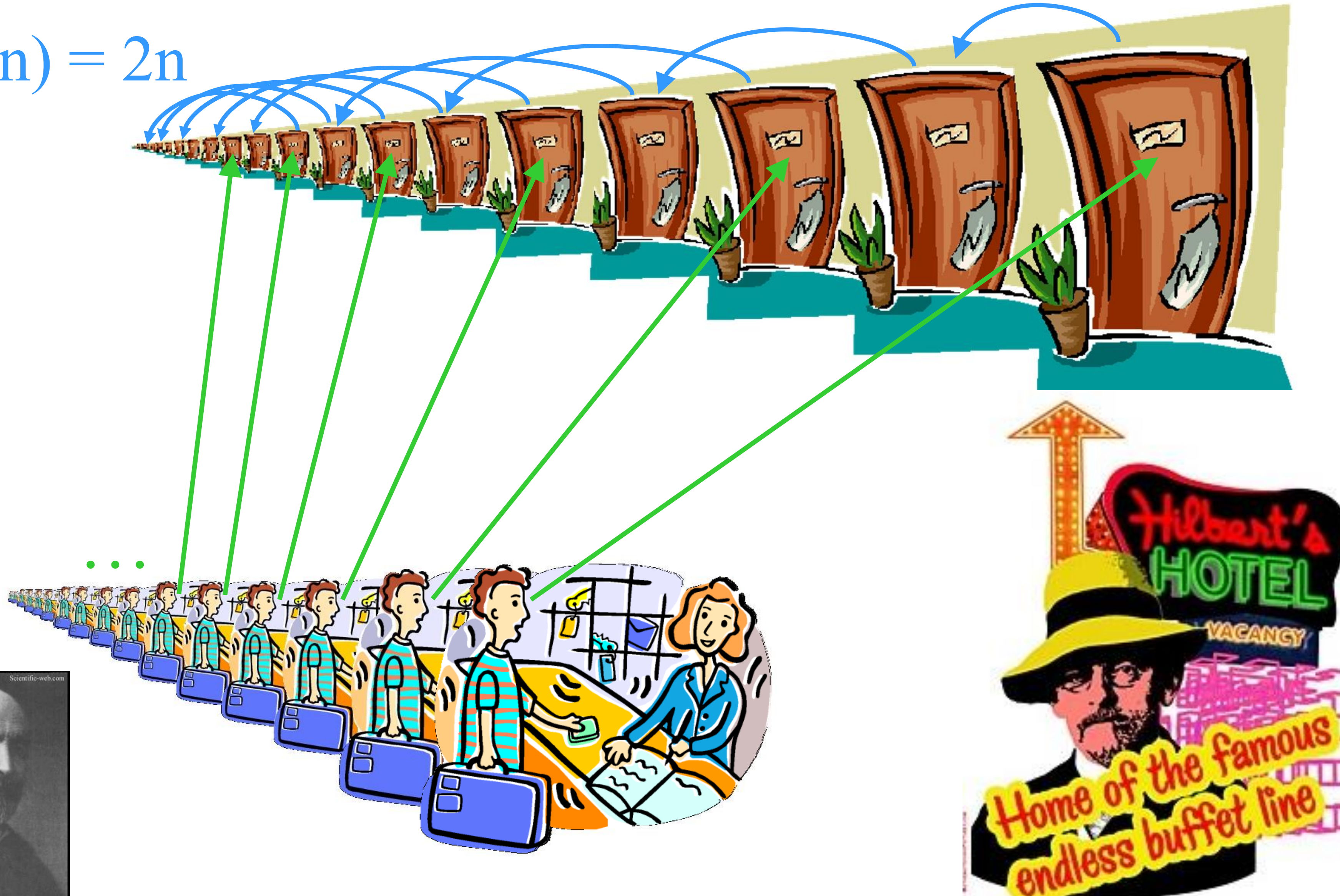
$f(n) = n+1$



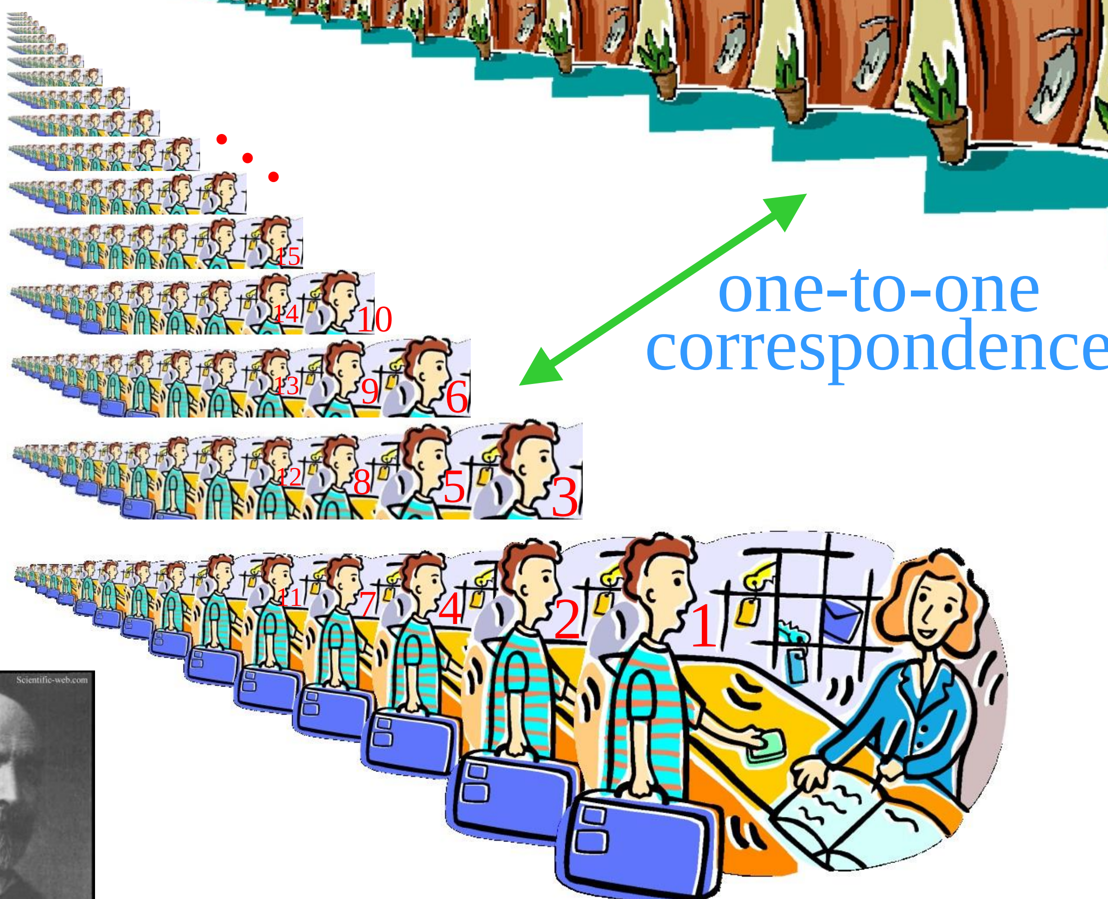
Problem: How can an infinity of new guests be accommodated in a full infinite hotel?

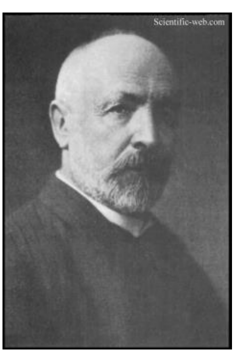
$f(n) = 2n$





Problem: How can an infinity of infinities of new guests be accommodated in a full infinite hotel?






Celebrity Cruises
a true departure
WELCOME
TO
INFINITY
Infinity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Stay curious / be proactive!